From Climate to Weather: Impacts on Society and Economy - Summary of a Forum, June 28, 2002, Washington, DC

A Summary to the Natural Disasters Roundtable, The National Academies

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THE NATIONAL ACADEMIES

FROM CLIMATE TO WEATHER: IMPACTS ON SOCIETY AND ECONOMY

SUMMARY OF A FORUM
JUNE 28, 2002
WASHINGTON, DC

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

A REPORT TO THE
NATURAL DISASTERS ROUNDTABLE

BY
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FOREWORD

The Natural Disasters Roundtable seeks to facilitate and enhance communication and the exchange of ideas among scientists, practitioners, and policymakers concerned with urgent and important issues related to natural disasters. Roundtable meetings are held three times a year in Washington, DC. Each meeting is an open forum focused on a specific topic or issue selected by the NDR Steering Committee.

The NDR Steering Committee is composed of 5 appointed members and sponsoring ex officio members. At the time of this forum, the appointed members were: Rutherford H. Platt, Chair, University of Massachusetts, Amherst; James P. Bruce, Global Change Strategies International, Inc., Ottawa, Canada; Wilfred D. Iwan, California Institute of Technology, Pasadena; Stephen P. Leatherman, International Hurricane Center, Florida International University, Miami; and Mary Fran Myers, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder. Ex officio members were: Stephen Ambrose, NASA, Lloyd S. Cluff, Pacific Gas & Electric; Dennis Wenger, NSF; Timothy Cohn, USGS; Margaret Lawless, FEMA; James Russell, IBHS, and Helen M. Wood, NOAA.

This paper presents the rapporteur's summary of the forum discussions and does not necessarily reflect the views of the roundtable members or other participants.

For more information on the Roundtable visit our website: http://nationalacademies.org/naturaldisasters or contact us at the address below.

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This summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this summary:

Joan Aron, Science Communication Studies, Columbia, Maryland
Raymond Ban, The Weather Channel, Inc., Atlanta, Georgia
Benjamin Preston, Pew Center on Global Climate Change, Arlington, Virginia

The review of this summary was overseen by Marvin Geller, State University of New York, Stony Brook. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the authoring committee and the institution.

FROM CLIMATE TO WEATHER

SUMMARY OF A FORUM

The objective of this forum was to review information on the linkages between climate variability and change and disasters due to extreme weather events. The forum provided the opportunity to discuss some of the scientific and policy implications of these linkages.

NATIONAL ASSESSMENTS AND CONGRESSIONAL RESPONSES

The first three speakers at this forum gave valuable insight into the assessments that have been conducted in the United States over the past few years. How the U.S. Congress has received these assessments and other information was also discussed.

Anthony Janetos of the Heinz Center gave an overview of the U.S. National Assessment[1] of climate variability and change. The Assessment used the Hadley Center for Climate Prediction and Research Climate Model 2 and outputs from the Canadian Climate Centre Global Climate Models (GCM) to give a range of potential future climates and their effects. He characterized the Canadian Climate Centre model as a "hot model" or a "very warm model". (Among the seven models considered by the National Assessment Synthesis Team [NAST], the Canadian Climate Centre Model produces the highest temperature for the 21st century although other models not used by the NAST can generate a greater warming.) An important finding in the National Assessment study was that derived by coupling climate model results with ecosystem models.[2] Janetos showed that even under the "cool wet" model there would be major shifts in the Eastern United States with northward migrations of ecosystems. If the 'warm' model results are used, there would be an increase in forest fire risks in the Southeastern United States in the second part of the century. The implications were rather severe in the warm model and still important in the cool model. These increasing heat indices would also affect the quality of life.

Vaughan Turekian of the National Research Council (NRC) reported on the National Academies' assessment report, *Climate Change Science: An Analysis of Some Key Issues* (NRC, 2001)[3]. This fast-track study was in response to a request from the White House to assist in identifying areas in the science of climate change

[1] The National Assessment of the Potential Consequences of Climate Variability and Change was an assessment of what we presently know about the consequences of climate variability and change. This assessment was conducted as part of the United States Global Change Research Program (USGCRP).

