National Severe Storms Laboratory

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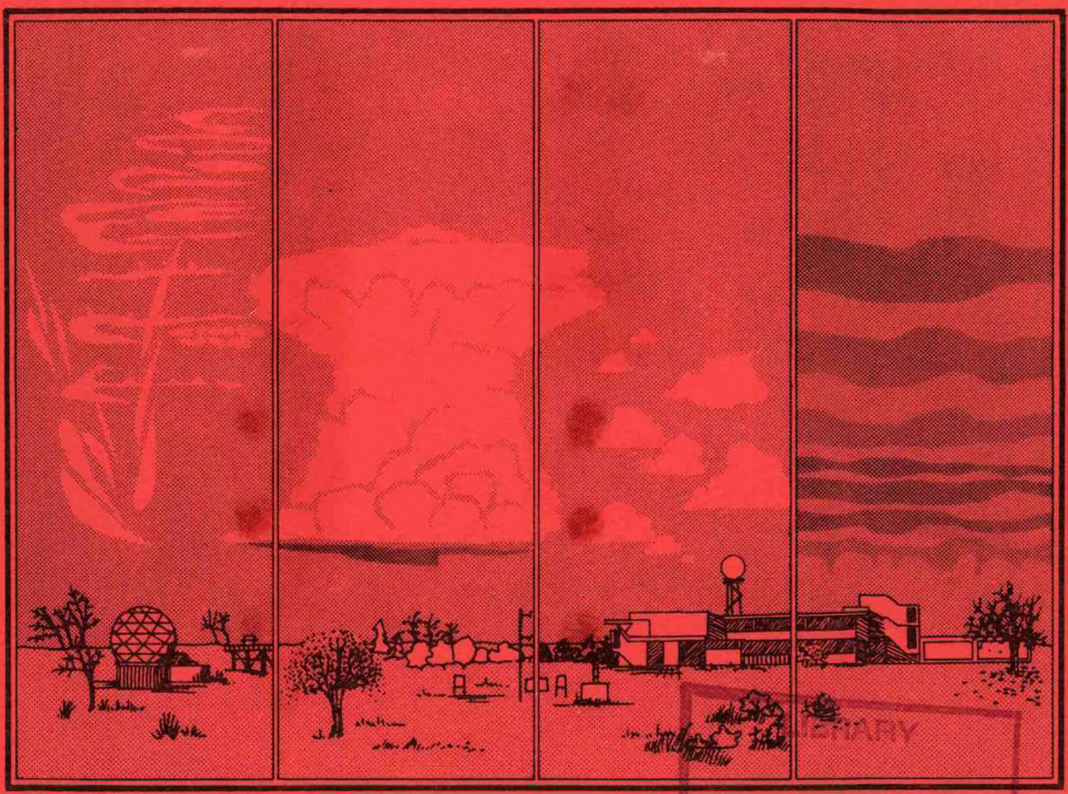

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NATIONAL SEVERE STORMS LABORATORY

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NATIONAL SEVERE STORMS LABORATORY

INTRODUCTION

Robert A. Maddox, Director

The historical antecedents of the National Severe Storms Laboratory (NSSL) were in the former U.S. Weather Bureau and its well-known National Severe Storms Project. From early emphasis on use of aircraft for storm investigations related to flight safety, the focus at NSSL has gradually moved to theoretical and empirical studies based on data from a multitude of sensors for new insights into the processes that lead to severe weather and intense thunderstorms.

More than one-third of NSSL's budget has historically been devoted to maintenance and operation of comprehensive instrumentation for sensing meteorological parameters. Instrumentation includes two 10-cm Doppler radars on a 42-km baseline, a 50 MHz wind profiling radar, the tallest meteorologically instrumented tower in the United States, a network of solar-powered surface stations, and a broad range of sensors for mapping lightning processes in clouds, locating ground strike points of lightning, and measuring electric field parameters.

The scientific staff of the Laboratory conducts research, technology development programs and operational implementation activities designed: to improve understanding of middle latitude severe weather phenomena--including tornadoes, lightning, hail, severe thunderstorms, high winds and wind shear, heavy precipitation, flash floods, mesoscale convective systems, fronts, and intense winter storms; to improve understanding of the large and mesoscale environments, and their evolution and interactions, which lead to the occurrence of severe weather phenomena; to improve predictions, on time scales from several hours to several days, of significant severe weather events; and to improve capabilities for detecting and warning for all types of severe weather phenomena, including lightning and other hazards to aviation safety.

The year 1986 has seen substantial change occurring on the North Campus of the University of Oklahoma, where NSSL is located. A multi-agency "Oklahoma Weather Center" has been coalescing in the vicinity of NSSL, and events of 1986 have been highlighted by the construction of a new NOAA building designed to house the NWS Oklahoma Forecast Office and the Operational Support Facility of the NEXRAD Program. It is expected that the Forecast Office will begin operations from this new facility around the beginning of calendar year 1987 and that the NEXRAD office will be fully staffed by late summer when delivery of the first NEXRAD system is anticipated. The co-location of these major organizations will allow expanded interaction between the researchers of NSSL and meteorologists of the operational components of the NWS.

The growth and new construction activity, however, were not the only noteworthy changes within the Oklahoma meteorological community. Dr. Edwin Kessler retired in June 1986, after heading and directing NSSL during all the years since its founding in 1964. The contributions of the laboratory to atmospheric science and especially the understanding of severe local storms made under Dr. Kessler's guidance are well known. Dr. Kessler, in addition to maintaining his Adjunct Professorship in the School of Meteorology, has also accepted a half-time appointment with the University of Oklahoma's Department of Geography. We're certain that his "retirement" will be active and scientifically fruitful. The entire staff of NSSL faces the challenge of making the work of the next 20 years a successful follow-on to the past accomplishments of the laboratory. Finally, Professor Yoshi K. Sasaki has announced that he will be leaving his position as Director, Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), at the end of 1986. In addition to university duties, Dr. Sasaki plans to continue working with the State of Oklahoma as an emissary to Japan and Japanese industry. CIMMS has grown, prospered and gained international scientific reputation under the leadership of Dr. Sasaki. It is expected that Professor Douglas K. Lilly will be appointed as new head of the cooperative institute early in 1987. Both Professors Sasaki and Lilly are George Lynn Cross research professors in the University of Oklahoma School of Meteorology. The staff of NSSL is indeed fortunate to be able to work directly with such distinguished university colleagues, and we anticipate a growing program of cooperative research.

PROGRAM AREAS

METEOROLOGICAL RESEARCH GROUP

John M. Lewis, Group Leader

INTRODUCTION

The Meteorological Research Group seeks to improve thunderstorm forecast and warning capabilities by developing conceptual, numerical, and laboratory models of major thunderstorm phenomena and of the pre-storm atmosphere. Analysis and interpretation of storm flow fields expand our understanding of external and internal forcing, thermodynamics, cloud physics, electrification, and cloud dynamics, which contribute to intense thunderstorms and their attendant phenomena. Subsets of the group objectives are addressed by two projects: Modeling and Dynamics led by Carl E. Hane, and Storm Evolution and Analysis led by Rodger A. Brown. During most of FY 1986 a permanent leader for the group was being sought. During that period, acting group leaders were: Rodger Brown (October 1985 - January 1986), Carl Hane (January 1986 - June 1986), and Edward Brandes (June 1986 - September 1986). John Lewis assumed leadership of the group in September 1986.

RECENT ACCOMPLISHMENTS

Thunderstorm Evolution and Morphology

Flow patterns in and about the middle levels of thunderstorms are often compared with the patterns around obstacles embedded in a mean flow. A kinematic analysis of several supercell storms indicates that supercell updrafts lack expected obstacle properties. Critical Reynolds numbers necessary for producing counter-rotating vortex pairs are not reached by the mean flow. Hodographs derived from updraft wind data and from environmental rawinsonde data show remarkable similarities. The momentum of the low-level environmental wind is not preserved in the updraft. Anticyclonic eddies, common features of supercell storms, are a part of a vortex pair that forms as horizontal vortex tubes are tilted by vertical motions. Such eddies are not shed as an obstacle effect but rather form as the updraft dissipates and the updraft remnants move to the rear of the storm where anticyclonic vorticity prevails (Johnson and Brandes, 1986).

Dual-Doppler radar data for nearly 2 1/2 h, collected on 19 June 1980, document the transition of a multicell storm into a nearly-steady-state storm with supercell characteristics (Vasiloff et al., 1986). Individual convective cells within the multicell storm increased in size and intensity while maintaining a nearly constant separation. A large region of weak background updraft, with embedded perturbations (maxima) representing individual cells, formed and propagated to the right of the mean wind. The differential motion of the persistent background updraft resulted in greater storm-relative streamwise vorticity, i.e., the component of vorticity in the direction of the storm-relative inflow wind, and consequently significant updraft rotation. Results suggest a continuum of storm types, rather than discrete categories.

Although the importance of environmental wind shear in producing severe weather is recognized, a tendency persists to classify storms only by their reflectivity properties. Recent studies with Doppler radar observations suggest that supercell features are determined in large part by their kinematic properties (Brandes et al., 1986). Multicell and single-cell thunderstorms should possess weak vorticity. In supercells, updraft rotation hinders the across-storm translation of small-scale radar reflectivity and updraft elements. Instead, convective elements are swept to stagnation points upwind of the updraft mesocyclone where they eventually become indistinguishable from the background reflectivity and updraft. The distribution of helicity and pressure gradients determines the organization of turbulence within thunderstorms. The steadiness of supercells seems to lie with large but simple updraft structures that are characterized by laminar flow and are undiluted by mixing.

