

The Corn and Climate Report

An overview of climate science
in the service of Midwestern agriculture



US Climate Change
Science Program
www.climatescience.gov



IOWA STATE UNIVERSITY
CLIMATE SCIENCE INITIATIVE

Acknowledgements

Corn and Climate Report Authors

Jim Angel, Illinois State Climatologist

David R. Easterling, Senior Scientist, National Climatic Data Center/NOAA

Roger Elmore, Professor and Extension Corn Specialist, Iowa State University

Mike Hayes, Director, National Drought Mitigation Center

Marty Hoerling, Meteorologist, Earth System Research Laboratory, NOAA

Keith Ingram, Research Scientist, Southeast Climate Consortium, University of Florida

Alexander E. MacDonald, Director, Earth System Research Laboratory, NOAA

Rezaul Mahmood, Associate Professor, Western Kentucky University; Associate Director, Kentucky Climate Center

Emerson Nafziger, Professor and Extension Corn Specialist, Iowa State University

Dev Niyogi, Indiana State Climatologist

Jian-Hua (Joshua) Qian, Research Scientist, International Research Institute

Danny Rogers, Professor and Extension Agriculture Engineer, Kansas State University

Peter Schulz, Director, US Climate Change Science Program Office

Eugene Takle, Director, Climate Change Initiative, Iowa State University

Dennis Todey, South Dakota State Climatologist

Ray Wolf, Science Operations Officer, Quad Cities Weather Forecast Office, National Weather Service

Editorial Board

Brendan Jordan, Great Plains Institute, staff for the North Central Bioeconomy Consortium

Doug Kluck, National Weather Service

Donald Mock, National Oceanic and Atmospheric Administration

Peter Schulz, US Climate Change Science Program

Gene Takle, Iowa State University

Sarah Wash, Great Plains Institute, staff for the North Central Bioeconomy Consortium

This report would not have been possible without the contributions of the following institutions:

Energy Foundation

Great Plains Institute

Iowa State University

National Oceanic and Atmospheric Administration

National Weather Service

North Central Bioeconomy Consortium

US Climate Change Science Program

Prepared by Megan Hassler and Sarah Wash



Contents

Introduction

Eugene Takle, Director, Climate Change Initiative, Iowa State University

Part I: Climate Change Science and the National Climate Service

Observed and Projected Changes in Climate for North America

David R. Easterling, Senior Scientist, National Climatic Data Center/NOAA

Improving the Usefulness of Climate Information

Peter Schulz, Director, US Climate Change Science Program Office

Part 2: Climate Impacts on Midwestern Agriculture: Monitoring and Data

The Kentucky Mesonet: Background and Future Applications

Rezaul Mahmood, Associate Professor, Western Kentucky University; Associate Director, Kentucky Climate Center

Climate Impacts on Midwestern Agriculture

Jim Angel, Illinois State Climatologist

Indiana Temperature Trends

Dev Niyogi, Indiana State Climatologist

Climate Factors Impacting Productivity and Yield Trends of the Midwest

Dennis Todey, South Dakota State Climatologist

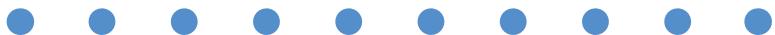
Part 3: NOAA and Seasonal Forecasting

NOAA “Down on the Farm”

Ray Wolf, Science Operations Officer, Quad Cities Weather Forecast Office,
National Weather Service

Seasonal Forecasts

Jian-Hua (Joshua) Qian, Research Scientist, International Research Institute



Part 4:What Producers are Saying about Crops and Climate

Corn Management Decisions: 2008 Planting Date Case Study

Roger Elmore, Professor and Extension Corn Specialist, Iowa State University

Corn and Weather: Could We Fine-Tune Plant Population and Nitrogen Rate If We Knew What's Coming?

Emerson Nafziger, Professor of Agronomic Extension, University of Illinois

KanSched:A Climatic Based (ET) Irrigation Scheduling Tool

Danny Rogers, Professor and Extension Agriculture Engineer, Kansas State University

Part 5: Preparing for Extreme Climates

Drought Probabilities

Mike Hayes, Director, National Drought Mitigation Center

Climate Change in the Grain Belt

Marty Hoerling, Meterologist, Earth System Research Laboratory, NOAA

RISA: Providing Climate Information for Agriculture

Keith Ingram, Research Scientist, Southeast Climate Consortium, University of Florida

Probabilities of Extreme Climates

Alexander E. MacDonald, Director, Earth System Research Laboratory, NOAA



Image Credits

Part 1

- 1.1: IPCC
- 1.2: IPCC
- 1.3: IPCC
- 1.4: NOAA
- 1.5: IPCC
- 1.6: NOAA
- 1.7: CCSP SAP 1.1 at www.climatescience.gov
- 1.8: National Snow and Ice Data Center
- 1.9: Rutgers University Global Snow Lab
- 1.10: Bruce F. Molnia, Ph.D., Research Geologist, US Geological Survey
- 1.11: IPCC AR4, Chapt. 3 of WG1
- 1.12: NOAA
- 1.13: IPCC
- 1.14: IPCC
- 1.15: IPCC
- 1.16: CCSP SAP 3.3 at same web site as 1.7
- 1.17: <http://www.ncdc.noaa.gov/paleo/newpdsi.html>, cite Cook et al 2004
- 1.18: IPCC
- 1.19: IPCC
- 1.20: IPCC
- 1.21: IPCC AR4 WG1 Chapt 10
- 1.22: Peterson T.P. (2008) personal communication
- 1.23: IPCC

Part 2

- 2.1: Rezaul Mahmood, Western Kentucky University
- 2.2: NOAA Midwestern Regional Climate Center
- 2.3: NOAA Midwestern Regional Climate Center
- 2.4: NOAA Midwestern Regional Climate Center
- 2.5: NOAA Midwestern Regional Climate Center
- 2.6: Dev Niyogi, Indiana State Climatologist

Part 3

- 3.1: Iowa State Mesonet
- 3.2: NOAA
- 3.3: NOAA
- 3.4: NOAA/National Weather Service
- 3.5: International Research Institute
- 3.6: International Research Institute
- 3.7: NOAA
- 3.8: International Research Institute
- 3.9: International Research Institute
- 3.10: International Research Institute
- 3.11: International Research Institute Climate Program
- 3.12: International Research Institute
- 3.13: International Research Institute
- 3.14: International Research Institute
- 3.15: J. Qian, International Research Institute
- 3.16: J. Qian, International Research Institute

Part 4

- 4.1: Roger Elmore, Iowa State University
- 4.2: Des Moines Register (Online). 10 June 2008

- 4.3: Roger Elmore, Iowa State University
- 4.4: Roger Elmore, Iowa State University
- 4.5: Roger Elmore, Iowa State University
- 4.6: Roger Elmore, Iowa State University
- 4.7: Roger Elmore, Iowa State University
- 4.8: Roger Elmore, Iowa State University
- 4.9: Roger Elmore, Iowa State University
- 4.10: Roger Elmore, Iowa State University
- 4.11: Roger Elmore, Iowa State University
- 4.12: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.13: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.14: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.15: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.16: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.17: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.18: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.19: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.20: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.21: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.22: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.23: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.24: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.25: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois
- 4.26: Emerson Nafziger, Professor and Extension Agronomist, University of Illinois

Part 5

- 5.1: National Drought Mitigation Center
- 5.2: National Drought Mitigation Center
- 5.3: National Drought Mitigation Center
- 5.4: National Drought Mitigation Center
- 5.5: Beijing Climate Centre
- 5.6: University College London (<http://drought.mssl.ucl.ac.uk/drought.html>)
- 5.7: Drought Management Centre for Southeast Europe (DMCSEE).
<http://www.dmcsee.org/dmcsee/>
- 5.8: NDMC
- 5.9: NDMC
- 5.10: NDMC
- 5.11: NDMC
- 5.12: NIDIS
<http://drought.gov>

- 5.13: Marty Hoerling, Earth System Research Laboratory
- 5.14: Marty Hoerling, Earth System Research Laboratory
- 5.15: Marty Hoerling, Earth System Research Laboratory
- 5.16: Marty Hoerling, Earth System Research Laboratory
- 5.17: Marty Hoerling, Earth System Research Laboratory
- 5.18: Marty Hoerling, Earth System Research Laboratory
- 5.19: Marty Hoerling, Earth System Research Laboratory
- 5.20: Marty Hoerling, Earth System Research Laboratory
- 5.21: Marty Hoerling, Earth System Research Laboratory
- 5.22: NOAA http://www.climate.noaa.gov/cpo_pa/risa/
- 5.23: Southeast Climate Consortium <http://AgroClimate.org>
- 5.24: Southeast Climate Consortium <http://AgroClimate.org>
- 5.25: Southeast Climate Consortium <http://AgroClimate.org>
- 5.26: Southeast Climate Consortium <http://AgroClimate.org>
- 5.27: Alexander MacDonald, NOAA
- 5.28: Alexander MacDonald, NOAA
- 5.29: Alexander MacDonald, NOAA
- 5.30: Alexander MacDonald, NOAA
- 5.31: Alexander MacDonald, NOAA
- 5.32: Alexander MacDonald, NOAA
- 5.33: Alexander MacDonald, NOAA



Introduction

by Gene Takle

Unprecedented pressures now are being exerted on the productive potential and sustainable use of Midwest landscapes. Demands for more food, livestock feed, biobased feedstocks for manufacturing, and biobased alternatives to fossil fuels raise questions about increased production of traditional crops and introduction of new ones. And looming in the background is the prospect of climate change—both within the region and globally. Of particular interest to producers in the Midwest is the prospect for climate change or increased climate variability in regions producing commodity crops similar to those grown in the central US. This region clearly is important to the future of the nation in areas of food security, energy independence, and availability of fresh water.

As climate continues to change in the region—a continued trend toward more frost-free days, possible continued increase in annual precipitation and heavy rainfall

events, continued humidity increases – growers will face new challenges with existing crops. And if there is a shift to more acreage planted to crops for the production of biofuels, new crop-climate learning curves will be launched. Both scenarios call for more dialog between producers and weather/climate service providers.

Producers and agribusiness providers in the region are known for their early adoption of sophisticated technology. GPS-guidance is used for managing tillage, planting, inputs, and harvesting operations, and specialized monitoring and forecasts are used for irrigation scheduling. Improvements in satellite observing systems to include soil moisture are forthcoming, and recommendations have been made for major expansion in nation-wide surface observing networks, including in-situ soil moisture measurements in every county (Carbone et al., 2009).

Climate changes mean agricultural changes

As climate continues to change in the region – a continued trend toward more frost-free days, possible continued increase in annual precipitation and heavy rainfall events, continued humidity increases – growers will face new challenges with existing crops.

Three time scales are considered important to agriculture and also to climate science: 0-10 days, 10 days to 2 years, and 2-30 years. The near term is considered important for timing of agricultural operations; meteorological information for the near term is provided from weather forecast models that provide predictions at 1 to 6 hour intervals, with skill declining to near zero beyond about 7 days. The intermediate (seasonal to interannual) time scale is important for agricultural purchases of inputs (seed, herbicides, fertilizer) and marketing; climate information for the intermediate term is supplied by statistical models based on slowly changing factors such as El Niño, La Niña, the North Atlantic Oscillation or by use of global and regional climate models. In the long term, producers decide on land purchases, conservation practices, construction of storage facilities, etc.; climate information for these time scales is provided by global and regional climate models.

Uncertainty is a hallmark of weather and climate information on all time scales. Quantifying uncertainty and enabling informed decision-making under various levels of uncertainty are on-going challenges that require more intense dialog between providers and users of weather and climate information. Development of commonly understood technical terms, use of probabilistic models and ensembles of deterministic models, and awareness of the consensus of scientific understanding are key elements of improving decision-making under uncertainty.

The Midwest has several of the nation's largest public universities, including several large land-grant institutions with research, education, and outreach capacity dedicated to serving the agricultural community. The state agricultural extension services, in particular, have vast networks that include trained professionals in every county across the region. This network enables rapid deployment of new information and decision-support tools for use by individual agricultural producers. Web-based delivery of information and products ensures wide access across the region and promotes development of communities of users who feed back experiences to tool developers.

The vision for launching this Workshop came from Workshop Co-organizer Doug

Kluck, Climate Services Program Leader, Central Region HQ, NOAA National Weather Service in Kansas City. He, along with Workshop Co-organizer Don Mock Executive Director of the NOAA Research Laboratories, helped recruit the high quality slate of presentations you see in this document. This workshop was an attempt to bring providers of weather and climate services (NOAA) together with producers, agribusiness providers, and advisors from state agriculture extension services to assess the latest scientific understanding of climate, climate variability, and climate change of the Midwest. The agenda was specifically designed to both provide the latest information in climate science and allow for discussion on possible new uses of climate science for agricultural decision-making.

In assembling this workshop summary we have made efforts to create a highly readable document for the non-specialist. The workshop itself was a collection of presentations by specialists from a variety of areas but presented informally with a lot of spirited discussion. We have attempted to capture this collegiality and upbeat interaction in the workshop summary. Our hope is that we have opened the door to more intense dialog among agricultural producers and weather/climate service providers. National investments in weather and climate observations and forecasting will not reach their full potential without strong and thoughtful feedback from the users of these services. To facilitate such ongoing dialog we provide contact information and encourage readers to get in touch with the organizers and presenters.

Finally, I must emphasize that this workshop and report would not have been possible without the very dedicated work of the Jill Euken, Deputy Director of Bioeconomy Institute at Iowa State, the Scheman Conference Center staff, and the staff from the Great Plains Institute. Jill's unique skills at coordinating the details of the Workshop from its inception, while concurrently organizing the Bioeconomy Conference held the previous two days, were truly amazing. Julie Kieffer, ISU Scheman Center Conference Planning and Management, ensured that our needs for food and technical equipment were met at the Scheman Center. Floyd Davenport, Information Technology Officer for ISU

Extension, oversaw the videotaping of the individual talks and posted all on the web.

Under the able leadership of Program Director Brad Crabtree, the Great Plains Institute's Program Manager Brendan Jordan and Program Associate Sarah Wash joined the NOAA and ISU members of the organizing team for several conference calls during the planning stages that led to the overall concept of this unique workshop summary. With Sarah's oversight and transcription help from Megan Hassler, intern at the Great Plains Institute, we were able to turn videotapes into this workshop summary in a remarkably short time.

To all these who helped make this event a success, including the presenters and Workshop participants, we offer our heartfelt thanks.

Eugene S. Takle, Workshop Co-Organizer
Director, Climate Science Initiative
Professor of Atmospheric Science
Professor of Agricultural Meteorology
Iowa State University
Ames, IA 50011
gstakle@iastate.edu
515-294-9871

References:

Carbone, R. E., J. Block, G. R. Carmichael, F. H. Carr, V. C. Chandrasekar, E. Gruntfest, R. M. Hoff, W. F. Krajewski, M. A. LeMone, T. W. Schlatter, E. S. Takle, J. Titlow, S. E. Boselly, J. F. Purdom, 2009: Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs. Natl. Research Council of the Natl. Acad. Sci., BASC, Richard E. Carbone, Ed., National Academies Press. (In Press)

Part I: Climate Change Science and the National Climate Service

Observed and Projected Changes in Climate for North America

David R. Easterling, Senior Scientist,
National Climatic Data Center/
NOAA

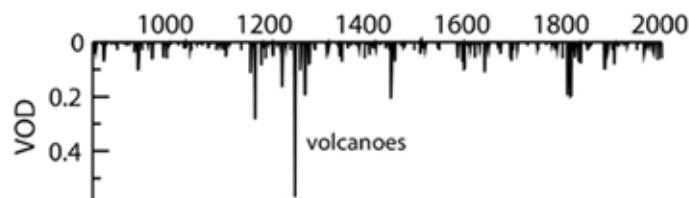
Part I: How do we know the earth is warming?

Climate change. Has it warmed? Has precipitation changed? Have extreme events changed? We just got through with a major report looking at climate extremes in North America, and Bill Gutowski of ISU was one of our lead authors on that report, which examines what models say about future climate in terms of temperature, precipitation, and extremes.

This paper begins by creating a global picture using the Intergovernmental Panel on Climate Change, the IPCC 4th Assessment Report, and then scaling down

to North America, finally ending with a few comments about Iowa because the bulk of this report deals specifically with changes in the Corn Belt.

Let's begin by taking a look at what causes climate to change. When we talk about the drivers of climate change, we're talking about something called climate forcings. There are two kinds of forcings: natural and anthropogenic. One of the obvious



natural forcings is volcanoes. Whenever a volcano erupts, it throws a lot of small particles in the atmosphere, and these particles have an effect on the climate. Typically volcanoes have a cooling effect. Figure 1-1 shows the temperature record for the globe over the past 1000 years, including the major eruptions of the 20th century. You'll see very clearly what the

Figure 1-1.

impacts of those major eruptions are on the temperature record. Then there's solar variability. In this reconstruction by Judith Lean of solar variability (Figure 1-2) you can see that it does not track with the large scale increase in temperature of the late 20th century. Those are the major natural forcings that can cause climate to change on the time scales that we are talking about here, which is on the order of a thousand to two thousand years. If you look at an even longer time scale, in terms of what causes the ice ages and other massive changes, it also has to do with solar forcing, but is more related to changes in the Earth's orbit around the sun. What we're really more concerned about is what humans can impact on the time scales that we're talking about with climate change.

Now let's look at human forcings. One of the types that everyone hears about is the increase in greenhouse gases. This graph (Figure 1-3) is from the Intergovernmental Panel on Climate Change 4th Assessment Report that came out in February '07. It shows you carbon dioxide changes in the atmosphere from 10,000 years ago to the present. The inset shows you changes from 1750 to the present. Most of the left-most portion is reconstructed using what we call paleoclimate proxies where, for example, you take air bubbles out of an ice core and measure the atmospheric concentration of greenhouses gases in it. What it illustrates is that the atmospheric concentration of CO₂ at around 10,000 years ago was somewhere around 270 parts per million, gradually increasing over time until the Industrial Revolution started. You can see very distinctly in this graph the rapid increase in carbon dioxide from the start of the Industrial Revolution. The red portion is the measurements taken at Mauna Loa starting at about 1958 or so, the Keeling Record. From the preindustrial levels of about 270 parts per million we're now up to about 381 parts per million of carbon dioxide, with similar rises in other greenhouse gases such as methane and nitrous oxides. Those are all the major greenhouse gases that have impacted our climate. A rapid rise in greenhouse gases results in rapid warming because these gases tend to absorb energy coming off the earth's surface, thereby warming the atmosphere. The other major forcing is sulfate particulates, and they have a more localized effect on the climate. Greenhouse gases are what we call well

mixed. They are fairly long-lived, they last in the atmosphere as long as a hundred years or so, maybe even longer. So they tend to get very well mixed through the atmosphere. Sulfate particles, on the other hand, have an effect that is more local. Sulfate particulates are emitted by power plants and other industrial processes. Again, you can see in this graph, beginning in 1600, the minor increases in sulfate particles until the Industrial Revolution, when we see a ramp up in sulfates. These particles tend to cool the climate, actually suppressing a little bit of the warming that we're seeing, so as we clean up power

plants we might actually be contributing a bit to the warming. One thing that's unclear is exactly how sulfate particles interact with precipitation, and that's one of the major questions in some of the modeling. A new paper recently came out in Science looking at sulfate particles and rainfall. Those are the major factors that would cause the climate to change.

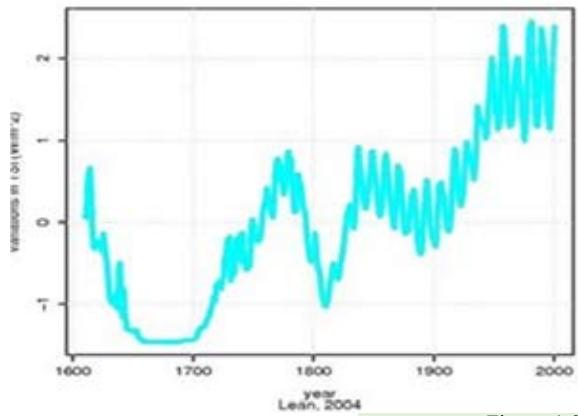


Figure 1-2.

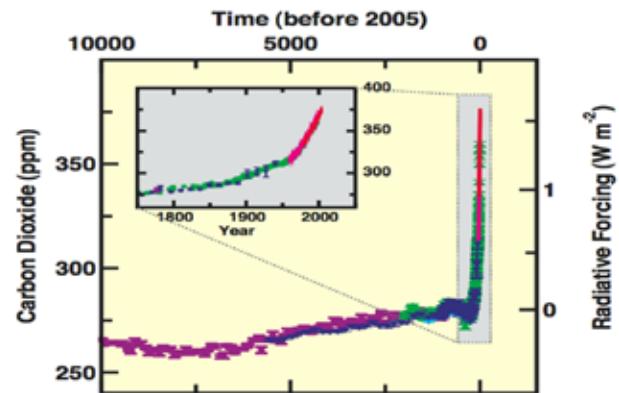


Figure 1-3.

Let's move on and ask the question: What do observations of past climate show? Figure 1-4 is a graph that we've routinely updated at our center at Asheville, and it shows the global average temperature. If you averaged all of the temperatures all over the Earth, both the surface air temperatures and the ocean surface temperatures, this is what you'd see—one number for each year, from 1880 through the present. This one stops in 2007. In each year there is a lot of variability, but over a long enough time horizon, you see a definite pattern emerge. The graph aggregates land and ocean data over the entire globe. The graph aggregates land and ocean data over the entire globe. The graph aggregates land and ocean data over the entire globe.

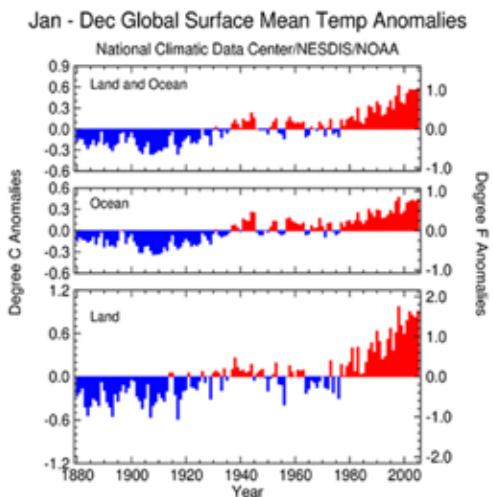


Figure 1-4.

mid-1970's rapidly warming. You see this behavior in the time series in the oceans as well as the land. The data is aggregated from all the weather stations as well as the ocean surface temperatures, and serve as a very good proxy or surrogate for the near

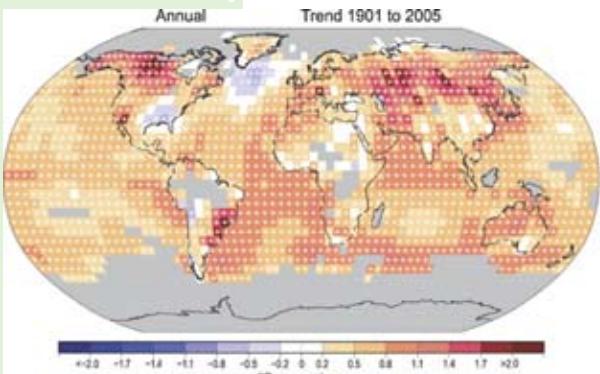


Figure 1-5.

air temperature.

Part II: Where is warming occurring?

Figure 1-5 shows a map that we did for the IPCC Report that shows where the temperature has warmed from 1901 to 2005. The areas

with the darkest reds show where it has warmed the most over this period. The greatest warming is occurring in the highest latitudes, especially in the

the ocean separated from the land. For both graphs you see a slight temperature increase beginning in about 1900, continuing until about 1940 or so, when it levels off and cools a bit, and then starting in the

northern hemisphere. Very few areas in the world have actually cooled over this period, and one of them is the southeastern United States. Another is an area off the coast of Greenland, and also a small area in South America, but in general, everywhere else is showing warming over this period. In Iowa it has warmed somewhere around one degree Celsius. Some of the areas have actually warmed quite a bit more, especially in the western part of the country and in Alaska.

Figure 1-6 shows the temperature for what we call the lower troposphere, which is a layer of the atmosphere between the earth's surface and around 8000 feet above it. The graph shows satellite-derived temperatures from two groups. The dark blue portion is from the University of Alabama in Huntsville, and the red is from a group in California called Remote Sensing Systems. We also have a couple of time series produced from weather balloons. One of the big controversies back in the mid-1990s through about 2002 or 2003, until the IPCC Report came out, was the fact that these time series for the lower troposphere were not tracking the same as what was going on at the surface. This was a bit of a controversy because you would expect the upper troposphere to warm at least as much as the lower troposphere. They solved the discrepancy a few years ago. These time series were stitched together from many different satellites. A satellite has a lifetime of about three to five years, maybe a little bit longer, so as one retires we have to put another one up there, and we have to do a lot of adjustments to the data to make sure they overlap seamlessly. Depending on how we make these adjustments, it can lead to a lot of discrepancies, because there are different ways to do it. Two different groups were doing their adjustments two different ways, and once they synchronized their methods, the end result in the report showed that the lower troposphere appears to be warming at about the same rate as what we see in the surface air temperatures over the period from 1979 to the present. Figure 1-7 shows what some of the major volcanic eruptions—Agung in the early 1960s, El Chichón in the 1980s, and Pinatubo in the 1990s—does to the air temperature. The next few years actually shows some cooling. So what other evidence is there for warming? We have solid temperature data from weather stations and balloons and other sources. But in order to have more confidence in what we're seeing in the data,

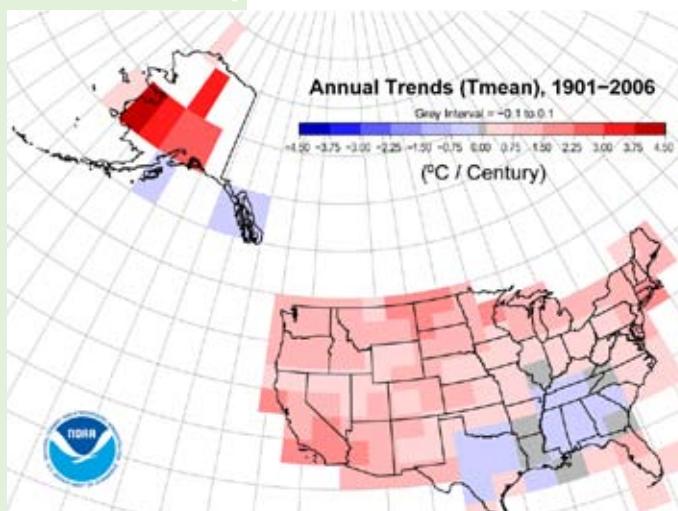


Figure 1-6.

we need other evidence.

Figure 1-8 shows one observation that is pretty striking. This is the Arctic sea ice extent in September; basically the Arctic freezes over in the wintertime and gradually melts throughout the summer. Since 1979, the Arctic sea ice extent in September has been rapidly decreasing. In 2007 it was down to a record low of 4.28 million square kilometers; this year it is potentially even lower. Northern hemisphere spring snow cover extent is another good example. Figure 1-9 shows spring snow cover extent from about the late 1960's to 2005, which was above average up until about 1985, and then after that it has dipped below the average for every year except for two since then. Seventeen of the last 20 springs have been below average. Glaciers are another good example. In Figure 1-10, the top photo shows Muir Glacier in southeast Alaska in 1941; you can see that the glacier extends all the way down the valley. The bottom photo shows the same location, but you can see that the whole area is now a lake. The glacier has retreated all the way back up the valley. There are literally hundreds of examples of the Alpine glaciers that are retreating like that. Data on global average sea level rise from 1860 to the present, from aggregated data sources, shows that sea level since 1875 rose 200 millimeters, or just about 8 inches.