[2] Specifically, the climate scenario generated by the Canadian Climate Centre GCM, when combined with the MAPPS (mapped atmosphere-plant-soil) ecosystem model, shows break-up of the forests of the southeast, replaced with open parkland and in some areas, grassland. This breakup is due to fire disturbance and subsequent inability of the present forest species to reproduce in place. These simulations do not take forest management into account, so are not able to account for potential fire suppression. The results that the author cites, an overall increase in productivity for US forests, stem from a different ecosystem model that does not have the same sensitivity to altered climate, and which handles CO_2 enrichment differently. The National Assessment did not try to calculate economic damages in most instances, including this one.

[3] In the U.S. Climate Action Report (US Dept. of State, 2002), this NRC report and the National Assessment report were the basis for the discussion of climate change and its impacts.

where there are the greatest certainties and uncertainties, and "views on whether there are any substantive differences between the Intergovernmental Panel on Climate Change (IPCC) Reports and the IPCC summaries."[4] In the 2001 NRC report, the greatest uncertainties identified were mainly over the role of natural variability instead of, or in collaboration with, anthropogenic climate change. Another significant uncertainty mentioned by Turekian was identifying a safe level of greenhouse gases in the atmosphere or greenhouse gas emissions for human welfare and ecosystems. Determining a 'safe level' is in large measure region-specific with vulnerable communities tolerating only the lesser effects of greenhouse gases for example, low-lying islands, and Arctic peoples. People on the island of Tuvalu would have a very different view than people in the central United States. In other words, the NRC report considered this to be a societal value-laden rather than scientific question. The IPCC's report conclusions were generally supported by the NRC report, which along with national academies from 16 other countries basically endorsed IPCC findings.

The NRC report agreed with the IPCC report that sea level will continue to rise, rainfall rates will increase in many regions and many semi-arid regions will experience more severe droughts. Much additional multi-disciplinary scientific work is needed to reduce uncertainties and to determine how serious a problem climate change may pose to the United States. Turekian noted that recent declarations from the Bush Administration, including the U.S. Environmental Protection Agency, state the recognition that climate change is a reality, produced from a build-up of greenhouse gases in the atmosphere.

The experiences with Congress that Jim Jensen (NRC) related made it clear that congressional members are very interested in disaster mitigation and are willing to support efforts in that area with better weather and hydrologic measurement and warning systems. However, Congress is not as well organized as the Administration, through the Federal Emergency Management Agency, to address natural disasters. Although two different congressional committees oversee the U.S. Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA) programs on climate, weather and water, the links with climate change have not been made and this is in part because Congress sees the task of trying to reduce greenhouse gases as very formidable. Jensen also made it clear that media plays an important role in how Congress is influenced in thinking about these issues. This was also emphasized by Steve Lyons of the Weather Channel in his presentation, as discussed below. In the forum discussion it was pointed out that the Kyoto Protocol would be just a small step on the way towards safe concentrations of greenhouse gases and reducing emissions to the atmosphere. He noted that impacts of climate change in Alaska and the recent wildfire season are drawing more attention from Congress to climate change.

SCIENCE AND UNCERTAINTIES

Jay Lawrimore of NOAA's National Climate Data Center noted the very serious difficulties that arise in trying to determine the past trends of extreme climatic events from the data records. These data have many problems to overcome, such as, gaps in the records and problems of inhomogeneity. Lawrimore showed convincing evidence of consistency in some climatic trends with model projections with past greenhouse-gas forcing. In particular, there have been higher maximum temperatures and even greater increases in minimum temperatures, heavier one-day rainfalls, earlier end of winter frost periods, and higher humidity in the lower layers of the atmosphere. Some of the changes in extremes that would be expected with greenhouse forcing of climate, are already evident. However, no increase in droughts has yet been detected. Trends in numbers and intensity of hurricanes are ambiguous with decadal changes being more significant than any long-term trends (see Knutson's analysis later). Lawrimore pointed out that trends in human vulnerability to some climatic extremes (e.g. heat waves affecting elderly and poor) are in many cases

[4] The scope of this presentation is only the report from IPCC Working Group I (http://www.ipcc.ch/).

more important than climatic trends. Better data sets and data management are needed to resolve many issues.