Mesoscale Convective Systems

Diagnosis of pressure and buoyancy fields in convective storms based upon velocity analyses from Doppler radar observations contributes to enhanced understanding of storm processes. In the recent past, pressure and buoyancy have been retrieved from isolated thunderstorms. A new effort has extended retrieval to diagnosis of these fields in mesoscale convective systems (Hane et al., 1986).

Scale interactions are prominently exposed in data sets collected on 26 April 1984 (Burgess and Curran, 1985). During the afternoon, isolated supercell storms formed and produced weak tornadoes; these were followed by nighttime formation of a continuous squall line. Violent tornadoes occurred when breaks developed within the line; it seems likely that an approaching shortwave trough aloft altered the mesoscale environment creating greater instability and a vertical wind shear profile more favorable for tornadoes.

Severe Thunderstorm Phenomena

A (Beltrami) flow model, in which vorticity and velocity are everywhere parallel, is being used to provide insights into the pressure field around an axisymmetric rotating updraft (Davies-Jones, 1985a). Although buoyancy is not included, this model is valuable because it has an exact analytical solution. Results explain how the surface mesolow can be several kilometers away from the updraft and circulation centers, and why mesocyclones have a characteristic size and rotation rate. This work is being extended to allow density to be a function of height.

The source of vertical helicity (the product of vertical velocity and vertical vorticity) in convective cells is being investigated, using theory and a three-dimensional numerical model (Davies-Jones, 1985a). For dry convection, vertical helicity is produced from the transfer of environmental horizontal helicity (scalar product of horizontal vorticity and storm-relative horizontal velocity). There is no net buoyant production of vertical helicity.

One channel of NSSL's Norman Doppler radar has been modified to achieve a large unambiguous velocity range (± 91 m s^{-1}), making possible nonaliased velocity spectra for sample volumes that include tornadoes. From spectral skirts, the maximum sampled velocity components have been inferred as tornado windspeeds. For moderate tornado (F2 classification) in 1977, inferred wind speed was 65 m s^{-1} and for a violent tornado (F4) in 1981 inferred wind speed was 90 m s^{-1} (Zrnic' et al., 1985b) Doppler measurements are hampered by an aspect ratio problem between a radar beam whose size increases with range, versus a relatively small tornado target. These factors sometimes cause an underestimate of true maximum speeds.

A portable instrument, TOTO (Totable Tornado Observatory), designed at NSSL, makes direct measurements of meteorological variables in tornadoes. Wind speed and direction, temperature, and pressure have been measured near tornadoes and beneath a rotating wall cloud. Data from damage surveys and Doppler radar are used in conjunction with TOTO measurements to obtain estimates of wind speeds in and near tornadoes. Wind speed and pressure estimates from the latest data collection (the Ardmore, Oklahoma, tornado of 29 April 1985) are 30 m s^{-1} maximum tangential velocity and 5.5 mb pressure drop (Burgess et al., 1985). The tornado was very weak as it passed over the device.

Applications and Technique Development

A simple technique for estimating vorticity, divergence, and vertical velocity from single-Doppler velocity data that contain mesocyclone and divergence signatures was developed (Wood et al., 1986). The technique has been applied to observations collected in the 2 May 1979 Lahoma, Oklahoma, tornadic storm and verified using vorticity and vertical velocity values obtained from dual Doppler analyses. Although magnitudes and vertical distribution of single-Doppler and mean dual-Doppler vertical velocity values differ, the patterns obtained from single- and dual-Doppler analyses are strikingly similar. Periods of vertical vorticity and vertical velocity intensification at low and middle levels are well depicted in the single-Doppler analysis.

Vertical velocities computed from multiple-Doppler radar measurements contain errors that exceed those expected on the basis of theoretical considerations. The nature and scope of these errors were investigated using actual data. Storm advection, incomplete sampling of low-altitude divergence caused by the radar horizon, top boundary errors, and uneven terrain were studied. All were dismissed as dominant sources of error for the case under consideration. A search for the cause of the errors continues because realistic vertical velocity adjustment schemes cannot be developed until the dominant source of the errors is discovered and understood.

A study of growth rates of radar reflectivity and updraft speed using NEXRAD real-time computer algorithms to evaluate an interlaced scanning strategy was completed (Vasiloff et al., 1985). This sampling strategy provides updates of low-level information every 2 1/2 min and may be important for detecting rapidly developing hazardous phenomena such as microbursts in roughly one-half the time of the current proposed scanning strategy. This evaluation reveals that detectability of hazards is not significantly impaired by interlaced scanning.

An algorithm developed at the National Severe Storms Laboratory uses decision thresholds to discriminate between mesocyclone shear and other shears not associated with organized circulatory flow (Zrnic' et al., 1985a). A detailed test of these and other thresholds was made by testing the algorithm on storms with and without mesocyclones. The algorithm requires storage and calculations on two consecutive radials of data, and thus is suitable for real time implementation. We have applied the algorithm to data from sixteen mesocyclones to evaluate detection performance. The probability of false alarm was 10%, and the probability of detection was 90%. The algorithm accounts for distortion of the shear pattern caused by the large antenna beam dimensions at long ranges.

Only about half of all observed mesocyclones are tornadic. A study was undertaken to address the problem of discriminating between tornadic and nontornadic mesocyclone types (Desrochers et al., 1986). The effort is based upon the premise that tornado formation is related to mesocyclone strength. This idea is examined through a parameter called Excess Rotational Kinetic Energy (ERKE), which represents the rotational kinetic energy of a mesocyclone after subtraction of energy corresponding to threshold mesocyclone shear. ERKE is a function of mesocyclone radius and rotational velocity, which are readily available from the Doppler velocity field, and so the parameter is suitable for real-time applications. Preliminary findings from an examination of 10 mesocyclones suggest that the magnitude and height distribution of ERKE distinguishes between mesocyclone types, and, if a mesocyclone is tornadic, gives an indication of upcoming tornado severity.

Microphysical and Electrical Properties of Thunderstorms

A one-dimensional cloud model using single-Doppler, aircraft, and balloon observations as input was used to study interrelationships among airflow, microphysics, and electrification in an isolated New Mexico mountain thunderstorm (Ziegler, 1985b; Ziegler and Ray, 1985). The calculated rate of noninductive charge transfer accompanying collision and separation of ice crystals and riming graupel particles, which exceeds 10 C km^{-3} min^{-1}, is in direct proportion to cloud and precipitation content. Agreement of model calculations with balloon measurements of space charge density and the vertical electric field suggests that the noninductive mechanism accounts for a substantial portion of the storm's total separated charge. A major and poorly understood process in cloud physics is the charging of thunderstorms. The significance of this study is the verification of calculation of cloud properties, radar reflectivity, charge separation, and electric field growth, using a comprehensive model-derived data set.

A microphysical retrieval sensitivity test demonstrated the critical dependence of microphysically retrieved precipitation and reflectivity fields on the detailed input wind field, and in particular the vertical velocity field (Ziegler, 1985a). Improved quantification of wind analysis error sources, whose distribution influences the analyzed vertical velocities, holds the promise of significantly improved retrievals of dynamic and microphysical variables from cloud models that accept Doppler-derived airflow as their primary input.

Relationships among electrical activity, airflow, and microphysical properties in a severe Oklahoma thunderstorm that occurred on 19 June 1980 were documented (Ziegler et al., 1986). The most likely charge separation mechanisms, as inferred from a temporal and spatial correlation of derived and microphysically retrieved cloud properties with observed electrical activity, involve the rebounding collisions between ice particles at cloud temperatures below freezing.

Rawinsonde Data

A processing and quality control continued on the Oklahoma-Kansas Preliminary Regional Experiment for Stormscale Operational and Research Meteorology (PRE-STORM) 1985 rawinsonde data set. Nearly 2,000 soundings are taken at supplemental and NWS network sites. There is considerable demand for the data in the research community, and research using the data is already beginning to appear in publications and at conferences.

Five supplemental rawinsonde sites were operated during the spring of 1986. Personnel and equipment were supported at four sites by USAF 6th Weather Squadron (mobile) from Hurlburt Field, Florida. A fifth site was operated by the U.S. Army Field Artillery Board from Fort Sill, Oklahoma. Between 4 April and 30 May 1986, 211 soundings were flown. Comparison flights were also made for the 50-MHz Wind Profiler. Two soundings per day were made for 5 days at NSSL, using the new GMD 5 ground station developed for the Air Force. Several software problems were identified and reported.

EXPECTATIONS FY 1987

(1) A case study of Oklahoma-Kansas (OK) PRE-STORM data sets capturing the central Kansas macroburst and colliding outflows on 23-24 June 1985 will continue. Emphasis is on understanding the macroburst and the surprising lack of convective development in the intense convergence zone along the associated outflow boundaries.

(2) A case study of the 12-13 May 1985 OK-PRE-STORM severe storms will examine destabilization mechanisms and investigate the use of OK-PRE-STORM Wind Profiler data in severe thunderstorm research.

(3) A study of 10-11 June 1985 PRE-STORM mesoscale convective system (MCS) is under way. The study will focus on the structure and orientation of convective updrafts along the leading edge of the MCS. A budget analysis of horizontal vorticity about the convective leading edge will be performed.

(4) The 2 May tornadic storm, the 6-7 May case and the 12 May 1985 MCS formation studies will be completed.

(5) An investigation will be made of the days during OK-PRE-STORM for which forecasts for convective weather were poor. Emphasis will be on understanding these difficult forecasting situations using both the high-density OK-PRE-STORM and the low-density NWS observing networks.

