REPORT OF THE

Workshop on

MESOSCALE RESEARCH INITIATIVE: SOCIETAL ASPECTS

10–11 December 1990

Michael H. Glantz, Conference Organizer

Lesley F. Tarleton, Conference Coordinator

Environmental and Societal Impacts Group

National Center for Atmospheric Research*

PO Box 3000

Boulder, Colorado 80307

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1. Introduction: The Mesoscale Weather Factor*

Mesoscale weather phenomena and their impacts have captured the attention of researchers and governments since the time of Aristotle. Many of these phenomena have major societal costs (for example, Hurricane Hugo) which are increasing as population and capital investment increase. Emerging new technologies and understanding of physical processes now offer much greater opportunities than in the past to mitigate losses and to enhance society's well-being in the face of such phenomena. Recognizing this, the National Science Foundation supported a day-and-a-half multidisciplinary workshop to consider and propose social science research that would enhance the nation's capabilities in addressing mesoscale weather phenomena. The following excerpt from a recent draft of the Mesoscale Research Initiative captures the importance of understanding weather phenomena and of using that information for improved decision-making at all levels of social organization.

> *Across the United States, weather works unceasingly to shape our prospects and fortunes. Blessing some, bringing suffering and hardship to others, weather penetrates so broadly and deeply into our everyday lives that its full influence is more instinctively felt than consciously recognized. Seasons in their turn bring spring and summer squalls, autumn hurricanes, and winter blizzards that endanger our citizens, whether at home or in transit. Precipitation molds our agriculture, our water resources, the navigability of our rivers, and our wetland habitats. Regional weather combines with our energy use to dictate the quality of our air. Once-insignificant weather features – small dust storms, or patches of fog or haze – today can compromise complex operations of a high-technology military.... Today, weather's influence is both expanding and changing. Population growth, demographic shifts, and economic development have combined to increase the number of lives and dollar value at stake. New technology creates opportunities for domesticating weather – harnessing its benefits and avoiding its hazards – but at the same time introduces new, unforeseen societal exposures.*

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* The term mesoscale in this document encompasses weather events such as droughts or floods which are not generally considered to be mesoscale phenomena. In this document, the term mesoscale is used to denote the effects of a weather event, of any scale, on small segments of the population.

The worldwide reach of US trade and strategic interests ... transforms a national challenge into a global one.

2. Mesoscale Research Initiative: Societal Aspects

The Mesoscale Research Initiative: Societal Aspects workshop was convened with the support of NSF's Division of Atmospheric Sciences through the Field Projects Office of the National Center for Atmospheric Research (NCAR), to provide an opportunity to social scientists to participate with physical scientists in mesoscale weather research activities. Clearly, there have been many social science studies on mesoscale events. These have usually been centered on extreme weather events and their societal and environmental impacts (e.g., tornadoes, hurricanes, or floods like the Big Thompson flood). The Environmental and Societal Impacts Group (ESIG) was asked by SAR's* Subcommittee on Mesoscale Research to give initial consideration to the development of a societal aspect of the Mesoscale Research Initiative program. Given the limitations of time and resources, the day-and-a-half workshop was organized like an Informal Planning Meeting (IPM) of the World Meteorological Organization (for the agenda, see Appendix 1). The purpose of this IPM was to gather ideas about how best to develop a social science component for the Mesoscale Research Initiative and to provide guidance for the "next step" in developing a social science/mesoscale research agenda.

The workshop on the societal aspects of the Mesoscale Research Initiative was convened by Michael Glantz, Head of the Environmental and Societal Impacts Group at NCAR on December 10, 1990. Twenty-seven participants from the US

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* SAR is the Subcommittee on Atmospheric Research, which is part of the Committee on Earth and Environmental Sciences.

and Canada attended the meeting. Their expertise represented a wide range of professional interests including physical and social sciences, and scientific research, applications, and administration. Disciplinary backgrounds included political science, economics, statistics, meteorology, hydrology, engineering, geography, psychology, and law (for complete addresses and a brief biographical sketch for each participant, see Appendices 2 and 3).

Each participant presented a brief statement about his or her interest in mesoscale research. Their names and organizational affiliation are as follows.

Barbara Brown . . .	Statistics and Meteorology, ESIG/NCAR
Stanley Changnon	Water Resources, Illinois State Water Survey
Hal Cochrane	Economics, Colorado State University
Margaret Davidson	Environmental Law, South Carolina Sea Grant Consortium, Charleston, South Carolina
Deborah Davis. . . .	Administration, Research Applications Program, NCAR
Mary Downton . . .	Computer Science, ESIG/NCAR
David George.	Meteorology, NOAA/ERL, Boulder, Colorado
Michael Glantz . . .	Political Science, ESIG/NCAR
Eve Gruntfest	Geography, University of Colorado at Colorado Springs
William Hooke . . .	Office of the Chief Scientist, NOAA, Washington, DC
Dale Jamieson	Environmental Ethics, University of Colorado
Richard Katz	Statistics, ESIG/NCAR
Margaret LeMone	Mesoscale Meteorology, NCAR
Gordon McKay . . .	Meteorology, Atmospheric Environment Services, Environment Canada (retired)
Kathleen Miller. . .	Economics, ESIG/NCAR
Larry Mooney	Meteorology, NWS Forecast Office, Denver, Colorado
Tom Potter	Meteorology, National Weather Service, Western Region, Salt Lake City, Utah
Roger Pulwarty. . .	Geography, University of Colorado at Boulder
Steven Rhodes. . . .	Political Science, ESIG/NCAR
William Riebsame	Geography, Natural Hazards & Research Applications Center, University of Colorado at Boulder
Art Shantz	Political Science, Research Applications Program/NCAR
Tom Stewart	Psychology, Center for Policy Research, State University of New York, Albany

Robert Stoffel .... Emergency Response Institute, Olympia, Washington
Edward Szoke .... Mesoscale Meteorology, NCAR
Lesley Tarleton ... Mesoscale Meteorology, ESIG/NCAR
Don Wilhite ...... Agricultural Meteorology, University of Nebraska, Lincoln
Jon Zufelt .... Hydraulic Engineering, Cold Regions Research & Engineering Laboratory, US Army Corps of Engineers, Hanover, NH

During his opening remarks Glantz noted that mesoscale weather events directly and indirectly affect a wide range of human activities. While there may be little that societies can do to stop the occurrence of such events, advanced and *ex post facto* information about them can provide society with an ability to minimize their present and future impacts. The judicious use of information about mesoscale events can shift the balance of responses from reaction to proaction as a result of increased awareness of the risks involved with mesoscale weather.

Glantz introduced William Hooke, Executive Director, Office of the Chief Scientist, NOAA. Hooke informed the participants that there was sincere, lasting interest in the development of a social science research agenda focused on mesoscale weather events, broadly defined, including extreme meteorological events and other weather hazards. The goal of such an agenda would be to enable society to capitalize on the benefits that might be derived from improved spatial and temporal weather information, as well as to mitigate the hazards that such events bring.

