NOAA TECHNICAL MEMORANDUM NWS CR-102

POSTPRINT VOLUME
NATIONAL WEATHER SERVICE AVIATION WORKSHOP
Kansas City, Missouri
December 10-13, 1991

Scientific Services Division
Central Region Headquarters
Kansas City, Missouri

MARCH 1992

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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CRTM 4 Heavy Rains in Colorado June 16 and 17, 1965. SSD Staff, WBCRH, July 1966.
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CRTM 11 Public Probability Forecasts. SSD Staff, WBCRH, January 1967.
CRTM 12 Heavy Snow Forecasting in the Central United States (an Interim Report). SSD Staff, January 1967.
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CRTM 14 Forecasting Probability of Summertime Precipitation at Denver. Wm. G. Sullivan, Jr., and James O. Severson, March 1967.
CRTM 15 Improving Precipitation Probability Forecasts Using the Central Region Verification Printout. Lawrence A. Hughes, May 1967.
WBTM CR 16 Small-Scale Circulations Associated with Radiational Cooling. Jack R. Cooley, June 1967.
WBTM CR 17 Probability Verification Results (6-month and 18-month). Lawrence A. Hughes, June 1967.
WBTM CR 18 On the Use and Misuse of the Brier Verification Score. Lawrence A. Hughes, August 1967 (PB 175 771).
WBTM CR 19 Probability Verification Results (24 months). Lawrence A. Hughes, February 1968.
WBTM CR 20 Radar Prediction of the Topeka Tornado. Norman E. Prosser, April 1968.
WBTM CR 21 Wind Waves on the Great Lakes. Lawrence A. Hughes, May 1968.
WBTM CR 22 Seasonal Aspects of Probability Forecasts: 1. Summer. Lawrence A. Hughes, June 1968 (PB 185 733).
WBTM CR 23 Seasonal Aspects of Probability Forecasts: 2. Fall. Lawrence A. Hughes, September 1968 (PB 185 734).
WBTM CR 24 The Importance of Areal Coverage in Precipitation Probability Forecasting. John T. Curran and Lawrence A. Hughes, September 1968.
WBTM CR 25 Meteorological Conditions as Related to Air Pollution, Chicago, Illinois, April 12-13, 1963. Charles H. Swan, October 1968.
WBTM CR 26 Seasonal Aspects of Probability Forecasts: 3. Winter. Lawrence A. Hughes, December 1968 (PB 185 735).
WBTM CR 27 Seasonal Aspects of Probability Forecasts: 4. Spring. Lawrence A. Hughes, February 1969 (PB 185 736).
WBTM CR 28 Minimum Temperature Forecasting During Possible Frost Periods at Agricultural Weather Stations in Western Michigan. Marshall E. Soderberg, March 1969.
WBTM CR 29 An Aid for Tornado Warnings. Harry W. Waldheuser and Lawrence A. Hughes, April 1969.
WBTM CR 30 An Aid in Forecasting Significant Lake Snows. H. J. Rothrock, November 1969.
WBTM CR 31 A Forecast Aid for Boulder Winds. Wayne E. Sangster, February 1970.
WBTM CR 32 An Objective Method for Estimating the Probability of Severe Thunderstorms. Clarence L. David, February 1970.
WBTM CR 33 Kentucky Air-Soil Temperature Climatology. Clyde B. Lee, February 1970.
WBTM CR 34 Effective Use of Non-Structural Methods in Water Management. Verne Alexander, March 1970.
WBTM CR 35 A Note on the Categorical Verification of Probability Forecasts. Lawrence A. Hughes and Wayne E. Sangster, August 1970.
WBTM CR 36 A Comparison of Observed and Calculated Urban Mixing Depths. Donald E. Wuerch, August 1970.

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NWS CR 37 Forecasting Maximum and Minimum Surface Temperatures at Topeka, Kansas, Using Guidance from the PE Numerical Prediction Model (FOUS). Morris S. Webb, Jr., November 1970 (COM 71 00118).
NWS CR 38 Snow Forecasting for Southeastern Wisconsin. Rheinhart W. Harms, November 1970 (COM 71-00019).
NWS CR 39 A Synoptic Climatology of Blizzards on the North-Central Plains of the United States. Robert E. Black, February 1971 (COM 71-00369).
NWS CR 40 Forecasting the Spring 1969 Midwest Snowmelt Floods. Herman F. Mondschein, February 1971 (COM 71-00489).
NWS CR 41 The Temperature Cycle of Lake Michigan 1. (Spring and Summer). Lawrence A. Hughes, April 1971 (COM 71-00545).
NWS CR 42 Dust Devil Meteorology. Jack R. Cooley, May 1971 (COM 71-00628).
NWS CR 43 Summer Shower Probability in Colorado as Related to Altitude. Alois G. Topil, May 1971 (COM 71-00712).
NWS CR 44 An Investigation of the Resultant Transport Wind Within the Urban Complex. Donald E. Wuerch, June 1971 (COM 71- 00766).
NWS CR 45 The Relationship of Some Cirrus Formations to Severe Local Storms. William E. Williams, July 1971 (COM 71-00844).
NWS CR 46 The Temperature Cycle of Lake Michigan 2. (Fall and Winter). Lawrence A. Hughes, September 1971 (COM 71-01039).

(Continued on Back Cover)

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UNITED STATES DEPARTMENT OF COMMERCE
Barbara Franklin
Secretary

National Oceanic and Atmospheric Administration
John A. Knauss
Under Secretary

National Weather Service
Elbert W. Friday, Jr.
Assistant Administrator

Foreword

The Organizing Committee of the Aviation Workshop consisted of Joseph T. Schaefer (NWS Central Region)[1], James T. Skeen (NWS Office of Meteorology)[2], Kenneth R. Rizzo (NWS Central Region)[3], Gary Schmeling (NWS Central Region), M. Douglas Mathews (National Severe Storms Forecast Center, National Aviation Weather Advisory Unit), Richard P. McNulty (NWS Training Center), and Beverly D. Lambert (NWS Central Region).

While many individuals provided assistance at the Workshop itself, special recognition belongs to William Henry (NWS Training Center, Retired). The onerous task of compiling, processing, and producing this document fell upon the most able shoulders of Beverly Lambert.

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1 Now affiliated with NWS Training Center, Kansas City, Missouri.

2 Now affiliated with the National Transportation Safety Board, Washington, D.C.

3 Now affiliated with National Weather Service Forecast Office, Milwaukee/Dousman, Wisconsin.

TABLE OF CONTENTS

PROGRAM FOR THE AVIATION WORKSHOP
December 10-13, 1991

Session One: **Aviation User Requirements Part I** -- 8:30-10:15 a.m., Tuesday, December 10, 1991

Chair - James Travers, NWS Aviation Services Branch

Welcome - Richard Augulis, Director, NWS Central Region

1.1 "Aeronautical Meteorology: A Global View" by Charles H. Sprinkle (Aviation Services Branch, NWS Office of Meteorology) and Ken MacLeod (World Meteorological Organization) [Presented by Dorothy Haldeman, NWS Aviation Services Branch]

1.2 "The Requirements Process for Aviation Weather" by Rick Heuwinkel (Federal Aviation Administration) [Presented by Myron Clark, Federal Aviation Administration]

1.3 "The Center Weather Service Unit" by John L. White (CWSU Memphis, TN)

1.4 "The Effects of Weather on Delays in the National Airspace System" by Steve Henderson (Central Flow Weather Service Unit)

1.5 "The Regional Airline's Unique Requirements" by Richard McAdoo (Henson Aviation/USAir Express)

Session Two: **Aviation User Requirements Part II** -- 10:45 a.m.-12:15 p.m., Tuesday, December 10, 1991

Chair - Tom Heffner, NWS Pacific Region

2.1 "General Aviation Requirements for Weather Services" by Steven Brown (Aircraft Owners and Pilots Association)

2.2 "The Professional Pilot's Perspective on Weather" by Tim Miner (American Airlines)

2.3 "The Impact of Terminal Forecasts on Fuel Loading Planning" by Jeff Hubright (Delta Airlines)

2.4 "The FAA Weather R & D Activities" by Arthur L. Hansen (Weather Research Program, Federal Aviation Administration)

Session Three: **Fog and Stratus Forecasting** -- 1:15-2:45 p.m., Tuesday, December 10, 1991

Chair - Dale Eubanks, NWS Alaska Region

3.1 "Development and Dissipation of Fog and Stratus" by Lynn L. LeBlanc (Northeast Louisiana Univ.)

3.2 "Sea Fog and Stratus: A Major Aviation Hazard in the Northern Gulf of Mexico" by G. Alan Johnson and Jeffrey Graschel (WSFO New Orleans, LA)

3.3 "The Effects of Summertime Stratus at San Francisco International Airport on the Nationwide Flow of Commercial Airline Traffic" by Walt Strach (CWSU Fremont, CA)

3.4 "An Objective Forecasting Aid for Summertime Low Clouds During San Francisco International Airport's Evening 'Rush'" by Henry Lau (WSFO San Francisco, CA)

Concurrent Laboratory Sessins 3:15 p.m. ...

Icebreaker - 5:30-7:30 p.m.

Session Four: **Forecasting Mesoscale En-route Weather** -- 8:30-10:00 a.m., Wednesday, December 11, 1991

Chair - Armando Garza, NWS Southern Region

4.1 "NMC's Monitoring and Aviation Branch: Organization, Products, and Forecasting Techniques" by Vince McDermott (Monitoring and Aviation Branch, National Meteorological Center)

4.2 "Development and Application of an Icing Prediction Equation" by David W. Bernhardt and Michael R. McCarter (WSO Springfield, IL)

4.3 "Forecasting Airborne Volcanic Ash in Alaska" by Lee Kelley (WSFO Anchorage, AK)

4.4 "Pilots' Understanding of Low-Level Wind Shear Terminology" by Robert L. Jackson (WSFO Seattle, WA)

4.5 "Observations and Conclusions on Low Level Turbulence in the Central United States" by Steve A. Amburn (WSO Tulsa, OK)

Session Five: **Special Aviation Related Services** -- 10:30 a.m.-12:00 p.m., Wednesday, December 11, 1991

Chair - Lans Rothfusz, NWS Southern Region

5.1 "Weather Forecast for Soaring Contests" by Dan Gudgel (CWSU Bakersfield, CA) and Larry E. Burch (NWS Western Region)

5.2 "Hot Air Balloon Pilot Weather Briefings" by Walt De Voe (WSO St. Cloud, MN)

5.3 "The Importance of Pilot Reports in Weather Service Operations" by Richard E. Arkell (WSFO Charleston, WV)

5.4 "Pilot Weather Briefings...Things to Consider and Steps to Follow" by Bernard Esposito and Vincente Carreras (WSFO Miami, FL)

5.5 "Aviation Weather Briefing Service Training for the Future" by Larry G. Sharron (Transport Canada Training Institute)

Keynote Address - Robert C. Landis, Assistant Administrator for Weather Services -- 1:00-2:00 p.m., Wednesday, December 11, 1991

Session Six: **Present Terminal Forecast Procedures** -- 2:15-3:15 p.m., Wednesday, December 11, 1991

Chair - Walter Rodgers, MIC, CWSU Palmdale, California

6.1 "National Weather Service Terminal Forecasts and Federal Regulations" by Joe Pedigo (WSFO St Louis, MO)

6.2 "EWINS (Enhanced Weather Information System)" by Randy Baker (United Parcel Service, Louisville, KY)

6.3 "Enhanced FT" by Lynn Maximuk (NWS Central Region, Transition Program Manager)

Concurrent Laboratory Sessions 3:30 p.m. ...

Session Seven: **Doppler Radar and Downbursts** -- 8:30-10:00 a.m., Thursday, December 12, 1991

Chair - Sylvia Graff, NWS Eastern Region

7.1 "Aviation Hazard Identification Using Doppler Radar" by Michael Eilts (National Severe Storms Laboratory)

7.2 "Application of the WSR-88D Combined Moment Product in Aviation Nowcasting" by Lee C. Anderson (WSFO Des Moines, IA) and Douglas Green (Operations Training Facility, NEXRAD Operational Support Facility)

7.3 "The Prediction of Pulse-Type Thunderstorm Gusts Using Vertically Integrated Liquid Water Content (VIL) and the Cloud Top Penetrative Downdraft Mechanism" by Stacy R. Stewart (Federal Aviation Administration Academy)

7.4 "An Examination of Downbursts in the Eastern Great Plains Associated with a Very Warm Mid-Level Environment" by Stephen F. Byrd (WSFO Omaha, NE)

7.5 "Toward a Climatology of South Texas Downbursts" by Nezette N. Rydell and Judson W. Ladd (WSFO San Antonio, TX)

Session Eight: **Profilers, MDCRS, and LDS** -- 10:30 a.m.-12:30 p.m., Thursday, December 12, 1991

Chair - James Skeen, NWS Aviation Services Branch

8.1 "Using Profiler Data in Aviation Forecasting" by Eric Thaler (WSFO Denver, CO)

8.2 "Some Considerations on a Density Current Nose and Low Level Jet in Case Study" by Jim Johnson (WSO Dodge City, KS)

8.3 "Use of Wind Profiler Data in Aviation Forecasting at the National Aviation Weather Advisory Unit" by Richard J. Williams and Franklin D. Woods (National Aviation Weather Advisory Unit, National Severe Storms Forecast Center)

8.4 "The Meteorological Data Collection and Reporting System (MDCRS): System Overview and Benefits" by Ralph Petersen and Clifford Dey (Development Division, National Meteorological Center), and Ronald Martin, Ronnie Londot and George Ligler (Aeronautical Radio, Inc.)

8.5 "Improved Weather Reconnaissance System" by R. Gale Carter (US Air Force Reserves)

8.6 "Use of Real Time Lightning Location Data at the National Aviation Advisory Unit" by William E. Carle (National Aviation Weather Advisory Unit, National Severe Storms Forecast Center)

Session Nine: **ASOS** -- 1:30-2:45 p.m., Thursday, December 12, 1991

Chair - Larry Burch, NWS Western Region

9.1 "On the Effect of Automated Surface Observations on National Weather Service Forecast Products" by Richard P. McNulty (National Weather Service Training Center)

9.2 "The Impact of the Automatic Weather Observing System (AWOS) on the Terminal Forecast Program at Hayden and Gunnison, Colorado and Jackson, Wyoming" by Ken Rizzo (WSFO Milwaukee, WI) and Charles Bejin (WSFO Cheyenne, WY)

9.3 "Automated Surface Observations: A Major Change for Aviation Operations" by Phil Clark (WSFO Omaha, NE)

9.4 "Improved Aviation-Oriented Observational Products" by Andrew D. Stern, Raymond H. Brady III, and Patrick D. Moore (WSFO Washington, DC) and Gary Carter (NWS Eastern Region, Scientific Services Division)

Concurrent Laboratory Sessions 3:00 p.m. ...

Session Ten: **Using Computer Generated Products and Satellite Data** -- 8:30-10:15 a.m., Friday, December 13, 1991

Chair - Ken Haydu, National Hurricane Center

10.1 "A Rapid Update Analysis and Prediction Cycle at NMC for Aviation Forecasting" by Thomas Schlatter (Forecast System Laboratory, Environment Research Laboratories)

10.2 "Thunderstorm Forecasting Using Gridded Model Output and the FAA's Meteorologist Weather Processor (MWP)" by Thomas M. Hicks and James R. Ott (CWSU Ft. Worth, TX)

10.3 "On the Possibility of Using the MRF Normal Modes for Short Range High Altitude Turbulence Forecasting" by Valerie J. Thompson (WSFO Washington D.C.)

10.4 "Verification of Canada's Regional Finite Element (RFE) Model's Aviation Package" by Claude Côté (Newfoundland Weather Centre, AES, Gander Newfoundland)

10.5 "Applications of GOES Satellite Data in the Analysis of Non-Convective Aviation Weather" by Gary Ellrod (National Environmental Satellite, Data, and Information Service)

10.6 "Forecasting for Aviation Weather Hazards in the Western North Pacific" by Thomas S. Yoshida (WSO Guam, Pacific)

Session Eleven: **The Future of Aviation Weather** -- 10:45a.m.-1:00 p.m., Friday, December 13, 1991

Chair - Lee Harrison, FAA Academy

11.1 "Advances in Meso-Scale Modeling at NMC" by John Ward (Development Division, National Meteorological Center)

11.2 "A Microcomputer-Based Climatological Information System for Terminal Forecast Prediction" by G. B. Jelly (Canadian Forces Forecast Centre, Trenton Ontario)

11.3 "STRATUS: A Prototype Expert System for Low Cloud Forecasting" by Dennis Jacob (Québec Weather Centre, AES, Montréal Québec), Michael C. Desmarais, Frances de Verteuil, and Peter Zwack (Centre de Research Informatique de Montréal)

11.4 "What is a Neural Network (and Can They be Useful to Weather Forecasters)?" by Donald W. McCann (National Aviation Weather Advisory Unit, National Severe Storms Forecast Center)

11.5 "Development of Graphic Aviation Weather Forecasting Techniques and Products Within Canada" by Brad Shannon (Prairie Weather Centre, AES, Winnipeg, Manitoba)

11.6 "Current and Future Capabilities in Forecasting the Trajectories, Transport and Dispersion of Volcanic Ash Clouds at the Canadian Meteorological Center" by Réal D'Amours (Canadian Meteorological Center, Montréal Québec) [Presented by Gilles Desautels, Atmospheric Environment Service]

11.7 "The Aviation Program at NOAA's Forecast Systems Laboratory" by Michael J. Kraus (Forecast System Laboratory, Environmental Research Laboratories)

Two hour laboratories to be given simultaneously on Tuesday, Wednesday, and Thursday afternoons:

L1 "Terminal Forecast - One Systematic Approach" by Steven A. Amburn (WSFO Tulsa, OK)

L2 "Downburst Forecasting" by Judd Ladd (WSFO San Antonio, TX)

L3.1 "Icing" by Ron Olson (National Aviation Weather Advisory Unit, National Severe Storms Forecast Center)

L3.2 "Turbulence" by Mike Streib (National Aviation Weather Advisory Unit, National Severe Storms Forecast Center)

AERONAUTICAL METEOROLOGY: A GLOBAL VIEW

Charles H. Sprinkle
President, Commission For Aeronautical Meteorology
World Meteorological Organization

Kenneth J. Macleod
Chief, Aeronautical Meteorology
World Meteorological Organization

1. INTRODUCTION

No other industry is more sensitive to weather than the aeronautical industry. In spite of our improved ability to observe and forecast the weather to a greater degree of accuracy than ever before, adverse meteorological conditions continue to severely impact the operational safety and efficiency, as well as the system's capacity.

The impact of severe weather and Instrument Meteorological Conditions (IMC) reaches far beyond the commercial aircraft in the sky. It reaches aircraft and crew scheduling, airport management, cost control, and passenger convenience. For the smaller general aviation fleet, it may mean canceling the flight which may have been for business or recreational purposes.

The impact of weather on aviation has been recognized since the turn of the century when aviation was starting. On the 17th of December 1903, the first successful flights by an engine-powered aircraft took place in North America. Take-off weight was approximately 380 kilograms. The longest flight lasted 59 seconds and the flight distance was 355 meters. After four flights, a wind gust overturned the aircraft and caused some damage. On that historic day, not only was the possibility of flight on the heavier-than-air principle demonstrated, but also the necessity for meteorological assistance to such an undertaking. This meteorological assistance has grown in tandem with the expansion of aviation. It encompasses not only safety issues which remain the prime consideration but also the economy and efficiency of air operations. This paper traces the historical involvement of meteorology, with both national and international aviation, outlines the present contributions and, with air travel expected to double in the next decade, attempts to foresee future trends.

2. HISTORICAL OVERVIEW

The First World War provided the spur that aviation needed to develop and because of the imperatives involved in war-time operations, came to depend more and more on advice from meteorologists. Some of the first national meteorological services were indeed expressly created to meet this growing demand for services. Following the war, the momentum continued.

Commercial air transport started on 8 February 1919 with the first public Paris to London flight -- two days later, the Paris to Brussels link was established. On the 25th of August that same year, operating airlines created the International

Air Transport Association (IATA), and the forerunner of the International Civil Aviation Organization (ICAO) was organized in Paris as an intergovernmental organization.

In the decade following the First World War, regular air transport networks developed in Europe and North America. It was recognized as an important contributing factor to the world economy. Meteorology also developed rapidly and because air transport, particularly in Europe, was primarily an international activity, the need for international cooperation and coordination in the carrying out and exchange of meteorological observations was agreed to be essential. As the conflict 25 years earlier spurred meteorology, the Second World War greatly expanded aircraft capabilities and meteorological knowledge.

The intergovernmental World Meteorological Organization (WMO), founded in 1950, is one of the specialized agencies of the United Nations. One of the arms of the WMO is the Commission for Aeronautical Meteorology (CAeM) which assists WMO in carrying out the purposes of the Organization with respect to aeronautical meteorology. There are now 311 experts from 120 Member countries of WMO in the CAeM, which usually meets every four years. The Commission carries out its work aimed at satisfying operational aviation requirements by a system of working groups and rapporteurs.

3. THE AERONAUTICAL WEATHER SYSTEM

The aviation weather forecast, warning, and information system serving the aviation community today is made up of three separate and distinct processes. While separate and distinct, each step is closely linked, and the failure of any one causes the entire system to fail. These processes are: 1) observing and detecting; 2) warning and forecast formulation; and 3) dissemination of the forecast, warning, and/or information.

3.1 Observing/Detecting

Before a forecast and warning program can be developed, present weather must be determined. In gathering this data, a wide variety of stations and observing systems is called upon. In the USA, for example, surface weather conditions are observed at more than 1,000 land stations. New sensor and computer technology will continue to revolutionize the taking of surface weather observations (including doppler radar technology), upper air (including automated aircraft reporting systems and atmospheric profilers) and earth observations from satellite.

3.1.1 World Weather Watch (WWW) and Global Observing System (GOS)

The WWW is a global system for the collection, analysis, and distribution of weather and other environmental information. It is an integrated system composed of national facilities and services owned and operated by individual countries which are Members of WMO. The operation of the WWW is based on the fundamental concept that each of the 160 Member countries of WMO undertakes, according to its means, in meeting certain responsibilities in

BASIC SYNOPTIC NETWORK STATIONS WITH COMPLETE OBSERVATIONAL PROGRAM

	Total	Aerodromes	Percent
Region I (Africa)	449	246	55
Region II* (Asia)	722	186	26
Region III (South America)	185	150	81
Region IV (North and Central America)	144	54	38
Region V (South-West Pacific)	230	112	49
Region VI* (Europe)	3775	1161	31
TOTAL	5505	1909	35

*except Members which do not specify observing stations

the agreed global scheme so that all countries may benefit from the consolidated efforts. It is a unique achievement in international cooperation; in no other field of human endeavor, and particularly in science and technology is there, or has there ever been, such a truly world-wide operational system to which virtually every country in the world contributes for the common good every day of every year.

WMO's WWW coordinates operational meteorological activities and planning on a global basis and has three basic components:

(i) The GOS comprising facilities on land, at sea, in the air, and in outer space for the observation and measurement of meteorological elements,

(ii) The GTS, a world-wide telecommunication system for the rapid exchange of observational information as well as analyzed and processed information, including forecasts, which are produced by,

(iii) The GDPS, a network of world and regional computerized data processing centers.

The GOS consists of over 9,500 meteorological land stations and some 7,000 merchant ships making standard observations throughout the world. About 900 of the land stations and 30 ships make upper-air soundings at least once a day to obtain data on pressure, temperature, humidity, and winds up to heights of 30 km. These are complemented by observations from about 3,000 commercial aircraft and satellite observations giving global coverage of the Earth's cloud cover, vertical temperature and humidity profiles, sea surface and land temperatures, and snow and ice cover. The 1980s saw the introduction of some 350 automated or partially automated weather stations on land, 100 moored buoys or other fixed platforms serving as automatic marine stations, and several hundred buoys, of which about 200 are presently active, drifting with the ocean currents, and some 600 ground-based weather radars. The GOS has developed into a composite system with no single observing component

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3.3 Dissemination

3.3.1 WAFS

At the joint WMO/ICAO meeting in 1982, in Montreal, at which the WAFS was adopted, there was agreement that during the initial phase of the WAFS, and until the improved ICAO Aeronautical Fixed Telecommunications Network was able to play its part, the WMO GTS would be the suitable means of fulfilling, in general, the requirements for communications from WAFCs to RAFCs, between WAFCs and between RAFCs, and to some extent, also from RAFCs to users. This has, in fact, been the case in the intervening years since 1982.

In the final phase of WAFS, there will be only two WAFCs preparing and disseminating both significant weather and upper wind and temperature forecasts. There are essentially two on-going efforts underway in WAFS to attain the final phase.

The first is the dissemination of data via satellite broadcast system(s). It was envisioned that small, receive-only stations would fulfill international aeronautical WAFS data dissemination requirements. The United States' part in dissemination is to provide for two satellite uplinks, one for the Caribbean/South American area and the other for the Asian/Pacific area.

The second ongoing effort concerns the automation of the significant weather elements objectively by computer. The final phase will not be attained until development of the capability by the WAFCs of producing significant weather forecasts by computer. When this is realized there would no longer be a need for RAFCs. However, since this realization is in the future, RAFCs would continue to prepare and to the extend possible, transmit their significant weather forecast charts to a WAFC for satellite broadcast.

The national meteorological services of individual States/Members would continue to receive and process forecast information directly from a WAFC via satellite communications.

3.3.2 National Responsibilities

The WAFS will provide for the dissemination of global products to a single authorized representative in a Member State, which will then have to disseminate that information within that State. Also, arrangements will have to be made to distribute those products prepared to serve flights below FL 100.

4. FUTURE TRENDS

The operational meteorologists who, from day to day, tries to contribute to the safety and efficiency of aviation, seems to be faced with an ever increasing range of requirements, from wind and temperature information for a particular runway on the aerodrome to global upper air data for centralized flight planning. Forecasts of flight conditions are required for light aircraft engaged in activities in the lower range of the boundary layer as well as for supersonic operations in the stratosphere. Nearly every new problem area in aviation has its meteorological aspects.

Although the advances in aviation technology will continue to make flying less weather-sensitive, meteorological information will remain essential for air transport operations. Because of the high operating costs of modern airliners, optimum use must be made of the meteorological data and forecasting accuracy available. The future air navigation system will be based on the establishment of reliable data links between aircraft and ground systems.

5. CONCLUSIONS

Scientific and technological advances are emerging that will enable us to make significant improvements to aeronautical information. Developing technologies seem to indicate that the detection and warning phases of our trilogy are somewhat more in hand as far as planning, development, and implementation are concerned than is the final dissemination of that vital information to the end user, the enroute pilot. The use of these technologies by the meteorologists, communicators, and processors to provide pertinent and succinct information to the pilot is a complex task that points to an ever increasing role of education and training in order to take full advantage of the evolving aeronautical weather system.

Finally, and back to a Global point of view, the WAFS is very significant since it allows for the dissemination of state-of-the-science global model output data to potentially every meteorological service in the world.

Session 1.2

THE REQUIREMENTS PROCESS FOR AVIATION WEATHER

Rick Heuwinkel
Federal Aviation Administration
Washington, D.C.

MANUSCRIPT WAS NOT AVAILABLE AT THE TIME OF PUBLICATION

A BRIEF REVIEW OF THE CENTER WEATHER SERVICE UNIT'S REAL TIME WEATHER SUPPORT TO THE AIR ROUTE TRAFFIC CONTROL CENTER

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Center Weather Service Unit
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We cannot look at the role of the Center Weather Service Unit (CWSU) without first looking at the Air Route Traffic Control Center (ARTCC). The ARTCC is housed in a large multi-floored building. The buildings at all 21 ARTCCs are basically the same with the exception of a few sites. Each center has a vast complex of varied communications being fed into it. Almost all of the radar and radio communications used by the air traffic controllers are ingested from remote sites, often several states in distance.

Around 600 people work in an ARTCC. Two to three hundred of these people (depending upon the site) are air traffic controllers. The rest are electronic technicians, communication specialists, maintenance and administrative people.

There are also four CWSU meteorologists on the ARTCC staff. We are National Weather Service employees and are considered a vital part of the center's operations. I should also point out that our salaries are reimbursed by the FAA.

The Memphis ARTCC airspace runs from Tulsa, Oklahoma, on the west to beyond Nashville, Tennessee, on the east. The northern extent of the area is from just south of Evansville, Indiana, and the southern boundary is near Hattiesburgh, Mississippi.

The large airspace that a center controls is broken up into smaller areas called sectors (much like counties in a state). This allows a one to three person team to control the air traffic in this sector. The airspace is further divided into low, high and ultra high sectors to facilitate the safe and efficient flow of air traffic.

The routes that the planes fly are called airways and have a distinctive nomenclature. These routes are much like the freeways of the sky and run from one radio beacon to the next. This also means that controllers think in terms of sectors and airways, not states and cities. The CWSU meteorologist must also learn this same convention to be able to effectively brief ARTCC personnel on weather situations.

The mission of the CWSU is to promote the safe and efficient flow of air traffic by providing accurate and timely weather information and forecasts to the air route traffic control center, towers and flight service stations.

I should point out that 85-95% of the air traffic delays in the southeast are weather related. We cannot change the weather but being prepared for it can greatly improve operational efficiencies.

The prime area of responsibility for the CWSU meteorologist is the multi-state air space of the ARTCC. However, we must also watch the weather at all of the major airports across the country since a delay at any airport may eventually affects the flow of traffic in our airspace. A delay at Chicago will often mean a delay at Memphis because it is frequently the same aircraft, or a connecting one, that is scheduled to ultimately arrive here. Departing flights must also be delayed if the acceptance rate at the destination airport is reduced. It is safer and much more cost effective to hold an aircraft on the ground rather than delay it in the air in an area that is experiencing bad weather.

Some of the busiest days at the center are when the weather in our area is good. If there is a strong line of thunderstorms running from north of Detroit, Michigan, to southern Illinois much of the east to west air traffic from each coast is forced south across the Memphis area. This requires additional air traffic controller staffing and is frequently one of our main forecasting concerns.

I mentioned earlier that the CWSU staff members are National Weather Service employees. The CWSU receives its administrative support from the National Weather Service. This support is provided by the WSFO in the state that the ARTCC is located in.

Operationally the CWSU falls under the FAA ARTCC staff. This means that the FAA tells us what to do and the WSFO MIC-AM writes our efficiency reports on how well we did our job. This can, of course, theoretically present some administrative problems but usually does not.

The other problem with this arrangement is that there is some question as to what each agency should provide to the CWSU in the way of support. NWS says that we are working for the FAA and they should provide everything needed. The FAA on the other hand states that since they are reimbursing our salaries plus more than a 20% overhead fee that the NWS should provide almost all administrative and training functions.

Austere budgets make the issue more acute. This is especially true when the CWSU MICs need an administrative computer or a Professional Development Weather system is needed for training the CWSU staff.

The hours of operation at a CWSU are usually from 5:00 or 6:00 a.m. to 9:00 or 10:00 p.m. (depending on the site and centers requirements).

Communications at a CWSU are composed of standard FTS and commercial phone lines to the CWSU office and operational area. The CWSU also has access to the FAA's dedicated hotline system. This gives the CWSU dedicated hotlines to the controllers in the center, most Towers and Flight Service Stations in the centers airspace and to the meteorologist at surrounding centers. Many centers also have access to the local WSFO on this system. Care should be taken when talking on these systems since all of the hotlines and some of the other lines are recorded. Radio protocol should be used and one should never say anything that should not be recorded or slip out over the airways if the line is a multi-use line and may be on a speaker phone near a controllers position where open microphones are common.

The interface for exchanging information between the CWSU and the user in the ARTCC is the Traffic

Management Unit Weather Coordinator. The Traffic Management Unit (TMU) is the section that is responsible for the coordinated, safe and efficient flow of air traffic within the entire center's airspace. The person in this section assigned meteorological issues is designated as the Weather Coordinator. They have direct access to the Air Traffic Control System Communications Center in Washington, D.C. by hotline and computer for required coordination.

The CWSU works closely with the TMU Weather Coordinator and helps make operational decisions affecting the safe and efficient flow of air traffic. The Weather Coordinator is also responsible for passing and receiving weather information to and from the air traffic controllers and their supervisors.

The CWSU participates in stand up briefings several times a day. The weather presentation is routinely a critical part of the briefing. These briefings are held just prior to the major traffic rushes each day. Additional briefings are held in bad weather situations as needed.

The meteorologist also prepares written briefings several times a day. This written briefing is being replaced by graphic weather briefing loops on the Meteorologist Weather Processor Briefing Terminals (the new interactive color computer system installed in each center). The Briefing Terminals are installed in the air traffic controllers work areas. These terminals provide excellent color graphics and are and exceptional briefing tool.

The CWSU also provides support in the form of written products. The Center Weather Advisory (CWA) and Meteorological Impact Statement (MIS) are non scheduled bulletins created by the CWSU. These two products are issued as required and sent out on the Service A line as well as being distributed internally on the FAA communication system. The FAA system transmits the CWA and MIS to the controller positions as well as towers and approach control facilities.

The CWA is a 1-2 hour nowcast and closely equates to SIGMET/ Convective SIGMET criteria, but is usually issued for a smaller areal extent. It may also be used to enhance an existing SIGMET/ Convective SIGMET when needed to meet local operational requirements.

The MIS is a 4-12 hour forecast and is used as more of a planning forecast for the FAA. The MIS criteria equates to much the same criteria as that used in an AIRMET but is again tailored to the centers needs.

The CWSU also provides critical weather support for aircraft emergencies, tailored airway (route) forecast and tailored terminal forecasts. We provide short range and extended forecasts to help schedule planned equipment outages for maintenance.

We also provide valuable input for ARTCC staffing functions. ARTCC supervisors must adjust their manning to meet the air traffic loads and adverse weather definitely impacts these workloads. Additional controller staffing is frequently based on the CWSU's weather forecast.

The success of the Memphis CWSU has largely been due to the location we have on the operational floor.

The Area Manager, Traffic Management Unit, System Maintenance Supervisor and CWSU are located in a command console area. This puts these vital operational functions in a central area and greatly facilitates coordination efforts.

This location is beneficial to the CWSU. We can continually keep up with the operational and maintenance functions of the ARTCC and can easily provide the meteorological input needed to help accomplish the centers mission.

The installation of the Meteorologist Weather Processor (MWP) has been invaluable to the CWSU. The MWP will eventually replace the DIFAX, Harris Laser FAX (GOES) and The Service A/B System. The Remote Terminal to AFOS (RTA) will be maintained, however, and will still give us access to the Memphis WSFO AFOS.

MWP is a leased system funded by the FAA for use by the CWSUs. The contractor is Harris Inc., and they provide all the services and supplies for the system. The Harris offices in Melbourne, Florida, receive the NWS Family of Services and GOES data. This information is relayed via satellite to the MWP receiver at each ARTCC. A dual micro-computer system processes the data and relays it to the workstation at the CWSU position.

The workstation consists of two color CRTs, a keyboard and an optical mouse. The system also has a color printer for graphics and a dot matrix printer for alphanumerics.

MWP is an interactive system and is capable of creating and modifying weather maps, soundings, cross sections and a host of other essential products. Many of these products can be generated automatically by the system and are available as needed. This is especially beneficial when there is no meteorologist on duty at night or when the CWSU meteorologist arrives in the morning to open up the station.

The ability of MWP to create a mosaic of NWS radar data from sites in and around the ARTCCs airspace is invaluable. The ability to run the radar mosaic in a continuous loop makes it an outstanding tool for forecasting as well as briefing.

The satellite looping feature has also expanded our capabilities for forecasting. Overlaying radar data and surface/upper air data over the satellite has further expanded our insight into how weather systems interact and how these systems affect air traffic. The graphic editing capabilities of MWP have allowed us to send accurate, timely and professional looking weather products to the MWP Briefing Terminals located in the areas where the controllers work. This provides the CWSU meteorologist a new avenue of passing vital weather information on to the user in an easily read format.

This concludes our brief look at the operations of the CWSU. I hope it was enlightening and I would like to encourage everyone to make arrangements to visit an ARTCC and see the CWSU in operation. This would be of particular benefit to the NWS aviation forecasters. I am sure that it would be interesting to see how your Terminal Forecasts are used and how they affect the aviation industry.

Session 1.4

THE EFFECTS OF WEATHER ON DELAYS IN THE NATIONAL AIRSPACE SYSTEM

Steve Henderson
Central Flow Weather Service Unit
Washington, D.C.

1. INTRODUCTION

Some 70% of the delays to commercial air traffic in the U.S. are due to weather. The mission of the Air Traffic Control System Command Center (ATCSCC) is to minimize delays while maintaining the safe, efficient, and expeditious use of the National Airspace System (NAS). In support of this mission, the Central Flow Weather Service Unit (CFWSU), provides meteorological advice to the Air Traffic Controllers who make decisions regarding the management of the flow of air traffic.

An airport's ability to accommodate arriving and departing aircraft depends on several factors. The primary factors are number, length, and configuration of runways; and also the type of approach in use (visual or instrument). Weather determines runway configuration and whether instrument or visual approaches are in use.

Airlines create their schedules based on public demand and marketing techniques. As a result there are peak demand times when the number of aircraft scheduled to land at a given airport nears or exceeds the capacity of that airport. When demand exceeds capacity, airborne holding of aircraft results. In order to decrease or eliminate airborne holding, ATCSCC assigns varying amounts of delay to the departure time of an individual aircraft which is scheduled to arrive during a time when the demand exceeds the landing capacity of the destination airport. Holding on the ground is generally preferable to airborne holding since it reduces air traffic congestion and reduces costs to the airline. Hourly airborne holding costs are approximately $10,000 per airliner while ground holding costs are approximately $1800 per airliner.

The five airports which experience the greatest number of delays are: ORD 18%, LGA 10%, EWR 9%, SFO 8%, and JFK 7%. The focus of the ATCSCC, and consequently also that of the CFWSU, is largely directed toward the busiest twenty two airports in the country (Figure 1).

2. FACTORS AFFECTING THE CAPACITY OF AN AIRPORT

All major airports have multiple runways and thus, several types of landing configurations. Weather is the factor which determines which configuration is to be used. Each configuration has its unique landing capacity. At Boston (Figure 2), with visual approaches, a northeast wind will allow for an acceptance rate of 62 aircraft per hour. However, a northwest wind requires the use of a different runway configuration which has an acceptance rate of only 30 aircraft per hour. On a recent Friday at Boston, for example, there were 11 hours during which the demand exceeded 30 aircraft per hour.

Ceilings and visibility can have a significant impact on an

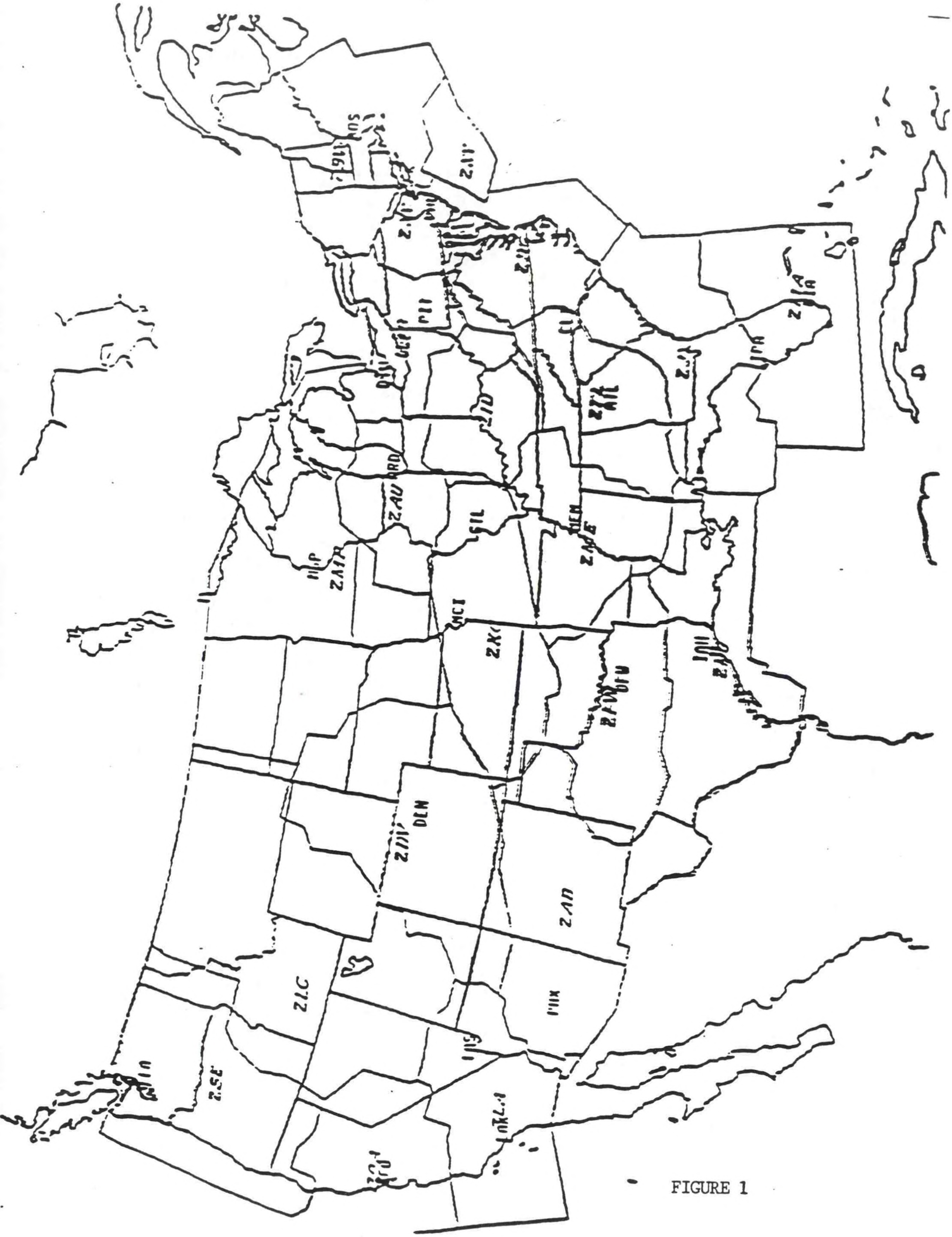


FIGURE 1

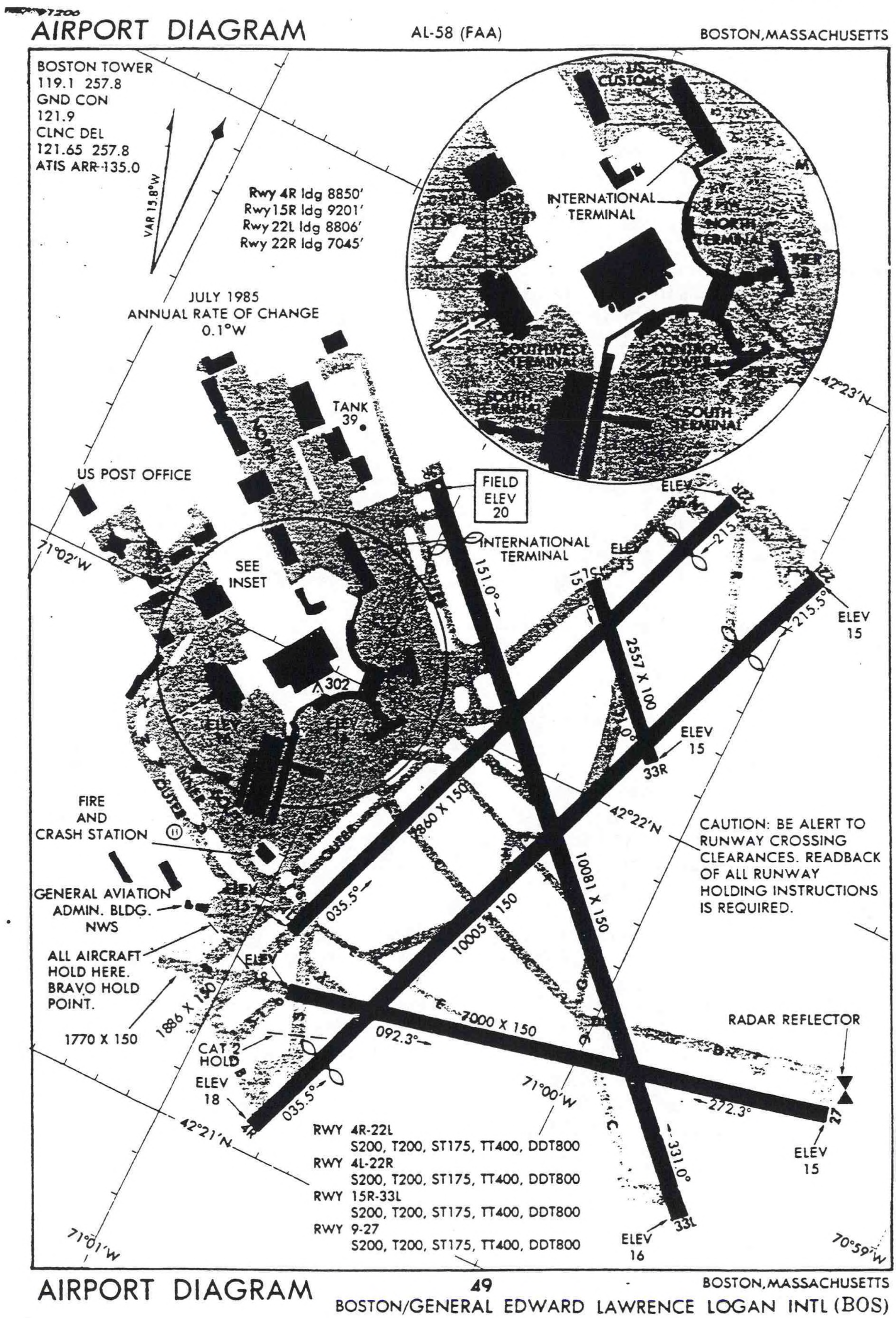

AIRPORT DIAGRAM
AL-58 (FAA)
BOSTON,MASSACHUSETTS
BOSTON TOWER
119.1 257.8
GND CON
121.9
CLNC DEL
121.65 257.8
ATIS ARR 135.0
VAR 15.8°W
Rwy 4R ldg 8850'
Rwy 15R ldg 9201'
Rwy 22L ldg 8806'
Rwy 22R ldg 7045'
JULY 1985
ANNUAL RATE OF CHANGE
0.1°W
US CUSTOMS
INTERNATIONAL TERMINAL
NORTH TERMINAL
SOUTHWEST TERMINAL
CONTROL TOWER
SOUTH TERMINAL
42°23'N
TANK 39
US POST OFFICE
FIELD ELEV 20
INTERNATIONAL TERMINAL
71°02'W
SEE INSET
302
151.0°
215.5°
ELEV 15
2557 X 100
33R
42°22'N
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
FIRE AND CRASH STATION
GENERAL AVIATION ADMIN. BLDG. NWS
ALL AIRCRAFT HOLD HERE. BRAVO HOLD POINT.
1770 X 150
1886 X 150
7860 X 150
035.5°
10005 X 150
10081 X 150
7000 X 150
092.3°
RADAR REFLECTOR
CAT 2 HOLD
ELEV 18
4R
42°21'N
71°00'W
272.3°
27
ELEV 15
331.0°
RWY 4R-22L
S200, T200, ST175, TT400, DDT800
RWY 4L-22R
S200, T200, ST175, TT400, DDT800
RWY 15R-33L
S200, T200, ST175, TT400, DDT800
RWY 9-27
S200, T200, ST175, TT400, DDT800
ELEV 16
33L
71°01'W
70°59'W
AIRPORT DIAGRAM
49
BOSTON,MASSACHUSETTS
BOSTON/GENERAL EDWARD LAWRENCE LOGAN INTL (BOS)

FIGURE 2

airport's capacity to land aircraft. Airports with parallel runways less than a mile apart are especially impacted. For example, at Seattle (Figure 3) as two aircraft turn onto final approach of the parallel runways if clouds or visibility prevent them from seeing each other, then instrument approaches must be used instead of visual approaches. The acceptance rate for visual approaches is 55, while it is 34 for instrument approaches. Analogous situations exist at San Francisco, Denver, Atlanta, and Charlotte.

When runways are wet, the use of crossing runways is prohibited. This, of course, reduces the acceptance rate of an airport. This is a factor at Chicago's O'Hare (Figure 4) airport where with visual approaches and dry runways the acceptance rate is 80-85. When runways are wet under visual conditions the acceptance rate is reduced to 60-62.

Noise abatement procedures at some airports designate a preferred runway configuration. However, some weather conditions prevent the use of the preferred configuration. Charlotte, North Carolina, and Washington, D.C.'s National airports are two examples of airports with weather sensitive noise abatement procedures. At Charlotte there is a preferred direction for landing and departing on the north-south oriented runways due to a school which is located near the end of the runways. At Washington's National Airport, arriving aircraft follow the twisting Potomac River if weather conditions permit. Each runway configuration can have different arrival capacities. New York City airports, JFK, LGA, and EWR are also affected by noise abatement procedures.

Due to the proximity of the three New York City area airports, arriving and departing traffic requires a high degree of coordinated integration. Any weather that affects the traffic at one airport can have a domino type affect on traffic at the other two airports even though those airports themselves may not be directly affected by the weather. A good example is the seabreeze front that sometimes requires that the runway configuration at JFK (Figure 5) be changed while the other two airport configurations remain unchanged. Changing the runway configuration at JFK causes its traffic to conflict with traffic at LGA and EWR.

3. THE IMPACT OF WEATHER ON TERMINAL OPERATIONS

If the traffic contains aircraft with different landing approach speeds, then additional spacing is necessary to keep the faster aircraft from overtaking the slower aircraft. This decreases the number of aircraft that can land in a given hour.

Some airports, such as Boston and St. Louis (Figures 2 and 6), have a short runway which is primarily used for slower flying aircraft. By separating the slower from the faster aircraft, the landing capacity is increased. If the crosswind component becomes too great to use the short runway, the slower traffic must be mixed with the faster traffic which is using a more favorable runway. This will, of course, reduce the acceptance rate of the airport.

Air traffic rules specify the horizontal distance that is to be maintained between aircraft as they land. As the headwind component of

91038

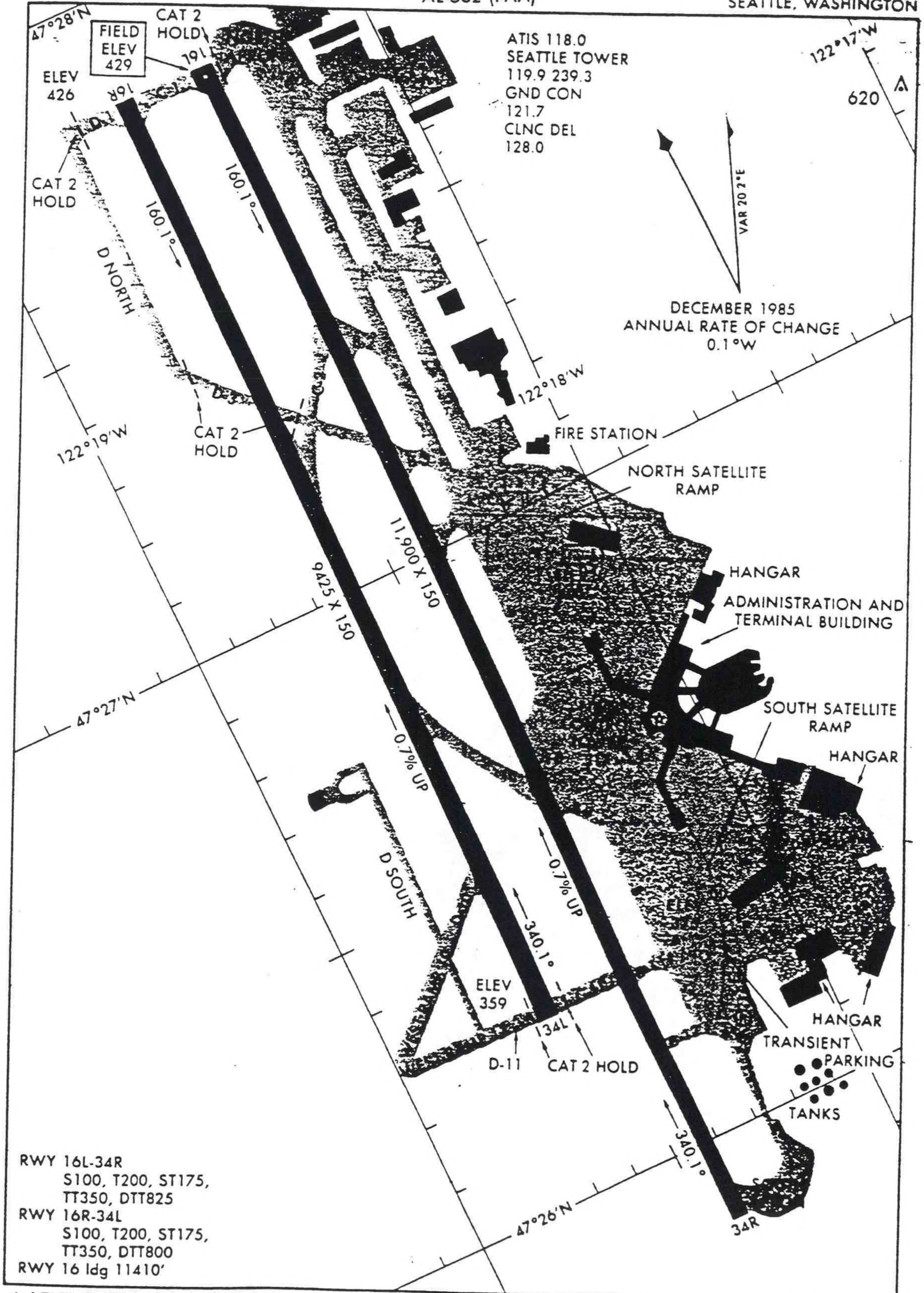
AIRPORT DIAGRAM

214

AL-582 (FAA)

SEATTLE-TACOMA INTL (SEA)

SEATTLE, WASHINGTON



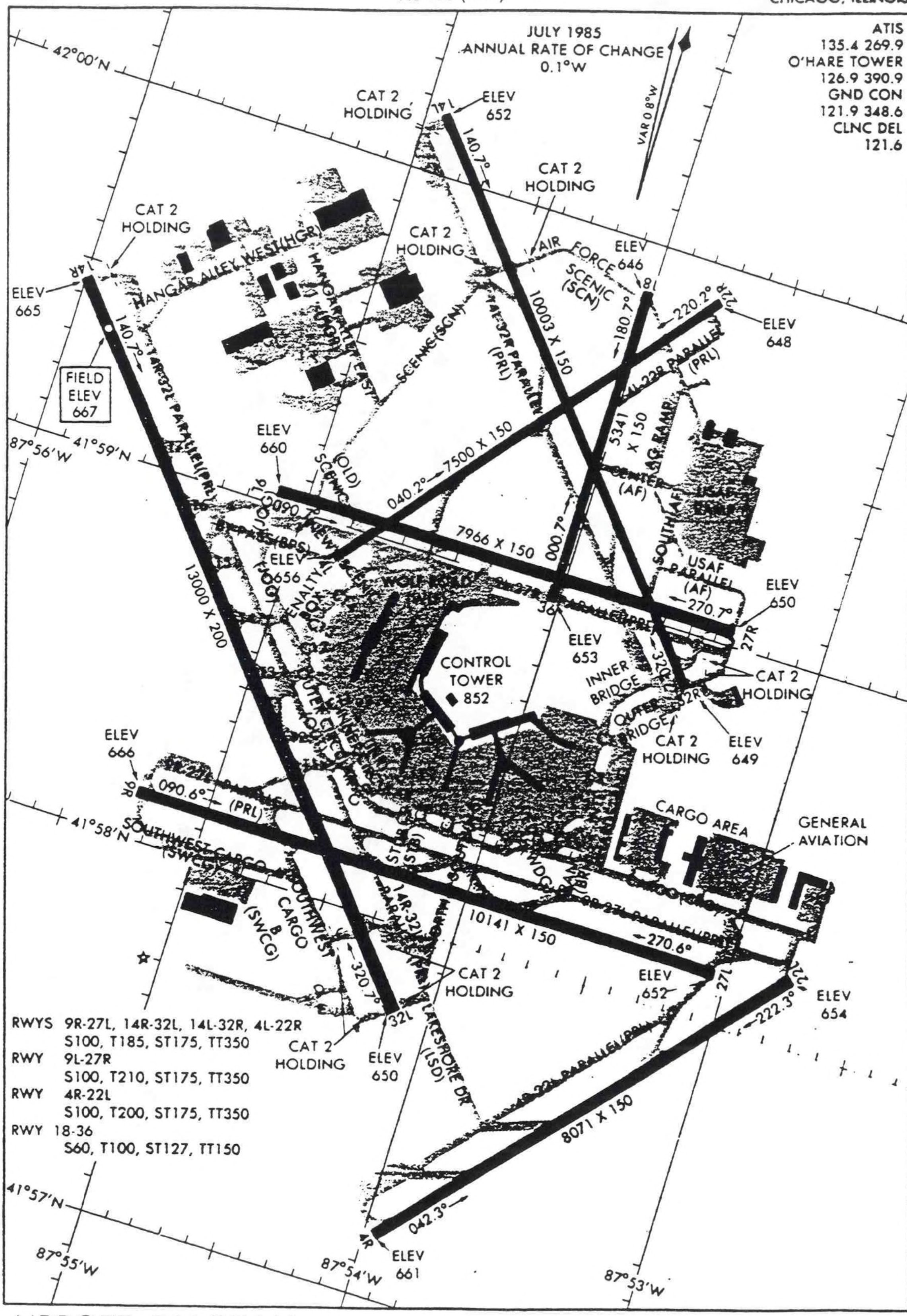
AIRPORT DIAGRAM

SEATTLE, WASHINGTON

FIGURE 3

SEATTLE-TACOMA INTL (SEA)

91150
AIRPORT DIAGRAM
86
AL-166 (FAA)
CHICAGO-O'HARE INTL (ORD)
CHICAGO, ILLINOIS



AIRPORT DIAGRAM
CHICAGO, ILLINOIS
CHICAGO-O'HARE INTL (ORD)

FIGURE 4

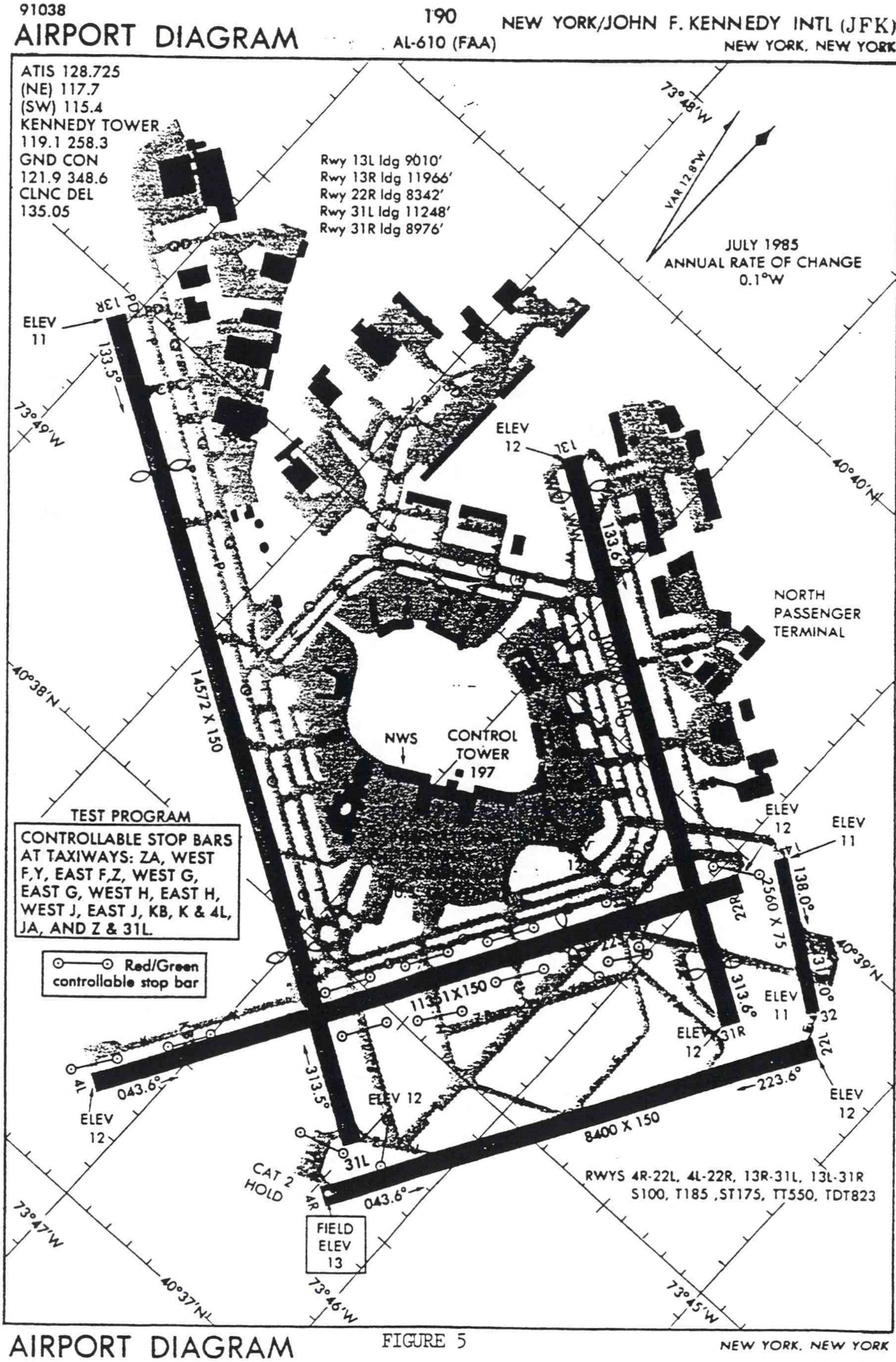
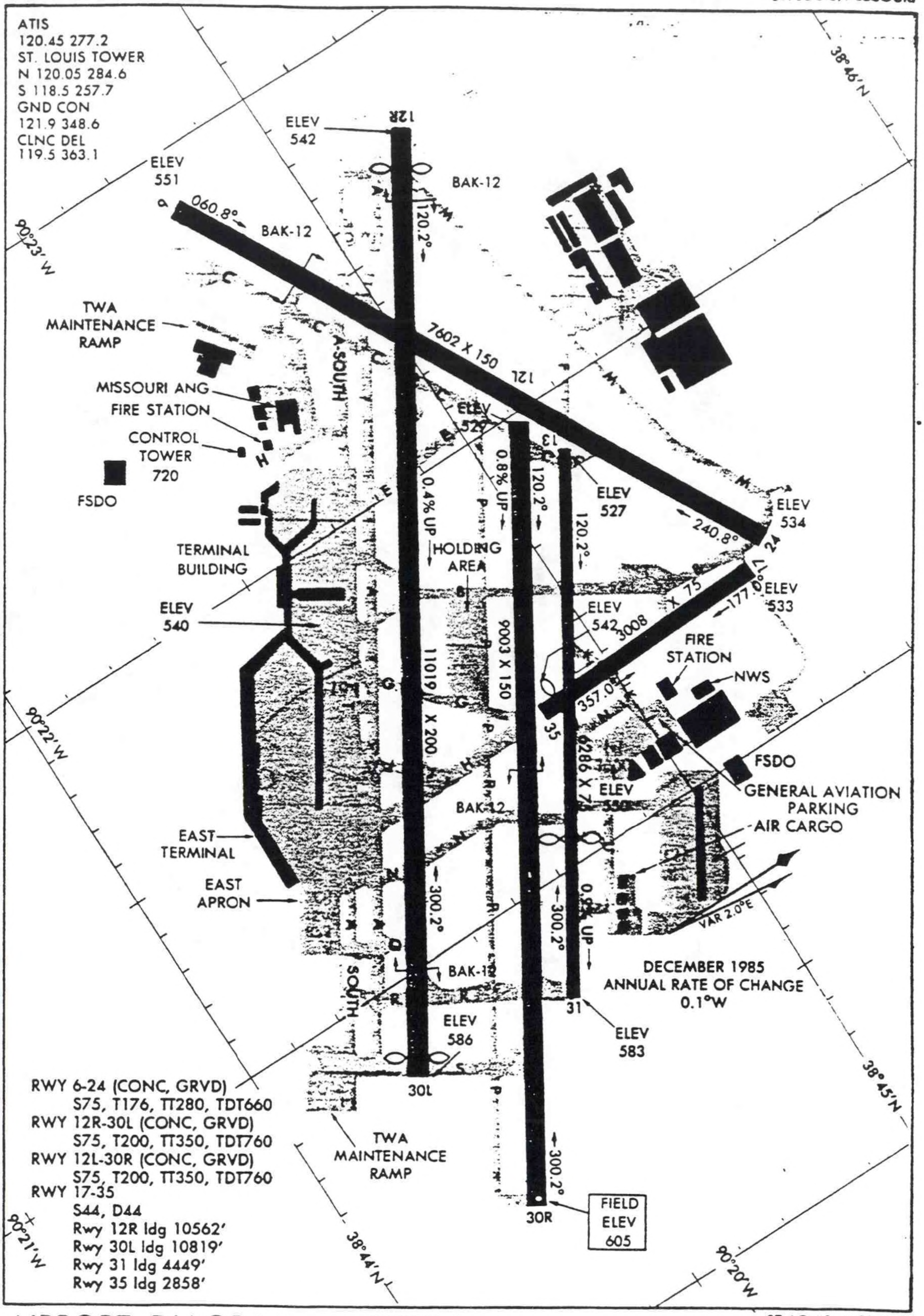

91038
AIRPORT DIAGRAM
190
AL-610 (FAA)
NEW YORK/JOHN F. KENNEDY INTL (JFK)
NEW YORK, NEW YORK
ATIS 128.725
(NE) 117.7
(SW) 115.4
KENNEDY TOWER
119.1 258.3
GND CON
121.9 348.6
CLNC DEL
135.05
Rwy 13L ldg 9010'
Rwy 13R ldg 11966'
Rwy 22R ldg 8342'
Rwy 31L ldg 11248'
Rwy 31R ldg 8976'
VAR 12.8°W
JULY 1985
ANNUAL RATE OF CHANGE
0.1°W
NORTH
PASSENGER
TERMINAL
NWS
CONTROL
TOWER
197
14572 X 150
11351 X 150
8400 X 150
2560 X 75
TEST PROGRAM
CONTROLLABLE STOP BARS AT TAXIWAYS: ZA, WEST F,Y, EAST F,Z, WEST G, EAST G, WEST H, EAST H, WEST J, EAST J, KB, K & 4L, JA, AND Z & 31L.
Red/Green controllable stop bar
CAT 2 HOLD
FIELD
ELEV
13
RWYS 4R-22L, 4L-22R, 13R-31L, 13L-31R
S100, T185, ST175, TT550, TDT823
AIRPORT DIAGRAM
NEW YORK, NEW YORK

FIGURE 5

90207 | 248 | ST. LOUIS/LAMBERT-ST. LOUIS INTL (STL)

AIRPORT DIAGRAM | AL-360 (FAA) | ST. LOUIS, MISSOURI



AIRPORT DIAGRAM | FIGURE 6 | ST. LOUIS, MISSOURI

ST. LOUIS/LAMBERT-ST. LOUIS INTL (STL)

the wind increases, an aircraft's groundspeed decreases. When groundspeed decreases, fewer aircraft can land in a given time interval. This effect is especially significant at airports like Atlanta where the downwind leg and final approach are parallel.

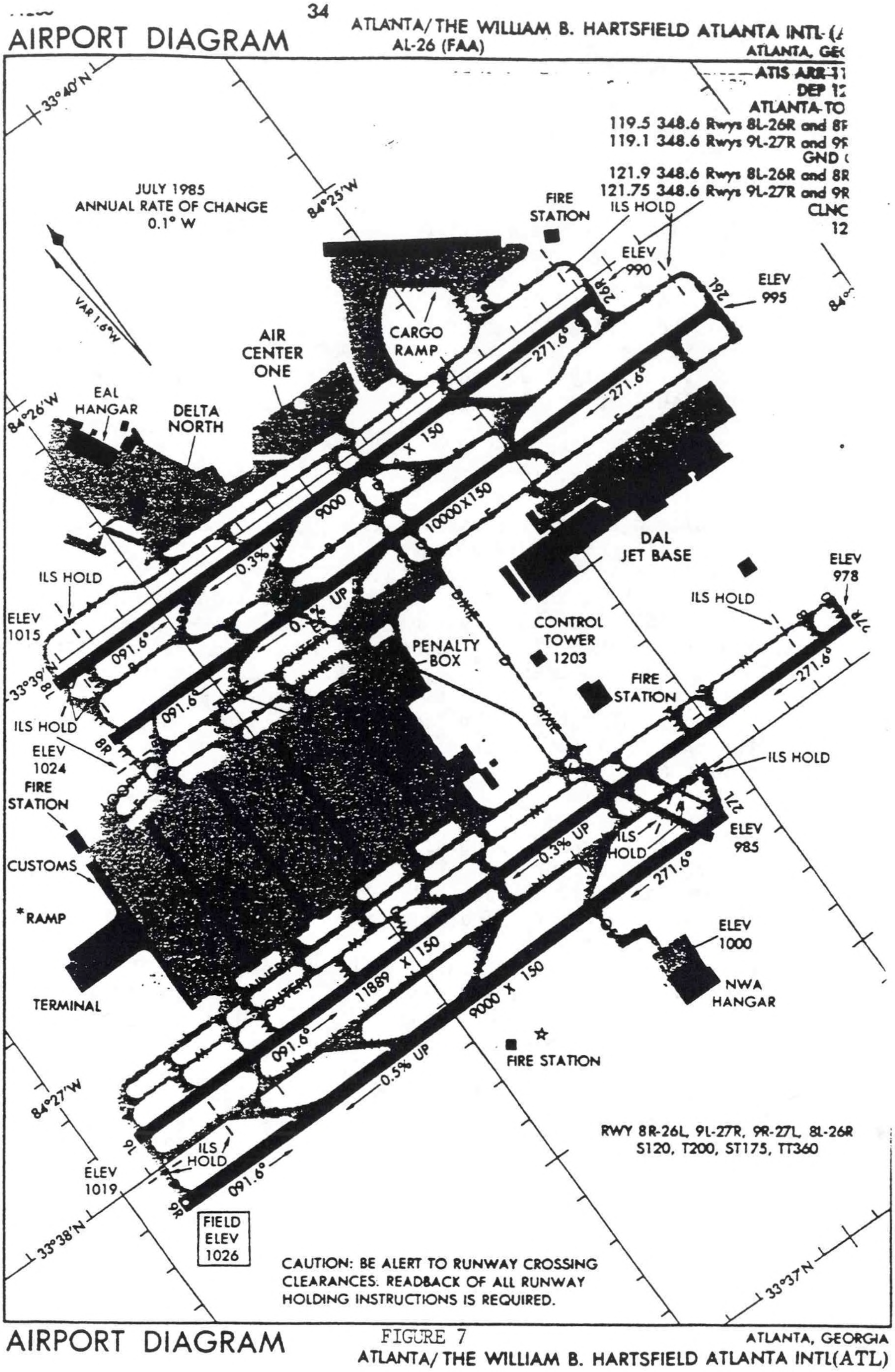
Most reduced acceptance rates are due to the presence of clouds or reduced visibility that preclude the use of visual approaches. This is a factor at all airports, though all are not affected the same way. At Atlanta (Figure 7), for example, clouds with bases as high as 4500 feet and/or a visibility as high as 5 miles will prevent visual approaches. At St. Louis visual approaches can be made, with ceilings as low as 1500 feet and a visibility as low as 3 miles. Some landing patterns are such that the ceiling and/or visibility 4 to 6 miles from the airport is just as significant as that at the airport itself. San Francisco and Atlanta are two such airports.

Thunderstorms are probably the most difficult factor to deal will in trying to adjust the arrival demand for an airport. The greatest disruption occurs when a thunderstorm is over or just off the end of the runway. Generally, all departure and arrival operations stop until the thunderstorm dissipates or moves several miles away. The impact is generally not dependent on the intensity of the thunderstorm. All thunderstorms are treated the same. Therefore, the duration of a thunderstorm is more significant than its intensity. Consequently, a slow moving thunderstorm will cause more and longer delays than a faster moving severe thunderstorm.

Other than the terminal itself, there are other locations in the vicinity of a terminal where the presence of a thunderstorm will cause significant disruption and delays. There are predefined arrival fixes and departure gates through which air traffic normally passes. When one or more of these fixes or gates are blocked by a thunderstorm, aircraft request deviations. In the terminal environment, the room for deviating from the normal traffic patterns is very limited. When deviations are required, the acceptance rate is reduced and sometimes arrivals are stopped entirely for a period.

Some airports have a Severe Weather Avoidance Program (SWAP). The SWAP specifies alternate approach and departure patterns and routes which can be used when thunderstorms impact the normal operations. Although the SWAP specifies alternate routes, these usually cannot handle as much traffic as the normal gates and routes. It is usually not possible to preplan exactly when and which alternate routes will be utilized to minimize the disruption due to thunderstorms. When thunderstorms can be forecasted to occur within a specific time frame, ATCSCC may delay the departure time for aircraft destined for the impacted airport.

Some northern airports which seldom experience delays during the warmer part of the year may have significant delays in winter due to snow. Other than the obvious necessity of keeping the runways cleared of snow; taxiways and gate areas must also be plowed. When plowing operations are underway, acceptance rates are reduced. Proper plowing is more involved than street plowing. Care must be taken not to



34
AIRPORT DIAGRAM
AL-26 (FAA)
JULY 1985
ANNUAL RATE OF CHANGE
0.1° W
VAR 1.6°W
FIRE STATION
ILS HOLD
ELEV 990
ELEV 995
CARGO RAMP
AIR CENTER ONE
EAL HANGAR
DELTA NORTH
9000 X 150
10000X150
DAL JET BASE
ELEV 978
ILS HOLD
ELEV 1015
PENALTY BOX
CONTROL TOWER 1203
FIRE STATION
ILS HOLD
ELEV 1024
FIRE STATION
ILS HOLD
ELEV 985
CUSTOMS
*RAMP
TERMINAL
11889 X 150
9000 X 150
ELEV 1000
NWA HANGAR
FIRE STATION
RWY 8R-26L, 9L-27R, 9R-27L, 8L-26R
S120, T200, ST175, TT360
ELEV 1019
FIELD ELEV 1026
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.
AIRPORT DIAGRAM
ATLANTA, GEORGIA
ATLANTA/THE WILLIAM B. HARTSFIELD ATLANTA INTL(ATL)

FIGURE 7

obscure runway and taxiway lights. Also, snow cannot be allowed to pile up beside the runways and taxiways to a depth that becomes an obstruction to aircraft wings.

Snow removal operations are, of course, sensitive to snowfall rates and also to strong winds and drifting snow. Departing aircraft may encounter additional delays due to the need for deicing and/or snow removal.

4. THE IMPACT OF WEATHER ON ENROUTE OPERATIONS

The primary cause of weather related delays to the enroute phase of flight is due to thunderstorms. Although icing and turbulence cause altitude deviations, these usually do not cause significant delays. The ATCSCC coordinates and implements the rerouting necessitated by thunderstorms. Rerouting is implemented for long lines of thunderstorms and large areas of numerous thunderstorms. The enroute delays due to thunderstorms can be in excess of an hour for the longer solid lines of thunderstorms. Even short lines or clusters of thunderstorms can cause significant deviations and delays when they affect parallel airways that are close together. Across northern Illinois there are three nearly parallel major airways which can be impacted by a line of thunderstorms as short as 50 miles.

5. SUMMARY

Weather is the major factor affecting the landing capacity of an airport. At the busier airports, the air traffic scheduled to arrive sometimes exceeds the airport's capacity. Most often this occurs when the acceptance rate of the airport is reduced due to weather conditions. The ATCSCC requires precise and timely weather information in order to make the air traffic management decisions which minimize the delay of aircraft destined for airports where the demand exceeds capacity.

THE REGIONAL AIRLINE'S UNIQUE REQUIREMENTS

Captain Richard McAdoo
Director of Flying
Henson Aviation/USAir Express

I would first like to thank the National Weather Service for giving the Regional Airline Association the opportunity to address this workshop. We feel it is most important that all facets of our industry be knowledgeable of the strengths and weaknesses of each of the users and suppliers, so that we can operate in the National Aerospace System safely, and efficiently.

The letter we received inviting us to participate stated the workshop's purpose was to "...improve NWS service to the aviation community through the application of technology and advanced forecasting techniques....dedicated to user requirements,...." This morning I will address user requirements as they pertain to the regional/ commuter activities in our nation. By the nature of the presentation, I will address issues where we, as short haul carriers, need better, expanded support. I will be asking for changes in policy, philosophy, and financial priorities. This in no-way reflects on the current performance of the National Weather Service. The issues are real, as is the need for your support -- they are safety related.

In verifying the validity of a carrier's analysis of weather conditions and data collection, the Inspector's Handbook (8400.10) states: The purpose...is to prevent unsafe flight operations." What I will try to show over the next quarter hour is how the regional air carriers are far more capable of operating in the National Aerospace System than what appears to be the government's understanding, and how regional carriers are limited in serving the public by antiquated rules, interpretations, and in some cases a hesitation by the service to change to meet the changing technological world in which we live and work.

This morning I represent the Regional Airline Association. An organization representing 75 regional/commuter airlines which carry 97% of the passengers flying in the regional, short haul market. The carriers which comprise the membership of the RAA fly everything from Cherokee 6's and Cessna 172s to British Aerospace 146s and Fairchild F-28s. The carrier for whom I work flies 38 deHavilland Dash 7 and Dash 8 aircraft, and will carry over 2 million passengers in 1991. The capability of the high performance turbo-prop aircraft the regional/ commuter carriers fly is far superior to that which the "major airlines" flew just a few years ago. The regional carriers are capable and in fact are qualified, to operate category II ILS approaches. The state of the art on-board computers fully support every segment of the revenue flight. To use a phrase currently in the advertising media, this is not the commuter your daddy used to fly.

Why am I spending a few precious minutes explaining where the regional airline is located on the technological time line? I want us all to have the same foundation upon which to build while I discuss the association's evaluation of the National Weather Service.

Our aircraft and crews are the best in the business. But, no matter how good they are, they have to have support. In the regional airline marketplace we usually begin and end our flights within the same weather mass or system. Simplistically said, if I experience a weather delay outbound, I will probably experience a weather delay inbound. The next question we ask ourselves, does this weather also affect one or both of our alternates. Usually the answer to that is yes.

But, just because the departure, destination and alternates are affected by the weather, does that mean all the forecasts are the same, and should run concurrently the same? I say not so. The forecasts for HPN, ISP, JFK, and LGA should not be identical -- they are each influenced differently by the water, the factories, and the winds.

Most regional aircraft will fly between 8 and 16 legs per day. That, by the way, is probably higher usage than the KCI Express bus that brought us in from the airport. Needless to say, but I will anyway, that type of commitment with the equipment requires on-time performance all day, every day. We cannot afford to experience delays due to conservative weather forecasting. I will talk more about that in a minute.

Henson Aviation/USAir Express dispatches 38 aircraft from nearly 40 cities over 320 times per day -- 320 flights east of a line between Pensacola, Florida, to Huntsville, Alabama, to Cleveland. Even a moderately insignificant weather system can have tremendous influence on our operation.

Most of the regional carriers have a hub and spoke operation with a major carrier. On bad weather days I believe we run a spoke and rim operation, but that is not our plan.

This type operation brings the regional aircraft back to a major terminal virtually every other leg. If the weather is forecast below minimums at either the major airfield, or the feeder field, the carrier looses 2 legs, and passengers are poorly served, inconvenienced in our National Aerospace System. Again here, too conservative a forecast, or a forecast with marginal or below minimums weather over an extended period of time is unsatisfactory.

This conservative approach, under the umbrella or safety, fails to meet either the requirements of the carriers or of the traveling public. A lot of what I will talk about is related to risk taking -- risk taking, but not at the expense of safety.

I identified 7 areas where increased support by the National Weather Service should be a high priority in that they are for the Regional Airline Association. The list is not all inclusive, but it is a starting point for putting what needs to be fixed, in the fix-it bin.

1. The Forecast
2. Contract Forecasting Services
3. Enhanced Weather Information Services
4. Winds Aloft

5. RVR Reporting in the Hourly Sequence
6. AWOS/ASOS
7. Turbulence and Icing Reports

1. THE FORECAST

Along with "conditional words", an extended forecast without revision and with an unusually long validity period can and does limit the regional carrier's operations.

For example:

FT AMD 1 261508 1508Z C8 OVC 11/2R-F 1810 OCNL C20 OVC 5F CHC C5 OVC 1/4TRW. 23Z 21 SCT C45 BKN 5H OCNL C21 BKN 3 FH -- ETC

Lets assume this was Philadelphia, for instance. Now, unless you are operating under the exemption, the carrier cannot file to PHL as a destination -- chance of 1/4 mile visibility. But how else does this forecast close down operations from Harrisburg, Allentown, Baltimore, Washington, and Kennedy?

Is it realistic to believe that there is a chance of 1/4 mile in TRW from 10:00 a.m. local all the way through to 6:00 p.m. such that it would not be possible for aircraft to land for 8 hours?

If this forecast is not revised, a carrier without the exemption will be virtually shut down the entire revenue day. Of course magically, at 6:00 p.m. the chance of 1/4 mile disappears, and an occasional appears at 3 miles.

From an operator's point of view, this type forecasting indicates either a misunderstanding or the regional carriers's needs, or a lack of concern on the part or the duty forecaster in examining and determining when the visibility should be acceptable for most users.

This is not a unique example as far as the forecast is concerned, but with the unique route structure of a regional carrier, such a forecast would have a major impact in the carrier's ability to serve the public -- a charter the National Weather Service also holds.

In this forecast, it is actually the conditional words "chance of" that shuts down the airport.

Every forecast should be, in the best judgement of the forecaster, honest, forthright, and reasonable. There is no doubt that some forecasts have conditional words added to compensate for liability if something out of the ordinary occurs. I have strong reservations in use of conditional words since conditional words, according to the inspector"s handbook, are binding.

We, the carriers, have to dispatch taking into account the worst possible weather scenario. The forecasters give me the worst possible weather conditions as if they will exist for the entire forecast period. This whole process is inefficient, costly, and certainly not in the best interest of the traveling public or the air carriers.

The carrier should only be bound by the main body of the forecast, and then be charged with the responsibility to evaluate the conditional phrases and determine their impact on safety and the operation.

2. CONTRACT FORECASTING

Carriers, given the forecast weather, closely watch the trends in the real world. When those trends indicate that the forecast should be revised, such requests have been made. I think it is important for this group to know, that carriers have begun giving up in their efforts to ask for assistance from the NWS. For years we have asked, when the actual weather conditions were not developing as the forecast, for an amendment to the forecast. For years we were told it would be looked at. For years we were given the argument that what we were experiencing was an anomaly (for 5 hours), or just plain shut out. In our case, and in the case of an increasing number of regional/commuter carriers, we have decided it is no longer worth the aggravation and effort to get a reasonable response, and switched to a contract forecaster.

The contract forecaster gives us bi-hourly forecasts, and rarely utilizes conditional phrases or words. Yes the contract forecaster was expensive in the beginning, but when I can continue to run revenue producing flights, the costs become negligible. We have switched all our forecast data to a contractor, and the cost per airport has been significantly reduced, and the quality is excellent.

As a note, the contract forecasting has consistently been more optimistic in the forecast conditions, and we have not missed a flight into a destination based on the contract forecast.

Please do not read more into this statement. All this last comment means, or should mean, is that the NWS forecasts are too conservative, too restrictive, and could be considerably more realistic, and still absolutely safe. To help put this into perspective, an airline is guaranteed never to have an aircraft accident if it never flies an aircraft -- but what is an airline for?

3. ENHANCED WEATHER INFORMATION SYSTEMS -- EWINS

Along this same vein or thought, the Regional Airline Association is aware of 2 regional carriers that are either already qualified in the EWINS program, or will be shortly. An EWINS dispatcher is really looking at the proposed forecast, the real world, and determining if they are in sync. Why should a carrier be required to revise a forecast, if the weather service fully supports its mission? EWINS is an alternative to the contract forecaster. I believe Mr. Randy Baker from United Parcel will be addressing this workshop later on today.

4. WINDS ALOFT

Throughout all of the Henson Airlines route structure, there are only 20 (possibly 21) stations providing data for winds aloft. Additionally, the winds aloft program provides for winds at 12,000, 18,000, 24,000 and 30,000. The 6,000 foot spacing fails to give enough data for the dispatcher and the pilot to choose the best altitude for the route of flight.

The high performance turbo-prop aircraft is measurably more efficient the higher it flies. The difference of 2,000 or 4,000 feet makes a considerable difference in the amount of fuel consumed. But, it is difficult to properly flight plan taking into account winds and temperature when the data comes to us in 6,000 foot increments, and then only sporadically along the route structure.

5. RVR ON HOURLY SEQUENCE REPORTS

RVR or VR is reported on the hourly sequence reports for the primary instrument runway. There appears to be no flexibility in that program. I am sure part of that is in the software for the 10 minute averaging that is reported, but still, the reported VR may not be applicable, nor useful.

Two weeks ago those of us on the East Coast had the opportunity to live through several days of just basic miserable weather -- for and low visibility. The category III runway at JFK was not available due to construction activity. We were all using other runways, but the VR on the sequence reports was for a closed runway -- now I ask, does that make sense.

It turns out that in this case, the NWS was told not to transmit the VR for runway 4 until further notice. It is interesting to note, no one knows who told the NWS not to transmit -- neither the FAA nor the NWS -- and no one knew how to get the VR turned on.

More salient to our situation here today though, is, that VR for alternate runways should be made available on the sequence reports. Regional/commuter aircraft are making every effort to avoid the primary, heavy jet runway, but the smaller carriers must receive support from the system.

Dispatchers and pilots should be able to receive hard copy transmission of the VR on the runways they will be using. As I mentioned before, any delay while telephone calls are made to destination airports does disservice to the public for that leg, and usually for many legs thereafter.

And, even for the heavy jets, if the prevailing winds dictate using other than the primary runway, the VR for a runway not being used at all is both a waste of time and precious dollars in transmission.

6. AWOS VERSES ASOS

That short title sounds like the beginning of a battle, which I understand it may be. The question is, should it be?

I think it is important to leave here believing, maybe even knowing, that the Automated Weather Observation Systems and the Automated Surface Observation Systems can be complimentary.

Of the airfields served by Henson Aviation, 10% are AWOS equipped. Without the automated systems, some of which have been in place for several years now, those communities might not have aircraft service to our great nation.

Obviously there has been a tremendous amount of testimony concerning the switch-over. I am sure all the arguments have been made. Unfortunately, I have not heard all the answers. I do not want to throw the baby out with the bath water. AWOS is alive and well. Maybe it is not all you would like it to be, but it is considerably better than looking for a part-time weather observer, full time airport employee to give you his or her best guess when you're outer marker inbound.

The cost of AWOS is about a third of that for ASOS. Would not cost be a major factor while we are trying to balance a budget?

My last comments on this relate to the availability and installation of the equipment. It is the understanding of the Regional Airline Association that the ASOS units will be installed first in medium to high density airports, with the smaller community airports to follow. With the cost per unit in excess of $100,000 per unit, how long will it take to get out to the community and county airports? And will there be any funding left?

The regional/commuter airlines were started to carry passengers from small rural airports into the metropolitan airports. The small community passengers keep the regional carriers, as well as the major carriers financially alive. Without the automated system, the smaller airports will loose 121 carrier service. Is that serving the public? I don't think so.

There are AWOS units available now. They work well in Alaska, and Florida. They increase safety for the flying public, and they financial are affordable to most non-metropolitan airports.

The phasing out of AWOS must be readdressed in the light of safety, reasonableness, common sense, and finance.

7. TURBULENCE AND ICING REPORTS

I only have a one liner here, -- please return those reports to the Area Forecasts. Sigmets and Airmets are fine, but from a regional carrier point of view, they better serve the user in the FAs.

THIS IS THE WRAP-UP

The National Weather Service grew up with the airline industry. The technology kept pace with the advancing capabilities of the jet aircraft. Unfortunately, the NWS left behind a void when the high performance commuter aircraft took to the skies.

The commuter aircraft of today serve a necessary and useful purpose to the public. With the advent of deregulation, the major carriers left the small towns and concentrated on metropolitan areas, and long haul. The regional carriers sprung up to carry those passengers needing access to our nation and the world. NWS does not always appear to see it that way.

There are 3 strata of aircraft now operating in the National Aerospace System -- the high performance jets, the high performance turboprops, and the general aviation piston driven aircraft. Lets make sure we are supporting all users of the system.

Lets not approach the forecasting business with the worst awfulism we can think of. Lets give the user the basic information and realize, if the weather is not ideal, the carrier has the responsibility, and will exercise that responsibility, to operate its aircraft safely.

Get rid of the conditional phrases, or at least make them reasonable and justifiable.

It is my understanding the regulations on forecasting and user requirements date back to 1936. I don't remember 1936, but a lot has happened since then -- a lot has happened since I started flying in

1966. Lets update our rules and regulations to 1991. The technology is here now, lets use it.

Lastly, concerning automated weather reporting equipment. Airlines constantly address the most economic means for accomplishing a task. Lets make sure we are getting the best product for our dollar. The user here is not only the regional/commuter carrier, but also the passenger. The passenger pays the price, no matter how it is buried initially.

Thanks for the opportunity to address this workshop. I hope I have sparked an interest to look at our system, and examine how it supports all the users, and insure all the users are receiving the best product.

Session 2.1

GENERAL AVIATION REQUIREMENTS FOR WEATHER SERVICES

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THE PROFESSIONAL PILOT'S PERSPECTIVE ON WEATHER

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There is a gap developing between the professional pilot and the aviation weather community. This gap is an increasing unawareness of the needs of the aviator and the capabilities of the weather program. It is important that the weather community understand the nature of this gap because ultimately aviation safety will suffer if it continues to grow.

1. The Role of Aviation Weather for the Pilot

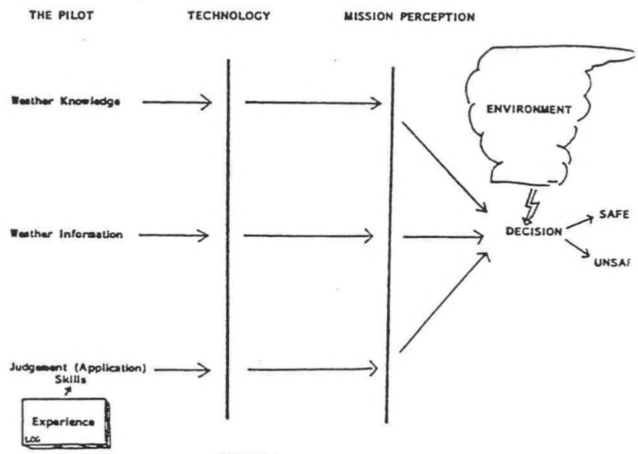

FIGURE 1
A SIMPLE VIEW OF PILOT WEATHER INTERACTION

Figure 1 shows a "model" of the pilot's perspective of aviation weather. By examining each element of the model, one can understand some of elements that make up the weather-aviator gap. The model focuses around the point when the environment causes the aviator to have to make a weather-related decision. The outcome can be a safe course of action or an unsafe action. The decision to fly or not to fly, the best route of flight to avoid a perceived hazard, or how to get away from a hazard that is already encountered are some of the more important decisions that the weather can force on a pilot. How the pilot handles the environmental situation will depend on three types of knowledge. The first is how much weather "theory" the pilot learned during basic and advanced training. The second type of knowledge is a situational awareness of what is going on in the atmosphere right now--a weather briefing prior to flying or an update during the flight. Finally, there is a knowledge based on experience using the theory and briefing in a similar situation--this is judgement that

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Opinions expressed in this paper are strictly those of the author.

only comes from prior experience or from discussing the situation in detail with an experienced aviator.

The knowledge base is then changed based on two different attitude-filters to arrive at the environmental situation where the airman has to make the safety-related decision. If one looks at each component of the model, then some of the causes for the gap between pilots and weathermen become obvious.

1.1 Pilot Weather Training

There have been many papers recently published that describe the current trend to decrease the amount of aviation weather training for pilots (Aviation Weather..., 1986; Massey, 1989; Miner and McCoy, 1989). This paper summarizes some of the main points.

The military, where the bulk of airline new hires come from, may not be a good role model for weather training. Currently the United States Air Force pilot-candidate receives 16 hours of weather instruction, eight of which are presented in question and answer format on a computer. The subject is "taught" by a young instructor pilot--many times the newest. To its credit the Air Force does require some annual "refresher" training (several hours in a classroom) on meteorology. The Navy and Army spend about 30 hours of classroom time teaching weather but neither require follow-on training.

Civilian oriented weather training is both a success and potentially a failure. Many universities have already established aviation departments and majors in aviation science, along with offering flight training. Most of these programs offer one or two college courses in meteorology either through their own department or in cooperation with local atmospheric science departments. Pilots coming from this type of training seem to be the most "weather wise". At the other end of the spectrum is the pilot trained by a local fixed-base operator, a flight school located at a local airport. Student pilots are guided by a single instructor and are at the whim of that instructor's strengths and weaknesses. All too often, weather is a weakness. In 1989 this author asked for inputs on weather training from the readership of a national popular flying publication. One letter is very interesting.

> "...The knowledge requirement in the weather theory area is appropriate for pilot training. My sense of the requirement is taken from practical experience and the information needed to pass FAA written exams.... The knowledge requirement for reading weather reports, forecasts, and charts exceeds the reality of the operational environment. In over 2,000 hours of flying I never had to read a weather report, forecast, or chart...My point is that getting weather information in an understandable format is not a problem. Therefore, reading weather reports, forecasts and charts need not be a testable event on written tests. Instead, training and testing should emphasize decision-making..." (Miner,1990)

This letter came from an FBO instrument and ground school instructor pilot. While he is correct that for his level of flying a Flight Service Station briefing is sufficient, his students who go off to become pilots for regional, national, and international flagship airlines will be missing a critical skill--providing a self-briefing for weather. This pilot also states that his guide to how much weather theory is necessary is based on the FAA written examinations.

In 1986 the FAA's Aviation Weather Task Force reported that the FAA's testing program was inadequate. It is probably common knowledge that a pilot can take all four written examinations for pilots, can miss everyone of the weather questions, and still pass each test to eventually become a captain of an international jet. The task force's report also stated that the weather material tested was in sore need of revision.

Guidance from the FAA Federal Aviation Regulations (FARs) is also lacking. To earn a commercial pilot certificate a pilot must pass a test on "Meteorology, including the characteristics of air masses and fronts, elements of weather forecasting, and the procurement and use of aeronautical weather reports and forecasts" (FAR 61.125). The requirements for the Airline Transport Pilot certificate (the PhD of flying in the United States) state that a test must be passed on seven meteorological topics. They include "(c) The general system of weather collection and dissemination; (d) Weather maps, weather forecasting, and weather sequence abbreviations symbols, and nomenclature; (e) Elementary meteorology, including knowledge of cyclones as associated with fronts; (f) Cloud forms; (g) National Weather Service Federal Meteorological Handbook No. 1, as amended; (h) Weather conditions, including icing conditions and upper-air winds, that affect aeronautical activities;... (j) Information from airplane weather observations and meteorological data reported from observations made by pilots on air carrier flights; (and) (k) The influence of terrain on meteorological conditions and developments, and their relation to air carrier flight operations" (FAR 61.153). The ATP requirements come only AFTER 1500 hours of flying time--the pilot with the most experience has the greatest requirements for weather knowledge.

So what do the air carriers do to increase the weather knowledge of their new-hire pilots? Very little. Training costs money and most carriers assume that the pilots they hire already have the skills they need. In the initial new-hire six to eight week training programs only one to three hours is spent on weather training--usually on how to read company weather reports.

Weather training for professional pilots is weak at best.

> IF YOU ARE GOING TO GIVE A PILOT WEATHER INFORMATION, THEN KEEP IT SIMPLE. AVOID METEOROLOGICAL TERMINOLOGY (I.E. BAROCLINICITY, ADVECTION, ETC.)

1.2 Pilot Weather Briefings

The second base of knowledge a pilot must have to make a safe flight decision relating to weather is an understanding of the current weather situation in which he or she is flying. Unfortunately this is the area that has the least consistency between airlines.

Most of the professional pilots in the United States have no direct access to meteorologists from their own company. This is direct contrast to the military, where most professional pilots come from and receive their initial training. Only the four largest passenger-carrying companies and the night-freight operations even have company meteorology staffs. In between the meteorologist--which would probably be the NWS--and most professional pilots is the dispatcher, an individual responsible for accomplishing the route selection, flight planning, and flight following. Dispatchers receive about the same amount of training as a pilot--the dispatcher's test and the ATP certificate test have the same question pool. Most dispatchers are located at a central facility so that the pilot must usually provide a weather "self-brief" before every flight.

All airlines provide textual information to their pilots as part of the flight documentation process. Most textual information includes a synoptic description, which consistently generates comments from pilots like, "How about spelling out the words all the way, guys!" Other textual information includes SAs and FTs for the take-off, landing and alternate airports, and significant weather hazard descriptions for terminals, thunderstorms, and clear air turbulence. Wind information usually comes out in printed flight plans but only for the filed route and altitude.

While most pilots receive textual weather briefings and have a dispatcher as a point of contact, very few have access to aviation weather graphic products that can provide the "big picture". In the fall of 1991, the Board of Directors of the Airline Pilots Association (ALPA) approved the recommendation of its Aviation Weather Committee to formally recognize the need for graphic weather displays to provide adequate and safe weather briefings.

It is appropriate to show how the three largest companies provide graphic weather information to its pilots. American Airlines uses an Alden C-5000 Graphic Weather Display in each of its major hubs (15 airports). This system uploads by satellite a dozen NWS graphic products and two satellite images for display on a color CRT or printed on paper. It also carries two color weather maps created by AA meteorologists. To support the South American operations, the Miami hub obtained a Jeppesen-Dataplan terminal--which had a staff of meteorologists behind it--to provide Significant Weather Prognostic Charts below Peru. AA provides no weather graphics to any of the remaining 150 airports that are not major hubs. Delta Airlines uses the Kavourous Vista system to provide custom graphics--made by Kavourous meteorologists-- and satellite images to its pilots at Atlanta. In 1992 several other hub airports will also have Vista systems, but again most of the airports have no graphic support. United Airlines does provide graphic weather pictures to all 105 airports in the continental United States. This airline has a three-year contract with Jeppesen-Dataplan--with its own meteorology staff--to provide a two-panel weather map on an 8 1/2 by 11 sheet of paper which contains radar data, frontal locations, significant hazards at flight level and weather depiction information. This sheet is faxed to each station from one to four times a day depending on the level of activity at that airport.

In two out of three cases the NWS products are not used by major international airlines for pilot briefings.

RECOGNIZE THAT MOST PROFESSIONAL PILOTS NEVER TALKED TO A METEOROLOGIST NOR SAW GRAPHIC WEATHER INFORMATION BEFORE FLYING.

Because of the lack of weather graphics, pilots have had to look for alternate sources of information. Massey (1989) cited one survey that showed the most common weather graphic used by professional pilots in the United States is the back page of the USA Today. When asked what single improvement could be made to their company's weather briefing program, over 40 percent of the professional pilots polled said they would like to have the Weather Channel permanently running in their flight planning rooms. The appeal of this weather source is that it is REAL TIME--a quality that pilots crave.

MOST PROFESSIONAL PILOTS HAVE A HEALTHY SKEPTICISM ABOUT WEATHER INFORMATION THAT GROWS THE FARTHER AWAY THE INFORMATION IS FROM REAL-TIME.

Pilots are also looking for concise forecasts. The more fudging and conditional a forecast is, the less credibility it has to the user. To be well received, a forecast must show the pilot as precisely as possible forecasted weather conditions--especially when terminal forecasts are made.

1.3 Pilot Experience

Finally, a pilot comes to weather decision point with a set of aviation experiences which allow the pilot to use the weather theory and the weather briefing in a safe manner. The experience level depends on the pilot's flight time and the opportunity to deal with weather.

The average level of experience within the professional pilot corps is decreasing. Because of the FAR that states that airline pilots must retire after reaching 60 years of age, there is a finite level of experience that professional pilots reach. American Airlines and Delta Airlines have been hiring pilots for the last three to four years. As American has grown the average experience level of its new captains has decreased to about seven to eight years. United Airlines is on the verge of a major hiring effort due to increasing number of retirements. As some airlines have ceased operations, the younger pilots are being hired but rarely do the older pilots return to flying. Flying experience levels continue to decrease which create captains with less and less experience to make weather-related decisions.

2. Weather Attitudes That Change Pilots Perspectives

There is more to the equation. The professional pilot arrives at a weather-decision point with a knowledge of weather theory, a knowledge of current weather events, and an experience level. The same pilot can make different decisions on different days because of two "attitude filters" that can directly influence how weather is perceived.

2.1 Technology Perception

The first filter is the pilot's perception of the technology that is at his or her disposal. The technology is usually the type of aircraft under his or her command.

Icing is an excellent example. These conditions are a terror to a single-engine Cessna. Icing is a concern to the pilot of a light twin. But, icing is usually only a bore--only one more switch to turn on and off--to the pilot of a jetliner. As technology "increases" the need to worry about the weather decreases.

Unfortunately, there is a small percentage of "jet-jockeys" that have become convinced that their technological marvels are immune to weather's hazards. They are the one's that can be heard saying, "...WHY THIS BABY WILL GO THROUGH ANYTHING..." This unprofessional attitude has the potential to lead to injury and equipment damage.

Even more common is the subtle filter that aviation decision-makers have that adding more and more technology to aircraft (i.e. radars, stormscopes, etc.) produces safer aviation. What is dangerous is that many times there is little or no time spent training the pilot to use this technology. There are many documented cases of pilots just turning off equipment because they were not trained to use it properly. This is the biggest reason for the overall decrease in pilot weather education--aircraft have gotten bigger and fly higher.

2.2 Mission Perception

The final attitude that influences just how a pilot responds in a weather-decision situation is that pilot's perception of the mission. Examples of this are the importance of the flight and how fast it needs to be completed. Some pilots might take shortcuts through areas of forecasted turbulence or icing if it means getting to the destination faster. When a company puts pressure on a captain for on-time schedule performance, there is a chance that some weather conditions will be discounted.

Unfortunately, it is very common in the airline industry to hear the phrase, "WHO CARES ABOUT THE WEATHER, WE'RE GOING TO GO ANYWAY." It is a attitude that runs from the line pilots all the way up the corporate ladder to the most senior company officers. Flights canceled for weather don't make money.

3. Fixing the Problem

The gap between the professional pilot and the aviation weather system is all too evident now. The amount of weather theory taught to pilots has decreased as the aircraft technology has improved. Professional pilots have fewer and fewer opportunities to directly consult with a meteorologist or to view weather graphic products before flying. The experience levels of professional pilots, which might compensate for the decrease in theory and briefing, are also decreasing. Two attitudes exist in the aviation world that further the gap. The first is that more technology--even without training--is better. Second, in the world of professional aviation planes are going to fly anyway. This gap must be decreased before safety is compromised.

Much of the weight of fixing the current relationship between pilots and weather falls on the airlines and the FAA. There must be a healthy regard for the basic airmanship skill of weather from those responsible for pilot training. To help bridge the gap, weather forecasters working with aviation must be aware of three key rules.

KEEP IT SIMPLE

Keeping the weather simple and non-technical helps pilots understand what is going on with only limited amounts of meteorological training.

KEEP IT REALISTIC

Forecasts with many conditional statements are only confusing to pilots and disruptive of flight operations. The weather forecaster must work to insure that all products are as precise as possible.

KEEP IT CURRENT

By keeping weather products as current as possible they are not only more realistic, but they are also more credible. Whenever possible, forecasted weather that is different from reality should be amended, even when amendment criteria have yet to be met.

4. Conclusions

Despite technology advances and an ever growing aviation segment in the United States, the professional pilots and the aviation weather system that was designed to keep them safe are growing further apart. From the flight departments there must be a heathy reevaluation of the role of weather training in preparing airmen to maintain safe flying --the primary goal of aviation. From the aviation weather system there must be an emphasis in communicating effectively with an audience with limited skill levels and a skeptical attitude about the product. There must also be an ongoing dialogue between pilots and forecasters to insure that the historic relationship between these two groups of professionals is not lost.

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THE IMPACT OF TERMINAL FORECASTS ON FUEL LOAD PLANNING

Jeff Hubright
Delta Airlines

The Delta Air Lines meteorology department utilizes a staff of 27 individuals to provide worldwide meteorological support from its office in Atlanta. One of the functions of the department is to provide valuable input to the Flight Control Superintendents as they determine how much fuel to load on each flight. This load is largely determined by the terminal forecast for the flight's destination. The flight control superintendent is required by FAR to dispatch each flight with enough fuel to operate in a safe manner. However, it costs to carry fuel, and it is the further responsibility of the Superintendent to minimize this cost.

One hundred forty North American terminal forecasts are issued by the Delta surface forecasters every eight hours. These fourteen hour category forecasts are issued by two individuals, who divide their areas of responsibility at the Mississippi River. The three forecast categories are defined below:

NA "No Alternate"	cig/vis greater than 2000'/3 mi No TRW activity No freezing precipitation
NF "No Factor"	cig/vis less than 2000'/3 mi but greater than/equal to 600'/2 mi No TRW activity No freezing precipitation
Detailed	cig/vis less than 600'/2 mi specifies TRW activity specifies freezing precipitation

Adverse weather, or the forecast of adverse weather, causes flight control superintendents to increase the amount of time the flight will be able to hold inbound to its destination and to designate alternate airport(s) for the destination. The flight control superintendents will consider items such as the volume of traffic at the specific destination and the type of adverse weather in determining how much additional hold fuel will be required. In some cases, especially those involving convective activity, two alternate airports may be designated to make sure the flight has valid options should the destination airport be unusable.

Carrying additional fuel to enable the flight to hold or divert to an alternate airport costs money. Carrying fuel is the same as carrying passengers or cargo in that more energy has to be expended to carry more weight. A general rule of thumb used at Delta to calculate this cost is to take 3 or 4 percent of the product of the additional fuel required and the time en route. Consider, for example, a flight from Los Angeles to Atlanta with an alternate airport of Knoxville and an additional 30 minutes of hold time planned.

The use of Knoxville as an alternate airport requires an additional 4500 to 6000 pounds of fuel, (depending on aircraft type), as does the extra 30 minutes hold time. The flight, then, is carrying an additional 10000 pounds of fuel for its four hour duration. To calculate the cost of carrying this extra fuel (at 3.5%):

$$10000 \times 4 \times 0.035 = 1400 \text{ lbs.}$$

In other words, it takes 1400 pounds of fuel to carry 10,000 pounds of fuel for four hours. At the current fuel price of $0.10 per pound, the cost for this flight to designate an alternate and hold an additional 30 minutes is $140. While this may seem to be a trivial sum, consider the effect of multiplying this number by hundreds, (number of daily flights into Delta hub cities), and hundreds again, (number of days per year when weather significant to flight operations could reasonably be expected to occur.)

To verify the 3-4% rule of thumb, look at the example of August 2, 1991. The original Delta forecast for Hartsfield Atlanta International called for isolated thunderstorms, a detailed forecast for air mass convection. Flight control superintendents responded accordingly, designating alternate airports for flights inbound to ATL. By 1700Z the Delta surface forecaster had reconsidered his original forecast and amended the ATL terminal forecast to NA. Several superintendents were able to rewrite flight plans, allowing for an "apples-to-apples" comparison of the cost of designating an alternate. Three examples are shown below:

	JAX-ATL	DFW-ATL	LAX-ATL
ACFT	B-757	L-1011	B-767
PAX	187	302	254
Time/ Burn	0:43/6610	1:35/30250	3:54/45560
Time/Burn to TYS	0:28/4290	0:25/9350	0:28/6210
NO ALTN Time/ Burn	0:43/6490	1:35/29790	3:54/44670
Fuel Saved	120	460	890
% of fuel load req'd by altn	2.4	3.3	3.6

Flight control superintendents utilize weather information from a number of sources. In making a decision to designate an alternate, both Delta and National Weather Service forecasts are considered. When these forecasts disagree, the superintendent must decide which is the more accurate. Some will discuss the situation with the Delta meteorologist, others will utilize the more conservative of the two forecasts, and still others will rely on their personal experience and weather expertise with the airport in question. Some superintendents are influenced by conditional language in the NWS forecasts. To illustrate, the Delta forecast for ATL issued at 0700Z on 13 September 91 was NA (or no alternate) through 1700Z. The NWS forecast for Atlanta, issued at 0800Z, called for OCNL 11/2F between 1000Z and 1300Z. Of 102 Delta flights arriving at Atlanta between 1100Z and 1400Z on the 13th, 32 carried an alternate and 70 did not.

The question may be asked, "What would have happened to those 70 no alternate flights had Atlanta's weather deteriorated in fog?" A number of flights would have diverted to locations throughout the Southeast due to their inability to hold for sequencing into Atlanta. Both direct and indirect costs are incurred by the airline when this occurs. The direct costs such as landing fees and the additional fuel burned to fly to and land at the diversion airport and return are bad enough, but the indirect costs - frustrated passengers, missed connections, down-line delays caused by the aircraft not being where it is supposed to be, additional congestion and workload at the diversion airport - are more significant. It is a tribute to the teamwork of flight control superintendents and meteorologists at Delta that the company led the industry during 1990 with the fewest diversions, according to an FAA - directed study.

Never forgetting that the primary concern of the airline is safety, Delta meteorologists strive to provide flight control superintendents with concise, accurate forecasts for each terminal. Category forecasts ease the burden of typing and monitoring the weather. Precise timing of the onset and ending of events and the avoidance of conditional language allow superintendents to make timely and accurate decisions. Responsive amendments aid the process, regardless of whether the situation is deteriorating or improving more rapidly or more slowly than originally forecast. Amendments of a few hours and "good weather" amendments can make significant differences. Waiting for the next scheduled forecast time can waste significant resources. Conditional language that covers too long of a period causes inefficient airline operations and in this period of airline bankruptcies may lead to loss of jobs.

Most Delta meteorologists use the NGM as their primary synoptic-scale prognostic tool. The NMC upper air and surface analyses are available, as are most of the NMC-produced facsimile products. Synoptic scale surface analyses are done manually three times a day and may be supplemented by regional surface analyses at the discretion of the individual forecaster. A PC-based subscriber system allows for displaying, rectifying and looping satellite and radar imagery. This system also allows forecasters to develop their own custom prognostic charts, covering regions and using parameters the individual forecaster feels are significant.

Delta meteorologists provide an invaluable service to the company by helping flight control superintendents safely plan each flight. By clearly communicating the onset of good flying weather at Delta destinations, meteorologists can also take an active role in the economic well-being of the company.

Session 2.4

THE FAA WEATHER R & D ACTIVITIES

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MANUSCRIPT WAS NOT AVAILABLE AT THE TIME OF PUBLICATION

Session 3.1

DEVELOPMENT AND DISSIPATION OF FOG AND STRATUS

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MANUSCRIPT WAS NOT AVAILABLE AT THE TIME OF PUBLICATION

SEA FOG AND STRATUS: A MAJOR AVIATION AND MARINE HAZARD IN THE NORTHERN GULF OF MEXICO

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1. INTRODUCTION

Sea fog and stratus can affect extensive areas of the northern Gulf of Mexico, especially during the Winter and early Spring months (December - March). During this time of year, polar and/or arctic outbreaks bring colder air south across the Gulf cooling the shallow waters of the continental shelf. Cooler water from the major rivers emptying into the Gulf also adds to the cooling effect of the immediate coastal waters. Dense sea fog and the associated low ceilings and visibilities can create a major aviation hazard for over 700 daily helicopter flights to and from offshore oil platforms. Over 35,000 persons are working in the Gulf in support of the oil industry, most transported by helicopters. This paper describes four types of sea fog (cooling, evaporation, frontal, and radiational) including the associated low ceilings and visibilities which develop across the northern Gulf. Most of the research on forecasting the onset, duration, and dissipation of sea fog has been for such geographical areas as the west coast of the United States, Sea of Japan, China Sea, North Sea, and the western north Atlantic. Very little research has been conducted on this significant weather problem in the northern Gulf of Mexico.

The purpose of this study was to develop techniques to help the forecaster identify those synoptic patterns which are conducive to the development of sea fog and stratus in the northern Gulf of Mexico. Graphical aids using important meteorological parameters were developed to assist the forecaster. The significance of this study is to reduce or eliminate the loss of life and property due to aviation and marine accidents in the northern Gulf, and the immediate coastal plains.

There is no numerical fog model available for use in the Gulf of Mexico. This paper will highlight a forecast technique recommended to the forecast staff at the New Orleans National Weather Service Forecast Office (WSFO). An application program has been written on a personal computer (PC) for use in plotting several key parameters that are available twice daily in bulletin format from the Nested Grid Model (NGM).

2. METHODOLOGY

Climatological data for ten Supplementary Aviation Weather Reporting Stations (SAWRS) located across the northern Gulf of Mexico were evaluated for the Winter and early Spring months during the years of 1985-86, 1988-89, and 1989-90. These stations are located generally along and north of a line from 28 N to the coast and west of 89 W (Fig 1). Sea fog and stratus occurs most frequently in this area. Observations were taken from oil platforms which average near 35 m above the water. The data analyzed for this study were air temperature (Ta), dew

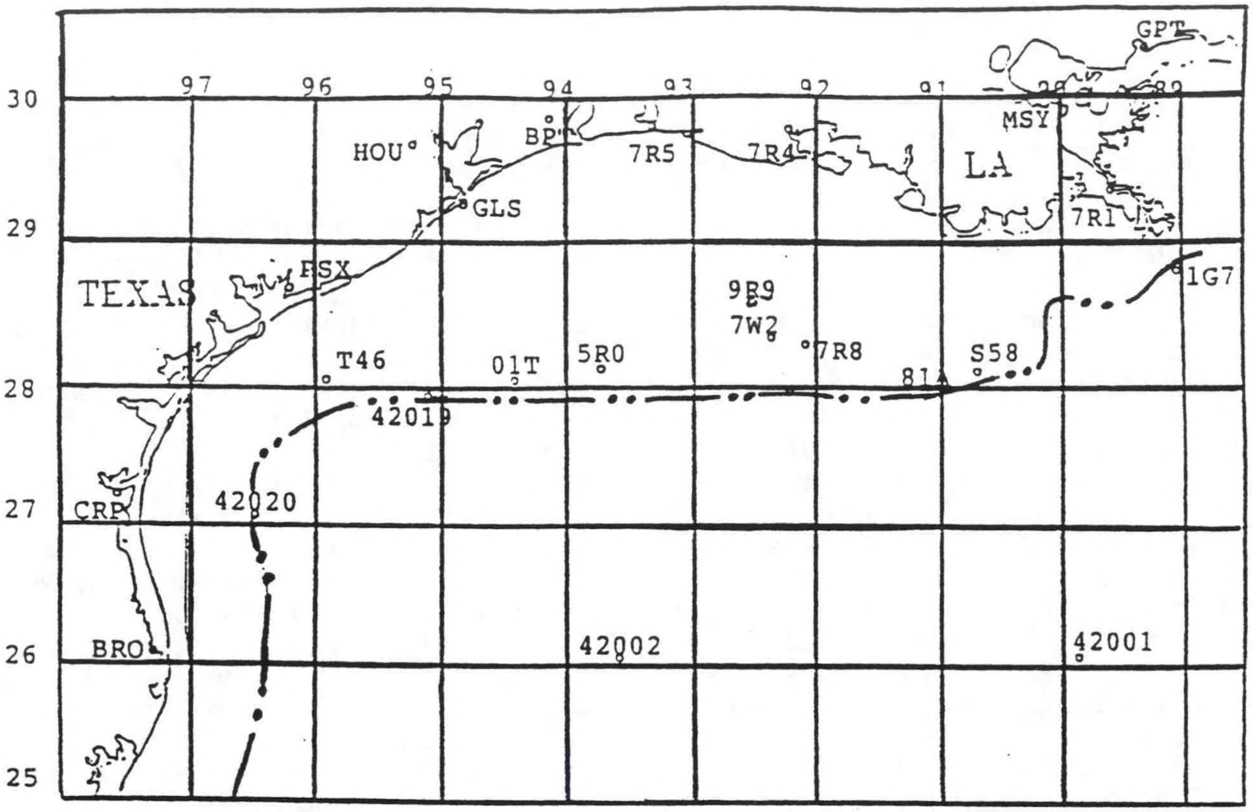

Fig. 1. Geographical map of SAWRS in the northern Gulf.

BRO - Brownsville, Texas
CRP - Corpus Christi, Texas
PSX - Palacios, Texas
HOU - Houston, Texas
GLS - Galveston, Texas
BPT - Beaumont, Texas
7R5 - Cameron, Louisiana
7R4 - Intracoastal City, Louisiana
7R1 - Venice, Louisiana
MSY - New Orleans, Louisiana
GPT - Gulfport, Mississippi
42001, 42002, 42019 and 42020 weather buoys in the Gulf. 200 m contour ——— . . ———

point temperature (Td), wind direction and speed, ceilings, and visibilities.

Sea surface temperature (SST) analyses for this study were provided by the oceanographer at the National Hurricane Center (NHC) in Coral Gables, Florida. This information was used with other meteorological data to develop a forecast technique for sea fog and low stratus.

3. TYPES OF SEA FOG IN THE NORTHERN GULF

Sea fog develops mainly during the Winter and early Spring and can occur with several synoptic patterns. The four different types of sea fog identified in the northern Gulf were: warm advection (cooling), cold advection (evaporation/ steam), frontal (mixing), and radiational. Also, typical ceiling heights and visibilities have been identified with each type of fog.

Sea fog and the associated low ceilings and visibilities are possi ble from November to April. However, they are more likely from December to March with January and February having the greatest frequency. The coldest air masses of the season usually invade the Gulf during January and February creating the more ideal conditions for widespread sea fog. Of the four types of sea fog, warm advection (cooling) and cold advection (evaporation) are the most prevalent and produce the most critical weather for aviation and marine operations in the northern Gulf.

There are two main synoptic patterns that dominate during sea fog development. Warm advection (cooling) fog forms with the first pattern. Kotsch (1983) and Mullan (1984) describe the dynamics of this process very well. This pattern is characterized by warmer air with higher dewpoints flowing over colder water which is found in the shallow waters of the continental shelf. The continental shelf is delineated in Fig. 1 by the 200 m contour. The boundary layer flow is anticyclonic around a surface high pressure system which is usually located in the southeast United States. The air mass spreads north or northwest over the northern Gulf and is initially maritime polar and warmer than the water (mPw). It can eventually become maritime tropical (mT) if return flow continues long enough before another cold front moves into the Gulf. Figure 2 illustrates a typical synoptic pattern during the wintertime which is conducive for advection (cooling) fog to develop. This is a stable pattern as described by Binhau (1985) and Hsu (1988) with the prevailing surface wind direction from southeast to southwest (120-220 degrees). Figure 3a indicates what type of wind speed is desired under certain Ta - Td conditions (Ta is air temperature and Td is dew point temperature) for sea fog. Figures 3b and 3c give another estimate of visibility associated with sea fog under certain conditions of water temperature (Tw), Ta, and Td. The depth of the sea fog is usually < 100 m, depending greatly on the wind speed. This type of fog is usually extensive in coverage with a longer duration. Depending on the synoptic pattern and wind profile, this type of fog could have a duration of several days.

The second synoptic pattern which characterizes the Winter regime over the Gulf is the cold advection (evaporation) fog which is commonly known as steam fog. As described by Wessels (1979), colder air accompanied by moderate to strong wind flows south over warmer waters such as the Gulf of Mexico. The wind direction is normally from northwest to northeast (310-040 degrees). The lowest visibilities with this type of fog are found with relative humidities of 90 percent or greater and Tw - Ta ≤ 15 C. This can be noted on Fig. 4. Ceilings and visibilities can be reduced to zero even with a north wind of 30 kt (15 m/s). This type of sea fog forms in an unstable air mass as described by Binhau (1985) and the depth of the fog is usually < 35 m. Note from Fig. 4, visibilities are generally ≤ 3 mi (4800 m) when there is fog. Duration of steam fog is normally < 18 hours with duration of dense steam fog 6 hours or less. Table 1 gives the various ceilings, visibilities, and frequency of occurrence with this type of fog. Areas of dense steam fog are usually not as widespread as fog due to warm advection.

The third type of sea fog is the frontal type commonly known as

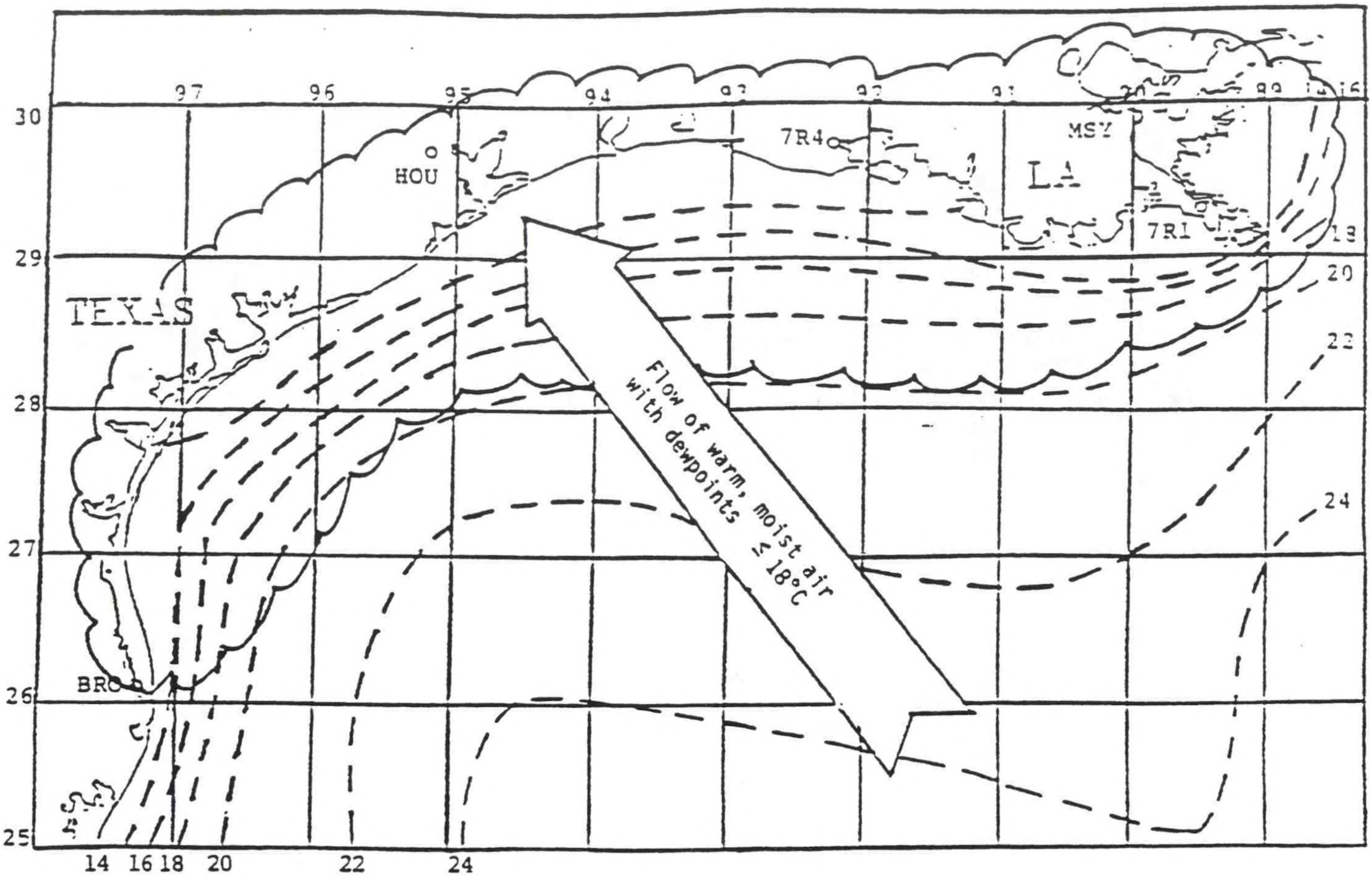

Fig. 2. Typical synoptic pattern during the wintertime with return flow of warm air with higher dewpoints over colder water in the northern Gulf. Scalloped area is areas of potential sea fog. Dashed lines are SST in °C.

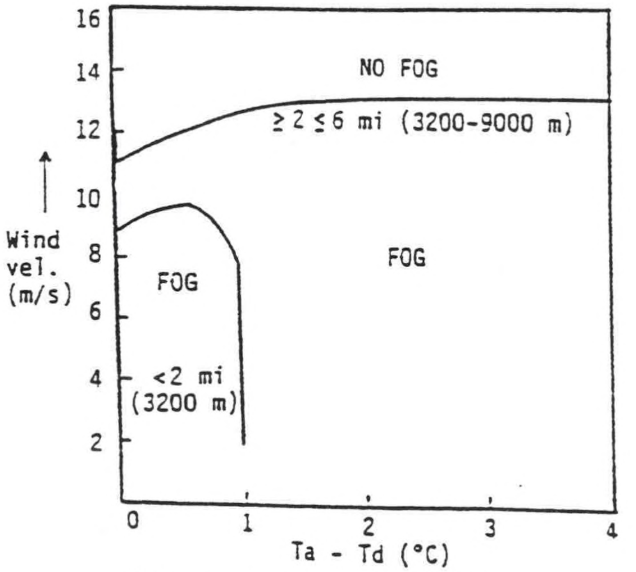

Fig. 3a. Warm advection (cooling) fog

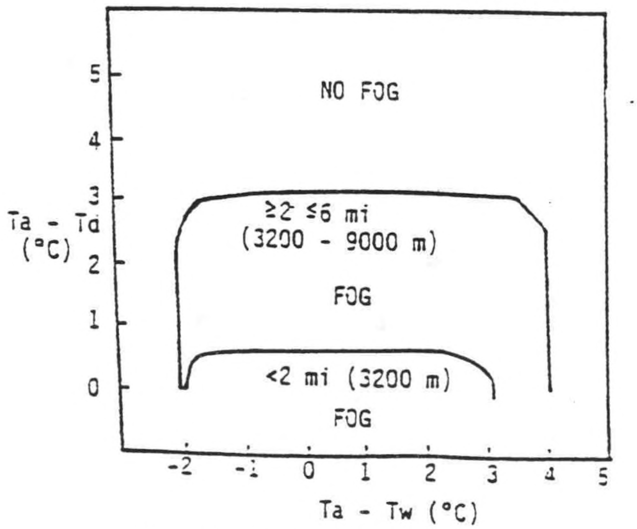

Fig. 3b. Warm advection (cooling) fog

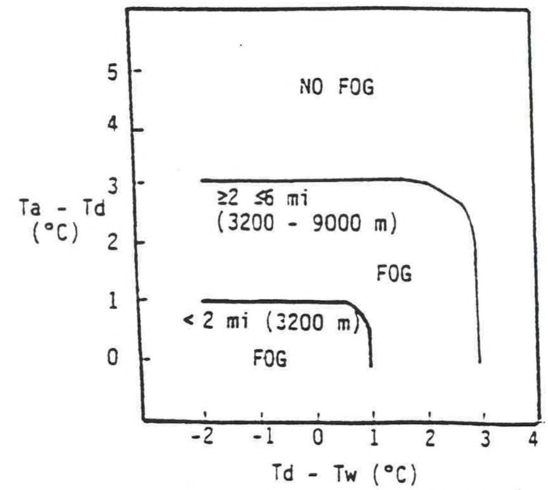

Fig. 3c. Warm advection (cooling) fog

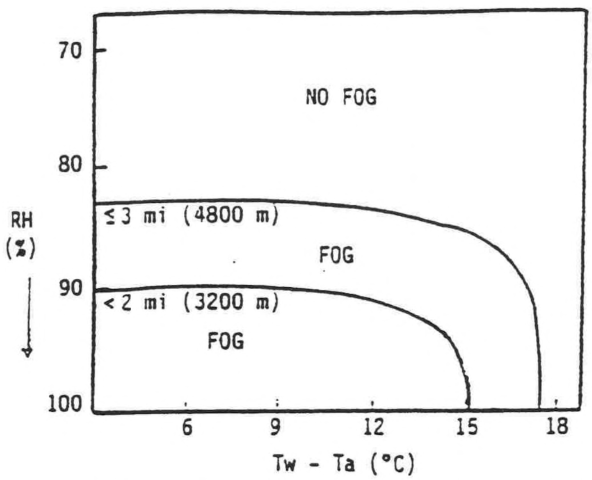

Fig. 4. Advection (evaporation/steam) fog

Table 1. Guideline of values for ceilings and visibilities when forecasting sea fog and low stratus in the northern Gulf of Mexico from December to March

Type of Sea Fog	Ceilings hnds ft/m	Visibilities mi/m	Occurrence	Frequency %
Warm advection (cooling)	<5/152	<2/3200	Occasional	50
	5-10/156-304	2<6/3200-9000	Frequent	
	>10/304	≥6/9000	Frequent	
Cold advection (evaporation) (steam)	<5/152	<2/3200	Occasional	25
	5-10/152-304	2-3/3200-4800	Frequent	
	>10/304	>3/4800	Occasional	
Frontal (along and 50-70 nm north of warm or stationary front	<5/152	<2/3200	Frequent	20
	5-10/152-304	2-4/3200-6000	Occasional	
	>10/304	>4≤6/6000-9000	Occasional	
Radiational (light wind - clear skies)	≤2/061	≤½/0800	Frequent	5
	>2-5/061-152	>½≤2/0800≤3200	Occasional	

Note: Sea Fog occurs most often when SST is ≤20° C (68° F)

the mixing fog. This type forms with a nearly stationary front or warm front in the northern Gulf. Warmer air aloft overruns a shallow layer of cold air near the surface which may not be more than 100-300 m in depth. This process has been described very well by Hsu (1988).

The fourth type of sea fog is formed by radiation over a calm sea under clear skies and very light wind. This type comprises a very small percent of the sea fog episodes across the northern Gulf.

Duration and dissipation of sea fog greatly depends on the wind speed and dewpoint temperature of the air as well as the temperature of the water (Tw). A critical Tw of 20 C was identified during this study for the development of significant sea fog (visibilities < 2 mi or 3200 m). With a Tw of 20 to 24 C, light to moderate fog was likely and above 24 C, no fog was observed. Our findings were similar to those of Binhau (1985). An estimate of these parameters can be derived from the forecast technique which will be described in Section 5.

4. GRAPHICAL FORECAST AIDS

Several graphical aids (scatter diagrams) have been developed using climatological data for ten SAWRS in the northern Gulf along and north of 28 N and west of 89 W (Fig. 1). In addition to the parameters discussed in Section 2, sea water temperatures (Tw) were used in developing the graphical forecast aids. These aids will serve as another tool for the meteorologist to use in preparing aviation forecasts for the northern Gulf and adjacent coastal plains during the Winter and early Spring seasons. The first three graphs have been developed for advection (cooling) fog (Figs. 3a, 3b and 3c). Fig. 3a which utilizes wind speed is more representative of the area north of 28 N and west of 92 N, especially in depicting dense sea fog (visibilities < 3200 m) where the areal extent of colder water is greater. This follows the outline of the continental shelf (Fig. 1) where the sea surface temperature (SST) gradient is greatest. As mentioned earlier, if the wind velocities are too high (> 13 m/s), fog is unlikely even if the Ta - Td is small (Fig. 3a). Dense sea fog is observed with wind speeds < 10 m/s. Hsu (1988) found similar results in his study of the north Gulf.

If Ta - Td is too large (> 3 C), then fog is unlikely regardless of Ta - Tw (Fig. 3b). The fourth graph (scatter diagram) was developed for forecasting cold advection (evaporation) fog or commonly known as steam fog (Fig. 4). Visibilities normally associated with this type of fog are usually ≤ 3 mi (4800 m). Fog is unlikely with relative humidities < 83 percent. Dense sea fog is normally found with relative humidities > 90 percent with Tw - a ≤ 15 C.

Another forecast aid which is useful to the forecaster is illustrated in Table 1. This table gives the most likely ceilings and visibilities associated with each of the four types of sea fog as well as frequency of occurrence. These guidelines can be very useful despite the limited data sample (3 Winter seasons) used in this study.

5. OPERATIONAL FORECAST TECHNIQUE

An operational numerical fog model is not yet available for the Gulf of Mexico. An experimental fog model is under development for the Atlantic Ocean. In view of the critical nature of sea fog and low stratus for aviation and marine operations in the northern Gulf, a local technique for forecasting these parameters was developed. An application program was written for a personal computer (PC) for use in plotting several key parameters which are available twice daily in bulletin format from the Nested Grid Model (NGM) at 6 hour intervals. These parameters are: 1) boundary layer temperature (surface - 965 mb), 2) boundary layer relative humidity (surface - 965 mb), 3) sea level pressure in mb, and 4) boundary layer wind direction and speed (surface - 965 mb). This information is plotted by computer on a map background and then the latest SST

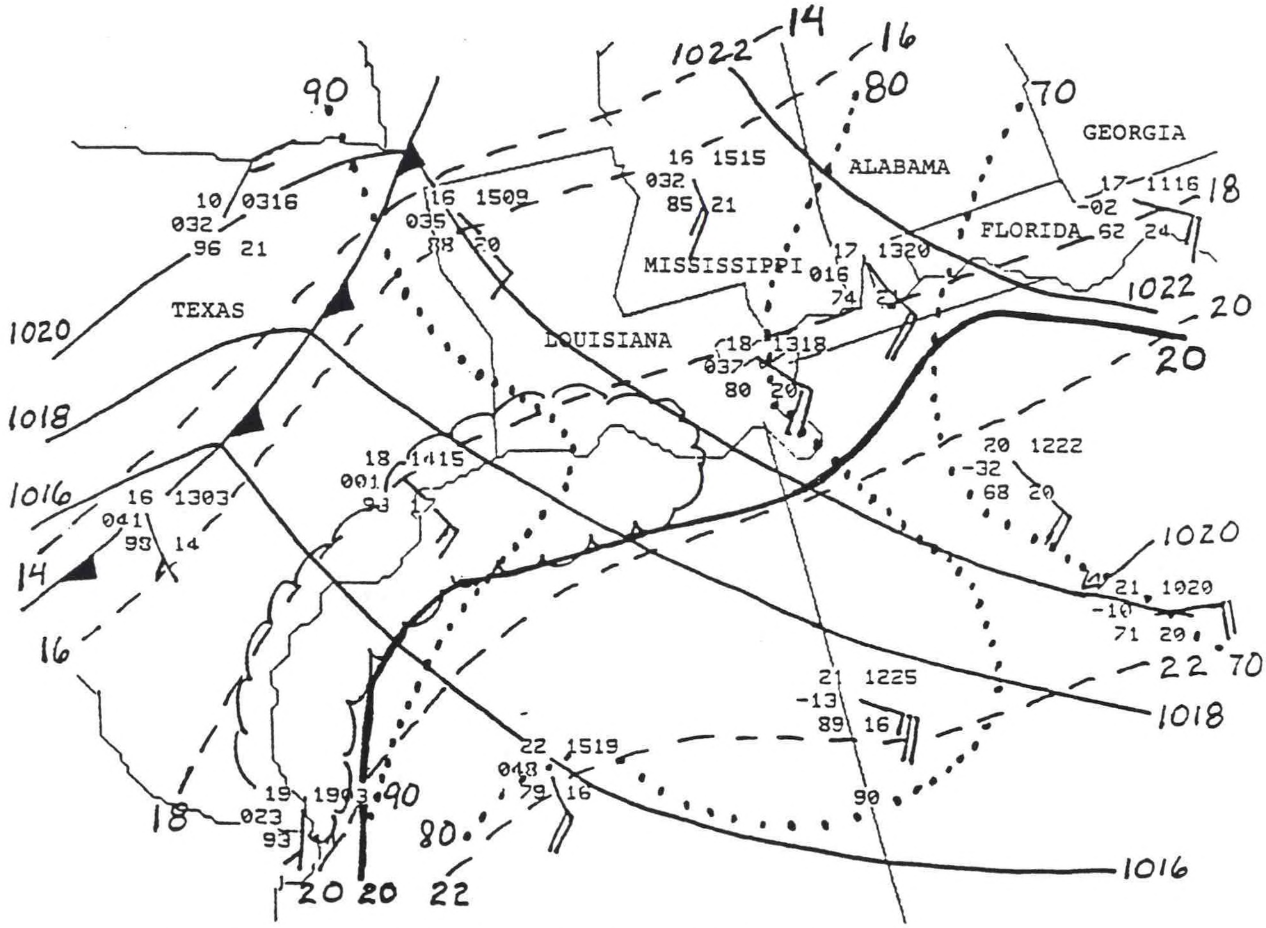

Fig. 5. Example of computer output (forecast) from NGM with parameters analyzed.

Legend for Analysis

- SST — heavy solid line
- T — dashed line
- R — dotted line
- SLP — solid line
- Threat Area of Sea Fog — scalloped outline
- Cold Front — line with triangles

Station Plot Legend

TT ——> 18   1318 <—— DDFF
VV ——> 037   o
RR ——> 80   20 <—— SLP

T - Boundary layer temperature (°C)
R - Boundary layer relative humidity (%)
DDFF - Boundary layer wind direction and speed (KT)
SLP - Sea level pressure (mb)
VV - Vertical velocities (10^{-3} mb)

critical isotherm of 20 C is overlaid. The parameters (guidance) from the NGM closely approximate the expected values near the surface. These parameters are analyzed and the potential threat area for sea fog development is identified. See Fig. 5 for an example of this product. Forecasters should note that in a study of return flow events in the Gulf of Mexico during the Winters of 1989-90 and 1990-91, the NGM was about 12 h slow on a 36 to 48 h forecast in returning moisture northward across the northern Gulf. This study was accomplished by some of the forecast staff at the New Orleans WSFO. Similar results were achieved by Janish (1991) in a study of return flow events. Therefore, this should be taken into consideration when making aviation forecasts concerning return flow. This method is still in an experimental stage.

6. RECOMMENDATIONS FOR IMPROVEMENT IN SEA FOG FORECASTING

In an effort to improve the forecasting of sea fog and low stratus ceilings in the northern Gulf, additional gridpoint data from the NGM has been requested. This additional data from the model over the northern Gulf would be in an area along and just north of 28 N and between 89 W and 96 W. Currently the only grid point data (in bulletin format) available for forecasts in this area is along the Gulf Coast and generally in the central and south Gulf. The additional data requested would be in an area where numerous SAWRS are located. Additional graphical aids should be developed for immediate coastal areas as well as east and west of 92 W over the water. This should give greater detail to the forecast guidance. Also, enlarging the data sample may improve the graphs a little more.

7. CONCLUSIONS

This paper described the reasons for developing a technique for forecasting sea fog and low stratus in the northern Gulf. This meteorological phenomena is a major aviation hazard in the northern Gulf. Little if any research has been done on this aviation problem in this geographical area.

After evaluating and analyzing the climatological data, a series of graphical forecast charts using various meteorological parameters were developed as an aid for forecasting visibilities associated with sea fog. In addition, a table of recommended ceilings and visibilities were developed for the different types of sea fog and stratus.

Using the application program, graphical aids (scatter diagrams), and table; the aviation forecasts should be improved for the northern Gulf and adjacent coastal plains.

8. ACKNOWLEDGMENTS

Dan Smith, Scientific Services Division of National Weather Service, Southern Region Headquarters, made available climatological data for the SAWRS in the northern Gulf. The authors wish to thank Joel Schexnayder, WSFO, New Orleans, for his helpful comments. In addition, Jim Moser wrote the application program for the PC for use in the fog forecast. Also, a special thanks to Paula Bolline for typing the manuscript.

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THE EFFECTS OF SUMMER TIME STRATUS AT SAN FRANCISCO INTERNATIONAL AIRPORT ON THE NATIONWIDE FLOW OF COMMERCIAL AIRLINE TRAFFIC

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INTRODUCTION

Suppose it is 6 PM CDT and you are at the airport in Kansas City. You have checked your baggage and are ready to board your plane for San Francisco. Much to your surprise, a voice comes over the loud speaker announcing a one hour delay in take off due to weather at San Francisco.

You check with the National Weather Service. The weather is clear with a west wind of 18 knots. The forecast for your time of arrival is for some cloud cover at 1200 feet but no rain, no storms, and good visibility.

So, why the ground delay?

GROUND DELAYS INTO SAN FRANCISCO

More ground delay programs are issued for San Francisco International than any other major airport. For 1989, the last year for which we have statistics, there were over 200 delay programs. This number is more than one and one half times the number issued for the second highest delay airport, Newark (Fig. 1).

It's not that the weather is particularly harsh at San Francisco, it's not. The weather is mild. Thunderstorms rarely occur. Fog is rarely a problem. So why the delays?

There are three reasons:

1. Close proximity of the main runways.

2. Large volume of traffic during peak arrival times.

3. Summer stratus requiring instrument approach procedures.

NATIONAL GROUND DELAY PROGRAMS
ALL MONTHS...1989

AIRPORT OF PROGRAMS	NUMBER
San Francisco	202
Newark	124
Boston	118
Kennedy	113
O'Hare	113
Philadelphia	110
LaGuardia	101
Denver	86
Saint Louis	66
Charlotte	63
Atlanta	61
Dallas/Ft. Worth	58
Midway	52
Seattle	45
Pittsburg	23
Detroit	22
Minneapolis	16
Houston International	8
Los Angeles	8
National	6
Orlando	6
Memphis	5
Dulles	5
Baltimore	5
Cincinnatti	4
S. Florida	2
Cleveland	1
Nashville	1
Portland, OR	1
TOTAL	1445

Figure 1.

CLOSE PROXIMITY OF THE MAIN RUNWAYS

The runways at San Francisco International Airport were built in the early 1950's, adjacent to San Francisco Bay. Under normal conditions, aircraft land on the two main runways, 28R and 28L; landing from the east southeast toward the west northwest (Figs. 2a & 2b). The airport has Instrument Landing System (ILS) equipment which allows most aircraft to land under just about any weather condition.

The traffic patterns are such that aircraft coming in from the north, east, south, and west are merged together 5-15 miles east southeast of the airport in an area known as the approach zone (Fig. 3). If weather conditions are clear, and the arriving aircraft can see one another, the aircraft are allowed to land side by side using the two runways at the same time. This allows for an acceptance rate of up to 52 aircraft landings per hour.

If arriving aircraft cannot see one another in the approach zone, control personnel will have to separate aircraft so they land in single file, one after the other. The result is that the arrival rate is decreased from 52 per hour to 33. This is a problem whenever there are clouds with bases below 3500 feet or visibility below 5 miles over the approach zone of San Francisco International Airport.

The arrival rate would remain considerably higher if the main runways were built farther apart. From center line to center line the main runways are only 750 feet apart. Under ideal conditions they would be 4200 feet apart. Unfortunately, due to urbanization, there is not sufficient room to add another runway to the south, west or northwest. San Francisco Bay, to the east and northeast, cannot be filled to create additional land because of environmental restrictions.

SUMMER STRATUS

Ocean water temperatures along the northern California coast are in the 50's year around due to a cold northerly current and upwelling. Upwelling is the process by which surface water is drawn out to sea allowing cooler water from the depths of the ocean to rise to near the surface.

Cold water under the semi permanent Pacific high sets up a marine inversion. Cooling of the air from below allows stratus and stratocumulus to form under the inversion. These clouds are present along the California coast most of the summer from May through September (Fig. 4).

During the day, California's interior valleys frequently heat up into the 90's. As the warm air rises, thermally induced low pressure develops over the interior. By mid afternoon (22 UTC), it is not uncommon to see a pressure gradient of 4 mb form between San Francisco, near the coast, and Sacramento in the central valley, a distance of about 75 miles. This strong pressure gradient sets up a sea breeze which brings the cooler marine air into San Francisco Bay (Fig. 5).

The influx of marine air can result in a ceiling at San Francisco International Airport as early as 6 PM (01 UTC). At other times, the marine air aided by night time cooling will result in a ceiling as late as midnight to 7 AM (07-14 UTC).

