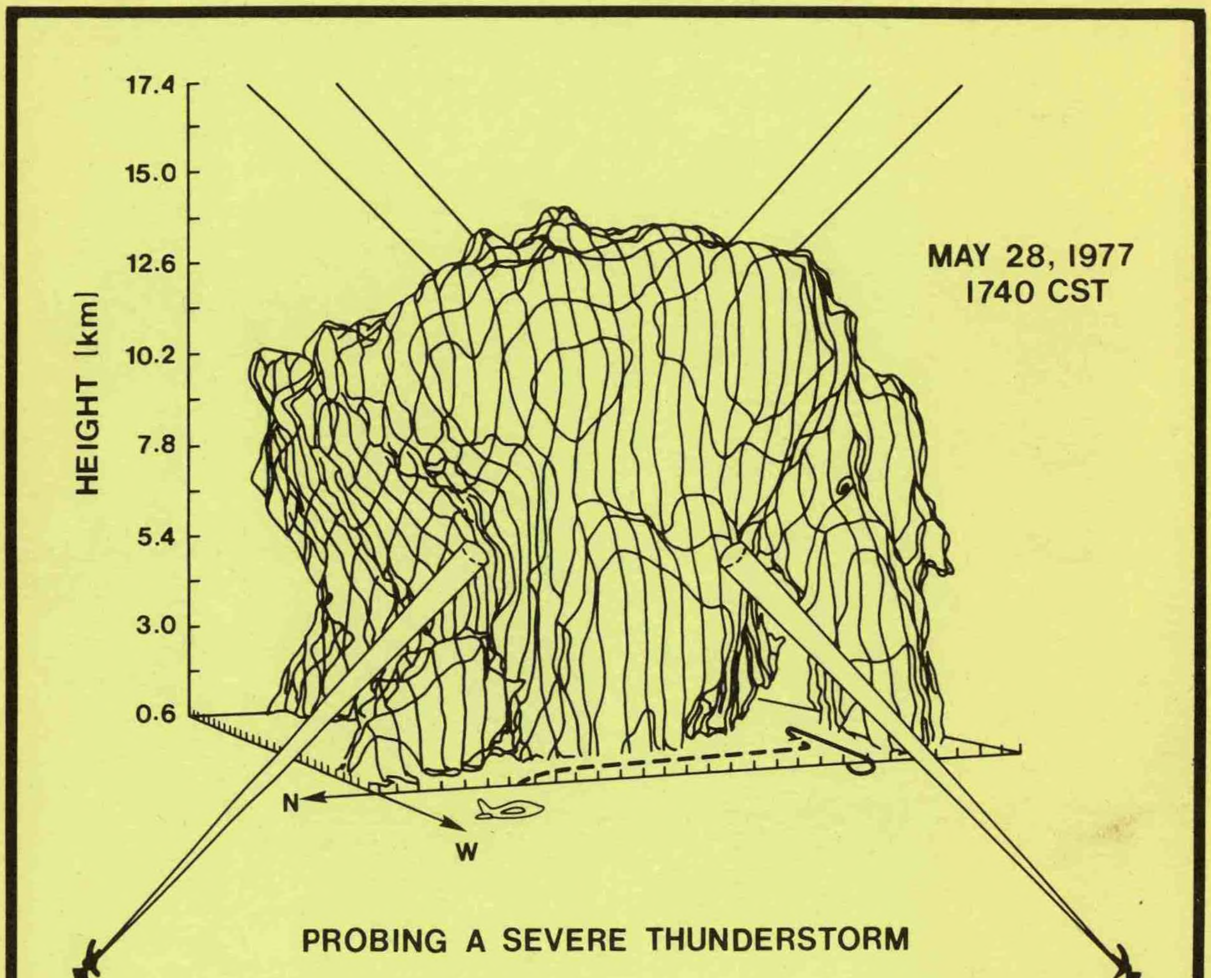
# National Severe Storms Laboratory

# ANNUAL REPORT FY-80




UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Environmental Research Laboratories

## COVER

Perspective view of a surface of the 20 dBZ radar reflectivity factor at 1740 CST, 28 May 1977, as seen from the northwest; the depicted storm produced hailstones 5-cm in diameter near Wynnewood, Oklahoma. Radars at Norman (operated by NSSL) and Anadarko, Oklahoma (the CHILL radar operated jointly by the University of Chicago and the Illinois State Water Survey) observed this storm while hailstones were collected on the ground and while radiosonde crews and the NCAR Queen-Aire aircraft collected data on wind, thermodynamics, and moisture. While flying along the solid portion of the flight track indicated in the figure, mostly below the lowest altitude of 0.6 km illuminated by radar, the aircraft also obtained deuterium samples from the inflow air. With time and location of hailfall accurately noted and many stones preserved by quick-freezing, the data are well suited to study of the mechanisms of hail growth and storm evolution by cooperating scientists of the several organizations. (Computer graphics are courtesy of NCAR.)

# NATIONAL SEVERE STORMS LABORATORY

ANNUAL REPORT - FISCAL YEAR 1980

October 1, 1979 - September 30, 1980

National Severe Storms Laboratory
1313 Halley Circle
Norman, Oklahoma 73069
December 1980



UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige,
Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
James P. Walsh,
Acting Administrator

Environmental Research
Laboratories
Joseph O. Fletcher,
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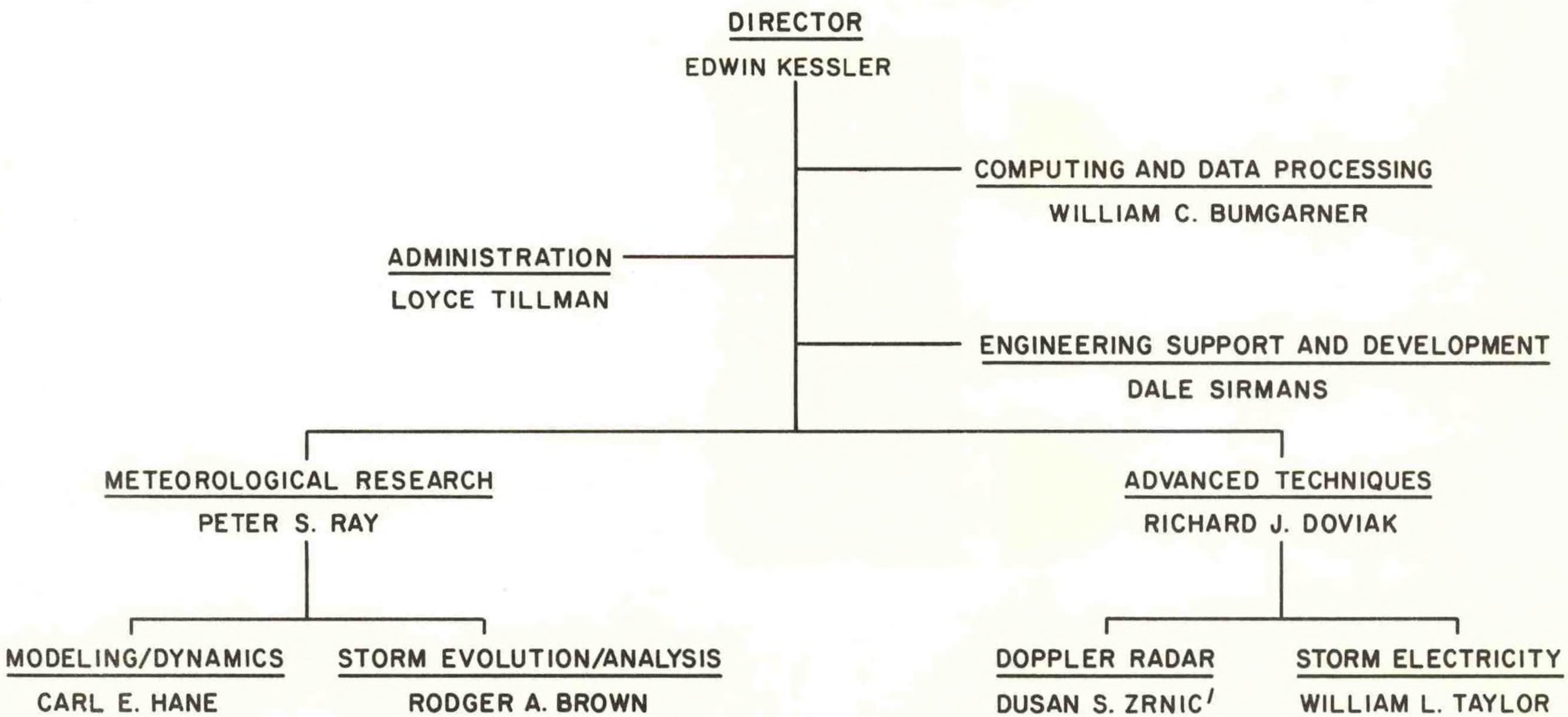
## ORGANIZATIONAL CHART*




*Before July 1980, there was also an Operations and Technology Transfer Group, led by Kenneth E. Wilk. Personnel in this group were reassigned to the Radar Techniques Development Branch of the National Weather Service and to other groups within NSSL. See pp 21-22.

As of September 30, 1980

NATIONAL SEVERE STORMS LABORATORY

PERSONNEL STATISTICS

FY 1980

October 1, 1979 - September 30, 1980

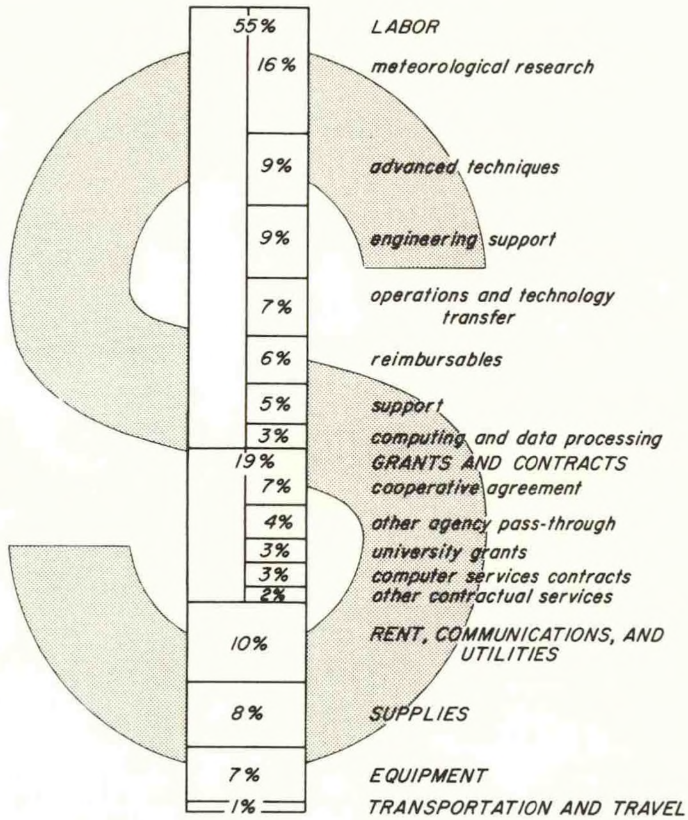
| | | Oct. 1, 1979 | Sept. 30, 1980 |
|---|---|---|---|
| Full-time: | Professional | 27 | 25 |
| | Technical | 10 | 9 |
| | Clerical/Admin. | 6 | 6 |
| | Total Full-time | 43* | 40* |
| Number of full-time holding doctoral degrees | | 10* | 10* |

In addition to the above, the Laboratory employs a variable number of part-time employees, including two under the Cooperative Student Program, and two in the Junior Fellow Program during FY-80. Other Oklahoma University students are assigned with NSSL staff who are Adjunct Professors at the University. The Cooperative Institute for Mesoscale Meteorological Studies employs nine Graduate Research Assistantships supported by NSSL. The students draw salaries equivalent to those of student assistants paid by the University. The number of full-time equivalent man-years in these categories during FY-80 was five. In addition, there were 26 other part-time employees (about 13 full-time equivalent man-years) comprised of four professional, 16 technical, and six who supported NSSL clerically and administratively.

*Includes one National Research Council Post Doctoral Fellow.

NATIONAL SEVERE STORMS LABORATORY

October 1, 1979 - September 30, 1980




Distribution of FY-80 Total Funding by Object Class

| | | |
|---|---|---|
| NOAA Operations Research and Facilities | | $2,408,014 |
| NOAA Support* | | 336,500 |
| Other Agencies: | | |
| Federal Aviation Administration | - $475,000 | |
| National Aeronautics & Space Administration | - 116,000 | |
| Office of Naval Research | - 21,000 | |
| United States Department of Energy | - 226,000 | |
| Total Other Agencies - | | 838,000 |
| GRAND TOTAL | | $3,582,514 |

*This category is regularly provided as a percentage of labor costs.

# PROGRAM AREAS

# NATIONAL SEVERE STORMS LABORATORY

Edwin Kessler, Director

## INTRODUCTION

This is an annual report on activities of the National Severe Storms Laboratory, one of NOAA's Environmental Research Laboratories, located in Norman, Oklahoma. Descriptions are given of the various activities with background for perspective, and discussions of recent results and plans for the near future.

The National Severe Storms Laboratory has historical antecedents that parallel NOAA's National Weather Service, through the former U.S. Weather Bureau to its former National Severe Storms Project, located in the early 1960's in Kansas City, Missouri. As described more fully in a 1976 special report (NSSL History and 1976 Program, 66 pp) the NSSL mission has changed little over the years, but the areas of major thrust have changed considerably, in response to new technological developments, new scientific discoveries, and new expectations. The Laboratory studies severe storm circulations and dynamics, and investigates techniques for improved storm detection and prediction. From an early emphasis on use of aircraft for storm investigations related to problems of flight safety, the Laboratory has progressively given greater relative emphasis to development of Doppler radar and its applications and to studies of storm electricity, and the Laboratory has significantly supported operational agencies with technologies for better use of weather radar and improved safety of flight.

The Laboratory maintains a 50-station capability for digital recording of surface meteorological parameters, and maintains instrumentation on the tallest tower in the United States that is equipped for recording of boundary layer parameters. Two 10-cm Doppler radars on a 42 km baseline provide unique capabilities for recording atmospheric circulations in both precipitating weather systems and the optically clear boundary layer. A comprehensive range of instrumentation for recording of electrical parameters has been brought to a high peak of refinement so that distributions of wind, water and electric fields can all be recorded contemporaneously, and their interactions examined.

Through numerous relationships with other government agencies and universities, the National Severe Storms Laboratory constitutes a resource for severe storms data examined by researchers around the country, and overseas. With many partners, the Laboratory is moving from editing and archiving data collected during the large field program, SESAME 1979 (Severe Environmental Storms and Mesoscale Experiment), to analyses of these data and their application to improved understanding and prediction of severe storms, and to improved use of our means for observing them. Our special relationship with the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at the University of Oklahoma is discussed in a separate section.

## METEOROLOGICAL RESEARCH GROUP

Peter S. Ray, Group Leader

### INTRODUCTION

The Meteorological Research Group seeks to improve thunderstorm forecasting and warning capabilities through evolving conceptual, numerical, and laboratory models of major convective phenomena. Analysis and interpretation of storm flow fields expand our understanding of processes of external and internal forcing, thermodynamics, and cloud physics which contribute to intense thunderstorms and their attendant phenomena. The Group is divided into two projects: Modeling and Dynamics (MAD) led by Carl E. Hane and Storm Evolution and Analysis (SEA) led by Rodger A. Brown.

