National Severe Storms Laboratory

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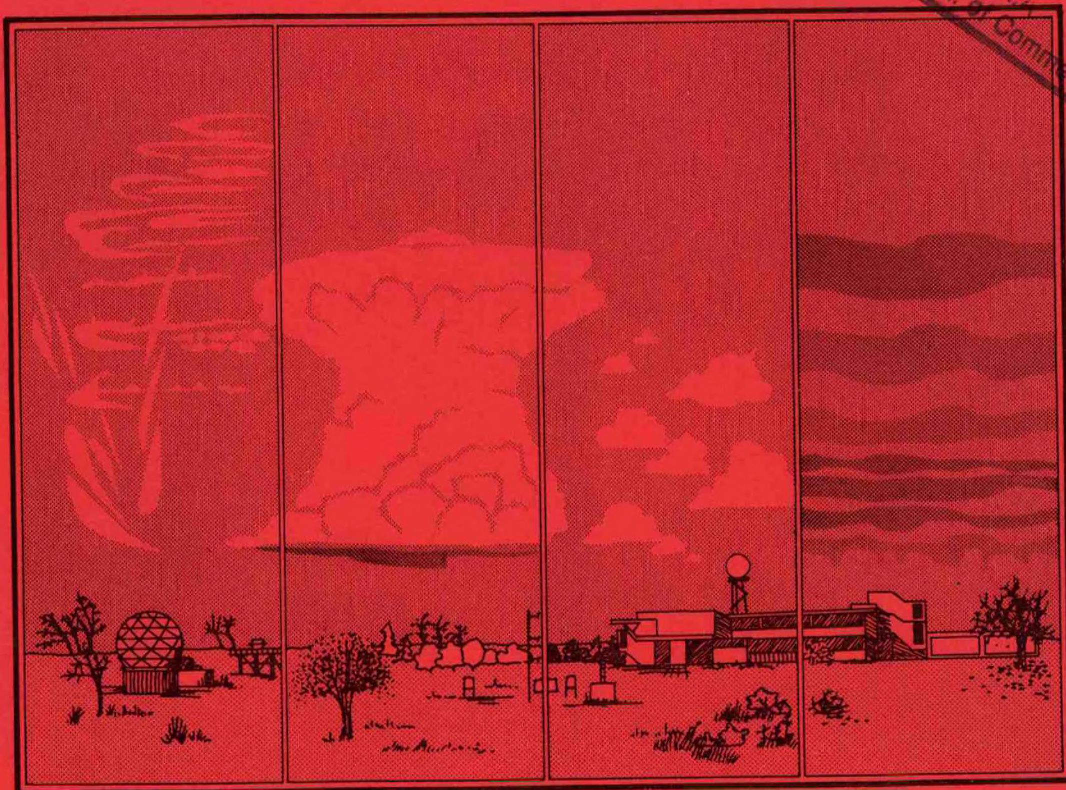

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NATIONAL SEVERE STORMS LABORATORY

ANNUAL REPORT - FISCAL YEAR 1987

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National Severe Storms Laboratory
1313 Halley Circle
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NATIONAL SEVERE STORMS LABORATORY

INTRODUCTION

Robert A. Maddox, Director

The National Severe Storms Laboratory (NSSL) develops improved means for weather observing and forecasting through studies of storm processes, numerical and conceptual modeling of storm phenomena, and applications of new technologies in remote sensing. New technological developments, new scientific discoveries, and new requirements are reflected in changing approaches to achieving the goals of accurate precipitation forecasts and storm warnings well in advance of events. Recent studies have drawn heavily on observations by Doppler radar and lightning-mapping systems, and we have developed more effective methods for using Doppler radar and lightning data for forecasts and warnings of severe storms. The work at NSSL, probably the most substantial precursor of the major national initiative NEXRAD, continues to support that program in critical ways. A major effort in the Laboratory is directed toward operational implementation of an effective national weather radar network for the late 1980s and beyond, in support of the NEXRAD (Next-generation weather radar) Joint System Program Office, Silver Spring, MD. The Laboratory worked extensively with the National Weather Service (NWS) and the NEXRAD program during an expanded Doppler/lightning experiment (DOPLIGHT-87); results from this project will facilitate the operational transition to a modern radar system.

The Laboratory's two 10-cm Doppler radars, on a 41-km baseline, provide unique capabilities for recording atmospheric circulations both in precipitating weather systems and in the optically clear boundary layer. A comprehensive range of instrumentation for measuring parameters of both in-cloud and cloud-to-ground lightning has been brought to a high level of refinement so that distributions of wind, water substance, and lightning can be recorded contemporaneously, and their interaction examined. Through numerous relationships with other government agencies and universities, NSSL constitutes a resource for severe-storm data examined by researchers around the country and overseas. NSSL directly participates in many research projects outside Oklahoma; for example, during FY 1987 NSSL staff participated in the Terminal Doppler Weather Radar field project at Stapleton International Airport, Denver, CO. During FY 1988, NSSL staff plan to participate in thunderstorm and hailstorm studies in North Dakota and wind shear studies in eastern Colorado. The laboratory will utilize the NOAA P-3 research aircraft and satellite data to study the destabilization of polar air masses over the Gulf of Mexico early in calendar year 1988 as part of a new effort to study larger-scale phenomena and circulations of importance to operational weather forecasting.

Other work at NSSL is providing a base in understanding to support deployment and use of national networks for lightning sensing. During two decades, NSSL has examined individual storm cases to garner knowledge of physical processes in convective storms. Our research efforts are starting to address the important problem represented by forecasting precipitation in the

0-24 hr range. During coming years increasing emphasis will be given to the expansion of research to include larger scales of meteorological phenomena, and to the incorporation of modern research workstations, wind profilers, and digital satellite data into case study analyses. The blending of data from diverse and asynchronous observing systems (e.g., Doppler radar, wind profilers, and satellites) must be accomplished if work is to progress rapidly in these areas. A laboratory plan of action to bring edge-of-the art capabilities for computing, data synthesis, and analysis to the Laboratory during the remainder of this decade has been developed and implementation begun.

SPECIAL PROJECTS - DOPLIGHT 87

Douglas E. Forsyth, Leader

The decision to relocate the Oklahoma Weather Service Forecast Office (WSFO) of the NWS to Norman was predicated upon perceived advantages of interaction and cooperation between an operational forecast office and a NOAA research facility, the National Severe Storms Laboratory (NSSL). The DOPpler LIGHTning (DOPLIGHT) project represents NSSL's first opportunity to increase the capabilities and efficiency of the WSFO through expanded integration of meteorological research activities and operational services. Although this project has occurred the past several years, this is the first year that DOPLIGHT has been given top priority within the Laboratory, involving over 70% of the staff and an operating budget of approximately two hundred thousand dollars.

The NSSL Norman Doppler radar was operated in a NEXRAD-like scanning strategy, and its use was dedicated solely to NEXRAD-related projects. The radar was operated during day shifts and swing shifts (i.e., approximately 11 a.m. to 11 p.m.) each day from 1 April through 15 June. The base-level processed reflectivity, mean velocity, and spectrum width fields were transmitted to the WSFO over a fiber optics link. Lightning strike data were processed and also sent over the fiber optics link for display in the WSFO. The Doppler fields were displayed in real-time in full color and at high resolution on three high quality terminals. In addition, several algorithms were executed in real time and the derived products displayed on a Chromatics 7900 color display system. The Radar Coded Message (RCM) was produced and transmitted to the WSFO every thirty minutes for manual editing and then distributed to the Air Force Global Weather Central (AFGWC - Omaha, NE) and the National Severe Storms Forecast Center (NSSFC - Kansas City, MO) over 9600 baud communications lines. The network TV stations in Oklahoma City were provided with processed Doppler data through a Personal Computer (PC) interface. These displays were used by the TV stations to present Doppler weather information to the public. The mobile laboratory and TOtable Tornado Observatory (TOTO) were used to gather ground truth data on algorithm signatures, e.g., mesocyclones, TVS, hail, gustfronts, etc. The NSSL mobile laboratory was also equipped with a Cross Chain Loran Atmospheric Sounding System (CLASS), provided by NCAR, that was used extensively to gather soundings of the atmosphere at other than routinely scheduled times and locations. The sounding information was transmitted back to the WSFO using amateur frequencies and packet radio technology. The sounding information provided both NWS and NSSL forecasters with updated information for making warning and storm intercept decisions.

The NSSL forecasters worked with the WSFO staff in producing the Oklahoma thunderstorm outlook, along with several other types of forecast, that were later verified. This exercise produced some interesting statistics; for example, it was found that the late evening forecast for the next day's convective weather was essentially just as accurate as the forecast prepared during the next morning. The NWS, IOTF, and NSSL all feel that DOPLIGHT 87 was a successful project that provided new NEXRAD-type data for a wide-variety of interesting weather, although very little intense, severe weather occurred in Oklahoma. The data collected will enable NSSL and NWS scientists to increase their understanding of severe weather and provide data bases for continued study of the performance of NEXRAD algorithms. Additional details and findings are described in the DOPLIGHT 87 summary and preliminary results, available upon request from the Laboratory. Since NEXRAD program plans will bring the operational prototype to Norman for acceptance testing next spring, this is probably the final year of operation for the DOPLIGHT project.

PROGRAM AREAS

METEOROLOGICAL RESEARCH GROUP

John M. Lewis, Group Leader

INTRODUCTION

Research in the Meteorological Research Group of NSSL encompasses a range of scales from larger synoptic phenomena to tornadic storm circulations. There is also a concerted effort to blend basic research goals with operational forecasting activities at the WSFO that is colocated with NSSL. In addition to the short discussions of work completed, two major efforts are underway, the GUFMEX and mesoscale data assimilation. These projects are summarized briefly.

RECENTLY INITIATED PROJECTS

Gulf of Mexico Experiment (GUFMEX)

The Gulf of Mexico has long been recognized as one of the major components in meteorological processes that contribute to high frequency of severe convective weather in the midwestern and eastern U.S.A. Nevertheless, the sparsity of data over this body of water has made it difficult to clarify the precise nature of physical processes that occur over and near the Gulf and contribute to the convective storms.

We have identified one aspect of the Gulf's influence that is poorly understood and impacts significantly upon the prediction of convective storms and rainfall in the midwest. The event in which we are interested is the "return flow" of cold continental polar or Arctic air that penetrates the Gulf in late winter and early spring, undergoes modification, and subsequently returns to the North American continent within a 3-7 day period. This return flow has continually baffled Gulf coast weather forecasters. With the advent of weather satellites, they have relied on visible and infra-red imagery to detect the stratus clouds that often are strung along the leading edge of the return flow. This does not always occur, however, and even when it occurs, characteristics of the return flow can only be approximated climatologically. Key characteristics are the depth of the boundary layer, the stability of the air and depth of the moist layer.

Intimately tied to the problem of forecasting the return flow is the rate at which the air mass is modified as it enters the Gulf. The character of the sea surface as well as the position of the warm Loop Current and its associated eddies are key to calculating the rate of moistening and heating that transforms the air mass from a continental one to a maritime one. Keeping track of air mass boundaries is important because the return air is quite likely a combination of the modified continental air and tropical maritime air that resides in the far reaches of the Gulf and oftentimes escapes modification or is beyond the area of both modification and reliable analysis.

In order to examine the processes that occur during the late cold season outbreaks, we have designed an experiment that will hopefully take place in the 45-day window between 1 February 1988 through 15 March 1988. The primary observational platform will be the NOAA P-3 aircraft of OAO and 45 hours have been set aside for this particular experiment. Flight plans are being finalized with the OAO, but briefly stated, they involved a mission to measure the synoptic environment as cold air plunges into the Gulf and also to make boundary layer measurements within both the cold and warm air sides of the air mass boundary. We then will wait for return flow to set up and attempt to measure the characteristics of this returning air along trajectories of the flow as it moves from the Gulf onto the continent.

The team of scientists involved in this project includes NWS forecasters, university and government research meteorologists and oceanographers, and engineering personnel. The basic team consists of five forecasters, nine research meteorologists, two oceanographers, and two engineering support people. Of these, five are ERL/NSSL employees, five are National Weather Service employees, two are Texas A&M faculty, three are from CIMSS/Wisconsin and NOAA/NESDIS, Wisconsin, one is from AOML/ERL, one is from NOS, and one is from NORDA.