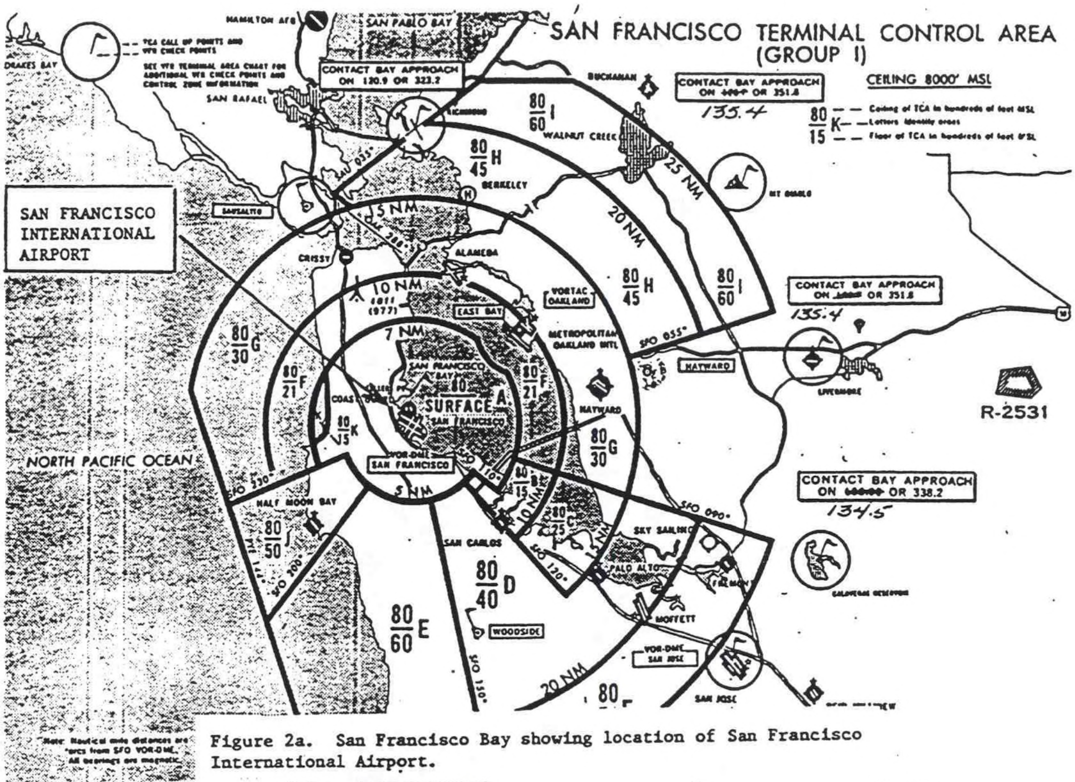

Figure 2a. San Francisco Bay showing location of San Francisco International Airport.

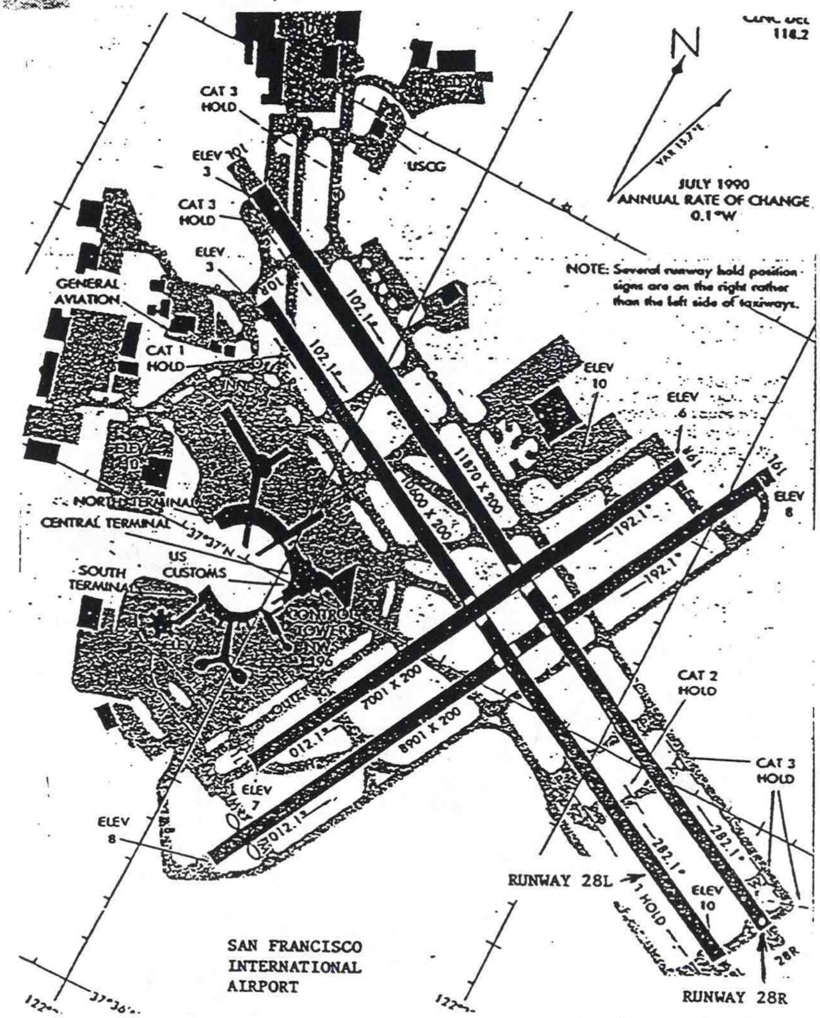

Figure 2b. Orientation of the runways at San Francisco International Airport.

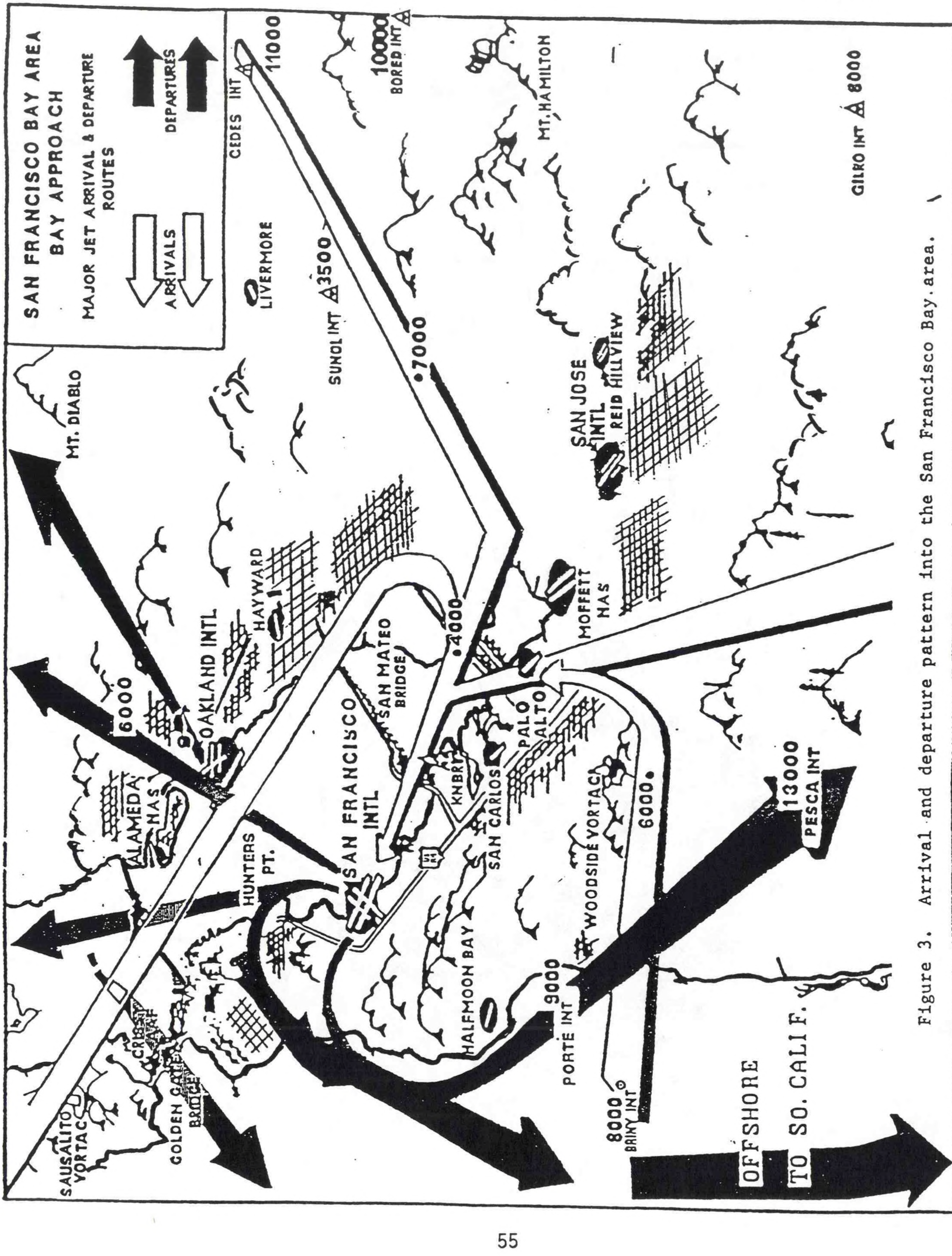

Figure 3. Arrival and departure pattern into the San Francisco Bay area.

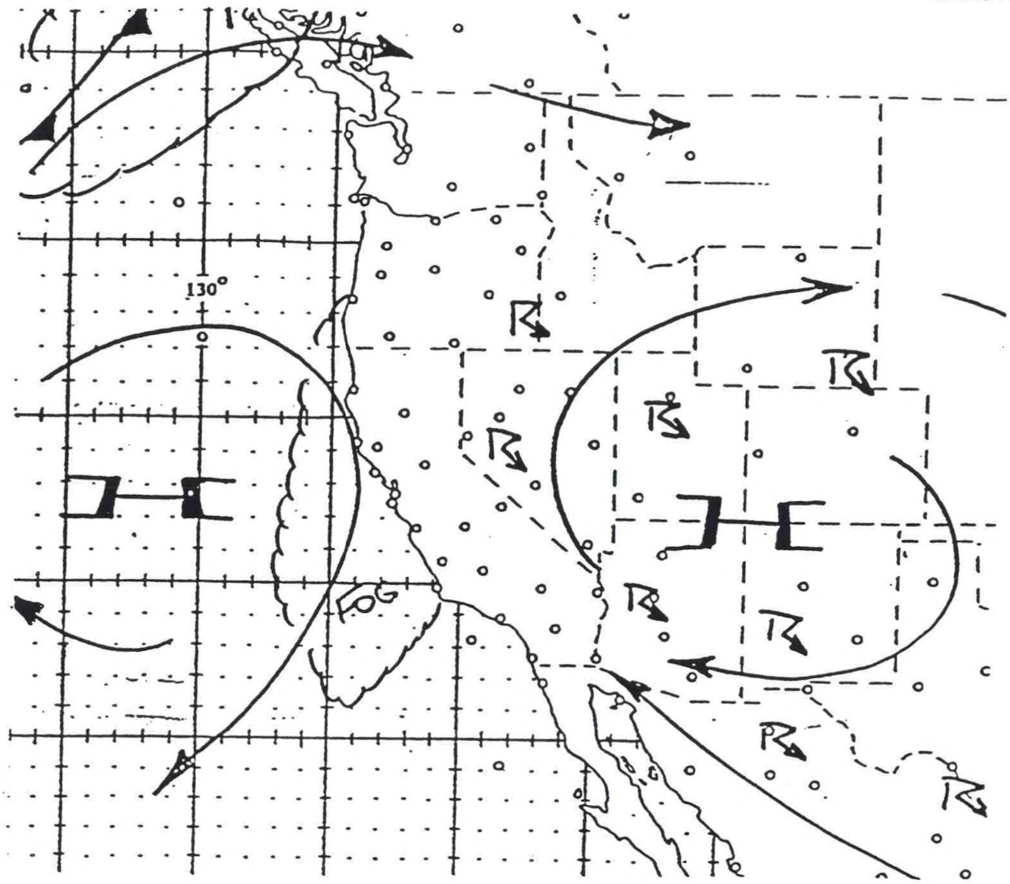

Figure 4. Typical summer weather pattern for California.

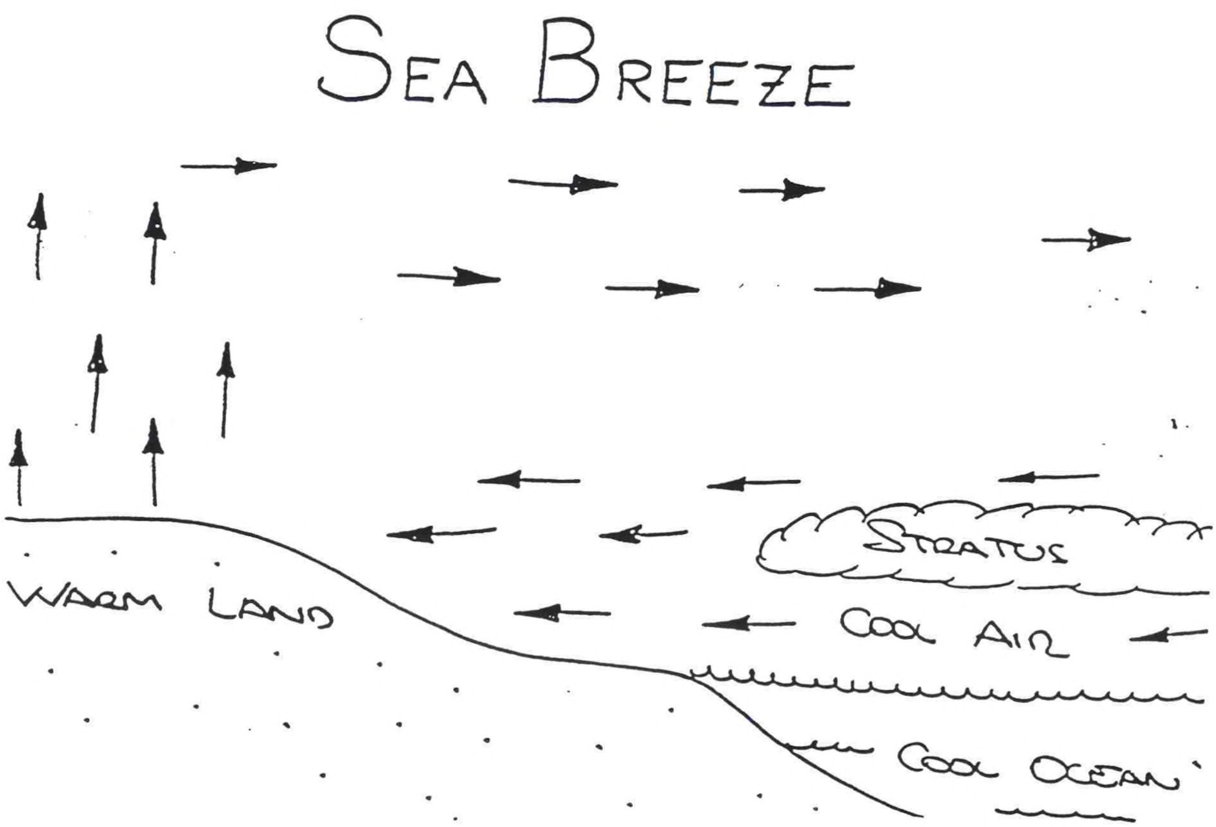

Figure 5. Sea breeze circulation.

By morning, San Francisco Bay is frequently filled with stratus clouds. Cloud bases and tops are usually fairly uniform. On a day to day basis, bases will generally range from 800-1500 feet and tops 1500-2500 feet.

Morning solar insolation normally causes the cloud cover over San Francisco Airport to become scattered by between 9:00-11:00 AM local time (1600-1800 UTC). However, sometimes it will be an hour later before aircraft in the approach zone can see one another well enough to land in pairs...using the two runways simultaneously.

RUSH HOUR TRAFFIC

Just as our freeways experience rush hour traffic, so do our airports. Figure 6 shows the normal hourly arrival rate of air traffic at San Francisco Airport. Note there are two major peaks. One is for morning arrivals between 10:30 AM and 12:00 noon (1730-1900 UTC) and another during the evening between 8:00 and 9:00 PM (0300-0400 UTC). These times correspond to the times when the stratus is burning off in the morning and coming in during the evening.

During the night, the airport can accommodate arriving aircraft despite the stratus because the traffic volume is low. However during the evening and late morning when volume is high, it sets up a serious problem. Significantly more aircraft want to land than can be accommodated by the landing rate.

So what can be done with the extra aircraft?

NATIONAL GROUND DELAY PROGRAM

Fifteen years ago, when more aircraft arrived at an airport than the airport could handle, controllers would put the aircraft into a holding pattern. There, an aircraft would remain until there was room for the aircraft to land. As the number of aircraft has increased and the price of fuel has soared, this procedure has become outdated.

Today, to cut down on peak arrivals, aircraft are spaced out by delaying departures. This is done by using a ground delay program.

OAKLAND AIR ROUTE TRAFFIC CONTROL CENTER

Requests for a ground delay program for San Francisco International Airport frequently originate with the Federal Aviation Administration's Traffic Management Unit at the Oakland Air Route Traffic Control Center.

Each day they examine the hourly statistics for scheduled arrivals at San Francisco International Airport. For those times that the arrival rate is expected to exceed the acceptance rate, the traffic management unit will request a national ground delay program.

A reduced runway acceptance rate could be because of runway maintenance or due to weather problems.

CENTER WEATHER SERVICE UNIT

Collocated with the traffic management unit is a group of NWS meteorologists in the Center Weather Service Unit (CWSU). One of the responsibilities of the CWSU meteorologist is to advise traffic management unit concerning weather that

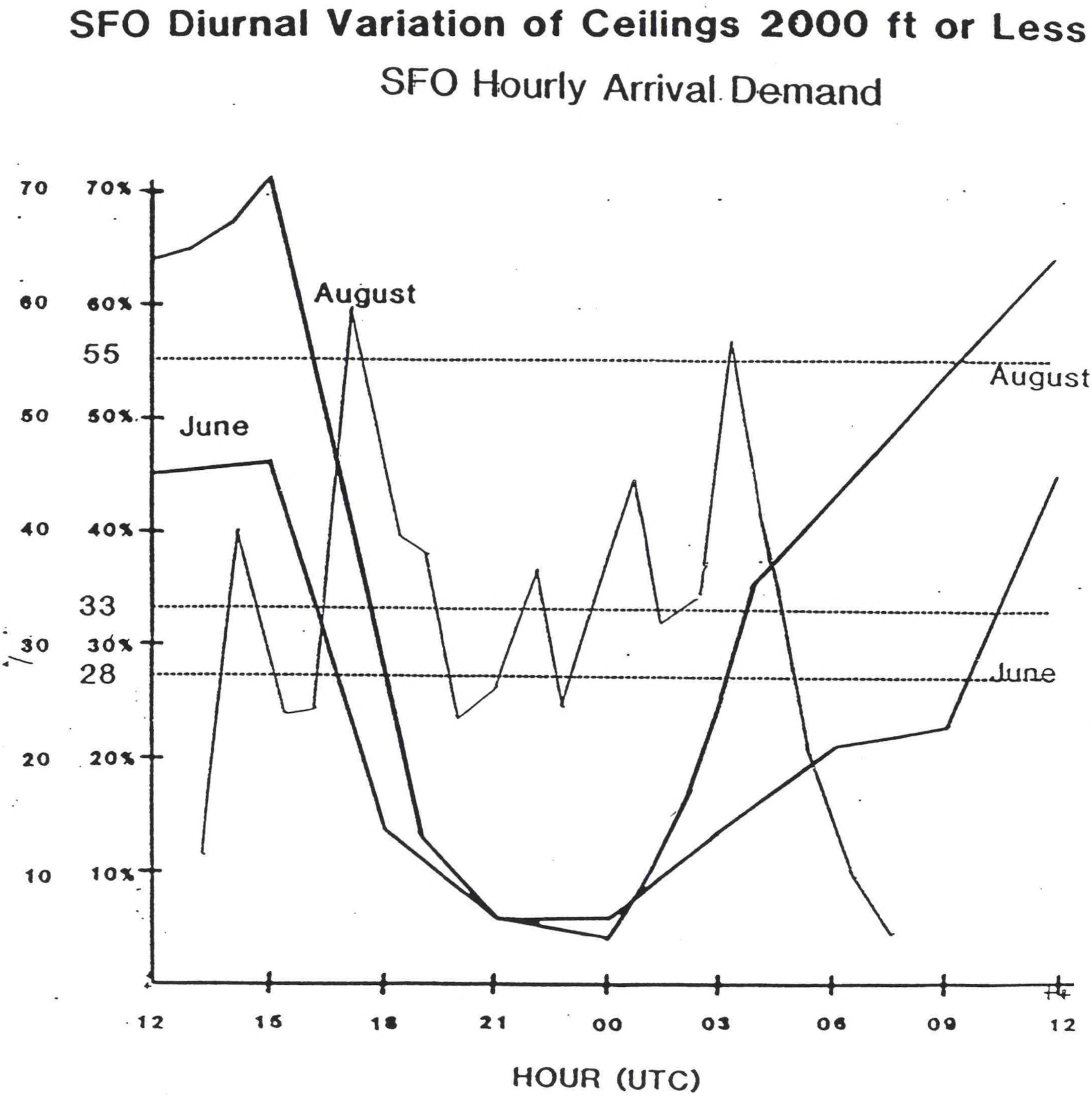

Figure 6. Diurnal variation of the probability of a stratus ceiling at San Francisco International are indicated in heavy solid lines. Narrow lines indicate a typical hourly demand for arrivals. Dased lines indicate the acceptance rate of arrivals for clear weather (55 per hour) and for stratus ceiling (33 per hour).

will be a factor in flow of traffic in and out of San Francisco Airport.

Weather factors which affect the flow of traffic at the airport include:

1. Clouds in the approach zone lower than 3500 feet
2. Visibility over the approach zone less than 5 miles.
3. Wind direction if it is other than the west northwest when velocity is more than 10 knots.
4. Wind velocity of more than 20 knots when wind direction is from the west northwest.
5. Precipitation causing a wet runway.

By far, the most frequent occurrence of weather related traffic flow problems is due to clouds over the approach zone below 3500 feet, especially during the summer coastal stratus season.

AIR TRAFFIC CONTROL SYSTEM COMMAND CENTER

When a ground delay program is deemed necessary, Oakland Center's Traffic Management Unit will request one by telephoning the FAA's Air Traffic Control System Command Center, (ATCSCC).

The ATCSCC is located at the FAA Headquarters in Washington D.C. and is responsible for maintaining a smooth flow of air traffic across the United States. They are supported by a collocated group of National Weather Service meteorologists of the Central Flow Weather Service Unit.

If Oakland Center wants a national ground delay program for San Francisco, the decision has to be made at least 5 hours ahead of time to catch the air traffic along the east coast before those aircraft depart. It takes 4 - 5 hours for an aircraft to fly across the country. If the request is made any later, the ground delay program usually is made just for the airfields under control of the following western Air Route Traffic Control Centers:

Seattle	Salt Lake City
Oakland	Denver
Los Angeles	Albuquerque

See Fig. 7.

Once a ground delay program has been agreed upon, the ATCSCC will put it into a computer system which will adjust the takeoff times of those flights departing for San Francisco.

NATIONAL WEATHER SERVICE FORECAST OFFICE SAN FRANCISCO

Aviation terminal forecasts for San Francisco are used as a guide by the ATCSCC. These forecasts are written by the National Weather Service Forecast Office in San Francisco (WSFO SFO).

During the hours the Center Weather Service Unit at Oakland ARTCC is closed, 9:00 PM - 5:30 AM (0400-1230 UTC), the ATCSCC relies heavily on the terminal forecast written by WSFO SFO as a guide in determining whether weather will be a factor in limiting traffic into San Francisco Airport.

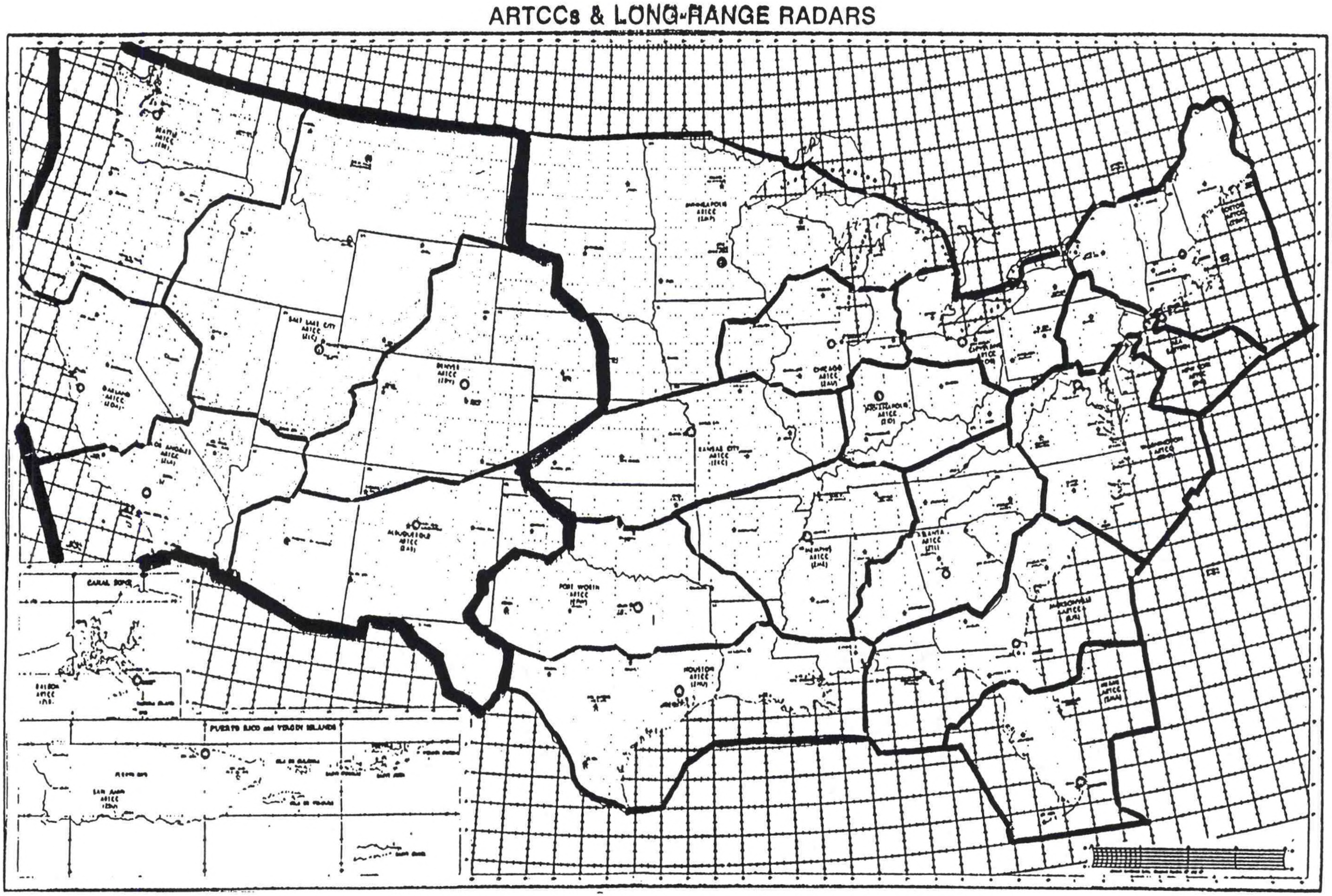

Figure 7. Outlined area indicates airspace under the control of the western air route traffic control centers.

COORDINATION

Since the ATCSCC and Oakland Center TMU are receiving weather forecasts from three NWS sources, CFWSU Washington, CWSU at Oakland ARTCC, and WSFO San Francisco, it is important to maintain forecast consistency among weather units. When necessary this is usually best done through telephone coordination. (Fig. 8)

To minimize forecast inconsistencies between meteorologists at the CWSU Oakland and WSFO San Francisco, the CWSU prepares a preliminary terminal forecast for San Francisco Airport and sends it to the WSFO SFO aviation forecaster prior to the issuance of the 0200 UTC and 1900 UTC terminal forecast. There is no meteorologist on duty at the CWSU at the time of the 1000 UTC terminal forecast.

Additionally, there is an on going visitation program between meteorologists at CWSU Oakland and WSFO San Francisco. Personnel at each office are encouraged to visit the other office and work an occasional shift. This allows each to meet the people from the other office and become familiar with their operation.

There are times when consistency is not always possible. This is because She objectives of the product or unit are not the same. The aviation terminal forecast written by WSFO SFO is written for the airport terminal itself. The forecasts prepared by the CWSU are for the approach zone of San Francisco Airport. The weather over these areas is not necessarily the same.

There are times when stratus will be over the approach zone of San Francisco when the airport is clear. This happens most often in the morning when stratus clears over the airport before it does so over the approaches to the runways.

There are also times when a haze layer aloft will reduce slant range visibilities over the approach zone but not seriously affect the horizontal visibility at the airport.

SUMMARY

Because the main runways at San Francisco International Airport were built to close together, the airport cannot handle the large volume of aircraft during peak arrival times if there are clouds in the approach zone below 3500 feet. This is a common occurrence in the summer months.

To minimize the result traffic flow problems, the FAA's ATCSCC issues ground delay programs to spread out the flow of traffic. Since many of these delays are due to weather, the FAA is highly dependent of accurate weather forecasts from NWS meteorologists.

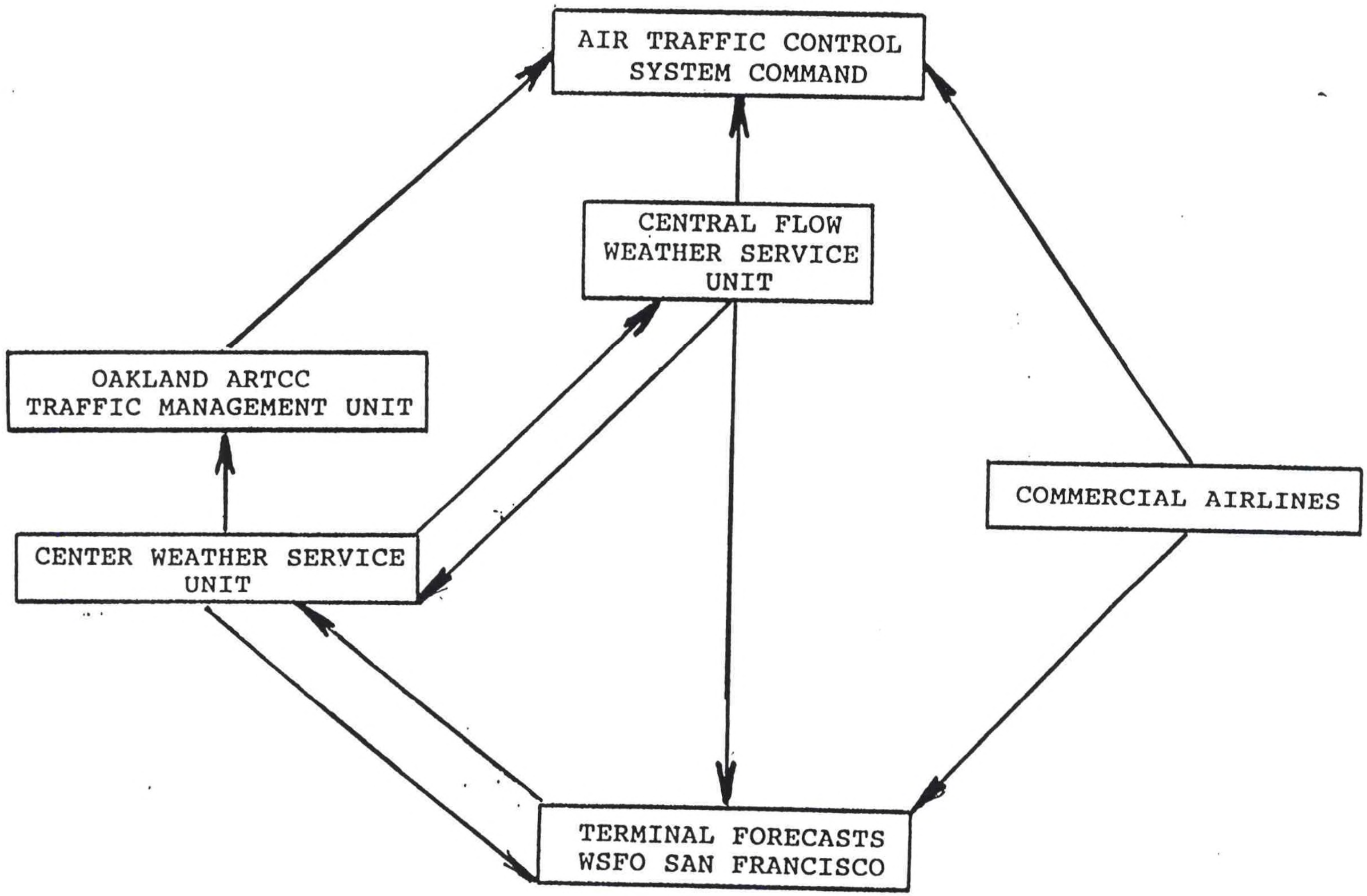

Figure 8. Diagram showing the flow of information regarding the decision to issue a ground delay program for San Francisco.

AN OBJECTIVE FORECASTING AID FOR SUMMERTIME LOW CLOUDS DURING SAN FRANCISCO INTERNATIONAL AIRPORT'S EVENING RUSH

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1. INTRODUCTION

The closeness of San Francisco International Airport's (SFO) runways to each other makes the operation of the airport sensitive to the weather elements, such as low clouds below 3500 (thirty-five hundred feet).

Between the months of May and September, low clouds made up of stratus and stratocumulus, frequent the coastal sections of California (Fig. 1). Their presence over the coastal sections between the Golden Gate Bridge and Half Moon Bay (known in this manuscript as the San Mateo coast, Fig. 2) during the afternoon and evenings represents a threat to SFO's evening peak arrival period (known as the "rush") between 03 and 04 UTC (2000 to 2100 Local Time (LT)).

These low clouds can cause delays of up to two hours if not forecasted. Because of today's high jet fuel prices, the demand for on-time performance and SFO's sensitivity to the weather elements, the SFO terminal forecast (FT and TAF), issued by the National Weather Service Forecast Office at San Francisco (WSFO SFO), is extremely critical to the airlines. It is used by them to determine the amount of fuel for the flight, and, whether or not the flight will be delayed. The Central Flow Weather Service Unit (CFWSU) and their Federal Aviation Administration's (FAA) Air Traffic Control System Command Center (ATCSCC) in Washington D.C. also count heavily on the SFO FT.

The FAA's lingo when these clouds (usually a ceiling of six-tenths or more sky cover) lower the arrival rate into SFO to a minimum is known as "IFR (Instrument Flight Rules)" or 33 rate (aircraft an hour). When the arrival rate is at maximum, the term "VFR (Visual Flight Rules)" or 52 rate is used. It is assumed, and most commonly it is the case, that a ceiling results in a 33 rate. Also, seldom does SFO experience IFR rate due to scattered (less than six-tenths sky cover), but it does happen.

For the aviation forecasters at WSFO SFO and Oakland Center Weather Service Unit (OAK CWSU), determining whether a low ceiling will be over SFO before 03 UTC or during the "rush" can be an agonizing task. This is due to the unpredictable nature of the low clouds, the poor data coverage over the eastern Pacific and the San Mateo coast, and the terrain of the San Francisco peninsula.

Typically, the initial ceiling occurs after 07 UTC (midnight LT), but occasionally it materializes just before the start of the 03 UTC rush. This scenario shall be known in this manuscript as "early return" or "early onset."

This paper discusses a procedure (or scheme) subjectively formulated to assist the forecasters in preparing and updating the 19 UTC (1200 LT)

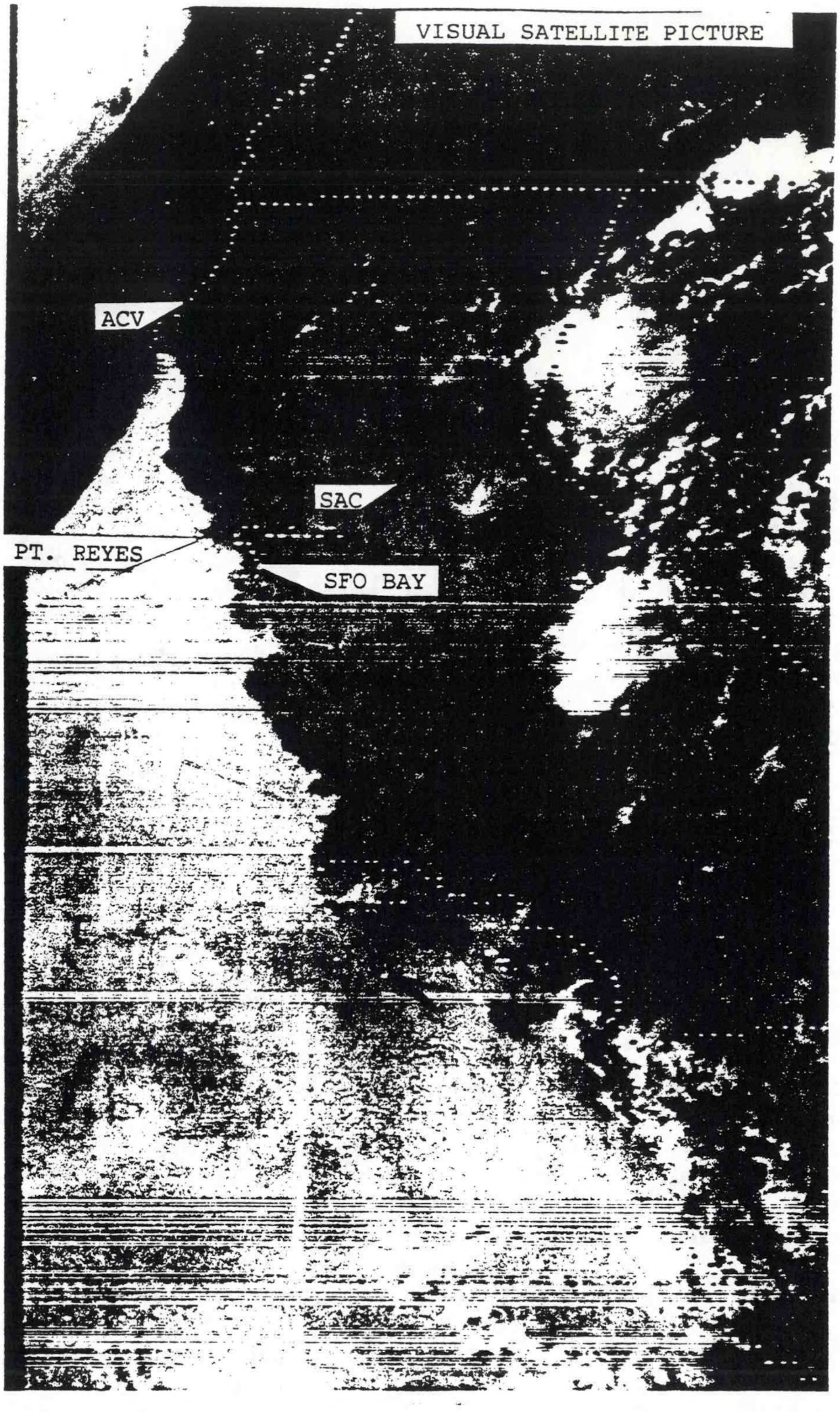


Fig. 1. Stratus/stratocumulus clouds shrouding a good part of the California coastal sections on July 30, 1991 at 00 UTC.

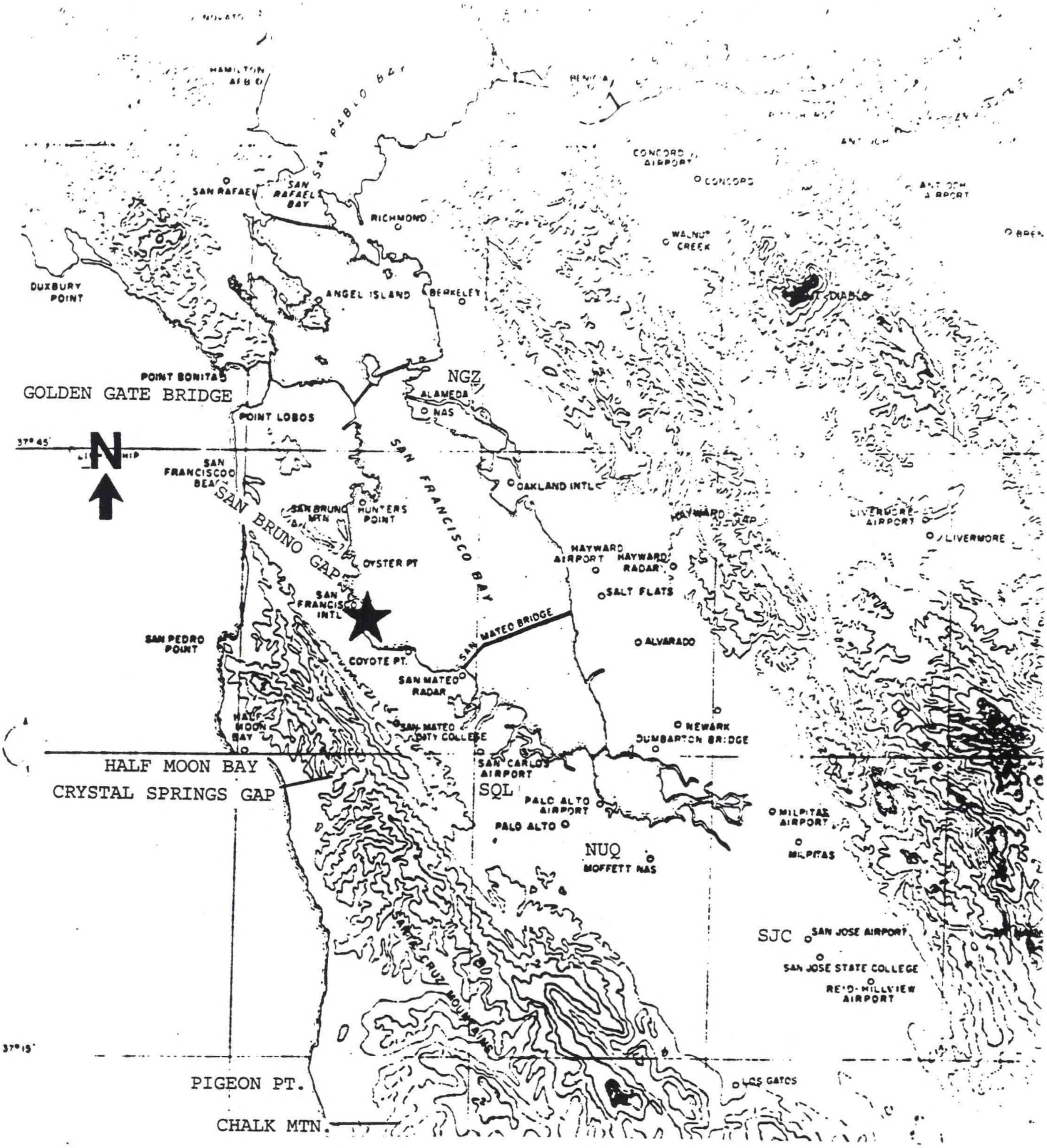


Fig. 2. The map of the San Francisco Bay Area and its vicinity. The "★" indicates the location San Francisco International Airport (SFO).

SFO terminal forecast. The scheme's goal is to alleviate some of the uncertainties (of the presence of low clouds during the SFO's evening "rush") in the 19 UTC FT. This is accomplished by recognizing certain synoptic scale patterns (both at the mid-levels and/or at the surface) that are found to have an influence on the weather at SFO.

The paper also touch on the basic principles of low cloud forecasting, with particular attention given to SFO.

2. THE 19 UTC FT

The SFO 19 UTC FT is critical to the users for it contains the "rush" hour forecast. The CFWSU, in particular, uses this product to brief their FAA counterparts shortly after its receipt to see, initially, if a delay program is needed for SFO during the ensuing 10 hours.

The ATCSCC preferably would like the SFO 19 UTC F? to be as accurate as possible, especially for the "rush." This sometimes is not feasible. An "in-house" FT is issued by OAK CWSU no later than 23 UTC after coordination with WSFO SFO and CFWSU. Many flights destined for SFO from points along the East Coast would not be affected by-a delay program implemented at 23 UTC. However, flights originating elsewhere would be prevented from taking off on schedule.

3. DATASET

The dataset consist of three summers. They are from July 1, 1989 to September 20, 1989; and June 1, 1990 and '91 to September 20, 1990 and '91.

The main criteria for this study is the presence of low clouds over the San Mateo coast. Areal coverage was then subjectively assigned, such as patchy; cloudy for areas of or widespread low clouds; and increasing for clouds increasing over the area. Exempted from this study were days where convective showers and stratiform rain occurred during the "rush."

Terms were assigned according to the cloud condition during and prior to the "rush." Those evenings when SFO was "IFR rate" during or prior to the "rush" were designated "positive." The "IFR rate" can be due either to a ceiling that materialized over the airport, scattered amount of clouds situated over the final approach zone, or a ceiling that persisted throughout the day. Cases where the sky was clear during the "rush" were classified as "negative." In addition, evenings where a scattered amount of low clouds was observed but did not affect the flow of traffic were termed "marginal."

The pressure gradient values between Arcata (ACV) minus (SFO), and SFO minus Sacramento Executive Airport (SAC) were documented on a daily basis, at two hour intervals between 18 and 00 UTC (1100 and 1700 LT, respectively). The SFO wind component was also recorded with the pressure gradient values.

Most of the 00 UTC analyses of the NGM's and NMC's surfaces, the NGM's 500 mb initial vorticity and heights, and Oakland's radiosonde were retained, particularly on days when SFO was threatened by low clouds. These data were then subjectively reviewed.

GOES satellite pictures were available for a few of the cases.

A statistical test was applied to the two pressure gradient components to determine their averages, and of which set of the components correspond best to the early onset cases.

4. DISCUSSION

The review of the data revealed that at least 93 percent of the early return cases involved a synoptic scale disturbance or trigger, such as an active surface front or boundary, a deepening and/or approaching trough between the West Coast states and about 135 west longitude (135w), or an approaching shortwave or vorticity maxima with a westerly or northerly component (Table 1).

Although low clouds are common over the coastal sections along the San Mateo coast, it does not necessarily mean these clouds will spread into San Francisco Bay (SFO Bay) overnight nor that they will move over SFO before 04 UTC. Of the 230 days where clouds were present along the San Mateo coast during the afternoons and evenings, 51% (117/230) were negative, 15% (34/230) were marginal, and 33% (75/230) were positive (Table 2). Included in the statistics are two cases where the San Mateo coast was clear during afternoon, only to experience IFR rate during the "rush" due to frontal systems reaching the SFO Bay area just prior to the start of the "rush."

Many of the WSFO SFO/OAK CWSU forecasters monitor two pressure gradient components (the difference between ACV and SFO and SFO and SAC) to determine whether the low clouds (and amount of it) will enter SFO Bay overnight. The author applied this concept for short term forecasting purpose for SFO and noticed a weak correlation between specific values (of these components) at a reference time of 22 UTC and early onset.

A value of 3.4 mb (millibars) was determined to distinguish the terms "offshore" and "onshore" pattern in the ACV to SFO component. As shown in Table 2, 36% (70/195) of the early onset cases involved "onshore" (less than 3.4 mb at 22 UTC with the presence of a trigger). Only 7% (2/27) did an early onset occurred under "offshore" (due to a trigger). More importantly however is the inland SFO to SAC pressure gradient where a weak correlation (about 60%) exist between early onset and the critical value of 3.6 mb at 22 UTC. From Table 2, 63% (45/72) of the early onset cases were associated with values 3.6 mb or more at 22 UTC. The topic of "offshore" and "onshore" will be discussed further in the sections to follow.

Since the 19 UTC FT is critical to many users, the author took a closer examination of the three summers of data, which then revealed that there are certain synoptic patterns associated with early onset.

5. LOCATION OF SFO AND ITS SURROUNDING

As in Figure 1, San Francisco International Airport is located on the west shore of San Francisco Bay. The San Bruno Mountain, located 5 miles to the north and northwest, rises to around 1300 feet. The Santa Cruz Mountains, with elevations of 700 to 1900 feet, extend from the south through the northwest.

The ridge immediately west of SFO is 4 miles away with an elevation of 1300 feet. The broad San Bruno Gap with minimum elevation of 150 feet

Table 1. The yearly distribution of the five types of triggers.

TYPE	1989	1990	1991	TOTAL
1. Deepening/approaching trough	2	3	13	18
2. Perturbation in the westerlies	7	9	14	30
3. Back side of 500 mb trough	2	5	0	7
4. Pre-frontal stratus	0	4	4	8
5. Front with Vorticity advection	1	7	1	9

Table 2. The statistical breakdown by combining the two surface pressure gradient components with the triggers. For days to be accounted in the table, low clouds must be present over the San Mateo coast during the afternoon and evenings, and of any early onset cases that occurred at SFO.

Legends: Negative (NEG) = VFR rate during the SFO's "rush";
Marginal (MAR) = scattered low clouds of less than six-tenths during the "rush", but was not a factor;
Positive (POS) = IFR rate during the "rush", which includes cases where SFO had a ceiling (six-tenths or more cloud cover) for most, if not all of the day, and scattered low clouds at IFR rate

#	Surface pattern/trigger	NEG	MAR	POS	TOTAL	%POS
1.	Onshore/trigger/≥3.6 mb	6	9	44	59	75
2.	Onshore/trigger/<3.6 mb	15	6	23	44	52
3.	Onshore/no trigger/≥3.6 mb	9	5	3	17	18
4.	Onshore/no trigger/<3.6 mb	61	14	0	75	0
5.	Offshore/trigger/≥3.6 mb	0	1	1	2	50
6.	Offshore/trigger/<3.6 mb	4	0	1	5	20
7.	Offshore/no trigger/≥3.6 mb	1	0	0	1	0
8.	Offshore/no trigger/<3.6 mb	18	1	0	19	0
	SUBTOTAL	114	35	72	221	
	# of cases with insufficient data	5	1	5	11	
	GRAND TOTAL	119	36	77	232*	

* 230 days of low clouds present along the San Mateo coast. 2 days where the SM coast was clear during the afternoon only to be at IFR rate during the "rush".

sits northwest of the complex facing runways 10L and 10R. It separates the San Bruno Mountains from the Santa Cruz range. This gap results in prevailing wind directions of northwest to west for all months of the year. The gap is also well known to local Weather Service and FAA personnel, for low clouds are commonly sighted there.

Another break in the terrain is the Crystal Spring Gap (elevation 850 feet, Fig. 2). It is located west of San Carlos Airport (SQL), along the Santa Cruz Mountains, or southwest of SFO. Low clouds occasionally sneaks through this gap affecting the finals.

6. PRESSURE GRADIENT COMPONENTS

A. The San Francisco to (minus) Sacramento Component A notable characteristic involving positive cases is the SFO to (minus) SAC pressure gradient at 22 UTC. This pressure gradient component, which is also known as the inland gradient, is an indicator utilized by the forecasters at WSFO SFO in bringing low clouds into SFO Bay.

The statistical analysis indicated that the 22 UTC SFO to SAC gradient of 3.6 mb or more corresponded best to the early onset cases. Any instance before 21 UTC (1400 LT) was unreliable. This 3.6 value (or more) is rather strong for 22 UTC (the average was 3.1 mb for negative cases). Typically, the minimum occurs during the late morning hours, which may dip as low as 1.5 mb. The significant gradient increase usually occurs after 21 UTC, due to maximum daytime heating in interior California. Forecasting for this value of 3.6 is rather difficult 3 to 5 hours in advance. Also, not all early onset cases involve a strong inland gradient. Thus, using it as a precursor for early onset remains subjective at the present time.

B. SURFACE PATTERN/RECOGNITION AND PRESSURE GRADIENT - The Arcata to San Francisco Pressure Gradient Component

Recognizing the surface pattern is a major step in determining whether the clouds will enter SFO Bay overnight. There are generally two patterns that are of concern to SFO's weather; that is "onshore" and "offshore." To determine whether it is "onshore" or "offshore", we use the pressure gradient between ACV and SFO (Fig. 1).

1. OFFSHORE (ACV to (minus) SFO gradient of 3.4 mb or more)

Occasionally, a ridge of high pressure nosing into the Pacific Northwest and northern California from the eastern Pacific Ocean will result in an "offshore" component across the area including the SFO Bay Area (Fig. 3a).

This pattern is known to the forecasters at WSFO SFO as "offshore." Strocker (1945), noted that this pattern is associated with (at most) patchy coastal low clouds. It is also safe to add that it is associated with minimal low cloud penetration into SFO Bay overnight (given the absence of a trigger) and therefore a 52 rate for SFO's evening rush.

It was determined from the statistical analysis that a value of 3.4 mb or more at 22 UTC between ACV and SFO will keep SFO at a VFR rate through the evening "rush." The most SFO is likely to report (without the influence of a trigger) during this time is scattered amount of clouds

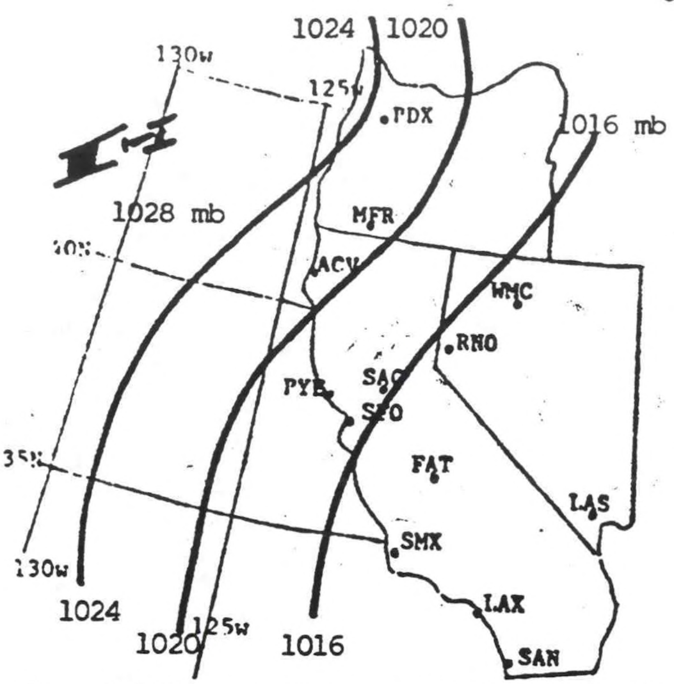


Fig. 3a. Offshore pattern associated with minimal coastal low clouds and fog.

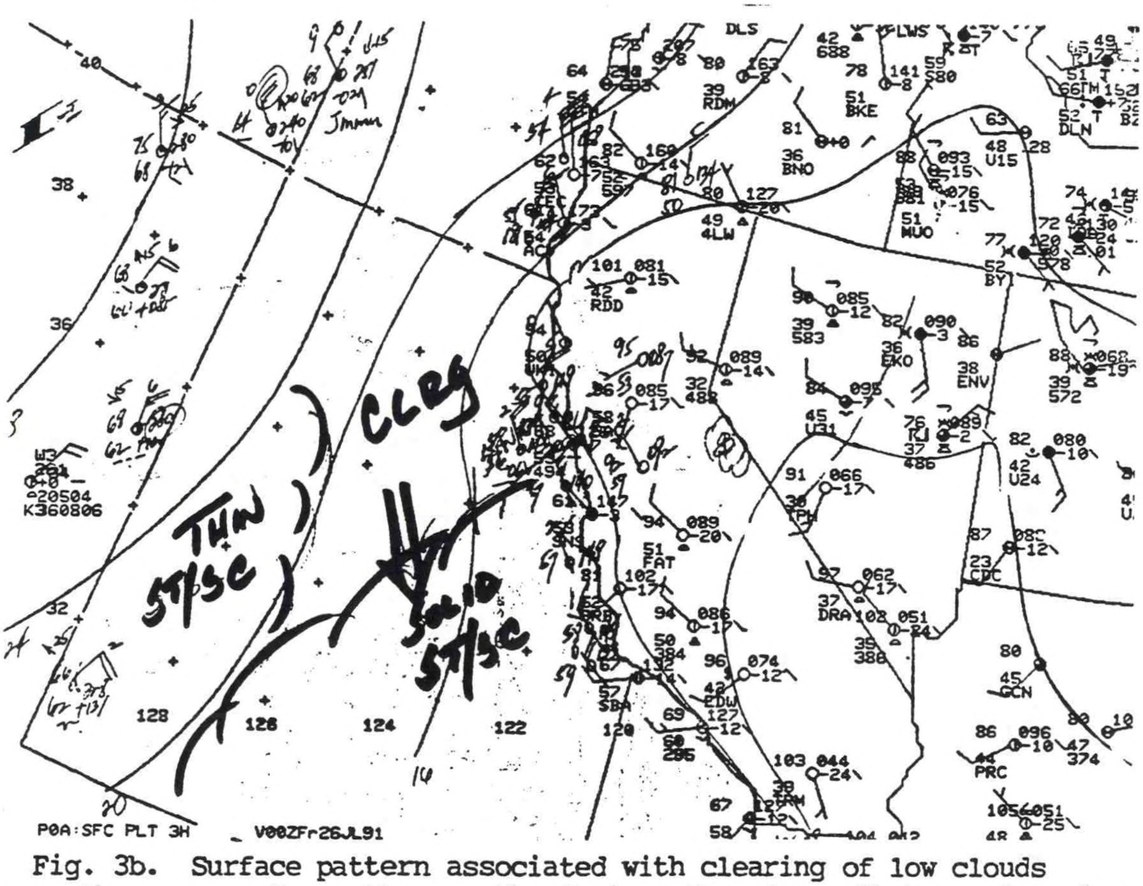


Fig. 3b. Surface pattern associated with clearing of low clouds over the ocean from the north during the day. The clearing line reached Golden Gate Bridge area at around 00 UTC and continued south for an additional 20 miles before spreading north to Pt. Reyes the ensuing 10 or so hours.

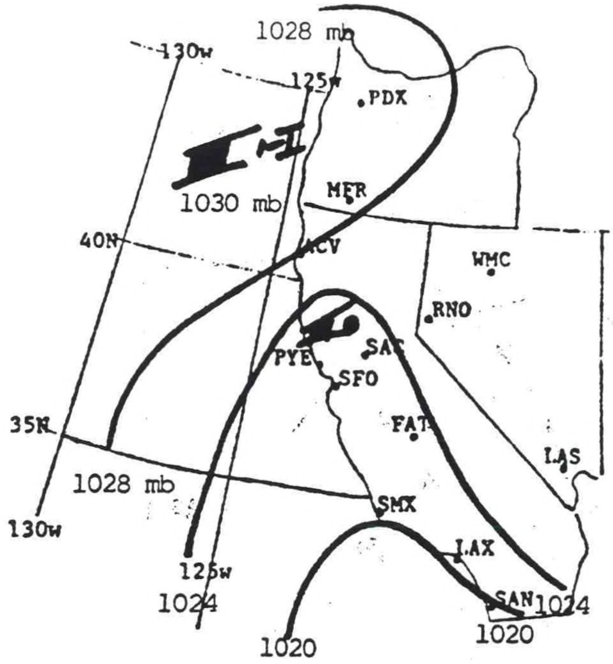


Fig. 3c. Another pattern associated with minimal coastal low clouds and fog.

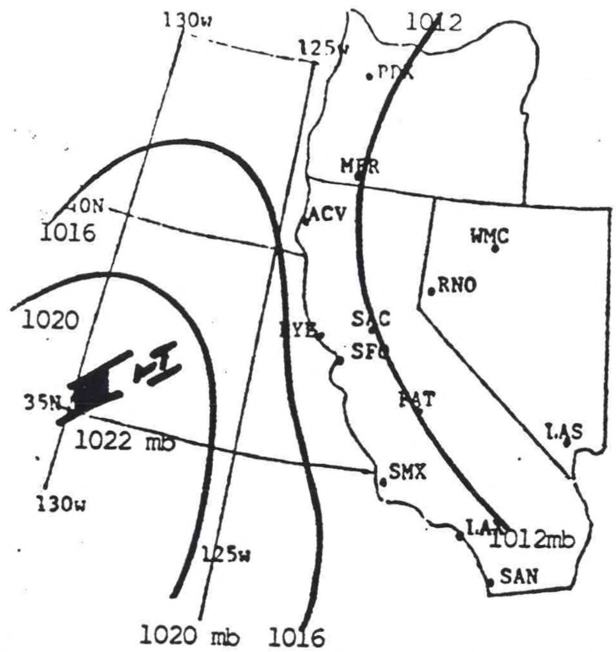


Fig. 4a. Onshore pattern associated with the potential for widespread coastal low clouds and fog.

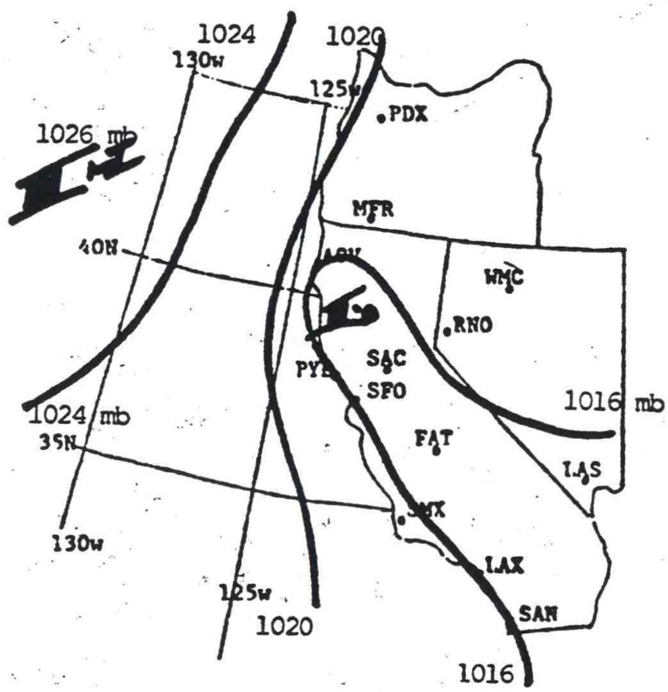


Fig. 4b. Another "onshore" pattern associated with the potential for widespread coastal low clouds and fog.

with the bulk of them located to the north of the complex. This is despite a very strong inland gradient of more than 3.6 mb at 22 UTC. The same result applies to a strengthening field after 00 UTC. This rule is violated if there is an "active" surface front or boundary located between ACV and SFO that is moving towards SFO. Subsequently, SFO is likely to receive a ceiling before 04 UTC. The definition of "active" is low clouds ahead of or along the feature that can be accompanied by positive vorticity advection.

It should be emphasized that a value of 5.0 mb (ACV to SFO) gradient at 00 UTC does not constitute clear or scattered clouds in the bay overnight, for the gradient might reverse (to below 3.4 mb) during the ensuing 12 hours. Such a scenario can result in scattered to broken clouds at SFO occurring around daybreak and lasting until 15 UTC (0800 LT). The low clouds over the coastal sections will more than likely be patchy at 03 UTC, but can be widespread by 12 UTC.

At times it is difficult to tell how far or much clearing there will be during the afternoon over the coastal sections while the 19 UTC SFO FT is being prepared. There were several occasions where the clearing line (usually from north to south) reached the Golden Gate Bridge at 00 UTC, only to retreat north to near Pt. Reyes during the ensuing 12 hours. Figure 3b illustrate the surface analysis for such a scenario. The shaded area indicates the low clouds. Both SFO and Oakland International Airport (OAK) observed a brief ceiling around sunrise.

A resemblance to Figure 3a is that the isobaric alignment is offshore north of Pt. Arena, with the heat trough present along the coast south of there. It may be accompanied by a heat low (Fig. 3c). The position of the trough axis is critical. This pattern is also related to minimal low cloud penetration into SFO bay overnight despite its pronounced presence over the coastal sections and a strong inland pressure gradient of at least 3.6 mb during the afternoon and evenings.

2. ONSHORE (ACV to (minus) SFO Gradient of less than 3.4 mb)

In the second surface pattern, called "onshore", the ACV to (minus) SFO pressure gradient is less than 3.4 mb at 22 UTC (including negative values). This basic pattern is one where the isobars parallel much, if not all of the northern and central coast (Fig. 4a). It favors the existence and widespread penetration of low clouds into SFO Bay overnight, a common pattern associated with early return.

The most familiar pattern for early onset bears a close resemblance to Fig. 3c. The only difference is that the heat trough axis falls inland across the Sacramento and San Joaquin Valleys (Fig. 4b). Also included under "onshore" is a weakening offshore pattern with the value falling below 3.4 mb by 22 UTC.

At least 93% of the positive cases fell under "onshore." Thus, if the models depicts this pattern, and widespread low clouds are likely to maintain their presence over the coastal sections through at least 00 UTC, then one should investigate (from the forecast charts and latest available data) for any of the triggers about to be mentioned.

7. INFLUENCE OF LOW CLOUDS BY THE INVERSION AND TOPOGRAPHY

A common summertime feature along the California coast is a temperature inversion. The base and strength varies from time to time, but is usually below 1200 feet and moderate to strong at 00 UTC. Below the inversion is the marine layer usually accompanied by stratus and fog.

The low cloud penetration into SFO Bay is influenced by the topography of the San Francisco peninsula and the temperature inversion. It restricts the low clouds from invading the bay in force when the base of the inversion is below 1000 feet (given there is no trigger). The terrain also keeps the low clouds away from the airport complex and the final approach zone. The major area where the low clouds enter the bay is between the Golden Gate and just north of the airport. The second area of low cloud intrusion into the bay is the Crystal Springs Gap.

There are several scenarios in the way the low clouds enters the bay overnight. The most common setting is low clouds moving into the bay at around dusk, mainly north of SFO. This is due to a low inversion of below a thousand feet. The low clouds tend to pile over the east side of the bay with OAK and Alameda Naval Air Station (NGZ) first to report a ceiling (around 02 UTC (1900 LT)). The clouds will then spread south reaching the San Jose area around 12 UTC before curling north towards SQL. In the mean time, a low ceiling materializes over SFO around 09 UTC (0100 LT). The SQL area can be the last place to receive a ceiling. There are other occasions where SFO is the last location to receive a ceiling.

Forecasting where the inversion base will be during the evening is difficult. The Oakland RAOB is not reliable due to its inland location. Neither is the SOSF temperature. The site is only at the 580 foot elevation of the San Bruno Mountain northwest of the airport. Chalk Mountain (CKSCI, elevation 1600 feet), can give an indication of where the inversion stand (Thomas 1990). It is located on the west side of the Santa Cruz Mountains (maximum elevation 1609 feet), southwest of San Jose. Other sources of data that can be of use are cloud top measurements from pilot reports of SFO Bay, and Half Moon Bay's observation (HAF) which appears in pilot report format. These sources are available on an occasional basis. They can be retrieved through AFOS pilot report collective PRCCA.

The terrain west through northwest of SFO complicates the intrusion of the low clouds into SFO Bay during the night. At times the low clouds will move in over the airport complex from the gap only to suddenly retreat. At other times, the low clouds will sneak through the Crystal Springs Gap, thus affecting the finals. Most often though, the low clouds moves over SFO in force, especially well after 04 UTC.

8. EARLY CEILING ONSET TRIGGERS (SURFACE AND 500 MB)

It was determined that any of the five synoptic features assisted the earlier than normal arrival of the low clouds at SFO. They are as follows:

1. The deepening mid-level trough a cross the eastern Pacific (about 135w eastward) including California. Height falls up to 50 meters in a 12 hour period are possible, but not

necessary, and could have occurred 12 to 24 hours prior to onset. Two versions are shown here, involving a vort max dropping south towards northern California (Fig. 5a), and a short wave trough off the central California coast (Fig. 5b). Low clouds are typically present along the coast prior to onset. This pattern is usually associated with "all-day" low cloudiness, a afternoon burn-off, or partial clearing such that "scattered" IFR may occur.

2. A mid-level shortwave trough/vorticity maximum embedded in a southwest (Fig. 6a) or westerly flow (Fig. 6b) that is forecast to be near the California coast or passing through the Bay Area during the ensuing 12 to 24 hours. The perturbation can be part of a broad 500 mb trough over the eastern Pacific. "All-day" low clouds, an afternoon burn-off, or partial clearing such that "scattered" IFR can occur with this pattern.

3. A mid-level long wave trough with its axis just east of the Bay Area. The trough is expected to deepen overnight due to a vort max dropping south along the Oregon coast or the immediate offshore waters (Fig. 7). Other characteristics include: 1) a moist air mass with the absence of an temperature inversion; 2) a strong inland (SFO to (minus) SAC) pressure gradient of more than 3.6 mb at 22 UTC; and 3) the low clouds can be a patch over the Santa Cruz Mountains during the afternoon, only to increase substantially around sunset. It is most common in the month of June.

4a. Pre-frontal low clouds associated with a shallow front (or boundary) that is expected to reach the Oregon and northern California coast during the ensuing 12 to 24 hours. Low clouds can be fragments of the main cloud band such as in the visual satellite photo in Figure 8a, or widespread along and ahead of the front (Fig. 8b), including the San Mateo coast during the afternoon. Negative vorticity can be present over the Bay Area. The pressure field off the northern California coast is rather weak, thus allowing the low clouds to exist.

In the June 2-3 (UTC), 1990 example, the patch of low cloud ahead of the eastward moving front experienced an increase in size as it impacted the coastal sections west of SFO during the late afternoon/early evening hours. The increase in size was attributed to several factors that included orographic effect, cooler sea surface temperature off the San Mateo coast and nightfall (cooling). The advection of the low clouds into SFO Bay and SFO was aided by a strong inland pressure gradient of more than 3.6 mb during the afternoon and evening. SFO picked up a ceiling and a 33 rate shortly after 03 UTC, June 3.

The September 12-13 (UTC), 1991 case, involved areas or large patches of low clouds ahead of the system. Although the inland pressure gradient was rather weak (maximum 3.4 mb at 00 UTC), the surface pattern was onshore (isobars paralleled the northern California coast). The existence of areas of low clouds was due to a weak pressure gradient ahead of the system. The ceiling and 33 rate occurred toward the end of the "rush."

4b. A similar type trigger is the remnants of a shallow front (or boundary) located just off or on the northern California coast at 00 UTC (Fig. 8c). Negative vorticity can be present over the Bay Area.

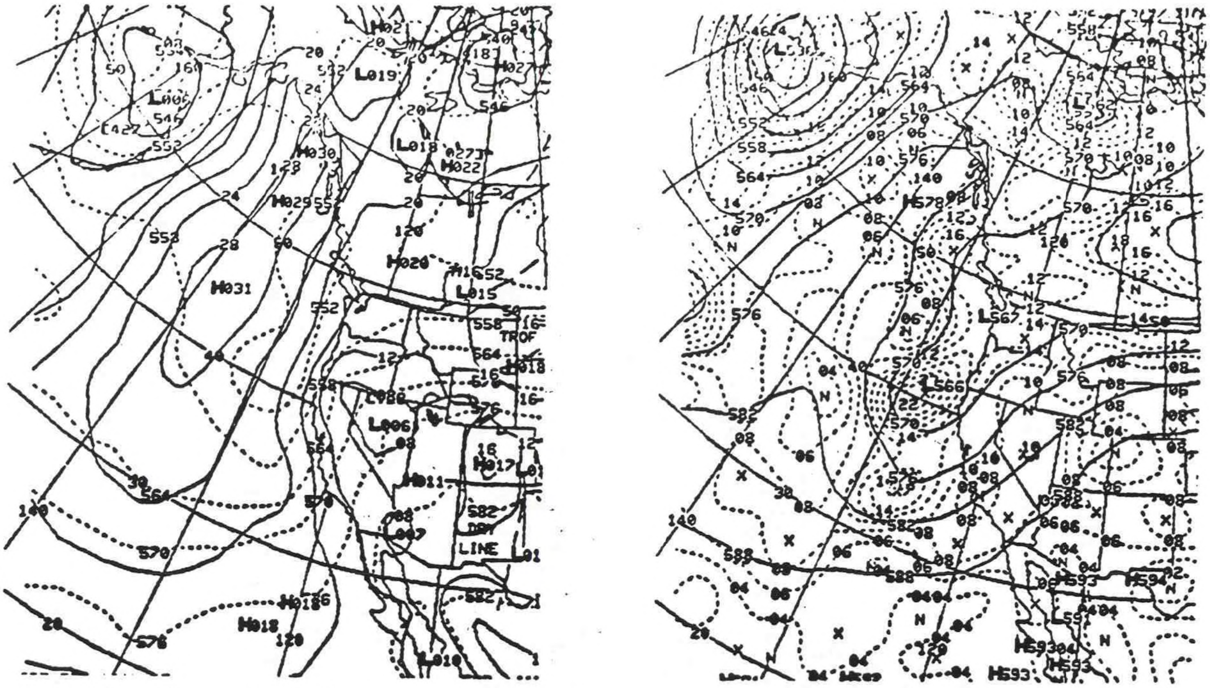


Fig. 5a. One of two versions of a type one trigger (deepening trough). Lefthand panel depict the initial surface analysis and 1000 to 500 mb thickness. The righthand panel shows the 500 mb heights and vorticity field. Time of ceiling onset occurred during the morning hours of June 18, 1991 but lasted into the evening hours (June 19, 1991 (UTC)).

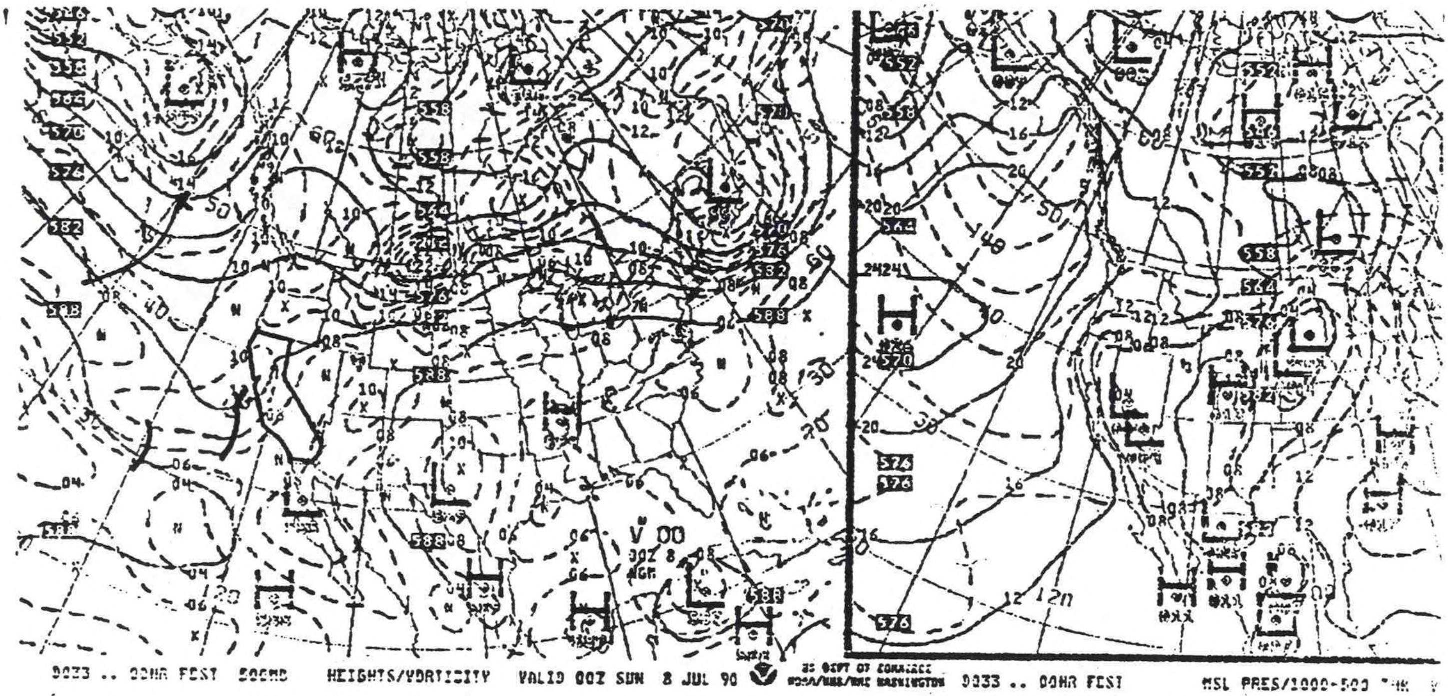


Fig. 5b. Another example of a type one trigger involving a weak stationary trough along the central California coast. The flow at the mid-levels became cyclonic during the day of July 7, 1990 (UTC), and the trough deepened even further during the night of July 8, 1990 (UTC). Time of ceiling onset was 03 UTC, July 8, 1990.

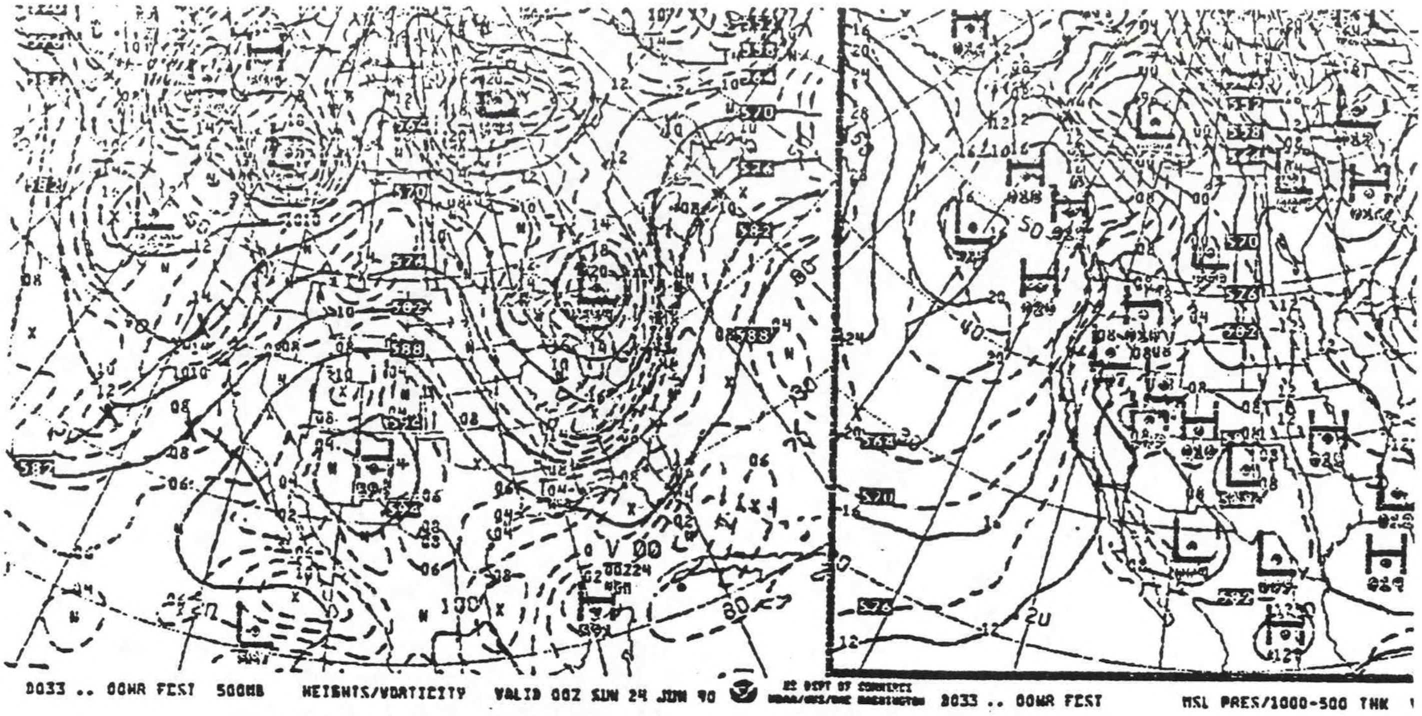


Fig. 6a. An example of a type two trigger (perturbation) in the southwesterly flow. Time of ceiling onset for this particular case (June 24, 1990 UTC) was 02 UTC.

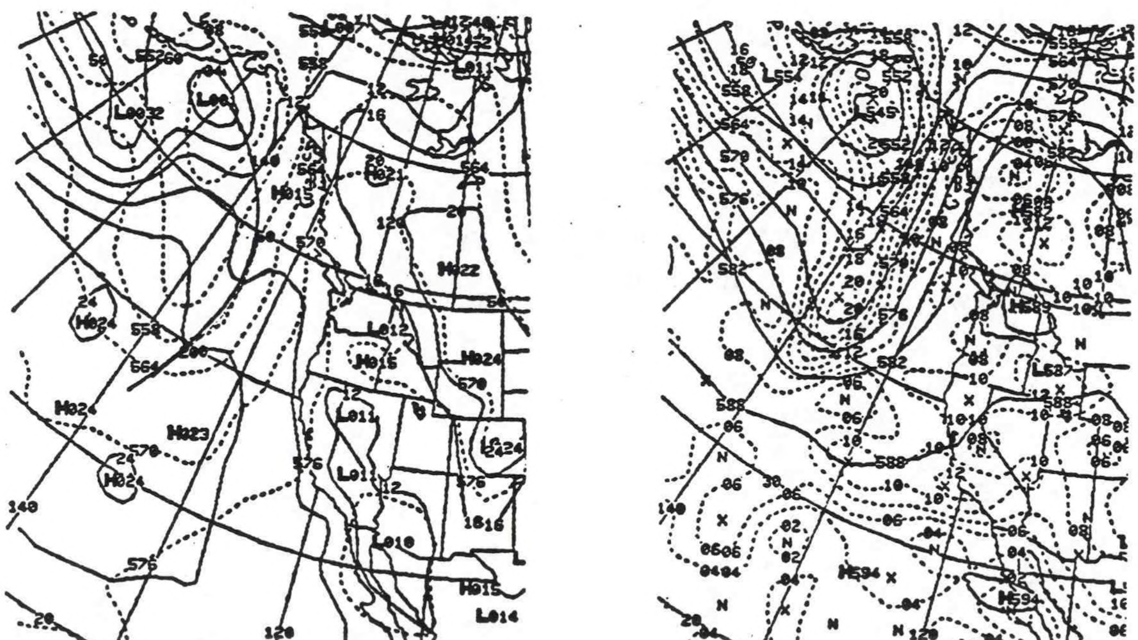


Fig. 6b. The second of two versions of a type two trigger...a perturbation in the westerly flow...seen in this case on 00 UTC July 24, 1991 as the shortwave approached northern California and the Pacific Northwest. Time of the ceiling onset was 02 UTC July, 24.

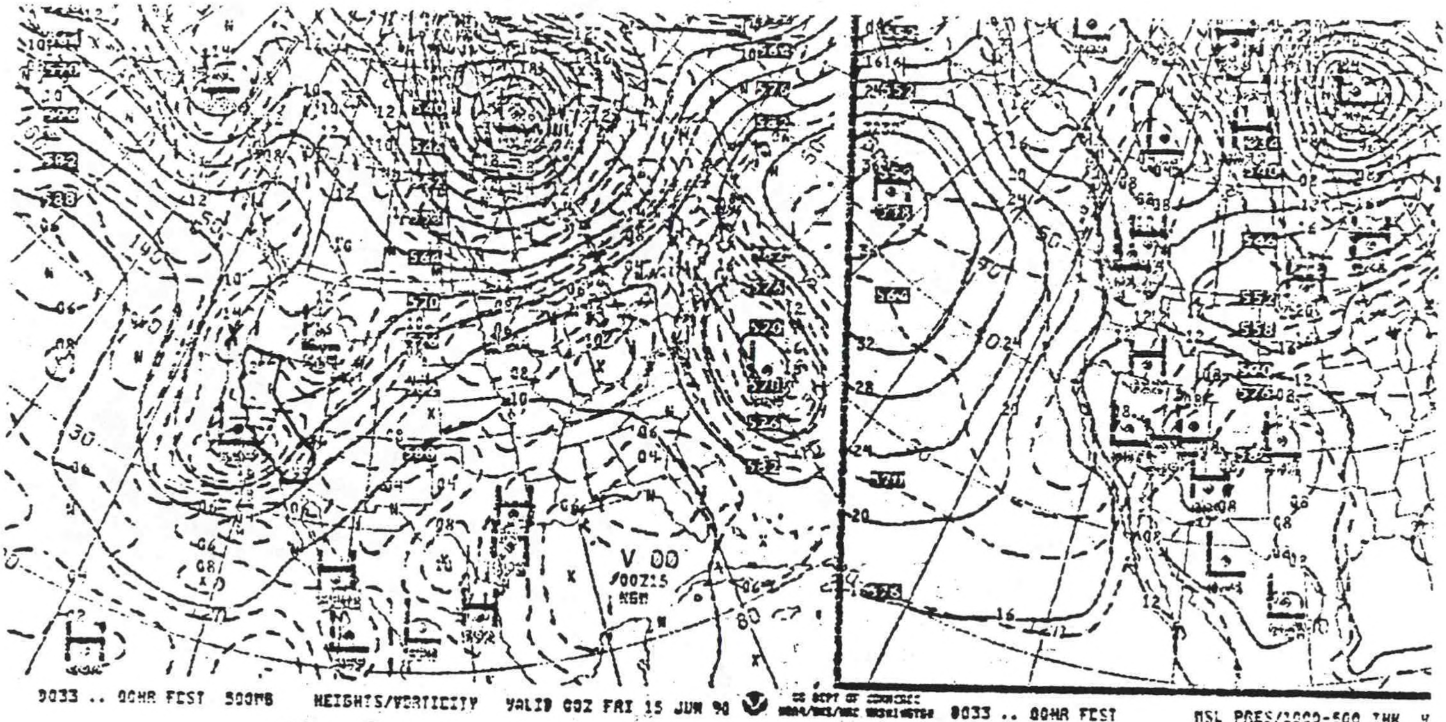


Fig. 7. An example of a type three trigger (vorticity maxima located on the backside of a 500 mb trough) that is situated over California and adjacent states. On June 15 1990 UTC produced scattered to broken clouds during SFO's evening "rush."

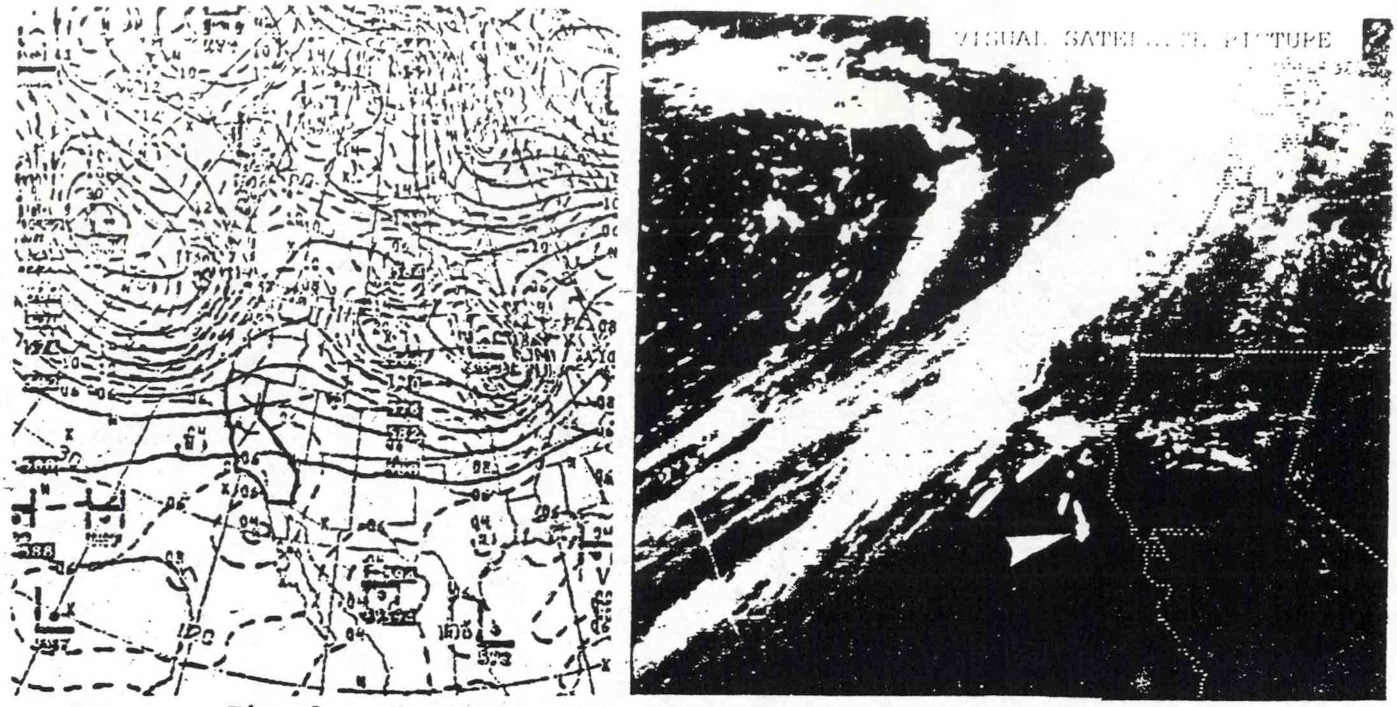


Fig. 8a. The NGM's 500 mb heights/vorticity analysis (left hand panel) and the corresponding satellite picture of pre-frontal low clouds (righthand) taken at 22 UTC (June 2, 1990). The patch of stratus (indicated by the arrow) was responsible for a ceiling at SFO about 5 hours later at 03 UTC (June 3, 1990).

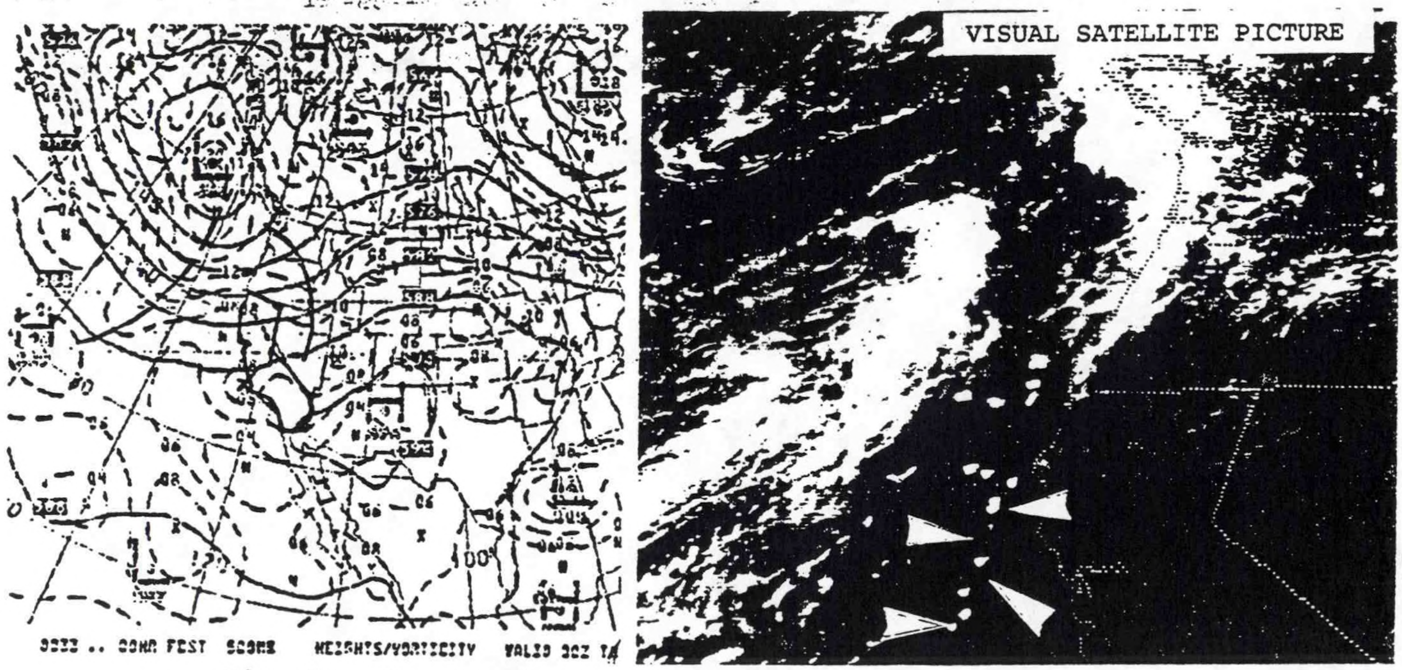


Fig. 8c. The second of two versions involving a type four trigger (diffuse boundary). The arrows on the satellite picture shows the position of the boundary at 22 UTC, June 27, 1990.

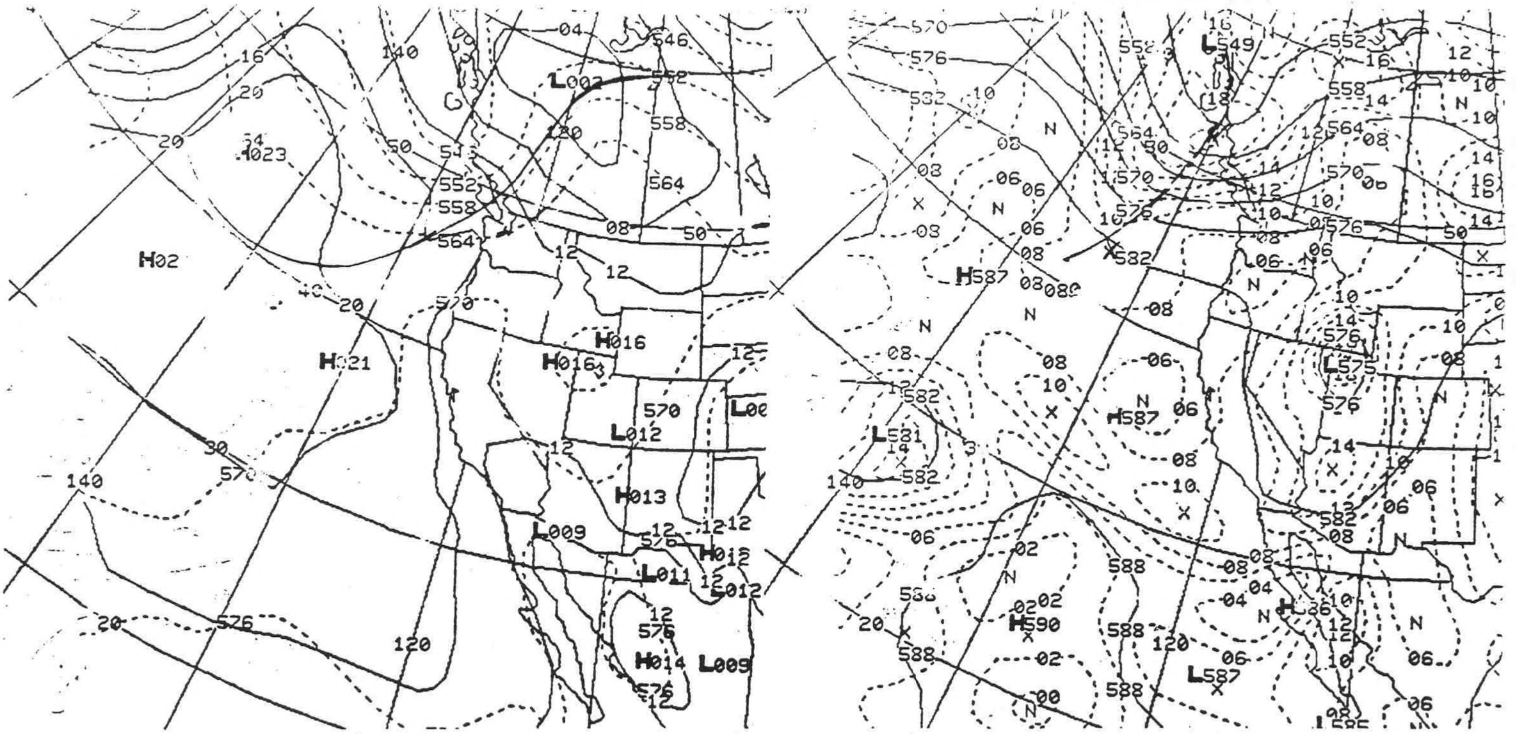
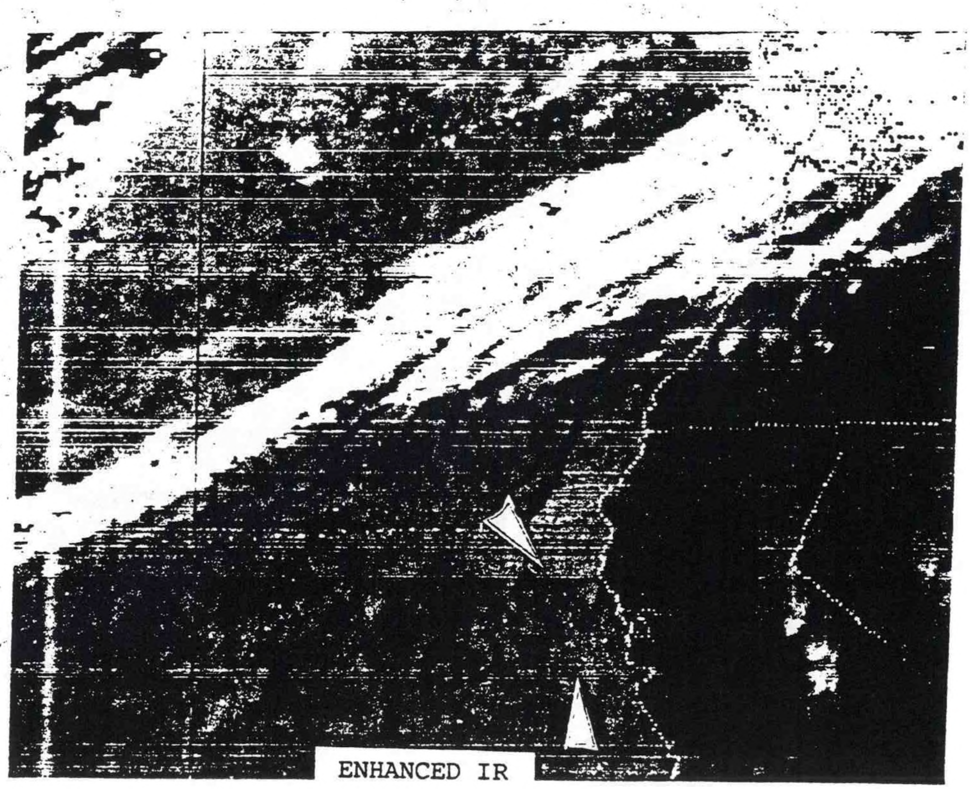


Fig. 8b. The surface and corresponding 500 mb pattern (top left and right panels respectively) on Sept. 13, 1991 at 00 UTC as an example of low clouds ahead of a frontal system approaching the Pacific Northwest (indicated on the satellite picture taken at 0131 UTC Sept. 13, 1991) by the arrows. SFO reported a ceiling shortly after 03 UTC.



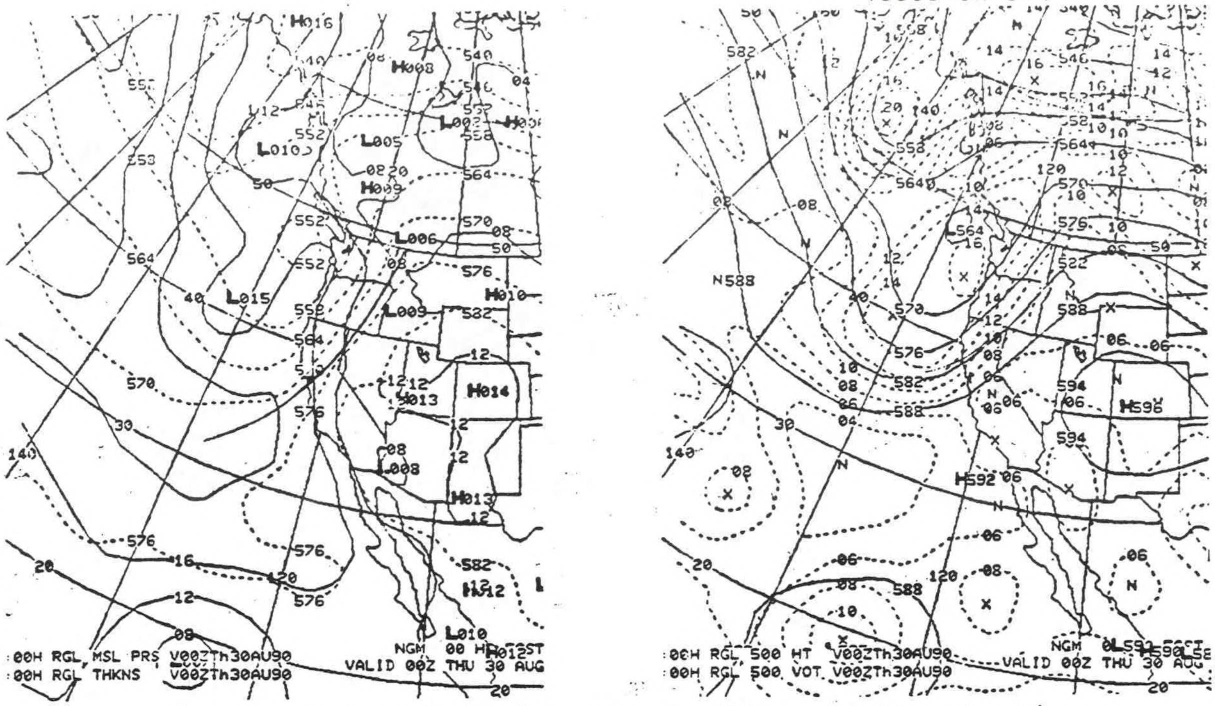


Fig. 9. A case involving a front with vorticity advection. Time of the ceiling onset was 01 UTC, Aug. 30, 1990.

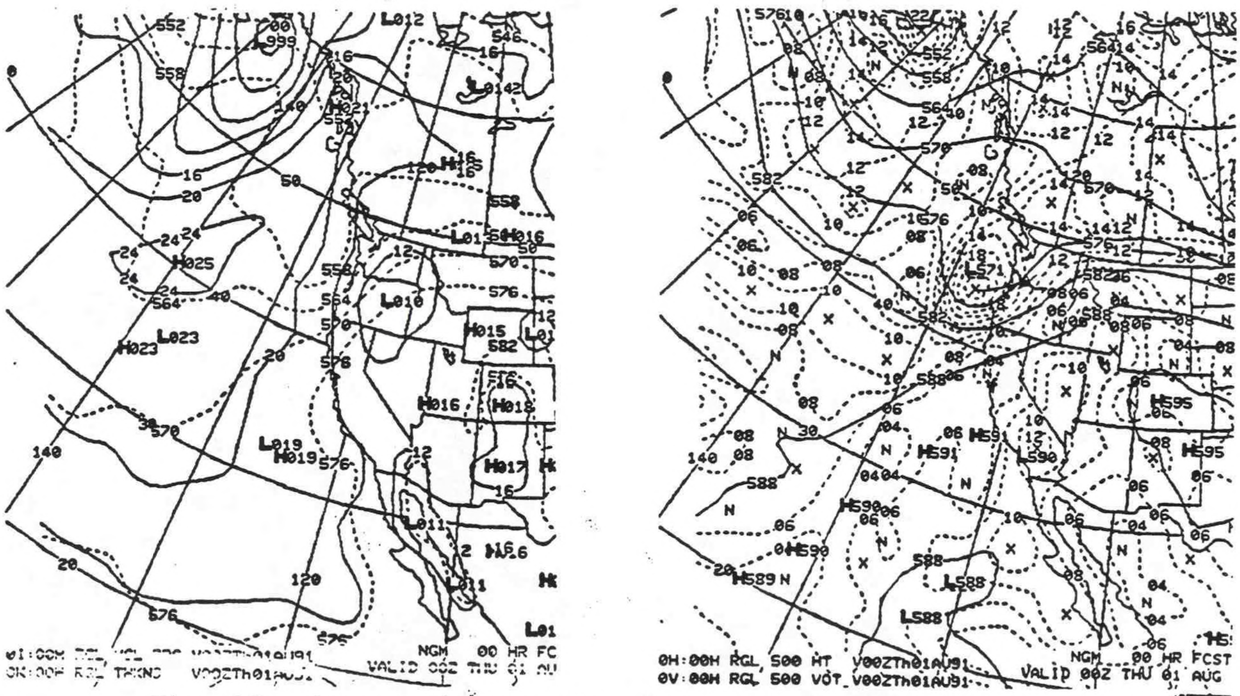


Fig. 10. A case example of a shortwave with most of its energy moving into the Pacific Northwest and extreme northern California. This example caused local ceiling in SFO bay during the night of Aug. 1, 1991 (UTC). SFO experienced scattered "VFR" during the rush, with a ceiling commencing at 07 UTC.

In this example of June 27-28 (UTC), 1990, the much benign appearance of the old boundary experienced a rather rapid increase in low clouds once it came in contact with the cooler coastal waters west of SFO. Orographic process also was a player as well as the onset of nightfall. The inland pressure gradient was more than 3.6 mb during the late afternoon and evening, which aided in the continual advection of low clouds into SFO Bay and SFO. SFO observed a ceiling and a 33 rate at 02 UTC June 28.

5. A surface front extending across northern California and the eastern Pacific, and is approaching the SFO Bay Area. It is accompanied by vorticity advection and low clouds over the waters, thus representing an active front (Fig. 9). The onset time for an early ceiling depends on when the front reaches the Bay Area.

Other note of interests are:

- If a trigger is identified and scattered clouds exist into the late afternoon hours (e.g. 00 UTC), there is the likelihood of an early onset.

- A perturbation passing either south or remaining east of the Bay Area is likely to produce at most scattered clouds (VFR) over SFO.

- "Dry" fronts, identified by water vapor imagery, that moves into northern California and the adjacent coastal waters from the north usually do not cause an early ceiling at SFO although low clouds are present along and/or ahead of the system.

- SFO will more than likely experience, at most, scattered (VFR) clouds during the "rush" when thunderstorms are observed around the Bay Area during the day.

The usual onset time for a ceiling (rounded off to the nearest hour) is 02 UTC with a standard deviation of one and one-half hours.

9. IFR RATE DUE TO NON-CEILING CONDITION

Evenings where a scattered amount of low clouds prevailed were classified marginal. The term "scattered", however, has a ambiguous meaning (besides being subjective), particularly to the forecasters at OAK CWSU and CFW-SU. The condition over the finals is most important, more so than the airport complex itself.

The amount of "scattered" clouds does not have to be five-tenths to cause an IFR rate. All it takes is a minimal one-tenth located in the final approach zone. The suspect cause of "scattered" IFR is the Crystal Springs Gap. The weather observer at SFO may have a difficult time detecting the low clouds moving over the finals from this gap especially after nightfall due to obstructions. This is where the SQL observation can come in handy, for the observer has an excellent view of the approach zone into SFO.

There were not many occasions where SFO experienced an IFR rate due to "scattered" (or occasional broken) low clouds during the "rush." Only 4 cases have been documented during the last 3 summers...all caused by a trigger (involving types 1, 2, 3 and 4a). Two common scenarios leading up to the "rush" are 1) absence of low clouds prior to the "rush" over the San Mateo coast; 2) remnants of low clouds from a late daytime burn-off (around 23-01 UTC), where the remnants are enough to affect the finals (trigger 1 and 3). A ceiling materialized over SFO between 04 and 07 UTC in each case.

10. MARGINAL CASES (SCATTERED "VER RATE")

Comprising 15% of the 230 days where low clouds were present along the coast, a majority of this 15% had clouds north of the airport's complex. In other words, VFR occurred during the "rush."

About 26 of the 36 involved a weak vorticity maxima/shortwave over the Bay Area during the evening. The most notable pattern is a shortwave with the bulk of its energy forecast to move into Oregon and extreme northern California (Fig. 10). The tail end of this feature, however, was forecast to brush the Bay Area overnight. The result was locally cloudy skies in the bay during and after the rush. SFO was scattered VFR during the "rush" with broken to scattered clouds between 07 and 13 UTC.

It is suggested that a forecaster call for scattered clouds for SFO during the rush should such a situation arise.

11. PREVAILING WIND DIRECTION

Although more research is required to determine the relationship between the wind pattern and the low clouds around SFO, there are clues in the wind field that can foretell the weather condition for SFO's evening "rush." The following are a few scenarios the author has noticed.

If the prevailing wind direction around the SFO Bay Area indicated by the buoys (12, 26, 42) and Pigeon Point are south to southwest, SFO will more than likely stay VFR during the "rush." The East Bay airports such as OAK and NGZ may have ceiling at 03 UTC, but SFO can (at most) be scattered during the rush (possibly due to downslope). This is despite a SFO to SAC gradient of more than 3.6 mb at 22 UTC. A common characteristic of this pattern is the sea breeze component at SFO (northwest wind) materializing later than the usual time of 19 to 21 UTC). SFO instead, experiences an northeasterly component. This condition is usually due to an eddy off the San Mateo coast.

SFO will also stay clear through the night if the lower Sacramento Valley airports, including Travis Air Force Base (SUU), reports wind from the north during the afternoon. (This condition is associated with a strong offshore pattern which minimizes the infiltration of the marine air mass into the bay.)

A majority of the early return cases were accompanied by a west-southwest to northwest wind components at SFO, with the directions ranging from 250 to 300 (true) degrees during the afternoons and evenings. Buoys (12, 26, and 42) and Pigeon Point would also show a west through northwest component. The only exception to the rule is an "active" front nearby. The wind speed was at least 12 knots.

12. PROCEDURE TO PREPARING AND UPDATING THE 19 UTC SFO FT

The following is a suggested procedure for preparing the 19 UTC SFO FT.

1. Continuous monitoring of the satellite pictures over the eastern Pacific from about 135w eastward and between 42 and 30 north latitudes,

including the California coast. Pay particular attention to the low clouds over the waters that are moving eastward towards the San Mateo coast (especially on days where the coast is clear). Determine if these clouds will impact the coast before 03 UTC. Advection of low clouds are usually associated with a vorticity maxima or fragments of the main frontal band. If there is clearing along the coast from the north, determine how far south the clearing will be (see "Surface Pattern and Recognition" for more details). The water vapor imagery is useful in detecting vorticity maximas and shortwaves.

Determine from the 12 UTC progs (mainly surface and 500 mb) if a trigger is present between 135w and the California coast. If YES, and if it is moving eastward, determine if it is on track by comparing the first 12 hour period with the latest satellite imagery and other pertinent information.

The Kansas City satellite discussions (under AFOS - the National Weather Service's Automated Field Operational System - product headers SIMMKC and SIMPSM, and their graphics CSM and IPG) are useful in describing important features and their trends.

The suggested forecast is as follows:

- If the prognostic charts valid 00 UTC resembles any of the five triggers discussed earlier (Early Ceiling Onset and Triggers), forecast early onset (a ceiling).

- If the prognostic charts valid 00 UTC does not resemble any of the triggers and you feel it will not affect the 03 UTC "rush", then forecast clear to scattered amount of clouds.

- If unsure, then forecast scattered to broken amount of low clouds.

After the 19 UTC FT has been sent, keep a close tab on the situation not only by monitoring the latest satellite pictures but also the following items:

2. Monitor the pressure gradients between ACV and SFO, and the SFO to SAC gradient. Then determine from the 12 UTC progs what the surface pattern will be during the ensuing 24 hours, e.g. offshore or onshore. AFOS products such as the surface plot (p0a) or surface analysis (90i), the hourly comparison of surface observations across California and adjacent states (24hchg), and the graphical display of the trend of the pressure gradients between selected locations during an 18 hour period (gdl) should be monitored closely.

3. Monitor the wind condition around the SFO Bay Area, such as the buoys off the San Mateo Coast (#12 and 26) and Monterey Bay (#42) (found under BOYCM7); the remote DARDC (Device for Automatic Remote Data Collection) wind sensor at Pigeon Point under SFODARDC; the three hourly Coast Guard observations under WRKDAR; and the remote wind/temperature sensors at South San Francisco (SOSF) whose data is appended at the end of the SFO's hourly observations.

4. Try to determine where the inversion base may be during the evening. Some of the products to aid you are pilot reports (PRCCA), Chalk Mountain whose SHEFcoded (remote sensors - Standard Hydrologic Exchange Format) identifier is CKSCI - found

under NNCRRACA1, and SOSF temperature.

Then pertaining to Table 2 on page 4, if the situation fits...

..#1: forecast an early ceiling.
..#2: forecast an early ceiling when the trigger or situation is identical to any of the examples given. Otherwise, forecast scattered amounts (VFR) of low clouds. There is about a 50% chance of an early onset.
..#3: forecast scattered (VFR) clouds. There is about a 20% chance of an early onset.
..#4: forecast clear to scattered (VFR) clouds.
..#5: forecast an early ceiling when the feature is identical to any of the examples given. The one positive case involved a back door front.
..#6; forecast scattered (VFR) clouds, with a 20% chance of a IFR rate.
..#7: forecast clear to scattered (VFR) amount of clouds. There is about a 20% chance of an early onset.
..#8: forecast clear skies.

If a significant change from the original forecast is anticipated, where it will affect the normal flow of traffic into SFO, it is advisable to coordinate with OAK CWSU and WSO SFO prior to updating the SFO terminal.

It should be emphasized that the scheme is not perfect and should be use with discretion. This paper is to serve as a stepping stone in understanding the "mysteries" of early onset at SFO, in hope of eliminating many of the uncertainties that goes in forecasting the sky condition for SFO's evening "rush.

13. CONCLUSION

The review of three summers of daily weather data for the SFO and vicinity has yield a scheme in assisting the forecasters in preparing the 19 UTC FT (and TAF) and 22 UTC update by OAK CWSU. The scheme assist the forecaster in identifying so-called triggers that is found to be the cause of an early onset of a low ceiling during the SFO's critical arrival period of between 03 and 04 UTC.

The findings of these synoptic scale features, known as triggers, will increase the awareness and accuracy of SFO's approach zone forecast. In addition, there are signatures that materializes during the afternoon that dictates the outcome of the "rush." This can be accomplished by recognizing parameters such as the pressure gradient components between ACV and SFO, and SFO and SAC; the prevailing wind at SFO and vicinity, including buoys and remote wind sites; and the sky condition at NGZ and OAK, and SFO during the afternoon.

Five triggers in the synoptic scale were identified. An example of each is included. These five triggers are also responsible for a majority of the scattered "VFR" and all scattered "IFR" conditions during SFO's "rush."

The findings of this study by no means solve the problems of an early onset at SFO. The checklist should be used with caution not only because it is subjectively prepared, but there can be additional scenarios associated with early onset. Also, there are elements on the list that required further research. Only time will allow the list to be refined.

Acknowledgements. The author wish to thank Walter J. Strach, Jr (MIC OAK CWSU) for all his valuable time and assistance, to Mike Mogil and Dick Pritchard of NESDIS for the quick response for requests of satellite pictures. In addition, thanks to S.K. Harner of NESDIS SAB, the staff of WSFO/WSO San Francisco and Oakland CWSU for their inputs; to Bill Aldridge, Ernest Daghir and PRC staff for the fast, efficient service for additional satellite pictures. Special thanks goes to Charito Brillantes and Shirlee Lowe for editing this paper.

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NMC'S MONITORING AND AVIATION BRANCH: ORGANIZATION, PRODUCTS, AND FORECASTING TECHNIQUES

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1. ORGANIZATION OF THE MONITORING AND AVIATION BRANCH

The Monitoring and Aviation Branch (MAB) is part of the Meteorological Operations Division of the National Meteorological Center (NMC). One of its main responsibilities is producing centralized operational forecast guidance in support of U.S. and international aviation activities. The branch consists of the Senior Duty Meteorologists, the Aviation Section, and the Satellite and Marine Section (SMS), located at the NOAA Science Center in Camp Springs, MD, and the Central Flow Weather Service Unit (CFWSU), located at FAA headquarters in Washington. A description of the activities of the CFWSU is contained in a companion paper. The Spaceflight Meteorology Group (SMG), located in Houston, TX, once a part of MAB, was transferred to the Southern Region of National Weather Service (January 1992).

Five Senior Duty Meteorologist (SDMs) are responsible for monitoring the production of NMC guidance on a round-the-clock basis seven days a week. As such, they are constantly reviewing the status of NMC computer runs and the dissemination of NMC guidance products. Senior aviation meteorologists sometimes serve as substitute SDMs.

The SDMs also monitor the quality and quantity of upper-air observations, including radiosonde, aircraft, and satellite reports. The SDMs, assisted by aviation meteorologists, may alter, purge, or keep questionable observations. This data monitoring function is an essential part of the overall process of producing quality aviation products.

A recent analysis of the functions of the SDM position revealed a complex array of responsibilities. Among other duties, the SDMs are forecasters, monitors, supervisors, and coordinators. They act for the MAB branch chief in his absence, and act for the Director of NMC during non-administrative hours.

Much of the coordination effort is spent interacting with National Weather Service's Office of System Operations (OSO). In very general terms, OSO collects raw meteorological data and transfers it to NMC's computers. NMC runs the computer models and sends model output products to OSO for distribution to the user community. The three main OSO facilities which handle this function are Tech Control, Facsimile, and the Systems Monitoring and Coordinating Center (SMCC). These facilities are the prime user contact point for dissemination problems. These and other OSO facilities are now being moved from Suitland, MD to Silver Spring, MD.

2. PRODUCTS AND FORECASTING TECHNIQUES - AVIATION SECTION

Among other products, the aviation section produces low-level ceiling/visibility, turbulence, and freezing level forecasts for domestic aviation; high-level significant weather progs for international aviation; and amendments of computer-produced wind forecasts. Twelve meteorologists are assigned to the section.

Low-Level Products

There are four low-level products produced each day. Each consists of two 12 and 24 hour forecasts, with valid times of 12Z/00Z; 18Z/06Z; 00Z/12Z; and 06Z/18Z. The forecast area covers the continental U.S. and portions of southern Canada, and extends from the surface to 24,000 feet. Two forecasters work on each product; one completes the ceiling/visibility forecast, while the second does the turbulence and freezing levels forecast.

Ceiling/Visibility. Three categories are forecast:

1) IFR - ceiling less than 1000 ft and/or visibility less than 3 miles;
2) MVFR - ceiling 1000 to 3000 ft and/or visibility 3-5 miles;
3) VFR - ceiling above 3000 ft and visibility greater than 5 miles. Areas of IFR and MVFR are depicted on the product.

Primary forecast tools used are manual guidance provided by NMC's Forecast Branch; MOS guidance from the LFM run; LFM, NGM, and AVN model products, including relative humidity fields and boundary level winds; airport climatological data; and satellite pictures. These inputs are then subjectively modified based on forecaster experience to produce the resultant forecasts. The 24-hour forecast is verified by a computer program and compared to the Techniques Development Laboratory (TDL) automated forecast. Cumulative scores are kept.

Freezing levels. The surface freezing line, as well as 4000 ft, 8000 ft, 12000 ft and 16000 ft freezing levels are forecast. The forecaster focuses on upper-air height, temperature, and thickness fields, surface winds, cloud cover, and diurnal tendencies. A comparison between analyzed thickness values and observed upper air freezing levels is made, and forecasts are made using the observed correlation and forecast thickness values from the model runs. Forecasts are verified subjectively by branch quality control focal points.

Turbulence. Forecasts of moderate or greater turbulence are depicted. If the Forecast Branch meteorologist predicts an area of broken thunderstorms, a depiction of at least moderate-to-severe turbulence below 24,000 ft is required. In addition to model forecast of boundary layer and upper air winds, vorticity, thermal advection and stability, forecasting tools include computer-produced turbulence report summaries and charts; radar summaries; satellite pictures; and computer produced probability of CAT guidance. Forecasts are verified subjectively by branch quality control focal points.

High-Level Products

Packages of high-level significant weather progs for international aviation are produced four times daily. The valid times of the products are 00Z, 06Z, 12Z, and 18Z. In order to meet facsimile deadlines and to provide enough time for the final products to reach the users, the forecasts are made 16 to 18 hours prior to valid time.

The high-level progs cover a vertical area from 24,000 ft to 60,000 feet. The area of responsibility extends primarily from 100E eastward across the Pacific, North America, the Atlantic, and Europe to 35E, from the equator to the North Pole. Small portions of the Southern Hemisphere (from the equator to 20S, from 130W westward to the International Dateline and a portion of the west coast of South America and adjacent waters from the equator to 13S, from 73W westward to 98W) are also included in the area. Two aviation forecasters work on each package.

One forecaster, usually called the "Pacific" forecaster, is responsible for the area from 100E to 100W north of 20N, and a tropical "strip" from 100E to 150W south of 20N to the equator, plus a region south of the equator from 180 eastward to 150W. The second, or "Atlantic" forecaster, is responsible for the area from 100W to 35E north of 20N, and a tropical strip from 150W to 05W south of 20N to the equator, plus the portions of the Southern Hemisphere east of 150W. The two forecasters coordinate their forecasts where their areas of responsibility abut.

Forecasting tools include Aviation model products, including forecasts of 250-mb heights/isotachs, maximum wind levels and speeds, tropopause heights, 500-mb heights/isotachs, 500-mb vorticity, relative humidity, lifted index, surface isobars, and 1000-500 mb thickness fields; satellite pictures; cloud top estimates provided by the Synoptic Analysis Branch (SAB) of NESDIS; tropical cyclone bulletins; manual guidance from the Forecast Branch of NMC (for the contiguous U.S.); and computerized turbulence probability charts.

The progs contain surface frontal positions and speed of movement, turbulence, embedded CB activity, flight level and wind speed of jets, tropopause heights, tropical cyclone information, and data on volcanic ash clouds.

Forecasts are verified subjectively by branch quality control focal points.

These high-level forecasts represent a large amount of work. The two forecasters who work on each package are responsible for a huge geographical area, forecast a large number of parameters, and spend a lot of effort formulating their progs.

Wind Amendments

Forecast wind speeds of the Aviation forecast model from 24,000 to 39,000 ft. can be amended twice daily, based on 12Z and 00Z data. Areas of wind amendments are defined by four coordinate points. The forecasts can cover 12, 18, 24, and 30 hour periods from forecast time. The area of responsibility extends from 120E eastward to 30E, north of the equator. Amendments are made for wind speed changes of a minimum of 20 knots and 20% of forecast wind speed. Amendments may increase or decrease wind speeds. Wind amendments information is disseminated on facsimile and by coded message. Twenty-four hour forecasts are verified by computer analysis. There are an average of four amendments each day.

3. SATELLITE AND MARINE SECTION (SMS)

In addition to its marine forecasting responsibilities, the SMS provides international SIGMETS and Satellite Interpretive Messages (SIMs) over oceanic areas, and an area forecast (FANT) over the Atlantic for the New York Air Route Traffic Control Center (ARTCC). One supervisor and fifteen meteorologists are assigned to the section, with five working in each of the Atlantic marine, Pacific marine, and satellite groups.

International SIGMETS

SIGMETs are short-term (0-4 hours) advisories of in-flight weather which may be hazardous to aircraft operations. They contain information on specified weather phenomena of an intensity and/or extent that concerns pilots and operators of an aircraft. These phenomena include active thunderstorms, tropical cyclones, severe turbulence, and volcanic ash clouds.

The forecasters use AIREPs, satellite imagery, vertical wind shear analysis and forecast charts from the Aviation model run, hemispheric turbulence report summaries, and probability of CAT forecasts from the Aviation model when making their forecasts. They coordinate with and obtain information from Meteorological Watch Offices (MWOs), Central Weather Service Units (CWSUs), and ARTCCs.

The area of responsibility over the Atlantic Ocean is the New York Oceanic Flight Information Region (FIR). It extends from 30N to 45N, west of 40W, to a line from 30N 70W to 42N 67W to 45N 40W. The Pacific Ocean area of responsibility is included in the Oakland Oceanic FIR. It extends from 37N 165E to 46N 166E to 57N 150W to 30N 120W.

SIMS

The Satellite Interpretive Message (SIM) provides a meteorological interpretation of satellite imagery, described in a concise narrative. It includes correlation of satellite data with conventional analyses and numerical forecasts. The areas of responsibility for the Atlantic and Pacific SIMs are the same as for the SIGMETS.

Information on jetstream axes, upper air lows, upper air troughs, vorticity maxima, upper air ridges, and precipitation area is included in the SIM. Direction, speed, and acceleration are indicated for lows, vorticity maxima, ridges, and troughs.

SIMS are issued every six hours for specific areas of responsibility over the Atlantic and Pacific Oceans. A graphic SIM, which illustrates features mentioned in the Pacific alphanumeric SIM, is issued at the same times.

The area of responsibility for the SIM, which is done for the Pacific Ocean only, is the same as for Atlantic Ocean SIGMETs.

FANTS

The FANT is a low-to-mid level (surface to 24,000 ft) significant weather forecast issued in alphanumeric form. It is issued four times daily, at 04Z, 10Z, 16Z, and 22Z. The forecast is valid for a twelve-hour period beginning at two hours past the issue time. The area of responsibility covers the North Atlantic Ocean from 32N to 40N, west of a line from 32N 63W to 40N 67W, including Bermuda.

The FANTs include the following: a synopsis, which describes the movement and any trend of the weather systems that will affect the forecast area during the valid time of the forecast; significant weather, including areas of widespread ceilings, areas of IFR conditions, heights of cloud bases and tops, heights of CBs, and causes of IFR conditions; information on icing, including areas of moderate or severe icing and freezing levels; areas of moderate or greater turbulence, including flight levels of the turbulence; and an outlook, which includes a brief statement of the movement of weather systems affecting the forecast area and the trends of the significant weather affecting the area. The outlook covers the twelve-hour period following the valid time of the FANT.

Forecasters utilize hemispheric surface analyses, AIREPs, radar summaries, computer model products including relative humidity fields, freezing level analyses, and upper air soundings when preparing their forecasts.

SIGMETs, SIMs, and FANTs are verified subjectively by SMS personnel.

4. PLANS FOR THE FUTURE

A number of ongoing projects indicate that there will be a number of improvements in areas directly affecting the MAB. With respect to the quality control of upper-air observations, branch meteorologists will be monitoring data in a work station environment. Computer programs will take care of routine corrections, leaving the meteorologists with more time to handle difficult correction decisions that the machine cannot make. Branch forecast products will be produced on and disseminated through work stations, improving the quality of the product and speed of dissemination. NMC is investigating a 6-hour Aviation model forecast cycle and evaluating a rapid update cycle (RUC), both of which utilize new data sources, including automated aircraft reports. New computer-generated turbulence forecasts are being worked on as well.

5. SUMMARY

The forecasters of the Monitoring and Aviation Branch predict a wide variety of meteorological parameters over a huge geographical area on a round-the-clock basis. They produce a large number of products, which are disseminated to members of the worldwide aviation community. Plans for the future include improvements in the quality control of upper-air observations; continued improvement in the quality of forecast products through updated production and dissemination facilities; and improvements in NMC's forecast models, which will assist the meteorologists in making better forecasts.

DEVELOPMENT AND APPLICATION OF AN ICING PREDICTOR EQUATION

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1. Introduction

Forecasting methods for aircraft icing developed and used by the United States Air Force (AWS, 1980) and the U. S. Navy (NAVEDTRA, 1974) have been shown to have an accuracy not much better than chance (Bernhardt, 1989). As a result, we undertook the development of an improved approach to icing forecasting which was based on meteorological parameters easily computed from operational data. These included condensate supply rate (CSR), vapor flux rate (VFR) (Rhea, 1979), adiabatic condensate, Appleman's (1954) -8D parameter, static stability (Holton, 1979), and dew-point depression.

Development data came primarily from measurements by the University of North Dakota Citation II aircraft (Grainger et al., 1986) and secondarily from pilot reports. The study included data from an area encompassing parts of Oklahoma, Kansas, Colorado, and Missouri. These data were taken from 1987-90 winter seasons. Known icing layers were compared to output from a linear regression equation which was developed on data from icing layers. The resulting icing predictor equation was used in daily forecasting support for a winter (1989-90) field season, with very good results. Also, in order to formulate an icing potential outlook, an attempt was made to predict the amount of supercooled liquid water (SLW) from commonly measured parameters.

2. Icing Equation Development Background

The seven (7) different parameters correlated against icing were chosen to compare past research with results of our own, as in the case of -8D, and to find if other relationships could be found, not yet documented. For each of the parameters, a short summary of their definition and derivation follows.

2.1 Adiabatic Condensate Formula

The adiabatic condensate (ACON) is the amount of moisture that falls out of a parcel as it is lifted from one level to another. As long as the parcel is unsaturated, the lift is by an adiabatic process, but once saturated, the process is assumed to be pseudoadiabatic. As noted by Rhea et al. (1982), ACON can be approximated by subtracting the specific humidity at the level to which the parcel was lifted from the specific humidity at the original level, i.e.,

$$ACON_{(L)} = q_{(0)} - q_{(1)} \qquad (1)$$

where $ACON_{(L)}$ is the adiabatic condensate at the original lower level (g kg^{-1}); $q_{(0)}$ is the specific humidity (g kg^{-1}) at the original level; and $q_{(1)}$ is the specific humidity at the level to which the parcel was lifted. No limiting thresholds were established on the value of $ACON_{(L)}$.

Icing layer thicknesses varied as synoptic conditions changed. A previous study (Bernhardt, 1989) had found that through synoptic classification of patterns accompanying icing, different thicknesses of parcel lift to sustain icing can be established. In this study, a 20 hPa (approx. 220 m) lift was assumed for cases of isentropic and warm frontal lift, ranging up to 100 hPa (approx. 950 m) for vertical motions associated with moderate to strong cold fronts. This allowed lifting of thicknesses variably dependant upon the synoptic features affecting a region.

2.2 Vapor Flux Rate Formula

The vapor flux rate (VFR) is the advection rate of water vapor into a layer, accounting for directional shear moving vertically through the atmosphere. VFRs incorporated specific humidities, wind speed and wind direction at the same level at which it was computed. The direction was algebraically subtracted from the wind direction at an altitude determined to be a point of condensate renewal. If there was no significant shear through the lowest 3300 m (10,000 ft) of the sounding, the condensate renewal direction was assumed to be the average wind direction in this layer. However, if an inversion existed, this was the wind direction near the top of the inversion. Clouds were often capped at the inversion and a strong directional shear frequently occurred, therefore this was considered the point of strongest condensate renewal.

The formula for vapor flux rate (Rhea et al., 1982) follows:

$$VFR_{(L)} = q_{(L)} \times V_{(L)} \times \cos(WDR) \times \frac{TH}{g} \qquad (2)$$

where $VFR_{(L)}$ is the vapor flux rate (g cm^{-1} s^{-1}); $q_{(L)}$ is the specific humidity at the level; $V_{(L)}$ is the level wind speed (cm s^{-1}); **WDR** is the component wind direction; **TH** is the thickness of the parcel lift (hPa); and **g** is the acceleration due to gravity (cm s^{-2}).

The preceding formula gave us values which were widely variable. High values were found with stronger winds, which did not necessarily relate to higher icing incidence. Due to this problem, we decided against establishing a specific threshold cut-off point. Rather, we looked for value maximums in the vertical profile of the VFR, which did appear to have a relationship to icing potential.

2.3 Condensate Supply Rate Formula

The condensate supply rate (CSR) is the advection rate of new water vapor into a region, which is then converted to available condensate. It is based on many of the same parameters used in computation of VFRs, but also includes the adiabatic condensate and width of a surface over which a vertical lift of the moisture is assumed. The lift may be either topographic or dynamic.

The CSR formula -- derived from the atmospheric water balance equation for two-dimensional, steady-state flow up a barrier -- was computed using a scheme similar to that outlined in the adiabatic condensate and VFR discussions (Sec 2.1 and 2.2). An up-slope plane (Fig. 1) of 150 to 200 km was used to account for gentle up-slopes often found in isentropic and warm frontal lifts. The plane was shortened to 100 km in synoptic cases involving moderate to strong cold fronts.

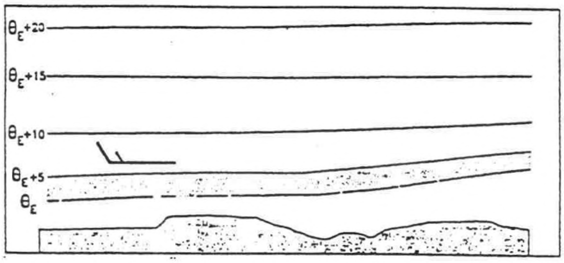

Fig. 1. Condensate Supply rate along an equivalent potential temperature up-slope plane. Condensate is supplied from the left of the diagram with lifting occurring along isentropic surfaces. The layer and lift of the condensate is denoted by the hatching between isentropes. The wind speed and direction of condensate renewal is indicated by the wind flag.

The formula for CSR (Rhea et al., 1982) is:

$$CSR_{(L)} = \frac{TH \times V_{(L)} \times \cos(WDR) \times ACON_{(L)}}{\rho \times g \times WDTH} \quad (3)$$

where **$CSR_{(L)}$** is the condensate supply rate at the level (mm hr^{-1}); ρ is the density of water (g mm-1); and **WDTH** is the width of the up-slope plane (cm). The other variables have been previously defined.

As noted in the vapor flux rate discussion, the CSR formula also gave widely variable values, mostly relating to variations in the wind speed. Once again, no threshold limits were set on the data to allow testing of all values. One limitation placed on the data was to allow only those values that fell between 0°C and -20°C. We found icing in temperatures as low as -40°C, but concurred with an AWS (1980) study which showed the incidence of icing drops sharply at temperatures colder than -20°C.

The CSR and VFR were found to be positive indicators of icing potential. CSR went further by assuming a lift of condensate from a lower level, over a geographic distance. This was important as continued condensation of water vapor is necessary for the production and sustenance of SLW.

2.4 Mixing ratio

The mixing ratio is a dimensionless ratio of the mass of water vapor to the mass of dry air in an air parcel (AMS, 1959). AWS (1980) established that with higher mixing ratios, there was a greater potential for icing. Our study set a lower limit of 1 g kg^{-1} as we felt that at concentrations of less than 1 g kg^{-1}, the potential hazard of icing to aircraft would be low due to lack of sufficient moisture.

2.5 Minus 8D technique

Appleman's (1954) -8D method indicates layers which are supersaturated with respect to ice. These values are found by multiplying the dew-point depression by eight (8). The resultant value is then compared with the ambient temperature. If the value is warmer than the ambient temperature, the layer is considered supersaturated and thus, has a greater potential for icing.

2.6 Static Stability

As defined by AMS (1959) and shown by Holton (1979), this is the stability of an atmosphere in hydrostatic equilibrium with vertical displacements, usually considered by the parcel method. The occurrence and rate of vertical motions are highly dependant on thermal and moisture properties of the lower and middle troposphere.

2.7 Dew-point Depression

The dew-point depression is the difference between the ambient and dew-point temperatures. Past studies (AWS, 1980) have shown that the potential for icing conditions greatly decreases if the dew-point depression is greater than 6°C. This study used a threshold of 6°C in concurrence with the AWS study and due to the lack of significant moisture at larger depressions.

3. Initial Steps of the Icing Equation Development

Initially, several icing cases were studied to find the correlation between meteorological parameters and icing. After deriving correlations based on icing-only cases, we randomly picked other dates of no icing throughout the data period (1987-90), so we would not be biased by icing-only cases (Table 1). The following parameters were used in the equation development: adiabatic condensate, VFR, CSR, mixing ratio, minus 8D (Appleman, 1954), static stability and dew-point depression. The correlation coefficients calculated using each individual parameter are summarized in Table 1.

The second column in Table 1 shows the correlation coefficient of each parameter to known icing conditions from seventy-eight (78) events. The third column shows the correlation of each parameter to a combined data set of both the 78 icing events, and non-icing conditions, including 100 random non-icing days. This secondary data set is the more desirable situation for operational procedures, as it includes both types of conditions.

Parameter	Icing-only	Combined Data Set (Null Set)
Adiabatic Condensate	-0.25	0.71
Dew-point Depression	0.49	-0.71
Vapor Flux Rate	0.27	0.61
Static Stability	-0.58	-0.05
Mixing Ratio	-0.07	0.85
Condensate Supply Rate	0.32	0.40
Minus 8D	0.08	0.11

Table 1. Comparison of the different parameters and their individual correlation coefficients derived from an icing-only data set (Col 2). The last column shows the correlations using a combined data set, which included both icing and non-icing cases.

The icing-only list in Table 1 indicated that even though the highest positive correlation was only 0.49 (dew-point depression), this was still a significant relationship, given the number of events. Furthermore, the correlation coefficient for static stability, though negative, had an even more significant relationship with icing incidence. With the icing-only cases, it showed a high correlation, but when combined with non-icing situations, its correlation fell to near zero. We found the minus 8D method performed poorly as shown by the correlation coefficients in Table 1. Given the poor correlation coefficient and poor results attained from an earlier study in the central United States (Bernhardt, 1989), it was dropped from further consideration and is shown only for comparison.

As shown in Table 1, when the non-icing data set (called the null set) was included, the results were markedly different, with mixing ratio having the highest individual correlation. This was a predictable result because of the moisture requirement for icing conditions to develop. The decision to use a combined data set was based on the need for an operational predictor. In this study, an operational predictor was defined as a technique that successfully predicted cases of either icing or non-icing conditions.

All parameters, with the exception of static stability and minus 8D, showed a significant increase in correlation coefficient when combined with the null set (Table 1). Parameters that had an increase in their individual correlation coefficients all measured moisture in some manner. Static stability was initially included as a potential icing predictor, as it had a high correlation, but the need for a simple operational predictor and the low correlation coefficient in the combined data set forced us to eliminate it.

In addition to the parameters listed in Table 1, others were analyzed to determine their correlations to icing incidence. Temperatures were correlated against icing, with significant relationships found between the 0°C to -20°C range. Because no one specific temperature range had a higher correlation than another, it was decided to limit temperatures between a 0°C to -20°C range. Furthermore, as noted earlier, prior studies (AWS, 1980) indicated the potential for significant icing greatly diminishes at temperatures colder than -20°C.

4. Methodology of the Icing Equation Development

Since individual parameter values fluctuated widely in the icing and non-icing events, it was necessary to develop a methodology which eliminated subjectivity. All observed icing layers from the earlier listed samples were categorized; those less than 150 m thick, 150 to 305 m thick, and those greater than 305 m thick. The null set (non-icing data) used layers of less than 610 m, 610 to 1525 m, and greater than 1525 m. These layers were broader to allow for the thicknesses within the temperature spread of 0°C to -20°C.

A "best scenario" was then developed for each set. The "best scenario" used the highest values of the parameters to develop the icing data set and the lowest value was used for the null data set. Depending upon the thickness of the layer, as earlier noted, two to four values of each of the parameters were chosen, evenly spaced in the layer. In cases of icing, the values came from icing layers, whereas in the null data set, the values came from the interval between 0°C to -20°C (Table 2). These values were then averaged to determine mean conditions in the layer. The icing-only data set was used for comparison, because the presence of super-cooled liquid water is often a mesoscale phenomena usually occurring in layers a few hundred meters thick. The maximum icing layer thickness during this study was 1220 meters (4000 ft). The most appropriate scheme for operational use would be that of the null set, since this sample would be more representative of routine atmospheric conditions, which is also why the layers are somewhat thicker.

Icing Data Set		Null Data Set	
Lyr Thkness (m)	# of values	Lyr Thkns (m)	# of values
< 150	2	< 610	2
150 - 305	3	610 - 1525	3
> 305	4	> 1515	4

Table 2. Grouping of layer thicknesses from icing cases and the null data set. The number of values averaged in each layer is listed opposite the thickness of the layer. Approx. English equivalents for the figure values are: 150 m = 500 ft; 305 m = 1000 ft; 610 m = 2000 ft; and 1515 m = 5000 ft.

The temperature range of 0°C to -20°C introduced a bias to the temperature correlation by limiting temperatures in the null set to between 0°C and -20°C, while non-icing conditions may occur at any temperature. Due to this problem, temperature was not used in the combined data correlation, but as stated earlier, a limit of 0°C and -20°C was placed on the output.

Additionally, we averaged pilot reports of icing intensity and centered them around the synoptic hours of 0000 UTC and 1200 UTC to coincide with the rawinsonde information. Averaging of the pilot reports was also performed because of their nature, which have an element of subjectivity and could introduce a bias. These values were later used in the statistical comparison of reported icing to icing equation output.

4.1 Icing Equation

All parameters thus far discussed were weighted through linear regression to find the best fit of the range in their values to a predicted icing value. They were all found to have a relationship to icing potential and intensity through their inherent properties relating to moisture and stability. They were then combined into an equation to find how this combination could be related into an icing potential equation. The multiple linear regression equation which resulted is:

$$\text{ICING} = -0.023 * \text{Dew-point Depression} + 0.210 * \text{Condensate Supply Rate} + 0.006 * \text{Vapor Flux Rate} + 0.340 * \text{Mixing Ratio} + 0.757 * \text{Adiabatic Condensate.} \quad (4)$$

Where **ICING** is a number giving a predicted icing intensity. The other parameters have been described earlier. As noted earlier, static stability and minus 8D were not incorporated into the final equation. The correlation coefficient yielded by comparisons of output from Eq. 4 and that of actual icing conditions was 0.90. This indicated good prediction potential between this equation and actual icing incidence.

5. Procedures and Skill Involved in Applications of the Icing Equation

5.1 Procedures Followed in Forecast Verification

Improvements in icing forecasting during this project evolved with time, experience and technique development. All forecasts issued from 6 November 1989 through 8 March 1990 at Kansas City were verified and scored. Known icing soundings were analyzed to find the success of the icing equation. This amounted to a sample size of 53 soundings over the winter. We then included an analysis of a random sample of non-icing soundings from the same period to determine if the equation over-forecasted icing potential. Finding this not a problem, these 32 random soundings were not included so the data sample would not be contaminated by non-icing conditions. Finally, we verified all 144 forecasts issued over the winter to determine the probability of a correct (POC) icing levels and intensity forecast and a false alarm rate (FAR).

All icing forecasts were compared with actual reports of icing based on UND Citation investigations or pilot reports. The intensities and levels of reported icing were compared against the icing equation predictions. Assigning intensity values (Table 3), they were algebraically compared with actual icing conditions. The minimum and maximum altitudes of icing were likewise compared with the icing equation output.

Icing Intensity	Category Assigned Value
None	0
Trace	1
Light	2
Moderate	3
Severe	4

Table 3. **Listing of icing intensities from the icing equation output and the output numerical value assigned to each.** The assigned values of icing intensity were arbitrarily chosen to be linear.

5.2 Results of Operational Forecast Verification

The icing equation had success in forecasting non-icing conditions but did have some weakness in forecasting high rates of accumulation. We found some under-forecasting in cases of moderate to severe icing. The situations where over-forecasting occurred most frequently were with the null data set. The over-forecasting problem was partially rectified by setting individual parameters to zero when they did not meet earlier listed threshold values. Though the sample size for moderate to severe icing was small, five of the seven cases which occurred were under-forecast by only half of a category. This under-forecasting in high rates of accumulation was found to be a problem in the initial equation development and re-verified in applications of the equation to Kansas City data from 1989-90. Though slight under-forecasting occurred, the equation still predicted virtually all cases of icing.

In forecasting altitudes of icing, the lower icing altitude was underforecast by 150 m (500 ft), while the top of the icing layer was slightly over-forecast by 35 m (115 ft) (Table 4). We considered both of these errors to be minimal.

Icing Intensity		Minimum Altitude		Maximum Altitude	
Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
-0.4	0.5	-150 m	700 m	+ 35 m	810 m

Table 4. Icing equation forecasts compared to verified icing reports. The altitudes are given in meters and give bases and tops of both predicted and reported icing levels.

The altitudes of predicted icing were determined by interpolating the sounding data from raw observed data and assigning altitudes based on hypsometric equation evaluations. The verified icing layer altitudes were determined primarily by UND Citation II penetrations, and secondarily from pilot reports in the study areas.

In evaluating the critical success of our forecasts, we computed a POC and FAR based on procedures followed from 1987-89, then later (1989-90) when the icing equation was used as part of daily operational forecasting. The first data set (198788) in Table 5 illustrates the value of subjectivity and experience in the forecast product. In this case, the sounding (objective) method incorporated some of the techniques, such as -8D and AWS procedures, which were later rejected in this study. The other method (objective and subjective) incorporated forecaster experience. Forecast results from Denver during 1988-89 were similar to this and are not presented here. The final data set (1989-90) shows the influence of the icing equation, together with forecaster experience, and a strong reliance on the equation output.

Forecast methods		POC	FAR
Sounding (objective only)	1987-88	85.0%	38.0%
Objective and subjective	1987-88	97.7%	8.5%
Objective and subjective	1989-90	99.3%	0.7%

Table 5. **The probability of a correct (POC) forecast and false alarm rates (FAR) for two forecasting data sets, Denver (1987-88) and Kansas City (1989-90).**

Though the icing equation was developed using data sets from two different areas, it was possible that the increased success rate (Table 5) was due to the geographic location of Kansas City. Often up-slope situations and other icing producing events moved into and developed quickly in the Denver area, whereas Kansas City's upwind conditions were much more evident with the lack of major upstream topographic features to modify the inward moisture flow. Nonetheless, informal tests using the icing equation across the nation during winter 1989-90 showed success in all regions.