Skeptics have recently said that it's all urban warming due to land use change that has distorted the thermometer record and that none of the warming we're seeing is actually occurring. Well, we've done a lot of work at our center to try to exclude these city stations and leave the rural stations in to see what impact it has on the global temperatures, and it has very little impact, if any at all. The oceans are warming at a similar rate as you saw earlier in Figure 1-4. The troposphere, again, is warming at a similar rate, as is the cryosphere, and the snow, ice and glacier melting and sea level rise all taken together show changes consistent with warming. All of this taken together is what leads the IPCC 4th Assessment Report to say that the warming we're seeing is unequivocal. The atmosphere has very definitely warmed especially since the 1950's.

What about rainfall, precipitation? We've got less confidence in this data. Precipitation is a lot harder to measure accurately than is

temperature, and it leads to a lot less confidence in the large scale changes we're seeing in observed precipitation. It's much more variable in space and time, so we have less confidence in the changes

we've seen globally. On a regional scale where we've done many different studies, especially looking at heavy rainfall events, we've got more confidence.

Figure 1-11 is a graph that we put together at the center for the latest IPCC Report from two large data sets from our center, the Global Historical Climate Network (GHCN) and from a group in Great Britain, the Climatic Research Unit (CRU).

If you look at this graph you see what appears to be an increase starting in about 1900 up until about the middle of the 20th century. So there appears to have been an increase up until about the middle of the 20th century based on this data set globally, average over the land area of the entire globe, but then after that there's just a lot of variability. There even seems to have been a decrease in precipitation since the 1950's. If you were to create a trend line you would see a slight increase, but overall a higher degree of variation after about 1950. All of these other lines are just different ways of measuring rainfall. Some are satellite-based, where you look at the clouds and

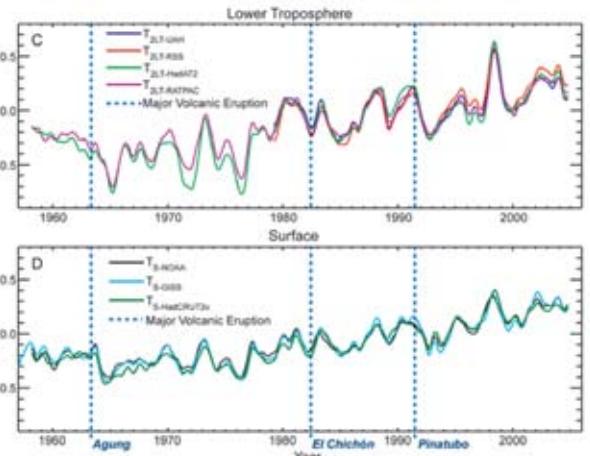


Figure 1-7.



Figure 1-8.

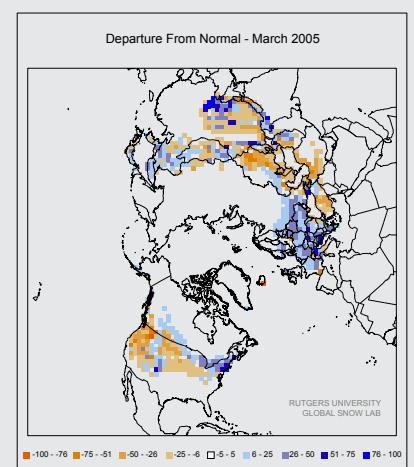
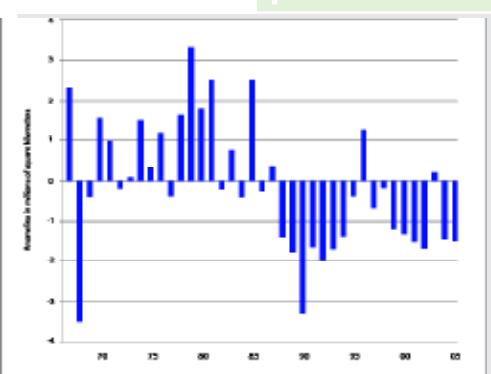


Figure 1-9.



Figure 1-10.

try to estimate the rainfall from the cloud, and they all say slightly different things. Some of the large-scale variability is similar, but the trends, especially since about 1979 or so, are different. Some trends are upward and some are downward. So we've got less confidence about global precipitation. If you look at where we do have data, in Figure 1-12 for example, you can see that the general pattern is what you'd expect in terms of increases in the precipitation. Increases are occurring in the higher latitudes and decreases are happening in the tropics. In general, though, we have

less confidence in globally averaged precipitation because we have a lot less data in these areas, and so we can't say a whole lot about what's going on there, but where we do have data you can see strong evidence of change. If you look at the US, because we do have very good data over the US, especially compared to other parts of the world, you can see the areas with the largest increases in rainfall. Parts of Iowa have seen pretty large increases. In general, we've actually seen an increase over the US, especially in the continental lower 48 states, but there are a few pockets where we've seen decreases.

We have a lot of data on extreme events, in terms of temperature, precipitation, and drought. I know that

drought is an important issue in the Midwest, but the heavy rainfall events are significant as well. Figure 1-13 is a graph that appeared in the IPCC Report and in our assessment on extremes. The idea here is to show what we're talking about with an extreme climate. It shows a normal distribution of temperature for a current climate, perhaps somewhere in Iowa. If you're looking at our current climate, you see that days over 90 degrees doesn't occur very often, but if we were to warm the climate by shifting this whole thing upward by 3 degrees, these extreme degree days suddenly become much more common. We're also seeing fewer colder days. So if we're going to see climate change in the future, we're going to see this shift where there will still be days like we're currently seeing but there will be more days that are a little bit warmer and fewer cool days.

There was a study in the IPCC Report done by Lisa Alexander of all the daily maximum and minimum temperature data. Usually we break down that globally averaged temperature into what we call the daytime high and the nighttime low because that's the way most of these climate stations measure temperature. So we're looking at the change in how cold it gets at night and how warm it gets during the day. We're looking at the extremes, where a cold night would be a marker for unusually cold nights and cold days would be unusually cold days. What we're seeing is a reduction in the number of unusually cold nights averaged over the entire globe and over a time series. We're seeing bigger changes at night than during the day. There are some slight increases in the number of cold days in the central part of the US. The bottom line is that we're seeing much of this warming occurring at night and we're seeing more unusually warm nights than warm days. In Figure 1-14 you can see that from 1948 to 1999, there was a lengthening of the frost-free season, especially in the area west of the Mississippi, especially in the western part of the country and the West Coast. We're seeing very large changes consistent with the warming trend. We're seeing more of the warming in the western part of the country, especially in terms of extremes and quantities, like the frost-free season. Heavy rainfall is one area that we've observed quite a bit from a compilation of several different regional studies, and as a result, we have more confidence in this data than in other data sets because we

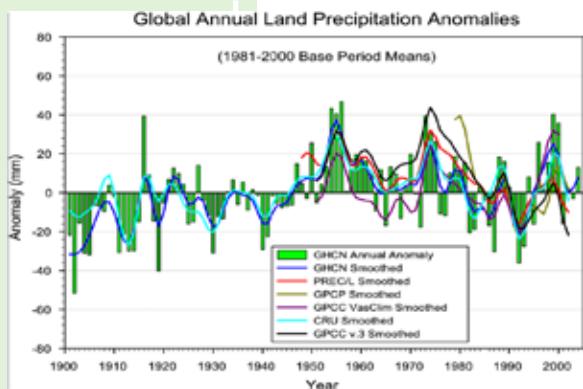


Figure 1-11.

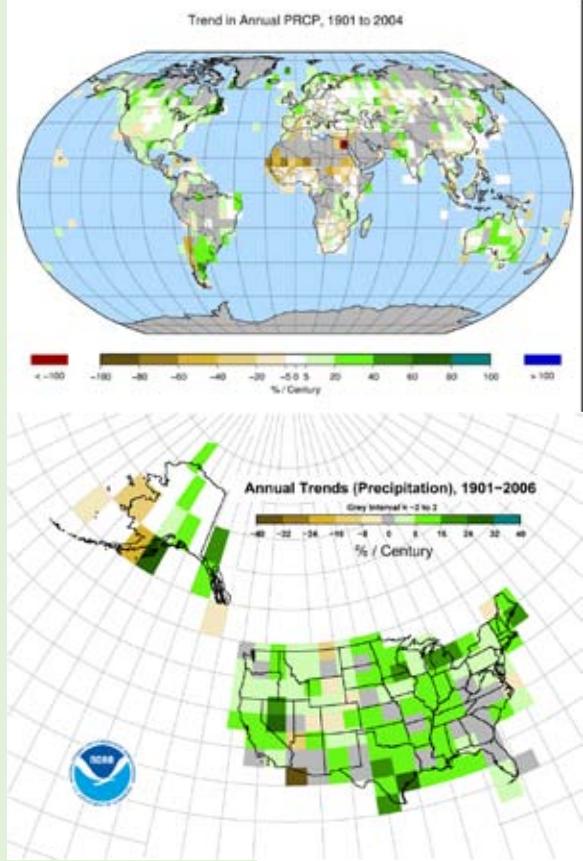


Figure 1-12.

extreme events, in terms of temperature, precipitation, and drought. I know that

think these regions have reliable data. The blue crosses in Figure 1-15 are regions where we have found increases in heavy rainfall events from about the middle of the 20th century to the present. The red minus signs are the few areas where we actually found decreases, but in general we're seeing these blue crosses.

Figure 1-16 depicts drought data for the US. In the 1930's, almost 65% of the country was in severe to extreme drought. There's a lot of variability in drought in the US; if you were to graph a trend line, you would probably see a decrease but no overall trend in US drought. Figure 1-17 is a drought reconstruction for eastern Iowa, starting in about 1200 AD to the present, reconstructed using tree rings. It is clear that there have been major droughts in the past 1000 years that dwarf what we see in the 20th century. What that means is that droughts and wet periods are a very persistent feature of the climate system. Droughts have always been here and always will be here.

So why do we think the observed increase in globally averaged temperature at least since the mid 20th century is very likely? The term "very likely" is used in the IPCC Report because it has a probability assigned to it, meaning that we have a 90% certainty or so that we think that observed increases are due to increases in greenhouse gases. We say it's warmed unequivocally, but we say it's very likely that it's due to increases in greenhouse gases. To do this we have to look at climate models. Figure 1-18 depicts globally averaged temperatures; the black line is the smooth version of the earlier red and blue graph (Figure 1-4) showing the globally averaged temperatures, broken down again into land and ocean temperatures. If you look at the blue shaded area, these are the temperatures that are produced by several different climate models that have been averaged together and show you the range of what the different climate models say over the period from 1900 to 2000, using only the natural forcings, just the volcanic eruptions and the solar variability. The red shaded portion shows what happens when you include all of the human-induced forcings, the increase in greenhouse gases and sulfate aerosols, as well as the volcanoes and solar variability. You can see that you cannot reproduce the behavior of the observed record, the black line, in a climate model without including

all of those human-induced forcings. With just the natural forcing, by the time you get to the end of the 20th century, there is no warming; the temperature would actually go down a little bit. Same thing if you break it down into land and oceans, the natural forcings alone, just the volcanic eruptions and solar variability, cannot produce that level of warming. The only way you can get it is to include all of the forcings, including all the anthropogenic greenhouse gas forcings. This graph of human-caused warming is how we can make the statement of greater than 90% probability.

And if you look at it by continents, you see a very similar pattern, what we call a likely statement, to about a 66% probability. We've got more confidence that global temperatures are due to increases in greenhouse gases than we have continent by continent, but the point is that the model can't reproduce the observed record unless you include all the forcings, so if you don't have the greenhouse gas forcings, you don't see the warming.

Part III:
What
might the
future
hold?

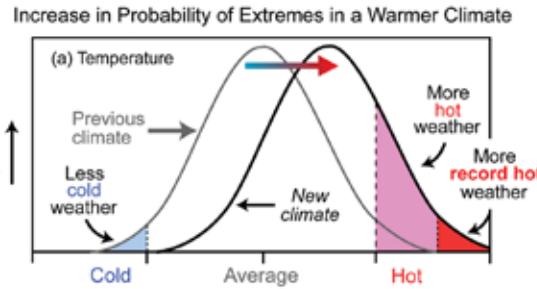


Figure 1-13.

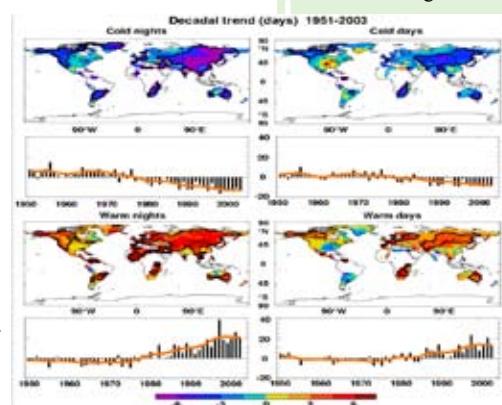


Figure 1-14.

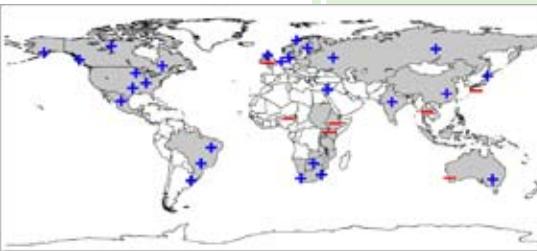


Figure 1-15.

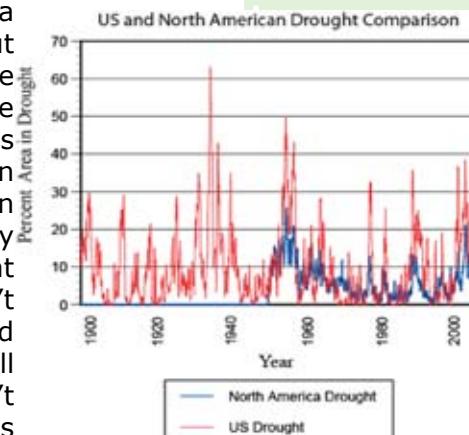


Figure 1-16.

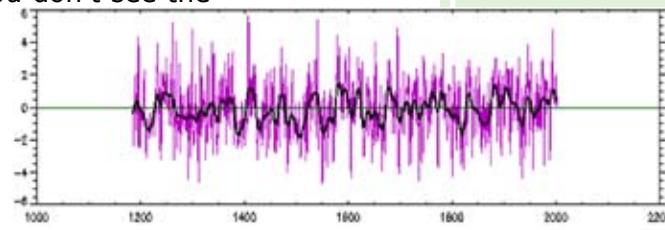


Figure 1-17.

Figure 1-19 comes from the 4th Assessment Report and shows warming over the 20th century in the aggregated model simulations. We use these models to produce what we

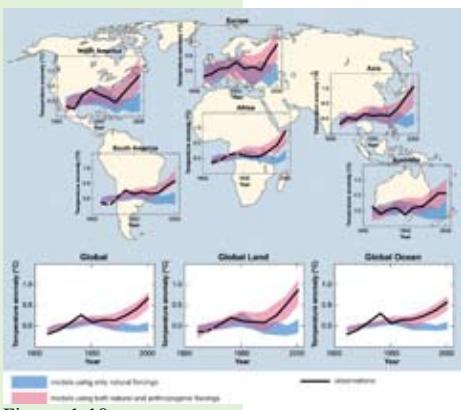


Figure 1-18.

call forcing scenarios, and this one shows what happens with the largest greenhouse gas increase. You can see that you get the greatest amount of warming in the models, approaching 4 degrees Celsius averaged over the entire globe, with a range up to about 4 ½ degrees. The green line shows lower greenhouse gas emissions, producing less warming. What's interesting about this is that if you look at about 2040 or so, it doesn't matter which trajectory

a moderate increase by the end of the 21st century, and the other shows a large increase in greenhouse gases. The two maps show the decade of the 2020's, from 2020 to 2029; both show about the same amount of warming, which is not a huge amount. It is only when you get to the end of the 21st century, 2090 to 2099, that you can see the big difference between what we would get if we cut back our emissions versus what would happen if we just kept on going.

Where would it warm? We would have very dramatic warming in the higher latitudes, in the highest emissions scenario, approaching 7 degrees Celsius, whereas with reduced emissions scenario you're getting warming somewhere around 3.5 degrees up in the highest latitudes. So depending on which emissions trajectory we take, it can make a big difference by the time we reach the end of the 21st century.

What about some of the extremes? Figure 1-21 looks at frost days, the number of days where the night time temperature goes below freezing, from the different model scenarios, averaged over the entire globe. You can see, depending on which scenario, that you get a reduction of the frost days on all of them, but as you would expect, the highest greenhouse gas scenarios produce the largest reduction in the number of frost days, and again you can see it's consistent with where you've seen the most warming. The same is true with heat waves; again you're seeing the largest increase in heat waves in the scenarios that have the largest greenhouse gas increases. Figure 1-22 shows you where precipitation is changing the most. This is not the highest greenhouse gas increase, but it shows you December, January, February increases on the left side and June, July, August increase on the right side, and you can see the largest increase in the higher latitudes. The areas that are in white are areas where there's not a lot of agreement from the different models. The stippled areas are places where we have the highest confidence, where the majority of the models agree. So they're agreeing in the highest latitudes, especially in the northern hemisphere, on an increase in rainfall as well as some areas where there are decreases shown, and this is consistent with what we've seen in the observed record with rainfall patterns in the highest latitudes over one hundred years, out to the end of the 21st century. As Figure

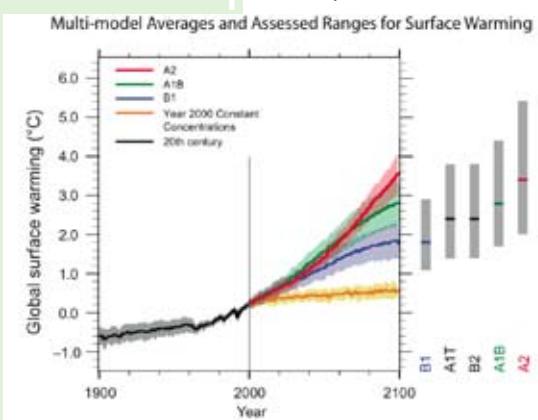


Figure 1-19.

diversions and really get the strong warming if you don't cut back on the greenhouse gas emissions. The yellowish line is interesting because it is what we call the climate change

we follow, whether you're putting a lot of greenhouse gases into the atmosphere or cutting back, you still get about the same amount of warming; it's only when you get out toward the end of the 21st century that you really begin to get those or global warming commitment. If the world was to stabilize carbon dioxide at 381 parts per million right now, we would still get a little bit of warming,

probably about .7 degree Celsius, because the climate would not have come back into equilibrium yet. So even if we were to stabilize the greenhouse gas emissions right now, we'd still have a little bit of warming left in the system. Figure 1-20 shows two emission scenarios; one

is the low greenhouse gas scenario with

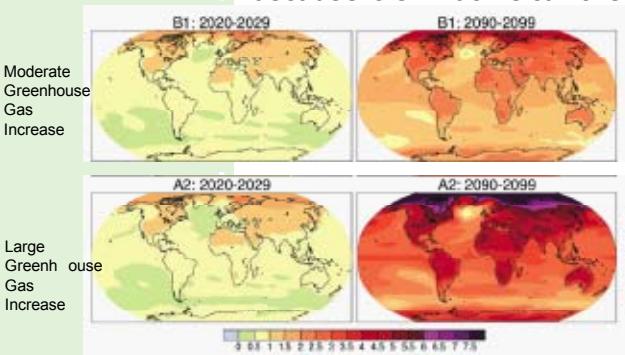


Figure 1-20.

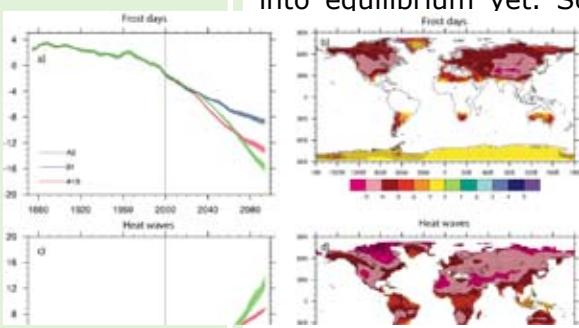


Figure 1-21.

1-23 shows, we also see some fairly large increases in heavy rainfall events in North America. In terms of regional affects, if you look at the region that includes Iowa, you see that with the highest greenhouse gas emissions scenario, by the end of the 21st century, there could be an increase of as much as 5 degrees Celsius in this region. That's fairly consistent over the entire United States. Where it gets interesting, though, is looking at rainfall; if you look at the multi-model average for all the climate models, you see an increase in this region, although some models show decreases, while some show a fairly large increase in this region. So the model precipitation is much less certain than the temperature.

What do these changes mean for Iowa? The amount of warming is uncertain, but it's very likely to warm some amount. We've already seen some warming here, and if we continue to increase greenhouse gases we're going to continue to see warming. It just depends on how much we increase greenhouse gases. Precipitation changes are much less certain but likely to increase, although there are still some uncertainties. One thing to point out is that climate models used in the last two IPCC reports show what we call mid-continental summer drying of the soil, so that as the air temperatures go up, even if we do see an increase in rainfall, the air temperature may go up in a lot of these areas to the point where you see a drying of the soil. There will be possibly more drought by the end of the 21st century, and it's likely that there will be more heavy rainfall events, which sounds a little bit contrary, because you could potentially end up with more drought, but if you're getting the rainfall in more heavy events, then that rainfall will run off more than sink into the ground.

Temperature Projections using Scenario A2

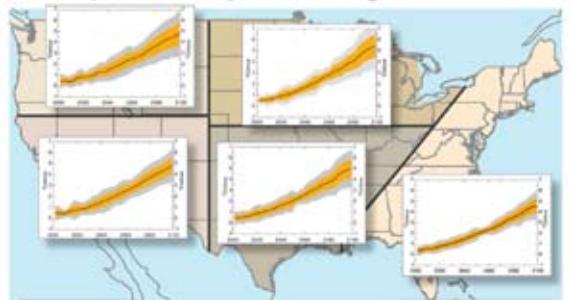


Figure 1-22.

Precipitation Projections using Scenario A2

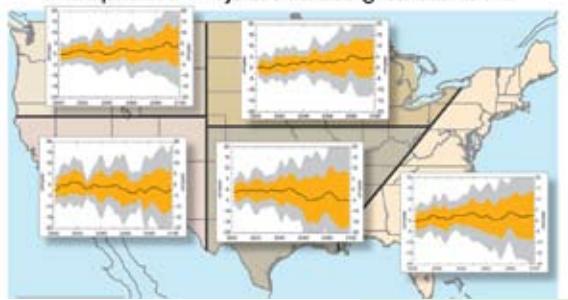


Figure 1-23.

Improving the Usefulness of Climate Information

Peter Schultz, Director, US Climate Change Science Program Office

The US Climate Change Science Program's vision is to foster a nation and global community empowered with the science-based knowledge needed to manage the risks and opportunities associated with change in the climate and related environmental systems. We do this through a program of research, observations, decision support, and communication. And the way that it's carried out is through the coordination and integration of thirteen participating departments and agencies. The Climate Change Science Program is a 2 billion dollar program. It's not a command and control organization; it is a coordination and integration mechanism. We help to set the intellectual directions for the overall federal funding of climate research. The program doesn't tell agencies what to do, but the individual agencies use the intellectual framework that has been established and agreed upon at a high level within the government to help argue for the soundness of their proposals. The program adds value through integration so that the whole made up of the parts of those 13 departments and agencies is greater than the sum. There are 5 goals for the Climate Change Science Program, and I won't go into them in detail, but very briefly they range from improving basic understanding of processes, through understanding the drivers of change, to improving predictions and projections, to understanding the impacts of climate change, to understanding how we can better use the information that's produced. Some of the things that we're engaged in are:

- Strategic planning. The last strategic plan that we produced was in 2003; it was slightly updated earlier this year.
- Annual research prioritization process, carried out by representatives from each of the 13 departments and agencies to identify issues that require focused interagency attention.
- Coordination of specific research topics. We have about a dozen different topical working groups where we try to coordinate the activities that are happening

across the agencies, so that the right hand knows what the left is doing and that the federal government is working at common purposes.

- Assessments. The program is currently completing a series of 21 reports synthesizing and assessing the state of knowledge in key sectors and scientific disciplines.

The program's synthesis and assessment products address issues that are complementary to the IPCC reports, with a particular focus issues and sectors relevant to the United States. They are scientific consensus reports that bring together the best experts across the country and internationally to state what we know about climate change. One of these reports focused on the effects of climate change on agriculture, land and water resources, and biodiversity. The report documented that with increasing levels of CO₂ and temperature, the life cycle of grain crops will likely progress more rapidly, and that has significant implications for grain filling. As the temperature increases more these crops will increasingly begin to experience failure, especially if climate variability increases and precipitation lessens or becomes more variable. Climate change is likely to lead to a northern migration of weeds, and disease pressure on crops is likely to increase with earlier springs and warmer winters, which may allow the proliferation and higher survival rates of pathogens and parasites.

Understanding how year-to-year climate variations affect yields, as well as how changes in extremes such as droughts, late frosts, and heavy precipitation events affect yields is also a research frontier for us; often it's the extremes that are more important than changes in the averages. CCSP recently released a synthesis and assessment product dealing with climate extremes. It deals with things like the projections for the occurrence of fewer cold days and nights in the future, and the projection that heat waves are likely to increase; the heat waves of today are likely to be normal summer days in the future. This report also deals with the consequences of increasing levels of water vapor in the atmosphere, which fuels convection, leading to "gully washers" that have very significant consequences for agriculture. The storms discussed include hurricanes, which may have implications for corn growing when these storms dissipate

over the Corn Belt. The report also looks at changes in drought. One of the things that is really interesting is that some areas have seen a decrease in drought over the last 100 years, which may seem counterintuitive in the face of the recent droughts in the southeast and elsewhere. As we move forward into the future, we expect to see a drying of the continental interiors in many places. Specifically what those patterns of change will be is something of an open question, especially in terms of how important that information is for corn growers. I would think it's quite important, but I hope we can have some more dialogue going forward about what the scientific uncertainties are and what information would be most helpful to you in better managing the decisions that you face.

Regarding precipitation projections for the future, a general rule of thumb is: wet areas will get wetter; dry areas will get drier. We can also begin to see where some of our largest uncertainties are with precipitation, such as in those regions between wet and dry areas—these areas of intermediate levels of annual precipitation make up large parts of the United States.

International observations and projections tell us what growing conditions competing agricultural markets face. June, July and August happen to be the timeframe for which climate models do not have agreement on whether precipitation will increase or decrease over most of the United States in the summertime. Does that mean that we know nothing about the moisture regime in the summer? No, because we are very confident that it will become warmer and that overall temperature increases can overwhelm relatively small change in terms of total precipitation amount that might occur.

2005 was a wild hurricane season. The last decade or so has been relatively anomalous with respect to the last several decades. However, if we look even further into the past, there were very active periods. Irrespective of the cause of the recent changes, they're heightening people's awareness. And, the warming that we've seen this last decade is the warmest decade in the historical records, which is very likely due to human activities.

I list these issues not so much to tell you

anything new about the science but to also begin to ask what information you need that you would like the federal climate research program to be addressing. Do we have enough information to think about what effective adaptation strategies are? Do we know enough about how variability might change in the future? Do we know enough about biochemical processes and how they intersect with water availability, nutrient availability, and photosynthetic processes to have the types of definitive statements that people need to better manage systems to which they are responsible? We do have value-added information for producers. But are they currently using it? Are they aware of where the Midwest's climate might be going in the future so that they can plan their investments more effectively over the long term? How important is it, for instance, that we don't have agreement among the projections in the summertime for precipitation change? Your views on these and other questions will be greatly appreciated.