Beside the P-3 aircraft, supporting upper-air observations are planned using the NCAR CLASS system. We hope to place three to four of these high quality sounding systems on either ships (U.S. Navy, U.S. Coast Guard, or NOAA Fleet) or commercial oil company platforms in the Gulf. We will also request special soundings from the Gulf coastal stations of the NWS.

Data Assimilation Research

We envision a significant, long term effort into the area of 4-D diagnosis and assimilation of diverse meteorological data. This, is of course, a very prominent research topic in the arena of operational numerical weather prediction. It has become apparent that the research community must also be concerned with the assimilation question, since meteorology has experienced a proliferation of new observing platforms that are inherently different, but that must be used in concert to describe the atmospheric state. The new systems that we are particularly interested in combining data from, are: the wind profiler network currently planned for the midwestern U.S.A., the NEXRAD Doppler network over the U.S.A. and data derived from satellites. These asynchronous data would be combined with conventional data from upper-air and surface networks.

We envision work with both hydrostatic and non-hydrostatic forecast models. The non-hydrostatic models would be used to study convectively active environments where Doppler data will be used to infer thermodynamic information in the convective environment. The hydrostatic model is intended for use in studies of larger-scale circulations associated with extratropical cyclones and fronts.

We hope to coordinate our efforts with others that are currently underway in ERL. In particular, we are hopeful that we will be able to cooperate with Wave Propagation Laboratory and Geophysical Fluid Dynamics Laboratory on research related to assimilation of wind profiler data into hydrostatic models. Since WPL has been doing work in this area with NCAR, we hope to join the effort and contribute to the development of improved schemes for assimilation, as well as, basic studies related to validation of profiler winds.

Work with the non-hydrostatic model and assimilation of data into the model are underway and will receive a boost with the addition of Dr. Hartmut Kapitza to our staff late in 1987. Dr. Kapitza has accepted a CIMMS post-doctoral fellowship and has already been involved in non-hydrostatic modeling at Forschungscentrum in Hamburg, Germany.

A significant part of our effort in 4-D assimilation will be related to designing adjoint models in direct association with the prediction models mentioned above. These adjoint models have been receiving scientific attention for the past five years and are just now being tested at operational centers. These models basically adjust observations, in a least squares sense, subject to the constraint that they satisfy the governing prediction equations. The adjoint set of equations provides a means of carrying observational information backward in time, in much the same way that forecast models take observational information and extrapolate into the future. This forward/backward process has been shown to be an extremely powerful tool in the research environment, but because of large computational requirements, does present problems for operational implementation, at least at the current time.

There are several centers of expertise in this area of research. The French meteorologists (notably Talagrand and LeDimet) have made strong contributions with research models and are just now working with ECMWF to try the methodology in operations. In the U.S.A., John Lewis and John Derber applied the methods to satellite data with success. Also, Carlisle Thacker at AOML used these ideas in ocean data assimilations. These three U.S. scientists are now all affiliated with ERL, and the effort at NSSL will draw upon the talents of these scientists to contribute to the solution of these problems. John Lewis and Hartmut Kapitza will be at NSSL, but make use of consultations with John Derber and Carlisle Thacker. We also have had visits from both Talagrand and LeDimet to NSSL this past year and will continue to work closely with them. John Lewis will visit France in 1988 as part of the NSF USA/France cooperative agreement to work on these adjoint problems. John Derber is also scheduled to visit France on this same proposal. Carlisle Thacker will be visiting Forschungscentrum in Hamburg (Kapitza's institution) as part of the cooperative effort to work in data assimilation.

RECENT ACCOMPLISHMENTS

Synoptic Scale Research

A project was initiated to examine significant tornado events in Oklahoma, to be conducted jointly with the OKC WSFO. The ten worst tornado days in Oklahoma during the past 30 years have been selected for study. Data are being collected for analysis, and analysis tools are being considered (e.g., the McIDAS workstation).

During DOPLIGHT '87, upper-air data were saved on PC-compatible diskettes, and these data have been run through the Quasi-Geostrophic (QG) package developed by Dr. Stan Barnes of ERL/WRP. By having a more or less package developed by Dr. Stan Barnes of ERL/WRP. By having a more or less complete archive of upper-air data for about 90 days, considerable insight into the application of QG diagnostics to operational forecasting should be possible. Other products were also archived to enhance the value of the DOPLIGHT '87 data set, including NMC surface and upper-air analyses, satellite images, NMC prediction model initial and 12-h forecast maps, etc. All these data have been filed systematically for review by cognizant NSSL scientists and OKC WSFO meteorologists.

Assistance was rendered to Fred Beeler, OKC WSFO Lead Forecaster, in his study intended to improve wintertime forecasting of dewpoint temperature and surface winds; these improvements would lead directly to more accurate minimum temperature forecasts. This study combines empirical relationships with limited statistical analysis, techniques that have been applied to other forecast problems successfully at the WSFO.

Mesoscale Research

Outflows from two mesoscale convective systems (MCSs) collided near Salina, KS, and propagated southward into a conditionally unstable atmosphere on 24 June 1985 during OK-PRE-STORM. It is well known that new convection often develops along such intersecting outflows. However, in this case, no new deep convection developed in the area of convergence along the colliding outflows. It is hypothesized that mesoscale subsidence occurred between the two MCSs as their upper-level outflows converged (Stensrud and Maddox, 1987). This sinking air appeared to help maintain a capping inversion at the top of a deepening moist layer and apparently was sufficiently strong to inhibit development of new convection, even in the face of strong low-level lifting.

An extremely rapid destabilization of the air mass over central and western Oklahoma occurred on 12 May 1985 during OK-PRE-STORM. This destabilization was more substantial than what might be expected given the morning soundings; however, numerous severe thunderstorms developed by 2300 GMT and produced five tornadoes, large hail, and strong winds. In collaboration with Ken Howard (ERL/ESG/WRP), this data set will be examined to determine the mechanism for the rapid destabilization. In a separate project using data from the same day (Burgess, 1986), it has been determined that the intense squall line in central Oklahoma was apparently triggered by a large outflow (macroburst) from weak showers in western Oklahoma. The outflow boundary was detected by Doppler radar. Squall line associated mesocyclones produced tornadoes in central Oklahoma. The environment of these mesocyclones is being investigated in collaboration with Dr. John Marwitz of the University of Wyoming, whose aircraft made measurements in the mesocyclone inflow region.

Work continues on the 10 May 1985 OK-PRE-STORM tornado outbreak in northwest Kansas just east of a stationary dryline. At stations in the dryline zone large oscillations in dewpoint are indicative of waves having a 150 minute period and 18 m s^{-1} phase speed. OK-PRE-STORM data are being analyzed to learn the roles that dryline and gravity waves, a low-level jet, an upper-level jet streak, and a strong capping inversion east of the dryline played in the outbreak.

Work continued on application of a dynamic retrieval method to Doppler radar data from a large squall line that occurred on 19 May 1977. A method was developed to ascertain the optimum reference frame for retrieval and other calculations. This is especially important since a steady state must be assumed. Reference frames essentially move along with the mesoscale system or subvolumes of the data analysis region. Preliminary retrievals of pressure and buoyancy in the line appear reasonable based upon current knowledge of physical processes involved and upon comparison with results of similar studies (Hane et al., 1987).

Analysis of the 8 May 1986 Edmond, OK, tornadic storm environment has been performed to determine why only one supercell storm formed, although convection was widespread across the state. Data from 24 special soundings indicate that an appropriate supercell environment occurred only over a limited area in conjunction with a small-scale atmospheric wave and surface mesolow. Diagnostic parameters to detect the supercell environment have been calculated for all the soundings. A Severe Storms Conference paper is in preparation.

Solutions of the cubic frequency equation for linear biconstituent diffusion processes were programmed. This work is designed to explore the application of biconstituent diffusion instability theory to certain atmospheric processes associated with the moist boundary layer.

An analysis of the interactions among static stability, vertical motion, and vorticity was begun. This effort is designed to seek a linear, inviscid process yielding a most unstable wavelength in the mesoscale range. The project is being carried out in collaboration with WRP and SUNYA scientists.

Thunderstorm/Tornado Scale Research

The performance of a supercompressible numerical model was evaluated (Droegemeier and Davies-Jones, 1987). In this model the fully compressible equations of motion are used, but the sound speed is slowed by artificially increasing the compressibility in the continuity equation, thus allowing longer time steps to be used. In small-scale meteorological models, the speed of gravity waves are little affected by this method.

The Beltrami flow model, used to provide insights into the pressure field around an axisymmetric rotating updraft (see NSSL Annual Report FY 86), has been generalized by solving the equations for the case where density varies with height. Results are qualitatively the same as, but quantitatively different from the constant density case.

Observations of the 20 May 1977 tornadic storms were used to evaluate recent theories on the initiation of rotation at mid- and low-levels, and the cyclic regeneration of rotation along gust fronts. It appears that the mechanism that initiates low-level rotation is different from that at mid-levels. Attempts to identify the source of the low-level rotation as vertical tilting of baroclinically-generated horizontal vorticity were inconclusive. Successive regeneration of mesocyclone cores along the gust front and discrete mesocyclone propagation appear to result from the concentration of low-level, preexisting vertical vorticity through convergence.

Observations of the 2 May 1977 tornadic storms were used to demonstrate the effects of streamwise vorticity on supercell morphology and persistence.

Streamwise vorticity and accelerating pressure gradient forces combine to organize and maintain the large-scale, persistent background, smooth updrafts and inflows that characterize supercells by inhibiting small-scale perturbations. Downdraft air possesses almost no streamwise vorticity and so is highly turbulent. Mixing of downdraft air into the storm's updraft is detrimental to supercells because it decreases the streamwise vorticity and increases turbulence in the updraft.

Norman National Weather Service Forecast Office staff were trained in interpretation of single Doppler radar in anticipation of DOPLIGHT '87. During the time period of DOPLIGHT '87 execution (15 March - 15 June), Donald Burgess, Arthur Witt, Edward Brandes and Charlie Crisp worked shifts in the National Weather Service Forecast Office radar room to help with Doppler interpretation and to observe the overall effectiveness of storm detection and warning processes.

Storm intercept teams under the direction of Robert Davies-Jones were used during DOPLIGHT '87 to observe severe weather events in progress and to report them to base. They also collected mobile surface and upper-air data in the field. The NCAR CLASS was tested as a fully-mobile ballooning system for obtaining soundings in fair weather, near and within thunderstorms. Its performance is currently being evaluated.

Some aspects of United States tornado climatology were explored. Charles Doswell and Donald Burgess have suggested that the co-called F-scale is most appropriately considered a tornado damage scale, rather than a tornado intensity scale. Further, they have indicated that many of the long-track tornado events in the climatological record are most likely made up of a series of intermediate- and short-track events. A publication is in press.

Development of advanced and updated Severe Storms Spotter training materials continues in collaboration with the National Weather Service Southern Region. Substantial progress has been made in developing a new slide series and preliminary research into a possible new spotter movie is underway. A paper on this topic has been accepted for presentation at the next Severe Storms Conference.

The chapter on morphology of individual thunderstorms and attendant phenomena for FMH No. 11 has been revised. The chapter provides information that will help radar interpreters use NEXRAD to identify threatening storms. Review of National Weather Service Remote Training Modules was performed. The modules were prepared by the NWS Training Center and are intended to provide the necessary radar background for NWS staff so that they will be ready to accept formal NEXRAD training.

An invited review paper (co-authored with Les Lemon) has been prepared for the Battan Memorial 40th Anniversary Radar conference. The paper deals with operational use of radar (conventional and Doppler) in severe thunderstorm detection and warning.

The use of conventional and Doppler radar as tools in mesoscale meteorology are explored in Burgess and Ray (1986). Fundamentals of radar design and signal processing are given. Application of radar to deduce meteorological information is provided with special emphasis on the contribution of Doppler radar.

