NATIONAL HURRICANE RESEARCH LABORATORY

FISCAL YEAR 1982 PROGRAMS - FISCAL YEAR 1983 PROJECTIONS

Atlantic Oceanographic and Meteorological Laboratories
Miami, Florida
January 1983

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

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National Hurricane Research Laboratory
Coral Gables, Florida

Atlantic Oceanographic and Meteorological Laboratories
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January 1983

UNITED STATES
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Secretary

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ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORIES

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INTRODUCTION

The National Hurricane Research Laboratory (NHRL), an element of the Atlantic Oceanographic and Meteorological Laboratories (AOML), is NOAA's primary focus for research on hurricanes and tropical meteorology. NHRL's research is directed at improving hurricane prediction and increasing our knowledge of the storms' structure, dynamics, and multiscale interactive processes. The laboratory's hurricane field program uses the highly instrumented Research Facilities Center (RFC) aircraft to acquire data sets that are analyzed to describe and understand the dynamics and energetics of hurricanes.

The laboratory is collocated with the National Weather Service's (NWS) National Hurricane Center (NHC) and interacts with NHC in all phases of its program, but most strongly in hurricane prediction modeling and in hurricane storm-surge model development. NHRL also interacts with NWS's National Meteorological Center (NMC) on problems of hurricane prediction and modeling, and with the National Center for Atmospheric Research (NCAR) on scientific investigations of the hurricane's inner core.

The primary goal of NHRL's 1982 Hurricane Field Program was to gather observations of the environmental flow around mature hurricanes in the western Atlantic, Caribbean, and Gulf of Mexico (i.e., the Atlantic Hurricane Basin). Researchers have expressed a need for observations of the wind and height fields in the middle and lower troposphere on the periphery of hurricanes, especially over normally data-void oceanic regions, to improve hurricane track forecasts. Accordingly, missions for the 1982 field program were designed to collect these data by releasing omega dropwindsondes (ODW's) from the two NOAA/RFC WP-3D aircraft in the synoptic-scale environment of mature hurricanes within 150-1500 km from the storm's center over intervals of about 100 to 250 km along the aircraft's flight tracks. Observations thus obtained were to be transmitted in real time to both the National Hurricane Center (NHC) and the National Meteorological Center (NMC) for operational use by forecasters and "storage" in the NMC data base for subsequent use in analyses and model predictions.

Although the 1982 Hurricane Season in the Atlantic Basin did not provide any suitable storm, NHRL scientists and technicians were able to complete four research missions in Tropical Cyclone Debby on September 14 and 15. The first set of two aircraft missions was conducted when Debby was at tropical storm intensity. Twenty-eight ODW's were released from one of the NOAA/RFC aircraft on Debby's periphery to gather synoptic-scale environmental flow data, marking the first time that ODW's were used for this purpose. On the same day, September 14, the other NOAA/RFC aircraft flew a research mission designed to support studies of the planetary boundary layer (PBL) and the evolution of cumulus convective events in a developing storm. In addition, a unique set of wind measurements was obtained with the aircraft's airborne Doppler (tail) radar system. On September 15, a full, two-aircraft, synoptic-flow experiment was flown in Debby, which by that time, was at hurricane strength. During these missions, 45 ODW's were released. As planned, data obtained on both research mission days (September 14 and 15) were transmitted in real time to NHC and NMC for use in the preparation of operational forecasts.

The lack of other suitable storms in the Atlantic Hurricane Basin allowed the NOAA/RFC aircraft and crews and NHRL researchers to investigate Hurricane Olivia in the Eastern Pacific on September 23 and 24 while the storm was located about 500 miles southwest of San Diego, California. Two missions were flown on each of the two research days to gather synoptic-flow environmental data.

Olivia was classified as a minimal hurricane on the first mission day (September 23). Although Olivia was downgraded to a minimal tropical storm by the second research day (September 24), operational forecasters at the National Weather Service (NWS) in California were interested in receiving the synoptic-scale environmental data from the aircraft to aid in their forecast and warnings program. These data aided forecasters in predicting storm recurvature toward central and southern California, and in predicting that Olivia would continue to weaken before making landfall. While no significant storm-related winds reached land, widespread rainfall was produced by Olivia, adversely affecting agricultural interests in California.

Data obtained from the eight research missions conducted by NHRL during the 1982 Hurricane Field Program will be processed and analyzed (at NHRL) so that scientists may learn more about the (a) effect of the synoptic-scale environmental flow on the motion of a hurricane and its prediction, (b) PBL in tropical cyclones, (c) evolution of cumulus convective events in developing tropical cyclones, and (d) impact and future use of airborne Doppler radar wind data on the understanding and description of multiscale interactive processes in hurricanes.

PERSONNEL

Composition of Full-Time Staff - FY-82

Degree	NHRL Personnel
Ph.D.	7
M.S.	10
B.S.	4
B.A.	1
A.S.	1
Paraprofessional	6

Composition of All Staff (Full- and Part-Time) - FY-82

Degree	NHRL Personnel
Ph.D.	7
M.S.	11
B.S.	12
B.A.	2
B.B.A.	1
A.S.	1
A.A.	2
Paraprofessional	11

UNIVERSITY RELATIONS

Research Contracts*

University	Research/Principal Investigator
Colorado State University	Hurricane typhoon studies in support of NOAA hurricane research and forecasting - Dr. William M. Gray
Desert Research Institute	A. Florida Ocean Cumulus Study (FOCUS) B. Hurricane Ella (1978) Analysis - Dr. John Hallett
University of Chicago	Mesoscale wind fields for Hurricane Strike Program (landfalling hurricanes) - Dr. T. Theodore Fujita

University-Associated Seminar Speakers at NHRL

1981

October 7	Richard Greatbatch: University of Cambridge "The Response of the Ocean to a Moving Hurricane"
November 3	Yi-Hui Ding: Academy of Sciences of China "Telecommunications Affecting Tropical Cyclone Formation"

1982

February 4	William Cotton: Colorado State University "Current Status of Dynamic Modification of Cumulus Clouds - Modeling Inferences"
March 18	Frederick Sanders: Massachusetts Institute of Technology "Quasi-Geostrophic Diagnosis of the MONEX Monsoon Depression"
August 26	William Gray: Colorado State University "Highlights of Present and Planned Research on Tropical Cyclones"

*Summaries are in Contracted Research section.

Scientists With the NOAA/University of Miami

Cooperative Institute for Marine and Atmospheric Studies (CIMAS)

Kenneth C. Belle - Mr. Belle is cooperating with Dr. Robert W. Burpee (NHRL) on the analysis of sea breeze data gathered in the summers of 1980, 1981, and 1982. He has developed a mixed-layer model to determine the effect that the sea breeze inflow has on the development of the mixed layer over the Florida peninsula.

Thomas Cheng - Dr. Cheng's research effort for FY-83 will be centered on a statistical study of the precipitation patterns in Hurricane Allen (1980). An autocorrelation analysis will be made on the radar reflectivity time composites of Hurricane Allen. The results will then be used to determine the fraction of the area covered by convection, and the three-dimensional structure of the convective areas. The ultimate goal is to determine the water budget of the inner core of the hurricane.

Harry F. Hawkins - Dr. Hawkins has completed a synoptic-scale study of Hurricane Allen (1980) and presented his findings as part of the NHRL Seminar Series. The 200-mb streamline analyses will be published in a NOAA Technical Memorandum. Analyses of the omega dropwindsonde data obtained during the four mission days of Dr. Robert W. Burpee's synoptic-flow experiment in FY-82 have been also completed.

Stephen J. Lord - Dr. Lord is studying the results of an axisymmetric, nonhydrostatic tropical cyclone model with and without parameterized ice phase cloud microphysics. The time and height variations of the various microphysical processes and the impact of the additional latent heat release due to ice formation on the tropical cyclone dynamics are being studied. Dr. Lord is also continuing cooperation with Dr. Robert Burpee on the analysis of the NHRL omega dropwindsonde data collected during the summer of 1982, and with Dr. K.V. Ooyama on the development of a system of physical equations for use in the quasi-spectral, nested-grid prediction model.

George A. Soukup - Dr. Soukup continues to cooperate with Dr. K.V. Ooyama on the quasi-spectral prediction model. The two-dimensional version of the model, now operational, is being tested. Tests on vortex motion in an external flow are under way. Improvements soon to be incorporated in the model are (1) extension of the model to nested grids on a spherical earth, and (2) extension of the model to allow the submeshes to move during the calculation. Upon completion of these extensions, the model will be used in a barotropic prediction of hurricane motion using real data for initialization.

Adjunct Faculty Members (1981-1982)

NHRL Scientist	Academic Affiliation	Discipline
Mr. Howard A. Friedman	Miami-Dade Community College	Aviation Meteorology
Dr. Stanley L. Rosenthal	University of Miami	Atmospheric Science
Dr. Lloyd J. Shapiro	University of Miami	Atmospheric Science

University Student

David Gerald: Junior Fellow from New Mexico State University; NHRL Physical Science Student Trainee.

FY-82 PROGRAMS - FY-83 PROJECTIONS

1. Observational Hurricane Studies

1.1 The Synoptic-Scale Environmental Flow Around Hurricanes

Goal

Omega dropwindsonde (ODW) data gathered on the periphery of mature hurricanes approaching the U.S. mainland will be used to define the synoptic-scale flow around a hurricane more accurately than is possible with the operational upper air radiosonde network.

Accomplishments (FY-82)

Field program planning and coordination with other agencies were completed. Aircraft and ground personnel were trained in operational duties. Procedures for transmitting data from the aircraft to the National Hurricane Center (NHC) and then to the National Meteorological Center (NMC) were tested. Programs to postprocess the omega dropwindsonde (ODW) data were obtained from the Research Facilities Center (RFC) and the National Center for Atmospheric Research (NCAR), but required significant modifications before they could be run on the NHRL computers. A terminal was purchased and software written for interactive data processing on the terminal that is linked to the NHRL HP computer system. The NCAR software was modified to complete final processing of temperature, humidity, pressure, and winds on the (ERL) CYBER 750. Data collected in Atlantic Hurricane Debby and Eastern Pacific Hurricane Olivia were transmitted to NHC and NMC in real time.

Plans (FY-83)

The first research task of the project is to assess whether the special omega dropwindsonde observations helped to improve the operational hurricane track forecasts. Comparisons of forecasts, from the operational dynamical and statistical hurricane models, with and without the ODW data, will help to determine the impact of increased data coverage on hurricane track forecasts. After final processing, these data will be available for researchers at NHRL and many other institutions for use in diagnostic and prognostic studies of hurricanes and to evaluate satellite soundings over the tropical oceans.

Within a few months after the end of the 1982 hurricane season, track forecasts from operational dynamical and statistical models will be computed from initial analyses with and without the ODW data. A paper will be prepared for the Bulletin of the American Meteorological Society describing the objectives of NHRL's 1982 flights and discussing the impact of these data on the official and objective forecasts. In addition, a technical memorandum describing the ODW data processing methodology will be written.

The ODW data will be reprocessed at NHRL and a final data set prepared. After the data processing is completed, subjective analyses of the observations at one or two pressure levels will be prepared. At the same time, work will begin on diagnostic studies of the environment near the hurricane and on incorporation of these data in simple prognostic hurricane models. (Burpee, Franklin)

1.2 Convective Studies in Recent Hurricanes

Goal

The analysis of rainband data from recent hurricanes indicates that modification of the low-level inflow occurs in the vicinity of these bands as a result of the downward transport of low Θ_e air in convective-scale drafts. This could have a substantial impact on the structure and evolution of the eyewall and the hurricane vortex as a whole. Through better understanding of the physical processes occurring on the convective scale within these outer rainbands, we hope to learn more about the factors that contribute to hurricane intensity fluctuations.

Accomplishments (FY-82)

Hurricane Convective Band Studies. The initial data processing and analyses of two hurricane rainband experiments (Hurricane Allen on August 5, 1980, and Hurricane Floyd on September 7, 1981) have been completed. These analyses present a striking contrast in band structure between the mature eyewall (Allen) and the outer rainband (Floyd). The principal differences in structure are the organization of the ascending air and the thermodynamics of the downdraft air. Within the eyewall, this ascent is highly organized on the mesoscale, with the updraft cores (above 500 m) consistently observed 1-5 km inward of the radius of maximum winds. Mesoscale vertical velocities computed from measurements of radial divergence agree fairly well with vertical velocity observations composited with respect to the location of the tangential wind maximum. This implies that a substantial part of the eyewall is dominated by organized mesoscale ascent rather than by a few discrete convective cores. Mass flux in Allen's eyewall is about four times greater than observed in a typical GATE slow-moving convective line, although maximum and average updraft core strengths are nearly identical. This increased mass flux is realized through the increased area covered by active updrafts (20-25%, as opposed to 4-5%).

