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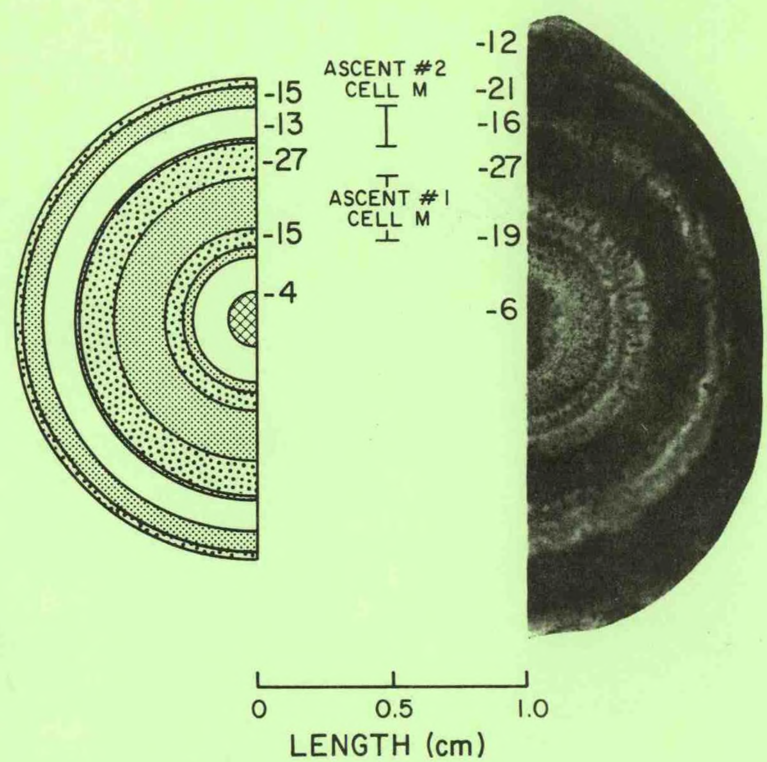
National Severe Storms Laboratory

ANNUAL REPORT FY-83



UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Environmental Research Laboratories

COVER

Cross-sections of modeled hailstone (left) and thin section of a corresponding sampled hailstone in transmitted light (right). Temperature (°C) at which corresponding ice layers formed are indicated. In the model stone, the cross-hatched region represents the hailstone embryo. Lightly stippled layers denote high density (>0.75 g cm^{-3}) dry growth in the model, and heavily stippled layers represent low density (<0.75 g cm^{-3}) dry growth. Clear layers represent wet growth. Periods of ascent in major updraft are indicated near center. (From Ziegler, C.L., P.S. Ray and N.C. Knight, 1983: "Hail growth in an Oklahoma multicell storm," J. Atmos. Sci., 40 (7), 1768-1791.)

NATIONAL SEVERE STORMS LABORATORY

ANNUAL REPORT - FISCAL YEAR 1983

October 1, 1982 - September 30, 1983

National Severe Storms Laboratory
1313 Halley Circle
Norman, Oklahoma 73069
April 1984

UNITED STATES
DEPARTMENT OF COMMERCE

Malcolm Baldrige,
Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

John V. Byrne,
Administrator

Environmental Research
Laboratories

Vernon E. Derr
Director

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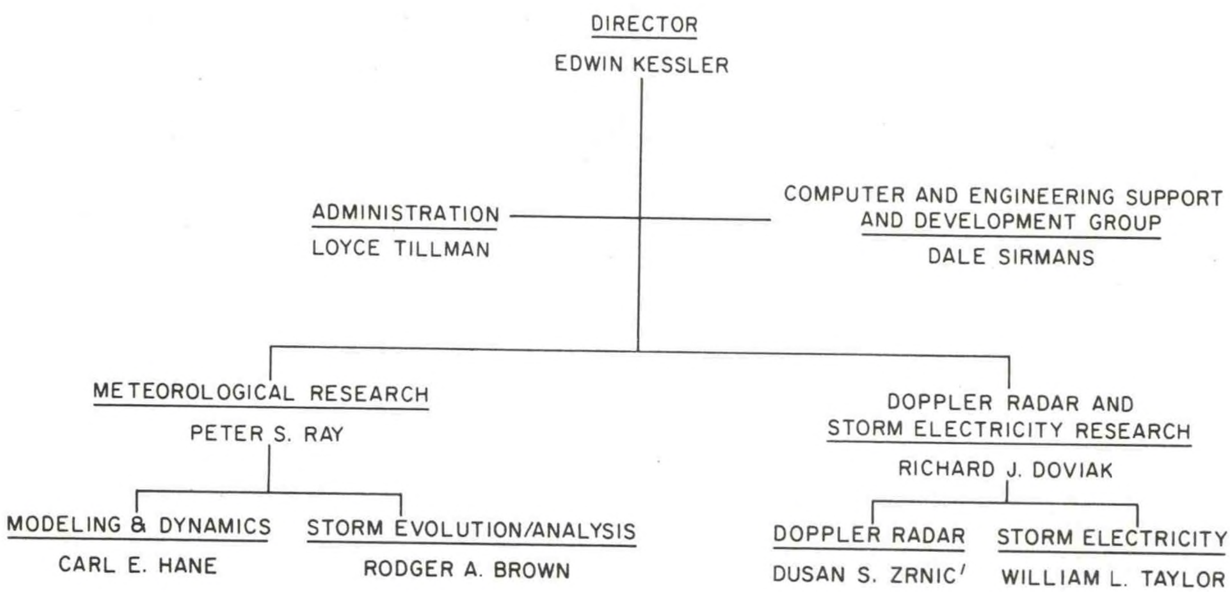
NATIONAL SEVERE STORMS LABORATORY

ORGANIZATIONAL CHART



Valid Throughout FY 83

NATIONAL SEVERE STORMS LABORATORY

PERSONNEL STATISTICS

FY-1983

October 1, 1982 - September 30, 1983

	October 1, 1982		September 30, 1983	
	Full-time	Part-time	Full-time	Part-time
Professional	26	2	27	2
Technical	8	3	8	3
Clerical	5	4	5	4
TOTAL	39	9	40	9

Number of full-time holding doctoral degrees on September 30, 1983: 12

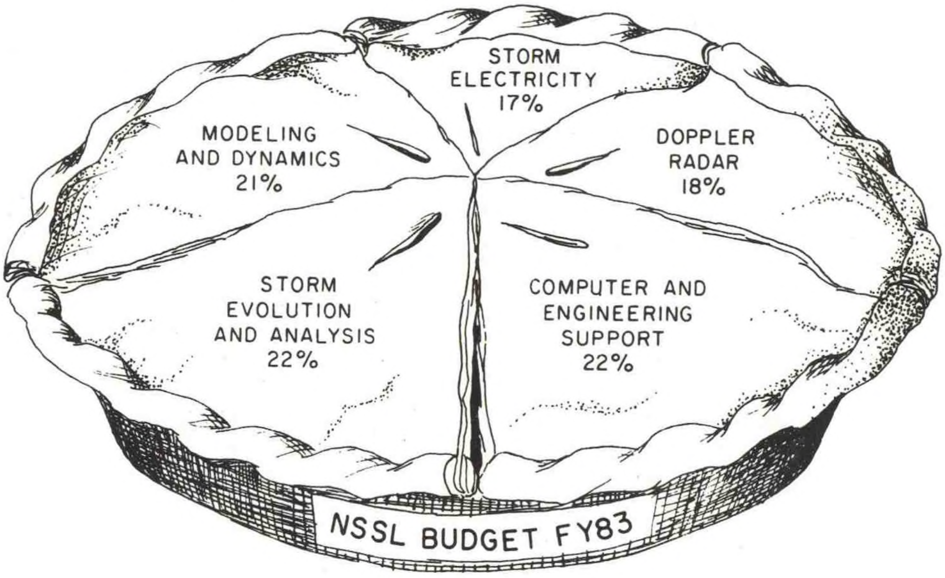
In addition to the above, the Laboratory employs 16 U. of Oklahoma (OU) students having assignments with NSSL staff who are Adjunct Professors at OU. The Cooperative Institute for Mesoscale Meteorological Studies employs nine Graduate Research Assistants, three computer programmers, one draftsperson, and two part-time Secretaries supported by NSSL.

NATIONAL SEVERE STORMS LABORATORY

FY-1983 Budget and Funding

NOAA Operations Research and Facilities			$3,249,900
Support			420,000
Other Agencies: (FY-1983 New Funds, in thousands)			
Air Force	$ 20.0		
Federal Aviation Administration	100.0		
National Aeronautics & Space Admin.	85.0		
Total Other Agencies			205,000
		TOTAL	$3,874,900

*Storm Evolution & Analysis	22%
Modeling & Dynamics	21%
Computer & Engineering Support	22%
Storm Electricity	17%
Doppler Radar	18%
	100%



*A portion of administrative costs is included in each of the percentages shown.

PROGRAM AREAS

NATIONAL SEVERE STORMS LABORATORY

INTRODUCTION

Edwin Kessler, Director

The Laboratory staff studies severe-storm circulations and the processes through which they develop, and investigates techniques for improved storm detection and prediction, in support of NOAA's operational mission as carried out by the National Weather Service. There was remarkable progress during FY 1983 in research and its applications.

(1) Detailed observations on velocity and radar reflectivity fields have facilitated inference of forces and processes that produce storms.

(a) Study of a major tornadic storm indicates that the intense rear flank downdraft develops as a response to intensification of the mesocyclone and pressure reduction at the ground. This finding establishes a conceptual link from the mesocyclone to the downdraft-updraft couplet often closely identified with tornadoes.

(b) The major hail-producing storms have been shown both empirically and theoretically to be represented by large updraft regions where the ascent rate is moderate rather than strong. There are indications that hail production is primarily responsive to the flow field, and that little control of the hail process can be gained through efforts to manipulate microphysical processes.

(2) A theoretical study has indicated that storm rotation is closely connected to vertical shear of the ambient horizontal winds relative to the storm. Radar observation of storm motion, and a wind sounding in the storm environment provide an experimental basis for forecasting mesocyclone formation.

(3) Several projects at NSSL are contributing foundation materials to guide the effective operational use of NEXRAD, a system of meteorological Doppler radars scheduled for deployment across the United States in the late 1980s, and effective research use of airborne Doppler radar.

(a) A unifying theory on clear air returns developed at NSSL explains anisotropic scatter which can degrade wind profiler performance. Theoretical expressions derived to estimate the accuracy of some wind profiling techniques should provide a good starting point for designing the deployment and use of a mixed system of NEXRAD radars and VHF Profilers for comprehensive wind finding when precipitation targets are absent.

(b) Development of procedures for analyzing radial velocity data advanced substantially. Algorithms were designed for automatic use with single Doppler radar data to measure boundary layer divergence and its distribution, identify mesocyclones, recognize regions of intense wind shear at low altitudes, and map the low-level wind field in clear air with considerable generality.

(c) An atlas of single Doppler signatures of idealized circulation patterns, including rotatory and divergent features singly and in various combinations, shows that the human observer can develop useful skills in identification of the complex circulation patterns implicit in single Doppler data. The atlas is a starting point for refinement of second-generation algorithms to define these patterns automatically.

(d) The NOAA P-3 aircraft equipped with numerous data recording systems and sensors, including a Doppler radar in the tail, was flown near thunderstorms in Oklahoma. Data from several storms manifesting severe hail and winds confirmed both the aircraft capability as an independent sensor, and also its value in augmenting capabilities of coordinated ground-based systems. NSSL scientists have become proficient in use of this remarkable facility and are contributing to design of optimum strategies for future data acquistion.

(4) Studies of rotatory, outflow, and inflow phenomena produced in the boundary layer by thunderstorms have defined a phenomenological envelope of the hazards that must be considered in design of the aviation weather system. NSSL staff have contributed substantially to precision in definition and description of gust fronts, mesocyclones, and the scales and amplitude of various exchange phenomena collectively perceived as turbulence; have refined means for their detection; and have projected means for timely communication of information about them to places where the information is needed.

(5) NSSL's strong program in storm electricity has provided important new insights to the lightning process, and a capability for mapping the discharge process accurately in three dimensions.

(a) It has been shown that there is often a near-continuum of weak discharges in the upper reaches of thunderstorms (near 10-12 km), not closely relatable to major in-cloud and cloud-to-ground discharges that originate at lower altitudes (5-8 km).

(b) Lightning discharges to ground in regions of heavy precipitation invariably lower negative charge to ground, but occasional discharges from high altitudes in storms lower positive charge. Positive flashes usually have only one return stroke, a submicrosecond rise time (faster than negative flashes), and a continuing-current phase that makes them particularly prone to start fires.

(c) Cooperative studies involving NSSL staff with other agencies have shown that nearly all lightning strikes to aircraft are initiated by the aircraft, and that very large electric fields may exist in the plumes of major storms tens of kilometers downwind from the convectively active region. These programs have also contributed satellite-based ground truth on lightning events, to aid design of a satellite-based system for synoptic detection of lightning over the whole Earth.

NSSL's historical antecedents in the former U.S. Weather Bureau and its former National Severe Storms Project are described in an NSSL Special Report prepared in 1976. From early emphasis on use of aircraft for storm investigations related to flight safety, the focus at NSSL has moved to theoretical and empirical studies based on data from a multitude of sensors for new insights into storm mechanics, and for new applications to storm warning, prediction and safety of flight.

