CIMMS

Five-Year Plan

July 1, 2001-June 30, 2006

December 2000

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FIVE YEAR PLAN FOR CIMMS

July 1, 2001 through June 30, 2006

I. Background

(A) Introduction

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) is a research institute of the University of Oklahoma (OU) within the College of Geosciences. CIMMS was created in 1978 through a Memorandum of Agreement (MOA) between OU and the National Oceanic and Atmospheric Administration (NOAA). The cooperative agreement provides a mechanism to bring together the resources of OU and NOAA, which include the NOAA Office of Atmospheric Research (OAR), the National Weather Service (NWS), and the National Environmental Satellite, Data, and Information Service (NESDIS), to provide a center of research excellence in mesoscale meteorology, regional climate, and related subject areas.

Direct NOAA partners of CIMMS include the OAR National Severe Storms Laboratory (NSSL), the NWS National Centers for Environmental Prediction's (NCEP) Storm Prediction Center (SPC), the NWS Norman Forecast Office (NWSFO), the NWS Radar Operations Center (ROC; formerly known as the WSR-88D Operational Support Facility), the NWS Southern Region Headquarters (SRH), and the NESDIS National Climatic Data Center (NCDC).

CIMMS promotes research collaboration between scientists at OU, NOAA/OAR, NOAA/NWS, and NOAA/NESDIS, as well as with scientists at other NOAA laboratories, centers, and forecast facilities. CIMMS provides a center at which government and academic scientists may work together to learn about and apply their knowledge of mesoscale weather systems and regional climate patterns. CIMMS pursues and supports research on severe storms, short-range prediction and warning, regional climate variations, meteorological phenomena of the U.S. Southern Great Plains, radar development, and many other related subject areas.

CIMMS research contributes to the NOAA mission through the improvement of the observation, analysis, understanding, and prediction of weather elements and systems ranging in size from cloud nuclei to multi-state regions. Advances in observational and analytical techniques lead to an improved understanding of the evolution and structure of these phenomena. Understanding provides the foundation for more accurate prediction of adverse weather. Better prediction and warning contributes to improved social and economic welfare. Because small- and regional-scale weather phenomena are also important causes and manifestations of climate, CIMMS' research on mesoscale processes may contribute directly to improved understanding of the global climate system and possible climate change.

(B) Research Themes and Outreach

CIMMS proposes over the next five years to concentrate on six research themes, one of which is new (Climate Change Monitoring and Detection), and public outreach to disseminate and interpret the results. CIMMS fellows, scientists, post-doctoral researchers, graduate students and collaborators will work to meet the goals of these research themes. The goals of these thematic areas and activities are as follows:

(i) Basic Convective and Mesoscale Research

The primary goals of this original CIMMS theme are to understand cloud and mesoscale dynamics, microphysics and the precipitation process, and their relationships to large and small scale forcing, and to develop procedures for assimilation of meteorological data into simulation and prediction models of these processes.

(ii) Forecast Improvements

The main goal of this theme is to accelerate the transfer of research knowledge and skills between the academic and operational mesoscale meteorological communities to improve the design and utilization of mesoscale weather observing systems and to improve mesoscale weather prediction and warning.

(iii) Climatic Effects of/Controls on Mesoscale Processes

The goal of this theme is to extend and apply the understanding of mesoscale processes to the problem of climate maintenance and change, in several contexts. For example, stratiform cloud cover in the boundary layer, which is a primary uncertainty in the climatic energy balance, is to a large extent controlled by mesoscale and microscale processes. Lightning, another mesoscale phenomenon, produces chemically and radiatively active chemicals that should be considered in the greenhouse problem. This theme also includes investigation of the influence of the large-scale climatic environment on mesoscale systems in various regions of the world.

(iv) Socioeconomic Impacts of Mesoscale Weather Systems and Regional Scale Climate Variations

The goal of this theme is to estimate the socioeconomic impacts and values of mesoscale weather systems and regional-scale climate variations to facilitate the mitigation of adverse impacts and enhancement of beneficial ones. This work makes extensive use of climate scenarios and economic modeling, and is performed in collaboration with agricultural economists and social scientists.

(v) Doppler Weather Radar Research and Development

The goal of this theme is to accelerate the transfer of knowledge between the meteorological and engineering communities to improve the design, usability, and supportability of the NEXRAD WSR-88D Doppler weather radar. This theme also includes development of severe weather applications for the WSR-88D and transferring these applications and knowledge to the operational community. This theme introduces, examines, and analyzes present and future technologies, including the U.S. Navy's Phased-Array (Spy-I) radar system, with the goal of meeting the unfulfilled needs of the NEXRAD program.

(vi) Climate Change Monitoring and Detection

The goal of this new theme is to study the homogeneity or lack thereof of the historical station records in the U.S. and to use this information to help address the climate change questions, including those stemming from the Intergovernmental Panel on Climate Change (IPCC) process. This work will be done in collaboration with NESDIS and its NCDC in Asheville, North Carolina.

(vii) Public Affairs and Outreach

An active program of public affairs and outreach allows our research and expertise to be disseminated and interpreted to the general community and also to schoolchildren in an easily understood way. This is embodied through media interviews, feature stories in the electronic and print media, photo opportunities, guided tours, open houses, web-based educational activities for school children, teacher in-services, lesson development, and telephone calls and e-mails.

CIMMS' objectives are addressed by a scientific, technical, and managerial staff, with the research staff consisting mainly of resident research scientists and fellows, postdoctoral and visiting scientists, and graduate students. In addition, a modification to the OU-NOAA MOA in 1986 included provisions for CIMMS collaboration with, and direct support of research in, all OU departments and not just the School of Meteorology. All staff scientists, NOAA fellows, and supported faculty are selected competitively on the basis of their qualifications and potential ability to contribute effectively to the research themes. CIMMS staff scientists and fellows also attract support from other government agencies outside of NOAA, usually as competitive grants awarded for submitted proposals. These broaden and strengthen the research program, provide exposure to a wide community of scientists, and so feed back to enhance NOAA expertise and knowledge in critical areas.

(C) Description of Tasks

For budgetary and administrative purposes, NOAA-funded work at CIMMS is partitioned into three tasks.

Task I. Support of administrative staff, postdoctoral and visiting scientists, research associates, and graduate research assistants housed in OU/CIMMS. The supervision and administration of Task I personnel is principally conducted by the OU/CIMMS management.

Task IIa. Support of graduate research assistants, research associates, computer programmers and system analysts, and technical staff for NSSL-related work. Scientific direction is provided jointly by OU/CIMMS and NSSL/CIMMS management.

Task IIb. Support of graduate research assistants, research associates, computer programmers and system analysts, and technical staff for ROC-related work. Scientific direction is provided jointly by OU/CIMMS and ROC/CIMMS management.

Task IIc. Support of graduate research assistants, research associates, computer programmers and system analysts, and technical staff for SPC-related work. Scientific direction is provided jointly by OU/CIMMS and SPC/CIMMS management.

Task IId. Support of graduate research assistants, research associates, computer programmers and system analysts, and technical staff for SRH-related work. Scientific direction is provided jointly by OU/CIMMS and SRH/CIMMS management.

Task IIe. Support of graduate research assistants, research associates, computer programmers and system analysts, and technical staff for NCDC-related work. Scientific direction is provided jointly by OU/CIMMS and NCDC/CIMMS management.

Task IIf. Support of staff for NOAA Weather Partner Outreach-related work. Scientific direction is provided jointly by OU/CIMMS and NSSL/CIMMS management

Task III. Support of NOAA sponsored research. This task is actively conducted independently by faculty members and CIMMS and NOAA scientists, under the budgetary supervision of OU and CIMMS management.

II. Proposed Research

The following sections describe the work proposed under each of the research themes and activities during the next five years and its specific relevance to NOAA's mission.

(A) Basic Convective and Mesoscale Research

We learn and teach about the processes that produce local weather phenomena with direct impact on everyday human activity, such as thunderstorms and mesoscale convective systems, as well as the gentler processes that produce cumulative effects on local and large scale environments, such as cumuliform and layered cloud arrays. Although a general understanding of most of these processes exists, it is insufficient to allow accurate prediction of either the intense elements or the statistical effects of the more benign systems. The funding for the work proposed here will be used to conduct studies and participate in field programs that will lead to improvements in both the basic understanding and its application in the following areas.

Cloud Physics

Study of Stratiform Cloud Precipitation Processes

Stratiform cloud layer precipitation can significantly alter the cloud-topped boundary layer (CTBL) structure through vertical redistribution of moisture and heat. Many studies have

suggested that precipitation can have a stabilizing influence on the CTBL, leading to the decoupling of the cloud from the subcloud layer. As a result of the decoupling, precipitating cloud systems exhibit complex spatial and temporal variability and often include cumulus clouds transporting moisture from the surface to the stratocumulus cloud layer. The dependence of precipitation surface coverage on meteorological conditions is not well understood and needs to be further investigated. The CTBL dynamics also have an important effect on precipitation. Turbulent motions in the stratiform clouds should enhance the precipitation process by increasing the raindrops dwell-time in the cloud layer. Models predict that stratocumulus cloud layers with more vigorous turbulent circulations allow for repeated coalescence cycles producing, as a result, larger drops and precipitation rates than clouds with weaker circulations. In oceanic environments, the CTBL dynamics can also affect precipitation through surface winds that determine the sea-salt fraction of the cloud condensation nuclei (CCN) distribution.

Clearly, many important aspects of the precipitation process, and its parameterization in numerical weather prediction models, involve complex feedbacks between dynamical and microphysical processes that require further study. The CIMMS Cloud Physics group will investigate the interactions between these processes using the CIMMS LES explicit microphysical model. The research program will incorporate both numerical simulations and observational data analysis to improve understanding of the precipitation process in stratiform cloud layers.

Statistical Formulation of Cloud Parameters over the U.S. Southern Great Plains

The goal of this new CIMMS Cloud Physics project is to obtain the statistical descriptions of stratiform cloud parameters using ARM Program observational platforms for the Southern Great Plains (SGP), including millimeter wave cloud radar and microwave radiometer. We will also explore the possibility of using other meteorological data to investigate the relationship between the weather systems and cloud statistics over the ARM SGP site. The latter are essential to determine the probability distribution functions, which are an important part of cloud physics parameterizations in mesoscale and large-scale models. The observational data analyses will be supplemented by modeling studies aimed at finding associations between radar reflectivity and microphysical parameters used in calculations of cloud radiative properties.

Effects of Horizontal Radiative Transport on Cloud Thermodynamical Evolution

The objective of the study is to investigate the effects of horizontal radiative transport on dynamical evolution of the cloud-topped boundary layer. The project is planned as a collaborative effort between the CIMMS Cloud Physics group and colleagues at the DOE Pacific Northwest and Los Alamos National Laboratories and NASA. The specific objective is to develop a new three-dimensional longwave radiative code interactively linked with the CIMMS LES model. Evolution of the stratocumulus topped boundary layer using 3D radiative transfer will be contrasted with a conventional two-stream delta approximation. We will analyze the potential discrepancies between the two approaches and aim for refinement of the two-stream approximation. The results of this pioneering research should provide insight and guidance into the development of an improved parameterization of radiative transfer in mesoscale weather prediction models.

Dynamical Meteorology

Research on the Origins of Rotation in Tornadoes

The well known Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) was carried out in 1994-1995. Smaller, sub-VORTEX experiments were conducted in 1996-1999. The Severe Thunderstorm and Electrification Study (STEPS) was conducted in 2000. Many useful data sets have been collected. Extensive analysis of those data sets, including detailed case studies, is in progress at NSSL and CIMMS and will continue for some time. Consensus or diversity among case studies will be examined. New hypotheses concerning tornado formation will be formulated. Small, focused, data collection efforts will be undertaken in 2001-2004 to further confirm and refine the hypotheses. A second, larger-scale VORTEX field program will be undertaken in 2004-2006 to test the new improved hypotheses. Associated with the field programs will be highly innovative development and testing of a new generation of "turtle" in situ sensors for tornado measurements. Also associated with the field programs will be highly innovative development and testing of rapidly deployable, semi-autonomous, formation-capable Remote Piloted Vehicles (RPVs) for in situ sensing in the immediate vicinity of tornadoes.

Intermountain Precipitation Experiment (IPEX)

The objective of IPEX is to advance the understanding and prediction of orographic and lake effect precipitation events over the Great Salt Lake Basin and adjoining Wasatch Mountains in the Intermountain West. The field phase of IPEX was conducted in 2000. Extensive analysis of IPEX data will be performed at CIMMS and NSSL for several years.

Numerical Study of Boundary-Crossing Supercells

This NSSL and CIMMS project seeks to better understand how changes in local environmental CAPE, low-level vertical wind shear, and boundary-layer moisture content influence the dominant cloud-to-ground (CG) lightning polarity, CG flash rate, mesocyclone strength, and hail/graupel development in supercells. This will be studied in numerically simulated supercell thunderstorms (with electrification, CG lightning capability, and sophisticated microphysics) that traverse a non-homogeneous environment. Also, CG lightning behavior will be documented for supercells observed in VORTEX-94/95 and the Severe Thunderstorm Electrification and Precipitation Study (STEPS, 2000) that interacted with identifiable low-level mesoscale boundaries or low-level moisture tongues. These investigations will initially exploit the methodology used in the June 2, 1995, Dimmitt, TX study.

Mesoscale Dynamics

A new NSSL and CIMMS project will study modal and non-modal growths and related instabilities in mesoscale flows. The work will improve our understanding of storm initiation and will allow development of mathematical formulations and/or concept models useful for storm forecasts.

Mechanisms Leading to Long-Lived Derechos

Results from preliminary NSSL-CIMMS studies indicate that upper-level wind shear plays a significant role in the development of derechos. Both observations and numerical models will be used to further our understanding of these events.

Three-Dimensional Modal and Nonmodal Structures in Frontal Rainbands

The goal of this proposed work is to explore new instability mechanisms that will provide possible explanations for some observed three-dimensional substructures, including severe storm elements embedded in frontal rainbands. As one of the possible dynamic mechanisms, symmetric instability (SI) and conditional SI have been shown to have many attractive features in interpreting the gross structures of some observed frontal rainbands. However, the often observed three-dimensional substructures in frontal rainbands are obviously beyond the description of the existing SI theories. Our recent studies suggest that nonlinear SI circulations are unstable in three dimensions and the related secondary unstable modes resemble some observed mesoscale substructures. The results so far obtained are still very preliminary but shed light on a number of important issues which need to be further investigated beyond our previous NSF research project. To this end, three objectives are proposed:

(a) Nearly-symmetric circulations and their stability and instability;
(b) Nonmodal growths and singular vector structures;
(c) Nonlinear evolution of modal and nonmodal structures.

The spectral model developed from the prior NSF support will be used for the proposed studies. The proposed research is also expected to contribute to the basic stability theories of fluid flows.

Using Oklahoma ARM Program and Mesonet Data to Test and Improve Soil-Vegetation Physics in Mesoscale Models

The full-potential uses of the Oklahoma ARM Program and Mesonet data will be explored by NSSL and CIMMS to test and improve soil-vegetation physics in mesoscale models. New data assimilation methods will be developed for soil-vegetation data assimilation and related parameter estimation.

Storm-Scale Assimilation

Data Integration

Traditional methods of retrieval of wind, pressure, and temperature from dual-Doppler data have progressed to qualitatively reproducing key features in thunderstorms, but still yield results that are of limited use for quantitative analysis. An ongoing NSSL-CIMMS project instead involves the application of both a model and adjoint retrieval to a multiple-Doppler data set of the Dimmitt (Texas) tornadic thunderstorm from VORTEX-95. The goal of this approach is to produce a dynamically consistent data set, suitable for detailed quantitative analysis, that

matches convincingly the time series of observations in a least squares sense. This method also appears to be ideal for including data from other platforms (e.g., in situ measurements from mobile mesonets) in the retrieval. Current work includes adapting the model to use aircraft (P3) analyses data from VORTEX and testing the inclusion of other observational platforms (such as mobile mesonet) into the retrieval/assimilation.

Assimilation of Observed Divergence

A variational technique for "reconstructing" a gridded wind field that has its divergence and vorticity equal to that of the observed wind field will be used by NSSL-CIMMS to provide the initial conditions for a numerical model. This wind field, containing accurate divergence and thus vertical motion, may allow for improvements in the performance of numerical simulations of mesoscale systems.

Boundary Layer Meteorology and Turbulence

Thunderstorm Initiation Studies

A broad-collaboration field experiment is planned by NSSL-CIMMS for the 2002 to 2004 time period. Emphasis will be on measurements of turbulent fluxes of moisture, heat, and momentum in and above the convective boundary layer, and on either side of crucial horizontal boundaries (drylines, outflow boundaries, fronts). A critical focus will be on physical mechanisms responsible for the change in state from fair-weather convection to deep, severe-thunderstorm convection. After the field program, extensive data analysis is planned for the rest of the 5-year period.

Measurement and Analysis of the Pre-Convective Boundary Layer and Convective Initiation During the International H2O Project (IHOP)

The goal of this NSSL-CIMMS project is to improve understanding of processes leading to initiation of deep, moist cumulus convection and storms. As one focus of the field phase of the International H2O Project (IHOP), planned for the spring and summer of 2002 in the U.S. Southern Great Plains, we propose to acquire and analyze three-dimensional, multiple ground-based radar-derived boundary layer airflow and in-situ measurements of winds and thermodynamic parameters from soundings, remotely-piloted vehicles, and mobile mesonets. Combining boundary layer airflow measurements with in-situ absolute humidity and virtual temperature data constitutes the only means of documenting the dynamical and transport processes acting in the boundary layer to regulate precipitable water and force the development of secondary circulations. Our mobile observations are thus essential for evaluating all hypotheses concerning the impact of water vapor supply and airflow evolution on boundary formation and convective initiation.

The proposed field operations call for targeting segments of surface boundaries with anticipated storm potential, such as drylines, fronts, decayed outflows, and other convergence lines. We will document the morphology and evolution of the pre-convective moisture, airflow, and virtual temperature fields, and probe the initial stages of any cumulus clouds and deep convection that develop coincidentally. The project has several objectives. The first is to

document the dominant spatial and temporal scales of boundary layer structure both in the vicinity of and along/across surface boundaries. These are poorly understood, yet may have a large impact on convective initiation. A second objective is to provide observations needed to test various processes hypothesized to govern convective initiation. These hypotheses are generally based on concepts of local enhancements of either mesoscale lifting or precipitable water (or both), which should be directly linked by the divergence field. A third objective is to assimilate these enhanced observations into mesoscale models to determine the dynamical forcing of localized boundary layer circulations that either promote or prevent convective initiation.

High-Resolution Dual Doppler Study of the Atmospheric Boundary Layer

As noted above, there is high interest in understanding boundary layer structures, particularly those that may be involved with convective initiation and fluxes of heat, moisture, and momentum. The surface observing networks developed by the ARM SGP Program and the Oklahoma Mesonet are very well suited for characterizing these phenomena at or just above the surface. A coordinated observational study involving data from these surface networks and high resolution/high sensitivity dual-Doppler measurements by CIMMS and OU scientists would not only characterize the surface thermodynamic state but also increase understanding of how these conditions interact with the atmospheric boundary layer. The 3-cm, 0.93-degree beam width Doppler-on-Wheels (DOW) mobile radars are able to detect clear air boundary layer structures, and have observed both boundary layers and dry cellular convection at ranges of 0 to 30 km. By establishing dual-Doppler baselines of as little as 1 km to as great as 30 km, three-dimensional fields of vector winds can be measured with resolutions ranging from 15 m to 500 m. Additional platforms may be available for this study, such as remotely piloted vehicles and rapid boundary layer sonde launching systems, that would greatly enhance the observations in the lower troposphere.

Atmospheric Electricity

Thunderstorm Dynamics/Electrification Relationships

NSSL has acquired a total lightning mapping array system to provide the highest quality data on total lightning occurrence, both cloud-to-ground and intra-cloud. Extensive data analyses by NSSL and CIMMS scientists will determine relationships between many lightning and storm properties. Particular attention will be given to those properties that show promise as storm warning tools, and those properties that can be used to assimilate lightning data into numerical forecast models. There will also be emphasis on comparing the ground-based total lightning sensors to satellite detection of total lightning; this research is in cooperation with NASA. Particularly useful electric field soundings were acquired in the Severe Thunderstorm Electrification and Precipitation Studies (STEPS) experiment in 2000. These data will be analyzed to better understand how and why some severe storms produce large amounts of positive cloud-to-ground (+CG) lightning and why total flash rates vary widely. Successful completion of the basic research will allow for the creation and testing of new applied techniques for severe storm detection, warning, and short- range forecasts. The techniques will be tested in joint experiments with the NWS (SPC and other units), NASA, and FAA (for aviation hazards).

Electrification in Winter Storms

This NSSL-CIMMS study of winter storms will include an initial determination of their electrical structure. The investigation will include the relationship between electrical structure as measured with instrumented balloons and airplanes and the lightning activity in the storms. The electricity in winter storms will then be examined in the context of the precipitation types, rates, and storm amounts. It is envisioned that the basic understanding derived from such a study will lead to hypotheses designed to help in forecast improvements.

Feedback from Forecasters to Better Understand Mesoscale Processes

Using Numerical Forecast Models as Diagnostic Tools to Help Understand Atmospheric Processes

NSSL and CIMMS will take advantage of our proximity and close working relationship with SPC forecasters and research scientists to identify and target poorly predicted and understood atmospheric processes as the foci of new research objectives. We will combine the keen observational instincts and experience of SPC forecasters with the research skills and tools (i.e., field experiment design, numerical model simulation) of NSSL and CIMMS scientists to address research challenges that now constitute impediments to improvements in operational forecasting.

(B) Forecast Improvements

Improvements in our basic understanding of convective and mesoscale weather phenomena must be transitioned to the operational weather community in the form of knowledge and tools, so that it can provide continually improved forecasts and warnings to the public and government. Through the SPC, NWSFO, and SRH, CIMMS is able to contribute to this process by providing developmental support for daily forecasting operations and for timely and accurate short-term guidance and support for hazardous weather. In recent years, this research area has expanded from a relatively parochial Southern Great Plains perspective to have a much more national focus. This development was particularly stimulated by the establishment of the SPC in Norman in 1997. Research is proposed in the following areas.

Storm Prediction Center Research

The fundamental research challenges for the SPC remain the development of better understanding of mesoscale atmospheric processes and translation of new knowledge into techniques to forecast severe weather (e.g., tornadoes, large hail, damaging straight-line winds), winter weather, fire weather and heavy rains. The challenge also involves developing computer-based methods to manipulate, display, and interpret the voluminous data available, to assist SPC

forecasters to extract the information critical to their mesoscale forecasts, and to effectively convey information to forecasters and other scientists.

Research and development requirements include:

Physical Process Studies in Support of Forecast Tool Development

Studies will focus on direct forecast improvement through investigation of mesoscale and synoptic scale systems that cause "extreme" events involving severe weather, heavy rains or flash floods, heavy freezing rain, heavy snow, or the rapid spread of wildfires. Studies will also be undertaken relative to weather events in which one type of hazardous weather evolves into another type (e.g., severe weather evolving into heavy rains or flash floods) and in which systems involve multiple hazardous weather elements simultaneously.

Specific research efforts anticipated include investigations of cloud-to-ground and total lightning climatologies and the development of techniques to refine their prediction. Additional efforts are needed to improve understanding of convective initiation (both timing and location) to aid forecasts of severe convection and produce improved tornado and severe thunderstorm lead times. Better understanding of the physical processing governing the initial mode of deep convection and the processes governing the temporal evolution of convection are also essential to improved forecasts. Finally, all investigations will include efforts to create and exploit synergies between the forecast and research communities.

Forecast Tool Development

Advances in fundamental understanding of the processes governing mesoscale weather systems obtained through the above research must be effectively translated into tools and techniques that help forecasters make needed decisions. This science and technology infusion requires new tools in the form of data, techniques, software, and displays. It also requires forecast system optimization to allow the new tools to be applied efficiently within the forecast arena.