Tony Busalacchi (University of Maryland) discussed the El Niño, La Niña, Pacific Decadal Oscillation and the North Atlantic and Arctic Oscillations. These large-scale natural modes of climate variability are linked to climate extremes in many regions of the world in complex ways. For example, El Niño events are linked to fewer Atlantic hurricanes and reduced tornado activity in Louisiana. On the one hand, modeling of these phenomena can lead to valuable seasonal forecasts of drought and flood conditions, but on the other hand, modeling for some regions (e.g., Africa) is not very reliable. A key issue that scientists are struggling with is, "How are global warming and seasonal and also intraseasonal variations connected to each other?"

Howard Bluestein, University of Oklahoma, reminded the audience with some dramatic photos of the devastation that tornadoes, hail, supercells, and other severe thunderstorms can bring. Supercells last longer than ordinary thunderstorms and are the most prolific producers of tornadoes and hail. On average, there are 1,000 tornadoes that occur each year in the United States but only 536 occurred during 2002[5] These numbers vary depending on distribution of low-level water vapor, and the difference between surface and upper air temperatures, and the vertical wind shear. Bluestein and others pointed out that there is no evidence of change so far in the frequency or distribution of tornadoes. The climate models are far too coarse in scale to make a prediction of tornadoes or their parent storms. In the discussion it was noted that the modeled future changes suggest an increase in conditions under which supercells capable of producing tornadoes, may form. Models project a warmer lower atmosphere and cooling in the upper atmosphere, and an increase in low-level water vapor, which are conditions favorable to the formation of storms that can spawn supercell tornadoes. However, reliable wind shear predictions are probably beyond the realm of modeling capability at this stage.

Tom Knutson of NOAA's Geophysical Fluid Dynamics Lab (GFDL) took on the difficult task of summarizing the actual and potential trends in tropical cyclones (tropical depressions, tropical storms, and hurricanes) in a changing climate. Although warming sea surfaces could add to tropical cyclone intensities, there appears to have been no significant trends to date in frequency, intensity and area of effect from hurricanes or tropical storms. Knutson presented some careful modeling work to show the most plausible outcome by year 2100. In a greenhouse forced climate it is predicted that there will be a 5-10 percent increase in the intensity of the winds in the most intense hurricanes and a 15-30 percent increase in precipitation in the most severe storms (with the range depending on the type of precipitation measure evaluated). A ten percent increase in the wind speed may not appear significant but Alan Davenport of the Institute for Catastrophic Loss Reduction (London, Ont.) noted that this means there would be at least a 20 percent or maybe larger, increase in the windforce stress on structures. Harold Cochrane of Colorado State University noted later that a 1 percent increase in windspeed in Florida gave a 10 percent increase in damage, so that the damages from a 10 percent increase in the intensity of the most intense tropical cyclones or hurricanes could be very great. In addition, the increase in height of ocean storm surges has a greater than linear relation to windspeed. For the recent hurricanes in Honduras and in southeastern United States, the rain and floods caused more damage than the winds. Therefore, an increase of 15-30 percent in rainfall in severe hurricanes could be equally devastating. If these severe storms should develop, even Knutson's modest projected increases could be very serious for disaster losses.

Francis Zweirs of the Canadian Climate Centre for Modeling and Analysis, Victoria, reviewed many of the problems faced in climate data analysis and modeling future climate. Data for model verification are at times unavailable or of questionable quality, especially for extreme events. Zweirs showed that modeling extreme events using GCMs can be very difficult and complex, but not impossible. The Canadian Climate Model predicts that rains with an 80-year return period would become 25-year events by the end of the 21st century if the climate is forced according to the IPCC IS92a emissions scenario. (The IPCC (1992) developed

[5] These numbers are still preliminary for 2002. See the National Weather Service/Storm Prediction Center website for updates http://www.spc.noaa.gov/climo/torn/monthlytornstats.html.

a range of scenarios, IS92a-f, of future greenhouse gas and aerosol precursor emissions based on assumptions concerning population and economic growth, land use, technological changes, energy availability, and fuel mix during the period 1990 to 2100. Scenario IS92a is a mid-range emissions scenario.) This change in the frequency of high intensity rainfalls has enormous implications for storm drainage design and flash floods, for erosion and erosion control, and other events and their associated controls that are greatly influenced by high rain intensities. According to predictions for maximum temperatures, 20-year return period values would go up some 4-6° C over most of North America and as much as 10° C in southeast United States. Minimum temperature extremes would rise with greater intensity.