These nationwide tests involved the analysis and comparison of soundings from across the United States and Canada to reported icing conditions, using only pilot reports of icing as verification. The same procedures were followed for these tests as were used in the forecast verification, with local sounding information used, and an icing potential forecast made. This test was also applied on a data set from the northern plains from 1985-87. These tests showed comparable results to those of other geographic regions summarized earlier, and thus showed potential as a nationwide icing predictor.

Comparing winter 1989-90 icing forecast results to those from Denver 1987-88 and 1988-89 (Bernhardt, 1989), it became evident that there was a continued improvement in icing forecasts. Less sophisticated CSR and VFR forecast procedures utilized from 1987-89 were improved by the inclusion of significant-level winds and a broader and more gentle up-slope. These improvements brought more confidence and success to the forecasts. This was noted by the significant drop in the FAR and closing of the gap between subjective and objective forecasting methods (Table 5). With the success rates of icing forecasting established, the next step was an attempt to forecast liquid water content, since this would more closely represent icing intensities.

6. Development of Super-cooled liquid water prediction

Encouraged by the results attained from the forecasting experiment, we decided to try to forecast supercooled liquid water content. We felt that this would be the appropriate approach to eventually forecast potential icing loads based on aircraft type. Utilizing a sequence of icing and non-icing data samples from Denver and Kansas City, we correlated aircraft data to measured SLW contents. Initially, seven parameters were included in an icing correlation: 1) temperature, 2) dew-point depression, 3) adiabatic condensate, 4) CSR, 5) VFR, 6) aircraft-determined vertical velocities, and 7) mixing ratio.

Using a multilinear regression approach again, we weighted each parameter and developed a SLW prediction equation. Results from this equation showed a correlation coefficient of 0.5 between these and measured SLW (Table 6). It was interesting to note that a higher than 0.5 coefficient was attained using a variety of combinations of the parameters. It was also noteworthy to see the role of vertical velocity in producing higher correlations.

TEMP	DEWDP	ACON	CSR	VFR	VV	MXRT	R
X	X	X	X	X	X	X	0.53 0.59
X	X	X	X	X	X	X	0.53 0.64
X	X	X	-	X	X	X	0.53 0.63
-	-	X	X	X	X	X	0.53 0.64
X	X	X	X	X	X	-	0.53 0.63
X	X	X	X	-	X	X	0.53 0.62
-	-	X	X	-	X	X	0.53 0.64
-	X	-	X	X	X	X	0.52 0.60
X	X	X	X	X	-	X	0.40 0.20
-	-	X	X	X	X	-	0.50 0.66

Table 6. The parameter combinations used to predict liquid water contents with resultant correlation coefiecients. An 'X' indicates which the parameter combinations used to derive the resultant R. Identification of the variables follows: TEMP = Temperature; DEWDP = Dew-point depression; ACON = Adiabatic condensate; CSR = Condensate supply rate; VFR = Vapor flux rate; VV = vertical motion; and MXRT = Mixing ratio.

Table 6 summarizes the derived correlation coefficients and the combinations of parameters which were used to calculate them for observed liquid water contents to a predicted value. It does not include all combinations attempted, but shows a sample of the results. The top number for each set, reading across, is the correlation coefficient resulting from an initial data set involving icing-only cases from the Denver, Colorado area. It showed correlations from 0.50 to 0.53, until vertical motions were removed, then it dropped to near 0.40. Only one case is shown in which vertical motion is removed, but all other iterations of the data samples were similar when vertical motion was removed. This illustrated the role vertical motions have on the sustenance of SLW in a cloud.

The second set of coefficients, reading across, involved a different data set using both icing and non-icing data, including data from different years and locations. Much high coefficients were attained. With this set, the role of vertical motion was accented, with coefficients averaging close to 0.60 with most parameter combinations. It dropped to near 0.20 when the vertical motions were removed. In this correlation of SLW prediction, 100 data samples were used in the first set and 105 were used in the second set.

Computations of the significance level of the correlation coefficient for the first data set indicated that the results were significant. In the case where the correlation coefficient was 0.40, there was a 0.5% chance (Student's T, Taylor, 1982) that this high of a correlation would be found in data which was uncorrelated with a data set size of 100. This meant that there was a "significant" relationship between the measured and predicted values of the SLW. This further implied that the highest correlation coefficient (0.53) could be considered 'very significant', with only a 0.007% chance of a correlation with uncorrelated data.

Encouraged by these results, we decided to investigate further using another data set. This data set once again included only aircraft data, but used aircraft data from different years and locations (Denver and Kansas City). Furthermore, this set included regions with no SLW or icing. Results from this group of 105 samples concluded with a composite correlation coefficient of predicted liquid water content to measured liquid water of near 0.60. Furthermore, it showed that as temperature and moisture (dew-point depression and mixing ratio) parameters were implicit in computations of adiabatic condensate and CSR, removing these improved the correlation to slightly greater than 0.60. Additionally, it indicated a significant relationship between the SLW content and adiabatic condensate, CSR, VFR and vertical velocities (Table 6 - last group), with a near zero percent chance of this high a correlation with uncorrelated data. This was not really surprising because of the dynamic relationships between these parameters and SLW production. These relationships include moisture availability, advection and parcel lift.

Finding predictive success using only aircraft data, we wanted to find if similar results could be attained with 12-hourly rawinsonde information. The same set of 105 icing-only days was analyzed and verified with Citation investigations and pilot reports. This sample showed a correlation of 0.73 using the combined data group. When the variables of temperature and dew-point depression were removed, the coefficient dropped to 0.69. The high correlation of this combined data set was encouraging as it indicated that there was yet potentially a high probability of predicting SLW content using the techniques described earlier. Some under-forecasting still occurred but was not too severe, as the maximum liquid water contents ranged up to 0.4 g m^{-3} while the maximum predicted value was slightly higher than 0.3 g m^{-3}. Most under-prediction occurred at the higher liquid water contents.

In the final iteration, a data sample of sounding information was analyzed from the Kansas City 1989-90 season to find if a correlation or predictive value may be determined using both icing and non-icing data-sets with model-derived vertical motions. We found a problem in obtaining reasonably accurate vertical velocity estimates. The National Weather Service's Nested Grid Model (NGM) 700 hPa vertical motion field was used as an initial starting point. Since these velocities are synoptic-scale values, they were about an order of magnitude lower than those measured by the Citation. Nonetheless, we proceeded with this data sample to determine if it was feasible to predict liquid water using rawinsonde data.

Using 100 data samples, a correlation coefficient of 0.50 was attained. Though significant with the number of data samples, the influence of vertical motions brought the coefficient to a point lower than was expected. Comparing this with the near 0.70 correlation described earlier, it became apparent that more representative vertical motion estimates were integral to the predictive capability of the equation. Adjusting the weighting of each parameter for use with NGM 700 hPa vertical motions, the following equation was formulated:

$$SLW = 0.009 * MXRT + 0.065 * ACON + 0.106 * VFR + 0.003 * CSR + 1.119 * VV \quad (5)$$

where **SLW** is the predicted supercooled liquid water (g m^{-3}), and **VV** is the NGM vertical velocity (microbars s^{-1}, where 1 microbar ~ 1 centimeter). The other parameters were defined earlier and in Table 6.

This equation yielded a predicted SLW content which we then compared to observed (measured) conditions. The correlation coefficient derived from this test was 0.68. As noted before, temperature and dew-point depression had little contribution to the outcome, so were dropped from consideration in this formulation. Rather, temperature limits of 0°C to -20°C were set and moisture measured by dew-point depressions were implicit in the formula's moisture parameters of CSR, mixing ratio and adiabatic condensate. Little over-forecasting occurred with this equation which indicated a greater potential application.

7. Conclusions

The statistical procedure followed in developing the icing equation demonstrated that there was a statistically significant correlation between the parameters selected and the risk of icing. Despite the limited size of the data set, we hoped that the technique would be useful in providing forecasters with guidance in predicting layers of potential icing conditions. Further testing and implementation of the icing equation during the Kansas City, Missouri, 1989-90 winter icing program showed continued improvement in icing forecasts using its output.

No model output is used in the icing equation, but melding it with models, such as the NGM or the Local Analysis and Prediction System (LAPS) icing algorithm (Rasmussen and Politovich, 1990), could extend a potentially successful icing forecast past 24 h, depending on the success of the forecast model. A major quality of the equation is that parameters which are important to the production and sustenance of super-cooled liquid water are incorporated into the equation. Advantages of the equation were the elimination of subjectivity and use as a predictor by the ability to look at conditions over a broad synoptic scale. By analyzing upstream soundings and finding their icing potential, this gave the forecaster a better idea of icing potential in a forecast area. Further, the equation output was helpful as it was objective, efficient and operationally easy.

In searching for a potential application of the equation to predict SLW content, correlations were found between seven different parameters and atmospheric liquid water content. Varying data sets have all shown a correlation, so the potential prediction of SLW was pursued. Applying this technique to NWS 12-hourly rawinsonde data, a correlation of over 0.7 was found. Investigations continued in an attempt to predict liquid water, using readily available thermodynamic data and vertical velocity values from NGM output. Initial results were less than desirable, but with adjustments made for lack of good vertical motion values, much better predictive values were attained. We feel that with improved vertical wind computations, which could be derived from profilers, Doppler radar or LAPS (Rasmussen and Politovich, 1990), that the formula's predicted SLW value will more accurately represent the environmental liquid water content. This would therefore serve as a better index by which to guide forecasters through the aircraft icing hazards problem.

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FORECASTING AIRBORNE VOLCANIC ASH IN ALASKA

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A Comparative Study of Pilot's Understanding of Low-Level Wind-Shear Terminology

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1. Introduction

The National Weather Service Forecast Office in Seattle has sponsored numerous aviation weather seminars over the last decade that have been attended by large numbers of pilots. At these seminars, a high level of confusion has been noticed regarding the difference between non-convective Low-Level Wind Shear (LLWS) and microbursts.

LLWS related to microbursts has received a great deal of attention from the research and airline communities. This is evidenced by the large number of technical papers, airline training programs, and aviation training films that are available. Nonetheless, this attention has apparently failed in differentiating between non-convective LLWS and microbursts.

A survey taken at a Certified Flight Instructor (CFI) clinic sponsored by the Washington State Division of Aeronautics, showed that there was confusion among those questioned about LLWS terminology (Jackson 1991). A continuation of the initial study in an area where convection was more frequent was thought to be more appropriate. The Aviation Division of the Texas Department of Transportation agreed to take the same survey at CFI clinics held in Texas.

A Certified Flight Instructor teaches "hands-on" pilot training, and must hold either a Commercial or Air Transport Pilot (ATP) license. A person must attend a CFI Clinic every two years and pass a written test in order to maintain certification as a flight instructor by the Federal Aviation Administration (FAA). The CFI is generally considered among the elite of the general aviation pilots.

The term "pilot" in this paper refers to general aviation pilots, i.e. pilots of small aircraft, and does not refer to pilots of commercial airlines.

2. The Survey

Both surveys were taken at CFI clinics sponsored by respective states. The Washington survey was taken in January of 1991 and the Texas survey was taken at four CFI clinics during the summer of 1991. The CFIs were asked to be truthful in their answers and not guess when answering questions. There were 134 respondents from Washington, and 126 from Texas.

The list of questions and the wording of each question on the survey was reviewed by personnel from the training department of Alaska Airlines, SEA-TAC air traffic control tower, and by the Regional Aviation Meteorologist of the National Weather Service Western Region.

The following is a list of the questions that were in the survey:

1. What license do you now hold?
   (A) Private
   (B) Commercial
   (C) Air Transport Pilot (ATP)
2. Is there a difference between low-level wind shear (LLWS) and Microburst?
3. You are on approach and are told by the tower that there is a Low-Level Wind-Shear Alert (LLWA) in effect. Would you expect microburst activity in the area?
4. If you see LLWS mentioned in the Aviation Terminal Forecast (FT), would you expect microburst activity in the area?
5. Does LLWS in the FT and LLWA given out by the tower mean the same thing?
6. Is the recovery procedure the same for LLWS as it is for microbursts?
7. If microburst activity is expected to occur in the terminal area, it will be indicated in the FT as:
   (A) LLWS
   (B) TRW+G50
   (C) Don't know/Unsure

8. Is a microburst always accompanied by severe turbulence?

Except for questions 1 and 7, the multiple choice answers were:
(A) Yes
(B) No
(C) Don't know/Unsure

3. Results of the Survey

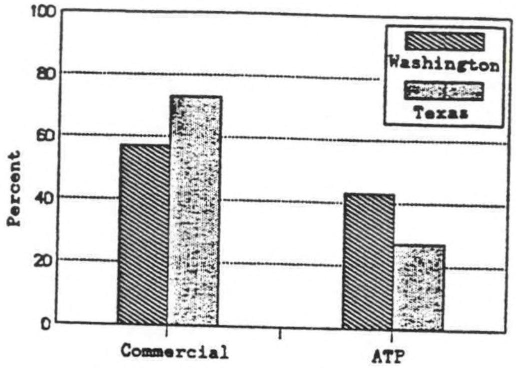

Fig.1. Survey response to: "What license do you now hold?"

Figure 1 shows the percentage of commercial and ATP rated pilots. A previous paper concerning the survey given to CFIs in Washington state compared commercial and ATP rated pilots, and shows no significant difference in responses between the two groups (Jackson 1991). The same result is apparent in the responses from the Texas survey. Therefore, pilots in this paper are grouped by respective states, not by type of license held.

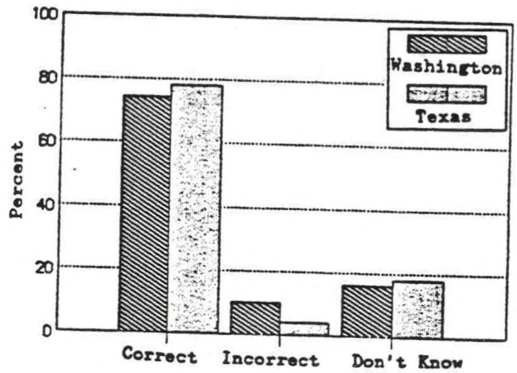

Fig. 2. Survey response to: "Is there a difference between LLWS and microburst?"

The majority of the pilots knew there was a difference between LLWS and Microbursts, although nearly 20% did not (Fig. 2).

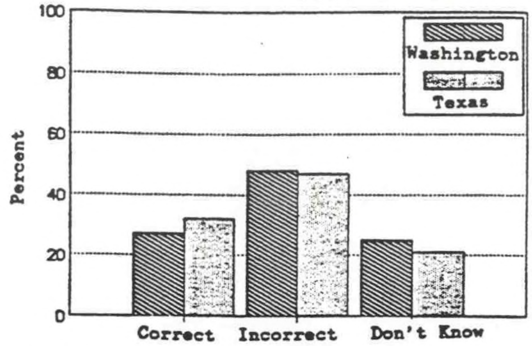

Fig. 3. Survey response to: "You are on approach and are told by the tower that there is a LLWA in effect, would you expect microburst activity in the area?"

A Low-Level Wind-Shear Alert (LLWA) is issued by Air Traffic Control Tower (ATCT) personnel when pilot reports of LLWS are received. There are no speed or directional criteria listed for identification purposes.

An LLWA may also be issued by the ATCT personnel based on information from an anemometer network called "Low Level Wind Shear Alert System (LLWAS), which has been installed at some airports. This system compares the wind speed at outlying anemometers with that at a center point. An LLWA is issued by ATCT personnel when outlying wind differ from the center value by locally determined speeds and directions (FAA, 1990).

A "Microburst alert" may be issued if a microburst is identified, but it is not necessary for ATCT to make a distinction between convective and non-convective LLWS when issuing an LLWA. So, an LLWA does not automatically indicate microburst activity in the area. Figure 3 shows that nearly 50% of the pilots believed that an LLWA implied microburst acitvity.

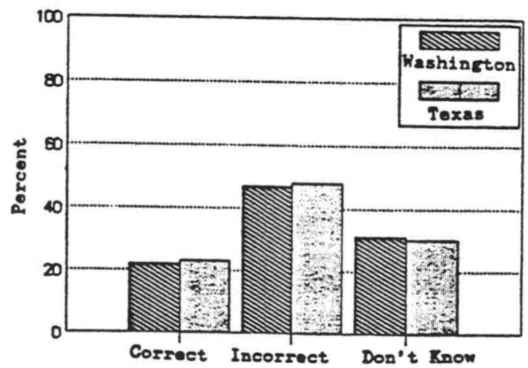

Fig. 4. Survey response to: "If you see LLWS mentioned in the FT, would you expect microburst activity in the area?"

Non-convective LLWS can be mentioned in an Aviation Terminal Forecast (FT) while convective LLWS can not. LLWS is included in the FT if there are: pilot reports of wind shear causing airspeed gain or loss of 20 knots or more within 2000 feet of the surface, or vertical shears of 10 knots or more per 100 feet within 2000 feet of the surface, or if meteorological conditions are such that LLWS intensities similar to those just listed can be expected (NWS 1984). Therefore, by definition, LLWS mentioned in an FT does not indicate microburst activity, since microbursts are associated with convection. Figure 4 shows that 77% of both groups were incorrect or did not know this.

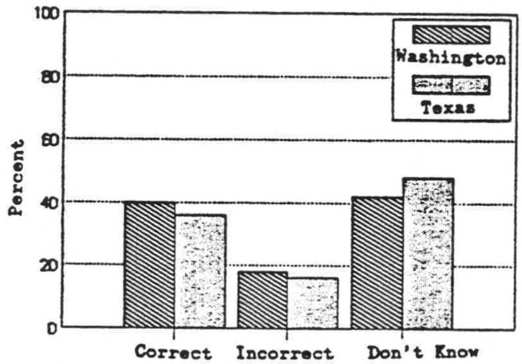

Fig. 5. Survey response to: "Does LLWS in the FT, and LLWA given out by the tower mean the same thing?"

It is possible for LLWS to be included in an FT and an LLWA to be issued by the ATCT for the same phenomenon. But, because of different criteria, it is also possible for the tower to issue an LLWA without LLWS being mentioned in the FT. Fewer than 40% of the respondents of both states knew that LLWA and LLWS are not interchangeable terms.

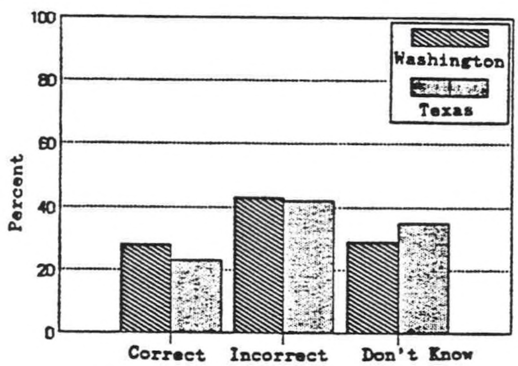

Fig. 6. Survey response to: "Is the recovery procedure the same for LLWS as it is for microburst?"

The proper inflight recovery techniques for a head-on encounter with a microburst and for non-convective LLWS are opposite. Figure 6 shows that more than 60% of the respondents either did not know or answered incorrectly. A head-on encounter with a microburst at normal flight speeds allows precious little time for the pilot to determine the proper response. The wrong choice may very well make the difference between a rough ride and a mishap. Thus, it is paramount that the flight crew know ahead of time what type of phenomenon they are likely to encounter and also know the proper response.

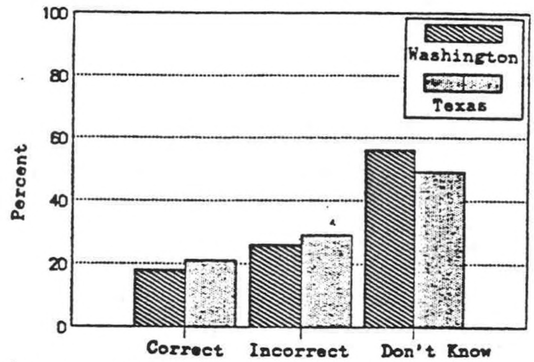

Fig. 7. Survey response to: "If microburst activity is expected to occur in the terminal area, how would it be indicated in the FT?"

It has been previously stated that convective LLWS cannot be mentioned in an FT. If the forecaster determines that microburst activity will occur in the terminal area, then the following forecast is suggested by the NWS: "...Occasional TRW+G50" (NWS 1984). Figure 7 shows that more than 80% of the respondents form either state didn't know or were unsure how a microburst was identified in an FT.

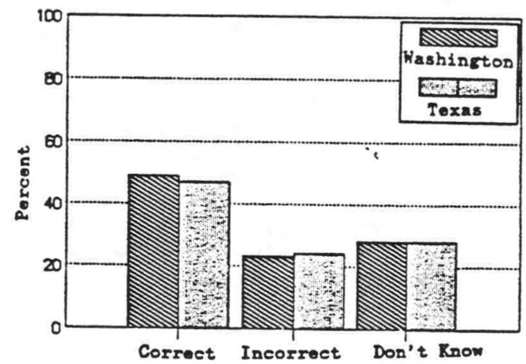

Fig. 8. Survey response to: "Is a microburst always accompanied by severe turbulence?"

The first indication of a head-on encounter with a microburst is most often an increase in head wind, and a resultant increase in the efficiency of the aircraft; turbulence is not always an indication of a microburst (Fujita 1985). Figure 8 shows that fewer than half answered this question correctly.

4. Discussion

A majority of the pilots surveyed knew there was a difference between LLWS and microbursts (Fig. 2) but less than one third knew that the recovery procedure was different for each phenomenon (Fig. 6).

Less than 20% of all respondents knew how a microburst was identified in an FT. This suggests that when microburst activity is suspected and IS mentioned in an FT by the prescribed method, most pilots do not interpret this as such.

It is assumed that all pilots answered question one correctly, so disregarding that question, only 2% of the pilots surveyed answered the remaining seven questions correctly, and 13% got them all wrong. Additionally, more than 90% of the pilots questioned would have failed if the "passing grade" were 70%.

5. Conclusion

Responses from both states were similar, and indicate that pilots' misunderstanding of mechanical LLWS and microbursts is not confined to one region, nor is it dependent upon the relative amount of convective activity common to that region. Thus, this study suggests a need to improve training programs that now exist and those of the future.

CFIs receive recurrent training and testing and are considered among the elite of the general aviation pilots. They could be expected to score better on this questionnaire than the average pilot. Therefore, results obtained from this study are likely to be better than results that would be obtained if the questionnaire was given to non-CFI, general aviation pilots.

The user community needs consistency in the use of all terms regarding LLWS phenomena. In this author's opinion, much of the confusion would be eliminated if convective and non-convective LLWS were each given separate terms. For example, LLWS of convective origin, including that associated with microbursts, could be labeled as Convective Low-Level Wind Shear or "CLLWS." Non-convective LLWS could be labeled as "NCLLWS."

Regardless of how these separate phenomena are labeled, there needs to be a distinction made between the two types. Until such steps are taken, there will continue to be a dangerously high level of confusion in the aviation community regarding microbursts and LLWS.

6. References

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ADDENDUM TO

"A Comparative Study of Pilot's Understanding of Low Level Wind-Shear Terminology"

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The survey that was given to Certified Flight Instructors in Washington and Texas was also given to the attendees of the National Weather Service Aviation Workshop, held in Kansas City, Missouri, December 10 through 13, 1991. The attendees at the conference were from a broad spectrum of the aviation meteorology community, and included administrators, forecasters, pilots, and flight dispatchers. Thirty-seven of the 151 workshop attendees responded to the survey. Responses were collected before the topic was presented to the Workshop. The following is a summary of those responses. In addition, the responses of the CFIs of Washington and Texas were combined and included in this addendum for comparison. The responses from the CFIs are labeled below as "CFI."

In response to "What license do you now hold?" it was found that less than 10% of the respondents at the workshop were pilots and there was no significant difference in the pilot's answers from those of the remainder of the group.

Response to "Is there a difference between LLWS and microburst?"

	Correct	Incorrect	Don't know
Workshop	92%	3%	5%
CFIs	76%	7%	17%

Response to "You are on approach and are told by the tower that there is a LLWA in effect, would you expect microburst activity in the area?"

	Correct	Incorrect	Don't know
Workshop	38%	38%	24%
CFIs	30%	47%	23%

Response to "If you see LLWS mentioned in the FT, would you expect microburst activity in the area?"

	Correct	Incorrect	Don't know
Workshop	51%	19%	30%
CFIs	23%	48%	31%

Response to "Does LLWS in the FT, and LLWA given out by the tower mean the same thing?"

	Correct	Incorrect	Don't know
Workshop	62%	11%	27%
CFIs	38%	17%	45%

Response to "Is the recovery procedure the same for LLWS as it is for microburst?"

	Correct	Incorrect	Don't know
Workshop	49%	16%	35%
CFIs	25%	43%	32%

Response to "If microburst activity is expected to occur in the terminal area, how would it be indicated in the FT?"

	Correct	Incorrect	Don't know
Workshop	43%	11%	46%
CFIs	20%	28%	53%

Response to "Is a microburst always accompanied by severe turbulence?"

	Correct	Incorrect	Don't know
Workshop	65%	30%	5%
CFIs	48%	24%	28%

Summary

While nearly 80% of the CFI group did not know how microburst activity is identified in the Aviation Terminal Forecast, it was surprising to find that nearly 60% of the participants of the Aviation Workshop did not know.

Only half of the responding aviation experts at the workshop knew that the term "LLWS" in an FT does not mean that "microbursts are expected." The term LLWS does mean that non-convective LLWS is expected.

Only 5% of the respondents of the Workshop answered all questions in the survey correctly.

Conclusion

Surveys taken thus far suggest a common misunderstanding of the terms "LLWS" and "Microburst" among pilots and meteorologists. This study shows that the problem exists, but does not attempt to identify the cause of the problem, nor does it offer a solution to the problem. Nonetheless, it suggests that not only pilots, but aviation meteorologists also need training in the proper use of the terms "Microburst" and "LLWS" as applied to aviation meteorology and forecasting.

OBSERVATIONS AND CONCLUSIONS ON NON-FRONTAL, LOW LEVEL TURBULENCE IN THE CENTRAL UNITED STATES

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1. INTRODUCTION

Low level turbulence over relatively flat terrain often presents a difficult problem in aviation forecasting. Some studies have related low level turbulence (below 15,000 feet mean sea level) to specific climatologies (Cundy, 1989), or trough and frontal movements (Darrah, 1989). Stanton (1965) developed a nomogram that can be used to predict low level turbulence from wind speed and stability. Through advancements in technology at the National Aviation Weather Advisory Unit (NAWAU) in Kansas City, Missouri, forecasters have been able to make real-time correlations of aircraft reported, low level turbulence with satellite imagery and other data. These correlations confirm the findings of others and further suggest that, in the absence of fronts and troughs, convective thermals are the primary mechanism for producing non-frontal, low level turbulence over the central United States.

Three mechanisms which can result in turbulence are: wind shear, convective thermals, and physical obstructions. Of these three, physical obstructions to the flow represent the most simple and effective means of producing aircraft reported turbulence. Wind shear also produces turbulence, but mainly in the vicinity of strong fronts or high velocity wind fields. Convective thermals result in aircraft reported turbulence, but are generally more of a nuisance than a problem.

However, evidence indicates that convective thermals act as obstructions to the flow, resulting in turbulent eddies. In light winds, turbulent eddies near thermals are generally weak. Where winds are strong, the resulting eddies are also strong, and can result in widespread outbreaks of moderate or greater turbulence for small aircraft.

Forecasting non-frontal, low level turbulence over the central United States then becomes a three part problem. First, the forecaster must identify areas of strong winds aloft. Second, areas where low level insolation will be strong enough to develop convective thermals must be identified. Third, the forecaster must determine if the atmospheric stability will allow thermals to rise into layers of strong winds. Where the areas overlap will then identify the area of expected turbulence.

2. FLUID FLOW WITH OBSTRUCTIONS

Fluid dynamics teaches there are two types of flow: laminar and turbulent. One mechanism to disrupt laminar flow is to introduce obstructions to that flow which effectively increases the surface roughness and produces turbulent eddies. Rigorous discussions of the relationship of wind and surface roughness can be found in many textbooks including Hess (1959). These discussions generally describe roughness parameters related to wind over smooth snow or wheat fields. Larger obstructions, i.e., mountains, produce larger eddies, but that relationship is not as easily documented and formalized.

Figure 1 is an excellent example of how large obstructions affect the air flow to create aircraft turbulence. On November 12, 1989, moderate northwesterly winds (25 to 40 knots) were approximately normal to the Appalachian Mountains. Skies were mostly cloudy north of Pennsylvania and generally clear from Pennsylvania southward. The lack of turbulence reports west of the mountains indicates the flow was mostly laminar. East of the mountains, the flow was so turbulent that not all the reports could be plotted clearly.

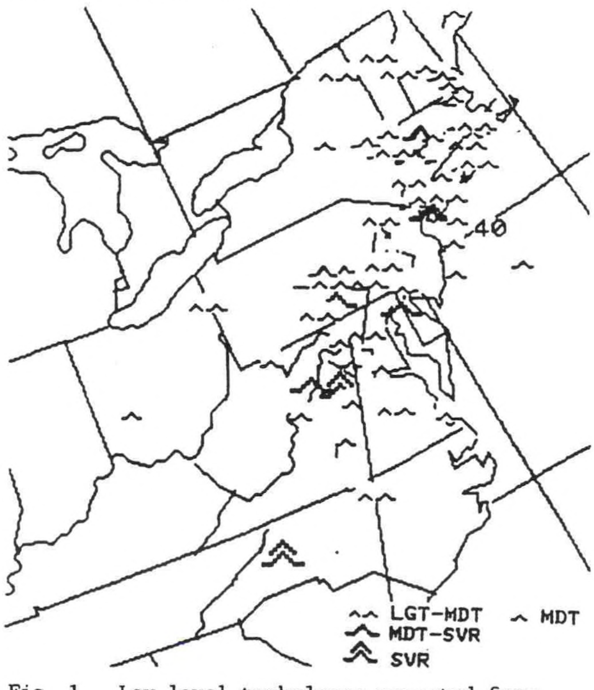

Fig. 1. Low level turbulence reported from 1200 UTC through 2000 UTC, 12 November 1989.

Since there are virtually no mountain ranges through the central United States, it is realistic to assume that air flow should normally remain laminar. Observations indicate otherwise, which implies there is some other kind of obstruction present in the flow.

Recent improvements in technology at the NAWAU have allowed forecasters to make real-time correlations of weather events and weather parameters. Software was developed that decodes and plots pilot reports to map backgrounds for hourly, three-hourly, and six-hourly intervals. These real-time reports could then be assimilated, along with satellite imagery and surface and upper air observations, to help show possible causes of turbulence over flat terrain.

It was obvious that most non-frontal low level turbulence was reported during daylight hours when the atmosphere was most unstable. It also became apparent that in the absence of fronts, the turbulence reports tended to come from cloud free areas which were favorable for the development of convective thermals. Further examination showed that cloud free areas with weak winds aloft did not result in significant numbers of turbulence reports, even when lapse rates were super-adiabatic.

Except for requiring clear skies, this was in agreement with Stanton's Low-level Turbulence Nomogram (1965). It was also in agreement with Byers (1944), who stated that the degree of turbulence depends on the velocity of the wind, the roughness of the surface, the vertical lapse rate, and other lesser factors. Newton and Newton (1959) also showed that strong enough upward motion due to convection distorts the wind pattern around it (see Figure 2) resulting in turbulent eddies. Scorer and Ludlam (1953) contribute to the solution by suggesting that rising convective "bubbles" produce a wake of turbulent air beneath them (see Figure 3). Hess (1959) continued that idea by stating that as bubbles rise, the wake they produce should be carried downstream.

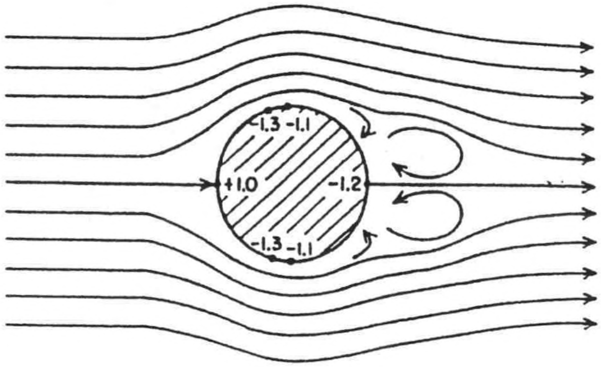

Fig. 2. General character of flow around a circular cylindrical obstacle. Numbers denote relative hydrodynamic pressure. (From Newton and Newton (1959).

It therefore seems reasonable that convective thermals act as obstructions to the air flow in a manner similar to mountainous terrain. The wind must deviate around the thermals resulting in turbulent eddies. These eddies are then carried downwind some distance before dissipating. It can be postulated that the intensity of turbulence is related to the intensity of the thermals and the wind velocity. Also, when low level insolation is reduced by clouds or nightfall, production of convective thermals diminishes or ends, as does non-frontal low level turbulence.

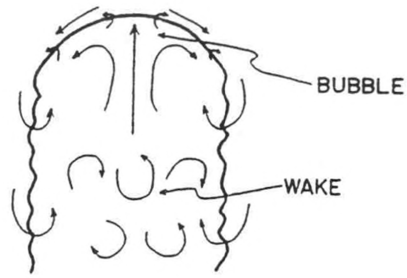

Fig. 3. Schematic representation of the assent of a buoyant bubble through a relatively descending environment. Note the turbulent mixed wake. (From Hess (1959)).

3. CASE STUDIES

3.1 Case 1

On 27 October 1990, a strong cold front was moving through the Great Lakes and Mississippi Valley toward Michigan and Indiana Winds were strong both ahead of and behind the cold front with surface winds gusting above 30 knots over northern portions of the area. During the day, low level turbulence reports were quite numerous from the eastern Plains to Indiana and Michigan (see Figure 4). Most of the turbulence was reported after 1400 UTC and was generally below 5000 feet mean sea level.

At 1630 UTC (see Figure 5), thick low and middle clouds covered extreme eastern Minnesota and the northwestern two-thirds of Wisconsin extending northward into Canada. This area of clouds moved eastward, clearing Minnesota and moving over all of Wisconsin and Lake Michigan by 1830 UTC. Reported turbulence over southeastern Minnesota generally occurred early in the day and were likely associated with shower activity.

Around 1800 UTC (see Figure 6), an area of thick low clouds developed over northwestern Lower Michigan. This area of clouds increased and moved southeastward to cover all of Michigan by 2000 UTC (see Figure 7). Reported turbulence ended over northern Michigan by 1800 UTC and ended over southern Michigan by 1930 UTC.

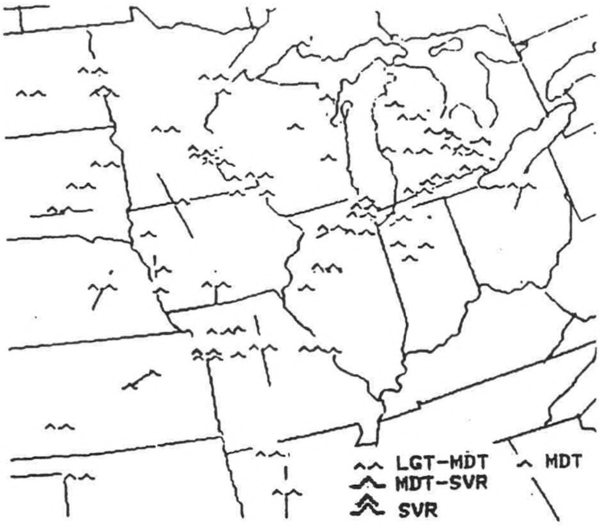

Fig. 4. Low level turbulence reported from 1200 UTC through 2000 UTC, 27 October 1990.

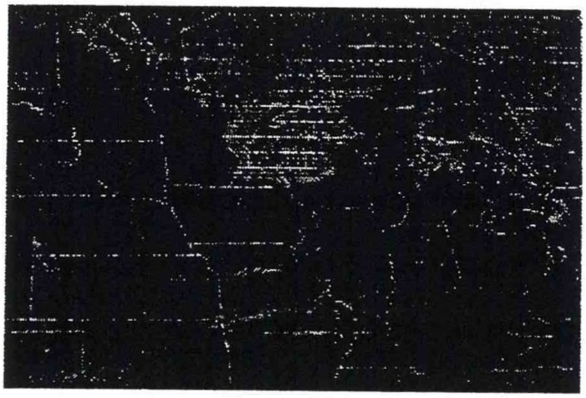

Fig. 5. Visible GOES satellite imagery valid 1631 UTC, 27 October 1990.

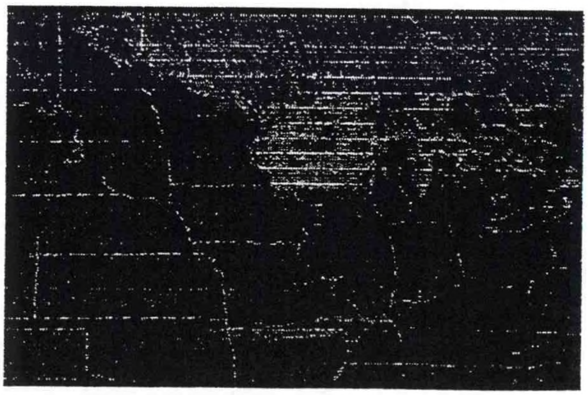

Fig. 6. Visible GOES satellite imagery valid 1831 UTC, 27 October 1990.

Another area of mostly opaque cirrus extended from southern Missouri across southern portions of Illinois and Indiana to central Ohio. These clouds persisted throughout the day; elsewhere, skies were clear.

Figure 4 shows that there were few reports of turbulence over Wisconsin. It can also be seen that there were no reports of low level turbulence from southeastern Missouri to central Ohio. Both of these areas were generally cloudy throughout the day. Most of the turbulence reports came from other areas, where skies were clear.

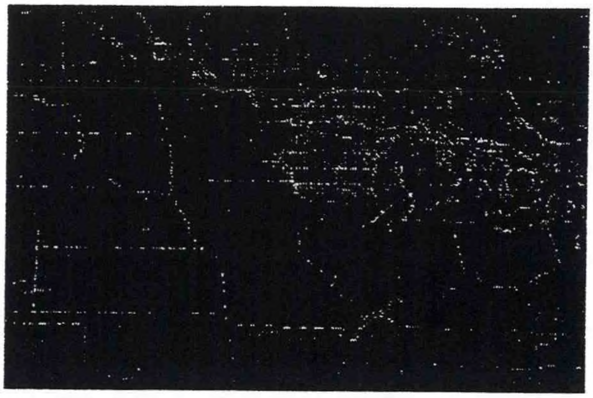

Fig. 7. Visible GOES satellite imagery valid 1931 UTC, 27 October 1990.

Lower Michigan presents a particularly interesting event. Reports of turbulence ended where clouds developed and spread across the state. Even though low level winds remained strong, there were virtually no reports of moderate turbulence after 2100 UTC although aircraft continued to operate in the area. Pilots reported generally smooth conditions or made no mention of turbulence.

3.2 Case 2

At 1500 UTC on November 9, 1989, a cold front extended from the middle of Lake Superior to southern South Dakota. The front moved southeast during the day and by 0000 UTC extended from southern Lake Michigan to northern Missouri and back northwest to western South Dakota and Montana. Southwest winds ahead of the front gusted between 15 and 20 knots at the surface. Behind the front, northwest winds gusted to more than 20 knots.

Figure 8 shows numerous reports of turbulence which occurred ahead of the cold front in clear skies. Note the lack of reported turbulence over Illinois and the amount of cloud over the state during the day (see Figures 9 and 10). Other areas with a noticeable lack of turbulence reports include Michigan, Wisconsin, and Minnesota which were generally cloudy. Conversely, several reports of turbulence were received over North Dakota and South Dakota which can be easily correlated with the area of clear skies.

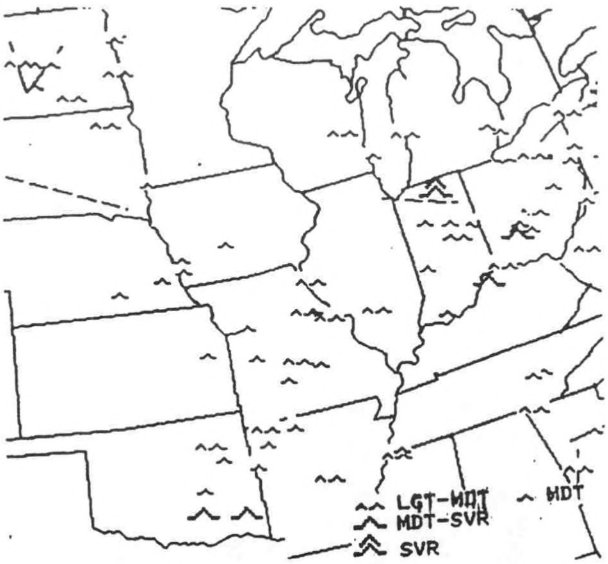

Fig. 8. Low level turbulence reported from 1200 UTC through 2000 UTC, 9 November 1989.

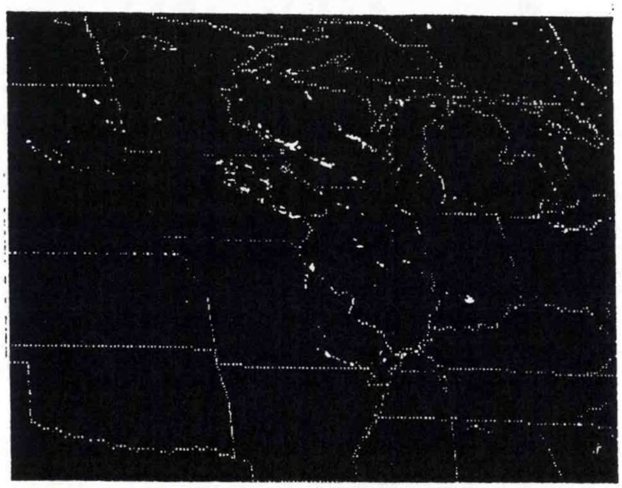

Fig. 9. Visible GOES satellite imagery valid 1531 UTC, 9 November 1989.

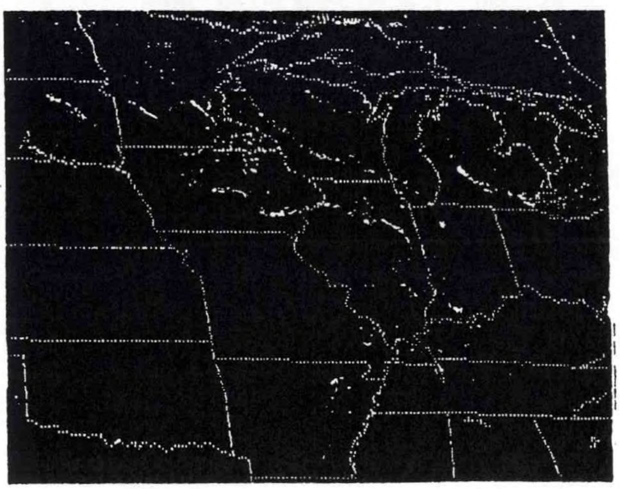

Fig. 10. Visible GOES satellite imagery valid 1831 UTC, 9 November 1989.

3.3 Case 3

On 13 November 1989, a slow moving cold front extended from the northern Great Lakes to the Texas Panhandle. At 1500 UTC, ahead of the front, surface winds were already gusting to more than 15 knots. By 1800 UTC surface gusts of 20 knots or more were common from Texas and Oklahoma to Michigan and Ohio. Behind the cold front, winds were considerably lighter. Figure 11 shows all reports of light to moderate or greater turbulence from 1200 UTC to 2000 UTC.

Fig. 11. Low level turbulence reported from 1200 UTC through 2000 UTC, 13 November 1989.

At 1530 UTC, skies were clear across Missouri (see Figure 12). However, low level mixing developed clouds over the area. By 1830 UTC, stratocumulus had developed over much of the state (see Figure 13). After that time, no reports of low level turbulence were received over the cloudy areas. However, moderate reports continued over Illinois and Indiana where skies remained clear.

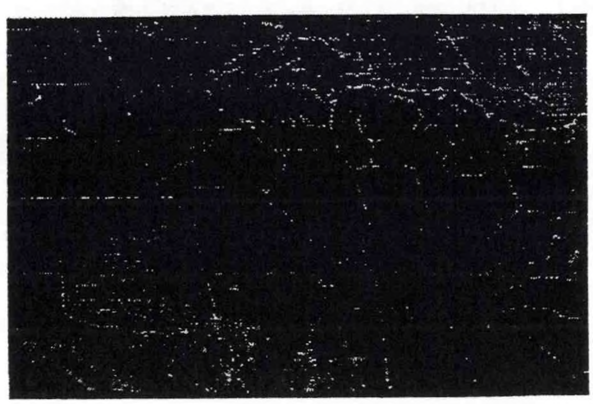

Fig. 12. Visible GOES satellite imagery valid 1531 UTC, 13 November 1989.

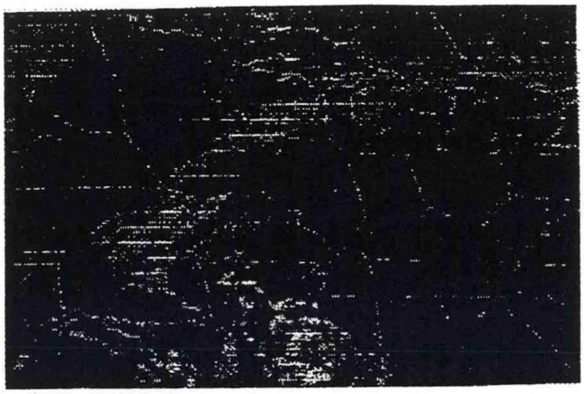

Fig. 13. Visible GOES satellite imagery valid 1831 UTC, 13 November 1989.

4. WIND, LAPSE RATE, AND SKY CONDITION

Wind, lapse rate, and sky condition are critical to the development of significant outbreaks of aircraft reported turbulence. Temperatures aloft must be cool enough to allow steep lapse rates to develop during the day. Sky conditions must be conducive to strong surface heating for the development of strong thermals. Finally, wind velocities must be sufficient to create significant turbulent flow around the thermals.

0000 UTC soundings were examined for the three cases. The soundings indicated that lapse rates were nearly dry adiabatic where low level turbulence was reported. The steep lapse rate would allow convective thermals to rise to several thousand feet before reaching equilibrium, thereby creating a deep layer of turbulence.

Cloud amounts were subjectively determined using satellite imagery and the locations and times of turbulence reports for October 27, 1990 and November 13, 1989. Using 102 turbulence reports, the average cloud amount was 0.09, or approximately one tenth cloud cover. On the same days, 85 pilots provided the altitude at which turbulence was encountered. A wind velocity was subjectively interpolated both spatially and temporally for each report of turbulence. The average wind velocity at the altitude of the reported turbulence was 32 knots.

Finally, equilibrium heights for potential thermals were estimated for sounding stations in each of the three cases presented. The maximum temperature for the day was determined from the 0000 UTC sounding. That temperature was plotted on the previous 1200 UTC sounding plot, to determine the maximum possible equilibrium height. Virtually every report of turbulence was below the equilibrium height interpolated for its location. It is important to mention however, the equilibrium height changed throughout the day and could not be precisely determined at the time of each turbulence report.

5. FORECASTING LOW LEVEL TURBULENCE OVER FLAT TERRAIN

In the absence of fronts or troughs, forecasting low level turbulence involves three elements. First, it is necessary to forecast sufficient low level insolation (sunshine) for the development of thermals. Second, the stability of the atmosphere should be conducive to the development of strong convective thermals to a considerable altitude, i.e., lapse rates should be steep. Third, it is necessary to forecast the location and strength of the wind from the surface to that altitude.

The intensity of the three elements will affect the overall degree of low level turbulence. There are numerous National Meteorological Center (NMC) guidance products and rules-of-thumb that will be helpful.

5.1 Sunshine

Sunshine must be of sufficient intensity to develop a super-adiabatic lapse rate from the ground to some height. The atmosphere should therefore be clear of clouds, fog, haze, or smoke that would prevent such strong surface heating.

Forecasting the amount and intensity of sunshine is not always a simple matter. Mean relative humidity forecast data are available from NMC, both in graphic and alpha-numeric form. These, combined with satellite and surface data, will assist in determining the amount of sunshine. The FOUS, FOUM, and MOS forecasts are also helpful.

The earlier examples showed that most of the turbulence occurred in areas of clear air. Only 10 of 102 reports of turbulence were determined to be in areas of greater than four-tenths cloud cover. This is in agreement with the World Meteorological Organization (WMO) Technical Note Number 158 (1978) that suggests cumulus cloud amounts of four oktas (four eighths) or more cause a significant reduction of insolation and general reduction in the number and intensity of convective thermals. Similarly, the National Weather Service (NWS) Handbook Number 3 (1972) suggests that convective thermals are often weak and few in number even when thin, or patchy, middle or high-level clouds are present.

5.2 Stability

Ultimately, the stability of the atmosphere determines the height and intensity of convective thermals. A super-adiabatic lapse rate near the ground is necessary to develop a thermal. Once developed, the thermal will rise to its equilibrium height.

The NWS Handbook Number 3 states that strength of the thermal is proportional to the depth of the super-adiabatic layer near the ground. Deeper layers produce the strongest thermals.

The maximum height of convective thermals can be found by determining their equilibrium level. This can be estimated by locating the dry adiabat which corresponds to the expected afternoon high temperature. Where that adiabat intersects the morning sounding should indicate the maximum height of the thermals for that day. Occasionally, this intersection will be the result of an inversion.

Although this method ignores warm or cold advection, those factors should also be considered. Advection of warm air aloft will stabilize the atmosphere, resulting in weaker thermals, a lower equilibrium level, and earlier cessation of activity as the sun angle decreases. Also, low level cold advection and the accompanying increase in stability will limit the height of thermals or end their development completely.

In the three cases presented earlier, soundings were examined and an equilibrium height was determined. Virtually all the reports of turbulence shown in figures 4, 8, and 11 occurred below the maximum equilibrium height for those days. Additionally, nearly all the reports of smooth flight (not shown here) occurred above the equilibrium height.

5.3 Wind Speed

Forecasting wind speeds and locations is a relatively easy task, given the amount of guidance available from the NMC. Forecasts for winds aloft are available for three, six, and nine thousand feet and higher. Surface and/or boundary layer winds are available at six hourly intervals from a variety of products including the FOUS, FOUM, and MOS.

A general rule in forecasting turbulence in mountainous areas suggests that winds at ridge level should be 25 knots or greater. It is common practice at the NAWAU to use gradient winds of around 25 knots or higher in forecasting low level turbulence in the Plains. The three examples shown here suggest a wind speed of around 30 knots at flight level, which is not inconsistent with previous findings. However, since the turbulence is proportional to both wind speed and thermal strength, a change in one should be compensated by the other to produce the same degree of turbulence.

It is also important to note that winds should increase in speed with altitude. Occasionally, surface winds are stronger than those aloft. When this occurs, convective thermals will quickly transfer the horizontal momentum vertically resulting in a decrease in the low level wind. Typically, the winds aloft will change little. In this case, significant turbulence will only last a few hours, or until the momentum transfer is complete.

6. CONCLUSIONS

Observations of non-frontal, low level turbulence events over relatively flat terrain indicate that the major contributing factor is the development of convective thermals which rise into a layer of moderate or greater winds. The thermals act as obstacles to the laminar flow, resulting in turbulent flow. The degree of turbulence is a function of the strength of the wind field, the atmospheric stability, and the intensity of the convective thermals. Additionally, any factors that will reduce or prohibit the development of thermals, e.g., clouds, haze, wet ground, nighttime, will also reduce or prohibit turbulent flow, in favor of laminar flow.

The three cases presented showed that where significant turbulence occurred, moderate (around 20 knots) or greater winds were always present through a relatively deep layer. Lapse rates were at or near dry adiabatic, indicating the unstable conditions. In fact, analysis of surface conditions and sounding data showed that super-adiabatic conditions existed during the period in which the turbulence occurred. These super-adiabatic conditions are necessary for the development of convective thermals.

The data presented also showed that turbulence diminished or ended with the development of significant cloud layers. The cloud layers reduced surface heating, which ended the production of thermals. In the cases presented, pilot reports of smooth or occasional light turbulence indicated that aircraft did continue flying.

It was found that turbulence events can occur on both the warm and cold side of fronts, providing low level insolation is sufficient to produce thermals. Additionally, the height of the turbulence can be found by determining the height to which thermals will rise, i.e., the equilibrium height. This height may also be represented as a stable layer or inversion, above which the flow is generally laminar.

In summary, most non-frontal, low level turbulence events may be forecast by finding areas with moderate or greater winds in combination with areas that produce convective thermals. The height of the turbulent layer will vary throughout the day as a function of the equilibrium level with respect to the individual thermals. Conditions not conducive to the development of thermals, such as cloudy skies, wet ground, etc., will generally not result in low level turbulence. Additional research should be done to further define the relationship of wind speed and the strength of thermals to turbulence. However, given that low level turbulence is a function of wind speed and convective thermals, it appears reasonable that NMC model output could be used to generate derived fields of expected low level turbulence over relatively flat terrain.

ACKNOWLEDGEMENTS

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WEATHER FORECASTS FOR SOARING CONTESTS

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1. INTRODUCTION

Unlike jets or airplanes, sailplanes depend totally on the atmosphere for lift and power during flight. Sailplane pilots, also known as glider or soaring pilots, often look for lift in meteorological conditions that their power counterparts try to avoid. Sailplane pilots look for lift in thermals and convergence boundaries, as well as over mountains. Experienced pilots love to soar along the ridges of the nation's mountains, including the Blue Ridge Mountains and Sierra Nevada Mountains. On the extreme end of soaring, pilots fly sailplanes in strong mountain-waves over the Sierra Nevada reaching altitudes of 50,000 feet.

Sailplane pilots are very aware of micro-scale meteorology. They are hungry for as much weather information as they can get. You'll never here a glider pilot say, "Why check the weather, I'm flying anyway." Many sailplane pilots can interpret atmospheric sounding, and most are familiar with the various stability indices. However, sailplanes are still subject to the same dangers as other aircraft. While an unstable airmass is desireable for lift, an airmass too unstable, with abundant thunderstorms, poses a safety threat to the pilot and sailplane. The cessation of low-level convection due to the over development of clouds often forces the sailplane pilot to land in fields away from the airport.

Meteorological support for sailplanes pilots poses interesting challenges for the meteorologist. This paper will describe the meteorological information that the soaring pilot needs, along with a discussion of the weather support given during the 1991 World Soaring Championships (WSC-91). WSC-91 was selected to illustrate the support required at the highest level of this facet of aviation.

2. WEATHER REQUIREMENTS

Weather support for sailplanes range from single pilot weather briefing to specialized support during multi-day contests. Soaring contests usually involve a loop course, consisting of 3 or 4 legs, with the size of the loop being governed by the weather forecast. A typical loop course, also known as the "task", may be 300 miles in length, but can be as long as 500 miles under ideal meteorological conditions. The task is determined on a daily basis by the tasking committee after consultation with the meteorologist.

Soaring contest winners are the pilots who fly the course in the shortest elapsed time. Winners are awarded 1000 points for the day. Subsequent finishers are assigned points by virtue of the time difference between themselves and the winner-of-the-day. During multi-day events the overall winner is the pilot who accumulates the highest total points.

Since the glider is dependent upon the atmosphere for flight, various meteorological parameters need to be examined by the meteorologist before briefing a soaring pilot or contest tasking committee. These parameters include:

(1) Information on thermal development. This information is best represented by plotting thermal altitude as a function of the time of day, and thermal lift rates as a function of the time of day.
(2) Trigger-temperature and time-of-day at which thermals begin to support soaring flight.
(3) Various atmospheric stability indices such as the 850-to-500 millibar temperature lapse rate, "K" index, thermal index, and a soaring index. The latter two indices are those specifically established to quantify expected sailplane climb rates.
(4) Freezing levels are important to the pilot since water is carried in the wings for ballast and to achieve faster glide speeds.
(5) Winds and temperatures aloft are needed by the pilots to calculate optimum speeds.
(6) Sky condition, including the convective cloud base, is necessary because the race must be flown in visual meteorological conditions, obeying Federal Aviation Regulations concerning visibility and cloud separation.
(7) General information on the weather-for-the-day must be provided so that pilots are briefed not only for soaring possibilities but also for implications of severe weather.

3. WEATHER SUPPORT FOR THE 1991 WORLD SOARING CHAMPIONSHIPS (WSC-91)

During late July and early August 1991, the National Weather Service provided support for the 22nd World Soaring Championships at Uvalde, Texas. WSC-91 was the "Olympics" of soaring with 114 pilots from 26 countries competing over a two week period. The contest area for WSC-91 was 140 miles by 240 miles, centered 140 miles west-northwest of the Texas coast on the Gulf of Mexico. Uvalde Airport served as the start and finish.

The meteorological support team began work at 4:30 a.m. (local time) each day preparing the forecasts for the tasking committee. This weather forecast package, which was used for the contest course selection, was completed by 8:00 a.m. Once the tasking committee was briefed, the meteorologists began preparing for the mass pilot weather briefing, which was presented to all pilots and crew at the daily pilot's meeting. Figure 1 shows the meteorological information sheet used during WSC-91. Each pilot was given a copy of this sheet prior to the daily pilot's meeting. The meteorological information sheet was displayed on an overhead projector in conjunction with a monitor displaying satellite pictures. Overlays indicting the weather problem-of-the-day were also presented. In the course of these meetings, the contestants and crews were given information to enable them to make decisions for safety considerations as well as contest strategy.

The weather office at WSC-91 was well equipped with meteorological data systems. The meteorologists had access to high resolution satellite imagery and overlaying graphics capability from the National Severe Storms Forecast Center. They also had computer access to NWS alphanumeric and graphical data bases, and radar information. A personal computer provided programming ability to analyze weather plots with applications in soaring and atmospheric instability.

Site weather idiosyncrasies must always be considered by the meteorologist at a soaring contest. At WSC-91, morning stratus was common and the length of the contest day was determined by when the stratus would give way to convection. In addition, differential surface heating and resulting pressure gradients would drive a sea breeze front deep into Southwest Texas. This boundary would then act as a convection focal point varying in intensity from light to severe depending upon accompanying atmospheric characteristics.

The tasks flown during WSC-91 were usually over 300 miles with the farthest pilot-chosen task being 476 miles. Pilots usually launched by 11:30 a.m. (local time) and flew until 7:30 p.m. Pilots often chose to delay their start until after the thermal convection was well underway, which sometimes was as late as 1:30 p.m.

It was a large undertaking to support 114 competing sailplanes. In addition to sailplanes, a fleet of sixteen towplanes were used to launch the gliders. At launch time during WSC-91, the Uvalde Airport became as busy as any major hub airport. 342 take-off and landing operations occurred in less than one-hour as the 16 towplanes launched the 114 gliders.

Landing operations were also quite spectacular as many gliders finished together, despite individually chosen start times. One of the busier days saw 22 gliders fly through the finish gate and land within a two minute interval. Winning speeds for the daily tasks reached 90 knots over the tasks of 300 nautical miles. The overall winner of the open class (sailplanes with a wingspan of greater than 15-meters) was Janusz Centka of Poland. His points total was 11,111. The second place finisher was only a mere 10 points behind the winner after 12 contest days!

Besides the role that meteorologist's have in aiding sailplane pilots in contest task selection, the large number of landing and takeoff operations highlight the need for meteorological warning concerns. Twice during WSC-91, local airport advisories were issued by the National Weather Service support unit due to microburst winds which threatened both grounded and landing aircraft.

4. CONCLUSION

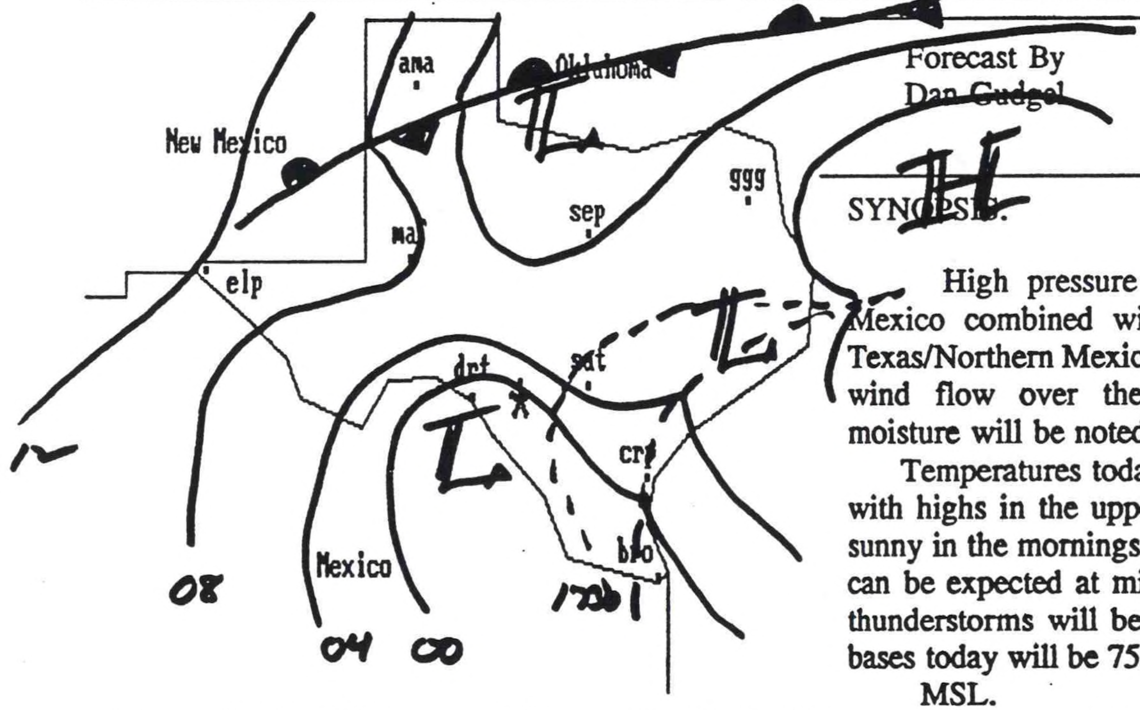
The components of a successful meteorological support team for soaring contests must have local knowledge, soaring forecast expertise, data, and personnel management. The management of such a team must be able to understand the needs of the contest, in addition to meteorological forecast and warning responsibilities.

At WSC-91, the team effort within the National Weather Service garnered recognition from international soaring meteorologists as one of the finest seen to date. Through the effort of this team, the National Weather Service was able to serve this category of aviation, thereby enhancing safe flight.

SOARING WEATHER FORECAST WORKSHEET

Freezing Level 14,000 Ft / 4.3 Km	Date AUGUST 4, 1991	Contest Day SEVEN (7)
Trigger Temp °F/°C 90°F / 32°C	Time (Local) 1230	SFC Winds (Deg/Kt) 160/15
Max Temp °F/°C 98°F / 37°C	Time (Local) 1600 - 1730	Max Alt (Ft/Km) 8,500 Ft / 2.6 Km
850-500 Lapse 29°C	"K" Index 36	Showalter Index -3
Soaring Index 3.3 M/S	"TI"@850 Mb -4	Lifted Index -6

WIND DEG/Kt	TEMP C°	FT/Km
170/14	-53	40/12
180/11	-33	30/9.1
210/10	-18	24/7.3
160/15	-9	18/5.5
150/13	4	12/3.7
140/16	8	10/3.0
150/17	13	08/2.4
140/16	20	06/1.8
160/15	26	04/1.2
160/15	33	02/0.6



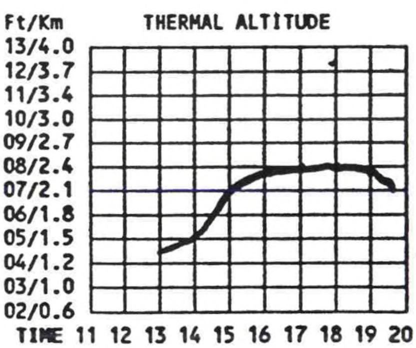
Forecast By
Dan Gudgel

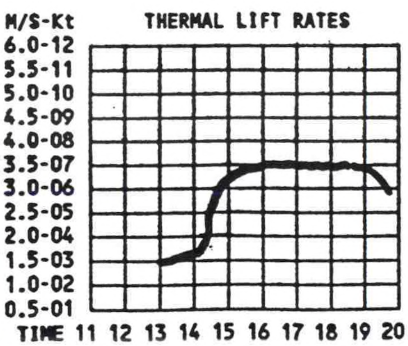
SYNOPSIS:

High pressure over the Northern Gulf of Mexico combined with low pressure over West Texas/Northern Mexico is providing a south-easterly wind flow over the contest area. Increasing moisture will be noted from this type of flow.

Temperatures today will be similar to yesterday with highs in the upper 90s (37 deg C.) and skies sunny in the mornings to early afternoon. Cumulus can be expected at mid-day but also the chance of thunderstorms will be increased. Afternoon cloud bases today will be 7500 to 8000 feet (2500 meters) MSL.

The sea breeze will move into the contest area after 1600 hours again but unlike yesterday make better westward progress. With the sea breeze scattered thunderstorm activity is ________ expected.





Satellite pictures and loops provided by
WSI CORPORATION

HOT AIR BALLOON PILOT WEATHER BRIEFINGS

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Good morning...we will start with a little balloon history... on November 21, 1783, two Frenchmen, the Montgolfier brothers, took their balloon to a Parisian park for man's first aerial voyage. A crowd of 400,000, including the King and Queen of France, assembled to witness the event. The men set up the balloon, checked the drift of chimney smoke and the fluttering of flags and decided to launch their aerostat. The Marquis d'Arlands and a Pilatre de Rozier drifted over the city of Paris and landed safely about 30 minutes later. Aviation, manned flight was born.

Ballooning became the rage of Europe. Clumsy hot air balloons were replaced by gas-filled balloons. Later, with the invention of a light weight and powerful gasoline engine, man achieved steerage and the dirigible came into existence.

After several disastrous explosions of the hydrogen filled balloons and the success of heavier-than-air-machines, the sport of ballooning nearly disappeared. Balloon flight was reduced to just a few scientific efforts (they could still fly higher than airplanes) and a handful of pleasure flying aeronauts.

In the past 20 years ballooning has made a dramatic comeback. The development of tough and inexpensive nylon envelopes and a burner system that cheaply and efficiently produces tremendous amounts of heat brought ballooning back in grand style.

On November 21, 1983, exactly 200 years after the Montgolfier flight, a pilot with a French-sounding name took his balloon, the Espirit de Saint Cloud to a city park, checked the fluttering of flags and the drift of chimney smoke and decided to launch his aerostat.

Two hundred years, and yet a common thread bound the Montgolfier balloon and the spirit of St. Cloud. The final decision to fly was made with simplistic meteorological information based on drifting smoke and fluttering flags.

Balloon pilot weather briefings need to be more detailed than what can be determined by the smoke/flag method.

When I call flight service and request a briefing for a VFR local flight in a Cessna 152, the briefer is able to give me a flood of information. If I call the weather service even more details are available. A pilot with an IFR briefing request gets the deluxe version of a briefing. However, when I identify myself as a balloon pilot planning a local flight, I suddenly feel like the Rodney Dangerfield of aviation, getting no respect and little in the way of usable balloon flight information. I believe the difference in the two briefings comes, not from bad intentions, but because the briefer is not familiar with (1) the flight characteristics of a balloon, (2) the regulations governing balloon flight and (3) the weather needs of a balloonist.

This presentation is intended to present material addressing those three items.

First, the balloon flight system. The envelope, the balloon itself, is made of rip-stop nylon. The gores, or up-and-down panels, extend from the throat to the equator and from the equator to the apex of the balloon in various widths and designs. With some variation the top or the side of the balloon will have pilot controlled lines that run to deflation or venting ports. Balloon envelopes come in several sizes up to well over 200,000 cubic feet.

A passenger and crew basket, or gondola, is attached to the balloon envelope with aviation cabling. It is a basket when made of wicker and a gondola when made of rigid material; most balloonist prefer the traditional wicker.

The burner system is supported on uprights connected to the basket and by flexible hose to propane fuel tanks which are strapped into the basket. The burner has a pilot light ignition system, a blast value, and burner coils. A "burn" creates millions of instantaneous btu to heat the air in the envelope.

Instrumentation in the balloon usually consists of fuel gages, a compass, an altimeter, a rate of climb indicator, and a pyrometer to measure the temperature at the top of the envelope.

A mid-sized balloon system has a gross weight of just under 1500 pounds and depending on the ambient air temperature can safely accommodate a pay load of about 600 pounds. A balloon flight starts by deploying the envelope, attaching the basket, installing the burner system and instrument package and forcing cold air into the balloon with an inflator fan. It takes a ground crew of 4, including the pilot, to get set up. Once the envelope is inflated and the system safety checked, the pilot aims the burner into the throat of the balloon and adds enough heat to bring the balloon into an upright position. The ground crew assists the passengers into the basket and everything is ready to "weigh off". The pilot adds heat to reach a pre-determined lift off temperature. The lift off temperature is based on the systems total weight and the outside air temperature. In the wintertime in Minnesota it is possible to fly maximum payloads with envelope temperatures of 120 to 160°F. However, in the summertime minimum payloads require temperatures of over 200°F.

Most balloon envelopes can be heated to over 250°F before damaging the fabric. The envelope temperature will of course also determine the flight time duration. The hotter the required flight temperature, the shorter the flight duration time.

It is customary to overheat for takeoff to offset the effects of false lift created by wind flow over the top of the balloon. Once the ascension starts the aerodynamic effect of that horizontal wind flow is lost and a rapid loss of altitude can occur.

The ground crew puts their weight on the outside of the basket until the pilot is satisfied that everything is ready. The pilot calls for the ground crew to stand clear and the flight begins. As soon as the balloon lifts off the flight is at the mercy of the winds.

Once aloft, flying a balloon would seem rather simple; add heat and go up, cool off and come down. It is just a bit more involved than that and like any flying requires constant pilot concentration to the flight details. Balloon flight is very sensitive to changes in air temperature...to wind shear...direction or speed...to thermals...especially to thermals. I was once in one so violent that I could look up from the basket and see the equator of the envelope. That was panic time! A balloon pilot must anticipate the slightest changes in atmospheric conditions and be ready to deal with them; in a balloon you cannot do a 180 and fly out of trouble.

Before we go drifting away on an imaginary flight let's set the balloon back down long enough to make ourselves familiar with the FAA regulations that apply to balloons and balloon pilots.

FAA Advisory Circular No. 438 says, "hot air balloons are subject to the same maintenance rules that govern other types of U.S. registered aircraft. They operate from self-contained, generated heated air and are considered, by definition, a "lighter-than-air aircraft".

Part 31 of the FAA regulations spells out the airworthiness standards that apply to free flying balloons. The regulations require that the balloon system be inspected each 100 hours of flight and annually by FAA approved repair stations.

Often I get the impression that pilot weather briefers put balloons in the same general category as ultra-lights and hang gliders. Here is a sample of what the regulations say about those systems: (part 103.7a) Ultralight vehicles and their component parts and equipment are not required to meet the airworthiness certification standards specified for aircraft or to have certificates of airworthiness."

In addition to meeting airworthiness and certification standards, balloons are registered and assigned "n" numbers just as fixed-wing category aircraft. National Weather Service briefers should be recording the balloon "n" numbers in pilot briefing logs (WS Form D-10).

Part 61 of the FAA regulations covers pilot and flight instructor certification. The part lists types of certificates issued...student, private, and commercial with aircraft category ratings in (a) airplane, (b) rotorcraft, (c) glider and (d) lighter-than air. In the lighter-than-air category there are class ratings for either airships or free balloons. The hot air balloon pilot is subject to flight tests, log book requirements, flight reviews and proficiency tests and medical certification. Part 61 also spells out the aeronautical experience necessary for each type certificate.

Ratings are gained through flight training programs that included both ground school and dual flight instruction with a certified flight instructor. Solo flight practice is also required of the student pilot. An FAA written examination must be passed at the private and commercial rating level. To obtain either rating the pilot must successfully complete an oral exam and flight test given by an FAA flight examiner. At all stages of flight training weather is included in the program.

Many other parts of the FAA regulations apply to balloon flight. Part 91 prescribes general operating and flight rules. This part covers a wide variety of topics from drinking before a flight, to lights on the aircraft, to weather minimums. They all apply equally to a balloon as to any other type aircraft. Fortunately, the regulations say nothing about the traditional champagne after a flight.

Part 91 directs that "each pilot-in-command shall, before beginning a flight, familiarize himself with all available information concerning that flight. This information must include...weather reports and forecasts..." The balloon pilot is obligated by regulation, if not by good sense, to get a weather briefing.

Some balloonist are setting up their own pibal systems and even computerizing them, but most pilots still rely on the weather service to provide surface and winds aloft forecasts.

Let me suggest other briefing items that need to be stressed and why they are important to balloon flight safety:

(1) Low level inversions: besides the obvious effect on low level winds the temperatures are critical to calculating allowable payload weights.

(2) Wind shear, especially speed, which can cause false lift that, when lost, can result in hard or unintended landings.

(3) Thermals: encountering a strong thermal can cause collapsing or distortion of the balloon to the point of crashing from an inability to control the heat needed keep flying.

Why do we in the National Weather Service need to concern ourselves?

(1) There is a rapidly growing number of users. The sport is affordable and appealing.

(2) The National Weather Service Operations Manual requires it.

(3) And without a doubt...done with skill pilot weather briefing greatly improves balloon flight safety.

PILOT REPORTS AND AIRCRAFT IDENTIFICATION: THEIR IMPORTANCE IN WEATHER SERVICE OPERATIONS

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1. INTRODUCTION

Pilot reports are important sources of weather information. They can help the aviation forecaster produce better forecasts. They can help both the aviation forecaster and the Weather Service specialist give better briefings. And they can also help the public forecaster by giving him information not available from any other source.

This paper takes a closer look at pilot reports and how they can be used in daily National Weather Service (NWS) operations. It also provides a reference on aircraft types based on the Federal Aviation Administration's (FAA) aircraft designators used in pilot reports.

2. DATA SAMPLE

The basis for statistical analyses is a sample of 12,500 pilot reports collected randomly over a two year period from December, 1989, to November, 1991, from 15 eastern states and the District of Columbia. The 15 states consist of: Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, West Virginia, Virginia, Ohio, Indiana, Kentucky, Tennessee, Georgia, South Carolina, and North Carolina. Pilot reports where the aircraft was identified with a non-specific designator, such as JET, UNKN (unknown), CSNA (Cessna), or HELO (helicopter), were excluded from the sample. Duplicate pilot reports were also excluded.

3. THE PILOT REPORT

3.1 Issuance and Dissemination

Pilot reports can be initiated by either the pilot or an FAA air traffic control (ATC) facility. The FAA is required to solicit pilot reports when the following conditions are reported or forecast (FAA 1991b): ceilings at or below 5,000 ft; visibility at or below 5 miles; thunderstorms; icing -greater than a trace; turbulence - moderate or greater; or wind shear. The pilot can initiate the report if he is encountering either significant weather or weather that deviates significantly from the forecast.

Pilot reports can be transmitted by the pilot on one of several radio frequencies to any one of several FAA facilities including the Flight Service Station (FSS), the Air Route Traffic Control Center (ARTCC), or approach or terminal ATC. The FSS collects and disseminates the pilot reports and rebroadcasts them to other pilots. Some of the frequencies most commonly used are: Flight Watch, the Airport Advisory Service, and the VHF Omnidirectional Range (VOR).

The FSS also enters the reports into the FAA computers, which routes them to the switching center in Kansas City where they enter the NWS's Automation of Field

Operations and Services (AFOS) system. From there they go to the Systems Monitoring and Coordination Center (SMCC) in Silver Spring, MD, where they are reformatted and sent out as pilot report collectives for each state every 20 minutes. The AFOS product format is cccPRCxx, where ccc is the local node and xx is the state abbreviation.

During fair weather, around 1,000 pilot reports are received in AFOS every 24 hours. On active weather days the total can exceed 3,000; however, not all pilot reports reach the NWS. The primary reason is that, when the work load at FAA facilities is heavy on a very active day, some pilot reports are not encoded into the FAA computers. When the number of pilot reports is very large, the FSS often combines similar reports from several aircraft and enters them into the computer under a general header such as JETS. In addition, automated meteorological reports are transmitted from many instrumented commercial aircraft using ACARS (Aircraft Communications Addressing and Reporting System). These instrument platforms report a total of 150 to 400 temperature, wind, and pressure observations every 3 hours through the Meteorological Data Collection and Reporting System (MEDCARS) to the National Meteorological Center (NMC). In the future, humidity and turbulence reports may be added to these instrument platforms.

3.2 Applications

Pilot reports have several applications. In the FAA, the ARTCC, approach control, and tower use them to expedite the flow of traffic and avoid hazardous weather. The FSS uses them to brief pilots, helping them find favorable routes and altitudes.

In the NWS, the aviation forecaster can use pilot reports to verify or amend conditions in aviation forecasts and advisories. Both the aviation forecaster and the Weather Service specialist can use pilot reports in briefing pilots. Of particular importance are reports of low level wind shear, winds aloft, areas of turbulence and icing, and cloud decks not reported in surface observations.

Pilot reports can also provide additional information, sometimes unavailable from other sources, to both the aviation and public forecasters. Examples include: pinpointing the location of fronts; comparing winds and temperatures aloft to guidance to see if the models are on track; determining the height of the freezing level, or warm air intrusions, so that the type of precipitation (rain, sleet, freezing rain, or snow), and the height of the snow line at higher elevations, can be determined; using the thickness of a cloud layer or fog to determine the persistence of the feature; determining the height of an inversion, haze layer, or smoke plume; and obtaining severe weather reports of phenomena such as a funnel cloud or downburst.

4. REPORTED FLIGHT AND WEATHER ELEMENTS

4.1 Flight Elements

The format of a pilot report is shown in Figure 1. The five flight elements (Figure 1; items 1-5) are disseminating office, location, time, flight level, and aircraft type. The disseminating office is the FSS from which the pilot report originated. The location element gives the direction and distance in degrees and nautical miles from a three-character location identifier, such as an airport or navigational aid (VOR or VORTAC [VOR Tactical Air Navigation]). The location can either be a point or a segment of the route flown. The time element is the time of the report in UTC. The flight level is the altitude in feet MSL at which the aircraft is flying at the time of the report; the weather being reported does not have to be at this level. The aircraft type element is the FAA designator for the aircraft, which will be discussed in detail in Section 5.

4.2 Weather Elements

The seven standard weather elements are sky condition, weather, air temperature, wind velocity, turbulence, icing, and remarks (Figure 1; items 6-12). The sky condition includes cloud bases and tops in hundreds of feet MSL. The weather element includes flight visibility (FV) in miles and obscuring phenomena (e.g., rain or haze). The air temperature element is given in degrees Celsius. The wind velocity element provides the wind speed and direction in degrees and knots. The turbulence element classifies the turbulence in 7 categories: NEG or SMTH for no turbulence; LGT for light turbulence; LGT-MDT for light to moderate turbulence, MDT for moderate turbulence, MDT-SVR for moderate to severe turbulence, SVR for severe turbulence, and EXTREME for extreme turbulence. The term CHOP can be added with light or moderate turbulence. The term CAT should be added for clear air turbulence. The icing element gives aircraft icing in 7 categories: NEG for none; TR or TRACE for trace, LGT for light, LGT-MDT for light to moderate, MDT for moderate, MDT-SVR for moderate to severe, and SVR for severe. The terms CLEAR, RIME, or MIXED are often added to describe the type of icing. The remarks element is for reporting low level wind shear (LLWS) and other meteorological phenomena that are not adequately described in the other elements. The normal method for reporting LLWS is in knots gained or lost (e.g., +/- 10).

Criteria for turbulence and icing intensities are given in the "Airman's Information Manual," Sections 7-20 and 7-21 (FAA 1991b) and in the Weather Service Operations Manual (WSOM) Chapter D-22 (NWS 1991). Criteria for LLWS are given in WSOM Chapter D-21 (NWS 1988).

Routine pilot reports are designated UA and urgent reports UUA. The threshold for urgent criteria varies to some degree depending upon the reporting FSS, the circumstances, the time of year, the altitude, and the location. In general, it includes turbulence that is moderate to severe or greater, icing that is moderate to severe or greater, LLWS, or any other meteorological phenomenon considered significantly hazardous, such as a tornado or hail. Sometimes the threshold used for icing is lowered to moderate if the condition is unusual for that time, place, and altitude.

The pilot report is not required to contain all weather elements, but rather only those considered relevant or significant. The average number of elements reported, based on the sample used in this study, was 2.04 per report. The frequencies of the individual elements are given in Table 1. Turbulence and sky condition were the most common, and weather and wind velocity the least.

Urgent pilot reports accounted for 9% of all reports. On days with bad weather this percentage went as high as 25%, and on fair weather days down to zero. Turbulence was the critical element to make the report urgent 47% of the time, LLWS 39%, icing 17%, and weather (such as freezing rain, hail, or funnel cloud) 3%. Note that the total is slightly more than 100% because there were, occasionally, multiple critical elements.

LLWS is an unusual parameter in that it is sometimes reported in the turbulence section instead of in the remarks section, as is the customary practice. The primary reason for this variation of format is the interrelated nature of LLWS and turbulence. What one aircraft may report as LLWS on take-off or landing, another aircraft may report as turbulence. In most cases, the intensity of turbulence, if reported, goes in the turbulence element, and any report described as LLWS goes in the remarks.

4.3 Abbreviations and Contractions Commonly Used

Most of the language and syntax in a pilot report is the same or similar to that used by the NWS. Table 2 lists some commonly used abbreviations and contractions found in pilot reports that are not commonly used by the NWS.

4.4 Frequency of Pilot Reports by Altitude

The frequency of pilot reports by altitude was computed. Most reports, 63.4% of the total, were filed below 10,000 ft MSL. Of these, an approximately equal number pilot reports were filed at altitudes below 5,000 ft MSL and between 5,000 at 9,900 ft MSL, with 29.8% and 33.6%, respectively. Between 10,000 to 19,900 ft, there were 18.6%; between 20,000 and 29,900 ft, 7.4%; and at and above 30,000 ft, 10.6%. A detailed breakdown is provided in Table 3.

The large number of reports coming from lower altitudes reflects two factors. First is the large number of single and twin-engine private and small business aircraft. Aircraft equipped only for Visual Flight Rules (VFR) without pressurization or oxygen equipment are limited to altitudes of less than 12,500 ft MSL except for short periods of less than 30 minutes at altitudes of up to 14,000 ft. With oxygen, VFR aircraft can go up to 17,500 ft. Only IFR (Instrument Flight Rules) equipped aircraft with pressurization or oxygen equipment can fly at 18,000 ft or higher. The second reason for the large number of reports at lower altitudes is the active weather regime, with sharp contrasts and terrain influences, that generally exist in the lowest 10,000 ft of the atmosphere.

Cruising altitudes are usually greater than 1,000 ft AGL, except for special purposes such as crop dusting. Therefore, most pilot reports filed near the surface are departures and approaches.

5. AIRCRAFT TYPES

5.1 Common Aircraft Types and Specifications

To best interpret a pilot report or to give the most effective briefing, it is important to understand the type of aircraft involved. Is it single or multi-engine? Is it equipped for IFR? What is its weight and size? What is its cruising speed and ceiling? The answers to these questions will determine how to interpret weather conditions with respect to that aircraft. For example, a single-engine Cessna reporting moderate turbulence is not usually experiencing the same conditions as a Boeing 727 reporting moderate turbulence.

It is not possible or necessary for the NWS aviation forecaster or briefer to know all the details and specifications of common aircraft. However, he or she can gain some knowledge on the subject in two ways. The first is through familiarization with the kinds of aircraft most common to their region. The second is through access to easy-to-use references.

The FAA provides several excellent sources of information for aircraft identification. Among these are the "Aircraft Type Designator" tables (FAA 1991c and 1991d) which list 579 two to four character designators for 547 types of aircraft. (There is some duplication due to civilian and military variants.) A larger list of designators is provided by the International Civil Aviation Organization (ICAO 1991). For each aircraft type in the FAA publications, the following information is given: type and number of engines; general weight class (small, large, and heavy); climb rate; descent rate; SOIR (simultaneous operations on intersecting runways) group; and SRS (same runway separation) category. These specifications are designed primarily to help the air traffic controller.

The FAA also publishes the "Controller Reference Aircraft Manual" (FAA 1991a), which shows color photographs and silhouettes for over 200 civilian and military aircraft, along with an expanded list of specifications. This is an excellent reference and can be a very good familiarization tool for the aviation forecaster and Weather Service specialist.

An additional reference has been developed as part of this paper for NWS use. "Quick Reference - Frequent Aircraft Types and Specifications," based on "Jane's All the World's Aircraft" (Taylor 1982-1991), is presented in Table 4. This reference lists the 46 most common types of aircraft found in the data sample used for this report.

5.2 Most Frequent Types

The most common fixed-wing powered aircraft types were divided into five general categories to examine the frequency of different aircraft types filing pilot reports. The categories are:

1) private, sport, light business, and light cargo (single prop)
2) private, business, light commuter, cargo (twin prop; < 15,000 lbs)
3) business, commuter, and cargo (twin prop; > 15,000 lbs)
4) executive jet
5) airliners and large cargo

The most common types were, as expected, the smaller aircraft; categories 1 and 2 filed a combined 66.2% of the reports, 36.9% and 29.3% respectively. Airliners were next with 14.4%. Then came executive jets with 9.9%, and larger business/commuter aircraft with 9.5%. Eight individual types filed 3% or more of the reports. They are: the Piper Cherokee, Cessna 172, Beechcraft King Air, Boeing 727, Beechcraft Bonanza, Beechcraft Super King Air, Beechcraft Baron, and Piper Navajo/Mojave/Chieftain. All together, 41 types with 1.0% or more accounted for 85.3% of the reports. A detailed summary is given in Table 5.

These figures show that all sectors of the aviation community contribute to the pilot report process. They also show that although there are over one thousand types of aircraft flying in the skies today, knowing something about a relatively small number of them can provide a good foundation for the aviation forecaster and briefer.

6. SOME EXAMPLES OF PILOT REPORTS

Table 6 shows some examples of pilot reports taken primarily from the 12,500 pilot reports in the data base for the period December, 1989, to November, 1991. A few examples are from outside the data sample but are still within the same two year period in the same 14 states. These pilot reports illustrate both the impact of weather on aircraft, and the sense of humor it sometimes takes to be a pilot.

7. SUMMARY AND CONCLUSIONS

The primary purposes of this paper were to highlight the importance of pilot reports in both aviation and public forecasting, and to provide an aircraft reference that can be used as a familiarization and briefing tool. Towards this second goal, Table 4 provides a quick reference of common aircraft types. This table can be used in conjunction with the FAA's pictorial glossary "Controller Reference Aircraft

Manual" (FAA 1991a), which provides color photographs for many of the aircraft listed in Table 4.

While the pilot reports used in this paper were from only 15 states, the examples and references are applicable in a more general sense to the whole country.

An appreciable portion of the NWS mission is related to the service of aviation. Aviation in turn has given the NWS a valuable service in return, the pilot report.

References:

FAA, 1991a: Controller Reference Aircraft Manual, ATG-2. Federal Aviation Administration, Oklahoma City, OK, April, 1991.

FAA, 1991b: Airman's Information Manual. Federal Aviation Administration, Washington, D.C., July 25, 1991.

FAA, 1991c: Contractions, Order 7340.1L CHG 4. Federal Aviation Administration, Washington, D.C., October 1, 1991.

FAA, 1991d: Air Traffic Control, Order 7110.65 CHG 7. Federal Aviation Administration, Washington, D.C., November 14, 1991.

ICAO, 1991: Aircraft Type Designators. International Civil Aviation Organization, Montreal, Canada.

NWS, 1988: Weather Service Operations Manual, Chapter D-21. National Weather Service, March 11, 1988, 23 pp.

NWS, 1991: Weather Service Operations Manual, Chapter D-22. National Weather Service, May 22, 1991, 44 pp.

Taylor, J., 1982-1991: Jane's All the World's Aircraft. London, England, 800pp.

Weather Element	Frequency All	Frequency UA	Frequency UUA	Critical element triggering UUA
Sky (SK)	.40	.43	.08	0%
Weather (WX)	.11	.11	.06	3%
Air temp (TA)	.22	.25	.02	0%
Wind Vel (WV)	.11	.13	0	0%
Turbulence (TB)	.55	.54	.64	51% *
Icing (IC)	.33	.34	.18	17%
Remarks (RM)	.32	.30	.50	36% (mostly LLWS)
Total Elements Per Report	2.04	2.09	1.48	107%

* includes 4% LLWS reported in TB
Note: 91% of total were UA and 9% were UUA.

Table 1. Frequency of weather elements in pilot reports.

A/S (or AIR SPD) - air speed *
APCH - approach
BL (or BTWN LYRS) - between layers
CA - clear above *
CAT - clear air turbulence
CAVU - clear and visibility > 10
DEPG - departing
DPTG - departing *
DWNDFT - downdraft
DURC - during climb
DURD - during descent
ENRT - enroute
EBND - east bound
FA - final approach
FAP - final approach *
FRZLVL - freezing level
FZL - freezing level *
FV - forward visibility
GS (or GND SPD) - ground speed
HDWND - headwind
HP (or HLDG PAT) - holding pattern
IAO - in and out of (clouds)
IAOC - in and out of clouds *
IAS - indicated air speed
IBND - inbound
ICGIC - icing in clouds
ILS - instrument landing system
IMC - instrument met. conditions
INC - in clouds
INVOF - in vicinity of
IOVC - in overcast
MTW (or MTN WV) - mountain wave
MXD - mixed (icing)
NBND - north bound
OBND - outbound
OG - on ground
OMTNS - over mountains
OTAS - on top and smooth
OTP - on top
PUP - pickup (ice)
RWY - runway
RY - runway
SBND - south bound
SMTH - smooth
TFC PAT - traffic pattern
TKOF - take-off
TLWD - tailwind
TURBC - turbulence
UDDF - up and down drafts
UPDFT - updraft
UNRSTD - unrestricted
WBND - west bound

* common usage but not listed in "Contractions" (FAA 1991c)

Table 2. Some common abbreviations and contractions used in pilot reports.

Flight Level (feet, MSL)	Percentage of reports Total	Subtotal
surface- 4,900	29.8	
surf - 1,900*		7.6
2,000 - 2,900		6.9
3,000 - 3,900		8.1
4,000 - 4,900		7.2
5,000 - 9,900	33.6	
5,000 - 5,900		7.2
6,000 - 6,900		9.5
7,000 - 7,900		6.6
8,000 - 8,900		5.6
9,000 - 9,900		4.7
10,000 - 14,900	11.8	
15,000 - 19,900	6.8	
20,000 - 24,900	4.0	
25,000 - 29,900	3.4	
30,000 - 34,900	3.7	
35,000 - 39,000	5.7	
40,000 - 44,900	1.2	
Total	100.0	

* Includes take-off, landing, and on ground

Table 3. Frequency of pilot reports by altitude.

FAA Designator	Manufacturer	Model	Type	Max Takeoff (lbs)	Max Cruise (mph)	Service Ceiling 100s ft	Typical Passeng	Engine Config P=prop J=jet
AC69,6T	Rockwell	Turbo Commander, Jet Prop	business	10,500	300-340	32	8-11	2P
B727	Boeing	727	large airliner	200,000	600	37	160	3J
B737	Boeing	737	medium airliner	115-150,000	560	37	110-150	2J
B757	Boeing	757	large airliner	240,000	570	40	180	2J
BA31	British Aerospac	Jetstream	commuter, business	15,000	300	25	10-20	2P
BE02	Beechcraft	1900	commuter	16,500	305	25	21	2P
BE10,90; U21F	Beechcraft	King Air; Ute	business	11,500	270	25	8-15	2P
BE20,30; C12	Beechcraft	Super King Air; Huron	business, commuter	13,500	350	35	8-15	2P
BE33,35,36	Beechcraft	Bonanza	private	3,400	185-225	17-25	4-6	1P
BE55,58	Beechcraft	Baron	priv, lt business	5,200	200-230	20	6	2P
BE90	Beechcraft	King Air 90	business	10,000	255-285	27	6-10	2P
BE99	Beechcraft	Airliner	commuter	10,900	280	27	17	2P
C150,152	Cessna	150, 152	private, trainer	1,600	120	14	2	1P
C172	Cessna	172/Skyhawk	private, trainer	2,400	135	13	4	1P
C182	Cessna	182/Skylane, Skylane RG	private	3,100	160-190	15-20	4	1P
C208	Cessna	208/Caravan	utility	7,300	210	27	2-10	1P
C210	Cessna	210/Centurion	light business	3,900	190-235	17-27	6	1P
C310,320	Cessna	310,320; Skyknight	business	5,500	225-255	19-28	5	2P
C401,402,414	Cessna	401,402,414,Chancellor	business, commuter	6,300	245	26-31	8	2P
C421	Cessna	421, Golden Eagle	business	7,400	270	30	8	2P
C500,501	Cessna	Citation I	executive jet	11,600	400	41	7-9	2J
C550,551	Cessna	Citation II	executive jet	12,600	440	43	8-12	2J
DA20	Dassault-Breguet	Falcon 20,200,FJF	executive jet	29,000	530	42	10-16	2J
DC9	McDonnell Dougl	DC-9 (Series 10-50)	medium airliner	92-120,000	570	35	100-120	2J
FK10	Fokker	100	small airliner	98,000	535	35	112	2J
FK27, FA27	Fokker/Fairchild	F27 Friendship	feederliner	45,000	295	29	47	2P
FK50	Fokker	50	feederliner	45,000	330	25	52	2P
G2,3,4; C20	Gulfstream	Gulfstream 2,3,4	executive jet	66,000	570	45	13-22	2J
HS25	British Aerospac	HS-125	executive jet	27,000	510	42	10-16	2J
LR23,24	Gates Learjet	Learjet 23,24	executive jet	13,500	525	45	8-10	2J
LR25,28,31	Gates Learjet	Learjet 25,28,31	executive jet	15,500	520	45	10	2J
LR35,36	Gates Learjet	Learjet 35,36	executive jet	18,000	525	45	10	2J
MD80 through 88	McDonnell Dougl	MD-80 through 88	medium airliner	140-160,000	575	37	130-160	2J
MO20,21	Mooney	Mark 20,21,Ranger,M20	private	2,600	170	17	4	1P
MU2	Mitsubishi	Marquise, Solitaire	business	10-11,500	350	30	9-12	2P
PA28	Piper	Cherokee,Archer,Cadet	private, trainer	2,400	140	11-14	2-4	1P
		Arrow II, III; Dakota	private	2,800	165-195	16-20	4	1P
PA31	Piper	Navajo,Chieftain, Mojave, T-1020	business, commuter	7,500	225-265	16-29	7-10	2P
PA32	Piper	Cherokee 6,Lance,Saratoga	private	3,600	165-200	14-20	6	1P
PA60, TS60	Piper/Ted Smith	Aerostar 600, 700	business	6,000	250-310	22-30	6	2P
PARO	Piper	Cherokee Arrow IV	private	3,000	195-225	16-20	4	1P
PASE, PA34	Piper	Seneca II, III	light business	4,500	190-220	19-25	6-7	2P
PAYE	Piper	Cheyenne I, II	business	9,200	310	21-25	6-8	2P
PAZT	Piper	Aztec	light business	5,200	210-245	21-30	6	2P
SF34	Saab/Fairchild	SF-340	feederliner	27,000	315	25	39	2P
SW3,4	Fairchild/Swear	Metro, Merlin 4	business, commuter	15,000	320	27	12-22	2P
WW23,24; AC21	IAI/Rockwell	Westwind, Jet Commander	executive jet	22,500	520	45	12	2J

Note: Specifications averaged, weighted by approximate number of each variant in service.

Table 4. Quick reference - Frequent aircraft types and specifications.

1) Private, Sport, Light Business, and Light Cargo (single prop)		
Piper Cherokee	6.0 %	PA28
Cessna 172	5.7	C172
Beechcraft Bonanza	3.7	BE33,35,36
Cessna 150,152	2.9	C150,152
Cessna 182/Skylane	2.2	C182
Mooney 20, 21	2.1	MO20,21
Cessna 210/Centurion	1.9	C210
Piper Cherokee Six/Saratoga	1.6	PA32
Cessna 208/Caravan	1.5	C208
Piper Seneca II, III	1.4	PASE, PA34
Piper Cherokee Arrow IV	1.0	PARO
Other	6.9	
Total	36.9%	
2) Private, Business, Light Commuter, Cargo (twin prop less than 15,000 lbs)		
Beechcraft King Air	4.0%	BE10,90; U21F
Beechcraft Super King Air	3.3	BE20,30; C12
Beechcraft Baron, Cochise	3.3	BE55,58
Piper Navajo/Chieftain/Mojave/T-1020	3.2	PA31
Cessna 310/320/Skyknight	2.9	C310,320
Piper Cheyenne I, II	1.4	PAYE
Beechcraft Airliner	1.3	BE99
Cessna 401,402,414, Chancellor	1.2	C401,402,414
Cessna 421, Golden Eagle	1.2	C421
Piper Aerostar	1.1	PA60, TS60
Mitsubishi Marquise, Solitaire	1.0	MU2
Rockwell/Gulfstream Turbo Commander, Jet Prop	1.0	AC69, AC6T
Piper Aztec	1.0	PAZT
Other	3.4	
Total	29.3%	
3) Business, Commuter, and Cargo (twin prop; 15,000 lbs or more)		
Fairchild/Swearinger Metro/Merlin 4	2.8%	SW3,4
Beechcraft 1900	1.6	BE02
BAC Jetstream (prop)	1.2	BA31, HP31
Fokker/Fairchild Friendship F27	1.1	FK27, FA27
SAAB/Fairchild SF-340	1.0	SF34
Other	1.8	
Total	9.5%	
4) Executive Jet		
Cessna Citation 1, 2	2.9%	C500,501,550
Lear (24 through 36)	1.8	LR23,24,25,28,31,35,36
BAC HS-125	1.3	HS25
Grumman Gulfstream 2, 3, 4	1.0	G2,3,4; C20
Dassault-Breguet Falcon 20, 200; HU-25A; FJF	1.0	DA20
IAI Westwind/Rockwell Jet Commander	1.0	WW23,24; AC21
Other	0.9	
Total	9.9%	
5) Airliners and Large Cargo		
Boeing 727	4.0%	B727
McDonnell Douglas DC-9 (Series 10-50)	2.8	DC9
Boeing 737	2.5	B737
McDonnell Douglas MD-80 through 88	1.4	MD80 through 88
Boeing 757	1.0	B757
Fokker 50	1.0	F05
Other	1.7	
Total	14.4%	

Table 5. Most frequent types of aircraft filing pilot reports (1.0% or more).

Turbulence

02/13/90 MKL UUA /OV MKL180007/TM 1345/FL045/TP AA5/TB MDT CHOP/RM VERY ROUGH BELOW 20 HEAD HIT TOP OF CABIN COUPLE OF TIMES
02/16/90 BUF UUA /OV BUF270040/TM 2040/FL270/TP BE20/TB SVR/RM COULD NOT MAINTAIN ALT WITH FULL POWER
04/05/90 MRB UUA /OV HGR/TM 2039/FL025/TP HELO/TB SVR/RM OVR RIDGES
04/10/90 LEX UUA /OV AZQ-FLM 180020/TM 1820/FL040/TP C210/TB SVR/RM ONE PILOT/ ONE VERY SCARED PASSENGER
09/30/90 PKB UUA /OV PKB-ZZV/TM 1640/FL040/TP PARO/WX R+/TB MDT-SVR/RM PILOT LOST HAT 2 OR 3 TIMES
02/04/91 LAF UUA /OV DNV 180010/TM 1930/FL270/TP B727/TB SVR CAT
02/20/91 ACY UUA /OV CYN 270010/TM 1855/FL120/TP B727/TB EXTRM (Only extreme report in data base)

Mountain Waves

04/04/90 CHO UUA /OV MOL/TM 1547/FL100/TP PA32/WV 330052/RM MOUNTAIN WAVE IN PLACE/ HARD TO MAINTAIN ALT
02/20/91 EKN UUA /OV ESL-EKN/TM 2052/FL060/TP PA31/TB MDT OCNLY SVR/RM VERY STRONG MOUNTAIN WAVES
09/27/91 CHO UUA /OV 30N CHO/TM 1155/FL065/TP C172/RM FULL POWER TO MAINTAIN ALT IN MOUNTAIN WAVE W OF RIDGE/ NO PROBLEM E/SMTH AIR WHOLE TIME

Updrafts and Downdrafts

07/01/90 CRW UUA /OV ECB225020/TM 2017/FL040/TP BH06 BELL RANGER/TB SVR/RM MICRO DOWN BURST LOST 500 FEET
08/19/90 EKN UUA /OV EKN090025/TM 0205/FL065/TP C182/RM SVR DWNDFTS LOST 800 FT WITH FULL THROTTLE COULD NOT MAINTAIN ALT
06/16/91 CHA UUA /OV RMG360010/TM 1755/FL035/TP PA28/TB MDT-SVR/RM 1500 FT PER MIN UDDF
07/26/91 TRI UUA /OV TRI/TM 2018/FLUNKN/TP HP13/RM/RM FINAL RWY 5 1400 FT PER MIN UPDFT

Thunderstorms

02/15/90 MEM UUA /OV GQE/TM 2135/FL120-180/TP B727/TB MDT-SVR/RM IN WX PILOT RCMDS NOT PENETRATING THIS LINE OF TSTMS
04/10/90 RMG UA /OV CSG-RMG/TM 2105/FL000/TP BE58/RM PILOT LANDED AT RMG JUST AHEAD OF THE SQUALL LINE. GLAD TO BE ON THE GROUND
06/16/91 CSV UA /OV CSV 090020-CHA/TM 1805/FL075/TP BE35/RM LN CB'S BUILDING DIVERTED CHA-WEST AROUND
07/26/91 TYS UA /OV TYS 360050/TM 1643/FL080/TP C206/RM TCU TOPS E200 BLDG RPDLY
09/14/91 CRW UUA /OV CRW 030050/TM 0015/FL310-370/TP JETS/TB SMTH OUTSIDE TSTM/RM TWO AIRCRAFT RPTD WORST TSTM THEY EVER SAW

Low Level Wind Shear

03/30/90 HLG UUA /OV HLG/TM 1655/FLUKN/TP PA28/RM LLWS LOST 30 KTSAND 100 FT DURG SHRT FA RY21
04/10/90 LOZ UUA /OV K20/TM 1903/TP BE58/TB SVR 020-SFC/RM LLWS -30KTS TO +15KTS
02/14/91 LYH UUA /OV LYH/TM 1831/FL003/TP N265/TB LLWS +40/-10KTS/RM DH8 & BA31 ACFT RPT LLWS +20/-10 KTS AND MDT TURB FAP 21

Winds Aloft

02/16/90 CAK UA /OV ACO/TM 2231/FL350/TP C550/TA -42/WV 242175/TB SMTH
02/27/90 MRB UA /OV MRB/TM 1605/FL060/TP BE55/IC MDT RIME/RM HEADWIND 52 KTS
04/05/90 HTS UA /OV HTS/TM 1735/FL160/TP UNKN/WV 2800090/RM WNDS STRGR THAN FD
04/28/91 SBY UA /OV SBY/TM 1122/FL090/TP MO20/RM WINDS MORE WSTRLY THAN FCST

Icing

02/15/90 CMH UUA /OV APE 180012/TM 2345/FL210/TP BE20/IC SVR/RM 10 KTS LOSS A/S
02/16/90 ERI UUA /OV ERI 300030/TM 2035/FL160/TP BE10/IC SVR RIME/RM PUP 3/4 INCH IN 1 MIN
10/11/91 MFD UUA /OV TVT/TM 1751/FL058/TP MO20/TA 0/IC MDT-SVR MXD @ 060 LOST ICE @ 058
12/29/91 MGW UUA /OV MGW 338006/TM 2345/FLUNKN/TP PA28/IC SVR/RM DURGD MGW PILOT DECLARED EMERGENCY

Haze, Smoke

06/15/91 EWN UA /OV EWN360060/TM 1230/FL085/TP BE35/RM 085 HAZE TOP
11/01/91 GSO UA /OV GSO075014/TM 1439/FLUNKN/TPBE36/SK K LYR 045-065/WX VSBYS 2-3K 045-065/TA 12/RM DURC GSO/ VSBY UNRSTD ABV 065
11/01/91 BKW UA /OV BKW/TM 1439/FL080/TP C310/RM ACTIVE FIRE 15 SW BKW FV 2-6K TOPS E070

Table 6. Interesting and illustrative examples of pilot reports.

Temperatures Aloft, Freezing Level

02/27/90 AGC UA /OV AGC/TM 1402/FL125/TP BE90/SK 030 OVC 115 CA/TA -05/TB NEG/IC NEG/RM TEMP ABV FRZG 030-090 DURC EBND
02/18/91 AVP UA /OV LHY 270029/TM 1936/FL150/TP SW3/WX BTWN LYRS/TB SMTH/IC TRACE/RM INCLDS DURGC MULTI LYRS/ TEMP INVERSION 053-070
10/30/91 SBN UA /OV ARR-GIJ/TM 1232/FLDURC/TP BE20/SK OVC 260-270/WX R-/TA FRZLVL 160/TB SMTH SFC-270/IC NEG

Conditions less than VFR

06/17/91 SHD UA /OV SHD-PHF/TM 1237/FL030/TP C172/RM UNABLE VFR MTNS OBSCRD
10/13/91 ABE UA /OV ETX/TM 1259/FL035/TP C172/SK RTNG ABE DUE WX DETRNG
10/14/91 ELM UA /OV ELM/TM 1225/FLDURD/TP C150/SK OVC 15/RM MISSED APCH IN FOG
11/05/91 CRW UUA /OV CRW/TM 1633/FL015/TP BH06/WX FV 1/4K/RM CRW-HTS RTNG CRW

Severe Weather

07/02/91 MCN UA /OV DBN 084024/TM 0112/FLUNKN/TP UNKN/RM PILOT OG TSTMS OV SBO HAIL 1 INCH, SIZE OF 50 CENT PIECE
07/02/91 FWA UUA /OV FWA 160015/TM 1930/FL250/TP JET/WX WELL DEFINED FUNNEL
11/03/91 ISP UUA /OV DPK/TM 2048/FLUNKN/TP UNKN/RM FUNNEL CLOUD NE GLEN COVE RPT BY MAN OG

Airport related

02/15/90 MEM UUA /OV MEM/TM 2230/FLOG/TP UNKN/RM LTNG HIT RWY 36R CREWS CHECKING
08/07/90 HTS UA /OV PMH/TM 0233/FLUNKN/TP C550/RM COW RUNNING ALONG RWY

Other Interesting

02/04/91 YNG UA /OV YNG 090020/TM 1549/FL065/TP C182/TB NEG/RM DURGD TO NEW CASTLE...A BEAUTIFUL DAY TO FLY
10/13/91 MIV UA /OV ILG-MIV/TM 1840/FL020/TP PA28/RM SEVERAL FLOCKS OF GEESE BTWN 020-027

Table 6. Continued.

Encoding Pilot Weather Reports (PIREP)

1. **UA -** **Routine PIREP, UUA - Urgent PIREP**

2. **/OV -** **Location:** Use 3-letter NAVAID idents only.
   a. Fix: /OV ABC, /OV ABC 090025.
   b. Fix to fix: /OV ABC-DEF, /OV ABC-DEF 120020,
   /OV ABC 045020-DEF 120005, /OV ABC-DEF-GHI.

3. **/TM -** **Time:** 4 digits in GMT: /TM 0915.

4. **/FL -** **Altitude/Flight Level:** 3 digits for hundreds of feet. If not known, use UNKN: /FL095, /FL310, /FLUNKN.

5. **/TP -** **Type aircraft:** 4 digits maximum, If not known use UNKN: /TP L329,/TP B727. /TP UNKN.

6. **/SK -** **Cloud layers:** Describe as follows:
   a. Height of cloud base in hundreds of feet. If unknown, use UNKN.
   b. Cloud cover symbol.
   c. Height of cloud tops in hundreds of feet.
   d. Use solidus (/) to separate layers.
   e. Use a space to separate each sub element.
   f. Examples: /SK 038 BKN, /SK 038 OVC 045,
   /SK 055 SCT 073/085 BKN 105, /SK UNKN OVC

7. **/WX -** **Weather:** Flight visibility reported first. Use standard weather symbols, Intensity is not reported: /WX FV02 R H, /WX FV01 TRW.

8. **/TA -** **Air temperature in Celsius:** If below zero, prefix with a hyphen: /TA 15, /TA -06.

9. **/WV -** **Wind:** Direction and speed in six digits. /WV 270045, /WV 280110.

10. **/TB -** **Turbulence:** Use standard contractions for intensity and type (use CAT or CHOP when appropriate). Include altitude only if different from /FL.
    /TB EXTRM, /TB LGT-MDT BLO-090.

11. **/IC -** **Icing:** Describe using standard intensity and type contractions. Include altitude only if different than /FL: /IC LGT-MDT RIME, /IC SVR CLR 028-045.

12. **/RM -** **Remarks:** Use free form to clarify the report. Most hazardous element first:
    /RM LLWS -15KT SFC-003 DURGC RNWY 22 JFK.

Refer to FAAH 7110.10 for expanded explanation of TEI coding.

Examples: **CRW UA /OV** HVQ 022050/**TM** 1230/**FL**045/**TP** PA42/**SK** 025 OVC 038 E100 OVC/**WX** S-/**TA** -2/**WV** 220045/**TB** LGT CHOP/**IC** TRACE RIME/**RM** BTWN LYRS

ROA UUA /OV PSK 360010/**TM** 1645/**FL**060/**TP** C208/**TB** SVR/**RM** E OF RDGS

Figure 1. The structure of a pilot report.

PILOT WEATHER BRIEFINGS
THINGS TO CONSIDER AND STEPS TO FOLLOW

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1. INTRODUCTION

The authors have noticed that many NWS employees, not only those recently hired, do not know the proper techniques in pilot weather briefing. It is our hope that this paper will aid all employees in this facet of their job in the Weather Service.

Three types of pilot weather briefings are defined by both the FAA and the NWS. They are: standard, outlook, and abbreviated. Since one of the requirements of all NWS employees enrolled in the Pilot Weather Course is to successfully give a standard briefing, this paper will deal with the techniques needed in giving a standard briefing.

2. STANDARD PILOT BRIEFING

To provide a proper briefing, the briefer needs the following information:

I. APPROPRIATE BACKGROUND INFORMATION,
II. ADVERSE CONDITIONS,
III. A SYNOPSIS,
IV. CURRENT CONDITIONS (MAY BE OMITTED IF THE PROPOSED DEPARTURE TIME IS MORE THAN 2 HOURS),
V. ENROUTE FORECAST,
VI. DESTINATION FORECAST,
VII. WINDS ALOFT,
VIII. TEMPERATURES ALOFT (UPON REQUEST), AND
IX. A REQUEST FOR PILOT REPORTS.

The remainder of this paper will go into detail on each of the nine items above.

I. APPROPRIATE BACKGROUND INFORMATION

To give an adequate pilot briefing, the briefer needs to get nine items of information from the pilot on his/her proposed flight.

1. Type of flight (VFR or IFR),
2. Aircraft I.D. or Pilot Name,
3. Aircraft Type,
4. Departure Point,
5. Route of Flight,
6. Destination,
7. Altitude,
8. Time of Departure, and
9. Time Enroute.

Once the briefer has this information, he/she should have enough information to give a thorough and hopefully an accurate pilot weather briefing.

The briefer should now begin gathering weather observations, forecasts, and maps from his/her computer system. Individual weather reports or forecasts should not be read unless, in the briefer's judgement, it is necessary to emphasize an important point or unless specifically requested to do so by the pilot.

II. ADVERSE CONDITIONS

The most important and possibly most difficult part of a briefing is gathering the information dealing with adverse conditions. This is done whenever atmospheric conditions are reported or forecast that might influence the pilot to alter his/her proposed flight. Conditions that are particularly significant are: low level wind shear, embedded thunderstorms, reported icing, volcanic activity, and frontal zones along the route of flight. Weather advisories--FA Flight Precautions, SIGMET's (WS), AIRMET's (FA), Convective SIGMET's (WST), Center Weather Advisories (CWA) and Severe Weather Watch Areas (AWW)--shall be given by stating the type of advisory.

AREA FORECASTS

Six Area Forecasts (FA's) are issued by the National Aviation Weather Advisory Unit (NAWAU) in Kansas City. These areas are: FA1, NORTHEAST; FA2, SOUTHEAST; FA3, NORTH-CENTRAL; FA4, SOUTH-CENTRAL; FA5, ROCKY MOUNTAIN; and FA6, WEST COAST.

The FA's of primary concern to the Southern Region are: SOUTHEAST (FA2)...Georgia, Florida, and Coastal Waters; SOUTH-CENTRAL (FA4)...rest of Southern Region excluding New Mexico; and ROCKY MOUNTAIN (FA5)...New Mexico.

Each FA consists of two sections: H for Hazards/Flight Precautions section, and W for the Synopsis and VFR Clouds/Weather section.

The AFOS pil for the Southern Region will be FA2H/FA2W for the MIA area; FA4H/FA4W for the DFW area; or FA5H/FA5W for the SLC area.

SIGMETS/AIRMETS

Federal Aviation Regulations distinguish between small and large aircraft. The In-Flight Weather Advisory program also recognizes that distinction by the issuance of two types of advisories: (1) Significant (SIGMET), and (2) Airman's Meteorological Information (AIRMET).

SIGMETS (Nonconvective) contain information on specified weather conditions of such severity that it should concern all aircraft. Each SIGMET automatically amends the appropriate Area Forecast (FA); therefore, SIGMET's will be issued whether or not the specified criterion was included in the FA. SIGMET's in Conterminous U.S. are valid for up to 4 hours.

Nonconvective SIGMET's relevant to areas within the conterminous U.S. will be issued by NAWAU when any of the following weather phenomena occur or are forecast over an area of at least 3,000 square miles.

a. Severe or extreme turbulence, or clear air turbulence (CAT), not associated with thunderstorms.
b. Severe icing not associated with thunderstorms.
c. Widespread dust storms, sandstorms, or volcanic ash lowering surface and/or in-flight visibility to less than 3 miles.
d. Volcanic eruption.

SIGMET's are found in AFOS files under WS#*, where # gives the area, i.e., WS2...SIGMET's for the Southeast U.S. and WS4...SIGMET's for the Southwestern U.S., and * is the alphanumeric designator--NOVEMBER, OSCAR, PAPA, QUEBEC, ROMEO, UNIFORM, VICTOR, WHISKEY, XRAY, and YANKEE are used for nonconvective SIGMET's. SIERRA, TANGO, and ZULU are not used because they are used for AIRMET's.

AIRMET's advise of weather phenomena less severe than that of a SIGMET, and are generally of concern to single-engine and light twin-engine aircraft but may be of significance to all aircraft. AIRMET's are routinely issued every 6 hours with a 6 hour valid time for the following weather phenomenon that is occurring or is forecast to occur within an area of at least 3,000 square miles:

a. Moderate icing
b. Moderate turbulence
c. Sustained wind of 30 knots or more
d. Ceilings less than 1000 feet and/or visibility less than 3 miles affecting over 50 percent of the area at any one time
e. Extensive mountain obscurement.

If none of these weather conditions are expected to occur, a negative statement is made in the AIRMET.

There are routinely three AIRMET's: SIERRA (S) for IFR conditions and mountain obscurations; TANGO (T) for turbulence and low level wind shear; and ZULU (Z) for icing. All three should be examined to see if AIRMET conditions are in existence.

AIRMET's are found in AFOS files under WA#S, WA#T, and WA#Z. The # gives the area, i.e., WA2 for the Southeast U.S., and WA4 for the Southwestern U.S.

CONVECTIVE SIGMETS

Convective SIGMET's are issued hourly (H+55) by NAWAU for thunderstorms and their related phenomena. Any Convective SIGMET (WST) issuance implies severe or greater turbulence, severe icing, and low-level wind shear (gust fronts, etc.); therefore, these conditions will not be specified in the advisory. A negative message will be sent each hour (H+55) when the forecaster determines that there is no need for a convective SIGMET in the region in question.

WSTs shall be issued when either of the following occurs and/or is forecast to occur for more than 30 minutes of the valid period regardless of the size of the area affected (i.e., including isolated):

- severe thunderstorm(s)
- embedded thunderstorm(s).

WSTs shall also be issued when, during the valid period, wither of the following criteria occur or are forecast to occur:

- a line of thunderstorms,
- an area of active thunderstorms affecting at least 3,000 square miles.

WSTs for severe thunderstorms may include specific information or tornadoes and/or occurrence of hail of 3/4-inch or greater diameter and/or wind gusts of 50 knots or greater. Tornadoes, 3/4-inch hail or wind gusts to 50 knots or greater alone are sufficient criteria for issuing a WST for severe thunderstorms.

Embedded thunderstorms, for the purpose of WSTs, are defined as thunderstorms occurring within and obscured by haze, stratiform clouds, or precipitation from stratiform clouds. WSTs for embedded thunderstorms are intended to alert pilots that avoidance by visual or radar detection of the thunderstorm could be difficult or impossible.

A line of thunderstorms is defined, for WSTs, as being at least 60 miles long with thunderstorms affecting at least 40 percent of its length.

Active thunderstorms are defined, for WSTs, as thunderstorms having a VIP level of 4 or greater and/or having significant satellite signatures and affecting at least 40 percent of the area outlined.

Convective SIGMET's can be found under the AFOS header WSTE for the Eastern U.S.; WSTC for the Central U.S.; and WSTW for the Western U.S. ALWAYS remember, whenever giving a Convective SIGMET during a briefing to give the number, i.e., Convective SIGMET 12E or Convective Sigmet 5C. Be sure it is the latest Convective SIGMET issued, and if it is close to H+55, and there is an area of thunderstorms, it would be wise to advise the pilot to get the latest information either on the ground before departure or while in-flight.

CENTER WEATHER ADVISORIES

A Center Weather Advisory (CWA), issued by NWS meteorologists at the Center Weather Service Units (CWSU) located at the 21 FAA Air Route Traffic Control Centers (ARTCC) around the country. The CWA is an unscheduled in-flight flow control, air traffic, and air crew advisory.

A CWA is not a flight planning product. It is generally a Nowcast for conditions beginning within the next 2 hours and also should reflect the weather conditions in existence at the time of issuance.

In the Southern Region, there are 7 CWSU's. These are: ZMA Miami, ZJX Jacksonville, ZTL Atlanta, ZME Memphis, ZHU Houston, ZFW Ft Worth and ZAB Albuquerque.

Center Weather Advisories can be found under the AFOS header by entering CWA000. Since CWA's are unscheduled, it would be best to check your individual PIL, i.e., P:CWA to see if there is an active CWA. During a briefing, it is important to give the center and number of the CWA. Example: ZHU CWA4. If your office does a large number of briefings, CWA's from adjacent centers should be in the AFOS database for easy recovery.

III. A SYNOPSIS

Provide a brief statement describing the type, location, and movement of weather systems and/or air masses which might affect the proposed flight. The synopsis may be combined with adverse conditions when it will help to more clearly describe conditions.

IV. CURRENT CONDITIONS

SUMMARIZE from all available sources, e.g., SAO's, PIREP's, currently reported weather conditions applicable to the flight. Unless the information is requested by the pilot, this element may be omitted if the proposed time of departure is beyond 2 hours.

V. ENROUTE FORECAST

SUMMARIZE from appropriate data, e.g., FA's, prognosis charts, weather advisories, etc., forecast conditions applicable to the proposed flight. Provide the information in a logical order, i.e., climb out, enroute, and descent.

VI. DESTINATION FORECAST

Provide the destination terminal forecast (FTA), including significant changes expected within 1 hour before and after the estimated time of arrival. It is very important that the briefer know how to read and understand the FTA.

VII. WINDS ALOFT

VIII. TEMPERATURES ALOFT (UPON REQUEST)

SUMMARIZE forecast of both winds and temperatures aloft for the proposed route. Interpolate wind directions and speeds along with temperatures between levels and stations as necessary. Winds and temperatures aloft are under AFOS header FD1/2/3 (where 1, 2 or 3 is the time period) FA1/2/3 or 4 (where 1, 2, 3 or 4 is the FA forecast area). An example is FD1FA2 which is a 12 hour wind/temperature aloft forecast for the southeast U.S.

The wind and temperature aloft forecasts are issued for the following levels: 3,000, 6,000, 9,000, 12,000, 18,000, 24,000, 30,000, 34,000 and 39,000 feet.

Wind direction is indicated in tens of degrees (two digits) with reference to true north, and wind speed is given in knots (two digits). Light and variable wind or wind speeds of less than 5 knots are expressed by "9900". Forecast wind speed of 100 through 199 knots are indicated by adding 50 to the coded direction and subtracting 100 from the speed. A forecast of 250 degrees at 145 knots is encoded as 7545. Forecast wind speed of 200 knots or greater are indicated as a forecast speed of 199 knots.

Temperature is indicated in degrees Celsius (two digits) and is preceded by the appropriate algebraic sign for the levels from 6,000 through 24,000 feet. Above 24,000 feet, the sign is omitted since temperatures are negative.

A forecast of 175849 at 30,000 feet would be read as: Wind 170 degrees...58 knots with a temperature of -49C.

IX. REQUEST FOR PILOT REPORTS

Solicit PIREP's for the effected areas when any of the following weather conditions exist, or forecast to occur:

a. Ceilings at or below 5,000 feet,
b. Visibility 5 miles or less reported at the surface or aloft,
c. Thunderstorms and related phenomena,
d. Turbulence of moderate intensity or greater,
e. Icing of light intensity or greater, and
f. Wind shear.

ABBREVIATED PILOT BRIEFINGS

Provide an abbreviated briefing when a pilot requests information to SUPPLEMENT mass disseminated data, update a previous briefing, or when the pilot requests that the briefing be limited to specific information. Conduct abbreviated briefings as follows:

1. When a pilot desires specific information only, provide the requested information. If adverse conditions are present or forecast, advise the pilot of this fact.

2. When a pilot requests an update to a previous briefing, obtain from the pilot the time that the briefing was received and necessary background information. To the extent possible, limit the briefing to appreciable changes in meteorological conditions since the previous briefing.

OUTLOOK PILOT BRIEFING

Provide an outlook briefing when the proposed departure is 6 hours or more from the time of briefing. Limit the briefing to forecast data applicable to the proposed flight.

When the proposed flight is scheduled to be conducted beyond the valid time of available forecast material, provide a general outlook and then advise the pilot when complete forecast data will be available for the proposed flight.

CONCLUSION

As you can see, giving a pilot briefing can be quite cumbersome. To do a proper job, extensive data gathering is necessary in order to compile the appropriate information. This takes time and experience.

It is hoped that this paper helps make pilot weather briefing an easier task.

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AVIATION WEATHER BRIEFING SERVICE TRAINING FOR THE FUTURE

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1. Background

The delivery of Aviation Weather in Canada has been the responsibility of Transport Canada (TC) for the past several decades. Prior to 1971, the Canadian Weather Service was a branch of the Transport department and, as such, was mandated to administer all weather related activities in Canada. In 1971 the Weather Service changed its name to the Atmospheric Environment Service (AES) and became part of the newly formed Department of Environment and Fisheries Canada. It soon became obvious that environmental concerns and fish did not make a good blend, so the department divided, with the AES remaining a major component of Environment Canada (EC). Today in Canada most weather related activities, including the production of all aviation forecast products, are the responsibility of the AES. The delivery of aviation weather however, remains the responsibility of Transport Canada.

For the first years after the division, AES continued to provide for the aviation weather requirements at Canadian airports through a cooperative effort by both departments. In 1974 a program to upgrade the weather knowledge and dissemination skills of Flight Service Specialists began. For 10 years the Meteorology Training Centre of AES delivered a 4 week training program in Aviation Weather Information Services (AWIS) at a rate of 10 courses per year, each course loaded to 16 operational specialists. By the early 80s, all Canadian Flight Service Stations, more than 100, were certified to provide the Aviation Weather Information Service.

The AWIS level of briefing service is based totally on information received in an alphanumeric format. Specialists were trained to locally produce graphic displays to depict current and forecast weather and to provide weather information for low and mid level aviation activities within 500nm. of the station. The FSS was directed to pass requests for weather information for flights in excess of 500nm. or for high level operations to a designated AES Weather Office staffed with Weather Service Specialists and equipped with a full array of alphanumeric and graphic products.

In the fall of 1988 the Transport Canada Aviation Group (TCAG) adopted a job analysis to reflect an upgrade in the aviation weather briefing knowledge and skill of the Flight Service Specialist to a level comparable to the AFS briefer. The premise of this initiative was to ensure that the FSS at selected locations could provide an interpretative level of consultation to the pilots who require a detailed analysis of weather, including specific advice concerning factors which could affect the safety and/or efficiency of aviation activities. The advantages of this reallocation of responsibility were seen to be:

a. The FSS are readily accessible by toll-free telephone;

b. The FSS can provide NOTAM and flight plan service from the same toll-free call;

c. FSS can provide VHF enroute briefings; and

d. TC could more easily manage the complex allocation of resources devoted to the delivery of the aviation weather service.

2. The Development

In June of 1989 TCAG requested AES to proceed with the development of a training program for FSS to address the knowledge and skill levels of the Aviation Weather briefing Services job analysis. The Meteorology Training Centre (MTC), a division of the AES Training Branch, was given the mandate to develop the course and to assist with establishing an equipped simulation facility for the training. As the AWBS job analysis had been developed from a selection of the AES Weather Service Specialists (WSS) job analysis, training objectives and materials from the AES training programs were selected for the course.

The recruitment standards for the AES briefer has always included mathematics and physics, at least to the high school level, and consequently training has always been designed to complement that background. There is no such requirement for FSS. In order to address the aviation orientation of the AWBS knowledge and skills inventory and to compensate for the trainee population lack of math and physics, considerable changes had to be made to the training materials, particularly in Theoretical Meteorology. Much of the material was modified to use more of a verbal description of meteorological concepts rather than the traditional mathematical approach.

As with all MTC training programs, as soon as materials are ready for print in one language, the process of translation to the second language begins. In the case of the AWBS course, materials were first developed in English and, because the first French serial was not scheduled to begin until September of 1990, there was sufficient time to run an English pilot course and fine tune the materials before the French version was finalized.

An operational model of an AWBS facility had not yet been developed at the time of the course development. The selection of products to be used for training and the determination, purchase and installation of cost effective systems to deliver these products to the AWBS simulation lab became a significant part of the development workload. The complexities of dealing with several divisions of a major federal department as well as several private sector agencies within a limited time frame and budget made for some anxious moments as deadlines approached.

The lab dedicated to AWBS training at TCTI occupies approximately 100 square meters designed to accommodate 12 trainees and up to 4 instructors. The lab is equipped with MIDS III terminals for alphanumeric data, an Alden printer for satellite imagery and a PC with

SPIES software linked to an ink jet printer to receive and print weather charts via the METSIS system. Only specified imagery and charts are selected from the full METSIS array for distribution and printing in the AWBS lab. Another PC is used to receive real time Radar imagery from the closest AES system located approximately 100km from Cornwall. The lab has an internal telephone system to link the 12 trainee positions to the instructor desks.

3. The Course

The AWBS training program concentrates on increasing the specialists knowledge in Theoretical Meteorology and skills in using alphanumeric and graphic products to provide an interpretative level of aviation weather services. The course spans 30 training days which is subdivided into the following training activities.

Subjects	Time (hours)
Theoretical Meteorology	60
Climatology	6
Radar Meteorology	11
Satellite Meteorology	10
Meteorological Data	26
Weather Services	25
Familiarization Visits	6
Simulated Operations and Evaluation	30
Administration	6
Total	180

Each training day is divided into three 80 minute blocks and one 120 minute block. The course combines classroom academic instruction with simulation exercises, ending with 5 days of simulated operations and evaluations. Knowledge areas are tested in the classroom setting and skills are evaluated during simulated operations. Most of the classroom activities occur between 0800 and 1200 whereas the afternoons are largely devoted to reinforcement exercises and simulations. Towards the end of the course, trainees are taken on a familiarization visit of the AES Quebec Weather Centre in Montreal. The Regional Weather Centres are to serve as the designated resource centre for FSS AWBS outlets.

4. The Training

The pilot AWBS course began in March of 1990. Since then there has been 3 serials delivered in English and, at the end of next week, the 4th French course will be completed. The courses are scheduled at a rate of 5 courses per year with a full loading of 12 trainees. French courses are generally not fully loaded due to fact that most candidates are representing only one region.

The AWBS course is, for many of the specialists, the first return to formal training for many years. Although the FSS Basic training program has a total of 63 training days devoted to Meteorology, much of that training is oriented towards weather observing skills. Meteorological theory is only covered at a very elementary level. Getting back to the classroom and nightly study has been difficult and somewhat intimidating for many AWBS trainees. The very sight of the Theoretical Meteorology reference has caused many moments of despair during the first days of each course.

The program however, is designed for training, not screening. A Training Program Plan guide book contains all the administrative and evaluation procedures of the course as well as all objectives for each subject. The guide is designed to lead the trainee through the material with space for notes following each objective. Progress tests are given to alert the instructional team and trainee to problem areas. Counselling and/or extra help is offered as soon as difficulties are identified. By the end of the first week, the atmosphere tends to become somewhat more relaxed but the program continues to demand considerable concentration and study.

The final academic test, which falls on day 24 of the course, marks the end of the heavy study period. The final days of the program are totally devoted to simulation, skill evaluation and familiarization, including the trip to the Weather Centre in Montreal. The skill evaluation can be a stressful time for some trainees however, the activities are such that after hours study is general minimal.

One of the rewarding features of this program is the motivation and enthusiasm that many of the trainees have clearly demonstrated for weather briefing. It would be stretching the truth a little to say that trainees develop a love for Theoretical Meteorology, however many clearly enjoy working with the products, explaining the daily features and discussing the details of weather. And they are good at it. The combination of a sound understanding of meteorology and close working relationship with the aviation community makes for an effective aviation weather briefer.

5. Conclusion

At present TCAG plans to upgrade one FSS facility to the AWBS level in each of the 6 regions in Canada. Site selection, communication equipment upgrade and local procedural changes are well underway to implement the service in the near future. The present rate of training would train sufficient specialists to staff these centres within the next two years. After that, a reduced training program to accommodate attrition and transfers will most likely continue with changing user requirements and technology advances making periodic adjustments to the course necessary.

The process of development and delivery of the AWBS training has been, and continues to be a cooperative effort of two major federal departments of Canada. The implementation of the AWBS program is resulting in a change to the existing Partnership, however, it is expected that both departments will continue to work together to meet the needs of the aviation community. The program to train specialists who can continue the tradition of providing an effective interpretative level of weather services easily accessible to the aviator in Canada, is a significant part of that partnership.

NATIONAL WEATHER SERVICE TERMINAL FORECASTS AND FEDERAL REGULATIONS

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1. INTRODUCTION

National Weather Service aviation products have taken a more important role to the national aviation industry since the Federal Aviation Administration (FAA) began a more strict enforcement of Chapter 121 of the Code of Federal Regulations. Current records indicate an average of nine hundred sixty flights per day are delayed or canceled. Seventy to eighty percent of those flight alterations are due to impending weather or FORECASTS OF IMPENDING WEATHER. In other words, bad weather is not the only element that can delay or cancel a flight, but even a FORECAST describing adverse weather at a destination airport can cause major problems.

The objective of this paper is to show how critical terminal forecasts are in day-to-day operations of the national aerospace system. This paper will expand upon the various federal regulations and critical minimums that control the national aviation system. National Weather Service forecasters should be cognizant of these rules. Furthermore, possible solutions to improve NWS products and service to the aviation community will be explored, by:

(1) Enumerating some of the more significant Federal Regulations which authorize the National Weather Service to issue forecasts and regulate the airline industry.

(2) Listing various aircraft approaches and critical weather minimums for a particular airspace.

(3) Relating specific terminal forecasts to these federal regulations and airport requirements, to show how important it is for NWS aviation forecasters to understand how their forecasts are an integral part of the national aerospace system. Special emphasis will be placed upon the use of conditional phrases in terminal forecasts.

(4) Offering some suggestions as to how the National Weather Service can improve aviation products and develop a method of in-house quality control of those products, increasing the expertise of NWS forecasters, and

(5) Stressing the importance of improvement of NWS products to the aviation community AND to the National Weather Service. Technological advances in communication and increased use of private sources for aviation information makes it imperative for the NWS to respond to the meteorological needs of the national aviation industry.

This paper serves to document some of the needs and shortcomings of the NWS aviation program. Hopefully, NWS personnel who oversee this program will realize how tenuous this program is with the user industry, even though it is mandated by the FAA.

2. FEDERAL AND NATIONAL WEATHER SERVICE GUIDELINES...THEIR EFFECTS

Every aircraft that soars through our nation's skies is carefully controlled by federal regulations. Recently, a change in the interpretation of some of these regulations has resulted in a more conservative attitude on the part of the FAA regarding the dispatching and flight of aircraft from one point to another.

The FAA has also been very specific in its requirements for weather reporting and information facilities by the air carriers. The FAA Code of Federal Regulations requires the aviation industry to rely on the National Weather Service or NWS-approved products for their operations. Federal Aviation Regulation (FAR) 121.101 states:

> "Each domestic and flag air carrier must show that enough weather-reporting services are available along each route to ensure weather reports and forecasts necessary for the operation...No domestic or flag air carrier may use any weather report to control flight unless, for operations within the 48 contiguous states and the District of Columbia, it was prepared by the U.S. National Weather Service or a source approved by the U.S. National Weather Service..."

The Federal Aviation Administration has issued a mandate to the airline industry for dispatching and flight operations advising them to plan for the worst-case scenario, rather than the best-case situation, as noted in the FAA Manual 8400.10. Chapter 7, Section 1, Paragraph 1407, titled "Policy on Conditional Phrases in Remarks Portion of Weather Forecast" states:

> "Weather forecasts provided by the National Weather Service (NWS) and other sources often have conditional phrases such as "occasional," "intermittently," "chance of," or "tempo" in the remarks portions of the forecasts. These phrases supplement the main body of the forecast by indicating the probability of changing conditions during the forecast period. These modifying phrases, used in the remarks portion of a terminal forecast (FT), indicate the weather conditions for an area within five nautical miles of a runway complex. Certain regulations concerning the selection of destination and alternate airports require that "weather reports or forecasts, or any combination thereof, indicate that the weather conditions will be at or above..." the minimum weather conditions specified in those regulations. The FAA's Office of Chief Counsel has consistently interpreted these regulations to mean that the WORST weather condition in any of the reports or forecasts used to control a flight movement is the controlling factor. These interpretations make the remarks portion of a forecast as operationally significant as the main body of the forecast. Therefore, it is FAA policy THAT THE WORST WEATHER CONDITION IN THE MAIN BODY OR THE REMARKS PORTION OF A TERMINAL

FORECAST, as well as any weather report used, is the controlling factor when selecting a destination or alternate airport."

The NWS policy on conditional phrases is much more general. The National Weather Service Operations Manual, Part D, Chapter 21, Section 5.2, states:

> "...Remarks are pertinent to an area within 5 nautical miles of the center of the runway complex and amplify or change elements described in the body of the forecast group. Within the limits specified in the following instructions, conditions described in remarks must be considered whether an amendment criterion has been met.
>
> It is recognized that situations occur which logically dictate using one or more terms in the remarks portion of a forecast group, however, these terms should be used sparingly and be as concise as possible. It should be noted that the FAA requires that the remarks portion as well as the body of the FT be considered by pilots and dispatchers in determining "legal" destinations, alternates, and fuel loads. This makes the content of remarks operationally more significant than the body of the forecast when they describe lower conditions..."

NWS policies need to be more specific, and perhaps include the aforementioned FAA policies from the FAA Manual 8400.10 in the Operations Manual.

Flight movements, take-offs, and landings have very detailed requirements, and each forecaster needs to know how his(her) forecasts and conditional phrases impact local and national air traffic flow. The purpose is not to "steer" his(her) forecasts, but to teach the forecaster how to advise the users what weather conditions can be expected during departure, flight, and arrival of the aircraft. Additionally, the forecaster must forecast the ceilings, visibilities, and other meteorological phenomena as accurately as possible during those times when the weather most affects the flights. Amendments of forecasts which have gone awry must be accomplished as quickly as possible when it becomes evident that the forecast is incorrect...even slightly. If the forecaster has the knowledge of the consequences of his/her forecast for the aviation community, he/she will be less apt to issue a "cover-yourself" conditional phrase just because his/her confidence factor is not one hundred percent. The major airport within the St. Louis Forecast Office area of responsibility is St. Louis Lambert International Airport. This airport is the hub airport of Trans World Airlines. Approximately eighty percent of the flights in and out of Lambert Field are with TWA.

In the remaining parts of this paper, examples of critical airport minimums and terminal forecasts will refer to Lambert Field. Forecasters from other areas will have different carriers and may have different minimum criteria at the airports within their forecast area of responsibility.

3. FEDERAL REGULATIONS REGARDING DISPATCH AND FLIGHT RELEASE

All air carriers are required to adhere to the Code of Federal Regulations. Chapter 121 of the Federal Regulations contains the major rules regarding release of flights from one location to another. A list of some of these regulations which are profoundly affected by terminal forecasts is included in Appendix C. The reader is advised to review these regulations prior to further reading, as these regulations will be referenced in the following sections.

4. TYPES OF AIRPORT APPROACHES, ASSOCIATED MINIMUMS AT LAMBERT FIELD

In this section, the following is a listing of various airport approaches and associated airport minimums for St. Louis Lambert International Airport. These approaches are categorized into four types: visual, staggered visual, circling, and instrument approaches. These approaches are defined as follows:

A. VISUAL APPROACH...under good weather conditions, visual approaches are used. The pilot must ba able to see the airport AND the aircraft ahead of him during the approach. Forty- five percent of the yearly operations are done in this configuration. Minimums includes no clouds below 4,000 feet and visibility at least 5 miles. Details of the airport capacity under this configuration are noted in Appendix A, Section 1. Aircraft can negotiate side-by-side arrivals and departures.

B. STAGGERED VISUAL APPROACH... used with minimum ceiling 3,500 feet and visibility 3 miles. Details of the airport capacity under this configuration are noted in Appendix A, Section 2. Thirty-five percent of yearly operations are under this configuration.

C. CIRCLING APPROACH...when ceilings are too low to permit visual approaches, a circling approach may be used. The aircraft uses some type of navigational aid to get under the cloud layer. The pilot then is able to see the airport, then circles around to the desired runway and lands. Minimum conditions include a minimum ceiling of 1,000 feet and visibility of 3 miles. This procedure is listed at Lambert Field but is never used. It would be more likely to be used at an airport that has an ILS only on one end of the runway, where surface winds were unfavorable to land on the ILS runway.

D. INSTRUMENT APPROACH...used when visual approaches cannot be conducted. Types of instrument approaches include:

ILS	Instrument Landing System
ILS/LDA	Combination using Instrument Landing System and Localizer Directional Aid
VOR	VHF Omnidirectional Range
NDB	Non-Directional Radio Beacon
LDA	Localizer-type Directional Aid
ASR	Airport Surveillance Radar
LOC	Localizer
LOC(B/C)	Localizer Back/Course

The ILS/LDA approach (See Appendix A, Section 3) is the most used instrument approach. About 10 percent of the yearly operations use this configuration.

The arriving aircraft use the ILS for vertical course guidance, and the LDA for left/ right course guidance, on simultaneous approaches. Once on the localizers they descend 4600 feet apart, and not exactly on course with the runways. The LDA ends at 2.6 miles from the end of the runway on "final". The pilot must have the airport AND the other aircraft in sight. He then performs a small S-turn and lines up with the runway. If the pilot cannot observe the runway at that moment, he shoots a "missed approach" and tries again.

When the aircraft are on the LDA approach, they follow the LDA while maintaining 4600 feet separation. Since the runways are 1300 feet apart, the aircraft will converge once the pilots have each other in sight. Minimums for the ILS/LDA approach are ceilings of 1,200 feet, or visibilities of 4 miles on Runway 12 or 5 miles on Runway 30.

Wind direction at Lambert Field is also critical with the ILS/LDA approach. If the prevailing wind direction is between 210 degrees and 330 degrees, the tower personnel can also use Runway 24 in addition to Runway 30. This is called "running simultaneous converging approaches", and allows smaller aircraft to land on Runway 24 short of the runway intersection, and thus increases airport arrival and departure capacity.

The ILS Approach is the second most often used instrument approach configuration (See Appendix A, Section 4). It is labor intensive, and requires a minimum of ten controllers to accomplish it. Airport acceptance rates are cut in half resulting in aircraft performing a "staggered approach". During the ILS approach, each aircraft are required to maintain a separation of three miles. One plane approaches the right runway, while the other accesses the left runway. Additionally, there must be a six mile separation between aircraft landing on the same runway. Minimums with the ILS-type approach are ceilings of 500 feet and visibilities of 2 miles.

When conditions lower to ceilings at or below 500 feet and visibilities two miles or less, all aircraft are aligned into single file. This approach lowers the acceptance rate even further (Appendix A, Section 4), with Non-Category 2 (NON-CAT 2) minimums, ceilings 200 feet and minimum visibilities 1/2 mile or Runway Visual Range (RVR) values of at least 1800 feet. RVR is the distance the pilot can see the high intensity runway lights from the touchdown zone. In contrast, "visibility" is the distance a person with 20/20 corrected vision can see ordinary lights at night or objects during the day. The RVR has a readout every minute, and is usually greater than the visibility. RVR values are appended to surface observations and are measured in hundreds of feet. For example, RVR 36 is defined as a Runway Visual Range of 3600 feet, and RVR10- implies a Runway Visual Range of below 1000 feet. "Non-Cat 2" is defined as any aircraft which does not have the instrumentation to make a Category II landing (defined below). Most aircraft are Non-Cat 2 aircraft.

The ILS is composed of three components: the Localizer, the Glide-Slope, and the Markers. The Localizer is the course guidance, usually along the runway centerline. The Glide Slope gives altitude guidance to the aircraft. The markers (the outer marker, middle marker, and inner marker) are radio aids that help the pilot identify exactly where he is located along the approach to the runway.

E. CATEGORY II OR III APPROACHES (ONLY RUNWAY 30R HAS THIS EQUIPMENT)

When weather conditions are too low for even ILS approaches, some of the wide- bodied aircraft maintain enough technology to land or take off with even lower minimums. Approach Charts used by the pilots contain "decision heights" (DH) or "minimum descent altitudes" (MDA). At these points during the approach, the pilot must see the required visual reference (either the runway in the daytime or runway lights at night). Each pilot AND aircraft is qualified to land at a certain minimum RVR value and MDA. If the RVR is out of service, minimum visibilities to land are usually 1/2 mile.

Typical minimums for CAT II and CAT III approaches include:

(1) RVR values of RVR 12 or 16 (1/4 mile and DH of 100 or 150 feet for CATEGORY II approaches, and

(2) RVR values down to RVR 6 and DH 50 feet for Category III approaches.

Besides the minimums set forth above, each company develops a set of Operations Specifications for each airport which is filed with the FAA. Terminal forecasts which exceed these specifications can also curtail flight activity for that airline. For example, TWA uses the following specifications, which they call "Ops Specs", for Lambert Field:

(1) TAILWIND RESTRICTIONS
The maximum tailwind, which is the average windspeed parallel to the active runway (the runway the aircraft are using), cannot exceed 10 knots.

(2) CROSSWIND LIMITATIONS
The crosswind component is the vector wind speed perpendicular to the active runway. For TWA, the maximum crosswind component varies between 29 and 35 knots, depending upon the aircraft type. For aircraft making a CAT II landing, the crosswinds cannot exceed 10 knots.

(3) PRECIPITATION RESTRICTIONS
TWA "Ops Specs" require no take-offs or landings during the occurrence of:

A. Heavy freezing drizzle (ZL+)
B. Moderate or heavy freezing rain (ZR OR ZR+)
C. Heavy wet snow (S OR S+)
D. Moderate or heavy thunderstorms (TRW, TRW+)

Take-offs are disallowed when: Standing water, slush, wet snow exceeds a depth of one half inch on the active runway.

Landings are not permitted when: Standing water, slush, wet snow exceeds a depth of one inch on the active runway.

5. TERMINAL FORECASTS AND THEIR RELATIONSHIP TO FEDERAL REGULATIONS

In light of the aforementioned regulations and critical airport minimums, this section will focus on how National Weather Service terminal forecasts affect take offs, flight movements, landings, and the dispatching requirements thereof.