The rainband's vertical motion pattern is much more stochastic, resulting from the actions of convective cells that move down the band. The radar echo pattern reveals many more discrete cores of 40-45 dBZ in the rainband as opposed to the more uniform eyewall radar depiction. The distribution of cells along the rainband is also nonuniform. The upwind third of the band contains many more reflectivity cores than the downwind third, with the downwind end merging into an area of pronounced stratiform precipitation.

The apparent modification of low-level inflowing air by convective-scale downdrafts within the outer convective rainband is another important difference. Equivalent potential temperature (Θ_e) decreases of 10-12° K were observed at low levels across the Floyd rainband. Cross sections of Θ_e revealed that this decrease was likely caused by midlevel air being transported to the surface by convective-scale downdrafts. This Θ_e discontinuity acts somewhat like a "barrier" to the low-level flow crossing the band and leads to a zone of convergence on the outside edge of the band feeding the convective cells within the band. This barrier is not always evident when crossing the band (as observed in squall lines), but is strongly coupled to the location of the convective cells. This modification of the inflow has implications for the buoyancy of the eyewall clouds and may explain the common observation that storms with strongly convective spiral rainbands (typically located to the north and east of the eye) often have incomplete eyewalls with the eye open to the south. This may also be one of the mechanisms by which outer convective rings (double eyes) destroy the inner eye. Because of the near-moist adiabatic environment of the eyewall, very little modification of the boundary-layer air takes place in that region, although convective-scale downdraft cores are just as strong as in the rainband (2-3 m s^{-1}).

Data processing and analyses have been completed for an intercomparison study to evaluate the airborne Doppler radar measurements from the vertically scanning, X-band, tail radar of the NOAA/RFC WP-3D aircraaft. Specifically designed experiments to gather airborne Doppler radar data in the vicinity of ground-based Doppler radars were carried out in the Boston, Massachusetts, area [in conjunction with the Massachusetts Institute of Technology (MIT) radar] and in the Seattle, Washington, area (in conjunction with the CYCLES program and the two NCAR Doppler radars). Measured horizontal velocities compare to within a few meters per second of ground-based Doppler radar estimates and, given the sampling techniques employed by both airborne and ground-based radars, better agreement than that would not be expected. Intercomparisons of vertical velocity measurements compare to better than 1 m s^{-1}, although the variance of the airborne observations is several times that of ground-based values (~ 1 m s^{-1}). This is felt to be caused by antenna "jitter" of 0.2°-0.3°. These tests were conducted in stratiform precipitation. An additional data set was obtained during the JAWS project in Denver, Colorado, in the vicinity of the NCAR triple-Doppler radar network. Data were gathered in very intense (~ 70 dBZ) convection. This will allow an evaluation to be made of the sampling errors associated with making airborne Doppler radar measurements in convection when periods for the data gathering are about 10-20 min. Also, data were obtained that will allow us to test the feasibility of horizontally scanning airborne Doppler radar.

An extensive set of computer processing programs was written to reduce the airborne Doppler radar data to maps of wind velocity on a 2-km grid with 1-km vertical resolution. Software was also written to display the airborne Doppler radar data on a color monitor and to unfold the data objectively.

Plans (FY-83)

After we have evaluated the 1982 airborne Doppler radar hurricane data, we will complete plans for the proposed 1983 hurricane convective dynanmics experiment. This experiment will be carried out using the two NOAA/RFC WP-3D aircraft to study, further, the convective rainbands of the hurricane. Here the emphasis will be on the upwind structure and the modification of the boundary layer by convective-scale downdrafts and possible effects on the storm intensity.

Additional software will be developed to perform airborne Doppler radar data processing. This will enhance our capabilities to integrate the Doppler radar data with other data sets. A cooperative project with Peter Hildebrand (NCAR) to evaluate the airborne Doppler radar data taken during the JAWS program will continue. Detailed analyses and intercomparisons with tri-Doppler radar-derived winds for several convective cells will be made. It is expected that this evaluation will lead to an improved understanding of the performance of the airborne Doppler radar in strong convection. This is needed to design the 1983 experiment properly.

The processing of the July 28 and August 12, 1982, sea-breeze airborne Doppler radar data sets will begin. This analysis will emphasize convective-scale motions within the cells along the western edge of the precipitation feature that formed, initially, along the sea-breeze convergence zone. Vertical motions will be kinematically derived from the analysis of horizontal winds at several vertical levels. This will give some insight into the origin of the convective-scale downdrafts (relative to the reflectivity cores) and their interaction with the sea-breeze convergence zone. A comparison of downdraft dynamics that are thought to operate in GATE with hurricane convective lines will be made. The Doppler radar data set gathered during Hurricane Debby (1982) will also be analyzed. (Jorgensen, Marks)

1.3 Mesoscale Precipitation Features in Hurricanes

Goals

The goals of this research are to identify the mesoscale convective features in mature hurricanes and to describe their basic organization and structure.

Accomplishments (FY-82)

Analyses of the vortex-scale precipitation features observed with the airborne radars in Hurricane Allen (1980) were finalized. Time composites of the horizontal and vertical structure of the precipitation features have been completed for seven flights into Hurricane Allen during August 5-10, 1980. The compositing approach, used to define the horizontal structure, mapped radar data from each flight leg into storm-relative coordinates. To minimize signal losses caused by beam filling and intervening precipitation attenuation, a number of sweeps from the radar were composited along the flight track into a single map that maximized the returned signal at each point. By mapping all of the radar data in storm-relative coordinates, flight legs through different quadrants of the vortex can be combined to provide a complete map of the precipitation over the whole storm. However, a sacrifice must be made in temporal resolution to improve spatial coverage; i.e., the longer the period covered by the time composite, the longer the period before changes in structure can be observed. The Hurricane Allen composites covered 2-3 h periods, which are useful in determining changes on the vortex-scale in the eyewall or rainband structure and orientation. Some of the interesting results from the analysis of Hurricane Allen are summarized below.

1) Analysis of the time composites for the seven flights in Hurricane Allen revealed that the eyewall radius varied in a similar manner to the tangential wind profiles discussed by Willoughby et al. [35]. Initially, on August 5, the eyewall had a radius of 40 km, but by August 7, the radius was 17 km. The largest change in the eyewall radius occurred between the two flights on August 6. The first flight (1500-1800 GMT) showed an eyewall radius of 28 km, while the second flight (2100-2300 GMT) showed the radius was 22 km, a change of 1 km h^{-1}.

2) The eyewall structure was clearly delineated in both the horizontal and vertical time composites. An interesting observation was the variability in the eyewall height in different quadrants of the storm. Often, one quadrant of the eyewall had tops 3-4 km higher than those in the other quadrants. These differences were especially pronounced when the eyewall radius was about 15 km (August 7-8). Such differences show that, even though the eyewall may appear symmetric in the wind profiles, the convection, and subsequently the three-dimensional rainfall distribution, responds to higher order wave numbers.

3) In contrast to the clearly defined eyewall structure, the rainbands outside the eyewall (the rainband region) were harder to identify. Their structure and orientation varied from one composite to the next. The most consistent feature in the rainband region from flight to flight was an extensive area of stratiform precipitation. The stratiform precipitation region was characterized by a distinct "bright band" near the height of the 0° C isotherm (4-5 km). The rainbands rarely extended above this height.

4) The time composites were also used to estimate rainfall rates in Hurricane Allen using the Z-R relationship derived by Jorgensen and Willis [15]. The rainfall rate distributions observed in Hurricane Allen were similar to those observed by Miller (1958)[1] in 14 Florida hurricanes; only 3-4% of the rainfall rates within a 1° radius of the storm were >13 mm h^{-1} or 40 dBZ. The very high rainfall rates were only observed in the eyewall. Within 1° radius of the storm center, the azimuthally averaged rainfall rates ($\overline{R}$) in the eyewall region were 4-6 times larger than those in the rainband region. The average $\overline{R}$ for all level flights was 10.8 mm h^{-1} in the eyewall and 2.5 mm h^{-1} in the rainband region. However, since the rainband region encompassed a much larger area than the eyewall region, the total rain flux (area times mean rainfall rate) in the rainband was roughly 60% of the total rain flux within 1° radius of the storm center.

To stratify the precipitation patterns in mature hurricanes between stratiform and convective type rainfall, a three-dimensional tail radar time composite of the reflectivity pattern in Hurricane Allen was made. Data for Hurricane Allen on August 8, 1980, were selected for this study, and the

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[1] B.I. Miller, "Rainfall Rates in Florida Hurricanes." Mon. Wea. Rev., 86 (July 1958):258-264.

three-dimensional tail radar precipitation patterns were stratified into stratiform and convective areas.

Preliminary findings from these investigations indicate that the precipitation pattern was largely stratiform below the melting level in the rainband region. However, very high reflectivity values occurred above the melting level (>50 dBZ) at some isolated regions within the eyewall. A study of the reflectivity patterns for individual times revealed that the locations of the high reflectivity values were constant relative to the center of the storm. An upwind tangential tilt of these high reflectivity cores was also found. Whether these high reflectivity cores were the result of convective-scale or large magnitude mesoscale vertical motion within the eyewall is still uncertain.

Plans (FY-83)

The mesoscale features in one or two more asymmetric storms will be studied. Gert (1981) is the most likely candidate for this study, since it is already being studied by other NHRL scientists, and good radar data coverage exists for more than one day of the storm. The analysis will stress the differences and similarities in the precipitation organization and structure between symmetric storms of the Allen type and asymmetric storms of the Gert type.

High priority is being given to the preparation of a manuscript that will summarize the airborne radar data processing techniques used at NHRL. At the moment, NHRL is the only facility capable of analyzing the WP-3D airborne radar data. We have received many requests for the processing of airborne radar data from other organizations. The manuscript will include a discussion of beam-filling problems and the typical losses that can be expected; the intervening precipitation attenuation problem; and the beam-blockage problem at low altitudes. The horizontal time compositing will be described along with its advantages and drawbacks, as well as applications of the data; i.e., rainfall analysis. The three-dimensional time compositing, which incorporates the tail radar data, will be included with a description of the formats used in our analysis. (Marks, Jorgensen, Cheng, Houze [University of Washington])

1.4 Eye Dynamics Data Analysis

Goal

The purpose of this work is to provide an observational basis for the formulation and evaluation of theoretical and numerical hurricane models.

Accomplishments (FY-82)

Nearly continuous aircraft and radar observations were obtained in Hurricane Gert (1981) over a 48-h period on September 11-13, 1981. These data have been largely processed; reprocessing of an earlier data set from Hurricane David (1979), to take advantage of recently developed computer software, has begun. Hurricane Gert showed substantial east-west asymmetries. The eastern semicircle was moist, dominated by inflow, and contained most of the storm's convection. The western semicircle was dry and dominated by outflow. Except for a few hours, late on September 11, the convection occurred in spiral bands rather than in closed convective rings [as observed in Allen (1980)]. The storm's failure to intensify, as well as its ultimate weakening, appears to be related to its passage over cold water.

Plans (FY-83)

The principal effort for 1983 will involve completion of the analyses of Hurricanes Gert and David. The Gert data are nearly complete, but the David data have serious problems that will take some care to correct. Nevertheless, we may anticipate that the study will be completed and submitted for publication in 1983. (Willoughby)

1.5 Microphysics Studies in Hurricanes

Goals

The purpose of this research is to describe the amounts and partitioning of water substance in hurricane clouds. The goal is to describe liquid and ice particle number density spectra, partitioning, and generation and depletion rates within the dynamic framework of the storm. The emphasis is on determining the microphysical characteristics of the hurricane clouds as a function of the measured vertical velocity of the air at meaningful structural locations within the storm.

Accomplishments (1982)

Drop spectra data from well below the freezing level for Hurricanes Anita (1977) and Frederic (1979) were analyzed in detail. A procedure to normalize drop size distributions was adapted and implemented. This allows a comparison of the spectral shape from data stratifications that involve multiple spectra, irrespective of water contents or rainfall rates. From this analysis, it was found that the spectral shape exhibited considerable curvature at a diameter of about 1 mm. Several "fitting" functions were explored and the gamma distribution gave the best fit based on effective parameterization of accretive growth and drop evaporation. A manuscript [60] reporting these results is nearing completion.

The ice analysis of Hurricanes Allen (1980) and Irene (1981) reveals voluminous amounts of ice and very little liquid water, except in strong updrafts in the eyewall. The data show evidence of large-scale recirculation of ice particles throughout the storm from deep convection in the eyewall.

