COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES
THE UNIVERSITY OF OKLAHOMA

Annual Report 2000:

FY 2000 Progress/FY 2001 Plans

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The University of Oklahoma (OU) and NOAA established the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) in 1978. Through mid-1995, CIMMS promoted cooperation and collaboration on problems of mutual interest among research scientists in the NOAA Environmental Research Laboratories (ERL) National Severe Storms Laboratory (NSSL), and faculty, postdoctoral scientists, and students in the School of Meteorology and other academic departments at OU.

The Memorandum of Agreement (MOA) between OU and NOAA that established CIMMS was then updated in 1995 to include the National Weather Service (NWS). This expanded the formal OU/NOAA collaboration to the Operational Support Facility (OSF) for the WSR-88D (NEXRAD) Program, the NCEP (National Centers for Environmental Prediction) Storm Prediction Center (SPC), and the NWS Forecast Office, all located on the OU campus in Norman, Oklahoma. Management of the NSSL also came under the NOAA Office of Atmospheric Research (OAR) in 1999. The Norman NOAA groups are known as the NOAA Weather Partners. In the new cooperative agreement to take effect in 2001, it is anticipated that NOAA/NESDIS, and specifically the National Climatic Data Center, will become a formal CIMMS partner to work on historical climatologies.

Through CIMMS, OU faculty and NOAA OAR/NWS scientists collaborate on research supported by NOAA programs and laboratories as well as other agencies such as the National Science Foundation (NSF), the U.S. Department of Energy (DOE), the Federal Aviation Administration (FAA), and the National Aeronautics and Space Administration (NASA).

The present 5-year cooperative agreement between OU and NOAA for CIMMS funding took effect on July 1, 1996. Under this agreement, CIMMS concentrates its efforts and resources on the following five principal research themes, the fifth of which is new under the current plan: (1) basic convective and mesoscale research, (2) forecast improvements, (3) climate effects of/controls on mesoscale processes, (4) socioeconomic impacts of mesoscale weather systems and regional-scale climate variations, and (5) Doppler weather radar research and development.

This document describes research progress made by CIMMS scientists assigned at OU and at our cooperative NOAA units during fiscal year 2000 (July 1, 1999 through June 30, 2000) and presents research plans for fiscal year 2001 (July 1, 2000 through June 30, 2001), and as such represents the fourth annual report written under the present agreement. The NOAA units where much of the research documented here was performed are indicated as throughout.

1. RESEARCH PROGRESS AND PLANS

BASIC CONVECTIVE AND MESOSCALE RESEARCH

Progress - FY 00

Parameterization of Cloud Microphysics and Radiation

A new integral moment microphysics parameterization for stratiform clouds has been developed by the CIMMS Cloud Physics group for cases of moderate and heavy drizzle. This bulk parameterization has been implemented into the CIMMS LES model and its performance evaluated by comparing it with benchmark explicit microphysical simulations. An important part of the parameterization is the link between the ambient aerosol load and cloud microstructure. It was found that the composition of atmospheric aerosol, its non-sea salt (sulfate) aerosol fraction and the shape of the ambient sulfate aerosol spectrum all have a strong effect on cloud microphysical and radiative parameters. Accounting for these parameters in NWP model parameterizations is an important task for cloud and precipitation forecast improvement.

The second thrust of the project was the development of cloud drop effective radius parameterization for drizzling marine stratocumulus. In case of moderate drizzle, a quite accurate two-variable parameterization can be used. For heavy drizzle, however, only a three-variable parameterization proves to be sufficiently accurate. A unified form of the parameterization for all drizzle cases, which can be conveniently used in mesoscale models, has also been formulated. It is concluded that a three-variable full moment parameterization provides the most accurate representation of effective radius in precipitating stratocumulus clouds. The effective radius parameterization study has now been completed; its results were presented at AGU and ARM meetings and at the 13th International Conference on Clouds and Precipitation. These results were also submitted for journal publication.

Development of Cloud Microphysics Retrieval Algorithms

The performance of a number of cloud liquid water (W) retrieval algorithms based on various Z - W power-law relationships has been evaluated by the CIMMS Cloud Physics group. Two case studies were considered: a marine stratocumulus layer observed during the ASTEX program on June 12, 1992 and a continental stratus layer observed during the ARM field experiment on April 30, 1994. It is shown that algorithms based on radar reflectivity alone are not capable of adequately retrieving the horizontally averaged vertical profile of cloud liquid water content. The knowledge of the exact cloud droplet concentration does not necessarily improve the retrieval, either, as the errors in these cases are related mostly to the assumption of a prescribed width of the droplet size distribution. The retrieval algorithms can be refined through introduction of an additional constraint based on the independently measured liquid water path. We were able to find the parameters that provide the most accurate retrieval results. Horizontal averaging of liquid water path over the domain of several kilometers does not affect the accuracy of the retrieval. This justifies the use of the algorithm with a passive microwave radiometer even when it has a wider field of view and uses longer averaging times than millimeter-wavelength cloud radars.

The Effects of Horizontal Radiative Transport on Cloud Absorption

The spectral dependence of the radiative horizontal transport and its effect on the accuracy of near-infrared absorption retrieval was investigated by the CIMMS Cloud Physics group using an LES cloud model with explicit microphysics and a 3D Monte Carlo radiative transfer model. Using measurements made during the ASTEX observational campaign, a field of highly inhomogeneous broken stratocumulus clouds with approximately 50% coverage was simulated. It was found that the small-scale (~100 m) variance of the radiative horizontal transport depends significantly on the wavelength. The cloud droplet absorption at λ=1.65 μ leads to the increase in the variance of horizontal transport, *var (E)*, at some cloud locations by as much as 20%. The water vapor absorption at λ=0.94 decreases the *var (E)* by as much as 15%. As a result, estimates of spectral absorption in the near-infrared using the values of horizontal transport outside the absorption interval (e.g., in the visible range) may be quite inaccurate with errors at some locations as large as 100%. In the studied case of a broken cloud field, a much weaker spectral dependence of horizontal transport and a more accurate absorption estimate can be obtained by averaging cloud radiative parameters on a scale of about 500 m.

Mesoscale Dynamics

The viscous semigeostrophic (SG) solutions obtained for the baroclinic Eady wave fronts with two types (free-slip and non-slip) of boundary conditions were analyzed by CIMMS and NSSL scientists in terms of generation of cross-frontal temperature gradient in the boundary layer. The non-slip semigeostrophic solution was compared with the Ekman-layer model solution to quantify errors in the vertical motion estimated by the Ekman-pumping in the frontal boundary layer during the mature stage of the frontogenesis (near and after the time of inviscid frontal collapse).

Unbalanced dynamics were studied in terms of departures from viscous semigeostrophy (SG) in baroclinic Eady wave and fronts. The unbalanced perturbation was found to be generated mainly by a vector forcing defined by the SG Lagrangian time derivatives of two ageostrophic wind components in the cross-frontal and along-frontal directions. In the case of free-slip boundary condition, the along-frontal wind forcing is weaker than the cross-frontal one and the unbalanced perturbations are generated largely as a linear response in the form of inertial gravity waves to the forcing. In the case of nonslip boundary condition, the along-frontal wind-forcing component is slightly stronger than the cross-frontal forcing, but the unbalanced perturbations are generated in the form of enhanced planetary-boundary-layer pumping immediately ahead of the front and in the form of inertial gravity waves in the warm sector further away from the front.

Mesonet Data Assimilation

A new variational method was developed by CIMMS and NSSL scientists for Doppler radar data assimilation in combination with other observations. The method uses a set of mesoscale model equations as weak constraints. The equations are discretized in time using an implicit scheme to synchronize the model's time steps with the radar volume scans. The assimilation is cycled every model time step in association with each new volume scan. The method is tested with simulated radar data. It is found that the adjusted fields can reach high accuracy if the observations, model constraints and initial fields are sufficiently accurate.

A single-Doppler radar data assimilation package was incorporated into the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS, developed by the Naval Research Laboratory). This package performs three tasks: radar data quality control, three-dimensional wind retrieval, and thermodynamic retrieval. The quality control corrects radial velocity errors caused by range folding and velocity aliases. The wind and thermodynamic retrievals make variational adjustments to model produced background fields that minimize the cost function constrained by radar observations and model equations. The package was successfully tested with real Doppler radar data for the 7 May 1995 Oklahoma squall line case.

Statistical Analysis of Innovation Vector

The statistical analysis of innovation (observation minus forecast) vector is the most common, and currently the most accurate, technique for estimating observation and forecast error covariances in large-scale data assimilation. Following the work of Hollingsworth and Lonnberg (1986), the technique was further developed by CIMMS and NSSL scientists and those at the Naval Research Laboratory in spectral representations of wind forecast error covariance functions based on the classic theory of two-dimensional homogeneous turbulence. The technique was applied to geopotential and wind innovation data over North America for a 3-month period from the Navy Operational Global Atmospheric Prediction System (NOGAPS). The major products of the analysis include (i) observation error variances as functions of height, (ii) forecast error auto-covariances and cross-covariances as functions of height and horizontal distance and their spectra as functions of height and horizontal wavenumber, and (iii) forecast error geostrophy measured, at each height and horizontal wavenumber, by the ratio between the geopotential-streamfunction cross-covariance spectrum and the streamfunction power spectrum.

Using GOES Data to Improve COAMPS Cloud Analysis and Forecasts

A 3D cloud analysis package was developed by CIMMS, NSSL, and Naval Research Laboratory scientists to utilize GOES satellite imagery data with a model background field generated by the Navy's COAMPS. The analyzed field was used to initialize the cloud and moisture fields for the squall line case over the U.S. east coast on 9-11 September 1999. The model's predictions were verified against the GOES images, NEXRAD radar images, and products from the National Precipitation Analysis. Comparisons were made between forecasts with and without using the 3D cloud analysis. A positive impact of the cloud analysis is seen in the very short term forecast (1-3 h).

A Case Study of Severe Storm Development along a Dryline within a Synoptically Active Environment. Part I: Dryline Motion and an Eta Model Forecast

Through a case study approach, the motion of a dryline within a synoptically active environment in the Southern Plains, along which severe storms ultimately developed, was examined in detail by NSSL, OU, and CIMMS scientists. Observations from research aircraft, surface mesonetwork stations, mobile ballooning laboratories, radar, wind profilers, satellite, and operational surface and upper air networks were examined and combined. Additionally, output from an operational mesoscale model (Eta Model) was examined to compare predictions of dryline motion with observations and to aid in interpretation of observations. The dryline on this day (16 May 1991) not only advanced rapidly eastward, but also in at least two instances exhibited redevelopment (loss of definition at one location and gain at another). Aircraft observations revealed that an eastward redevelopment occurred in the early afternoon and was characterized by a series of four "steps" along the western edge of the boundary layer moisture. The westernmost and easternmost steps coincided with the locations of the dryline before and after redevelopment, respectively.

The Eta Model forecast initialized at 1200 UTC produced dryline features that were qualitatively similar to observed fields. The eastward motion of a broad area of enhanced moisture gradient agreed well with observations following an initial spin-up period. A north-south moisture convergence axis preceded the rapid eastward motion of the dryline by several hours. Lack of subsidence in the air behind the modeled dryline leads to the conclusion that processes other than downward transfer of horizontal momentum by larger scale motions (that would support eastward advection) produced the rapid dryline motion and observed eastward dryline bulge. Results of diagnosing physical processes affecting model dryline motion point toward boundary layer vertical mixing coupled with advection of dry air aloft as vital components in rapid advance of the dryline eastward in this synoptically active case.

A Case Study of Severe Storm Development along a Dryline within a Synoptically Active Environment. Part II: Multiple Boundaries and Convective Initiation

On 16 May 1991 a dryline occurred within a synoptically active environment and was examined in detail using research aircraft, radar, surface, satellite, and upper air observations. In Part I of this case study, detailed measurements concerning the complex nature of dryline motion were illustrated by NSSL, OU, and CIMMS scientists. The work described in Part II focused on multiple boundaries in the dryline environment, initiation of storms in two areas along the dryline, and late-afternoon retreat of the dryline. Aircraft measurements in the boundary layer revealed that both the east-west extent of moisture gradients and the number of linear regions containing large moisture gradients varied in the along-dryline direction. Aircraft penetrations of "thinlines" observed in clear air return from radar revealed that all thinlines contained cross-line convergent signatures and moisture gradients, and that more distinct thinlines were associated with stronger convergence. Significant moisture gradients in some cases were not associated with either thinlines or convergent signatures, leading to the conclusion that clear air targets consisted of other than moisture gradients.

Based upon comparison of satellite and radar fields, convective clouds on this day formed at the dryline rather than significantly east of the dryline. The three thunderstorm cells that developed in east-central Oklahoma developed along a 20-km section of the dryline south of a dryline bulge and within a 30-minute period. The storms appear to have developed in this location owing to enhanced convergence resulting from backed winds in the moist air in response to lowered pressure in the dry air to the northwest. Aircraft measurements in the boundary layer and satellite sensed surface temperature both indicated localized warming in this area to the northwest. Farther north there was a 70-100-km segment along the dryline where few convective clouds formed during the afternoon. This coincided with a swath of cooler boundary layer air that resulted from significant thunderstorm rainfall during the previous night. A severe thunderstorm complex that developed along the Kansas-Oklahoma border was initiated at the intersection of the dryline and a cloud line that extended into the dry air. An aircraft penetration of the cloud line about 12 km from its intersection with the dryline showed convergence and deepened low-level moisture at the cloud line. The cloud field that evolved into the cloud line over a period of several hours developed over the area that had received the heaviest rainfall during the previous night. The retreat of the dryline in the central and southern portion of the analysis domain in the late afternoon and early evening included both continuous motion and redevelopment toward the west-northwest. In addition, within the region over which the "jump" took place there were other thinlines in the radar return that were verified to be convergent in the low levels based upon a vertical cross-section derived from aircraft data through both the dryline and a secondary thinline. This dual-mode retreat of the dryline

was accompanied by a gradual backing of the winds and a moistening in low levels, based upon clear air radial velocity measurements and soundings.

Severe Thunderstorm Electrification and Precipitation Study (STEPS) Field Program

A variety of data analyses on severe storms and mesoscale convective systems were continued this year by NSSL, CIMMS, and OU scientists. This included work under a NSF grant for "Measurements and Analysis of Vertical Profiles of the Electric Field in Severe Storms during STEPS." The field phase of STEPS (Severe Thunderstorm Electrification and Precipitation Study) was based and conducted from Goodland, KS, during spring and early summer 2000. Several undergraduates, including females and minorities, were hired and participated in mobile ballooning. Volunteers also included minority students and staff from the Goodland NWS forecast office, which served as the host and was deeply involved in the program. The NWS participation blended elements of research and operations. Information on STEPS and example results may be viewed at http://www.mmm.ucar.edu/community/steps.html and under STEPS observations at http://ibis.nmt.edu/nmt_lms/, respectively. The database appears rich, in spite of a substantial drought in the northwest Kansas area where the project was held. Our particular role in this study involved flying balloons instrumented with electric field meters and an NCAR radiosonde. The sonde is a modification of the standard dropsondes, but configured with a full GPS system 'engine' that allows accurate tracking inside thunderstorms. More than 30 field meters were flown. Data analysis is now beginning.

Analysis of MEaPRS Serial Soundings of Electric Field through a Mesoscale Convective System

Analyses continued at NSSL on data collected during the Mesoscale convective system Electrification and Polarization Radar Study (MEaPRS) field program conducted in 1998. This case is from an MCS that occurred in central Arkansas. Five balloon soundings of electric field and thermodynamics were made. Data came the convective, transition, and stratiform regions. In the convective region, both a major updraft and outside updrafts were sampled. In the updraft, we found an average speed of 15 m/s with a peak of 27 m/s, the largest found to date in MCS convection. As with previous measurements, the electric field profile was simpler and fewer charge regions were inferred within the updraft than elsewhere. Together the first four soundings support, with two exceptions, a previously published conceptual model from the convective region updraft to the transition zone (also done with CIMMS participants). The four soundings outside the stratiform region showed evidence for 3 to 5 charge regions across the front of this MCS. Two additional soundings from the stratiform region of another MCS indicated the upper three charge regions in the transition zone are connected to the stratiform cloud, as depicted in earlier conceptual models.

Positive Charge in the Stratiform Cloud of a Mesoscale Convective System

A balloon sounding of the electric field in the trailing stratiform cloud of a bow echo mesoscale convective system revealed only two substantial in-cloud positive charge regions. They were located at 5.1-5.6 km and 6.4-6.8 km altitude, respectively. They were well above the 0° C level of 4.2 km. The two positive charge regions were the likely sources of six positive ground flashes with large peak current (>32 kA) that occurred within 60 km of the balloon's flight path. The amount of charge transferred by three of these positive ground flashes that made Q bursts is calculated to be in the range of 97-196° C. Flashes of this sort are known to produce sprites and elves in the mesosphere. This work was conducted by NSSL MRAD and collaborators.

Electric-Field Changes of Lightning Observed in Thunderstorms

Observations of electric-field changes at altitudes of thunderstorms indicated that the changes are lightning. Deploying several balloon-borne electric-field-change antennae in storms during 1998, NSSL, CIMMS, and OU scientists concluded that the observed field changes resulted from charge motion relatively near the balloon and are possibly associated with distant ground flashes.

The Radiative Impact of the Radiosonde Relative Humidity Dry Bias

The radiative impact of the relative humidity dry bias in radiosondes launched from the Atmospheric Radiation Measurement (ARM) Southern Great Plains Central Facility (CF) in 1998 has been analyzed by a CIMMS scientist with the Community Climate Model (CCM3) stand-alone radiation scheme. More than 800 soundings, uncorrected

and corrected for the moisture bias, have been used, covering the entire year of 1998. For these preliminary calculations, the cloud cover is not taken into account. Thus, the radiative impact that was obtained can be interpreted as an upper limit. Radiative fluxes are calculated for each sounding with both the uncorrected and the corrected moisture profile. By nature, the moisture bias shows a pronounced seasonal cycle: it is weaker during the fall and winter, and increases dramatically in spring and summer. The modification of the radiative fluxes follows a similar seasonal cycle, which is strongly related to the precipitable water increase induced by the correction. Although radiative fluxes are relatively more sensitive to moisture changes in winter, the larger radiative impact is found during summer/spring. The longwave radiative flux at the surface is particularly sensitive to this correction. For the yearly average, the impact is larger than 2 W/m^2, and frequently reaches more than 5 W/m^2 during the moister months.

An Examination of the Accuracy of Vaisala Radiosondes

Vaisala radiosondes (RS-80 and RS-90 versions) were tested in a Thunder Scientific temperature and relative humidity chamber at the ARM SGP central facility by a CIMMS scientist to examine if a more accurate calibration could be developed than that which accompanies the radiosondes on a paper-tape. Three "old" RS-80 sondes (2-3 years old), two "new" RS-80 sondes (less than one year old), and two RS-90 sondes were tested simultaneously in the chamber over the temperature range –15° C to + 25° C and relative humidity from 10% to 95%. The mixture of old and new RS-80 sondes was included to examine the extent of the sonde dry bias that has been documented by scientists at NCAR and in the ARM Program. The RS-90 sondes were tested because ARM will be changing over to this new version soon. After the sondes were calibrated at multiple temperature and relative humidity points, the sondes were launched in pairs. The data are still being analyzed. Along with an Argonne National Laboratory scientist, work on how to incorporate the chamber calibration data into an improved sonde calibration will be examined.

The Effects of Dome Heating on the Eppley PIR Pyrgeometer

The Eppley pyrgeometer (PIR) has a single temperature sensor installed at the base of its dome that can be used to account for the effects of dome heating on its measurement. However, it is not known if the PIR dome has large temperature gradients across it when there is strong solar forcing. A specially designed PIR with three dome thermistors was designed by Eppley and installed on a PIR sensor. NCAR has PIR sensors with three dome thermistors but they wire the thermistors in series and get only an average temperature instead of three separate temperatures. The PIR used in this study by a CIMMS scientist was designed so that each temperature could be measured separately to specifically examine the temperature gradient across the dome and the effects of this gradient on the measured longwave flux (when the dome temperature correction is applied). The PIR sensor can also be ventilated using fan-forced air to further reduce temperature gradients on the dome. The PIR sensor was ventilated some days and not ventilated other days to examine the effects of ventilation on the dome temperature gradient.

Preliminary results indicate that the temperature difference between the dome temperature sensors can approach 0.5º C and this results in a peak-to-peak difference in radiative flux of > 10 W/m^2. When the sensor is ventilated, the temperature difference decreases to about 0.25º C and the resulting difference in radiative flux decreases to < 5 W/m^2.

The Formation and Climatological Distribution of Tornadoes within Quasi-Linear Convective Systems

This NSSL MRAD project will study to the formation and climatological distribution of tornadoes within quasi-linear convective systems (QLCSs). The horizontal extent of viable tornado-breeding sites is an order of magnitude larger in QLCSs than in individual supercells. QLCS tornadoes can be strong and produce extensive damage despite "conventional wisdom" that suggests otherwise. Also, QLCS tornadogenesis appears to occur, on average, more rapidly than does supercell tornadogenesis from the perspective of Doppler radar. The geographical, seasonal, and diurnal distributions of QLCS tornadoes are unknown.

A complementary, two-part study has been initiated. In the phase 1 of the project, the annual number of U.S. tornadoes associated with QLCSs is being estimated using existing radar and verification data. QLCS tornado attributes such as average duration and damage-based intensity will then be determined, and possible geographical, seasonal, and diurnal dependencies will be explored. Initial portions of this work were accomplished recently by a student participating in the Significant Opportunities in Atmospheric Research and Science (SOARS) program. Phase 2 is described in the *Plans* section below.

The Intermountain Precipitation Experiment (IPEX) Field Program

The Intermountain Precipitation Experiment (IPEX) is a field and research program designed to improve the understanding, analysis, and prediction of precipitation and precipitation processes in complex terrain. The project involves scientists from the NSSL, University of Utah, and Desert Research Institute (DRI). The field phase of this experiment was successfully conducted during 31 January - 25 February 2000. A CIMMS scientist in NSSL MRAD is one of the program's scientific leads. The major scientific objectives of IPEX are to:

- Advance fundamental knowledge of orographic precipitation, with an emphasis on the narrow, steeply sloped Wasatch Mountains of northern Utah,
- Improve knowledge of lake-effect precipitation of the Great Salt Lake,
- Validate and improve high-resolution data-assimilation systems, mesoscale model performance, and quantitative-precipitation forecasts over complex terrain, and
- Validate and improve quantitative-precipitation estimates produced by WSR-88D radars located at high elevation.