In the discussion of this presentation, it was noted that in the Canadian model the most severe winter storms are increasing in intensity although the number of storms is not increasing. It was pointed out that models tend to simulate a smooth response in global mean temperature to IS92a forcing. However, looking at how temperature evolves at individual grid points or in regions, it can be seen that the response is not smoothly upwards because the local temperature is a combination of the warming signal and a lot of natural variability. There has been considerable investigation of abrupt changes in the global mean temperature using models that have evaluated scenarios under which the thermohaline circulation might suddenly collapse. However, as Bob Hirsch (USGS and Chair of the session) and others pointed out the paleo record makes it clear that very abrupt changes in climate over short periods of time have occurred in the past. Caution should be used when assuming that changes are going to occur in a steady smooth way.

FRAMING POLICY IMPLICATIONS

William Hooke of American Meteorological Society, who chaired this session, noted that given the evidence so far, climate change may be a more important issue for local government officials than for federal politicians and officials.[6]

David Changnon, Northern Illinois University, noted that most of the disaster loss increases in the United States, except for those due to heavy rains or floods, are due to changes in where we live and changes in how we live. This suggests that better prevention measures can achieve a reduction in disaster losses. For instance, the annual average number of thunderstorms has not increased and while hail is more frequent in a few regions of the United States, the frequency of very severe tornadoes (F4 and F5) has appeared to decline. Changes in society are major factors in disaster losses. For example, from 1960 to 1975 property loss was 42 percent of total U.S. insured hail losses and crop losses were 58 percent. Over the past decade, the ratio has nearly reversed for the two categories with 61 percent of total U.S. insured hail losses attributed to property losses and 39 percent related to crop losses. Large property losses are also due to the increase over the past 30 years of expensive buildings constructed in flood plains, along vulnerable coasts, and in densely-packed urban areas—some have called this “mansionization”.

Harold Cochrane, Colorado State University, showed that estimates of direct and indirect economic losses is not a simple matter, requiring closer examination of methods to calculate these losses. He suggested a way to reduce vulnerability following the idea that the best-built structures withstand major damages. As an example, many blamed the years of lax enforcement of building inspections and enforcement of building codes for much of the $15-20 billion insured losses caused by Hurricane Andrew in Florida in 1992. He claimed that this is a myth since the age of damaged structures was not relevant in explaining losses. Although a few local companies filed for bankruptcy after Hurricane Andrew, the insurance losses were mostly

[6] Note: As a confirmation of this the Federation of Canadian Municipalities (with 84 percent in favor) called on the Canadian government to ratify the Kyoto protocol, while many industrial groups are urging against such ratification.

localized and did not have big economic impacts on the national economy. Cochrane suggested that insurance rate incentives could encourage citizens to take preventive measures. For disaster mitigation activities preventive measures through incentives are worth exploring. Using insurance rates as incentives to plan for climate variability and change should be used with prudence, however. As insurance can have positive behavioral effect, it can also produce unwanted results, e.g., the national flood insurance program has allowed affected communities to rebuild homes in areas with high flood risks.

Tom Wilbanks of Oak Ridge National Laboratory began his presentation by emphasizing the many ways that climate and weather are important to all of us including the non-human inhabitants of the planet. Wilbanks then discussed sensitivity, exposure, and resilience and the thresholds of vulnerability in adaptation measures and disaster mitigation. He pointed out that in Cochin, India, self-assessment tools are being developed that should be very valuable both there and elsewhere. Cochin is a city of 1.5 million in Kerala on the west coast of India and is particularly vulnerable to sea level rise and storm surges both of which will affect the city's tourism, shipping and canal traffic sectors. Although, mitigation of climate change (actions to reduce climate change) is considered by some as a more important strategy than adaptation (disaster prevention), both strategies are in fact complementary. Wilbanks said that some mitigation could make adaptation possible because adaptation can then address less extreme climatic changes. However, Wilbanks considered adaptation measures to be of higher importance for such communities like Cochin.