FEDERAL AVIATION REGULATIONS 121.101 and 121.107 require dispatch offices to maintain adequate weather services to ensure that weather reports and forecasts will be available along the entire route of flight. The dispatcher must ensure legal planning of these flights, using current weather observations and terminal forecasts. Additionally, dispatchers must also keep abreast of up-to-the-minute weather conditions, particularly when changes may impact flight operations until the aircraft reaches the arrival gate.

According to FEDERAL AVIATION REGULATION 121.613, the dispatcher is restricted to release a flight only when the destination point is at or above landing minimums. Under minimum Non-CAT II conditions, the ceiling forecast is not as important as the visibility. For most aircraft a visibility 1/2 mile is the minimum allowed (see ILS Approach).

Suppose the following terminal forecast was in effect:

FT1 STL C0 X 1/2F

Non-CAT II aircraft can still operate using the single-file ILS approach. However, if the forecast was written as:

FT2 STL C0 X 1/4F 3014

The airport would be shut down for all aircraft except the CAT II or III aircraft due to a visibility forecast less than 1/2 mile. The CAT II flights would still be able to arrive and depart on Runway 30R. (See CAT II Approach above).

If the terminal forecast for St. Louis was:

FT3 STL C6 X 1F SLGT CHC C0 X 0F L-F

the visibility noted in the conditional language of this forecast would completely shut down the airport to all arriving and departing flights (FAR 121.613). This holds true even though the prevailing forecast conditions were well above minimums.

Ceilings and visibilities are not THE ONLY conditions for which the terminal forecasts can close the airport to incoming traffic. For example:

FT4 STL C2 X 1/4F 1312G22

Only CAT II aircraft would be allowed to land, due to visibilities being forecast less than 1/2 mile. However, at Lambert Field, only Runway 30R has CAT II instrumentation. Since the forecast wind direction is nearly parallel to the active runway, the "tailwind restriction" guidelines would shut down the airport (average tailwind speed would be in excess of 10 knots).

Crosswinds observed OR forecast can also shut down the airport. If the following terminal forecast was in effect:

FT5 STL C2 X 1/4F 2112

Then, this forecast would close the airport. In this case, ceiling and visibility forecast would allow a CAT II landing on Runway 30R. However, the crosswind component exceeds 10 knots (see Appendix B).

6. TERMINAL FORECASTS...ALTERNATE AIRPORT AND FUEL REQUIREMENTS

A. The Effect of Terminal Forecasts on Fuel Consumption

This section focuses on how faulty terminal forecasts cause spiraling fuel costs to the aviation industry. FAR 121.619 emphasizes the requirement for an alternate airport on the Dispatch Release if the destination observed AND forecast weather is not at least a ceiling of 2,000 feet and a visibility of 3 miles within one hour either side of expected arrival time. This is very important to major air carriers, because if an alternate IS required, FAR's 121.641, 121.643, and 121.645 specify a significant additional fuel supply to be carried aboard. In most cases, major airlines are under U.S. registry, and can operate in the U.S. and all foreign countries. They are identified as "flag carriers" in the Federal Regulations.

When alternate landing sites are required, jets must carry enough fuel to: 1) fly to and land at the airport to which it is dispatched, and 2) carry enough fuel to reach the most distant alternate, still retaining 30 minutes of fuel on-board. Using these guidelines, a total fuel consumption is calculated, based on normal cruising speeds. Then, an additional fifteen percent of the calculated fuel consumption is required to adhere to Regulation requirements.

The Manager of Operations for Trans World Airlines, Don Eick, stated that on a normal day there are 334 TWA flights into St. Louis. With forecast conditions below 2,000 feet and/or a visibility of less than 3 miles, FAR 121.619 would require those flights to carry an extra 2,000,000 pounds of fuel. To carry this amount of fuel, aircraft would burn 500,000 pounds of fuel (90,000 gallons) just to carry the extra weight! Since diesel fuel costs $.65 per gallon, TWA must spend about $60,000 per day to transport the additional fuel to adhere to this regulation. General aviation aircraft are affected even more, since many cannot navigate in poorer weather conditions. In general, CAT II flights can become very expensive, since CAT II-equipped alternate airports are often 250 to 350 miles away from the destination airport.

Multiplying these costs times the number of airlines at each airport, for five hundred or more major airports, the financial costs can easily result in millions of dollars each day. Besides the financial aspect of the loss, there are massive losses of precious natural resources, and untold hours of passenger inconvenience.

B. Alternate Airport Selection Based Upon Terminal Forecasts

Once it is determined that an alternate is needed (destination airport is less than 2000 ft or 3 miles) the dispatcher must select an airport that meets the alternate minimum. These minimums are usually 400 feet and 1 mile or 600 feet and 2 miles. Smaller airports might require alternate minimums of 800 feet and 2 miles or 1000 feet and 3 miles (Note FAR's 121.621, 121.623).

Consider a flight from New York to St. Louis. The terminal forecast for St. Louis:

FT6-1 STL C16 ovc 5H 1206

Ceilings are less than 2000 feet. Therefore, accordingly to FAR 121.619, an alternate airport is required. The dispatcher decides to use Springfield, Missouri (SGF) as the alternate, due to a snow storm further north. The Springfield forecast is:

FT6-2 SGF C9 x 4f 1207

Alternate minimums for Springfield are 600 feet and 1 1/4 miles. Suppose the flight is in progress, and the SGF terminal forecast is amended to:

FT6-3 SGF FT AMD 1 C5 X 2F 1207

According to FAR 121.625, the dispatcher will have to change the alternate airport while the aircraft is in flight, even though the weather at St. Louis did not change. If the amendment of the SGF forecast had been:

FT6-4 SGF FT AMD 1 C10 OVC 4F SLGT CHC C5 X 2F

the conditional phrase of this forecast would ALSO have required the dispatcher to change the alternate airport. Considering the current fuel on-board, if none of the nearby alternate airports meet alternate minimums, the aircraft will be required to stop for additional fuel prior to reaching the destination airport.

7. CENTRAL FLOW CONTROL MINIMUMS

The significant increase in air traffic flow in the National Aerospace System has created the need for a nationwide program to provide an orderly progression to the flight system. This section focuses on the central flow control system.

When ceilings at St. Louis are observed or forecast to go below 800 feet or visibilities below 3 miles, the Central Flow Control Facility in Washington D.C. can invoke a program limiting the number of flight operations for the various airports involved. This is accomplished by initiating a national ground delay program. Fuel costs and massive congestion are reduced when this program is activated. Aircraft are delayed at the departure airports and traffic is controlled both in the air and on the ground. (Other airports may have different minimums.)

8. CRITICAL AIRPORT MINIMUMS FOR ST. LOUIS

Critical weather conditions which affect St. Louis Lambert International Airport have been summarized into a one-page list (see Attachment B). Similar lists should be compiled for every major airport and be supplied to the National Weather Forecast Office with forecast responsibility for that airport.

9. RECOMMENDATIONS FOR NATIONAL WEATHER SERVICE ACTION ITEMS

The National Weather Service has found itself in a difficult position regarding the issuance of terminal forecasts and other aviation forecast products to the aviation industry. The NWS has rested in the shadow of the FAA mandate, thinking that effective and proper aviation information is being supplied to the nation. However, several presentations at the National Aviation Workshop told a different story. Pockets of disenchantment from several users have surfaced resulting in a crossover from receiving "free" NWS information to "paid" forecasts supplied by private interests.

A number of major airlines have embarked on the Enhanced Weather Information System (EWINS) program which collects, evaluates, and disseminates weather data, including the authority to issue weather forecasts for the control of flight movements (Baker, 1992). This is being done because the NWS is not supplying the quality forecasts that should be available with today's technology.

The National Weather Service needs to make some IMMEDIATE changes. The following are several recommendations for consideration:

RECOMMENDATION 1...Issue Specific Forecasts

Aviation forecasters should be familiar with airport minimums at each airport within the forecast area of responsibility. When critical weather conditions exist, they should write their forecasts as concise as possible. Conditional language is often over-used and should be introduced judiciously. Consider the following two terminal forecasts:

FT 7-1 STL FT C50 OVC 6R-F
3115 SLGT CHC C7 OVC 1/2L-F
FT 7-2 STL FT C7 OVC 1/2L-F

From an airline's standpoint, the two terminal forecasts above generate the same restrictions to the flight.

When conditions lower into the "critical value areas" forecasters should do their best to forecast exactly what they expect will happen, rather than state several possible conditions. If there truly is a "chance", forecast it. Do not issue a "cover-your-bases" forecast.

Jackson (1984) noted that United Airlines conducted an eight-month study of aviation forecasts written for two major airports. The study showed that, "Conditions requiring a weather alternate, and thus extra fuel, were being forecast at nearly twice the rate of actual occurrence."

RECOMMENDATION 2...Amend Out-Of-Tolerance Forecasts Quickly

Forecasts should be amended with haste when they are out of tolerance, especially when airport "critical values" are involved. Too often, forecasters review a forecast, noting that the body of the forecast is within tolerance. Even though the weather noted in conditional phrases are no longer needed, forecasters fail to amend the forecasts thus leaving the aviation industry in a quandary. In changing conditions, during worsening OR improving weather situations, time is of essence and amend promptly!

RECOMMENDATION 3...Improve Training

The Flight Service gives each briefer a four-month training course at the FAA Academy in Oklahoma City, followed by six to twelve months of intensive training on-station, before they are deemed qualified to brief pilots. In addition, each Area Flight Service Station has a full-time training staff of three individuals to work with the operational staff on-station. Staff members are required to attend ten to twelve days per year in formal training at the station.

The National Weather Service has initiated several training programs including the WSR-88D, the Science and Operations Officers Residence Course, and Professional Development Work Stations, as part of Modernization and Restructuring. It appears that WSR-88D-related items will be top training priority for the next two to three years. However, several presentations by the user aviation community at the December 1991 National Aviation Workshop stated that National Weather Service meteorologists are uneducated of the users' requirements. This point was further emphasized by the FAA and AOPA.

Since the FAA is funding the aviation portion of the NWS budget, and the AOPA gives very large sums of monies to the industry, the NWS should formalize a training program for its forecasting staff. The program should be developed with significant input from the airline industry, the AOPA, and the FAA. Training should be jointly funded from each of these users (FAA, AOPA). Additionally, the airline industry should assist and provide training so the forecasters acquire a view from the 'airlines' prospective. This training should be ACCOMPLISHED WITHOUT DELAY!

In addition, when a forecaster transfers to a new office, he(she) should be given time to visit each terminal forecast site and other FAA facilities (e.g. tower, Central Weather Service Unit, Air Route Traffic Control Center) which has responsibility for his(her) forecast area. The forecaster "needs to know" the his (her) area of forecast responsibility.

RECOMMENDATION 4...Change National Weather Service Forecast Policy

The National Weather Service should change the current policy in which aviation forecasts must be a reflection of the public forecasts. Aviation forecasters should be allowed to issue terminal forecasts which might at times become independent of public forecasts. However, coordination between the aviation and public forecaster should be common practice in any type of weather situation.

Here are some typical examples:

A. When the public forecasts indicate a "20", "30", or "40" percent chance for precipitation, conditional phrases are introduced into the terminal forecasts for coordination purposes. These phrases often include forecast conditions at or below 2000 feet and 3 miles, triggering the requirement for alternate airports. In addition, the aviation forecaster often keeps the conditional phrase in the terminal forecast for extended periods of time, when a much shorter period of time could be adequate.

B. In most situations when a watch is issued by the National Severe Storm Forecast Center, the public forecasts are updated. Terminal forecasts are also amended immediately with a forecast including "chc C5 X 1/2TRW+A G50" to indicate the possibility of severe storms for that airport. In most cases, that conditional phrase is valid for the entire period the watch is in effect. However, such conditions rarely occur for extended periods.

One final reason why terminal forecasts should become independent of the public forecast lends credence to the areal forecast of responsibility. The areal coverage for terminal forecasts is an area within five nautical miles of the airport (or about eighty square miles). In contrast, the areal coverage of a zone or local forecast is often two orders of magnitude larger.

This policy should be changed quickly to give the aviation forecaster the freedom to tailor the forecast to the runway complex without overstepping regional policies.

RECOMMENDATION 5...Develop a Method of Aviation Quality Control

Aviation products issued by NWS forecasters are rarely quality controlled, except for an occasional brief evaluation by the Lead Forecaster on-station. The National Weather Service needs to establish a method of quality control of the aviation products on a regular basis.

To solve the QC problem, each Region Headquarters should institute a plan whereby the Weather Service Evaluation Officer (WSEO) would continuously monitor aviation products within the region for a three-week period. The WSEO should call a particular office when a product is written incorrectly, or is not consistent with current weather or trends. Advantages of this type of quality control would:

1. Free the regional aviation meteorologist to accomplish more administrative duties and supervise the overall quality control program.

2. Provide forty weeks or more of monitoring of aviation products within each region.

3. Eliminate any possible personality conflict that can develop from continued on-station quality control.

Modernization and Restructuring will result in a host of new aviation forecasters with a very limited amount of aviation experience. A planning schedule of who will be monitoring aviation forecast products should be distributed the NWS forecast offices. Aviation forecasters could call that person, if a particular question arises. This will become even more necessary as the METAR code comes into its own across the U.S. Additionally, the WSEO on quality control duty might also serve as a contact point for the user industry to call to coordinate forecast problems.

RECOMMENDATION 6...Establish Time for a Roundtable Discussion and Interaction at the Next Aviation Workshop

Another national aviation workshop should be planned for the future with additional percentages of AOPA, FAA, and user input. The next workshop should include roundtable discussions to give attendees a chance to interact, make suggestions, and establish action items.

RECOMMENDATION 7...In-House Research Should Be Done by NWS Staff

Art Hansen, of FAA Weather Research and Development, stated that FAA has contracted a local university to do a research study on ceilings and visibilities. Contract monies should be retained by the National Weather Service in which climatological studies unique to aviation can be accomplished by staff members on-station. Forecasters need statistical answers to meteorological questions, including the probability of ceilings at various heights during thunderstorm activity at airports over various regions of the United States. NWS forecasts of ceilings and visibilities are often much too conservative, usually denoted with conditional phrases.

10. CONCLUSIONS

The National Weather Service needs to take immediate and drastic measures to assure that its services will be retained as the major aviation forecasting service for our nation. These changes cannot wait for the Modernization and Restructuring phase. They must begin immediately, and a public relations effort notifying the airlines and other aviation interests of these changes should be made.

At the National Aviation Workshop Steve Brown of AOPA asked the question, "Do we need to attack the weather?" The answer is "Yes!" At least, the National Weather Service needs to attack aviation ignorance and create a new sense of urgency with aviation forecasting quality.

Larry Sharron, meteorologist with the Atmospheric Environment Service in Ontario, Canada made a statement that everyone should remember as we re-evaluate the NWS position in aviation forecasting: "If you think training is expensive, try ignorance!"

The National Weather Service is spending large sums of monies to do research on future aviation forecasting techniques. While this is being accomplished, the users are scattering like sheep with no shepherd. NWS is the most capable organization in the nation to issue these forecasts, and the only organization with a federal mandate to do the job. NWS needs to show the aviation industry it is READY to make major strides to improve quality and service, so that the users can once again rely on its products.

With so many changes needed in a short time, it would take more than a handful of people at the national level can tackle these problems. Perhaps a committee of qualified people in the field could be selected to help identify problems and implement changes in how aviation products are released to the aviation industry.

Conditions are ripe for change. The National Weather Service must be an integral part of change, or it will not be a part of the new aviation industry. It is time to "attack the weather with all vigor".

11. ACKNOWLEDGEMENTS

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APPENDIX A
APPROACH MINIMUMS AND RUNWAY CONFIGURATIONS
FOR ST. LOUIS LAMBERT FIELD

1. SIMULTANEOUS VISUAL APPROACH...the most often used visual approach configuration (45 percent). On runway 30 configuration some commuter aircraft can utilize Runway 24 for arrival. This capability makes runway 30 the preferred configuration.

   A. Minimums.....Ceiling 4,000 feet   Visibility 5-6 miles
   Note...the actual minimums required to issue a visual approach based on FAA 7110.65 is Ceiling 1,900 feet and visibility 3 miles. However the STL Tower states that the minimums mentioned earlier are the actual minimums necessary to successfully utilize the visual approach configuration.

   B. Arrival runways: 12L/12R or 30L/30R
   Departure runways: 12L/12R or 30L/30R

   C. Arrival capacity (arrival-priority)
   Runway 30 configuration 84 per hour
   Runway 12 configuration 84 per hour

   D. Arrival capacity (departure-priority)
   Runway 30 configuration 60 per hour
   Runway 12 configuration 54 per hour

   E. Arrival capacity (50/50 arrival/departure mix)
   Runway 30 configuration 60 per hour
   Runway 12 configuration 54 per hour

2. STAGGERED VISUAL APPROACH...the second most often used approach (35 percent)

   A. Minimums.....ceiling 3,500 feet   Visibility 3 to 4 miles

   B. Arrival capacity (arrival-priority)
   Runway 30 configuration 60 per hour
   Runway 12 configuration 54 to 60 per hour

   C. Arrival capacity (departure-priority)
   Both 12 and 30 configuration 54 per hour

   D. Arrival capacity (50/50 arrival/departure mix)
   Both 12 and 30 configuration 54 per hour

3. ILS/LDA APPROACH...most often used instrument approach configuration (10 percent of total flights in this configuration). Additional staffing required.

A. Minimums.....ceiling 1,200 feet Visibility 4 miles
Arrival runways ILS 12R LDA/DME 12L or ILS 30R LDA/DME
Departure runways 12L/12R or 30L/30R...Aircraft separation should be: on runway 12, 4350 feet and runway 30, 4600 feet.

B. Arrival capacity (arrival-priority) 84 per hour

C. Arrival capacity (departure-priority) 84 per hour.

D. arrival capacity (50/50 arrival/departure mix) 60 per hour.

4. STAGGERED ILS...THE LOWEST NON -CAT 2 APPROACH...the second most-often used instrument approach configuration (5 percent of total flight operations are done in this configuration).

A. Minimums.....Ceilings 200 feet Visibility 1800 RVR

B. Arrival capacity (arrival-priority) 42 per hour

C. Arrival capacity (departure-priority) 36 per hour

D. Arrival capacity (50/50 arrival/departure mix) 42 per hour

Note, due to noise sensitivity of Runway 24 the tower does not normally use it for jet arrivals. This can, at times, reduce arrival capacity in a Runway 30 approach configuration.

APPENDIX B
Airline Critical Minimums at St. Louis

FILING WITHOUT ALTERNATES	
Visual Approach	4000 feet, 5 miles
Staggered Visual Approach	3500 feet, 3-4 miles
ALTERNATE MINIMUMS REQUIRED	
Observed or Forecast	2000 feet, 3 miles +/- 1 HR OF ETA
ILS/LDA APPROACH	1200 feet, 5 miles on Runway 30 feet, 4 miles on Runway 12
VFR	1000 feet, 3 miles
ATC INITIATES DELAY PROGRAMS IF:	800 feet, 3 miles
ALTERNATE MINIMUMS (AT ETA AT ALTERNATE AIRPORT)	
STL	400 feet, 1 mile
MCI	400 feet, 1 mile
COU	600 feet, 1 1/2 or 1 3/4 miles
SGF	600 feet, 1 1/4 or 1 3/4 miles
Other airports, commonly	400'-1 to 600'-2.
sometimes	800'-2 to 1000'-3
LANDING MINIMUMS	
Staggered ILS, NON-CAT II	200 feet, 1/2 mile
CAT II	100 feet, 1/4 mile or RVR 12
CAT III	50 feet, 1/4 mile or RVR 6

(Ceiling does not control for landing minimums)

TAILWIND	Maximum 10 Knots

CROSSWIND
Maximum crosswind component 20-35 Knots
Under CAT II conditions, Maximum is 10 Knots

PRECIPITATION RESTRICTIONS
ZL+, ZR OR ZR+, S OR S+ IF WET, TRW OR TRW+
(Cannot takeoff OR land with the above precipitation conditions)

APPENDIX C
Excerpts from the Code of Federal Regulations

Appropriate regulations which have been referenced in this paper are included in this section. Some portions of each regulation may not be included in interest of brevity, or because that portion of the regulation does not apply to this paper.

1. Federal Aviation Regulation 121.613
DISPATCH OR FLIGHT RELEASE UNDER IFR OR OVER THE TOP

"Except as provided in 121.615, no person may dispatch or release an aircraft for operations under IFR or over-the- top, unless appropriate weather reports or forecasts, or any combination thereof, indicate that the weather conditions will be at or above the authorized minimums at the estimated time of arrival at the airport or airports to which dispatched or released."

2. Federal Aviation Regulation 121.615
DISPATCH OR FLIGHT RELEASE OVER WATER: FLAG AND SUPPLEMENTAL AIR CARRIERS AND COMMERCIAL OPERATORS

Section A..."No person may dispatch or release an aircraft for a flight that involves extended overwater operation unless appropriate weather reports or forecasts or any combination thereof, indicate that the weather conditions will be at or above the authorized minimums at the estimated time of arrival at any airport to which dispatched or released or to any required alternate airport."

3. Federal Aviation Regulation 121.617
ALTERNATE AIRPORT FOR DEPARTURE

"If the weather conditions at the airport of takeoff are below the landing minimums in the certificate holder's operation specifications for that airport, no person may dispatch or release an aircraft from that airport unless the dispatch or flight release specifies an alternate airport located within the following distances from the airport of takeoff:

...for an aircraft having two engines...not more than one hour from the departure airport at normal cruising speed in still air with one engine inoperative.

...for an aircraft having three or more engines...not more than two hours from the departure airport at normal cruising speed in still air with one engine inoperative."

4. Federal Aviation Regulation 121.619
ALTERNATE AIRPORT FOR DESTINATION: IFR OR OVER THE TOP: DOMESTIC AIR CARRIERS

"No person may dispatch an airplane under IFR or over-the-top unless he lists at least one alternate airport for each destination airport in the dispatch release. When the weather conditions forecast for the destination and first alternate airport are marginal, at least one additional airport must be designated. However, no alternate airport is required if for at least 1 hour before and 1 hour after the estimated time of arrival at the destination airport the appropriate weather reports or forecasts, or any combination of them, indicate...

1. The ceiling will be at least 2,000 feet above the airport elevation, and
2. Visibility will be at least 3 miles.

For the purposes of the first paragraph of this regulation, the weather conditions at the alternate airport must meet the requirements of FAR 121.625. No person may dispatch a flight unless he lists each required alternate in the dispatch release."

5. Federal Aviation Regulation 121.621
ALTERNATE AIRPORT FOR DESTINATION: FLAG CARRIERS

"No person may dispatch an airplane under IFR or over-the-top unless he lists at least one alternate airport for each destination airport in the dispatch release, unless...

1. The flight is scheduled for not more than 6 hours and, for at least 1 hour before and 1 hour after the estimated time of arrival at the destination airport, the appropriate weather reports or forecasts, or any combination of them, indicate the ceiling will be:

    (a) At least 1,500 feet above the lowest circling MDA, if a circling approach is required and authorized for that airport; or,

    (b) At least 1,500 feet above the lowest published instrument approach, or 2,000 feet above the airport elevation, whichever is greater; and

    (c) The visibility at that airport will be at least 3 miles, or 2 miles more than the lowest applicable visibility minimums, whichever is greater for the instrument approach procedures to be used at the destination."

6. Federal Aviation Regulation 121.625
ALTERNATE AIRPORT WEATHER MINIMUMS

"No person may list an airport as an alternate in the dispatch or flight release unless the appropriate weather reports or forecasts, or any combination thereof, indicate that the weather conditions will be at or above the alternate weather minimums specified in the certificate holder's operation specifications for that airport when the flight arrives."

7. Federal Aviation Regulation 121.629
OPERATION IN ICING CONDITIONS

"No person may dispatch or release an aircraft, continue to operate an aircraft en route, or land an aircraft when in the opinion of the pilot in command or aircraft dispatcher, icing conditions are expected or met that might adversely affect the safety of the flight. No person may take off an aircraft when frost, snow, or ice is adhering to the wings, control surfaces, or propellers of the aircraft.

EWINS (ENHANCED WEATHER INFORMATION SYSTEM)

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1. INTRODUCTION

Within the past two years, the Federal Aviation Administration has introduced to commercial aviation something called EWINS, which stands for Enhanced Weather INformation System. It is a system for gathering, evaluating, and disseminating weather data, including the authority to issue weather forecasts for the control of flight movements. EWINS helps an airline to make quick, flexible, and operationally efficient responses to changing meteorological conditions.

Recent interpretations of the Federal Aviation Regulations would prohibit an airline from operating a flight to an airport that had a terminal forecast with a "SLGT CHC" of conditions below landing minimums, regardless of the current conditions or trends. From the perspective of the users, it often seems that the National Weather Service uses conditional language in terminal forecasts in lieu of frequent updates. This can and does severely hamper airline operations, even when actual observations show that the weather is well above minimums.

With an EWINS, any EWINS-certified dispatcher or meteorologist can use current observations, trends, and their meteorological knowledge and experience to issue a forecast for a flight. Historically, a number of airlines have been allowed to let Dispatchers make their own forecasts, so this is nothing new. What is new is the specific framework whereby airlines can do this, namely EWINS. Before getting into the specifics, here is some background information regarding how airlines and other commercial aviation operators have to use available weather information.

2. BACKGROUND INFORMATION

Federal Aviation Regulation 121.613 is one of several regulations that have similar language regarding the use of weather reports and forecasts.

> "...NO PERSON MAY DISPATCH OR RELEASE AN AIRCRAFT FOR OPERATIONS UNDER IFR OR OVER-THE-TOP, UNLESS APPROPRIATE WEATHER REPORTS OR FORECASTS, OR ANY COMBINATION THEREOF, INDICATE THAT THE WEATHER CONDITIONS WILL BE AT OR ABOVE THE AUTHORIZED MINIMUMS AT THE ESTIMATED TIME OF ARRIVAL AT THE AIRPORT OR AIRPORTS TO WHICH DISPATCHED OR RELEASED."

Historically, different airlines and commercial operators have had different interpretations on just how this regulation was to be applied. Even within the FAA, different FAA inspectors have had differing interpretations. Thus, some airlines were allowed to modify forecasts based on current observations and trends; others were not.

The FAA has recently issued an Inspector's Handbook in an attempt to standardize government policies. Here is what it has to say about this FAR:

> "THE FAA'S OFFICE OF CHIEF COUNSEL HAS CONSISTENTLY INTERPRETED THESE REGULATIONS TO MEAN THAT THE WORST WEATHER CONDITION IN ANY OF THE REPORTS OR FORECASTS USED TO CONTROL A FLIGHT MOVEMENT IS THE CONTROLLING FACTOR."
>
> "THESE INTERPRETATIONS MAKE THE REMARKS PORTION OF A FORECAST AS OPERATIONALLY SIGNIFICANT AS THE MAIN BODY OF THE FORECAST."
>
> "THEREFORE, IT IS FAA POLICY THAT THE <u>WORST</u> WEATHER CONDITION IN THE MAIN BODY <u>OR THE REMARKS PORTION</u> OF A TERMINAL FORECAST, AS WELL AS ANY WEATHER REPORT USED, IS THE CONTROLLING FACTOR WHEN SELECTING A DESTINATION OR ALTERNATE AIRPORT." (Underline mine)

2.1 Impact On Terminal Weather Forecasts

This means that any terminal forecast that uses conditional language such as CHC, SLGT CHC, or OCNL followed by zero visibility can shut down an airport. All airlines, even with the most advanced equipment, require at least some visibility above zero to land. But with a forecast of below minimums visibility, no airplane can legally begin the flight.

Some of the larger airlines have meteorology staffs that make their own forecasts, but the rest would normally have to cancel, delay, or divert a flight to that particular destination.

2.2 Weather Information System

The FAA requires that all commercial airlines and operators have a Weather Information System for gathering and disseminating meteorological data. The FAA Inspector's Handbook goes on to list the basic requirements of this system. Alphanumeric data would include such things as Terminal Forecasts, Winds and Temperatures Aloft, Surface Observations, Notices to Airmen, AIRMETs, SIGMETs, Convective SIGMETs, Pilot Reports, Center Weather Advisories, and Radar Reports.

The basic required weather charts would include the Surface Analysis and Surface Progs, Radar Summaries, the Severe Weather Outlook, Wind and Temperature Progs at various Flight Levels, Weather Depiction charts, the Freezing Level chart, Constant Pressure charts, the High Level Significant Weather Prog, and the Tropopause Height/Vertical Wind Shear chart.

2.3 Adverse Weather Phenomena Reporting and Forecasting Subsystem

Passenger-carrying airlines have some additional requirements so as to avoid such things as thunderstorms, clear air turbulence, and low altitude windshear. The FAR's require commercial passenger-carrying airlines to have an FAA-approved Adverse Weather Phenomena Reporting and Forecasting Subsystem. The FAA Inspector's Handbook says:

> "THESE SUBSYSTEMS MUST INCLUDE FORECASTING ABILITIES WHICH ARE AT LEAST EQUAL IN CAPABILITY TO GOVERNMENT WEATHER SYSTEM FORECASTING ABILITIES."

3. EWINS

Those are the basic requirements on commercial operators. EWINS has requirements over and above the basics just mentioned. EWINS is not mandatory, but any airline or commercial operator can apply for EWINS certification if they wish to gain the advantages that it can bring.

To qualify for an Enhanced Weather Information System, there must be advanced technical capabilities. This could include such things as dial-up radar, infrared and visible satellite imagery, and lightning detection. The FAA must approve such a system before it can be used as an EWINS. Also, it must handle ordinary weather conditions as accurately as adverse weather phenomena. The FAA Inspector's Handbook says:

> "AN EWINS USES REPORTED AND FORECAST WEATHER CONDITIONS NOT ONLY TO AID IN CONTROLLING DAILY FLIGHT MOVEMENTS, BUT ALSO TO PERMIT SHORT AND LONG-TERM OPERATIONAL PLANNING FOR ENHANCING AN OPERATOR'S CAPABILITY TO PROTECT SCHEDULES AND TO USE EQUIPMENT AND PERSONNEL WITH MAXIMUM EFFICIENCY."

The basic idea is to help an airline make quick, flexible and operationally efficient responses to changing meteorological conditions. Here are some quotes taken from the FAA's Inspector's Handbook, regarding the use of EWINS.

> "FLIGHT MOVEMENT FORECASTS (FMF) ARE OFFICIAL WEATHER FORECASTS WHICH CONTROL SPECIFIC FLIGHT OPERATIONS FOR A PARTICULAR OPERATOR."

> "AN AVIATION METEOROLOGIST OR A DISPATCHER WITH FLIGHT MOVEMENT FORECAST AUTHORITY MUST CONTINUOUSLY BE ON DUTY WHEN ANY FLIGHT OPERATIONS ARE IN PROGRESS."

> "PROPERLY TRAINED AND QUALIFIED AVIATION METEOROLOGISTS AND DISPATCHERS WITH FMF AUTHORITY WHO OPERATE AN EWINS MAY BE AUTHORIZED TO PREPARE AND ISSUE FLIGHT MOVEMENT FORECASTS."

> "BASED ON CONCLUSIONS DERIVED FROM EWINS DATA, AUTHORIZED PERSONNEL MAY PREPARE AND ISSUE FLIGHT MOVEMENT FORECASTS... TO CONTROL FLIGHT MOVEMENTS."

Further requirements include an EWINS Policy and Procedure Manual, a training program with at least the minimum specified curricula, quality assurance procedures, work facilities and equipment, and back-up capabilities to provide uninterrupted operation should any single component of the system fail.

UPS received EWINS approval in December of 1989, becoming the very first airline to operate under EWINS. Since that time at least 3 other airlines have become EWINS-approved, and several more have requested approval.

As of December, 1991, UPS has a total of 16 individuals who are authorized to issue Flight Movement Forecasts. 15 are Dispatchers, some of whom have over 20 years of experience. Collectively, they average 11.5 years of Dispatching experience. In addition, UPS has a Meteorologist who has 8 years of professional experience as a forecaster and meteorology instructor.

4. EXAMPLES

Following are two examples of Flight Movement Forecasts and how they are used at UPS. First is a recent example of a flight operating from Louisville to Atlanta. The flight is scheduled to arrive at 1530 UTC, and the required landing minimums at Atlanta are 1/2 mile visibility.

ATL FT 140808 C5 BKN 50 OVC 4RW-
OCNL -X 5 SCT C12 BKN 2F
CHC C2 X 1/2L-F. 12Z C3 OVC 2F
OCNL 1RW- CHC C1 X 1/4L-F. 16Z
C12 BKN 5F CHC 2TRW. 21Z 25
SCT C80 BKN CHC C25 BKN 3TRW.
02Z MVFR CIG F..
ATL RS 0950 M11 BKN 35 OVC 4R-F
158/71/70/1604/003
ATL RS 0850 5 SCT M70 OVC 4R-F
158/71/70/3006/003/ 70704 172/

Note that the forecast at ETA (Estimated Time of Arrival) calls for 2 miles in fog with occasional 1 mile in light rainshowers and a chance of 1/4 mile in light drizzle and fog. That chance term puts it below legal minimums. Legally, without EWINS this flight would have cancel, delay, or reroute to another airport based on this forecast.

However, the current observation for Atlanta shows the visibility holding at 4 miles in light rain and fog. The Dispatcher looked at the trend over the past several hours at Atlanta and surrounding stations, along with other meteorological information. He concluded that 1/4 mile would not occur at the ETA, so he decided to issue a Flight Movement Forecast, as shown.

The Dispatcher writes in the Flight number and date, along with the destination city code. A valid period is listed, along with his forecast that visibilities would be no worse than 1/2 mile. This is now a legal forecast for the operation of this flight to Atlanta.

FLIGHT MOVEMENT FORECAST (FMF)

FLIGHT NUMBER/DATE: 2931/14AUG CITY: ATL

ISSUED BY: SCHEITER

VALID TIME: 1200-1600 Z

FLIGHT MOVEMENT FORECAST: C3 OVC 2F OCNL 1RW- CHC C2 X 1/2L-F

TERM TIMES: 1538 / 1544 Z

NOTE: ATTACH THE FOLLOWING INFO:

1) NATIONAL WEATHER SERVICE FORECAST
2) A.R.T.R.
3) SEQUENCE WEATHER

...PLEASE FORWARD TO FLIGHT CONTROL SHIFT MANAGER...

For documentation purposes, the Dispatcher must attach to this Flight Movement Forecast the National Weather Service forecast, the ARTR (Amend Release to Read), and the actual weather observations. These are retained for 90 days.

Here is the ARTR that the Captain received from the Dispatcher that contained the Flight Movement Forecast.

```
* * * * * * * * * * * * FLIGHT RELEASE AMENDMENT * * * * * * * * * * * * *
CAPTAIN: ATTACH TO THE FLIGHT RELEASE OF
FLT UPS2931/14 ONT-ATL
ARTR-1
ATL FMF 12Z C3 OVC 2F OCNL 1RW- CHC C2 X 1/2L-F TIL 16Z..
ISSUED BY SCHEITER

BALANCE RELEASE SAME.
FLIGHT CONTROL DISPATCHER/DUNN            /1018Z
.......................................................................
. NOTICE: THIS ARTR VALID ONLY WITH CAPTAIN'S CONCURRENCE. FLIGHT    .
.         DISPATCHER MUST BE ADVISED OF CAPTAIN'S CONCURRENCE PRIOR  .
.         TO DEPARTURE OF FLIGHT.                                    .
.......................................................................
```

A Flight movement forecast is all that is legally required to operate a flight. However, UPS goes one step further by issuing an ARTR, which means "Amend Release To Read." This allows the Captain a voice in the decision so that the Captain must indicate concurrence before the flight is allowed to operate. If the Captain does not concur, the flight does not operate.

Here is what actually happened. The flight landed with visibilities well above landing minimums, as reported visibilities were between 2 and 2 1/2 miles.

ATL SA 1451 8 SCT M65 OVC 21/4VR-F
173/69/65/2007/007/ VSBY 2V2
1/2/21052 172/

Here is another example for Ontario, California. Again, landing minimums are 1/2 mile visibility. At 1207 UTC Estimated Time of Arrival, the forecast calls for 1/2 mile in fog and haze with occasional zero visibility.

ONT FT 040202 CLR. 12Z C2 X 1/2FH
OCNL C0 X 0F. 16Z -X 3FH. 20Z MVFR
H..
ONT SA 0546 CLR 10 67/60/0000/991
ONT SA 0451 CLR 20 68/59/2308/990
ONT SA 0346 CLR 20 74/59/2910/989

However, the current observations show rather high visibilities, and in looking over the situation, the Dispatcher did not think there was going to be a problem at ETA. Here is the Flight movement forecast she issued, valid from 1100 to 1300 UTC.

FLIGHT MOVEMENT FORECAST (FMF)

FLIGHT NUMBER/DATE: UPS 1918/04 OCT 91 CITY: ONT

ISSUED BY: C PIERSON

VALID TIME: 1100-1300 Z

FLIGHT MOVEMENT FORECAST: CLR

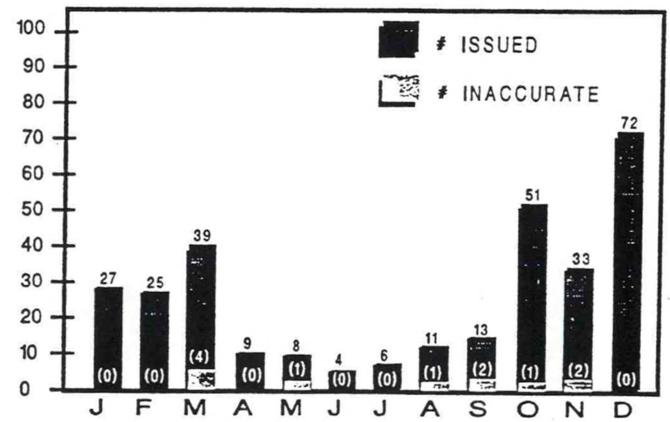
Here's what really happened. The flight landed with the following weather report:

ONT SA 1147 CLR 7 66/50/000/984/H
ALQDS

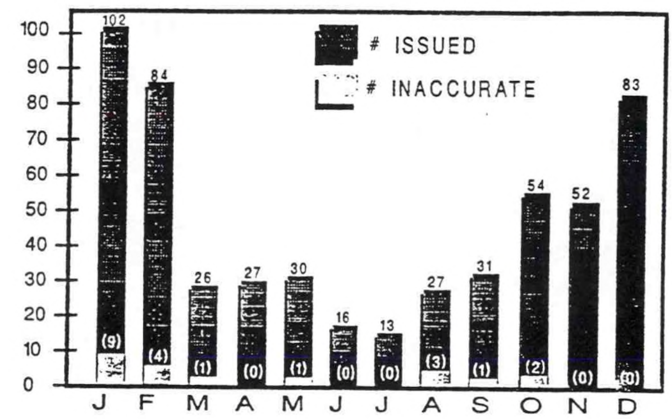
5. EWINS VERIFICATION

How well has EWINS worked over the last 2 years? Here are the statistics for the first two years of operation. It shows month by month the number of Flight Movement Forecasts issued. Not as many Flight Movement Forecasts were issued during the summer months when weather is generally better than during the rest of the year. At the bottom in parentheses is the number each month that were inaccurate. An inaccurate Flight Movement Forecast is defined as one in which the flight did not have landing minimums when it arrived over the destination so that it could not land.

1990 EWINS FLIGHT MOVEMENT FORECASTS



1991 EWINS FLIGHT MOVEMENT FORECASTS



It should be noted that EWINS does not give blanket authority to modify NWS forecasts. The person issuing the Flight Movement Forecast must be able to differentiate between those situations that really could go below minimums versus those that are very unlikely to go below minimums. Whenever the Dispatcher agrees with the NWS forecast that the weather could go below minimums, no Flight Movement Forecast is issued. However, if based on current observations and trends the Dispatcher believes the weather will stay above minimums, a Flight Movement Forecast is issued and its accuracy verified as part of UPS's quality assurance program.

6. SUMMARY

Summing up the first two years of EWINS operation at UPS, a total of 843 Flight Movement Forecasts were issued. Of those, 811 were accurate, giving an accuracy rate of 96.2%. This represents 811 flights that were not delayed, canceled, or rerouted to another airport, and were able to operate normally due to EWINS. Looking at this from a business standpoint, this represents over 4 million packages that otherwise might not have been delivered on time.

EWINS allows UPS to plan flight operations with weather information that is more current and more accurate, allowing the completion of more arrivals on time with no compromise of safety. EWINS provides UPS the capability to better meet the needs of its customers, enhancing UPS's reputation for being the "tightest ship in the shipping business."

Session 6.3

PRELIMINARY RESULTS OF THE ENHANCED TERMINAL FORECAST RISK REDUCTION AT DENVER, COLORADO

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1. INTRODUCTION

The requirement for up-to-date, high resolution, short-term aviation forecasts for use in aviation terminal operation has long been recognized. Terminal forecast users have indicated that they require forecasts to be issued more frequently with higher resolution in the short-range (0-6 hours) portion of the forecast. Users have also indicated that amendment criteria should reflect operational procedures and critical values whenever possible. Several segments of the aviation community have also expressed a need for specific element forecasts for the full period covered by aviation terminal forecasts.

It is believed that new technology, which will be available at Weather Forecast Offices (WFOs) after the Modernization and Associated Restructuring (MAR) of the National Weather Service, will provide forecasters with the opportunity to provide the services discussed above. To evaluate the risks associated with providing these services, a risk reduction activity was conducted at WSFO Denver, Colorado, during the period January 16, 1991 through November 26, 1991. WSFO Denver was chosen as the location for the activity due to the high temporal and spacial observational data sets and advanced processing and display capabilities of the DAR3E-II system in use at the station. The office also has access to doppler radar information from the Mile High radar.

This paper will briefly discuss some preliminary results of the risk reduction. A complete report on the results of the activity will be completed by spring 1992.

2. OBJECTIVE OF THE RISK REDUCTION

There were several objectives to be achieved during the risk reduction. They were: evaluate forecaster workload, evaluate advanced workstation capabilities as they related to the EFT, determine value added by the EFT, evaluate user perception of the EFT, and evaluate the effect of change in amendment criteria.

3. TRAINING

All forecasters at WSFO Denver had training and experience working on the DAR3E-II workstation before the beginning of the risk reduction. All of the forecasters were experienced in issuing terminal forecasts, however several of the journeyman forecasters were relatively new to the Denver area at the beginning of the risk reduction. All forecasters also had training on interpretation of the doppler radar data before the activity began. The forecasters were provided with guidelines on the format, content, and amendment criteria for the EFT and issued practice forecasts before the risk reduction began. Before the activity started the DMIC at Denver certified that the staff was sufficiently prepared to issue EFTs.

4. FORMAT OF THE RISK REDUCTION

WSFO Denver staffed five aviation forecast shifts per day, providing aviation forecast double coverage for 16 hours. Between the hours of 10:00 p.m. and 6:00 a.m., one aviation forecaster issued both the conventional and enhanced terminal forecasts. During the rest of the day one forecaster was responsible for the conventional forecasts, while the other concentrated on only the EFTs. The intent of this work distribution was to provide the EFT forecaster with an environment in which it was possible to determine the exact workload, equipment, and data sets required to produce the EFTs.

The structure of the EFT was somewhat different from conventional terminal forecasts. The changes were made to attempt to better satisfy identified terminal forecast user requirements. Some of the major changes in structure are listed below.

The first three hours of the EFT were specifically forecast without the use of probability terms. To provide increased temporal resolution during hours 0 through 3 in the EFT, forecasters were encouraged to indicate forecast change groups to the nearest 15 minutes. The changes were made in an attempt to get forecasters to provide more specific short range forecasts with less variable terms and wide range forecasts in that time period.

Hours 3 through 24 were specifically forecast and the use of conditional terms was permitted during that time period. It should be noted that this was a change from the conventional FT in which hours 18 through 24 are an outlook rather than a specific forecast.

Change groups (new forecast periods) were added to the EFTs when significant changes in forecast conditions were expected to occur. Each forecast change group began on a new line.

The amendment criteria for the EFT was adjusted to reflect observed or forecast changes which directly affect aircraft operations. Forecasts were amended when the observed or forecast weather changed category, i.e., IFR to LIFT, etc. An additional amendment threshold was added for ceilings of 200 feet and/or visibilities of one-half mile since those values are representative of minimums for operations at many airports.

5. ISSUANCE TIMES AND VALID PERIODS

Core EFTs were valid for a period of 24 hours and issued one-half hour before the beginning of the valid period. The valid periods during MST began at 05 UTC, 11 UTC, 17 UTC, and 23 UTC. Scheduled updates of the EFT were required whenever one of the following conditions occurred: the current core forecast had a first period less than three hours long (this eliminated old forecasts for time which had already passed), a probability term was used before the sixth hour of the core forecast, or expected weather conditions differed from what was forecast. The ending time of the forecast period was not extended at the scheduled or non-scheduled update times.

6. PRELIMINARY OBSERVATIONS

While a full analysis of the risk reduction results has not yet been completed, some preliminary observations are presented here.

A. Forecaster Workload

Interviews with forecasters involved in the risk reduction indicated that the workload associated with the three EFTs in the Denver area was manageable. On quiet weather days the forecasters had a considerable amount of free time which was utilized for professional development and research work. On rapidly changing weather days the forecaster was pressed to keep up with the forecast updates. It was the consensus of the forecasters that the maximum EFT workload which would be handled by one forecaster with a DAR3E-II type workstation would be three to six terminals.

B. Workstation Capabilities

Integration of data sets was critical to providing the resolution desired in the EFT. The DAR3E-II workstation provided this ability. The forecasters were universal in their stated need for two graphic and one alphanumeric screens for support of the EFT effort. The perception of the forecasters was that the most frequently used products in the EFT activity were the doppler radar reflectivity and velocity displays, the meso-net surface observations, and the satellite graphics. It was interesting that the meso-net surface observations were one of the most frequently used tools in this activity.

C. Scientific Value-Added by the EFT

Preliminary verification results for March and April 1991 showed that the Denver forecasters did not add to the accuracy of the EFT forecasts. Verification numbers were no better, and possibly a bit worse than previous samples for the same terminals in previous years. There are several possible reasons for these early results. Many of the forecasters were new to the Denver area and may not have been familiar with the local topographical effects. It is also possible that in trying to add resolution to the forecasts, and eliminate the hedging with a lack of probability terms, the forecasters may have missed more forecasts than when they were permitted more frequent use of variability and probability terms. It will be interesting to see whether this trend continues when the final verification is completed.

Going into the risk reduction there was a great deal of discussion concerning the ability of the forecasters to provide specific forecasts for the 18 to 24 hour time period. Interviews with the forecasters indicated that most forecasters felt that they did have skill in providing those specific forecasts. While the skill was not perceived at the same level as short range forecasts, the forecasters did feel that they could add value to the current outlook forecast by providing specific forecasts.

The forecasters also felt that there was value added to the terminal forecasts by the more frequent issuances, and the required updates. They felt that these requirements forced them to make changes to the forecasts that didn't require updating due to the amendment criteria. In many instances these changes, due to observed or changed forecast trends, made the forecasts more up-to-date.

D. User Perception of the EFT

Preliminary user perceptions were obtained through interviews with several FAA Flight Service Station employees in Denver, and from comments received from other Flight Service Stations and private pilots. Virtually all of the early user comments with respect to the EFT were positive. The number one positive comment was concerning the format of the EFT. Almost all people interviewed, and the written comments, stated that the users liked the new format with each change group beginning on a new line. This made the product easier to user. In general, the forecasters shared this view stating that the new format made updating easier, and that the EFTs were easier to read.

The users, especially the FAA personnel, were very pleased with the 18 to 24 hour specific forecast. They felt that the accuracy of that forecast period was adequate to fill their needs. The briefers stated that this aspect of the EFT was more important to them than the specificity in the early part of the forecast since much of their workload is in providing planning outlooks. Several briefers stated that they felt much more comfortable with the NWS 18 to 24 hour forecast than they did in making their own interpretation of the conventional categorical outlook forecast.

All early user comments indicated satisfaction with the more frequent issuances of the EFTs. For briefing purposes this provided FAA personnel with longer forecast periods. With conventional terminal forecasts there are times when the period covered by a forecast drops to 15 hours, while with the EFTs this period never drops to less than 18 hours and frequently is 21 hours or more.

Contrary to early verification statistics, the users perceived the EFTs to be more accurate than the conventional FTs. Its quite likely that the more frequent issuances and scheduled updates led to this perception. The users felt that forecasters were issuing better amendments and that the forecasts were more representative of the weather. They noticed the greatest improvement in perceived accuracy during the early periods of the forecasts when there were less variability and probability terms. It is interesting that while the NWS was unable to demonstrate a significant improvement in forecast skill, some user segments perceived the forecast product to be better. It remains to be seen if the major airline operations people share this perception of improved accuracy as it relates to their short range planning activities. All early user comments indicated that the accuracy of the 18 to 24 hour forecast was sufficient to satisfy their needs.

E. Effects of Change in Amendment Criteria

The early reviews of the change in amendment criteria were mixed. The users felt that the changes were good, and led to forecasts being more useful operationally. Some comments were made that amendment criteria for very low ceilings and visibilities should be even more strict, possibly being site specific based upon local airport minimums. The forecasters were very apprehensive about the new criteria at the beginning of the risk reduction. As the activity progressed some of that apprehension disappeared as forecasters became more comfortable with the change in criteria. However, several forecasters were unhappy with the amendment criteria in the lower visibility and ceiling range. They felt that they did not have the skill necessary to meet the requirements, especially in the range of ceilings below 500 feet. It will be interesting to see if verification results bear out the forecasters concerns. This aspect of the EFT needs to be explored further to fit the user needs more with the forecasters measured abilities.

7. SUMMARY AND CONCLUSIONS

Preliminary observations from the EFT risk reduction indicate that the NWS is moving in the right direction in trying to better serve the users through the EFT. Some adjustments in the concept will be necessary as Modernization and Associated Restructuring (MAR) planning continues. The risk reduction also showed that some changes leading to better user services in the terminal forecast program may be possible before the MAR is completed. Changes in forecast format, with change groups beginning on a new line, increased number of issuances, and specific 18 to 24 hour forecasts may all be possible in the current NWS environment. It may also be possible to adjust the amendment criteria to better fit user operational needs. However, significant improvements in spacial and temporal forecast resolution will have to wait until advanced observational and workstation equipment and improved guidance is available.

AVIATION HAZARD IDENTIFICATION USING DOPPLER RADAR

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1. INTRODUCTION

The Federal Aviation Administration (FAA) is in the process of deploying their Terminal Doppler Weather Radar (TDWR) system at 47 airports in the continental United States (Fig. 1). At the same time, 135 WSR-88D Doppler radars are being deployed throughout the continental United States by the Departments of Commerce (DOC), Defense (DOD), and Transportation (DOT) (Fig. 2). Although these Doppler radar systems are very similar, their functional utility is quite different due to the needs of the different agencies using the system. Both of these Doppler weather radar networks will be important tools for detecting and warning of weather phenomena that are potentially hazardous to penetrating aircraft. This paper will describe these two Doppler radar systems along with the automated algorithms designed to detect weather phenomena that may be hazardous to aircraft in flight.

2. TERMINAL DOPPLER WEATHER RADAR SYSTEM

The principal motivation for the TDWR system is to improve air safety by warning of wind shears and precipitation in the terminal area of major airports. A 1983 National Research Council study identified low-altitude wind shear as the cause of 27 aircraft accidents and incidents, which resulted in 488 fatalities between 1964 and 1982. At least 3 other low-altitude wind shear incidents have occurred since that study, one which resulted in 137 fatalities (Evans, 1991a).

Another goal of the TDWR system is to increase capacity and efficiency of operations by short-term prediction (up to 20 minutes) of wind shifts and wind shears that may impact the terminal area. The system has the capability of detecting, tracking, and forecasting the location and movement of fronts and estimating the winds behind the fronts. This information can be used by air traffic control supervisors to anticipate runway changes, as opposed to reacting to them after a wind shift occurs. To attain these goals, TDWRs will be sited between 5 and 25 km from the airport, and will be sited along the extension of the principal Instrument Flight Rules (IFR) runway as much as land availability allows (Evans, 1991).

The scanning strategy used by the TDWR system consists of sector volume scans of approximately 100° azimuth over the airport which update every 2.5 minutes, two low-altitude full 360° scans for gust front detection which update every 5 minutes, and a low-altitude sector scan over the airport every minute for microburst detection. Since the area of interest will generally be within 25 km of the radar, the algorithms will only ingest data out to 70 km range, ensuring coverage over the airport yet allowing for the detection of fronts that may impact the runways in 20 minutes.

Figure 1. Planned locations of the initial 47 terminal Doppler weather radars.

Figure 2. WSR-88D network coverage at 10,000 feet above site level for the contiguous United States. Hatched regions represent areas not covered below 10,000 feet. Dots represent locations of radar towers.

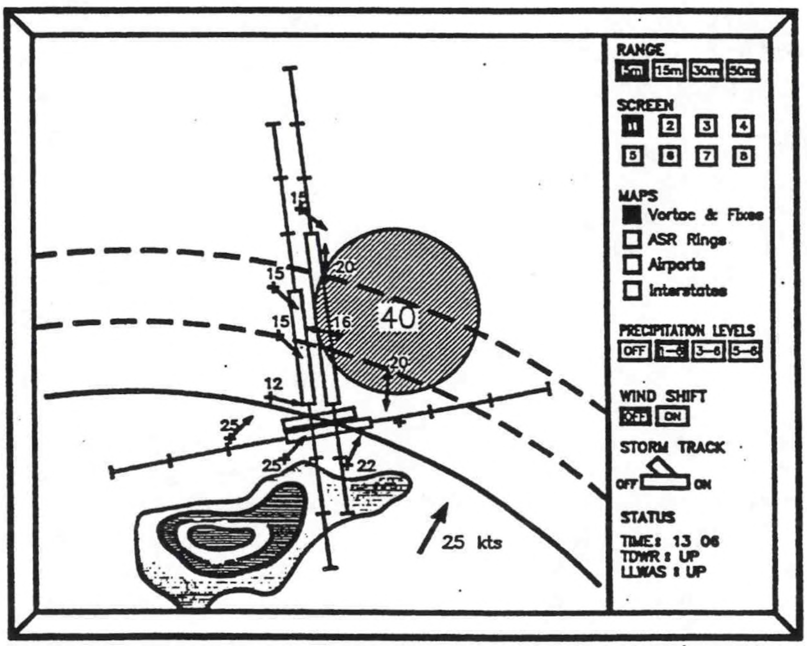

Figure 3. A schematic of the details found on a Geographical Situation Display. A microburst is displayed as a circle with the strength indicated by the number inside it. The solid curved line represents the gust front detection and the dashed lines are the 10 and 20 minute forecasts. Levels of intensity of precipitation are shown in various shadings and LLWAS wind vectors are displayed for each of 12 sites.

There are 3 main automated algorithms in the TDWR system. They are the Microburst Detection, Gust Front Detection, and Wind Shift Prediction algorithms. The FAA has invested heavily in the development and operational readiness of these algorithms because the output of the algorithms will go directly to the air traffic control users with no human intervention. Thus, the performance of these algorithms has to be very good.

The Microburst Detection Algorithm identifies small-scale low-altitude divergence events which can cause an aircraft to lose a significant amount of airspeed while attempting to land or depart. The Gust Front Detection Algorithm detects significant fronts (i.e., wind shifts), which can cause aircraft to gain airspeed while departing or landing. Turbulence is also often associated with fronts. Finally, the Wind Shift Prediction Algorithm forecasts the location of a gust front 10 and 20 minutes in the future and estimates the winds on either side of the front. This information can be used by Air Traffic Control Supervisors to anticipate runway shifts, rather than react to wind shifts after they have occurred. The output of these three algorithms will be displayed on a Geographical Situation Display (GSD) for air traffic control supervisors. A schematic of how the output of these algorithms will look is shown in Figure 3. Another set of runway specific output will be given to the Air Traffic Controllers on a Ribbon Display Terminal as shown in Figure 4.

3. WEATHER SURVEILLANCE RADAR - 1988 DOPPLER (WSR-88D)

The WSR-88D (formerly called NEXRAD) system was developed by three agencies to meet their common operational needs. Initially, the WSR-88D system will employ four different scanning strategies: 1) two clear-air modes which complete seven or eight 360° scans between 0.5° and 4.5° elevation angle in ten minutes; 2) the precipitation detection mode, which completes nine full 360° azimuthal scans in six minutes at elevation angles between 0.5° and 19.5°; and 3) the severe weather mode, which completes 14 full azimuthal scans between 0.5° and 19.5° elevation angle.

Because the WSR-88D network spacing is rather sparse in certain regions of the country, the radars will need to process data out to ranges over 300 km in some instances to be able to cover most of the continental United States. The diagram in Figure 5 shows the effective ranges of the WSR-88D system for both the reflectivity and velocity fields. Velocity data are collected out to 230 km in range with range resolution of 250 m and reflectivity data are collected out to 460 km with range resolution of 1000 m.

There are a number of automated algorithms as part of the WSR-88D system. The data flow through the different algorithms is shown in Figure 6. In total, these algorithms identify, track, and forecast the movement of storm cells, examine their reflectivity characteristics to determine the likelihood of severe weather, and examine the velocity field to determine if there is a mesocyclone (the parent circulation of a tornado) or possible tornado

Type of wind shear	Runway	Threshold winds	Wind shear Headwind change (kts)	Location
	CF	190 16 G 25		
MBA	35 LD	160 22	50-	RWY
MBA	35 RD	180 5	25-	RWY
MBA	35 LA	030 23	55-	1 MF
	35 RA	180 10	60-	3 MF
MBA	17 LA	180 5	25-	RWY
MBA	17 RA	160 22	55-	RWY
	17 LD	180 10	60-	RWY
MBA	17 RD	030 23	55-	RWY

Figure 4. An example of the alphanumeric information shown on a Ribbon Display Terminal. A message would be read to a pilot as "Microburst Alert, Runway 35LA, Threshold wind 030 at 23, 55 knot loss, 1 mile final, centerfield wind 190 at 16, gust 25" (from Turnbull et al., 1989).

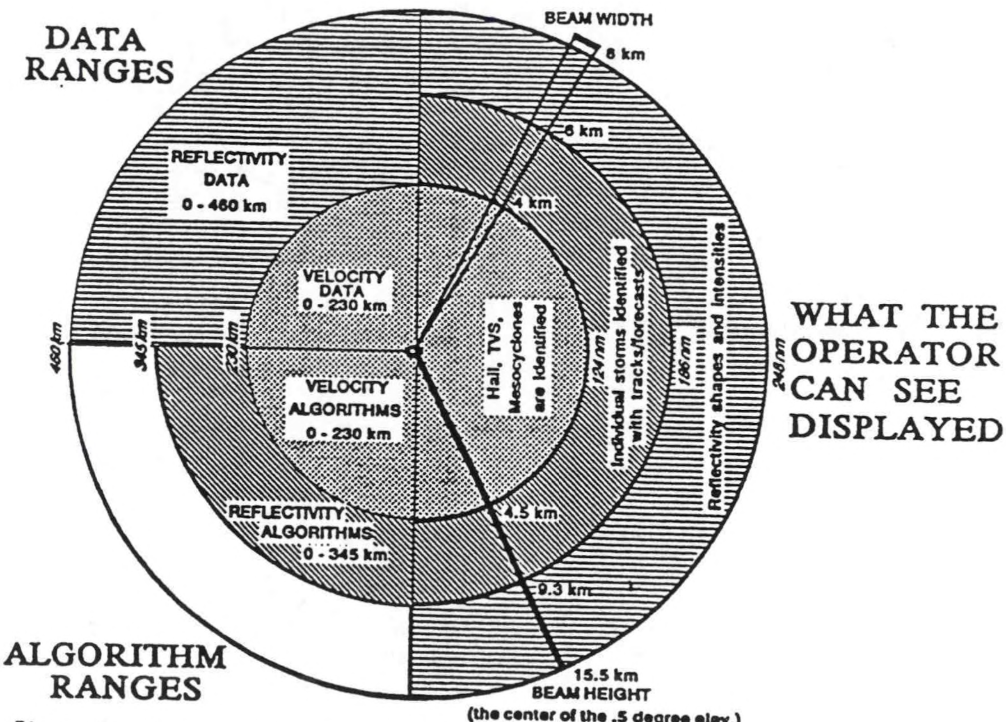

Figure 5. Range considerations for the WSR-88D (from Alberty et al., 1991).

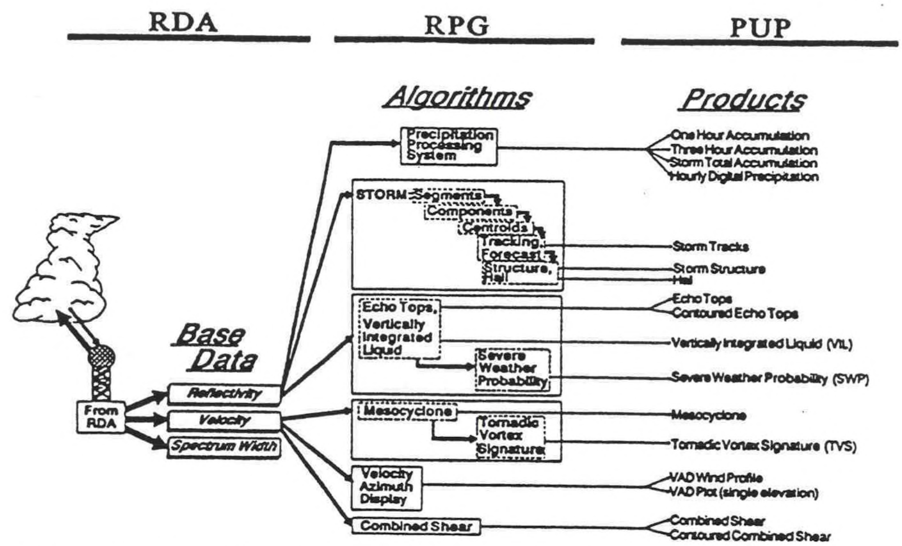

Figure 6. Data flow through the WSR-88D System (from Alberty et al., 1991).

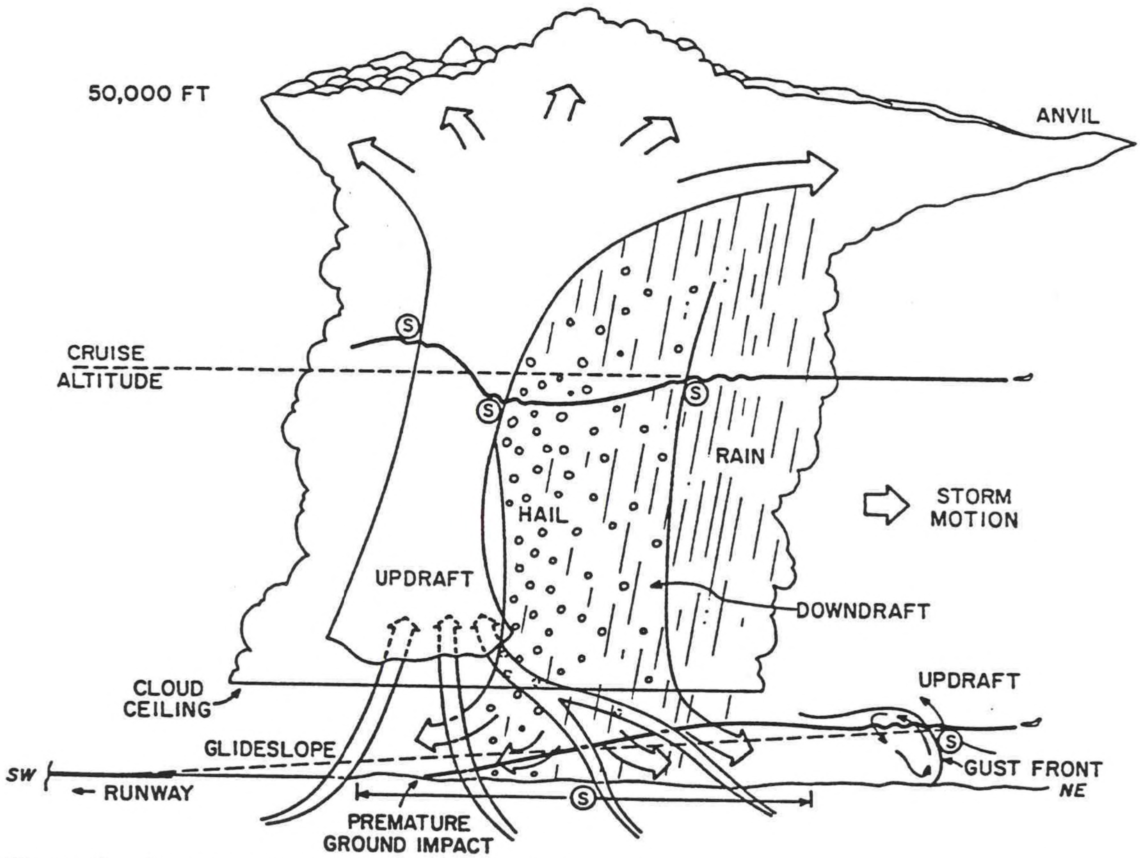

Figure 7. The structure of a typical thunderstorm in the Midwest United States, and its effects on aircraft during cruise and landing. Dotted lines represent expected flight paths and solid lines are actual paths. The notation (S) indicates the likely zones of wind shear, and the wavy segments of flight paths are the result of turbulence.

associated with the storm. In addition, there is a series of algorithms that determine accumulated rainfall and another that profiles the winds in the atmosphere (Alberty et al., 1991).

4. AUTOMATED ALGORITHMS TO DETECT AVIATION WEATHER HAZARDS

There are a number of weather phenomena that can be detected using a Doppler weather radar. These include microbursts, gust fronts and synoptic fronts, tornadoes, mesocyclones, hail, heavy precipitation, and strong vertical shear of the horizontal wind. Most of these phenomena are associated with convective storms as is shown in the schematic in Figure 7. All of these weather phenomena are potentially dangerous to aviation. A number of automated algorithms have been developed to detect these phenomena for the two Doppler radar systems described above. In this section, some of the important algorithms for detecting aviation weather hazards will be briefly described. And enhanced versions of the algorithms will be discussed when appropriate.

The Microburst Detection Algorithm was developed for the TDWR system by the FAA. This algorithm detects low-altitude divergence signatures in Doppler radar data and also uses microburst precursor signatures aloft (e.g., convergence, rotation, or descending core aloft) to give earlier warnings of microbursts (Merritt, 1991, Campbell, 1989). A contour plot of the Doppler velocities observed in a strong Oklahoma microburst at low-altitudes is shown in Figure 8. The Microburst Detection Algorithm examines radials of velocity data to locate runs of increasing radial velocities (which indicate radial divergence). To declare a potential microburst detection, a minimum number of runs of radial divergence have to be located near each other azimuthally, the strongest run has to be above a minimum threshold, and a minimum area has to be surpassed (Merritt, 1991). To actually declare a microburst, a potential microburst has to be declared on two consecutive scans in close proximity to each other OR a microburst precursor feature aloft has to have been detected. The Microburst Detection Algorithm has been tested on data collected near Huntsville, Alabama; Denver, Colorado; Kansas City, Missouri; and Orlando, Florida. The algorithm detects greater than 98% of the events with differential velocity greater than 15 m s^{-1} and has a less than 5% probability of false alarm (Evans, 1991a).

The Gust Front Detection Algorithm was also developed for the TDWR system. It detects lines of radial convergence in Doppler radar velocity fields. A contour plot of a radial velocity field associated with a strong Oklahoma gust front is shown in Figure 9. In a manner similar to the Microburst Detection Algorithm, the algorithm initially examines radials of Doppler velocity to locate runs of decreasing radial velocity (which indicate radial convergence). It then groups runs near each other into features. To declare a gust front detection, the algorithm locates features using data collected at two low-elevation angles (nominally 0.5° and 1.0°) and then vertically associates them to ensure that the detection is valid. The Gust Front Detection Algorithm detects over 80% of gust fronts that have a differential velocity >15 m s^{-1} with a probability of false alarm <6%, except in the Kansas City environment where the probability of

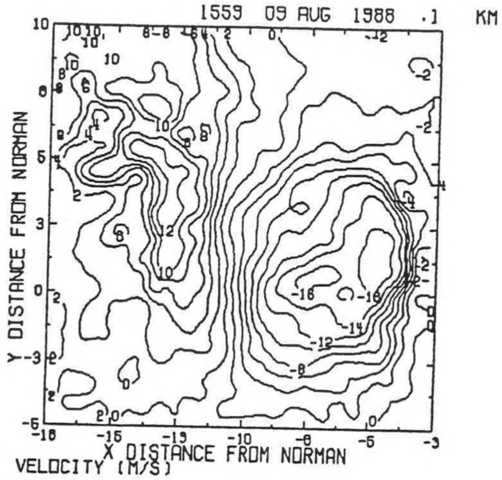

Figure 8. Contoured Doppler velocity field from 9 August 1988, 1559 CST. Data were collected with the National Severe Storms Laboratory's Norman Doppler radar. Data are from approximately 100 m above ground level, and the negative velocities are towards the radar, positive away. The signature is mainly divergent which was associated with a strong microburst which caused wind damage west of Norman, Oklahoma.

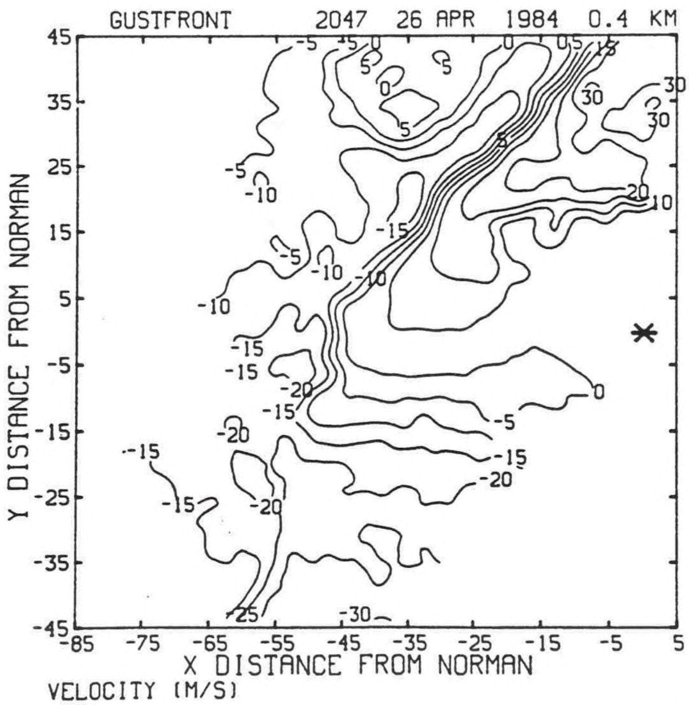

Figure 9. Same as Figure 8, except for gust front convergence signature observed on 26 April 1984, 2047 CST.

false alarms was 13% (most were caused by strong vertical wind shear associated with the low-level jet) (Hermes et al., 1990). An improved version of the Gust Front Detection Algorithm has been developed, which uses additional information observed in Doppler radar data (e.g., azimuthal shear and reflectivity thin line) to help the algorithm detect a larger portion of long gust fronts (Eilts et al., 1991).

The Wind Shift Prediction Algorithm relies on the Gust Front Detection Algorithm to detect fronts and then it tracks them and forecasts their locations 10 and 20 minutes in advance. When the algorithm tracks them (50% of fronts are tracked) it correctly forecasts their location over 95% of the time for the 10 minute forecasts and over 75% of the time for the 20 minute forecasts.

A series of algorithms have been developed for the WSR-88D system (called the Storm Series Algorithms), that identify individual storms and create tracking information. Tracks indicate the past movement of thunderstorm cells and their expected movement in the next hour. When individual storms are identified, the Hail Detection Algorithm examines the reflectivity structure of the cell to determine the likelihood of hail. Enhanced versions of the Storm Series algorithms and the Hail Detection Algorithm have been developed (Witt, 1991 and Witt, 1990a). From limited testing, the enhanced version of the Hail Detection Algorithm has a Probability of Detection (POD) of 92% with a False Alarm Ratio (FAR) of 30%. The present WSR-88D Hail Detection Algorithm has a similar POD, but its FAR is 50% greater than that of the new algorithm.

A Tornado Detection Algorithm has been developed for both the TDWR and WSR-88D systems (Vasiloff, 1991). Presently the TDWR system does not have a tornado detection algorithm. The WSR-88D system has a Tornadic Vortex Signature (TVS) Algorithm that relies on the Mesocyclone Detection Algorithm to identify regions of possible tornadoes before it is can detect tornadoes. This may not allow the WSR-88D algorithm to detect a number of smaller tornadoes which may not be associated with mesocyclones. The Tornado Detection Algorithm, recently developed at NSSL, identifies tornadic vortex signatures (TVS) in Doppler velocity fields independently of the detection of a larger-scale circulation. A TVS is characterized by highly localized, strong azimuthal shear. An example of a TVS from a very large tornado is shown in Figure 10. The shaded area on the figure is the area which the algorithm declared a feature. When three features are identified, at different elevation angles from the same volume scan, the algorithm declares a tornado detection. Almost all tornadoes observed with Doppler radar, at ranges less than 40 km, have TVS's associated with them. The new Tornado Detection Algorithm has a POD of 76% and an extremely low FAR.

The Mesocyclone Detection Algorithm that was developed for the WSR-88D system examines radial velocity fields for azimuthal shear over several azimuths, rather than just two as does the Tornado Detection Algorithm. An example of a single Doppler radar signature of a mesocyclone is shown in Figure 11. Recent enhancements to the WSR-88D algorithm have been made to reduce an apparent high false alarm ratio

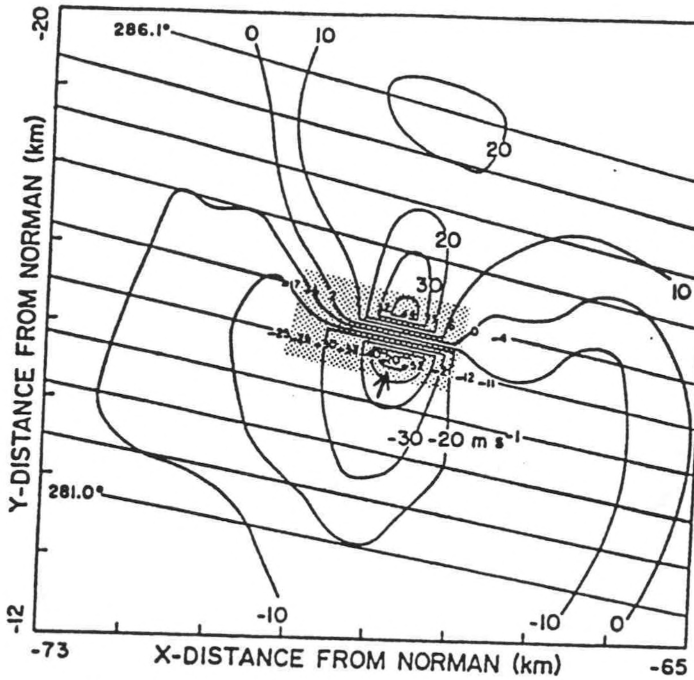

Figure 10. Same as Figure 8 except for Tornadic Vortex Signature observed on 22 May 1981. The hatched area is the location that the Tornado Detection Algorithm found a potential tornado.

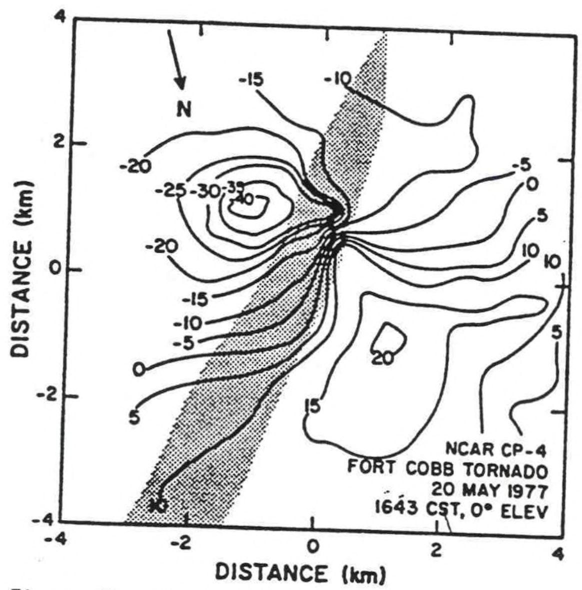

Figure 11. Same as Figure 8 except for mesocyclone signature that was observed on 20 May 1977 with NCAR's CP-4 radar. The radar was located to the SSW of the mesocyclone. Notice that the mesocyclone signature is of larger scale than the TVS in the Figure 10 (from Brown and Wood, 1983).

of the present Mesocyclone Detection Algorithm (Witt, 1990b).

Strong vertical shear of the horizontal winds at low-altitudes can be dangerous to landing aircraft. Low-level jets, which occur frequently in the Central Plains, are one cause of strong vertical shears at low-altitudes. For example, a moderate strength low-level jet was observed with Doppler radar on May 4, 1989 near Kansas City. If an aircraft attempted to land through this jet, it would potentially lose 17 m s^{-1} airspeed in the last 500 m of descent (Figure 12) (Mahapatra and Zrnic, 1991). The Velocity Azimuth Display (VAD) Algorithm estimates the vertical profile of horizontal winds in the atmosphere. An example of the output from this algorithm, running on the WSR-88D, is shown in Figure 13.

5. FUTURE PLANS

The amount of data available to detect aviation weather hazards will increase greatly with the deployment of the TDWR and WSR-88D radar networks throughout the country. The challenge is to convert these data into information that can be delivered to individuals needing it in a timely manner. Automated algorithms are an important step in this direction. Some of the algorithms developed for the TDWR and WSR-88D radar systems have been well tested and have been enhanced over a number of years. Other algorithms are in a state of infancy. It is important that all of the algorithms are evaluated and enhanced in the coming years.

In addition, there are plans to integrate Doppler radar data with other data sources, such as profilers; automated surface weather observing systems; aircraft-reported winds, temperature, and turbulence; and satellites, to get a complete look at weather phenomena and to forecast their movement and evolution (McCarthy, 1991; Evans, 1991b). In addition, mesoscale models will ingest data from some of these data sources and their output will be integrated with data from an Aviation Gridded Forecast System (AGFS) (Sherretz, 1991). The FAA is proposing to use the AGFS as input to Regional and National Aviation Weather Products Generators which will generate products specifically tailored to aviation users (McCarthy, 1991). All of the new weather sensors and the new systems being developed to use the increased amounts of data will increase safety and increase the operational capacity of the airspace system.

6. CONCLUSIONS

The deployment of the Terminal Doppler Weather Radar and WSR-88D (NEXRAD) radar networks during the next few years, throughout the continental United States, will allow the detection and prediction of aviation hazards that was not possible before now. Because of the large amounts of data that are collected, the short life-time of some of the hazardous weather phenomena, and the necessary timeliness of information dissemination, it is important to use automated algorithms to detect the hazards. It is also important to automatically send the information to the user, whether it be the pilot or air traffic control personnel.

Further applied research using Doppler weather radars is needed to produce better algorithms in the future. In addition, all of the present algorithms should be refined

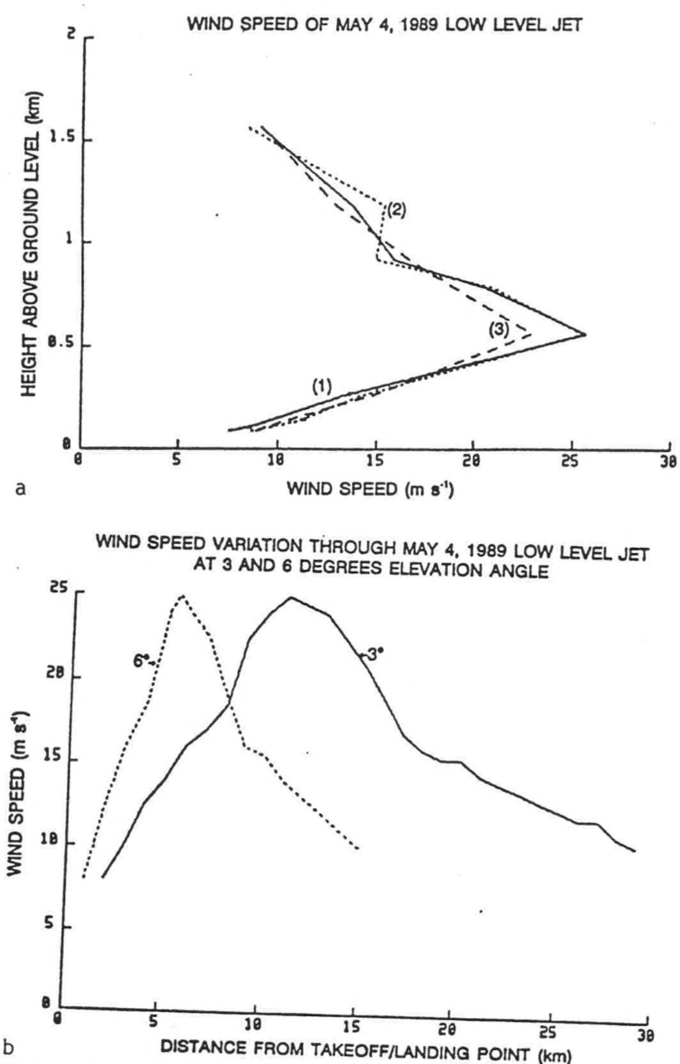

Figure 12. Wind speed profiles during a low-level jet observed on 4 May 1989 near Kansas City using the Lincoln Laboratory's FL-2 radar. The vertical profile (a) shows a sharp peak at about 500 m altitude. An aircraft attempting to take off (at a 6° angle) or land (along a 3° glideslope) would experience the wind variations shown in (b).

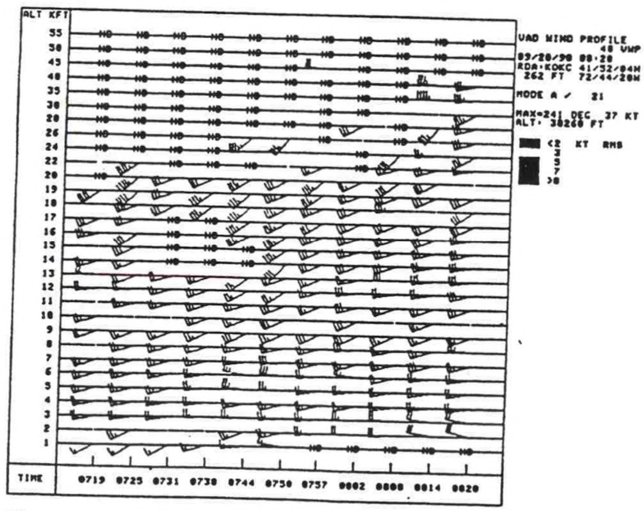

Figure 13. WSR-88D Velocity Azimuth Display (VAD) wind profile product for data collected in Oklahoma City, Oklahoma, on September 20, 1990. "ND" indicates insufficient data to make an estimate at that height.

to increase their skill and further increase the safety of air travel in the United States.

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Session 7.2

APPLICATION OF THE COMBINED MOMENT PRODUCT IN AVIATION NOWCASTING

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1. INTRODUCTION

In 1989, the implementation of the WSR-88D (Weather Surveillance Radar-1988 Doppler) commenced at NWS (National Weather Service) field sites. Aviation meteorologists in the NWS, for the first time, will be able to generate forecasts, warnings and briefings using this Doppler radar information. Data obtained from the WSR-88D allows the meteorologist to examine the Doppler spectrum's principal moments (reflectivity, radial velocity, and spectrum width). Usually, these fields have been individually analyzed by meteorologists to determine the location of precipitating systems, examine storm structure, determine the degree of storm severity, and identify potential areas of turbulence associated with these systems. Only one product, the combined moment (CM), allows the user to view all three principal moments simultaneously on one display.

This paper describes the CM product and an application of the product in aviation nowcasting. A case study emphasizes the operational usefulness of the CM product with respect to examination of the three base moments. Strengths and weaknesses of the CM are considered and suggested modifications that could increase the product's practicality in a real-time operational setting are presented.

2. DESCRIPTION OF COMBINED MOMENT PRODUCT

The CM product is a presentation of Doppler moments in a B-scan format. This type of format is a display of radial data shown as a cartesian-type design. On the CM product, the mean radial velocity is represented by arrow direction (Fig. 1) and the zero radial velocity is a horizontal arrow pointing right. Nonzero radial velocities are proportional to the angle between the arrow and its zero position. The maximum radial velocity that may be depicted by this product is ± 51 ms^{-1} (100 knots), represented by a horizontal arrow pointing left (all velocities are depicted in knots on the WSR-88D system). If the arrow points toward the bottom (top) of the display, the flow depicted possesses a component of motion toward (away from) the radar. A 50 knot component of wind toward the radar is indicated if the arrow is shifted by 90 degrees toward the bottom of the display.

Information about the spectrum width is displayed by means of arrowhead size; three arrowhead sizes conform to given ranges of width

(Fig. 1). Arrows are displayed every 0.50 km (0.27 nmi) in range. The azimuthal spacing is at one degree intervals, which is the best resolution the WSR-88D system provides.

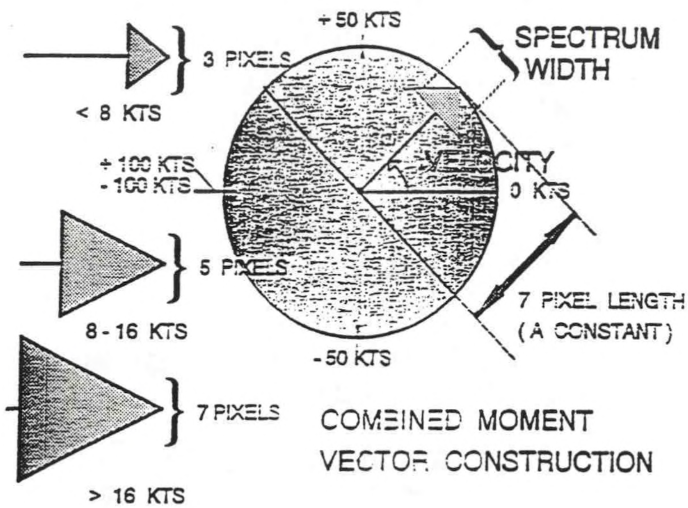

FIG. 1. Combined moment vector construction (Adapted from Unisys Corporation 1990).

Reflectivity information is displayed every 1 km (0.54 nmi) in range with one degree azimuthal spacing. A maximum of eight color levels is used in the reflectivity part of the CM display (Fig. 4). Reflectivity levels three to eight coincide with the six D/VIP (digital video integrator and processor) levels used on the WSR-57 and WSR-74 NWS radar displays. Levels one and two on the CM product correspond to reflectivity levels less than VIP 1. (The WSR-88D detects and displays information from targets that cannot be detected by conventional radars.)

3. APPLICATION

The NEXRAD Initial Operational Test and Evaluation Phase II (IOT and E(2)) was conducted in Norman, Oklahoma from April through August 1989. During this test, WSR-88D data were periodically collected and archived. The data used for the case described below was acquired from the test. This case features a practical application of the CM product.

On the evening of 14 May 1989, thunderstorms developed over the Oklahoma panhandle and moved southeast. By early afternoon, these storms had spread into north-central Oklahoma.

The 0.5° base reflectivity product at 1838 UTC from the WSR-88D system showed an area of echo (labeled "A" in Fig. 2) of moderate intensity (35 to 54 dbZ). (The data levels located on the side of the base products are lower bound thresholds. The radar is located just below the lower right corner of the data on Fig. 2 at Norman, Oklahoma.) This particular area is near the border of Garfield and Kingfisher counties. From 1725 to 1850 UTC, hail 2.2 cm (0.88 inch) in diameter occurred with these storms in the vicinity of "A" (USDC, 1989).

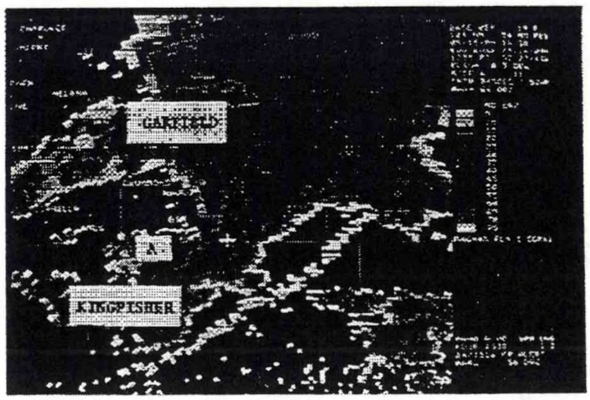

FIG. 2. WSR-88D base reflectivity product (0.5°), 1838 UTC 15 May 1989. Area of high reflectivity is labeled "A".

The 0.5° base velocity product at 1838 UTC (Fig. 3) showed an area of radial velocities as high as 10 ms_{-1} (19 kt) in the area labeled "B". At the same time and in the same location (labeled "C" on Fig. 4), the 0.5° spectrum width product displayed an area of values ranging from up to 10 ms^{-1} (19 kt). This value of spectrum width indicates high potential for the presence of moderate to severe turbulence (National Weather Service Operational Support Facility 1991). These values seem reliable since they were associated with high reflectivity values. Typically, higher reflectivity values exhibit high signal-to-noise thresholds. Reflectivity values near the radar's signal-to-noise threshold will lead to erratic estimates of spectrum width. A high potential of moderate to severe turbulence exists in this area because the data was derived from reflectivity data associated with thunderstorms. This category of turbulence typically occurs with thunderstorms.

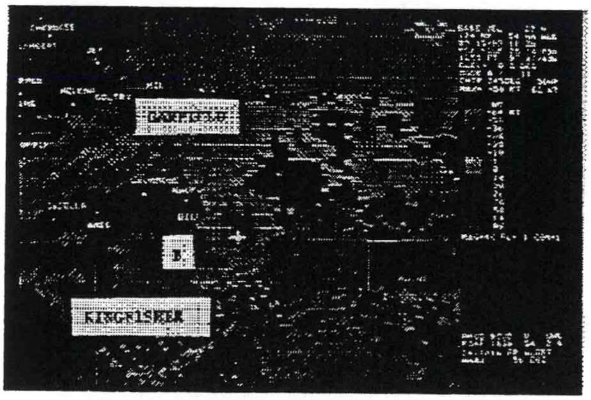

FIG. 3. WSR-88D base velocity product (0.5°), 1838 UTC 15 May 1989. Area of high velocities is labeled "B".

Examination of the 0.5° CM product (Fig. 5) at 1838 UTC, obtained from area "A" in Fig. 2, indicated reflectivity values as high as 55 dBZ (labeled "D" in Fig. 5), maximum inbound radial velocities of 10 ms^{-1} (19 kt) near the higher reflectivities and maximum spectrum width values of 10 ms^{-1} (19 kt values or large arrows) near the bottom center of the Fig. 5. Appropriately, these values agree with those values observed on the base products. However, examining the CM product allows the user to view all three moments simultaneously on one display over a small (27 x 27 nm) area. This capability permits the meteorologist to apply the information for smaller areas that may be needed for aviation duties.

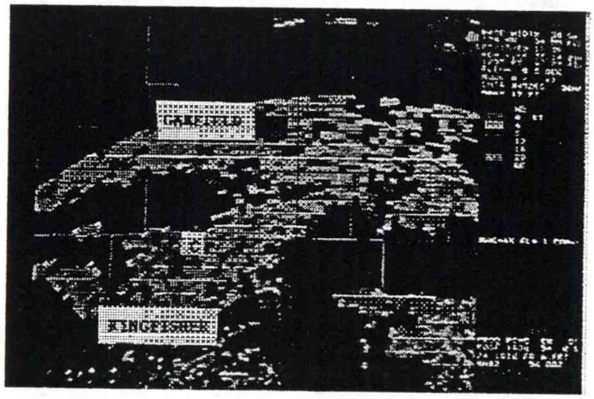

FIG. 4. WSR-88D spectrum width product (0.5°), 1838 UTC 15 May 1989. Area of high spectrum width is labeled "C".

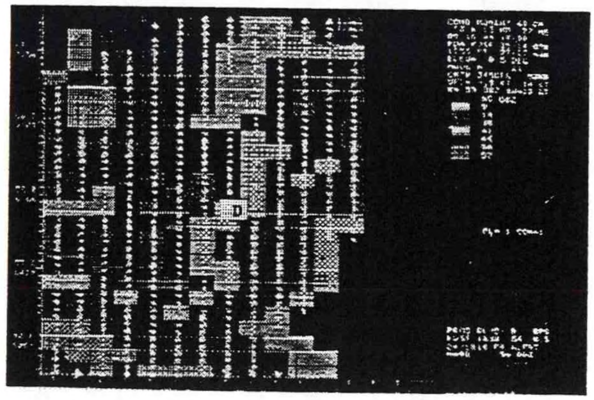

FIG. 5. WSR-88D combined moment product (0.5°), 1838 UTC 15 May 1989 showing area of maximum values of base data labeled "D" associated with data displayed in FIGS. 2-4.

4. STRENGTHS, LIMITATIONS AND SUGGESTED MODIFICATIONS

The CM product possesses operational strengths. The duty of assimilating information from the three principal moments may be difficult for a radar meteorologist, especially during operations. At any given time, one or more of the moments may provide important information in potential warning situations. If an operational meteorologist uses only one of the base moments, information regarding an important meteorological feature may not be acquired. Thus, a less-than optimum warning decision may result. Valuable warning lead time may be lost if severe storm indicators are apparent in a base moment that is not examined by the meteorologist. Examining the CM product could alleviate this potential problem.

Valuable applications of this product include the detection of vortical-flow fields (Anderson and Green 1990, Unisys Corporation 1990) and the computation of storm-top divergence. Determining the maximum velocity difference (the absolute value of the difference between the maximum outbound and inbound radial velocities) in a region of divergence near a storm summit allows the meteorologist to estimate the maximum hail diameter (Witt and Nelson 1991). Typically, the base velocity product will depict the same color for all outbound velocities greater than 33 ms^{-1} (64 kt) and another color for all inbound velocities greater than 33 ms^{-1} (64 kt). In contrast, the CM allows the operator to "see" wind speed changes up to ± 51 ms^{-1} (± 100 kt). Using the base velocity product to compute the maximum velocity difference for a storm top may result in an underestimate of the divergence near the storm summit. Therefore, an underestimate in the maximum hail size may result. Utilizing the CM product could yield more accurate estimates of storm-top divergence and associated updraft strength.

One disadvantage of the CM product is that it is difficult to interpret without practice (Burgess et al. 1990). Filtering out or regrouping reflectivity levels on the CM may simplify the display. However, important reflectivity information may be overlooked if filtering is performed. Another disadvantage of the CM product is that no background maps are available to use with the product. However, the azimuth (degrees) is displayed on the product's horizontal axis, and the range (km) and height (ft) are displayed on the vertical axis. Additionally, the user must estimate the wind speeds based on vector orientation since numerical radial velocities are not provided. The highest inbound and outbound radial velocities are not displayed on the CM product as is shown on the base velocity product.

Finally, the Center Weather Service Units (CWSU), located in all regional Air Traffic Control Centers, will be non-associated users of the WSR-88D system (National Weather Service Operational Support Facility 1991). Therefore, the CM must exist on the generation and distribution list at the RPG site in order for the meteorologists at the CWSUs to have access to this product. These users are not capable of generating the CM product at predetermined locations.

To make the CM product more practical operationally, some modifications are suggested. Rather than changing the arrow direction to display different radial velocities, plot the actual base velocity values numerically. Instead of using different arrowhead sizes to represent spectrum width variations, use simple geometrical figures (e.g., a circle). Plotting velocity values in different colors corresponding to the magnitude of spectrum width while depicting reflectivity information in gray shades would ease product interpretation.

5. SUMMARY

The combined moment (CM) product generated by the WSR-88D has been described and applications have been highlighted. The CM allows the user to examine the three principal Doppler moments simultaneously on one display. The product may help aviation meteorologists identify important meteorological features such as areas of potential turbulence, areas of convergence/divergence, and vortical flow fields. Without practice, the product may be difficult to interpret in its present form. Certainly, uncomplicated interpretation of the WSR-88D products is desired by all users. However, operational meteorologists should attempt to use the CM product to improve their skills at interpreting and to increase the potential to gain information about meteorological features observed during operations. If the CM product is modified in the manner outlined, more operational meteorologists will find the product helpful.

6. ACKNOWLEDGEMENTS

The authors thank Liz Quoetone, Dave Imy, and Robin Radlein (WSR-88D Operational Support Facility's Operations Training Branch) for their help in acquiring the data and the graphics used in this paper.

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THE OKLAHOMA CITY, OK (WILL ROGERS WORLD AIRPORT) SEVERE WET MICROBURST EVENT OF 27 SEP 1986-- USE OF A POTENTIAL GUST FORECAST TECHNIQUE

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1. INTRODUCTION

Severe wet microbursts emanating from summertime, pulse-type thunderstorms can occur at any time of day and at any geographical location. Certain empirical and qualitative forecast techniques have been developed during the past decade to assist warning forecasters in determining which thunderstorms are severe. However, a significant amount of subjectivity remains in the preparation of a severe thunderstorm warning and many pulse-type thunderstorms are not warned on until after damage reports are received due to the relatively short-lived nature of this type of storm. Fortunately in this case, the severe wet microburst occurred at a major airport during a time period when air traffic was at a minimum.

Stewart (1991) proposed a simple warning technique utilizing Vertically Integrated Liquid (VIL) water content and radar echo heights (TOP), combined with the penetrative downdraft mechanism, to produce maximum potential (downdraft) gust forecasts for individual thunderstorms. Warning lead times are usually at least 15 minutes prior to the severe weather event and lead times of 30 minutes or more are not uncommon when using this technique.

This paper focuses on (1) the rapid development of a pulse-type severe thunderstorm during weak, synoptic-scale forcing and (2) the application of a potential gust forecast technique for pulse-type thunderstorms.

2. SYNOPTIC SITUATION

The environment in which pulse-type thunderstorms develop is one characterized by little or no vertical wind shear and a deep, nearly saturated lower troposphere that is topped by an elevated dry layer of low theta-e (θ_e) air which is the primary source for generating penetrative thermals (downdrafts). Strong evaporational cooling and precipitation loading combine to produce enough negative buoyancy (with respect to the in-cloud lapse rate) to accelerate downward the entrained dry parcel (fig. 1). Caracena, Holle, and Doswell (1989) noted that the low θ_e air must be located high enough above the surface to allow the negative buoyancy force to accelerate a parcel downward and reach a severe downdraft velocity. After the parcel reaches the surface, the air diverges and spreads out such that the speed of the horizontal flow is assumed to equal the maximum downward speed the parcel achieved during descent.

However, during those times when moderate, unidirectional flow exists in the troposphere, pulse-type thunderstorms can still develop if the storm lifetime is relatively short ($\leq$ 30 minutes) so as not to allow the updraft to become tilted. Figure 2 is the 1200 UTC Oklahoma City, OK (OKC) sounding on the day of the wet microburst event. Note

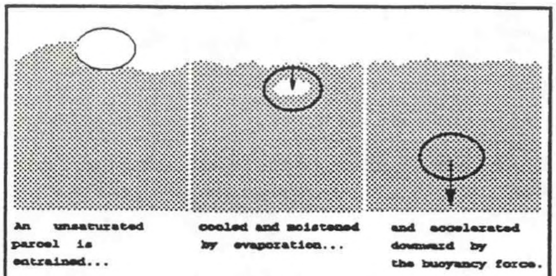

Figure 1. A schematic representation of a dry parcel being entrained at the top of a cloud. The stippled area denotes the cloudy air.

the very moist lower troposphere below the 600 mb level topped by extremely dry air (dewpoint depressions ≥30°). Lifting a well mixed parcel from the lower-troposphere to the 500 mb level would have resulted in a lifted index value of -5 and a moderate area of positive buoyancy. The OKC wind field indicated moderate unidirectional flow below the 250 mb (approx. 34000 ft) with about 30° of veering above that level. The lapse rate was steep (nearly dry adiabatic) between 850 mb and 680 mb indicating that a parcel would accelerate upward rapidly once the level of free convection was reached. The mean wind vector in the lower 5000 feet was 225° at 21 kt and the storm motion vector (average wind vector from the condensation level to the equilibrium level) was 244° at 35 kt. It is also important to mention that the actual OKC balloon launch time was 1100 UTC which means that this sounding was representative of the pre-storm environment.

3. DESCRIPTION OF THE POTENTIAL GUST FORECAST

The potential gust forecast technique used in this paper only requires VIL and TOP data to calculate the maximum potential downdraft or peak gust (for a complete description on VIL and how VIL and

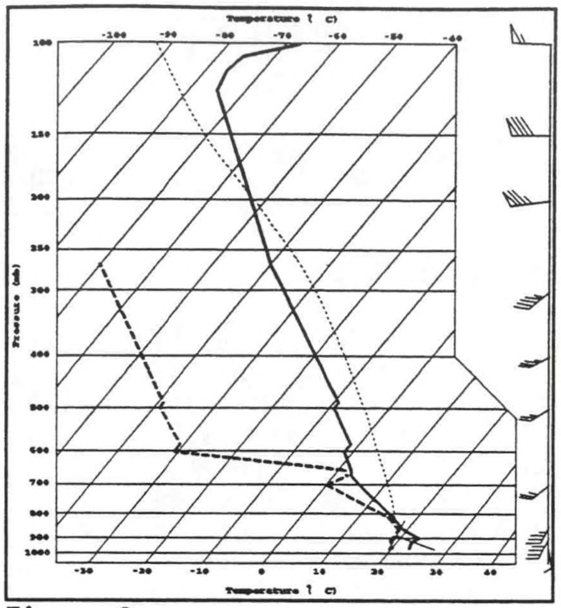

Figure 2

TOP are calculated by radar, see Greene and Clark, 1972, and DOC Issue No. 19-WSH, 1984, respectively). VIL is obtained by calculating the rainwater liquid water content (R_c) in several layers of a precipitating system (e.g. a thunderstorm) until the top (TOP) of the radar echo (18 dBz) is reached. The R_c of each layer is then summed up over the depth of the system. The specific equation for calculating VIL is

$$VIL = 3.44 \times 10^{-6} [(Z_i + Z_{i+1})/2]^{4/7} dh \qquad (1)$$

where **VIL** is vertically integrated liquid water content (kgm^{-2}), Z_i and Z_{i+1} are equivalent reflectivity values (mm^6m^{-3}) at the lower and upper portions of a sampled layer, and **dh** is the vertical thickness of the layer sampled.

A parcel or volume of dry, low θ_e air is assumed to be entrained into the mid-levels of a thunderstorm. Once inside the storm, the "dry" parcel entrains rainwater (and ice) which results in strong evaporative cooling and the production of negative buoyancy which accelerates the penetrative parcel downward. This implies that the lower the θ_e value of the entrained air and the larger the rainwater content within a storm, the greater the downward velocity of the downdraft and associated horizontal outflow that can be generated. Equation 2 is used to calculate potential gusts,

$$W=\sqrt{(20.628571\bar{R}_c H-3.125x10^{-6}H^2)} \qquad (2)$$

where **W** is the maximum downdraft velocity/surface wind gust (ms^{-1}) produced by an entrained dry air parcel, $\bar{R}_c$ is the storm-averaged rainwater liquid water content (gg^{-1}) entrained by a parcel, and **H** is the height (meters) above mean sea-level of the 18 dBz (VIP 1) echo (i.e. the precipitation top of a thunderstorm). Equation 2 is a modified form of Emanuel's (1981, JAS, eq. 26) equation for calculating the downdraft velocities for penetrative thermals. The first coefficient on the R.H.S. of eq. 1 has dimensions of ms^{-2} while the second coefficient has dimensions of s^{-2}.

The storm-averaged rainwater content ($\bar{R}_c$) is determined by using equation 3,

$$\bar{R}_c = VIL/TOP \qquad (3)$$

where **VIL** is the maximum value (kgm^{-2}) of Vertically Integrated Liquid water content associated with a thunderstorm and **TOP** is the maximum height (m) of the 18dBz echo. To convert $\bar{R}_c$ to a dimensionless value, 1 m^3 volume of dry air is assumed to have a specific mass of 1 kg. The maximum downdraft velocity is assumed to be the horizontal wind velocity after the parcel reaches the surface and begins to spread out laterally.

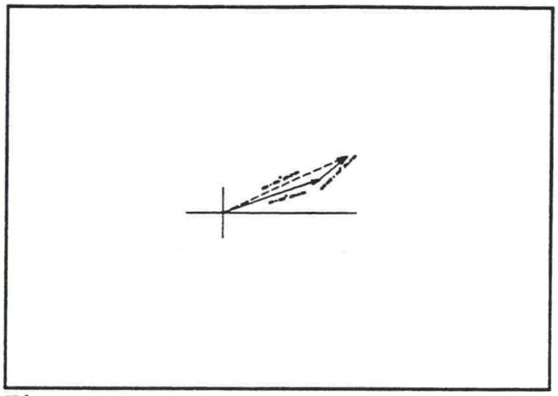

Figure 3

Once the potential gust has been calculated for a specific storm, the maximum final potential gust (FPG) vector is obtained by taking into account the mixing of low-level horizontal momentum. Miller (1967) recommended adding (vectorially) one-third of the mean wind in the lower 5000 feet (mean layer wind) of the troposphere. Figure 3 is an illustration of the vector addition of a 48.8 kt potential gust vector (the PG vector is assumed to be in the same direction as the storm motion vector but having the speed of the calculated gust, not the storm motion speed) and the one-third mean layer wind (1/3MLW) vector. Using the cosine law, an additional 10.7 kt would have to be added to a 48.8 kt PG vector on this day which would result in a final potential gust (FPG) vector of 241° at 59.5 kt.

4. STORM MORPHOLOGY

As mentioned previously in section 3, there was no apparent large-scale synoptic forcing occurring across Oklahoma. However, as the divergent left-front quadrant of the subtropical jet maximum ap-

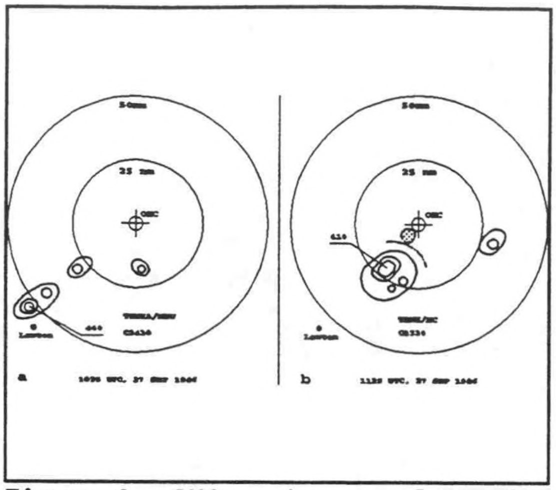

Figure 4. OKC radar overlays for (a) 1025 UTC and (b) 1125 UTC. Contours are drawn for VIP levels 1, 3, and 5 (18, 30, and 50 dBz).

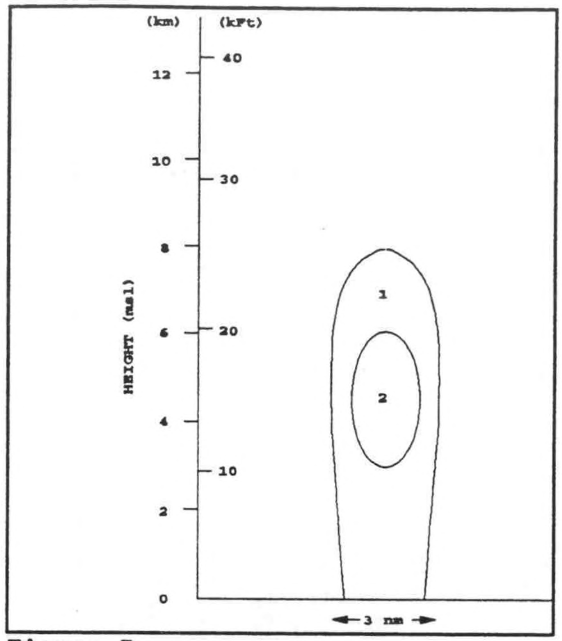

Figure 5

proached the state, moderate deep convection began to develop southwest of OKC around 1000 UTC. By 1025 UTC, a small cluster of thunderstorms had developed 25 to 50 nm southwest of the airport moving northeast (240°) at 30 kt (fig. 4a). The highest radar echo tops were 46000 ft and were associated with the 50 dBz (VIP level 5) core located 10 nm north of Lawton, OK. The OKC radar operator was indicating small hail with this storm based on an intermittent elevated 57 dBz (VIP level 6) core appearing near the melting level. The initial storm motion indicated by the OKC radar operator was in good agreement with the storm motion vector (244° at 35 kt) determined from the 1200 UTC OKC upper-air sounding.

The RADAP II computer equipment attached to the OKC WSR-57 radar indicated a radar echo height (TOP) of 45000 ft (13720 m) and a maximum VIL of 45 kgm^{-2} associated with the storm due north of Lawton. Using those values in equations 2 and 3 indicates that a 35.8 kt PG could have been generated. Adding 10.8 kt for the vector addition of the one-third MLW means that a maximum FPG of 46.6 kt could have occurred.

By 1125 UTC (fig. 4b), the cluster of thunderstorms had moved northeast to a position approximately 20-30 nm southwest of OKC. The maximum radar echo height had decreased to 41000 ft (12500 m) and the RADAP II system detected a TOP of 40000 ft (12195 m) and a maximum VIL of 35 kgm^{-2}, an indication that the complex of storms was collapsing and that the downdrafts were reaching the ground.

A thunderstorm gust front (indicated by the curved dot-dashed line) became apparent in advance of the main complex and a weak rainshower (towering cumulus) had

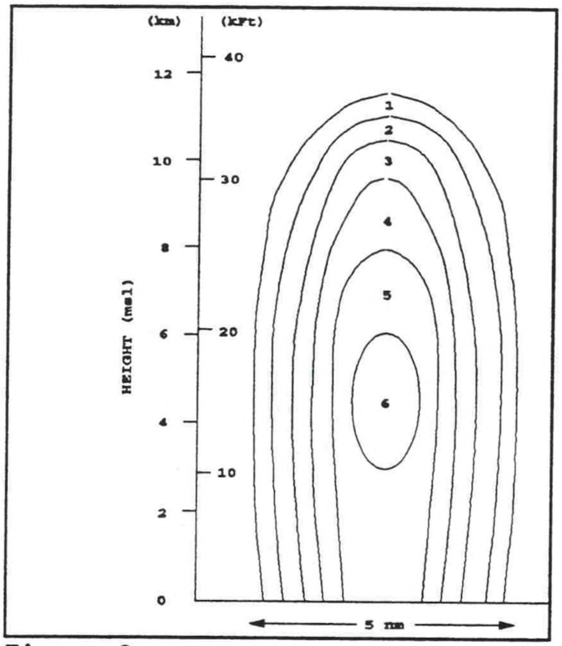

Figure 6

developed 12 nm southwest of OKC (indicated by the shaded circle). Figure 5 is a vertical depiction of the distribution of reflectivity within the towering cumulus that was indicated by the OKC WSR-57 radar. Only light rain (18 dBz) was reaching the surface with a 30 dBz core (VIP level 2) elevated between 10000 ft and 20000 ft. The diameter of the cell was only about 3 nm across and had a maximum radar echo height of about 25000 ft.

By 1145 UTC (fig. 6), the small cell located 12 nm southwest of OKC had moved to a position about 7 nm southwest of the airport and had only increased to a 5 nm diameter. However, notice the rapid increase in the reflectivity values and the elevated 57 dBz core (VIP level 6) that developed between 10000 ft and 20000 ft. The explosive development of the thunderstorm was likely a result of the strong boundary layer forcing produced by the advancing gust front which was generated by the strong downdrafts from the collapsing storms that were situated further to the southwest. The storm was too close for the RADAP II system (11 nm range limit) to determine VIL and TOP values. However, the OKC WSR-57 radar was still able to give a good presentation of the reflectivities below 25000 ft and this information was collaborated with radar information from the Tulsa, OK (TUL) WSR-74C radar. The TUL radar operator confirmed the reflectivity distribution indicated by the OKC radar and also determined the height (38000 ft/11500 m) of the storm and the distribution of the reflectivities above 25000 ft.

5. EVOLUTION OF THE WET MICROBURST EVENT

To calculate the maximum FPG that could have occurred with the storm located just southwest of OKC at 1145 UTC, the peak VIL value must first be determined. Fig. 7 is an enlargement of fig. 6 with the corresponding VIL values calculated for each layer indicated. It is important to remember to use the equivalent reflectivity values and the not the power returned (dBz) or the VIP intensity levels. Table 1 is a list of VIP levels, the corresponding power returned, and the associated equivalent reflectivity values.

It is apparent from the calculations depicted in fig. 7 that VIL is biased towards large intensity levels (> VIP 5) and the vertical depth over which the specific intensity level occurs. In this case, the total VIL (in the center of the cell along a vertical axis) was 50.5 kgm^{-2}. Using equation 3 and a VIL value of 50.5 kgm^{-2} and a TOP value

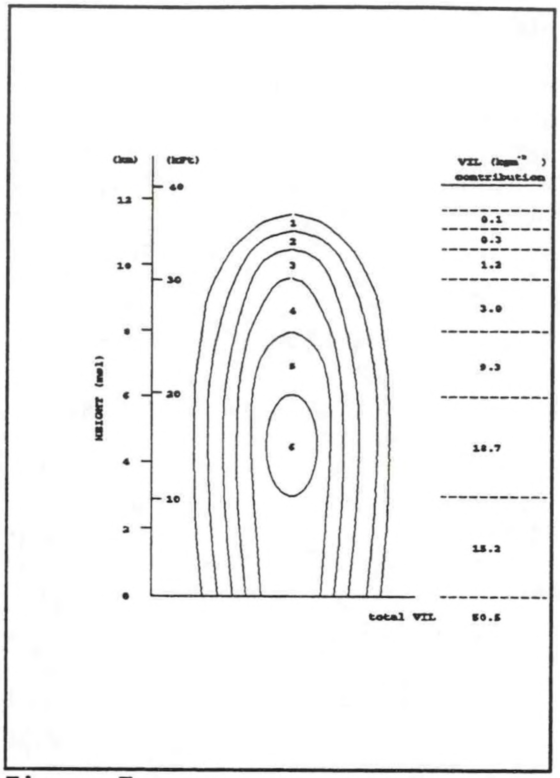

Figure 7

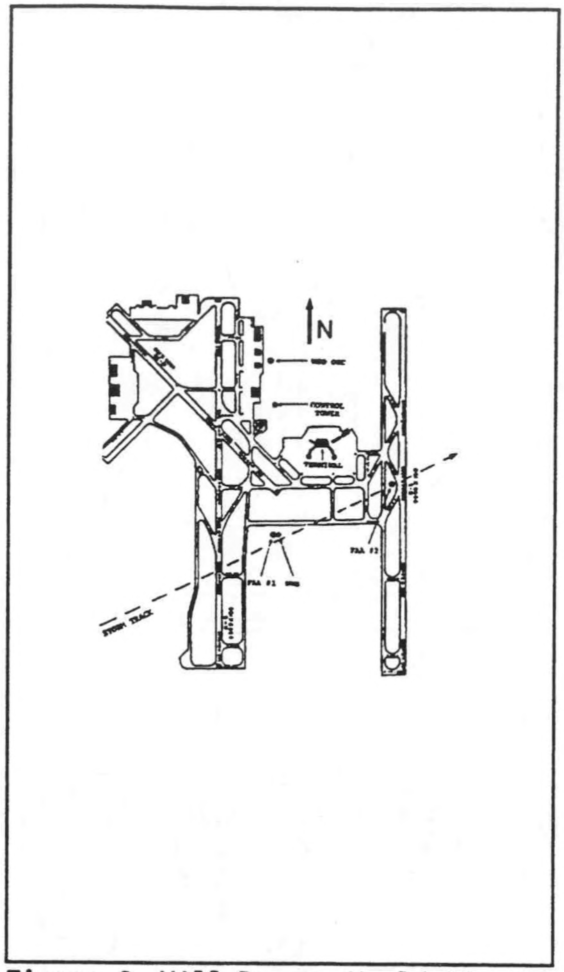

Figure 8 Will Rogers World Airport Oklahoma City, Oklahoma

of 11500 m, R_c is 4.3913 . Substituting that value for R_c into equation 2 yields a potential gust (PG) of 25.1 ms^{-1} or 48.8 kt. Adding 10.7 kt for the vector addition of one-third MLW to the PG of 48.8 kt means that a maximum FPG of 59.5 kt could be expected with this storm.

TABLE 1

VIP LEVEL	POWER RETURNED (dBz)	EQUIVALENT REFLECTIVITY (mm^6m^{-3})
1	18-(30)	0-999
2	30-(41)	1000-12588
3	41-(46)	12589-39810
4	46-(50)	39811-99999
5	50-(57)	100000-501186
6	$\geq$ 57	$\geq$ 501187

Figure 8 is a map of the Will Rogers World Airport (OKC) runway complex. The north-south runways are almost 10000 ft long and the National Weather Service Office (WSO OKC) is located in the north-central part of the runway complex. The FAA anemometer #1 (FAA #1) was located beside the NWS anemometer and both were situated near the south-central part of the runway complex. However, FAA #1 was inoperable that day. FAA anemometer #2 (FAA #2) was located in the center of runway 35R-17L (the easternmost runway) and was in operating that day. The apparent track of the wet microburst is depicted by the dashed arrow extending north-east-southwest across the south-central part of the runway complex. This track is based on visible observations from the roof of the WSO and from the control tower, and the surface wind directions recorded by the NWS and FAA #2 anemometers. The following OKC aviation surface reports will help to give a better understanding of the sequence of events leading up to, during, and after the severe wet microburst event:

OKLAHOMA CITY, OK (OKC--
WILL ROGERS WORLD AIRPORT)
SURFACE WEATHER OBSERVATIONS,
27 SEP 1986

OKC SA 0848 CLR 20 128/73/69/2007/ 995/CB FQT LTGICCC DSNT SE-S MOVG NE/103 1900

OKC SA 0948 CLR 20 128/73/68/1908/ 995/CB FQT LTGICCC DSNT SE MOVG NE CB OCNL LTGIC SW MOVG NE FEW CU AC SW

OKC SA 1048 300 SCT 20 129/73/68/ 1909/996/CB OCNL LTGICCC SW MOVG NE CB FQT LTGICCC E-SE MOVG NE MDT CU SW-W

OKC SP 1136 M38 BKN 75 BKN 300 OVC 20T 1911/998/TB35 SW MOVG NE FQT LTGICCC RB26E32

OKC SA 1148 20 SCT 38 SCT 75 SCT E300 BKN 20T 136/73/70/2013/998/ TB35 SW-S MOVG NE FQT LTGICCCCG TCU W RB26E32/30200 1963 68 20144 RADAT 22136

OKC SP 1155 E20 BKN 75 BKN 300 OVC 15T+RW+ 2145G58/996/T S-SW AND OVHD MOVG NE FQT LTGICCCCG RB54 PRESFR

OKC SP 1219 20 SCT E75 BKN 300 BKN 15 1910/999/TE18 DSIPTD CB SE OCNL LTGIC MOVG NE RE05 PRESRR PK WND 2158/1155

By 1048 UTC, some of the anvil cirrus from the newly developed storms to the southwest began to spread across the area and thunder was reported on station by 1136 UTC. The main core of the thunderstorm passed approximately 1 nm south of WSO OKC and only 0.01 inch of rainfall was recorded in the raingage located on the north side of the weather office. The brief heavy rainfall lasted less than 30 seconds (i.e. the "machine-gun bullet" effect), with the heaviest rainfall occurring on the southside of the WSO.

The maximum wind gust recorded by the NWS anemometer was 58 kt from a direction of 210° at 1155 UTC while surface winds at WSO OKC gusted to only 20 kt based on visual observations. The very sharp surface wind and rainfall gradients attest to the very small diameter of the thunderstorm. The control tower was immediately informed of the severe wind gust and the likelihood of additional microburst activity for the airport complex. At 1157 UTC, the control tower advised WSO OKC that the FAA #2 anemometer recorded a surface wind gust of 240° at 61 kt. The predicted FPG prior to the occurrence of the event was <u>241° at 59.5 kt</u>! Based on the two anemometer reports, the FPG gust error was only ± 1.5 kt.

Surface temperatures at WSO OKC remained at 73°F prior to and during the wet microburst event. However, a weak rainshower had passed over the northern portion of the runway complex prior to the event between 1126 UTC and 1132 UTC the resulting evaporation caused the surface dew-point to increase from 68°F to 70°F. The slight increase in the surface virtual temperature and the resulting decrease in the density may be a possible explanation for the higher than predicted wind gust (61 kt vs. 59.5 kt) observed.

Less than 10 minutes after the occurrence of the last severe wet microburst report, visual observations indicated the thunderstorm was rapidly dissipating. A well-defined, classical cumulonimbus cloud was located approximately 5 miles east of OKC, but was very translucent with the rising sun dimly visible through the middle portion of the cloud. The storm was dissipating as quickly as it had formed and apparently had unloaded all of its liquid water during the severe wet microburst event. The lack of any significant liquid water within the remains of the storm resulted in its thin, translucent appearance and the rapid evaporation of the remaining cloud water (recall the extremely dry air above the 600 mb level).

6. SUMMARY AND CONCLUSIONS

Fortunately there was no significant damage and no aviation accident reported with this microburst event. However, had this event occurred during a time of the day (e.g. late afternoon) when air traffic would have been at a maximum, the results could have been devastating.

Despite the relatively small size of this storm (both vertically and horizontally), a severe wet microburst occurred and did so during the most unlikely (climatologically speaking) time of day. This example should further strengthen the fact that severe wet microbursts can occur at any time of day or time of the year if favorable atmospheric conditions exist.

During periods of weak synoptic-scale forcing, strong low-level forcing due to enhanced convergence resulting from gust front interaction can produce strong upward vertical motion which can lead to a sudden and rapid release of conditional instability. Strong low-level moisture convergence can result in extremely large amounts of liquid water (and ice) being suspended in the mid-levels of a storm where the entrainment of dry, low θ_e can result in the development of a severe penetrative downdraft.

An objective warning forecast technique has been presented to help eliminate much of the subjectivity and "guesswork" involved in issuing severe thunderstorm warnings on short-lived thunderstorms which are capable of producing severe wet microbursts. The typical gust prediction error associated with this technique is ±2 kt and the average lead time is 15 minutes with occasional lead times of 30 minutes or more (the lead time in this case was only 10 minutes due to explosive storm development). The only variables required are radar derived values of VIL and TOP. This technique could easily be employed in the existing RADAP II system and in the oncoming NEXRAD doppler radars. For those stations still using conventional weather radar data, a slightly less accurate form of the technique can be used by developing a simple nomogram (or computer program) containing specific VIL values associated with various equivalent reflectivities and vertical depths. That data would then be incorporated into another nomogram of total VIL and maximum TOP to generate a potential gust forecast. The final potential gust would then be determined by adding one-third of the mean layer winds in the lower 5000 ft.

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AN EXAMINATION OF DOWNBURSTS IN THE EASTERN GREAT PLAINS ASSOCIATED WITH A VERY WARM MID-LEVEL ENVIRONMENT

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1. Introduction

It has long been suggested that in the eastern part of the Great Plains the chances for thunderstorms becomes small with a 700 mb temperature greater than +10°C. It has also been suggested that the areas of thunderstorms occur on the cool side of the 700 mb +10°C isotherm (Fig. 1). Since generated 700 mb temperatures are not available, a field forecaster relies on the 5760 meter 1000-500 mb thickness contour which closely corresponds to the 700 mb +10°C isotherm (Fig. 2). Schaefer (1986) mentions this rule and also notes that in forecasting nocturnal Mesoscale Convective Complex (MCC) events that a 700 mb temperature greater than 12°C suppresses organized convection. This 700 mb isotherm rule of thumb for the Eastern Plains would not have the same application in the Western Plains due to the higher surface elevations.

Rules of thumb are convenient empirical tools that can be of great use to a forecaster "under the gun". There are scientifically based reasons why the rules work. Sometimes, however, they will fail. Doswell (1986) has pointed out that it is the responsibility of all meteorologists to not only be empiricists, but also to understand the foundations of the rule. Otherwise it is impossible to know in advance when the rule will fail.

The author has found the "+10 rule" very useful and also has helped to locate the greatest probability of thunderstorms. The author has also observed that when the rule fails and thunderstorms do occur with very warm mid-level temperatures in the Omaha area, that downbursts or microbursts are possible. One example of when the rule failed was July 15, 1988 when strong forcing overcame 700 mb temperatures +12°Celsius or better. The strong forcing mechanisms were a Mesoscale Vortex Center (MVC) (as described by Johnston (1982)), along with differential heating and moisture convergence. The MVC developed with a flash flood producing MCC the previous night in southwest Nebraska and moved into east central Nebraska in the afternoon. The resulting severe thunderstorm produced a tornado at Council Bluffs, Iowa, along with several downbursts and microbursts.

This paper investigates the situation in which thunderstorms occur with 700 mb temperatures greater than +10°C or +12°C. Forecasters should be alert to the possibility of downbursts or microbursts under such conditions.

2. Case Studies

A. Case I - A Major Downburst Event in Northeast Nebraska

During the pre-dawn hours of August 5, 1989 thunderstorms developed in North Central Nebraska.

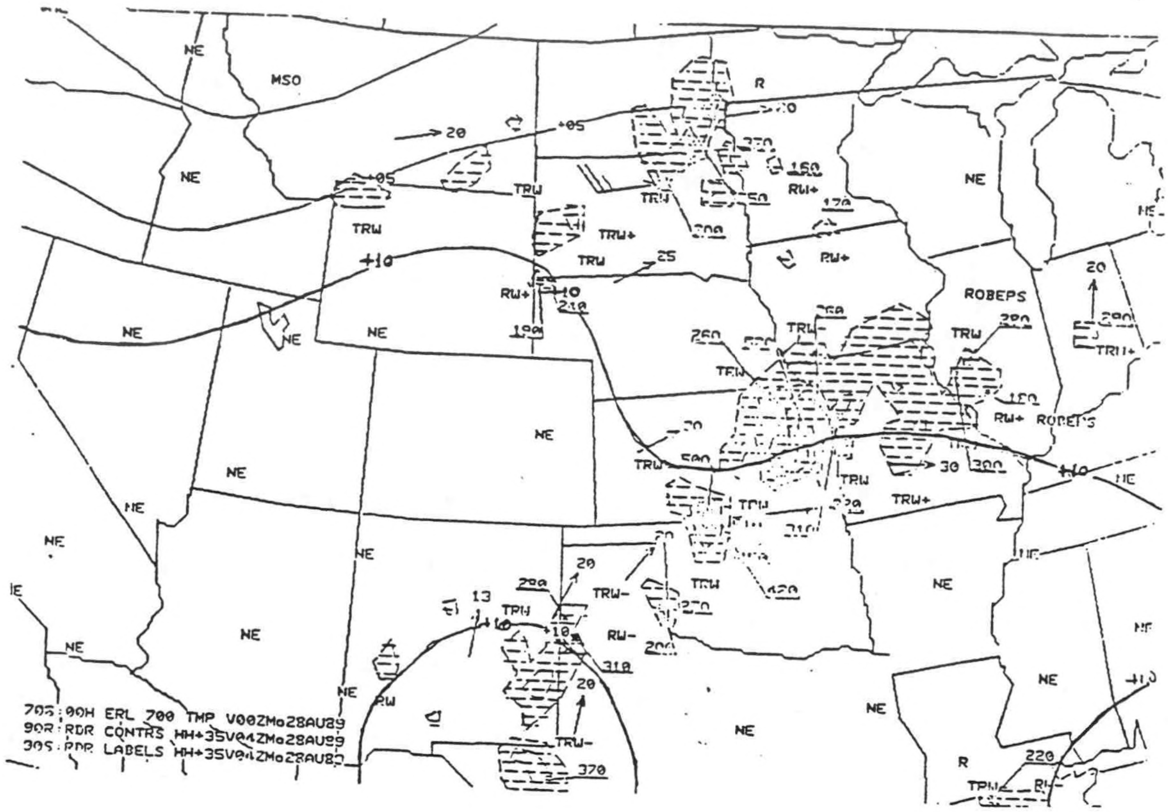

Figure 1. Radar analysis for 04Z and 700 mb temperature analysis for 00Z August 28, 1989.

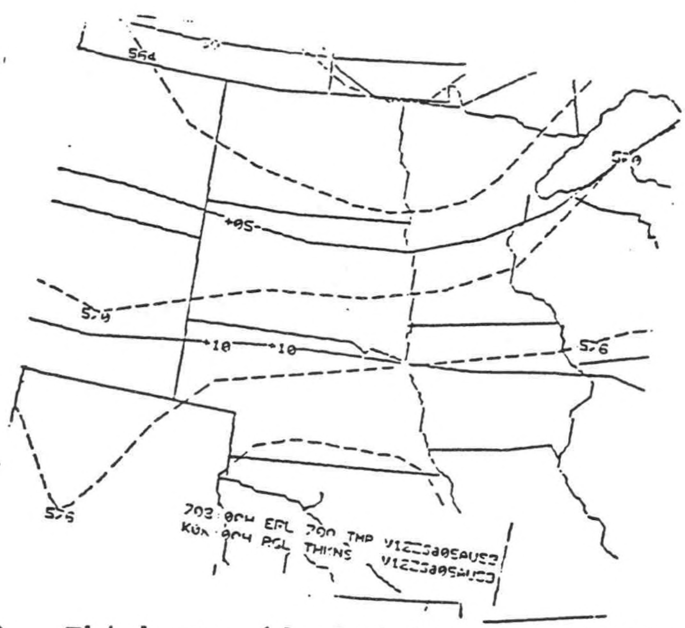

Figure 2. Thickness (dashed lines) and 700 mb temperature (solid lines) analysis for 12Z, August 5, 1989.

The 00z and 12z August 5, 1989 Omaha Nebraska (OMA) showed 700 mb temperatures of +12°C. The +10°C 700 mb isotherm extended east-west across northern Nebraska. The high based thunderstorms developed in an area of divergence aloft in the right rear quadrant of a jet max. Also there was enough mid level cold advection to break the capping effect of the warm mid-level temperatures (see Fig. 3). A violent thunderstorm produced widespread damage due to downbursts across northeast Nebraska extending to just north of Omaha. Winds gusted to 81 mph when the thunderstorms were in the Norfolk, Nebraska, (OFK) area. The WSFO at Omaha reported wind gusts of 55 mph with the passage of the outflow boundary.

Thus, with this case there was strong forcing with a warm mid-level environment, and although low level moisture was not lacking (a 12°C dew point at 850 mb) on the 12Z August 5, 1989 OMA sounding (see Fig. 4), the warm lapse rate below the high cumulonimbus cloud base allowed entrained air, cooled by evaporation, to become extremely negatively buoyant.

In light of this case in which strong forcing was necessary for thunderstorm production due to the warm mid-level environment, it can be seen that even with a high low level mean mixing ratio the thunderstorms on the morning of August 5 were high based. Note that the thunderstorms did remain near the +10°C 700 mb isotherm, and that in the warmer air to the south no thunderstorms occurred. The strong outflow boundary generated by the downbursts moved well south of the parent thunderstorms, which remained north of the +12° 700 mb isotherm.

The thunderstorms favored the area along the +10°C isotherm at 700 mb.

So the "rules of thumb" worked in this case. But it is suggested that the "rules" be expanded so that, if thunderstorms do occur with these warm mid level temperatures, forecasters are aware of the potential for downbursts and especially microbursts.

The next three cases are examinations of warm mid-level environments in which microbursts occurred in the WSFO Omaha county warning area. In these cases the dynamics and thermodynamics the processes producing the microbursts will be examined.

From Haltiner and Martin's Dynamical and Physical Meteorology

$$d\,(w^2/2) = -R_d\,(T_v' - T_v)\,d(\ln p) \qquad (1)$$

where w = vertical velocity, R_d = the gas constant for dry air, T_v' = the virtual temperature of a parcel, T_v = the environment virtual temperature, and P = atmospheric pressure. The equation shows that the change in the vertical velocity of an accelerated parcel is a function of the difference between the virtual temperature of the environment (T_v) and the parcel (T_v'). The parcel method is a familiar analysis tool and potential energy for the updraft can be determined from the positive area on the skew-T after lifting a parcel through saturation and then along a moist adiabat through the equilibrium point, usually above the troposphere in strong storms.

Here in this paper the concern is the acceleration of a parcel of air that has been cooled by evaporative cooling below the high based thunderstorm in the below cloud base

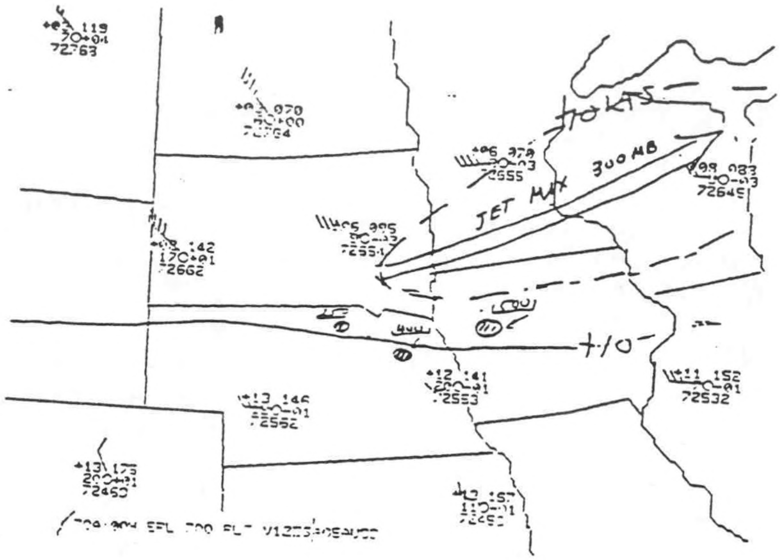

Figure 3. **12Z August 5, 1989 300 mb jet overlaid on the 700 mb analysis**

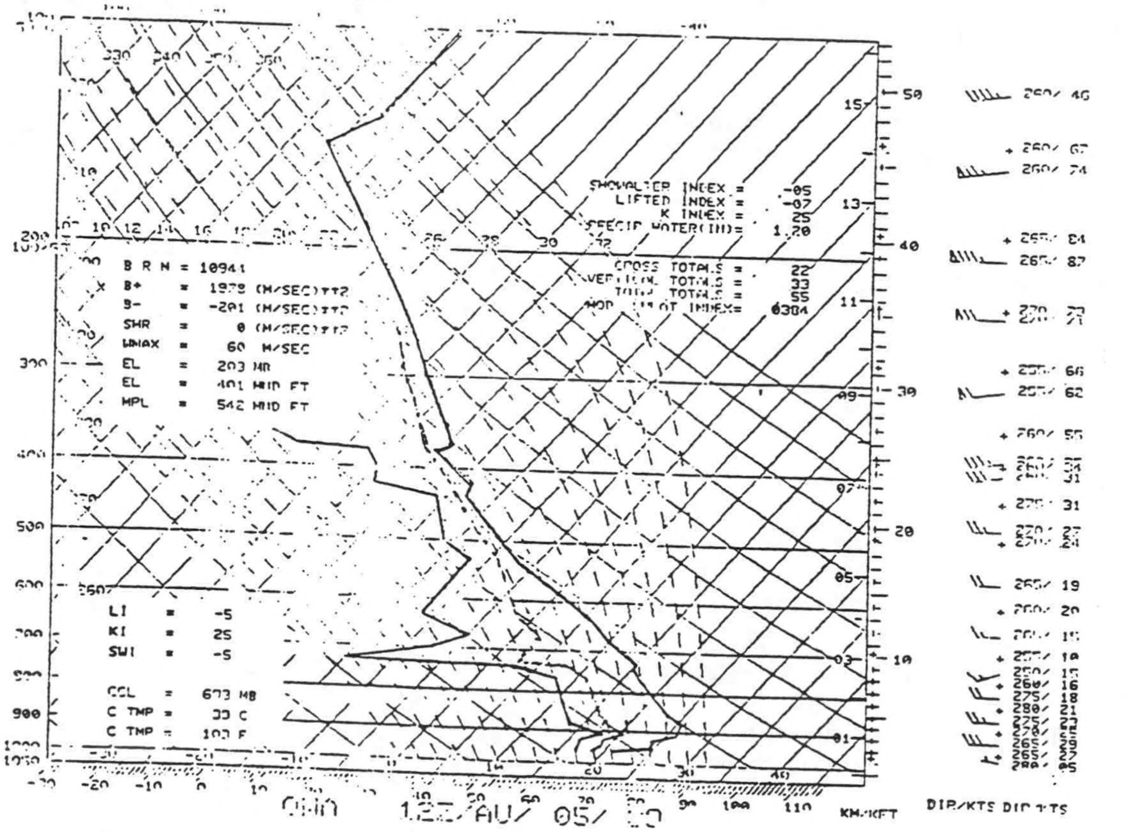

Figure 4. **12Z August 5, 1989 OMA Sounding with CONVECT parameters. Dashed line between the temperature/dew point plot is the wet bulb temperature.**

environment. The source of the entrained air that is accelerated downward to cause downbursts or microbursts can either be air cooled at or below the cloud base, or as Kessler (1985) suggests, from areas above the base. Downbursts and microbursts that occur in low based thunderstorms in a very moist low layers most likely originate well up into the cloud layer where some dry air is entrained as stated by Kessler (1985). Kessler based this fact on the evidence of the low wet bulb temperatures observed beneath severe thunderstorms. Kessler pointed out that negatively buoyant air will descend at the moist adiabatic lapse rate as long as there is enough precipitation to keep the descending air saturated. Fujita and Black (1986) studied the SST (Small Severe Thunderstorm) and pointed out that the mid level dry air can be drawn into the descending current easily by virtue of the small cloud diameter. Darkow and McCann (1975) show that the relative wind flow from 121 thunderstorms was at a minimum at this level, suggesting that this is the most likely level for injecting environmental air into the storm. If, however, the entire liquid content of the descending parcel is evaporated (as is the case in some microbursts from high based thunderstorms) the descent would be dry adiabatic.

In the three cases of microbursts that are examined here the soundings are not of a pre-storm environment, but rather of the microburst environment beneath high based cumulonimbus. It was assumed that the air near the cloud base is cooled to the mean wet bulb temperature, then descended moist adiabatically for a short time, with the parcel then descending and warming somewhere between the dry and moist adiabatic lapse rate. The energy of the negative parcel is proportional to the areas shown on the curves of Figures 5, 6 and 10. The vertical velocity profile of a descending parcel can be constructed using the equation:

$$\frac{dw}{dt} = w\frac{\partial w}{\partial w} = \frac{\partial\left(\frac{w^2}{2}\right)}{\partial} z = g(T_v' - T_v)/T_v \qquad (2)$$

where w = parcel vertical velocity m/sec, g = 9.8 m/sec2, and T_v = degrees K
rewriting

$$\Delta\left(\frac{w^2}{2}\right) = g(T_v' - T_v)/(T_v)\Delta Z \qquad (3)$$

using z = .5 km and assuming w=0 at cloud base, and w(sfc) diverges out becoming a near surface horizontal velocity. The vertical velocity (i.e., w (sfc)) can be computed by adding each w^2 computed for every .5 km below the cloud base to about .5 km above the ground, then taking the square root of the sum.

From the equation it can be seen that having a deep layer below the cloud base contributes to a stronger w (sfc). Also, the warmer the environment the greater the negative buoyancy of the parcel. Finally, the lower the wet bulb temperature of the entrained air the greater the acceleration of the parcel downward.

B. Case II - July 14, 1200z

Although the 700 mb temperature at 1200Z (Fig. 5) from the OMA sounding was a very warm 14.8°C, there were widely scattered small

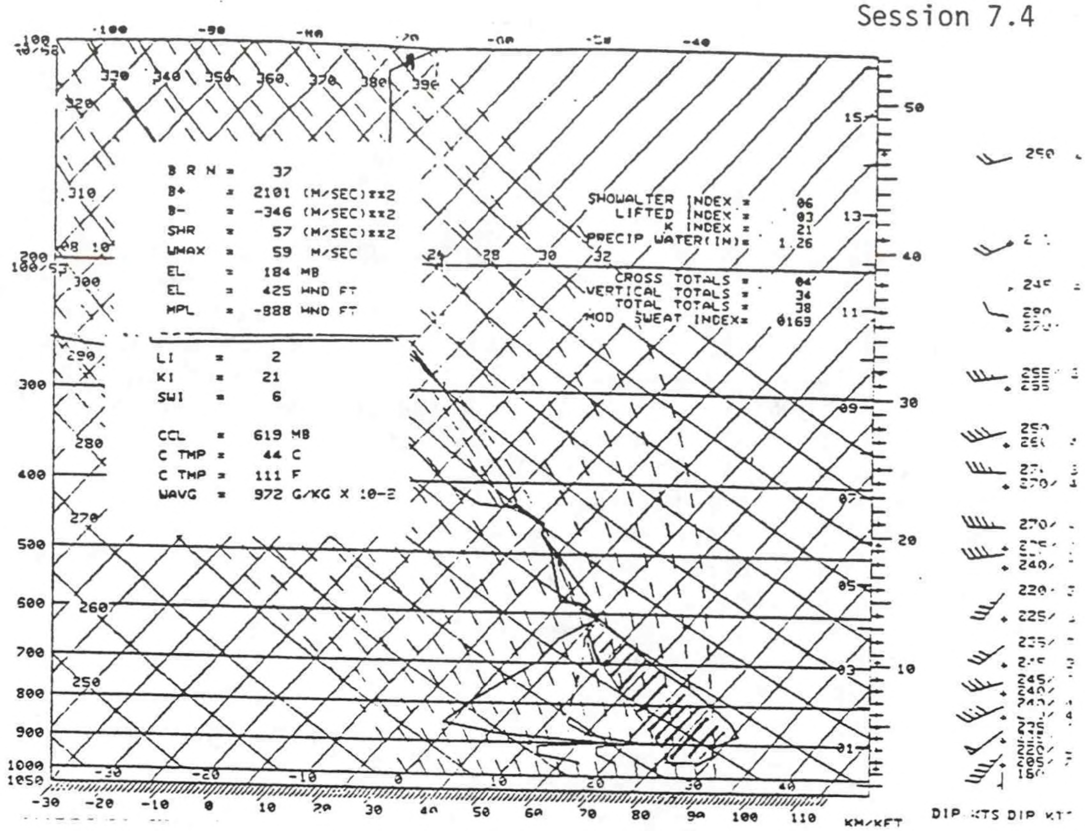

Figure 5. 12z July 14, 1980 OMA sounding with CONVECT parameters and negative area for estimating microburst winds.

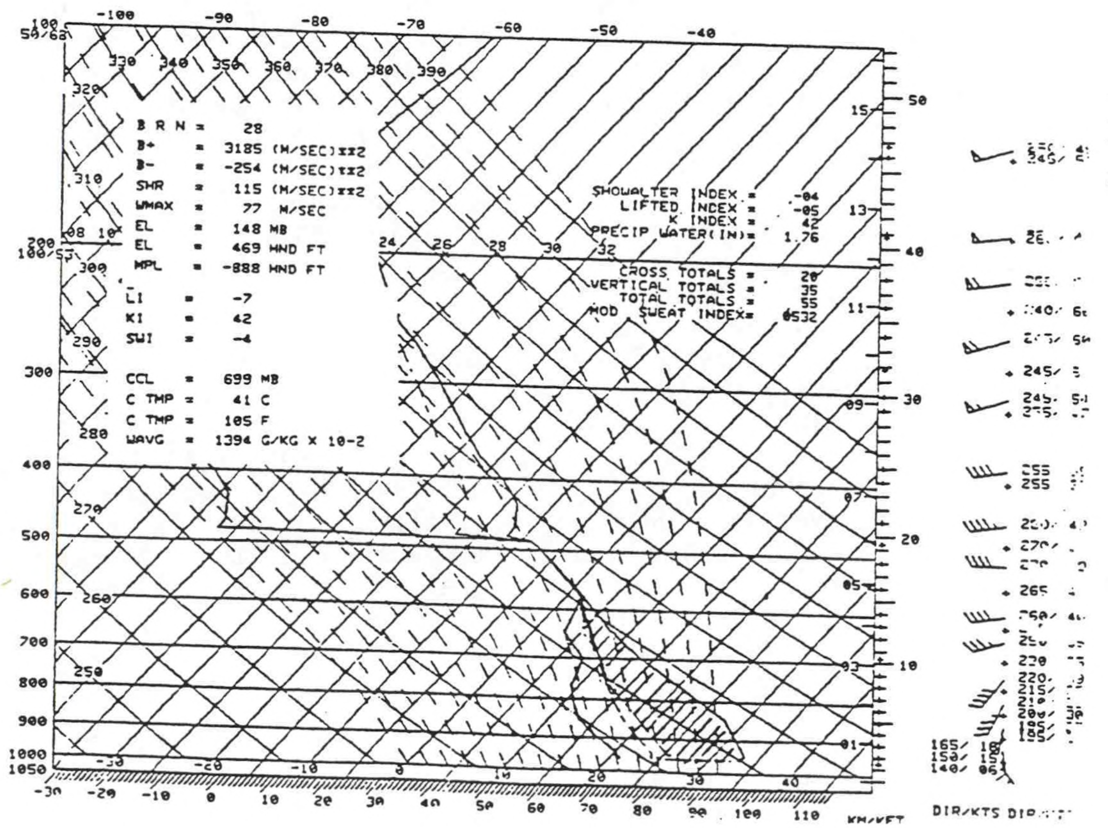

Figure 6. 00Z July 16, 1980 OMA sounding with CONVECT parameters and negative area for estimating microburst winds.

thunderstorms in the Omaha local area. The sounding indicated a cloud base of 14,000 ft (4.3 km). With such a warm T_v and a low T_v', due to the low wet bulb temperature of the layer, the stage was set for the microburst. At 10Z Valley Nebraska just Northwest of Omaha reported a 90 mph wind gust, damaging six homes and a factory.