Data from Hurricanes Anita and Frederic have been sorted by vertical velocity. The initial results of this study, surprisingly, do not indicate obvious differences in spectral shape for updraft regions versus downdraft regions.

Plans (FY-83)

We plan to stratify nearly all the available hurricane microphysical data, based on vertical winds. Particular attention will be paid to ice distributions and the analysis will be expanded to include the full three-probe (3-600 μm) spectra for selected cases. A study of graupel in hurricanes will be initiated. Particular attention will be paid to its location and formation regions, and the vertical fluxes of water by graupel.

FY-83 will see the preparation and submission of a manuscript on ice production and distribution in hurricanes. A manuscript describing the performance of the airborne WP-3D NOAA/RFC aircraft vertical wind system will be completed. (Willis, R. Black)

1.6 Rainfall Estimates and Convective Structure Determined From Radar Observations as Hurricanes Make Landfall

Goal

The main purpose of this project is the analysis of digital land-based radar data gathered during the landfall of tropical cyclones.

Accomplishments (FY-82)

Rainfall estimates for the 26-h period centered on the landfall of Hurricane Frederic (1979) were compared with amounts observed by rain gages within 200 km of Slidell, Louisiana. Calculations of nearly continuous rainfall estimates, during the period that significant precipitation was within range of the NWS (Slidell) radar, have been completed.

Land areas covered by the highest radar reflectivity in Frederic were compared with surface peak wind contours estimated from a ground damage survey and were found to be in reasonable agreement with each other. Time series of the highest wind gusts from anemometer data were related to the radar structure at the same location.

Plans (FY-83)

Further work on the Hurricane Frederic land-based radar data will be conducted. The motion, growth, and dissipation of convective and mesoscale areas, relative to the storm's center, will be determined from radar scans every 2 min during the time Frederic was within quantitative range of the NWS (Slidell) WSR-57 radar. This research on storm structure will emphasize (1) differences between the eyewall and outer mesoscale bands, (2) relationships between wind speeds at various levels and echo motion, and (3) changes caused by landfall. The low-level radar sweeps will also be used to help explain details of the three-dimensional CAPPI scans, which were recorded about once an hour. A paper containing these mesoscale and convective-scale hurricane analyses will be prepared for publication.

A black-and-white animated film is planned. The Frederic printouts will be filmed approximately every 2 min of the time spanning the storm's landfall. In this manner, echo motion and changes in eyewall characteristics should become easily discernible. Since each of the printouts is produced relative to the storm center, echo motion components caused by Frederic's translational speed will be removed, and an accurate depiction of the transition upon landfall is expected to result.

Joint recording sessions with NHRL and NWSTC teams are planned during the 1983 field season in the event of a significant hurricane landfall between Hatteras, North Carolina, and Brownsville, Texas. (Burpee, Parrish)

1.7 Observational Studies of the Hurricane Atmospheric Boundary Layer

Goal

The purpose of this study is to determine the structure of the hurricane boundary layer over open water and during landfall. The work is required to produce more effective short-term forecasts and warnings during landfall, and to aid in verification and development of hurricane landfall models.

Accomplishments (FY-82)

A study of the changes in boundary-layer wind structure before and during the landfall of Hurricane Frederic (1979) was completed during FY-82. The frictional effects of landfall acted to shift the region of maximum inflow angle to the landward side of the storm and to decrease coastal wind speeds by 20% relative to the winds over the nearby water. Most of the damage caused by the storm was associated with the northern eyewall and occurred about 2 h before the actual center made landfall. Results of the study were summarized in a paper published in Monthly Weather Review [26].

Plans (FY-83)

Work on this project will be suspended during 1983 while the principal investigator takes further graduate training at the Florida State University. (Powell)

1.8 Hurricane-Ocean Energy Exchange Processes

Goal

The purpose of this work is to describe the patterns and causes of sea-surface temperature (SST) changes in the inner core of hurricanes, and to determine the effect of reduced inner core SST values on surface sensible and latent heat fluxes.

Accomplishments (FY-82)

The data processing and analysis of more than 500 airborne expendable bathythermographs (AXBT's) obtained in 18 hurricanes over the past 10 years was completed. Extensive reports [44, 45, 48, 49] are in preparation that describes the results of this study.

Detailed analyses of AXBT and infrared radiation thermometer data have shown that hurricanes decrease SST in a consistent pattern with respect to the hurricane center. The pattern of cooling is crescent-shaped, with maximum cooling in the right rear quadrant of the storm between the radius of maximum wind (RMAX), and 2 RMAX, and there is little or no cooling in the left front quadrant. The size of the area cooled increases with increasing hurricane eye diameter. The magnitude of the cooling is independent of storm translational speed, U, for $U > 5$ m s^{-1}, but increases nonlinearly as U decreases when $U < 5$ m s^{-1}. In addition, the magnitude of the cooling is a linear function of storm intensity. No significant cooling occurs at any storm speed or intensity for mixed layer depths (MLD) exceeding about 70 m. Maximum cooling greater than 5° C occurs for storms moving slower than 2 m s^{-1} in regions of shallow MLD (30-40 m).

The MLD decreases beneath the storm center beginning with the passage of the positive wind stress curl (negative in the Southern Hemisphere) associated with the leading edge of the hurricane eyewall. The minimum MLD occurs to the rear of the storm and along the track at a distance proportional to the speed of the storm. Increases in MLD are observed beyond RMAX to the right of the track with very little change evident to the left of track. The maximum surface and mixed-layer (ML) cooling occurs to the right of the storm track, where the thermocline gradient is maximum. This location corresponds with the transition region between the MLD minimum along the track and the MLD maximum between RMAX and 2 RMAX.

The observations indicate that some combinations of U, RMAX, and latitude can lead to particularly large changes of SST and MLD. It is speculated that a resonance occurs between the wind and current on the right side of the storm when both rotate clockwise with time at approximately the inertial period. This resonance could lead to a rapid acceleration of the ML currents, resulting in rapid ML cooling and deepening through shear generation at the base of the ML.

Following the initial response, the residual SST and MLD patterns are modulated by an internal wave response. For some intense storms, a transition region exists, of about one to two inertial wavelength/periods, where a 100-200 km scale of variation in the patterns is most pronounced. It is speculated that this may be a harmonic of the longer inertial wavelength/period excited by finite amplitude effects due to the extreme magnitude of the forcing. Wake patterns at larger distances and longer periods (two to five inertial periods) after storm passage reflect scales of variation consistent with inertial wavelengths.

Cross section analyses of temperature as a function of depth reveal consistent patterns of warming and cooling with respect to the storm center for various storm speeds. For sections normal to and through the center of slow-moving storms, upward isotherm displacement occurs at the center of the track from the MDL to about 150 m, while at about 2 RMAX to the right of the storm, strong subthermocline warming extends to 100 m. A much smaller region of subthermocline warming is evident to the left of the center. The warming is associated with the MLD increases, while the maximum ML cooling is located between the subthermocline cooling and warming regions. The magnitude of these anomalies is a function of storm speed and initial thermocline depth.

In large, slow-moving storms, surface cooling induced by a storm can cause a reduction in the sensible heat flux by (up to) a factor of 4, and in latent heat flux by (up to) a factor of 2. A significant downward heat flux at the top of the boundary layer is observed on the rainband scale (20 km). Secondary circulations caused by longitudinal roll vortices are shown to exist with a vertical scale on the order of the boundary layer depth and a horizontal scale of about 2 km, leading to a 1:2 aspect ratio. These calculations also act to transport sensible heat downward. Together, these scales contribute to a downward sensible heat flux across the top of the planetary boundary layer (PBL), which is on the order of air-sea sensible heat fluxes (100 W m^{-2}).

A hurricane PBL experiment was carried out in Hurricane Debby (1982) that involved the NOAA/RFC Doppler radar-equipped aircraft. The aircraft made stepped descents from above cloud base to as low as 100 m at several radial distances from the storm (in between the rainbands) so as to assess changes in the vertical profile of bulk parameters.

Plans (FY-83)

The Debby data will be compared with vertical wind profiles derived from on-board airborne Doppler radar data. Forward scattering spectrometer probes (FSSP) and two-dimensional Knollenberg spectrometer data will be used to assess the sea spray drop size distribution as a function of height in precipitation-free regions. Two manuscripts on the ocean response measurements will be submitted for journal publication [46, 49]. An extensive report on the AXBT data processing methods will be prepared for other potential users [48]. (P. Black)

1.9 Sea-State Photo Catalog

Goal

The objective of this study is to provide a comparison between hurricane sea-state photographs (obtained with a down-viewing vertical camera system) and surface wind speed over a wide range of Beaufort scales. The end product will be designed for use as a training aid to assist U.S. Air Force reconnaissance flight crews in accurately estimating surface wind speed.

Accomplishments (FY-82)

A first draft (text) for the Sea-State Catalog [47] has been completed. PBL model-derived 20-m winds have been calculated from flight-level INE

(Inertial Navigation) measurements corresponding to more than 80 frames (vertical camera photos) that have been selected as representative of the 15 Beaufort force categories from 3 through 17. Approximately six sea-state photos per category have been selected from the more than 71,000 frames reviewed, and have been printed.

Plans (FY-83)

Publication of the Sea-State Catalog [47] is planned for 1983.

We plan to install a 70 mm Hasselblad camera and data annotation system on one of the NOAA/RFC WP-3D aircraft this year to obtain higher quality sea-state photographs.

Two additional cases of wind veering with height in the hurricane PBL will be analyzed. The first case involves the derivation of surface wind directions from SLAR data collected in Gert (1981) and flight-level data. In the second case, surface data from buoys in Hurricane Frederic (1979) will be compared with flight-level data. (P. Black, Adams, Ross [AOML/SAIL])

1.10 Hurricane Boundary-Layer Remote Sensing Research

Goal

The object of this study is to determine the accuracy with which satellite and airborne passive and active microwave sensors can measure surface wind speed and direction and rainfall rates in hurricanes.

Accomplishments (FY-82)

A paper [10] on the initial results of airborne radiometer and scatterometer-derived winds and rainfall rates in Hurricane Allen (1980) was published. Work on the data from August 5 and 8, 1980, in Allen has continued. It has been found that lags of up to 10 km occurred between 850-mb aircraft measurements and the surface radiometer measurements because of the slope of the radius of maximum wind (RMAX) with height near strong convection. Wind speed comparisons of microwave winds and model-reduced flight-level winds within 15 km of RMAX indicate the microwave winds in this region are biased (high) by 15%. Inside and outside of this region, microwave winds are biased (low) by 15%. Microwave rainfall measurements are biased (high) near RMAX compared with airborne weather radar derived estimates. Corrections to the algorithm based on a dependent data subset are being developed to correct some of these biases. However, the radial advection of tangential convection near strong eyewall convection appears to invalidate simple PBL models for reducing flight-level winds to the surface in the eyewall region. These effects increase VMAX and decrease RMAX at the surface, compared with values deduced from the application of PBL models to flight level-winds.

A report [37] was prepared that summarizes wind, rain rate, and sea surface temperature estimates in and near tropical cyclones by Seasat microwave sensors. The summary emphasizes comparisons with airborne measurements during the 1978 hurricane season in Atlantic Hurricanes Ella and Greta and Eastern Pacific Hurricane Fico. A paper [36] describing the use of Seasat winds in the evaluation of gale-force wind radii in Western Atlantic, Western Pacific, and Eastern Pacific tropical cyclones was accepted for publication.

Plans (FY-83)

Refinements in the Allen (1980) microwave measurements of wind and rain rate will be made based on a dependent data subset and tested on an independent data subset.

Seasat precipitation measurements will be recalculated, for several tropical storm cases, using passive microwave data without the grid point averaging inherent in previous data. Comparisons with airborne rain-rate measurements will be conducted and satellite microwave techniques for measuring tropical cyclone rainfall rates will be evaluated. (P. Black)

1.11 Easterly Wave Composite During GATE

Goal

This study tracks each easterly wave trough during June, July, August, and September 1974, from its origin in Central Africa to Central America (or to the longitude of its decay). GATE observations enable this tracking to be considerably more accurate than the operational tracking that is summarized annually by the National Hurricane Center (NHC). The structure of the easterly waves in the Eastern Caribbean will be determined from the track information and compared with the structure previously determined over Western Africa and the Eastern Atlantic.

Accomplishments (FY-82)

A paper [3] on synoptic-scale motions during GATE, co-authored with Professor R.J. Reed of the University of Washington, was published.