### RECENT ACCOMPLISHMENTS

#### Theoretical Studies

Modeling: In most numerical weather models the fields of motion, cloudiness, and precipitation are derived from a system of equations which relates these properties to forcing, primarily in deviations of temperature and pressure. The temperature and pressure can be accurately observed at the ground, but only poorly aloft and in either case resolution is usually very coarse, on the order of several storm diameters. Until the advent of high-resolution observations by multiple Doppler radars, the distributions of motion and precipitation were also only poorly defined. Now, great strides in sensor development provide a basis for inferring ("retrieving") fields of temperature and pressure from Doppler-observed fields of motion and precipitation. Studies in this area should lead to improved knowledge of motions in their relationship to the forces which produce them.

Related earlier work in NSSL won an ERL Outstanding Paper Award. We have now completed testing in collaboration with outside investigators on a three-dimensional retrieval method (Gal-Chen and Hane, 1980). Some encouraging results of this work are illustrated in Fig. 1 where temperature is derived to within a fraction of a degree starting from numerical model output wind and water fields similar in spatial and time resolution to that possible from Doppler radars. We are planning to apply this method to a data set collected during the multi-agency SESAME field program which took place during Spring 1979.

Another area of study relates to the observing program conducted each spring at NSSL with many investigators from the academic, private, and government sectors. A collaborative study with NASA on how we might improve our forecasts in support of the observing program resulted in a paper by Weaver and Robertson (1980) evaluating the performance of 72-hour 500 mb numerical forecasts produced at the National Meteorological Center. They concluded that the forecasts were good indicators of weather type, but they characteristically showed systems too weak before they arrived at the west coast and too strong upon landfall.

Analysis Techniques: A technique has been developed to estimate the three-dimensional wind field from multiple Doppler radar data when the radar data does not extend to storm top. This technique permits the determination of vertical velocities in situations where computations otherwise would not be possible (Nelson, 1980a). As part of an assessment of one procedure used in this analysis, the response of a three-dimensional filter used for spatial smoothing was evaluated (Nelson and Weible, 1980).

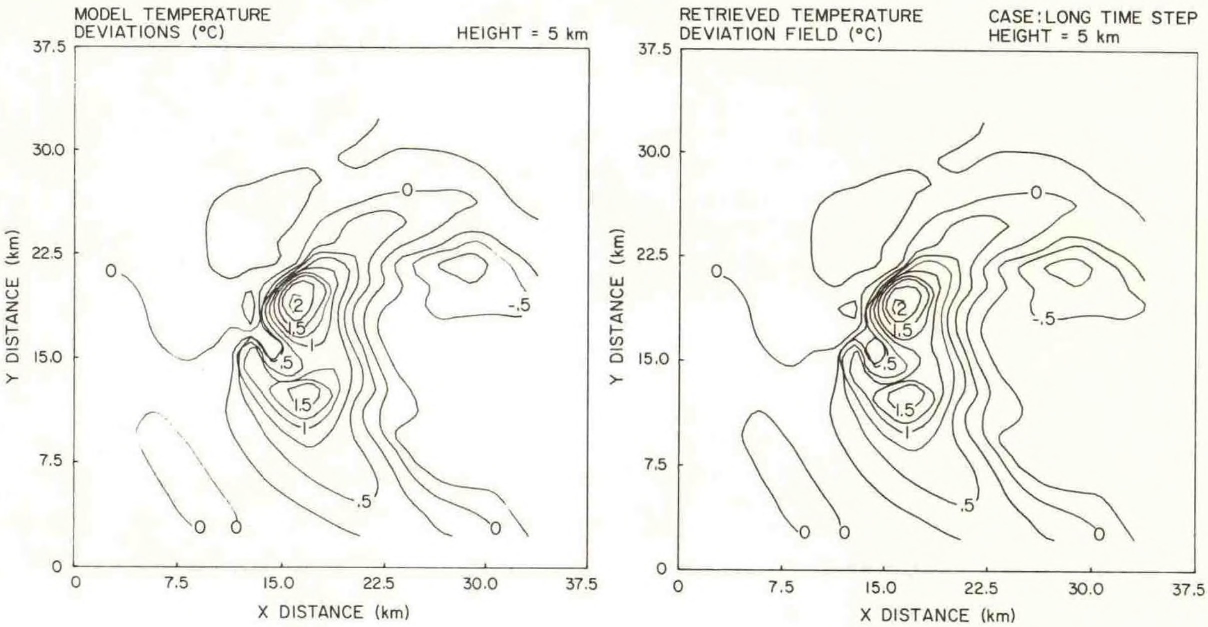



*Figure 1. The deviation of potential temperature from its horizontal average (°C) at a height of 5 km. On the left is output directly from the 3-D numerical cloud model which involves calculations of developing distributions of wind, water substance and temperature and pressure deviations from given initial conditions. On the right is a distribution of temperature deviations "retrieved" from equations modified to use the fields of wind and water as observables. There the time interval used in calculating local time derivative terms corresponds to intervals between Doppler radar observations.*

## Observational Studies

Tornadoes: Work over the last eight years on tornado intercept photogrammetry, tornado damage surveys, tornado modeling, and other related topics has been summarized for a final report to the Nuclear Regulatory Commission (to appear as an NSSL Technical Memorandum). This planned report on the findings of the Tornado Intercept Project is about 90% complete at this writing.

During the 1980 spring season the Tornado Intercept Project intercepted three mesocyclones, tracking and filming two of them for several hours. Two brief mini-tornadoes and several funnel clouds were also sighted. The films obtained from these events will be combined with other data to provide a more complete picture of storm structure. From movies obtained during the SESAME program, photogrammetric analyses of the 10 April 1979 Seymour, Texas and the 2 May 1979 Orienta, Oklahoma tornadoes (see Fig. 2) were completed. Maximum windspeeds in these tornadoes were 90 m $s^{-1}$ (201 mi/hr) and 76 m $s^{-1}$ (170 mi/hr) respectively. Results of these and similar studies are helping define construction standards.

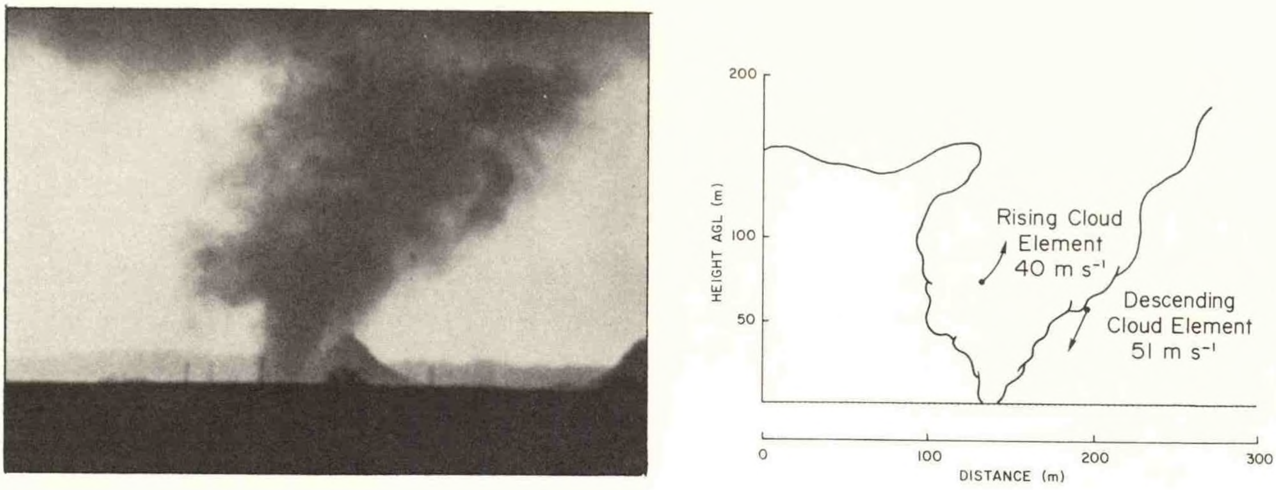



*Figure 2. This photograph is a frame in the Tornado Intercept Project movie of the 2 May 1979 Orienta, Oklahoma tornado viewed from the north (looking south). This tornado had a distinct multi-vortex structure. The highest wind speed measured in photogrammetric analysis of the movie was 75 m $s^{-1}$ (170 mph), the speed of one of the vortices relative to the ground. The overall tornado had a translation speed of 25 m $s^{-1}$ (56 mph) to the east. Large pieces of debris were clocked at 65 m $s^{-1}$ (145 mph).*

*At the time of the photograph, some intense vertical velocities were apparent near the tornado. A rapidly evaporating cloud element was descending rapidly (51 m $s^{-1}$ or 115 mph) at about 60 m (200 ft) above the ground on the southwest side of the tornado, while rapid ascent (40 m $s^{-1}$, 90 mph) was seen on the north (or near) side. In this particular case, the intense downdraft may have been associated with a horizontal vortex filament, but the general vertical velocity pattern observed in the film was updraft on the north side, downdraft on the south side. This agrees qualitatively with the Doppler radar data and indicates that the tornado occurred near an updraft-downdraft interface. A horizontal gradient of vertical velocity twists the vorticity associated with variations of the horizontal wind with height into the vertical plane and thus may help to produce and sustain the tornado.*

*Comprehensive data on the Orienta tornado are now part of the SESAME '79 data set, being analyzed in several university departments and Federal agencies.*

Another study related tornado occurrence to the 300 mb jet stream. Data from May 1977 revealed that tornadoes generally occurred within 1250 km of a jet streak, in a region of weak 300-mb relative vorticity in the left front or right rear quadrant of the jet streak. Values of 300-mb divergence and vorticity advection were significantly positive, but 300-mb anticyclonic shear was not a statistically significant variable in tornado occurrence. These results are applicable to storm forecasting practice and have been printed as an NSSL Technical Memorandum (Kloth and Davies-Jones, 1980).

Severe Storms: A series of papers presented the first results of COMPASS, the Cooperative Observational and Modeling Project for the Analysis of Severe Storms, involving investigators at the University of Illinois, the National Center for Atmospheric Research, and NSSL. The papers detail the development and interaction of several severe storms that occurred on 20 May 1977. Two of these storms eventually became tornadic. Observation of these storms with several Doppler radars over most of their development provided a unique set of observations and a unique opportunity to study the dynamical evolution and interaction of tornadic storms.

The evolution of the storm system started with the interaction of two storms (Klemp et al. 1980). The storms which became tornadic were addressed by Klemp et al. 1979, and dynamical details have been described by Wagner et al. (1980) and by Johnson et al. (1980), who also presents an overview. These studies compare the observed and numerically simulated severe storms. As shown in Figure 3, remarkable similarities represent a new and exciting research capability. Knowledge of all fields at all times in the modeled storm allows quantitative determination of mesoscale interactions and processes important in tornadogenesis. In both the real and modeled storms of this day, vorticity (spin) was seen to increase rapidly at low levels some time after being apparent at mid-levels. The functions of horizontal convergence are also being evaluated.

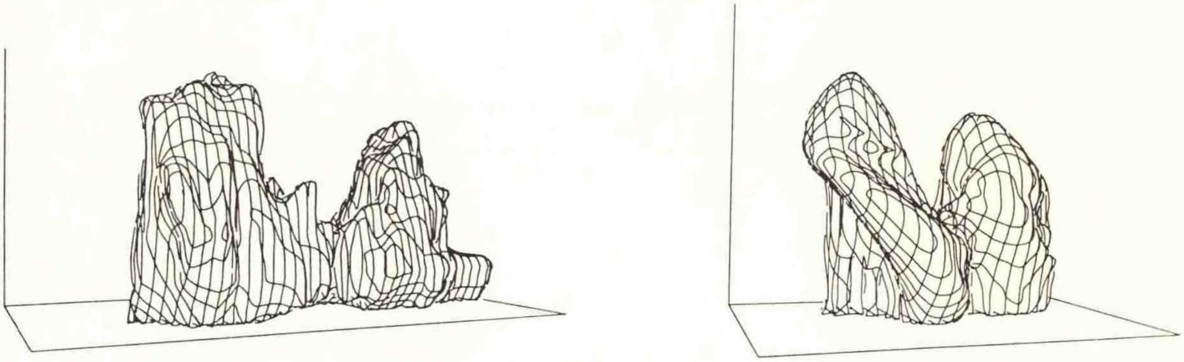


*Figure 3. Observed and simulated interaction of two storms on 20 May 1977 as viewed from the east-southeast. The left figure shows the surface of the 40 dBZ radar reflectivity factor at 1715 CST, about 1-1/2 hours before the storm on the left intensified and produced a tornado. The storm on the right continued to decline in intensity owing to effects of the growing storm to the south. The modeled complex, right figure, during 85 minutes of simulated time, evolves in fashion similar to that actually observed. Here the surface shown corresponds to a liquid water content of 0.5 gm/kg air.*

Related research on the Del City tornadic storm of 20 May has focused on the structure of mesocyclones, which are often dangerous and may harbor tornadoes. In one study, Brandes (1979) found a conspicuous intense downdraft that formed on the storm's rear and descended to ground during tornadogenesis. The mesocyclone was formed of subsiding air, a hook-shaped precipitation-filled region which appears as a prominent radar echo, and inflow air all wrapped in a large spiral about the tornado. The rear downdraft may contribute to dynamical destabilization of the mesocirculation and encourage growth of small perturbations. For this same storm, Wood et al. (1979) compiled tornado cyclone characteristics as detected by NSSL's single-Doppler radars. The vorticity and divergence fields are among those studied with single Doppler radar; these fields are essential elements in vortex development and real-time tornado recognition.

Considerable headway has been made in preparing dual Doppler radar data for three major studies of severe thunderstorms. Two of the data sets were collected during Project SESAME '79 on the tornadic storms of 2 May 1979 and the supercell hailstorm of 6 June 1979. The third set was collected 19 June 1980 on one multicell and one supercell hailstorm.

Hail growth in a supercell storm was studied using a numerical growth model coupled with three-dimensional wind fields from an analysis of data collected with three Doppler radars (Nelson, 1980a, b). A major conclusion is that the storm updrafts were so strong that only embryos on the periphery of the updraft could experience much growth (see trajectories $H_2H_3$ and $E_2H_1$ in Fig. 4). Embryos in the updraft center cannot grow significantly since they are rapidly carried aloft to cold regions with little of the liquid water which must be collected and frozen onto small hailstones to make large ones. The trajectory $E_2H_1$ coincides with the radar reflectivity zone known as the "embryo curtain." Results of this study suggest that this region of high reflectivity is not a source of embryos, but is on the edge of the region of maximum hail growth. This has important implications for *in situ* and remote sampling considerations, modification strategies, and for hail identification by radar in real time.