Analysis and Weather Forecasting

A forecasting experiment was conducted during DOPLIGHT 87, with the intent being to serve the needs of the project and to form the basis for a scientific evaluation of forecasting for field programs. C. Doswell was the forecast team leader and the following people served on the forecast team:

Forecasters	Assistant Forecasters
C. Doswell	D. Stensrud
R. Maddox	K. Thomas
C. Ziegler	T. Schuur
D. Burgess	K. Nielsen
S. Vasiloff	R. Rabin

A verification of the DOPLIGHT 87 experimental forecasts has been completed. Results suggest some rather unexpected implications for forecasting in support of field experiments and, at the same time, tend to confirm other aspects of what we felt we knew (subjectively) about such forecasts. This verification study is being completed in collaboration with Dr. John Flueck of WRP and it is expected that a co-authored paper will be submitted soon for formal publication.

Forecasters for DOPLIGHT 87 were given training in AFOS in order that they be able to use the AFOS workstation dedicated to their purposes during the exercise. This also included the creation of informal handbooks on AFOS for quick reference. During a short NSSL Spring Program (15-30 June 1987), Don Burgess coordinated forecasting support for collection of specialized storm electricity and dual-polarization data sets. NSSL staff serving as daily forecasters in cooperation with Norman WSFO staff included: Donald Burgess, Carl Hane, Robert Rabin, and Conrad Ziegler.

In response to some requests from the OKC WSFO, an informal guide to the use of wind hodographs in forecasting convective storms was prepared. The guide contains basic presentations on hodographs and their use, as well as copies of relevant scientific papers for easy reference. Several other WSFO's have requested their own copies, and consideration of an appropriate medium for further dissemination is underway as soon as the guide can be finalized.

A guide to on-station research is being prepared, in cooperation with other ERL and NOAA groups (WRP, NESDIS, and NWS), to provide guidelines to those in the operational forecasting community who wish to conduct research projects. It was felt by the working group of researchers and forecasters that operational forecasters desire to study and solve some of their own forecasting research needs, and this guide would be an important resource for helping them plan and execute their local studies. It is expected that the guide will be published as an ERL Technical Memorandum.

A guide for interpreting Doppler velocity patterns has been completed, which contains a number of simulated Doppler velocity displays, with explanations. The guide is being expanded into a full-fledged training manual by adding sections with actual Doppler radar data examples and associated problem sets to help the users gain confidence in pattern interpretation. Also, a chapter is being added to show examples of real data problems such as ground clutter, anomalous propagation, side lobes and obscuration of radar echoes by superimposed, range-folded echoes (Brown and Wood, 1987).

A study of the role of mesoscale processes in severe weather episodes has been completed. This work distinguishes between "large scale" and "mesoscale" by defining large scale processes as those associated with quasi-geostrophic dynamics. Using a case study example, the separate contributions of large scale and mesoscale processes are examined. This work appears in Doswell (1987).

A report on the 1986 demonstration of the PROFS POWER workstation was completed and sent out for outside review. The 1987 SERS workstation was demonstrated during DOPLIGHT '87 and included both NSSL and OKC WSFO staff. A review of the data archived has been completed. A McIDAS workstation, connected to the mainframe McIDAS computers in Madison, WI, has been installed at NSSL. D. Stensrud is engaged in training NSSL staff in its use. Paul Menzel from NESDIS visited during the spring and lectured to NSSL, OU, and OKC WSFO staff on the VAS satellite sounding system.

Activity is underway to develop new, larger-scale analysis software for NSSL's VAX 11/780, including graphics programs, statistical analysis packages, etc. A copy of a 3-D recursive filter has been obtained from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at Madison, WI, and is presently being adapted for use by NSSL staff.

Comments on a recent article by W. Sangster in the Monthly Weather Review are being prepared. The substance of these comments includes some additional elucidation of the concept of geostrophic divergence at the earth's surface and some minor algebraic simplifications. Also, the issue of the relevance of the case studies cited in Sangster's paper is discussed.

Work has been completed, in collaboration with Fernando Caracena of WRP, on an examination of the interpolation of vector fields, concentrating on wind field applications. Results of the analysis show that it is important to recognize certain aspects of sampling theory if one wishes to preserve the kinematic properties of the wind field during interpolation whenever the data are gathered at irregular points and at marginal sampling density. This work is scheduled to appear in the Journal of the Atmospheric Sciences in December of 1987.

A preliminary study of the application of wind profiler data to certain diagnostic problems, done in collaboration with R. J. Zamora and M. A. Shapiro of WPL, has been completed (Zamora et al., 1987). This work has demonstrated the value of wind profilers in providing needed temporal resolution for the study of mesoscale phenomena, and has introduced techniques for deriving kinematic quantities efficiently from the profiler data and for calculating estimates of the geostrophic and ageostrophic components of the flow field.

Three contributions in a monograph that explores nonlinear analysis of solutions to hydrodynamic model systems were completed. They appear in Nonlinear Hydrodynamic Modeling: A Mathematical Introduction, edited by H. N. Shirer and concern polynomial root-finding and a treatment of branching solutions (Stensrud, 1987a,b,c].

In the field of astrophysics, piecewise-continuous numerical schemes have been used to achieve highly accurate solutions in areas of fluid containing large spatial gradients. One of the schemes is being evaluated for future application to such meteorological processes as rising buoyant thermals, interactions along cloud edges, and thunderstorm outflows.

OTHER GROUP ACTIVITIES

Kevin Kelleher was assigned to a five-man Computer Initiative Task Force which is responsible for identifying NSSL's current and projected computer needs over the next 5 to 8 years. In this regard, the task force met with each group at NSSL to determine their computer requirements. They then traveled to PMEL in Seattle and the laboratories in Boulder (PROFS, WRP, NCAR, etc.) to examine their facilities and discuss with them how they intend to meet future computer requirements. The findings and recommendations of the task force were presented in a seminar at NSSL in late July. A finalized initiative package was prepared and briefed to the Director, ERL, in August.

EXPECTATIONS FY 1988

(1) A multi-faceted effort will be made in the area of 4-D assimilation. Both hydrostatic and nonhydrostatic models will be used and associated efforts to develop and test adjoint models will begin. This work will contribute to the task of wind Profiler assessment, and hopefully, can be coordinated with other laboratories in ERL. We will also address the problem of thermodynamic retrieval from Doppler winds in convective storms with the goal of using more dynamical constraints and handling time evolution of the winds in a physically consistent manner.

(2) The GUFMEX project will involve a large contingent of scientists from both NSSL and outside agencies. The research will concentrate on understanding the modification of cold continental air masses that plunge over the Gulf in late winter and the subsequent thermodynamic charactertistics of the return flow to the continent. If we are successful in getting an episode to study, a very active year or two coordinating the work and dissemination of data to interested investigators will ensue.

(3) Many of the diverse research efforts discussed in the preceding section will continue during the coming year.

STORM ELECTRICITY AND CLOUD PHYSICS RESEARCH

W. David Rust, Chief

Forecasting and Climatology with Lightning Strike Data

NSSL is involved in two efforts utilizing climatological lightning strike data. One effort is a collaborative study with the NWS/Techniques Development Laboratory in which a climatology for the entire region covered by our present network (N. Texas, Oklahoma, Kansas, S. Nebraska) is being developed from spring-to-fall data for the two years that are available, 1985-1986. This climatology will be used (1) to search for techniques for making 0-6 hour lightning forecasts, (2) to examine whether lightning strike activity can be used as a fine-scale measure of convective activity for refining predictions of synoptic forecast models, and (3) to search for correlations that would be useful in applying lightning data to nowcasting operations. Preliminary results indicate a pattern in the location of lightning activity that may be useful for the first two of these tasks. Furthermore, analyses have found that some boundary layer parameters are good predictors of positive ground flash activity and that the positive ground flashes have a strong correlation with severe weather. These relationships are being examined in greater depth to investigate their utility for NWS operations.

Our second effort is compilation of a lightning strike climatology of Oklahoma, based on data collected from 1981-1984 by the NSSL locating network.

National Network and National Plan for Lightning Detection Systems

Under the auspices of the Working Group on Lightning Detection Systems in the Office of the Federal Coordinator for Meteorology (OFCM), we are participating in the development of a national plan for use of lightning detection systems and in coordinating three existing lightning strike locating networks to form a demonstration national network. The plan is needed to insure that efficient use is made of federal resources in addressing the needs of several agencies for lightning strike data. The demonstration network should assist all the agencies by providing a national data base that can be used to test the utility of lightning strike data and to develop procedures and algorithms for operational applications of the data. This network was formed initially by combining data from the networks owned and operated by NOAA/NSSL, the Bureau of Land Management, and the State University of New York at Albany. Its coverage encompasses all of the contiguous United States except large regions between the Rocky Mountains and the Mississippi River outside the coverage of the NSSL network. Ironically, this area contains some of most severe weather phenomena in the nation and is planned as a test bed for the profiler network.

As part of longer-term implementation of a national lightning mapping network, we continue to collaborate with, and be supported by NASA, to investigate potential applications of data from the satellite lightning mapper. (Note that the satellite mapper is scheduled to be a part of GOES L or M.) During this year, we have completed our inputs to the analysis of optical pulse characteristics of lightning observed from above storms with an instrumented NASA U2 research aircraft. That analysis forms part of a background study, which is led by colleagues at NASA/MSFC, of space-observable optical parameters of lightning.

Other analysis pertinent to application of satellite lightning-mapper data includes measuring a parameter that is fundamental to defining lightning activity in storms, the ratio of intracloud to cloud-to-ground flashes. We are ascertaining the range of values for the ratio and investigating whether the ratio, or changes in the ratio, have diagnostic value for forecasting/warning. Data from our mobile storm intercept laboratory show the ratio can be more than an order of magnitude larger than values often quoted in the literature.

Evaluation of Two Lightning Strike Mapping Systems for the OFCM

Use of lightning strike locating systems has continued to increase steadily in federal agencies this year. Two technologies are available commercially, a direction-finding system from Lightning Location and Protection, Inc., and a time-of-arrival system from Atlantic Scientific Corp. (marketed as Lightning Position and Tracking System). However, there has been no objective comparative test of the two systems to determine their performance characteristics and to judge competing claims by the two manufacturers. NSSL began an evaluation of the two systems in May 1986 for the OFCM. Ground truth lightning strike locations were acquired from an all-azimuth television system and from television cameras mounted on NSSL's mobile laboratory (MacGorman and Rust, 1986). Results from data acquired in 1986 indicate that when using the manufacturers' real-time strike locations the direction-finder network was somewhat more accurate close to the network (<100 km), while the time-of-arrival network was more accurate at longer ranges <200 km). However, the time-of-arrival system seemed to suffer from a significantly smaller detection efficiency (MacGorman and Rust, 1987a). Because it was the first year of operation for the time-of-arrival network and Atlantic Scientific Corp. claimed that there had been starting-up problems with the system that were fixed shortly after the evaluation ended, the OFCM asked us to continue in 1987 to examine whether the performance of the time-of-arrival system improved significantly. We are completing acquisition of the ground truth lightning strike data and beginning analysis.

DOPLIGHT 87

All SECPR personnel were involved in DOPLIGHT 87. Our participation included major responsibilities for forecasting/nowcasting, acquisition of ground truth data for verification of NEXRAD algorithms, and operation of the ground strike locating network and data displays. To accomplish this, we undertook a major upgrade of our mobile laboratory by incorporating a unique solid state wind sensor and sensors for pressure, temperature, and dew point. In addition, we arranged for loan of an NCAR cross-chain Loran-C atmospheric sounding system (CLASS) to begin an evaluation of its potential use in a mobile configuration for pre-storm atmospheric soundings for the WSFO and the NSSFC and for making in-situ measurements of meteorological and atmospheric electrical parameters inside storms utilizing storm intercept capabilities. To measure electric fields aloft, we used a large balloon (1200 gm of lift capacity) to carry an electric field meter into several important regions of storms: updraft, anvils, and stratiform rain. We obtained a 'first ever' profile of the electric field through the large stratiform precipitation region behind a squall line system. Our analysis of such stratiform rain encompasses storm structure and dynamics, positive and total lightning flash activity, and the electric field profile. It is important to note that knowledge of the electrification of stratiform rain has become a critically important aspect of space vehicle launch safety and is being considered in proposed launch rule changes.