Another interesting feature concerning the atmospheric conditions the morning of this microburst was the possible contribution of downward mixed momentum of the low level jet. (Note in Fig. 5 the 50 kt southwest wind 4 to 5 thousand feet.) Brown *et al*. (1982) suggest that for microbursts in high based cumulonimbus clouds was not a negligible factor, but that divergence forced by the downdraft induced by evaporative cooling impinging on the surface of the surface of the earth is primarily responsible for the strong winds.

Calculations of the vertical velocity attained near the ground using equation (3) for this sounding suggest that a damaging microburst could occur simply from the thermodynamics. Assuming that the .5 km above the ground is converted at the surface to a horizontal component, a wind speed of 85 mph was calculated. This compared well with the observed microburst at Valley Nebraska.

C. Case III - July 16, 1980 0315z

On the evening of July 15 at 10:15 p.m. CDT, a microburst with winds estimated at 100 mph caused severe damage to the town of Silver City, Iowa, 20 miles southeast of Omaha. Boards were blown through the sides of houses and a huge ammonia tank was hurled several yards. A survey of the damaged area verified a narrow band of straight line wind caused the damage. Rain with the microburst was reported to be hard for just a brief time.

Looking at the 00Z OMA sounding (Fig. 6) note that the 700 mb temperature was 13.4°C. A high cloud base of 15,000 ft (4.6 km) was indicated, and there were widely scattered thunderstorms in the area. Although the below cloud base environment was moist, the warm environment temperature and the high thunderstorm base allowed a large negative buoyancy area. Calculations indicated a potential surface wind gust of 77 mph. It was also noted that the that this the Mills County area during the evening were small, placing this storm in the class of an SST as was the storm in Case II.

D. Case IV - June 5, 1990 1100Z

The June 5, 1991 00Z upper air data showed that the +10°C at 700 mb extended across eastern Nebraska. In fact, the Omaha (OVN) sounding at this time was a +10°C, with continued mid level warm advection. There was also strong warm advection at 850 mb with a tongue of 850 mb dew points 5 to 6°C. By 06Z convection was becoming more organized to the right of the +10°C isotherm in South Dakota and extreme northeast Nebraska (see Figure 7). The 700 mb analysis for June 5, 1990, 1200z (Figure 8) showed that very warm +13°C temperatures had spread across all of eastern and central Nebraska, and that there was a close correspondence of the +10 isotherm to the 5760 meter contour.

Forcing was strong, with the advance of a weak pacific into cen-

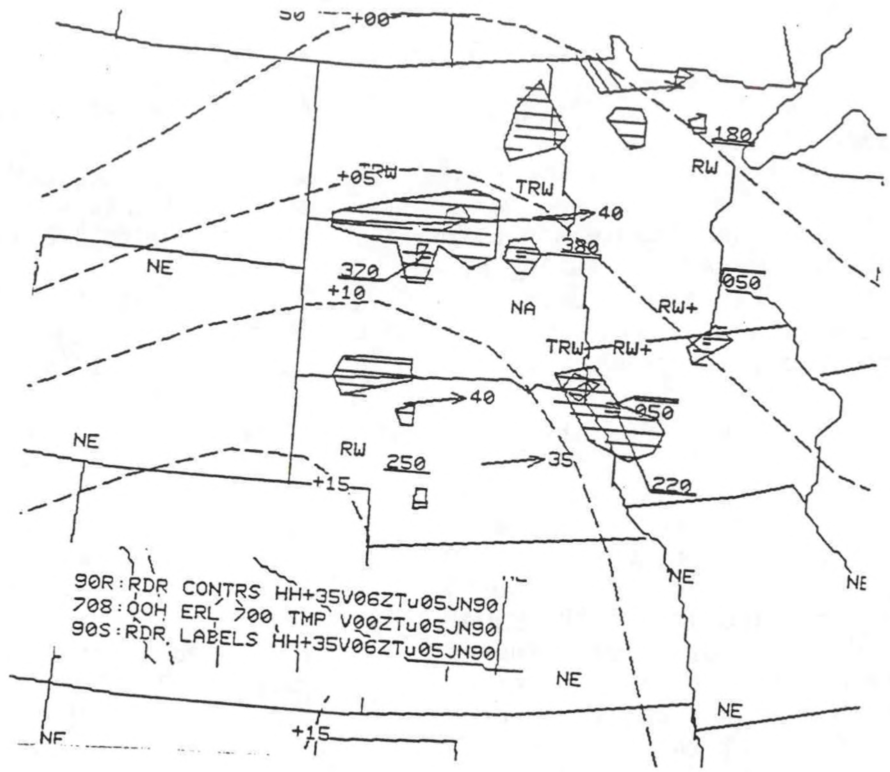

Figure 7. 06Z June 5, 1990 radar summary chart with 00Z June 5, 1990 700 mb isotherms overlaid.

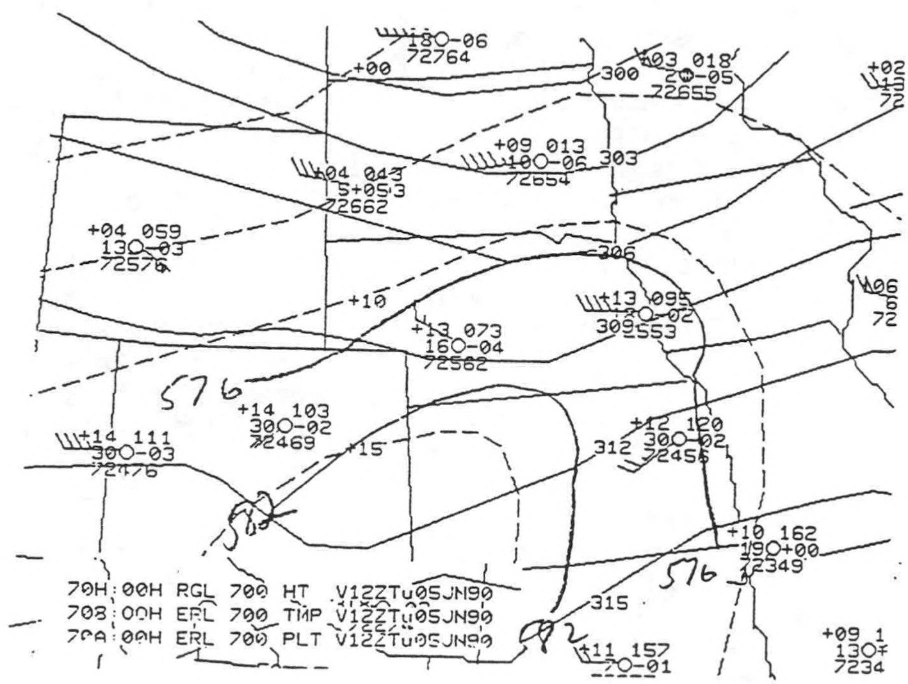

Figure 8. 12Z June 5, 1990 700 mb plot and analysis with 1000-500 mb thickness contours overlaid.

tral Nebraska after 06z, and by 09Z isolated convection had developed around Grand Island, while the widespread and well organized convection had moved into Minnesota and northwest Iowa (see satellite picture Figure 9). Initially, wind gusts from the small thunderstorms cluster in the warm mid levels at Grand Island reached 35 mph with the passage of the storms. Using the hypothesis developed from the 1980 thunderstorms in cases I, and II, the forecaster could then be alert to the threat of microbursts with the isolated convection as it moved east. At 1130-1145Z thunderstorm induced wind gusts of 60 to 70 mph occurred in localized areas of western Douglas county and in the city of Omaha as the small cluster of thunderstorms that had developed earlier around Grand Island moved into the area. The June 5, 12Z Omaha sounding, with CONVECT data is shown in Figure 10. Using the shaded area of parcel negative buoyancy a negative vertical velocity of 41 m/sec (82 mph) was computed as an estimate of potential microburst velocities.

Also worthy of note is the very strong low level wind of 40 to 50 knots in the lower 2000 feet, indicating the possible effects of momentum transfer to enhance microburst strength, though the author believes that the evaporative cooling mechanism to be the most significant mechanism.

3. Summary and Conclusion

A rule of thumb in the eastern part of the Plains is that the chance of thunderstorms decreases significantly when the 700 mb temperature is above +10°C, especially +12°C or better. Often organized thunderstorm areas are found to the cold side of the +10°C isotherm. For forecast purposes the +10°C isotherm at 700 mb corresponds closely to the 5760 meter 1000-500 mb thickness contour.

These rules of thumb like all others, do not always work. At times large scale forcing is strong enough to overcome the capping effect of the warm mid-levels. A thorough mesoscale analysis and use of the CONVECT AFOS Applications program (Stone, 1986) can help in determining when the rule will work or not work. But as a hypothesis, once thunderstorms develop in the Eastern Plains with these very warm mid-level temperatures, the potential for damaging downbursts and microbursts is enhanced. Theoretical values for computing a downburst vertical velocity profile can be easily derived using parameters obtained from the sounding and the CONVECT program output.

A pre-storm scheme developed by McDonald (1976) for the Western Region computes the upper level stability index (UI) from the raobs and considers the 700 mb temp/dew point spread. A parcel is lifted from 500 mb to the LCL then follows a saturation adiabat through 400 mb to 300 mb. UI is then expressed as,

$$UI = [T(400mb) - T(500mb\ parcel) + [T(300mb) - T(500\ mb\ parcel)$$

Using the nomogram in Figure 11 enter the 700 mb depression and the UI. The results are interpreted as: Area 1 is too moist for storm gusts; Area 2 is too stable for upper level thunderstorms; Area 3 yields gusts > 30 kts; and Area 4 - yields gusts > 40 kts.

Eastern Plains offices could develop similar gust potential indi-

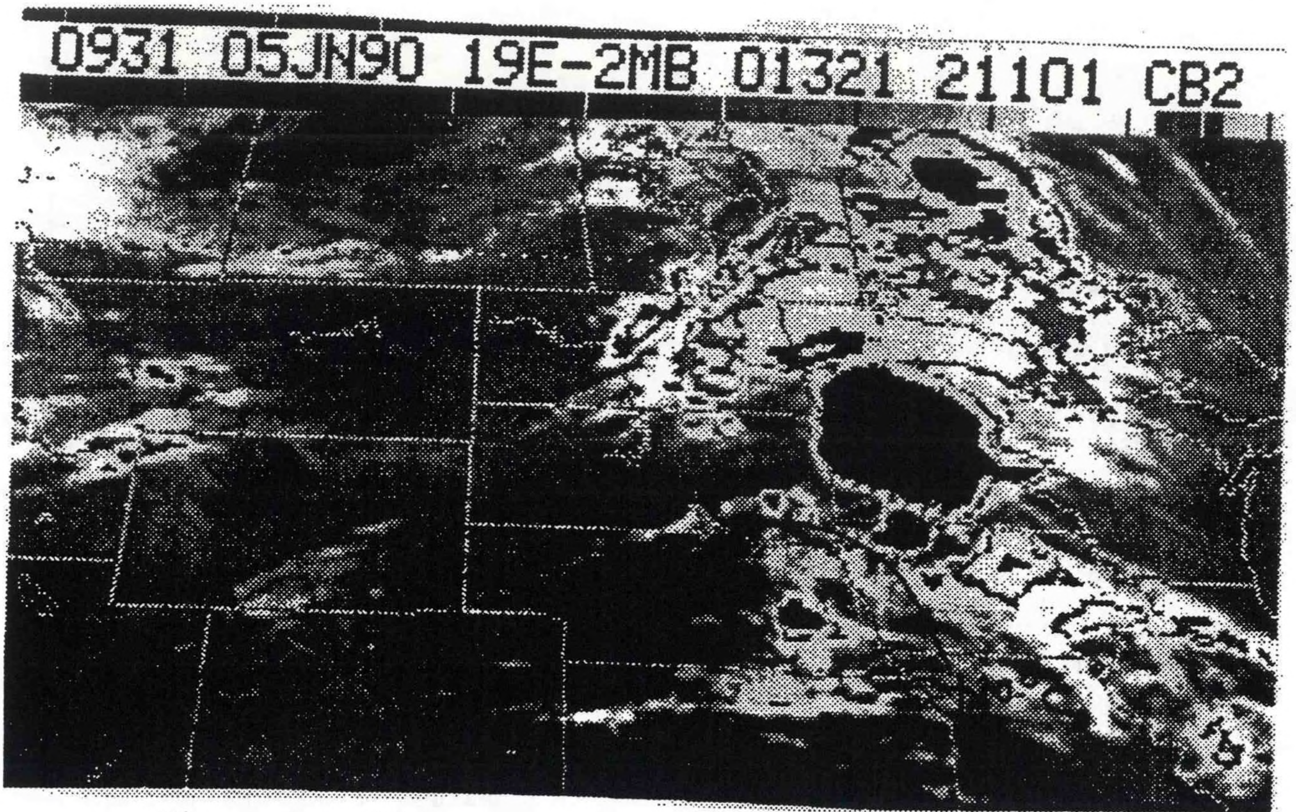

Figure 9. 0930Z June 5, 1990 GOES satellite imagery with +10 degree Celsius isotherm at 700 mb at 12Z overlaid.

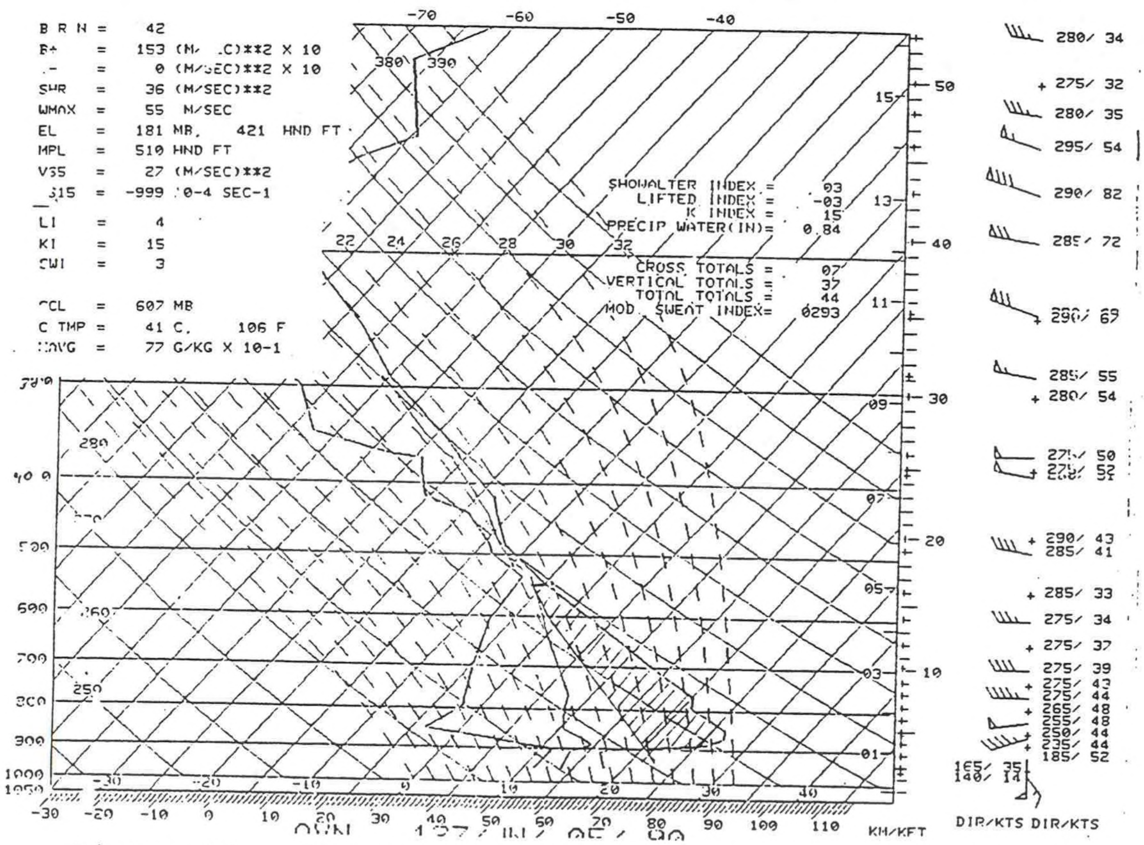

Figure 10. 12Z June 5, 1990 OVN sounding with CONVECT parameters and showing negative area for estimating microburst winds.

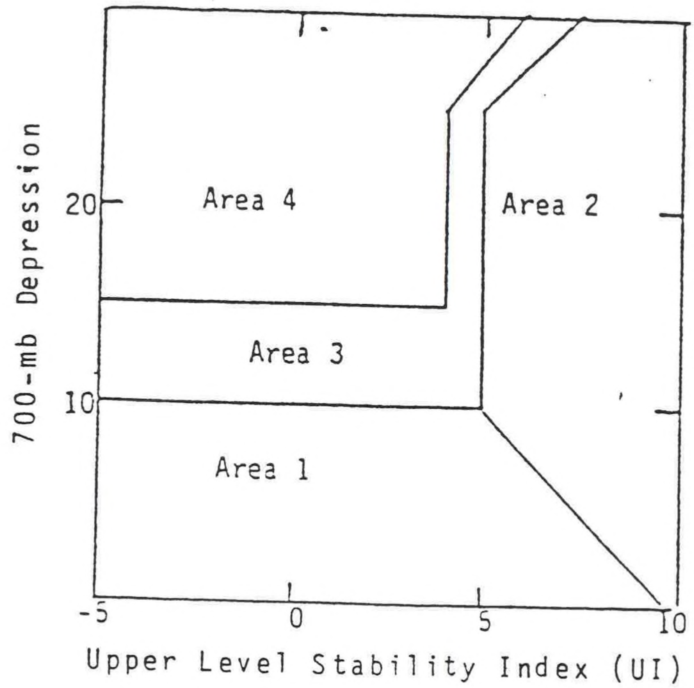

Figure 11
Nomogram for estimating gust potential based on the Upper level Stability Index (UI) and the 700 mb Depression.

ces based on this scheme but lifting from 700 mb and using the depression at 850 mb and the upper level stability charts 70s and 7qs from the Upper Air Diagnostics program developed by Foster (1989).

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TOWARD A CLIMATOLOGY OF SOUTH TEXAS DOWNBURSTS

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1. INTRODUCTION

The aviation community has devoted considerable attention in recent years to the role of downbursts in aircraft mishaps and accidents. In response to this concern, research and operational meteorologists have conducted various studies in an effort to determine the environmental factors contributing to downburst generation. Early efforts described the classic dry environment downbursts which occur quite frequently on the High Plains. More recent studies have shown downburst events to occur in a wide variety of meteorological environments with multiple factors playing a role in the production of the winds.

The variability of environments and causal factors mandates a need for regional climatologies. In Texas, one such climatology has been developed. Read (1987) and Read and Elmore (1989) documented some 55 cases of downburst occurrence in North Texas for the 1985-87 summer seasons. This climatology identified several characteristics thought to be responsible for downburst generation and resulted in the development of a forecast and warning technique currently being utilized operationally.

Some work has been done regarding West Texas downbursts as well. Sohl (1987) examined two microburst events in May 1986. Garner (1990) looked at an additional event with particular regard to establishing a forecast and warning technique.

Preliminary work toward a climatology for South Texas was done by Ladd (1989) who looked at two summer events in the San Antonio area. Ten events that occurred during the summers of 1982-90, including the two previously examined by Ladd, are included in this study. Our aim in producing this climatology is not only to describe downburst events and identify their probable generating mechanisms in South Texas, but also to provide the operational forecaster with a tool in forecasting and possibly warning for downburst occurrence.

2. CONTROLS ON SUMMERTIME CONVECTION

Downbursts are a product of the convective process. Therefore, a natural starting point for any climatology of these phenomena is to identify the common controls on convection. Thunderstorms occur in South Texas in every month of the year. However, since all of the events examined in this study occurred in the summer months, our discussion of thunderstorm development will be limited to that season.

The predominant air mass overlying South Texas in summer is tropical. The Azores-Bermuda high pressure system is typically positioned over the southeastern tier of states during that time of year, with the circulation around its western periphery producing prevailing breezes off the Gulf of Mexico and across South Texas. Abundant low-level moisture carried by this flow results in a fair degree of convective (potential) instability. Mixing promoted by the instability continually works to deepen the moist layer and produce a characteristic vertical profile that is quite warm and moist, often to a height of 5 km or more.

Thus, two of the necessary conditions for thunderstorm development, abundant moisture and instability, exist for a high percentage of summer days in South Texas. However, synoptic-scale triggering mechanisms are generally lacking in the summer season. As a result, thunderstorm activity is typically widely scattered and has its impetus in strong afternoon heating. Due to the high precipitable water content of the air, this activity can produce locally heavy rainfall; but severe weather, if any, is brief and marginal.

On the rare occasion that a synoptic-scale disturbance in the westerlies finds its way far enough south, severe thunderstorms can and do develop across the area. Since wind and temperature fields aloft are weak and the Wet-Bulb Zero Height is quite high, the severe weather usually takes the form of strong straight-line surface outflow, i.e. gust fronts and downbursts.

A more common scenario leading to the production of summertime severe weather involves outflow from thunderstorms, often many miles away, that triggers what can be termed "second-generation" convection in increasingly unstable air. Further interaction with a strong thermal gradient at the surface or a late afternoon seabreeze front off the Gulf of Mexico increases the likelihood of severe weather.

3. ANALYSIS PROCEDURES

Ten downburst events that occurred in Southeast Texas, South Central Texas and along the Coastal Plains were examined. Nine events occurred during the afternoon from July to early September. The remaining event occurred at night in early June, before the official start of summer.

The analysis techniques used were similar to those employed in Read's (1987) North Texas study. The aim was to provide continuity across the two adjacent areas as well as discern significant differences, if any, that may exist in atmospheric structure and downburst generation mechanisms. Considerable effort was devoted to the examination of upper-air patterns to ensure that subtle synoptic features were not characteristically evident in the pre-downburst environment over South Texas.

Hourly surface charts, from several hours prior to as near the time of downburst occurrence as possible, were analyzed for notable mesoscale features. Isobars were drawn at 1 mb intervals. Isotherms and isodrosotherms were drawn at 2°F intervals. Three-hour wind vector change charts were constructed to aid in determining areas of convergence.

Standard level charts up through 200 mb were analyzed for each event. With the emphasis on the pre-downburst environment, the charts used were generally those produced at 1200 UTC. Height contours were drawn at 20 m intervals. Isotherms were analyzed at 1-2°C intervals in search of weak thermal troughs that might have posed a threat of storm development in an otherwise tranquil environment.

Soundings of the pre-storm environment (again, generally those based on 1200 UTC data) were analyzed in great detail. Each sounding was modified to approximate atmospheric conditions as close to the time of actual downburst occurrence as possible. The surface temperature just prior to thunderstorm occurrence and the average mixing ratio in the lowest 100 mb were used to compute the Lifted Condensation Level (LCL), Convective Condensation Level (CCL) and Lifted Index (LI). From these modified soundings, a composite, or mean, sounding was constructed (Figure 1).

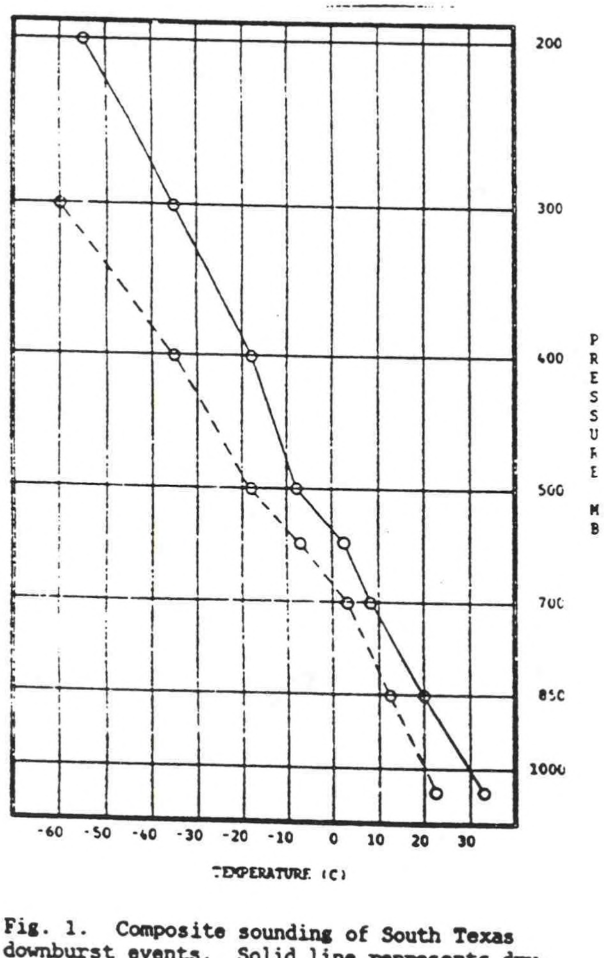

Fig. 1. Composite sounding of South Texas downburst events. Solid line represents dry-bulb temperature and dashed line represents dew point temperature.

4. RESULTS OF THE ANALYSES

The results of the analyses are summarized in Table 1. Of some interest is the fact that none of the downbursts studied were directly spawned by the parent thunderstorm complex. Rather they were produced as a result of secondary storm development brought about by the interaction of outflow from the non-severe parent complex and some other low-level forcing feature. The role of this convective-scale interaction in producing second generation severe storms has been described by Purdom and Sinclair (1988).

As was the case in the North Texas study, a close surface isobaric and thermal analysis revealed the existence of some type of forcing boundary in each of the events. In most cases, outflow from an upstream thunderstorm complex was sufficient to trigger the downburst-producing storm. However, on two occasions, interaction with a northwest-moving seabreeze front aided development of severe convection.

Analysis of 3-h wind vector change fields supported the existence of these boundaries and provided some clues to the extent of surface moisture convergence in the vicinity of the downburst. Dew point pooling was thought to play an important role in the North Texas cases and appears to have been a significant factor in South Texas downbursts as well.

No apparent pattern emerged in the upper air analysis that could be successfully linked to downburst production. While in many cases troughing was apparent at some level(s) in the atmosphere, downbursts also occurred at times underneath an extensive ridge (e.g. the events of 24 August 1986 and 24 August 1988). Upper winds were quite weak and in most cases did not support the development of severe weather.

The use of the qualifiers "wet" and "dry" in the table to describe the events refers to the structure of the sounding and, by implication, the suspected generating mechanisms driving the downdraft. This is in general agreement with reasoning set forth by Wilson et al. (1984).

A detailed examination of the soundings indicated a number of differences from those associated with downbursts in North and West Texas. These differences are most apparent when compared with the sounding classification scheme described by Ellrod (1989). Of the ten events studied, eight were typically wet with deep moisture extending above the 500 mb level and capped by a dry (although not nearly as dry as in other studies) layer. The remaining events were most closely identified as hybrid-type, including one event (2 September 1982) previously thought to be dry (Ladd, 1989). As a result, the composite sounding (Figure 1) is uniformly moist at all levels and therefore only slightly convectively unstable. This would support the need for a mechanical means of lift for storm development and subsequent downburst generation.

As in the North Texas study, high surface temperatures did not correlate well with the production of downburst winds. In several of the cases, the estimated surface temperature at the time of the downburst was below seasonal normals. A weak capping inversion was present in only two events. Thus, convection was

Table 1. Summary of South Texas downburst events.

	9-2-82	8-6-84	8-2-85	8-21-86	8-24-86	6-2-87	9-7-87	7-3-88	7-27-88	8-24-88
LOCAL TIME (CDT)	1700	1430	1830	1800	1500	0345	1700	1356	1800	1845
NEAREST NWS OFFICE	SAT	VCT	BPT	CRP	BPT	SAT	SAT	ALI	HOU	SAT
ESTIMATED MAX WIND (MPH)	61	70	70	65	70	70	68	57	?	?
CLASSIFICATION	HYBRID	HYBRID	WET	WET	WET	WET	WET	WET	WET	WET
SFC TEMP (°F AT TIME OF DB)	97	93	98	91	89	75	89	93	96	100
SFC DEWPOINT (°F AT TIME OF DB)	66	72	76	71	74	71	69	76	69	66
SFC BOUNDARY	O/S	T	O	O	O	O	O/S	O	O	O
LIFTED INDEX	-4	-6	-8	-10	-5	-7	-3	-10	-8	-6
K INDEX	23	31	39	27	22	28	34	35	32	35
850-700 MB LAPSE RATE (°C/KM)	-4.9	-5.3	-6.5	-6.0	-5.4	-5.5	-5.5	-6.7	-7.7	-6.2
CAPPING INVERSION	WEAK	NONE	NONE	NONE	NONE	NONE	WEAK	NONE	NONE	NONE
CCL (FT)	4800	3200	4800	3200	4800	2600	5800	4400	5200	5800
AVG MIX/RATIO (G/KG LWR 100 MB)	16.8	17.0	18.5	17.5	15.0	15.0	15.0	18.0	16.0	17.5
600-500 MB MOISTURE	NO	YES	YES	NO	YES	NO	YES	YES	YES	YES
DRYING ABOVE 500 MB	NO	YES	NO	YES	YES	YES	YES	YES	NO	YES
LOW LEVEL CONVERGENCE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
SFC TEMPERATURE RIDGE	OVER	OVER	TO WEST	OVER	OVER	OVER	OVER	OVER	OVER	OVER
SFC MOISTURE RIDGE	TO EAST	OVER	OVER	OVER	OVER	OVER	TO EAST	OVER	OVER	TO EAST
850 MB PATTERN	T/R	T/R	R	T	R	T/R	T/R	T/R	R	R
700 MB PATTERN	T	T/R	R	R/T	R	T	T	T/R	R	R
500 MB PATTERN	T	T/R	R/T	R/T	R	T	T	T	T	R
300 MB PATTERN	T	T	R	R/T	R	T	T	T	T	R
500 MB WIND (KTS)	10	10	15	40	10	30	25	10	5	5
300 MB WIND (KTS)	10	10	20	40	5	50	40	30	10	25

O=THUNDERSTORM OUTFLOW BOUNDARY
T=THERMAL BOUNDARY
O/S=THUNDERSTORM OUTFLOW BOUNDARY INTERACTING WITH SEABREEZE FRONT
T/R=TROUGH TO WEST/RIDGE TO EAST
R/T=RIDGE TO WEST/TROUGH TO EAST
T=UNDERNEATH TROUGH
R=UNDERNEATH RIDGE

allowed to progress virtually unimpeded, often at a Convective Temperature less than the afternoon maximum surface temperature.

Steep subcloud lapse rates (≥8°C/km) have been noted by several researchers as a precursor to downburst occurrence. For dry environments at high elevations, such as Denver, this would translate to a layer extending from 700-500 mb. At lower and more moist environments, e.g. Dallas-Ft. Worth, the comparable layer would extend from 850-700 mb. This lower layer was examined for the South Texas events. However, none of the cases exhibited a lapse rate as steep as 8°C/km, giving a preliminary indication that more than evaporative cooling must be at work in producing the South Texas downburst.

5. POSSIBLE GENERATING MECHANISMS

It is likely that a number of different processes were at work in generating the South Texas downbursts. Evaporative cooling in the subcloud layer or through the penetrative downdraft process, water loading and the form of precipitation within the cloud, and vertical momentum transport have been suggested as generating mechanisms. The role of each in the production of South Texas downbursts was considered.

Research has pointed to a threshold value of 8°C/km for lapse rates from 850-700 mb for downburst occurrence (Caracena et al., 1986). This layer was taken to represent the subcloud layer. In the South Texas events, this was not always the case. Analysis of the soundings indicated cloud bases were well below 700 mb and often below 850 mb. However, the lapse rate from the surface to the CCL was dry or near dry adiabatic in most of the cases despite high moisture content and so probably approached the threshold value in those cases.

In those events where the subcloud lapse rate was less than dry adiabatic, we cannot rule out evaporative cooling as a generating mechanism. Srivastava (1985) has shown that as lapse rates become more stable, higher rainwater content may compensate for the increasing stability, providing energy to the downburst through the evaporative cooling process. With the high surface dew points, subcloud mixing ratios (Table 1) and precipitable water content in the events studied, evaporative cooling may also play a much more significant role in these events than previously thought (Ladd, 1989).

The penetrative downdraft process probably plays only a minor role, if any, in South Texas. In a high percentage of the events examined, moisture extended well above the 500 mb level where it was capped by a somewhat drier layer. This dry layer was not nearly as impressive as in the North Texas environment.

Water or precipitation loading certainly would be a major contributor to downburst generation in South Texas. As was mentioned, precipitable water contents were high and, according to Table 1, K Index values were often above 30°C. Further, instability values and the extent of positive areas on the soundings suggest the existence of updrafts that could have supported high rainwater content. Indeed, heavy rain was reported with many of the events.

An additive effect to the water loading process would be the rapid melting of precipitation in the form of ice. Caracena and Maier (1987) have pointed out that the melting of large quantities of ice particles could add to the negative buoyant energy in the downdraft. Large hail was reported in two of the South Texas events, with small hail reported in another.

As suggested in the preliminary study by Ladd (1989), it is unlikely that vertical momentum transport contributes much to downburst generation. The additional events examined bore this out. Upper-level wind speeds in a high percentage of the events were generally quite weak.

6. OPERATIONAL CONSIDERATIONS

The initial aim of this climatology was to identify common characteristics of downburst-producing thunderstorms across South Texas. Experience has shown that many of these characteristics exist to a certain degree on a large number of summer days. No comparisons were made to atmospheric conditions that either were not conducive to thunderstorm development or did produce storms without reported downbursts. Such a comparison would be a natural extension to this study. Nevertheless, a first attempt at an operational checklist for downburst forecasting can be made.

Such a checklist is given in Figure 2. It is important to emphasize that this checklist is based only on characteristics identified in South Texas downbursts and may not prove useful in other areas of the country. In addition, independent testing to determine the validity and uniqueness of the parameters cited is needed. Such testing and subsequent refinement are planned beginning in the summer of 1991.

The checklist is quite subjective in nature and is intended for use once a potential for thunderstorm activity has been determined. It focuses on two phases of the forecast problem; assessing the potential for downburst development and determining the most likely location for downburst occurrence. In assessing the potential for downburst occurrence, the upper-air sounding is most significant, since the South Texas downburst appears to be highly thermodynamic-driven. However, close attention should be given the surface chart, since the triggers are mechanical in nature.

Once it is judged that the potential is high, close monitoring of convection across the area and for some distance outside the area is required. Satellite and, to a lesser degree, radar and hourly surface analyses are useful in tracking outflow boundaries that could act as triggers of second-generation convection.

Of primary concern is the movement of outflow boundaries into an area of increasing instability and moisture convergence. AFOS Data Analysis Program (ADAP) charts (Bothwell, 1988) are particularly useful in assessing these parameters. If the outflow moves into these areas and collides with an existing temperature ridge and/or another boundary, such as a sea-breeze front, the likelihood of downburst occurrence dramatically increases.

Hopefully, as additional cases are collected and examined in forthcoming summer seasons, an attempt can be made to quantify the checklist.

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SOUTH TEXAS DOWNBURST CHECKLIST

DATE: ______________________ FORECASTER: ______________________

**** NOTE: This checklist is not designed to assess the potential for convective storm development across South Texas. Rather, it should be used to assess the potential for downburst production from any storm that does develop.

PART 1 -- ASSESSING THE POTENTIAL FOR DOWNBURSTS

MODIFY the most recent sounding by using the expected afternoon maximum temperature and changes in the boundary layer mixing ratio:

	YES	NO
1. Will the subcloud layer approach dry-adiabatic?	___	___
2. Will there be only a weak cap at best?	___	___
3. Will the instability increase?	___	___
4. Will precipitable water remain high?	___	___

From an analysis of hourly surface and wind vector change charts, satellite, and radar:

	YES	NO
5. Is upstream convection producing outflow?	___	___
6. Is moisture increasing over a particular area?	___	___
7. Is a temperature ridge developing?	___	___
8. Is wind field convergence increasing?	___	___

PART 2 -- DETERMINING THE LOCATION OF PROBABLE DOWNBURST OCCURRENCE

From a continued analysis of hourly surface charts, ADAP moisture convergence and instability charts, and wind vector change charts:

	YES	NO
1. Is instability increasing in a particular area?	___	___
2. Is moisture pooling into that area?	___	___
3. Is the temperature ridge persisting?	___	___
4. Will outflow interact with other boundaries?	___	___
5. Will outflow (or the interaction) impinge on the area of increasing instability, pooling of moisture and temperature ridge?	___	___

THE DOWNBURST WILL MOST LIKELY OCCUR FROM A STORM TRIGGERED BY OUTFLOW THAT IMPINGES ON THE TEMPERATURE RIDGE IN THE VICINITY OF THE GREATEST MOISTURE POOLING (CONVERGENCE).

Fig. 2. Preliminary checklist for forecasting South Texas downbursts.

USING PROFILER DATA IN AVIATION FORECASTING

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1. Introduction

The National Weather Service Forecast Office in Denver, Colorado, has been integrating wind profiler data into its daily operations for about ten years. These data have been used in all aspects of the forecast function and have been particularly useful in aviation forecasting. Due to the short term nature of the aviation forecast, hourly winds aloft provided by the profiler are very useful in identifying many features that have a direct impact on the aviation community. Shown below are several cases where information provided by the wind profiler has had a direct impact on the aviation forecast or has been used to better understand the physics of a particular situation. This understanding can then be applied to similar cases which occur in the future.

2. Case A

Figure 1 shows a vertical time section of winds aloft as observed by the wind profiler located at Stapleton Airport in Denver, Colorado. Time runs from right to left. The first profile at 1200 UTC 15 February 1990 (15/12, this date/time group symbol will be used throughout the paper) shows weak upslope (northerly) winds at the lowest level with strong south southwesterly winds aloft ahead of an approaching upper level low. As time goes on, note the changes in the winds. In the mid levels (around 500 mb) the winds back around to easterly, then to northerly and finally to north northwesterly. This signature depicts the passage of the cyclone to the south of the profiler. Notice that after the cyclone passes the low level winds increase. This stronger low level flow intensifies the upslope which in turn lowers the ceilings and visibilities as the snowfall increases.

The trend in the winds at the end of the time section pointed to a rapid improvement in conditions. The westerly winds in the 700-600 mb layer are downslope off the Front Range of the Rockies which leads to drying and warming. Indeed, the snow ended and the ceilings and visibilities rapidly increased in the two hours following the 15/21 observation in the time section.

It is important to realize that everything depicted in this figure occurred between the usual upper air observations at 0000 and 1200 UTC. Consequently, the forecaster had detailed knowledge of the upper winds throughout the event, which would not be available using only the standard rawinsonde data. Since this type of pattern is often repeated, knowing what occurred in this case can be translated into timely terminal forecast updates in future cases.

3. Case B

Figure 2 shows the profiler data from Stapleton on 23 January 1990. Again time runs from right to left. The concern on this day was

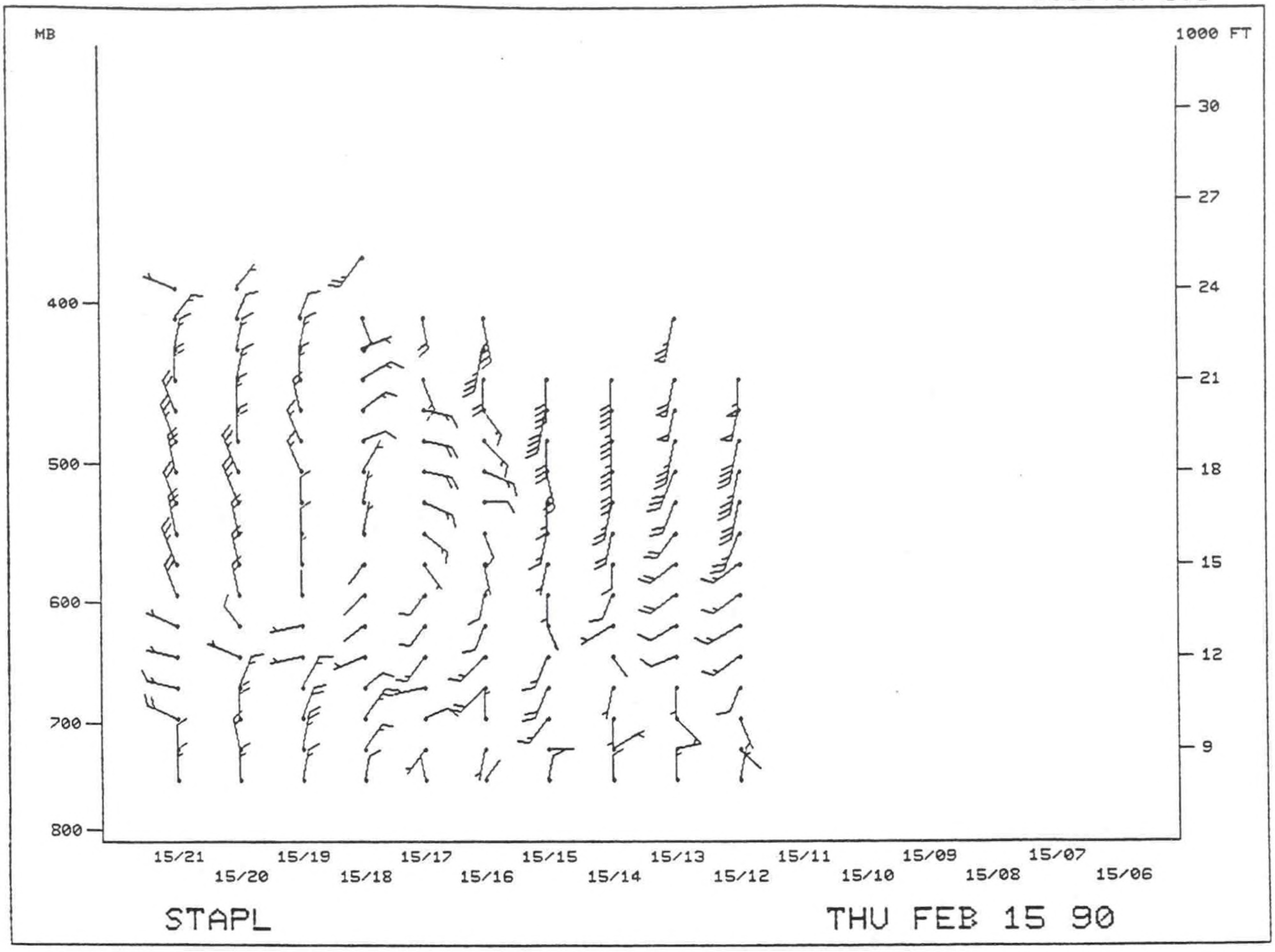

Figure 1.

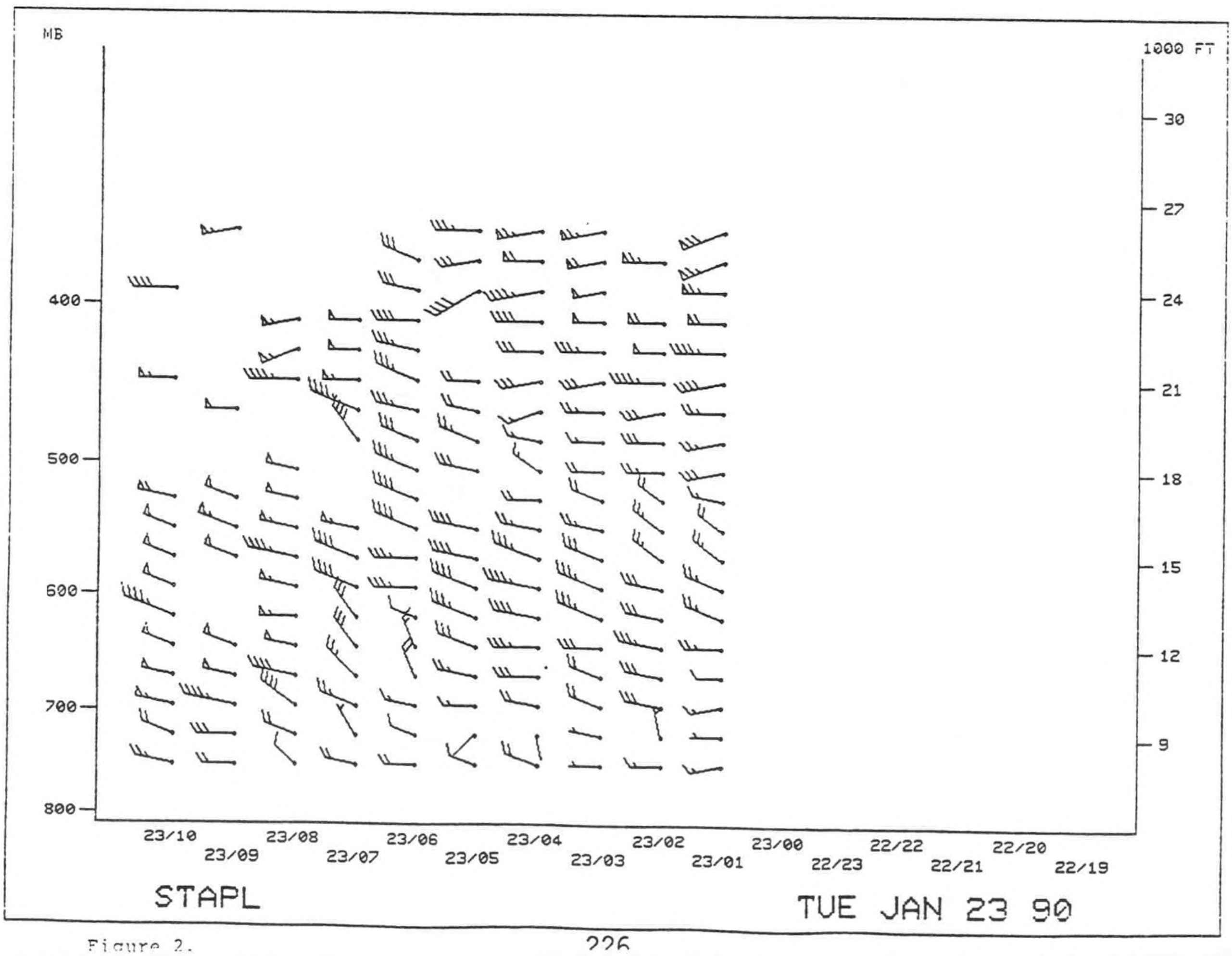

Figure 2.

whether or not high winds would occur. The first profile (23/01) is close to the standard time of rawinsonde release and shows relatively weak winds in the lower to middle levels. Standard upper air charts (not shown) were equally unimpressive as to the high wind threat based on upstream data. The profiler information portrays a different story as winds aloft increase significantly throughout the time period shown. By 23/10, 55 knots are being observed just 5000 feet above the ground. It was decided that a high wind warning was needed based solely on the profiler data. Again all of these changes occurred between rawinsonde releases. The forecaster in this case did not have to wait for the 1200 UTC rawinsonde data to determine the evolution in the winds aloft and was able to provide several hours of lead time on the warning.

In a similar high wind case, model data indicated that winds aloft would be increasing within the 0000 UTC to 0600 UTC time period. Comparing the 6-hour winds aloft forecast (gridded data) from the 0000 UTC NGM model run with 0600 UTC profiler data showed that the NGM had overforecast the 700 mb wind speeds by 30 knots. The decision was made to continue the high wind watch rather than upgrade to a warning. If the decision to warn had been issued based solely on model data, a false alarm would have resulted.

4. Case C

Figures 3a and b depicts the vertical time sections from both the Stapleton and Platteville (about 30 miles north of Denver) profilers for the 2-3 February 1990 time period. Due to a different frequency of the radar, the lowest range gate available from Platteville is just above 700 mb. The Platteville 350 mb winds show an intriguing pattern in this time section. First, note the backing of the flow after 02/00 from north to west and then to southwest as a short wave ridge passes overhead. The southwest flow then increases rapidly as the next short wave trough approaches. The flow decreases again as the trough line nears the profiler and switches to westerly at 03/00. Thereafter, as the trough pushes east, the northwest winds behind it increase quite rapidly. Note that the trough at 500 mb passed the Platteville profiler at 02/18, a good six to eight hours ahead of the higher level system. This nicely depicts the westward tilt with height of the wave. There is also an indication that the trough may have possessed a closed circulation as shown by the easterly winds at 02/20 between 400 and 500 mb.

If the sole source of winds aloft data had come from the rawinsondes, only three profiles would have been available during this time frame. This may have resulted in the omission of pertinent meteorological information to the forecaster.

The Stapleton profiler data show a similar trend aloft but the lower level winds are even more important. Surface analyses showed no obvious indication of frontal activity in the Denver area and the sea level pressure gradient (not shown) suggested an easterly wind (this is a good example of how misleading sea level pressure analysis can be in higher elevation areas). Seeing the increase in low level northerly winds on the profiler, forecasters were able to anticipate

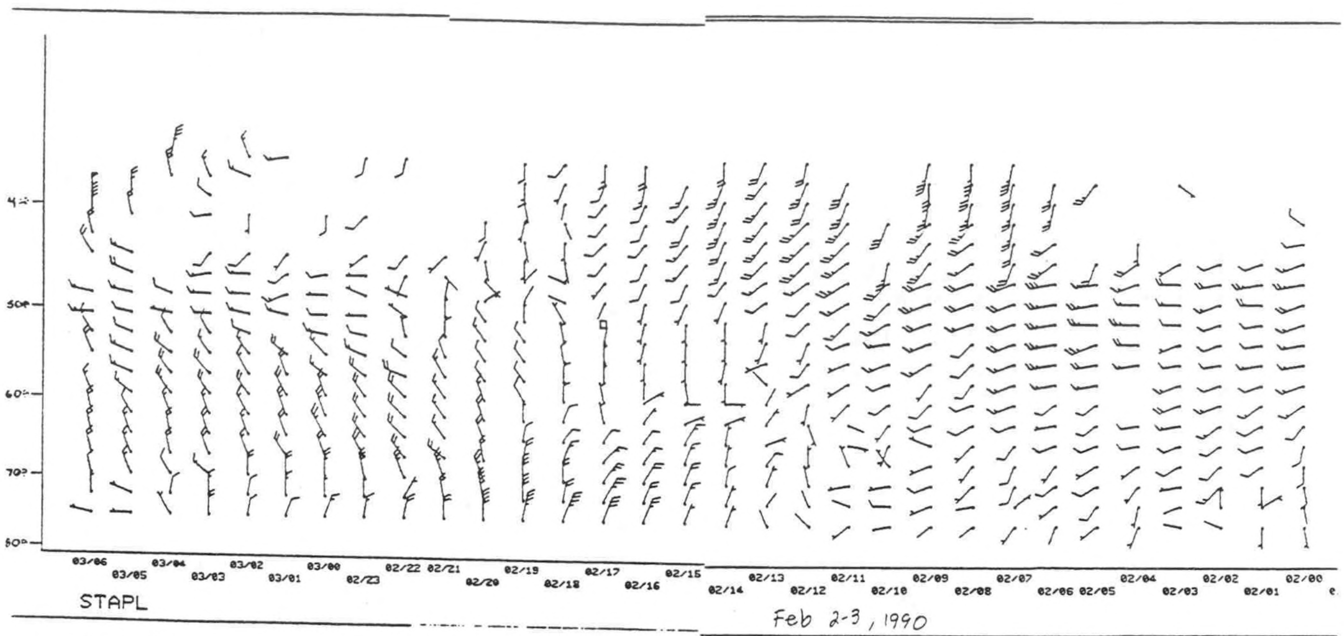

Figure 3a.

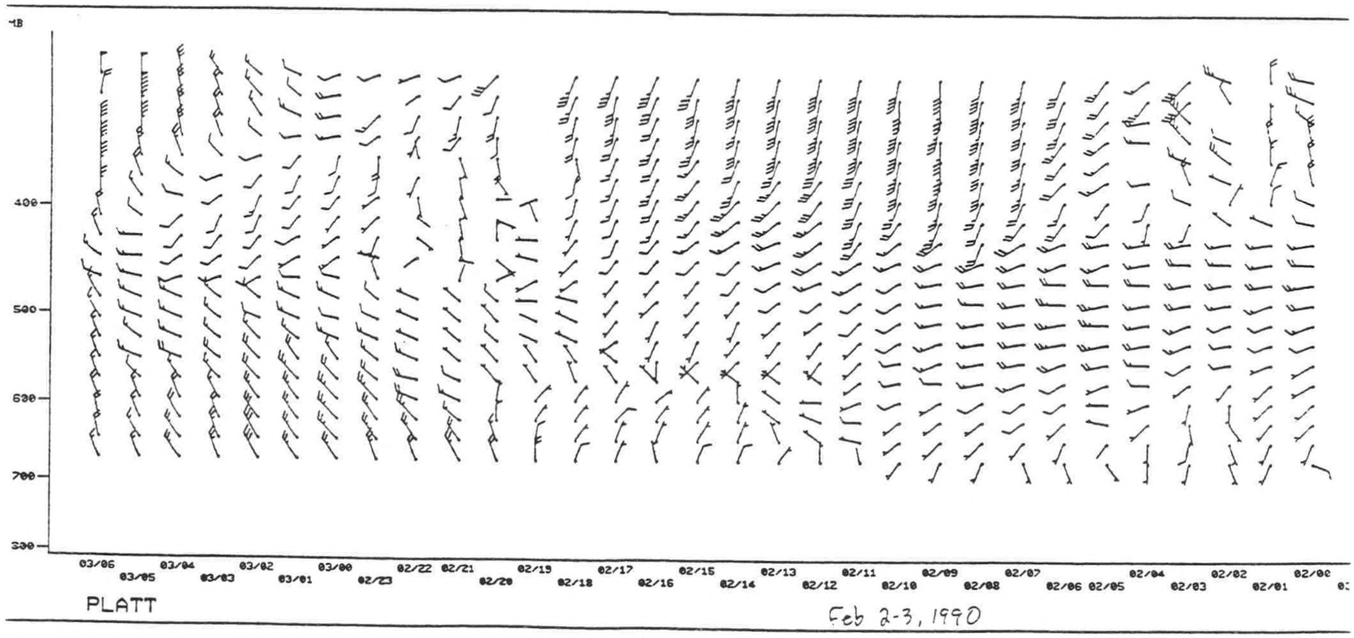

Figure 3b.

strong northerly winds at the surface several hours prior to their arrival and make the necessary adjustments ahead of time. As in Case A, the strong northerlies that are seen in the Stapleton data between 02/15 and 02/20 provided excellent upslope conditions to the Denver area, keeping low ceilings and visibilities at the airport through early afternoon (2000 UTC). In addition, Doppler radar showed snow increasing rapidly in this upslope flow. After 2000 UTC, the snow ended, ceilings and visibilities improved markedly and the surface winds died out. This trend is indicated in the profiler data by a decrease and turning of the lower level winds to westerly.

This type of situation has been seen over and over again in the profiler data and coupled with the Doppler radar imagery, aviation forecasters have been able to fine tune the timing and intensity of deteriorating and improving weather conditions for Stapleton airport.

5. Case D

Figures 4a and b shows the data from the Stapleton and Platteville profilers for 10 January 1990, another high wind day. As is the case with most high wind events along the Front Range, it was difficult for the forecaster to decide whether or not high winds would occur. All the traditional parameters (upper flow, static stability, shear) that are normally considered in determining the potential for high winds pointed to a marginal event. In fact, throughout most of the morning winds were very light along the Front Range. Then between 1700 and 1900 UTC the surface winds increased abruptly throughout the Front Range area with numerous gusts in excess of 60 mph reported. The high winds continued until around 2300 UTC before diminishing.

Why did the traditional approach to this problem fail? The answer to this question may lie in the profiler data for that day. Notice the steady increase in the winds around 550 mb in the Platteville data from 10/14 through 10/16 with a rapid decrease thereafter. Furthermore, notice the 100 knot wind at 550 mb in the Stapleton data at 10/18. This 100 knot wind appears to be embedded in some sort of perturbation that shifted the winds to westerly and increased them significantly between 10/17 and 10/19. Combining the profiler data with animated satellite imagery (not shown) suggested that the core of a jetstreak passed either directly over or to the south of the Stapleton profiler. This orientation would put the left entrance region of the jetstreak, a region experiencing subsidence, over the Denver area and points to the north (where the strongest surface winds occurred). Consequently, the high momentum air in the jetstreak would be transferred down to the surface, causing the sudden increase in the winds. As the jetstreak moved to the southeast and its left entrance region propagated away from the Front Range, the strong downward flux of high momentum air ended, bringing a decrease in the surface winds.

It is clear that attempting to forecast the above high wind event would be tough. However, after having seen this event forecasters are much more aware of the fact that jetstreaks may be involved in high wind events, a proposition that has not been addressed up until now. In fact, after this case occurred,

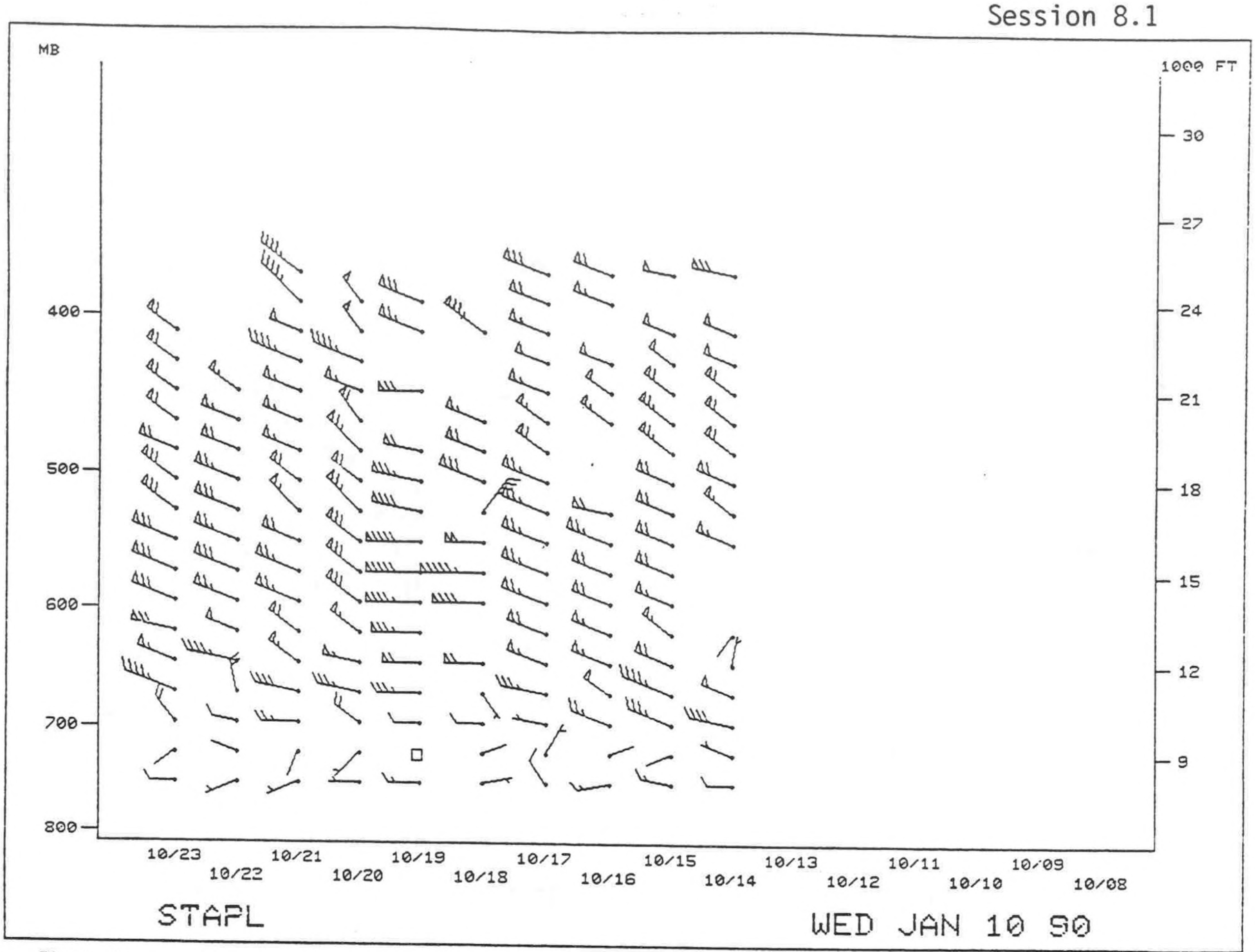

Figure 4a.

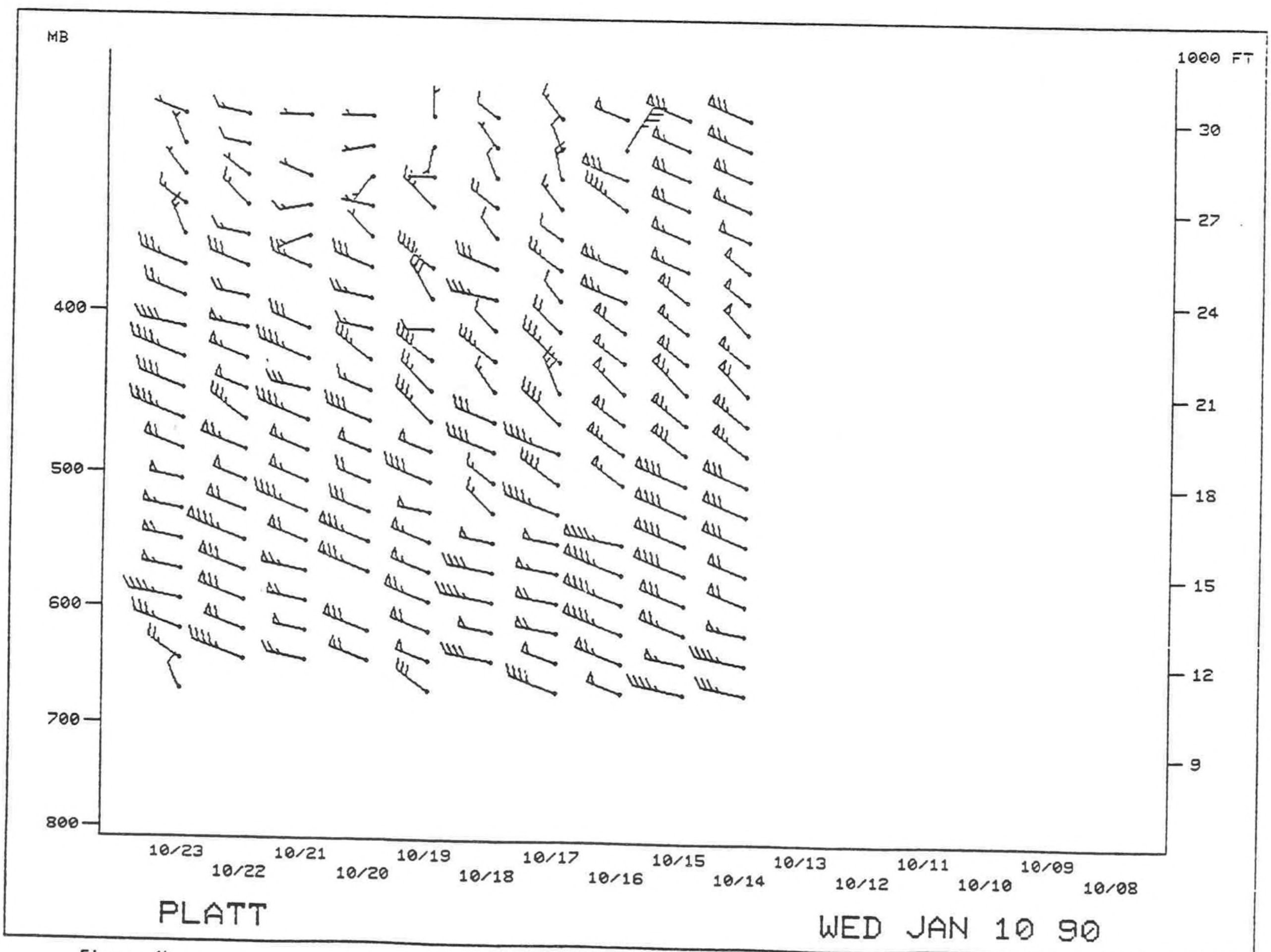

Figure 4b.

several other high wind events have been observed which appear to be linked to the presence of a jet-streak at mid or high levels. Meso-scale models are able to analyze these small scale features and forecasts from these models may provide lead times of up to 12 hours in the near future.

6. Case E

The last case to be discussed has to do with a rather ordinary yet important pattern that occurred on 6 October 1988. Figure 5 shows the data from the Stapleton profiler from 0900 UTC until 2100 UTC. Note the rather abrupt wind shift at the higher levels from west to north at 1700 UTC and an increase in the low and mid level northerlies toward the end of the time section. This wind shift was the result of the passage of a deformation zone. The axis of dilatation associated with the deformation zone was oriented east-west and the zone was undergoing frontogenesis. This had set up a direct circulation around the zone with ascent to the south of the axis and subsidence to the north. As the axis approached Denver showers and thunderstorms developed to its south with generally clear skies to the north. As the axis passed the Stapleton site around 1700 UTC showers ended, clouds dissipated and skies were clear by 0000 UTC 7 October 1988.

As seen from the 2100 UTC wind profile, light northeasterly winds (upslope) developed behind the axis and continued into the night. The subsidence behind the axis resulted in clearing skies and very stable conditions, and coupled with the low level upslope flow made the air mass ripe for the development of fog overnight.

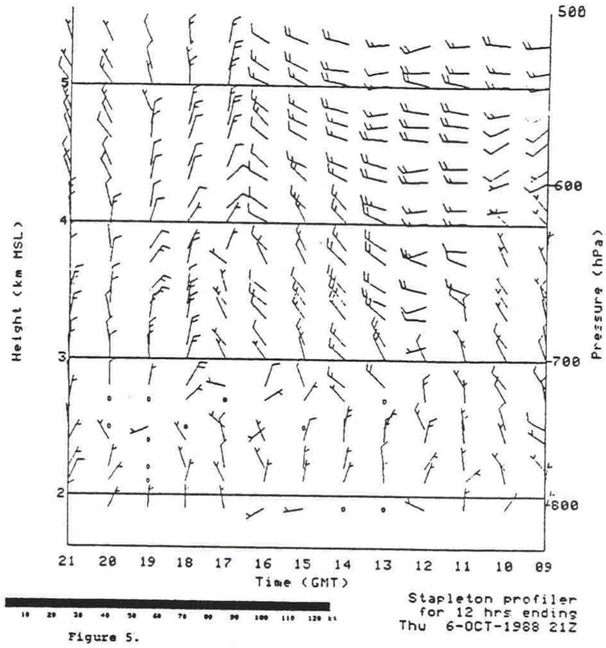

Figure 5.

Although not shown here, the movement of this axis was tracked through a mini network of wind profilers located throughout northeast Colorado. Thus the arrival time of the deformation zone at Denver could be calculated based on the upstream movements and compared with satellite imagery. This would enable the forecaster to better time the ending of convective activity. Additionally, having knowledge of the subsidence and stabilization occurring behind the axis along with monitoring the developing upslope would allow for a better forecast for the next day during peak air traffic times.

7. Concluding Remarks

This paper has shown several examples of how wind profiler data have been used at the Weather Service Forecast Office in Denver to both help in the prediction of aviation weather and also gain an understanding of some of the smaller scale features that have an impact on aviation weather.

Although not documented here, wind profiler data does get heavy use in the warm season as well as the cool season. Two of the most important uses of these data in the warm season include monitoring the vertical wind shear and the steering flow for thunderstorm, tornado and heavy rain forecasting. As in the cool season, profiler data are also used to monitor low level winds to determine the existence of upslope and downslope flow and the development or dissipation of low ceilings.

The cases presented here have been based, for the most part, on data from a single wind profiler. As more profilers are installed, forecasters will quickly discover the benefits of a network of such systems and how the data these profilers provide can improve aviation forecasting.

Session 8.2

SOME CONSIDERATIONS ON A DENSITY CURRENT NOSE AND LOW LEVEL JET IN CASE STUDY

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1. INTRODUCTION

With the advent of the wind profiler demonstration network across the central United States, meteorologists have been able to obtain hourly vertical wind profiles yielding a temporal resolution hitherto available only occasionally in research projects. The result has been that wind configurations which do not initially seem to meet our present understanding of the atmosphere have occasionally appeared. The following investigation involves one such event.

A 404 Mhz, three beam array wind profiler is located at Haviland, Kansas. On February 23, 1991, a polar airmass invaded the western high plains passing over this profiler. A synoptic composite and an AFOS produced time cross-section from the profiler are offered in Figures 1 and 2. The front on the leading edge of the polar airmass was preceded by a low level jet event. As seen on the AFOS time cross-section, a sharp wind shift has occurred some 1200 to 1500 meters above the surface two hours before the surface boundary passed the profiler.

Analysis of the data set was limited to what could be gained from the time cross-section data available from the AFOS computer. Basic surface analysis was used to locate the front and find the velocity of propagation. Using wind direction and velocity, computations were accomplished for speed and directional shears in the vertical and for directional shears in the horizontal. Vertical motion associated with the wind field was computed via a stream function.

Except where x-y plane (plan view) representation is helpful for visualization, the majority of the calculations were performed in two different orientations of the x-z plane.

A few possible explanations for the configuration are offered based upon the results of the data analysis.

2. ANALYSIS SCALES AND PHYSICAL MODELS

A brief discussion of the physical scale involved is needed. Since we are dealing with a large scale event in plan view, the length scale becomes synoptic. The data represented by Figure 2 (the AFOS time cross-section) is in the range of a few kilometers in the vertical. Therefore, the x-z plane analyses presented are generally in the Meso-β scale (Fujita, 1981). The assumption was also made, for this study, that the time cross-section was a reasonable approximation of the frontal environment at a mid-point in that time frame. Thus, using the velocity of propagation, time "t" in the abscissa may be converted to length "x".

The study of any frontal system must be conducted under certain assumptions as to the physical model involved. Hoskins and Bretherton (1972) found that inviscid, adiabatic frontogenesis produces infinitesimally narrow fronts within a finite time. Their work was based upon the assumption of cross-front geostrophic balance. It is clear from the time cross-section presented in this case that accelerations involved are largely ageostrophic and non-hydrostatic. As will be seen in the data analysis, there is also reason to believe that Kelvin-Helmholtz instabilities are occurring so that mixing effects may lead to the breakdown of Hoskins' and Bretherton's (1972) model.

The author found two conceptual models which lend themselves to the wind field found on the time cross-section. The first is a density current model as detailed in the laboratory by Simpson (1972, 1982), Simpson and Britter (1979, 1980); in the atmosphere by Charba (1972), Goff (1975) and Shapiro *et al.* (1985), Young and Johnson (1984), Smith and Reeder (1988); and finally numerically simulated by Sha *et al.*, (1991). The second is the conceptual model of a katafront as described by Bergeron (1928).

3. THE DENSITY CURRENT MODEL

Although this particular case is of nearly an order of magnitude larger, there is a resemblance to the density current model. In order to equate this case study with the above mentioned work in density currents, several computations were undertaken.

A Froude number as computed by Simpson and Britter (1979) and by Charba (1972) was not possible owing to the lack of both temperature and density except for the bottom of the fluid. A hybrid type of Froude number was available however. It was defined to be the ratio of the height of the density current (cold dense air behind the front) to the total depth of the fluid (taken as the troposphere). This ratio has been used by Simpson and Britter in their laboratory models and is suggested in accepted texts on fluid dynamics (White, 1991). Simpson and Britter (1979) found in laboratory model density currents that this ratio was normally 1/5 if the depth of the Kelvin-Helmholtz billows collapse region was omitted. Assuming the absence of K-H billows in this case, and a total winter tropospheric depth of approximately 10 kilometers, a Froude number of 1/5 was found also. Even allowing for the presence of the K-H instabilities along the top of the cold air boundary (which there is some evidence for), this hybrid Froude number still compares quite favorably to those found by Simpson and Britter (1979) in the laboratory and by Charba (1972) in the atmosphere.

Simpson and Britter (1980) also found that ambient flows in the direction of movement of the front (as in this case) increased the frontal speed. They compared their laboratory data to atmospheric data compiled by Miller and Betts (1977), Clarke (1961), and Goff (1976). The results of a ratio of ambient flow, U_2, to the speed of the flow behind the front, U_3, gave values of between positive and negative unity while a ratio of velocity of propagation of the front, U_q, to the velocity of the flow behind the front, U_3, produced values of just less than unity. Computing these same ratios for the present case study, values of just less than positive unity were found for both.

Reynolds and Prandtl number computations were also not possible due to the lack of temperature and density profiles of the two airmasses (Rawinsondes were available in both airmasses but with height scales in the Meso-β range it is hardly appropriate to mix in temperature and density profiles of synoptic spacing). It was possible, however, to use surface data in the frontal and pre-frontal zone to approximate virtual temperatures for the boundary layer. Using these values, a velocity of propagation for the leading edge of the boundary was calculated as 9.2 ms^{-1} after Shapiro *et al.* (1985), Carbone, (1982) and von Kármán (1940). This is exceptionally close to the velocity of propagation of the boundary calculated from 12 hours of surface synoptic data as 9.17 ms^{-1}.

In a study of thunderstorm outflow boundaries treated as density currents, Goff (1975) included two cases where there was a pronounced "overhang" at approximately 1 kilometer above the ground. In fact, the average velocity of propagation for 17 cases presented by Goff (1975) is found to be 9.72 ms^{-1} which again compares closely to the 9.17 ms^{-1} found in this study.

Goff (1975) also gave an empirical equation for the frontal advance velocity U_o, in terms of the wind behind the front U_3 and the ambient flow U_2,

$$U_o = .7U_3 + .3U_2 \qquad (1)$$

Using "front relative" values of velocity from this case study, a value for U_o of 9.25 ms^{-1} is arrived at which again compares closely to the manually calculated velocity of propagation of 9.17 ms^{-1}.

Considering these factors, there seems to be a reasonable basis for applying density current theory to this particular polar boundary.

4. THE KATAFRONT MODEL

The basic conceptual model for the Katafront (Bergeron, 1928) involves the ambient flow (in the less dense air) being of greater velocity than the propagation velocity of the more dense air comprising the front as was found in this case. This leads to a katabatic wind with essentially downward motion just ahead of the frontal zone in the lowest levels. Although somewhat complicated by the presence of the low level jet, this type of a model is somewhat evident from cursory examination of the time cross-section winds. The actual calculated motions will show that while the ambient flow is indeed away from the frontal zone, there is <u>upward</u> motion occurring in the region where the katafront model requires only downward motion. For this reason, the katafront model was not used.

5. CALCULATED MOTIONS

In order to focus upon the area of interest, the wind data from the time cross-section was reduced to a temporal range of 0900 UTC to 2000 UTC and a height scale of 0 to 2500 meters. The rest of the calculations and analysis of data were performed in this range and domain (Figure 3).

Initially, the wind data were reduced to their zonal and meridional components on a standard polar coordinate axis. Analysis of the zonal wind component (u) in ms^{-1} can be seen in Figure 4. The greatest velocities in the zonal direction are away from the front and located above and to the right of the low

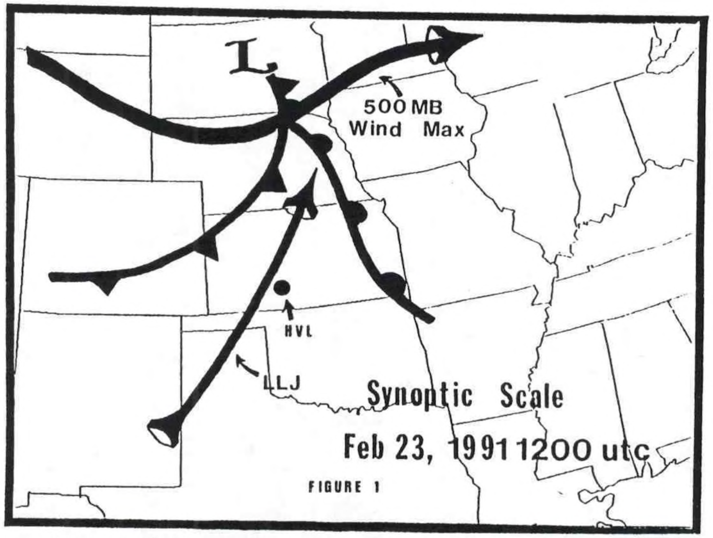

Figure 1. The mid-latitude cyclone in the early stages of occlusion. A well developed low level jet was apparent at 1200 UTC from the Texas panhandle to just west of Haviland, KS (HVL).

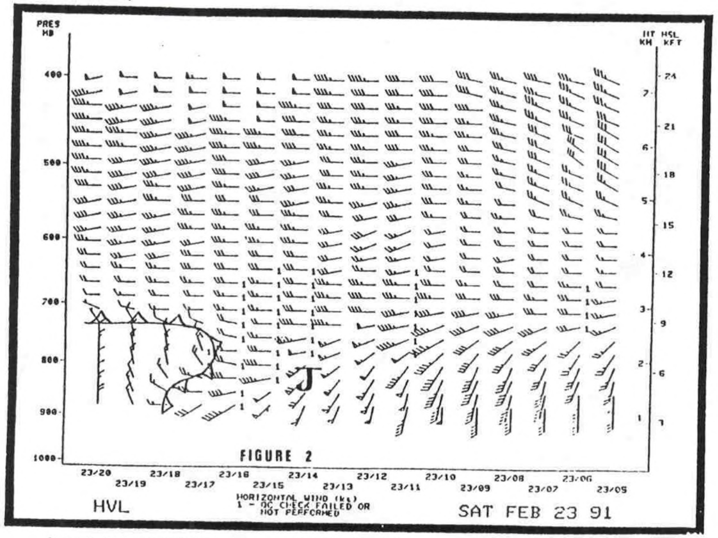

Figure 2. AFOS output of time cross-section winds from the Haviland profiler. Time increases to the left with height increasing in the vertical. The low level jet core is plainly visible as is a distinct wind shift in the 4th, 5th and 6th range gates of the prufiler. The approximate location of the cold air density current is as indicate.

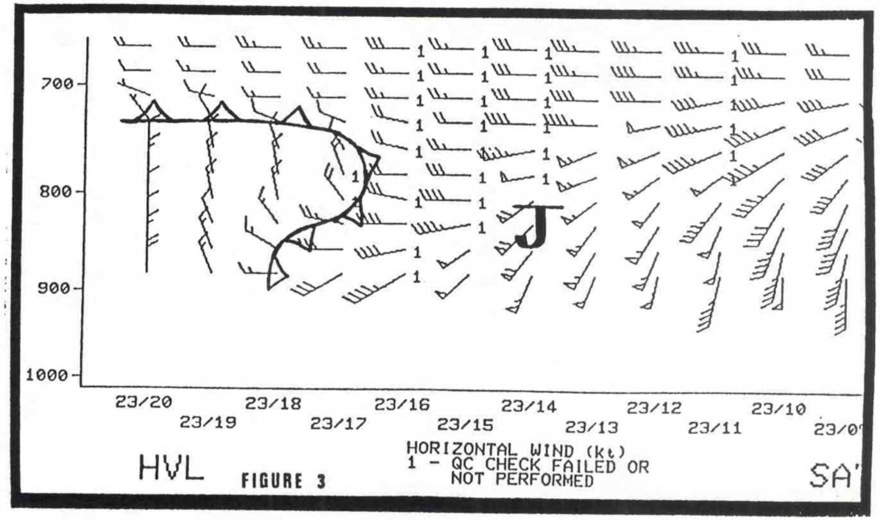

Figure 3. The portion of the time cross-section selected for data analysis.

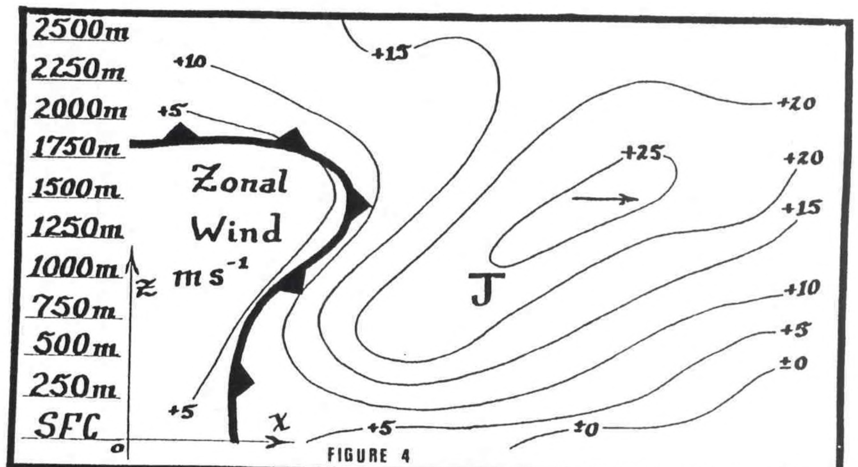

Figure 4. The zonal wind (u) in ms^{-1} with the apparent density nose and low level jet core. Mass extraction by the low level jet may have produced a horizontal pressure gradient sufficient to deform the upper portion of the cold air boundary.

level jet. The indication is, as expected, that the low level jet of some 65 knots is rapidly extracting mass in this area. It is therefore possible that some horizontal pressure gradient has established itself between the low level jet and the more dense cold air aloft at the leading edge of the boundary. The existence of the density nose aloft may be the result of these forced mass adjustments in the horizontal.

At this point, a new set of axes were constructed with the abscissa being normal to the front (Figure 5). Figure 6 offers a view of the results with values for u now being "front relative". Again, the greatest velocities are away from the boundary. There is still a maxima that seems to be associated with mass extraction by the low level jet but there is now a second maxima located just ahead of the advanced wind shift aloft.

Analysis now proceeded after Charba's (1972) gravity current model analysis of a thunderstorm gust front. The assumption was made that values for $\partial v/\partial y$ become an order of magnitude smaller than the values for $\partial u/\partial x$ when the x axis is normal to the boundary. In the mass continuity equation for incompressible flow then, $\partial v/\partial y$ is assumed negligibly small compared to $\partial u/\partial x$ everywhere in the vertical plane from the surface to 2500 meters and using the boundary layer assumption

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0 \qquad (2)$$

After Clarke (1961), a stream function is developed such that

$$u=-\frac{\partial \Psi}{\partial z} \qquad (3)$$

and

$$w=\frac{\partial \Psi}{\partial x} \qquad (4)$$

It is important to remember that this represents only the rotational, non-divergent part of the wind.

Since u is known as a function of height, the stream function field is computed by

$$\Psi=-\int u\partial z \qquad (5)$$

After the stream function has been computed, w can be obtained by finite differencing with

$$w=\frac{\Psi_{(x+\Delta x)}-\Psi_{(x-\Delta x)}}{2\Delta x} \qquad (6)$$

Figure 7 shows the stream function analysis. A few intermediate contours have been added in the vicinity of the top of the density current. They indicate the presence of a series of small circulations beginning at the density current nose and extending back along the top of the current. One must remember that the resolution between data points in the horizontal is quite coarse; approximately 33 kilometers as opposed to only 250 meters in the vertical.

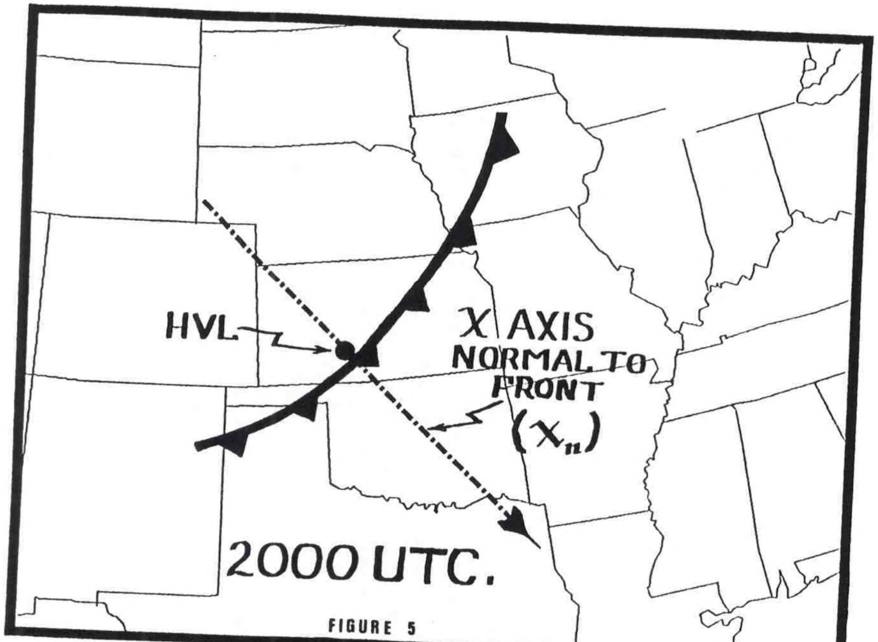

FIGURE 5

Figure 5. A new axis configuration was constructed with the abscissa positive towards the southeast and the ordinate positive to the northeast along the front.

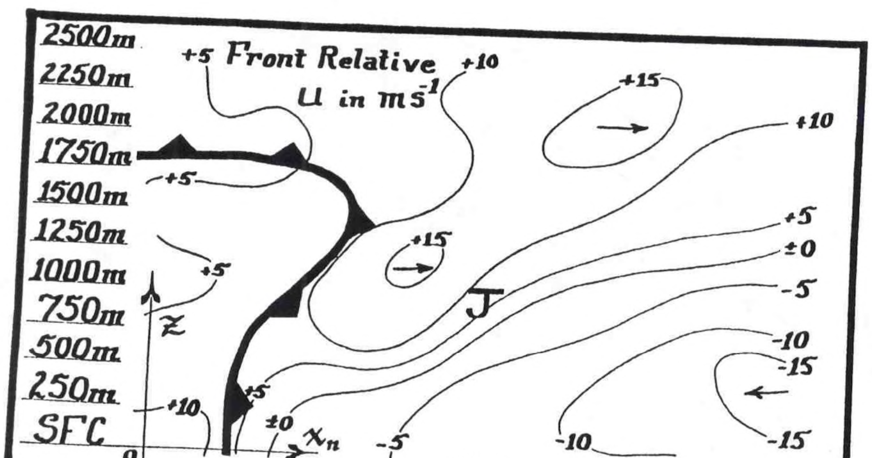

FIGURE 6

Figure. 6. Analyzed values of "front relative" u in ms^{-1}. An area of relative maximum away from front velocities is located between the apparent density current nose on the front and the low level jet. This could be due to the horizontal pressure gradients in this area.

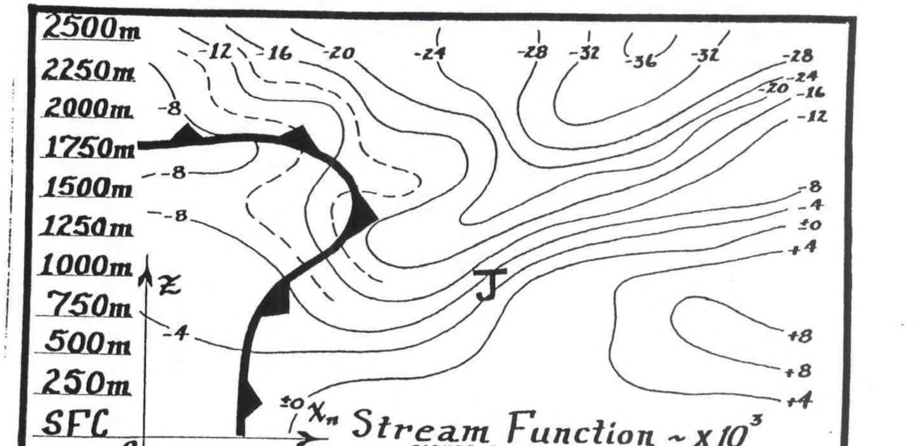

FIGURE 7

Figure. 7. The stream function analysis. Intermediate contours indicate a series of smaller scale circulations from the density current nose backward along the top of the cold air boundary. These could be reflections of Kelvin-Helmholtz billows.

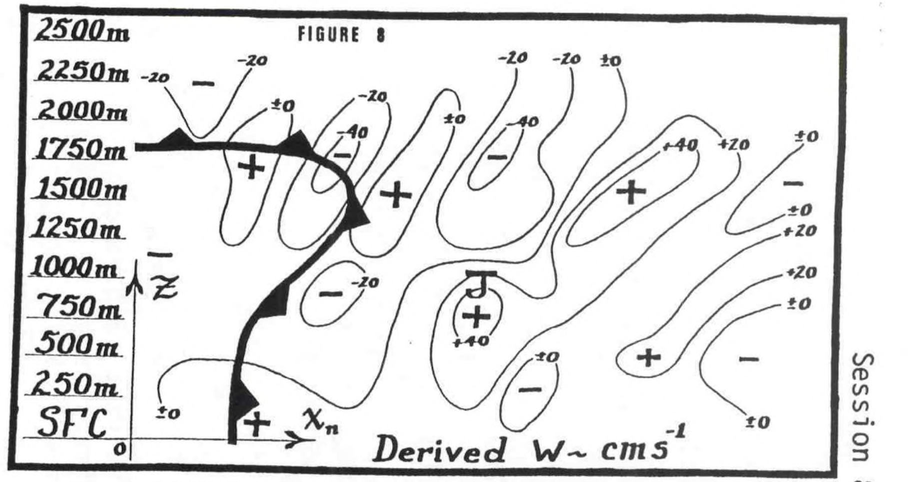

FIGURE 8

Figure. 8. Derived vertical velocities in the x-z plane showing relative maxima with and to the right of the low level jet. There is a secondary maxima of nearly 20 cms^{-1} just ahead of the density current nose with weakening vertical circulations backward along the top of the current. This may be the region of Kelvin-Helmholtz billows collapse.

Derived values of vertical velocity, w, are analyzed in Figure 8. Values are in cms^{-1} and represent only the vertical velocities of the rotational, non-divergent wind. It is not unreasonable to assume that, were divergence known, values could be as much as one order of magnitude larger. Even without the divergence of the wind however, there is still substantial upward motion occurring in several places.

As expected, the strong warm air advection occurring along and just to the right of the low level jet is reflected in two relative maxima of upward motion. A secondary maxima of upward vertical velocities appears in the vicinity of the apparent density current nose. It is useful to look at these locations in plan view (Figure 9).

Of additional interest is the identification of the smaller vertical circulations just above the density current which were hinted at with the stream function analysis. Note that the vertical circulations are of decreasing magnitude as distance from the density nose increases. In a density current model, this would be analogous to a region of Kelvin-Helmholtz billows collapse.

6. WIND SHEARS

Analysis of various wind shears appear in Figures 10, 11 and 12. Nothing untoward is found in the values of directional and speed shear in the vertical but horizontal directional shear across the apparent density current nose and at the surface position of the boundary become significant. Computations here were based upon the assumption that, due to strong stretching at the boundary by $\partial v/\partial y$ (front relative), the boundary can be expected to approach a zero order discontinuity in wind velocity as suggested by Shapiro, *et al.* (1985) and by Hoskins and Bretherton (1972). Treating the boundary as such a discontinuity, horizontal directional shears approach an order of magnitude greater than those deemed hazardous to aircraft (Snyder, 1968). In fact, there is a close similarity between this case and the TWA Flight 163 severe turbulence event investigated by Brandes (1990).

In the Flight 163 occurrence, the aircraft was on descent to Will Rogers Airport, Oklahoma City when, at an altitude just below 1800 m (AGL), severe turbulence was encountered. In this case, a gust front similar to the present case was located northwest of the airport and a low level jet of some 35 ms^{-1} was located southeast of the airport. The aircraft descent was occurring in the approximate location and altitude where the apparent density current nose is located in the present case study.

An effort to study the impact of this particular environment is currently under way. The wind field from the Haviland profiler is being loaded into a computerized flight simulator for a Boeing 747 at The Wichita State University Aeronautical Engineering department. The boundary area is being treated as a density current nose with a zero order discontinuity in wind velocity (the extreme case). Data was not yet available at the time of this writing but will be published later. The aircraft ascent/descent scheme is presented in Figure 13.

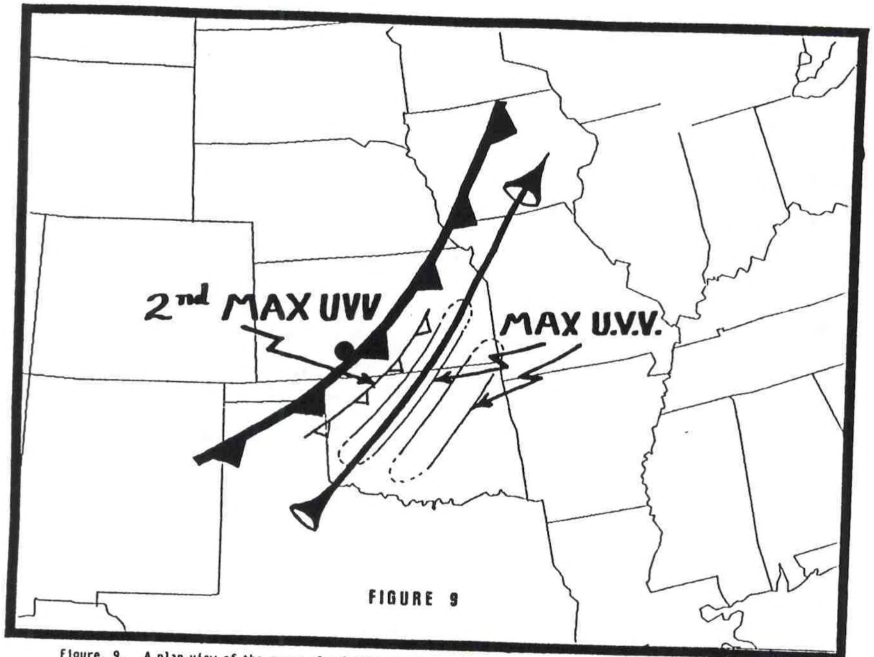

FIGURE 9

Figure. 9. A plan view of the areas of relative vertical velocity maxima. Greatest upward motions appear in the warm sector along and to the right of the low level jet. This would be the favored area for meso-convection.

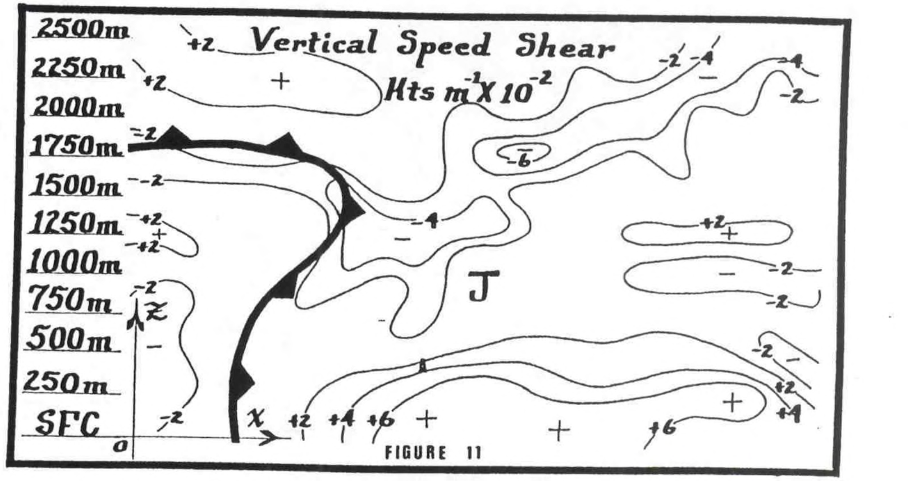

FIGURE 11

Figure. 11. Vertical speed shear analysis shows the strongest speed shears as expected just below the region of the low level jet.

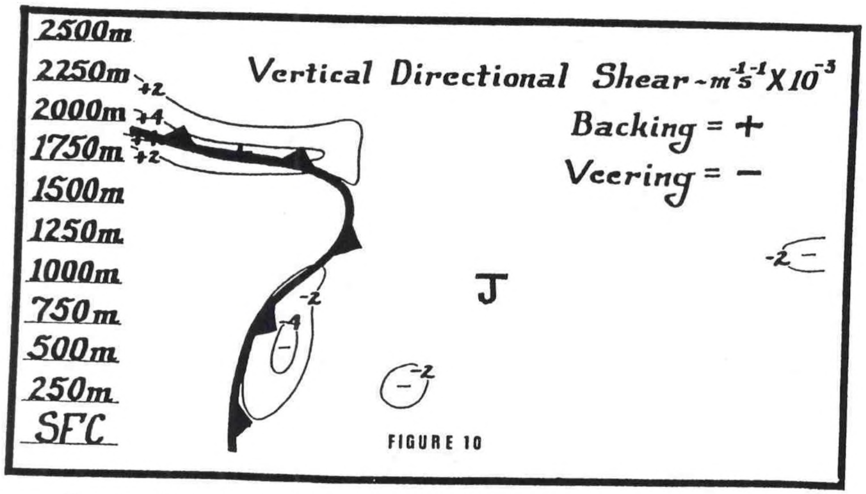

FIGURE 10

Figure. 10. Vertical directional shear analysis for the wind profile.

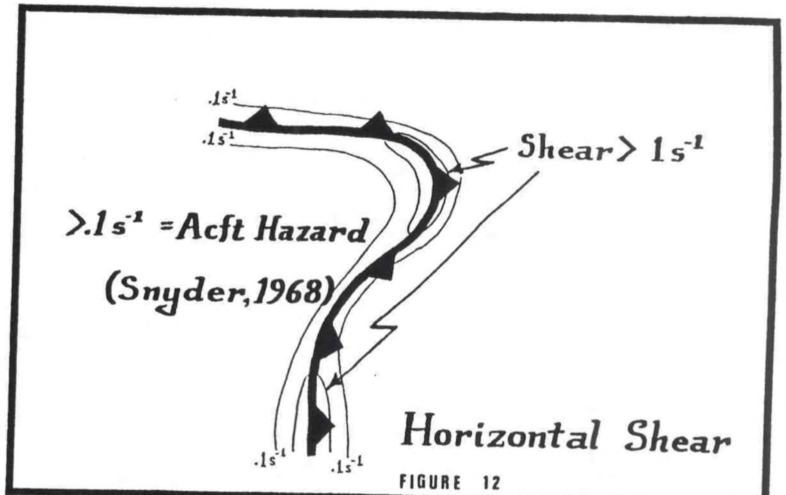

FIGURE 12

Figure. 12. Horizontal directional shears through the region of the density current. The assumption was made that the boundary was a near zero order discontinuity in wind velocity.

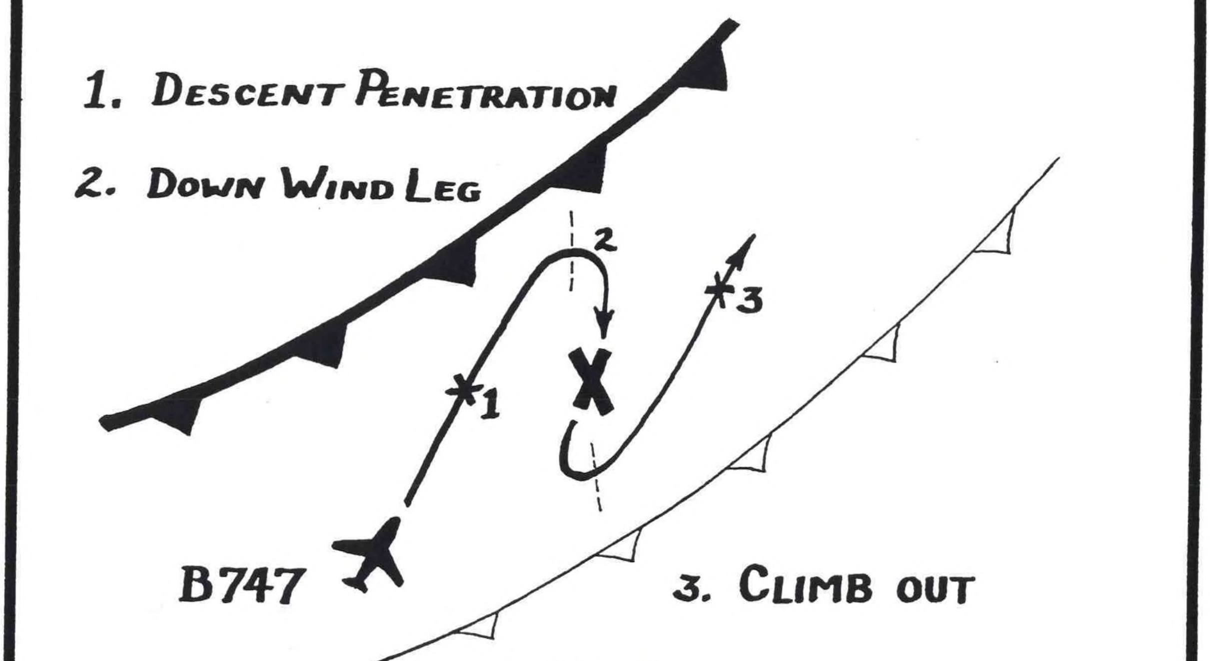

FIGURE 13

Figure. 13. The planned ascent/descent of the Boeing 747 through the apparent density current nose using The Wichita State University Aeronautical Engineering department computer model.

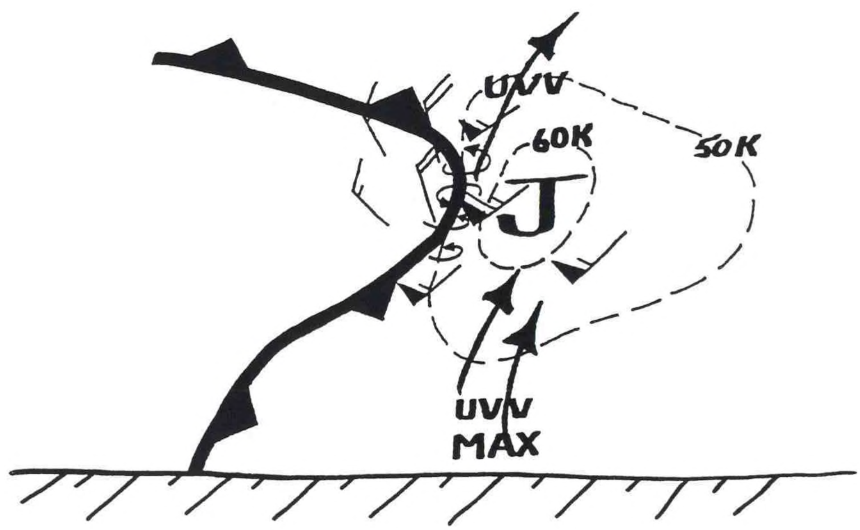

FIGURE 14

Figure. 14. Should the density current nose approach the left side of the low level jet core, strong cyclonic shears would develop coincident with an area of near convective scale upward motion.

7. MESO-CONVECTIVE FORCING

Assuming that at some point in time the density nose comes into close proximity to the left side of the low level jet core, something similar to Figure 14 may occur. Here, the cyclonic shears between the density nose and the low level jet core become immense. Further, this is occurring in a region of relatively strong upward vertical motion. It is possible that, in the presence of deep moisture (lacking in this case), total vertical velocities on the order of several ms^{-1} could couple with this strong cyclonic shear to produce significant rotating convection. Further, if it were to occur, this convection would be physically located in the warm sector of the mid-latitude cyclone, a favored area for severe convection during the spring and summer season of the plains.

8. SUMMARY AND CONCLUSIONS

Due to the poor horizontal resolution of data points and the lack of temperature and density profiles in the atmosphere involved, it is unclear exactly what type of atmospheric phenomena occurred on February 23, 1991. However, non-dimensional analysis provided values coincident with those of an atmospheric density current model.

Velocity vector analysis showed maxima away from the front towards the region where the low level jet was located. It is hypothesized that the advanced wind shift aloft is possibly a density nose produced by the mass adjustments resulting from strong horizontal pressure gradients between the low level jet and the frontal boundary aloft.

Stream function and derived vertical velocities identified areas of upward vertical motion which could reach convective scale in intensity. The strongest were with the low level jet. Additional vertical circulations were possible from the leading edge of the density current nose rear-ward along the top of the density current. These bear a strong resemblance to Kelvin-Helmholtz instabilities (billows).

Given the possibility of convective scale upward motions along and to the right of the low level jet, it is reasonable to assume that in the presence of deep moisture, this atmosphere could have produced meso-convection in the warm sector. Further, assuming that at some point in time the apparent density current nose may approach the left side of the low level jet core, the strong cyclonic shears involved could be conducive to rotating convection in that region.

Assuming a near zero order discontinuity in wind velocity both at the apparent density current nose aloft and at the surface boundary location, wind directional shears were found to be an order of magnitude above those considered hazardous to aircraft operations.

It is clear that more definitive analysis of this type of environment is needed. Arrangements are being made to obtain the six minute data sets from several of the demonstration network profilers for this day. Subsequent analysis of this new data set may provide the needed resolution in the horizontal to test the ideas proposed in this paper. Additionally, flight simulator data using the February 23, 1991 wind profile may provide additional insights into the dangers posed to aviation.

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USE OF WIND PROFILER DATA AT THE NATIONAL AVIATION WEATHER ADVISORY UNIT

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National Aviation Weather Advisory Unit
Kansas City, MO 64106

The Wind Profiler Demonstration Network, WPDN, engineered by NOAA's Environmental Research Lab and built by UNISYS is now nearing completion. At the end of 1991 26 of the 30 stations in the network are routinely providing data to NWS forecasters. The demonstration network will be completed in early 1992.

Wind profilers are fixed beam, vertical-looking, doppler radars. The 404 Mhz (74 cm) profiler radars in the WPDN provide hourly vertical plots of wind direction and speed from approximately 1600 to 53,000 ft above ground level. The standard graphic plot available to NWS forecasters on the AFOS system is a time cross section of 16 consecutive hourly winds.

The 20 meteorologists at the National Aviation Weather Advisory Unit (NAWAU) in Kansas City are now using profiler data along with their traditional data sources in preparing Sigmets, Area Forecasts, Convective Sigmets and Airmets.

The work of NAWAU encompasses a number of specialized duties for the 48 contiguous states. These include:

Turbulence -- Airmets and Sigmets (WA/WS)
Icing -- Airmets and Sigmets
IFR and Mountain Obscuration -- Airmets
General clouds and weather -- Area Forecasts (FA)
Significant thunderstorms -- Convective Sigmets (WST)

Each NAWAU FA forecaster is responsible for approximately one third of the contiguous U.S. while one Convective Sigmet meteorologist issues WST messages coast to coast. The large areas covered and the varied meteorological duties limit the time available for analysis and forecasting. Profiler data can in many cases provide unique and timely input.

Some examples of the utility of profiler data in NAWAU operations include:

1. Turbulence -- vertical and horizontal shears shown on the time cross sections and in computed and contoured shear charts derived from profiler winds. Such data have been available for several years along Colorado's Front Range.

2. Profilers provide detail in both the vertical and horizontal never before available to forecasters. They aid in determining the onset, cessation, vertical and horizontal extent of turbulence events.

3. Low level winds -- Peak afternoon gusts may be indicated or implied by the lowest range gates of profiler plots. Profiler time cross sections provide an excellent depiction of the low level jet.

4. Upslope/downslope conditions. Profiler data often indicate the development, strengthening or weakening of upslope or downslope conditions.

5. Frontal positions/slopes/ strength -- These important features are well depicted by the time sections and plan view plots of standard level winds. They are also made evident constructing profiler derived horizontal cross sections. Profilers provide an excellent depiction of overrunning situations.

6. Mid level features -- These features area often missed or ignored by confining one's attention to 500 mb features. Profilers are picking up many 700/600 mb short waves. Also the hourly data reveal short-lived or developing features often missed by the two-a-day Raobs.

7. Continuous display of the wind field -- Profilers avoid the 12 hour RAOB gap and the 04-12 UTC PIREP/ACARS "blackout". Profilers will prove useful in monitoring and updating the FD winds aloft forecasts.

8. Prog following and model comparison -- the bread and butter of all meteorologists. Profilers, along with satellite imagery, provide instant updates on movement and development of upper air features.

These are a few of the areas already noted by NAWAU meteorologists and even better things lie ahead. Researchers working with the 6 minute data (not yet available in the field) are finding important turbulence and icing signatures in those detailed plots.

Two examples of the operational utility of profiler data are presented here. The first example shown in figure 1 illustrates use of the 500 mb plan view. Meteorologist Carolyn Kloth, of the Convective Sigmet portion of NAWAU, identified a diffluent upper air pattern in the wind field above the surface warm sector. Her Convective Sigmet Outlook area is shown as a dashed line in Figure 1. The text of her discussion is shown at the bottom of the figure. Profiler data provided unique input at a time of day exactly midway between the 1200 and 0000 UTC soundings.

Forecaster Henry Fields of the Area Forecast/Inflight Advisory section of NAWAU made use of profiler data in determining the horizontal and vertical extent of a non convective Sigmet for severe turbulence in November 1991. This case is shown in figures 2 through 5.

This turbulence event was somewhat unusual in that many of the turbulence reports occurred in middle altitudes, from 15,000 to 25,000 ft The meteorologist, recognizing the potential for severe turbulence, utilized Demonstration Network time cross sections to correctly anticipate these middle altitude reports. Figure 2 shows a series of profiler plots bracketing the issue time of the Sigmet. Note the middle altitude shears evident in the plots. Figure 3 provides the plan view of the area of interest and Figure 4 portrays the areal extent of Sigmet Whiskey 1. Finally, figure 5 depicts the pilot reports occurring after issuance of the Sigmet.

NAWAU meteorologists will be conducting a more systematic evaluation of profiler data during 1992. The network is now nearing comple-

MKCWSTC
WSUS41 KMKC 141955
MKCC WST 141955
CONVECTIVE SIGMET...NONE

OUTLOOK VALID 142155-150155
FROM STL-EVV-MCB-ACT-FSM-BUM-STL
AMS DRYING OUT THRU CNTRL OK INTO NW TX BUT HAD DSTBLZD CNSDBLY OVER ERN OK/NE TX. STGST MSTR CNVGNC ALIGNED ALG WRMFNT FM NE CORNER OF OK INTO CNTRL AR. PROFILER NETWORK DATA SHOWS STGLY DIFFLUENT FLOW ALF OVER WARM SECTOR. WATVAP STLT IMGRY SHOWS UPR CIRCLN CTR MOVG E ALG KS/OK BRDR S OF ICT. MOST FVRBL AREA FOR TSTM DVLPMT NEXT 2-3 HRS APRS TO BE ERN OK/WRN AR VCNTY INTSXN OF WRMFNT AND DRYLN. SOME OF THE CELLS MAY EXCEED SVR LVLS.

KLOTH

Figure 1

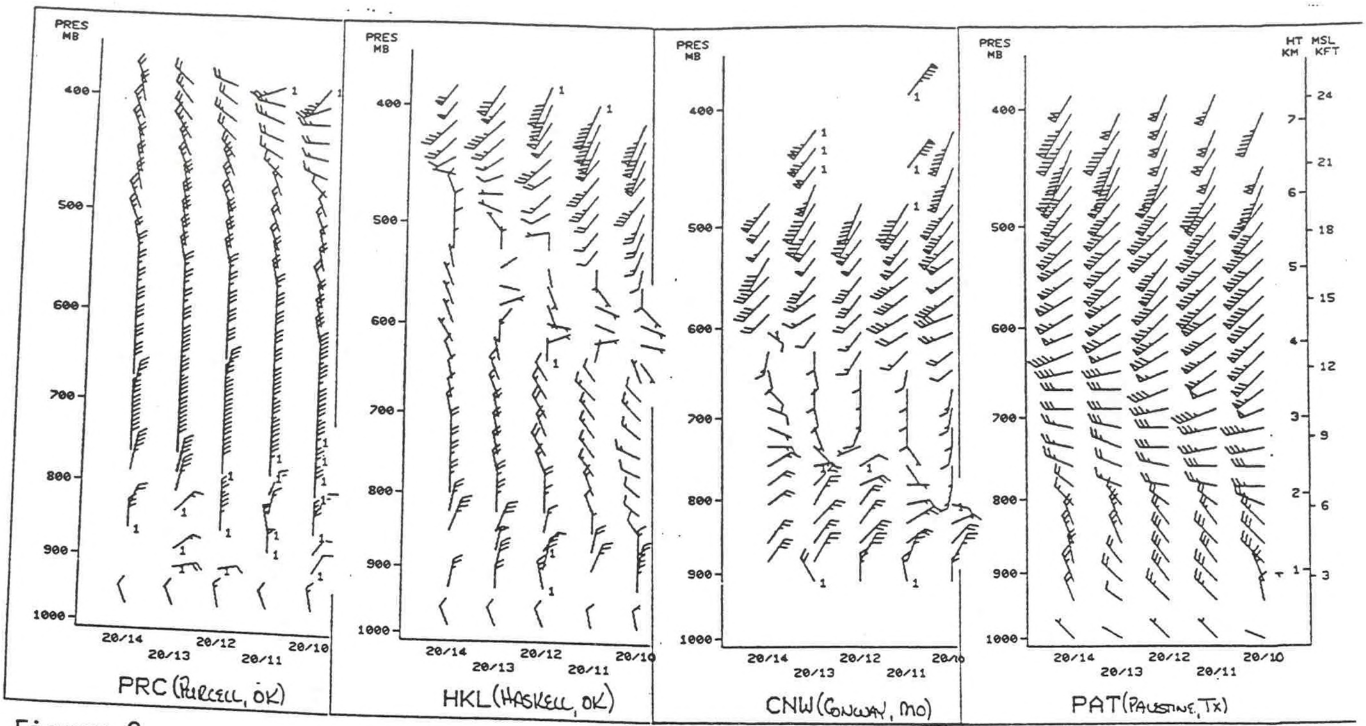
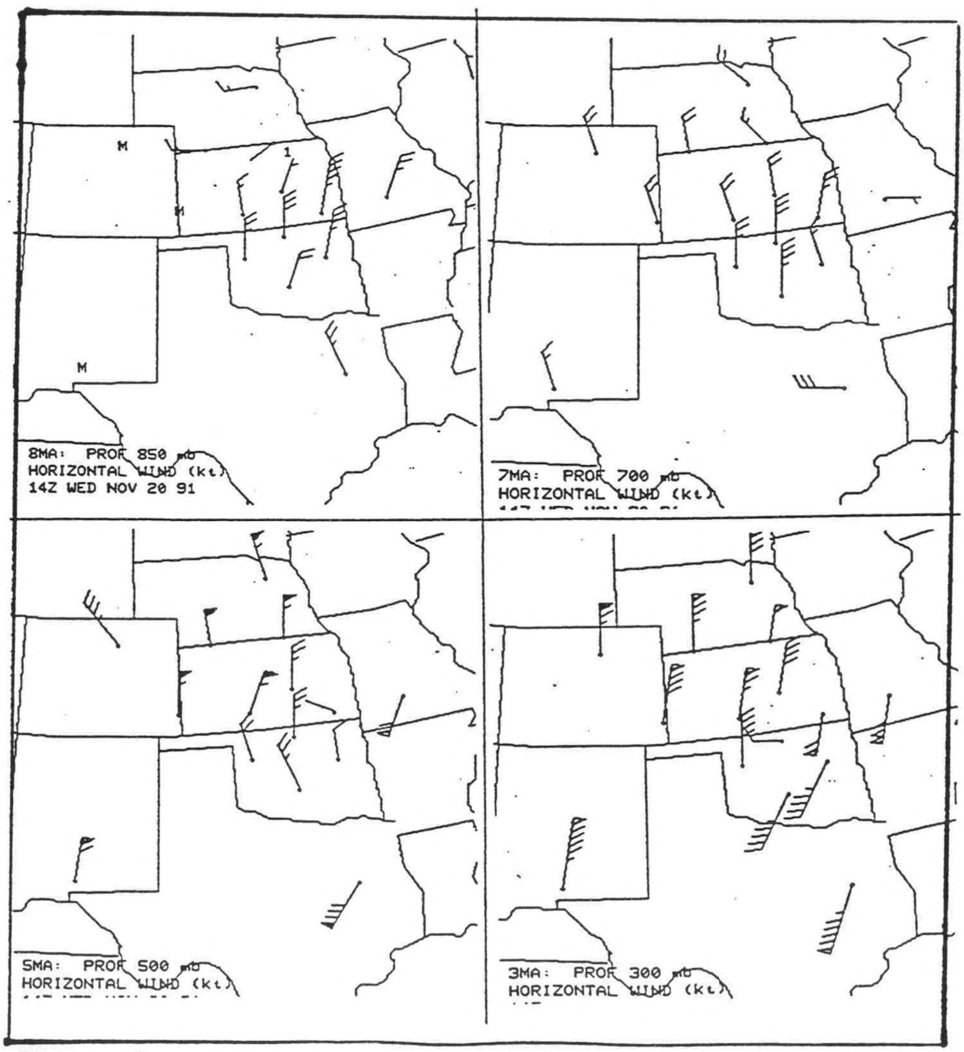


Figure 2



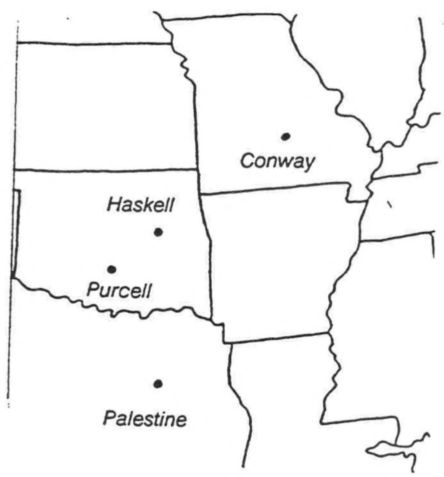
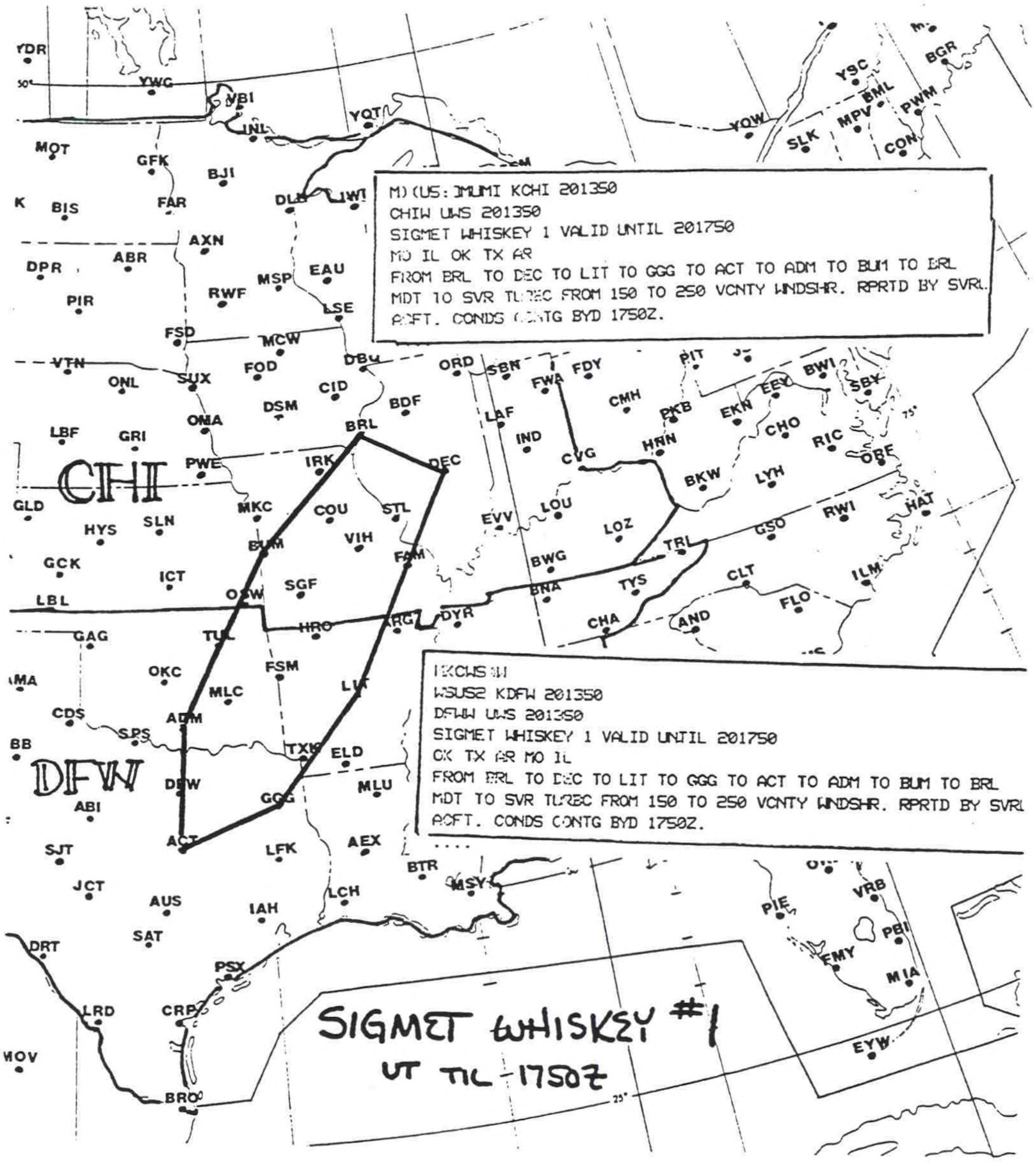


Figure 3.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ACFT. CONDS CONTG BYD 1750Z.
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MDT TO SVR TURBC FROM 150 TO 250 VCNTY WNDSHR. RPRTD BY SVRL
ACFT. CONDS CONTG BYD 1750Z.
SIGMET WHISKEY #1
UT TIL 1750Z

Figure 4

tion. The data are being received more reliably from the Boulder Hub and the local AFOS applications programs are running more consistently. All in all, forecaster confidence is increasing in the data flow and the use of profiler fields is being incorporated into the forecast routine. The challenge and opportunity for NAWAU and other forecasters will be to explore the best and most efficient uses of the array of profiler products now and soon to be available.

Severe and extreme turbulence reports during valid time of Sigmet Whiskey 1.

= Severe Turbc

= Extreme Turbc

Figure 5

Session 8.4

The Meteorological Data Collection and Reporting System (MDCRS): System Overview and Benefits

Prepared for

National Weather Service Aviation Workshop
Kansas City, Missouri

December 10–13, 1991

Prepared by

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BACKGROUND

In the spring of 1986, the ad hoc Aviation Weather Forecasting Task Force, headed by Dr. John McCarthy of the National Center for Atmospheric Research, made 20 recommendations for improving aviation weather products and services provided to the aviation community by the National Weather Service (NWS). These recommendations[1] were made in the belief "that relatively simple changes in the collection, processing, and dissemination of weather data can greatly improve the safety and efficiency of the National Airspace System (NAS)." One of the six recommendations with *vital* technical priority was to implement, nationwide, an automated aircraft weather data reporting system. The Task Force reported that "a modest investment in an automated airborne weather data collection system in the United States would have an enormous impact on the accuracy and specificity of aviation weather forecasts and warnings. In fact, *the group placed the highest priority on recommendations to develop a national capability to collect and use automated reports from aircraft.*"

Subsequent actions on this recommendation have led to development and implementation of MDCRS by Aeronautical Radio, Inc. (ARINC).

SYSTEM OVERVIEW

MDCRS (see Figure 1) collects, organizes, and disseminates automated position and weather reports with the NWS as the primary high-volume recipient of the resulting observational data. Aircraft that serve as sources for MDCRS are operated by numerous airlines and other agencies. A number of formats exist in which the reports are transmitted, because aircraft operators implement software consistent with their own operational requirements. MDCRS converts, as required, aircraft reports into a standard format specified by the NWS. MDCRS reports are encoded for dissemination in the Binary Universal Form for the Representation of Meteorological Data (BUFR), which is the World Meteorological Organization (WMO) standard code designed to optimize the communication of weather observational data.[2]

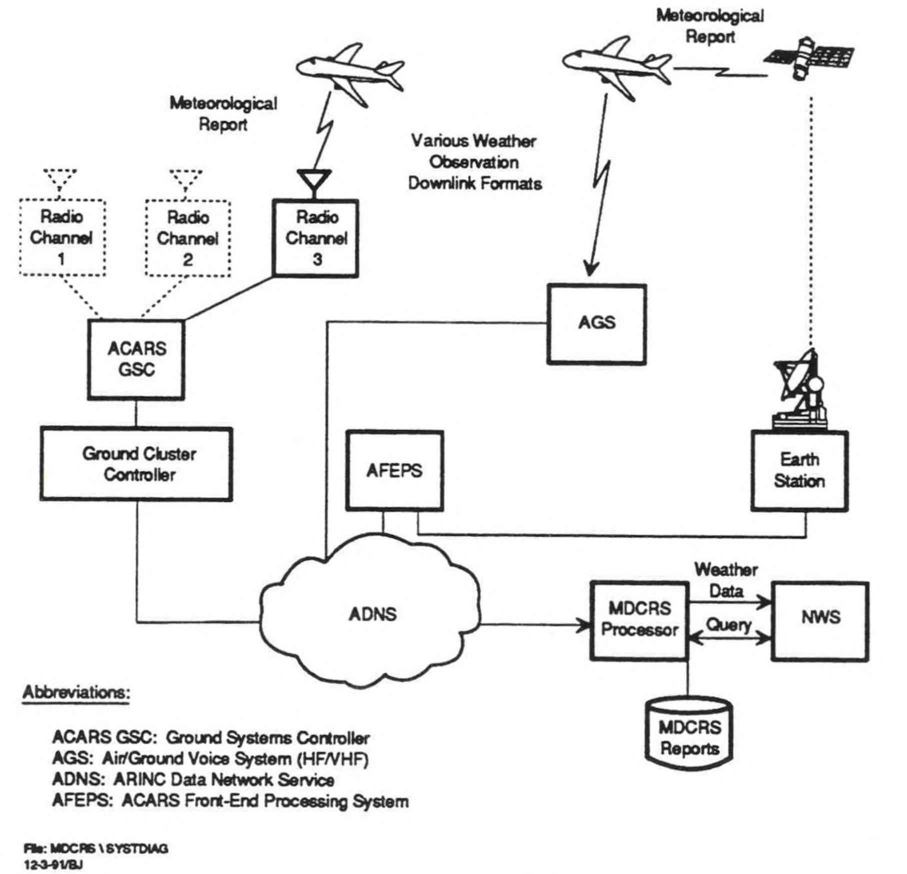

Figure 1. MDCRS Overview

Today, airline meteorological reports generally provide a subset of the fields shown in Table 1. Several parameters in the standard report will be derived where possible by MDCRS. One example of such a derivation is improved upper air turbulence reporting through the use of vertical gust velocities[3]. Future developments in avionics and position reporting will supply parameters, such as altitudes measured using the Global Positioning System (GPS) and additional observational figures of merit. Work on MDCRS has led to the proposal of several new WMO standard observational parameters.

Table 1. MDCRS Report Fields

Aircraft Flight Number	Roll Angle
Year, Month, Day, Hour, Minute	Airframe Icing
Latitude (1/100th of a Degree)	Phase of Flight
Longitude (1/100th of a Degree)	Aircraft Tail Number
Aircraft Navigation System Code	Reported Precision of Latitude/Longitude
Time-Averaged or Instantaneous Measurements	Method of Report (Automatic, Manual)
Wind Speed Flag	Precision of Temperature Observation
Wind Speed (Meters/Second)	Degree of Turbulence (Code Table)
Wind Direction	Vertical Gust Velocity (If Reported or Derivable)
Temperature	Pressure
Vertical Gust Acceleration	GPS Altitude

Major MDCRS features are presented in Table 2. MDCRS will be capable of processing weather observations from ground level to 43,000 feet in 100-foot intervals, with a latitude-longitude precision of 1/100th of a degree. All observations are time-stamped, and all reports processed will be transmitted to the NWS every 15 minutes.

Table 2. MDCRS Major Features

Observations collected from ACARS and aircraft equipped to use satellite data link
Availability of most current data: six-hour retention
Observations clustered along airline flight routes
Emphasis given to data derived from inertial systems and Omega
Scheduled transmissions of information about predefined geographic areas, routes, and altitudes
Reports associated with locations defined by VHF Omnirange (VOR), intersection, predefined waypoint, structural gridpoint, or latitude-longitude
Implementation on the ARINC Tandem Fault-Tolerant Information Services Platform

USE OF MDCRS OBSERVATIONS BY THE NWS

The National Meteorological Center (NMC) currently receives ACARS data through the Forecast System Laboratory (FSL), decodes the data, and uses the data in both the Global Data Assimilation System (GDAS)/Aviation Forecast Model and the Regional Data Assimilation System (RDAS)/Nested Grid Forecast Model. Data in the GDAS is collected over a six-hour time window, with *super-obing* (local area averaging) of nearby reports performed to reduce the total data volume. The RDAS uses three-hour data windows and more localized *super-obing*, thereby resulting in less averaging of the data. In both systems the ACARS reports are subjected to an Optimal Interpolation Quality Control procedure to ensure that the observations are within acceptable bounds of other nearby data. The tests have shown the data to be of exceptional quality, with very little data rejected.

ACARS data, together with Wind Profiler data and surface observations, provide the primary *off-time* data to the RDAS. Use of ACARS data in the RDAS has reduced errors in the short-range forecasts and guess fields used in the analysis system by 25 to 30 percent. ACARS data will also provide the primary source of off-time data for NMC implementation of the FSL Mesoscale Analysis and Prediction System (MAPS).

With the acquisition of MDCRS data, NMC will be relieved of the responsibility of decoding data for different airlines in a variety of formats that can change over time. In addition, the redundancy in MDCRS will ensure consistent and timely delivery of operational data at NMC. The timely delivery is especially important, because the goal of the NMC MAPS implementation is to produce hourly analyses within 30 minutes of the nominal hourly data times. In addition to the flight-level data, ascent and descent profiles of wind and temperature data will be used to construct soundings at a number of airport locations. These soundings will be helpful to the analysis systems—not only on their own merit, but also in providing temperature data to *anchor* nearby Wind Profiler reports.

MDCRS EVOLUTION

While MDCRS and other *interim* solutions to the collection and dissemination of aircraft meteorological reports have been implemented in various parts of the world, planning is under way for the aircraft meteorological reporting application in the long term.

Recent progress in the definition of the Aeronautical Telecommunications Network (ATN) provides an opportunity for the long-term standardized acquisition and management of aircraft meteorological reports. The ATN, based on international data communications standards, provides for the interchange of digital data between end users over dissimilar air-to-ground and terrestrial communications links in a manner transparent to the user. To take full advantage of the capabilities of the ATN, binary reporting codes (as opposed to current character-oriented report formats) become necessary; therefore, an opportunity exists to standardize automated meteorological reports. ATN further provides end-to-end addressability between reporting aircraft and report users. In essence, aircraft meteorological reporting becomes an *ATN application*, and a variety of arrangements will be made with air carriers for providing meteorological data. For example, for the optimal collection of reports, specific aircraft might have their reporting capabilities turned on and off by real-time commands from appropriate agencies on the ground.

An ad hoc international Working Group was formed in August 1990, with the primary purpose to define a standard binary format for meteorological reports automatically generated by transport aircraft. The resulting recommended format[4] is expected to be an important input to the ICAO/WMO Study Group on Air Reporting, which will be holding its initial meeting in December 1991.

A recommended alphanumeric report format that mirrors (to the degree possible) the binary format is being developed for potential use before full ATN implementation, by air carriers not already committed to a specific alphanumeric format.

Other subjects considered by the ad hoc Working Group have included the following topics:

- Initiatives needed to define institutional requirements and procedures

- Definition of what meteorological parameters desired by the meteorological services can be provided from existing and planned aircraft systems (turbulence reporting was the subject of a September 1991 meeting between aircraft manufacturers and meteorologists)

- The aircraft-reporting interval to be used and the scheme that should be used to minimize redundant data on heavily traveled routes

Major elements of the aircraft meteorological reporting *application* in an ATN environment are shown in Figure 2. Flexible ATN meteorological reporting arrangements with air carriers are envisaged, that is, with one or more *application management entities* collecting and forwarding reports, after required processing.

PROJECTED VOLUMES AND DISTRIBUTION OF MDCRS OBSERVATIONS

As currently implemented, MDCRS will receive its primary data from participating aircraft equipped with ACARS operating throughout North America. In addition, satellite data link-equipped aircraft will become a source of worldwide observations as these systems become available to airlines and other aircraft operators.

Current volumes of ACARS aircraft meteorological reports are between 10,000 and 20,000 a day. Additional voice oceanic reports add approximately 2,400 to this total. Projected 1995 worldwide volumes of automated aircraft meteorological reports[5] are estimated to be between 47,000 and 76,500. Discussions with airline meteorological, operations, and avionics personnel have led to the requirement that MDCRS be capable of handling a maximum of up to 150,000 automated reports a day in the late 1990s.

MDCRS BENEFITS

In addition to the accuracy benefits to World Area Forecast Center (WAFC) forecasts and analyses from incorporating MDCRS data into global and mesoscale numerical weather prediction models, MDCRS can provide additional returns to the aviation industry.

The Oceanic Advanced Automation System (OAAS) currently under development will automate ATC functions over the FAA Oceanic Flight Information Regions (FIRs). Implementation of this program using MDCRS data for real-time analysis of winds aloft could allow a reduction in transoceanic fuel reserves and aircraft separation standards.

The Terminal Air Traffic Control Automation (TATCA) implementation is projected by the FAA to save the industry $3.5 billion a year in fuel, crew pay, and flexible routing. MDCRS data is a key factor to the TATCA program.

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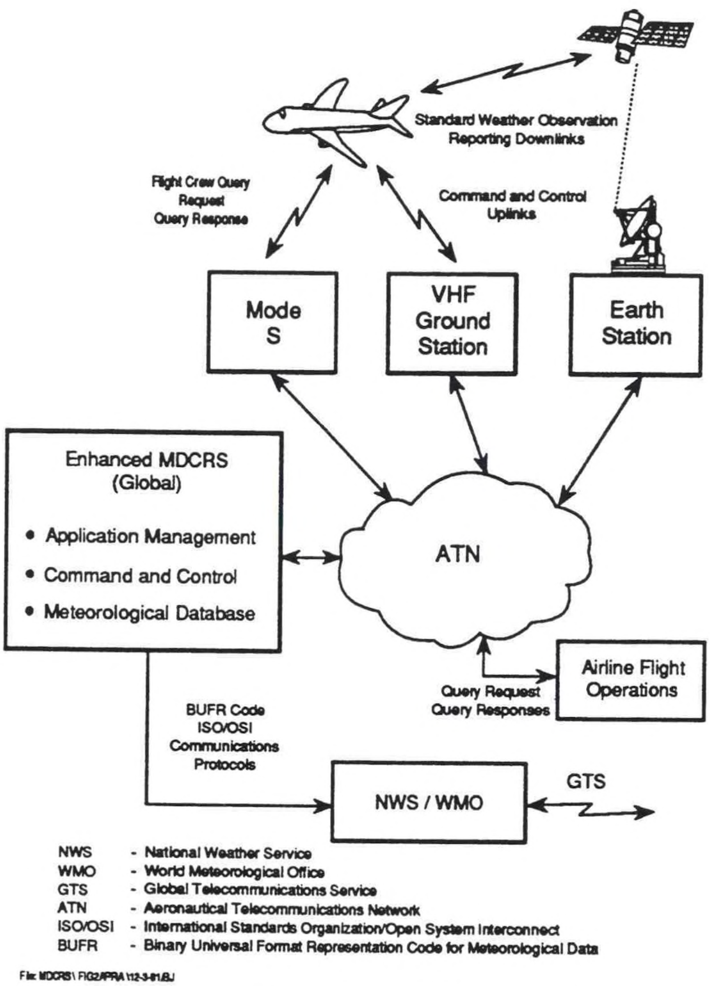

Figure 2. MDCRS Evolution

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BIOGRAPHIES

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Clifford Dey, Chief of the Data Processing Section, Data Applications Branch, NWS, is responsible for decoding and databasing meteorological observations for the Aviation Division of the NMC.

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IMPROVED WEATHER RECONNAISSANCE SYSTEM

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The Air Force has provided hurricane reconnaissance for the United States since WWII and had a peak strength of over 100 weather reconnaissance aircraft about 1960. The current size of the Air Force weather reconnaissance fleet consists of 12 Air Force Reserve WC-130's belonging to the Storm Trackers based at Keesler AFB in Biloxi MS. They have sole responsibility for operational hurricane reconnaissance for the United States and also fly synoptic weather reconnaissance tracks for East Coast Winter Storms.

The current area of responsibility for tropical cyclone reconnaissance includes the North Atlantic Ocean, Gulf of Mexico, Caribbean Sea, plus the Central and Eastern regions of the North Pacific Ocean. Large population growth and economic development in these areas make them particularly vulnerable to hurricane damage. The precise location and measurement of tropical cyclones by aerial weather reconnaissance improves the accuracy of National Hurricane Center forecasts and warnings by about 25 percent.

Previous weather reconnaissance data was collected using an Air Force system called SEEK CLOUD, utilizing manual data reduction techniques and data transmission with HF voice-radio phone patches to ground weather monitors. This system produced reliable data but did not meet the specifications for the National Hurricane Center's need for High Density/High Accuracy data for improved forecasts and warnings.

Soon after Hurricane Camille hit the Mississippi Gulf Coast in 1969, a Presidential Directive yielded the Advanced Weather Reconnaissance System (AWRS) to improve quality of Hurricane Reconnaissance data. This system fell short of expectations and was cancelled. The joint AF/NOAA Improved Weather Reconnaissance System (IWRS) program produced 12 fully operational IWRS-modified aircraft for the 1991 Hurricane Season.

IWRS has three subsystems: 1) Atmospheric Distributed Data System (ADDS) - collects flight-level meteorological data, 2) Omega Dropwindsonde System (ODWS) - collects vertical meteorological data and 3) Satellite Communications (SATCOM) - transmits the data to ground stations. The Self-Contained Navigational System (SCNS) is not part of the IWRS modification per se, but provides vital Inertial Navigation System parameters to the IWRS system including geographical position and wind data input.

The Atmospheric Distributed Data System (ADDS)collects High-Density/High-Accuracy data at flight level (usually 700 Mb for hurricanes and 300 Mb for Winter Storms). It samples data eight times per second and displays it every second. This data is averaged into ten-second data groups and one-minute data groups which are stored on disc for research and post-mission analysis. MINOBS are shortened versions of the one-minute data groups which are transmitted in packages of 20 groups each.

The ADDS station is called the executive station and is manned by the Weather Officer. It is linked to the ODWS and controls the SATCOM data-link. A PC computer with a nine inch color monitor serves as the ADDS controller. A back-up ADDS controller provides redundant data storage and is located on the ODWS pallet in the cargo compartment. With ADDS, the meteorologist is freed from data-crunching and has more time to observe meteorological details of tropical cyclones and perform his mission director duties. He needs good IWRS systems knowledge to understand how individual data elements affect total meteorological data output in order to correct problems through operator interface.

Screen displays can be divided into five different types: 1) Messages display all coded weather data plus plain text messages for communication between IWRS and the ground station, 2) Initialization screens allow configuration adjustments and default input for the system, 3) Status screens show the operator the system, data and SATCOM products status, 4) Plot graphically displays the data while 5) Other various screens are utilities for specialized applications.

The ODWS component receives pressure, temperature, humidity and Omega data from the dropwindsonde in real time. The data is automatically encoded ready for transmission. The sonde is an 18.5 inch cylinder containing a parachute a battery and electronic circuitry to sample the atmosphere. Two sondes can be airborne and tracked simultaneously. The Dropwindsonde Systems Operator ejects the sonde and monitors it as it falls to the surface at 1000 feet per minute. It sends back pressure, temperature and humidity readings every ten seconds and wind data every 30 seconds. The pallet is located in the rear of the cargo compartment and contains a PC computer which processes and encodes the dropwindsonde data.

The SATCOM system transmits data to aground station and is relayed to the Automated Weather Network (AWN) at Carswell AFB, TX. The Miami ground station is primary and is also linked directly to National Hurricane Center computers. Keesler is the alternate ground station and is linked to the AWN only.

The Improved Weather Reconnaissance System provides data that is a tremendous advance over manually computed data which involved manual reading of instruments, tables , pencil and paper. The programmable desktop calculator improved speed somewhat in the 1980's but aircrews still verbally transmitted data over High-Frequency (HF) phone patches to the hurricane center. Communication was still frustrating because HF radio quality was often degraded by atmospheric conditions inside the hurricane. IWRS improves weather reconnaissance data quality by providing High-Density/High Accuracy meteorological data collection and dissemination. The Improved Weather Reconnaissance System has dramatically advanced Weather Reconnaissance by every measure.

DATA LABELS

ATK	ANGLE OF ATTACK	PBT	SIDESLIP BETA TRANSDUCER
DPR	DYNAMIC PRESSURE	PSS	SIDESLIP DPR TRANSDUCER
DV	D-VALUE	RA	RADAR ALTITUDE
FLP	FLIGHT LEVEL PRESSURE	SLP	SEA LEVEL PRESSURE
GA	GEOPOTENTIAL ALTITUDE	SS	ANGLE OF SIDESLIP
GS	GROUND SPEED	TA	AIR TEMPERATURE
HC1	HYDROCARBON DETECTOR 1	TAS	TRUE AIR SPEED
HC2	HYDROCARBON DETECTOR 2	TD	DEWPOINT TEMPERATURE
HCL	HYDROCARBON LEVEL	THD	TRUE HEADING
HSS	HEIGHT OF STANDARD SURFACE	TRK	GROUND TRACK
LG	LONGITUDE	TT	TOTAL TEMPERATURE
LT	LATITUDE	VE	VELOCITY EAST
MXW	MAXIMUM WIND SPEED	VN	VELOCITY NORTH
PA	PRESSURE ALTITUDE	WD	WIND DIRECTION
PAA	AOA DPR TRANSDUCER	WS	WIND SPEED
PAL	AOA ALPHA TRANSDUCER		

FIG. 1 A list of the 31 parameters sampled or computed by IWRS. Sixteen are meteorological in nature and 15 are aircraft data inputs used for higher level meteorological computations. Eleven parameters are measured directly, while the rest are computed values. One-minute data sets which record all 31 parameters produced by the IWRS system are stored on disc.

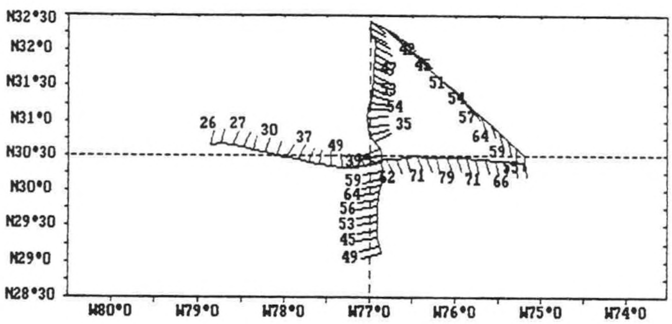

FIG. 2 The track plot is an important tool for the weather officer to analyze the flight level wind field. Digital wind barbs overlay the 700 Mb track plot of the alpha pattern for Hurricane Bob 0520-0800Z on 18 Aug 91. It is a cross-shaped pattern with 105NM legs centered on the eye of the hurricane.

