February 12, 2004

Annual Report (2003/2004)
NCAR Weather and Climate Impact Assessment Science Initiative

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I. Introduction

Climate and weather create hazards and opportunities for society at multiple scales. However, most of society does not have scientific expertise, and most scientists are unfamiliar with how societal decision-making processes work. In the climate context, this process of bridging between scientific knowledge and societal need is known as "*assessment,*" while the weather community might more familiarly call it "developing usable forecast information." Assessment can be broadly defined as "the entire social process by which expert knowledge related to a policy problem is organized, evaluated, integrated and presented in documents to inform policy or decision-making" (GEA 1997). Assessments such as the U.S. National Assessment of the Potential Consequences of Climate Variability and Change (USNA) and the international Intergovernmental Panel on Climate Change (IPCC) assessment reports focus on synthesizing, evaluating and reporting on what is known about climate variability and change and its impacts

Not all processes and products that fall under the rubric of assessment are the same however. The NCAR Assessment Initiative focuses on impact assessments, a more narrow focus that aims to assess the severity, likelihood, and effects of a given phenomenon, such as climate change and extreme weather events, on a system of concern to society, such as agriculture, health or energy supply. Within this area of research lie a number of critical scientific gaps that currently limit our ability to effectively assess future impacts and provide quality information to decision-makers. These difficulties include differing perceptions of uncertainty and extremes between climate scientists, social scientists, and decision-makers; lack of tools for quantifying current and future frequency of extremes; and so on (e.g., Moss and Schneider 2000, Webster et al. 2003, Parson et al. 2003). This initiative concerns both filling these critical gaps and integrating the different scientific disciplinary research necessary for informing decision makers regarding current and future weather and climate hazards.

The Weather and Climate Impacts Assessment Initiative is organized around three themes: characterizing uncertainty in all phases of impacts assessment, extreme weather and climate events, and climate and health. It is mapped onto the following specific scientific objectives.

- To quantify uncertainties related to multiple forcings (i.e., greenhouse gases plus land cover change, and natural forcings--solar variability, aerosols from volcanic eruptions) in climate models;

- To characterize uncertainty on regional scales in climate projections that support decision-making;

- To determine new robust measures of changes in weather and climate extreme events and their uncertainties (using extreme value theory), for extremes relevant to societal impacts;

- To nurture an interdisciplinary research community to address the interactions between climate and human health; and

- To work towards end-to-end integrated projects in extreme events and uncertainty that encompass physical science, impacts, and decision-making.

These objectives are fulfilled by a number of individual tasks (described below) that have been selected because they address identified weaknesses of existing national and international assessment processes such as lack of uncertainty estimates for climate projections, missing elements of scenarios, or differences in the perceptions of the most appropriate way to consider extremes (e.g., Moss and Schneider 2000, Webster et al. 2003, Parson et al. 2003).

NCAR is uniquely poised to study these topics, as it has a mission firmly grounded in the atmospheric sciences, including climate and weather, as well as the responsibility as a national center to provide science in service to society. NCAR also is staffed by renowned scientists in these areas and has a multidisciplinary structure--the capability to mobilize scientists from different disciplines around a central topic. This initiative is also of critical relevance for NCAR because it provides timely, needed input to ongoing processes of national and international importance—for example the IPCC, and future national and regional assessments.

II. Functional Organization Chart

This section lists the major projects, and major personnel based on NCAR division and external participation.

Task I. Characterizing Uncertainty in Impact Assessment Science
Subtask A. Uncertainty in model simulations
1. ESIG - (Mearns, Tebaldi)
2. CGD - (Meehl, Wigley)
3. GSP - (Nychka, Drignei)
4. RAP - (Yates)

Subtask B. Land Cover Forcing in SRES
1. ESIG - (Mearns, Feddema- U of Kansas)
2. CGD - (Bonan, Oleson)

Subtask C. Climate Variability of Past Centuries
1. ESIG - (Wahl)
2. CGD - (Amman, Tomas, Graham-Scripps Institution)
3. E&O - (Johnson, Forster)