The tracking of the easterly wave troughs from Central Africa to Central America was completed and compared with the operational tracks compiled by forecasters at NHC and to subjective and objective tracks determined by GATE researchers. The operational tracking has been carried out since 1967 and described in published annual summaries. NHC's operational tracking is based on radiosonde observations obtained at three stations and appropriate satellite images, while the GATE analyses have used the full set of data available for research. The tracks compiled by NHC indicate that about 5-15 of the wave troughs that pass Dakar each summer decay over the Atlantic and an additional 5-15 new synoptic-scale wave troughs form in the Atlantic. These tabulations suggest that some mechanism is initiating synoptic-scale disturbances over the Atlantic. The tracking completed as part of this project indicates that the operational methods overestimate both the total number of waves passing Dakar and the number of waves that decay over the Atlantic and that all of the wave troughs passing Dakar actually reach the Eastern Caribbean. While this comparison is possible only for the summer of 1974, it suggests that synoptic-scale disturbances probably are not being initiated in the Tropical Atlantic north of the ITCZ on a regular basis.

Plans (FY-83)

The tracking analysis will be completed, the composite structure of easterly waves in the Caribbean determined, and comparisons made with other GATE studies. A manuscript will be prepared for publication. (Burpee)

2. Twelve-Level Nested-Grid Model

Goal

The goal of this project is to develop numerical models of huricanes that are suitable for application to the problems of operational prediction of hurricane tracks and intensity. Present efforts are directed toward attaining a deeper understanding of hurricane motion, first in idealized environments and later with real data. Currently, work is under way on an idealized simulation of hurricane landfall.

Accomplishments (FY-82)

A 13-day hurricane simulation experiment was completed. This experiment differed from previous experiments in that the initial radius of maximum wind was placed at 100 km radius rather than at 240 km. The outer radius of the vortex was also reduced from 600 to 150 km, but the maximum wind speed of the vortex was retained near 19 m s^{-1}. A similar change of initial stage had been introduced into the two-dimensional analog of this model. This change resulted in a minimum radius of maximum wind of 20 km on the 10-km grid, which was 30 km smaller than previous comparable results. The two-dimensional model also showed a significantly weaker mature vortex (about 15 m s^{-1} weaker) when the sea-surface temperature was given as 27.5°C. The three-dimensional experiment, which has 27.5°C for the sea temperature, also resulted in a minimum radius of maximum wind of 20 km, which was 20 km smaller than comparable results. However, the two- and three-dimensional models differ on other points. The three-dimensional model hurricane grew at a much slower rate, but achieved greater ultimate intensity than the two-dimensional model. The three-dimensional vortex required more than 13 days to reach maximum strength, compared with about 8 days in two dimensions. In three dimensions, the ultimate intensity approaches that attained when one begins with the maximum radius at 240 km. This is about 898 mb central pressure and 92 m s^{-1} mean tangential wind speed and is the same in both two and three dimensions for comparable results. There are also large transients of the maximum wind and central pressure in two dimensions that are absent in three dimensions. These transients ranged over 25 m s^{-1} and 40 mb. As noted above, when the initial maximum wind radius is 240 km, both two-and three-dimensional models have similar mature strengths. The growth rates are also similar and the vortex structure is reasonably similar. Thus, with the smaller initial maximum radius, three-dimensionality clearly asserts itself. This contrast has not been examined carefully yet, but it is reasonable to assume that the three-dimensional nature of convection is at the heart of the matter. In this pair of experiments, there is less moisture in the boundary layer in two dimensions for comparable vortex strengths, but the two-dimensional vortex grows faster. One is led to suggest greater restraint of convection by downdrafts into the boundary layer in three dimensions. This is possible by surrounding updrafts with downdrafts in three dimensions, a process that is only possible at the origin of two-dimensional grids. Preliminary examination of three-dimensional results agrees with this view. A large contrast between two and three dimensions is not apparent when the initial maximum wind radius is 240 km, probably because much smaller areas of the ocean are covered by the higher wind speeds when the initial maximum wind radius is 100 km. This, in turn, greatly reduces the surface flux of moisture into the boundary-layer and significantly increases the time for boundary-layer moisture to recover from losses due to convection. It seems that if boundary layer moisture sources are great enough, downdraft control of convection is inhibited.

We plan careful diagnosis of the two- and three-dimensional model experimental results to examine the above problems as well as to examine the structure and dynamics of the hurricane model. Exact equations for the balance of moisture, heat, temperature, momentum, angular momentum, kinetic energy, divergence and vorticity have been programmed in three dimensions for arbitrary volumes. It remains to interpolate these results to cylindrical coordinates and consider graphics. Preliminary evaluation of the diagnostic balances shows reasonable relationships among the various terms, but some relationships merit further study. We may be transporting too much moist static energy upward at the top of the boundary layer. We are now drying the boundary layer by vertical mixing processes over most of the 10-km grid, even at points where no clouds are present to enhance the mixing coefficient.

Plans (FY-83)

A hurricane landfall simulation was also completed in 1982. The model simulation will be compared with real data sets that have been assembled at NHRL. The emphasis will be upon wind and rainfall changes caused by the storm moving over land. Changes are noted by comparison with the same model run, but without the land. The storm track will also be examined for influence of land. The strategy is to compare the simulation with land with a prior simulation with no land, which is known as the control experiment. The evaluation of the landfall experiment will be supported by observational studies both within and outside of NHRL. We are particularly interested in changes of low-level winds, rainfall, and the storm track as a result of landfall. Preliminary evaluation of this experiment and preparation of a manuscript outline are planned for FY-83.

Part of the evaluation of the control and landfall experiments requires use of the diagnostic balance equations that were developed during FY-82.

Introduction of Hovermale's Kuo parameterization into our models is planned. An experiment will be run that will allow us to compare the Kuo parameterization with resolvable heating in three dimensions.

3. Quasi-Spectral Hurricane Modeling

Goal

This is a long-range project to understand and, eventually, to predict, the motion of a hurricane. Although there are several operational hurricane-prediction models, it is also recognized that basic studies of various physical and dynamical factors affecting the motion, as well as changes in intensity, are needed to make substantial progress in the accuracy of prediction. The major goal is to understand interactions among various scales of atmospherical motions and between different dynamic regimes and, then, to incorporate them into a numerical model for further tests. For this purpose, the complex interaction question will be reduced to a number of more tractable problems that can be solved by analytical means and simpler numerical models. To facilitate the indiviual studies, which may range from the cloud scales of hurricane internal dynamics to the synoptic scales of tropical circulations, and also to ensure an efficient synthesis of those studies, the development of a general purpose base model will be continued, using an accurate and flexible numerical method, called QSTING (Quasi-Spectral Time Integration on Nested Grids).

Accomplishments (FY-82)

A two-dimensional version of the base model (code name: QVADIS), which may run on any level of nesting with general boundary conditions, was completed and showed that all the theoretical expectations of the QSTING method, as derived from the one-dimensional tests in the previous year, were perfectly met.

The first application of QVADIS to a hurricane problem was performed (July 1982) in association with semi-analytic work on the asymmetric boundary-layer flow of a moving hurricane (a translating circular pressure field was prescribed). The model results, which were fully nonlinear, confirmed the somewhat truncated analytical theory within the anticipated accuracy of the latter. The model test also revealed that the interface conditions of the QSTING method worked flawlessly on the vortical flow that cuts corners of nested-square meshes, but that the multiple nesting (six, here) created a hitherto unsuspected problem of representational aliasing. The cause of the difficulty has been found (paradoxically, too much accuracy in the calculation of certain terms), but a remedy requires further investigation.

Plans (FY-83)

The base model, QVADIS, needs an improvement to eliminate or reduce representational aliasing in application to multimesh (more than two) problems. Plans are to complete a major extension of the model to nested domains on the spherical earth and to implement moving submesh features.

With the extended version of the model, applications will be made to a study of short-period oscillations of a hurricane track. Also, applications will be made to an experimental barotropic prediction of real hurricanes, using the initial data objectively analyzed. Exploratory investigations of moist processes and parameterization will be continued. (Ooyama, Lord, Soukup)

4. Observational Study of the South Florida Sea Breeze

Goal

The field phase of the sea-breeze experiment was designed to provide a description of the mixed layer, the cloud layer, and the evolution of the sea-breeze circulation from shortly after sunrise until midafternoon, when deep convection is normally prevalent. In addition, it became possible to specify changes in the kinematic structure of the sea-breeze circulation during the transition of the convective field from cumulus congestus to the mature stage of cumulonimbus by adapting the aircraft patterns to take maximum advantage of the airborne Doppler radar.

Accomplishments (FY-82)

The field phase of the experiment was completed with aircraft flights on three days in 1982. It appears that a reasonable sampling of phenomena was achieved. With the availability of the airborne Doppler radar, the emphasis in the field program in 1982 was in gathering Doppler observations of the development of rain in the deep convection. Excellent data were collectd on two occasions when the sea-breeze convergence zone was moving inland at 1-2 m s^{-1}. Analyses of the kinematic structure on these days should provide an interesting comparison with faster moving lines of deep convection that are being studied at other institutions.

Considerable progress was made in the processing, analysis, and interpretation of the 1980 and 1981 sea-breeze aircraft missions. From the aircraft observations, the time variation of the ground temperature, the sea-breeze inflow and outflow at the coastline, and the inward propagation of the sea-breeze convergence zone were determined. The side-camera observations were analyzed and the time variation of cloud base, height, width, and percentage of area covered were estimated. Divergence values at low levels were computed on the peninsular scale for the National Weather Service coastal stations at hourly intervals and on the scale of the sea-breeze convergence zone from the flight data at 300 m. Additional analyses of the radiosonde, aircraft, radar, and satellite observations are in progress.

A numerical model was developed that extends Johnson's[2] model to include the effects of differential horizontal advection on the growth of the mixed layer. Debugging of the model's (computer program) code has been nearly completed.

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[2] R.H. Johnson, "Characteristic Structure and Growth of the Nonprecipitating Cumulus Layer Over South Florida." Mon. Wea. Rev., 106 (October 1978): 1495-1504.

Plans (FY-83)

Analyses describing the peninsular-scale relationships between the sea-breeze circulation and the large-scale environment will be completed, and a manuscript prepared for publication. The mixed-layer model will be tested and final results interpreted and synthesized. The Doppler radar observations of the development of deep convection in the sea-breeze convergence zones will be analyzed in detail. (Burpee, Belle)

5. Hurricane Prediction: Study of Long- and Short-Term Hurricane Track Forecast Errors

Goals

Three of the greatest hindrances to both short- and long-term hurricane-track forecasts have been the: (1) quality of the large-scale analyses over data-sparse oceanic regions; (2) inability of the numerical track forecast models to incorporate data within the influence radius of the hurricane (~ 300 nmi); and (3) errors caused by short-term (trochoidal) oscillations. The first purpose of this project has been the improvement of the operational barotropic hurricane-track forecast model (SANBAR), which is being used by NHC. These changes include: (1) a better analysis of the large-scale, deep-layer mean flow; (2) the incorporation of wind data within the hurricane influence radius; and (3) an evaluation of other numerical features of the model. The second purpose is to use recently available hurricane track data to extend the work begun by other investigators by better understanding the period and amplitudes of the trochoidal motions. An improvement in the predictability of trochoidal oscillations will aid short-range prediction (just before landfall) as well as improve the initial steering input for numerical hurricane-track forecast models.

Another objective of this project is to evaluate statistical regression models for the prediction of hurricane tracks and intensity changes, using predictions based on synoptic geopotential height data. The models developed by NHC will be complemented and extended by using alternative statistical models and methods. Improvements in predictive skill should result. Also, the statistical analyses will provide guidance for the optimal collection of aircraft data in the environment of the hurricane.

Accomplishments (FY-82)

SANBAR Model. At the end of FY-81, a new scan analysis using the method of successive corrections (MSC) was operationally implemented to provide a revised large-scale deep-layer mean (DLM) wind field as input to the prognostic section of the current SANBAR forecast model. During FY-82, this new package was tested in both operational and research modes. The goal at this stage of development was to produce an average forecast error (AFE) that was equal to or less than the AFE in the current operational SANBAR model. For the last half of the 1981 hurricane season, the AFE for the scan analysis (SCAN1) was lower at almost all forecast times than the AFE from the forecasts using the Eddy[3] analysis technique, which is currently used by the SANBAR package.