Ian Burton's (recently of Environment Canada and University of Toronto) first message was "adapt and thrive". Noting that losses due to climate related disasters are rising globally, he emphasized the need to bring the climate adaptation and disaster mitigation communities together. He noted that if we adapted better to climatic events of the past few decades, we would now be well on the way to adapt to long-term climate change. Burton discussed the need to reduce mal-adaptation. He also spoke about the need to look at present and future vulnerability, as society and infrastructures changes. Although the United States has unequalled capacity to adapt, it has not always done so. This is evident in the fact that disaster losses continue to rise, which may be due in part to a failure to adapt or an increase in maladaptation. In providing assistance to developing countries to strengthen adaptive capacity it should be recognized that greater wealth, technology, and social organization are not guarantees of effective adaptation. A broader approach based upon political will, a culture of mitigation and adaptation, and integration with sustainable development are all needed as well.

Steve Lyons of the Weather Channel gave a presentation on the role of the media. He reinforced the importance of the media to policymakers and lessons learned from weather forecast dissemination. Lyons emphasized that not all problems of forecasting are from models. When forecasting one would need to know the information base of the audience in order to assess and explain uncertainty clearly. He gave a graphic demonstration that landfall hurricanes in the United States are only 16 percent of the total number of Atlantic storms yet some storms at sea can still cause major coastal damage and this type of information needs careful public presentation. Communicators should not go beyond the knowledge they have and should explain the potential impacts of an event. He noted that there may be a bias in the media (even the Weather Channel) towards news of bad weather, but responsible journalists and commentators try to correct for this to ensure the all important high credibility with viewers.

WRAP-UP

James Bruce of Global Change Strategies International, Ottawa, and member of the Natural Disasters Roundtable, summarized some of the key observations made at the forum.

- There is a need for better interaction between the climate change community, the seasonal forecast community, weather forecasters, and the natural disaster reduction community. All of these stakeholders were represented at the forum.

- There is a need for improved models for climate change projections involving the nature of land cover, the biological aspects of the land, oceans and the geochemical cycles.

- The climate analysts indicated that some extreme weather events, such as heavy rainfalls and maximum and minimum temperatures, appear to be increasing, as was projected by climate models. But for other events there are either no recognizable trends or natural variability is so great that it will probably be some time before patterns can be detected. Improved models would be helpful.

- While climate modelers suggest some extreme events are likely to increase in a greenhouse gas-forced world, and this appear to be beginning, a close watch needs to be kept on the relative importance of hazard severity, and exposure to risk. Some increase in disaster losses might best be explained by increased exposure to risks such as building on coasts and flood plains. Understanding of the relative importance of these factors requires more systematic research.

- Adapting to the present range of weather extremes requires more effective disaster-loss prevention measures. Adapting to the extremes of climate as it evolves in order to reduce human suffering and economic losses is also a great challenge.

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APPENDIX A

AGENDA

NATURAL DISASTERS ROUNDTABLE
June 28, 2002
Washington, DC

Forum on
From Climate to Weather:
Impacts on Society and Economy

8:30 AM Welcome and Introductions
Rutherford Platt, NDR Chair

8:45 AM Lessons from U.S. National Assessment
Anthony Janetos, Heinz Center for Science, Economics, and the Environment

9:05 AM Lessons from the NAS Assessment
Vaughan Turekian, National Research Council

9:25 AM Role of Congress in Shaping Policy Regarding Extreme Events
Jim Jensen, National Research Council

9:45 AM Discussion

10:00 AM Break

10:15 AM Panel on Understanding the Science and Uncertainties
Chair, Robert Hirsch, USGS

10:20 AM Climate Record and Extreme Weather
Jay Lawrimore, National Climatic Data Center, NOAA

10:40 AM Role of Natural Modes of Variability in Influencing Extreme Events
Antonio Busalacchi, University of Maryland

11:00 AM Role of Climate Change in Severe Weather Events
Howard Bluestein, University of Oklahoma

11:20 AM Role of Climate Change on Tropical Cyclones
Tom Knutson, Geophysical Fluid Dynamics Laboratory/NOAA

