Extreme Weather and Climate in a Changing World

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My name is Michael F. Wehner and I am a staff scientist at the Lawrence Berkeley National Laboratory. I am privileged to have been a member of the lead author teams of the U.S. Climate Change Science Program's Synthesis and Assessment 2008 Product 3.3, "Weather and Climate Extremes in a Changing Climate" and the USGRCP 2009 report "Global Climate Change Impacts in the United States". I have also been selected to be a member of the lead author team for Chapter 12 (long term projections) of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change. The statements that I make today are my own and may not represent the views, policies or positions of the United States Department of Energy, the Lawrence Berkeley National Laboratory or the University of California.

Extreme weather and climate events can have serious impacts on human and ecological systems. Changes in the magnitude and frequency of extreme weather associated with changes in the average climate are likely the most serious consequence of human induced global warming. Understanding what the future portends is vital if society hopes to adapt to a very different world.

The definition of "extreme" event is highly subjective. Some types of weather and climate events are extreme because of their rarity. Others types of events are extreme in the context of their impacts. My written testimony will contain examples of both kind of extreme weather and climate events as well as analyses of their projected changes that could impact the United States.

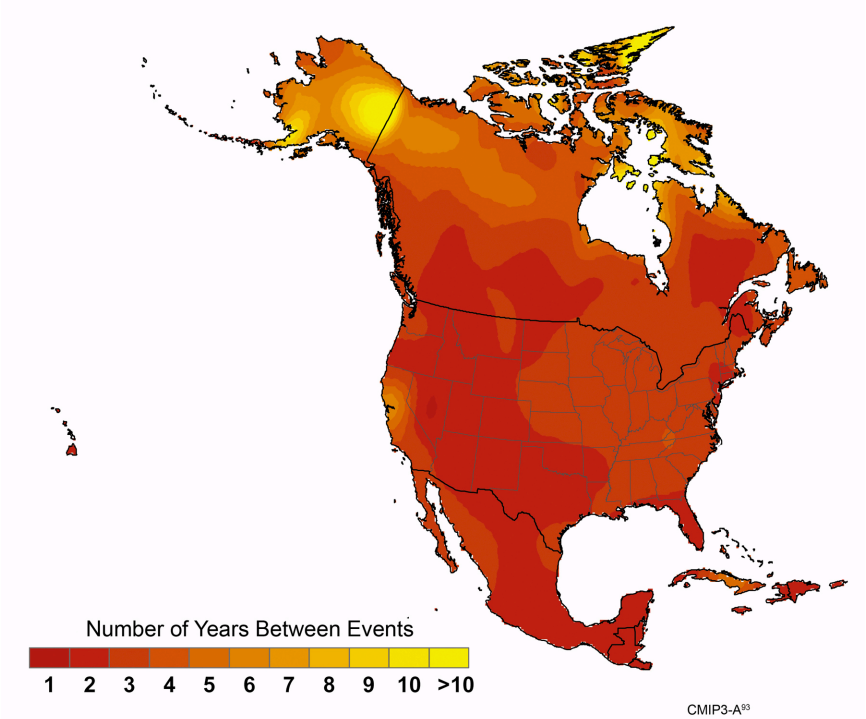
About projections of future climate change

Any projection of the future, whether it be tomorrow's weather, the next century's climate, next month's stock market or even next season's fashion trends, contains elements of uncertainty. Consensus projections of future climate change, are detailed in reports such as the 4th Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) and the United States Global Change Research Program's (USGCRP) 2009 report "Global Climate Change Impacts in the United States". These projections are based on model simulations of the future climate, theoretical considerations, observed changes, if any, and most importantly, the expert judgments of leading scientists in the field. Climate models are often misunderstood by those outside the scientific community. These computer simulations are far from perfect. Nonetheless, they can provide valuable insight into how the Earth's climate system behaves. Climate model projections are most useful when they confirm or reject theoretical expectations. In the testimony below, I will describe some examples of changes in extreme weather and climate events that are robust to both theoretical and model analysis. Sometimes climate

models inform us of phenomena that are not expected and the scientific community gains valuable insights in these cases. Other times, model projections are inconclusive. This could be either due to climate model deficiencies or that the change in that particular aspect of the climate is inconsequential or even unpredictable.