The winds of change are blowing, and we are at a revolutionary period in terms of thinking about climate change. Within the administration, new regulations are afoot to cope with climate change. Endangered Species Act interpretation is a "hot" issue in terms of the science and the extent that climate can be linked to threats to specific species. On the congressional side, there was a bill in the 110th Congress that would reauthorize the inter-agency research program and retool it. There was also a related bill for a national climate service. And, of course, there is a large set of cap and trade bills. Cap and trade legislation could have significant implications for corn growers both in terms of mitigation and adaptation. There's a relatively small part of the cap and trade legislation that doesn't receive a lot of attention: provision of adaptation funds, perhaps as much as 10 billion dollars a year that would be distributed in a series of large grants.

At the state and local level, the focus has also been primarily on mitigation. However, irrespective of the extent of plausible reductions in greenhouse gas emissions over the next 30 years, we'll stay roughly on the same track for warming and we will be forced to adapt. We have not had a national dialogue about the need to adapt, which could lead to reactive not proactive responses. If we are not engaged

in long-range adaptation planning, the alternative—a reactive response—is likely to lead to the loss of lives and billions of dollars. We need to get out in front of this issue, beginning with a national-scale discourse on it.

We need to think about knitting together the available information and potential adaptation responses into an effective, local-to-national-scale adaptation strategy. Let me give you an anecdote. I was invited to talk to some developers about climate change. In the Q&A period I began talking about a new kind of pervious asphalt that allows water to rapidly infiltrate into it and not form deep puddles. It could help road systems cope with the increasing intensity of precipitation events that is projected with global warming. The developers were aware of this new type of asphalt, but were not using it because if they did, the local transportation department would probably cap it with impervious asphalt within a few years and thereby squander the developer's investment. Federal insurance and disaster relief provide similar case studies, and there are many others. There's virtually no coordination across the parts and scales of government that are in the position to undertake climate adaptation. We do not have a national adaptation strategy and I'm convinced that we need to develop one.

The science has evolved significantly within the past 10 years, and this new knowledge speaks to new directions that we might be pursuing. At the same time, demands for this information have increased and evolved. The federal government is currently engaged in strategic planning to understand where we should be going. At this stage, we are not putting together a formal new plan. We're going around the country, listening and developing the building blocks for the next federal strategy for approaching this issue.

One thing that is happening as part of this process is that we're considering changes in the rationale for the research. It used to be that we were providing quite general rationales for research, e.g., "to improve understanding," "to close the water budget," "to close the carbon budget," etc. However, that will no longer carry the day like it did back in the 1990's. Now we need to be clearer about how the science can improve decision making for prospective mitigation and adaptation. That might seem like a

subtle point to most people, but it's actually pretty important inside the beltway.

Part of our strategic planning process includes identifying who our stakeholders are and fostering cooperation with them. An element of this is a limited series of listening sessions we and others are convening around the country. One of the questions that we're beginning these dialogues with is what types of decisions need to be made. So, I pose that same question to you. What decisions are you facing, for which climate is one factor? And are you getting the information that you think that you need to better manage in the face of climate variability and change? What are the scientific uncertainties that you'd like to see resolved? How can we more effectively link the development of science to your decision making process? We've produced a large array of assessments. Are they salient to you or are they just books on a shelf? Are there other ways we might more effectively communicate what we know both over the long term and the short term regarding climate over the next month, the next 6 months, or the next year, to better inform your decisions? If you do need information in a more timely fashion, what are the features of that information? What's important to you in the delivery of that information? Do you need a single point of delivery? Do you need access to information that you haven't previously been able to have access to? Do you need to have the information tailored? Do you need it at a specific resolution, either in time or space?

One of the messages that has come through clearly in the listening sessions is that there's great confusion about where to get timely and credible information to inform decisions. The federal government, state and local governments, the general public, the private sector, and the scientific community need a coherent, comprehensive strategy and mechanism to receive authoritative climate information in an integrated and focused manner to meet evolving national needs. There is a need for a mechanism through which activities relevant to the application of climate information are coordinated, that would focus on the production and evaluation of ensuring highly usable, actionable, issue-focused information. This motivates the consideration of a national climate service to help meet this demand. NOAA has taken

the initial lead on the consideration of such a service. So what would this national climate service provide? It might, for example, provide historical and real time data, predictions and projections, decision support tools, and early warning systems that are directly targeted at key areas, sectors, regions. And it would focus on the timely availability of information.

NOAA is beginning to explore options for doing this with a closely knit set of partners. It is not clear that a single agency, or even the entire federal government, can effectively address the existing needs. We shouldn't create a new wheel, but we need to better coordinate those wheels so they are pointing in the same direction and have access to the same kind of fuel—to extend the car analogy. So, we need to think about entraining a wide range of information providers. We also need to think about a diverse network for facilitating communication, including, e.g., weather forecast offices, agricultural extension, EPA and USGS regional offices, state climatologists, the private sector, NGOs, academia, etc.

I invite comments that I hope to use to inform both the overall federal climate planning process for research, service, adaptation, and mitigation. If you would like to, and even if you wouldn't like to be kept in the loop about this, we'd like to know who you are and what your area of expertise is and what your comments are as part of the strategic planning process, input@usgcrp.gov.



Part 2: Climate Impacts on Midwestern Agriculture: Monitoring and Data

The Kentucky Mesonet: Background and Future Applications

**Rezaul Mahmood, Associate Professor,
Western Kentucky University;
Associate Director, Kentucky Climate
Center**

The Kentucky Mesonet is a network designed for observing weather and climate. What is Mesonet? Mesonet is an abbreviation of Mesoscale network. It provides high density data in space and time, so rather than having eight or nine stations crossing a state, we should have many more because weather and climate variables change over space very rapidly. For example, it can be raining here, but 200 or 500 yards from here it would not be raining. Historically, the backbone of our weather and climate observation is

cooperative observer networks, wonderful folks that collect daily precipitation and temperature, and that's about it. When it comes to Mesonet, however, you can bring in data at any time scale: minute-by-minute data, five-minute data, fifteen-minute data, basically whatever you want. We can collect data from many sensors.

There are other Mesonets and we are basically following them. Oklahoma Mesonet is one of the prime examples of a world class system. They have about 112 stations, and research quality data comes in every five minutes. That data can be used for decision making, research and many other things. There's a Nebraska Mesonet that's slightly different. Nebraska Mesonet data doesn't come in real time. At the end of the day we get the data, but it's high quality data also. Nebraska Mesonet is in the center of the automated weather data network of the northern Great Plains, which extends from Kansas up to North Dakota, including a few stations from western Iowa, western Minnesota, and other western

states like eastern Colorado and eastern Wyoming. And there's an Iowa Mesonet which is in fact a conglomeration of real time weather observation done by different entities, including DOT, the state, and others. But where we'd like to go is having homogeneous instrumentation systems, such as either Nebraska or Oklahoma. In Kentucky, we are following the lead of these other existing Mesonets.

At our existing stations we are measuring the air temperature, precipitation, solar radiation, relative humidity, wind speed and direction. We are also planning to collect soil moisture and temperature data at five different depths. We haven't instrumented our station with soil moisture and temperature probes yet because it is very labor and time intensive. So we want to implement our tower and atmospheric measurements and then we'll slowly start to instrument stations to the last variable. For all of our site selections, instrumentation, testing and calibration, maintenance, and overall operation, we have become complementary to CRN and NERON. The latter is a federal effort to build a national Mesonet. They have established a number of stations in the New England area. Research quality data is very critical; in other words, you need to convince users and decision makers that this is good data that can be used to make decisions. So when we built our instrumentation package, we had extensive discussion with NOAA folks, NWS and NCDC both. For example, in our case, for temperature, we are using three sensors within an aspirated shield so that if one sensor drifts we know that there is some bias. We are also using a weighing bucket rain gauge with a single alter shield, and for the site selection we are following the NERON and CRN criteria. Obviously we are talking to NOAA folks on a regular basis; all of our technicians are trained at NOAA's Atmospheric Turbulence and Diffusion Division facility (ATDD) at Oak Ridge. For our sites we make multiple seasonal site visits, and when needed, emergency visits, although we haven't done that yet, since the network has just started to operate. We have been installing stations since last summer. We have 11 stations operating. We have site licenses for about eight more sites and we have negotiations continuing for another eight, which requires a lot of collaboration with local communities and local government entities, and that has been a big learning experience for us,

because we in the academic community are not used to doing that. We wanted to find out which sites would be least likely to change for the next 50-100 years and where we would have 24/7 access. For all of these we really needed to talk to the local folks which is a new experience but also exciting. If you talk to the right people, in the right manner, you can get a great level of cooperation.

Figure 2-1 is a flow chart of how our station of operating data comes in, from the tower to the data logger. NOAA has been very generous; they have offered use of their weather satellite to communicate with the mesonet stations. However, the satellite does not provide 5 or 15 minute communication or 2-way communication. These are critical for our network. When we designed our network we made sure that we can communicate to the stations whenever we want. For example, we sample air temperature

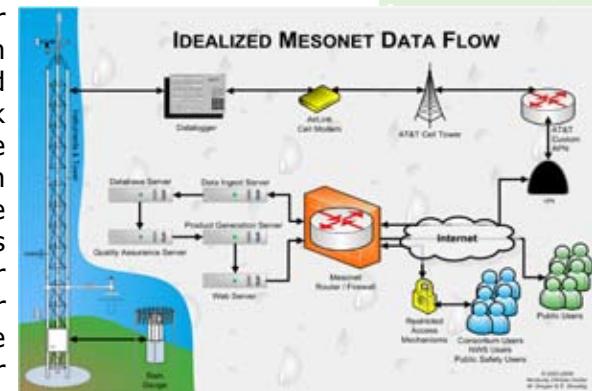


Figure 2-1.

every three seconds and average every five minutes and that's our five minute temperature, but if we want to change it to five seconds, we can do it with a key stroke. The data gets entered into the data base and then we do quality control. With a network like that, you can say, what am I going to do with five-minute data or 15-minute data? I care about tomorrow's data, or I'm going to plant five days from now. My response would be when you have this high density data, in other words, within a small distance, you can see the changes, like precipitation gradients, and when you can see moisture levels, you can plan. Our network also helps to decide when you're going to spray and things like that. For example, we added wetness sensors to verify precipitation, which becomes a very useful tool for spraying, pesticide applications, and so forth. These are some examples of applications for the agricultural community.

Climate Impacts on Midwestern Agriculture: Monitoring and Data

Jim Angel, Illinois State Climatologist

This essay deals with climate events and climate service trends in Illinois. In the spring of this year, heavy rainfalls across the Midwest caused considerable economic and human hardship. Figure 2-2 shows

a rainfall map of the first 15 days of June. There were large areas where 10 to 15 inches fell across Iowa and in Wisconsin, while slightly less rainfall fell in central Illinois and Indiana. Obviously, this rain caused considerable problems, not only in the areas where

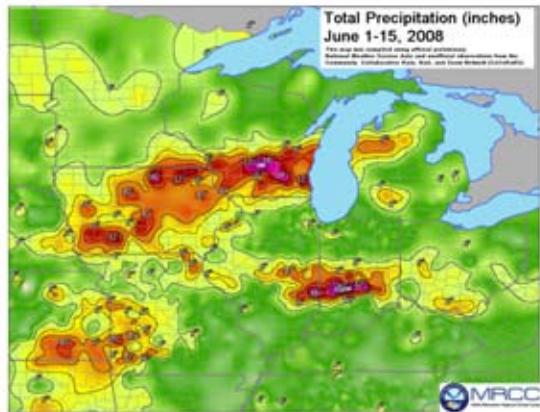


Figure 2-2.

the rain fell, but also downstream. In fact in Illinois we had major flooding along the rivers that drained out of Wisconsin into

Illinois, as well as along the Mississippi River in western Illinois. The key point of this map is that it was drawn using two separate networks. One was the traditional National Weather Service Cooperative Network (COOP) and the other one was the newer Collaborative Community Rain, Hail and Snow Network (CoCoRaHS). The CoCoRaHS observers have standard training and equipment, resulting in the same quality data as from the COOP network. So, we

CoCoRaHS sites enhance the detail in these maps. Meanwhile, the COOP sites have a long historical record that gives a historical perspective of the event.

Besides the state climatologist office, the Illinois State Water Survey is home to the Midwestern Regional Climate Center. One of the things that I use frequently is their Climate Watch [<http://mrcc.sws.uiuc.edu/climwatch/watch.htm>]. Their climate watch gets around the problem of trying to keep track of what is going on in the Midwest by flipping back and forth between sites. One thing that we can do for producers is building websites that are information portals, collecting data from a variety of sources and putting it all into one spot. For example, on the Climate Watch page there are temperature and precipitation maps for the last seven to 14 days, the departures from normal, etc. Growing degree day information is available as well – something that was especially important this year with the planting delays. A soil moisture model is featured on the site. In addition, there are weekly highlights where all the climate impacts for the Midwest are summarized week by week. So with one page you get a clear picture of the current climate situation and impacts across the Midwest.

Elsewhere in this report Mesonets are discussed in more detail. The Illinois State Water Survey has a network that is almost a Mesonet, maybe not quite that dense yet, but one that has been going on for over 20. We have the usual atmospheric measurements (temperature, precipitation, and wind), but what is unique about the network are the observed soil moisture data. These 19 sites now have enough data to construct a reliable climatology of soil moisture. Soil moisture can be a challenge to measure and characterize because of large variations over small distances due to rapid changes in rainfall, soil types, drainage, etc. However, you can compare between sites a little better if you look at departures from normal rather than absolute values. And that is something that comes in handy, especially with drought monitoring (or in this year more like flood monitoring). Figure 2-3 shows a snapshot of the latest soil moisture survey that we did. The main point here is that these maps are all green, which means that soil moisture is at or above normal for this time of year. When you get into a drought year then a lot of these will turn yellows and oranges



Figure 2-3.

are seeing a trend in the last five or ten years of using multiple networks, meshing them together to get a more detailed picture of what is going on in the Midwest. Ten years ago we would have used the COOP network alone, providing a lot less data overall. The

and reds. With a soil moisture network you can see things like we saw in the drought of 2005 in northern Illinois. We had better than expected corn yields in that area. I think it was because they literally mined all of the soil moisture out of the top 72 inches of the soil. According to our survey, the whole profile in the top 72 inches was completely dried out by the end of the growing season. So I think there is some really useful information that you can get when you have a soil moisture network in place.

Another thing that cropped up this year, after all of this talk about the heavy rains up through July, is that August was actually pretty dry across the Midwest. Figure 2-4 shows the precipitation departure from August first through September third, and the areas in oranges and yellows are one or two inches below normal. It's a complete reversal of what happened earlier in the season. This caused great stress in the shallow rooted and late developing crops. Figure 2-5 shows what the same map looked like if you added another two days with the rains of Hurricane Gustav. And the point here is that sometimes we have things that happen in the Midwest that really started out far away. In this case it was Gustav. Back in 2005, we had the case where four tropical storm systems moved through a relatively dry Midwest. In the case of Illinois, it prevented southern Illinois from getting into drought conditions because of an extra eight inches or so of rain.

Finally I want to talk about something that happened two years ago. We had an unusual combination of a very mild winter and a very warm March, followed by a significant cold air outbreak in early April. The warm weather early on caused crops, and vegetation in general, to get ahead of schedule by almost a month. When the really cold air in April came in, with temperatures in the teens and twenties, it really hammered a lot of the orchard crops. It also damaged winter wheat, alfalfa, and some of the early planted corn. The point is that sometimes we get fixated on temperature or precipitation trends but I think some of the key impacts are in these more unusual and extreme events. I am especially interested in what I call one/two punches, where it was not the warm March that got us, but it was the warm March combined with a very cold April. These one-two punches can set us up for some pretty

serious losses. Just to give dollar amounts, the losses in Illinois from this April freeze were about \$150 million dollars. Some of the other states had even more significant damage than that.

Hopefully, the issues that I briefly described will stimulate discussion and further collaboration between ag producers and climatologists.

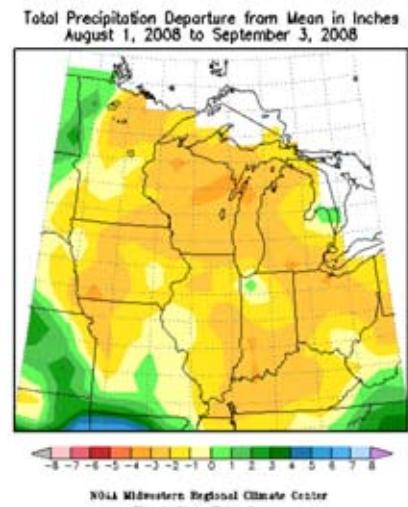


Figure 2-4.

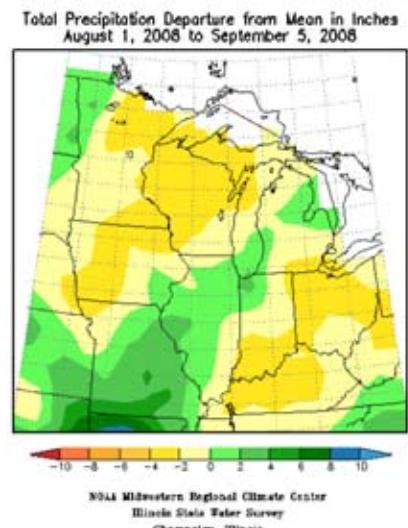


Figure 2-5.

Indiana Temperature Trends

Dev Niyogi, Indiana State Climatologist

Indiana, much like the majority of the other states in the Midwest, has not necessarily seen all the effects of climate change that have been seen in models, where we have seen three to five degree changes projected around. So if you start looking at some of the data sets and interacting with individuals, and we are trying to make this issue a priority, it doesn't necessarily always resonate because of the traditional measures that we have been using, such as temperature change and rainfall change.

For instance, if you look at one of the data sets, there is a tremendous inter-annual variability that you start seeing, and there is a modest, by many standards, one degree change that we have seen over 25 years. This is perhaps the warmest station we have seen in Indiana. Across the state we get correlations which are not something we would be highlighting very often. So it has been traditionally, across the state, when we are trying to work with organizations and growers, that temperature is not necessarily our measure for what's happening with climate right now. However, the fact that we have not necessarily seen, for whatever reasons, a significant temperature trend, does not mean that Indiana's climate has not been changing. So we just have to look for other measures, and that's one of our challenges that we have been trying to meet because you could have irrigation, you could have crop changes, and a number of things that could balance out, and then that effect might start looking as if nothing is happening.

We have to look at measures beyond temperature, beyond rainfall. This has been one of the aspects that we have been working on. For example, when we start talking to the community we do notice

that people have already adapted by using earlier planting dates. Typically, corn is planted now much earlier now than what it was 15 or 20 years ago in Indiana. And we are trying to study whether this is almost an intuitive response that the growers have made now that they are seeing that the frost season is changing and the growing season is becoming longer and longer. There is some belief that if you plant the corn earlier, you get higher ears, but how much earlier is a question that we are still trying to understand, whether or not there is a negative feedback and so forth. So what we see with regard to the first fall date is that it's coming later and later with every decade. In fact, the number of frost-free days or what we will call the growing season, has been increasing except for when we have such frost in the late season like we had last year. In general, our frost-free period has been increasing, making the growing season much longer here, and that has been a positive thing that has been helping the growing community, but at the same time that is one signature of climate change that we are starting to notice. When we start looking at the locations where we do start seeing temperature and rainfall changes, we can identify snapshots within the region where we have tremendous changes in the urbanization of land use. So in areas which are growing, you actually start seeing increasing temperature.

To one of my classes I show the number of Starbucks and increasing temperature, and that graph is pretty well correlated and there's logic for that, because Starbucks and Wal-mart come into areas where you have higher populations and larger urban sprawl and as a result you start seeing the changes in temperature. And this is probably one example of where you are starting to see two to three degree change in the period of about 25 years in and around Purdue and we have confirmed that this is not academic hot air. We now are seeing regional changes due to our urbanization because of the manner in which we are changing our land use for economic development purposes, and that is starting to show an impact on our regional weather and climate. Figure 2-6 shows central Indiana in 1980. The red spots are the urban area and green and yellow are the rural areas or the places where we have agricultural activities. This is 2000 and in using models and economic data sets, one can project what might happen ten years from now or

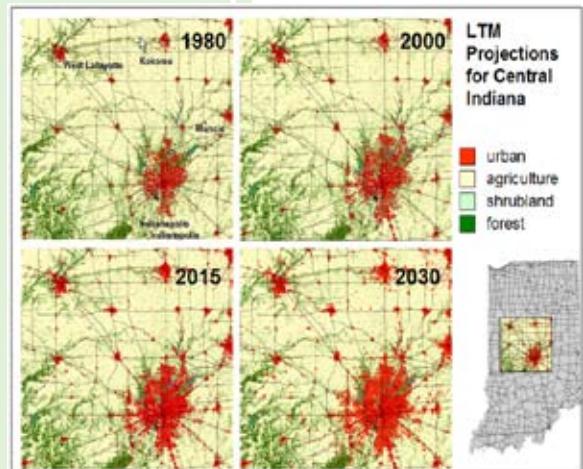


Figure 2-6.

20 years from now and you can see this red area starts getting bigger and bigger. So what we are trying to understand is what would be happening as we start making our economic development in the region, how will our landscapes change and how will that affect the climate. And so that is one of the things that we are trying to focus on in our assessments. We clearly know that as you look at stations in urban areas like the Midway airport region, which is a fairly rural area, they traditionally have about a five degree temperature change between them. So if the area starts to get more urban we are going to start seeing the temperatures creeping more towards what it would be like if it was Midway.

So that's the regional-scale climate change, if you will, but it's something that affects local scale operations and people who are working in that region. And so that's something that we are monitoring at a local scale because this is a scale that is not necessarily monitored when you start looking at global scenarios. And it's something we've started looking at a state and regional level. It has not only been affecting our temperatures, but the changes in our landscape are changing our rainfall. Thunderstorms are dangerous but they are a prime source of rainfall for agriculture in our region. We did a number of radar studies, and what seems to be happening is these thunderstorms start coming in and as they go over urban regions, they split into two cells and go around them. This is not unique to Indiana. It has been seen over Atlanta, New York City and a number of other locations. So what we are seeing is that a thunderstorm, massive at it may be, somehow knows where you have an urban area and then starts splitting away.

So what does it mean? If we continue to have this urban area growing, there may be a time when the regions which once had a certain availability of water are now suddenly going to have a shadow of that rain amount, and you're going to have regions with new water sources availability which have traditionally not received that water. This becomes important as we start working with the state agencies and trying to come up with a water shortage plan and trying to come up with a drought response, emergency response, and so forth. Local scale processes are really the feature that affect you and I as we start doing our operations, and there's a merit in looking

at all the global scenarios because they are useful for national policies, as is the intertwining of this local scale information that we try to put together that provides the feedback as to what can be done into the short term about how things can be used here.

In building our business model, we started out by thinking of the postal service—a federal service that businesses actually use, which is a highly reliable process. It's so reliable that some businesses like Netflix rely on it entirely. And that's essentially what we are trying to do as our local scale climate service. We have incredible existing federal services, and what we want to do is build off them and try to provide you with the information you need, so rather than you coming to us and becoming the old Blockbuster, we want to be your new Netflix. And that's essentially where we see our strategy changing. One of the first things we are doing is working with the state government in trying to come up with a new drought plan, a water shortage task force. But rather than just drought information, we are looking at providing multiple resources. The drought monitor, as discussed elsewhere in this report, is an incredible tool. And that's something that we're trying to use as a starting point. We are developing, as previously mentioned, the web portals. A focus that has been changing is that we no longer are simply interested in rainfall and temperature. For soil moisture and soil temperature, what we are seeing as agents is an increasing need for economic data, environmental data, pollution data and we're trying to see if we can use a couple of watersheds to pull this information together. We want to know what would be of interest to you so that we can try to put it together. The good news is that for all these things that I'm talking about, the funding is in place. And so what we need now is ideas for how we can put the funding to use for you. What we are trying to do right now is use remote sensing products, test some hydrology products to see, can we predict drought? Can we predict flood? The answer is that most of the models are great under clear sky conditions. As soon as you go to an extreme, like really dry conditions and really wet conditions, we seem to have a problem and we are trying to see how that can be more accurate. There's a new project that has just started. The idea is that you have a federal drought map, but we want to use

this information to translate into something else. For instance, does the formation of a drought mean the regional air quality is going to go bad? Does it mean that the water quality is going to be bad? What does it mean with regards to the availability of resources for emergency management? These are the kind of portals that we are trying to come up with, and what we want is to have more examples from users that we can try to incorporate into our research into these portals. I heard yesterday of the relationship between drought and health as a possible thing. In urban areas, in fact, there are some possibilities of increased asthma in a drought and thunderstorm event. So we can get the drought information easily; it's the health data that becomes difficult, but that's where we talk about the interlock where you take the diverse and heterogeneous datasets and put them together to get some new information out of them.

The last thing I'm going to talk about is that we all say climate change is a challenge for the next generation. Here I think as a community it is fortunate that we have been working with the National Science Foundation, school teachers, extension communities, the 4H community, and trying to put together modules for climate change for high school and middle school teachers and we've been field testing with a number of schools. This is, again, not a Democrat or Republican thing, but is more of just the climate science that we are trying to put together. We have modules on CDs that have been available to the schools, and we want to integrate whatever topics that you think are of interest. We look for your ideas. We have the technology and the expertise, but now we need to know what information you'd like to see.

Climate Factors Impacting Productivity and Yield Trends of the Midwest

Dennis Todey, South Dakota State Climatologist

Corn and Climate is an excellent topic. After the start of the ethanol boom, I heard about an ethanol conference, I won't say where it was or who was sponsoring it, but I called and said, you know, we've done some yield climate relationship work and I'd like to come and talk at your conference. The essential response was, we really don't care about climate. I can tell you from living in South Dakota in the drought of 2006 that corn is impacted by climate. If it doesn't rain, corn doesn't grow, end of story. Certainly, I've talked to people who have said that corn is much more forgiving than it used to be about stress during tasseling. Yes it is. But there are also people who think that genetics will solve everything about corn. Sorry, it's not going to happen. We still need to have this discussion.

I am the South Dakota State Climatologist at South Dakota State University, but I'm also working as acting director at the High Plains Regional Climate Center in Lincoln. Let me give you a little background of what these two are very briefly. Currently, 45 states have state climatologists. There are many different flavors. Most of them are housed at universities. But there are some, like Harry Hillaker in Iowa, who work in the Department of Agriculture or other state agencies. They are on-the-ground people who can help you in your state. We also have people like Elwynn Taylor, from Iowa at Iowa State University who are extension climatologists. Several states have extension climatologists; I wear the same hat in South Dakota. Beyond the state connections, all states in the country are affiliated with regional centers that are funded in large part by NOAA, who are doing work on a regional basis dealing with data needs, and helping people make decisions using this data. That is a great deal of what state climatologists and regional centers do on a regional basis. These entities create a package of climate services. There's the question of what data we have, but it's also about how we make use of that data to help people make decisions.

Those are the two parts of this package. You have to have more and better data for the people. When I was going to South Dakota, people were asking about conditions in a specific area. I've said "I don't know" on many occasions. There were no stations in the area, so we didn't have any on-the-ground measurements. Radar data is a little bit sparse in some parts of South Dakota because of distances from the radar. Thus, at times I didn't know what was happening specifically. Part of what we were trying to do with the state climate office was to get more stations to collect data. But then the question is raised, what do you do with that data? How can we take that data and make a decision? How can we take a hundred years of frost dates and make a decision using that data? Everybody talks about an average frost date. Does an average frost date mean anything? Not really. It's a good number, but it's also inherently variable. As with hurricanes, we have to be able to express not only averages, but also some idea of the variability involved. That is where we have to have people have that discussion; we can't talk in sound bites. We must have a little bit longer discussion about climate information to be able to put in some of the ideas of variability.