Verification tests were performed on SCAN1 and for several modifications with archived data from the 1979-81 hurricane seasons. The results met the above stated goal. The revisions that yielded positive results were combined to create SAN82, which was operationally implemented for the 1982 hurricane season. SAN82 consists of the MSC analysis and forecast package as run in the 1981 season with the folowing changes: (1) the addition of a bogus vortex to the large-scale analysis (as is currently done in the Eddy analysis for the operational SANBAR model); (2) a modified Pike steering method whereby the current storm motion is introduced into the analysis at the storm position rather than at all stations inside the storm's influence radius (IR); (3) revised filtering in the north-south direction (local 1-2-1 replacing Fourier-based); (4) automatic setting of the storm IR to 300 nmi (for numerical reasons); and (5) the use of the vorticity center to track the storms rather than the mean of the vorticity and stream function centers. SAN82 was used in 1982 by NHC's hurricane forecasters. In addition to these modifications, facsimile maps of the large-scale DLM wind fields, were produced and the archiving of the operational data has been greatly improved.

The introduction of a relocatable grid has been completed. The first application of the relocatable grid has been the operational implementation of the East Pacific SAN82 (EPSAN82) model during the 1982 season.

The program that processes the station wind data for the scan program has also been greatly improved. It presently incorporates more levels of the mandatory data, can use rawindsonde data from stationary and moving ships, omega dropwindsonde data (ODW) from research and reconnaissance aircraft flights, and contains revised rejection criteria for the station data. To use the NHRL ODW data, regression equations have been developed to construct an approximate DLM wind field from the mandatory reporting level data supplied by the ODW's.

Simultaneous runs of SAN82 can now be made in real time with and without the ODW data to examine the effects of these additional data on forecasts. The results from both runs will be available to forecasters in real time. In addition, special modifications to the scan and plotting programs have been developed to show, graphically, the large-scale steering current as resolved by the ODW data. This has been done by allowing the current storm motion at the storm center to be used only in the first scan. In subsequent scans, the ODW winds will be allowed to override the storm motion input.

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3 F. Sanders, A.C. Pike, and J.P. Gaertner, "A Barotropic Model for Operational Prediction of Tracks of Tropical Storms." J. Appl. Meteorol., 14 (April 1975):265-280.

A technique to allow the incorporation of data within the IR of the storm (Jensen[4] scheme) is nearly complete. The priority for the completion of this scheme was lowered to allow preparations to be made for use of the ODW data.

Statistical Models. Upper level geopotential height data from 1965-1980 is being used to develop new statistical regesssion models for hurricane-track forecasts jointly with the Research and Development Unit of NHC. Deep-layer mean heights are represented on a grid that translates with the storm. The grid comprises 113 points on a 150 nmi Cartesian grid in a 900 nmi radius circular domain centered on the storm. For forecasts of 24-h storm displacements, 795 cases (individual forecasts) make up the sample.

First, a step-wise screening regression technique is used. On a non-rotated, geographically oriented grid using the current synoptic height data alone, the 24-h mean forecast error (m.f.e.) is about 150 nmi. The speed bias (s.b.) is about -1.5 kt (slow). By rotating the grid with respect to the direction of current storm motion (as defined by the -12 to +12 h displacement vector), the m.f.e. is reduced to about 125 nmi and the s.b. to only about -0.5 kt. The reduction in m.f.e. is associated with the reduction of the variance of the 24-h displacements in the rotated system and the reduction in s.b. with the tendency of the 24-h displacement vectors to be close to the direction of current storm motion.

An estimate of hindcast skill at large lag is used to estimate the effective sample size (number of serially independent cases), which is about 300 for 24-h displacements. A measure of artificial skill, derived from a Monte Carlo method, is used to estimate forecast skill and limit the number of grid-point predictors selected for the forecast model. The root-mean-squared (r.m.s.) expected forecast error is decreased from the nonrotated to rotated grid system in nearly the same proportion as the m.f.e.

Next, an empirical orthogonal function (EOF) analysis has been made of the height fields. The use of 10 EOFs, selected in an a-priori manner as predictors of hurricane motion, provides an alternative to the grid-point screening technique. Expected forecast errors are slightly smaller for the EOF model.

Principal estimator patterns (PEPs) are also being evaluated in the rotated grid system to describe, efficiently, the coupling between hurricane tracks and the height patterns that have greatest predictive skill. These patterns allow physical interpretations to be made of the grid points selected in the step-wise screening analysis.

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4 F. Sanders, A.L. Adams, N.J.B. Gordon, and W.J. Jensen, "Further Development of a Barotropic Operational Model for Predicting Paths of Tropical Storms." Mon. Wea. Rev., 108 (May 1980):642-654.

Plans (FY-83)

SANBAR Model. The new verification program will be completed. SAN82 forecast errors will then be calculated and compared with results from the other current hurricane-track models for the 1982 season. The results from the new EPSAN82 will be verified and studied. Verifications for SAN82 will also be made from archived data runs for the 1979-1981 seasons.

Further tests and modifications will be made using the relocatable grid version. Error checking (for bad wind data) will be incorporated into the scan analysis package. The use of a finer grid, revised smoothing during the prognostic step, and the use of an alternate Helmholtz solver will be tested. Those revisions yielding favorable results will be incorporated into the 1983 operational version (SAN83).

ODW data will be used in three ways. Simultaneous runs of SAN82 with and without the ODW winds will be made during the 1982 season. In addition, graphics output of the storm steering as resolved by the ODW data will be produced. A third use of the ODW data will be made during the verification of the Jensen scheme through which data inside the storm IR can be used in the scan analysis.

Statistical Models. Evaluation of the results of the statistical hurricane-track forecast models will be completed. A feasibility study will be made for a statistical forecast model of hurricane intensity changes with an EOF analysis using deep-layer mean heights and height changes. If the results are encouraging, the analysis will be extended and an evaluation will be made of the expected forecast skill of such a model. (Shapiro, Goldenberg)

6. Hurricane Vortex Dyanmics

6.1 Asymmetric Evolution of the Hurricane

Goals

The objectives of this research project are to evaluate and predict the asymmetric structure and evolution of the hurricane vortex, including its interaction with the large-scale environment. The asymmetries are central to the track prediction problem, as well as the distribution of winds and convection in a moving vortex.

Accomplishments (FY-82)

An investigation has been made of the role of the translation of a hurricane in determining the distribution of boundary-layer winds and in organizing convection. A slab boundary-layer model of constant depth has been used to analyze the steady flow under a specified translating symmetric vortex in gradient balance. The feedback of the induced asymmetric convective distribution to the structure of the hurricane is not included. A truncated spectral formulation is used, including asymmetries up to wavenumber two. The roles of linear and nonlinear asymmetric effects, relevant to relatively slowly and rapidly translating hurricanes, respectively, in determining the boundary-layer response, have been diagnosed. Faster translation of the hurricane tends to move the radius of maximum wind radially inward, as well as to concentrate winds and convergence more on the right side of the storm. The analysis is related directly to observations of Hurricanes Frederic (1979) and Allen (1980) and to previous observational and theoretical studies.

It is found that the simple boundary-layer formulation simulates the qualitative features of the wind field in Frederic. The distribution of convection in Frederic and Allen compares favorably with boundary-layer convergence diagnosed from the model. Differences between the hurricanes are related to the greater translation speed of Allen.

Plans (FY-83)

Numerical experiments will be initiated to investigate the interaction between an isolated vortex and its environment and its effect on hurricane tracks. Dr. Ooyama's quasi-spectral nested-grid model will be used in barotropic (one-layer) form on a spherical earth or beta plane. The interactions will be studied for initially symmetric and asymmetric vortices in idealized large-scale flows. Interactions with boundary-layer frictional drag may be included in some experiments, using a two- or three-layer formulation. Special attention will be given to understanding the dynamics of short-period (trochoidal) oscillations in path, which are central to the problem of short-range predictions of hurricane tracks. A comparison will be made between the simulated trochoidal oscillations and observations as well as with previous theories. The numerical studies will be made in conjunction with a theoretical investigation of wavenumber one stream function asymmetries and vortex motion. Alternative theoretical methods may also be used to diagnose the motion. (Shapiro, Willoughby)

6.2 Prototype Nonhydrostatic Hurricane Model

Goal

This project involves simulation of the axisymmetric nonhydrostatic convective dynamics of the hurricane vortex. The current version of the numerical model has a 1500-km radial domain with 2-km horizontal resolution in the inner 100 km of domain and 1-km vertical resolution throughout. The model employs a microphysical parameterization that has either two water phases (cloud water and rain water) or the two water phases and three ice phases (cloud ice, snow, and graupel).

The model is used to explore the factors that control intensity and eye size as well as the influence of ice microphysics upon the evolution of the vortex. We are particularly interested in simulation of concentric eye cycles.

Accomplishments (FY-82)

A number of experiments exploring the effects of ice microphysics and changes in sea-surface temperature or atmospheric sounding have been conducted. We are also examining the influence of upper level momentum sources on the vortex evolution. Further experimentation may indicate what factors control several aspects of the evolution of the vortex.

Preliminary results indicate that this model is most sensitive to changes in the moisture sounding, sea-surface temperature and microphysics. If the sounding is extremely moist in the upper troposphere, convection induced by midlevel convergence competes with that induced by frictional convergence in the boundary layer. This restricts contraction of the eyewall. In the ice model, melting of frozen precipitation forces mesoscale downdrafts, which dries the midtroposphere, supresses midlevel convergence, and permits both contraction of the eye and formation of multiple concentric convective rings. Many of the details of the convection closely resemble those observed in real hurricanes. These include slope of updrafts and precipitation shafts, relative location of updrafts and maximum precipiation, and formation of large-scale stratiform rain areas.

Plans (FY-83)

Continued experimentation with the ice model, diagnostic calculations and perhaps some final integration of the water model will occupy the early part of FY-83. Upon completion of our program of numerical experimentation, we intend to prepare two manuscripts describing the formulation of the model and its response to both external parameters and changes in physics. In addition, we plan to program and run a two-dimensional version of the model suitable for simulation of the squall-line-like rainbands in which tangential advection plays a major role. This effort poses some numerical difficulties, but if it can be made to work, it will greatly enhance our understanding of such bands. (Willoughby, Lord, Piotrowicz)

7. Storm Surge

Goal

The immediate storm-surge goals are the completion of the modeling of selected bays and the analysis of computer printouts of various storm surge envelopes. These projects will lead to local evacuation studies and the development of a storm surge atlas.

Accomplishments (FY-82)

Four Sea-Lake-Overland Surges from Hurricanes (SLOSH) basins were developed, tested, and put in an operational status in 1982. For two of these basins, Corpus Christi, Texas, and Lake Sabine, Texas, a series of hypothetical hurricanes was created and used as input to the SLOSH model. Evacuation plans, based upon the results of the model runs, are being developed by Texas

A&M University. Construction of atlases from the same model runs, to be used by hurricane forecasters, has also begun. Similar studies are planned for the remaining two basins for next year (Mobile Bay, Alabama, and Florida Bay, Florida).

Work has continued on the atlases for Charlotte Harbor, and Tampa Bay, Florida; and Galveston Bay, Texas. A draft of the Charlotte Harbor (Southwest Florida) atlas was completed in December 1982 [53].

Plans (FY-83)

Atlases will be complete for Corpus Christi, Texas; Tampa Bay, Florida; Galveston Bay, Texas; and Sabine Lake, Texas. For Sabine Lake, Texas, hypothetical hurricane data for input to the SLOSH model will be completed, leading to evacuation plans for the Sabine Lake, Texas, locale. A series of hypothetical hurricane runs for evacuation studies will also be run on the following bays and harbors: Charleston Harbor, South Carolina; Mobile Bay, Alabama; and Florida Bay, Biscayne Bay, and Pensacola Bay, Florida.

Work on atlases for these regions will begin in FY-83. Basin data for Appalachicola Bay, Florida, and Cape Canaveral, Florida, will be developed. (Trout, Wiggert, Lockett, Putland, NHC Staff)

COOPERATIVE RESEARCH WITHIN NOAA

National Hurricane Center (NHC)/NWS

Principal Investigator: Charles J. Neumann, Chief
Research and Development Unit

Project A: A Revised Statistical-Dynamical Model for the Prediction of Atlantic Tropical Cyclone Motion

Progress Report:

Error analyses and experience indicate that statistical-dynamical models (i.e., models which use numerical output in a statistical prediction framework) should continue to provide an optimum method for the prediction of tropical cyclone motion. Such models capitalize on the ability of persistence, climatology and current analysis to excel as predictors for the first half of a 72-h projection, and for numerical prognoses to excel as predictors for the second half. NHC already has a statistical-dynamical model in its inventory (NHC73), but it is critically in need of revision.