He also noted that the National Weather Service (NWS) is at an important juncture in its history. The multi-billion-dollar modernization program to upgrade the technological support of the NWS has strengthened the potential for developing an improved weather forecast system. The need for a modernization program was recognized as urgent, as the NWS infrastructure was rapidly becoming outmoded. Modernization made it possible to improve the system, especially, for example, with such tools as Doppler radar. This technology produces measurable improvements in tornado and other severe thunderstorm forecasts/warnings. Hooke noted, as an example, that with the change from relying solely on spotters (tornado warnings were issued only after a spotter had sighted a tornado) to using Doppler radar, the lead time changed from 3 to 20 minutes and there was a drastic reduction in error rate. Although a tornado will cause damage regardless of the forecast, the degree of harm to individuals, and to some extent to property, could be reduced with improvements in forecast skill and information dissemination.

In addition to upgrading the hardware, there is a recognized need to improve forecasts and their usage. Hooke noted that a common question asked by the staff of the Office of Management and Budget relates to the benefits of improved forecasts. What are the realistic benefits of improved forecasts of mesoscale weather events? To date many responses to this question have been anecdotal. There is a demand for reliable and credible quantitative as well as qualitative forecast value assessments. Hooke recognized the need to support research on societal aspects of mesoscale weather events on a sustained, as opposed to *ad hoc*, and long-term as opposed to a short-term basis. He identified four important motives behind the strong interest in mesoscale research: life, property, national defense and science. He also emphasized the importance of mesoscale weather to the economic productivity of the nation. He closed his presentation with the following: What questions should we be asking now?

Participants then raised issues about mesoscale research in general. As society evolves, and as climate (and therefore weather) varies, new results are expected of the forecasting community. There is a constant need to identify areas where forecasting methods can aid in the decision-making process, such as in agriculture and in aviation. In addition, available technology is always changing. Thus, vulnerabilities and risks may also be changing. Hooke cited the example of the switch from propeller-driven aircraft to jets and how this changed the weather forecast needs of a particular segment of the forecasters' user community.

Participants expressed the view that it is as beneficial to improve the use of existing forecasts as it is to develop improved forecasts, especially of extreme meteorological events. This was based on the belief that it is not enough to produce and disseminate a forecast of a specific weather event but that there is a need to improve society's understanding and use of that forecast.

Discussion highlighted the general acceptance of the view that research on the physical and the societal aspects of mesoscale weather-related events is extremely important for the following reasons: (1) People are most aware of weather events in their locale, and each locale has its own set of specific weather-related hazards with which it must contend. (2) This is the scale at which human activities directly interface with atmospheric processes. (3) Mesoscale research is more tractable than research on broader time and space scales and can, therefore, yield tangible results in relatively shorter periods of time.

The overriding objective of the Mesoscale Research Initiative is the improvement of science to enhance societal well-being. This workshop was supported in order to provide social scientists with an opportunity to provide a framework for a societal aspects research program that would be a part of the Mesoscale Research Initiative, through the identification and enhancement of the social, economic and environmental benefits associated with improved mesoscale research.

Interest in the value of forecasts specifically, and of mesoscale research in general, is high in such agencies as the Federal Aviation Administration, Department of Agriculture, National Oceanic and Atmospheric Administration, Department of Energy, Department of Defense, Federal Emergency Management Administration, and the National Aeronautics and Space Administration, among many others. In addition, mesoscale research output will be required as input to global change research activities.

It was suggested that with regard to the impacts of weather events on society, the focus has been on accounting for loss of life and of property. Yet, there is an important factor that is often omitted from discussion of adverse impacts. Adverse weather impacts include displacement, relocation, community breakdown, and suffering; what one might call a "misery quotient." Incorporating this factor along with quantitative assessments would provide a more accurate picture of the actual impacts of mesoscale weather events on society.

It was also noted that there is a need to develop a framework for communicating impacts research output, such as, for example, what information is needed and in what form it is most beneficial, back to the meteorological forecasting community in order to ensure that information flows in both directions. It is no longer acceptable nor sufficient for forecasters to provide their forecasts to potential users with the hope that either the users will know what information is most important for their needs or that the users will know how best to use the information provided by the forecasters.

Glantz then provided the workshop participants with a plan of action for the remainder of the meeting. The participants were divided into three working groups centered on forecasts (with Tom Stewart, SUNY-Albany, as chairperson), impacts (with Stan Changnon, Illinois Water Survey, as chairperson) and responses (with Skip Stoffel, Emergency Management, Inc., as chairperson). It was noted that these categories were not mutually exclusive. Assignment to each of these groups was based on the primary interest of each of the participants.

The **forecasts** category relates to the entire process of forecasting, from constructing forecasts to their dissemination. **Impacts** refers to the interactions between society and mesoscale weather events as well as the societal impacts of forecasts. **Responses** refers to societal reaction to either meteorological events or to forecasts of such events. A list of possible issues that might be encompassed within these categories was supplied to the participants, who were advised that the list was meant to be suggestive, not exhaustive. It was provided to spark discussion. The working groups were free to set their own agendas.

With regard to forecasts, it was suggested that the group consider users' needs and communication processes, as well as the research and technology that go into improving forecasts. Along these lines the group might consider discussing perceptions of societal and environmental costs and benefits of forecasts. "Nowcasting" (in addition to or as part of the forecasting process) is important, as quantitative information is often desired about the status of a freeze, a snow storm, a flash flood, and so on, while the event is still in progress. Research on the use and value of forecasts is important to assess what improvements in forecast output are feasible, most needed, and most valuable.

With respect to impacts, suggestions for possible discussion on impact assessment included consideration of a "misery quotient" or a way to capture the true costs of extreme meteorological events; indirect as well as direct and long-term as well as short-term impacts (although a tornado occurs in a matter of minutes, its impacts can linger for years); psychological factors associated with forecasts and with impacts, and so forth. Research on these and similar topics would enable researchers to better apportion responsibility between nature and society for the severity of impacts of extreme or anomalous weather events at the mesoscale. It was suggested that more attention be given to the idea of "hindcasting" with regard to impact assessment; that is, reviewing the cost/benefit assessment after some time has passed so that a more realistic assessment can be made.

Responses to mesoscale events as well as to forecasts can be categorized as follows: preventive, mitigative, and adaptive. Suggested issues that could be addressed included: How do migrants to a new area adjust to the local weather hazards? To what extent can policy changes reduce vulnerability? How can one change social responses to extreme meterological events? What are the land-use policies that can minimize or exacerbate the level of risk from mesoscale weather events? How best might one measure the efficiency of responses to mesoscale forecasts? How best can users' needs for information be fed back to forecasters?

Some common themes were suggested to the working groups: methods of assessment, climate change issues, risk probability factors. The following questions were suggested to focus group discussions: (1) What has been done in this area? (2) What is not being done? (3) What are the critical gaps in our knowledge? (4) What are priority issues to be addressed in this area? (5) What are the next steps?