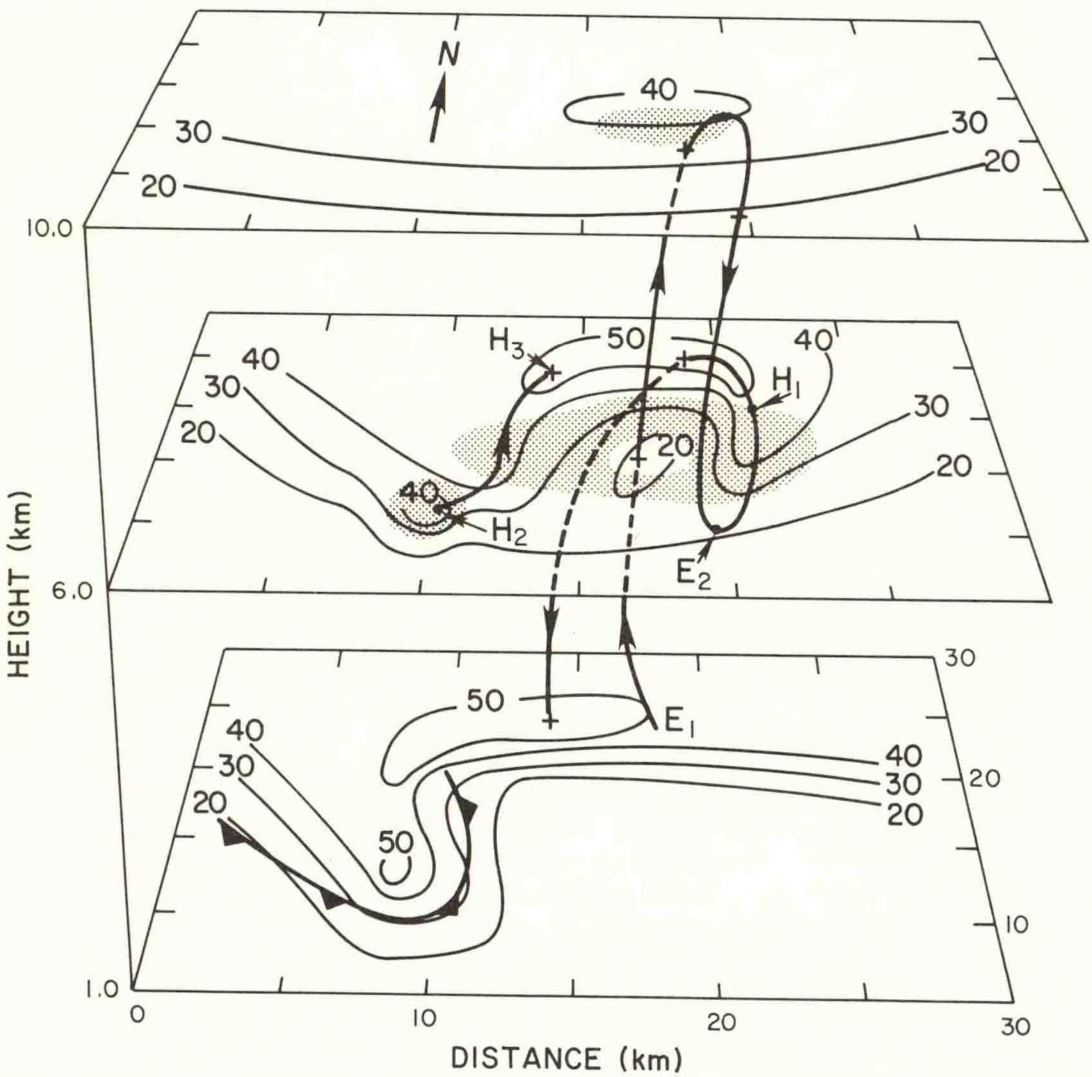



*Figure 4. Conceptual model of hail growth in a supercell storm. Light lines are reflectivity (dBZ), shaded areas represent updrafts of 2 m s$^{-1}$ or more with unshaded interiors indicating updrafts of 40 m s$^{-1}$ or more. Heavy lines with arrows show proposed hailstone ($\overline{H_2H_3}$, $\overline{E_2H_1}$) and embryo ($\overline{E_1E_2}$) trajectories. Solid lines with barbs at 1 km shows the position of the gust front, the leading edge of cool air outflow at low altitudes.*

Nelson also found that some model hailstones which grew to large diameters (5-cm) had near neighbors which did not reach such a large size. Due to an ideal set of circumstances, these hailstones retained a wet surface as they grew in a region where smaller liquid and frozen particles coexisted. Growth, therefore, occurred more rapidly than if the cloud water had been all liquid, since the large release of latent heat of fusion as liquid freezes retards the freezing process.

Another study blended single Doppler radar and storm intercept observations to form a clearer picture of the evolution of a storm on 30 May 1976. A tornado at a rare location on the line of flanking cumulus removed from the mesocyclone was documented. There was a conference presentation on this case (Lemon and Burgess, 1980) and a technical memorandum manuscript is in preparation.

While studying mature storms, we also seek understanding of the processes involved in their initiation. Thus we examined severe storm activity in relation to deformation at intersection of cold fronts and drylines. (This latter is a boundary between dry and moist air, with little temperature contrast.) Deformation can cause the gradient of potential temperature and frontal intensity to increase. Frontogenesis is accompanied by inward motion of the warmer air which may aid storm development. We developed objective analyses of the frontogenetical function for four storm days (4 June 1973, 5 December 1975, 16 May 1978, and the SESAME day, 10 April 1979). In each case, severe activity was associated with a local maximum in the rate of frontogenesis.

Additional SESAME data are being used to ascertain the environmental characteristics of severe storm systems. This study will focus on similarities and differences between storm days and will include documentation of severe weather events for each storm system. Two publications thus far (Bluestein et al. 1980, and Alberty et al. 1980) carry implications for future analyses of SESAME data sets.

## GENERAL STUDIES

Desirable characteristics in Doppler radar systems depend substantially on qualities of observed phenomena including the range of wind velocities and the depth and intensity of precipitation. The distribution of velocities likely to be observed in Oklahoma severe storms was considered by Johnson et al. (1979). Precipitation acts to attenuate radar signals at the 5-cm wavelength commonly used by television stations. In a comparison with data from 10-cm radar, Allen et al. (1980) found the 5-cm reflectivity had been attenuated as much as 25 dB (a factor of nearly 400), with loss of echo shape characteristics on the back side of a storm.

A more detailed accounting of the Doppler radar collection during interagency Project SESAME was compiled by Ray (1980). The impact of the Joint Doppler Operational Project (JDOP) managed from NSSL, continues to be felt, perhaps most importantly in the establishment of the NEXRAD Office in the National Weather Service to oversee introduction of a new national radar system by the late 1980's. Out of the recent JDOP experiment, two papers were presented at the 11th Conference on Severe Local Storms (Burgess and Devore, 1979, and Burgess and Donaldson, 1979) and at the Eighth Technical Exchange Conference (Glover et al. 1979).

# EXPECTATIONS FOR FY-1981

During FY-1981, major efforts of the Meteorological Research Group will continue to emphasize analyses of multi-Doppler data on severe storms and establishment of relationships connecting the coevolving distributions of wind, temperature, and hydrometeors in storms. In particular:

1. We should complete the major study on storm interaction and tornadogenesis for several tornadic storms that occurred on 20 May 1977. This is the first large comprehensive study relating numerical modeling to Doppler-radar revealed storm structure.

2. The case study, including analysis and modeling, of the 19 May 1977 squall line will be completed with insights to the internal flow fields of a squall line of large horizontal extent. Retrieval of temperature and pressure information in a storm whose fields of motion and hydrometeors were observed in fine detail by Doppler radar should be in an advanced stage of analysis. Studies of the storms of 2 May 1979 and 6 June 1979 in progress should also be completed.

3. The reports on the Tornado Intercept Project and the analysis of the Seymour and Orienta movies should be completed, and there will be a mathematical investigation of photogrammetric techniques as applied to tornado movies. The theory of tornadogenesis will be further explored in expectation of improved conceptual models of the life cycle of mesocyclones.

4. There will be some detailed analysis of microphysical processes (i.e., those that govern condensation and formation of precipitation from cloud) and Doppler derived flow fields in Oklahoma hailstorms, in cooperative projects with the National Center for Atmospheric Research, the South Dakota School of Mines, and the Illinois State Water Survey. We will be comparing hailstone trajectories and growth characteristics computed from data on hailstone crystalline structure and from a numerical hail growth model using winds defined by Doppler radar data in order to identify the regions in storms where hailstones originate and to define their growth histories.

## ADVANCED TECHNIQUES GROUP

Richard J. Doviak, Group Leader

### INTRODUCTION

The Group consists of two projects: Doppler Radar and Storm Electricity. The Doppler Radar Project recommends and develops new radar techniques to acquire, process, and analyze data on the storm environment. The Storm Electricity Group measures electric fields in and around thunderstorms, maps lightning channels and generally examines the distribution and development of electrical activity in relation to fields of motion and precipitation revealed by the Doppler radars.

### Spring Program - 1980

The 1980 Spring Observation Program was reduced substantially from the SESAME program hosted by NSSL a year ago. Nonetheless, eleven outside organizations participated by bringing in their own equipment and support. The Advanced Techniques Group was heavily involved in the organization and overall supervision of the spring program.

The prime purpose of the 1980 observational effort was to further understanding of electrical processes in thunderstorms. Corona current sensors were added to NSSL's automated stations for recording meteorological parameters beneath severe storms. A limited number of surface observing stations were operated in the vicinity of Will Rogers Airport, in support of an FAA turbulence experiment. A third station for better triangulation was incorporated into equipment manufactured by Lightning Location and Protection, Inc. (LLP system) for more accurate location of lightning ground strikes within a 200 km radius. Also, storm electricity measurements were collected from a mobile platform operating far beyond the range of field sensors located in Central Oklahoma. Eight of eighteen experiments which were attempted involved coordination of storm electricity measurements. One of the largest undertakings of this laboratory involved dual mapping of storms by both Doppler radars and VHF lightning detection equipment.

In another experiment, lightning flashes were recorded by vertically pointing Doppler radar. A preliminary examination of spectra indicates little change in precipitation fallspeed following a lightning flash, but the lightning channel was revealed to be the site of strong upward vertical velocity, probably to be identified with air motion.

Some particular goals of the 1980 data collection were: 1) to make observations in the prestorm environment using NSSL's Doppler radars modified for this purpose, 2) to support data collection for FAA experiments on storm hazards to aircraft, 3) obtain storm scale measurements on severe thunderstorms containing hail or tornadoes. (But no tornadic storms passed within NSSL's dual Doppler observational area during the 1980 season. In fact, there was an unusually low incidence of severe weather in Oklahoma.)

Although prestorm data were collected on several days when Areas of Deep Convection (ADC) formed, only on two days did showers develop within the dual Doppler area. Some analyses completed for 19 June 1980 with single Doppler radar indicate convergence upwind of clouds. This convergence was confirmed with dual Doppler analysis. Severe thunderstorms subsequently developed from an ADC which appeared to form near strong convergence. These storms passed through the area illuminated simultaneously by both of NSSL's Doppler radars, while hail was collected for analysis by a joint NSSL-NCAR team. Rawinsondes were released in the vicinity of a gust front and more hail was collected from another storm under dual Doppler coverage the same night.

Turbulence measurements were made on nine days of coordinated aircraft and single Doppler data collection. Although no severe storms were sampled, moderate to severe turbulence was recorded on several days.

Doppler Project (Dusan Zrnic')

A comprehensive review of Doppler weather radar techniques and applications to fair and stormy weather is given in the Proceedings of the IEEE. (Doviak, Zrnic', and Sirmans, 1979) Comparison of winds measured by Doppler radar and aircraft is presented (McCarthy, Elmore et al. 1980) and results are used to suggest a method of measuring shear along the glide slope of descending aircraft (McCarthy, Frost et al. 1980).

The following is a synopsis of other recent accomplishments and work in progress in the Doppler Project.

Momentum flux and energy exchange in the convectively driven boundary layer has been estimated using winds derived from dual Doppler radar analysis (Rabin, 1980). The dual Doppler-radar analyses also provide standards for evaluating the information content inherent in single-Doppler data. Thus, displays of Doppler velocity vs. azimuth acquired by single-Doppler radar have been shown to reveal the vertical distribution of horizontal divergence of the air and hence the subsynoptic scale vertical velocity profile in the lowest kilometer or two in clear skies (Rabin and Zrnic', 1980).

A review of methods to estimate weather spectrum moments was given by Zrnic' (1979a). A theoretical study on the effects of time, angle and range averaging of radar echoes from distributed targets was published (Walker et al. 1980). This work describes an optimum sampling strategy for logarithmic, square-law, and linear radar receivers, and finds application in the design of radars for use in operational weather observing and forecasting.

Doppler radar has been used to estimate maximum wind speeds in a tornado. Examination of Doppler spectra of echoes from tornadic vortices reveal large spectral widths when the whirls are contained within the radar's resolution volume (Zrnic' and Istok, 1980).

1. Mapping Divergence Fields in a Prestorm Environment Using Doppler Radar

Methods of statistical regression have been applied to single radar radial velocity fields to map certain mesoscale (20-100 km) kinematic properties (e.g., divergence) of the convective boundary layer (CBL) before precipitation and clouds form. It has been shown that when wind fields are linear on the meso- or larger scale, then single Doppler velocity measurement accuracies allow the estimation of horizontal divergence with an accuracy of about $3 \times 10^{-5} s^{-1}$ and a resolution of about 30 km, which may be sufficient to sense convergence preceding thunderstorm formation.

Computational algorithms referred to as modified Velocity Volume Processing (VVP), have been applied to radial velocity fields from an environment void of precipitation and clouds a few hours in advance of storm development. The divergence fields (Fig. 5) appear realistic and the implementation of more sophisticated data editing procedures, necessary to remove anomalous point target echoes (e.g., birds, aircraft, etc.) from the weather returns, should give even better results. The divergence patterns measured independently by NSSL's two Doppler radars agree reasonably well as do the divergence estimates computed from synthesized dual radar wind. Cumulus clouds occur downwind of the low-level convergence zones, and there is evidence that one of the more intense regions of convergence formed an ADC within two to three hours after first observation in the CBL with thunderstorms four to five hours later.

The structure of turbulence and waves in the planetary boundary layer, as perceived by dual Doppler radar is illustrated in a recent publication (Doviak and Berger, 1980).

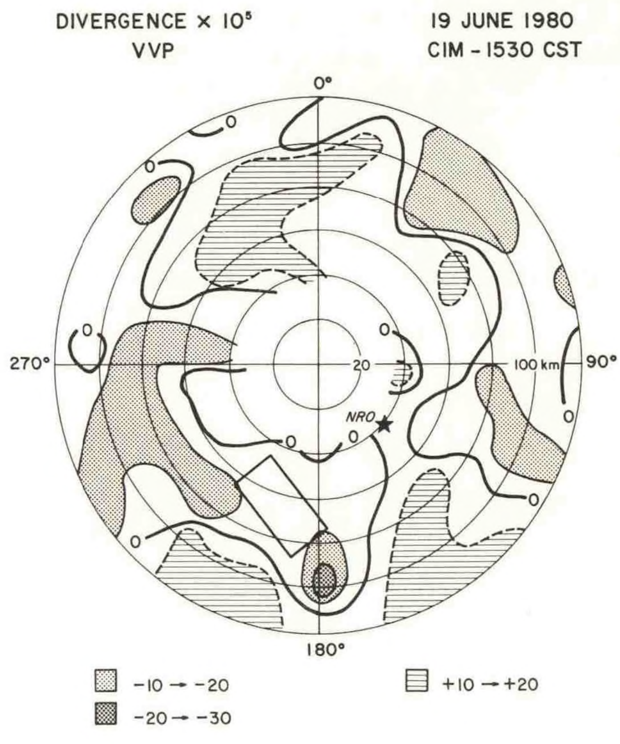



*Figure 5. The divergence field obtained by applying a VVP algorithm to the Cimarron (CIM) Doppler velocity field. Echoes are from clear air targets and no precipitation is present at this time. Regions of large convergence to the NE and SW developed clouds and areas of Deeper Convection (ADC) a few hours later and thunderstorms formed to the SW at about 1950 CST. The boxed area locates region within which dual Doppler-radar estimates of divergence were compared to single Doppler ones.*

2. Lifetimes and Scale Sizes of Weather Features

A 10-cm Doppler radar was used to measure reflectivities and radial velocities in the optically clear planetary boundary layer and in a storm (Smythe, 1980). The temporal decay of features, their spatial extent and their velocities are objectively defined by correlation techniques applied to arrays of small regions (boxes in the polar coordinate system natural to radar). Correlations of storm data are comparable to those from clear air. Scale sizes are obtained from autocorrelations (i.e., correlations of patterns with themselves at different spatial lags) while lifetimes are deduced from cross correlations (i.e., correlations of patterns at different times) (see Figs 6 and 7). In the clear air, velocities have higher correlations than reflectivities which means that the velocity structure is more enduring than the reflectivity structure. Scale sizes are about 2 km for velocities versus 300 m for reflectivities, while the lifetimes are near 500 s and 300 s, respectively.

