Summary of Major Points: Christopher B. Field, PhD[1], Carnegie Institution for Science[2], Energy and Commerce Committee, Subcommittee on Energy and Power: "Climate Science and the EPA's Greenhouse Gas Regulations", March 8, 2011

The modern understanding of climate change is based on many lines of robust, independent evidence, providing a foundation of well established conclusions, including the following, from the US Global Change Research Program: (*1) Global warming is unequivocal and primarily human-induced, (2) Climate changes are underway in the United States and are projected to grow, and (3) Widespread climate-related impacts are occurring now and are expected to increase.*

Against these foundations, I want to talk about the observed (not simulated) climate sensitivity of two important processes – US agriculture and wildfires in the Western US.

- Observed yields of corn, soybean, and cotton all have clear temperature thresholds, below which yields are stable and above which yields fall quickly with rising temperatures. A single day of 104˚F instead of 84˚F reduces corn yields by about 7%. Modest warming over the century is expected to reduce yields by 30-46% below levels that would otherwise occur, and severe warming could reduce yields by 63-82%
- Large wildfires in the Western US are more frequent, last longer, and occur over a longer fire season in years that are unusually warm. Based on observed patterns, a 1.8˚F warming would increase the annual area burned from 1.3 million acres (the average for 1970-2003) to 4.5 million acres.

[1] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the Carnegie Institution for Science or the IPCC
[2] The Carnegie Institution for Science is a not-for-profit organization dedicated to basic research for the benefit of humanity.

Statement of

Christopher B. Field, PhD[3]

Director, Department of Global Ecology

Carnegie Institution for Science[4]

Co-chair, Working Group II of the IPCC

Mailing Address:

Carnegie Institution for Science

260 Panama Street

Stanford, CA 94305

Before the

U.S. House of Representatives

Energy and Commerce Committee

Subcommittee on Energy and Power

“Climate Science and the EPA’s Greenhouse Gas Regulations”

10:00 a.m., March 8, 2011

Room 2123, Rayburn House Office Building

[3] Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the Carnegie Institution for Science or the IPCC

[4] The Carnegie Institution for Science is a not-for-profit organization dedicated to basic research for the benefit of humanity.

Climate Science and the EPA's Greenhouse Gas Regulations

Introduction

I thank Chairman Upton, Ranking Member Waxman, Chairman of the Subcommittee Whitfield, Ranking Member of the Subcommittee Rush, and the other Members of the Committee for the opportunity to speak with you today on observed impacts of climate on important processes in our country. My name is Christopher Field. I am director of the Department of Global Ecology at the Carnegie Institution for Science, a not-for-profit organization dedicated to basic research for the benefit of humanity. In addition, I am a professor in the Department of Environmental Earth System Science and the Department of Biology at Stanford University. Since September of 2008, I have served as co-chair of Working Group 2 of the Intergovernmental Panel on Climate Change. Working Group 2 is tasked with assessing scientific information concerning impacts of climate change, options for adaptation to climate changes that cannot be avoided, and vulnerability to climate change.

My personal research focuses on interactions among climate, the carbon cycle, and ecosystem processes, using approaches that range from ecosystem-scale climate manipulations to global climate models. I have published over 200 peer-reviewed papers in leading scientific journals, and was a coordinating lead author on the topic "North America" for the Working Group 2 contribution to the IPCC Fourth Assessment Report. I have served on many committees of the National Research Council and International Scientific Organizations. I am an elected member of the US National Academy of Sciences and the American Academy of Arts and Sciences as well as an elected Fellow of the American Association for the Advancement of Science.

In today's testimony, I will focus on two aspects of observed sensitivity of important processes to climate. The two processes are agricultural yields in the United States and wildfire in the Western United States. The sensitivities I want to discuss today are based on observations and not on simulations. All of the material I will be discussing today is based on publications in peer-reviewed scientific journals or on national or international assessments of thousands of scientific sources.

Robust Foundations of Current Knowledge

The starting point for the material I want to discuss today is a series of robust conclusions from climate science, synthesized in a number of recent major assessments including two 2010 reports from the US National Academy of Sciences, "Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia" (Solomon 2010), and "Advancing the Science of Climate Change" (Matson 2010), the 2009 report from the US Global Change Research Program, "Global Climate Change Impacts in the United States" (Karl et al. 2009) and the Fourth Assessment Report of the IPCC (IPCC 2007a, c, b). These documents provide a scientifically rich picture of a changing climate, the mechanisms that underlie observed and projected changes, impacts of climate change on individuals, ecosystems, economies, and regions, and the costs and benefits of changing practices to decrease the amount of climate change from a business-as-usual scenario.