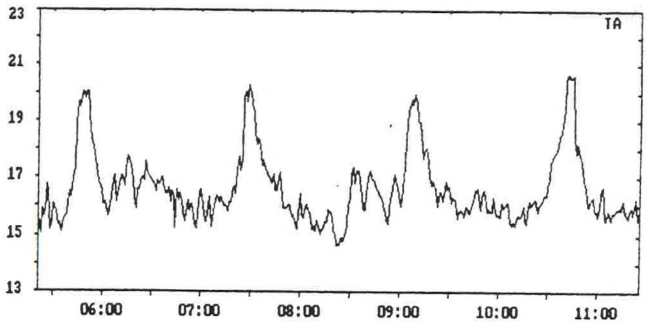

FIG. 3 A time plot of flight level temperature for Hurricane Bob 0520-1125Z on 18 Aug 91. The temperature rise is obvious for each of the four passes through the eye. Time plots use one-minute data and can be rescaled for both time and values.

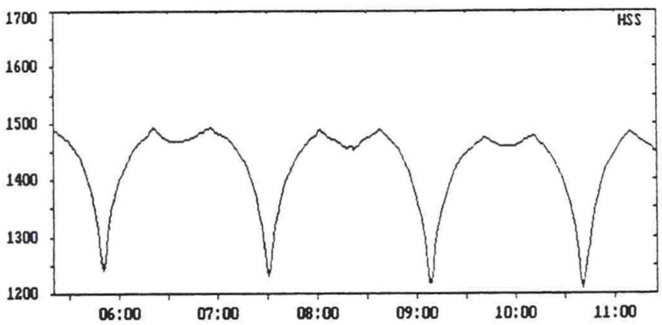

FIG. 4 Hurricane Bob's time plot of height of the 700 Mb pressure surface shows the steep height falls during each of the four eye penetrations 0520-1125Z on 18 Aug 91.

USE OF REAL TIME LIGHTNING LOCATION DATA AT THE NATIONAL AVIATION WEATHER ADVISORY UNIT

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1. INTRODUCTION

The National Aviation Weather Advisory Unit (NAWAU) is part of the National Severe Storms Forecast Center (NSSFC) in Kansas City, MO. The NAWAU is responsible for issuing aviation area forecasts and in-flight weather advisories for the conterminous United States and adjacent coastal waters. In April, 1988, a system for the display of data from a national lightning detection network was installed at the NSSFC. This paper describes the display and applications of real-time lightning data in the NAWAU.

2. LIGHTNING DATA ACQUISITION AND DISPLAY

The lightning location display system used at the NSSFC utilizes data gathered from three networks. The Bureau of Land Management maintains a network covering the western United States while the National Severe Storms Laboratory network provides coverage over the Oklahoma and Kansas region. The State University of New York at Albany (SUNY) operates the largest network which covers the eastern, north central and south central United States.

Lightning detection sensors used by the networks are manufactured by Lightning Location and Protection, Inc (LLP) and described in Krider, et.al. (1976). When a sensor detects a cloud to ground flash, information is transmitted to SUNY where data are collected and processed (Orville, 1987). When two or more sensors detect the same flash the location is computed by triangulation. Real-time flash information is transmitted by SUNY via satellite and is received at NSSFC with a small antenna on the roof of the federal office building.

An IBM compatible PC/AT displays the lightning location data using software developed by SUNY. Flashes are plotted on a color graphic display monitor with special characters to denote positive and negative strikes. The software allows for both static and time-lapse display of lightning data with flashes color-coded according to age. Data may be shown on the U.S. map background showing total network coverage or may be zoomed in on an area of special interest. Special user-defined maps may also be used.

A second monitor displays menu options and various information on flashes being reported. Map backgrounds, color coding, time increments for animation and other display options are chosen from the menu via a keyboard. Flash data include a running hourly total of cloud to ground strikes within the total network and a separate total for those strikes inside the zoomed display. The system also counts flashes that have occurred in the last five minutes and displays this number multiplied by twelve. This feature allows for a quick look at changing flash frequencies by comparing five and sixty-minute strike rates.

3. NAWAU PRODUCTS

The NAWAU is comprised of two sections: the Convective SIGMET unit and the In-Flight Advisory and Area Forecast (FA) section. Convective SIGMETs are in-flight advisories for thunderstorms that are especially hazardous to aviation. These include severe thunderstorms (those producing tornadoes, hail greater than 3/4 inch or wind gusts of 50 knots or more), thunderstorms developing in lines, large clusters of strong thunderstorms (VIP level 4 or greater) and thunderstorms embedded in non-convective clouds and/or precipitation. Convective SIGMETs are issued between 40 and 55 minutes after each hour with special issuances as needed.

The FA forecaster issues non-convective SIGMETs and AIRMETs for weather phenomena that are hazardous to aviation, including moderate or greater turbulence and icing as well as areas of low ceilings and/or visibilities. The area forecast includes a flight precaution for thunderstorms if coverage is expected to be at least scattered or if Convective SIGMET criteria are forecast.

4. APPLICATIONS OF REAL-TIME LIGHTNING DATA

Lightning strike location and trends are vitally important in the preparation of hourly Convective SIGMETs, while flash data are only one part of the information used in the preparation of area forecasts. Therefore, the lightning display system is situated on the desk of the Convective SIGMET unit and this paper will emphasize the use of the data by the Convective SIGMET meteorologists.

4.1 INITIATION

The lightning strike display is often the first indicator of the start of deep convection. The real-time nature of flash information makes it more timely than other data sources used by the NAWAU. These include radar reports, surface observations, pilot reports, satellite imagery and composite radar imagery. Lightning strike data may also reveal developing convection before the associated precipitation can reach the dropsize and altitude where it is detected by radar. As a result, Convective SIGMET issuances have become more timely for fast-developing convective systems.

4.2 LOCATION

Lightning data have been useful in locating thunderstorms where National Weather Service radars cannot reach or are unreliable. The NAWAU area of responsibility includes coastal waters and large areas of the western U.S. which are beyond the range of the N.W.S. radar network. Real-time flash information is also useful where radars are out for maintenance or are operating below performance standards.

Low-topped convection and embedded thunderstorms present special problems for the Convective SIGMET meteorologists. When radar reports carry echo tops of 20 to 25 thousand feet and low visibilities preclude surface reports of lightning, it is unclear whether the meteorologist is working with embedded rainshowers or thunderstorms. A lack of cloud-to-ground lightning strikes does not preclude thunderstorms, but the presence of lightning may be the determining factor in issuing a Convective Sigmet.

Lightning data may also be displayed on the NSSFC's Vas Data Utilization Center (VDUC) (Browning, 1992). With the last hour's strikes plotted on top of current satellite or radar imagery, the meteorologist may draw the Convective SIGMET using an interactive program and a mouse for input. This capability has increased the accuracy of Convective SIGMET placement.

4.3 CONFIGURATION AND COVERAGE

Convective SIGMETs may be issued for thunderstorms developing as lines, areas and isolated cells. Lightning location data may depict which of these categories best describes the convective system. This is especially true when radar use is limited by attenuation associated with heavy precipitation and when a cirrus shield obscures areas of convection in satellite imagery (Goodman and MacGorman, 1986; Reap, 1988). Lightning data also show configuration and coverage of thunderstorms over the western U.S. and over the coastal waters where radar data are not available.

Lightning data has shown that many storm systems are more linear in configuration than previously thought. This has lead to an increasing percentage of "LINE" type SIGMETs to be issued (McCann and Mathews, 1989). This has the dual benefit of reducing the threat area as well as making the Convective SIGMET easier for pilots to understand during in-flight briefing.

4.4 MOVEMENT

The SUNY display system with its ability to animate color-coded lightning data gives an excellent depiction of the movement of convective systems. One or two-hour time-lapse sequences show thunderstorms sweeping across the map with older strikes becoming progressively darker and disappearing, while newer brightly-colored strikes are plotted along the leading edge of the convection. This provides better continuity of movement than 15 or 30 minute satellite imagery. When flash locations are plotted on the VDUC, an interactive program can measure the direction and speed of system movement.

4.5 DISSIPATION AND REDEVELOPMENT

The Convective SIGMET unit uses lightning flash data as an indicator of dissipation and redevelopment within convective systems. A decreasing flash frequency may be used along with other meteorological data to anticipate the demise of a storm system. While the percentage of positive strokes within a convective system will often increase as dissipation begins (Orville, et.al., 1983), there is not a perfect correspondence and this indicator must be used with caution. Lightning data may also be faster than radar to indicate thunderstorm dissipation. Precipitation may maintain radar echoes ten to thirty minutes after the updraft and lightning have ceased (Edman, 1986). An increase in flash frequency and an increase in the percentage of negative strokes generally signal redevelopment of a convective system.

5. CONCLUSION

During the four years that the NAWAU has had access to real-time lightning location data, the display has become an invaluable source of information on thunderstorm development. The initiation, location, movement, configuration, coverage, dissipation and redevelopment of convective systems is well shown by the SUNY display. After a ten month evaluation period ending in August 1989, Convective SIGMET forecasters reported that lightning data contributed unique and useful information about convection in 74 percent of all cases (Lewis, 1990). The FA meteorologists reported unique information in 25 percent of all cases.

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ON THE EFFECT OF AUTOMATED SURFACE OBSERVATIONS ON NATIONAL WEATHER SERVICE FORECAST PRODUCTS

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1. INTRODUCTION

Automated surface observations from both the National Weather Service (NWS) Automated Surface Observing System (ASOS) and the Federal Aviation Administration (FAA) Automated Weather Observation System (AWOS) are in place in some parts of the United States. The impact of these systems on aviation weather can be expected in three areas: surface observations themselves; the forecast preparation process; and product formats and content.

This paper will deal with the first and last of these areas. In the surface observation area Sections III and IV will concentrate on ASOS and how ASOS observations differ from human observations. Only brief remarks will be made in Section VI on changes in products and services due to the fact that explicit policy changes are still in the formulation stage.

2. ASOS VERSUS HUMAN OBSERVATION

In form, an ASOS surface aviation observation (SAO) will look very much like a manual SAO. For example, under the same weather conditions, the ASOS report would be transmitted as:

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RIC SA 1950 A02 M80 BKN 5H 123/45/40/1106/013
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while the human observation might report:

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RIC SA 1951 E80 BKN 140 OVC 6H 123/45/40/1106/013
FEW CU 20
```

Notice that both SAO's contain the station ID, observation type, time, sky condition, visibility, obstruction to vision, sea-level pressure, ambient temperature and dew point temperature, wind and altimeter setting.

At first glance, the main differences are the ASOS station type (A02) signifying an unattended observation (human oversight not provided), the 12,000 foot upper limit on the ASOS SAO for reporting cloud height, the lower visibility increment reported by the ASOS observation (due to the reportable values used by ASOS), and the cloud type remark in the manual SAO. Closer examination reveals that the ASOS reported ceiling is always measured (M), while the manual ceiling height may be estimated or measured, depending upon available means.

In the next two of sections each weather element of the ASOS observation will be reviewed to see what new technology and new concepts are used by ASOS.

3. OBJECTIVE ELEMENTS

Four weather parameters contained in the ASOS observations are considered "objective elements" because the ASOS software can read, format and transmit their values just as easily as the human with no change in the basic observing method. These parameters include: temperature, dew point temperature, wind and pressure.

A. Temperature and Dew Point Temperature

Temperature and dew point temperature are determined from a modification to the fully-automated "HO-83" hygrothermometer which has been in use by the NWS since 1985. This instrument uses a resistive temperature device to measure ambient temperature and a chilled mirror to determine the dew point temperature.

The values shown by ASOS are 5-minute averages. The range of observational values is -80 deg F to +130 deg F for temperature, and -30 deg F to +86 deg F for dew point temperature.

B. Wind Speed and Direction

The rotating cup anemometer and the simple wind vane are the principle indicators of wind speed and wind direction with ASOS. The wind sensors are exposed at a height of 10 meters (32.8 feet) on a tower that can be (literally) tipped over for maintenance purposes.

ASOS measures wind speed and wind direction once every second and produces a 5-second average wind. These 5-second averages are used to compute the 2-minute average wind shown on ASOS, as well as accompanying gusts and squalls, and remarks such as wind shift, variable winds, and peak winds. The 2-minute average wind is different from the manual 1-minute average wind but conforms to World Meteorological Organization (WMO) recommendations.

The ASOS sensors measure wind speed up to 125 knots. The wind display in the control tower (Controller Video Display or CVD) gets an updated 2-minute average wind every 5 seconds.

C. Pressure

The ASOS barometers consist of either two to three digital pressure transducers to measure atmospheric pressure. Pressure values are taken every 10 seconds and produce a 1-minute pressure average. This 1-minute average is used to calculate the various operational pressure values: altimeter setting, sea level pressure, density altitude, pressure altitude, and pressure change/tendency.

4. SUBJECTIVE ELEMENTS

The ASOS parameters of sky condition, visibility and present weather are considered "subjective elements" because the ASOS software must transform a human judgement process into a machine operation. The basic assumption used in developing this process is to substitute a time averaging process for the spacial averaging process used by the human.

A. Sky Condition

The ASOS cloud sensor is a laser ceilometer, commonly referred to as a Cloud Height Indicator (CHI). This instrument has a vertical measurement range of 12,600 feet, and a vertical reporting range from 100 feet to 12,000 feet. It is capable of distinguishing between opaque and thin translucent clouds but will only report opaque clouds.

The laser ceilometer measures a cloud height every 30 seconds and uses 30 minutes of height values to produce the sky condition measurement shown on ASOS. This time average replaces the spacial average of the human observer. The cloud height values from the last 10 minutes are double weighted to increase the algorithm response to new cloud layers. Up to three cloud layers are reported by ASOS.

If no clouds are detected by the laser ceilometer at or below 12,000 feet, ASOS reports "CLR BLO 120", read "clear below 12,000". Otherwise, the standard SCT, BKN, OVC and W indicators are used. The lowest obscuration observed by ASOS will be "WX1".

On airports where one ceilometers is considered less than adequate for determining cloud conditions, up to three laser ceilometers can be attached to the system.

B. Visibility

ASOS visibility is based on a forward-scatter instrument that senses visibility restrictions via the amount of light received by the instrument. Visibility values are computed every minute. The visibility value shown on ASOS is a 10-minute harmonic mean of these 1-minute values.

Reportable values for ASOS visibility are quarter-mile increments up to 2 miles, half-mile increments from 2 to 4 miles, and 5, 7 and 10+ miles. The lowest reportable value is "<1/4".

On airports where one visibility sensor is considered less than adequate for determining visibility conditions, up to three sensors can be attached to the system.

C. Present Weather

There are currently two ASOS present weather sensors: the Precipitation Indicator (PI) (or LEDWI) which discriminates between rain and snow, and the Freezing Rain (ZR) sensor.

The ASOS algorithms use with the sensor values to determine if light, moderate or heavy rain (R-, R, R+), light, moderate or heavy snow (S-, S, S+), or light or moderate freezing rain (ZR-, ZR) is occurring. When the temperature is between 26 deg F and 40 deg F, and a mixture of precipitation types are falling, it is possible that ASOS will not be able to determine what type of precipitation is occurring. In those cases ASOS will sense precipitation and indicate that "P-" is occurring.

ASOS will not distinguish between rain and rain showers, or snow and snow showers. Drizzle (L), ice crystals (IC), ice pellets (IP), hail (A), and thunderstorms (T) will not be reported by ASOS.

An ASOS algorithm determines the occurrence of obstructions to vision (fog and haze only) based on visibility, dew point depression, and present weather.

5. TOTAL SURFACE OBSERVATION CONCEPT

ASOS, by itself, has never been advertised as a total replacement for the manual SAO. In the modernized NWS the Total Surface Observation Concept will provide the user with as much, if not more, information than is available from a manual SAO. This concept envisions surface data derived from three main components: the airport operational component (basically ASOS); a supplementary component consisting primarily of ancillary networks; and complementary technology such as satellite, radar, profilers and lightning detection networks. The synergistic effect of these three components will enhance the overall surface observing database.

6. PRODUCT IMPACT

It is difficult to make any definitive statement on the impact of automated surface observations on products and services because policies have not been finalized in these areas. The comments made below are preliminary in nature, and based on current discussions on policy changes due to automated surface observations.

In the area of terminal forecasts (FT), no FT's are anticipated at unaugmented AWOS sites. The standard FT will be based on the ASOS observation plus any supplemental network data that are available. Amendment criteria are still under discussion.

Little change is anticipated in route (TWEB) forecasts.

Pilot briefing will remain essentially unchanged but whenever the briefer uses data from an automated observing system, the briefer must inform the pilot that these data are from an automated source.

7. CONCLUDING REMARKS

ASOS and AWOS are new technologies and use new concepts to observe the state of the atmosphere. They will create a new way of doing business. The meteorological and user community will need to learn how to effectively use these new technologies and concepts. As ASOS and AWOS continue to be deployed, keep an open mind. There are many advantages with these new systems.

8. REFERENCES

National Weather Service, 1991: ASOS User's Guide [Preliminary version], 84 pp.

THE IMPACT OF THE AUTOMATIC WEATHER OBSERVING SYSTEM (AWOS) ON THE TERMINAL FORECAST PROGRAM AT HAYDEN AND GUNNISON, COLORADO AND JACKSON, WYOMING

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1. Introduction

Beginning in January 1990, WSFOs Cheyenne and Denver began issuing Terminal Forecasts based on AWOS observations at Jackson, Wyoming (JAC), Hayden (HDN), and Gunnison (GUC), Colorado. Prior to the installation of AWOS, all three sites were Supplementary Aviation Weather Reporting Stations (SAWRS) where the observations were taken at the site by local aviation interest. The Jackson, Wyoming observations were the only observations augmented by the SAWRS cooperator after AWOS was installed. Jackson was augmented from 6:00 a.m. to 10:00 p.m. LST as the SAWRS cooperator's time and workload permitted. From 10:00 p.m. to 6:00 a.m., the Jackson AWOS observation was unaugmented and provided three observations an hour. AWOS at Hayden (HDN) and Gunnison (GUC), Colorado provided three unaugmented observations per hour, 24 hours a day.

Weather Service Operations Manual Letter 4-90, dated 9/6/90, provided regulations for the issuance of Terminal Forecasts based on automated observations. Essentially, when the AWOS site was augmented, the forecaster issued a traditional FT. When AWOS was unaugmented, the FT parameters that were not sensed by the system were not forecast in the FT. The AWOS system senses sky conditions below 12,000 feet, visibility, wind direction and velocity, temperature, dew point, and barometric pressure (altimeter setting). The only exception to the rule was thunderstorms. If thunderstorms were expected within the ten nautical mile radius of the airport complex, the remark "trw vcnty" was added to the FT.

2. Methodology

Prior to and after the implementation of AWOS at Jackson, Wyoming, WSFO Cheyenne, Wyoming, kept a detailed record of the number and reasons for FT amendments at that site. FT amendments were tallied and recorded in the following categories:

- Ceiling
- Visibility
- Wind (included amendments for speed, direction, and gusts)
- Thunderstorms
- Quality (missing, missing element, or poor observations)
- Better forecast (amendments made before required)
- Other (amendments not recorded in the other categories)

Forecasters at WSFOs Cheyenne and Denver were encouraged to document problems associated with the

AWOS FT program. In addition, WSFO Cheyenne documented problems with system performance. Both offices were encouraged to send periodic reports concerning the program to Central Region Headquarters.

3. Analysis

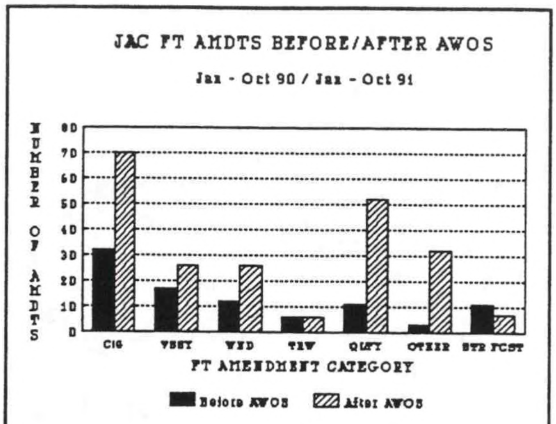

Figure 1

Figure 1 shows the number of FT amendments in each amendment category for the ten-month period, from January-October, based on human observations in 1990, compared to the ten-month period, from January-October 1991, based on a combination of unaugmented/ augmented AWOS observations at Jackson, Wyoming. Due to the increase in the number of observations and time span of observational coverage of the AWOS system, increases were seen in most categories of amendments except for thunderstorms and better forecasts. Dramatic increases were seen in the number of amendments related to quality (missing, missing element, or poor observations) and the "other" category. These two amendment categories were related due to the fact that after an amendment was issued to cancel the FT based on the quality of the AWOS observation, some subsequent amendments to reissue the FT were categorized in the "other" category. Thunderstorms were not sensed by AWOS, thus little change was noted in the number of thunderstorm amendments prior to and after the implementation of AWOS.

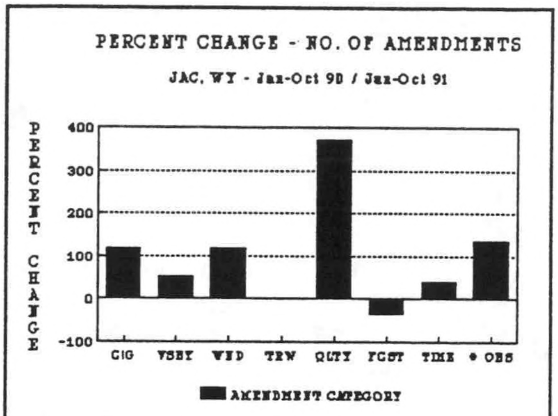

Figure 2

Figure 2 shows the percent change in the number of amendments in each category after AWOS was implemented at Jackson. The "other" category was left off the graph due to the tainted nature of the data. Added to the graph was the percent increase in the time span of observational coverage (TIME) and the percent increase in the number of minimum observations (OBS). The implementation of AWOS expanded the time span of observational coverage 41 percent. AWOS provided 3 observations per hour during the period of increased observational coverage. This increased the number of minimum observations 136 percent.

The percent increase in the three main categories of FT amendments, mainly, ceiling, visibility, and wind when compared to the increase in time span of observational coverage and the number of observations was reasonable. The percent increase in the number of amendments due to observational quality was not.

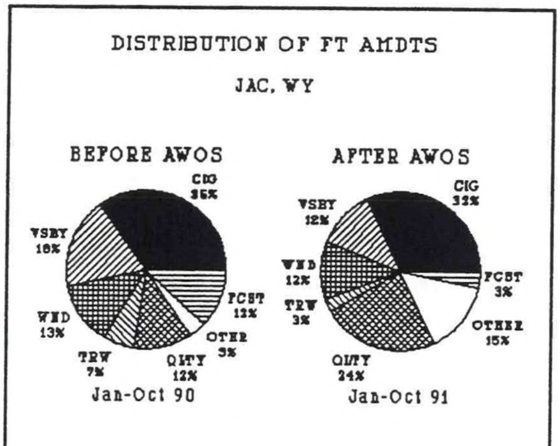

Figure 3

Figure 3 depicts the percent distribution of FT amendments prior to and after the implementation of AWOS at Jackson, Wyoming for the same January-October period. Little change was seen in the traditional amendment categories of ceiling, visibility, and wind. Again, dramatic changes are seen in the quality and "other" category.

The number of documented comments by both WSFOs for each site and the number of comments tabulated according to general topic are listed:

HAYDEN,CO	GUNNISON,CO	JACKSON,WY
10 COMMENTS	10 COMMENTS	19 COMMENTS
7 Fluctuating ceiling and or visibility	4 Fluctuating ceiling and/ or visibility	13 Missing observation or element in observation
2 Conflicting information from nearby observations and/or other technologies	4 Conflicting information from nearby observations and/or other technologies	1 Conflicting information
1 Other	1 Missing critical element	5 Inconsistent data from consecutive observations

Most of the documented problems fell into three categories. **One** category was system performance problems associated with missing observations, or missing critical elements in AWOS observations. An example of this type of problem follows during a possible fog and stratus situation where the temperature and dew point suddenly stopped reporting.

2/18/91

JAC SA 1514 AWOS M M 3/3/0209/005
JAC SA 1454 AWOS CLR BLO 120 10 5/2/0405/004

The FT was amended to show "FT NOT AVBL".

Second was problems pertaining to fluctuating ceiling and visibility. This can be attributed to the relatively small area sensed by the system compared to human observations and the different response time of ceiling and visibility algorithms. An example this type of problem in April 1991, at Hayden, Colorado, follows:

HDN SA 0134 AWOS M3 BKN 10 32/30/2807/994
HDN SA 0114 AWOS M3 BKN 16 BKN 10 32/30/2707/994
HDN SA 0054 AWOS 3 SCT M9 BKN 14 BKN 3 32/30/2710/993
HDN SA 0034 AWOS 3 SCT 6 SCT M10 BKN 5 32/30/2710/994
HDN SA 0014 AWOS 12 SCT 22 SCT 50 SCT 5 33/30/3004/993
HDN SA 2354 AWOS 49 SCT 10 32/30/3004/993
HDN SA 2334 AWOS -X M9 BKN 13 OVC 3/4 31/29/3405/993

The visibility jumps from 3/4 mile at 2334 to 10 miles at 2354. From the 0054 to 0114 AWOS observation, the visibility increases from 3 to 10 miles while the ceiling falls from M9 BKN to M3 BKN. The forecaster canceled the FT.

The **third** category was problems with conflicting information from nearby observations and/or complementary technologies such as satellite pictures, pilot reports, etc. In most of these cases, the forecaster did not believe that the AWOS observation was representative of the entire terminal area. The most serious example of this problem type occurred on April 8, 1991 at Gunnison. The observation sequence is as follows:

GUC SA 1933 AWOS CLR BLO 120 10 35/21/2315G24/003
GUC SA 1913 AWOS 14 SCT 33 SCT 7 33/23/2212/002
GUC SA 1833 AWOS CLR BLO 120 10 39/18/2418G22/999

A note from the WSFO Denver forecaster said, "According to the CWSU forecaster...a pilot missed his approach into GUC about 1850z due to low ceilings. As you can see...the latest observation had CLR BLO 120 and there was no 1853z observation."

4. Conclusions

Some of the differences in the number of amendments can be attributed to the different weather of the periods sampled from Jackson, Wyoming. The periods sampled for the data, January-October in 1990 and 1991, both received around 12 inches of precipitation. The study neglected to address the possibility that forecasters may have compensated for variability in ceiling and visibility with broad brushed FTs that do not require amending.

The data and comments from WSFO Cheyenne and Denver point out that FT programs for AWOS observations thus far have serious deficiencies. None of them are not insurmountable. Amendments associated with system performance and reliability can be eliminated with modifications for improvement and better maintenance. Amendments due to fluctuating ceiling and visibility values can be addressed by improvements in algorithms that govern them or changes in amendment policy to deal with automated observations.

The main source of forecaster concern associated with conflicting information for complementary technologies arises from WSOM D-21, Section 5., which states, "FT relates to weather conditions within 5 nautical miles of the center of the runway complex", but the sensed conditions of unaugmented AWOS were those only near the touchdown zone. These AWOS sites are remote mountainous locations where the forecaster did not have an adequate complement of technologies to determine with confidence conditions in the entire terminal area.

Resolving the source of this conflict (seen mainly for remote FT sites with an inadequate complement of technologies), warrants either a change in the terminal area definition or the establishment of a point forecast (PF) where the FT relates to weather conditions only near the touchdown zone. The later change essentially would cut the mental linkage between the standard FT and the FT based on unaugmented AWOS for both forecaster and pilot.

5. Acknowledgements

The authors wish to thank the forecasters at WSFOs Cheyenne, Wyoming, and Denver, Colorado, who took the time to document the problems associated with this program.

AUTOMATED SURFACE OBSERVATIONS
A MAJOR CHANGE FOR AVIATION OPERATIONS

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1. INTRODUCTION

The reorganization and modernization of the National Weather Service is driven by advances in technology and computers. To efficiently utilize this technology offices will be relocated and additional meteorologist will be hired. Products and services to the aviation industry will also be changed over the next 10 years.

One pillar of this reorganization will be automated surface observations. These systems will provide 24 hour observations, often at sites presently without observations. Yet, the aviation industry must realize automated observations are NOT identical to observations currently taken by human observers. Automated surface observations will change operational procedures and force a greater reliance on other weather information to obtain a complete picture of flight weather.

Let me preface the remainder of this discussion by saying that automated surface observations are definitely useful sources of data, but they are not observations like we know it today. Automated surface observations will be only a single piece of the vast data system of the future.

2. OVERVIEW

The two major automated systems being installed are the Automated Surface Observation System (ASOS) which is a joint National Weather Service, Federal Aviation Administration, and Department of Defense project; and the Automated Weather Observation System (AWOS) installed by the FAA and private operations. The systems are similar in principle and thus both included in this discussion. The ASOS system alone will be approximately 1200 units distributed throughout the United States (Fig. 1). This will provide a greatly increased number of 24 hour surface observations.

Automating many of the observation functions poses little difficulty. Automated sensors are currently measuring temperature, dew point, wind speed, wind direction, barometric pressure, precipitation, visibility, and ceiling height. The capabilities of the ASOS system are neatly summarized in Figure 2. Also to avoid a lengthy discussion the limitations of ASOS are noted in Figure 3. The design of these systems allows human augmentation which may be required at some sites. Yet the majority of the systems are planned to stand alone, unaugmented.

So wherein lies the major differences that effect the aviation industry?

3. APPLES AND ORANGES

The new automated unaugmented, meaning unmanned, observation systems are sampling weather at a point...a single location. A human observer reports weather over an

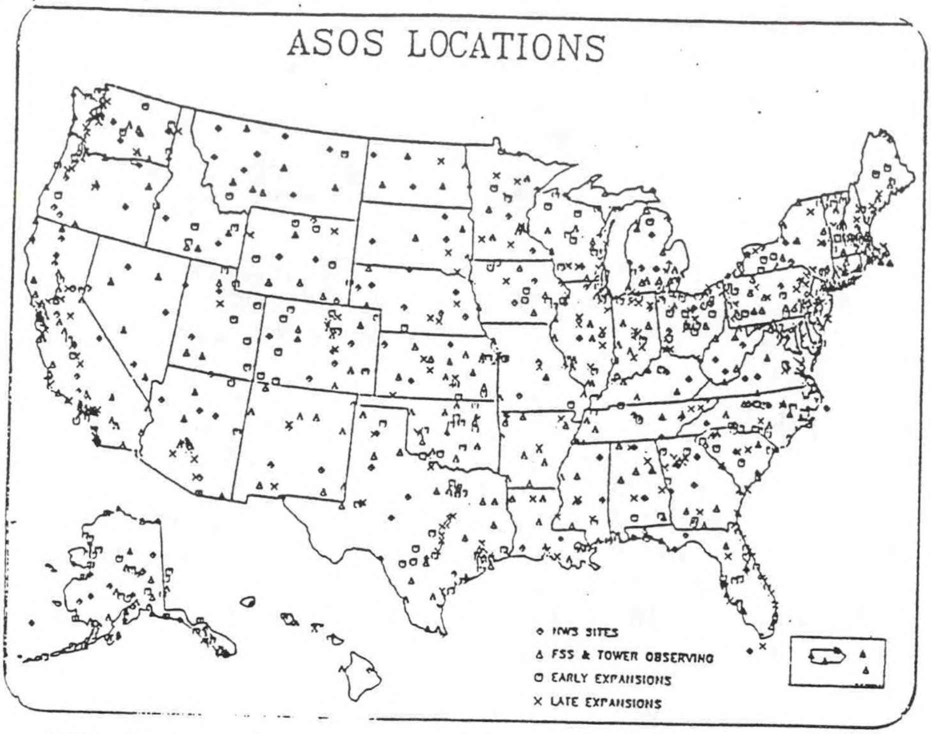
ASOS LOCATIONS
FSS & TOWER OBSERVING
EARLY EXPANSIONS
LATE EXPANSIONS

FIG. 1

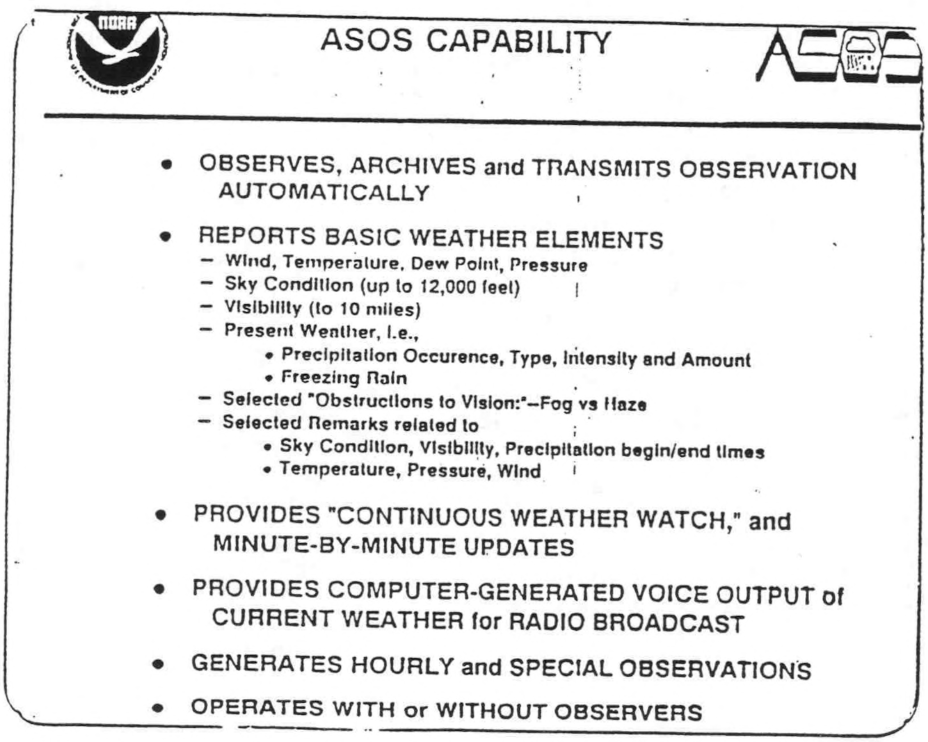
ASOS CAPABILITY
NOAA
• OBSERVES, ARCHIVES and TRANSMITS OBSERVATION AUTOMATICALLY
• REPORTS BASIC WEATHER ELEMENTS
– Wind, Temperature, Dew Point, Pressure
– Sky Condition (up to 12,000 feet)
– Visibility (to 10 miles)
– Present Weather, i.e.,
• Precipitation Occurence, Type, Intensity and Amount
• Freezing Rain
– Selected "Obstructions to Vision:"–Fog vs Haze
– Selected Remarks related to
• Sky Condition, Visibility, Precipitation begin/end times
• Temperature, Pressure, Wind
• PROVIDES "CONTINUOUS WEATHER WATCH," and MINUTE-BY-MINUTE UPDATES
• PROVIDES COMPUTER-GENERATED VOICE OUTPUT of CURRENT WEATHER for RADIO BROADCAST
• GENERATES HOURLY and SPECIAL OBSERVATIONS
• OPERATES WITH or WITHOUT OBSERVERS

FIG. 2

entire airport area. Do not consider automated and human observations as equals...think apple and oranges. The new systems are data collection devices...they cannot observe.

The sensor locations for the ASOS at large airports are depicted in Figure 4. Visibility and ceilings will be determined at the touchdown point of the primary runway. This may pose a serious problem if you are shooting an instrument approach at the opposite end of a two mile runway or on another runway with a touchdown point miles away from the sensor site.

Observers determine visibility by evaluating the entire airport area, this is called sector visibility. The prevailing visibility is that which is prevalent over 50% or greater of the entire 360 degree area, horizon to horizon. Automated sensors will determine the visibility only at a very small point, approximately a three feet area. Most of the time point visibilities will be adequate. Unfortunately there are airports with runways jutting into the ocean, near rivers, or nearby lakes that are prone to fog or special local weather problems where point visibilities may not be adequate.

At some airports a pilot may be taking-off or landing in fog when the sensors are not reporting any restrictions (Fig. 5). Since the sensors are not recording a restriction is this pilot legally able to take-off even though he cannot see? If the sensors are in fog and the majority of the airport is clear will the airport be closed? At large airports with widely displaced runways multiple sensors or human augmentation may be needed to present a full evaluation of the weather.

For years ceiliometers have determined ceiling heights and the human observer has determined the coverage. He evaluated the total 360 degree visual dome to determine the total cloud coverage. The automated systems will measure the clouds passing over a single point straight above the sensor. Coverage will be based on persistence of the clouds measured over a period of time. The automated system may actually be more accurate in calculating the actual coverage of clouds, especially over uniform cloud fields. Unfortunately, the accuracy of the automated system may be diminished by converting the coverage into the values of clear (CLR), scattered (SCT), broken (BKN) or overcast (OVC). There will be no remarks describing cloud types or movements.

The automated system more accurate? Yes! Human observers overestimate cloud coverage due to increased visual angles when viewing toward the horizon. The example in Figure 6 highlights the problem. The automated system evaluates the cloud deck as 5 tenths coverage and sends out SCT on the observation. The human observer, under identical conditions, tends to overestimate the coverage at 7 tenths and transmits BKN. The lower the cloud deck the greater the overestimate of coverage because of the increased viewing angle toward the horizon.

How does a pilot view the cloud field? Straight up and down or at an angle? If you are flying in the summer with a visibility of 4 to 5 miles in haze and a cloud deck covering half the sky develops below

DATA NOT AVAILABLE FROM ASOS (IOC)

ASOS

- TORNADOS, WATERSPOUTS
- THUNDERSTORMS (‡)
- CLOUDS ABOVE 12,000 FT (‡)
- CLOUD TYPES
- HAIL
- DRIZZLE (•)
- ICE PELLETS
- OFF-SITE WEATHER
- BLOWING PHENOMENA
- WATER EQUIVALENT OF SNOW ON THE GROUND
- SNOW DEPTH (•)
- MINUTES OF SUNSHINE (•)

(•) MAY BECOME AVAILABLE AFTER IOC WITHIN ASOS
(‡) MAY BECOME AVAILABLE THROUGH COMPLEMENTARY TECHNOLOGIES

FIG. 3

TYPICAL LARGE AIRPORT SENSOR CONFIGURATION

ASOS

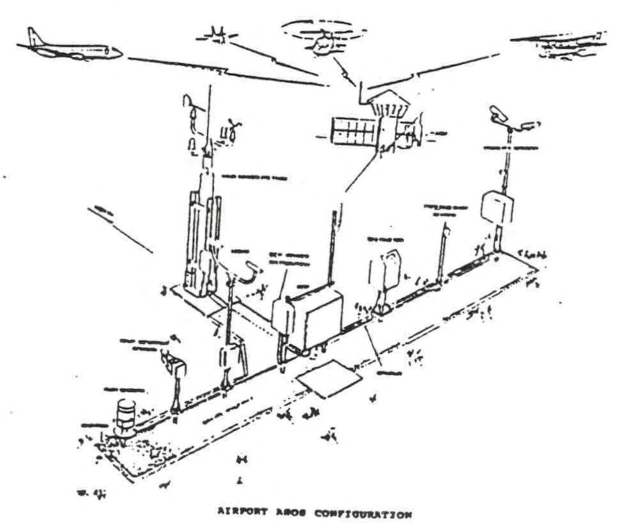

FIG. 4

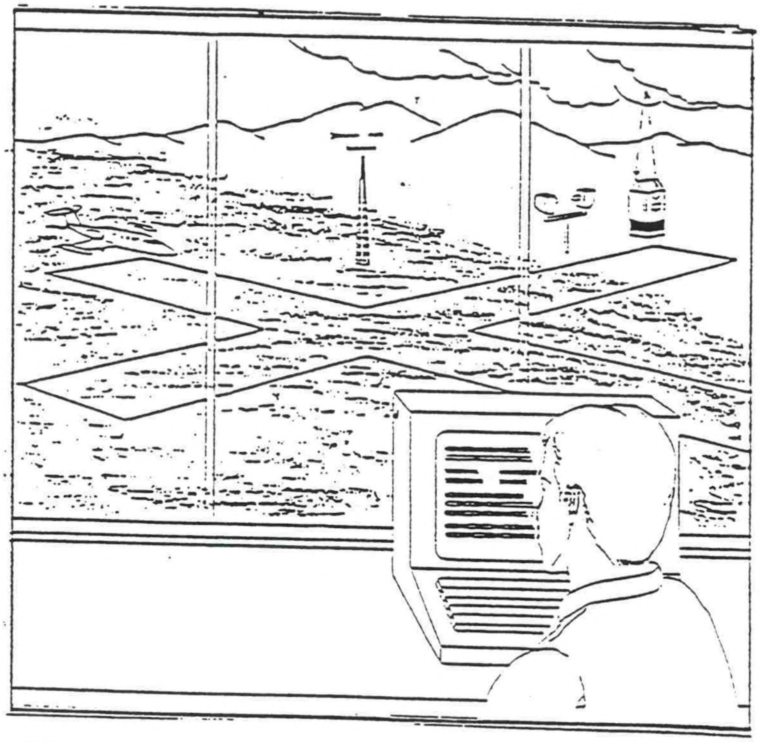

FIG. 5 FOG ON AIRPORT

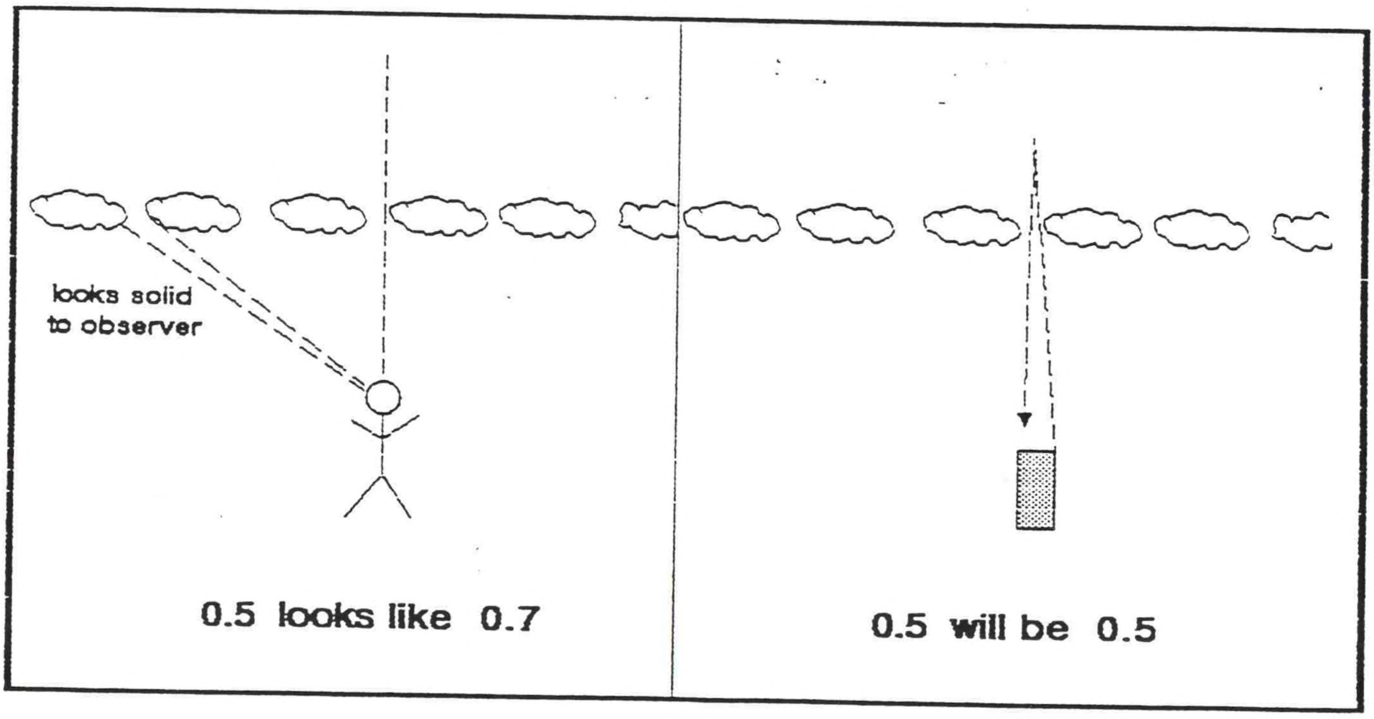

Fig. 6 What will it look like to the pilot????

you, visually finding an unfamiliar airport may be difficult. The automated system may send out SCT, but if the coverage is near 5 tenths the pilot will have difficulty seeing the ground. To the pilot the coverage will be greater due to his slanted viewing angle and visual compression from his forward flying speed. This could create a flight safety problem until pilots better understand that automated systems do not evaluate sky cover like human "eyes".

It would also help if the pilot knew whether SCT meant 1 tenth or 5 tenths. It is time to break the "human vs automated" system comparisons by actually transmitting the coverage values. Pilots and meteorologists would no longer have to decide if SCT meant 1 tenth or 5 tenths or if BKN was 6 tenths or 9 tenths. The installation of automated observation systems provides the opportunity to change to numerical coverage values.

The new weather discriminators will not be able to determine many types of weather that pose hazards to flight safety such as thunderstorms, blowing snow and dust, ice pellets, drizzle and possibly mixed precipitation (Fig. 3). Without off-site weather remarks locations of thunderstorms will not be sent.

What will the pilot do? The pilot will have to rely on his ability to see approaching weather from the air, use pilot reports, and obtain information from enroute traffic control. More than ever the pilot will have to be alert to changes in the weather and understand how weather systems affect flight.

When many airport observations are automated, pilots will have to rely on other information to determine multiple cloud layers above 12,000 feet, off-site weather, locations of thunderstorms, and other enroute weather. New products and dissemination systems will arise to fill these needs.

4. SUMMARY

Automated observations are a reality. They will provide 24 hour observations at more sites than currently available. They are not an exact replacement for human observations. They are only data collection systems for a single point. Multiple sensors or human augmentation may be necessary to fulfill aviation operational and safety requirements.

Pilots will need increased meteorological training. They will have to understand automated weather observation systems and be able to determine an accurate weather picture from multiple data sources such as radar, satellite, and lightning detectors. Pilots will also have to strengthen their decision making skills about the flight weather environment.

The National Weather Service will supplement the automated observations with additional technologies such as doppler radar, vertical wind profilers, and improved satellites. The agency will develop new products and services to provide safer and more efficient aviation operations.

IMPROVED AVIATION-ORIENTED OBSERVATIONAL PRODUCTS

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1. INTRODUCTION

Traditionally, surface observations have been variably scheduled, labor-intensive measurements (or estimates) of numerous weather elements. Implementation of the Automated Surface Observing System (ASOS; Short and McNitt 1991) will allow these reports to become more objective, automated, regularly produced products. In particular, the observation is likely to evolve from a subjective, pattern-oriented report of a spectrum of weather phenomena at, or within a variable radius of, the reporting site, to an objective sampling of specific elements throughout a cross section of the atmosphere near each sensor. Observations of this new genre might be enhanced considerably through the selective integration of information from remote sensor data obtained from radar, lightning detection, and satellite complementary technologies. Hence, it appears that the integration of data from diverse sources is required to produce a modernized observation product. The product should not be a direct extension of the ASOS observation, but rather a fusion of information from complementary technologies, as depicted by Figure 1.

It is with this goal in mind, that the National Weather Service (NWS) Eastern Region has undertaken a national risk-reduction exercise to demonstrate that the supplementation of ASOS with information from other sources can provide comprehensive, state of the atmosphere weather reports that promote aviation safety and enhance airport operations. The implementation of ASOS will have important implications for aviation forecasting and airport operations. For example, the identification, location, and movement of thunderstorms is of considerable significance for aviation activities, but will not be provided by ASOS.

Supplemental, thunderstorm-related information is readily available from radar and lightning detection system data. In particular, we have begun to develop techniques and applications to integrate information from the conventional radar system and a lightning detection network into an aviation-oriented observation of the conditions within a specified area around the ASOS site near an airport. Eventually, high-resolution information from the Weather Surveillance Radar-1988, Doppler (WSR-88D; Alberty and Crum 1991) system and the new GOES satellites will be introduced to create additional products.

The validation and verification of this concept is a fundamental aspect of the ASOS risk-reduction exercise. The acquisition, installation, and operation of each different type of remote sensor will involve considerable risks. Several key

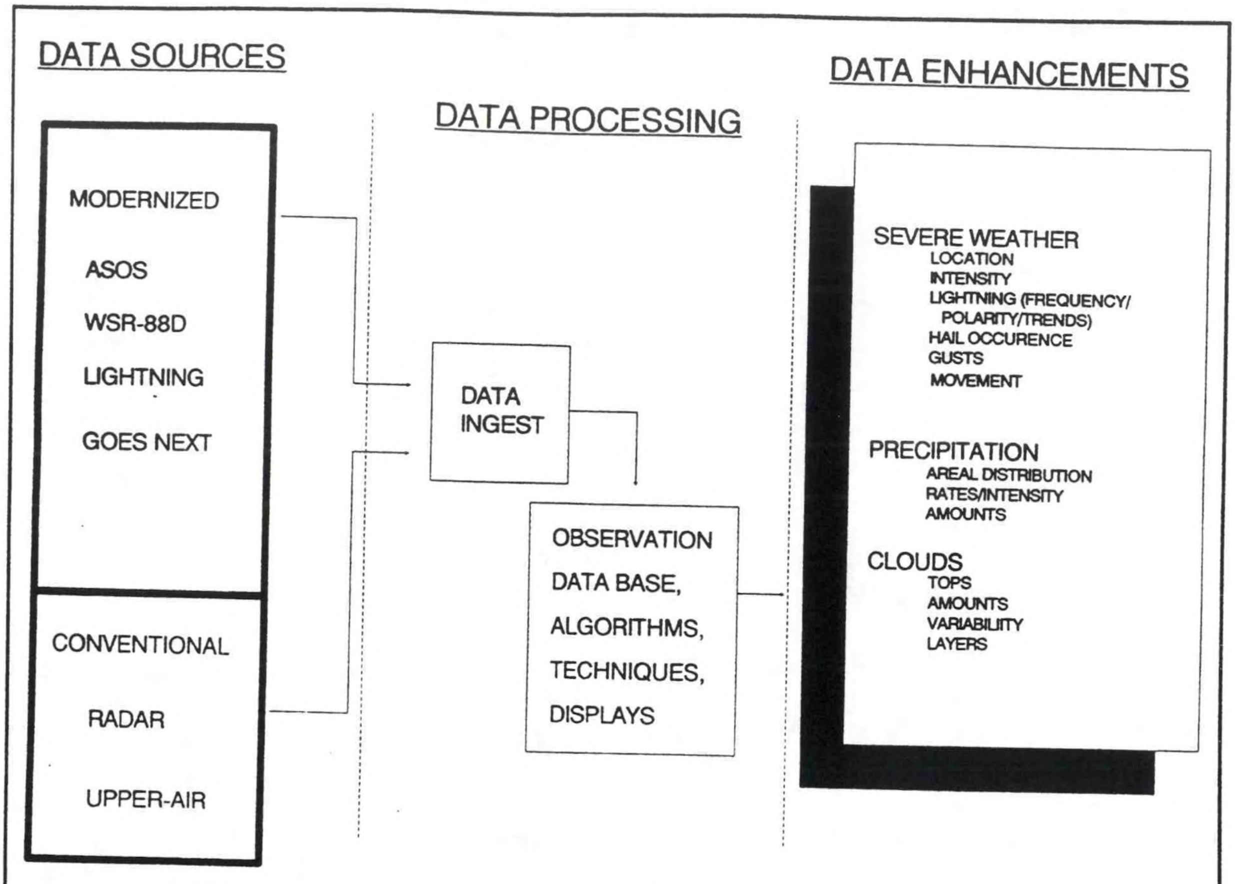

Figure 1. Schematic representation of input data sources, processing capabilities, and weather elements amenable to the production of enhanced, aviation-oriented observational products.

questions must be addressed. What hardware, software, and human resources are necessary to accomplish these goals? Will the technology and applications work? Can data from several remote sensor technologies be integrated in a timely and cost-effective manner? Can similar information be provided by alternate sources of data? How much value is added? Is the payoff worth the cost? Can these types of techniques and products be produced at, and for, other locations throughout the NWS?

2. THE DEVELOPMENTAL FACILITY

During mid-1989, when the risk-reduction project was formulated, Weather Service Forecast Office (WSFO) Washington, D.C., was preparing to relocate to a modernized facility in Sterling, VA, in anticipation of becoming the first Eastern Region site to obtain the WSR-88D. As a result, personnel with diverse backgrounds and considerable expertise were attracted to the office. This appeared to be an opportune time to embrace the challenge and excitement of an operational applied research project. Being located in the Washington metropolitan area allowed for relatively easy access to, and coordination with, personnel from the National Meteorological Center (NMC), NWS Headquarters, the National Environmental Satellite, Data, and Information Service (NESDIS), and other public and private research organizations. It was expected that representatives from these groups occasionally would serve as expert consultants for various aspects of the project.

From the beginning, we realized the success of the project would depend to a large degree upon the acquisition and evaluation of data from new sources, such as ASOS, the WSR-88D, a lightning detection network, and digital satellite data. The location of the NWS Equipment Test and Evaluation Center at Sterling, VA, provided reasonable assurance that data from the prototype version of ASOS would be available for use in the exercise. Also, WSFO Washington operationally has had access to a dedicated line from the WSR-74S radar at the Patuxent River, MD, Weather Service Meteorological Observatory, and was scheduled to receive one of the first 10 WSR-88D units nationwide. The lightning detection network administered by the State University of New York (SUNY) at Albany (now operated by GeoMet Data Services, Inc., Tucson, AZ) appeared to be a feasible source for real-time lightning data (Orville et al. 1983). Finally, digital satellite data could be obtained via access to the NESDIS/NMC interactive VAS Data Utilization Center computer (VDUC; Siebers et al. 1988) system.

Of course, the computer hardware and software required to support a variety of sophisticated data ingest, processing, and techniques development activities had to be procured and installed at the new office. In order to assure that the plans and activities for this project were compatible with the advanced systems and processing capabilities of the future, we sought the advice of experts from the Forecast Systems Laboratory (FSL) at the Environmental Research Laboratories (ERL) in Boulder, CO. With the help of FSL, the basic system configuration was specified. This system is comprised of: a microcomputer fileserver; a high-resolution graphics display workstation; two PCs; and assorted peripherals such as printers, modems, etc. A local area network is required to link these devices and allow for data transfer, communication, and the sharing of resources. An important benefit associated with the system was that FSL-developed software for the ingest, conversion, formatting, databasing, and retrieval of remote sensor data would be available to support some aspects of the ASOS risk-reduction exercise.

3. SPIN-UP ACTIVITIES

In January 1990, after the project development plan was approved by NWS Headquarters, the Eastern Region created and filled a Technology Transfer Meteorologist position at WSFO Washington to facilitate and support the risk-reduction exercise. With funding provided by the NWS Transition Program Office, the initial PC hardware was procured and installed, and the developmental and coordination activities were begun, at the original office site collocated with NMC in Camp Springs, MD. In addition, various liaison activities were initiated to investigate potential sources of data, expertise, and guidance. It was an opportune time to work closely with the newly formed Complementary Technologies Working Group at NWS Headquarters. Also, with the assistance of personnel from the Office of Hydrology, a high-resolution map background data set was migrated to the project's developmental PC.

Next, we focussed on the integration of data from the conventional radar and the lightning detection network. Obtaining access to data from the WSR-74S proved to be particularly challenging, since expertise with the continuous synchronous ingest of radar reflectivity into a PC environment was extremely limited. This function was accomplished through procurement of a special ingest board, decoding software, and a modem. The software was comprised of a low-level program to read and reformat the incoming data in a form that would be readily accessible to additional code prepared by project support personnel. The primary purpose of the additional software is to quality control, format, and store the reflectivity information in a form suitable for later developmental aspects of the risk-reduction exercise. In addition, routines were written to display the radar data on a high resolution, local map background. As is the case with many field office applied research projects, the existing operational priorities, coupled with the lack of extensive electronic systems support, resulted in a series of trials and tribulations, which made this aspect of the project a challenging learning experience for all involved. However, routine access to digital reflectivity data from the WSR-74S was assured in November 1990.

The receipt and real-time ingest of cloud-to-ground lightning data proved to be a more straight-forward task via procurement of a satellite ground station, ingest and display software, and an output port to forward ASCII data to the risk-reduction fileserver, as specified by the vendor. This capability has been operational at the site of the new office in Sterling, VA, since July 1990.

In addition, the microcomputer fileserver, a high-resolution graphic display station, and several peripheral devices were installed at the new office during Fall 1990. Also, at this time, dial-in access was effected for hourly and special reports from the Equipment Test and Evaluation Center's ASOS unit at Sterling. Via interface with the local area network, the fileserver was configured to serve as the host for information from conventional radar, cloud-to-ground lightning detection, and ASOS technologies. Figure 2 shows the overall hardware and network configuration for the project. Please note, the systems to ingest, process, integrate, and display the new technology data sets were configured in a manner that allows the operational staff to make use of and to interact with the information, but does not eliminate or adversely impact the traditional procedures for analysis and forecasting.

Hence, various efforts to provide for access to sources of data, and to procure, install, and interface computer hardware and software were completed during 1990. In contrast, the work during 1991 focused on the local development of computer software to store, process, and format a product that contains information supplemental to the ASOS observation. This involved the transfer, storage, and processing of radar, lightning, and ASOS reports as part of a common data base on the fileserver. Several critical milestones were accomplished throughout the Spring, Summer, and Fall of 1991. The development and testing of the Phase I radar/lightning product is described later in this report.

During the period of equipment procurement, data acquisition, and software development, various liaison activities to solicit support and advice from personnel throughout the meteorological and aviation communities were completed. This, in turn, led to formulation of various groups to focus on and support key aspects of the project. In particular, the overall management is provided by the Eastern Region Director, with scientific oversight and systems support delegated to the respective Chiefs of the Scientific Services and Systems Operations Divisions. At the local office, the project is administered by the Area Manager, WSFO Washington, with key support provided by the local

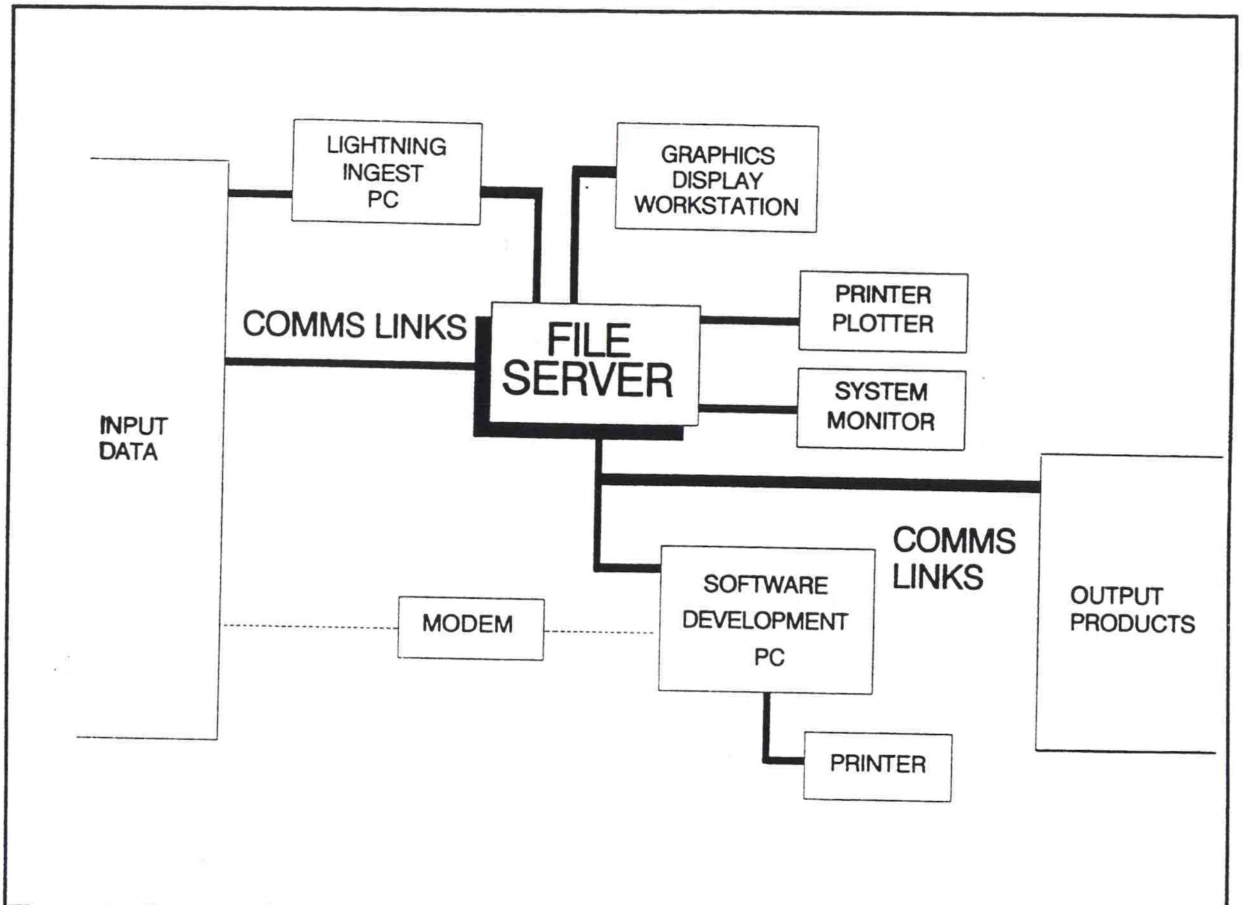

Figure 2. Computer hardware system configuration for the developmental facility at the new forecast office in Sterling, VA.

focal point, one of the lead forecasters. The implementation team is comprised of several personnel from Eastern Region Headquarters, with the local focal point and the technology transfer meteorologist responsible for directing the implementation activities at Sterling. Likewise, these same two individuals comprise the local development team with added support from a meteorologist intern and a forecaster at WSFO Cleveland (now employed at the Ohio River Forecast Center in Cincinnati). More recently, an evaluation team was formed with personnel from WSFO Washington's Management Area and the Chiefs of the Meteorological Services and Scientific Services Divisions. In addition, it was determined that 6-monthly progress reports, regular meetings with the Complementary Technologies Working Group, and, at least, an annual national program review, would help to ensure that project objectives and accomplishments were in keeping with NWS transition goals and objectives. The composition of these support teams is shown in Figure 3.

4. DEVELOPMENT AND TESTING OF PHASE I RADAR/LIGHTNING PRODUCT

The office at Sterling is located about 65 miles northwest of the Patuxent River WSR-74S radar, which results in a beam height of about 7000 feet above ground level under normal refractive conditions for a 0.5 degree scan. The effective resolution of these data are approximately 2 km when mapped onto the high resolution projection developed for the project. Analogously, the advertised accuracy of data from the lightning detection network is from 2 to 5 km (Orville et al. 1983). Each flash datum contains a date and time stamp, location (latitude and longitude), amplitude, polarity, and multiplicity.

Software was developed to ingest, store, and process the radar signal for time windows from 5 to 15, 25 to 35, and 45 to 55 minutes past each hour. An important aspect of this task was to overcome the difficulties associated with the transmission of two different data formats (RRWDS and Kavouras) via the dedicated line from Patuxent River. The radar data are ingested on a PC and then transmitted to the fileserver.

Similarly, the lightning data are obtained via another PC with the aid of software provided by the vendor, and then transmitted in ASCII format for storage and further processing on the fileserver. Fifteen-minute ingest windows from 0 to 15, 20 to 35, and 40 to 55 minutes past each hour are used to summarize the lightning observations. Note, the 15-minute window for the lightning ingest--starting 5 minutes prior to corresponding 10-minute window for the radar data--compensates for both the variability and delay (approximately 3 minutes) in the transmission of radar observations.

From this data base, the initial work has focused on the development of an aviation-oriented, significant weather product to summarize the location and intensity of both radar and lightning

Project Management	Implementation Team	Development Team	Evaluation Team
o ERH:	o ERH:	o WSFO WBC:	o ERH:
Director SSD Chief SOD Chief	SSD Chief SOD Chief SIB Chief Computer Analyst Elec Tech Facilities Liaison Eng	Lead Forecaster Tech Transfer Met Met Intern	SSD Chief MSD Chief
o WSFO WBC:	o WSFO WBC:	o WSFO CLE/OHRFC:	o WSFO WBC:
Area Manager Lead Forecaster	Lead Forecaster Tech Transfer Met Area Elec Supervisor Elec Tech Elec Tech (WSFO PIT)	Forecaster	Area Manager Lead Forecaster Tech Transfer Met WBC Forecasters CWSU/WSO Fcstrs

Oversight and Funding: Transition Program Office

Additional Guidance and Support: ASOS Complementary Tech Working Group
ERL/FSL
OSD/TDL
OH/HOD
NOS/OPC
NMC/MOD

Figure 3. Overview of management, implementation, development, and evaluation support structures for the risk-reduction exercise.

reports within a circle of 30 nautical mile radius centered over selected airports. In particular, appropriate information from the radar and lightning reports are analyzed for nine sectors: each octant of the 360 degree circle and a center area overhead of 5 nautical mile radius. This is similar to the approach under development by the FAA for a thunderstorm product based solely on lightning detection network data. In contrast, the NWS product makes use of both the radar and lightning reports, as well as trends in the lightning data since the previous observation 20 minutes earlier.

Figure 4 shows the five test sites for product generation and evaluation within WSFO Washington's Management Area. The corresponding product evaluation circles are divided into sectors and projected onto the high-resolution map background. Also depicted is the location of cloud-to-ground lightning strikes during the period from 2136 to 2151 UTC on June 6, 1991, throughout an area within 120 nautical miles of the WSR-74S radar at Patuxent River, MD. The five airports for which test messages are produced include: Washington Dulles International (IAD); Baltimore-Washington International (BWI); Wilmington/New Castle County (ILG); Richmond International/Byrd Field (RIC); and Norfolk International (ORF). As presented, most of the lightning activity was observed in a region to the north of Richmond, VA, with a total of 79 cloud-to-ground flashes during the 15-minute period.

The corresponding radar reflectivity pattern for the 10-minute period centered 2146 UTC, June 6, 1991, is indicated on Figure 5. Here, an area from Central Virginia to the southern tip of New Jersey was covered with showers and thunderstorms with intensities as high as VIP level 5.

Figure 6 displays the experimental radar/lightning product for each of the five test sites valid for 2155 UTC, June 6, 1991, about 10 minutes later than the lightning and radar reports presented in Figures 4 and 5. As indicated for BWI, 13% of the 30 nautical mile evaluation circle was covered by radar echoes of VIP level 1, or greater; echoes were observed in the octant sectors from East through North, and for a 5 nautical mile circle overhead. For less than 1% of the entire circle, within the octant sectors from South to Southwest, moderate echoes of VIP levels 3 and 4 were noted. (Note, for this product, VIP levels 1-2 are classified as light, 3-4 as moderate, and 5-6 as heavy. For cloud-to-ground lightning, the category designations of occasional, frequent, and continuous correspond to frequencies of less than 1, 1 to less than 6, and 6 or more flashes-per-minute, respectively.) In addition, a few heavy echoes (less than 1% of the entire octant sector) of VIP level 5 were observed over the Southwest sector. In addition, 56% and 3% of the South sector was covered by light and moderate radar echoes, respectively, with occasional cloud-to-ground lightning of less than 1 flash-per-minute. Finally, for the Southwest octant, the echo coverages were 33%, 2%, and 1%, for light, moderate, and heavy, with occasional lightning. The overall lightning flash tendency increased by 13 flashes, as compared to the previous 15-minute product prepared 20 minutes earlier. The products for the other four test sites can be interpreted in a similar manner.

As you can see, these messages provide a great deal of information about conditions not only at each airport, but within the vulnerable approach and climb-out areas surrounding the airports. Currently, test products such as these are produced routinely and transmitted to the Weather Service Offices at Wilmington, DE, Baltimore, MD,

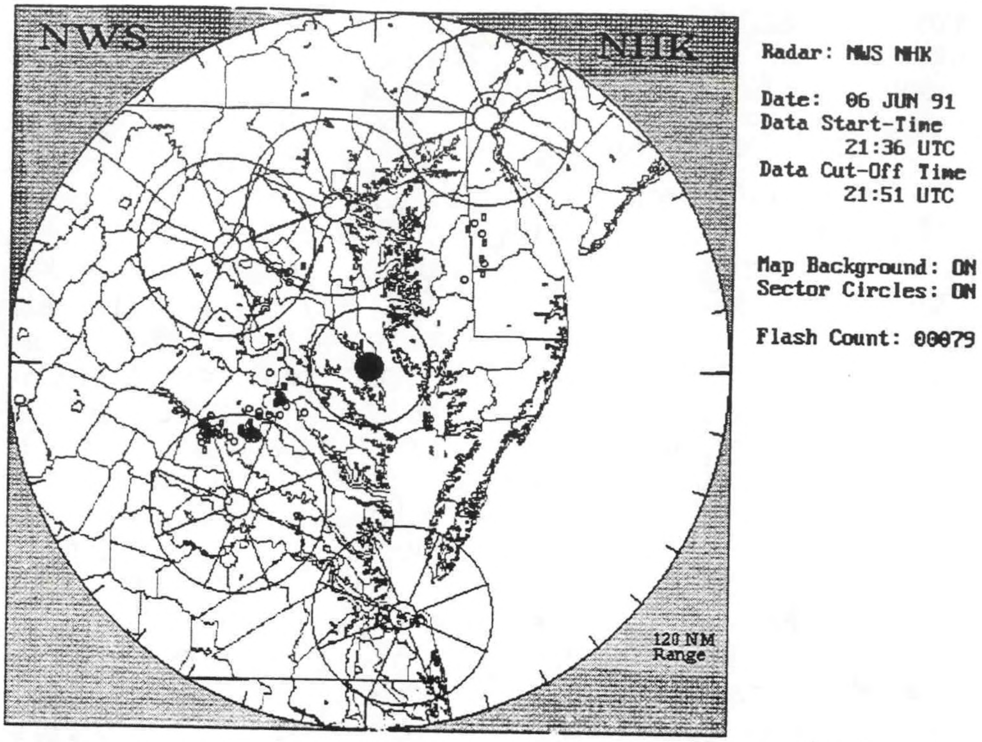

Figure 4. Depiction of the high-resolution map background, the location of the Patuxent River radar site (center circle), the five test sites with the corresponding 30 nautical mile data evaluation areas indicated, and observed cloud-to-ground lightning strikes (small open circles and boxes) from 2136 to 2151 UTC on June 6, 1991.

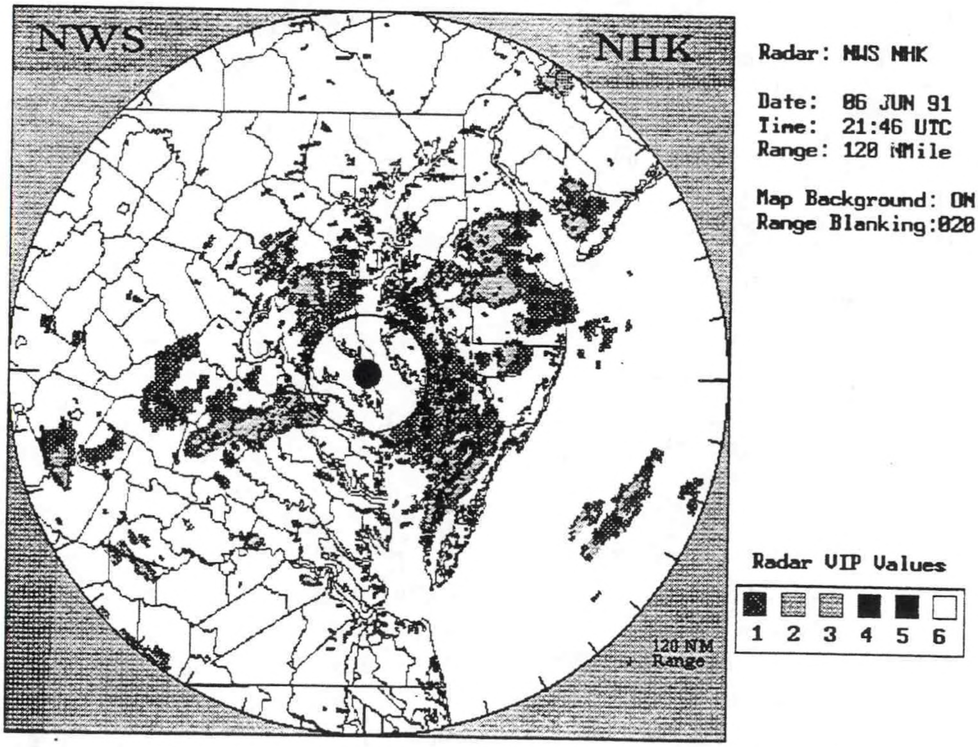

Figure 5. Radar reflectivity pattern from the WSR-74S radar at Patuxent River, MD, during a 10-minute period centered at 2146 UTC on June 6, 1991.

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ZCZC WBCWRKRRP SDC
TTAA00 KWBC DDHHMM

EXPERIMENTAL RADAR/LIGHTNING PRODUCT
NATIONAL WEATHER SERVICE WASHINGTON DC
2155 UTC THU JUN 6 1991

IAD 2155 TOTAL ECHO CVRG WITHIN 30 NM OF IAD: 010%
         %CVRG LGT  009%  SECTORS: ALL
         %CVRG MDT <001%  SECTORS: E...SE
         %CVRG HVY <001%  SECTORS: E...SE
         E  SECTOR %CVRG LGT 040.7%/MDT 002.9%/HVY 001.3% OCNL LTG
         SE SECTOR %CVRG LGT 016.7%/MDT 000.9%/HVY 000.3% NO   LTG
         15 MIN LTG FLASH TENDENCY: -3

BWI 2155 TOTAL ECHO CVRG WITHIN 30 NM OF BWI: 013%
         %CVRG LGT  013%  SECTORS:  E..SE..S..SW..W..NW..N..OVHD
         %CVRG MDT <001%  SECTORS: S...SW
         %CVRG HVY <001%  SECTOR:  SW
         S  SECTOR %CVRG LGT 055.8%/MDT 002.8%/HVY 000.0% OCNL LTG
         SW SECTOR %CVRG LGT 033.3%/MDT 002.2%/HVY 001.0% OCNL LTG
         15 MIN LTG FLASH TENDENCY: +13

RIC 2155 TOTAL ECHO CVRG WITHIN 30 NM OF RIC: 008%
         %CVRG LGT  007%  SECTORS: NE...SE...S...SW...NW...N
         %CVRG MDT  001%  SECTOR:  N
         %CVRG HVY  000%
         NW SECTOR %CVRG LGT 019.0%/MDT 000.0%/HVY 000.0% OCNL LTG
         N  SECTOR %CVRG LGT 031.3%/MDT 006.0%/HVY 000.0% FREQ LTG
         15 MIN LTG FLASH TENDENCY: +33

ORF 2155 TOTAL ECHO CVRG WITHIN 30 NM OF ORF: <001%
         %CVRG LGT <001%  SECTORS: NW...N
         %CVRG MDT  000%
         %CVRG HVY  000%
         NO LTG DETECTED

ILG 2155 TOTAL ECHO CVRG WITHIN 30 NM OF ILG: 004%
         %CVRG LGT  004%  SECTORS: NE...E...S...SW...W...N...OVHD
         %CVRG MDT <001%  SECTOR:  NE
         %CVRG HVY  000%
         NE SECTOR %CVRG LGT 008.7%/MDT 002.2%/HVY 000.0% NO   LTG
```

Figure 6. Alphanumeric experimental radar/lightning product for each of the five test sites valid at 2155 UTC on June 6, 1991.

Richmond, VA, Norfolk, VA, and the Center Weather Service Unit at Leesburg, VA, for critique and evaluation by NWS personnel.

5. FUTURE PLANS AND ISSUES

As outlined here, much has been accomplished; however, in some respects, the risk-reduction exercise has just begun. The evaluation of the Phase I product is underway, and adjustments and enhancements will be introduced based on review and comment by NWS field personnel, and input from the Complementary Technologies Working Group. Pending the outcome of this activity, further efforts to provide for more complete integration of the radar and lightning data will be pursued, possibly including the production and dissemination of a graphical product. Most importantly, interaction and liaison with potential outside user groups such as the FAA and aircraft pilots will be initiated with the advice and assistance of OM's Aviation Services Branch. This will be followed by integration of data from the new WSR-88D radar at Sterling, and perhaps a wider evaluation at another location. Access to WSR-88D will build upon the recently successful efforts of FSL personnel in conjunction with the pre-AWIPS WFO Emulation at Norman, OK (McCarthy et al. 1992). In addition, as resources permit, information from NMC's short-range guidance system and digital satellite data will be incorporated via a high-speed modem or direct interface with the VDUC system.

6. ACKNOWLEDGEMENTS

Although it is not practical to list the names here, Figure 2 indicates the organizations and position titles for many of the individuals that have made important contributions to this project during the past 2 years. We are deeply appreciative of these efforts.

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A RAPID UPDATE ANALYSIS AND PREDICTION SYSTEM AT NMC FOR AVIATION FORECASTING

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Forecast Systems Laboratory
Boulder, Colorado

1. Introduction

At NOAA's Forecast Systems Laboratory (FSL) in Boulder, Colorado, a team has been working for several years to develop a Mesoscale Analysis and Prediction System (MAPS), which exploits several sources of atmospheric observations available almost continuously. At present, analyses of upper air conditions from the National Meteorological Center (NMC) are available twice a day, at 0000 and 1200 GMT. However, more than enough observations are available over the contiguous United States to support upper air analyses every three hours. MAPS assimilates these surface and tropospheric observations every three hours in order to better describe atmospheric conditions and make accurate short-term forecasts (out to 12 hours).

The remainder of this paper, describes

- how MAPS works
- sample output
- how MAPS compares to NMC's Nested Grid Model (NGM)
- porting MAPS to NMC and experimental dissemination

2. How MAPS Works

The Mesoscale Analysis and Prediction System (MAPS) provides high-frequency analyses and short-range forecasts that incorporate "off-time" as well as synoptic observations. The current resolution of the MAPS grid is 60 km. The intended users of MAPS are commercial aviation and operational forecasters who need short-term guidance for the next 6-12 hours. The main components of MAPS are shown in Fig. 1.

2.1 External Data Sources

The upper air assimilation cycle relies upon two external sources of data: 1) a variety of meteorological observations from the surface, troposphere, and lower stratosphere (see Section 2.2); and 2) time-dependent boundary conditions supplied by NMC's NGM. These boundary conditions are needed for the MAPS hybrid prediction model (see Section 2.4). They specify the evolution of the predicted variables along the four edges of the current domain, which pass through southern Canada, northern Mexico, and the coastal waters of the Atlantic and Pacific Oceans.

2.2 Observations

The upper air assimilation cycle begins with the ingest of observations from four major sources in the contiguous United States and adjacent portions of Canada and Mexico.

- Rawinsondes: about 80 every 12 hours; winds heights, temperatures, and moisture.

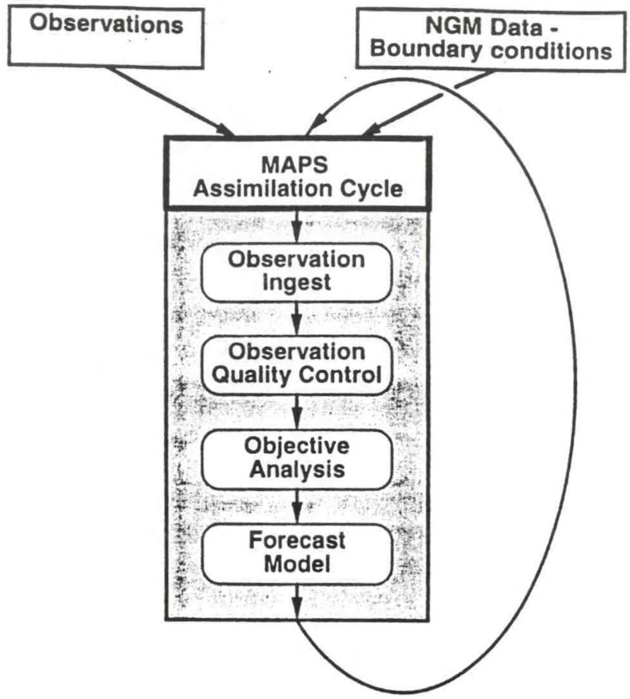


Fig. 1. The major building blocks of the Mesoscale Analysis and Prediction System (MAPS). The upper-air assimilation cycle is self-contained except for the external inputs noted at the top. NGM refers to the Nested Grid Model at the National Meteorological Center, which supplies time-dependent lateral boundary conditions for the MAPS forecast model.

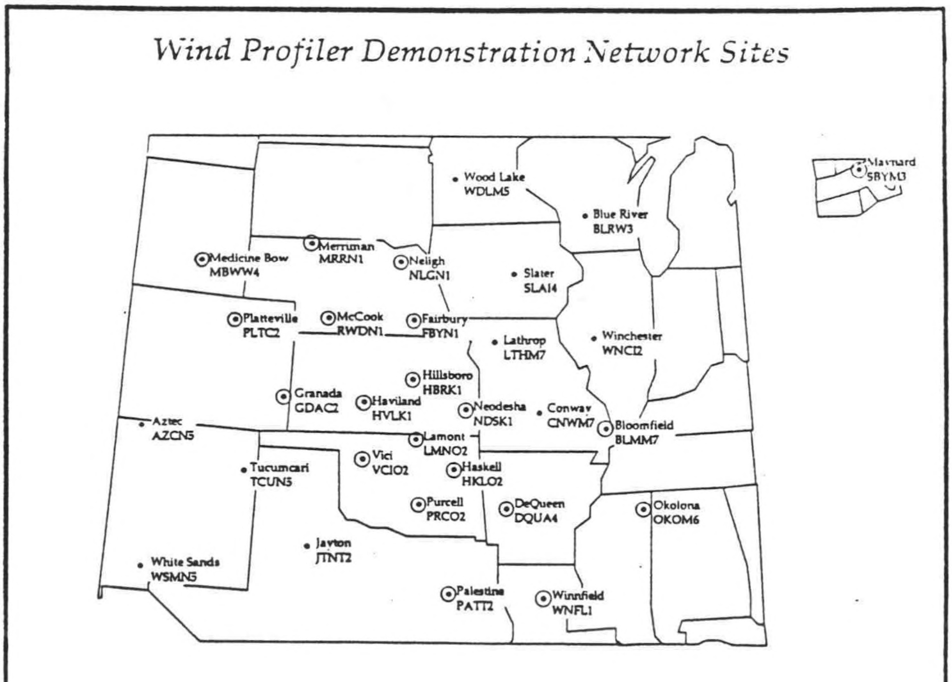


Fig. 2. The NOAA Wind Profiler Demonstration Network. Circled stations were producing data in mid-December 1991.

- Wind Profiler Demonstration Network in the central U.S.: 20 of the 30 expected profilers were operational by mid-December 1991 (Fig. 2). Wind profiling radars provide accurate profiles hourly in the troposphere and lower stratosphere.

- Surface observations: 600-900 per hour depending upon the time of day plus about 25 fixed buoys; these observations are used to analyze low-level heights, temperatures, and moisture.

- ACARS aircraft reports: These are fully automated reports of temperature and wind collected from the airlines by ARINC, Aeronautical Radio, Inc., and made available through ACARS, the ARINC Communications Addressing and Reporting System. An average of 380 to 1550 reports were available every 3 hours during December 1991, as shown in Fig. 3. The density of reports can be quite remarkable, as in Fig. 4, for peak travel time. Figure 4 also shows wind profiler observations in bold face.

ACARS observations are perhaps the single most important data source for a three-hour assimilation cycle (Benjamin, 1991). They are numerous and distributed fairly evenly over the lower 48 states, mostly between 400 and 150 mb. Ascent and descent data will become much more common once reports are triggered as aircraft pass through specified altitudes. Profilers provide excellent wind data in the lower troposphere, where ACARS reports are still lacking.

All incoming observations are subjected to several stages of quality control. The most rigorous of these is a buddy check. At each observation location, we interpolate a value from neighboring observations. If the interpolated value differs significantly from the observed value at that point, we run further tests to determine whether the central observation or one of its neighbors is at fault.

2.3 Objective Analysis

Checked observations are the basis for estimating basic meteorological parameters on a regular grid of points--the function of objective analysis--but not only the observations are involved. The prediction model, to be described in the next section, provides a background or first-guess, which becomes the default analysis if no observations are available. To be more specific, a 3-hour forecast, valid at the analysis time, provides the background, that is modified by a linear combination of differences between the predicted and observed values.

Optimum interpolation (Gandin, 1963) is the method of objective analysis. The wind and mass fields are analyzed together: observations of the wind influence the analysis of mass distribution and vice versa. Pressure and moisture are analyzed independently. All analyses are performed in a hybrid vertical coordinate system: isentropic coordinates in the free atmosphere and terrain-following coordinates near the ground.

2.4 Numerical Prediction Model

A numerical prediction model is an essential component of any system that assimilates meteorological

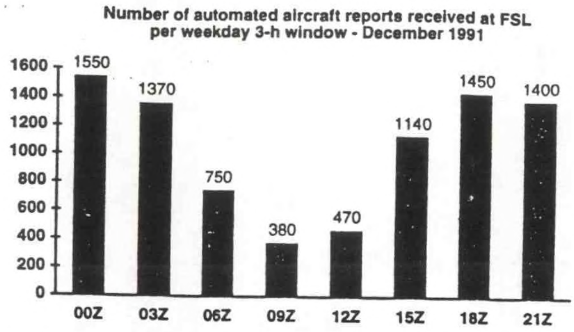


Fig. 3. Average number of ACARS (fully automated) aircraft reports received in 3-h windows during December 1991. There are decided peaks in air traffic at midday and late afternoon.

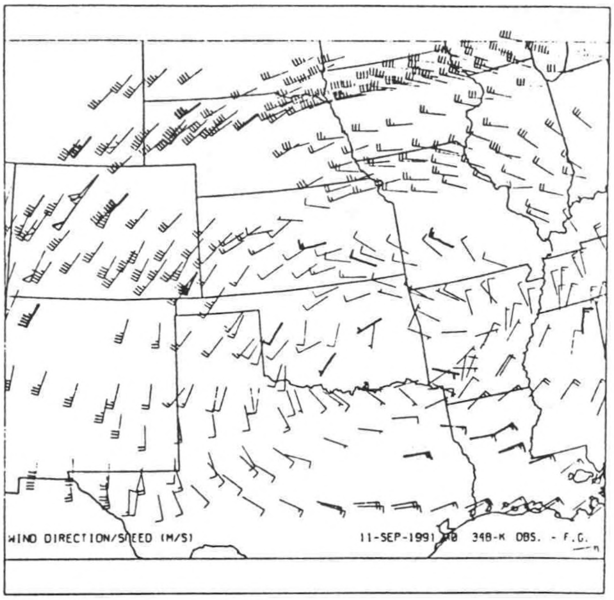


Fig. 4. ACARS aircraft reports in the vicinity of the 348 K isentropic surface received between 2230 UTC 10 September 1991 and 0130 UTC 11 September 1991. Wind profiler observations for 0000 UTC are also plotted, in bold. Small wind barbs count for 5 m s^{-1}, full barbs for 10 m s^{-1} , and flags for 50 m s^{-1} .

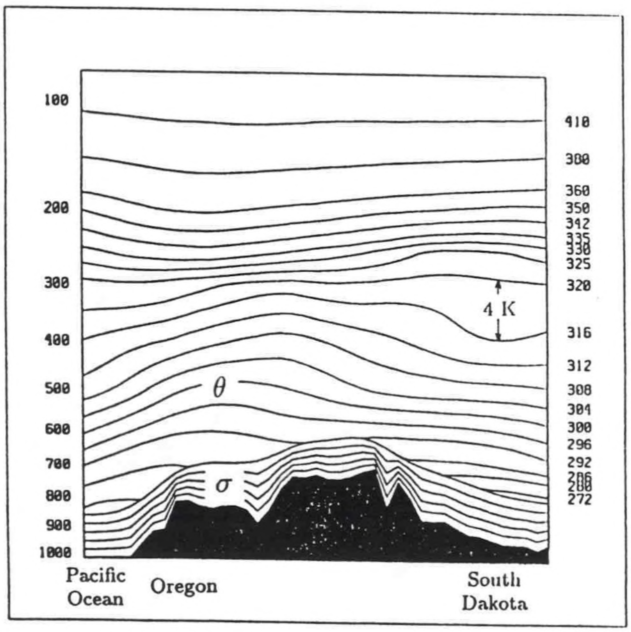


Fig. 5. An illustration of the hybrid vertical coordinates used in MAPS. This vertical cross section was taken at 1200 UTC 1 February 1990. It runs from the Pacific Ocean off the Oregon coast on the left to South Dakota on the right. The terrain is silhouetted in black. Six terrain-following surfaces, each higher one smoother than the one below, occupy, on average, the first 150 Hpa above ground. In the free atmosphere, up to 19 isentropic surfaces with variable spacing (generally from 4-10K) are used for computation (from Benjamin et al., 1991a).

data. The primary reason is that our best a priori estimate of the current state of the atmosphere comes from a numerical prediction, if the model is reasonably accurate. This prediction provides the background for the next analysis. The statistics of model performance tell us how to weight the model prediction (the background) relative to the observations. Second, the model imposes dynamical consistency on the system and retains the effects of all past observations.

The prediction model in MAPS, an outgrowth of one introduced by Bleck (1984), is based on the so-called primitive equations of motion. Calculations for both the analysis and prediction are performed on a 60-km grid at each of 25 levels in the vertical. The model allows for stratiform and convective precipitation and turbulent transfer of heat, momentum, and moisture in the vertical.

MAPS employs a hybrid vertical coordinate (Benjamin et al., 1991a), a combination of two vertical coordinates, as illustrated in Fig. 5. In the free atmosphere, MAPS uses isentropic coordinates (19 surfaces of constant potential temperature). In adiabatic flow (when there are no heat sources or sinks), air on a particular isentropic surface will remain there. Under this assumption, the prediction problem becomes two-dimensional. The vertical spacing of isentropic coordinates is tied to the stability; the surfaces are close together when the atmosphere is stably stratified and widely spaced when the lapse rate is steep. This property gives enhanced spatial resolution where it is needed--in the vicinity of fronts and jet streams.

One drawback of isentropic coordinates is that they become too widely spaced in deep, well-mixed boundary layers, which develop often on hot summer days and over high terrain. To overcome this drawback, MAPS employs terrain-following coordinates, spaced about 30 hPa apart on average, for the lowest 6 surfaces. This gives reasonable precision in the calculation of vertical fluxes close to the ground.

Since the hybrid coordinate surfaces move up or down depending upon atmospheric conditions, the depiction in Fig. 5 corresponds to a specific time and date. Figure 6 compares the MAPS hybrid coordinates with the NGM coordinates for a particular day. Note the enhanced resolution in MAPS near the ground and at the tropopause.

Figure 7 gives an overview of the assimilation cycle. New observations are introduced every 3 hours, followed by a 3-hour forecast, which extrapolates atmospheric conditions forward to the next analysis time. Twice a day, at 0000 and 1200 UTC, the forecast runs out to 12 hours. As soon as NGM results are available, the time-dependent lateral boundary conditions are updated.

3. Sample Output

Because adiabatic flow is confined to isentropic surfaces, the depiction of atmospheric fields tends to be more informative in isentropic coordinates than in other coordinates. This is especially true of the humidity field, as illustrated in Fig. 8 from Benjamin (1989). The pressure topography of the 305 K isentropic surface is depicted in Fig. 8a for 1200 UTC 17 March 1987. A deep trough dominates

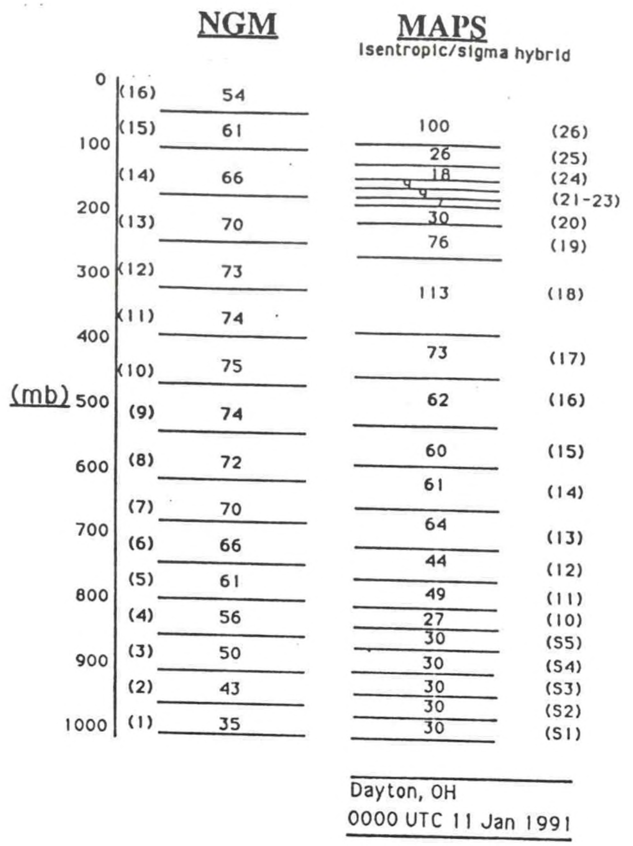


Fig. 6. A comparison of the vertical coordinates of the NGM and MAPS for Dayton, Ohio, at 0000 UTC 11 January 1991. Note that the spread between isentropic (theta) surfaces in MAPS depends upon atmospheric stability. For MAPS, S1 through S5 are labels for the terrain-following (sigma) surfaces. A few of the 19 designated isentropic surfaces lie below the sigma-theta interface in this example.

MAPS Three-Hour Assimilation Cycle

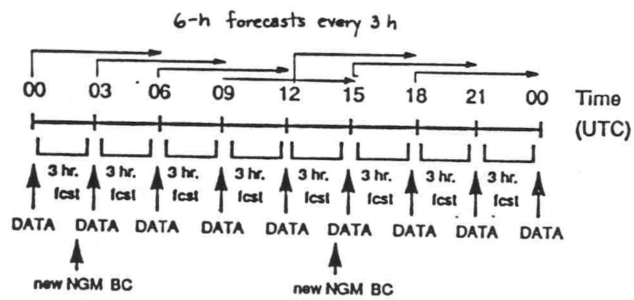
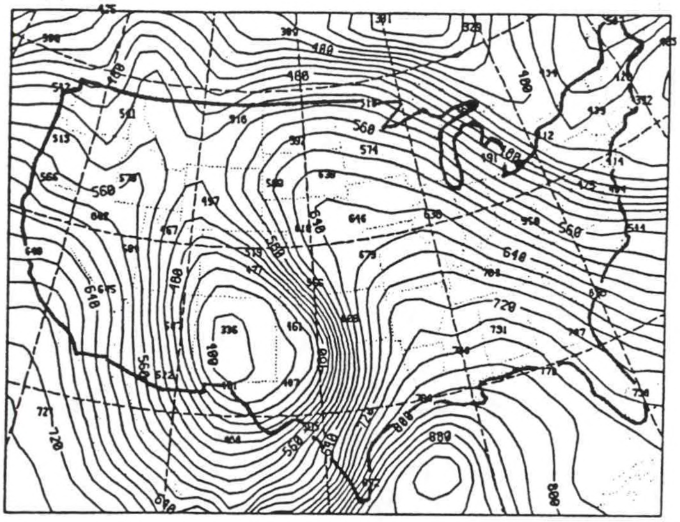
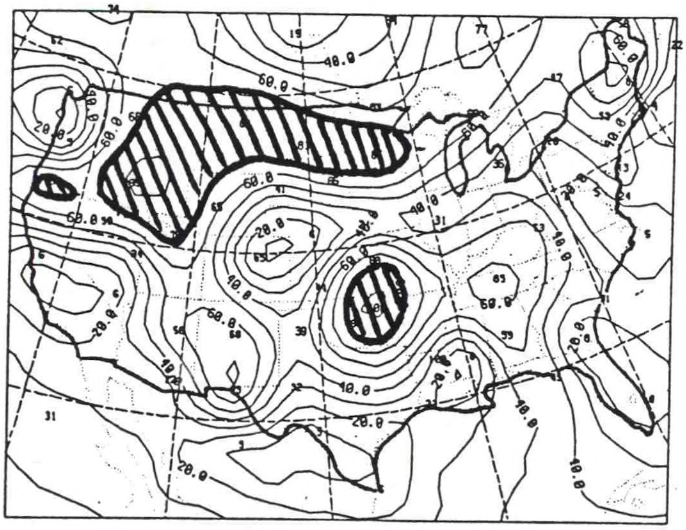


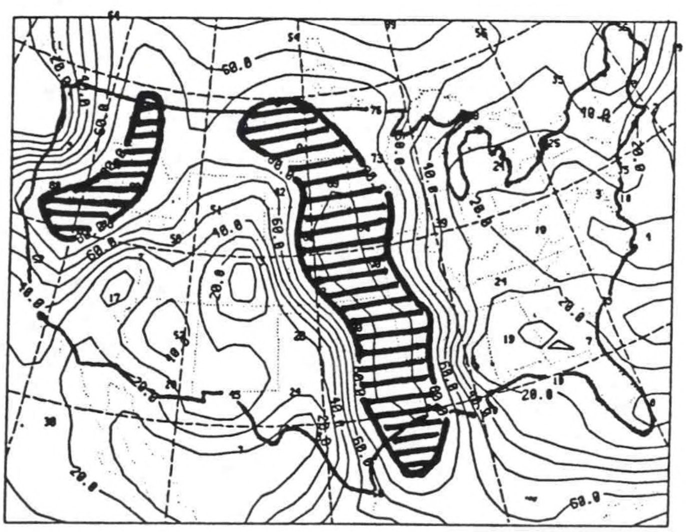
Fig. 7. A 3-hour assimilation cycle. Every 3 hours, newly observed data are used to analyze atmospheric conditions. These analyses supply the initial conditions for a numerical prediction, which advances the atmospheric state forward to the next analysis time, when another batch of observations is assimilated. In practice, the forecast runs beyond 3 hours, out to 6 hours. Twice a day, at 0000 and 1200 UTC, the forecast goes out to 12 hours (not illustrated here). Each time the NGM runs, a new set of time-dependent lateral boundary conditions replaces the old set.



(a)



(b)



(c)

Fig. 8. An illustration of the difference in viewpoint when a relative humidity analysis is displayed in isobaric and isentropic coordinates: (a) Pressure topography of the 305 K isentropic surface for 1200 UTC 17 March 1987; the contour interval is 20 hPa; (b) Relative humidity (RH) analysis at 500 hPa for the same time; contour interval is 10%, and regions with RH > 80% are striped; (c) Same as (b) except that the RH anlaysis is on the 305 K surface. In all three panels, observed values are plotted in small numbers (from Benjamin, 1989).

the West, including a closed circulation over New Mexico, and a large ridge stretches from the Gulf Coast to the northern Great Plains. A short wave has entered the Pacific Northwest states. Note the 500-mb contours, one crossing the northern U.S. and southern Canada, and the other enclosing the circulation over New Mexico.

The relative humidity field at 500 mb is shown in Fig. 8b, with values greater than 80% striped. One patch of moist air is centered near Oklahoma City, Oklahoma; another stretches from Idaho to Minnesota. The connection between these patches and the flow pattern is not obvious. Contrast this with Fig. 8c, the relative humidity analysis for the 305 K isentropic surface. The moist air in the Pacific Northwest is associated with the short wave. The tongue of moist air from the Gulf Coast to North Dakota is associated with a moist conveyor belt and upgliding motion in advance of the western trough.

The second example is taken from Benjamin *et al.* (1991b). The MAPS 250-mb wind analysis for 0000 UTC 20 January 1990 is shown in Fig. 9a. Note that the short and long barbs and flags correspond to 5, 10 and 50 m s^{-1}, respectively (not knots). A strong jet stretches from southwest Texas to New England. The jet is particularly strong (more than 90 m s^{-1}) over the northern Great Lakes, having strengthened considerably in the previous 12 hours. The error in the 12-hour NGM forecast (Fig. 9b) verifying at 0000 UTC exceeds 10 m s^{-1} from Minnesota to Maine. The corresponding error in the 3-hour MAPS forecast (Fig. 9c) verifying at the same time is less than 5 m s^{-1}. The improvement lies in the frequent assimilation of ACARS data by the MAPS model and, to a lesser extent, in the use of isentropic coordinates, which are closely spaced near the tropopause.

4. How MAPS Compares to NMC's Nested Grid Model

Figure 10 gives the RMS vector error of wind forecasts verified for the month of December 1991. These forecasts were interpolated to the locations of rawinsonde sites in the U.S. and southern Canada and differenced with the observed winds at 0000 and 1200 UTC. Forecast accuracy clearly improves with assimilation frequency. Improvement is greatest in the high troposphere, where ACARS reports are plentiful, but it is also substantial in the lower troposphere, in part, because of the hourly wind profiles now available in the central United States. The models have access to the same data and have comparable resolution, but the NGM has more sophisticated physics.

5. Porting MAPS to NMC and Experimental Output

During 1991, MAPS was ported to computers at NMC. As of this writing (mid-February 1992), most problems associated with the transfer from a VAX-based system at FSL to a Unix-based system at NMC have been worked out. Modules for data ingest, quality control, and objective analysis are running successfully on the NAS 9000 and Cray Y-MP computers at NMC. The complete system is expected to be running at NMC by March 1992, at which time it will become known as the Rapid Update Analysis and (short-range) Prediction System (RUAPS).

In support of STORM-FEST (the STORM Fronts Experiment Systems

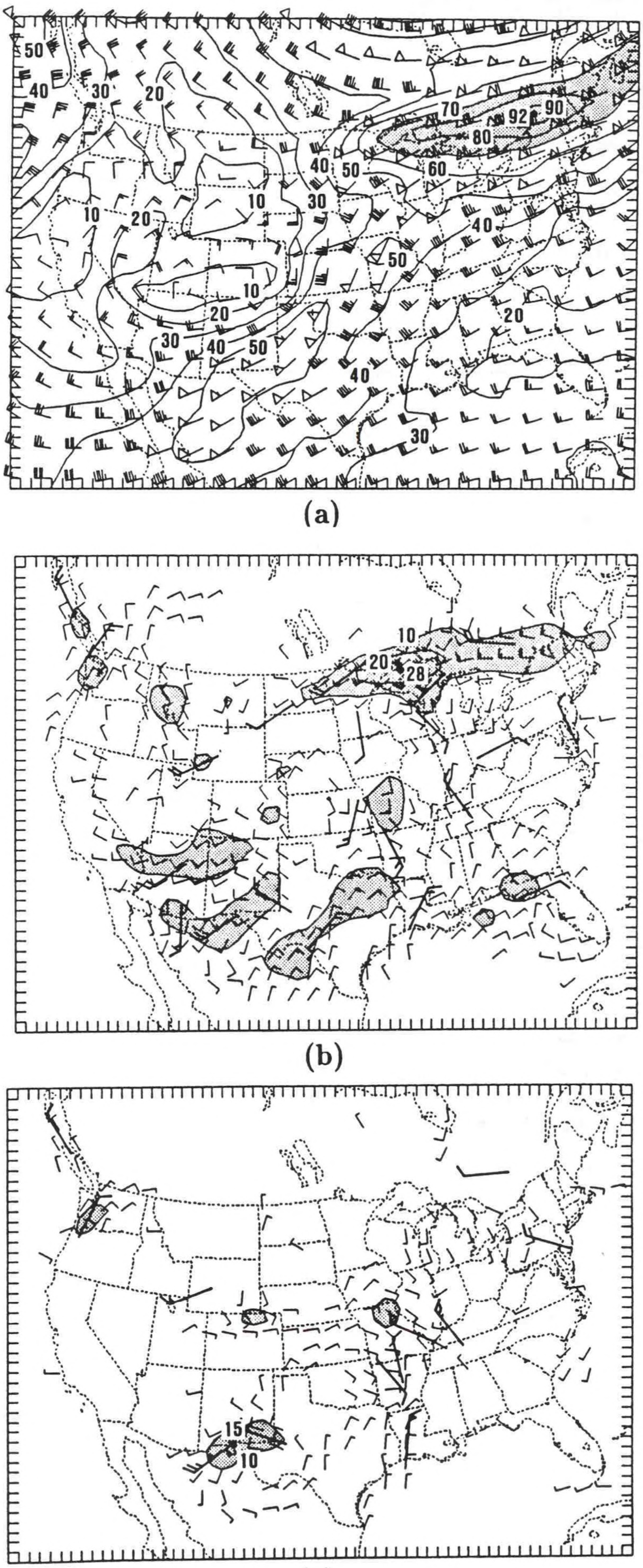


Fig. 9. (a) the MAPS 250-hPa wind analysis for 0000 UTC 20 January 1990. The next two panels illustrate vector differences in m s^{-1} (analysis minus forecast) at 250 hPa between wind forecasts and the verifying analysis in (a). (b) For NGM 12-hour forecast. (c) For MAPS 3-hour forecast (from Benjamin et al., 1991b).

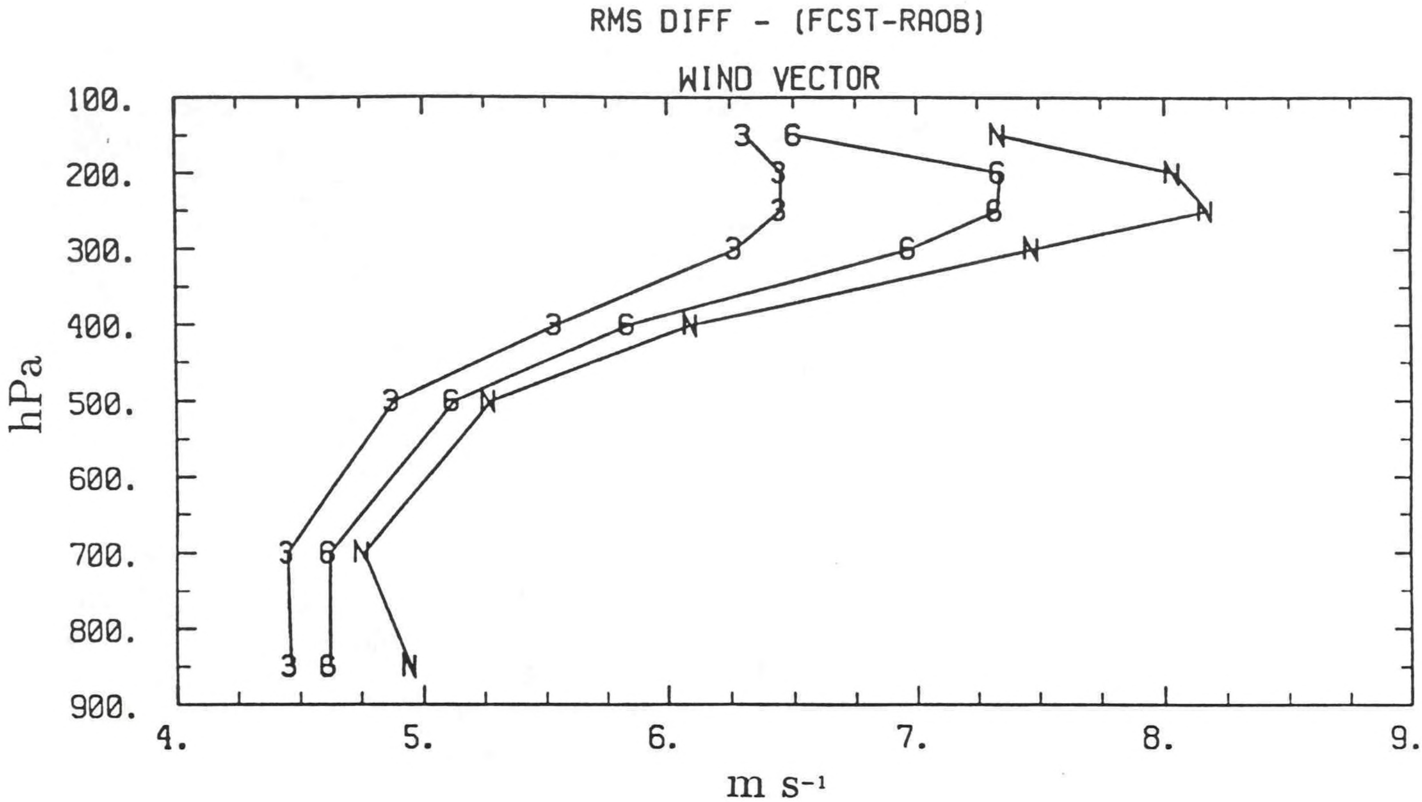


Fig. 10. The root-mean-square vector error (m s^{-1}) in wind forecasts produced by MAPS and the NGM. The error was estimated by comparing the predicted winds with winds measured by rawinsonde in the U.S. and southern Canada during December 1991. The symbols labelling the curves have the following meanings: 3 - MAPS 3-hour forecast; 6 - MAPS 6-hour forecast; N - NGM 12-hour forecast.

Test) from 1 February through 15 March 1992, FSL is sending output fields from MAPS to NMC for experimental dissemination. The output is interpolated to the 80-km C-grid (the standard grid used for NMC model output), converted to GRIB (GRIdded Binary) Version 1 format, and stored in "common" (COM.) files on disks at NMC for access by authorized users. During 1992, these users are located in Kansas City, Missouri (National Severe Storms Forecast Center and the National Aviation Weather Advisory Unit); Norman, Oklahoma (National Severe Storms Laboratory and the National Weather Service Forecast Office); and Denver/Boulder, Colorado (Forecast Systems Laboratory and the Weather Service Forecast Office). Kansas City receives the output via its VDUC line to NMC. Other sites receive it via Internet.

Once MAPS/RUAPS runs regularly and reliably on NMC's computers, the transmission of output by FSL to NMC will cease, and dissemination will occur directly from NMC. If tests of the rapid update cycle are successful in 1992, national dissemination is possible by 1993, but it should be noted that the current communications network (AFOS) cannot accommodate the required bandwidth.

ACKNOWLEDGMENTS

I thank my colleagues, Stan Benjamin, Patty Miller, Tracy Smith, Kevin Brundage, Dongsoo Kim, Pan Zaitao, and Dezso Devenyi, who helped develop MAPS. Special thanks to Stan Benjamin, who supplied many of the figures used here. From the beginning, the National Meteorological Center has supported efforts to incorporate MAPS into its operational cycle. The Facilities Division of FSL has assisted on numerous occasions by decoding incoming data.

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THUNDERSTORM FORECASTING USING GRIDDED MODEL OUTPUT AND THE FAA'S METEOROLOGIST WEATHER PROCESSOR (MWP)

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1. INTRODUCTION

One of the primary concerns of the Center Weather Service Unit (CWSU) is that of forecasting thunderstorms. This paper presents an aid for thunderstorm forecasting that uses the gridded model output and the FAA's Meteorologist Weather Processor, or MWP. Before we begin, let us briefly introduce the MWP.

2. MWP BASICS

The MWP is part of the FAA modernization plan and represents a major step forward in technology for the CWSU. In terms of technology, the CWSU has always been near the bottom of the scale. Teletypes and facsimile machines have continued in the CWSU, while the rest of the Weather Service has been using AFOS. But with the MWP, technology in the CWSU is now considerably more advanced than that offered by AFOS.

The MWP is basically a communication and processing system consisting of a satellite dish, two minicomputers, a meteorologist workstation, and nine briefing terminals. Data is transmitted by satellite to the CWSU and consists of satellite, radar, alphanumerics, and graphic products. Graphics can be AFOS products, manually generated products produced in the CWSU, or GRIB (gridded binary) products.

3. GRIB (Gridded Binary Products)

GRIB data is output from the NGM and AVN models and is available twice daily. Forecast data is available for six-hour intervals, and some of the forecast parameters include:

height
temperature
relative humidity
u & v components
vertical velocity
precipitation
pressure
lifted index.

4. OBJECTIVE

Our objective was to use the gridded data on the MWP to produce a graphic product that displays thunderstorm-related parameters--but only those that meet certain <u>threshold</u> values. By combining several parameters on a single composite chart, the most favorable location for convection should be the point where the most "bullseyes" converge. Such a chart could be evaluated much more quickly than could a number of individual charts of different parameters.

From the available GRIB data, we chose the following parameters to be related to thunderstorm development:

- Surface moisture convergence
- 850 mb moisture
- 850 mb convergence

- 700 mb Omega (vertical motion)
- 250 mb divergence.

This very basic model simply states that convection is most likely where we have low level (surface and 850 mb) moisture and convergence, vertical motion, and upper-level divergence. The intensity and areal coverage of the convection should be related to the magnitude of the parameters.

5. EXAMPLE 1: November 29, 1991

Figure 1 is an example of our composite chart for November 29, 1991. This chart at first glance appears quite busy, with many lines and colors. But after becoming familiar with the parameters and colors, the chart can be quickly evaluated. (Note: The charts in this paper may be difficult to evaluate properly due to printing limitations. The MWP workstation, however, produces these charts with outstanding resolution and quality. The MWP also permits toggling off selected colors for easier interpretation.)

<u>12-hr Relative Humidity</u>. The first thing to look at is the legend at the bottom of the chart. The bottom-most legend indicates that NGM 12-hr 850 mb relative humidity is depicted in brown. The threshold value for this parameter is of 60%. Any lower value will not be printed at all. The second legend from the bottom is also NGM 12-hr 850 mb relative humidity, but in this case humidity values of 90% or more will be shown in white for quicker interpretation. On this day 850 mb relative humidity was forecast to exceed 90% over a large part of the country from Utah to New England and southward to northeast Texas.

<u>12-hr 850 mb Convergence</u>. The next legend up from the bottom is 850 mb divergence. But our threshold value was chosen so that contours would be drawn (in blue) only for areas of <u>convergence</u>. In this case, the strongest 850 mb convergence was forecast over an area extending from the southwestern U.S. across the northern plains and southward to Missouri and northern Oklahoma.

<u>12-hr 700 mb Omega</u>. The legend indicates that 700 mb Omega is shown in yellow. Our threshold value was chosen to indicate only areas of <u>upward</u> vertical motion. In this case, vertical motion was forecast to be most pronounced over the southwestern U.S. and from the northern plains southward to Oklahoma and Missouri.

<u>12-hr 250 mb Divergence</u>. The legend indicates that 250 mb divergence is shown in violet. On this day, strong upper divergence was forecast over the southwestern U.S. and over the northern plains with an axis extending southward to Missouri.

<u>12-hr Surface Moisture Convergence</u>. There is no legend for surface moisture convergence because this is an AFOS graphic that is overlaid onto the other data. (There is no GRIB data for this parameter available through the Family of Services, which is the data source for the MWP). Surface moisture convergence is indicated in green; and on this day, an axis of particularly strong values was indicated from southeastern Nebraska to northeastern Texas.

<u>The Big Picture</u>. To reach a conclusion about what the data is suggesting, we must consider the

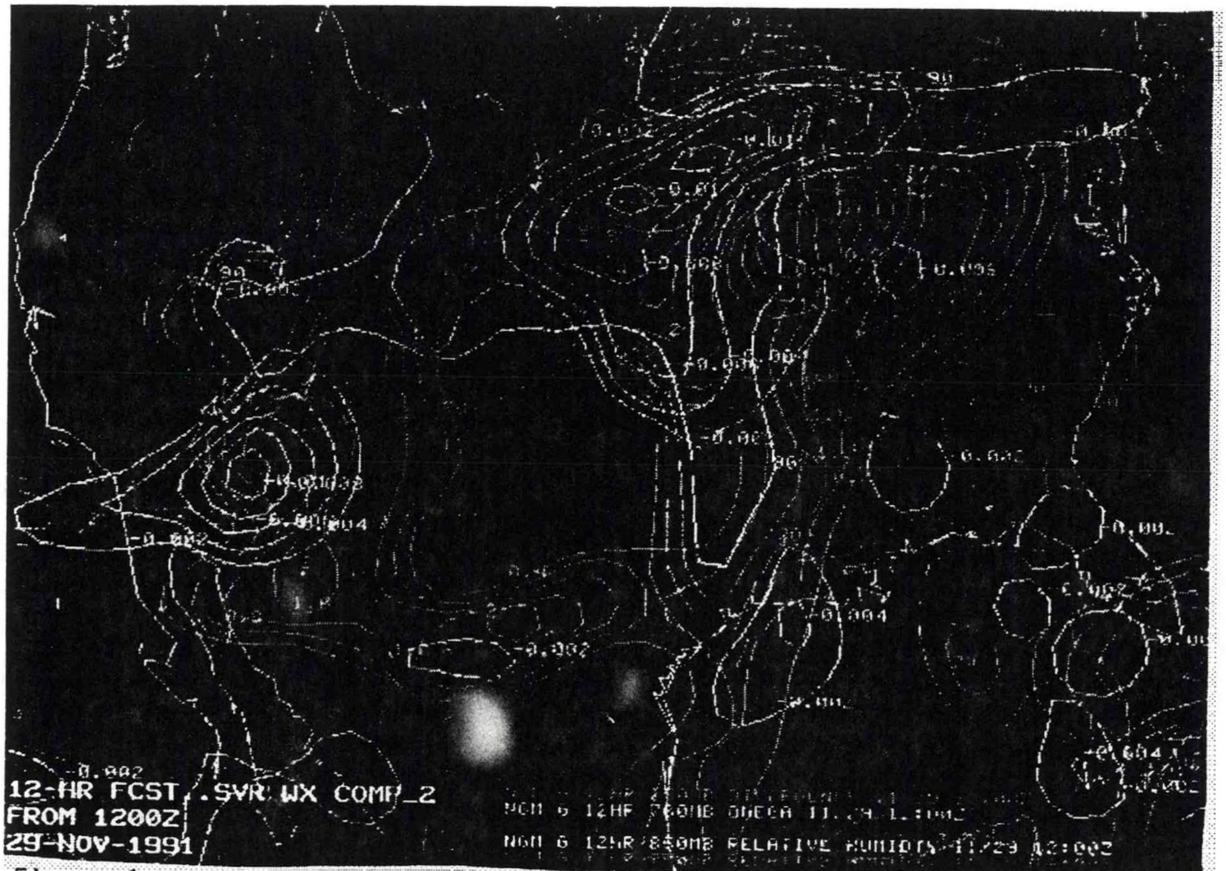

Figure 1

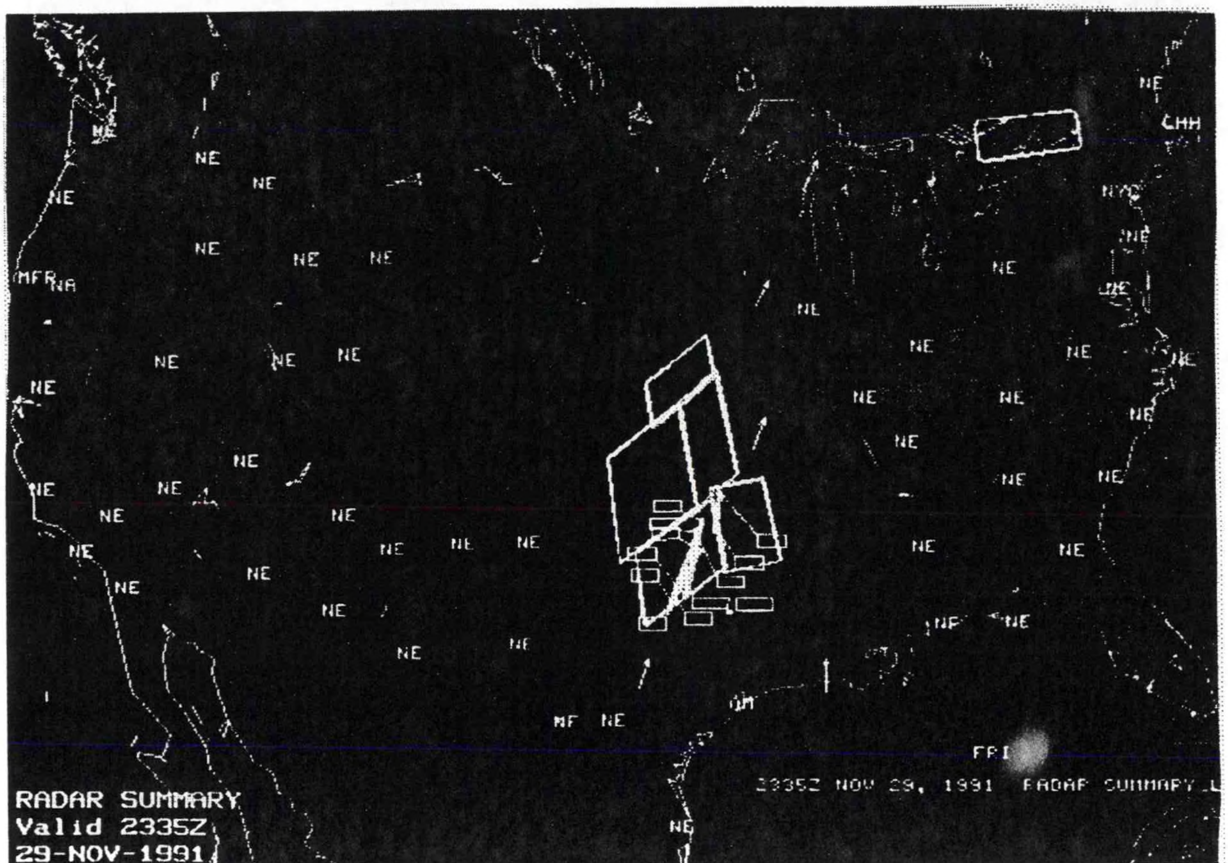

Figure 2

locations of the bullseyes and how they coincide with one another. In this case, the bullseyes converge over the northern plains with an axis of bullseyes extending southward to northeastern Texas. Surface moisture convergence values over this area are especially high.

Bullseyes are also indicated over the southwestern U.S., but one important ingredient, 850 mb moisture, is missing over Arizona.

Verification. The forecast was verified by evaluating the corresponding radar summary (AFOS products 90R and 90S) which was valid at 2335Z. Figure 2 shows this chart and indicates first of all that several severe thunderstorm an/or tornado watches were in effect at the time. The chart also shows lines of thunderstorms from northwestern Arkansas to northeastern Texas. Additional reports indicated that a devastating tornado occurred during the afternoon over Missouri. The composite chart performed extremely well for this event.

6. EXAMPLE 2: August 29, 1991

Figure 3 is an example of the 18-hr composite chart from the 12Z model output of August 29, 1991. In this case, the 850 mb relative humidity contours of 60-80% had been switched off at the MWP workstation to facilitate viewing the other parameters. The bullseyes especially converged over southern Mississippi and southern Alabama, and convection did indeed occur over this area. But this example will deal with the bullseyes over southern Oklahoma and northern Texas. Figure 3 shows high forecast values of 850 mb and surface moisture convergence, along with quite strong vertical motion. The only ingredient which was not depicted was 250 mb divergence.

Verification. Figure 4 shows the MWP radar mosaic which was valid at 0630Z on August 30, corresponding to the 18-hr forecast from 12Z on August 29th. The radar reflectivity (and ground clutter) is shown for Amarillo, Oklahoma City, Little Rock, Longview, Stephenville, and Midland. An area of strong thunderstorms (levels 4 to 6) is shown over southern Oklahoma near the Texas border. This area corresponds extremely well with the 18-hr forecast. This example was especially interesting, because the composite chart actually performed better than the Weather Service forecasts of August 29th.

7. CONCLUSIONS

This paper has presented only two examples. But since this composite chart was first developed, many cases have verified extremely well. The gridded model output has shown itself to be an excellent forecast tool, and it has proven to be particularly helpful for forecasting thunderstorms. Also, the capability of producing composite charts of gridded data that meet threshold values is very important and should be made available on future meteorologist workstations (AWIPS).

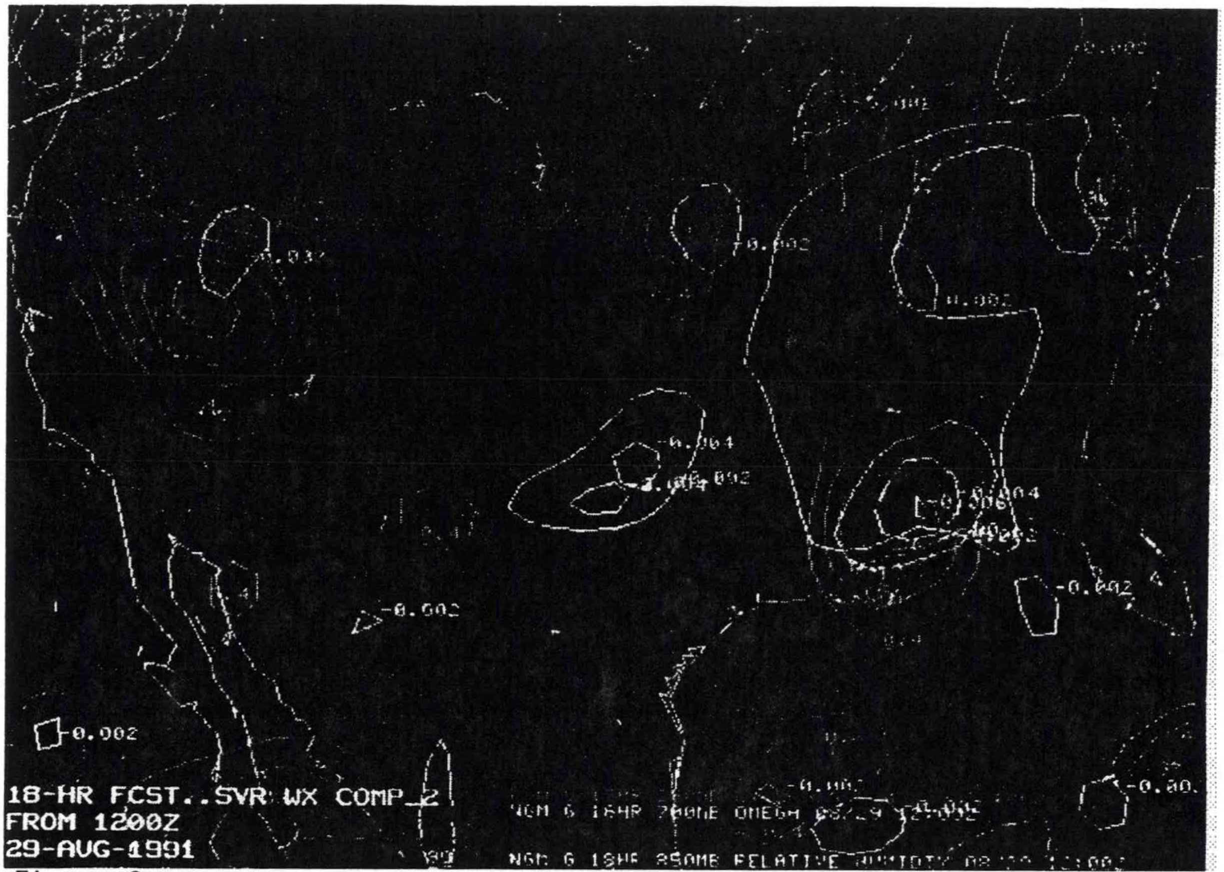

Figure 3

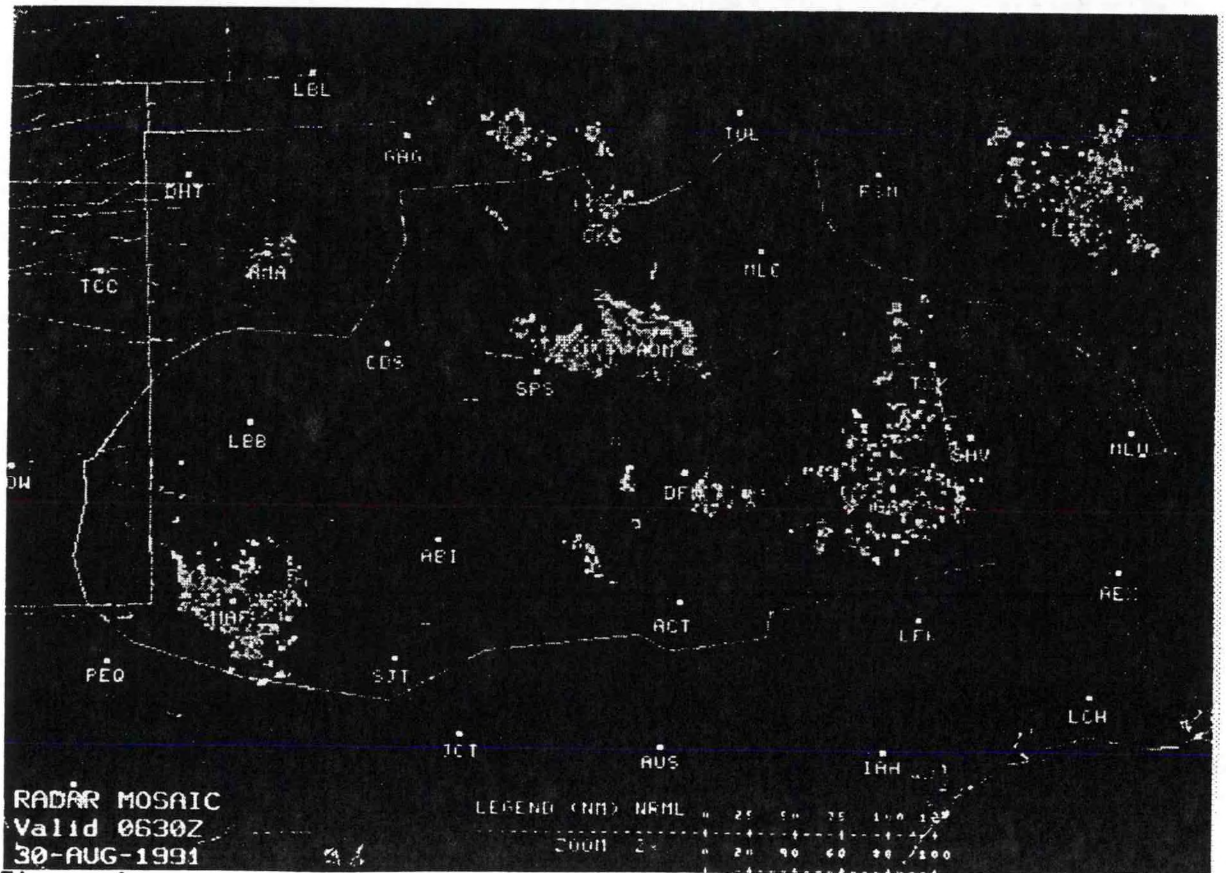

Figure 4

APPENDIX
MWP COMMAND STRING FOR COMPOSITE CHART

```
* H12_TSTM_COMP
* composite chart of key tstm-related parameters
* can be adapted for 6 and 18 hrs by changing 12 to 06 or 18
* command string should be scheduled to run around 0445z and 1645z
*
MAP,A_US  * any suitable map will do
* 850 MB RELATIVE HUMIDITY
ISO,G,N,L85,F12,RH,60,100,S,E,N "C:BROWN"
LEG,OFF   * turns off legend
ISO,G,N,L85,F12,RH,70,100,S,E,N "C:BROWN"
ISO,G,N,L85,F12,RH,80,100,S,E,N "C:BROWN"
LEG,ON    * legend back on
ISO,G,N,L85,F12,RH,90,100,S,E,N "C:WHITE"
* 850 MB CONVERGENCE
ISO,G,N,L85,F12,DIV,-0.4,100,S,E,N "C:BLUE"
LEG,OFF
ISO,G,N,L85,F12,DIV,-0.8,100,S,E,N "C:BLUE"
ISO,G,N,L85,F12,DIV,-1.2,100,S,E,N "C:BLUE"
ISO,G,N,L85,F12,DIV,-1.6,100,S,E,N "C:BLUE"
ISO,G,N,L85,F12,DIV,-2.0,100,S,E,N "C:BLUE"
ISO,G,N,L85,F12,DIV,-2.4,100,S,E,N "C:BLUE"
LEG,ON * 700 MB OMEGA (vertical motion)
ISO,G,N,L70,F12,OMG,-.002,100,S,E,N "C:YELLOW"
LEG,OFF
ISO,G,N,L70,F12,OMG,-.004,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.006,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.008,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.010,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.012,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.014,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.016,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.018,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.020,100,S,E,N "C:YELLOW"
ISO,G,N,L70,F12,OMG,-.022,100,S,E,N "C:YELLOW"
LEG,ON * 250 MB DIVERGENCE
ISO,G,N,L25,F12,DIV,0.4,100,S,E,N "C:PURPLE"
LEG,OFF
ISO,G,N,L25,F12,DIV,0.8,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,1.2,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,1.6,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,2.0,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,2.4,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,2.8,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,3.2,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,3,6,100,S,E,N "C:PURPLE"
ISO,G,N,L25,F12,DIV,4.0,100,S,E,N "C:PURPLE"
LEG,ON
* SFC MSTR CONVERGENCE
```

```
RET,A,A,EXACTLY,NMCGPHL2Z
*
LAB,SCR,8,33,MB,"12-HR NGM FCST...TSTM COMPOSITE" "C:WHITE"
LAB,SCR,8,18,MB,"FROM $VTIME2Z" "C:WHITE"
LAB,SCR,8,3,MB,"$VDATE1" "C:WHITE"
LAB,SCR,600,3,SB,"CTIME2Z" "C:GRAY"
SHP,AA_TSTM_COMP,COMP_12HR * or your choice of names
CLR,P
```

ON THE POSSIBILITY OF USING THE GLOBAL SPECTRAL MODEL'S NORMAL MODES TO FORECAST HIGH ALTITUDE TURBULENCE

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ABSTRACT

Previous studies have linked CAT to enhanced gravity wave activity. This study indicates that the forecast fields may contain gravity wave information that can be used as an aid in forecasting potential high altitude turbulence areas. A subset of permissible oscillations as modeled by the National Meteorological Center's (NMC) Global Spectral Model (GSM), namely gravity modes with periods less than 36 hours, are examined as a high-altitude turbulence forecasting tool. Preliminary results show a low false alarm ratio of 9.1 and critical success index of 38.5 for a winter regime set of forecasts. The area of study covers most of the Northern Hemisphere with verifying observations of turbulence from Pilot reports (PIREPs).

1. INTRODUCTION

Turbulence can be encountered in varying degrees depending on atmospheric conditions. Aircraft size and structure also influence the sensitivity to turbulence. Turbulence is both an economic and physical hazard that constitutes a serious threat to all vehicles that must fly in or traverse the atmosphere. Generally turbulence, including clear air turbulence (CAT) and turbulence associated with mountain waves, has been referred to as a mesoscale phenomenon. However, areas of moderate or greater turbulence sometimes extend over a synoptic scale horizontal domain with a vertical thickness of a few thousand feet. Certain satellite signatures within developing baroclinic disturbances have been associated with observed high-altitude turbulence (Ellrod 1985). It also has long been recognized that high-altitude turbulence (including jet cirrus associated turbulence) ahead of a developing low is common, especially in winter, and particularly in cases of jet stream associated explosive cyclogenesis (Bosart and Cussen 1973; Rammer 1973). CAT may arise from various effects, not all of which are well understood, and may be manifested through many scales, some of which are very difficult to measure (Baumgardner et al. 1990; Shapiro 1974).

The interaction of mesoscale jet streaks within synoptic scale weather features as a generator of gravity wave activity is receiving substantial attention, especially in association with cyclone development near warm ocean currents such as the Gulf Stream and Kuroshio Current. Several studies have linked gravity wave activity with cyclogenesis or the enhancement of a synoptic scale or mesoscale weather feature associated with a synoptic scale weather disturbance. See Appendix A for examples. Internal gravity (or buoyancy) waves exist only when the atmosphere is stably stratified, and they are responsible for the occurrence of mountain lee waves. Thus, gravity waves are often associated with the formation of CAT (Holton 1979). Similarly, mountain waves have their maximum amplitude in the layer of strongest stability, which is usually at the tropopause.

A favorable place for mountain lee wave formation is under an upper level ridge. The middle and upper level wind direction has a westerly component, which often is normal to the north-south oriented topographic features common across the continental United States, and wind speeds are generally 40 to 80 knots. With such velocities, wave motions fit an example of mountain forced vertical propagation of stationary waves discussed by Charney and Drazin (1961). At least one in every twenty-seven weather related aircraft accidents during the period from 1964 to 1982 was related to a mountain wave condition according to Blake (1988). In operations, routine dynamical model output and satellite signatures have been used to develop conceptual models relating synoptic scale patterns with the incidence of aircraft observed turbulence (Hopkins 1977). These conceptual models are part of the techniques applied by NMC's Monitoring and Aviation Branch (MAB) meteorologists to produce forecasts of turbulence.

In this paper, a new turbulence forecasting technique, based on dynamical model output, is presented. The objective of this technique is to use the numerical output from the GSM to assess the potential for high altitude turbulence associated with gravity wave activity. This was achieved by normal modes decomposition to extract gravity wave information from the model's output. The decomposition was done in the model's sigma domain. The gravity mode oscillation periods were those with periods faster than 36 hours. Relatively high frequency gravity wave content in the temperature and winds fields on the sigma surfaces were chosen as model output parameters possibly indicative of turbulence. The horizontal domain of the experiment covered most of the Northern Hemisphere. A summary of the study, verification results, and suggestions for further work will be presented.

2. METHODOLOGY

2.1. Extracting Gravity Wave Activity from the Dynamic Model Forecast

The GSM utilized for this experiment had 18 non-equally spaced levels and a triangular truncation of 80 waves. Levels 11 through 14 were packed in the region of the expected jet stream, from approximately 400 to 200 mb while levels 5 through 9 were between 850 and 500 mb.

Excessive gravity wave activity can be eliminated from a model's initial conditions by projecting the initial fields on the model's gravity modes. The undesired fast components are then removed and the data are then transformed back into the model's variables. Further improvement in the balance of these data can be achieved if this process is also applied to the tendencies of the model's variables. When both steps are performed the method is known as the Baer-Tribbia non-linear normal modes initialization.

In this study, the first step of the initialization technique was used to filter out the gravity waves contained in the forecast from the Medium Range Forecast (MRF) model. The operational MRF forecasts at 24 hours were projected on the MRF model's first four vertical modes and the associated horizontal modes. The gravity wave components with wave periods of less than 36 hours were zeroed out and then returned to the model's spectral expansion. The difference between the original forecast and the filtered forecast represents the "fast" gravity wave content of the forecast. In this experiment the first four vertical modes employed in operations were used to project the data. More vertical modes, or a subset of internal vertical modes, should be used in future experiments.

2.2. Examining Gravity Wave Activity on Sigma Surfaces

The method of extracting gravity wave activity as described in the previous section was applied to a total of 20 cases. During two, 30-day periods (summer 1988 and winter 1988-89), gravity wave content in some of the 0000 UTC MRF model forecast fields was calculated, mapped and compared to manual turbulence forecasts and to observations every second, third, or fourth day. Additionally, for one winter case and one summer case, the gravity wave content in the temperature and wind speed fields on various sigma levels from 5 through 16 were examined. While the model's sigma surfaces are not the usual quasi-horizontal surfaces operational meteorologists typically study to forecast weather related phenomena, they are closest to the true model forecast and the least contaminated (by, sigma to pressure interpolation) numerical output available. Sigma level maps were made for each of two levels, usually 7 and 12, on the Gaussian grid, for the entire globe. Three charts were made for both temperature and wind fields. For each, the forecast parameter is depicted, then the parameter with the gravity wave content removed, and finally the difference between the two, which is the gravity wave content of the displayed field.

International and domestic pilot reports (PIREPs) are among the data collected at NMC. From these PIREPs, turbulence maps are made four times a day covering a 6-hour period with a geographic area covering most of the Northern Hemisphere. Groups of moderate or greater turbulence are encircled. These charts were compared to previous 24-hour prognoses for verification of manual turbulence forecasts. Similarly the gravity wave content of the displayed field was compared to the encircled observations to assess the performance of this scheme. Of course, the reliance on PIREPs is a weakness of this high altitude turbulence verification scheme (and others), mainly due to the limited coverage of PIREPS which are concentrated along flight routes.

Advances in radar and lidar techniques may be useful in the future for turbulence verification. For example, a weak gravity current has been observed by Raman Lidar (Koch et al. 1991).

3. RESULTS FROM SUMMER AND WINTER CASE STUDIES

In this study, an area of turbulence was considered predicted by the gravity wave scheme if the wind speed difference was greater than 3 m/s (6 kts) or if the temperature difference was greater than 2°C at level 12. Usually, only the former criterion was met. The gravity wave maps were subjectively evaluated as in the manual forecast scheme by using PIREPs with the following criteria:

HIT = forecast area of turbulence touching or overlapping any observed area of moderate or greater turbulence.

MISS = forecast area of turbulence in (or near) an observed area of light or no turbulence.

UNFORECAST = no forecast area of turbulence in (or near) an observed area of moderate or greater turbulence.

UNVERIFIABLE = forecast area of turbulence with no observations in or near the area.

"Near an area" was defined to be within 300 nmi of the particular location measured locally by 5° of latitude on the Polar Stereographic map projection. When an area would have been unverifiable due to lack of data, but where observations were available within 300 nmi, those nearby observations were assumed to be quasi-representative of the conditions at the normal modes scheme forecasted location.

In the winter case for which many vertical levels were examined it was found that most of the gravity wave amplitude in temperature and wind speed occurred over mountainous regions above level 13. It was also found that wind speed amplitude was highest near the elevated polar regions of Antarctica and Greenland. The amplitude of the temperature difference in levels 13 to 16 was nearly double that in level 5 to 9, and was greatest over mountain ranges. Because of this difference in behavior at middle troposphere levels and near tropopause levels, for each of the cases in the study, at least two levels were examined, mainly level 7 and level 12.

The choice of a level near the tropopause was done to reflect the capping effect on mountain wave energy transport. The lowest internal mode used in the projection had an equivalent depth near a subtropical or summer tropopause (200 mb). There have been recent studies of undulations in the tropopause (Hirschberg and Fritsch 1991a,b) which support the choice of levels near the tropopause as especially relevant to turbulence generation.

The first series of experiments used Northern Hemisphere summer data separated 2 to 4 days apart during June 1988. Preliminary verifications were similar to the manually produced turbulence forecasts. The next set of experiments were conducted 6 months later. The purpose of the winter experiments was to determine whether meteorological phenomenon associated with strong baroclinic systems, or rapidly developing extratropical cyclones, such as merging jets or strong baroclinic instability, produce more predictable turbulence. Figures 1a-c show a summer case, and Figures 2a-c depict a winter case. These examples are among the better ones in terms of verifiability and diversity of turbulence generating mechanisms. The verification area covered the Northern Hemisphere westward from 30°E to 120°E. Solid lines in Figure 2c enclose areas of gravity wave scheme forecast turbulence. Turbulence was forecast when the gravity wave content exceeded 3.0 m s^{-1} as defined by the mark on the unit vector depicted in the lower left corner of Figure 2c. Table 1 summarizes the overall results of the gravity wave content forecast scheme.

	SUMMER CASES	WINTER CASES
# Forecast	10	16
HITS	1	10
UNFORECAST	7	15
MISSES	1	1
UNVERIFIABLE	3	8
POD	0.13	0.40
FAR	0.50	0.09
CSI	0.11	0.38

where:

$$POD = \frac{HITS}{HITS + UNFORECAST}$$

$$FAR = \frac{MISSES}{HITS + MISSES}$$

$$CSI = \frac{HITS}{HITS + UNFORECAST + MISSES}$$

Table 1. Results of the gravity wave content forecast scheme.

The winter results show a low false alarm ratio of 9% with a somewhat encouraging probability of detection of 40%. While these values are promising, more cases

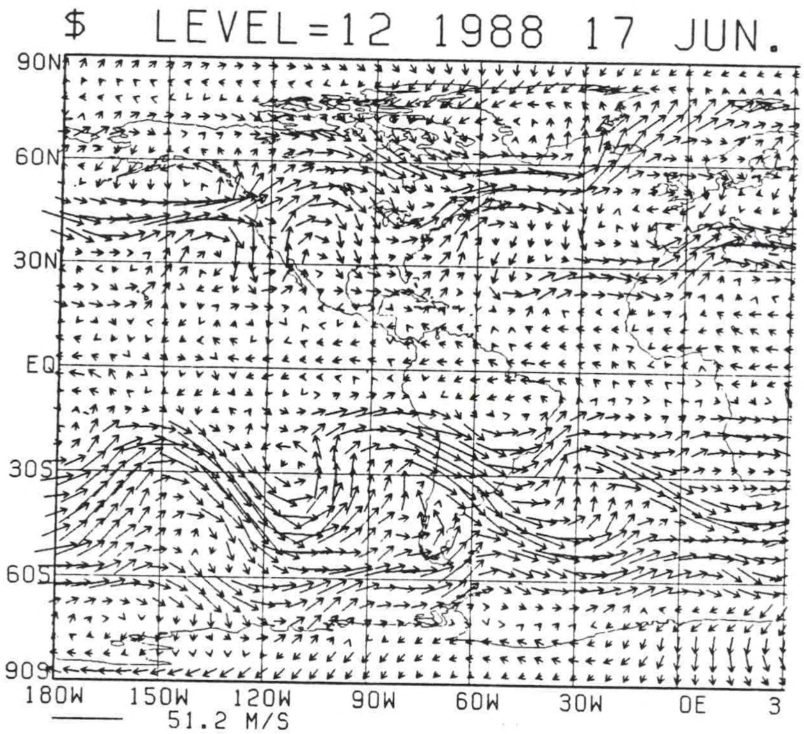

Figure 1a. Summer case - 24-hour wind forecast on sigma level 12 depicted on a Gaussian grid.