About one-fourth of the NSSL's budget is devoted to maintenance and operation of comprehensive instrumentation for sensing meteorological parameters. There are two 10-cm Doppler radars on a 42-km baseline, 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.

Staff of NSSL, the Interim Operational Test Facility of NEXRAD, the Weather Service Forecast Office at Oklahoma City, and several meteorological groups at the University of Oklahoma work closely together to support improvement of weather services, excellence in education for the future, and a productive program of basic and applied research. This important cooperation was formalized at the University of Oklahoma during the past year, through creation of the Weather Center, whose Executive Committee is composed of the directors of meteorological organizations representing public, private and university activities in central Oklahoma.

METEOROLOGICAL RESEARCH GROUP

Peter S. Ray, Group Leader

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 prestorm atmosphere. Analysis and interpretation of storm flow fields expand our understanding of processes of external and internal forcing, thermodynamics, cloud physics, and cloud dynamics, all of which contribute to intense thunderstorms and their attendant phenomena. Subsets of the group objective are addressed by two projects: Modeling and Dynamics led by Carl E. Hane, and Storm Evolution and Analysis led by Rodger A. Brown.

RECENT ACCOMPLISHMENTS

HAIL

We would like to know why some severe storms are accompanied by much hail and some are not. We do know that microphysical processes regulate the growth of hail in cloudy updrafts. New diagnostic methods, being refined at NSSL by Ziegler and Ray (1982), lead from sounding data and the detailed velocity distributions defined by Doppler radar to estimates of temperature, water vapor hydrometeor fields, and the microphysical processes that accompany hail growth within the observed storms. Because there is some working backward as well as forward with equations representing dynamical and/or microphysical processes, the methods are described as "retrievals" of state parameters and processes. The methods are proving to be powerful aids to understanding. A retrieval system for microphysical processes and parameters, developed at NSSL, includes different forms of ice, expanded descriptions of cloud and raindrop distributions, and physical models of warm cloud processes.

A recently completed study of hail growth in an Oklahoma multicell storm reveals that hail embryo injection into the main updraft provides the bulk of large hail formed in this case (Ziegler et al., 1982, Ziegler et al., 1983). Good agreement is obtained between the growth trajectories and structures of hailstones sampled beneath the storm and hailstones simulated numerically by use of a kinematic microphysical growth model. Actual and simulated stones compare favorably with respect to overall size, layer structure, and layer growth temperature (see cover).

Hail in two other severe storms was studied with a numerical model and multi-Doppler data. One storm, although tornadic, was not a major hail producer; the other was a very severe hailstorm, but did not spawn any significant tornadic activity. With respect to storm flow structure, the results indicate that a factor more critical for large and extensive hail than maximum updraft speed (~50 m s^{-1} in both storms) is a broad region of moderate updraft (20-40 m s^{-1}). This is because hail cannot grow in the strongest part of the updraft, but only on the edges or in regions of updrafts only moderately strong. Therefore, convective instability beyond a certain threshold seems not as important as whatever factors determine the shape and size of the updraft region.

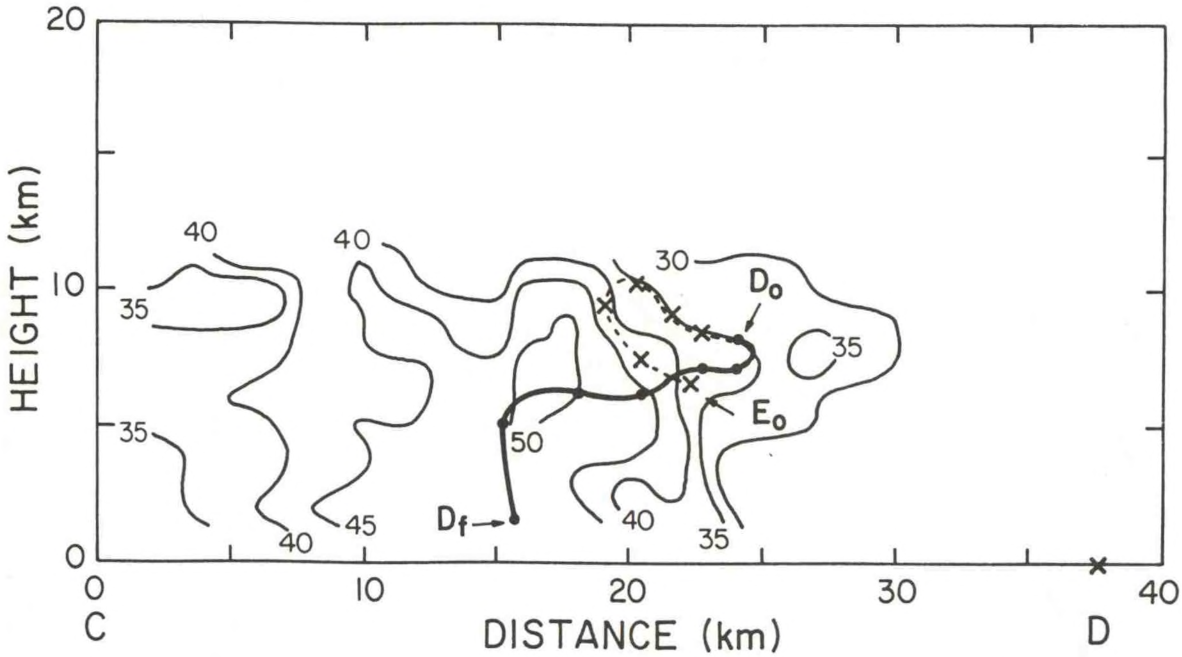


Figure 1. Vertical cross section of reflectivity (dBZ) with model hailstone trajectory, 29 May 1976. Dashed line roughly corresponds to embryo growth state (E_0=100 μm diameter; D_0=6 mm) and solid line corresponds to growth from embryo to a hailstone (D_f=2.5 cm). X's and dots are at 2-minute intervals.

The model also showed that while embryos may undergo a recycling process, the overwhelming majority of hailstone mass is acquired in one pass of hailstones across the updraft at a nearly constant level and at temperatures warmer than -25°C (Fig. 1). Some hailstorms typically produce quite wide hailswaths (15 to 20 km); in order to produce such a wide swath, the embryos must be injected across the broad front of the updraft, thus implying a rather extensive embryo generation region (Nelson, 1983).

A control of microphysical processes on hailstone production was demonstrated in a model of low density growth (riming with immediate freezing of liquid water on contact). Low density hailstones ascended more quickly in the updraft by virtue of their smaller fallspeed relative to the air, and their trajectories were markedly different from model hailstones of density 0.9 g cm^{-3} (Foster et al., 1982).

TORNADOES

Better understanding of tornadoes and improved methods for predicting them should grow out of better understanding of the origins of storm rotation. Most tornadic storms rotate cyclonically, but a few rotate anticyclonically. An application of linear inviscid convection theory by Robert Davies-Jones indicates that the difference is tightly related to the vertical shear of ambient winds relative to the motion vector of a storm. When the vertical shear of the environmental wind is large, updrafts rotate cyclonically and downdrafts anticyclonically when the storm-relative winds veer with height in the lowest 3 km.

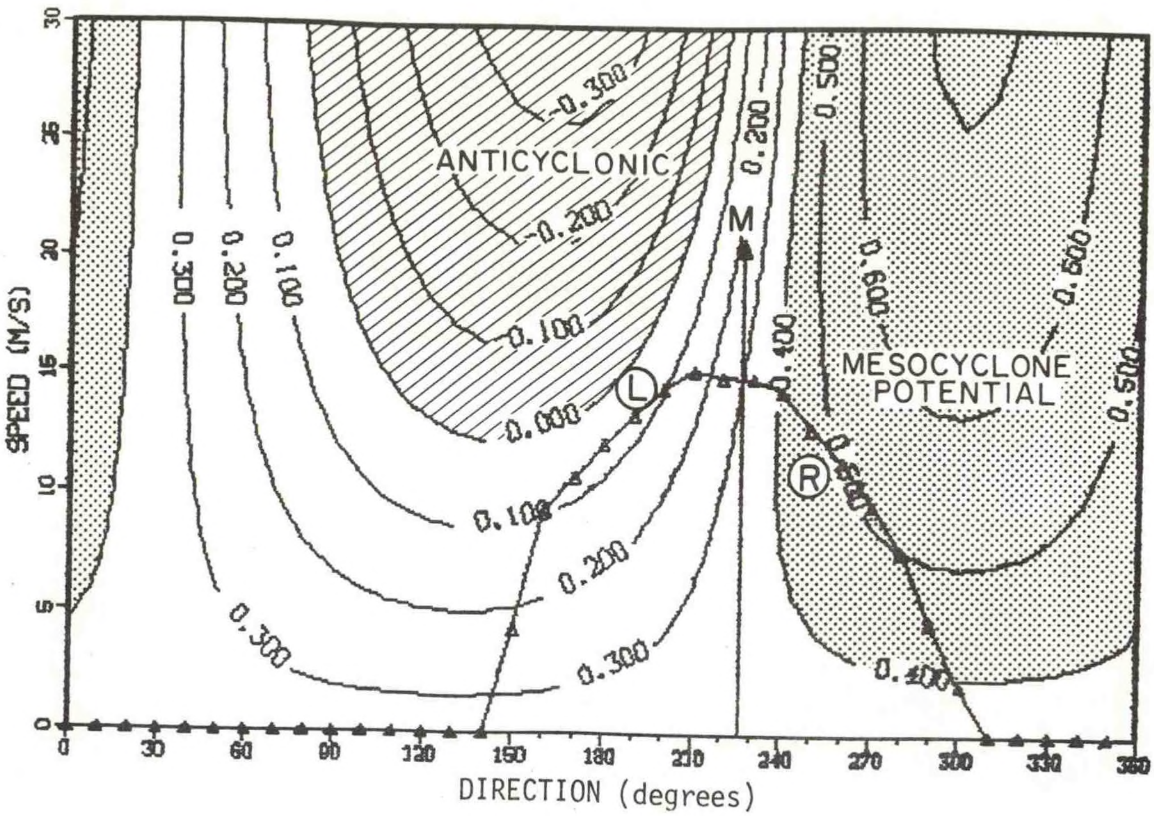


Figure 2. Forecast chart for storm rotation for the 3 April 1964 case, based on Davies-Jones model and proximity sounding data. Storm velocities are plotted, and contours give expected correlations between vertical velocity and vorticity. "L" and "R" are left- and right-moving storms, which are observed to have anticyclonic and cyclonic rotation, respectively. "M" is mean wind. The curve marked by triangles denotes storm velocities predicted from Colquhoun mass model.

The theory, with the addition of some work of J. R. Colquhoun*, has suggested a model for determining potential storm intensity and rotation given a sounding and observed storm motion. Robert Rabin has tested the combined model with rawinsonde data for a few severe-storm cases. Results are encouraging regarding the potential for short-term forecasting when sounding data of high temporal and spatial resolution are available. Figure 2 is an example of a forecast chart for storm rotation using a single observed wind profile.

The retrieval methods for recovery of microphysical data noted in the preceding section are, with appropriate differences, also applicable to description of the field of perturbation pressure to which the air velocity is linked

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*J.R. Colquhoun, 1980: A method of estimating the velocity of a severe thunderstorm using the vertical wind profile in the storm's environment. Preprints, 8th Conf. on Weather Forecasting and Analysis, Am. Meteor. Soc., pp. 316-323.

fundamentally. Edward Brandes and Carl Hane have applied retrieval methods to exhaustive study of a storm that occurred on 20 May 1977.

In this storm's pretornadic stage, horizontal pressure gradients near the updraft maximum and the characteristic couplet of high and low pressure were oriented at each altitude parallel to the environmental wind shear vector there. This agrees with recent analysis with a linear theory. The vorticity maximum is coincident with a strong pressure gradient in the pretornadic phase, and is coincident with minimum pressure in the tornadic stage.

Tornadogenesis in this storm was accompanied by intensification of the mesocyclone at the ground and development of a larger pressure deficit there. The normal upward-directed pressure gradient force in vicinity of the mesocyclone, required to lift nonbuoyant air at low altitude, was reduced and eventually reversed. We deduce that the sudden formation of a concentrated rear downdraft with a strong horizontal gradient of vertical velocity near the tornado resulted from intensification of the low level mesocyclone and associated pressure reduction at ground. It follows that rear flank downdrafts in severe storms do not cause mesocyclone intensification but respond to it; i.e., the two-cell vertical flow represents a fundamental change in mesocyclone dynamical properties (Brandes, 1983b).

Results of study of post-tornadic stages of the Harrah tornadic storm of 8 June 1974 are consistent with this theory. As shown in Figure 3, the rear downdraft was well developed and filled the eastern quadrant of the mesocyclone. Strong downward pressure gradient forces existed in regions of the mesocyclone penetrated by the downdraft. Maximum vertical vorticity at this stage was observed near ground level.