Heat waves.

As average temperatures continue to rise due to the human changes to the composition of the atmosphere, it is very likely that events we currently consider to be heat waves will occur more frequently and be more severe over the course of this century. In fact, events that are currently considered rare will become commonplace. For instance, daily temperatures currently expected to occur about once every twenty years are projected to be experienced as frequently as every other year over large portions of the continental United States by the end of the 21st century if greenhouse gas emissions continue to follow historical trends as shown in figure 1. Likewise, rare events will become more severe. The once in twenty year heat wave at the end of the 21st century in much of North America is projected to be about 10° Fahrenheit warmer than it is now (USGCRP 2009). Evidence that such changes in heat waves is currently underway is compelling. Meehl et al (2009) finds that the number of daily high temperature records are being broken at rates greater than what would be expected if the climate was not changing. Although it is not possible to attribute a single weather event to human causes, it is possible to calculate the fraction of the risk of a particular heat wave to human activities. For instance, Stott, Allen and Stone (2004) calculated that 75% of the risk of the 2003 European summer heat wave was due to human caused greenhouse gas increases.



Simulations for 2080-2099 indicate how currently rare extremes (a 1-in-20-year event) are projected to become more commonplace. A day so hot that it is currently experienced once every 20 years would occur every other year or more frequently by the end of the century under the higher emissions scenario.[91]

Figure 1 (excerpted from the USGCRP 2009 report)

Intense precipitation.
Accurate simulation of precipitation presents a much more difficult problem to climate models than does temperature. It has recently become clear that the relatively crude spatial fidelity of the global climate models prepared for the IPCC AR4 limits the faithful reproduction of the most intense storms over the United States (Wehner, et al 2010a). However, the substantial Federal investment in high performance computers is rapidly advancing our ability to perform the high-resolution simulations necessary to produce intense precipitation. The North American Regional Climate Change Assessment Program (NARCCAP) is a coordinated multi-model high-resolution numerical simulation focusing on present and future North American climate. Preliminary analysis suggests that the RCM3 model accurately simulates observed rare intense precipitation. Figure 2 shows this model's projected percentage change at the middle of this century in the magnitude of winter storms expected about once every twenty years over the continental United States. This model, driven by greenhouse gas increases consistent with a "business as usual" scenario, suggests that increases of 25% or more could be widespread over much of the midwestern and eastern states. Caution should be exercised in the interpretation of this figure. This projection comes from a limited set of simulations causing the detailed structure to be quite uncertain. Nonetheless, the projection reinforces the theoretical expectations that a warmer atmosphere can contain more water vapor causing extreme precipitation events to be more intense.