(6) Initial data editing has begun on a pair of merging severe hailstorms that occurred in central Oklahoma on the evening of 26 May 1985. Since both storms contained mesocyclones, it is anticipated that the completed study will help to improve our understanding of mesocyclone evolution.

(7) Analysis of pressure and velocity fields and the overall organization of the 19 May 1977 squall line will continue.

(8) The study of single-Doppler mesocyclone and divergence signatures on 2 May 1979 and comparison of results with dual-Doppler derived fields will continue. A formal publication will be prepared.

(9) Documentation of the Binger storm with respect to kinematics of an echo weak hole, microphysics deduced from vortex evolution, and storm dynamics will be completed and results submitted for publication.

(10) A study of microphysical retrieval sensitivity to the variation of modeled microphysical processes in thunderstorms will be finalized. An extensive analysis of the relations of microphysical and electrical properties in the 19 June 1980 storm, using time-spaced wind analyses and the time-dependent solution of the cloud model, will be concluded.

(11) Study of the microphysical and electrical properties of the New Mexico mountain thunderstorms of 31 July 1984 will continue.

(12) A simplified numerical model is being developed for simulating the initiation and evolution of vorticity (mesocyclone) within severe thunderstorms. Vorticity is computed from the vorticity equation in which a constant environmental wind field and time-dependent kinematic and thermodynamic parameters within the storm are specified by analytical functions. The model will be used in conjunction with the study of the Agawam severe thunderstorm that occurred on 6 June 1979. This storm is one of the first within which the mesocyclone initiation process has been documented.

(13) Planning for NSSL's installation of a PROFS Operational Weather Education and Research (POWER) system during Spring 1987 will be completed. NSSL will work with PROFS in developing specifications of capabilities needed in a workstation designed primarily for research applications.

(14) A training manual on the interpretation of NEXRAD Doppler radar displays will be prepared.

(15) Documentation of the 1986 Spring Program will be completed.

(16) Winds and reflectivity fields from an analytical hurricane model are to be used for constructing simulated single-Doppler radar signatures for mature hurricanes. A formal publication describing the technique that produced the analytical fields of 3-D hurricane wind and reflectivity data will be prepared.

(17) The generation of 30 universal format Doppler radar data tapes containing reflectivity, radial velocity, and spectrum width values within a mature hurricane continues. The data tapes will be used for testing NEXRAD Doppler radar algorithms.

DOPPLER RADAR AND STORM ELECTRICITY RESEARCH

Richard J. Doviak, Group Leader

The objectives of the Doppler Radar and Storm Electricity Research Group include (1) determining relationships between lightning, thermodynamics, and precipitation in thunderstorms, to develop improved indicators of thunderstorm severity and hazards; (2) developing and refining remote-sensing techniques for locating, tracking, and predicting thunderstorms and their attendant hazards; (3) defining lightning and kinematic characteristics of storms for inputs into engineering criteria for hazards to aircraft and ground facilities, and into models used in environmental studies; (4) providing ground truth and supportive data for development of new and refined observational techniques. These objectives are addressed through both theoretical and observational studies. The Doppler Radar Group interprets prestorm and storm phenomena, using data from Doppler radar and other sensors. The Storm Electricity Group analyzes simultaneously acquired Doppler radar and storm electricity data.

RECENT ACCOMPLISHMENTS

Studies of the Boundary Layer and Storm Initiation

Using a unique data set from an airborne Doppler lidar, two ground-based Doppler radars, and a 440 m instrumented tower, the wind structure of the convective boundary layer was investigated (Eilts et. al., 1985). The vertically averaged wind over the boundary layer was found to be insensitive to baroclinicity supporting earlier theoretical work. Horizontal wind spectra from lidar, radar, and tower data compared well with each other both in shape and magnitude. A consistent peak in the spectra found near 4 km might have been caused by horizontally symmetric cells with wavelength 4 times the boundary layer height.

Model development continued with the goal of diagnosing short-term temperature and moisture changes aloft. The model is intended to help both researchers and forecasters to monitor stability changes associated with the moisture-capping inversion prior to possible thunderstorm development. The model updates initial temperature and moisture profiles measured by rawinsondes, using subsequent radar wind data and models for evaporation, sensible heating, and mixed layer growth. Comparison of the results with later soundings and total precipitable water measured by a vertically pointed radiometer indicates skill in the diagnosed soundings (Zrnic' et al., 1986b). Radar estimates of vertical air motion appear to have the most diagnostic value in the model.

Radar reflectivity in clear air has been observed to vary systematically with insolation, both during a solar eclipse and over the usual diurnal cycle (Doviak et al., 1986a). Observed reflectivity is considerably greater than expected from a mixed layer model for refractive index fluctuations. Also, the change in reflectivity is observed simultaneously above the mixed layer. We are continuing this research to understand the physical mechanisms responsible for observed reflectivity characteristics.

Divergence fields were related to cloud and storm development as viewed on visible satellite images and radar reflectivity displays (Rabin and Davies-Jones, 1986). The results of a modified velocity volume processing (MVVP) analysis indicate the potential for using this technique as a short-term (1-2 h) forecast tool. For example, storms developed early in the prestorm data collection period within a broad area of analyzed convergence to the northwest of the radar. Given the magnitudes of the measured convergence and the required lifting that air parcels must undergo to reach their level of free convection, storm development in this region could be realized in 1-2 h. In regions of divergent winds, skies were generally cloud-free although small cumulus were present in the area to the southwest of the radar.

Heat and Moisture Flux Measurements

In the Spring of 1983 the Wave Propagation Laboratory and the National Severe Storms Laboratory conducted an experiment in the planetary boundary layer to explore the possibilities of combined radiometer-radar remote sensing of water vapor. The two channel microwave radiometer was pointed vertically to measure integrated vapor and liquid water, while radar data was collected on velocity azimuth display (VAD) scans to directly estimate mass convergence. From these two sensors and surface conditions we budgeted the moisture change due to convergence, evaporation and advection. Also a relationship between radar reflectivity and moisture fluctuation is examined. It is found that reflectivity near the ground increases in time with evaporation (Zrnic' et al., 1986a,b).

Measurement of Wind, Waves and Turbulence

Researchers at the National Severe Storms Laboratory have had the opportunity to observe and compare measurements of wind, waves, and turbulence made with ground-based Doppler radars, airborne Doppler lidar, and tall-tower (444 m) based anemometers. Vertical profiles of wind measured by all sensors agreed to within a meter per second after corrections were made to account for temporal displacement of the data, the different spatial resolution of the instruments, and drift in the inertial navigation system estimated aircraft locations (Doviak et al., 1986b).

Wind

We have examined the feasibility of wind measurement in the lower atmosphere using centimeter wavelength (microwave) Doppler radars. Because it is assumed that only natural scatterers contribute echoes, their frequency and distribution over continental United States are presented. A method to retrieve environmental winds from radial velocity fields measured in isolated cells is developed and demonstrated through comparisons with winds synthesized from two radars and with rawinsonde observations (Smith, 1986a). It is shown that 10 cm wavelength radars should be consistently capable of profiling winds in the convective boundary layer. In the winter during stable atmospheric conditions, the echoes are primarily due to dynamic instabilities and subsequent turbulent breakdown of waves that mix gradients of refractivity; whereas, in warmer months convective mixing of gradients and/or insects are the main contributors (Zrnic' et al., 1986).

During the Spring of 1986 we placed a rawinsonde system adjacent to the GPA radar wind profiler site to make comparisons of wind measurements. Preliminary analysis of the data show rms differences of about 2 m s^{-1} for most height locations. There were anomalously larger differences both at the lowest altitudes (i.e., $\leq$3 km) and higher altitudes ($\geq$9 km) in one wind component which appears to be related to malfunctions in the radar wind profiler. These malfunctions were not at all obvious from just an examination of the radar data (Kessler et al., 1986).

Work was initiated to examine OK-PRE-STORM Wind Profiler data for consistency and for use in determining ageostrophic winds.

The procedure to track balloons with a Doppler weather radar was modified. We successfully tested the modifications and were able to track a balloon automatically from about 1 km above ground until it burst at above 10 km. The agreement between radar winds and rawinsonde winds obtained from that same balloon was extremely good (rms error less than 1 m s^{-1}).

On 30 June 1981 the wind fields around an Oklahoma severe thunderstorm were observed in detail using an airborne Doppler lidar operated by NASA. Despite uncertainties caused by inertial navigation errors and problems in sampling some of the aircraft attitude and motion parameters, reasonably clear pictures of the distributions of horizontal wind velocity near the cloud base have been obtained. Aspects of the design and functioning of the NASA lidar relevant to the collection and analysis of the data have been described (McCaul et al., 1986).

The Doppler weather radar, operated in a high PRF mode can measure unambiguously, maximum winds in tornadoes if sufficient reflectivity is present in the region of maximum winds (Burgess et al., 1985). Direct measurements of maximum velocities from Doppler spectral skirts yielded a maximum tangential speed of 90 m s^{-1} and a diameter of maximum winds equal to 1 kilometer for the 22 May 1981 Binger tornado. Centrifuging of radar targets was estimated to be at a radial velocity of about 20 m s^{-1} (Zrnic' et al., 1985a).

Solitary Wave Research

Examination of microbarograph records revealed that a substantial number of pressure disturbances occurred in central Oklahoma in May and June of 1985 during the OK-PRE-STORM observational period. Examination of radar records has begun, to determine which of these disturbances might be associated with solitary waves and for which do we also have data recorded by the Doppler radars.