We have a continuing program to provide lightning strike data from NSSL's lightning strike locating network to the Oklahoma City WSFO. Since the fall of 1985, lightning strike data have been displayed at the WSFO continuously. In early experience with the display, the WSFO reported that the data appeared useful in identifying thunderstorms, in discriminating against radar echoes from anomalous propagation, and in helping to decide when to use generator power. As part of DOPLIGHT 87, we worked with the WSFO to develop a questionnaire to encourage use of lightning strike data by forecasters and to attempt to quantify the utility of lightning data in daily NWS operations.

As part of increased usage of lightning ground strike data, we developed a real-time display system for the network data using a standard IBM AT compatible personal computer with enhanced color graphics. This prototype was successfully used as part of the nowcasting facility at the WSFO and was available for dial-up by the NSSFC.

Lightning Hazards to Aviation and Space Vehicle Launch

During the past few years, we have become integrally involved in several aspects of the overall problem of lightning hazards to airborne vehicles. This continually expanding effort on our part is in response to an increasing national awareness that lightning and other atmospheric electrical phenomena cannot be ignored if safe and successful flight operations are to be achieved. As part of this effort, we have collaborated with the FAA, NASA, and USAF in several field programs and studies. A key contribution by NSSL has been the discovery that most strikes to aircraft are triggered by the aircraft, not merely intercepted by it.

As a result of our expertise concerning lightning hazards to aviation, we have been consulted by NASA and the USAF regarding lightning hazards to rocket launches. This year we served on the lightning/EMP advisory subpanel for the Atlas/Centaur-67/FLTSATCOM F-6 Mission Failure Investigation Board. This mission failed because of damage sustained from a triggered lightning strike. We are also participating on the USAF Lightning Review Team to review thoroughly the state of understanding of atmospheric electric hazards and to propose interim and long term launch constraints and long term research. The work of the review team is aimed at helping to avoid devastating losses of launch vehicles for U.S. commercial, military, and scientific endeavors. After preparing a draft of a report to the USAF, the review board briefed government agencies and contractors on the report in September.

International Aerospace and Ground Conference on Lightning and Static Electricity.

In activities related to the problems of aviation hazards discussed above, we have continued to serve as NOAA's representative to the National Interagency Coordinating Group (NICG) of the Atmospheric Electricity Hazards Protection Program, which is concerned primarily with protection of aircraft and facilities against the hazards of lightning and static electricity. Activities of the group include annual interagency meetings, the setting of engineering and testing standards for airplanes and helicopters, and sponsorship of periodic international conferences to encourage a broader exchange of ideas and research results. Chairmanship of the conference rotates among the NICG members. Since being appointed as NOAA's representative to the NICG in 1983, NSSL has participated in all of these activities to some extent, and we are presently serving as chairman of the 1988 International Conference in Oklahoma City.

Data Analysis and Modelling of Storms and Storm Systems

We continue to be a cornerstone of efforts to use models to define and understand the relationships among cloud dynamics, microphysics, and electrification. We have successfully retrieved the microphysics and modelled a possible mechanism to account for the large-scale electrification in an isolated thunderstorm observed over Langmuir Laboratory for Atmospheric Research in New Mexico. Comparison of the modelled results and in-situ measurements made with instrumented airplanes and free balloons demonstrate that the model accurately reproduces internal storm processes.

In related modelling work, we are assessing the sensitivity to the model of the derived precipitation processes and the subsequent redistribution of condensate. Collaborative work also continues with other scientists to put advanced microphysics modelling code into a dynamical cloud model in support of work to develop a mesoscale model in the Central Oklahoma Mesoscale Modeling and Analysis (COMMA) project.

Another study of large storm systems has been our continuing examination of mesoscale convective systems (MCSs). We have worked with NASA to determine characteristic patterns in ground strike rates relative to the evolution of mesoscale convective complexes (MCCs) (Goodman and MacGorman, 1986), an important subclass of MCSs. Ground flash rates were generally most concentrated under the colder cloud tops in satellite imagery, and rates typically exceeded 1000 flashes/hr for several hours, increasing exponentially to a peak 1-2 hr before maximum cloud shield extent and decreasing exponentially from the peak rate until termination of the MCC stage. We are also participating in a cooperative study of a squall line (another subclass of MCS's) and its attendant stratiform rain region and ground flash activity with the University of Oregon.

A collaborative study of anvil cloud electrification continues with two universities, the University of Mississippi and New Mexico Institute of Mining and Technology, and extends our earlier work with NASA in the study of lightning to the F-106B instrumented aircraft while penetrating anvils. The interest in anvils is not only for basic understanding, but also stems from concern for launch safety at Kennedy Space Center (KSC). It is now obvious that anvils are a very important aspect of airborne vehicle safety because of (1) their large areal extent, (2) frequent aircraft triggering of lightning by the NASA F-106B at anvil heights, and (3) the small amount of information that is available on the electrical structure of anvils. At about the same time, balloon measurements were begun to provide vertical profiles of the electric field through anvils of small isolated storms in New Mexico and through anvils of large storms in Oklahoma. Our analysis confirms that there are very large electric fields (> 100 kilovolts per meter) in the anvils of both large and small storms. It is now obvious that anvils, even distant from the storm core, are not necessarily innocuous, but can be very hazardous. Analysis is continuing to define better the electrical properties of anvils.

Relationships between lightning location and storm structure were examined for a supercell and a multicell severe storm by using the NSSL VHF (very high frequency) lightning mapping system and dual-Doppler radar data (Ray et al., 1987). In the supercell, lightning tended to occur along streamlines and downshear of the updraft and precipitation core and was most concentrated in reflectivities of 30-40 dBZ, but was distributed uniformly with respect to the updraft. In the multicell storm, however, lightning tended to coincide with the vertical reflectivity and updraft core and with the diverging streamlines near the storm top. The results suggest that the location of lightning in these severe storms was most directly associated with the wind field relative to updraft and reflectivity cores. It appears that the magnitude and vertical shear of the environmental are fundamental in determining lightning location.

We have continued NSSL's pioneering research on naturally occurring positive cloud-to-ground (+CG) flashes. In our examination of strike data during real-time operations for several years, +CG flashes appear to occur (1) in the stratiform precipitation of mature squall lines, (2) in severe storms producing hail, strong winds, or tornadoes, and (3) in the decaying stages of some storms. We have recently begun trying to quantify the relationship of +CG flashes with hail and mesocyclone development. In addition, during DOPLIGHT 87, we acquired measurements of the velocity of propagation of +CG return stroke channels by using our unique, optical instrument developed and installed on our mobile laboratory as described in our report last year. Return stroke velocity is important to understanding the physics of lightning flashes, and we now have completed an initial analysis that indicates the velocity near the ground is occasionally very close to the physical limit of the speed of light (Mach and Rust, 1986).

We evaluated transient changes in the Doppler radar spectra of precipitation associated with lightning. An average transient increase of 5-10 dB of noise power was found. We examined three hypotheses to explain this observation and found that the most likely explanation is a refractive index discontinuity.

Lightning Physics, Strikes to Aircraft, and Phenomenology

Analysis of lightning initiation and subsequent flash development for strikes to aircraft is nearing completion (Mazur et al., 1986). A new understanding of the intracloud lightning flash is being put forth (Mazur, 1987).

Our concept is supported in part by the radio pictures of lightning mapped with VHF systems, a conceptual model proposed several years ago, and our interpretation of the mapping data in light of in-situ measurements of lightning to the airplane. This work will form the foundation for additional research on the fundamental process of lightning initiation and for applied research on lightning strikes to airplanes and space vehicles.

EXPECTATIONS FOR FY 1988

(1) Continue development of potential uses of lightning data in NWS operations, including continued evaluation of ground strike data by the WSFO.

(2) Work with other organizations in NOAA to obtain funding to fill the voids in the present coverage of the ground strike locating network, especially within the profiler array.

(3) Present results of the evaluation of two lightning strike mapping systems for the OFCM.

(4) Continue work with the OFCM Working Group on Lightning Detection Systems in developing a national plan for use of lightning detectors.

(5) Analyze mobile laboratory satellite imagery, and other data to continue development of potential uses of satellite lightning mapper data.

(6) Install and test mobile version of CLASS for in situ measurements in thunderstorms. Evaluate several aspects of CLASS in the deployable and fully mobile modes.

(7) Complete our inputs to the final report of the U.S.A.F. Lightning Review Team on launch safety relative to lightning and atmospheric electrical hazards. We will also continue efforts to participate in weather related problems to space launch, shuttle reentry, and aviation through the U.S.A.F. Lightning Review Team, Shuttle Flight Rule 4-57(d) workshop, and other appropriate interagency forums.

(8) Complete initial study and analytical model of electric field distribution in anvils.

(9) Finalize the arrangements and host the 1988 International Conference on Lightning and Static Electricity in Oklahoma City, April 1988.

(10) Continue collaborative research on dynamical cloud model in COMMA project.

(11) Complete initial study of hail production and lightning flashes to ground.

(12) Collaborate with the OKC WSFO to continue of use of lightning data.

(13) Complete a cooperative study with the University of Oregon on lightning strikes in stratiform rain.

(14) Complete collaborative study with the State University of New York, Albany on the first direct measurement of return stroke velocity for +CG flashes.

(15) Complete analysis of return stroke velocity in natural lightning in Oklahoma, and Alabama (part of collaborative effort during the Coordinated Huntsville Meteorological Experiment, COHMEX), and of return stroke velocity in natural and rocket triggered lightning in Florida at the Kennedy Space Center.

(16) Complete work on lightning strike climatology of Oklahoma, based on data collected from 1981-1984 by the NSSL locating network.

DOPPLER RADAR GROUP

Dusan S. Zrnic', Group Leader

INTRODUCTION

The objectives of the Doppler Radar Group are (1) to determine the relationships among the thunderstorm hydrodynamic, thermodynamic, and precipitation variables and the parameters measured by radar to develop improved indicators of thunderstorm severity and hazards; (2) to study the preconvective environment and to improve understanding of storm formation and their forecast; (3) to develop and refine remote sensing techniques for locating, tracking, and predicting thunderstorms and their attendant hazards; and (4) to provide expertise and support for successful implementation and use of National Weather Service related programs. These objectives are addressed through both theoretical and observational studies. The Group interprets prestorm and storm phenomena using data from Doppler radars, satellite, profiler, tall tower, and other sensors. General overviews of group activities can be found in references by Brown, 1987a,b; Eilts, 1986; and Zrnic' et al., 1986 and 1987.

RECENT ACCOMPLISHMENTS

STUDIES OF THE BOUNDARY LAYER AND STORM INITIATION

Diagnosis of Stability Changes Aloft

A model to diagnose short term temperature and moisture changes aloft from single-Doppler radar data has been documented, and results of the model have been tested against synoptic data (Rabin, 1987a,b). The model is intended to help forecasters monitor stability changes between regularly scheduled soundings and, in particular, changes in the strength of the moisture-capping inversion which are often critical to the formation of thunderstorms.

The basis of the model are the equations of local temperature and moisture change which include the following effects:

1) Horizontal thermal advection is deduced from the general form of the thermal wind relation. Wind measurements as a function of time and estimations of wind gradients are required. In general, horizontal wind gradients computed from a single radar include smaller scales than those obtained from a synoptic sounding network. The accuracy of the linear wind terms was determined from actual data (Rabin 1987b). The effects of nonlinear terms on the estimations are being investigated in a separate study using simulated and observed wind fields from dual-Doppler measurements.

2) Vertical temperature and moisture advection are deduced from an initial sounding and vertical air motion. Spatially averaged vertical air motion is obtained from radar estimates of horizontal divergence; the accuracy of divergence and vertical velocity is superior to that obtained from a network of anemometers or soundings, due to the relatively large number of radial velocity measurements as a function of azimuth. Also, estimates of the diverg-

ence and vertical air velocity are not affected by the presence of nonlinear wind if the Doppler data are contiguous around the circle of the Velocity-Azimuth Display (VAD) analysis.

3) Parameterizations are used to account for the effects of sensible heating, evaporation, and boundary layer growth. These variables depend principally on stability deduced from net radiation, humidity, and wind speed.