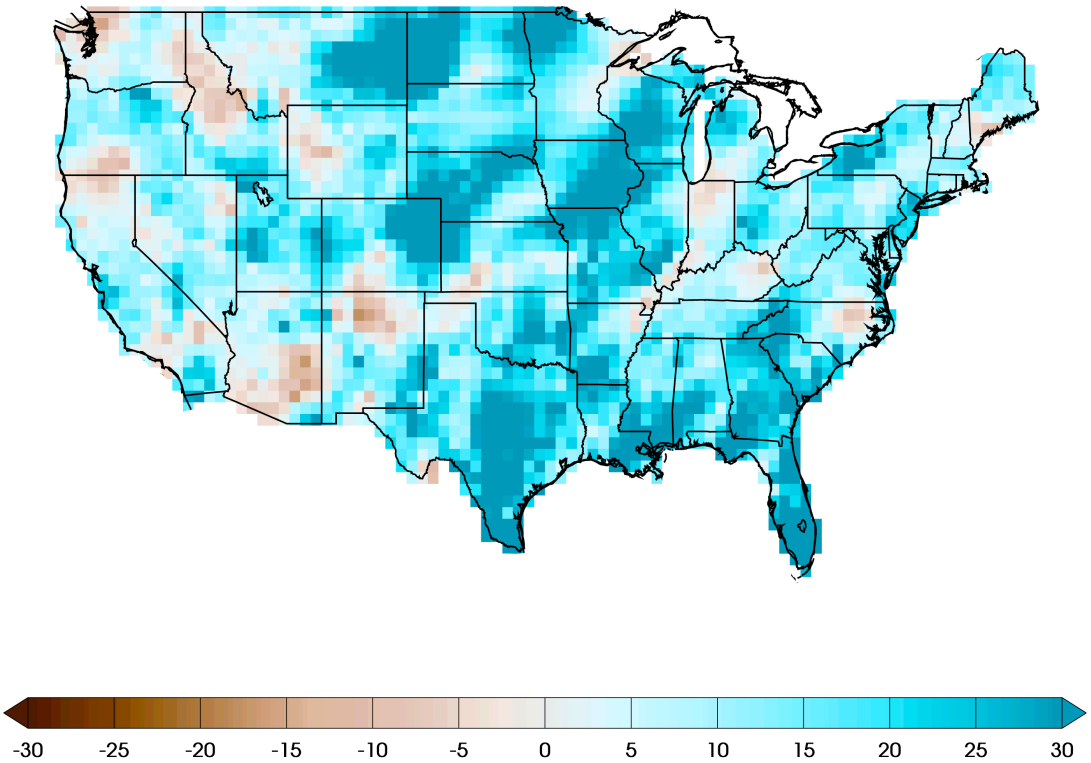


Figure 2. The projected percentage increase in wintertime daily precipitation expected once every twenty years at the middle of this century relative to present.

Drought

There are several different measures of drought, each targeted to specific interests. For instance, water resource managers may be concerned with the amount of water flowing into reservoirs while farmers may more interested in the amount of water available in the soil for their crops. One commonly used measure of soil moisture drought is the Palmer Drought Severity Index (PDSI). There is emerging evidence that global drought severity as measured by PDSI is increasing due to human changes to the composition of the atmosphere (Burke, et al 2006). Recent calculations suggest that this trend will continue over the course of this century in North America. Figure 3 shows a multi-model projection of this drought index at the end of the 21st century under a "business as usual" greenhouse gas emission scenario. The National Climatic Data Center classifies values of this index less than negative two as "drought", values less than negative three as "severe drought" and values less than negative four as "extreme drought". This projection exhibits widespread drying out of soil moisture across North America. Much of the western United States would experience severe drought conditions and much of southern Mexico would experience extreme drought as a new "normal" condition. Yet drier conditions on shorter time scales would frequently occur. This projection reinforces the theoretical expectation that evaporation increases due to warmer temperatures will tend to decrease soil moisture. In fact, although much of the northern United States and Canada are robustly projected to experience increases in precipitation, projected increases in evaporation are yet larger, causing drought to be projected even in these regions.