A critical tool requiring further development involves use of NWP model output and new observing systems for forecasting severe weather, heavy rains/flash floods, freezing rain, heavy snow, or conditions favorable for wildfires. Diagnostic and prognostic tools are needed to exploit existing model output and observations for forecasting these short-term hazardous weather events and to refine existing models and their output to better forecast extreme events. Powerful tools are needed to extract information critical to accurate severe weather forecasts from the copious data produced by high-resolution deterministic model forecasts and by large-member ensemble prediction systems. These forecast tools are essential to allow forecasters to make effective decisions based on the huge quantity of raw model output now produced.

Specific projects within this broader effort will include: the efficient processing, display, interpretation, and use of data from new lightning observing systems in the forecasting of thunderstorms within the U.S.; the development of improved forecast techniques and tools for forecasting conditions favorable for the initiation and spread of wild fires; and improvements to the transfer of meteorological information to both forecasters and forecast users through application and refinement of new technologies.

An important aspect of any weather forecast is the assessment of its accuracy. Questions as to the timeliness and spatial accuracy of the forecast need to be evaluated. Techniques to

weigh the relative "cost" of responding to a missed event verses not preparing for a correctly forecast event must be designed. Since forecasts of nonoccurrence of many rare weather events are not made, commonly used metrics of forecast skill are not appropriate. Research on parameters to measure the skill of rare event forecasts need to be conducted.

Analysis of Forecast and Forecast Tool Performance

We will develop effective techniques and tools for the verification of forecast products that are essential to forecast improvement. The measures must be robust scientifically and the information must be conveyed effectively to forecasters and developers to highlight areas where the forecast process must be improved. The needed improvements will likely require improved physical understanding and the development of new forecast tools or techniques.

Systematic evaluation will also take place of the performance of operational weather prediction models during extreme weather events (severe weather, heavy rains/flash floods, freezing rain, heavy snow or extreme fire weather conditions) to identify critical model strengths and weaknesses. These studies must include assessment and refinement of relevant model physics packages and analysis systems, with the goal of identifying ways to improve the operational models. In addition, NWP model trends, strengths, and weaknesses with respect to forecasting short-term hazardous weather events must be determined. Studies will include evaluation of the optimal use of ensemble forecast systems in the forecasting of rare extreme events. This includes severe weather, heavy rains/flash floods, heavy freezing rain, heavy snow, or extreme fire weather conditions.

Regional Scale Numerical Weather Prediction

Implementation of CIMMS Stratiform Cloud Parameterization into a Regional Numerical Weather Prediction Model

The CIMMS Cloud Physics group has recently implemented the CIMMS cloud physics parameterization into the U.S. Navy Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) and performed analyses of simulations of the cloud/fog system over the central California coastal region. A further objective of this project will be to investigate the scale dependence of precipitation production mechanisms and understand the factors responsible for accurate forecasting of stratiform cloud system precipitation on a 10-20 km grid. The specific goal will be to produce, for mesoscale weather prediction models, the probability distribution functions that reflect the subgrid variability of cloud prognostic parameters.

The Joint Numerical Analysis and Prediction (JNAP) Team

During the past decade, OU has made significant progress in the numerical analysis and prediction of intense mesoscale weather, much of it due to the efforts of the Center for Analysis and Prediction of Storms (CAPS) -- an NSF Science and Technology Center that was birthed out of CIMMS in 1989. The work to date has emphasized the use of WSR-88D Doppler radar data to initialize storm-resolving models, as well as extensive operational tests and evaluations of such models in collaboration with the SPC, NWS Aviation Weather Center (Kansas City, MO), and local NWSFO. During the past few years, these CAPS efforts have expanded to include: (a)

the development of a test bed for acquiring WSR-88D base data in real time via the Internet (a strategy that may eventually expanded to the entire radar network and bring significant benefits to NOAA); (b) a multi-institutional experiment that demonstrated the value of multi-model ensembles in mesoscale numerical prediction (a capability that, because of that experiment, is now being implemented at NCEP); and (c) participation (as one of four core organizations) in the development of the next-generation operational/research community model (Weather Research and Forecasting model, or WRF) for NCEP. All of these CAPS-related activities are bringing significant benefit to NOAA, in many cases with non-NOAA funding or with significant leveraging of funds from multiple agencies including NOAA. They also involve collaborations with some elements of NSSL.

We now propose to focus and elevate these activities to a more formal status within CIMMS, and in so doing strengthen research collaborations with both the NSSL and operational community. In particular, we seek to establish the Joint Numerical Analysis and Prediction (JNAP) Team, which would emphasize the numerical prediction of storm and mesoscale weather using non-hydrostatic models and high-resolution observations. The JNAP Team would comprise scientists from both OU and the NSSL, and also would involve operational meteorologists from other NOAA units both locally and nationally. Through basic research, as well as experimental real time testing, the JNAP Team would focus on practical problems of concern to the NWS and NCEP, as well as expose operational forecasters to new technology prior to its formal implementation.

Effects of Real-Time Land Use Data on Numerical Weather Prediction

This NSSL research will explore uses of real-time land use and land cover data as derived by NOAA AVHRR satellite data in operational numerical weather prediction with emphasis on the evolution of the planetary boundary layer and convective initiation.

Model Guidance

Improving and More Effectively Using Numerical Guidance Products for Severe Weather

New numerical guidance models and products for operational forecasting will continue to be developed during the next five years, such as the above WRF model. NSSL and CIMMS will continue to take advantage of our close working relationship with the NCEP Environmental Modeling Center, the NOAA/OAR Forecast Systems Laboratory, the SPC, and other NWS units to facilitate the operational implementation and optimal utilization of these tools. Specifically, we will serve as a conduit for technology transfer from model-development scientists to the operational forecasting community and for feedback in the opposite direction -- from forecasters to modelers -- so that models can be specifically tailored to meet the needs of operational forecasters. In addition, new verification tools will be developed to objectively evaluate the performance of forecast models.

Mesoscale Convective Systems

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

This NSSL-CIMMS project is now and will continue to be funded under a COMET NWS Cooperative Project grant. The goal of the work is to provide the NWS with improved tools for nowcasting and forecasting the evolution of mesoscale convective systems (MCSs) during the 09-17 UTC period over the Great Plains during summer. This diurnal period is generally one of MCS weakening or dissipation, but some systems are maintained into the afternoon. The research will seek environmental clues to help discriminate between cases of MCS dissipation and maintenance. A major effort is the development of a climatology of such systems that affected the Norman, OK, and Dodge City, KS, NWS office areas of responsibility during the 1996-2000 warm seasons. MCS tracks, speeds, intensity changes, modes of initiation, and environmental influences are being noted on a system-by-system basis. The ability of mesoscale operational models to predict the factors that are found to influence system evolution will also be assessed.

Convective Initiation

Influence of Heat and Moisture Flux on the Initiation of Convective Storms near the Dryline

This planned COMET NWS Cooperative Program project at NSSL-CIMMS would have the goal of providing additional tools for forecasters to better nowcast the location and timing of convective initiation along the dryline. The existence of the Oklahoma Mesonetwork, with its full array of meteorological sensors that includes instrumentation to measure surface heat and moisture fluxes, provides an opportunity to better understand the effect of those fluxes on dryline convective initiation. The Mesonet would be used to determine the horizontal and temporal variations in fluxes, and to assess the effects of fluxes on other meteorological fields. Another vital measurement platform for determining fluxes is the meteorological satellite, which can provide additional information on such factors as surface temperature, vegetative greenness, and cloud distribution. Doppler radars within the national network can provide detailed information through clear air returns from drylines and other boundary layer features.

Hazardous Winter Weather

Developing and Evaluating Hazardous Winter Weather Forecast Techniques

This NSSL-CIMMS project involves applied research related to hazardous winter weather. Work will include the evaluation of observed hazardous winter weather phenomena to diagnose and understand the underlying physical processes, and the development of operational forecasting techniques that would assist forecasters with predicting hazardous weather events.

Radar Operations and Forecasting Support

Support of WSR-88D Operations And Forecast Improvements

CIMMS personnel at the ROC Operations Branch will provide direct support to forecasters at field sites where WSR-88D systems are located. They will play a key role in the transition of the ROC and WSR-88D field sites to an open systems Radar Product Generator (Open RPG) and an open systems Radar Data Acquisition (Open RDA). In addition, they will play a lead role in the transition of the Air Force operational weather squadrons and base weather stations to the Open Principal User Processor (Open PUP). The Open RPG will provide the basis for improved forecast performance through the addition of new and more sophisticated WSR-88D algorithms. The Open RDA will provide improved data quality. The Open PUP will allow Air Force forecasters to transition to centralized weather warning and forecasting operations and the local base short-term forecasting concept. All of these tasks will directly contribute to improved short-range forecasts and weather warnings.

These CIMMS personnel will also assist field personnel in optimizing their use of these new technologies and advanced scientific applications of radar data. They will be involved in evaluating new training tools, assisting sites in developing new forecast techniques, improving radar data quality, and resolving real-time "glitches" that may be discovered using the new technologies.

Warning Decision Support

Warning Decision Training Improvement Project

The new NWS Warning Decision Training Branch (WDTB) develops and delivers training to NWS personnel on how to issue weather-related warnings and short-term forecasts in the multi-sensor environment brought about by AWIPS. CIMMS employees at the WDTB are an integral part of supporting the transfer to new weather service employees of technology and ideas used in fundamental radar and warning decision training. They also provide advanced higher order training for veteran forecasters. Part of the technology transfer involves modifying current operational hardware and software to support training functionality. A second part of the technology transfer involves developing Internet and CDROM modules that address the current challenges facing warning forecasters. CIMMS personnel are also involved in evaluating and developing techniques to issue graphical and text products in ways that concisely convey information and uncertainty.

Precipitation and Hydrologic Prediction

Regional Satellite Precipitation Estimates in Support of GAPP

The GEWEX Americas Prediction Project (GAPP) addresses primary objectives of part of the U.S. Global Climate Research Program water cycle initiative by (i) developing and demonstrating the capability to make monthly-to-seasonal predictions of precipitation and land surface hydrological variables and (ii) helping "transfer the results of improved seasonal predictions for the optimal management of water resources". Among the studies that GAPP will

pursue in support of its objectives are the development of data sets (including new satellite data sets) necessary for transferring models from data rich to sparse areas.

Precipitation estimates are among the most crucial data sets necessary for this effort. The importance of precipitation data on spatial-scales of tens of kilometers and hourly time-scales were stressed at the Global Precipitation Climatology Project Workshop on "Use of Precipitation in the Study of Global and Regional Climate Variability, Modeling, Surface Hydrology and Water Resources" held in May 1999. Precipitation data on such scales are needed to drive land surface hydrological models, close the water budget on regional scales, and validate outputs of coupled land-atmosphere prediction models, which will be the focus of GAPP. During the GEWEX Continental-Scale International Project (GCIP) over the Mississippi River basin of the United States, satellite estimates of precipitation were not heavily utilized because of good radar and raingauge coverage. However, GAPP represents a much broader effort than GCIP. It encompasses North America, Central America, and South America, as well as surrounding coastal waters. For example, GAPP will seek to transfer models developed for GCIP to South America and will study the warm season precipitation regime of the North American Monsoon System (NAMS). Most of these areas outside the GCIP domain area do not have high-density raingauge and radar data available. In fact, many of these areas have little or no gauge or radar observations (especially over coastal waters), and even in parts of the continental U.S. there are gaps in radar coverage, especially in mountainous areas and other complex terrain. Clearly, satellite data are necessary to provide the required precipitation estimates.

Many algorithms have been developed for satellite rainfall estimation, ranging from single channel infrared (GPI) and microwave estimates (SSM/I) to complex multi- spectral algorithms (GMSRA), and to neural network algorithms (Persiann) that incorporate satellite and other inputs. Some of these algorithms are designed for fairly large space- and time-scales such as used in the Global Precipitation Climatology Project (GPCP); others are designed for high spatial and temporal applications such as flash floods or mesoscale models. The GPCP and other efforts have sponsored a variety of campaigns to assess the accuracy of different models under a range of conditions. However, the one constant in all of these assessments has been the scarcity of accurate, reliable ground reference data, thus making it difficult to answer the most fundamental of questions, such as "what are the biases and random errors of the satellite based estimates?" Only if this question can be answered will we be able to adequately measure differences between algorithms and intelligently select the best relevant to GAPP. This will become especially important as attempts are made to derive precipitation on spatial scales of tens of kilometers and hourly-to-daily time-scales. At these scales one does not have the advantage of spatial and temporal averaging to reduce algorithmic errors. At present, we know of no other comparison experiments that would evaluate satellite products at such high spatial and temporal resolution. Recognizing this, a multi-phase project is proposed as follows:

- Phase I: Conduct a regional satellite precipitation algorithm comparison experiment (RSPACE) to identify the algorithm or algorithms that will provide the most accurate satellite based precipitation estimates in support of GAPP. This main feature of the experiment will be a fully characterized (in terms of its errors) and validated (reference) data set for at least two locations and for various cold and warm season precipitation events. The scientific community will be invited to participate by applying their existing algorithms to a specifically prepared satellite data set and we will evaluate the resulting product errors.

- Phase II: Implement the selected algorithms in support of GAPP. This task will also include analysis of the generated precipitation data to ensure accuracy and spatial and temporal continuity. We will use selected target areas maintained by the GPCP's Surface Reference Data Center to ensure quality of the derived precipitation estimates for different locations.
- Phase III: This phase will concentrate on development and evaluation of procedures to merge satellite, radar, and gauge data into a final analyzed precipitation data set.

The proposed project is also considered crucial for the future progress of climate research. Only through rigorous validation activities can the credibility of space-based products and model outputs based on such information be established.

(C) Climatic Effects of/Controls on Mesoscale Processes

The possibility of major changes in the earth's climate, due either to natural or anthropogenic effects, has become a serious attention point for both the scientific and the larger political and economic communities of the U.S. and world. The factors that control global and local climate are now being identified and tested in various kinds of climate simulation models. As with day-to-day weather, while many of these factors are of large, global, or extraterrestrial scale, regional climates are also responsive to many kinds of small and mesoscale influences. Several meso- and regional-scale climate-influencing processes are within the research environment of CIMMS. As part of this five-year plan, we propose to continue efforts to enhance the accuracy of key parameterizations in global climate models.

Climate Research and Development

Use of the ECHAM5 GCM for Regional Climate Modeling

CIMMS wishes to pursue additional climate research and applications over the next five years. In particular, this would involve work with the imminent ECHAM5 GCM from the Max-Planck Institut für Meteorologie (MPIM), including nesting the CAPS regional scale model (ARPS) within ECHAM5 to address regional climate issues. The ECHAM5 GCM would be ported to and operate on the OU supercomputing system. On the basis of preliminary discussions with MPIM, we expect this will be collaborative between our institutes. This collaboration will likely include MPIM sending a sequence of Visiting Scientists to CIMMS for periods of 1-2 years per person. The collaboration may also extend to involve a large multinational company that is interested in using ECHAM5 to guide its season-to-season planning and operations.

Role of Tropical Atlantic Ocean in West African and North Atlantic Climate Variability

The response of the Atlantic Ocean to ENSO is currently an important theme for the developing international Climate Variability and Predictability (CLIVAR) Program. The subsequent response of the Atlantic-North Africa climate system, especially in terms of the finer fabric of climate, such as changes in weather events, is a further important theme, establishing

the science that will lead to societal applications of the CLIVAR program. This project will deal with both of these themes following on from previous findings by CIMMS and other researchers that suggest the problems posed here are tractable. The focus is on a particular period in the annual cycle and for two particular regions – subtropical Northwest Africa in March-April and West Africa in May-October. The research will be conducted through analysis of a range of data sets and model simulations. Daily rainfall data sets for West Africa and Morocco will be used in conjunction with the reanalysis data sets, outgoing longwave radiation, global sea-surface temperature (SST), and the PIRATA moored array in the tropical Atlantic. Diagnostic findings will be supported and further investigated through a set of targeted modeling experiments. The ECHAM5 GCM will be used to study the large-scale response of the atmosphere to SST in selected years, while the ARPS Limited Area Model (LAM) will be nested within the ECHAM5 to investigate the extent to which the finer fabric of the climate anomalies (e.g. changes in weather system frequency) can be simulated by the models, and to investigate details such as how SST modifies the moisture fluxes feeding to individual weather systems. The ARPS model has already been successfully nested in the ECHAM4 GCM in house at CIMMS.

Climatic Effects of Atmospheric Aerosols

Study of Effects of Atmospheric Pollution on Stratiform Cloud Layer Longevity and Cover

Precipitation is closely related to atmospheric pollution in general, and aerosol concentration and size distribution in particular. Environments with more abundant aerosol concentrations increase cloud drop concentrations and therefore, given the same amount of liquid water, decrease drop sizes that inhibit precipitation formation. When precipitation consists primarily of large drops, the evaporative cooling is spread over the entire depth of the CTBL. This tends to stabilize the subcloud layer. On the other hand, when precipitation drops are relatively small, the maximum cooling is more likely to be confined near the cloud base, which tends to destabilize the subcloud layer. Observations also show that the precipitation flux is often of comparable magnitude or even larger than other water substance fluxes. As a result, the precipitation flux can substantially deplete the cloud layer water content, which will reduce the buoyancy flux and the turbulent kinetic energy in the cloud layer. Thus, the atmospheric aerosol load and resulting stratiform cloud layer precipitation may lead either to the break-up of stratocumulus cloud decks or the enhancement of such cloud cover through reduction of turbulent kinetic energy and entrainment.

In a similar way, the aerosol concentrations may affect cloud fraction and lifetimes. A relatively small number of giant nuclei (e.g., produced from sea-salt by surface winds) can play an important role in triggering precipitation. At the same time, precipitation also depends on the aerosol environment and is an important factor in scavenging aerosols from the boundary layer and, therefore, sets their equilibrium concentrations. Thus, aerosol effects on stratiform cloud layer longevity and cover have important climate implications. The CIMMS Cloud Physics group plans a research project to investigate these aerosol climatic effects using the CIMMS LES model, as well as analyses of observations from the ACE and MAST field projects.

Climate Variability and Modeling in the North Atlantic and Africa

Storm Track Variability over the North Atlantic

Storm track variability over the North Atlantic has significant economic and sociological impact for the eastern U.S., Western Europe, and northwest Africa. This CIMMS project will quantify the intensity and frequency of these storm tracks over subregions across the North Atlantic, using Serreze's cyclone tracking algorithm. Analyses of periodicities and episodic events within these "storm track" time series will be performed using spectral and wavelet analyses. Another component of this project is to identify how much of the storm track variance can be explained by the Southern Oscillation, the North Atlantic Oscillation, and sea surface temperature anomalies both in the Pacific and Atlantic Oceans. A further goal will be to quantify the Moroccan precipitation variance explained by various storm tracks. A major component of this project will be the modeling of the storm track variability using the ECHAM5 Global Climate Model. This will involve sensitivity analyses, nested modeling, ensemble runs, and testing of the model under different climate scenarios.

Regional Climate Studies over Morocco and the African Sahel

The precipitation variability over Morocco and the West African Sahel during the last half-century has been quite striking. This CIMMS project will use two different state-of-the-science approaches to understand the mechanisms behind this climate variability. The first approach will be to nest a regional climate model (such as OU ARPS or NCAR MM5) within the ECHAM5. There are many scientific and computational challenges associated with this approach. Among them are the development of a correct physics package for the regional climate model and the nesting of the two models, where domain size, data assimilation, and uncertainties in the data are all significant issues. The second approach will be to study the climate variability of these regions by designing neural network models. In a sense, this approach is a statistical downscaling scheme to study the relationship between large-scale circulation variability and regional precipitation. Hastenrath and colleagues have been successful in building a neural network model for the prediction of summer rainfall over South Africa. The knowledge and data sets that we have acquired from previous research will constitute a firm basis for building and training these neural network models over Morocco and the Sahel.

Mesocyclone Climatology

Warning Improvement Through Better Knowledge of Mesocyclone Climatology

CIMMS and OU, with support provided by the NWS ROC Applications Branch, seeks to improve warnings of severe thunderstorms through development of a regional mesocyclone climatology based on WSR-88D data. Doppler radar mesocyclone signatures are indicative of thunderstorm rotations and high likelihood of tornado formation. While mesocyclones have been investigated for more than two decades, climatological studies have covered only small regions for limited periods. The intent of this project is to develop a prototype regional mesocyclone climatology for a significant portion of the Southern Great Plains using data streams from several

WSR-88Ds (analyzed in real time) over a period of at least one year. This effort will lay the groundwork for development of a mesocyclone climatology for the entire United States that can be used as guidance in operational training materials.

Recent efforts by CAPS, working in partnership with the ROC and NSSL, have resulted in the base (Level II) data streams from eight WSR-88D radar's being available to the Norman weather research community in real time. The availability of these data streams presents a unique opportunity to extend and refine the climatology of mesocyclones and attendant severe weather. The mesocyclone detection algorithms developed by ROC and NSSL will be adapted and extended to the processing of the data streams from these eight radars. Experiments will be conducted on detection of the onset of rotation, extension of rotations through the storm, and (in severe cases) the appearance of tornado vortex signatures. Initial development and prototype work will likely be done with archived data, but the goal will be to develop tools that will allow processing and compositing of the data streams as they are received. This work will provide a foundation for establishment of a national climatology in the future when base data from more of the national research network of WSR-88Ds becomes readily available.

Atmospheric Radiation Measurement (ARM) Program

Southern Great Plains Site Scientist

During the next five years, the U.S. DOE ARM Program Southern Great Plains (SGP) site scientist team, located at CIMMS, will continue to provide scientific support for operating and maintaining the ARM SGP Cloud and Radiation Testbed (CART) site. This effort began in 1992. It now includes helping site operations run as efficiently and productively as possible by maintaining bi-weekly visits to the site and constant communications, continued support in the planning and operation of intensive observational periods (IOPs) and campaigns, and managing the Data Quality Problem Report data base that communicates instrument data quality problems to site operations for timely corrective maintenance scheduling.

Instrument Mentoring

Instrument mentoring activities within the Site Scientist Team at CIMMS will also continue for chilled mirror hygrometers and the soil water and temperature system. Mentors are charged with deploying, maintaining, and improving instrument systems, and assuring the quality of the data from them.

Continued Improvements for Calibration Facilities

The SGP CART Central Facility is quickly becoming a high quality, NIST traceable calibration facility with ever-expanding capabilities. Recently, a temperature and relative humidity calibration chamber was installed by CIMMS at the Central Facility and is used on a weekly basis for calibration and sensor verification. This chamber is ideally suited for calibrating relative humidity sensors, but is not well suited to perform extensive testing of temperature sensors because of the equilibration times required when changing temperature set points. A temperature chamber capable of calibrating sensors over a wide meteorological range (-50 to +50° C) would be a valuable addition to the existing suite of instrumentation at the ARM

CART Central Facility. CIMMS will pursue the possibility of this enhancement during the next five years.

Evaluation of Radiosonde Accuracy

The absolute accuracy of Vaisala radiosondes used in the ARM Program is being examined by CIMMS and Argonne National Laboratory to ensure that accurate estimates of column water vapor can be obtained. A more detailed analysis of radiosonde accuracy is needed and will be conducted during the next two years. This analysis will include the dual sonde launches that have occurred at the ARM Central Facility during intensive observation periods, and comparison of surface sonde measurements with highly accurate surface measurements of temperature and relative humidity. This research may result in a procedure that can be used to scale the sonde relative humidity over the entire vertical profile based on a surface reference point (the temperature measurements from the sondes have proven very accurate, so a temperature scaling will not be necessary).

Incorporation of Oklahoma Mesonet OASIS Data into the ARM Program

The Oklahoma Mesonet has recently completed a major upgrade of its network to permit the surface energy balance to be monitored in real time across the entire state of Oklahoma. Sensible heat flux, latent heat flux, ground heat flux, and net radiation are all measured and reported every five minutes. The data being produced by this OASIS Project are extremely rich and have many potential applications within the ARM Program. It would therefore be useful to incorporate the OASIS data set into the ARM Program's data archive and allow the research community full access to them. This project will be undertaken in the near future and will require development of data ingest and quality assurance procedures.

