sum4.htm

Events-Workshops-
Southeast

DRAFT

Draft Final Report
of the
Workshop on Climate Variability and Water Resources Management
in the Southeastern United States

Held June 25-27, 1997
at Vanderbilt University
Nashville, Tennessee

Sponsored by
National Aeronautics and Space Administration
United States Geological Survey, and
National Oceanic and Atmospheric Administration

DRAFT

DRAFT

WORKSHOP ON CLIMATE VARIABILITY AND WATER RESOURCE MANAGEME SOUTHEASTERN UNITED STATES

EXECUTIVE SUMMARY

A regional workshop on Climate Variability and Water Resource Management in the Southe United States was held at Vanderbilt University in Nashville, Tennessee on June 25-27, 1997 workshop was jointly sponsored by the National Aeronautics and Space Administration (NAS National Oceanic and Atmospheric Administration (NOAA) and the US Geological Survey (U This is one of a series of workshops on the effects of climate variability and climate change o regional environment and regional economics. These workshops are being coordinated by the Global Climate Change Research Program (USGCRP) and the Office of Science and Techno Policy (OSTP). They are expected to identify and examine high priority regional environment affected by current climate variation and future climate change. Information will be assemble regional scale that can eventually be aggregated across regions to support the identification c climate-related impacts and vulnerabilities at the national scale.

The overall purpose of the Southeastern Regional Workshop was to examine the impacts of clir variability and potential vulnerability to future climate change on natural resources various ec sectors, with an emphasis on water resources, in the following southeastern states: Alabama, A Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina and Tennessee. In ac to examining the regional vulnerability of current climate variability and future climate change workshop was organized to initiate dialogue between federal agencies and universities engaged climate-related research with key regional stakeholders who are responsible for the day-to-day management operations. al decisions of natural resources management.

At the workshop, Dr. Jim O'Brien of Florida State University demonstrated the enormous effect Nino and its opposite El Viejo has on the climate variability of the southeastern US. When there El Nino in the winter, for example, we can expect a reduction in hurricanes, reduction in tornadc winter rain, cool temperatures, but an adverse effect on crops in Florida. On the other hand, whe is a cool tropical Pacific Ocean (El Viejo or La Nina), we can expect more hurricanes, forest fire coastal regions of the Carolinas and in south Florida. In addition, we can have adverse effects or crops.

Dr. O'Brien also reported that the southeastern US does not seem to be affected by the North Atla Oscillation but is still affected by interdecadal variability which changes the frequency of the ENS Nino-Southern Oscillation) phenomena. Global climate change has created mild cooling in the

southeastern US.

During the workshop four basic themes became apparent. First, the regional infrastructure in the areas covered during the breakout discussions is already being stressed by resourse limitations near-term weather and climate variations. In addition, Mmeeting current day-to-day operations already consumes most of the time and budget of a regional stakeholder in the absence of climate-related issues. If the magnitude of climate variability increases or there are more frequent extreme events, the system will be stressed even further. Incorporating climate variability and change into these operational decisions will only exacerbate this situation.

Second, although our climate predictive skills are improving, especially with short-term forecasts (i.e., up to 72 hours) and data are currently available or are emerging from the climate community, this information is not widely used by the regional stakeholders. In essence, there has been an inadequate communication of climate risk at the regional and local levels. there is considerable uncertainty at the regional level about the nature and extent of climate variability and future climate change. Decision-makers at these regional and local levels are interested in want additional information on climate variability and change if they can obtain answers to questions about the magnitude of effects, the timing, and the potential costs. Given the inherent uncertainties in recognizing climate change against a background of normal climate variability, regional stakeholders must decide in a world of considerable uncertainty. The workshop intended to highlight some of the new approaches and new data emerging from the climate community. It is anticipated that this workshop and any follow-on efforts will help mold these approaches and data for better use by the regional stakeholders.

Third, regional stakeholders are generally unable to use effectively use information, data, and products currently that are available from the climate community. A clearer understanding of the products that are available or will be available in the near future from the scientific community is greatly needed. Individual scientists performing research are not generally interested in expected to negotiateing and communicateing their results directly with the policy- and decision-makers. An exerted effort will be required to identify scientific results that can be used in the public and private sectors and can contribute more directly to near-term economic and societal applications. One cause of the current deficiency is that existing delivery or distribution systems (e.g., county extension program for agriculture) are not generally linked to the outputs of the climate community.

Fourth, stronger, stronger partnerships among federal and academic researchers, regional, state, and local stakeholders, and the private sector are needed to adopt and incorporate advanced science results, technology, and data products into everyday decision-making.. Better linkages are required between researchers and regional stakeholders to define better the needs of a broader user community

and to identify scientific results that will meet these needs. The use of selected pilot studies Adoption and incorporation of advanced science results, technology, and data products into everyday decision-making is strongly encouraged. that demonstrate this approach is strongly encouraged.

The workshop consisted of plenary talks that set the context and framework and also breakout discussions (see Appendix A for the agenda). In the plenary sessions several topics were covered such as current climate variability in the Southeast, climate and weather extreme events and their social and economic consequences, perspectives of the regional stakeholders, global climate change trends in the Southeast, and the educational aspects of climate. The breakout sessions were focused on important economic sectors including: agriculture, coastal and fisheries, education, extreme events, parks and public lands, urban areas and human health, and water resources.

The following four questions were posed in each of the breakout sessions:

- What are the current concerns and stresses of the regional stakeholders in each sector?

- How can current climate variability and climate change amplify these concerns and stresses?

- What information and data is needed to address these climate-related issues?

- What types of strategies and approaches are available for coping with or mitigating these stresses?

The responses to these questions served as points for discussion within the breakout session and as the major output of the workshop. In this summary, we provide a set of key findings and recommendations that represent the deliberations of the seven working groups and the final, plenary session. These findings are either unique to the Southeast or are important enough to warrant serious consideration in future national assessments. There are gaps in the areas considered in these recommendations, especially for forestry and fisheries. These gaps will be addressed in future workshops and discussions. The full set of findings and recommendations for each of the breakout topics are also presented as a record of the workshop discussions.

There is much more to learn about the effects of climate variability and climate change

on the key economic sectors in the Southeast. The findings and recommendations of this workshop provide a beginning discussion on what is important and how to proceed. It is expected that these recommendations will be reviewed and updated at regular intervals. In this way, we can better prepare for an uncertain future.

Key Findings and Recommendations

Water Resources

Findings:

• The overriding water resources issue in the Southeast is that the demand for water is beginning to exceed the available supply and competition among water uses is intensifying. This competition for water is exacerbated by climate variability and change.

• As water conflicts in the Southeast have intensified, it has become apparent that there are inadequate mechanisms for the equitable allocation of water. Since some of the most important water issues are not of a technical nature, but are political, social, and institutional issues, a major concern is how to develop, flexible and adaptive institutions, legal frameworks, and problem solving mechanisms to allocate water among its competing uses.

Recommendations:

• Bridges are is needed between information that can be produced regarding future climate variability and change and the information required to understand tradeoffs among different water management alternatives including reliability of climate information, use of hydrologic models to translate climate information into streamflow, water levels and soil moisture, and decision support systems.

• There is also a need for demonstration or pilot projects to assure appropriate linkages are made among water resources stakeholders, water system operators, government

agencies, and the scientific community. The Global Water and Energy Cycle (GEWEX) Continental-scale International Project (GCIP), which is about to be initiated in the Southeast, is encouraged to undertake such pilot projects to accelerate the development of models and information related to the prediction of precipitation, soil moisture, and streamflow and to test their value to the water resources community.

• To better allocate water and resolve water conflicts, innovative supply side management (i.e., water credits, pricing strategies, inter-basin transfers, etc), integrated basin management using multi-governmental and stakeholder teams to solve problems, and flexible institution/mechanisms for resolving conflict are needed.

Agriculture

Findings:

• Because aAgricultureal in the sector in the Southeast is productive yet diverse both in systems (cropping and farming systems as well as, diseases, insects, weeds, and pest-complexes) and stresses. and Because irrigation is not as prevalent as in other parts of the country, the effects of climate variability and change on agriculture can be amplified.

• The heterogeneous nature of topography, soil structure and quality, and climate (e.g., strong ENSO signal) is unique in the Southeast. The interrelationships among these characteristics and their role in sustaining productivity is not well understood.

Recommendations:

• In the agricultural sector, a need exists to develop, validate, and evaluate new technology capabilities such as climate forecasting, use of remotely sensed data, biophysical modeling, and precision agriculture using a multidisciplinary approach that includes producers, researchers, government agencies, farmers and others in the private sector.

• In agriculture there is also the need to explore the transfer/communication of relevant information on climate variability/change over a full spectrum of temporal and spatial scales to users and user-specified applications. This may be best realized through the support of demonstration or pilot projects with the county extension system or similar outreach programs.

Urban Areas and Human Health

Findings:

• Air quality is a major concern of urban areas and it contributes to a host of environmental and human health problems (e.g., secondary air pollutants such as tropospheric ozone and chronic and acute respiratory diseases). These problems can be exacerbated by climate variability and change.

• Urban heat islands, land use changes, and urbanization in general directly contribute both to air quality degradation through their influence on photochemical processes and to the local and regional climate (e.g., elevated air temperatures, altered precipitation patterns, changes in surface albedo, etc.).

Recommendations:

• Data are needed to identify susceptible populations that will be affected by changes in climate extremes and variability, to correlate respiratory health to air quality changes resulting from climate variability, and to evaluate the cost of local and regional climate variability impacts on urban areas for urban planners and decision-makers.

• Improved education of both the public and decision-makers and effective communication by scientists to the public on the effects of climate variability and change on urban areas and human health and on how urban areas affect local and regional climate is essential in developing mitigation strategies.

Coastal

Findings:

• Populations on and near the coast of the southeastern US grew at phenomenal rates over the past 30 years leading to complex social and economic concerns related to mitigating the impact of climate variability and change such as sea level rise, storm surges, and extreme events.

• The potential range of climate-related impacts on ocean and coastal resources has been fairly well documented but a comprehensive assessment of the magnitude of environmental and economic costs associated with coastal impacts and hazards is still lacking.

Recommendations:

• Better compilations of life history data for coastal ecosystems and improved understanding of carrying capacities for sensitive species are needed so that managers can better understand the range of impacts and assess mitigative actions. These data need to be merged with socioeconomic and climate variables to improve our understanding of and ability to communicate the potential impacts.

• The current natural systems approach, which relies on biogeographical provinces, needs to be expanded to include climatic relationships. Further, various controlled-use sites (e.g., National Wildlife Refuges, National Estuarine Research Sites, LTERs, and LMERS sponsored by NSF) in the region should be linked to develop a baseline reference system for studying change.

Parks and Public Lands

Finding:

• Southeast region is forecast as the fastest growing in the country causing expansion of

stresses on parks and public lands (introduction of non-native, invasive species, habitat fragmentation, island biomes, water and air quality issues), while at the same time, current fiscal conditions results in managers of public lands being stressed. Public managers are not well equipped to deal with extreme climate events and they have specific information needs related to decadal climate fluctuations, storm predictability, and extreme events.

Recommendations:

• There is a need to develop firm federal policy on infrastructure in public areas so as not to exacerbate or expand development pressures from outside the public area or create more fragmented systems.

• Regional cooperation among federal, state, and local agencies and the private sector need to be encouraged for maintenance of community continuity to allow for adaptive change in habitat/biological communities. Southern Appalachian Assessment (SAA) might serve as an example of multiagency cooperation for integrated planning and development of information for use in local and regional decisions.

Extreme Climate Events

Finding:

• Extreme climate/weather events have a considerable impact on stakeholders in the Southeast associated with sectors that include energy, emergency management, and water resources. The Southeast is becoming increasingly vulnerable to extreme events including hurricanes, floods, droughts, ice storms, heat waves, and tornadoes because of rapid population growth and development in vulnerable coastal locations.

Recommendations:

• There is a need to maintain and extend our ability to collect, analyze, and disseminate data related to climate over the long term. In the case of extremes, such data have a demonstrable relationship to decision-making. Given that societal and environmental

problems associated with climate extremes are complex, data causes must also be collected on non-climate factors (i.e., social and economic impacts and causes).

• Bridge building must increase to develop processes to determine what climate information and tools would be of use to stakeholders. Existing organizations such as the National Climatic Data Center, Regional Climate Centers, and State Climatologists should be used to enhance the linkage between climate science and regional stakeholders.

Education

Finding:

• Since education cuts across each of the breakout topics, there are many opportunities for the educational community to contribute to the climate research agenda, to use scientific results to enhance educational programs, and to educate future generations of teachers to implement earth science systems science programs.

Recommendation:

• From the educational perspective, the most important recommendation is to promote the adoption and expansion of existing educational authentic learning programs, such as Global Learning and Observations to Benefit the Environment (GLOBE), that involve students and their teachers in data collection, data manipulation, and data interpretation. The upcoming Global Water and Energy Cycle (GEWEX) Continental-scale International Project (GCIP) in the Southeast was suggested as a candidate program for establishing a partnership between the scientific and educational communities to demonstrate this approach.

I. Introduction

The US Global Climate Change Research Program (USGCRP) and the Office of Science and Technology Policy (OSTP) are coordinating a series of workshops on vulnerabilities of various regions of the United States to climate variability and climate change. These workshops are expected to engage key regional stakeholders to identify and examine high priority regional environmental issues affected by current climate variation and climate change and to obtain information that can be aggregated across regions to support analyses of climate-related impacts and vulnerabilities at the national scale. The workshop on the southeastern United States, which was jointly sponsored by the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA), was held at the Vanderbilt University campus in Nashville, Tennessee on June 25-27, 1997.

The purpose of the Southeast Regional Workshop was to examine the impacts of climate variability and potential vulnerability to future climate change on various economic sectors, with an emphasis on water resources, in the following southeastern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee. The initial basis for this workshop was to develop better long-term dialogue between federal agencies engaged in climate-related research and key regional stakeholders who are responsible for the operational decisions of natural resources management for the purpose of demonstrating the value of federal earth science research for practical applications. This workshop focus was later expanded in accordance with the USGCRP and OSTP themes mentioned above to include an examination of the regional vulnerability in a broader range of potential impact areas such as agriculture, forestry, and human health to current climate variations and climate change.

The emphasis on how climate variation and climate change will influence hydrology and water resources of the southeastern United States, and in turn, how these changes may affect interests such as agriculture, forestry, water resource management, etc., was selected for several reasons. First, there is a relatively strong El Nino-Southern Oscillation (ENSO) signal in the southeastern United States that can be related to interannual variations in precipitation and temperature. Thus, any improvements in these ENSO forecasts in the future can provide significant economic benefits to farmers, utilities, and other natural resource managers in this region depending on their ability to use them effectively. Second, better forecasts of precipitation and temperature have enormous economic benefits to large power producers in the region including the Tennessee Valley Authority, Duke Power, and the Southern Company. For example, improved precipitation forecasts are estimated to save $2M over a five-year period for one southeastern utility. Also, better short-term (48-72 hours) temperature forecasts offer significant economic benefits to utility load management decisions. As the nation's utilities move toward a more competitive environment, such forecasts will become invaluable. These potential economic benefits, however, are related not only to better forecasts but also to improvements in how water and energy resources managers use these forecasts. Finally, the southeastern United States has suffered over the years from extreme climate events including hurricanes, tornadoes, lightning, and winter storms. A better understanding of climate and weather data, and the application of this information to private and public sector decisions on disaster prevention and mitigation could have significant benefits for society.

In addition to the economic implications of climate variability in the Southeast there are also scientific considerations for emphasizing hydrology and water resources, and their influence on various economic sectors. For example, beginning in 1998 the GEWEX Continental-scale International Project (GCIP), a study of the Mississippi River Basin intended to improve scientific understanding and to model on a continental scale the coupling between the atmosphere and land surface for climate prediction purposes, will focus its attention on the eastern part of the basin - namely the Tennessee-Cumberland and Ohio River Basins. One aim of these intensive studies is to generate inputs for operational hydrologic and water resources management models for use in local level decision making. Other major ongoing studies in the Southeast such as the EPA's Gulf of Mexico Program and USGS's National Water Quality Assessment Program also provide the scientific underpinnings for the workshop focus.

DRAFT

WORKSHOP ON CLIMATE VARIABILITY AND WATER RESOURCE MANAGEMENT IN THE SOUTHEASTERN UNITED STATES

EXECUTIVE SUMMARY

A regional workshop on Climate Variability and Water Resource Management in the Southeastern United States was held at Vanderbilt University in Nashville, Tennessee on June 25-27, 1997. The workshop was jointly sponsored by the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and the US Geological Survey (USGS). This is one of a series of workshops on the effects of climate variability and climate change on regional environment and regional economics. These workshops are being coordinated by the US Global Climate Change Research Program (USGCRP) and the Office of Science and Technology Policy (OSTP). They are expected to identify and examine high priority regional environmental issues affected by current climate variation and future climate change. Information will be assembled at the regional scale that can eventually be aggregated across regions to support the identification of climate-related impacts and vulnerabilities at the national scale.

The overall purpose of the Southeastern Regional Workshop was to examine the impacts of climate variability and potential vulnerability to future climate change on natural resources, with an emphasis on water resources, in the following southeastern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina and Tennessee. In addition to examining the regional vulnerability of current climate variability and future climate change, the workshop was organized to initiate dialogue between federal agencies and universities engaged in climate-related research with key regional stakeholders who are responsible for the operational decisions of natural resources management.

DDuringuring the workshop four basic themes became apparent. First, the regional infrastructure in the areas covered during the breakout discussions is already being stressed by resourse limitations near-term weather and climate variations. In addition, Mmeeting current day-to-day operations already consumes most of the time and budget of a regional stakeholder in the absence of climate-related issues. If the magnitude of climate variability increases or there are more frequent extreme events, the system will be stressed even further. Incorporating climate variability and change into these operational decisions will only exacerbate this situation.

Second, although our climate predictive skills are improving, especially with short-term forecasts (i.e., up to 72 hours) and data are currently available or are emerging from the climate community, these information are not widely used or understood by the regional stakeholders. In essence, there has been an inadequate communication of climate risk at the regional and local levels. there is considerable uncertainty at the regional level about the nature and extent of climate variability and future climate change. Decision-makers at these regional and local levels are interested in want additional information on climate variability and change if they can obtain answers to questions about the magnitude of effects, the timing, and the potential costs. Given the inherent uncertainties in recognizing climate change against a background of normal climate variability, regional stakeholders must decide in a world of considerable uncertainty. The workshop intended to highlight some of the new approaches and new data emerging from the climate community. It is anticipated that this workshop and any follow-on efforts will help mold these approaches and data for better use by the stakeholders.

Third, regional stakeholders are generally unable to use effectively use information, data, and products currently that are currently available from the climate community. A clearer understanding of the products that are available or will be available in the near future from the scientific community is greatly needed. Furthermore, individual scientists performing research are not generally interested in expected to negotiateing and communicateing their results directly with the policy- and decision-makers. An exerted effort will be required to identify scientific results that can be used in the public and private sectors and can contribute more directly to near-term economic and societal applications. One cause of the current deficiency is that existing delivery or distribution systems (e.g., county extension programs for agriculture) are not generally linked to the outputs of the climate community.

Fourth, stronger, stronger partnerships among federal and academic researchers, regional, state, and local stakeholders, and the private sector are needed to adopt and incorporate advanced science results, technology, and data products into everyday decision-making.. Better linkages are required between researchers and regional stakeholders to define better the needs of a broader user community and to identify scientific results that will meet these needs. The use of selected pilot studies Adoption and incorporation of advanced science results, technology, and data products into everyday decision-making is strongly encouraged. that demonstrate this approach is strongly encouraged.

The workshop was highlighted by several key presentations including Vice President Al Gore, Mayor Bill

Campbell of Atlanta, Dr. Jack Gibbons, the President's Science Advisor, and Dr. Jerry Melillo from the Office Science and Technology Policy. Several plenary talks set the context and framework for the breakout session discussions (see Appendix A for the workshop agenda). The topic of climate was framed by Dr. Jim O'Brien of Florida State University, who demonstrated the enormous effect that El Nino and its opposite El Viejo (La Nina) has on the climate variability of the southeastern United States. In addition, Robert Quayle of the National Climatic Data Center, discussed observed climate trends for the globe and the Southeast. Dr. Roger Pielke, Jr. of the National Center for Atmospheric Research organized a panel of scientists and stakeholders representing agricultural, coastal, and energy interests on climate extremes and societal impacts. Many of the regional stakeholder perspectives were outlined by Dr. Michael Helfert, head of the Southeast Climate Center in South Carolina. Finally, Dr. Roger Bybee, National Research Council, offered insights on the educational aspects of climate. Extended abstracts of these plenary talks are presented as part of this summary.

AThe breakout sessions were focused on important economic sectors including: agriculture, coastal and fisheries, education, extreme events, parks and public lands, urban areas and human health, and water resources.

The following four questions were posed in each of the breakout sessions:

- What are the current concerns and stresses of the regional stakeholders in each sector?
- How can current climate variability and climate change amplify these concerns and stresses?
- What information and data is needed to address these climate-related issues?
- What types of strategies and approaches are available for coping with or mitigating these stresses?

The responses to these questions, which served as points for discussion within the breakout sessions, are the major output of the workshop. In this summary, we next provide extended abstracts of the various plenary talks followed by the full set of findings and recommendations representing the deliberations of the seven working groups and the final, plenary session. These findings and recommendations warrant serious consideration in future national assessments of climate impacts. However, there are gaps in the areas considered at the workshop, especially for forestry, fisheries, and freshwater ecosystems. These

gaps will be addressed in future workshops and discussions.

There is much more to learn about the effects of climate variability and climate change on the key economic sectors in the Southeast. The findings and recommendations of this workshop provide a beginning discussion on what is important and how to proceed. It is expected that these recommendations will be reviewed and updated at regular intervals. In this way, we can better prepare for an uncertain future.

Key Findings and Recommendations

Water Resources

Findings:

- The overriding water resources issue in the Southeast is that the demand for water is beginning to exceed the available supply and competition among water uses is intensifying. This competition for water is exacerbated by climate variability and change.

- As water conflicts in the Southeast have intensified, it has become apparent that there are inadequate mechanisms for the equitable allocation of water. Since some of the most important water issues are not of a technical nature, but are political, social, and institutional issues, a major concern is how to develop, flexible and adaptive institutions, legal frameworks, and problem solving mechanisms to allocate water among its competing uses.

Recommendations:

- Bridge is needed between information that can be produced regarding future climate variability and change and the information required to understand tradeoffs among different water management alternatives including reliability of climate information, use of hydrologic models to translate climate information into streamflow, water levels and soil moisture, and decision support systems.

- There is also a need for demonstration or pilot projects to assure appropriate linkages are made among water resources stakeholders, water system operators, government agencies, and the scientific community. The Global Water and Energy Cycle (GEWEX) Continental-scale International Project (GCIP), which is about to be initiated in the Southeast, is encouraged to undertake such pilot projects to accelerate the development of models and information related to the prediction of precipitation, soil moisture, and streamflow and to test their value to the water resources community.

Agriculture

Finding:

• Because agriculture in the Southeast is diverse (cropping and farming systems, diseases, insects, weeds, and pest-complexes) and irrigation is not as prevalent as in other parts of the country, the effects of climate variability and change on agriculture can be amplified.

Recommendations:

• In the agricultural sector, a need exists to develop, validate, and evaluate new technology capabilities such as climate forecasting, use of remotely sensed data, and precision agriculture using a multidisciplinary approach that includes producers, researchers, government agencies, farmers and others in the private sector.

• In agriculture there is also the need to explore the transfer/communication of relevant information on climate variability/change over a full spectrum of temporal and spatial scales to users and user-specified applications. This may be best realized through the support of demonstration or pilot projects with the county extension or similar outreach programs.

Urban Areas and Human Health

Findings:

• Air quality is a major concern of urban areas and it contributes to a host of environmental and human health problems (e.g., secondary air pollutants such as tropospheric ozone and chronic and acute respiratory diseases). These problems can be exacerbated by climate variability and change.

• Urban heat islands, land use changes, and urbanization in general directly contribute both to air quality degradation through their influence on photochemical processes and to the local and regional climate (e.g., elevated air temperatures, altered precipitation patterns, changes in surface albedo, etc.).

Recommendation:

• Data are needed to identify susceptible populations that will be affected by changes in climate extremes and variability, to correlate respiratory health to air quality changes resulting from climate variability, and to evaluate the cost of local and regional climate variability impacts on urban areas for urban planners and decision-makers.

Coastal

Findings:

Recommendations:

Parks and Public Lands

Finding:

• Southeast region forecast as the fastest growing in the country causing expansion of stresses on parks and public lands (introduction of non-native, invasive species, habitat fragmentation, island biomes, water and air quality issues), while at the same time, current fiscal conditions results in managers of public lands being stressed. Public managers are not well equipped to deal with extreme climate events and they have specific information needs related to decadal climate fluctuations, storm predictability, and extreme events.

Recommendations:

• There is a need to develop firm federal policy on infrastructure in public areas so as not to exacerbate or expand development pressures from outside the public area or create more fragmented systems.

• Regional cooperation among federal, state, and local agencies and the private sector need to be encouraged for maintenance of community continuity to allow for adaptive change in habitat/biological communities. Southern Appalachian Assessment (SAA) might serve as an example of multiagency cooperation for integrated planning and development of information for use in local and regional decisions.

Extreme Climate Events

Finding:

• Extreme climate/weather events have a considerable impact on stakeholders in the Southeast associated with energy, emergency management, and water resources. The Southeast is becoming increasingly vulnerable to extreme events including hurricanes, floods, droughts, ice storms, heat waves, and tornadoes because of rapid population growth and development in vulnerable coastal locations.

Recommendations:

• There is a need to maintain and extend our ability to collect, analyze, and disseminate data related to climate over the long term. In the case of extremes, such data have a demonstrable relationship to decision-making. Given that societal and environmental problems associated with climate extremes are complex, data must also be collected on non-climate factors (i.e., social and economic).

• Bridge building must increase to develop processes to determine what climate information and tools would be of use to stakeholders. Existing organizations such as the National Climatic Data Center, Regional Climate Centers, and State Climatologists should be used to enhance the linkage between climate science and regional stakeholders.

Education

Finding:

• Since education cuts across each of the breakout topics, there are many opportunities for the educational community to contribute to the climate research agenda, to use scientific results to enhance educational programs, and to educate future generations of teachers to implement earth science systems programs.

Recommendation:

• From the educational perspective, the most important recommendation is to promote the adoption of existing educational programs, such as Global Learning and Observations to Benefit the Environment (GLOBE), that involve students and their teachers in data collection, data manipulation, and data interpretation. The upcoming Global Water and Energy Cycle (GEWEX) Continental-scale International Project (GCIP) in the Southeast was suggested as a candidate program for establishing a partnership between the scientific and educational communities to demonstrate this approach.

IMPACTS OF ENSO GENERATED CLIMATE VARIATIONS IN THE SOUTHEAST US

James J. O'Brien

Distinguished Research Professor

The Center for Ocean-Atmospheric Prediction Studies

The Florida State University

Tallahassee, FL 32306

Introduction

The Planet's earth, air, water, ice, biological system experiences climate variability over many time scales. As humans, we are acutely aware of the diurnal and seasonal time scales. Persons who are fortunate to travel discover the effect of latitude on the range of air temperature and

precipitation on these daily and annual signals. Folks who talk to grandparents or live past 40 years' experience interannual variations, i.e., "last winter was the coldest, I have experienced"; we never had a hurricane as long as I have lived in this town," etc.

When the author was studying to be a chemist at Rutgers, all these interannual events were blamed on Soviet bomb tests in the upper atmosphere. As recent as the early 1960's, geophysicists predicted an ice age and people were talking about moving equator- ward. Now the tabloid presentations of Global Warming impacts have people considering moving inland and poleward.

Scholars have found that there are other potential short term variability events such as 5 - 10 year or 10 - 20 year natural variability events such as the dust bowl in Oklahoma in the 1950's, the

droughts in Texas in the 1950's, the lack of hurricanes in the 1970's, the drought in the Sahel in the 1980's, etc.

In the 1960's, El Niño was discovered but except for some oceanographers who worried about

anchoveta stocks off Peru, the climate variability caused by El Niño in all the Pacific Rim countries and other far away places like southern Africa, India, etc. were not studied. El Niño means warm water (+1.0 degree) along the equator west of the Galapagos Islands in the

Pacific which lasts for five or more months. El Niño occurs every 3 -7 years. The climate variations created by El Niño over North America are substantial as will be discussed below.

Recently, climate scientists were investigating some "new" phenomena, such as the "North Atlantic Oscillation" as a creator of both 2 - 5 year and 18 - 25 year climate variability.

All in all, upon reflection, we can identify time scales of climate variability from day, season, year, interannual, decadal, multi-decadal and longer. Unfortunately, we do not have the climate records to study longer time scales and we resort to the marvelous fingerprints of climate variability in trees, fossils, ice, mud, etc.

In fact, in the southeast, we are experiencing a slight cooling over the past tens of years. The main point is that climate variability occurs on many time scales. Our climate records are very short. In the southeast United States, we have very few stations more than 150 years long. This means that we have not experienced the outliers in a NORMAL stationary climate record. We must really expect to experience hotter, colder, wetter, dryer weather than ever measured before. A few years ago, everyone in Tallahassee was commenting on a drought near the end of the year because we had 15 inches less rainfall during that year. Some blamed the event on global warning or the new high magnetic fields produced at Florida State University which pushed the rain away. In fact, such a deficit should occur about every 12 - 14 years. An inspection of the climate record for Tallahassee indicated this was true, but everyone has too short a memory.

The economic impacts of climate variability are vast. The impacts on food production, energy, fisheries, recreation, etc. are enormous. We are gradually learning about climate variability and how to anticipate climate variability. We need to learn to forecast climate variability and bring these understandings and prediction to the stakeholder level.

Climate Change

There will certainly be global climate change and regional climate change. The increase in human population, the change of land use and many other man-created changes will affect climate

change. Some will be permanent changes. The emission of radiatively-active gases such as CO_2 and methane have a radiation interaction with the atmosphere and increase the greenhouse effect. Whether we get warming from CO_2 or cooling from a coming ice age, is not as important as identification of the cause and magnitude of climate variabilities.

The existing record shows an increase of 0.5° C in the globally-averaged surface air temperature more than 100 years. Is this signal a remnant of the difference between warming and cooling or is it a part of a 200-year long variability?

In the southeast United States, the largest cause of climate variability is El Niño and its counterpart (Mr. Hyde), or "El Viejo," the scientific term for a cold ocean along the Equator in the eastern Pacific Ocean. After one subtracts the diurnal and seasonal signal from the climate record, then floods and droughts, heat waves and ice storms, more or fewer hurricanes, more or fewer tornadoes, etc., in the southeast United States are directly linked to the occurrence of warm or cold water in the Pacific Ocean west of the Galapagos Islands.

Hurricanes and Things

The biggest single effect of the number of hurricanes to strike U.S. landfalls (almost all in the southeast) is El Niño. If there is warm water in the eastern equatorial Pacific, the probability

of 2 or more hurricanes striking the southeast United States is *one in every five years*. If the ocean water is not 0.5° C warmer, the probability of two or more hurricanes striking the southeast United States is *one in every two years*. Hurricanes and tropical storms are a major source of fresh water for most of the southeast. Unfortunately, they do lots of damage when striking popular coastal regions. Recent studies have shown that the incredible increase in damage due to hurricanes is not due to global warming, but due to the fact that more people live in the coastal zone.

The increase in the number of Atlantic hurricanes in the 1995 season was due to El Niño going away. The large number was natural variability. The Insurance Industry asked the author to discover whether global warming would mean more Atlantic hurricanes. A study by the Max Planck Institute shows that warm ocean in a CO_2 doubling experiment is similar to a semi permanent El Niño and, thus fewer hurricanes in the Atlantic.

Unfortunately, there will be more intense Pacific hurricanes (the kind that strike Hawaii or Mexico) and more typhoons for Asia. (After all, the Planet general circulation must have hurricanes to transport the heat poleward to high latitudes and tropical storms are very efficient

to accomplish this.)

The conclusion is, if we have more global warming, there will be fewer hurricanes for the southeast. We need to calculate how much loss of water for the Carolinas, Georgia and Florida. On the other hand, a recent study by Cane, et al. indicate that the 100-year SST record in the Pacific shows more El Viejo or cold events. This means more Atlantic hurricanes!

What is going on? The models are not good enough! Maybe! The coupled ocean ice-atmosphere models show warming when one increases the CO_2, but the ocean in the Pacific shows cooling and the minimum temperatures in the southeast United States show cooling.

El Niño is a Good Dude

El Niño is a wonderful positive climate happening for the southeast United States! El Niño suppresses hurricanes. El Niño gives winter rain to the coastal Carolinas, the State of Florida and the coasts of Alabama, Mississippi, Louisiana, and Texas. This greatly suppresses forest

fires, helps winter vegetables, produces better oranges. And, nicely, it is only a "bit of extra rain," so it does not hurt tourism.

The opposite of El Niño is called "La Niña" by some scientists, "El Viejo," by COAPS, and more properly, the cold phase of ENSO by the educated scientific community. El Viejo is very bad for the southeast United States. We have more hurricanes, winter droughts in the coastal regions of the southeast, and therefore, raging forest fires. But there is a newly discovered serious climate variability problem. When El Viejo is alive, near the Galapagos Islands, a new tornado belt exists from Mississippi to Indianapolis. In Tennessee, the probability of four or more tornadoes occurring in the spring (March, April, May) when El Viejo has occurred in the winter is 4 - 5 times more likely than other years. This recently discovered fact arose from studying climate variability and not secular trends.

The Future

There will be an alarming climate change in the southeast United States due to growth of population, and, accompanied land use changes. On the bright side, oceanographers and meteorologists are learning how the ocean controls the climate variability on daily, seasonal, interannual and decadal time scales. If we learn to educate the stakeholders on the new scientific knowledge and the new ability to forecast these events, a great economic benefit will be achieved.

A Gift

A video of the animations I showed in my talk was made. You can have a copy by emailing me at OBRIEN@COAPS.FSU.EDU.

4

Observed Climate Trends for the Globe and the Southeastern U.S.

Robert G. Quayle and Thomas R. Karl, National Climatic Data Center

The Intergovernmental Panel on Climate Change has concluded that man may indeed have begun contributing to the Earth's process of climatic change. Probably with help from an enhanced greenhouse effect, global average temperature has increased by about half a degree Celsius over the past century and is predicted to rise further and raise sea level (see Fig. 1). The southeastern U.S. is one of the handful of places on Earth showing a net cooling over the 20th century (see Fig. 2). This is not entirely unexpected, as some climate model simulations show a tendency toward reduced warming in the eastern U.S. due to anthropogenic sulfate aerosols. U.S. precipitation has also increased, in general agreement with model projections that as the globe warms, mid- to high-latitude precipitation will increase. Nationally, most of this increase has been in the more extreme events, and very little in the more moderate events (see Fig. 3). While moderate rains generally benefit agriculture and the water supply, heavy rains are less efficient (more water runs off into the sea), and are more likely to cause flooding. And, with a climate warming, it is also likely that there will be increased drought frequency. This strange combination of generally increasing precipitation interspersed with increased drought frequency is exactly what the Southeast has experienced during summer in recent decades.

Fig. 4 shows regional model predictions of changes in precipitation median intensity for the 48 contiguous U.S. This experiment was run to estimate the likelihood that observed precipitation trends (generally toward more intense events) would continue. For most areas an increase in heavy precipitation is evident, while the median is relatively unchanged. This experiment used two 20-year simulations, one consisting of a control run with today's carbon dioxide, and the other a series of runs with doubled carbon dioxide. The difference between today's precipitation climate and the climate with doubled carbon dioxide was calculated and mapped for 9 U.S. regions and the contiguous U.S. as a whole, with the overall mean of all 9 areas plotted to the right off the SE coast. Because of the increasing precipitation intensity, increased flooding, runoff, and erosion are quite possible in a greenhouse enriched atmosphere.

Climate has changed many times in the past, but the current rate of change seems to be large and there are enough similarities between observed changes and expected changes due to increased greenhouse gas that most scientists now believe that the evidence for man=s impact on climate is compelling. While there is still uncertainty, the primary concern has shifted from the question "Will climate change? to the question "What will be the nature of the impending climate change, and most important, what will be the consequences?"

List of Figures:

Fig. 1. IPCC 1995 projections of a) global warming and b) sea level rise (after Houghton et al., 1996). The shaded area represents spread between the smallest projected warming & sea level rise (dashed line, assuming stabilization at 450 ppmv carbon dioxide in 2100), and the largest warming & sea level rise (solid line, assuming stabilization at 650 ppmv carbon dioxide in 2200).

Fig. 2. Mean annual temperature and precipitation trends for the globe based on data collected from a variety of sources. Closed dots (positive trend) depict warming or moistening, and open dots (negative trend) depict cooling or drying. The size of the dot is proportional to the trend (in degrees C and % per century) as noted on the Figure. The period of these data is 1901-1996.

Fig. 3. Past precipitation trends (% per century) regionally for the contiguous U.S., for various percentiles of daily precipitation. To calculate these, daily precipitation amounts for all days of each year-month were arrayed from the lowest to the highest, and the threshold amounts calculated for all precipitation events falling in 5-percentile increments of successively increasing precipitation intensity, (e.g., <5%, 5-10%, ... >95%) for each month, season, and year. The yearly precipitation amounts for each category of precipitation intensity were then subjected to time series analysis, and the resulting linear trend expressed as the precipitation change per century in each interval as a percentage of the overall total mean precipitation. The period of record is 1910-1995. This diagram shows the contribution of various precipitation class intervals to the total increase of precipitation during this time of approximately 10%.

Fig. 4. Goddard Institute for Space Studies (GISS SI95) global climate model predictions of: (a) the percentage change in the proportion of total annual precipitation from 1-day events over 1 inch; and (b) the change (in mm) of the median 1-day precipitation amount. Closed circles depict increases and open circles depict decreases.

-end-

Trends in Extreme Events and Societal Impacts

Roger A. Pielke, Jr.

ESIG/NCAR

> We do not know. . . for sure that the warming of the Earth is responsible for what seems to be a substantial increase in highly disruptive weather events, but many people believe that it is, and that we have to keep looking into it. . . If there is a larger cause which can be eased into the future, we ought to go after that solution as well.

President Bill Clinton, April 22, 1997

The recent statement by Present Clinton reflects two common perceptions. First, it reflects a sense that the economic impacts associated with extreme weather events have increased in recent years. Second, a perception exists that the recent increase in weather-related events is due to changes in climate related to global warming. In recent years, these perceptions have resulted in almost every extreme event being attributed, by someone, to global warming.

The perceptions are more than simply idle speculations -- they underlie policy decisions with important social, economic, and political ramifications. For instance, in December of this year representatives from nations around the world will meet in Kyoto, Japan to discuss and debate implementation of the Framework Convention on Climate Change. Because policy is based on the perceptions that policy makers hold about climate, it is worth determining the validity of the two perceptions.

In the case of economic losses associated with extreme weather events (specifically hurricanes, floods, and tornadoes), there is a trend of increasing losses in recent decades in the United States. Thus, the first perception is demonstrably valid. There is, however, no reliable evidence to date to support the perception that recent trends in economic losses in the United States are attributable to changes in climate -- *regardless of the hypothesized cause*. Clearly, climate has varied regionally with respect to particular phenomena, however, this variation is difficult to discern in the historical record of societal impacts (e.g., dollar losses). Instead, the strongest signal present in the historical record is that increased societal vulnerability is the primary cause of recent increases in documented economic losses. Note that this finding in no way refutes the global warming hypothesis. Rather, it refutes the claim that past losses can be attributed to the increased frequency or magnitude of extreme weather events. This is consistent with the findings of the Intergovernmental Panel on Climate Change, published in 1996.

The two attached figures show trends in hurricane damages during this century. Figure 1 shows the data for 1900-1995 adjusted only for inflation. Figure 2 shows the data "normalized" to 1995 values. That is it presents what damages would have been had each hurricane season occurred in 1995, based on inflation, increased wealth, and population growth. (A full copy of the paper is available at http://www.dir.ucar.edu/esig/HP_roger/hurr_norm.html.) The analysis shows that for hurricanes, increased losses are driven by societal changes, and not climate changes.

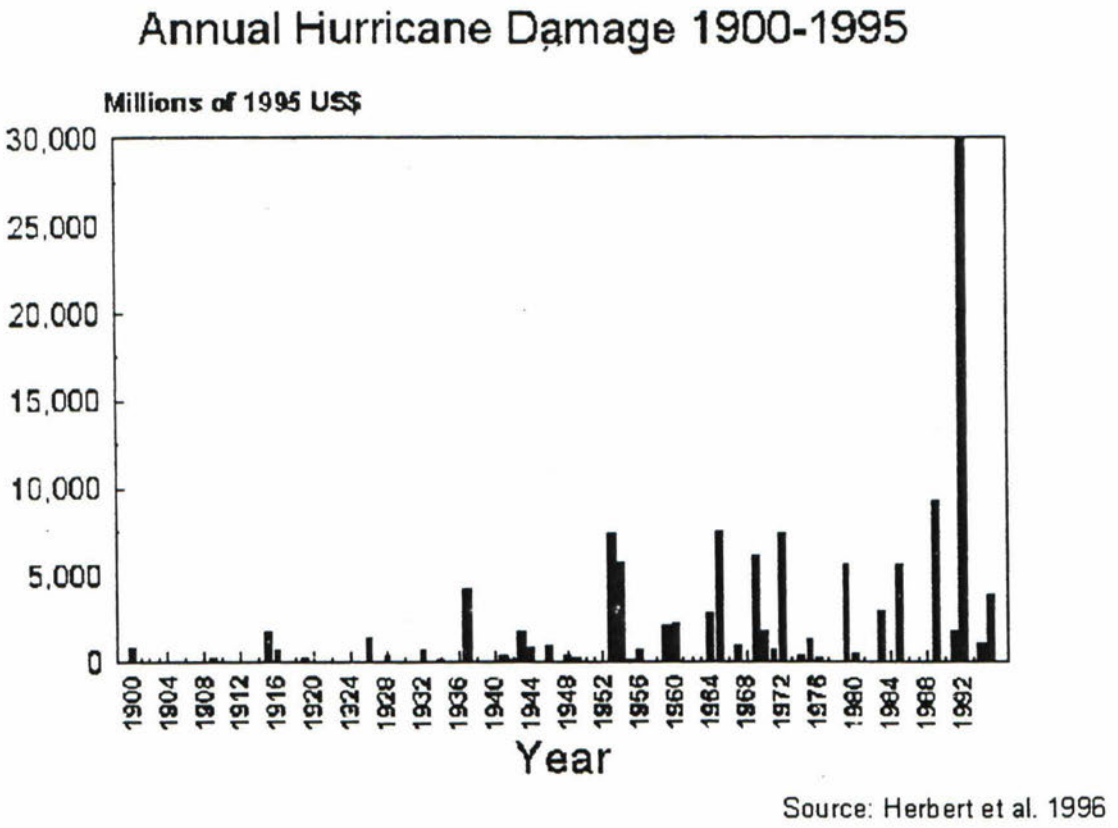


Figure 1. Time series of United States hurricane-related losses (direct damages in millions of 1995 U.S. Dollars) from 1900 to 1995.

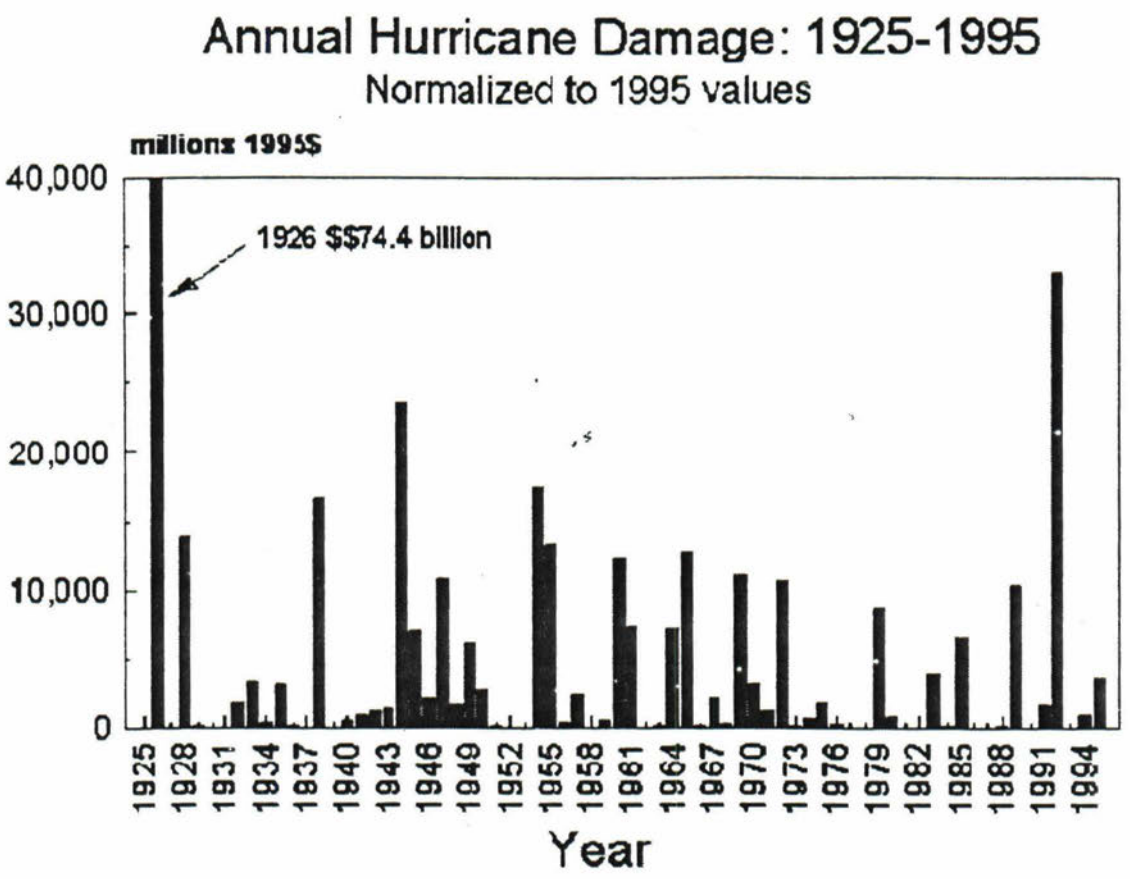


Figure 4. Time series of United States hurricane-related losses (direct damages in millions of 1995 U.S. Dollars) from 1925 to 1995 in normalized 1995 damage amounts (utilizing inflation, coastal county population changes and changes in wealth).

CLIMATE VARIABILITY IN THE SOUTHEAST UNITED STATES AND ITS POTENTIAL SOCIETAL IMPACTS

Michael R. Helfert

Southeast Regional Climate Center

Columbia SC 29201

There is little doubt that global warming is occurring in the 20th Century, and that it is occurring due to anthropogenic emissions. The most objective and most comprehensive of the several scientific analyses concerning recent changes of climate indicate strongly that an increase of the average global temperature has increased about 1° F during the past century. A further minimum increase of 1-2° F should be planned for in the lifespans of our children and their immediate children. It is possible that an increase of up to 6° F during the same time frame if our

species modifications of the Earth's atmosphere constituents and transparency do not decrease or stabilize.

The primary causes of OUR global warming are increases in the discharge of greenhouse gases, particularly carbon dioxide, from industrial processes, energy consumption patterns and practices, agricultural inefficiencies and practices, forest conversion and biomass burning . In the Southeast U.S., we do not contribute to all these imbalances in an equal way - nor do we redress these ills when recognized in necessarily logical or scientific ways. Like the other regions of the U.S., we have too many cars, too much air-conditioning and other artificial environmental contrivances, too much wealth and too much consumption, and a rather profligate attitude towards time, space, and the environment. In reality and in generality, this is but typical

Americana - societally irresponsible and genuinely immoral. In the end this will change, but only at the point of Reality.

Equally as environmentally distressing and equally as immoral as the behavior of our American society on a finite planet subject to both physical and biological limits are similar activities in other regions - whether the excessive consumption of Western Europe and Japan; the excessive consumption of low-quality fossil fuels in China, India, or Russia, or the landscape burning that typifies the Southern hemisphere in particular.

The yearly conversion to other uses of 35-50 million acres of former tropical forest has had at least a selected regional climatic impact directly through seasonal and multiyear albedo changes and carbon capture in Africa, Latin America, and South/Southeast Asia. These albedo differences are so marked from space that I use national boundaries as landmarks to teach astronauts and cosmonauts where they are over the face of the Earth. Burning from Southern Hemisphere and equatorial latitude forest conversions has formed 2-4 month duration smoke palls each year since the early 1980's. These smoke palls are so pervasive that they have their own seasonal names in Latin America, that they have interfered with air transport between the Philippines, Malaysia, Indonesia, and India (usually during El Nino years...), that they impinge upon general biotic health in the underlying areas, and that we have documented them at sizes approaching that of the continental United States with multi-monthy persistence.

In the observations of the Shuttle and Mir astronauts and cosmonauts, the Amazonian smoke pall alone stretches from north of the Equator to the Falkland Islands and the fringes of the Antarctic.

Largely still unrecognized is the importance of both seasonal and multiyear regional albedos due to such forest conversion programs in the tropical latitudes.

Likewise important to regional-scale changes of albedo and likewise visible from space are the air-pollution smogs of the Eastern United States stretching from the Mississippi-Ohio River Valleys east to Bermuda and perhaps Iceland (somewhat euphemistically known as "hazes"), China, Russia, India, and the great megacities worldwide. No city of 5 million souls or greater appears to be immune no matter how well ventilated. Perhaps this will be a limit on the size of our connurbations if we graduate to a more civilized future?

Now, it would be most productive to graduate from the regional or national finger-pointing stages of problem recognition to integrated problem mitigation. Can it be done? Yes, it can. But only after education of not just the policy makers and the general public, but also after unification of the opinions and noise of the science community.

We aren't there yet. And time is slipping away. Listen up. My PRIMARY PURPOSE AT THIS CONFERENCE IS NOT TO LECTURE TO YOU OR AT YOU, but rather to LISTEN TO AND INTERACT OR NETWORK WITH YOU.

As a TV lady of some directness has questioned: "Can we talk?" If so, I will give you some regional background and unregulated concerns that I have. Let's go from there.

My observations on regional concerns in the Southeast are based upon not only upon my global observations as a teacher of astronauts, but also by my analysis of the two million inquiries received per year by our small center from the state and local governments in Virginia-the

Carolinas-Georgia-Alabama-Florida-Puerto Rico & the Virgin Islands; from various COG's; from private sector meteorologists whom we support, from various Federal agencies; from local Chambers-of-Commerce; from taxing authorities of various scales and charters; from the legal, banking, and insurance industries throughout our region; from the construction, engineering, planning, transportation sectors; from the forestry, agriculture, silviculture and aquacultural concerns in the Southeast; and from the general public throughout the South and Southeast.

These inquiries represent two million questions of climatic concern per year from these people and from representatives of the people. Let me mention that, for this conference, I have also been asked to represent the Southern Regional Climate Center located at Louisiana State

University in Baton Rouge, Louisiana, which services like inquiries for climate data and information for Texas, Oklahoma, Arkansas, Louisiana, Mississippi, and Tennessee. Similarly, the other four Regional Climate Centers: the Midwest, the Northeast, the High Plains, and the Western United States -also address about 16 million other inquiries all told each year.

My given charter is to represent the regional interests or "stakeholders" for the Southeast United States in getting the National Government to listen to us in the Southeast. In turn, we need to listen, question, and derive information from Federal sources that may be useful to us at the local, state, and regional levels so that we may form our own judgments. Thus, it is apparently hoped that our democracy will at least have a feeling that there is governance "by consent".

That charter is difficult given that the National Government has a strong history of poor and indirect Telling and some of the States have a habit of Yelling. In the most extreme case of Federal Deafness and State Hollering, this has led to a circumstance of what is still known in our

region as The Recent Unpleasantness.

Hopefully, our discourse has grown a wee bit more mature over the past 135 or so years. Therefore, I sincerely doubt that such a situation will prevail in the 21st Century - which is advancing with more certain velocity than even the postulation of a Congressional decision of real gravity or merit.

The problem of global warming is bigger than all of our governmental constructs, or our historical attitudes and misconceptions, much less the past realities than our forefathers have had to deal with - at least since the Little Ice Age in the middle and higher latitudes of the Northern

Hemisphere. That was a period of a wee bit of a chill, not a "warming". Additionally, that earlier time was not marked by a technological or energy-rich society that was interconnected on a global scale. The situational parallels are therefore not parallel - biologically or ecologically, physically, or societally.

Let's drop the foo-frah-rah for a moment here. Why are we here? Where are we going? What are our objectives? I am of the opinion that we are only in the definition phase, and that we need periodic vice a periodic informational briefings and strategy assessments and modifications in order to maintain a sensible and progressive societal temporal tree.

I doubt that this conference should be viewed as more than a start position in problem and program definition, and of even more import, as only a start in a meaningful and objective dialogue between and among the parties who construct our REGION. If this meeting is a one-time administrative burp to allow the checking off of some bureaucratic box then this is a farce, and we are all wasting our time.

That position gives us a clue as to what we should question here. We need to take control; we need to enunciate our needs and positions; the Federal guys need to listen. The real question is not identifying the regional stakeholders. Every person in this region is a stakeholder.

Rather our question at this conference and in this review stage is identifying just WHAT are the regional stakes. This should be done in each of the following sub-discipline meetings.

This has to be done at such a level that every citizen and every governance level will voluntarily and energetically understand the implications of Non-Change at both the individual and societal levels. That may be a more successful tactic in educating our society to change than to state the desired changes that MUST be made. My teenagers only listen, think, and act in desired ways when they are empowered; not when they are dictated to. It is the same with the American psyche as a whole.

It is therefore a question of education; it is a question of both individual and social responsibility; it is a question of providing for and caring a recognizable and desirable future; it is a question of

participation in governance.

With that philosophical introduction, and with my desire to provoke to discussion, and thence to action, let me now go to a survey of the regional implications to the U.S. Southeast of global warming. We can euphemize and say "climate variation", but let's not play-act - let's do.

That involves moving beyond the premise of global warming and perpetually and tiresomely arguing its presence or absence or non-velocity or non-causation based upon an ego agenda or political agenda or the comfy confines of some non-participatory reality or academic tower.

We can't afford that luxury here. Let's get to work.

OK. Where to start?

What is our regional stake? Easy. UNCERTAINTY and thus changes of our habits, our expectations and perceptions, even our derivations of Futures.

More specifically - Given: Climate Change is occurring. The Climate Change that is occurring is global warming.

FAULT IS NOT THE QUESTION; MITIGATION IS.

Thus we have the question; the position; and the attitude. Anomaly: Of all the places on the face of our small planet Earth (with a big E) that are being impacted by climate change, one of the few places that is thus far benefiting is the Southeast United States, where we are having a small regional climate cooling. That makes it hard to sell "global warming" on a regional basis where cooling is measured.

Unfortunately our luxury may only be a small temporal blip before we too are impacted as is already the case in the U.S. Southwest, in South Africa, in India, in Australia, in portions of Russia, or in the Indo-Pacific. Probably the first thing that we notice will be a minor rise in our mean sea level. That is a very sneaky impact.

Changes of concern to our region are of two classes:

Internal (social and economic): We have become an even more energy-dependent society; we have become more isolated from our physical realities; we have migrated and continued to migrate to the areas of greatest exposure to climate risk - the river bottoms, the water, the

coasts; we continue to involve towards mega-cities that are verily dependent upon resource hinterlands that are not sustainabie; we continue to make babies with the assumption that biology does not have to respond to physics. These are not very intelligent societal situations. They assume that stasis is evolution. We will pay the price of our deliberate ignorance. Soon.

External (physical, chemical, and biologic): Global warming is here. We are but seeing its beginning. With global warming is coming the need, in our environment for a complete replanning of hydrologic systems - the availability, patterns of use, and replenishment of water resources and resource systems. New housing will be needed, new transportation systems and arteries to handle our influx of population, new energy planning and installations and

systems for energy production and distribution, and we must have new general awareness- many of them centered around our relationships with water.

Immediate changes that we need plan for are new diseases and new disease vectors, new susceptibilities to disease due to changes in our immune systems. Additionally, I can foresee lowered air quality below even that already so prevalent for the United States east of the

Mississippi. Our present region air quality is so bad - in reality - that from space in the autumn it is sometimes impossible to tell if one is over North America, the smoke-filled Legal Amazon Basin of someplace South America, a dense Saharan duststorm seemingly lost over the extreme

Western Pacific Ocean, or the smog-covered Western Atlantic Ocean downwind of North America.

We are looking at the future where the application of sun-screen is an individual automatic action prior to going outside; what a gardener plants in one's garden or lawn is quite foreign to his or her family history; where the daily commute is different in form, time, distance,

and complexity than anything that has come before; where leisure activity is a prioritization and balance of risk and reward; where diet changes and qualities must be accepted; where education must be viewed as a lifelong, personal responsibility; where social discipline is more

required than is now acceptable in our small society; so here we physically live or do NOT live has to be a responsible choice of both the developer and the individual; where we must interact with and be aware of our neighbor - at various levels - for more than is now either the habit

or the need. This is extreme news.

Cities such as Atlanta, Savannah, Jacksonville, Miami may be untenable in the near future without interbasin water transfers such as have become habit in the Intermontane or Cadillac West. An alternative may be desalinization or reverse osmosis or something not yet thought

of. Water is a limit. Water will be a husbanded resource in those areas where "development" is still a goal.

Even Nashville is likewise pushing its foreseeable limits of quantity and quality given its most probable climatic and demographic futures. None of us will any longer have the ideal and habitual luxury of freedom of ignorant action nor individual environmental irresponsibility in the systematically interconnected and more fragile future. I'm sorry - it just does NOT compute.

Rainfall patterns are already most likely changing with a new pattern of regional climate warming. We are getting more events of more rainfall all at once, and fewer small events. Our total is remaining about the same, but the character of our wetter and drier seasons is already changing.

Of even more interest to the Southeast precipitation change cause is a question from far away. The atmosphere knows no political or regional boundaries. It goes where and when and how it darn well wishes to go. In this instance of finding a cause for precipitation changes in our

region, the question is one of warming and mounding of seawater over the shallow shelf seas of the Western Pacific Ocean, of all places.

Let us look at this last point a bit more closely. This mounding and warming of Pacific Ocean seawater causes a periodic pulses of warm water to be sent outwards resulting in global and regional climatic anomalies (large Kelvin pulses or Kelvin waves) to be sent out bimodally - that is, both to the west towards Africa via the Bay of Bengal and the Arabian Sea, and to the east to the Gulf of Panama, the southern California Current areas, and the coastal currents of Peru and and Chile. Why the mounding occurs at all is a potential, still largely unaddressed base question for climatology.)

A second base question that is worthy of investigation in climate studies is how many El Ninos must occur before we recognize that the global climate system has changed? What is awry in the Pacific that we need understand for our own regional welfare? What are the implications of El Nino changes upon summer and winter rainfall patterns in the Southeast U.S.?

We are standing here today while watching on the tube 22 new additional feet of water backed up behind the spillway of the dam at Lake Travis, Texas upstream from the capital city of Austin in late June. Two days of rain in June did that. In Central Texas, that is big news - the

last time it did that was during the El Nino year of 1957.

In Australia, they are shooting cattle today in order to not have to feed them when the 1997-1998 El Nino finally reaches such a level of crisis that the American media will finally notice. Our turn is coming in a couple of months.

Think about it. We are having the fourth or sixth year of El Nino effects of one level or another occurring in the seven years of this decade. Such a frequency of warm water in the Pacific impacting our regional and global climates has rarely occurred in the instrumental (1876 to the present), the historical (c. 1530 AD for the Americas; c. 1200-1500 BC for Southern China), or the known archeological records (c. 2500 BC). The delicate outdoor pre-Incan chalk drawings of the Northern Atacama survived until the 1925 El Nino washed them away. Likewise the deep guano deposits on the offshore islands that were traded away as fertilizer for English gardens in the 1870's, would have most likely not have otherwise survived past the rains of1982-83 El Nino.

In the earlier records, El Nino years usually have occurred every two to seven years on the average. Any new pattern of increased frequency, if that is what it is, may well be a strong sign of global warming.

For the Southeast, another El Nino is good news. It brings us more rain; it reduces temperatures; it provides more generally amenable growing conditions; it reduces the number of Atlantic Basin hurricanes below forecasted levels.

As an example of El Nino benefits to our region, Florida is in danger IF a future pattern of more frequent El Ninos does NOT occur. That is, the population growth and concentrations of humans are already beyond advisable levels. Florida is a climatic disaster based upon the old normals of water resources, of extreme climatic events (tropical cyclones) that is waiting to happen. In Florida, climatic exposure or risk is already beyond the advisable limits of the insurance or lending industries. To evacuate Dade County and the Miami region in advance of a hurricane will take about three times more time than is available from the present warning capability.

Now a few vu-graphs illustrating some few of our problems and of the climate impacts of a global warming trend in the Southeast. These are:

1. For vu-graphs of the Southeast Regional Climate Center Home Page, you

are directed to: *http://water.dnr.state.sc.us/water/climate/sercc/dat_prod_serv.html*

2. Specifics on the climate, climate trends, and climate history of the Southeast (Virginia, the Carolinas, Georgia, Alabama, Florida, Puerto Rico, and the Virgin Islands) may be accessed through: *http://water.dnr.state.sc.us/water/climate/sercc/historical_data.html*

3. For vu-graphs of the State Climatology Office of the State of South Carolina, you are directed to: *http://water.dnr.state.sc.us/water/climate/sco/index.html*

4. Specifics on South Carolina climate, climate trends, and climate history may be found through: *http://water.dnr.state.sc.us/climate/sco/climate_sc.html*

5. Further information on the El Nino and the Southeast may be found through:

http://water.dnr.state.sc.us/water/climate/sercc/el_nino.html

Educational Aspects of Climate

This section is still in preparation and will be available in the Final Report.

Agriculture Sector Findings, SE Regional Workshop, June 25-27, 1997

Jim Jones, University of Florida

David M. Legler, Florida State University

Gerald F. Arkin, University of Georgia

James W. Hansen, University of Florida

Nature of the Problem

Agriculture has been called "the most weather dependent of all human activities" (Oram, 1989). Because of this dependency, variability of climate from year to year results in uncertainties in agricultural production and risks to the well-being of farmers, to local and regional economies, and even to global food security. One reason that climate variability is so devastating to agriculture is that we do not know when to expect favorable or unfavorable weather. Many critical decisions must be made several months or seasons before the impacts of weather are realized, putting at risk large investments in resources applied to the crop. There are many recent examples where drought, floods, and freezing temperatures have resulted in total or partial failure of agricultural systems in the SE USA and other regions and countries. Agriculture's vulnerability to weather variability is expected to increase as the world's population increases and marginal lands are brought into production (Glantz, 1994), and as other sectors (urban, industry, recreation) grow and compete for land, water, energy, and other natural resources. In addition to year to year variations in climate, indicators highlight a contrarian trend toward cooler temperatures in the SE during the past century. Evidence also points to more frequent occurrences of extreme precipitation and thermal events in the US (Karl, et al. 1996). Changes in the global climate are expected over the next 50 years as atmospheric CO2 and other greenhouse gases increase (IPCC, 1990a). Although the magnitude of this change is not certain, many studies have shown that agriculture could be affected in many parts of the world if global climate changes as anticipated (IPCC, 1990b; Rosenzweig and Parry, 1994; Rosenzweig et al., 1995).

Characterization of Agriculture and Forestry Systems in the SE USA

The Coastal Plains region of the Southeastern United States has a very productive agricultural sector that produces many high value crops such as citrus (oranges and grapefruit), vegetables (tomatoes, green peppers, celery), strawberries, sugarcane and tobacco, fruits & nuts, rice; and also several field crops (peanuts, cotton, maize, maizetobacco and soybean). This diversity isn production is accompanied by equally diverse cropping and farming systems, including animal systems, aquaculture and forestry; diseases, insects, weeds, and pest-complexes. The heterogeneous nature of topography, soils, and climate (both regional and dynamic, e.g. ENSO as well as longer time scales) are unique in the US. Additionally, the relationship between managed agroecosystems and wetlands in coastal regions is not encountered elsewhere. Rainfed field crops are vulnerable primarily to drought stress, particularly on sandy soils. Fresh vegetables, sugarcane, citrus and some field crops are irrigated. However, since irrigation is not as prevalent in the SE as in other regions, stresses induced by climate variability/change are amplified. Southern Florida produces about 50% of the nation's fresh winter vegetables. Although irrigation reduces sensitivity to rainfall fluctuations, these vegetable crops are particularly vulnerable to low temperature stress, as the unanticipated January 1997 freeze painfully demonstrated. Likewise, the citrus industry has been set back by a series of severe frosts in the late 1980s.

While supplemental irrigation offers farmers options for reducing risk, irrigation raises broader concerns from the perspective of natural resource managers. The source of groundwater for irrigation in the coastal plains is rainfall in the previous one to three years. Due to the interaction between groundwater and surface waters, over drafting can have harmful effects on wetlands, lakes and streams, as well as aquifers. Aquifer recharge and water availability are likely to be least when crops need irrigation most. ENSO influences both the demand for irrigation water and its supply.

Impacts and Vulnerability

Climate variability in the SE USA has been associated with El-Niño Southern Oscillation (ENSO) activity (Ropelewski and Halpert, 1986; Kiladis and Diaz, 1989; Sittel, 1994). El Niño years tend to be cool and La Nina years tend to be warm between October and April. El Niño years tend to be wet and La Nina years dry during these months. Recent studies have confirmed vulnerabilities of some crops in the SE to climate variability. Hansen et al. (1997) analyzed historical records for six crops in four states in the SE USA (Alabama, Georgia, Florida, and South Carolina) to characterize annual variability in agriculture and to determine how much of the variability is be associated with ENSO activity. They found that corn yields were high in La Nina years and low in years that followed these years. The magnitude of ENSO influence on corn yield variability was more than $200 million, or 26% of the annual average value of corn produced by these four states. The effects of ENSO activity on the values of annual soybean, peanut, and tobacco production were also significant, but not as large as for corn. Similar findings have been shown for crops in other parts of the world (Cane et al., 1994; Handler, 1984; Carlson et al., 1996). The demonstrated influence of ENSO on agricultural production and the emerging capacity to forecast ENSO events with lead times exceeding several seasons (Chen, et al. 1995) suggest an unprecedented opportunity to tailor agricultural decisions to anticipated weather conditions, either to mitigate the impacts of adverse conditions or to take advantage of favorable conditions. The value of an improved ENSO forecast to producers and consumers for four field crops in the SE is estimated to exceed $100 million per year (Adams, et al. 1995).

Few studies on climate change effects on agriculture and forestry in the SE USA have been conducted. Curry et al. (1990a) studied two crops (corn and soybean) grown under current and two General Circulation Model (GCM) scenarios. Their results suggested that yields of soybean would decline by 11% and 52% in the two climate change scenarios under rainfed production whereas corn yields would decline by 8% and 73% for the two scenarios, respectively. In addition, Curry et al. (1990b) estimated relatively large increases in evapotranspiration and irrigation water requirements for soybean under the two climate change scenarios. In a national study, Adams et al. (1989) suggested that shifts of field crops from the SE to other parts of the USA could occur under climate change scenarios.

Potential for Changes in Policy, Management Decisions (Adaptation)

What can be done to reduce the unwanted impacts of climate variability on agriculture and forestry and take advantage of positive impacts? Effective application of climate forecasts to agriculture depends on 1) the availability of regional climate forecasts of adequate lead time and accuracy, 2) the vulnerability of agriculture to weather variability, 3) the existence and awareness of options for using knowledge of future weather to improve decisions and policies, and 4) the ability and willingness of decision and policy makers to modify their decisions based on available information (Lamb, 1981; Sonka et al., 1986; Mjelde, 1993). These decision makers include farmers who choose crops, management practices, areas to plant, and resources to use; advisors in public (e.g. agricultural extension agents/offices) and private institutions who make recommendations and supply information to farmers; those who supply seed, manage irrigation resources, and provide other resources for production; and public policy makers who

develop and provide information or influence decisions by policies, such as insurance, credit, and price supports. Additional research is needed to assess the likely impacts of annual climate variability and possible changes in climate on agriculture and forestry in the SE USA, and to facilitate improved decision making to reduce unwanted impacts and reduce risks. Research should be aimed at providing the necessary information, tools, and analyses to these agricultural decision makers, tailored to specific conditions in the SE region. Based on existing relationships of agricultural community to information providers, a combination of public/private approaches appears to have many advantages, but requires significant forethought regarding the role of climate forecasting centers, likely forecast products, uncertainties/skills associated with these forecast products, and delivery mechanisms/implementation plans to maximize information utilization.

Identified Stresses/Concerns:

Nutrients (fertilizers): Management of the supply, application and deposition of nutrients, including both commercially produced and naturally occurring, e.g. poultry, swine, dairy, can be impacted by climate variations. The choice of fertilizer is highly dependent on soil type, desired yields, etc. Prescriptions for application are commonly available, but do not consider climate issues. Deposition of naturally occurring materials are related to water resource and soil quality issues.

Water quality and quantity: Multiple scales (farm, county, state, region) as well as tactical vs. strategic concerns of multiple user interests make this issue very complex. For example, irrigation scheduling is typically affected by precipitation availability (in an immediate sense for crop development and on longer time scales regarding water availability/supply) but relates equally to resource management. Runoff issues directly relate to water quality, erosion and sedimentation of streams and water courses.

Soil structure and quality: The unique characteristics of soil structure and quality in the SE plays a relatively large role affecting and being affected by climate variability/change in its role for sustaining productivity. Soil quality in the SE is declining. This is partly attributable to streamflow and runoff issues and may also be impacted by climate variability.

Market Competition: Timely updates and predictions of productivity, time-to-market, and other evolving characteristics of competing markets (local, regional, international) can maximize profit. In some markets, these are directly impacted by climate issues. Thus knowledge of climate-related impacts worldwide are valuable.

Policy/Subsidies: This stress includes not only economic policies (e.g. assistance programs), but also environmental (e.g. regulatory use of pesticides). These affect farm practices and decision making flexibility. Risk factors are associated with fundamental changes of state and federal programs. To what extent should climate issues be incorporated into policy design and implementation?

Depopulation: The long term viability of rural farms is dependent upon sustained farming communities. How do rural and/or small farming operations compete with larger operations which have more resources to incorporate new technology such as climate-related management practices?