Subtask D. Managing Fire Risks
1. ESIG - (Miller, Katz, Barry, Cullen- U of Washington, Muller- U of Colorado B)

Task II. Methods and Assessment of Extreme Weather and Climate Events
Subtask E. Extremes toolkit
1. ESIG - (Katz)
2. RAP - (Brown, Gilleland)
3. GSP - (Nychka)

Subtask F. Extremes in Aviation
1. RAP - (Politovich, Brown, Pocernich)

Subtask G. Downscaling of Extremes
1. ESIG - (Katz, Tebaldi, Brooks- NSSL)

Subtask H. Extreme Events in climate models
1. ESIG - (Katz, Naveau- U. of Colorado, Smith- U of N Carolina, Schneider)
2. GSP - (Nychka)
3. CGD – (Meehl, Tebaldi)

Subtask I. Flood Hazards
1. ESIG - (Downton, Morss, Wilhelmi, Crandell, Gruntfest- U of Colorado, CS)
2. GSP – (Nychka, Schneider)

Task III. Development of a Climate/Human Health Program
Subtask J. Climate and Health
1. ESIG - (Mearns, Patz- Johns Hopkins U)

Task IV. Project Integration and Decision-Making (To be enhanced, FY05. ESIG, CGD, GSP)
Subtask K: Uncertainty in Decision-Making (Moser, Downton, Morss, Miller, Dilling, Wilhelmi, Wigley, Nychka, Wahl, Mearns)
Subtask L: Decision-Making Across Scales (Dilling, Moser, Mearns)
Subtask M: Theme Integrations (Mearns, all)
Subtask N: NARCCAP (Mearns)
Subtask O: National and International Outreach (All)
Subtask P: Project Management - (Dilling)

Unit Defintions: ESIG – Environmental and Societal Impacts Group; CGD - Climate and Global Dynamics; RAP - Research Applications Program; GSP - Geophysical Statistical Project; E&O - Education and Outreach.

III. Progress to Date, Plans for FY04-05

A. Task 1. Characterizing uncertainty in impact assessment science

The projects grouped under this theme tackle some of the key uncertainties that have been identified by previous assessment processes. Subtasks 1, 2 and 3 involve characterizing the uncertainty of Atmosphere Ocean General Circulation Models (AOGCMs) to better express levels of confidence in future projections of climate change. The fourth subtask focuses on wildfire policy and the use of decision models to understand how individuals perceive wildfire risk and uncertainty. NOTE: Most of these

projects began in mid-FY03 or FY04 and therefore can expect many more additional results as the projects mature.

1. Progress to Date:

Subtask A: Uncertainty in model simulations. To quantify the uncertainty surrounding the origin of low frequency variability in the observations of globally averaged surface air temperature in 20th century climate, analyses have been undertaken to quantify the influences of various anthropogenic and natural (volcanic and solar) forcings over the 20th century in the PCM. Early century warming is shown to be mainly due to solar forcing, with enhanced tropical convection contributing to amplifying the solar forcing. Late century warming is attributed mainly to increases of anthropogenic greenhouse gases. *We have developed a Bayesian statistical model that, for the first time, synthesizes multiple AOGCM's climate projections and historical data to produce a probability distribution for future climate changes on regional scales*. These distributions will then be used to propagate uncertainty for future climate to finer scales and be evaluated in a hydrologic analysis for watersheds in California, to produce probabilistic estimates of the impacts of climate change on water resources. We have also explored the range of spatial scales at which pattern-scaling works, and attached uncertainty to the scaled signals of climate change by modeling the error as a gaussian random field over the AOGCM grid. In addition, users can now directly access the models and data used by the IPCC TAR for its projections of future global-mean temperature and sea level rise through the MAGICC/SCENGEN software package (downloadable from the CGD web page).

