June 2001

The Weather and Climate Impact Assessment Science Initiative

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This initiative is composed of three elements, which were chosen based on consideration of recurring themes and issues that have emerged in assessments of the effects of climate variability and change on human society and the environment, and in which there are important research gaps. The two most recent noteworthy assessments have provided considerable material for consideration of the state of assessment science and what aspects of it would most benefit from further development. These are the U. S. National Assessment and the Intergovernmental Panel on Climate Change Third assessment Report (TAR), both published in 2001. A number of NCAR scientists have been involved in one or both activities, and there is a wealth of experience at NCAR in earlier assessment activities (e.g., SAR and FAR). This initiative also directly concerns weather impacts, which is a rapidly expanding research area. The three aspects of assessment science discussed in this initiative are: 1. characterizing uncertainty in various phases of assessment work, 2. extreme weather and climate events, and 3. climate/health interactions. The initiative encompasses both research and service or application components. Aspects of the initiative are also highly congruent with the role of NCAR as a national center that should be providing services to the broader atmospheric sciences (e.g. university community).

I. Characterizing Uncertainty in Impact Assessment Science

"To know one's ignorance is the best part of knowledge" (Lao Tzu).

The importance of characterizing uncertainty in all aspects of climate impact assessment work is becoming more obvious as assessment science develops. We consider here five areas that will greatly benefit from improved characterization of uncertainty. Additional areas may be considered as the Initiative develops. These are: A. emissions scenarios; B. climate projections and scenarios; C. impacts models (e.g., agriculture and ecosystems models); D. environmental data sets these models use (e.g., climate observations, soils); and E. decision-making.

A. Emissions Uncertainties

Uncertainties in future greenhouse gas emissions are very considerable, since these are based on the very wide range of uncertainties attendant on our predictions of future economic, political, and technological development of the world over the next one hundred years. This also, of course, figures prominently in uncertainties in climate projections (see B. below).

Work is being planned in collaboration with the Battelle Pacific Northwest Laboratory to improve on the Special Report on Emissions Scenarios (SRES) emissions scenarios developed for the IPCC Third Assessment Report (TAR), and to assess, in probabilistic terms, the climate implication of emissions scenario uncertainties. Areas under consideration are: implications of troposheric ozone-related and air-quality issues for future emissions of the ozone precursors NOx, CO VOCs; future emission of black carbon (soot) aerosols and their precursors; and the aerosol consequences arising from the reduction in deforestation and biomass burning. Consideration of the more direct effect of land use/ cover change may become an added element in this investigation of uncertainty since scenarios of land use/cover change were developed in the context of the SRES scenarios but were not directly used as external forcings for climate model projections.

B. Climate Projections and scenarios

Climate projections and scenarios are by their nature concerned with characterizing uncertainty. There is a cascade of uncertainty associated with scenario development. The cascade consists of uncertainties in calculations of emissions of greenhouse gases and aerosols (see above), determination of concentrations of greenhouse gases and aerosols in the atmosphere, and in the calculation of the forcing within the climate system. There are also uncertainties in other human-induced changes in the earth-atmosphere system that would affect future climate, such as land use/cover change (see above), as well as uncertainties in natural future perturbations to the climate system, such as solar output and aerosol production from volcanoes (see Cascade of Uncertainty – Figure 1).

One of the largest uncertainties is the modeling of the response of the climate system to a given forcing, i.e., the responses of different climate models. There is a further uncertainty in producing regionalizations of the results of transient atmosphere-ocean general circulation model (AOGCM) experiments for use in detailed regional impacts assessment. While these uncertainties are now well recognized, research to completely characterize and quantify them remains in a relatively primitive state.

NCAR is particularly well positioned to explore AOGCM modeling uncertainties, due to uncertainties in future forcing and in modeling responses to future forcing. The availability of multiple ensemble runs from the Parallel Climate Model (PCM) in particular make this type of work quite feasible at NCAR. The further development of the NCAR CSM and the possibility of producing multiple runs using a suite of emissions scenarios with either the PCM or the CSM is also quite desirable.