Increasing Urban Population Growth: Closely linked to depopulation concerns are the

stresses associated with heightening competition for resources in urban/rural fringe zones.

Sustainable Productivity: Maintaining yields and/or profits from agricultural, and forestry activities is the ultimate stress/concern on the farming community in the SE USA.

Climatic Variables

Precipitation, temperatures, solar irradiance, wind, and humidity are all key variables with demonstrated or likely impacts on identified stresses. The diverse nature of these stresses for the agricultural sector in the SE USA necessitates a quantification of climate variability/changes over a wide spectrum of temporal and spatial scales. For example, fairly precise predictions of extreme events as well as shifts of agriculturally relevant characteristics are required because of the critical nature of their intersection/impact on farming system development (plant growth, harvest, scheduling, etc.). Climate variables currently available are often insufficient (spatially and temporally) to adequately address probable climate change/variability induced impacts.

Recommendations

Based on discussions during the SE Regional Workshop, we identified areas in which multi-disciplinary activities should be encouraged in order to first probe and then field-test first order impacts of incorporating climate variability/change information into a number of agriculture-related systems. Additionally, given the limited participation of the user-community in developing these recommendations, we encourage additional review of pertinent planning documents in order to maximize involvement of the agricultural communities in future activities.

I Research

Develop, validate, and evaluate new technology *capabilities* (e.g. climate forecasting, remote sensing, precision farming).

> *A multi-disciplinary approach involving scientists, producers, private sector, government, non-government entities and users should focus on first identifying the agriculturally-relevant capabilities of new technology, and then developing, validating (through modelling and experimentation), and evaluating experimental products suitable for utilization in agriculture systems.*

Develop, validate, and evaluate agriculture models (cropping systems, grazing, disease, watershed, production) with regards to climate forcings.

> *It is not clear that current models correctly respond to climate forcings. Many agriculture system models do not include climate forcings as a driver. Expanding current modeling development activities to cover a much wider range of farming systems will address a larger number of the identified stresses on the agricultural system and provide a testbed for exploring the experimental products described previously. Further development of multi-system models would be particularly welcome for investigating the relations between complex systems such as water, soils, nutrients, and production.*

Relevant agricultural mitigation options need to be explored, especially those related to change of climate variability (greenhouse gasses, etc.).

Two types of mitigation options are recognized as critical components to adaptation of new information: 1) those identified as reducing undesirable impacts of climate variability; and 2) those identified as related to climate change (e.g. reducing greenhouse gasses).

II Application:

Because the incorporation of new climate-related technology capabilities into agriculture systems is relatively new and yet unproven, pilot projects should be identified to explore transfer/communication and adaptation issues.

This collective effort should involve public and private constituents as well as the end users to foster multiple feedbacks and to optimize the adaptation process. The county extension progradelivery system and individuals associated with it are valuable resources and can play an important role. Communications should include discussion of risks, uncertainty, and trade-offs between skill and confidence.

Agri-climate programs being developed in South America and already implemented in Australia can serve as models for implementation, however fundamental differences in policy, infrastructure, and farming practices may limit transfer of knowledge base and subsequent application to the SE USA.

III Post-Meeting Review, and Implementation Activities

Additional stakeholder participation in subsequent review and implementation planning of regional plans is encouraged. After the SE Regional workshop, continued/additional communications are recommended in order to prepare future activities. More formal organizational structures may be required to foster continued interest and generation of results by scientists, producers, private sector, government, non-government entities and users.

IV Funding

There is an expressed need for funding mechanisms to support agri-climate research, particularly those multi-disciplinary efforts aimed at translating/transferring identified basic research results to users and user-specified applications.

References

Adams, R. M., C. Rosenzweig, R. M. Peart, J. T. Ritchie, B. A. McCarl, J. D. Glyer, R. B. Curry, J. W. Jones, K. J. Boote, and L. H. Allen. 1990. Global climate change in U. S. agriculture. *Nature* **345**:219-224.

Adams, R. M., K. J. Bryant, B. A. McCarl, D. M. Legler, J. J. O'Brien, A. Solow, and R. Weiher, 1995:

The value of improved long-range weather information: Southeastern US ENSO forecasts as they influence US agriculture. *Contemporary Economic Policy*. **13**: 10-13.

Cane, M. A., G. Eshel, and R. W. Buckland. 1994. Forecasting Zimbabwean maize yield using eastern equatorial Pacific sea surface temperature. *Nature* **370**:204-205.

Carlson, R. E., D. P. Todey, and S. E. Taylor. 1996. Midwestern corn yield and weather in relation to extremes of the southern oscillation. *J. Prod. Agric.* **9**:347-352.

Chen, D., S. E. Zebiak, A. J. Busalacchi, and M. A. Cane, 1995: An improved procedure for El Niño forecasting: implications for predictability. *Science*. **269**: 1699-1702.

Curry, R. B., R. M. Peart, J. W. Jones, K. J. Boote, and L. H. Allen. 1990a. Simulation as a tool for analyzing crop response to climate change. *Trans. ASAE* **33**(3):981-990.

Curry, R. B., R. M. Peart, J.W. Jones, K.J. Boote, and L.H. Allen, Jr. 1990b. Response of crop yield to predicted changes in climate and atmospheric CO2 using simulation. *Trans. ASAE*. **33**:1383-1390.

Glantz, M. H. 1994 Drought follows the plow. Cambridge Univ. Press, Cambridge. 197 pp.

Handler, P. 1984. Corn yields in the United States and sea surface temperature anomalies in the equatorial Pacific ocean during the period 1868-1982. *Agric. For. Meteor.* **31**:25-32.

Hansen, J. W., A. Hodges, and J. W. Jones. 1997. ENSO influences on agriculture in the Southeastern US. *J. Climate* (Accepted).

IPCC. 1990a. Climate Change: The IPCC Scientific Assessment. J. T. Houghton, G. J. Jenkins, and J. J. Ephramus (eds.). The Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge. 365 pp.

IPCC. 1990b. Climate Change: The IPCC Impacts Assessment. W. J. Tegart, G. W. Sheldon, and D. C. Griffiths (eds.). The Intergovernmental Panel on Climate Change. Australian Government Publishing Service, Canberra.

Karl, T. K., R. W. Knight, D. R. Easterling, and R. G. Quayle, 1996: Indices of climate change for the United States. *Bull. Amer. Meteor. Soc.* **77**: 279-292.

Kiladis, G. N., and H. F. Diaz. 1989. Global climate anomalies associated with extremes in the southern oscillation. *J. Climate* **2**:1069-1090.

Lamb, P. J. 1981. Do we know what we should be trying to forecast -- climatically. *Bull. Am. Meteor. Soc.* **62**:1000-1001.

Mjelde, J. W., D. S. Peel, S. T. Sonka, and P. J. Lamb. 1993. Characteristics of climate forecast quality: Implications for economic value to Midwestern corn producers. *J. Climate* **6**:2175-2187.

Oram, P. A. 1989. Sensitivity of agricultural production to climate change, and update. P. 25-44. In Climate and Food Security. IRRI, Manila, The Philippines.

Ropelewski, C. F., and M. S. Halpert . 1986. North American precipitation patterns associated with the El Niño/southern oscillation (ENSO). *Mon. Wea. Rev.* **115**:1606-1626.

Rosenzweig, C., and M. L. Parry. 1994. Potential impact of climate change on world food supply. *Nature* **367**(13)133-138.

Rosenzweig, C., L. H. Allen, Jr., L. A. Harper, and J. W. Jones (eds.). 1995. Climate Change and Agriculture: Analysis of Potential International Impacts. ASA Special Publication 59, Am. Soc. Agron., Madison, WI.

Sittel, M. C. 1994. Differences in the means of ENSO extremes for maximum temperature and precipitation in the United States. Tech. Rep, 94-2. Center for Ocean-Atmospheric Studies, Florida State University, Tallahassee, Fla.

Sonka, S. T., P. J. Lamb, S. E. Hollinger, and J. W. Mjelde. 1986. Economic use of weather and climate information: Concepts and an agricultural example. *J. Climatol.* **6**:447-457.

CLIMATE VARIABILITY AND ITS IMPACT ON SOUTHEASTERN COASTAL RESOURCES

Margaret Davidson, Session Leader

Virginia Burkett, Reporter

The group which focused on this topic area was comprised of a fisheries scientist, a wetlands scientist, a government data assimilation scientist and a coastal policy analyst. Our small group met and developed a matrix for identifying the interactions between climate variables and the interwoven coastal resource ecosystems of the southeastern US. After we worked through the general state of awareness that was possessed by our group, we then began to discuss the relationship between existing stressors and the degree to which those impacts were be further exacerbated by changes in climatic variables.

After developing the matrix and the reference list of existing stressors, we then systematically discussed the current status and existing gaps in our understanding of the interactions between the climatic variables and the various representative ecosystems. This information is encapsulated under the section entitled 'Data Needs'. It is readily apparent from our discussions that much more needs to be done to further our understanding of the relationships and effects resulting from changes in temperature (ambient air and water column), carbon dioxide, and UV-B. There are very complicated feedback loops within and across these ecosystems which would further complicate the interactions and effects: our ability to understand these feedback loops and tease out the resultant impacts is very limited.

We then identified a number of 'activities' that could be readily undertaken which would mitigate known or presumed impacts. A number of these refer to efforts already underway that would 'buy time' until we do have better understanding of the range of change and effects. For instance, it would be most appropriate to repeat the western experience of 'flush and flow' release of rivers to help restore marginalized riverine ecosystems: this might strength the resiliency of various organisms. In addition to specific actions such as expanding river corridor protection, promoting bypass mechanisms during the course of FERC relicensing of the many dams found throughout the region, and working harder to expand setbacks and conservation easements. We also recognize that as a society and community, we need to work harder on communicating the importance and seriousness of these issues to a broad audience throughout the region. Further, we need to recognize that the southeastern US is closely interlinked with its Mexican and Caribbean neighbor.

Our final task effort was to identify approaches and tasks that should be undertaken by the scientific and decision making communities to enhance our ability to both understand and respond to the range of

associated impacts. These recommendations include:

1. Our approach which currently relies on biogeographical provinces needs to be expanded to includes climatic relationships. Further, we should link various 'controlled use' sites around the region to develop a baseline reference system for studying change. These would include the National Wildlife Refuges, the National Estuarine Research Sites, the LTERs and LMERs supported by NSF.

2. The community needs to develop clearer statements (in plain English) about various projects, probable impacts and the relative level of certainty (and just what that means).

3. We need to do a better job of integrating climate variables to improve interannual

forecasting because that is the level of frequency that is most important to sensitive

ecosystems.

4. We need to integrate socioeconomic variables with climate variables so that the 'real' impacts---especially long range economics--can be clearer to decision makers. We also need to build upon the work by Costanza et al in quantifying the economic value of our natural ecosystems.

5. We need better compilations of life history data for these ecosystems so that managers can better understand range of impacts and assess mitigative actions.

6. We also need to improve our understanding of carrying capacities for these ecosystems, particularly since they are already substantially stressed by anthropogenic influences

7. We must recognize (and communicate) that coastal ecosystems-and particularly estuaries- do not have unlimited capacity to respond to the changes that are occurring: changes in climate reduce resilience, increase stress, and have profound negative impact on productivity and diversity.

8. We need to figure out how to bridge interagency turf particularly vis-à-vis sharing data. This

involves states, federal agencies, and universities.

9. Finally, we need to do a much better job of communicating and educating the broad citizenry about the importance of these systems, the nature and range of probable changes, and how it will impact our lives and our economy.

EXISTING STRESSORS

Hydroalterations:

Dams, channelization, dredge & fill, water withdrawals/additions

sheet flow disruption, sediment changes

Infrastructure:

Sea walls, jetties, dams, barriers to biological organisms

Pollution:

NPS, atmospheric, sos, industrial & murk discharges, spills, elutro pug forms

Cumulative impacts/depleting uses/overharvests/exotic/invasive species
ATV/PWS/ships/coral

Fragmentation of habitats

DATA INFORMATION NEEDS

1. Sea Level Rise: ESTIMATES, LATE/TIME PERIODS:

Tools to distinguish global from regional/local

Relation to circulation/estuaries

Vulnerability assessments:

- regional & local scale

- plant communities at risk

- fine scale modeling/GIS --> planning

Better monitoring: tide gauges, GPS, RS

Storm surge: update slosh slam etc.

Finer Coastal topography

2. Precipitation: Historical trends, finer scale modeling

relationships --> sinkholes, perched water tables

more/better proxy/analogs

specify relation - BE/rainfall/flows & aquatic species

3. Extreme Events:

Frequency - }

intensity - } timing/delivery

duration - } 200+ yr record: analog/anecdotal

? = Os of departure overtime

- information on sub-regional scale or place-based

- how do natural perturbations occur

- overall perturbation environment (floods, droughts, storms)

- for each biogeographic area, has there been a departure from the norm

Products: climate/biography class. Framework - GIS layer

4. To -temp. sensitivity of tourists

-location of thermal affluents

Species distribution; sea temperature charges:

examples: Formosan termites, plants

-more rapid turnover rate

-interaction w/nutrient cycling ?/decomposition rates

-growing season & productivity

-effects on dissolved CO2 + O2

-Increase in disease vectors (Vibrio example)

Products: ? GOM thermal maps

- updates, synthesis documents

5. CO2: -need to understand pathways

-response of living organisms to enriched carbon

-pH + CO2 interactions affects on freshwater + blood

-magnitude unknowns

6. UVB: -does this impact plant reflectance/i.e., insect recognition

-physiological (dose) response of plants & animals to UVB

-diminished productivity in top meter of water

MITIGATION

- river corridor:

protection/preservation

- "flush and Flows"

- FERC relicensing process (promote) and bypassed

- revised, actuarially-based NFIP (national flood insurance programs)

- setbacks: easements: developing rational arterial

-for ID priorities, incorporate climate variables, (Costanza's work/recognize value of coastal ecosystems)

- reinvigorate stewardship authorities & basis for decision-making - stewardship ethics

* - international connections - communication/education

-

OVERALL NEEDS

1) Geophysical province references sites

NWR, NEERS, LTERs, LMERs add in climate

(link these as reference sites)

2) Broad use of indicator species as affected by climate variables

3) Clear statements about projections & level of certainty

4) Integrate climate variables to improve interannual forecasting

5) Integrate socioeconomic variables w/climate to increase appeal to decision values

6) Better compilations of life history data for managers

7) Carrying capacities.

Must recognize that estuaries do not have unlimited capacity to respond to change that are occurring

>s's = resistance, stress, production + diversity

8) Bridge interagency data/turf - Universities, States, Federal agencies

9) Communicate + educate

Southeastern Science Education Sector

Gregory Cox, Global Hydrology and Climate Center,

Univ. of Alabama in Huntsville

Richard Duschl, Vanderbilty University

Nora Normandy, NASA HQ, Mission to Planet Earth

How can education contribute to the research agenda?

-Promote adoption of education programs (e.g. Global Learning and Observations to Benefit the Environment (GLOBE); Earth System Science Education (ESSE) program; Earth Systems Science curriculum; and Problem-based curriculum units - Mission to Mars) that involve learners in data collection, data manipulation, data interpretation.

- Explore the possibility of enhancing the spatial and temporal density of land-based measurements - climate variability & breakout session topic indicators.

- Recruitment of teams of individuals to coordinate, implement and report measurement activities.

- Promote the involvement of both informal (e.g., parks, zoos, nature centers, science centers, after school programs) and formal science education sectors of society.

- Evaluate programs of study for educating the next generation of earth scientists (undergraduate/graduate education).

- Identification of measurements and analyses (Micro Models) that can be carried out by students (K-16).

- Training of preservice and inservice teachers to use data gathering programs;

- Creation of more franchises and consortia of franchises to introduce educators to research protocols,

- Establish Leadership Team from research areas, stakeholders,

- Establish Partnerships between cohorts of schools/informal agencies and scientific constituencies.

How can educators use scientific results to enhance education?

- Identification of project-based science themes.

- Address the National Science Education Standards with an emphasis on doing science as inquiry and on social perspectives of science.

-Access to data sets for student modeling and analysis.

-Access to data for risk/benefit analysis of extreme climate variables.

-Cooperative agreements with scientists to promote and sustain curriculum innovations.

- Access to summary results, visualizations, and computer modeling and analysis skills that are comprehensible and useful to K-12 students and teachers;

-Access to clearly identified science objectives, problems, deliverables.

-Constituencies develop age appropriate techniques, classification and identification schemes, and indicators (i.e., 'cloud charts') for monitoring trends of critical variables.

How do we educate the public?

-Educate the future generations of teachers to implement earth systems programs.

-Make alterations to undergraduate preparation of earth scientists and science educators.

-Establish cooperative education programs with scientists and stakeholders.

-Establish kids journal of results.

-Promote and publish involvement of students in collaborative research projects.

-Build partnerships with institutions that serve the public's recreational and informal education interests; e.g., nature centers, extension services, park visitor centers, libraries, cooperative extension agencies, etc.

An example partnership & collaboration:

National Parks in the Southeast (n=62) can serve as collaborative sites between informal and formal educational programs. Individual parks located in different physiographic provinces can become labs for monitoring relationship between climate variability, scientific sectors, and the various environmental, demographic, and economic constituencies in the Southeast. Individual classrooms, programs or cohorts of schools can become research partners with Park staff and visitors. The goal would be to monitor and model the patterns of select physical, biological, hydrological, and geological indicators of importance.

Park personnel could highlight site specific problems that schools could investigate. Schools, in turn, would propose data gathering activities after an analysis of models of the Park. Park staff and visitor science educational programs would implement both newly proposed and ongoing data gathering activities. In this way, any school in any region of the Southeast could participate in research of any Park. Research problems, methods, and reports could be monitored by a grade/age appropriate peer review panels. Publications announcing the program and providing reports of student research would be made available to Park visitors. Park brochures could advertise research opportunities/programs at their location.

A demonstration project such as this could show how climate change could impact local and regional resources. It could also serving as an example of how can education contribute to the research agenda. Formal and informal educators could also use scientific results to enhance science education and demonstrate the relevance of climate change at a local level.

Seven Principles

to

Guide the Design of Learning Environments

Robert Glaser (1994), keynote address delivered at the 23rd International Congress of Applied Psychology, Madrid

1. *Structured Knowledge* - "Instruction should foster increasingly articulated conceptual structures that enable inference and reasoning in various domains of knowledge and skill. Education that teaches isolated memorization of facts and definitions of concepts will not accomplish this purpose"

2. *Use of Prior Knowledge and Cognitive Ability* - "[R]elevant prior knowledge and intuition of the learner is . . .. an important source of cognitive ability that can support and scaffold new learning . . . . . the assessment and use of cognitive abilities that arise from specific knowledge can facilitate new learning in a particular domain" (p 18).

3. *Metacognition: Generative Cognitive Skill* - "[T]he use of generative self-regulatory cognitive strategies that enable individuals to reflect on, construct meaning from, and control their own activities . . . . is a significant dimension of evolving cognitive skill in learning from childhood onward. . . . These cognitive skills are critical to develop in instructional situations because they enhance the acquisition of knowledge by overseeing its use and by facilitating the transfer of knowledge to new situations . . . [T]hese skills provide learners with a sense of agency." (p 18).

4. *Active and Procedural Use of Knowledge in Meaningful Contexts* - "Learning activities must emphasize the acquistion of knowledge, but this information must be connected with the conditions of its use and procedures for it applicability. . . . School learning activities must be contextualized and situated so that the goals of the enterprise are apparent to the participants" (p 19, emphasis in original).

5. *Social Participation and Social Cognition* - "The social display and social modeling of cognitive competence through group participation is a pervasive mechanism for the internalization and acquisition of knowledge and skill in individuals. Learning environments that involve dialogue with teachers and between peers provide opportunities for learners to share, critique, think with, and add to a common knowledge base" (p 19).

6. *Holistic Situations for Learning* - "[L]earners understand the goals and meanings of an activity as they attain specific competencies. . . . [C]ompetence is best developed through learning that takes place in the course of supported cognitive apprenticeship abilities within larger task contexts" (p 19 -20).

7. *Making Think Overt* - "[A] significant mechanism in environments for learning is to design situations in which the thinking of the learner is made apparent and overt to the teacher and to students. In this way, student thinking and reasoning can be examined, questioned, and shaped as an active object of constructive learning" (p 20).

EXTREME EVENTS

Roger A. Pielke, Jr., Group Leader

Rick Piltz, Rapporteur

Extreme events are a theme which cuts across each of the breakout groups.

FINDINGS

* Extreme events have a considerable impact on stakeholders in the southeast region. Examples discussed include energy, emergency management, and water resources. Data on impacts is available for some phenomenon (e.g., floods), but not others (e.g., droughts).

* There are different types of extremes:

- statistical extremes associated with probabilities of exceeding some arbitrary threshold. These extremes can be associated with events of high frequency/low magnitude. For instance, for some construction companies rainfall events of greater than 0.10 inch disrupt business operations.

- impact extremes associated with a large net impact on society or environment. These can be typical events which are not extreme in a statistical sense (i.e., medium frequency/high magnitude) but have a large impact. Hurricanes, floods, droughts, ice storms, cold spells, and heat waves, are examples.

- extreme extremes associated with catastrophic impacts on society or environment. These events are also extreme in a statistical sense (i.e., low frequency, high magnitude). An example would be a Category 5 hurricane striking New Orleans.

* The southeast is becoming increasingly vulnerable to extreme events. This means that impacts would likely increase without changes in climate that increase the frequency or magnitude of extremes. (The possibility was raised that in some cases impacts would increase *even if* extreme events became less frequent or severe, e.g., as has been documented in the case of hurricanes.) Climate surprises or changes in variability which increase the frequency or magnitude of extremes would impact a region increasingly sensitive to their impacts.

* Climate extremes are one of many stresses in the region. Population growth, land use, urbanization, development, and technological sophistication are among the factors that serve to increase societal and environmental vulnerability to extreme events. While a few sectors/stakeholders have become increasing resilient to climate, many have not, and have actually become more vulnerable.

* Because climate extremes are one factor in a complex inter-related system of stress, the way in which we research extremes must take that complexity into account in order to understand the relation between climate extremes and stakeholders.

* Use of climate information varies contextually; i.e., different stakeholders have different needs, levels of sophistication, and sensitivities with respect to extreme events. Availability of information on extreme events does not necessarily mean that it will be used.

* Many stakeholders do not fully use existing climate information related to extreme events. Using climate information has become increasingly important to some stakeholders as the business environment has become more competitive and decision makers look to better understand the exact nature of risk in their decisions. The example of Scottsdale, AZ was cited as an example of an extremely sophisticated user of climate information.

* In some cases, stakeholders have sufficient climate information related to extreme events. In such cases obstacles to reduction of vulnerability lie in other areas, e.g., such is largely the case in improving floodplain management. Often it is the occurrence of an extreme event which triggers stakeholders to improve their response.

* In general, with respect to extreme events seasonal and inter-annual climate information/forecasts are of more use and value to stakeholders than is information on decadal/century timescales. In other words, stakeholders respond to climate variability, not

climate change. There are exceptions, such as floodplain development and other large-scale capital development which require consideration of climate variability over the longer term.

* Reduction of vulnerability to extreme events will also contribute to preparation for the impacts of climate change (whatever the scenario). In other words, "no regrets" adaptation efforts make sense, given documented sensitivities to impacts associated with extreme events.

* The issue of extreme events, preparing for and responding to them, will remain regardless of how the climate changes long-term.

RECOMMENDATIONS

* Maintain and extend our ability to collect, analyze, and disseminate data related to climate over the long term. In the case of extremes, such data has a demonstrable relationship to decision making.

* Given that societal and environmental problems associated with climate extremes are complex, data must also be collected with respect to the non-climate factors which play a part in the cause of the problems or which serve as a measure of impacts (i.e., social and environmental indicators). Research must focus on the interactions between climate extremes-society-environment.

* Focus on utilizing the historical climate record better than we have in the past to understand the range of observed climate extremes and the spatial and climatic patterns associated with their occurrence. The O'Brien tornado study is an example of such a study.

* Continue efforts to develop climate forecast tools, including development and implementation of probabilistic tools.

* Bridge building must increase. For instance, develop processes to ascertain what climate

information/tools would be of use to stakeholders. Also for climate information to be of great usefulness to stakeholders, they must understand it in the context of the extreme event-related decisions which they face. To enhance the linkage between climate science and stakeholders support existing organizations and groups such and National Climatic Data Center, Regional Climate Centers, and State Climatologists. This linkage also includes activities such as this workshop and other activities which bring together scientists and stakeholders. Other possibilities including making use of invited/targeted research proposals focused on particular issues of concern to stakeholders.

* View climate change mitigation (e.g., emissions reductions) and adaptation to extreme events as complements, not as tradeoffs. There is a commensurate need to understand the economics associated with each.

IMPACTS OF CLIMATE CHANGE ON PUBLIC LAND MANAGEMENT

Hubert Hinote, Session Leader

Suzette Kimball, Rapporteur

General Comments

Region forecast to be fastest growing in the country – public lands provide amenities that promote population migrations

Public land manager - not managing for economic return, managing for the long term ("for future generations") – different management ethic than private interests.

(Godschalk, Berke and Kaiser, 1997): Governments subsidizing risk associated with using sensitive areas results in exacerbation of pressure and resistance to change and variability.

System of parks and refuges leads to expectations that a natural area can be preserved in situ over time; management strategies are not coping with the concept of natural evolution of place

Southeast region as a whole has great range of microclimates and habitats and tremendous biodiversity – insular areas such as parks and refuges can be areas particularly sensitive to small changes in natural factors

Most public lands carry multiple-use mandates (e.g., visitor accessibility and habitat conservation), which makes management more difficult when natural variables (climate) are changing and the impacts of those changes are not well understood.

Current Concerns and Stresses in the Region

Demographic shifts – more people in the area and increasing rates of development – how to provide the amenities and infrastructure needs for water supply, roads, agriculture, etc., without destroying the aesthetic values that brought the people to the area.

Expansion of tourism in an area undergoing economic growth creates pressures in protected areas; even ecotourism creates stresses to fragile habitats and populations.

Even in areas not undergoing growth, there is a greater level of use of public areas –more visitors demanding greater variety of services and activities.

Current fiscal conditions results in the managers of public areas being stressed – leads to reactive (crisis) management rather than proactive long-term planning.

More people in the region requires community managers to provide more water, agricultural products, employment, etc., which impacts the ability of the natural system to absorb the effluent of all the various activities; extremes of climate and systematic changes in the hydrosystem exacerbate those pressures, increasing pollutant loads.

Introduction of non-native, invasive species threatens native populations.

Results: habitat fragmentation; island biomes; water pollution; air pollution; nutrient additions; salt water intrusion .

-

-

Role of Climate Variability to Amplify/Lessen Stresses

Rate of change more important than absolute magnitude of change ; land use pressures and habitat fragmentation preclude rapid-response migration and adaptation.

Mind of developers – land use change causes more change than climate: reduced migration corridors, use pressures preclude adaptations; public lands become more insular variability -- development can make remaining fragments of natural areas more vulnerable to change.

Water temperatures – throw reproduction and food production cycles out of sync.

Temperatures and water levels impact the interaction of noxious weeds and other organisms and native species – many invasive and opportunistic species have wider ranges of tolerance than native species.

Managing recreation areas – high and low flows and the distribution of those flows on an annual cycle are important for managing water-based recreational activities (fishing, boating, rafting, kayaking, etc.).

Public water supplies – managing reservoirs including recreational use is dependent on flow regimes.

-

Increasing water levels and temperatures, forces habitats upslope, but development immediately adjacent to protected areas often precludes migration, further restricting the "core habitat" protection afforded by public land designations.

\

Information and Data Needs

Inadequate information about organisms/habitat in public areas (need baseline inventories).

Data and information – a lot of info available, but not accessible -- public managers are particularly interested in shorter time scales (decadal fluctuations); storm predictability; extreme events.

Need to know baseline information and dose response for multiple stressors (organisms in insular environments will feel pressures from several factors, not just climate change).

Spatial resolutions need to be refined – elevation effects (3-D projections).

Information needs: the managers don't need data, they need information that is directed to specific management issues (e.g., forest manager needs to know forest health: pests, fire,).

Predict viability of organisms or communities of organisms under a suite of stresses – non-linear responses (thresholds beyond which organisms cannot adapt or recover).

Predictions in short range – wetter/dryer; stormier/less stormy --- ENSO variations for management – small variations in temperature not critical to manager at this predictive level..

Location of public structures – predictive process information for infrastructure design (e.g., flooding, erosion, etc.).

Need to develop long-term monitoring strategies in order to make course corrections in management strategies as conditions change.

-

Coping Strategies

-

Range of actions –

Do nothing (natural regulation) – face loss of biodiversity and habitat over the short-term; can no longer afford to ignore impacts of adjacent land-use pressures combined with natural progressive change.

Need to --

develop firm federal policy on infrastructure in public areas (do not exacerbate or expand development pressures from outside the public area into the area or create more fragmented systems),

promote regional cooperation for maintenance of community continuity (greenways; conservation easements, etc.) to allow for adaptive change in habitat/biological communities, and

develop new ethic – recognize the dynamic nature of natural areas and promote the concept of evolution of place – define landscape as change and accept change as integral part of system (education and outreach activity).

(Markham and Malcolm, 1996): resilience to change can be increased by (1) conserving biological diversity (2) reducing fragmentation and degradation of habitat; (3) increasing functional connectivity among habitat fragments, and (4) reducing anthropogenic environmental stresses.

(Stohlgren, 1997): (1) Maintain or restore natural disturbance regimes in order to minimize impacts of climate-induced changes during extreme events.

(Malcolm and Markham, 1997): Promote the use of public lands as core habitat for species survival as climate changes (requires working with communities to develop greenways and conservation buffer zones around the protected areas).

URBAN AREAS AND HUMAN HEALTH

Breakout Session Final Summary

Southeast Regional Workshop on Climate Variability and Change

Nashville, TN -- June 24-27, 1997

Session Co-Chairs:

Dale A. Quattrochi

NASA

Global Hydrology and Climate Center

HR01

George C. Marshall Space Flight Center

Marshall Space Flight Center, AL 35812

Philip Edelman

Vanderbilt University Medical Center

Center for Clinical Toxicology

501 Oxford House - 1161 21st Avenue South

Nashville, TN 37232-4632

This session explored the potential influences and effects that climate variability and climate change or disruption could have on urban areas and human health in the southeastern United States. Because cities are the home to 80% of the population of the United States, the interrelationship between human health and the urban environment is inextricable. Thus, climate variability or change would not only impact the functioning and environmental characteristics of the city as an entity, but would also have potentially significant effects on the health of the human populations of cities. Additionally, urbanization exists along with deforestation and agriculture as the most profound example of human alteration of the Earth's surface. Changes that result from urbanization impact biophysical, hydrological, and climatic processes, which in turn, affect

adjacent natural ecosystems. These influences brought on by urbanization, particularly those related to the affects on climate, can extend from the local to the regional scale, depending upon the size of the city and other factors. Urban areas, therefore, can not only be affected externally by climate variability or change, but can also influence the development of local or regional climatology. Ultimately, human health can be both directly and indirectly affected by these climatological processes, which can have very pervasive impacts on human society.

The real goal of our session was to view how climate variability and change affects cities in the southeastern U.S. as sustainable, habitable environments. The southeast is one of the fastest-growing regions in the nation. To insure that urban areas in the region will be capable of sustaining habitation by our children and their progeny in the next millennium and beyond, we must become aware of how the perceived impacts of climate variability and change as we know them today, will affect cities as livable environments. From this perspective, we viewed climate variability and change on cities, along with the impacts of urbanization on local and regional climate, as a series of interactions and effects as illustrated in Figure 1.

Figure 1. Relationship of primary, secondary and tertiary effects of climate variability or change as a function of processes-responses on urban areas and human health.

From Figure 1, primary effects of climate variability or change can be measured as major stressors on urban areas and human health; for example, climate change would potentially impact air quality that could be measured as an increase in ozone concentrations over cities. Climate variability or change on urban areas and human health would also have secondary impacts that would not be felt immediately, but would precipitate a change in the urbanization process or affect human health; e.g., a secondary effect of climate on air quality would be loss of tourism or population from an area because of "dirty" air or the cost of coming into compliance with air

quality attainment standards. Tertiary effects are associated with changes in the decision-making process as an adjustment or adaptation by humans to climate variability or change; for example, degradation in air quality brought on by variability or changes in climate would force actions to mitigate or reduce further air quality impacts by developing alternative fuels and transportation or industry restrictions, along with bearing the substantial costs associated with implementing these measures.

The strategy outlined in Figure 1 was used to define 10 key categories that could be impacted or affected by climate variability or change, along with their attendant effects on urban areas and human health: 1) Air Quality; 2) Severe Storms; 3) Floods/Droughts; 4) Human Health; 5) Stormwater; 6) Water Management; 7) Energy Management; 8) Food Supply; 9) Urbanization; and 10) Political Risk. The data needs for observing, measuring, and modeling the impacts of climate variability or change on each of the 10 categories were also identified; e.g, to track air quality, air quality monitoring, and temperature, humidity and wind data are required. In addition to defining the primary, secondary, and tertiary effects on each of the 10 categories, mitigation strategies or programs that could be used to alleviate the impacts of climate change or variability on urban areas and human health were also identified. For example, tree planting programs or emission controls could be some of the ways that air quality degradation over cities could be mitigated or improved. The end product of the breakout session was the development of a matrix that presents the 10 categories, along with the primary, secondary, and tertiary effects, data needs, and mitigation strategies given by category. This matrix is presented in Appendix B.

Eight of the 10 categories presented in the matrix are listed in order of seriousness of impact on urban areas or human health as a response to climate variability or change. The first four categories, Air Quality, Severe Storms, Floods/Droughts, and Human Health in actuality were ranked equally in importance as far as being affected by climatic variability or change. Water Management, Energy Management, and Food Supply were perceived as being less egregiously affected by climate variability or change than the first 4 categories. The last two categories, Urbanization and Political Risk, exist to some extent as "outliers" from the preceding eight categories, but still warrant attention in respect to analyses of climate variability and change effects. Urbanization relates primarily to the effects and dynamics associated with the city-building process and the growth of cities on the local an regional climate, such as that exhibited by the Urban Heat Island phenomenon where air temperatures over large urban areas are elevated in contrast to their rural surroundings. Political Risk pertains to the possible loss of the public's confidence in political leaders that could result from either not responding, or not responding quickly enough, to the effects of climate variability or change on urban areas and human health. Albeit political risk is tangential to the whole question of climatology, political leaders exist as the "lightening rods" to which public attention will be focused if policies to mitigate the effects of climate variability or change are not made or enforced.

Although the primary, secondary, and tertiary effects, data needs, and mitigation strategies expressed in the matrix are category-dependent, there are some common threads that pervade throughout all 10 categories. Improved education of both the public, and decision-makers and

leaders, on the potential effects of climate variability and change on urban areas and human health, is essential in developing mitigation strategies for all the categories listed in the table. Also, effective communication by scientists to the public of the possible impacts and dynamics that climate variability or change may have on cities and human health, is paramount to insure that actions can be taken to prepare for or mitigate these effects. Moreover, although not explicitly stated in the matrix, the data both required and used to mitigate the effects of climate variability or change need to be consistent and high quality. This includes providing adequate metadata to support and augment the analytical, modeling, and decision-making processes on how urban areas will be affected by, or affect, climate and what impacts will occur on human health.

A summary of the research needs as related to the 10 categories given in the matrix and the attendant effects, data needs, and mitigation strategies is presented below. These are listed in order of priority to address the critical issues this breakout session has identified on how climate variability and change will impact urban areas and human health in the southeastern United States.

- Air quality is a major concern of urban areas and contributes to a host of environmental and human health problems. Accordingly, surveillance systems that correlate respiratory health to air quality changes resulting from climate variability are needed.

- The urban heat island and land use changes directly contribute to air quality degradation through their influence on photochemical processes. More remotely sensed data and modeling simulations are needed to further evaluate these changes.

- Urbanization has several significant effects on local and regional climate such as elevated air temperature, altered precipitation patterns, sunlight intensity, etc. In particular, climate variability or changes that effect an increase in temperature and intensity in rainfall will be exacerbated over cities because of urban climatological processes. More research into the local and regional effects of urbanization on climate are needed to better understand the magnitude of these impacts.

- Hurricanes account for a major loss of property and infrastructure in the southeastern U.S. The impacts of hurricanes has become even more devastating as major increases in population centers have occurred along the Gulf of Mexico and the Atlantic Coast in the southeastern U.S. Research needs to be conducted on the interaction of population growth, land use/land cover change, and projected impact of future hurricanes on cities located on the coasts of the southeastern region.
-
- Water supply, volume, and quality are critical to sustaining urban environments. Changing

precipitation trends and intensities are of particular interest in monitoring water levels (groundwater and surface), runoff capacity, reservoir management, and water quality.

- Regional climate variability has the potential to impact energy usage from extreme temperature changes. Better prediction of climatic events and trends that effect energy usage is needed, such as summer heat waves or extended wet periods as a result of ENSO.

- Peak rainfall events are especially important to urban areas due to stormwater runoff and flooding concerns. Better historical data and prediction of peak events both in frequency and intensity are needed to minimize adverse public health and urban infrastructure impacts.

- Data are needed to identify susceptible populations that will be affected by changes in climate extremes and variability. This would include conditions caused by solar radiation (skin cancer) or individuals with immunodeficiency susceptible to infectious diseases from climate-effected vectors. The elderly, and maternal-child susceptibilities are most vital.

- Training programs for public health officials need to redeveloped for the recognition and proper reporting of conditions directly and remotely caused by climate variability and change.

- The cost of local and regional climate variability impacts on urban areas needs to be evaluated for planners and decision makers.

- Food supply to urban areas is susceptible to climate variability. Climate variability research is needed on the impact of the production and distribution of food supply, such as temperature, precipitation extremes, and severe storms. Studies should include an investigation of the possible affects on food produced in close proximity to, or distant from, the city.

- Planners and decision makers have an expressed need for more comprehensive data on the affects of climate variability and change on urban infrastructure.

Workshop on Climate Variability and Water Resource Management

in the Southeastern U.S.

June 25-27, 1997

Nashville, TN

WATER RESOURCES

1. Executive Summary

Although the Southeast receives a great deal precipitation and has an extensive system of water supply projects, water demand is beginning to exceed the available supply due to increases in population, urbanization, and agricultural uses. Even in this relatively water-rich area, serious conflicts have emerged over how water resources should be used and how the water systems should be operated. Competition for water in the Southeast is currently exacerbated by climate variability and would be further aggravated by potential changes in climate and any increases in variability. The key issue facing water managers in the Southeast is 'How do we equitably allocate water in the face of growing populations and increased competition among water uses ... and climatic uncertainty ?'

To address this issue, better water management approaches are needed. A wide range of coping strategies were identified, including: water use reallocation; demand-side management; innovative supply side management; flexible and adaptive approaches to water management; improved methods for analyzing trade-offs between alternative uses; and new patterns for negotiation and problem resolution. Some of the most difficult challenges facing water managers in the Southeast are not of a technical nature, but are of a social and political nature, which require flexible and adaptive institutions, legal frameworks, and problem solving mechanisms.

Additionally, a bridge is needed between the information that can be produced regarding future climate variability and change and the information required to understand the trade-offs between different water management alternatives. This bridge involves the use of hydrologic models that translate climate information into streamflow, water levels, soil moisture, and other hydrologic variables. Also, the reliability of the climate information must be assessed and the uncertainty in possible future events must be represented quantitatively.

To assure that appropriate bridges are built and that available climate information is used as well as

possible, a few demonstration or pilot projects should be undertaken. These must involve water resources stakeholders, water systems operators, appropriate government agencies and the scientific community.

As a first step, it is recommended that climate projects such as the Global Water and Energy Cycle Experiment (GEWEX), Continental-Scale International Project (GCIP) be encouraged to undertake demonstration projects in the Southeast. These projects will: (1) accelerate the development of models and information related to the prediction of precipitation, soil moisture, temperature, and streamflow over forecast periods up to a year ahead and (2) test model and information value to water resources interests.

2. Current Concerns and Stresses

The overriding water resources issue in the Southeast is demand for water, which is beginning to exceed the available supply. As a result, competition among water users is intensifying. Water use conflicts are becoming more prevalent despite the fact that precipitation in the region is relatively abundant and an extensive system of water storage reservoirs exists throughout the Southeast. Water demands, however, have grown significantly and become more complex due to rapid population growth, increased urbanization, rising agricultural uses and increased irrigation, and changing public priorities. Reservoir systems, such as the Tennessee Valley Authority (TVA) reservoir system, designed for the traditional needs of water supply, flood control, navigation, and power production, must now accommodate public demands for recreation and improved water quality. Large metropolitan areas such as Atlanta, Georgia must compete with other states for water, as evidenced by Alabama suing the U.S. Army Corps of Engineers after reservoir storage in Corps projects was reallocated from hydropower to water supply for Atlanta. In south Florida, the Department of Interior, Corps of Engineers, South Florida Water Management District, and a suite of other private and public groups are working together to restore ecosystem functions of the Everglades and resolve conflicts over water use by agricultural, urban, and environmental interests. Additionally, water quality issues have become increasingly important as degraded quality and salinity intrusion resulting from depleted water tables renders water unavailable for intended uses, thereby increasing water demand as well as reducing the utility of the available supply.

As water conflicts in the Southeast have intensified, it is become apparent that there are inadequate mechanisms for the equitable allocation of water. It appears that many important water resources issues are not of a technical nature, but are political, social, economic, and institutional/organizational issues. A major concern in the Southeast is how to develop flexible and adaptive institutions/organizations, legal frameworks, and problem solving mechanisms to allocate water among competing uses.

Other water resources stresses in the Southeast are of a localized nature and/or important to specific hydrologic systems, such as inland freshwater river basins, coastal areas, or the wetlands of the

Everglades. Some of the more important water resources problems in the Southeast are related to:

Saltwater intrusion

Sea level rise

Water temperature (assimilative capacity, power, water quality)

Extreme events (hurricanes, tornados)

Sensitive ecological areas (wetlands, estuaries, Everglades)

Groundwater overdraft and contamination

Urbanization & aging infrastructures

Instream flow needs

Nonpoint source pollution (agricultural, mine, toxic)

Loss and lack of data and monitoring

3. Implications of Climate Change

In the Southeast, as snowmelt is minimal, the primary climatic factor which directly influences water resources is the magnitude and distribution of precipitation. Expected increases in temperature resulting from climatic change will impact water availability through changes in evapotranspiration, soil moisture, and water quality, as well as by increasing water demand. At the present time, general circulation model (GCM) predictions for the Southeast yield varying results, with some GCM's predicting increases in precipitation, and others predicting reductions. Consequently, it is difficult to predict precise impacts to current water uses, as a wetter vs. a dryer climate would have very different implications. In general, however, it can be said that regardless of the direction, changes in climatic conditions will exacerbate existing stresses and intensify competition among water uses. Decision makers will come under increased pressure to improve water management.

4. Coping Strategies

Many coping strategies exist to solve problems associated with climate variability and change, including:

Water use reallocation

Demand-side management

Innovative supply side management

Integrated river basin management

Flexible and adaptive approaches to water management

Effective approaches for resolving water use conflicts

Each strategy is examined briefly below.

4.1 Water Use Reallocation

Water use reallocation requires reprioritizing needs and developing allocation optimization techniques. Optimization techniques must consider the reprioritized needs and water costs. Costs are either direct or indirect. A direct cost is the value of water, and an indirect cost is the price associated with not having sufficient water for some activity (i.e. recreation).

4.2 Demand Side Management

Demand side management involves the re-use, efficient use, and conservation of water by users. Examples include using grey water for irrigating golf courses, using flow-reduction devices in plumbing fixtures, and xeriscape landscaping techniques.

4.3 Innovative Supply Side Management

Examples of innovative supply side management techniques are water credits, creating water markets, developing pricing strategies, facilitating inter-basin transfers, and improving existing infrastructures. The use of water credits will require oversight by governmental agencies. Water markets, used in the west, will require that governmental agencies give up some of their traditional water management powers. Pricing strategies will change people's views of water as an abundant, relatively inexpensive commodity. Interbasin transfers will require more flexibility on the part of water management agencies, and the

funding required for infrastructure improvement will require increased taxes or cut-backs in other governmental services.

4.4 Integrated River Basin Management

Integrated river basin management uses multi-governmental and stakeholder teams to solve water problems that cross political (i.e. jurisdictional) and professional (e.g. engineering, ecology, planning, social science, economics) boundaries. These teams must use flexible and adaptive approaches to address basin-specific problems. Flexibility is needed to cope with annual climatic variability, and adaptability is needed to deal with changing water use patterns (e.g. new demands, changes in demands).

4.5 New Patterns for Negotiation and Problem Solving

An effective approach for resolving water use conflicts is collaborative problem solving by multi-level governmental and stakeholder teams. For example, Florida, Georgia, Alabama, and the Corps of Engineers created interstate commissions to develop equitable allocations of water taken from basins shared by the three states and containing water control projects operated by the Corps of Engineers. While implementation will vary from one situation to the next, collaborative problem solving is a powerful strategy for resolving water use conflicts.

5. Information Needs and R&D

5.1 Improved Communication with Decision Makers and the Public

Relevant information must be presented concisely and clearly. This should include assessments of consequences, risk, uncertainty and trade-offs among these factors for different alternatives. Improved communication with the public also improves chances of public buy-in for initiatives undertaken to reduce the stresses caused by climate variability and change.

5.2 Improved Modeling Capabilities

Critical parts of the bridge between climate information and water resources decisions are: (1) hydrologic models that translate climatic variables into streamflow and (2) water resources models to simulate the operations of reservoirs, diversions, and other water projects. Hydrologic models must represent flow conditions at both gaged and ungaged locations. One of the most costly and difficult steps in hydrologic modeling is to estimate model parameters. Better hydrologic models are needed with parameters that can more easily be estimated, both by calibration using historical data and by a priori means for ungaged locations. Improved water resources systems models are needed to represent system components that can be operated or controlled and for which decisions must be made.

5.3 Improved Decision Making Tools

Decision support systems are needed to present information and help users understand the relevancy of complex information sets. These systems must be flexible, adaptable to changing user interests, and able to integrate all relevant information. They must incorporate uncertainty into analyses and express outcomes in terms of probabilities. To help users handle complexity, decision support systems must accommodate a hierarchy of system scale definitions.

5.4 Maintenance of Long-term, Continuous Data

Long-term, continuous data are needed as a record of past and present climatic and hydrologic conditions, and to show how conditions have changed over time. The data record should be of sufficient temporal resolution to display short term variabilities and long term changes. Towards this end, historical data sets must be preserved, current monitoring continued, and if needed, new monitoring efforts initiated.

5.5 Improved Weather and Climatic Information and Forecasts

Weather and climate information and forecasts have started to be produced in a probabilistic context. This includes ensemble predictions from weather and climate prediction models. Each member of an ensemble is intended to represent an equally-likely event so that probabilistic estimates can be made. Ensemble members can be input to hydrologic models to produce an ensemble of hydrologic model outputs. Similarly, hydrologic model ensemble members can be input to water resources systems models. Because all models have limitations and biases and only can approximate real world complexity, appropriate data analysis steps are necessary to process the output information from one model before using it as input to the next model.

It is essential that research be continued to improve the reliability of the weather, climate and hydrologic forecast models. Also, research is needed to ensure that uncertainty is adequately quantified.

Forecast information is needed over a wide range of time horizons. Water resource system operations require forecasts from a few days to a year or two into the future. Water resources planning involves time horizons of many decades into the future. A key issue for planning is how to use historical climate information with results from climate change studies.

It is essential that the hydrologic processes (i.e. rainfall) simulated by weather and climate models be accurately simulated. The hydrologic information produced by these models is most important for water resources applications.

5.6 Improved Technologies for Conservation, Efficiency and Re-use

To meet increasing water demands, and the possible reduction of supplies, improved technologies for water conservation, efficient use and re-use are needed. These technologies should address domestic, industrial, hydropower, and irrigation uses. Emphasis will be on maximizing resource use (e.g. development of turbines and generators to maximize hydropower production, irrigation techniques that minimize evaporation losses).

5.7 Flexible Institutions and Mechanisms for Resolving Conflict

Conflict resolution is best handled by institutions that can adjust their operational strategies in accordance with a changing environment. Environmental change is impacted by climate variability/change, new water demands, and changes in old demands. Institutions that can adjust operational strategies usually are empowered to provide multiple services, instead of just one. For example, a water management agency that provides flood protection, hydropower, and water for consumptive use can adjust much better to new demands for services than an agency that only provides hydropower.

5.8 Demonstration Projects

Demonstration projects are needed to test if research results actually meet user needs and to assist in the development of more useful forecast information. Also, these projects should be done in a realistic institutional setting to assure that diverse public and private interests are represented and reasonable opportunity exists to correctly assess the potential value of new information.

5.9 Statistical Methods and Applications Strategies

Creative statistical approaches are needed to deal with uncertainty in forecasts of climate variability and change and to evaluate the reliability of these forecasts. Statistical analyses used in most water resources planning, design and management are based on the assumption of a stationary climate. Methods for dealing with a changing or non-stationary climate should be explored and more widely practiced. Also, statistical downscaling techniques are needed to account for fine-scale climatic variability. Fine-scale variability is important to the behavior of non-linear hydrologic models but is not provided by climate models. Additionally, issues such as the potential impact of climate change on the probable maximum precipitation (PMP) and probable maximum flood (PMF) could have important implications for design criteria and dam safety.

Water_gcc.wpd

APPENDIX:

Potential Impacts of Climate Variability and Change to South Florida

Background

Water managers in south Florida are concerned primarily with flood control, water supply, and environmental protection. To accomplish these functions, water is moved through an extensive network of canals, which are connected to natural lakes and large water impoundments. Water movement is controlled by numerous pumps and gravity driven, flow control structures. The most notable of south Florida's lakes is Lake Okeechobee. The diked impoundments, called water conservation areas, encompass large tracts of the original Everglades.

South Florida's landscape is widely varied. The Southeast coast (Dade, Broward, and Palm Beach Counties) is a major urban center, with a population of over three million people. This area continues to grow and expand at a high rate. Agriculture, an important industry in south Florida, is a major sugar

producer and provides large quantities of vegetables to the east coast of the United States during the winter. Critus also is very important. Large tracts of land are devoted to environmental preservation and recreation. National and state parks and wildlife refuges are found throughout south Florida. Lake Okeechobee is a major recreational resource. These areas provide wildlife habitat, have navigable waterways, and constitute the basis of a highly profitable recreation/ecotourism industry.

The operation of south Florida's water management system requires that water levels and deliveries be kept within certain limits. Excessive water or drought impact the ability of water managers to control flooding, supply water, and protect the environment. Specific examples are given below.

Water levels in canals are directly related to groundwater levels. During south Florida's wet season (June to October), canal levels are kept low to improve drainage and minimize flooding. During extremely wet periods, if canal levels cannot be kept sufficiently low, water tables rise towards the land surface and the possibility of flooding increases. During the dry season, canal levels are managed to keep the water table near the root zone in agricultural areas and to minimize salt water intrusion along the coast. During extended dry periods, reduced canal levels enable the water table to recede below the root zone, requiring increased groundwater pumping for irrigation. Lower groundwater levels also increase salt water intrusion.

Water levels in Lake Okeechobee must be kept within a certain range to prevent environmental degradation. If levels are too low, turbidity increases in open water areas (adversely impacting the pelagic environment). Too much water damages submerged aquatic vegetation because of reduced light transmittance through the water column. Environmental degradation impacts wildlife habitat, navigation, and recreation/ecotourism.

The Caloosahatchee and St. Lucie River estuaries (located on Florida's west and east coasts, respectively) receive freshwater inflows from their watersheds and Lake Okeechobee. During extremely wet periods, large quantities of fresh water are discharged to these estuaries. During extended dry periods, sufficient fresh water may not be available. Too little or too much freshwater adversely impacts estuarine environments, causing the degradation of wildlife habitats and economic losses to the recreation/ecotourism industry.

A series of stormwater treatment areas (STAs) will be built to remove phosphorus from water discharged to the Everglades from Lake Okeechobee and the Everglades Agricultural Area, south of Lake Okeechobee. Excess phosphorus comes from Lake Okeechobee and agricultural activities. The STAs will contain a variety of aquatic plants that require a specific range of water depths. Too much or too little water will harm the plants. Too much water also will reduce residence times in the STAs and require some flows to by-pass the STAs. Thus, water discharging to the Everglades may contain higher phosphorus concentrations.

Water Resources Issues

Based on the above discussion, important water resources issues in south Florida are: water supply; flood control; and environmental protection. During extended dry periods, sufficient water may not be available to satisfy the competing demands of urban areas, agriculture, and the environment. During periods of extreme precipitation, excess water may not be conveyed out of the water management system fast enough to prevent flooding. A growing population is adversely impacting all three of these issues.

Connections Between Water Resources Issues and Climate

Rainfall variability impacts how the water management system is operated for water supply, flood control and environmental protection. More rainfall means an increased potential for flooding, which adversely impacts agriculture, urban areas, and the environment. Less rainfall increases competition for water. Temperature variability affects water supplies, due to changes in evapotranspiration, and demand. Thus, as with the rest of the Southeast, climatic changes in South Florida will exacerbate existing stresses and intensify competition among water uses. Decision makers will come under increased pressure to improve water management.

Coping Strategies and Management Needs

The coping strategies and management needs for south Florida are basically the same as for the rest of the Southeast. Because south Florida's climate, weather, hydrology, and water management systems are significantly different from much of the Southeast, a separate suite of climate, meteorology, hydrology, and operations models are needed. To ensure that these models work correctly and properly interface with one another, south Florida water management agencies should become involved in demonstration projects involving technology transfers from research institutions to public agencies and private organizations. Research also is needed on how to best modify/reconfigure the water management system to better handle climate variability and change.

Water_gcc.wpd

Appendix A

Workshop on Climate Variability and Water Resource Management in the Southeastern United States

Vanderbilt University

Nashville, Tennessee

June 25-27, 1997

AGENDA

Time Subject Speaker

June 25, 1997

7:00 Registration

8:00 Plenary: Introduction Dr. John Venable, Vanderbilt U., *Associate Provost*

8:05 Plenary: Roadmap of workshop Dr. R. Ritschard, *UAH/GHCC*

8:15 Plenary: National Perspective Dr. Jack Gibbons, *President's Science Advisor*

8:30 Plenary: Current Climate Variability Dr. Jim O'Brien, *Florida State University*

in Southeast

9:30 Break

10:00 Plenary: Regional Perspectives on Climate Dr. Michael Helfert, *South Carolina Department*

Variability and Impacts *of Natural Resources*

11:00 Plenary: Keynote Talk Bill Campbell, *Mayor of Atlanta*

12:00 Plenary: Educational Aspects of Climate Dr. Roger Bybee

12:30 Plenary: Breakout Session Charge Dr. Jerry Melillo, *Office of Science and Technology*

Policy

12:45 Lunch

1:45 Breakout Sessions

5:00 Exhibitor Presentations

6:00 Dinner at University Club of Nashville Vice President Al Gore, *Guest Speaker*

June 26, 1997

8:00 Plenary: Panel Discussion on Stakeholder Dr. Roger Pielke, Jr., *National Center for*

and Scientist Perspectives *Atmospheric Research (NCAR), Panel Leader*

Dr. Linda Mearns, *NCAR*

Margaret Davidson, *Coastal Services Center/NOAA*

Dr. R. Nick Keener, *Duke Power*

9:00 Plenary: Global Climate Change Trends Robert Quayle, *Natl. Climatic Data Center/NOAA*

10:00 Break

10:30 Plenary:Examples of Regional Applications Dr. Doug Rickman, *NASA/MSFC*, Session Chair

Wilson Orr, *City of Scottsdale*

Dr. Roger Clapp, *Hydrology Consultant*

Paul Trimble, *South Florida Water Mgmt. District*

11:30 Luncheon Dr. Virginia Burkett, *USGS, Guest Speaker*

1:00 Breakout Sessions

5:00 Exihibitor Presentations

June 27, 1997

8:00 Breakout Session Reports and Discussion

12:00 Adjourn Workshop

IMPACTS OF GLOBAL CLIMATE CHANG
ON THE
PACIFIC NORTHWEST

Amy Snover
JISAO Climate Impacts Group
University of Washington

Prepared for the
US Global Change Research Program and
Office of Science & Technology Policy
Pacific Northwest Regional Climate Change Workshop
Seattle, Washington, July 14-15, 1997

REPR[illegible]AT GOVT EXPENSE

INTRODUCTION & SCENARIO

Increasing atmospheric concentrations of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), appear to have changed the earth's climatic system, warming the earth's surface and producing other changes in climate. Global average surface air temperature has warmed 0.3-0.6°C (0.5-1.1°F)* since the late nineteenth century, a warming that appears to be caused at least in part by human activities. Continued emissions of greenhouse gases due to human activities are expected to cause continued warming, at a rate more rapid than any experienced in the last 10,000 years. By 2100, the earth's average surface temperature is projected to be 1-3.5°C (1.8-6.3°F) warmer than it was in 1990. This warming will not be uniform; some parts of the world will warm more than others. Increasing levels of greenhouse gases are also expected to cause an enhancement of the global mean hydrological cycle, and an accelerated rate of sea level rise.[28]

While the various general circulation (computer) models (GCMs) that are used to predict future climate tend to agree on the global aspects of how climate will change, they are not yet sophisticated enough to produce dependable, consistent projections of climate change for smaller regions, such as the Pacific Northwest (defined for the purposes of this paper as the states of Washington, Oregon and Idaho). The coarse resolution of GCMs is insufficient to resolve local geographic features -- such as the Cascade Mountain range -- that are extremely important for regional climate. Regional-scale predictions of future climate are also hampered by the large amount of natural variability inherent to our climate. The climate modeling research community is actively improving model inputs and design in order to improve regional-scale climate predictions but is still hampered by GCM resolution, imperfect representation of atmospheric physics and lack of detailed local observations for model validation.

Throughout this paper, we will use a specific scenario of future temperature and precipitation changes in the Pacific Northwest to frame our discussion of the impacts of the region to future climate change. However, we will place much of the emphasis on vulnerabilities. The climate scenario that we use is taken from a GCM simulation of future climate, performed by a major GCM modeling center (the Max Planck Institute für Meteorologie, Hamburg),** interpolated to the regional scale. While MPI's global climate predictions agree in general with climate predictions made by other GCMs, agreement does not imply correct simulation of future climate. In addition, predictions made by different GCMs usually differ more substantially at the regional level; a different GCM would not predict the same scenario of climate change for the Pacific Northwest. The scenario chosen as a basis for discussion is *plausible* in light of our current understanding and computing capabilities, but should not be considered to be a *prediction.*

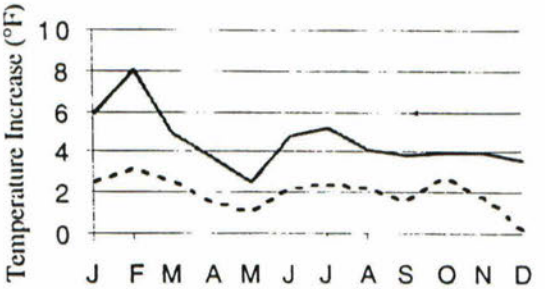
Under the MPI climate scenario, the Pacific Northwest would experience warmer, wetter winters and warmer, drier summers (see Figure 1). Annual average Pacific Northwest temperatures would increase 1.1°C (2°F) (by the decade 2020 and 2.5°C (4.5°F) by the decade 2050. The warming would be fairly uniform over the course of the year, with slightly more warming during the winter (Fig. 1A). Because of the thermal inertia of the climate system, temperature is expected to continue to increase beyond 2050, even if atmospheric concentrations of greenhouse gases were stabilized by that time. Under the MPI scenario, precipitation would increase somewhat during the wintertime and decrease during summers (Fig. 1B), although projected precipitation changes are less certain than changes in temperature.

---

* To convert °C to °F, muliply by 1.8.

** The model simulation was a time-evolving, transient climate simulation using a coupled ocean-atmosphere GCM (MPI model ECHAM1-A; Cubasch *et al.*, 1992). The model was forced with increasing emissions of greenhouse gases using emission scenario IPCC IS90a (≈1%/year as CO_2). This model run is one of several archived by the Intergovernmental Panel on Climate Change (IPCC) at the National Center for Atmospheric Research in Boulder, CO for use in integrated assessments.

1A. Monthly average temperature increase.



1B. Monthly average precipitation change.

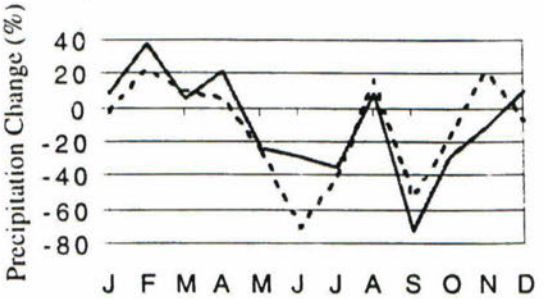


Figure 1. Average changes projected for the Pacific Northwest (Washington, Oregon and Idaho) in 2020 (dashed lines) and 2050 (solid lines) under the MPI climate scenario. (A) monthly average temperature increase; °F. (B) Monthly average precipitation change; % of current precipitation. Precipitation changes are a spatial average of fractional change in precipitation.

The model scenario indicates only how regional *average* temperature and precipitation might change; it doesn't address how climate variability would be affected by climate change. GCMs predict that climate change will lead to a decrease in the daily range of temperature in most regions. Overall, warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days. Climate change may also result in an increase in precipitation intensity, or extreme rainfall events. These predictions are less certain than projections of average changes in temperature and precipitation and may or may not specifically apply to the Pacific Northwest. It is currently impossible to predict whether there will be future changes in storminess. Although GCMs currently project gradual climate change, there is a possibility that the climate system may respond in surprising and/or sudden and unforeseen ways.[28.8]

Much of the variability in Pacific Northwest climate results from variations in the wintertime position and intensity of the Aleutian low pressure system. Characteristics of the Aleutian Low have been linked to interannual fluctuations in the tropical ocean-atmosphere system (the El Niño/Southern Oscillation, ENSO) and interdecadal changes in the Pacific Decadal Oscillation (PDO). Both ENSO and the PDO affect the delivery of water to the Pacific Northwest (via precipitation and river runoff).[40] How will climate change affect the frequency or intensity of these climate oscillations? Will it alter their impacts on Northwest climate?

Past climate variability has been shown to cause a chain of impacts in the Pacific Northwest, beginning with the region's hydrologic cycle and spreading to affect the disparate areas of forests and rangelands, aquatic ecosystems, coastal activities, agriculture, human health, energy production and utilization, and urban centers. What follows is a summary of our current understanding of the ways in which each of these eight dimensions is vulnerable to future greenhouse gas-induced climate change. Many of these systems are already under a great deal of human-induced stress. While the additional stress brought by climate change may be small in comparison, the combination of climate change with past and current stresses may result in increased vulnerability. Incorporation of an understanding of regional vulnerabilities into management planning will be important, both to prepare for climate impacts and to minimize aggravation of such impacts by related human activities.

Quite apart from vulnerabilities, will climate change of the magnitude predicted create opportunities for and in the Pacific Northwest? Obvious examples exist in the realm of agriculture, where increasing temperatures may lengthen the growing season, increasing productivity in this region. Opportunities are also likely to arise in the arena of energy

REPRODUCED AT GOVT EXPENSE

production. The share of Northwest electricity provided by hydropower is likely to continue to decrease in the future, necessitating an increase in the amount of power provided by other sources. In view of the current international debate and the possibility of future regulation of CO_2 emissions, alternatives to fossil fuel powered energy production and transportation may become increasingly attractive. This suggests openings for development of alternative energy sources and associated technologies as well as for the development of efficiency technologies.

HYDROLOGY & WATER RESOURCES

The Pacific Northwest is characterized by two types of river basins, or catchments, that will be affected differently by climate change. Rivers east of the Cascade mountains are primarily fed by spring snowmelt; wintertime mountain snow accumulation melts during the spring, causing flows that typically peak in early June. West-side river runoff is dominated by winter rains, augmented by spring snowmelt at higher elevations. Some Pacific Northwest rivers (parts of the Snake, for example) are fed heavily by ground water. Large rivers, such as the Columbia, have all these features.

The climate scenario for the Pacific Northwest projects precipitation increases during winter and decreases during summer. Increased temperatures imply that less wintertime precipitation will fall as snow and more will fall as rain, resulting in decreased snowpack accumulation, and therefore decreased water storage. Snowmelt would occur earlier in the year, due to warmer temperatures and the possibility of an increased frequency of rain-on-snow events. These climate changes would alter the flow patterns of snowmelt dominated rivers, shifting the period of peak runoff from springtime toward a rainfall-dominated peak in the winter. Flow patterns in rainfall-dominated rivers are likely to be amplified by climate change, with wintertime flows increasing and summertime flows decreasing. Consequences of these changes for water resource management include the need for more deliberate spillage in west-side rivers and the possibility for decreased water supply in summer, given reservoir storage limitations.

In order to understand these consequences more fully, the MPI climate scenario was used to run regional hydrologic and river reservoir models. It is important to note that current GCMs cannot provide the watershed-specific information or the details of future climate variability that are necessary to predict future hydrologic responses accurately. Future projections are also limited by lack of information on how climate change related vegetation changes would affect future basin water budgets and how future water and energy demands will change. Thus, these studies can be used to indicate what the projected changes in monthly average temperatures and precipitation would mean for Pacific Northwest water resources, given today's understanding and structure of the hydrologic system.

West-side rivers (Green River Case Study)

The temperature and precipitation changes predicted by the MPI climate scenario were applied to a hydrological model of the Green River, the source of Tacoma, Washington's water supply.[76] Results of this study may be generally applicable to similar rivers west of the Cascades. Annual runoff increased in the lower (rainfall-dominated) basin, particularly during the winter. As expected for a snowmelt-dominated system, peak flows in the upper basin shifted towards the winter. Summer and fall river runoff decreased substantially.

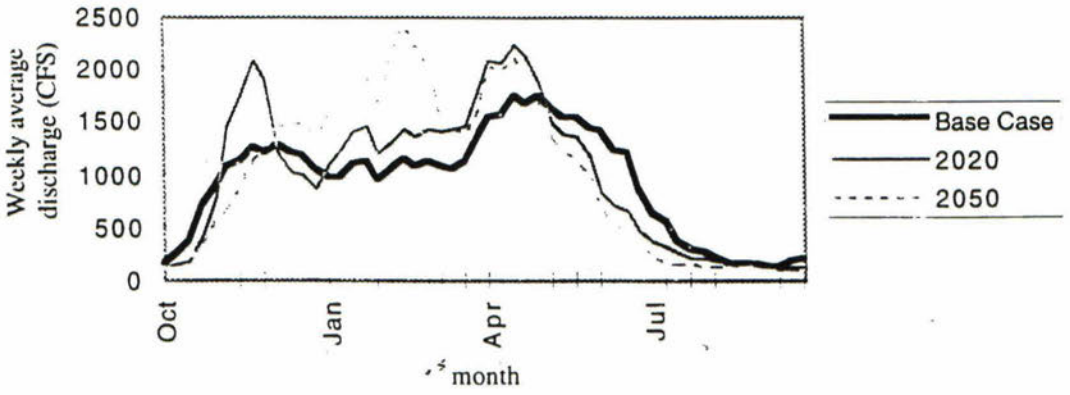


Figure 2. Average hydrographs for the upper Green River, Washington; base case and projections for 2020 and 2050. Vertical scale is weekly averaged river discharge in cubic feet of water per second.

Climate change alone (without future demand growth caused by population increases) was found to have little or no adverse effect on either the performance of the Tacoma Water Department's water supply system or on system revenues. However, the number of times the system failed to meet instream flow requirements (relevant to fisheries protection) more than doubled in 2050, assuming that current rules for reservoir operations are followed in the future (*i.e.*, no adaptive management). Supplemental reservoir releases might be necessary to mitigate the effects of lower flows, but would be unlikely to resolve the issue given current Tacoma Water Department water rights. In addition, climate change resulted in a considerable increase in flood frequency. Mitigation of the larger flood peaks that would occur under a warmer climate may not be possible within the constraints of the existing physical infrastructure. How will climate change affect uncontrolled river systems directly affected by short-term flooding events?

The Columbia River Basin

The Columbia River is the fourth largest river in North America. It drains catchments in Washington, Oregon and Idaho, as well as Montana, British Columbia and Nevada. Regional growth, as well as changing water allocation priorities, are increasingly stressing the river system. According to the three major Columbia River operating agencies, "there is simply not enough water flowing in the system to meet all the demands. Trade-offs must be considered...in recent years, demands by the various users of the river have increased dramatically, resulting in increasing conflicts among users."[6]

Under the MPI climate scenario, the Columbia River Basin, which is currently a snowmelt-dominated system, would experience a shifting of peak flows toward a winter rainfall-dominated peak.[37] In the basin overall (represented by the Dalles, Figure 3A), average annual runoff would decrease and flow would peak one month earlier. Decreases in average runoff are driven by a decrease in average annual precipitation of ~10% over the basin. Upriver, where the Snake River joins the main stem (at Ice Harbor, Figure 3B), peak flows would decrease and spread over a period of several months. In general, flows would decrease throughout the Columbia River Basin during the low flow period of August-January. The hydrologic changes are extremely sensitive to the spatial distribution of future changes in precipitation: changes which -- under the MPI climate scenario -- do not occur uniformly over the Columbia River Basin.