Subtask B: Land cover forcing in SRES. The separate and combined uncertainties of land cover change and increased greenhouse gases (ghgs) (and aerosols) based on components of the IPCC SRES scenarios are being tested through a series of equilibrium and transient PCM/LSM model runs. *These are the first such runs performed with a full AOGCM that incorporates changes in land cover from an SRES scenario.* There is significant sensitivity to land cover datasets. For example, land cover changes such as replacing forested land cover with agricultural lands could induce a mid latitude cooling effect. These in turn can alter the Asian monsoon intensity and global circulation features. Two transient simulations have been completed that show that the inclusion of the land cover change results in substantial further modifications in the future regional temperature changes, on the same order of magnitude as the effect of the ghg and aerosols forcing alone, suggesting a very significant effect for future climate change.

Subtask C: Uncertainty of climate variability in past centuries. Three types of uncertainty in millennial scale simulations have been explored: uncertainty in the solar forcing and aerosols from volcanism; uncertainty in the proxy data used to evaluate the climate of the past; and uncertainty in the teleconnections between large scale dynamics and regional climate. Results suggest solar forcings of smaller amplitude are most consistent with simulation of past climate trends as well as paleo-reconstructions. *For the first time, the "stationarity" of proxy data relationships to climate patterns has been systematically examined over long time periods using model output, demonstrating that uncertainty in climate proxies using short calibration periods can be underestimated*.

Subtask D: Managing fire risks. Research in the wildfire risk subtask has focused on community and homeowner responses to wildfire risk and national wildfire policy. A case study area in the wildland-urban interface of Boulder County is measuring how the perception of the uncertainty over the likelihood wildfire damage to property affects the willingness of a homeowner to invest in preventative measures.

2. Task 1 FY04-05 Statement of Work

Subtask A. The Bayesian model will be expanded to analyze joint probabilities of temperature and precipitation. These results will be presented to water resource and other policy makers to refine data presentation. We will downscale the large regional results used in Tebaldi et al. to Northern California watersheds and apply results of stochastically generated weather time series to water resource models. Pdfs of water resources for Northern California and pdfs for south central China for rice and wheat yields will be produced.

Subtask B. Further experiments with a lower end SRES scenario (e.g., B1) will be performed in 04 to try to cover the full envelope of land cover and atmospheric constituent forcing. In FY05 other factors concerning land surface changes will be investigated including inclusion of multiple crop types, soil degradation, and expanded urbanization (tied to demographic shifts). Higher resolution regional models will be employed, particularly for the modeling of expanded urbanization.

Subtask C. Our confidence in characterizing anthropogenic influence on current and future climate partially rests on our ability to estimate past climate variability from proxy data. The multi-proxy approach of Mann, Bradley, and Hughes (MBH) will be applied to paleo-model output to understand variability and biases in this method, and how it can be better used in data-model comparisons. We plan to bring together a group of leading paleo-reconstruction experts to outline key remaining uncertainties in the global and regional climate patterns and mechanisms of the past millenium, and develop a program of improved mathematical reconstruction tools for reducing these uncertainties. Climate runs will be conducted to further explore climate sensitivity to solar forcing, the role of the tropics in climate reconstructions, and regional behavior of the East Asian Monsoon.

Subtask D. In FY04-5, this project will be incorporated into the larger decision-making and uncertainty project being developed as an integrating activity (see **Task 4**).

B. Task 2: Methods and assessment of extreme weather and climate events

Loss of life and economic damage from extreme weather and climate events have been steadily increasing since the 1930's in the United States (Changnon and Easterling 2000) and can be attributed to the increased vulnerability as population shifts to coastal areas (Kunkel et al. 1999). There is also considerable evidence that shifts in the frequency of extremes may occur with changes in climate, thus exposing additional segments of the population and infrastructure in harm's way (Easterling et al. 2000). Projects under Task

2 fill several of the gaps in knowledge needed to assess the frequency, intensity and impacts of extreme events for the IPCC Fourth Assessment Report (IPCC Workshop on Changes in Extreme Weather and Climate Events, Beijing China, 2002).

1. Progress to Date:

Subtask E: Extremes toolkit. There is a strong need for updating the types of statistics that are applied to the analysis of weather and climate extreme events. *The "Extremes toolkit" is a user-friendly, open source application developed to make it easy to apply the statistical theory of extreme values to weather and climate extremes and their impacts.* The toolkit has now been nearly completed, and documentation includes a tutorial to facilitate its use by nonstatisticians.