The application of the model to one set of data indicates that the ascension of air was the dominant cause of the destabilization of the atmosphere one to three hours before the development of thunderstorms (Rabin, 1987a,c). The estimation of horizontal advection is much more uncertain than vertical advection. Nevertheless, it has been shown that horizontal gradients of temperature, horizontal temperature advection, and time rate of change of temperature gradient can be determined with some skill. An error analysis shows that the accuracy could be improved by considering longer periods (> 1 hour) between radar wind estimates. The error in geostrophic wind is about 1 m s^{-1} when the interval is chosen to be about three hours.

Profiler Wind Assessment

Work continued on the examination of Oklahoma-Kansas PRE-STORM wind profiler data and the comparison with rawinsonde observations (12 May 1985). Considerable filtering of the wind data in the time domain is required to obtain meaningful synoptic scale gradients, but significant discrepancies in some wind components derived from the profilers and soundings are still present after filtering. Nevertheless, vertical air motion estimated from the divergence of horizontal winds between three profiler sites is in qualitative agreement with that estimated from wind data at the nearest three rawinsonde sites. To evaluate the utility of the profilers in weather analysis and forecasting further, properties diagnosed from the time-space variations of profiler winds are being compared with independent measurements of the horizontal pressure gradients, the ageostrophic wind, and the horizontal temperature gradients.

A joint experiment between the Wave Propagation Laboratory, the National Severe Storms Laboratory, and the University of Oklahoma was conducted in Oklahoma and Colorado with a steerable antenna 405 MHz system with the purpose of obtaining data on the anisotropy of scattering. Doppler spectra were collected in Oklahoma as the beam was varied from zenith to 35°. Similar spectra, but with a phased array antenna and from several azimuths as well, were obtained in Colorado. Finally, a data set from a sophisticated 50 MHz Japanese radar was collected by Dr. Doviak. The angular dependence of echo power (important for wind profile measurements) will be investigated, and the physical causes for its variation will be sought.

Moisture Variations

Concurrent with the University of Wisconsin's boundary layer experiment in Oklahoma during the spring of 1983, the Wave Propagation Laboratory and the National Severe Storms Laboratory conducted an experiment to explore the possibilities of combined radiometer-radar remote sensing of water vapor. Observed changes in vertically integrated water vapor over a three- to six-hour period are tied to evaporation and large scale horizontal convergence detected by single-Doppler radar measurements. The causes of higher frequency fluctuations of integrated water vapor are now under investigation.

Preconvection Measurements During Doplight

Near real time wind profiling from single-Doppler velocity data was performed for comparison with the NEXRAD VAD output during Doplight. Estimations of mean wind, deformation, divergence, and vertical air velocity were available during diverse weather conditions. An apparent bias due to ground clutter was observed to effect divergence and vertical velocity estimates deduced with data from 50 km radius or less.

The preconvection experiment was designed to estimate kinematic properties of the three-dimensional wind field from a volume scan of a single radar and to supply this information to duty forecasters. Specifically the analysis package includes: 1) data editing in real time (i.e., the removal of point targets, weak signals, and range and velocity unfolding); 2) the running of VAD analysis to retrieve the horizontal wind, divergence, and deformation; 3) the computation of vertical velocity profiles from vertically-integrated divergence values; and 4) the generation of constant altitude PPI's and vertical cross-sections of horizontal wind vectors from the VAD output. Plots of vertical velocity with height and horizontal wind vectors are standard displays.

Estimating Surface Heat Flux Using Tower Data

An indirect method of estimating the surface heat flux from instrumented tower measurements of the vertical velocity variance in the mid-levels of the convective boundary layer was developed (Eilts et al., 1987). Comparison of surface heat flux estimates from this method, with those from the boundary-layer heating rate, is good. This method seems to be suitable for inhomogeneous terrain where surface layer profile methods cannot be used.

Thermal Plume Study

The feasibility of indirect tracking of a silver iodide plume with NSSL's 10 cm Doppler radar has been investigated for cloud seeding studies to be conducted by the Oklahoma Water Resources Board. It was recommended that Doppler radar wind data could be combined with a model of average plume density (which is a function of boundary layer depth, mean wind speed averaged through the depth of the boundary layer, and surface heat flux) to provide guidance for *in situ* plume measurements with airborne instrumentation (Sirmans and Rabin, 1987).

STORMS AND RELATED PHENOMENA

Mesoscale Convective Systems

Doppler radar, rawinsonde, and surface mesonetwork observations are being used to examine a mesoscale convective system that evolved during the OK-PRE-STORM experiment on the early morning hours of 7 May 1985. Development began as an eastward-moving trough overtook a nearly stationary complex of scattered severe thunderstorms that had persisted in northwestern Oklahoma and western Kansas from the previous afternoon. The convection rapidly reorganized into a nearly continuous north-south squall line that swept through the PRE-STORM observational network. A trailing region of stratiform rain developed in conjunction with the squall line and increased in areal coverage until a meso-β scale vortex began to form. Afterward, the stratiform rain area began to erode at its western boundary and convection to the south of the vortex was accelerated eastward. By the time the combined system passed the observational network, all convection became detached from a reduced stratiform rain region that remained wrapped about the slower moving mesovortex.

Wind fields synthesized from radar observations (Brandes and Johnson, 1986) reveal that the stratiform rain region developed during the period of strong front-to-rear relative flow. Inflow air originated at low levels ahead of an accompanying gust front, and ascended in convective updrafts and a broad mesoscale updraft zone toward the rear of the system. Mesovortex development caused a rear-to-front flow which was first detected between 0.5 and 4 km AGL at the rear of the stratiform rain area. Rawinsonde and radar observations indicate that the intruding flow tended to sink. Further, the rawinsonde observations (Brandes, 1987) show that the subsiding air warmed appreciably ($\sim 6°C$) in the lower troposphere (below 3.5 km); a pressure deficit of several millibars marked its location. Ahead of the spreading downdraft air, a convergent zone was created that triggered a secondary convective line.

The intruding flow eroded the stratiform rain area and eventually, as the flow passed south and then east of the mesovortex, severed all convection from the remnant stratiform rain area. Only in final stages, when the separation between the mesovortex and the low center associated with the intruding flow became large, did the surface data reveal a weaker, second low pressure center, hitherto obscured, that coincided with the mesovortex. The secondary low center and mesovortex seem related to latent heat released in the middle and upper troposphere.

A study is in progress to understand the dissipation of the Oklahoma segment of the 10-11 June 1985 mesoscale convective system. Objectives of the study are 1) to document the structure and environment of the squall line, 2) to compare results with those from Kansas data, and 3) to determine to what extent the system's decay was due to internal and environmental effects.

Key factors leading to system decline appear to be outflow surging ahead of the line and decreasing potential instability. The transition from mature to decay phases is being examined in terms of the radar reflectivity fields, the 2-D circulation in planes perpendicular to the squall line, and the environment ahead of the squall line. Vertical cross sections of Doppler velocity and composite hodographs from environmental soundings in squall line coordinates reveal that relative air-flow during the transition from maturity to dissipation was predominantly front-to-rear, sloping upward toward the rear over weak rear-to-front flow near the surface. The rear inflow intruded beneath the convective and transition zones; in contrast the real inflow much farther north in Kansas intersected the ground only in the convective region. The composite thermodynamic profile of the mature squall line environment reveals little negative area to be overcome by air parcels rising from the boundary layer into convective updrafts. Inspection of soundings taken later shows that the airmass ahead of the squall line became much more stable with time. The increase in static stability was primarily the result of surface cooling due to radiation.

Downbursts and Microbursts

Doppler radar data collected each spring in 1979-1984 were examined to investigate downbursts in Oklahoma (Eilts and Doviak, 1986 and 1987). In three downbursts for which dual-Doppler radar data were available, it was found that outflows from convective storms in Oklahoma can be highly asymmetric. Shear along the axis of maximum divergence can be as much as five times the shear along the minimum shear axis. The downbursts detected were superposed with the maximum reflectivity core of intense thunderstorms. This contrasts with the typical microburst detected during the Joint Airport Weather Studies (JAWS), (Denver, CO) experiment, in which little or no rain fell during the event. The mechanism for the initiation of a majority of the JAWS microburst was evaporative cooling, which occurred when precipitation fell into a deep, dry, and nearly adiabatic boundary layer. It appears that other mechanisms are responsible for the initiation of the observed Oklahoma downbursts because of a lower cloud base, and a more moist and slightly more stable boundary layer.

Examination of data collected with two Doppler radars during JAWS (Denver), FLOWS (FAA-Lincoln Laboratories Operational Weather Studies; Huntsville), and NSSL (Oklahoma) experiments continues, with the goal to quantify asymmetries of microburst outflows. Analysis of Oklahoma data suggests that the shape of reflectivity contours of downburst producing cells may have some predictive value to estimate asymmetries in the low altitude outflow. This study is aimed at developing techniques that may be able to estimate the actual component of wind shear along the runway using a single-Doppler radar that is not aligned with the runway.

In order to provide timely warnings of impending microbursts, we have been engaged in a search for precursors. Convergence at midlevels, 1 to 5 km above ground, in cells associated with a descending reflectivity core was found to be a definite precursor to divergence at the surface. Furthermore, the strength of convergence aloft is related to the strength of divergence at the surface. Convergence aloft preceded divergence at the surface by one to ten minutes (Eilts, 1987c).

An investigation into the feasibility of using NEXRAD to detect low altitude (< 100 m AGL) wind shears near airports was conducted (Eilts, 1987a,b). By comparing horizontal radial shears detected by radar with that detected by surface stations during gust front passage, it was determined that Doppler radar estimates of wind shear (at heights between 50-600 m) averaged 1.6 times surface shear estimates. Data collected from instruments on a 440 m tower as five gust fronts passed over it was used to ascertain the vertical profile of the horizontal wind shear. It was found that wind shear increased with height in the lowest 90 m of the atmosphere in all cases. Due to surface friction, it is expected that wind speeds, and thus shears, will increase with height in both downburst and gust front phenomena. Thus, if FAA requirements of a lowest scan of 60 m AGL in the airport area are met, a Doppler radar should be able to detect the strongest radial velocity shear in the airport area.

Hail

It has been proven, both theoretically and experimentally, that when strong thunderstorm cores are illuminated by radars, scattering interaction between hydrometeors and the ground produces three-body scatter signatures (Zrnic', 1987a,b). The process consists of (1) scattering by the hydrometeors, (2) backscattering by the ground to the hydrometeors, and (3) scattering by the hydrometeors to the radar. When viewed on radar displays, the signatures have an elongated shape, radially aligned behind strong (60 dBZ) reflectivity cores. A radar equation for echo power is developed and predicted r^{-3} dependence of the echo power on the range between the center of scattering volume, and a reflecting ground ring is confirmed by a least squares fit to actual data. It is shown theoretically that mean Doppler shifts associated with three-body scatter are caused by the vertical and radial components of hydrometeor velocities; this is also verified from least square fits of range profiles of measured Doppler velocities to theoretical curves based on geometrical considerations. For the examined cases our theory attributes scattering to wet hail having diameter to wavelength ratios that place it in the Mie scatter region.

Doppler Lidar Observations in Thunderstorm Environments

On 30 June 1981, the wind fields around a variety of convective clouds, ranging from large thunderstorm complexes to isolated cumulus congestus, were observed in some detail using an airborne Doppler lidar operated by the National Aeronautics and Space Administration (NASA) and a reasonably clear picture of the main features of the flow fields near several clouds have been obtained.

Features of special interest seen in the lidar analyses are the wind shears at the leading edge of a gust front marked by an arcus cloud formation, and secondary surges of outflow behind another gust front, which was mostly free of clouds and rain at flight level. Observations from one of the NSSL mesonet stations, overflown by the lidar aircraft in the vicinity of the arcus cloud, serve to confirm the approximate location and character of the gust front at the surface depicted by the lidar analyses in that area. The storm system which contained the gust front vortices moved eastward, intensified, and within one hour produced a damaging gust front tornado in Norman, Oklahoma.