REPRODUCED AT GOVT EXPENSE

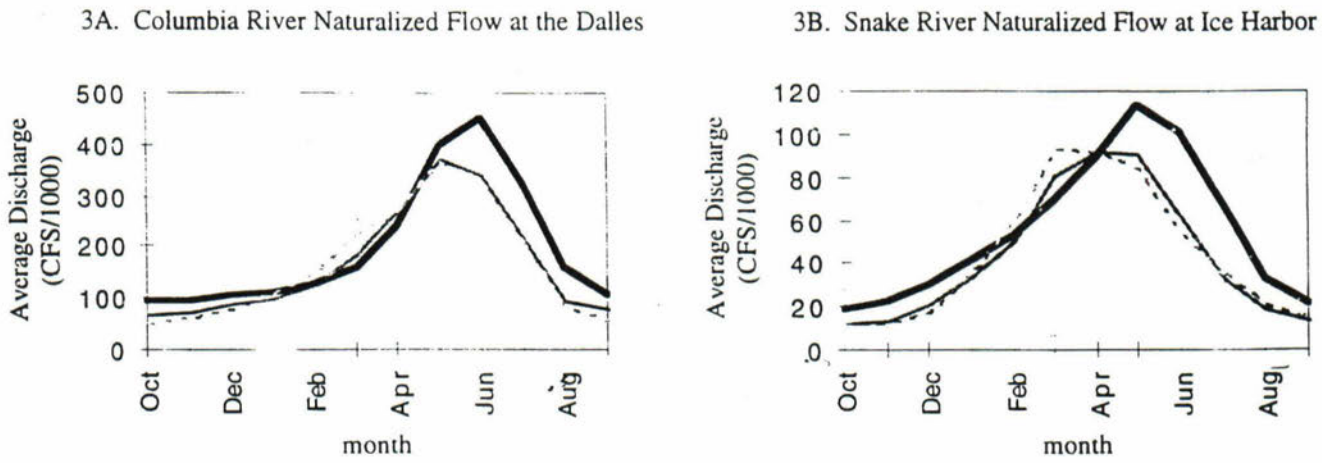


Figure 3. Monthly mean hydrographs for the base case (heavy solid line) and MPI climate scenario in decades 2020 (solid line) and 2050 (dashed line) for (A) the Columbia River at the Dalles and (B) the Snake River at Ice Harbor. Vertical scale is monthly averaged river discharge in thousands of cubic feet of water per second.

The projected shifts in runoff timing and changes in average streamflow will have implications for energy production, fish protection and irrigation water supply.[27] The changes in seasonal timing of runoff associated with the warmer climate scenarios tend to be advantageous for hydropower production in February and March, a period of high demand, but may jeopardize subsequent reservoir refill and hydropower production for the following year. Under the MPI scenario, failure to meet firm-energy production requirements occurred more often, were larger and lasted longer. The reliability* of the system to meet firm-energy production requirements was found to decrease from 96% in the modeled base case to 69% in 2050, while the average magnitude of shortfall quadrupled. If the MPI scenario were to occur, there probably would be a need for additional power sources to supplement hydropower.

Hydropower system managers use the concept of the "critical period," the three-year period of lowest extended flows in the historical record, to determine the hydro system's firm energy capability and rules for system operation. Will the current critical period used for system planning be relevant in the future? How might future climate change and climate variability affect the Columbia River system's vulnerability to drought?

The projected decreases in streamflow have negative implications for fish protection. The reliability of meeting the minimum flow requirements set by the 1995 National Marine Fisheries Service Biological Opinion[41] for McNary Dam on the main stem of the Columbia dropped from 85% in the base case to 76% in 2020 and 2050. These flow requirements are difficult to meet today, due to the limited storage available to support them, and become more difficult to meet under the MPI scenario.

Over seven million acres of agricultural land in the Columbia River Basin rely on irrigation water from the Columbia. Current irrigation demand cannot always be met in heavily allocated basins like the Snake and the Yakima. The model explored the reliability of meeting a fixed irrigation demand (90% of 1989 demand) under the MPI climate scenario. This reliability would decrease from 97% in the base case to 84% in 2020 and 2050 in the upper Snake River basin. Demand reliability in the middle Snake would decrease from 86% to 69%. Would decreased ability to meet demand from surface sources result in increased groundwater pumping? How would that impact long-term river flows and groundwater quality?

* Reliability is a measure of the hydropower's system to meet demand. A reliability of 96% means that the system met demand 96% of the time and failed 4% of the time.

To accommodate recreational use of the Columbia River Basin system, dam operators try to keep storage reservoirs that are used for recreation as full and stable as possible during the summer. For June 1 through Labor Day, reservoir elevation at Grand Coulee can be maintained between 1285 and 1290 feet 74% of the time in the base case. That reliability would drop to 67% in 2020 and 2050. However, the average elevation deficit would increase only slightly -- from 19 feet in the base case to 20 feet in the future.

The current reservoir model can evaluate floods caused by spring snowmelt events that are important over the course of a month. Under the MPI scenario, decreased peak flows indicate reduced severity of spring floods.

Another important issue that cannot be addressed with current models is the impact of climate change on water quality. Dilution of wastes, from point and nonpoint sources, depends on river flows. Irrigation runoff, the largest nonpoint source of pollutants to the Columbia,[7] peaks during the summer months when river flows are lowest. Warmer air temperatures could result in increased river temperatures, and therefore affect dissolved oxygen concentrations in some lakes and tributaries. How will these changes affect fish populations? Will climate change impacts on water quality be significant?

The reliability of meeting the demands of major uses -- hydropower production, fisheries protection and irrigation supply -- are projected to decrease under the MPI climate scenario. This suggests that either changes to the management system will be required to operate the system more effectively, or that the system's goals would be met less frequently in the future. If climate changes in a manner similar to that predicted by the MPI scenario, increased competition for resources among major users of the river seems inevitable. How would a diverse and fragmented management system cope with increased competition? Could water demand be managed in such a way as to reduce potential conflicts and/or system failures? Will the system be more or less sensitive to changes in future variability? Will the diverse management groups of the Columbia River Basin be flexible enough to respond to the increased uncertainty due to climate change?

FORESTS & RANGELANDS

The distribution of tree species and the composition of ecosystem communities in the forests of the Pacific Northwest are tied to the climate of the region, particularly to moisture availability. Past variations in climate have been shown to alter forest carbon budgets (through tree growth and carbon sequestration), shift forest composition along environmental gradients, and alter disturbance regimes.[25] Forests are most strongly linked to climate during regeneration, and through climate's impact on disturbances. It is through these links that the impacts of future climate change will be manifested most clearly.[25]

Forests will be directly impacted by temperature and precipitation changes as well as by increased levels of atmospheric CO_2. Photosynthesis, respiration and other important physiological processes are directly affected by temperature and moisture regimes.[25] Forest productivity in many parts of the Pacific Northwest is particularly sensitive to available moisture. As temperature increases, the moisture available for plant growth will decline, even with no change in precipitation. Projected summertime decreases in precipitation are likely to intensify the typical Pacific Northwest summer dry period. Benefits of increased CO_2 (increased water-use efficiency, growth rate, productivity and nitrogen-use efficiency) have been observed in seedling studies, but may not apply to mature plants in the field and are still quite controversial.[33] In addition, species are likely to adapt to increased levels of CO_2 over time and ecosystems may reach carrying capacities imposed by other limits.[4]

The vegetative shifts likely to result from climate change are difficult to predict with specificity. Although a climate warming of 2.5°C (4.5°F) has been likened to a shift of climatic zones 100-250 km (60-150 miles) northward or 500-600 m (~1800 feet) up in elevation, forest ecosystems are not expected to shift as intact communities. In general, warming may cause earlier snowmelt, lengthening the growing season at cool, wet, high

REPRODUCED AT GOVT. EXPENSE

elevation sites, making them more hospitable to trees in the future. Lower elevation, currently dry locations (on the lower east slopes of the Cascades, for example) are likely to become inhospitable to forests in the future.[25] Redistribution of tree species will depend on the new combinations of temperature and precipitation that are likely to result from climate change. Tree species response to these changes is likely to be highly individualistic. Species response will also be site-dependent, varying with elevation, aspect and competitive interactions with other species. The combination of these factors is likely to result in new combinations of species.[46]

Changes in forest composition or location would be slow to occur in the absence of other disturbances. Mature trees tend to be long-lived and resilient and can survive long periods of marginal climate.[9] It is during the stage of tree regeneration, or seedling establishment, that forests are most vulnerable to climate change.[25] Seedlings are especially sensitive to temperature and may not be able to establish and grow under altered climatic conditions. Because climate zones are likely to shift faster than natural tree migration rates,[15,29] established adults of appropriate species and genotypes will be separated from the location where seedling establishment is needed in the future.

Climate change is likely to increase the frequency and/or the intensity of disturbance regimes, such as wildfires and pest outbreaks. Such disturbances will act to hasten the otherwise slow response of established forests to climate change. Regions of increased summer drought will experience increased risk of fire, perhaps extending hazard into areas not now affected, especially where forests are dead or already stressed by drought or pests.[33] Fires may initially be of higher intensity, due to the increase in forest biomass resulting from fire suppression activities during much of the 20th century.[2] Increased temperatures are likely to allow forest pests, such as the balsam woolly adelgid, to expand their ranges into higher-latitude or higher-altitude environments from which cold temperatures currently exclude them. Warming will also enable some insects to complete more generations per year. Direct climate stresses, such as drought, can also make forests more susceptible to pest attack.[33] Mono-specific stands common to many forestry practices are particularly vulnerable to outbreaks of pests and diseases.[33] Disturbances may be followed by atypical patterns of succession with early domination by weedy annual plants, exotic species, or fast-growing early successional hardwoods.[45,46]

In light of these impacts of climate change, several questions need to be addressed. Do current forestry management plans adequately encompass the possibility of climate variability and change? How will climate change impact forest productivity overall? What threshold of combined stress can forests withstand? If changes aren't gradual, but occur suddenly, will managers be able to cope/respond? How should national parks -- with their fixed borders and moving ecosystems -- be managed?

Rangelands of the Pacific Northwest are characterized by sagebrush shrub steppe and pinyon-juniper woodlands. Because of the high correlation between rangeland types and climatic zones, future changes in temperature and precipitation are highly likely to result in changes in rangeland boundaries.[29] Rangelands are also characterized by large temperature and precipitation extremes; small changes in variability or in extreme events may have disproportionate effects on rangeland productivity, with precipitation changes considered most important.[25] How will changes in future precipitation and/or temperature variability be magnified in rangeland ecosystem response? Will future changes be bigger than the swings currently observed?

Increased atmospheric CO_2 may result in decreased forage quality by increasing plant C:N ratios.[3] Increased CO_2 could also change the competitive relationships of some range ecosystems in favor of some exotic grasses.[54] Future rangeland boundaries and ecosystem types will also be influenced by wildfires which may increase with increased exotic invasion and/or a drier climate.

Current human activities on rangelands alter the hydrological cycle, plant species abundance and distribution, and soil erosion and may constitute equal or greater changes than those induced by future climate change.[3] How much plasticity is present in the current

system? Will significant adaptive management response be required to maintain rangelands in a productive state?

AQUATIC ECOSYSTEMS

The aquatic and marine ecosystems of the Pacific Northwest are a regional economic, cultural and recreational resource. Many of these ecosystems are currently stressed by historical over-harvesting, pollution, habitat losses, hatchery practices and dams. Climate change is likely to cause increased stress to many of these systems.

In general, freshwater fisheries (especially in small rivers and lakes) are expected to be most vulnerable to climate change. Estuarine fisheries, particularly those impacted by sea level rise and decreased river flow, will be next most sensitive. High seas fisheries are expected to be the most robust to climate change.[20]

Climate change impacts to freshwater ecosystems will primarily result from hydrological changes. The decreases in summer and fall runoff and the increased failure to meet minimum instream flow requirements that are predicted for controlled west-side rivers as a result of the MPI climate scenario* could negatively affect salmon migration and spawning. The predicted increases in flooding and wintertime runoff would alter sedimentation patterns, possibly harming fish habitat and decreasing egg-smolt survival.[12] High flows could also increase egg mortality. Changes in river flow patterns will affect smolt out-migration and survival[12], but the specific impact is difficult to predict. Climate change will also impact freshwater lakes by altering connectivity with other bodies of water, changing mixing regimes and therefore impacting dissolved oxygen content.[20]

Increased temperature in freshwater bodies will affect the survival, reproductive capacity and growth of fish. It may result in increased mortality via increases in disease, predation and the energetic demand of migration.[20] Warming is expected to result in a general northward shift of freshwater species.[29] Those populations currently living at the extremes of their ranges are most susceptible to change. Temperature increases have been shown to alter the timing of migratory return in anadromous species that can adapt to altered river temperatures: Columbia River shad return currently occurs 38 days earlier than in 1938, in response to the earlier spring warming of the river.[48]

A modeling study examining the implications of a (2°C) warmer and (35%) drier climate for salmonids in the Columbia River Basin[42] suggested that steelhead, which can tolerate warmer temperatures and intermittent stream conditions, and lower-basin fall chinook and coho could benefit from the changes in streamflows and temperatures associated with such a climate change. On the other hand, sockeye and spring and summer chinook would be adversely affected, due to warmer lake temperatures (sockeye) and earlier timing of peak river flows (chinook). However, this study may neglect the considerable capacity of fish to maintain core body temperature by finding areas of cool water within the river.[5]

Climate change will also impact estuaries and coastal areas which provide important habitat for outmigrating salmon, spawning grounds for some oceanic species, and feeding, nesting and breeding habitat for various animals and shorebirds. Accelerated sea level rise (discussed in the following section, *Coastal Activities*) is likely to cause permanent loss of habitat as low-lying coastal areas are increasingly squeezed between rising water levels and shoreline development. Coastal areas will also be impacted by any changes in nutrient supply caused by alterations of offshore upwelling processes. Long-term natural climate variability is also known to affect mixing processes in large coastal basins such as Puget Sound, altering nutrient supply.[16] How would projected decreases in freshwater runoff affect the dynamics of Puget Sound? What implications will that have for local fish stocks?

---

* see *Hydrology & Water Resources* and Lettenmaier, *et al.* 1995.

REPRODUCED AT GOVT. EXPENSE

Climate change impacts to oceanic fisheries (and to the oceanic life-phase of anadromous stocks) are difficult to predict, due to considerable uncertainty about the physical changes that climate change will induce in the ocean. GCMs best predict future changes in air temperature, but these changes are not nearly as important to oceanic ecosystems as the larger physical forcing factors of winds, currents and ocean mixing. The results of climate change on physical ocean dynamics, including coastal upwelling rates and mixed layer structure cannot currently be predicted.

In addition, the link between past climate and fisheries production is complicated and difficult to disentangle from impacts caused by human activities. Retrospective studies have provided evidence that climate variability impacts fishery productivity on both the interannual (ENSO) and interdecadal (PDO) time scales. Past climate variations have led to restructuring of oceanic ecosystems, and perhaps alteration of the oceanic carrying capacity for some species.[24,32,50] The PDO regime shift of 1976-77 provides a good example of how a past climate change has significantly altered oceanic ecosystems. Intensification of the Aleutian atmospheric low pressure center resulted in a transition to cooler than average sea surface temperatures in the central North Pacific and warmer than average temperatures along the NE Pacific coastline.[40] This climate shift resulted in dramatic shifts in salmon production regimes throughout the Pacific Ocean; salmon production in Alaska has been at historical highs since the climate shift, while that in the Pacific Northwest has been near historic lows.[40]

Climate change is thought to impact oceanic ecosystems from both the "bottom-up" and the "top-down".[24] Changes in advective processes affect primary and secondary oceanic productivity,[32,50] impacting higher trophic levels through changes in the timing, species mix and distribution of food supply. Stock recruitment will be affected through redistribution, loss, or mortality of eggs and larvae. Temperature changes will also impact fish stocks directly, by impacting fish metabolism rates (especially for larvae and juveniles[24]), reproductive cycles, migratory timing and patterns, and species ranges.[53] Birds and marine mammals will primarily be impacted through changes in food availability and abundance.[24]

If climate change impacts on oceanic ecosystems result in increased mortality for anadromous species, efforts to improve stock survival would need to focus on their freshwater and estuarine environments, areas most closely linked to human control. Are the dynamics of fish survival sufficiently understood to enable intervention? How would such efforts coordinate or collide with efforts to respond to climate change impacts on other dimensions (hydrology/water resources or forestry, for example)? How can predictive capability for evaluating the impacts of climate change on oceanic ecosystems be developed?

COASTAL ACTIVITIES

Climate change will be manifested in an accelerated rate of sea level rise, due to thermal expansion of the oceans and increased melting of glaciers and ice caps. The current best estimate of future sea level rise is 50 cm (20 inches)* by 2100 (with a range of 20-86 cm), which is much larger than the increase of 10-25 cm that occurred during the past century. In the short-term, sea level rise predictions are more certain**: about 7 cm by 2020 and 20 cm by 2050. These predictions are based solely on estimates of human-caused climate changes and they are likely to be underestimated.[56]

---

* To convert centimeters to inches, divide by 2.54.

** Short-term predictions reflect changes already induced to the global climate system and do not depend on projections of future greenhouse gas emissions.

Local sea level change is modified by vertical land movements; where land is subsiding, relative rates of sea level rise will be higher than average, while areas of land uplift will experience smaller changes in sea level. In Washington state, land subsidence makes the South Puget Sound region particularly vulnerable to accelerated sea level rise.[51]

Other potential impacts to the coastal zone include changes in ocean wave characteristics, coastal upwelling dynamics and any alterations in the frequency and intensity of winter storms. The impact of climate change on these processes cannot be accurately predicted at this time.

Anthropogenic processes such as coastline armoring, wetland filling, logging, agriculture, dredging, exotic species introductions and other disturbances have had a far greater impact on the coastal zone than past climate-related impacts. While future climate change is unlikely to supersede these effects, it represents an additional stress to systems already under a great deal of development and population pressure. Accelerated sea level rise is likely to aggravate existing coastal management problems, including erosion and landsliding, flooding of low-lying areas, decrease in wetland areal extent and saltwater intrusion.[11]

Higher sea levels provide a higher base for storm surges, leading to increased flooding potential. Soil saturation may also result from a rise in the groundwater table, limiting water runoff during floods. The higher sea levels that currently occur during winter (vs. summer) and during El Niño (vs. non-El Niño) years may increase current flood risk during those times, but are not necessarily accounted for in current risk assessment.[22] The City of Olympia, WA found that the most serious risk posed to the city by future sea level rise is the potential increase in the frequency and severity of flooding to the port and central downtown areas.[13] What are the risks of incorrectly assessing periodic flood magnitude both now and in the increased flooding regime of the future?

Increased coastal erosion is also likely, both within Puget Sound and on the outer coasts of Washington and Oregon. In interior waters, landslides and bluff failures result from heavy winter rains, which may increase, and from undercutting by extreme tides and storm surges. On the Pacific Coast, severe storms leading to extreme erosion events have often coincided with El Niño events (and its associated higher sea level) during the past several decades.[34] Sandy beaches throughout Oregon and in Southwest Washington are especially vulnerable to erosion. If climate change also results in altered ocean storm dynamics, future coastal patterns of accretion and erosion may substantially change.[35] Current increases in beach erosion rates from Gray's Harbor south to the Columbia River have been linked to the loss of sediment supply from the Columbia River.[47] Erosion has also begun in previously stable or accreting parts of Washington, such as Leadbetter Point and Ocean Shores.[10,47,55] Areas such as these will be particularly vulnerable to climate change-induced increases in coastal erosion.

Sea level rise will also result in inundation of low-lying coastal areas and wetlands. Parts of Highway 101 in Oregon are likely to be flooded and may need to be moved with a 30 cm (1 foot) rise in sea level.[43] Coastal wetlands may be increasingly squeezed between rising seas and existing or planned human developments, resulting in loss of habitat for migratory birds, fish, shellfish and water fowl.

Coastal hardening - protection of shoreline property by bulkhead construction or other armoring - has increased dramatically over the past 20 years. In one study along the Oregon coast, shoreline protection and hardening has been shown to be related to ENSO-related winter storm activity.[43] Such hardening causes habitat loss, loss of shoreline wetland and/or riparian vegetation, loss of migratory corridors, loss of large organic debris and supplies for accreting landforms as well as loss of spawning habitat.[52] Significant institutional barriers currently prevent effective control over the rate of coastal hardening in Washington and Oregon.* As hardening trends continue, and are perhaps accelerated by

* Single-family residential construction and residential shoreline erosion-control structures are exempt from the requirement for a Shoreline Substantial Development permit in Washington state. See also Good, 1994.

REPRODUCED AT GOVT. EXPENSE

relative sea level rise, detrimental changes in physical and biological processes may be expected to occur with increasing frequency. How can the motivation for property protection be balanced by other concerns in the coastal zone? Can the process of coastal management be improved to account for such concerns?

Other impacts of climate change on the coastal zone include increased seawater intrusion into coastal freshwater aquifers, disruption of the operation of coastal storm drains, altered sewage treatment plant outfall hydraulics and increased possibility of groundwater contamination by landfills and underground hazardous waste tanks. Coastal ecosystems may also be altered by water column warming and salinity changes.

AGRICULTURE & GRAZING LANDS

As a whole, US agriculture is not considered vulnerable to climate change. It is at the regional level, rather than in the national aggregate that impacts of changing temperature and precipitation patterns and increased levels of atmospheric CO_2 are likely to be felt.[1]

Higher temperatures may lead to crop heat stress and decreases in yield stability,[18] especially for crops with specific temperature requirements, such as corn, soybeans and wheat which are sensitive to high temperatures during blooming.[18] Changes in day-to-day and year-to-year temperature and precipitation variability (changes which cannot currently be predicted) will also impact crop yields. However, warmer temperatures may benefit Pacific Northwest agriculture by extending the growing season. Double-cropping would become possible for some crops in Eastern Oregon if the growing season lengthened by only 20 days.[43]

Increased temperatures are likely to increase demand for irrigation water.[30,23] This may be a problem in heavily allocated water basins such as the Snake and the Yakima. If climate changes as indicated by the MPI climate scenario, the reliability of the Columbia River Basin system to supply irrigation water demand (given current physical and management constraints) will decrease significantly.* West of the Cascades, increased soil saturation and flooding in low-lying river valleys may negatively impact agriculture there.

Increased levels of atmospheric CO_2 have been found to have a positive effect on crop growth and yields of plants such as wheat and soybeans with a three-carbon (C3) photosynthetic pathway.[49] This effect may counteract negative implications of temperature and precipitation changes,[44] although the amount and sustainability of the benefit depend on temperature and precipitation (both of which will change), as well as crop species, nutrient availability, and soil quality. Increased CO_2 will also benefit growth of C3 weeds. In addition, plants grown in higher levels of CO_2 may have less nutritive content (higher C:N ratio), causing increased feeding by pests such as the soybean looper[38] and/or increased mortality of pest larvae.[21] Temperature increases may expand the ranges of agricultural pests and/or accelerate their life cycles. For example, warming may result in up-valley expansion of orchard pests that are currently confined to lower elevations in fruit-growing regions of eastern Washington.

Livestock production will be affected by changes in grazing and pasture productivity. Some vector-borne livestock diseases may increase, similar to vector-borne human diseases. Increased winter temperatures may decrease the incidence of livestock respiratory disease.[18] Intensively managed livestock systems such as those in North America are thought to have more potential for adaptation than crop systems.[49]

Any attempt to assess the implications of this suite of impacts to regional agriculture must consider multiple system interactions and feedbacks. Will climate change affect optimal planting and harvesting dates? How will farmers and the agricultural infrastructure adapt to limit losses or adjust to take advantage of improved climatic conditions? Will climate changes be gradual enough for farmers and technology to adapt? How will climate-

* see *Hydrology & Water Resources* and Hamlet *et al.*, 1997.

driven changes in the rest of the world impact the Pacific Northwest's export-driven agricultural sector? If climate change increases pest problems, how will farmers respond in light of current pressure to limit chemical usage?

HUMAN HEALTH EFFECTS

Warmer temperatures are known to increase photochemical smog production. The warmer, drier summers predicted for the Pacific Northwest may also result in elevated pollen counts. Because smog build-up and removal over urban areas is determined by weather patterns, urban air pollution could change in the future. Increased air pollution will impact infants and small children as well as all those with preexisting respiratory or cardiac diseases.[39] One study predicts that climate change could increase wintertime mortality in Seattle due to increased incidence of high-risk air masses. This study projects a small decrease in Portland, Oregon. Summertime mortality decreases slightly in Seattle and increases somewhat in Portland.[31]

Climate change could result in an increase in vector-borne diseases. Increased temperatures and/or altered rainfall patterns may allow vectors to expand into higher-latitude or higher-altitude environments from which they are currently excluded. Warming could also enable some insects to complete more generations per year, increasing the potential for outbreaks.[29,57] How will climate change affect vector populations in this area? Will the relatively rare vector-borne diseases of arthropod-borne encephalitis, Yersiniosis, hantavirus or lyme disease increase in the Pacific Northwest? Infectious and vector-borne diseases (such as malaria, cholera and dengue fever) are highly likely to increase throughout the tropics and into the southern US.[57] How will the Pacific Northwest be impacted by disease transmission via travelers from other parts of the world?

Climate change may also result in water-borne health problems. Sea level rise may cause contamination of drinking water by salt-water intrusion. This is already a problem in parts of the region and one of the City of Olympia's concerns with respect to sea level rise.[13] Increasing water tables may also cause increased contamination from underground hazardous materials storage tanks.[11] Leakages from onsite sewage disposal systems are a widespread problem that has led to closing of shellfish beds throughout Puget Sound and in Willapa Bay.[11] Warmer temperatures may also result in an increase in freshwater cyanobacteria in open calm expanses such as lakes or reservoirs.[17] If sea surface temperatures increase, an increase in the frequency of paralytic shellfish poisoning events is possible; exceptional PSP outbreaks on the Washington coast seem to be correlated with higher than average sea surface temperatures.[19] Decreased stream-flow in smaller rivers may result in inadequate dilution on instream wastes.

How will new seasonal patterns of temperature and precipitation affect diseases such as influenza that seem to be related to current climate patterns? How will warmer temperatures affect patterns of emerging infectious disease? Will the public health infrastructure be prepared to address these risks?

ENERGY PRODUCTION & UTILIZATION

Increased regional temperatures would decrease energy demand for winter space heating, but increase the demand for summer cooling. The net demand shift is difficult to predict. One study suggested that the annual heating and cooling load in commercial buildings in Seattle might increase by one-third as a result of the climate change associated with a doubling of atmospheric CO_2 (expected to occur during the second half of the 20th century), but the single family home heating and cooling load could decrease by more than one-fourth.[43] Will population growth overwhelm climate change related demand shifts?

REPRODUCED AT GOVT EXPENSE

Transportation uses constitute another major component of energy consumption in the Pacific Northwest, as in the US as a whole. Direct climate change impacts to the transportation sector are likely to be small in this region.

The Pacific Northwest is highly dependent on hydropower (hydropower provides ~70% of the region's electricity[43]). Hydropower production is highly dependent on climate. If climate changes as projected by the MPI climate scenario, the reliability of meeting current firm and non-firm energy production requirements in the Columbia River system would decrease significantly (see *Hydrology & Water Resources*). The reliability of producing firm energy requirements would decrease from 96% to 89% in 2020 and 69% in 2050. Non-firm energy reliability would decrease from 65% to 88% in 2020 and 81% in 2050. If the MPI scenario were to occur, there probably would be a need for additional power sources to supplement hydropower.

The effect of climate change on regional energy production besides hydropower is likely to be indirect. Coal-fired power plants may be increasingly affected by future regulations of CO_2, SO_2 and/or N_2O emissions. Thermal generating plants and combustion turbines operate less efficiently in warm weather and the former may require larger amounts of water for cooling.[43] Increased stream temperatures may decrease cooling efficiency.

Will regional hydropower supply and demand curves become more or less coincident in the future? What happens if summertime electricity loads change significantly during a time when hydro resources are limited? Will a larger proportion of Pacific Northwest power need to be imported from fossil-fuel burning power plants in other regions? How would increased temperatures affect electricity transmission line losses?

URBAN CENTERS

A consideration of the vulnerability of urban centers to climate change combines many of the potential impacts discussed in the preceding seven sections. Urban issues of population growth, economic health, water and energy supply and demand, waste disposal, public health and environmental conditions may all be impacted by climate change.

Population growth and economic health depend to some degree on the surrounding environment, either directly (via resource extraction or agricultural productivity, for example) or indirectly (quality of life). How will climate change impact Pacific Northwest cities' dependence on the productivity of their surrounding areas? How will the Pacific Northwest be impacted by migration to or from other parts of the country? How will economic changes wrought by climate change in the rest of the world affect the economy of the Pacific Northwest?

Climate change adds uncertainty to the process of planning for future energy and water demand. While the studies cited here found that municipal water supply is not likely to be adversely affected by the changes implied by the MPI climate scenario, the amount and timing of electricity supplied by hydropower is likely to change.* How can these factors be incorporated into future planning?

Wetter winters may contribute to increased flooding or landslides. What are the implications for floodplain development policies or local zoning ordinances? Could increased winter rains overwhelm some storm sewerage capacity? In Olympia, Washington, the water table is currently about a foot below the surface during the wet winter months.[13] How would higher water levels impact structural stability of pavements and building foundations? How will coastal cities deal with accelerated sea level rise and increased wintertime precipitation?

What changes will be required to the public health infrastructure to deal with climate change? Will the overall costs and concerns of climate change to cities be minor compared

* see *Hydrology & Water Resources* and Hamlet *et al.*, 1997

to continued population growth? Or will the combination of several climate-related impacts create a significant concern? Can urban planning be expanded to include the uncertainty introduced by future climate change?

TOWARDS AN INTEGRATED ASSESSMENT

This paper has discussed the ways in which eight dimensions of the Pacific Northwest, in turn, are vulnerable to climate change. A thorough evaluation of the vulnerability of each dimension would include an evaluation of how the eight dimensions interact. Where will climate change act to limit the supply or threaten the reliability of a resource on which several dimensions depend? What are the connections between the different dimensions, the linkages through which climate change-related impacts to one are felt in another? Will existing stresses and feedbacks between dependent or related systems combine to produce unpredictable responses to the additional forcing caused by climate change?

It is becoming evident that climate change will be manifested most directly in the Pacific Northwest through changes to the region's hydrologic cycle. Changes in water availability and in the timing of supply will impact all aspects of the region: forests, fisheries, coastal ecosystems, agriculture, human health, energy supply and urban centers. Thus water provides us with a framework for constructing an assessment of the impacts of global climate change on the Pacific Northwest.

The ultimate goal of a regional assessment is a simultaneous evaluation of the various vulnerabilities of a region, with an understanding of their associated linkages and feedbacks. It also requires an understanding of the opportunities provided by climate change. This report represents the first step in that direction. Until a regional assessment is complete, it will be important to expand our planning capabilities and management thinking to incorporate the risk and uncertainty added by future climate change into Pacific Northwest decision making and planning processes.

REPRODUCED AT GOVT EXPENSE

REFERENCES

(1) Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Ritchie, B.A. McCarl, J.D. Glyer, R.B. Curry, J.W. Jones, K.J. Boote, L.H. Allen, Jr., 1990. Global climate change and US agriculture. *Nature*, 345: 219-224.

(2) Agee, J.K., 1990. The historical role of fire in Pacific Northwest forests. In: Natural and Prescribed Fire in Pacific Northwest Forests; J.D. Walstad, S.R. Radosevich, and D.V. Sandberg, eds. Oregon State University Press: Corvallis, OR, pp. 25-38.

(3) Allen-Diaz, B., F.S. Chapin, S. Diaz, M. Howden, J. Puigdefabregas, M. Stafford Smith, 1995. Rangelands in a Changing Climate: Impacts, Adaptations, and Mitigation. Chapter 2 in: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Intergovernmental Panel on Climate Change (IPCC), R.T. Watson, M.C. Zinyowera, R.M. Moss, eds. Cambridge University Press: New York, pp. 95-130.

(4) Bazzaz, F.A., S.L. Bassow, G.M. Berntson, and S.C. Thomas, 1996. Elevated CO_2 and terrestrial vegetation: implications for and beyond the global carbon budget. In: Global Change and Terrestrial Ecosystems; B. Walker and W. Steffen, eds. Cambridge University Press, Cambridge, pp. 43-76.

(5) Berman, C.H. and T.P. Quinn, Behavioural thermoregulation and homing by spring chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. *Journal of Fish Biology*, 39:301-312.

(6) Bonneville Power Administration, US Army Corps of Engineers, and Bureau of Reclamation, 1990. *The Columbia River, A System Under Stress*. Portland, OR.

(7) Bonneville Power Administration, Bureau of Reclamation and US Army Corps of Engineers, 1995. *Columbia River System Operation Review: Final environmental impact statement*. US Department of Energy Report #DOE/EIS-0170.

(8) Broecker, W.S., 1987. Unpleasant surprises in the greenhouse? *Nature*, 328:123-126.

(9) Brubaker, L.B., 1986. Responses of tree populations to climatic change. *Vegetatio*, 67:119.

(10) Burch, T.L. and C.R. Sherwood, 1992. "Historical Bathymetric Changes Near the Entrance of Grays Harbor, Washington." Report #PNL-8414: Battelle Marine Science Laboratory.

(11) Canning, D.J., 1991. "Sea level rise in Washington state: State-of-the-knowledge, impacts, and potential policy issues." (Version 2.1) Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia.

(12) Chatters, J.C., D.A. Neitzel, M.J. Scott and S.A. Shankle, 1991. Potential impacts of global climate change on Pacific Northwest spring chinook salmon (*Oncorhynchus tshawytscha*): An exploratory case study. *NW Environmental Journal*, 7:71-92.

(13) Craig, D., 1993. "Preliminary Assessment of Sea Level Rise in Olympia, Washington: Technical and Policy Implications." Policy and Program Development Division, Olympia, Public Works Department, Olympia, WA.

(14) Cubasch, U., K. Hasselmann, H. Höck, E. Maier-Reimer, U. Mikolajewicz, B.D. Santer and R. Sausen, 1992. Time-dependent greenhouse warming computations with a coupled ocean-atmosphere model. *Climate Dynamics*, 9:55-69.

(15) Davis, M.B., 1989. Lags in vegetation response to global warming. *Climatic Change*, 15: 75-82.

(16) Ebbesmeyer, C. C., C. A. Coomes, J. M. Cox, G. A. Cannon, and D.E. Bretschneider. 1988. Decade-long regimes of a fjord basin's oceanography, hydrology, and climatology: Puget Sound, 1916-1987. In: Proceedings of the First Annual Meeting on Puget Sound Research, March 18-19, 1988, Seattle, Washington.

(17) Elder, G.H., P.R. Hunter, G.A. Codd, 1993. Hazardous freshwater cyanobacteria (blue-green algae). *The Lancet*, 341:1519-1520.

(18) EPA, 1989. *The Potential Effects of Global Climate Change on the United States; Appendix C: Agriculture*. US Environmental Protection Agency, Office of Policy Planning and Evaluation, Washington, DC. Document # EPA230-05-89-050.

(19) Erickson, G. and L. Nishitani, 1985. The possible relationship of El Niño/Southern Oscillation events to interannual variation in *Gonyaulax* populations as shown by records of shellfish toxicity. In: *El Niño North: Niño Effects in the Eastern Subarctic Pacific Ocean*; W.S.Wooster and D.L. Fluharty, eds. Washington Sea Grant Program: Seattle.

(20) Everett, J.T., 1995. Fisheries. Chapter 16 in: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Intergovernmental Panel on Climate Change (IPCC), R.T. Watson, M.C. Zinyowera, R.M. Moss, eds. Cambridge University Press: New York, pp. 511-537.

(21) Fajer, E.D., M.D. Bowers, F.A. Bazzaz, 1989. The effects of enriched carbon dioxide atmospheres on plant-insect herbivore interactions. *Science*, 243:1198-1200.

(22) Field, J. and M.Hershman, 1997. "Assessing coastal zone sensitivity and vulnerability to regional climate variability and change in the Pacific Northwest." Year Two Draft Progress Report for JISAO Climate Variability, Impacts, and Response Strategies Group.

(23) Fleagle, R.G., 1991. Policy implications of global warming for the Northwest. *NW Environmental Journal*, 7:329-344.

(24) Francis, R.C., S.R. Hare, A.B. Hollowed and W.S. Wooster, 1997. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific,*Journal of Climate*. In press.

(25) Franklin, J.F., F.J. Swanson, M.E. Harmon, D.A. Perry, T.A. Spies, V.H. Dale, A. McKee, W.L. Ferrell, J.E. Means, S.V. Gregory, J.D. Lattin, T.D. Schowalter, and D. Larsen, 1991. Effects of global climatic change on forests in northwestern North America. *NW Environmental Journal*, 7:233-254.

(26) Good, J.W. 1994. Shore protection policy and practices in Oregon: An evaluation of implementation success. *Coastal Management*, 22:325-352.

(27) Hamlet, A., D.P. Lettenmaier, and B. Nijssen, 1997. "Effects of climate shift on water resources objectives in the Columbia Basin." JISAO Climate Variability, Impacts, and Response Strategies Group Report. [Included in packet of background materials for the July Pacific Northwest Regional Climate Change Workshop.]

(28) Intergovernmental Panel on Climate Change (IPCC), 1995. *Climate Change 1995: The science of climate change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change* . J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell, eds., Cambridge University Press: New York.

(29) -----, 1995. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses: Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. R.T.

REPRODUCED AT GOV'T EXPENSE

Watson, M.C. Zinyowera, R.M. Moss, eds. Cambridge University Press: New York.

(30) Kaczmarek, Z., 1995. Water Resources Management. Chapter 14 in: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Intergovernmental Panel on Climate Change (IPCC), R.T. Watson, M.C. Zinyowera, R.M. Moss, eds. Cambridge University Press: New York, pp. 469-485.

(31) Kalkstein, L.S. and J.S. Greene, 1997. An evaluation of climate/mortality relationships in large US cities and the possible impacts of a climate change. *Environmental Health Perspectives*, 105:84-93.

(32) Karl , D.M., R. Letelier, D. Heďel, L. Tupas, J. Dore, J. Christian & C. Winn, 1995. Ecosystem changes in the North Pacific subtropical gyre attributed to the 1991-92 El Niño. *Nature*, 373:230-234.

(33) Kirschbaum, M.U.F. and A. Fischlin, 1995. Climate Change Impacts on Forests. Chapter 1 in: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Intergovernmental Panel on Climate Change (IPCC), R.T. Watson, M.C. Zinyowera, R.M. Moss, eds. Cambridge University Press: New York, pp. 95-129.

(34) Komar, P.D. and D.B. Enfield, 1987. Short-term sea-level changes and coastal erosion. In: Sea-level fluctuation and coastal evolution; D. Nummedal, O.H. Pilkey, and J.D. Howard, eds. The Society of Economic Paleontologists and Mineralologists, Special Publication 41, pp. 17-27.

(35) Komar, P.D. and J.W. Good. 1989. Long term erosion impacts of the 1982-83 El Niño on the Oregon Coast. *Coastal Zone '89* (ASCE):3785-3794.

(36) Lettenmaier, D.P., S.M. Fisher, R.N. Palmer, S.P. Millard, J.P. Hughes & J.C. Sias, 1995. "Water Management Implications of Global Warming: 2. The Tacoma Water Supply System," Report to the US Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, VA, December.

(37) Lettenmaier, D.P., D. Ford, S.M. Fisher, J.P. Hughes & B. Nijssen, 1996. "Water Management Implications of Global Warming: 4. The Columbia River Basin." Report to the US Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, VA. March.

(38) Lincoln, D.E., D. Couvet, and N. Sionit, 1986. Response of an insect herbivore to host plants grown in carbon dioxide enriched atmospheres. *Oecologia*, 69: 556-560.

(39) Longstreth, J., 1991. Anticipated public health consequences of global climate change. *Environmental Health Perspectives*, 96:139-144.

(40) Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society*, 78:1069-1079.

(41) National Marine Fisheries Service (NMFS), 1995. Biological Opinion: Reinitiation of Consultation on 1994-1998 Operation of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years. Endangered Species Act, Section 7 Consultation. NMFS, Northwest Region. March 2, 1995.

(42) Neitzel, D.A., M.J. Scott, S.A. Shankle and J.C. Chatters, 1991. The effect of climate change on stream environments: The salmonid resource of the Columbia River Basin. *NW Environmental Journal*, 7:271-293.

(43) Oregon Task Force on Global Warming Report to the Governor and Legislature, 1990. Part One: Possible Impacts on Oregon from Global Warming, Oregon Department of Energy.

(44) Parry, M.L. and Rosenzweig, C., 1993. Food supply and risk of hunger. *The Lancet*, 342:1345-1347.

(45) Perry, D.A., J.G. Borchers, D.P. Turner, S.V. Gregory, C.R. Perry, R.K. Dixon, S.C. Hart, B. Kauffman, R.P. Neilson, & P. Sollins, 1991. Biological feedbacks to climate change: Terrestrial ecosystems as sinks and sources of carbon and nitrogen. *NW Environmental Journal*. 7:203-232.

(46) Peterson, D.L., E.G. Schreiner, and N.M. Buckingham, 1997. Gradients, vegetation, and climate: Spatial and temporal dynamics in the Olympic Mountains, USA. *Global Ecology and Biogeography Letters*. In press.

(47) Phipps, J.B., 1990. "Coastal Accretion and Erosion in Southwest Washington: 1977-1987." Washington Department of Ecology. Report #90-21.

(48) Quinn, T. P. and D.J. Adams, 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. *Ecology*, 77:1151-1162.

(49) Reilly, J., 1995. Agriculture in a Changing Climate: Impacts and Adaptation. Chapter 13 in: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Intergovernmental Panel on Climate Change (IPCC), R.T. Watson, M.C. Zinyowera, R.M. Moss, eds. Cambridge University Press: New York, pp. 427-467.

(50) Roemmich, D. and J. McGowan, 1995. Climatic warming and the decline of zooplankton in the California Current., *Science*, 267:1324-1326.

(51) Shipman, H., 1989. "Vertical Land Movements in Coastal Washington: Implications for relative sea level changes." Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia. Report #PV-11.

(52) Shreffler, D.K., R.M. Thom, and K.B. Macdonald, 1995. Shoreline armoring effects on biological resources and coastal ecology in Puget Sound. Puget Sound Research 1995 Proceedings. Puget Sound Water Quality Authority: Olympia.

(53) Sibley, T.H. and R.M. Strickland, 1985. Fisheries: Some relationships to climate change and marine environmental factors. Chapter 5 in: *Characterization of information requirements for studies of CO_2 effects: water resources, agriculture, fisheries, forests and human health*; M.R. White, ed. US Department of Energy Report DOE/ER-0236.

(54) Smith, S.D., B.R. Strain and T.D. Sharkey, 1987. Effects of CO_2 enrichment of four Great Basin Grasses. *Functional Ecology*, 1:139-143.

(55) Terich, T. And T. Levenseller, 1986. The severe erosion of Cape Shoalwater, Washington. *Journal of Coastal Research*, 2(4):465-477.

(56) Warrick, R.A., C. Le Provost, M.F. Meier, J. Oerlemans, P.L. Woodworth, 1995. Changes in Sea Level. Chapter 7 in: *Climate Change 1995: The science of climate change* . Intergovernmental Panel on Climate Change (IPCC), J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell, eds., Cambridge University Press: New York, pp. 359-405.

(57) World Health Organization Task Group, 1990. *Potential health effects of climatic change*. Geneva: World Health Organization.

REPRODUCED AT GOVT. EXPENSE

ALASKA

*** DRAFT ***

INFRASTRUCTURE:

EFFECTS OF CLIMATIC WARMING ON PLANNING, CONSTRUCTION AND MAINTENANCE

T. E. Osterkamp[1], D. C. Esch[2] and V. E. Romanovsky[1]

1.Geophysical Institute
University of Alaska
Fairbanks, AK 99775-7320
2. PO Box 4411
Palmer, AK 99645-4411

July, 1997

One of five final papers

REPRODUCED AT GOVT. EXPENSE

Introduction

Infrastructure consists of the basic installations and facilities on which individuals, families, communities and governments depend for their continuance and growth. In a broad sense, these systems include providing for food (including subsistence activities), water, waste disposal, transportation, communication, education, health and medicine, power, and goods and services for society. Disruption of these systems, including increased costs as a result of climatic warming, would have negative impacts on individuals and directly influence social, economic and political functions.

Approximately eighty per cent of Alaska is underlain by permafrost which is the foundation on which the infrastructure and ecosystems rest. Much of this permafrost is warm and ice-rich and some of it is currently thawing (Osterkamp, 1994; Osterkamp and Romanovsky, 1997). If the current climatic warming continues, additional ice-rich permafrost will thaw creating thermokarst terrain. This is an uneven surface topography consisting of pits, troughs, mounds, and depressions (which may be filled with water) that forms as a result of thawing large volumes of underground ice. Thermokarst terrain severely impacts human and animal activities and can damage or even destroy the infrastructure and ecosystems that rely on the permafrost for a foundation (Osterkamp, 1982, 1994).

The ice in ice-rich permafrost occurs primarily in the top 10 to 15 m of permafrost. Since permafrost thaws slowly from the top downward in response to warming at its surface (sparse data indicates values <0.2 m yr^{-1}; Osterkamp and Romanovsky, 1997), the problems caused by thermokarst terrain will be long-term. They would begin at the time that thawing starts and can be expected to last for a century or more. The amount of vertical settling produced by thawing ice-rich permafrost depends on the amount of ice in the permafrost. In Interior Alaska, maximum values for subsidence of the ground surface because of thawing ice-rich permafrost are in the range from 5 to 10 m (Osterkamp et al.1997).

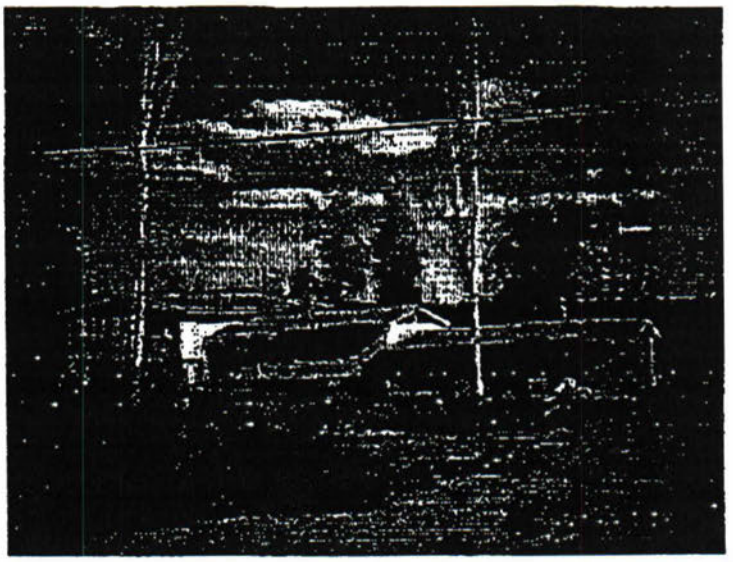


Figure 1. This house damaged by thermokarst in the Fairbanks had to be abandoned.

Placeholder

Figure 2. Thawing of ice-rich permafrost and the resulting thermokarst caused this road to settle which required repeated patching to keep the road in service.

The past is replete with examples of the effects of ice-rich permafrost on human activities and ecosystems (Pewe, 1982; Osterkamp, 1982, 1994; Osterkamp et al., 1997). These include:

1. Abandoned and damaged houses in Alaskan communities (Fig. 1).
2. Abandoned building at a radio transmitter site near Fairbanks.

REPRODUCED AT GOVT. EXPENSE

Placeholder

Figure 3: Trans-Alaska pipeline showing the above ground portion of the pipe supported by naturally refrigerated pilings. This expensive construction mode was required because of the presence of ice-rich permafrost which had to be kept frozen.

3. Abandoned hospital in Kotzebue.
4. Abandoned and damaged roads and bridges (Fig. 2).
5. Specialized and more expensive con struction methods for roads, airports, pipelines and other structures (Fig. 3).
6. High maintenance costs for roads, buildings and airports.
7. Shortened lifetimes for roads and airports requiring short reconstruction cycles.

8. Relocation of roads and airports caused by the presence of ice-rich permafrost and other related factors such as land slides.
9. Thermokarst damage to agricultural fields.
10. Increased sediment loads and siltation in rivers (Fig. 4).
11. Destruction of trees in the boreal forest (Fig. 5).
12. Ecosystem damage and destruction such as that occurring in the Tanana Flats, Mentasta, Healy and Cantwell areas (Fig. 5).

Figure 4. This river bank in ice-rich permafrost has been undercut a distance of several meters. The bank will eventually collapse putting trees, shrubs, organic material and large volumes of silt into the river increasing the sedimentation problem.

These impacts are a direct result of thawing ice-rich permafrost, subsequent settlement of the ground surface and creation of thermokarst terrain. Individuals have most often abandoned or moved houses and cabins when the effects of thaw settlement made them unusable. In a few cases, innovative designs were developed to retard or reverse the thawing which allowed continued use of the structures.

Much of the public infrastructure in Alaska has been placed under the Alaska Department of Transportation and Public Facilities (DOTPF) which is responsible for design, construction and maintenance of most roads, airports and many public buildings. Local government, federal agencies and industry are also responsible for design, construction and maintenance of the infrastructure. In 1990, in a cost-cutting move, the Alaskan legislature dissolved the DOTPF research laboratory which was involved in geotechnical research on permafrost. This may have led to the failure of remediation schemes used in recent road reconstruction efforts over ice-rich permafrost. Current and future projects where thermokarst degradation has occurred or is expected to occur include:

REPRODUCED AT GOVT. EXPENSE

1. Chena Hot Springs Road near Fairbanks which is being reconstructed because of thermokarst damage to the roadway. However, no special precautions are being taken to mitigate thermokarst problems. Pavement failures are expected soon after construction.

2. The Deadhorse Airport runway and taxiway are being reconstructed because of settlement due to thawing permafrost. That permafrost has warmed about 4 °C during the last decade.

3. The recently proposed route for a road or railroad into Kantisha is over warm ice-rich permafrost and some of that permafrost is currently thawing (Osterkamp, 1994).

Figure 5: Examples of how existing ecosystems have been destroyed and are being replaced by new ecosystems as permafrost thaws: a) Active thermokarst that is altering the boreal forest near Tok, Alaska, in an area of warm, discontinuous permafrost; b) Active thermokarst in an area of continuous permafrost on the Gydan Peninsula, Russia; c) An active thermokarst that has resulted in a pond. More than 5 m of vertical settling occurred. Note the dead trees in the water and tilted trees on the island, indicating that settling is still in progress (photos by Tom Osterkamp).

REPRODUCED AT GOVT. EXPENSE

Thermokarst reduces the useful lifetime of highways and airports and many highway and runway sections on permafrost must be releveled and repaved on a 6 to 8 year cycle. It is sometimes necessary to shorten airport runways due to a lack of funds for pavement repair which necessitates the use of smaller and more expensive aircraft. Some airports and road sections have been abandoned because of thermokarst problems.

It appears that engineers have few solutions to thermokarst problems. The policies of the DOTPF and other state entities and federal agencies have resulted in large maintenance costs for Alaska and direct public impacts. Apparently, there are no studies evaluating these policies.

Current Pressures and Anticipated Pressures

Bases for concern

While global and climatic changes are ongoing processes in the earth system, scientists have several reasons for concern. Global climate has warmed since the mid to late 1800s (Hansen and Lebedev, 1987). In the circumpolar Arctic, permafrost has generally warmed, particularly in Russia, China, Alaska, and western Canada. In Alaska, the continuous permafrost warmed 2 to 4 °C over the last century (Lachenbruch and Marshall, 1986). Indications are that the discontinuous permafrost also warmed during this time period (Osterkamp and Romanovsky, 1997). Climate and permafrost in

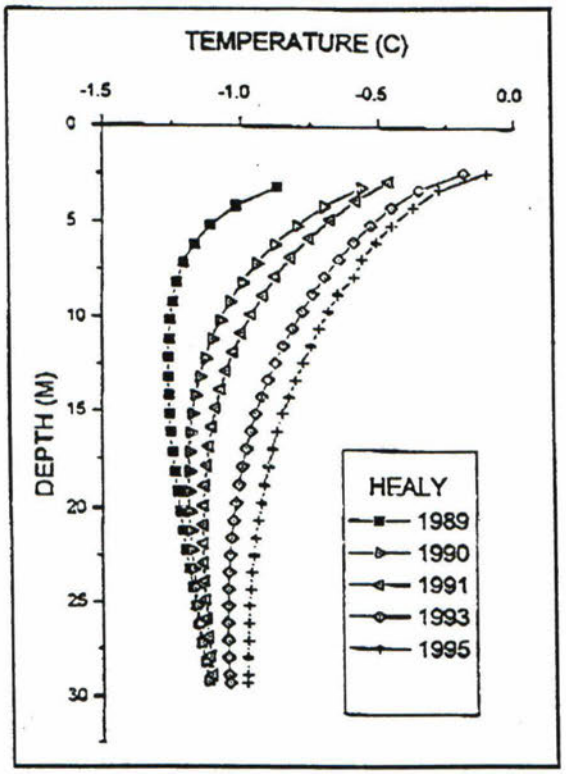


Figure 6. Temperature profiles in permafrost at a site near Healy, Alaska showing the warming of the permafrost that has occurred since 1989. Thermokarst has developed in this area in response to the warming.

REPRODUCED AT GOVT. EXPENSE

many areas of the circumpolar Arctic continue to warm particularly in Alaska and parts of Eastern Russia in the Bering Sea region (Fig.6).

All of our permafrost research sites along a North-South transect from Prudhoe Bay to Glennallen warmed between the mid to late 1980s and 1996 (Osterkamp and Romanovsky, 1996,1997). In the continuous permafrost region, the warming ranges up to 4 °C in the active layer and at the top of the permafrost. In the discontinuous permafrost region, the warming is typically between 1 and 2 °C. At some of the sites, permafrost is presently thawing at both the top and bottom.

Thawing of ice-rich permafrost has been identified as the primary problem for infrastructures. Continued warming will cause additional permafrost to thaw. The effects of thawing ice-rich permafrost in response to climatic change will be superimposed on the effects associated with the infrastructure. Current climate scenarios predict 5 °C additional warming in the next half century for northern regions. These results are causing considerable concern about the future of permafrost in Alaska and the impacts associated with warming and thawing of the permafrost.

Potential impacts

An expected climate scenario for the Bering Sea region has been outlined by Weller et al. (1995) which indicates about a 5 °C warming with the winter warming larger than the summer warming and with more precipitation in both the summer and winter. Air temperatures and depth of the snow cover influence permafrost temperatures. If the depth of the snow cover increases with no change in air temperatures then permafrost will warm. If there is an increase in air temperatures as well as depth of the snow cover then the effects of this climatic change will be magnified over that of an increase in air temperatures only.

Impacts of Permafrost

The impacts of a climatic warming of this magnitude (5 °C) will differ considerably for the continuous and discontinuous permafrost zones of the earth. A central paradigm of current research is that thawing permafrost will result in the release of carbon deposits frozen in the permafrost and that these deposits will lead to increased fluxes of trace gases to the atmosphere creating a positive

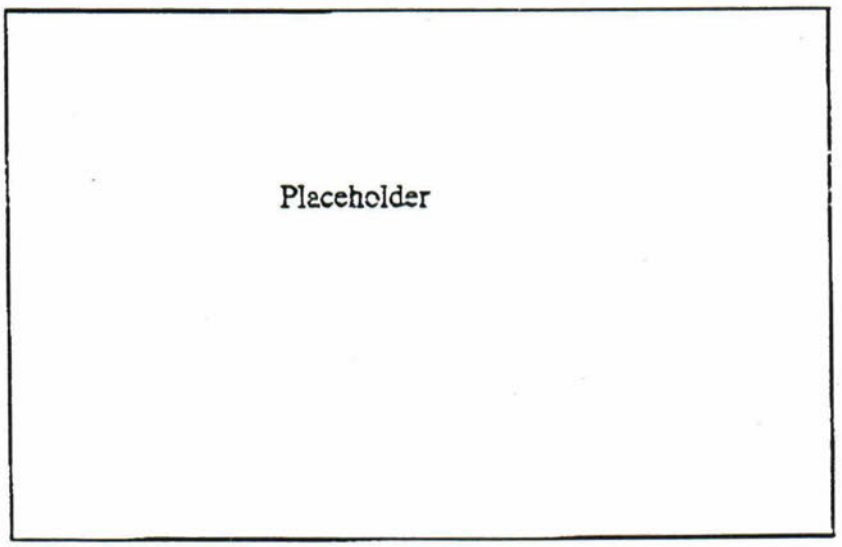


Figure 7. Figure 7. Schematic diagram showing relationships between climate, soil and permafrost, biota and human activities.

REPRODUCED AT GOVT EXPENSE

feedback loop. Figure 7 is a schematic showing some of the relationships between climate, soil and permafrost, biota and human activities.

1. Continuous permafrost

Some of the continuous permafrost has warmed almost continuously since the mid-1980s. However, mean surface temperatures are still typically colder than -5 °C so that only warming of the permafrost is expected with no widespread thawing anticipated except that which will be associated with localized sites such as south facing slopes, with possible thickening of the active layer and with two-dimensional heat flow effects as in the banks of rivers and lakes. Increases in the depth of the snow cover would lead to a greater warming of the permafrost than indicated by a warming of air temperatures alone.

Thaw lakes, eolian activity, vegetation, and coastal, geomorphic and hydrologic processes in this region may be sensitive to climatic warming (Brown and Andrews, 1982). If the active layer thickens by thawing of the near-surface permafrost, this will result in the release of carbon currently stored (frozen) in the permafrost leading to enhanced production of carbon dioxide and methane gases. Where the permafrost is ice-rich, this thawing will produce subsidence of the ground surface resulting in thermokarst terrain commensurate with its ice contents and thickness of the new active layer. This thermokarst would result in some damage to the ecosystem.

2. Discontinuous permafrost

Permafrost temperatures south of the Yukon River in Alaska and on the south side of the Seward Peninsula are very warm, typically within 2 °C of thawing (Osterkamp, 1994). Data from a north-south transect of Alaska shows that all of the sites south of the Yukon River warmed between 1989 and 1996, a period with unusually heavy snow fall (Osterkamp and Romanovsky, 1997). The warming ranged from > 1/2 °C to about 2 °C at the permafrost table. At some of the sites, permafrost is presently thawing at both the table and base in response to this warming.

If these data can be extrapolated to other areas, then it can be inferred that the discontinuous permafrost south of the Yukon River and on the south side of the Seward Peninsula has recently warmed and that much of it is currently thawing.

The impacts of thawing permafrost on human activities and the physical environment will differ depending on the permafrost ice content.

a. If the permafrost is not ice-rich, warming and thawing of the permafrost will be limited to thermal effects and to the effects of converting the ice to water. Impacts on the infrastructure will be relatively minimal.

b. Where the permafrost contains massive ground ice or is ice-rich, extensive thaw settlement (resulting in thermokarst) is expected. The magnitude of this thaw settlement has been observed to exceed 5 m and to reach 10 m, in some cases, of vertical settling of the ground surface. Induced thaw settlement is presently responsible for damage to houses, roads, airports, military installations, pipelines, and other facilities founded on ice-rich permafrost.

REPRODUCED AT GOVT. EXPENSE

Impacts on the infrastructure

Engineering Concerns in Permafrost Terrain

The surface vegetation (moss) and underlying organic soil are usually destroyed or severely damaged during construction. This vegetation and organic soil insulates the permafrost from the effects of summer warming and its removal causes the permafrost to warm by several degrees and the active layer to become deeper or for a talik (thawed layer) to form. Once a talik forms the permafrost thaws continuously (throughout the year) from the top downward inducing thaw settlement if it is ice-rich. A heated structure on the permafrost will enhance thawing of the permafrost.

Induced thaw settlement is presently responsible for damage to houses, roads, airports, military installations, pipelines, and other facilities founded on ice-rich permafrost. Any natural increase in the MST of permafrost and subsequent thaw settlement would create severe maintenance problems for facilities in Alaska adding to effects already being observed. Some structures, airports and roads might have to be abandoned if funds are not adequate to continue repairs (Esch and Osterkamp, 1990).

The physical and mechanical properties of permafrost are generally temperature dependent and, for warm permafrost (permafrost within one or two degrees of thawing), depend strongly on temperature. Most of the engineering concerns related to a climatic warming can be classified into those related to an increase in permafrost temperatures, those related to increases in the active layer thickness (annual thaw depth), and those related to the degradation of the permafrost.

Engineering concerns related to a general warming of the permafrost result primarily from the decrease in mechanical strength, especially compressive and shear strengths, and the increase in creep rates of frozen ice-rich soils. Ad-freeze bond strengths between permafrost and piles or structures are also strongly temperature dependent. As an example, piling designed for a permafrost temperature of -4 °C will experience a 70% loss in load capacity if the permafrost temperature rises to -1 °C. Because of the presence of unfrozen soil pore water solutions in warm permafrost, the problems may be expected to be even more severe as the temperature of warm permafrost approaches the thawing point. Reliable methods of predicting permafrost temperatures over the life of a facility and information on the physical and, especially, the mechanical properties of warm permafrost are needed to help evaluate these problems.

Systematic increases in the thickness of the active layer may be expected to lead to thaw settlement of underlying ice-rich permafrost. Increased frost heaving during winter and increased frost heave forces on pilings may also be expected when the active layer thickness increases. Better understanding of the processes associated with active layer development are needed to evaluate this problem. The effects of saline soil solutions found in coastal and other areas on freezing and thawing in the active layer need to be understood.

Active layer thicknesses generally depend, among other factors, on the amplitude, timing and duration of temperatures during the thaw season. Therefore, climatic predictions must address changes in seasonal temperatures to be helpful in evaluating active layer problems.

REPRODUCED AT GOVT. EXPENSE

As noted above, continued climatic warming and increases in the depth of the snow cover will eventually cause much of the discontinuous permafrost in Alaska to thaw. Thawing begins with thickening of the active layer and, eventually, a talik (a layer of ground that remains unfrozen throughout the year) develops when the thaw depth exceeds the depth of seasonal freezing. Continued thawing at the permafrost table results in continued thaw settlement in ice-rich permafrost. The effective length of a piling in the permafrost will decrease while the frost heave force on the piling reaches its maximum. Thermokarst terrain, increased downslope soil movement and landslides, and other terrain features common to degrading permafrost may be expected to appear (Osterkamp, 1982). Roads, airfields, railway embankments and other foundations on degrading permafrost may be subject to continuing deformations as a result of the thaw settlement. Accurate predictions of the climate-permafrost response at a regional level are needed to assess the timing, duration, and severity of these problems. New and innovative engineering designs will be required to solve them.

Ecosystems effects

In areas of ice-rich permafrost, thaw settlement and the development of thermokarst will destroy the substrate on which the current ecosystems rest dramatically changing the nature of the ecosystems. It has been observed to result in damage to the ecosystems and sometimes in the total destruction of the ecosystems and their conversion to other types of ecosystems. Most of the following impacts have already been observed and are not speculation.

1. Destruction of trees and reduction in area of boreal forests (Fig. 5 and 6).
2. Expansion of thaw lakes, grasslands and wetlands (Fig. 6).
3. Destruction of habitat for caribou and terrestrial birds and mammals.
4. Increased habitat for aquatic birds and mammals.
5. Increased rates of coastal and riverbank erosion (Fig. 4).
6. Clogging of salmon spawning streams with sediment and debris (Fig. 4).
7. Increased slope instability, landslides, erosion.
8. Talik development with increased depth to water table.

The infrastructure also has some effects on the landscape and biota which may change as a result of climatic warming. For example, small birds are known to migrate along north-south highways. In areas of low hydrologic gradients, the roadbed can dam the surface water flow causing the death of trees and thereby modify the ecosystem on that side of the roadbed.???????????

If the climate does not change from the current condition where air temperatures in Alaska have been warmer for the last twenty years (since 1976) than the previous twenty years and where snow cover has been unusually thick during the last decade (Osterkamp and Romanovsky, 1997), then permafrost will continue to thaw. The data base on permafrost temperatures is too sparse to predict the distribution of this thawing.

Other impacts

Other impacts that were considered included increased snow fall, increased frequency of storm events and increased run-off, glaciers and frost heaving. Increased snow fall would decrease visibility, increase snow removal costs and possibly lead to increased frequency of road and airport closures. Increased run-off from storms, increased precipitation and increased flooding would create problems for bridges and culverts and drainage structures. This would add to the problem of in-

REPRODUCED AT GOVT EXPENSE

creased discharge from glaciers. Wetter soils may lead to increased frost heaving of structures. However, these potential impacts are considered to be of minor importance compared to the major impacts associated with thawing ice-rich permafrost.

Uncertainties

Uncertainties associated with the above potential impacts are primarily related to the predictions of current climatic models, a lack of knowledge of current conditions and a lack of information on the economic impacts of thermokarst on the infrastructure. The spatial scales of current climatic models are too large for use by design engineers who need information on temperature, precipitation and wind at local scales for design purposes. Information on current conditions, particularly climate and permafrost is sparse in Alaska. There are only 2x? primary climate stations in Alaska, an area one xth? the size of the contiguous U. S.. Information on temperatures in permafrost on the Alaskan side of the Bering Sea come from two sites, one at Nome and one at Bethel. The next closest sites are more than 400 miles to the east.

Costs of thawing permafrost do not appear to have been evaluated. These costs appear to be staggering. Some idea can be obtained by considering that the original cost of the Trans-Alaska Pipeline was $900 million dollars for a conventionally built pipeline buried in the ground. The final cost was over $7 billion dollars, an eight-fold increase, largely because of the presence of unavoidable ice-rich permafrost along the route. Another example is a 1 km length of Farmer's Loop Road adjacent to the University of Alaska at Fairbanks built on ice-rich permafrost where in excess of $5 million dollars has been spent on maintenance and reconstruction of the road without solving the problems.

Thermokarst could lead to the abandonment of villages in low-lying areas. Relocation of these villages would be a major economic impact. The DOTPF had to move their maintenance facility at Gardiner Creek because of damage to the buildings by thawing and settling of the ice-rich permafrost.

Direct costs to the public of thawing ice-rich permafrost have also not been evaluated. As noted previously, some homes have been damaged or abandoned because of thermokarst. There are increased costs associated with shorter airport runways. There is clearly lost time and increased wear and tear on vehicles because of rough roadways and it is believed that some lives may have been lost because of rough roadways.

Additional Research Needed

Climate

Thorough analyses of recorded climatic data in the Bering Sea region is needed to assess the timing, magnitude and distribution of recent climatic changes and those during the last century, particularly changes in air temperatures and snow depth. Remote stations that are not influenced by local anthropogenic changes need to be established. Climate models should be verified using data through the mid-1970s and should be capable of predicting the changes that occurred at that time. Improved high resolution climatic models need to be developed to improve climatic change scenarios, to improve predictions of seasonal changes in air temperatures and precipitation and to improve the spatial resolution of the models for engineering design purposes.

REPRODUCED AT GOVT. EXPENSE

Permafrost

Investigations of the current and past state of the permafrost in the Bering Sea region are needed to develop an improved understanding of how permafrost has responded and is responding to changes in climate over the last century. The processes by which permafrost thaws are poorly understood. For example, data on heat and mass flow during talik formation and the creation of thermokarst are almost nonexistent. More information is needed on the distribution of ice-rich permafrost and on the formation of thermokarst since thermokarst is responsible for most of the engineering concerns in permafrost regions.

Engineering

Engineers need to know the state of the permafrost at the project site and what will happen to the permafrost during the life of the project. Information on the properties of warm and thawing permafrost will be needed. At some point, strategy should shift from mitigating the effects of thawing permafrost to that of causing the permafrost to thaw. Methods for pre-construction thawing of the permafrost need to be identified and developed. New and innovative engineering designs for construction on warm and thawing permafrost will be required. Geophysical methods for detection of ground ice and potential thermokarst areas are available (Kawasaki and Osterkamp, 1985). Policies and personnel for their use should be developed within DOTPF.

Policy and Economics

Current policies of the DOTPF and federal and state agencies for construction on permafrost terrain carry associated costs and have a direct impact on the public. These policies, costs and impacts need to be identified and documented. For example, case studies of pipeline, road and airport design, construction, repair and reconstruction are needed to define the costs and impacts of policies during a climate warming scenario and to identify new policies that would reduce these costs and impacts.

Mitigation and Adaptation Measures

Research is needed to identify the problems, impacts and costs of a climatic warming associated with maintaining the public infrastructure and develop ways and means to mitigate the negative effects of a climatic warming.

Programs are needed to inform the public, develop an awareness of the potential problems and provide aid in identifying problems and solutions not only in the major population centers but also in the many villages in rural Alaska.

State and federal agencies should identify areas, sites and facilities that may be subject to the negative impacts of climatic change. These should also be rated according to the severity of the impacts expected for them.

Changes in current policy of the DOTPF and federal government could help to mitigate the effects of thawing ice-rich permafrost. For example, purchase of the necessary land and easements for a construction site or route selection is currently done just prior to the construction project. This

REPRODUCED AT GOVT. EXPENSE

policy does not allow sufficient time to carry out inexpensive mitigation measures prior to construction. One method would be to strip the vegetation and organic soil at the ground surface five years or more prior to construction to let the permafrost thaw naturally. Installation of a gravel pad or roadbed for summer use could be done during this period. This method would allow the location of the ice-rich permafrost to be determined and the top several meters to thaw naturally.

Acknowledgments

This paper was prepared with funding from the Center for Global Change and Arctic System Research, University of Alaska. It is based on research funded by the State of Alaska, National Science Foundation (Office of Polar Programs, Arctic Natural Sciences Program) and by the Department of Energy (National Institute for Global Environmental Change, Western Regional Center, Univ. of California, Davis, CA).

References

Brown, J., and J. T. Andrews, Influence of short-term climatic fluctuations on permafrost terrain, in DOE/EV/10019-02, v. 2, pt. 3, Dept. of Energy, Washington, D.C., 1982.

Esch, D. C., and T.E. Osterkamp, Cold regions engineering: Climatic warming concerns for Alaska, *J. Cold Regions Eng., 4*(1), 6-14, 1990.

Hansen, J., and S. Lebedev, Global trends of measured air temperature, J. of Geophys. Res., 92(D11),13345-13372, 1987.

Kawasaki, K., and Osterkamp, T. E., Electromagnetic induction methods in permafrost terrain for detecting ground ice and ice-rich soils, UAG R-300, Geophysical Institute, Univ. of Alaska, Fairbanks, AK, 195 pp., 1985.

Lachenbruch, A. H., and B. V. Marshall, Changing climate—Geothermal evidence from permafrost in the Alaskan Arctic, Science, 234, 689-696, 1986.

Osterkamp, T. E. (1982). Potential impact of a warmer climate on permafrost in Alaska. In *Proceedings of a Conference on the Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska*, April, 1982, Misc. Pub. 83-1, SALRM, University of Alaska, Fairbanks, AK.

Osterkamp, T.E., Evidence for warming and thawing of discontinuous permafrost in Alaska, EOS Trans. Am. Geophys. Union, 75(44), 85, 1994.

Osterkamp, T.E. and V.E. Romanovsky, Impacts of thawing permafrost as a result of climatic warming, *EOS, Trans. AGU, 77(46)*, F188, 1996.