The plenary session ended with the workshop dividing into the three working groups (see Appendix 2b for the membership of these working groups). The working group meetings were interspersed with plenary sessions to assess the direction and progress of discussion of each group. The final statements produced by each of the working groups are presented in the following section.

3. Working Group Statements

FORECAST Working Group Report

General Comments:

In order to achieve the full societal benefit of improved forecasting capability resulting from the National Weather Service modernization and the Mesoscale Research Initiative (MRI), the following must occur:

- **Forecasting process.** A forecasting process must be implemented which translates improved technology-based observational capability and improved research into improved forecasts (in terms of skill, events forecast, and spatial and temporal coverage).

- **Communication process.** Forecasting outputs must be produced in a timely fashion with appropriate content and format and in a medium that can be used effectively by users in their decision-making processes.
- **Users' decision processes.** Users must incorporate the forecast product into their decision-making in order to make better choices among available alternatives.
- **Decision outcomes.** Implemented decisions must result in outcomes that have higher overall value than would be the case without the improved information.

Each step involves both technical and social processes, but the contribution of technical processes decreases and the contribution of social processes increases as we go down the above list.

Overview of proposed research:

The communication process is a critical link in the chain stretching from improved technology and research to improved societal benefits. We propose a research program focused on the design and dissemination of forecasting products to achieve the most effective use by decision makers. This research would require close collaboration between meteorologists and social scientists. Meteorologists' primary responsibility would be to study the forecasting process to determine what kinds of forecasts can be improved and what kinds of products will be feasible, given new technology and mesoscale research findings. The primary responsibility of social scientists would be to identify users' weather information needs and to determine the weather products that best fit those needs. The meteorological community includes private consultants, as well as government meteorologists. Private meteorologists are also *users*, in that they use government data and forecasts and tailor the information to their clients' needs. Research into the forecast process must include the part that private meteorologists play. If there is a gap between what is feasible and what is needed, meteorologists and social scientists will apply their collective knowledge of the forecasting process and the user's decision processes to develop the most useful, feasible product. The outcome of this research will be useful both in educating forecasters about the users' needs and educating users about how best to use available information and forecasts.

Forecasting Process

The following are the steps necessary to determine what kinds of forecast products will be feasible given improved technology and mesoscale research findings:

1. Identify a set of forecast problems that will be addressed by MRI or improved technology. For example, such problems may include quantitative precipitation forecasts and tornado watches and warnings. Specific examples of new operational forecasts include nowcasts issued hourly by the Denver NWS Forecast Office and enhanced warning efforts for thunderstorms and tornadoes using Doppler radar in Norman, Oklahoma.
2. For each forecast problem, evaluate the forecasters' use of improved technology, research, and increased information to determine their impacts on the forecasting process.
3. Use the results of this study to identify gaps in operational methodology, forecaster training, and hydrometeorological knowledge and gaps in basic understanding.
4. Develop methods to fill the identified gaps. Such methods may include conceptual models and new operational procedures. It *must* include forecaster training in science and in using new technology.
5. Develop and apply appropriate methods to evaluate changes in forecast quality.

User Needs and Decision Processes

The following are the steps required in the research to identify users' needs as well as forecast products that would be most valuable to users:

1. Identify a representative sample of important weather–information–sensitive decisions and decision makers (or decision-making groups). Decisions studied should include those from the public and private sectors, sophisticated and unsophisticated users, and routine and emergency decision making.
2. For each decision, specify the range of alternatives available to the decision makers. Consider how this range of alternatives may change as forecasts are improved.
3. Identify the information that can be used to make the decision. Determine how that information is obtained. Include all information, not just weather information.
4. Model the relationships between information (input to the decision process) and the decision (output of the decision process). Both descriptive and prescriptive models should be developed. The modeling process should include an analysis of the effect of forecast content and format on the decision process.

Communication Processes

These two lines of research – forecast products and users' needs – will converge in developing the means to improve the communication process. The following are steps for research designed to understand and improve the transfer of weather information and forecasts from meteorologists to users:

1. Identify a representative sample of communication systems used for dissemination of weather information. "Systems" includes networks for emergency management and for communication of routine forecasts, as well as emergency

management plans (or lack thereof), policies, agencies (public and private), agency interaction, technology and media for information transfer.

2. For each system, undertake case studies to evaluate the effectiveness of existing communication processes. Different types and sizes of user groups need to be included in the case studies.
3. Identify essential components of effective systems and delineate problems that need to be addressed to improve inadequate systems.
4. Identify possible solutions (including new types of communication systems) for situations where communications have failed to meet users' needs. Test solutions by implementation and comparison of results with a "before and after" evaluation.
5. Develop and evaluate methods for educating users (e.g., emergency managers, farmers, individuals) regarding interpretation of forecast products.

Comments:

1. The research related to users' needs differs from most previous research on the value of forecasts because it focuses on finding ways to formulate forecasts to improve communication between forecasters and users.
2. The first two lines of research – forecasts and user needs – described above can be carried out simultaneously with close collaboration between meteorologists and social scientists.
3. The value of forecasts depends on an interaction of the quality and form of the forecast (which will change due to improved technology and research), how the information is used by decision makers, and social and environmental changes which will lead to shifts in vulnerability among various segments of society. The modeling process must take these changes into account or it will quickly become outdated.

4. Technology and research will change the forecasting process. They will affect both the social processes of interactions among forecasters and forecasting centers and the mental information processing strategies of the forecasters. Unless these changes are understood and included in training programs (e.g., COMET), they may have unanticipated consequences and the full value of improved forecasts resulting from improved technology and research may not be realized.
5. Education of users regarding appropriate use of available forecasting products and education of forecasters about users' needs are important, as is ongoing feedback from users to forecasters to indicate any changing needs and for continued improvement of forecast output.

IMPACTS Working Group Report

What has been done?

A wealth of information already exists that is either directly or indirectly relevant to assessments of the impacts of mesoscale weather on society. For instance, several bibliographies (e.g., Riebsame et al., *A Bibliography of Weather and Climate Hazards*, 1986) and reports (e.g., Howe and Cochrane, *Natural Hazard Damage Handbook*, 1990) have been compiled that include mesoscale weather events within their scope. Moreover, descriptive studies have been performed on an *ad hoc* basis, compiling direct effects for events that happen to attract attention (e.g., Hurricane Hugo). Another resource that could be exploited consists of the impact assessments for weather modification published in recent decades (e.g., Changnon et al., *Hail Suppression: Impacts and Issues*, 1977). The somewhat parallel effort to introduce an impacts component into the global change agenda should not be neglected. Although the compelling need for assessing the societal impacts of mesoscale weather events in a systematic fashion has not yet been broadly recognized, many institutions (such as those with representatives at this workshop) have worked on these related issues and are well prepared to attack this difficult problem.