For the current fiscal year, work on the new model has focused on structuring the dependent data, which consist of gridded historical deep-layer mean geopotential height analyses over the years from 1962 to 1981. The grid system employed is relative to a storm's current direction of motion. Thus, all forecasts are relative to a persistence forecast; that is, along and across the current track. Results, to date, are very promising. A test version of the new model is expected for the 1983 Atlantic Hurricane Season.

A paper by C.J. Neumann on this topic was presented at the 14th Technical Conference on Hurricanes and Tropical Meteorology-AMS, 1982, San Diego, California.

Project B: Tropical Cyclone Forecast Errors

Progress Report:

Over the past 2 years, the National Hurricane Center has made rather extensive error analyses of Atlantic tropical cyclone motion forecasts. While most of the research on this topic was completed in the previous fiscal year, three publications appeared during the 1982 fiscal year. The first dealt with trends in the ability to predict 24-h tropical cyclone motion over the period 1954-79 (Neumann, 1981). The second of these three publications (Neumann, 1982) was tailored to marine interests and discussed 24-h forecast errors and reasons for these errors. The third study (Crutcher et al., 1982) dealt with the adequacy of the bivariate normal distribution to describe tropical cyclone forecast errors. This latter study has further utility in the specification of huricane track forecasts in terms of probability ("strike" probabilities).

Project C: Study of Atlantic Tropical Cyclone Tracks

Progress Report:

The National Hurricane Center (NHC) responds to numerous requests, from both the scientific and nonscientific communities, for information relative to Atlantic tropical cyclone tracks and frequency. To satisfy these requests, the NHC (often in conjunction with the Environmental Data and Information Service) prepares and publishes statistical-type summaries. Over the previous and current fiscal years, these efforts have focused on documentation of Atlantic and Eastern Pacific (see Project D) tropical cyclone tracks. Approximately 2000 copies of the publication, Tropical Cyclones of the North Atlantic Ocean, 1871-1980 (Neumann et al., 1981) were received by NHC in December, 1981.

Project D: Prediction Models for the Eastern Pacific Tropical Cyclone Basin

Progress Report:

The National Hurricane Center routinely provides objective guidance on Eastern Pacific tropical cyclone motion to the Eastern Pacific Hurricane Center, located at the Weather Service Forecast Office near San Francisco, California. A new statistical-dynamical model for this basin was inaugurated by the NHC last fiscal year. During the current fiscal year, efforts have focused on monitoring the performance of the model, and documenting the program through a NOAA Technical Memorandum (Leftwich, 1981), issued by the Western Region Headquarters of the National Weather Service. The model was also reported on by P.W. Leftwich at the 14th Technical Conference on Hurricanes and Tropical Meteorology-AMS, 1982, San Diego, California.

In connection with the new model, further work has also been accomplished on the documentation of Eastern Pacific storm tracks. This work is summarized in a National Hurricane Center Technical Memorandum (Brown and Leftwich, 1982).

Project E: Evaluation of VAS and Omega Dropwindsonde Data

The National Hurricane Center has been requested to evaluate the utility of VAS (Visible Infrared Spin Scan Radiometer [VISSR] Atmospheric Sounder) and NHRL omega dropwindsonde data (ODW) in reducing tropical cyclone forecast errors. For this purpose, a statistical prediction model has been developed that is sensitive only to geopotential height data. The model is not intended for operational use, since it does not include predictors relative to climatology and persistence. Both of these latter factors are known to provide substantial reductions of variance of tropical cyclone motion for the early forecast periods. Their inclusion, however, would cloud the issue of the effectiveness of VAS or ODW data in providing independent predictive information. The model is yet to be tested on VAS or ODW data, but appears to perform well on conventional height analyses.

Project F: Summer Students at NHC in Support of NHC's R & D Programs

This past summer (1982), with NHRL funds, NHC was again able to employ a number of college students [Colorado State University, (1); Florida State University, (2); Rensselaer Polytechnic Institute, (2)]. These students, one of whom was assigned to NHRL to assist in the SANBAR project, provided substantial support to NHC's Research and Development programs.

Project G: Storm Surge Program

The National Hurricane Center, in cooperation with NHRL and the NWS Techniques Development Laboratory (SDO), continues to play an active role in the development and application of storm surge models. Focus at NHC during the current fiscal year was on preparing a storm surge atlas for Charlotte Harbor. The atlas is about 95% complete. In addition, numerous survey trips, consultant meetings, and computer runs for other storm surge basins were accomplished during FY-82.

NHC FY-82 Publications (Partially Supported by NHRL):

Brown, G.M., and P.W. Leftwich, 1982: A compilation of Eastern and Central North Pacific tropical cyclone data. NOAA Tech. Memo. NWS NHC-16, Fort Worth, Texas, 15 pp.

Crutcher, H.L., C.J. Neumann, and J.M. Pelissier, 1982: Tropical cyclone forecast errors and the multimodal bivariate normal distribution. J. Appl. Meteorol., 21 (7), 978-987.

Leftwich, P.W., 1981: A statistical-dynamical model for prediction of tropical cyclone motion in the Eastern North Pacific Ocean. NOAA Tech. Memo. NWS WR-169, Salt Lake City, Utah, 16 pp.

Neumann, C.J., 1981: Trends in forecasting the tracks of Atlantic tropical cyclones. Bull. Amer. Meteorol. Soc., 62, 1473-1485.

Neumann, C.J., 1982: Some characteristics of Atlantic tropical cyclone forecast errors. The Marine Observer, Her Majesty's Stationery Office, Vol. LII, 141-148.

Neumann, C.J., G. W. Cry, E.L. Caso, and B.R. Jarvinen, 1981: Tropical cyclones of the North Atlantic Ocean - 1871-1980. Special EDIS Publication, Supt. of Documents, Washington, D.C., 174 pp.

CONTRACTED RESEARCH

1. Desert Research Institute (DRI)

Principal Investigator: Dr. John Hallett, Professor of Meteorology

Project: Cloud Microphysics of Hurricanes and Tropical Convection

Analysis of aircraft cloud data has been undertaken from the viewpoint of assessing the relative importance of droplet coalescence and ice crystal growth and riming in the precipitation processes in deep tropical convection. Precipitation and cloud properties have been examined from three hurricanes [Ella (1978), Allen (1980), and Irene (1981)], together with penetrations of individual cumulus towers off the Florida Coast. The evidence is pointing to the role of the deep convection of the eyewall of a mature hurricane serving as a source of ice for the whole outer part of the storm, both in and between the rainbands; this appears to seed, naturally, most supercooled water in these regions. In the case of an asymmetrical or immature hurricane, however, there appear to be substantial regions where deep supercooled clouds may exist. These may be similar to the individual cumuli which grow over the ocean in summer. These latter clouds have been found to contain much supercooled water in the form of both rain and cloud drops. The ice phase evolves through graupel growth and multiplication at temperatures near -10°C. The processes appear to be different from convection over land, where (with stronger updrafts) the ice phase evolves more rapidly. Vapor-growth ice columns are much more evident over land than over the ocean, which is to be associated with the faster evolution of the ice particulates. It is evident that the evolution of the raindrop spectrum by coalescence is crucial to the subsequent ice phase evolution, since the drops appear to be frozen (to continue growth as graupel) by hydrodynamic capture of the vapor-grown ice particles. Penetrations of the hurricane eyewall indicate a wide spectrum of drop sizes, suggesting that the wall itself is a region of substantial mixing. It is hoped that future work will link the detailed structure of these clouds with the radar vertical velocity structure.

<u>In Print:</u>

Lamb, D., J. Hallett, and R. Sax, 1981: Mechanistic limitation to the release of latent heat during the natural and artificial glaciation of deep convective clouds. <u>Q. J. R. Meteorol. Soc.</u>, 107 (454), 935-954.

2. National Center for Atmospheric Research (NCAR)

Principal Investigator: Dr. Edward J. Zipser

Project: Mesoscale Structure of Rainbands in Hurricanes

Successful research flights into Floyd (1981) and Irene (1981) were carried out and were properly positioned with respect to rainbands. A main focus of this project during the past year has been the analysis of the Floyd data, which have yielded, for at least that one rainband, a surprisingly clear answer to some of the questions that were posed 1 year ago.

For the Floyd rainband, it is clear that the air flowing into the hurricane at low levels does not simply continue through the band toward the eyewall without major disruption. Further, and similarly to bands in GATE cloud systems, the air in the lower 500 m differs in its characteristics and its history in crucially different ways from air higher than 1000 m. The subcloud-layer air ascends in convective clouds in the band, to be replaced by air initially 1000-3000 m in altitude, which descends in convective downdrafts within the band. The net effect of the band on the air at 150 m is an equivalent potential temperature drop of 10°C. This is obviously large enough to have a significant impact on convective processes as the air proceeds radially inward toward the eyewall. A paper describing these results (Barnes et al., 1982) has been submitted for publication.

Other work completed during the past year includes a statistical study of vertical profiles of radar reflectivity in convective cells in GATE and in hurricanes (Szoke et al., 1982). Taken with the statistics on updraft and downdraft strength in these types of cells, it seems to be established that the GATE and hurricane cells compare very closely, and that both are weaker than their continental counterparts.

Plans include testing the representativeness of the results obtained for the Floyd rainband, and examining suspected differences in the upwind versus downwind characteristics of rainbands. This will be done initially with the Irene data, but mainly will depend upon participation on the 1983 NHRL Hurricane Field Program using Doppler radar data, which may prove to be a far more efficient way of determining aspects of the structure of rainbands on the mesoscale. These studies should prove to be of importance in several ways, including better understanding of the variations in radial and tangential winds within, and influenced by, rainbands; and ultimately, the effect of the rainbands upon the convection radially inward, including that within the eyewall.

<u>Submitted:</u>

Barnes, G.M., E.J. Zipser, D.P. Jorgensen, and F.D. Marks, Jr., 1982: Interactions between convective downdrafts and mesoscale airflow through a hurricane rainband. <u>Mon. Wea. Rev.</u>

Szoke, E.J., and E.J. Zipser, and D.P. Jorgensen, 1982: Radar study of convective cells in GATE, Part I: Vertical profile statistics and comprison with hurricane cells. <u>J. Atmos. Sci.</u>

3. University of Chicago

Principal Investigator: Dr. T. Theodore Fujita, Professor of Meteorology

Project A: San Marcos, Texas, Tornado Analysis

San Marcos, Texas, tornado locations were related to Hurricane Allen's (1980) path between 1800 CST, August 8, and 0000 CST, August 10. IR imagery at 1202 CST and composite radar echoes at 1200Z were compared to show that this landfalling hurricane generated a large number of tornadoes in the forward right quadrant (Stiegler and Fujita, 1982).

Project B: Analyses of Hurricane Dennis and the South Florida Flood

Dennis (1981), a landfalling hurricane, was not too strong, but it produced 10.3 inches of rain to the southwest of Miami. Isohyet analysis for the total rainfall was made (Fujita and Sheets, 1982a).

Project C: Analysis of Hurricane Floyd (1981) Wind Field; Analyses of Pressure/Wind Speed Relationships of Hurricanes Harvey (1981) and Irene (1981).

The real-time display of Hurricane Floyd wind field measurement by NHRL aircraft was analyzed in an attempt to show the effectiveness of such a display. Maximum wind speed and central pressure of Hurricanes Harvey and Irene were interrelated (Fujita and Sheets, 1982b).

Project D: Texas-Oklahoma Flood Analysis

Satellite photos of Hurricane Norma (1981) from its landfall on the Pacific Coast of Mexico to Oklahoma were analyzed to show that the storm maintained its circulation characteristics. The disintegrated system produced 23-26 inches of rain near the Texas-Oklahoma border. Results suggest that even a weakened hurricane can induce serious flooding (Fujita et al., 1982).

Published Papers - FY-82

Fujita, T.T., and NWS Fort Worth and Oklahoma City Offices, 1982: Texas-Oklahoma flood induced by Norma, which had disintegrated after crossing the Mexican Plateau. Storm Data, 23 (10), National Climatic Center, EDIS, NOAA, Asheville, North Carolina, 7-9.

Fujita, T.T., and R.C. Sheets, 1982a: Hurricane Dennis and the South Florida flood on August 16-18, 1981. Storm Data, 23 (8), National Climatic Center, EDIS, NOAA, Asheville, North Carolina, 8-9.

Fujita, T.T., and R.C. Sheets, 1982b: Wind field of Hurricane Floyd, and central pressure/maximum wind speed relationship of Hurricanes Harvey and Irene. Storm Data, 23 (9), National Climatic Center, EDIS, NOAA, Asheville, North Carolina, pp. 7 and 9.

Stiegler, D.J., and T.T. Fujita, 1982: A detailed analysis of the San Marcos, Texas, tornado induced by Hurricane Allen on 10 August 1980. Prepr., 12th Conf. on Severe Local Storm-AMS, January 11-15, 1982, San Antonio, Texas.