Graphical Visualization

The SGP site scientist team at CIMMS will also continue to provide support for quicklook (visual aid) development on SGP data streams as part of its routine duties. Scientists from Argonne National Laboratory, the University of Utah, Eastern Illinois University, and OU have also recently received notification of NSF funding related to ARM quicklooks. The goal of the project is to use near-real time visualization of atmospheric data and the associated visualization code as a collection for the National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL)-Atmospheric Visualization Collection, and as a research training ground for students. CIMMS will be involved in this project as a programming and scientific consultant on ARM instrumentation and associated data streams. The initial funding is for two years beginning in late 2000. This project will represent a new aspect for ARM quicklooks and educational outreach, and help ARM meet its needs for providing real time quicklooks.

Data Quality Office

CIMMS became home in 2000 to the ARM Program Data Quality Office. This multi-year effort will give CIMMS the responsibility of quality assuring ARM Program data from all three CART sites -- the SGP, the Tropical Western Pacific (stations on Manus and Nauru Islands), and the North Slope of Alaska (stations in Barrow and Atqasuk). This project involves interaction with the DOE National Laboratories, some NOAA laboratories, and various universities. Initial funding is for three years and would be extended beyond 2003 subject to satisfactory performance.

Tropical Pacific Studies

Accuracy of Atoll Rainfall Measurements

Rainfall and its associated processes are important for the balances involved in the global climate system. In situ measurements of rainfall in the tropical Pacific are almost exclusively made from islands. It is clear that islands with imposing terrain strongly affect local meteorological conditions, and that the rainfall amounts measured on those islands are not representative of open ocean conditions. Less clear is the representativeness of rainfall measurements taken on atolls or islands with minimal terrain, where orographic lifting likely does not influence weather conditions. However, heating of shallow water in the lagoons encircling these islands and the resulting increased ocean-atmosphere heat flux (relative to the open ocean), plus the greater roughness of the island surface itself, may have an impact on the initiation of convection. If so, conditions over on the leeward side of the atoll may not be representative of conditions over the open ocean.

A combined rain gauge and radar study conducted by CIMMS is proposed to reveal whether there are variations in the weather and climate across atolls or islands and also to the leeward side of atolls. The Doppler-on-Wheels (DOW) radars would be transported by ship to an atoll such as Majuro (which has paved road around 180 degrees of the atoll ring), or other atolls in the tropical Pacific region of interest, to study precipitation systems and investigate if rain preferentially initiates on or near the atolls. In addition, a network of automatically recording raingauges would be placed at roughly 30-degree intervals around the Majuro atoll (i.e., a total of approximately 12) to study whether, in a climatological sense, there is an enhancement of precipitation on different sides of the atoll having different wind regimes. The surface-based rain data and the radar data would also be compared with TRMM rainfall measurements.

Latin American Studies

Long-Term Climate Monitoring with Atmospheric Sounding Networks

Special sounding networks, using both pilot balloons and recoverable radiosondes, will continue to be operated and expanded in Latin America by NSSL-CIMMS for monitor climate variations on regional scales. The current research network will evolve into a quasi-operational system for both the climate research community and national weather forecasting activities throughout the region.

Educational Programs Development for Latin America

Current educational activities associated with the NSSL PACS-SONET will expand to include specialized courses offered for the Latin American meteorological community.

North American Monsoon Project

NSSL-CIMMS will participate actively in the preparation and field observation phase of the North American Monsoon project, currently being planned for the years 2003-2004. This activity will include NOAA aircraft operations and the development of sounding networks in Mexico.

South American Low-Level Jet Field Program

NSSL-CIMMS will participate in the South American low-level jet field program planned for the years 2001-2002. Participation will include coordinating sounding networks and organizing NOAA research aircraft operations.

South African Studies

Glidersonde Activities in South Africa

Present joint glidersonde activities between NSSL-CIMMS and the South African Weather Bureau will expand into a regional sounding network for southern Africa. These observations will provide essential observational support for understanding the regional and mesoscale climatology of the South African monsoon, which affects the interior (especially) and eastern regions of that nation in austral summer. This is perhaps the least well described regional-scale monsoonal circulation.

(D) Socioeconomic Impacts of Mesoscale Weather Systems and Regional-Scale Climate Variations

Study of the economic and social impacts of mesoscale weather systems and regional-scale climate variations has become an important research area in recent years. Locally, the devastating May 3, 1999 tornado outbreaks in Oklahoma-Kansas produced social and economic impacts that will be felt for many years to come. On the regional climate scale, the agricultural economics of Oklahoma and Texas were severely impacted by droughts during two of the last three summers. Nationally, recent devastating hurricanes and weather systems with roots in El Niño or La Niña have caused havoc. This work typically involves collaborations between atmospheric scientists and scientists in the fields of economics, hydrology/water resources, social sciences, and agronomy, and makes extensive use of tools like climate scenarios and economic and plant simulation models. Work in this area will continue to help NOAA further demonstrate its relevance and economic value to society.

Regional Climate Impact Studies

Recent years have dramatically reinforced that seasonal climate extremes can have profound societal and economic impacts, and, conversely, that climate information and predictions can be used for public good and economic advantage. Fortunately, 35 years of scientific discovery have provided understanding and methods needed to predict – several months in advance and with considerable confidence and accuracy – seasonal precipitation and temperature anomalies for some regions in some years. Further progress must and will occur as world demand for climate information and predictions increases.

During the next five years, CIMMS proposes to undertake focused research and development to underpin regional climate impact prediction capabilities for areas of 10^3 to 10^6 km. The goal of this effort will be the development and demonstration of complete, rigorously scientific technologies that connect regional climate predictions with socioeconomic impacts to facilitate formation of societal response strategies. It will draw on, integrate, and enhance expertise at three locations – OU (weather system observation and simulation; regional climate diagnostic and impact analysis and prediction; energy economics and policy; science and public policy); Texas A&M University (economic, environmental and natural resource, public health, hydrologic, and biophysical analysis and simulation; communications and public policy); and Scripps Institute of Oceanography (regional and global climate simulation, ocean-atmosphere interaction analysis and simulation; hydrologic impacts).

CIMMS will develop prediction capabilities for spatial extent, timing, and magnitude of regional climate impacts, to capitalize on improving capability to simulate and predict large-scale global climate system behavior. Its uniqueness will result from targeting specific demonstration regions to quantify crucial climate-environment-society linkages. These linkages extend from the global climate system through weather patterns to regional-scale climate anomalies, and on to environmental and biophysical impacts with societal consequences. We will establish these linkages through combined use of environmental, economic, and behavioral data, statistical techniques, and a suite of models. This will complement and assist operational climate prediction units emerging worldwide.

This focus is at the forefront of the U.S. Global Change Research Program (USGCRP). A U.S. National Assessment of the potential consequences of climate variability, mandated under the USGCRP, is now under review. CIMMS will develop the capability to routinely perform such a function in the future through interactions with public and private sector decision-makers, and so could act as a prime facilitator and coordinator of subsequent Assessments.

Elements of this project will start soon, as OU President David Boren has agreed to provide $1 million over the next five years to expand the Climate Research and Development done within CIMMS. This new money will support three positions -- a Climate Outreach Coordinator, who will be shared with the OU Institute for Energy Economics and Policy (IEEP); a post-doctoral scientist to statistically investigate the linkages between regional climate variability and energy demand/prices (also to be shared with IEEP); and another post-doctoral scientist to conduct experiments with the ECHAM 5 GCM (solely within CIMMS; as indicated above, probably with a person on loan from Max-Planck Institute). The initial effort will emphasize interactions between regional weather/climate and energy demand, availability and price. There will likely be significant involvement of the private sector. A major national workshop on this topic is being planned.

Impacts of Severe Weather

Mitigating Severe Weather Impacts on Society and the Civil Infrastructure

Over the last 35 years, the costs of weather-related disasters have doubled or tripled each decade. Weather-related natural disasters alone have taken lives, damaged property, and produced other costs averaging at least $50 billion per year. The mid-continental U.S. from the Gulf coastal plains to Canada experience natural hazards related to severe storms every year. The May 3, 1999 tornado outbreaks in Oklahoma and Kansas, and numerous flood events, are potent examples of the hazards that severe storms pose to communities. The reported costs of such disasters are just a fraction of the actual costs, which include damages to natural resources, loss of landfill capacity, loss of wages, productivity, and threats to public health. The costs of natural hazards are projected to increase if steps are not taken to help communities reduce their vulnerability and prevent natural hazards from becoming natural disasters. These increasing costs are of great concern to government agencies, the private sector, and the public.

In response to a multitude of natural hazards and disasters, national focus is changing from reactive to proactive efforts to reduce impacts to society. For efforts ranging from learning the best methods of response to developing of mitigation measures, a venue is needed that brings together the diversity of stakeholder organizations, both public and private, to formulate strategies for improving the safety and well being of society so that a natural hazard does not become a disaster. Mitigation planning is an emerging industry requiring expertise ranging across scientific and engineering disciplines. As a start to research on these subjects, a symposium is being planned. It will focus on weather-related disasters, bridging engineering and meteorological disciplines, to reduce societal impacts, loss of life, and property loss. This symposium, to be held in 2001, will address the issues of severe weather impacts on the civil infrastructure, best methods to mitigate disasters, and new technologies for prediction and dissemination of information and warnings. The ultimate goals will be to develop intervention strategies, identify challenges for the future, and determine how to proceed. Anticipated topics will include flooding, wind, drought and other severe impacts of weather and storms. Groups planning this event include the Oklahoma Weather Center (of which CIMMS is part), the OU International Center for Natural Hazards and Disaster Research, and the OU School of Civil Engineering and Environmental Sciences, in collaboration with FEMA Project Impact, Tulsa (Oklahoma) Project Impact, the Oklahoma Department of Civil Emergency Management, NWS, NSSL, and other local, state and federal agencies.

(E) Doppler Weather Radar Research and Development

Transfer of knowledge between the academic, engineering, and operational communities is essential to improve the design, usability, and supportability of the NEXRAD WSR-88D. Continual enhancements are needed to improve the quality, format, accuracy, resolution, and update rate of the base data. The work under this theme will introduce, examine, and analyze the potential of present and future technologies for meeting unfulfilled needs of the NEXRAD program. It will also be concerned with helping to develop the meteorological radar system that will ultimately replace NEXRAD.

Radar Development

Phased Array Radar

SPY-1 technology (U.S. Navy) will be tested and enhanced at NSSL with the vision of using this technology to potentially upgrade the WSR-88D radars. The Department of Defense has allocated $10 million for the project, which will create a testbed facility in Norman during its initial stage. SPY-1, a phased array radar, uses multiple beams and frequencies, controlled electronically, which allow it to scan the atmosphere six times faster than the WSR-88D. Phased array radar uses electronic scanning to quickly provide a full three-dimensional picture of the atmosphere, and it could ultimately allow weather forecasters to increase the average tornado warning lead time from the current 12 minutes to as much as 22 minutes. SPY-1 was originally developed by Lockheed Martin to support tactical operations aboard U.S. Navy ships.

Radar Product Development

NEXRAD Product Improvement Project

In conjunction with the three federal agencies (Commerce, Defense, FAA) that support NEXRAD under NWS Program Management, and in partnership with ROC, NEXRAD Product Improvement (NPI) will continue at NSSL-CIMMS for the next five years. It has several components.

Work will continue in 2001 and 2002 to complete the Open Radar Product Generator (ORPG) Project. The Open Radar Data Acquisition (ORDA) Project, already begun, will continue through 2005. This project will involve working with the NWS in developing and replacing the legacy RDA component of the NEXRAD system with one that complies (where possible) with Open System's standards and provides greater flexibility and processing capacity. New techniques will be implemented on the ORDA to reduce range and velocity ambiguities that currently limit operational effectiveness.

The Dual Polarization Project will begin in 2001 and continue through 2005. It will involve working with the NWS to develop dual polarization capability, operationally test it, and, if the tests are successful, implement the capability within all NEXRAD radars. Two other related projects are also underway: Open Principal User Processor (OPUP) and Common Operational Development Environment (CODE). A replacement (OPUP) for the current NEXRAD radar display (PUP) is being developed for the Department of Defense, but may be expanded for use by other agencies (e.g., it is being investigated as a means by which the NCDC can service legal archive data from their central data base). OPUP will be open systems based. CODE is being developed to aid in integrating applications more easily and efficiently into the new open systems platforms.

Warning Decision Support System/Integrated Information (WDSSII)

The development of an experimental, radar-based, Warning Decision Support System (WDSS) has been underway at NSSL for several years. The new WDSSII effort will integrate radar data with other sensor data to provide warning forecasters with the best possible guidance

for warning issuance decisions. A part of the system development is the development of a series of experimental radar and other-sensor algorithms to identify severe storm threats (hail, wind, tornado) and track the severe weather. The development of WDSSII is closely linked to CODE, since the WDSSII software is intended to operate in the new NEXRAD open-systems environment. WDSSII will continue to be deployed at a number of user/customer sites during the next five years. Special grants have been made or will be proposed with a number of customers/partners such as Salt River Project, Georgia Tech Research Institute, Australia Bureau of Meteorology, and others to enhance the algorithms and display systems and further develop them for specialized needs.

Radar Algorithm Development

Independent Verification and Validation of NEXRAD Algorithms

Algorithms presented for inclusion in the WSR-88D baseline historically have been tested in-house by their developers, after which limited, and often subjective, field-testing has occurred under the supervision of NSSL and the NEXRAD ROC Applications Branch. The purpose of this project is three-fold. First, the project intends to develop independent data sets (case studies) made up of well-truthed, diverse meteorologically, climatologically, and geographically situations representative of the phenomenon the algorithm is designed to measure or estimate. The data sets must be large enough to divide three ways – one-third for use by the developers in their initial work; one-third by the developers for further in-house testing; and, one-third for independent verification and validation by the ROC. Second, the project seeks to develop objective, statistical methods to evaluate algorithms that measure in varying space and time domains. Third, it is hoped the project can develop automated methods to create the data sets described herein, that largely are independent of human truthing and thus save many hours and related expenses.

Data Mining of NEXRAD Level II Base Data

The special statistical arena of data mining and knowledge discovery continues to grow, especially in the atmospheric sciences, as evidenced by the increasing number of publications both in the refereed literature and in conference *Proceedings*. Level II base data, representing the three moments of Doppler radar (reflectivity, velocity, spectrum width), appear to contain patterns (linear and nonlinear) in individual moments and, more importantly, relationships among at least two and perhaps three moments. For example, the well-proven Tornado Detection Algorithm (TDA) uses velocity data to reveal mesoscale circulations that represent precursors to and tornadic activity itself. It may be possible to improve the TDA by integrating reflectivity data into an improved TDA process. The improved TDA may take into account differential velocities of droplets of different sizes, thus revealing something of drop size distribution. If drop size distribution may be estimated, a good Z-R relationship may be approximated. If this approach is productive, it may be possible to develop an improved precipitation estimation algorithm. Such an algorithm certainly would not replace dual polarization techniques, but the algorithm could be a gap-filler -- it could improve precipitation estimation from time of implementation until such time the fielding of dual polarization hardware and software could be completed. This work will be pursued by NSSL and the ROC

Applications Branch with considerable involvement of CIMMS scientists and computer specialists.

Development of a New Class of Statistically Based NEXRAD Algorithms

This ROC Applications Branch/CIMMS project is founded in the previous project, namely data mining of NEXRAD Level II base data. If data mining is successful, it may be possible to create a new class of statistically-based algorithms where the probability and/or the intensity of certain events may be predicted by (1) the structure in the NEXRAD base data and (2) events occurring in the near-storm environment. Because it is likely these algorithms will rely on data external to the NEXRAD RPG (Radar Product Generator), where algorithm computations now occur, statistically based algorithms likely will execute in an agency-specific processing environment.

Specialized Radar Applications Development for the NEXRAD Agencies

Specialized radar sampling, radar algorithm, and display concepts are being developed at NSSL-CIMMS for the three NEXRAD agencies (NWS, FAA, AFWA), sometimes as joint NEXRAD projects and sometimes as individual agency projects. The experimental radar algorithms interface to the multi-sensor WDSSII experimental integration algorithms. They involve fuzzy logic, artificial intelligence, and neural networks. Some of the algorithms utilize multiple radars and feature mosaics of radar outputs (reflectivity, velocity, derived parameters) over areas larger than the coverage area of one radar. The new radar sampling concepts allow for better coverage of the operational radar coverage area and faster updates of the radar outputs. During the next five years, specialized dual-polarization algorithms will be developed to estimate precipitation amounts and discriminate between precipitation particle types.

Quantitative Precipitation Estimation Using Multiple Sensors

During the past three years, a quantitative precipitation algorithm has been developed at NSSL-CIMMS that utilizes a multi-sensor (radar, satellite and environmental data) approach to generate improved quantitative precipitation estimates which, in turn, are being used to identify conditions leading to flash floods and flooding. This development was stimulated by ongoing research establishing that reliance on any one method of estimating precipitation by a single instrument can be faulty for some applications. In contrast, we found the use of a multi-sensor approach to show significant promise in improving precipitation amounts, especially in extreme events and over complex terrain. This effort led to the development and prototyping of the Quantitative Precipitation Estimation and Segregation Using Multiple Sensors (QPE-SUMS) algorithm. The objective of QPE-SUMS is to accurately estimate precipitation types and rates using an optimal blend of radar, satellite, and gauge rainfall, and environmental data in ways that are scientifically sound and physically based. Over the next five years, the QPE-SUMS suite of algorithms and related display concepts will be tested and enhanced in regions of the United States with a high incidence of flash flooding. Additional research and development during the five years will focus on the integration of QPE-SUMS into a Distributed Hydrological model to improve the accuracy of runoff predictions. Successful completion of basic research and

QPE-SUMS Algorithm development will allow for improved detection and mitigation of flash flooding and improved hydrological management of surface water storage.

Radar Data Dissemination

Real-time Access and Dissemination of WSR-88D Doppler Radar Data Using the Next Generation Internet (I2)

This multi-year effort is designed to leverage existing NSSL RIDDS infrastructure (used to communicate to the wideband ports of the WSR-88D radars) to move the WSR-88D Level II data via the Next Generation Internet (I2/Abilene) to NCDC for archival. The project will also make these data available over the Internet to universities and other NWS-approved users of the WSR-88D data in real-time using Unidata's LDM software (with a data compression module). The project is a collaborative effort between NSSL, NOAA's Forecast Systems Laboratory, NCDC, NWS, and OU.

The broad geographic distribution of the project will provide a test of overall reliability, network efficiency, and real-time ingest at 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 rapid scanning strategies. NCDC will move its base data ingest system over to a new T3 line and will begin receiving data from each of the new Collaborative Radar Acquisition Field Test (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.

The overall project will also include work with the NOAA OAR Sea Grant Extension Office. NSSL is collaborating with Sea Grant in the Carolinas, where an additional four radars connected to the soon-to-be installed WDSS-II station at Wilmington, NC, will provide complete radar coverage of the Carolina coastal area for studying landfalling tropical systems, storm runoff, sea breezes, and model initializations.

Radar Data Climatologies

Radar Signature Climatology of Supercell and Quasi-linear Convective Systems

The percentage of U.S. tornadoes that form annually within quasi-isolated supercells and squall lines/bow echoes is being estimated by NSSL and CIMMS through development of climatologies using data from individual WSR-88D radars. Geographical, seasonal, and diurnal

distributions of isolated and line-type tornadoes will be computed. Research on commonly observed features of squall lines/bow echoes would lead to better understanding of line-storm tornadoes and tornadogenesis.

Radar Data Assimilation

Refractivity Analysis Improvement

Variational methods will be developed at NSSL-CIMMS for radar refractivity analysis in the boundary layer. The objective is to improve the refractivity field analysis by assimilating non-primitive variables of trapping layer base, strength, and thickness. The goal is to improve our skills in nowcasting (or future forecasting) EM propagation conditions.

3.5-Dimensional Variational Package

A 3.5-dimensional variational (3.5DVAR) package will be developed at NSSL-CIMMS for Doppler radar data assimilation. Work will be done to combine other data sources such as surface mesonet and satellite data into this package. The package will be used in the U.S. Navy's COAMPS model. Another project will transfer and adapt the 3.5DVAR package to other operational mesoscale models, such as the ETA and RUC models at NCEP.

(F) Climate Change Monitoring and Detection

The goal of this new theme is to study the homogeneity or lack thereof of U.S. historical station records and to use this information to help address the climate change question. This work will be done in collaboration with NESDIS and its NCDC. Research is proposed in the following areas.

National Climatic Data Center Research

The objective of this new collaborative effort between CIMMS and NCDC will be to develop products for improved climate change monitoring and detection for the United States. Climate monitoring is part of NCDC's mission; any improved abilities developed through interactions between NCDC and CIMMS will be transitioned to NCDC's Climate Monitoring Branch.

There are many new sources of data and new combinations of data that can and should be used for U.S. climate change monitoring and detection. However, NCDC itself lacks the resources and/or expertise to address many of these opportunities. Developing products and monitoring capabilities utilizing these new data sources, in collaboration with CIMMS, could greatly assist NCDC in its monitoring and detection activities. The projects briefly outlined below would be multi-year, multi-scientist efforts for the entire United States. With the tremendous influx of new data, opportunities for additional work should abound. Opportunities to be explored over the next five years include:

Radar Precipitation Product

Develop a radar climate precipitation product that puts radar-derived precipitation into historical perspective, thereby making it possible to use this information for real-time climate monitoring.

Improved Monitoring Products

Develop improved quality control procedures that merge satellite, radar, and in situ information to improve the final climate monitoring products over what might be derived from each of these data sources alone.

Wind Climatology

Develop a wind climatology suitable for putting real-time ASOS winds into historical perspective, thereby making ASOS data useful for climate monitoring.

Lightning Climatology

Develop a lightning climatology to help make lightning network data useful for climate monitoring and to set individual events into historical perspective.

Quality Control Using Climate Reference Stations

Develop an improved quality control approach that properly utilizes the highly reliable Climate Reference Station data in the quality control of nearby cooperative stations.

Storm Climatology

Develop storm climatologies and climate monitoring capabilities that will help answer a key set of lingering questions -- has there been a change in number, climatology, or intensity of nor-easters or Arctic clippers? When a strong, early- or late-season storm hits, NCDC is asked these questions but presently lacks a robust means of determining an answer.

Quality Control of Historical Climate Data

Develop systems for performing a high level of quality control (including temporal, spatial, and complex elemental relationships) for data that have been recovered via the NOAA Data Rescue Program and the Climate Database Modernization Program.

North American Daily Climate Data

Extension of Richman-Lamb Data Sets

The well-known Richman-Lamb daily weather data sets for North America east of the Rocky Mountains will be extended through the year 2000. These daily data sets contain

precipitation totals and maximum and minimum temperatures for a grid-like network of stations (~110 km separation) across southern Canada and all of the United States east of the Rockies. The data sets commence in 1949 and currently run through 1992. They have provided the basis for many diagnostic and prognostic investigations of the regional climates of North America. The proposed extension of these unique data sets through 2000 will permit further CIMMS contributions in the area of climate change monitoring and detection.

North Atlantic Variability

Prediction of North Atlantic Variability

North Atlantic climate variability is the product of complex interaction and integration of many different components of the climate system, including the ocean, troposphere, cryosphere, and stratosphere. Intuitively, we would expect that North Atlantic variability on shorter time-scales (e.g., interannual) would be modulated by different interactions within the climate systems than longer time-scale (e.g., decadal) variability. For this reason, the first component of this CIMMS project will be to design and train separate neural networks for the interannual and decadal time-scales. However, neural network models must address some challenges when they are applied to meteorological problems. According to a recent article in the *Bulletin of the AMS*, these shortcomings arise from use of short time series that amplify non-linear instabilities in the model, from sampling over large spatial dimensions, and from difficulties in physically interpreting the non-linear results. Ensembling of neural network runs, prefiltering of the input data (such as by EOF analysis), and phase-space interpretation of the results are all ways of overcoming the above problems and will have to be considered during this component of the project. The other component of the project will be to assess the ECHAM5 GCM's ability to forecast North Atlantic climate variability.

Tropical Pacific Rainfall

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

The Surface Reference Data Center (SRDC) is expected to continue operation over the next five years. The SRDC is a raingauge data base that is expanding throughout the tropical Pacific. It is used as ground truth for satellite-based rainfall algorithms and is constituting a long-term climate observing network in the Pacific.