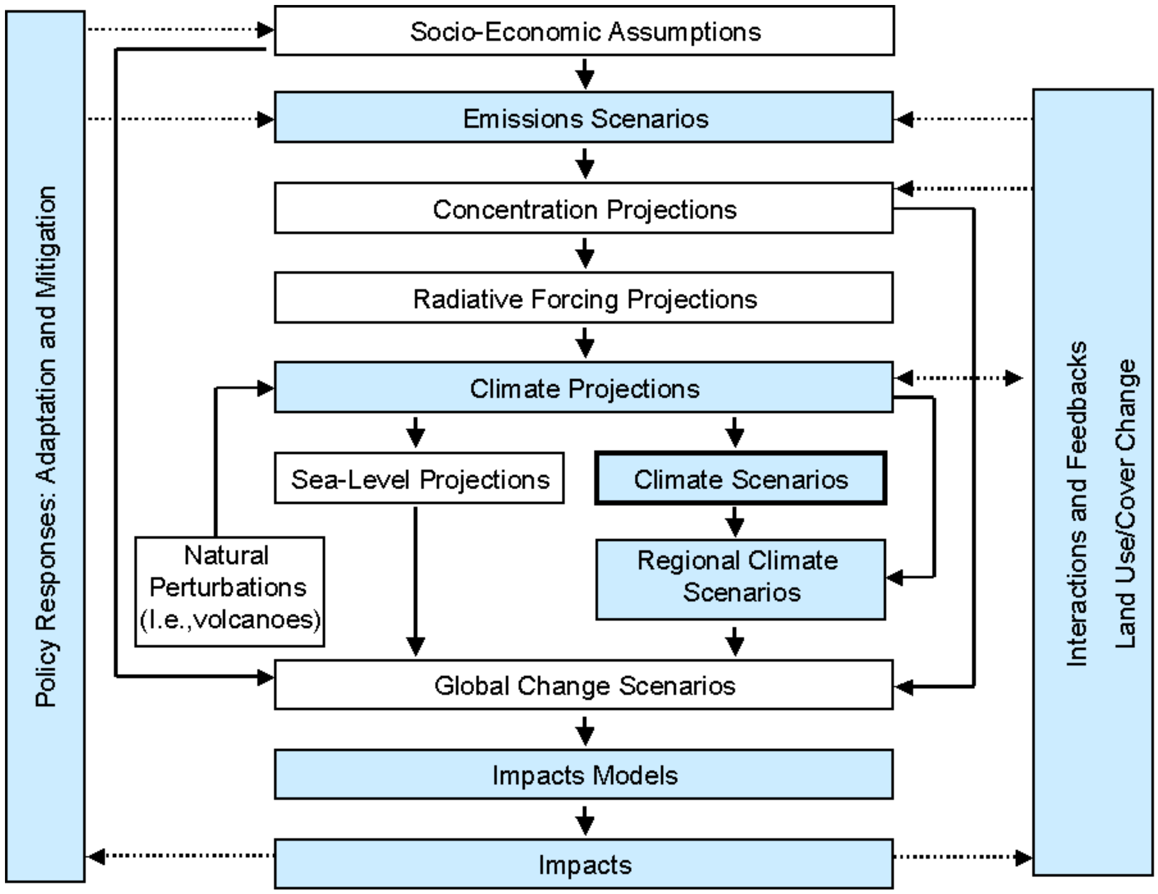

Figure 1: The Cascade of Uncertainty (modified from Mearns et al., 2001). The shaded components are those uncertainty factors considered in this initiative.

1. Climate model projection uncertainties

We consider three research foci that systematically explore uncertainty in climate model responses. The first is to evaluate the observed climate sensitivity that is the target for models based on recent observational analyses; the second is evaluating current uncertainties of multi-model responses; and the third is addressing the critical question of why different responses occur in different models.

a. Quantifying the sensitivity of the climate system

Recent observed ocean heat content change results from Levitus provide, for the first time, an estimate for observed ocean heat uptake over the 20th century that can be used in concert with the observed surface air temperature response to calculate the actual sensitivity of the observed climate system. Since the coupled climate system response to an external forcing consists of the atmospheric sensitivity and the ocean heat uptake, knowledge of the latter will assist in narrowing the uncertainty in the former. New research in this area with the NCAR coupled models will contribute to a more accurate quantification of the uncertainty of the magnitude of the climate system response to a change in external forcing, such as an increase in greenhouse gases, that can be compared with the new target from observations.

b. In-depth climate model intercomparison

Recent coupled model intercomparison projects, such as CMIP, are making it possible to better quantify the uncertainty of response across groups of models both globally and geographically. A first step is to identify what the uncertainty is in model responses. This can be done through analysis of the CMIP models by calculating multi-model ensemble statistics in more detail following initial calculations done recently in the IPCC Third Assessment Report.

c. Parameterization sensitivity experiments

Following from the first two research foci above, the third involves conducting a series of simulations with changes to key parameterizations such as clouds, surface albedo, ocean processes, etc. that will help identify the reasons for the different model responses. We anticipate that some of the differences are caused by feedback mechanisms being too large or too weak in the various modeling approaches. The Climate Change Research Section of CGD with participation from the Climate Modeling Section will lead this effort in conducting carefully constructed experiments to systematically get at the role of different parameterizations in climate models that explain the different responses of global models to perturbations in forcing.

2. Uncertainties in regionalizing climate model projections

Research in methods of regionalization (e.g., regional climate modeling, statistical downscaling) has emerged very forcefully in the past decade, and is very important for advancing our understanding of regional climate in the future. Yet there are a number of unresolved issues associated with these techniques. ESIG recently hosted a workshop on issues in regionalization techniques funded by DOE and NSF, in April 2001. Typical research issues raised there included examination of uncertainties related to two-way-nesting and limitations of statistical methods for long-term regional projections. This aspect of uncertainty will involve cooperation between CGD, MMM, RAP, and ESIG. Significant participation from the University community and government agencies will be encouraged. The Regional Climate Model Initiative is related to this segment of the Assessment Initiative.

It has clearly been demonstrated that climate projections from regional models and statistical downscaling depart significantly from those generated by the global climate model providing the boundary conditions or large scale variables used in the downscaling technique. Thus downscaling provides an additional level in the propagation of uncertainty. ESIG and CGD will be part of efforts to quantify the further uncertainty in future climate projections generated through downscaling. This effort will include cooperation with regional modeling groups such as at PNNL, Iowa State, and statistical downscaling groups at Penn State, University of South Africa and King's College London. While there have now been a small collection of comparisons of the results of downscaling exercises, more dedicated experiments are necessary to better quantify this additional uncertainty.