Subtask F: Extremes in aviation. Icing of airplane equipment is a hazardous situation that can result in loss of life and economic disruption. *NCAR is developing a statistical model to forecast the potential of icing in order to improve decision-making during extreme weather conditions.* Experiments were conducted using data from research flights where icing conditions could be monitored. Variables important to forecasting icing potential have emerged from this study and include the initial forecast, temperature and relative humidity.

Subtask G: Downscaling of extremes. Severe thunderstorms (those containing large hail, strong wind gusts, or tornadoes) carry with them the potential for damage from several factors, including lightning, hail, extreme precipitation and high winds. So far, however, it has been difficult to express how the frequency of these types of high impact local weather phenomena might change under a changing climate. Work is needed to connect variables reliably reproduced by climate models with the occurrence of severe thunderstorms Relationships between sounding data, re-analyses and severe thunderstorms and tornadoes in the U.S. are being extrapolated to the rest of the world using a comprehensive new database.

Subtask H: Extreme events in climate models and spatial scaling of extremes. Analyses are being performed to study changes in variability and extremes in ensembles of future climate projections. This work is using statistical analyses of extremes as well as threshold methods to study changes in weather and climate extremes in the PCM (a global coupled climate model). *An analysis of frost days in the PCM shows that change in sea level pressure, indicative of regional atmospheric circulation changes, is a prime contributor to the pattern of reductions in frost days, with soil moisture and clouds of secondary importance.* We are currently examining the occurrence of heat waves in the 20th century climate model simulations, and assessing their changes in the future climate model projections.

Subtask I: Climate variability and uncertainty in flood hazard planning

Extreme storms create serious flood hazards in areas of steep topography such as the Colorado Front Range. Estimates of flood risk, however, are highly uncertain because of the sparsity of data and the high spatial and temporal variability in precipitation. The study to date has obtained information on past storm and flood events, how Colorado

communities currently manage and insure floodplain risks, and how meteorological information affects the decision-making process. *The study identified serious inadequacies in the precipitation frequency information available for the foothill and mountain regions of Colorado and other Rocky Mountain states*. Precipitation data is now being analyzed using extreme value statistics and GIS maps are being produced.

2. Task 2 FY04-05 Statement of Work

Subtask E. In FY04, the web-based version of the Extremes Toolkit and tutorial will be completed, and disseminated to a number of potential users outside of NCAR for extensive testing. An expository article in BAMS or EOS will further publicize the availability of this product to the larger community.

Subtask F. The aviation hazards project will expand its application of extreme value theory to other types of hazards, including convective weather events based on data from the NCAR Auto-nowcasting system.

Subtask G. Better relationships between events and sounding parameters for thunderstorms will be derived for the world-wide data base. The relationships developed in the soundings and reanalyses will be applied to future climate scenarios from AOGCMs and regional climate models. A General Analysis Tool for use in determining future changes in these phenomena based on global and regional climate model output will be produced and provided to the research community. Linkages will be developed between subtasks 2 and 3 and results will be further analyzed in relation to mosaic radar reflectivity for smaller scale convective events.

Subtask H. To address the problem of how extremes for temperature and precipitation scale over space and how they are represented in current AOGCM projections this task will conduct an inter-comparison concentrated on Western North America among point located observational data, gridded reanalysis fields and model output from global and regional climate models. The result will be a rigorous characterization of the bias in extremes events simulated by a numerical model and the relationship between the extremes gridded average fields and point locations.

Subtask I. For the rest of FY04, publications will be written on decision-making under uncertainty in the context of flood hazard planning and lessons learned on the interaction of scientific information, policy and uncertainty. Statistical methods will be used to develop prototype methods for developing a new precipitation frequency atlas for the Rocky Mountain region. In FY05, this work will be folded into the integrated program in Decision Making and Uncertainty under **Task 4.**

C. Task 3: Develop a Climate and Health Program

The area of the human health impacts of climate is complex, requiring the interdisciplinary efforts of health professionals, climatologists, biologists, and social

scientists to analyze the myriad relationships among physical, biological, ecological, and social systems relevant to health impacts. This is an impact area where an integrated assessment framework is obviously most needed Burke et al., 2001, Smolinski et al., 2003; McMichael et al., 2003). The goal of this task is to develop a unique interdisciplinary research and educational program that will bring together leading institutions in health and climate science (i.e., NCAR, Johns Hopkins U, CDC). The task has important connections to the other tasks, including extreme events and characterizing uncertainty in the relationship between climate and health (McMichael, 2003).