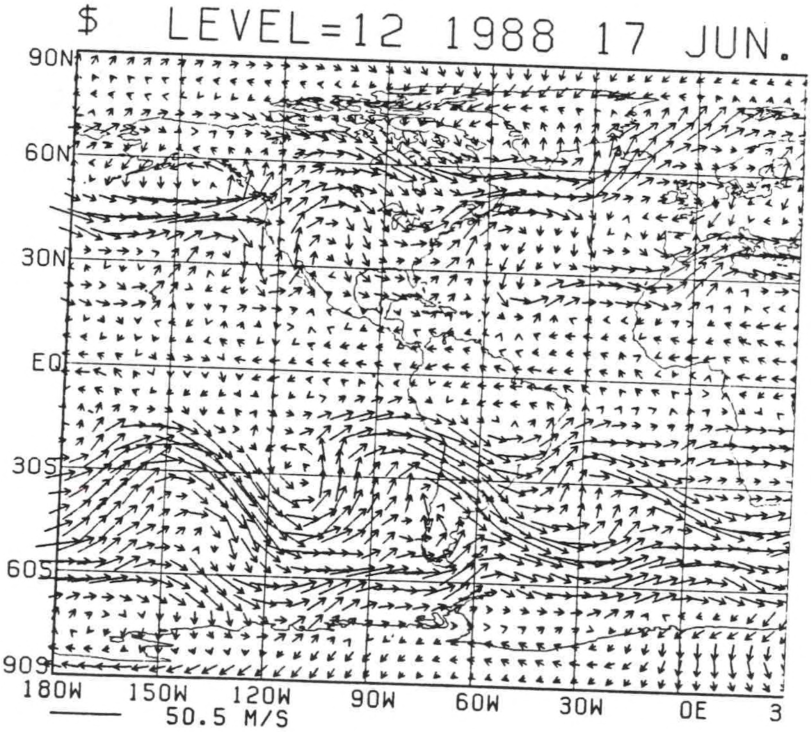

Figure 1b. Summer case - Same as Figure 1a except the "fast" gravity wave content has been removed.

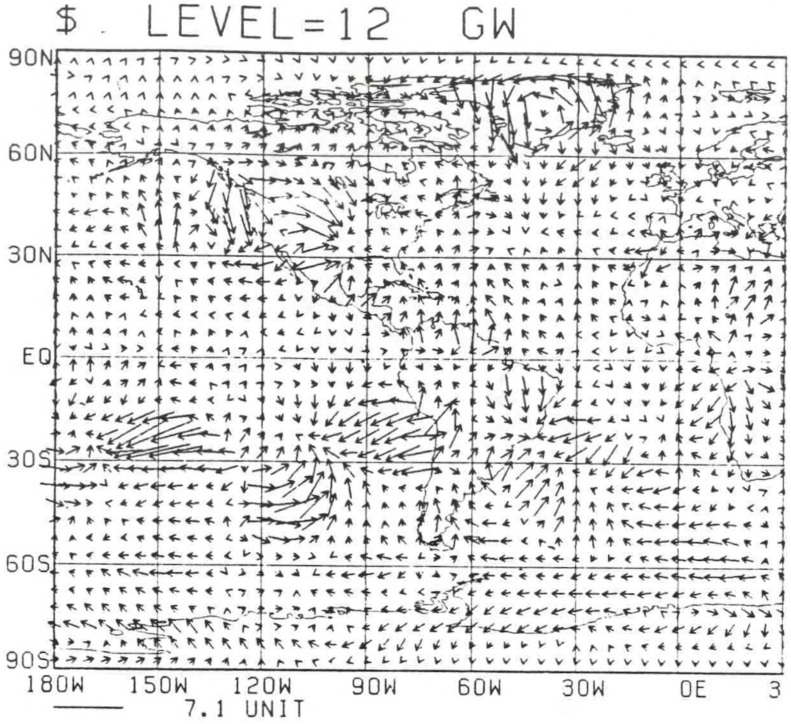

Figure 1c. Summer case - The fast gravity wave content in the forecast winds (e.g., Figure 1b subtracted from Figure 1a).

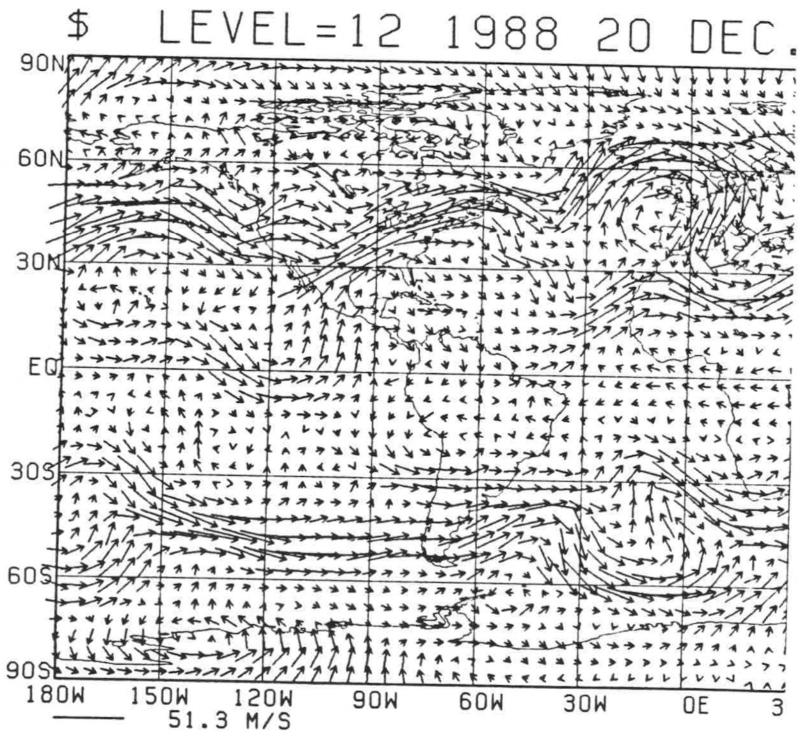

Figure 2a. Winter case - 24-hour wind forecast on sigma level 12 depicted on a Gaussian grid.

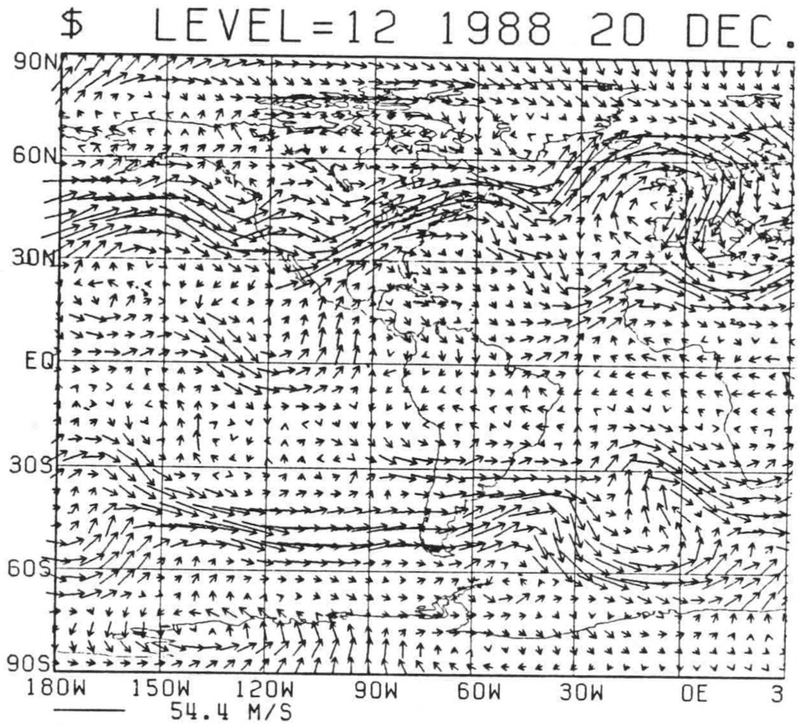

Figure 2b. Winter case - Same as Figure 2a except the "fast" gravity wave content has been removed.

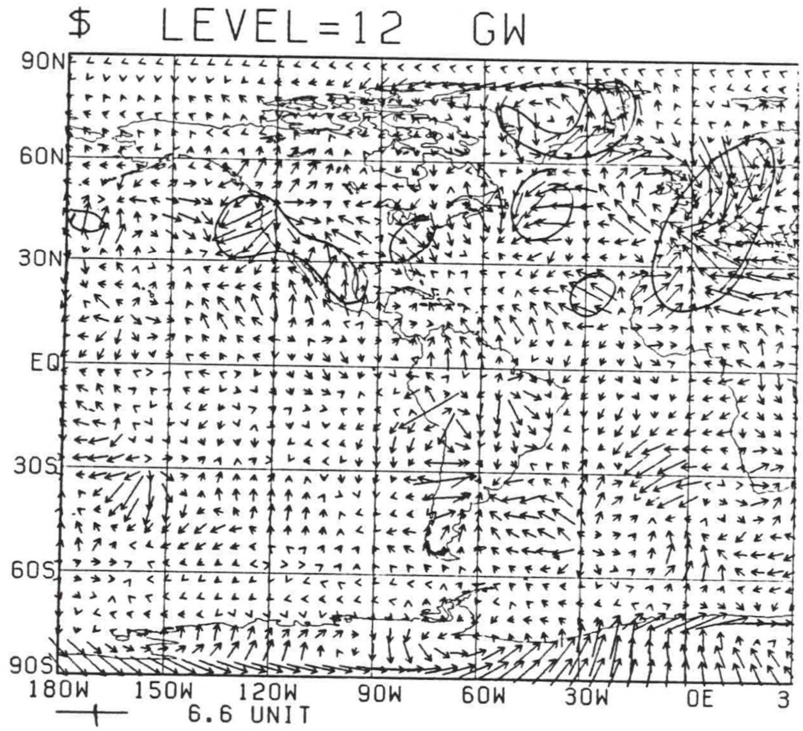

Figure 2c. Winter case - The fast gravity wave content in the forecast winds (e.g., Figure 2b subtracted from Figure 2a).

are needed to accurately evaluate the performance of gravity wave content as a turbulence forecast parameter. These results may be compared to another index used in MAB operations during 1988, the "TIGE" index, which has given very good results over the continental United States. "TIGE" is derived from an objective deformation and shear-based scheme (Mancuso and Endlich 1966) that was evaluated from NGM output on the VAS Data Utilization Center (VDUC) by NESDIS and MAB personnel in real-time during April, May, and September of 1988. The POD was 70%, the FAR was 20%, and the CSI was 60% (G. Ellrod, personal communication). The forecast area for this test was the continental United States where data sparsity is much less of a problem. The gravity wave scheme also performed well over the Rocky Mountains.

In real-time operations, the availability of more than one scheme is useful, especially if the different methods corroborate each other by highlighting the same geographic areas for enhanced high altitude turbulence potential.

4. SUMMARY

It was demonstrated that numerical model forecasts of gravity wave activity, especially in the winter can be used to identify potential regions of turbulence. The origin of this turbulence is usually orographically induced, or associated with developing baroclinic systems.

5. ACKNOWLEDGEMENTS

I would like to express my gratitude to all of the NMC personnel who helped me in this study. In particular I would like to thank Joseph Sela for adapting the initialization codes to extract gravity wave information from the global model. Thanks are also due to management of NMC's Meteorological Operations Division and Monitoring and Aviation Branch for their support during this study. Thank you also to Eastern Region management and staff members for their encouragement and support in the continuation of this study. I am also grateful to Gary Ellrod of NESDIS for many helpful discussions.

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APPENDIX A - SOME EXAMPLES OF GRAVITY WAVE ASSOCIATED WEATHER FEATURES

WEATHER FEATURE	LOCATION	REFERENCE
Enhancement of convection due to **a gravity wave.**	United States	Uccellini (1975)
Amplification of **a gravity wave** related to mesoscale heavy rainfall.	Japan	Ninomiya (1980)
Mountain induced orographic **cirrus** associated with **turbulence.**	United States	NWS (1986)
Tropopause undulations with **strong cyclone development**.	United States	Hirschberg and Fritsch (1991a,b)
Dissipating **gravity current** revealed by Raman Lidar.	United States	Koch et al. (1991)

VERIFICATION OF THE EXPERIMENTAL AVIATION PACKAGE BY THE NEWFOUNDLAND WEATHER CENTRE

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1. INTRODUCTION

Early in 1989 an Experimental Aviation Package (Jones, 1989) was developed at the Canadian Meteorological Centre (CMC) to provide forecasts of various meteorological elements considered important to high and low level flight operations. The transmitted forecast charts were for an area encompassing eastern Canada and the western North Atlantic Ocean. The Newfoundland Weather Centre (NWC) carried out a systematic evaluation of the products for the winter months of 1989-1990. After the evaluation process was completed, a report was to be produced specifying the strengths and weaknesses of the package so that it could be modified and later adapted for operational use.

During July and August of 1989, the package was transmitted twice daily for a period of preliminary evaluation. In late October, a few suggestions for improvement in package format and content were communicated to CMC. After the suggested changes were implemented in November, three NWC staff meteorologists began to verify several components of the package on a systematic and regular basis. The process continued until the end of April 1990. Preliminary results of the evaluation process were summarized and presented at the Third Workshop on Operational Meteorology held in Montreal in May 1990 (Cote *et al.*, 1990).

The Experimental Aviation Package is based on the CMC Regional Finite Element (RFE) model run at 00Z and 12Z daily. Charts comprising the package were transmitted via the regular facsimile circuits. Twenty-four hour forecasts, at 6-hour steps, were provided for each of isobaric pressure fields, wind fields, surface stress (mechanical turbulence), cloud cover, rime icing, freezing level, wind shear, buoyant energy and clear air turbulence. Each panel provided coverage between 40 degrees N and 65 degrees N latitude and 25 degrees W and 80 degrees W longitude.

The results of the evaluation indicated that the Experimental Aviation Package has considerable skill in forecasting a number of meteorological parameters important for flight operations. It was concluded that if these forecasts were available routinely to the aviation forecaster, it is likely that a more accurate forecast product could be produced for terminal and enroute flight operations.

2. VERIFICATION

The evaluation period from November 1989 to April 1990 corresponded to the time of peak occurrence for some of the more hazardous phenomena for low and high-level aircraft operations over eastern Canada and the North Atlantic Ocean. During these winter months most weather systems are strong and well defined, especially as they approach the east coast of Canada and move out to sea. High level clear air turbulence (CAT) is a common occurrence in the winter over these areas as high velocity jet streams develop in the strongly baroclinic atmosphere. Since the controlled airspace traffic corridors between North America and western Europe are affected by these weather systems, hundreds of pilot reports (PIREPS) may be generated each day giving locations and magnitudes of CAT.

At the same time, the tight surface pressure gradients generate strong low level wind fields. Their interaction with local topographical features can produce wind shear and mechanical turbulence which may affect aircraft on approach or departure from airports. Although not as numerous as high altitude PIREPS, a few local PIREPS of wind shear and mechanical turbulence are received each day depending on the synoptic situation existing at the time.

Most flights in Newfoundland and the Maritimes involve short haul routes of only a few hundred kilometres. The aircraft frequently spend a significant amount of time in cloud and may report the occurrence and magnitude of rime icing when it occurs.

Because of the large number of PIREPS available, they could easily form the basis of confirming or negating a forecast for mechanical turbulence, rime icing or CAT. As a result, almost every PIREP received at the NWC between November 1989 and April 1990 was examined and details noted about the location and magnitude of any of the weather elements mentioned in it. These details then were compared with those extracted from the aviation package charts noting differences and similarities between observed and forecast elements. The process was laborious but yielded a large data file from which some basic conclusions were eventually drawn.

The forecasts for cloud heights and extent were verified using representative atmospheric soundings and satellite pictures. Buoyant energy was not evaluated. The wind shear forecast did not warrant much attention as the shear forecast was for the lowest ~ 6000 feet and was considered to be of little value to aviation forecasters.

The results of these evaluation techniques follow.

2.1 Mean Sea Level Pressure, Wind Field and Surface Stress Forecast

A 4-panel chart containing the contoured sea level pressure pattern forecast at 6-hour steps for the following 24 hours was one of the components of the package. Superimposed on each forecast isobaric pattern were surface wind isotachs drawn at intervals of 10 kt and a measure of surface stress (related to wind speed) contoured at increments of 0.25 pascals. Each 6-hour forecast panel was verified.

The isobaric pressure field forecasts were not verified since they followed directly from the RFE model output. The isotach forecasts were verified qualitatively by comparing them with hand drawn isotach analyses produced at the NWC using real winds. It was found that forecasts of wind speed were underestimated by about 5 kt prior to the new RFE model becoming operational on April 1, 1990. After April 1, it appeared that the wind speed forecasts agreed more closely with the reported winds.

The forecast of mechanical turbulence (a result of surface stress) was verified using PIREPS. Figure 1 indicates that about 80 per cent of the low level mechanical turbulence reports were correctly forecast in terms of surface stress values. As Figure 2 indicates, the magnitude of reported mechanical turbulence appeared to correspond to particular levels of surface stress (a function of wind speed forecast by the model). Thus, it was possible to associate a particular category of reported mechanical turbulence with a particular level of surface stress.

There were 145 PIREPS reporting LGT-MDT mechanical turbulence or greater. Of these, 116 had a surface stress contour 0.50 PA or greater. The distribution was as follows:

Table 1: Distribution of Successful Predictions per Category of Mechanical Turbulence

Category	# of Hits Events/ Percent	Range of Predicted Indices for 70% Hits	Average Value
LGT-MDT	39/34%	0.25-1.5	0.69
MDT	50/43%	0.25-1.5	0.90
MDT-SVR	20/17%	0.75-1.5	1.04
SVR	7/ 6%	0.50-1.0	0.82

For all but the extreme category of turbulence, the forecast intensity was slightly higher at T+12 hrs than for T+24 hrs. In cases where turbulence categories did not correspond to the appropriate surface stress forecast values, wind direction (as well as speed) may have played a part. The RFE model utilizes a rather incomplete representation of topography with which wind speed is allowed to interact. However, it was the experience of the meteorologists evaluating the package that wind direction played an important part in initiating local occurrences of mechanical turbulence. This was especially true for aircraft operating from airfields in western Newfoundland where topographical features affect wind from certain directions more than others.

It was felt that the surface stress forecast would be helpful in identifying only general areas of low level mechanical turbulence. The forecast was not site specific and sometimes failed to predict correctly the occurrence and/or magnitude of turbulence. Wind directions were considered to be an important consideration for generating turbulence at sites such as Deer Lake, which is located in a northeast-southwest oriented valley. Furthermore, reporting turbulence is a subjective matter depending on the experience of the aircrew and the size of the aircraft. In any case, a liberal mix of forecaster experience and model output would be essential for a proper diagnosis and forecast of mechanical turbulence.

2.2 Cloud Forecast

The cloud forecast charts depicted the horizontal and vertical extent of synoptic scale broken low and middle cloud areas. Two different shades were used to differentiate the two layers. Sets of two numbers scattered about the depictions represented the forecast bases and tops of the layers in thousands of feet.

Tephigrams representing vertical profiles of temperature and moisture at Sable Island, St. John's, Stephenville, Goose Bay, Keflavik (Iceland), and Narssarssuaq

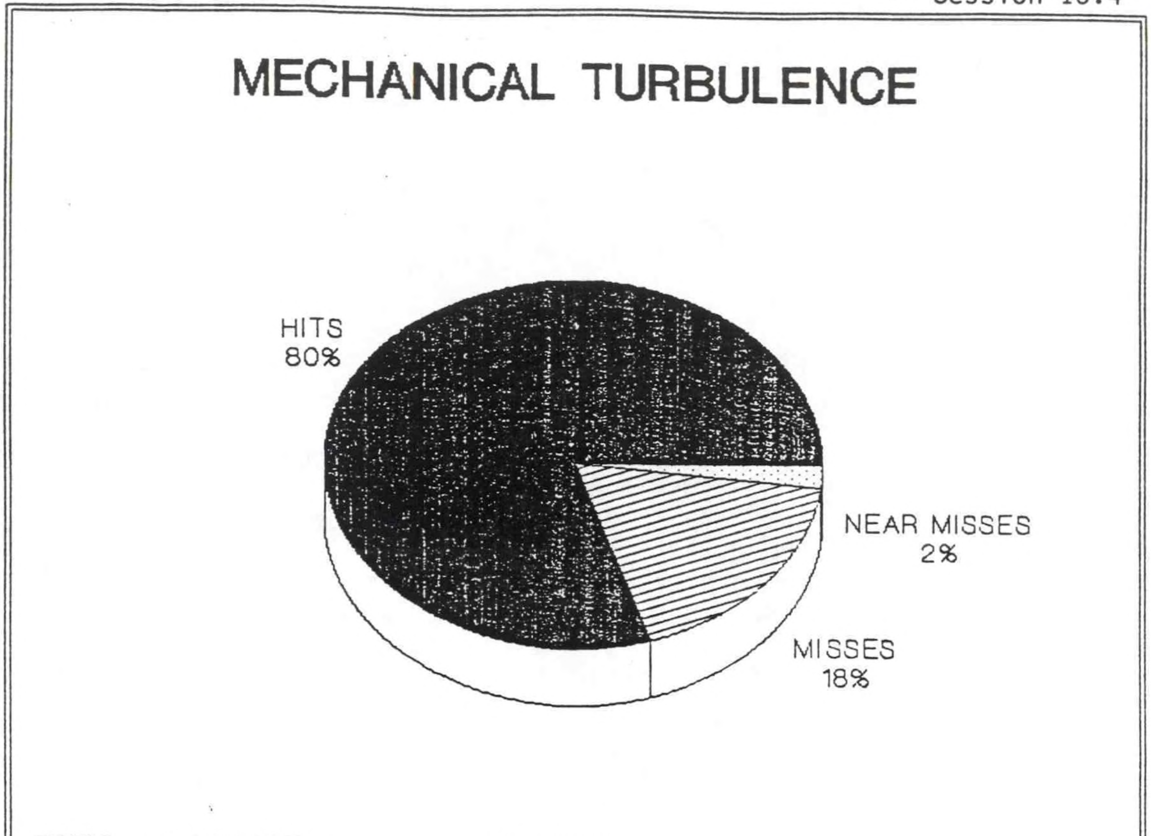


FIGURE 1.

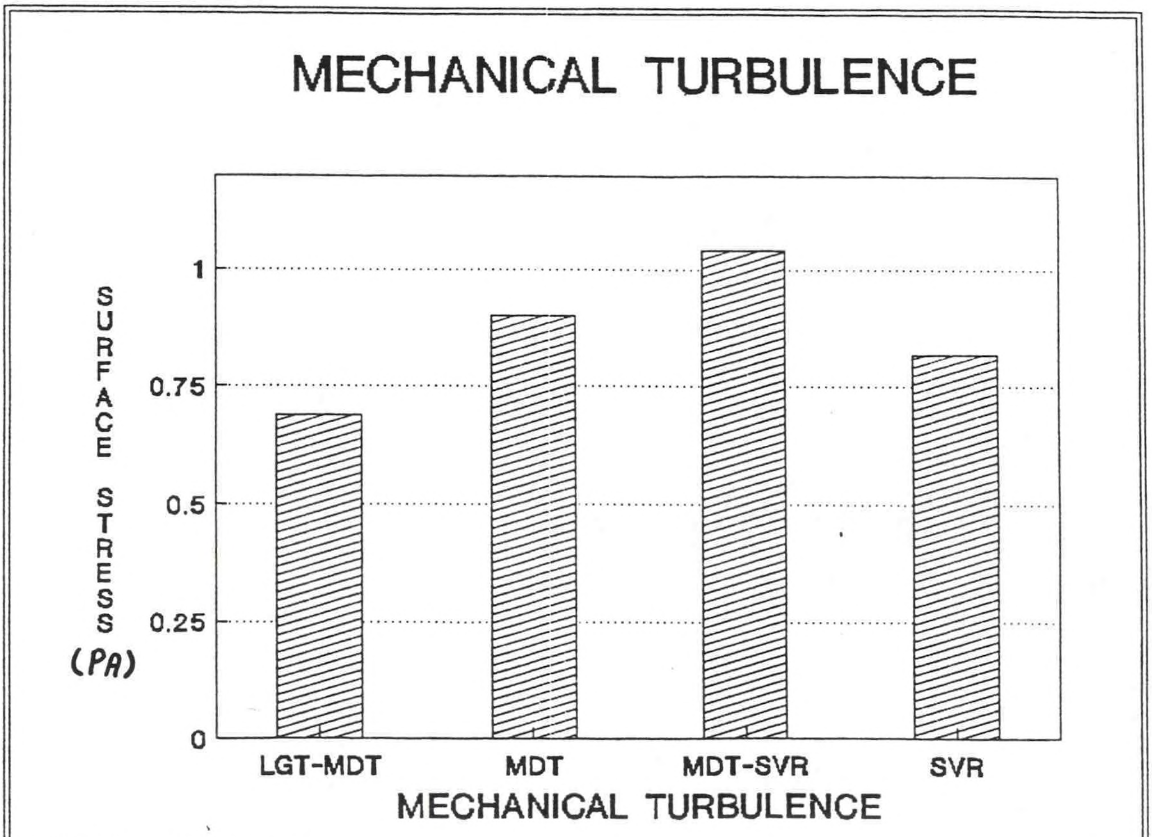


FIGURE 2.

(Greenland), were used to verify the bases and tops of broken layers. Satellite pictures were used to assess, qualitatively, the horizontal extent of the cloud systems. Only cloud forecasts valid for 00Z and 12Z were verified to coincide with the availability of upper air data.

In general, there was good agreement between the forecasts and real time data depicting middle cloud systems. There appeared to be a slight bias to overforecast the tops of mid-cloud layers by including cirrus layers above. The differences were not large. Low cloud forecasts, however, were more wanting. Topographically forced low cloud was almost never forecast, nor was stratiform cloud over water, but low cloud formed during cold air outbreaks across open water was depicted only when water-air thermal contrasts were strong.

The forecasts provided valuable assistance to public forecasters whose main concerns lie in predicting motions of large scale synoptic mid cloud systems and their associated precipitation areas. But as it stands, the forecast charts are of little utility to the aviation forecaster whose concerns lie mainly in predicting cloud bases below 3000 feet. In Newfoundland, for example, success in writing terminal forecasts is achieved by knowing when to forecast onshore stratus or stratocumulus since most of the terminals are located close to the coast. However, the model's greatest utility lies in its ability to adequately forecast synoptic scale cloud systems over the water. This will prove to be especially beneficial to weather centres whose problems involve synoptic systems moving onshore from data-sparse ocean areas.

2.3 Icing and Freezing Level Forecast

Another important component of the Experimental Aviation Package was the rime icing and freezing level forecast. Forecast freezing levels were contoured at intervals of 2500 feet. Categories of forecast rime icing were depicted by shading with scattered pairs of numbers indicating the bottom and tops of the icing layer.

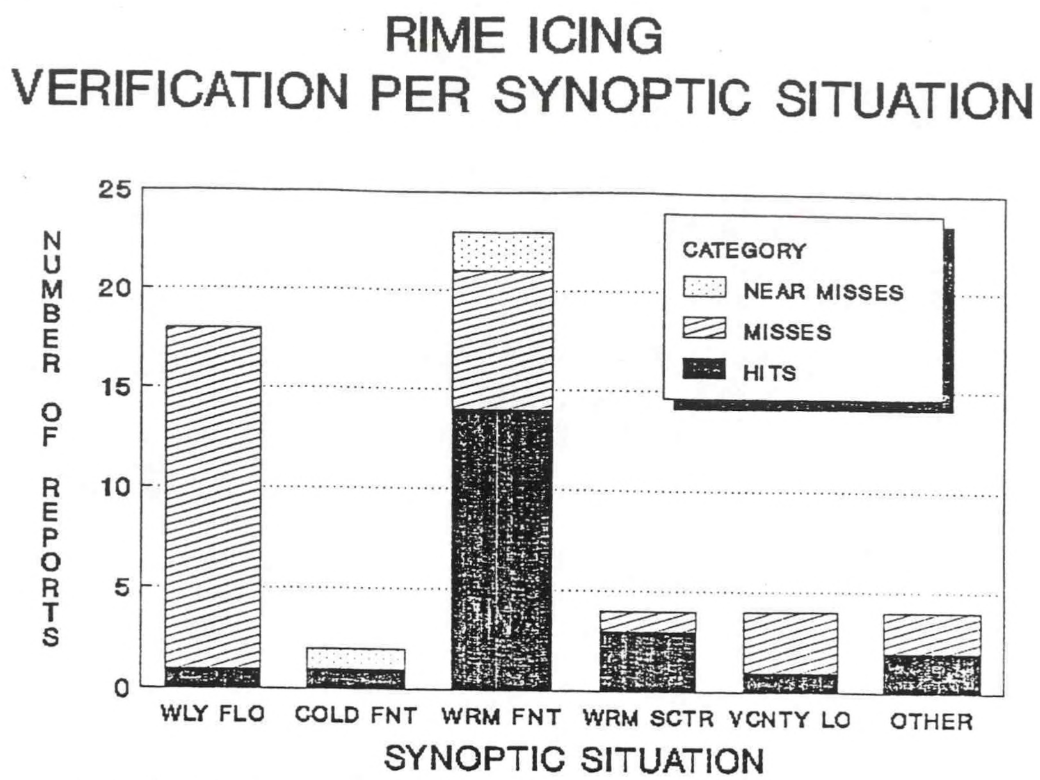
The forecast freezing levels were verified using the same soundings as in the cloud forecast verification scheme. Only cases where no strong thermal gradients existed near the stations were used. This would eliminate interpolation difficulties associated with frontal slopes. From Table 2 it is apparent that the forecast freezing levels lie within about 1000 feet of the observed freezing levels.

Table 2: Freezing Level Verification for Four Upper Air Sites, August 1989 to April 1990

	WSA	YYT	YYR	Ship CHARLIE
Number of Cases	130	101	82	32
Maximum Underforecast	-4200	-3700	-5100	-2000
Maximum Overforecast	5700	2100	4200	1000
Mean Forecast Error	-280	22	93	-103
Std Dev of Fcst Error	1090	900	1213	788

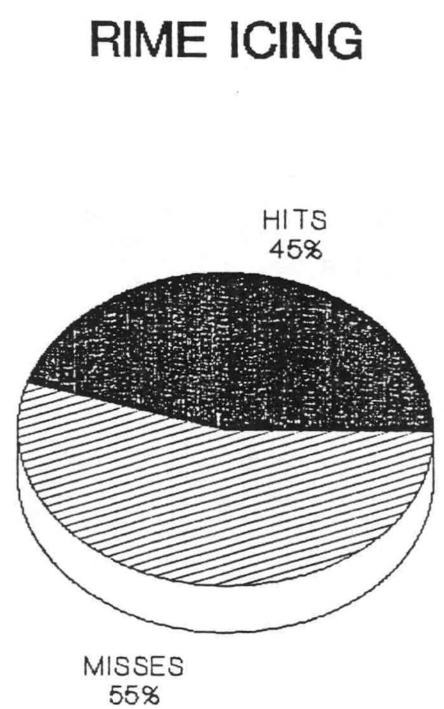
Values are in feet.

Where rime icing was forecast there were frequent PIREPS indicating same. However, success in forecasting rime icing is very dependent on the ability of the model to forecast cloud. There was a high success rate at forecasting rime icing in synoptic scale mid cloud as revealed by Figure 3. But results were poor where low cloud was involved. In the winter month it is low cloud with which rime icing is most frequently associated. Since low cloud



TOTAL: 55 REPORTS

FIGURE 3.



TOTAL: 55 REPORTS

FIGURE 4.

was not resolved adequately by the model, there were many PIREPS of rime icing which were not supported by a positive forecast. Figure 4 indicates only a 45 percent total success rate in identifying areas of reported rime icing regardless of category.

Freezing levels warrant consideration only in the presence of clouds. Hence, it would seem more appropriate to have the freezing levels superimposed on the cloud depictions rather than have the features depicted separately.In this way, there would be an immediate visual impact indicating areas of potential rime icing in cloud.

2.4 Buoyant Energy and Wind Shear Forecast

The ability to forecast wind shear is often critical when, for example, strong low level temperature inversions tend to damp out wind flow near the earth's surface. Shear of 10-20 kt per 1000 feet can be observed under certain conditions. Shears of that magnitude can have significant impact on aircraft during ascent or descent. Therefore, a good forecast for low level wind shear would be very valuable to an aviation forecaster.

The forecast wind shear (kt per 1000 ft) as provided in the Experimental Aviation package represented the average shear anticipated in the lowest ~6000 feet. The model could not resolve the strong shears close to the surface, a knowledge of which is important for low level flight operations. Consequently the forecast shear values were of little interest to the aviation forecaster.

Buoyant energy was not verified as no adequate means to do so were achieved.

2.5 Clear Air Turbulence Forecast

Two indices, Ellrod and Empirical, were used to provide forecasts of clear air turbulence. Two separate charts were produced, one for each index. Both sets of charts featured contoured indices of CAT at the high levels. The Empirical and Ellrod indices were contoured at increments of 10 and 30 respectively. Each index increases as the horizontal and/or vertical shear increases.

Figure 5 shows the number of North Atlantic ocean-crossing flights for 1989. The numbers justify the need for accurate forecast information along these busy corridors. During the same period the NWC issued 267 SIGMETS for CAT over the Northwestern Atlantic as indicated in Figure 6. These SIGMETS represent at least 534 h of forecast CAT in one year assuming that each SIGMET has a life span of 4 h but must be updated every 2 h.

PIREPS of clear air turbulence, mostly over the North Atlantic Ocean, were used to confirm or negate a forecast for same. Both indices had similar success rates in predicting the various categories of CAT. Figure 7 indicates that the Ellrod Index had the higher number of total successes.

Tables 3 and 4 indicate the number of prediction successes for each category of CAT for the Ellrod and Empirical indices, respectively. Obviously, there is no clear winner. Both indices had nearly identical prediction success scores for each category of CAT.

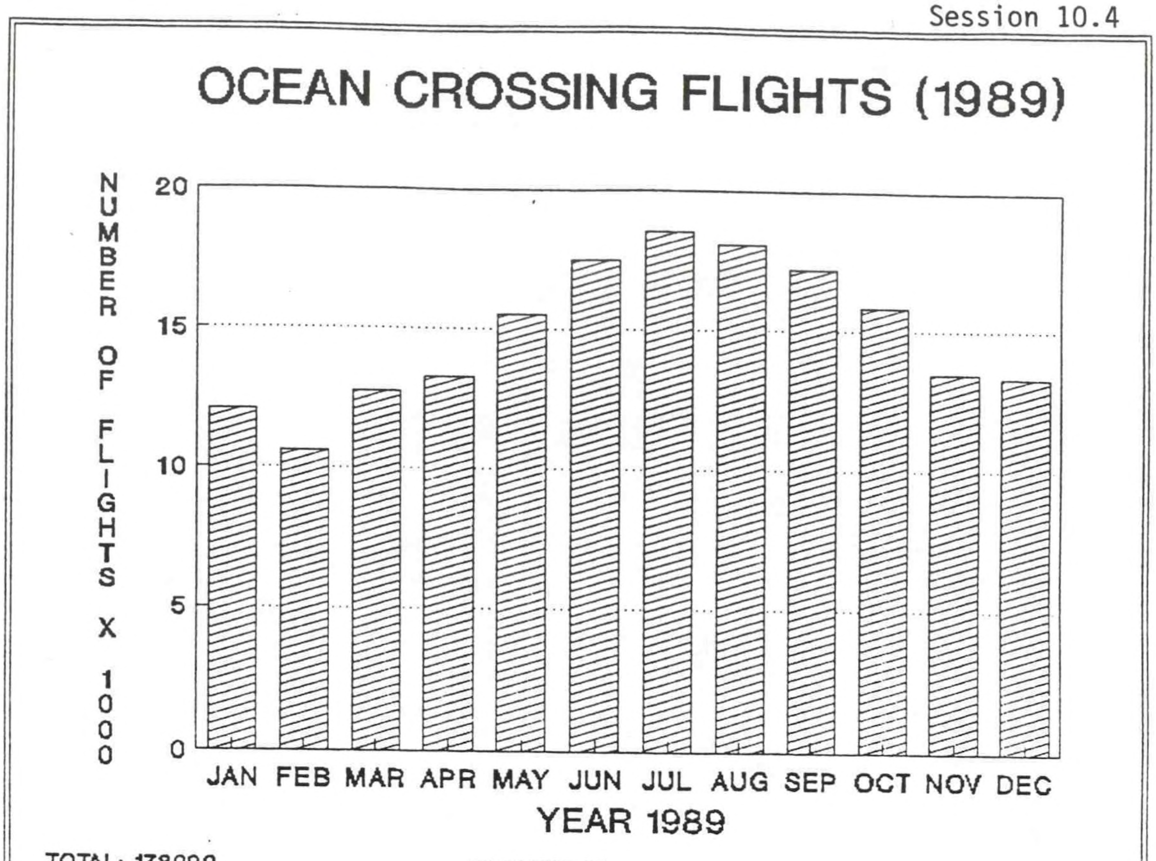


FIGURE 5.

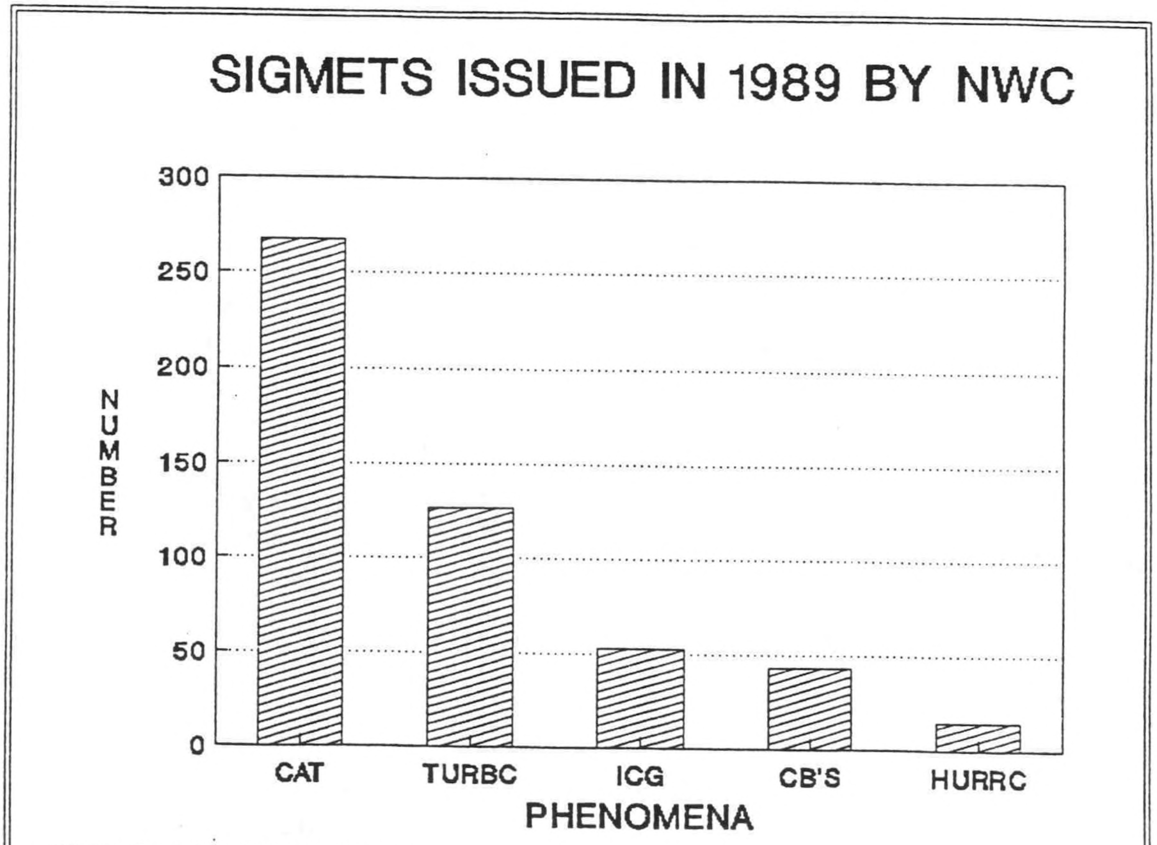


FIGURE 6.

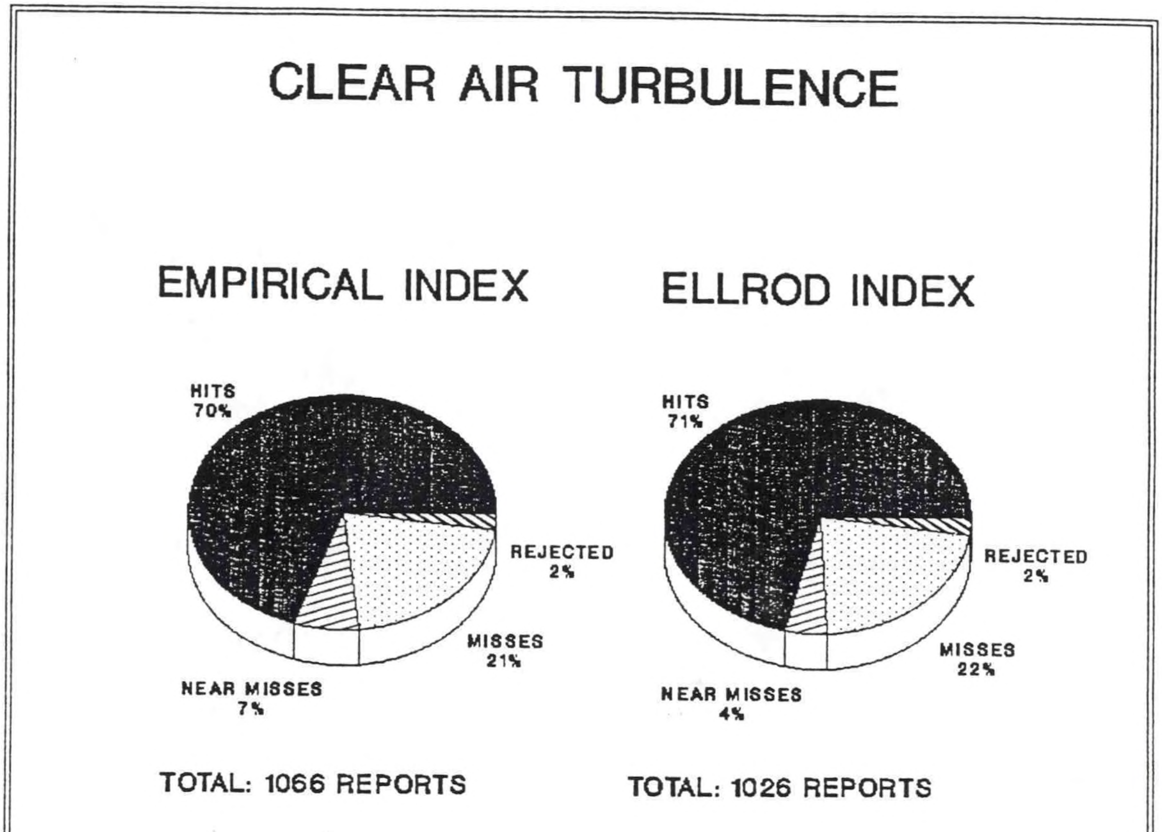

CLEAR AIR TURBULENCE
EMPIRICAL INDEX
HITS
70%
REJECTED
2%
MISSES
21%
NEAR MISSES
7%
TOTAL: 1066 REPORTS
ELLROD INDEX
HITS
71%
REJECTED
2%
MISSES
22%
NEAR MISSES
4%
TOTAL: 1026 REPORTS

FIGURE 7.

Table 3: Distribution of Successful predictions per Category of CAT - Ellrod Index

Category	# of Events/ Percent	Range of Predicted Indices for 70% Hits	Average Predicted Index
LGT-MDT	283/39%	30- 90	55
MDT	334/45%	30- 90	65
MDT-SVR	95/13%	60-210	111
SVR	20/ 3%	90-330	179

Table 4: Distribution of Successful Predictions per Category of CAT - Empirical Index

Category	# of Events/ Percent	Range of Predicted Indices for 70% Hits	Average Predicted Index
LGT-MDT	295/40%	20-40	26
MDT	335/45%	20-40	30
MDT-SVR	100/13%	20-50	39
SVR	16/ 2%	50-80	60

When it came to overpredicting the incidence of CAT, namely, generating false alarms, the Ellrod Index was somewhat more reliable. Figures 8 and 9 show relative performance in terms of false alarm forecasts.

The modified false alarm ratios presented in Figures 8 and 9 were determined using 500 PIREPS with no turbulence selected randomly between November 1989 and March 1990. In the case of the Ellrod Index a threshold value of 55 (from Figure 8) was associated with the category of light-moderate CAT. But the nearest contoured value of CAT on the forecast chart was 60. Therefore, a false alarm event was considered to have occurred every time a PIREP with no reported turbulence came from a location where the forecast Ellrod Index was 60 or greater. The same procedure was followed for the other categories of CAT for both the Ellrod and Empirical Indices.

Many of the major episodes of CAT were associated with upper ridging. Under these conditions, the Ellrod Index performed somewhat better. But both indices tended to predict CAT through too deep a layer. Theory would suggest that CAT associated with upper ridging is limited to a relatively thin layer from just above the tropopause to a couple of thousand feet below it.

Consultations with aviation forecasters, weather briefers, and potential users produced a unanimous agreement for the need of a good forecast for CAT. In addition, the Canadian Pilots Association (Aviation Weather Services meeting, January 1990) indicated that the chart should also include the forecast height of the tropopause to replace the discontinued TVWS chart. But despite the minimal shortcomings of the experimental forecasts, aviation briefers at the NWC considered CAT forecasts to be very valuable when assessing its potential over the Western North Atlantic and elsewhere.

3.0 CONCLUSIONS

The Experimental Aviation Package shows considerable skill in forecasting some aviation-related weather phenomena. Most of the charts in the package were able to provide the necessary additional information if the quality of aviation-related forecast products is to improve. It was felt that, whatever adjustments are necessary to correct some of the forecast shortcomings they be made quickly so that the package can become operational with minimum delay.

Two recommendations are made with regard to changes in format. The first recommendation is that the cloud charts have the freezing levels superimposed. The second is

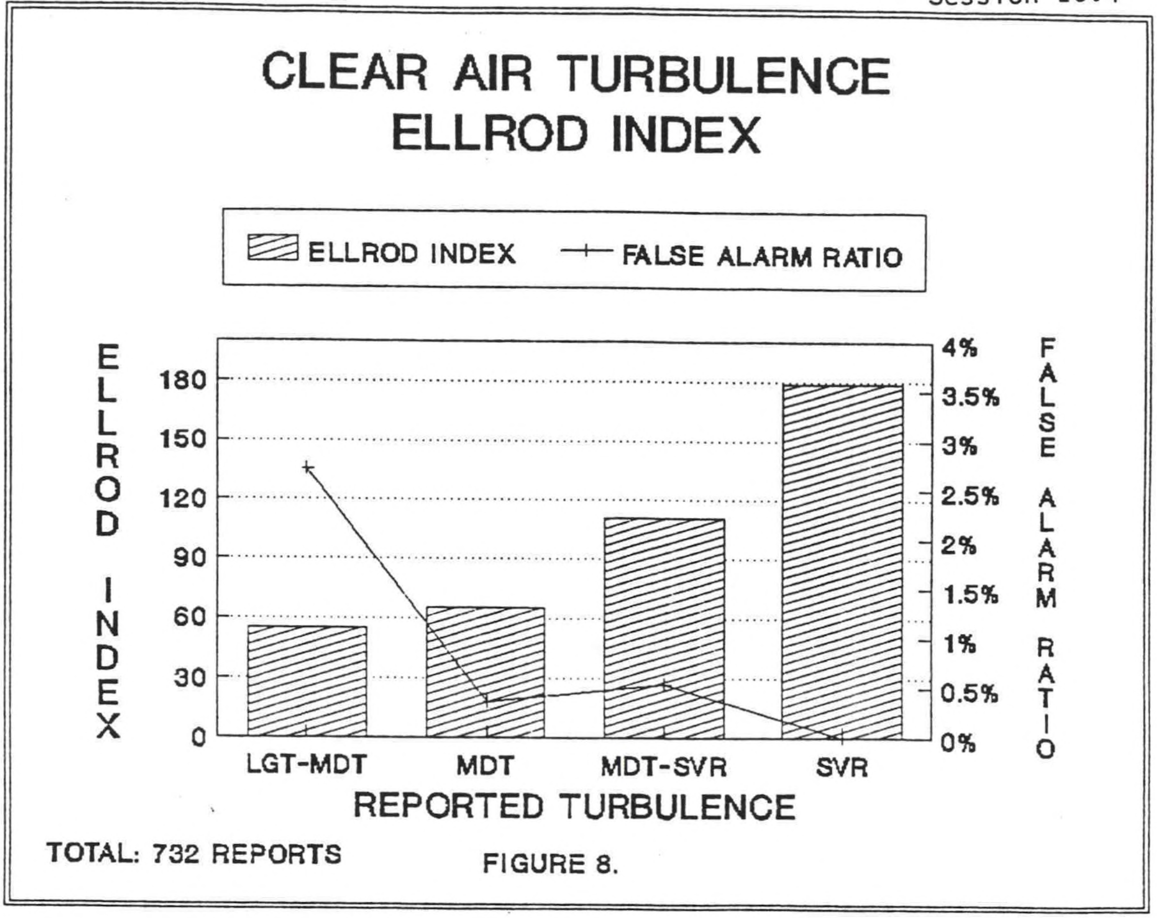


FIGURE 8.

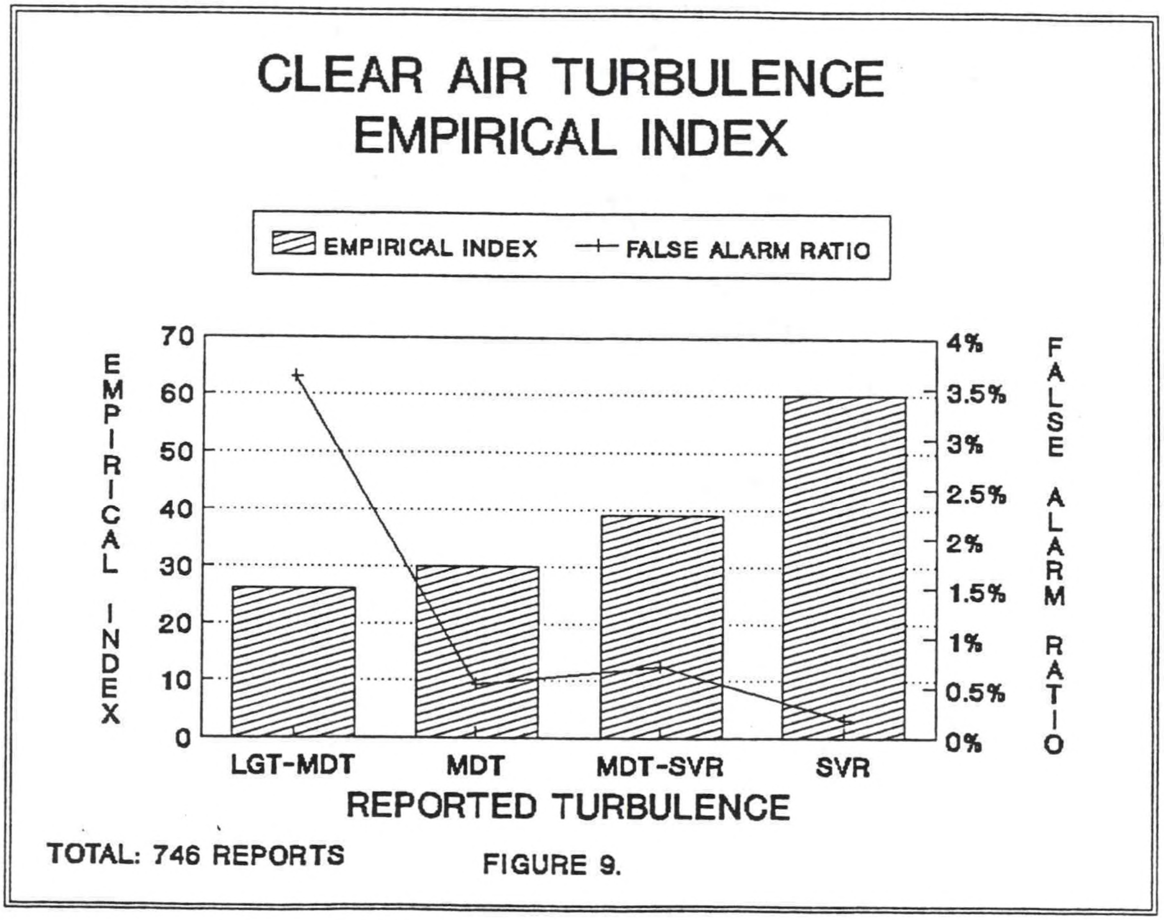


FIGURE 9.

that the tropopause heights be contoured on the Ellrod Index chart.

The NWC verification team realize that not all elements in the package have been verified in depth. But the verification process was conducted in as complete a fashion as was possible given the time and means available.

It was recognized that these forecasts, like all others, can never be perfect because all parameters were developed from the numerical models. However, as the RFE is improved over time, so should the precision of its products. Most of the aviation package products, however, cannot by themselves represent the "final forecast." Forecaster experience is a necessary ingredient in preparing the final forecast. The additional forecast information provided by an operational aviation package will prove most valuable to all concerned.

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Cornwall, Ont., Aviation Weather Services Meeting, January 29-30, 1990.

APPLICATIONS OF GOES SATELLITE DATA IN THE ANALYSIS OF NON-CONVECTIVE AVIATION HAZARDS

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1. INTRODUCTION

Imagery from geostationary satellites can be an invaluable tool in the analysis and short range prediction of aviation weather hazards. Even where dense observational networks are present such as over the United States, knowledge of conditions above the surface is limited, and remote sensing techniques must be used to estimate the extent and severity of weather conditions. This paper will describe some of the ways that satellite imagery can assist in the detection of non-convective aviation weather hazards such as: (1) fog and stratus, (2) icing, (3) clear air turbulence (CAT), and (4) mountain waves.

2. FOG AND STRATUS DETECTION

Fog and stratus clouds result in low ceilings and visiblities that are a significant contributor to weather-related aircraft accidents each year. Fog is easily detected during daylight hours using high resolution (1 km) visible imagery from the GOES (Geostationary Operational Environmental Satellite). However, it is much more important to observe the presence of fog at night, when only low resolution (7 km) infrared (IR) is available. When fog forms in relatively warm conditions, and in coastal or mountainous regions, there is often insufficient thermal contrast for detection of fog in IR images. In such cases, the use of two IR channels has shown to be superior.

The use of multispectral IR imagery in nighttime fog detection relies on the fact that low level stratiform clouds appear colder in the near-IR window channels (3.5-4.0μm wavelength) than in the long-wave window (11μm) due to a difference in the emissivities (Hunt, 1973). The temperature difference is typically small (3-7°C) but detectable. In cloud-free regions, temperatures are similar in both IR channels. When the difference image of the two channels is enhanced, the low clouds stand out very clearly. The presence of thin cirrus clouds will counteract this temperature difference, however, and obscure the presence of fog. This technique was first used in Europe with imagery from the NOAA Advanced Very High Resolution Radiometer (AVHRR) imager (Eyre *et al.*, 1984), and was later adapted for use with GOES data (Ellrod *et al.*, 1989).

Figure 1 shows a case where fog and low ceilings occurred in Missouri and western Illinois on 25 September 1991. GOES imagery was obtained at 0920 UTC, when multispectral IR data was available. The 11μm IR channel (Figure 1a) (routinely received at all weather offices via the GOES-Fax network) revealed a broad, dark grey area from western Illinois to northern Arkansas, suggesting a region of low level moisture. Obscuration of terrain features such as rivers and lakes within this region indicated that fog could be present, but there

FOG IDENTIFICATION WITH GOES INFRARED IMAGERY

25 SEPTEMBER 1991 - 0920 UTC

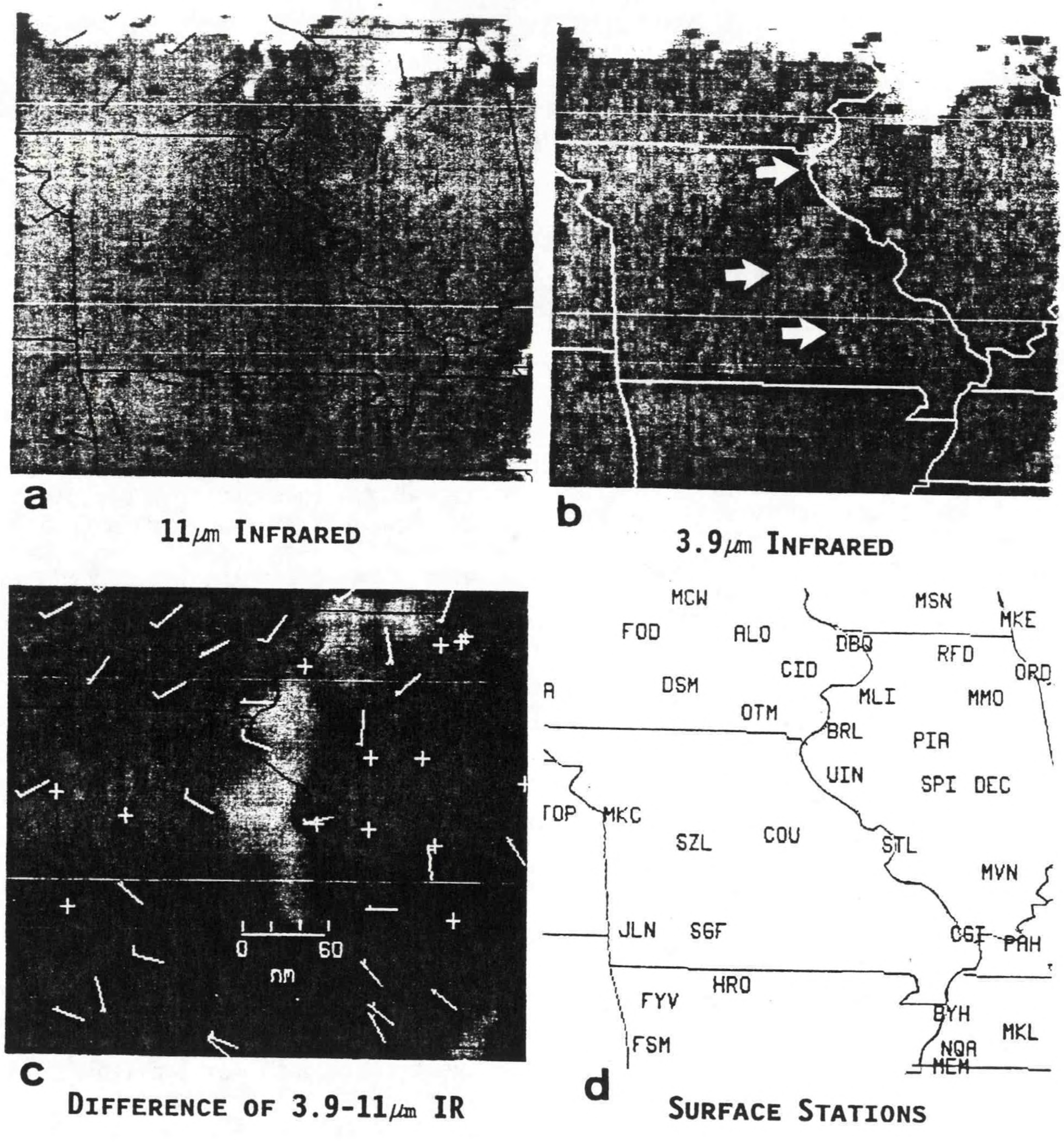

Figure 1. GOES infrared images at 0920 UTC, 25 September 1991 for (a) 11µm wavelength, (b) 3.9µm wavelength and (c) the smoothed, enhanced difference of 11µm and 3.9µm channels. Stations reporting surface weather conditions at 0900 UTC are shown in (d).

was no clearly defined border. The 3.9μm channel image at the same time (Fig. 1b) showed a brighter area with distinct edges (arrows) embedded within the moist region. The lower resolution of this channel is evident from the "blocky" appearance of this image. The enhanced, smoothed difference in the two images (Fig. 1c) clearly marks the suspected fog layer. Significant fog was not reported anywhere in Missouri at 0900 UTC because of the sparse reporting network (Fig. 1d). Light westerly winds advected the low ceilings and visibilities into St. Louis (STL) and Peoria, Illinois (PIA) areas shortly before 1200 UTC. The use of multichannel IR imagery would have been a great help to the aviation forecaster in this situation.

Recently, a technique has been developed to estimate the thickness of fog and stratus from the temperature difference in the 3.9μm and 11μm IR channels (Ellrod, 1991). The depth of fog is useful in estimating the time that clearing will occur. The fog thickness was determined from aircraft cloud top reports within several hours of the image time. A linear regression relationship based on 60 cases showed that for every 1°C change in the temperature difference, the thickness increased by about 100 meters (314 ft). Image enhancements have been developed to show spatial variations in fog depth, after smoothing the imagery to remove the effects of instrument noise. Comparisons of satellite-derived fog depth to aircraft reports for more than two dozen independent cases indicate an average error of less than 100 meters.

3. AIRCRAFT ICING

The occurrence of aircraft icing requires the presence of supercooled water clouds, preferably with large drop sizes and high liquid water contents. At temperatures around -13°C and colder, ice crystals grow rapidly at the expense of the supercooled water (e.g., Byers, 1965), fall out as precipitation, and the potential for icing is diminished. One simple way to use IR satellite imagery in icing analysis is to enhance cloud top temperatures to show the optimum 0°C to -15°C range. This technique is effective for stratiform cloud systems such as cold advection stratocumulus and warm frontal cloud systems that lack extensive cirrus. This enhancement scheme is less reliable when embedded convection is present, since convective clouds often contain supercooled water at temperatures of -30°C or colder. Also, mid-level layered clouds originating in the subtropics can produce extensive icing at relatively cold temperatures.

4. CLEAR AIR TURBULENCE

In the same way that turbulence intensity is now measured subjectively, satellite imagery can provide valuable qualitative information on the presence of non-convective turbulence, also known as clear air turbulence (CAT). Most large outbreaks of CAT are accompanied by various signatures in IR, visible (VIS) or water vapor (WV) imagery (Ellrod, 1989). Water vapor imagery is perhaps the most useful tool in turbulence analysis because it provides information on both cirrus cloud features (albeit at low resolution) and dynamic processes in cloud-free regions, such as sinking and cold advection associated with upper level fronts. Animation of the imagery is preferred because trends can be seen much more clearly.

4.1. Mesoscale signatures

One of the most common CAT signatures is transverse cirrus banding often seen on the anticyclonic side of the subtropical jet stream. These bands are accompanied by moderate or strong vertical shear (at least 5-6 kt/1000ft). The turbulence intensity is typically light to moderate. Cases with severe CAT occur when wide, thick transverse bands are present that sometimes resemble convective cloud plumes. This sometimes occurs in diffluent flow patterns. Inspection of radiosonde temperature profiles near such features frequently reveals nearly dry adiabatic lapse rates just below the tropopause.

Jet cirrus that has sharply curved (in an anticyclonic sense) segments with ragged or scalloped edges may contain moderate or severe CAT. These ripples (or bulges) are believed to be related to mesoscale speed maxima along the jet, referred to as "jet streaks." When the curved portion of the cirrus is relatively short (<500 nm), the likelihood of severe turbulence is greater, provided that upper winds are >75 kt. Sharply curved jet cirrus is often found along the jet in advance of an upper trough when convective systems are present that strengthen the upper winds by latent heat release.

The GOES water vapor image in Figure 2 shows an example of a this type of jet cirrus boundary. Many curved cirrus segments can be seen east of an upper trough from eastern Texas to Missouri at both 0800 and 1600 UTC on 20 November 1991. Note the bright, cold clouds associated with thunderstorms along the leading edge of the cloud system. Moderate to locally extreme turbulence was reported along the edge of this jet cirrus during the day.

4.2. Synoptic scale signatures

Col regions in the upper atmosphere, often called "deformation zones," can be significant CAT-producers. Cloud or moisture edges are often seen in satellite images along the stretching axis of deformation zones (Anderson *et al*., 1982). The same process that stretches and compacts the cloud edge (or moisture boundary) in these regions contributes to upper level frontogenesis, and thus an increase in vertical wind shear necessary for CAT. The intensity of CAT varies with the synoptic situation, becoming especially strong in cases of cyclogenesis with a building upper ridge, the confluence of the polar and subtropical jet streams, or the interaction of a strong jet with a closed upper low.

A useful CAT signature often observed in WV imagery is a progressive darkening with time that is related to enhanced convergence, cold advection and sinking in the middle and upper troposphere. Although not all CAT episodes are accompanied by WV darkening, 80% of all darkening events have moderate or greater turbulence associated with them (Ellrod, 1989). The synoptic situations that seem to be especially conducive to WV darkening are deformation zones with positively-tilted (NE-SW) troughs. An example of such a case is shown in Figure 2, with the accompanying 300mb plot at 1200 UTC, 20 November 1991 in Figure 3. The WV imagery became

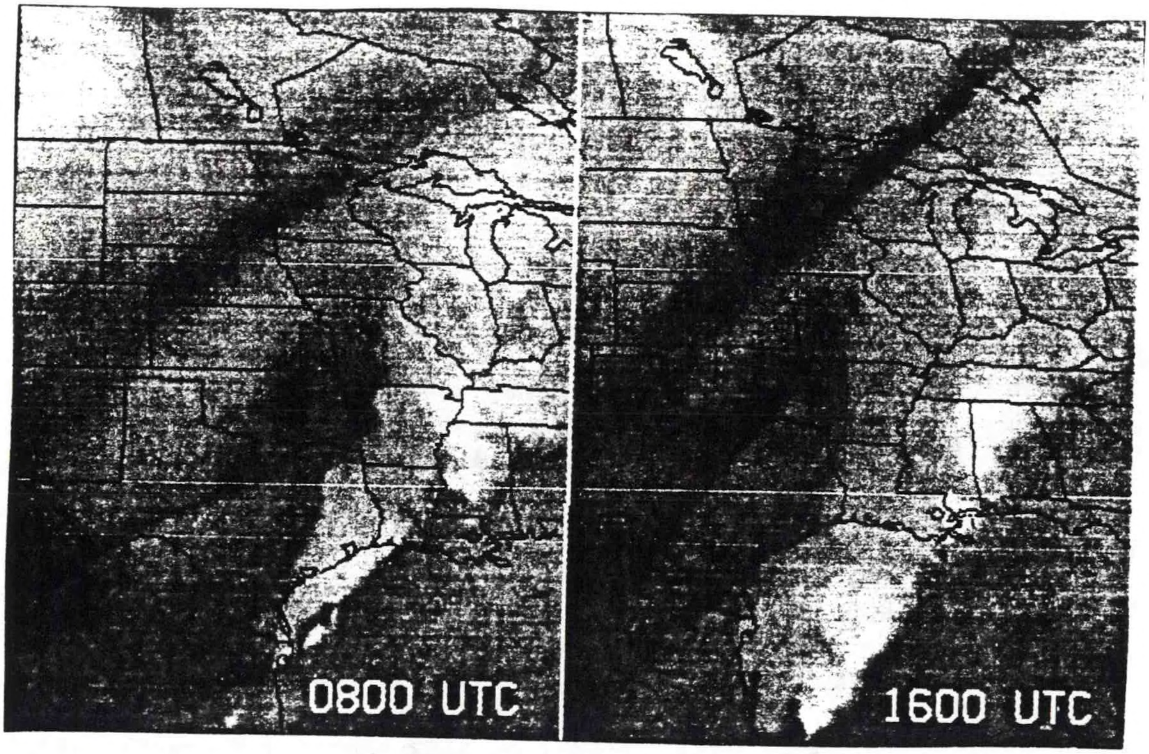

Figure 2. GOES 6.7μm water vapor images at 0800 UTC (left) and 1600 UTC (right) on 20 November, 1991.

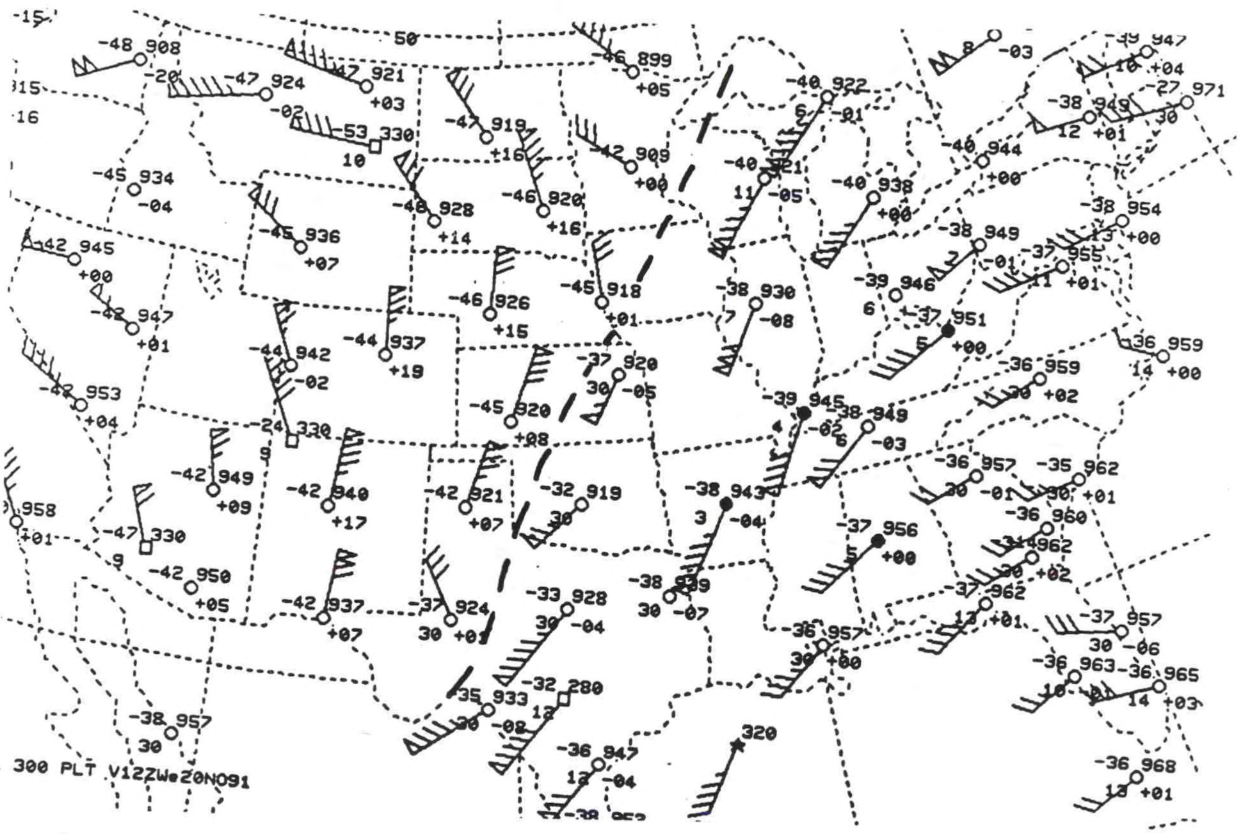

Figure 3. 300mb upper air plot at 1200 UTC, 20 November 1991.

darker from 0800 to 1600 UTC in a band from upper Michigan southwestward to Kansas. This dark band appears to be related to the upper trough axis. The most pronounced darkening was from Iowa northeastward, where the the convergence in the upper winds was strongest. Moderate turbulence was reported with this band. Darkening also occurred in central Texas at the base of the upper trough.

5. HIGH LEVEL MOUNTAIN WAVES

When strong winds cross mountains in stable conditions, the flow is disturbed, often to high altitudes. Thick, cold, orographic cloud plumes can form that become anchored along the mountain ridges and persist for many hours. The majority of these cirrus cloud plumes seem to be non-turbulent, however. In the cases where moderate or greater high level turbulence is reported, a subtle but important characteristic has been noted about the orographic cirrus. In these situations, the upstream edge of the cirrus is displaced slightly downstream from the mountain ridges (Ellrod, 1987). The result is often a gap or trench in the high clouds along the lee slopes. Figure 4 is an example of this feature over northern Montana on 25 January 1990. These cloud-free trenches often occur during strong chinook wind events along the lee slopes of the Rockies from New Mexico to Montana. High amplitude mountain waves have been observed by aircraft during these windstorms (Lilly, 1978). The strongest turbulence occurs just downstream from the clear zone.

6. LOW LEVEL MOUNTAIN WAVES AND WIND SHEAR

If there is an absence of cloudiness over and west of the mountains, the water vapor image will sometimes show a distinct dark (warm) zone along the lee slopes. This suggests that pronounced drying and katabatic warming is occurring due to strong downslope winds. When there is no cirrus present, the occurrence of these dark zones in WV images usually indicates moderate to strong low level winds and possible wind shear. The WV image in Figure 5 shows this type of signature along the east slopes of the Front Range in Colorado on 3 March 1991 near the time a passenger jet crashed while approaching the Colorado Springs airport. Low level wind shear and turbulence were believed to be factors in the disaster. The 1200 UTC radiosonde profile from Denver showed low level westerly winds of 20-30 kt increasing to 50 kt near the mountain top level.

When sufficient low level moisture is present, transverse wave clouds are often seen downwind of mountain ranges. In general, the longer the wavelength of these clouds, the more intense the turbulence encountered, since wavelength is proportional to wind speeds. The observation of these waves in low resolution IR imagery usually indicates the presence of turbulence. Wave cloud patterns are also seen in visible imagery in areas of strong low level wind shear caused by low level jet streams and near frontal boundaries.

7. SUMMARY AND CONCLUSIONS

Satellite imagery has proven to be a valuable supplement to other types of information available to

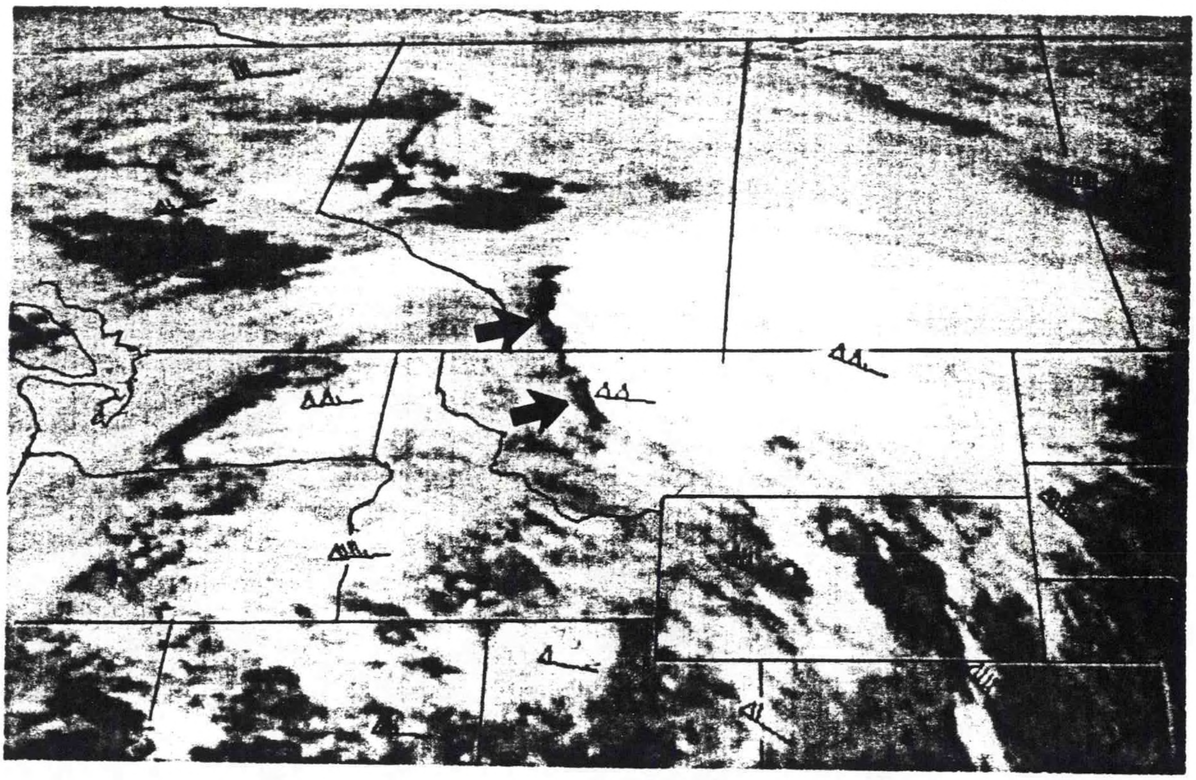

Figure 4. GOES infrared image at 2130 UTC, 25 January 1990 showing a clear zone caused by a mountain wave east of the Rockies in western Montana (arrows). Upper winds are for 300 mb at 0000 UTC, 26 January 1990.

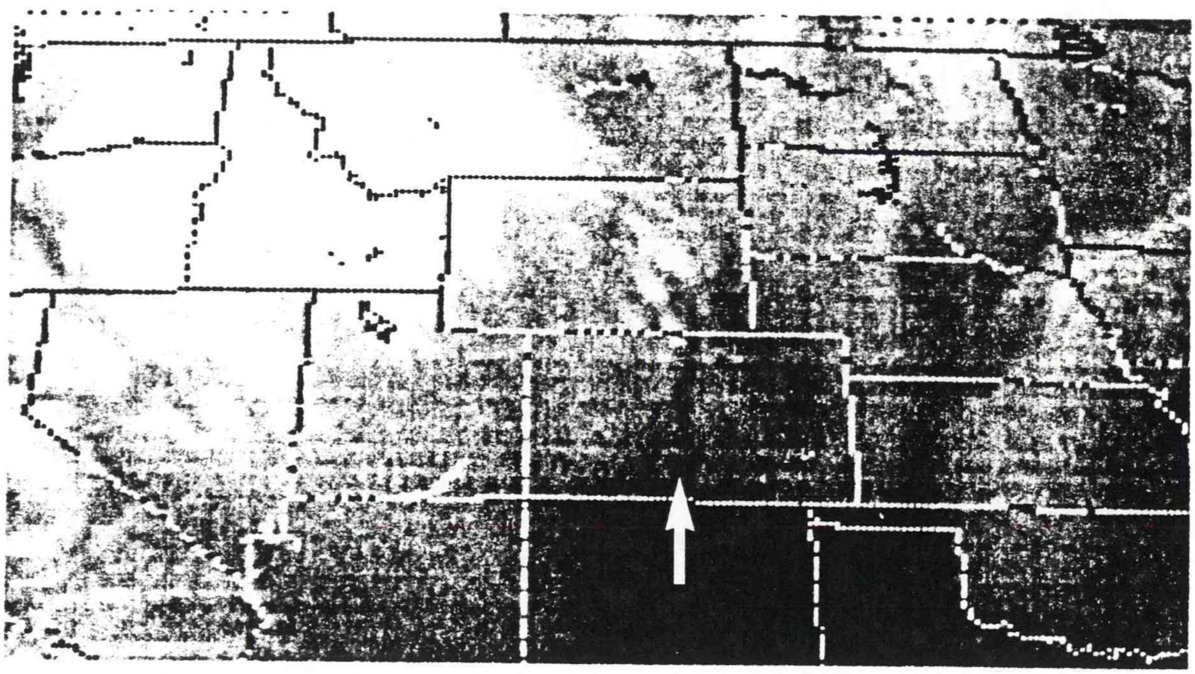

Figure 5. GOES water vapor image at 1600 UTC, 3 March 1991. Arrow refers to a north-south oriented dark band caused by katabatic warming from downslope winds east of the Rockies.

the aviation meteorologist. In remote or data-sparse regions, satellite imagery may be the only information available. The use of multichannel IR imagery appears to have great potential in fog detection at night. Inferences can also be made about the presence of icing, clear air turbulence, mountain waves and in some cases, low level wind shear.

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Session 10.6

FORECASTING FOR AVIATION WEATHER HAZARDS IN THE WESTERN NORTH PACIFIC

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Session 11.1

ADVANCES IN MESO-SCALE MODELING AT NMC

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MANUSCRIPT WAS NOT AVAILABLE AT THE TIME OF PUBLICATION

A MICROCOMPUTER-BASED CLIMATOLOGICAL INFORMATION SYSTEM FOR TERMINAL FORECAST PRODUCTION

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1. INTRODUCTION

Quicklimate permits the operational meteorologist to easily and quickly access over 55,000 graphs and associated data sheets on the climatology of individual airports. This proves especially useful in training new meteorologists or in forecasting for new locations.

2. DISCUSSION

Hourly observations for airports for up to 35 years have been accessed from the Canadian Climate Centre. The Quicklimate program, produced under contract for the Canadian Forces Weather Services, then produces a wide range of statistics. Annual and seasonal overviews and diurnal variations are available for all parameters. Statistics are provided for each month and for three 10-day periods in each month.

Weather elements include:

ceiling
visibility
temperature
wind speed
wind direction
relative humidity
total cloud opacity
rain
drizzle
freezing rain
freezing drizzle
snow
ice pellets
hail/thunderstorms

All calendar periods and weather element combinations may be stratified by time of day or wind direction. Ceiling and visibility can be further stratified by the occurrence of either liquid or solid precipitation.

3. OPERATIONAL UTILIZATION

Especially for the new forecaster, or as a quick reminder for more experienced forecasters as the seasons change, Quicklimate can quickly provide answers to questions like:

* What is the probability of ceiling height with winds from a given direction?
* When will the sea breeze begin?
* What is the probability of ceiling/visibility given rain is expected with winds from the southeast?
* What is the frequency of fog this month? (10-day period)?

4. OUTPUT

Graphs are generated based on the nature of the variable: continuous variables - probability distribution functions (fig. 1) and percentile plots (fig. 2); discrete variables - stacked bar charts (fig. 3); and, duration statistics (fig. 4).

5. INTERPRETATION

In Figure 1 the variability of ceiling height at Gander, NF in January is depicted. It is quickly seen that winds from the west bring higher ceiling heights than average while north and northeast winds are associated with much lower than average ceiling heights. Ceilings are less than 1000 feet approximately 5% of the time with westerly winds as compared to about 60% for northerly and northeasterly winds.

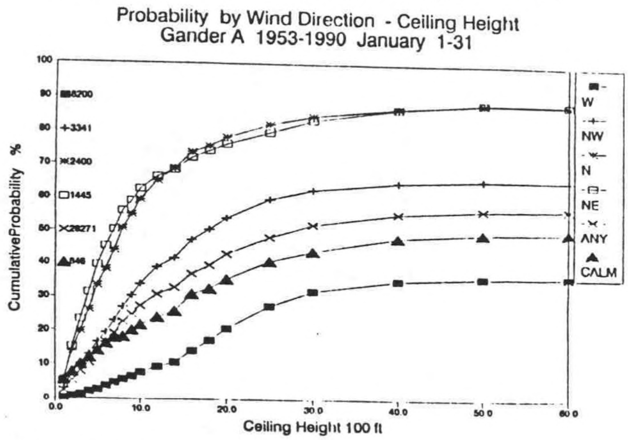

Figure 1

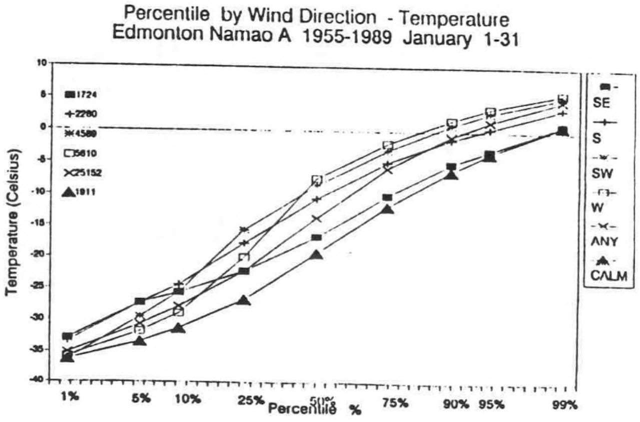

Figure 2

Figure 2 shows the January temperature percentile plot for Edmonton, AB stratified by wind direction. Temperatures are normally distributed (relatively straight lines) with calm, southeast and south winds. There is pronounced curvature, the effect of Chinooks, with southwest and west winds.

Figure 3 shows the relative frequency of winds from different directions by time of day for Trenton, ON in July. The onset of the sea breeze between 15 and 17 UTC is clearly evident as is the predominance of calm conditions at night.

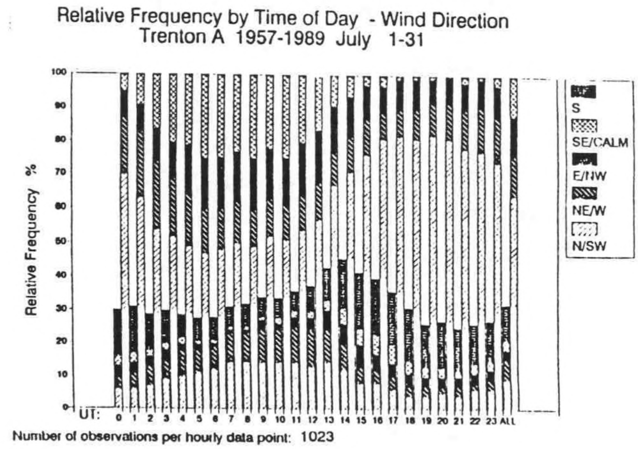

Figure 3

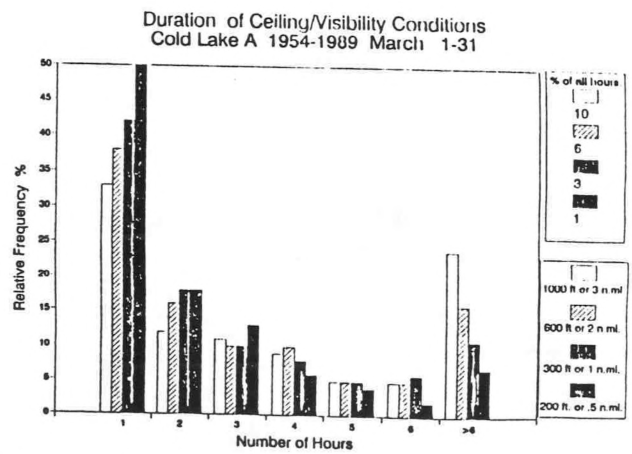

Figure 4

In Figure 4 duration of operationally significant ceiling/ visibility categories are indicated for Cold Lake, AB in March. Information of the percentage occurrence of each of the categories is also shown. Conditions less than 1000 feet/3 miles last greater than 6 hours almost one sequence in four whereas conditions below 300 feet/1 mile last beyond 6 hours on about one sequence in 10.

6. EQUIPMENT REQUIREMENTS

Quicklimate runs on any microcomputer with an MS-DOS 3.2 or higher operating system. A hard disk is required to store the main program (200 K) and the data files for each airport of interest (1300 K per station). Colour graphs are produced on EGA or VGA monitors and can easily be printed.

7. FUTURE DEVELOPMENT

Since forecaster/briefer workstations at both military and civilian weather offices in Canada are UNIX-based, work is currently underway to adapt Quicklimate to operate in X-windows. This will permit quicker, easier access to climatological information to assist in the development of terminal forecasts.

Many desired enhancements have been identified with this first release of the program. These will be addressed over the next year and will, among other things, provide more display options and increase the definition of ceiling/ visibility in the lower categories.

Session 11.3

STRATUS: A PROTOTYPE EXPERT SYSTEM FOR LOW CLOUD FORECASTING

Denis Jacob[1], Michel C. Desmarais and Frances de Verteuil[2], Peter Zwack[3]

1. Introduction

Stratus is a 26-month project aimed at developing a prototype expert advisory system, based on physical principles, to assist the meteorologist in the production of airport terminal weather forecasts. This million dollar project began in July 1989. The multi-disciplinary team is made up of personnel from the private, university and government sectors. OASIS, the feasibility expert system prototype, developed by CRIM and Météoglobe Canada Inc. during a 5-month joint project was used as a starting point [4].

2. Overview of the Forecasting Process

The complexity of the weather forecasting process is well known. It involves numerous data sources which consist not only of quantitative and qualitative observations, such as temperature and cloud type, but also include a large number of analyses, forecasts from numerical models and climatological information. To this data, the meteorologist is expected to apply complex physical laws and empirically derived rules to produce a forecast. Because of time constraints and the complexity of the physical processes, the forecaster rarely uses analytical reasoning. Instead they use the same approach as do experts in other fields working with similar constraints, namely, Recognition Primed Decision, [2],[3]. The experienced forecaster, using a personal choice of parameters among those available, rapidly categorizes or prototypes the meteorological situation according to his experience and generates future weather events that correspond to this prototype. Expert systems based on such empirical and pattern matching techniques replicate the ability of a particular meteorologist for a specific location. Such systems link specific conditions to specific conclusions without requiring a clear chain of causal links.

3. Objectives

The long term objective of STRATUS is to develop an operational model of the fundamental physical rules that govern the existence and evolution of clouds. Because of its universal nature, this model is, in

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principle, easily adaptable to new location. The development philosophy behind STRATUS is to try at first to model the physical phenomena mathematically and, when this is not feasible, qualitative modelling is used. The integration of qualitative modelling with quantitative modelling and the integration of different sources of meteorological data constitute the two major theoretical problems for the project.

The problem of forecasting low clouds can be broken down into two totally independent processes. The first simulates the time evolution of atmospheric parameters which are relevant to low cloud formation. The second is the analysis of these parameters, at a specific time, to determine the low cloud coverage. STRATUS addresses these two aspects of meteorological forecasting. The relationship between the evolution and diagnostic processes is shown in Figure 1. In this paper, the emphasis will be on the design and testing of the diagnostic module and the X-Window visualization tools that were developed to assist the operational meteorologist in his validation efforts. The preliminary results of the forecasting module will be presented as well.

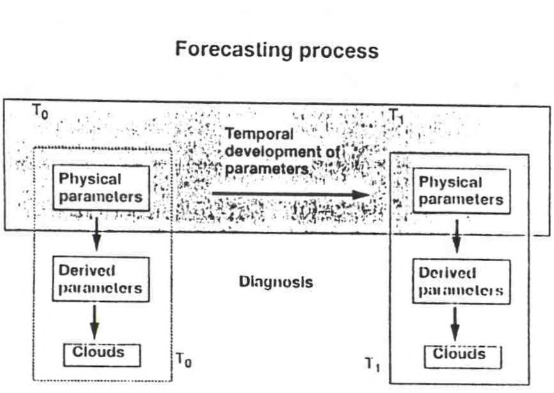

Figure 1. The diagnosis and evolution of physical parameters

4. The Diagnostic Module

The following methodology was used to develop the qualitative physical model for the diagnostic module. The physical conditions/ scenarios and relevant parameters which lead to the formation of low clouds were identified. The rules and algorithms that define the relationship between the parameters and the formation of low clouds were then established. It must be noted that a considerable amount of work had been done on the qualitative physical model for low clouds prior to the start of the STRATUS project[4]. Figure 2 shows the architecture of the diagnostic module.

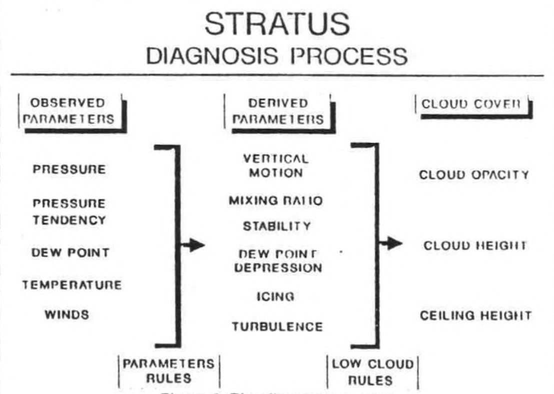

Figure 2. The diagnostic module

The diagnosis of low clouds involves two sets of parameters. The first set is directly observable. The second set, the "derived parameters", is obtained from the observable parameters by using a set of rules/algorithms, the "parameters rules". The "derived parameters" constitute the relevant physical variables involved in the diagnosis of low clouds. These are the parameters which an atmospheric physicist would use to explain the formation and dissipation of low clouds. To determine cloud cover, the diagnostic process shown in Figure 2 is applied to the values of each parameter at a number of altitudes, depending on the resolution required for the diagnosis. Specifically, this involves obtaining the five observable parameters from the appropriate data sources, then applying the "parameters rules" followed by the low cloud rules to obtain the cloud opacity at a particular altitude. This process yields a sequence of cloud opacities from which we derive a total cloud cover, a ceiling and a ceiling height. Those metrics are then used in the validation process to compare the diagnostic module with actual observations.

The design philosophy followed in the development of the diagnostic module has been to simplify the physical rules of low clouds with the understanding that as progress was made the rules and the relationships would be modified, refined and expanded.

5. Architecture of STRATUS

The first prototype was implemented in Knowledge Craft, an expert system shell, on a TI Explorer. Preliminary testing showed that a relatively sophisticated database management utility which provides fast access to the data was essential. Besides being extensively used in the expert system module, the data is also required for diagnostic and analytical tools that the meteorologist would need for evaluating the system. Consequently, it was decided to change the development environment to UNIX and implement an efficient database utility in C. 'X' was chosen as the windowing standard for the interface and graphical tools. The architecture for the fifth prototype is shown in Figure 3.

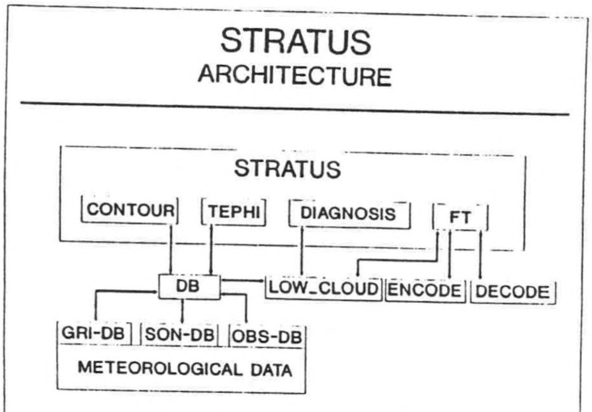

Figure 3. Architecture of STRATUS

The database is composed of a controlling module and three submodules, one for each data source. The data sources for STRATUS are numerical model output (RFE, the Canadian Regional Finite Element Model), ground observations and vertical soundings. Each physical parameter can be indexed in four dimensions: time, height, latitude and longitude. It now takes only 10 seconds to load a day's worth of data and 10 milliseconds to access a particular record. On average, the database manager handles 10 MB of data per day. It is this fast and flexible access to the different data sources that has enabled us to validate the system statistically with a large number of cases. The database utility is written in C, while the diagnostic module is implemented in PROLOG. Several standalone analytical tools have been developed like an interactive tephigram and most of them have been integrated into a user-interface described hereafter.

6. Tools

In order to generate an expert score, the expert would have to evaluate a large number of cases. These evaluations involve examining, modifying and calculating parameters from the vertical soundings of temperature and humidity on tephigrams and from horizontal contours of both observations and numerical model forecasts. Using available tools, the expert was only able to complete one or two cases per day. Clearly special tools were needed to accelerate the process in order to have a data set large enough for statistical evaluation. Therefore, an interactive tephigram and a contouring program were developed.

The interactive graphical tephigram (Figure 4) displays profiles of either observed or numerical model forecast temperatures and dew points, allows for zooming, and can be modified using the mouse. A new set of parameters can be calculated automatically from the modified sounding. Also included in the tephigram tool is a hodograph (Figure 4) that displays the wind profiles. With the interactive tephigram, the expert is able to analyze 25 cases per day.

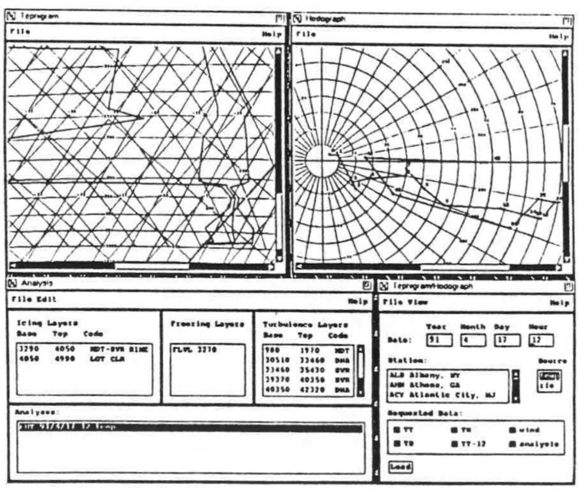

Figure 4. The tephigram tool

The contouring program (Figure 5) displays surface observations, analyses of either observations or numerical model forecasts. The former are analyzed objectively using a Barnes objective analysis scheme[1]. From the menu, the user can choose the date, time, variable and contour interval. Presently over 20 numerical model output variables (e.g.,- pressure, temperature, vertical motion and dew point depression) are available at 3 hour intervals in either pressure or sigma coordinates. The module automatically interpolates numerical model output from sigma coordinates to the desired level. Also it allows for zooming, overlaying and animation. Included in the contour device is a program that estimates lower tropospheric vertical motion from the objective analyses of a series of pressure observations using the method suggested by Zwack and Kabil[5]. This vertical motion, not yet used in STRATUS, is now undergoing further development and evaluation.

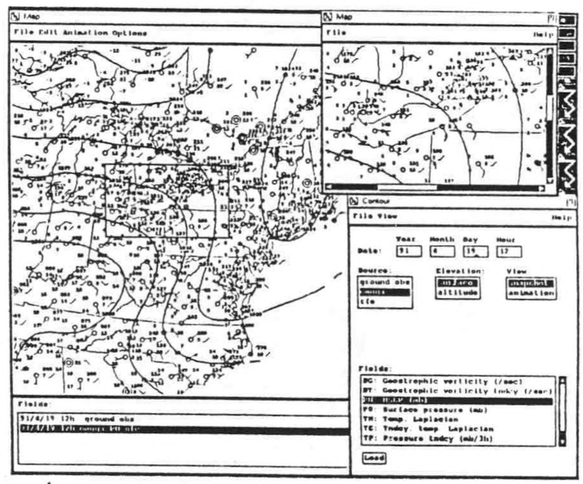

Figure 5. The contouring program

Two other display panels complete the graphical tools. These panels show all the parameters used and the results obtained by the diagnostic and forecasting processes. They help the expert meteorologist in the evaluation of the strengths and weaknesses of the diagnostic and forecast modules. Underlying the forecast module are an FT encoder to write the forecast and an FT decoder to check for mistakes.

7. General Performance Evaluation

In order to validate the diagnostic module, evaluation criteria had to be established. This is a very important procedure as it sets the performance expectation levels. For the second prototype, the metrics were chosen to facilitate comparison with actual observations. The metrics are the detection of ceiling, height of the ceiling and total cloud cover below 6,500 feet. Climatology which is based on historical statistics, has a success rate of about 55% for ceiling detection. This figure provides a baseline for the evaluation of our system's performance. For an upper bound, we expect the system to be able to perform at the level of an expert given the same input data.

To accurately assess the performance of the diagnostic module, the most reliable data sources for the five input parameters were used, namely, vertical soundings and ground observations (SA) at 0Z and 12Z. The output of the diagnostic module is then compared with the ground observation at the corresponding station and time. The test data set consists of 789 cases spread over 23 stations for 27 days in May 1990. The stations are within a 2,500 km grid centered near Albany.

The results for the second prototype (V2.4) indicated a 79% success rate (Phi of .51) for ceiling detection, a correlation of .42 for the ceiling height and a correlation of .69 for the cloud cover. Our expert examined by hand the cases where the diagnostic module performed badly. He was quickly able to identify several shortcomings in the second prototype. After these corrections were addressed, the success rate in the third prototype (V3.7) became 87% (Phi=.71) with a ceiling height correlation of .50 and a cloud cover correlation of.74. Other shortcomings, these mainly related to below zero conditions, have been corrected and allow for a more stable diagnostic throughout the year. The success rate of our last prototype (V5.4) is now 88% (Phi=.72) with a correlation of .61 for the ceiling height and .78 for the cloud cover, the most improved being the ceiling height score.

For 119 different cases during the month of June 1990, clearly not a big enough sample to draw definitive conclusions, we compared the performance of the fifth prototype to our expert. The success rate for the ceiling detection was 87% (Phi=.64) for the expert and 78% (Phi=.54) for STRATUS while the ceiling height correlation was .79 for the expert and .67 for STRATUS and the cloud cover correlation was .68 for the expert and .63 for STRATUS. Figure 6 shows these results.

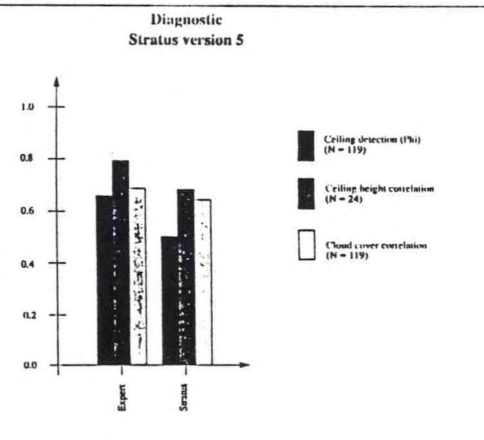

Figure 6. Expert vs. Stratus performance

The preliminary results of the forecasting module of the fifth prototype were obtained with forecast parameters coming entirely from the canadian RFE numerical model (see [6]). These results lead us to the integration of a technique frequently used by meteorologists for short range forecasting, namely persistence, aimed mainly at the first six hours. We also tested the integration of the cloud data coming directly from the numerical model. The integration scheme adopted is as follow: a weight of 1 is given to persistence at time zero and it decreases to 0 at time 12h with the remaining weight being split equally between the diagnosis of RFE and the cloud data of RFE (NB). Also, as it was done for the diagnosis, the cloud forecast has been compared to professional meteorologists' forecasts. Figure 7 shows the results for the cloud cover correlation. The integration curve (pers + NB + diag) shows good potential as a forecasting tool for cloud cover. On the other hand, for the ceiling height correlation shown in Figure 8, only persistence gives interesting results and that only for the first 4 hours. This last sample is too small to draw conclusions, but preliminary results on a bigger set shows a more stable score with time for the diagnostic of the RFE. Nevertheless the score remains below .4 and a more refined technique will have to be implemented to improve the ceiling height forecast.

8. Sensitivity Analysis

During the qualitative modelling of some of the physical phenomena, experts make a number of approximations. For instance, they attribute weights to different parameters involved in a relation according to their empirical or theoretical experience. It is crucial to give experts some feedback on the accuracy of their guesses. The more detailed the feedback is, the more the model can be improved.

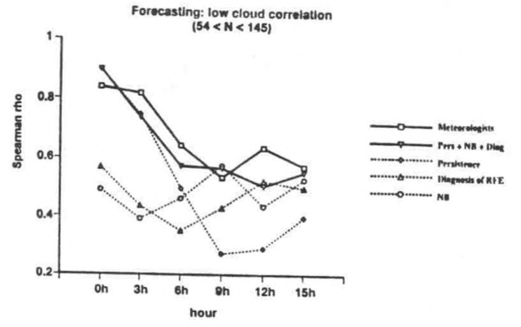

Figure 7. STRATUS forecasts vs. meteorologists' forecasts

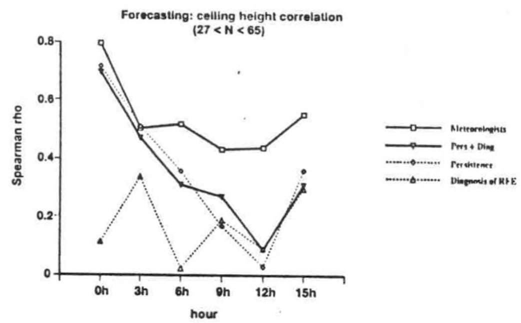

Figure 8. STRATUS forecasts vs. meteorologists' forecasts

One technique, known as sensitivity analysis, provides such a feedback. The basic principle is to make one of the parameters involved in the model ineffective by randomizing its values. The performance degradation of the whole model is indicative of the parameter's weight. If the performance fails to degrade, the parameter is ineffective. This can be due to a number of reasons. For example, the data that were used in the derivation of the parameter are too noisy, or the parameter is incorrectly implemented in the model, or the model is simply wrong. However, if the performance of the model degrades totally, it means the model is highly dependent on that parameter.

We have conducted a sensitivity analysis of the six derived parameters identified in Figure 2, to analyze the effect of each on the diagnostic process. The randomization is done by repeating the performance analysis with the original data, except that the data for a single parameter is reassigned randomly to a different station at a different date and time. We do not randomize by altitude because this would, in effect, change the actual distributions of the parameters and invalidate the sensitivity analysis. The results are shown in Figure 9. The decrease in performance is represented by the difference between the STRATUS prototype (V5.4) performance in the first column and the performance for each one of the parameter randomized as shown by the next six columns.

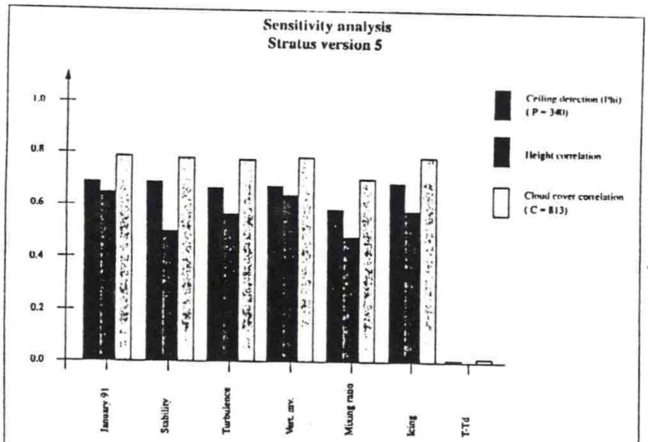

Figure 9. Sensitivity analysis for January 1991

The same work was done with the third prototype and the results were a surprise to everyone. There was virtually no performance decrease for the turbulence and stability parameters. This indicated to us that one of the reasons cited above applied and a revision of the diagnostic module lead to the fifth prototype which gives a small but significant degradation of the scores, specially those of the ceiling height correlation. For the latter prototype, only the vertical motion scores remain almost unchanged and is now under investigation. However, the contribution of the dew point depression is overwhelming compared to the other parameters. These results indicate that the model is highly sensitive to dew point depression and that the bulk of the effort in the forecasting process should probably be spent arriving at good estimates for the temperature and dew point temperature.

9. Summary

A diagnostic process for predicting low clouds has been developed and tested. This process is location independent as the qualitative model is structured on the fundamental physical rules that govern the existence of clouds. The database management utility allows for fast access to the data and for statistical validation. The tools developed concurrently display many of the data needed by the meteorologist to evaluate the weather conditions and then validate the diagnosis and the forecast given by STRATUS. Finally the performance of the diagnostic module and the preliminary results of the forecasting module suggest that STRATUS could become a valuable forecasting tool to the aviation forecaster.

10. Acknowledgements

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WHAT IS A NEURAL NETWORK?
(And How Can They Be Useful to Weather Forecasters?)

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1. INTRODUCTION

Artificial intelligence (AI) is a scary phrase to many humans. It evokes feelings of inferiority and a fear that computers will take over society. These feelings were explored in the movie 2001-A Space Odyssey. Fear sometimes comes from ignorance, and most people just do not know much about artificial intelligence. This article's goal is to explain a new AI tool called a neural network. There has been little research done with neural networks in meteorology, yet they have the potential to solve problems heretofore methods have been unable to solve.

In meteorology, we recognize that enhancing the strengths of both machines and humans results in improved weather forecasts. Each new generation of computers has allowed better modelling of the atmosphere. Much of the emphasis on improved forecasts has been placed on the machine.

Enhancing the meteorologist means improving his/her pattern recognition ability. Much of the research in pattern recognition is in presenting case studies. These case studies arise when one meteorologist recognizes a pattern and shares it with others. However, the patterns associated with a particular weather phenomenon are not always easy to see.

I remember a midnight shift on 11 April 1979 (the day after the famous Wichita Falls tornado outbreak) during which I had remarked to other forecasters how similar the forecasted 500 mb pattern for the upcoming evening was to the 500 mb pattern for the Jumbo Tornado Outbreak of 3-4 April 1974. The report for that previous outbreak was lying on the forecast desk that morning. While there were many severe thunderstorms subsequently that day, activity nowhere approached that of the Jumbo Outbreak. Obviously there were significant differences in the patterns that I did not recognize.

There are many problems outside of meteorology that humans have difficulty seeing the pattern because of subtleties in what they perceive or the shear complexity of the problem. Artificial intelligence is becoming a helpful tool in solving those problems. The goals of any AI technique are twofold. First is to help gain knowledge of potential solutions to problems so that humans can recognize them better. The second is to help bring less knowledgeable people to skill levels of those with greater knowledge.

Two successful AI techniques are expert systems and neural networks. Expert systems are just like the name implies. A knowledge engineer tries to extract the knowledge from one or more experts who know how to solve the problem in question. Many times the knowledge engineer and expert are the same person.

Decision trees which are popular in many weather offices are simple expert systems.

Neural networks, on the other hand, do not require any prior knowledge of a solution. As you will see, a neural network "learns" what it needs to know about a particular problem. It is very similar to a grade-schooler learning the alphabet. Once a student learns the letter "A", the letter can take on various looks (lower case, cursive, etc.) and it will still be the letter "A". Neural networks have solved many problems in pattern recognition. Some examples are speech recognition, speech synthesis, vision and image processing, robotics and autonomous vehicles, game playing, financial forecasting, and gambling analysis (Stanley, 1988).

2. NEURAL NETWORK PRIMER

Neural networks are constructed much like that of a human brain. In the brain there are 100 billion nerve cells (neurons) each connected to maybe thousands of other cells (Figure 1). A stimulus of some kind (example: listening to a piano) starts the process of a series of neurons firing from the ear to the brain. The first neuron receives the input then decides whether to fire or not to fire. If it does not fire, the signal ends there. But if it does fire, it sends the signal down its axon to other neurons. Each connection at the synaptic junction has chemicals that enhance or inhibit the signal. The next neuron then sums the input from the previous neuron and all others to which it is connected. Then it decides to fire or not depending on this sum. The process continues until the brain recognizes the stimulus. Deciding a response is part of this process. After receiving the same stimulus often, the brain will respond in a predictable way. This is called learning.

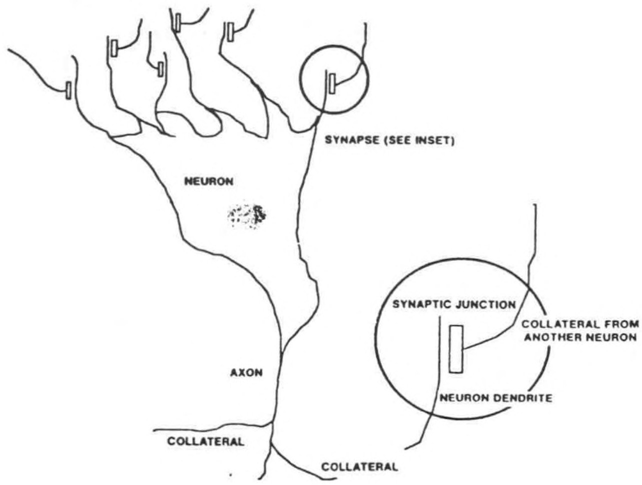

Figure 1. Diagram of a typical brain nerve cell (taken from Caudill, 1990).

An artificial neuron works in the same way (illustrated in Figure 2). Each input is multiplied by the weight of its connection with the neuron. The connection weights may be positive (stimulative) or negative (inhibitive). The connection weights help determine which inputs are important and which are not. All the inputs are summed. Then a transfer function determines the output. The output from one neuron may be connected to many others and becomes those others' input.

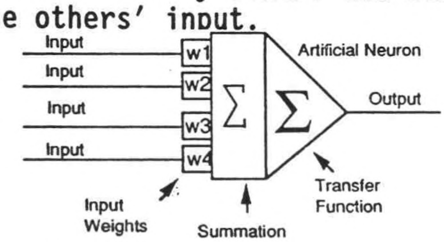

Figure 2. Diagram of an artificial neuron. Input is multiplied by the weights, then all the products are summed. This sum becomes the argument of the transfer function. The result of the function is the neuron's output (taken from Stanley, 1988).

There are many kinds of neural networks. Back-propagation networks are easy to implement and have solved many kinds of problems and so are the most popular (Caudill, 1990). A simple back-propagation network is shown in Figure 3. It has one input layer of neurons and one output layer and often has one or more hidden layers between the input and output layers. Each of the neurons in a layer is connected to each of the neurons in the layer below. The network learns by example. A teacher shows the network a set of inputs which flow through the connection weights into the hidden layer which, in turn, produce output to the output layer via their own connection weights. The output layer contains the network's response to the input. The teacher then compares this output with the desired output. If the error between the two is small enough, the network has learned that input. If not, the error is back-propagated through the network by adjusting the connection weights. Then the input is presented again, and again, if necessary, until the network output is close to the desired output. It is the connection weights between the input and output layers through the hidden layer that store the knowledge of the neural network.

The teacher shows the network as many patterns and variations to those patterns that the problem suggests. When the network has learned most or all of them, the network is considered trained. The teacher then presents a set of inputs the network has not seen and tests its ability to recognize the correct patterns. If testing is successful, then the network can be used to predict output from any input data.

The approach to input and output is similar to screening regression (Charba, 1979) and multi-variate (McNulty, 1981) methods of statistics. However, a neural network is highly non-linear so it can resolve many problems traditional statistical methods cannot. Furthermore, a neural network needs many fewer examples to learn than statistical approaches as long as the examples represent the entire spectrum of expected patterns.

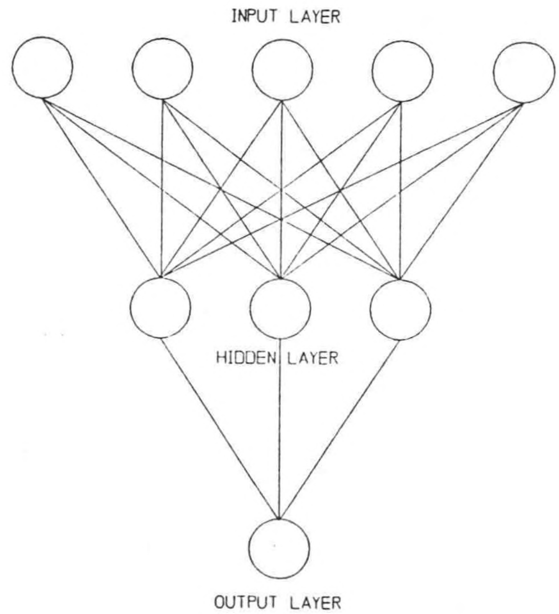

Figure 3. Schematic diagram of a back-propagation neural network showing the connections of each of the neurons.

3. IMPACT OF NEURAL NETWORK FORECASTS

McCann (1992) describes development of a neural network significant thunderstorm forecast (NNET) to aid National Aviation Weather Advisory Unit (NAWAU) meteorologists in their issuance of 2-6 hour Convective SIGMET (WST) outlooks. NNET is based on patterns of surface-based Lifted Index and moisture convergence. Some patterns of these two fields are known to be precursory to significant thunderstorms (Ostby, 1975; Darkow and Livingston, 1975; Hales and Doswell, 1982; Maddox and Doswell, 1982; Hirt, 1982; Doswell, 1982; Ostby, 1984;

Livingston and Wilson, 1986; Bothwell, 1988; Waldstreicher, 1989). For years, as one of the NAWAU forecasters, I overlaid these two fields to make successful thunderstorm outlooks. Many favorable patterns have preceded significant thunderstorm development by several hours.

NNET showed substantial skill when compared subjectively with actual significant thunderstorm occurrence on three randomly chosen days in 1990 as shown in Figure 4. NNET output for the continental United States and adjacent areas has been available to NSSFC forecasters hourly since mid April, 1991, on the Center's VDUC computer system.

Although NNET was developed from 1800 UTC data, computing it at other times of the day has produced forecast fields of similar usefulness. It is quite interesting to see hour-by-hour changes of NNET output as it forecasts the usual diurnal trend of convection. Areas of maximum output increase in size and magnitude from early morning to late afternoon; then they decrease into the night.

My personal experience from using NNET on a daily basis is that by making adjustments to NNET output based on current convective trends, the size of my WST outlooks were reduced substantially (compared with those made with older techniques in previous years) without an adverse affect on the ability to capture WST issuances in the outlooks. This was tested by verifying some of my WST outlooks for June and July, 1990 and 1991, before NNET and after NNET. Outlooks verified were east of the Rocky Mountains at issuance times of 1855 UTC, 0055 UTC, and 0955 UTC. Each of these outlook times poses a different forecast problem. The 1855 UTC outlook challenge is to forecast the major late afternoon convection. The 0055 UTC outlook question is how long will significant thunderstorms continue. The 0955 UTC outlook may be the most difficult of the three times because it is a forecast for strong convection at the daily climatological thunderstorm minimum. Each two month period in both years was about equally active convectively as measured by the number of subsequent WSTs issued.

Each outlook during the period was verified by seeing how well subsequent WST issuances were captured in the outlook. For example, the four WST hourly issuances at 2155 UTC through 0055 UTC verified an 1855 UTC outlook. The union of the outlook area and the area of ensuing WSTs divided by the total WST issuance area defined a probability of detection (POD). The outlook area not capturing WSTs divided by the total outlook area defined a false alarm ratio (FAR) (Charba and Klein, 1980). A Critical Success Index (CSI) can be calculated using a standard formula, $CSI = (POD^{-1} + (1-FAR)^{-1} - 1)^{-1}$.

Table 1 gives the verification results. Indeed, the median outlook area size for 1991 was 36% smaller than the median size for 1990, and the total area outlooked per issuance (more than one outlook area could be issued at one issuance time) was 29% smaller for the same comparison. The POD for 1991 is slightly higher than the POD for 1990 and, combined with the reduced 1991 FAR, results in a large improvement in the CSI results. Note that NNET had only been operational for a little more than one month in June, 1991, so WST outlooks are

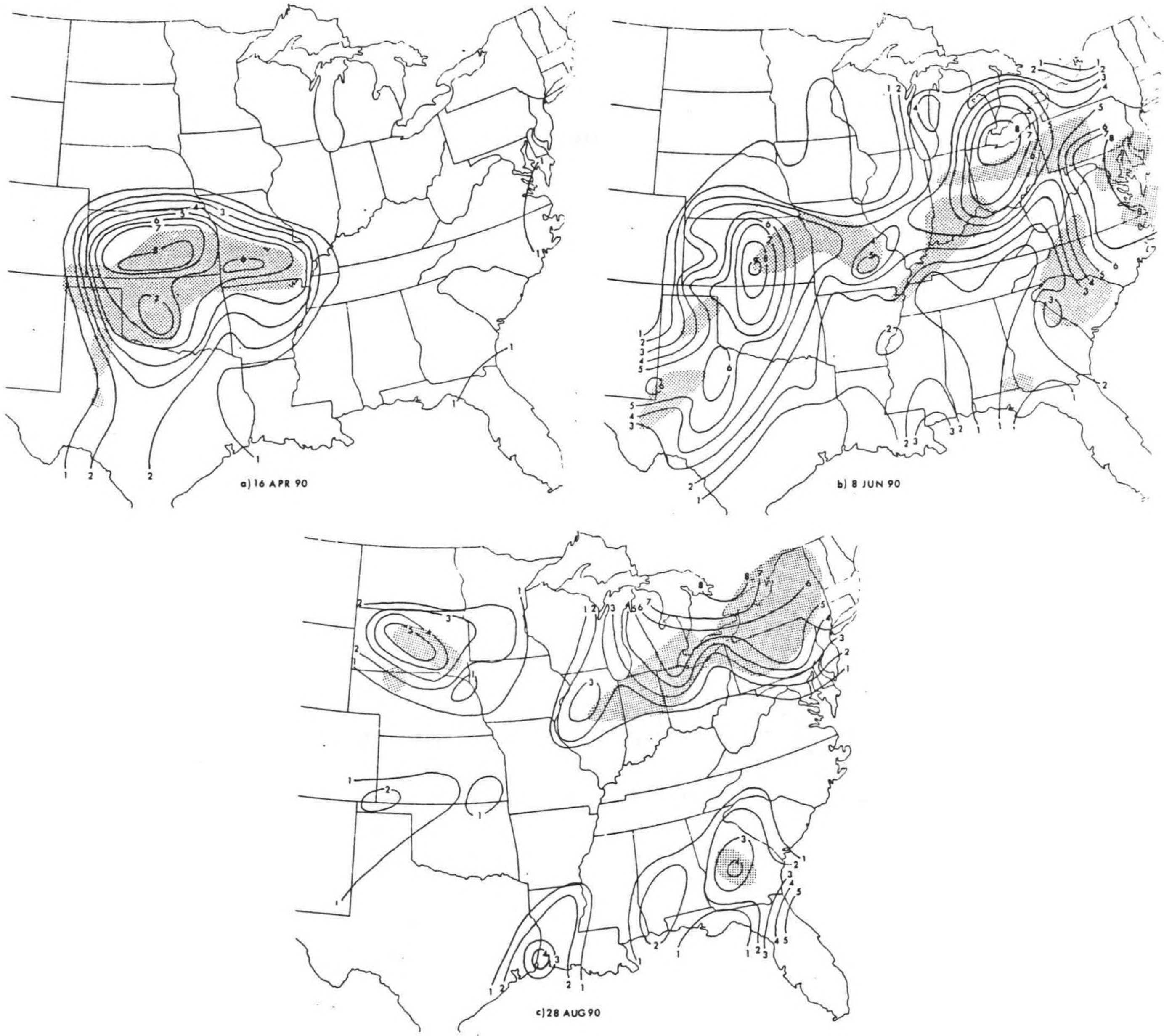

Figure 4. NNET output on 1800 UTC for three days: a) 16 April 1990, b) 8 June 1990, and c) 28 Aug 1990. Contours are NNET output/10 and stippled areas are the areas of significant thunderstorms subsequently needing WST issuances from 2100 UTC to 0100 UTC.

TABLE 1. Verification results for WST outlooks for June/July, 1990 and 1991

1990	Median Area	Total Area per forecast	FAR	POD	CSI	Total WSTs issued
1855	97056	277608	.760	.493	.192	120
0055	82391	139667	.793	.527	.175	82
0955	37916	25266	.743	.189	.121	79
All	80671	127499	.772	.441	.177	281
1991						
1855	64521	212998	.722	.403	.197	145
0055	38809	106910	.647	.596	.285	86
0955	0	0	----	.000	----	45
All	51870	90272	.688	.459	.228	276

Note: All times UTC. All areas in square nautical miles.

likely to continue improving with more experience on how to use NNET.

One qualitative observation of the potential impact of NNET on WST outlooks is that NNET seems to have the ability to highlight where the strongest and the most intense thunderstorms will be located. Areas of high NNET output generally have larger storms in them and have more solid coverage of significant thunderstorms. Additionally, in some cases NNET has been able to forecast late night or early morning activity that would have not been forecast normally given the time of day.

Other forecasters have found NNET helpful. The forecasters in the FA/Inflight Advisory section of NAWAU occasionally work in the Convective SIGMET Unit in order to maintain proficiency and to occasionally fill in. They do not have the experience of the regulars, and by their own admission sometimes feel less confident about their outlooks as compared with those of the regulars. They also have found that they can favorably reduce the size of their outlooks with NNET. Feedback from those infrequent workers who have tried NNET has been very positive.

Additionally, at least one NSSFC Lead Forecaster has used NNET output in severe weather watch formulation. NNET's design is primarily for significant, WST-type thunderstorms, not necessarily severe. However the union of these two sets of thunderstorms is large. The time frame for NNET is also about the same as those for watches. Since NNET forecasts 2-3 hours beyond the present, it says nothing about the immediate prospects of a thunderstorm system, but says much about its prospects late in a watch valid period. NNET should add value to the severe weather watch program even though it was not created specifically for that problem.

NNET is succeeding in both the goals of AI techniques mentioned in the Introduction. NNET has boosted me up the "significant thunderstorm forecast" learning curve by doing preliminary pattern recognition and eliminating areas of improbable development. That has allowed more time to concentrate on the favorable areas and to refine them further. NNET also has aided less experienced forecasters who work infrequently as WST meteorologists. Even if they do not understand why a particular pattern is favorable for forecasting significant thunderstorms in one area and not in another, they issue better forecasts when they incorporate NNET in their routine. By getting guidance to where favorable and unfavorable conditions are located, they can begin to understand the dynamical processes of thunderstorm development and eventually have more confidence in their forecasts.

4. CONCLUSIONS

In the future artificial intelligence can help meteorologists sort through the expansion of meteorological information and help relieve the probable data overload that such an expansion will bring. NNET is an initial step that demonstrates how neural networks can systematize pattern recognition and help solve important meteorological problems. A neural network's ability to recognize patterns will probably be useful in radar and satellite analysis when greater computer power becomes more available. Neural networks could enhance numerical model output and analysis and perhaps give new insights into old forecasting problems.

I have developed a generic neural network program that runs on an IBM-compatible computer, and I will make it available to anyone who wants to use it. Preferably, your computer should be a fast 80286 or better with a math coprocessor. It can take many hours to train a network even on the fastest of systems. This program is easy to use and does not require an intimate knowledge of neural networks. Feeding the network input and desired output is easy, and learning is automatic.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF GRAPHIC AVIATION WEATHER FORECASTING TECHNIQUES AND PRODUCTS WITHIN CANADA

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ABSTRACT:

As the primary supplier of forecast weather information to the aviation community in Canada, the Atmospheric Environment Service (AES) of Environment Canada is in the process of evaluating the provision of forecast products and services. This is in response both to changing user requirements and to new opportunities offered by changing technologies.

A transition from traditional alphanumeric forecast products to a suite of graphics is now feasible. This direction has support from the aviation user, given the potential of a more easily interpreted product, and from the forecasting community where there is the opportunity to move away from highly coded products towards a product which more closely approaches the way a meteorologist works with conceptual models of atmospheric structures. The meteorological graphics editor being developed is running on a workstation platform which will provide the interactive speed demanded by the operational forecasting environment. Forecast or diagnostic model fields can be edited to create a graphic or a product can be developed from scratch using only observed data. The system design will incorporate the ability to have the user create areal graphic forecast products for different valid times and from them automatically generate point forecasts through a space & time interpolation process.

1. INTRODUCTION

The quality, utility and timeliness of aviation weather information has a direct impact on the safety and efficiency of aircraft operations. In an effort to improve these aspects of aviation weather services to the aviation community in Canada the Atmospheric Environment Service, in cooperation with Transport Canada (TC) and the Canadian Forces Weather Service (CFWS), are developing techniques and systems to create and deliver graphic diagnostic and forecast weather products. An existing forecast product, the Aviation Area Forecast (FA), has been targeted as the first and most critical to improve. While this discussion and the most immediate objectives in this initiative relate to changes in the FA, the potential application to other products will also be addressed.

2. BACKGROUND

In Canada the provision of Aviation Weather Services is a cooperative venture involving AES, TC, and CFWS. Transport Canada, as the direct user of aviation weather information provided by AES, sets their requirements & standards for the aviation data, products and services.

The aviation area forecast (FA) was first issued in Canada in 1941 using a format based on the US equivalent. The requirement for a highly abbreviated textual product was based on the constraints of communications systems of the 1940's. Today, it remains one of the primary sources of forecast aviation weather information for the aviation user. In almost half a century the Canadian FA (Figure 1) has undergone only minor changes to format and content. With current data transmission rates which are hundreds of times faster and many options as to format, the FA product, its production & delivery system are now

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HGTS ASL UNLESS NOTED
CB TCU AND ACC IMPLY SIG TURBC AND ICG. CB IMPLIES LLWS

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LO AND WV ON ARCTIC FNT NR NORWAY HOUSE 18Z WITH COLD FNT WV-
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TO 60 NW TROUT LAKE 06Z WITH TROWAL WV-TADOULE LAKE-NWWDS AND COLD
FNT WV-SWDS. E TROWAL AND WV RGNS IN MDT-STG SELY FLO MOIST UNSTBL
ARCTIC AMS. MDT WLY FLO IN WRM SCTR WITH PTCHY MOISTURE BCMG UNSTBL
NR COLD FNT. N COLD FNT AND W TROWAL RGNS IN MDT-STG NWLY FLO MOIST
UNSTBL ARCTIC AMS

GRAND RAPIDS THE PAS THOMPSON GODS LAKE INDIAN LAKE
SEAL RIVER CHURCHILL YORK RGNS
CLDS AND WX. BYND 200 NE WV AND TROWAL...40 SCT V BKN 60 100 SCT V
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OVC LYRS 180 1-6S- WITH EMBDD 100 SCT ACC 180 GVG LCLY 1/4S+ AND
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ICG. LGT-MDT RIME ICIGIC WITH MDT CLR IN ACC. FRLVL SFC

TURBC BLO 50... MDT-SVR LLWS JUST E TO VCNTY COLD FNT....MDT-SVR
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Figure 1 Sample alphanumeric FA

under review. The entire aviation product suite will soon receive the same scrutiny.

AES now issues 24 routine FA's from nine Weather Centres every 6 hours which forecast aviation weather over the area described in Figure 2.

3. ADVANTAGES OF GRAPHICS

The primary advantage is that associated with product utility. A graphic can be interpreted more quickly and accurately than conventional textual information. This issue has been the topic of several recent papers on aviation safety.

Another advantage of the meteorological graphic product, is that when a forecaster is involved in the process he/she normally develops a 4-dimensional conceptual model of the atmosphere and from this the various forecasts are created. This process is especially true for aviation forecasts where they are short range and where the quality of the forecast depends directly upon the forecaster's ability to diagnose and model the processes causing the existing weather.

Another significant example of potential gains relates to the use of the conventional FA. The textual FA is created as a simplification of the model of the atmosphere which the forecaster has developed either conceptually or in some hardcopy form. Many significant compromises and much smoothing is done in the process of creating the FA message. Aviation Weather briefers, who frequently work in an environment without the benefits of any graphic material (even a surface analysis) will typically read,

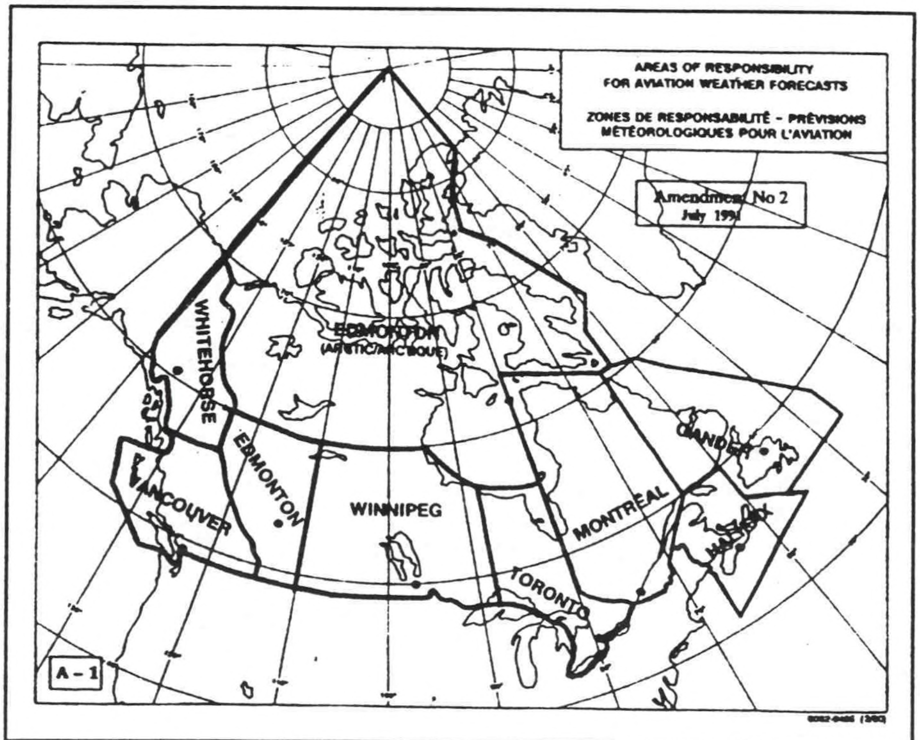

Figure 2 Area of Forecast Responsibility

interpret and then draw out the several FA's which cover their area of interest. This process of going from graphic concept to alphanumeric message and back to a graphic product represents a significant loss of information and detail. To take a graphic right from the hands of the forecaster and present it to the end user would alleviate this type of loss.

4. DISADVANTAGES OF GRAPHICS

The disadvantages of the product itself are few although there are some associated with communication costs which are discussed in Section 7. One argument against the graphic is that there will be differences or conflicts between products issued for adjacent areas from different weather centres. In fact these differences exist now with the textual FA but they are occasionally missed in the forecast centres. The graphic would make differences between forecasts more evident and thus they would demand appropriate action.

5. THE GRAPHIC FA

Products similar to the "Graphic FA", referred to as "Horizontal Weather Depictions" (Figure 3) and containing detailed aviation weather information have been manually produced & distributed between weather centres & weather offices for many years especially in the CFWS. The limiting factors have always been insufficient resources to produce a full complement of these depictions from the Weather Centres and the lack of a communications system capable of sending and receiving the graphic at the user end. The proposed Graphic FA could be produced either manually or through a number of levels of automation where the degree of automation directly determines the extent of resource commitment in terms of human resources.

The current proposal is that the Graphic FA will contain all the information presently included in the alphanumeric FA and will present it on two panels valid at the beginning and end of a 12 hour window which starts at the issue time of the forecast. Thus the product will continue to deal with meteorological systems & features, cloud layers, weather, visibility, ceilings, icing, turbulence and freezing levels.

6. PRODUCTION TECHNIQUES

The production techniques will involve a number of options as to the level of automation but a significant mix of man & machine is planned. The forecaster will be provided a workstation environment with sufficient tools to create and/or edit graphic products. Functional specifications for the graphics editor include many operations common to computer "Paint", "Draw" or CAD programs. These include such tools and controls as:

- text entry--edit--move--copy
- text size
- text font
- text orientation--angle
- line creation--editing (vector)
- line thickness--type
- area texture--shading
- meteorological symbols creation--editing--movement
- graph creation--editing

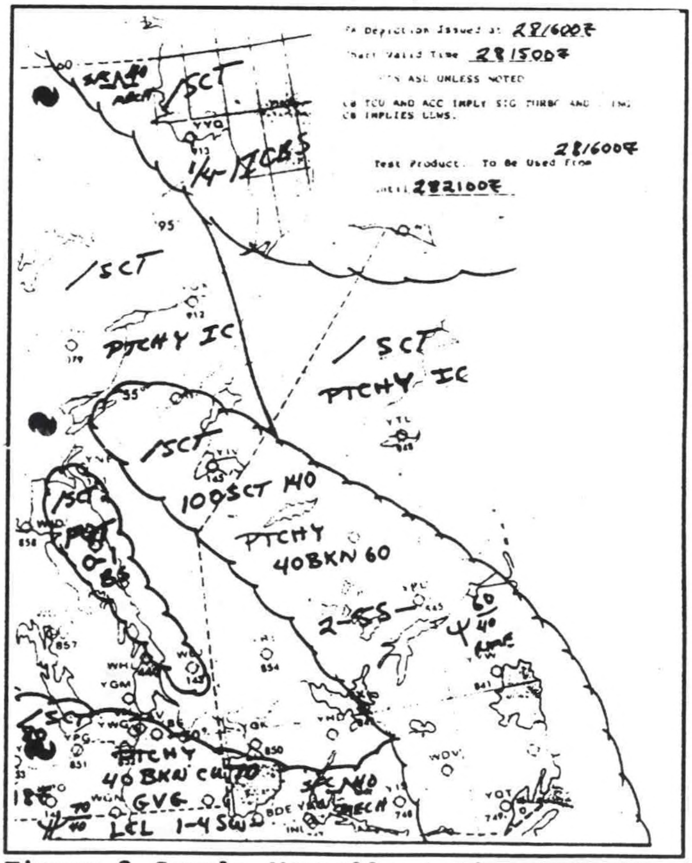

Figure 3 Sample Manually produced Weather Depiction

- sampling (from meteorological fields)
- meteorological field editing tools (vector)
- basemap creation--selection--zooming--panning.
- overlay capability of several fields or products.
- product label creation--editing
- default lines--symbols--map backgrounds attached to certain product types
- macro creation--editing to simplify repetitious tasks
- product--file management system

The features which will make the system completely functional in the Weather Centre will be those which also display and allow direct use of meteorological data and fields. As the system evolves it will include access to the following:

- model fields (primarily the Canadian Finite Element Model)
- conventional meteorological data (surface and upper air observations)
- remotely sensed data

One possible configuration for the forecasting process is shown in Figure 4 which depicts products of various types as being available at different levels in the flow diagram. It also maximizes the number of opportunities for the forecaster to add value in what may vary from an entirely manual to a semi-automated or completely automated process depending on the complexity of the situation and how well objective tools are handling the situation.

Some of the functions described above have already been built into meteorological systems in Canada although they have yet to be integrated into a single user environment to provide full graphic editing capability. The Forecast Production Assistant (FPA) (ref. McLeod, J. Carr:1990) has an interactive graphic editor (INGRED) used to create areal weather descriptions and also allows editing of model fields. The FPA was not designed to create production graphics but rather to use the graphic interface as one step in producing text forecasts. Some software modules have been added to the FPA editing capability to improve its handling of lines and meteorological features such as fronts but more work required. A second Canadian graphic editing system based in meteorology is one created

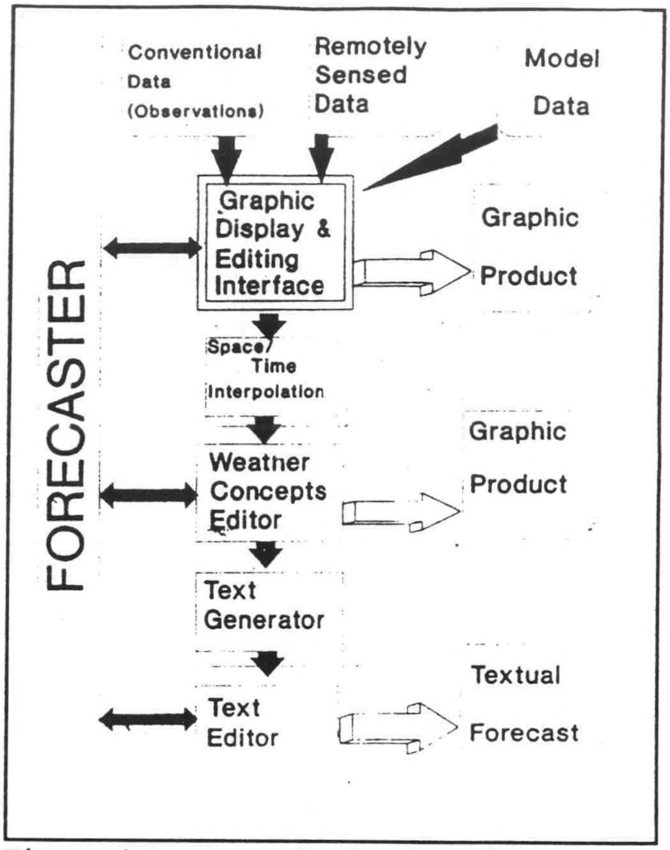

Figure 4 Forecast Production Flow

in the Development Division of the Canadian Meteorological Centre (CMC) called EDIGRAF. The Edigraf system was designed for the purpose of creating production graphics and as such performs many of the functions described in the lists above. As prototypes, the FPA and Edigraf each have features which will benefit the development of the operational system. Figures 5 & 6 show examples of what can be produced using Edigraf and other drawing packages.

7. DELIVERY

The most significant hurtles to be overcome in provision of graphic products directly to the aviation user are:

1. the higher cost of communicating the data associated with graphic products. These costs have fallen to the point where graphics can be sent economically. There remains the constraint of the bandwidth

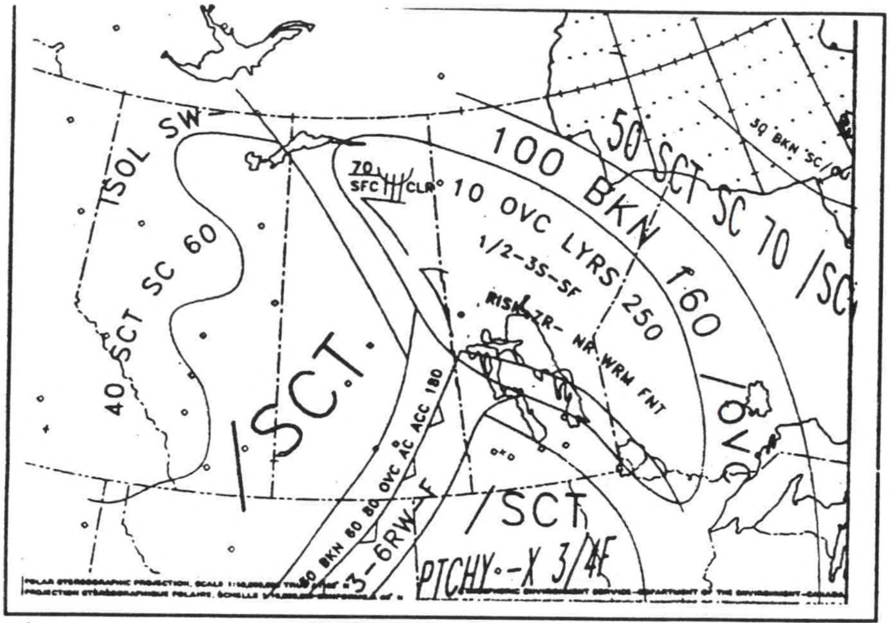

Figure 5 Sample Graphic

(capacity) of existing communications systems and that adding more graphics products will push the systems to the point where more capacity is be required.

2. the aviation user must have the technology to receive the graphic products and there must exist a data transmission/reception standard. The technology t[illegible]ive the graphics [illegible]ilable and it r[illegible] put the system[illegible] place.

Present plans call for transmission of graphic products over the AES Meteorological Information System (AMIS) using the ANIKOM 100 satellite communication system. At 4800 baud using compressed data (BUFR) a typical product transmission will be 1.5 minutes. It is expected that by implementation transmission/reception rates of 9600 and 19.2 Kbaud will be available.

8. OTHER AVIATION PRODUCTS

With the precedent of delivery of the Graphic FA to the aviation user will come the opportunity to provide a broad suite of graphic products. The list becomes lengthy very quickly...

- weather warnings
- radar summaries

Diagnoses and Prognoses of:

- low level windshears
- convective weather
- turbulence
- icing/freezing levels
- satellite nephanalyses
- flying categories
- surface isobarics/fronts
- cloud layers

The system described retains the contingency to use a graphic not only as an end product but also

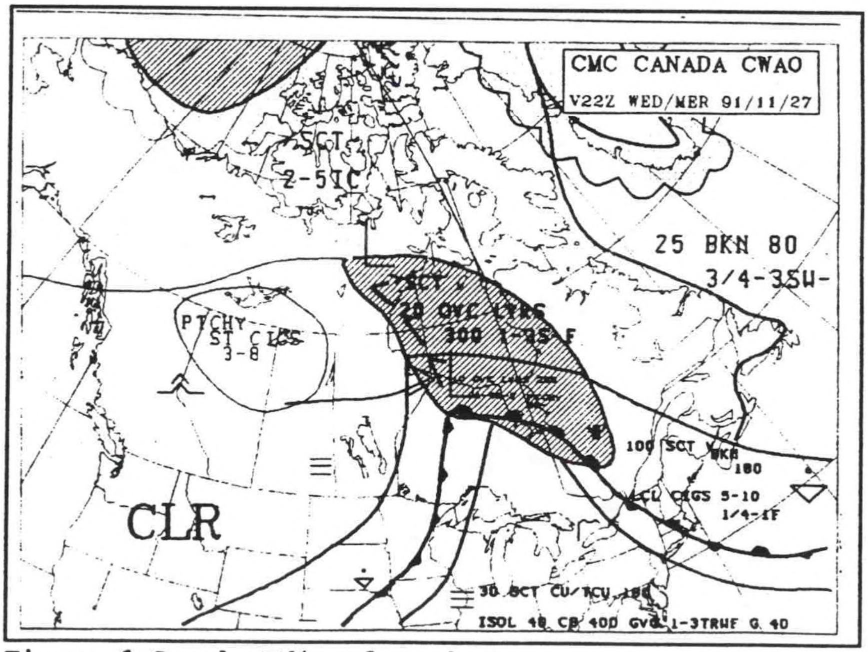

Figure 6 Sample Edigraf product

as a source of meteorological data to be used in the automatic production of text or coded forecasts such as terminal forecasts. This has considerable potential in production of a terminal outlook (3-12 hours) where a recovery or trend forecast is produced either manually or through a slightly different procedure.