A few case studies dealing with direct effects, as well as the value of short-term weather forecasts (e.g., snow removal), have been produced. But the lack of an acceptable theoretical framework has limited the "generalizability" of these studies and hindered the reliance on their policy recommendations. Attempts to develop a theoretical framework have been based on the so-called "hazard" paradigm and on the normative, prescriptive decision-analytic methodology (i.e., "risk-benefit" analysis). Although it is clear that improved information about weather is of potential economic value, the circumstances under which this value will be at least partially realized and how best to quantify it are still open questions.

What is not being done?

The vast majority of impact assessments that have been conducted have only addressed direct effects of mesoscale events. Very few of these studies have traced further (i.e., second-order) impacts and implications of these direct effects. This would include linkages to other economic sectors and ecological effects in the long term. For example, there continues to be concern about both the economic and ecological impacts associated with the 1978 storm-related breakup of the Amoco Cadiz oil tanker. However, there is little research available to document the indirect and long-term effects of this accident.

Much of the impacts assessment research has been aimed at estimating economic impacts in dollar terms. However, it is well recognized that the full social costs of mescoscale events includes psychological consequences and other social disruptions. Examples include residual fears and anxieties, altered social relationships, effects of damages to public services and facilities, and civil disorder.

There is also minimal literature on assessment methodologies for mesoscale impacts research. Each research community has informally adopted a different and varying set of definitions, criteria for mesoscale impact assessment, and methods of quantification (including economic impacts). This has contributed to a lack of communication between the physical and social sciences, and limits the credibility of impact value estimates.

Changes in demographics, technology, energy costs, and public policies will also change societal and economic vulnerabilities, as well as alter the value of improved mesoscale forecasts. As an example, it is estimated that by the year 2000 more than 80% of the US population will reside within 50 miles of a coast. This has significant implications for business and economic activity at risk to severe storms (e.g., hurricanes, tornadoes, Great Lakes severe weather).

Anticipation of future demographics and patterns of economic activity and technological development would allow better tailoring of economically beneficial weather services. At present, the design for better weather services comes from the day-to-day interaction of weather service providers and users. Rather than being future-oriented, weather service design is present-oriented. In an increasingly integrated global economy, rapid responses will become more important; and improved mesoscale forecasts will facilitate more efficient use of resources.

There is a need for centralization and networking in the development and use of mesoscale impact data bases. Currently most data base development is project-specific and tends to be unavailable to other researchers working on weather-related impacts studies.

At present there exist limited opportunities for education and training in weather-related impacts research. Limited interaction between the physical and social sciences, coupled with episodic funding which focuses primarily on major disasters, has resulted in minimal concern and support for continuous multidisciplinary research on weather services and impacts.

Because most impacts-related research has focused on catastrophic events, there has been little emphasis placed on long-term follow-up or on phenomena which occur over longer time periods and affect larger geographic regions. Validation of impacts-related research findings, or what might be termed impacts re-assessment, has not been widely practiced. The value of such re-assessments would be to confirm impacts research methods in order to ensure a degree of comparability between research on mesoscale events and impacts in different geographic regions. In addition, such re-assessments would provide comparability between impacts in different economic sectors. The policy implications of improved understanding of mesoscale impacts and better forecasts are evident: better information (both past and future) can yield improvements in commercial transportation (rail, air), public works (snow removal, road maintenance, water management and treatment) and public safety.

Priority Activities

The following list of suggested activities is based on gaps identified in current knowledge. Criteria for selection were feasibility of the study and potential impact on policy.

1. Develop an impacts assessment framework. (6 months)

   This is of highest priority because it is needed for the assessments recommended below. It should continue to be refined as it is used in a variety of examples.

   Case studies in the past have usually focused on direct economic effects of damaging events. It is important that assessment research include evaluation of weather forecast impacts, as well as impacts of mesoscale weather events.

That is, studies must differentiate between weather-sensitive and weather-information-sensitive. The impact assessment framework should include secondary effects such as degradation of infrastructure, supply bottlenecks, continued loss of business and employment, multiplier effects of reduced investment demands. It also should address the issue of indirect effects such as human suffering, psychological effects, and damage to cultural assets and ecosystems.

An initial model for such a framework already exists in the natural hazards field. It could readily be expanded to include issues of economic efficiency and competitiveness.

2. Validate mesoscale impacts through re-assessments. (1–2 years)

   Typically, the effect of mesoscale events is assessed during and immediately following the event. Often validation of the estimates does not take place, and effects of intangibles are not included. Validations would take an in-depth look at impacts of both the weather events and related government policies.

   A few recent examples should be selected in which a detailed re-assessment of impacts is feasible. Possible examples are: 1988 drought, West Virginia floods, Hurricane Hugo, the Limon (Colorado) tornado, 1987-88 winter storms, among others.

3. Evaluate the impact of actual cases of improved forecasts, services, and use of forecast information. (1–2 years)

   Such an evaluation would compare impacts of services with and without an improvement in mesoscale forecasting or use of mesoscale forecast information.

   Possible examples demonstrating such effects are: tornadoes, agricultural weather forecasting centers, Great Lakes storm forecasting, fire weather forecasting, airport policy to avoid microbursts, downslope wind forecasting for the Colorado front range. (This list is only meant to be suggestive.)

4. Assess changing social sensitivities and resiliences to mesoscale events and assess the need for improved forecasts which may mitigate effects of mesoscale events. (On-going studies).

   Possible examples:

   Coastal cities – rapid growth increases their vulnerability. Urban heat islands – health risks increase for aging population. Aviation – increasing air traffic and fuel costs creates the need to reduce delays. Colorado River water – growing population in the US West increases demand for efficient water use. Energy shortage – rising and fluctuating energy costs create need for conservation and efficiency. Environmental quality – relating weather conditions to emissions control can improve efficiency. Financial capacity – heavy reliance on debt increases sensitivity to hazardous events, for individuals, businesses, and government.

RESPONSE Working Group Report

Development of a response capability commensurate with national needs depends on the existence of adequate response systems and the effective input and use of meteorological information. Three factors critical to the proper input and use of meteorological information are: communications, individuals and institutions, and decision-making. Research related to these factors is of critical importance in order for the United States public and private institutions to be adequately equipped, able to interact and motivated to respond appropriately to the hazards, opportunities and consequences of mesoscale atmospheric phenomena.

1. Communications

Convert scientific information to a form useful to decision makers and the public and address its dissemination (Question of language, vehicles, and effectiveness).

Many emergency response practitioners (and users) currently view scientific research related to mesoscale weather-related hazards as unavailable or difficult to access, for the following reasons: lack of knowledge about sources, expense, no centralized information system, material "unreadable" due to jargon and unfamiliar terms from different disciplines, and important "bottom line" information buried in obscure publications, or unpublished.