Progress has been made in the theoretical analysis of wave parameters for some specific vertical profiles of potential temperature and wind shear that have been observed to support solitary wave propagation. Solutions for nonlinear waves above the inversion layer were derived, and equations incorporating wind shear were developed.

Radar, surface, and tower observations revealed the wave-like nature of the leading edge of one thunderstorm cold outflow that was moving in a stably stratified lower atmosphere (Fulton and Zrnic', 1985). Three distinct waves, spaced 12 km apart, were detected within the leading portion of the gravity current. The leading wave had the largest amplitude, and the amplitudes decreased thereafter. These wave disturbances were generated by the density current intrusion, and they eventually propagated ahead of the current within the continuously stratified ambient environment in a manner similar to that simulated by others in laboratories. These waves resemble solitary and internal undular bore waves. The uniqueness of this data set lies in the fact that observations were collected during the early, formative stages, when the waves had not yet completely separated from the gravity current (Fulton, et al., 1986).

Turbulence

After an extensive search of NSSL's dual-Doppler radar data files, we found eight volume scans containing valid spectral width data for the same time from both the Norman and Cimarron Doppler radars. Although the data base is limited, comparisons of spectral widths from the two radars suggest that storm turbulence is isotropic on scales less than the radars' resolution volume (~1 km). Spectral widths agree to within 2 m s^{-1} with about a 90% confidence.

We have compared eddy dissipation rates computed from spectral widths with those derived from spatial spectra of mean Doppler velocities in resolution volumes. The data were obtained at close range from a vertically pointed beam in a passing thunderstorm so that the outer scale of turbulence was much larger than the size of the resolution volume. For this case we found good agreement in dissipation rates computed from the two independent data sets (Brewster and Zrnic', 1986).

Doppler radar data have been used to examine the evolution of Turbulent Kinetic Energy (TKE) in a rapidly growing storm. The largest contributions to the TKE budget were (in order of their magnitude) production (inferred), horizontal transports, eddy dissipation, and vertical transport (Brewster and Zrnic', 1986).

Lightning Strikes to Aircraft

Lightning strikes to the NASA F106-B research airplane were used to infer properties of naturally occurring intracloud flashes. Data analyzed included airborne measurements of currents flowing through the nose and tail fin cap of the airplane, electric field derivatives, transient light changes, TV recordings of lightning strikes, and radar echoes of lightning. We found that strike development usually consists of an initiation period having rapid current pulses at rates up to 10^4 s^{-1} for less than 3 ms, followed by continuous current of tens of amperes lasting up to 400 ms. During the continuous-current period, pulses resembling previously documented intracloud return surges were documented.

Our analysis of lightning strikes to the NASA F106-B shows the majority of direct strikes to the airplane at low altitudes (6-8 km) occurred during the decaying stage of storm cell evolution (Mazur et al., 1986d and e). All strikes to the F106-B associated with cloud-to-ground flashes were intracloud portions of the discharge, not the return stroke channels that may represent a more severe threat to aircraft. As for higher altitudes, the probability of aircraft being struck was found to increase as the natural occurrence of lightning decreases.

Use of Doppler Weather Radar in Aviation

Studies of weather hazards to safe flight suggested that, because of the short lifetime and dimensions of hazardous phenomena and because of the relatively poor spatial and temporal resolution of Doppler weather radars, it is advantageous to monitor the larger scale phenomena that harbor hazards to aviation (Doviak and Lee, 1985).

The Next Generation Weather Radar (NEXRAD) is slated to have an important role in the integrated and automated air traffic control system being planned by the Federal Aviation Administration. One major point of debate is the minimum rate at which weather data collected by NEXRAD must be updated so that no phenomena potentially hazardous to aviation go undetected.

Methods whereby the NEXRAD radar scan strategy can be altered to improve the temporal resolution of low altitude hazardous weather phenomena have been examined to determine if these scan strategies would cause problems in the measure of other storm attributes such as total liquid water content, storm size, etc. (Vasiloff, et al., 1985; 1986).

Doppler Lidar Measurements of Wind Shear

The detection of wind shear using pulsed Doppler lidar on board aircraft has been examined. It is shown that shear can be measured in the clear air surrounding thunderstorms (McCaul et al., 1985). The methodology and limitations of the technique are described in a recently published article (McCaul et al., 1986).

Downdrafts and Gust Fronts

Study of downdrafts (downbursts) produced by severe storms and squall lines in Oklahoma was completed (Eilts, 1986). Often these outflows are asymmetric, generate strong shears, and are accompanied by heavy rain and/or hail. Such conditions present potential hazards to aviation, but the reflectivity intensity is sufficiently high that it should provide a warning so that aircraft would not penetrate the cell. On the other hand, summer downbursts produced by small explosive cells may be difficult to detect and predict; their reflectivity intensity may not preclude aircraft penetration, yet the shears produced by them can be lethal if encountered by aircraft on the approach path. We have been engaged in a modest data-gathering effort to supplement our knowledge of such summertime microbursts. Data collection was successful in that several microbursts were observed in a tropical air mass with our two Doppler radars. Preliminary examination of the data indicates that convergence aloft (2.5 km above ground) preceded by several minutes the outflow near the ground.

Gust fronts have lifetimes and dimensions that are large compared to the temporal and spatial resolution capabilities of Doppler radar. Therefore it becomes practical to consider automated means to track and project their present and future positions (Uyeda and Zrnic', 1986). Comparison of gust front wind shear measured with in situ surface based anemometers and remotely with Doppler radar a few hundred meters above the surface show that shear measured above the ground is higher by about 1.6 (Eilts, 1986).

Hail Detection

A study of hail signatures was conducted. The study was based on our observation that strong reflectivity cores may be involved in a three-body scattering such that the microwave energy scattered by hail is reflected from the ground back to the hail and then to the radar. Observed reflectivities and velocities follow expected theoretical profiles remarkably well.

Further studies on the relationship between parameters that measure storm top divergent outflow magnitude and maximum hailstone diameters continued with analysis of 49 cases. For the best measurement techniques, the results showed correlation coefficients of 0.8 to 0.9 (Witt, 1985).

Polarization Studies

First measurements of differential propagation phase shift constant K_{DP} were provided by NSSL's dual polarized radar to compare with our theories (Sachidananda and Zrnic', 1986a). Programs were developed to estimate K_{DP} from the time series records and to generate color displays of K_{DP}. A comparative analysis of the rainfall rate (R) calculated using Z,R, Z_{DR},R, and K_{DP},R relationships has indicated that the K_{DP},R relationship is most useful at higher reflectivities (>45 dBZ). The estimated rain rates from polarization measurements are higher than rates from a Z,R relationship (Sachidananda and Zrnic', 1986b). It appears that drops are more oblate than equilibrium shapes. Also, at lower reflectivities (<30 dBZ), the spread of K_{DP} and Z_{DR} is larger than predictions based on statistical uncertainty. We are examining which combination of Z_{DR}, Z_H, and K_{DP} might best indicate the presence of hail.

During the spring of 1986 several polarization measurements were conducted in rain and hail storms while a disdrometer collected data on drop size distributions.

A theoretical analysis was performed to determine optimum signal transmission and processing scheme so that both polarization and Doppler measurements can be obtained in minimum time (Sachidananda and Zrnic', 1986c). So far the best approach consists of an alternating transmission sequence of horizontally and vertically polarized electric fields. Doppler velocities are computed after the propagation phase shift has been isolated from the autocovariance at lag one.

Algorithms for Next-Generation Weather Radar (NEXRAD)

We further refined and tested several NEXRAD algorithms. The gust front algorithm was improved and expanded on the basis of past analyses. We compared algorithm outputs based on data from our two radars that viewed the same gust front. The locations of the gust front agreed to within 1 km. Agreement was similarly favorable between gust front positions inferred from surface station data and obtained with the algorithm. We also incorporated into the algorithm a capability to track in rectangular coordinates, a vertical continuity requirement, and a uniform wind analysis on either side of the front. The algorithm was transferred to MIT's Lincoln Labs and first used in real time in the Cooperative Huntsville Meteorological Experiment (COHMEX) in Huntsville, Alabama.

A single-Doppler analysis technique known as modified velocity volume processing (MVVP) was thoroughly tested. Of specific interest is the capability of the linear wind model to estimate horizontal velocity divergence. It was shown that the accuracy of the estimates depends on several factors. Very important is the geometry of the MVVP analysis volume, which plays an integral part in determining the magnitudes of bias and variance errors in the parameter estimates. For a properly designed analysis volume, the uncertainty in divergence due to velocity measurement errors was found to be on the order of 10^{-5} s^{-1}, nearly an order of magnitude less than the intensity of convergence usually significant for thunderstorm initiation. Bias, on the other hand, can be quite large ($\sim 10^{-4}$ s^{-1}) for typical values of second-order mesoscale wind variations.

An algorithm to detect tornadic vortex signatures and an algorithm to characterize storm severity from divergence measurements were documented in reports to the NEXRAD Joint System Program Office.

The wind field in the pre-storm convective boundary layer can be mapped using an algorithm that least squares fits observed radial velocities to within small sectors with azimuthal resolution of about 30° and range resolution of about 20 km (Smith, 1986b).