APPENDIX

A.1 PUBLICATIONS[5]

In Print

[1] BLACK, P G., 1982: Tropical storm structure revealed by stereoscopic photographs from Skylab. Advances in Space Research. Pergamon Press.

[2] BLACK, R., P. WILLIS, and J. Hallett, 1982: Case studies of ice distribution in hurricanes. Conf. on Cloud Physics-AMS, Nov. 15-17, 1982, Chicago, Ill., 335-357.

[3] BURPEE, R.W., and R.J. Reed, 1982: Synoptic-scale motions. Chapter 4. The GARP Atlantic Tropical Experiment (GATE) Monograph Series, GARP Publications Series No. 23, WMO, Geneva, Switzerland, 61-120.

[4] BURPEE, R.W., 1982: Book Review. The Hurricane and Its Impact. R.H. Simpson and H. Riehl. EOS, Trans. Amer. Geophys. Union 63 (17), April 27, 1982, p. 252.

[5] FEINBERG, R., W.J. BROWN JR., R. GLASS, J. GRIFFIN, and R. KOHLER, 1982: National Hurricane Research Laboratory HP-1000 user's guide. NHRL, Coral Gables, FLorida, 80 pp.

[6] FRIEDMAN, H.A., 1982: Analysis and forecasting in the tropics. Chapter 5. Guide on the Global Data Processing System. WMO Publication No. 305, 2nd edition, Geneva, Switzerland.

[7] FRIEDMAN, H.A., 1982: Hurricanes and "neutercanes." In "Weather Queries," Weatherwise, 35 (4), 182-183.

[8] FRIEDMAN, H.A., W.J. BROWN JR., and J.D. Michie, 1982: Airborne research meteorological data collected by the National Hurricane Research Laboratory during the NOAA/RFC WP-3D era -- inventory and availability. NOAA Data Report ERL AOML-2, March, 390 pp.

[9] Hawkins, J., and P. BLACK, 1982: Satellite-model interaction. Proc. Oceans 82 Conf.-MTS/IEEE, Sept. 20-22, 1982, Washington, D.C., 161-165.

[10] Jones, W., P. BLACK, V. Delnore, and T. Swift, 1981: Airborne microwave remote sensing measurements of Hurricane Allen. Science, 214 (4518), October 16, 1981, 274-280.

[11] JORGENSEN, D.P., 1981: Meso- and convective-scale characteristics common to several mature hurricanes. Prepr., 20th Conf. on Radar Meteorol.-AMS, Nov. 30-Dec. 3, 1981, Boston, Massachusetts, 726-733.

[5]NHRL authors' names appear in all caps.

[12] JORGENSEN, D.P., 1982: The structure of Typhoon Irma (1974) as revealed by 700-mb aircraft data. NOAA Tech. Report ERL 418-AOML 32, April, 58 pp.

[13] JORGENSEN, D.P., 1982: Vertical-draft properties of mature hurricane cumulonimbus clouds. Conf. on Cloud Physics-AMS, Nov. 15-17, 1982, Chicago, Ill., 531-534.

[14] JORGENSEN, D., 1982: The organization and structure of hurricane convective bands with applications to NEXRAD. Proc., NEXRAD Doppler Radar Symposium/Workshop-CIMMS, September 22-24, 1982, Norman, Oklahoma.

[15] JORGENSEN, D.P., and P.T. WILLIS, 1982: A Z-R relationship for hurricanes. J. Appl. Meteorol., 21 (3), 356-366.

[16] LEWIS, B.M., and H. HAWKINS, 1982: Polygonal eyewalls and rainbands in mature hurricanes. Bull. Amer. Meteorol. Soc., 63 (11), 1294-1300.

[17] LORD, S.J., 1982: Interaction of a cumulus cloud ensemble with the large-scale environment. Part III: Semi-prognostic test of the Arakawa-Schubert cumulus parameterization. J. Atmos. Sci., 39 (1), 88-103.

[18] LORD, S.J., W.C. Chao, and A. Arakawa, 1982: Interaction of a cumulus cloud ensemble with the large-scale environment. Part IV: The discrete model. J. Atmos. Sci., 39 (1), 104-113.

[19] MARKS, F., 1981: Evolution of the structure of precipitating convection in Hurricane Allen. Prepr., 20th Conf. on Radar Meteorol.-AMS, Nov. 30-Dec. 3, 1981, Boston, Massachusetts, 720-725.

[20] O'Brien, J.J. and S.B. GOLDENBERG, 1982: Atlas of Tropical Pacific Wind Stress Climatology, 1961-1970. Florida State University Press, 150 pp.

[21] OOYAMA, K.V., 1982: Evolution of the theory and modeling of the tropical cyclone. J. Meteorol. Soc. Jap., 60 (1), 369-380.

[22] OOYAMA, K.V., 1982: On basic problems in the theory and modeling of the tropical cyclone. Topics in Atmospheric and Oceanic Sciences. Intense Atmospheric Vortices. Bengtsson/Lighthill, eds., Springer-Verlag, Berlin, 21-34.

[23] PARRISH, J., 1981: WSR-57 observations during the landfall of Hurricane Frederic. Prepr., 20th Conf. on Radar Meteorol.-AMS Nov. 30-Dec. 3, 1981, Boston Massachusetts, 99-103.

[24] PARRISH, J., R. BURPEE, F. MARKS, JR., and R. Grebe, 1982: Rainfall patterns observed by digitized radar during the landfall of Hurricane Frederic (1979). Mon. Wea. Rev., 110 (12).

[25] POWELL, M.D., 1982: The boundary-layer wind field of Hurricane Frederic. Proc. 4th U.S. Nat. Conf. on Wind. Eng. Res., Seattle, Wash., July 1981, Pergamon Press, 79-92.

[26] POWELL, M.D., 1982: The transition of the Hurricane Frederic boundary-layer wind field from the open Gulf of Mexico to landfall. Mon. Wea. Rev., 110 (12).

[27] SHAPIRO, L.J., 1982: Hurricane climatic fluctuations. Part I: Patterns and cycles. Mon. Wea. Rev., 110 (8), 1007-1013.

[28] SHAPIRO, L.J., 1982: Hurricane climatic fluctuations. Part II: Relation to large-scale circulation. Mon. Wea. Rev., 110 (8), 1014-1023.

[29] SHAPIRO, L.J., and H.E. WILLOUGHBY, 1982: Response of balanced hurricanes to local sources of heat and momentum. J. Atmos. Sci., 39 (2), 378-394.

[30] WIGGERT, V., and G. LOCKETT, 1981: Reflectivity structure of Hurricane David (1979) from two radars at Miami. Prepr. 20th Conf. on Radar Meteorol.-AMS, Nov. 30-Dec. 3, 1981, Boston, Mass., 713-719.

[31] WIGGERT, V., R. Sax, and R. Holle, 1982: On the modification potential of Illinois summertime convective clouds, with comparison to Florida and FACE observations. J. Appl. Meteorol. 21 (9), 1293-1322.

[32] WILLIS, P., J. Hallett, and J. Jordan, 1982: The development of precipitation near the top of a maritime convective cloud. Conf. on Cloud Physics-AMS, Nov. 15-17, 1982, Chicago, Ill, 211-214.

[33] WILLIS, P., and D. Jorgensen, 1981: Reflectivity relationships for hurricanes. Prepr. 20th Conf. on Radar Meteorol.-AMS, Nov. 30-Dec. 3, 1981, Boston, Mass., 85-90.

[34] WILLOUGHBY, H.E., and M. Chelmow, 1982: Objective determination of hurricane tracks from aircraft observations. Mon. Wea. Rev., 110 (9), 1298-1305.

[35] WILLOUGHBY, H.E., J. Clos, and M. Shoreibah, 1982: Concentric eyewalls, secondary wind maxima, and the evolution of the hurricane vortex. J. Atmos. Sci., 39 (2), 395-411.

Accepted

[36] Hawkins, J., and P. BLACK: Seasat scatterometer detection of gale-force winds near tropical cyclones. J. Geophys. Res.

Submitted

[37] BLACK, P., R.C. Gentry, V.J. Cardone, and J. Hawkins: Seasat microwave wind and rain observations in severe tropical and midlatitude marine storms. Chapter 6. Advances in Geophysics.

[38] HAWKINS, H.: Note: Hurricane Allen and island obstacles. J. Atmos. Sci.

[39] JORGENSEN, D.P.: Mesoscale and convective-scale characteristics common to several mature hurricanes. Part I: General observations by research aircraft. J. Atmos. Sci.

[40] JORGENSEN, D.P.: Mesoscale and convective-scale characteristics common to several mature hurricanes. Part II: Inner core structure. J. Atmos. Sci.

[41] JORGENSEN, D.P., P. Hildebrand, and C.L. Frush: Feasibility test of an airborne pulse-Doppler meteorological radar. J. Appl. Meteorol.

[42] MARKS, F.D.: Principal mesoscale precipitation features observed during phase III of GATE. Mon. Wea. Rev.

[43] SHAPIRO, L.J.: The asymmetric boundary-layer flow under a translating hurricane. J. Atmos. Sci.

In Preparation

[44] BLACK, P.G.: Ocean temperature changes induced by tropical cyclones. NOAA Tech. Report.

[45] BLACK, P.G.: Supplementary analyses and data distributions in support of ocean response observations due to tropical cyclones. NOAA Tech. Report.

[46] BLACK, P.G.: The measurement of sea-surface temperature in the tropical environment of hurricanes from an airborne platform. J. Appl. Meteorol.

[47] BLACK, P.G., and W. Adams: Estimation of surface winds in hurricanes from airborne sea-state observations: Part I: Overview of methods and hurricane boundary-layer structure. Part II: Sea-State Catalog. NOAA Tech. Report.

[48] BLACK, P.G., and J.O. BERKELEY: An archive of airborne expendable bathythermograph observations in hurricanes - data book and processing algorithms. NOAA Tech. Report.

[49] BLACK, P.G., G. Holland, and M.D. POWELL: Boundary-layer dynamics in Cyclone Kerry (1979). Mon. Wea. Rev.

[50] BLACK, R.A.: Laser depolarization and geometric tests to measure ice content in tropical convective clouds. J. Appl. Meteorol.

[51] FRIEDMAN, H.A.: Creating an awareness of the hurricane problem in at-risk coastal communities of South Florida with a cognitive and affective learning model (CALM). Environmental Education and Information.

[52] FRIEDMAN, H.A., N.L. Frank, and R.I. Coleman: Social aspects of the hurricane problem--Individual and community response to hurricanes. Bull. Amer. Meteorol. Soc.

[53] JARVINEN, B.R., 1982: A storm surge atlas for southwest Florida. NWS, National Hurricane Center.

[54] JIN, H, H.E. WILLOUGHBY, and J. PIOTROWICZ: Computational stability of the advection equation with a nonuniform grid. NOAA Tech. Report.

[55] JORGENSEN, D.P.: Mesoscale and covective-scale characteristics common to several mature hurricanes. Part III: Cumulonimbus-vertical draft properties. J. Atmos. Sci.

[56] MARKS, F.D., JR.: Origin of an inertially unstable air mass along the boundary of the Saharan air layer. J. Atmos. Sci.

[57] MARKS, F.D., JR.: Evolution of the structure of precipitating convection in Hurricane Allen. Mon. Wea. Rev.

[58] POWELL, M.D.: Low-level features of hurricane Frederic at landfall. Mon. Wea. Rev.

[59] SHAPIRO, L.J., and C.J. Neumann: On the structure and orientation of grid systems for the statistical prediction of tropical cyclone motion. Mon. Wea. Rev.

[60] WILLIS, P.T.: Optical array spectrometer observations of drop size distributions in tropical convective systems. J. Atmos. Sci.