Many useful technologies have been developed to prevent or mitigate the effects of mesoscale weather events and other natural hazards. However, these are not being effectively and efficiently used because of the lack of awareness of their existence, and lack of a format in which information can be quickly read and understood and readily applied. A study should be made of how the effectiveness of communication can be enhanced to remedy this deficiency. Candidate studies could include the Washington State floods of December 1990 and hurricane Hugo. A guide, based upon an examination of effective communication mechanisms from such case studies, could be prepared for use in coping with future hazardous mesoscale events.

Develop, establish, and maintain communication networks.

At least two kinds of problems emerge as data moves along the continuum from forecasting to response. First, there is a large variety of data sources with diverse data formats that are not readily known to potential users. Second, there are large numbers of institutional sources of information (with overlapping or conflicting mandates), as well as diverse users.

To address these problems, we need to identify sources of information, dissemination methods, and the "users" and their responsibilities. With this information, we can then suggest a model framework for the establishment of communication networks of sources and users. To ensure effectiveness and continuity, efficiency and economic analyses should be conducted periodically as "fine tuning" mechanisms, and included in operational costs.

Identify and use nongovernmental organizations (NGOs) and civic groups in developing public awareness and educational activities with respect to appropriate responses to mesoscale weather events.

Broad-based use of improved forecasting is necessarily predicated upon widespread public awareness of and education about the significance of the information. This issue is inadequately addressed by educational and management institutions. Current NGO activities in other fields of endeavor suggest that there is a significant role for NGOs as well as civic groups in educating the public. It is important to develop a plan for identifying and actively involving these groups.

2. Individuals and Institutions

Examine psychological, social, and cultural aspects of vulnerability to hazards.

Different individuals and cultures often identify different phenomena as hazardous and may also have different attitudes toward what might constitute from their perspective an acceptable risk. Research is necessary to correlate desired responses to mesoscale weather events with people's values and attitudes. Effects of public policy should be identified and evaluated within this framework: the public must determine whether these effects are acceptable.

The societal aspects of mesoscale research must emphasize societal responses, as well as detection. Physical and social scientists must realize that institutions and social groups that collectively constitute the public vary. This diversity must be taken into account in order to encourage effective responses. Age, gender, ethnicity, and ability to pay are some of the social variations which should be considered.

Address need for integrated planning and response.

Too frequently, integrated planning for responses to mesoscale phenomena either fails or is less effective than desired because of the inability of the planning teams to obtain the full support of all agencies or organizations. More effective ways must be found for exploiting and advancing the societal benefits of meteorological research and services.

An integrated emergency management system is essential to successful community disaster response: this requires positive and constructive interaction among different disciplines. Because of jurisdictional issues and concerns about autonomy, specialized professions and disciplines may fail to exchange information that could improve the outcome. In order for mesoscale weather research to be used effectively, a clear understanding of the potential contribution of all disciplines needs to be identified. The disciplines of ecology, sociology, meteorology, economics, emergency management, and hydrology, among others, need to play an interactive role in response to and recovery from extreme meteorological events.

3. Decision-making

Encourage individual and collective responsibility.

Responses to mesoscale events can be long-term and collective, as well as short-term and individual. Long-term, collective responses include policy decisions about land use, insurance, and compensation. Such policy decisions greatly affect future societal vulnerability. Research is needed on existing policies and their effects, and also on the impacts of alternative policies.

Government increasingly accepts responsibility for actions and measures meant to ensure public safety. Government cannot assume total responsibility for citizen safety and welfare related to hazardous weather phenomena. Research is needed to address growing concerns over tort liability and the need for more definitive limits and guidelines in the area of government versus private sector responsibility and liability.

Develop mesoscale planning models.

Considerable effort has been invested in recent years in the development of drought contingency plans by state governments to improve the effectiveness of response to drought. It is imperative that these plans be evaluated. Existing plans and models for drought planning should be considered for their applicability to other mesoscale weather events.

Develop and enhance institutional capabilities and memory.

The relative infrequency of many natural hazards results in a lack of sustained effort to achieve needed understanding and a less than adequate capability to respond where they recur; examples include major floods and droughts which are priority items only when they are in progress. A viable sustained capability can be achieved by addressing the whole array of hazards, and by extending areas considered to be at risk. Post-disaster evaluations, particularly for drought and floods, have concluded that assessment and response efforts have been poorly coordinated, untimely, and largely ineffective. To address these problems, more post-disaster evaluations are needed and the results must be used in disaster planning: the studies should include costs of preparedness versus benefits, how planning and disaster preparedness (e.g., disaster drills) may reduce future impacts and the need for response programs, i.e., long-term vulnerability.

Address probabilities of exposure to risk.

Hazard response teams do not have an adequate basis for assessing the potential level of risk posed by extreme events nor the potential uses of improved forecasts. Hindcasting techniques have been successfully used to reconstruct the physical dimensions of historic events. Hydroclimatic data should be used to estimate the probability of recurrence of historical extreme events and their probable impacts, given current and projected land-use change, development and habitation. Initially, this information would be developed, for example, for the Columbia Basin and the utility of that information assessed. On the basis of the experience of this pilot project the procedure would be applied to other locations determined to be at high risk to weather-related natural hazards such as hail, snowstorms, extreme sustained heat, etc.

Assess and enhance community capabilities.

During and immediately after extreme events, only highly localized responses are practical: institutions are generally unable to react quickly and comprehensively. Anecdotal information exists on the appropriateness and effectiveness of community/neighborhood-based response; e.g., Oakland, California, during the Loma Prieta earthquake. Research is needed on the processes by which these community/neighborhood capabilities are fostered, refined and maintained. Information on grassroots organization and on the development of team skills needs to be adapted to mesoscale problems. These models, then, need to be disseminated through locally based education and training programs.

Identify and quantify the nature and perception of risk.

Experts need to be sensitive to the fact that their perceptions may vary radically from public perceptions. There is a need to more closely align these differing perceptions of risk. While the National Weather Service has retained jurisdictional responsibility for issuing watches and warnings, this has not always resulted in timely, effective dissemination of information to the public. And if the public gets this information, it will not necessarily be interpreted correctly. For example, people involved in the transfer of risk perception to the public now include meteorologists, emergency management offices and private consulting firms.

Populations at risk must be educated to have reasonable expectations about the limits of scientific predictions. There is a limit to the accuracy of predictions. The public must acknowledge that probabilities need to be interpreted and people must be capable of making decisions based on the probabilities. Current designations of risk are ambiguous by their very nature and are likely to remain that way. Exploration into new concepts of risk designation is necessary.

* * *

At the final session of the workshop, each of the working groups presented a brief statement that highlighted an important aspect of the working group's area of interest. Those statements were presented as follows:

Forecast Group

- The nation needs to ensure that improved forecasts meet user needs. To achieve this goal, research is needed to assess the transfer of new knowledge into improved forecasts, the forecasting process itself, the communication process, and users' needs and decision processes.