Osterkamp, T. E., and V. E. Romanovsky, Evidence for warming and thawing of discontinuous permafrost in Alaska, in preparation, 1997.

REPRODUCED AT GOVT. EXPENSE

Osterkamp, T. E., L. Viereck, Y. Shur, M. T. Jorgenson, C. Racine, L. Falcon, A. Doyle, R. D. Boone, and D. Verbyla, Observations of thermokarst and its impact on boreal forests in Alaska, 7th Int. Conf. On Permafrost, in preparation, 1997.

Pewe, T. L., Geologic hazards of the Fairbanks area, Spec. Rept. 15, Alaska DGGS, College, AK, 1982.

Weller, G., A. Lynch, T. Osterkamp, and G. Wendler, Climate change and its effects on the physical environment in Alaska, Proc. Of a Workshop, AAAS, Fairbanks, AK, 1995.

REPRODUCED AT GOVT. EXPENSE

IMPACTS OF CLIMATE CHANGE ON THE PACIFIC NORTHWEST: VULNERABILITIES AND OPPORTUNITIES

prepared by Amy Snover, University of Washington, JISAO

Climate change will be manifested most directly through changes to the region's hydrologic cycle. Changes in water availability and in the timing of supply will subsequently impact all aspects of the region: forests, fisheries, coastal ecosystems, agriculture, human health, energy supply and urban centers. Following is a summary of how climate change (as described by the Pacific Northwest climate change scenario) would impact the Northwest. Vulnerabilities are denoted (–) and opportunities (+).

HYDROLOGY & WATER RESOURCES

West-side rivers...

– need for more deliberate spillage and possibility of decreased water supply in summer
– lower summer flows and increased failure to meet minimum instream flow requirements would be detrimental to fisheries protection
– increased flood frequency
  – uncontrolled river systems are especially vulnerable to larger flood peaks that may occur with climate change

Columbia River Basin...

– decrease in annual run-off
– increased competition among major users of the river system: hydropower production, fisheries protection, irrigation water supply
– failures to meet firm energy production requirements would occur more often, be larger and last longer
  – need for additional power sources
– increased difficulty of providing water to meet minimum flow requirements for fisheries protection
– less water available to satisfy irrigation demand

FORESTS & RANGELANDS

– increased drought stress
  – may make lower elevation, currently dry locations (on the lower east slopes of the Cascades, for example) inhospitable to forests in the future
  – drought stress increases tree susceptibility to pest outbreaks
– increased pest outbreaks
  – warmer temperatures will expand pest ranges and/or accelerate pest life-cycles
– increased risk of wildfires and increased fire intensity
– tree seedlings are especially sensitive to temperature increases and may not be able to establish and grow in the same place under altered climatic conditions

+/– forest ecosystems would consist of new combinations of species

– decreased forage quality of rangelands
– increased rangeland invasion by exotic species
– possibility of increased rangeland wildfires

AQUATIC ECOSYSTEMS

– freshwater fisheries, especially in small rivers & lakes, are most vulnerable to climate change
– west-side salmon migration & spawning harmed by decreased summer & fall run-off in West-side rivers
– fish habitat and egg-smolt survival may be harmed by increased wintertime river flows
– increased difficulty of providing adequate water flow for fish protection in the Columbia River Basin
– loss of coastal habitat for outmigrating salmon, spawning oceanic species, animals and sea birds

+ stimulation of growth and expansion of ranges of warm-water species
  + especially near current northern boundaries of species' ranges

[OVER]

COASTAL ACTIVITIES

- landslides & bluff failures
- coastal riverine flooding
- inundation of low-lying coastal areas and wetlands
  - increased loss of wetlands between existing and future coastal development and rising seas
  - loss of habitat for migratory birds, fish, shellfish & water fowl
- increased saltwater intrusion into freshwater areas
  - would alter animal/fish habitat
  - could harm human drinking water supply
- vulnerable areas:
  erosion: SW WA coast, central OR coast
  flooding/inundation: south Puget Sound

AGRICULTURE & GRAZING LANDS

- decreased irrigation water supply coincident with increased water need in warmer, drier summers
- increased agricultural & livestock pests
- stimulated weed growth
- decreased forage nutritive quality
- increased crop heat stress and decreased yield stability
- increased flooding and soil saturation in low-lying areas west of Cascades

+ extended growing season due to increased temperature, perhaps enabling double cropping in some areas
+ improved crop growth and yields due to increased CO_2
+ overall productivity in Pacific Northwest may increase while productivity in other regions may decrease

HUMAN HEALTH EFFECTS

- increased photochemical smog production
- increase in vector-borne diseases, resulting from an expansion of pest (i.e. ticks) ranges and/or an acceleration of pest life-cycles
- increase in water-borne health problems
  - contamination of drinking water by saltwater intrusion
  - leaks from underground hazardous material storage tanks or landfills with rising water tables in coastal areas
  - increase in paralytic shellfish poisoning events

+/– decrease or increase in mortality due to changed incidence of high-risk air masses

ENERGY PRODUCTION & UTILIZATION

- decreased capacity for hydroelectric power production in Columbia River Basin
  - more frequent. longer lasting and larger system failures
  - reliability of meeting firm energy production requirements decreases from 96% to 89% in 2020 and 82% in 2050; average shortfall increases by a factor of 8.5
  - reliability of non-firm energy production decreases from 96% to 88% in 2020 and 86% in 2050
  - will be exacerbated by demand increases due to population growth
- future national/international agreements may limit CO_2 emissions, impacting transportation and/or energy production/utilization sectors

+ increased opportunities for development of alternative energy sources and associated technologies
+ increased market for energy-efficiency technologies

URBAN CENTERS

- flooding and landslides
  - environmental impacts on buildings and infrastructure
- public health concerns of increased air pollution and water-borne health problems
- altered sewage treatment plant outfall hydraulics and drainage issues, especially in coastal areas
- increased uncertainty in planning for future energy and water demand

+ opportunity for stimulating economic growth by attracting alternative energy and energy-efficiency industries

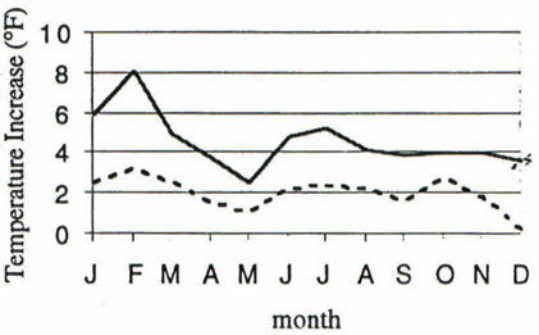
+/– impacts to the economy of the Pacific Northwest vs. economic impacts to other regions
+/– migration to Pacific Northwest from other more stressed parts of the world

PACIFIC NORTHWEST CLIMATE CHANGE SCENARIO

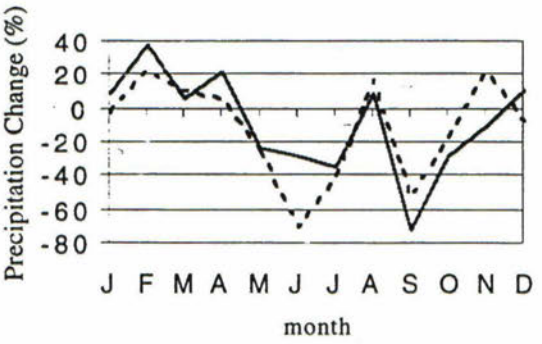
prepared by Amy Snover, University of Washington, JISAO

Warmer, wetter winters and warmer, drier summers

A. Monthly average temperature increase.



B. Monthly average precipitation change.



Average changes projected for the Pacific Northwest (Washington, Oregon and Idaho) in 2020 (dashed lines) and 2050 (solid lines) under the MPI model climate scenario, relative to present climate. (A) monthly average temperature increase; °F. (B) Monthly average precipitation change; % of current precipitation. Precipitation changes are a spatial average of fractional change in precipitation.

TEMPERATURE:

- annual average temperatures increase 1.1°C (2°F) by 2020; 2.5°C (4.5°F) by 2050
- more warming during the winter
- temperature increases beyond 2050, even if atmospheric concentrations of greenhouse gases are stabilized by that time

PRECIPITATION:

- average wintertime precipitation increases
- average summertime precipitation decreases
- precipitation changes are less certain than changes in temperature

SEA LEVEL RISE:

- 50 cm (20") by 2100 (with a range of 20-86 cm)
- 7 cm (3") by 2020
- 20 cm (8") by 2050
- will be exacerbated by land subsidence (occurring in south Puget Sound, Washington)

OTHER POTENTIAL CHANGES:

- a decrease in the daily temperature range
- more extremely hot days and fewer extremely cold days
- an increase in precipitation intensity; extreme rainfall events
- These predictions are less certain than projections of average changes in temperature and precipitation and may or may not specifically apply to the Pacific Northwest.

IMPORTANT UNKNOWNS:

- Will the future be more or less stormy?
- What will be the future frequency and intensity of El Niño?
- Although climate models currently project gradual climate change, there is a possibility that the climate system may respond in surprising and/or sudden and unforeseen ways.

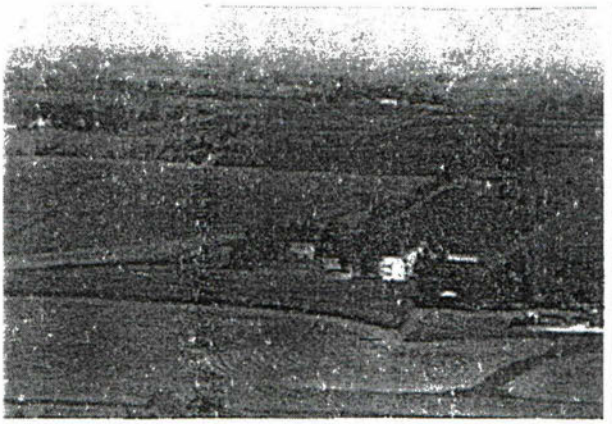
SCENARIO:

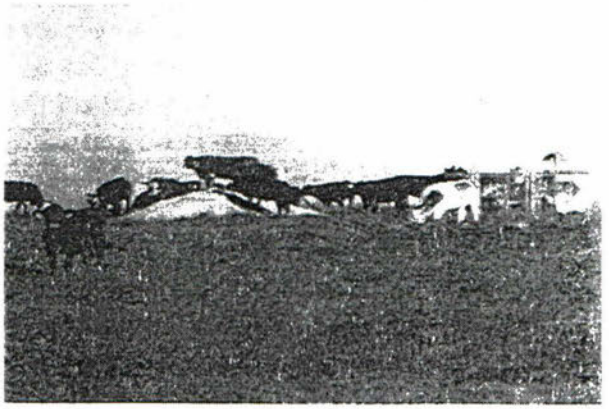
- The scenario chosen as a basis for discussion is *plausible* in light of our current understanding and computing capabilities, but should not be considered to be a *prediction*.
- The scenario was taken from a transient coupled ocean-atmosphere general circulation (computer) model simulation of future climate from the Max Planck Institute (MPI) interpolated to the regional scale.

OSTP/USGCRP WORKSHOP

DRAFT REPORT

CLIMATE CHANGE IMPACTS ON THE GREAT PLAINS





Colorado State University

27-29 May 1997

TABLE OF CONTENTS

I. Workshop Description 2

II. Great Plains Today 4

III. Economic Factors Affecting Agronomic Systems within the Great Plains
Mark Drabenstott 27

IV. Working Group Reports Summary 38

V. Appendices

A. Agenda 66

B. Participant List 68

I WORKSHOP DESCRIPTION

Title: CLIMATE CHANGE IMPACTS ON RANCHING, FARMING AND WILDLIFE CONSERVATION IN THE CENTRAL GREAT PLAINS (COLORADO, KANSAS, NEBRASKA, WYOMING)

OSTP SPONSORED

The evidence for climate change is becoming more compelling, yet most regions of the United States do not have a strategy to deal with the potential impacts of climate change. In the Central Great Plains region (i.e., the Colorado, Kansas, Nebraska and Wyoming area), the potential impact of climate changes is anticipated to affect winter snowfall, growing season rainfall amounts and intensities, minimum winter temperatures, and summer time average temperatures. The combined effect of these changes in weather patterns and average seasonal climate will affect numerous sectors critical to the economic, social and ecological welfare of this region.

Water resources already scarce in the region may come under greater competition among the various users, for instance urban demands for drinking water may compete for water available for agriculture and wildlife conservation. Climate warming may severely impact the wetland areas of the region bringing about severe consequences to the migratory and local water fowl and wildlife populations. Climate change may also result in greater crop damages due to increased drought stress resulting from higher growing season temperatures. The loss of soil from these croplands may be enhanced by the lack of plant cover. Ranchers in the region may not be able to support the current number of animals on the existing rangelands due to reduced dryland pasture production and lack water resources for their animals.

Associated with climate change will be a number of indirect effects that will modify the ecological integrity of many of the ecosystems in the region. The increased number of noxious weeds, greater pest outbreaks, increased rate of aquifer use, and loss of wetlands for water fowl may result due to increased temperatures in the region. The economic and aesthetic costs of these changes have not been evaluated within the region, nor strategies for mitigating or adapting to these changes have been developed.

In order to better understand the scope of climate change issues and the potential economic and political implications of these climate impacts, we propose to hold an initial workshop of critical stakeholders in this region and the scientific community to highlight the regional concerns and knowledge. The initial focus of this workshop will be on the ranching, farming, and wildlife sectors within the region.

The goals of the workshop are:

- To determine the stakeholder perspective of critical climate change impacts on their sector;
- To more clearly understand the scope of the potential climate changes impacts that this region may need to deal with in the future;
- To identify the critical climate related constraints to economic, environmental,

and social well-being in the region among the stakeholders of the region;

- To begin the development of a regional mitigation and adaptation strategy that is politically, economically, and socially feasible.

The workshop participants will include representatives from the following sectors:

- Land management sector
- Agricultural extension agents, rangeland extension agents, water conservation board members, wildlife conservation mangers, national and state park resource managers
- Non-governmental organizations: The Nature Conservancy, Audubon Society, Cattlemen's Association
- Commercial and Industrial sector
- Seed developers, agribusiness, crop insurance
- Citizens
- Ranchers, farmers, recreationists, hunters, fisherman
- Scientists: Climatologists, social scientists, ecosystem scientists, hydrologists, agricultural scientists, wildlife scientists

The structure of the workshop will be designed to provide a forum to present what is known about the climate change issues and identify the impacts of these changes and then to provide a platform for identification of critical issues related to climate impacts on various economic and environmental sectors critical to the region. We anticipate a three day workshop in order to address these issues. The location of the meeting will be in the Fort Collins, Colorado area
near Colorado State University: The time frame of the forum is set for May 27, 28, 29 1997.

Day 1: Presentation of climate change issues and potential impacts relevant to the region; identification of potential vulnerabilities and risks associated with regional climate change impacts

Day 2: Discussion of critical constraints to economic, social, and ecological sustainability in the region; development of possible mitigation and adaptive strategies.

Day 3: Develop framework for needed community efforts to deal with climate change impacts and identify critical issues for further development. Plenary discussion of Summary comments and future plans.

The outcome of the workshop will be a regional appreciation of what critical climate change issues are that would affect the regional development and sustainability. The workshop will provide forum for better understanding of the scientific basis of climate change impacts and the socio-economic and environmental fabric from which the climate change impacts will be interwoven.

II THE GREAT PLAINS TODAY

In order to address the possible effects of climate change on the Great Plains and its stakeholders later in this document, we first need to present a current description of the area and its condition. This section will describe the linkages that have developed between the socio-economic activities of the people living in the Great Plains, the climate and environment of the region, and the land use patterns of the region. Each of these three sectors have affected and been affected by the other two creating the current mosaic of landscapes characteristic of the Great Plains today.

A. DEFINING THE GREAT PLAINS

The boundaries of the U.S. Great Plains are variously defined, but we will use the one defined by Riebsame (1990) [See Figure 1] which is bounded on the west by the Rocky Mountains, and the north by Canada's southern border. The other boundaries are based on changes in climate and vegetation type. The east boundary is the edge of the bluestem area and the south boundary is the edge of the desert/scrub. The Great Plains includes portions of 10 states (Montana, North Dakota, Wyoming, South Dakota, Nebraska, Colorado, Arkansas, New Mexico, Oklahoma, and Texas) and occupies 1/3 of the land mass of the United States. The area covered is roughly 1.3 million km^2. There are currently 6.2 million inhabitants of the Great Plains with a population density of 4.74 persons/km^2 (Riebsame 1990).

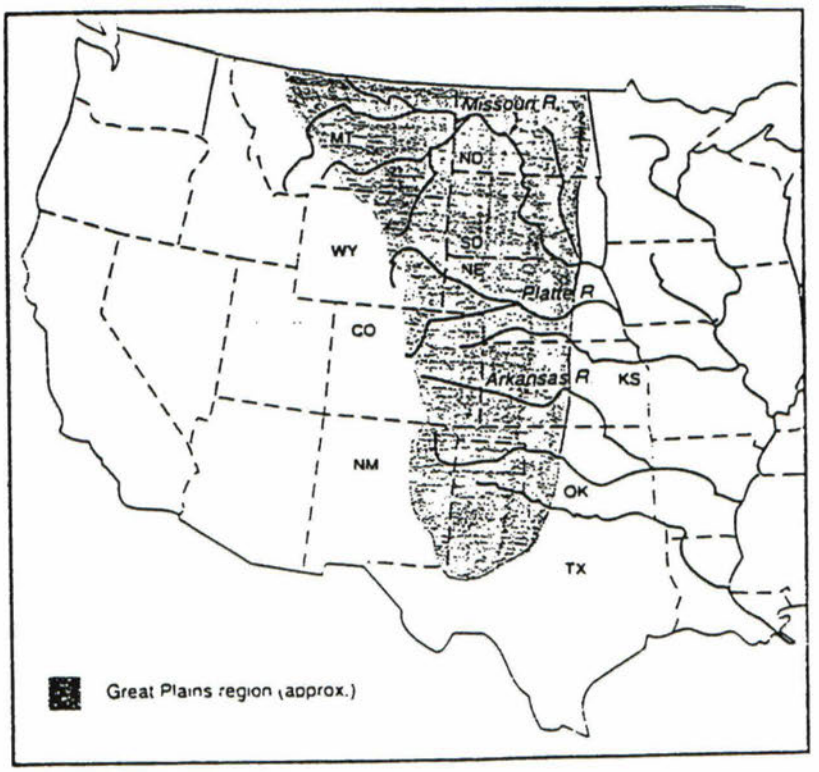


Figure 1. The Great Plains Region of the United States. Riebsame 1990.

1. Socio-economic activities

The social-economic environment of the Great Plains can be characterized by risk and marginality (Riebsame 1990). Since the time of settlement, the variable and dry climate have made it difficult for people to live off the land. This has led to a shift in the population from primarily rural to increasingly urban. Some have described the rural social fabric as thinning (Riebsame 1997). However, the economy is still largely rural, with over half of its counties having populations <2500, and dependent on agriculture for its income (Skold 1997) [See Figure 2 and Table 1]. This percentage of rural counties is six times the national average with about half living in the Great Plains. As a result, agriculture is still a dominant lifestyle in this region compared to other regions in the U.S. Narrowing profit margins have been a driving force behind the trend in farm consolidation in the Great Plains as well as technology (Duncan et al.). With farm consolidation, there are fewer and fewer farmers left, and more people are moving to the urban centers [See Figure 3].

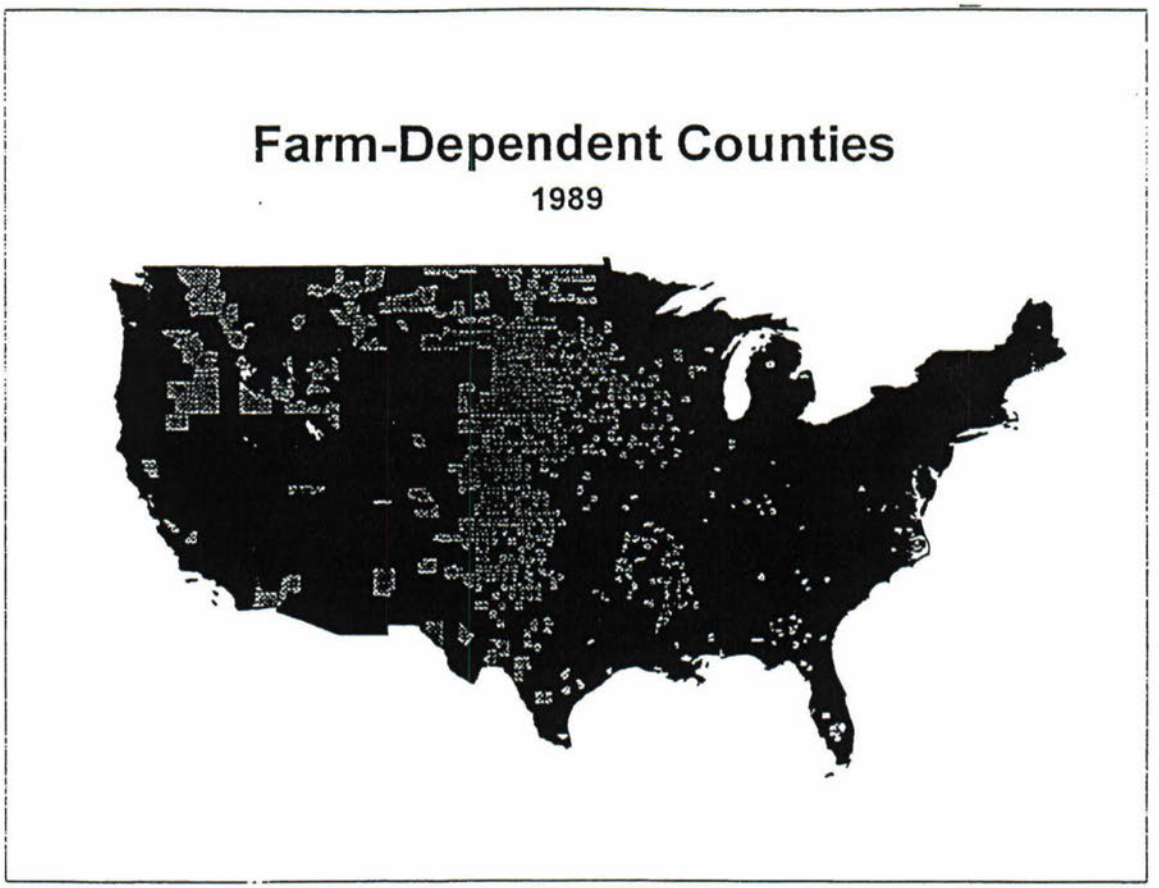


Figure 2. Farm-dependent counties 1989. Drabenstott 1997.

Rank	State	Farm share of gross state product: Share (percent)	Rank	State	Share (percent)
1	South Dakota	12.10	26	Georgia	1.44
2	Nebraska	9.63	27	California	1.37
3	North Dakota	9.33	28	Utah	1.30
4	Idaho	8.05	29	Hawaii	1.23
5	Iowa	6.95	30	Texas	1.22
6	Montana	6.04	31	Tennessee	1.19
7	Kansas	3.82	32	Maine	1.18
8	Arkansas	3.63	33	Delaware	1.13
9	Minnesota	3.17	34	Illinois	1.10
10	Kentucky	2.85	35	Ohio	0.96
11	Wisconsin	2.84	36	South Carolina	0.92
12	Oklahoma	2.73	37	Virginia	0.91
13	Oregon	2.55	38	Michigan	0.89
14	Wyoming	2.52	39	Louisiana	0.81
15	Mississippi	2.19	40	West Virginia	0.75
16	North Carolina	2.18	41	Pennsylvania	0.69
17	New Mexico	2.14	42	Maryland	0.58
18	Alabama	2.01	43	Nevada	0.52
19	Colorado	1.91	44	New Hampshire	0.39
20	Vermont	1.89	45	New York	0.32
21	Washington	1.79	46	Connecticut	0.31
22	Florida	1.63	47	Rhode Island	0.27
23	Missouri	1.60	48	New Jersey	0.21
24	Indiana	1.55	49	Massachusetts	0.20
25	Arizona	1.51	50	Alaska	0.07
				National Average	1.43

Source: U.S. Department of Commerce, Bureau of Economic Analysis.

Table 1. The importance of farm production in the 50 States, 1989-91 average.

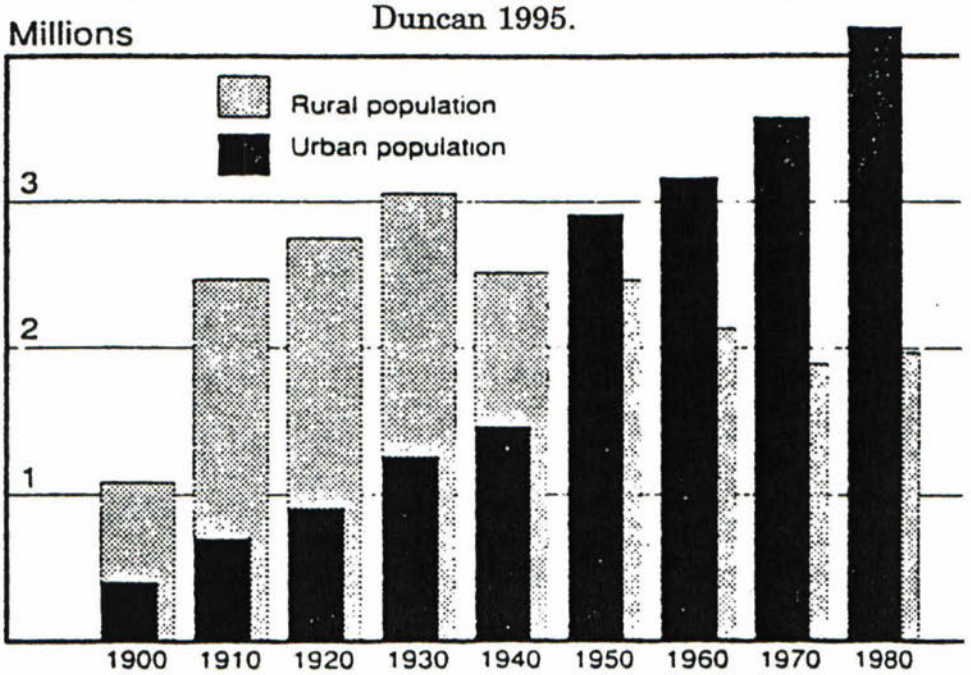


Figure 3. Great Plains urban and rural population per square mile. Source: U.S. Census Bureau. Riebsame 1990.

Fifty-nine percent of the counties have lost population in the last 10 years (Duncan et al.) However overall the population of the area increased 16% from 1969 to 1991. Of the annual 0.77% increase, only 0.13% of it was outside of urban centers (Skold 1997). These centers are thriving as trade locations for broader market regions. This is mainly where the 1990s economic rebound of the Great Plains has been felt (Drabenstott 1997). Real income grew 1.3% a year from 1980 to 1992, mainly in the urban areas, with the Great Plains as a whole showing lower per capita incomes than the national average. Employment has grown by 1% in the period from 1990-1994, which is about 40% less than the national average (Duncan et al.) [See Table 2 and Figure 4]. About 1/3 of the rural counties are doing well economically, mainly those that are in scenic areas or near urban centers. Small size and remoteness of rural areas has proven to be a liability (Drabenstott 1997). Many rural economies and governments are considered to be unsustainable (NRCS 1996).

	Share of population in 1992	No. of counties	Annual growth rate, 1980–92 *Per capita:* Population	Real income	Employment
Nonmetro counties	51.7	375	-0.34	2.11	0.32
Winners	3.5	12	1.60	2.31	3.39
Neutral	21.6	221	-0.55	3.43	0.37
Losers	26.7	142	-0.40	0.22	-0.07
Farming	13.8	212	-1.14	2.98	-0.34
Manufacturing	0.9	3	-0.11	0.58	0.60
Mining	3.7	16	0.11	0.13	0.31
Government	7.6	28	0.35	1.11	0.96
Retirement	1.4	4	0.71	0.61	0.83
Trade	21.4	94	-0.37	0.93	0.23
Other	0.2	2	-1.32	1.62	-0.42
Mixed	2.6	16	1.44	2.08	3.01
Metro counties	48.3	21	1.14	0.18	1.74
All Great Plains counties	2.7	396	0.34	1.99	0.98
All U.S. counties	100.0	3,078	0.96	1.40	1.70
U.S. nonmetro counties	22.6	2,359	0.46	1.46	1.24
U.S. metro counties	77.4	719	1.11	1.24	1.82

Note: "Winners" are counties with per capita income growth and employment growth above the U.S. nonmetro average. "Neutral" counties are those with per capita income growth or employment growth above the U.S. nonmetro average. "Losers" are counties with per capita income growth and employment growth below the U.S. nonmetro average.
Source: U.S. Department of Commerce.

Table 2. Economic performance of Great Plains Counties, 1980-92 (US benchmark). Duncan 1995.

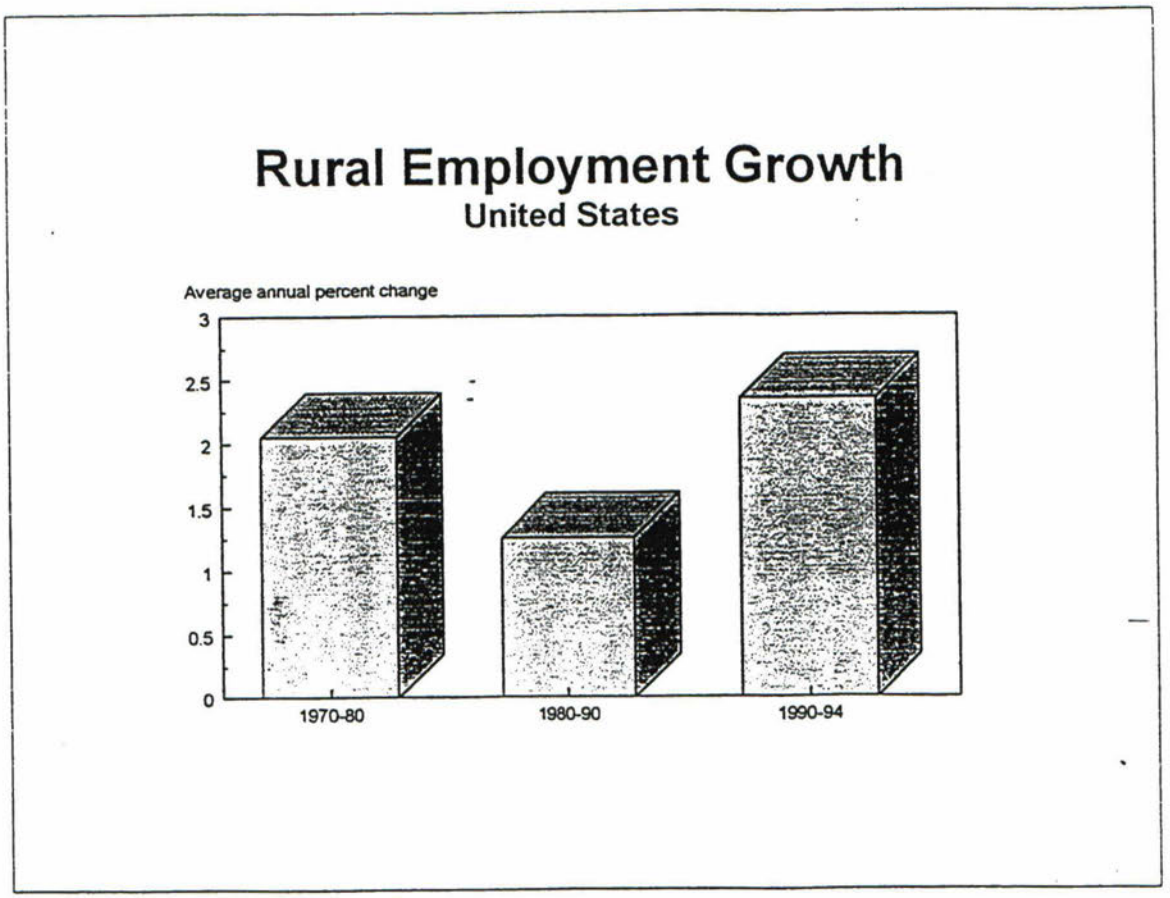


Figure 4. Rural Employment Growth in United States. Drabenstott 1997.

Agriculture has been the base of the economy in the Great Plains despite the constraints of the environment. The east to west gradient of declining moisture has determined the crop production for the area. The variability of this climate has somewhat been overcome with technology (fertilizer, irrigation, new crop varieties, etc.). Most farmers are wheat producers, but increasingly farm cash receipts are coming from livestock operations moving into the area [See Figure 5]. Sixty percent of cattle industry is now concentrated in 3 Great Plains states [See Figure 6]. They are attracted by the dry climate, which allow feedlot cattle to thrive, and the open space far from population centers that allow for waste disposal (Drabenstott 1997, Hubbard 1997).

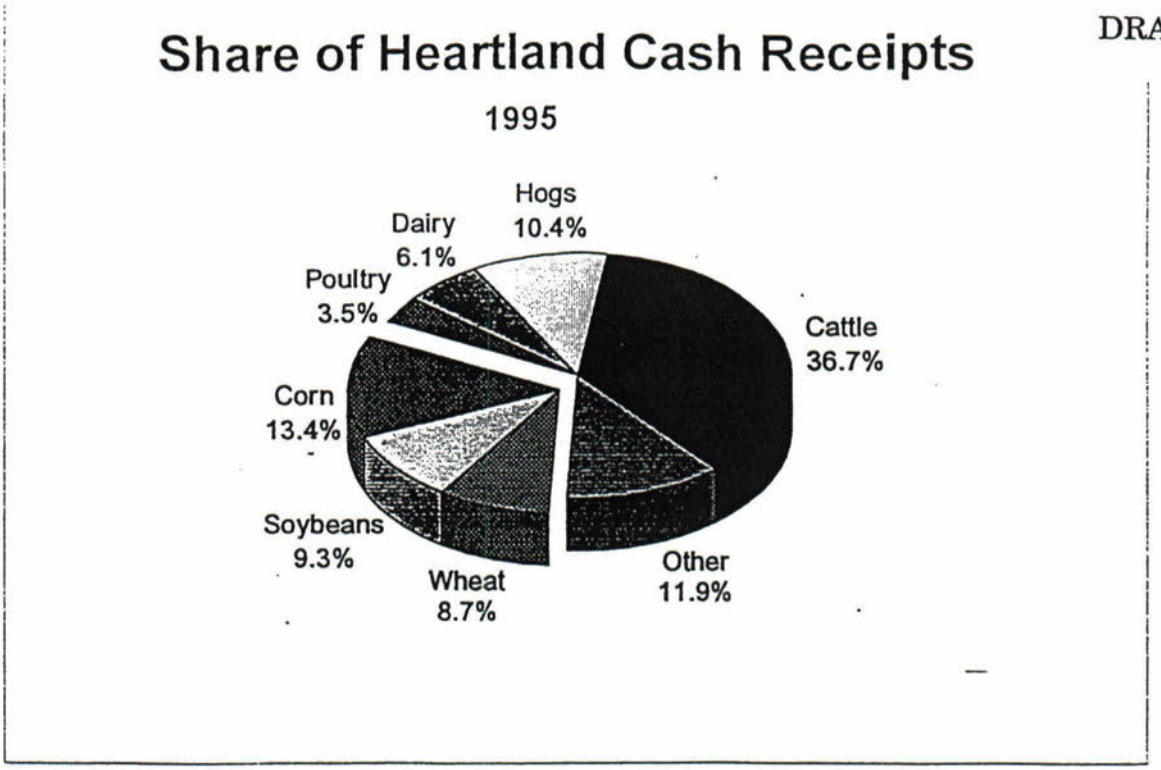


Figure 5. Share of Heartland Cash Receipts. Drabenstott 1997.

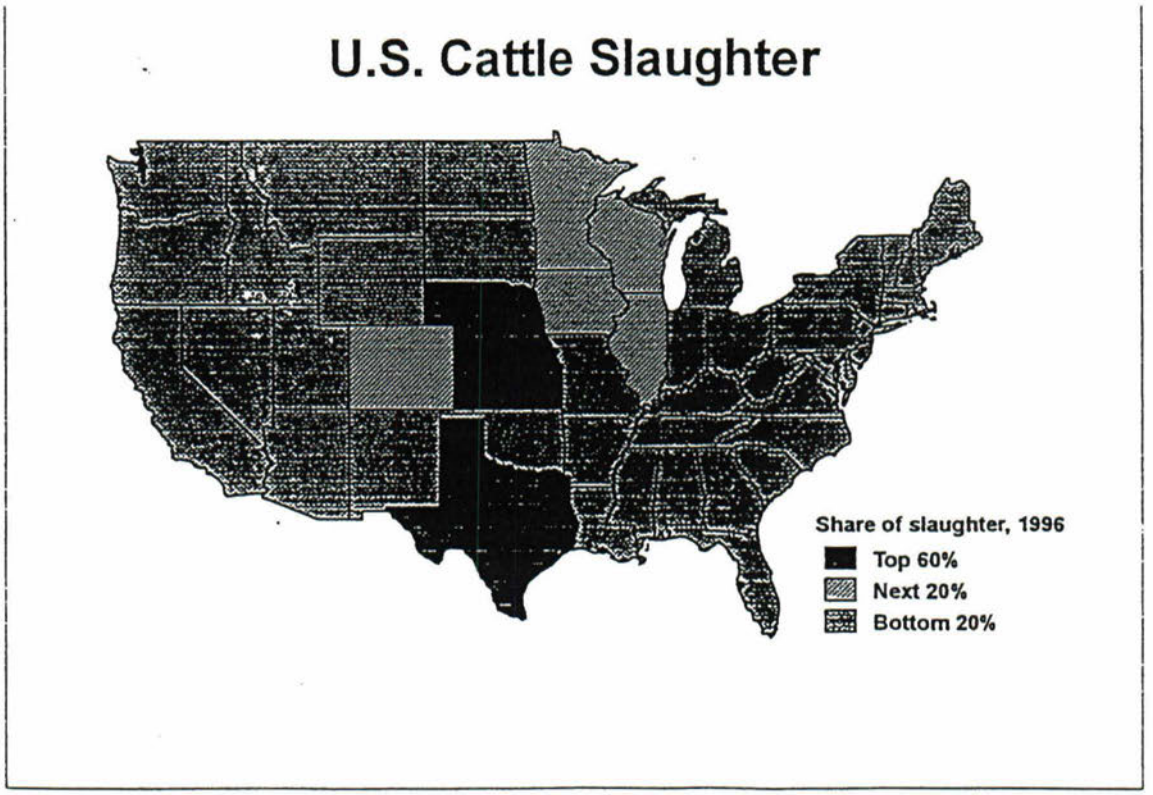


Figure 6. U.S. Cattle Slaughter 1996. Drabenstott 1997.

The variable market contributes to the agricultural economy's instability. Market outputs have followed the declining precipitation gradient from east to west [See Figure 7]. Because the Great Plains has more marginal land and variable yields, the farmers are more vulnerable to market swings [See Figure 8]. The buffer in the past has been government subsidy programs, but they are being reduced. A positive sign for the farmers is a strong world food demand, and reduced world grain inventories, which is increasingly becoming the driver for land use decisions [See Figure 9]. Nevertheless, there is the threat of international competition as evidenced by a declining trend in real wheat prices since 1955 [See Figure 10].

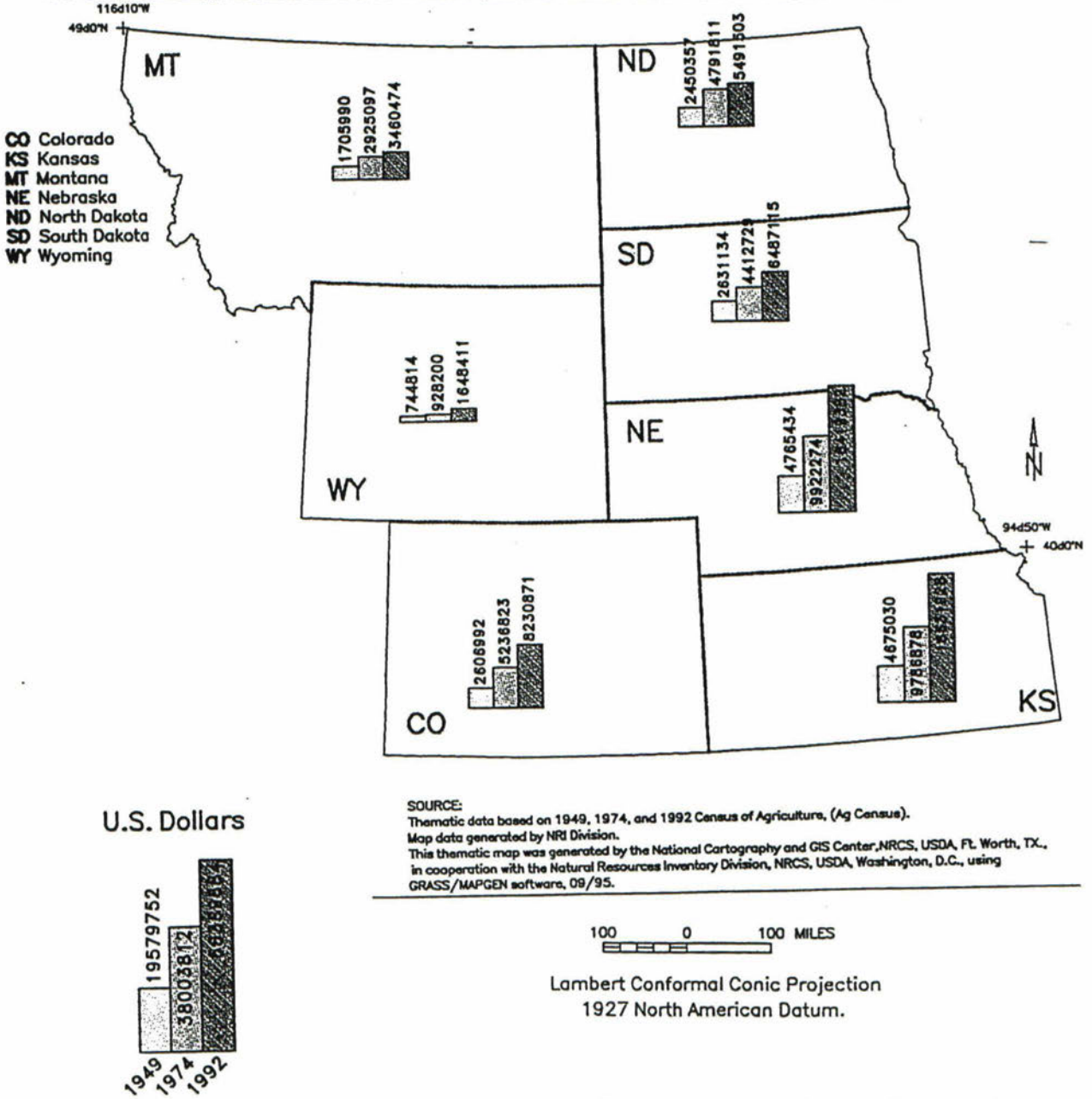


Figure 7. Market Value of Agricultural Products, Northern Plains Region. NRCS 1996.

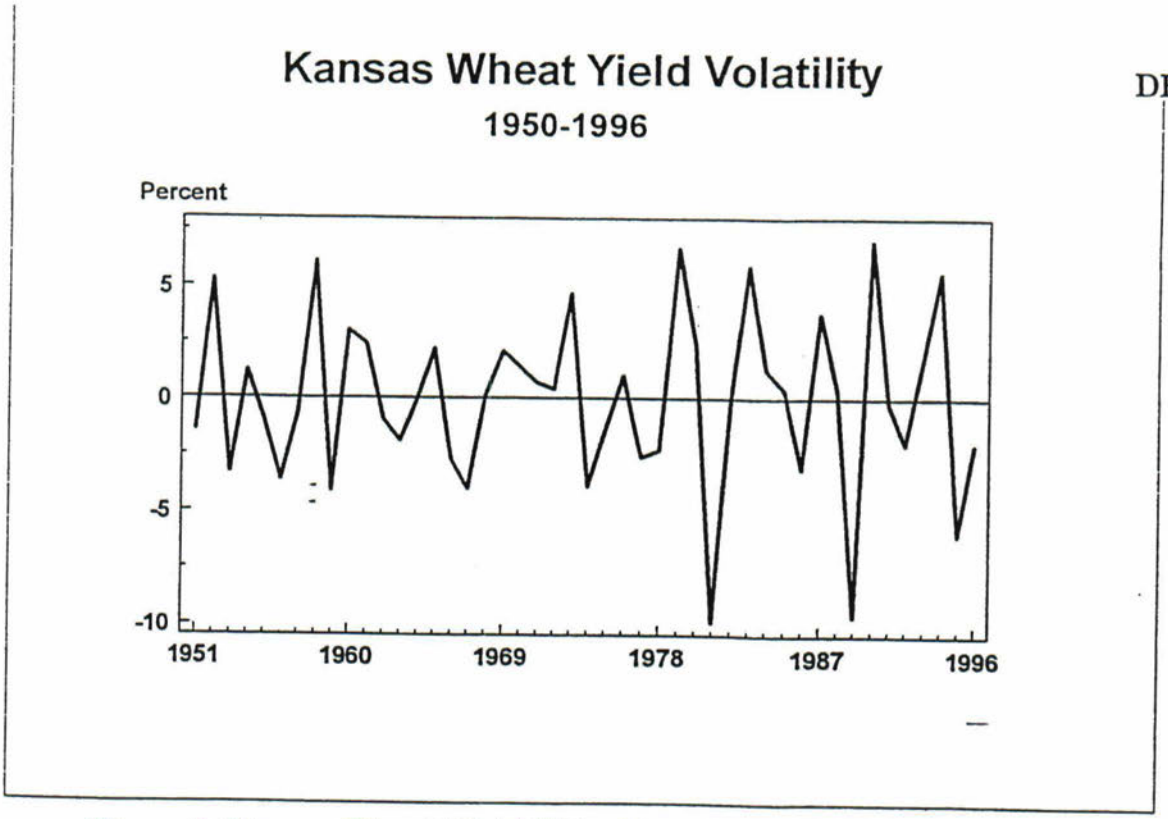


Figure 8. Kansas Wheat Yield Volatility, 1950-1996. Drabenstott 1997.

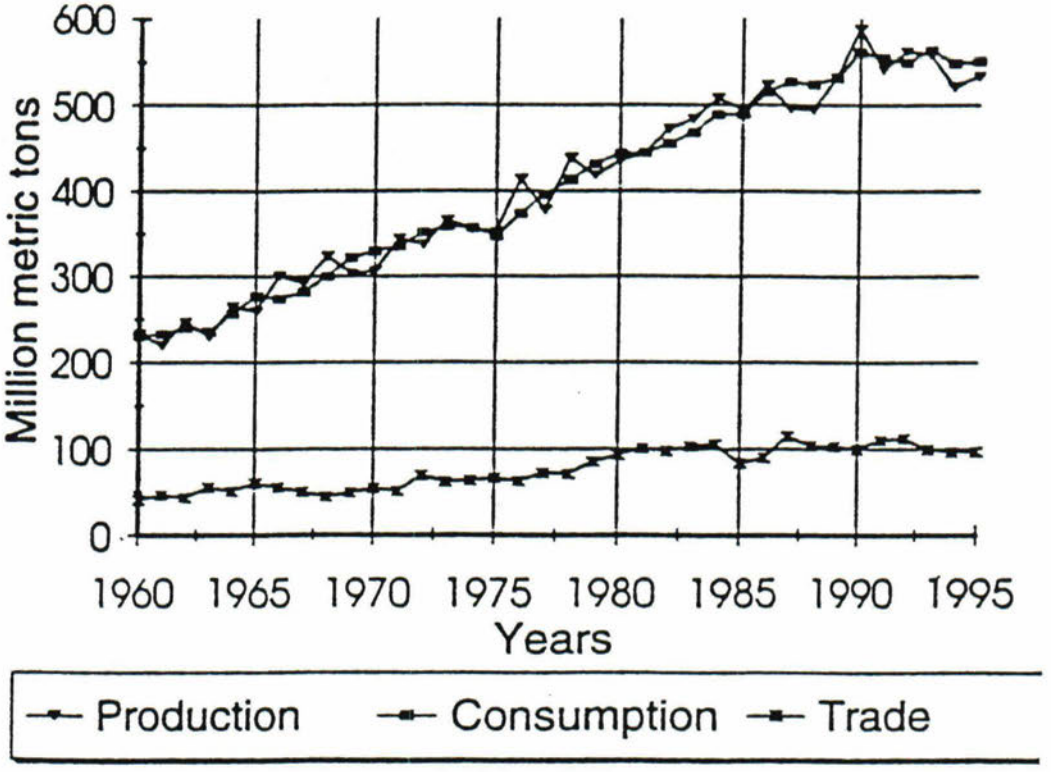


Figure 9. World Wheat Production, Consumption and Trade, 1960-1995. Antle 1997.

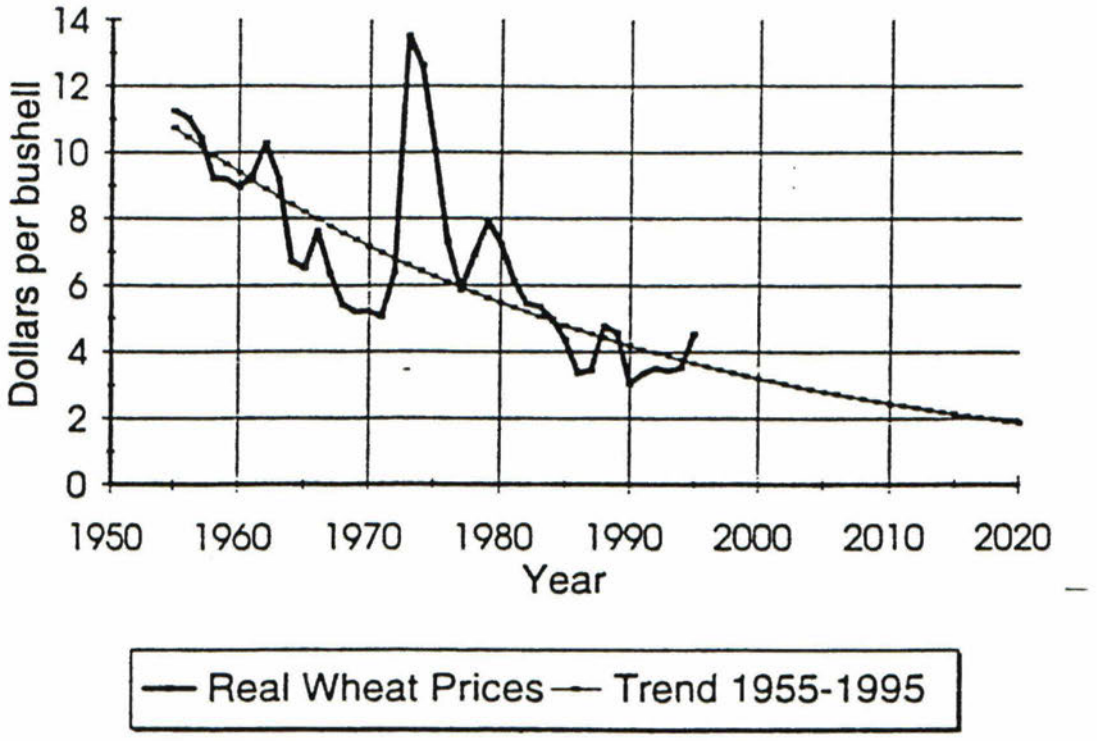


Figure 10. U.S. Wheat Prices 1955-1995 and Trend Forecast to 2020. Antle 1997.

2. Climate and Environment

The climate of the Great Plains is characterized by two primary gradients which form the boundary for the area and determine the environment; these are precipitation (decreasing east to west) and temperature (decreasing south to north) [See Figure 11]. They have interacted to affect human settlement and use of the area (Riebsame 1990) Total annual precipitation ranges from 30 inches to the east, and < 15 inches to the west (or 800 to 250 mm) (Hubbard 1997, Parton et al. 1994). Rainfall is least in winter and most in summer. Temperatures are lowest in January-February and highest in July-August. The soils are nutrient limited and susceptible to erosion (both wind and water) [See Figure 12]. Growing season varies form 110 days in the north to 300 days in the south (Skold 1997).

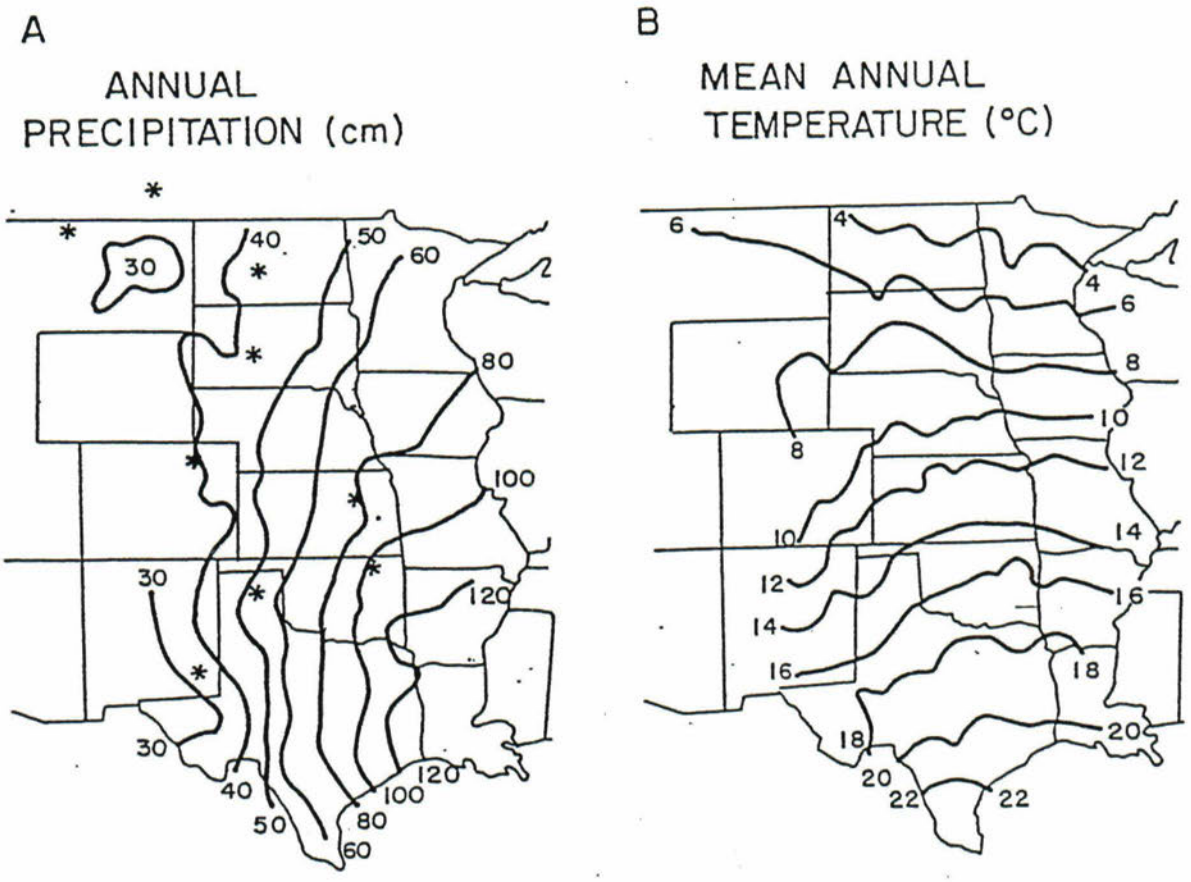


Figure 11. Gradients of (a) mean annual precipitation and (b) mean annual temperature in Central United States. Schimel et al. 1990.

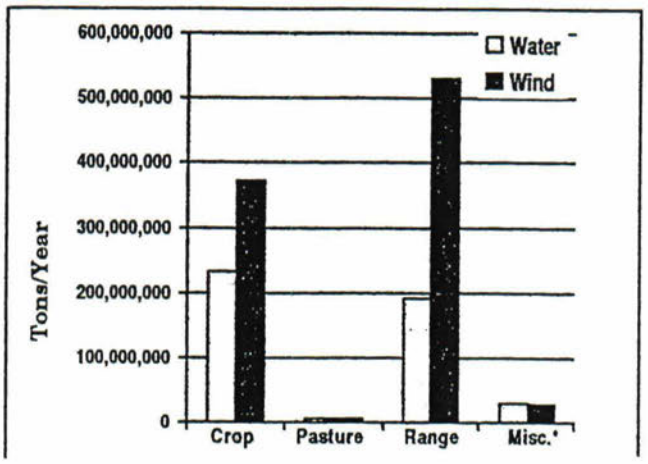


Figure 12. Total Annual Soil Loss by Land Use in the Northern Plains (USDA/NRCS 1994). NRCS 1996.

The lack of moisture results in a steppe or semi-arid grassland ecosystem, which has historically been adapted to frequent fires, grazing and extreme weather, including droughts. Much of the natural state has been transformed to crop and rangeland, and altered by other human impacts such as tree-planting for windbreaks. Plant growth is limited by precipitation and nutrient availability (Parton et al.1994) [See Figure 13]. The combination of precipitation, temperature, and wind characteristic of the Plains leads to extreme weather patterns, including droughts, floods, blizzards, tornadoes and hail. This makes the area very vulnerable for plant and animal production. Drought has always been a factor in these grasslands, with the degree and timing controlled by temperature, precipitation, and the ratio of precipitation to potential evapotranspiration (Parton et al.1994).

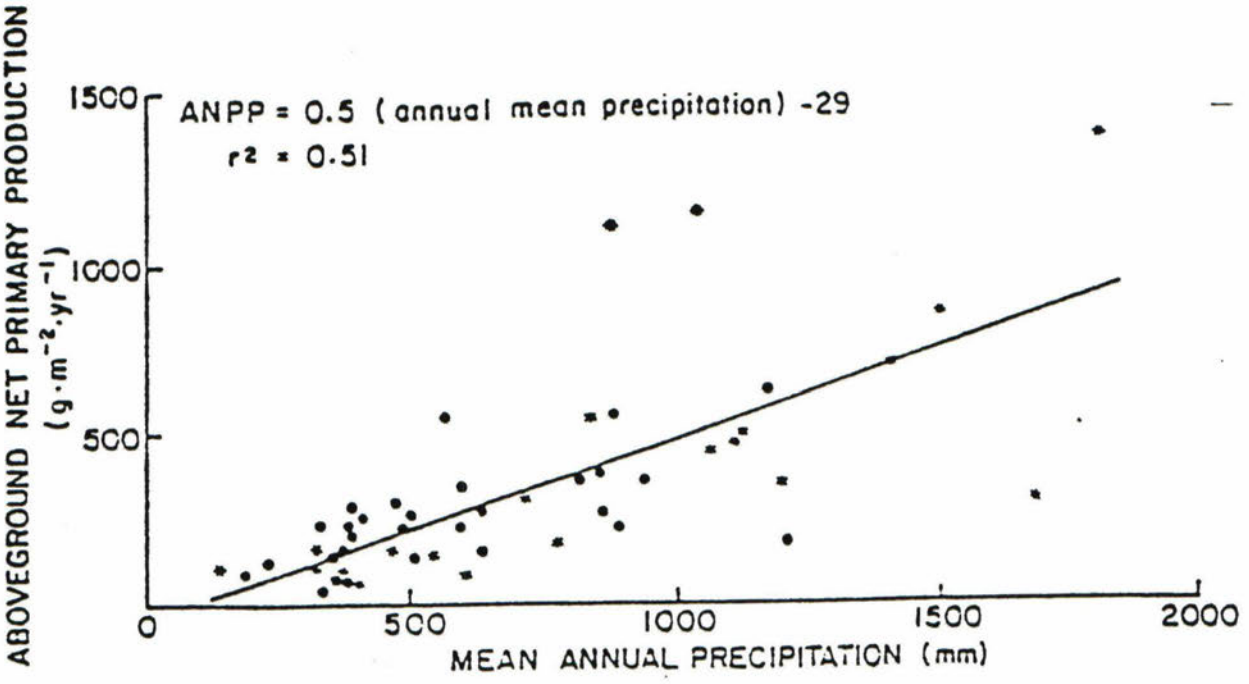


Figure 13. Aboveground net primary production and mean annual precipitation at 52 grassland sites in North American grasslands are represented by dots, others by stars (Lauenroth 1979). Parton et al. 1994.

Despite these limitations, humans have managed to transform this area through their resource use, overcoming various setbacks. The Dust Bowl of the 1930s shows an extreme example of the social disruption caused by mismanagement of this type of environment. This was followed by improvements in land practices (reduced tillage, land retirement) that prevented a disaster of that scale again. While the environment has constrained land uses, technology has overcome some of them, but not without problems. This has resulted in the widespread transformation of the original landscape by humans [See Table 3]. Some of the environmental problems from urban and agricultural uses have been siltation of waterways from erosion, increased salinization from irrigation, increased alkalinity of soil, reduced carbon storage of soil, and increased runoff [See Figure 14 and 15]. A 1980 USDA study estimated 16% of the cropland exhibited serious water erosion and 25% showed wind erosion (Riebsame 1990). Ten percent of the N. Plains landscapes are affected by salinity with a 10% annual increase (NRCS 1996 and Riebsame 1990) [See Figure 16]. "Tillage pan" from soil compaction is found in half of the cultivated land in the region (Riebsame 1990).

Transformation	Areal extent	Dispersion	Naturalness
Tillage. cropping	Regional	Diffuse	Natural
Tree planting	Subregional	Concentrated	Seminatural
Runoff change	Subregional	Diffuse	Seminatural
Water impoundment	Local	Concentrated	Nonnatural
Groundwater depletion	Subregional	Diffuse	Nonnatural
Soil structure change	Regional	Diffuse	Nonnatural
Soil chemistry change	Regional	Diffuse	Nonnatural
Soil and water pollution	Regional	Diffuse	Nonnatural

Table 3. Major human transformations of the Great Plains. Riebsame 1990.

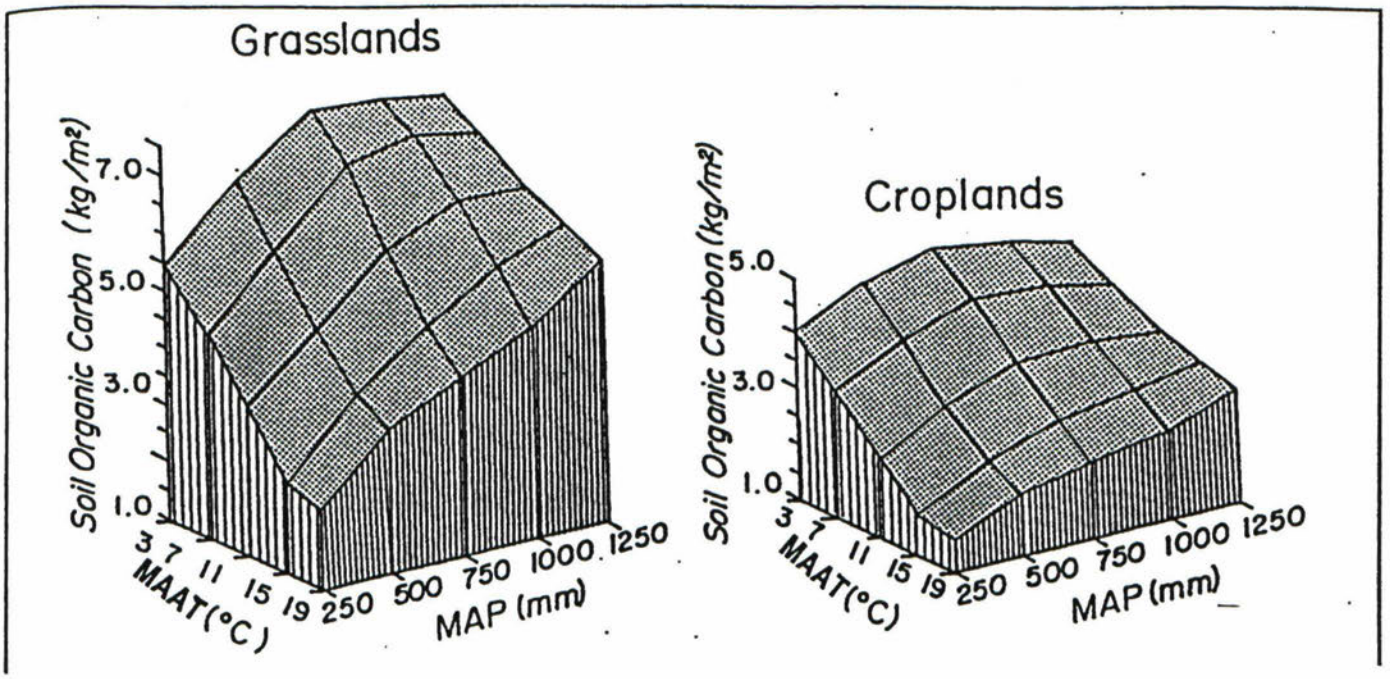


Figure 14. Simulated levels of soil organic C as a function of mean annual air temperature (MAAT) and precipitation (MAP) in the Great Plains. A) Native grasslands on fine-textured soils. B) Croplands on find-textured soils after 40 years of cultivation in wheat-fallow (Cole et al., 1989) NRCS 1996.

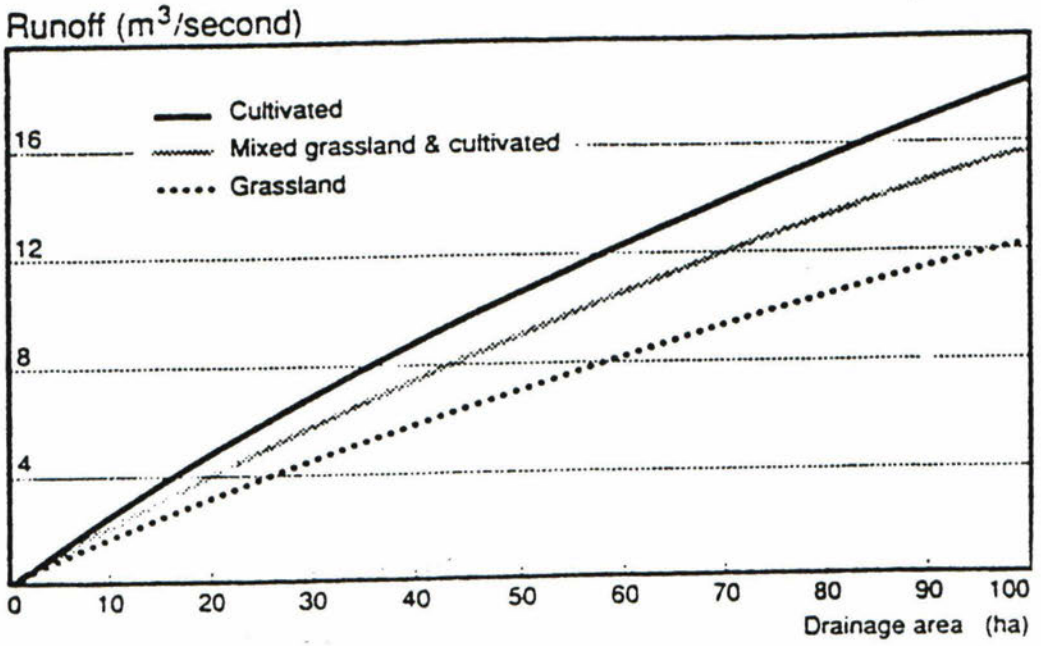
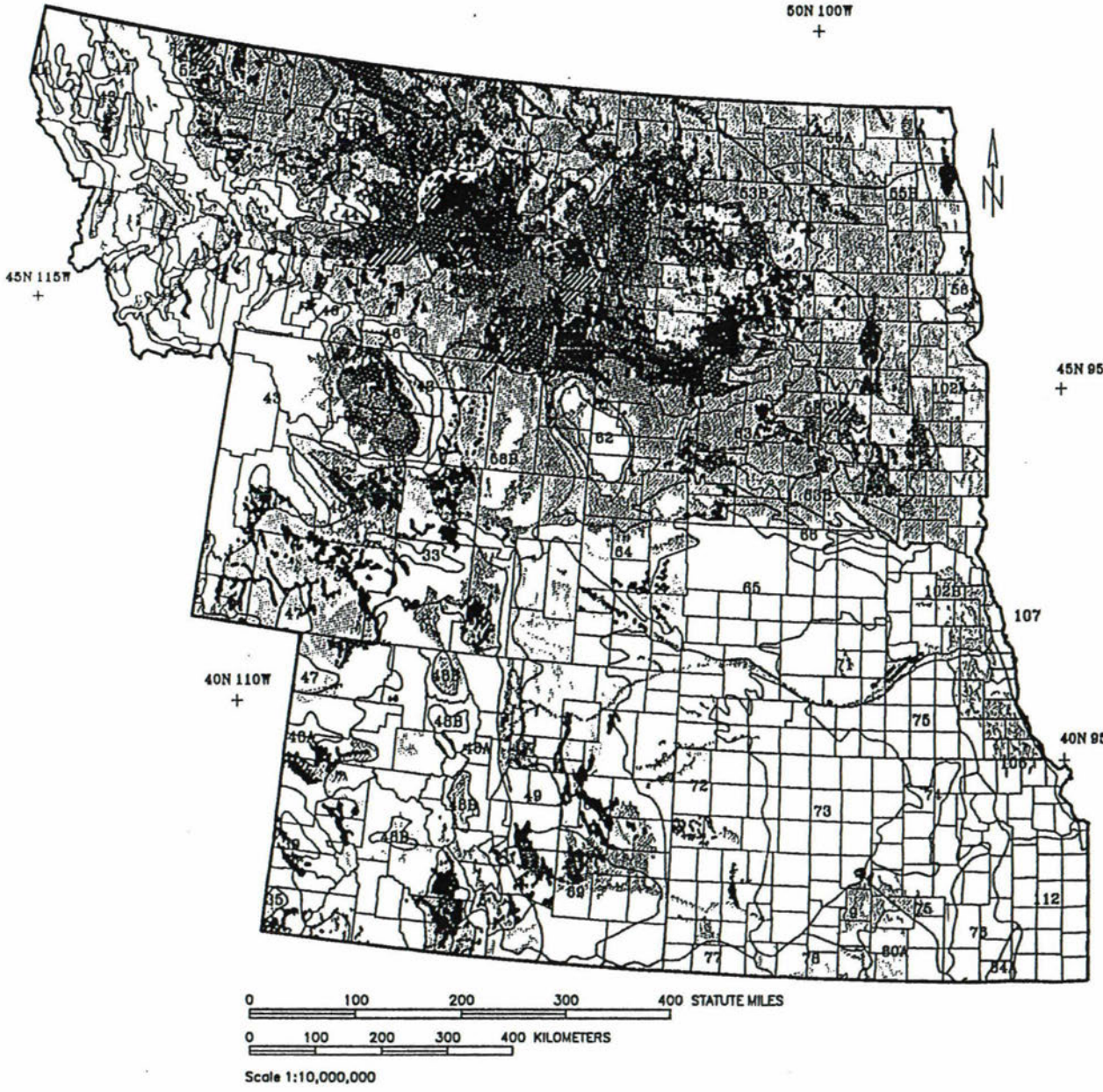


Figure 15. Peak runoff rates for different land covers in the central Great Plains. Source: Allis 1948. Riebsame 1990.