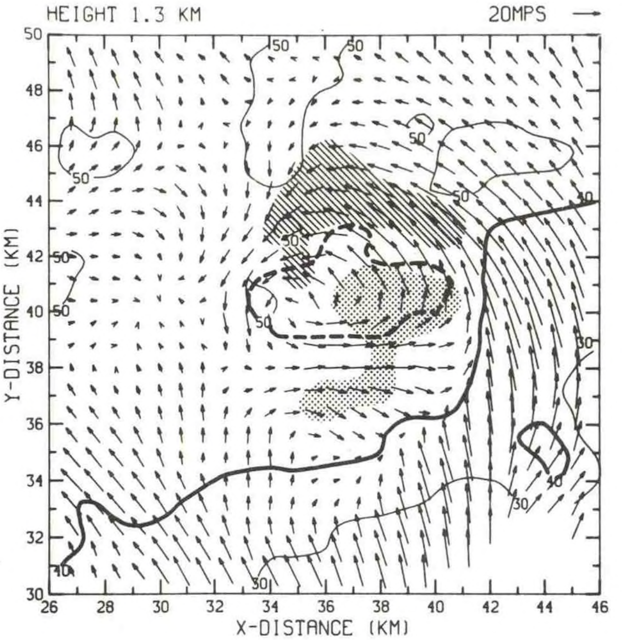
Related insights have been provided by dual-Doppler analyses of the major Binger tornadic storm of 22 May 1981. The mesocyclone is identified with a two-cell vertical circulation. A reflectivity minimum colocated with the mesocyclone developed at about 6 km and extended nearly to the storm top. A 3-D temperature retrieval model (Ziegler and Ray, 1982) has helped to explain the origins of the reflectivity minimum in the mesocyclone and interactions among the gust front cell, mesocyclone, and reflectivity minimum.

Doppler velocity spectra measured in the Binger tornado have provided important independent data on tornadic wind speeds. Ground-relative rotational velocities of up to 90 m s^{-1} have been resolved; these are slightly less than the estimates from damage surveys. We think that the Doppler radar underestimated the maximum velocity by 10% to 20% in this large tornado because of resolution limitations and other sampling considerations. Radar targets at low levels were centrifuged outward with velocities of 20 m s^{-1}.

During the 1983 NSSL Spring Program, members of the Tornado Intercept Project observed three tornadoes and provided photographic documentation of other features prominent in severe thunderstorms.

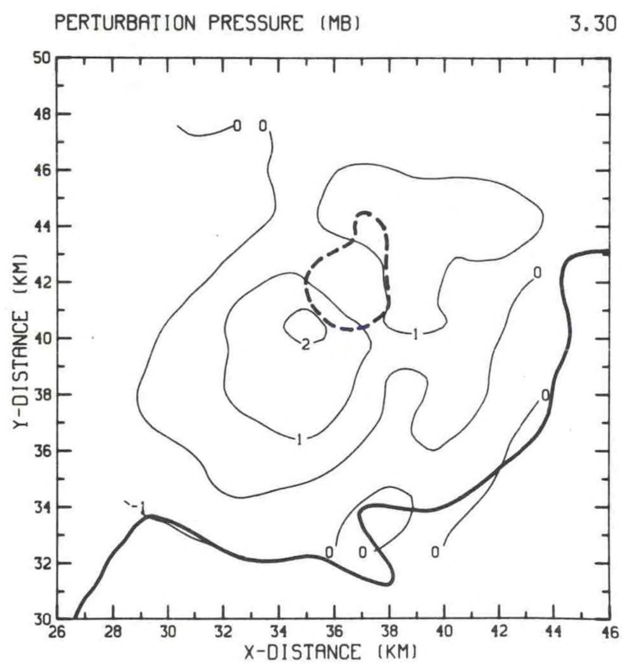
DOPPLER RADAR TECHNIQUE DEVELOPMENT

Doppler velocity spectra collected at vertical incidence contain information on vertical air motions and drop size distributions with high spatial and temporal

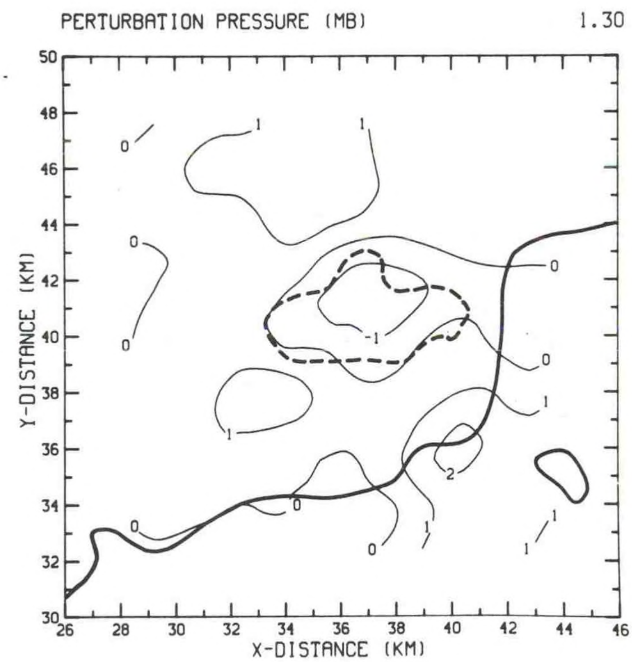


(a)

Figure 3a. Wind flow during dissipation stage of Harrah storm (1611 CST). Horizontal wind indicated by arrows; updrafts >4 m s^{-1} are hatched, and rear downdrafts <4 m s^{-1} are stippled. Solid contours are radar reflectivity in dBZ (40-dBZ contour accentuated). Heavy dashed line denotes mesocyclone.



(b)



(c)

Figure 3b,c. Retrieved perturbation pressure in millibars for dissipation stage of Harrah storm (1611 CST) at altitudes of 3.30 (left) and 1.30 km. Heavy solid line indicates 40-dBZ contour and heavy dashed line indicates mesocyclone. Note positive perturbation pressure at the higher altitude, which contributes to downdraft.

resolution. In the past, the computational interdependence between vertical air velocities and drop size distributions has severely limited the accuracy with which they could be estimated. A new dual-wavelength technique was applied by Sangren and Ray (1982, 1983) in which vertical air motion is determined independently of the drop size distribution. It was found that there is a trade-off between potential accuracy and potential for successful application. For example, the dual wavelength method is theoretically quite accurate but is extremely sensitive to poor data quality.

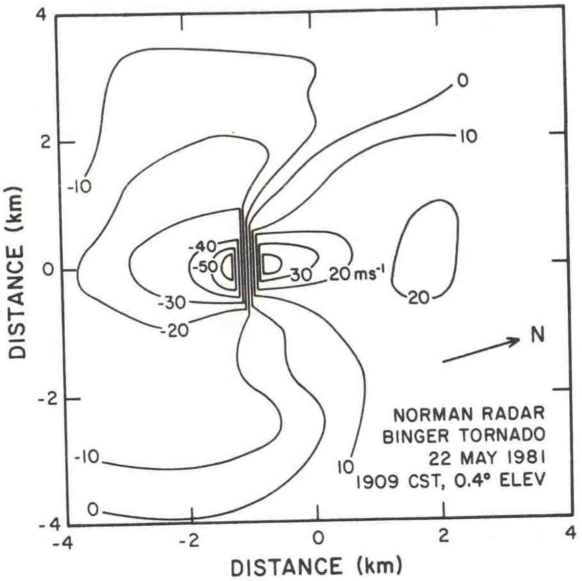
A proposal to bring the NOAA P-3 aircraft to Oklahoma was supported. We wanted to learn how to make effective use of this facility, particularly the airborne Doppler radar, while we obtained data useful to storm research and demonstrative of the capabilities of this sensing platform. During the first flight, data were collected on a hailstorm that produced 2-inch hail. The storm was in a good position for being viewed with NSSL's two Doppler radars on the ground, but accuracy of the analysis was considerably enhanced with the addition of the aircraft data. During the second flight, aircraft Doppler radar data were collected on a squall line approximately 600 km long. Most of the cells produced large hail and strong winds. On the third day, the airplane flew to collect data in conjunction with a single ground-based radar near the range limit of useful data. One storm was tornadic, and all storms on which data were collected were severe or soon became so. All data will be examined to see how well the various systems performed and how much can be done with the aircraft data alone.

Doppler radars in observing programs should be deployed for economy and best satisfaction of experimental objectives. Ray and Sangren (1983) examined possible networks of two to nine radars for two different error specifications in which the network was chosen that maximized the quantity (AREAL COVERAGE/ERROR). In all cases, the network considering all radars simultaneously was superior to that combining optimum smaller sub-networks. These results suggest expected benefits for networks with additional constraints, reflecting more complex experimental objectives particular to some individual field program. For example, the number of radars needed and their optimal configuration can be determined for a field program requiring a specified areal coverage (probability that a desired event will occur) and resolution (to retrieve a specified scale of motion).

The NEXRAD program envisions a network of Doppler radars over most of the United States. It is accordingly important to know how to interpret the patterns of radial velocity that will be depicted by these radars. To this end, an atlas of the signatures of various small-scale wind regimes as seen by single Doppler radar has been prepared at NSSL (Wood and Brown, 1983). Figure 4, taken from the atlas, illustrates a simulation of the Binger storm in single Doppler data.

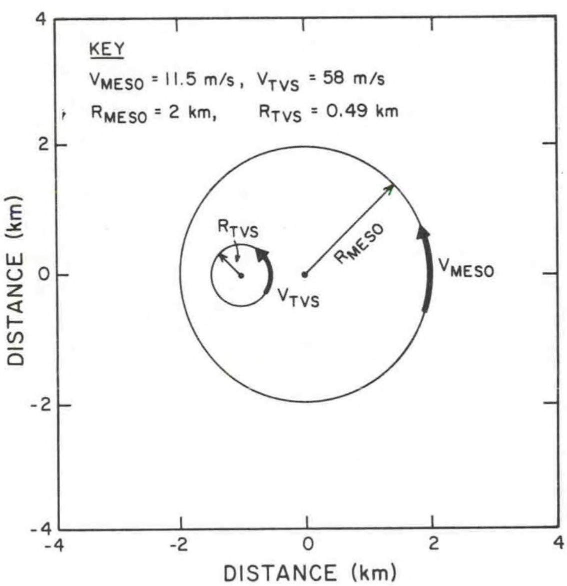
DATA PROCESSING AND ANALYSIS

Subjective interpretation of data from meteorological satellites has provided improved diagnoses of major weather systems and warnings of severe weather, but there is a substantial unrealized potential in objective analysis of satellite data. Radiance data provided by the most technologically advanced satellites present important opportunities because the data are descriptors of thermal distributions. Detail in thermal fields is enhanced by matching the shape of analyzed thermal gradients to the shape of satellite-observed radiance gradients, subject to coincidence of analyzed data with radiosonde observations at points. When



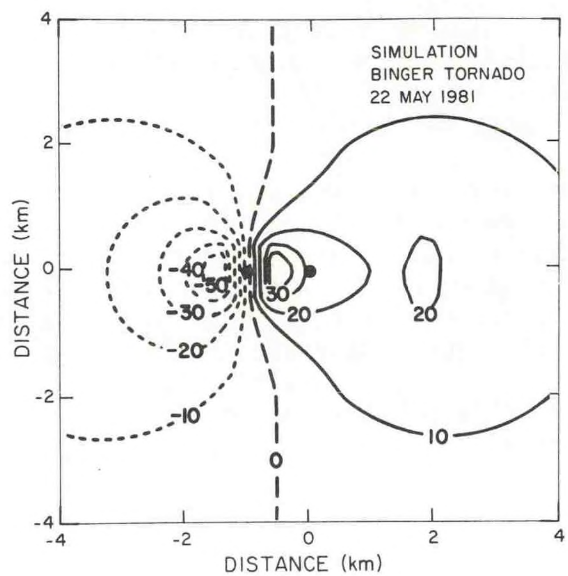
(a)

Figure 4a. Single Doppler velocity signature for the Binger, Okla. tornadic storm on 22 May 1981. The center of the mesocyclone signature is 70.8 km at azimuth 284 from the Norman Doppler radar; however, the signature has been rotated so the radar is beyond the bottom of the figure. Measured Doppler velocities (m s^{-1}) are positive for flow away from radar, negative for flow toward radar. [After Lemon et al., 1982]



(b)

Figure 4b. Mesocyclone and tornadic vortex signature (TVS) parameters for simulating the single Doppler velocity measurements in Fig. 4a.



(c)

Figure 4c. Simulation of single Doppler TVS--mesocyclone signature as in Fig. 4a. Positive (negative) values of single Doppler velocities (m s^{-1}) are represented by solid (short-dashed) contours. Contour increment of 10 m s^{-1} begins at zero Doppler velocity (long dashed contour). Dark dots indicate the centers of the mesocyclone signature and TVS.

fields so analyzed were tested with a quasi-geostrophic numerical model, upward motion defined by the model correlated 35%-100% better with cloud locations when satellite and rawinsonde data had been combined, than when rawinsonde data alone had been used. Additional development of the method at NSSL leads to objective analysis of temperature through the whole atmosphere, given radiance distributions in four to six wavelength channels.