Several consecutive scans are used to calculate the temporal correlation function, and it is shown that often a two-thirds decay in time best fits the data. This is in accordance with Chandrasekhar's theory of turbulence. The space-time correlation is also being investigated. Besides implications for turbulence, the studies have shown that the transverse component of the Doppler wind field can be retrieved (Smythe, 1980). This means that we may be able to use single Doppler radars to provide elements of two-dimensional velocity fields whose definition has usually required two or more Doppler radars.

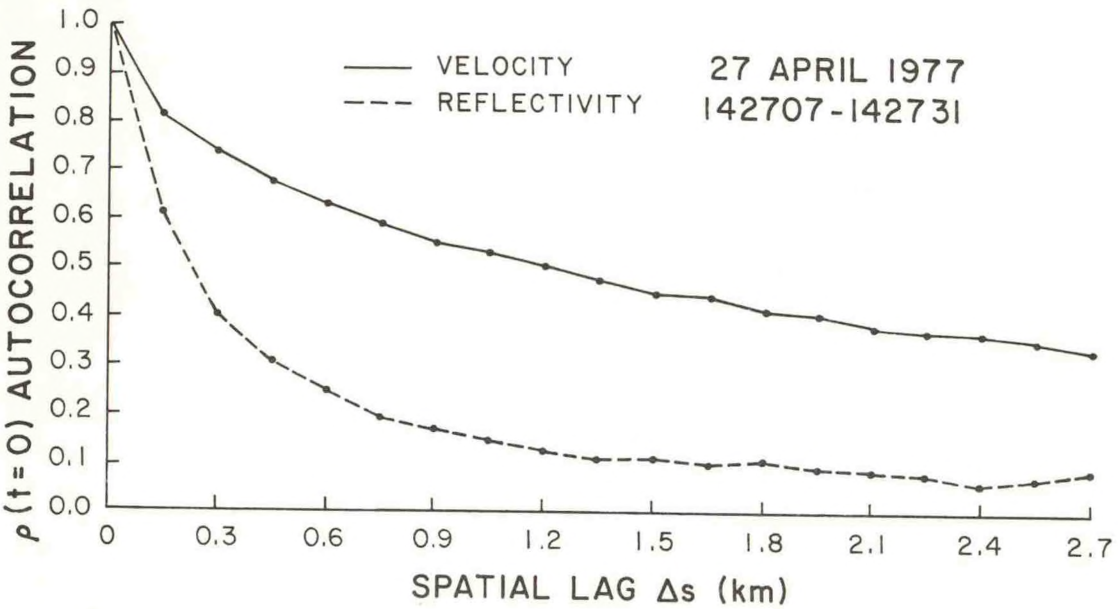



*Figure 6. Autocorrelation of velocity and reflectivity. The values are from averages of data contained in 9 km X 12 deg. arrays.*

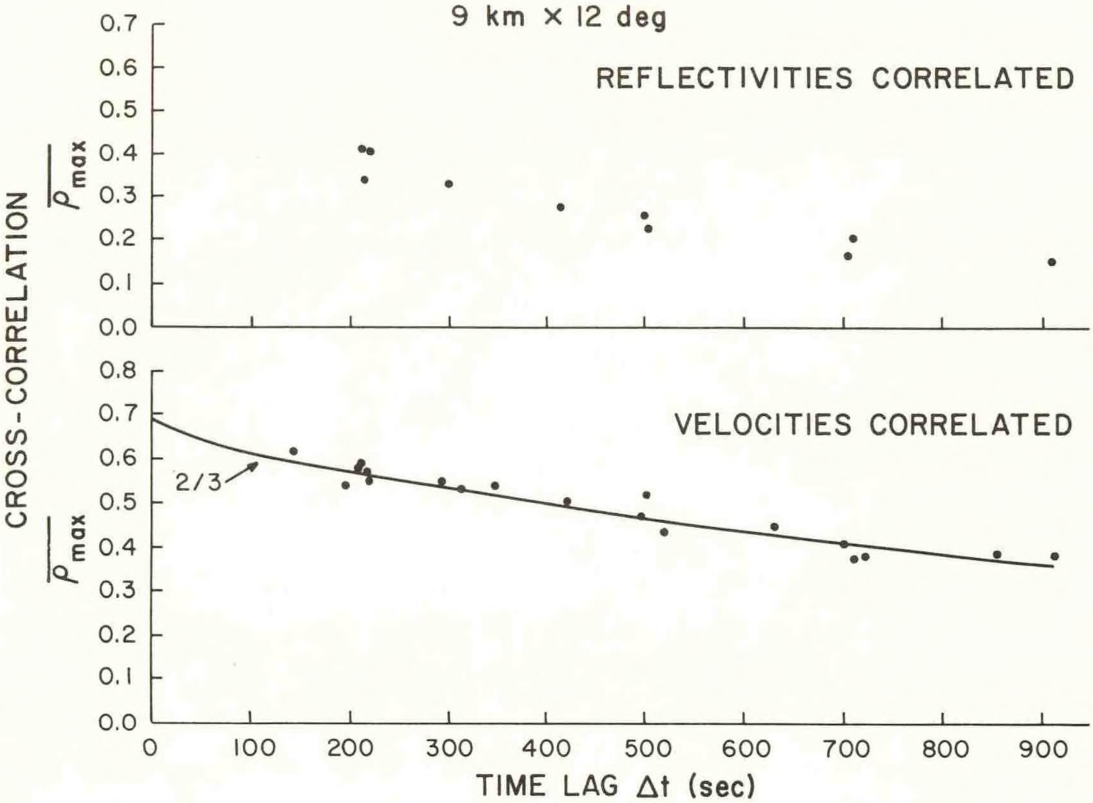



*Figure 7. Correlation coefficient of best fit between patterns of velocity and reflectivity separated by time Δt.*

## 3. Spectra of Precipitation and Lightning at Vertical Incidence

As part of the Spring 1980 experiments, long time records of Doppler video data were recorded. The Doppler radar at Norman was pointed vertically and samples at sixteen contiguous range gates were collected. Simultaneously, radiation from lightning flashes was recorded with a nearby instrument. On several occasions lightning had occurred within the radar resolution volume. This provided an opportunity to estimate the reflectivity per unit volume of a lightning channel. Its value of about $10^{-8} m^2/m^3$ suggests that the reflections are from an underdense plasma, i.e., a partially ionized gas in which the electron density is less than that required for complete reflection of the incident energy. Often the spectral peaks due to lightning are separated from the peak produced by precipitation. Of course, the precipitation falls relative to the air while the channel is probably moving with the air. On the example (Fig. 8) the lightning peak is at 9 m $s^{-1}$ while the highest precipitation velocity is -10 m $s^{-1}$. Thus a maximum fall speed of 19 m $s^{-1}$ suggests presence of hail in the volume illuminated by the radar. Our lightning studies are discussed further below in the section devoted to work of our Storm Electricity Group.

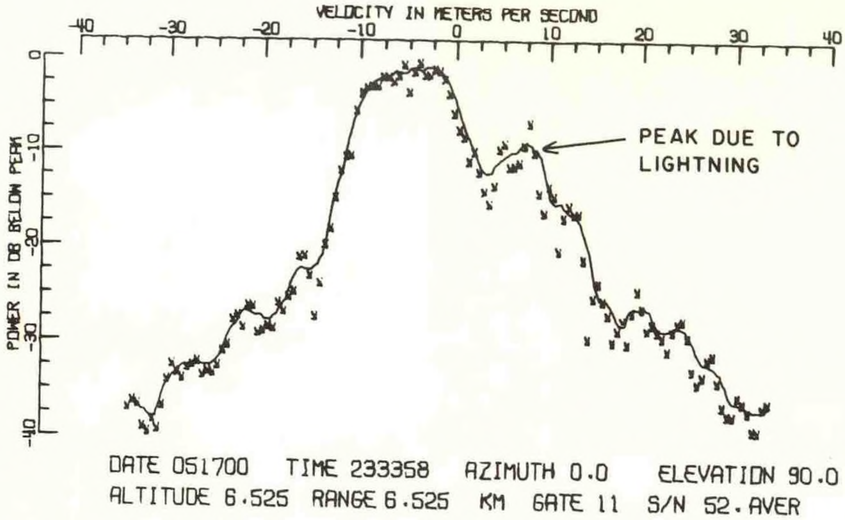



*Figure 8. Spectrum of precipitation and lightning obtained with a vertically pointing antenna. A total of 12 spectra were averaged to obtain this smooth estimate. Time sequence for each periodogram lasts about 0.1 s and contains 128 complex time samples. The peak at about 9 m $s^{-1}$ is from lightning and persisted for about 0.3 s, while the broad part between -10 and 0 is generated by hail, graupel and rain.*

## 4. Real-Time Processing and Display

The real-time display and processing capabilities of both Cimarron and Norman Doppler radars were substantially improved throughout the year. New products developed for the Norman radar were: 1) An RHI display of reflectivity Z, mean velocity $\bar{v}$, and spectrum width $\sigma_v$ (Fig. 9a, b, c), and 2) A time height display of the three spectral moments (Fig. 10a, b, c, and d). Power spectra were transmitted from the Cimarron radar to Norman; this capability provides for real time comparison of the data from two radars and helps quality control.

A new Computer Automation minicomputer system and display transferred from the National Weather Service was interfaced to the Cimarron radar and software development is in progress.

Results of various activities devoted to resolving velocity and range aliases were published (Hennington, 1980; Zahrai, 1980); another paper treats estimation of weather spectrum width (Zrnic', 1979b).

## 5. Weather Echo Signal Simulator

In cooperation with the University of Oklahoma Electrical Engineering Department (Dr. Gene Walker, principal investigator), a weather echo simulator was

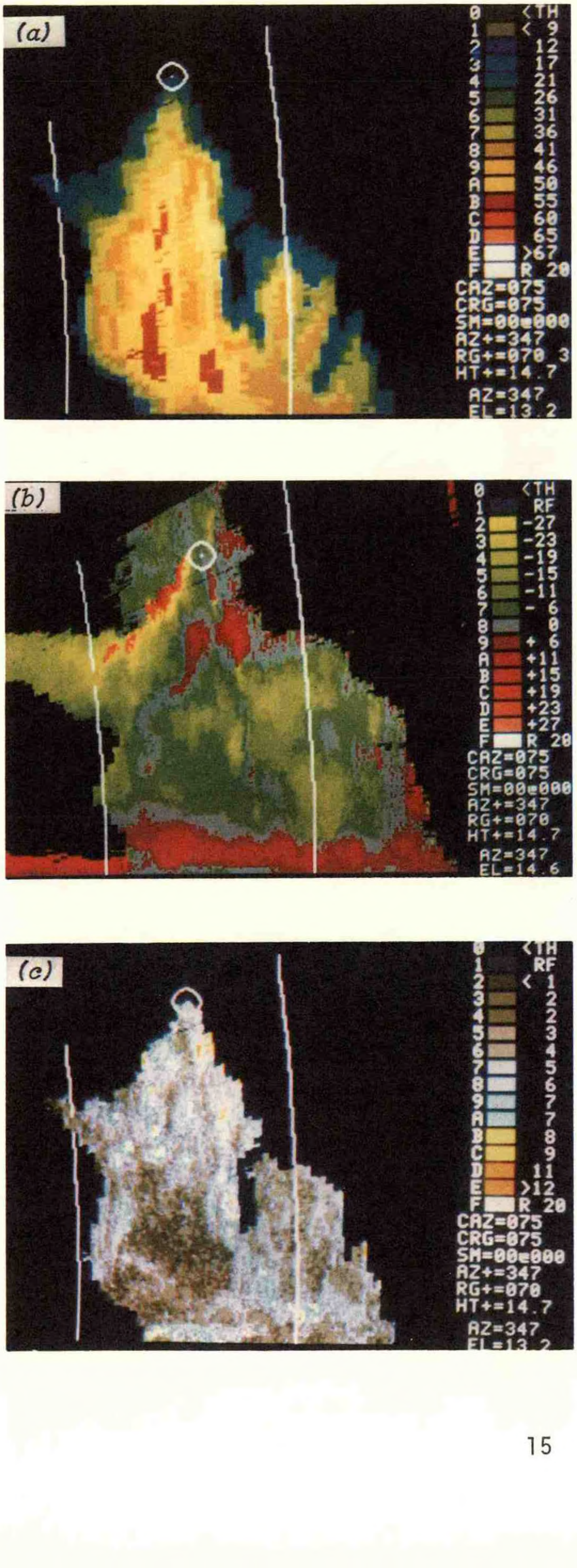



*Figure 9. Range Height Indicator (RHI) display of a severe storm on June 16, 1980, at 20:42 CST. These are vertical cross sections of reflectivity (a), Doppler velocity (b), and spectrum width (c) along a 347° azimuth. The cursor (white circle with dot center) indicates the storm top at 14.7 km. Display (b) shows a larger data field because an SNR threshold was set near 0 dB in order to show storm inflow and anvil outflow. The radar is to the left and the range marks are at 60 and 80 km. (a) The top reaches an altitude of almost 15 km. The weak echo anvil is at 10 km; echo overhang and strong reflectivity gradients between surface and 2 km suggest strong inflow; (b) Motions to the right and away from the radar appear in red and motion toward the radar in green. Weak echoes in the convective boundary layer (low altitude red region between 50 and 60 km) show flow into the storm; and (c) Most regions in this cross section have widths exceeding 5 m $s^{-1}$ suggesting turbulence that can be hazardous to aircraft.*

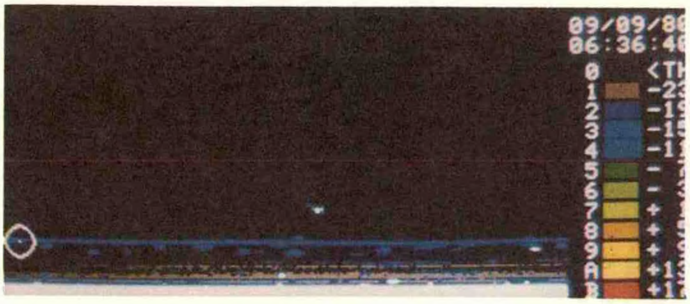


*Figure 10*a. *Time-height display of reflectivity. Colors show DBZ values; the cursor indicates an echo layer about 3 km AGL at 0636 CST, Sept. 9, 1980. Absence of weather returns below corresponds to lack of heating at the ground. Radial data are 5 seconds apart; the display was made in about 2 minutes, with later time to the right.*

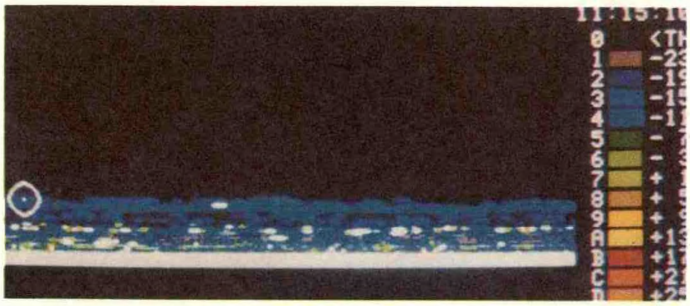


*Figure 10*b. *Same as* a, *but at 11:15 CST. Note the layer echoes about 4 km above ground and strong returns in the boundary layer between ground and about 2.0 km. Reflectivities saturating the receiver appear in white and usually associate with strong point reflectors.*