These objectives are directly related to two major foci of the U. S. Weather Research Program (USWRP): quantitative-precipitation forecasting and the optimal mix of observations in numerical weather prediction. Results from IPEX will also have positive scientific and socio-economic benefits for the Intermountain West, including Salt Lake City, host of the 2002 Winter Olympics.

IPEX field observing platforms included the NOAA P-3 research aircraft, two portable Doppler radars on Wheels (DOW), two NOAA/NSSL mobile laboratories with cross-chain LORAN Atmospheric Sounding Systems (CLASS), a surface-based microwave radiometer, a vertically pointing S-band radar, supplemental soundings from regional National Weather Service upper-air observing sites, and the Utah Mesonet. Data collected during the field program are beginning to allow project scientists to examine a number of questions and testable hypotheses concerning the interaction of dynamical and microphysical processes during orographic precipitation events, including factors controlling the distribution and intensity of precipitation across a narrow, steeply sloped mountain range like the Wasatch Mountains. The complex interactions between thermally- and terrain-driven circulations that produce lake-effect snowbands of the Great Salt Lake will also be examined. Other project activities will validate and improve mesoscale model quantitative precipitation forecasts and quantitative precipitation estimates using WSR-88D radars.

Educational benefits include the participation of graduate and undergraduate students from the Universities of Utah and Oklahoma. IPEX datasets will also be used for classroom and laboratory instruction. Early returns include:

<u>Research results</u>:

- First intensive observations of winter storms in Teton and Wasatch Mountains
- Detailed observations of the two largest storms in the Wasatch Mountains this winter
- Exceptional radar data collected during Valentine's Day wind storm (caused a fatality in Brigham City; 73 mph wind gust in Cache Valley)
- Unprecedented measurements of electrification and lightning in winter storms
- First dual-Doppler radar analysis of a cold front interacting with the Great Salt Lake and surrounding mountains
- Demonstrated value of the Mesowest Cooperative Networks for detailed analysis and short-range forecasting of winter storms (such as might be employed during the 2002 Olympics)
- Testing of experimental forecast products (that might be employed in the future by the National Weather Service for public dissemination)
- Real-time interaction of IPEX scientists and forecasters and National Weather Service forecasters
- Educational experience for 20 University of Utah undergraduate and graduate students who assisted in collection of data and forecasting
- 120 local junior high school students toured the NOAA WP-3D Orion Hurricane Hunter aircraft
- Multiple local media stories helped explain the project's purpose and educate the public about the complex weather forecasting challenges in the Intermountain West

Flight information:

- The NOAA P-3 flew a total of 41 research hours and logged 10,000 miles
- About one gigabyte of data was collected per flight

Doppler on Wheels:

- First use of two mobile Doppler radars in winter-storm research
- 70 total hours of operation
- 7 gigabytes of radar data collected during IPEX
- Unique observations of complex airflow within Tooele Valley

Weather balloon releases:

- NWS released 205 additional balloon launches at the following locations: Salt Lake City, UT (55); Reno (14), Elko (58), and Desert Rock/Las Vegas, NV (9); Grand Junction, CO (16), and Boise, ID (53)
- 100 research balloon launches from the two NSSL mobile laboratories

S-Band vertically pointing Doppler radar:

- 1 Gigabyte of data collected
- Observed air motions and reflectivity from clouds producing rain, snow, and graupel at very fine temporal and spatial (60 m) resolutions
- Interactions with Ski Patrol at Snowbasin Ski Resort were invaluable in helping maintain in situ measurements on the mountain

VORTEX Related Studies

During the past year in NSSL MRAD, the Dimmitt, TX, case study was completed and major progress was made on the Friona, TX, case study. A paper was written on the supercell storm morphology on 2 June 1995, giving an overview of cloud-to-ground lightning and radar characteristics for 20 supercells in relation to a pre-existing baroclinic boundary. Major progress was also on a multi-case analysis of the angular momentum budgets and other tornado features observable with single-Doppler mobile radar. Other progress included development of a single-Doppler technique for determination of azimuthally averaged flow and development of a technique to improve dual-Doppler estimates of velocity in evolving flows.

Plans - FY 01

Parameterization of Cloud Microphysics and Radiation

The work on an integral moment microphysics parameterization for stratiform clouds will continue by the CIMMS Cloud Physics group. Formulation of drop activation and cloud condensation nuclei regeneration, as well as coagulation processes, will be verified in LES experiments comparing bulk and explicit descriptions of microphysics. We will continue the analysis of the feedbacks between drizzle, boundary layer thermodynamical parameters and surface winds in defining the cloud microstructure. The bulk parameterization work will be part of a PhD dissertation research conducted by an OU School of Meteorology graduate student. The role of surface winds will be described in a Masters dissertation by another OU graduate student. The major findings of the research will be presented at the 13th International Conference on Clouds and Precipitation in Reno, NV.

The Statistical Formulations of Cloud Parameters over the Southern Great Plains

The goal of this new project within the CIMMS Cloud Physics group is to determine the statistical descriptions of stratiform cloud parameters using ARM Program observational platforms, including millimeter wave cloud radar and microwave radiometer. We will also explore the possibility of using other meteorological data in order to investigate the relationship between weather systems and cloud statistics over the SGP ARM site. The latter are essential to determine the probability distribution functions, which are important part of cloud physics parameterizations in

mesoscale and large-scale models. During the coming year we will begin developing software for processing the ARM archive data and calculating the necessary cloud statistics.

The Effects of Horizontal Radiative Transport on Cloud Thermodynamical Evolution

The project is a collaborative effort of the CIMMS Cloud Physics group and scientists from NASA and Los Alamos National Laboratory. A new 3D-longwave radiative code will be developed that will be linked with the CIMMS LES model. The objective of the study is to investigate the 3D radiation effects on cloud layer dynamics and boundary layer evolution. The study will show the potential and limitations of the commonly used two-stream delta approximation for radiative transfer models.

Mesoscale Dynamics

Recent studies discovered that in the presence of viscosity, the most unstable mode tends to be horizontally tilted in a symmetrically unstable flow. Related new scientific questions concern whether these tilted linear modes can develop nonlinearly to steady states and remain stable (or become unstable) with respect to three-dimensional perturbations. To address these questions, steady-state nonlinear solutions will be obtained by CIMMS and NSSL scientists for nearly symmetric circulations. Their stability (or instability) and associated environmental conditions are under investigation.

Using ARM and Mesonet Data to Test COAMPS Soil-Vegetation Physics

Comprehensive surface observations and soil-vegetation data collected at the Oklahoma ARM central facility are being utilized by CIMMS, NSSL, and Naval Research Laboratory scientists to test the recently installed soil-vegetation physics in COAMPS. The soil-vegetation physics code was developed by the CAPS based on Noilhan (1989). A column version of the code was extracted and installed into COAMPS with minor modifications. The ARM data include surface wind, temperature, humidity, solar and longwave radiations, eddy correlation fluxes, Bowen ratio energy balance fluxes, soil heat fluxes, and soil temperature and water content. These data provide not only the necessary boundary conditions (in the vertical) for the time-integration of the column model but also the key internal parameters to verify the model's prediction. Currently, the COAMPS soil-vegetation physics is being further improved and will be tested with both ARM and Oklahoma Mesonet data.

Severe Thunderstorm Electrification and Precipitation Study (STEPS) Field Program

The coming year will see CIMMS students and staff involved in analyses of the STEPS data collected in spring and early summer 2000.

Microphysics of Mesoscale Convective Systems

Work is nearing completion at NSSL SRAD on analyzing NOAA WP-3D aircraft microphysics data collected during MEaPRS. The data are being combined with 3D wind fields derived from the WP-3D tail-Doppler radar data to investigate 1) hydrometeor fluxes from MCS convective lines and 2) precipitation development in stratiform clouds.

A Remotely Piloted Aircraft for Lower-Tropospheric In Situ Observations

A Dataplane is a mid-engine powered radio-controlled aircraft with a five to seven foot wingspan fitted with a modified Vaisala radiosonde package to measure temperature, barometric pressure, and relative humidity at a rate of 1 Hz. A pilot on the ground flies the aircraft via direct line of sight. GPS data are also collected to provide accurate time, position, speed, and course data. All of the data are stored on a PCMCIA card able to store continuous data for many days. Data can also be relayed in real time to a ground station so that in-flight changes in the Dataplane flight plans can be made. Upon collection, data are ready for immediate analysis.

The Dataplane can fly vertically and horizontally to approximately 1 km and can fly as low as approximately 2 m above ground level. Flight times are approximately twenty-five minutes. Because a human guides the plane, almost any kind of flight pattern is possible. Current capabilities include multiple low-level passes, soundings to approximately 1

km AGL, and three-dimensional data collection strategies. The plane can fly at speeds of 15 to nearly 40 ms^{-1}. The Dataplane does not currently allow the capability to determine wind speed and direction.

A CIMMS scientist is working with OU scientists to deploy the Dataplane in the September-October 2000 water vapor intensive experiment at the ARM central facility in northern Oklahoma. The Dataplane will be used to provide in situ moisture observations for validation of moisture measurements from lidars, radiosondes, and other devices. It is hoped that ARM will continue supporting the Dataplane by using it in other field experiments and projects. A proposal is also being written to secure funding for future deployments of the Dataplane.

An Examination of the Accuracy of Vaisala Radiosondes

Data continue to be analyzed. CIMMS and Argonne National Laboratory scientists will examine how to incorporate the chamber calibration data into an improved sonde calibration.

An Improved Radiosonde Scaling

A CIMMS scientist continues to analyze radiosonde prelaunch data and compare it with chilled mirror hygrometer temperature and relative humidity measurements to determine if a correction for the sonde dry bias can be developed. This prelaunch data will be examined to see if the sondes can be scaled using a point comparison at the ground. This study may result in a change to how the sonde data are ingested to include archiving the prelaunch data in the sonde data file.

The Formation and Climatological Distribution of Tornadoes within Quasi-Linear Convective Systems

Work will continue on this NSSL MRAD study of the formation and climatological distribution of tornadoes within quasi-linear convective systems. In phase 2 of the project, hypothesized mechanisms of QLCS tornadogenesis will be investigated numerically and theoretically, as will limitations on subsequent tornado intensity and duration. In collaboration with NCAR and Lyndon State College, some of the idealized model experimentation has begun, as has the analysis of the model results.

The Intermountain Precipitation Experiment (IPEX) Field Program

The data analysis phase of IPEX will continue throughout the next year. Data collected during six to eight intensive observational periods will allow project scientists to examine a number of questions and testable hypotheses concerning the interaction of dynamical and microphysical processes during orographic precipitation events, including factors controlling the distribution and intensity of precipitation across a narrow, steeply sloped mountain range like the Wasatch Mountains. The complex interactions between thermally- and terrain-driven circulations that produce lake-effect snowbands of the Great Salt Lake will also be examined. Other project activities will validate and improve mesoscale model quantitative precipitation forecasts and quantitative precipitation estimates using WSR-88D radars. In particular, research plans for the next year include further data analysis of intensive observing periods 4, 5, and 7. Efforts will be concentrated on the analysis and synthesis of data collected by the NOAA P-3 Doppler radar and the OU Doppler on Wheels radars.

Numerical and Observational Studies of Tornadic Supercells

Traditional methods of retrieval of wind, pressure, and temperature from dual-Doppler data qualitatively reproduce features in thunderstorms but yield results that are of limited use for quantitative analysis. An ongoing NSSL MRAD project instead utilizes the application of a model and adjoint retrieval (Sun and Crook 1997) to a multiple-Doppler dataset of the Dimmitt, TX, tornadic thunderstorm from VORTEX-1995. The motivation for this approach is to produce a dynamically consistent dataset, suitable for detailed quantitative analysis that matches the time series of observations in a least squares sense. This method also appears to be ideal for including data of other types (e.g., in situ measurements from mobile mesonets) in the retrieval. Current work includes adapting the model to use P3 analyses from VORTEX data sets and testing the inclusion of other observational platforms (such as mobile mesonet) into the retrieval/assimilation.

VORTEX Related Studies

A NSF proposal is being written to continue supercell lightning research at NSSL MRAD ("A Numerical and Observational Study of the Kinematic, Electrical, and Microphysical Changes Occurring in Boundary-Crossing Supercells During VORTEX-94/95 and STEPS"). If funded, it will involve scientists from CIMMS, OU, and NSSL.

Rasmussen's single-Doppler circulation analysis technique will be used to investigate several tornadic and non-tornadic tornado cyclones from VORTEX. This work is still several months away from completion.

A detailed analysis/data synthesis is underway of the Beaver County storm from VORTEX. This should generate a manuscript for publication within the next year.

Two other projects are being finalized for submission to refereed journals that describe further analysis of the 2 June 1995 storm. One analyzes detailed cloud-to-ground lightning and radar characteristics for three supercells in relation to a pre-existing baroclinic boundary, and another looks at the characteristics of simulated storms and their comparison to radar observations.

RPV Aircraft Design

The design and testing of a remotely piloted vehicle (RPV) aircraft capable of flying in the mesocyclone environment is ongoing with the University of Colorado Department of Aeronautical Engineering. Significant progress has been made to date in developing the control and state algorithms and avionics for RPVs capable of autonomous formation flying, in work done with Wyndemere, Inc.

FORECAST IMPROVEMENTS

Progress - FY 00

Implementation of CIMMS Stratiform Cloud Parameterization into a NWP Regional Model

The CIMMS Cloud Physics group continued testing the CIMMS cloud physics parameterization implemented into COAMPS. A mesoscale simulation of the summer cloud/fog system in a clean marine air environment over the central California coastal region produced a broad region of drizzling stratocumulus whose areal coverage was in reasonable agreement with satellite data. The effects of drizzle tended to be more pronounced at the 2 km resolution mesh, where an average drizzle rate became as large as 0.74 mm/day just before sunrise. On this mesh, temperature and total water profiles showed a tendency to become more stable with time, a result of the falling drizzle evaporating, cooling and moistening the sub cloud layer, and suppression of total kinetic energy production. A spatial transition from unbroken stratocumulus to boundary layer cumulus was present across the domain. The effect of drizzle on the cloud microstructure was only readily apparent on the high-resolution mesh, and little fine scale cloud structure was seen in the coarser grids. Results of the study indicate that the physically realistic formulation of cloud/drizzle processes in operational forecast models using an 18 km coarse mesh is still a challenging and unresolved task.

Using Satellite-derived Land Use Data to Improve Meso- and Storm-scale Numerical Weather Prediction

In a collaborative project between CIMMS, NSSL MRAD, CAPS, University of Nebraska-Lincoln, and the University of Kansas, the Parameterization for Land-Atmosphere-Cloud Exchange (PLACE) module is being used within the Pennsylvania State University–NCAR Mesoscale Model version 5 (MM5) to determine the importance of individual land surface parameters in predicting surface temperatures. Sensitivity tests indicate that soil moisture and the coverage and thickness of green vegetation (as manifested by the values of fractional green vegetation coverage – fVEG - and leaf area index - LAI) have the greatest effect on the magnitudes of the surface sensible heat fluxes. The combined influence of LAI and fVEG is larger than the influence of soil moisture on the partitioning of the surface energy budget.

Real-time, biweekly maximum values for fVEG, albedo, and LAI, derived from the Advanced Very High Resolution Radiometer sensor, have been inserted into PLACE and the changes in model-predicted 1.5 m air temperatures in Oklahoma during July 1997 were documented. Use of this 1-km resolution land cover data provided a clear

improvement in afternoon temperature simulations when compared to model runs with monthly climatological values for each land cover type or with constant values across the entire domain. However, temperature simulations from MM5 without PLACE were significantly more accurate than those with PLACE, even when the high-resolution land cover data were incorporated into the model. This is attributed to a warm bias in the PLACE runs that likely is produced by the climatological soil moisture values used for initialization. However, when only the warmest 30% of the observations were analyzed, the simulations from the high-resolution land cover data set with PLACE significantly outperformed MM5 without PLACE. The ability to improve model predictions of surface energy fluxes and the resultant temperatures in a diagnostic sense provide promise for future attempts at ingesting real-time land cover data into numerical models. These model improvements would likely be most helpful in predictions of extreme temperature events (during drought or extremely wet conditions), where current numerical weather prediction models often perform poorly. The potential value of real-time land surface information for model initialization is difficult to overstate.

Comparing Two Methods for Wind Analysis: Numerical Simulations of a Severe Convective Event

Previous research has suggested that the traditional method for evaluating spatial derivatives of the wind field (i.e., mapping the individual wind components onto a regular grid and then performing finite differencing) is inferior to a line integral approach, whereby spatial derivatives are calculated directly from the observations. In an upcoming publication, results from empirical testing at NSSL MRAD are shown to suggest that the magnitude of the improvement depends on the degree of irregularity of the data distribution, an expected result. An unexpected result is that the improvement by the line integral method over the traditional approach does not diminish as the wavelength of the input field increases. Overall, the test results make it abundantly clear that the traditional method is generally inferior to derivative estimates via the line integral methodology.

Improving Numerical Guidance for Quantitative Precipitation Forecasting

Experimental testing of NCEP's Eta model at NSSL MRAD has expanded during the past year. NSSL's model configuration differs from the operational version in that it uses the Kain-Fritsch convective parameterization and higher-order, reduced-magnitude horizontal diffusion. A "frozen" version of this experimental configuration has been run continuously at NSSL over the past year - once per day through September 1999 and twice daily since then - providing a valuable database for comparison with the operational product. This testing has been done in close collaboration with scientists at NCEP's Environmental Modeling Center (EMC), Hydrometeorological Prediction Center (HMC), and the SPC. In addition, in collaboration with scientists from the COMET program, this configuration has been made available in a workstation version of the Eta model designed for use by local NWS forecast offices.

Evaluation of Primary Guidance Products used at SPC

A formal collaborative study between SPC forecasters and NSSL MRAD scientists was planned during the first part of the year and then carried out during a six week period this spring. This study was designed to evaluate three primary guidance products that are used routinely by SPC forecasters: 1) the prediction of convective initiation and evolution in EMC's Eta and RUC-2 models and in NSSL's experimental configuration of the Eta model, 2) surface objective analysis routines based on the RUC-2 model, and 3) hail forecasting algorithms. Representatives from EMC and the NOAA Forecasts Systems Laboratory (FSL) also participated in this experiment. A summary of this experiment is being prepared and will be posted on the world wide web.

Mesoscale models continue to be used as diagnostic tools. For example, a diagnostic version of the Eta model was used this year in a detailed study of the physical mechanisms responsible for dry-line formation and position changes. In addition, MM5 was used to quantify the role of latent cooling associated with melting precipitation in causing an unexpected snowstorm. Manuscripts involving both of these studies have been submitted to the AMS journal *Weather and Forecasting*.

Verification of Quantitative Precipitation Forecasts

Automated procedures for collection of quantitative precipitation forecasts from NCEP's operational Eta model as well as the experimental version of this model that is currently running twice daily at the NSSL have been established by NSSL MRAD. These data are verified against observations from the River Forecast Center using Equitable-Threat (ET) and bias scores. They are compiled on a monthly basis and updated daily for these two model runs. The scores

can be viewed graphically at http://vicksburg.nssl.noaa.gov/verf/. In addition, other measures of "ground truth" for convective activity, including hourly gridded fields for lightning frequency and various fields derived from radar, were collected and archived during the springtime NSSL-SPC experiment and will be used for additional verification studies.

Evolution of Warm-Season MCS Activity over the Great Plains during Late-Morning Hours: Insights into Short-Term Forecasting

This project has the goal of developing a tool that can be used to aid in forecasting the evolution of MCSs that affect the Great Plains during late morning hours in the summer. It is a cooperative effort among OU, NSSL, and the NWS forecast offices in Norman, OK, and Dodge City, KS. A primary sub-task of the work is producing a climatology of such events that have occurred during the summers of 1996-2000, affecting the county warning areas of Norman and Dodge City. Work began on the project in January 2000 with the appointment of an OU graduate research assistant. This work will result in a Masters thesis.

Work began on the climatology by going through the NCDC hourly mosaic base level reflectivity images from the WSR-88D network for the summers of 1997, 1998, and 1999. These images are readily available from the NCDC web site, and the archive covers the period 1997 to present. About 85 cases were identified that met the criteria for inclusion. For 1996 data, tapes had to be ordered from NCDC containing level II data from individual radar sites. These have arrived and are being read and displayed for the 1996 cases. Much of the data for the summer of 2000 is being saved through an arrangement with the SPC. The work by the graduate student is being benefiting greatly from frequent help from the Norman NWS forecast office. For the 1997-99 cases maps have been produced that show the track and timing of each selected system. Estimates from this have been made of the direction and speed of system motion and noted the evolutionary tendency of each. Severe weather events have been logged for each system, along with a preliminary assessment of the initiating mechanism and a description of the synoptic environment in which each event occurred.

Hazardous Winter Weather Climatology

The goal of the NSSL MRAD hazardous winter weather climatology project is to document and learn about the climatology of hazardous winter weather, particularly freezing rain, to improve short-range forecasting of these hazards. This goal is being pursued with a former CIMMS employee who has since relocated to the NOAA/Tropical Prediction Center. Research during the previous year has focused on a climatological study of freezing rain over the Great Lakes and a North American climatology of freezing rain, freezing drizzle, and ice pellets, the first of its kind to appear in a formal scientific journal. Already, preliminary results of this research have been shared with forecasters at the SPC and the HPC, who provide the nation with hazardous winter weather guidance for NWS forecast offices. The results of this study have identified where these hazards occur as well as provided some explanations for why they occur at these locations.