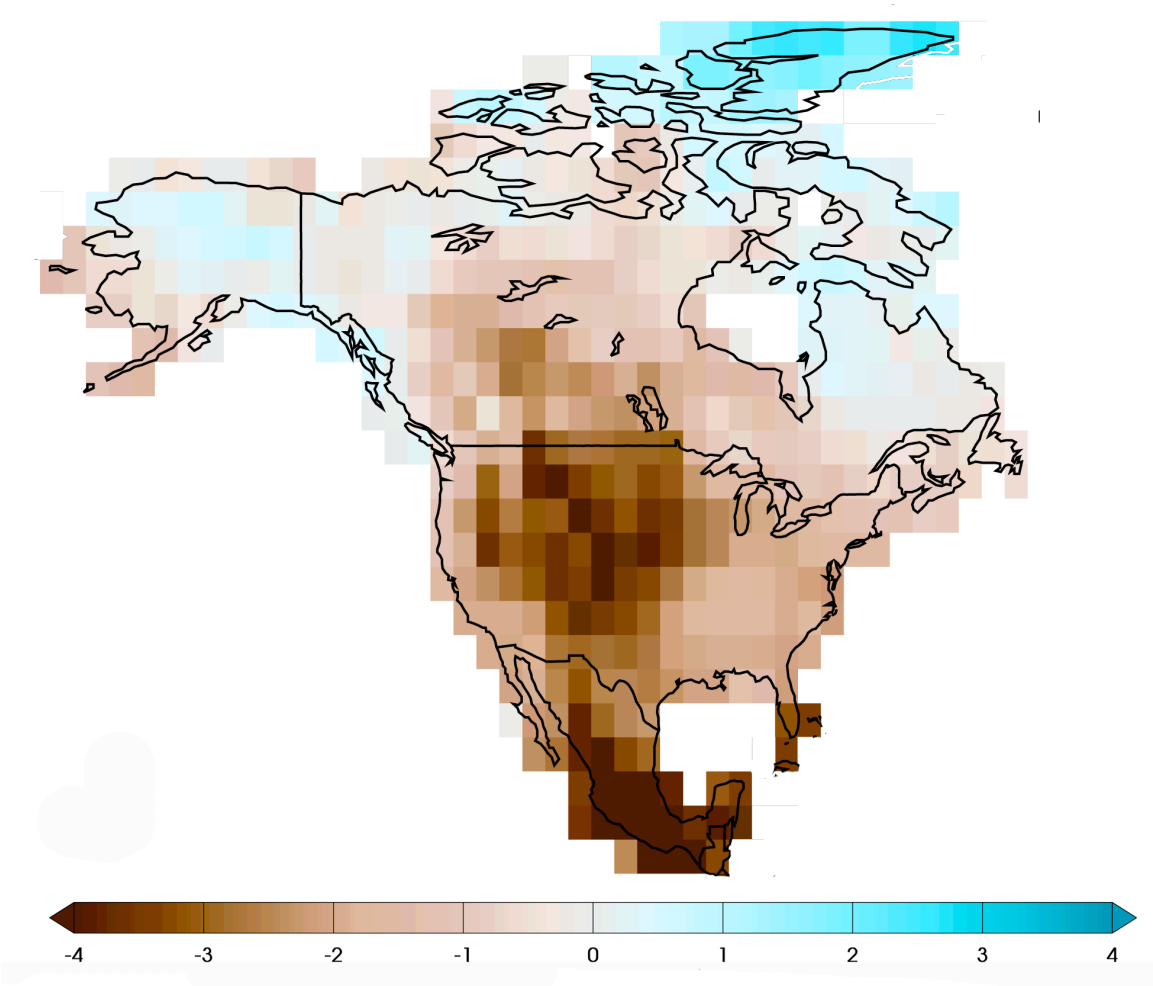


Figure 3: A multi-model projection of the average Palmer Drought Severity Index at the end of this century consistent with a "business as usual" greenhouse gas emissions policy (Wehner, et al 2010b).

Tropical Cyclones

Hurricanes are not rare events as they occur every year. However, their impacts can be extreme, especially for intense hurricanes (categories 4 and 5 on the Sapphir-Simpson scale). The effect of climate change on hurricanes and tropical storms is presently undergoing intense scientific scrutiny and many questions remain unanswered. Direct numerical simulation of tropical cyclone global statistics has recently been made possible by the aforementioned Federal investments in high performance computing. An emerging consensus view from this class of simulation is that the frequency and severity of intense hurricanes could increase as the Earth warms (Oouchi, et al. 2006, Bengtsson, et al. 2007, Knutson, et al. 2008, Bender et al. 2010, Wehner et al 2010c). This projection is consistent with the theoretical expectation that storms forming under conditions conducive to intensification would be more likely to experience ocean temperatures high enough to permit 130 miles per hour winds. A projection of the total number of future tropical cyclones in all categories across the Earth is less certain. Most of the aforementioned studies suggest little change or a slight decrease in the global frequency

of tropical cyclones. However, at least two studies (Federov et al 2010 and Wehner et al 2010c) project substantial increases in the global frequency of tropical cyclones. This field of research promises to be interesting for some time to come.