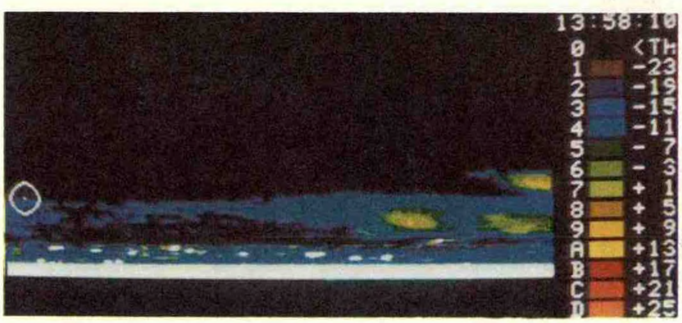



*Figure 10*c. *Same as* a, *but taken at 13:58 CST. Convective features are passing over the radar.*

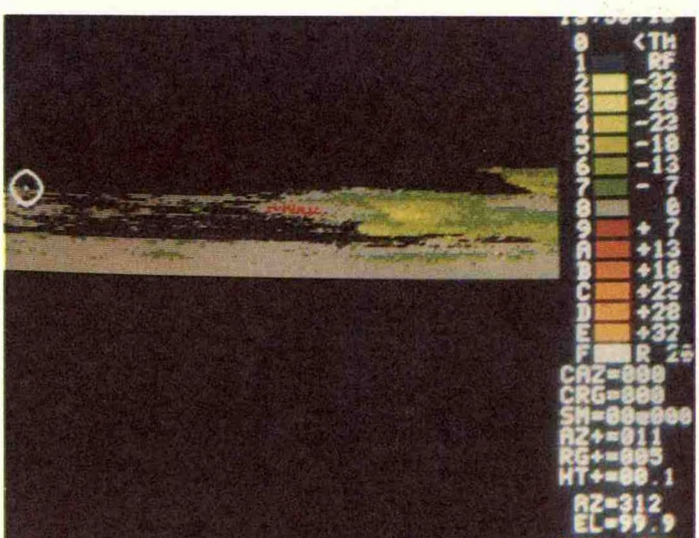



*Figure 10*d. *Velocity display of the same data as on* c. *Divide velocity scale by 3. A slight updraft (red) precedes the downdraft (green) of the stronger (+5 dBZ) reflectivity region.*

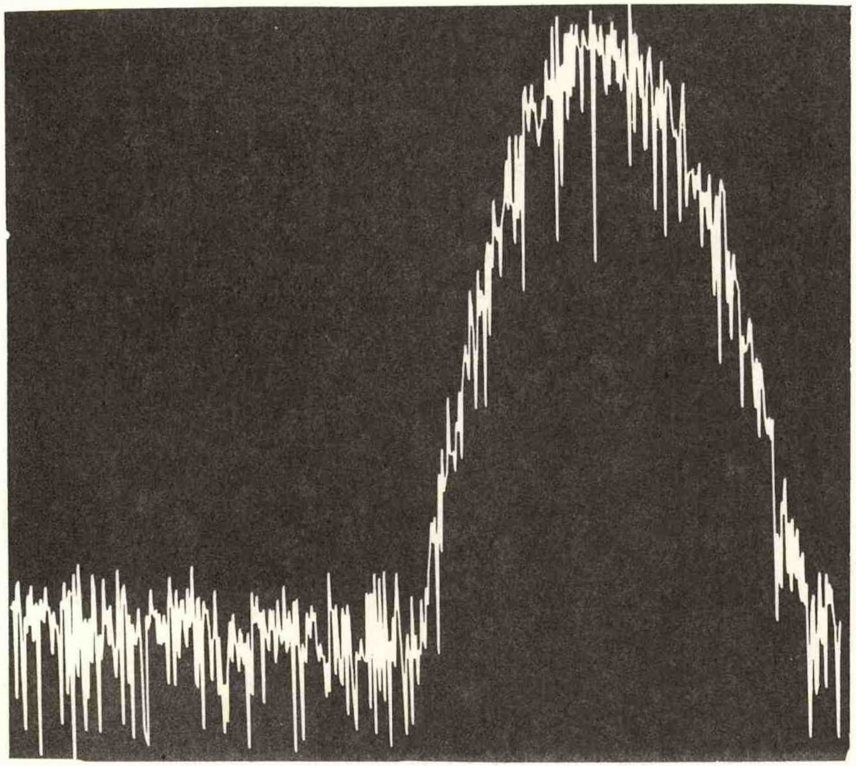


*Figure 11a. Simulated input spectrum. Vertical scale is logarithmic and the lowest noise value due to 12-bit quantization is 100 dB below the spectral peak. The width of this Gaussian spectrum is 2.5 m $s^{-1}$, and the horizontal scale is from -32 to 32 m $s^{-1}$,*

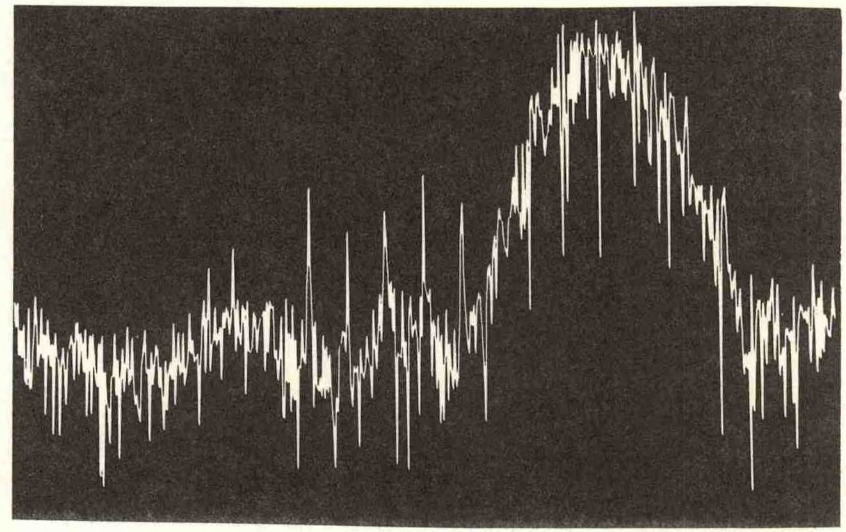


*Figure 11b. This spectrum resulted after the time series data for the spectrum shown on the left were up converted to 30 MHz and passed through the receiver chain, phase demodulator, and A/D converter. Slight image, harmonics, and a rise in noise level are evident.*

developed, installed and tested on the Norman radar (Mohd et al. 1980). The simulator uses a pseudo-random number generator to produce a weather-like power spectrum of desired shape with exponentially distributed power and uniform phases. Digital spectra are transformed and resulting time samples converted to analog form. The analog inphase and quadrature signals are combined and upconverted to 30 MHz and then passed through the receiver chain. A comparison of the spectra before and after passage through the receiver reveals the extent of various artifacts, such as amplitude and phase imbalances, clipping, saturation, receiver nonlinearities, and quantization noise. (Figs. 11a and b).

6. Study of a Ground Clutter Filter

Radar echo returns from ground targets interfere with identification of weather elements. Therefore, we have examined clutter cross section and spectrum width as a function of antenna rotation rate, with the Norman radar, with a view toward development of an improved device to filter out ground clutter. Our findings with simulated and real data indicate that a DC notch filter with variable width matched to the antenna rotation should achieve 50 dB clutter rejection in a notch of 1 to 8 m $s^{-1}$, and with a passband ripple of 1 dB.

Storm Electricity (William L. Taylor

1. Observational Effort

Relating lightning location and the many other facets of discharge processes with the precipitation and internal wind structure of severe storms is the primary task of the Storm Electricity Group (MacGorman and Taylor, 1979). Definitive results require exceptionally good data obtained simultaneously from a wide variety of sophisticated sensors (MacGorman et al. 1980). Storm structure is obtained from NSSL's dual Doppler radars while the lightning and electrical parameters are obtained from space-time mapping of VHF lightning processes, changes in the electric field, location of cloud-to-ground strike points, television and photographic pictures, acoustic location of channels, optical transients, corona currents, radar echoes from lightning and a mobile unit with a variety of sensors to observe severe storms from close range.

Cooperative programs were conducted during the past spring observational period with Dr. Roy Arnold of the University of Mississippi, Dr. Christopher Church of Purdue University (Church, 1979), Michael Maier of the National Hurricane and Experimental Meteorology Laboratory, Professor Gene Walker and Vladislav Mazur of the University of Oklahoma, Drs. Richard Orville and Bernard Vonnegut of State University of New York at Albany and Marx Brook of New Mexico Tech.

2. Recent Results

a. When we analyze the time sequence of arrival of VHF sources obtained by the space-time mapping technique, it is possible to delineate the intracloud lightning channel structure of a discharge (Taylor, 1980) as shown by the azimuth-elevation display in Figure 12. Individual sources are represented by circles and the line code connecting these change each 50 m s to assist in realizing how the discharge developed. Arrows are indicated on some lines where space permitted to show apparent direction of discharge movement. This discharge was not comprised of a single interconnected flow of current made up of many channels and branches, but was composed of several closely related discharges. Initiation points of the component discharges are shown by solid dots. The discharge progressed systematically from left to right with an average about $10^5$ m $s^{-1}$ and reveals lightning structure that was not identifiable prior to development of the VHF mapping system.

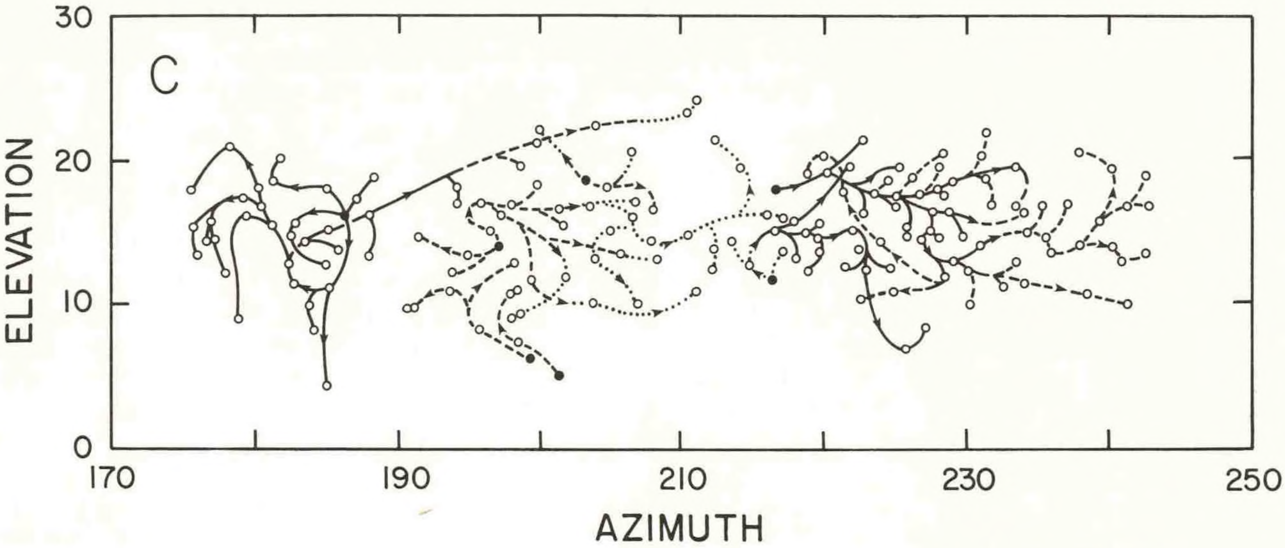



*Figure 12. Progression of intracloud lightning discharge processes.*

b. Although cloud-to-ground flashes (CG's) lowering positive charge to earth occur in nonsevere storms, their occurrence is generally limited to the dissipative stage in a storm's life cycle (Arnold and Rust, 1979). However, positive CG's have been observed in severe storms to emanate from the downwind anvil, the main storm tower under the upwind anvil, and the mesocyclone region. Evidence is mounting that the occurrence of positive CG's may be linked with shear.

c. Echoes from lightning channels identified with 10-cm Doppler radar have been detected to ranges of 180 km (Rust, 1980) and generally have peak signals 10-25 dB greater than the surrounding precipitation echo in the storm. Since very intense precipitation echoes at 10-cm wavelength can obscure the presence of lightning itself, and using the Doppler radar for detecting lightning requires an operational mode different from other observations, we have placed into operation a 23-cm conventional radar with circular polarization, which will greatly expand our capability to study lightning with radar. Using lightning echo observations in real time as a part of study of lightning hazards to aircraft we tracked a NASA instrumented 106B aircraft and successfully vectored the pilot into a storm region that resulted in a lightning strike to the aircraft.

A new effort in studying precipitation processes uses 10-cm Doppler radar with the antenna pointing vertically for storms moving overhead. Preliminary results indicate the lightning channel moves with the air motion or winds (as reported above in the Doppler Project section) which give us a means for measuring wind structure in clouds independent of precipitation particles. It also seems feasible to determine if changes in drop velocity occur after lightning has altered the electric field structure of the cloud. Such changes would indicate a direct connection between lightning and precipitation processes in a cloud and estimates could be made concerning electric charge on drops and changes in the growth rate of drops.

Mike Maier joined the group from ERL's National Hurricane and Experimental Meteorology Laboratory in Miami, Florida, and brought with him a multi-station direction finder for locating the ground strike points of lightning return strokes. The locations of these strike points are being related to storm precipitation structure and will be utilized in determining lightning climatology of Oklahoma.

## EXPECTATIONS FOR FY-1981

1. Field experiments during Spring 1981 will again emphasize storm electricity and prestorm environments. NASA scientists are expected at NSSL with a lidar equipped aircraft to evaluate lidar capabilities for wind mapping in clear air. Storm intercept and tracking with our mobile laboratory in cooperation with university scientists should continue to increase our knowledge of lightning and electrical phenomena in tornadic storms. Data for studies of storm feature lifetimes and lightning echoes will be collected and analyzed.

2. We expect to compare L-band radar lightning echoes with VHF space-time mapping of lightning. Optical and ELF waveforms from lightning will be recorded for analysis in cooperation with other agencies as part of the development of satellite sensors to detect cloud-to-ground discharges.

3. Improved lightning sensors should provide data necessary to a) further document the lowering of positive charge in lightning near mesocyclones prior to tornado development and b) more clearly reveal some of the interrelationships between lightning structure and the kinematic properties of storms. A four-station lightning ground strike locator should be functioning prior to the spring thunderstorm season to aid real-time tracking of storms, help identify which flashes strike ground, and to begin a lightning climatology study for Oklahoma.

4. Investigation of the planetary boundary layer will continue, and we will be emphasizing retrieval of wind field properties from single Doppler data, and triggering mechanisms of storms.

5. Relationships between turbulence in storms and Doppler spectral moments will be examined. Turbulence generating mechanisms will be investigated and gust fronts sensed by Doppler radar will be examined.

6. We are designing interfaces and developing programs for a signal processor for real-time identification of meteorological phenomena such as mesocyclones, tornadoes, and gust fronts.

7. We expect to continue theoretical and engineering studies towards better ground clutter canceler design, faster data acquisition, greater range of detection of winds in nonstormy skies and applications of polarization techniques for estimating the size and phase of hydrometers.