Precipitation-type Algorithm Testing (COMET Project)

The objective of this two-year COMET project is to examine numerical methods of accurately predicting precipitation type using numerical model output. Before COMET funding began, NSSL MRAD scientists had identified several precipitation-type algorithms and began some preliminary algorithm testing. Since the beginning of the COMET project, the scientists involved have continued testing the algorithms that will be used during the 2000-2001-winter season at the SPC and HPC. Work has also started on creating a web site that will allow NWS meteorologists to learn about these algorithms and the status of the project.

SPC Winter Weather Training

During the fall of 1999, NSSL MRAD organized and provided extensive training to SPC forecasters on winter weather forecasting. Lectures taught by CIMMS and SPC employees included: (1) the climatology of hazardous winter weather, (2) the use of precipitation-type algorithms in forecasting, (3) various techniques for winter weather forecasting, (4) jet-stream dynamics, and (5) conditional symmetric instability.

Comparison of Deterministic Thunderstorm Prediction with the Statistical Growth and Decay Tracker

The purpose of this project is to demonstrate the potential level of accuracy of a fine-scale numerical weather forecast system for providing terminal forecast guidance. CAPS has developed the Advanced Regional Prediction System (ARPS) under an 11-year Science and Technology Center NSF grant and has in recent years conducted a series of real-time operational tests by which 3-km forecasts were generated over select domains. In a subjective sense, the forecasts did well in predicting strongly forced convective events, such as squall lines and large thunderstorm complexes. For verification purposes, however, a more objective method of evaluating forecast accuracy is desired. On scales of 10 km or finer, the traditional method of verification, as used for synoptic forecasts, is not entirely appropriate. This is due primarily to the phase-error. Although a forecast that correctly handles storm initiation, duration, intensity, and general movement can be valuable to pilots and air traffic controllers, errors in the position of a storm at a given time can lead to low probability of detection scores (POD) and high false alarm ratios (FAR). It is essential, therefore, to use techniques that allow for some error tolerance. A "fuzzy logic" approach is used by which a forecast scores high if a storm (identified by reflectivity greater than 41 dBZ) develops within an arbitrary threshold distance of where it was predicted to occur.

A case that occurred near Wichita, KS on 21 May 1999 has been thoroughly evaluated. A 3-km forecast of this squall line event had been generated in real-time as part of a CAPS spring operational test. The results showed a POD of 0.684 and FAR of 0.784 for the 6-hour forecast. To demonstrate the extent to which phase-error contributed to overall forecast error, the forecasted squall line was shifted spatially to correspond optimally with the radar observations. The verification statistics improved significantly giving a POD of 0.8883 and reducing FAR to 0.587, which indicated that the primary cause of error was due to a phase-lag and showed further that the forecast performed well in predicting the orientation, coverage area, and intensity above a given threshold. Work is currently underway to evaluate up to 6 more storm events that have been identified from the past year. ARPS forecasts will be compared with results generated by the Storm & Decay Tracker for these same cases as provided by collaborators from NSSL.

Warning Decision Making Workshop Training

During the past fiscal year the Operations Training Branch (OTB) has been in transition from the OSF to the NWS Training Core, becoming the "Warning Decision Training Branch" (WDTB). With this change in name and management comes a more explicit representation of the branch's purpose: to improve performance of warning decisions and short-term forecasts for the NWS. The Warning Decision Making (WDM) workshops held at the COMET facility in Boulder, CO, have been an integral part of delivering warning decision training to NWS personnel. A principle component of these workshops is the displaced real-time (DRT) scenarios where participants practice warning decision-making techniques in a simulated real-time environment using the Advanced Weather Information Processing System (AWIPS). In the past year CIMMS personnel have supported and made improvements to the DRT software and the data used in the scenarios. One outgrowth of these workshops has been a project for the NWS Southern Region to transfer the workshop DRT software in a cost effective manor to machines in NWS forecast offices to support local training.

Warning Decision Making Internet Training

During the transition of the OSF/OTB to the WDTB of the NWS Training Core, the Internet has been an area of growth for training. A new challenging event module has been created for the unique warning decision aspects of the Salt Lake City, UT, tornado event that occurred in August 1999. The most recent tornado warning guidance from NSSL, OSF, and WDTB has been incorporated in the on-line version of the tornado warning guidance document, a yearly publication that focuses on transferring the latest research and techniques to NWS forecast offices. Several Java tools have also been created for WDTB's training on convective initiation and for viewing multi-source AWIPS imagery in the online modules.

Common Operations and Development Environment (CODE)

Work began at NSSL SRAD on the development of the WSR-88D Common Operations and Development Environment (CODE) and the Warning Decision Support System - Integrated Information (WDSS-II). The CODE and WDSS-II software packages will provide a tool to ease the meteorological algorithm development effort. Algorithms

being developed for the WSR-88D ORPG will make use of CODE Application Programmer Interfaces (API) to provide access to WSR-88D data and computational modules. The WDSS-II will provide a platform for algorithm development that includes WSR-88D data from multiple radar product generators (RPGs) and other data sources.

The OSF Applications Branch tested installation procedures for the first developer release of CODE. When fully deployed, CODE is intended to serve the NEXRAD algorithm developer community by providing an algorithm development, product display, and testbed environment.

Improvements to Severe Weather Algorithms

The OSF Applications Branch continued to evaluate and work with the NSSL to improve the NEXRAD Tornado Detection Algorithm (TDA) and Mesoscale Detection Algorithm (MDA).

Improvements to the (Existing) Precipitation Processing Subsystem (PPS)

The OSF Applications Branch is working with the Office of Hydrology to implement several improvements to the existing precipitation processing subsystem (PPS). The new algorithm ingests base reflectivity data from a number of tilts and combines them into a Hybrid Scan Reflectivity file. The new algorithm is not restricted to fixed elevation angles. It employs improved radar beam blockage information, eliminates bi-scan optimization logic, and simplifies filtering of anomalous reflectivity points. In the future, logic will be implemented to incorporate vertical profile of reflectivity.

Tornado Warning Guidance

The OSF Applications Branch joined with the OSF OTB and the NSSL to prepare and distribute a Tornado Warning Guidance training package. This series of documents teaches forecasters the subtleties of the latest version of TDA and makes suggestions as to how to select the best set of adaptable parameters for a particular location, storm type, and time of year. This guidance is described in more detail in the section on Doppler Weather Radar Research and Development.

Warning Decision Support System (WDSS) Testing and Feedback

Designed by the NSSL, the Warning Decision Support System (WDSS) hardware and software emulate the WSR-88D and provide the NEXRAD OSF a platform by which they may test new and existing algorithms, products, and display options. The WDSS has the advantage over a playback-only system of being able to operate in real-time and thus augment the WSR-88D itself during real weather events.

Real-time testing of WDSS was done at a number of locations. NSSL deployed the WDSS for realtime testing at Tucson, AZ, NWS forecast office during the 1999 summer monsoon. Feedback from the forecasters was positive overall regarding use of WDSS in the warning decision making process. The forecasters were especially enthusiastic with the speed at which WDSS products could be invoked and with the performance of the Damaging Downburst Prediction and Detection Algorithm (DDPDA). The Tucson WDSS was then removed and deployed to the Missoula, MT, NWS forecast office for winter testing of the U.S. Bureau of Reclamation Snow Accumulation Algorithm. The WDSS remained in the Missoula office through April 2000.

An additional WDSS was deployed at the St. Louis, MO, NWS forecast office for the spring/early summer 2000 severe/tornadic weather. The system was well received by the St. Louis staff, with the DDPDA and MDA playing crucial roles in the forecasters' warning decisions and operations.

NSSL has also partially supported WDSS sites at NWS forecast offices in Fort Worth, TX, Norman and Tulsa, OK, Sterling, VA, Melbourne, FL, Peachtree City, GA, Phoenix, AZ, Salt Lake City, UT, Jackson, MS, Houston, TX, and Denver, CO.

NSSL is working with the Australian Bureau of Meteorology (BOM) to support WDSS operations in Sydney during fall 2000 (the Australian spring) by deploying a WDSS-II system. The MDA and TDA have been modified there to detect clockwise storm-scale vortices. Work will be planned to study the severe storm algorithm climatology of the

region, and to address concerns about 5-cm radar dealiasing. The WDSS-II testing will occur in conjunction with the 2000 Summer Olympics.

WDSS-II Early-Prototype Deployment in Georgia

In response to the Georgia Governor's task force on improving the weather warning process in Georgia, NSSL was tasked in 1999 to design and implement an early prototype of the next-generation WDSS-II in northern Georgia. Specifically, two systems were deployed; one in the Peachtree City NWS forecast office (installed in April 1999) and another in the Georgia Tech Research Institute (GTRI) Cobb County Facility (completed October 1999). The entire system is capable of ingesting data from the three WSR-88Ds that cover northern Georgia. The radars included in this network are Hytop, AL, Peachtree City, GA, and Greenville/Spartanburg, SC. All radar data are received, processed and displayed in Peachtree City. Furthermore, the Peachtree City forecast office serves as the data hub where the radar data are compressed and redistributed (via Unidata's LDM package) to the GTRI Cobb County Research Facility via a single T-1 line for the benefit of research and development of new radar technologies aimed at identification and display of severe/tornadic radar signatures. Although T-1 lines are currently utilized, lower bandwidth communications can be used to transmit compressed base data. A collaborative relationship has been established among the NSSL, GTRI and the NWS to leverage the expertise of each in the development of new algorithms and enhanced displays for the benefit of improved warnings of severe/hazardous weather.

A summary of the activities regarding the Georgia WDSS-II early-prototype can be found at:

http://www.nssl.noaa.gov/~mitchell/georgia_wdss/georgia_ssrc.html.

New Volume Coverage Patterns (VCPs)

Since the inception of the NEXRAD program, field forecasters have been asking for faster algorithm update cycles and more emphasis on information gathered at lower elevation angles. Unfortunately, many of the original algorithms were hard-coded for specific elevation angles or combinations thereof. This OSF Applications Branch project seeks (1) to identify and eliminate the limitations arising from hard-coded elevations and (2) to identify new volume coverage patterns (VCPs) that will update faster and provide more useful views of storms. Testing is on going, and new VCPs are expected to be available in time to take advantage of the hardware upgrades necessary to run them.

OSF Operations Branch Support of WSR-88D Operators

The Operations Branch continued supporting WSR-88D field sites to improve the quality of data and reliability of access to WSR-88D data. It also assisted operators in interpretation and application of WSR-88D data, products, and algorithm output. These efforts improved the ability of forecasters to accurately apply radar data to their forecast operations and the decision process of issuing severe weather and tornado warnings. The improvements to data quality were even more important with the new weather radar display platforms the NEXRAD agencies are fielding that put more WSR-88D data in front of more users on a continuous basis.

SPC Forecast Verification

During 1999 a CIMMS scientist at SPC continued to work on SPC forecast verification. Software was developed to allow for verification of both Day 1 and Day 2 Convective Outlooks in addition to severe weather watches. With these capabilities, all SPC forecasters now receive feedback on their forecasts. Work has continued on methods to verify the new set of experimental probabilistic convective outlooks issued by the SPC. The primary focus has been on the Day 1 forecasts of the individual severe weather hazards: hail, wind, and tornadoes. Recent work has been done to modify software to verify Day 2 and Day 3 probabilistic forecasts. Part of this work will be presented orally at the 20th AMS Conference on Severe Local Storms in Orlando, FL, in September 2000.

SPC Web Site

Work continued by a CIMMS scientist on enhancement and usability of the SPC web site. In particular, work continued on improved access to climatological severe weather databases, archived SPC forecast products, and new displays of existing SPC products.

Local SPC software

The SPC forecasters continue to rely heavily on observational data when making short-term decisions related to Convective Watches. There remains a need to continue to develop software that allows SPC forecasters to interrogate all available data to their fullest extent. New programs have been designed by a CIMMS scientist and implemented operationally to allow SPC forecasters to access and interact with these data in a timely manner. Work will continue to enhance the functionality of existing programs as well as exploring new methodologies for improving the forecast process at the SPC.

National Basin Delineation

The NSSL SRAD Western Intermountain Storms and Hydrometeorology (WISH) team has partnered with the USGS Earth Resources Observation Systems (EROS) Data Center (EDC) to delineate flash flood basins for the conterminous U.S. These basins are a necessary component of the Flash Flood Monitoring and Prediction (FFMP) Program to be included in AWIPS Build 5.1. The FFMP will include functionality similar to the Areal Mean Basin Estimated Rainfall (AMBER) Program for assisting forecasters in flash flood warning decisions. The FFMP will calculate average rainfall rates and accumulations from radar precipitation estimates for every flash flood basin within a radar coverage area.

The basin delineation is being performed using ArcView and ARC/INFO Geographic Information Systems (GIS), and is based on digital elevation data from the National Elevation Dataset (NED). Produced at the EDC. The NED is a seamless mosaic of the highest-resolution, best-quality elevation data for the U.S. Data of this quality are essential for accurate delineation of the flash flood basins required for the FFMP (minimum headwater drainage area of 2 mi^2). The processing unit for the basin delineation is the USGS 8-digit Cataloging Unit; that is, flash flood basins are delineated within each 8-digit Cataloging Unit. There are over 2000 8-digit Cataloging Unit basins in the U.S., of which approximately one-third have been processed for this project to date.

AMBER Evaluation

The Areal Mean Basin Estimated Rainfall (AMBER) Program has been used in real-time operations for several years at the Pittsburgh, PA, and Honolulu, HA, NWS forecast offices and in 1998 was implemented as part of NSSL's Warning Decision Support System (WDSS) at the Tulsa, OK, and Sterling, VA, forecast offices. Work is currently underway in the NSSL SRAD WISH team to implement an "AMBER-like" functionality in the FFMP Program, which will be included in AWIPS Build 5.1. To obtain quantitative feedback on AMBER's utility as a flash flood forecasting tool prior to its implementation in the FFMP, NSSL was tasked with providing an objective evaluation of AMBER's performance in nine case studies from the Tulsa and Sterling county warning areas. For each case study, archived Level II data from the KINX and KLWX radars, flash flood reports, rain gage data, and flash flood guidance (FFG) values were analyzed to determine the pre-existing hydrologic conditions, the nature of the precipitation event, the accuracy of the radar precipitation estimates, and the extent and severity of the resultant flash flooding. Average basin rainfall rates and accumulations from AMBER were analyzed to determine whether the algorithm would have indicated flash flood potential and, if so, the approximate lead-time. The methodology and results of this evaluation have been provided in a formal report.

Ensemble Cloud Model Applications

A three-year effort in developing a way to forecast thunderstorm lifetime using a cloud model ensemble forecasting approach has been completed by the NSSL SRAD SWAT team. These forecasts describe the range and distribution of thunderstorm lifetimes that may be expected to occur on a particular day. Such forecasts are crucial for both anticipating severe weather and ensuring the smooth flow of air traffic at busy, hub airports. By extension, any storm characteristic can be probabilistically forecast using this method.

The work was done on eighteen days distributed over two warm seasons. Soundings valid at 1800 UTC, 2100 UTC and 0000 UTC, provided by the 0300 UTC run of the operational Meso-Eta model from the NCEP, are used to provide initial conditions for the cloud model ensemble. These soundings are from a 160 x 160 km square centered over the location of interest and represent a likely range of atmospheric states. A minimum threshold value for maximum vertical velocity within the cloud model domain is used to estimate storm lifetime. Forecast storm lifetimes are verified

against observed storm lifetimes, as derived from the Storm Cell Identification and Tracking algorithm applied to WSR-88D radar data from the NWS.

When kernel density estimates are applied to the pooled data set consisting of all 18 days, a vertical velocity threshold of 8 m/s results in a forecast probability density function (pdf) of storm lifetime that is closest to the observed pdf. One of the most interesting results is that the storm lifetime resulting from a given input sounding cannot be determined by analyzing the bulk sounding parameters, such as convective available potential energy, bulk Richardson number (BRN), BRN shear, or storm relative helicity. Standard 2 x 2 contingency statistics reveal that, under certain conditions, the ensemble model displays some skill locating where convection is most likely to occur. Contingency statistics also show that when storm lifetimes of at least 60 minutes are used as a proxy for severe weather, the ensemble shows considerable skill at identifying days that are likely to produce severe weather. Because the ensemble model appears to have skill in predicting the range and distribution of storm lifetimes on a daily basis, the forecast pdf of storm lifetime is used directly to create probabilistic forecasts of storm lifetime, given the current age of a storm. Such a product can furnish useful information to air-traffic controllers by providing guidance about how soon a storm is likely to affect (or cease to affect) air traffic at a specific location. Similarly, this product can provide NWS forecasters with guidance about how likely it is that a particular cell will affect a given community.

Integrated Sensor Training for the National Weather Service

NSSL SRAD created the ISTPDS Instructional Component Unit 6.2.4: Three Classes of Storm Top Signatures in Infrared Satellite Data. This self-teaching module provides background material for Instructional Component 9.1.2, The Enhanced-V: A Satellite Severe Storm Signature. The material was partially derived from a COMET Satellite Meteorology course session titled "Multispectral Analysis of Convection." The on-line session can be found at http://www.nssl.noaa.gov/istpds/icu624/.

NSSL also co-mentored a Research Experience for Undergraduates (REU) student during the summer of 1999 on a project to explore what would be necessary to complete a climatology of the enhanced-V signature. NSSL also provided web space and designed the Internet version of the LaDue and Grant IC9.2 series on Low-Level Boundaries and Convection.

Plans - FY 01

Implementation of CIMMS Stratiform Cloud Parameterization into a NWP Regional Model

Additional analyses of simulations of the cloud/fog system over the central California coastal region using the U.S. Navy COAMPS forecast model will be performed by the CIMMS Cloud Physics group. The focus of the effort will be to understand the scale dependence of drizzle production mechanisms and to identify the main factors responsible for accurate forecast of stratiform clouds microphysical and radiative parameters on a coarse (of the order of 20 km) grid. The coming year will mark the completion of a 5-year project supported by the Department of Defense Grant to OU under the Multidisciplinary University Research Initiative Program. Presentation of the research findings at scientific conferences and in journal publications will be an important part of this year's effort.

Using Satellite-Derived Land Use Data to Improve Meso- and Storm-scale Numerical Weather Prediction

In a collaborative project between CIMMS, NSSL MRAD, CAPS, University of Nebraska-Lincoln, and the University of Kansas, the PLACE module will continue to be used within the Pennsylvania State University – NCAR MM5 to determine the importance of individual land surface parameters in predicting surface temperatures.

Improving Numerical Guidance for Quantitative Precipitation Forecasting

Verification statistics will be utilized to identify weaknesses and improve the performance of convective parameterizations in operational forecast models. Daily model runs with the Eta model, along with dissemination of forecast products will continue at NSSL/SPC. In collaboration with EMC, the NSSL configuration of the Eta model will begin running parallel to the operational version as part of a short-range ensemble forecasting experiment. In addition, the new Weather, Research, and Forecasting model (WRF) will be tested at NSSL/SPC.

Evaluation of Primary Guidance Products used at SPC

Another formal collaborative study will be designed this year and executed in the spring of 2001. Interactions between NSSL MRAD scientists and SPC scientists/forecasters will include forecast-shift participation by NSSL scientists, additional diagnostic analyses using numerical weather prediction models, and daily map discussions.

Verification of Quantitative Precipitation Forecasts

Computation of Equitable-Threat and bias scores for various versions of the Eta model will continue at NSSL MRAD. These scores will be computed in an automated fashion for the verification of quantitative precipitation amounts, and will also be utilized to compare the various datasets collected in the NSSL/SPC spring experiment. New verification techniques will be developed and compared with these traditional measures. This work will proceed as a collaborative effort between the NWS (including the SPC, EMC, and HPC), OU, and NSSL.

Evolution of Warm-Season MCS Activity over the Great Plains during Late-Morning Hours: Insights into Short-Term Forecasting

The five-summer climatology of morning MCSs will be completed. For each case, environmental conditions ahead of the system will be investigated. This will include assessing system normal wind and wind shear structure and their evolution through profiler and WSR-88D VAD data, and assessing stability structure and changes to the degree possible. Changes in the environment will then be compared with evolutionary tendencies of each system. Two systems will be selected for case study examination by NSSL and OU scientists, including detailed examination of satellite data. An OU graduate student will visit the Dodge City, KS, NWS forecast office for two weeks during the summer of 2000 to become familiar with forecast techniques. NWS forecasters in Norman and Dodge City will log comments in real time on applicable MCS activity at a project web site, and this information will be summarized for the summers of 1997- 2000.

Comparison of Deterministic Thunderstorm Prediction with the Statistical Growth and Decay Tracker

In total, six cases have been identified by CAPS to evaluate the potential accuracy of the ARPS in predicting convective weather. Cases were chosen that were strongly forced and developed significant precipitation within 1 hour of ARPS forecast initialization time. This will allow for better comparison with the Growth & Decay Tracker, which cannot forecast convection initiation. Verification statistics (POD and FAR) will be calculated for the forecasts by hour out to 6 hours. Considerable effort will be made to interpret model performance. This will also involve a critical assessment of what the statistics represent in forecast accuracy and what they fail to adequately measure. For example, the phase error tends to highly overwhelm the POD and FAR even though it is just one of many characteristics (such as storm initiation, intensity, and orientation) that would define forecast accuracy.

Warning Decision Making Workshop Training

WDM workshops continue to be an integral part of WDTB's training for the NWS under the new management of the Training Core. Significant improvements to the DRT software are planned for the 2001 workshops. AWIPS software Build 5.0, which includes a version of NSSL's WDSS called SCAN 2.0, is a key component of these improvements. The WDM workshops will also implement training for using mesoscale analysis in the warning process and polygon-based warning verification techniques (rather than the standard county-based warning verification technique). CIMMS personnel will continue to provide guidance for the development of timely and cost-effective solutions for DRT training at local NWS forecast offices using the WDM-workshop DRT software.

Warning Decision Making Internet Training

WDTB will continue to expand the use of Internet training for NWS forecasters on warning decision-making issues. More challenging event modules are planned to address recent situations of complex warning decision-making. A recent events page will be added to the WDTB web site to allow NWS forecast offices to view data from recent significant events quickly after they occur to expose the offices to the diversity of significant events nationwide. The tornado warning guidance document will be updated to reflect the incorporation of mesoscale environment data to the large statistical study of radar-derived parameters being investigated by NSSL. Web-based applets will be created for the continuing series of training on convective initiation and affects of boundaries on storm morphology. As the

NWS training community shifts to using new Java-based software for teletraining live over the Internet, CIMMS personnel will assist in its implementation and further development.