As the SRDC begins to use data from a wider range of sources, it is becoming more difficult to work with the various formats. Goals for the next few years include the design of data ingest and analysis procedures that are modular. This will ensure that individual components can be changed easily without impacting other procedures. This will also allow new data sets 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. These goals will be accomplished with the implementation of a new database management system.

(G) Public Affairs and Outreach and Professional Development

An active program of public affairs and outreach ensures that our research and expertise is regularly explained and distributed in an easily understood way to the general community in the Southern Great Plains and across the rest of the United States. This occurs through media interviews, feature stories in the electronic and print media, photo opportunities, guided tours, open houses, web-based educational activities for school children, telephone interviews, and e-mail exchanges. CIMMS also recently initiated a series of "Workshops on Regional Climate Prediction and Applications" to provide professional development for promising young meteorologists from across the developing world. Outreach and professional development activities planned for the next five years are as follows:

NOAA Weather Partners Outreach Activities

Outreach for the NOAA Weather Partners includes public affairs, outreach, and educational activities, including hosting public events. Beginning in 1998, CIMMS has provided a full time public affairs person to serve the four Norman NOAA units (NSSL, SPC, ROC, WFO) that comprise the Norman NOAA Weather Partners. This shared person provides coordination among the four units for news conferences, special events, and tours. Three recent examples of coordinated activities include:

- Tornado season kick-off news conference and media workshop;
- Tour and presentations to Leadership Norman and other local community groups; and
- Tour during a national meeting of a female pilots group (Ninety-Nines).

In addition, two CIMMS staff members design and maintain the NSSL web page and another CIMMS staff member designs and maintains the SPC web page. One of the NSSL web designers also performs outreach, which includes conducting a standing weekly tour and other special group tours, answering e-mail and phone questions from the public, and participating in events such as the Ham Holiday and the Oklahoma Mesonet Science Fair. The other NSSL web designer is the in-house computer graphic artist. The NSSL librarian answers all written questions from the public.

Continuing and planned outreach activities for the NOAA Weather Partners during the next five years include:

- Public Affairs:
    - Write and distribute news releases as needed
    - Initiate news coverage
    - Hold news conferences as needed
    - Respond to media inquiries
    - Host a spring severe weather media event
    - Participate in web chats
    - Prepare B-roll of field programs
    - Work with production companies to produce science-based programs

- Public Events:
    - Host and improve annual Open House
    - Participate in public annual events such as Ham Holiday, State Fair, and Oklahoma Mesonet Science Fair

- Outreach/Education:
    - Host weekly tour and update and expand self-guided tour
    - Host special tours as requested
    - Provide speakers for groups as requested
    - Respond to written and e-mail questions, phone calls, visitors
    - Maintain and improve web pages
    - Manage automated library services
    - Prepare and provide reference materials to students and teachers
    - Expand educational activities
    - Create education coordinator position
    - Host teacher workshops and projects
    - Begin a K-12 program such as a mini-camp

- Other Plans:
    - Hire a professional video crew to film field operations and create B-roll
    - Host grand opening event in new OU/NOAA weather building
    - Create displays for the new building

Oklahoma Climatological Survey Outreach Activities for the ARM Program

During the past eight years, the Oklahoma Climatological Survey (OCS) has established a solid infrastructure for atmospheric science education, primarily at the pre-college (K-12) level, with the support of the U.S. DOE ARM Program. Environmental data, including those from the ARM Southern Great Plains site in Oklahoma and Kansas and the Oklahoma Mesonet, are available to educators who have World Wide Web access (http://outreach.ocs.ou.edu/arm/). Unique display software has been developed to provide student interactivity with the data. Reference materials and lessons are online and in printed form to aid the educator in the application of the data in the classroom. And, most importantly, master teachers have been educated to understand and use the data in their activities. These master teachers represent a significant resource to provide workshop instruction to additional K-12 teachers.

As the OCS continues to upgrade this infrastructure, the primary goal of the next several years of the ARM SGP outreach program will be to expand the awareness and use of this infrastructure across not only Oklahoma and Kansas, but also across the entire nation. To this end, we will enhance our Web pages by including more data types, display types, and with help from the ARM Program, data from the ARM Tropical Western Pacific and North Slope of Alaska locales. We will conduct workshops at local schools in Oklahoma and Kansas and at appropriate educational conventions, using several of our current master teachers as instructors. In concert with the Oklahoma EPSCoR program, we will offer instruction to faculty at Oklahoma's two- and four-year colleges so that they can include ARM/OCS materials in the courses they offer to pre-service teachers. We will produce newsletters, conduct science fairs,

and give conference presentations that help publicize the availability of the data and materials to educators.

In addition, we will continue to develop scientifically accurate reference materials and pedagogically sound teaching lessons, placing them online and producing them in print. We will enhance our software to allow the overlay of data from different networks, such as ARM's extended facility stations, Oklahoma Mesonet sites, and National Weather Service ASOS, satellite, and NIDS networks.

Series of Workshops on Regional Climate Prediction and Applications

This Workshop Series was initiated by CIMMS in 1999-2000 and will continue through the next five years. The Workshops are intended to improve the capabilities of national meteorological services (NMSs) in developing nations in the following respects – to understand the behavior of the global climate system; to use such understanding to develop or adapt seasonal climate (especially rainfall) prediction schemes for their countries; and to work with other professionals in their countries to apply the prediction schemes in the management of agricultural production, water resources, energy generation and consumption, and public health. The need for these Workshops emerged from NMS leaders of many developing nations recognizing that their organizations did not possess the expertise to capitalize on the seasonal prediction and application opportunities offered by the 1997-98 El Niño.

Workshops are held at the OU College of Continuing Education, with the primary financial sponsorship of the International Activities Office of the U.S. National Weather Service, and additional support from NOAA's Office of Global Programs, the World Meteorological Organization, and other U.S. and international agencies. Each Workshop extends, on a full-time basis, for 6 weeks and has 12-20 participants. Lectures are given by the CIMMS Director, one or two additional Course Lecturers, and several Guest Lecturers. The participants develop small research projects using data from their country. The series is intended primarily for young NMS personnel who have received excellent training in basic meteorology at a University (B.Sc. level) or World Meteorological Organization Training School (Class II level), but who have limited exposure to the fundamental principles of modern climate dynamics and their application to economic management and other environmental and societal issues. Meteorologists who work outside their NMS (e.g., in regional meteorological centers like ACMAD and the DMCs, universities, other government agencies, or NGO's), but who have strong working relationships with the NMS, may also be accepted. Applications are particularly encouraged from meteorologists who have attended preliminary training workshops in climate prediction (e.g., the African Centre of Meteorological Applications for Development, ACMAD) or had other opportunities to acquire some basic knowledge of climate dynamics and its applications. These Workshops further develop the skills of such individuals, especially since substantial material is presented from the University of Oklahoma M.Sc. module in Climate Dynamics.

The first Workshop (late 1999) and Second Workshop (mid-2000) both focused on the Tropical Atlantic Basin and trained 25 meteorologists from the following nations in Africa, Central and South America, and the Caribbean – Mexico, El Salvador, Costa Rica (2), Barbados, Netherlands Antilles, Venezuela, Brazil (4), Paraguay, Argentina, Algeria, Morocco, Senegal, Ghana, Burkina Faso, Niger, Bénin, Nigeria, Chad, Cameroon, Congo, and Tanzania. The Third Workshop in mid-2001 will deal with the Tropical Pacific Islands and Rim, and have approximately 20 participants from Malaysia and Vietnam in the west, across the Pacific Islands

to Ecuador and Chile in the east. Subsequent workshops in 2002 and later years will deal with the Circum-Indian Ocean Region and then return to the Tropical Atlantic Basin.

III. Personnel

The various personnel categories at CIMMS are determined according to policies of OU and CIMMS. CIMMS employees, as of November 15, 2000 comprise 148 individuals in the following categories:

Senior Research Scientists	1
Research Scientists	19
Senior Research Associates	2
Research Associates	24
Visiting Senior Research Scientists	1
Visiting Research Scientists	3
Visiting Research Associates	3
Visiting Scholars	2
Visiting Post-Doctoral Fellows	1
Computer Specialists and Systems Support Staff	36
Post-Doctoral Fellows	2
Graduate Research Assistants	21
Student Assistants	18
Administrative Staff	7
Media Coordinator	1
Electronics Technicians	1
Graphic Artists	1
Special Projects Consultants	3
Temporary Employees	2

NOAA support, through this Cooperative Agreement, funds all or part of the activities of 108 of these staff. Staff members were assigned, as of 15 November 2000, to the units as follows:

OU	34
NSSL	99
ROC	12
SPC	3

Senior Research Scientists, Research Scientists and **Visiting Senior Research Scientists** at CIMMS are senior level researchers holding doctoral degrees. Each carries out independent research in his/her field of specialization and usually leads a research team. Each is responsible for the design, execution, and interpretation of research projects and their results. **Senior Research Associates, Research Associates, Visiting Research Scientists,** and **Visiting**

Research Associates are typically intermediate-level researchers with advanced degrees who carry out independent research under general supervision. Each significantly contributes to project design, execution, and interpretation. **Visiting Scholars, Visiting Post-Doctoral Fellows,** and **Post-Doctoral Fellows** are usually beginning level researchers who work under the general guidance of one or more NOAA scientists or OU faculty. These positions are designed to enable individuals to continue research studies in a specialty area. Each would have earned a doctoral degree within the last two years. **Graduate Research Assistants** are students pursuing advanced degrees on research topics relevant to CIMMS and its NOAA partners and are guided by CIMMS and NOAA scientists. **Student Assistants** are typically undergraduate students who perform a variety of hourly support activities for CIMMS research projects. The various **Computer Specialists and Systems Support Staff** perform myriad support functions related to research computing, including tasks such as scientific programming, computer system setup, operation, maintenance, and administration, and network maintenance and administration. **Administrative Staff** assist in and conduct the operational, financial, and personnel administration of CIMMS. The **Media Coordinator** provides overall coordination for the four Norman NOAA organizations regarding news conferences, special events, tours, and other outreach activities. **Graphic Artists** provide creative and graphical support to effectively present research results and may also help perform web page development. **Electronics Technicians** perform technical work related to the construction, maintenance, repair, and operation of electronic equipment and instruments in support of research activities. **Special Projects Consultants** support and help conduct field operations. **Temporary Employees** are hired to perform short-term activities.

IV. Performance Measures

CIMMS research has been and will continue to be reported in refereed scientific journals, conference/symposia/workshop proceedings, technical reports, and CIMMS annual reports. CIMMS scientists and visitors will continue to present papers at seminars, conferences, workshops, and symposia, locally, nationally and internationally.

Collaboration with scientists at our cooperating NOAA units and other government agencies will facilitate the transfer of research results and knowledge to the operational and engineering communities, which will help to provide better forecasts and warnings to the taxpaying public.

In all of these ways, CIMMS acts as a liaison between the academic and operational elements of meteorology to improve our understanding of meteorology for the purpose of protecting life and property.

V. Intellectual Property

The University of Oklahoma, of which CIMMS is a part, has an Intellectual Property (IP) Rights policy for its employees regarding the disclosure and ownership of such property. The Department of Commerce (DOC), of which NOAA is a part, has developed an IP policy for use by its Joint Institutes such as CIMMS. The DOC policy is used by all of NOAA's Joint Institutes, and has been agreed to by the University of Oklahoma

These policies will be enforced at CIMMS during the five-year period. Each disclosure of IP will be reviewed on a case-by-case basis because of the collaborative nature of most CIMMS research activities. In many cases (but not all), this collaboration will be with NOAA staff members who are U.S. government employees. Regardless, all intellectual property should be disclosed in a timely manner and should be done in accordance with the guidelines stated in the policies and with the full knowledge of the CIMMS Director.

VI. Budget

The following pages contain the proposed budgets for each of the five years covered by this plan.

While the budgets presented below cover the entire period of this five-year proposal, it is recognized that proposals are individually reviewed and funded on the basis of 12-month, or shorter, funding project periods. The budgets herein are severable in that each research task supports research personnel and associated costs based on the duration of the five-year proposal. Further, because the proposal separately funds the administrative costs on an annual basis and separately funds the research proposals, should future funding not be available, work can be stopped in a timely fashion. This CIMMS proposal is divided into major tasks that allow it to be severed proportionately as needed. Since the cooperative agreement operates on a research exchange basis, administrative offices can be closed and results of research conducted with the funds under this agreement (to the point when funding is no longer available) will be documented and submitted to NOAA as CIMMS' product unless other specific arrangements are made.

Travel will be reimbursed at actual, reasonable, and necessary costs.

(Budget not shown here)

VII. Appendices

(A) Accomplishments Statements Prepared for the University of Oklahoma

CIMMS accomplishment statements prepared for the University of Oklahoma are attached here for the calendar years 1996 through 1999.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES (CIMMS)
UNIT ACCOMPLISHMENTS -- CALENDAR YEAR 1996

INFRASTRUCTURAL ACCOMPLISHMENTS

- 1996 was a year of infrastructural consolidation that built on two important recent developments -- (1) the 1995 broadening of the Memorandum of Agreement (MOA) between the National Oceanic and Atmospheric Administration (NOAA) and the University of Oklahoma to add the participation and sponsorship of NOAA's National Weather Service to the long standing involvement of the NOAA Environmental Research Laboratories; and (2) the adoption of a new CIMMS Five-Year Plan for 1996-2001 that is accordingly providing for interactions and collaborations with, and funding from, the National Weather Service units on the OU campus (Forecast Office, WSR-88D Operational Support Facility, Storm Prediction Center), as well as the traditional counterpart involvement with the National Severe Storms Laboratory of NOAA's Environmental Research Laboratories. The Bylaws that accompany the new MOA were finalized and approved (by the CIMMS Council) during 1996.

- The research themes being pursued have accordingly also been significantly enhanced, and now include basic convective and mesoscale research, forecast improvements, the climatic effects of/controls on mesoscale processes, the socioeconomic effects of mesoscale weather systems and regional-scale climate variations, and Doppler weather radar research, development, and training.

- This broadening was reflected in the increased involvement of CIMMS scientists, engineers, and support personnel in the programs of the National Severe Storms Laboratory (NSSL, 68 individuals, who now outnumber the Laboratory's 52 federal employees), WSR-88D Operational Support Facility (12), and Storm Prediction Center (2). This level of activity constitutes a ten-fold increase from five years ago, and the infrastructural challenges that have resulted are now being successfully addressed.

PROGRAM REVIEWS

- On November 7, CIMMS programs were subject to a mini-review (with the theme "CIMMS in Transition") by the Director of NOAA's Environmental Research Laboratories. The outcome was highly favorable.

- During June 11-12, an external Site Advisory Committee conducted a further review of the CIMMS “Site Scientist” program for the Southern Great Plains component of the U.S. Department of Energy’s Atmospheric Radiation Measurement (ARM) Program. This CIMMS program, which commenced in 1992, had previously been renewed for 1995-1998. The review focused on the Site Scientist Research Program and the interactions of the Site Scientist Team with the Site Program and Operations Managers. The preliminary report of the review panel was strongly supportive of the CIMMS activities to date, and also offered

constructive suggestions for the further enhancement of our programs and their adjustment to the evolving nature of the total ARM Program.

INTERNATIONAL ACTIVITIES

- The following activities occurred under a Memorandum of Agreement between CIMMS and the Moroccan Direction de la Météorologie Nationale (DMN) -- two DMN engineers were at CIMMS for most of the year performing research into the causes and predictability of Moroccan growing season precipitation; the CIMMS Director visited Morocco in July and November to update a range of Moroccan Government officials on the status of this project and to give an invited presentation based on it to the "Second International Conference to the African Meteorological Society"; in July. a series of lectures were given at DMN on "Nowcasting, Flash Flooding, and Radar Meteorology", by OU Regents' Professor of Meteorology Kenneth C. Crawford; CIMMS and DMN began issuing a series of "Experimental Precipitation Predictions for Morocco for 1996-97", which were correct for the core of the rainy season; a draft proposal entitled "The Development of an Improved Hydrometeorological Nowcasting Service for DMN" was prepared by Professor Crawford and submitted to the DMN Director.

- As part of developing, funded collaborations with Japanese private and public sector organizations, the CIMMS Director visited Japan during March 11-15. He gave seminars at Kyoto University (Disaster Prevention Research Institute), the Japan Marine Science and Technology Center, Weathernews International, Hitachi Ltd., and Tokyo University (Ocean Research Institute). In return, CIMMS hosted visits from representatives of most of those organizations. CIMMS played a major role in arranging Hitachi Ltd.'s gift of a SR2201 Parallel Processor to OU. The *Proceedings from the UJST Workshop on the Technology of Disaster Prevention Against Severe Local Storms* were published after compilation by the CIMMS Director and a CIMMS Director Emeritus. This important workshop was co-hosted by CIMMS in late 1994 as part of the U.S.-Japan Science and Technology Agreement, and had the goal of establishing the joint research agenda of the two countries for the next decade. In addition, substantial planning was undertaken concerning a potential CIMMS initiative to be pursued within the new "Towards Understanding and Prediction of Global Change Program" of the Japan Science and Technology Agency.

- CIMMS cosponsored the Joint US-Korea Workshop on Storm- and Mesoscale Analysis and Prediction held at OU during February 5-8, the purpose of which was to facilitate collaboration between the two countries on this topic.

- In addition to the above collaborations, CIMMS Scientists are actively working with counterparts at Ben-Gurion University (Israel), the Instituto per lo studio delle Metodologie Geofisiche Ambientali (IMGA, Italy), the National Climate Center and Institute of Atmospheric Physics (P. R. China), the Institute of Atmospheric Physics (Russia), the Queensland Department of Primary Industry (Australia), and the African Center of Meteorological Applications for Development (ACMAD, Niger).

INTERNATIONAL AND NATIONAL FIELD PROGRAM LEADERSHIP

- As part of our ARM "Site Scientist" role, CIMMS Scientists continue to provide vital day-to-day scientific guidance for the development and continuous operation of the Southern Great Plains ARM Site. This is the World's first comprehensive climate observatory, and now generates ~250 continuous data streams from 30 locations spread over 55,000 square miles in southern Kansas and northern and central Oklahoma. Beginning in February, the Site Scientist Team assumed increased responsibility with respect to the quality assurance of the above data streams. The Site Scientist Team also played a strong role in the planning, execution, and initial analysis phases of the first of three "Water Vapor Intensive Observing Periods" (September 10-30, 1996).

- CIMMS Fellows and Scientists continued to analyze data collected during the 1994-95 Verification of the Origin of Rotation in Tornadoes EXperiment (VORTEX) across the Southern Great Plains, for which they had also designed and built several special, mobile, observing systems. Unique tornado measurements made by those observing systems were presented in a *Science* paper that attracted considerable attention in the popular press *(Time, New York Times)*. VORTEX is yielding important new information about tornado genesis that will likely be translated into improved forecast skill for this devastating phenomenon.

- A CIMMS Scientist continued installing instrumentation that will contribute to the routine monitoring of soil water and temperature across the Southern Great Plains. When completed in 1997, the ~70-station network will be the world-leader for the regional-scale monitoring of these important environmental parameters. This effort is part of the World Climate Programme's Global Energy and Water Cycle EXperiment (GEWEX), as well as the aforementioned international ARM Program of the U.S. Department of Energy, and is being undertaken in collaboration with the Oklahoma Mesonet.

- In collaboration with NSSL and the OU School of Meteorology, CIMMS established the Joint Meteorological Observing Facility (JMRF) that is coordinating the development and deployment of the observing capabilities of those units. This facility is expected to increase the efficiency of field programs at the national and international levels, and ultimately be reflected in improved forecast skill for severe weather.

SCIENTIFIC INNOVATION AND ACTIVITY

- The traditional core emphasis of CIMMS on mesoscale and convective weather systems has been further developed through the following "cutting edge" activities -- continued involvement in the above analyses of VORTEX data and associated refinement of tornadogenesis hypotheses; the further development and deployment (including during the landfall of Hurricane Fran) of unique mobile observing systems (Doppler radars, automated weather stations, balloon soundings) that were originally developed for VORTEX and earlier field programs; theoretical advances concerning the treatment of pronounced physical discontinuities in storm simulations; the development and technology transfer of algorithms for severe weather detection by the nationwide WSR-88D radar system; the completion of a graduate-level text on *The Electrical Nature of Storms* to be published by Oxford University

Press in 1997; completion of the first comparative study of the electrical structure of air mass storms, supercell storms, and the convective regions of mesoscale convective systems, which revealed surprising consistency; and development of an experimental Warning Decision Support System that was tested in National Weather Service Offices around the country and then used as a major component of the weather program for the 1996 Olympics in Atlanta.

- The following newer areas of CIMMS activity continued to be vigorously developed -- quantification of socioeconomic effects of mesoscale weather systems and regional-scale climate variations; development and application of multivariate spatial statistics to weather and climate problems; fine-resolution modeling of microphysical and radiative processes within clouds; regional-scale climatic controls on/effects of mesoscale weather systems; and observational and modeling investigations of regional climate variability. In addition, Doppler radar research and development efforts were initiated in 1996. Most of these activities are not only pioneering with respect to the history of meteorological research on the OU Campus, but are at the national and international forefront.

- During 1996, the external funding for CIMMS totaled $3+ million, and supported research that was reported in 21 refereed journal articles, approximately 40 papers that appeared in conference *Proceedings*, and many further articles that were accepted for 1997 publication in refereed journals. In addition, CIMMS compiled and published the *Proceedings from the UJST Workshop on the Technology of Disaster Prevention Against Local Severe Storms* (November 28-December 2, 1994).

- During 1996, CIMMS Scientists and Fellows presented invited papers at international meetings in Casablanca (Morocco) and Trieste (Italy), and gave contributed papers at the above meetings and at others in Clermont-Ferrand (France), Zurich (Switzerland), and Osaka (Japan), and in several U.S. locations.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES (CIMMS)
UNIT ACCOMPLISHMENTS -- CALENDAR YEAR 1997

INFRASTRUCTURAL ACCOMPLISHMENTS

- The high level of CIMMS scientific activity during 1997 was facilitated by the infrastructural consolidation of 1996, and especially involved increased research and development within the National Oceanic and Atmospheric Administration (NOAA) units participating in CIMMS. In particular, much research and development took place within the research themes of Doppler Weather Radar Research and Development (newly added in 1995) and Basic Convective and Mesoscale Research. This research involved collaborations between CIMMS and federal employees at the Environmental Research Laboratories' National Severe Storms Laboratory (NSSL) and the three National Weather Service (NWS) units on the University of Oklahoma (OU) campus (Weather Forecast Office; WSR-88D Operational Support Facility, OSF; and Storm Prediction Center, SPC).

- The broadening of the CIMMS MOA in 1995 has continued to be reflected in the increased involvement of CIMMS scientists, engineers, and support personnel in the programs of the NSSL (86 individuals, who now substantially outnumber the Laboratory's 52 federal employees), WSR-88D OSF (11), and SPC (3). This level of activity constitutes a ten-fold increase from five years ago, and the infrastructural challenges that have resulted are now being successfully addressed.

PROGRAM REVIEWS

- On October 21, CIMMS programs were subject to a full review by the Director and Deputy Director of NOAA's Environmental Research Laboratories, the Manager of NOAA's Joint Institute Program, and the Chief Scientist of the National Weather Service's Office of Meteorology. Two additional non-NOAA reviewers were also included in the Review Team -- Dr. Eugene M. Rasmusson, Senior Research Associate in the Department of Meteorology at the University of Maryland; and Dr. Mitchell W. Moncrieff, Senior Scientist at the National Center for Atmospheric Research (NCAR) and co-leader of NCAR's Clouds and Climate Program. The outcome of the review was highly favorable, both programmatically and scientifically.

INTERNATIONAL ACTIVITIES

- The following activities occurred under a Memorandum of Agreement between CIMMS and the Moroccan Direction de la Météorologie Nationale (DMN) -- one DMN meteorological engineer was at CIMMS during the month of April to participate (because of the permission of the NWS Director) in the final OSF Doppler Radar Training Course; another DMN meteorological engineer was at CIMMS for the second half of the year, performing further research into the causes and predictability of Moroccan growing season precipitation (Al Moubarak Project); the CIMMS Director visited Morocco in July to update a range of Moroccan Government officials on the status of the Al Moubarak Project; in September, the

CIMMS Director and OU Regents' Professor of Meteorology Kenneth C. Crawford submitted proposals to DMN for the continuation of the Al Moubarak Project and initiation of a new Nowcasting Project, respectively; on November 1, CIMMS and DMN issued an "Experimental Precipitation Prediction for Morocco for 1997-98", most of which has verified well thus far.