Statistical analyses of severe storm parameters have been prepared from NSSL mesonetwork data. The data indicate that surface parameters associated with severe storms and squall lines are statistically nonstationary and nonhomogeneous. The greatest variance in most squall line parameters occurs ahead of the line while the greatest variance identified with isolated storms is beneath those storms. Time-space correlation analyses indicate that pressure decorrelates least of all fields, and winds decorrelate fastest in both time and space. The wind field correlations also exhibit the greatest anisotropy in both isolated storm and squall line cases, with major axes oriented NE-SW. During the course of this study, all NSSL mesonetwork data associated with storm events occurring within the network during the years 1973 through 1979 were archived in universal format and documented (Kelleher, 1983).

A large portion of the analysis of the 19 May 1977 squall line was completed (Kessinger et al., 1983). Data sources include networks of rawinsondes and surface sites, aircraft, and Doppler and surveillance radars. A new technique for multiple Doppler analysis was used (overdetermined dual Doppler analysis) with results shown to be improved over a "conventional" triple Doppler analysis on this data set. Internal wind fields were analyzed over a 180 x 60 km area throughout the vertical extent of the squall line including three convective cells near the leading edge of the line and a large stratiform area of precipitation toward the rear. These wind fields were compared with the structure of other extratropical and tropical squall lines and with results of a numerical simulation.

Dual Doppler analyses of the 2 May 1979 tornadic storms are essentially complete. We are seeking to explain the vorticity pulsations that occurred in the Lahoma mesocyclone about every 15 minutes.

MISCELLANEOUS

A heat burst, or warm wake event, occurred over most of central Oklahoma on the night of 29 May 1976. Though it is well known that heat bursts are typically associated with nearby convective storms and strong winds aloft, the mechanism causing the heat burst phenomenon is not well understood. Our study includes a historical overview of similar heat burst events (Johnson, 1983).

An axisymmetric cloud model was used to simulate a thunderstorm that occurred in southern Florida during the 1978 TRIP (Thunderstorm Research International Program) experiment (Bothwell et al., 1982). Comparison of the simulated storm with radial velocity data from a Doppler radar showed qualitative agreement with respect to storm duration, growth rates, velocity structure, and pattern of evolution.

Documentation was completed on an accurate theoretical approximation for adiabatic condensation temperature (Davies-Jones, 1983). The approximate solution lies within 0.01 K of the corresponding iterative solution for dewpoint depressions up to 40 K and represents a refinement in data processing accuracy.

A cooperative effort with the University of Oklahoma College of Environmental Design has identified procedures for making houses more wind resistant (Conner et al., 1983). Wall-to-roof connections of many houses will not withstand the wind forces generated by even weak to moderate tornadoes (over 90% of the total number of tornadoes) and the wind forces generated by violent straight-line windstorms and hurricanes. Houses can be inexpensively retrofitted with improved wall-to-roof connections that will withstand all wind storms except violent tornadoes and rare hurricanes (storms with windspeeds greater than 160 mph).

With NSSL support, a station of the National Air Deposition Program was established near Criner, Okla., on 28 March 1983. Rainwater samples are collected weekly and analyzed for pH and conductivity at NSSL; dry dustfall samples are collected at intervals of eight weeks (Fig. 5). All samples are shipped for detailed analyses to the Central Analytical Laboratory at the Illinois State Water Survey.

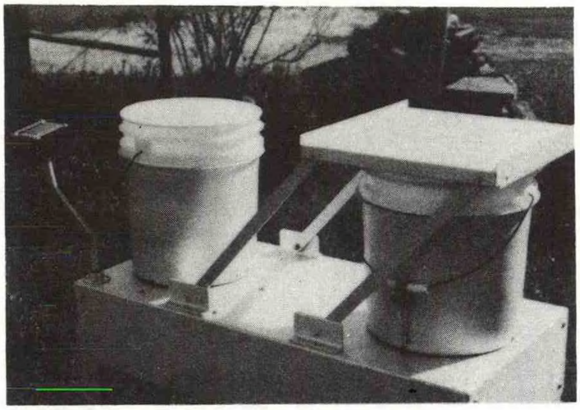


Figure 5. Sampling buckets for wet and dry deposition at the NSSL-operated station of the National Air Deposition Program.

A considerable number of NSSL staff and student affiliates are engaged in developing a capability for on-site use of the Anthes-Warner (Penn State) mesoscale numerical model for general research purposes, including tests of model initialization with satellite data as discussed above. Mesoscale modeling is perceived as an area that will become increasingly fruitful with matched advances in capabilities for acquiring and processing high resolution data.

A three-volume documentary on thunderstorms edited by E. Kessler was published by the U.S. Government Printing Office in 1981 and 1982. Arrangements have been completed for issuance of second editions, typeset in hard cover, by the Oklahoma University Press. Volume 1 is to be available in December 1983, and the two subsequent volumes will be published at intervals of about one year. Two new chapters are planned, and several others are to be substantially expanded.

EXPECTATIONS FOR FY-1984

Results of studies on kinematical structures for hail growth will be used to develop and test single Doppler algorithms for distinguishing between major and minor hailstorms.

Predicted air bubble and crystalline structure of modeled hailstones will be compared with samples collected at the ground. The field phase of a cooperative project to use in situ measurements, surface hail collections, multi-Doppler radar, and numerical models is planned for Spring 1984. A major feature of the study is to initialize a model and check model results with actual in-cloud and surface-collected hailstones.

A diagnostic model will be completed; it treats the dynamics involved in vortex formation by using velocity and thermodynamic fields from both observational and numerical modeling studies as input data.

Documentation will be completed on observational and modeling studies of the 19 May 1977 squall line and on dynamic retrieval experiments for the 20 May 1977 tornadic storm case.

Theoretical and observational investigations into the formation of mesocyclones will continue. A technique for predicting mesocyclones, given a sounding and observed storm motion, will be evaluated.

Documentation will be completed covering research on severe storm objective analysis, experimental design, and the 20 May 1977 case study.

Documentation of a microphysical and thermodynamic retrievel model will be completed. The model will be applied to storm data for case studies of 27 May 1979, 28 May 1977, 22 May 1981, and 7 August 1979 (Socorro, New Mexico) and integrated with other data for these days.

Refinement of techniques for real-time identification of severe storms through single Doppler velocity signature recognition will continue.

DOPPLER RADAR AND STORM ELECTRICITY RESEARCH (DRASER)

Richard J. Doviak, Group Leader

The NSSL facility to observe electrical and kinematical processes contemporaneously with precipitation phenomena has no parallel. Employing this facility, DRASER deals with many complex aspects of storm kinematics, precipitation, and electricity. Major objectives include (1) determining relationships between processes of lightning discharge, thermodynamics, and precipitation in thunderstorms, in order to develop improved indicators of thunderstorm severity and hazards, (2) developing and refining remote-sensing techniques for locating, tracking, and predicting thunderstorms, (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 instrumentation and refinement of observational techniques.

These objectives are addressed through both observational and theoretical studies. Simultaneous observations of various storm parameters and cooperative efforts in the analysis and interpretation of storm data are combined in a unique research effort on severe thunderstorms.

The Doppler Radar Group focuses its efforts on interpretation of atmospheric phenomena using Doppler radar both for prestorm and stormy weather. The group responds to FAA and NEXRAD needs in developing techniques for identification and display of storm hazards. In FY 1983, the Storm Electricity Group has concentrated its analyses on data, simultaneously obtained from our many storm electricity sensors, such as ELF (extremely low frequency) radio waveforms from lightning, electric field changes, TV video and photographic images of lightning and clouds, VHF (very high frequency) lightning maps, lightning ground strike locations, Doppler spectra from a vertically looking radar, balloon-borne electric field and rawinsonde measurements, and data from various sensors onboard the University of Mississippi (UM)/NSSL mobile laboratory and the NASA U2 aircraft.

RECENT ACCOMPLISHMENTS

DOPPLER RADAR

Wind Profiling - Theoretical Studies: A unifying theory that incorporates the characteristics of atmospheric turbulence has been formulated to explain the anisotropic scattering properties of clear air observed with VHF Doppler radar wind profilers (Doviak and Zrnic', 1983a). Strongly anisotropic scatter can degrade wind profiler performance. In this theory an integral expression for scatter is developed. It shows that echo intensity depends not only on a weighting function for resolution volume, but also on a more important Fresnel term. An example of the theoretically derived angular dependence on echo power (Doviak and Zrnic', 1983b, Fig. 6) shows that the theory can explain the observations. The developed theory embraces several echoing mechanisms used to explain observations and extends the existing formulations for the case where the Fresnel zone radius is comparable with or smaller than the correlation length. Conditions are specified under which Fraunhofer and Fresnel scatter from turbulent air can be

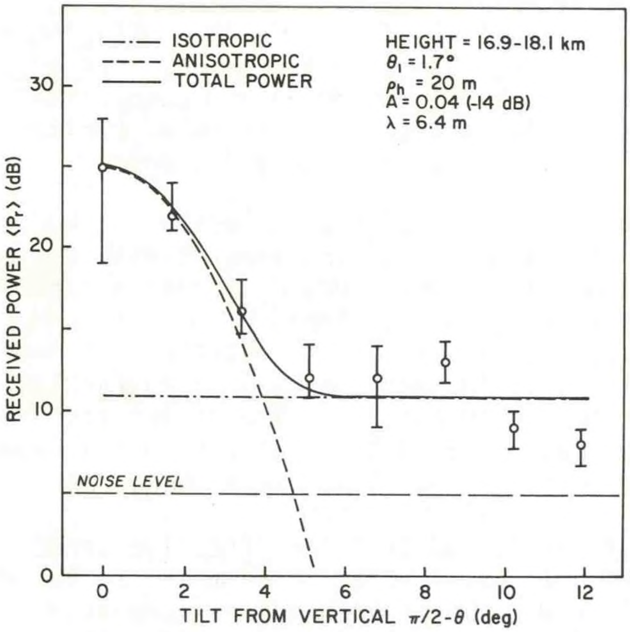


Figure 6. Observed anagular dependence of mean backscatter power (open circles and bars) as radar beam axis is tilted away from the vertical (from J. Rottger, 1981: Investigations of lower and middle atmosphere dynamics with spaced antenna drift radars. J. Atmos. Terr. Phys., 43, 277-292). Fitted to the data is a model that consists of anistropic turbulence with a three-dimensional (but horizontally isotropic) correlation function in an isotropic background.

distinguished. Furthermore, it is demorstrated that the spectral sampling function is independent of the resolution volume location.

Three techniques used to retrieve the three wind components simultaneously from measurements of radial velocity made with single Doppler radar employ triple fixed beams, an azimuthally scanning beam (VAD), and an elevation scanning beam (VED). We have examined errors in the retrieved wind field components when each of these techniques is applied, and equations have been derived for the bias and variance of the uniform wind estimates under assumptions of spatial linearity, time invariance and a specified radial velocity variance (Koscielny and Doviak, 1983a,b). A sample result (Fig. 7) shows that the estimation efficiency, inversely proportional to the number of measurements required to achieve a prescribed error, is a maximum near elevation angle θ_e = 55° for each of the three sampling strategies.

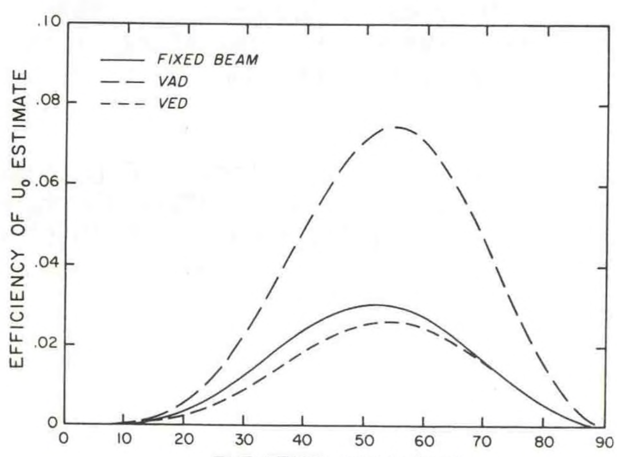


Figure 7. Estimation efficiency for a horizontal wind component U_0 retrieved from single Doppler radial velocity measurements using three scanning strategies. The wind at a height of 5 km is estimated.

Because echo intensity decreases with increasing range (and hence decreasing θ_e) and horizontal wind estimate variance increases when the horizontal wind projects smaller values along the beam (i.e., at larger θ_e), we find a maximum efficiency at a $\theta_e \simeq 55°$. Although estimate variance can be reduced by averaging, bias errors cannot. Furthermore, selection of an elevation angle can require a compromise based on the desired accuracy of the measurement because bias errors of horizontal wind decrease as θ_e decreases whereas for vertical wind they increase.

Wind Profiling Experiments: An experiment was designed to verify the hypothesis that UHF Doppler weather radars with 10 dB edge over the present NSSL system should be capable of measuring winds to about 12 km when eddy dissipation rates exceed 10^{-3} m^2 s^{-3}. NSSL's Engineering Support group developed a data recorder interface to be attached to NASA's ultra-sensitive UHF radars (which do not have Doppler processors) at Wallops Island, Virginia, to record analog video for later playback through NSSL's Doppler processor and color display. The system has been successfully tested, and coherent and continuous echoes to about 7 km height were observed from the clear air on the one day during which tests were conducted.