Common Operations and Development Environment (CODE)

As we begin the 2001 fiscal year, CODE is not mature. The OSF was unable to install the first version we received from the developers, and the software does not yet offer developers a vehicle for algorithm development. During FY2001, the OSF Applications Branch expects to develop the software and the process and be able to deploy to alpha testers.

Improvements to Severe Weather Algorithms

The OSF Applications Branch and NSSL continue to make improvements to the TDA using refined adaptable parameters. Working with field forecast offices, we will conduct verification studies and invite offices to conduct their own analyses. In addition, the NSSL has made improvements to the MDA, and the MDA may be presented for implementation in a future software build.

Improvements to the (Existing) Precipitation Processing Subsystem (PPS)

The OSF Applications Branch is working with the NSSL, the NWS Office of Hydrology, and colleagues at the University of Iowa to develop and test the improvements in the PPS. We expect these activities to continue through FY2001.

Tornado Warning Guidance

The NWS Training Center Operations Branch, the NSSL, and the OSF Applications Branch will continue to produce specialized guidance for use of the TDA. This guidance emphasizes, but is not limited to, correct choice of adaptable parameters and interpretation of the TDA output during severe weather operations. This guidance is described in more detail in the section on Doppler Weather Radar Research and Development.

Warning Decision Support System (WDSS) Testing and Feedback

The two WDSS units owned and operated by the OSF Applications Branch will be deployed to the Amarillo, TX, NWS forecast office to test severe weather algorithms in an environment subject to influence by the dry-line, and to the Tallahassee, FL, forecast office to test the TDA, MDA, and the PPS in a tropical environment with anticipation of testing during a hurricane landfall. NSSL will also support the realtime testing of the soon-to-be-deployed WDSS-II for one or more multiple-radar sites. However, WDSS-II test sites for FY2001 have yet to be determined.

WDSS-II Early-Prototype Deployment in Georgia

The NSSL staff will continue to support the WDSS-II early-prototype in Georgia. In addition, personnel from NSSL, GTRI and the NWS will work together in 2000 to develop enhanced algorithms and displays for future implementation into the NWS warning system.

New Volume Coverage Patterns (VCPs)

During FY2001, the OSF Applications Branch will continue to collect new VCP test data from the research radar. In addition, we are working with the OSF Engineering and Operations Branches to discover which current NEXRAD algorithms are hard-coded with specific elevations and scan strategies. Finally, we continue to work with the U.S. Air Force and the FAA (the other members of the NEXRAD tri-agencies) to ensure that the proposed scan strategies and algorithm update cycles meet all agency requirements.

OSF Operations Branch Support of WSR-88D Operators

CIMMS personnel will continue to provide support to WSR-88D field sites and play a key role in the transition of the OSF and NEXRAD field sites to an open systems RPG. This RPG will provide the basis for increased forecast performance through the addition of new and more sophisticated WSR-88D algorithms.

Hazardous Winter Weather Climatologies

Research related to hazardous winter weather climatological research will continue throughout the next year at NSSL MRAD. During the next year, a North American climatology of freezing rain, freezing drizzle, and ice pellets will be completed. Although this research will be beneficial to NWS forecasters, other industries (such as those related to energy) will benefit from these results as well. A climatology on wintertime lightning will also be completed during this period.

Precipitation-Type Algorithms

During the next year, NSSL MRAD scientists will investigate the usefulness and accuracy of several precipitation-type algorithms with NWS forecasters at the SPC and the HPC. Results from this study will used to improve the accuracy of the algorithms as well as determining an effective method of displaying the data for forecasters.

SPC Forecast Verification

Work will continue by a CIMMS scientist on SPC forecast verification. This work will include the verification of SPC Probabilistic Outlooks and probabilistic Watch information. Further, work will begin to implement the verification schemes in near real-time so that forecasters can judge their performance as quickly as possible. Once the current SPC verification scheme is operational, work will begin on a next generation set of forecast verification schemes in collaboration with scientists at NSSL. These will begin to address some of the problems with the current verification scheme as well as develop schemes for the verification of additional SPC forecasts. These verification efforts are critical to establish measures of individual and collective SPC performance in support of strategic planning and forecast improvement.

Local Software Development within the SPC

Research continues by a CIMMS scientist in looking at the local probabilities of severe weather. In the next decade, the SPC will likely begin to issue probabilistic guidance for forecast products rather than using arbitrary thresholds for severe weather occurrence and intensity. Preliminary work is being done to look at the feasibility of developing a national climatology of severe weather occurrence as it relates to SPC Convective Watches and Convective Outlooks. These probabilities, once developed, would give NWS forecasters an idea of the likelihood of severe weather in their area based on the SPC decision to include their area in certain categories of Convective Watches or Outlooks. Owing to uncertainties and limitations contained within numerical model data, SPC forecasters continue to rely heavily on observational data when making short-term decisions related to Convective Watches. There remains a need to continue to develop software that allows the SPC forecasters to interrogate all of the data to its fullest extent. This development continues.

Climatology of SPC Products

Interaction with NWS forecasters has shown that they are very interested in seeing a climatology of SPC Convective Watches and Outlooks so that they may have a general idea of when and where to expect the SPC to issue watches across the U.S. on a monthly basis. Currently, the SPC Convective Watches verify with severe weather approximately 90% of the time. By having a watch climatology, the NWS forecasters would then use this research to adjust staffing levels and for other advanced planning, which would help provide better service to the local communities that they are tasked with providing guidance.

SPC Web Site

Work will continue by CIMMS scientists to develop innovative techniques to best convey SPC forecast product information to professional partners as well as the general public. These efforts will include the development of new techniques to help simplify and unify the access and display of SPC and individual NWS forecast office mesoscale hazardous weather information.

Comparisons of ARPS, MM5, and Growth and Decay Storm Tracker Forecasts

As part of the FAA's FY2000 Convective Weather PDT, NSSL is tasked with assessing the skill and ability of ARPS, MM5, and the Growth and Decay Tracker for terminal and/or en route forecasts in the 1-6 hour forecast time frame. CAPS will choose several line storm and/or supercell storm cases. CAPS will run the ARPS model on these cases, and the forecasts will be transferred to NSSL for evaluation. NSSL will run the MM5 model and the Growth and Decay Tracker for these same cases. Performance assessment metrics will be based on those used at MIT/Lincoln Laboratories to assess the skill of the Growth and Decay Tracker. NSSL will write a final report detailing the results of the comparisons of the forecasts.

CLIMATIC EFFECTS OF/CONTROLS ON MESOSCALE PROCESSES

Progress - FY 00

Collaborative Research on "Al Moubarak" and Moroccan Precipitation

The "Al Moubarak" (North Atlantic Oscillation) research project conducted at CIMMS has had two major focuses: one to provide the Kingdom of Morocco with timely seasonal rainfall prediction statements, and the other to understand the fundamental causes (past, present and future) of Moroccan precipitation. During the past fiscal year, we have continued to issue Experimental Precipitation Prediction Statements to Moroccan government officials before and during the October-April precipitation season. These Prediction statements are based on knowledge gained throughout the course of this project. In preparation for making future winter precipitation forecasts from a Global Climate Model (GCM), our Moroccan researcher-in-residence has performed experimental runs with the ECHAM4, a state-of the-art GCM from the Max Planck Institute in Germany. Sea surface temperatures will force these precipitation forecasts.

In order to augment our basic understanding of Al Moubarak, a "mobile" NAO index was developed that would optimize the seasonal signal. Previous studies had focused on the winter part of the year, where the traditional locations of Iceland/Azores or Iceland/Portugal were well positioned to capture the wintertime signal of the NAO. However, our previous results from the Al Moubarak project had indicated the importance of the other seasons and their predictive potential for the winter season. Among these results was 1) the evolution of the NAO during years with extreme January values indicating a August-November-January oscillation; 2) the curious discovery that March had the highest monthly signal-to-noise ratio for the NAO index and the only long-term trend for that index over the last 50 years; 3) the transitional character of spring in the seasonal evolution of the NAO.

Summertime Moisture Budget over the Midwestern United States

Land-atmosphere interactions are central to our environment. The hydrological cycle is a manifestation of this interaction with the surface fluxes of precipitation and evapotranspiration being balanced by the large-scale surface fluxes of the overlying atmosphere. This balance is represented by the atmospheric moisture budget. A paper summarizing this work on the relationships between the moisture budget components on daily, monthly, and seasonal time-scales was accepted for publication. This paper offers a conceptual model that describes the temporal relationships among the budget components for eastward moving large-scale, "wavelike" disturbances with 3-10 day time-scales.

Variability of West African Disturbance Lines

A large set of historical daily rainfall data from the West African Sahel is being used by a CIMMS graduate student to document the role that variations in the characteristics of individual rainfall disturbances have played in the long-

term decline and the large interannual variability of seasonal rainfall totals in that region. The existing rainfall data set has been completely updated through 1998. Analysis of these data suggests that a long-term decrease in both the size and intensity of disturbance lines has contributed to the decline in seasonal rainfall totals in the Sahel. Large, well-organized disturbance lines have become less frequent, and small, weak disturbances have become more common. The seasonal average size and intensity of disturbance lines decreased from the 1950s until the mid-1980s throughout the Sahel. Since then, the trends in seasonal average disturbance line characteristics have varied according to location within the study area. On the intraseasonal time scale, composites of extremely dry and extremely wet years show that throughout the entire rainy season, disturbance lines tend to be larger and more intense during wet years and smaller and less intense during dry years. In collaboration with the TAMSAT group at the University of Reading, satellite rainfall estimation techniques have been applied (for those years when both satellite and raingauge data are available) to verify sections of the raingauge based rainfall indices used to obtain the results summarized above. A manuscript is currently being prepared for submission to an appropriate journal.

Diagnosis and Predictability of East African Rainfall on Intraseasonal to Interannual Time Scales

Almost all facets of societal and economic activities in East Africa are critically dependent on the variability of seasonal rainfall that mostly occurs during the boreal spring (Long Rains, March-May) and autumn (Short Rains, September/October-December). However, the societies are often unprepared to adjust quickly to dramatic deviations from normal rainfall regimes (both seasonal total and frequency of extended wet/dry spells within the season), and valuable resources are often wasted. The fundamental goal of this CIMMS study is to understand the mechanisms that govern the intraseasonal and interannual rainfall variability and hence improve existing climate monitoring and forecasting in East Africa.

This research first assessed the representativeness of the predictability of the large-scale rainfall at smaller spatial scales within East Africa. In addition, the validity of using outgoing longwave radiation anomalies as a proxy for rainfall anomalies was evaluated. Diagnostic analyses were also made of the relationship between East African rainfall and ocean-atmosphere structures associated with El Niño/Southern Oscillation (ENSO) and non-ENSO variability, with a view to establishing the physical basis for remote teleconnections with sea surface temperature (SST) and therefore improving reliability and confidence in SST-based prediction schemes for East Africa. Having defined the teleconnection structures for the seasonal mean, this study then took a first look at the role of extended wet spells over East Africa in the October-November rainfall anomalies and associated teleconnection structures that, in addition to enhancing understanding, sheds light on the potential for anticipating intraseasonal rainfall events. Finally, the research looked at the large-scale boundary layer moisture relative to rainfall variability, which also leads to a better understanding of the evolutions of wet spells.

The results of the study have provided insight into rainfall variability in East Africa, in view of global tropics ocean-atmosphere climate patterns and underlying mechanisms. These results will feed into real-time monitoring and forecasting at intraseasonal to interannual time scales to enhance early warning and disaster preparedness activities and minimize the climate-related catastrophes that are prevalent in the region. This work was performed and completed at OU by a doctoral student from the University of Nairobi in Kenya.

Verification of Satellite-Based Rainfall Algorithms for the Global Precipitation Climatology Project: The Surface Reference Data Center

OU scientists completed an error analysis of the tropical rainfall database and the results are now on-line at:

http://www.evac.ou.edu/srdc.

Based on conversations at the Sea Level Rise/Climate Change meeting held in Rarotonga, Cook Islands, a new collaborative effort between the Surface Reference Data Center (SRDC) with Pacific regional meteorological directors is being organized. In essence, the collaboration involves a minimal amount of support to help initialize and maintain new raingauge networks throughout the Pacific. The funding for this effort has been tentatively approved by NOAA's Office of Global Programs. The collaboration also involves the sharing of information on long-term forecasting, data, and education between the SRDC and the meteorological directors. The effort was initiated due to the long-term decline in the climate observation network in the Pacific and the need to reverse this decline. A trip to Apia, Western Samoa was also taken to attempt to increase the number of participants in this collaboration. A

presentation was given of the initial work and success with the Kiribati Meteorological Service in establishing 15 new raingauge sites on different low-lying atolls within this atoll nation.

Expansion and Analysis of the Comprehensive Pacific Rainfall Data Base

Taylor's Atlas data have been placed on-line and quality controlled by OU scientists. Errors found have been flagged. The quality check of the Comprehensive Pacific Rainfall Data Base (CPRDB) rainfall data, which include daily rainfall data, has been completed. The following was investigated:

- Neighboring station data with significant discrepancies
- High/low percentage of zero rainfall amounts
- Unusually high rainfall amounts
- Comparing rainfall to ENSO events and season
- Identifying possible rainfall errors due to the specific instrument used

We recently compiled a database of Pacific hurricane data that was used to study unusually high rainfall amounts (as well as suspicious low/zero rainfall amounts during a tropical storm) to establish a physical basis for the amounts. It was discovered that observers commonly report zero rainfall on weekends, when in fact the data are missing. This tends to create biases on weekend values and on Monday, as the Monday value is often recorded as a daily value when in fact it is an accumulation. A report on the above results is being prepared as a journal publication.

A Special Atmospheric Sounding Network for Studies of Climate and its Variability in the Tropical Americas

A special network of pilot balloon sounding stations has been operated and expanded over the past year to include 10 countries ranging from Paraguay to Mexico. Daily observations from approximately 15 sites have been used by NSSL MRAD to monitor lower tropospheric wind variations associated with the annual cycle and with climate anomalies over the region. Of special interest have been observations in Bolivia to describe the major low-level jet east of the Andes and twice-daily observations at several sites in Mexico around the Gulf of California to better describe the annual cycle of winds associated with the Mexican monsoon. The data from the network have been used to describe wet and dry periods both in Central America and in Peru during the recent 1997-98 El Niño event. A major thrust in the past year has been to convert the network observations from a strictly research mode to one where the observations arrive in real-time for use by the forecasting communities throughout the region.

Investigation of Temporal and Spatial Variations of Broadband Surface Albedo across the ARM Southern Great Plains Area

Knowledge of the broadband surface albedo, defined as the ratio of the hemispherical reflected solar flux to the hemispherical incoming solar flux, is important in modeling the surface energy budget because the quantity (1-albedo) is the proportion of the incoming solar flux available for sensible and latent heating at the land-atmosphere interface. Clear sky albedo varies with time of day, day of year, vegetation type and health, soil type and moisture, and presence or absence of early morning dew or frost.

This OU research activity to date includes a visit to each ARM Southern Great Plains extended facility (EF) location to document the uniformity of vegetation and landform in and around the facility. The purpose was to establish the degree to which site measurements of downward and reflected solar radiation, particularly the latter, are representative of the size of satellite footprints, i.e., at least a few square kilometers. Each of the 21 EF sites visited was classified as "good", "fair", or "poor" with regard to the extent of vegetation and landform uniformity. Six sites were classified as "good". These are Plevna, KS; Coldwater, KS; Pawhuska, OK, Morris, OK; El Reno, OK; and Cordell, OK. Solar and Infrared Radiation Stations (SIRS) data for 1998 and 1999 for these six sites were extracted from the ARM repository and each day classified into one of six cloud cover indices: clear entire day; continuous clear portion(s) $\geq$ 3 h; continuous clear portion(s) $<$ 3 h; significant periods of cloudiness; overcast; and indeterminate.

Detecting Non-Meteorological Influences on Daily Temperature Observations

The first effort of this OU project was to develop, verify, and implement automated diagnostic schemes for detecting non-meteorological influences on daily temperature observations from the thousands of stations that comprise the NWS Cooperative Network. The second effort was to develop and verify automated methods for identifying impossible and improbable precipitation observations by combining radar and rain gauge methods. The third effort was to apply automated diagnostic schemes to other NOAA data collection networks such as hourly precipitation data, 15-minute precipitation data, upper air data, and first-order stations. This project was completed on December 31, 1999.

Implementation of the U.S. Climate Reference Network (CRN)

The purpose of this OU project is to provide advice on station design and development in connection with implementation of the U.S. Climate Reference Network (CRN). The work includes recommendations on selection of instrumentation for measuring temperature, precipitation, global solar radiation, and wind speed and procedures for (a) calibrating the various sensors and documenting the results, (b) verifying system performance in the "System Field Comparison" phase among co-located stations, and (c) analyzing the data from the "Validation Phase" which leads to station commissioning. Work will be conducted with NCDC personnel to develop real-time quality control measures applied to CRN data.

To date the principal accomplishments have been an investigation of windscreens for reducing under catch of rain and snow (especially the latter), and the design of calibration procedures of a vibrating-wire type all-weather precipitation gage. Both efforts are ongoing and are being carried out with personnel at the Atmospheric Technology Division of NCAR through the Frozen Precipitation Research Project.

Soil Moisture from the Oklahoma 'Moistnet'

Coordination with the USDA/ARS and Oklahoma Mesonet soil moisture measurement networks for similarity in calibration and validation procedures continued at OU and the University of Idaho. This effort was facilitated by an "Oklahoma Soil Moisture Summit" held at the USDA/ARS Grazinglands Research Laboratory in March 1999. Delivery of ARM SGP soil moisture data to GCIP under present contracts is nearing completion.

ARM Southern Great Plains Site Observations of the Smoke Pall Associated with the 1998 Central American Fires

Drought-stricken areas of Central America and Mexico were victimized in 1998 by forest and brush fires that burned out of control during much of the first half of the year. Wind trajectories at various times during the episode helped transport smoke from these fires over the Gulf of Mexico and into portions of the U.S. Visibilities were greatly reduced during these favorable flow periods from New Mexico to south Florida and northward to Wisconsin as a result of this smoke and haze. Public health advisories and public information statements were issued by agencies such as the NWS in May in Oklahoma. This event was also detected by the unique array of instrumentation deployed at ARM's SGP CART and by sensors of the Oklahoma Department of Environmental Quality/Air Quality Division. Observations from these measurement devices suggested elevated levels of aerosol loading and ozone concentration over the CART during May 1998 when flow conditions were favorable for the transport of the Central American smoke pall into Oklahoma and Kansas.

Trajectories ending at the CART Central Facility in May indicated that May 13-15 and May 17-19 should have been particularly good days for observing the smoke pall in Oklahoma and Kansas. Indeed, analyses from the ARM Aerosol Observing System, Raman lidar, Solar and Infrared Radiation Stations, Multi-Filter Rotating Shadowband Radiometer, Cimel Sunphotometer, Micropulse Lidar, a University of Utah Polarization Diversity Lidar, and condensation nuclei counters on the North Dakota Citation aircraft showed elevated levels of aerosols. Additionally, ozone monitors of the Oklahoma Air Quality Division showed concentrations on May 11 in excess of EPA clean air limits of 0.080 parts per million, although the weather conditions that day (not excessively hot or stagnant) were not conducive to producing ozone, suggesting transport into the region. Interestingly, the smoke pall intrusion of May 13-15 was generally limited to the lowest two kilometers of the atmosphere, while the later intrusion, which occurred after a strong cold front had cleaned the atmosphere late on May 15, showed elevated aerosols up to six kilometers. This multi-collaborator observational study, coordinated by a CIMMS scientist, particularly showcased a new

capability for retrieving aerosol extinction profiles from Raman lidar data. A manuscript describing the ARM detection of this smoke event is being published and featured on the cover of the November 2000 issues of the *Bulletin of the American Meteorological Society*.

Plans - FY 01

Collaborative Research on "Al Moubarak" and Moroccan Precipitation

Pending approval by the Moroccan government, the next phase of the Al Moubarak Project, Al Moubarak II, will begin at CIMMS. Al Moubarak II will concentrate on 1) the development of precipitation forecasts for Morocco by the ECHAM4 global climate model; 2) comparison of the ECHAM4 and ARPEGE-Climate models' ability to predict Moroccan rainfall for different time-scales; 3) statistical studies to further our understanding of the characteristics and predictability of the agriculturally important start of the precipitation season (October/November), and 4) continued refinement of the Experimental Prediction Statements to tailor them for the needs of other Moroccan sectors (e.g. hydraulics, and agriculture).

Another upcoming endeavor is the publication of a second NAO paper. A main focus of this paper will be the intraseasonal evolution of the NAO, the coupling between the seasons, and how this coupling might be changing with time.

Our research group will be participating in the AGU Chapman Conference on the NAO to be held from 28 November 28 through 1 December 2000 at the University of Vigo in Orense, Galicia, Spain. The director of CIMMS has agreed to serve as a member of the Program Committee and is also a chair for the *Impacts of the NAO* session. At least one presentation by our group is planned for this conference.

Effects of Oklahoma's Winter Wheat Crop on the Pre-Storm Environment

A host of past studies has highlighted the impacts of mesoscale vegetative regions on atmospheric conditions; however, these studies are limited in their real-world applicability. Past observational studies have focused on specific events, relatively short time periods, or small regions. Past numerical studies have produced highly idealized simulations or have lacked an extended set of regional observations for model initialization and verification. In all cases, the authors acknowledge these shortcomings and note that they result from a lack of long-term, mesoscale observations across a large area. The research to be completed by Oklahoma Mesonet scientists and NSSL will attempt to fill this gap with adequate measurements by employing Oklahoma Mesonet surface data, including measurements from newly installed sensors to measure the surface energy budget and soil moisture, in both observational and numerical experiments. This work will result in a PhD dissertation.