W.J. Waltman and B. Stephens

LEGEND

Soils and landscapes affected by salinity problems were derived from the State Soil Geographic Database (Soil Survey Staff, 1994).

The areas of saline-affected soils were based upon the presence of a horizon with electrical conductivities greater than 4 dS/m, within 50 cm of the surface. The estimates of electrical conductivity followed the saturated paste method of the National Soil Survey Laboratory (1995).

- 0 to 10 percent of Landscapes with Saline Conditions
- 11 to 20 percent of Landscapes with Saline Conditions
- 21 to 30 percent of Landscapes with Saline Conditions
- 31 to 40 percent of Landscapes with Saline Conditions
- 41 to 50 percent of Landscapes with Saline Conditions
- 51 to 100 percent of Landscapes with Saline Conditions
- Major Land Resource Areas

SOURCE: R. Srinivasan (1995); Blackland Research Center, Texas Agric Expt Station, Temple, TX 76502; Albers Equal Area Projection.

Map Series No. 96-0021
NORTHERN PLAINS GIS/REMOTE SENSING

3. Land Use Systems

The primary land use that has transformed the Great Plains grassland has been agriculture, with urban and industry use increasing being lesser factors. Over 90% of the land is in farms and ranches, and 75% is cultivated (Riebsame 1990) [See Figure 17]. There are five major production systems in the Great Plains: range livestock, crop fallow, groundwater irrigation (aquifer-dependent), river valley irrigation (snowmelt-dependent), and confined livestock feeding (Skold 1997). Great Plains agriculture is land-extensive and uses relatively few chemical inputs and labor per unit of land (Antle 1997).

The crops grown vary according to the climatic gradients [See Figure 18]. Corn and soybean are rainfed and produced in the east, with dryland wheat and sorghum production in the west. As productivity decreases along this east-west moisture gradient, risk increases. Spring wheat is planted in the north and winter wheat in the south. Cool season (or C3) plants do better further north than warm season (or C4) plants (Parton et al. 1994). Increasing irrigation to the west allows for more corn production. The rangeland grazing is concentrated in the drier areas to the west. Wheat is considered the "indicator species" of the Great Plains, with its changes in production reflecting various forces at play during different periods [See Figure 19]. The Great Plains is the most productive dryland wheat area in the world, and pivotal to world grain supplies (Riebsame 1990). Great Plains production accounts for 51% of the nation's wheat, 40% of its sorghum, 36% of its barley, 22% of its cotton, 14% of its oats, and 13% of its corn. It produces 40% of the nation's cattle (Skold 1997).

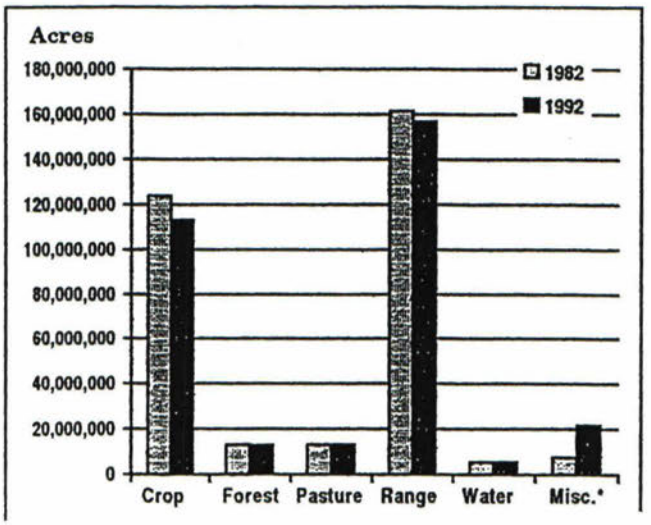


Figure 17. Uses of nonfederal land in the Northern Plains (USDA/NRCS, 1994). *Miscellaneous use includes CRP. NRCS 1996.

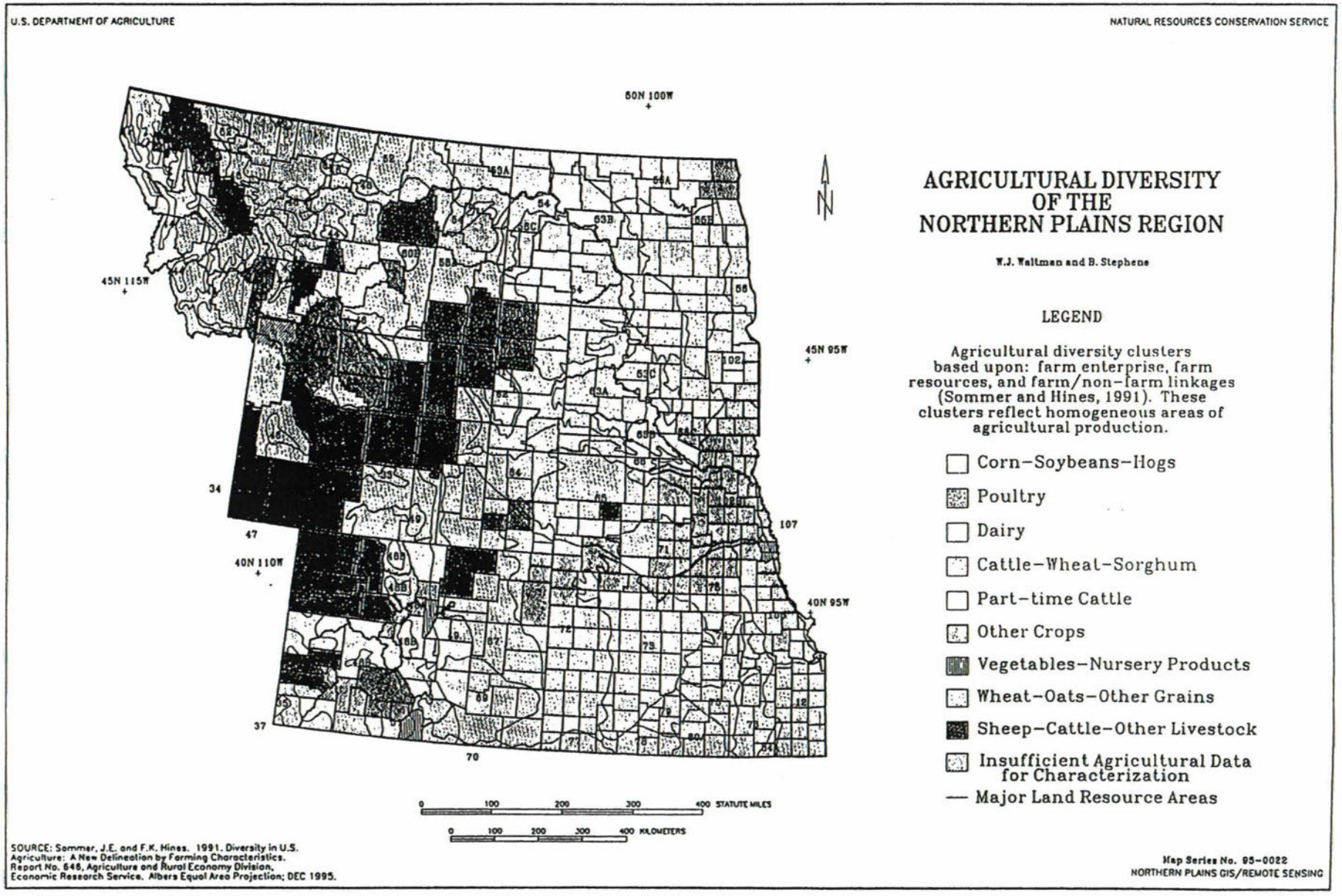
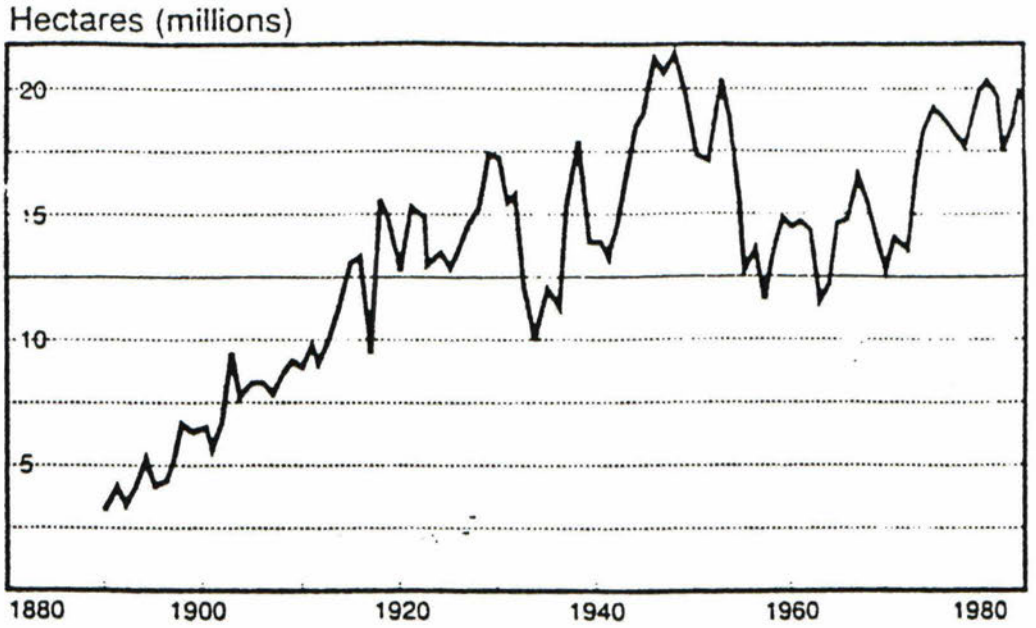


Figure 18. Agricultural diversity of the Northern Plains Region. NRCS 1996.



DRAFT

Figure 19. Total Great Plains wheat area. Sources: U.S. Census Bureau, U.S. Department of Agriculture, and state statistics. Riebsame 1990.

The agriculture operations are becoming larger and more businesslike and technical. Great Plains farms are an average of three times larger than others in the U.S. (Skold 1997). As mentioned earlier, feedlot operations are increasing on the Great Plains as well. Undiversified agriculture has been the trend resulting from policy and market pressures and technological advances. This uniformity has contributed to an increase in invaders, pest problems, and loss of natural biodiversity.

While there has been some improvement in land management practices through conservation measures (e.g., fallow, minimum tillage) to reduce soil loss, increase soil moisture, and stabilize wetlands, much of the area has been defined to be in need of conservation treatment by a 1992 National Resource Inventory study (45% of cropland, 68% of irrigated land, 62% of rangeland) (NRCS 1996). Nine percent of the rangeland is considered in decline, while 2% is improving [See Figure 20].

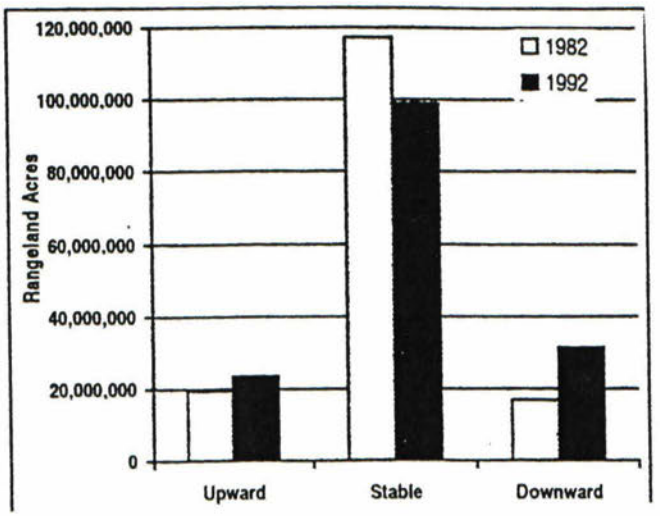


Figure 20. Acres of apparent trend on rangeland in the Northern Plains (USDA/NRCS, 1994). NRCS 1996.

Even though more farm land continues to be lost to other uses (preserves, industry, infrastructure, urban development), increases in crop acreage are still occurring (the maximum cultivated acreage was reached in 1983) (Riebsame 1990). Conservation Reserve Program has kept much of the marginal land out of production (40-45% of all CRP land is in the Great Plains, >40% of Great Plains wheat acreage is in CRP), but may or may not continue into the future (Drabenstott 1997, Antle 1997). Market demands and prices may determine if this buffer program is maintained.

The land use development patterns of the Great Plains have shown a strong bias towards growth [See Figure 21]. Riebsame (1990) explains, "The dominant historical pattern of Great Plains agricultural development is its consistent trend toward both expansion and intensification of dryland small-grains production and marketing by owner-operated ("family") farms. Except for minor set-backs, this pattern has been insensitive to negative feedback from the environment ... and from the economy.... This persistent pattern of development is better explained as the result of historical social values, institutions, and symbols, rather than the guiding force of Darwinian adaptational mechanisms." Farmers have made use of new technological improvements (e.g. irrigation, fertilizer, conservation practices) for overcoming physical constraints (e.g. droughts, low nutrients, wind). In turn, they have affected the physical characteristics of the area and even the climate through such things as: weather modification, greenhouse gas production, increased runoff, changing soil structure, pollution & overuse of groundwater, and loss of soil carbon [See Figure 22]. Social policies and lifestyle choice have been driving forces in land use decisions as well. The result is that Great Plains farmers are not necessarily economic optimalists.

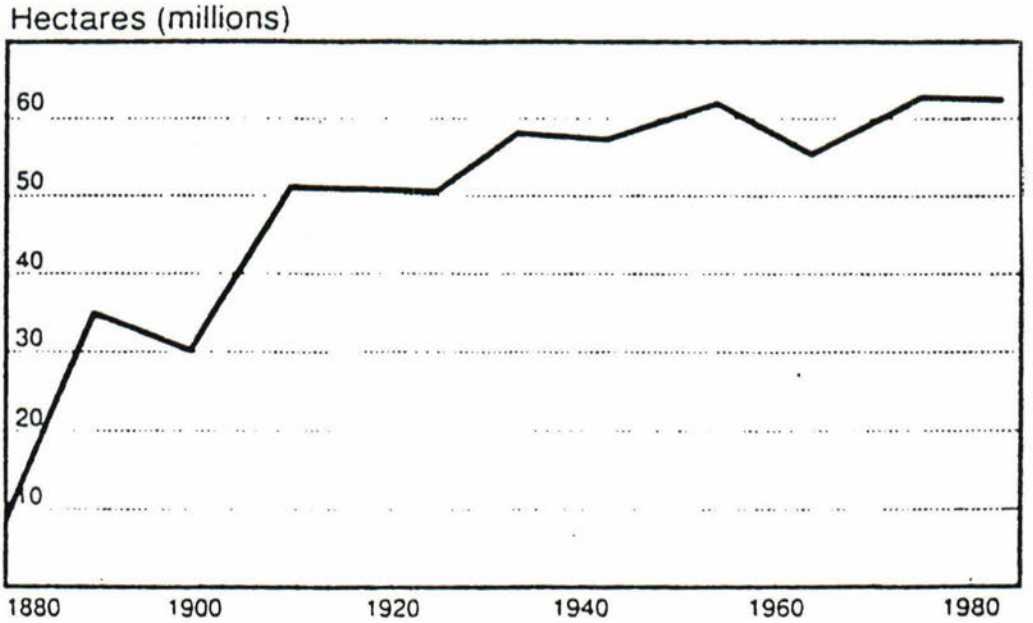


Figure 21. Total Great Plains cropland. Sources: U.S. Census Bureau and state statistics. Riebsame 1990.

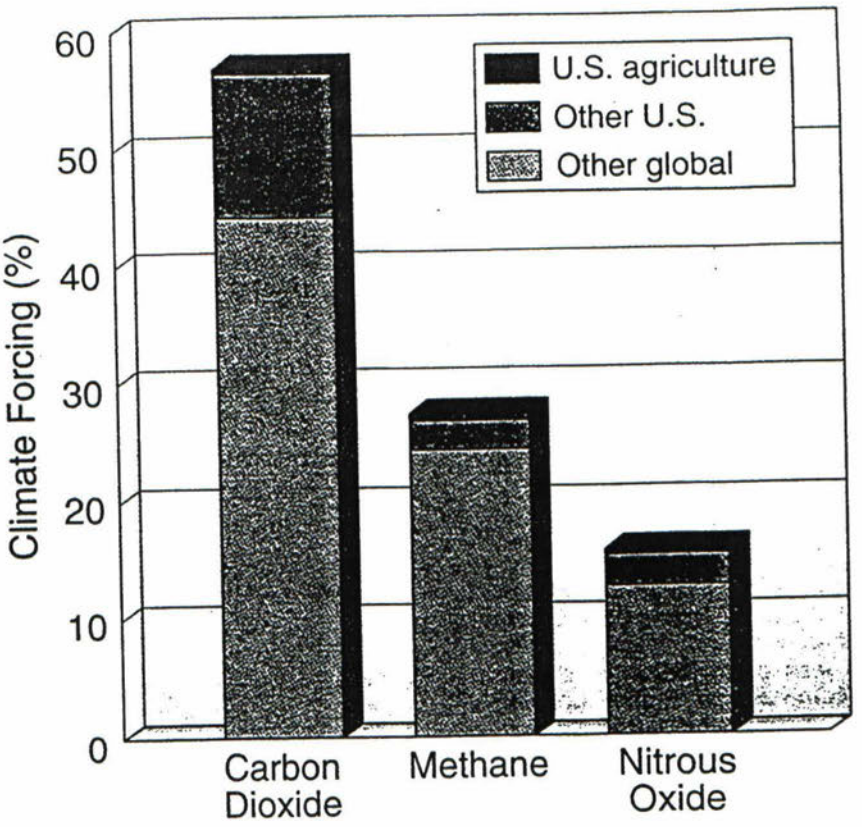


Figure 22. The climate forcing by U.S. agriculture related to that by other activities on the globe.

To compare the contribution of different activities to climate change requires a single measure called climate forcing. It combines estimates of emissions of the various greenhouse gases by each activity with the absorption of long-wave radiation from the earth and het estimated lifetime in the atmosphere of each gas. In this figure, climate forcing is expressed as the percentage of the forcing during the next 100 years by the 1990 global emission of three gases. For example, emissions of methane from the globe are 27% of all forcing, and methane from U.S. farming is 0.4% of all forcing. U.S. Agriculture's emissions of all the three gases is 0.8% of the global forcing from the three gases. Council for Agricultural Science and Technology 1992.

4. Water Issues

Water is mentioned as a component of the above three sections describing the socio-economic activities, climate and land use patterns of the Great Plains today. As has been mentioned, this region of the country is characteristically dry, but human's have managed to transform the land to overcome this limitation. Water has been a critical component of that transformation, which makes the issue of a continued sufficient supply of water of particular concern to the inhabitants. Water sources for these activities include rain, surface water in rivers, streams and lakes, primarily from snowmelt, and groundwater in aquifers. These flows have been altered by

humans through diversion, impoundment, and irrigation for urban and agricultural uses. Rainfall is not sufficient, particularly in the western portion of the Plains, to support the food production systems there now. There is some surface water impoundment, but not a great amount. So the greatest supplementation has been through irrigation from aquifers, which makes their depletion a serious concern.

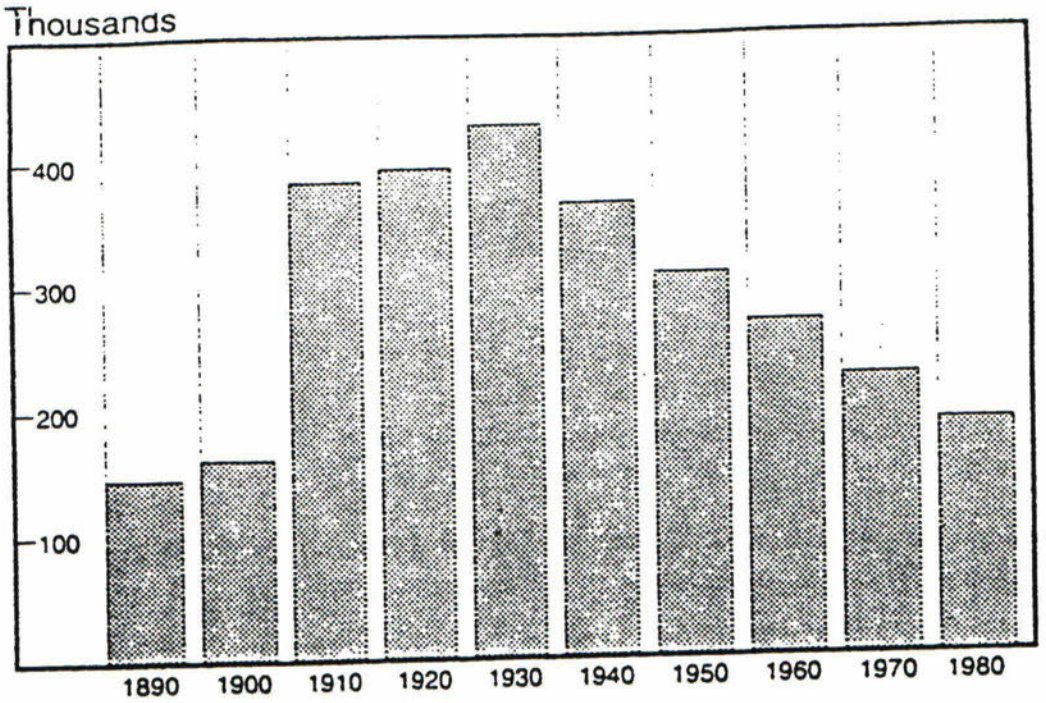
As agriculture is the primary economic activity in the Plains, it is not surprising that it is also the main user of water. Eighty percent of the consumptive use of water in the arid west is estimated to be from agriculture. Twenty million of the 200 million acres in cropland in the Great Plains are irrigated (Skold 1997). In 1982, 12% of the Great Plains cropland was irrigated, over half of which was with groundwater (Riebsame 1990). The South Platte River Basin alone has over 30,000 wells providing 30% of the water used for agriculture (Garcia 1997). The depletion of the aquifers is associated with the areas of increased irrigation. Irrigated land increased from 3.5 million acres in 1950 to 15 million acres in 1990 (Opie 1996). The other uses of water in this region are urban or domestic use, wildlife habitat and recreation. The Platte River is critical for migratory waterfowl and shorebirds food and habitat. The prairie pothole area has suffered greatly from loss of wetland habitats.

Nearly all freshwater ecosystems in the Great Plains have been modified by direct or indirect human activities and land uses, including habitat destruction from dams, diversions, and channelizations, altered groundwater flow patterns as a result of pumping, erosion and the alteration of thermal regimes. Point and non-point source pollution have introduced a wide array of organic chemicals, toxic metals, and fertilizers such as nitrogen and phosphorous into the ecosystem. The alteration of vegetation, the introduction of non-native plant and animal species, and overharvesting of native species have also negatively impacted the aquatic ecosystem (Baron 1997). Considerable pollution results from sedimentation, fertilizer, pesticide and waste runoff. This results in increased salinity, nutrient loading, turbidity, and siltation of streams. Shallow aquifers are also suffering from these pollution problems (NRCS 1996). Agricultural runoff contributes 2/3 of the river pollution and ½ of the lake and reservoir pollution in this country (Garcia 1997). Drinking water quality is reduced as a result of pollution, particularly in small towns. This decrease in water quality has affected food production, human consumption and wildlife habitat.

Water shortage is already a problem. Most water is distributed by prior appropriation laws, but costly litigation results from numerous water rights battles. Also, these laws sometimes inhibit efficient use of the water by better management practices (Garcia 1997). Water supply issues will become increasingly important where competition between urban development and agriculture uses is increasing.

The following items define certain trends that are expected given conditions observed in the Great Plains today:

- Increased size and reduced number of farms [See Figure 23]
- Increased importance of technology to achieve those increases
- Increased livestock operations
- Continued water competition between agriculture and urban [See Figure 24]



DRAFT

Figure 23. Total number of commercial farms on the Great Plains. Sources: U.S. Census Bureau and the state statistics. Riebsame 1990.

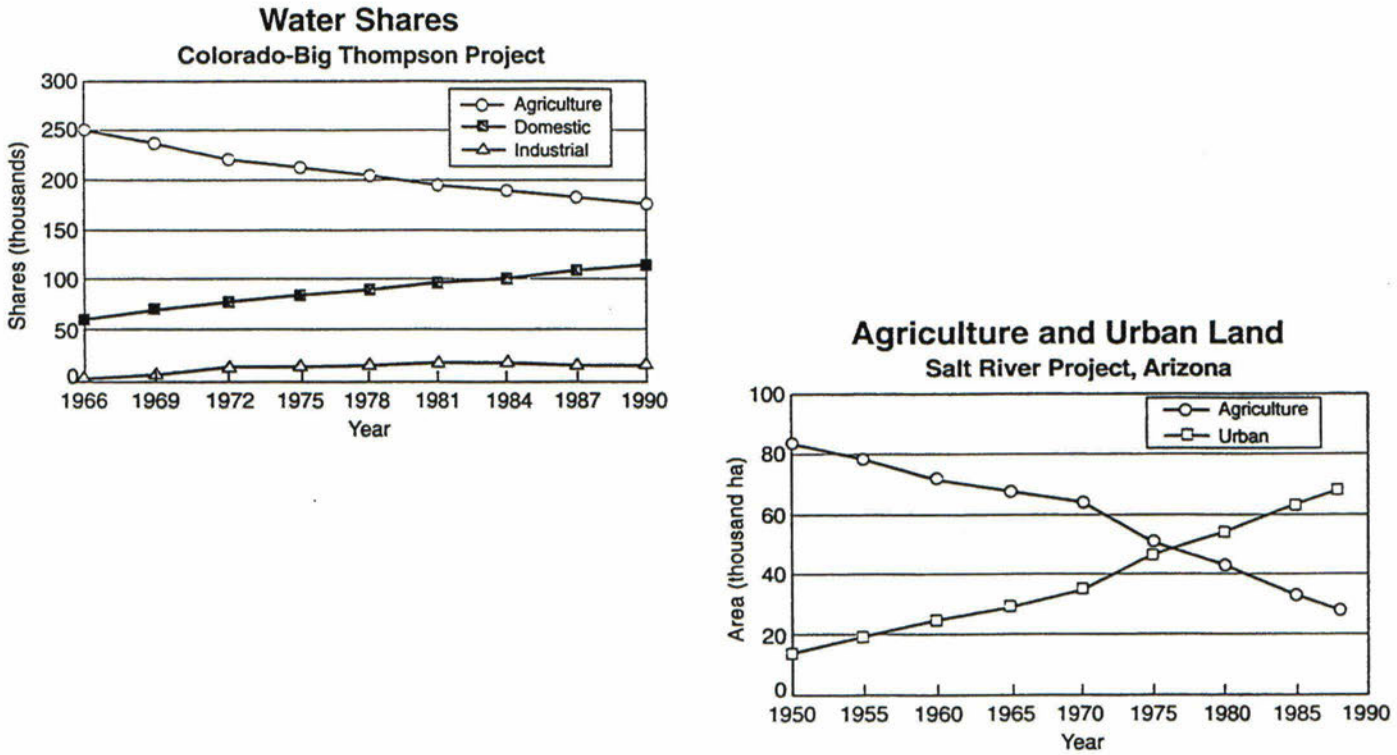


Figure 24. Agriculture and Urban Land Transfer of Water Rights. Upper: Colorado-Big Thompson Project 25 year water rights transfer from farming to cities for domestic and industrial use. Lower: Salt River Project, Arizona 38 year land and accompanying rights transfer from farming to urban. Council for Agricultural Science and Technology 1992.

SOURCES CITED:

Antle, John M. 1997. Climate Change and Economic Constraints Facing Great Plains Agriculture. 6 p. Briefing Document for Great Plains Climate Change Workshop 5/97.

Baron, Jill. 1997. Effects of climate change on in-stream biology and freshwater ecosystems. Briefing Document for Great Plains Climate Change Workshop 5/97.

Council for Agricultural Science and Technology. 1992. Preparing U.S. Agriculture for Global Climate Change. Task Force Report #119.

Drabenstott, Mark. 1997. Economic factors affecting agronomic systems within the Great Plains. Presentation at Great Plains Climate Change Workshop 5/27/97.

Duncan, Marvin, Dennis Fisher, and Mark Drabenstott. 1995. Planning for a Sustainable Future in the Great Plains. Pages 23-42 in Donald A. Wilhite, Deborah A. Wood, and Kelly Helm Smith. Proceedings of the Symposium 'Planning for a Sustainable Future: The Case of the North American Great Plains'. IDIC Technical Report Series 95-1.

Garcia, Luis. 1997. Limits to Water. Presentation at Great Plains Climate Change Works^Gop 5/^F7/97.

Hubbard, Ken. 1997. Great Plains Region: Climate System Characteristics. Presentation at^HGreat Plains Climate Change Workshop 5/27/97.

NRCS, Northern Plains Regional Office. 1996. State of the Land for the Northern Plains Region. USDA, Natural Resources Conservation Service, Northern Plains Regional Office, Lincoln, NE. 64 p.

Opie, John. 1996. Does its history doom the Plains to failure? Putting chaos theory to work. Pages 5-18 in Cathy Bruce and Lori Triplett. The Great Plains Symposium 1996: The Ogallala Aquifer: Sharing the Knowledge for the Future. The Great Plains Foundation.

Parton, William J., Dennis S. Ojima, and David S. Schimel. 1994. Environmental Change in Grasslands: Assessment Using Models. Climate Change 28:111-141.

Riebsame, William E. 1990. The United States Great Plains. Ch. 34, pages 561-575 in B.L. Turner II et al., The Earth as Transformed by Human Action. Cambridge University Press, NY.

Riebsame, William E. 1997. Links between climate change, vulnerability, and coping strategies to environmental and socio-economic changes. Presentation at Great Plains Climate Change Workshop 5/27/97.

Schimel, D.S., W.J. Parton, T.G.F. Kittel, D.S. Ojima, and C.V. Cole. 1990. Grassland

biogeochemistry: Links to atmospheric processes. Climatic Change 17:13-25.

Skold, Melvin D. Agricultural Systems and Economic Characteristics of the Great Plains. 4 p. Briefing Document for Great Plains Climate Change Workshop 5/97.

Waltman, W.J., H.R. Sinclair, and S.W. Waltman. 1997. Characterizing and Mapping Soil Climate in the Northern Plains Region. Briefing Document for Great Plains Climate Change Workshop 5/97.

FIGURE and TABLE LEGEND

#	Title	Author
1	US GP REGION	RIEBSAME
2	US FARM DEPENDENT COUNTIES, '50 & '89	DRABENSTOTT
3	GP URBAN/RURAL POPULATION 1900-1980	RIEBSAME
4	US RURAL EMPLOYMENT GROWTH '70-'94	DRABENSTOTT
5	HEARTLAND AG CASH RECEIPTS	DRABENSTOTT
6	US CATTLE SLAUGHTER BY STATE '96	DRABENSTOTT
7	N. PLAINS MARKET VALUE OF AG. PRODUCTS '49-'92	NRCS
8	KS WHEAT YIELD VOLATILITY '51-'96	DRABENSTOTT
9	WORLD WHEAT PROD., CONS, TRADE '60-'95	ANTLE
10	US WHEAT PRICES '55-'95	ANTLE
11	GP PRECIP AND TEMP GRADIENTS	SCHIMEL ET AL.
12	N. PLAINS SOIL LOSS BY LAND USE	NRCS
13	PRECIP/NPP IN US GRASSLANDS	PARTON ET AL
14	GP SOIL CARBON W/ TEMP AND PRECIP	NRCS
15	GP RUNOFF BY COVER TYPE	RIEBSAME
16	N. PLAINS SALINITY AFFECTED LANDSCAPES	NRCS
17	N. PLAINS NONFEDERAL LAND USE	NRCS
18	N. PLAINS AGRIC. DIVERSITY	NRCS
19	GP WHEAT AREA 1890-1980	RIEBSAME
20	N. PLAINS RANGELAND APPARENT TREND '82, '92	NRCS
21	GP CROPLAND 1880-1980	RIEBSAME
22	GHG SOURCES	CAST
23	GP # OF FARMS 1890-1980	RIEBSAME
24	WATER RIGHTS TRANSFER IN WEST	CAST
Table 1	IMPORTANCE OF FARM PRODUCTION BY STATE	DUNCAN ET AL
Table 2	GP COUNTIES ECONOMIC PERFORMANCE '80-'92	DUNCAN ET AL
Table 3	GP TRANSFORMATIONS	RIEBSAME

III DRABENSTOTT'S WORKSHOP PRESENTATION 5/27/97

ECONOMIC FACTORS AFFECTING AGRONOMIC SYSTEMS WITHIN THE GREAT PLAINS

Good afternoon, everyone. It is a great pleasure for me to be here. I always am impressed when a meeting of scientists is willing to begin their program with an economist. I think that is somehow a great act of courage on your part, Dennis. What I would like to do today is to lay out the changes that I see occurring in the rural economy of the heartland. Second, to talk about the changes that are occurring in the agricultural economy of the heartland. In each case, suggest to you how I think they may be impacted by potential changes in climate. And finally, I would like to lay out a few things for you to consider as you begin to discuss policies that will help this region prepare for perhaps a more uncertain future. All of this I hope will serve as a useful stage setter for your discussion. In that respect, I think beginning with the economics perhaps is a laudable way to begin the program.

Let me begin by talking about the rural economy. We have 7 states in our 10th federal reserve district which starts in Kansas City and comes out here to the Rockies. This part of the country has as much rural character to it as any part of the nation. And there have been some very fundamental changes occurring and I think we would do well to recognize those and not put all of our attention just on the farm economy. Because even in the GP you will find places that are not farm-dependent. And thus I think it's useful to look not only at the farm economy but at the rural economy as well. I want to make just a couple of points of what's been happening in the rural economy, all of which will lead me to a conclusion with respect to climate change.

We have had a substantial rural rebound in the 1990s. It is much heralded. It's gotten front page coverage in the New York Times and the Washington Post and the Wall Street Journal. Everyone seems to rather glibly assume that the rural economy is back on track and that we are back in the 1970s again. If you were to look at the rural economy as a whole, there are good reasons for reaching that conclusion. This chart shows you what's been happening to jobs in the nation's 2300 odd non-metropolitan counties. And as you can see in the 1990s we have done much better than the 80s and are running a little bit ahead of the 1970s. What these averages do not tell you is that most of these gains are concentrated in a little over 1/3 of the rural counties. Just to make that point I would like to share with you a map. If you'll focus for a moment just on the green counties in this chart, the green counties are those that are the metropolitan areas. We are going to set those aside for the moment, although most of you probably live in metropolitan areas. Focus next on the yellow splotches on this map. Those are rural counties that have had above average growth in jobs in the 1990s. Average meaning the average for all 2400 odd counties. Finally the gray counties are those that have had below-average job growth in the 1990s. You'll notice that there are a lot of yellow splotches here in the intermountain west. Mountains are a magnet. They have been especially so in the 1990s. You'll also notice that in other parts of the country where you have scenic amenities. Look for example at northern Minnesota and the Upper Peninsula of Michigan. What I call Lake Wobegon country. It's been doing very very well. But finally notice the GP and notice what color it is. There's a lot of gray in the GP. Yes, there are

splotches of yellow. You can pick out I-80 there in the state of Nebraska. But in general, the growth centers in the GP tend to be trade centers. They are the places that have the WalMarts. They are the places that are serving as market centers for ever-widening regions. And in most cases that is a zero sum game. The trade centers are gaining, neighboring communities are declining. So we find as we look at the rural economy that there is a rebound, but it's concentrated in roughly 30-40% of the counties. And it tends to be concentrated in places that have scenic amenities. Places that are next to metropolitan areas, the suburban and ex-urban areas. Places that are becoming part of the metropolitan area. Meanwhile if we look at characteristics of the rural communities that we have typically associated with rural places, one their smallness in size, and second, their remoteness, in general, those characteristics have been a liability in the 1990s.

Well what does all of that suggest when we think about a future in which we may see some climate change and perhaps even more climate change than in other parts of the country? I think it probably mitigates those communities here in the heartland that have been and may continue to be laggards. They simply have not achieved the critical mass, they don't have the scenic amenities that make for a natural growth strategy. Places that, enter a period in which we have a more uncertain, perhaps a more volatile climate, I think it probably mitigates those. And in particular, I think the changes are going to be very substantial when we think about public infrastructure. I would suggest to you today that over the next ten years, one of the major issues that will be fought in the GP will be county courthouses. How we deliver public services in the GP in communities that have shrinking tax bases, shrinking populations and simply don't have the wherewithal to do it the way they always have. There is now one county in Kansas where, when court is in session, they have to bring in a restaurant meal from the next county over. These are going to be substantial questions I believe in the next ten years, not in all parts of the GP, but in some. Where we have to think about adjusting capacities of water systems for a more uncertain climate, I think it will have a very substantial impact on these lagging parts of the rural heartland.

Let me go on now and talk about the farm economy, which is probably going to be the focus of your discussions the next few days. Obviously agriculture is very very important to this part of the country, more so than any other part of the country. I would like to begin by just talking a bit about some of the characteristics about heartland agriculture here in the GP. First is a very obvious point, the point I've already made, that agriculture is more important to this region than any other. Just to show you a couple of pictures that drive that point home. The yellow splotches on this map are those rural counties in 1950 that were classified by the US Department of Agriculture as farm-dependent. What essentially that means is that agriculture was the single most important source of income in that county. And you'll notice that agriculture had a very widespread effect on rural America. We could say in 1950, that agriculture was a tide that would lift all boats. Now we are going to leap forward to the 1990s. These are the counties that today are farm-dependent. First of all, you'll notice that they number less than 1/4 of those rural counties nationwide. One reason I think that we have had shrinking support for agricultural policy in the United States. But secondly, you'll notice that they are heavily concentrated here in the GP, from Texas to the Canadian border. That's where you find counties where agriculture is number one. And thus, this region will have a very substantial interest in what happens to the climate. A second point I would make is that we often think about states like Kansas being a wheat state, Nebraska being a corn

state. But the truth of the matter is that livestock is more important to the agriculture of this region than is our crops. Thus it is very important that we not simply limit our analysis of climate change to wheat yields and corn yields. We have to think about what it means to the livestock industry. Just to drive this point home, you can see that the three slices on the left [corn, soybeans and wheat] account for just about 1/3 of the total cash receipts in the 12 heartland states. Meanwhile, cattle, hogs, dairy and other livestock enterprises represent 2/3 of the total. So it is very important that we think about both animal and plant effects of climate change.

A point also that I'm sure you are already familiar with, but I will underscore it at the outset of this conference is that the land is more marginal here in the GP and the yields are more variable as a result. It's clearly I think going to be the case that as we think about the effects of climate change, the effects are going to show up first and perhaps biggest on the margins. They are not going to show up as much in Champaign County, Illinois as they will in the panhandle of Nebraska. Thus I think it makes sense to begin our analysis of climate change by thinking about some of these marginal areas and how they are going to be affected. Just the make the case with respect to the character of this region. This is a chart that shows you the annual deviation from a five year moving average of wheat yields in the United States. As you can see there is a fair bit of deviation over time. The 1960s were a little more calm, the 1980s we had some volatility, but in general it bumps around a little bit. Now we are going to focus on the state of Kansas. The scale on the left hand side is going to stay the same. You'll notice in Kansas you have much bigger swings and in particular we have had much bigger swings in the 1980s and early 1990s. Thus I think it only makes sense to think about climate change affected the marginal areas first, because that's probably where the impacts may be first seen.

The final point I want to make about the characteristics of agriculture in this region is that it is more sensitive to swings in international markets than it is to the rest of the country. To borrow an analogy from the accounting world, the GP is sort of like LIFO accounting. It's the last in and first out. When there is a big buildup in demand, it's the last region to be pulled into supply and when there is a downturn such as we saw in the 1980s, what are the first acres that the farmers decide not to plant, they are probably going to be here in the GP.

Let me talk now for a minute about the environment that I see looking out over the next decade or so. What is the economic environment in which we may have to deal with climate change? The first is that we have a very new policy setting for agriculture. I would argue that we did cross the continental divide in 1996 when we passed the Federal Agriculture Improvement and Reform Act, just for those of you that are keeping track of the acronym, that adds up to FAIR. I would point out that's the first time in history that a farm bill has ever been called fair. This is going to be what I would call a market era. Farmers are going to live and die by what they plant, not by farming the program. This is a fundamentally different mind set for farmers. It is going to be a very different atmosphere in which that agriculture does business. Having said that, we are going to retain one important feature of the government bureau policy setting. That is the Conservation Reserve Program. There remains a very solid core support for that program. We probably have something on the order of 40-45% of total CRP in the US located here in the GP. That is going to remain as a very important program. That is going to act as something of a buffer to any swings in international markets, to any swings in climate. It was fortuitous I think that Congress decided

to enter this market era, and it probably wasn't shear coincidence. Congress I think saw a world market in the years ahead that they think is going to remain strong. Thus they saw a very opportune time to wean farmers away from government supports. I concur with the assessment in which we are facing an environment in which agriculture's market worldwide are going to be strong. Many people remember the 70s that went bust. But there are a lot of important differences today with the 1970s. The 1970s agriculture boomed for three reasons: 1. Europe, 2. Japan, 3. Soviet Union. The Soviet Union really provided the margin to push markets into very tight condition. Today if you look at where the growth is coming from, it's coming from a lot more places. It's coming from China, it's coming from a whole host of east Asian and south Asian countries like Indonesia and Korea and Malaysia, it's coming from Latin America, it's coming from Mexico, it's coming from eastern Europe. In all of these cases you have people that are low on the income ladder, population growth rates tend to be high, and of every dollar of additional income, up to a third of it gets spend on food. That's a very potent recipe for increased world food demand. At the same time, you have trade barriers tumbling after the Uraguay round. All of that I think adds up to a very good market for US agriculture in the period ahead. Having said that, however, for those of us who are thinking about how a marginal region like the GP responds to changes in markets and to climate, a very important feature of the next five years is that we are going to have very thin world food supplies. [tape change]... grain reserves going all the way back to 1960, 1997 is the second lowest in the last 36 years. The only other year that was lower, 1996. So we have a very thin supply in the grain bin throughout the world. I think that will keep prices volatile as we move over the next 5 years. On balance however, I think we are probably going to see perhaps stable real prices with perhaps some slight uptick in nominal levels.

What are the implications of climate change on an agriculture that has these characteristics and that appear to be in the market setting that I've just sketched out. First, I think we are in an environment in which we could have big potential swings in acreage and crop production. I often got the question from reporters when the new farm bill was being debated: What's it going to do to farm income?. I think that probably is the wrong question, because I think the regional variation of the impacts will far outweigh what happens to the US average. Here on the GP, I think it's quite possible that we could have very substantial swings on planted acreage just on the basis of the economics. Because the GP tends to be again the last in, first out. If prices are strong, we are going to keep adding more land in the region, particularly with the new CRP giving farmers a quicker and easier out of that program. So I think look for one of the things to be big potential swings. Now if we get substantial changes in climate on top of this, I think those two things will only amplify each other. The tight world market and the potential for climate change I think add up to some very substantial volatility in terms of planted acreage. But again I would call your attention to the livestock industry. The really big heart and soul of agriculture in the GP is livestock. And the big question is: What might climate change do to the location of the livestock industry here in the GP?. I think this will ultimately come down to an issue of space versus feedstuff supplies. For a long time now economists have tended to think that if we were to see climate change and/or if we were to see higher energy prices, we would probably tend to see the livestock industry begin to move back to where the feedstuffs are in surplus, which is the corn belt, because it costs more to produce feedstuffs in the GP. You have to pump the water, you have to add the chemicals, it's a much more intensive process than it is in the corn belt

states. On the other side of this issue is the fact that the livestock industry is in the midst of a revolution. It's revolutionizing its very structure. It's moving away from the traditional small farm produced industry to a much more vertically integrated industry. The broiler industry did this first, the pork industry is now in the process of doing it. As it's doing it, it is moving to the GP. Why? Because it is looking for space for the waste. It's looking for places where the environmental impacts are farther from dense populations. So you're going to have a tradeoff. If indeed we see the climate change, the tradeoff will be: If feedstuffs grow more scarce in the GP, the tendency will be to move back to the corn belt. On the other side of it, the industry is looking for the wide open spaces where it can put much larger producing facilities in places where it can handle that and where there are fewer people. Just to make the point, concerning the livestock industry. This is what the cattle industry looked like in 1960. The dark green states of Iowa, Nebraska and California accounted for 30% of the industry. There was another tier here in the light green, about 6 states that accounted for another 30% of the industry. The yellow states accounted for about another 20%, about a half dozen states there. Finally, the orange states were the bottom 20%. Look at where the cattle industry is today. It's in 3 states, it's in Nebraska, it's in Kansas, its in Texas, and where it is in Texas, it's in the GP part of Texas. It's up in the panhandle. Those 3 states account for 60% of the cattle industry. They are very important to the rural economy of those 3 states.

Now what does climate change mean about where that industry goes? Is it going to stay there? Or will the higher feedgrain prices that might result from climate change push that industry back to the GP [corn belt?]? Again the issue will come down to I believe a tradeoff between higher feedgrain prices and the availability of wide open spaces, where you can put a much more concentrated industry without having too many people be concerned about it.

Let me move finally to my third point that I want to make with you today. That is, how do we prepare for a future in which there may be more climate change given the rural economy that I see, given the agricultural economy that I see? First I think it's important to remind all of you of a point that you already know and that is that agriculture has a tremendous capacity to adapt. There is no question that US agriculture has a lot of tools that it can use to adapt to any changes that we might have in climate. But we don't know at this point what kinds of adaptations we are going to need. Therefore I think it is very important to encourage what I would call a portfolio approach to climate change. I have a couple of colleagues in the audience here that participated with me in a report that was prepared 5 years ago now. This was the conclusion that we reached then, and I think that it has stood the test of time. If anything, if uncertainty has increased, perhaps it is even more relevant today. The principle is a very simple one. If all of us were investors gathered in this room, and we were concerned about uncertainty in the economy and in financial markets and we each had a million dollars to invest, how would we invest it? Well, we would not put all of our eggs in one basket because we wouldn't be quite sure where the best investment returns might lie. Instead we would diversify. I think the same principle holds true if we think about agriculture in the GP. We are not quite sure how the climate will change, we are not quite sure which enterprises are going to be most affected, therefore I think it is very prudent for us to think of a portfolio in which we develop of a variety of tools, any one of which may be the ultimate savior for the region. But we aren't sure which one of those we are to invest in at the present time.

Let me stop at that point. I would be happy to address any questions you might have.

[See Figures following this section]

Questions/Answers:

Do you have any guess as to what sort of cropping changes are to be seen with CC?
I think we will see a movement away from high-water use crops, like corn. I think we will see a dramatic cut down in irrigated wheat production. Meanwhile we'll see more milo production, which tends to be very water-conserving. I think we'll see a reversion of some cropland to rangeland. Those would be the big impacts that I would expect.

If what you say is true about increased vulnerability and volatility within the heartland, how is that going to impact things like crop insurance and other economic features within the GP?
One of the things that Congress is doing is to put more and more importance on things like crop insurance as a risk management tool. For six decades now, farmers have had a very simple risk management tool: If the markets move against you, sell it to Uncle Sam. That is not available anymore. There is a renewed interest in crop insurance. Congress is trying to 'prime the pump'. But I think in a world in which there are fewer federal budget dollars to go around, it is going to be a much more 'pay as you go' program. Thus, you will be able to buy crop insurance in western Kansas, but it will probably cost you more than in central Illinois. And that is as it should be; the risk in higher in central Kansas than in central Illinois. Yes, there will be means of insuring against the risk but there will be a price tag attached and more of that price will fall to the farmer producer himself.

I was wondering about the CRP issue, as we move towards climate change, it can be a stabilizing factor, but how long is it going to be around or what would be its future here?
We've just given the CRP a new 10 year lease on life. I would argue that the CRP, when it was first created in 1985, was created for economic and not conservation purposes. It was when farms were being sold on CBS news. It was being put forward when we had a huge surplus in the world and in the United States. Today I think it got its new lease on life for conservation reasons, not for economic reasons. The wildlife community, environmental community, the soils community, everybody loves this program. And that's why in the end I think it was renewed. What will happen 10 years from now I think is hard to say. My best guess would be that we keep the program but we will trim down its size. Because I suspect the federal budget dollars will carry even a higher premium 10 years from now than they will today.

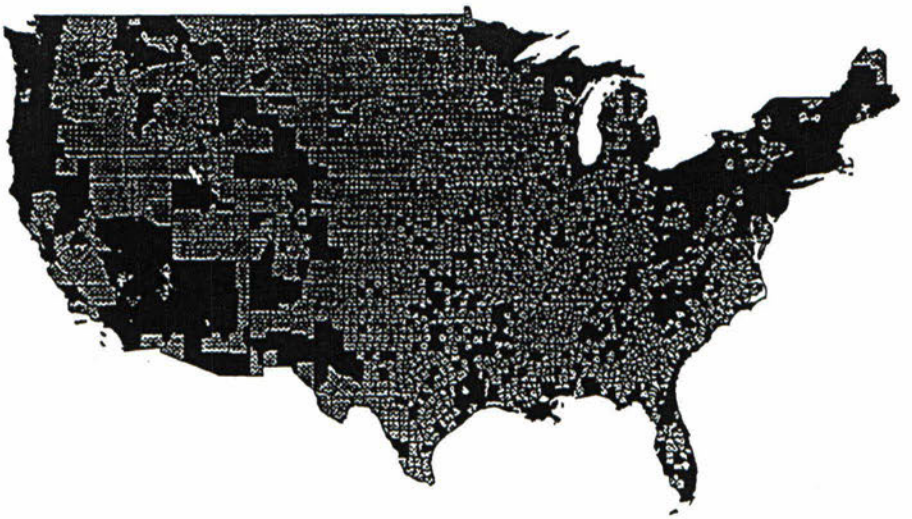
What do you see as the major environmental trends that may very well cause real prices of production to rise on the farms of the GP?
I guess I'm not convinced that prices will rise for environmental reasons so much as that they will rise because of fundamentally strong demand. I think if you look at the capacity that the world has today to produce food and you look at the half-life that technology has in reaching new producers throughout the world, I am persuaded that we have a large capacity to respond to climate change throughout the world. However I also am persuaded that we are entering a period in which demand is growing for very fundamental reasons throughout the globe and I think that will continue to put pressure on available supplies and will probably prevent prices

from declining over the next few years as they have if you look at long-term trends.

I meant costs of production, rather than prices for the commodities themselves. Do you see any chance that the environmental damages from farming could cause costs of production to rise on farms if farmers were held accountable for those in economic terms?
I guess that I am not convinced that we are going to see substantial change in environmental regulations that will substantially raise the cost of farming. I think that we are on the edge of a new horizon of biotechnology tools. There is a great debate among economists as to whether these will be output-increasing or cost-reducing. I think the tendency tends to be that they will be cost-reducing, so that might very well offset any increases in costs that might be due to new environmental regulations.

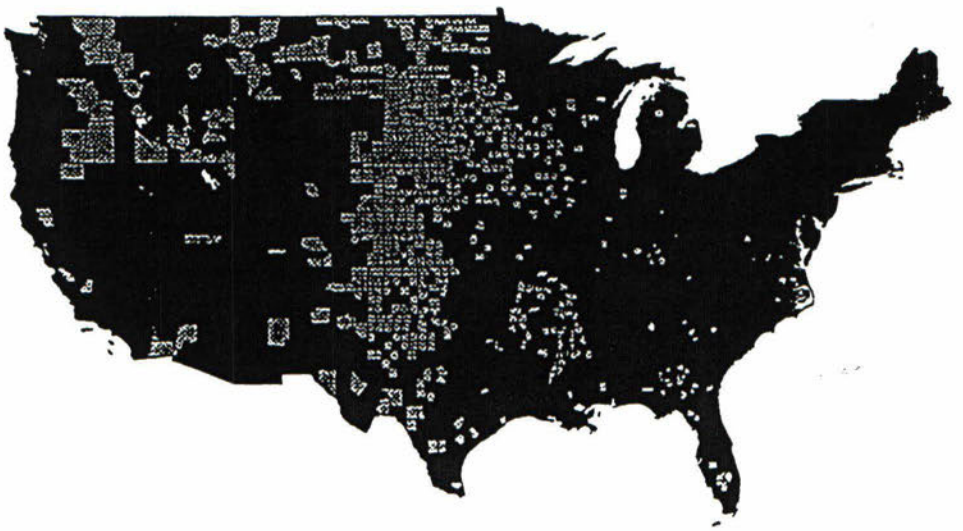
Farm-Dependent Counties

1950

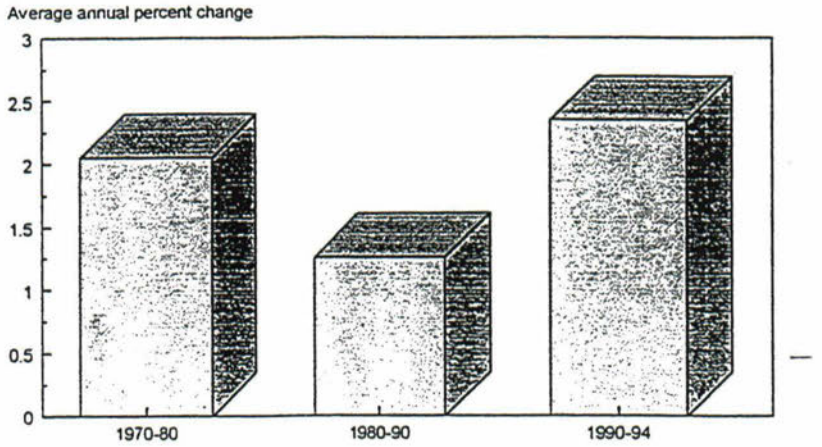


Farm-Dependent Counties

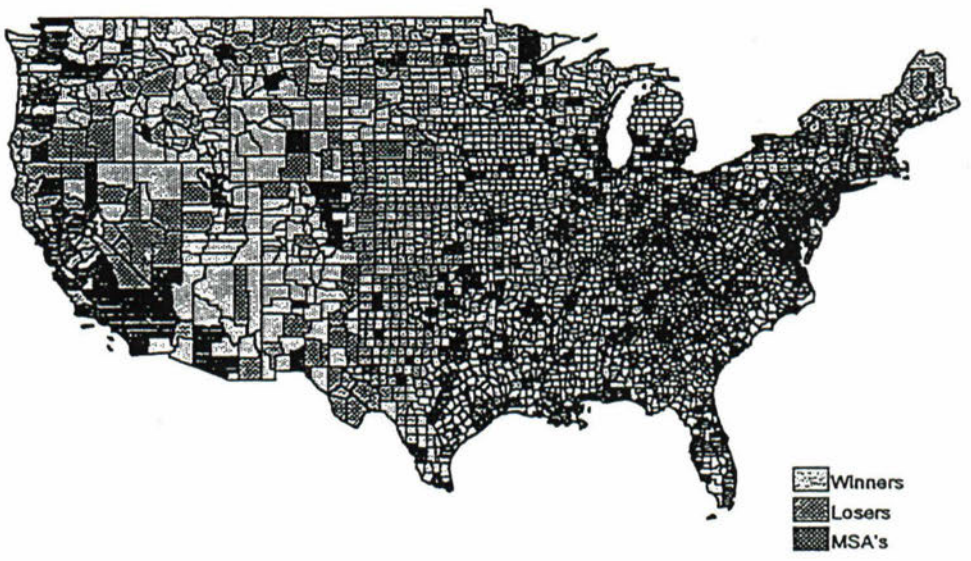
1989



Rural Employment Growth
United States

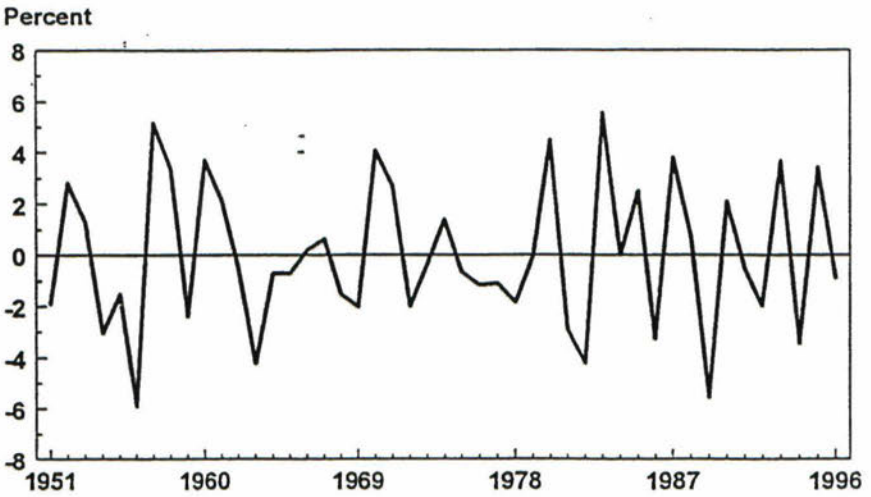


Rural Winning and Losing Counties



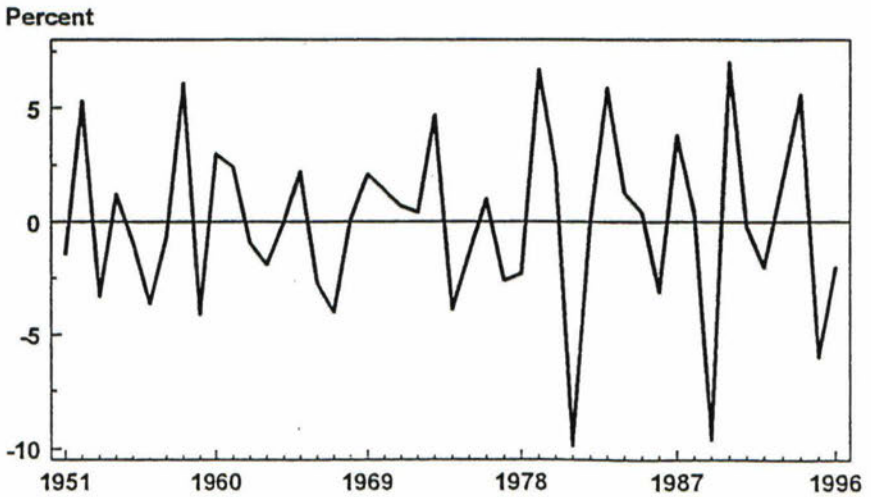
U.S. Wheat Yield Volatility

1950-1996



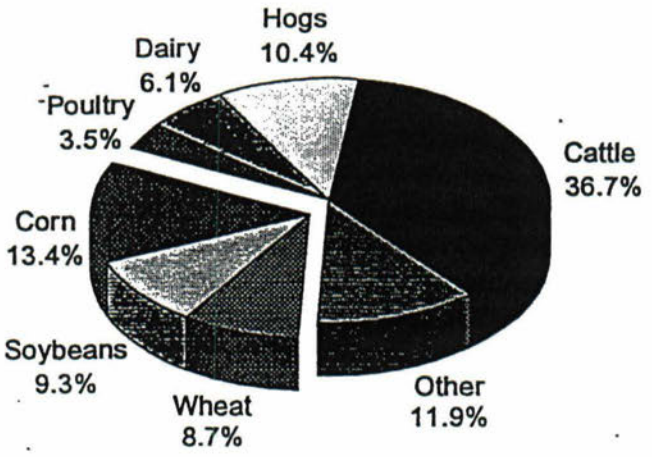
Kansas Wheat Yield Volatility

1950-1996

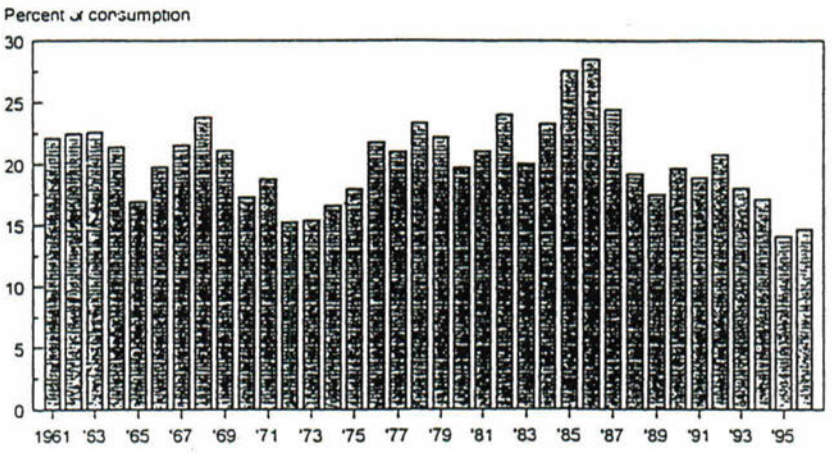


Share of Heartland Cash Receipts

1995



World Grain Inventories



iV WORKING GROUP REPORTS SUMMARY

The following is a summary of the results of the four working groups from the great Plains Climate Change workshop. Each group focused on the resource issues of one of the following areas: Biology, Social, Soil, or Water. It was the intention for these discussions to be cross-cutting and to some degree cover areas related to the other groups. The individual working group reports have been consolidated and issues reorganized to artificially fall under only one group. An additional category of Information was added to capture some items common to all the groups.

GROUP FOCUS:

Biology: To discuss issues related to changes in communities of plants and animals, such as invasive weeds, specialized crop or animal breeds, or pest outbreaks.

Social: To discuss issues related to vulnerability or risk of different communities in the Great Plains, social or political structures availability to offset impacts, economic and political considerations for developing strategies for coping with climate change impacts.

Soil: To discuss issues related to soil erosion, soil fertility, carbon storage, salinization.

Water: To discuss issues related to water quantity and quality and how these may affect human and ecological conditions.

GROUP CHARGE: To address the following questions for their resource area:

What issues are of concern in this area presently?

How might climate change affect those issues?

What are the research needs for preparing for and understanding climate change consequences in this area?

What are the coping strategies available for needed for dealing with climate change effects in this area?

REPORT ORGANIZATION:

I Issues
II Climate Change Effects
III Research Needs
IV Coping Strategies.

Group 1: BIOLOGICAL RESOURCES

The focus for this group was to address issues of concern related to biological resources such as, changes in plant and animal communities, including introduction of invasive weeds or pests, and specialized crop and livestock breeds.

Categories:

A. Native biota and processes
B. Cultivation agriculture and livestock
C. Recreation

I and II ISSUES AND CC EFFECTS

A. Native Biota and Processes

This category includes population-, community- and ecosystem-level considerations of native biota that persist in small preserves and interstices of the eastern, intensively cultivated portion of this geographic domain, and expand to be the dominant components of the rangelands in the western part of the domain. The entities of focus here--populations, communities and ecosystems of mainly native biota, have a different character from cultivated agricultural systems in particular, in that they are often complex in their composition, and are self-maintaining. They survive from one year to the next on the adaptive value of the traits with which they have evolved. They are less likely to benefit from ameliorative actions by humankind. As a result, they are more vulnerable to land use change and climate change, and have a lower potential for adaptation to climate change than do agricultural systems. Particularly because of landscape fragmentation, native species will have difficulty dispersing or migrating to new locations of appropriate physical environments as opposed to deliberate planting and transport of agriculturally important species.

- Invasive plants and animals

Changes in climate due to human-caused increases in CO2, methane and/or N2O have a high probability of augmenting the invasion of non-indigenous plants and animals and increasing the vulnerability of native flora and fauna to disease. It is assumed that native species will not be able to adapt fast enough to new climate regimes and thus will be stressed, lowering their competitive edge and resistance to infections. Scenarios of increased average temperatures and precipitation may allow problem invasive plants now found further south to migrate into the central Great Plains (e.g. kudzu, Johnson grass). A warming and drying trend may reduce vegetative cover and provide open niches for invasion of species. Changes in water regimes may favor the invasion and increase of exotic mussels and fish at the expense of the native aquatic biota. Impacts could range from shifts in the relative abundance and distribution of native species, decrease in forage quality of rangeland, significant changes in species richness and assemblages to extirpation of native species.

It would be prudent to take the steps now to better understand the process of invasion and effects of invasive plants and animals. Information is needed on a regional basis on the distribution and abundance of non-indigenous species. Analysis should be conducted species by species to determine which species pose a serious threat to managed resources (usually a

small percent), and those that have a high potential to spread rapidly and cause impacts (based upon life history characteristics and history in other areas with similar climates).

- Predator-prey imbalances

There are already imbalances in predator-prey relations that are due to either the loss of the top predator (e.g., by loss of habitat or loss of prey such as black-footed ferrets and prairie dogs, or deliberate extermination such as with wolves, etc.) or the rapid response of the prey populations to climatic factors (e.g., temperature and precipitation). Examples were given of growing difficulties managing Plains waterfowl in the face of red fox predation thought to be due to a complex reaction to coyote management by Ray Stendell. Climate change could accelerate these changes either directly (e.g., temperature response of insect/prey populations) or indirectly (e.g., through habitat fragmentation and underlying changes in the food web).

Insect populations tend to be tightly coupled with climatic variability (i.e. temperature and precipitation) because of the potential rapid response of the population dynamics. Predator population dynamics are generally damped and slower relative to the prey dynamics. There are many examples of this issue throughout insect populations: e.g., grasshopper population boom under dry conditions; increasing dry conditions are a part of tentative climate change scenarios for the Central Plains.

- Habitat change and fragmentation

Terrestrial habitat is largely defined by vegetation. Species composition, physiognomy or spatial distribution of vegetation types vary with environmental conditions and disturbance events. Typically, particular environments also feature one or more recurring disturbance type with a characteristic frequency. In presettlement time, vegetation (ecosystem) types occurred as large tracts, extensive continua, or mosaics. In some cases, similar habitats were connected by corridors of analogous environmental conditions such as rivers and ridgetops. For some species, these corridors were critical for maintaining metapopulations over large areas.

The original extent and spatial pattern of habitat was disrupted in the Great Plains more or less in proportion to the conversion of land to agricultural or urban use. Thus, original types of habitat are widely dispersed or absent in the agriculturally rich, eastern portions of the Great Plains, they are more frequent, if disconnected, in the central portion, and are highly continuous and in most ways similar to former condition in the western margin of this geographic area. This regional-scale, quasi-gradient represents the template for the persistence of native species. The existence of some species may be dependent on sufficient appropriate habitat, sufficient core areas, or sufficient connectibility between patches of appropriate habitat. For such species, appropriate habitat may entail very special edaphic or disturbance properties as well as climatic envelopes.

Maintenance of native biota is a difficult problem under circumstances prevailing in the wester margin of the region, where native habitat is more or less continuous. Maintaining sufficient habitat with sufficient connectibility is nearly impossible in the intensively agricultural parts of the region. If climate change is added to a highly fragmented and altered landscape, the problem of maintaining relatively common species, much less rare and endangered species, becomes highly problematic. Changes in temperature, precipitation amount and timing, and variability can all influence such species through a number of

unpredictable mechanisms ranging from straightforward ecophysiological requirements, to pollination, predator-prey, and esoteric pest/parasite relations.

While maintenance of the original biota may be extremely difficult in the eastern portion of this geographic area, the problem becomes perhaps easier where native rangelands still prevail. Vegetative physiognomy, species composition, and other ecosystem properties may change in unpredictable ways, but there is a higher probability that native species may find themselves in acceptable habitat where dispersal is not inhibited by fragmentation.

- Biodiversity

Biodiversity encompasses the full array of native plants, animals, natural communities, and ecosystems that occur within the Great Plains. While the plains do not contain high numbers of species, there is a significant number of species that are (globally) rare, threatened, endemic, and/or declining. For example, there is much concern over the decline of endemic grassland birds, such as the mountain plover. Adequate habitat for shorebirds and neotropical migratory birds is another major concern. Biological inventories have been limited, and thus we lack a good understanding of the current systematic status of biodiversity. Additionally, there is a lack of baseline reference information on areas, particularly those that support large intact (naturally functioning) ecosystems, to preserve and maintain native species and communities. Biodiversity has become a societal value in itself, but ecosystem preservation is also important for hunting, fishing, recreation, and tourism.

Climate change will have variable impacts on biodiversity. With temperature change, not only will species need to migrate, but a number of species will likely go extinct, both locally and regionally. It is likely changing land uses will also impact habitats of native plant and animal species. Natural migratory routes will likely be altered/interrupted with changing climate.

B. Cultivated Agricultural Systems and Livestock

This category includes those agroecosystems totally managed by farm operators. They involve tillage, planting of prescribed crops, often monocultural, fertilization, and sometimes herbicide treatment and irrigation. These are relatively simple but highly productive systems, particularly in terms of commodities useful to man or poultry or livestock. Because they are so intensively managed by man, they can benefit from management strategies and decisions by farm managers. In that sense, they are more adaptable to climate change.

- Crop plant gene pool maintenance

Changes in demographics results in an increasing destruction of habitats and this leads to an attrition of the biological diversity. Most countries of the world are experiencing a loss of species diversity or a loss of heterogeneity within a species at an alarming rate. The US has one of the lowest rates of extinctions in the world. While the US and the Great Plains in particular, must be concerned with the loss of heterogeneity of their indigenous species, the well being of the US agricultural system must also be concerned with the loss of biological diversity in other countries (which is happening at a faster rate than in the US).

The concentrations of genetic diversity of species occurs near the centers of origin of that species. With few exceptions (e.g., sunflower, cranberry) most of the agronomic species in the US originate from other parts of the world. The main crops for the Great Plains: corn,

soybean, and wheat, have centers of diversity in Latin America, Manchuria, and Mid-East Asia, respectively. Thus, for raw materials for breeding of our cropping systems do not belong to us and are being lost.