A region of high wind shear always accompanies large intense tornadoes. Such shear is readily measured by Doppler radar and thus can be used to identify regions in storms where tornadoes are likely to form. An algorithm developed at the National Severe Storms Laboratory uses decision thresholds to discriminate between mesocyclone shear and other shears not associated with organized circulatory flow. A detailed test of these and other thresholds was made by testing the algorithm on storms with and without mesocyclones. The algorithm requires storage and calculations on two consecutive radials of data, and thus is suitable for real time implementation. We have applied the algorithm to data from sixteen mesocyclones to evaluate detection performance. The probability of false alarm was 10%, and the probability of detection was 90%. The algorithm accounts for distortion of the shear pattern caused by the large antenna beam dimensions at long ranges (Zrnic' et al., 1985b).

National Lightning Programs

NSSL has continued to represent NOAA at the National Interagency Coordinating Group (NICG) of the Atmospheric Electricity Hazards Protection Program. NSSL received the Group's annual award in 1986 for significant contributions to basic research on lightning hazards and for NSSL's contribution to the success of the NASA Hazards to Aviation Program. As part of our continued participation in the NICG, we are organizing the 1988 International Aerospace and Ground Conference on Lightning and Static Electricity, which we will chair.

NOAA Needs for Lightning

The Storm Electricity Group, in collaboration with colleagues in ERL's Weather Research Program, developed part of a NOAA-wide identification of lightning needs in order that the agency can address its needs more effectively. Areas identified are in the NWS, NESDIS, and ERL. An important aspect of the report is that it formed NOAA's input to NASA on potential uses of data that could be provided by a geosynchronous satellite-based lightning mapper. We found NOAA needs in the area of lightning data for identification, forecasting and/or warning included (1) direct thunderstorm identification with objective data, (2) precipitation and flash floods, (3) severe storms, (4) mesoscale convective systems, (5) aviation hazards, and (6) thunderstorms over oceans, mountains, or in ground clutter. Other NOAA operational uses are verification of forecasts and warnings and a national ground strike climatology. This plan also includes NOAA's needs for lightning data within basic research on: (1) storm severity, (2) mesoscale convective systems (Goodman and MacGorman, 1985), (3) atmospheric chemistry studies and modeling, (4) electrical and microphysical interactions (e.g., Mazur et al., 1985a and 1986a), (5) modeling using climatological parameters, (6) associated and long-path-length lightning, (7) relationships among storm dynamics, precipitation, and lightning (e.g., Ziegler et al., 1986), and (8) lightning frequency in thunderstorm forecasts.

Several of these can only be served by the continuous global mapping of all lightning flashes. These inputs and subsequent meetings between NOAA and NASA has resulted in approval from NASA to begin the process of getting the mapper flown on a GOES-series satellite. Included in this are the removal of space and power constraints that could have compromised NOAA research on the satellite. Indications now are that we can realistically expect to have a new and valuable research sensor, with several potential applications for NOAA.

Many of these same needs have also been incorporated in the National Plan for Lightning Data site above.

Lightning and Vertical Reflectivity Structure

Radars with 10-cm and 70-cm wavelength were used to determine the vertical precipitation structure and lightning activity, respectively, in a multicell thunderstorm during 1.5 h of continuous observations. In all six cells of the storm, vertical growth was about three times faster than decay. All cells had lower flash density centers at 7 km that produced up to 32 flashes/min/km. We found a positive correlation between the maximum flash density and the heights of both the 40- and 50-dBZ cores. We found the following repetitive patterns in reflectivity and lightning in all six cells: (1) During the initial rapid growth of a cell, lightning is concentrated on the leading edge of the 50-dBZ core of the cell and between this cell and the dissipating neighboring cell, and (2) in the decaying stage of a cell, lightning activity spreads farther into the cell's main reflectivity core (Mazur et al., 1985b; 1986b).

Participation in COHMEX

We were asked to participate in COHMEX (Cooperative Huntsville Meteorological Experiment) under the SPACE (Satellite Precipitation and Cloud Experiment) portion of the program. Our three major collaborative experiments all required storm intercept with NSSL's mobile laboratory: (1) acquire electrical data to study the interaction between electricity and cloud microphysics and dynamics, (2) acquire ground truth lightning data to compare with observations made above the same storm with a NASA U2 aircraft as part of our ongoing role in the satellite lightning mapper project, (3) do mobile ballooning in collaboration with the University of Mississippi to measure the electric field vector, temperature, and pressure within storms.

We were able to adapt storm intercept techniques used on the Great Plains to intercept a large percentage of targeted storms within the mountainous research area. Highlights of our data collection include: (1) complete life cycle of an isolated storm cell, documented with dual-polarized radar and ground based electrical measurements; (2) during several storms, coordinated data acquisition with instrumented airplanes; (3) more than a dozen mobile balloons that provide storm-environment electrical and meteorological soundings; and (4) observations of a fascinating and likely significant tie between changes in echoes from dual-polarized radar and the onset of lightning.

One balloon flight of interest entered a long-lived storm during its initial development and remained in the storm. We recorded electric fields from within the storm during its lifetime of about 4 h, as we tracked about 100 km with the storm. This case has been selected as the primary analysis candidate in SPACE. Although unplanned, we were also able to provide other scientists in COHMEX with qualitative data as to wind speed and direction for several downburst events.

Other scientific benefits of COHMEX with NSSL's mobile lab include measurement of Maxwell currents beneath storms in collaboration with the University of Arizona. Maxwell current is hypothesized to be a measure of the thunderstorm generator, with electrical implications extending from individual cells to the global circuit.

Finally, we demonstrated the utility of the mobile ballooning concept to make new measurements in NSSL's planned studies of severe storm microphysics with dual-polarized radar.

Radar Antenna Sidelobe Effects on Observations of Lightning

As part of the study of lightning and storm structure, we analyzed the effect of echoes received in antenna sidelobes (since lightning is an intense target). By using radar cross-section discrimination, we concluded that the distribution of lightning within storms as obtained with radar depicts reliably the location of the flash activity maxima and the trends with time (Mazur et al., 1986b).

Lightning and Mesocyclone Evolution

We continue to find evidence that the intracloud lightning rate is directly tied to severe storm evolution; in particular, the intracloud rate is higher when the mesocyclone is intensifying and at peak strength aloft. We have also found this same correlation with the existence of high reflectivity aloft. In contrast, ground flashes reach their maximum rate after dissipation of the mesocyclone and any tornadic (MacGorman et al., 1985). Thus both intracloud and cloud-to-ground lightning need to be evaluated for possible inclusion in forecast and warning applications. The lack of widespread and routine acquisition of intracloud flash data has been noted in other sections; significant and rapid progress on these problems awaits data from the satellite-borne lightning mapper system.

Evaluation of Two Lightning Ground Strike-Locating Systems

We are evaluating two networks of commercial devices for locating lightning ground strikes, to determine their detection efficiency and accuracy. We are also comparing results of one of the networks with a single station thunderstorm sensor manufactured by the same company. This project is being done for the Office of the Federal Coordinator for Meteorological Services and Supporting Research. One network is a time-of-arrival system manufactured and operated by Atlantic Scientific Corporation, who transmit their system data to us. The other is a direction-finder network manufactured by Lightning Location and Protection, Inc., and operated by the Government. The two networks will be evaluated by comparing their results with "ground truth" data from three sets of instrumentation: (1) an all-azimuth television (TV) system at NSSL (Mach et al., 1986), (2) an all-azimuth TV system at Tulsa International Airport, and (3) two TV cameras mounted on remotely steerable pan-tilt units on NSSL's mobile laboratory. In addition to video data, extremely low frequency electric field signals will be recorded to evaluate whether positive ground flashes detected by the two networks are false detections. Analysis of these systems will continue into next year.

Measurements of Lightning Return-Stroke Velocities

We have improved the response of our system developed last year to measure the speed of propagation of channels between the ground and the cloud by using eight silicon detectors behind horizontal slits in the focal plane of a lens on a camera body. The device and a TV camera to record channel geometry are installed in an environmental enclosure atop the mobile laboratory, allowing channel geometry, and subsequently two-dimensional velocity, to be recorded for the first time. Analysis plans call for calculation of velocities and determination of their relationship with electric field change wave forms for lightning from Oklahoma, Alabama (during COHMEX), and from ground flashes triggered at Kennedy Space Center. Knowledge of channel velocity is important in basic physics studies and in applications where peak currents need to be modeled.

Quasi-Stable Lightning

Analysis was completed on unusual and rapidly occurring electrical discharges that were recorded by radar in an active thunderstorm. The maximum rate of these discharges was 200 per minute; average duration was only about 13 ms. These have been defined by us as "quasi-stable" discharges and are hypothesized to be different from a fully developed flash in that they do not propagate outside their initiation volume. This suggests that the region where lightning begins is only tens to hundreds of meters across (Mazur, 1986). This phenomenon seems similar to the high intracloud lightning we first documented a few years ago. There are applied implications of this study for lightning strikes to aircraft operating inside clouds.

Cloud Electricity Measurement Techniques

We completed for inclusion in the forthcoming edition of THE THUNDERSTORM (edited by E. Kessler), a chapter on techniques for measuring electrical parameters within the thunderstorm environment. This work contains sufficient detail to provide understanding of various instruments and their proper use. This compilation is the only known collection describing modern techniques. Further information was provided by an analysis of optimal mounting site selection for electric field mills on airplanes (Mazur et al., 1986c).

Enhancement of Observing Capabilities

A NASA-supported project to estimate errors in wind fields measured by airborne Doppler lidar was conducted. Aircraft position data obtained from INS, LORAN-C, and nadir photos were computer-processed for comparison.

Experimental and computational procedures were developed for real-time estimates of wind fields using VAD data collected prior to storm formation.