1. Task 3: Progress to Date

A small amount of funding from the Assessment Initiative is being used to develop program plans and leverage funding from outside agencies. A workshop was held in the summer of 2003 to help organize intellectual resources at NCAR, Johns Hopkins, and CDC. *From this workshop plans have been laid for a major Climate/Health Meeting at NCAR in July 2004 that will also act as an additional ASP summer colloquium for students interested in pursuing research in climate/health interactions*. A steering committee for the workshop and program planning has been formed.

2. Task 3: FY04-05 Statement of Work

Following on the Summer Meeting, a report will be completed that will clearly describe the crucial research problems in climate and health, prioritize them, and set out a research agenda, which will include a vigorous post-doc and visitor program to work on issues topics such as vector-borne diseases and heat morbidity/mortality.

Task 4: Overall Project Integration and Service to Assessment Processes

The themes of uncertainty, extremes and climate and health are key research gaps in advancing climate impact assessment science. However, in order for any scientific information to be useful in decision-making it must be credible, legitimate, and salient in the decision context at hand (Clark and Dickson 1999). This seemingly straightforward requirement contains a myriad of difficulties for bridging the science-society interface and effectively informing societal decisions. To address this challenging goal, the initiative will initiate a fourth component that will focus on decision-making specifically, examining the problem of uncertainty from the perspective of the decision-maker, as a complement to the scientific perspective in tasks 1-3. The objectives of this component are to develop a systematic approach to determining where the decision-making environment is particularly sensitive to uncertainty in the information provided—i.e. when does uncertainty matter? This approach can be visualized as working backward from a given impact or decision-making problem to trace the information pathways relevant to the decision—jumping up backward through the "cascade of uncertainties" as it were. This initiative will examine the usefulness of an "end-to-end" characterization of uncertainty and alternate approaches in climate change research relevant to climate impacts and decision-making on various spatial scales (i.e. national/international policy through to regional and local resource management).

1. Task 4. Progress to Date:

In July 2002 Mearns held a workshop on Climate Projections, Change, Uncertainties, and Scenarios for Impacts Assessments (www.esig.ucar.edu/projections), which was highly visible nationally, and successful in attracting additional participants into the initiative. She has also conducted a number of visits to other centers active in the initiative themes (detailed in the appendix) that have greatly increased the visibility of NCAR in this area.

2. Task 4. FY04-05 Statement of Work

Subtask K: Uncertainty in decision-making. Moser will attend and synthesize a workshop led by Moss and Schneider in March 2004 focusing on downscaling SRES scenarios and characterizing the uncertainty inherent in that approach. The workshop is expected to generate a research agenda that the Assessment Initiative will build upon to focus its work in uncertainty and decision-making. Activities that will be explored in FY04 are: developing a framework for synthetic analysis of case study work on uncertainty in decision-making to map out sensitivities to uncertainty (the "impacts-driven" approach); understanding the scales of decision-making relevant to characteristics of the physical system such as land use types (see subtask L); evaluating the sensitivity of the use of information uncertainty or certainty to decision-making context; and developing accessible methods for communication of uncertainty to non-scientist decision-makers.

Subtask L: Decision-making across scales. One of the emerging themes of research on improving the use of climate and weather information for societal decision-making is how the issues of spatial and temporal scale among different decision-making processes and institutions affect needs for climate and weather information (Cash and Moser, 2000). The assessment initiative will focus on a study of scales of decision-making that complements the scales of the physical phenomena being addressed in the first three tasks (e.g., regional water management in California; heat wave mitigation; regional and local climate policy implementation). Subtask L also incorporates work on wildfire from Subtask D starting in FY05. Future work on wildfire involves working with Brian Muller of the Wildfire Initiative and studying the empirical relationship between fire probabilities and homeowner investment decisions.