Oklahoma's winter wheat crop provides an ideal real-world environment to examine mesoscale vegetative influences on the atmosphere. The following hypotheses will be examined in this study:

- The spatially averaged diurnal cycle of surface latent and sensible heat fluxes measured within Oklahoma's winter wheat belt is distinctly different from that measured adjacent to the crop both during the growing season and within a month after the wheat harvest in June.
- On certain days during and within one month after the growing season, the horizontal gradient of sensible heat flux is larger than 100 W/m² per 30 km across the crop and its adjacent region; hence, the gradient is large enough to establish a mesoscale circulation.
- The surface moisture field is significantly affected by the evolution of Oklahoma's winter wheat crop
- Advection of surface moisture resulting from Oklahoma's growing winter wheat crop can influence the pre-storm environment outside the boundaries of Oklahoma.

The proposed experiments will be divided in two parts: (1) observational evidence and (2) numerical modeling. The goals of the observational study are to document evidence that (a) horizontal gradients in surface fluxes across Oklahoma's wheat belt are sufficient to produce mesoscale circulations and (b) surface moisture is significantly impacted by the winter wheat crop, both during its growth phase and within one month after harvest. The goals of the numerical study are (a) to assess the impacts of the measured horizontal gradients in surface fluxes and moisture on the wheat field's local environment, (b) to quantify the effects of mature and harvested cropland on the planetary

boundary layer (PBL) by comparing these simulation results with those of a control run without cropland, and (c) to determine how far downstream the wheat field influences near-surface moisture.

Results from this study will extend the current state of knowledge in the atmospheric sciences by providing evidence of the extent to which a mesoscale crop belt can impact its environment. Because low-level moisture, PBL development, and atmospheric instability directly influence convection, the results also will offer evidence of the anthropogenic modification of the pre-storm environment by large crop regions. It is expected that improved knowledge of the impact of the wheat crop on the pre-storm environment will aid forecasters during spring and early summer.

Closure of the Surface Energy Budget

This work, to be conducted by Oklahoma Mesonet, OU, and NSSL scientists will entail an investigation of the surface energy budget at 10 OASIS super sites across the Oklahoma Mesonet. This is a detailed study of the four components of the energy budget, and the problems and challenges in their measurement. This work represents an attempt to identify reasons for the non-closure of the energy budget - approximately 20-30% of the incoming energy remains unaccounted for in the observations. The goal is to quantify this error and identify possible explanations for this error.

Verification of Satellite-Based Rainfall Algorithms for the Global Precipitation Climatology Project: The Surface Reference Data Center

OU scientists continue operational validation of the Global Precipitation Climatology Project (GPCP) merged product over areas analyzed, which thus far have included Oklahoma, the Pacific, and Australia. Other tasks to be completed include production of *The Validator*, completion of an error analysis of the Australian data and production of gridded maps, and production of the error characterization of the Japanese data. These will be completed and on the web by the end of calendar year 2000.

As the SRDC begins to use data from a wider range of sources it becomes more difficult to work with all of the different formats. Every scientist and researcher has experienced this: a dataset needs to be processed, so a program is written to put it into some usable format. Next, another program is written to actually process the reformatted data. Depending on the complexity of the task even more programs may need to be written to do additional analysis. Then the unthinkable happens - the original data format changes or another dataset needs to be used. All of the original programs must either be modified to read the new data or completely rewritten. Even with the best intentions and modular programming design there are quickly dozens of programs to work with several widely different datasets. If anyone other than the original programmer has to work with this system, things quickly deteriorate. One of our goals for the next year is to design data ingest and analysis procedures that are maintainable. In other words, the system will be highly modular so that individual components can be easily changed without breaking anything else. This will allow new datasets and analysis procedures to be integrated in a "plug-and-play" fashion. Sustainability is another goal; the system should be robust and simple enough that anyone can maintain it with a minimal amount of instruction. Data integrity and security are also important concerns. Last but not least is the user interface to the data. The main purpose of SRDC is to allow interested researchers access to our datasets. The needs of each researcher will be different, so a "one size fits all" interface is clearly undesirable. Ideally, the interface should be flexible enough to allow you to get the just the data you need in roughly the format you need it in. For example, one of the largest problems that has been encountered is converting data from a one station/all times format to an all stations/one time format, and vice versa. The ideal interface would allow the user to choose either option before downloading. We plan to accomplish these goals with the implementation of a database management system (DBMS). The main purpose of a DBMS is to facilitate data integrity and security. Modularity and sustainability can be achieved through careful design. The querying facilities of a DBMS allow for data to be retrieved in almost any combination.

A Special Atmospheric Sounding Network for Studies of Climate and its Variability in the Tropical Americas

A special network of pilot balloon sounding stations will continue operating in 10 countries, ranging from Paraguay to Mexico. Daily observations from approximately 15 sites will continue to be used by NSSL MRAD to monitor lower tropospheric wind variations associated with the annual cycle and with climate anomalies over the region. Of special interest are observations in Bolivia that describe the major low-level jet east of the Andes and twice-daily

observations at several sites in Mexico around the Gulf of California to better describe the annual cycle of winds associated with the Mexican monsoon. The data from the network will also be used to describe wet and dry periods both in Central America and in Peru.

Investigation of Temporal and Spatial Variations of Broadband Surface Albedo across the ARM Southern Great Plains Area

Using the clear sky data from the six EF sites, the first goal of OU scientists is to investigate the space and time variability of albedo. The primary interests here are the seasonal variation of the 200 km east-to-west and north-to-south gradients of albedo and their causes. There is a 50% increase in annual precipitation from west to east across the Southern Great Plains area. Since there is a significant change in vegetation and soils across the region in response to precipitation, it will be important to see if there is a corresponding response in albedo. The second goal of the research is to develop a climatology of surface albedo across the ARM area for all days, not just clear days. The results from the first goal should provide physical insight into why albedo varies as it does for both cloudy and clear days. The climatology includes both temporal and spatial analyses. The third goal is to verify satellite radiance algorithms for estimating surface broadband albedo on the different spatial and temporal scales.

Implementation of the U.S. Climate Reference Network (CRN)

OU scientists expect to complete the work with NCAR and NCDC on the Frozen Precipitation Research Project by spring 2001. Advice to personnel at NCDC will continue as needed. Work beyond spring 2001 with the CRN depends on funding.

SOCIOECONOMIC IMPACTS OF MESOSCALE WEATHER SYSTEMS AND REGIONAL-SCALE CLIMATE VARIATIONS

Progress - FY 00

No progress was made in this area during the fiscal year.

Plans - FY 01

Engineering Research Center for Natural Hazard and Disaster Research

Floods are the most devastating of all weather-related hazards in the U.S. On average over the past 30 years, 139 lives are lost each year due to flooding, with the death toll in recent years rising to over 200 per year. In Texas alone, 28 people died in floods during 1998. Though often drawing more media attention, lightning, tornadoes, and hurricanes caused an average of only 87, 82, and 27 lives lost per year, respectively. During the same 30-year period, property damage amounted to $1 billion annually with recent figures averaging over $2 billion per year due to floods.

Considering that

- Flooding is a $2 billion-per-year problem (considering damages and lost revenue)
- Big-government solutions are no longer feasible or even available
- Historically, the record shows increasing numbers of extreme storm events, such as the Mississippi floods of 1993
- Development in urban areas has increased the flooding impact of storms
- Few alternatives exist for alleviating flood damages in the built environment; and
- The NRC and NSTC both agree that flooding disasters is a national priority,

an NSF Engineering Research Center (ERC) has been proposed at OU that would develop the only feasible alternative left - an improved information system for stakeholders to make their own decisions.

Specific ERC goals are to

1) Develop flood prediction, warning and design methodologies using radar estimates of rainfall for river basins and urban watersheds,

2) Involve industry/practitioners in specification of the *engineered system*, and provide needed education them in the potential uses of this technology, and

3) Develop the *engineered system* capitalizing on recent developments in radar and mesonet technology, atmospheric/hydrologic modeling, and information management techniques.

The strategic plan of the proposed ERC will focus on an investment in the development of technology to reduce societal costs of weather-related disasters. The *engineered system* consisting of a ***S***ystem for ***I***nformation, ***M***easurements, and ***M***odeling, will be referred to as SIMM. The end-to-end *engineered system* will begin with radar/mesonet rainfall and other meteorological measurements ingested into atmospheric/hydrologic models to predict floods, and will filter customizing and delivering disaster information to stakeholders.

DOPPLER WEATHER RADAR RESEARCH AND DEVELOPMENT

Progress - FY 00

NSSL SRAD Severe Weather Warning Applications and Technology Transfer (SWAT) Team Activities

The Severe Weather Warning Applications and Technology Transfer (SWAT) team members continued their mission of developing severe weather applications, primarily for the WSR-88D, and transferring technology and knowledge to the National Weather Service (NWS) and the Federal Aviation Administration (FAA). Projects undertaken are described below.

NSSL/OSF Level II Database

The Level II database continues to be an important data source for the greater Oklahoma Weather Center community. The NSSL, with support from the OSF, continues to collect Level II data for the purposes of various research needs and algorithm development and evaluation. Much of the data acquired in 1999 included those associated with WDSS proof-of-concept tests in Tucson, AZ, the western/inter-mountain region of the U.S. to assess the performance of the TDA, and for significant severe/tornado events. In addition to the Level II data, upper air data have also been collected and made available via anonymous FTP and on the web. The 1998 SPC Smooth Log was obtained and used to create the necessary ground truth files for all in-house 1998 Level II data contained within the NSSL/OSF Level II database. Data inventories, soundings, and ground truth data can be found at

http://www.nssl.noaa.gov/~mitchell/level2dbase/level2dbase.html.

New additions to the database are the site weather summaries provided to NSSL by the St. Louis, MO, forecast office. These summaries contain valuable information regarding various storm types captured by the Level II archive device in St. Louis and the associated National Climatic Data Center (NCDC) tape catalog number. These site summaries are available via the above web site.

NWS Tornado Warning Guidance

NSSL and OSF scientists (both at the Applications Branch and OTB) completed the 1999 NWS Tornado Warning Guidance document (TWG99). The TWG99 is based on an update of our latest ideas about and understanding of tornado prediction. A majority of the new guidance comes from an extensive analysis of WSR-88D data using the NSSL experimental vortex detection algorithms. Numerous radar-based parameters, which measure different aspects of thunderstorm vortices, were evaluated to determine how well they discriminate between tornadic and non-tornadic storms.

This new document includes sections on:

- Qualitative general guidance information gleaned from the latest basic and applied research experience.

- Supplemental information for the Build 10 Tornado Detection Algorithm (TDA).
- Results of statistical analyses of 43 cases of MDA, TDA, and BWER data to determine "best predictors" and decision thresholds for tornado warnings.

There was no update to the 1999 NWS TWG document made for the 2000 convective season. However, the development of a TWG document for the 2001 convective season is now underway.

Climatology of Radar Signatures Using the WSR-88D

Database Development:

Since 1995, Level II data have been routinely collected at NWS and Department of Defense (DOD) WSR-88D sites and archived at the National Climatic Data Center. As a result, climatologies of radar observed signatures (e.g., hail, mesocyclones, tornadic vortex signatures -TVS) using a relatively large Doppler radar data set are now possible. In 1998, the NSSL embarked upon a pilot study to ultimately determine a more reliable estimate of the frequency of these radar signatures and how often they are associated with tornadoes and other severe/hazardous weather. This pilot study incorporated the use of NSSL's enhanced severe weather and tornado detection algorithms to identify the radar signatures associated with severe storms and their attendant tornadoes. This work continued into 1999 with the processing of all Level II data (precipitation data only, i.e. volume coverage patterns 11 and 21) collected by the Pittsburgh, PA radar (KPBZ) in 1997 and 1998. Approximately 350 KPBZ 8mm Level II data tapes spanning 1996 through 1998 have now been processed by NSSL's severe/tornadic weather detection algorithms. In addition, the study incorporates the SPC Smooth Log as the source of reports of tornadoes and severe weather. The output of radar signatures and their attributes are being prepared for spatial (geographical) and statistical analysis. Concrete results are still pending as the analysis continues.

Synthetic Tornado Climatology:

NSSL developed a study to determine whether radar-observed storm-scale vortex signatures (e.g., mesocyclones and TVSs) can be used as a proxy to synthesize tornado climatologies where verification is problematic. Tornado verification can be problematic in certain locations, such as those with low population density, in mountainous and forested regions, and where storm verification is not as actively pursued (such as in Europe and other countries).

Starting with a database of "well-verified" tornado events (43 cases with about 207 tornado reports), and the associated output from both mesocyclone and TVS detection algorithms, we determined the likelihood that particular detections are tornadic based on a variety of detection attributes (such as rotational velocity, depth, etc.). We then apply the posterior probabilities of the well-verified dataset to a test data set that is assumed to be poorly verified (the poorly-verified data set is actually a three-year nearly-conclusive set of all the storm-scale vortex detections collected from the Pittsburgh radar during 1996-1998). The resulting synthetic climatological values for number of tornadoes are quite similar to the actual number of reported tornadoes within the domain of the radar for the poorly verified data set.

New Volume Coverage Pattern (VCP) Development and Testing

NSSL personnel developed a set of volume coverage patterns (VCPs) that satisfy the WSR-88D users' needs for improved vertical and temporal resolution. Capabilities of the existing and proposed VCPs were compared by using simulated datasets based on a composite time-height cross section of maximum reflectivity within the typical cell of a multicell hailstorm. Vertically integrated liquid and downburst lead times were computed from the reflectivity cross-section. Evaluations of these quantities indicate that the types of new VCPs proposed here provide improved vertical and temporal resolution.

Archive Level II data for experimental VCPs were collected using the OSF KCRI radar on 11 separate events during spring 1999, including the May 3, 1999 tornado outbreak. Archive Level II data for experimental VCPs were collected data using KCRI on seven separate events during spring 2000.

Severe Storms Analysis Program (SSAP)

The SWAT team continued to develop, maintain and enhance their Severe Storms Analysis Package (SSAP), including the following meteorological algorithms that have been evaluated off-line and in real-time NWS forecast office operational tests:

- Tornado Warning Applications:
  - Mesocyclone Detection Algorithm (MDA)
  - Tornado Detection Algorithm (TDA)
  - Vortex Detection and Diagnosis Algorithm (VDDA)
  - Bounded Weak Echo Region (BWER) algorithm

- Severe Storm Warning Applications:
  - Storm Cell Identification and Tracking (SCIT) algorithm
  - Hail Detection Algorithm (HDA)
  - Damaging Downburst Prediction and Detection Algorithm (DDPDA)

- Applications related to both:
  - Near-Storm Environmental (NSE) algorithm

Development is about midway completed to convert the SSAP algorithms to C-language and for the future WSR-88D Open-Systems RPG. The SCIT algorithm and TDA are nearly complete. The infrastructure to use terrain data has also been incorporated into the SSAP.

Rapidly Updating Algorithm Output

The SCIT algorithm, HDA, TDA, and MDA were incorporated into NSSL's Severe Storms Analysis Package (SSAP) with rapid update capability. This allows detections and warnings generated by these algorithms to be output at the end of each radar tilt (about every 30 seconds) as opposed to at the end of each volume scan (every 5-6 minutes). This new output can be displayed in WDSS-II for all data tilts, or in RADS for the current of latest data tilt. An initial evaluation of the output indicated that the software functions properly and should be of great utility to forecasters.

Integration of Scale Separation/Correlation Tracker and SCIT

The benchmark test between the NSSL and MIT/Lincoln Laboratories versions of SS/CT continued. Sources of the differences between the two versions were investigated, including the filtering, bilinear interpolation, and advection techniques. The final difference between the two versions is thought to be in the advection technique. New code for the advection technique has recently been acquired from MIT/Lincoln Laboratories and is being incorporated into the NSSL version.

Vortex Detection and Diagnosis

The NSSL MDA has been accepted by the OSF to be implemented in the next feasible Open Systems RPG Build (most likely Build 3). To that end, the MDA code will be delivered to the OSF Applications Branch (after some minor debugging and clean-up) for their validation.

NSSL continued to test the MDA on an ever-expanding database consisting of a variety of tornadic and non-tornadic supercell cases. The MDA allows for the detection of storm-scale vortices of various sizes and strengths, and classifies them into a number of different vortex types (including mesocyclone, low-topped mesocyclone, etc.). Trends of vortex attributes are also computed. The database now contains about 70 individual storm event days from a variety of locations across the country. The database includes over 400 tornadoes with over 390 hours of radar data. This represents 12 more events analyzed since FY1998.

NSSL has been developing a special web-based case study collection of a variety of storm types collected nationwide. This study depicts a wide range of the types of tornadic storms that have been observed with the WSR-88Ds, provides detailed discussions, images, and algorithm output evaluations.

NSSL also maintains the TDA, which was implemented as part of Build 10 of the WSR-88D system. During FY1999, NSSL had worked with the OSF Applications Branch as well as several NWS forecast offices to help develop local adaptable parameter sets.

Both the MDA and TDA have been modified so that they can detect clockwise storm-scale vortices. These modifications were developed in part to support real-time algorithm testing in Sydney, Australia, in the Southern Hemisphere. The "Anti-MDA" was also tested on a few Northern Hemisphere left-moving supercell cases.

Enhancements made to the MDA include the addition of NSE algorithm parameters (as derived from RUC mesoscale model grids). Over 100 NSE parameters have been incorporated into the MDA (and TDA). Work was completed to statistically analyze the integrated data. Although individual NSE parameters showed little skill by themselves to discriminate tornadic from non-tornadic detections, a NN trained on the integrated data set showed nearly a doubling in the skill (using Heidke skill score as a measure) in diagnosing the probability of tornado for each detection (from about 35% to 60%).

Bounded Weak Echo Region (BWER) Algorithm

A BWER algorithm was developed in 1998 to detect and classify (using probabilistic "confidence" factors) weak-echo vaults within severe thunderstorms using WSR-88D reflectivity data. The BWER data have now been integrated with the MDA (and TDA) data with 43 of the 58 cases. These combined MDA/TDA/BWER data were used to develop a new NN and to develop statistical analyses for the 1999 NWS Tornado Warning Guidance (TWG99) documentation.

Neural Network (NN) and Statistical Analyses

MDA/TDA Neural Network:

The original set of MDA/TDA NNs was updated with a few revisions. In addition to the inclusion of near storm environment variables as inputs into the NNs, the inputs were transformed to principle components. In order to avoid overfitting, only a subset of the principal components were employed as inputs. A brute force, bootstrapping approach was employed to determine the optimal number of principal components employed as inputs into the NNs.

MDA/TDA Statistics:

The data were preprocessed in a number of ways for the purpose of extracting information that may be useful for producing tornado warning guidance. This information, however, was not released in order to provide a larger database.

HDA/NSE Neural Network:

Given the success of NNs in the prediction/detection of tornadoes, that work was extended to include the HDA. The development of such a NN can be broken into two tasks - a NN developed to detect/predict the existence of hail, and a NN that predicts the size of the forecast hail. The latter was developed first. In fact, two NNs were developed for the prediction of hail size - one that predicts hail size in some physical unit, and another that assesses the probability of belonging to one of three classes of hail size (coin size, golf ball size, and baseball size). Due to the small sample size, Bayesian inference was employed to estimate some of the parameters of the NNs. The first NN has produced size estimates that are approximately 30% improved over the estimates of the existing rule-base. The latter NN produces probabilities that are highly reliable and discriminatory, with the exception of forecasts of golf ball size hail. The latter calls for more data, and will be re-examined in the future. A formal article reporting these findings has been submitted to *Weather and Forecasting*.

Tornadoes and El Niño:

A number of nonparametric methods were employed to examine the correlation between sea surface temperatures in the Pacific and tornado activity in various geographic regions of the U.S. A formal article was produced and has been conditionally accepted for publication in *Monthly Weather Review*.

Hail Detection Algorithm (HDA) - New Techniques for Severe Hail Detection/Prediction

A substantial amount of time was spent investigating the utility of a volumetric severe hail index (VSHI). Although the VSHI was found to have a higher correlation with hail size for isolated storm cells compared to the simple 1-D severe hail index (SHI) parameter, testing on squall-lines showed relatively poorer performance for VSHI at predicting hail size. Test results also showed identical discrimination skill (for severe hail) for both VSHI and SHI. It would appear that the VSHI parameter offers limited potential for improving the performance of the HDA. This work led to a conference presentation.

Due to the lack of significant positive test results associated with development of the VSHI, emphasis was shifted to increasing the amount of NSE data used by the HDA. This involved the addition of four new parameters:

- Height of the wet-bulb zero
- Vertically-integrated wet-bulb temperature
- Wind speed at the equilibrium level (EL)
- Storm-relative flow at the -20º C level

A program was written to calculate these parameters from sounding data, and output was generated for all the storm days in the HDA database.

Conditional probability functions for different hail size categories were developed for users of HDA output. A graph and table relating the maximum expected hail size (MEHS) parameter to probabilities of hail size ≥ 1.5 and 2.5 inches, respectively, were created, and this information was disseminated to the operational community via a report on NSSL's web page and with announcements on the SOO-TALK and WX-TALK mailing lists, and in an article in the OSF publication *NEXRAD Now*.

Work started on the development of a NN for the HDA. However, the size of the HDA database was considered to be a limiting factor in our ability to fully utilize the capabilities of a NN. Therefore, additional time was spent analyzing new cases for the HDA database. At the beginning of FY2000, the database contained algorithm output that has been filtered based on population density, and near-storm environment data, for more than 60 storm days. The database also has less of a "Southern Plains" character. These data have been provided for NN development. Initial test results for a NN that predicts hail size show a reduction in the mean-squared error of ~30% compared to the operational HDA. It is estimated that about half of this improvement is due to the addition of the near-storm environment data and the other half due to the use of a NN.

Hydrometeor Classification Using Polarimetric Radar Data

A hydrometeor classification algorithm has been developed through collaboration between NSSL and NCAR. The algorithm uses polarimetric radar data and a fuzzy-logic membership function to infer meteorology hydrometeors. Based on NCAR's implementation, the algorithm was modified. The NSSL algorithm classifies eleven hydrometeor types: light rain (LR), moderate rain (MR), heavy rain (HR), large drops (with low concentration) (LD), rain/hail mixture (R/H), graupel/small hail (GSH), hail (HA), dry snow (DS), wet snow (WS), and horizontally- and vertically-oriented ice crystals (IH and IV). The classified particle fields are reasonable according to the conceptual model and known results.