- CIMMS continued to play the lead role at OU during 1997 concerning the Hitachi SR2201 Massively Parallel Processor that was donated by Hitachi Ltd. in 1996. The progress of several research projects in the areas of meteorology and geophysics has been greatly accelerated by use of this compact but powerful machine. Once additional peripherals are added to the SR2201, the machine will be more widely used within science and engineering at OU.

- CIMMS' activities in Subsaharan Africa expanded further during 1997. The CIMMS Director visited the African Center of Meteorological Applications for Development (ACMAD, Niamey, Niger) in July, as an Invited Lecturer for its "First Regional Training Course on Practical Applications of Seasonal-to-Interannual Climate Predictions for Decision-Making in Agriculture and Water Resources Management in Africa". While at ACMAD, he and the ACMAD Director-General prepared a proposal for CIMMS-ACMAD collaboration within the "ACMAD Core Demonstration Project in Climate Prediction". The International Activities Office of the U.S. National Weather Service has now funded this proposal. The CIMMS Director also participated in International Workshops in Subsaharan Africa on "Weather and Climate-Based Technologies to Benefit Water Resources Management" (Pretoria, South Africa, April) and "Climate Variability, Prediction, Water Resources and Agricultural Productivity: Food Security Issues in Subsaharan Africa" (Cotonou, Bénin, July). A Visiting Research Associate from the Drought Monitoring Center/Kenya Meteorological Department was in residence at CIMMS for all of 1997, performing research into the predictability of the East African rainy seasons.

- In addition to the above collaborations, CIMMS Scientists are actively working with counterparts at Ben-Gurion University (Israel), the Instituto per lo studio delle Metodologie Geofisiche Ambientali (IMGA, Italy), the National Climate Center and Institute of Atmospheric Physics (P. R. China), the Institute of Atmospheric Physics (Russia), the Queensland Department of Primary Industry (Australia), the Australian Bureau of Meteorology Research Centre, and the Canadian Atmospheric Environmental Service.

NATIONAL FIELD PROGRAM LEADERSHIP

- As part of our Atmospheric Radiation Measurement (ARM) Site Scientist role, CIMMS Scientists continue to provide vital day-to-day scientific guidance for the development and continuous operation of the Southern Great Plains ARM Site. This is the World's first comprehensive climate observatory, and now generates ~250 continuous data streams from 30 locations spread over 55,000 square miles in southern Kansas and northern and central Oklahoma. During 1997, the Site Scientist Team assumed increased responsibilities with respect to the quality assurance of the above data streams, and in the planning, execution, and

initial analysis phases of several Intensive Observing Periods (IOPs). The most notable of these IOPs was a fall 1997 field program that featured experiments in the areas of atmospheric aerosols, cloud physics, water vapor, and shortwave radiation. CIMMS staff were instrumental in the success of this large IOP.

- CIMMS Fellows and Scientists continued to analyze data collected during the 1994-95 Verification of the Origin of Rotation in Tornadoes EXperiment (VORTEX) across the Southern Great Plains, for which they had also designed and built several special, mobile, observing systems. Dr. Erik Rasmussen, a CIMMS Research Scientist, was bestowed the Presidential Early Career Award for Scientists and Engineers in 1997 for his pioneering work in VORTEX. VORTEX case studies continue to yield important new information about tornadogenesis that has been reported in 10 formal publications in scientific journals so far, and is being further documented in a similar number of additional papers that are in various stages of preparation. This work will also be translated into improved forecast skill for this devastating phenomenon. A number of CIMMS staff were involved in a follow-up field program in May-June 1997 called Sub-VORTEX, which sought to fill unmet observational needs left by VORTEX.

- CIMMS scientists completed installation of instrumentation that is now contributing to the routine monitoring of soil water and temperature across the Southern Great Plains. The approximately 80-station network will be the world-leader for the regional-scale monitoring of these important environmental parameters. This effort is part of the World Climate Programme's Global Energy and Water Cycle EXperiment (GEWEX), as well as the aforementioned international ARM Program of the U.S. Department of Energy, and is being undertaken in collaboration with the Oklahoma Mesonet. This network was an essential part of a U.S. Department of Agriculture/NASA field program (Southern Great Plains '97), conducted during the summer of 1997, to establish that retrieval algorithms for surface soil moisture developed at higher spatial resolution using surface- and aircraft-based sensors can be extended to the coarser resolutions expected from satellite platforms. CIMMS and NSSL scientists participated in this experiment, including through the deployment of a tethersonde to profile boundary layer properties.

- In collaboration with NSSL and the OU School of Meteorology, CIMMS successfully administered the operations of the Joint Mobile Research Facility (JMRF) during its first year of existence in 1997. The JMRF coordinates the development and deployment of the mobile observing capabilities of those units, including the mobile Doppler radars. This facility is expected to increase the efficiency of field programs at the national and international levels, which will ultimately be reflected in improved forecast skill for severe weather.

- CIMMS scientists were also involved in the CASES (Cooperative Atmosphere-Surface Exchange Study) field program in May-June 1997 in south central Kansas. The goal of this program was to examine the performance of a polarimetric algorithm for rainfall estimation using the NCAR S-POL dual-polarization radar.

- CIMMS staff at NSSL and OSF have been instrumental in the installation of RIDDS (Radar Ingest and Data Distribution System) at NWS WSR-88D installations across the country.

RIDDS is a Sun SPARC5 workstation that connects to a WSR-88D to provide external research facilities, forecast offices, and certain government agencies with a real-time link to weather radar data. This has permitted the deployment of NSSL's WDSS (Warning Decision Support System) at weather forecast offices to help field meteorologists analyze severe weather events and give timely warnings. It has also facilitated the development of a new airport terminal weather center in conjunction with the Federal Aviation Authority's Lincoln Laboratories, along with the development of SCAN (System for Convective Analysis and Nowcasting) with NCAR.

SCIENTIFIC INNOVATION AND ACTIVITY

- A graduate-level text on *The Electrical Nature of Storms* was completed in late 1997 (for publication by Oxford University Press in early 1998) by CIMMS Resident Fellow Dr. Donald R. MacGorman and CIMMS Fellow Dr. W. David Rust; high recognition of pioneering work on the use of polarimetric radar data to improve rainfall estimation was given to CIMMS Research Scientist Dr. Alexander Ryzhkov and CIMMS Fellow Dr. Dusan Zrnic by the World Meteorological Organization (Vilho Vaisala Award); and CIMMS Fellow Dr. David Stensrud received word in late 1997 that he was to receive the American Meteorological Society's Clarence Leroy Meisinger Award in January 1998, for his innovative research into the structure, dynamics, and predictability of mesoscale convective systems and their impact on larger scales.

- The following areas of CIMMS research activity were particularly prominent during 1997 -- development and implementation of a three-dimensional Monte Carlo model within the CIMMS three-dimensional Large Eddy Simulation XMP model to study radiative transfer in inhomogeneous cloud media; development of generalized adjoint formulations to deal with various complex situations in numerical prediction models; development and evaluation of a shallow convection parameterization for mesoscale meteorological models; improvement of quantitative precipitation forecasting for the 1-2 day forecast period; scientific training of NWS staff on new techniques for winter weather prediction; development of a detection algorithm for bounded weak echo regions and its testing as part of NSSL's Warning Decision Support System (WDSS); investigation of the relationships between tropical Pacific sea surface temperature anomaly events and regional climate patterns; examination of the climatic importance of low-level jets over the Southern Great Plains and a mid-tropospheric jet over West Africa; research on and deployment of state-of-the-art devices for the *in situ* measurement of water vapor; investigation of the occurrence of freezing temperatures in the southeastern U.S. and their relationship with insurance claims and losses due to pipe bursting; documentation of the evolution of the El Niño of 1997-1998 and its possible effects on the property insurance industry, the results of which were published in an insurance industry White Paper and explained to 80 of its top executives from across the nation in a day-long Workshop in Washington, DC; development of a number of severe storm detection algorithms for the WSR-88D radar, including those for storm-scale vortices, tornadoes, hail, and damaging downbursts; and the integration of such severe storm detection algorithms into the daily forecasting regimen of the NWS and the Federal Aviation Administration.

- During 1997, the external funding for CIMMS totaled $4+ million, and supported research that was reported in nearly 50 refereed journal articles (published or accepted for publication) and many further articles that appeared in conference and workshop *Proceedings*.

- During 1997, CIMMS Scientists and Fellows presented invited papers and lectures at international and national meetings in Copenhagen (Denmark), Niamey (Niger), Cotonou (Bénin), and Washington, DC (several), and gave contributed papers at meetings in a number of U.S. cities.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES (CIMMS)
UNIT ACCOMPLISHMENTS -- CALENDAR YEAR 1998

INFRASTRUCTURAL ACCOMPLISHMENTS

- During 1998, CIMMS played a national leadership role for the NOAA Joint Institutes (JIs). This resulted from the CIMMS Director being Chair of the JI Directors for 1998-99, and involved CIMMS hosting a JI Administrators' Meeting (April) and planning two JI Directors' Meetings scheduled for January and April 1999. These activities enhanced CIMMS' familiarity with NOAA's Office of Oceanic and Atmospheric Research and the ten other JIs that extend across the U.S., including in Hawaii and Alaska.

- The high level of CIMMS scientific activity during 1998 continued to involve increased research and development within the National Oceanic and Atmospheric Administration (NOAA) units participating in CIMMS. In particular, much research and development took place within the research themes of (1) Doppler Weather Radar Research and Development and (2) Basic Convective and Mesoscale Research. This research involved collaborations between CIMMS and federal employees at the Environmental Research Laboratories' National Severe Storms Laboratory (NSSL) and the three National Weather Service (NWS) units on the University of Oklahoma (OU) campus (Weather Forecast Office, WFO; WSR-88D Operational Support Facility, OSF; and Storm Prediction Center, SPC).

- Consistent with the above, there has been continued growth in the involvement of CIMMS scientists, engineers, and support personnel in the programs of the NSSL (88 individuals, who now substantially outnumber the Laboratory's 52 federal employees), WSR-88D OSF (10), and SPC (3). This level of activity constitutes a ten-fold increase over five years ago. The resulting infrastructural challenges are being successfully addressed, including through a January 1999 Workshop that was planned in late 1998.

INTERNATIONAL ACTIVITIES

- A high level of collaboration and cooperation occurred between CIMMS and the African Centre of Meteorological Applications for Development (ACMAD, Niamey, Niger) during 1998. These activities are funded by an ongoing grant from the International Activities Office of the U.S. National Weather Service. The 1998 interactions included the following -- extended (4-8 week) visits to CIMMS by two African meteorologists (Professor J. Bayo Omotosho, Federal University of Akure, Nigeria; Mr. Yaya Berte, National Meteorological Service, Ivory Coast); a brief visit to CIMMS by the ACMAD Director (Mr. Mohamed Boulahya); a 9-week visit to ACMAD by a CIMMS graduate student (Mr. Michael A. Bell), where he collaborated with Professor Omotosho; continued full-time research at CIMMS on East African rainfall variability and predictability by Mr. Charles Mutai (Kenya Meteorological Department/Drought Monitoring Centre-Nairobi) for a University of Nairobi Ph.D. Dissertation; a 4-week visit by Mr. Mutai to Kenya and ACMAD during September for consultations and data acquisition concerning his Ph.D. research, and to present results from that research at ACMAD and two meetings in Mombasa (Climate Outlook Forum for Eastern

Africa Short Rainy Season; Fourth Kenya Meteorological Society Workshop); and the visit of the CIMMS Director to the Economic Commission for Africa (Addis Ababa, Ethiopia) to give the lead scientific address to a "Conference on Climate as a Resource for Development" and to participate as a Partner Observer in the "Ninth Session of ACMAD Board of Governors"

- CIMMS scientists participated in several Regional Climate Outlook Forums in West Africa, East Africa, and Southern Africa, and a Training Workshop at ACMAD prior to the West African Forum. This Workshop led to national meteorological services from that region developing seasonal prediction schemes for their countries, using tropical Atlantic and Pacific sea surface temperature predictors. CIMMS scientists also undertook collaborative work with the Drought Monitoring Center-Harare, to develop the first system for verifying the forecast maps from the Regional Climate Outlook Forums. Further, as part of the World Bank funded "Environmental Management Project" in Malawi, CIMMS Senior Scientist M. Neil Ward made two visits to the Malawi Meteorological Service. Reports were written to assist the development of climate information and prediction services for the private and public sectors in that country, including recommendations on the technical infrastructure and training required.

- Collaboration between CIMMS and the Kingdom of Morocco continued to investigate the climate system causation of the interannual-to-decadal variability of Moroccan winter precipitation, and to use the resulting knowledge to develop a seasonal prediction capability. One Meteorological Engineer from the Moroccan Direction de la Météorologie Nationale (DMN) was in residence at CIMMS for most of 1998. The principal DMN-CIMMS collaborative activities were -- the development and issuance of "Experimental Precipitation Predictions for Morocco" for 1997-98 and 1998-99, both of which verified extremely well; the finalizing of a book chapter and scientific paper that summarize the results obtained to date; preparations for the continuation of the project, and associated transfer of the funding responsibility from USAID to the Moroccan government; and presentation of an overview paper on the project to the "ABIDJAN'98: International Conference on Water Resources Variability in Africa during the XXth Century" (Abidjan, Ivory Coast, November 16-19).

- In addition to the above collaborations, CIMMS Scientists are actively working with counterparts at Ben-Gurion University (Israel), the Instituto per lo studio delle Metodologie Geofisiche Ambientali (IMGA, Italy), the National Climate Center and Institute of Atmospheric Physics (P. R. China), the Institute of Atmospheric Physics (Russia), the Queensland Department of Primary Industry (Australia), the Australian Bureau of Meteorology Research Centre, and the Canadian Atmospheric Environmental Service.

NATIONAL FIELD PROGRAM LEADERSHIP

- As part of our Atmospheric Radiation Measurement (ARM) Site Scientist role, CIMMS scientists continue to provide vital day-to-day scientific guidance for the development and continuous operation of the Southern Great Plains ARM Site. This is the World's first comprehensive climate observatory, and now generates ~300 continuous data streams from

30 locations spread over 50,000 square miles in southern Kansas and northern and central Oklahoma. During 1998, the Site Scientist Team continued its increased responsibilities with respect to the quality assurance of the above data streams, and in the planning, execution, and initial analysis phases of several Intensive Observing Periods (IOPs). These activities were facilitated by a new CIMMS Scientist (Chad Bahrmann) being permanently located at the ARM Site's Central Facility (CF) in north central Oklahoma, where he provides daily scientific guidance for the Site Operations staff. The most notable of the 1998 IOPs was a summer field program that featured experiments in the area of shortwave radiation. CIMMS staff were instrumental in the day-to-day success of this IOP.

- CIMMS scientists also played leadership roles in two major innovations at the ARM CF. First, they installed chilled mirror dewpoint hygrometers to provide NIST traceable moisture measurement capabilities. These sensors act as calibration standards for other moisture measurements at the CF and provide a high level of confidence and accuracy. During 1998, CIMMS scientists also provided one of these systems to the University of Wisconsin for use in CAMES-III (Andros Island). Second, CIMMS scientists spearheaded the establishment of a NIST traceable temperature and relative humidity chamber at the ARM CF. This chamber will raise the quality of ARM measurements, including by establishing the absolute accuracy of the Vaisala radiosondes used by ARM and other agencies.

- In collaboration with NSSL and the OU School of Meteorology, CIMMS successfully administered the operations of the Joint Mobile Research Facility (JMRF) during its second year of existence in 1998. The JMRF coordinates the development and deployment of the mobile observing capabilities of those units. This facility is expected to increase the efficiency of field programs at the national and international levels, which will ultimately be reflected in improved forecast skill for severe weather.

- CIMMS scientists participated in the planning and implementation (including forecasting) of the pioneering MCS Electrification and Polarimetric Radar Study (MEaPRS), conducted in central Oklahoma from May 15 through June 15, 1998, and in a subsequent small adjunct field program. The two primary objectives of MEaPRS were (1) to investigate mesoscale convective system (MCS) electrification processes, and (2) improve understanding of polarimetric radar measurements. In the MCS electrification component, investigators participated in the mobile ballooning of instruments to record lightning field changes, particle charge, and X-rays. Electric field profiles and airborne radar data were obtained in two mesoscale convective systems. Electric field profiles and multiparameter radar data were also obtained in several isolated severe thunderstorms. These storms and storm systems included several in which the majority of ground flashes lowered positive charge, instead of the more usual negative charge. Acquiring data on such storms addressed the goals of a NSF grant to CIMMS. In some of the storms, the three-dimensional location of cloud flashes and ground flashes were mapped by a system developed by the New Mexico Institute of Mining and Technology and operated by them in cooperation with NSSL during the field program. These storms will be the subject of considerable research by CIMMS scientists and graduate research assistants during the next few years.

- In the polarization radar component of MEaPRS, emphasis was placed on collecting high quality microphysical data with which to compare polarimetric measurements made by the NSSL Cimarron radar. NOAA P-3 flights were conducted in seven mesoscale precipitation systems to document the microphysical structure of several MCS stratiform clouds. Complementary data sets were also collected using airborne Doppler radar and ground-based polarimetric radar. Over a three-month period that encompassed MEaPRS, a 2D-video-disdrometer (leased from Joanneum Research of Graz, Austria) collected data that documented drop size distributions. Disdrometer data were collected for ten distinct precipitation events. These included both convective and stratiform precipitation and at least one event that contained large hail. These data were collected approximately 41 km from the Cimarron radar. Initial analyses of these data indicate that polarimetric radar-derived rainfall is likely more dependent on drop size distribution than drop shape. CIMMS scientists also documented the performance of the NCEP Eta model during MEaPRS.

- The SubVORTEX-RFD (Rear Flank Downdraft) field program (May-June 1998), which included CIMMS scientists, collected excellent data on eight nontornadic supercells. The primary goal of this field program was to collect data on the RFD and determine the role that it, inflow, and near-ground circulation and divergence play in both tornadogenesis success and failure (i.e., production of tornadic and nontornadic supercells). Data analysis will include comparison with tornadic supercell data obtained during VORTEX.

- CIMMS scientists were involved in the CALJET experiment from January 15-March 30, 1998, conducted from a base in Monterey, California. They included staff operating the radar onboard the NOAA P-3 aircraft. The experiment investigated landfalling low-level jets that strike the western coast of the United States, including using dropwindsonde launches that enhanced forecast model performance significantly during the then ongoing El Niño event.

SCIENTIFIC HONORS, INNOVATION, AND ACTIVITY

- CIMMS Fellow Dr. David Stensrud received the American Meteorological Society's Clarence Leroy Meisinger Award for 1998 in recognition of his innovative research into the structure, dynamics, and predictability of mesoscale convective systems and their impact on larger scales; a graduate level text *on The Electrical Nature of Storms* (Oxford University Press) was published by CIMMS Resident Fellow Dr. Donald R. MacGorman and CIMMS Fellow Dr. W. David Rust; CIMMS Senior Scientist Dr. Erik N. Rasmussen was honored with a 1998 Presidential Early Career Award for Scientists and Engineers for his planning and direction of the VORTEX Program; CIMMS Fellow Michael D. Eilts received both the NOAA Administrator's Award and a FAA Special Recognition Award in 1998 for his contributions to the operational use of the WSR-88D radar system; and CIMMS Fellow Dr. Richard J. Doviak was elected a Fellow of the American Meteorological Society.

- In addition to the research already mentioned above, the following areas of CIMMS research activity were particularly prominent during 1998:

- Use of a Monte-Carlo radiative transfer model linked with the CIMMS Large Eddy Simulation (LES) Explicit Microphysics Model to investigate radiative transfer in heterogeneous cloud media, especially the role of vertical inhomogeneity in determining the extinction coefficient, asymmetry parameter, and scattering functions;

- Development of new methods to estimate the surface fluxes of latent and sensible heat from standard energy balance and surface mesonet systems, that overcame the major limitations of the conventional Bowen Ratio and Profile Methods;

- Derivation of a set of nonlinear perturbation equations to investigate the balanced and unbalanced dynamics of fronts and frontal circulations, the numerical solution of which revealed how unbalanced perturbations were generated by fronts;

- Incorporation and testing of parameterizations of electrical processes into the OU Advanced Regional Prediction System (ARPS) model, so that simulations of electrification can be performed using that model;

- Development, testing, and implementation of stratiform cloud physics parameterizations into the ARPS and the U.S. Navy Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS);

- Collaborative development (with NCAR and Penn State) of a mass-flux-based parameterization of shallow non-precipitating convective clouds that captures their complete life cycle, and its full integration into the NCAR/Penn State MM5 model where it is compatible with existing parameterizations of deep penetrating convection and non-convective precipitation processes as well as being designed to drive sophisticated air chemistry models;

- Assessment of the utility of tornado vortex signatures (TVS) observed by the WSR-88D radars for very short-term tornado detection, which was found to depend on the mode of tornadogenesis (e.g., that within convective lines tends to be associated with non-descending TVSs) and the deleterious effects of radar sampling on TVS representativeness;

- Confirmation that the NWS transition from on-site to distance-learning systems for training has not degraded forecast and warning skills, through a collaborative investigation with the OU College of Continuing Education;

- Implementation and operation of NCEP's Eta and Regional Spectral Models in a research mode, including experimentation with the Kain-Fritsch convective parameterization in the Eta model that improved its resolution of mesoscale systems;

- Development and testing of parameterizations of cloud drop effective radius for use in NWP and GCM models;

- Definitive documentation of the effects of tropical Pacific sea surface temperature anomalies on North American precipitation east of the Rocky Mountains, using historical data since 1950;

- Completion of a cloud and (using a semi-physical model) solar radiation climatology for the U.S. Great Plains for 1950-92, which identified the most important variability on a range of space- and time-scales;

- Further application of phase-coding methods to simulated weather signals to identify the most appropriate scheme for the mitigation of radar range and velocity ambiguities, with the goal of implementation on the WSR-88D; and

- Use of a large set of daily raingauge data to document the weather system changes (decreased size and intensity) that have produced the multi-decadal rainfall decrease in Sahelian West Africa since the early 1950s.

- During 1998, the external funding for CIMMS totaled more than $6 million and supported research that was reported in more than 50 refereed journal articles (published or accepted for publication) and many further articles that appeared in conference and workshop *Proceedings*.

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES (CIMMS)
UNIT ACCOMPLISHMENTS -- CALENDAR YEAR 1999

INFRASTRUCTURAL ACCOMPLISHMENTS

- During 1999, CIMMS continued to play a national leadership role for the NOAA Joint Institutes (JIs). This resulted from the CIMMS Director being Chair of the JI Directors during 1998-99, and involved planning and conducting two JI Directors' Meetings that took place in January and April 1999. These activities enhanced CIMMS' familiarity with NOAA's Office of Oceanic and Atmospheric Research (OAR) and the ten other JIs that extend across the U.S., including in Hawaii and Alaska.

- The high level of CIMMS scientific activity during 1999 continued to involve increased research and development within the National Oceanic and Atmospheric Administration (NOAA) units participating in CIMMS. In particular, much research and development took place within the research themes of (1) Forecast Improvements and (2) Doppler Weather Radar Research and Development. This research involved collaborations between CIMMS and federal employees at the OAR National Severe Storms Laboratory (NSSL) and the three National Weather Service (NWS) units on the University of Oklahoma (OU) campus (Weather Forecast Office, WFO; WSR-88D Operational Support Facility, OSF; and Storm Prediction Center, SPC).

- Consistent with the above, 1999 saw a continuation of the recently increased involvement of CIMMS scientists, engineers, and support personnel in the programs of the NSSL (93 individuals, who now substantially outnumber the Laboratory's 52 federal employees), WSR-88D OSF (12), and SPC (3). This level of activity constitutes a ten-fold increase over five years ago. The resulting infrastructural challenges are being successfully addressed, including through a day-long "NOAA-OU Directors' and Administrators' Workshop" that was held in January at the Oklahoma Memorial Union.