There are existing climate services out there for people to use. In this discussion of a national climate service there are people out there already who have on-the-ground knowledge. We need to make use of them and then add to and build on those services that exist already in order to build the most useful system. We need to avoid getting caught up in the larger climate change topic and its political nature. There's a huge package of climate services that is completely apolitical. There's discussion about what the frost dates are over the past one hundred years; it's not a political discussion. There are a lot of things that are completely apolitical. What happens in the face of climate change and the direction we're going? We talked about some of the inherent variability, and that discussion still needs to occur, but there is a lot of climate information and a lot of discussion that can happen that is completely apolitical and can serve a large number of users.



Part 3: NOAA and Seasonal Forecasting

NOAA “Down on the Farm”

**Ray Wolf, Science Operations Officer,
Quad Cities Weather Forecast Office,
National Weather Service**

Throughout much of this report we have looked at climate change and heard about what's going to happen in the next 100 years. This essay focuses on weather and climate information at the producer level, what farmers can use to assess what happened with this year's crop, what's going to affect their decision making for farm operations today, and what might be happening in the future that would affect marketing decisions. The essay organizes the information in a past, present, and future format. This is not an all-inclusive view of what is available, but it does point out some of the key information available.

Starting out with assessing the past, one of the products that NOAA puts out jointly with the USDA is the Weekly Weather and Crop Bulletin. We used this in the former National Weather Service's Ag Weather Service often. And this record goes back quite a few years. It's a great assessment of what's going on in the different states, what the weather has been in those states, and what the crop progress has been. You can look at different parts of the country for different commodities and what the impact of the weather on the crops is. Within that weekly weather and crop bulletin is a subset of information, an international weather and crop summary, where meteorologists in Washington D.C., who are monitoring the weather in the key agricultural regions all over the globe, are writing weekly assessments along the same line as what we do for our nation. These reports are readily available on the internet.

One of the interesting changes that have taken place in the last few years is between science and technology and the internet. The amount of information that is available at the producer level has increased by multiple orders of magnitude.

For instance, the National Climatic Data Center, NCDC, maintains a storm event data base. It is a database about severe weather events, such as hail and floods, which is collected by local NWS offices and then shipped off to NCDC. This database is useful for two reasons; one, for example, an individual farmer can go back and search this database for all the hail events that have occurred in Story County for the past year to see if there were any reports or impact. The other is that in the bigger picture, looking at the climate change and the assessment of extreme events, this sort of database is key and it is important that we get this kind of information in so we can look at temporal changes and spatial relationships with these significant events.

Another example of information provided by the NWS is the April 2007 Freeze Assessment. Two key points about this assessment: The first is, again, relating to climate impacts, this was probably one of the least publicized weather disasters in the last decade. What we found was that between the agricultural and horticultural industries across the central and southeast United States, there was on the order of 2 billion dollars worth of damage. That's a conservative estimate and was focused primarily on direct losses. The other part of this freeze report that was key was the partnerships used to put it together. It involved the state climatologists from at least those impacted states that have climatologists; we had folks from the USDA, from the NCDC, the Regional Climate Centers, the NWS Climate Prediction Center (the folks who look at the long term forecasts and climate anomalies) and academics. What perhaps was most important was the input from the state extension services, those folks who are closest to the producers and understand the types of impacts and the magnitude of the impacts.

This report deals quite a bit with data networks. Availability of weather data has grown tremendously in recent years. Figure 3-1 represents the current data network

in the state of Iowa. It is made up of airport weather stations supported by the weather service and the FAA, stations at smaller airports provided by the Iowa DOT, roadway sensors provided by the DOT, and the NWS cooperative observing network. We have weather station networks started by television stations, school nets and such, and the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS).

So the amount of data and the detail that we're getting, as Jim mentioned earlier, is significantly enhanced. At your local weather service office website, a lot of this data is collected and presented in a variety of formats. There's the old text format that just gives you the straight max/min temperatures and various other types of information. That's a heavily used product in our area by the energy industry. There are also narrative summaries describing what the weather was within the last month, and many offices have also developed daily precipitation and temperature maps. Many offices have graphs like Figure 3-2. This graph in particular is for Cedar Rapids, Iowa, this year, starting from January going through August. The bottom part shows snow accumulation.



Figure 3-1.

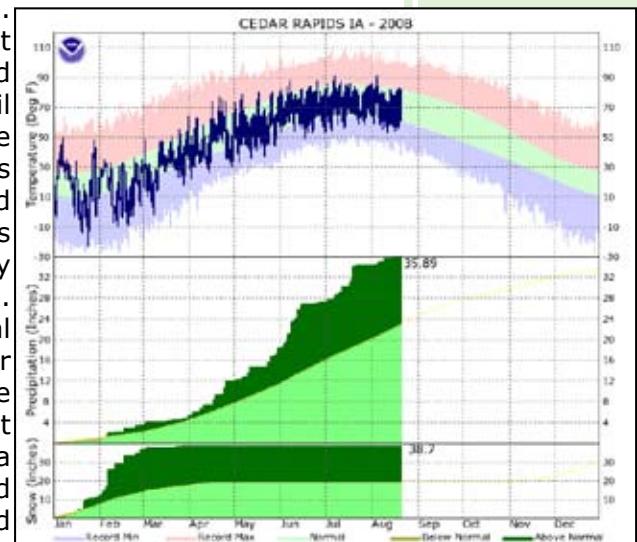


Figure 3-2.

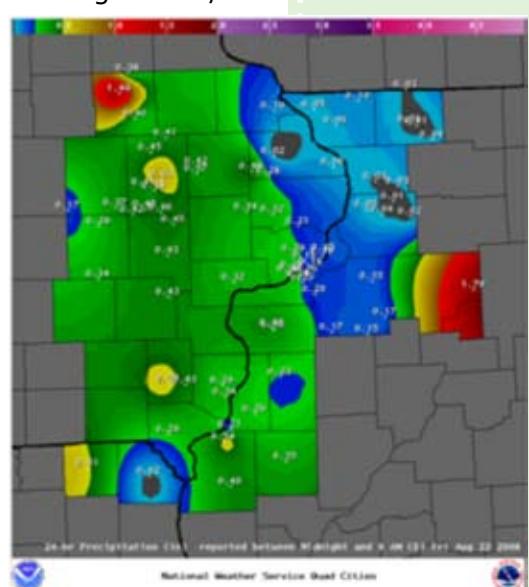


Figure 3-3.

The shading difference between the light green and the dark green, the dark green is the accumulation above normal. So Cedar Rapids had a significant accumulation of snowfall, especially in February, which continued into March. Figure 3-3 shows the same thing for precipitation. So you see the increase in precipitation that occurred in June—record proportions—that was part of the cause of the flooding situation. These types of graphs include the actual, normal, and record the temperatures too. One of the newer features on the NWS website is NOW data. The NOAA Online Weather data page gives you access to the current year, the previous years worth of data, records and normals. There is a whole set of products with information that you can choose from including daily information, extremes, records, etc. Some of the examples I've picked out here are for Independence, IA, near Waterloo. The

and precipitation. For more information on these summaries and other drought information NOAA has a web portal for the country at drought.gov.

When I first started monitoring the weather we had old Difax maps (paper) of the radar information, and due to the nature of the technology and the old radars we would see big blobs of precipitation moving across the cotton belt. We would get calls from the Board of Trade wondering how much precipitation there was because those old maps used to make the precipitation area and magnitude look a lot more significant than it truly was. Between the new Doppler radar network and the internet, much of this information, not only where rainfall is occurring but also estimates of rainfall amounts are available on a pretty fine scale. A relatively new product, within the past two years, is the rainfall estimates map. The radar provides a first guess estimate of what the rainfall extent is, and by and large it does a decent job, but with some limitations. Actual precipitation gauges are then added in as ground truth to better estimate the rain. The observation network is pretty decent in many areas, but there are places where there are gaps in the observing network. By merging the two, the radar and the rain gauge network, you can get a pretty good quality estimate of rainfall and that is what Figure 3-4 depicts in Iowa for the early part of June. Significant amounts, on the order of 10 to 15 inches, of rainfall occurred over a good part of the state with the wet pattern that led to the flooding.

In terms of predicting the future, the NWS's main mission is focused on forecasts and warnings for severe weather for a variety of areas. Nationally, of course, hurricanes get a lot of our attention. We do long range climate forecasts for 13 months, and fire weather, aviation, river hydrology forecasts, and relatively new to the organization are the space forecasts. In addition to our mission of collecting surface data, we also collect weather balloon information from the upper atmosphere, and the radar data. NOAA's National Environmental, Satellite and Data Information Service (NESDIS) collect the satellite data, and our space and environment center collects solar related data. At the local NWS office where we produce the forecasts for local areas, we have your traditional 7-day forecasts in a text type format. There are also graphical

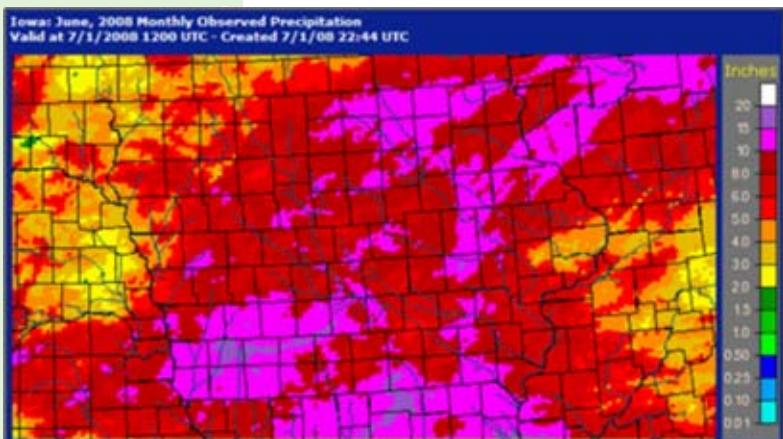


Figure 3-4.

first and last freeze dates are shown and also the lowest minimum temperatures in May so you can get an example of what the record temperatures are and what sort of freeze threat is possible in late May.

The National Drought Mitigation Center is leading the drought monitoring program and many of the weather service offices also provide information from their local area regarding weather data and analysis and the impacts they are seeing. In our part of the world the impacts are primarily on agriculture, but we are on the Mississippi River so hydrology and its impact on barge and other river operations are important too. Also, local weather service offices nationwide are writing drought statements when drought becomes severe (depicted as D2 on the Drought Monitor). The local office will write a summary of the impacts in the local area and include predictive information for temperature, stream flow

forecasts available, but from my ag weather days, I think the most useful things for farm decision making are what we call meteograms, which are basically graphs of various weather parameters such as temperature and relative humidity through time. When you look at this information you can integrate, for example, the combination of relative humidity, wind speed and clouds to get estimates of when dew will fall or dry off for harvesting decision making times. Or in the wintertime when you're drying grain, you can look at the relative humidity forecasts to see when you might have to add heat or when you wouldn't have to add heat to keep the crop moisture status appropriate. The University of Kentucky has taken the digital forecasts that we have put out nationwide on a 5 kilometer grid and they have added value to these by running the data through algorithms that provide things like drying conditions, spraying conditions, livestock heat stress index, an estimate of dew fall and leaf wetness. There was a question earlier about how the public private partnership can work. This is a good example of how the NWS provides the basic set of information and then folks in support of the industries, such as agriculture in this case, can run with it and use that information and add value to specific industrial needs.

The 6 to 10 day and 8 to 14 day forecasts from the Climate Prediction Center (NWS) are popular in the agricultural community. Since I've gotten into the agency, the 6 to 10 day forecasts that have been created for over 30 years, the skill of the temperature forecasts in that timeframe has doubled and the skill of the precipitation forecasts have increased by 50%. Now these 6 to 10 day and 8 to 14 day forecasts, pretty consistently beat forecasts of climatology. So we've made some great strides there. These forecasts are done in a probabilistic format: they're not deterministic forecasts, although they allow you, to some extent, to play the odds. I've even used these in my own garden. There was one year that I planted tomatoes the 3rd week of April, which is generally unheard of, but when you take a look at the 7 day forecast and you see we're going to be pretty warm, and then you use the 6 to 10 day and the 8 to 14 day forecast and see that warm anomaly is still centered over Iowa, you can cheat and get your growing season going early. Now it is a little different between my garden and a farmer, because I'm making a decision

that if I'm wrong will cost me a couple of bucks, as opposed to replanting hundreds of acres of corn. But you can see that those products with the skill level they bring to the table today can be quite helpful. For the monthly and seasonal forecasts for our part of the world, the story is a little bit different. Other parts of the report can give you more technical details, but basically the skill in the seasonal forecasts essentially comes from whether we're in an El Niño or a La Niña and also what the trend has been, particularly in temperatures, over the last decade. Unfortunately, for our part of the world here in the heart of the Corn Belt, those signals are not particularly strong; thus these forecasts show only marginal skill. But on the upside, what we've seen in the last decade alone is a greater understanding of the climate forcing factors that are used in producing these forecasts. This is another situation where the NWS is working in partnership with the International Research Institute and NOAA's climate analysis lab. So these forecasts are much more of a community-produced product than they used to be years ago. There is hope that as we gain a better understanding of the climate system that there can be some gains made in our area.

Every local NWS office has a local web page. You can go to weather.gov; simply clicking on this map will take you down to that specific area. Many of the web links that I have shown on that sheet are available at the local offices. There are also links to some of the folks like the regional climate centers and the state climatologist where there is also a good amount of information. One thing the National Weather Service needs to hear is what sort of information on this time scale is needed that is not currently available, and is that information something that is appropriate for the weather service to provide or is that something that is more appropriate for the private sector or perhaps the state extension folks to provide.

Seasonal Forecasts

Jian-Hua (Joshua) Qian, Research Scientist, International Research Institute

This essay briefly introduces the IRI (International Research Institute for Climate and Society) seasonal climate forecast system and gives some examples

any local area is closely connected to that of its neighboring regions and even globally, we have to consider a broader spatial scale for climate forecasts. Meanwhile, the uncertainties associated with climate forecasts are larger than those of weather forecasts.

In climate forecasts, we issue probabilistic forecasts for categories such as above normal or below normal rainfall. That is, instead of giving a definite forecast like a weather forecast, we have to give the probability distribution in climate forecast due to its large uncertainty. F

Can we forecast what kind of winter we will have? Yes, a little bit. Weather forecasts lose almost all accuracy in one or two weeks, so how can we have an accurate forecast for the next 3 months? It only works if you forecast a seasonal average or averaged seasonal weather characteristics, but we cannot forecast exactly how each day will be. And a strong key to seasonal forecasts is sea surface temperature (SST), especially in the tropical regions, because of the slow evolving ocean dynamics. We have some skill in seasonal and inter-annual SST forecasts, then we use the SST to forecast atmospheric status.

Figure 3-5 shows an example of SST forecasts. The forecast was made in January 1986. The top panel is the observed SST. The bottom panel shows a one-year-lead forecast for 1987 SST in the central Eastern Pacific ocean, and the red is the warmer than normal SST. That's an example of a successful forecast of El Niño, with positive SST anomalies over the Central Eastern Pacific. We usually use an SST index over the central Eastern Pacific because this region is quite sensitive to the year-to-year variability of cold and warm ENSO (El Niño – Southern Oscillation) events. Figure 3-7 is another example of a successful forecast by NOAA for the '97 – '98 El Niño case, and the top panel is observation and the bottom panel is forecast. This is a 9-month-lead forecast, so we can see that it's quite a useful successful forecast because people can prepare for it well in advance. The anomaly correlation of the SST forecast with observation is as high as 0.93.

Figure 3-8 illustrates the IRI seasonal to inter-annual climate forecast system. We use a two-tier forecast system. First we forecast SST, sea surface temperature.

Weather & Climate Prediction

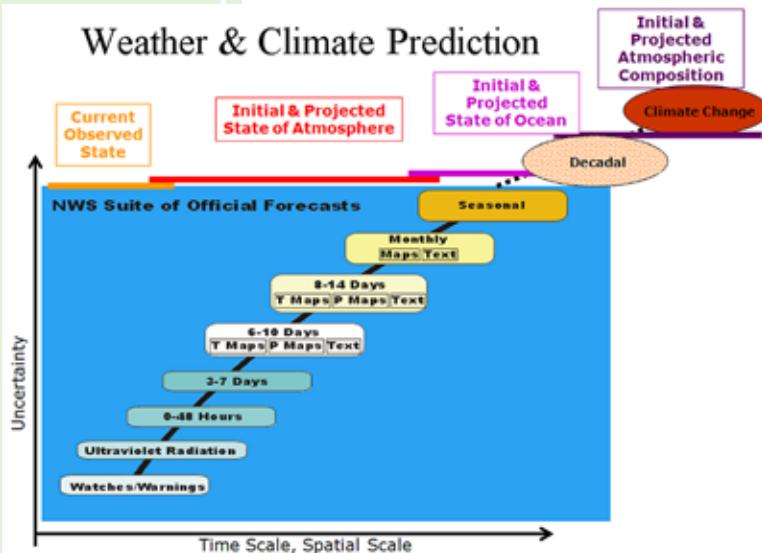


Figure 3-5.

of how to use a seasonal forecast. First I'll explain why we can do seasonal forecasts, how we do it at IRI, and finally how to use it for climate risk management.

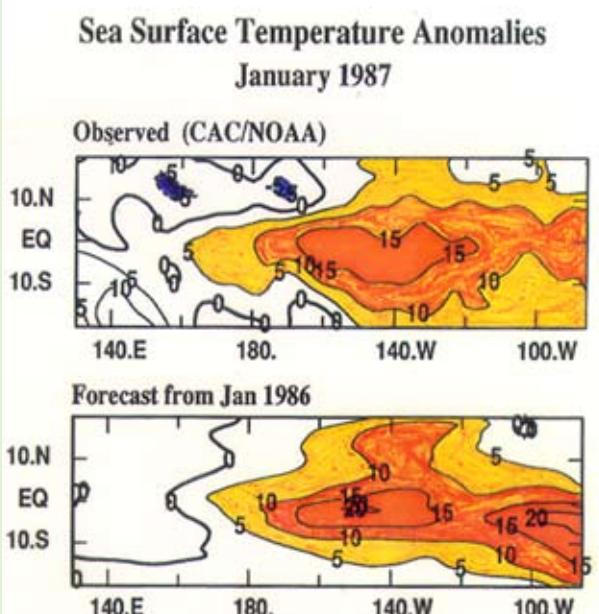


Figure 3-6.

in space. For climate forecasts, we deal with problems of longer time and larger spatial scales (monthly or longer time scales). Because at longer time scales, climate in

Figure 3-5 illustrates the difference between weather and climate forecasts. The x-axis is the time and spatial scales and the y-axis the uncertainty associated with those scales. For weather forecasts we look into problems such as thunderstorms, frontal systems and cyclones, which are of short time scale and also regional

Then we use the forecasted SST to drive physically based atmospheric numerical models, to forecast temperature and precipitation. We currently use seven global climate models (GCM's) and also some regional climate models. For each climate model we have multiple ensembles of forecasts, say 10, 20 or 30 members. For example, for the National Centers for Environmental Prediction (NCEP) model, we use a 30-member ensemble because we have to take into account those uncertainties related to the atmospheric nonlinear dynamics and errors from observation. And then we compare those forecasts with model results by using a historical simulation, and compare against observations for model verification. Then we can use regional models to downscale information from global models to have localized high-resolution information for users. Currently we do one to six month lead forecasts. For example, in August, we forecast September 2008, October to February 2009, by taking overlapping 3-month moving averages of precipitation and temperature to reduce high-frequency uncertainties.

Because the El Niño Southern Oscillation (ENSO) is a strong signal in inter-annual climate variability, with its strong impacts over global climate, we forecast the ENSO events. Figure 3-9 is the forecast of Niño 3.4, an SST anomaly over central Pacific Ocean. We have 15 global dynamic models and eight statistical models, a total of 23 models, for ENSO forecast. IRI only runs two models, the other models are provided by other institutes. These lines are different model forecasts for ENSO. They are quite spread. The top half of the shaded area in this figure indicates warm SST anomalies in the Niño 3.4 region and the bottom shaded area denotes cold SST anomalies. The majority of this forecast from August is close to the zero, forecasting a high probability of a neutral condition. From this distribution or spread of the forecasts from different models we can generate a probabilistic ENSO forecast, as shown in Figure 3-10. The green is for the neutral condition, the red for El Niño and the blue for La Niña. Because most of the models generate a neutral condition, the probability of a neutral condition is higher.

Figure 3-11 is an SST forecast over the globe. Even though the ENSO is a major driver of the global climate, the SSTs of other

oceans also have some impacts over global and regional climate. Therefore, we also forecast the SST in Atlantic and Indian Ocean. As a two-tiered system, we forecast SSTs first. Figure 3-11 is the forecast made in August for SST in October to December. And then we use several different scenarios for SST. With the MEAN, MINUS and PLUS in terms of its variance to account for the uncertainties in the SST forecast.

In Figure 3-12, the probabilistic forecast of rainfall is shown in two basic colors: green is for above normal rainfall and brown for below normal rainfall. The probabilistic g l o b a l precipitation forecast shows that the Indonesian region would probably be drier than normal in October to December of 2008. And it would be wetter than normal in western Africa. The rainfall in white regions would probably be near its seasonal climatology.

We also need to verify how accurate the climate forecast was. The real-time forecast over the past four years were compared to observations to examine how the model performed in rainfall forecast. This is the ranked

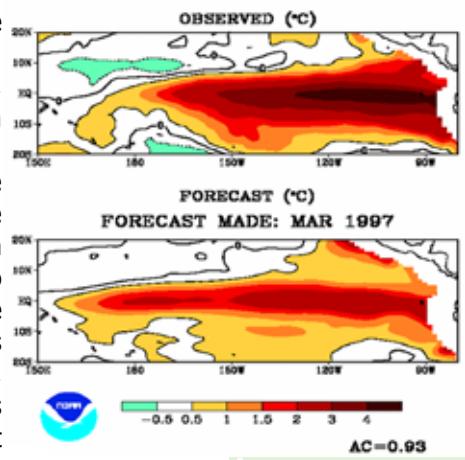


Figure 3-7.

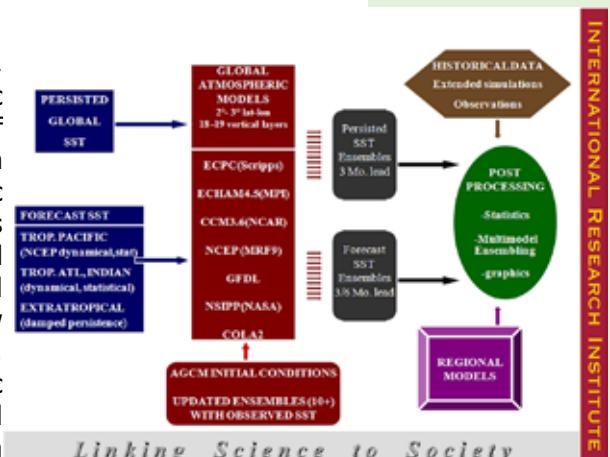


Figure 3-8.

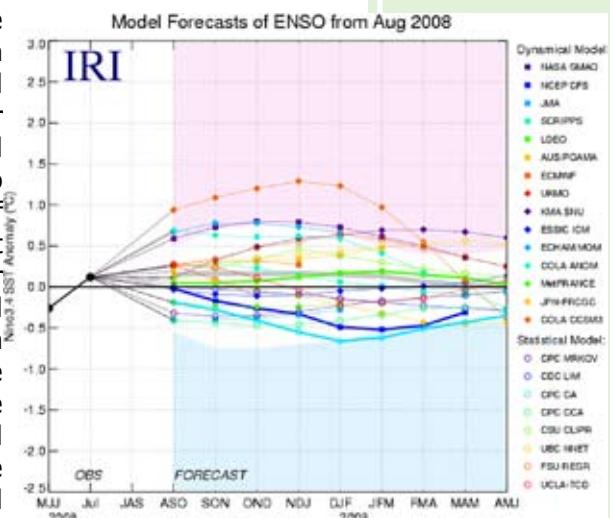


Figure 3-9.

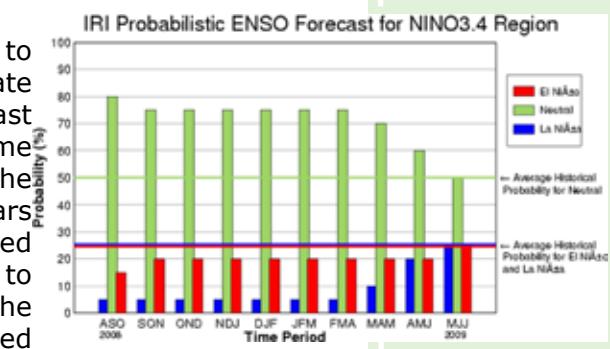


Figure 3-10.

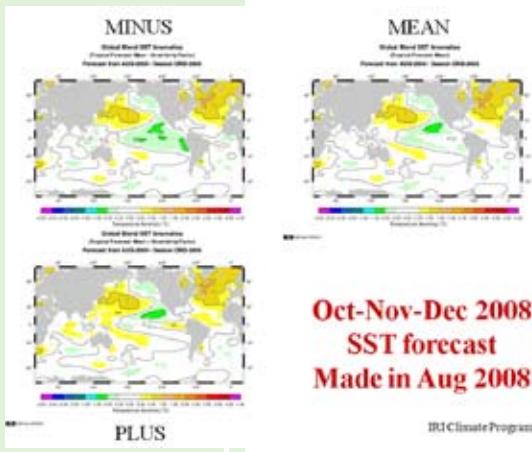


Figure 3-11.

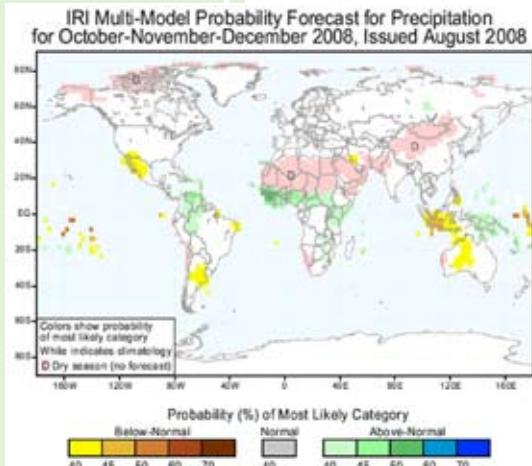


Figure 3-12.

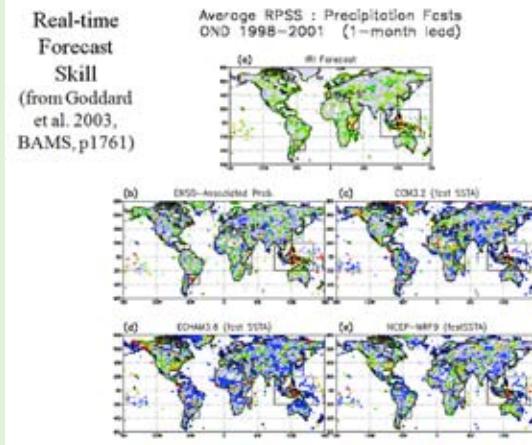


Figure 3-13.

probability skill score (RPSS), used to evaluate the skills for climate models (Figure 3-13). For individual models, we see some places of a high skill score, such as the Indonesian region, because this region is strongly influenced by ENSO. Results from many models can be combined to generate a multi-model ensemble forecast, of which the skill is shown in the top panel of Figure 11. Note that the RPSS is a relative skill compared to a reference state. We use climatology as a reference state—seasonal varying climatology over a specific region. So Figure 3-13 shows the skill beyond the reference state, i.e., beyond the seasonal climatology. If we have positive skill over some place, it means that the forecast would be better than the seasonal climatology. If the skill is not good (white), we just use the seasonal climatology as the forecast. Generally we see some positive skills. Better skills are usually in the tropics, and marginal skills in the mid-latitudes.

We do regional climate downscaling because global climate models use

rather coarse grid resolution because of computational constraints. Grids of 200 to 300 kilometer distance are not good enough for local users in various sectors. So if we want to look at local, detailed information, we need to do regional climate downscaling. We also want to look at some specific variables that are relevant for users. For example, for agricultural application, we look at dry and wet spells and the timing of season onset. We try to check higher resolution information and the different characteristics of weather. For example, in Northeast Brazil, it is found that the drought index, derived from dry spell information in models and observations, is negatively correlated with maize productions (courtesy of L. Sun).