A.2 SEMINARS AT NHRL DURING FY-82

1981

October 7	R. Greatbatch: University of Cambridge "The Response of the Ocean to a Moving Hurricane"
November 3	Y. Ding: Academy of Sciences of China "Telecommunications Affecting Tropical Cyclone Formation"

1982

January 7	F. Hasler: Goddard Space Flight Center "True and Synthetic Stereo Analysis Using Geostationary Satellites -- New Tools for the Study of Intense Convection"
February 4	W. Cotton: Colorado State University "Current Status of Dynamic Modification of Cumulus Clouds -- Modeling Inferences"
February 24	A. Leetma: Atlantic Oceanographic and Meteorological Laboratories/Physical Oceanography Laboratory "EPOCS Overview -- Oceanographic Program in the Eastern Pacific"
March 10	D. Ross: Atlantic Oceanographic and Meteorological Laboratories/Sea-Air Interaction Laboratory "Directional Properties of Hurricane Waves"
March 18	F. Sanders: Massachusetts Institute of Technology "Quasi-Geostrophic Diagnosis of the MONEX Depression of 5-8 July 1979"
March 31	E. Zipser: National Center for Atmospheric Research "Squall Lines: What Are They? Tropical Versus Midlatitude"
April 7	G. Barnes: National Center for Atmospheric Research "State and Kinematic Fields Associated with GATE Convective Lines"
May 12	M. Fiorino: Naval Environmental Prediction Research Facility "Recent Results From Navy Nested Tropical Cyclone Model"
May 26	R. Sheets: National Hurricane Center "Hurricane Tracking: A New Look -- A New Approach"
August 20	H. Hawkins: Cooperative Institute for Marine and Atmospheric Studies "Synoptic Study of Hurricane Allen"
August 26	W. Gray: Colorado State University "Highlights of Present and Planned Research on Tropical Cyclones"

A.3 INFORMAL RESEARCH REPORTS AT NHRL DURING FY-82

1981

November 16	R.W. Burpee: "Observations of the South Florida Sea Breeze Circulation"
November 23	K.V. Ooyama: "Dynamic Shock Front in the Boundary Layer of an Axisymmetric Hurricane"
December 11	J.M. Gross: "Quality Control on a Standard RFC Aircraft Tape"
December 14	L.J. Shapiro: "Asymmetric Boundary-Layer Flow Under a Translating Hurricane"

1982

January 8	M.D. Powell: "Hurricane Frederic Boundary-Layer Wind Field Transition"
January 18	R.W. Jones: "Recent Results From the 12-Layer Nested Grid Model"
February 8	S.J. Lord: "Preliminary Results of a Slab-Symmetric Version of the Willoughby Nonhydrostatic Axisymmetric Hurricane Model with Ice-Phase Microphysics"
February 19	K.C. Belle: "Data Analysis of the Sea Breeze" and "Development of a Mixed-Layer Model"
February 22	P.W. Leftwich: "A Southerly Monsoon Current as Depicted by Operational Analyses" (NHC)
March 11	F.D. Marks Jr.: "The Three-Dimensional Structure of the Eyewall of Hurricane Allen"
March 16	S.B. Goldenberg: "Verification Results for Modified SANBAR Model"
March 22	P.T. Willis: "Development of Precipitation in Maritime Cumulus Clouds"
March 29	V. Wiggert: "Storm Surge, the SLOSH Model, and the Basin Containing Sabine Lake, Texas/Louisiana
April 12	D.P. Jorgensen: "Results From an Airborne Doppler Radar"
April 19	R.A. Black: "Ice Distribution in Hurricanes" and "Temperature Measurements in Hurricane Clouds"

May 17	H.E. Willoughby: "Aircraft Observations in Hurricane Gert"
May 29	J.R. Parrish: "Frederic Convective Structure and Rainfall"

A.4 PRESENTATIONS GIVEN OUTSIDE BY NHRL STAFF DURING FY-82

1981

November 12	L.J. Shapiro: "Hurricane Climatic Fluctuations: Patterns, Cycles and Their Relations to the Large-Scale Circulation" (at Colorado State University)
December 2	H.E. Willoughby: "Concentric Eyewalls, Secondary Wind Maxima, and the Evolution of the Hurricane Vortex" (at Geophysical Fluid Dynamics Laboratory/NOAA)

1982

March 24	K.V. Ooyama: "Theorization of Tropical Cyclones" (at Atlantic Oceanographic and Meteorological Laboratories/NOAA)
May 25	D.P. Jorgensen: "Results of Recent Airborne Doppler Tests" (at Research Facilities Center/NOAA)
June 1	F.D. Marks, Jr.: "Processing Airborne Radar Data in Hurricanes" (at Research Facilities Center/NOAA)
July 6	H.E. Willoughby: "Determination of Meteorological Fields in Hurricanes from Aircraft Observations" (at Research Facilities Center/NOAA)

A.5 CONFERENCE PRESENTATIONS

18th Annual NWS/NOAA Hurricane Conference,
December 8-10, 1981, Coral Gables, Florida

and

36th Interdepartmental Hurricane Conference
January 26-28, 1982, Homestead AFB, Florida

S.L. Rosenthal	NOAA Support for Hurricane Prediction Research

R.W. Burpee	The 1981 and 1982 NHRL Hurricane Field Programs
H.E. Willoughby	Operational Implications of Recent Hurricane Research Observations
D.P. Jorgensen	The Mature Hurricane Eyewall: Mesoscale and Convective-Scale Properties

NWS/ERL Technical Exchange Conference May 10-13, 1982, Estes Park, Colorado

R.W. Burpee	A Field Program for Determining the Synoptic-Scale Environment Around Atlantic Hurricanes

14th Technical Conference on Hurricanes and Tropical Meteorology-AMS, June 7-11, 1982, San Diego, California

P.G. Black	The Effect of Air-Sea Interactions on the Hurricane Boundary Layer
R.W. Burpee	A Field Program for Determining the Synoptic-Scale Environment Around Atlantic Hurricanes
C.P. Cheng	The Structure of Stratiform and Convective Precipitation in Hurricane Allen
S.B. Goldenberg	Recent Modifications to the Barotropic Operational Hurricane Forecast Model (SANBAR)
E. Zipser (NCAR), G. Barnes (NCAR), D.P. Jorgensen F.D. Marks Jr.	The Mesoscale Structure of Hurricane Rainbands
F.D. Marks Jr.	The Structure of Precipitating Convection in Hurricane Allen
K. Ooyama	Design of a Numerical Model for Hurricane Prediction
M. Powell	Low-level Features of Hurricane Frederic at Landfall
L. J. Shapiro	Asymmetric Boundary-Layer Flow Under a Moving Hurricane Vortex
H.E. Willoughby	The Dynamics of Eye Formation

COSPAR, 24th Plenary Meeting. Tropical Session on Stereoscopic Observations From Meteorological Satellites, May 1982, Ottawa, Canada

P. Black	Tropical Storm Stucture Revealed by Stereoscopic Photographs

A.6 SYMPOSIA

<u>Symposium on Mesoscale Modeling-CIMMS, University of Oklahoma, Norman, Oklahoma, June 1-2, 1982</u>

S.L. Rosenthal, R.W. Burpee

<u>Symposium on Mesoscale Meteorology, Colorado State University, Fort Collins, Colorado, July 6-8, 1982</u>

K.V. Ooyama — Hurricanes and Mesoscale Convection

<u>Symposium/Workshop on NEXRAD Doppler Radar-CIMMS, Norman, Oklahoma, September 22-24, 1982</u>

D.P. Jorgensen — The Organization and Structure of Hurricane Rainbands as They Apply to NEXRAD

A.7 WORKSHOP PARTICIPATION

<u>Cumulus Dynamics and Microphysics Program Workshop-ERL/OWRM, Boulder, Colorado, January 18-21, 1982</u>

P.T. Willis

<u>Atmospheric Distributed Data System Configuration Meeting-920th WRC, Keesler, AFB, Mississippi, March 2-4, 1982</u>

R.W. Burpee

A.8 COMMITTEE MEMBERSHIPS AND OFFICES IN SCIENTIFIC ORGANIZATIONS

Robert W. Burpee	Editor, "Focus on Forecasting," <u>Bulletin of the American Meteorological Society</u>
Howard A. Friedman	Chairperson, American Meteorological Society Board of School and Popular Meteorological Education Education and Manpower Commission, American Meteorological Society Chairperson, Local Speaker's Bureau, Miami Chapter, American Meteorological Society
Frank D. Marks, Jr.	Secretary-Treasurer, Miami Chapter, American Meteorological Society

Katsuyuki V. Ooyama	Editorial Advisory Board, Papers in Meteorological Research, The Meteorological Society of the Republic of China, Taiwan
Stanley L. Rosenthal	Council of the American Meteorological Society American Meteorological Society Committee on Tropical Meteorology and Tropical Cyclones

A.9 HIGH SCHOOL STUDENTS AT NHRL

Students working at NHRL under the Dade County Public Schools Community Laboratory Research Program:

Chris Landsea - Palmetto Senior High School
Assisting Jack Parrish

Vic Wong - Sunset Senior High School
Assisting Stanley Goldenberg

A.10 VISITORS

Gary Barnes, National Center for Atmospheric Research, Boulder, Colorado
Donna Blake, NASA, Bay St. Louis, Mississippi
Joseph Boatman, ERL, Office of Weather Research and Modification, Boulder, Colorado

William R. Cotton, Colorado State University, Fort Collins, Colorado

Colin Depradine, Caribbean Meteorological Institute, Barbados

Stanely Eames, NOAA, Office of Public Affairs, Rockville, Maryland
Russell Elsberry, Naval Postgraduate School, Monterey, California

R. Cecil Gentry, Clemson University, Clemson, South Carolina
William Gray, Colorado State University, Fort Collins, Colorado
Mark Griffith, University of the West Indies, Kingston, Jamaica

Raymond Hartman, NOAA, Office of Public Affairs, Rockville, Maryland
Fritz Hasler, Goddard Space Flight Center, Greenbelt, Maryland
John Hovermale, NOAA, National Meteorological Center, Washington, D.C.

Paul Julian, National Center for Atmospheric Research, Boulder, Colorado

Jack LaCovey, NOAA, Office of Public Affairs, Washington, D.C.
George Ludwig, ERL, Office of the Director, Boulder, Colorado

Roger Reinking, ERL, Office of Weather Research and Modification

Frederick Sanders, Massachusetts Institute of Technology, Cambridge, Massachusetts

George Walker, James Cook University, Australia
David Wise, General Accounting Office, Washington, D.C.

Edward Zipser, National Center for Atmosperic Research, Boulder, Colorado

A.11 NHRL STAFF ON SEPTEMBER 30, 1982

Stanley L. Rosenthal, Director	FTP
Juanita A. Simpkins, Secretary	FTP
James W. Trout, Assistant Program Manager; Supervisory Meteorologist	FTP

Support Services

Arnhols, Constance A.	Writer-Editor	FTP
Jorge, Vivian	Administrative Officer	PTP
Marques, Frank D.	Secretary	PTP
Martin, Dale B.	Scientific Illustrator	FTP
Nole, Suzanne	Accounting Technician	PTP
Stephens, Carla	Clerk-Typist	PTP
Tatnall, Thomas	Photographer	PTP
Tillman, Angel P.	Clerk-Typist	WAE

Scientific and Technical Staff

Becerra, Irma M.	Computer Assistant	WAT
Berkeley, Joyce O.	Meteorological Technician	FTP
Black, Peter G.	Meteorologist	FTP
Black, Robert A.	Meteorologist	FTP
Bogert, Philip D.	Meteorological Technician	PTP
Brown, Winfield J., Jr.	Supervisory Mathematician	FTP
Burpee, Robert W.	Supervisory Meteorologist	FTP
Creech, Barbara	Computer Operator	FTP
Darby, Evan R.	Computer Clerk	WAT
Dorst, Neal	Meteorologist	PTP
Farr, William A.	Electronics Technician	FTP
Feinberg, Robert J.	Computer Programmer	PTP
Figueroa, Nancy	Computer Assistant	FTT
Franklin, James L.	Meteorologist	PTP
Friedman, Howard A.	Meteorologist	FTP
Gerald, David	General Science Trainee	Jr. Fellow
Glass, Raymond M.	Computer Programmer	FTP
Goitia, Ana	Computer Assistant	WAT

Goldenberg, Stanley B.	Meteorologist	FTP
Griffin, Joseph S.	Computer Programmer	FTP
Jones, Robert W.	Meteorologist	FTP
Jorgensen, David P.	Meteorologist	FTP
Kelly, Lorraine A.	Meteorological Technician	FTP
Kohler, Robert	Computer Programmer	PTP
Lockett, Gloria J.	Mathematician	FTP
Marks Jr., Frank D.	Meteorologist	FTP
Ooyama, Katsuyuki V.	Meteorologist	FTP
Parrish, John R.	Meteorologist	PTP
Piotrowicz, Jacqueline M.	Computer Programmer	PTP
Powell, Mark D.	Meteorologist	FTP
Ramirez, Pablo R.	Computer Clerk	WAT
Shapiro, Lloyd J.	Supervisory Physicist	FTP
Wiggert, Victor	Meteorologist	FTP
Williams, Helen	Computer Operator	FTP
Willis, Paul T.	Meteorologist	FTP
Willoughby, Hugh E.	Meteorologist	FTP