Waves Associated with Thunderstorms

Observations suggest that solitary and other nonlinear waves might be a source of wind shear hazard to flight and thus should be studied both experimentally and theoretically. A derivation of the Benjamin-Davis-Ono (BDO) equation by a perturbation method is reviewed and extended to the case in which a stably stratified atmosphere is in sheared flow. For nonsheared flows, the solution for the upper layer differs markedly from that derived by Benjamin. The internal steady-state solitary wave, described in the solution of the BDO equation, is compared with a boundary layer solitary wave observed with NSSL's Doppler radar, a network of eight meteorological stations, and a 444 m tall instrumented tower (Chen and Doviak, 1987). It is shown that agreement between the theoretical results of the weakly-nonlinear internal wave theory of BDO and observations of wind and temperature near the ground is incidental because horizontal advection of the wave and frictional drag markedly affect wave properties to force this agreement. Only tall tower and Doppler radar measurements provided the necessary data to determine that an observed solitary wave was strongly nonlinear, and that it trapped thunderstorm outflow which leaked out the rear of the wave. Wave-induced vertical transport of the horizontal momentum of the strongly-sheared ambient air contributed much to the observed wind perturbations and horizontal wind shear. Comparison of wave amplitude data, with numerical results from strongly-nonlinear internal wave theory, shows fairly good agreement. Wind shear produced by the solitary wave appears to be significant (7.6×10^{-3} s^{-1} over a horizontal distance of 700 m), even though it is 60 km from the storm which initiated it.

TECHNOLOGY TRANSFER TO THE NEXT GENERATION WEATHER RADAR (NEXRAD) AND THE TERMINAL DOPPLER WEATHER RADAR (TDWR)

Training

With NEXRAD Doppler radars starting to be used in weather forecasting offices during the next few years, training is becoming a high priority consideration. NSSL, with support from the NEXRAD Joint System Program Office (JSPO), is preparing a training manual to assist in the interpretation of Doppler velocity patterns with simulated data (Brown and Wood, 1987). The radar operator is challenged to interpret actual Doppler velocity patterns through the use of a set of problems. Because there are no ground-based Doppler data from hurricanes, a simulation of these will prove valuable to both students and researchers (Wood and Brown, 1987).

NEXRAD Research and Development Plan

In support of the NEXRAD Doppler radar network, NSSL has prepared a research and development document for the NEXRAD JSPO. The document indicates changes that should be made in the current NEXRAD computer algorithms and indicates areas in which research should take place during the next five years in order to develop additional needed algorithms.

Gust Front Algorithm

Research and development work concerning gust fronts was directed toward making a gust front algorithm fully operational. Tests were performed on data from Oklahoma, Memphis (FLOWS), and Denver. The algorithm was fully automated and made ready for real-time operational testing. Several changes have been incorporated in order to simplify the algorithm with more than one set of thresholds. When appropriate thresholds were used, there were very few false alarms (on average, less than one per volume scan).

The outputs of the algorithm were checked for consistency and compared to data from other sources (Witt and Smith, 1987). For instance, vector winds from uniform wind analysis were compared with surface and rawinsonde observations, as well as with general trends of the Doppler velocities. Agreement was beyond expectations; moreover, the uniform wind analysis proved, on at least one occasion, to be a better indicator of gust front motion than tracking of the centroid. Times of gust front passage over surface stations were generally within two minutes of interpolated or extrapolated positions by the algorithm. Also, in the only intercomparison between the positions obtained from two spaced Doppler radars, the average RMS errors were less than 0.9 km. We emphasize here that these good comparisons are for strong, single, well-defined gust fronts.

The algorithm was transferred to Lincoln Laboratory and a real time test in the TDWR-87 experiment began at the end of May in Denver, CO. Lincoln Laboratory, NCAR, and NSSL are participating in this FAA-sponsored experiment with the objective to develop and validate techniques for the automatic detection of phenomena such as microbursts, gust fronts, turbulence, and heavy rain. The results of this development program will be incorporated into the hardware and/or software components of the Next Generation Weather Radar (NEXRAD) and the Terminal Doppler Weather Radar (TDWR) systems which are being procured by the FAA.

Because detection of gust fronts and other aviation hazards requires frequent radar scans, a study of an interlaced scanning strategy was conducted (Vasiloff et al., 1987). It was demonstrated that such scans have no adverse effects on storm analysis and tracking algorithms.

Turbulence

Doppler radars offer unique data from which it is possible to estimate the turbulent eddy dissipation rates, ε. If the inertial subrange extends to lengths longer than the radar resolution volume size, ε can be obtained from the Doppler spectrum width. Spatial spectra of mean Doppler velocities can also yield ε estimates but only if a significant portion of the analysis length is contained within the inertial subrange. We compare dissipation rate estimates obtained with the two independent measurement techniques (Brewster and Zrnic', 1986). At close range and vertical incidence, agreement between the two independent estimates of ε is within 10%. Furthermore, the slope of the spatial energy densities is very close to -5/3 predicted by Kolmogorov. The energy input is mainly from buoyancy-driven updrafts and the transition wavelength (about 3 km) between the input scale and the inertial subrange is consistent with the updraft-downdraft circulation cell, which is about 10 km. For a more distant storm at a range of 60 km, the filtering of mean velocities by the resolution volume precludes precise estimation of ε from spatial spectra of mean velocities.

A technique to separate ordered flow in a tornadic thunderstorm from the random velocities associated with turbulence is described. The relative importance of the ordered-flow shear and turbulence in the broadening of the Doppler velocity spectrum is evaluated by least-squares fitting an assumed linear model of radial velocities to measured ones over an angular analysis domain (about 3° in azimuth and 3° in elevation). Fields and cumulative probabilities of Doppler spectral widths associated with turbulence and velocity shear, of root-mean-square (rms) velocity residuals, and of the turbulent kinetic energy dissipation rates ε are presented (Istok and Doviak, 1986). Within this storm, turbulence contributed much more to spectral broadening than ordered-flow shear. However, in a very small portion of the storm, shear and nonturbulent eddies are responsible for nearly all spectral broadening. Fifty percent of the volume of this tornadic storm had ε larger than $0.1\ m^2\ s^{-3}$.

The Doppler spectral width also shows promise of better defining gust fronts and microbursts. To be a useful quantifier of turbulence and to serve as detector of these other phenomena, the spectral width estimates must be interpreted and quantitatively related to meteorological phenomena and/or turbulence hazards. For that reason, we have examined four storm cases where valid spectral widths from two Doppler radars were available. These data suggest that turbulence with scales less than the resolution volume size (~ 1 km) is isotropic and thus independent of radar viewing angle.

Ground Clutter Filter

A design study of a clutter filter for staggered pulse trains is in progress. Results demonstrate that a workable scheme is feasible but requires a combination of filters. A filter operating on staggered pulses can be designed to have a very flat amplitude characteristic but phase nonlinearities are concentrated at discrete bands of sub-stagger frequency. This filter needs to be combined with a filter that operates on uniform pulses and with input/output power measurements in order to reduce the deleterious effects of staggering.

DEVELOPMENT OF OBSERVATIONAL AND ANALYTICAL TECHNIQUES

Multiple Doppler Radar Synthesis

Measurements from two or more Doppler radars can be synthesized to reconstruct the three-dimensional flow field within convective storms. However, computations of the vertical component of motion are more sensitive than estimates of the horizontal components to errors in the Doppler velocity measurements. Adjustment schemes are required in order to produce realistic vertical velocity values. Nelson and Brown (1987) used actual data to investigate the nature and source of these errors. After exploring the several most likely sources, they found that none of them were dominant sources of error. Not being able to find a dominant error source, Nelson and Brown concluded that there is no compelling reason to deviate from the usual adjustment assumption that error sources are uniform with height.

Attenuation

Attenuation problems arise when short wavelength radar is used for severe storm identification and structure analysis. These problems were studied by comparing observations from 5 and 10-cm Doppler radars (Johnson and Brandes, 1987). Reduced and fragmented storm representations were obtained with the 5-cm wavelength radar. Signal losses exceeding 30 dB so greatly distorted the reflectivity structure of one thunderstorm that the expected association between mesocyclone and reflectivity pattern was not evident. Attenuation of the received signal reduces the signal-to-noise ratio and increases the variance of the spectral moment estimates. However, velocity measurements remain unbiased as long as the received signal remains above the system noise level. Correcting for attenuation appears futile.

Polarization

One of the Doppler radars operated by the National Severe Storms Laboratory has a new capability to measure the difference between propagation phase shift constants at horizontal and vertical polarization. We use this parameter, K_{DP}, in addition to the reflectivity factor, Z_H, and the differential reflectivity, Z_{DR}, to obtain new information about rain and hail. It is shown from theory and experiments, that a third parameter of the drop size distribution, obtained from K_{DP} may support Z_{DR} measurements, and/or point out mixed phase hydrometeors. Quantitative information on hail size distribution may be obtained from small-size hailstones in cases when their major axes are oriented vertically, giving rise to negative Z_{DR} and K_{DP} values. Reasonable hail size distribution parameters, N_0 = 2 to 300 mm^{-1} m^{-3} and Λ = 0.3 to 0.8 mm^{-1}, are obtained from radar data of a hail storm (Steinhorn and Zrnic', 1987).

EXPECTATIONS FOR FY 1988

1) Examination of wind profiler data from OK-PRE-STORM experiment will continue.

2) The study of the morphology and evolution of the 6-7 May 1985 mesoscale convective system and mesovortex will continue.

3) We plan to conduct a feasibility study to determine whether "clear air" observations from the NSSL Doppler radars can be used to reconstruct the wind fields of dry fronts.

4) Profiler data and 10 cm radar will be integrated into a diagnostic model. Evaluation of profiler data through controlled comparisons will continue.

5) Reflectivity data collected in 1980-81 will be used to investigate precursors to storms and wind data will be used to study atmospheric destabilization.

6) To predict downdrafts and gust fronts, study of their origin and evolution will continue. Data from different U.S. locations will be studied.

7) An investigation into ascertaining the asymmetry of microbursts using only single-Doppler radar data will be completed.

8) Preparations of algorithms for the TDWR-88 real time experiment will be made, and we will participate there.

9) NEXRAD algorithms for detection and tracking of hazardous weather will be improved.

10) Plans call for the study of relationships of the spatial patterns of landscape and soil moisture to the initiation of local convection. We plan to explore the remote measurement of fluxes over large areas using radar and lidar data. The importance of this research is to improve or replace the parameterizations used for turbulent diffusion and soil moisture in forecast models.

11) We shall continue to analyze polarization data from the 1985 and 1986 spring experiments to determine the quality of rain rate estimates and assess the capability to identify hydrometeors remotely in storms. Disdrometer data collected in the spring of 1986 will be used to derive drop size distributions and rain rates.

12) A joint NSSL/Australian National University analysis of solitary wave data will continue.

13) The angular dependence of echo power for 50 MHz and 405 MHz profiles will be investigated.

COMPUTER AND DATA MANAGEMENT

William C. Bumgarner, Group Leader

RECENT ACCOMPLISHMENTS

This new group was formed to manage the NSSL's computer resources, to provide centralized data management, and to provide quality control of NSSL collected data.

In preparation for major computer purchases in FY 1988, a computer initiative committee was constituted to write a six-year computer initiative plan. Over five-man months were spent to create this document, and it was forwarded to Boulder and thence to the DOC for approval.

A data management committee was created to provide overall guidance on the storage and retention of data. Efforts were made to eliminate all remaining punched cards and seven track tapes. All rawinsonde and tower tapes plus selected Doppler tapes will be converted from seven to nine track tapes by March of 1988. Scientists desiring to do research with Doppler data dating back to 1971 have identified data sets which will be tracked as personal data sets in the future. The computer and data management group will be responsible for sets from the two major programs in 1979 and 1985 plus all data collected since 1984. Except for those major programs, the committee has decided to keep data only for five years unless it becomes a scientist's personal data set. Outside users of NSSL data will be notified of this new policy.

A McIDAS workstation was leased from the University of Wisconsin and a 9600 baud phone was leased from AT&T. For the first time, NSSL scientists now have the capability to manipulate and examine satellite data in a research mode.

For the second season a PROFS workstation was loaned to the NSSL for the 1987 DOPLIGHT program period. The system consisted of a DEC MicroVAX II with a RAMTEK 9465 color graphics display. Data were supplied over a 56K baud leased line from Boulder, CO.

The MICOM electronic switch is being expanded with 16 more ports to satisfy the growth of personal computers and graphics terminals within NSSL. Over 75 per cent of the senior staff now have terminals in their office with 9 terminals available for general usage by students and other researchers. By the end of next year, all scientists requiring a terminal should have one in their office.