3. Methods of quantifying uncertainties in climate projections, scenarios

This program element will be developed by the Geophysical Statistics Project (GSP), ESIG, and CGD. While the emphasis of this element is on uncertainties in Climate Projections, some of the techniques described could be applied to other areas of uncertainties in climate change research, such as uncertainty in emissions scenarios, impacts models, and data sets. Quantifying uncertainty involves a hierarchy of methods ranging from very simple descriptive statistics (e.g., standard deviation) to sophisticated techniques (e.g., wavelet bases).

a. Development of new methods

i. Combining known sources of uncertainty in global projections on regional scales.

Two criterion that are commonly discussed in quantifying uncertainty in climate projections is the bias of climate model control runs, and the degree of convergence of model responses to perturbed greenhouse gases. ESIG will be developing new means of combining these two factors to provide overall 'reliability criteria' for climate model simulations of climate change. The method will rely upon the availability of multiple climate model simulations (from different global models) using the same emissions scenario. Initially these measures will be climate variable dependent, i.e., there will be a separate temperature reliability measure and precipitation measure. As work progresses methods for combining these individual criterion will be developed. Further on, these methods will be expanded to consider evaluation of spatial coherence of control run biases across regions.

ii. Quantification of the uncertainty of spatial scale -- Weather generation and effects of spatial aggregation scaling

A statistical challenge is to convert simulated climate changes from GCMs into meaningful meteorological scales and statistical distributions. The results of GCM or regional climate model results are most accurately interpreted as spatial averages over a model grid box. One component of uncertainty is variation of point locations about the spatial averages over a model grid. Typically the variation for points will be larger and extreme events more pronounced. One approach is to estimate spatial statistical models for meteorological fields based on observational data and compute directly the relationship between spatial averages and point values. A similar exercise can be carried out based on coarse resolution model results and fine resolution regional models. New methodology is needed to handle the multivariate relationship among several variables and possible variation in spatial in coherence (correlation) due to changes in mean level. Determining the dependence of spatial structure on mean behavior is important in order to transfer the analysis of observations to cases when the climate is altered. New methods will include estimating covariance models that include covariates related to the mean values of the variables and estimating multivariate and nonlinear transformations to reduce the problem to a Gaussian distribution.

b. Importation, application of existing methods

As the need for quantification of uncertainty has grown, application of methods used to quantify uncertainty in other scientific fields has been explored. Risk assessment techniques are among the first to be applied in a climate change context. These methods usually involve assigning probabilities to the possible future climate projections in question. One attempt at this is provided by Jones (2000), who assigned probabilities to climate projections based on random sampling of components of ranges of climate change from a GCM simulation.

Particular attention will be paid to evaluating how apposite the applications of risk assessment methods are and exploring the potential pitfalls of inappropriate assignation of probabilities.

c. Quantifying propagation of uncertainty

As described in section B, multiple sources contribute to the aggregate uncertainty in climate model projections, climate scenarios, and down through impacts models themselves. These uncertainties cascade through the different levels of development in the climate projection production process in interdependent but not necessarily additive or multiplicative manners. Various means of investigating the propagation of uncertainty, and modeling what the relationships are among the different uncertainty levels will be explored. For example combinations of uncertainty will be evaluated, such as from observed data sets, downscaling, and impacts models. Essentially, in its most complete form, such investigations would include investigation of uncertainty through all levels of integrated assessments.

d. Application of methods across multiple spatial scales

Recent developments of wavelet bases for spatial fields and for time series have provided tools for summarizing spatial-temporal data at different scales. These methods allow for the decomposition of the model output into different levels of resolution and so provide a framework to compare models at different scales. Because wavelet basis functions are localized in space and time they also make it possible to focus on particular regions and time periods. In this way, different fields may agree at one level of resolution under particular conditions but differ at other times and on other regions. Discrimination methods are needed to test whether structure in the multiresolution decompositions are different and new regression methods are needed to relate distinctive features in the multiresolution to different forcings and changes in climate.

4. Science and service component: Provision of climate scenarios for use in impacts assessments

Projections and regionalized projections of future climate must be developed further to produce climate scenarios, i.e., useable future climate inputs for impacts models and analysis. This usually entails combining the climate projections with observed data, since the output of the climate models are not accurate enough for direct use as input to impacts models. ESIG will lead this aspect of uncertainty in assessment science. An important aspect of this element is creating scenarios that include appropriate measures of uncertainty. These might include simple measures of ranges of possible climate change (e.g., box and whisker diagrams, standard deviations) and application of techniques described above in section 3 on methods.

A point of departure for this component will be holding a workshop of experts to assess the selection and use of climate scenarios for the first US Assessment.
This meeting will involve key groups in CGD (CCR, CSM, the VEMAP group) and ESIG, and will draw upon the leadership of the US National Assessment Scenarios task force, and will involve other climate modeling groups (e.g., GFDL, GISS). Some international participation may also be desirable.

Service component

As a service component of this element, NCAR plans to become a developer of, repository for, and distributor of climate scenarios for impacts work. The United States has been poorly organized in this arena of climate assessments. NCAR is obviously an appropriate place for such activities. This task will also be facilitated by the plans in SCD to develop a high power, web-based data acquisition tool. The scenarios will be easily accessible through this system. Ease of access is one of the most important issues in whether climate model based scenarios are actually used by the impacts community.