Since the large set of comprehensive in-situ observations is not available at this time, a sensitivity study was conducted to verify the hydrometeor classification algorithm based on common sense and known results. The study revealed the following. The reflectivity factor and differential reflectivity combined have the strongest discriminating power. Inclusion of the temperature profile helps eliminate a substantial number of spurious errors. Although the absence of temperature information degrades the scheme, it appears that the resultant fields are generally coherent and not far off from the fields obtained by adding temperature. The qualitative comparison of the effects of polarimetric variables reveals that the (Zh, Zdr) ranks as the most important variable pair for the hydrometeor classification, followed by (Zh, T) and then (Zh, Kdp).

Damaging Downburst Prediction and Detection Algorithm

Fifty-one severe downburst events were successfully analyzed and added to NSSL's Damaging Wind Events Database, as were 664 cells that did not produce severe downbursts. Many potential downburst precursor parameters produced by the DDPDA were cataloged for these 715 cells. Discriminant analysis was employed to create a prediction equation for severe downbursts using two-thirds of these data. Using the other half of the data as an independent test set yielded a Probability of Detection of 0.61, False Alarm Rate of 0.67, and a Heidke Skill Score of 0.40. The average lead-time from the prediction of the event to the time of the event was 5 minutes. For early FY00, the Damaging Wind Events Database was expanded to include 100 severe cells and 1308 non-severe cells. Severe improvements have been made to the calculations of downburst precursor parameters.

Multi-PRF Dealiasing Algorithm (MPDA)

The MPDA has been under development for a total of six years. It has matured into a robust range and velocity dealiasing algorithm. One high point of recent accomplishments was MPDA data collection during the May 3, 1999 tornadic event. This data set provided a wealth of analysis with respect to strong tornadic signatures. It was hypothesized that the MPDA would not perform well in an environment such as that on May 3. On the contrary, it performed exceptionally well in this situation and handled the tornadic signatures very well, and in many cases, better than the operational KTLX data collection.

This is a joint effort between the OSF Applications Branch and the NSSL and represents part of a broader effort to improve overall NEXRAD data quality. An artifact of Doppler radar data is uncertainty in position of a return echo at certain distances from the radar antenna. There are hardware improvements that are possible in the out years; the MPDA is a low-cost, interim software solution. We anticipate the MPDA will be recommended for implementation in an early software build under Open Systems.

Near-Storm Environment (NSE) Algorithm

The goal of the Near-Storm Environment (NSE) algorithm is to integrate Doppler radar and mesoscale model data to provide to the NSSL WSR-88D algorithms information concerning the environment of each storm cell, such as shear and stability parameters. Currently, NSE uses output from the Rapid Update Cycle-2 (RUC2) model to help determine the environment of storm cells.

During FY1999, NSSL had completed a statistical study of integrated MDA, TDA, and NSE data. This represented 14 cases, or about 31,000 vortex detections. NSE gridded data are bilinearly interpolated to the location of the MDA and TDA centroids to determine values for each vortex detection. Initial results looked at bivariate distributions of the data, and this suggested that only a few NSE variables offer some diagnostic value for determining whether or not an algorithm-detected storm-scale vortex is tornadic or non-tornadic. Later, a NN was developed on the data set. This NN showed nearly a doubling in the skill (using Heidke Skill Score as a measure) in diagnosing the probability of tornado for each detection (from about 35% for an NN with no NSE data to 60% for an NN that included NSE data). NSE data were also used to improve the HDA and the DDPDA.

Vertical and Time Association Failure Analysis

NSSL conducted a failure analysis of vertical association (VA) techniques of algorithms within the SSAP. A range of vertical association failures were identified for MDA, TDA, and SCIT for several different storm types including:

- Warm-season/high-shear/supercell (KTLX, 3 May 1999)
- Squall-line (KLSX, 15 April 1994)
- Cool-season/high-shear/supercell (KMPX, 26 October 1996)
- Southwest-monsoon/weak-shear/pulse (KIWA, 14 August 1996)
- Hurricane (KLWX, 13 July 1996)

Failures in the VA code are similar for all schemes when more than one 2D algorithm feature is identified at a given elevation angle, forcing the 3D code to choose between the multiple 2D features. TDA also had an added VA feature that created problems when two TVS signatures were correctly diagnosed within 4 km of one another. Problems outside the 3D code also caused VA failures such as dealiasing problems and an improper setting of the reflectivity

threshold below which velocity data are set to missing. Failures occurred in less than 10% of all volume scans studied in all cases except for the high shear/fast moving case of May 3, 1999. Thy cyclic nature of the supercells in that case created conditions in which the VA code often failed (nearly 50% of the time).

Based on VA code failures, it appears the most logical solution to this problem can be found by examining all elevation angles at one time when constructing 3D features rather than examining just two elevation angles at a time. Basically, the results from this study suggest that the most appropriate 2D feature at each elevation angle should be identified according to location rather than strength rank (MDA) or gate-to-gate velocity difference (TDA). A final report on VA failures can be obtained at

http://www.nssl.noaa.gov/~porter/vertassoc/.

As part of an effort to improve the time association (TA) process of several algorithms in the SSAP (SCIT, MDA and TDA), a failure analysis was conducted to identify the primary causes of TA errors. Algorithm output was generated using Level II data from several storm days representing different storm types (see list above). The analysis results indicated that the most common cause of TA failure was due to multiple detections in close proximity to one another, where the TA process chose the wrong candidate for time association. Often, multiple detections were produced because of VA failures. At other times, the algorithm was simply detecting weaker, secondary features. To a lesser extent, bad first-guess locations caused by bad motion vectors also led to TA failures.

This study points toward two primary areas for improving time association. First, the algorithm detection/identification process needs to be optimized, including the minimization of VA failures. Then, the TA process should be expanded to utilize additional storm/feature characteristics versus simply selecting the candidate that is closest to the first-guess location. This would involve developing a "cost" function that would compare various algorithm parameter values for all available TA candidates, thereby leading to a more robust TA procedure.

RIDDS Support, Maintenance and Installations

In support of and cooperation with the OSF, MIT/Lincoln Laboratories, the DOD, and the University of Oklahoma, the NSSL continued to support, maintain and install the Radar Ingest and Data Dissemination System (RIDDS) during 1999 in support of the diverse yet complimentary objectives of each organization. Additional RIDDS workstations were deployed to the following NWS sites in 1999 as well as maintained by NSSL:

- Tucson, Arizona (NSSL/OSF WDSS PoCT)
- St. Louis, Missouri (OSF WDSS PoCT)
- Amarillo, Texas (CRAFT)
- Lubbock, Texas (CRAFT)
- Hytop, Alabama (Georgia WDSS-II)
- Greenville/Spartanburg, South Carolina (Georgia WDSS-II)
- Sacramento, California (MIT/LL)
- Missoula, Montana (NSSL/OSF Winter WDSS PoCT)

A significant amount of effort was expended to upgrade the RIDDS for Y2K compliance. The RIDDS was retested and certified in accordance with OSF policy in June 1999, and Y2K deployment was completed in December 1999.

WATADS Support

The NSSL, in cooperation and support from the OSF, continued WSR-88D Algorithm Testing And Display System (WATADS) support in 1999. Major activities included the development and release of the WATADS version 10.1 which included the AMBER package and the USBR SAA. In addition, the WATADS was made Y2K compliant with the release of version 10.2 in November 1999. The WATADS continues to be a valuable tool used principally by the NWS, DOD, and the University community.

Real-Time Testing Facility

The real-time testing facility, sometimes referred to as the Warning Applications Research room (WARROOM), was implemented during the spring 2000. However, only the WDSS-II was fully functional by the second half of May. A

real-time algorithm evaluation exercise involving the WDSS-II was started at that time, and lasted until the end of June. Over 30 participants from NSSL SRAD were recruited for the exercise, and teams of 2-4 worked on individual storm days. The teams made comments on various aspects of the WDSS-II, and these will be used to make improvements in the system.

Collaborative Radar Acquisition Field Test (CRAFT): A Prototype for Accessing and Distributing WSR-88D Base Data in Real Time

In order to provide real time base (Level II) WSR-88D data for evaluation in storm-scale numerical weather prediction, and to begin addressing the long-term base data archival problem at the NCDC, the CAPS joined forces in 1998 with UCAR, the University of Washington, the NSSL, and the OSF to establish the Collaborative Radar Acquisition Field Test (CRAFT). Funded initially by a grant from the Oklahoma State Regents for Higher Education, CRAFT is an experiment in the real time compression and Internet-based transmission of NEXRAD base data from multiple radars. The initial test bed of radars at Oklahoma City, Tulsa, Fort Smith, Fort Worth, Lubbock, and Amarillo has been delivering data continuously for over a year with virtually no outages.

During the past 12 months, the funds received from the OSF were used to pay the communications costs of the data lines for the six radars listed above, for maintaining the data ingest computers, and for archiving the data at OU. CRAFT data also are received in real time by the NSSL and used in development of the WDSS-II. In early June 2000, the NCDC began receiving compressed base data in real time from the six CRAFT radars via the commodity Internet. These data are now ingested directly onto the NCDC mass storage system.

Radar-Based Warning Decision Training

Radar continues to be the primary tool that NWS forecasters use in the AWIPS era to interrogate convective phenomena for severe potential. Radar training has become the primary focus of the new WDTB. CIMMS personnel have been supporting radar use training in AWIPS, advanced velocity interpretation, and new radar-based warning decision tools. Support for radar use training in AWIPS has included converting the primary OTB training course, Distance Learning Operations Course (DLOC), to an AWIPS format. Support for more advanced training of radar fundamentals has included developing a CD-ROM module, "Velocity Explorer", which uses dual-Doppler analysis and 3D-imagery of severe storms to illustrate single Doppler sampling limitations. Other advanced radar applications include understanding reflectivity and velocity characteristics of tornadic storms using close-range radar data. CIMMS personnel have also supported the development of training for WDSS SCAN2.0, which is scheduled to be integrated into AWIPS in 2001.

Improved NEXRAD Precipitation Estimation

The OSF Applications Branch partnered with and funded the OU Schools of Meteorology and Industrial Engineering to study Level II Doppler radar data with the aim of improving precipitation estimation. The goal is to search for non-linear relationships among the three radar data moments and, if found, to exploit the information to improve forecaster's ability to estimate precipitation amounts over a large area.

NEXRAD Open Principal User Processor (OPUP)

The WSR-88D has been used operationally for over eight years and has become an indispensable tool for short-range weather forecasting. The Department of Commerce, Department of Transportation, and the DOD were the three organizations that had the vision that drove the development and implementation of NEXRAD. Though the current NEXRAD Graphical Display System (referred to as Principal User Processor, or PUP) has served the operations community well in the past, each of the three agencies have initiatives to replace the graphics display system. Thus, the OPUP will become the replacement display system. OPUP is a DOD-funded program to implement NEXRAD display functionality in the context of the Air Force Weather Agency centralized forecast Hub concept. The Hub operational scenario established four regional hubs that collect weather data and disseminate them to weather data customers (i.e., Air Force and Army bases). The OPUP is capable of ingesting WSR-88D products from as many as 20 Radar Product Generators (RPG). It will enable Air Force forecasters at the hubs to issue forecasts and severe weather warnings for Air Force and Army bases in their geographic region of responsibility. The OSF Open Systems Group and NSSL SRAD are contributing to this effort.

In order to establish an OPUP presence early, a staged approach was established, deploying limited functionality versions of OPUP, to be followed with releases of increased functionality at a later time. The initial deployment, termed Spiral I, was deployed in June/July 2000 to the four hubs, with positive feedback from the users. Spiral II, the more complete OPUP implementation, has just begun.

Joint Polarization Experiment Planning (JPOLE)

Work has begun at NSSL SRAD in planning the Joint Polarization Experiment (JPOLE). The primary goal of JPOLE will be to operationally demonstrate the value of the polarimetric upgrade of the KOUN WSR-88D radar. The experiment will include an operational focus on polarimetric rainfall and hydrometeor identification tests combined with dense ground-based and airborne data collection to support verification. A significant hydrological component is also planned. Present plans call for a multi-seasonal project with an intense observation period in the spring of 2003.

Polarimetric Radar Developments

Results of regular measurements of raindrop size distributions with a newly acquired 2D-video-disdrometer at NSSL SRAD have been compared with rainfall estimates made with an operational WSR-88D radar and polarimetric Cimarron radar. It has been shown that natural variations of DSD are the major cause of the errors in the radar rain estimation (at least at distances closer than 100 km from a radar).

A new version of a polarimetric rainfall algorithm based on the joint use of the specific differential phase K_{DP} and differential reflectivity Z_{DR} has been developed and tested for several "outlier" rain events in Oklahoma for which the currently used WSR-88D precipitation algorithm fails. The new algorithm, which takes into account variations in the drop median volume diameter D_0, shows substantial improvement.

An analysis of full polarimetric matrix measurements made with the NCAR SPOL and Colorado State University CHILL dual-polarization radars in Colorado, Florida, and Brazil has been performed. The results reveal the tremendous power of multi-parameter radar measurements for hydrometeor classification. A study of a new polarimetric parameter, co-cross-polar correlation coefficient, has revealed its possible use for particle orientation determination.

QPE-SUMS

QPE-SUMS is an improved precipitation algorithm that utilizes data from multiple sources. Its functionality includes ground clutter removal, convective/stratiform separation, radar data mosaicing, and flexible Z-R equations. Since its inception, it has been redesigned as an operational, real-time algorithm. Precipitation products are generated every 5 minutes on a grid covering the state of Arizona. Users may display products in a workstation environment, or on a PC via a web-based client developed by the Oklahoma Climate Survey. Water and power managers have the option to view algorithm output with several important overlays, such as power lines, canal locations, gauge sites, or watershed boundaries. This work is done by the NSSL SRAD WISH team.

Vertically Pointing Radar for Precipitation Monitoring

During the winter of 2000, a 10-cm vertically pointing radar was deployed in Utah and Arizona by the NSSL SRAD WISH team to study the vertical structure and temporal evolution of precipitating clouds. Snow, graupel, melting layer, and rainfall were observed in concert with many other observational platforms during the IPEX field campaign. Observational periods spanned over 26 days from February through April. After the data were collected, a program was written to process and display the results for ongoing analysis. The time-height cross sections were able to show reflectivity from heavy snow. The 45-m height resolution of the radar captured unprecedented detail in wintertime precipitating clouds affecting the southwest U.S.

High-Resolution Convection Climatology for Central Arizona

During the monsoon season (roughly July-September), central Arizona receives a significant portion of its yearly rainfall. Storms that develop over this area can produce flooding, severe weather, and lightning. Hence, a better knowledge of areas favorable and unfavorable for storm development would be useful for forecasters, utilities, and

fire managers. The goal of this NSSL SRAD WISH team study is to create a high-resolution convection climatology, and examine the role of terrain forcing and synoptic-scale effects on convective initiation, modes, and movement.

Toward this goal, volumetric reflectivity mosaics with 1-km resolution are being created using Level II radar reflectivity data collected from Phoenix (KIWA) and Flagstaff (KFSX) radars during July and August of 1996-2000. Also, diurnal reflectivity frequencies above a selected threshold are being created to document areas of persistent convective initiation. These fields are being spatially analyzed with respect to the mountainous terrain and synoptic conditions to understand better the role of terrain forcing and synoptic regime in producing convective initiation over central Arizona. This work is exciting for the field of meteorology because it 1) illustrates a new method for improving the resolution of convection climatologies applicable to most regions in the U.S. (especially mountainous regions), and 2) attempts to identify better ways to forecast convective initiation areas of mountainous terrain.

Three-Dimensional Multiple Radar Reflectivity Mosaics

A real-time 3D multiple radar reflectivity mosaic scheme has been developed by the NSSL SRAD WISH team. The multi-scheme can remap and mosaic reflectivity fields from up to 10 radars for any given 3D Cartesian grid. Applications of the scheme to winter and summer cases have shown that the mosaic fields provide more complete depictions of storm and precipitation events than products from single radars. Gridded data could allow various WSR-88D users to benefit from a wide-variety of products and displays (flexible horizontal or vertical cross-sections and regional rainfall are examples) that could be extracted easily from multiple radar analysis grids. Gridded radar data can also be easily combined with information from other data sources (e.g., satellite, gridded model analyses, or forecast fields), increasing their value in the overall forecast and warning process.

Plans - FY 01

NSSL SRAD Severe Weather Warning Applications and Technology Transfer (SWAT) Team Activities

The Severe Weather Warning Applications and Technology Transfer (SWAT) team members will continue their mission of developing severe weather applications, primarily for the WSR-88D, and transferring technology and knowledge to the NWS and the FAA. Plans are described below.

<u>NSSL/OSF Level II Database</u>

The NSSL, with support from the OSF Applications Branch, will continue to acquire additional radar data and make them available to the local community.

<u>NWS Tornado Warning Guidance</u>

The 2001 TWG document will expand upon the 1999 edition. It will include an updated qualitative general guidance section based on leading-edge research results. It will also include results from a new statistical analysis of MDA, TDA and BWER data, and will include:

- Integrated NSE data from the RUC1 and RUC2 mesoscale models
- A division of data into subsets that represent various storm types as dictated by the NSE (e.g., mini-supercell, squall line tornadoes, tropical-cyclone tornadoes, HP, LP, CL supercells, etc.)
- A division of data by range (km) from the radar
- A greatly expanded data set (about 50 cases with integrate data from all 4 algorithms).

<u>Climatology of Radar Signatures Using the WSR-88D</u>

Future plans include completion of the statistical analysis using the KPBZ data and presentation of a status report of the study and results at the upcoming 20th AMS Conference on Severe Local Storms in September 2000. In addition, the NSSL will begin processing and analyzing the Level II data from other radars across the U.S.

New Volume Coverage Pattern (VCP) Development and Testing

NSSL personnel will collect KCRI data in shallow events using VCP 51 and evaluate algorithm responses. Also, the question of why some WSR-88D algorithms (WATADS) malfunction using the new VCPs will be evaluated.

Using experience gained from 1998 and 1999 work, NSSL personnel will develop specific recommendations for new VCPs and present them to the NEXRAD Technical Advisory Committee (TAC) to be included in the next feasible Open-Systems RPG Build (most likely Build 3).

NSSL personnel will evaluate WSR-88D detection of reflectivity signatures using fine-scale spatial resolution. Using the KCRI Archive I data collected during the tornado outbreak on 3 May 1999 to produce two different sets of Archive II data, the quality of reflectivity hook echoes will be subjectively compared as a function of range, azimuthal increment (0.5 vs. 1.0 deg), and range increment (0.25 vs. 1.0 km). NSSL personnel will also collect Archive I data sets in a variety of weather situations. These sets will be used to test refined algorithms.

NSSL personnel will use KCRI data to evaluate the use of finer azimuthal resolution WSR-88D data for improving detection of mesocyclones and tornadoes. Using the KCRI Archive I data collected during the tornado outbreak on 3 May 1999 to produce two different sets of Archive II data, the strengths of 0.5 deg azimuthal resolution mesocyclone and tornadic vortex signatures will be compared with the strengths evident from conventional Archive II data having 1.0 deg azimuthal resolution.

Severe Storms Analysis Program (SSAP)

NSSL will complete the conversion of the SSAP algorithms to C-language and to the upcoming Open-Systems RPG. HDA, MDA, and DDPDA algorithm conversions will also commence. More robust methods for vertical and time association will be developed in the next fiscal year. Also, terrain information will be integrated into the algorithms. Also, future algorithm development will be facilitated by use of CODE.

Rapidly Updating Algorithm Output

Algorithms in the SSAP have been modified to produce output after each elevation scan rather than at the end of the volume scan. To date, four NSSL algorithms (SCIT, HDA, TDA and MDA) have been equipped with this 'rapid update' capability. The major task remaining for this work is to integrate rapid update output within the WDSS-II framework. Other features will be added as the work proceeds.

Integration of Scale Separation/Correlation Tracker and SCIT

After the new advection code from MIT/Lincoln Laboratories is incorporated into the NSSL version of SS/CT, both versions will be compared again. Pending the outcome of the benchmark test, work will commence on incorporating SS/CT into the WDSS-II framework using CODE. SS/CT and SCIT forecasts and output will be integrated according to the display concepts developed during FY1999. SS/CT is now referred to as the "Growth and Decay Storm Tracker" by MIT.

Vortex Detection and Diagnosis

Work will continue with the OSF Applications Branch to implement the NSSL MDA into Open Systems for fielded operations in 2002. NSSL will aid in the development of training documentation.

NSSL will develop web-based instructions and software to aid the NWS forecast office forecasters in the development of local MDA and TDA data sets suitable for local adaptable parameters studies, and for the incorporation of field data into the nationwide database to be collected at NSSL. The software will guide the forecasters by using the same truthing, association, and scoring methods employed by the NSSL and OSF so that validation efforts are consistent.

As the first versions of the CODE are released, initial source code development for the Vortex Detection and Diagnosis Algorithm (VDDA), an algorithm that combined ideas of MDA and TDA with improved vortex detection and diagnosis techniques, will commence.

Bounded Weak Echo Region (BWER) Algorithm

Work will continue to evaluate the BWER algorithm, including integrating the information with other data sources.

Neural Network (NN) and Statistical Analyses

The MDA and TDA NNs will be elevated to Bayesian NNs, as has been done for the HDA NN. Work will also continue on the analysis of MDA/TDA data for the purpose of producing guidance for tornado warnings.

Hail Detection Algorithm (HDA) - New Techniques for Severe Hail Detection/Prediction

Work will continue on the development of a NN for the prediction and detection of hail, including hail size. Also, a second NN will be developed for predicting the probability of severe hail (POSH). Additional storm cases will be analyzed to further increase the size of the HDA database. These changes to the HDA will be incorporated into the next feasible Open-Systems RPG Build.

Hydrometeor Classification Using Polarimetric Radar Data

Plans include continuation of dataset analysis with respect to hydrometeor classification algorithm results. Major fiscal year milestones are to have the scientific plan in place for the Central Oklahoma JPOLE, and to collect polarization data for the first time with the prototype WSR-88D.