Fiber optics cables connecting the NSSL building to external buildings and multiplexing hardware now allow IOTF personnel in the new WSFO/NEXRAD building access to the Perkin Elmer and VAX at 9600 baud. Laboratory terminals and computers are now safe from cloud-to-ground lightning striking the ground near underground terminal lines. There have still been terminal and MICOM damages from strikes hitting power lines and entering the building. Lightning protectors are being examined to prevent this damage.

In the area of color graphical displays, there have been improvements and increased usage of the NSSL computing system to peruse and edit Doppler radar data; and, with support from WRP, a capability for displaying and looping satellite images has been added. Also, a project is near completion which allows the transfer of graphics metacode files over phone lines from the CDC 855 at Gaithersburg, MD, and subsequent display in color on the NSSL system.

Areas of increased data accessibility are represented by the completion of the 1982, 1985, and 1986 SAM data bases which allows individual researchers on-line access. Work is progressing in the completion of the 1984 data set and other years will be completed in the future.

Another important effort has been the assignment of a group meteorologist to work with the NEXRAD IOTF group on development of software products for DOPLIGHT 87 and the IOTF. These included mosaicing multiple radar data sets, implementation of the Layer Composite Reflectivity product to accept RADAP II data, and modification of the Radar Coded Message to run in a fully interactive and real-time environment for evaluation during DOPLIGHT. Other accomplishments include the modification and implementation of real-time versions of the VIL algorithm for NWS NEXRAD and RADAP comparisons.

During the DOPLIGHT project, a group staff member served as project data manager. This effort included the filing, cataloging, and semi-permanent archival of all activity forms and meteorological information that was routinely collected each day. Daily quality control of SAM and tower data was performed and routines were written and/or enhanced for daily real-time use by NWS and DOPLIGHT participants.

Research collaboration included a paper with engineer Dale Sirmans studying clear air echoes with a dual polarization radar (Dooley and Sirmans, 1987). Other assistance was given in the preparation of a report for NEXRAD involving research with Anomalous Propagation data as observed by the Norman Doppler radar. Some other independent research work was done with historical tall tower data sets in the study of the low-level jet in the lower boundary layer.

NSSL supplied data sets to these outside users:

Meteorological Research Institute Tsukuba, Japan	(M. Ishihara)
NASA Goddard Space Flight Center Greenbelt, MD	(G. Heymsfield, R. Fulton)
University of Oklahoma Norman, OK	(H. Bluestein, G. Byrd, G. Martin, S. Keighton, D. Hays)
University of Western Ontario	(M. Mikituik)

EXPECTATIONS FOR FY 1987

1) In FY 1988 of funding will become available from a previous computer initiative. Planned upgrades to the existing VAX 11/780 will include a MicroVAX II for enhanced Analog/Digital capability in storm electricity research, a second CPU with comparable speed to the VAX 11/780, clustering hardware for interconnection of the VAX computers, a laser printer, a copy camera for the existing RAMTEK graphics monitors, local area networking for interconnecting of PCs and the computer network, and a laser optical disk. The purchase of the first of many laser disks will allow NSSL to reduce the storage of both NSSL and future data collected during cooperative field programs such as GUFMEX and STORM and allow more rapid random access to the data. A PROFS level-one workstation will be purchased and connected to the PROFS network for continuing real-time and non real-time research.

2) A 9600 baud phone line will be installed connecting NSSL and Boulder to provide a continuous connection into the PROFS network. This will allow NSSL researchers access to VAXes within PROFS, WRP, WPL, and NCAR and further enhance the exchange of data and programs with other government agencies.

3) The University of Oklahoma has started the installation of a local area network which will allow connection to the new NSF MIDNET network. When that is completed, A high speed link will be established between the NSSL and Geosciences VAXes to allow NSSL COMMA coinvestigators access to the NSFnet and supercomputer network.

4) In the areas of data management more work will be done in creating more user friendly, on-line indexes for determining what data NSSL has and how it can be accessed. Experiments will be performed to determine how to establish a NSSL data base using laser disk technology and commercially available data base management systems.

FIELD FACILITIES OPERATIONS AND DEVELOPMENT

John K. Carter, Group Leader

The Field Facilities Operations and Development (FFOD) Group develops techniques and equipment, maintains the NSSL observational facilities, and supports the observational programs associated with the meteorological research. The NSSL base facilities consist of two 10-cm meteorological Doppler radars, a tall (444 m) tower, a 52-station surface network, air/ground communication for directing aircraft operations, and equipment for measuring electrical phenomena in the atmosphere. The Group also provides engineering support for the NEXRAD Joint System Program Office (JSPO) Operational Support Facility (OSF) of the National Weather Service.

RECENT ACCOMPLISHMENTS

Facilities Engineering

DOPLIGHT '87 Program: Remote radar display and control functions from the NSSL Norman Doppler radar were installed and operational in the WSFO at Norman, OK, for the 1987 DOPLIGHT Program. Operations began March 15 and continued through June 15 on a 16 hour per day, 7 day per week schedule. Field facilities for collection of surface, tall tower, and mobile rawinsonde were also operational.

Lightning Detection and Cloud Physics Experiment: Both the Norman (NRO) and Cimarron (CIM) Doppler radars were operated in support of two experiments during the period 15 June through 30 June 1987.

Data were collected from the CIM radar in the common volume sampled by the NRO vertically pointing radar for studies in the detection of precipitation enhancement due to lightning discharge. One case was archived during the operations period.

Data were collected from the CIM radar to investigate detection of water phase states within the thunderstorm by way of post analysis of differential reflectivity and differential phase algorithm. Two cases were archived during the operational period.

Cooperative SAM/Profiler Site at Plattville, CO: The Stationary Automated Mesonetwork (SAM) site installed at Plattville, CO, co-located with WPL's 405 MHz wind profiler system, was routinely operated throughout FY 1987. Data were made available by way of telephone dialup at NSSL for quality control and maintenance purposes. PROFS "MESOTALKER" data were also made available for tracking system performance. A preliminary proposal was drafted for installation of SAM sites at all 31 profiler network sites as a source of ground truth data.

405 MHz Profiler Experiment: A 28-foot parabolic dish antenna was assembled, tested, and installed on a pedestal. This antenna terminal was coupled to the WPL 405 mHZ wind profiler transmitter/receiver system in

support of a joint NSSL/University of Oklahoma (OU) boundary layer study. Data were collected and are currently being analyzed by OU Meteorology staff. A joint NSSL/WPL experiment evaluating the parabolic antenna terminal and simultaneous clear air measurements at a radar wavelength of 75 cm and 10 cm was also conducted. The parabolic antenna system is being transferred to WPL at Boulder, CO.

Thermal Plume Tracking by Radar: An experiment to examine the feasibility of detection of the thermal plume from a ground fired AgZ generator was conducted with the NRO Radar. Results are given in a report prepared for the Bureau of Reclamation, United States Department of Interior.

NCAR CLASS System Evaluation: Cross Chain Link Atmospheric Sounding System (CLASS) was acquired on loan from the National Center for Atmospheric Research (NCAR) at Boulder, CO, for evaluation in a mobile application. The system was repackaged in the NSSL-2 van instrumented for severe storm electricity measurements. Tests were conducted to determine the utility of LORAN-C balloon tracking in an Oklahoma severe thunderstorm environment. Tests extended from November '86 through the end of the DOPLIGHT '87 Program in June '87. Data are presently being analyzed for publication.

McIDAS: NSSL acquired and installed a McIDAS satellite imaging workstation from the University of Wisconsin at Madison. FFOD Group personnel attended maintenance courses at Madison to allow NSSL on-site first-level maintenance capability.

WSR-57 Radar: The NSSL WSR-57 radar system first commissioned at NSSL in 1963 was decommissioned and transferred to the City of Woodward, Oklahoma.

Ground Clutter Canceller: Data from the Ground Clutter Canceller device designed and fabricated at NSSL were collected and are being analyzed in support of the NSSL/FAA Memorandum of Understanding (MOU).

NEXRAD Support: Various members of the Group continue to provide general engineering consulting and support under the JSPO/NSSL MOU. In addition, the specific project work includes: contribution and editorial review of the FMH-11 Part B, continued research into the utility of dual polarization measurement, and development of a scheme for anomalous propagation signal detection and suppression.

Facilities Development

Fiber Optics Data Distribution/Communications System: A state-of-the-art data communications/distribution system was installed to interconnect the main NSSL facility with the NRO Doppler radar and the adjacent WSFO.

A fiber optic system was assembled using "off-the-shelf" components. Multifiber cables connected the three main buildings. Radar video was distributed from the NRO Doppler to the WSFO by way of wideband analog channels. Digital communications interconnected the NRO Doppler radar control computer, the NRO Perkin-Elmer computer, the NSSL VAX 11/780, and the WSFO.

The system proved to be highly reliable throughout the DOPLIGHT '87 operation period virtually eliminating chronic lightning induced voltage transient problems experienced in previous wire cable systems.

Radar Preprocessor/Display System: The new radar preprocessors for the NRO and CIM radars designed and implemented at NSSL were deployed and commissioned for operation during FY 87. The preprocessor provided an interactive, menu-driven, color display system capable of executing essential signal processing tasks at higher antenna scan rates than previously possible. The system, designed using modern multiprocessor technology, achieves a new level of automation in signal processing and control of the Doppler radar systems.

Prototype Surface Network Station: Software was developed and tested for collection, processing, storage, and retrieval of field data for the prototype surface station. Instrument platforms and sensors have been tested to achieve improved field deployability.

EXPECTATIONS FOR FY 88

Facilities Engineering

CIM Radar Upgrade: A comprehensive upgrade of the NSSL CIM radar facility is planned for FY 88 and FY 89. Work will include basic facilities changes designed to improve radar system performance and reliability, data processing hardware, and real-time data communications and display.

NEXRAD Recording System: A prototype transportable data recording system interfaced to the NEXRAD Level II data port will be designed and fabricated for the archiving of high density, research quality data. Acquisition of several commercial systems manufactured to prototype specifications is anticipated.

Mobile Rawinsonde System: NCAR CLASS system components will be used to assemble a completely operational mobile rawinsonde system in support of nation-wide NOAA upper-air research sounding data needs.

Portable Surface Station Prototype: An operational portable prototype station will be commissioned, in preparation for possible acquisition of a multi-station network based on the prototype specifications.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) was established in 1978 as a joint venture of the University of Oklahoma (OU), through the School of Meteorology (SOM) and other academic units, and NOAA, principally through NSSL. Basic and applied research studies are conducted with emphasis on convective storms and other mesoscale weather phenomena and their environments, and on relevant observing techniques, especially remote sensing.

ACCOMPLISHMENTS FY 1987

Convective and Mesoscale Physics and Dynamics

An invitational conference was held in May on the dynamics of atmospheric convection, with presentations from about 25 scientists, half from outside the Norman area. A recurrent impression was that the CISK (Conditional Instability of the Second Kind) concept of interaction between convective clouds and their larger scale environments is being deemphasized or abandoned in favor of more specific mechanisms. A particular attraction was the opportunity for scientific participants to engage in direct field observation of the intense southern plains convective storms that occur at that time of year.

Experiments were initiated with a numerical simulation model of convective storms, adapted from the Colorado State University RAMS model. The initial emphasis is on deep convection in a tropical environment with mesoscale forcing. The inclusion of ice physics is found to increase the amplitude substantially, apparently due to melting layer cooling. The ultimate objective is to predict the evolution of multi-storm environments, such as that in the Florida peninsula or in mesoscale convective complexes. The Central Oklahoma Mesoscale Modeling and Analysis (COMMA) program continued, in collaboration with the SOM and NSSL, with emphasis placed on building modeling components. The Piecewise Parabolic Method (PPM) for accurately simulating regions of intense gradients, originally developed for handling shock waves, has been adapted for use in convective dynamics problems. Also a technique has been developed for improving the microphysical interactions in the simulation of rain-loaded convective downbursts, the events which often produce dangerous airport wind shear.

The generation of mesoscale convective complexes (MCCs) has been considered as a perturbation problem. The results suggest that the gross structure of MCCs may be controlled by the competition between advective inflow of moist air and turbulent dissipation.