Appropriate measures of uncertainty (discussed in 3. above) will be provided for the scenarios. Also annotations will be provided regarding: correct use of scenarios, and expert judgment information on potential scenario `inaccuracies' based on control run errors. Scenarios provided would include global model, regional model, and statistically downscaled scenarios.

C. Uncertainty in Environmental Data Sets

As more work is performed in climate change detection, detailed evaluation of climate model performance, and the development of spatially extensive impacts assessments, the need grows to understand and quantify the uncertainties inherent in certain types of observational datasets. NCAR develops and archives numerous multi purpose spatial data sets. Some efforts have been devoted to evaluating the uncertainties inherent in certain atmospheric data sets, but less has been done in the evaluation of datasets used in impacts assessments. Data sets are now developed at NCAR for the explicit use in impacts assessment (e.g., VEMAP data set of atmospheric variables and soils data, ESIG data sets for agricultural assessments). Methods for investigating the uncertainties in these sorts of datasets need developing. A project funded by the NSF-MMIA program to evaluate and develop methods to quantify such uncertainties recently has started in ESIG, which involves the collaboration of members of the Geophysical Statistics Project (GSP), CGD (VEMAP), ESIG, and the U. of Florida.

This strategic plan element also will have an important service component in that the quantitative uncertainty analysis will be made available to the users of the data sets (i.e., will be an integral part of the datasets).

It will also figure prominently in the provision of scenarios discussed in (4) above. Climate scenarios usually involve a combination of climate model output with baseline climatological data sets. Hence, one possibility would be to provide complete datasets wherein the climate model output is already combined with the observed data sets. Such was the case in the US National Assessment when EDAS provided the climate scenarios, which consisted in combining output from two climate models with the VEMAP baseline climatological data set.

D. Uncertainty in Impacts Models

While the uncertainty in climate model projections has long been recognized, less attention has been focused on uncertainty in impacts models, such as crop, ecosystem and hydrologic models. Research has been performed in ESIG and EDAS of CGD regarding this somewhat neglected area for uncertainty. In ESIG, several of the main crop/climate models have been used with the same inputs including climate change scenarios and comparisons of the responses made. Substantial contrasts in response in the CERES and EPIC crop models, for example, have been found. Similarly, in the Vegetation/Ecosystem Modeling and Analysis Project, (VEMAP) terrestrial biogeochemical and dynamic global vegetation models have been compared regarding their time-dependent response to specific scenarios of climate and CO2 change. Six models evaluated by VEMAP provide qualitatively comparable but in other ways significantly different views of future carbon dynamics for the conterminous U.S. under climate and CO2 change. The models agree reasonably well in suggesting a steady future C sink from CO2 fertilization interacting with climate change. The magnitude of the sink, however, varies among models, depending on whether and by what mechanism the models include the role of disturbance.

These two research activities will continue in the future, and further analysis of the sources of contrasting responses to inputs will be explored. These types of explorations may be expanded to include analysis of uncertainty in hydrologic models as well.

E. Decision/Policy Making

Decision making is based on expectations of the consequences of purposive action. While 'uncertainty' can take on different meanings in different contexts, essentially making decisions (for policy purposes or for research) can be viewed as the focus of analysis. The importance of uncertainty for decision making can be considered both for weather and climate.

<u>1. Role of uncertainty in different phases of the policy decision process.</u>

Not all scientific uncertainty surrounding an (environmental) issue is relevant to decisions concerning the issue. Obviously then the first distinction to make regarding uncertainty is to determine those aspects that are actually relevant to the decision. The decision-making process can be broken into different stages: problem identification, formulation of options; and implementation. Research will entail exploration of the role of uncertainty regarding climate change in the different phases of decision making. Example contexts might be: 1) formulating research priorities for a government funding agency; and 2) decisions by corporations (e.g., Mobil oil) to shift public position on the recognition of climate change. Key research questions include: What are the implications of uncertainty for the structure of decision making? How ought uncertainty be defined in various decision contexts?

<u>2. Multiple decision makers and uncertainty.</u>

Many environmental policy problems involve multiple decision makers interacting with one another in the context of institutions that may be well, or poorly, suited to making efficient use of uncertain information and to responding effectively to environmental perturbations. For example, individuals interested in the management of publicly owned resources often have conflicting objectives. Actual management decisions are typically influenced by strategic lobbying efforts and bargaining among the interested parties. There is uncertainty regarding the outcomes of such policy processes because they may be very sensitive to changes in the balance of competitive power or varying interpretations of available scientific information.

The relevance of conflicting interests often has been ignored in climate impacts work. However analysis of problems of this sort has been a long tradition at NCAR. We propose to build on this research theme by focusing on the relevance of uncertainty for the assessment of policy responses to such environmental issues. For example, research might focus on the widely noted tendency for competing interest groups to `use science as a weapon' to support their competing visions for the proper management of a publicly owned natural resource. The relevant research question is: How can this tendency be managed to inform rather than hinder the development of management plans that will foster sustainable resource availability?