We need to be concerned that climate change will accelerate the extinction of local populations that are endangered. The same principles apply to foreign populations. It is the loss of these foreign populations that will make American agriculture extremely vulnerable to climate change because it puts at risk the raw materials we will use to breed crops to adapt to the local biotic and abiotic stresses that result from changes in climate.

- Maintaining livestock germ plasm

As with the genetic engineering of new and more resistant crop varieties, geneticists/breeders of livestock will hopefully be able to develop new lines of livestock which are better able to tolerate extreme heat waves combined with high humidity. Additionally, breeding programs should select for improved resistance to pests, disease, and pathogens. An additional goal would be to breed for reduced methane production or to improve forage quality which could also reduce methane production.

C. Recreation

- Wildlife and Fisheries Resources

The rural communities of the four state area highly value their access to public lands for hunting, fishing and general recreation. In the case of fishing and hunting, land and water resources are often intensively managed by state or federal agencies to provide the public with the prey species of choice. The ability of these agencies to add or change these resources is extremely limited given that they are dependent on the availability of tax money.

Should climate change negatively impact the management situation of one of these resources, the recreation opportunity could decrease or disappear altogether. For example, spring rainfalls of increased frequency and intensity could severely impact the nesting success of ground nesting upland birds in a public hunting area. Likewise, bodies of water used by anglers are very susceptible to increases in water temperature. Each of these examples could eliminate a public use opportunity.

Wetland and riparian systems are critical part of the lands intensively used by hunters, anglers, and non-consumptive recreators (birdwatchers, etc.). The impacts to these habitats are covered elsewhere in this document but their importance to the public land users is worth noting here.

The hunting and angling communities represent an important political constituency within this issue. Let's face it, these folks invest considerable sums towards these activities and negative changes due to global warming will not be ignored. So they need to be involved as soon as possible. One way to do this is to develop models to help determine how habitat and quality changes will impact wildlife and fisheries. Use these studies as communications and education methods to involve this constituency. Although it's important to get them involved, the information must be translated into "lay people" terms. They should be supportive if they clearly understand.

Recreational activities play a large role in the lifestyle of those who live in the Great Plains, and to those who are attracted to it for purposes of recreation and tourism.

Climate variability will add a great deal of uncertainty to those who plan activities in

the Great Plains area. The economic base may also be eroded though decreased tourism and recreational dollars coming into the Great Plains states.

III RESEARCH NEEDS

- Invasive Species

Prevention remains the preferred method of management of invasive species. Thus systems need to be developed for early detection of known invasive and disruptive species. Additional research needs to be conducted targeted to increasing our understanding of what effects the invasability of various habitats has, how climate change will affect invasability, and what management practices increase the resistance of habitats to invasion.

Research on effective control of known invasive and disruptive species needs to be accelerated. Methods developed should employ the principles of integrated pest management (IPM).

Finally efforts need to be made to develop regional cooperative invasive plant and animal management programs with commitment from all concerned parties. Closely related, further efforts should be made to increase the awareness of the public of the threats and impacts of invasive species.

- Predator-Prey

Research needs focus on the refinement of understanding of the basic ecological interactions that underlie several of these predator/prey dynamics and their sensitivities to climatic variabilities. Research should focus both on the direct impacts of climatic variables on predator/prey populations dynamics and the indirect impacts through altering habitat.

- Habitat Change

Research needs in this area that bear on contemporary problems as well as climate change considerations are:

- Refine continental and regional scale climate change and vegetation modeling as a means for planning on coarse changes in potential or actual vegetation, and thus, habitat, change.

- Connect continental and regional scale climate models to land use models in order to predict how land use change will impact the spatial distribution of remaining habitat in terms of patch size, patch shape, corridors and connectivity in general.

- Refine our knowledge of the ranges of tolerance of keystone or diagnostic species within habitat types.

- Develop effective partnerships with private land owners to protect habitat on private lands.

- Biodiversity

Research is needed to address impacts of climate change on biodiversity. First, we need inventory and information in order to effectively monitor species and communities and need to support/maintain biodiversity databases. We need to pursue identification and formal protection of reference areas and/or conserved areas which conserve places to observe and detect climate change impacts on natural grassland systems. We need to build experimental

designs to test hypothesis over long time periods. We need to research the impacts of climate change on our already declining Plains native fish populations.

Native plants/perennials need to be diverse to withstand a wide variety of climate conditions. Warm/wet, cool/wet, etc. (Diversity and resiliency)

- Diversity of crops and livestock species

Historically agricultural geneticists have improved cultivars of crop species making them more drought- and temperature-tolerant etc. as well as greatly improving yields. The hope is that such "precision agriculture" will continue to improve crop varieties making them even more resilient to drought, extreme heat, pests, pathogens, diseases and other stresses, especially under elevated CO2 atmospheres. We believe that this is a critical and highly profitable research goal. How quickly the geneticists can develop new more resistant crop varieties may be come an essential challenge. The private sector seed companies may play an important role in this effort.

An essential element which will enable this genetic engineering is maintaining populations of the crops' ancestral gene pools. In many cases, those ancestral populations are found in remote regions of the world. Conserving this wealth of biodiversity may enable geneticists to breed new and improved varieties which will be better able to cope with climate change.

Additionally, there should be further research into the use of alternative crop species which may be better able to thrive under the changing climate regimes. The expansion of legume crops may help to reduce the use of fertilizers.

Genetic research should be targeted toward specific, well-defined goals. First, crops resistant to a highly variable climate, such as drought or heat resistant strains, should be developed. Next, species diversity rather than monoculture should be encouraged to ensure the survival of crops that might otherwise be vulnerable to plant disease or resistant pests. Research should also utilize genetic modification of livestock, or select livestock species capable of withstanding the increased stress associated with climate variability.

- Recreation

The agencies responsible for management of these public lands need to increase their vigilance of fish and wildlife population trends to react appropriately. In some cases, adjustments to the habitats (such as additional cover species planted on uplands) could allow the land to continue in its present use.

IV COPING STRATEGIES (?)

Group 2: SOCIAL RESOURCES

The focus for this group was to address issues of concern related to social resources such as, the vulnerability and risk of different communities in the region, existing social and political structures available to offset impacts, and economic and political considerations for developing strategies in place for coping with change.

Categories:
A. Economic
B. Political
C. Social

I and II ISSUES AND CC EFFECTS

A. Economic

- Economic/Profit Variability

Market variability combined with the high climate variability affecting production can lead to even more extremes in year-to-year profit variability, which makes long-term investments more difficult. Current tax policies exacerbate the problem (see government policy below).

CC effects: Increased climate variability would exacerbate the present stress associated with high precipitation variability. There would be increased problems, especially if there were increases in the frequency of hail and intense storms.

Costs of Production

Increasing costs of production inputs such as fertilizer, pesticides, seed for specialized niche crops was seen as an increasing stress. High capitalization costs for more diversified operation (e.g. incorporating livestock) was seen as a constraint.

B. Political

- Government Policy/Agricultural subsidies

Farmers had adopted to the Federal policies that had been in place for years; now they must adapt to a new, market-based policy. Their safety net has been cut. This change will stress the system, and climate change will exacerbate the stresses by forcing parallel adaptation to new crops and practices. In the future we can expect that global market changes will impact the farmer more under the market-based policy, making adaptation to changing climate even more difficult.

General Government Policy Issues

It was pointed out that in the past farmers were able to income average for tax purposes, but this is no longer allowed. Because of the inherent high profit variability for Great Plains farmers, the lack of income averaging possibilities hits them disproportionately hard. It can force them to store more grain than they might like to, requiring additional investment in storage facilities and may mean that they're not able to sell when the market is most favorable. Declining support for research and extension was seen as an issue. Greater

multi-use demand on public lands with conflicts over grazing licenses, riparian areas, rangeland condition and access was discussed as a possible "stress" factor.

CC effects: There would be an increased need for maximizing water use efficiency and a tendency to adapt management to "catch every drop" from intense storms (e.g. furrow diking, retention ponds). This would strengthen needs to implement of watershed approach to maximize water use efficiency and prevent conflicts with other water users.

Conservation Reserve Program (CRP)

There was a generally favorable view of the CRP but suggestions that some of the regulations and side effects were detrimental. Limitations on use of legumes in some areas resulted in poor stands due to N limitations and therefore reduced benefits for soil recovery and enhanced soil C storage. More flexibility in uses of CRP (e.g. grazing) should be considered to improve the vegetation (e.g. low-moderate grazing is beneficial to grassland health) and derive additional benefits. It was pointed out that CRP had undesirable side affects such as decreased rural employment in areas with a high percentage of CRP and elevated land prices.

Water Laws: Present legislation, regulations and compacts sometimes limit the water management practices that could result in more effective use of surface and groundwater. Diverting water from a river just to protect a diversion or water right is not the most efficient and economical use of that water. Over-irrigation and seepage with this diverted water leaches nutrients and potential pollutant into the groundwater aquifer while runoff caries nutrients, salts ant other pollutants back into the river. Transfer of water from basin to basin and aquifer to aquifer would, in many instances, allow these waters to be used from maximum, or at least, optimum returns.

C. Social

- Air

Air quality is a social issue because many sectors of society interact as winds transport air pollutants across regions. Examples include: Feedlot odors affect property values; particulate matter from transportation and agricultural operations affect health and visibility, consequently affecting tourism and recreation; drifting pesticides can affect health of humans, animals, and crops. All of these can be affected by a change of climate regime. Other environmental concerns that can impact air quality are issues involving nitrogen deposition, ozone, methane emissions, and visibility.

- Capture and use of wastes

Many farming, livestock, and urban wastes represent both potential energy resources and/or sources of greenhouse emissions. As such they represent both potential assets and liabilities for society as a whole, but may be neither valuable enough nor noxious enough for the original generator to deal with them productively. Accordingly, society might benefit by providing incentives for waste generators (or others) to convert these waste potentials into actual benefits.

- Farming Options

Flexible grazing choices: Rapid climate change may result in a response of range

vegetation which could include significant changes in species composition, productivity, palatability, and forage quality. Changes could be of a scale that would require changes in stocking levels, grazing regimes, or may require a shift from cattle as the primary product to alternatives such as buffalo, goats, sheep. Changes may be so drastic as to warrant major shifts in marketed animal protein to exotics such as emu and ostrich, or prairie rodents such as rabbits. As the future is difficult to predict, it would be prudent to research the feasibility of various alternatives under different climate changes scenarios.

Diversity pertains to diversity of production and income. Off-farm income is an important risk aversion technique, especially for monoculture enterprises.

Marginality relates both to the quality of the land and its resources and the economic stability of the farmers/ranchers. Marginality is tied to resiliency, e.g. land resources and human resources have been pushed to their limit, areas with marginal soils rarely bring in enough income to allow for wide-based risk aversion strategies. Under the stress of climate change, the marginal land resources and/or the human resources will not be able to respond. Resources have been "used up". Marginality/resiliency affect land resources, human resources, endangered species, etc.

Options includes issues such as the availability of jobs to provide off-farm income as a risk aversion strategy in the event of climate change or other events. Options also includes availability of credit, avenues for information dissemination, etc.

Farmers don't want to be part of the problem, they want to help find a solution. Through diversity, farmers would be able to meet these challenges and better position themselves in the market. The ability to diversify would also help them to minimize their risk by allowing them to better meet the variability that climate change may present. What crops are more drought tolerant and more resilient to climate change variability? Are some species of livestock stronger, better able to adapt to changes?

Constraints on Agriculture Diversification

The climate of the Great Plains limits options for diversification in management, i.e. less flexibility in planting dates, a limited number of suitable crops. The need for legumes that can be successfully integrated in dryland crop locations, along the lines of the Australian annual legumes, was emphasized, both as a source of forage and as an N source to help rebuild soil organic matter stocks. Social and lifestyle issues are important factors relating to diversification with many younger farmers lacking interest (e.g. wanting free time in winter) or experience in dealing with livestock, with increasing specialization in straight cash grain production systems.

CC effects: Climate change could act negatively on some diversification options, such as incorporation of summer crops (e.g. corn) in rotations due to an increased vulnerability to extreme events such as hail. There could be some new opportunities for use of additional crop types with increased temperatures, but added moisture stress might outweigh the positive effects. However, with greater climate variability diversification of agricultural options would become even more important.

- Tribal Lands (not fully addressed)

Consideration of economic, social, and ecosystem impacts on tribal land must be included in climate change discussions of the Great Plains and other regional workshops, e.g.,

North and South Dakota.

- Human health impacts

Human health concerns are a top priority to discussions involving environmental considerations. Under a scenario including variability, concern was raised that increased disease vectors and pest infestations may become more prevalent in the agricultural sector of the Great Plains. The concern expressed from the farmers/ranchers in the group was focused, in particular, on the impact of disease and pests on crops and livestock. Big issue problems, like Mad Cow disease, etc., can impact the public perception and/or markets.

Health impacts are also important as they relate to air borne pollutants. If, for example, under some climate change scenarios, the evaporative demand of soil moisture increases and soil dries out. The loss of vegetation to agricultural fields and open areas may make these areas more susceptible to soil erosion and blowing dust during high wind events.

Ozone can also become more prevalent given higher temperatures in the urban areas. Making a determination about ozone levels in rural areas is more difficult to estimate because ozone monitoring networks are concentrated in the heavily populated urban areas, and not in rural areas.

Regional transport of air pollutants (and blowing dust) are concerns given climate variability, coupled with new particulate matter and ozone/visibility standards that EPA will announce this summer. The new standards need to be looked at when considering various climate change scenarios.

Concerns were raised that certain groups of the human population are more likely to be affected by climate change than others. Examples include: poorer populations, marginal rural areas, intercity poor, migrant/ethnic groups, Native American groups.

- Development/Population

Rural housing development: On both the eastern and western margins of this region, grazing land is being taken out of production by urbanization or being fragmented by construction of small acreage homesites (ranchettes). While not large in magnitude, it is significant because this phenomenon is mainly taking place in ecotonal areas around metropolitan areas on the eastern margin, and around the ecotonal foothill zones of the western margin of the region. This trend is especially critical from a wildlife point of view.

Population issues include both population growth and depopulation of rural areas. Growth issues cross cut issues of land and water use. Growth in nearby urban areas can impact the amount of water allocated to agriculture. Depopulation is a response to changing conditions. This response is often a relocation of the population rather than a depopulation.

Absentee Ownership

There is an increasing trend towards absentee ownership in the region. This acts as a general disincentive (in most cases) for tenant farmers to make investments in improving the soil resource. A very striking example was given of the interaction between social and ecological stresses in regards to reducing the amount of bare fallowing by adopting more continuous crop rotations. It was suggested that for tenant farmers, paying 1/3 of the harvest for land rental, it was more economical to use wheat-fallow (thereby effectively paying rent on only

1/2 of the land each year) then to pay higher rental rates (with more crops harvested) if more continuous cropping were adopted (presumably because of the lower marginal return from a summer crop (e.g. corn) following wheat than for wheat following fallow. However, the reverse could be true for owner-operators, with the more continuous cropping (i.e. more environmentally beneficial) systems being more economical.

New Farmer Recruitment

Problems with new farmer recruitment and the "graying" of the present farm population was seen as an important stress. Increased cost and land availability as well as changes in life style contribute to this. Related issues are needs to secure knowledge transfer and mentoring of new farmers, since there are more farms which are not being taken over by the farmer's children.

Decline in Rural Lifestyle

Lack of amenities, compared to modern urban life, and a declining infrastructure and service sector in rural communities was seen as a stress that contributes to problems of recruiting new farmers.

Urbanization

Stresses include the loss of prime agricultural land and water supply conflicts with the increasing population and urban growth along the Front Range and in the Platte River system.

III RESEARCH NEEDS

- Policy/Regulations

Water Laws: There is a need to evaluate existing water law to identify where changes are needed and if uniformity of law is necessary for the practical adaptation of water management strategies to meet changing conditions.

Environmental regulations: A better understanding of the relationship between environmental regulations and water demands/availability will help define management strategies. Adaptation to future climate stresses require an understanding of constraints imposed by environmental regulations. For example, permitting processes under the Endangered Species Act require maintaining river flow conditions that may constrain water management strategies.

- Waste

Research needs on (1) how to do the conversions, and (2) how to provide cost-effective incentives

- Health questions to be answered include:

What are the health issues related to climate change scenarios? What are the air pollution issues related to agricultural operations and climate change? Alternative energy sources such as biofuels, wind, methane as an alternative fuel, etc. What role can farmers play in this technology?

- Options

Flexible grazing: Animal husbandry research on unconventional herbivorous animals along with market and production economics is needed to make these options available to livestock producers.

Develop models and decision-support technologies to examine options beyond the traditional crop and management practices.

Incentives: How can incentives be used to shape adaptability, resiliency, etc.? What incentives work, which are politically viable?

- Development

Rural housing development: This phenomenon is not particularly climate related but mainly requires some social science research and planning considerations.

IV COPING STRATEGIES

- Economic viability

Ranchers/farmers need to get out of debt and stay out of debt, while maintaining a systemic approach. "Living with what they have to work with". In short, cropping practices need to minimize the costs, risks, and failures.

- Policy

Development of mitigation plans at the local level will facilitate better coping with climate change. A vital component to any mitigation strategy is planning. Physically, emotionally, and psychologically, people better cope with a disaster or a change if a preparedness or response plan is in place. In the Great Plains region, the first priority in planning is to make planning decisions at a local level. Although a federal agency should be appointed to lead and coordinate planning efforts, the plans must originate from the community. The plans should allow for maximum flexibility in dealing with the variability of the climate.

Group 3: SOIL RESOURCES

The focus for this group was to address issues of concern related to soil resources such as, soil erosion, fertility, salinization as well as land management issues. Many issues related to solving soil problems relate to problems in the socio-economic sector that inhibit implementation of sustainable practices. They are addressed under that sections of the report.

Categories:
A. Soil Quality/Degradation
B. Land Management
C. Disturbance

I and II ISSUES and CC EFFECTS

A. Soil Degradation

The current stresses on soil and land resources for agriculture in the Central Great Plains are to a large degree associated with the conventional dryland cropping system of wheat-summer fallow practiced in the region. Briefly, this practice consists of fall (Sept) planting of winter wheat which is harvested in early summer (June-July) the following year. Fields are then bare-fallowed for the remainder of the year and through the following year until the new fall planting. In the bare fallow phase the soil is periodically cultivated to suppress weeds. Thus, over the two year period the soil is without vegetation cover and is periodically disturbed over a 14 month period. This system was developed to cope with the low and highly variable precipitation in the region, in that the fallow period allows soil water to be stored for use in the subsequent crop. In addition, nutrients released during the fallow period are often sufficient to meet crop requirements and historically nil or only low rates of fertilization have been used. This system has conferred production stability, in the short-term, to farmers in the region but has also led to a variety of problems which call into question its long-term sustainability. Under wheat-fallow, soil organic matter typically declines by 50% or more due to the low rates of residue return and the favorable conditions for decomposition, with intense soil disturbance, during the fallow phase. The 'mining' of nutrients and organic matter is highly negative to soil structure and fertility. Crop water use efficiency is low and with periods of excess water, nutrient leaching below the root zone and formation of saline seeps on hillslopes can occur. Clean fallow practices leave the soil susceptible to wind and water erosion.

These ecologically-based stresses interact with a variety of other stress factors relating to economic, policy and social conditions for agricultural communities in the Great Plains. While solutions (see section on Coping Strategies) to the problems of soil degradation due to conventional farming practices are largely known (and are to some degree being implemented at present), many of the economic, policy and social stress factors interact, often in subtle ways, to inhibit opportunities for the greater implementation of more sustainable practices. Therefore many considerations of interest to this group regarding barriers to improved management of the soil resource can be found in the Social Section of this report.

- Soil Quality

As outlined above soil degradation has been and remains a problem particularly with summer- fallow management practices, leading to soil organic matter depletion, degraded soil structure, increased erosion risk, potential for nutrient leaching and saline seeps together with reduced water use efficiency.

- Soil degradation and rangeland conditions

Warmer temperatures would add an additional stress on organic matter maintenance due to higher potential decomposition rates. More intense storms could lead to increased erosion. It was believed likely that climate change could result in an increase in exotic pests. Warmer conditions in spring and fall would be expected to favor increased competition from cool season weeds.

B. Land Management

- Rangeland utilization/management

Mixed farming operations incorporating livestock and rangeland with crop production offers advantages in diversification and efficient use of resources. However, economic and particularly social factors (see below) are significant barriers. Low rates of return make it difficult to invest in rangeland improvement. Invasive weeds are a problem due to the greater fragility of semi-arid rangelands and again high costs relative to economic return for control measures. Producers in the workgroup perceived a decline in government support for research focusing on mixed livestock-crop production systems.

Management of native, semi-native and domesticated rangeland becomes a widespread land use in the central portion of the Great Plains where terrain is rough and in the Nebraska sandhills and is the dominant land use throughout much of the area in the westernmost portion, except where flood and riverine-derived spray irrigation dominates along riparian systems. Some rangelands are composed of domestic or native cultivars planted as highly managed pastures, but much of it is composed of native grass-dominated ecosystems derived in an unknown form from presettlement time. These more extensively managed rangelands of the western margin of the geographic domain overlap with the native biota part in the Biology section.

The rangelands of the western portion of the Great Plains have undergone extensive changes in use from presettlement grazing by native bison and pronghorn antelope and small mammals, to extremely heavy use by cattle and sheep in the late nineteenth century, to the more moderate grazing levels practiced in the latter part of this century. While it is widely accepted that rangelands are in better condition now than they were in the 1880s, we do not have good benchmarks for the state of rangelands before the introduction of exotic ungulates. The issue of "rangeland condition" and "good range management" is an undying one of intense resource use and political debate. Recently, the traditional measure of rangeland condition within a successional paradigm has been discarded, but as of yet, there has been no replacement in terms of structural or functional properties. Setting criteria for, and judging rangeland condition is a research issue today.

Evaluation of range quality and ecologically sound range management is best divided between the vast areas of upland range and the much smaller but crucial riparian zones. While most would agree that the upland range is generally in good condition by most criteria,

the situation for riparian zones is quite different and quite variable. In some instances, improper use of the riparian zone through overgrazing or grazing in the wrong season has led to loss of riparian vegetation and disruption of the geomorphological balance of the stream system itself. Streams that formerly had broad floodplains are now deeply entrenched and surrounded by low grade vegetation of the high, surrounding benches. Another problem with riparian zone management is the withdrawal or impoundment of springtime and storm flows so that seasonal floods are rare or non-existent. Without occasional floods of the appropriate frequency and magnitude, some riparian species such as cottonwood are not reproducing and entire gallery forests are being lost to attrition of aging trees. With the loss of gallery forests are lost non-game species and game species habitat.

Climate change, involving either long-term secular trends, or changes in variability around current mean conditions, is likely to change the character of rangelands. Native rangelands usually involve a number of plant species sorted in various ways along environmental gradients or reflecting historical accidents of disturbance. Climate change in terms of temperature ranges, precipitation amounts or timing, are likely to alter the composition of the rangelands in either a more xeric or more mesic direction. Climate change may also alter the occurrence or abundance of woody, graminoid or forb species. Such changes will redefine baselines for range conditions on particular sites and along environmental gradients. In the processes of native species losses and replacements, disturbances may enhance establishment opportunities for alien plant species. Changes in soil carbon, nitrogen dynamics and erosional processes are likely to be complex as are plant herbivore relations with mammals and insects. These disruptions will extend to riparian zones as well as to the upland matrix and in some circumstances may be even more serious where regular water supply and particular flood frequencies and magnitudes are mandatory for ecosystem maintenance.

C. Disturbance

- Disturbance regimes

Disturbance patterns play a major role in structuring biotic communities, creating a range of environments that favor different species over time. Mortality or removal of plant material by fire, drought, freezes or erosion creates environments that may favor some species of plants or animals over others. Since many disturbances are linked to climate, if climate patterns change, then the types and frequencies of disturbances may also change. For example, changing patterns of temperature and precipitation could affect wildfires directly and indirectly by favoring more or less combustible vegetation. Climate changes could likewise alter streamflow regimes, impacting low water or flood impacts on aquatic and riparian communities. In evaluating the effects of climate change on natural and managed ecosystems, the possibility that effects may be manifest through changes to disturbance, rather than by direct physiological effects on organisms, must be given a high priority.

Land is closely tied with water and with issues of allocation and control of the water. The salient trend is increasing development of land, a social phenomenon, and stresses develop when growing population collides with multiple competing uses: farming, grazing, timber, watershed protection, mining, and recreation. Fire and pests also "compete" with these uses.

Climate change will potentially change the dynamics of balance among these

competitors, increasing social tensions. For example, decreasing precipitation and/or increasing temperature could make watershed protection more important and fire more likely.

- Fire

Agricultural burning and wildfire in the forest areas of the Great Plains were two concerns raised by the group, but not further discussed. The concerns raised include: a change in the frequency of fire (especially with wildfire). If precipitation increases, fuel will increase on the forest floor. Under a drought scenario, forests will be more susceptible to fire. The use and frequency of agricultural burning may also increase under climate variability.

- Coal mining

Extensive strip mining for soft coal occurs in thick beds in the Powder River Basin of northeastern Wyoming. All of the minable coal seams lie in an area which is a coarse mosaic of sagebrush-dominated, or grass-dominated rangeland. The vast majority of this rangeland is composed of native species in generally good condition, and is managed for cattle, and to a limited extent, bison. Upland wildlife is abundant, particularly pronghorn antelope, small mammals, raptors and various plains carnivores. After the coal is mined, the mined land is returned to original contour and replanted into nurse grasses, native grasses, and shrubs. Considerable effort is put into careful reclamation as the mining companies have to place a bond in reserve guaranteeing reclamation following coal extraction. A goal of reclamation is to return the area to productive rangeland much like that found originally, and to return the overall area to the original landscape pattern. This entails topsoil banking and redistribution, planting, fertilization and irrigation. Changes in climate may require a change in the target rangeland ecosystem type. Furthermore, it may produce new problems in preventing erosion and guaranteeing establishment of desired plant species.

- Emissions

The traditional separation of land use and emission impacts on climatic changes should be reexamined as emissions into the atmosphere and land use practices have likely produced changes on climate of the Great Plains. Land use practices considerably change the distribution and timing of water vapor returning to the atmosphere. Some land use practices that may alter climate include the change from short grass prairies to deep rooted dryland and irrigated crops. These, as well as potential changes from greenhouse effects, may affect changes in Great Plains temperatures and precipitation.

III RESEARCH NEEDS

- Soil and Production Research/ Information
  - More research on grass/legume mixtures to incorporate in dryland crop rotations.
  - Better cropping systems impacts on C budgets and trace gas emissions.
  - Deep soil carbon studies.
  - More soil characterization data.
  - A more resource-oriented approach to watershed management - soil moisture monitoring, vegetation indices, soil carbon budgets, and water budgets.

Soil organic matter - what can be learned of carbon loading in soils? How can this help farmers adapt to climate change variability? What quantity of carbon is needed to create the most productive soils? Farmers want to know how to use the information on SOM.

- Rangeland Management

Among pressing research needs are the following:

- Better define the relationship between the diversity of both plant and animal components of rangeland ecosystems with data on averages and variances with respect to forage quality and quantity.

- Design manipulative research to simulate the reaction of vegetation and animals to increases in direct effects of CO2 and climate change.

- Develop a system for defining rangeland condition that makes ecological sense from a sustainability point of view, and that is generally applicable across the span of rangeland types.

- Intensify research on understanding how increased temperature and soil moisture affect the soil-plant system.

- Develop effective management strategies for coping with climate change including alteration of changes in frequency and intensity of grazing.

Several questions were raised such as the following: What kind of management systems for resources do we see working now? Are the ones in place working? Do similar systems exist that can be used to compare, refine, or adapt to CC scenarios? Do they work in the face of CC? What institutions work?

- Disturbance

Disturbance is already high on the agenda of the ecological community, but few ecologists consider how extant disturbance regimes might change within the context of climate change and land use change scenarios. This shift in attention should be on the research agenda.

- Coal Mining

Research on coal mine lands reclamation should be rejuvenated to take into consideration climate change.

- Emissions

Action now needs to promote understanding of the relative importance of the possible effects of greenhouse gases on temperature and precipitation. Delineation of the relative significance and impacts of the respective mechanisms needs better definition. The land use impacts likely are of importance to more than just the Great Plains. The greenhouse mechanism likely has importance to both the Great Plains and the more extensive global domain. Action also needs to include continued research into cropping management and sustainable agricultural practices

IV COPING STRATEGIES

Many of these practices are already being increasingly adopted as ways of coping with

the already difficult climate of the Great Plains. However there are a number of economic, policy and social factors which inhibit a more rapid and widespread adoption of these more sustainable practices. These strategies favor improvement and maintenance of soil and land resources and can definitely be classified as "no regrets" options.

- Reduce Tillage
  - tillage releases CO2 and H20
  - no-tilled crops reverses CO2 loss

- Minimize Long Fallow Periods
  - eliminate bare fallow

- Increase Crop Diversity
  - essential for no till crop systems
  - reduces financial risk and total crop failure

- Integrate Livestock into Farming Systems
  - increases financial stability
  - allows long crop rotations involving pasture/crop sequences
  - pasture legumes provide N to stabilize organic C compounds in soil

- Utilize Seed Legumes in Crop Rotation
  - biological fixation reduces crop N costs
  - commercial N sources major gas polluters

  Perennial plants that can anchor soil and provide sequestration benefits.

These strategies require continued and innovative agriculture research.
Government incentives/disincentives affect ability to cope using these strategies.

- Emissions

Options to reduce greenhouse gas emissions from agriculture(crops and livestock). Greenhouse gas emissions from agricultural systems are influenced by the amount and timing of applications of nutrients and the form and technique of application. These emissions from livestock are influenced by diet, management of waste, and the degree of integration between crop and livestock systems. Sustainable agricultural practices incorporating the use of crop rotation and green manure can reduce the need for nitrogen based fertilizers that can easily return to the atmosphere or leach into the groundwater. Cropping practices, including the return of crop residue, can be important in removing carbon dioxide from the atmosphere and returning the carbon to the soil in the form of organic matter. Continued research into cropping management and sustainable agricultural practices will improve these management techniques.

Mitigative strategy	CC Benefit	Farmer/Rancher benefit
1. Soil management Organics	Increase carbon loading & storage in soils	Increase soil moisture capacity. Get paid a rental fee for sequestering carbon.
2. Precision farming Pesticide application Fertilizer application Water application	Reduce N2O emissions	Reduce fertilizer, pesticide costs. Spend less on water.
3. Managing livestock wastes	Reduce CH4 emissions	Derive usable energy
4. Energy from biomass	Reduce CO2 emissions from fossil fuels	Diversifies farmers income.

Group 4: WATER RESOURCES

The focus for this group was to address issues of concern related to water resources such as, water quantity and quality and the effects of both on human and ecological conditions.

Water cross cuts all issues. Changes in water availability are felt on local, regional, national, and global scales. Water use in Colorado from the Colorado rivers, for example, affects the quantity of water for Nebraska and Kansas. Water use in Nebraska of the reserves in the Ogallala Aquifer affect supplies in Kansas and Colorado.

General Categories:
A. Water supply
B. Water demand
C. Water quality

I and II ISSUES and CC EFFECTS

A. Water Supply

- Water storage.

Increased demands for water will necessitate innovative methods of increasing water storage. Population growth in the western Great Plains is already creating additional water demands that may increase with climatic variability. There will be increasing demands for water storage to maintain a sustainable water supply.

- Infrastructure/Engineering

Changes in the flow regime and the social acceptability of structural solutions will require a reexamination of infrastructure and systems operations. Water development has moved away from structural development solutions. In the past years we have seen extreme events in the Great Plains (e.g. floods in the Mississippi) that might require the reevaluation of the current structures.

Although some large Federally-funded infrastructure projects may have been designed with excess capability which serves as a reserve against climate change, many smaller, locally- funded projects do not have such excess capability. Examples might include reservoir capacity, height of dikes, capacity of flood-diversion channels. Consequently, climate change could cause such systems to be unable to perform their functions, leading to increased stress on local resources.

- Wetlands

Wetlands are already under significant stress throughout the world due to human activities such as draining for agriculture and urban expansion. Globally about half of all wetlands have been lost since around 1940. In the U.S., excluding Alaska, about 40-60% of wetlands have been lost, with percentages in some states such as Ohio as high as 90% (Baron paper). Wetlands in the Great Plains have undergone similar losses; in central Nebraska near

the Platte River, most wetlands have been lost and those that remain are federal and private wetland projects (Tebbel paper). Changes in the timing, areal distribution, intensity or form of precipitation (rain, snow, hail, etc.) coupled with increased evaporation/transpiration rates will affect biological/ agricultural resources in the Great Plains. Already, regulation of streams and rivers have resulted in loss of the natural hydrograph reducing riparian habitat. Instream flow requirements required for biological diversity increasing will compete with consumptive uses. Furthermore, problems associated with salinity and other pollutants in surface and groundwater will increase with an intensified hydrologic cycle.

Wetlands provide critical hydrological, biological and biogeochemical functions, which have corresponding benefits valued by society: they provide flood control and water storage, the assist in pollution filtering and waste processing, they provide critical habitat and breeding ground for birds and other species, and they assist in the global cycling of carbon and nitrogen. Any wetland loss or degradation that interferes with these functions would have corresponding effects on the benefits valued by society. In the Great Plains, prairie potholes have traditionally provided critical water storage and waterfowl habitat; it is estimated that prairie wetlands supply more than half the annual waterfowl population produced in North America. The central section of the Platte River has provided both a source of food and protection for waterfowl and shorebirds during spring and fall migrations.

Wetlands will be affected by any changes in temperature, precipitation, and evaporation/evapotranspiration, which alter the water supply to the wetland through changes in runoff, streamflows, and groundwater recharge. Both the seasonal patterns and intensity of precipitation events are important. In the northern prairies, it is predicted that as evapotranspiration increases and snowmelt runoff decreases, a dramatic loss of meadow and shallow marsh lands would result (Baron paper). Wetlands in the central flyway in Nebraska would be adversely affected by any drop in river water levels during migration periods (Tebbel paper). However, wetlands could be enhanced if increased precipitation exceeds evapotranspiration so as to consistently provide increased streamflow and groundwater supply.

Prairie potholes are considered particularly vulnerable to climate change due to their inability to adapt through migration or other processes; this has been further exacerbated by human development in surrounding areas. Riverine ecosystems tend to have a higher potential to adapt through natural or assisted migration due to the high degree of spatial and temporal variability of their natural environment.

B. Water Demand

- Aquatic Ecosystem Needs

The scientific basis for determining needs of aquatic ecosystems under current and climate change scenarios should be further refined. Aquatic ecosystems in the Great Plains face numerous existing stresses caused by competing demands of agriculture (including water quality issues such as nitrogen runoff) and urban uses. Climate changes will place the aquatic ecosystems under additional pressure. Temperature and precipitation changes will have a wide range of effects on already vulnerable ecosystems. These effects range from dry wetlands and stream beds to extreme instream flow variability to increased demands on water supplies from agriculture and urban/residential users. Warmer air temperatures will affect

water temperatures and the ability of exotic/non-native species of pests, fish, and plants to migrate into Great Plains aquatic ecosystems and disrupt these already stressed systems.

- Agricultural Water Management.

Consumptive water use by agriculture involves both flood irrigation from surface waters, particularly in the western portion of this region, and spray irrigation derived from both surface waters and groundwater. Management of both sources is a major political and management concern for this region - A concern that will be magnified by any decrease in available water concomitant with climate change. Considerable water is drown from riparian aquifers which can be recharged quickly through appropriate riverine management. More difficult are the regional groundwater aquifers which are , to some extent, not rechargeable in the present climate region. The most widespread and best known among these is the Ogallala aquifer. There is a need to match the drawdown from the Ogallala Aquifer to the recharge from precipitation in order to avoid depletion of the water resource. Changes in precipitation and evapotranspiration demand may lead to changes in recharge and drawdown respectively. Use of surface water for irrigation is another water management issue. More efficient application methods (water pulsing, etc.) could decrease water needed. Water availability in dryland systems and irrigated systems can both be impacted by residue management and tillage practices.

C. Water Quality

Quantity of water available for particular uses depends on political/social/economic means of allocation and control. Water quality is compromised by salinity and runoff of fertilizers and wastes. Pressures for more high quality water stresses regulatory and decision mechanisms. These stresses will be exacerbated if climate change reduces water availability.

Further research is needed to help determine the effects of climate change on water quality and ways to best correct and mitigate water quality problems. In addition to water quantity issues, water quality is currently an important topic in the Great Plains. Salinity management is an important issue in certain areas of the Great Plains. Rivers become more saline due to runoff and percolation through high saline soils. High salinity affects crop production and adversely impacts fish and wildlife habitat. Drinking water quality in the Great Plains is also an important issue. Many small towns struggle to meet current drinking water standards. Non-point source pollution can contain contaminants from fertilizers, herbicides, pesticides, livestock wastes, salts, and sediments that reduce the quality of both surface water and groundwater drinking water supplies. Changes in climate may also affect the numbers and types of pests. Pest control operations have the potential to affect water quality as water drains through crop fields. Currently, water quality and quantity have severely impacted fish and wildlife habitat in the Great Plains. Deterioration in water quality could have additional adverse impacts on the ecosystem.

III RESEARCH NEEDS

Research needs to build capability to better address the current competition among the water needs of agriculture, urban and industrial uses, and natural ecosystems.

- Water storage

There are creative and innovative means of storing water that should be explored in order to augment traditional surface water storage. These reservoirs could be less damaging to aquatic ecosystems than traditional reservoirs that disrupt natural flows, destroy riparian areas, change thermal regimes, and fragment migration corridors. .

- Water budgets

A detailed understanding of water budgets and cycles at regional scales needs to be achieved. Regional water budgets need to be quantified so that temporal and spatial distribution of water availability is better understood. These budgets need to address all components of the water cycle, including water content in the atmosphere, soils, surface and groundwater reservoirs, and vegetative cover. The interaction between these components needs to be linked to current and future climate regimes and made available with high spatial resolution for land management decisions..

- Infrastructure

If runoff is changing (due to hydrologic or land use changes), we need to understand the capabilities of the current reservoirs to provide flood control and/or urban and agricultural needs. Research should focus on reservoir operation and the evaluation of any additional structural requirements and/or reservoir management changes necessary to adapt to new climatic conditions.

- Wetlands

Wetlands research needs include both preservation of species habitat and biogeochemical cycling. However, both are a function of the hydrological regime of wetland systems, how these are altered by climate change, and how these changes interact with other human stressors.

- Aquatic Ecosystem Needs

Current understanding of the needs of aquatic systems to survive under current demands and climate is incomplete. Water apportionment decision making between aquatic ecosystems and human needs must be reassessed. We must begin to evaluate the effects that projected climate change will have on Great Plains aquatic ecosystems. To resolve both current and future water issues we must develop an institutional mechanism that fosters information flow, tolerance, and compromise, so that the natural capital inherent in our aquatic resources is not lost in hasty or one-sided decision making.

- Agricultural water management

More study of water application technology is needed to increase irrigation efficiently. On sprinkler systems, sprinklers formerly at the top of center pivot systems have been moved down into the canopy. This has significantly reduced spray losses. More efforts to develop precision irrigation in the context of precision agriculture are needed. Scientific irrigation scheduling should be expanded to include the movement of agric-chemicals in conjunction with water applied and the movement of salts in the crop root zone. Efforts to develop and implement policy are needed to avoid significant depletion of the Ogallala and other

groundwater reserves in the region.

- Water Quality

Further research is needed on the effects of reduced precipitation and on the effects of extreme precipitation events that can affect runoff and water quality. For example, research is also needed on how to best manage livestock wastes during extreme precipitation events.

- Monitoring

A fundamental research consideration that pertains to most of the issues is the importance of maintaining and augmenting strategically selected long-term monitoring systems. In many respects, monitoring systems initiated in the 1970s, such as for water quality, are being cut back. Some of these need new support, but other monitoring systems such as for diagnostic population fluctuations, lake levels, etc. need to be instituted.

IV COPING STRATEGIES

- Water storage

By applying and experimenting with new storage techniques such as groundwater storage reservoirs, snowpack storage in mountain forests through forest management practices, snow capture and storage in alpine basins, crop management practices that enhance soil moisture through crop stubble, wind breaks, mulches, and snow management strategies on the Plains, the quantity of stored water can increase to meet the demands of a changing climate.

- Agricultural water management

Increased irrigation demand may lead to a wide-spread adoption of the scientific approach to irrigation scheduling, adjustment of yield target to match available water, and/or the change of cropping system/land use in the event irrigation costs exceed the worth of increased production effected by irrigation.

INFORMATION NEEDS

Information needs were gathered from all four groups, but have been provided here as a separate section that commonly applies to any of the groups.

A. Information transfer

Criticality - The communication of information is critical to an effective response to the potential impacts of climate change in the Great Plains. Decisions about mitigation and adaptation will rely fundamentally on technical, scientific, practical, legal, and political information. Individuals at all levels of scale and from all sectors will require effective, credible and relevant information in order to make sound long-term decisions. As we create a regional process of assessing and responding to climate change we have identified key questions we need to ask in order to understand present information systems better and create effective ones in the future: For whom is what information important? What sources of public and private information are relied upon? What are the current and potential global to national to local linkages in information transfer? What institutions and processes encourage or discourage the transfer of "useful" and "usable" information?

Information links - It is essential that there is a dialogue between users of information and suppliers of information. Information transfer, therefore, will be effective if there is a two way flow so that both needs and useful information can be communicated effectively. There has been a cut back of on-farm demonstrations. The farmers and ranchers in our group see this as a serious gap in information transfer. This highlights the importance of understanding the linkages between users and suppliers of information.

Developing collaborative links and database development within and between agricultural research site networks, LTERs, EROS, and private sector data generators relevant to climate change.

Cross-cut disciplinary and agency boundaries to share info.

Utilize inhabitants of Plains for sources of info.

Formation of "farmer information cooperatives" to share available grain yield data and harvest info for regionalization.

Technology - There are variety of different media or mechanisms through which technology transfer can happen: Web, private firms, extension agents, chemical companies, agro- businesses, NRCS, and farm literature such as journals. This information must be effective, credible, relevant, and usable.

Information channels and use - switch from paradigm of production to systems for farming - how to get to the farmer who does not know what he does not know?

- Education and dissemination.

Climate change information should be responsibly and widely disseminated. Although the scientific community has discussed climate change for more than a century, the general public lacks basic knowledge of climate change. To better educate all age levels and social groups, more information should be made available through a wide variety of periodicals,

localized conferences, and electronic communication. A credible information clearinghouse is necessary to responsibly distribute information.

Understanding the relative positive and negative impacts of temperature and precipitation changes on agriculture, social, and environmental resources at local, regional, and global scales will assist policy decisions. Numerous impacts, both positive and negative have been identified that could result from various types and degrees of climate change. A continually improving understanding of these impacts is needed to define the relative balance between the negative and positive impacts and among respective stakeholders. Continued focused studies are needed to identify all stakeholders, understand the net effect among them from climate change, and consider ways of adjusting equity among those positively and negatively impacted. This understanding is important both on a local and a global scale and needs to be an item of high priority because it affects the resources allocated to the control of emissions. It addresses the ultimate impact of possible global warming on the agriculture of the Great Plains and the world.

B. Data Needs

Research needs should focus on the need for useful, credible, and effective information needs, the dissemination of which is critical. How can this be done? First, by finding the appropriate background information; second, identify key players; third, physically demonstrate success of strategies to the agricultural community (conduct the studies in the farmers fields, not in the laboratory); and finally, make the information available in a readily usable form (packaging of information needs to be user-friendly to the agricultural community). In short, move from passive to more active research and dissemination of this information.

Another important determinate is to establish from the onset, what message the information is trying to convey? The message must be able to get the attention of the farmer and/or rancher. For example, a statement such as climate variation is happening and may worsen, and in short, may impact the farmers' bottom line. By opening a dialogue with the agricultural community and forming a partnership in these discussions, together we can help agriculture to remain a viable business and to remain viable in the marketplace.

- Weather

Drought is a stress/condition that characterizes the region and water is the main limiting factor for plant production. In addition to the low average precipitation, the high variability in precipitation is a major concern which has led farmers to adopt wheat- fallow as a 'hedging' strategy. Severe weather, particularly hail, is a major risk factor for crop producers.

Currently, extreme climatic variation in conjunction with limitations in long-term weather forecasting severely limit the application of management practices. Any increase in this climatic variability would further impact crop, livestock, and economic management. Meaningful seasonal weather forecasts would greatly benefit management plans. These forecasts could be beneficial for developing cropping plans, computing fertilization rates, crop seeding rates, etc. For longer range planning, inter-annual predictions would assist such activities as allocating multi-year water supplies, managing livestock herd sizes, etc. These advances in long-range forecasting would require the continuation and expansion of both

computer modeling and empirical analyses.

- Spatially Distributed Data Needs

- High resolution (~1 m), temporally dynamic imagery available to monitor soil quality, range health, and urbanization.

- A quicker delivery mechanism of water resource information and greenness indices (vegetation health) for land management planning.

- Improving communications between the agriculture research community and the geographic/remote sensing community.

- Higher resolution climate modeling.

- Better weather station networks with sensors for soil climate parameters to use in conjunction with new imagery and water supply forecasting; should be added to existing networks.

- Focusing on "fragile" landscapes across the Northern Plains , e.g. the Sandhills, NE (using them as potential early "indicators" of climate change impacts).

- Need to research impacts of localized changes in 'climate' which have recently occurred-- e.g. Prairie Pothole Region, Prairie Coteau, where precipitation amounts and wetland area have changed significantly over the past decade.

- Scaling up from point info to regional perspectives--climate data, soils data, research from farms and experiment stations.

Comments:

Working together, farmers, ranchers, government agencies, academicians, and other stakeholders can create win/win situations for the agricultural community of the Great Plains region. Focusing on the key issues and addressing the research and informational needs of the farmers and ranchers, much of the work of adaptation and mitigation will fall into place. If successful adaptive and mitigative strategies are developed and put into place, a number of benefits can be realized that will cut across a number of different sectors.
If agriculture is to meet the challenges of climate change, the people in agriculture will have to do the work. There are 2 factors involved, at least:

1. Respect them and value their contributions.
2. They must see the benefits to themselves and their families.

Farmers and ranchers must take responsibility for problems ranging from groundwater quality to degradation of public lands. Apparently our contribution to climate change is relatively small. That's a relief! Fortunately, the changes in practices that may enable us to cope with climate change will probably also address the problems we have caused. It's more effective to draw on farmers' ingenuity and appreciate their positive contributions than to criticize present practices.

Engaging farmers and ranchers means answering the human questions, "What's in it for me?". The challenge for science is to move climate change from the abstract to the concrete. Even

then, climate change is a long-range problem compared to making a living now. "One day at a time" can be more pressing than "sustainable for generations", even though one is not possible without the other.

V APPENDIX

A. AGENDA FOR GREAT PLAINS CLIMATE CHANGE IMPACTS WORKSHOP

May 27, 1997 Tuesday Afternoon
Lory Student Theater, Colorado State University Campus

1:00 Opening Remarks
Dennis Ojima, Co-Chairman of Great Plains Workshop
Diana Freckman, Director of NREL
Jud Harper, Vice President for Research, CSU

1:20 Presentation on Economic Factors affecting agronomic systems in the Great Plains
Mark Drabenstott (Federal Reserve Bank, Kansas City, Missouri)

1:40 Great Plains Region: Climate System Characteristics
Ken Hubbard, High Plains Climate Center, Lincoln, Nebraska)

2:00 Panel Discussion of Limitations to Sustainable Land Use Among Critical Conservation, Ranching, and Farming Sectors in the Great Plains and Mountain Regions
Panelists:
George Bluhm, USDA, Farmer
Jim Geist, Colorado Corn Administrative Committee
Paul Tebbel, Rowe Sanctuary, Gibbon, NE
Jody Farhat, US Army Corps of Engineers
(Moderated By: Bill Easterling, National Director of NIGEC)

2:40 Break for 20 minutes

3:00 Framework of Regional Climate Change Impacts on National and International Policy: What does this all mean to you, the citizen
Timothy E. Wirth (Under Secretary of State for Global Affairs)

3:40 Climate Change in the Industrial Era: Past and Future Considerations
David Schimel, NCAR, Boulder, CO

4:00 Links between climate change, vulnerability, and coping strategies to environmental and socio-economic changes
Bill Riebsame, University of Colorado

4:20 Panelist Response to Climate Change Implications
4:50 Closing Remarks

May 28, 1997 Wednesday Morning
Sylvan Dale Guest Ranch, Loveland, CO

8:30 Working Group Instructions
Review of Working Group Objectives and Outcomes of meeting
Identification of critical questions

9:00 Working Group Discussions
Biological Resources
Social Resources
Soil Issues
Water Issues

11:00 Plenary Presentations:
Limits to Water
(Luis Garcia, Center for Water Resources Engineering Science, Colorado State University)
Economic Constraints to Great Plains Land Use
(John Antle, Trade Resource Center, Montana State University)

12:00 Lunch

3:00 Working Group Discussions

6:00 Dinner

May 29, 1997 Thursday Morning
Sylvan Dale Guest Ranch

8:30 Plenary Presentations:
Coping Mechanisms for Global Change
(Phyllis Breeze, Colorado Department of Public Health and Environment)
Methods of Integrated Assessment
(William J. Parton, NREL, CSU)

9:30 Working Group meetings
Research Agenda / Definition

12:30 Lunch

1:30 Summary Presentation

4:00 Close of Workshop

B. PARTICIPANT LIST

Altenhofen, Jon
NCWCD
P.O. Box 679
Loveland, CO 80539
tel: (970) 667 2437
fax: (970) 663 6907

Antle, John
Economist
Trade Resource Center
312 Lindfield Hall
Montana State University
Bozeman, MT 59717
tel: (406) 994 3706
fax: (406) 994 4838
email: jantle@montana.edu

Baron, Jill
USGS/BRD
Colorado State University
Natural Resource Ecology Laboratory
Fort Collins, CO 80523
tel: (970) 491 1968
fax: (970) 491 1965
email: jill@nrel.colostate.edu

Bassow, Susan
Office of Science and Technology Policy
Old Executive Office Building
17th and Pennsylvania Ave., N.W.
Washington, DC 20506
tel: (202) 456 6083
fax: (202) 456 6025
email: sbassow@ostp.eop.gov

Berg, Walt
Recom Applied Solutions
2919 W. 17th St., Suite 207
Longmont, CO 80503
tel: (303) 678 9601
fax: (303) 678 9609
email: walt@white_hawk.org

Bluhm, George
University of California
Land, Air, Water Resources
151 Hoagland Hall
Davis, CA 95616-8627
tel: (916) 752 1018
fax: (916) 752 1552
email: bluhm@crocker.ucdavis.edu

Bohren, Lenora
Coordinato of Int'l Programs and Field Research
National Center for Vehicle Emissions Control and Safety
202 Industrial Sciences Bldg.
Colorado State University
Fort Collins, CO 80523
tel: (970) 491 1805
fax: (970) 491 7801
email: bohren@cahs.colostate.edu

Breeze, Phyllis
Colorado Department of Public Health & Environment
APCD-ADM-B1
4300 Cherry Creek Dr. South
Denver, CO 80222-1530
tel: (303) 692 3221
fax: (303) 782 5493
email: phyllis.breeze@state.co.us

Brown, Jesslyn
Hughes STX
USGS EROS Data Center
Mundt Federal Building
Sioux Falls, SD 57198
tel: (605) 594 6114
fax: (605) 594 6529
email: jbrown@edcmail.cr.usgs.gov

Byerly, Radford
Science & Technology Policy
3870 Birchwood Drive
Boulder, CO 80304
tel: (303) 546 6654
fax: (303) 449 6243
email: byerly@jila.colorado.edu

Cash, David
Center for Science and International Affairs
79 J.F. Kennedy St.
J.F.K. School of Government
Harvard University
Cambridge, MA 02138
tel: (617) 496 9330
fax: (617) 495 8963
email: cashdav@ksg.harvard.edu

Cole, Vern
Natural Resource Ecology Lab
Colorado State University
Fort Collins, CO 80523
tel: (970) 491 1990
fax: (970) 491 1965
email: vern@nrel.colostate.edu

Dennehy, Kevin
USGS
NAQWA
Box 25046,
MS 415 Federal Cnt.
Denver, CO 80225-0046
tel: (303) 236 4882 ext 312
fax: (303) 236 4912
email: kdennehy@usgs.gov

Easterling, William, Director
Great Plains Regional Center
for Global Environmental Change
Department of Agricultural Meteorology
University of Nebraska - Lincoln
15 L.W. Chase Hall
P.O. Box 830725
Lincoln, NE 68583-0725
tel: (402) 472 7887
Fax: (402) 472 6614
email: agme014@unlvm.unl.edu

Edgerton, Sylvia
ER-74 GTN Building
US Department of Energy
19901 Germantown Road
Germantown, MD 20874-1290
tel: (301) 903 0040
fax: (301) 903 7576
email: sylvia.edgerton@mailgw.er.doe.gov

Eriksen, Stacey
8-EPR-EP
EPA Region 8
999 18th Street, Suite 500
Denver, CO 80202-2466
tel: (303) 312 6692
fax: (303) 312 6071
email: eriksen.stacey@epamail.epa.gov

Farhat, Jody
Army Corp of Engineers
12565 W. Center Rd.
Omaha, NE 68144
tel: (402) 697 2686
fax: (402) 697 2677
email: jody.s.farhat@mrd01.usace.army.mil

Follett, Ron
USDA-ARS
Box E
Federal Building
Fort Collins, CO 80522
tel: (970) 490 8220
fax: (970) 498
email: rfollett@lamar.colostate.edu

Garcia, Luis
The Water Center
Integrated Decision support Group
Colorado State University
Fort Collins, CO 80523
tel: (970) 491 5144
fax: (970) 491 2293
email: garcia@engr.colostate.edu

Geist, Jim
Field Services Director
Colorado Corn Administrative Committee
5500 South Quebec, #111
Englewood, CO 80111
tel: (303) 740 4328
fax: (303) 694 5814
email: ccac_ccga@compuserv.com

Grant, Lewis
Piedmont Farms, Inc.
515 W. County Rd. 72
Wellington, CO 80549
tel: (970) 568 7654
fax: (970) 568 7655
email: lgrant3309@aol.com

Hiebert, Ron
Assistant Regional Director for
Natural Resources and Science
Midwest Region - NPS
1709 Jackson St.
Omaha, NE 68102
tel: (402) 221 4856
fax: (402) 221 3480
email: ron_hiebert@nps.gov

Hubbard, Ken G.
High Plains Climate Center
242 LW Chase Hall
University of Nebraska-Lincoln
Lincoln, NE 68583-0728
tel: (402) 472 6706
fax: (402) 472 6614
email: khubbard@hpccsun.unl.edu

Johnson, Richard
USDI-USGS-Biological Res Division
4512 McMurry
Fort Collins, CO 80525
tel: (970) 226 9434
fax: (970) 226 9230
email: Richard_L_Johnson@usgs.gov

Joyce, Linda
USDA/FS
Rocky Mountain Forest and Range
Experimental Station
240 W. Prospect #135
Fort Collins, CO 80524
tel: (970) 498 2560
fax: (970) 498 1314
email: ljoyce@lamar.colostate.edu

Kermond, John
NOAA, Office of Global Programs
Silver Spring, MD 20910
tel: (301) 427 2089 ext 22
fax: (301) 427 2082
email: kermond@ogp.noaa.gov

Kleinschmit, Martin
Center for Rural Affairs
56149 Hwy 12
Hartington, NE 68739
tel: (402) 254 6893
fax: (402) 254 6891
home: (402) 254 3310
email: ceruaf01@nol.org

Kustra, Clara
Public Relations Coordinator
Institute for the Study of
Earth, Oceans and Space (EOS)
Morse Hall - Room 305
39 College Road
University of New Hampshire
Durham, NH 03824-3525
tel: (603) 862 3484
fax: (603) 862 1915
email: clara@unh.edu

Leaf, Forrest
Central Colorado Water
Conservancy District
3209 West 28th Street
Greeley, CO 80631
tel: (970) 330 4540
fax: (970) 330 4546

Lindstrom, Gilbert
Box 1741
Sterling, CO 80751
tel: (970) 522 0866

Mearns, Linda
Climatologist
NCAR
P.O. Box 3000
Boulder, CO 80307-3000
tel: (303) 497 1824
fax: (303) 497 1695
email: lindam@ncar.ucar.edu

Melillo, Jerry
Office of Science and Technology Policy
Old Executive Office Building
17th and Pennsylvania Ave., N.W.
Washington, DC 20506
tel: (202) 456 6202
fax: (202) 456 6025
email: jmelillo@ostp.eop.gov

Mesnikoff, Ann
Sierra Club
408 C St. NE
Washington, DC 20002
tel: (202) 547 1141
fax: (202) 547 6009
email: ann.mesnikoff@sierraclub.org

Mortensen, Lynn
Education Director
PCSD/ES
730 Jackson Pl. NW
Washington, DC 20503
tel: (202) 408 5028
fax: (202) 408 7590
email:lynnmort@aol.com

Neely, Betsy
Director of Conservation Planning –
The Nature Conservancy of Colorado
1244 Pine Street
Boulder, CO 80302
tel: (303) 444 2985 ext. 115
fax: (303) 444 2986
email: bneely@tnc.org

Ojima, Dennis
Natural Resource Ecology Lab
Colorado State University
Ft. Collins, CO 80523
tel: (970) 491 1976
fax: (970) 491 1965
email: dennis@nrel.colostate.edu

Parton, Bill
Natural Resource Ecology Lab
Colorado State University
Ft. Collins, CO 80523
tel: (970) 491 1987
fax: (970) 491 1965
email: billp@nrel.colostate.edu

Paustian, Keith
Natural Resource Ecology Lab
Colorado State University
Ft. Collins, CO 80523
tel: (970) 491 1547
fax: (970) 491 1965
email: keithp@nrel.colostate.edu

Quick, James
Dept. of Soil and Crop Sciences
C117 Plant Sciences
Colorado State University
Fort Collins, CO 80523
tel: (970) 491 6501
fax: (970) 491 6517
email: jquick@ceres.agsci.colostate.edu

Ramirez, Jorge
Hydrologist
Civil Engineering
Colorado State University
Ft. Collins, CO 80523
tel: (970) 491 8650
fax: (970) 491 7727
email: ramirez@lance.colostate.edu

Ravenscroft, Rob
HC 32 Box 28
Valentine, NE
tel: (402) 376 3632
fax: (402) 376 3228
email: robr@concentric.net

Reiners, William
Department of Botany
University of Wyoming
Laramie, Wyoming
tel: (307) 766 2235
fax: (307) 766 2371
email: reiners@uwyo.edu

Remington, Ken
22520 County Rd. 18
Akron, CO 80720
tel: (970) 345 6473

Riebsame, William
Campus Box 260
University of Colorado
Boulder, CO 80309-0260
tel: (303) 492 6312
fax: (303) 492 7501
email: riebsame@spot.colorado.edu

Sale, Michael
Oak Ridge National Laboratory
P.O. Box 2008, MS 6036
Oak Ridge, TN 37831-6036
tel: (423) 574 7305
fax: (423) 576 8543
email: jon@ornl.gov

Sanders, Phil
9143 Rd 56
Dalton, NE 69131-2231
tel: (308) 377 2231

Schafersman, Dave
BLM
Denver Federal Center, BLDG 50
PO Box 25047
Lakewood CO 80225-0047
tel: (303) 236 0161
fax: (303) 236 3508

Schimel, David
GCD, NCAR
P.O. Box 3000
Boulder, CO 80307-3000
tel: (303) 497 1410
fax: (303) 497 1695
email: schimel@ncar.ucar.edu

Skold, Mel
Agricultural and Resource Economics
Colorado State University
Fort Collins, CO 80523
tel: (970) 491 7370
fax: (970) 491 2067
email: mskold@ceres.agsci.colostate.edu

Smith, Joel
Hagler Bailly Consulting, Inc
P.O. Drawer O
Boulder, CO 80306-1906
tel: (303) 546 5318
fax: (303) 443 5684
email: jsmith@habaco.com

Stendell, Rey
USDI-USGS-Biological Res Divn
4512 McMurry
Fort Collins, CO 80525
tel: (970) 226 9398
fax: (970) 226 9230
email: rey_stendell@usgs.gov

Taylor, Melissa
Office of the United States Global Change Research Program (USGCRP)
NASA Headquarters, Code YS-1
300 E St., SW
Washington, DC 20546
tel: (202) 358 1299 (main: 358 0421)
fax: (202) 358 4103
email: mtaylor@usgcrp.gov

Tebbel, Paul
Rowe Sanctuary, National Audubon Society
44450 Elm Island
Gibbon, NE 68840
tel: (308) 468 5282
fax: (308) 468 5627
email: rowe_sanctuary@kfn.org

Triplett, Lori
The Great Plains Foundation
9008 Hadley Street
Overland Park, KS 66212
tel: (913) 385 7775

Valliant, Jim
Cooperative Extension/AES
Colorado State University
P.O. Box 190
Rocky Ford, CO 81067
tel: (719) 254 7609
fax: (719) 254 7650
email:otero@coop.ext.colostate.edu

Van Haveren, Bruce
Chief Scientist
BLM
Denver Federal Center, BLDG 50
PO Box 25047
Lakewood CO 80225-0047
tel: (303) 236 0161
fax: (303) 236 3508
email: bvanhave@blm.gov

Walters, Christina
National Seed Storage Lab
Colorado State University
Fort Collins, CO 80523
tel: (970) 495 3202
fax: (970) 221 1427
email: chrisv@lamar.colostate.edu

Waltman, Bill
Natural Resources Conservation Service
100 Centennial Mall North, Rm 152
Denney Federal Building
Lincoln, NE 68508
tel: (402) 437 4095
fax: (402) 437 5381
email: grass@fire.np.nrcs.usda.gov

Wilbanks, Thomas J.
Developing Country Programs
Oak Ridge National Laboratory
Bldg. 4500N, MS-6184
Oak Ridge, TN 37831-6184
tel: (423) 574 5515
fax: (423) 576 2943
email: twz@ornl.gov

Woodmansee, Robert
Larimer County Rural Land Use Board
703 E. County Rd. 68
Fort Collins, CO 80521
tel: (970) 568 7019
fax: (970) 491 2339
email: bobw@nrel.colostate.edu

Climate Change and Its Impacts on New England: A White Paper

When people think of the climate in New England they think either of crisp, clear fall days enhancing the spectacularly colorful foliage of maple, birch and hickory, sunny summer days and cool starry evenings, or pristine winter snowscapes, with snug cabins and bustling ski slopes. Those of us who live in the New England/upstate New York region, also know that the weather can be highly variable ("...if you don't like the weather, just wait a few minutes...") and unpredictable ("...last year, summer was on July 5th..."). For us, weather (day-to-day meteorological phenomena such as temperature, precipitation and cloud cover) is thought of as highly variable, while climate (the longer-term weather patterns characterizing an area, such as temperate or tropical climates) is considered to be more stable. However, more and more we are hearing about a changing climate, and most of us are not sure what climate change is or if it is something that we should really be concerned about.

As we begin to look at climate change issues and their potential impacts on the New England region (the New England states and upstate New York), it is important to note that the term "climate" can refer to both the physical climate and the chemical climate. The physical climate includes variable such as temperature, precipitation patterns, and storm patterns which characterize an area, while the chemical climate includes variations in the chemical make-up of the atmosphere and precipitation. Increasing severity of storms or rising temperatures would be an example of physical climate changes, while increasing levels of ground-level ozone (a form of air pollution or SMOG) or acidity of rain would be examples of chemical climate changes.

The concept of climate change is vague to the average person, for a number of reasons.

- Often, the media presents climate change issues such as the "greenhouse effect" and "Global Warming" as controversial and unproven, even among members of the research community studying the problem.
- A common view is that if scientists who are climate change specialists can't agree on what is happening, why should we worry about it.
- A second perception is that climate change involves global processes that are poorly understood, and are largely beyond our control, at least at the local or regional level.
- Often the problems associated with climate change are seen by the public as somehow involving tropical deforestation or ozone depletion in the Antarctic and Arctic regions, and are not considered as relevant or important to New England.
- In addition, climate change problems are seen as very complicated and are considered to be too difficult to be easily understood by the non-scientist.
- Finally, the public perceives the problems of climate change, if real, as far in the future and not of immediate concern. Lets look at some of these public concerns.

REPRODUCED AT GOVT EXPENSE

Is the "Greenhouse Effect" real?

Yes, the greenhouse effect is real, and in fact, essential for life as we know it on our planet. Many of the gases in our atmosphere (including water vapor, ozone, nitrogen and carbon dioxide) allow sunlight to pass through, but once the sunlight interacts with the Earth's surface, the resulting heat released is retained, leading to a global warming essential for the maintenance of life. The presence of these gases in our atmosphere make the Earth a living planet (compare the Earth and its atmosphere with the moon: both are approximately the same distance from the sun, but there the similarity ends). What a difference a few gases make! Human activities, however, have resulted in a significant increase in some of these and other gases in our atmosphere. The growing concern voiced regarding future climate change relates to this ***enhanced*** greenhouse effect.

From the beginning of the Industrial Revolution (in the 1870s), human activities have increased the introduction of greenhouse gases such as carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), ozone (O_3), chlorofluorocarbons (CFCs), and nitrous oxide (N_2O), into the atmosphere. All of the gases trap heat as described above. The overall increases in CO_2 over time (1750 - present) is shown in Figure 1. The detailed study of ice core records from glaciers in Greenland and the Antarctic shows the climate change is normal and closely correlated with changes in CO_2 and CH_4 in the atmosphere. Dramatic climate change has occurred in the past, even in the absence of human activities, and in all cases, warming is associated with high levels of greenhouse gases, while cooling is characterized by decreased levels of these gases.

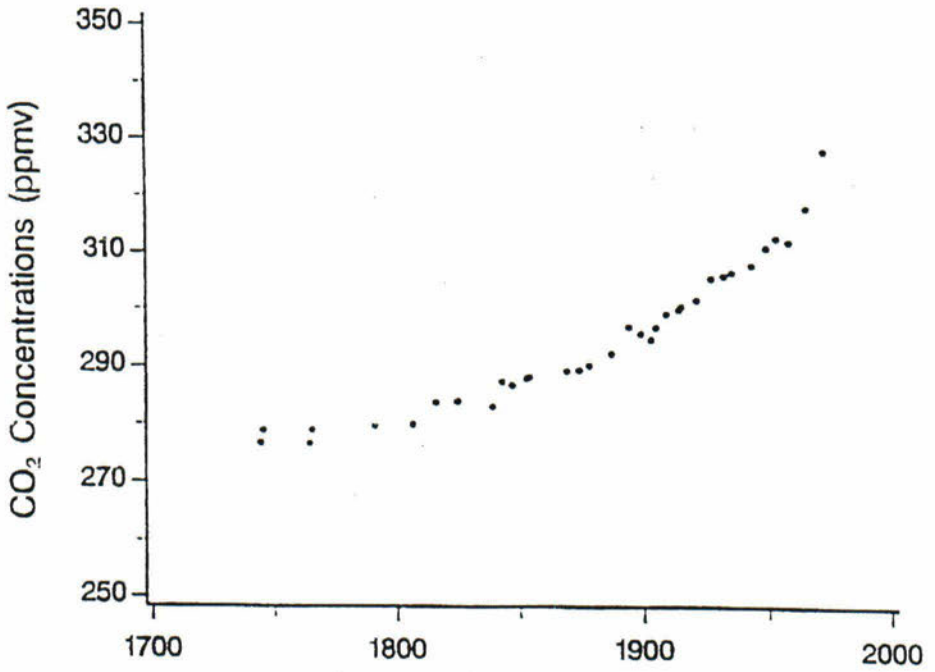


Figure 1. Atmospheric carbon dioxide concentrations derived from ice core data.

REPRODUCED AT GOVT EXPENSE

What about "Global Warming?"

While large fluctuations in both greenhouse gases in the atmosphere and climate change are clearly normal for our planet, 1997 levels of atmospheric CO_2 are the highest they have been over the last 150,000 years (based on the ice core record). There is **no** debate about this! Everyone agrees that greenhouse gas levels are increasing in the Earth's atmosphere as a result of human activity. What **is** being "hotly" debated at present, is what effect this ***enhanced*** greenhouse effect will have in terms of a warming of the atmosphere. If CO_2 levels continue at the present rate of increase. global temperatures are predicted to rise 2-5°C by 2050. Temperatures in the Arctic are predicted to rise twice as fast. And, if the past is any indication of what will happen in the future, ice core records indicate an unvarying and direct correlation between CO_2 levels in the atmosphere and temperature (cooler periods characterized by low CO_2 levels, while warmer periods are characterized by higher levels of CO_2).

In 1995, an international panel of approximately 2,000 scientists--the Intergovernmental Panel on Climate Change (IPCC)--stated that the observed warming trend seen over the past decade is connected with the increasing levels of greenhouse gases in the atmosphere. This IPCC Report represents the first broad scientific consensus that the ***enhanced*** greenhouse effect has led to increased temperatures. It is important to note that even if overall warming is seen, temperature trends at the local level will continue to be highly variable for a range of reasons.

Doesn't climate change involve global processes that are poorly understood, and largely beyond our control, at least at the local or regional level?

Climate change is a global phenomenon and is based on properties of the atmosphere such as temperature and precipitation. But, climate has many regional action centers. Some are very large such as the *El Niño*-Southern Oscillation action centered over the tropical Pacific which extends in some phases to a near global scale. Another regional climate action center is the North Atlantic Oscillation which can affect storm patterns over New England.

As we have come to know from watching the evening weather on TV, high and low pressure systems, storms, and associated temperatures and precipitation patterns move rapidly across the United States (as well as the rest of the world) from west to east. Weather affecting the west coast soon affects us. Figure 2 shows that we are in the unenviable position of being down-wind from the rest of the country. Weather and climate are clearly global processes.

Our understanding of how the climate system works, although incomplete, has improved dramatically as a result of our venturing into space. Observing Earth from orbit has significantly improved our ability to predict storms and to monitor pressure systems as they move across the country. Weather satellites are now taken for granted, and our understanding of the processes that result in what we call weather have greatly improved in the past 25 years (coinciding with the launch of the first satellites). What **is poorly understood** at present is how to predict the weather (and thus, the climate). Two primary limitations in predicting weather/climate are: limited computing power and limited knowledge of regional factors affecting both weather and climate.