## OPERATION AND TECHNOLOGY TRANSFER GROUP

Kenneth E. Wilk, Group Leader

### INTRODUCTION

The Operations and Technology Transfer Group has had two functions: (1) During the severe storm season, staff have assisted in the calibration and operation of NSSL's radars, meteorological tower, 50-station surface network, and rawinsonde facilities, and (2) Staff have worked with representatives from the National Weather Service (NWS), Federal Aviation Administration (FAA), and Air Force Air Weather Service to develop and test operational techniques for advanced weather radar systems to detect and track thunderstorm regions which contain heavy rain, dangerous turbulence, damaging winds, and/or tornadoes. Toward the close of FY-80, Mr. Wilk and meteorologist David Zittel were transferred administratively to the NWS's Joint System Program Office; their workplace will continue to be at NSSL but their efforts will be directed toward implementation of a national network of meteorological Doppler radars. OTT functions have been assumed by other groups within NSSL, and the OTT personnel have been accordingly reassigned.

### RECENT ACCOMPLISHMENTS

As a result of the Joint Doppler Operational tests (JDOP) conducted in 1977, NSSL entered into an agreement with NWS's Joint System Program Office (JSPO) to establish a Radar Techniques Development Branch at the Laboratory. This branch was established in July, 1980 as a part of the newly formed JSPO which is directing development and procurement of the Next Generation Radar (NEXRAD).

Thus, activities in the Operations and Technology Transfer Group were split between maintaining field operations research, and preparing for reassignment of staff. In July, Ken Wilk and Dave Zittel transferred to the RTDB; Jean Lee transferred to the Advanced Techniques Group; Les Showell joined the Meteorological Research Group; and the remaining staff joined the Engineering Support Group. Most of the year the Meteorological Technicians continued data processing for Project SESAME and the 1980 Spring Program.

Twelve stations were operated in the Spring Program, to gather data for gust front studies. Also, arrangements were made to record data from six FAA anemometers in use at Will Rogers International Airport, Oklahoma City. These data were collected to aid in the synthesis of aircraft and Doppler radar data, as part of FAA-sponsored research on hazardous conditions in and around Airport Approach Zones.

Prior to his transfer to the RTDB, Dave Zittel directed the test and transfer of data from NSSL's Stationary Automated Meteorological (S.A.M.) stations. He developed numerous computer routines to calibrate the instruments and perform quality control checks on the SESAME project data sets.

In conjunction with NASA and FAA, a thunderstorm turbulence and lightning program was conducted by Jean Lee during the spring season. A union of the South Dakota School of Mines T-28 armored aircraft and an F-106 aircraft instrumented by NASA for lightning and turbulence measurement were used to obtain *in situ* measurements within a thunderstorm concurrently with Doppler radar observations. These data will be a basis for further assessment of Doppler radar's potential for identifying aviation weather hazards. A paper on this subject was presented to the 19th Conference on Radar Meteorology (Lee and Wilk, 1980).

A report to Federal Aviation Administration on weather radar interpretation of severe storms, and discussion of weather detection capabilities of FAA radars was accepted for printing by FAA.

## ENGINEERING SUPPORT AND DEVELOPMENT GROUP

Dale Sirmans, Group Leader

### INTRODUCTION

The Engineering Group provides engineering development, maintenance, and operations support for the National Severe Storms Laboratory. The Group develops techniques and equipment for support of evolving laboratory programs while maintaining existing systems and assisting in data acquisition and data quality control monitoring. The Group also provides engineering support to the storm electricity program and consultation to the Radar Techniques Development Branch (RTDB) of National Weather Service which is colocated with NSSL.

Major research facilities at NSSL consist of two 10-cm Doppler weather radars, a WSR-57 surveillance radar, an MPX-7 IFF Interrogator, a meteorologically instrumented 1500 foot tower (KTVY), and a surface network of 52 stations for meteorological observations.

### RECENT ACCOMPLISHMENTS

The Spring Program for FY-80 was configured primarily for support of the storm electricity program. There was a limited aircraft program and special projects including clear air observations and meteorological studies in support of in-house research and the NEXRAD program. Participation by organizations outside NSSL was small, but the in-house effort was essentially the same as in previous years.

Facilities engineering in FY-80 consisted of reconfiguration of the radar systems to support observations, addition of new equipment such as a hardcopy device for recording surface winds at the Will Rogers Airport Controller's Terminal, and deployment of a reduced surface network (13 stations).

Design and construction of a data acquisition and processing terminal for storm electricity studies was completed. This is a minicomputer-based terminal with sufficient memory and computational power to support real-time acquisition and recording of various storm electricity parameters as well as real-time data editing and analysis. Executive and analysis software for the system is being developed.

Two prototype photovoltaic power systems for the SAM stations were designed, fabricated and tested during FY-80 (Fig. 13). These tests established the validity of the design and allowed field evaluation of two sets of hardware, particularly the photovoltaic panels. Engineering and operational requirements of the system are well established and procurement of the hardware is underway.

During FY-1980, staff of the Engineering Support and Development Group designed and constructed a device for calculation of Doppler radar velocity for use on the NOAA P-3 aircraft tail radar. The device represented by the block diagram which is Fig. 14, has been delivered to Mr. Trotter of ERL's Weather Modification Program Office, for interfacing to a digital recorder system and integration into the airborne system.

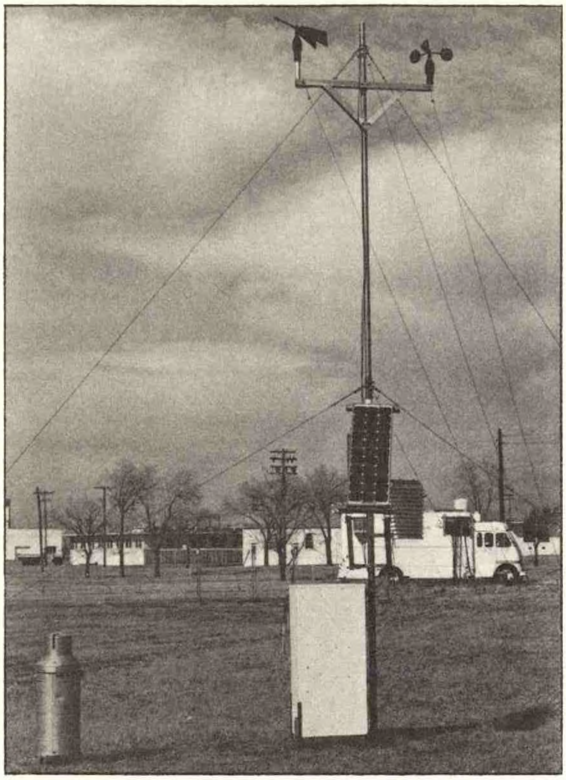


*Figure 13. NSSL SAM station for recording surface weather observations equipped with prototype photovoltaic power system. The photovoltaic panel is mounted on the tower above the equipment shelter and there is a voltage/current regulator, and 12 volt storage battery. The system will deliver 10 watts continuously and has a 200 amp-hour reserve.*

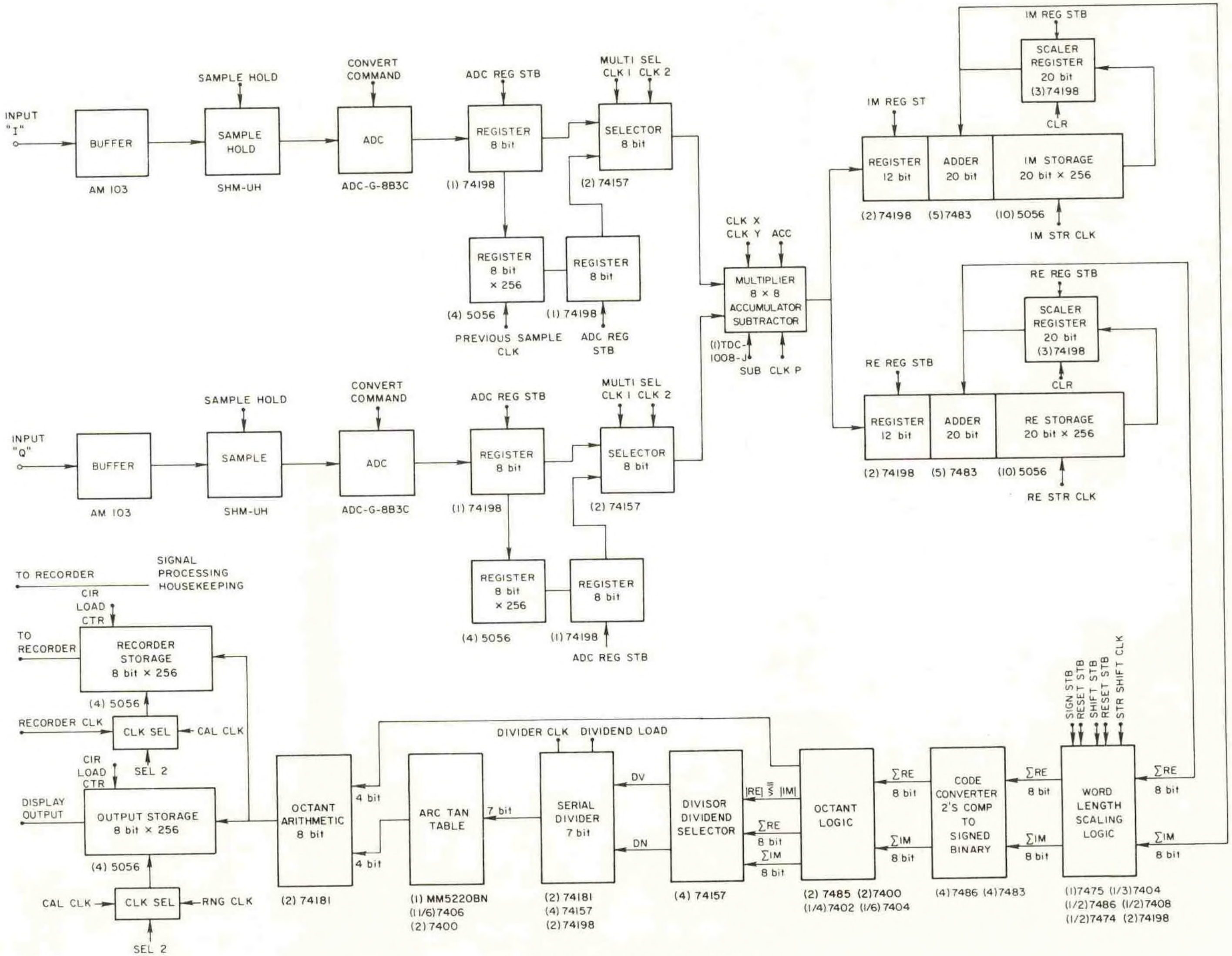
A study of characteristics of radar ground clutter and an evaluation of suppression techniques specifically applicable to incoherent radar systems was completed (Sirmans and Dooley, 1980). This study presents the behavior of distributed clutter targets at short ranges (less than 15 km for this site) and the stratification by spectral density of clutter into two general target types, one type fixed and the second a combination of fixed and moving targets. Several clutter cancellation schemes were simulated by computer and evaluated with real data. A simple two-pulse canceler allows recovery of about 55 percent of the weather echoes otherwise concealed by terrain echoes.

The Engineering Support Group continued to provide engineering consultation to the Joint System Project Office in support of the NEXRAD system development. An engineering study of the radar subsystem was made (Sirmans, 1980) and advice on NEXRAD system requirements and engineering is offered on a continuing basis.

## EXPECTATIONS FOR FY-81

Engineering development and support in FY-81 will, as in previous years, be concerned with two general missions, the Spring Data Acquisition Program and equipment development for special studies and general facilities upgrading.

The FY-81 NSSL Spring Program will--as in 1980--be configured primarily for support of storm electricity observations and research aircraft. Participation by outside agencies will be closely identified with the aircraft program, and their accommodation will require a longer scheduled operational period than has been usual. As in previous years, the program will require all NSSL facilities.




VELOCITY CALCULATOR

*Figure 14. Block diagram of the Doppler mean velocity calculator designed for the NOAA WP3D Aircraft tail radar. Numbers beneath the blocks are part number. For example, in 74198, 74 refers to the family TTL, transistor-transistor logic, industrial grade, and 198 refers to a shift register. These numbers are indexed in data books giving the specifications of solid-state, logical devices.*

Engineering development in progress which will culminate during FY-81 includes major upgrading of the NSSL air traffic control and weather surveillance radar system. This consists of replacement of the MPX-6 Interrogator, addition of an IFF Decoder, and addition of a signal processing and color display terminal. System design is complete and major hardware components are being procured.

Components of the Solar Power System for the SAM network will also be procured and the entire network deployed during FY-81.

Subject to identification of funding support, it is also planned to initiate major changes in the NSSL 10-cm Doppler radars. This will be the beginning of a five-year engineering development program which addresses not only the replacement of dated peripheral equipment on these radars but also major changes of basic systems in order to accommodate new research initiatives.

FY-1981 will be the first year for NSSL active support of the RTDB/JSPO in developing Doppler data handling and analysis techniques applicable to NEXRAD. The NSSL Doppler radar at Norman, Oklahoma will serve as the test bed for this effort.

## COMPUTER AND DATA PROCESSING GROUP

Bill Bumgarner, Group Leader

### INTRODUCTION

This group operates the NSSL computer system; develops application software for engineering and meteorological support; performs quality control of data, archives data, and disseminates data to outside groups; and maintains systems software for in-house computers. The Engineering Support and Development Group and CDP consult for selection of data acquisition and real-time processing equipment, evaluation of computer requirements, and recommendations for replacement hardware.

### RECENT ACCOMPLISHMENTS

Following the 1979 SESAME data collection period, a large effort was and is still being devoted to the final archival of the data. The WSR-57 radar archival produced 43 tapes; the rawinsonde data set consisted of 864 soundings residing on 12 magnetic tapes; and the instrumented KTVY tower produced seven blocked tapes. Rain gage data from the 185 station ARS network was digitized for selected cases.

In support of the 1980 collection program quality control runs and indexing were provided for this data set - Norman Doppler radar, 247 tapes; Cimarron Doppler, 90; wide-pulse Doppler tapes, 179; Doppler test tapes, 184; WSR-57 radar, 28; and instrumented tower tapes, 40. In addition, the four station rawinsonde network took 175 soundings and the NSSL surface network (SAM) operated 13 stations.

Meetings were held at NCAR to design and establish a universal exchange format for both radar and surface data. Represented were NSSL, NCAR, CHILL, WPL, PROFS, and the Water and Power Resources Services. Since that meeting NCAR has converted their tapes for May 2, 1979, to the new format and NSSL has successfully read and converted the data to the NSSL internal format.

The amount of data disseminated to universities and other government agencies has risen this year. The largest increases were for NSSL's Doppler radar data which is being used more since the 1979 SESAME project.

In cooperation with the University of Oklahoma and CIMMS, programs are being developed on a PDP 11/70 and VAX 11/780 computer to interactively unfold Doppler velocity data and to provide graphical displays of other parameters.

The final feasibility study for the ERL Computer Resources Management Plan was approved at the Department of Commerce level, and if funded in FY-82, NSSL will have a $750,000 replacement computer for the present SEL 8600 and IBM 1401. In parallel with this plan, NSSL is considering a proposal from CIMMS for the procurement of a small interactive computer to be located at NSSL for use by both CIMMS and NSSL scientists.