A related experiment with NSSL's radar indicated that the effective structure constant in prestorm midday convection has values near 10^{-13} $m^{-2/3}$ at 0.5 km and decreases to about 10^{-14} $m^{-2/3}$ at 2.5 km AGL above which echoes were not detected. The height dependence of measured reflectivity was compared with theoretical predictions based on insect densities measured elsewhere by other investigators. The comparison showed remarkable agreement in the decrease of reflectivity with height (Rabin, 1983a).

Storm Initiation: Analysis of Doppler radar and rawinsonde data has revealed some interesting aspects to the evolution of boundary layer winds and stability just prior to the development of tornadic thunderstorms. In contrast to another case previously studied, widespread vertical motion was not the cause of destabilization observed just prior to thunderstorm formation on 17 May 1981 (Rabin, 1983b). In fact, VAD analysis of Doppler radar data reveals mesoscale subsidence up to within a half-hour of subsequent storm development. Satellite photos show a corresponding dissipation of widespread cumulus east of the dry line during this period.

A computer program was developed to evaluate the stability of air parcels lifted from the lower atmosphere with initial conditions defined by rawinsonde data. This has been used to determine how much forcing (convergence) would be required to initiate deep convection. The analysis suggests that the first air to become freely buoyant originated from about 1.5 km above the ground, rather than from the surface. The destabilization of this layer was a result of rapid vertical mixing of heat and moisture, which occurred within one hour of storm formation near the dry line zone.

An example of horizontal divergence in the boundary layer using dual Doppler analysis is given in Figure 8. The data were obtained 15 minutes before the formation of two severe thunderstorms (located by circles on the figure). Both storms developed near clusters of the strongest cells of convergence that were intensifying at this time.

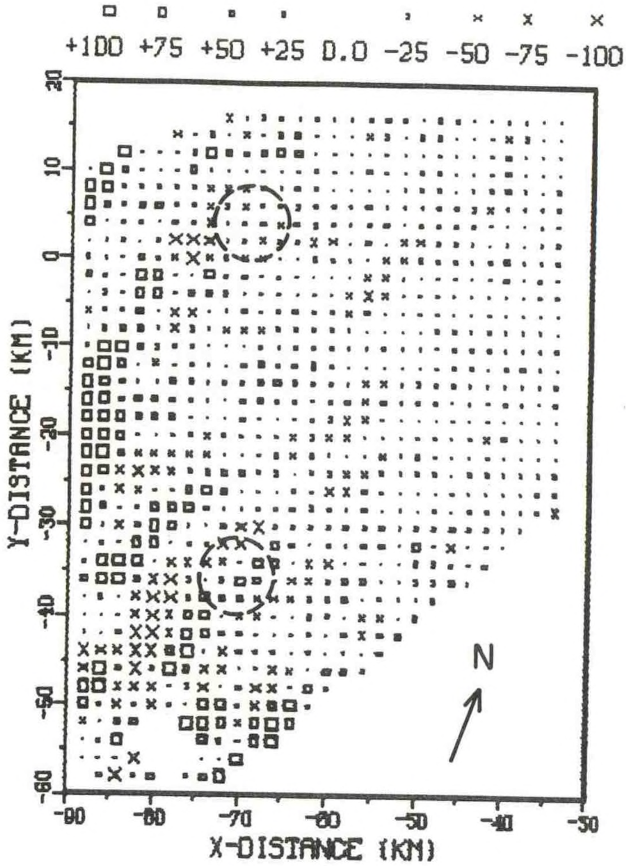


Figure 8. Divergence in units of $10^{-5}\ s^{-1}$ (note code at top of figure) at height 0.75 km, 1431 CST on 17 May 1981. Data was from two radars about 15 minutes before thunderstorm (circles) formation. Distances are from the Norman Doppler radar.

Boundary Layer Studies: The time continuity of Doppler radar measurements of prestorm divergence was investigated (Rabin, 1983). Theory predicts well the uncertainty ($\sim 10^{-5}\ s^{-1}$) in divergence at ranges greater than 30 km. At nearer ranges, ground clutter greatly decreases the coherence of divergence measurements.

Refinements to the single-Doppler linear wind algorithm have improved the accuracy of divergence estimates. The divergence fields mapped using single Doppler radar sets collected 3 minutes apart show high correlation. A graphic method was used to check the linearity of radial velocity field, an assumption for Velocity-Volume processing (VVP).

The project was modestly involved in cooperative field experiments with the boundary layer group from the University of Wisconsin and with the radiometer group of the Wave Propagation Laboratory (WPL). Clear-air radar reflectivity and velocity data were collected on several days in conjunction with measurement of refractive index using an airborne refractometer (NCAR), sensible and latent heat fluxes using a sodar and fast response in situ instruments (NCAR and Argonne National Lab.), boundary layer height using a lidar (University of Wisconsin) and total precipitable water using a radiometer (WPL).

A multivariate data-editing technique to retrieve radial velocities in the presence of ground clutter, anomalous targets, and noise has been studied and appears to give good results. This editing technique and a uniform wind analysis have been applied to data for a low-level jet on April 11, 1983 with excellent early results.

Reflectivity and/or velocity perturbations provide tracers of larger scale motion. A method for estimating these large scale wind fields for a clear-air boundary layer case has been examined, and results are encouraging (Smythe and Zrnic', 1983). Lifetimes of perturbations in the velocity field are shown to be longer than those in the reflectivity field.

Airborne Lidar and Doppler Radar Intercomparison: Airborne lidar can greatly enlarge the area over which wind observations can be made. As part of an interagency effort to develop such a capability, clear-air boundary layer wind data were collected on 29 June 1981 by NASA's airborne Doppler lidar, NSSL's two Doppler radars, an instrumented tower, and a rawinsonde (Fig. 9). Vertical profiles of horizontal wind speed and direction measured by the two remote-sensing systems were constructed by interpolating data to common grid volumes at different heights throughout the boundary layer. All the vertical profiles agreed well with each other after the lidar data were corrected for a Schuler oscillation in the inertial navigation system aboard the aircraft.

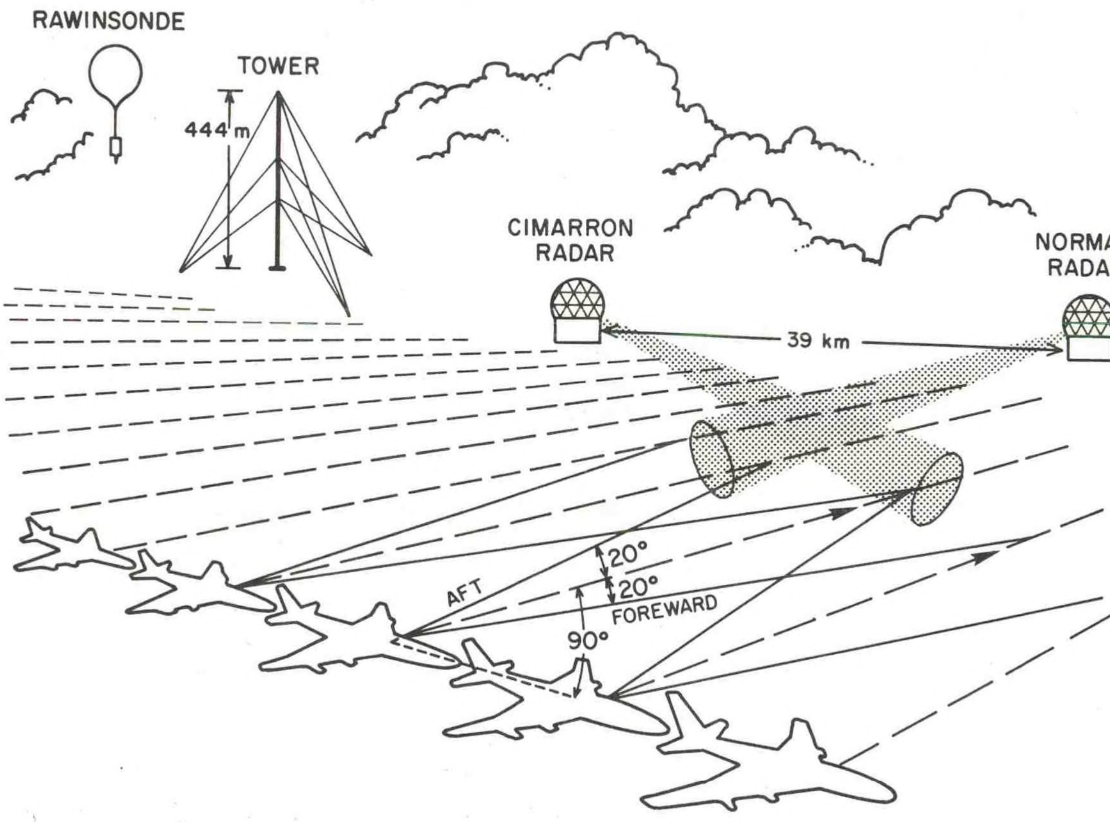


Figure 9. The NASA/NSSL Doppler lidar/radar wind measurement system used to observe the kinematic structure of the convective boundary layer.

Velocity variance spectra of the north and east components of the wind field were computed from the lidar and radar data (Eilts, 1983). To compare results from the lidar and radar, spectra were calculated from velocity data interpolated to common grid points, 500 m apart and situated along lines parallel to the flight path. Wavelengths between 1 and 16 km were resolvable. Averaged spectra (averages of spectra along six lines 500 m apart) from lidar and radar compared well; peaks in both spectra were near the 4 km wavelength predicted by theory.

STORM ELECTRICITY

Positive Cloud to Ground Lightning: Flashes that lower positive charge to ground, as opposed to the more frequent flashes lowering negative charge, are receiving increasing attention both in the applications and research communities because of their apparent hazard both at the ground and in the air (Rust et al., 1982; MacGorman et al., 1982). It appears that a high percentage of these positive flashes (+CG) have continuing current, i.e., sustained current flow of several hundred amperes for tenths of seconds. The +CG flashes were confirmed to be downward propagating and therefore are initiated from within the cloud and not simply triggered by tall structures as is often assumed.

The characteristics of over a hundred ELF waveforms were analyzed to determine the efficacy of this system to detect +CG flashes, and verification was made by comparing results obtained from electric field mills, a 4-station lightning strike locator, VHF mapper, and 35 mm photographic data. Theoretical studies are being made to relate channel characteristics to the transient wave forms of the electromagnetic radiation fields (Liaw and Rust, 1982). Analyses continue to correlate +CG flash occurrence with storm severity and evolution (Rust et al., 1983).

We have observed this year for the first time a few isolated storm cases in which almost all ground flashes lowered positive charge. Figure 10 shows, for example, the cloud-to-ground lightning on a day in which there was an isolated severe storm to the southeast producing the normal predominantly negative CG flashes, a squall line to the northwest with a mixture of positive and negative CG flashes, and an isolated storm (which had moved to the southern end of the squall line) with predominantly positive CG flashes. By studying the different storms on this day, we can better understand the conditions under which positive CG flashes occur.

Storm Structure and Lightning Discharge Locations: Two and a half hours of single Doppler radar and lightning ground strike data from a tornadic storm were examined (MacGorman et al., 1983). The number of strokes per flash increased significantly after the tornadic stage of the storm ended. Within 10 km of the mesocyclone center, ground flash rates were lower both before and during tornadoes and increased after the tornadic stage. An inverse relationship was also found between trends in lightning ground strike rates and mesocyclone strength as measured by cyclonic shear.