3. Evaluation of climate assessments for their effectiveness in providing information on uncertainty useful for policy makers

A number of university groups perform high-level research evaluating climate assessments (e.g., Carnegie Mellon, Harvard), but here we propose to evaluate these efforts specifically regarding their formulations of uncertainty and its effectiveness for various policy making contexts. Particular focus will be on the Third Assessment Report and the US National Assessment.

4. Provision of feedback on policy makers' needs for quantification of uncertainty to the development of measures of uncertainty (in Section B.3 above).

Research questions explored would be, are the measures of uncertainty proposed for quantifying uncertainty in climate projections, for example, what policy makers actually need regarding climate change? If not, what are the needs? How can the needs of policy makers affect the priorities for types of uncertainty explored? (Again the issue here is feedback to Part B.)

5. Value of reducing uncertainty in weather and climate information

If the uncertainty inherent in any forecast is ignored, then decisions must be based on only the "most likely" outcomes and are consequently suboptimal. In these circumstances, quantifying the forecast uncertainty has "added value" for decision makers (i.e., the value of "knowing how much you know"). NCAR has performed much research on quantifying the economic value of imperfect information about weather and climate to decision makers, mostly dealing with shorter-term weather and climate forecasts (e.g., a day to a season ahead). Thus NCAR is in a position to apply this same expertise to the problem of determining the value of not only any hypothetical reductions in uncertainties about climate change, but of specifying present uncertainties as well.

Ensemble forecasting techniques have received increased emphasis in recent years, with the promise of directly generating probabilistic information. A study of the economic value of such forecasts will be performed. Besides being of interest for its own sake, such work should shed light on how to make use of ensembles in practice for operational forecasting (how best to derive probabilistic forecasts from a set of ensembles, the effect of the number of ensembles, etc.).

The decision-analytic methodology for estimating the potential economic value of imperfect weather and climate forecasts has met with at least limited success. Whether an analogous approach can be used to quantify the value of hypothetical reductions in uncertainty for various sources involved in climate impact assessments will be examined.

Potential External Collaborators

Ron Stouffer, GFDL; David Rind, GISS; Larry Gates, LLNL; Mike Hulme, U. East Anglia; Tim Carter, Finnish Impacts Organization; Bill Easterling, Penn State; Alison Cullen, U. Washington, Bill Gutowski, Ray Arritt, Iowa State; Ruby Leung, Bill Pennell, PNNL; Jonathan Taylor, Argonne; Rob Wilby, University College, London; Bruce Hewitson, U. South Africa; Bryson Bates, CSIRO; James Murphy, Hadley Center; Hadi Dowlatabadi, Morgan Granger, James Risbig, Carnegie Mellon; Stephen Schneider, Stanford; Filippo Giorgi, ICTP, Italy; Sally Kane, NOAA OGP.

NCAR Internal Collaborators

Maurice Blackman, Bill Collins, Tim Kittel, Jerry Meehl, Warren Washington, Tom Wigley, CGD; Doug Nychka, Sarah Streett, GSP; Tom Warner, Fei Chen, RAP; Rit Carbone, MMM; Bob Harriss, Linda Mearns, Rick Katz, Kathy Miller, Mary Downton, Ruth Doherty, Roger Pielke Jr., ESIG.

Estimated Resource Requirements

Workshop on Scenarios: to be funded by NCAR ($45 K). Computer time for multiple AOGCM runs: 1000 CPU per year. Human resources: One managing scientist, one programmer for Scenarios Service component; one programmer for AOGCM uncertainty effort (primarily CGD), one half project scientist or associate scientist III for ESIG effort on uncertainty and decision making.

Sponsoring Organizations (current)

DOE, USWRP, NOAA, NSF-MMIA, EPA, NASA

II. Extreme Weather and Climate Events

NCAR's current research program involves several aspects of research in extreme weather and climate events. In the new program element, however, these different strands will be better integrated and expanded. As described below, this will enrich all research endeavors. There is a very direct connection between weather and climate extremes. Both research areas would benefit from more common work with the other (i.e., integration of research on weather and climate), and a focus on extremes would make such integration more feasible. Chiefly CGD, MMM, RAP and ESIG currently perform research on extreme events. This initiative element will seek to appropriately integrate the following aspects of research in weather and climate extremes:

A. the atmospheric science of extremes (processes responsible for their formation and the modeling of extremes in global climate and mesoscale models),
B. the statistical aspects of extremes (further development of and application of extreme value theory), and
C. the societal impacts of extremes and assessment of society's vulnerabilities to them.

Of particular interest is furthering research in the interactions between the physical and social science aspects of extremes. This need was very recently illustrated in conflicts between WGI (Climate Science) and II (Impacts) of the IPCC, concerning what constituted a climate extreme and what could be said about changes in their frequencies in the future.

A. Atmospheric Processes and Modeling of Extremes

<u>1. Research in the physical processes of extremes</u>

We need to increase our understanding of physical processes that lead to extreme events. We currently have very low predictive skill for many kinds of extreme events, such as warm season heavy rainfall and tropical cyclone landfall. This is due to both limited knowledge regarding the processes and difficulty in modeling the processes, as well as to some extent neglect of the research problem. For the moment in this initiative we will focus on processes leading to precipitation extremes.

The Water Cycle Initiative includes a section on Cloud Systems and Precipitation, which concerns initiation of convection, organization of convection, parameterization of convection, and the diurnal cycle of precipitation, particularly for warm season mid-latitude convection. Those involved with the Assessment Initiative will cooperate with scientists involved in the Water Cycle Initiative to insure that processes responsible for extreme precipitation events are sufficiently considered in that research plan.