11:40 AM Extreme Weather Projections from Climate Models
Francis Zweirs, Canadian Climate Centre for Modeling and Analysis

12:00 Noon Panel Discussion

12:30 PM	Lunch (cafeteria available)
1:30 PM	Framing Policy Implications Chair, *William Hooke, American Meteorological Society*
1:40 PM	Societal Impacts – Sorting Out Increased Vulnerability from Changes in Extremes *David Changnon*, Northern Illinois University
2:00 PM	Economic Impacts of Extreme Weather Events *Harold Cochrane*, Colorado State University
2:20 PM	Human Vulnerability and Adapting to Climate Change *Thomas Wilbanks*, Oakridge National Laboratory
2:40 PM	Adaptation and Resilience ("No Regrets" Strategy) *Ian Burton*, Environment Canada
3:00 PM	Role of Media in Public Education and Perception *Steve Lyons, The Weather Channel*
3:20 PM	Panel Discussion
4:00 PM	Wrap up *James P. Bruce, Global Change Strategies International, Inc.*
4:20 PM	Adjourn

APPENDIX B

BIOGRAPHICAL INFORMATION

Howard B. Bluestein is Professor of Meteorology at the University of Oklahoma, where he has served since 1976. His research interests are the observation and physical understanding of weather phenomena on convective, mesoscale, and synoptic scales. Bluestein is a fellow of the American Meteorological Society (AMS) and the Cooperative Institute for Mesoscale Meteorological Studies. He is past chair of the NSF Observing Facilities Advisory Panel, the AMS Committee on Severe Local Storms, and UCAR's Scientific Program Evaluation Committee, and a past member of the AMS Board of Meteorological and Oceanographic Education in Universities. He is also the author of a textbook on synoptic-dynamic meteorology and Tornado Alley, a book for the scientific layperson on severe thunderstorms and tornadoes. He received his Ph.D. in meteorology from the Massachusetts Institute of Technology.

James Bruce is the Senior Associate for Global Change Strategies International, Inc. in Ottawa, Canada. In his early professional life, he was a weather forecaster, established the flood warning system for the province of Ontario, and undertook research and teaching in hydrometeorology. Since then, he has held many positions, including being the Acting Deputy Secretary-General of the World Meteorological Organization, Geneva during which he assisted the Secretary-General in overseeing the establishment of the Intergovernmental Panel on Climate Change and the Global Atmosphere Watch for assessment of chemical changes in the Earth's atmosphere. Mr. Bruce has written several books, papers and articles, especially on climate change, environmental management, water resources, and disaster mitigation.

Ian Burton is an independent scholar and consultant. He holds several honorary positions including Scientist Emeritus in Environment Canada; and Emeritus Professor at the University of Toronto. He has recently served as a member of the Independent World Commission on the Oceans and is on the editorial board of three scientific journals including *Mitigation and Adaptation to Global Change* (Kluwer) and *Global Environmental Change* (Pergamon) as well as the *International Journal of Biometeorology*. Recent assignments include technical assistance to the UNEP (United Nations Environment Programme) Country Studies Programme on Climate Change Impacts and Adaptation; the GEF (Global Environment Facility) on the costs of adaptation; the World Resources Institute on climate change and economic development in Africa; the IPCC (Intergovernmental Panel on Climate Change) Expert Group on Adaptation; the European Commission in Brussels; and the World Bank on the inclusion of climate impact assessment considerations in Bank investments.

Antonio J. Busalacchi, Jr. is the founding director of the Earth System Science Interdisciplinary Center (ESSIC) at the University of Maryland College Park and Professor in the Department of Meteorology. ESSIC is a joint center among the Departments of Meteorology, Geology, and Geography at the University of Maryland in collaboration with the Earth Sciences Directorate at NASA's Goodard Space Flight Center. Dr. Busalacchi began his professional career as an oceanographer at the NASA/Goodard Space Flight Center. In 1991, he was appointed to the Senior Executive Service in the U.S. Government as the Chief of the NASA/Goodard Laboratory for Hydrospheric Processes. In that capacity he furnished scientific direction to a broad, many-faceted program in Earth system science.