Impacts Group

- Major social, economic, and technological trends are driving the U.S. to a position where the nation will desperately need, and can effectively exploit, better weather information. Well-recognized trends exist in key weather-sensitive areas like energy costs and use, air transportation, agricultural competition, urban air quality, and society's vulnerability to natural hazards. It is time to launch the scientific research needed to achieve the advances in weather information and forecasts to help the nation address these trends.

Response Group

- At present there are major obstacles to the effective and efficient communication of severe weather information, leading to inadequate and delayed societal responses. Such constraints exist both in the method of communication and in institutional arrangements for communicating and acting. Research in both areas is of critical importance if the United States public and private institutions are to be adequately equipped, able to interact and motivated to actions that address the risks, opportunities and consequences of mesoscale atmospheric phenomena.

The workshop concluded with discussion about how best to foster an expanding interest in the societal aspects of the Mesoscale Research Initiative. It is important to note that several issues, such as communication systems and the transfer of research results to operational needs, were emphasized in more than one group. Suggestions included identifying groups, centers, and institutes involved in mesoscale-related research as well as identifying those groups within government agencies concerned about the societal aspects of the Mesoscale Research Initiative. This would serve as a first step toward the development of a coalition of interests in the societal aspects of mesoscale research activities.

Appendices

Appendix 1

Agenda

Mesoscale Research Initiative: Societal Aspects

10-11 December 1990

NCAR - Damon Room

Boulder, Colorado

December 9

7:00–9:00 p.m.	Informal reception at Golden Buff Motel Conference Room

December 10

8:45–9:30	Welcome to meeting Michael Glantz (NCAR) William Hooke (NOAA) Introductions around the table
9:30–10:00	"Charge" to participants; goals, objectives Identify small groups by concept (forecast, impacts, responses)
10:00–10:30	Break
10:30–12:00	Small groups, meeting 1
12:00–1:00	Lunch
1:00–1:30	Plenary: problems, prospects for small group output
1:30–2:30	Small groups, meeting 2
2:30–2:45	Break
2:45–4:00	Small groups, meeting 3
4:00–4:30	Plenary: Are we on the right course? (mid-course correction)
4:30–5:00	Collect any written output from small groups
6:30–8:30	Working dinner

December 11

8:30–9:00	Plenary: collect any additional written output
9:00–11:00	Writing session
11:00–12:00	Plenary: identification of issues common to the 3 working groups
12:00–1:30	Lunch and closing session What should our message be? What should be the next steps?

Appendix 2a

Workshop on
MESOSCALE INITIATIVE RESEARCH: SOCIETAL ASPECTS
10–11 December 1990
National Center for Atmospheric Research
Boulder, Colorado

Barbara Brown
ESIG/NCAR
(303) 497-1607

Stan Changnon
Illinois State Water Survey
605 East Springfield
Champaign, IL 61801
(217) 333-2210
Fax: (217) 333-6540

Hal Cochrane
Ag. and Nat. Res. Economics
Clark Building
Colorado State University
Fort Collins, CO 80523
(303) 491-6493
Fax: (303) 491-0528

Margaret Davidson
SC Sea Grant Consortium
287 Meeting Street
Charleston, SC 29401
(803) 727-2078
Fax: (803) 727-2080

Debbie Davis
Research Applications Prog./NCAR
(303) 497-8448
Fax: (303) 497-8401

Mary Downton
ESIG/NCAR
(303) 497-1604

David George
NOAA/ERL
325 Broadway, R/E1
Boulder, CO 80303
(303) 497-6840
Fax: (303) 497-6951

Michael H. Glantz
Head, Environmental & Societal
Impacts Group (NCAR)
PO Box 3000
Boulder, CO 80307
(303) 497-1619
Fax: 497-1137

Eve Gruntfest
Department of Geography
Univ. Colorado at Colorado Springs
Colorado Springs, CO 80933-7150
(719) 593-3513
Fax: (719) 593-3362

Bill Hooke
Department of Commerce
Subcommittee on Atmos. Research
14th & Constitution Ave., NW
Washington, DC 20230
(202) 377-1437
Fax:(202) 377-8203

Dale Jamieson
Ctr. for Values & Social Policy
Campus Box 232
University of Colorado
Boulder, CO 80309
(303) 492-6539
Fax: (303) 492-5105

Richard Katz
ESIG/NCAR
(303) 497-1614

Peggy LeMone
Mesoscale & Microscale Met./NCAR
(303) 497-8962
Fax: (303) 497-8520

Gordon McKay
(formerly Atmos. Env. Svcs.)
122 Brooke Street
Thornhill, Ontario L4J 1Y9
(416) 889-3752

Kathleen Miller
ESIG/NCAR
(303) 497-1615

Larry Mooney
Denver NWS Forecast Office
10230 Smith Road
Denver, CO 80239
(303) 361-0661
Fax: (303) 371-5508

Tom Potter
Head, NWS Western Region
PO Box 11188
Salt Lake City, UT 84147-0188
(801) 524-5122
Fax: (801) 524-5246

Roger Pulwarty
CIRES/Campus Box 216
University of Colorado
Boulder, CO 80309
(303) 492-6115
Fax: (303) 492-2468

Steven Rhodes
ESIG/NCAR
(303) 497-1621

Bill Riebsame
Nat. Hazards & Res. Application Ctr.
Campus Box 482
University of Colorado
Boulder, CO 80309-0482
(303) 492-6818
Fax: (303) 492-6924

Art Shantz
Research Applications Prog./NCAR
(303) 497-8496
Fax: (303) 497-8401

Tom Stewart
Ctr for Policy Research, Milne 300
State University of New York
Albany, NY 12222
(518) 442-3850
Fax: (518) 442-3398

Robert Stoffel
Emergency Response Institute
4537 Foxhall Drive, NE
Olympia, WA 98506
(206) 491-7785

Ed Szoke
Mesoscale & Microscale Met./NCAR
(303) 497-8961
Fax: (303) 497-8181

Lesley Tarleton
ESIG/NCAR
(303) 497-1647

Don Wilhite
Dept. of Agricultural Meteorology
University of Nebraska
241 Chase Hall
Lincoln, NE 68583-0728
(402) 472-6707
Fax: (402) 472-6338

Jon Zufelt
CRREL
US Army Corps of Engineers
72 Lyme Road
Hanover, NH 03755-1290
(603) 646-4275
Fax: (603) 646-4278

Appendix 2b

Workshop on
MESOSCALE INITIATIVE RESEARCH: SOCIETAL ASPECTS
10–11 December 1990
National Center for Atmospheric Research
Boulder, Colorado

FORECAST:

Barbara Brown
ESIG/NCAR
(303) 497-1607

Peggy LeMone
Mesoscale & Microscale Met./NCAR
(303) 497-8962
Fax: (303) 497-8520

Larry Mooney
Denver NWS Forecast Office
10230 Smith Road
Denver, CO 80239
(303) 361-0661
Fax: (303) 371-5508

Tom Potter
Head, NWS Western Region
PO Box 11188
Salt Lake City, UT 84147-0188
(801) 524-5122
Fax: (801) 524-5246