The following 10 points, quoted from (Karl et al. 2009), form the foundation for any discussion of climate change and its impacts:

"*1. Global warming is unequivocal and primarily human-induced.*

Global temperature has increased over the past 50 years. This observed increase is due primarily to human induced emissions of heat-trapping gases.

2. Climate changes are underway in the United States and are projected to grow.

Climate-related changes are already observed in the United States and its coastal waters. These include increases in heavy downpours, rising temperature and sea level, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons in the ocean and on lakes and rivers, earlier snowmelt, and alterations in river flows. These changes are projected to grow.

3. Widespread climate-related impacts are occurring now and are expected to increase.

Climate changes are already affecting water, energy, transportation, agriculture, ecosystems, and health. These impacts are different from region to region and will grow under projected climate change.

4. Climate change will stress water resources.

Water is an issue in every region, but the nature of the potential impacts varies. Drought, related to reduced precipitation, increased evaporation, and increased water loss from plants, is an important issue in many regions, especially in the West. Floods and water quality problems are likely to be amplified by climate change in most regions. Declines in mountain snowpack are important in the West and Alaska where snowpack provides vital natural water storage.

5. Crop and livestock production will be increasingly challenged.

Many crops show positive responses to elevated carbon dioxide and low levels of warming, but higher levels of warming often negatively affect growth and yields. Increased pests, water stress, diseases, and weather extremes will pose adaptation challenges for crop and livestock production.

6. Coastal areas are at increasing risk from sea-level rise and storm surge.

Sea-level rise and storm surge place many U.S. coastal areas at increasing risk of erosion and flooding, especially along the Atlantic and Gulf Coasts, Pacific Islands, and parts of Alaska. Energy and transportation infrastructure and other property in coastal areas are very likely to be adversely affected.

7. Risks to human health will increase.

Harmful health impacts of climate change are related to increasing heat stress, waterborne diseases, poor air quality, extreme weather events, and diseases transmitted by insects and rodents. Reduced cold stress provides some benefits. Robust public health infrastructure can reduce the potential for negative impacts.

8. Climate change will interact with many social and environmental stresses.

Climate change will combine with pollution, population growth, overuse of resources, urbanization, and other social, economic, and environmental stresses to create larger impacts than from any of these factors alone.

9. Thresholds will be crossed, leading to large changes in climate and ecosystems.
There are a variety of thresholds in the climate system and ecosystems. These thresholds determine, for example, the presence of sea ice and permafrost, and the survival of species, from fish to insect pests, with implications for society. With further climate change, the crossing of additional thresholds is expected.

10. Future climate change and its impacts depend on choices made today.
The amount and rate of future climate change depend primarily on current and future human-caused emissions of heat-trapping gases and airborne particles. Responses involve reducing emissions to limit future warming, and adapting to the changes that are unavoidable."

Recent Results: Observed Responses of the Temperature Sensitivity of US Agriculture

Globally and in the US, advancements in agriculture are among the crowning accomplishments of human ingenuity. Especially over the last century, yields have increased dramatically (Lobell et al. 2009), more than keeping pace with the growth of human population. One recent analysis concludes that agricultural intensification since 1961 has increased yields so much that the area in crops has not needed to change, even as demand has soared (Burney et al. 2010). As a consequence, intensification of agriculture has prevented deforestation that otherwise would have emitted 161 billion tons of carbon to the atmosphere.

Over recent decades, yields of most major crops have increased at 1-2% per year (Lobell and Field 2007), but an increasing body of evidence indicates that obtaining these yield increases is becoming more and more difficult, as climate change acts to resist or reverse yield increases from improvements in management and breeding. Using global records of yield trends in the world's six major food crops since 1961, my colleague David Lobell and I (Lobell and Field 2007) concluded that, at the global scale, effects of warming are already visible, with global yields of wheat, corn, and barley reduced since 1981 by 40 million tons per year below the levels that would occur without the warming. As of 2002 (the last year analyzed in the study), this represents an economic loss of approximately $5 billion per year.

In the United States, the observed temperature sensitivity of three major crops is even more striking. Based on a careful county-by county analysis of patterns of climate and yields of corn, soybeans, and cotton, Schlenker and Roberts (Schlenker and Roberts 2009) concluded that observed yields from all farms and farmers are relatively insensitive to temperature up to a threshold but fall rapidly as temperatures rise above the threshold. For farms in the United States, the temperature threshold is 84˚F for corn, 86˚F for soybeans, and 90˚F for cotton. For corn, a single day at 104˚F instead of 84˚F reduces observed yields by about 7%. These temperature sensitivities are based on observed responses, including data from all of the US counties that grow cotton and all of the Eastern counties that grow corn or soybeans. These are not simulated responses. They are observed in the aggregate yields of thousands of farms in thousands of locations.