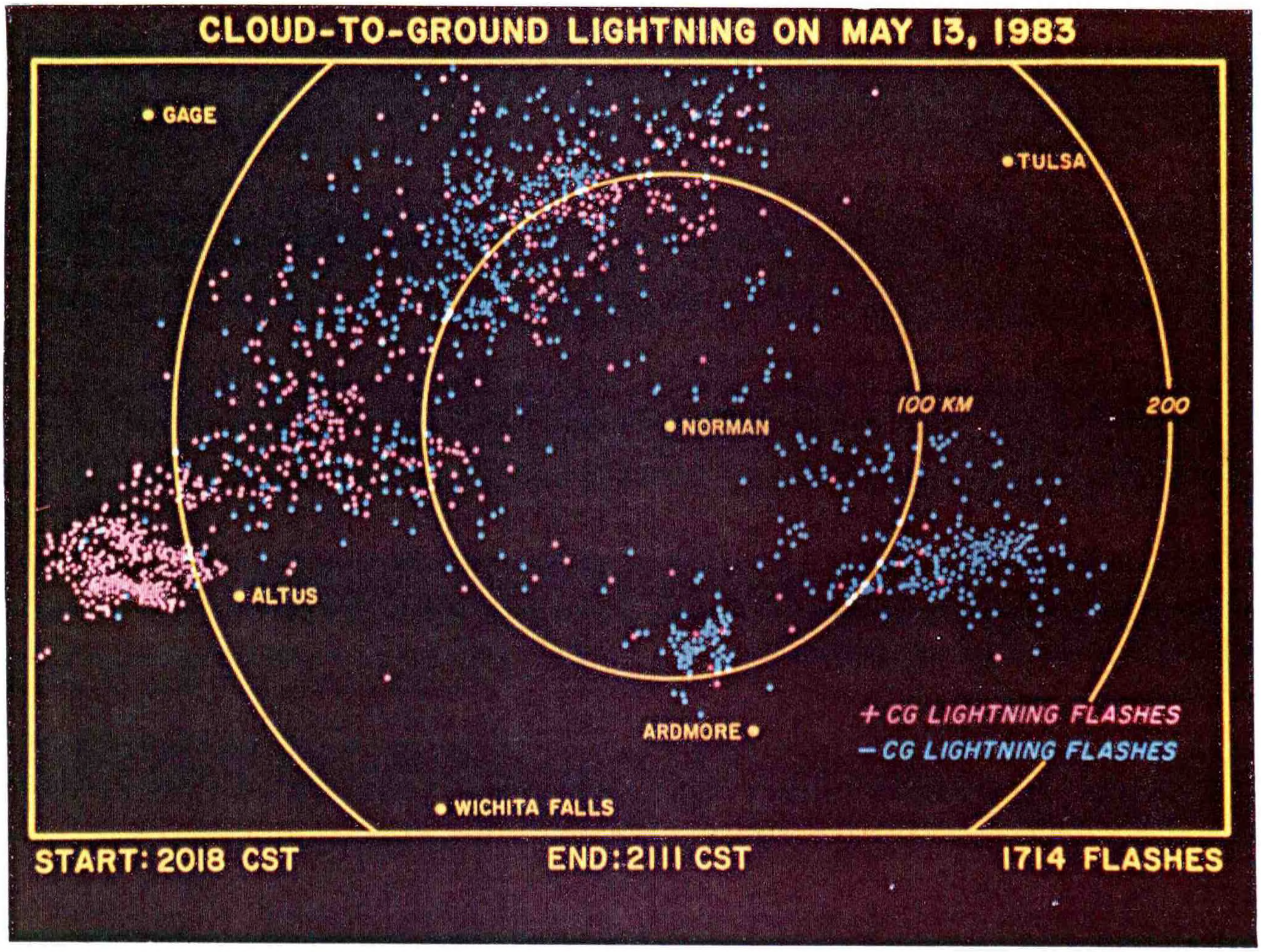


Figure 10. The spatial distribution, during a 53-minute period, of cloud-to-ground strikes for flashes that lowered positive (red dots) and negative (blue dots) charge.

The association of mapped lightning locations, determined from the VHF mapping system, with the precipitation and winds of severe storms, synthesized from Doppler radar data, has been difficult but is starting to reveal new insights (Taylor et al., 1983). A representative example of lightning and storm structure relationships on one day is shown in Figure 11. In Figure 11a, the VHF source locations from all major lighting flashes are superposed onto reflectivity contours and streamlines of horizontal winds. A major flash usually occurs in the lower half of the storm and contains more than 30 mapped sources (each source is an element along a lightning channel that generates a VHF burst). It is clear that the VHF sources are concentrated in the high reflectivity regions of this storm.

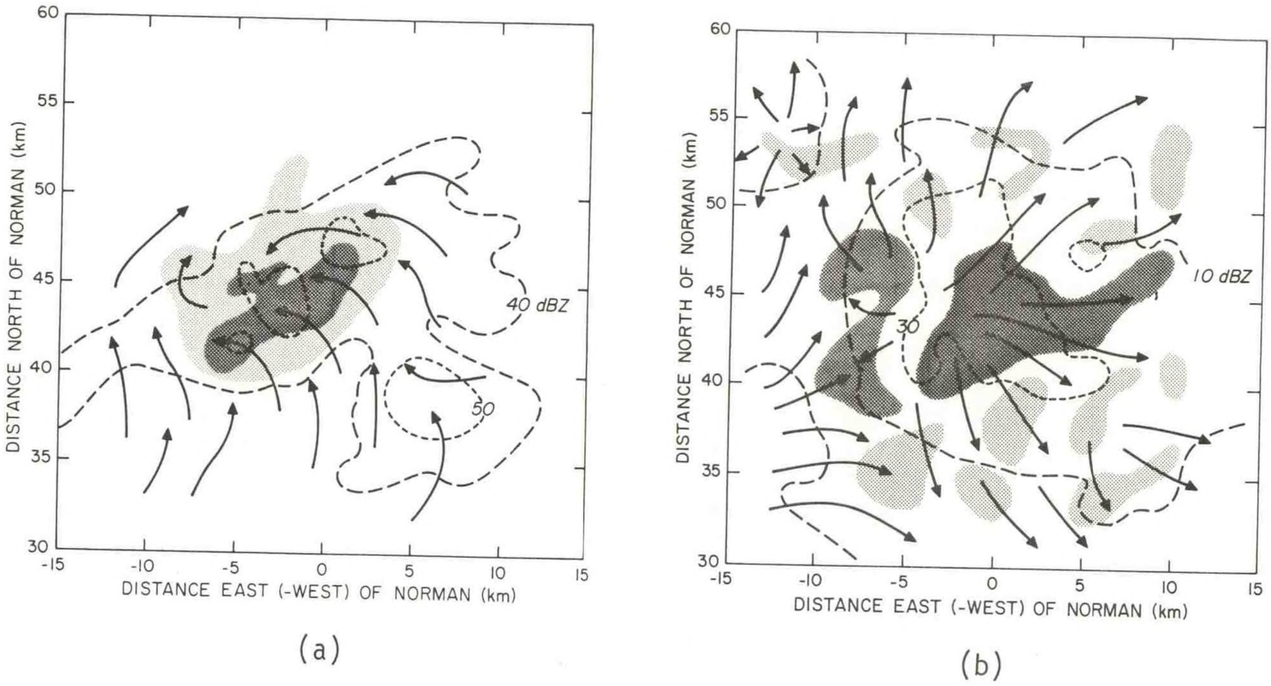


Figure 11. Plan view of VHF source (shaded areas) locations, radar reflectivity (dashed contours), and Doppler-derived wind streamlines, for flow relative to storm #1 on 19 June 1980. The total shaded area contains 80% of all mapped sources; 50% are within the darker shading. The radar scan time was 2222-2227 CST, and the lightning occurred between 2219-2227. (a) The locations of sources along major flashes at all altitudes are plotted, but the 40-dBZ and 50-dBZ radar reflectivity contours and Doppler-derived horizontal wind streamlines are at 5-km altitude. (b) The locations of sources along minor flashes at all altitudes are plotted, but the 10-dBZ and 30-dBZ radar reflectivity contours and horizontal wind streamlines are at 13-km altitude.

The VHF source locations for all minor flashes are superposed onto reflectivity contours and streamlines of horizontal winds in Figure 11b. Although each minor flash is generally localized in a relatively small region in the upper half of the storm, the distribution of VHF sources from all minor flashes is very patchy and covers a much larger area than the distribution of sources from the major flashes.

We reached these conclusions from our study of the storms on 19 June 1980: 1) The locations of VHF sources indicate that lightning activity tends to concentrate in high reflectivity regions, in the lower part of a storm, and in divergent horizontal winds in the upper part of a storm. 2) There is a class of small (minor) flashes that produces a few pockets of VHF sources to an altitude of at least 16 km in a large canopy over the main lightning producing region. 3) These minor flashes produce continual lightning activity centered at 11-13 km altitude and have no apparent temporal association with the large (major) flashes sporadically occurring in the lower portions of storms. 4) Major flashes are within or near high-reflectivity regions, centered at 4-6 km altitude, and seldom extend above 10 km altitude.

The NASA Wallops Island 70 cm and 10 cm wavelength radars have been used simultaneously to sense lightning channels and precipitation in our continuing research to determine whether reliable relationships exist between storm structure and lightning echo properties (Mazur et al., 1983). A theoretical study to estimate the lightning channel radar cross section has been completed (Mazur and Doviak, 1983). The radar cross section of a lightning element is modeled as a finite length plasma cylinder at an oblique angle of incidence. The model is based on an exact solution of Maxwell's equations for a dielectric cylinder of infinite length, and assumptions are made about reflection and transmission at joints between neighboring lightning elements.

Interaction Between Electric Fields and Precipitation: Doppler velocity spectra, reflectivity, and electric field changes are being analyzed for 75 lightning flashes that propagated through the beam of the vertically looking Norman Doppler radar. In addition to continuing earlier work on the use of lightning as a tracer of updraft velocity, we are also searching the data for possible interaction between the lightning and precipitation within the radar beam. We have already documented changes in the Doppler spectra at higher altitudes at the time of flash occurrence.

The presence of a lightning channel within the radar resolution volume provides a better estimate there of average vertical air motion $\bar{w}$ within a resolution volume when the channel echo spectrum is resolved within the Doppler spectrum of precipitation. If $\bar{w}$ is better estimated, the drop size distribution N(D) can be more accurately obtained from the Doppler spectrum. An example of N(D) for hail is plotted on Figure 12. The speed of the updraft was estimated to be 11 m s^{-1}, and a terminal velocity for spherical hail was assumed to follow a theoretical relation. An estimate of spectral spreading due to turbulence is also needed to estimate N(D). This spread was estimated from the positions of the lightning peak in several consecutive spectra. Drop size spectra were derived from Doppler

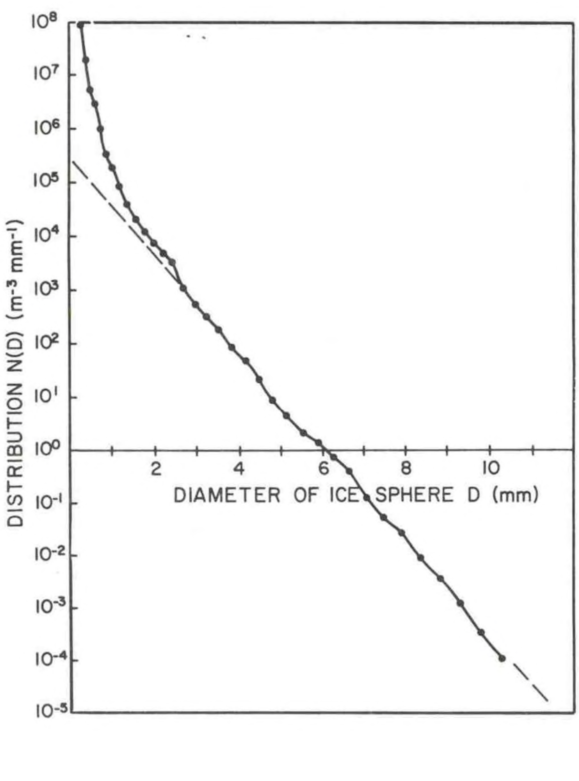


Figure 12. Size distribution of ice spheres obtained from the Doppler spectrum of a vertically pointed radar.

spectra for spectral coefficients having power density larger than a threshold set 30 dB below the spectrum peak. Evident in the figure is the tremendous (10^{13}) span of the N(D) and a remarkably good fit to an exponential model for sizes larger than 1 mm. With these sizes the calculated equivalent reflectivity factor is 55.5-dBZ whereas we have measured 55-dBZ. In this particular experiment the resolution volume was about 10^8 m^3, and even though we conclude from Figure 12 that the probable number of hailstones between 9.5 and 10.5 mm is 10^{-4} per m^3, there are on the average 10^4 such stones in the resolution volume.

Electric Fields: In cooperation with a NOAA Postdoctoral Fellow from the University of Mississippi, we installed instruments in a trailer for reception of data from balloon-borne electric field meters. Analysis of a sounding made through the downshear anvil of a severe storm shows electric fields of about 100,000 V/m at distances 60 km and more from the 50-dBZ precipitation core of the storm. This is 100 times larger than fields previously measured in anvils of smaller storms elsewhere and is comparable with most values previously found within and near precipitation cores. These initial results raise intriguing questions regarding the formation and distribution of charge, and the production of lightning in severe storm anvils, and about hazards to aircraft.

Equipment Improvements: The NSSL system for locating lightning ground strikes has been improved to provide more convenient and reliable operation of the central processor and to display data in real time. In addition, work has begun to develop software to reduce the ground strike data so that they can be used in case studies.

Circuit design was completed for new logic units with full hemisphere coverage to replace the "sector-limited" units in the VHF lightning-mapping system. When these new units are fabricated and installed, each site will be capable of mapping lightning signal sources to 0.5° accuracy throughout the full hemisphere at rates of 64,000 per second (four times the present rate). The new system will provide three-dimensional locations of VHF sources along lightning channels occurring within a nominal range of 80 km. That expands the coverage greatly, and will improve quality of VHF mapping data while requiring less operator interaction.

Experiment for Mapping Lightning from a Satellite: With the University of Mississippi/NSSL mobile laboratory, we intercepted a large, isolated storm in southeastern Oklahoma and tracked it from the ground as the NASA U2 aircraft, instrumented for storm electricity measurements, made 10 flight passes over the top of the storm. Data acquired include radar reflectivity and Doppler velocity, optical spectra obtained with an airborne spectrometer looking downward, electric field changes, and optical data for mapping the space and time evolution of lightning as seen by TV cameras from above and below the cloud. At the same time, we acquired continuous data on cloud-to-ground (CG) flashes at NSSL, using our CG strike-locating system and our ELF receivers located at NSSL and Huntsville, Alabama (NASA/MSFC). We have data on about 500 flashes that were observed simultaneously from the ground and above the storm. This unique data set will help provide information needed in the design of a satellite lightning mapper for use in the detection and study of severe storms.