Tom Stewart
Ctr for Policy Research
Milne 300
State University of New York
Albany, NY 12222
(518) 442-3850
Fax: (518) 442-3398

Ed Szoke
Mesoscale & Microscale Met./NCAR
(303) 497-8961
Fax: (303) 497-8181

Lesley Tarleton
ESIG/NCAR
(303) 497-1647

IMPACTS:

Stan Changnon
Illinois State Water Survey
605 East Springfield
Champaign, IL 61801
(217) 333-2210
Fax: (217) 333-6540

Hal Cochrane
Ag. and Nat. Res. Economics
Clark Building
Colorado State University
Fort Collins, CO 80523
(303) 491-6493
Fax: (303) 491-0528

Mary Downton
ESIG/NCAR
(303) 497-1604

David George
ERL/NOAA
Boulder, CO
(303) 497-6840
Fax: (303) 497-6951

Richard Katz
ESIG/NCAR
(303) 497-1614

Kathleen Miller
ESIG/NCAR
(303) 497-1615

Steven Rhodes
ESIG/NCAR
(303) 497-1621

Bill Riebsame
Nat. Hazards & Res. Application Ctr.
Campus Box 482
University of Colorado
Boulder, CO 80309-0482
(303) 492-6818
Fax: (303) 492-6924

Art Shantz/Debbie Davis
Research Applications Prog./NCAR
(303) 497-8496

Jon Zufelt
CRREL
US Army Corps of Engineers
72 Lyme Road
Hanover, NH 03755-1290
(603) 646-4275
Fax: (603) 646-4278

RESPONSE:

Margaret Davidson
SC Sea Grant Consortium
287 Meeting Street
Charleston, SC 29401
(803) 727-2078
Fax: (803) 727-2080

Eve Gruntfest
Department of Geography
Univ. Colorado at Colorado Springs
Colorado Springs, CO 80933-7150
(719) 593-3513
Fax: (719) 593-3362

Dale Jamieson
Ctr. for Values & Social Policy
Campus Box 232
University of Colorado
Boulder, CO 80309
(303) 492-6539
Fax: (303) 492-5105

Gordon McKay
122 Brooke Street
Thornill, Ontario L4J 1Y9
(416) 889-3752

Roger Pulwarty
CIRES/Campus Box 216
University of Colorado
Boulder, CO 80309
(303) 492-6115
Fax: (303) 492-2468

Robert Stoffel
Emergency Response Institute
4537 Foxhall Drive, NE
Olympia, WA 98506
(206) 491-7785

Don Wilhite
Dept. of Agricultural Meteorology
University of Nebraska
241 Chase Hall
Lincoln, NE 68583-0728
(402) 472-6707
Fax: (402) 472-6338

Appendix 3

Short Biographical Sketches of Participants

Barbara Brown is Associate Scientist in the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. She holds master's degrees in statistics and environmental sciences, from Oregon State University and the University of Virginia, respectively. Her research interests are in applications of statistics in the atmospheric and environmental sciences. She has studied various aspects of the quality and economic value of weather information, as well as user requirements for such information.

Stanley Changnon is Chief Emeritus and Principal Scientist at the Illinois State Water Survey and Adjunct Professor in Geography at the University of Illinois. Professor Changnon has done extensive work on the impacts of weather and climate on water resources and agriculture. Other areas of study include advertent and inadvertent weather modification, climate change and severe storms.

Harold Cochrane is Professor of Economics at Colorado State University, specializing in resource and environmental management, economics of hazards, and macroeconomics. He has published on such topics as the economics of weather warnings, floodplain management, global warming, the socioeconomic consequences of nuclear war, and natural hazard damage assessments.

Margaret Davidson has been serving as the Executive Director of the South Carolina Sea Grant Consortium since 1983. She is a professor with the Institute for Public Policy Studies at the College of Charleston, and holds adjunct appointments with Marine Science at the University of South Carolina and in Agriculture and Applied Economics at Clemson University. She earned her BA and JD from Louisiana State University and MMA from the University of Rhode Island. Her work has focused on climate change, changing sea levels, and local adaptation to global phenomena. She also makes more than 40 presentations a year on a wide range of coastal issues to civic, private and professional organizations.

Deborah Davis is Special Assistant to the Director of the Research Applications Program at the National Center for Atmospheric Research. She works with a broad network of aviation system users and researchers on hazardous weather. Her work includes the exchange and dissemination of information about aviation weather research and the transfer of hazardous weather forecast and detection technology.

Mary Downton is Associate Scientist and computer programmer in the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. Her research interests include the impacts of weather and climate on society and the application of statistical methods to climate-related problems.

David George is responsible for coordinating climate and global change research in the Director's Office of the Environmental Research Laboratories (ERL) of the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado. He holds an MBA and worked in the National Weather Service (NWS) Headquarters as Severe Storms Program Leader, before coming to ERL's Program for Regional Observing and Forecasting Services (PROFS) as Service Requirements Team Leader. While working as a forecaster, he developed a strong interest in users' needs and the value of weather services, and is currently heavily involved in the socioeconomic aspects of NOAA research and services.

Michael H. Glantz is Senior Scientist with the National Center for Atmospheric Research (NCAR) and Head of the Environmental and Societal Impacts Group, a program of NCAR. He earned a PhD in political science (international relations) from the University of Pennsylvania. His research focuses on how climate affects society and how society affects climate, especially how the interaction between climate anomalies and human activities can affect quality of life. He is a member of numerous national and international committees and advisory bodies and is a recipient of United Nations Environmental Programme (UNEP)'s "Global 500" award. He has edited several books and is the author of numerous articles on issues related to climate, environment and policy.

Eve Gruntfest is Associate Professor of Geography at the University of Colorado, Colorado Springs. She has been active in flash flood mitigation research since the Big Thompson flood disaster of 1976. Recent work has included the development of a Flood Hazard Mitigation Plan for the city of Manitou Springs, Colorado; the organization of a multidisciplinary symposium ten years after the Big Thompson flood to assess ways in which this disaster served as an opportunity to reduce future vulnerability; and the review of the status of flood detection and warning systems in the US for the US Bureau of Reclamation. With support from the National Science Foundation, she is currently directing a three-year comprehensive assessment of the flash flood hazard in the US.

William Hooke is the Executive Director, Office of the Chief Scientist, National Oceanic and Atmospheric Administration (NOAA). He has been Director of the National STORM Program Office since 1985. He is also a member of the National Academy of Sciences/National Research Council Advisory Committee on the International Decade of Natural Hazard Reduction, as well as a member of numerous other national and international committees and advisory panels. He is author of over forty publications, and co-author of the book, *Waves in the Atmosphere.* His earlier research was in ionospheric physics. He has been in science administration and management since 1973.