<u>2. Modeling of Extremes</u>

This initiative will further research on how well climate and weather models reproduce extreme events. In evaluating climate models, how much weight should be to given to extreme event reproduction? Higher resolution climate models (e.g., mesoscale and regional models) in general are better at reproducing daily extremes than are global climate models. But what are the limits of improvements in reproducing precipitation extremes based on resolution alone? What timescales of extremes should be evaluated (e.g., hourly output of precipitation from climate models)? Climate models fail to produce sufficient CAPE (convective available potential energy) necessary to produce extremes. Without sufficient instability and moisture, production of precipitation extremes is not possible. What improvements in parameterizations of convection can be made specifically for improving simulation of extreme precipitation events? These schemes could and should be evaluated regarding how well they reproduce extremes. Moreover, the representation problem of convection at smallest scales needs to be resolved. Again, these concerns in this initiative will be addressed through interaction with the Water Cycle Initiative.

Spatial scaling of extremes

A subtopic concerning modeling and observation of extremes is their scaling properties. This element will concern research on how extremes scale in observations and in models of various resolutions. A statistical approach to this problem might be to construct spatial, stochastic models for the high resolution fields and calculate the distribution for extremes in the aggregated (spatially averaged) values. The models for the field at high resolution can be inferred from observational data on a dense network of stations. This will provide a mathematically rigorous link between point extremes and extremes of average quantities represented by numerical models.

Projections of changes in extremes with climate change

This type of research has increased considerably in the past ten years. At NCAR this research is performed in both CGD and ESIG. To more thoroughly analyze simulations of changes in precipitation extremes in climate models, it would be desirable to examine hourly output of models to examine the diurnal cycle of precipitation.

There is an ongoing project in ESIG in cooperation with CGD to evaluate the PCM for its ability to reproduce extremes (of temperature and precipitation) and to determine changes of extremes in its climate change runs. This project will be ongoing for several years, and could be expanded to include runs of the CSM as well.

An additional possible project is to evaluate precipitation extremes in several regional climate model simulations of future climate over the conterminous U.S.
This could be an integrating project in that aspects of extreme value theory could be used in evaluating the extremes (see section B below), and also recent research on specific precipitation extremes associated with economic damage could be among those analyzed (see section C below). Daily and hourly output could be evaluated for selected years of the simulations.

3. Downscaling of extreme events

One of the problems in evaluating changes in extremes in climate models (and perhaps forecasting models) is the fact that a number of extremes of great importance to human impacts are not directly modeled in climate or most mesoscale models. There are research opportunities in determining if we can deduce changes in these extremes based on relationships with variables that are produced by climate or weather models. A typical example of such an extreme is hail, which tends to be a very localized and sporadic phenomenon. Research in downscaling can be approached in two ways or stages. The first is to more thoroughly analyze the physical relationships between large-scale variables and localized extremes such as hail. This work will be performed in MMM and RAP. The second is, once these relationships are known, to perform statistical downscaling. This second phase of downscaling work would be performed in ESIG.

Statistical downscaling has become quite popular in recent years, but has focused little on extreme weather or climate events per se. On the other hand, there is also a long history of the use of the statistics of extremes in applied climatology and hydrology (e.g., for engineering design). ESIG plans to expand efforts to unify these two approaches through the use of the statistics of extremes with covariates (e.g., indices of large-scale atmospheric and oceanic circulation) to downscale extreme weather and climate events.

B. Application of Extreme Value Theory

Although much discussion in recent years has been devoted to the importance of extreme events in climate change, it is quite rare that modern statistical theory for extremes is applied. Application of extreme value theory would allow for more systematic study of extremes (i.e., consideration of a wide spectrum of extreme events simultaneously) -- as opposed to present ad hoc treatment of a few somewhat arbitrary events. Its application would result in more accurate estimation of likelihood of events, trends, etc. Specifically extreme value theory will be used in several different research contexts:

<u>1. Use of heavy-tailed distributions</u>

In searching for trends or in generating climate scenarios, virtually all the statistical methods used, either explicitly or implicitly, have relied on distributions with medium tails. The statistics of extremes can be applied to determine the extent to which weather and climate variables and their corresponding economic impacts actually possess "heavy-tailed" distributions (i.e., Pareto-like as opposed to exponential-like). The question of whether heavy-tailed distributions for impacts are attributable to the underlying weather or climate variable or to the impact variable itself should also be examined.

<u>2. Determining extreme trends in observations</u>

The statistics of extremes, with the incorporation of time as a covariate, also will be applied to reexamine apparent trends in extreme weather and climate events and their impacts that previously have been found. This reanalysis is not anticipated to result in much change in the magnitude of any apparent trends. But allowance for heavy-tailed distributions could well result in substantial differences when such trends are expressed in terms of design or return values.

<u>3. Application to climate and weather model output</u>

The statistics of extremes will also be applied in the context of evaluating climate change projections from global and regional climate and models. This application will enrich our understanding of the modeling of extremes. Such application could also become a climate model diagnostic (see A.2 above). However, the issue of support (i.e., appropriate match between point observations and model grid boxes) needs to be resolved.