Analysis of a ground clutter canceling scheme on a staggered pulse train was completed. We found that a finite impulse response filter based on a window approach cancels the DC component. Its notch also appears at several locations in the extended unambiguous velocity interval; this must be accounted for when filtered velocity data are interpreted.

A scheme to recover spectral moment data when overlaid with multiple trip echoes has been examined and found promising to improve performance of Doppler weather radar observation of wind fields (Sachidananda and Zrnic', 1986d).

A variety of approaches have been devised to deal with the problem of aliasing of Doppler weather radar velocity data. These techniques tend to fall in one of two categories: those that modify the basic radar in order to prevent aliasing from occurring and those that attempt to correct the data after its acquisition using computer implemented algorithms. Researchers at NSSL and the University of Oklahoma in a joint project have developed an expert system to automatically dealias velocity fields (Boren et al., 1986).

A procedure to design a switched pattern antenna array has been developed and demonstrated on a 16- and 8-element array. The variable spacing of elements allows us to reduce the number of switchable elements to a minimum and to reduce the sidelobes of the effective pattern. Based on this design, we have built and tested an eight-element prototype array. Pattern measurements carried out in an anechoic chamber (courtesy FAA in Oklahoma City) demonstrated the feasibility of a pattern-switching concept for sidelobe signal suppression in pulsed-Doppler radars.

An improved antenna design and a new site at Mustang, Oklahoma, has been selected for our unique VHF system to replace the present one at Page Field allowing more flashes to be mapped with higher detail in the future.

Our mobile laboratory was replaced as planned with a new one by instrumenting a van (15-passenger) with a 4 kW 110 V AC generator, electric field sensors, optical detectors, two remotely controlled pan-tilt units with azimuth position readouts for the TV cameras atop the lab, a 14-channel wide-bandwidth tape recorder, a LORAN-C navigation receiver for position location, and provisions for meteorological sensors and balloon telemetry receiving equipment.

Studies of our LLP system that were completed this year show that the LLP system discriminates strikes lowering positive charge to ground from intra-cloud flashes. These preliminary results indicate that false detections occur no more than 10% of the time, and if they do occur, it is only with flashes having the lowest radiation signal amplitudes (MacGorman, 1985). We also completed a study of the Oklahoma portion of our system. We found that random errors in the direction to lightning strikes from each station is 1-2°, and flash detection efficiency is typically 70% (Mach et al., 1986).

EXPECTATIONS FOR FY 1987

(1) To develop improved operational capabilities for forecasting the locations and intensities of storms, we shall continue in-depth examinations of preconvective radar data relative to data from other sources and to theory. An effort will be made to diagnose, in real time, changes in stability and convergence of the lower atmosphere from Doppler radar data.

(2) The wind-profiling capability of weather radars will be examined both theoretically and experimentally. The accuracy of the 50 MHz Wind Profiler will be evaluated, and examination of Wind Profiler data from the OK-PRE-STORM experiment will begin.

(3) To predict downdrafts and gust fronts, study of their origin and evolution will continue. An attempt will be made to collect data on downbursts in summer storms, the kind that have been implicated in aircraft accidents.

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

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

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

(7) Increased consultation with other NOAA groups to develop possible uses of lightning data, e.g., NWS, NSSFC, and TDL.

(8) Continue developing hypotheses from basic research to test with and develop possible applications for satellite lightning mapper data.

(9) Expand the study of lightning and vertical storm structure to include more detailed effects on cloud microphysics.

(10) Begin analyzing data from COHMEX, especially storms studied with multiple Doppler and dual-polarized radars through which we flew electric field soundings.

(11) Analyze the physical characteristics of positive cloud-to-ground flashes.

(12) Analyze additional tornadic storm case studies to determine relationships among intracloud flashes, ground flashes, high reflectivity, and development of cyclonic shear in the mesocyclone.

(13) Prepare the initial evaluation document for two lightning ground strike locating systems.

(14) Determine return stroke velocities from lightning data obtained on the Great Plains, during COHMEX, and from rocket-triggered flashes at Kennedy Space Center, and evaluate our device for obtaining such measurements.

(15) Complete analysis of the characteristics of lightning strikes to the F106-B airplane along with ground measurements to infer properties of naturally occurring intracloud flashes.

(16) Upgrade NSSL's VHF lightning-mapping system by improving antenna systems, moving one site, upgrading the real-time data display, and moving the electronics from old vans into buildings.

(17) Increase the instrumentation on our mobile laboratory in support of DOPLIGHT-87, and begin to fabricate balloon launching and tracking system into a new truck scheduled to be delivered by GSA late in the year.

(18) Analyze the occurrence of associated lightning flashes as observed with our ground strike locating system.

(19) Provide ground truth data of winds, etc., for algorithm verification as part of DOPLIGHT-87.

(20) Begin analysis of lightning activity in the Edmond, Oklahoma, tornadic storm of 1986 for eventual comparison with dual-Doppler analysis of storm structure and winds.

(21) Perform initial analysis of long term lightning effects on precipitation and on the reorientation of hydrometeors by lightning.

COMPUTER AND ENGINEERING SUPPORT AND DEVELOPMENT

Dale Sirmans, Group Leader

The Computer and Engineering Support Group develops techniques and equipment, maintains the NSSL observational facilities, and supports the observational programs associated with the meteorological research. The NSSL base facilities consist of two 10-cm meteorological Doppler radars, a WSR-57 surveillance radar, a meteorologically instrumented 444 meter tall tower, a 52 station surface network, an aircraft beacon interrogation system for air traffic control, air-to-ground communications equipment and equipment for atmospheric electricity measurements. The Group also provides engineering support for the NEXRAD/JSPO Interim Operational Test Facility for the National Weather Service.

RECENT ACCOMPLISHMENTS

Computer and Data Processing

The NCAR graphics radar editing system was implemented on the NSSL VAX and supplemental programs for using the universal format were implemented in support of the graphics workstation and data analysis performed on the CDC 855. A visual Doppler editor was implemented on the VAX and implemented into the NSSL version of the NCAR editor. The NSSL VAX 11/780 was modified to include a seven track tape drive.

A PROFS workstation was loaned to the NSSL for the 1986 Spring Program period and for several subsequent months for research purposes. The system consisted of a DEC Micro-VAX II with a Ramtek 9465 color graphics display. Data were supplied over a 56K baud leased line from Boulder, Colorado.

The MICOM electronic switch local area network continued to grow with the addition of terminals within the building. The use of the switch to access the CDC 855/205 in Gaithersburg continues to increase.

Numerous electrical storms caused damage to the MICOM switch, to ports into the VAX and the Perkin-Elmer computers and to various terminals. Fiber Optics cables interconnecting the main NSSLs building to external buildings have been installed and hardware for multiplexing has been reviewed.

NSSL supplied data sets to numerous external users.

Facilities Engineering

1. Facilities Operations

NSSL radars, SAM Surface Station Network and KTVY Tall Tower facilities were operated in support of the Spring/Summer 1986 severe storm operational program.

The NSSL WSR-57 radar data processing and recording equipment were loaned to support the GALE Weather Research Project at Athens, Georgia, from mid January to mid March 1986.

2. Cooperative SAM/Profiler Site at Plattville, Colorado

A standard SAM Mesonetwork equipment compliment was calibrated and delivered to the WPL Profiler site at Plattville, Colorado, in September 1986 as a source of ground truth data. The surface data will be integrated into the Profiler data message reported at six minute intervals. Provisions were made for transmission of the SAM data to NSSL for quality control and monitoring via dial-up telephone link to the Boulder computer.

3. Engineering Evaluation of Dual Polarization Radar

Engineering tests and data utility preliminary evaluation were completed; data were collected and analyzed; and three papers were presented at the Severe Storms Conference at Snowmass, Colorado, in September 1986. This work completed the engineering evaluation and documentation of the CIM Dual Polarization S Band Doppler radar.

4. Water Resources Board Weather Modification Project

This project was developed in cooperation with the Oklahoma Water Resources Board to evaluate the effectiveness of the 10-cm Doppler radars at NSSL in detecting meteorological parameters pertinent to the thermal plume distribution of silver iodide particles from ground-based generators and thus the feasibility of using NSSL radars to vector sampling aircraft into a seeded region to measure particle concentrations. This work is underway and will be completed by March 1, 1987.

Facilities Development

1. Radar Preprocessors

A radar data preprocessor designed around the Motorola 68000 Microcomputer was designed and fabricated. The preprocessor thresholds incoming data from the real time intensity and velocity calculators for establishment of contour display levels, dealiases incoming range and velocity data and generates the color pictures for the intensity, velocity and spectral width displays.

2. Wind Profilers (50 MHz and 405 MHz)

NSSL CESD personnel were involved in various aspects of data collection and processing and equipment maintenance in the operation of the 50 MHz wind profiler located near Purcell, Oklahoma.

A 27-foot parabolic antenna and pedestal assembly were assembled and made ready for operation in anticipation of the arrival of the transmitter, receiver and data processing components from WPL in Boulder, Colorado, in a cooperative experiment to evaluate the 405 MHz wind profiler capabilities in central Oklahoma. WPL will provide the transmitter, receiver, and data processing components, and NSSL will provide the antenna system.

3. Fiber Optic Communications System.

Fiber Optic cables have been purchased to allow digital and wideband analog data transmission between the NSSL Doppler radar, the NSSL VAX computer and its numerous data terminals, and the WSFO facility adjacent to the NSSL building. Specifications were written and contracts were awarded to Fiber Optic equipment vendors to supply the necessary Fiber Optic transmission terminal equipment to allow completion of a Fiber Optic communications system.