## DATA DISSEMINATION

October 1, 1979 - September 30, 1980

Data collected and processed at the National Severe Storms Laboratory is being used in basic studies and in university course work. Those receiving NSSL data and/or computer programs during the past year include:

Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts (Kenneth Glover)
Florida State University, Tallahassee, Florida (J. J. Stephens)
G.E./MATSCO, Beltsville, Maryland (Roy H. Blackmer, Jr.)
Illinois State Water Survey, Urbana, Illinois (Arthur Jameson)
MIT, Lincoln Laboratory, Lexington, Massachusetts (John Anderson)
Mitre Corp, McLean, Virginia (Pete Bergstrom)
NASA, Goddard Space Flight Center, Greenbelt, Maryland (Andrew J. Negri and Gerald Heymsfield)
National Center for Atmospheric Research, Boulder, Colorado (James Wilson and Joe Klemp)
NOAA/NWS TDL, Silver Spring, Maryland (Robert Saffle)
NOAA, Boulder, Colorado (Ron L. Alberty)
New Mexico Tech, Socorro, New Mexico (Raymond and Adrian Marroquin)
Northwestern University, Evanston, Illinois (Sam Meiri)
St. Louis University, Department of Earth and Atmospheric Sciences, St. Louis, Missouri (Robert Paskin)
Sperry Microwave Electronics, Clearwater, Florida (Charles A. Waldorff, Jr.)
Texas A&M University, Department of Meteorology, College Station, Texas (Daniel J. McMorrow)
Texas Tech University, Lubbock, Texas (Bruce D. Campbell)
University of Oklahoma, Meteorology Department, Norman, Oklahoma (Rex Inman)
University of Wisconsin, Madison, Wisconsin (Fred Mosher)
Water and Power Resources Services, Denver, Colorado (Richard Eddy for Robert Crane, ERT)

## EXPECTATIONS FOR FY-81

The procurement cycle will continue for purchase of a computer in FY-82. This effort includes agreeing on computer functional specifications among the ERL laboratories, the issuing of an RFP to the private sector, preparing benchmarks for evaluations, preparing the physical site for the anticipated computer replacement, and preparing and implementing a software conversion plan.

Radar data from both NSSL Doppler radars and the WSR-57 from the 1979 SESAME data sets and from 1980 will be made available in the universal format designed by the user community, for use both internally and externally. With the availability of NCAR and CHILL data in the new form, all scientists at all levels should have easy access to radar data.

# SPECIAL PROJECTS

Edwin Kessler

Here we discuss several projects on the fringe of NSSL's major work which this report emphasizes.

John Weaver of the NSSL's Meteorological Research Group had a short article published in Popular Mechanics on wind and home construction (1980). It explains how homes could be built better to withstand severe windstorms and tornadoes at low additional expense and has stimulated over 1,000 requests from the public for additional information.

Robert Davies-Jones and David Rust (1979) and Richard Doviak et al. (1979) wrote summary articles on "Thunderstorm" and "Storm Detection" for the McGraw-Hill Encyclopedia of Ocean and Atmospheric Sciences. These articles also appear in two other McGraw-Hill encyclopedias.

Meteorological conditions in the boundary layer, particularly the wind and the vertical gradient of wind and temperature, greatly influence the distribution of chemical sprays, much used in present agricultural practice. The paper by Kessler (1980) discusses some of the economic factors which promote extensive use of herbicides nowadays, and documents some damage pursuant to a use of 2,4-D when wind conditions were not properly accounted for. (There are thousands of papers on 2,4-D but very few on 2,4-D accidents.) In a subsequent study by Fred and Kessler (1980), reports of pesticide accidents in files of the Oklahoma Department of Agriculture are related to associated weather conditions as portrayed on National Weather Service's Daily Weather Map and to boundary layer winds and temperatures as revealed by data collected at the KTVY transmitter tower in Oklahoma City. Copies of the paper by Fred and Kessler were distributed with a memorandum prepared by the Chairman of the Oklahoma Pollution Control Coordinating Board and was cited in the discussion therein of regulations which govern aerial spray applications in Oklahoma. Don Fred is a student at the University of Oklahoma and is employed by CIMMS. He is working toward a master's degree in meteorology.

NSSL staff are pleased to have supported staff of the Air Resources Laboratory in an experiment to test diffusion models via sampling at distant points of the concentration of heavy-methane tracers released at ground level at Norman. J. Wardius, J. Weaver, L. Showell, J. T. Lee, and K. E. Wilk provided forecasts and real-time wind data from our tall tower, helped coordinate radiosonde releases at Tinker Air Force Base, and assisted with the mechanical set-up for controlled release of tracers. The experiment was successful with measurements of the tracer plume on both 100 km and 600 km sampling arcs. Controlled releases were conducted in 100 F+ temperatures on July 8th and 10th.

During FY-81, E. Kessler hopes to see, with important collaboration from ERL's Publications Office in Boulder, Colorado, all of the necessary editorial work completed on a typescript titled "Thunderstorms, A Social, Scientific, and Technological Documentary." This effort with contributions from 53 authors, has taken a substantial effort since 1976. We expect the work to be published by the U.S. Government Printing Office.

Also during FY-81, E. Kessler expects to be studying wind generated power in relation to site topography, meteorological factors, and electrical usage. Inputs to this study will be the metered outputs from three actual wind-driven generators within 35 km of NSSL, digital data from an NSSL surface station (colocated with one of the generators), statistical data from the WSFO climatological base station in Oklahoma City, and 15-minute data on electrical usage from a local substation. Two local electrical utilities are cooperating in this study.

# 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 and NOAA/ERL through the National Severe Storms Laboratory. CIMMS received first funding in late FY-78 and began major efforts during FY-79. CIMMS is modeled after other NOAA joint institutes on university campuses. The program objectives and activities of CIMMS should complement and supplement those at NSSL and the University through research conducted by Visiting Fellows, NOAA and University staff, and student appointees.

During its first two years CIMMS was led by Interim Director Rex L. Inman, also Head of the Department of Meteorology at the University of Oklahoma. During 1980, Dr. Yoshi K. Sasaki, George Lynn Cross Professor of Meteorology at O.U., was appointed Acting Director. The Council of Fellows which consults with the Acting Director concerning ongoing matters of policy, numbers four at present: Drs. Peter S. Ray and Dusan S. Zrnic' of NSSL, both of whom hold adjunct appointments at O.U., Dr. Inman of O.U. and Dr. John McCarthy, formerly professor at O.U. and now at the National Center for Atmospheric Research. The Advisory Council meets annually and includes several officials of NOAA, officers of the University of Oklahoma, and representatives of other government agencies and the academic community.

During FY-79, CIMMS hosted six visiting scientists from periods of a few days to a few months. Longest in residence was Dr. Kerry Emanuel of UCLA, whose comprehensive analyses of inertial motions and mesoscale convection were printed as reports of CIMMS, and more recently in the Journal of Atmospheric Sciences.

During FY-80, CIMMS produced two significant reports, the first a collection of lecture notes, "Dynamics of Mesometeorological Disturbances," which are proceedings of a symposium on that subject held from May 12th to 16th, 1980 and attended by approximately 70 meteorologists from around the United States. The second report is a comprehensive review by CIMMS Visiting Scientist N. Monji, "Laboratory Tornado Vortices." A third report in preparation by Dr. Steven Koch deals with storm initiation by gravity waves. Dr. Koch was a CIMMS Fellow in FY-80, and is now employed at NASA's Goddard Laboratory for Atmospheric Sciences. At this writing, CIMMS scientists Drs. Stephen Bloom, Donald R. McGorman, and Anthra Sundararajan, are developing projects in areas of mesoscale dynamics, boundary layer phenomena and storm electricity. Other projects in CIMMS, with funding from non-NOAA sources, include wind loading on electrical transmission lines, and three-dimension satellite data assimilation.

The outlook for FY-81 in CIMMS is bright. There are several highly worthy applicants, there are plans for a CIMMS lecture series in 1981 as a follow-on to the successful 1980 Symposium, and there is now a cadre of bright students in CIMMS, transferred from NSSL during 1979 along with funds for their continued support as research assistants working toward graduate degrees.

## ADMINISTRATION

Loyce Tillman, Project Manager

### PERSONNEL

At the end of FY-80 the NSSL had a staff of 40 full-time, four part-time, two COOP's, one Junior Fellow and 22 intermittent employees.

Our personnel staff continues to be supplemented by contracts with the University of Oklahoma and Computer Engineering Associates, Inc., of Avon, MA.

### FACILITIES

In August, 1972, NSSL occupied a new two-story reinforced concrete and glass building leased from the University of Oklahoma at a cost of approximately $120,000 annually. The building contains about 20,000 square feet and is situated on approximately one and one-half acres of land.

Two relocatable structures (14' x 46' workspace) are also located on the above leased land. One building is used as a central facility adjacent to the Doppler Radar Laboratory Building. The other one is used to house lightning equipment for our Storm Electricity Project.

Other space rented from the University of Oklahoma includes:

a) A warehouse containing 3,840 sq. ft. of usable space.

b) Ground space of 718 sq. ft. for a rawinsonde facility.

c) Ground space of 17,280 sq. ft. adjacent to the new quarters, with the Doppler Radar Laboratory Building owned by NSSL, plus a tower supporting a rangefinder.

d) Ground space of 17,820 sq. ft. north and across the street from the NSSL, with the following facilities:

   1) small modulator building;
   2) WSR-57 radar atop a 20-meter tower;
   3) a second tower with UHF and VHF radio antennae;
   4) a third tower, with IFF equipment (MPX-7 radar) to interrogate transponders aboard aircraft to determine aircraft position.

e) Ground space of 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.)

f) Ground space of 120,000 sq. ft. of land used for placement of sensors to measure various parameters of storm electricity. Located on ground space is a 800 sq. ft. portable building used by NSSL personnel for observations and data acquisition.

Total cost for all of the leases in items a through f above is approximately $8,000 annually.

Additional leased space includes:

h) One acre of land leased from Will Rogers Airport Trust at Cimarron, Oklahoma, about 45 kilometers northwest of Norman containing a second Doppler radar unit.

i) Leased space at Chickasha, Oklahoma containing a rawinsonde site and mesonetwork equipment.

j) Levels at the 457 meter KTVY Television Systems, Inc. tower, Oklahoma City, Oklahoma, 40 kilometers north of Norman. During most of FY-80, wind and temperature sensors were operated at seven levels on the tower with vertical wind at top and bottom, and digital data on 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.

k) During the NSSL's 1980 Spring Program, an additional 0.5 acre of land was leased at Cimarron, Oklahoma for use as a storm electricity data collection site.

l) Land agreements for 52 network sites.

Total annual cost for all items h through l above is approximately $28,000.

## OTHER

In 1978, the NSSL acquired from GSA surplus, a one-acre parcel of land in Garfield County to be used as an observational site. An existing building (22' x 16') is used to store supplies needed for rawinsondes and as an operational office area.

## GRANTS AND CONTRACTS

NSSL is the cognizant or monitoring office for certain grants and system contracts started or renewed during FY 1980 and listed below. These were funded both directly from the NSSL budget and from funds of other agencies. The aggregate amount of the grants is $138,219.00 and the listed contracts total $461,271.82.

| Description | Number | NSSL Cognizant Officer | Start Date | Term Date |
|---|---|---|---|---|
| | GRANTS | | | |
| University of Oklahoma "Radar Studies of Lightning in Thunderstorms" (Walker) | NA80RAD00002 ($12,754.00) | Rust | 10-1-79 | 9-30-80 |
| University of Oklahoma "Research on Severe Local Storms" (Inman) | 04-6-022-44035 ($26,113.00) | Ray | 9-1-79 | 9-30-80 |
| University of California "Mesoscale Convection Systems" (Emanuel) | NA80RAD00017 ($3,370.00) | Ray | 7-1-80 | 10-31-80 |
| University of Mississippi "Research on Severe Storms Electricity" (Arnold) | NA80RAD00008 ($38,737.00) | Rust | 4-1-80 | 9-30-80 |
| University of Mississippi "Determination of Tornado Wind Speeds from Tornadic Sounds" (Arnold) | NA80RAD00008 ($9,992.00) | Rust | 3-1-80 | 9-30-80 |
| University of Mississippi "Field Operations Expenses for the Mobile Atmospheric Electricity Laboratory" (Arnold) | NA80RAD00002 ($6,165.00) | Rust | 1-1-80 | 12-31-80 |

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| Purdue University "A Field Investigation of Electric Currents Associated with Severe Local Storms." (Church) | NA79RAD00014 ($5,727.00) | Rust | 1-1-80 | 12-31-80 |
| Purdue University "Research on Severe Local Storms" (Agee) | 04-4-022-15 ($7,000.00) | Ray | 9-1-80 | 8-31-80 |
| University of Illinois Urbana-Champaign "Storm Modelling and the Use of Observational Data" (Wilhelmson) | NA80RAD00005 ($8,000.00) | Ray | 10-1-79 | 9-30-80 |
| University of Toronto "Hail and Severe Storms Modeling" (List) | NA80RAD00024 ($10,400.00) | Nelson | 8-1-80 | 7-31-80 |
| University of Washington "Studies of Severe Convective Storms: (Houze) | NA80RAD00025 ($9,961.00) | Ray | 9-15-80 | 9-15-81 |

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|---|---|---|
| NOAA | $ | 63,377.00 |
| OTHER AGENCY | | |
| FAA | $ | 2,000.00 |
| NASA | | 38,737.00 |
| NRC | | 34,105.00 |
| TOTAL | $ | 74,842.00 |
| GRAND TOTAL | $ | 138,219.00 |

| Description | Number | NSSL Cognizant Officer | Start Date | Term Date |
|---|---|---|---|---|
| | CONTRACTS | | | |
| Applied Computer Systems "Services for Facilities Management to Operate NSSL Computer Equipment" | NA80RAA02430 ($28,108.59) | Bumgarner | 10-1-79 | 6-1-80 |
| Computer Engineering Associates, Inc. "Services for Facilities Management to Operate NSSL Computer Equipment" | NA80RAE00036 ($49,992.50) | Bumgarner | 6-2-80 | 9-30-80 |
| Systems Engineering Laboratories "Lease and Maintenance of Computer." | NA80RAE00032 ($68,772.00) | Bumgarner | 10-1-79 | 9-30-80 |
| U.S. Air Force, Tinker, OK "6th Weather Squadron (Mobile) support to NSSL Spring Program" | NA80RAA2418 ($4,702.32) | Lee | 5-1-80 | 6-15-80 |
| Environmental Research & Technology, Inc. "Radar Analyses for Severe Weather Detection, Tracking and Prediction, and Depiction" | NA80RAC00110 ($76,512.00) | Wilk | 4-1-80 | 3-31-80 |
| University of Oklahoma "Cooperative Institute for Mesoscale Meteorological Studies" | NA80RAH00004 ($261,293.00) | Kessler | 10-1-80 | 9-30-81 |

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| NOAA FUNDING | $380,057.50 |
| OTHER AGENCY | |
| FAA | 81,214.32 |
| TOTAL FUNDING | $461,271.82 |

PUBLICATIONS AND REPORTS OF THE LABORATORY

October 1, 1979 - September 30, 1980

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Fred, D., and E. Kessler, 1980: Pesticide accidents in relation to weather conditions. Environmental Conservation, 7(3) Autumn, 219-222.

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Johnson, K. W., B. C. Johnson, P. S. Ray, J. S. Bradberry, and K. K. Wagner, 1980: Vorticity development in two tornadic storms. Preprints, 19th Conf. on Radar Meteorology, April 15-18, Miami, Fla., Am. Meteorol. Soc., Boston, Mass., 328-334.

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Nelson, S. P., and M. L. Weible, 1980: Three-dimensional Shuman filter. J. Appl. Meteorol., 19(4), April, 464-469.