<u>4. Applications to other types of extremes relevant to aviation</u>

Many of the weather events that affect aviation (convection, icing, turbulence) are essentially extreme events. Although extreme value theory has not yet been applied directly in the effort to forecast these events, it would be valuable to explore such applications and evaluate their potential for improving forecasts of aviation weather variables and other weather variables with large impacts.

C. Societal Impacts of and Vulnerability to Extremes

Research in climate and weather extremes is fundamentally motivated by their impacts on society. The ESIG-hosted and NSF-funded Workshop on Extreme Events: Developing a Research Agenda for the 21st Century (June 2000) was an important step in developing an agenda focused primarily on the societal side of extreme event research. Research themes identified in that workshop included some that will form part of the current research initiative.

1. Identification of societally significant extremes

One of the most important aspects of research in the impacts of climate and weather extremes is the determination of what aspects and magnitudes are responsible for significant impacts. This kind of research also provides a critical feedback to the research in A. above, and should aid the atmospheric sciences community in determining what extreme events are most important to physically understand and represent in climate models. Research will also be developed to investigate the correlations among extremes, and to determine, if possible, good overall 'proxy' extremes that can generally represent precipitation extremes, for example. Such work on temperature and precipitation extremes is ongoing in ESIG. The analysis of extreme events in regional climate model simulations of future climate referred to in section A. above is an example of the integration of research. That science plan calls for the use of regional specific extremes indicators of precipitation that are highly correlated with flood damage in different parts of the US in the analysis of climate model output.

2. Modeling of impacts of extreme events

a. Modeling economic damages

Recent research has established that representing total economic damage from hurricanes as a "random sum" is a useful stochastic modeling approach. The advantage of this technique is that the variations in damage totals can be decomposed into two sources: (i) those attributable to variations in the number of events; and (ii) those attributable to variations in damage from event to event. In particular, this decomposition provides a natural way to interpret trends in damage from extreme events or the effects of large-scale circulation patterns (e.g., El Nino events). This work will be extended to consider the economic damage from other extreme weather and climate events, especially floods.

b. Evaluating the ability of impacts models to simulate system response to extremes

It is well known that impacts models, such as crop models, do not simulate well the crop system's response to extreme events. ESIG is continuing research in evaluating impact model response to extreme weather events and is considering performing research on how to improve the model's ability in this regard.

c. From meteorological extremes to hydrology and flooding

The combination of complex, extreme weather events combined with land use/land cover changes as a result of both land management practices and riverine corridor manipulation make the prediction of extreme flood events difficult. The forecasting of flood stage of both large-scale floods and smaller-scale flash floods requires accurate estimates of precipitation both temporally and spatially. Physical process models used in this forecast process have many physically based parameters, many with a high degree of uncertainty. In the cases of smaller-scale flash floods in complex terrain, understanding the nature of the precipitation extreme, and its relation to the underlying topography is crucial. In research connecting meteorology to hydrology and flooding, hydrological models will be used to identify precipitation extremes that most highly relate to hydrologic floods in various regions of the US.

3. Research on reducing societal vulnerability to extremes

Society's vulnerability to extreme events is at the core of research interests in extremes. The key to the importance of extreme events to society is vulnerability, a systems susceptibility to change under the impetus of an extreme event. Vulnerabilities often lie at the interface between different systems, e.g., a town (cultural), a storm (meteorological), and a flood (hydrologic). Understanding vulnerability thus requires knowledge of the behavior and interactions of all systems involved in an extreme event. Current research evaluating societal vulnerability to floods and hurricanes in the US will be expanded by evaluating methods typically used to compute flood probabilities for floodplain mapping in light of information about types of hydrologic conditions and severe storms that tend to produce damaging floods. Also, this type of research will be expanded to include studies of the impacts of winter storms.

Routinely disruptive weather

A series of studies of common disruptive weather events, in which impacts are not necessarily disastrous but have severe economic consequences will be initiated. Examples include lingering heat waves, and in-flight icing of aircraft. Studies would assemble data on the economic impacts of such weather events, investigate the kinds of forecasts that are needed by decision makers.

Potential external collaborators:

Dave Easterling, NOAA; Pasha Groisman, NOAA; Bill Gutowski, I. Pan, Iowa State; Tim Osborn, U. East Anglia; Marc Parlange, Johns Hopkins; Roger Pulwarty, NOAA and U. Colorado; Ken Kunkel, Illinois Water Survey; Susan Riha, Cornell; Richard Smith, U. North Carolina; Dan Wilks, Cornell; Francis Zwiers, Canadian Climate Center.

NCAR internal collaborators:

Kevin Trenberth, Jerry Meehl, Tom Wigley, CGD; Barb Brown, Roy Rasmussen, David Yates, RAP; Rit Carbone, Mitch Moncrieff, MMM; Linda Mearns, Mary Downton, Mickey Glantz, Rick Katz, Roger Pielke Jr., Kathy Miller, ESIG.

Estimated Resource Requirements:

One Additional Programmer or Associate Scientist (perhaps shared across the divisions for model evaluation of extremes reproduction). One post-doc or entry level Scientist position for application of extreme value theory work. Some computing time (but may be possible to cover within divisional allocations). One half FTE Associate Scientist in ESIG for impacts and extremes research.