4. Prototype Portable Surface Network.

Work began on the development of a prototype portable Mesonetwork Surface Station. A new data acquisition and processing system was designed and fabricated. Work began on evaluation and design of the platform and associated instruments for a prototype station.

NEXRAD/JSPO Support

In addition to the routine engineering support and consultation, a special study of antenna pattern blockage by a microwave relay tower was made. Results are summarized in an interagency report. Generalized effects of this type antenna blockage have also been summarized.

EXPECTATIONS FOR FY 1987

Computer and Data Processing

(1) Upgrades to the VAX 11/780 will include the installation of an electrostatic plotter and a laser printer as well as an increased disk storage capacity.

(2) The hardware and software to create a research PROFS workstation will be purchased and networked to the NSSL VAX. It is planned that this investment will be the beginning of a research interactive workstation network for NSSL.

(3) In cooperation with the University of Oklahoma, a Decnet link will be established between the NSSL and the O.U. Geosciences VAX computers to allow NSSL co-investigators access to work directly with university collaborators.

Engineering

(1) The first phase of major repair and upgrading of the NRO-CIM Doppler radars will be initiated. Planned improvements include: replacement of the antenna pedestal and addition of a clutter canceller at NRO; replacement of the microwave power train components at both the Norman and CIM radars, design and fabrication of a hardwired differential reflectivity and phase calculator for the CIM radar, commissioning of the radar signal preprocessor for the NRO radar, commissioning of a second generation data display terminal for the NRO radar, and installation of a remote display and NRO radar control system in the OKC WSFO for use in the DOPLIGHT-87 Program.

(2) The Fiber Optics data communications system between NSSL and the new OKC WSFO building will be finalized and become operational for the 1987 DOPLIGHT Program.

(3) Studies of data from the 405 and 50 MHz profiler will be completed.

(4) Design and acquisition of prototypes for new NSSL mobile surface station and rawinsonde balloon observing systems will be continued.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) was established in 1978 as a joint research institute between the University of Oklahoma (OU) and the National Oceanic and Atmospheric Administration (NOAA), primarily NSSL. CIMMS is administered by the University. Program objectives and activities of CIMMS are designed to complement the research activities of NSSL and of other NOAA/ERL Laboratories, and the University of Oklahoma. During 1986 CIMMS has addressed the following specific themes:

- Mesoscale models
- Mesoscale dynamics
- Orography and lee cyclogenesis
- Variational optimization analysis and remote sensing

ACCOMPLISHMENTS FY 1986

Mesoscale Models

Mesoscale modeling research at CIMMS focused on investigations of optimal analysis techniques and the numerical prediction of severe storms and hazardous weather. Specifically, work was done in the areas of model initialization and data assimilation. The OU version of the Florida State University primitive equation model was used to study initialization and assimilation problems for meso-α-scale forecasting. Variational initialization was shown to be promising for further studies. Scientists at CIMMS, along with researchers from the OU School of Meteorology and NSSL, have also begun work on a next-generation mesoscale model. The objective of this Central Oklahoma Mesoscale and analysis (COMMA) project is to use new types of remote-sensing data (such as Wind Profiler, NEXRAD, and satellite data) to deduce a thermodynamically and dynamically sound initialization method and to develop a next-generation mesoscale model, in a cooperative effort of the Norman, Oklahoma, meteorological community. The development of such a model appears to be timely because of the availability and power of computer resources and numerical techniques, the advancement of theoretical understanding of mesoscale and convective phenomena, and the new high-resolution data to be available within the next half decade. CIMMS researchers have significant roles in developing this project.

The microsymmetry method was used to construct a two-dimensional horizontal wind field from the radial velocity components detected by a single-Doppler radar wind observation. This method may significantly broaden usage of data from the forthcoming Next-Generation Weather Radar (NEXRAD) observation network. An initialization and assimilation experiment simulated incorporation of NEXRAD and Wind Profiler observations into a mesoscale forecast model. Considerable improvement of wind and pressure patterns in the vicinity of fronts was obtained.

Mesoscale Dynamics

Progress in understanding mesodynamics during the last year was most significant in two areas: (1) Documentation of the important role of conditional symmetric instability on rainband formation and development of other convective systems; (2) laboratory simulation of mesocyclone and tornado-like vortices in vertically sheared flow. In the latter, advanced techniques for velocity measurement were employed, and an apparatus was designed to simulate the vertical shear of the horizontal wind. The new design altered the laboratory tornado vortex chamber so that the inflow air feeding the vortex was caused to veer horizontally with height, in analogy to the sheared environment of a typical tornado-producing supercell storm. A workshop on Modeling of Tornado Vortices was held on 14-15 November 1985 at CIMMS.

Orography and Lee Cyclogenesis

Research continued on the processes of alpine lee cyclogenesis, using the Alpine Experiment (ALPEX) data. This research was funded mostly by the National Science Foundation. Emphasis was placed on the effect of mountains on the mechanisms of vorticity production on the lee side and regeneration of fronts passing over the mountains. Because of the extensive data available from ALPEX, this research is expected to hint at new ideas of genesis and development of short wave troughs, fronts, and severe storms, which occur on the lee side of the Rocky Mountains in this country. The CIMMS mesoscale model was used to produce high-resolution balanced data sets for the study of dynamical processes associated with alpine lee cyclogenesis. In this study, the effects of diurnal heating of the high mountains and high plateau were examined in the development of thermal-frontal depressions and their relation to forcing of convection.

Variational Optimization Analysis and Remote Sensing

Work was continued to develop efficient and accurate techniques for analysis of remotely sensed data including satellite-sensed radiation, NEXRAD Doppler radar wind information, and ground-based vertical wind profiles. Development of these techniques was recognized as important for timely and proper diagnoses of hazardous mesoscale severe weather and for providing appropriate initialization and assimilation methods for mesoscale forecast models.

The microsymmetry method was tested for several selected cases. It showed excellent agreement between known two-dimensional wind fields, and those derived from Doppler radar radial wind velocity by use of the microsymmetry method. It thus became possible to derive two-dimensional wind fields from only NEXRAD-type radial velocity observations. Three-dimensional velocity fields may be obtained from the calculated two-dimensional wind using the mass continuity equation.

De-aliasing of radial wind components was investigated by means of an artificial intelligence approach. The approach includes three assumptions: (1) spatial continuity of the velocity field, (2) temporal continuity of the velocity field, and (3) use of a reliable mental model of the wind field. In another NEXRAD-related study, an algorithm to characterize storm severity using divergence measurements at storm top was investigated.

Another observing system of interest and of potential use for the future is airborne lidar. Results from our analysis of lidar data were beyond expectations; strong evidence of an entrainment zone around clouds was observed, and two-dimensional velocity fields obtained from lidar data resolved fine undulations and vortex fluctuations at the edge of a gust front.

Storm lightning strikes were studied in a NASA-supported project, using data obtained by instrumented aircraft penetrations of thunderstorms. It was concluded that although the number of lightning strikes to an airplane could be as much as one third of all strikes, all strikes to an airplane were intercloud portions of discharges rather than return strikes, which have relatively much stronger currents and rise times. An investigation of lightning effects on precipitation, including data analysis of the 1985 season, showed that lightning caused refractive index changes due to shock wave propagation through the radar resolution volume. Another study suggested a parameter for estimating rainfall rate that is better than the parameter used in conventional methods. The parameter is the differential propagation phase shift constant.

International Symposium

In October 1985, CIMMS was host to the International Symposium on Variational Methods in Geosciences co-sponsored by the American Meteorological Society and several other scientific societies. This symposium featured ten internationally renowned scientists as keynote speakers, and more than 40 papers were presented. These presentations related the use of variational mathematical theories and techniques in the presenters' current research. The variational methods presented and discussed in the symposium offered solutions to important problems of Doppler radar data (NEXRAD and Wind Profiler) analysis and initialization and assimilation problems of mesoscale forecast models.

EXPECTATIONS FOR FY 1986

(1) Continue modeling efforts at CIMMS with NEXRAD Doppler and vertical Wind Profiler data, parameterization of diabatic processes and terrain-influenced boundary layers on the mesoscale.

(2) Further develop the COMMA project, to implement a fine mesh, accurate numerical scheme, and a sound microphysical model into a mesoscale forecast model.

(3) Continue a study on symmetric and conditional instabilities to reveal mechanisms of initiation, development, and decay of severe weather systems.

(4) Continue laboratory experiments and numerical simulation of tornado-like vortex generation and structure.

(5) Study turbulent processes in tornado, gust-front, and other mesoscale systems.

(6) Continue research on the effects of mountains on synoptic and mesoscale weather systems.

(7) Continue research to discover the mechanisms of boundary layer formation and separation, and surface heating and cooling due to orography, and their influences on the onset of severe storms.

(8) Develop a more realistic and predictable terrain-influenced boundary layer parameterization for mesoscale models.

(9) Continue to develop initialization and assimilation methods of Doppler NEXRAD and Wind Profiler data into mesoscale models.

(10) Simulate NEXRAD and Wind Profiler data in a mesoscale forecast model to evaluate their sensitivity in mesoscale analysis and forecasting.

(11) Continue to test microsymmetry methods for generating two-dimensional horizontal wind fields from NEXRAD-type one-dimensional radial velocity information.

(12) Continue research on de-aliasing of Doppler wind velocity folding by using time/space continuity and human judgment of the appropriateness of resulting patterns.