Damaging Downburst Prediction and Detection Algorithm

Plans for the remainder of 2000 include the development of a new version of the DDPDA prediction equations based on the expanded data set. A formal DDPDA is in development as well. Finally, the DDPDA will be re-coded for insertion into CODE. The DDPDA is a candidate for the next feasible Open-Systems RPG Build.

Multi-PRF Dealiasing Algorithm (MPDA)

A major milestone will be reached with the delivery of the MPDA software to the OSF for implementation in the Open-Systems RPG Build 3 release. After the software is delivered, NSSL efforts will be devoted to ORPG technical discussion on MPDA implementation. Currently, funding is not allocated for FY2001, although there are tasks that could be performed that have arisen from FY2000 analysis.

The MPDA was to be presented to the NEXRAD Technical Advisory Committee in August 2000. Following anticipated approval, the algorithm will be coded and prepared for one of the first available software implementations, likely in FY2002 or 2003. In the interim and during FY2001, minor tuning and improvements to the algorithm will continue. In addition, the OSF Applications Branch is compiling verification and validation data for this important work.

Near-Storm Environment (NSE) Algorithm

NSE data will be run on at least 50 more MDA/TDA cases to develop a larger data set for the development of new TWG statistics and an improved NN. Data will also be integrated with information from the BWER algorithm.

Vertical and Time Association Failure Analysis

The failure analyses identified a number of techniques that are needed to improve the vertical and time association routines of the SSAP algorithms. It was felt that a large number of time association failures were due to upstream vertical association failures. Also, the failures impacted the SCIT algorithm more so than the MDA and TDA. NSSL recommends that work be carried out to improve the SCIT techniques as soon as possible.

RIDDS Support, Maintenance and Installations

An unsuccessful attempt was made to incorporate data compression software into the RIDDS to allow for economic distribution of base radar data. Other priorities such as Y2K prevented successful implementation. However, plans

for 2000 include implementing the compression software into the RIDDS in the Solaris 2 operating system. In addition, the NSSL will continue to support and maintain the 40 RIDDS sites. Information regarding the RIDDS can be found at:

http://www.nssl.noaa.gov/~sinclair/riddsguide.html

WATADS Support

WATADS support will continue until the end of FY2000. No new releases of WATADS software are anticipated prior to the release of the first versions of CODE, scheduled during late 2000 and into 2001. CODE will then become the replacement for WATADS.

Collaborative Radar Acquisition Field Test (CRAFT)

With new funding from a NOAA/ESDIM grant and a NOAA earmark, CAPS and the NSSL plan during the next 12 months to add approximately 30 RIDDS-equipped radars to the Internet2/Abilene infrastructure as part of CRAFT-2. The broad geographic distribution will provide an acid test of overall reliability, network efficiency, and real-time ingest at the NCDC (and, eventually, NCEP). As part of this effort, NSSL and OU will improve the radar data compression algorithms with a view toward accommodating larger data sets associated with dual-polarization and more dense scanning strategies. The NCDC will move its base data ingest system over to a new T3 line and will begin receiving data from each of the new CRAFT-2 radars as they are linked to the Abilene network. It is hoped that the associated Exabyte tape recorders can be decommissioned once the links are shown to be stable. Attention also will be directed toward implementing the LDM-based data compression and transmission capabilities in the new NEXRAD Open Systems architecture.

Real time base data will be of rather limited value if not accompanied by suitable analysis tools. Consequently, preliminary efforts are underway to explore the application of data mining techniques to base data, and the creation of synthetic climatologies and other metadata sets by running storm feature identification algorithms on the data as they arrive from the radar. Consideration also is being given to creating one or two sites that would maintain 2 or 3 years worth of base data online for immediate perusal and download.

The collaborating groups have submitted a proposal to the NOAA HPCC program in an effort to secure additional funding for testing the integrity of the CRAFT-2 network.

Radar-Based Warning Decision Training

The Warning Decision Training Branch will continue developing radar-based warning decision training for NWS warning operations in 2000-2001. The baseline radar-training course, DLOC, will be updated to reflect changes in future AWIPS software builds. SCAN 2.0 training materials will be created, and teletraining and web-based training will be delivered concurrently with field deployment of AWIPS Build 5.0. WDTB will interface with the NSSL and OSF to develop and deliver training for the Open Systems RPG, a hardware/software radar interface improvement scheduled for Fall 2001. Further studies into single Doppler sampling considerations of severe weather will continue using high-resolution Doppler On Wheels data in conjunction with other Doppler radars for the May 3, 1999 tornado outbreak.

Improved NEXRAD Precipitation Estimation

The OSF Applications Branch data mining and structure explorations are a work in progress. OSF and OU scientists expect to finish the non-linear analysis early in the fiscal year. If a coherent structure appears and an algorithm appears possible, the next phase will involve development of a statistical precipitation algorithm. It is anticipated that the algorithm will employ both reflectivity and velocity information.

NEXRAD Open Principal User Processor (OPUP)

As described previously, the OPUP is key to the Air Force Weather Agency strategy for centralized weather services. Based on Air Force requirements, work will continue at OSF Open Systems and NSSL SRAD to develop and fully implement a NEXRAD graphical display system that can be integrated into the Air Force weather

forecasting Hubs. These four regional Hubs will be responsible for Air Force weather services throughout the nation.

Joint Polarization Experiment Planning

Over the next year, a JPOLE Science Overview Document (SOD) and Operations Plan draft will be prepared by NSSL SRAD. The SOD will emphasize both 1) the tri-agency (NWS, FAA, and DOD) operational requirements of a polarimetric WSR-88D radar and 2) the meteorological and hydrological scientific objectives of the experiment.

Polarimetric Radar Developments

A new version of a polarimetric rainfall algorithm will be tested at NSSL SRAD on several new data sets, including the ones obtained by the NCAR SPOL radar in Florida during the TEFLUN experiment and in Brazil during the TRMM-LBA project. The range effects on the performance of polarimetric and nonpolarimetric rainfall estimators will be examined using ground-truth data collected from the Oklahoma Mesonet. Work will also continue to collect 2D-video-disdrometer data and to use them for the interpretation of radar rainfall estimates obtained from conventional and polarimetric radar measurements and to develop techniques to improve hydrometeor identification and precipitation intensity estimators. Finally, a preliminary evaluation of the design and viability of the prototype for the operational polarimetric radar will be performed.

High-Resolution Convection Climatology for Central Arizona

The NSSL SRAD WISH team will continue creation of volumetric reflectivity mosaics with 1-km resolution using Level II radar reflectivity data collected from Phoenix (KIWA) and Flagstaff (KFSX) radars during July and August of 1996-2000. Also, diurnal reflectivity frequencies above a selected threshold are also being created to document areas of persistent convective initiation. These fields are being spatially analyzed with respect to the mountainous terrain and synoptic conditions to understand better the role of terrain forcing and synoptic regime in producing convective initiation over central Arizona.

2. PUBLIC AFFAIRS AND OUTREACH

The NOAA Weather Partners Public Affairs coordinator responded to more than 500 local, national and international media inquiries during 1999, especially following the May 3, 1999 tornado outbreak, by setting up media interviews with the appropriate NOAA/Norman representatives, including directors, scientists and forecasters. NOAA/Norman organizations have been featured in stories on all the major networks and in many national publications. In Oklahoma, NOAA has appeared on the front pages of the local papers more than 20 times.

Scientists were interviewed by at least five production companies doing programs on tornadoes and severe weather during spring and summer 1999 for The Learning Channel, the Discovery Channel and the BBC. Examples include live broadcasts for the BBC and The Discovery Channel ("Twister Week"); a "Discovery Magazine" program on tornadoes that aired on The Discovery Channel in October; an "Understanding Weather" program that aired Nov. 14 on The Learning Channel; and a program on tornadoes that aired in February 2000 on The Learning Channel produced by Pioneer Productions.

Many tours were given throughout the year. At NSSL alone, 1,400 people participated in such tours. Additionally, 550 e-mails and 336 telephone calls were answered.

The NOAA Weather Partners Public Affairs coordinator wrote and distributed about 30 national and local news releases and suggested several additional story ideas or photo opportunities to area media. News releases included:

- Kimpel Named AMS President Elect
- StormLink Seeks Severe Weather Reports
- Lilly Elected to National Academy of Sciences
- Partnership Formed to Improve Weather Warning System
- Tornado Myths DeBunked (*Norman Transcript* supplement)

- Hometown news releases for each of the 10 Research Experiences for Undergraduates (REU) students who participated in the summer program
- NOAA Scientists, Research Aircraft and Doppler Lidar Join Massive Weather Research Study in Europe
- Experts Provide Updated Lightning Safety Recommendations (AMS release distributed locally)
- NSSL to Receive "Phased Array" Spy-1 Radar (*NOAA Report*)
- Kimpel Named AMS President (AMS release distributed nationally)
- NOAA Research Office Honors Local Staffer
- Commerce Department Awards Silver Medal to National Severe Storms Laboratory
- Story Suggestions included:
    - Coverage of the unsafe rebuilding in Oklahoma City and Chuck Doswell's work with the Building Performance Assessment Team by Transcript, Oklahoman and ABC affiliate
    - Photo of Dave Evans visiting NSSL

Other outreach programs included:

- NSSL representatives participated in Aerospace America, the annual Oklahoma City air show held in June 1999 and attended by about 75,000 people.

- A NOAA Weather Partners Open House was held on October 30, 1999.

- NOAA Weather Partners staff participated in a tornado season kickoff news conference and media workshop March 2-3, 2000.

- NOAA Weather Partners staff participated in an exhibit and gave presentations at Sooner Mall in Norman on March 24-25, 2000.

- CAPS organized, facilitated, and led a national symposium in Oklahoma City on tornadoes during the week of May 1, 2000, the first anniversary of the devastating May 3, 1999 tornado outbreak. OU's other meteorology groups and the NOAA Weather Partners played a strong participatory role in this weeklong workshop.

- NSSL staff provided a facility tour and presentations for Leadership Norman, Leaders Plus, and York International President Stuart Amos and his family.

- The ARM Program, though CIMMS and the Oklahoma Climatological Survey, continued a pre-K through grade 12 outreach program for students and teachers in Oklahoma and Kansas. An instructional workshop for teachers was held in July 1999 and numerous tours were given throughout the fiscal year at the ARM central facility in northern Oklahoma. A website is dedicated to this outreach effort:

http://outreach.ocs.ou.edu/arm/

3. COMPUTER SUPPORT

CIMMS personnel assigned to NSSL and SPC play a strong role in the computer system and web page development and administration at those units. The main goal is to maintain systems so that the scientists can do their work without interruption. Some software is developed for the scientists as well.

Specific activities included:

- Administration of the NSSL Sun network, which has about 70 workstations. Most of these workstations are used by NSSL SRAD staff and students.

- Worked with data users from Australia to help them solve problems developing software to convert Australia Doppler data to WSR-88D format and coordinate algorithm installation. Their goal was to have realtime NSSL algorithms running for the upcoming 2000 Summer Olympics in Sidney.

- Developed software to process LDM data files and make available in realtime for processing. This system is used by GTRI (Georgia Tech Research Institute). These data come from a Sun workstation at the Peachtree City, Georgia, NWS office.

- Dealing with "Y2K". CIMMS staff spent three months on the process, including developing software that allowed modification of the time/date information on all WSR-88D data records. Only a few algorithms were discovered to have possible December 31/January 1 problems. One other algorithm had a possible February 28/29 problem, but this was due to a typographical error in the code. All errors were successfully fixed. The most serious problem encountered was that some algorithms printed out "100" instead of "00" when producing mm/dd/yy time stamps.

- CIMMS scientists are responsible for maintenance and development of the SPC and NSSL web pages. These two web pages receive a great number of "hits" on a daily basis, especially during times of unsettled weather.

- A CIMMS scientist at SPC participated in the investigation, design, and improvement of real-time data ingest, storage, enhancement and distribution systems. He also participated in the development of product generation and distribution systems and data archive retrieval and management systems using innovative technology and programming techniques. He conducted development and research in support of enhanced network security including firewalls and proxy servers. This work led toward efforts to benchmark SPC computation needs to optimize the use and procurement of servers and workstation systems and to research and enhance their performance.

SCIENTIFIC PUBLICATIONS

A list of publications submitted, accepted, in press, and published during the past fiscal year is presented below; the list may not be totally complete, as it depends on reporting from the individual scientists.

Beasley, W H, K Eack, H Morris, W D Rust, and D R MacGorman, 2000: Electric-Field Changes of lightning observed in thunderstorms. *Geophys. Res. Lett*., **27**, 189-192.

Bellue, K. G., M. I. Biggerstaff, and A. Witt, 1999: Performance of the NSSL hail detection algorithm for multicell storms over the coastal southern plains. *Preprints, 29th Intl. Conf. on Radar Meteor.*, Montreal, Canada, Amer. Meteor. Soc., 117-120.

Black, R. A., T. J. Schuur, and I. Winger, 2000: Ice particle morphology in an MCS: Implications for electrification of the stratiform areas. *13th International Conf. on Clouds and Precip*. Reno, Nevada, August 2000.

Brandes, E.A., A.V. Ryzhkov, D.S. Zrnic, 2000: An evaluation of radar rainfall estimates from specific differential phase. *J. Atmos. and Oceanic Technol*., accepted.

Brooks, H.E, M.P. Kay, D.S. Zaras, N. Blais, and B. Flickinger, 2000: Daily probabilities of severe thunderstorms in the United States. *Preprints, 12th Conf. on Appl. Climatol*., Asheville, North Carolina, Amer. Meteor. Soc., in press.

Brown, R.A., and V.T. Wood, 1999: Technique for improving WSR-88D detection of mesocyclones. *Preprints, 29th Int. Conf. on Radar Meteor.*, Montreal, Quebec, Canada, Amer. Meteor. Soc.

Brown, R. A., J. M. Janish, and V. T. Wood, 2000: Impact of WSR-88D scanning strategies on severe storm algorithms. *Wea. Forecasting*, **15**, 90-102.

Brown, R. A., V. T. Wood and D. Sirmans, 2000: Improved WSR-88D scanning strategies for convective storms. *Wea. Forecasting*, **15**, 208-220.

Burgess, D.W., and M.A. Magsig, 2000: Doppler radar data related to F-scale for the May 3rd Oklahoma City tornado. *Fujita Memorial Symposium*, Amer. Meteor. Soc., Long Beach, CA.

Burgess, D.W., and M.A. Magsig, 2000: Understanding WSR-88D signatures for the 3 May 1999 Oklahoma City tornado. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Burke, P. C., C. Hannon, V. McCoy, G. J. Stumpf, E. D. Mitchell, and D. L. Andra, 2000: Performance of NSSL Warning Decision Support System during the May 3, 1999 Central Oklahoma Tornado Outbreak. *23rd Nat. Wea. Assoc. Annual Meeting*, Biloxi, Mississippi, Nat. Wea. Assoc.

Ciach, G., M.L. Morrissey, and W.F. Krajewski, 1999: Conditional bias in radar rainfall estimation, *J. Applied Meteor*., accepted.

Conway, J.W., and M.D. Eilts, 1999: The NEXRAD Enhancements Product Development Team sponsored by the Federal Aviation Administration. *Preprints, 8th Conf. Aerospace, Range, and Aviation Meteor.*, Dallas, TX, Amer. Meteor. Soc., 514-517.

Cortinas, J. V., Jr., 2000: A climatology of freezing rain over the Great Lakes region of North America. *Mon. Wea. Rev*, accepted.

Cortinas, J.V., Jr., and M. E. Baldwin, 1999: A preliminary evaluation of six precipitation-type algorithms for use in operational forecasting. *Proc., 6th Workshop on Operational Meteorology*, Halifax, Nova Scotia, Environment Canada, 207-211.

Crawford, T.M., D.J. Stensrud, T.N. Carlson, and W.J. Capehart, 2000: Using the soil hydrology model to initialize soil moisture. *J. Hydrometr.*, in press.

Davies-Jones, R., R. J. Trapp, and H. B. Bluestein, 2000: Tornadoes and tornadic storms. *Severe Convective Storms, Meteor. Monogr.*, Amer. Meteor. Soc., in press.

Doswell, C.A. III, G.J. Stumpf, and D. Speheger, 2000: On the importance of post-event surveys in assessing tornado occurrence. *Symp. on The Mystery of Severe Storms*, Long Beach, CA., Amer. Meteor. Soc.

Doviak, R.J., V. Bringi, A. Ryzhkov, A. Zahrai, and D. Zrnic, 1999: Considerations for WSR-88D upgrades to improve rainfall measurements. Preprints. *29th Int. Conf. on Radar Meteorology,* Montreal, Canada, Amer. Meteor. Soc., 278-280.

Doviak, R.J., V. Bringi, A.V. Ryzhkov, A. Zahrai, D.S. Zrnic, 2000: Considerations for polarimetric upgrades to operational WSR-88D radars. *J. Atmos. Oceanic Technol.*, **17**, 257 - 278.

Droegemeier, K.K., 2000: The real time acquisition and archival of WSR-88D base data. *Unidata Newsletter*, summer edition.

Droegemeier, K.K. and Co-authors, 2000: The real time acquisition and archival of WSR-88D base data. *J. Atmos. Oceanic Technol*., in preparation.

Eilts, M.D., J.T. Johnson, K.D. Hondl, G.J. Stumpf, E.D. Mitchell, J.W. Conway, and K.W. Thomas, 1999: Warning Decision Support System - the next generation. *Preprints, 15th Int. Conf. on Interactive Information and Processing Systems (IIPS) for Meteor., Oceanography, and Hydrology*, Dallas, TX, Amer. Meteor. Soc., 154-157.

Erlick, C., A. Khain, Y. Kogan, and M. Pinsky, 2000: Sensitivity of the radiative properties of stratiform clouds to environmental conditions. *13th Inter. Conf. on Cloud and Precipitation*, 14-18 August 2000, Reno, Nevada.

Ferek, R. J., T. Garrett, S. Strader, K. Nielsen, G. E. Innis, J. P. Taylor, A. S. Ackerman, Y. Kogan, Q. Liu, B. A. Albrecht, and D. Babb, 2000: Drizzle Suppression in Ship Tracks. *J. Atmos. Sci*., **57**, 2669-2681.

Ferrare, R. A., D. D. Turner, L. A. Heilman, W. F. Feltz, R. A. Peppler, T. Tooman, and R. Halthore, 2000: Raman lidar profiling of water vapor and aerosols over the ARM SGP site. *Preprints, Symp. on Lidar Atmospheric Monitoring*, 9-14 January 2000, American Meteorological Society, 1-4.

Fulton, R., A. Ryzhkov, and D. Zrnic, 1999: Areal rainfall estimation using conventional and polarimetric radar methods. Preprints, *29th Int. Conf. on Radar Meteorology*, Montreal, Canada, Amer. Meteor. Soc., 293-296.

Ganger, T., A. White, and R. Saffle, 2000: Development and integration of new hydrometeorological algorithms into the WSR-88D using the Common Operations and Development Environment (CODE). *Preprints, 16th Int. Conf. on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Long Beach, CA, Amer. Meteor. Soc. 4 pp.

Gibson, B.A., S.E. Postawko, J. Ensworth, M.L. Morrissey, J. Wurman, and S. Ellis, 1999: The Pacific Rainfall Climate Experiment: Using high tech and low tech equipment in the tropical Pacific to survey the earth system.

Gilmore, M. S., and L. J. Wicker, 2001: Supercell storm morphology on 2 June 1995. Part 1: Overview of cloud-to-ground lightning and radar characteristics for 20 supercells in relation to a pre-existing baroclinic boundary. *Mon. Wea. Rev*., in preparation.

Gilmore, M. S., and L. J. Wicker, 2001: Supercell storm morphology on 2 June 1995. Part 2: Detailed cloud-to-ground lightning and radar characteristics for three supercells in relation to a pre-existing baroclinic boundary. *Mon. Wea. Rev*., in preparation.

Gilmore, M. S., and L. J. Wicker, 2001: Supercell storm morphology on 2 June 1995. Part 3: Characteristics of simulated storms and their comparison to radar observations. *Mon. Wea. Rev*., in preparation.

Goodman S.G., D. Buechler, K. Driscoll, D.W. Burgess, and M.A. Magsig, 2000: Tornadic supercells on May 3, 1999 as viewed from space during an overpass by the NASA TRIMM observatory. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Gu, W., and Q. Xu, 2000: Baroclinic Eady wave and fronts - Part III: Unbalanced dynamics - Departures from viscous semigeostrophy. *J. Atmos. Sci*., in press.

Hane, C.E., T.M. Crawford, M.E. Baldwin, R.M. Rabin, and H.B. Bluestein, 1999: Multiple boundaries in the mesoscale environment of a dryline observed by radar and aircraft. *Preprints, 29th Int. Conf. on Radar Meteor*., Montreal, Quebec, Canada, Amer. Meteor. Soc., 408-411.

Hane, C.E., D.L. Andra, S.M. Hunter, F.H. Carr, R.M. Rabin, and J.C. Derby, 2000: Evolution of warm-season heavy rain systems over the Great Plains during late-morning hours. *Preprints, 15th Conf. on Hydrology*, Long Beach, CA, Amer. Meteor. Soc., 176-179.

Hane, C.E., R.M. Rabin, T.M. Crawford, H.B. Bluestein, and M.E. Baldwin, 2000: Severe thunderstorm initiation along the dryline: A mesoscale case study. *Preprints*, 20th Conf. on Severe Local Storms, Orlando, FL, Amer. Meteor. Soc., in press.

Hodanish, S., and G. J. Stumpf, 2000: Case study of an unforecasted mini-supercell with a high top in Colorado. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL in press.

Istok, M. J., W. Armstrong, D. Burgess, M. Eilts, R. Saffle, and G. A. White, 1999: Next generation WSR-88D applications development - A change in paradigm. *Preprints, 29th Conference on Radar Meteorology*, Montreal, Canada, Amer. Meteor. Soc., 4 pp.

Janish, J. M., 2000: A multiple scale precipitation tracking and forecast package. *Preprints, 9th Conf. on Aviation, Range, and Aerospace Meteor*., Orlando, FL, Amer. Meteor. Soc., in press.