Sponsoring Organizations (current):

NOAA, USWRP

III. Further Research in Attribution of Impacts to Perturbations in Climate: Establishment of a Climate/Human Health Program

A. Rationale

The area of human health impacts of climate is an extremely complex one, which requires the interdisciplinary efforts of health professionals, climatologists, biologists, and social scientists to successfully analyze the myriad relationships among physical, biological, ecological, and social systems relevant to health impacts. Health impacts is an endeavor where an integrated assessment framework is obviously most needed. It is particularly important that as complete, rigorous knowledge as possible regarding health/climate interactions be obtained, in the context of all appropriate technological and social considerations. The flurry of commentary over the past few years on health/climate connections and the dangers of oversimplifying relationships as well as the recent (April 2) release of the NRC panel report that addresses issues in human health and climatic variability reflects this importance.

Much progress towards enhancing institutional coordination and collaboration to enrich climate/health research has been and will continue to be brought about through development of specific multidisciplinary projects. However, to effect more complete progress, an ongoing multi-year program in health/climate issues would be particularly desirable, since problems in appropriately developing needed health/climate linkages often transcend the specifics of any one study. In essence, specific studies in the context of a broader climate/health program may be the most effective context for rapid development of this complex impacts area. The NRC Report explicitly recommends the establishment of interdisciplinary climate/health programs to foster research, training, and appropriate communication to policy makers on issues concerning climate and health.

B. Program Plan

NCAR plans to develop a unique interdisciplinary research program via a health-climate collaboratory. It will bring together leading institutions in health and climate science. Such a program is necessary to properly train individuals in performing the kind of complex interdisciplinary research necessary to successfully tackle research questions in climate/health/society interactions. Thus the program will include a post-doctoral training program that will produce the first generation of scholars dedicated to an integration of the health and climate sciences. We envision a multi-year program that would be dedicated primarily to establishing interactions between climate scientists and health scientists. Interaction between these groups, social scientists, and ecologists acts as an additional goal. Three main institutions will initially form the center of the Program: the National Center for Atmospheric Research, Johns Hopkins University, and the Center for Disease Control and Prevention.

C. Program Elements

We will consider studying a wide range of issues in climate and health, ranging from heat-related mortality and morbidity, to complex models of vector-borne disease (e.g., malaria and dengue fever). Consideration of interactions between climate variability (interannual fluctuations in climate) as well as longer term climate change and human health effects will be included in the program plan. One focus of the program will include careful research regarding dangers of extrapolating research results across different temporal scales. In conjunction with the research interests within the Atmospheric Chemistry Division at NCAR, health effects of increased UV-B radiation and air pollution will also be considered as initial research topics. In addition to fostering in general greater interaction between the two main communities, the following specific goals will be sought:

1) Evaluation of vector-borne disease and other health-climate models - with particular attention to their completeness in how climate effects are represented and their adequacy for use in a climatic change context; this will also entail the determination of the completeness of the models in representing the linkages between climate, disease incidence, and the complex societal and environmental contexts of the interactions of all factors (societal, environmental, medical);

2) Examination of and inclusion of the modeling of other resource systems (particularly agriculture and water resources) in conjunction with the disease models;

3) Examination of the adequacy of climatological databases for use in human health models and development of recommendations for extending the climatological and epidemiological data bases necessary for performing effective research in climate/health interactions;

4) Examination of adequacy of field data collection and measurement techniques for model development and evaluation;

5) Formal scholarly exchanges between NCAR and others institutions, such as Johns Hopkins, and the Center for Disease Control (e.g., summer visits at NCAR);

6) Establishment of a formal post-doctoral program at NCAR for health researchers, and climatologists interested in health problems;

7) Visitor program for policy makers and public health workers to become more informed regarding climate and human health interactions.

D. Initial Development Plan

A meeting of interested collaborators will be held in late fall 2001 at NCAR, when a detailed program plan will be developed. The program plan could be submitted within the existing RFP cycles of interested funding agencies or presented directly to interested program managers.

External Research Collaborators

The following individuals have already been contacted and have expressed and interest in participating in such a program: Dr. Duane Gubler, Director, Division of Vector-Borne Infectious Diseases, Center for Disease Control and Prevention; Dr. Dana Focks, USDA, Gainesville, Florida; Dr. Joan Rose, Department of Marine Sciences, U. of S. Florida; Dr. Jonathan Mayer, U. of Washington; Dr. Jonathan Patz, Johns Hopkins University; Dr. Peter Webster, U. of Colorado; Dr. Elizabeth Whitcolmbe, Royal Hospital for Neuro-disabilities, London, U. K.; Dr. Mark Wilson, U. of Michigan, Michael Sharpe, Health Canada.

The collaborators include experts in epidemiology, disease-society interactions, microbiology and water-borne diseases, environmental health sciences, and climatology.

NCAR Internal Collaborators

Bob Harriss, Mickey Glantz, Linda Mearns, Roger Pielke Jr., ESIG; Sascha Madronich, ACD.

Resources Needed

Funding from NCAR to hold the workshop to develop the details of the program ($45K). One new Scientist position in climate/health research would be essential. The postdoctoral program, institutional exchange program, and visitor program could be partially supported through external grants. Development of GIS capability for data analysis of disease incidence, climate variability, land use etc.

Program managers at EPA, NOAA, and NSF have been contacted and have expressed interest in funding such a program.

Contact for further information:
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