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Session 11.6

CURRENT AND FUTURE CAPABILITIES IN FORECASTING THE TRAJECTORIES, TRANSPORT AND DISPERSION OF VOLCANIC ASH CLOUDS AT THE CANADIAN METEOROLOGICAL CENTRE

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1. Introduction

The Canadian Meteorological Centre (CMC) is part of Environment Canada, and is the main Canadian Centre for processing weather information. It supports the 9 Regional Weather Centres of Atmospheric Environment Service (AES), plus the National Defence Weather Centres. CMC operates the AES supercomputer, a Cray XMP 432, plus a variety of other mainframes, and the AES communication systems. CMC runs Numerical Weather Analysis and Prediction Models for AES. Weather observations from the world are continuously arriving at CMC through the Global Telecommunication System as well as through the AES telecommunication network.

Weather analysis is performed automatically for the global atmosphere, through a data assimilation system. Analyses are done for the four main synoptic times: 00 UTC, 06 UTC, 12 UTC 18 UTC. The data assimilation system consists in an Objective Analysis (OA) procedure based on a multivariate optimum interpolation method, and a Global Spectral Numerical Weather Prediction Model. The prediction model produces 6-hour forecasts which serve as trial fields; those fields are corrected with observational data by the OA. Analyses are done for temperature, geopotential height, wind and humidity, at 15 vertical levels. The analyzed fields are used as initial conditions for the various forecast models.

Two Numerical Weather Prediction (NWP) Models are currently in operation a CMC. A Regional Finite Element Model for the short range, and a Global Spectral Model for the medium range. The Regional Finite Element (RFE) Model is an hemispheric model with variable resolution; the high resolution (100 km) area covers North America. The model is executed twice a day, at 00 UTC and 12 UTC , and produces forecasts to 48 hours. The Global Spectral Model is also executed twice a day, to day 6 at 00 UTC, and to day 3 at 12 UTC. The accuracy of the forecasts produced by these models is comparable to forecasts produced by other National Meteorological Centres (Table 1).

Table 1. RMS Error of the Wind Vector, 24 Hour Forecast for North America.

Models	500 hPa (knots)	250 hPa (knots)
Canadian Global Spectral Model	.12.7	19.2
US Global Model (Aviation Run)	11.6	17.1
UK Met Office Global Model	12.1	19.2

The verifications were done by the issuing centres, following WMO recommendations, for a standard set of radiosondes stations.

At all times, CMC has an accurate knowledge of the actual state of the atmosphere, and of its most probable evolution for the next few days. CMC is therefore the Canadian agency which can most rapidly respond to information requests about the large scale evolution of pollution clouds during environmental emergencies. For that reason, a 3-D Trajectory Model and a 3-D Transport/Diffusion/Deposition Model have been implemented in CMC's operations. The primary purpose for implementing these models was to increase preparedness for nuclear emergencies. The models are also used to estimate the motion of volcanic ash plumes.

2. The Trajectory Model

CMC's Trajectory Model is a simple 3-dimensional Lagrangian Model. Given a 3-D wind field, it will calculate the motion of a neutrally buoyant air parcel, starting from a specified point of origin. The model considers no other process than advection by the wind.

CMC's Trajectory Model operates on a polar stereographic grid in the horizontal, and in pressure coordinates in the vertical. It was designed mostly for use over North America (Figure 1).

In the present operational configuration the model is executed in forecast mode only. It uses interpolated wind fields and vertical motions produced by the Global Spectral Model. Trajectories are calculated for 3 air parcels originating from a single location, but from 3 different vertical levels, all user specified. Positions are calculated in 3-hourly time steps up to 48 hours.

The Trajectory Model executes very quickly on CMC's super computer. Results can be made available to the users within five minutes of request. The results may be transmitted in chart form through the AES Meteorological Satellite Information System (METSIS), or via telecopier. Three-hourly positions (latitude, longitude and height) along the trajectories are also available in the form of alphanumeric messages on AES telecommunications networks.

The trajectory model can be useful for emissions of short duration. However it does not provide information on plume shape, air concentrations or surface deposition.

3. The Canadian Emergency Response Model (CANERM)

The Canadian Emergency Response Model was developed by J. Pudykiewicz of Environment Canada, following the Chernobyl nuclear accident (Pudykiewicz, 1989). CANERM is a 3-D advection/diffusion model. It simulates the effects of wet and dry scavenging, estimates wet and dry deposition, and models the mixing effects within the planetary boundary layer. Although the model was designed to assess the motion of radioactive clouds resulting from large nuclear accidents, it can be adapted to model volcanic ash clouds.

In the current operational setup, CANERM executes on a polar stereographic grid. Two configurations are available: an extended hemispheric domain, covering the Northern Hemisphere and the northern part of the Southern Hemisphere (90•N-20•S), at a horizontal resolution of 150km, and a regional domain

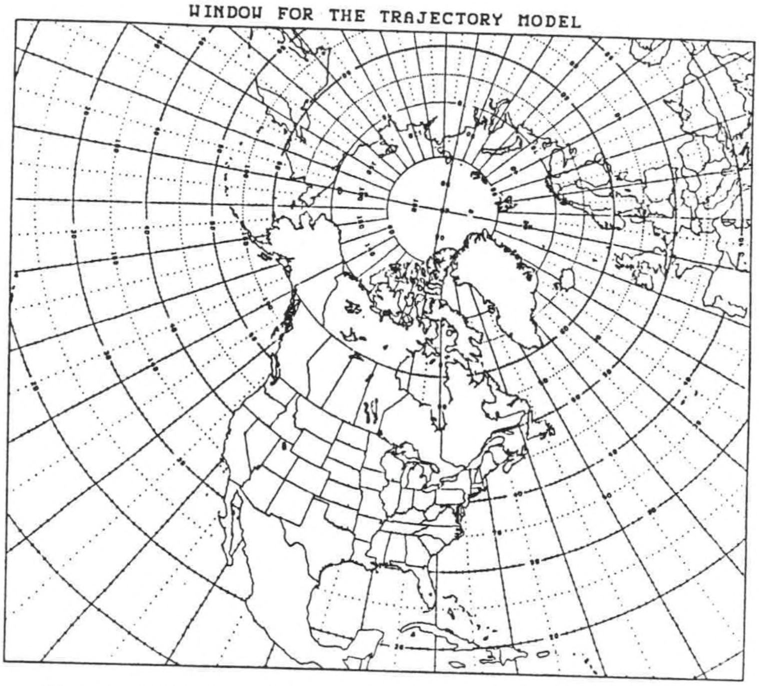


Figure 1: Window for the Trajectory Model. Trajectories for parcels exiting the window will terminate at the point of exit.

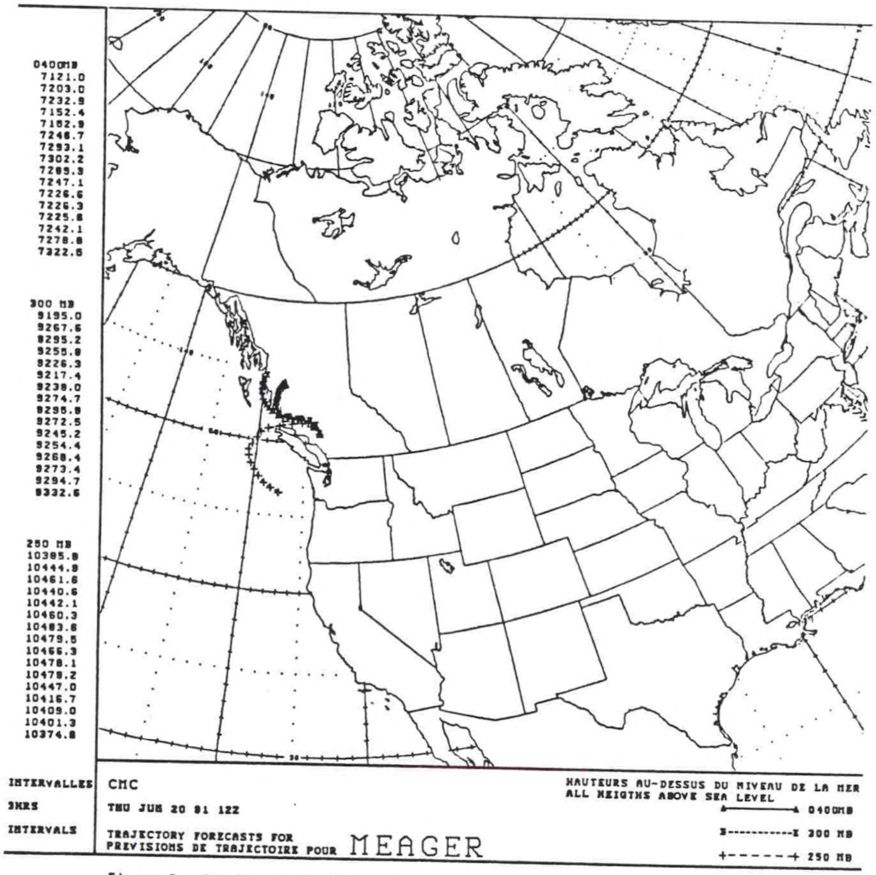


Figure 2: Sample output of Trajectory Model as it is made available to the user. Positions are plotted at 3 hour intervals. Heights along the trajectories are given on the left side of the map, in metres above mean sea level. The map is centered on the origin of the parcels, for the North-South direction, but somewhat displaced to the west, as in most circumstances, parcels move rapidly eastward.

with a resolution of 50km. The vertical coordinate is the terrain following σ-coordinate (σ is the ratio of the atmospheric pressure at a given vertical level, to the surface pressure at that location). The model has 11 vertical levels up to about 100 hPa (σ=.1). Fields of wind, temperature, moisture and geopotential must be provided to the model. These may come from an historical sequence of objective analyses, in HINDCAST mode, or from the output of the Global Spectral Model, in FORECAST mode. The HINDCAST mode is used to obtain the best estimate of the actual state of the plume, and the FORECAST mode, the expected state. The two modes can be used in sequence for events of extended duration.

The release to the model atmosphere near the source is modelled by a Gaussian function. The standard deviation is one grid length in the horizontal, and .1 σ in the vertical. For volcanic ash, the source elevation is set at σ=.4 ($\approx$ 400 hPa). The time dependence of the release follows the right side of the Gaussian function, with a standard deviation of 3 hours; the total emission is 1.3 megaton. To simulate volcanic ash, an inert neutrally buoyant gas tracer, not subject to washout, is used.

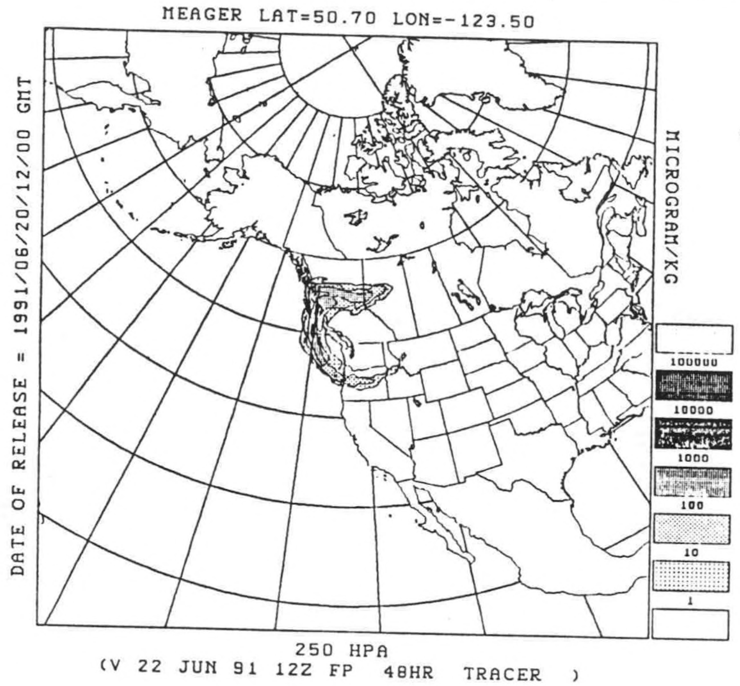
CANERM produces estimates of the 3-D shape of the ash plume as it evolves in the atmospheric flow. If the actual source strength is known, the results can be scaled to yield estimates of ash concentrations.

CANERM results can be made available to users within about one hour after request, in chart form via telecopier.

4. An Example: Hypothetical Eruption at Mount Meager B.C.

Mount Meager is part of the Garibaldi Volcanic Belt in British Columbia where a volcanic eruption of consequence is possible (Hickson, 1991). A simulation was done for a hypothetical eruption at 1200 UTC, June 20 1991. Sample outputs of the Trajectory and CANERM are illustrated in Figures 2 and 3, as they would be made available to users. An experimental run of CANERM was also done, at a resolution of 10km, using interpolated fields produced by CMC's operational RFE Model.

An enlargement of the trajectories of Figure 2, is given in Figure 4. The meteorological situation was characterized by a weak wind circulation over western North America at all levels. That is apparent in the unusual behavior of the trajectories which indicate a northwestward motion at the beginning. The trajectories at 400 hPa and 300 hPa recurve northeastward after about 18 hours, and southeastward, at 250 hPa. Figure 3 shows the ash plume produced by the CANERM run at 50km resolution, after 48 hours, at 250 hPa. The modelled plume reaches far inland over Oregon and Idaho, while the end point of the trajectory at 250 hPa, which should indicate the 48 hours position of an air parcel originating from above the volcano, is still over the ocean. The plume has also spread over Northern British Columbia; this is not indicated from the trajectory at 250 hPa, but is hinted by the lower trajectories. The extent of the plume produced by CANERM is greater than what could be inferred from the trajectories. This can be explained by the fact that the trajectory model has no diffusion in its formulation, and tracks an air parcel



MODEL ASSUMPTIONS

ISOTOPE: TRACER
TOTAL RELEASE : 1.3E6 TONS

MAXIMUM INTENSITY OF RELEASE: 1.0E6 TONS/3H
HEIGHT OF RELEASE: SIGMA = .4

SOURCE DESCRIPTION

GAUSSIAN FORCING
GRID LENGTH: 50 KM

STANDARD DEVIATION (HOR) : 1 GRID LENGTH
STANDARD DEVIATION (VERT): .1 SIGMA COORDINATES
STANDARD DEVIATION (TIME): 03H

Figure 3: Sample output of CANERM as it would be transmitted to the user. This is a 48-hour forecast, at 250 hPa, from an execution with a resolution at 50 kM. Ash concentration units are in μg/kg (ppbm) of air, given an emission of 1.3 megatons.

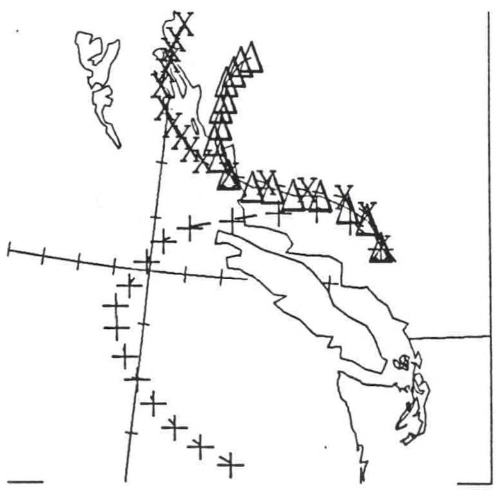


Figure 4: Enlargement of the trajectories given on map in Figure 2. The starting levels of the trajectories are 400 hPa (▲), 300 hPa (X), and 250 hPa (+).

that has in no dimensions, whereas CANERM has a well developed ash column to begin with, because of the Gaussian source model, and that the plume continues to spread throughout the simulation because of the diffusion.

A test run of CANERM at a resolution of 10km, based on interpolated wind fields produced by the RFE model was performed for the same case. At that resolution, about 96% of the plume at 400 hPa is within a radius of 20km, at initial time; this is comparable to the size of the umbrella cloud generated shortly after an eruption (Woods, 1991). The winds provided to CANERM do not have information at scales below 100km; it can be argued however, that at upper levels, which are of interest for aviation, the flow is relatively smooth, and most of the variability is in the synoptic scales, which are adequately resolved by the RFE. The evolution of the plume at 250hPa is depicted in Figures 5 to 10. At 3 hours (Figure 5) a tendency for the plume to bifurcate is evident. At 12 hours (Figure 6), the cloud has spread considerably, and the maximum concentrations are well detached from the source. At 24 hours (Figure 7), the stretching is underway, with a branch starting to move rapidly southward. From 36 to 48 hours (Figures 8 and 9) it can be seen that whole cloud over the Pacific has started to translate eastward, as the atmospheric flow aloft begins to reorganize. The final shape of the cloud at 250 hPa could not have been easily deduced from the trajectories.

5. Future Capabilities

The next supercomputer (NEC SX3 model 44) will have been installed at CMC in early October 1991. The conversion of CMC's operational system to the new computer will be completed in late 1992. Response time should improve to about 15 minutes for CANERM. With the conversion, a global mode for the Trajectory Model and CANERM will be implemented. Following the installation of the new computer, higher resolution Analysis and Forecast Models will be implemented - a 50-25km Regional Model expected - with a proportional increase in the resolution of CANERM.

When information about ash particles size distribution and settling velocities is available, CANERM's capacity to provide estimates of ash surface deposition will be activated. Improved wet scavenging will also be possible, using available precipitation fluxes from NWP models.

Over the next few years, estimates of air concentrations and of surface deposition very near the source will improve, with the introduction of more sophisticated submodels to better estimate the initial plume rise, the vertical distribution of ejected materials, and other subgrid scale effects. Eventually a dedicated high resolution non-hydrostatic meteorological model will be included to resolve the detailed structure of the atmospheric motions in the vicinity of the source.

6. References

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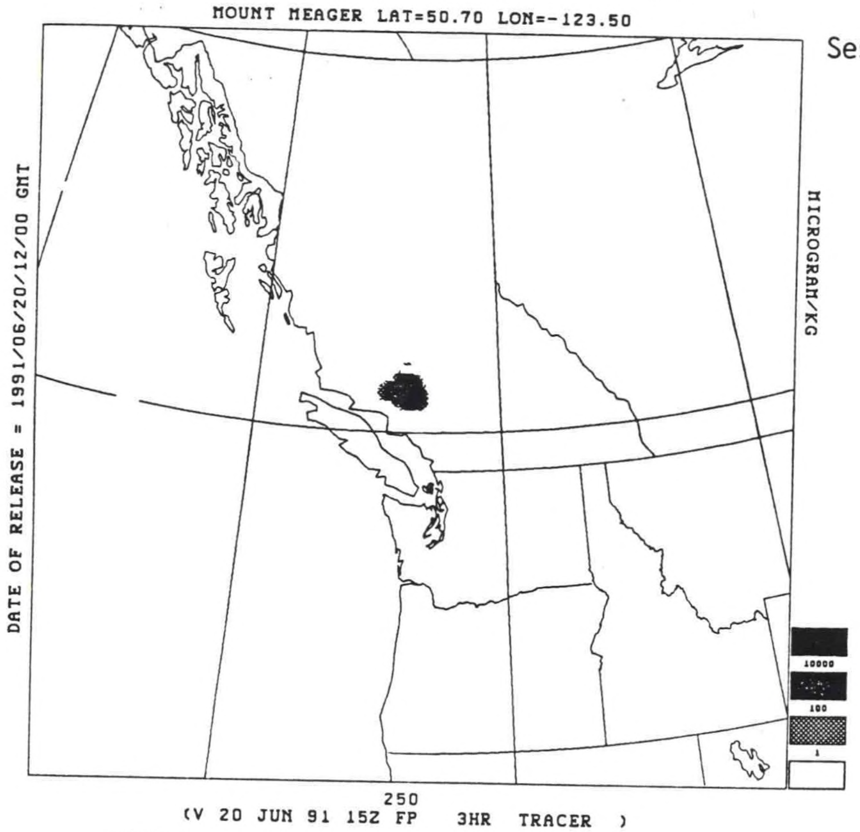

Figure 5: 3 hour forecast at 250 hPa from a test CANERM run at 10km resolution using interpolated winds produced by the Regional Finite Element Model. The coordinates of the source are given at the top of the chart, in degrees. The geographical area shown on the map constitutes the total domain of the model, for this run. Ash concentration units are in μg/kg (ppbm) of air, given an emission of 1.3 megatons.

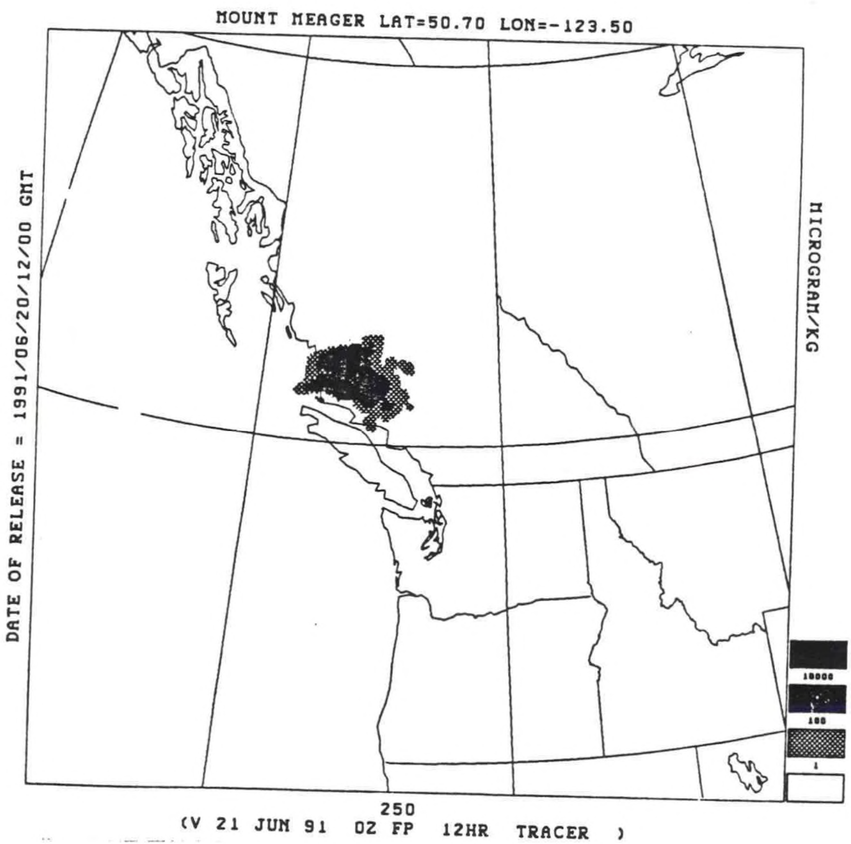

Figure 6: Same as in Figure 5, but for 12 hours.

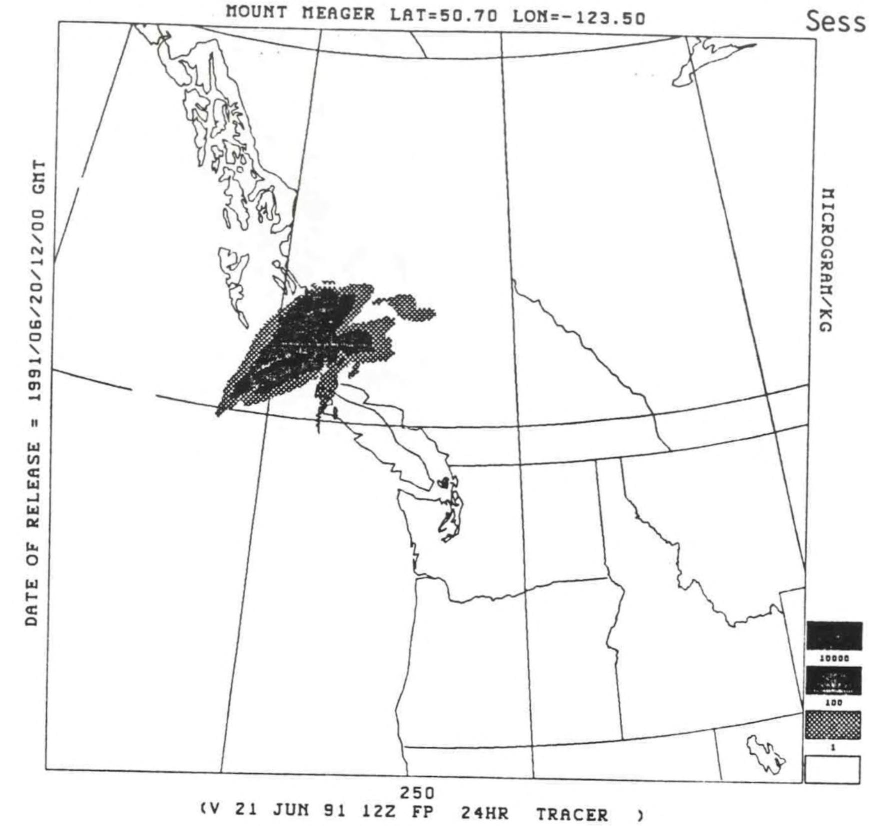

Figure 7: Same as in Figure 5, but for 24 hours.

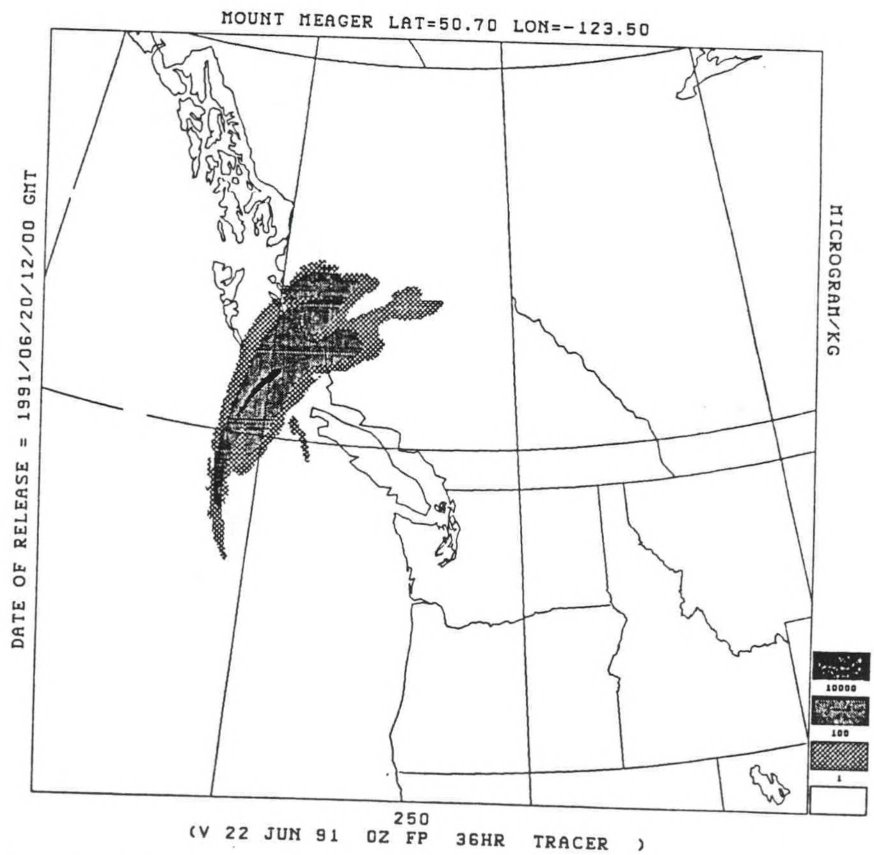

Figure 8: Same as in Figure 5, but for 36 hours.

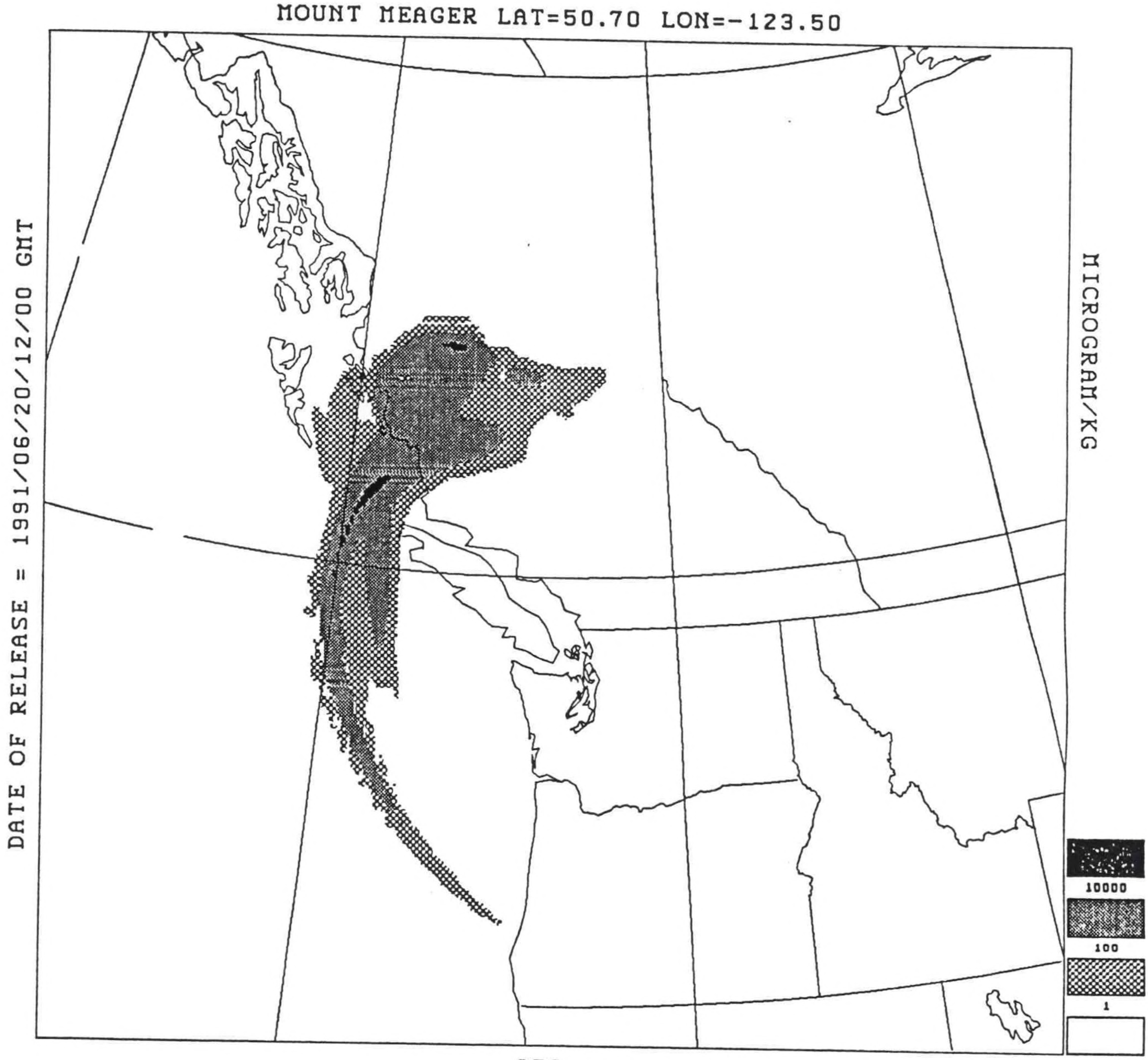

Figure 9: Same as in Figure 5, but for 48 hours.

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THE AVIATION PROGRAM AT NOAA'S FORECAST SYSTEMS LABORATORY

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The Aviation Division, added in the past year, is the newest division in FSL. It works with the Federal Aviation Administration (FAA) and the National Weather Service (NWS) on two major activities: developing the Aviation Gridded Forecast System (AGFS) and developing aviation weather products for the FAA's Advanced Traffic Management System (ATMS).

The first, AGFS, is an interactive information-processing system that will generate high-resolution analyses and gridded forecasts for state-of-the-atmosphere variables, e.g., winds, and aviation-impact variables, such as icing and visibility. These analyses and forecasts will support automation of the nation's air traffic control system. They will be used by the FAA to generate products tailored to aviation users. Resolution on the national scale will be 15 km in the horizontal with 50 levels in the vertical. On the regional scale (400 x 400 km), horizontal resolution will be 10 km for forecasts and most analyses, but 2 km for analyses of winds, clouds, and radar reflectivity. The system will:

- ingest observations and gridded guidance from the National Meteorological Center,
- generate high-resolution analyses and gridded forecasts using state-of-the-art analysis methods and forecast tools such as algorithms and dynamic models,
- merge and reconcile graphic meteorological products for regional and national domains,
- enable forecasters to interact with these forecast tools and the grids they provide, and
- distribute grids to the FAA's regional and national air traffic control and air traffic management facilities.

As now planned, the system will reside at several locations: National Meteorological Center, within AWIPS at weather forecast offices, Center Weather Service Units within FAA's Area Control Facilities, and within AWIPS at the National Aviation Weather Advisory Unit in Kansas City.

FSL staff members are developing ways of using massively parallel processing to generate the high-resolution analyses and gridded forecasts that the system will require. We plan an operational test of a functional prototype of the system in 1994.

Developing the AGFS will mean close coordination with FAA, NWS, The National Center for Atmospheric Research (NCAR), and MITRE's Lincoln Laboratory. NCAR is tailoring weather information for aviation users, while Lincoln Lab is developing an Integrated Terminal Weather System.

The Aviation Division's second major activity, the Advanced Traffic Management System (ATMS), focuses on developing accurate and reliable weather products for air traffic management. It is a joint program with the Volpe National Transportation Systems Center of the Department of Transportation; its purpose is to validate the utility of advanced meteorological products for air traffic management.

Weather information is essential for planning and managing flight operations. The Advanced Traffic Management System is a real-time data integration and display system used for air traffic management at FAA facilities around the country. It assists traffic managers with strategic control of air traffic flow to minimize delays while safely increasing the capacity of the nation's airspace.

Meteorological products under development are derived from FSL's Mesoscale and Local Analysis and Prediction Systems (MAPS and LAPS) and from National Meteorological Center data. NOWrad (a trademark) radar data has been added. These products come into a network of Apollo computers in Boulder and are then sent to the Volpe National Transportation Systems Center in Cambridge, MA, via a Contel satellite link. Developers of the prototype there evaluate the utility of the meteorological data and provide feedback for continued product development and iteration at FSL.

Early in 1992, enroute and terminal products derived from real-time meteorological data will be released to ATMS sites for experimental validation of advanced weather information for air traffic management. The sites include FAA's Central Flow Control Facility in Washington, DC, air route traffic control centers, and terminal radar control facilities.

Enroute aviation weather products developed for the ATMS will be derived from numeous data sources: rawinsonde observations (RAOBs), wind profiler observations, surface aviation observations (SAOs), aircraft reports (voice and automated), GOES visible and multichannel digital data, and national radar data. Those products requiring detailed analyses and shortrange numerical forecasts are derived from the MAPS hybrid model.

MAPS was developed by FSL to take advantage of the growing volume of asynoptic tropospheric observations. It provides detailed analyses if diverse surface and upper air data over the contiguous United States and very short-term numerical forecasts (0-6 h at 3-h frequency) to support aviation and local short-range forecasting. MAPS uses a 3-h data assimilation and provides a 60-km horizontal grid resolution with 25 vertical levels configured in isentropic coordinates. Isentropic surfaces are surfaces of potential temperature which have the advantage of providing extra resolution near upper-level fronts and associated wind maxima and moisture features. As a result, MAPS provides enhanced resolution of jet streams, horizontal and vertical wind shear, and the three-dimensional structure of moisture. Sufficient resolution of jet streams, wind shear along isentropic surfaces, and moisture gradients is critical for development of aviation weather products.

Four enroute products are being developed for testing within the ATMS environment.

- NWS Radar Summaries. The national radar summary and legends graphic is an hourly national radar mosaic generated at the National Aviation Weather Advisory Unit. For ATMS, the radar graphic is retrieved from the NWS AFOS network and is processed and reformatted for display on the aircraft situation display hourly.

- Jet Stream. The jet stream product is being developed from MAPS gridded 3-h forecasts for the display. The graphic is generated every 3 hours and provides isotachs (for wind speeds greater than 70 knots), height of isotachs (in flight levels), and streamlines.

- Gridded Winds Aloft. This product is being developed from the MAPS gridded 3-h forecast. It differs from the jet stream graphic in that it will be used internally by ATMS traffic management models and not for display.

- Pilot Voice Reports. PIREPS are being decoded and stored at FSL for development of turbulence and icing plots. Additionally, these turbulence and icing data will be used to facilitate the development of turbulence and icing algorithms for graphical presentation on the display.

A critical component of the ATMS environment is the aircraft situation display (ASD), and interactive workstation that integrates real-time flight data from all aircraft operating within the airspace system. The display gives air traffic managers a flexible tool to focus attention on congested airspace and take appropriate action to reduce delays. The system can be found at the Central Flow Control Facility in Washington, DC, all 20 air route traffic control centers, terminal radar control facilities, and FSL.

Terminal area traffic management products are being prototyped for ATMS by integrating the singularly rich mix of data sources surrounding Stapleton Airport. They will be derived from surface aviation observations, an automated mesoscale surface observing network at 22 sites surrounding Stapleton Airport, Doppler radar volume scans, wind profiler observations, GOES visible and multi-channel digital data, and aircraft reports. Potential terminal area ATMS products will use detailed analyses from the LAPS database.

LAPS was contrived by FSL to exploit new local-scale observing technology which provides high-resolution meteorological data. It produces hourly detailed analyses of surface and upper air parameters over the Stapleton terminal area. It uses a 1-h data assimilation cycle and provides 10-km horizontal resolution on a 61 x 61 grid and 1-km vertical resolution at 17 levels, with Stapleton Airport located near the center. Using the data sources described above, LAPS produces gridded fields of wind, pressure, temperature, dew point, cloud base, cloud tops, precipitable water, cloud coverage, vertical motion and surface-based lifted index. These high-resolution gridded fields provide a valuable database for developing prototype terminal area weather products for ATMS.

Four such products will be developed for ATMS:

- Surface Winds. A surface winds product is being developed using LAPS gridded data. The surface winds graphic will appear on the aircraft situation display as surface streamlines and a "wind-shift line" depiction through the terminal area.

- Cloud Ceilings. A cloud ceiling graphic produced from LAPS-analyzed SAO data will contain ceiling contours.

- Profile Descent Cross Sections. These are vertical depictions of terminal area weather through each arrival gate into Stapleton Airport. Four ATMS profile descent cross sections are planned for the Stapleton terminal area that will also illustrate the approximate descent path of large jets and heavy aircraft. Additionally, a notation of visual or instrument flight rules will be depicted at the airport location on each cross section graphic.

- Convective Forecast. A terminal area convective forecast graphic will portray short-term predictions of thunderstorm movement through the LAPS domain. It will display contours of expected thunderstorm cell motion on the aircraft situation display.

In addition to the enroute and terminal area products described above, FSL has initiated development of more sophisticated traffic management products for ATMS validation:

- High-Resolution National Radar Mosaic. A national radar graphic derived from 2-km NOWrad data is displayed on the ASD to highlight areas of precipitation; it is updated every 5 minutes.

- Convective Airspace Volumes. This graphic will be derived from high-resolution radar data, infrared satellite digital data, SAOs, lightning strike data and MAPS gridded model output to identify volumes of airspace that aircraft are likely to avoid. This product will appear as a simple easy-to-assimilate graphic on the ASD.

- Aircraft Icing. A national aircraft icing guidance product which uses Nested Grid Model temperatures and relative humidity will be introduced into the ASD.

- Lightning Graphic. This product displays areas of cloud-to-ground lightning activity.

- Automated Instrument Flight Rules Area Outline. This product will be derived from the MAPS surface analysis infrared satellite digital data, national radar data, and topography. It will be generated hourly.

The FAA and Volpe National Transportation Systems Center are major participants and contributors to program funding. For further information on the Aviation Division, contact Mike Kraus, Chief, 303-497-5200; on the Aviation Gridded Forecast System, Lynn Sherretz, 303-497-5580; on the Advanced Traffic Management System, Rich Jesuroga, 303-497-6936. FTS prefix for all three numbers is 320.

TERMINAL FORECAST - ONE SYSTEMATIC APPROACH

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Terminal weather forecasts are one of the most important products issued by the National Weather Service. They greatly affect flight decisions made by both the private and commercial aviation industries. The primary purpose of the workshop was to establish a concise methodology for writing a terminal forecast. The attendee learned a systematic approach to making decisions regarding cloud height and amount, visibility, and general weather. Prognostic charts and other guidance material were also briefly discussed. In addition, the role of forecaster experience was discussed in regard to knowledge of local effects, local climatology and local "rules of thumb". Finally, a method of forecast assembly was presented that could be used for both transient and stagnant weather systems. Two terminal forecast worksheets were presented for use in constructing forecasts during a one hour forecast exercise.

DOWNBURST FORECASTING

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1. INTRODUCTION

Concepts and techniques presented in this laboratory session were directed at forecasters/meteorologists working in NWS Weather Service Forecast Offices (WSFO) and Center Weather Service Units (CWSU). Much of what was presented took into account current levels of technology within the field offices. However, where appropriate, participants were exposed to more recent and sophisticated approaches in anticipation of expected NWS modernization efforts.

Initial stages of the laboratory session focused on giving participants some introduction into downdraft physics as well as a broad overview of the various downburst-producing systems and associated environments. With this as a foundation, a suggested detailed methodology for arriving at a forecast of downburst occurrence was presented and subsequently applied to a well-documented case study. The laboratory session concluded with a brief discussion of effective wording of downburst potential in forecast products.

2. DOWNDRAFT PHYSICS

A downburst is a somewhat small and concentrated convective downdraft and, as such, should be subject to laws governing downward vertical motion. Following a discussion given by Doswell (1985), buoyancy, specifically negative buoyancy, processes play a major contributory role in generating and/or maintaining a downburst. Changes in buoyancy are brought about by changes in the vertical pressure gradient force. These forces, in turn, can be changed by altering either the gradient itself or the density of the air.

Changing the density of air parcels is the most common means of altering the vertical pressure gradient. Of course, density is affected by variations in both temperature (adiabatic and diabatic) and parcel constituents (mainly water vapor). As pointed out by Srivastava (1985), downdrafts are enhanced by small drop sizes (which evaporate rapidly), large liquid water content (which keeps the evaporative cooling process going), and an environmental lapse rate close to dry adiabatic (which offsets adiabatic warming in the descending air).

Physical processes play a role in downdraft enhancement as well. Water loading in environments of high liquid water content and strong instability contributes to negative acceleration of the air. As this acceleration commences, precipitation drag, or the transfer of a portion of the falling rain drops' momentum to adjacent ambient air, begins to operate.

Also included as a physical effect would be the contribution that vertical momentum transport might make to downdraft enhancement. This is known to be a major contributory factor in some of the larger downburst-producing systems, i.e.

those developing in environments conducive to severe thunderstorm development, where one or more jet streaks are present.

The processes contributing to downdraft, or more specifically downburst, generation and maintenance are summarized in Figure 1.

3. DOWNBURST SYSTEMS AND THEIR CHARACTERISTICS

It is natural at this point to think that if we are to have any success in forecasting downbursts, then we must know something about the weather systems that promote conditions of evaporative cooling, water loading, precipitation drag, and momentum transport. The systems that were discussed in the laboratory session and their associated characteristics are outlined in Figure 2.

The Spearhead Echo

The spearhead echo was first recognized by Fujita (1976) in the aftermath of the crash of Eastern Airlines Flight 66. According to Fujita, it is an isolated multicell storm that occurs in an environment of scattered cells of various size. The echo appears linked to high momentum air with low humidity that is entrained into the echo near its top. Part of the momentum is transferred into the vertical with the remainder contributing to horizontal translation of the echo downstream.

The entrainment of low humidity high momentum air into the storm top contributes to downburst generation through the penetrative downdraft process and the transfer of momentum vertically to the surface. Spearhead echoes generally move fast and straight with the downburst weakening as it progresses downstream.

The Bow Echo

The bow echo is an organized system that is generally part of a synoptic-scale squall line, mesoscale linear echo configuration or cluster, or combination of a supercell and weaker storms. Usually, it evolves through a process as depicted in Figure 3. Downbursts are most probable as the echo takes the form of a spearhead with a weak echo channel oftentimes developing at low levels in the area of strongest wind.

Being an organized storm system, this type of echo develops in an environment that supports the generation of severe thunderstorms. In other words, usually there is a marked low-level and upper-level jet present, high instability, high precipitable water, moderate wind shear, and a layer of dry air at mid levels. The generation of downbursts are brought about by the penetrative downdraft process and the transport of momentum from mid and upper levels toward the surface. Downbursts from these type of storm systems usually are macro in scale (often 20 km or more across).

Shallow High-Based Convection

Downbursts from shallow high-based benign-looking convective clouds are common across the High Plains. The environment is one of elevated moisture (usually around 500 mb) overlying an extremely dry and deep surface-based layer. The driving force behind the downburst is evaporative cooling in the dry subcloud layer. Although radar reflectivity is quite low (usually less than 30 dBZ), virga often is seen falling from the cloud base.

A great deal of success has been had in the forecasting of these

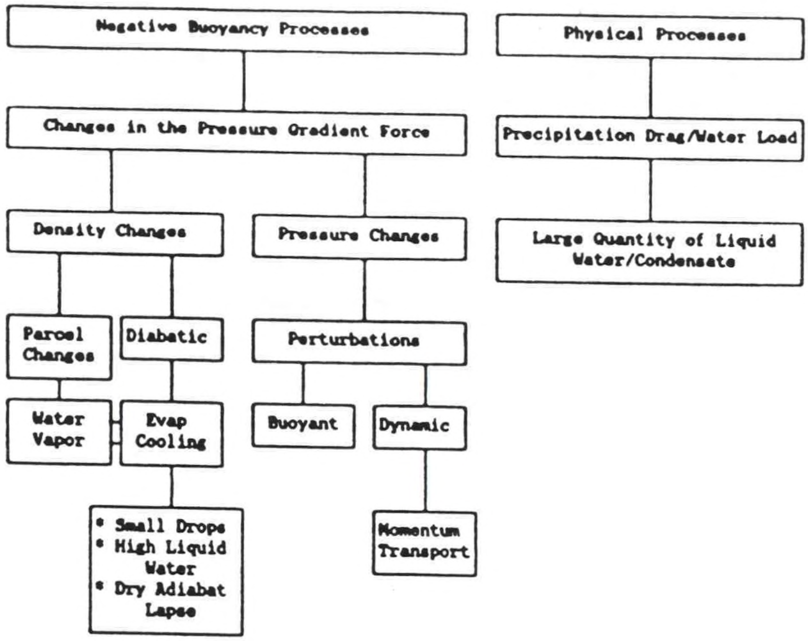

Figure 1. The processes contributing to downdraft generation and maintenance.

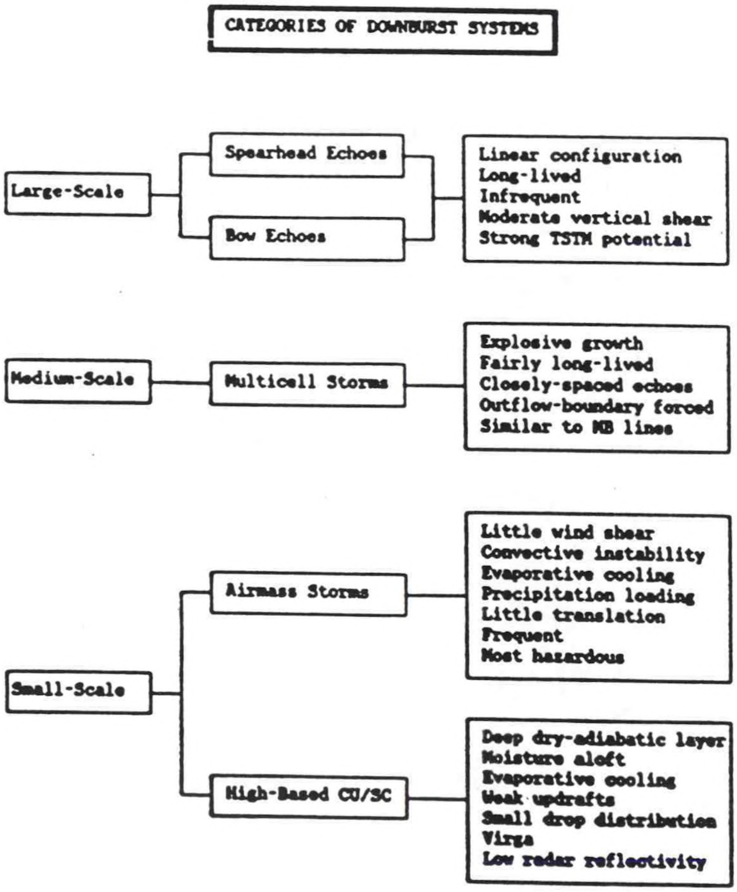

Figure 2. Downburst-producing systems and their associated characteristics.

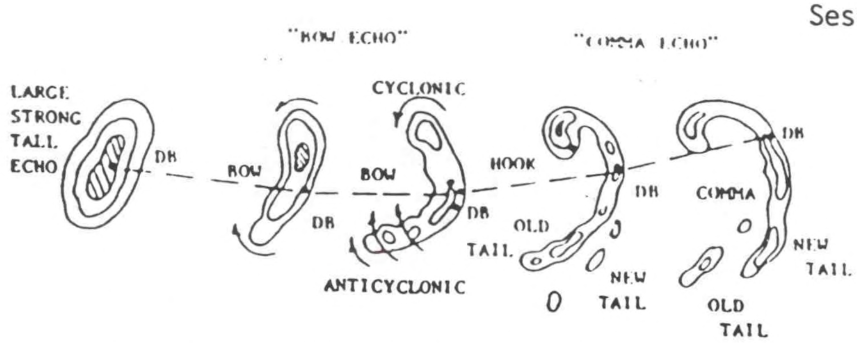

Figure 3. Radar depiction of the evolution of a bow echo. (After Fujita, 1976).

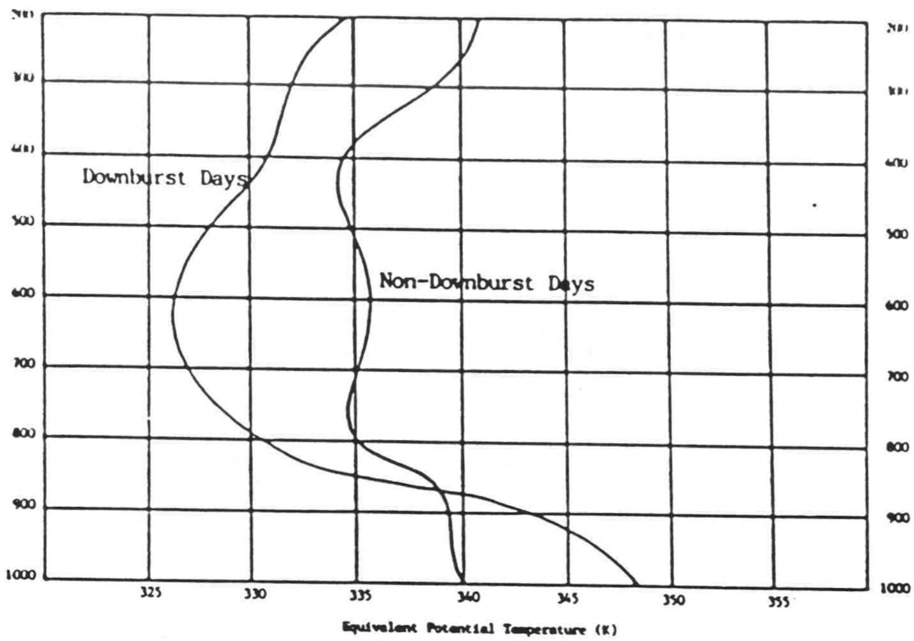

Figure 4. Vertical profile of equivalent potential temperature for downburst and non-downburst days. (After Atkins and Wakimoto, 1991).

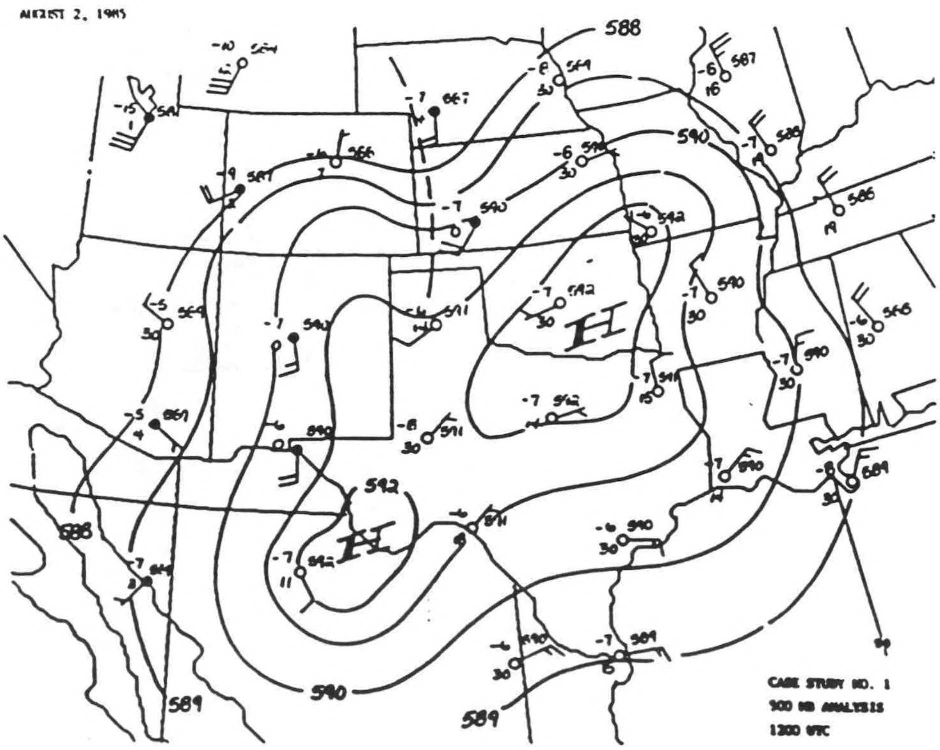

Figure 5. 500 mb analysis for 2 August 1985 at 1200 GMT.

types of downbursts. As a rule, forecasters can predict them with good accuracy by noting a dew point depression of greater than 8°C at 700 mb and less than 8°C at 500 mb.

The Microburst Line

These systems have been studied along the front range of the Rocky Mountains. Again, they appear to be associated with cloud systems that are high-based and shallow. They probably are initiated by sustained surface convergence brought about by orographic influences. They can cause major disruption of air traffic in and around an airport due to their long lifetime (usually on the order of an hour).

The Airmass Thunderstorm and Pulse-Type Severe Thunderstorm

These storm systems occur in an environment of high convective instability, high low-level moisture, and little or no vertical wind shear. In many cases, a distinct layer of much drier air is superimposed on the lower moist layer. Downbursts from these systems are of the wet type.

The penetrative downdraft process plays a significant role in downburst generation and maintenance in this environment. In addition, water loading appears to be important. As such, intense updrafts would be required which is supported by the large positive energy profiles often noted in many of these storms' soundings.

These are the least understood of the downburst-producing systems, yet recent studies and field experiments have begun to uncover some clues to their development and prediction. The most promising to date, appears to be a radar detection technique developed by Stewart (1991). The technique requires the examination of Vertically-Integrated Liquid (VIL) water content and radar echo heights as provided by the RADAP II system. These parameters are incorporated into a form of a vertical velocity or gust equation by Emmanuel (1981). The final gust estimate takes into account horizontal momentum transport in the lower 1.5 km (5000 ft) through the addition of the layer mean wind speed. The estimate was found to be quite accurate and aided the forecaster in warning for these wind storms that characteristically have lower VILs and echo heights than those of hail-producers. Lead time on predicting downbursts from these pulse-type storms was on the order of 20-30 minutes.

Read and Elmore (1989) noted very high reflectivity (VIP 5) aloft in downburst-producing storms. They observed that whenever this elevated VIP 5 core extended to at least 9 km (approximately 30,000 ft), the potential was very high for downburst occurrence and a warning should be issued. The resultant lead time was 5-10 minutes.

Another promising finding emerged from work by Atkins and Wakimoto (1991) in the Southeast U.S. They noted a significant difference in the vertical profile of equivalent potential temperature in downburst-producing storms versus non-downburst-producing storms. The different profiles are shown in Figure 4. Most apparent is the layer of rapid decrease in theta-e values for the environment of the downburst-producing storms, indicative of high convective instability.

6. AN APPROACH TO FORECASTING DOWNBURSTS

With a brief understanding of the types of downburst-producing systems, a systematic approach to downburst forecasting was presented to laboratory participants. The approach was geared toward the hybrid- or true wet-type downburst environments and consequently resulted from the work done by Read (1987) in North Texas and Rydell and Ladd (1991) in South Texas. Laboratory participants applied the approach to the forecasting of a well-documented downburst event; that of the Delta 191 accident at DFW in 1985.

The forecasting process can be broken down into two phases: assessing the potential for downburst development and determining the most likely location for downburst occurrence. Concentrating on the first phase, it too can be broken down into two sub-phases: a thermodynamic assessment of the atmosphere and a kinematic assessment of evolving features.

A good thermodynamic assessment of the environment naturally requires a close examination of sounding data. However, we first must make an attempt at narrowing the region of suspicion based on upper-level flow regimes and expected advection of properties. So, an analysis of the upper-level charts is a must.

Being that many downburst-producing systems are spawned by subtle features in an otherwise tranquil environment, it is important to carry out the height analysis at a 10-20 meter interval and the temperature and dew point analysis at a 2-3 °C interval. In the lower levels (i.e. 850 and 700 mb), location of convergence zones, temperature ridges and moisture axes are important. Higher up, the positioning and tracking of dry layers becomes vital.

For the DFW event, the most notable upper-air feature was the existence of a large dome of high pressure over North Central Texas which resulted in very weak flow (see Figure 5). High dew points were noted over East Texas in the lower levels with a wedge of dry air in the upper levels extending from West Texas across Oklahoma and into Arkansas. The upper flow pattern, despite being weak, could be expected to advect the dry air over the lower moist layer during the day. Thus, a characteristic profile for a wet downburst event was establishing itself over North and East Texas.

Laboratory participants, now focusing on this region, shifted their attention to an examination of the Lake Charles (LCH), Longview (GGG), and Stephenville (SEP) sounding data. It is important to modify the soundings to take into account the expected afternoon maximum temperature, moisture content in the lowest 100 mb, and changes in the upper temperature and moisture profiles due to advection. Determining the Convective Condensation Level (CCL) and noting the degree of positive energy available on these modified soundings should follow. It was pointed out that with the advent of the Skew T/Hodograph Analysis and Research Program (SHARP) in the field offices, modification of soundings will become much easier.

All the soundings supported the possibility of downburst generation to some degree. However, the further west you went, the more definitive the sounding data became. The modified SEP sounding (Figure 6) exhibited high cloud bases despite high precipitable water, strong instability, little or no capping inversion and very dry potentially colder air aloft. Comparing the SEP sounding with some conceptual models of "dry-type", "hybrid-type" and "wet-type" downburst soundings (Figure 7), one can argue that the DFW event most closely resembles that of a hybrid-type environment.

An analysis of subcloud lapse rates ended the thermodynamic assessment and solidified in the forecaster's mind the region of greatest concern. High subcloud lapse rates (700-500 mb) have been positively correlated with downburst potential over the High Plains. Critical values appear to be 8°C/km or greater. However, owing to lower terrain and higher moisture content, subcloud layers across North and East Texas are more aptly represented by the 850-700 mb layer. The analysis (Figure 8) showed an axis of 8-9 °C/km lapse rates extending north-to-south across Central Oklahoma into North Central and Southeast Texas.

At this point, it was time to shift our attention to the surface chart. Paramount in importance was the detection and tracking of boundaries, development of temperature ridges, and increased moisture pooling (or convergence) into an area. It has been noted in the South Texas study (Rydell and Ladd, 1991) that downburst occurrence always occurred in what could be termed "second-generation" convection. In other words, outflow from a parent storm complex eventually triggered the downburst-producing thunderstorm. So, an hourly 1-2 mb analysis is necessary, as well as close monitoring of radar and satellite, to detect and track these outflows.

This proved necessary in the DFW event. A strong and persistent line of thunderstorms was evident along the Red River and into Northwest Louisiana throughout much of the day. This line was associated with a slow-moving cold front and was producing outflow. The outflow was moving south and west into North and East Texas. A well-defined surface temperature ridge was noted developing ahead of the outflow boundary with some evidence of dew point pooling occurring as well.

Noting the coming together of these features constitutes the major task during the second phase of the forecast. A conceptual model of composite surface features and the probable location of downburst occurrence (Figure 9) was presented at the laboratory session to assist the forecaster. The AFOS Data Analysis Programs (ADAP) charts should be ideal in tracking increasing instability, temperature and moisture convergence into an area. As an outflow boundary approached this area, the downburst could be expected to occur on the warm side in the vicinity of greatest moisture pooling. In South Texas, we must also note the role that additional boundaries, such as the seabreeze, may play in increasing the moisture convergence into an area.

All in all, the conditions associated with the DFW event fit the conceptual models (both surface and sounding) quite well. Most laboratory participants were able to zero in on the area a couple of hours before the downburst occurred. Thus, it was agreed that some skill in forecasting these type of events could be had given the time and attention to detail needed to accurately detect and track important features.

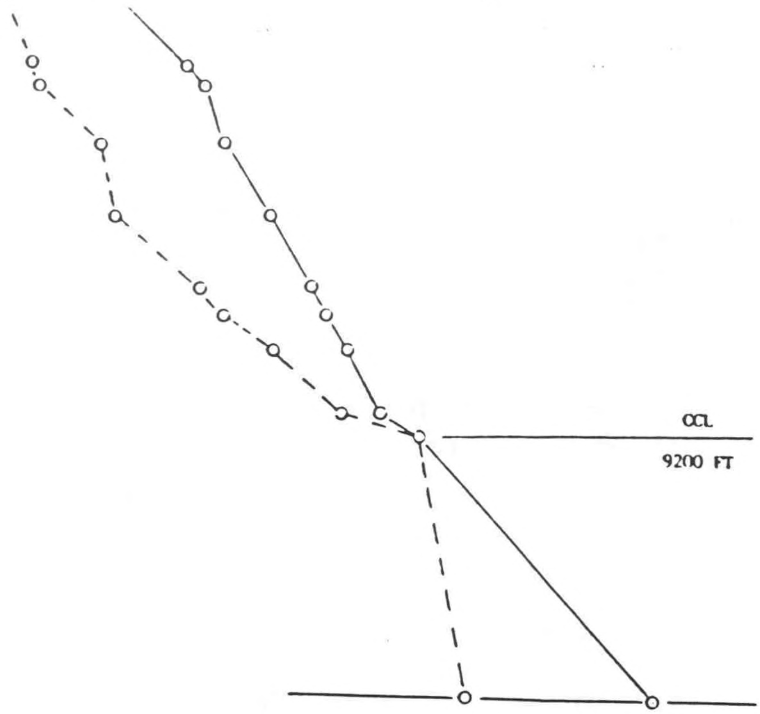

Figure 6. Modified sounding for Stephenville, TX (SEP) on 2 August 1985 at 1200 GMT.

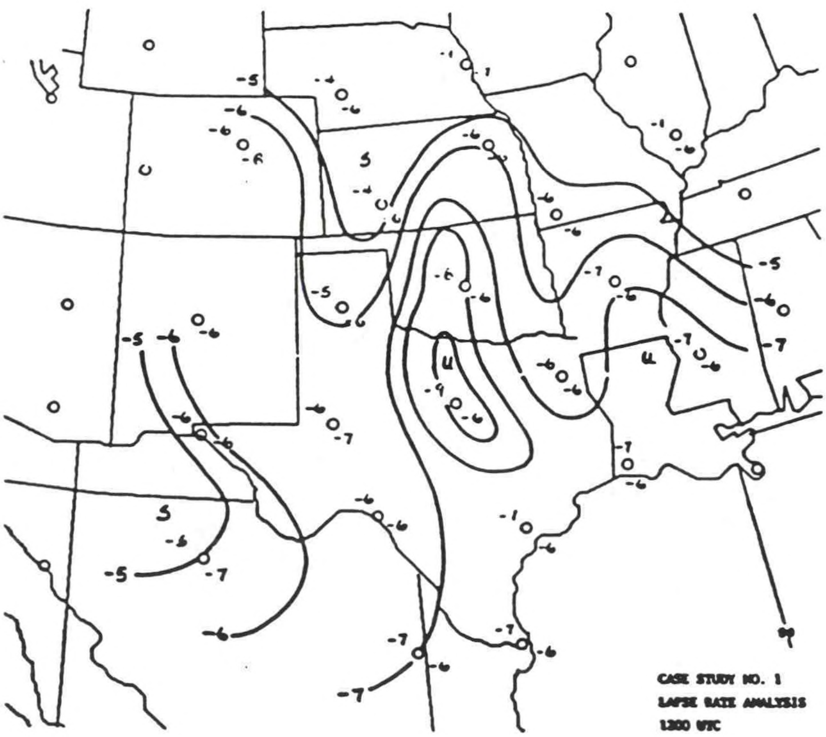

Figure 8. 850-700 mb lapse rate analysis (deg C/km) on 2 August 1985 at 1200 GMT.

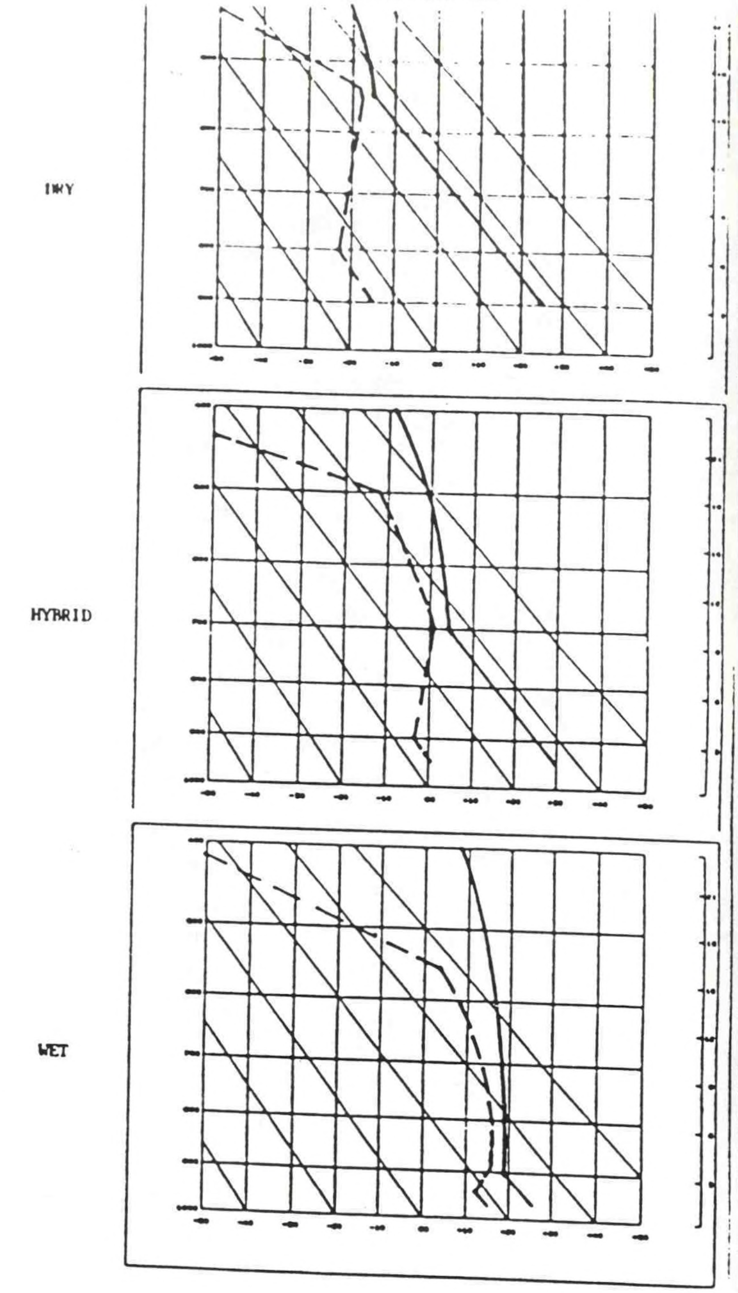

Figure 7. Conceptual sounding models for "dry-type", "hybrid-type" and "wet-type" downbursts. (After Ellrod, 1989).

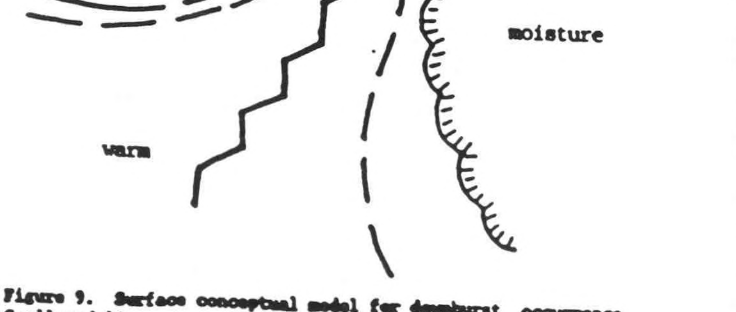

Figure 9. Surface conceptual model for downburst occurrence. Scalloped lines represent moisture, dashed lines temperature and hatched area probable location of downburst.

5. NOTING DOWNBURST POTENTIAL IN TERMINAL FORECASTS

The laboratory session concluded with a brief discussion of possible terms that could be used in airport Terminal Forecasts (FT) to alert pilots and controllers of downburst potential. Given that we are limited at present in noting downburst potential in our FTs, Read and Elmore (1989) explained that the forecasters at NWS Fort Worth (FTW) employed terms along the lines of the following:

FTW FT 021818 40 SCT 1808. 20Z 60 SCT 1408 SLGT CHC T+RW+ G55. 01Z 250 -SCT. 12Z VFR NO CIG.

This certainly would get the point across to aviation users.

However, over the High Plains, conditions are different. Often downbursts develop from rather innocuous high-based clouds. Perhaps, the following would be of some benefit to pilots and controllers:

DEN FT 021818 250 -SCT 1506. 21Z 100 SCT 1506 SLGT CHC R- G55. 01Z 250 -SCT. 12Z VFR NO CIG.

Thought has been given by some researchers to the establishment of a special aviation product for use in issuing a "Downburst Watch" or "Downburst Warning".

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AIRCRAFT ICING
Laboratory Session

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The ability to forecast aircraft icing has predominately been associated with the experience and savvy of the forecaster. Objective forecasting techniques were developed in the late 1950's and early 1960's by the U.S. Air Force using radar and analyzing Skew T plots. Those methods, though useful, were often time consuming, and more valuable for nowcasting than forecasting. Two new methods were presented. A case study was passed out to allow the participants to try Method 1.

Method 1:
This method has been used by some of the forecasters in the National Aviation Weather Advisory Unit (NAWAU) since 1984. This method utilizes model forecasts of the 1000-500 mb mean RH, the 1000-500 mb thickness, and vertical motion to delineate areas of potential icing. A supplement to this method was presented for cases where the cloud tops are low and the freezing level is at or near the surface using forecasts of boundary layer RH and 850 mb temperature.

Method 2:
This is an automated guidance product now available to NAWAU forecasters. Paul Schultz of NOAA's ERL developed this method and assisted its implementation at NSSFC. This procedure uses gridded model output of RH, temperature, and vertical motion. Contours of two icing threat categories are displayed over a satellite projection.

TURBULENCE FORECASTING

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National Severe Storms Forecast Center
Kansas City, Missouri

1. INTRODUCTION

One of the tasks of the area forecaster at the National Aviation Weather Advisory Unit (NAWAU) is to try and forecast the occurrence of moderate or greater non convective turbulence from the surface to 45,000 feet in his/her area of responsibility. The problem can be broken down into the forecasting of low level turbulence (surface to 15,000) and high level turbulence (above 15,000 feet to 45,000 feet). The forecasts of moderate turbulence are covered in the Airmet Tango series which is a regularly scheduled product and is valid for 6 hours with an outlook for another 6 hours. Forecasts of severe or extreme turbulence are handled by Sigmets and are issued as needed. The forecaster tries to keep the areas as small as possible both in horizontal and vertical extent while still adequately encompassing the phenomenon.

Forecasters have routine access to conventional surface and upper air data, satellite imagery (visible, IR, and water vapor) at half hour or hourly intervals, numerical guidance from the various operational models, the latest pilot reports from the area, wind profiler data and an interactive computer system (VDUC) which allows manipulation of current data (cross sections) and output from the various numerical models.

Some of the techniques that have been found useful in the forecasting of both low and high level turbulence over mountainous and non-mountainous terrain will be presented and briefly discussed. Because the NAWAU forecaster is also responsible for icing, IFR, mountain obscuration and low level windshear in his/her area of responsibility in addition to forecasting turbulence, these methods must, by necessity, not be labor intensive.

2. LOW LEVEL TURBULENCE

A. FORECASTING MOUNTAIN GENERATED LOW LEVEL TURBULENCE

CONVENTIONAL DATA

Much of the early work on the operational aspects of mountain generated turbulence was done by United Airlines in the 1960's and 1970's. Working with NCAR (National Center for Atmospheric Research) they devised a forecasting scheme (which as been modified somewhat over the years by the Air Weather Service) using wind directions and speeds, sea level pressure differences, and hourly weather which is still useful today. Figures 1A and 1B show the major mountain wave zones over North America and the critical directions and speeds that are needed to generate mountain wave turbulence while Figure 4 shows the pressure pairs in those zones and any corrections to the raw calculations that may be needed. At this

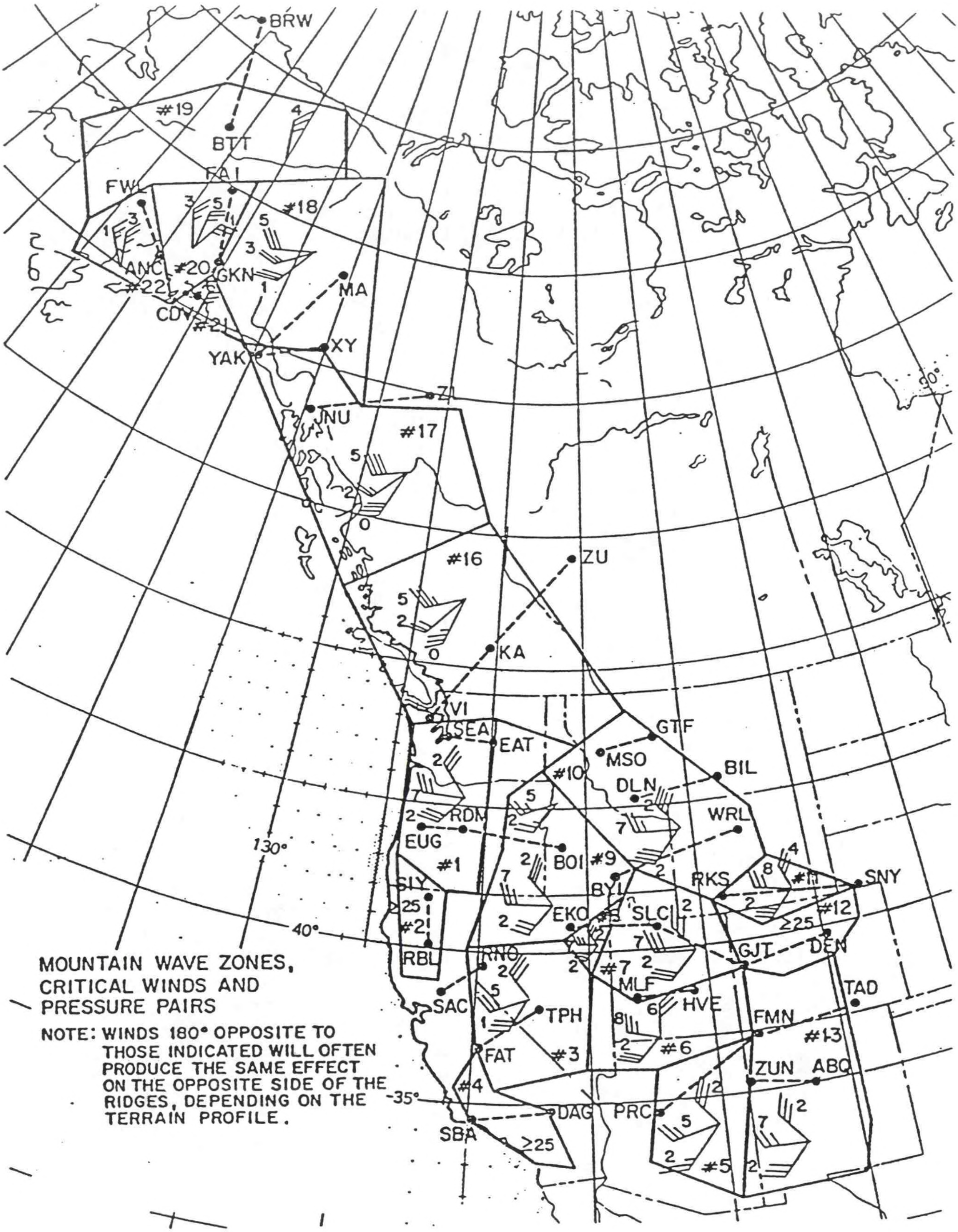
MOUNTAIN WAVE ZONES, CRITICAL WINDS AND PRESSURE PAIRS
NOTE: WINDS 180° OPPOSITE TO THOSE INDICATED WILL OFTEN PRODUCE THE SAME EFFECT ON THE OPPOSITE SIDE OF THE RIDGES, DEPENDING ON THE TERRAIN PROFILE.
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FIGURE 1A

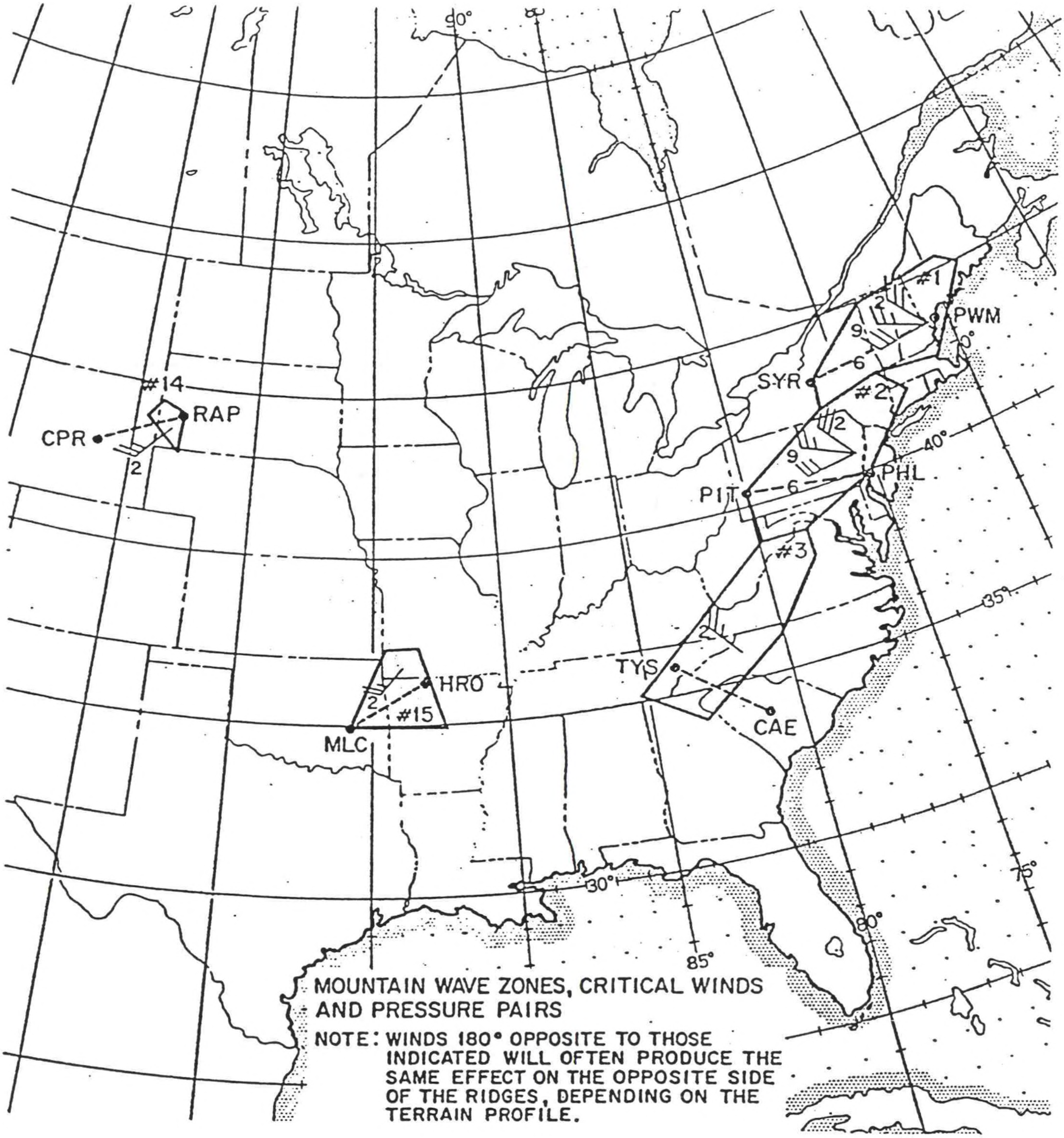
MOUNTAIN WAVE ZONES, CRITICAL WINDS AND PRESSURE PAIRS
NOTE: WINDS 180° OPPOSITE TO THOSE INDICATED WILL OFTEN PRODUCE THE SAME EFFECT ON THE OPPOSITE SIDE OF THE RIDGES, DEPENDING ON THE TERRAIN PROFILE.
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FIGURE 1B

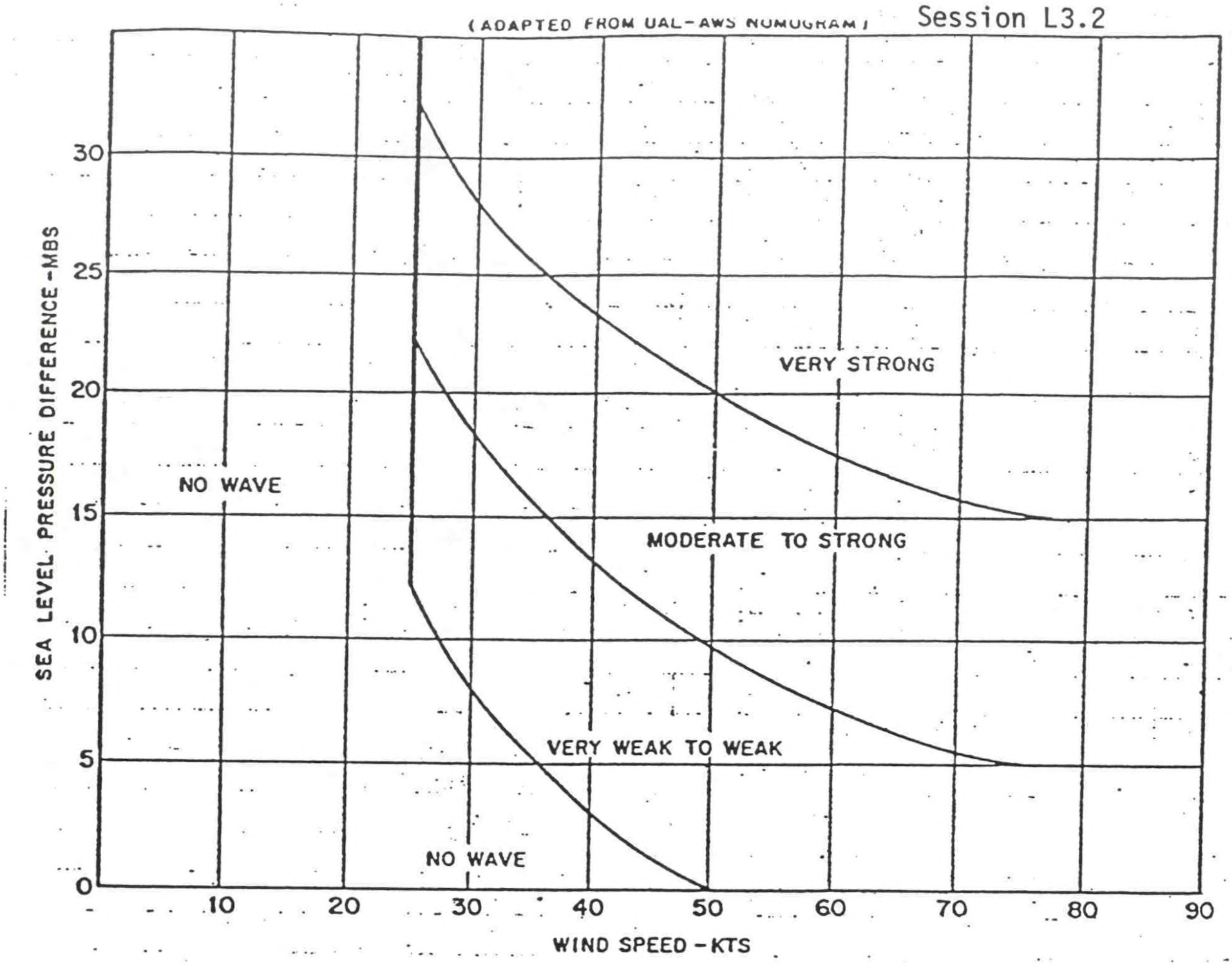


FIGURE 2

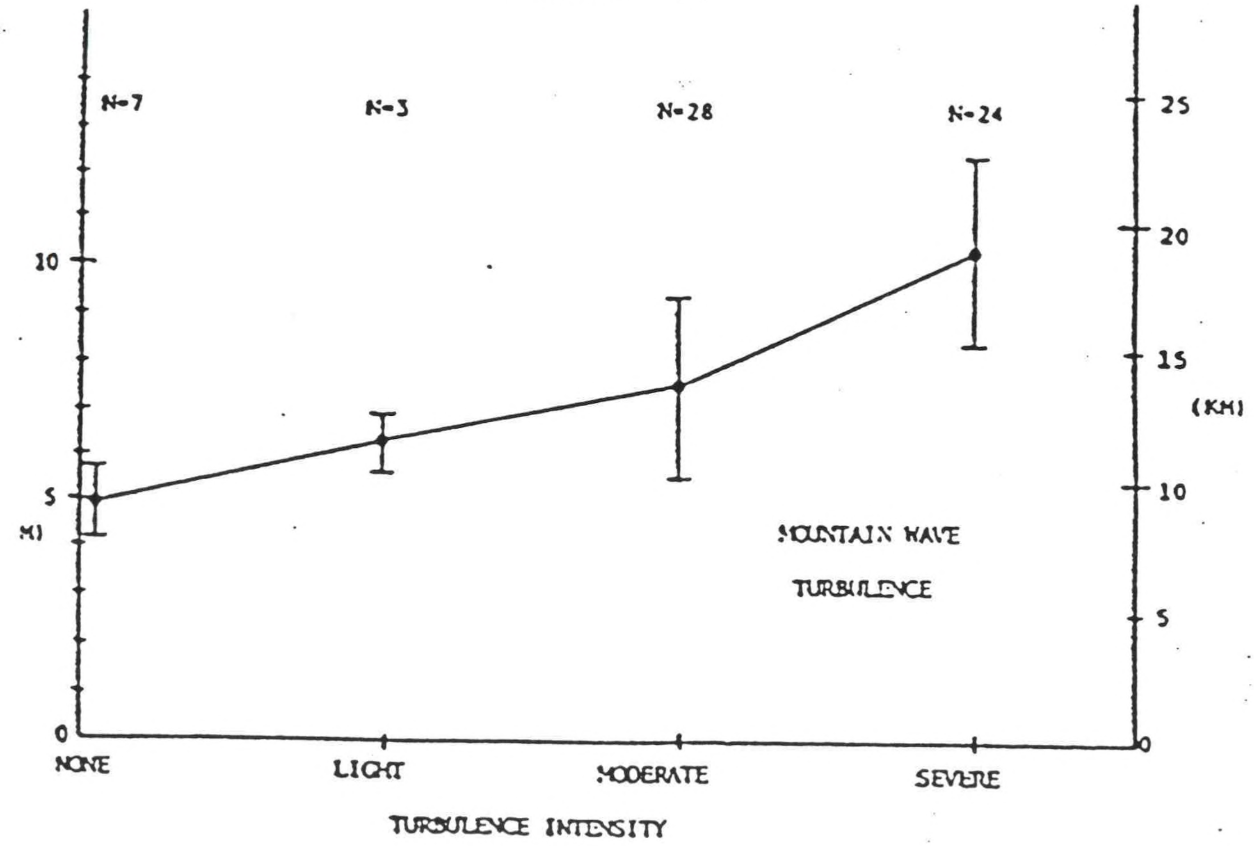


FIGURE 3

MOUNTAIN WAVE WORKSHEET

DATE_________ TIME______

ZONE	FD-1 MAX WIND 5-14K	STATION	FCST SLP	ΔP	COR. (MBS)	FINAL ΔP	MTN WAVE NOMO FCST	
1		SYR PWM			-4			
2		PIT PHL			-1			
3		TYS CAE			0			
14		CPR RAP			+1			
15		MLC HRO			+1			
	FD-1 MAX WIND 10-18 K							
1		SEA EAT			+4			
1		EUG RDM			+4			
2		SIY RBL			+4			
3		SAC RNO			+4			
3		FAT TPH			+2			
4		SBA DAG			+1			
5		PRC FMN			-3			
6		MLF HVE			+3			
7		SLC GJT			-1			
8		EKO SLC			0			
9		RDM BOI			-1			
10		MSO GTF			+4			
10		DLN BIL			0			
10		BYI WRL			-4			
11		RKS SNY			-4			
12		GJT DEN			0			
13		ZUN ABQ			+3			
13		FMN TAD			0			
16		VI KA			0			
16		KA ZU			-4			
17		JNU ZL			-4			
17		YAK XY			+1			
18		YAK MA			-4			
19		BRW BTT			-4			
20		FAI GKN			0			
21		GKN CDV			+4			
22		FWL ANC			+3			

FIGURE 4

point the distinction should be made that low level turbulence near mountains is not necessarily the same as low level mountain wave turbulence which can extend upwards to cruise levels.

The first step in the procedure is to determine whether or not low level turbulence (up to three thousand feet above the mountain tops) is expected near the mountains. Forecast low level turbulence if one of the following is forecast:

1. A temperature difference across the mountain range of 5 degrees C or more or a prominent warm air tongue over or to the lee of the mountains.
   a. Some wind component across the mountain range from colder to warmer air (direction not critical).

2. Temperature gradient of 5 C/150 NM or greater at 850 or 700 MB approaching the mountain range from the north or northwest.

3. UAL-AWS Mountain Wave nomogram conditions (Figure 2) are met calculating pressure differences either actual or forecast, applying the appropriate correction factor and using either observed or forecast winds aloft to find the forecast from the nomogram.

4. One of the following on the lee side of the mountains:

   a. Sharp warming surface temperatures with little or no warming upwind.
   b. Gusty surface winds.
   c. Pressure falling rapidly.
   d. Blowing dust picked up and carried aloft to 20,000 ft. MSL or higher.
   e. Rotor clouds are present.
   f. Broken or ragged-edged ACSL reported to the lee of the mountains.

The next step is to determine whether or not to forecast moderate low level mountain wave turbulence. In this step as opposed to the first, wind direction does become critical.

Forecast moderate low level mountain wave turbulence if:

1. The requirements for low level turbulence area met AND

2. The wind direction and minimum speeds are correct for the mountain wave zone (see Figures 1A and 1B).

Seriously consider forecasting severe low level mountain wave turbulence if:

1. Conditions for moderate low level mountain wave turbulence are met, <u>AND</u>

2. Winds over the mountain wave zones are 50 knots or greater at 500 MB over the Rockies and 40 knots or greater at 850 or 700 MB in zones east of the Rockies.

SATELLITE DATA

Quite often, careful inspection of the visible satellite imagery will reveal the presence of washboard pattern wave clouds over and downwind of mountainous terrain. In fact, this may be the forecaster's first clue that low level mountain wave conditions exist. Ellrod from the Satellite Applications Lab (NOAA/NESDIS) has developed a chart (see figure 3) which relates the average wavelength of low level mountain wave clouds to maximum turbulence intensity. One drawback to this chart is that it is for light aircraft only and may or may not be applicable to heavier transport type aircraft. That drawback aside, a combination of conventional surface and upper air data and visible satellite imagery can give the forecaster some good insights into the physical mechanisms that may be acting to produce low level mountain generated turbulence.

B. FORECASTING LOW LEVEL TURBULENCE OVER RELATIVELY FLAT TERRAIN

Forecasting low level turbulence in the central U.S. where the terrain is relatively flat presents a different challenge than forecasting in the mountains. **Observational evidence gained at NAWAU over the years indicate that strong low winds by themselves do not guarantee low level turbulence.** It appears that low level turbulence over the central U.S. can be divided into two main categories frontal and non-frontal.

FRONTAL TURBULENCE

Cold and warm fronts, their associated advection patterns, and their speed of movement are well known for generating low level turbulence over the central U.S. The strong advection patterns associated with them indicate an unbalanced atmosphere trying to come back into balance and turbulence is a method of energy release. In looking at frontal turbulence situations:

1. Identify frontal systems either in your area or expected to affect your area during the forecast period.
2. Note the strength the frontal systems by examining the temperature contrast across the front. The stronger the contrast the more likely turbulence.
3. Note the strength of the advection pattern associated with the frontal system.
4. Note the past frontal movement and expected frontal movement during the forecast period. The faster the front moves, the more likely there will be turbulence.
5. Pay attention to the air masses and their stability involved. There appears to much less turbulence associated with a fast-moving, strong temperature contrast, strong cold air advection arctic cold front whose air mass is inherently very stable than with a weaker Pacific cold front whose air mass is more unstable.
6. Usually can end the cold frontal turbulence with the passage of the trough or cold front at 700 MB.

NON-FRONTAL TURBULENCE

Experience at NAWAU indicates that most of the widespread low level turbulence over the central U.S. occurs in the warm sector away from the direct influence of the frontal systems and their associated windshears. This turbulence is more likely to occur on cloud-free days than on days with extensive cloud cover no matter how strong the low level flow is and decreases rapidly after sunset. It is suggested that in these type situations convective thermals act as obstructions to the air flow in a manner similar to mountainous terrain. The deviating wind results in turbulent eddies which are advected downstream and dissipate. In looking at non-frontal type turbulence situations:

1. Use conventional data and wind profiler data to identify areas of strong low level flow (25-30 knots or greater).
2. Identify areas of atmospheric instability that would allow strong thermals to develop.
3. Use satellite imagery to identify areas of little or no cloud cover that would allow enough solar heating to cause the thermals to develop.

3. HIGH LEVEL TURBULENCE

A. FORECASTING HIGH LEVEL NON-CONVECTIVE TURBULENCE

One of the more challenging aspects of aviation forecasting is the prediction of high level (15,000 - 45,000) turbulence that is not associated with convective activity. This turbulence may occur in clouds or in clear air but comes under the generic term of clear air turbulence (CAT). None the less, it does pose a hazard to the safe and efficient operation of jet aircraft. Although fatalities are rare with upper level turbulence serious injuries are not uncommon and there is a significant increase in fuel consumption during turbulent flights.

The problem in trying to forecast CAT is that we are trying to predict a micro-scale phenomena (horizontal dimensions ranging from 5 to 300 miles) that is highly transitory in nature with macro-scale upper air data taken at 12 hour intervals. Another problem is forecaster workload. The NAWAU forecaster is not only responsible for forecasting upper level turbulence but is also concerned with low level turbulence, low level wind shear, icing, ifr and mountain obscuration conditions. The NAWAU forecaster attempts to use conventional upper air data, satellite imagery, and numerical guidance to forecast upper level turbulence.

CONVENTIONAL DATA

Available twice a day at 00Z and 12Z, the NAWAU meteorologist attempts to make extensive use of conventional upper air data. Analysis includes:

1. Position of the Jetstream(s) and movements. Studies have shown that translating jetstreams are more likely to produce turbulence.
2. Position and orientation of the tropopause in relation to jetstream. Steeply sloping or falling tropopauses are more likely to produce turbulence.
3. Speed Convergence or rapid deceleration in the upper flow. Studies indicate

that there is a greater than 50 percent chance of severe turbulence with wind speed decelerations of 50 knots in 4 degrees of latitude or 450 KM.

4. Vertical Wind Shear. Long recognized as an important parameter, the value of 6 knots per thousand feet is still used.
5. Strong Thermal Gradients. Upper fronts are also needed to obtain high probabilities of CAT. Gradients of 5 degrees C per 120 NM or greater and a wind flow across the gradient (warm or cold advection in the upper levels) enhance the chances for severe turbulence.
6. Strong Negative Vorticity Advection appears to be more closely associated with CAT while positive vorticity advection appears to more closely related to convection.

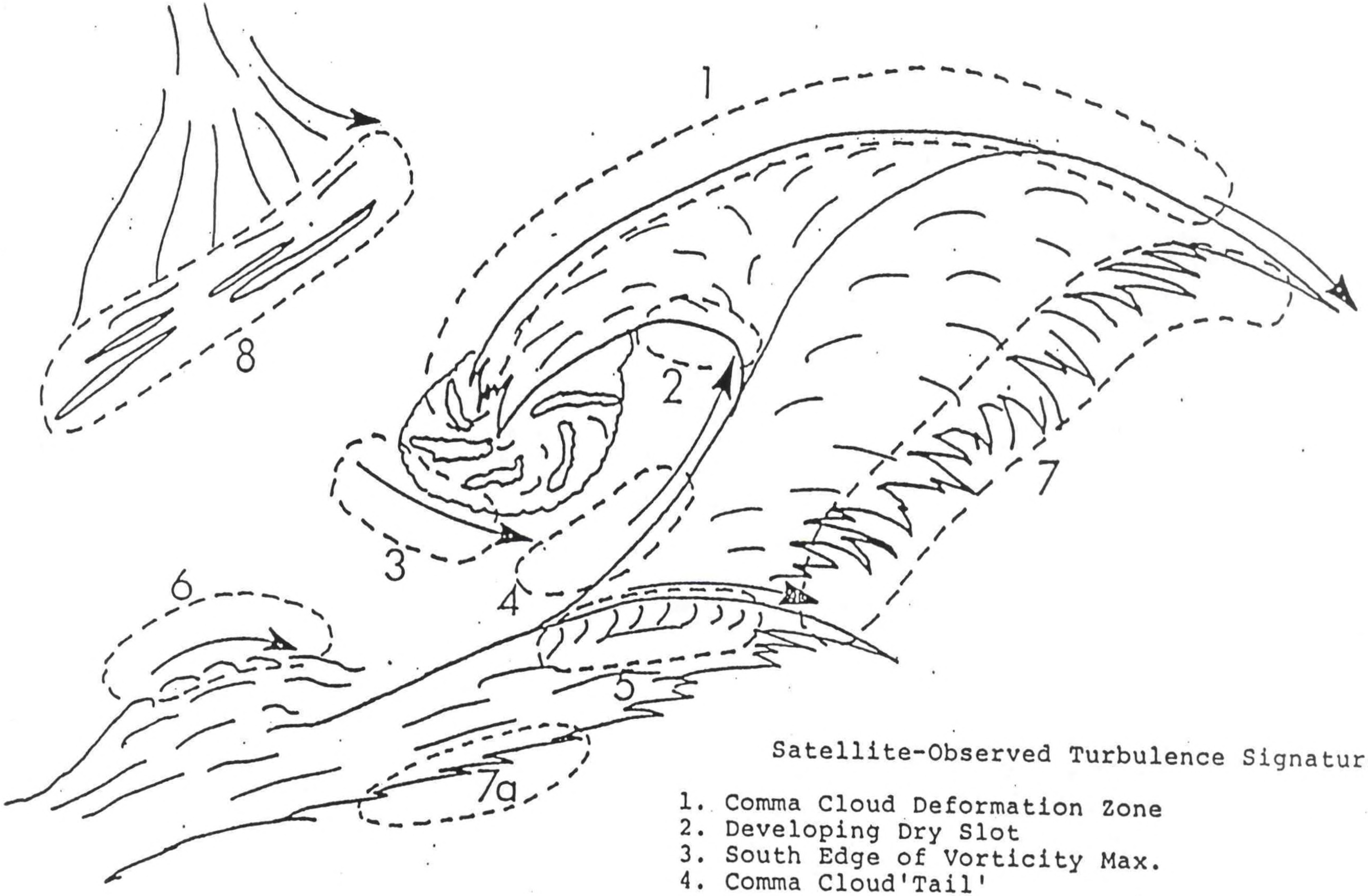
SATELLITE DATA

Although there have been many satellite signatures that have been identified with CAT, we will briefly discuss the four main patterns that can be readily identified on satellite imagery and are shown in figures 5 and 6. Most of the work on satellite signatures and upper level turbulence was done by Ellrod of the Satellite Analysis Branch (NOAA/NESDIS). These patterns are:

1. Sharp Anticyclonically Curved Bulges Along the Poleward Edge of Jet Cirrus (zone 6, figure 5). Usually related to a jet streak and its associated ageostrophic accelerations and decelerations. Turbulence normally occurs with wind speeds of 80 knots or more and extends from the crest of the bulge several hundred kilometers downstream.
2. Deformation Zones (zones 1 and 4, figure 5). More likely to be associated with turbulence during a developing cyclone or vorticity maximum, the development of a cut-off low or when an upper low opens up and lifts out when another trof approaches from the west. If the deformation zone has a favorable orientation with respect to the isotherms it becomes frontogenetical.
3. Developing Dry Slots (zone 2, figure 5). Occurs during cyclogenesis ahead of a jet max which is rotating through the upper trough.
4. Moisture Channel Darkening. Darkening with time in the water vapor imagery. This is not a precursor of the onset of turbulence but a pretty good indicator that turbulence is occurring. Figure 6 shows some of the common synoptic patterns in which darkening with time occurs in the water vapor imagery.

When evaluating satellite imagery keep several factors in mind.

1. Speed of movement of cloud features. The faster the movement of the cloud feature the more likely the turbulence. Speeds of



Satellite-Observed Turbulence Signatures

1. Comma Cloud Deformation Zone
2. Developing Dry Slot
3. South Edge of Vorticity Max.
4. Comma Cloud'Tail'
5. Transverse Banding
6. Sharp Bulge Along Jet Cirrus
7. Leading Edge of Baroclinic Zone Cirrus
8. Northwest Flow Deformation Zone

FIGURE 5

UPPER FLOW PATTERNS CONDUCIVE TO DARKENING IN MOISTURE CHANNEL

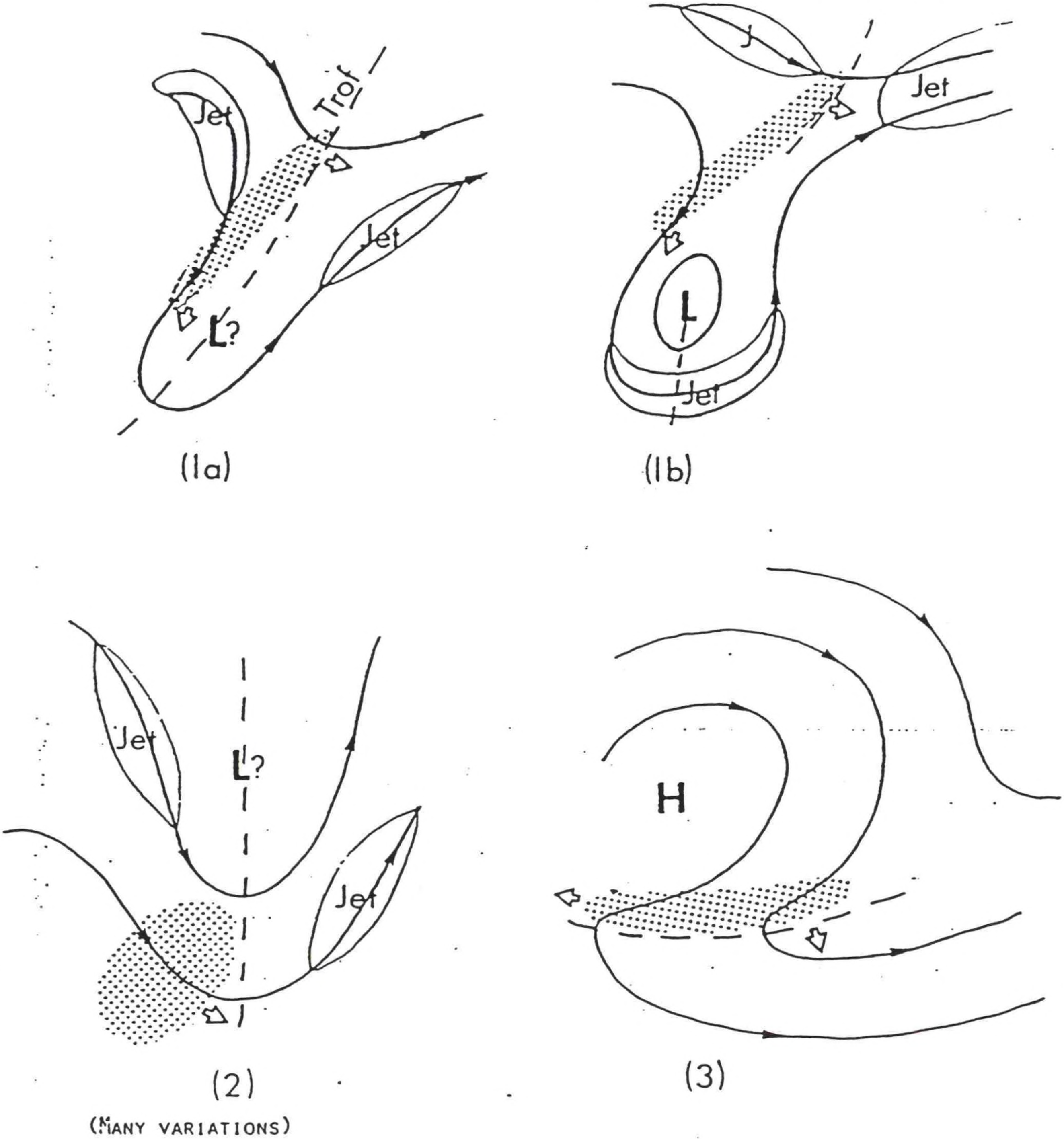


FIGURE 6

30 knots or greater appear to be very favorable for turbulence production.

2. <u>Sharpness of cloud boundaries.</u> The sharper the cloud boundary, the more likely the chance of turbulence. Physically speaking a sharp cloud boundary usually implies strong convergence and thermal boundaries at the upper levels. Deformation zones may exhibit a pulsating tendency first being rather diffuse, sharpening up as a jet max approaches from the southwest, then becoming diffuse once again as the jet max moves east of the area.

Figures 7 through 13 show a clear air turbulence decision tree based on satellite imagery developed by Ellrod of the Satellite Applications Laboratory.

NUMERICAL GUIDANCE

Ellrod from the Satellite Applications Laboratory (NOAA/NESDIS) has developed an objective technique for forecasting clear air turbulence based on the product of horizontal deformation and vertical wind shear derived from numerical model forecast winds aloft. At NAWAU this index is computed from both the LFM and NGM output for the 500 MB to 250 MB layer at 6 hour intervals out to 24 hours of the forecast and displayed graphically on the forecasters VDUC workstation (figure 14). Values of 4 or greater are considered indicative of a threat of moderate upper level turbulence. Generally the higher the number the greater the risk. The index has great value due to the fact that it is a forecast index rather than a diagnostic index.

B. FORECASTING HIGH LEVEL MOUNTAIN WAVE TURBULENCE

CONVENTIONAL DATA

Based heavily on work done by United Airlines in the 1960's and 1970's. Moderate mountain wave turbulence will extend to cruise levels if

1. Requirement for low level turbulence are met (earlier section and if

2. One of the following is forecast:
   a. The tropopause height versus temperature is in the shaded area of figure 15.

   b. The 200 MB isotherm configuration indicates a falling tropopause (strong warming upwind) accompanied or preceded by cold air advection at or below 500 MB.

Severe turbulence in the mountain wave should be considered if the above moderate mountain wave turbulence requirements are met plus one of the following:

1. Winds at 500 MB over the wave zone exceed 50 knots.

2. The thermal gradient in the falling tropopause configuration at 200 MB is 10 degrees per 150 NM or greater.

IV. TURBULENCE DECISION TREE

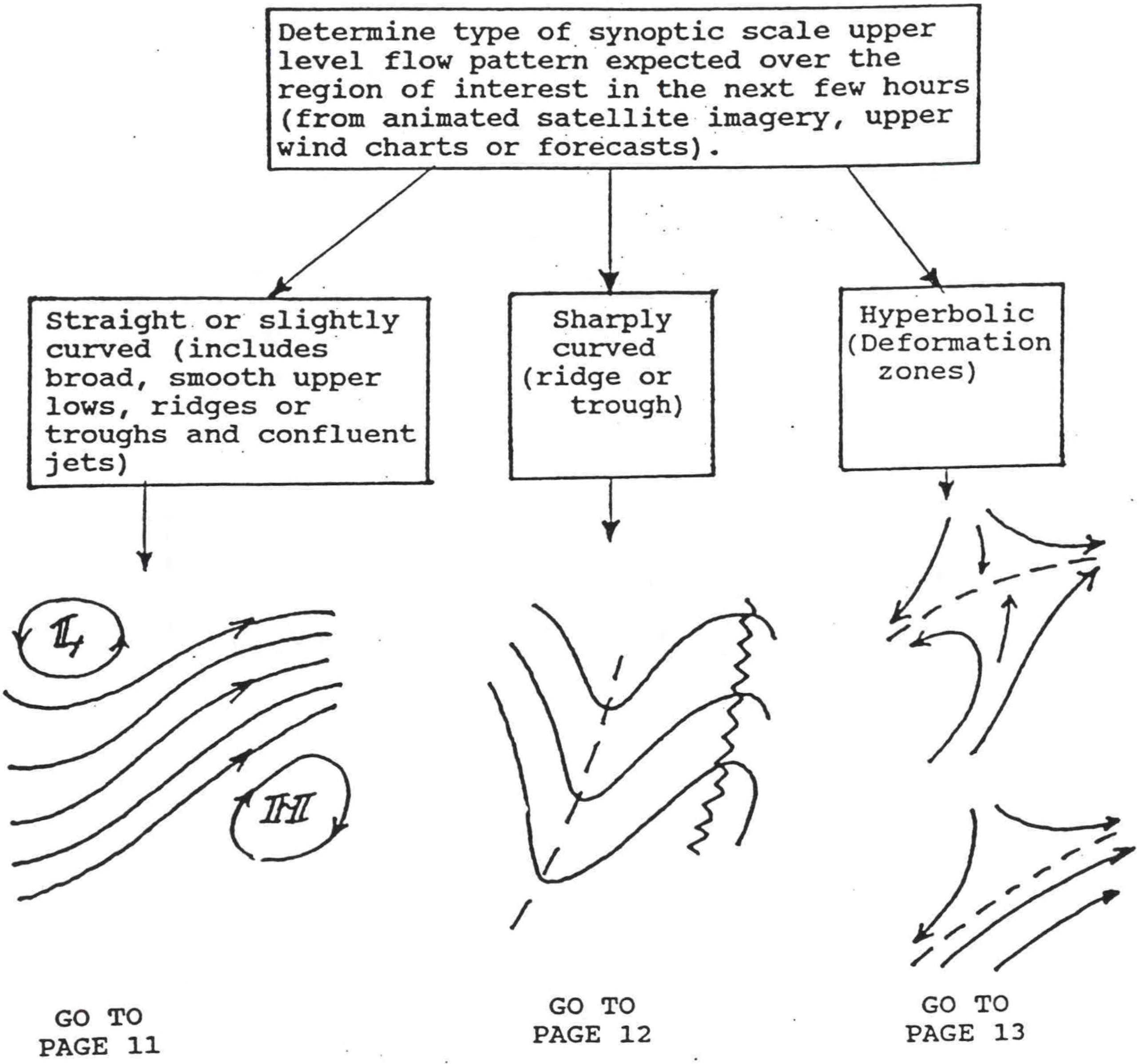


FIGURE 7

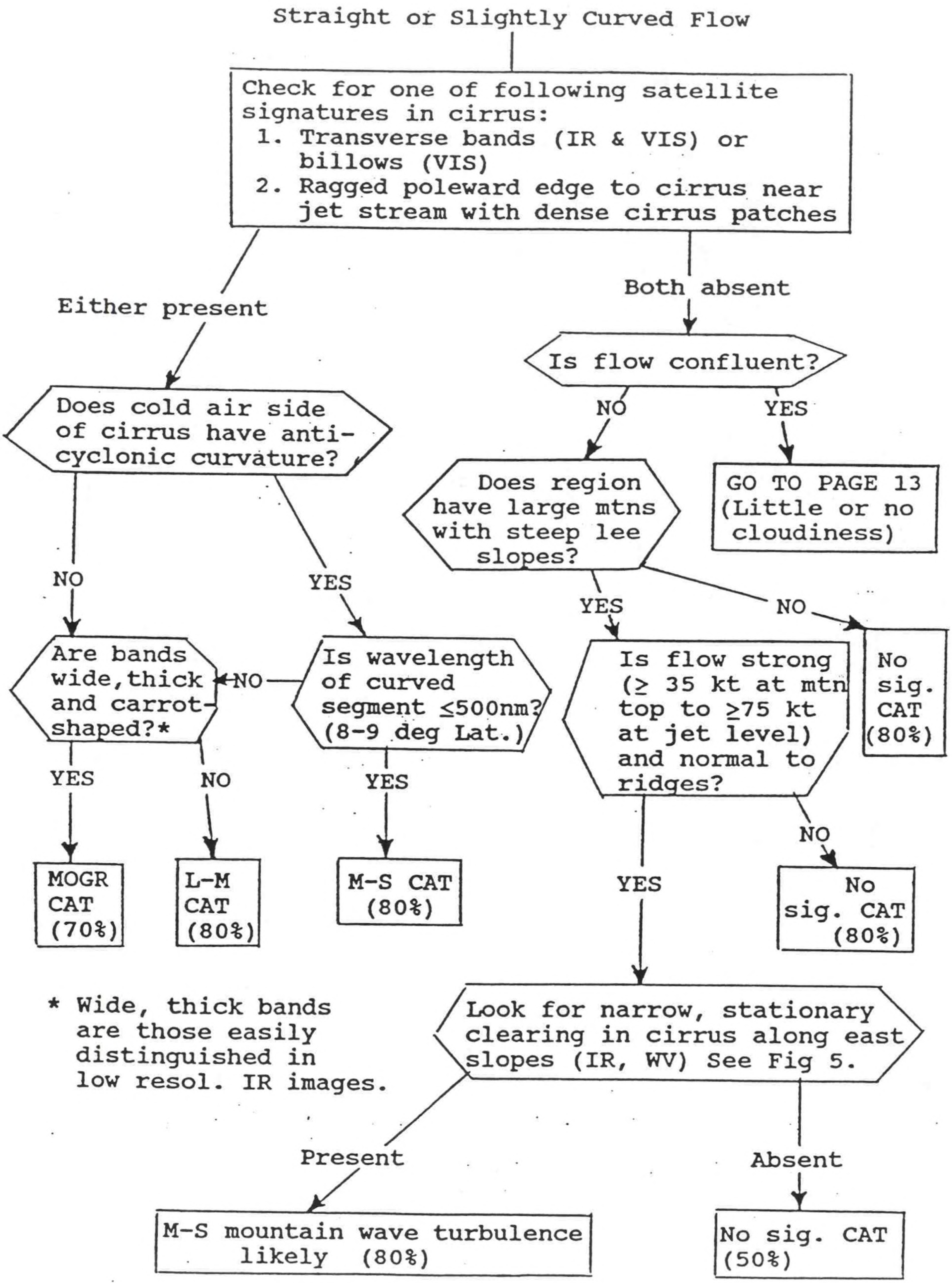
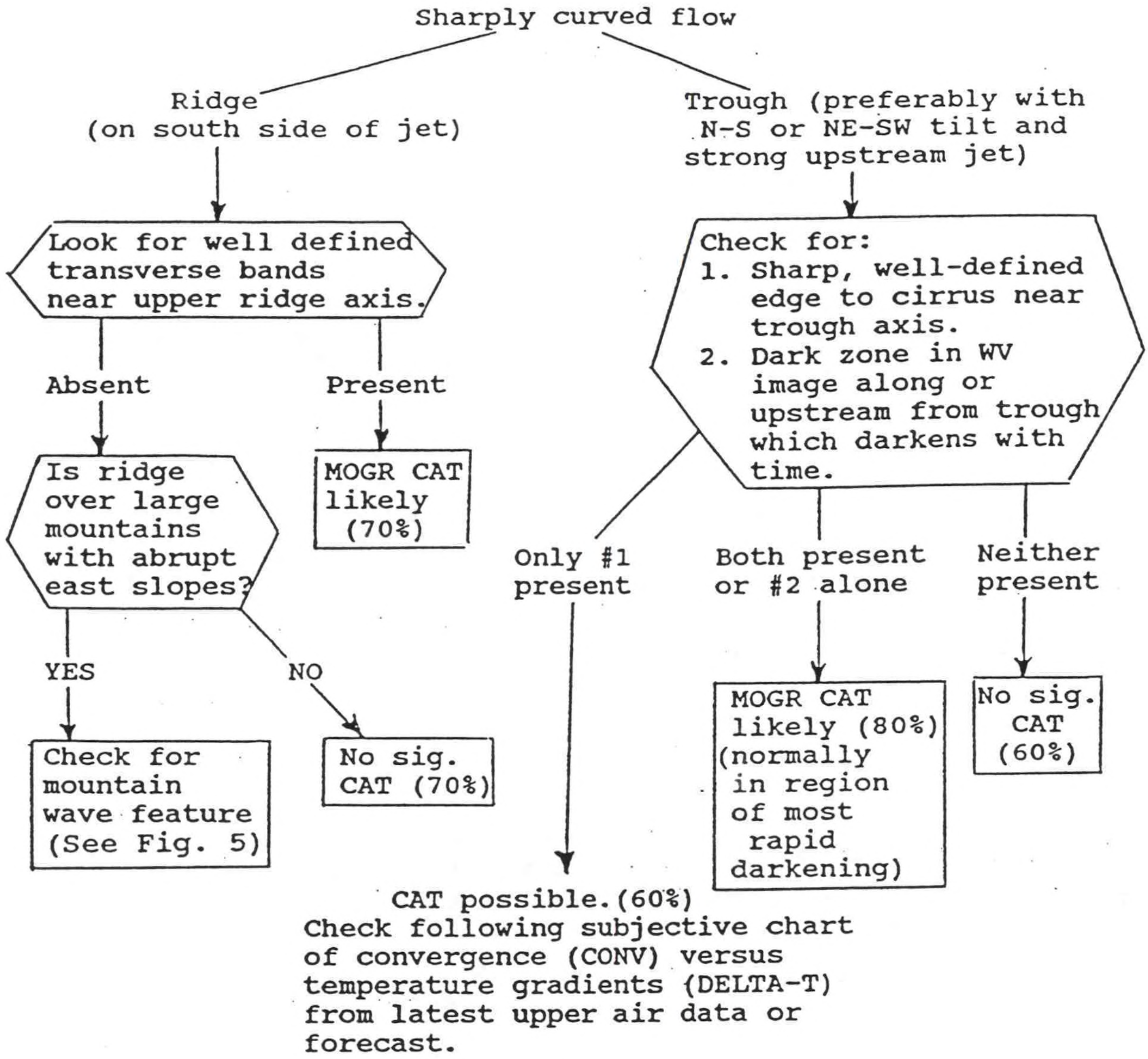

Straight or Slightly Curved Flow
Check for one of following satellite signatures in cirrus:
1. Transverse bands (IR & VIS) or billows (VIS)
2. Ragged poleward edge to cirrus near jet stream with dense cirrus patches
Either present
Both absent
Does cold air side of cirrus have anti-cyclonic curvature?
Is flow confluent?
NO
YES
Does region have large mtns with steep lee slopes?
GO TO PAGE 13 (Little or no cloudiness)
NO
YES
YES
NO
Are bands wide, thick and carrot-shaped?*
NO
Is wavelength of curved segment ≤500nm? (8-9 deg Lat.)
Is flow strong (≥ 35 kt at mtn top to ≥75 kt at jet level) and normal to ridges?
No sig. CAT (80%)
YES
NO
YES
NO
MOGR CAT (70%)
L-M CAT (80%)
M-S CAT (80%)
YES
No sig. CAT (80%)
* Wide, thick bands are those easily distinguished in low resol. IR images.
Look for narrow, stationary clearing in cirrus along east slopes (IR, WV) See Fig 5.
Present
Absent
M-S mountain wave turbulence likely (80%)
No sig. CAT (50%)

FIGURE 8



CONV [1]	DELTA-T [2]	CAT
Strong	Large	M-S
Strong	Small	M
Moderate	Large	M
Moderate	Small	L-M
Weak	Large	L-M
Weak	Small	None

1 Strong CONV is defined as a deceleration of about 50 kt (25 m/sec) in 4 degrees latitude. Moderate CONV would occur with about a 35 kt deceleration.

2 Large DELTA-T is $\geq 4°C/180$ nm (3 degrees latitude)

FIGURE 9

Deformation Zone Patterns

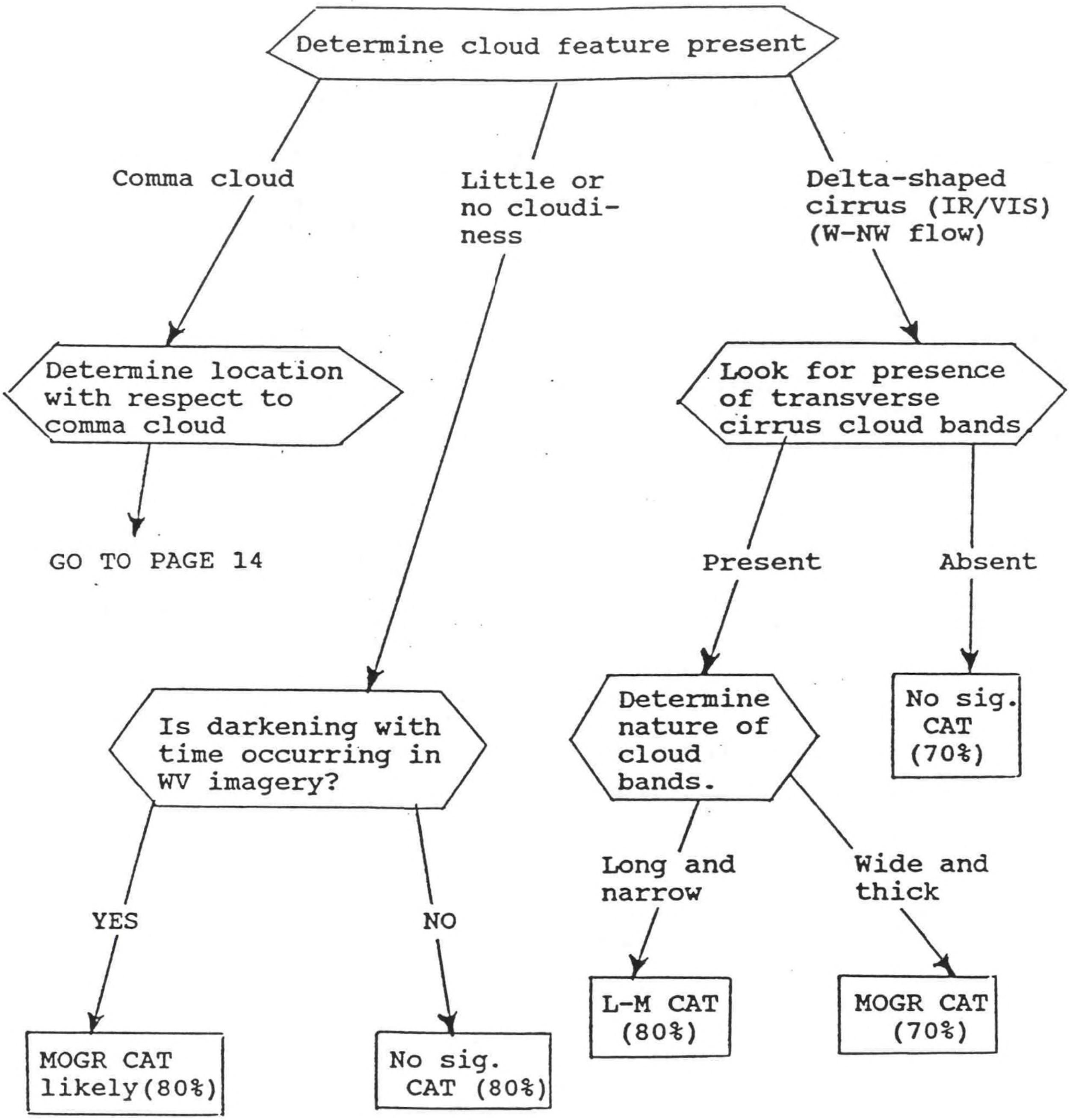


FIGURE 10

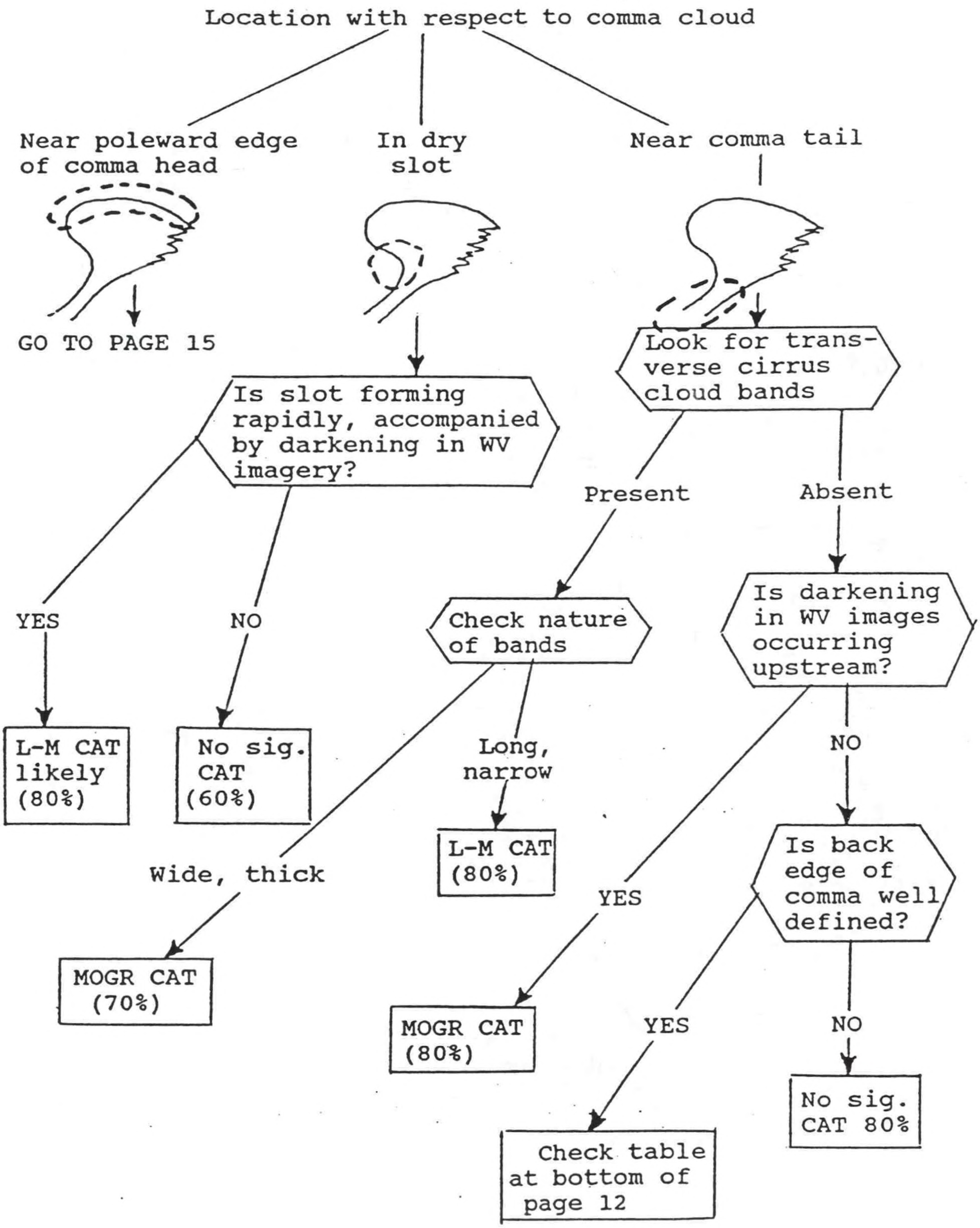
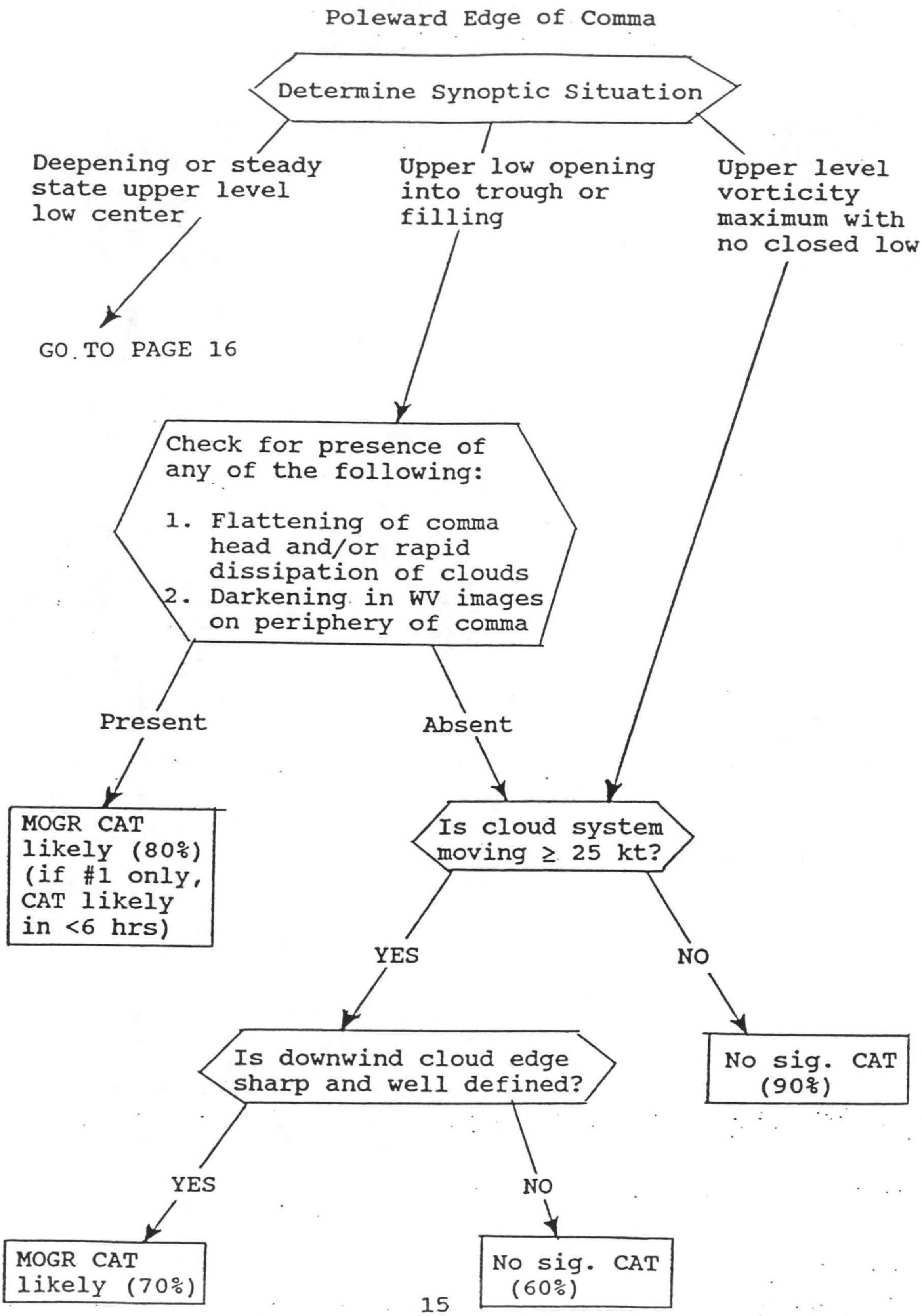

Location with respect to comma cloud
Near poleward edge of comma head
In dry slot
Near comma tail
GO TO PAGE 15
Is slot forming rapidly, accompanied by darkening in WV imagery?
Look for transverse cirrus cloud bands
Present
Absent
YES
NO
Check nature of bands
Is darkening in WV images occurring upstream?
L-M CAT likely (80%)
No sig. CAT (60%)
Long, narrow
NO
L-M CAT (80%)
Is back edge of comma well defined?
Wide, thick
YES
MOGR CAT (70%)
MOGR CAT (80%)
YES
NO
No sig. CAT 80%
Check table at bottom of page 12

FIGURE 11


Poleward Edge of Comma
Determine Synoptic Situation
Deepening or steady state upper level low center
Upper low opening into trough or filling
Upper level vorticity maximum with no closed low
GO TO PAGE 16
Check for presence of any of the following:
1. Flattening of comma head and/or rapid dissipation of clouds
2. Darkening in WV images on periphery of comma
Present
Absent
MOGR CAT likely (80%) (if #1 only, CAT likely in <6 hrs)
Is cloud system moving ≥ 25 kt?
YES
NO
Is downwind cloud edge sharp and well defined?
No sig. CAT (90%)
YES
NO
MOGR CAT likely (70%)
No sig. CAT (60%)

15

FIGURE 12

Developing or steady state
upper low with surface cyclone

Determine type of
comma system

Full comma

Check for one of the following conditions:

1. Cloud border well defined in IR or is becoming sharper with time.
2. Transverse bands or billows (VIS) near cloud edge.
3. Rapid movement of cloud edge (≥25 kt) toward clear air (occurs with building or rapidly propagating ridge)

One or more present

MOGR CAT likely along most of cloud edge, mainly just on clear air side. (2 or more 90% otherwise 70%)

None present

No sig. CAT (80%)

Sheared
(jet crosses over head cloud)

MOGR CAT possible from near crossover point to just east of downstream upper ridge. The presence of any of the following may be helpful clues:

1. Bands (in IR or VIS) or billows (VIS) near jet (80%)
2. Darkening in WV images north of jet. (80%)
3. Sharp, anticyclonically curved jet cirrus segments. (80%)

16

FIGURE 13

ELLROD INDEX

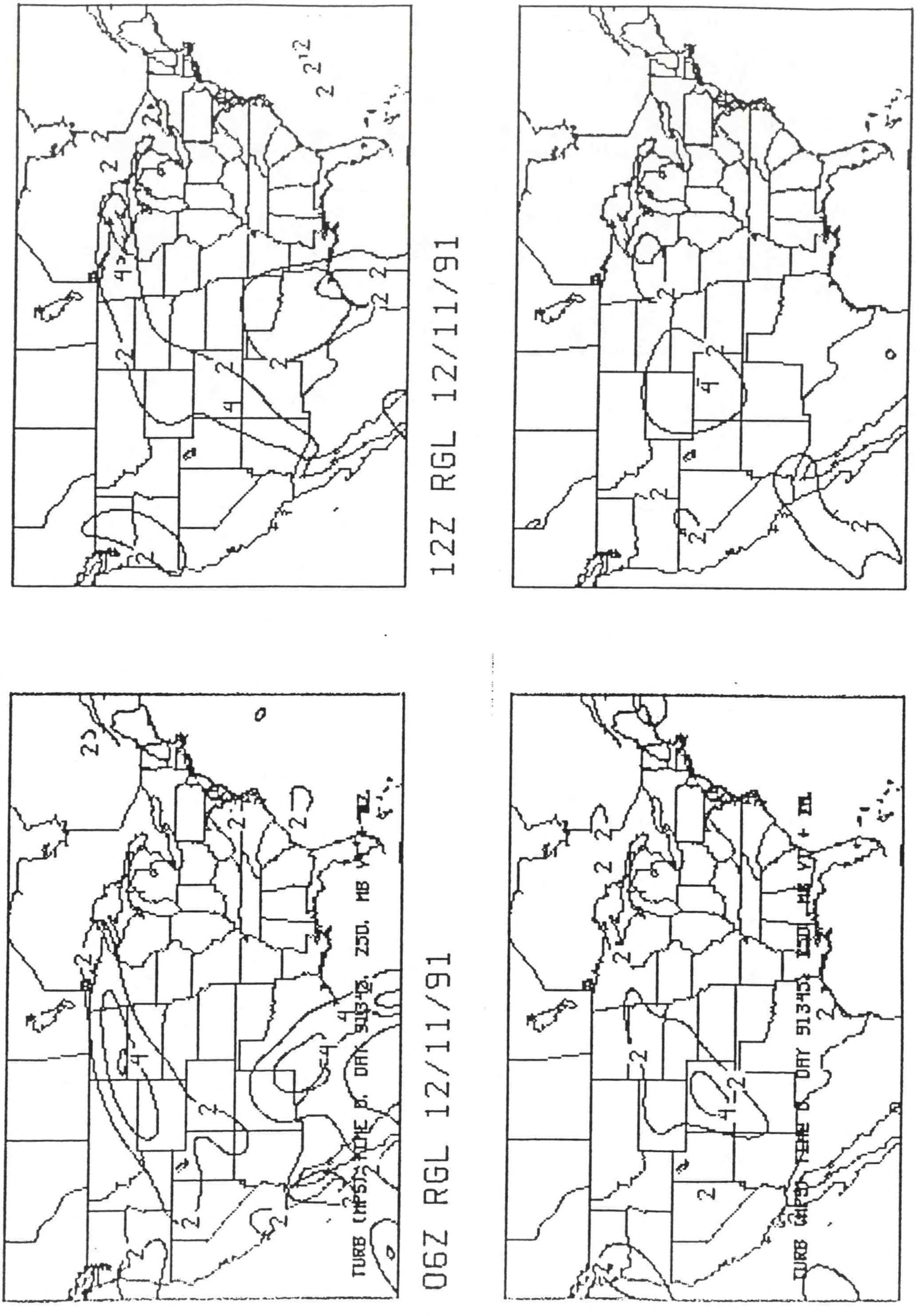


FIGURE 14

3. The tropopause versus temperature falls into the crosshatched area of figure 15. (Temperature -68 C or colder and tropopause below 150 MB.)

SATELLITE DATA

Ellrod (SAL, NOAA/NESDIS) has observed a satellite signature that distinguishes turbulent from non-turbulent high level mountain wave activity. He has noted that in some significant turbulence events the mountain enhanced cirrus has moved downstream from the ridge line leaving a sharply defined nearly stationary clearing zone just east of the ridge line with the most significant turbulence occurring in the western portion of the enhanced cirrus (figure 16). This differs from the non turbulent situation where the enhanced cirrus is right along the ridge line. Also, when the clearing zone ceases to exist, so does the significant upper level mountain wave turbulence.

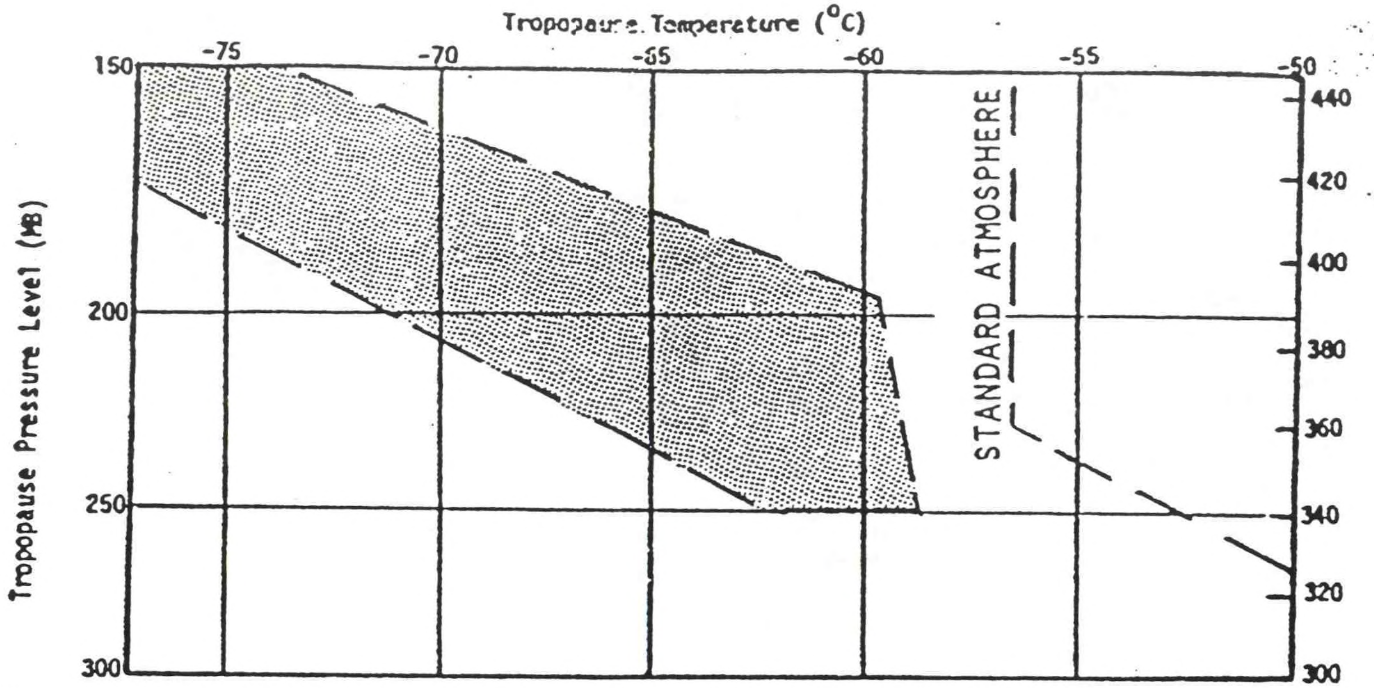


FIGURE 15

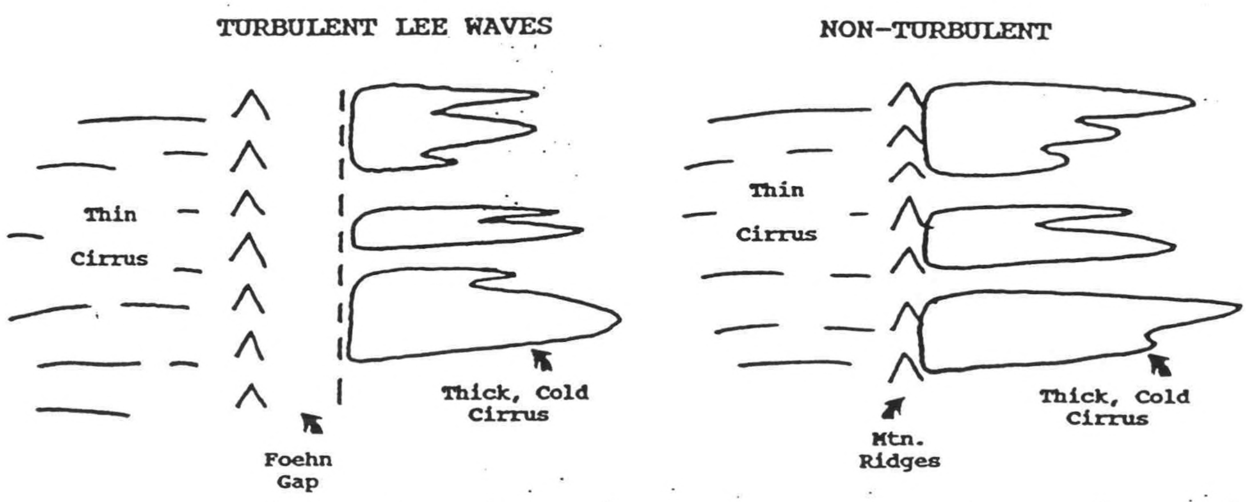


FIGURE 16

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