NEXRAD AND AVIATION-RELATED RESEARCH

Squall Lines and Gust Fronts: As part of NSSL's support to NEXRAD development, some characteristics of low altitude weather features that may be hazardous in aircraft terminal areas have been examined (Mahapatra et al., 1983). We have studied gust fronts associated with strong squalls in Oklahoma, and downdrafts behind these fronts. We have found that peak reflectivity of the gust fronts (outside of precipitation) are between 2 and 11 dBZ. A detailed analysis of one "solitary gust" demonstrates that refractive index fluctuations can account for a good portion of observed reflectivity profiles.

In a cooperative experiment with the FAA, data were obtained from recording the output of a Low Level Wind Shear Alert System at Will Rogers Airport on several storm outflows. Simultaneously, data were collected by a network of surface-based meteorological instruments, by an array of these on a 444-m-tall tower, and by Doppler radar.

Half a dozen downdrafts of different sizes and with reflectivities up to 60-dBZ were present simultaneously behind a gust front of a strong squall line (Fig. 13). The strong shears along and behind the front are produced by the constantly evolving and interacting cells that generate short-lived up/downdrafts. Maximum radial shear of $2 \cdot 10^{-2}\ s^{-1}$ was produced by the small downdraft (near the cursor), and it was measured with the beam center 800 m above ground. Maximum azimuthal shear of $4.7 \cdot 10^{-2}\ s^{-1}$ was detected in the gust front (30 km, 290°). At several locations behind the front we have measured radial shears of $1 \times 10^{-2}\ s^{-1}$. Although the maximum difference of outflow velocities produced by these downdraft depends little on the downdraft size, the maximum measured shear is associated with the smallest downdraft (Zrnic' et al., 1983)!

A mesocyclone-like signature develops at low altitudes along the advancing gust front, indicating the evolution of a whirlwind near the surface (Fig. 14). The circulation may produce a large decrease in headwind component of an aircraft and presents a hazard that has not been researched thoroughly (Zrnic' et al., 1983).

A study of solitary waves, in collaboration with a scientist from the People's Republic of China, is using observations from NSSL's instrumented tall tower, Doppler radar, and surface based instruments. Solitary waves that may persist many hours, even after the originating thunderstorm has dissipated, have recently been implicated in numerous incidents of dangerous shear, encountered by aircraft on their approach to and departure from airports.

<u>Turbulence</u>: Doppler measurements are characterizing turbulence hazardous to aircraft (Lee, 1983). The NASA B-57 aircraft and Gust Gradient Program personnel from Marshall and Arnold Space Flight Centers participated in a DRASER program coordinated by J.T. Lee to obtain data on turbulence and gusts in the vicinity of large organized storms during five flights.

Turbulent kinetic energy and energy dissipation rates were calculated for several volume scans of the 17 May 1981 storm. We found that the energy density of turbulence is about constant but the total energy increases as the storm grows. The locations of the maxima of energy density (deduced from spatial spectra of mean Doppler velocity) coincided with maxima in eddy dissipation rates (calculated from Doppler spectra width data). This suggests that the large-scale turbulent eddies fragment into scales small compared with the radar's resolution volume and fragmentation continues until the energy of microscale turbulence is transformed into heat in accordance with predictions by Kolmogorov.

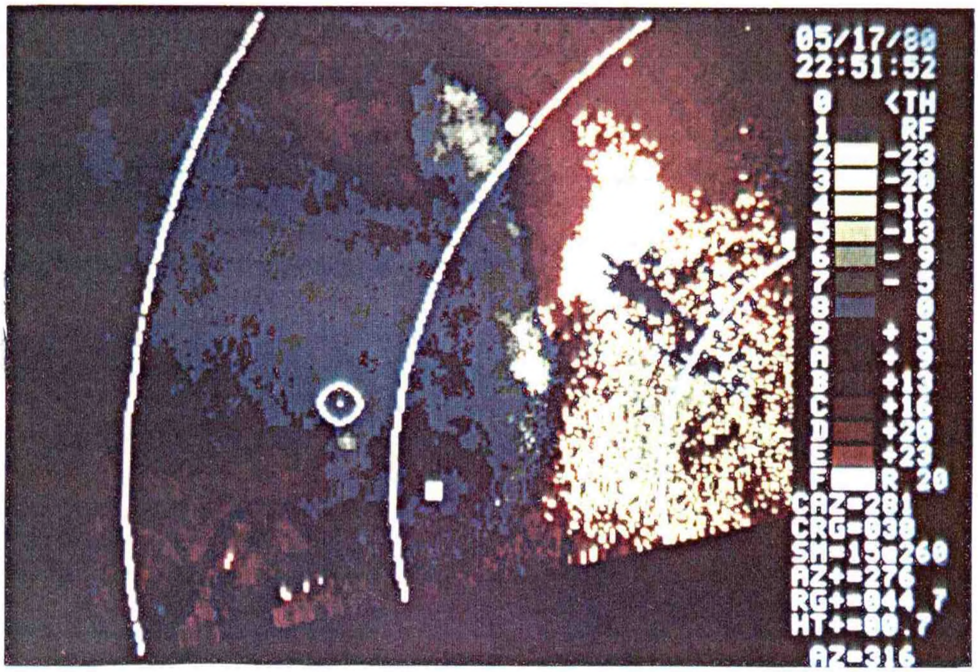


Figure 13. Doppler velocity fields in a thunderstorm with a gust front. The radar antenna is elevated 0.9°. Range marks are at intervals of 20 km. Peak radial velocities near 38 m s^{-1} relative to the ground are indicated by the yellow-green patch in the midst of blue near 40 km, 285°. Several signatures of divergent flow are apparent; their size ranges from 2 km just south of the cursor (oval with dot in center) to 10 km (just west of the white square near 20 km, 310°, the position of the Cimarron radar). The large-scale divergence signature exhibits some anticyclonic rotation.

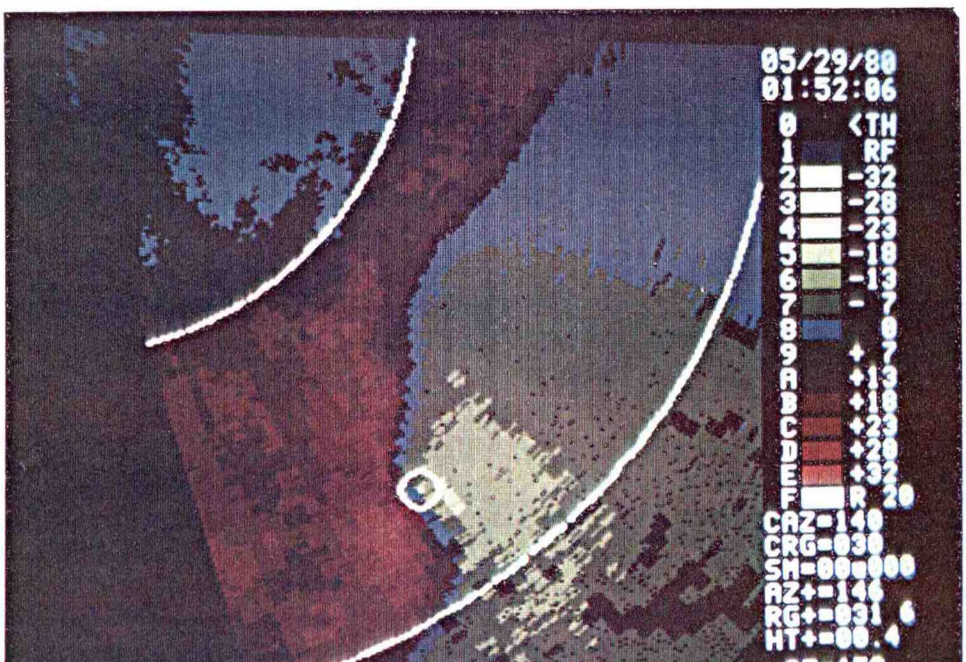


Figure 14. Strong azimuthal shear is present in a developing circulation along a gust front on 29 May 1980. Maximum velocity is immediately SE of the cursor.

Real Time Radar Data Processing: In support of the NEXRAD program, NSSL's VAD algorithm was integrated into the Modular Radar Analysis Software System (MRASS) for real time use in the 1983 Spring Program. This algorithm continuously provided wind profiles throughout the boundary layer. During 70 days of uninterrupted operation during afternoon and early evenings, there were only three days in which echoes were too weak for wind measurements with the Doppler radar in the clear air. On evenings when a low-level jet was present, the radar was able to measure a wind profile to 3-km altitude. The height of observations also increased when clouds were present. Furthermore, indications of turbulence from the radial velocity deviations about the uniform wind model generally agreed with turbulence experienced by nearby aircraft.

In support of research of weather hazards to aviation, software was developed to display Doppler moments on the Chromatics 1999 color graphics terminal, Interlaced scan data were prepared and run through MRASS to evaluate the impact that this scan technique has on products (e.g., rainfall rate) generated by the computer. Doppler weather radar scanning strategies have been examined in order to meet the requirements for detection of weather hazards to aviation. A report (Mahapatra and Zrnic', 1983) and a paper (Mahapatra and Zrnic', 1983) have been published.

A report to AFGL on a real time linear wind analysis program (VVP) was written. The program, which represents another facet of NSSL's support to NEXRAD, was incorporated into MRASS and was tested successfully in real time and on data from a stratiform rain embedded with convection. Programs were developed to display some of the analysis on the Chromatics 7900.

A pattern recognition algorithm has been developed and successfully tested for real-time estimates of storm divergence. This algorithm has been adapted from the successfully tested algorithm for the automatic detection of mesoclones (Zrnic' et al., 1982). Besides locating strong divergence areas in a thunderstorm and estimating its size and continuity, the algorithm also computes air mass flux (Zrnic' and Gal-Chen, 1983).

A test of the NSSL algorithm to detect mesocyclonic shear has been completed Probabilities of false alarm per cell are 0.1, and probabilities of detection are 0.9. These results are obtained from storm data containing about 800 cells and 200 mesocyclonic shears (Zrnic' et al., 1983).

OTHER ACTIVITIES

We continued cooperative work with other agencies and institutions, and a review paper on storm electricity research in Oklahoma was presented to the International Aerospace and Ground Conference on Lightning and Static Electricity in Ft. Worth, Texas (Rust et al., 1983). We completed a report to the Nuclear Regulatory Commission on lightning ground strike climatology. The manuscript for the book Doppler Radar and Weather Observations was edited and readied for typesetting.

NOAA joined the National Interagency Coordinating Group (NICG) for Atmospheric Electricity Hazards Protection Program, which is responsible for establish ing and maintaining communications of research programs and developments relative to lightning hazards. Staff of DRASER are NOAA's representatives to the NICG.

Our involvement has included (1) attending the annual meeting, (2) co-sponsoring the 8th International Aerospace and Ground Conference on Lightning and Static Electricity in June 1983, (3) presenting three papers at this conference, and (4) participating on the steering committee for the next international conference.

A survey of various radar techniques used to measure rainfall rate R has been completed (Doviak, 1983). It has been concluded that after many years of technique development there is still no satisfactory proven method to estimate rain rate or liquid water content accurately when high spatial and temporal resolution is required. Preliminary results from dual polarization measurements suggest a potential for significant improvement but continued research is required.

The many considerations that are required for the proper interpretation of Doppler radar data were presented to NWS at a NEXRAD Symposium/Workshop in Norman, Oklahoma (Zrnic', 1983).

EXPECTATIONS FOR FY-1984

Storm data (Doppler radar and electricity) collected during 1981, 1982, and 1983 will be analyzed to determine relationships among electricity, precipitation, and kinematics in storms.

We will upgrade and test the VHF mapping system to make it an all-hemispheric lightning mapper.

We will analyze the occurrence of positive cloud-to-ground (+CG) flashes and continue efforts to define their existence relative to storm severity.

We will assist in the transfer and interpretation of CG flash data to the NWS in Oklahoma City for use in storm forecasting and warning.

Instrumented balloon flights into severe storms will be conducted to measure electric fields and meteorological parameters.

Mobile and fixed-base lightning measurements will be obtained in cooperation with NASA/MSFC and Langley Research to compare with those acquired from a U2 overflying storms. The purpose will be to determine optical characteristics of flashes that can be observed from a geosynchronous satellite and to assess lighting hazards in the aircraft environment.

We expect to cooperate again with several universities during our spring research program, including the University of Mississippi, Rice University, the State University of New York, the University of Oklahoma, and the University of Illinois.

We will continue the in-depth examination of prestorm radar data from 17 May 1981. VVP divergence will be tested further, and dual Doppler analysis will be used extensively. Satellite data will be examined for information on low-level moisture variations. Computer programs for single Doppler estimates of wind field will be tested on real-time data next spring, some data may be collected from instrumented aircraft. To estimate the structure constant of refractive index and the turbulent dissipation rate, we will analyze integrated water vapor and liquid water data from a vertically pointing radiometer combined with radar reflectivity data for clear prestorm days. Our new dual polarization capability will also be used to investigate effects of electrical processes on cloud and rain development, and to investigate new approaches to measurement of rainfall rate. Appropriate signal-processing techniques will be examined, and alternate schemes for differential reflectivity estimation will be investigated. A study of the evolution of turbulent kinetic energy from first echo until mature stage will continue with an attempt to budget the storm's energy.