Winter precipitation bands in the southern plains, which are responsible for most of the cool season rain and snow in the Oklahoma area, have been investigated both theoretically and observationally. It is found that conditional symmetric instability and frontogenetic convergence are both important in initiating and controlling these events.

We discovered that intense vortices in a laboratory vortex chamber can be generated by tilting of inflow vertical shear without mean rotation, in a way apparently analogous to the evolution of tornadoes in supercell storms.

In-situ sampling of the microphysical characteristics of developing convective clouds over Oklahoma was conducted in cooperation with the University of North Dakota, using their instrumented aircraft. Preliminary analyses suggest that the clouds contained mixed continental and maritime droplet spectra and developed precipitation by an ice formation process.

Applications programs have been completed in several areas of interest to the National Weather Service. It was found that standard surface and sounding data could be combined with processed radar data from the RADAP-II system to provide guidance on the hail size potential of convective storms. Tests with independent data showed some success in 30-90 minute forecasts of hail location. Also a comprehensive study is nearly complete on the problem of predicting the type of winter precipitation over the southern Great Plains, i.e., whether it will be rain, sleet, freezing rain, or snow.

Remote Sensing and Analysis Techniques

Work has been carried out in several areas in collaboration with the SOM and NSSL. A technique has been developed for recovering the three-dimensional wind field, pressure and temperature from single Doppler radar data. The technique involves repeated application of a numerical model for predicting the flow field and its errors, periodically corrected by the radar observations. Testing has been done using a complete data set generated artificially by numerical simulation, with "observations" confined to a single component of the wind.

We have investigated the capability of wind "profiler" systems to enhance atmospheric sounding capabilities and provide initialization data for numerical prediction models. Experiments were conducted using 3-hour sounding data from the NASA Atmospheric Variability Experiment (AVE) networks. It was found that by assimilation of the wind data alone, temperature fields of accuracy $\approx 1.5^{\circ}C$ were recovered. These results verify similar predictions made earlier from modeling experiments. Similar analyses are being conducted using 3-station profiler data from the PRE-STORM experiment, for which vertical velocities, temperature gradients and ageostrophic winds will be compared between the profiler and soned networks.

The use of airborne Doppler lidar for observation of convective storms, was investigated by scientists at SOM and NSSL. The lidar data, obtained from a NASA system, was found to be useful in delineating outflow boundaries and other important features, but analysis was restricted by the limited range of the lidar beams.

EXPECTATIONS FOR FY 1987

1) Most of the areas of work indicated in the accomplishments section are being continued, with an emphasis on coalescing and coordinating many of our activities in remote sensing analysis and small scale modeling. We believe

that operational prediction models of the future will be principally of two kinds--global in extent, with a resolution down to 50 km or better, and of small regional extent, with resolution down to 1 km or better. The small scale models will, for their initiation, use both the larger scale analyses and small scale data, mostly from new remote sensing systems. To develop and test such small scale models, and to show how best to use the new sources of observational data to initialize them is a goal and a growing responsibility of the mesoscale meteorological research community, one in which CIMMS intends to participate.

2) In a new collaborative program with NSSL, we plan to participate in observing program to document the modification process by which cold and dry continental air which passes over the Gulf of Mexico becomes transformed into warm and moist subtropical air. The modified air, when it returns northward, forms the energy source for convective storms in the central U.S. Planned observations in FY 1988 will be conducted principally by a NOAA P-3 research aircraft and 3 NCAR CLASS sounding systems. This represents a new area of research for CIMMS, and recognizes the critical but partially neglected role of the boundary layer in establishing the environmental conditions for convective storm generation.

PERSONNEL OF THE
NATIONAL SEVERE STORMS LABORATORY

AS OF SEPTEMBER 30, 1987

OFFICE OF THE DIRECTOR

DIRECTOR - DR. ROBERT A. MADDOX
SECRETARY - JOY L. WALTON
CLERK TYPIST - PEGGY L. BAKER

SENIOR SCIENTIST - DR. RICHARD J. DOVIAK
SENIOR SCIENTIST/ASST. DIRECTOR - DALE SIRMANS
DOPLIGHT PROJECT LEADER - DOUGLAS E. FORSYTH

METEOROLOGICAL RESEARCH

MANAGER - DR. JOHN M. LEWIS
SECRETARY - SANDRA D. McPHERSON

METEOROLOGIST - MARK S. ANTOLIK (COOP)
METEOROLOGIST - DR. ROBERT P. DAVIES-JONES
METEOR. AIDE - ROGER EDWARDS (WAE)
METEOROLOGIST - DR. CARL E. HANE
METEOR. AIDE - KATHERINE M. KANAK (WAE)
METEOROLOGIST - DR. ROBERT M. RABIN
METEOROLOGIST - DAVID J. STENSRUD
METEOROLOGIST - VACANT
METEOROLOGIST - VACANT

ADMINISTRATION

ADMINISTRATIVE OFFICER - LOYCE M. TILLMAN
ADMINISTRATIVE AIDE - PATRICIA R. GREGORY
ADMINISTRATIVE AIDE - STEPHANIE K. KELLY
LIBRARIAN - MARY E. MEACHAM (WAE) (P)

APPLICATIONS

MANAGER - DONALD W. BURGESS
SECRETARY - VACANT

METEOROLOGIST - RODGER A. BROWN
METEOR. TECH. - CHARLIE A. CRISP
METEOR. AIDE - CHRISTOPHER W. PORTER (WAE)
METEOR. TECH. - LESTER C. SHOWELL
METEOROLOGIST - ARTHUR WITT (WAE)
METEOROLOGIST - VINCENT T. WOOD

DOPPLER RADAR

MANAGER - DR. DUSAN S. ZRNIĆ
SECRETARY - CAROLE J. HOLDER

METEOROLOGIST - DR. EDWARD A. BRANDES
METEOROLOGIST - DR. CHARLES A. DOSWELL III
METEOROLOGIST - MICHAEL D. EILTS
METEOR. AIDE - GREGORY A. HANSON (WAE)
PHY. SCI. AIDE - SUSAN K. OAKLAND (WAE)
METEOROLOGIST - STEVEN D. SMITH (WAE)
METEOROLOGIST - STEVEN V. VASILOFF
METEOR. AIDE - JEFFREY A. WALLENFANG (WAE)

SCIENTIFIC SUPPORT

MANAGER - VACANT

FIELD FACILITIES AND DEVELOPMENT

MANAGER - JOHN K. CARTER
SECRETARY - RUTH B. WILK
CLERK TYPIST - LAWRENCE S. DEVERICKS
METEOROLOGIST - SHERMAN E. FREDRICKSON
ELECTRONICS TECH. - JESSE D. JENNINGS
ELECTRONICS TECH. - LEONARD A. JOHNSON
ELECTRONICS TECH. - EUAL G. KELLY
COMPUTER CLK/ASSISTANT - DAVID E. MEDDERS
ELECTRONICS TECH.- JACK M. REECE (PTP)
ELECTRONICS TECH. - PAULA K. SADLER

RADAR SUPPORT

MANAGER - F. ALLEN ZAHRAI
ELECTRONICS TECH. - GLEN H. ANDERSON, JR.
METEOR. TECH. - CHARLES G. CLARK
ELECTRONICS TECH. - JAMES W. McGOWEN
ELECTRONICS TECH. - WILLIAM F. PHIPPS (FTT)
ELECTRONICS TECH. - J. MICHAEL SCHMIDT

COMPUTING AND DATA MANAGEMENT

MANAGER - WILLIAM C. BUMGARNER
CLERK TYPIST - RENEÉ L. DIXON
METEOROLOGIST - J T DOOLEY
METEOROLOGIST - MICHAEL H. JAIN
METEOR. TECH. - GERALD J. WARDIUS

FACILITIES MANAGEMENT CONTRACT

STEPHEN MILLION
JEFFREY PITTS
CHRISTOPHER WALKER
KELLI WEKER

STORM ELECTRICITY AND CLOUD PHYSICS

MANAGER - DR. W. DAVID RUST
SECRETARY - MARY LOU YOUNKINS

PHY. SCI. AIDE - WILLIAM H. BURNETT (WAE)
ELECT. ENGINEER - KEVIN N. CAMERON
ENGINEERING AIDE - CHRISTOPHER A. CORBETT (WAE)
PHYSICIST - DR. DONALD R. MacGORMAN
PHYSICIST - DR. VLADISLAV MAZUR
ELECT. ENG. AIDE - STANTON A. McCOURRY (WAE)
COMPUTER CLERK - GEORGE G. McGEHEE (WAE)
ELECTRONICS TECH. - DENNIS E. NEALSON
METEOROLOGIST - DR. CONRAD L. ZIEGLER

UNIVERSITY OF OKLAHOMA/NOAA
COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES (CIMMS)

DIRECTOR - PROFESSOR DOUGLAS K. LILLY

~15 FULL OR PART-TIME PERSONNEL
~15 GRADUATE STUDENTS

UNDESIGNATED PERSONNEL ARE FULL-TIME PERMANENT

PTP - PART-TIME PERMANENT, FIXED WORK SCHEDULE

FTT - FULL-TIME TEMPORARY, FIXED WORK SCHEDULE

PTT - PART-TIME TEMPORARY, FIXED WORK SCHEDULE

WAE - INTERMITTENT TEMPORARY, NO FIXED WORK SCHEDULE, UNDESIGNATED WAE'S ARE TEMPORARY STUDENT EMPLOYEES

WAE(P) - INTERMITTENT PERMANENT, NO FIXED WORK SCHEDULE; (P) DESIGNATES PERMANENT WAE EMPLOYEE

PERSONNEL, BUDGET, AND ADMINISTRATIVE STATISTICS

Personnel FY 1987

	October 1, 1986		September 30, 1987	
	Full-time	Part-Time	Full-time	Part-time
Professional	29	4	29	3
Technical	10	2	12	2
Clerical	5	3	6	3
	44	9	47	8

Number of full-time holding doctoral degrees on September 30, 1987: 12

In addition to the above, the Laboratory employs 13 University of Oklahoma (OU) students part-time; they are assigned to NSSL staff who are Adjunct Professors at O.U. The Cooperative Institute for Mesoscale Meteorological Studies employs 11 Graduate Research Assistants, 3 Research Associates and 7 supporting staff funded by NSSL.

FY 1987 Budget and Funding

OPERATIONS RESEARCH & FACILITIES

Recurring FY 1987 Base	2,945,000	
Severe Weather	300,000	
Computer Workstations	110,000	
Other One-time Funds	190,715	
		3,545,715
NWS/NEXRAD IOTF	128,800	
NWS/NEXRAD IOTS	236,250	
NWS/TDL	35,500	
NWS/OH	30,000	
		430,550
TOTAL NOAA OR&F		3,976,265
MANAGEMENT FUND		438,233

ADVANCES AND REIMBURSABLES

Department of Transportation	745,000	
National Aeronautics & Space Admin.	105,000	
Office of the Federal Coordinator for Meteorological Services	22,000	
		872,000
TOTAL FY 1987 FUNDING		5,286,498

GRANTS AND CONTRACTS

FY 1987

Grants and contracts administered by NSSL during FY 1987 are listed below. Other agencies are indicated in the first column where their funds were used to maintain the grant or contract.

Recipient organization, title of grant or contract, and prin. investigator	Number	NSSL Cognizant Officer	State Date	Term Date
Applied Computer Systems "Services for Facilities Management to Operate NSSL Computer Equipment	NA84RAE05057 ($71,000) ($25,000)	Bumgarner	10/1/86	9/30/86 3/31/87
Bradford Brothers, Inc. "Service for facilities Management to Operate NSSL Computer Equipment	50RANR700027 ($36,500)	Bumgarner	4/1/87	9/30/87
University of Oklahoma Cooperative Agreement "Cooperative Institute for Mesoscale Meteorological Studies" CIMMS	NA85RAH05046 ($469,742)	Maddox	10/1/86	9/30/87
NASA/Marshall Space Flight Center "Storm Physics Research" (Wilson) NASA	40RFNR730040 ($25,000)	Rust	1/5/87	1/15/88

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1 OCTOBER 1986 - 30 SEPTEMBER 1987

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