REPRODUCED AT GOVT. EXPENSE

Natural climate variability scales are extremely large and natural climate change events of significant magnitude can occur over timescales of decades or less, well within the range of human lifespans. Therefore, many of the factors affecting climate are beyond our control, such as incoming solar radiation and the relative areas of land and sea surfaces.

However, other factors, such as the levels of greenhouse gases in the atmosphere and the amount and health of terrestrial vegetation (and in particular, forest species) are directly related to our activities, and thus within our control.

Since we've already addressed the greenhouse gases, lets look at forest species. Along with the oceans, the Earth's vegetation acts as a large CO_2 sink (i.e. they remove CO_2 from the atmosphere due to the process of photosynthesis). Human activity is having a large negative impact on woody vegetation, either by removal (deforestation, especially in the tropics) or by pollution-induced forest decline (Camels Hump in Vermont is a well-known example). Tree species act as CO_2 "sponges," removing it from the atmosphere and converting it to wood (i.e. cellulose). Large-scale loss of forests result in increased levels of CO_2 in the atmosphere, as can be seen in Figure 1 (notice that CO_2 levels in the atmosphere began to rise in the early 1800s, before the Industrial Revolution, as a result of deforestation activities in the United States and Europe).

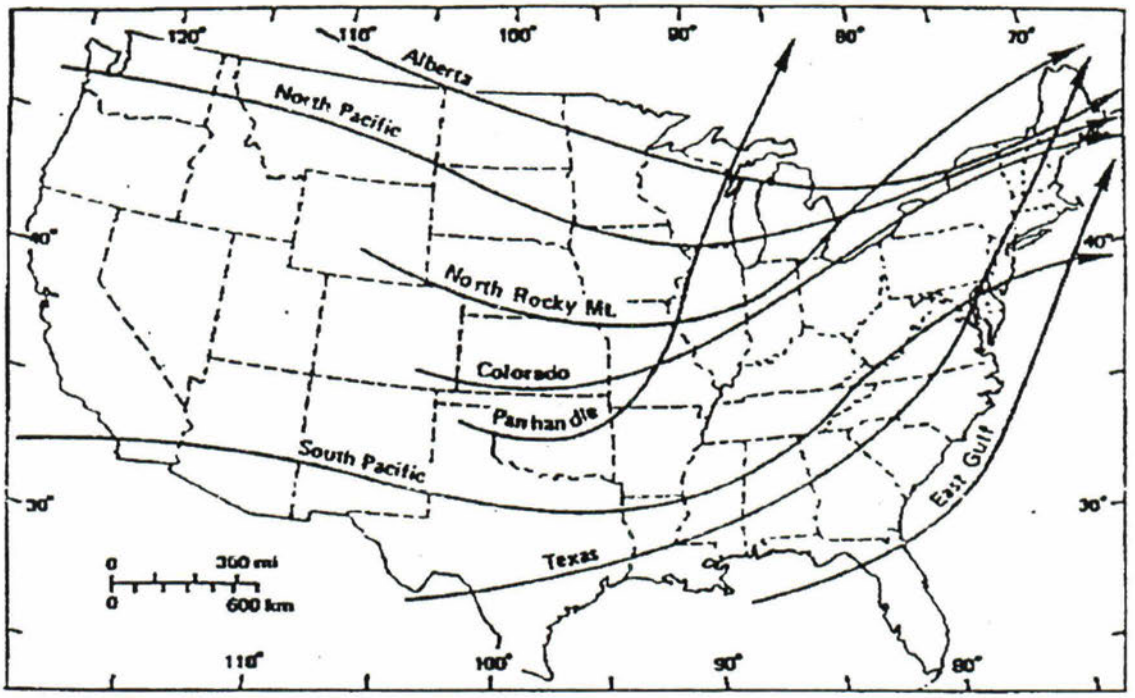


Figure 2. Major storm and airmass patterns for the United States.

REPRODUCED AT GOVT EXPENSE

New England Climate Patterns and the El Niño-Southern Oscillation (ENSO)

Believe it or not, our climate patterns of droughts and flooding here in New England have their origins in the equatorial Pacific. Scientists studying oceans and sea-surface temperatures have been able to show a strong linkage between sea-surface temperature patterns associated with cyclical warming and cooling of waters off the coast of Peru to climatic patterns in North America. Since we are down-wind from the rest of the country (Figure 2), what affects climate in North America, affects us. Climate-related events such as extremely cold winters, summer-time droughts, heat waves and associated crop failures and forest fires, flooding, etc. result in higher heating/cooling bills and higher food prices. In extreme cases, our homes and livelihood may be impacted. We need to better understand these linkages, both to be able to make better weather forecasts, as well as to be able to develop coping strategies,

The *El Niño* phenomenon has been known from the 1600's off the coast of Peru. On an irregular basis, anomalously warm waters off the coast around Christmas time were noted by Peruvian fishermen. These warm water events were called *El Niño* (Spanish for "the male baby"), in reference to the Christ child. Only recently have we come to recognize that the development of an *El Niño* event originates in the western Pacific. A relaxation of trade winds in the Pacific result in an eastward propagation of ocean currents along the equator, spreading warm sea-surface temperatures eastward toward the South American coast. The resulting *El Niño* is the warm extreme in interannual fluctuation of sea-surface temperature around the Galapagos Islands, while the cold extreme of this irregular cycle is called *La Niña* ("the girl baby"). Together, this fluctuation between warm waters and cold waters off the coast of Peru is referred to as the *El Niño*-Southern Oscillation, or ENSO, for short.

In general, years dominated by an *El Niño* event will be characterized by hot summers, droughts and forest fires in North American, while *La Niña* years will typically have cool, wet summers, and spring and/or fall flooding. The ENSO events also may vary with season, so that the timing of specific effects (cold/hot, wet/dry) is more complicated than this simplified explanation. However, this simple explanation does demonstrate how our understanding of the connections between sea-surface temperatures in the Pacific and climate patterns in New England are improving. This improved understanding will likely allow us to begin forecasting climate patterns 1-2 seasons in advance.

More specifically, researchers have determined several factors which affect North America and the Northeast due to ENSO. The Jet steam path and storm fronts have been found to related ENSO. *La Niña* events are associated with chaotic weather during winters in the Northeast. Additionally, researchers claim that ENSO is very powerful and can affect societal processes on a global basis. In the Northeast it has been found to cause increased occurrence of encephalitis outbreaks. These type of finding can have a significant impact on our concerns for regional climate variability.

It is interesting to note that hot, dry summers tend to be characterized by elevated levels of certain types of air pollutants, such as low-level ozone (tropospheric O_3) and sulfur dioxide (SO_2), while cool wet summers are characterized by better air quality. In this way, we can clearly see a

REPRODUCED AT GOVT. EXPENSE

connection between the physical climate and the chemical climate. Who would have guessed that ocean circulation patterns in the far-off Pacific would have such an impact on us in New England?

Do we have any control over the rates of greenhouse gas emission?

Figure 3 presents an example of how this has already been done. CFCs and other CFC-like compounds are greenhouse gases. They are better known as the major cause for ozone loss in the stratosphere. Figure 3 shows how levels of one specific chlorocarbon--methylchlorocarbon (CH_3CCl_3)--exhibited significant increases in the atmosphere between 1978 and 1995. The increase of greenhouse gas compounds such as these is a result of their use in manufacturing processes and as refrigerants. The dramatic reversal in 1992 is the direct result of the Montreal Protocol, adopted as a result of the Earth Summit held that year. This dramatic Figure clearly shows that a legislative decision can have a profound influence on a global-scale problem. We just need to know the facts about an issue and its solution.

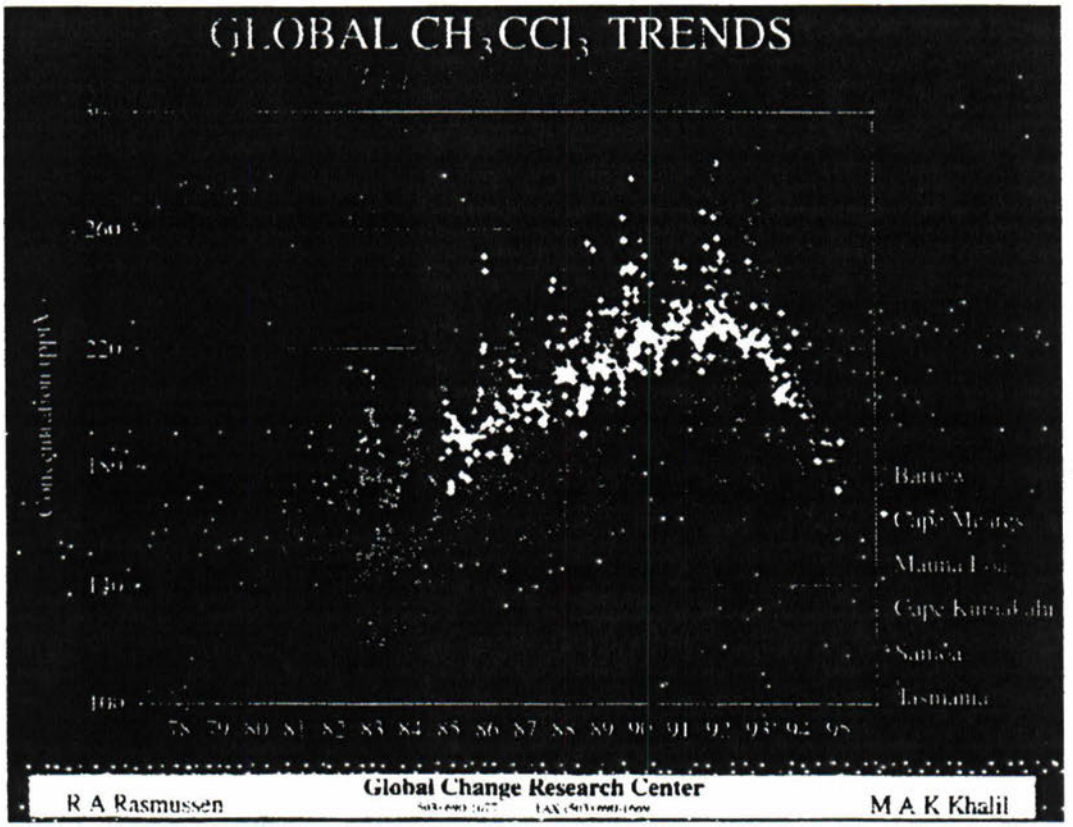


Figure 3. Global concentrations of a Freon-like compound, for selected collection sites.

One way to control greenhouse gas effects is to reduce the amount reaching the upper atmosphere by storing carbon in terrestrial ecosystems. The reduction of carbon dioxide to oxygen and stored carbon is the process plants use in photosynthesis. The forests of New England and New York contain 4.2 billion metric tons of carbon in forest ecosystems, and this amount is increasing at a

REPRODUCED AT GOVT EXPENSE

rate of about 20 million metric tons per year. Annual CO_2 emissions in the United States, primarily from burning fossil fuels for energy, are equivalent to 1.5 billion metric tons of carbon. I the international negotiating arena, the President is seeking ways to reduce or offset CO_2 emissions by 100 million metric tons, of which about 10 million would come from additional carbon storage in forests. The maturing forest of New York and New England are contributing in a very positive way to offset CO_2 emissions from other sources.

Are climate change issues relevant or important to the New England region?

Often when one thinks of climate change issues, one assumes that these processes occur in distant places (tropical deforestation in Brazil, the *El Niño* is somewhere in the Pacific Ocean, the ozone hole is in the Antarctic, etc.). We need to begin to consider what the impacts of climate change will be here in the New England region.

According to the *World Almanac and Book of Facts, 1997,* among the largest industries in the New England region are energy, manufacturing and tourism. We need to begin to think about how climate change issues will impact our businesses, our health and our way of life, right here in New England. The following examples of climate change impacts on New England industry (tourism), human health, and coastal issues (fisheries) are meant to give a flavor of how relevant climate change is to New Englanders. These examples represent just the tip of the iceberg, and the workshop in September will focus on these and many more stakeholder concerns and issues.

Climate Change Impacts on Tourism in New England

Tourism is one of the largest industries in New England and upstate New York, and for many residents of this region it is a way of life. This multi-billion dollar enterprise is composed of many small businesses and mom-and-pop operations which give the defining character to the New England region. New England is unique in that it offers a wide variety of recreational and leisure activities for a vast population. This region's lakes and rivers, oceans and beaches, mountains, scenic towns, and natural areas are within only a few hours drive of the Boston-New York urban corridor, which hold a substantial percent of the country's population.

The tourism industry and therefore the character of New England is vulnerable to the impacts of climate change. Weather and climate drive the tourism industry, if it rains during the summer, visitorship is down. If the snows don't fly and the temperatures are too high, the skiers and boarders don't head for the sky! New Hampshire Public Radio reported in June, 1997 that the popular 5-day Biker's Week event in New Hampshire's Lake Region resulted in $65 million in direct sales; that particular week was sunny and warm, with temperatures between 70-80°F. If the event happened the following week, with the forecasts of rain and thunderstorms, dollar figures could be assured to have been lower. Weather forecasting and predictability are important to the New England tourism industry. If predictability decreases, temperature increases and rain and severe weather events increase, tourism is bound to take a direct hit.

REPRODUCED AT GOVT EXPENSE

Another issue of concern for tourism and the recreationalists is the chemical climate of New England and upper New York. An interstate panel of pollution and weather experts, headed by the EPA. recently stated that New York and New England are indeed downwind of the smog produced by mid-western states. This smog directly affects the regions prized by outdoor enthusiasts, especially at higher elevations. The haze produced not only affects mountain vistas but is believed to affect the health of people utilizing high elevation areas for recreational purposes. And, the ozone and acid mists impact the health of the forests in these regions as well. If the current trend of increased air pollution continues to occur, human health and the tourism industry will be broadly affected.

New England's fall foliage season is one of the biggest tourist draws to this area by out-of-staters. The beautiful colors associated with fall foliage are created by the unique mixture of tree species found within the New England region, with maple being the most important. Yet, climate change predictions indicate that maple may be an affected species, causing delayed coloration, species collapse. or potential northern migration. Figure 4 shows two climate model scenarios and the impact on the future range of maple, based on a doubling of current carbon dioxide concentrations. Additionally, high elevation spruce and fir forests are in jeopardy of the incipient changes. New England's forests and lakes are the cornerstone of this region's way of life and the recreational opportunities it offers. Understanding climate change and how it will affect our natural areas and the tourism industry is important to protecting New England's heritage.

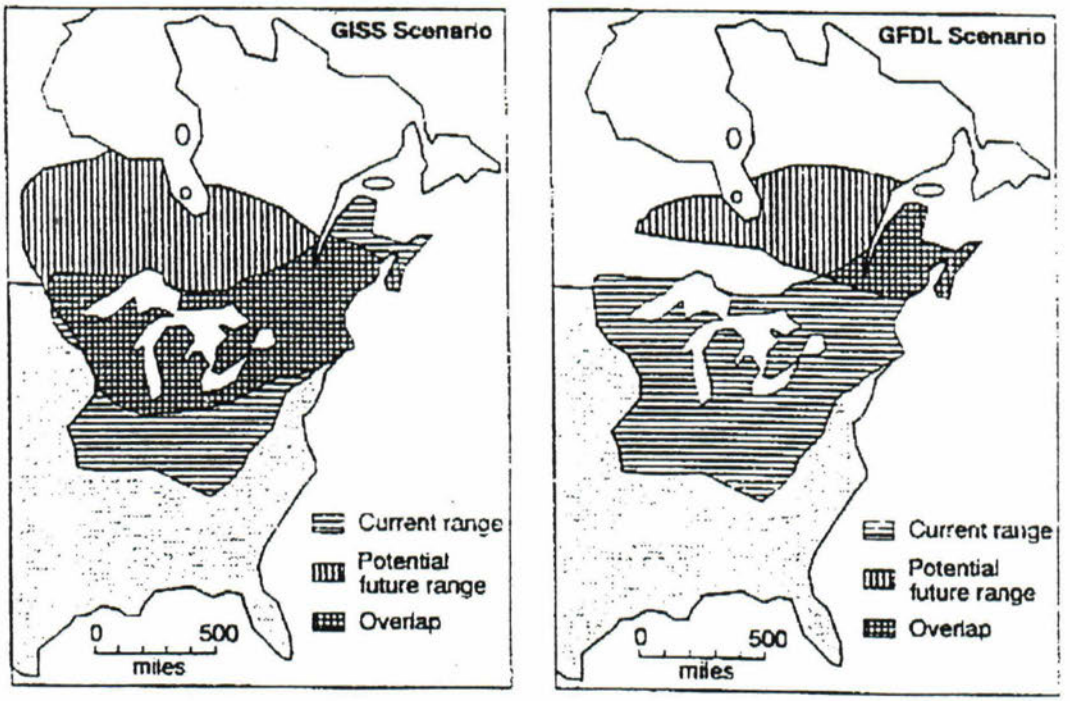


Figure 4. Two different climate models predict different ranges of sugar maple based on a doubling of atmospheric carbon dioxide concentrations. Yet, both predict a northern migration of the southern extent of maple distribution, with the GFDL model being most extreme.

Allan Auclair and colleagues of the Science and Policy Associates have cited extreme weather events as important mechanisms for causing forest dieback in the Northeast. They predict using climate models and forest maturation ages for the Northeast, that major dieback of naturally occurring New England forest species such as birch, maple and spruce are likely to occur in the mid 21st century. This will not only have dramatic impacts on the tourism and forest products industries but will mean a significant change in the way of life for children of the next two to three generations.

These issues are just examples of how climate change could affect one of New England's largest industries. The workshop being convened will solicit participant's input on their concerns regarding climate change effects on tourism and other issues. Much is still unknown regarding climate change and the particular effects on New England. Yet, it is important to begin now to address the issue of climate change.

Climate Change and Coastal New England Issues

Has climate change affected fisheries production in the Northeast?

Basically, the decline of fisheries in the Northeast where estimates of stocks of cod, haddock and yellowtail flounder are at historically low levels, has been blamed on overexploitation. All along the North Atlantic coast changes in species composition have also occurred with less desirable species such as dogfish and skates replacing the once abundant groundfish stocks, mainly as a result of over-fishing. It is not clear at present how these declines may be related to climate change.

Aquaculture has recently experienced widespread and rapid growth in New England with the development of state aquacuiture initiatives; extension of mussel, clam and oyster aquaculture; and the recent beginning of offshore finfish aquaculture efforts on the New England coast. While aquaculture cannot fill the gap left by declining wild stocks, there is a great deal of interest and money being devoted to developing more effective techniques for farming fish and shellfish here in New England.

While there is still uncertainty in the connections between fisheries resources and climate change in the Northeast, the association of fluctuations of *El Niño* events with the anchovy harvest off the coast of South America is well known. Also, the catch of salmon and steelhead in the Northeastern Pacific are sometimes associated with *El Niño* events. Researchers have shown that the present distribution of fish populations with water temperature can be used to estimate shifts in fish location resulting from climate change. Some scientists believed that a change in water temperature kept cod from returning to Newfoundland waters in 1995.

Ocean researchers reported a 1 degree Celsius rise in both the mean and maximum water temperature in August between 1976 and 1996 over Jeffries Ledge, located off Cape Ann, Massachusetts. Increases in ocean temperature can result in northward migration of certain

REPRODUCED AT GOVT. EXPENSE

invertebrate species. Species such as the resilient and aggressive starfish (*Asterias forbesii*), found near the Isles of Shoals, have already been observed to be migrating.

A recent and unusual outbreak of dense algae (an algal bloom occurred in March) turned Cape Cod Bay a murky brown, raising concerns about a disruption of the food supplies for the endangered Northern Right whales. This algal bloom appears to have been the cause of the whales abandoning their traditional feeding grounds this year at the earliest date ever recorded. Many of the 325 known remaining right whales, the most endangered of the world's large whales, typically spend the winter and early spring in Cape Cod Bay feeding on crustaceans called copepods. New calves in particular, need the spring copepod harvest to gain weight and strengthen prior to leaving the area. Most years the whales stay in the bay until late May. This year most of the whales were gone by late March.

Scientists know little about how the algae (genus *Phaeocystis*) affect the copepods that the whales eat. However, the coincidence between the algal bloom and the whales' early departure is a source of concern. Perhaps an even greater concern relates to the fact that a decline in copepods may signal a more general alarm for the health of the Cape Cod Bay ecosystem, and an alarm for the larger fish populations in Cape Cod Bay. It is clear that a current knowledge gap exists in our full understanding of the impact that climate change (warming waters, changing water quality, etc.) will have on New England coastal resources.

What are the potential effects of sea level rise on the New England coastal systems?

Since the rebound of the earth's surface after the last glacier receded in New England 12,000 years ago has pretty well ended, sea level rise is a reality that all low-lying coastal areas must face. Rising ocean temperatures and the accompanying expansion of the water itself contribute to sea level rise, as does more water entering the oceans via the melting of land-bound glaciers and ice sheets.

Rising sea levels causes intertidal animals and plants to move to higher elevations. Salt marshes in New England, one of the most productive of the intertidal habitats, are relatively new--only about 4,000 years old. They persist partly due to a balancing act between the rate of sea level rise and the accumulation of sediments and plant material which together form peat on the marsh surface. It is uncertain whether this balance will continue with sea level rising faster in the past fifty years (1.8 mm or 0.07 inches per year) than the rate of rise during the past 2-3,000 years (1 mm or 0.04 inches per year). In addition, man-made structures such as culverts and roads restrict the tidal flow and limit the inland migration of marshes. This results in the replacement salt marsh plants by fresh-water species.

Salt marshes and estuaries provide food and shelter for 70% of the fish and shellfish in the ocean, at some point in their life. A rise in sea level and development-curtailed inland migration of all the intertidal habitats will affect abundance and biodiversity of many plant and animal populations that are essential to food chains that support upper trophic-level animals such as fish.

What type of economic impacts will result from coastal systems affected by climate change?

Economic hardship in coastal communities is beginning to result from climate change. In the past decade, several New England coastal communities have refused shoreline development such as tourist hotels on the basis of predicted increases in sea-level.

As the predicted duration and severity of storms develops, as it now seems to be doing, coastal property owners face increasing economic loses. Coastal New England is continuously exposed to dynamic and corrosive environments whose complexities are exacerbated by harsh winters, severe storms, great tidal ranges from 3 to 50-plus feet and a very irregular coastline. By the year 2010, 70% of New England's population will live within 50 miles of the coast, and more and more people will be directly affected by storm damage to their homes and commercial properties. Development of environmentally-sound technologies for existing and new applications for the New England coast are dependent upon improved ecological knowledge of the environment. Developing a better understanding of how climate change will impact this economically-significant region is most important.

Storms also have a detrimental effect on some commercially important species. Excessive rainfall such as the 15 inches Great Bay estuary in New Hampshire received in 24 hours last September, caused death and migration of lobsters that traditionally inhabit the Bay, reducing the catch this year.

Marine and coastal educational programs are important for fostering a sense of stewardship of the New England coast and its resources. Developing programs that engage citizens of all ages in a wide spectrum of activities from water quality monitoring, in school programs, public forums, and teacher education are important for developing the kind of ethos and knowledge required to meet the challenge of climate change and its results.

The Impact of Climate Change on Human Health

When most people think of climate change issues and human health, they seldom go beyond the idea that the "ozone hole" allows more dangerous ultraviolet (UV) light to reach the surface of the Earth, and that this increased exposure to UV can cause skin cancer and glaucoma. They also assume that it is a problem for people living in Australia and New Zealand, but not here in New England. Dr. Paul Epstein, an Instructor in Medicine at the Harvard Medical School believes differently. He has written many general-purpose articles dealing with health and climate change (for example, the Op-ed article in the *Boston Globe*, April 10, 1997) and sees the New England area as likely to feel the impact of climate change in many aspects of human health.

Heat-related deaths in cities--which act as heat islands--will be exacerbated by air pollution and smog created both locally and up-wind (see Figure 2) of the urban areas. Infectious diseases will be on the increase, due to climate change conditions (wetter, warmer summers, less severe winters) that promote tick, mosquito and rodent populations, populations which carry diseases such as Lyme Disease, Ehrlichiosis, Eastern Equine Encephalitis, Hantavirus, etc. Increased run-off of nitrogen and other nutrients into estuaries and bays, coupled with hotter summers will lead

REPRODUCED AT GOVT EXPENSE

to increased occurrence of red-tides and shellfish poisoning, brown-tides (lowering oxygen levels in water), and bird, mammal, and fish die-off, due to disease. Food-borne diseases such as E. Coli, Salmonella, Cyclospora and Hepatitus-A will also be enhanced by warmer, moister conditions, as will water-borne diseases such as Cryptosporidia and Giardia. As the headline of Dr. Epstein's article stated: "Warm and wet conditions spell trouble for the world."

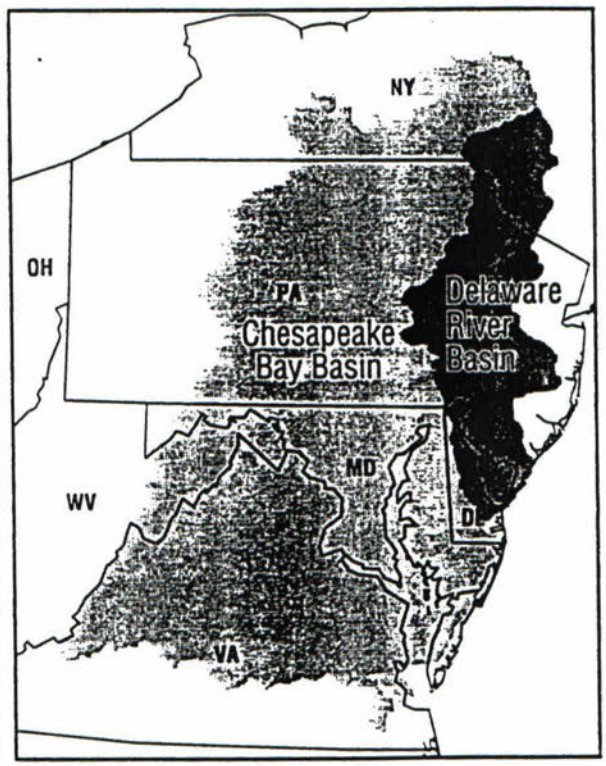
Although it is easy to respond to this "gloom and doom" scenario with a shrug of the shoulder or nervous laughter, it is most important that we need to view these issues as both important and something that we need to know more about. We can't continue to ignore the early-warning signs of what the future will hold if greenhouse gas emissions go unchecked. We as a people are conducting a global experiment, the outcome of which we are currently unable to predict. We have the records of the past, as well as sophisticated models to attempt predictions, but what is currently missing is the local knowledge of the real concerns, the vulnerabilities, and the current state of knowledge among a broad range of stakeholders who will be directly impacted by climate change. The U.S. Climate Change Research Program needs your input. The New England Regional Workshop will provide an ideal environment for developing an open dialogue among stakeholders, policy makers and research scientists. Please join us at the Climate Change Impacts Workshop, to be held at UNH, September 3-5, 1997.

Workshop on

Climate Change Impacts In the Mid-Atlantic Region

THE PENNSYLVANIA STATE UNIVERSITY
SEPTEMBER 9-11, 1997
Nittany Lion Inn

Climate variability has substantial impacts on agriculture, energy use, water resource availability, water quality, human health, ecosystems, recreation, commercial fisheries, and the frequency and severity of natural disasters. The effects of climate variability on economic vitality and the quality of life suggest that future climate change is of considerable global, national, and regional importance. Much of the climate research has focused on global predictions. Consequently, the impacts on human endeavors, most of which occur at the levels of regions and nations, have received far too little attention.



For this reason, Vice President Al Gore and the White House Office of Science and Technology Policy (OSTP) proposed the concept of major regional workshops on climate change impacts. The United States Global Change Research Program (USGCRP) is sponsoring a series of these workshops over the next few months, each focusing on a specific region. Penn State has been invited to host the Mid-Atlantic workshop, which will highlight major issues and the research agenda for the Chesapeake and Delaware Bay Regions, including their entire drainage basins. The U.S. Environmental Protection Agency (EPA) is the coordinating agency for this workshop, which will be held September 9-11 at the Nittany Lion Inn. The local organizing committee members are Ann Fisher, Eric Barron, Brent Yarnal, Greg Knight, and Jim Shortle.

Purpose: The workshops are being convened to examine climate change issues within regions and to obtain information that can be aggregated across regions to support analysis of climate change impacts at the national scale. Hence, the regional workshops are expected to be of national significance in setting priorities and policy. Specific objectives are to:

- Increase understanding of high priority regional environmental issues for which climate change is likely to be important.
- Increase understanding of the region's vulnerabilities to climate variability and climate change.
- Identify how individuals, governments, and industry in the region currently cope with environmental stresses, including climate stresses (e.g., drought and floods).
- Identify future coping mechanisms and options for adjustment and adaptation.

- Identify existing information and research needed to reduce vulnerability and improve adjustment and adaptation options.
- Define a preliminary, prioritized research agenda for the region.
- Define follow-on activities in the region.
- Initiate regional analysis to support national assessments of climate change impacts.

Participants: The workshop will include a broad research and stakeholder community, drawn from federal state, and local governments, universities, laboratories, industry, agricultural and natural resource managers, non-governmental organizations, and others. The address on the evening of September 10 will be open to the general public.

Steering Committee: Representatives from science, federal, state and local governments, industry and non-governmental organizations serve on a Steering Committee. Its role is to ensure participation by major leaders from research and stakeholder groups, to provide advice on the workshop program, to review drafts of short "white papers" intended to set the stage for workshop discussion, as well as to participate in the workshop. The Steering Committee's input will help ensure that the results of the Workshop on Climate Change Impacts in the Mid-Atlantic Region are of national significance.

The Steering Committee members are:

Janine Bloomfield
Environmental Defense Fund

Dan Botkin
George Mason University

Irene Brooks
PA Department of Environmental Protection

John Carberry
Dupont

Charles Carson
US Steel Corporation

Tom Cronin
OSTP and USGS

Joanne R. Denworth
Pennsylvania Environmental Council

Pat Devlin
Alliance for the Chesapeake Bay

Gerald Hansler
Delaware River Basin Commission

Larry Kalkstein
University of Delaware

John McSparran
Susquehanna River Basin Commission

Jon Plaut
NAFTA Environmental Commission

Joel Scheraga
U.S. EPA

Gwynne Schultz
Maryland Department of Natural Resources

Dave Schwarzwaelder
Columbia Gas of Pennsylvania and Maryland

Michael Slimak
U.S. EPA

Bud Ward
Environmental Health Center, National Safety Council

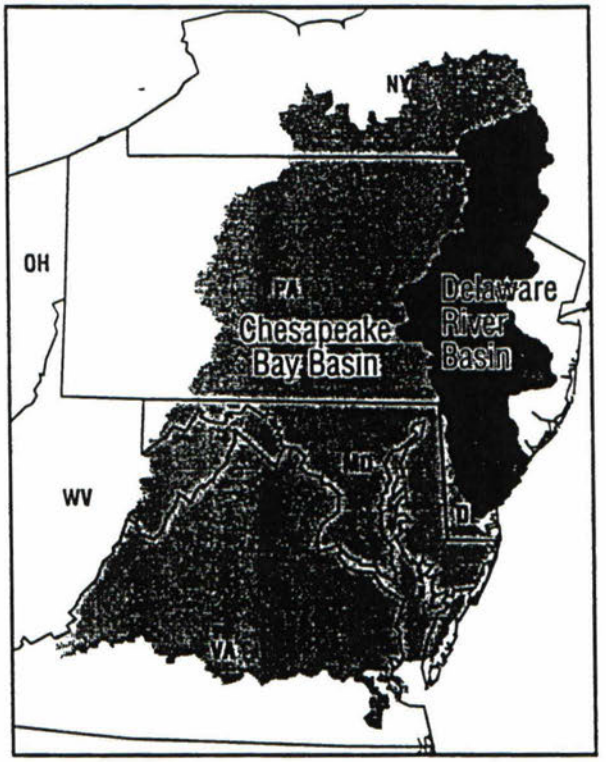
Output: A synthesis of the workshop's activities and findings will provide input for the National Workshop on Climate Change Impacts, November 10-12, 1997, which will relate regional to national-scale impacts, and plan a national science assessment.

Workshop on

Climate Change Impacts In the Mid-Atlantic Region

THE PENNSYLVANIA STATE UNIVERSITY
SEPTEMBER 9-11, 1997
Nittany Lion Inn

June 11, 1997 draft



(Hosted by: The Pennsylvania State University. Sponsored by: The United States Environmental Protection Agency; Earth System Science Center and Center for Integrated Regional Assessment in the College of Earth and Mineral Sciences; Department of Agricultural Economics and College of Agricultural Sciences; The Environmental Resources Research Institute; and Office of Research.)

The workshop will focus on the Chesapeake and Delaware Bay watersheds.
Three short white papers will be prepared and distributed to participants in advance.

PRELIMINARY PROGRAM

Tuesday, September 9, 1997

6:00-9:00 pm	Registration, reception/mixer, welcoming address and poster session

Wednesday, September 10, 1997

7:30 am	*Registration* (continental breakfast)
8:30 am	*Workshop purpose and goals*
8:45 am	Variability in Today's Climate in the Mid-Atlantic Region
9:15 am	*Panel:* Overview of Current Impacts and Adaptation to Climate Variability in the Mid-Atlantic Region

Wednesday, September 10, 1997 (continued)

10:00 am	*Break*
10:15 am	Our Changing Climate: Observed and Expected Future Changes in the Region's Climate - Science Overview
10:45 am	Linking Projected Climate Changes to Regional Impacts - Integrated Regional Assessment Overview
11:15 am	*Panel:* Perspectives on Regional Vulnerabilities to Climate Change
12:30 pm	*Lunch with speaker:* Relating the Region's High-priority Environmental Issues to Regional Impacts from Climate Change
2:00-5:00 pm	*Break-out sessions* Final topics will be based on pre-workshop input from participants. Current options: ▣ economic growth ▣ land use/land cover ▣ ecosystems ▣ water resources (quantity and quality) ▣ natural hazards ▣ human health ▣ agriculture and forestry ▣ recreation ▣ industry and commerce (including energy, transportation and fisheries) These working sessions will consider both the Chesapeake and Delaware Bays and their drainage basins. They will include presentations (by top experts for each topic), panel discussions, and full-group discussions, led by a session chair, co-chair, and rapporteur. The emphasis will be on: ▣ reviewing what we know now from the science, ▣ how this is related to identified vulnerabilities, ▣ identifying major gaps in information (e.g., data, scientific understanding), ▣ what coping measures might be used and barriers to adopting them, ▣ priorities for research a) to improve estimates of regional consequences from climate change, b) to identify adaptation and resource management strategies for reducing regional vulnerabilities to climate change impacts.
5:15 pm	Meeting of discussion leaders, co-chairs and rapporteurs
7:30 pm	*Public Address:* **Vice President Gore** has been invited; he may speak on International Negotiations on Climate Change.

Thursday, September 11, 1997

8:30 am	*Plenary session:* Panel on How the News Media Report on Environmental Issues
9:30 am	Reinforce charge to groups: their recommendations about a) research agenda for the region, b) follow-up activities in the region, and c) regional input/results to support national assessment of climate change impacts.
9:45 am	*Break*
10:00 am - noon	Break-out sessions
noon-1:30pm	Lunch with speaker
1:45-4:00 pm	*Plenary Session:* 1:45 pm Workgroup reports and discussion 2:30 pm Synthesis and Future Needs Panel 3:30 pm Concluding remarks
4:00 pm	Workshop adjourns (discussion leaders, co-chairs and rapporteurs meet)

Workshop on

Climate Change Impacts In the Mid-Atlantic Region

THE PENNSYLVANIA STATE UNIVERSITY
SEPTEMBER 9-11, 1997
Nittany Lion Inn

Poster Registration Form
Deadline: July 15, 1997

The working nature of this meeting makes it infeasible to have presentations on the full range of available research that has implications for climate change in the Mid-Atlantic region. Thus to maximize the exchange of information about what currently is known, posters will be an integral component of the workshop.

The workshop will begin with a poster session on Tuesday, September 9 from 6-9 pm. Posters will be accepted from workshop participants as well as nonparticipants and must be on research or data related to climate variability or change in the Mid-Atlantic region. Each poster must be free-standing to rest on a small table that is provided (36" wide by 30" deep), unless you wish to provide your own easel. After the September 9 session, posters will be moved to the corridors outside of the meeting areas and remain displayed for the duration of the workshop. Those preparing posters may wish to provide a short (1-4 page) write-up for participants to take with them.

Name: _____

Company / Institution: _____

Poster Title: _____

Department: _____

Office Address: _____

Institution: _____

City/State/Zip: _____

Phone: _____

Fax: _____

E-mail: _____

Please Return by July 15, 1997 to:

Earth System Science Center
Attn: Deb Detwiler
Penn State University
University Park, PA 16802
(814) 865-1073
FAX: (814) 865-3191
deb@essc.psu.edu

REGISTRATION FORM
Due by: July 15, 1997

Workshop on Climate Change Impacts in the Mid-Atlantic Region

September 9-11, 1997
Nittany Lion Inn Hotel
Pennsylvania State University
University Park, PA

Name: _____

Company/Institution: _____

Title: _____

Mailing address: _____
_____
_____

Phone: _____
Fax: _____
Email: _____

Hotel Information:

A block of rooms has been reserved at the Nittany Lion Inn at The Pennsylvania State University Park campus. Participants must make their own hotel reservations by calling 800-233-7505 or 814-231-7505. Please refer to the Earth System Science Center when making your reservation. Reservations must be made by **August 8, 1997**, to guarantee a reservation. Group rates for the Nittany Lion Inn will be $80 for a single and $90 for a double. All rates are subject to 6% state tax. After this date, rooms will be available on a first-come basis.

Return registration forms by **July 15, 1997** to:

Earth System Science Center
Attn: Deb Detwiler
Penn State University
248 Deike Building
University Park, PA 16802
(814)-865-1073 FAX: (814)-865-3191 deb@essc.psu.edu

Participant Interests Name:_____

1. Which of these best reflect your interests?

   _____ natural climate variability

   _____ human-induced climate change

   _____ both of the above

2. There are many Mid-Atlantic regional issues that could be affected by climate change. Some are listed below, as a draft list of topics for the workshop's break-out groups to examine. If you think important topics are missing, please add them to the list.

   Now please mark a "1" by your first choice for a break-out group, "2" by your second choice and "3" by your third choice:

   _____ economic growth

   _____ land use/land cover

   _____ ecosystems

   _____ water resources (quantity and quality)

   _____ natural hazards

   _____ human health

   _____ agriculture and forestry

   _____ recreation

   _____ Industry and commerce (including energy, transportation and fisheries)

   _____ _____

   _____ _____

   Depending on interests expressed by you and others planning to attend the workshop, the final list of break-out session topics will be adjusted to accommodate your suggestions. This may lead to new sessions. For impacts that would affect several topics, multiple groups may be asked to address the implications (e.g., sea level rise could be especially important for ecosystems, land use, and water resources).

DRAFT - 7/9/97

MID-ATLANTIC WORKSHOP ON REGIONAL CLIMATE IMPACTS

III. REGIONAL IMPACTS AND IMPLICATIONS OF CLIMATE VARIABILITY AND CHANGE

Eric Barron, Ann Fisher, Richard Horan, James Shortle, and Brent Yarnal

A. Introduction

Through heat waves, cold spells, floods, droughts, severe storms, and other variations, today's climate helps determine the functioning of societies, ecosystems, and their component individuals. For the most part, however, the human and natural worlds have adapted to the prevailing climate. In the coming years, natural climate variation and human-induced climate change may place increased or new climatic pressures on systems and individuals. Even if climate change presents a more benign future climate, it may be profoundly different, thereby demanding costly adaptations. The risks of and possible adaptations to climate variation and change are difficult to assess because it is unclear when, where, and how climate change will be manifest.

This uncertainty is especially large at the regional and daily-to-annual scales, precisely the space and time frames in which most decision makers operate. Although their concerns necessarily involve the known, tangible socioeconomic and environmental stresses that exist today, many decision makers also need to consider the uncertain, abstract threat of climate change. Not all decision makers need to analyze climate change risks and developing plans for dealing with climate change. But those decision makers who find that climate is consequential should find out if and how climate change might affect present and future problems in their jurisdiction. They need to know what climate impacts are possible, who is vulnerable to these impacts, and how possible adaptation measures might reduce impacts and vulnerability. They should assess the availability and costs of various adaptation strategies.

The goal of this paper is to provide background on climate impacts, vulnerability, and adaptation, giving special attention to the problems of the Mid-Atlantic Region. The remainder of this introduction defines key terms. The following section introduces the impacts of climate on issues important to the Mid-Atlantic Region, such as water resources, human health, and industry and commerce. Then, the paper covers factors that govern decision making, such as risk and vulnerability, and possible mitigation and adaptation strategies for the Mid-Atlantic Region. The concluding paragraph encapsulates what we know about the potential for Mid-Atlantic

climate impacts, and what we need to learn to make effective decisions in the face of climate change.

Sensitivity, adaptability, and vulnerability

The impacts of climate variation and change are a function of a system's or individual's sensitivity, adaptability, and vulnerability. *Sensitivity* indicates the degree to which a system is responsive to a variation or change in climate. For example, Mid-Atlantic ski resorts are sensitive to within-winter and year-to-year variations in snowfall. It is possible that climate change will mean shorter snow seasons on average, and more years with no appreciable snowfall. Thus, these resorts are also sensitive to the impacts of climate change. *Adaptability* defines the extent to which individual or systemic adjustments are possible in response to climate variation or change; such adaptations can be reactive or planned. For instance, Mid-Atlantic temperatures are still low enough during most winters with low snowfall to permit regional resorts to produce artificial snow. Such an adjustment is planned. If future winter temperatures were to become too high, this technical adaptation would not work. *Vulnerability* delimits the extent to which climate may damage or harm individuals or systems. Vulnerability not only depends on sensitivity, but also on adaptability. To complete the skiing example, the most vulnerable ski resorts are those that are especially sensitive to snowfall variations, or that cannot adapt by making snow (e.g., the owners cannot afford snow-making machines, or the organizational structure prevents management from reacting quickly enough to climate).

The Intergovernmental Panel on Climate Change (IPCC) Working Group on Impacts, Adaptations, and Mitigation of Climate Change, made the following conclusions in 1995:

- Climate impacts are difficult to establish and quantify at the regional scale because model projections are too coarse and uncertain.
- If future climate extends beyond documented impacts of past climate variation, then it is likely that actual impacts will include surprises.
- Most systems are sensitive to both the magnitude and rate of climate variation and change.
- Climate variation and change add an important additional stress, especially on individuals and systems that are most sensitive and least adaptable to climate. Most systems are subject to multiple climatic and non-climatic stresses.
- Vulnerability increases as adaptive capacity decreases.
- Successful adaptation depends on technological advances, institutional arrangements, availability of financing, and information exchange.
- Enhanced support for research and monitoring are essential.

B. Potential Impacts of Climate Variability and Change in the Mid-Atlantic Region

Economic growth

Economic growth can be loosely defined as the change in the overall level of economic activity (as measured by incomes, spending, or the number of jobs) in a region over time. Because it occurs over time, economic growth refers to a dynamic or evolving process. Catalysts include population growth, investment, increases in skilled and educated labor, technological innovations, improvements in productivity, and institutional innovations. In addition, growth is influenced by government policies.

Climate change will undoubtedly influence economic growth in the Mid-Atlantic region. The overall impact is uncertain but likely to be small. Agriculture, forestry, and fisheries are likely to be affected along with other industries that depend on water availability. Studies show that Mid-Atlantic agricultural productivity could increase or diminish as a result of climate change (see the following section on agriculture). Forest productivity may increase as a result of increased CO_2 levels, and a northern migration of forests may also occur. Bay fisheries will most likely experience diminished productivity as a result of climate change because predicted precipitation increases will increase agricultural and urban runoff into the Chesapeake and Delaware Bays, with adverse impacts to fish populations. Decreased productivity will most likely lead to decreased economic growth, although physical impacts must be distinguished from economic impacts. Ultimately, management practices, market responses, and policies determine economic impacts.

Impacts to the agricultural, fisheries, and forestry sectors will most likely affect economic growth in rural areas where these industries are important (e.g., in southern Maryland where watermen harvest oysters, crabs, and fish from the Chesapeake Bay). However, the growth impacts for the region as a whole are likely to be small because agriculture, forestry, and fisheries contribute less than 1% to the region's GDP (US Treasury Department). In addition, producers and consumers will adapt (to some extent) to any change that occurs. For example, agricultural adaptations may include switching to crops better suited to the new climate, altering the growing season, or changing pesticide usage. Input and output markets may be influenced as a result, altering prices and possibly influencing growth. New policies may also be implemented to help mitigate damages.

The speed of and expectations about change are also important. Growth will be most dramatically affected by relatively quick and unexpected changes in climate because it is difficult to adapt fully in a short period of time. In addition, immediate adaptation may require that resources be reallocated away from more productive, growth-enhancing uses. Alternatively, slow and expected change allows for gradual adaptation and with only a slight impact on growth.

Adaptation not only mitigates damages (or exploits benefits) resulting from climate change, but it often fuels the development of new innovations and provides firms with incentives to look for more efficient ways to operate under current

technology. In turn, innovations and increased efficiency in production are likely to spur economic growth. Thus, while climate change may adversely affect the status quo, society is capable of adapting to take advantage of new opportunities as they arise.

Investment and population growth along with increases in a skilled and educated workforce are likely to be the most important economic growth forces in the Mid-Atlantic region. It is possible that these forces would be influenced by climate change. For example, an increase in natural hazards (such as an increased frequency of hurricanes or flooding) would have negative impacts on the insurance industry while spurring economic growth in construction. In any case, rebuilding after a natural hazard would require that resources be reallocated from other uses, potentially slowing economic growth.

Some economic influences would be the result of changes in the region's climate relative to other regions. Because the Mid-Atlantic region is not a closed system, it is difficult to predict future growth patterns even in the absence of climate change. Prediction becomes even more uncertain when climate change is considered. Adaptation may require a reallocation of production and trade practices across regions and may influence people's migratory patterns, depending on changes in the region's climate relative to other regions. In addition, policies in effect in other regions may influence adaptation and growth in the Mid-Atlantic. For example, beach protection and restoration projects in North Carolina may induce emigration from Mid-Atlantic beaches to avoid the impacts of a sea level rise. In this case, tourism would decline in the Mid-Atlantic, reducing growth for the region. Alternatively, economic growth would increase if the Mid-Atlantic region became a relatively more desirable place to live as a result of climate change.

Ecosystems

Ecosystems in the Mid-Atlantic Region will continue to be affected by climate variability as well as the stressors accompanying economic development and changes in land use and land cover. Climate change may exacerbate some of these. Changes in average temperature and precipitation as well as increased frequency of extremes in climate variability (unusually wet or dry periods, unusually hot or cold spells) may overwhelm the resiliency of particular species of plants or animals. Their loss may be replaced by other "alien" species, but the characteristics of the ecosystem will be different both during the transition period and when the area approximates a new equilibrium.

For example, projected increases in global temperatures are expected to move the range of forest types northward, so that the Mid-Atlantic Region will have fewer sugar maples, and perhaps more of other species (Yahner). Such a change is expected to affect bird populations in this region, as migration corridors are disrupted when some tree species die off faster than suitable replacements. Because of their role in pollination, a change in insect and bird populations could decrease agricultural

productivity. Because of their more limited mobility, ecosystem impacts on small mammals may be more severe than on bird populations.

Projected increases in intense precipitation events will scour stream banks, decreasing the reproductive success of aquatic insects (which serve as food for fish as well as birds and waterfowl) and of fish that lay eggs near the edges of streams. While this currently happens when there is an intense rain event during the critical reproductive period, the relative infrequency of stream scouring gives the susceptible populations time to recover. But more severe and frequent extremes under climate change could push some species out of their niches in the ecosystem, with repercussions for other species such as the fish and birds that feed upon them. Increases in intense precipitation also are likely to flush more contaminants into streams, adversely affecting sensitive species.

Warmer winters could lead to more abundant insect pest populations, perhaps offset by larger populations of predators such as warblers and the eastern phoebe, which no longer would have their range as restricted by January temperatures (Root and Schneider).

We need to synthesize existing information to determine what can be said about which species in the Mid-Atlantic region are especially vulnerable to exacerbated climate variability and likely trends in average precipitation and temperature. Along with a preliminary assessment of the ecological roles of vulnerable species, this synthesis will allow identification of gaps in available data and suggest priorities for a research agenda.

Water resources and water quality

Recent climate variation has produced a Mid-Atlantic moisture regime that has varied dramatically. The 1960s was perhaps the driest decade in centuries, while the 1970s may have been the wettest. In the last twenty years, the region has not only suffered significant droughts (1986, 1988, 1991, and 1995), but has also experienced record snow packs (1996) and rainfall totals (1996), local flash floods (1996), and region-wide billion-dollar floods (1996). Model projections of greater climate variability and a more active hydrologic cycle mean that variations in water will be fundamental parts of climate change. It is possible that the recent hydrologic variation is an early expression of climate change.

Climate-induced variation in hydrology plays havoc with the region's users of water, from agriculture to industry, from households to institutions. For example, little of the Mid-Atlantic's agriculture is irrigated, and drought frequently has significant impacts on yields and income. Significant losses accrued during the short, sharp drought of 1995. Ironically, other years can be too wet for Mid-Atlantic farmers to carry out normal, timely mechanical operations, and can cause crop damage associated with fungus and pests; the very next year, 1996, produced these problems throughout the region. Furthermore, dry years engender problems in the dilution of agricultural runoff, while exceedingly wet years and floods cause the release of manure and associated pathogens into the region's waters. Thus, exceptional climate variation

directly affects the Mid-Atlantic's financial and environmental health, with subsequent effects on economics, ecosystems, human health, and so forth. Climate change could make the situation worse. For instance, if the future brings more frequent droughts, then farmers will have to consider investing capital in irrigation equipment. Such a switch to irrigation would also require major investments in regional water supply infrastructure.

Regional water supplies, water demand, and their management are also greatly affected by climate variation, and may be influenced even more by climate change. Present water management practices have been developed to adapt constantly to the present range of climate variation, but during the last decades numerous cases of supply problems have been evident. Still, they would probably allow future users to meet their needs if there were no change in the economic, cultural, regulatory, or climatic environments. However, it is likely that none of these environments will remain static, and that the impacts of economic growth, lifestyle change, and safe drinking water regulations may even be as large or larger than the effects of climate change. Successful adaptation of water supply systems to climate change must focus on increasing flexibility through demand management and institutional adaptation, and not necessarily on climate change itself. Still, it is important to consider that many technological adaptations to climate change, such as reservoir construction, require large investments and long lead times.

In short, climate has a huge influence on regional hydrology, and water is fundamental to most economic and environmental systems. Therefore, a range of water quantity and quality issues too broad to address here are touched by climate variation and change.

Human Health

Human health risks are governed by a large number of factors, ranging from socio-economic status, to the availability of clean water and nutrition, to the quality of the health care infrastructure. Over the last decade, climate and climate change have become recognized as one of the significant factors influencing health risk. Climate change and variability can affect health directly, through extreme thermal events such as heat waves and cold episodes, and through severe weather such as hurricanes and tornados. Climate change can also influence human health indirectly. The majority of the indirect influences involve (1) changes in the range and activity of vectors and infective agents, (2) changes in water and food-borne infective agents, and (3) altered food (especially crop) productivity. A number of examples of human health vulnerability in the Mid-Atlantic States serves to illustrate the nature of this problem.

The increases in average temperatures associated with global warming or with extremes in natural climate variability will probably be accompanied by an increase in the number of heat waves. The deaths of 726 people in Chicago during the summer of 1995 heat wave is an example of the potential direct impact of thermal extremes.

Summer 1995 brought a strong early-summer heat wave to the Mid-Atlantic and resulted in high mortality in Philadelphia, PA. Mid-latitude cities, already

characterized by large urban heat island effects, appear to be the most susceptible to heat waves. The heat-related mortality that has occurred in cities such as Chicago, St. Louis, Washington D.C., and New York City disproportionally affect the young, elderly, the economically disadvantaged, and the ill. Because many of these deaths stemmed from socioeconomic factors and were preventable, there is considerable hope for adaptations to help check the impacts of heat waves.

Phenomena, such as El Nino, are associated with changes in rainfall, producing flooding and droughts in different regions. Based on climate model predictions, climatologists have speculated about whether anthropogenic warming will produce increased intensity or an increased number of severe hurricanes along the east coast of the U.S. Severe weather has well-known potential to increase the number of deaths and injuries.

Vector-borne diseases are a major cause of illness and death across the world. These disease vectors (e.g. mosquitoes and rodents) are strongly influenced by climate. For example, Dengue fever is transmitted by the bite of a mosquito (Aedes aegypti and Aedes albopictus). Both mosquitoes are currently present in Florida and Texas (an outbreak of Dengue occurred in south Texas in 1986) but U.S. cases are uncommon, probably because of high standards of housing, adequate water, sewer and waste management systems. However, the mosquitoes that transmit Dengue are strongly controlled by winter temperatures. Warming, particularly in terms of minimum winter temperatures could substantially increase the range of this Dengue vector, including regions north of the mid-Atlantic states. Malaria, caused by the protozoan parasites of the genus Plasmodium and transmitted by Anopheles mosquitoes, would also substantially extend its range and activity under conditions of global warming.

Wet-dry cycles also influence human health risks because of its influence on predator-prey relationships. Historically, moving into a wet period following a few years of severe drought, provides advantages to rodent populations which can reproduce faster that their predators (e.g. owls, etc). Population explosions of rodents eventually leads to invasions into human habitats and human food stocks, increasing the risk of disease. Lyme disease, which is caused by a bacterium, has a strong climatic association as well. Lyme disease is transmitted by the bite of a tick (Ixodes scapularis) which feeds on the white-footed mouse, the white-tailed deer and other mammals. The number of Lyme disease cases is strongly correlated with the size of the deer population, and in turn. the size of the deer population is correlated with the severity of winter conditions in the northeastern U.S.

Increases in water temperatures and salinity increase the risk of cholera in the Delaware and Chesapeake Bays, especially from recreational contact. If sea level rise is high enough, salinity and accompanying pollution also could be a problem for water supplies.

Increased precipitation, especially if it occurs in intense events, could flush contaminants, including Cryptosporidium, into private wells and public water intakes. This protozoan is difficult to control because of its resistance to the typical water treatment technologies that rely on chlorine disinfection; filtering can be effective, but tends to be expensive and difficult to maintain properly. Children are at higher risk

of infection, partly because of their relative inattention to proper hygiene. People with compromised immune systems are particularly vulnerable, because they have difficulty clearing Crypto from their systems; there is no cure for the (usually self-limiting) illness, cryptosporidiosis (crypto). Secondary infection is not unusual for health and child care-givers or from exposure at public swimming pools. The effectiveness of boil-water advisories in reducing infection from contaminated water depends on issuing them quicky and on the public following them properly. The potential magnitude of impacts is suggested by the 1994 Crypto contamination of public water supplies in Milwaukee, where more than 50 percent of those exposed to contaminated water became ill--a total of 400;000 people.

The U.S. is less susceptible to problems of malnutrition and crop productivity compared to much of the world because of the breadth of food production and our capability for technological adaptations. None-the-less, climate change and variability may result in the need to change crops and planting practices, and may also influence the activity or emergence of crop diseases.

Health risks associated with climate change and variability have implications for policy. Such policy should involve (1) surveillance efforts, (2) increased research on changes in range and activity of vectors associated with climate change, (3) disease prevention programs, (4) education for medical and public health communities, and (5) public outreach.

Recreation

Tourism and a wide range of outdoor recreation are important for the local economies within the Delaware River Basin and Chesapeake Bay Region. Some of these activities depend fairly directly on temperature and precipitation, such as snow skiing. Others have a less direct relationship. For example, warmer summers might encourage more people to go to the beach. But increases in salinity and temperature in the Delaware and Chesapeake Bays might cause more algal blooms so that the beach experience is less pleasant. These conditions also could foster increases in cholera bacteria, leading to beach closings and subsequent decreases in the patronage of motels, shops and restaurants, etc., that cater to people vacationing at the beach.

The demand for many forms of outdoor recreation may decline if there is an increase in the number of extremely hot, cold, or cloudy days; outdoor recreation simply is not as much fun when weather conditions are less appealing. Some adaptation is likely: An increase in hot weather might lead to more requests for tee times very early in the morning or the installation of more water fountains. Golf course owners also may need to irrigate more, an illustration that some forms of outdoor recreation may become more costly.

Other recreation effects may derive from ecosystem impacts. For some people, recreational fishing may be less enjoyable when the species mix changes. Current research suggests that climate change will cause a decline in cold-water game fish in the Mid-Atlantic Region. However, Heberling, et al. find that anglers tend to care more about catching "something" than catching a target species. This suggests that

sport fishing in the Mid-Atlantic Region could become more attractive, because total fish populations might increase (even though the species mix would differ).

Substantial research is available on recreation in the Mid-Atlantic Region, but it may not cover all forms of recreation potentially affected by climate change. Relatively little of this research has been tied to factors that might be influenced by climate change. Thus we need a preliminary assessment of which types of recreation are likely to be most affected, the importance of these to the region, and gaps in information about important recreation types likely to be affected.

Natural hazards

Severe storms, floods, and heat waves are the principal natural hazards in the Mid-Atlantic Region today; each may become worse with climate change. For example, the enhanced climate variability of the last five years has been associated with more frequent, powerful, and unusual winter storms, and with greater snow accumulations and impacts. The billion-dollar January 1996 flood was the result of two strong storms. The Blizzard of '96 dumped record snowfall totals throughout much of the Mid-Atlantic. It was followed a week later by a storm with spring-like characteristics, including high rainfall totals and - most important - the ability to melt the thick snowpack in a half day. Two of the region's three biggest floods this century (March 1936 and January 1996) were associated with this scenario. Thus, if climate change means more powerful winter storms, greater snowfall accumulations, and more rapid-snowmelt events, then such floods and their impacts could become more commonplace.

The dozens of heavy thunderstorms that rumbled throughout the summer of 1996 contributed to the Mid-Atlantic's record precipitation total for the year. For instance, State College, PA received more than 5 inches of rain in 40 minutes on June 17, while Gettysburg, PA had nearly a foot of rain in 10 hours on June 19. Exactly one month later, five western Pennsylvania counties were declared federal disaster areas from a storm that contained 17 tornadoes and caused record flash flooding. More deadly thunderstorms and their floods hit the state in August. The localized flash floods that resulted from the 1996 thunderstorms were not restricted to Pennsylvania, but were ubiquitous throughout the Mid-Atlantic and occurred almost daily that summer. Observations have shown that the frequency of severe thunderstorms with excessive rainfall is becoming more common in the region; theory and modeling suggest that climate change should bring more of these events.

Industry and Commerce (Including Energy and Transportation)

Manufacturing, construction, transportation, and energy production are of great importance to income and employment in the region. Climate change and variability can have direct effects on industry and commerce. For instance, snow, wind, rain, and fog affect the speed and safety of air, land and water transportation. Weather influences the operation of tourist facilities, mining sites, construction sites, communications, power transmission, thermal power generation, and water-dependent

and other types of manufacturing processes. Road, bridges, parking lots, buildings, pipelines, power lines, sewers and other private and public infrastructure are constructed for operation in specific seasonal climatic norms and with specific expectations about the frequency and severity of extreme weather events.

Direct effects of climate change and variation on commerce and industry can be positive and negative. For instance, increased winter temperatures may reduce damages to highways from freeze-thaw cycles but also reduce economic activity dependent on cold weather outdoor recreation (e.g., ice fishing, skating, snow mobiling, skiing). Increases in the frequency and severity of extreme weather events that impair travel, manufacturing, construction, mining, and other activities will adversely affect economic productivity. Infrastructure costs may also increase as buildings, roads, bridges and other structures are constructed to withstand more extreme weather.

Industrial and commercial activities with forward or backward market linkages to climate-sensitive sectors are also potentially vulnerable climate change and variation. These sectors include electricity and fossil fuel production, agroindustries, and insurance. Increases in summer temperatures increase the demand for electric power for air conditioning homes and commercial facilities while increased winter temperatures reduce the demand for heating. Depending on the net effect, the demand for fossil fuels and optimal power generation capacity may increased or decreased. Agroindustry, which is economically important in some areas within the Mid-Atlantic states, is vulnerable to changes in the supply and cost of agricultural commodities. Increases in property damage and accidents with extreme weather events will increase the demand for insurance and payouts. The effects on the insurance industry will depend on how well it can adapt to changing conditions. Possible avenues for adaptation include incorporating more knowledge about actual risks when setting premiums, expanding available funds through further pooling and accumulation of funds, which may require significant changes in practices and institutional cooperation, and proactive efforts to reduce the likelihood of extreme weather.

Impacts of climate change and variation on industry and commerce in the region will depend on the direction and pace of change, the vulnerability of these sectors in the region, and the pace and impact of adaptation. Although these sectors are generally considered to be less vulnerable and more readily adapted to climate change than natural resource-based activities such as agriculture, fisheries, forestry, and natural ecosystems, current understanding of vulnerability is extremely limited. Research is needed to determine how changes in water supplies, both for use in production processes and dilution of effluents, temperature, and extreme weather events could affect the regions' economic productivity and competitiveness, and technological, economic, and public policy adaptations that could ameliorate adverse impacts. The expectations of the business community about climate change and variation are important because current investment decisions influence the regions' future vulnerability. A limited survey of water-dependent industry in the Susquehanna River Basin suggests that managers are not planning for climate change (Maynard et al.). Major reasons are the uncertainty about climate change, issues of more immediate concern to plant operations and profitability, and the long time scales

of climate change relative to industry planning cycles. Typical replacement cycles offer industry ample opportunity to respond to change. The survey also found that vulnerability to climate change and variability in municipal water supply was being reduced by adaptation to water quality protection laws.

Agriculture, Forestry, and Fisheries

The impacts of climate change on agriculture, forestry, and fisheries are an obvious concern given the importance of climate in these production systems. Critical issues in assessing the potential impacts of climate change on agriculture, forests, and fisheries include:

- Changes in climatic variables of direct importance to crop, livestock, forest and fisheries growth and production (for plants and forests these include temperature, solar radiation, soil moisture, and atmospheric CO_2; for animals, the direct effects of weather and extreme events; temperature and precipitation also influence fisheries).

- For agriculture and forests, changes in climate-affected soil processes (e.g., nutrient leaching, salinization, erosion), and in weeds, insects, and diseases that are affected by climate and atmospheric constituents. For fisheries, indirect effects on their aquatic habitat (e.g., increased intensity of rainfall and runoff events increase nutrient loads in estuaries like Chesapeake Bay).

- Biophysical responses of crops, livestock, forests, and fisheries to direct and indirect effects of climate. Both positive and negative effects have been identified. Increased CO_2 concentrations would increase the yields of most crops, corn being the only note worthy exception, and the primary productivity of the temperate forests found in the Mid-Atlantic region. For annual crops, increased temperatures tend to speed development but may reduce yields and increase the potential for moisture stress. Increased temperatures could increase primary forest production if accompanied by increased moisture. For both crops and forests, increased temperatures may increase the range of pests. Increased temperatures can increase the habitat for some valued fish species but reduce it for others. Increased nutrient flows into Chesapeake Bay due to an increase in the frequency and severity of rainfall events could offset gains from pollution control programs. Extreme weather events can cause severe damage to crops and livestock.

- Economic and policy adaptations to direct and indirect impacts of climate change. Direct and indirect effects of climate change will affect the profitability of farm, forest, and fishing enterprises. These changes will induce behavioral adaptations by producers, input suppliers, processors and consumers (e.g., changes in crops and production practices by farmers, changes in agricultural

trade flows between regions, changes in consumer food purchasing patterns) and stimulate the demand for new techniques that are better suited to new climatic and economic conditions. Changes in production will lead to changes in the prices of agricultural and forest commodities. Agricultural, forest, and fishery policy adaptations can also have beneficial impacts. For example, agricultural research and extension can enhance technological response capabilities and disseminate research findings to farmers. However, policies such as product price supports, input subsidies, agricultural trade barriers, and payments for crop failures can hinder adaptation when they encourage the production of climate-sensitive crops, the use of cropping systems ill-suited to the changed climate, or limit incentives for relocation or innovation.

- Economic versus physical impacts. In assessments it is important to distinguish between economic impacts and changes in physical variables. Economic impacts depend on price changes as well as changes in the underlying productivity of the biophysical systems. Prices are determined by national and international forces, and may move in ways that blunt or amplify the biophysical change. For example, yield reductions do not imply an economic loss to farmers, foresters, or fisherman if the prices they receive for their products increase.

- Impacts in other regions. Because agriculture and forestry in different regions are linked physically by the movement and management of weeds, pests, and diseases, and economically by prices, policies, and commodity flows, regional impact assessments require understanding of climate change, direct and indirect impacts and adaptations in other regions.

Several studies have explored the impacts of climate change on agriculture. Given the limited information about regional climate change, most focus on large regions. Results vary according to climate scenarios, modeling techniques, the extent to which economic and technological adaptations are considered, and other factors. These studies generally indicate that:

- Global economic impacts of projected climate change on agriculture will be small. Regions with increased productivity will compensate for the losses of regions with reduced productivity.

- Regional impacts will be more pronounced than global impacts. Projected climate change is expected to have little impact on the overall U.S. economy and domestic food production. Some other countries are expected to benefit while others are expected to be severly harmed. Within the United States, some regions may be adversely affected while others benefit. However, impacts of climate change on agriculture at the regional level are highly speculative. Both positive and negative impacts have been predicted for agriculture in the Mid-Atlantic states, with the results differing according to the methodology.

- Adaptation can greatly reduce the impacts of climate change.

There is less integrated climate change assessment research for forestry and fisheries than for agriculture. Increased temperatures would likely result in northern migration of temperate forests, but not in regions that become too dry. Primary productivity will also likely increase with increased CO_2 concentrations and nitrogen mineralization rates, again except in drier regions. In general, freshwater fisheries in small rivers and lakes are highly vulnerable to large changes in temperature and precipitation; freshwater fisheries in larger rivers and lakes are less so; marine fisheries are least vulnerable and are not generally expected to be significantly affected by climate change; the vulnerability of estuaries is less than that of freshwater fisheries but greater than that of marine fisheries. This generalization is not useful for anadromous species (i.e., species that spend time in fresh and marine waters). Striped bass and American shad, both of which are economically important in the region are of this type. In assessing impacts of fisheries and forests, it is important to bear in mind that economic importance and adaptation options and costs are not necessarily correlated to biophysical vulnerability.

Income and employment in agriculture, forestry, and commercial fisheries in the Mid-Atlantic region is small, so that large impacts on the regional economy are unlikely. Recreational fishing is economically more important than commercial fishing due to the large and growing public participation in this activity and the economic impacts of recreational spending.

Integrated regional scale research on the effects of climate change and variation on agriculture, forests, and fisheries is essential to understand impacts on people and communities who are economically dependent on these sectors in the region. However, beyond their contributions to income and employment, each of these sectors is a source of important nonmarket services (e.g., open space amenities, wildlife habitat, ecosystem services, cultural values) that could be increased or diminished. Further research on regional climate change and variation, direct and indirect impacts on biophysical productivity, and technological and economic adaptation options and costs in Mid-Atlantic agriculture, forests, and fisheries is essential to understanding potential consequences for land use, land cover, water supply and quality, and other issues of societal concern.

C. Mitigation and Adaptation Strategies

In the Mid-Atlantic Region (and elsewhere), there may be actions that "make sense" for reasons other than climate change, but that have additional benefits in terms of mitigation or adaptation. But considering only strategies that are desirable for other reasons could omit consideration of strategies that might ameliorate some important regional climate change impacts. Such strategies might prevent some of the

change or reduce its seriousness by adaptation. In either case, informed decision making depends on 1) assessing the risks, 2) identifying what components of the overall system are vulnerable to the risks, 3) determining how important impacts are to the vulnerable components, and 4) estimating the benefits and costs of strategies to offset the impacts. Risk assessment: Identifying the types of impacts and their likely severity is difficult for some of the types of impacts described above (in Section B). Consider assessing the human health risks from Crypto, for example. We can use downscaling models to project regional increases in precipitation. But there are many steps between that projection and an estimate of the potential increase in illness resulting from it. These steps include estimating how many water intakes would be inundated and how many defective well casings would be subject to overland flows; the concentrations of Crypto in the water at the intake (or well casing); how much the "finished water" is diluted by mixing from other water sources; the effectiveness of filtration or other Crypto removal techniques; the promptness of a boil-water advisory (BWA) if the water supply system cannot remove Crypto effectively; how many people potentially would be exposed to contaminated water; the share of them who become aware of the BWA and follow it effectively; the dose of Crypto for those who fail to follow the BWA; and the dose-response function to indicate what share of that group is likely to experience symptoms. Similar event-trees can be described for other types of impacts. Understanding of linkages often is poor, and data often are sketchy for conducting such risk analyses.

Vulnerability: The particular subgroups affected may differ greatly across the various topics discussed above. Continuing the Crypto example, wells and surface water intakes in low-lying areas tend to be more vulnerable to contamination, particularly in areas where livestock is raised. Children may be more vulnerable because of their relatively poorer hygiene, and those caring for people who are ill or working with animals (that are likely to be Crypto carriers) are more vulnerable because of higher exposure levels. The elderly and those with compromised immune systems may be more vulnerable because their bodies are more likely to react to a given exposure level.

Across various types of potential regional climate change impacts, there is substantial variability in the information currently available to identify vulnerable areas and groups, as well as in the ability to distinguish differing degrees of vulnerability.

Environmental Valuation: Relatively little research has been conducted on the societal importance of ecosystem changes, although rough approximations can be made for a few specific impacts. For example, farmers commonly import bees to pollinate their crops, so an increase in this expenditure could be estimated if pollinating bird and insect populations were expected to decline. But for most ecosystem impacts, value estimates currently are not available. Continuing the example of bees, the farmers' increased costs (to import bees for pollinating their crops) account for only some of the values lost to society when an ecosystem is affected. An important component of ecosystem values is the value people have for just knowing the ecosystem is there (and

undisturbed), regardless of whether they ever expect to visit or otherwise "use" the ecosystem. This component often is called "existence values." Information on the value of ecological impacts is improving, partly because of the potential transferability of research done for natural resource damage assessments (which are conducted after oil spills for publicly owned recreational resources). It may be feasible to use data or estimates from such studies for comparable privately owned facilities that would be affected. Research specifically related to valuing the ecological impacts from climate change is underway at Penn State and Carnegie-Mellon universities.