A study of the evolution and origin of gust fronts and downdrafts will continue as a prelude to determining the predictability of such events. The outflow signatures from two-radar data will be examined to deduce the intensity of the events and their symmetry. Vertical profiles of reflectivity and velocity of these features will be investigated, and solitary waves will be studied.

The divergence algorithm will be further tested and evaluated. An algorithm to detect and track gust fronts will be developed.

Advanced techniques for reduction of velocity and range ambiguities will be compared and evaluated.

COMPUTER AND ENGINEERING SUPPORT AND DEVELOPMENT

Dale Sirmans, Group Leader

This 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 444-m tower, a 52-station (maximum) surface network, an air traffic control facility, and equipment for measuring electrical phenomena in the atmosphere. The group also provides engineering support for the NEXRAD JSPO/Interim Operational Test Facility of NWS. Much of the CESD Group effort centers around support of the Spring Program both in terms of engineering and computer development and in operation support and data handling.

RECENT ACCOMPLISHMENTS

COMPUTING AND DATA PROCESSING:

NSSL's Perkin-Elmer 3242 data processor, on line with the Doppler radar at Norman, has been upgraded with a second nine-track tape drive, a seven-track tape drive, and a 300-megabyte disk drive. In support of quality control, data from our Doppler radars, lightning sensors, surface networks, and tower are now read and processed on the Perkin-Elmer.

Archiving of NSSL Doppler radar data for 1977-1983 is now possible on the CDC-750 at Boulder: the 1979 SESAME SAM data set was rebuilt to correct errors and was redistributed to users; all necessary programs from the decommissioned SEL-8600 have now been converted for use on the CDC-750.

Doppler radar research data were collected at Norman and Cimarron from May 17 through June 10. More than 560 magnetic tapes were written and subsequently copied as indexed at Boulder.

NSSL supplied data sets to these users:

Finnish Meteorological Institute, Helsinki	(R. King)
Florida State University, Tallahassee, Fla.	(J. Stephens)
McGill University, Montreal	(M. K. Yan)
NASA, Greenbelt, Md.	(J. Heymsfield)
NASA, Huntsville, Ala.	(S. Goodman)
NWS, Silver Spring, Md.	(K. Shreeve)
NWS, Columbus, Ohio	(C. Simpson)
NWS Training Center, Kansas City, Mo.	(D. Lowden)

Rice University, Houston, Tex.	(G. Byne)
Servicio Meteorologica Nacional, Buenos Aires	(J. Nunez)
Sperry, Southampton, Pa.	(L. Lemon)
University of Washington, Seattle, Wash.	(P. Dodge, B. Smull)
Weather Research Program, ERL, Boulder, Colo.	(I. Watson, J. Cunning)

FACILITIES ENGINEERING:

The first six weeks of the 1983 Spring Program of the NSSL, beginning on April 4, was devoted to support of the NEXRAD Operational Tests. Then on May 16, for a four-week period, the research experiments for NSSL and outside investigators were conducted. On June 13, support was returned to NEXRAD and continued until about mid-July. As usual, all NSSL facilities were utilized in support of the data acquisition program.

Coherent Ground Clutter Canceller: Design and fabrication of a ground clutter canceller for use with Doppler radars was completed with installation of some modifications suggested by initial tests.

WSR-57/IFF Terminal: Hardware development was completed with modifications to the computer terminal equipment and interface components to improve acquisition of aircraft position data and capabilities for data processing. Software was developed to utilize the system routinely to collect, display, and store color images of WSR-57 video in a PPI format. During the spring program, WSR-57 color display data were selectively recorded for rapid playback, data screening, and case study selection. This system was operated through the end of FY 1983 in support of a program to evaluate storm sensors aboard a B-52 aircraft.

KTVY Tower Data Collection System: A more reliable computer-based data collection and recording system was designed. Hardware components are assembled, software is being developed and debugged, and operational status is targeted for spring 1984 operational season.

Nine-Track Tape Drive for Norman Doppler: Two nine-track tape recorders were acquired from NSSL's decommissioned SEL-8600 computer. An interface was designed, fabricated, and put on line to allow the new drives to record and play back radar data at the Doppler data collection and control facility in Norman. This system was operational during the spring 1983 storm season.

EXPECTATIONS FOR FY 1984

Computer Support

If procurement proceeds on schedule, a VAX 11/780 computer system will be installed in late FY 1984 at NSSL. This system will give an opportunity for more timely examinations of data collected in the spring and will provide more rapid editing and playback of Doppler data.

Facilities Engineering

During the spring of 1984 the NSSL Doppler radar at Norman will be configured to support quasi-real-time transfer of Doppler radar data from Norman to the NWS Forecast Office at Will Rogers Airport. Lightning data will be transferred also. NWS will have a radar meteorologist at the Norman site for data selection and coordination. The spring research program will include participation by a number of instrumented aircraft, and the WSR-57/IFF terminal for display of aircraft targets at NSSL will be expanded.

A major engineering program for FY 1984 will be development of a capability for switching at the pulse repetition rate between vertical and horizontal polarizations with one of NSSL's Doppler radars. This capability is expected to provide improved methods for identifying hail, estimating rainfall rate, and studying physical processes attending electrification and hydrometeor formation. It is planned to have a system capable of providing differential reflectivity measurements at 16 range locations in early 1984.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

Edwin Kessler

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) is a joint venture of the University of Oklahoma (OU) and NOAA/ERL through the National Severe Storms Laboratory. CIMMS received first funding in late FY 1978 and began major efforts during FY 1979. The program objectives and activities of CIMMS complement and supplement those at NSSL and the University through research conducted by Visiting Fellows, NOAA and University staff, and student appointees.

CIMMS was first led by Interim Director Rex L. Inman, then head of the Department of Meteorology at the University of Oklahoma. During 1980, Dr. Yoshi K. Sasaki, George Lynn Cross Professor of Meteorology at OU, was appointed Acting Director and subsequently Director. In 1982, Dr. Peter Ray of NSSL was appointed Associate Director of CIMMS. In 1983 the death of Dr. Inman left a vacancy on the Council of Fellows, which remained unfilled at year end.

For periods of 16 months during 1983, CIMMS hosted researchers from China, India, Japan, and England who undertook studies in Doppler radar meteorology and meteorological data analysis, with principal financial support from their universities or governments. CIMMS scientist Dr. John McGinley represented CIMMS in the ALPEX field program and through attendance at the IGGU/IAMAP conference held in Hamburg, Germany, in August 1983. CIMMS scientist Dr. James Goerss conducted research under Navy contract on global satellite data assimilation--his method was implemented into the Navy Operational Global Atmospheric Prediction System (NOGAPS) at Fleet Numerical Oceanography Center, Monterey, Calif. He also conducted research on the development of a mesoscale variational temperature analysis scheme under a NASA contract. Postdoctoral Fellow Pinhas Alpert from Israel is engaged in investigations of mesoscale dynamics and sea-breeze, and four Postdoctoral Fellows with partial support from CIMMS on multi-year appointments work in areas of boundary layer dynamics, mesoscale modeling, mesoscale dynamics, and variational methods. Students employed by CIMMS are associated with both NSSL and the OU Department of Meteorology. Approximately 10 are engaged in research studies toward advanced degrees and five undergraduate students are variously employed. Research Associate Diane Ziegler works in the NEXRAD program.

The 1st Conference on Mesoscale Meteorology, co-sponsored by CIMMS and the American Meteorological Society, was held 31 May-3 June 1983; approximately 130 person attended this conference in Norman, Oklahoma.

CIMMS personel were authors or coauthors of approximately 17 reports and publications during FY 1983.

Although OU has recently suffered decrements in State funding, construction of new facilities for CIMMS and the School of Meteorology in the College of Geosciences began in July 1983. Prominent in plans is the "Symposium on Variational Methods in Geosciences" which will be held at Norman in 1985, jointly sponsored by CIMMS and the University of Clermont, France.

ADMINISTRATIVE GROUP

Loyce Tillman, Administrative Officer

The Administrative Management Group provides services in the areas of communications, budget, procurement, project reporting, security, employee utilization, personnel administration, and library. The major responsibilities involve interaction with NSSL staff, educational institutions and commercial concerns, administrators at ERL headquarters and in other agencies (such as FAA, DOE, NRC), and other components of NOAA.

PERSONNEL

At the end of FY-1983 the NSSL total staff included 40 full-time, six part-time and 16 intermittent employees.

The work of our staff continues to be supplemented by means of contracts with the University of Oklahoma, Applied Computer Systems, and the NEXRAD/IOTF.

LAND AND BUILDINGS

Leases on land and buildings utilized by NSSL during FY-1983 were renewed and entered into on 1 January 1983.

NSSL continues to occupy a two-story reinforced concrete and glass building leased from the University of Oklahoma. The building contains about 20,000 square feet and is situated on approximately 1.5 acres of land.

NSSL rents five other tracts of land from the University of Oklahoma:

(1) A warehouse containing 3,840 square feet of storage space.

(2) Ground space for the Doppler Radar Laboratory Building owned by NSSL, plus a tower supporting a rangefinder.

(3) Ground space across the street from the NSSL, with the following facilities:

- (a) Small modulator building
- (b) WSR-57 radar atop a 20-meter tower
- (c) A second tower with UHF and VHF radio antenna
- (d) A third tower with IFF equipment (MPX-7 radar) to interrogate transponders aboard aircraft to determine aircraft position.

(4) Ground space, one-half acre south and adjacent to the Laboratory which contains a "benchmark" weather station. (This facility represents cooperation among NSSL, the University of Oklahoma, and the City of Norman, Oklahoma).

(5) Ground space used for placement of sensors to measure various parameters of storm electricity. Located on ground space is an 800-square-foot portable building used by NSSL personnel for observations and data acquisition.

Total cost for all the leases in items (1) through (5) above is approximately $122,000 annually.

NSSL leases this additional space:

(6) One acre of land at Cimarron, Oklahoma, about 45 km northwest of Norman, containing a second Doppler radar unit.

(7) Levels at the 457 meter KTVY (Television Systems, Inc.) tower, Oklahoma City, Oklahoma, 40 km north of Norman. During most of FY-1983, wind and temperature sensors were operated at seven levels on the tower. Vertical wind data were obtained at the top and bottom, and digital data were obtained for pressure, rainfall, and solar radiation. An analog strip chart recorder operates at the tower site, with simultaneous telephone-line telemetry of digital data for real-time displays and magnetic tape recording at NSSL headquarters.

(8) Land agreements for 28 network sites.

Total annual cost for items (6) through (8) above is approximately $25.600.

GRANTS AND CONTRACTS

FY-1983

Grants and contracts administered by NSSL during FY-1983 are listed below. These were funded both directly from the NSSL budget and from funds of other agencies.

Description	Number	NSSL Cognizant Officer	Start Date	Term Date
Applied Computer Systems "Services for Facilities Management to Operate NSSL Computer Equipment"	NA81RAE00036 ($44,000)	Bumgarner	10/1/82	9/30/83
University of Washington "Studies of Severe Convective Storms" (Houze)	NA80RAD00025 ($11,382) O&R	Ray	10/1/82	8/30/83
Miami University "Analysis of Corona Current Measurements" (Church)	NA83RAA02276 ($5,685) A&R	Rust	6/1/83	9/30/83
University of Oklahoma Cooperative Agreement "Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)" (Sasaki)	NA80RAH00004 ($393,956)	Kessler	7/1/83	6/20/84

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UNIVERSITY OF OKLAHOMA - NOAA COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

DIRECTOR - DR. YOSHI K. SASAKI

~30 FULL OR PART-TIME PERSONNEL

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

CHIEF - KENNETH E. WILK

~7 FULL OR PART-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

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

AS OF SEPTEMBER 30, 1983

NATIONAL SEVERE STORMS LABORATORY

The NSSL Technical Memoranda, beginning at No. 28, continue the sequence established by the U.S. Weather Bureau National Severe Storms Project, Kansas City, Missouri. Numbers 1-22 were designated NSSP Reports. Numbers 23-27 were NSSL Reports, and 24-27 appeared as subseries of Weather Bureau Technical Notes. These reports are available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151, a microfiche version for $4.00 or a hard copy, cost dependending upon the number of pages. NTIS numbers are given below in parenthesis.

No. 1 National Severe Storms Project Objectives and Basic Design. Staff, NSSP. March 1961. 16 p. (PB-168207)

No. 2 The Development of Aircraft Investigations of Squall Lines from 1956-1960. Brent B. Goddard. 34 p. (PB-168208)

No. 3 Instability Lines and Their Environments as Shown by Aircraft Soundings and Quasi-Horizontal Traverses. Dansey T. Williams. February 1962. 15 p. (PD-168209)

No. 4 On the Mechanics of the Tornado. J. R. Fulks. February 1962. 33 p. (PD-168210)

No. 5 A Summary of Field Operations and Data Collection by the National Severe Storms Project in Spring 1961. Jean T. Lee. March 1962. 47 p. (PB 165095)

No. 6 Index to the NSSP Surface Network. Tetsuya Fujita. April 1962. 32 p. (PB-168212)

No. 7 The Vertical Structure of Three Dry Lines as Revealed by Aircraft Traverses. E. L. McGuire. April 1962. 10 p. (PB-168213)

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