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## **The Nature of Climate Science for the Rocky Mountain West: Implications for Economists Trying to Help Agriculture Adapt**

Christopher T. Bastian, Stephen T. Gray, Dannele E. Peck, John P. Ritten, Kristiana M. Hansen, James M. Krall, and Steven I. Paisley<sup>1</sup>

### **Introduction**

Climate change may impact the economic viability of farms, ranches and agricultural communities in multiple ways. Climate change will likely increase evaporation and water loss from plants, thereby increasing drought severity while also creating the potential for more frequent droughts (Karl et al., 2009). Drought impacts in the West will likely be amplified as declines in mountain snowpack affect runoff, water storage, and irrigation. Increased pest outbreaks, disease, and extreme weather will also pose critical challenges for crop and livestock production (Karl et al. 2009).

There have been literally hundreds of papers published on climate change and its potential effects. McCarl (2010) concludes there are still many gaps in the literature related to climate change impacts, climate change adaptation, and climate change mitigation analysis. He notes a need for greater identification of regionalized adaptation strategies and for communicating these strategies to stakeholders through outreach efforts. Similarly, Antle and Capalbo (2010) state that investments must be made to reduce the uncertainty about the value of adaptive alternatives for agriculture. In recognition of these needs, the United States Department of Agriculture's Agriculture and Food Research Initiative Competitive Grants Program has increased its emphasis on research and related outreach education regarding agriculture and its ability to adapt to, or mitigate, climate change (see <http://www.nifa.usda.gov/funding/rfas/afri.html>). As agricultural economists increase their research and outreach efforts on climate issues, understanding the nature of climate science as an input into regional and localized economic analyses will be critical if such efforts are going to have a positive impact. The uncertainty associated with the current state of climate science will be particularly challenging for agricultural economists working in the Rocky Mountain West.

### **Trend Analysis and Modeling Uncertainties**

Many previous studies have focused on changes in average conditions over time (see for example Adams, Hurd and Reilly, 1999; Karl et al. 2009). The use of mean conditions originates from approaches adopted by the Intergovernmental Panel on Climate Change (IPCC) that depict climate change as a more-or-less linear trend over the next 50 to 100+ years, or as a snapshot of conditions at some point in the future (e.g., climate averaged over the period from 2040-2060). In many cases these approaches also involve the examination of "ensemble" averages or other summary values intended to capture the consensus of projections. Likewise, IPCC-type assessments and related datasets almost invariably center on climate change at

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<sup>1</sup> Authors are, respectively, associate professor, Department of Agricultural and Applied Economics, University of Wyoming; Director, Alaska Climate Science Center, University of Alaska – Fairbanks, Anchorage; assistant professor, assistant professor and agricultural systems specialist, assistant professor and water resources specialist, Department of Agricultural and Applied Economics, University of Wyoming; professor in the Department of Plant Sciences and Director of Research Sustainable Agricultural Research and Extension Center – University of Wyoming; and, associate professor and beef cattle specialist, Department of Animal Science, University of Wyoming. Bastian is the corresponding author. His e-mail address is [bastian@uwyo.edu](mailto:bastian@uwyo.edu).

regional to continental scales. Thus, a focus on ensemble average outcomes at the regional or continental scales may create issues for decision making at finer or more local scales.

Because these coarse-resolution datasets are the most well-known and readily available sources of climate-change related information, many earlier economic analyses have also tended towards a “broad-brush” approach. Economic work building on this IPCC-type spatial and temporal framework has, in turn, offered a great deal of insight into the urgency of many climate change issues, and provided a general sense of how climate change might impact wide geographic areas or large segments of the economy. It is extremely difficult to apply lessons from these assessments at the local spatial or specific enterprise level, which is essential for agricultural adaptation. A broad-brush approach ignores key aspects of climate change *and* climate variability at finer scales. This general approach presents an overly simplistic picture of the adaptation and mitigation challenges agriculture may face.

The concept of climate change as a linear trend can be useful in some applications. Climate is the sum of myriad interactions between the oceans, atmosphere and land surface, all of which occur over a variety of spatial and temporal scales. These interactions also take place within the context of internal events such as periods of volcanism, and external forces such as changes in solar output. Treating climate change as a trend allows distillation of these factors into key elements, and the resulting visual depictions are often striking and broadly accessible. Moreover, they can provide vital input for broader policy relevant analyses.