PERSONNEL, BUDGET, AND ADMINISTRATIVE STATISTICS

Personnel FY 1986

	October 1, 1985		September 30, 1986	
	Full-time	Part-time	Full-time	Part-time
Professional	24	5	29	4
Technical	9	2	10	2
Clerical	5	4	5	3
TOTAL	38	11	44	9

Number of full-time holding doctoral degrees on September 30, 1986: 12

In addition to the above, the Laboratory employs 20 University of Oklahoma (OU) students part time; they are assigned to NSSL staff who are Adjunct Professors at OU. The Cooperative Institute for Mesoscale Meteorological Studies employs 17 Graduate Research Assistants, six computer programmers, and four supporting staff funded by NSSL.

FY 1986 Budget and Funding

NOAA Operations Research and Facilities........................$3,497,705.00

Support... 410,000.00

Other Agencies: (FY 1986 New Funds)

Department of Interior	$ 30.0
Joint System Program Office, NEXRAD	55.0
Federal Aviation Administration	160.0
National Aeronautics & Space Admin.	95.0
Weather Service	41.8

Total Other Agencies.. 381,800.00

TOTAL Funding.....................................$4,289,505.00

PERSONNEL OF THE
NATIONAL SEVERE STORMS LABORATORY

OFFICE OF THE DIRECTOR

DIRECTOR – DR. ROBERT A. MADDOX
SECRETARY – JOY L. WALTON

CLERK TYPIST – PEGGY L. BAKER

ADMINISTRATION

ADMINISTRATIVE OFFICER – LOYCE M. TILLMAN
ADMINISTRATIVE AIDE – PATRICIA R. GREGORY

ADMINISTRATIVE AIDE – VACANT
LIBRARIAN – MARY E. MEACHAM (WAE)(P)

DOPPLER RADAR AND STORM ELECTRICITY RESEARCH

MANAGER – DR. RICHARD J. DOVIAK
SECRETARY – CAROLE J. HOLDER
CLERK TYPIST – MARY LOU YOUNKINS

DOPPLER RADAR

LEADER (PHYS. SCI.) – DR. DUSAN S. ZRNIĆ
METEOROLOGIST – MICHAEL D. EILTS
METEOROLOGIST – MICHAEL H. JAIN
METEOROLOGIST – ROBERT M. RABIN
METEOROLOGIST – STEVEN D. SMITH (WAE)
METEOROLOGIST – ARTHUR WITT (WAE)
PHY. SCI. AIDE – SUSAN K. OAKLAND (WAE)

STORM ELECTRICITY

LEADER (PHYSICIST) – DR. W. DAVID RUST
PHYSICIST – DR. DONALD R. MacGORMAN
PHYSICIST – DR. VLADISLAV MAZUR
ELECTRONICS TECH. – KEVIN N. CAMERON (WAE)
PHY. SCI. AIDE – MONTY G. BATEMAN (WAE)
PHY. SCI. AIDE – WILLIAM H. BURNETT (WAE)
PHY. SCI. AIDE – DOUGLAS M. MACH (WAE)
PHY. SCI. AIDE – MICHAEL J. SAFOUTIN (WAE)
PHY. SCI. AIDE – LANCE A. SCUDDER (WAE)
PHY. SCI. AIDE – KRISTEL R. WICKHAM (WAE)
COMPUTER AIDE – KRISTI SHAFTO (WAE)

METEOROLOGICAL RESEARCH

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

MODELING AND DYNAMICS

LEADER (METEOROLOGIST) – DR. CARL E. HANE
METEOROLOGIST – DR. ROBERT P. DAVIES-JONES
METEOROLOGIST – DAVID J. STENSRUD
METEOROLOGIST – STEVEN V. VASILOFF
METEOROLOGIST – VINCENT T. WOOD (WAE)(P)
METEOROLOGIST – DR. CONRAD L. ZIEGLER

STORM EVOLUTION AND ANALYSIS

LEADER (METEOROLOGIST) – RODGER A. BROWN
METEOROLOGIST – DR. EDWARD A. BRANDES
METEOROLOGIST – DONALD W. BURGESS
METEOROLOGIST – BRENDA C. JOHNSON
METEOROLOGIST – DR. STEPHAN P. NELSON (NSF)
METEOR. TECH. – LESTER C. SHOWELL

GROUP SUPPORT

METEOR. AIDE – E. BRIAN CURRAN (WAE)
METEOR. AIDE – ROGER EDWARDS (WAE)
METEOR. AIDE – SUZANNE M. FORTIN (WAE)
METEOR. AIDE – GREGORY A. HANSON (WAE)
METEOR. AIDE – JEFFREY A. WALLENFANG (WAE)
METEOR. AIDE – CAROLYN R. WILSON (WAE)
PHY. SCI. AIDE – LINDA A. BARKER (WAE)

COMPUTER AND ENGINEERING SUPPORT AND DEVELOPMENT

MANAGER – DALE SIRMANS
SECRETARY – RUTH B. WILK (PTP)
CLERK TYPIST – LAWRENCE S. DEVERICKS

COMPUTER SYSTEMS ANALYST – WILLIAM C. BUMGARNER
ELECTRONICS ENGR. – JOHN K. CARTER
METEOROLOGIST – DOUGLAS E. FORSYTH (FTT)
ELECTRONICS ENGR. – F. ALLEN ZAHRAI
ELECTRONICS TECH. – GLEN H. ANDERSON
ELECTRONICS TECH. – JESSE D. JENNINGS
ELECTRONICS TECH. – LEONARD A. JOHNSON
ELECTRONICS TECH. – EUAL G. KELLY
ELECTRONICS TECH. – JAMES W. McGOWEN (PTP)
ELECTRONICS TECH. – DENNIS E. NEALSON
ELECTRONICS TECH. – WILLIAM F. PHIPPS (FTT)
ELECTRONICS TECH. – JACK M. REECE (PTP)
ELECTRONICS TECH. – J. MICHAEL SCHMIDT
ELECTRONICS TECH. TRAINEE – PAULA K. SADLER
ENGINEERING TECH. – KIRBY D. DEVORE (WAE)
METEOROLOGIST – JT DOOLEY
METEOROLOGIST – SHERMAN E. FREDRICKSON
METEOR. TECH. – CHARLES G. CLARK
METEOR. TECH. – GERALD J. WARDIUS

FACILITIES MANAGEMENT CONTRACT

RACHAEL DEALS
ROYCE LEEPER
STEPHEN MILLION
CHRISTOPHER WALKER
STACY WELLS

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

DIRECTOR – YOSHI K. SASAKI

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

NATIONAL WEATHER SERVICE NEXRAD JOINT SYSTEMS PROGRAM OFFICE INTERIM OPERATIONAL TEST FACILITY

CHIEF – KENNETH E. WILK

4 FULL-TIME PERSONNEL

UNDESIGNATED PERSONNEL ARE FULL-TIME PERMANENT

PTP – PART-TIME PERMANENT, FIXED WORK SCHEDULE

FTT – FULL-TIME TEMPORARY, FIXED WORK SCHEDULE

PTT – PART-TIME TEMPORARY, FIXED WORK SCHEDULE

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

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

AS OF SEPTEMBER 30, 1986

Grants and Contracts

FY 1986

Grants and contracts administered by NSSL during FY 1986 are listed below. Other agencies are indicated in the first column where their funds were used to maintain the grant or contract.

Recipient organization, title of grant or contract, and prin. investigator	Number	NSSL Cognizant Officer	State date	Term date
Applied Computer Systems "Services for Facilities Management to Operate NSSL Computer Equipment"	NA84RAE05057 ($71,000)	Bumgarner	10/1/85	9/30/86
University of Oklahoma Cooperative Agreement "Cooperative Institute for Mesoscale Meteorological Studies" CIMMS	NA85RAH05046 ($275,000)	Maddox	7/1/86	6/30/86
University of Oklahoma "Research on Severe Local Storms" (Golden) NASA	NA82RAH00003 ($20,590)	Rust	10/1/85	9/30/86
Florida State University "Analysis of Airborne Doppler Radar Data from a Pretornadic Storm" (Ray)	40RANR608326 ($9,999)	Ziegler	7/22/86	6/30/87

In addition to the above Grants and Contracts, $132.4K is disbursed annually for recurring services and maintenance agreements.

PUBLICATIONS
1 OCTOBER 1985 - 30 SEPTEMBER 1986

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Doswell, C.A., III, and R.A. Maddox, 1986: The role of diagnosis in operational weather forecasting. Preprints, 11th Conference on Weather Forecasting and Analysis, June 17-20, 1986, Kansas City, MO, American Meteorological Society, Boston, 177-182.

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Howard, K.W., R.A. Maddox, and D.M. Rodgers, 1985: Meteorological conditions associated with a severe weather producing MCS over the northern plains. Preprints, 14th Conference on Severe Local Storms. October 29 - November 1, 1985, Indianapolis, IN, American Meteorological Society, Boston, J43-J46.

Howard, K.W., R.A. Maddox, and D.M. Rodgers, 1985: Meteorological conditions associated with a severe weather producing MCS over the northern plains. Preprints, Sixth Conference on Hydrometeorology. October 29 - November 1, 1985, Indianapolis, IN, American Meteorological Society, Boston, J43-J46.

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McGinley, J.A., and P.S. Ray, 1985: Numerical modeling of a thermal-frontal disturbance (the SSL). Preprints, 14th Conference on Severe Local Storms, October 28 - November 1, 1985, Indianapolis, IN, American Meteorological Society, Boston, 194-197.

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Sachidananda, M., and D.S. Zrnic', 1986c: Characteristics of echoes from alternately polarized transmission. CIMMS Report No. 71, Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, OK, 54 pp.

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