Janish, J. M., R. A. Brown, and V. T. Wood, 1999: Comparison of the effects of WSR-88D volume coverage patterns 11 and 21 on the performance of severe weather algorithms. *Preprints, 29th Intl. Conf. on Radar Meteor*., Montreal, Quebec, Canada, Amer. Meteor. Soc., 780-783.

Kasyanov, E.I., and Y. L. Kogan, 1999: The effect of three-dimensional cloud inhomogeneity on longwave radiative transfer and cloud absorption. *Proc., Ninth ARM Science Team Meeting*, San Antonio, Texas.

Kassianov, E. I., Y.L. Kogan, and G. A. Titov, 1999: Solar radiative transfer in three-dimensional stratocumulus clouds: The effect of vertical inhomogeneity. *J. Atmos. Oceanic Opt*., **12**, 187-195.

Kassianov, E. I. and Y. L. Kogan, 2000: Spectral dependence of radiative transport and its effect on near-IR absorption. *J. Geophys. Res.*, submitted.

Kay, M. P., and H. E. Brooks, 2000: Verification of probabilistic severe storm forecasts at the SPC. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Khairoutdinov, M. F., and Y. L. Kogan, 1999: A large eddy simulation model with explicit microphysics: Validation against aircraft observations of a stratocumulus-topped boundary layer. *J. Atmos. Sci*., **56**, 2115-2131.

Khairoutdinov, M.F., and Y. L. Kogan, 2000: A new cloud physics parameterization for large-eddy simulation models of marine stratocumulus. *Mon. Wea. Rev*., **128**, 229-243.

Kogan, Y. L. and D. Mechem, 1999: On formulation of microphysical processes for marine stratocumulus in regional forecast models. *Proc., Third Conference on Coastal Atmospheric and Oceanic Processes and Prediction*, Amer. Meteor. Soc., New Orleans, November 3-5, 1999.

Kogan Y. L., and A. A. Belochitski, 2000: A new approach to parameterization of cloud physics processes. *13th Inter. Conf. on Cloud and Precipitation*, 14-18 August 2000, Reno, Nevada.

Kogan, Y. L. and Y. Y. Shprits, 2000: The effect of surface winds on marine stratus microstructure and drizzle. *13th Inter. Conf. on Cloud and Precipitation*, 14-18 August 2000, Reno, Nevada.

Kogan Z. N., and Y. L. Kogan, 1999: A new parameterization of cloud drop effective radius for precipitating marine stratocumulus. *AGU Fall Meeting*, San Francisco, CA, December 13-17, 1999.

Kogan Z. N., and Y. L. Kogan, 1999: Parameterization of drop effective radius in drizzling marine stratus for large-scale models. *Proc., Ninth ARM Science Team Meeting*, San Antonio, Texas.

Kogan Z. N., and Y. L. Kogan, 2000: Parameterization of drop effective radius for drizzling stratiform clouds, *J. Geophys. Res.*, submitted.

Kogan Z. N., and Y. L. Kogan, 2000: Parameterization of drop effective radius for drizzling marine stratus in global circulation models. *Proceedings of the 10th ARM Science Team Meeting*, San Antonio, Texas.

Kogan Z. N., and Y. L. Kogan, 2000: Parameterization of drop effective radius in drizzling marine stratus for large-scale models. *13th Inter. Conf. on Cloud and Precipitation*, 14-18 August 2000, Reno, Nevada.

Lakshmanan, V., 2000: Using a genetic algorithm to tune a bounded weak echo region detection algorithm. *J. Appl. Meteor.*, **39**, 222-230.

Lamb, P.J., M. El Hamly, M.N. Ward, R. Sebbari, D.H. Portis, and Said Khatri, 1999: Experimental Precipitation Prediction for Morocco for 1999-2000: Prediction Statement No. 1 (Nov 01, 1999). Report for Moroccan Ministry of Public Works, CIMMS, The University of Oklahoma, Norman, OK, 10pp.

Lee. R.R. and E.D. Mitchell, 1999: Performance of the WSR-88D Build 10 Tornado Detection Algorithm: Development of optimal adaptable parameter sets. *Preprints, 15th Inter. Conf. on Interactive Information and Processing Systems (IIPS)*, Dallas, TX, Amer. Meteor. Soc., 318-321.

Liu, Q., Y.L. Kogan, D.K. Lilly, D.W. Johnson, G.E. Innis, P.A. Durkee, and K. Nielson, 2000: LES modeling of ship track formation and its sensitivity to boundary layer structure. *J. Atmos. Sci.*, **57**, 2779-2791.

Liu, Y., J.W. Conway, E.A. Brandes, A.V. Ryzhkov, J. Vivekanandan, D.S. Zrnic, and R. Oye, 1999: The use of polarization data in the operational identification of hydrometeor and non-hydrometeor targets. *Preprints, 29th Int. Conf. On Radar Meteorology.*, Montreal, Canada, Amer. Met. Soc., 192-194.

Loney, M., A. Ryzhkov, D. Zrnic, and J. Straka, 1999: In-situ and multiparameter radar observations of an isolated Oklahoma supercell at far ranges. Preprints. *29th Int. Conf. on Radar Meteorology*, Montreal, Canada, Amer. Meteor. Soc., 188-191.

MacKeen, P. L., Brooks, H. E., and K. L. Elmore, 1999: Radar reflectivity-derived thunderstorm parameters applied to storm longevity forecasting. *Wea. Forecasting*, **14**, 289-295.

Maddox, R. A., D. S. Zaras, P. L. MacKeen, J. J. Gourley, R. Rabin, and K. W. Howard, 1999: Echo height measurements with the WSR-88D: use of data from one versus two radars. *Wea. Forecasting*, **14**, 455-460.

Magsig, M.A, M. Dickens-Micozzi, and M. Yuan, 2000: Analysis of tornado damage on May 3rd, 1999 using remote sensing and GIS methods on high-resolution satellite imagery. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc, in press.

Marshall, T.C, M. Stolzenburg, W.D. Rust, E.R. Williams, and R. Boldi: Positive charge in the stratiform cloud of a mesoscale convective system. *J. Geophys. Res.*, submitted.

Marzban, C. 2000: A neural network for tornado diagnosis. *Neural Computing and Applications*, in press.

Marzban, C., E. D. Mitchell, G. J. Stumpf, 1999: The notion of ``best predictors:" An application to tornado prediction. *Wea. Forecasting*, **14**, 1007-1016.

Marzban, C., V. Lakshmanan, 1999: On the uniqueness of Gandin and Murphy's equitable performance measures. *Mon. Wea. Rev*., **127**, 1134-1136.

Marzban, C., and J. Schaefer, 2000: The Correlation Between U.S. Tornados and Pacific Sea Surface Temperature. *Mon. Wea. Rev*., submitted.

Marzban, C., and A. Witt, 2000: A Bayesian neural network for hail size prediction. *Wea. Forecasting*., submitted.

Marzban, C., and A. Witt, 2000: A neural network for hail size prediction. *Preprints, 2nd Conf. on Artificial Intelligence*, Long Beach, CA, Amer. Meteor. Soc., 38-44.

Mechem, D., and Y. L., Kogan, 2000: A new microphysical parameterization for marine stratocumulus clouds in regional forecast models. *13th Inter. Conf. on Cloud and Precipitation*, 14-18 August 2000, Reno, Nevada.

Menne, M. J., and C. E. Duchon, 2000: A method for monthly detection of inhomogeneities and errors in daily maximum and minimum temperature. *J. Atmos. Oceanic Technol*., submitted.

Miller, D. J., C. A. Doswell, H. E. Brooks, G. J. Stumpf, and E. N. Rasmussen, 2000: Highway overpasses as tornado shelters: Fallout from the 3 May 1999 Oklahoma/Kansas violent tornado outbreak. *Preprints, 29th Conf. on Broadcast Meteor.*, Amer. Meteor. Soc., San Francisco.

Monteverdi, J. P., W. Blier, G. J. Stumpf, W. Pi, and K. Anderson, 2000: First WSR-88D documentation of a an anticyclonic supercell with anticyclonic tornadoes: The Sunnyvale/Los Altos tornadoes of 4 May 1998. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, in press.

Ovtchinnikov, M., 2000: Cloud droplet effective radius profile in stratiform clouds. *Int. Radiation Symposium*, 24-29 July 2000, Saint Petersburg, Russia.

Ovtchinnikov, M., and Y. L. Kogan, 1999: Retrieval Of cloud water profile in stratiform clouds from radar reflectivity: Algorithm assessment using in-situ measurements and large-eddy simulations. *Proc., Ninth ARM Science Team Meeting*, San Antonio, Texas.

Ovtchinnikov, M., and Y. L. Kogan, 1999: Evaluation of cloud water retrieval using radar measurements in stratocumulus clouds. *Proc., Ninth ARM Science Team Meeting*, San Antonio, Texas.

Ovtchinnikov, M. and Y. L. Kogan, 2000: An investigation of ice production mechanisms using a 3-D cloud model with detailed microphysics. Part I: Model description. *J. Atmos. Sci*., **57**, in press.

Ovtchinnikov, M., Y. L. Kogan, and A. M. Blyth, 2000: An investigation of ice production mechanisms using a 3-D cloud model with detailed microphysics. Part II: 9 August 1987 case study. *J. Atmos. Sci*., **57**, in press.

Ovtchinnikov, M., and Y. L. Kogan, 2000: Retrieval of cloud liquid water profile in stratiform clouds from radar reflectivity measurements: Algorithm assessment using large-eddy simulations, *J. Geophys. Res.*, in press.

Ovtchinnikov, M., and Y. L. Kogan, 2000: Retrieval of cloud droplet effective radius profile in stratiform clouds. *Proceedings of the 10th ARM Science Team Meeting*, San Antonio, Texas.

Ovtchinnikov, M., and Y. L. Kogan, 2000: On remote sensing of stratiform clouds: insight from large-eddy simulations. *13th Inter. Conf. on Cloud and Precipitation*, 14-18 August 2000, Reno, Nevada.

Peppler, R.A., D.L. Sisterson, and P.J. Lamb, 1999: *Site Scientific Mission Plan for the Southern Great Plains CART Site: July-December 1999*. U.S. Department of Energy, ARM-99-002, 38 pp.

Peppler, R.A., and Co-authors, 2000: ARM Southern Great Plains site observations of the smoke pall associated with the 1998 Central American fires. *Bull. Amer. Meteor. Soc.* **81**, in press.

Porter, C.W., D.J. Stensrud, and N.L. Seaman, 2000: Adjoint-method wind retrievals from the WSR-88D network. *J. Atmos. Oceanic Technol.* , submitted.

Portis, D.H., J.E. Walsh, M. El Hamly and P.J. Lamb, 2000: Seasonality of the North Atlantic Oscillation. *J. Climate*, submitted.

Postawko, S., M.L. Morrissey, J.S. Greene, B. Gibson, A. Wood, S. Ellis, D. Harrison, and J.B. McGavock, 1999: Schools of the Pacific Rainfall Climate Experiment: The value of real science in the classroom. *J. Sci. Educ. and Technol.*, in press.

Richardson, S. J., F. Guichard, and B. M. Lesht, 2000: The radiative impact of the radiosonde relative humidity bias. *Proc., 10th ARM Science Team Meeting*, 13-17 March, 2000, San Antonio, TX.

Ryzhkov, A.V., 2000: Interpretation of polarimetric radar covariance matrix for meteorological scatterers. Theoretical analysis. *J. Atmos. Oceanic* Technol, accepted.

Ryzhkov, A., R. Lopez, R. Fulton, D. Zrnic, T. Schuur, and Y. Liu, 1999: Hydrometeor classification with a polarimetric radar for improved rainfall measurements and detection of hail and electrically charged regions. Comparison with dual-polarization radar data, *Preprints, 29th Int. Conf. on Radar Meteorology*. Montreal, Canada, Amer. Meteor. Soc., 289-292.

Ryzhkov, A.V., D.S. Zrnic, and R. Fulton, 2000: Areal Rainfall Estimates Using Differential Phase. *J. Appl. Meteor.*, **39**, 263-268.

Ryzhkov, A.V., and D.S. Zrnic, 2000: Hydrometeor classification using full polarimetric radar covariance matrix. *Preprints, URSI National Radio Science Meeting*, Boulder, CO, 301.

Ryzhkov, A.V., D.S. Zrnic, E.A. Brandes, and J. Vivekanandan, 2000: Measurements of polarization covariance matrix for hydrometeors. Preprints, *URSI National Radio Science Meeting*, Boulder, CO, 300.

Schultz, D. M., W. J. Steenburgh, R. J. Trapp, D. Kingsmill, and L. Dunn, 2000: Preliminary results from the Intermountain Precipitation Experiment. *Preprints, Ninth Conf. on Mountain Meteorology*, Aspen, CO, Amer. Meteor. Soc., 316-317.

Schuur, T. J., and S. A. Rutledge, 2000: Electrification of stratiform regions in Mesoscale Convective Systems. Part I: An observational comparison of symmetric and asymmetric MCSs. *J. Atmos. Sci*., **57**, 1961-1982.

Schuur, T. J., and S. A. Rutledge, 2000: Electrification of stratiform regions in Mesoscale Convective Systems. Part II: Two-dimensional numerical model simulations of a symmetric MCS. *J. Atmos. Sci*., **57**, 1983-2006.

Schuur, T. J., A. V. Ryzhkov, D. S. Zrnic, and M. Schönhuber, 1999: Drop size distributions measured by a 2D-video-disdrometer. Comparison with dual-polarization radar data. *Preprints, 29th Conf. on Radar Meteorology*. Montreal, Canada, 655-658.

Schuur, T. J., A. V. Ryzhkov, D. S. Zrnic, and M. Schönhuber, 2000: Drop size distributions measured by a 2D-video-disdrometer. Comparison with dual-polarization radar data. *J. Appl. Meteor.*, submitted.

Smith, T. M., S. A. Myers, and K. L. Elmore, 2000: An evaluation methodology applied to the Damaging Downburst Prediction and Detection Algorithm. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL in press.

Spencer, P.L., D.J. Stensrud, and J.M. Fritsch, 2000: Comparing two methods for wind analysis: Numerical simulations of a severe convective event. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Splitt, M. E., R. A. Peppler, and K. M. Kuhlman, 2000: Sensitivity of convective indices to humidity adjustments. *Proc., Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, 13-17 March 2000, San Antonio, TX, U.S. Dept. of Energy.

Stolzenburg, M., T.C. Marshall, and W.D. Rust, 2000: Serial soundings of electric field through a mesoscale convective system. *J. Geophys. Res*., submitted.

Straka, J.M., D.S. Zrnic, and A.V. Ryzhkov, 2000: Bulk hydrometeor classification and quantification using multiparameter radar data. Synthesis of relations. *J. Applied Meteor*, accepted.

Stumpf, G. J., 2000: The national severe storms laboratory severe weather detection algorithms. *European Conf. on Tornadoes and Severe Storms*, Toulouse, France, Observatoire Midi-Pyrénées and Meteo-France.

Stumpf, G. J., R. R. Lee, and P. L. Spencer, 1999: Geographic Region or Near Storm Environment? *Nat. Wea. Assoc. Severe Wea. Conf.*, Des Moines, Iowa, Nat. Wea. Assoc.

Stumpf, G. J., E. D. Mitchell, V. T. Wood, and P. C. Burke, 1999: Vortex detection and diagnosis - Status of algorithm development at NSSL. *National Weather Service/Texas Tech University Severe Weather Conf.*, Lubbock, Texas.

Stumpf, G. J., and C. Marzban, 2000: Using Doppler radar vortex detection algorithms to develop synthetic tornado climatologies. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, in press.

Stumpf, G. J., E. D. Mitchell, and K. L. Elmore, 2000: Severe storm climatologies using Doppler radar algorithms. Presentation at European Conf. on Tornadoes and Severe Storms, Toulouse, France, Observatoire Midi-Pyrénées and Meteo-France.

Stumpf, G. J., D. Speheger, and D. W. Burgess, 2000: Verification of the tornado events in the Norman Oklahoma NWSFO county warning area for the May 3, 1999 severe weather outbreak. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, in press.

Tessendorf, S. A., and R. J. Trapp, 2000: On the climatological distribution of tornadoes within quasi-linear convective systems. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, Fl, Amer. Meteor. Soc., in press.

Tipton, G. A., J. T. DiStefano, and G. J. Stumpf, 2000: Cincinnati, Ohio tornadic outbreak 9 April 1999 - a case study. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Titov, G.A., and E. I. Kassianov, 1999: Radiative effects of inhomogeneous clouds. *Atmos. Oceanic Opt*., **12**, 873-882.

Trafalis, T. B., A. White, and C. Jeyabalan, 1999: Statistical analysis of base data from the WSR-88D weather radar and description of mesocyclone features using neural and radial basis function networks. *Artificial Neural Networks in Industrial Engineering 1999*, Univ. of Missouri, Rolla, MO.

Trafalis, T.B., A. White, and A. Fras, 2000: Data mining techniques for tornado pattern recognition. *Artificial Neural Networks in Industrial Engineering 2000*, Univ. of Missouri, Rolla, MO.

Trapp, R. J, E.D. Mitchell, G.A. Tipton, D.W. Effertz, A.I. Watson, D.L. Andra, and M.A. Magsig, 1999: Descending and non-descending tornadic vortex signatures detected by WSR-88Ds. *Wea. Forecasting*, 14, 625-639.

Trapp, R. J., D. M. Schultz, A. V. Ryzhkov, and R. L. Holle, 2000: Multiscale structure and evolution of an Oklahoma winter-precipitation event. *Mon. Wea. Rev*., in press.

Trapp, R. J., and M. L. Weisman, 2000: Preliminary investigation of tornadogenesis within quasi-linear convective systems. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, Fl, Amer. Meteor. Soc., in press.

Vivekanandan, J., G. Zhang, and A.V. Ryzhkov, 1999: Estimation of canting angle distribution of raindrop spectra using radar measurements. *Proc., Radar Symposium India-99*, Bangalore, India, 209-218.

Weisman, R.A., and V.T. Wood, 2000: A hole in the severe weather warning system: the limited access for the deaf and hard of hearing. *29th Conf. on Broadcast Meteor.*, 18-23 June, San Francisco, Amer. Meteor. Soc.

White, A., 1999: The use of CODE (Common Operational and Development Environment) at the NEXRAD Operational Support Facility. *Preprints, 29th Conference on Radar Meteorology, Montreal, Canada*, Amer. Meteor. Soc., 4 pp.

White, A., 2000: The use of CODE (Common Operations and Development Environment) at the NEXRAD Operational Support Facility. *Preprints, 16th Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Long Beach, CA, Amer. Meteor. Soc., 4 pp.

Witt, A., 1999: A volumetric reflectivity parameter for the identification of severe hail. *Preprints, 29th Intl. Conf. On Radar Meteor.*, Montreal, Canada, Amer. Meteor. Soc., 105-108.

Witt, A., 2000: The WSR-88D hail detection algorithm: A performance update. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Wood, A.C. and E.M. Quoetone, 2000: Evaluating warning verification statistics and methodologies for displaced real-time (DRT) scenarios. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., in press.

Wood, V., and R. Brown, 1999: The optimization of WSR-88D scanning strategies for convective storms. *Preprints, 29th Intl. Conf. on Radar Meteor.*, Montreal, Canada, Amer. Meteor. Soc.

Wood, V.T., and R.A. Brown, 2000: Oscillations in mesocyclone signatures with range owing to azimuthal radar sampling, *J. Atmos. Oceanic Technol*., **17**, 90-95.

Wood, V.T., R. A. Brown, and D. Sirmans, 2000: Technique for improving detection of WSR-88D mesocyclone signatures by increasing angular sampling. *Wea. Forecasting*, submitted.

Xu, Q., and J. Gao, 1999: Generalized adjoint for physical processes with parameterized discontinuities - Part VI: Minimization problems in multi-dimensional space. *J. Atmos. Sci*., **56**, 994-1002.

Xu, Q., B. Zhou, S. D. Burk, and E. H. Barker, 1999: An air-soil layer coupled scheme for computing surface heat fluxes. *J. Appl. Meteor.*, **38**, 211-223.

Xu, Q., and W. Gu, 2000: Baroclinic Eady wave and fronts - Part II: Geostrophic potential vorticity dynamics in semigeostrophic space. *J. Atmos. Sci*., **57**, 861-872.

Xu, Q, M. Liu, and D. L. Westphal, 2000: A theoretical study of mountain barrier jets over sloping valleys. *J. Atmos. Sci*., **57**, 1393-1405.

Xu, Q., L. Wei, and A. VanTuyl, 2000: Statistical analysis of innovation vectors. *Preprints, 15th Conf. on Probability and Statistics in the Atmospheric Sciences*, 8-11 May 2000, Asheville, North Carolina, Amer. Meteor. Soc., in press.

Young, C.B, A.A. Bradley, W.F. Krajewski, A. Kruger and M.L. Morrissey, 1999: An evaluation of NEXRAD multisensor precipitation estimates for operational hydrologic forecasting. *J. Hydrometeor.*, accepted.

Zangvil, A., D.H. Portis and P.J. Lamb, 2000: Investigation of the large-scale atmospheric moisture field over the Midwestern United States in relation to summer precipitation. Part I: Relationships between moisture budget components on different time-scales. *J. Climate*, accepted.

Zhou, B., and Q. Xu, 1999: Computing surface fluxes from mesonet data. *J. Appl. Meteor.*, **38**, 1370-1383.

Zrnic, D., A.V. Ryzhkov, and R.J. Doviak: 1999: Operational potential of weather radar polarimetry. *Proc., Radar Symposium India-99*, Bangalore, India, 156-165.

Zrnic, D.S, and A.V. Ryzhkov, 2000: The effects of drop size distribution on polarimetric measurements of rainfall. Preprints, *URSI National Radio Science Meeting*, Boulder, CO, 299.

Zrnic, D.S., A.V. Ryzhkov, J. Straka, Y. Liu, and J. Vivekanandan, 2000: Testing a procedure for automatic classification hydrometeor types. *J. Atmos. Oceanic Technol*, submitted.

Zuev, V.E., E. I. Kassianov, and Y. L. Kogan, 2000: Absorption and horizontal radiative transport in three-dimensional broken clouds: Spectral dependence. *Atmos. Oceanic Opt*., **13**, 6-12.