Benefit-Cost Analysis (BCA): This approach examines all the benefits and all the costs of a proposed action or strategy. Measurement issues often are important, as suggested immediately above. In examining how much impacts are worth, we also need to consider offsetting changes. For the example of the beach vacation, we need to recognize that the loss to the motel owners may be offset by an increase in revenues to the supplier of some other type of recreation. There still are some societal losses if people would have preferred that vacation at the beach to the one they end up taking at an indoor arcade. For health impacts, a BCA would compare, for example, costs of illness with costs of preventing Crypto contamination of water supplies or the cost of a more effective information program related to a boil-water advisory. Issues also arise because many mitigation and adaptation strategies would impose costs now to prevent adverse impacts far in the future. Conventional discounting, a common practice in business and public policy decisions, would reduce distant future benefits to very small amounts, thereby making it unlikely that decision makers would adopt mitigation and adaptation strategies on economic grounds.

What does this all mean for assessing mitigation and adaptation strategies for the Mid-Atlantic Region? The complex linkages suggest the need for an integrated regional assessment. But integrated assessments easily can get unmanageable. So we need to choose the key elements and linkages for an integrated regional assessment. The bigger the potential costs from climate change, the more it is worth conducting a careful assessment--so that the Mid-Atlantic Region is less likely to choose poor options. But keep in mind that there are other socioeconomic driving forces, especially for the long time scales associated with climate change. This caveat suggests an initial focus on impacts and corresponding strategies that might make sense even without climate change, especially in light of the other driving forces expected to be important.

Bibliography

Atlantic States Marine Fisheries Commission (1990), "Source Document for the Supplement to the Striped Bass Fisheries Management Plan - Amendment #4", Fisheries Management Report #16, ASMFC.

Crane, R.B., and Hewitson, B., 1997. Doubled CO_2 Climate Change Scenarios for the Susquehanna Basin: Azariadis, Costas (1993), "Intertemporal Macroeconomics", Blackwell Publishers, Cambridge, MA. Precipitation. *International Journal of Climatology* (in press).

Intergovernmental Panel on Climate Change. 1996. Climate Change 1995 - Impacts, Adaptations and Mitigation of Climate Change: Scientific and Technical Analysis. Cambridge University Press.

Heberling, et al.

Maynard, L., A. Fuentes, J. Shortle, R. Bord, R. O'Connor, and A. Fisher. "Interviews with Experts and Stakeholders About Water Resources and Climate Change in the Susquehanna River Basin." May 1997.

Mendelsohn, R., W.D. Nordhaus, and D. Shaw. 1994. "The Impact of Global Warming on Agriculture," American Economic Review, 84(4):753-771.

Root, T.L., and S.H. Schneider, 1993, "Can Large-Scale Climatic Models Be Linked with Multiscale Ecological Studies?" Conserv. Biol., 7:256-70.

USEPA (1995), "The State of the Chesapeake Bay", Washington, DC.

US Treasury Department, Bureau of Statistics (1996), "Statistical Abstract of the United States", Washington, DC.

Watson, R.T., Zinyowera, M.C., and Moss, R.H. (editors), 1996. *Climate Change 1995, Impacts, Adaptations and Mitigation of Climate Change.* Cambridge University Press, Cambridge.

Yahner, R.H., 1995, Eastern Deciduous Forest, Minneapolis: Univ. Of Minn. Press.

Yarnal,B., Johnson, D.L., Frakes, B.J., Bowles, G.I. and Pascale, P., 1997. The flood of '96 and its socioeconomic impacts in the Susquehanna River Basin. *Journal of the American Water Resources Association* (in press).

MID-ATLANTIC WORKSHOP ON REGIONAL CLIMATE IMPACTS

I. Climate Variability

Brent Yarnal

A. Introduction

Although climate is often thought of as average weather, it is much more than that. Weather is the hour-to-hour and day-to-day state of the atmosphere. In contrast, climate encompasses the longer-term condition of the atmosphere, with the full range of weather experienced at a time and place, including storms, cold outbreaks, and heat waves.

The climate system varies and changes because of the atmosphere's interaction with the total E: ı system of water, rock, soil, and life. This variation and change includes not onl ıe commonplace daily and seasonal cycles and short-term extreme events such as floods and droughts, but also long-term episodes such as wet and dry decades, cool or warm centuries, and glacial-interglacial cycles.

There is much confusion over the terms *climate variation* and *climate change*. However, for the United Nations Convention on Climate Change, scientists, decision makers, and other stakeholders have resolved that climate variation refers to natural variation in climate, while climate change pertains to those variations in climate attributable to human activity. For the purposes of the Convention, the most important human activities are those that influence the planetary energy balance. Included here are activities — such as industrial operations or land transformations — that emit or lead to the creation of the radiatively active gases carbon dioxide, methane, nitrous oxide, and the halon family, or that inject microscopic particles into the atmosphere. Radiatively active gases enhance the natural greenhouse effect and are believed to be warming the planet, while microscopic particles screen out incoming sunlight and cool the surface.

Climate change arises from human activity, but climate variation is the result of natural forces operating at different time scales. The two most fundamental variations in climate are day and night and the seasons, which are the result of relationships between the sun and Earth on time scales of days and years, respectively. The third most important identified variation in the climate system is El Niño-Southern Oscillation (ENSO) events, which perturb the global oceanic and atmospheric circulations and can produce droughts and floods in certain regions. For example, during warm phases of ENSO (known as El Niño), the southern United States tends to be very wet and may suffer floods; during ENSO cold phases (known as La Niña), this region is prone to drought. These extremes of ENSO usually occur

every three to five years and last for about a year and a half. Scientists are developing the ability to predict these events and their regional patterns of flood and drought many months in advance. Many other causes of variability on seasonal to interannual time scales are difficult to predict, such as volcanic eruptions.

Climate also varies on time scales ranging from decades to millions of years. Decade-long variations result from interactions among the different components of the Earth system (atmosphere, ocean, land, biosphere, and ice). Because each of these components is characterized by different response times, their interactions produce climate variations on many different time scales. Decade-long variations can also result from variations in solar output tied to sunspot cycles. On century time scales, planetary warming and cooling may be caused by long-term oscillations in solar output. In the last two to three million years and on time scales of ten thousand years or more, variations in Earth's orbit around the Sun may be responsible for more than 20 glacial-interglacial cycles. Even longer-term changes in the configuration of the continents and associated mountain-building episodes result in climate variations of ten million years or more, such as the ice age conditions of the last 35 million years or the generally warm Earth inhabited by the dinosaurs.

Climate varies over space as well as time. In any given year or decade, the weather in one region may appear anomalous, while in another region temperature and precipitation may be close to average. Similarly, weather patterns in some regions may be particularly sensitive to phenomena such as ENSO. Because such regional variations in weather and climate are normal, it may be difficult for individuals to distinguish anthropogenic climate change from natural climate variation. Climate change most likely will be experienced as altered patterns of, and other weather events.

There are many uncertainties about how future climate change will affect specific regions. For instance, how will the various regions respond to increases in global temperature? Will local temperatures rise or fall? Will precipitation totals increase or decrease? Will more precipitation fall as rain, and will the snow-accumulation season be shorter? Will there be more severe storms, floods, heat waves, droughts, and cold outbreaks? Will they be more intense or weaker?

A critical first step in analyzing the regional consequences of climate change for nature and society is to have climatologists develop methods to answer these and similar questions. What biophysical entities and human activities will be affected by regional climate change, and will these impacts be positive or negative? Which individuals, groups, and systems are vulnerable to climate change? How will the region adapt to climate change?

One way to estimate how a region will react to future global climate change is to study how the region has been affected by past climate variations. Thus, the goals of this white paper are to determine (1) what we already know about past climate variations in the Mid-Atlantic Region, and (2) what we need to learn. To achieve these goals, the paper first addresses seasonal and decadal climate

variations observed in the Mid-Atlantic Region during the past century. Then it looks at the longer-term climate variations of the last 1000 years. The paper concludes by summarizing what we know about Mid-Atlantic climate variation and what we need to learn. The second white paper assesses the likelihood for Mid-Atlantic climate change, while the third addresses potential climate change impacts and vulnerabilities, as well as mitigation and adaptation strategies.

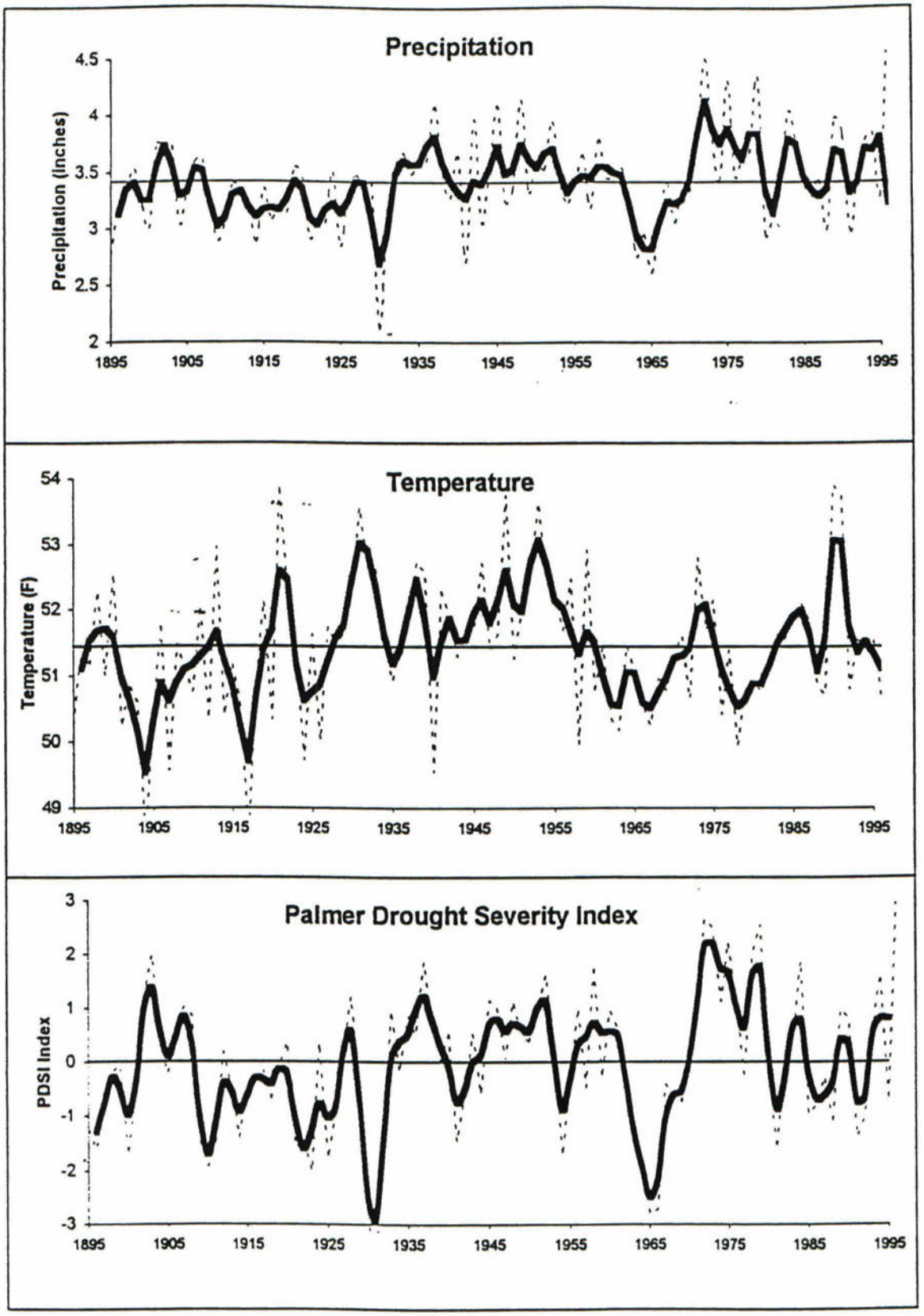
Interannual and Decadal Climate Variation in the Mid-Atlantic Region

There is a wealth of observed climate data from the Mid-Atlantic Region. However, the relatively short period of these data provides insight only on recent climate variations of years and decades; assessment of longer time scales of climate variation would require longer data sets. To deduce longer time-scale variations, or to determine how climate varied before the invention of weather-recording instruments, it is necessary to reconstruct climates by recovering and interpreting natural phenomena and human artifacts containing climate information. There are many sources of such paleoclimatic information, including tree rings, glacier ice, ocean and lake sediments, diaries, and crop records.

The National Climatic Data Center (NCDC) has monthly data for Mid-Atlantic temperature, precipitation, and Palmer Drought Severity Index (PDSI). The PDSI is important to agriculture because it tracks soil-moisture conditions. Observers of the National Weather Service Cooperative Daily Temperature-Precipitation Station network measure temperature and precipitation daily and send these data to the NCDC, where monthly averages are calculated from the raw data. The NCDC then computes the PDSI from the temperature and precipitation data. These climate data extend back to 1895 and are presented here for the Mid-Atlantic Region.

For the purposes of this analysis, the Mid-Atlantic Region was defined by the watershed boundaries of the Chesapeake and Delaware Bays. Then the monthly value for each of NCDC's climate divisions was weighted by the proportion of the region occupied by that division. In other words, if a given climate division covers 10% of the watershed, each monthly value was multiplied by 0.10; if another division occupies 5%, then each value was weighted by 0.05; and so forth. Next the weighted values for all the region's climate divisions were added to produce one number that represents the temperature, precipitation, and PDSI for each month. These data were entered into a spreadsheet and plots for the 102-year period 1895-1996 were produced. Annual variations are denoted by the dashed line, and decadal variations are represented by the solid, bold line, which is a five-year running average of the annual data (Figure 1).

The data show that the temperature, precipitation, and PDSI of the Mid-Atlantic Region have varied substantially on annual and decadal time scales over the last century. These surface climate variations can be linked to variations in the region's atmospheric circulation.



igure 1. Departures from long-term (1895-1996) average monthly precipitation (inches), annual temperature (°Fahrenheit), and annual Palmer Drought Severity Index for the Mid-Atlantic Region. The dashed line denotes average annual values, while the bold, solid line is a five-year running average.

Precipitation

The Mid-Atlantic appears to have experienced three distinct precipitation regimes during the last century; each was separated by a period with sharply reduced precipitation. The first regime extended from the beginning of the record until about 1930. With only a few exceptions, precipitation totals were below the long-term average. This period ended in the early 1930s when by far the driest period in the last century contributed to a sharp, but short-lived precipitation deficit. Then second regime started when precipitation rose to slightly above average totals. This regime ended with the 1960s, when nearly every year was well below average. In 1970, the third regime began when precipitation totals took a dramatic jump, with all but a few years in the last 27 being above normal. Many of these years were very wet; the wettest year in the record is 1996.

Temperature

From the beginning of the record until the late 1920s, Mid-Atlantic temperatures were well below the long-term average (although there were a few years during this period with noticeably above-normal temperatures). Then, with the exception of a couple of conspicuous cold years, temperatures from the late 1920s until about 1960 were well above average. It is important to note that from the beginning of the record to the mid-1950s, there was a marked warming trend. However, this trend ended when temperatures started to drop in the mid-1950s, falling well below average by the 1960s and staying there (except for a few years in the mid 1970s) until approximately 1980. Since then, temperatures have oscillated above and below normal, with a couple of remarkably hot years in 1988 and 1989.

Palmer Drought Severity Index

Except for several moist years in the 20th century's first decade, this index was well below the long-term average (i.e., conditions were dry) until the mid-1930s. The last few years of this period — the infamous Dust Bowl years in the Great Plains — were exceptionally dry. The succeeding period from the mid-1930s until the early 1960s tended to be moist. The 1960s were very dry, while the 1970s were extraordinarily wet. The period from the 1980s through the first half of the 1990s was the only time in the 102-year record that oscillated around the normal mark. The Mid-Atlantic droughts of 1980, 1986, 1988, and 1991 are evident. Also remarkable is the sharp spike at the end of the record caused by the exceptionally wet year 1996.

Relationship to atmospheric circulation variations

There are clear relationships among the Mid-Atlantic's precipitation, temperature, and PDSI variations of the last century. In general, from the beginning of the record to about 1930, the climate was cool and dry. The early 1930s experienced a couple of exceedingly hot, dry years that were associated with the midwestern Dust Bowl. This short, sharp drought was replaced by nearly three decades of relatively warm, moist climate. This period was replace by a cool and very dry climate in the 1960s. In contrast, the 1970s were exceedingly wet, but varied

between warm and cold. Since somewhere in the late 1970s-early 1980s, temperature and precipitation have varied above and below normal.

These variations in regional climate since World War II can be explained by changes in the atmospheric circulation. (Earlier periods lacked the jet stream-level data needed to make the following generalizations.) A zonal regime dominated the atmospheric flow over North America through the late 1940s and early 1950s.[1] Such a regime produced normal to slightly above-normal temperatures and variable precipitation over the Mid-Atlantic. Then in the mid- to late 1950s, the circulation experienced a change from zonal to meridional flow; a stable meridional-flow regime was fully entrenched by the 1960s. During this decade, the Mid-Atlantic tended to be influenced by an anomalous, deep trough of continental polar air, a storm track southeast of its long-term mean position, and precipitation often falling off the Atlantic coast. This regime promoted a relatively cool, dry climate. The early 1970s saw the continuation of this meridional regime, but the trough migrated westward, putting the average position of the storm track over the Mid-Atlantic Region. This change caused a significant increase in precipitation. Finally, the mid-to-late 1970s witnessed a large change in the atmospheric circulation. The period following this change — which has extended to the present — has been associated with significant increases in the interannual variability of the atmospheric circulation, with unusually large variations in the shape and positioning of the month-to-month and year-to-year jet stream flow over North America. Such major variations in circulation have produced a highly variable surface climate.

Recent Mid-Atlantic climate extremes

Temperature extremes associated with winter cold spells and summer heat waves are likely to have the greatest human impacts. Scientists have found seemingly contradictory trends have been found in Mid-Atlantic temperature extremes. On the one hand, the last frost of spring is tending to come progressively earlier, while there are fewer very cold winter days. These changes imply that the region's winters are warming. On the other hand, the number of very hot summer days appears to be decreasing (although there is some question about the reliability of these data). Together, these trends suggest a change towards a less extreme, rather than a more extreme regional climate. Many experts think that human-induced climate change will bring more extreme climate to most regions.

Comparison to nation and globe

How do the Mid-Atlantic variations discussed above compare to rest of the United States and the world? Comparable, but different, interannual and decadal variations in temperature and precipitation have been detected in all regions of the United States. Scientists have also found that the United States warmed by about 0.7°F over the last century. However, that increase was not linear, and not all areas

---

[1] A *zonal flow* regime means that the jet stream over the United States tends to flow from west to east, with few of the north-south excursions that produce ridges of warm air and troughs of cool air. In contrast, during periods of *meridional flow*, the jet stream has a much greater north-south amplitude, often producing a big ridge of warm sub-tropical air over the western United States and a deep trough of polar air over the eastern half of the nation.

of the country warmed. The nation was relatively cool until the 1930s, at which time temperature rose sharply. Temperatures fell during the 1950s to 1970s, with sharpest declines during the 1960s. Temperatures rose again in the 1970s and have remained high since then. These patterns roughly coincide with the temperature trends for the Mid-Atlantic, although the Mid-Atlantic has warmed more during the century than the national average. Comparisons to global surface temperature observations also find rough correspondence between the global variations and those of the Mid-Atlantic, with the region warming more than the global average of approximately 0.5-1°F.

Precipitation variations for the United States also show surprising resemblance to the Mid-Atlantic variations. Notably, since about 1970, precipitation has tended to remain above the 20th century mean and has averaged about 5% more than in the earlier part of the record. Some of the largest precipitation increases over the century occurred over the Mid-Atlantic, especially the northern parts of the Chesapeake and Delaware Bay drainage areas. Globally, precipitation over land has gone up 1% during the 20th century. However, global precipitation has been relatively low since about 1980, which does not correspond with Mid-Atlantic and United States observations.

The 1960s Mid-Atlantic drought shows in the national PDSI record, but is overshadowed by the great middle-American droughts of the 1930s and 1950s. Perhaps more important, similar to the Mid-Atlantic record, the United States has tended to be unusually wet since approximately 1970. PDSI is not calculated globally, so it is difficult to make comparisons with the Mid-Atlantic record for this variable.

Finally, has the global atmospheric circulation matched the variations noted over North America and the Mid-Atlantic Region? The behavior of the equatorial Pacific ENSO phenomenon has been unusual since the mid-1970s, especially since 1989. During that time, El Niño events have been more frequent and persistent than La Niña. These findings can partly explain the behavior of the atmospheric circulation over North America and the Mid-Atlantic since the mid-1970s, but cannot account for variations in the circulation and regional climate before then. Research suggests that these earlier variations were related to changes in the extratropical North Pacific and North Atlantic, not the equatorial Pacific.

The climate of the last 1000 years

Long records of climate variations are needed so that scientists can compare the natural variation of the period before the Industrial Revolution with the mixed natural and anthropogenic climate signal observed since then. Unfortunately, comprehensive climate observations are restricted to the last century and a half, and to even shorter periods in many regions. Consequently, pre-instrument (paleoclimate) climate variations must be deduced from proxy data from climate-sensitive phenomena, such as tree rings, corals, glacial ice cores, and alpine glacier advance and retreat chronologies. Quantitative data can also be culled from historical records, such as journals and tax and mercantile records. The data from the last 1000 years are especially important not only because they are the relatively

abundant and fresh, but because the variations they portray are most relevant to the current climate.

Although tree-ring data are the most plentiful of the natural proxy data, they are still too sparse to provide a complete global picture over time. Ice-core, coral, and glacier advance-retreat data are even less common. Thus, the majority of the data for the last millennium may reflect regional, rather than global climate signals.

Despite these data problems, paleoclimate reconstructions show that globally the 20th century has been warmer than any century since 1400 AD, and is probably the warmest century in the last 1000 years. Furthermore, some evidence suggests that this century is perhaps as warm as any comparable period in the last 10,000 years — that is, since the retreat of the continental glaciers from North America and Eurasia. On century time scales, it has also been estimated that the variability of global mean temperature over the last millennium has been less than ± 0.9°F. The temperature increase that coincided with the end of the Industrial Revolution may soon exceed this range. It is important to note that century-scale climate data suggest that natural variation can be abrupt and large.

Knowledge of Mid-Atlantic climate since the mid-17th century is based primarily on reconstructions using tree rings and historical data from diaries, newspapers, and periodicals. These and other data suggest that until the late 19th century, the region was cool and somewhat wet, but was affected by individual years of intense drought and occasional decades of prolonged drought. Overall, the year-to-year and decade-to-decade climate was highly variable and not unlike that observed in the latter 20th century. After about 1880, the area warmed gradually. Climate variation decreased until the latter 20th century. For the entire record, the longest drought extended from about 1850-1873, although the most severe prolonged drought occurred in the 1960s. Throughout the entire period of reconstruction, there is evidence that ENSO events have a significant affect on the hydrology of the Mid-Atlantic Region. In general, the climate patterns from these paleoclimate reconstructions are consistent with other regions of the eastern United States and the North Atlantic basin.

Conclusions

Climate varies on many space and time scales, with regional variations at interannual, decadal, and century time scales being of most immediate importance to society. Knowing how a region's climate has varied in the past provides a baseline against which future regional climate change can be compared.

Analysis of the Mid-Atlantic Region's climate shows that variations have been considerable. For example, each year in the 1960s was cool and very dry, while the 1970s possessed a more variable temperature regime, but were very wet. Other decades, such as the 1980s and first half of the 1990s, were distinguished by extreme year-to-year variation in all climate variables. These interannual and decadal climatic variations were closely associated with the atmospheric circulation over the region, and were also related to United States and global variations. Longer time scales of climate variation for the Mid-Atlantic are only crudely documented and

understood, but some facts are known. For instance, the 1960s appear to have been the driest decade of the last few centuries, while the extreme interannual climate variation of the 1980s and 1990s are not unprecedented.

Given its ecological and socioeconomic importance (and the concentration of climatologists that live in the region), the Mid-Atlantic's climate variation is surprisingly poorly understood. Yet, to discern how climate affects the region's ecosystems and society, and to determine if climate is changing, it is crucial that such an understanding be improved. Thus, more research is needed on interannual, decadal, and century-scale climate variation of the Mid-Atlantic Region. Specifically, research that promotes clearer answers to the following questions should be addressed:

- Is the Mid-Atlantic climate becoming warmer or cooler, wetter or drier, or more variable or extreme?
- Are these trends consistent with trends observed in other regions or globally?
- Are these trends unusual? That is, are these trends consistent with previous variations experienced in the region, or are they suggestive of human-induced climate change?

Bibliography

Baron, W.R., 1995. Historical climate records from the northeastern United States, 1640 to 1900. In *Climate Since A.D. 1500*, R.S. Bradley and P.D. Jones, editors. Routledge, London: 74-91.

Cook. E.R., and G.C. Jacoby, 1977. Tree-ring drought relationships in the Hudson Valley, New York. *Science* 198: 399-401.

Cook. E.R., and G.C. Jacoby, 1983. Potomac River streamflow since 1730 as reconstructed from tree rings. *Journal of Climate and Applied Meteorology* 22: 1659-1672.

DeGaetano, A.T., 1996. Recent trends in maximum and minimum temperature threshold exceedences in the Northeastern United States. *Journal of Climate*, 9: 1646-1660.

Guttman. N.B., and R.G. Quayle, 1996. A historical perspective of U.S. climate divisions. *Bulletin of the American Meteorological Society*, 77: 293-303.

Houghton, J. T., L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (editors), 1996. *Climate Change 1995 — The Science of Climate Change.* Cambridge University Press, Cambridge.

Karl. T.R., R.W. Knight, D.R. Easterling, and R.G. Quayle, 1996. Indices of climate change for the United States. *Bulletin of the American Meteorological Society*, 77: 279-292.

Yarnal. B., and B. Frakes. 1997. *Synoptic Climatological Atlas of the Northeastern United States.* Northeast Regional Climate Center, Cornell University, Ithica, NY.

Yarnal. B., and D.J. Leathers, 1988: Relationships between interdecadal and interannual climatic variations and their effect on Pennsylvania climate. *Annals of the Association of American Geographers*, 78: 624-641.

DRAFT 7/9/97

MID-ATLANTIC WORKSHOP ON CLIMATE CHANGE IMPACTS

II. CLIMATE CHANGE

Eric J. Barron .

A. Introduction

To what extent will the human-induced increases in greenhouse gases and atmospheric aerosols influence future climate? The answer to this question has become linked to issues of economic vitality and national security because of potential impacts from climate change on natural ecosystems, agriculture, water resources, human health, energy utilization and human migration. The record of observations based on meteorological instruments is too short to determine whether humans are responsible for the general warming trend over the last century. The only recourse to answer this question is to construct mathematical models of the Earth system and attempt to predict future change. Climate models are the principal tools available to predict how the climate will respond to increases in greenhouse gases. These models point to significant global warming, with large changes in the continental water balance, over the next decades and centuries. In every case, the climate models suggest that the familiar global and regional environments on which society has come to depend are in danger of changing. Many of the predictions imply serious stresses on society and have prompted discussion of sometimes costly mitigation and adaptation response measures. Are the predictions of climate models accurate enough to warrant such measures?

The complexity of the climate system is a major obstacle to predicting the details of future climate change. Neither the physical relationships described by climate models nor the available climatological observations are sufficient to project how climate will change with certainty. Consequently, society is left with a difficult decision. What steps should we take when the best predictions from state-of-the-science models suggest that climate change due to human activities will be large and significant, yet the predictions themselves have large uncertainties? The scientific debate over these uncertainties has truly entered the public arena, providing considerable confusion even in cases where the conclusions from climate models are robust. To be useful for policy development, the degree of certainty associated with the different elements of climate predictions must be evaluated and ranked. The credibility of the full range of climate model predictions must be described in order to elucidate the aspects of climate model predictions that are highly uncertain as well as those that are robust. Such an analysis not only guides policy development but focuses attention on the areas of research that are most likely to benefit

society. Accurate long term climate forecasts would most certainly have tremendous economic value.

B. A Foundation for Discussion

Many aspects of future global change, and particularly the topic of global warming, are far less controversial in scientific circles than they are in public discussion. For each of the following seven points there is no real credible debate or controversy. These points, which are based on a spectrum of scientific investigations, provide foundation and context for discussions of future climate-change.

First, laboratory experiments demonstrate that greenhouse gases - also referred to as radiatively-important gases - absorb and re-emit energy in the infrared wavelengths emitted by the Earth's land, oceans, and clouds. The most important of these so-called greenhouse gases are water vapor, carbon dioxide, methane and nitrous oxide.

Second, because of their infrared absorption, increased concentrations of greenhouse gases exert a global warming influence. The role of greenhouse gases as agents to promote warming is not in question; rather the issues of uncertainty involve only the timing and the magnitude of the warming.

Third, the atmospheric concentrations of carbon dioxide, methane, nitrous oxides and chlorofluorocarbons are significantly above their pre-industrial levels. These increases can be tied directly to human activities involving fossil fuel consumption, deforestation, agriculture, and some industrial processes.

Fourth, carbon dioxide levels are now about 30% above pre-industrial levels. A draw-down of carbon dioxide to near its pre-industrial level would take centuries even if emissions were substantially reduced in the near future. This conclusion stems from the fact that the sinks (e.g. deep ocean) for carbon dioxide operate on long time scales. In addition, since substantial reduction in global carbon dioxide emissions below current levels is unlikely over the next decades, atmospheric concentrations of carbon dioxide are expected to continue to increase.

Fifth, atmospheric aerosol (dust and soot) concentrations are also significantly increased in source regions over pre-industrial levels. The primary natural sources include windblown dust, hydrocarbons from vegetation and forests, and soot from forest and grassland fires. Increased aerosol concentrations are also found downwind from regions of high fossil fuel combustion and biomass burning.

Sixth, laboratory and atmospheric measurements demonstrate that sulfate aerosols from volcanic eruptions and from fossil fuel combustion exert a cooling influence on the climate. However, the magnitude, trends and extent of induced cooling effects are uncertain.

Seventh, global average surface air temperatures are about 0.4-0.6°C (~1°F) higher than average temperatures in the nineteenth century. Because of natural variations in climate, this warming cannot yet be attributed definitively to human activities.

These seven conclusions indicate that scientists have a strong basis for recognizing

that human activities are modifying the energy balance of the Earth system. The uncertainties center on the magnitude, timing and distribution of the associated climate changes. It is these predictions from climate models that are the subject of considerable debate.

C. Climate Model Predictions for the Future

Mathematical simulations or models of the atmosphere and ocean systems are the primary tools used to predict the future response of the climate system. The most sophisticated models are called General Circulation Models (GCMs), which attempt to include a comprehensive treatment of the physics that govern the behavior of the atmosphere and oceans. These models are designed to calculate changes in the winds, temperatures, pressures and moisture budget given a specific set of "external" boundary conditions. External boundary conditions represent any specified variable, like the position of the continents, the amount of energy received by the sun, or the composition of the atmosphere. The power of these models lies in their ability to simulate systems that are too complex for simple, intuitive reasoning. The models are not without limitation. Obviously not every molecule of the atmosphere can be incorporated into a model. Since they are computationally very intensive, many simplifications are employed - one of which is to simulate the climate at a very coarse spatial resolution. In other cases, complex relationships such as the characteristics of land vegetation are turned into simple functions designed to approximate these relationships. The key is to incorporate all of the critical processes and feedbacks, while maintaining a tractable model.

We have a growing number of independently derived GCMs. These models have become the basis for intercomparisons as a means of evaluating the potential range of future climate change. More and better observations are available to test the capabilities of the model predictions and, with increased knowledge about how the climate system operates, we can provide a more critical assessment of climate model predictions. Figure 1 provides the range of predicted changes in global-mean surface temperature for the next eighty years from seven different GCMs each assuming an increase in carbon dioxide of one percent per year (the standard scenario for the Intergovermental Panel on Climate Change). Figure 2 gives an example from one model (Manabe and Stouffer, 1994) of the increase in annual-mean global surface temperatures predicted for a doubling of the present day amount of atmospheric carbon dioxide 50 to 100 years from now. This figure shows the coarse resolution of the global model predictions, while suggesting that the Mid-Atlantic States will be 4 to 5 °C warmer than at present. For context. the summer heat wave of 1988 was less than 1°C warmer than average in the Mid-Atlantic region. The predicted change is large.

Predictions from GCMs are imperfect because they are limited by our knowledge of natural variability, our inability to predict future greenhouse gas and aerosol emissions accurately, the potential for unpredicted or unrecognized factors such as volcanic eruptions or new or unknown human influences, and our incomplete knowledge of the

climate system. With this point in mind a large group of climate modelers gathered (USGCRP, 1995; Barron, 1995) to assess the levels of certainty associated with climate model predictions. The intent was to provide a list, ordered by degree of certainty, assessing the major policy-relevant predictions of climate models. This list, of necessity, is consistent only with known facts and is based only on the "best" current knowledge. Such a list also must include assumptions on the rate of growth of greenhouse gases. In this case, a scenario of a 1% per year increase in the concentration of carbon dioxide is assumed, which mimics the radiative forcing of the projected increase in the concentrations of all greenhouse gases.

The ordered list presented below is characterized in terms of probabilities, as virtually certain, very probable, probable and uncertain.

Virtually Certain:

(1) The increases in carbon dioxide and the decreases in stratospheric ozone will result in a large cooling in the upper atmosphere.

Very Probable:

(2) The global mean surface temperature will increase between 0.5 to 2.0°C (0.9 to 3.6°F) over the period of 1990 to 2050. The best estimate for a climate change resulting from a doubling of preindustrial carbon dioxide is a warming of 1.5 to 4.5°C, with 2.5°C being the most probable estimate. The estimated warming will be reduced if sulfur emissions are not controlled and the actual temperature change may even be outside the range described here if natural climate variations are large.

(3) A warming of the surface temperature of the globe will lead to an increase in global average precipitation because evaporation rates are closely tied to surface temperature.

(4) Northern Hemisphere sea ice will be reduced. Changes to the Southern Hemisphere are less certain.

(5) Arctic land areas should experience amplified wintertime warming associated with the reduction in land surface snow cover.

(6) Global warming will influence sea level. The most reasonable estimates are a sea level rise of 5 to 40 centimeters by 2050, compared to a rise of 5 to 12 centimeters if the rates of rise over the past century continue. These estimates ignore the long-term response of the ice caps or any potential catastrophic collapse of the West Antarctic ice sheet, which are the subject of considerable debate.

(7) Solar variability over the next 50 years will not induce a prolonged climate forcing that is significant in comparison with the effects of the increasing concentrations of carbon dioxide and other greenhouse gases.

Probable:

(8) Summer Northern Hemisphere mid-latitude continental dryness will increase.

(9) The increase in the amount of atmospheric moisture will produce regions of higher rainfall, including at high latitudes.

(10) Some regions may experience warming that is smaller than the global average, particularly in oceanic regions where surface waters are mixed downward or where deeper waters upwell.
(11) Historical records suggest that a few explosive volcanic eruptions are likely to occur during the next half a century. These transient events will result in some short-term relative cooling.

Uncertain:

(12) There is the potential for multifaceted and complicated, even counter-intuitive changes in climate variability, hence such predictions are uncertain. This aspect of climate change includes many possibilities, such as changes in winter storminess, changes in El Nino frequencies, and variations in thunderstorms.
(13) At present, there is only very limited capability to estimate how the climate of various regions will respond, although regional scale (from the scale of large metropolitan regions to the scale of states) changes are likely to be different from the global average changes.
(14) An increase in tropical storm intensity is plausible due to higher sea surface temperatures associated with global warming; however, there are too many unresolved issues to be certain.
(15) The details of climate change over the next twenty-five years are also uncertain. Uncertainties in the factors that control natural variability, in the model simulations, and in the changes in atmospheric chemistry make it extremely difficult to predict or even suggest decade-to-decade changes in climate. In any given decade, the changes in temperature and related variables could be substantially less than or more than the trend predicted by a climate model. Warming estimates in terms of degrees per decade and their use to analyze a single decade are unwarranted and misleading.
(16) Climate-biosphere feedback relationships may modify the magnitude of climate change, whether the feedbacks will amplify or moderate climate change is not known.

The level of confidence in the results of climate model simulations depends very much on time scale and spatial resolution. Note that the greatest confidence is assigned to ranges predicted for the Earth as a whole and for the longer time periods over which greenhouse gases will double. Regional predictions and predictions on a decade-by-decade basis are far less certain. Equally important, simulations of phenomena at very high resolution, such as the formation of hurricanes, are also less certain. A direct implication of this assessment is that uncertainties grow at the critical boundary where climate models intersect policy - at the spatial and temporal resolution of climate impacts on human and ecological systems. Yet the predictions by climate models are suggestive of substantial change, with large impact.

D. Opportunities for Reducing Uncertainties

The ranked order of the assessment of climate model capabilities provides a framework for focusing national and international research efforts. Over the last few decades, progress in reducing uncertainties in climate model predictions is clear. However, the issues and problems highlighted above are in many cases quite complex, or require long-term consistent measurements in order to reduce current uncertainties. For these reasons, significant reductions of uncertainties in projecting changes and trends in climate will require sustained efforts that are very likely to require a decade or more. Much of the research effort of the U.S. Global Change Research Program is designed to address uncertainties in cloud-radiation-water vapor interactions, ocean circulation, aerosol forcing, natural climate variability, land surface processes, including vegetation changes and chemical cycling, the frequency and intensity of extreme, high impact events such as hurricanes, effects that create the potential for surprises, and the interaction between chemistry and climate. Several research areas can also be identified as likely to reduce uncertainties over the coming decades.

(1) Many of the uncertainties associated with climate models can be attributed to their coarse spatial resolution. At higher resolutions, storms and circulation patterns are much better represented. Improvements in weather forecasts suggest that intensified efforts to tailor global predictions to specific regions using both finer-scale models and empirical techniques will lead to significant improvements in assessing regional vulnerability to climate change.

(2) Climate changes at the surface can be better represented by including significantly better representations of the boundary layer between the atmosphere and the surface and of vertical motions associated with features like thunderstorms.

(3) Substantially improved observations and representations of water vapor, a major greenhouse gas, will reduce a major source of uncertainty in model predictions.

(4) Improvement of the linkages that couple the atmosphere, ocean and land surface will result in better and more comprehensive simulations.

(5) Better representation of the land surface, including vegetation, soil characteristics, and carbon dioxide and ozone effects on plant function, will reduce uncertainties in estimates of soil moisture, summertime continental drying, and in regional climate change.

(6) The development of new data sets and expectations for new, long term, consistent observations from NASA's Earth Observing System, as well as current efforts to compare the full spectrum of climate models, suggest that model comparisons against observations and with other models can accelerate the rate of model improvement.

(7) Successfully demonstrating the capability of models to simulate climates different from the present day (i.e. past climates) would contribute substantially to

our confidence in model predictions.

(8) Changes in the concentration of non-greenhouse gases, in vegetation, and in aerosols may indirectly influence greenhouse gases. Improving the representation of these processes in climate models should improve prediction of climate change by incorporating the indirect mechanisms that influence the earth's energy budget.

Progress on these fronts is already yielding information of use in regional climate change assessments, which will help in assessing climate change for the Mid-Atlantic Region.

E. High-Resolution Predictions of Future Climate Change

The coarse resolution of GCMs is a major drawback for regional assessments. This point is most clearly illustrated by considering predictions of precipitation. If a GCM has a spatial resolution in which each model point is nearly the size of Pennsylvania, convective precipitation (thunderstorms) or frontal systems are not going to be well represented. Two procedures allow us to use coarse resolution climate model predictions to overcome this problem and assess the potential climate impacts in specific regions of the globe. The first technique couples global models with higher resolution regional models. This procedure is called nesting of model grids. The second technique relates particular states of the GCM atmosphere to specific patterns of weather at a regional level. This second technique is referred to as downscaling.

In model nesting, the GCM is used to compute the global circulation under conditions different from today, for example higher carbon dioxide levels. Then the results of the GCM (temperature, pressure, winds, moisture) are used to drive a high-resolution climate model over a limited area. The high-resolution model includes a better representation of topography and physical parameters. The promise of this technique is demonstrated in figure 3, in which the United States precipitation prediction from a GCM is illustrated for the spring 1980 is compared with observations. The GCM's coarse resolution is clearly evident by its failure to produce much of the detail for the United States. precipitation pattern. In figure 3b, the results from the same GCM simulation are portrayed, but the U.S. precipitation is derived from the higher resolution model nested within the GCM. The high resolution model has a horizontal resolution of 108 km. The improvement is dramatic. The nesting technique can also be employed using several nested grids (figure 4) at 36km, 12km, and 4km resolution. Figure 5 compares predictions of a single storm passing over the Mid-Atlantic Region, in which the high-resolution model is driven by observations at the boundary, and then the high-resolution model attempts to reproduce the observations as a proof-of-concept experiment. The match is excellent. This same technique of nesting is utilized to provide a higher resolution prediction for a doubled carbon dioxide planet in figure 6. In this experiment, the Mid-Atlantic Region is characterized by a substantially wetter winter (DJF -December, January, February) under

higher carbon dioxide conditions, but a very similar pattern of summer (JJA - June, July, August) precipitation . Such results must be viewed with caution, as the technique is still under critical evaluation.

The second technique (downscaling) assumes that the GCM is providing reasonable large-scale predictions. Using empirical relationships derived between the observed large-scale circulation and the temperature and precipitation in a region, the analysis predicts regional climate. The formulation can be optimized by writing a model that "learns" from trying repeated examples. Using this technique specifically for the Susquehanna River Basin, Robert Crane and Bruce Hewitson found increases in precipitation under conditions of higher atmospheric carbon dioxide. Only March had lower precipitation in comparison with present conditions. The largest increases were in May and June.

The two techniques derived above employed different GCMs and were very different in terms of resolution and focus. Although still in their infancy, the techniques of translating global climate predictions to resolutions of useful in developing policy and examining human systems has potential.

F. Summary and Conclusions

Three major conclusions are evident from this examination of the capabilities of climate models. First, the radiative properties of greenhouse gases are well known, the concentrations of these gases are increasing due to human activities, and these increases should result in some global warming. At issue is not the nature of the forcing, but rather the magnitude and timing of the climate change. Second, the degree of certainty associated with the results of climate models is a strong function of both spatial and temporal detail. The greatest certainty is associated with ranges given for global predictions. Regional predictions, predictions on a decade-by-decade basis, and predictions of higher resolution phenomena, such as hurricanes, are associated with much greater uncertainty in GCMs. This spectrum of confidence associated with the level of detail that is predicted provides a reasonable guide to policy decisions. Third, substantial opportunities, given consistent and long-term research efforts, exist for improving climate model predictions. These opportunities include efforts to enhance spatial resolution, improve coupling of the components of the climate system, and to better represent of some of the indirect effects of climate change. The nesting and downscaling techniques illustrate the potential of applying these approaches to assessments for specific regions, like the Mid-Atlantic Region.

The sense of the climate model simulations is one of significantly higher mean annual temperatures for the Mid-Atlantic Region under doubled carbon dioxide conditions, with increased precipitation in winter. Changes in summer precipitation appear less certain. The pattern of winter precipitation in the Northeast appears to be significantly different, but summer precipitation patterns appear similar to the present day. Of course, with higher temperatures, evaporation rates will also substantially increase.

Much additional research is required to assess changes in the nature of natural variability under higher carbon dioxide conditions, analyze the full spectrum of hydrologic variables, compare a variety of climate model results and improve the coupling of atmospheric models with other components of the Earth system. Future efforts must be directed towards the research and analysis that are critical for linking climate prediction to human endeavors.

Interestingly, the current focus on the policy relevance of climate models has largely been negative; a view that climate models are far too uncertain to be used in setting costly economic or national security policy. Certainly, the scientific debate over these uncertainties has resulted in considerable confusion even where the conclusions from climate models are robust. The objective of this white paper is to help define the degree of certainty associated with all the different elements of climate predictions in order to provide a more useful basis for policy decisions. However, the current negative focus on climate models as potential drivers of costly national policy is one-sided.

Accurate long term climate forecasts could also have tremendous economic value, as shown by recent use of improved forecasts in limiting the impact of El Ninos on food production and fisheries in developing countries. The importance of advance knowledge may well be the reason our European and Japanese colleagues are developing strong environmental observation and prediction efforts. The improvements in climate prediction, outlined in the section on opportunities and fostered by the U.S. Global Change Research Program, should be viewed as a path toward more accurate predictions. In some cases, these predictions may lead to warnings if associated with societal vulnerabilities. In many cases, these predictions will clearly contribute to economic vitality.

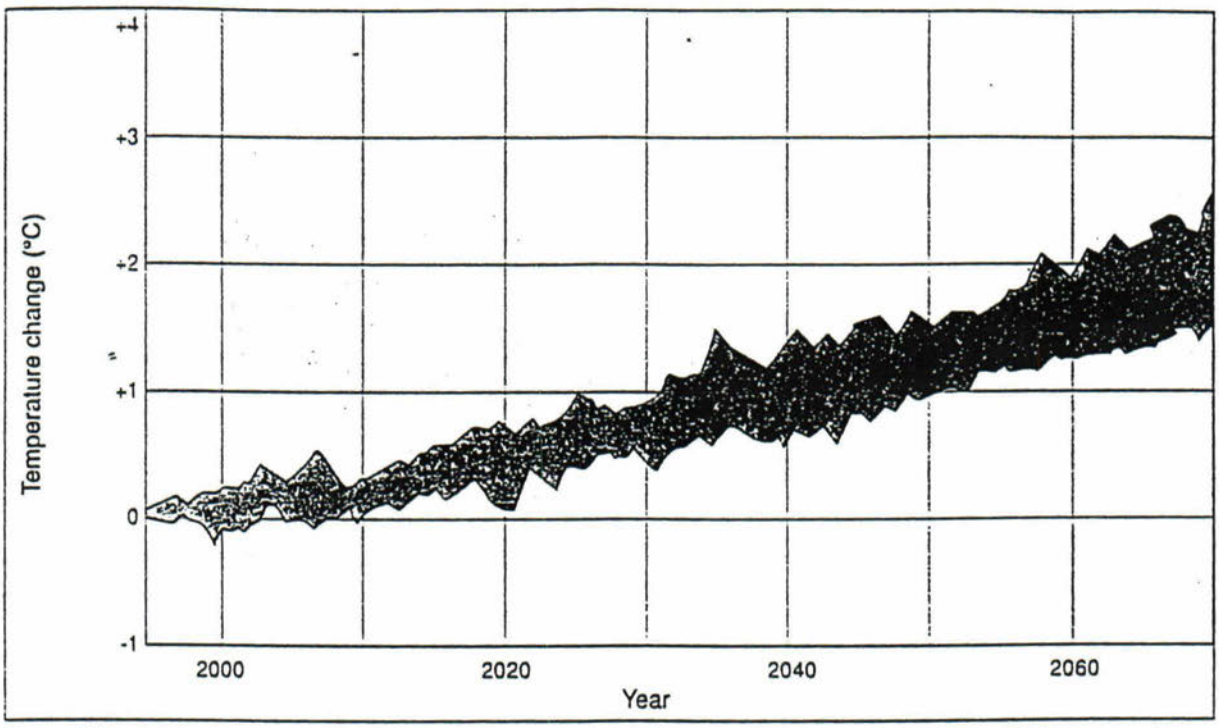


Figure 1 The range of predicted changes in global-mean surface temperature, in degrees C, for the next eighty years, shown as a band bounded by the upper and lower extremes of seven different GCMs, each of which assumed an increase of 1 percent per year in CO_2.

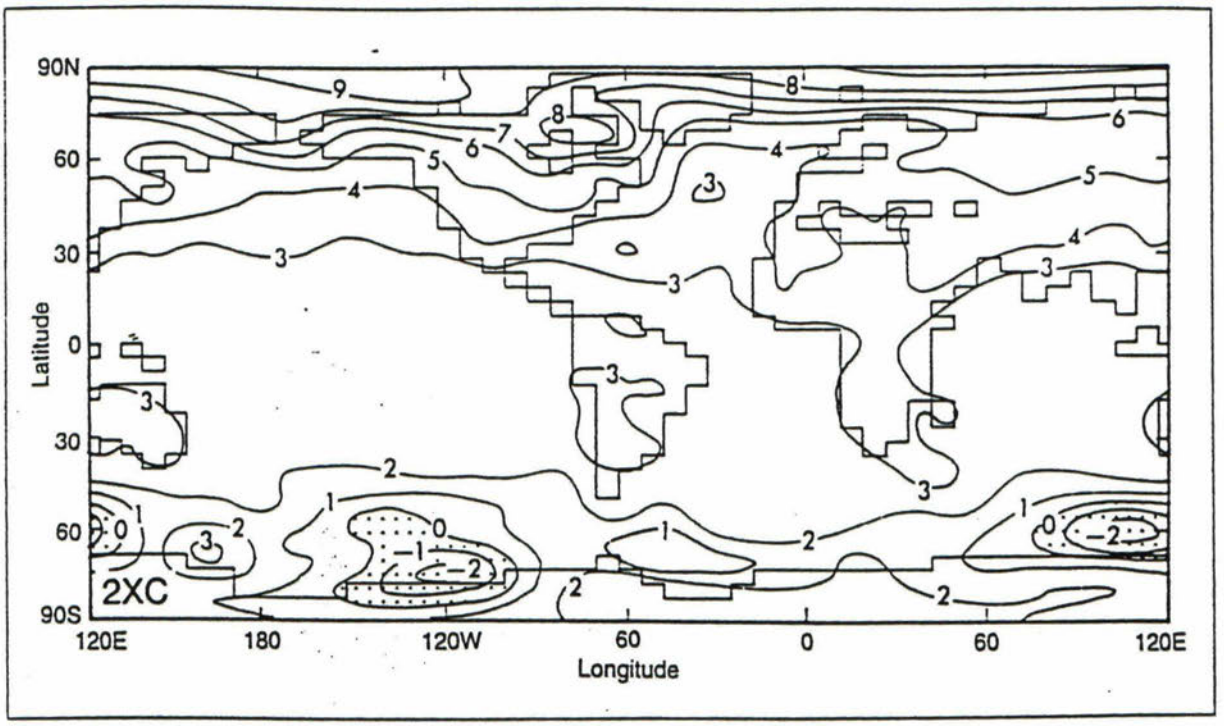


Figure 2 An example of the expected geographical distribution of an increase in annual-mean global surface temperature that would result from a doubling of the present amount of CO_2 in the atmosphere. Contours are in degrees C. From the GCM simulation of S. Manabe and R. J. Stouffer, Journal of Climate, vol 7, pp 5-23, 1994, with permission of the American Meteorological Society.

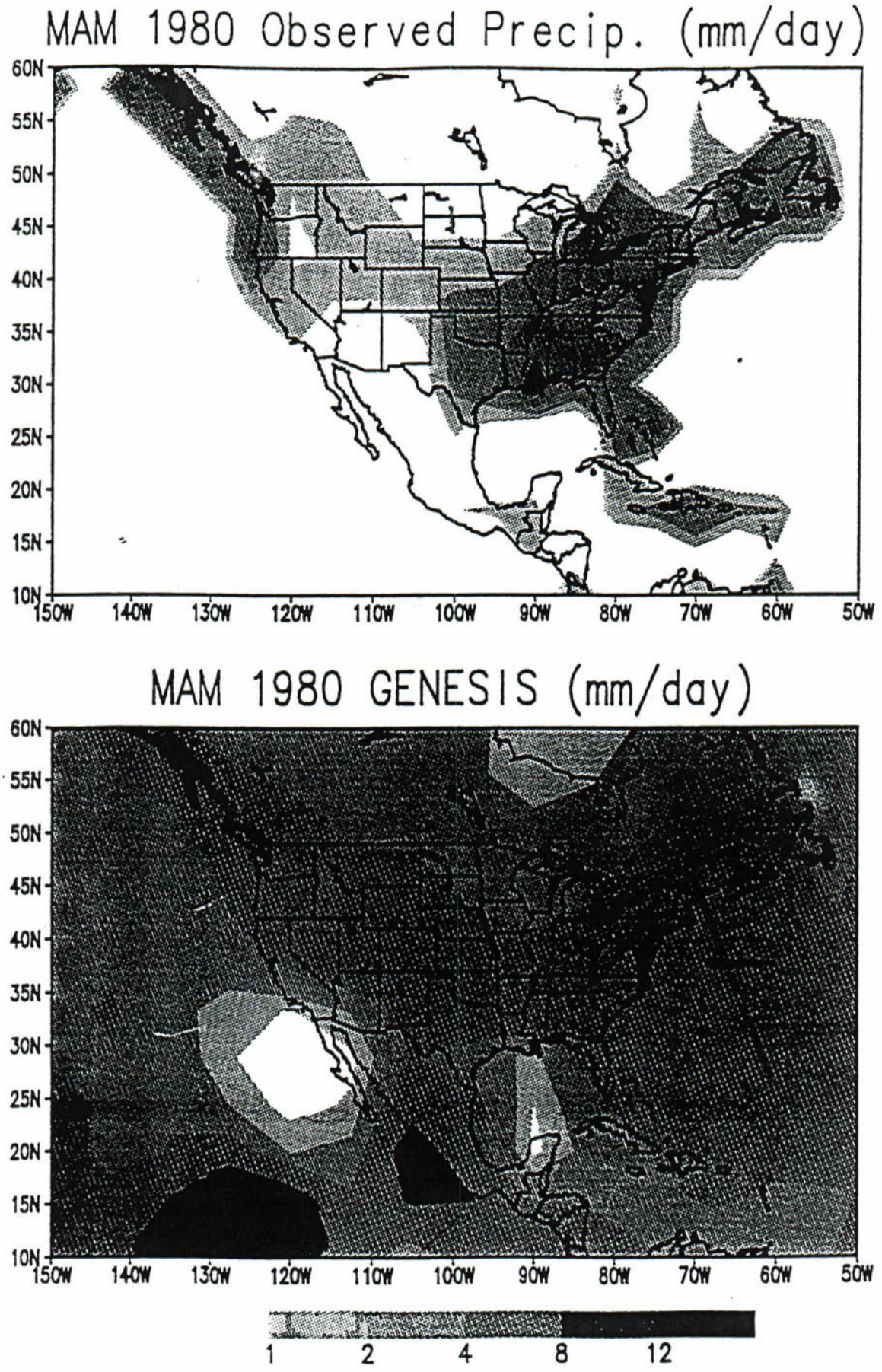


Figure 3a. Top - observed March, April, May 1980 observed precipitation

Bottom - GCM predicted March, April, May 1980 precipitation

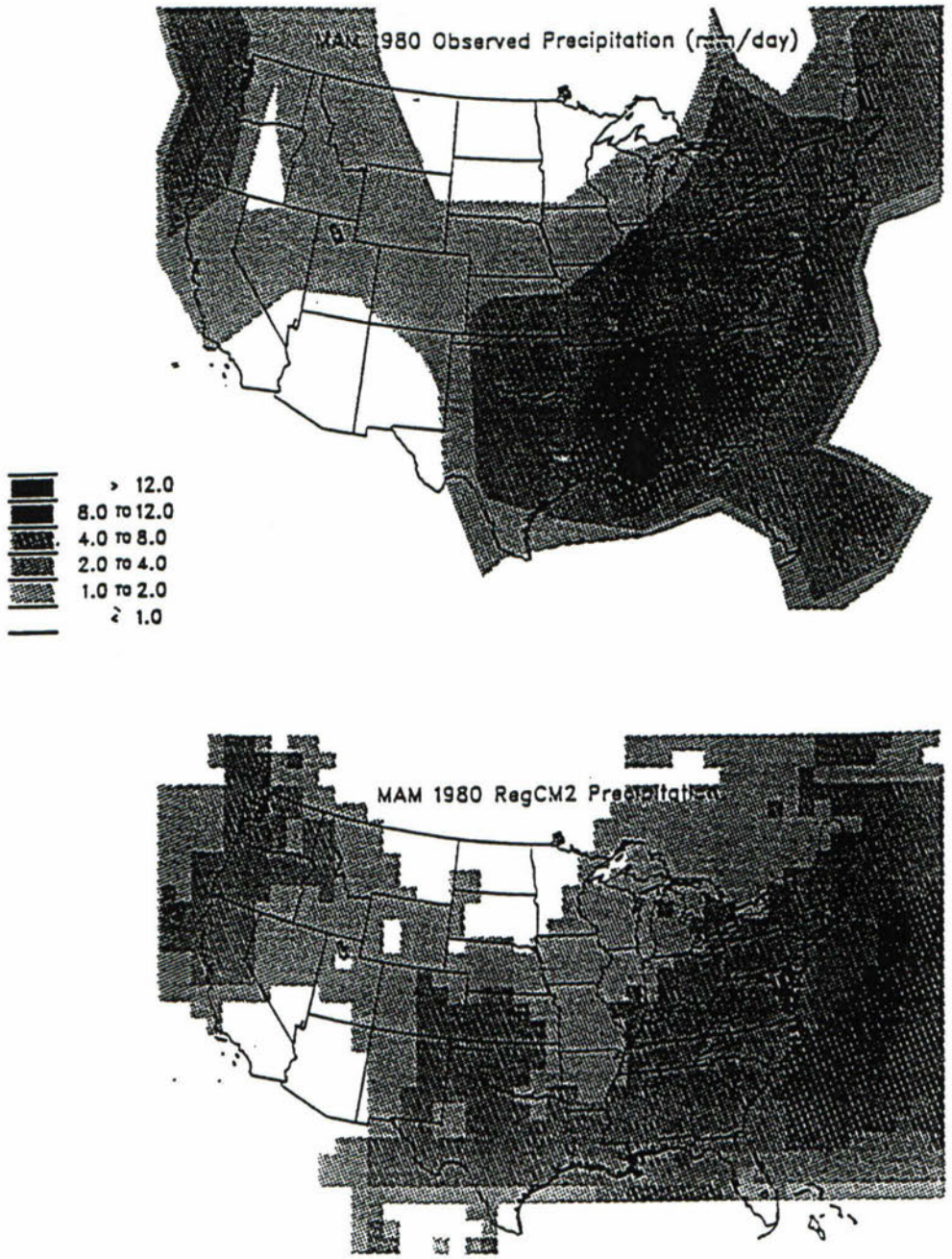


Figure 3b. Top - observed March, April, May 1980 precipitation

Bottom - precipitation output from Nested GCM-mesoscale model for March, April, May 1980

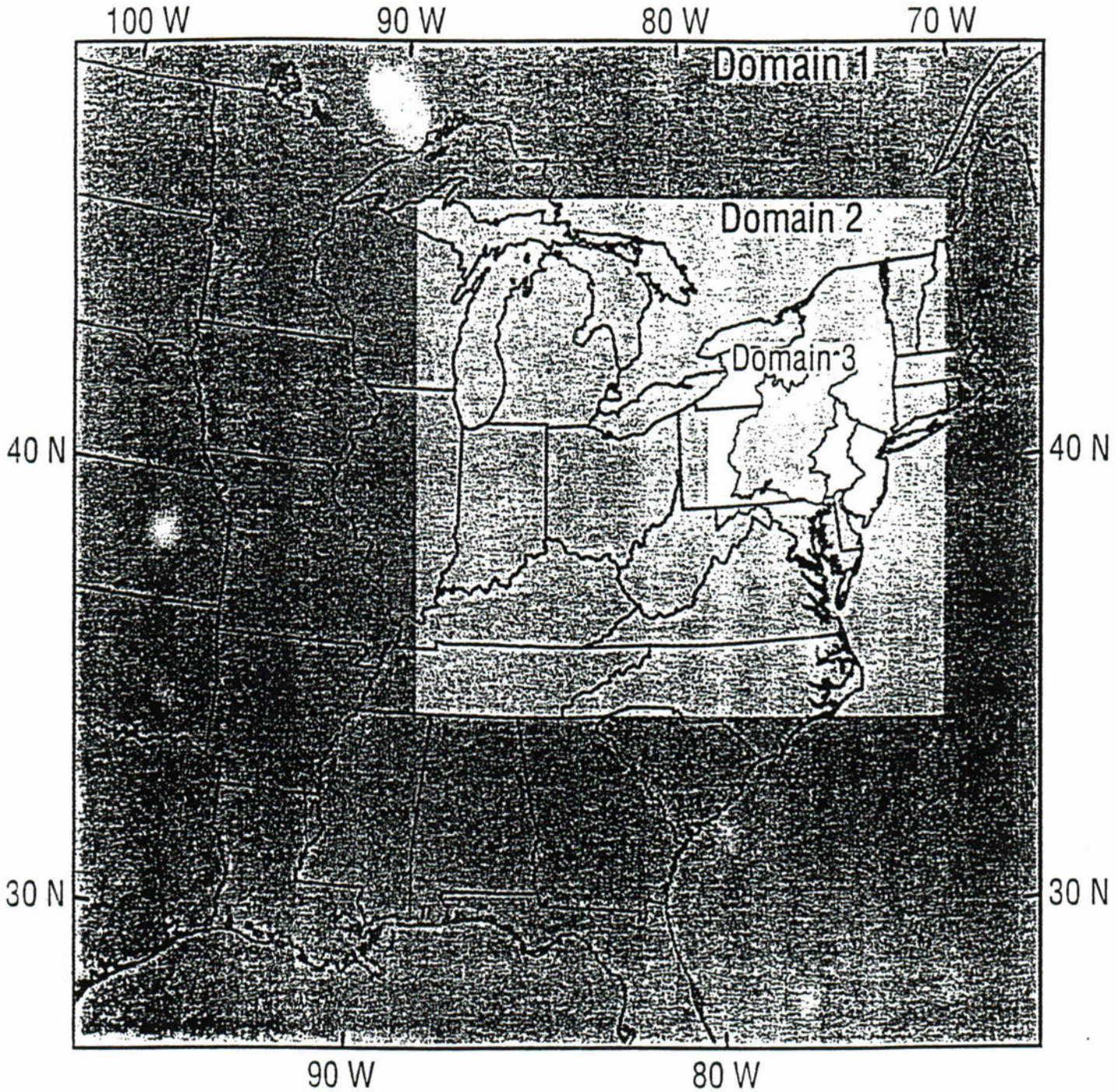
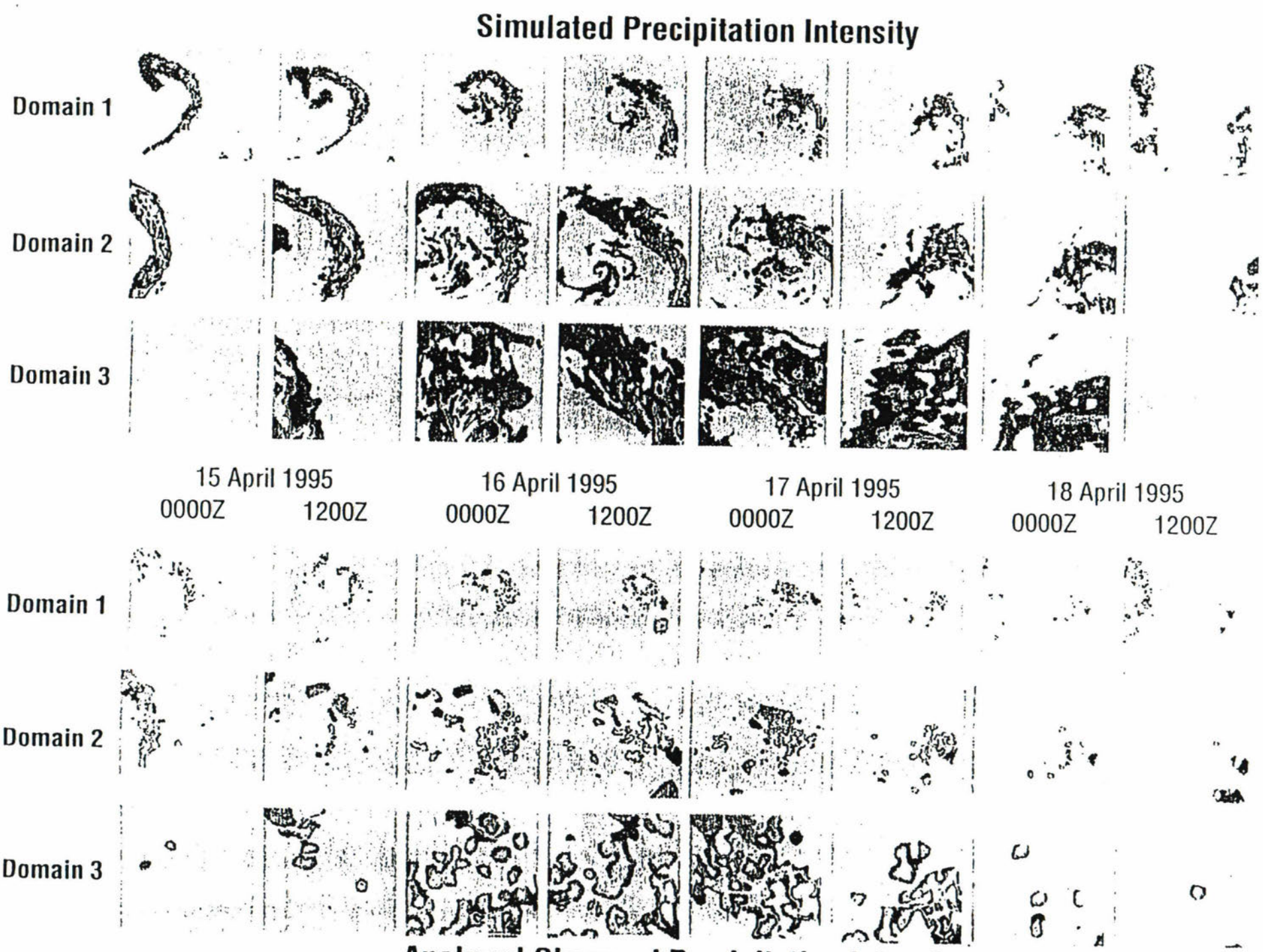


Figure 4. Nested Domains - Domain 1 36km gridspacing
Domain 2 12km gridspacing
Domain 3 4 km gridspacing


Simulated Precipitation Intensity
Domain 1
Domain 2
Domain 3
15 April 1995
0000Z
1200Z
16 April 1995
0000Z
1200Z
17 April 1995
0000Z
1200Z
18 April 1995
0000Z
1200Z
Domain 1
Domain 2
Domain 3
Analyzed Observed Precipitation Intensity

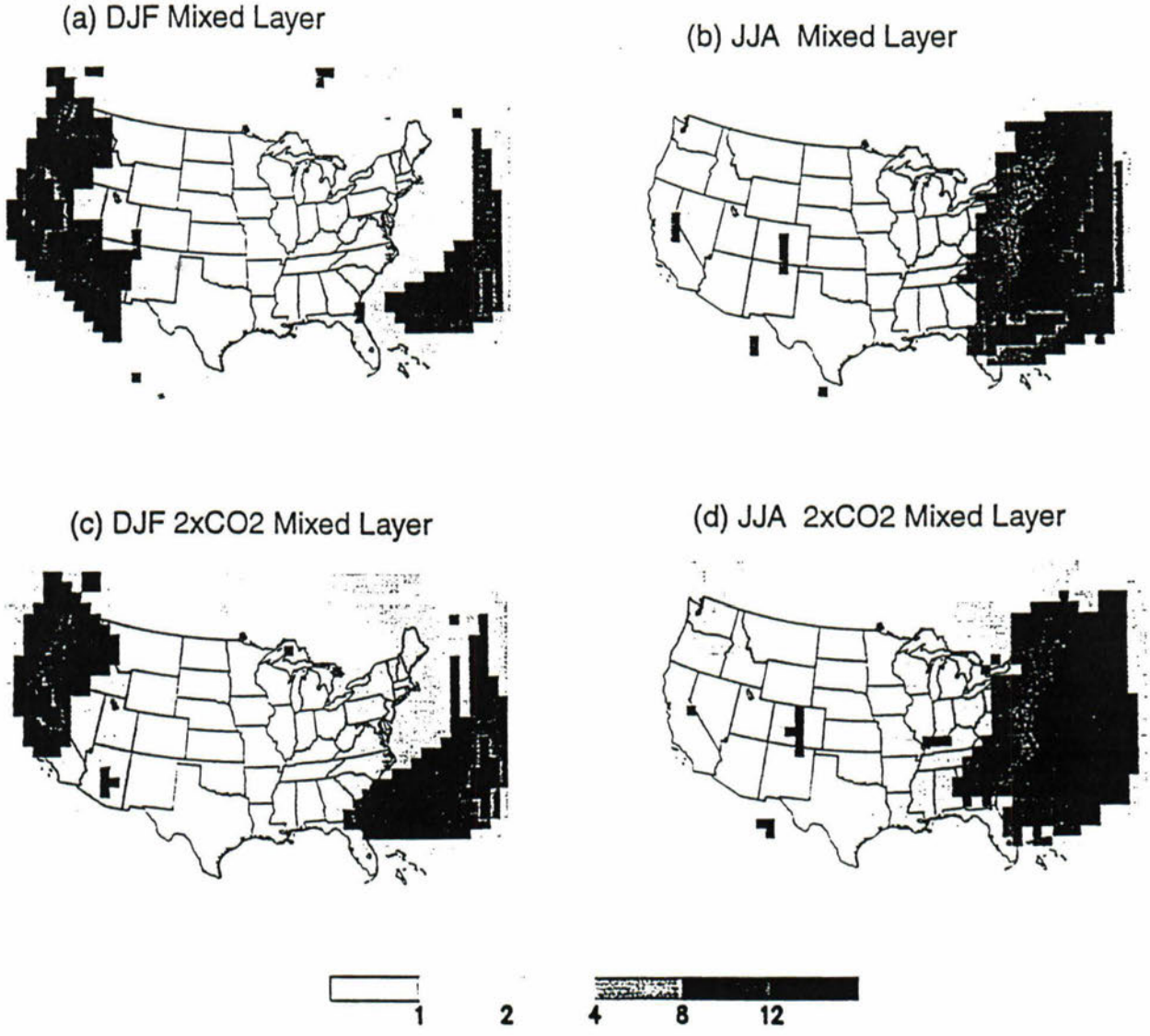


Figure 6: Precipitation Rates for DJF (December, January, February) and JJA (June, July, August) using observed SSTs; (a,b) Mixed layer ocean; (c,d) 2XCO2 mixed layer ocean. Units in mm/day.