INTERNATIONAL ACTIVITIES

- Probably the most important international activity undertaken by CIMMS in 1999 was the staging of the "First Workshop on Regional Climate Prediction and Applications -- Tropical Atlantic Basin" at the OU College for Continuing Education during October 11-November 12. The Workshop goal was to improve the capabilities of national meteorological and hydrological services (NMHSs) around the Tropical Atlantic to understand global climate system behavior, to use such knowledge to develop seasonal precipitation prediction schemes, and to collaborate with other national agencies to apply such prediction schemes in the management of agricultural production, water resources, energy generation, and public health. This first Workshop had 12 NMHS participants, equally divided between Latin America (representing 4 nations) and Africa (6 nations). This first Workshop was judged to be very successful by its NOAA financial sponsors (NWS International Activities Office, $84,000; OAR Office of Global Programs, $30,000), which are now encouraging us to

embark on a series of about 5 more such Workshops -- that will span the developing world -- on a twice per year basis. We are now organizing the Second Workshop (also on the Tropical Atlantic Basin) for mid-2000.

- A high level of collaboration and cooperation continued between CIMMS and the African Centre of Meteorological Applications for Development (ACMAD, Niamey, Niger) during 1999. These activities are funded by an ongoing grant from the International Activities Office of the U.S. National Weather Service. The 1999 interactions included the following -- initiation of a 5-year project entitled "New Radio and Internet Technology for Communication of Weather and Climate Information to Rural Communities for Sustainable Development in Africa" (RANET), that is funded by the U.S. Agency for International Development; a 1-week visit by the CIMMS Director to ACMAD in August, which included a field trip to Benin as part of the RANET project; and continued full-time research at CIMMS on East African rainfall variability and predictability by Mr. Charles Mutai (Kenya Meteorological Department Drought Monitoring Centre-Nairobi) for a University of Nairobi Ph.D. Dissertation that will be submitted in mid-2000.

- CIMMS scientists participated in several Regional Climate Outlook Forums in West Africa, and Southern Africa, and a Training Workshop at ACMAD prior to the West African Forum. This Workshop led to national meteorological services from that region developing seasonal prediction schemes for their countries, using tropical Atlantic and Pacific sea surface temperature predictors. CIMMS scientists also collaborated with ACMAD in the preparation of a manual for the above Pre-Forum training, and with the Drought Monitoring Center-Harare to develop the first system for verifying the forecast maps from the Regional Climate Outlook Forums.

- Collaboration between CIMMS and the Kingdom of Morocco continued to investigate the climate system causation of the interannual-to-decadal variability of Moroccan winter precipitation, and to use the resulting knowledge to develop a seasonal prediction capability. One Meteorological Engineer from the Moroccan Direction de la Météorologie Nationale (DMN) was in residence at CIMMS for all of 1999 as a Ph.D. student. The principal DMN-CIMMS collaborative activities were -- development and issuance of "Experimental Precipitation Predictions for Morocco" for 1998-99 and 1999-2000, the first of which verified extremely well and the second partially so; publication of a book chapter that summarize the results obtained to date; and a 1-week visit by the CIMMS Director to DMN in May to help prepare for the continuation of the project and the associated transfer of the funding responsibility from USAID to the Moroccan government. Further information on the research component of this collaboration appears below.

- In addition to the above collaborations, CIMMS Scientists are actively working with counterparts at Ben-Gurion University (Israel), the Instituto per lo studio delle Metodologie Geofisiche Ambientali (IMGA, Italy), the National Climate Center and Institute of Atmospheric Physics (P. R. China), the Institute of Atmospheric Physics (Russia), and the Canadian Atmospheric Environmental Service.

NATIONAL FIELD PROGRAM LEADERSHIP

- As part of its Atmospheric Radiation Measurement (ARM) Program Site Scientist role, CIMMS scientists continued to provide essential day-to-day scientific guidance for the development and continuous operation of the Southern Great Plains ARM Cloud and Radiation Testbed (CART) site. This is the World's first comprehensive climate observatory, and now generates ~300 continuous data streams from 30 locations spread over 50,000 square miles in southern Kansas and northern and central Oklahoma. During 1999, the Site Scientist Team continued its increased responsibilities with respect to the quality assurance of the above data streams, and in the planning, execution, and participation of several Intensive Operational Periods (IOPs). Among the 1999 IOPs conducted were the Mesoscale Convective Systems Campaign (May-September), the Southern Great Plains '99 Soil Moisture Campaign (July), and the International Pyrgeometer Intercomparison (September).

- Planning for the Intermountain Precipitation Experiment (IPEX) took place in 1999. The field phase of IPEX will be conducted in February 2000 in northern Utah. 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 is led by a CIMMS scientist at NSSL, and involves scientists from the University of Utah, the Desert Research Institute (DRI) of the University of Nevada-Reno, and the NWS Forecast Office in Salt Lake City. Students from the Universities of Utah, Nevada and Oklahoma will also participate. The major scientific objectives of IPEX are to: (1) advance fundamental knowledge of orographic precipitation, with an emphasis on the narrow, steeply sloped Wasatch Mountains of northern Utah; (2) improve knowledge of lake-effect precipitation of the Great Salt Lake; (3) validate and improve high-resolution data-assimilation systems, mesoscale model performance, and quantitative-precipitation forecasts over complex terrain; and (4) validate and improve quantitative-precipitation estimates produced by WSR-88D's located at high elevation.

SCIENTIFIC HONORS, INNOVATION, AND ACTIVITY

- NSSL's Stormscale Research and Applications Division, staffed by more than 70 CIMMS employees (scientists, computer specialists, technicians) was awarded the 1999 U.S. Department of Commerce Silver Medal *"for making significant enhancements to the National Weather Service warning program through developing, testing and transferring tools from a prototype Warning Decision Support System to NWS operational systems"*.

- Three research thrusts during 1999 are highlighted here:

  "Al Moubarak" and Moroccan Precipitation. Over the last five years, there has been a strong collaborative effort between CIMMS and the Kingdom of Morocco to increase our understanding of the interannual-to-decadal variability of Moroccan winter precipitation, particularly within the context of the North Atlantic Oscillation (known as "Al Moubarak" in Morocco). This effort has also included the wider global climate system (tropical Pacific sea surface temperatures) as it relates to the late rainy season. The project was motivated by a

predominance of extremely poor Moroccan winter precipitation seasons since the late 1970s. This understanding is being used to develop a seasonal precipitation prediction capability for Morocco. The work has been done in direct collaboration with the Moroccan Direction de la Météorologie Nationale (DMN) with the financial support of the U.S. Agency for International Development, including through DMN scientists being in residence at CIMMS. During this calendar year, the development and issuance to Moroccan government officials of "Experimental Precipitation Predictions for Morocco" continued, with the prediction for 1998-99 verifying extremely well. Also, a book chapter, "Climate Variability in Northern Africa: Understanding Droughts in the Sahel and the Maghreb", was published in *Beyond El Niño: Decadal and Interdecadal Climate Variability* (Antonio Navarra, ed., Springer Verlag, 1999). Among supporting sub-projects now being undertaken are the development of (1) a climatology of the intensity and paths of weather systems in the North Atlantic since 1958 and (2) an 18-year (1979-96) daily precipitation data set for Morocco.

Warning Decision Support System (WDSS). For six years, CIMMS and NSSL personnel have been developing and testing the Warning Decision Support System (WDSS). The WDSS includes enhanced Doppler-radar algorithms, data integration and imaging techniques, innovative algorithm product display capabilities, and a severe-weather warning generation system. It has been tested at 18 NWS forecast offices since 1994. Many of the concepts developed in the WDSS have received very favorable comments from the operational forecasting community. During this calendar year, CIMMS and NSSL personnel worked closely with the NWS Techniques Development Laboratory to implement WDSS functionality in the NWS Advanced Weather Interactive Processing System (AWIPS). Many of the best performing features of WDSS were implemented into AWIPS and are slated for release in 2000. The WDSS is now being enhanced to WDSS-Integrated Information (WDSS-II). The WDSS-II will support multiple data types to allow for easier inclusion of new algorithms, and will provide a new user interface for making more informed warning decisions. Version 1.0 of WDSS-II is expected to be ready for field testing during spring 2000.

Improved Quantitative Precipitation Forecasting (QPF) using Numerical Weather Prediction Models. Techniques for improving quantitative precipitation forecasting (QPF) using the NCEP Environmental Modeling Center's (EMC) Eta model have been investigated by CIMMS and NSSL scientists. An experimental configuration of the model was run in forecast mode at NSSL in parallel with the operational model at EMC, and in collaboration with EMC scientists. It was configured with the Kain-Fritsch convective parameterization and higher-order numerical diffusion than the operational model contains, both of which are designed to allow the model to produce and retain mesoscale structures. After a series of refinements, the experimental configuration of the model achieved comparable scores on traditional measures of skill for QPF, while providing higher resolution mesoscale guidance than the operational model. New verification techniques are being developed so that the accuracy of the model in producing finer-scale features can be better evaluated. Further model refinements are likely to be concentrated in the parameterizations of turbulent mixing, microphysics, and moist convection, all of which have been shown to have a significant impact on QPF. Forecasters from the Storm Prediction Center (SPC) will be involved in the identification of relevant model output fields as well as the development and implementation

of new verification techniques. Daily numerical predictions, comparisons with operational EMC models, and verification statistics have been made available on the World Wide Web.

- Finally, during 1999, the external funding for CIMMS totaled more than $7 million and supported research that was reported in more than 35 refereed journal articles (published or accepted for publication) and many other articles that appeared in conference and workshop *Proceedings*.

(B) Transfer of Research Knowledge to Operational and Field Meteorology

NSSL, in conjunction with NWS, ROC, and SPC have consistently demonstrated an ability to improve our nation's capability to forecast and warn for severe weather events by advancing the understanding of weather processes, improving forecast and warning techniques, developing new operational applications, and transferring this knowledge to the NWS and other public and private sector agencies. The severe weather research conducted provides a foundation for fulfilling NOAA's mission of providing integrated and reliable observations in support of assessing, forecasting, and warning for severe weather. These NOAA services enable the American people to make informed decisions regarding public safety, economic development, and environmental quality. CIMMS staff members assigned to these NOAA units have made significant contributions toward these efforts. The information below was compiled from sources provided by the NOAA units.

Historical accomplishments include:

- Recognizing the potential of Doppler radar to improve the detection and warning of severe weather, leading to the development of the NEXRAD program that has resulted in the nationwide WSR-88D operational network of Doppler radars. This important contribution was recently recognized by the Department of Commerce's presentation of its Gold Medal to NSSL.
- Continuing to refine and build new conceptual models of severe storms, supercell structures, and mesoscale convective complexes and systems. These conceptual models have led to improved forecasting and warnings of tornadoes, flash floods, damaging winds, hail, etc. In addition these models have led to understanding of environments conducive to the formation of thunderstorms, mesocyclones, and mesoscale convective complexes.
- Continuing to refine the use of airborne Doppler radar for the studies of both mesoscale and storm scale phenomena. Since the installation of Doppler radar on the NOAA P-3 in 1983 by the National Hurricane Research Laboratory (now part of AOML) and the National Center for Atmospheric Research, NSSL has continued to provide new insights into the structure of mesoscale systems. The laboratory obtained the first direct measurements of a tornado recorded with an airborne Doppler. New concepts of making dual Doppler measurements using the WSR-88D with the P-3 Doppler were first tested in 1989 and are now used routinely.
- Developing the first automated algorithm for the detection of mesocyclones and providing the first automated wind profiles using the Velocity Azimuth Display (VAD) technique. Both these algorithms were an important part of the first suite of algorithms used on the operational WSR-88D radars.
- Developing the first truly mobile capability for obtaining upper-air soundings of the atmosphere using the Cross-Chain Loran Atmospheric Sounding System mounted in 15-passenger vans modified to be mobile laboratories. The NSSL pioneered techniques and invented a high-wind launch device for launching helium filled balloons in very high winds. This capability allowed NSSL to take upper-air soundings in the vicinity of tornadoes, drylines, etc., obtaining critically needed observations in the near storm

environment of thunderstorms. In addition, this capability provided the first vertical profiles of electric fields inside a thunderstorm leading to new conceptual model of electrical structures within convective storms.

- Performing pioneering diagnostic and prognostic studies of seasonal-to-interannual, regional precipitation variability in central and eastern North America and Northern Hemispheric Africa that are now part of the knowledge base that NOAA and international forums draw on when preparing seasonal precipitation predictions.
- Conducted long-term multidisciplinary collaborations with agricultural economists and scientists to quantify the economic impacts of regional climate variations and help focus the development of economically beneficial seasonal-to-interannual climate prediction schemes.

More recent accomplishments include:

- NSSL has pioneered efforts in the area of using dual polarization radar to improve precipitation measurements and hail identification. One of many important findings is that differential phase measurements improve rainfall estimates when significant beam blockage occurs, for example with the 25 WSR-88D radars in the western U.S. that experience beam blocking by mountains.
- NSSL and CIMMS scientists led a large collaborative field effort called VORTEX (Verification of the Origin of Rotation in Tornadoes Experiment) that collected a rich data set containing a large number of non-tornadic supercell storms as well as several weak tornadoes, a strong tornado and four violent tornadoes. This data set will allow scientists to determine the physical processes that generate and maintain tornadoes and then allow them to dissipate.
- NSSL and CIMMS scientists have continued to improve automated algorithm detection tools for the WSR-88D that include the mesocyclone, tornadic vortex signature, storm series (identification and tracking), hail, and velocity azimuth displays. Several new versions of these algorithms have been delivered to the Radar Operations Center for implementation within the WSR-88D. NSSL is also leading an effort to change the WSR-88D from a proprietary computer platform to a UNIX based open systems platform, which will increase the flexibility and maintainability of the WSR-88D well into the next century.
- NSSL collaborated with OU (including CIMMS), the National Science Foundation and National Center for Atmospheric Research to build two new observational systems used in VORTEX. One, called the "Doppler on Wheels", is an X-band mobile Doppler radar that captured its first tornado in 1995, providing a new picture of the flows around and within a tornado. In addition, over a dozen mobile mesonets were built to obtain important environmental data in the vicinity of supercells and tornadoes. Both these observing tools have provided new data for unwrapping the mysteries of how tornadoes are formed and for eventually improving severe storm warnings.
- NSSL and CIMMS scientists have begun evaluating the ability of improved mesoscale models to simulate convective events. Slight improvements in forecast skill have already been demonstrated. NSSL, in collaboration with the National Environmental Centers for Prediction, is coordinating a pilot study to investigate mesoscale ensemble techniques in the 0-48 hour numerical weather prediction. Ensembles of the 80-km ETA model and

regional spectral model began on a weekly basis in May. Preliminary results show improvements in the quantitative precipitation forecasts over the single model runs.

- Helping establish the SPC in Norman in 1995. The SPC's mission is to provide timely and accurate forecasts and watches for severe thunderstorms and tornadoes over the contiguous United States. The SPC also monitors heavy rain, heavy snow, and fire weather events across the U.S. and issues specific products for those hazards. The SPC's very specialized mission requires meteorologists with a high level of expertise in convective storm forecasting, as well as excessive precipitation, winter weather, and conditions leading to high fire dangers. The SPC staff is also active in scientific research into severe and dangerous weather that is designed to enhance their forecasting capabilities.
- In 1988, the NEXRAD Agencies established the WSR-88D Radar Operations Center (ROC) in Norman. The nearly 130 ROC employees come from the NWS, Air Force, Navy, FAA, and support contractors, and include CIMMS personnel. The ROC provides centralized radar meteorological, computer software, maintenance, and engineering support for all WSR-88D Systems. The WSR-88D systems will be modified and enhanced during their operational life to meet changing requirements, technology advances, and improved understanding of the application of these systems to real-time operations. In addition, the ROC operates and maintains a WSR-88D system to assist in the ROC's life-cycle support and improvement responsibilities.
- The Norman NWS Forecast Office has played a key role in the modernization of the NWS. To improve forecasting skill, meteorologists at the Norman office also seek to better understand the atmosphere and to apply the latest knowledge gained by University and Government researchers. For many years, the Norman office has been leading the nation in implementing new technologies and concepts in meteorology. The office was the first to use data from the WSR-88D operationally in the spring of 1991. The Norman office was one of two offices which used a prototype AWIPS workstation, or Pre-AWIPS, designed by the NOAA Forecast Systems Laboratory (FSL) to ingest, display, and integrate many different meteorological data sets, such as satellite, gridded model data, and WSR-88D radar images. The Pre-AWIPS workstations utilized the latest thinking in meteorological data and display systems, much of it developed by scientists at FSL. The Pre-AWIPS workstations were then replaced in the Norman office in early 1998 by AWIPS workstations. AWIPS takes advantage of the rapidly-increasing power and rapidly-decreasing costs of modern UNIX workstations, brought about by technological advancements in the computing industry. The Norman office also has made software available to many NWS offices, such as SHARP (a sounding/hodograph analysis program) and PC-GRIDDS (a gridded model data display program), which allows forecasters to calculate and display many useful quantities derived from meteorological concepts such as Conditional Symmetric Instability (CSI) and Isentropic Potential Vorticity (IPV) thinking.

(C) Formal Publications -- 1996-2000

Askelson, M. A., J. P. Aubagnac, and J. M. Straka, 2000: An adaptation of the Barnes filter applied to the objective analysis of radar data. *Mon. Wea. Rev*., **128**, 3050-3082.

Atkins, N., R. Wakimoto, and C. Ziegler, 1998: Observations of the fine-scale structure of a dryline during VORTEX 95. *Mon. Wea. Rev*., **126**, 525-550.

Bahrmann, C. P., and V. K. Saxena, 1998: Influence of air mass history on black carbon concentrations and regional climate forcing in southern United States. *J. Geophys. Res.*, **103**, 23153-23161.

Bartels, D. L., J. M. Brown and E. I. Tollerud, 1996: Structure of a mid-tropospheric vortex induced by a mesoscale convective system. *Mon. Wea. Rev*., **125**, 193-211.

Bateman, M.G., K.B. Eack, W.D. Rust, and T.C. Marshall, 1999: Electrical current along balloon rigging line inside thunderstorms. *Atmos. Res*., **51**, 323-335.

Bateman, M.G., T.C. Marshall, M. Stolzenburg, and W.D. Rust, 1999: Precipitation charge and size measurements inside a New Mexico mountain thunderstorm. *J. Geophys. Res*., **104**, 9643-9653

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.

Bedient, P.B., B.C. Hoblit, D.C. Gladwell, and B.E. Vieux, 2000: NEXRAD radar for flood prediction in Houston. *ASCE J. of Hydrologic Engineering*, in press.

Blanchard, D.O., 1998: Assessing the vertical distribution of convective available potential energy. *Wea. Forecasting*, **13**, 870-877.

Blanchard, D.O., W. R. Cotton, and J.M. Brown, 1998: Mesoscale circulation growth under conditions of weak inertial instability. *Mon. Wea. Rev*., **126**, 118-140.

Bluestein, H.B. and D.R. MacGorman, 1998: Evolution of cloud-to-ground lightning characteristics and storm structure in the Spearman, Texas tornadic supercells of 31 May 1990. *Mon. Wea. Rev*., **126**, 1451-1467.

Bluestein, H.B., E. Rasmussen, R. Davies-Jones, R. Wakimoto and M.L. Weisman, 1998: VORTEX workshop summary, 2-3 December 1997, Pacific Grove, California. *Bull. Amer. Meteor. Soc*., **79**, 1397-1400.

Bond, N. A., C. F. Mass, B. F. Smull, R. A. Houze, M.-J. Yang, B.A. Colle, S. A. Braun, M.A. Shapiro, B.R. Colman, P.J. Neiman, J.E. Overland, W.D. Neff, and J.D. Doyle, 1997: The Coastal Observation and Simulation with Topography (COAST) Experiment. *Bull. Amer. Meteor. Soc*., **78**, 1941-1955.

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

Braun, S. A., R. A. Houze Jr., and B. F. Smull, 1997: Airborne dual-Doppler observations of an intense frontal system approaching the Pacific Northwest coast. *Mon. Wea. Rev*., **125**, 3131-3156.

Brock, F. V., and S. J. Richardson, 2001: *Meteorological Measurement Systems*. Oxford University Press, in press.

Brooks, H. E., and C. A. Doswell III, 1996: A comparison of measures-oriented and distributions-oriented approaches to forecast verification. *Wea. Forecasting*, **12**, 288-303.

Brooks, H. E., A. Witt, and M. D. Eilts, 1997: Verification of public weather forecasts available via the media. *Bull. Amer. Meteor. Soc*., **77**, 2167-2177.

Brooks, H.E., and D.J. Stensrud, 2000: Climatology of heavy rain events in the United States from hourly precipitation observations. *Mon. Wea. Rev*., **128**, 1194-1201.

Brotzge, J.A., C.E. Duchon, S.J. Richardson, S.E. Fredrickson, and D.L. Grimsley, 2000: Evaluation of a domeless net radiometer, *J. Atmos. Oceanic Technol*., submitted.

Brown, R.A., 1998: Nomogram for aiding the interpretation of tornadic vortex signatures measured by Doppler radar. *Wea. Forecasting*, **13**, 505-512.

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.

Burde, G., A. Zangvil, and P. J. Lamb, 1996: Estimating the role of local evaporation in precipitation for a two-dimensional region. *J. Climate*, **9**, 1328-1338.

Chau, J. L., R. J. Doviak, A. Muchinski, and C. L. Holloway, 2000: Tropospheric measurements of turbulence and characteristics of Bragg scatterers, using the Jicamarca VHF radar. *Radio Sci*., **35**, 179-193.

Chen, C.-R., and P. J. Lamb, 1997: Improved treatment of surface evapotranspiration in a mesoscale numerical model. Part I: Via the installation of the Penman-Monteith Method. *Terrestrial, Atmos. and Oceanic Sci.*, **8**, 481-508.

Ciach, G., M.L. Morrissey, and W.F. Krajewski, 2000: Conditional bias in radar rainfall estimation, *J. Appl. Meteor.*, accepted.

Cifelli, R., S. A. Rutledge, D. J. Boccippio, and T. Matejka, 1996: Horizontal divergence and vertical velocity retrievals from Doppler radar and wind profiler observations. *J. Atmos. Oceanic Technol*., **13**, 948-966.

Cohn, S. A., C. L. Holloway, S. P. Oncley, R. J. Doviak, and R. J. Lataitis, 1997: Validation of a UHF spaced antenna wind profiler for high resolution boundary layer observations. *Radio Sci*., **32**, 1279-1296.

Colle, B.A., C.F. Mass and B.F. Smull, 1999: An observational and numerical study of a cold front interacting with the Olympic Mountains during COAST IOP5. *Mon. Wea. Rev*., **127**, 1310-1334.

Cooper, M. A., R. Holle, and R. López, 1999: Recommendations for lightning safety. *J. Amer. Med. Assoc*., **282**, 1132-1133.

Cooter, E., M. B. Richman, P. J. Lamb, and D. A. Sampson, 2000: The development of a dimate change data base for biological assessments in the Southeastern United States. *Climatic Change*, **44**, 89-121.

Cortinas, J.V., Jr., J.M. Straka, W. H. Beasley, J.M. Schneider, and C.M. Machacek, 1996: The research experiences for undergraduates program: The 1995 program at the Oklahoma weather center. *Bull. Amer. Meteor. Soc*., **77**, 2925-2936.

Cortinas, J. V., Jr., 2000 : A climatology of freezing rain over the Great Lakes region of North America. *Mon. Wea. Rev*., **128**, 3574-3588.

Covich, A. P., S. C. Fritz, P. J. Lamb, R. D. Marzolf, W. J. Mathews, K. A. Polani, E. E. Prepas, M. B. Richman, and T. C. Winter, 1997: Potential effects of climate change on aquatic ecosystems of the Great Plains of North America. Chapter 8 in *Advances in Hydrological Processes: Freshwater Ecosystems and Climate Change in North America* (C. E. Cushing, ed.), John Wiley and Sons, Chichester, 175-203.

Covich, A. P., S. C. Fritz, P. J. Lamb, R. D. Marzolf, W. J. Mathews, K. A. Poiani, E. E. Prepas, M. B. Richman, and T. C. Winter, 1997: Potential effects of climate change on aquatic ecosystems of the Great Plains of North America. *Hydrological Processes*, **11**, 993-1021.