David Changnon is an atmospheric scientist specializing in climatological studies in the Department of Geography at Northern Illinois University (NIU). After receiving his PhD in atmospheric sciences in 1991

from Colorado State University, he spent two years at the Southeast Regional Climate Center in Columbia, South Carolina, before taking an academic position at NIU. His major expertise rests in developing climatological information and models for use by weather-sensitive decision makers in agriculture, utilities, insurance, and transportation. He has developed an innovative new "education-to-career" program to train students and simultaneously solve climatological problems facing government and private industry. He has served on various committees of two scientific societies. His research interests also involve the spatial and temporal variability of climate extremes in the U.S. Changnon is the author or co-author on over 30 journal articles, book chapters, and other refereed publications. He has participated in a number of climate change workshops including the July 1998 summer session of the Aspen Global Change Institute titled "Climate extremes: Changes, impacts, and projections." Recently he was involved in a project examining the use of El Niño-based seasonal forecasts by decision makers during the 1997-98 El Niño.

Harold C. Cochrane is Professor in the Department of Economics at Colorado State University where . He has been at Colorado State since 1974 and he teaches environmental and natural resource economics, energy economics, and macroeconomic theory. He has worked extensively in the field of natural and man-made hazards and has served on a number of National Academy of Sciences and National Research Council committees. He is the Director of Colorado State's Hazards Assessment Laboratory. He holds a B.S. in Industrial Engineering from Pennsylvania State University and a Ph.D. in economics from the University of Colorado.

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Thomas Knutson is a research meteorologist in the Climate Dynamics and Prediction Group at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory - one of the world's leading climate modeling centers. He has been author or co-author of 15 publications in major climate journals, including papers in Science on future hurricane intensities with global warming and (with T. Delworth) on simulation of early 20th century global warming. His recent research interests include: the impact of climate change on hurricane intensities and detection of climate change. He has been an invited expert at several workshops on climate change and extreme events (or tropical cyclones) including at the Aspen Global Change Institute, the Risk Prediction Initiative at the Bermuda Biological Station for Research, the U.S. Environmental Protection Agency, and the American Meteorological Society Conference on Hurricanes and Tropical Meteorology. He was an invited speaker and breakout session chair for the Tropical Cyclones Session at a recent Workshop on Changes in Extreme Weather and Climate Events organized by the Intergovernmental Panel on Climate Change.

Jay Lawrimore became Chief of the Climate Monitoring Branch at the National Climatic Data Center (NCDC) in May 2000. He was a Meteorologist with the North Carolina Division of Air Quality before joining NCDC in 1998. He was a contributing author to the IPCC Third Assessment - Climate Change 2001 and has been lead author on articles published in journals such as the Bulletin of the American Meteorological Society, Journal of Geophysical Research, Journal of Hydrometeorology, and Chemosphere. As Chief of the Climate Monitoring Branch, Mr. Lawrimore leads a team focused on providing access to high quality climate information while performing analyses to place the current weather and climate in historical perspective. The climate monitoring team also provides links between weather and climate and those sectors of the Nation's economy that are weather sensitive, while also working to develop a network monitoring and performance indicator access system which will provide early detection of time-dependent biases and other network problems. He holds an M.S. in Atmospheric Science from North Carolina State University.

Steve Lyons is a tropical weather expert with The Weather Channel. His expertise is in tropical and marine meteorology. He has participated in more than 25 national and international conferences and provided World Meteorological Organization training courses in marine meteorology, tropical meteorology and ocean wave forecasting. Prior to joining The Weather Channel in April 1998, Steve managed the Tropical Analysis and Forecast Branch of the Tropical Prediction Center, National Hurricane Center. He has worked directly for private weather companies and traveled around the world forecasting weather in various tropical locales. Dr. Lyons has also been a private consultant forecasting ocean waves for numerous surfing beaches. Among his many interesting jobs, he has been a research scientist for the U.S. Navy, for the Geophysical Fluid Dynamics Laboratory at Princeton University, and for the University of California at Los Angeles. He has also been a professor of meteorology at Texas A&M University and at the University of Hawaii. Dr. Lyons also worked for the National Weather Service South Region Scientific Services Division, where he trained NWS meteorologists. He has published more than 20 papers in scientific journals, and written more than 40

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