IRI mostly works with developing countries for their sustainable development. We are working on projects in climate risk management in Indonesia, and in other Southeast Asian regions. We work very specifically on climate application projects in hydrology, agriculture, forest fire and food security. For Indonesia, as an example, we are working in a region called Indramayu, which is about an area of 50 km by 50 km. It is a major rice production region and we are working with locals to see how climate forecasts can be used to increase their rice production. There are two planting seasons in Indramayu. People over there try to plant as early as possible when rainfall becomes available in the beginning of wet season, so that there will be enough time left for rice to ripe in the second planting season at the end of which the dry season is approaching. Rainfall in the second planting season is more critical than that in the first planting season, because rainfall is plenty in the peak wet season, but there would not be enough time for the second crop to be harvested if the wet season ends too early. So it is quite useful for farmers to know the timing of season onset.

Figure 3-14 shows the observed station data over Java, Indonesia. This is the composite of rainfall anomalies in the El Niño years, in the two seasons of September to November (SON) and December to February (DJF). In SON, it's dry anomaly all over Java. But in the December to February, which is period very important for the first planting season, the north and south coasts are opposite in rainfall anomalies. In coarse-grid global climate models, we cannot see this local dipole of rainfall anomalies

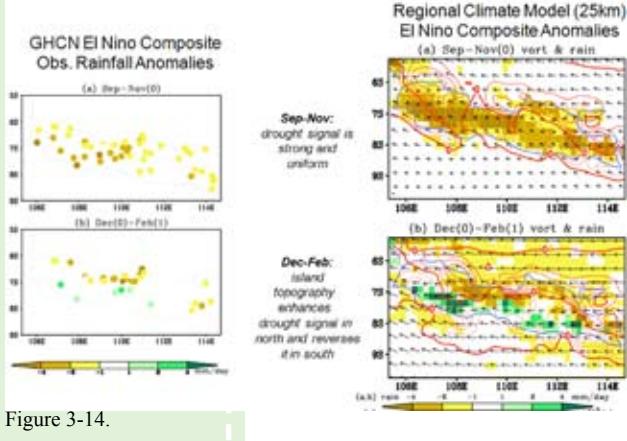


Figure 3-14.

because the island is only about 150 kilometers wide, which is of subgrid scale. We can do regional model downscaling to see this contrast between the north and south coast. The left panels are observed data. The regional model downscaling (right panels) can indeed generate more detail and differentiate local forcing from the land/sea breezes and mountain/valley winds.

Figure 3-15 shows an example of seasonal precipitation forecast in Southeast Asia that we made in earlier August for the 3-month period from December 2008 to February of 2009. Being probabilistic forecasts, Figure 3-15 shows the rainfall probability in percentage, for tercile categories: below normal, neutral and above normal. For example, in the Central Kalimantan Province in the Borneo island, the below normal rainfall category has less probability, and the above normal rainfall category has higher probability, therefore, more than normal rainfall would likely occur there. That illustrates how we present our climate forecasts in this probability format.

Then we need to evaluate the forecast skill. We used statistical tools in post-processing to calibrate our forecasts and try to improve the forecast skills in some local region. A climate predictability tool, called CPT, has been developed at IRI. It's quite a handy tool. IRI held workshops in Southeast Asia where people can learn how to use it in one day. They used their own station precipitation data or other datasets, and the IRI provided the SST and global model forecasts. They tried to do canonical correlation between SST and their local station rainfall to generate their own seasonal rainfall forecast in their countries. We have a huge amount of output data from models; the question always remains of how to distill useful information from those data. We use these CPT tools to abstract signals from the data and then use these signals for climate forecasts.

By using a global model and a regional model for a specific area, like the Philippines, in combination of statistical methods such as CPT, we can improve the climate forecast skill. Figure 3-16 illustrates the Pearson correlation for the Philippines, which is a simple correlation between the calibrated model forecast and the observation. The red color indicates the more skillful forecast for these Filipino regions achieved by regional

models, as compared to global model forecast, with the assistance of CPT. Therefore, it is possible to combine dynamical and statistical methods, with

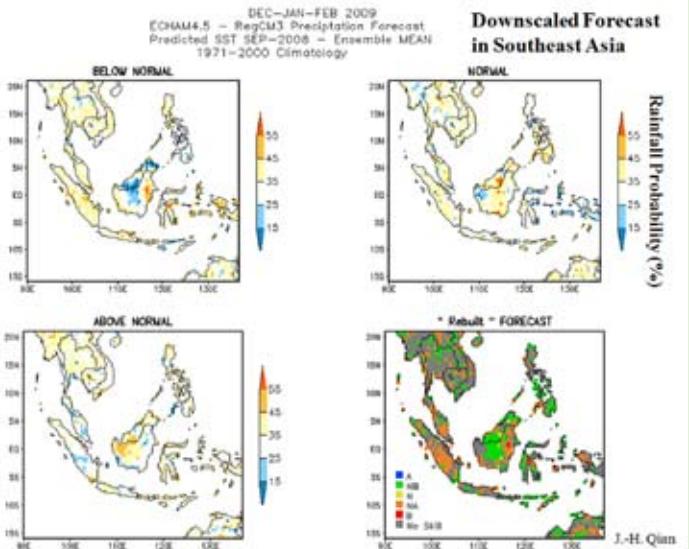


Figure 3-15.

appropriate calibration to observations, to improve climate forecast in some local regions, to facilitate its application in climate risk management.

In summary: first, as climate scientists, we want to learn what the users want, so that we have a clearly demand-driven seasonal

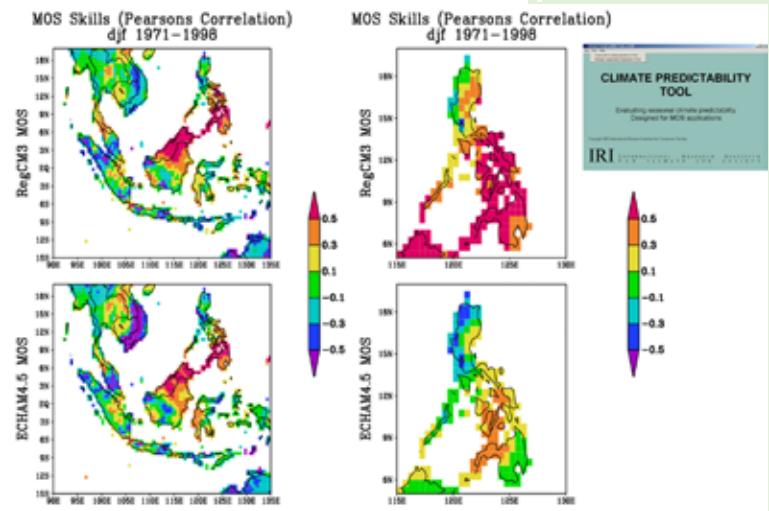


Figure 3-16.

climate forecast. The key of the seasonal forecast is SST because the top ocean layer has the low frequency variability and hence higher predictability. At IRI we do two-tier forecasts (forecast SST first, then forecast the atmosphere), but we're also working on the one-tier approach by using coupled land-ocean-atmosphere models. But currently, the two-tier forecast has a better skill. We try to tailor climate information to be relevant for users in public or private sectors in their decision and policy making processes. If you want to learn more about seasonal climate forecasts, you're welcome to check the IRI website at <http://iri.columbia.edu>.



Part 4: What Producers are Saying about Crops and Climate

Corn Management Decisions: 2008 Planting Date Case Study

Roger Elmore, Professor and Extension Corn Specialist, Iowa State University

It's interesting to address an audience with this kind of focus on corn and climate. I usually talk to people interested primarily in corn, but this is an opportunity to get a whole roomful of people thinking about corn in the context of climate and weather. I will focus on the impacts of specific weather variables and corn: whether or not it rains impacts corn, temperatures impact corn, and solar radiation impacts corn. The growing season of 2008 makes for a good case study. A question raised earlier was how did Iowa farmers cope with the year that we're seeing now in 2008. The season's not done yet, of course, and the final answer

is still out in the fields.

Basically I'm giving a case study of 2008 planting date decisions, what happened to influence those decisions, and what the outcome is to



Figure 4-1.

this point in the season. In Figure 4-1, I'm standing in a water-covered area that was planted probably about the middle part of June. All around this wet area is a field of pollinating corn. This was Iowa in 2008. The spring allowed normal or a little later than normal planting dates, but then it started raining. Even the early plantings, the ones made pretty close to normal, were made in wet and cold soil. So, aside from the northwest corner of Iowa, nothing looks good really as far as corn crop development in Iowa. Figure 4-2 shows a friend of mine

who was interviewed by the Des Moines Register saying "How can I plant this field?" In the lower right corner you see what these areas look like when those wet spots dried up. So what are your planting decisions in that kind of a situation?

I'm going to walk you through our normal extension decision support process—what I provide in a normal year—and then what I did this year, which was to use a crop yield model, Hybrid Maize, for assistance as the crop progressed. What should a producer do in the middle of June, or at the end of June, with regard to planting in fields having ponded areas where the crop was lost?

Figure 4-3 provides a table used a few years ago by one of my predecessors, Dale Farnham. On the left is the "stand", in thousands of plants per acre, and the decline in yield in percentage of maximum that would occur as planting dates get later in the season. For 2008 we need to focus on the right hand column—replanting drowned-out spots in the period June 24-28. Maximum expected yield is 52 percent, which would result from having 28,000-32,000 plants per acre. Therefore, we would tell growers in Iowa they could expect about 52 percent of normal yield if they could establish this stand in their fields. This chart was first published in the Journal of Production Agriculture by Garren Benson, who preceded Dale Farnham.

Figure 4-4 provides information on two types of hybrids—adapted and very early hybrids. The adapted hybrids would reach maturity in Ames 110 day after planting and the early hybrids 90 days. Garren had enough planting-date data across Iowa locations that he had some years with very early fall frosts, which I believe he considered as 2 weeks ahead of normal, and some with first freeze a week or two later than normal. For each of these hybrids and season-ending conditions he tabulated the maximum yield, again as percentage of normal, which would result from various planting dates. I have highlighted the column for July 1 which applies to the decision point for 2008. The decision then is to plant corn, switch to soybeans, or do something else. Of course, a decision to plant soybeans would be influenced by previous herbicide applications and previous crop histories for each particular field. From the table, if the producer planted an adapted, say 110 day, hybrid he or she could expect a 7 percent

yield potential if we have an early frost in 2008, 61 percent if we have a late frost. And planting a very early hybrid—an earlier hybrid than we've ever planted here (hybrids normally planted in Minnesota)—23 percent of maximum could be expected if we get an early frost or 75 percent for a late frost.

So what do I recommend that farmers do in 2008? In addition to the historical methods used by Benson and Farnham, I have access to the yield model, Hybrid Maize, which I had experience with while I worked in Nebraska. And I've learned a lot more this year how to use it than ever before. The next figure provides

the assumptions used to run the model. I show today one location—Ames, Iowa — where we use weather data from the weather station at the Agronomy and Agricultural Engineering

Influence of Planting Date and Plant Populations on Corn Grain Yield, 1997-2000 (from Dale Farnham)

Stand x 1,000	April 20- May 5	May 13- May 19	May 26- June 1	June 10- June 16	June 24- June 28
28-32	100	99	90	68	52
24	94	93	85	64	49
20	81	80	73	55	42
16	74	73	67	50	38
12	68	67	61	46	35

Figure 4-2.



Figure 4-3.

Studies with Late Planting in Iowa

Hybrid	Freeze date	Percent of Maximum Yield (from Garren Benson)					
		mid May	1-Jun	10-Jun	20-Jun	1-Jul	10-Jul
Adapted	Early	100	74	50	29	7	0
	Late	100	96	89	84	61	29
v.Early	Early	100	96	77	58	23	0
	Late	100	102	98	102	75	49

Figure 4-4.

farm 4 miles west of Ames. The model requires daily high and low temperatures, daily solar radiation, and precipitation. You select the planting date, hybrid (given with number of required growing-degree-days), and plant population. The weather conditions from planting date on then determines the yield. Our Ames database goes back to 1986. The 25th of April gives an optimum planting date, and June 30 is the date for decision-making on replanting ponded areas in 2008. I have selected an optimal stand of 32,000 plants per acre. I emphasize that the model only takes into account weather and assumes no weeds, no insects, no cold soils when you plant, no compaction, and every plant comes up and

Full-season hybrid planted 25 April vs. Early or very-early hybrid planted 30 June	
Ames	
Planting date	25-Apr 30-Jun
Hybrid (days to R6)	110 90
GDD (heat units)	2700 2160
RELATIVE YIELD	
Best yield	100 70
Median yield	85 53
Worst yield	64 14
Probability of frost at R6	0% 39%

Figure 4-5.

Full-season hybrid planted 25 April vs. Early or very-early hybrid planted 30 June					
Nashua		Ames		Crawfordsville	
Planting date	25-Apr 30-Jun	25-Apr 30-Jun	25-Apr 30-Jun	25-Apr 30-Jun	25-Apr 30-Jun
Hybrid (days to R6)	105 90 (adj gdd)	110 90	115 95	115 95	115 95
GDD (heat units)	2533 1850	2700 2160	2782 2284	2782 2284	2782 2284
RELATIVE YIELD					
Best yield	100 60	100 70	100 71	100 71	100 71
75% percentile	94 52	91 58	91 62	91 62	91 62
Median yield	92 51	85 53	85 58	85 58	85 58
25% percentile	86 43	76 47	80 53	80 53	80 53
Worst yield	65 23	64 14	59 29	59 29	59 29
Long-term average	89 48	83 50	83 56	83 56	83 56
Probability of frost at R6 _{Planting 1}	14% 66%	0% 39%	0% 29%	0% 29%	0% 29%

Figure 4-6.

Summary: Field Research & Hybrid-Maize Simulations						
		FIELD: 24-28 June	FIELD: 1 July	COMPUTER: 30 June		
Hybrid	Freeze Date	ISU Corn Planting Guide	Benson 1990	Ames	3 Location AVERAGE	
RELATIVE YIELD						
Adapted	Early	52	7	15	11%	
	Late		61	82	72%	
Early or Very Early	Early		23	14	22%	
	Late		75	70	67%	
AVERAGE		52%	42%	45%	43%	

Figure 4-7.

Summary: Field Research & Hybrid-Maize Simulations						
		FIELD: 24-28 June	FIELD: 1 July	COMPUTER: 30 June		
Hybrid	Freeze Date	ISU Corn Planting Guide	Benson 1990	Nashua	Ames	C'ville AVERAGE
RELATIVE YIELD						
Adapted	Early	52	7	8	15	10 11%
	Late		61	66	82	67 72%
Early or Very Early	Early		23	23	14	29 22%
	Late		75	60	70	71 67%
AVERAGE		52%	42%	40%	45%	44% 43%

Figure 4-8.

grows uniformly. Of course, that's not true in Iowa in 2008, by the way. But the model gives you the optimum, the maximum, the most you could possibly get.

I'll show the data in a couple different ways, and then I'll compare it to the methods used by my predecessors, Dale and Garren. The two columns in Figure 4-5 give the two different planting date scenarios and the relative yield potentials in percentages of maximum yields. So, if the best yielding year from the weather data period of 1986-2008 occurred in 2008, this is what the model uses at its reference. Median yield and worst yield are referenced to the year with maximum yield. The last

line gives the probability from the weather database that frost will occur by the time the selected hybrid reaches its R6 growth stage. So if you planted the early hybrid on the 30th of June,

you could expect 70% yield potential if the rest of 2008 is the most favorable year on record. The median expected yield is 53% of maximum, and the worst yield, with a high probability of frost, is 14%. So what do you think producers did? They went ahead and planted corn. And everybody I talked to was looking for numbers like that for yield potentials.

I then compared the Hybrid Maize results with the advisories based on previous methods, as shown in the next Figure. From Dale Farnham's method the result is 52 percent of maximum yield. The publication by Benson in 1990 provides more fine-tuned results, as does the computer-based Hybrid Maize model for different hybrids and season-ending freeze conditions. And if you have an early frost, yield from a short-season hybrid in the worst possible year would be 14 percent, or 70 percent if you have the best year possible. If you've planted a full-season hybrid and planted it on the 30th of June, you could get 15 percent of maximum yield in the worst possible case and 82 percent under ideal conditions. I also computed these percentages for two other locations and provided the averages. These results are pretty similar to what Dale would have advised and almost identical to advisories based on Benson's 1990 publication. I felt pretty good about using the model to simulate expected yields for late planting in 2008. The model-based advisory matched well with advisories that would have been delivered by Dale Farnham in the late 1990s and by Garren Benson in the 1970s. Our planting date studies allow advisories to be made out to about June 1, because we don't have yield data for planting beyond the 1st of June. That's part of the reason I tried out the model-based approach.

The next Figures show another way to look at the data for Ames. Each box and whisker represents the distribution of yield percentages of maximum that would occur for that combination of hybrid and planting date, represented by early-planted full-season hybrid (EF), early-planted early-season hybrid (EE), etc. The blue dot is the median yield for all years in the climate database, horizontal red lines represent 75th and 25th percentile yields, and the top of the black "whisker" represents the one best case and bottom of the whisker the worst weather-year for that hybrid and planting date. "Early" planting dates are

defined by the 25th of April. I also simulated the 25th of June planting dates (MF and ME), and the ones I've just shown you are the late planting dates, the 30th of June (LF and LE). As before, full season hybrid or early season hybrid refer to 90 day versus 110 day hybrid. Perfect conditions (100%) are shown by planting on the 25th of April with a full season hybrid under the best possible weather in the climate database, according to the model, and the worst weather in the database with this choice of hybrid and planting date would have given 65% of the maximum yield potential. So given these computer-based scenarios at the end of June 2008, which one would you plant? You'd go with early season hybrid, wouldn't you? However, by doing so you're missing out on the very best possible yield, which according to the model would be 82% of what you would have gotten from planting on April 25. But the risk is quite a bit greater, since the 75th percentile (43% of maximum yield) is so far below the best possible yield.

The proof is still in the field now of how close these simulations will be. It is interesting to note that the early season hybrid planted at 3 different dates (second, fourth, and sixth box/whisker) gives essentially the same yield. The left-hand box/whisker shows why we plant 110-day hybrids early.

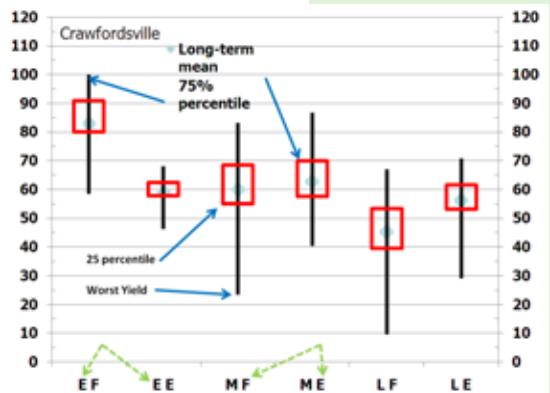


Figure 4-9.

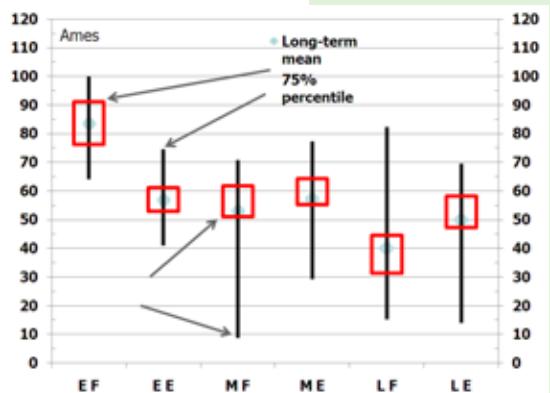


Figure 4-10.

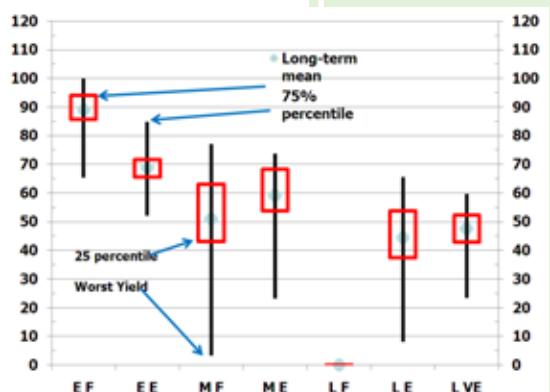


Figure 4-11.

Corn and Weather: Could We Fine-Tune Plant Population and Nitrogen if we Knew What's Coming?

Emerson Nafziger, Professor of Agronomic Extension, University of Illinois



Figure 4-12.

climate change; but what we're really concerned about is what effects the weather is going to have on crops.

Farmers are interested in weather, both in the weather that's going to happen this year and in climate, or the average of weather. Being "inside" the trend makes it difficult to distinguish between unusual weather and

for today are: can we fine tune plant population and nitrogen rate, and would it pay to do so, if we knew what weather was coming?

When I started at the University of Illinois in 1982, I had full confidence that within a few

years we would have some really good weather predictions for the growing season, and that this would allow us to fine-tune

management to take advantage of, or protection against, the weather to come. I don't think forecast have actually improved much since then. We've had dire predictions of drought just about every year, including this year, and in most years the drought has not materialized. Recognizing this failure to predict, all the data I will present here are empirical, resulting from observed responses of the crop to inputs under actual field conditions, with little attempt to model such responses in a predictive sense.

Yield stress in corn is not a simple phenomenon, and so predicting when stress will affect the yield in a certain way will require very good predictions, plus models to relate crop growth up to the time of stress to yield effects of stress. There's little consequence if corn is stressed during vegetative growth, as long as that stress is relieved. But the same stress produces large effects before and after anthesis, or silking, during which time stress causes diminished seed numbers and seed size. This effect continues to be large for about two weeks after pollination, then diminishes through the middle part of the grain fill period. So to predict weather effects on crops, we would need to know not just how much stress there's going to be, but specifically when it's going to happen. Even then, the crop doesn't always "cooperate:" sometimes stress during a stress-prone period causes less yield loss than expected. There is a considerable amount of history that the crop carries with it to get to a certain part of the season, and this affects its response to stress. As an example, the photograph in figure 4-12 was taken in 2007, one of our best corn yields ever. It's unlikely that such stress, severe as it seem, had any negative effect on corn yield. Had it come a month later, it would have.

We'll define stress here as anything that decreases photosynthetic rate of the crop, in a way that results in yield loss. The most direct stress is that imposed by problems such as leaf loss during pollination or grainfilling; such loss leads directly to loss of capacity to fill grain, in roughly the proportion by which leaf loss reduces the interception of sunlight. We have found maximum yield accumulation rates of 11 bushels of yield per acre per day, averaged over a one-week period. Yield accumulations rates in a typical field are only about half that number, indicating that stress is nearly always present, reducing yields on most days. If we could eliminate such stress, yields of 300 to 350 to 400

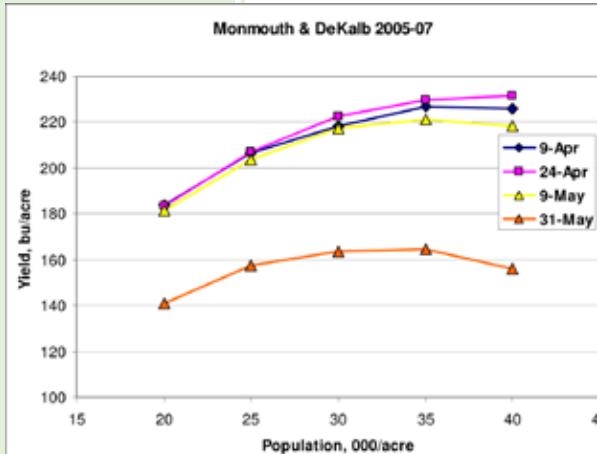


Figure 4-13.

years we would have some really good weather predictions for the growing season, and that this would allow us to fine-tune

Planting date	Final plant population, 000/acre				
	20	25	30	35	40
<hr/>					
bushels per acre					
1-Apr	181	205	220	228	228
10-Apr	186	209	224	231	230
20-Apr	188	210	224	230	228
30-Apr	186	207	219	224	221
9-May	178	198	210	214	210
19-May	166	185	196	199	194
29-May	150	168	178	179	173

Figure 4-14.

bushels would be routine. It is clear that modern hybrids have the ability to tolerate stress at high populations, and that's a major reason why yields are so high. I think this really means that the crop has been genetically selected to set seeds at high plant populations, which is a form of stress tolerance, and of course the plant has to have adequate root stalks and leaves for high photosynthetic rate, and to be able to allocate its photosynthate during grainfilling. Figure 4-13 shows planting date and populations responses from the past three years at two northern Illinois locations. Planting date didn't make a huge difference either in the maximum yield or in the response to population. Figure 4-14 shows how ear size changes when going from 40,000 to 15,000 plants per acre. As long as ears are getting smaller more slowly than the population is increasing, it pays to have more plants.

The idea that corn is has been bred to be immune to yield loss under all conditions is easy to dispel. Figure 4-15 shows yield decreases as population increased from 20,000 per acre at all planting dates in a very dry year at a southern Illinois location. Figure 4-16 shows response to population under moderate stress at another location, while the response in Figure 4-17 shows response under low stress. Though there are exceptions under very dry conditions, yields of modern hybrids tend to level off, rather than drop off, as population rises above that required for maximum yields for the conditions. Even so, under the more commonly stressful conditions in southern Illinois, the optimum population was the lowest population used (20,000 per acre) about one-third of the time (Figure 4-18). The optimum population is that point where the last bit of seed is just paid for by the yield increase it caused (Figure 4-19.) The shape of the population response means that having population higher than the optimum for conditions in a field means modest loss of seed costs, but no loss of yield. Losing seed cost is not insignificant, but when corn prices are high, chances of economic loss tend to be higher with low populations than with higher populations. Farmers understand this, and so tend to keep populations high.

The assumption that low yields are due mostly to weather problems is a reasonable one. There are pests and diseases, but we can generally manage those. Figure 4-20 shows the relationship between yield and optimum population over 26 site-years in

northern Illinois. The fact that there is some correlation between yield and population means that an accurate forecast for weather, along with a sound model relating weather to yield, would help us to set plant population in a way that would increase income. The ability to forecast a disaster, such as that illustrated in Figure 4-16, is of high value, in that having populations too high under very poor conditions costs both yield and seed costs. So, it would provide a modest return if we could forecast good weather accurately, and a better return if we could disasters accurately.

Let's move on and very quickly talk about nitrogen. Figure 4-21 shows the variation in corn's response to N rate over nine years in the same field, where corn followed corn. For each response curve, we can calculate optimum N rate much as we do for plant population, based on the price of corn and the cost of N. Figure 4-22 shows that there is little correlation between yield and the N rate it takes



Figure 4-15.

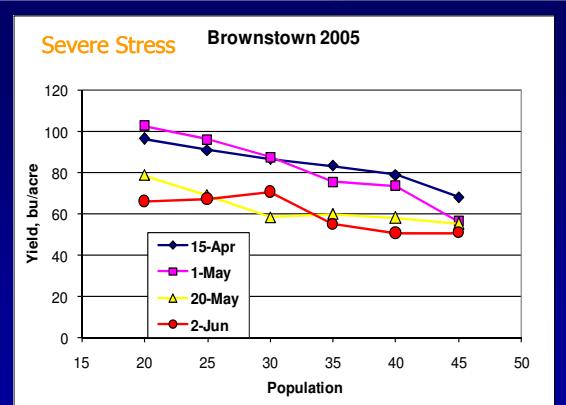


Figure 4-16.