Crawford, T. M., and C. E. Duchon, 1999: An improved parameterization for estimating atmospheric emissivity for use in calculating daytime downwelling longwave radiation. *J. Appl. Meteor.*, **38**, 474-480.

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

Crosson, W.L., B.E. Vieux, D. Armand, and J.P. Looper, 1999: Assessing the benefits of coupling a distributed land surface flux model and a surface runoff model. Supplement to *Eos Transactions*, Amer. Geophys. Soc. H51D-02.

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

DeGrand, J. Q., A. M. Carleton, D. J. Travis, and P. J. Lamb, 2000: A satellite-based climatic description of jet aircraft contrails and associations with atmospheric conditions, 1977-79. *J. Appl. Meteor.*, **39**, 1434-1459.

Dickinson, M.J., L.F. Bosart, W. E. Bracken, G.J. Hakim, D.M. Schultz, M.A. Bedrick, and K.R. Tyle, 1997: The March 1993 superstorm cyclogenesis: Incipient phase synoptic- and convective-scale flow interaction and model performance. *Mon. Wea. Rev.*, **125**, 3041-3072.

Dong, M., and Q. Xu, 1996: A sensitivity study of single column model. *Adv. Atmos. Sci.*, **13**, 313-324.

Doswell, C. A. III, H. E. Brooks, and R. A. Maddox, 1996: Flash-flood forecasting: An ingredients-based methodology. *Wea. Forecasting*, **11**, 360-381.

Doswell, C.A. III, and S.G. Lasher-Trapp, 1997: On measuring the degree of irregularity in an observing network. *J. Atmos. Oceanic Technol.*, **13**, 120-132.

Doswell, C. A. III, and H. E. Brooks, 1998: Budget cutting and the value of weather services. *Wea. Forecasting*, **13**, 206-212.

Doswell, C.A. III, and H.E. Brooks, 1999: Case analysis of a historic killer tornado event in Kansas on 10 June 1938. *Annals of Improbable Res.*, **5**, 14-15, 26.

Doswell, C.A. III, A.R. Moller and H.E. Brooks, 1999: Storm spotting and public awareness since the first tornado forecasts of 1948. *Wea. Forecasting*, **14**, 544-557.

Douglas, M.W., and S. Li, 1996: Diurnal variation of the lower-tropospheric flow over the Arizona low desert from SWAMP-1993 observations. *Mon. Wea. Rev.*, **124**, 1211-1224.

Douglas, M.W., and D.J. Stensrud, 1996: Upgrading the North American upper-air observing network: What are the possibilities? *Bull. Amer. Meteor. Soc.*, **77**, 907-924.

Douglas, M.W., and W. Fernandez, 1997: Strengthening the meteorological, sounding network over the tropical eastern Pacific Ocean and the Intertropical Americas. *WMO Bulletin*, **46**, 348-351.

Douglas, M.W., A. Valdez, and R. Garcia, 1998: Diurnal variation and horizontal extent of the low level jet over the northern Gulf of California. *Mon. Wea. Rev*., **126**, 2017-2025.

Doviak, R.J., R.J. Lataitis, and C.L. Holloway, 1996: Cross correlations and cross spectra for spaced antenna wind profilers, 1. Theoretical analysis. *Radio Sci*., **31**, 157-180.

Doviak, R. J., 1999: Atmospheric turbulence and its detection by radar. In *Aviation Weather Surveillance Systems-Advanced and Surface Sensors for Flight Safety and Air Traffic Management*, P. Mahapatra, Ed., IEEE and the AIAA, 375-405.

Doviak, R.J., and D.S. Zrnic, 1999: Meteorological Radar. In *Wiley Encyclopedia of Electrical and Electronics Engineering*, John Webster, Ed.. John Wiley & Sons, Inc., 596-602.

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

Dowell, D., H. Bluestein, and D. P. Jorgensen, 1997: Airborne Doppler radar analysis of supercells during COPS-91. *Mon. Wea. Rev*., **125**, 365-383.

Eack, K.B., W.H. Beasley, W.D. Rust, T.C. Marshall, and M. Stolzenburg, 1996: X-ray pulses observed above a mesoscale convective system. *Geophys. Res. Lett*., **23**, 2915-2918.

Eack, K.B., W.H. Beasley, W.D. Rust, T.C. Marshall, and M. Stolzenburg, 1996: Initial results from simultaneous observation of X rays and electric fields in a thunderstorm. *J. Geophys. Res*., **101**, 29637-29640.

Eack, K.B., D.M. Suszcynsky, W.H. Beasley, R. Roussel-Dupre, and E. Eymbalisty, 2000: Gamma ray emissions observed in a thunderstorm anvil. *Geophys. Res. Lett*., accepted.

El Hamly, M., R. Sebbari, P. J. Lamb, M. N. Ward, and D. H. Portis, 1998: Towards the seasonal prediction of Moroccan precipitation and its implications for water resources management. *Water Resources Variability in Africa during the XXth Century* (E. Servat, D. Hughes, J.-M. Fritsch, and M. Hulme, eds.), IAHS Publication No. 252, 79-88.

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.

Fuller, R.D., and D.J. Stensrud, 2000: The relationship between easterly waves and surges over the Gulf of California during the North American monsoon. *Mon. Wea. Rev*., **128**, 2983-2989.

Graham, B.L., R.L. Holle, and R.E. López, 1997: Lightning detection and data use. *Fire Management Notes*, **57**, 4-10.

Grice, G. K., Trapp, R. J., S. F. Corfidi, R. Davies-Jones, C. C. Buononno, J. P. Craven, K. K. Droegemeier, C. Duchon, J. V. Houghton, R. A. Prentice, G. Romine, K. Schlachter, and K. K. Wagner, 1999: The golden anniversary celebration of the first tornado forecast. *Bull. Amer. Meteor. Soc*., **80**, 1341-1348.

Gu, W., Q. Xu, and R. Wu, 1998: Three-dimensional instability of nonlinear viscous symmetric circulations. *J. Atmos. Sci*., **55**, 3148-3158.

Gu, W., and Q. Xu, 2000: Baroclinic Eady wave and fronts - Part III: Unbalanced dynamics - Departures from viscous semigeostrophy. *J. Atmos. Sci*.,**57**, 3414-3425.

Gyakum, J. R., L. F. Bosart, and D. M. Schultz, 1999: The Tenth Cyclone Workshop. *Bull. Amer. Meteor. Soc*., **80**, 285-290.

Hall, T., H. E. Brooks, and C. A. Doswell III, 1999: Precipitation forecasting using a neural network. *Wea. Forecasting*, **14**, 338-345

Hane, C.E., H.B. Bluestein, T.M. Crawford, M.E. Baldwin, and R.M. Rabin, 1997: Severe thunderstorm development in relation to along-dryline variability: A case study. *Mon. Wea. Rev*., **125**, 231-251.

Hill, H. S., J. W. Mjelde, W. Rosenthal, and P. J. Lamb, 1999: The potential impacts of the use of Southern Oscillation information on Texas aggregate sorghum production. *J. Climate*, **11**, 519-530.

Hirschboeck, K.K., L.L. Ely, and R.A. Maddox, 1999: Hydroclimatology of Meteorologic Floods. In *Inland Flood Hazards: Human, Riparian and Aquatic Communities*, E. Wohl, Ed., Cambridge Univ. Press, in press.

Hoblit, B.C., A.W. Holder, B.E. Vieux, and P.B. Bedient, 2000: A new approach to flood prediction. *Civil Eng. Mag*., in press.

Holle, R.L., R.E. López, L.J. Arnold, and J. Endres, 1996: Insured lightning-caused property damage in three western states. *J. Appl. Meteor*., **35**, 1344-1351.

Holle, R.L., and A.I. Watson, 1996: Lightning during two central U.S. winter precipitation events. *Wea. Forecasting*, **11**, 599-614.

Holle, R.L., A.I. Watson, and D. Purcell, 1996: A well-organized thunderstorm outflow in Florida. *Nat. Wea. Digest*, **21**, 18-20.

Holle, R.L., and S.P. Bennett, 1997: Lightning ground flashes associated with summer 1990 flash floods and streamflow in Tucson, Arizona: An exploratory study. *Mon. Wea. Rev*., **125**, 1526-1536.

Holle, R.L., R.E. López, K.W. Howard, K.L. Cummins, M.D. Malone, and E.P. Krider, 1997: An isolated winter cloud-to-ground lightning flash causing damage and injury in Connecticut. *Bull. Amer. Meteor. Soc*., **78**, 437-441.

Holle, R.L., and R.E. López, 1998: Lightning - Impacts and safety. *Bull. World Meteor. Soc*., **47**, 148-155.

Holle, R. L., R. E. López, and C. Zimmermann, 1999: Updated recommendations for lightning safety-1998. *Bull. Amer. Meteor. Soc*., **80**, 2035-2041.

Holloway, C. L. R. J. Doviak, and S. A. Cohn, 1997: Cross correlations of fields scattered by horizontally anisotropic refractive index irregularities. *Radio Sci*., **32**, 1911-1929.

Holloway, C. L., R. J. Doviak, S. A. Cohn, R. J. Lataitis, and J. S. Van Baelen, 1997: Cross correlations and cross spectra for spaced antenna wind profilers 2. Algorithms to estimate wind and turbulence. *Radio Sci*., **32**, 967-982.

Howard, K. W., J. J. Gourley and R. A. Maddox, 1997: Uncertainties in WSR-88D measurements and their impacts on monitoring life cycles. *Wea. Forecasting*, **12**, 167-174.

Johnson, D. L., S. H. Ambrose, T. J. Bassett, M. L. Bowen, J. S. Isaacson, D. E. Crummey, D. N. Johnson, P. J. Lamb, M. Saul, and A. E. Winter-Nelson, 1997: Meanings of environmental terms. *J. Env. Quality*, **26**, 581-589.

Johnson, J.T., P.L. MacKeen, A. Witt, E. D. Mitchell, G. J. Stumpf, M. D. Eilts, and K. W. Thomas, 1998: The Storm Cell Identification and Tracking Algorithm: An enhanced WSR-88D algorithm. *Wea. Forecasting*, **13**, 263-276.

Johnson, J.T., M.D. Eilts, D. Ruth, W. Goodman, and L. Rothfusz, 2000: Warning operations in support of the 1996 Centennial Olympic Games. *Bull. Amer. Meteor. Soc*., **81**, 543-554.

Joly, A., D. P. Jorgensen, M. A. Shapiro, A. Thorpe, P. Bessemoulin, K. A. Browning, J.-P. Cammas, J.-P. Chalon, S. A. Clough, K. A. Emanuel, L. Eymard, R. Gall, P. H. Hildebrand, R. H. Langland, Y. Lemaitre, P. Lynch, J. A. Moore, P. O. G. Persson, C. Snyder, and R. M. Wakimoto, 1997: The Fronts and Atlantic Storm Track Experiment (FASTEX): Scientific objectives and experimental design. *Bull. Amer. Meteor. Soc.*, **78**, 1917-1940.

Jorgensen, D. P., T. Matejka, and J. D. DuGranrut, 1996: Multi-beam techniques for deriving wind fields from airborne Doppler radars. *J. Meteor. Atmos. Phys*., **59**, 83-104.

Jorgensen, D. P., M. A. LeMone, and S. B. Trier, 1997: Structure and evolution of the 22 February 1993 TOGA - COARE squall line: Aircraft observations of precipitation, circulation, and surface energy fluxes. *J. Atmos. Sci*., **54**, 1961-1985.

Jorgensen, D. P., T. R. Shepherd, and A. Goldstein, 2000: A multiple pulse repetition frequency scheme for extending the unambiguous Doppler velocity of the NOAA P-3 airborne Doppler radar. *J. Atmos. Oceanic Technol*., **17**, 585-594.

Kain, J.S., and J.M. Fritsch, 1998: Multiscale convective overturning in mesoscale convective systems: Reconciling observations, simulations, and theory. *Mon. Wea. Rev*., **126**, 2254-2273.

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.

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 A. Shapiro, 1996: The simulation of a convective cloud in a 3-D model with explicit microphysics. Part II: Dynamical and microphysical aspects of cloud merger. *J. Atmos. Sci*., **53**, 2525-2545.

Kogan, Z. N., Y. L. Kogan, and D. K. Lilly, 1996: Evaluation of sulfate aerosols indirect effect in marine stratocumulus clouds using observation-derived cloud climatology. *Geophys. Res. Letters*, **23**, 1937-1940.

Kogan, Z. N., Y. L. Kogan, and D. K. Lilly, 1997: Cloud factor and seasonality of the indirect effect of anthropogenic sulfate aerosols. *J. Geophys. Res*., **102**, 25927-25939.

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

Kuo, Y.-H., J. Bresch, M.-D. Cheng, J.S. Kain, D.B. Parsons, W.-K. Tao, and D.-L. Zhang, 1997: Summary of a mini-workshop on Cumulus Parameterization for Mesoscale Models. *Bull. Amer. Meteor. Soc*., **78**, 475-491.

Lakshmanan, V., and A. Witt, 1996: A fuzzy logic classifier for the detection of Bounded Weak Echo Regions in meteorological images. *Artificial Neural Networks in Eng*., 513-518.

Lakshmanan, V., and A. Witt, 1997: A fuzzy logic approach to detecting severe updrafts. *AI Applications*, **11**, 1-12.

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

Lakshmanan, V., 2000: Speeding up a large scale filter. *J. Atmos. Oceanic Technol*., **17**, 468-473.

Lamb, P.J., M. El Hamly, and D.H. Portis, 1997: North Atlantic Oscillation. *Géo Observator*, **7**, 103-113.

Lamb, P. J., M. A. Bell, and J.D. Finch, 1998: Variability of Sahelian disturbance lines and rainfall during 1951-87. *Water Resources Variability in Africa during the XXth Century* (E. Servat, D. Hughes, J.-M. Fritsch, and M. Hulme, eds.), IAHS Publication No. 252, 19-26.

Lee, R.R. and A. White, 1998: Improvement of the WSR-88D mesocyclone algorithm. *Wea. Forecasting*, **13**, 341-351.

Lewis, J.M., 1996: Carl-Gustaf Arvid Rossby. In *Macmillan Encyclopedia of Earth Sciences*. E. J. Dash, Ed., Macmillan Publishing Co., 4 pp.

Lewis, J.M., 1996: Philip Thompson: Pages from a Scientist's Life. *Bull. Amer. Meteor. Soc*., **77**, 107-113.

Lewis, S. A., M. A. LeMone, and D. P. Jorgensen, 1998: Evolution and dynamics of a late-stage squall line that occurred on 20 February 1993, during TOGA COARE. *Mon. Wea. Rev*., **126**, 3189-3212.

Liu, M., D. L. Westphal, T. R. Holt, and Q. Xu, 2000: Numerical simulation of a low-level jet over complex terrain in Southern Iran. *Mon. Wea. Rev*., **128**, 1303-1327.

Liu, Q., Y. L. Kogan, D. K. Lilly, and M. P. Khairoutdinov, 1997: Variational optimization method for calculation of cloud drop growth in an Eulerian drop-size framework, *J. Atmos. Sci*., **54**, 2493-2504.

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.

López, R.E., and R.L. Holle, 1996: Fluctuations of lightning casualties in the United States: 1959-1990. *J. Climate*, **9**, 608-615.

López, R.E., and J.P. Aubagnac, 1997: The lightning activity of a hailstorm as a function of changes in its microphysical characteristics inferred from polarimetric radar observations. *J. Geophys. Res*., **102**, 16799-16813.

López, R.E., R.L. Holle, A.I. Watson, and J. Skindlov, 1997: Spatial and temporal distributions of lightning over Arizona from a power utility perspective. *J. Appl. Meteor*., **36**, 825-831.

López, R.E., and R.L. Holle, 1998: Changes in the number of lightning deaths in the United States during the twentieth century. *J. Climate*, **11**, 2070-2077.

Lu, Y. Y., R. J. Doviak, and C. Crisp, 1996: Estimating Large-Scale Vorticity using VAD Products and Reflectivity. *J. Atmos. and Oceanic Technol*., **13**, 1129-1138.

Ludwig, R.L., R.L. Street, J.M. Schneider, and K.R. Costigan, 1996: Analysis of small-scale patterns of atmospheric motion in a sheared, convective boundary layer. *J. Geophys. Res*., **101**, 9391-9411.

MacGorman, D. R., and W. D. Rust, 1998: *The Electrical Nature of Storms*. Oxford University Press, 422 pp.

Mach, D.M., and W.D. Rust, 1997: Two-dimensional speed and optical risetime estimates for natural and triggered dart leaders. *J. Geophys. Res*., **102**, 13,673-13,684.

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

Maddox, R.A., K.W. Howard, and C.L. Dempsey, 1997: Intense convective storms with little or no lightning over central Arizona: A case of inadvertent weather modification? *J. Appl. Meteor.*, **36**, 302-314

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.

Maddox, R.A., and C. Crisp, 1999: The Tinker AFB tornadoes of March 1948. *Wea. Forecasting*, **14**, 492-499.

Markowski, P.M., and D.J. Stensrud, 1998: Mean monthly diurnal cycles observed with PRE-STORM surface data. *J. Climate*, **11**, 2995-3009.

Markowski, P. M., E. N. Rasmussen, and J. M. Straka, 1998: The occurrence of tornadoes in supercells interacting with boundaries during VORTEX-95. *Wea. Forecasting*, **13**, 852-859.

Markowski, P. M., E. N. Rasmussen, J. M. Straka, and D. C. Dowell, 1998: Observations of low-level baroclinity generated by anvil shadows. *Mon. Wea. Rev*., **126**, 2942-2958.

Markowski, P. M., J. M. Straka, and E. N. Rasmussen, D. O. Blanchard, 1998: Variability of storm-relative helicity during VORTEX. *Mon. Wea. Rev*., **126**, 2959-2971.

Marshall, T.C., M. Stolzenburg, and W.D. Rust, 1996: Electric field measurements above mesoscale convective systems. *J. Geophys. Res*., **101**, 6979-6996.

Marshall, T.C., W.D. Rust, M. Stolzenburg, W. Roeder, and P.R. Krehbiel, 1999: A study of enhanced fair-weather electric fields occurring soon after sunrise. *J. Geophys. Res*., **104**, 24455-24469.

Marshall, T.C, M. Stolzenburg, W.D. Rust, E.R. Williams, and R. Boldi, 2000: Positive charge in the stratiform cloud of a mesoscale convective system. *J. Geophys. Res*., submitted.

Marzban, C, and G. J. Stumpf, 1996: A neural network for tornado prediction based on Doppler radar-derived attributes. *J. Appl. Meteor*., **35**, 617-231.

Marzban, C., H. Paik, and G. Stumpf, 1997: Neural networks vs. gaussian discriminant analysis. *AI Applications*, **10**, 49-58.

Marzban, C., 1998: Scalar measures of performance in rare-event situations. *Wea. Forecasting*, **13**, 753-763.

Marzban, C., 1998: Bayesian probability and scalar performance measures in Gaussian models. *J. Appl. Meteor.*, **37**, 72-82.

Marzban, C., and G. J. Stumpf, 1998: A neural network for damaging wind prediction. *Wea. Forecasting*, **13**, 151-163.

Marzban, C., and G. J. Stumpf, 1998: A neural network for tornado and/or damaging wind prediction based on Doppler radar-derived attributes. *Microcomputer Applications*, **17**, 21-28.

Marzban C., H. Paik, and G. J. Stumpf, 1998: Neural networks versus Gaussian discriminant analysis. *AI Applications*, **10**, 49-58.

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

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

Marzban, C., and J. Schaefer, 2000: The correlation between U.S. tornadoes 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.

Matejka, T., and S. A. Lewis, 1996: Improving research aircraft navigation by incorporating INS and GPS information in a variational solution. *J. Atmos. Oceanic Tech*., **14**, 495-511.

Matejka, T., and S. A. Lewis, 1997: Improving research aircraft navigation by incorporating INS and GPS information in a variational solution. *J. Atmos. Oceanic Technol*., **14**, 495-511.

Matejka, T., and D. L. Bartels, 1998: The accuracy of vertical air velocities from Doppler radar data. *Mon. Wea. Rev*., **126**, 92-117.

May, P., T.D. Keenan, D. Zrnic, L. Carey, and S. Rutledge, 1999: Polarimetric radar measurements of tropical rain at C-band. *J. Appl. Meteor*., **38**, 750-765.

Mazur, V., E. Williams, R. Boldi, L. Maier, and D. Proctor, 1997: Initial comparison of lightning mapping with operational time-of-arrival and interferometric systems. *J. Geophys. Res*., **102**, 11071-11085.

Mazur, V., and L. H. Ruhnke, 1998: Model of electric charges in thunderstorms and associated lightning. *J. Geophys. Res*., **103**, 23299-23308.

Mazur, V., X. M. Shao, and P. R. Krehbiel, 1998: Spider lightning in intracloud and positive cloud-to-ground flashes. *J. Geophys. Res*., **103**, 19811-19822.

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.

Michalsky, J., E. Dutton, D. Nelson, M. Rubes, T. Stoffel, M. Wesley, M. Splitt, J. DeLuisi, 1999: Optimal measurement of surface shortwave irradiance using current instrumentation. *J. Atmos. Oceanic Technol*., **16**, 55-69.

Mitchell, E. D., S. V. Vasiloff, G. J. Stumpf, M. D. Eilts, A. Witt, J. T. Johnson, and K. W. Thomas, 1998: The National Severe Storms Laboratory Tornado Detection Algorithm. *Wea. Forecasting*, **13**, 352-366.

Mjelde, J. W., T. N. Thompson, C. J. Nixon, and P. J. Lamb, 1997: Utilizing a farm-level decision model to help prioritize future climate prediction research needs. *Meteorol. Applications,* **4**, 161-170.

Montroy, D. L., M. B. Richman, and P. J. Lamb, 1998: Observed nonlinearities of monthly teleconnections between tropical Pacific sea surface temperature anomalies and central and eastern North American precipitation. *J. Climate,* **10**, 1812-1835.

Muschinski, A., P. P. Sullivan, D. B. Wuertz, R. J. Hill, S. A. Cohn, D. H. Lenshow, and R. J. Doviak. 1999: First Large-Eddy simulation of clear-air wind-profiler signals. *Radio Sci*., **6**, 1437-1459.

Nielsen-Gammon, J. W., and D. M. Schultz, 1999: Comments on ``The intensification of the low-level jet during the development of mesoscale convective systems on a mei-yu front." *Mon. Wea. Rev*., **127**, 2227-2231.

Neiman, P.J., M.A. Shapiro, F.M. Ralph, B.F. Smull and D. Johnson, 1998: An observational study of fronts and frontal mergers during the phasing of arctic and Pacific-polar synoptic-scale waves over the continental United States. *Mon. Wea. Rev*., **126**, 2521-2554.

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**, 2989-3003.

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**, 3004-3020.

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.*, **105**, 17351-17359.

Peckham, S. E. and L. J. Wicker, 2000: The influence of topography and lower-tropospheric winds on dryline evolution. *Mon. Wea. Rev*., **127**, 2165-2189.

Peppler, R. A., C. P. Bahrmann, J. C. Barnard, J. R. Campbell, M.-D. Cheng, R. A. Ferrare, R. N. Halthore, L. A. Heilman, D. L. Hlavka, N. S. Laulainen, C.-J. Lin, J. A. Ogren, M. R. Poellot, L. A. Remer, K. Sassen, J. D. Spinhirne, M. E. Splitt, and D. D. Turner, 2000: ARM Southern Great Plains site observations of the smoke pall associated with the 1998 Central American fires. *Bull. Amer. Meteor. Soc*., **81**, 2563-2591.

Pereira Fo, A.J., K.C. Crawford, and D.J. Stensrud, 1999: Mesoscale precipitation fields. Part II: Hydrometeorologic modeling. *J. Appl. Meteor.*, **38**, 102-125.

Petersen, W.A., R.C. Cifelli, S.A. Rutledge, B.S. Ferrier and B.F. Smull, 1999: Shipborne dual-Doppler operations during TOGA COARE: Integrated observations of storm kinematics and electrification. *Bull. Amer. Meteor. Soc.*, **80**, 81-97

Pielke, R. A., T. J. Lee, J. H. Copeland, J. L. Eastman, C. L. Ziegler, and C. A. Finley, 1997: Use of USGS-provided data to improve weather and climate simulations. *Ecological Applications*, **7**, 3-21.