The temperature sensitivity observed by Schlenker and Roberts (Schlenker and Roberts 2009) suggests a challenging future for US agriculture. Unless we can develop varieties with improved heat tolerance, modest warming (based on the IPCC B1 scenario) by the end of the 21st century will reduce yields by 30-46%. With a high estimate of climate change (based on the IPCC A1FI scenario), the loss of yield is 63-82%. These three major crops, in some ways the core of US agriculture, are exquisitely sensitive to warming. This result is very clear. We may be able to breed warming tolerant varieties, and it is possible that some of the yield losses due to warming will be compensated by positive responses to elevated atmospheric CO_2 (Long et al. 2006), but we will be trying to improve yields in a setting where warming is like an anchor pulling us back.

Recent Results: Observed Responses of the Temperature Sensitivity of Wildfires in the Western US

Wildfire is a common threat in the Western US. While historical, low-intensity wildfires can play an important role in sustaining the health of ecosystems (Minnich 1983), large, high-intensity wildfires destroy lives and homes, impact air quality, degrade watersheds, reduce economic activity, and eliminate wildlife habitat. In recent years, suppression costs have been over $1 billion per annum (Littell et al. 2009).

Westerling and colleagues (Westerling et al. 2006) compiled a database of 1166 large wildfires in the US during the period from 1970 to 2003. They observed a large increase in fire frequency, duration, and in the length of the fire season after the mid 1980s. This increase in fire activity was strongly related to warm spring and summer temperatures. Over this period, the length of time from snow-melt in the spring to the first snow-fall in the autumn is a good predictor of the fire risk.

Littell and colleagues (Littell et al. 2009) looked at a longer series of fire records and analyzed the data for relationships with temperature and rainfall. They found that, for most Western ecosystems, climate is a strong predictor of wildfire area burned, with current-year temperature explaining a significant amount of the variability in most regions. The striking feature of these results, based on observations and not simulations is the sensitivity. For most of the West, the annual area burned increases by 200 to over 600% for every 1.8˚F of warming (Solomon 2010). It is only in the driest regions, where warming makes it too dry for fire, that there is not a strong positive response. Based on these observed sensitivities, warming of 1.8˚F is expected to increase the area burned from 1.3 million acres per year (the 1970-2003 average) to 4.5 million acres (Solomon 2010).

Conclusion

Many lines of robust, independent evidence support the conclusion that the climate has been warming over the past century and that human emissions of heat-trapping gases are very likely responsible for much of the warming since the middle of the last century (IPCC 2007d). We are already seeing a wide range of impacts of these climate changes (IPCC 2007e). Although there is scientific uncertainty about the amount of future warming, it is very clear that, unless emissions of heat-trapping gases decrease dramatically, the planet will warm substantially in coming decades. New data on sensitivities, here I have discussed US agriculture and wildfire, emphasize the magnitude of the risk for the United States. Based on observations, not simulations, the sensitivities to warming of both agriculture and wildfire are more than sufficient to cause pervasive regional harm, with even modest warming.

Literature cited

Burney, J. A., S. J. Davis, and D. B. Lobell. 2010. Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences **107**:12052.

IPCC. 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, C.E., Eds. Cambridge University Press, Cambridge, UK.

IPCC. 2007b. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.

IPCC. 2007c. Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2007d. Summary for Policymakers. Pages 1-21 *in* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M.Tignor, and H. L. Miller, editors. Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2007e. Summary for Policymakers. Pages 7-22 *in* M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Karl, T. R., J. M. Melillo, and T. C. Peterson, editors. 2009. Global Climate Change Impacts in the United States. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Littell, J. S., D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. Climate and wildfire area burned in western US ecoprovinces, 1916-2003. Ecological Applications **19**:1003-1021.

Lobell, D. B., K. G. Cassman, and C. B. Field. 2009. Crop Yield Gaps: Their Importance, Magnitudes, and Causes. Annual Review of Environment and Resources **34**:179-204.

Lobell, D. B. and C. B. Field. 2007. Global scale climate–crop yield relationships and the impacts of recent warming. Environmental Research Letters **2**:doi:10.1088/1748-9326/1082/1081/014002.

Long, S. P., E. A. Ainsworth, A. D. B. Leakey, J. Nosberger, and D. R. Ort. 2006. Food for thought: Lower-than-expected crop yield stimulation with rising CO2 concentrations. Science **312**:1918-1921.

Matson, P. 2010. Advancing the Science of Climate Change. National Academies Press, Washington, D.C.

Minnich, R. A. 1983. Fire mosaics in Southern Califonia and Northern Baja California. Science **219**:1287-1294.

Schlenker, W. and M. Roberts. 2009. Nonlinear temperature effects indicate severe damages to US crop yields under climate change. Proceedings of the National Academy of Sciences **106**:15594.

Solomon, S. 2010. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. National Academies Press, Washington, D.C.
Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science **313**:940-943.