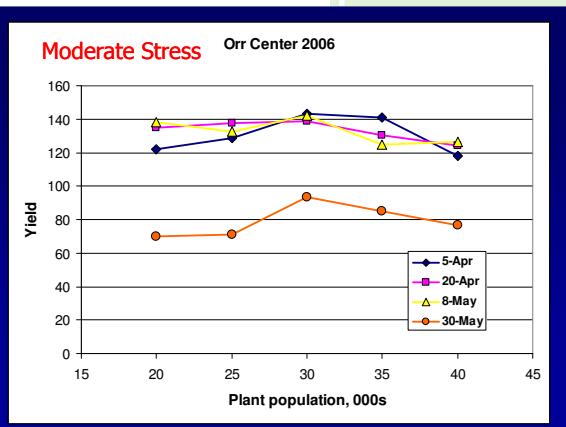


Figure 4-17.

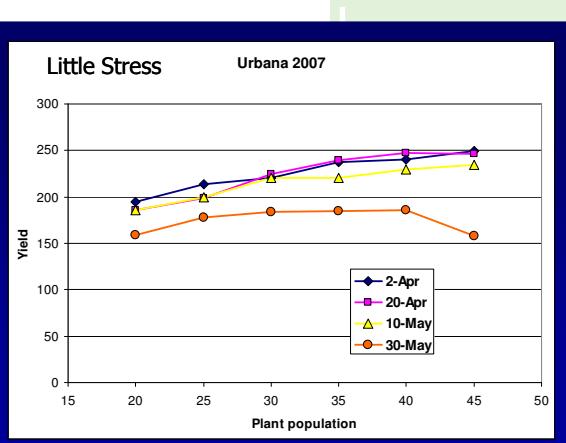


Figure 4-18.

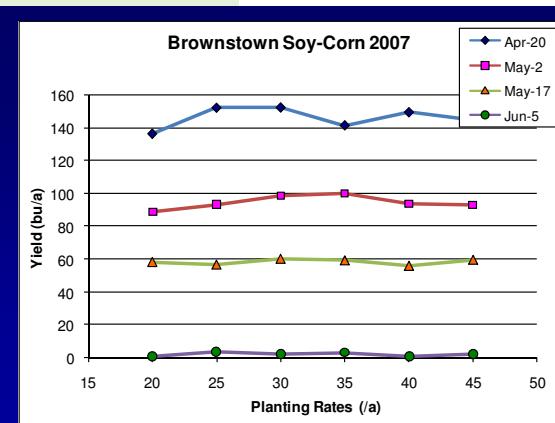


Figure 4-19.

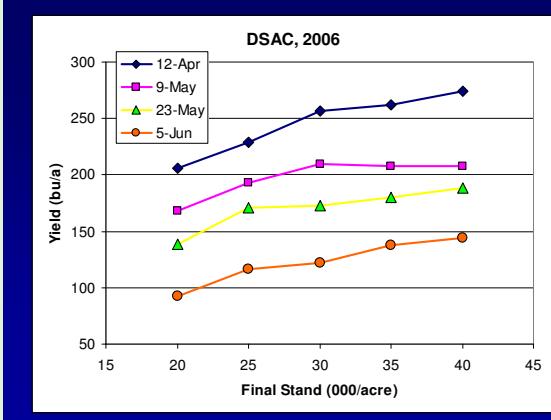


Figure 4-20.

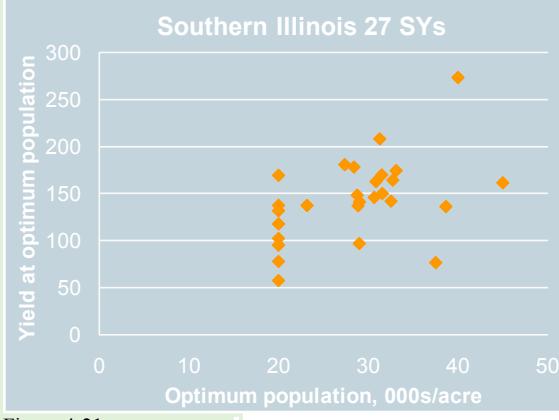


Figure 4-21.

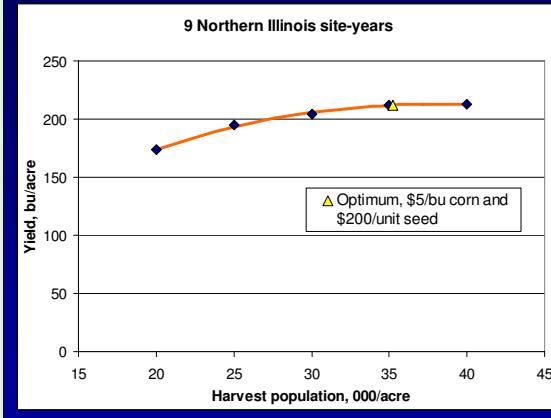


Figure 4-22.

us here, but soil N tests in the spring of 2006 would have helped us more. So the answer to the question of adjusting

N rate based on weather forecasts is "not much," since the optimum N rate shows little correlation with yield level. Thus we would not put extra N on even if we knew yields would be high, and low yields do not typically require much less N than high yields (Figure 4-22). But there's more to nitrogen than just application rate. Knowing the weather well help us to manage against N loss, with regard to timing, form, and application method. Knowing weather might help us model soil N supply better, and hence help us adjust N rates. Soil tests might also do this, although efforts to date have not proven to be very useful. While knowing the weather might help, current indications are that predicting N supply, loss, and therefore response may never be very exact.

KanSched: A Climatic Based (ET) Irrigation Scheduling Tool

Danny Rogers, Professor and Extension Agriculture Engineer, Kansas State University

My primary responsibility at Kansas State University is providing educational programs and technical assistance to producers involved with irrigated agriculture. My topic of discussion today is the Irrigation Scheduling Software Program that was developed to make adoption of ET based irrigation scheduling easier for our irrigators. The program is called KanSched. In Kansas, I say that the acronym stands for Kansas Scheduler but when I go out of state, I say it is short for "Can Schedule". It is a program that can be used to make ET based irrigation scheduling easy no matter where you are. It is an easy program to learn to use and adapt to different locations. It is used in at least 10 states now. It can basically be used wherever there is ET information available. This program is basically a spreadsheet and graphics program to help producers keep track of the soil water content in their crop's root zone.

I thought it might be interesting to review the status of Kansas irrigated agriculture, since it has some bearing on the adoption of various irrigation management practices by Kansas producers. Kansas water law is based on the prior appropriation doctrine. All of our water is owned by the people of the state but can be put to beneficial use by individuals who follow the appropriation procedures. This applies to all uses, whether it's municipal, industrial, or agriculture use. If water is diverted or pumped, its use is controlled by the state but an individual has a right to use it, so long as the use would not interfere with a previous use. There is an exception for private or domestic water use. All of our irrigators have an appropriated water amount and are required to make a report on their annual water use and nearly all are required to have water meters. So, we have a pretty good understanding of what's going on. Agriculture is the big water user of the state; about 85% of all permitted

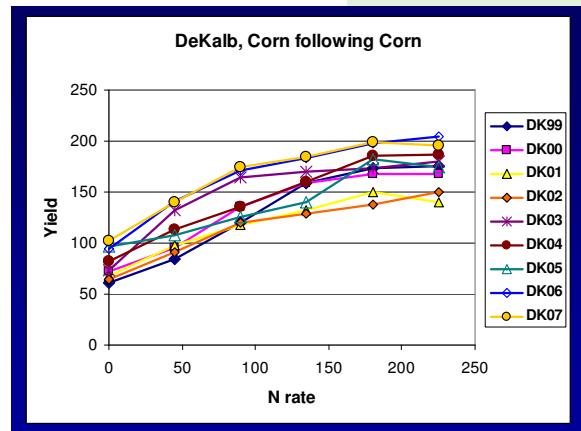


Figure 4-23.

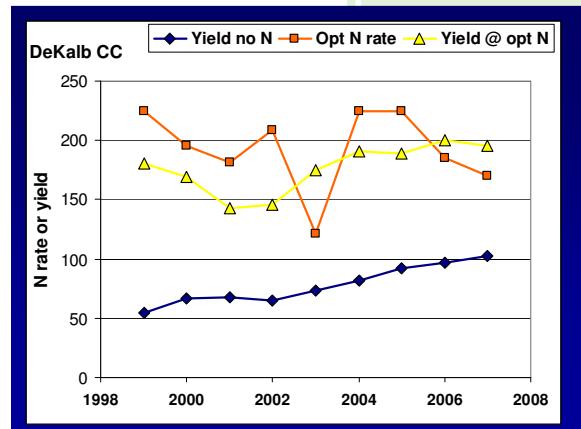


Figure 4-24.

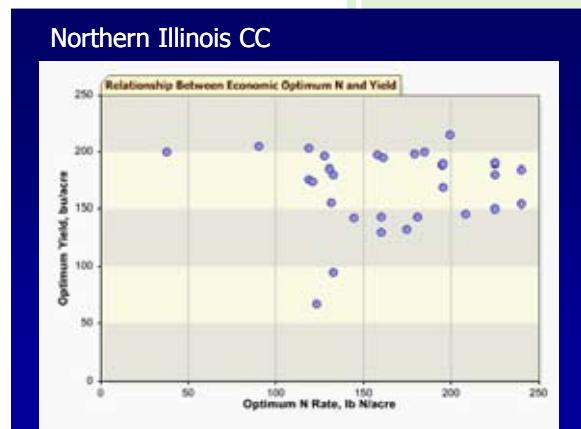


Figure 4-25.

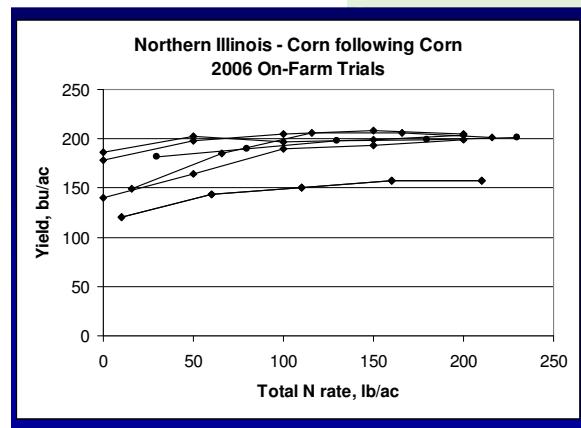


Figure 4-26.

water use goes to agriculture. There are over 20,000 irrigation points of diversions in Kansas and are primarily concentrated in the western part of the state drawing from the Ogallala Aquifer. Another area of concentration is in south central Kansas, location of the Big Bend Prairie and Equus Beds Aquifers. A referral to the High Plains aquifer is usually a reference to all of these aquifers as a combined complex.

Irrigated agriculture covers about 15% of Kansas' harvest acres that are irrigated and they represent about a third of the crop value. In some of the heavily irrigated counties of western Kansas, about 75% of the harvested acres are irrigated and represent 95 to 98% of the total crop value produced annually. Irrigation in this part of the state is very important but this is also the area that is having some problems with declining water supplies. Average net irrigation requirements for corn production range from about 15 inches in the west to 3 or 4 inches in the eastern part of the state. In the west, irrigation supplies about one half of the crop water needs. If more water supplies were available in the east, there would be more irrigation, so the yields would not be impacted by dry periods during the growing season. It seems eastern Kansas is plagued with a drought every year that can severely impact yields. An example from north central Kansas illustrates this impact. This is an area of the state which has an average rainfall of 32 or 34 inches, which if properly distributed could meet all the water requirements for corn production. In this example year, a single irrigation treatment increased corn yield to 122 bushels per acres, while the dry land yield was only 3 bushels. So irrigation, even on a limited or supplemental basis, can have a tremendous yield impact.

The timing of the irrigation application is important. Irrigation scheduling is the process to determine when and how much water to apply to meet specific management goals. Normally, the management goal is to prevent water limiting yield stress of the crop. When I first started my career, we were trying to get producers to schedule using soil water monitoring. Soil water monitoring is an indirect measurement of the crop water use. With regular soil water content measurements, you can back calculate the water use rate to predict when the next irrigation was needed or use the soil water reading to determine how

much irrigation was needed to refill the soil profile. Soil water monitoring is an effective scheduling method but is labor intensive; the devices have to be installed; they have to be read in the field, the information has to be processed to determine the need, and then a return to the field is needed to implement the irrigation decision. Needless to say, we made very little progress in getting individual producers to implement that type of irrigation procedure, although it was a common practice for irrigation consultants. In the mid-1990's technology, and producer interest in scheduling combined to make ET based scheduling a viable option. Declining water supplies and high pumping energy costs were a concern for many producers. Technology allowed easy access to the weather stations either by phone or by internet and most producers were using computers as part of their farm management process. The internet is now probably the most popular method for gathering the ET information. Energy costs in particular had a large impact as the cost of pumping went from an average of 3 dollars an inch to 10 or 12 dollars an inch in one year. At the time of the energy jump, the price of corn was still in the two-dollar range, making the pumping energy a significant production cost. So minimizing water use was important, although trying to conserve for the future was a factor as well. Energy and corn prices have kind of balanced out again now but there's still a high enough pumping cost that producers are interested in minimizing the irrigation costs while maintaining yield. We had very little success in getting producers interested in irrigation scheduling until we finally got the right combination of cost and technology together.

ET based irrigation scheduling is dependent upon a good weather network system. We do not have a very dense weather station network in Kansas but it is not needed unless there are regional weather variations. Kansas does not have Great Lakes or a lot of elevation changes, so while our climate is variable, i.e. it changes from day to day, it is pretty stable on any given day, i.e. it is about the same over a large area. So, if Garden City Kansas located in SW Kansas is hot and sunny, 120 miles away in Colby, KS in NW Kansas it is also likely to be hot and sunny, meaning the ET is about the same. Kansas producers are familiar with ET as the concept has been a part of our educational programs for

about 30 years. When I've talked to other states, I find that producers may not be quite as familiar with the concept. ET is short for evapotranspiration, a combination of evaporation and transpiration. ET is basically an energy driven process. All the plant breeding that has occurred has not changed the physics of the ET process. Basically, plants transpire for the same reason people sweat when they stand out in the sun; to control their body temperature. Except people can move to the shade, but a plant has to stay in its spot and take the heat and sunshine. Only about 1% of the water that goes through a plant is actually used in the growth process, most of the water is transpired to keep the plant from getting hotter than the ambient temperature around it. So in a sense, ET is a measure of the atmospheric demand that is placed upon a plant. ET is the input that is needed in the KanSched program to build the estimate of the crop water use, which is then used to calculate the soil water in the root zone that a producer uses to determine when to irrigate.

The ET value from a weather station is usually referred as reference ET. Crop coefficients are used to translate the reference ET or atmospheric demand that the plant is experiencing or exposed to into the actual or crop ET of the plant based on the stage of growth that it is in. Basically, a small plant or an immature plant will use less water than a fully canopied or rapidly growing plant. So, that's the basic concept. Many producers, whether in Kansas or Iowa or wherever else, will think the climate during the growing season is always hot and therefore the ET rate doesn't change much. But that is not true and here is an example. In the graph, the blue line represents the 30 year average ET values for the experiment station at Colby, Kansas. The ET rate averaged over a long time results in a smooth curve that is low in the spring, gradually increasing until it reaches a peak in late summer, and then gradually reduces in the fall. The long term average peak in western Kansas will be in the 0.35 to 0.4 inch per day range. The red dots plotted on the graph represent the daily reference ET values for 2004. Notice the tremendous variation that occurs on a day to day basis, going both above and below the long term average values. The five weather factors used to calculate reference ET are maximum and minimum temperature, humidity, wind, and solar

radiation. Some hot days may have high thin cloud cover that reduces solar radiation or the wind was less than the previous day that also was hot, so the ET would be different based on these climatic conditions. So these daily ET values are used in the day by day scheduling process of the KanSched program. The KanSched program is available for download at www.oznet.ksu.edu/mil. KanSched has been available since the mid 90's. At that time, we knew from producer surveys that many had personal computers but were not necessarily computer savvy. So when we started this program, we knew that the only way we'd get producers to use a decision support software program was to have training for them. When we first started this training program, we would have producers come in. We would bring laptop computers to set up our own computer lab so that we could have the producers run KanSched and get firsthand experience. It was an effective way to get them comfortable with the software. During the first several years of the training program, we sometimes had to start with very basic skills like, this is a mouse, use it to move the arrow on the screen and click on the item you want. That's not the case now. Our producers are well versed and in fact we do very little training on the newer versions of KanSched when they come out. It gets downloaded off the web and they update it and they go on, so it is not a big issue. But at the time when we were introducing this, even though we had been promoting ET based scheduling since 1980, it really didn't catch on until the weather station access and personal computers allowed timely and easy implementation of ET based scheduling.

We used in-field demonstrations on farmer fields to show that the data was accurate. Since most irrigation in Kansas is by center pivot, we would change nozzle packages on the inner span of a center pivot so that we could make three strips within the field that would be watered at a different amount than the rest of the field. The zones were at the inner part of the span so we'd only be affecting about half acre strips. Data from annual irrigation water use reports that Kansas irrigators have to submit each year indicated that many producers were over irrigating their crops and we had supporting data from our experiment stations as well. Farmer field demonstrations resulted in convincing evidence that ET scheduling could be

used to save water without yield loss. For example, this graph shows county average irrigated and dryland yields for the county of the demonstration field site. It shows that dramatic yield increases are possible with irrigation and that the producers in the demonstration were producing high irrigated corn yields. The test strips in the field were set up to apply water at 50, 75, or 100 per cent of whatever the producer applied. The producer made all irrigation management decisions, the demonstration project only collected data. The three bars next to the county average irrigated yield represent the yield from the test strips in order of 50, 75, and 100 per cent of the total irrigation applied. Notice in this graph of yields, in the first year of the project that there was very little yield difference between the three levels of irrigation for almost all of the sites. This means most of the producers were overwatering the field. We asked them to collect and record the ET information but they didn't necessarily use it to make irrigation decisions. However, the evidence from their own fields made a pretty powerful statement. Over time, with our encouragement, many decided that the ET information was ok, that it could be used to make irrigation scheduling decisions. Notice in later years of the demonstration the strips receiving less water were having yield suppression. Remember if the 100 per cent strip was receiving the correct amount of water, then the 50 per cent strip was receiving only half the amount of irrigation required, so yield was being suppressed since they should be getting 12 to 20 bushels an inch of water yield response. So when you start taking out half the irrigation water you'll get those kinds of suppressions. On the other hand, if there was no yield suppression in the deficit strips, they knew there was excess water being applied to the entire field and there was no advantage to additional water. Notice not all producers adopted improved water scheduling. Some of those fields were monitored for 4, 5 or even 6 years. Here is an example of a producer that, even after multiple years of data collection, had no yield suppression in the deficit irrigation strips, indicating he never adopted any improved irrigation scheduling practice.

The demonstration field data and the easy to use KanSched program combined to result in a high adoption rate of ET based scheduling by our cooperators. This also translated into a good acceptance by other

irrigators and consultants. It might be fair to say that the huge increase in energy costs which doubled to tripled the pumping costs, also contributed to adoption of ET based irrigation scheduling.

We thought it was important to try to design software packages that producers will find easy to use. So, KanSched's features are compartmentalized and accessed mostly by the point and click of the mouse. Many of our producers have multiple fields. Our largest producer at one time had over 300 quarters under irrigation, but many might only have 2 or 3 systems. When we get into western Kansas, I'd say 10 to 20 fields might be a common number. To accommodate multiple field management, KanSched allows fields to be organized into groups that we call field collections which can then be managed as a unit. A consultant using KanSched can organize each of his clients' fields into a collection and then they can email that collection's information to their client without having to send the information about other producers. We tried to make this as easy as possible, user friendly, so KanSched is set up to allow input by the point and click of the mouse. When you start to set up or initialize a field, KanSched asks for general information like name of the field, crop type, etc., using a series of input screens or pages. Each page is set up so that the entire page appears on the screen and the instructions or description of the input is next to the input, so no help screens have to be located if there is a question. KanSched has a lot of drop down menus so a producer can go click on the input box and a drop down menu will appear to allow them to select the needed information with a point and click of the mouse. Drop down calendars are available so they can easily enter the date the crop emerged or when they want to start the water budget or so forth. We have soil information loaded into KanSched, so they can point and click on the soil type for the field. They also have to select the crop coefficients for the field. KanSched has crop coefficients for the two common ET reference bases that are available in Kansas. Most of our K-State system initially used an alfalfa reference based Penman equation for reference ET but there is also a grass reference based Penman-Monteith equation. Our producers need to know which one they use based on which weather station they are getting reference ET information from. Our KSU

system now calculates both. KSU has historically used the alfalfa reference base. Several groundwater management districts established their own weather station networks and chose the grass reference base. So, we made KanSched to accommodate either. Our producers understand this very well and we get very few questions on this anymore, but we can accommodate both of those bases. Once that data is set up for a field, KanSched is ready to allow the start of a daily budget.

The daily water budget page is where the reference ET information is entered. Other inputs can include rain and irrigation amount. A column is also available to enter an observed soil water value, if desired. KanSched uses this information to track the root zone soil water content. Most producers use the soil water deficit value as their irrigation guide. Once it reaches a certain target or trigger point, then they will start the next irrigation event. So if they are deficit irrigating , meaning they have a low capacity irrigation system that they know will not be able to keep up with all water demands in many season, they might start watering as soon as sufficient root zone storage is available to store the water from an irrigation event. So, if they're putting on an inch at a time, as soon as they see an inch deficit, they'll start irrigation. This strategy will minimize the period of yield limiting water stress later in the season when crop water use increases. If they have a high irrigation capacity system and they are on deep high water-holding capacity soils—meaning they might have 8 or 10 inches of water in root zone storage—then they might wait until there is 2 or 3 inches of deficit before they start irrigating because they know they still have plenty on reserve and this leaves room for rainfall storage. This strategy can help them minimize pumping costs by taking as much advantage as possible from rainfall. The best strategy depends on their situation and irrigation systems.

KanSched has several other features that producers can use, if desired. The information from the budget page is plotted on the soil water chart and the seasonal data is totaled on the summary page. KanSched can be used to forecast ahead. It also has features to estimate pumping costs and a section to store well and water meter information.

Many of the producers get their ET information from internet sites now. One site is the KSU weather data library, located at www.oznet.ksu.edu/wdl. From the main page, they can click on Kansas Weather and ET Data and then chose whatever weather station that is available from the map or drop down menu.

We're working on the next KanSched update based on producer requests. To date, KanSched was developed as a stand alone program and distributed primarily by CD's. However, most new versions are now downloaded from the MIL website. Many producers want to be able to make an interface between KanSched and the weather station so that their computer will call the weather data library and get the ET data so they don't have to do it every day. Then all they would need to do is go to that field file and enter either rainfall or irrigation events. So, to accommodate that possibility, we are working on a web based version. The reason we went with the stand alone option was because web downloading was not all that reliable throughout the whole state in the early 1990's. We provided CD's to all in attendance whenever we did training. We also provided copies for distribution to county agents, Conservation District offices, and other water agency offices. The main problem with CD distribution is getting current users updated with newer versions. So when somebody calls me with a question, the first thing I do is find out if they have the latest version, because that will likely fix the problem they are encountering. We are working on KanSched 3 and also a web based KanSched. The web based KanSched will be updated automatically. The current KanSched could be modified to different ET bases and there is some other customization that could be done. It is downloadable from the Mobile Irrigation Lab (MIL) website at www.oznet.ksu.edu/mil. The Mobile Irrigation Lab project is funded by Kansas Water Plan funds thorough the Kansas Water Office.

Drought Probabilities

Mike Hayes, Director, National Drought Mitigation Center

There are two ways to consider drought. It doesn't really change drought probabilities, but it might change how you look at them.

You can either consider drought as a rare or unusual event or as a normal part of the climate. The view you take is going to determine how you look at drought probability. If you look at it as a rare or unusual case, what you're going to do is set yourself up to deal with drought in the hydro-illogical cycle (Figure 5-1).

Because drought is a creeping phenomenon and you don't realize you are in one until something happens, when you finally become aware, you get concerned and then you panic. Usually this transition happens very rapidly. And when you're panicking in a drought, or in any other emergency situation, for that matter, your responses are probably not going to be very efficient or timely and will not be effective in dealing with the problem. Eventually the rains return, you go back to being apathetic, and it sets the stage for the cycle to happen all over again. So if you look at drought as a rare and unusual event, you have a potential to deal with drought in this way, and that's not the way you want to deal with it. You want to be very proactive.

Figure 5-2 illustrates the percentage of the United States in severe to extreme drought from 1895 to the present. You can see from this graph that drought is a normal part of the climate in the United States. Almost every month has some part of the US in severe to extreme drought—about 14% of the total land mass at any one time. What also stands out are some of the major droughts on this curve. In the 1930's about 65% of the US was in severe to extreme drought.

The drought monitor map, when it started as a weekly assessment of drought conditions back in 1999, has done a great job of educating us that droughts aren't just a western United States issue. In fact, if you look at this current drought monitor map, you can see a huge drought in the southeastern United States that was there last year as well. Last year there



Part 5: Preparing for Extreme Climates

was a major drought in the Lake Superior basin. So droughts occur everywhere in the United States. What does the history of the drought monitor look like since this project began in 2000? Figure 5-3 shows the percent of the US in the various drought monitor categories from 2000 to the present. And what you see is that going into about 2002 we had an increase in drought areas that diminished during the 2003-2005 time period. We had a spike in 2006 and another in 2007, diminishing in 2008. This timeline shows the drought history over the past 8 to 10 years here in the US. You can also bring the focus down to a more local or regional level. Figure 5-4 is the same graphic but just for the major corn states of Iowa, Illinois, and Indiana. On the bottom left of the chart is 2000; on the right is 2008. We had a very dry spring part of 2000. Some of you probably remember big fears of drought that year. Some good rains came in to the three-state area and eliminated the problem. Both of the previous figures show droughts in 2003

and 2005. And then in 2007, Indiana had one.

So, droughts have been a regular pattern in parts of the Corn Belt area as well. When we talk to producers in Nebraska, for example, they say the drought monitor is an interesting tool, but what they'd really like to have is a drought monitor product for other parts of the world that are major agricultural commodity producers, especially for corn

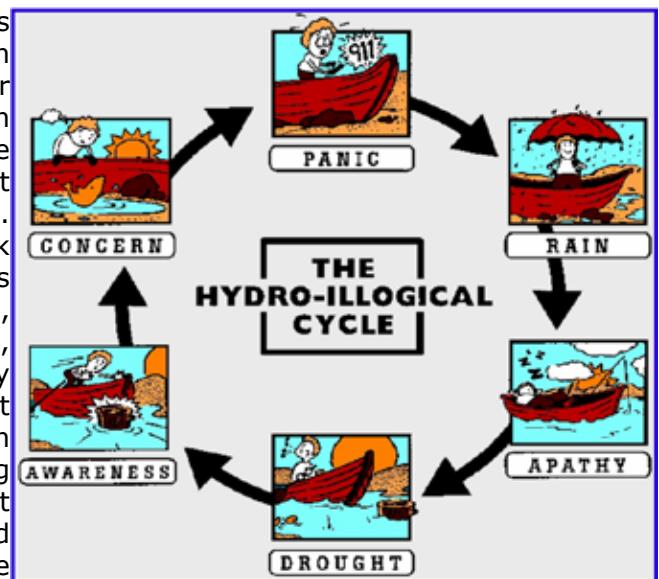
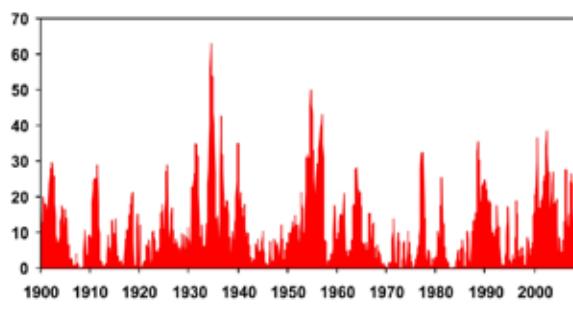


Figure 5-1.