Summary

Projected future changes in extreme weather and climate events in a warmer world are sobering. The cost and impacts of even small increases in the severity of these phenomena can be large. More severe heat waves, more intense precipitation events, longer and more severe drought and more intense hurricanes are all likely to be experienced in the United States as the global climate warms. Model simulations of the Earth's climate are far from perfect. However, recent advances in high performance computing are rapidly improving climate models' ability to simulate extreme event statistics. As a result, scientific understanding and confidence in projections of future extreme weather are also rapidly increasing.

References

Bender, M.A., T.R. Knutson, R.E. Tuleya, J.J. Sirutis, G.A. Vecchi, S.T. Garner, I.M. Held (2010) Modeled Impact of Anthropogenic Warming on the Frequency of Intense Atlantic Hurricanes, Science 327 454-458

Bengtsson, L., K.I. Hodges, M. Esch, N, Keenlyside, L. Kornblueh, J-J. Luo, T. Yamagata (2007) How may tropical cyclones change in a warmer climate?, Tellus 59a, 539-561

Burke, E. J., Brown, S. J., Christidis, N. Modeling the Recent. Evolution of Global Drought and Projections for the Twenty-First. Century with the Hadley Centre Climate Model, J. Hydrometeor. 7, 1113-1125 (2006)

Knutson, T.R, J.J. Sirutis, S.T. Garner, G.A. Vecchi, I.M. Held (2008) Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions, Nature Geosci. 1, 359-364

Alexey V. Fedorov, Christopher M. Brierley, Kerry EmanuelTropical cyclones and permanent El Niño in the early Pliocene epoch (2010) Nature 463, 1066-1070 doi:10.1038/nature08831

Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). (2009) Cambridge University Press, 2009. globalchange.gov

G. Meehl, C.Tebaldi, G. Walton, D. Easterling, and L. McDaniel (2009), The relative increase of record high maximum temperatures compared to record low minimum temperatures in the US, Geophys. Res. Lett., 36, L23701, doi:10.1029/2009GL040736

Oouchi K., J. Yoshimura, H. Yoshimura, R. Mizuta, S. Kusonoki, A. Noda (2006) Tropical Cyclone Climatology in a Global-Warming Climate as Simulated in a 20 km-Mesh Global Atmospheric Model: Frequency and Wind Intensity Analyses. J. Meteor. Soc. Japan 84(2): 259

Peter A. Stott, D. A. Stone & M. R. Allen (2004) Human contribution to the European heatwave of 2003, *Nature* 432, 610-614 (2 December 2004) | doi:10.1038/nature03089

Wehner, M.F. ,R. Smith, P. Duffy, G. Bala, (2010a) The effect of horizontal resolution on simulation of very extreme US precipitation events in a global atmosphere model. *Climate Dynamics* **32**, 241-247, doi 10.1007/s00382-009-0656-y

Michael Wehner, David R. Easterling, Jay H. Lawrimore, Richard R. Heim Jr., Russell S. Vose, Benjamin Santer (2010b) Projections of Future Drought in the Continental United States and Mexico. Submitted to *Journal of Hydrometerology*

Michael F. Wehner, G. Bala, Phillip Duffy, Arthur A. Mirin, and Raquel Romano (2010c), "Towards Direct Simulation of Future Tropical Cyclone Statistics in a High-Resolution Global Atmospheric Model," Advances in Meteorology, vol. 2010, Article ID 915303, 13 pages, 2010. doi:10.1155/2010/915303