Subtask M: Theme integrations. By the end of FY05, uncertainty research from Task 1 will be evaluated to characterize how uncertainty in climate models, SRES scenarios, and paleo-climate can be better communicated to decision-makers and scientists in the impact assessment community. Similarly, work in Task 2 will be evaluated and integrated to understand how work in on extreme value theory, extremes in heat waves, frost days, thunderstorms and other extreme events can be applied to specific decision-making contexts. This activity will also include a specific linkage with the Water Cycle across Scales Initiative to further develop the analysis of processes of extreme precipitation and the spatial scaling of extremes.

Subtask N: NARCCAP. The North American Climate Change Assessment Program (NARCCAP), is a program in which multiple Regional Climate Models (RCMs) will be run over North America (mainly US and Canada) using boundary conditions from multiple AOGCMs in a 4 X 4 experiment (4 RCMs and 4 AOGCMS). This program will enhance connections with the national and international community and seed a potential national impacts program in the future. Funds will be sought externally for this subtask.

Subtask O: National and International Outreach. Enhance interactions between national and international Assessment Science programs and members of the NCAR Assessment Initiative. This will require the establishment of an enhanced visitors program, facilitating international exchange of knowledge on assessment science.

Subtask P: Project management. Assist in theme integrations and communication of initiative internally and externally.

IV. Linkages

University Scientist Involvement [Major Collaborators only—many others not listed]
Johan Feddema, University of Kansas
Nick Graham, Scripps Institution of Oceanography
Alison Cullen, University of Washington
Harold Brooks, National Severe Storms Laboratory, University of Oklahoma
Philippe Naveau, University of Colorado
Richard Smith, University of North Carolina
Eve Gruntfest, University of Colorado, Colorado Springs
Jonathan Patz, Johns Hopkins University
Bill Easterling, Pennsylvania State University

V. Publications

Task 1:

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Tebaldi C, Smith RL, Nychka D, Mearns LO. Quantifying uncertainty in Projections of Regional Climate Change: a Bayesian Approach to the Analysis of Multimodel Ensembles, submitted to Journal of Climate.

Wahl E, 2003. Assigning Climate Values to Pollen Surface Sample Sites and Validating Modern Analog Climate Reconstructions in the Southern California Region. Madroño, 50:4, in press

Wahl E, 2004. A General Framework for Determining Cutoff Values to Select Pollen Analogs with Dissimilarity Metrics in the Modern Analog Technique. Review of Palaeobotany and Palynology, in press

Wahl ER, Ammann C. Stationarity and Fidelity of Simulated El Niño-Southern Oscillation Climate Proxies over the Last Millenium in Forced Transient AOGCM Output. In prep. To be submitted to Climate Dynamics

Task 2:

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Appendix 2: Initiative Diplomacy

An important goal of the Assessment Initiative is building linkages with US and non-US programs in Impacts Assessment. While on a collaborative leave at the Abdus Salam Centre for Theoretical Physics, Trieste, Italy, L. Mearns has visited a number of research institutes in Europe and presented talks about the NCAR Assessment Initiative. This included presentations and/or discussions at: Potsdam Institute for Climate Impacts Research (PIK), Berlin Free University, the Tyndall Centre, the Climate Research Unit (CRU), the Environmental Change Institute (ECI), Oxford, the UK Climate Impacts Project (UKCIP), the Swedish Environmental Institute, Oxford (SEI), Reading University Dept. of Meteorology, at the STARDEX (European Program on Downscaling of Extremes) and MICE (European program on impacts of extremes) meetings. She also plans to visit the International Human Dimensions Programme (IHDP) office in Bonn before her return to NCAR in early April 2004. In all these visits great enthusiasm was expressed for the NCAR Assessment Initiative as well as interest in establishing linkages with NCAR. In response to this enthusiasm, one of the plans for FY2005 will be the establishment of a more active international visitors program to build on these initial contacts. Already, at least 10 individuals have expressed interest in visiting NCAR based on their interest in one or more of the three themes.