Percent Area of the United States in Severe and Extreme Drought

January 1895–July 2008



Based on data from the National Climatic Data Center/NOAA

Figure 5-2.

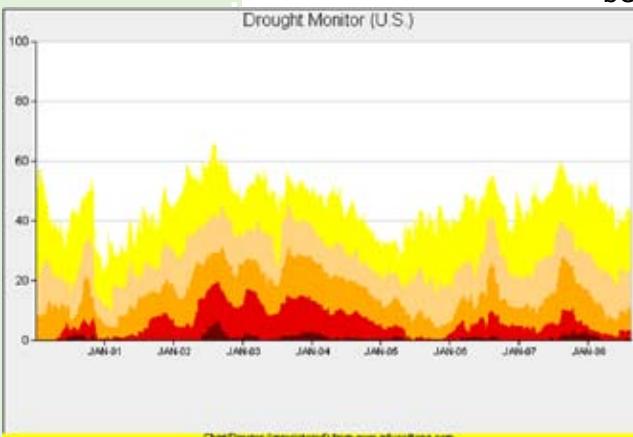


Figure 5-3.

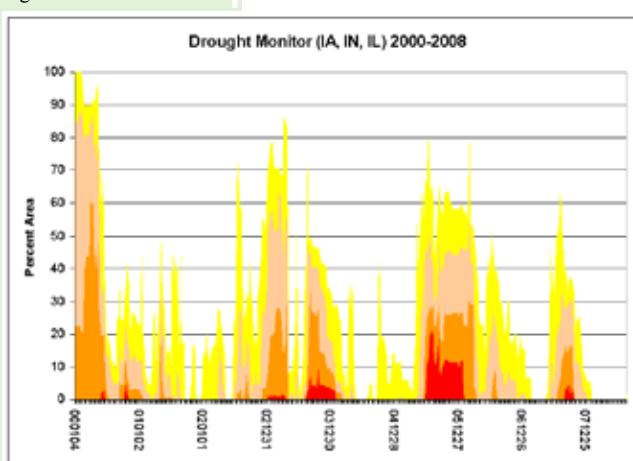


Figure 5-4.

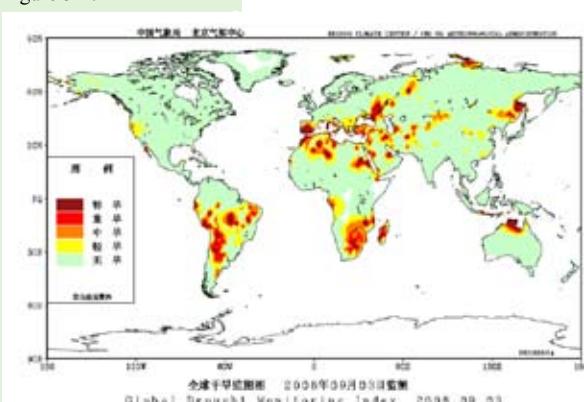


Figure 5-5.

and soybeans. Give us a drought monitor map for China, Argentina and Brazil. We don't have one, but there are some tools that are now evolving and developing that give us much more of that information now, in real time, than we've ever had before, and they

are available on the web. The Beijing Climate Center, for example, makes a daily update of drought conditions for China. They have a graphic that is very similar to ours, showing wet and dry areas in China, that is updated daily. If you overlaid the Chinese drought map with one that showed productive areas in China, it would be really

ults. The Beijing does this type of le world. Figure lated daily and it ought conditions There's a group a similar thing, tion Index (SPI), can't see where n the information jularly, that can of what is going Figure 5-7 comes

from a group out of southeastern Europe, the Drought Monitoring Center in Slovenia, and it shows the 12 countries in the region of Europe that is part of the continent's agricultural production belt. You can see this time the 6-month SPI index showing pretty dry conditions in Greece and Turkey as of June 2008. We worked closely with this drought monitoring center and had a visiting scientist housed with us at the NDMC for a while last year, and we really emphasized the need for better drought monitoring and the ability to provide this information to people, to communicate the severity of drought.

We also have a project where we're working with some very good scientists in the Czech Republic. This project looks at climate change models and uses the IPCC models to examine impacts on soil climate conditions in the Czech Republic. They've just now begun looking at similar things in Nebraska. Why the comparison of Czech Republic and Nebraska? Well, again, they're major agricultural production areas for Europe and the United States. They are generating climate information with a weather generator they call Met&Roll. They incorporate climate data into a soil climate model and produce an enhanced daily water balance model incorporating the interactions between the soil and atmosphere. Heat parameters, soil temperature, soil moisture, wet days and dry days based on the soil moisture, biological windows (a term the National Resource Conservation Service uses in the USDA), and evapotranspiration are some of the key parameters that influence decision making at a producer level. What this research addresses are some of the soil climate components or parameters that are important to producers. Here are a couple of basic products that have just been developed for this model for the central US. Data from North Dakota, Nebraska and Iowa stations have gone into this work. Figure 5-8 shows a gradient that begins in Ames, Iowa, and goes through Nebraska—West Point, Ord, Gudmundsen Ranch, and finally ending at Alliance in the west. Figure 5-9 is a graph of modeled soil temperature. If you look at these graphics, the top row is based on 1995 conditions in these global models. So Alliance is in the west, and the gradient goes to Ames in the east. What it shows is that, based on 1995 values, the soil temperature at 50cm is about 10 degrees C. If you then use the NCAR model to input 2050 values,

you see that the soil temperatures at that level in each of these areas from west to east increase about 1 degree C over the next 55 years. If you look at another model for the same time, the HadCM model, you see a greater temperature increase. So this analysis has provided a way to visualize some of the differences between the models used in global climate change projections. If you look at 2050 in the NCAR model, all stations have a decreased number of dry days, meaning they've gotten a little bit wetter based on the model, and the HadCM shows an increase in the number of dry days in each of those stations. So what that's telling me is that the NCAR model is wetter in its projections for what's going to be happening in this gradient across the central US and the HadCM model is drier. Another parameter called biological windows measures the number of days that are favorable to crop growth—meaning where the soil temperature is greater than 8 degrees C and where the soil is considered moist, the available water holding content of the soil. You'll see Alliance has fewer days in 1995 versus Ames. And again the NCAR model shows more days in Alliance because it's going to be warmer and wetter more days than in Ames. And then in the HadCM model you have fewer days in the Alliance situation than in Ames but in Ames you actually get better conditions, even in the HadCM model. So it shows that I think there are some opportunities for understanding how these global models are projecting at a local scale, and it's something we need to keep in mind.

Where do we go from here? I really want the National Drought Mitigation Center to be part of this question because I think it's a partnership between us and the academic, federal, and state organizations and those decision makers at the local scale. The first direction we need to go in is with the drought monitor. And the drought monitor, I believe, is the first national dialogue about drought. The conversation began in 1999 and I think it's still going strong today. Why is it important? The drought monitor is an important decision making tool for drought relief that affects individuals around the country. How can we all be involved? There's a list serve of communication that takes place for developing the drought monitor product. Figure 5-10 shows about 243 participants that take part in developing the drought monitor every week. That number is probably closer to 270 now. So a lot of

people are involved. I'm not necessarily suggesting that all regional producers need to be involved; but for example, you need to know who's involved in your state, and then provide your input on what drought conditions are in your state to that person, so they can provide it to the drought monitor authors during various weeks, because it's relying on the information that is taking place away from where the map is being developed, whether that's in Lincoln or Washington DC. We also need information to populate the drought impact reporter, which is an archive of

drought impacts that are occurring around the nation. Figure 5-11 shows what the drought impact reporter looks like on the National Drought Mitigation Center's website.

There's a place where a person can add information such as a drought impact. There's also the National Integrated Drought Information System (NIDIS), which is an initiative that's been put in place to facilitate interactions between drought officials and locals on the ground. NOAA is the lead agency for NIDIS. How does this impact you? There are some working groups that are involved with NIDIS: a Public Awareness and Education working group, how to better improve drought education and awareness; an Engaging Preparedness Communities working group; Integrated Monitoring and Forecasting; and the US Drought Portal. I think that when we talk about a national climate service, the

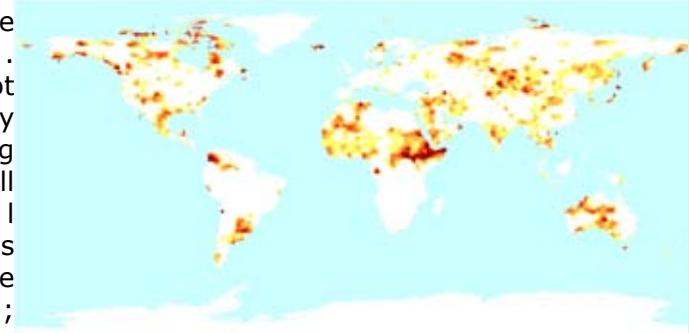


Figure 5-6.

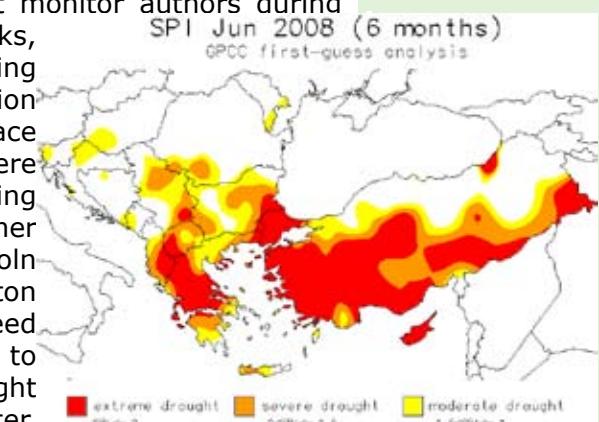


Figure 5-7.



Figure 5-8.

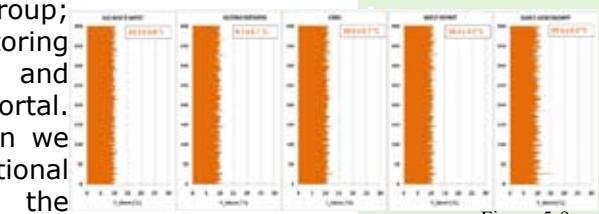


Figure 5-9.

USDM Listserve Subscribers (as of June 3, 2008)

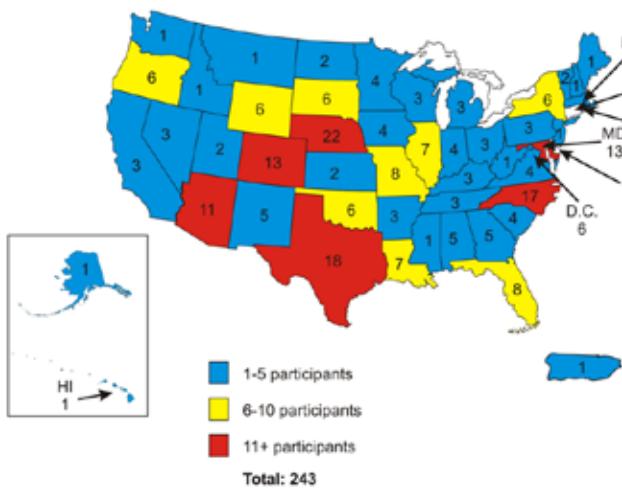


Figure 5-10.

drought aspect of that national climate service has already been formulated in a way with this NIDIS program. Figure 5-12 shows the web portal for NIDIS.

the world is going to have local impacts with producers here. The linkages between drought, climate, water, energy and food are only going to increase with time. If we're patient, there are going to be advancements in how we look ahead and in our expectations for drought. There's been a lot that has taken place within the past 10 years, and with that, we just need to be prepared and plan ahead.

Climate Change in the Corn Belt

Marty Hoerling, Meterologist, Earth System Research Laboratory, NOAA

Explaining climate change in the Corn Belt is in many ways a more complicated problem than explaining the change in globally averaged climate. Much has to do with the fact that a multitude of weather and other regional processes (for instance, changes in land use) play a role at the small spatial scale of the Corn Belt. We have had a new activity in NOAA, which started about a year and a half ago, called climate attribution, in which a group of scientists are trying to provide, on a near real-time basis, explanations of climate events as they are developing and unfolding at a regional scale. We call these folks NOAA CSI, where CSI stands for Climate Scene Investigators.

We were very struck by the flooding event in Cedar Rapids this year. As seen in the photo, it could have been a picture taken from New Orleans in 2005. NOAA was inundated with requests to explain why this happened, whether this was a climate-change-related phenomenon, and therefore, whether it is something that we may expect more of in the future. Events such as these can have significant consequences for corn yield, as we've seen in this year. How do you digest and distill all the available information to come up with some answers? Part of the dilemma has to do with, "well, what is this, a recurring 100-year flood or a 300-year flood?" Some local folks say they have now experienced three 300-year floods in the last 20 years. It is difficult to articulate the recurrence of these flooding events in the context of climate, especially when "climate" has become a moving target.



Figure 5-11.

We need to make progress with drought planning, and this is what that National Drought Mitigation Center definitely emphasizes. At the federal level we don't really do much with drought planning, but there's been a lot that's taking place at the state level and we heard that, for example, Indiana is revising and updating its state plan. This needs to be done on a continuous basis for all states. Native American tribes and producers also need to do drought planning. One of the projects we're working on at the National Drought Mitigation Center is a partnership with scientists at South Dakota State University and Texas A&M to develop a drought planning methodology for ranchers around the country. We're working with ranchers, particularly within the Plains states, on how to better plan and prepare for droughts ahead of time.

In conclusion, droughts are a normal part of climate anywhere in the US, so I think that it's a probability that we need to be aware of. Droughts are a global issue with local impacts, so what's going on in other nations around



Figure 5-12.

Figure 5-13 is a time series of May-June rainfall going back to 1895. It is an average over a region of the Corn Belt centered on Iowa. The greens are wet May and June months, the reds are dry May and June months. The recent flooding rain event is evident as a large green spike on the graph, but you can see that it is not an

unprecedented occurrence as there were comparable wet years at the early part of the century. This year's event ranks as maybe the fourth or fifth wettest. So the meteorology for this type of event is not unprecedented, even during the limited span of the modern era where we have reliable observations.

So were human causes important in the flood? Without time to go into this in any detail, I do feel that floodplain development, as one factor out of many, had a significant

If you take climate models that include the time history of greenhouse gases, as well as solar and volcanic forcings, you can see that volcanic events cause cooling episodes while warming from greenhouse gases dominates the time series. There is remarkable agreement between these two curves, which form the basis for the very high confidence scientists have that human influence is the primary cause for the warming in globally averaged land temperatures.

But the US Corn Belt has not warmed during the growing season. This so-called "warming hole" is contrary to the local expectations of warming due to the impact of greenhouse gas increases. Researchers are currently probing this issue, and in particular are seeking to learn whether the current lack of warming in the Corn Belt is transient, and is merely masking the human-related warming that is projected to occur by the models of the Intergovernmental Panel on Climate Change (IPCC).

The potential impact of higher temperatures on crop productivity in the Corn Belt is a very important problem. Figure 5-15, which is a US Department of Agriculture graphic from 2002 – a bit dated now, shows the U.S. areas of highest percent of corn harvested for grain. We can see that Iowa, northern Illinois, and in fact most of this area is not irrigated. As you go further west you get into the irrigated corn of Nebraska.

Figure 5-16 is a time series of temperature and precipitation averaged over this Corn Belt region to compare to what we have seen over the globe. We see right away that the time series for land temperature during the heart of the growing season is anything but simple. The main point is that it looks very little like the global land temperature time series, and that warming has not, at least yet, materialized.

We are challenged to explain this lack of warming for the growing season in the Corn Belt. Folks living in this region can certainly be forgiven for any skepticism they may have that global warming is occurring, since they are not experiencing it in their own backyards. We have to explain this discrepancy—when the models tell one tale and people's personal experience tells another. That's why NOAA invests in research to answer this very open question of why it has not warmed, for example, in

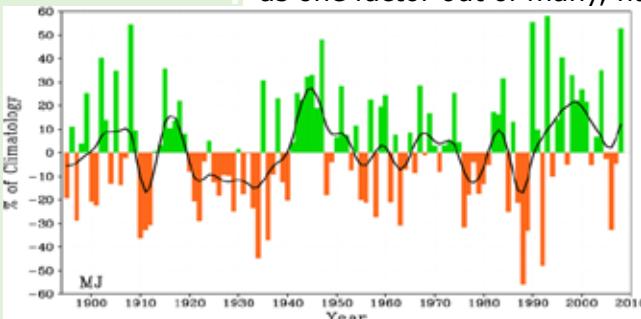


Figure 5-13.

for having, if you will, more land and less water. Wetlands have been reduced and our land is now planted with corn and soybeans basically right up to levee locations, so rapid runoff has become a characteristic of the engineered system around the rivers.

As far as the meteorology is concerned, springtime wet soils are common in the Midwest. That is to say, they are wet owing to accumulated winter snows, relative

to the minimal loss of water by evaporation, until the temperatures get warm enough. Nor are heavy rains in May-June uncommon as the previous graph showed. So we have to question what we are doing to the landscape in which these rains are being funneled and channeled into the rivers, rivers that are important for the life of this area for many purposes, such as commerce and agriculture.

Why has the earth been warming? David Easterling's essay in this report gives a good overview of the science behind the human impact on climate due to greenhouse gases. Figure 5-14 shows that global land temperatures have now warmed about 1°C above the average of the 50-year-long reference period between 1920 and 1970.

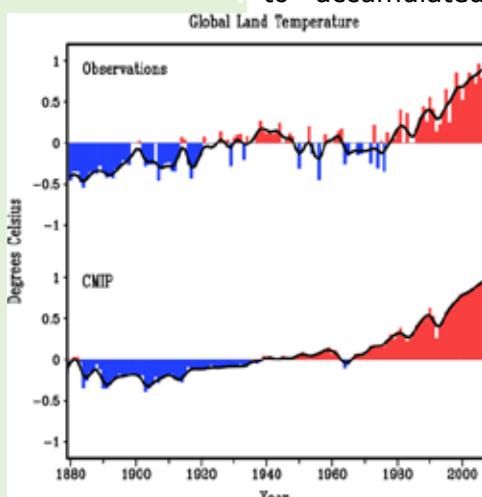


Figure 5-14.

this region, but it has in others.

The bottom image in Figure 5-16 shows the same picture for the same time period, but constructed from the climate models for global land temperature. It shows absolutely no relationship with the observed time series for the growing season in the Corn Belt. From the climate change simulations we would have expected the whole continent to warm. But it has not done so – the west has warmed more than the east – and that is interesting. The rate of regional warming in the summertime is about a degree Celsius – not much different than the global land temperature. But the variability is so much larger at this regional scale that this small signal is easily masked by the region's natural variability in temperatures. That was not the case for global land temperature, where the warming signal is much greater than the fluctuations due to natural variability. So it's possible to think that the planet hasn't warmed because we haven't seen it warm in this region, due to the very noisy characteristics of temperature at this scale.

It is also possible that the greenhouse gas signal is wrong in the models as applied to the Corn Belt. Is it an issue of temporary regional cooling, or a problem with the way we measure regional temperature, or that the signal is wrong and it is not going to warm or it may not warm for some time? These are important policy questions.

Figure 5-17 shows the observed precipitation time series. In the upper left box, greens show wetness, reds show dryness. There is almost no signal due to greenhouse gases for precipitation during the growing season as an average. There probably will be an increase in extreme rain events, but those events will likely become less frequent, so the seasonal average will not be terribly disturbed by greenhouse gas increases. The Corn Belt will likely be dominated by the variability that we have already had. There was a string of 20 years of dryness here between the two Wars. Lately it has been wet. It could just be fortuitous. It may just be coincidence, but have we prepared ourselves for climate change in terms of precipitation? If we have not prepared for climate change, then we certainly are not prepared for the climate sensitivity this region has experienced in the past related to its abundant natural rainfall variability.

And by the way, the wetness could explain the coolness. The region around Iowa has been wet for the last decade or so, about a 10-20% increase over the past 20 years. Historically there is a strong inverse climate relationship, such that wetter conditions in this region during the growing season cause cooler temperatures. Probably, the recent abundance of precipitation has caused the coolness, rather than the other way around. But we don't know why it's been wetter.

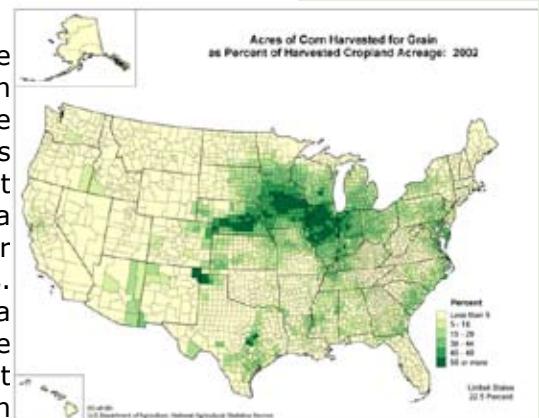


Figure 5-15.

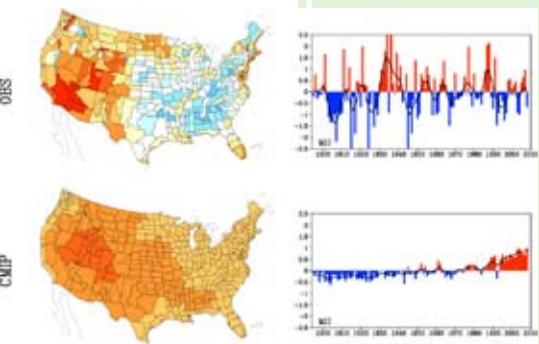


Figure 5-16.

In terms of corn yields and climate, the IPCC reports that crop plants in general will respond positively to a 2-3°C warming for mid-latitudes. However, the latest IPCC assessment indicates that corn yields might decrease from 5-20% for the amount of warming that we anticipate by the end of the 21st century. There is uncertainty in this estimate, because there really is not much known about the way corn responds to heat stress, except there are optimum temperatures, somewhere around 35°C, that one does not want to surpass. Up until that point though, there's really not too much negative effect of temperature on corn in a gross sense.

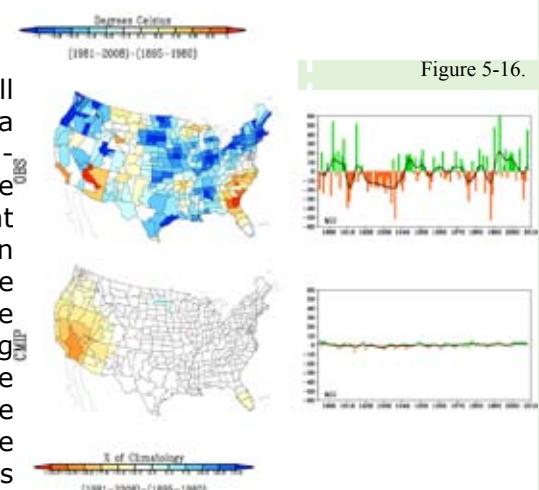


Figure 5-17.

Carbon fertilization from increasing CO₂ levels, which is usually viewed as having a positive effect, is not terribly positive for a C4 plant like corn. It is already pretty much at peak efficiency at current CO₂ concentrations. Most of the controversy centers on whether or not temperature and precipitation will change in a way that affects corn yields. Empirical relationships between observed corn yield and climate

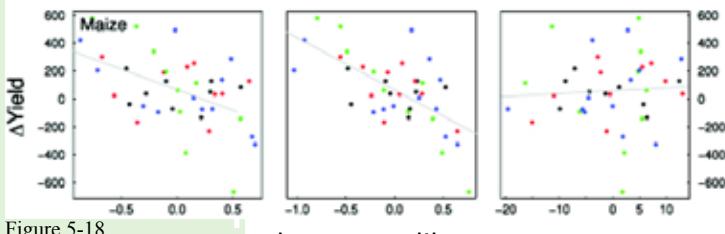


Figure 5-18.

elements like temperature, maximum temperature, minimum temperature, or precipitation are just beginning to emerge. My sense from reading various summary reports is that these results are being discounted. That is to say, it's a complicated enough game as it is.

What research has been done on the question of climate-crop yields? Well, Lobell and Field took 40 years of data for the globe for regions of corn production and then correlated maize yield as a function of minimum temperature, maximum temperature, and precipitation on a trend basis. They found that roughly for every 1°C increase in temperature there was about an 8% loss in the yield of corn. Most of this seems to be on the maximum temperature sensitivity side; there is really not too much precipitation sensitivity in their analysis. Does this mean that if you had a 3°C warming, as projected, you might anticipate as much as a 20- 25% reduction in corn yield? I don't know. It's beyond the sensitivity that's been highlighted in the IPCC reports.

This analysis was also done for the upper Midwest, for the relatively short time period of 1982 to 1998. Lobell and Asner found a strong negative correlation between corn yield and temperature. As shown in the scatter plot in Figure 5-18, they found about a 17% decrease for 1°C temperature rise over the Midwest, suggesting a greater sensitivity than the IPCC has reported. I don't understand enough about the sensitivity of these analyses. Obviously there's a lot being jumbled together when they do these types of gross climate analyses empirically, but they do suggest that there is a need for more research on this problem.

So just to go back to our US Corn Belt image in Figure 5-15, this is again the time series of precipitation for the Corn Belt during the growing season. The climate change projected for this region to the year 2100 is the average of 47 simulations from 21 modeling centers around the world. You can see that the projected increase is

very modest compared to the variability. So we really need to be thinking about the variability for precipitation. Again, the warmest year for the region was way back in history – 1934. That was 75 years ago. We haven't beaten that since, so where is climate change? We've had enough CO₂ increase, so why haven't we beaten 1934's value of about a 3.5°C warm departure? Maybe it's just a matter of time.

Figure 5-19 is the time series of temperature from the same sets of simulations. It is a different way of looking at it. I think it is useful because what one sees is that by the year 2040, in the average of all the runs using the business-as-usual scenario, temperatures would be as warm as they were in the late 1980's when we had drought and heat waves stressing crop yields. By the year 2070, the projection is that we would begin exceeding, on a regular annual basis, the warmest year on record. Now maybe from this point of view, one can get a better sense, knowing what crop yields were back in the 1930's and 1980's, what our fate is in the future. Of course these were also dry years, and I just showed you that dryness is not part of the signal, although variability will certainly always be with us in the future.

I was struck by this time series from the FAO indicating the changing yield of various grain crops around the world (Figure 5-20). Maize, the green one, has advanced the most in terms of yield, almost a factor of two fold in the past 40 years. The climate sensitivity is still a very small factor to-date relative to other aspects which have led to huge gains in the yield of maize. The question is whether these are sustainable increases or are we plateauing? It's hard to tell; we only have data through 2001 there. Whether or not this is a sustainable rate of increase is a question the ag sector as a whole is asking itself right now. If we add climate change on top of it, one wonders if we may start seeing some larger fluctuations that bring yield down from time to time relative even to current values. Soybeans by comparison have increased at a much slower rate. That might have to do with the nature of the genetic species that were introduced to the various crop plants.

In conclusion, Figure 5-20 is a picture taken from Quincy, Illinois, while I was visiting family and friends in July 2008. If you didn't know any better, you would

think there was a drought. There wasn't. Water had stood at about five inches deep in the field for a couple of weeks earlier in the season, so no oxygen, no corn. Floods can be just as damaging, if not more so, than drought, and so the question still is an open one whether indeed we will have more flooding rains like we had in 2008 as a part of climate change.

RISA: Providing Climate Information for Agriculture

Keith Ingram, Research Scientist, Southeast Climate Consortium, University of Florida

The Southeast Climate Consortium is one of NOAA's regional integrated science and assessments. The organization is in a state of flux for a couple of reasons. Part of it is because every organization has to evolve, or else it dies. And the other reason is that we've come up with some new information and we're trying to create a new identity.