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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
COOP - ALTERNATE BETWEEN WORK (25 WKS. MIN.) AND STUDY TIME

7 January 1981

# HIGHLIGHTS OF NSSL DEVELOPMENT

| | |
|---|---|
| 1955 | National Severe Local Storms Research Project established in Kansas City, Missouri. |
| 1961 | NSLSRP renamed National Severe Storms Project. |
| 1962 | NSSP field site established at Norman, Oklahoma. Facility work started. |
| 1963 | Some NSSP staff transferred from Kansas City, Missouri to Norman, Oklahoma. |
| 1964 | NSSP at Kansas City becomes NSSL at Norman, Oklahoma; programmatic focus on aircraft-based studies and technique development for aviation community. |
| 1964 | Development of a 3-cm Doppler radar for weather studies started at NSSL. |
| 1965 | NSSL transferred from USWB to Institute of Atmospheric Sciences, Environmental Science Services Administration, formed from USWB and groups from other agencies. |
| 1965-1968 | Essential instrumentation installed on the tall tower of WKY-TV (KTVY in 1980); at 457 meters, this is the tallest meteorologically instrumented tower in the United States. |
| 1965-1969 | Major development of digital recording and processing techniques for radar data. |
| 1969 | Publication of theory relating distributions of air flow and water substance. |
| 1969-1973 | Engineering development and installation of 10-cm Doppler weather radars at Norman and at Cimarron Field, Oklahoma. |
| 1970 | NSSL transferred to NOAA's Environmental Research Laboratories, formed from ESSA components and groups from some other agencies. |
| 1972 | New headquarters building occupied by NSSL and new computer facility installed. |
| 1972 | Landmark publication on tornado simulator, an important foundation for expanded studies by the meteorological community on tornado dynamics. |
| 1972 | Tornado and severe storm intercept program established using motor vehicles. |
| 1973 | First real-time display of digitally produced Doppler velocity and first measurement of tornado Doppler spectra. |

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| 1973-1977 | First measurements of the vertical extent and development of mesocyclones. |
| 1974 | First dual Doppler analysis of a tornadic storm. |
| 1974 | Significant reorganization of NSSL involving consolidation of the reporting chain with reduction of administrative components from seven to five. The new units were Meteorological Research, Operations, Advanced Techniques, Computing and Data Processing, and Administration. |
| 1975-1977 | Theoretical analysis and simulation of fast processing algorithms for mean velocity and spectrum width estimation. |
| 1975-1979 | Development of SESAME, with major field program in 1979, involving dozens of universities, agencies, and offices, managed from NSSL. |
| 1976 | First triple-Doppler analysis of a storm to be published and first report on use of NSSL Doppler radars for determination of winds in optically clear air. |
| 1976 | Establishment of COMPASS (Cooperative Observational and Modeling Project for the Analysis of Severe Storms). This brought laboratory and outside investigators together to relate numerical modeling and observations of storms more closely. |
| 1976-1979 | Joint Doppler Operational Project, cooperative project managed by NSSL with participation of National Weather Service, Air Force Geophysics Laboratory, Air Weather Service, and FAA. Three of NSSL's staff honored with Department of Commerce Silver Medals for contributions to Doppler radar and its applications. |
| 1977 | Consolidation of ERL's storm electricity research at NSSL with transfer of two scientists to NSSL from Boulder, Colorado. Establishment of Storm Electricity Project within Advanced Techniques Branch at NSSL. |
| 1977-1980 | Surface station equipment with digital recording designed, fabricated and deployed. |
| 1978 | Transfer of some personnel from Advanced Techniques and Operations groups to form Engineering Support group at NSSL. |
| 1978 | Relationship between Doppler spectrum width and turbulence established experimentally with radar and aircraft. |
| 1978 | Establishment of Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at the University of Oklahoma. |
| 1979 | Implementation of real-time color displays of reflectivity, velocity and spectrum width. |
| 1980 | JDOP recognized by National Society of Professional Engineers. |

1980 National Weather Service's Radar Techniques Development Branch activated at NSSL to guide operational implementation of techniques for storm identification, measurement of rainfall by radar, and "nowcasting" and to facilitate introduction of NEXRAD nationally; phaseout of NSSL's Operations and Technology Transfer group and transfer of personnel to NWS.

1980 Significant syntheses of observations and analyses of distributions of wind, water, and electricity in storms, and of winds in optically clear planetary boundary layer.

1981 J. T. Lee of NSSL staff receives Losey Award of the American Institute of Aeronautics and Astronautics, for contributions to safety of flight.

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 $3.50 or a hard copy, cost depending 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. B. B. Goddard. 34 p. (PB-168208)

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

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

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

No. 6 Index to the NSSP Surface Network. T. 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)

No. 8 Radar Observations of a Tornado Thunderstorm in Vertical Section. Ralph J. Donaldson, Jr. April 1962. 21 p. (PB-174859)

No. 9 Dynamics of Severe Convective Storms. Chester W. Newton. July 1962. 44 p. (PB-163319)

No. 10 Some Measured Characteristics of Severe Storms Turbulence. Roy Steiner and Richard H. Rhyne. July 1962. 17 p. (N62-16401)

No. 11 A Study of the Kinematic Properties of Certain Small-Scale Systems. D. T. Williams. October 1962. 22 p. (PB-168216)

No. 12 Analysis of the Severe Weather Factor in Automatic Control of Air Route Traffic. W. Boynton Beckwith. December 1962. 67 p. (PB-168217)

No. 13 500-Kc./Sec. Sferics Studies in Severe Storms. Douglas A. Kohl and John E. Miller. April 1963. 36 p. (PB-168218)

No. 14 Field Operations of the National Severe Storms Project in Spring 1962. L. D. Sanders. May 1963. 71 p. (PB-168219)

No. 15 Penetrations of Thunderstorms by an Aircraft Flying at Supersonic Speeds. G. P. Roys. Radar Photographs and Gust Loads in Three Storms of 1961 Rough Rider. Paul W. J. Schumacher. May 1963. 19 p. (PB-168220)

No. 16 Analysis of Selected Aircraft Data from NSSP Operations, 1962. T. Fujita. May 1963. 29 p. (PB-168221)

No. 17 Analysis of Methods for Small-Scale Surface Network Data. D. T. Williams. August 1963. 20 p. (PB-168222)

No. 18 The Thunderstorm Wake of May 4, 1961. D. T. Williams. August 1963. 23 p. (PB-168223)

No. 19 Measurements by Aircraft of Condensed Water in Great Plains Thunderstorms. George P. Roys and Edwin Kessler. July 1966. 17 p. (PB-173048)

No. 20 Field Operations of the National Severe Storms Project in Spring 1963. J. T. Lee, L. D. Sanders, and D. T. Williams. January 1964. 68 p. (PB-168224)

No. 21 On the Motion and Predictability of Convective Systems as Related to the Upper Winds in a Case of Small Turning of Wind with Height. James C. Fankhauser. January 1964. 36 p. (PB-168225)

No. 22 Movement and Development Patterns of Convective Storms and Forecasting the Probability of Storm Passage at a Given Location. Chester W. Newton and James C. Fankhauser. January 1964. 53 p. (PB-168226)

No. 23 Purposes and Programs of the National Severe Storms Laboratory, Norman, Oklahoma. Edwin Kessler. December 1964. 17 p. (PB-166675)

No. 24 Papers on Weather Radar, Atmospheric Turbulence, Sferics and Data Processing. August 1965. 139 p. (AD-621586)

No. 25 A Comparison of Kinematically Computed Precipitation with Observed Convective Rainfall. James C. Fankhauser. September 1965. 28 p. (PB-168445)

No. 26 Probing Air Motion by Doppler Analysis of Radar Clear Air Returns. Roger M. Lhermitte. May 1966. 37 p. (PB-170636)

No. 27 Statistical Properties of Radar Echo Patterns and the Radar Echo Process. Larry Armijo. May 1966. The Role of the Kutta-Joukowski Force in Cloud Systems with Circulation. J. L. Goldman. May 1966. 34 p. (PB-170756)

No. 28 Movement and Predictability of Radar Echoes. James Warren Wilson. November 1966. 30 p. (PB-173972)

No. 29 Notes on Thunderstorm Motions, Heights, and Circulations. T. W. Harrold, W. T. Roach, and Kenneth E. Wilk. November 1966. 51 p. (AD-644899)

No. 30 Turbulence in Clear Air Near Thunderstorms. Anne Burns, Terence W. Harrold, Jack Burnham, and Clifford S. Spavins. December 1966. 20 p. (PB-173992)

No. 31 Study of a Left-Moving Thunderstorm of 23 April 1964. George R. Hammond. April 1967. 75 p. (PB-174681)

No. 32 Thunderstorm Circulations and Turbulence from Aircraft and Radar Data. James C. Fankhauser and J. T. Lee. April 1967. 32 p. (PB-174860)

No. 33 On the Continuity of Water Substance. Edwin Kessler. April 1967. 125 p. (PB-175840)

No. 34 Note on the Probing Balloon Motion by Doppler Radar. Roger M. Lhermitte. July 1967. 14 p. (PB-175930)

No. 35 A Theory for the Determination of Wind and Precipitation Velocities with Doppler Radars. Larry Armijo. August 1967. 20 p. (PB-176376)

No. 36 A Preliminary Evaluation of the F-100 Rough Rider Turbulence Measurement System. U. O. Lappe. October 1967. 25 p. (PB-177037)

No. 37 Preliminary Quantitative Analysis of Airborne Weather Radar. Lester P. Merritt. December 1967. 32 p. (PB-177188)

No. 38 On the Source of Thunderstorm Rotation. Stanley L. Barnes. March 1968. 28 p. (PB-178990)

No. 39 Thunderstorm - Environment Interactions Revealed by Chaff Trajectories in the Mid-Troposphere. James C. Fankhauser. June 1968. 14 p. (PB-179659)

No. 40 Objective Detection and Correction of Errors in Radiosonde Data. Rex L. Inman. June 1968. 50 p. (PB-180284)

No. 41 Structure and Movement of the Severe Thunderstorms of 3 April 1964 as Revealed from Radar and Surface Mesonetwork Data Analysis. Jess Charba and Yoshikazu Sasaki. October 1968. 47 p. (PB-183310)

No. 42 A Rainfall Rate Sensor. Brian E. Morgan. November 1968. 10 p. (PB-183979)

No. 43 Detection and Presentation of Severe Thunderstorms by Airborne and Ground-based Radars: A Comprehensive Study. Kenneth E. Wilk, John K. Carter, and J. T. Dooley. February 1969. 56 p. (PB-183572)

No. 44 A Study of a Severe Local Storm of 16 April 1967. George Thomas Haglund. May 1969. 54 p. (PB-184970)

No. 45 On the Relationship Between Horizontal Moisture Convergence and Convective Cloud Formation. Horace R. Hudson. March 1970. 29 p. (PB-191720)

No. 46 Severe Thunderstorm Radar Echo Motion and Related Weather Events Hazardous to Aviation Operations. Peter A. Barclay and Kenneth E. Wilk. June 1970. 63 p. (PB-192498)

No. 47 Evaluation of Roughness Lengths at the NSSL-WKY Meteorological Tower. Leslie D. Sanders and Allen H. Weber. August 1970. 24 p. (PB-194587)

No. 48 Behavior of Winds in the Lowest 1500 ft in Central Oklahoma: June 1966-May 1967. Kenneth C. Crawford and Horace R. Hudson. August 1970. 57 p. (N71-10615)

No. 49 Tornado Incidence Maps. Arnold Court. August 1970. 76 p. (COM-71-00019)

No. 50 The Meteorologically Instrumented WKY-TV Tower Facility. John K. Carter. September 1970. 18 p. (COM-71-00108)

No. 51 Papers on Operational Objective Analysis Schemes at the National Severe Storms Forecast Center. Rex L. Inman. November 1970. 91 p. (COM-71-00136)

No. 52 The Exploration of Certain Features of Tornado Dynamics Using a Laboratory Model. Neil B. Ward. November 1970. 22 p. (COM-71-00139)

No. 53 Rawinsonde Observation and Processing Techniques at the National Severe Storms Laboratory. Stanley L. Barnes, James H. Henderson and Robert J. Ketchum. April 1971. 245 p. (COM-71-00707)

No. 54 Model of Precipitation and Vertical Air Currents. Edwin Kessler and William C. Bumgarner. June 1971. 93 p. (COM-71-00911)

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No. 56 Pilot Chaff Project at the National Severe Storms Laboratory. Edward A. Jessup. November 1971. 36 p. (COM-72-10106)

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No. 60 Simulated Real Time Displays of Velocity Fields by Doppler Radar. L. D. Hennington and G. B. Walker. November 1972. 10 p. (COM-73-10515)

No. 61 Gravity Current Model Applied to Analysis of Squall-Line Gust Front. Jess Charba. November 1972. 58 p. (COM-73-10410)

No. 62 Mesoscale Objective Map Analysis Using Weighted Time-Series Observations. Stanley L. Barnes. March 1973. 60 p. (COM-73-10781)

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No. 69 Papers on Oklahoma Thunderstorms, April 29-30, 1970. Stanley L. Barnes, Editor. May 1974. 147 p. (COM-74-11474/AS)

No. 70 Life Cycle of Florida Key's Waterspouts. Joseph H. Golden. June 1974. 147 p. (COM-74-11477/AS)

No. 71 Interaction of Two Convective Scales Within a Severe Thunderstorm: A Case Study and Thunderstorm Wake Vortex Structure and Aerodynamic Origin. Leslie R. Lemon. June 1974. 43 p. (COM-74-11642/AS)

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No. 73 Severe Rainstorm at Enid, Oklahoma - October 10, 1973. L. P. Merritt, K. E. Wilk, and M. L. Weible. November 1974. 50 p. (COM-75-10583/AS)

No. 74 Mesonetwork Array: Its Effect on Thunderstorm Flow Resolution. Stanley L. Barnes. October 1974. 16 p. (COM-75-10248/AS)

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No. 79 Subsynoptic Scale Dynamics As Revealed By The Use Of Filtered Surface Data. Charles A. Doswell III. December 1976. 40 p. (PB-265433/AS)

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No. 81 Mesocyclone Evolution and Tornado Generation Within the Harrah, Oklahoma Storm. Edward A. Brandes. May 1977 28 p. (PB-271675/AS)

No. 82 The Tornado: An Engineering-Oriented Perspective. Joseph E. Minor, James R. McDonald, and Kishor C. Mehta. December 1977. 196 p. (PB-281860/AS)

No. 83 Spring Program '76. R. L. Alberty, J. F. Weaver, D. Sirmans, J. T. Dooley, and B. Bumgarner. December 1977. 130 p. (PB280745/AS)

No. 84 Spring Program '77. P. S. Ray, J. Weaver, and NSSL Staff. December 1977. 173 p. (PB-284953/AS)

No. 85 A Dual-Doppler Variational Objective Analysis as Applied to Studies of Convective Storms. Conrad L. Ziegler. November 1978. 116 p. (PB-293581/AS)

No. 86 Final Report on the Joint Doppler Operational Project (JDOP) 1976-78. Prepared by Staff of the National Severe Storms Laboratory, Environmental Research Laboratories; Weather Radar Branch, Air Force Geophysics Laboratory; Equipment Development Laboratory, National Weather Service; and Air Weather Service, United States Air Force. March 1979. 84 p. (PB80-107188/AS)

No. 87 An Analysis of the Clear Air Planetary Boundary Layer Wind Synthesized from NSSL's Dual Doppler-Radar Data. Myron I. Berger and R. J. Doviak. June 1979. 55 p. (PB-300865/AS)

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