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, 2001: Seasonality of the North Atlantic Oscillation. *J. Climate*, accepted.

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.

Qiu, C., and Q. Xu, 1996: Least-square retrieval of microburst winds from single-Doppler radar data. *Mon. Wea. Rev*., **124**, 1132-1144.

Qiu, C., and Q. Xu, 1996: An improvement on the simple adjoint method for retrieving the wind fields from single-Doppler data. *Quart. J. Appl. Meteor. (China)*, **7**, 422-430.

Rabin, R, and D.W. Martin, 1996: Satellite observations of shallow cumulus coverage over the central United States: An exploration of land use impact on cloud cover. *J. Geophys. Res*., **101**, 7149-7155.

Rasmussen, E. N., and J. M. Straka, 1997: Supercell morphology variations. Part I. Observations of upper-level storm-relative flow. *Mon. Wea. Rev*., **126**, 2406-2421.

Rasmussen, E. N., and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*, **13**, 1148-1164.

Rasmussen, E. N., and J. M. Straka, 1998: Variations in supercell morphology. Part I: Observations of the role of upper-level storm-relative flow. *Mon. Wea. Rev*., **126**, 2406-2421.

Rasmussen, E. N., S. J. Richardson, J. M. Straka, P. M. Markowski, and D. O. Blanchard, 2000: The association of significant tornadoes with a baroclinic boundary on 2 June 1995. *Mon. Wea. Rev.*, **128**, 174-191.

Richardson, S. J., F. V. Brock, S. R. Semmer, and C. Jirak, 1999: Minimizing errors associated with multiplate radiation shields. *J. Atmos. Oceanic Technol*., **16**, 1862-1872..

Richardson, S. J., M. E. Splitt, and B. M. Lesht, 2000: Enhancement of ARM surface meteorological observations during the fall 1996 water vapor intensive observation period. *J. Atmos. Oceanic Technol*., **17**, 312-322.

Richardson, S. J., and F. V. Brock, 2000: System design, calibration, and quality assurance needs for networks. In *Handbook of Weather, Climate, and Water*. McGraw-Hill, in press.

Richardson, S. J., J. M. Straka, K. R. Nixon, and J. T. Snow, 2000: A rapidly deployable ruggedized wind measurement system for measuring winds in landfalling hurricanes and other extreme events. *Atmos. Res.*, submitted.

Risbey, J.S., P.J. Kushner, P.J. Lamb, R. Miller, M.C. Morgan, and G. Roe, 2000. Elucidating the structure of regional climate scenarios by combining synoptic and dynamic guidance and GCM output. *J. Climate,* submitted.

Romero, R., C. Ramis, S. Alonso, C.A. Doswell III, and D.J. Stensrud, 1998: On the application of a mesoscale numerical simulation model to three heavy rain episodes. *Mon. Wea. Rev*., **126**, 1859-1881.

Rust, W.D., and T.C. Marshall, 1996: On abandoning the thunderstorm tripole-charge paradigm. *J. Geophys. Res.*, **101**, 23499-23504.

Rust, W.D., T.C. Marshall, M. Stolzenburg, and J. Fitzgibbon, 1999: Test of a GPS radiosonde in thunderstorm electrical environments, *J. Atmos. Oceanic Technol*., **16**, 550-560.

Ryzhkov, A., and D.S. Zrnic, 1996: Assessment of rainfall measurement that uses specific differential phase. *J. Appl. Meteor*., **35**, 2080-2090.

Ryzhkov, A., and D.S. Zrnic, 1996: Rain in shallow and deep convection measured with a polarimetric radar. *J. Atmos. Sci*., **53**, 2989-2995.

Ryzhkov, A., D.S. Zrnic, and D. Atlas, 1997: Polarimetrically tuned R(Z) relations and comparison of radar rainfall methods. *J. Appl. Meteor*., **36**, 340-349.

Ryzhkov, A., and D. Zrnic, 1998: Beamwidth effects on the differential phase measurements of rain. *J. Atmos. Oceanic Technol*., **15**, 624-634.

Ryzhkov, A.V., and D.S. Zrnic, 1998: Polarimetric rainfall estimation in the presence of anomalous propagation. *J. Atmos. Oceanic Technol*., **15**, 1320-1330.

Ryzhkov, A.V., and D.S. Zrnic, 1998: Discrimination between rain and snow with a polarimetric radar. *J. Appl. Meteor*., **37**, 1228-1240.

Ryzhkov, A., D.S. Zrnic, and B.A. Gordon, 1998: Polarimetric method for ice water content determination, *J. Appl. Meteor*., **37**, 125-134.

Ryzhkov, A.V. and D.S. Zrnic, 1999: Discrimination between rain and snow with a polarimetric radar. *J. Appl. Meteor.*, **37**, 1228-1240.

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

Sachidananda, M., and D.S. Zrnic, 1999: Systematic phase codes for resolving range overlaid signals in a Doppler weather radar. *J. Atmos. Oceanic Technol.*, **16**, 1351-1363.

Sachidananda, M., and D.S. Zrnic, 2000: Clutter filtering and spectral moment estimation for Doppler weather radars using staggered pulse repetition time (PRT). *J. Atmos. Oceanic Technol.*, **17**, 323-331.

Schneider, J., F. L. Ludwig, R. L. Street, and K. R. Costigan, 1996: Analysis of small-scale patterns of atmospheric motion in a sheared, convective boundary layer. *J. Geophys. Res.*, **101**, 9391-9411.

Schneider, J.M. and D. K. Lilly, 1999: An observational and numerical study of a sheared, convective boundary layer. Part 1: Phoenix II observations, statistical description, and visualization. *J. Atmos Sci.*, **56**, 3059-3078.

Schultz, D.M., W.E. Bracken, L.F. Bosart, G.J. Hakim, M.A. Bedrick, M.J. Dickinson, and K.R. Tyle, 1997: The 1993 Superstorm cold surge: Frontal structure, gap flow, and tropical impact. *Mon. Wea. Rev.*, **125**, 5-39.

Schultz, D. M., 1998: Does it rain more often on weekends? *Annals of Improbable Res.*, **4**, 29.

Schultz, D. M., W. E. Bracken, and L. F. Bosart, 1998: Planetary- and synoptic-scale signatures associated with Central American cold surges. *Mon. Wea. Rev.*, **126**, 5-27.

Schultz, D. M., D. Keyser, and L. F. Bosart, 1998: The effect of large-scale flow on low-level frontal structure and evolution in midlatitude cyclones. *Mon. Wea. Rev.*, **126**, 1767-1791.

Schultz, D. M., 1999: Lake-effect snowstorms in northern Utah and western New York with and without lightning. *Wea. Forecasting*, **14**, 1023-1031.

Schultz, D. M., and C. A. Doswell III, 1999: Conceptual models of upper-level frontogenesis in southwesterly and northwesterly flow. *Quart. J. Roy. Meteor. Soc.*, **125**, 2535-2562.

Schultz, D. M., and C. A. Doswell III, 1999: Analyzing and forecasting Rocky Mountain lee cyclogenesis often associated with strong winds. *Wea. Forecasting*, **15**, 152-173.

Schultz, D. M., and P. N. Schumacher, 1999: The use and misuse of conditional symmetric instability. *Mon. Wea. Rev.*, **127**, 2709-2732.

Schultz, D. M. and W. J. Steenburgh, 1999: The formation of a forward-tilting cold front with multiple cloud bands during superstorm 1993. *Mon. Wea. Rev.*, **127**, 1108-1124.

Schultz, D.M., and C.A. Doswell III, 2000: Analyzing Rocky Mountain lee cyclogenesis often associated with damaging winds. *Wea. Forecasting*, **15**, 152-173

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, 2000: Drop size distributions measured by a 2D-video-disdrometer. Comparison with dual-polarization radar data. *J. Appl. Meteor.*, submitted.

Shafer, M.A., C.A. Fiebrich, D.S. Arndt, S.E. Fredrickson, and T.W. Hughes, 2000: Quality assurance procedures in the Oklahoma Mesonet. *J. Atmos. Oceanic Technol*., **17**, 474-494.

Shafer, M.A., D. R. MacGorman, and F.H. Carr, 2000: Cloud-to-ground lightning throughout the lifetime of a severe storm system in Oklahoma. *Mon. Wea. Rev*., **128**, 1798-1816.

Shaw, B. L., R. A. Pielke, and C. L. Ziegler, 1997: A three dimensional numerical simulation of a Great Plains dryline. *Mon. Wea. Rev*., **125**, 1489-1506.

Shepherd, T.R., W.D. Rust, and T.C. Marshall, 1996: Electric fields and charges near 0°C in stratiform clouds. *Mon. Wea. Rev*., **124**, 919-938.

Sherrick, B. J., S. T. Sonka, P. J. Lamb, and M. A. Mazzocco, 2000: Decision-maker expectations and the value of climate prediction information: Conceptual considerations and preliminary evidence. *Meteorol. Applications*, **7**, in press.

Skinner, B. D., D. Changnon, M. B. Richman, and P. J. Lamb, 1999: Damaging weather conditions in the United States: A selection of data quality and monitoring issues. *Climatic Change*, **42**, 69-87.

Skinner, B.D., D. Changnon, M.B. Richman, and P.J. Lamb, 1999: Damaging weather conditions in the United States: A selection of data quality and monitoring issues. In *Weather and Climate Extremes: Changes, Variations, and a Perspective from the Insurance Industry* (T.R. Karl, N. Nicholls, and A. Ghazi, eds.), Kluwer Academic Publishers, Dordrecht, 69-87.

Spencer, P.L., F.H. Carr, and C.A. Doswell III, 1996: Investigation of an amplifying and a decaying wave using a network of wind profilers. *Mon. Wea. Rev*., **124**, 209-223.

Spencer, P.L., and D.J. Stensrud, 1998: Simulating flash flood events: Importance of the sub-grid representation of convection. *Mon. Wea. Rev*., **126**, 2884-2912.

Spencer, P.L., P.R. Janish, and C.A. Doswell III, 1999: A 4dimensional objective analysis scheme and multi-triangle technique for wind profiler data. *Mon. Wea. Rev*., **127**, 279-291.

Stadler, S.J., F.V. Brock, J.D. Carlson, G.W. Cuperus, K.C. Crawford, J. Duthie, C.A. Doswell III, M.D. Eilts, R.L. Elliot, T. Hughes, and H.L. Johnson, 1997: Climatic Geography and the Oklahoma Mesonet. In *Geographic Perspectives on the Texas Region*, D. Lyons and P. Hudak, Eds., Assoc. of Amer. Geographers, 107-114.

Steenburgh, W. J., Schultz, D. M., and B. A. Colle, 1998: The structure and evolution of gap outflow over the Gulf of Tehuantepec, Mexico. *Mon. Wea. Rev*., **126**, 2673-2691.

Stensrud, D.J., 1996: Effects of a persistent, midlatitude mesoscale region of convection on the large-scale environment during the warm season. *J. Atmos. Sci*., **53**, 3503-3527.

Stensrud, D.J., 1996: Importance of low-level jets to climate: A review. *J. Climate*, **9**, 1698-1711.

Stensrud, D.J., and J.A. Skindlov, 1996: Grid point predictions of high temperature from a mesoscale model. *Wea. Forecasting*, **11**, 103-110.

Stensrud, D.J., J.V. Cortinas, Jr., and H.E. Brooks, 1997: Discriminating between tornadic and non-tornadic thunderstorms using mesoscale model output. *Wea. Forecasting*, **12**, 613-632.

Stensrud, D.J., R.L. Gall, and M. Nordquist, 1997: Surges over the Gulf of California during the Mexican monsoon. *Mon. Wea. Rev*., **125**, 417-437.

Stensrud, D.J., H.E. Brooks, J. Du, M.S. Tracton, and E. Rogers, 1999: Using ensembles for short-range forecasting. *Mon. Wea. Rev*., **127**, 433-446.

Stensrud, D.J., G. Manikin, E. Rogers, and K. Mitchell, 1999: Importance of cold pools to mesoscale model forecasts. *Wea. Forecasting*, **14**, 650-670.

Stensrud, D.J., J.-W. Bao, and T.T. Warner, 2000: Using initial condition and model physics perturbations in short-range ensembles of mesoscale convective systems. *Mon. Wea. Rev*., **128**, 2077-2107.

Stensrud, D.J., H.E. Brooks, J. Du, M.S. Tracton, and E. Rogers, 2000: Reply to comments on "Using ensembles for short-range forecasting". *Mon. Wea. Rev*., **128**, 3021-3023.

Stolzenberg, M., W.D. Rust, and T.C. Marshall, 1998: Electrical structure in thunderstorm convective regions, Part II: Isolated storms. *J. Geophys. Res*., **103**, 14079-14096.

Stolzenburg, M., W.D. Rust, and T.C. Marshall, 1998: Electrical structure in thunderstorm convective regions, Part III: Synthesis. *J. Geophys. Res*., **103**, 14097-14108.

Stolzenburg, M., W.D. Rust, B.F. Smull, and T.C. Marshall, 1998: Electrical structure in thunderstorm convective regions, Part I: Mesoscale convective systems. *J. Geophys. Res*., **103**, 14059-14078.

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., E. N. Rasmussen, and S. E. Fredrickson, 1996: A mobile mesonet for fine scale meteorological observations. *J. Atmos. Oceanic Technol*., **13**, 921-936.

Straka, J. M., and E. N. Rasmussen, 1997: Toward improving microphysical parameterizations of conversion processes. *J. Appl. Meteor*., **36**, 896-902.

Straka, J.M., D.S. Zrnic, and A.V. Ryzhkov, 2000: Bulk hydrometeor classification and quantification using multiparameter radar data. Synthesis of relations. *J. Appl. Meteor.*, **39**, 1341-1372.

Stumpf, G. J., A. Witt, E. D. Mitchell, P. L. Spencer, J. T. Johnson, M. D. Eilts, K. W. Thomas, and D. W. Burgess, 1998: The National Severe Storms Laboratory mesocyclone detection algorithm for the WSR-88D. *Wea. Forecasting*, **13**, 304-326.

Tachikawa, Y, B.E. Vieux, M. Shiiba, and K. Takara, 1999: How important is spatially explicit soil information for a distributed rainfall-runoff model. Supplement to *Eos Transactions*, Amer. Geophys. Soc. H52A-10.

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

Torres, S. and D. Zrnic, 1999: Ground clutter canceling with a regression filter. *J. Atmos. Oceanic Technol*., **16**, 1364-1372.

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., and R. Davies-Jones, 1997: Tornadogenesis with and without a dynamic pipe effect. *J. Atmos. Sci*., **54**, 113-133.

Trapp, R. J., 1999: Observations of nontornadic low-level mesocyclones and attendant tornadogenesis failure during VORTEX. *Mon. Wea. Rev*., **127**, 1693-1705.

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., and C.A. Doswell III, 2000: Radar data objective analysis. *J. Atmos. Oceanic Technol*., **17**, 105-120.

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.

Trier, S. B., W. C. Skamarock, M. A. LeMone, D. B. Parsons, and D. P. Jorgensen, 1996: Structure and evolution of the 22 February 1993 TOGA -COARE squall line: Numerical simulations. *J. Atmos. Sci*., **53**, 2861-2886.

Vivekanandan, J., D.S. Zrnic, S.M. Ellis, D. Oye, A.V. Ryzhkov, and J. Straka, 1998: Cloud microphysics retrieval using S-band dual-polarization radar measurements. *Bull. Amer. Meteor. Soc*., **80**, 381-388.

Wallace, C.L., and R.A. Maddox, 2000: Summertime convective storm environments in central Arizona: Local observations. *Wea. Forecasting*, **14**, in press.

Walsh, J.E., V.Kattsov, D. Portis and V. Meleshko, 1998: Arctic precipitation and evaporation: model results and observational estimates. *J. Climate*, **11**, 72-87.

Walsh, J.E, and D. Portis, 1999: Variations of precipitation and evaporation over the North Atlantic Ocean, 1958-1997. *J. Geophys. Res*., **104**, 16613-16631.

Ward, M.N., P.J. Lamb, M. El Hamly, R. Sebbari, and D.H. Portis, 1999: Climate Variability in Northern Africa: Understanding Droughts in the Sahel and the Maghreb. Chapter 6 in *Beyond El Niño: Decadal Variability in the Climate System*, A. Navarra, Ed., Springer-Verlag, Berlin, 119-140.

Watson, A.I., and R.L. Holle, 1996: An eight-year lightning climatology of the southeast United States prepared for the 1996 Summer Olympics. *Bull. Amer. Meteor. Soc*., **77**, 883-890.

Witt, A., M. D. Eilts, G. J. Stumpf, J. T. Johnson, E. D. Mitchell, and K. W. Thomas, 1998: An enhanced hail detection algorithm for the WSR-88D. *Wea. Forecasting*, **13**, 286 - 303.

Witt, A., M. D. Eilts, G. J. Stumpf, E. D. Mitchell, J. T. Johnson, and K. W. Thomas, 1998: Evaluating the performance of WSR-88D severe storm detection algorithms. *Wea. Forecasting*, **13**, 513-518.

Wood, V.T. and R.A. Brown, 1996: Effects of radar sampling on single-Doppler velocity signatures of mesocyclones and tornadoes. *Wea. Forecasting*, **12**, 928-938.

Wood, V. T., R. A. Brown, and D. W. Burgess, 1996: Duration and movement of mesocyclones associated with southern Great Plains thunderstorms. *Mon. Wea. Rev*., **124**, 97-101.

Wood, V. T., and R. A. Brown, 1997: Effects of radar sampling on single-Doppler velocity signatures of mesocyclones and tornadoes. *Wea. Forecasting*, **12**, 928-938.

Wood, V.T., 1998: Comments on AMS Policy Statement on tornado forecasting and warning. *Bull. Amer. Meteor. Soc*., **79**, 2746.

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.

Wurman, J., J. M. Straka, E. N. Rasmussen, 1996: Fine-scale Doppler radar observations of tornadoes. *Science*, **272**, 1774-1777.

Wurman, J., J. M. Straka, E. N. Rasmussen, 1997: Design and deployment of a portable, pencil-beam, pulsed Doppler radar. *J. Atmos. Oceanic Technol*., **14**, 1502-1512.

Xin, L., and G. W. Reuter, 1996: Numerical simulation of the effects of mesoscale convergence on convective rain showers. *Mon. Wea. Rev*., **124**, 2828-2842.

Xin, L., G.W. Reuter, and B. Larochelle, 1997: Reflectivity-rain rate relationships for convective rainshowers in Edmonton. *Atmosphere-Ocean*, **35**, 513-521.

Xin, L., and G. W. Reuter, 1998: VVP technique applied to an Alberta storm. *J. Atmos. and Oceanic Technol*., **15**, 587-592.

Xu, Q., S. Gao, and B. H. Fiedler, 1996: A theoretical study of cold air damming caused by upstream blocking of stratified flow. *J. Atmos. Sci.*, **53**, 312-326.

Xu, Q., M. Xue, and K. K. Droegemeier, 1996: Numerical simulations of density currents in sheared environments within a vertically-confined channel. *J. Atmos. Sci*., **53**, 770-786.

Xu, Q., 1996: Generalized adjoint for physical processes with parameterized discontinuities - Part I: Basic issues and heuristic examples. *J. Atmos. Sci*., **53**, 1123-1142.

Xu, Q., 1996: Generalized adjoint for physical processes with parameterized discontinuities - Part II: Vector formulations and matching conditions. *J. Atmos. Sci*., **53**, 1143-1155.

Xu, Q., and C. Qiu, 1997: A Variational method for computing surface heat fluxes from ARM Surface Energy and Radiation Balance Systems. *J. Appl. Meteor*., **36**, 3-11.

Xu, Q., and C. Qiu, 1997: Adjoint matching condition for parameterized discontinuities - A derivation using Lagrangian-form costfunction. *Adv. Atmos. Sci*., **14**, 49-52.

Xue, M., and Q. Xu, and K. K. Droegemeier, 1997: A theoretical and numerical study of density currents in non-constant shear flows. *J. Atmos. Sci*., **54**, 1998-2019.

Xu, Q., 1997: Generalized adjoint for physical processes with parameterized discontinuities - Part III: Multiple threshold conditions. *J. Atmos. Sci*., **54**, 2713-2721.

Xu, Q., 1997: Generalized adjoint for physical processes with parameterized discontinuities - Part IV: Problems in time discretization. *J. Atmos. Sci*., **54**, 2722-2728.

Xu, Q., J. Gao, and W. Gu, 1998: Generalized adjoint for physical processes with parameterized discontinuities - Part V: Coarse-grain adjoint and problems in gradient check. *J. Atmos. Sci*., **55**, 2130-2135.

Xu, Q., W. Gu, and J. Gao, 1998: Baroclinic Eady wave and fronts - Part I: Viscous semigeostrophy and the impact of boundary condition. *J. Atmos. Sci*. **55**, 3598-3615.

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.

Yang, S., and Q. Xu, 1996: Statistical errors in variational data assimilation - A theoretical one-dimensional analysis applied to Doppler wind retrieval. *J. Atmos. Sci*., **53**, 2563-2577.

Young, C.B, A.A. Bradley, W.F. Krajewski, A. Kruger and M.L. Morrissey, 2000: An evaluation of NEXRAD multisensor precipitation estimates for operational hydrologic forecasting. *J. Hydrometeor.*, accepted.

Yu, C.-K., B.F. Smull and B. J.-D. Jou, 1999: Formative stage of a long-lived mesoscale vortex observed by airborne Doppler radar. *Mon. Wea. Rev*., **127**, 838-857.

Yu, C.-K., and B.F. Smull, 2000: Airborne Doppler observations of a landfalling cold front upstream of steep coastal orography. *Mon. Wea. Rev*., **128**, 1577-1603.

Zangvil, A., and P. J. Lamb, 1997: Characterization of sky conditions by the use of solar radiation data. *Solar Energy*, **61**, 17-23.

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.

Zangvil, A., D. H. Portis, and P. J. Lamb, 2000: Role of local evapotranspiration for growing season precipitation and crop yields over the midwestern United States. *Science*, submitted.

Zhang, J. and T. Gal-Chen, 1996: Single-Doppler wind retrieval in the moving frame of reference. *J. Atmos. Sci*., **53**, 2609-2623

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

Ziegler, C., T. J. Lee, and R. A. Pielke, Sr., 1997: Convective initiation at the dryline: A modeling study. *Mon. Wea. Rev*., **125**, 1001-1026.

Ziegler, C., and E. Rasmussen, 1998: The initiation of moist convection at the dryline: Forecasting issues from a case study perspective. *Wea. Forecasting*, **13**, 1106-1131.

Ziegler, C., 1999: Issues in forecasting Mesoscale Convective Systems: An observational and modeling perspective. In *STORMS*, R. Pielke, Jr. and R. Pielke, Sr., Eds., Routledge Press, London, 26-42.

Zong, J., and Q. Xu, 1997: The dynamics of cold fronts passing over a quasi two-dimensional mountain ridge. *Tellus*, **49**, 559-576.

Zrnic, D.S., 1996: Weather radar polarimetry--Trends toward operational applications. *Bull. Amer. Meteor. Soc.*, **77**, 1529-1534.

Zrnic, D. S., and A. Ryzhkov, 1996: Advantages of rain measurements using specific differential phase. *J. Atmos. Oceanic Technol*., **13**, 454-464.

Zrnic, D.S., and A.V. Ryzhkov, 1998: Observations of insects and birds with a polarimetric. *IEEE Trans. Geosci. Remote Sens.*, **GE-36**, 661-668.

Zrnic, D.S., and A.V. Ryzhkov, 1999: Polarimetry for weather surveillance radars. *Bull. Amer. Meteor. Soc*., **80**, 389-406.

Zrnic, D.S., and M. Sachidananda, 2000: Signal processing and systematic phase coding for mitigation of range and velocity ambiguities in Doppler weather radars. *U.S. Patent No. 6,061,221*.

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.

(D) Web Site

The front page of the CIMMS web site is attached here. It is used to disseminate information about CIMMS. ***(Not shown here)***