It is a regional component of a national effort called the RISA program. RISA stands for Regional Integrated Sciences and Assessments. There are, at this point, 8 or 9 RISA centers in the US. These are all funded by NOAA, the National Oceanic and Atmospheric Administration. You'll notice from Figure 5-22 that there aren't too many RISA centers in the center part of the US. In fact there is a new one that's just been funded and it's in Oklahoma, Louisiana, Arkansas and a bit of Texas. There was previously a RISA center in the Northeast that has stopped functioning. We have started out with RISA centers where we thought we had a climate signal, where we could have some way of at least giving the seasonal climate forecast, and that's one of the things that makes us lucky in the Southeast, but there are certainly a lot of people who are interested in filling in this map with RISA programs.

What we do at RISA is try to take climate science and translate it into something that can be used by someone—in this case the users are farmers or water resources managers. Trying to make the link between science and application is what the Regional Integration Sciences and Assessment Centers are all about. The Southeast Climate Consortium has essentially that mission. We try to use advances in climate

sciences to focus on three sectors: agriculture, forestry and water resources. We are multi-disciplinary. We include climate scientists, biological scientists, and social scientists—not necessarily in equal numbers but we try to keep a fairly close to equal balance between those three groups. We're also multi-institutional; right

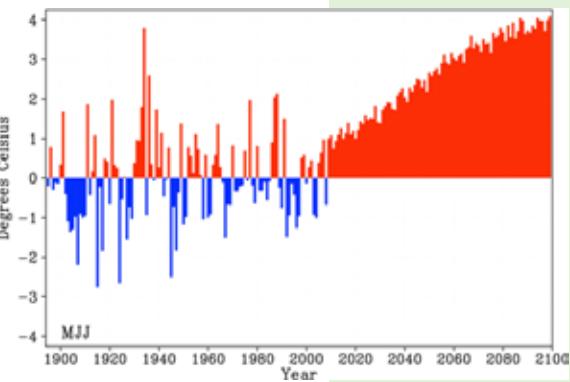


Figure 5-19.

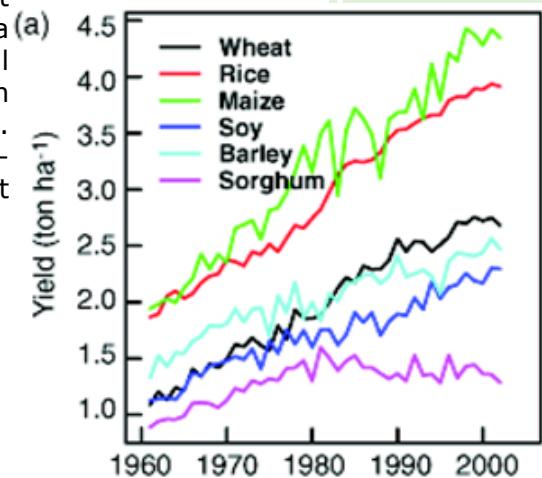


Figure 5-20.



Figure 5-21.

now we have seven member institutions. We do participatory research and outreach. People talk about participatory research; I'm not sure if everybody has heard what that means but the key there is that we engage the intended recipients of our research from the very beginning. That has led to a large part of our success.

We have done all of our work in close partnership with extension and education organizations. We work with seven universities. The first three were the University of Florida, Florida State, and University of Miami. And if you look at the areas of expertise—crop modeling, extension, and hydrology, as compared with climate sciences, state climatology, downscaling—each university has a different

one and as we've added universities we've tried to bring in new expertise and try to complement activities that we have ongoing.

The Southeast Climate Consortium is different from other RISAs. There's a RISA in Colorado, Arizona, and one of the differences is, we started off with a strong emphasis on agricultural risk

management. Until a couple of years ago, we were really the only RISA center focused on agricultural risk. Another thing that makes us different is that we've got a much more diverse funding base. Funding really drives things. The NOAA component of our funding budget is about 15 to 20 percent right now. The nice thing about the NOAA money is that it's very consistent. It forms our core budget. The other components are not nearly as reliable. We get about 60 to 70 percent from CSREES and Risk Management Agency right now, with USDA. We have a growing base of competitive grants. We have really strong administrative support. And, there's no overhead on "pass through" funds, where one university gets money and gives a sub grant contract to another university, typically they take off overhead on at least the first 25,000 dollars. Our administrators will waive that overhead on all sub contracts within the SECC. Frankly, they're not giving

up that much money, but they are really gaining a lot in terms of credibility. It helps us and it really helps the image we have with our funding agencies. We have regular meetings of our deans and vice presidents. We have 5 themes: climate, agricultural research, water resource management, decision analysis and assessment and agricultural extension. We had what we called AgClimate, which was our prototype decision support system. One of the reasons we're in transition is because we're trying to transition AgClimate from being a research prototype into an operational website. And I'm happy to say that we're getting there. The key is that AgClimate is now hosted by Florida Cooperative Extension. We still have several sponsors, and as we go along, you'll see the sponsorship rotate through.

Figure 5-23 is a brief summary of some of the tools. When you come up on the first page it'll tell you what the current phase is, what's likely to change and what's the probability that it'll change to something else. We have outlooks; we have a lot of tools. The products that we get started with were two basic products. We started with something that talked about the climate. This is not specific to agriculture, but it tells you on a county basis what your climate is, how the El Niño southern oscillation phenomenon affects your climate. We have crop yield risks, how is crop yield affected by these different climate phases. Everything else at the bottom has been added by the request from our extension agents and farmers that we work with. They say, hey, how about historic yields? If you can't tell us for sure what's going to happen in the future, can you tell us what's happened in the past, like regional outlooks, or how about chilling units and growing degree days tools? We have a Keetch Byram drought index which is a forecast for wildfire threat for forests and a lawn and garden moisture index. We try to keep it fairly simple. We can show the average rainfall in a month for the current climate phase. Under total rainfall, the other items that are available include average, average temperature, average max and min, extreme max and min temperatures, and if you look across the top we have probability distributions for the last five years. The last five was requested by our farmers. We can change the ENSO phase, so this is now the La Niña phase, which might be coming up. Figure 5-24 shows the last five years, the climate phase, and the rainfall or temperature for



Figure 5-22.

management. Until a couple of years ago, we were really the only RISA center focused on agricultural risk. Another thing that makes us different is that we've got a much more diverse funding base. Funding really drives things. The NOAA component of our funding budget is about 15 to 20 percent right now. The nice thing about the NOAA money is that it's very consistent. It forms our core budget. The other components are not nearly as reliable. We get about 60 to 70 percent from CSREES and Risk Management Agency right now, with USDA. We have a growing base of competitive grants. We have really strong administrative support. And, there's no overhead on "pass through" funds, where one university gets money and gives a sub grant contract to another university, typically they take off overhead on at least the first 25,000 dollars. Our administrators will waive that overhead on all sub contracts within the SECC. Frankly, they're not giving

the selected county.

Crop yield data, the historic yield tool, was something farmers requested. The chart in Figure 5-25 is organized by ENSO phase, and shows you the average yield for a crop, which in this case is corn in Dougherty County, Georgia. We also have anomaly maps. Figure 5-26 shows a map for a neutral year with yield loss on the top, yield gain on the bottom compared with normal. This was based on the preferences of our clientele. They are most concerned with the red—that is, avoiding losses. Outlooks were also developed in response to requests from our stakeholders. We developed outlooks by the climatologists then we worked with commodity specialists and these are disseminated and the commodity extension specialists tend to pick these out and put them in their bulletins, they take the climate outlooks and put them in their bulletins, these get widely used. One thing that we have been struggling with, most of what we've done so far has been looking at seasonal climate variability and as has most of the community, we've been getting a lot of questions about climate change and we've been trying to develop some tools for climate change, this is our first one, a fact sheet, it's been a struggle.

Just to give you an idea of some of things that people like, we have a movie called the Lawn and Garden Moisture Index which is a 4 kilometer by 4 kilometer resolution daily moisture index which is done solely from Doppler radar imagery. We try to do a lot of things with movies because it captures people's attention. We work in a traditional model of, research, extension, and county extension to farmers. We have multi disciplinary research teams, we have extension faculty, and we got commodity extension specialists. The latter are partners rather than part of the SECC. We also work on information delivery through state climatology and extension services, and then we have decision makers. We try to bring everyone together so that the decision makers are engaged from the beginning.

There is a lot that goes on behind the scenes of a project that uses integrated approaches. In order to do all of this, we emphasize the assessment and evaluation. We have a great team of social scientists which goes out and meets with farmers and extension agents, they are the ones

that take this tool and say hey does this help you, is this useful? One of the things is that people say oh, you have someone that goes out and talks to farmers, and that's not true. We all do part of this, but the key is to go out and listen to farmers and that's really what we try to do best and frankly, anthropologists do it better than I do, but I do my best. And so please visit the website.

I did want to take a moment to think out loud a little bit about what might be appropriate for the Midwest. I think it's clear that you have great folks working in the area, and I think a RISA would really be a useful approach for you because it would give you the resources and opportunity that you need to bring everyone together in a more formal fashion. And I see a real opportunity for working together, complementarily and synthesis, and I would encourage you to pursue a RISA program and to make sure you get your climate information applied to the people who are going to use it.

Probabilities of Extreme Climate

Alexander E.
MacDonald,
Director,
Earth
System Research
Laboratory,
NOAA

An important topic
in climate science



Figure 5-23.



Figure 5-24.



Figure 5-25.

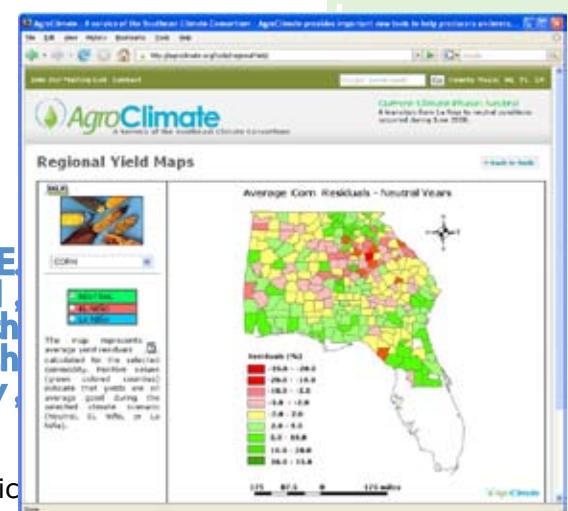


Figure 5-26.

is uncertainty and prediction. Anytime we think about the future, there is uncertainty. If you know what's going to happen with the stock market, please come talk to me – I need to understand better what it's going to do. This year we had Hurricane Ike in the Gulf of Mexico. It could have hit in Mexico, it could have hit in southern Texas. It actually swept over the West Indies and Cuba before finally making landfall in Galveston, Texas. We didn't know exactly what it was going to do up until it arrived. We ran about 20 models and got a spread of results. Some showed a landfall in Galveston, while others put it in Mexico. This example is illustrative, because this is what we face with climate models. We know what the processes are. Really, it's a pretty simple thing—carbon dioxide. You put in carbon dioxide, and part of the heat gets reflected from the atmosphere to the surface. That is simple physics that nobody can argue against. It gets complicated after that, when we put variables into complicated models, but the basic principles are pretty simple. So the question is, "What really is going to happen to our climate?"

Let's talk about the Corn Belt. If you look at Figure 5-27, it shows a change in temperature projection through 2100. There are not a lot of places that get cooler, except for a little place south of Iceland. What stands out in this image are the areas where temperature increases are in the range of 5-10°C (9-18°F). Another thing you notice is that the oceans don't warm as much as the continents, and the Arctic warms much more. That's because of the properties of our Earth system. The Earth, especially the ocean, can absorb a huge amount of heat. You can put a lot of heat into water before it warms up. A solid will heat up faster. And that is what the ocean is doing—it's been incorporating heat down to a mile deep over the last 50 years due to climate change that is already underway.

The first point of this paper is that the evidence that climate change is happening is unequivocal. The second point regards "what is the cause of this climate change?"

People can make it complicated, but I think that when you recognize the general uncertainty of it you realize that at its core it's pretty simple. The third point is "what is the range of predictions?" And here is where the uncertainty issue comes up. If you ask a weather forecaster "what's the high temperature for tomorrow in Ames going to be?" And he (or she) says, "Well, I think it's going to be between 50°F and 110°F." That's not really very useful. But that guy is going to feel good, because he is giving you a "correct" answer. So correct is generally not good enough. We have to think about how specific and how good is this information. Is it credible and reliable? We talk in terms of uncertainty, because anybody who is honest about the future will tell you that forecasts that include the limits of uncertainty are the only correct and complete statements we can make about the future.

There are things we do know about the future with some certainty, and it is fairly shocking what some of the potential changes in climate are. But where there is danger, there is also opportunity. And there is a huge opportunity here. People are recognizing that we have to transform our energy economy. The big question is how fast. You could say the global economy could change in 20 years, and maybe it could be done in 20 years. Or it could be done in 80 years. 80 years is a lot easier than 20 years, and the numbers in this paper speak to that issue.

Climate change is unequivocal. You've heard this many times from a lot of our best scientists. About 98% of the scientists do understand and agree that we're seeing unequivocal changes in the temperatures, and that it's highly likely that they're human-caused. So that's the backdrop. Figure 5-28 is a graph that is similar to ones you've seen elsewhere in this report, but I want to add something here that is important. If you look at the global ocean part of it, what you see is that the surface of the ocean has warmed about 0.65°C ($\sim 1^{\circ}\text{F}$). So that's the surface of the ocean, but the ocean basically takes a lot of that heat and pushes it down low. So there's a whole lot of heat that's gone into the ocean. How does this work? You can do a simple experiment, and in fact students have done this at science fairs. You just take one glass cylinder; you put in a lot of CO₂ and water vapor, which are both greenhouse gases;

you take another cylinder where you don't have any; you put a heat source in the bottom, and then see what happens. The CO₂ reflects the heat back down.

How long has that been going on? Well, it's been going on since the Industrial Revolution, when we first increased the amount of CO₂ in the atmosphere. We started reflecting more heat back down. But it's been getting more serious for about the last 50 years. You can do a simple physics calculation with all the CO₂ that we've put into the atmosphere, and see how much is being returned to the surface. The answer is one watt per square meter. Simple physics. You can then say that if you're really getting that additional watt, what has it done to heat up the ocean? NOAA has gone out and made millions of temperature measurements deep in the ocean. We find that down to about a mile depth the temperature has gone up $1/3^{\circ}\text{C}$ (about $2/3^{\circ}\text{F}$). That heat is exactly what we would have expected. With 50 years of extra heating, the ocean temperature has gone up exactly the amount expected due to the heat added by that CO₂ effect.

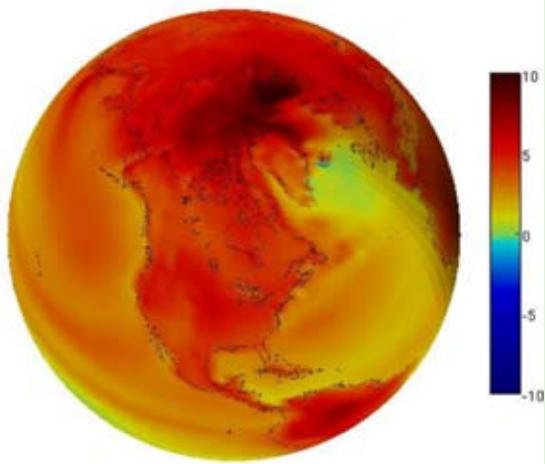


Figure 5-27.

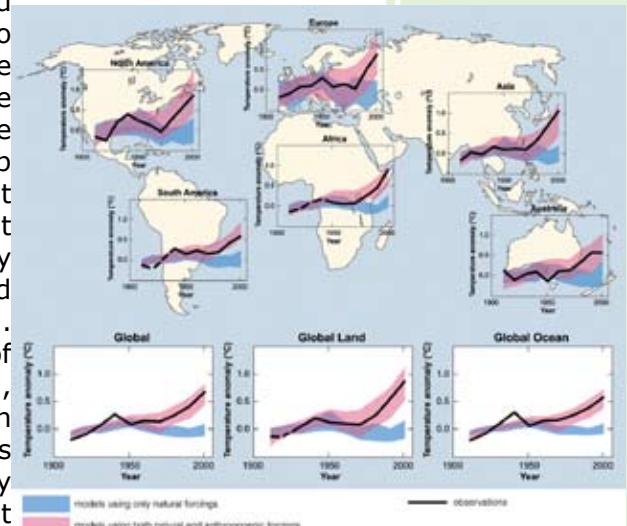


Figure 5-28.

That part is really simple, and you don't need a very complicated model for the future. We can say that with the amount of CO₂ that we are now adding, with the help of India and China, globally, we are now going to be running at two watts per square meter, and by mid-century, three watts per square meter. Thus we are going to double and triple the amount of heat we are putting into the ocean. What that leads to is a 2°C (3.6°F) warming that we should expect.

There is a more complicated model. I don't want to go far on this, but the Earth is an unstable system. Unstable is like you are up on a mountaintop, and you have a beach ball, and you throw it. Does it stay near you? No, it starts to bounce and goes down the mountain. So that is an unstable system. When we look through ice cores,

we see that the Earth is an unstable system. You push it a little bit with less solar heating over the continents at 60°N, due to orbital variations, and you go into an ice age. You push it the other

by some recent estimates, is more than half gone in terms of total mass. Figure 5-30 shows the Arctic sea ice as of 30 August 2008.

I want to emphasize the concept of feedback. When you have an expanse of ice, the ice rejects most of the sunlight that strikes it. Over 90% of it goes straight back out into space. So the Arctic normally acts like a giant refrigerator for the whole planet. What happens when that ice melts? Today the Arctic Ocean is more than 50% open water, so essentially all the sun that shines on that open water gets absorbed as heat. It goes into the ocean, and next year that heat is available to help keep the ocean from freezing again. That is called ice-albedo feedback. It is one of many known feedback cycles involving climate change, most of which are "positive." The idea of positive feedback is that as you increase the Earth's temperature, say due to CO₂, it is going to get warmer than you originally thought.

So we put these feedbacks in our models, Figure 5-31 shows some of the scenarios with various amounts of carbon dioxide. Scenario A1B basically ends up with a fair amount of warming. And these are presented as means of many climate models. So we don't know where that hurricane's going and we don't know exactly what the overall effect will be, but the effect's not small. The mean for the continents is about 40% warmer than the oceans, and if you convert Celsius to Fahrenheit, as shown earlier in Figure 5-27 by the Hadley Center Model, you see that the warmth in the polar regions and also in Iowa, the Midwest and North America and, in fact, all the continents become about ten degrees warmer by the next century than they are now, roughly a degree Fahrenheit per decade if this was just on the exact middle consensus.

Here is where I'm going to challenge you. Figure 5-32 shows a cumulative probability function. The white line is the amount of warming that we would get just from carbon dioxide and nothing else. It would be about 2°C (3.6°F) if we doubled the amount of CO₂ in the atmosphere compared to amounts prior to the Industrial Revolution. Pre-industrial CO₂ was 278 parts per million (ppm), and right now we are at 383 ppm. Doubling it would be about 550 ppm, and we are going to hit double in about 2050. It is very hard to see how we



Figure 5-29.

way, with a little more solar heating at 60°N, not really a lot, and we see in these ice cores that it goes clear back to an interglacial period. So the Earth is an unstable system, and the question is "what happens when we push it?"

Figure 5-29 shows what happened when Mother Nature pushed it a while back. This is a nice summer day 15,000 years ago. Not really a good day for corn in Iowa. How could the climate do this? How could it generate a 2-mile-thick ice sheet that came all the way down in to the Midwest? That's the unstable character of the Earth. You make it a little bit colder with a little less heat, and it generates a 2-mile-thick ice sheet. You make it a little bit warmer, which in

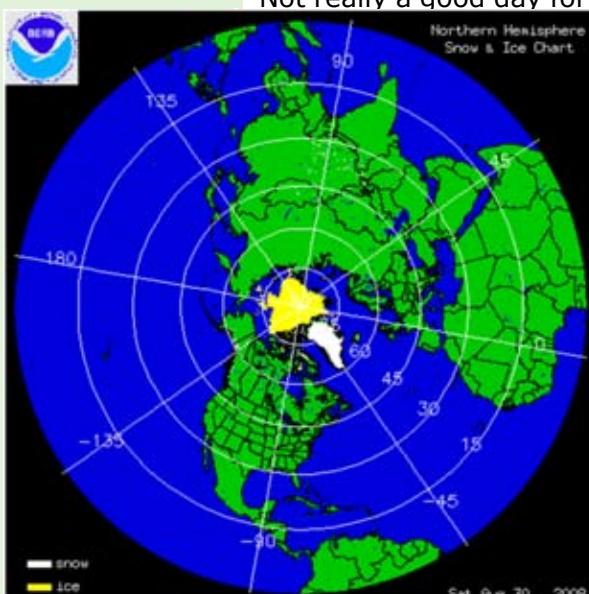


Figure 5-30.

the record we only see with the Milankovitch orbital variations, and the ice all melts. So where are we now with our added CO₂? We are really pushing it. The Arctic ice pack, the ice floating on the Arctic Ocean itself,

would stop from doubling CO₂, given what is happening globally. So what happens if we double it? How much temperature rise are we going to get? The cumulative probability function in the figure shows that because the feedbacks are positive the warming will likely be more than 2°C. It should be maybe as much as 3-5°C (5.4-9.0°F). In fact, there's a 50% chance that it would be 5°C (9°F), a 10% chance that its 10°C (18°F), and about a 5% chance that it is 13-14°C (23.4-25.2°F). That's a big change.

I want to help you to think about cumulative probabilities, so I've converted this figure to corn futures. Think of this as a cumulative probability of corn prices one year from now. The price today is about \$5.40 a bushel. What we can say for the futures market is that we don't know what the price is going to be. It could be as much as \$10 or it could be back to our prices of a few years ago of a couple bucks. You could say that there is a 10% chance on one side for \$2.30 corn and over on the other side is a 10% chance that corn could be \$10 next year. Similarly, this is what we really know about climate change. We don't know the future of what the corn prices next year are going to be and we don't know exactly what is going to happen with a doubling of carbon dioxide. Some of these results, like 10°C or 18°F of temperature rise, are pretty scary. When people talk about doing something about the energy economy and bringing CO₂ under control, it isn't so much that they are so frightened of a 5°F change; I think they are afraid of a much stronger runaway affect on the Earth. It's unlikely, but extremely dangerous, and it's something that has to affect the thinking of our policymakers, whose job it is to protect us.

In terms of summer precipitation, there are a number of the models that show a California type of climate advancing eastward—in other words, wetter winters over much of the northern US, especially north of the 35°N-40°N latitude, and dryer summers. Dryer summers are showing up for a simple reason. When you increase temperature by 5°C (9°F), you are really going to get a high evaporation rate that will dry out the soils. When you get precipitation, like a nice summer Iowa thunderstorm, about half of that is just recycled from the thunderstorm yesterday in Nebraska. In other words, wet soil evaporates moisture back into the

atmosphere and you get another storm. The corn likes it, because it helps it grow. If you bake the soil early on, say in May, it's not there for later in the season. What we are worried about would be both hotter and dryer summers and, perhaps, wetter winters, and that is something that a number of the climate models show, this so-called mid-continental dryness.

MULTI-MODEL AVERAGES AND ASSESSED RANGES FOR SURFACE WARMING

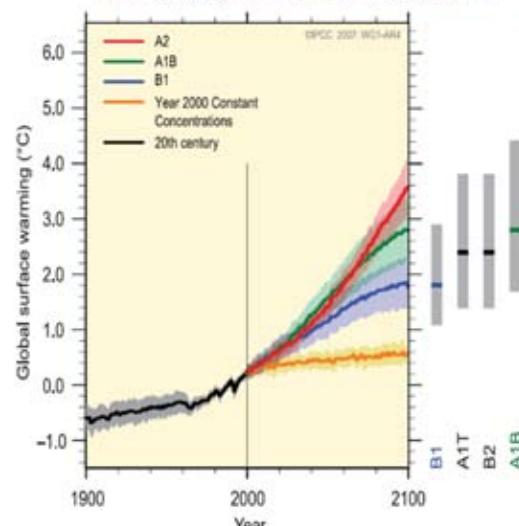


Figure 5-31.

To get a general idea of the possibilities of future extreme climates, Figure 5-33

shows average current annual temperatures (°F). Average annual temperatures are a nice, pleasant 50's in the Corn Belt, and as you go further south, it is warmer, and there are different crops. As you go further west, it is

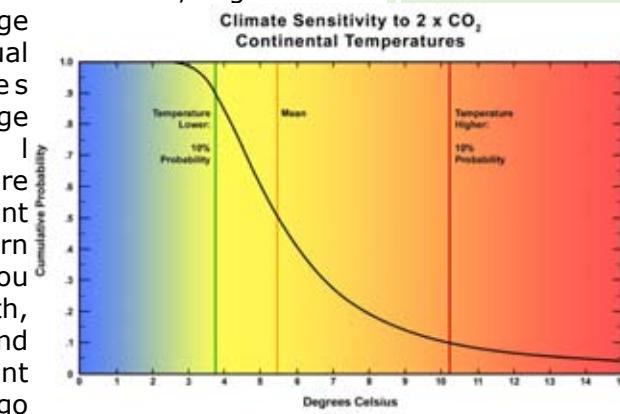


Figure 5-32.

dryer. A way to look at possible climates for Iowa is to look at those areas further south and west that have temperature and precipitation patterns similar to what is predicted for Iowa in the future. The really good scenario is that we only get 2-3°F of warming. The mid-range scenario is that we get 9°F, and the bad scenario is that we get 18°F. So if we are lucky, the Iowa climate could be like northern Kansas—a little bit warmer and a little bit dryer. The mid-range is more like western Oklahoma. Western Oklahoma is significantly drier, especially as you get into the summer, and significantly hotter. It doesn't mean you can't grow crops, but a change over a period of time toward that kind of climate would certainly be something with which our children and our grandchildren would have to deal. If we have 18°F of temperature rise—that 10% chance—it would be quite similar to the area to the northeast of El Paso.

The one message I could leave with you

is that the dangers of climate change are so great that you are going to see a big drive toward non-carbon energy. The

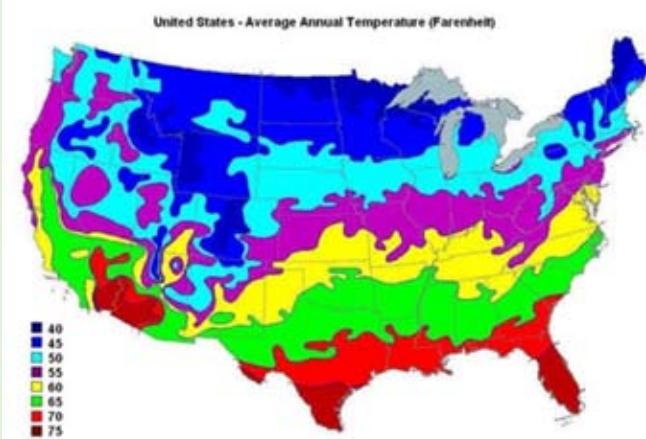


Figure 5-33.

opportunities are that a change in our energy economy could boost the overall economy, and the Midwest is well positioned to help and to benefit. Besides the obvious biofuels contribution, there is a part of the Corn Belt that is in the midst of a region ideally suited for wind power generation, from Nebraska to Minnesota. You can operate with your corn growing below and the wind turbines up above, and this could be a major economic boom for the area.

In summary, climate change is real. It is dangerous, in that it has potential with Earth's unstable systems to push us to even higher temperatures. Or it could be that we end up with less change. Regionally, the slow rise so far seen in the Corn Belt could mean that maybe the western United States, which is already almost 2.5 degrees warmer, could get all the heating, and the east not get as much. That's how climate works. Our responsibility to future generations leads to a natural conclusion that the risk from inaction is too great. That's the news that we can use—that we as a nation and as a world are going to have to do something about climate change.