Dale Jamieson is Director of the Center for Values and Social Policy and Associate Professor of Philosophy at the University of Colorado at Boulder. He is also an adjunct scientist with the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. He has worked on various topics in ethics, political philosophy, and environmental philosophy. He has written about various social aspects of global environmental problems, including difficulties in forecasting the future, policy problems about biodiversity loss, inadequacies of purely economic approaches to environmental problems, and the new values that are needed to cope with life in an interconnected, highly technological world.

Richard Katz is a scientist in the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. He has a PhD in statistics and works on applications of statistics to environmental problems. These application have included the decision–analytic assessment of the economic value of information about weather and climate.

Margaret "Peggy" LeMone is a scientist in the Mesoscale and Microscale Meteorology Division at the National Center for Atmospheric Research. She studies bands of deep convection, such as squall lines, and also does research on the winds, clouds, and the transfer of heat, moisture, momentum, and pollutants in the boundary layer (lowest few kilometers) of the atmosphere. She is author or co-author of numerous articles in scientific journals, and of popular articles on weather and about women in meteorology; and she contributed to the weather and climate chapters in the District of Columbia high school school text, *Earth Science*.

Gordon McKay is former Head of Environment Canada's Canadian Climate Centre. Following careers as operational meteorologist and hydrometeorologist, he developed Canada's national program in applied climatological research, pioneered in the development of the Canadian Climate Program, and served extensively on climate-related committees and panels of the world and of international and national scientific organizations. In retirement, he organized and managed the 1988 Toronto conference on the 'Changing Atmosphere' and is adjunct senior scientist to the Division of Hydrology, University of Saskatchewan.

Kathleen Miller is an economist with the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. She holds a PhD from the University of Washington. Much of her research has focused on aspects of the interaction between climate and water institutions. She has also studied the socioeconomic impacts of climatic variability, including the effects of severe freezes on Florida's citrus industry and the effects of climatic variations on the Pacific Northwest salmon fishery. Her other research interests include the economic management of climatic uncertainty.

Larry Mooney is the Area Manager for the National Weather Service operations in Colorado. Prior to assuming this position, he served as Deputy Meteorologist-in-Charge of the National Weather Service Office at Norman, Oklahoma. He has served as project leader for a number of operational research and test initiatives, including the evaluation of the Next Generation Weather Radar (NEXRAD). He has considerable experience with severe weather warning operations and natural disaster preparedness.

Thomas D. Potter is Regional Director of the Western Region of the National Weather Service, based in Salt Lake City, Utah. He holds a PhD in atmospheric sciences from the Pennsylvania State University. He was Director of the World Climate Programme and later Director of the World Weather Watch at the World Meteorological Organization in Geneva, Switzerland, from 1982–1989. Prior to those assignments, he was Director of the NOAA Environmental Data and Information Service and the Director of the National Climate Center. He was on the faculty of the Atmospheric Sciences Department at St, Louis University following his tour as Vice-Commander of the USAF Air Weather Service. He has been involved in impact studies since 1975.

Roger S. Pulwarty is a doctoral candidate in Geography at the University of Colorado, Boulder. He holds a BS in Atmospheric Sciences (Honors) from York University and an MA in Geography from the University of Colorado. He has taught courses in natural resource management and on land forms and soils at CU Boulder, and has published papers on various aspects of climate over the tropical Americas.

Steven L. Rhodes is a political scientist with the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. He earned a PhD from the University of Colorado in 1980. He has written about environmental issues such as acid rain and other atmospheric pollution, renewable energy technology policy, the use of climate-related information in resource management, desertification, and cleanup of contaminated federal facilities in the United States. He has managed and participated in the preparation of several environmental impact assessments.

William E. Riebsame is Director of the Natural Hazards Research and Applications Information Center and Associate Professor of Geography at the University of Colorado. The Center was founded in 1976 as a national clearing house of information on the social and economic aspects of natural hazards and their mitigation. His work has been on the social impacts of weather and climate hazards, and adaptation to environmental change. His recent work includes studies of the effects of climate change on water resources management and trends in meteorological hazards vulnerability in the US.

Art Shantz is Associate Director for Strategic Planning in the Research Applications Program at the National Center for Atmospheric Research (NCAR). He plans the mechanisms for developing and transferring atmospheric science and engineering applications from field and laboratory demonstrations to systems addressing public and private sector needs. He is involved in the initiation and development of a multi-year, aviation weather research program for NCAR. He received his PhD in political science from the University of Michigan in 1972.

Thomas R. Stewart is Acting Director and Director for Research at the University Center for Policy Research, the State University of New York at Albany and an adjunct professor in the Graduate School of Public Affairs, the Nelson A. Rockefeller College of Public Affairs and Policy. He is interested in the study of judgment and decision-making and environmental policy. He has studied the use of weather forecasts in agriculture and is currently investigating how weather forecasters make use of the large amounts of information provided by advanced computer workstations.

Robert "Skip" Stoffel is co-founder and current President of the Emergency Response Institute, a small publishing, training and consulting company located in Washington State. He has over 16 years of practical, hands-on experience in all aspects of emergency management and "search and rescue" (SAR) response at local, state and federal levels. He has written, co-authored and/or edited 18 training manuals and books on emergency management and SAR. He is currently doing training, publications development and other consulting work for state and local government agencies, business and industry, colleges and universities, volunteer groups and some organizations abroad. His company's publications and training courses are now being used in every region of the US.

Edward J. Szoke is Associate Scientist with the Mesoscale and Microscale Meteorology Division of the National Center for Atmospheric Research. He holds a joint position with the Forecast Systems Lab and the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). The position includes a mix of applied research and online forecasting at the NWS Forecast Office in Denver, Colorado, as part of a new type of interaction between the research and operational branches of meteorology, called the Experimental Forecast Concept. He has published a number of journal and conference papers ranging from tropical radar studies to mesoscale analysis and forecasting.

Lesley F. Tarleton is a visiting scientist in the Environmental and Societal Impacts Group at the National Center for Atmospheric Research. She earned a PhD in geography (climatology) from the University of Colorado. Her recent work with a water engineering firm included assessments of flash floods and flash flood warning systems for city governments, and environmental site audits. As visiting professor at the University of Oklahoma, she taught courses in meteorology, climatology, and climate change. She has done mesoscale meteorology research on convective storms at NCAR and co-authored several journal papers on this topic.

Donald A. Wilhite is Associate Professor of agricultural climatology in the Department of Agricultural Meteorology at the University of Nebraska–Lincoln. He is

Director of the International Drought Information Center at the University of Nebraska and has an adjunct appointment with the National Center for Atmospheric Research. He specializes in studies on the impact of climate on society and societal response to climatic events.

Jon Zufelt is Research Hydraulic Engineer with the US Army Cold Regions Research and Engineering Laboratory (USACRREL) in Hanover, NH. He has worked on a variety of topics in river and ice hydraulics, concentrating on methods of flood control. His writings focus on methods of ice jam control, including their effects on open water hydraulics and on the environment. His present areas of interest include the unsteady aspects of ice jam formation and numerical modeling of river ice processes.