Unfortunately, the simple climate trend model neither provides a practical, operationally-relevant portrayal of the future conditions that producers are likely to face nor captures the range of potential changes that producers should expect. First, the simple trend fails to capture climate variability over multi-year to multi-decadal timescales. Numerous studies using actual observations from the past ~150 years and paleo-proxy data (e.g., tree-rings, lake sediments, etc.) stretching back 10,000 or more years show that regional climates tend to fluctuate between predominately wet and dry or predominately cool and warm conditions over periods of roughly 10-60 years (Cook et al. 2004; Gray et al. 2004). At times, the magnitude of these inherent fluctuations can equal or exceed expected changes in mean climate over the next 50-100 years (Figure 1). In the western United States, the resulting drought and wet phases have been a defining feature of regional climates, and the resulting consequences for ecosystems and agriculture have been enormous (McCabe et al. 2008).

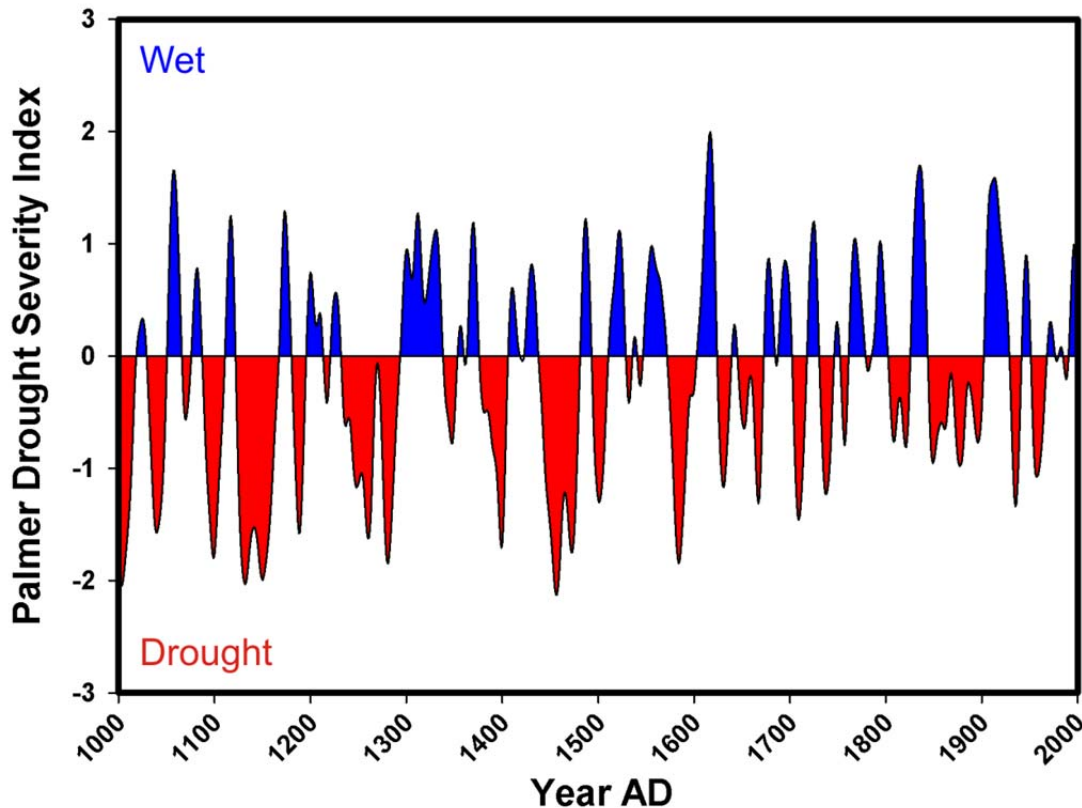


Figure 1. Reconstructed Palmer Drought Severity Index values for southeastern Wyoming. The reconstruction is based on tree-rings (Cook et al. 2004), and the values have been smoothed with a 20-year moving average. This 1,000 year record shows marked decadal to multidecadal variability that results in persistent drought (negative values) and wet (positive values) regimes through time.

Such “D2M” (decadal to multidecadal) variability results from a complex set of drivers. Much of this activity originates from processes related to ocean circulation and the associated movement of heat from the equator towards the poles. Given the nature of these processes, the D2M-type variability that has always brought the Rocky Mountain West persistent droughts or periods of frequent flooding is likely to be in operation for the foreseeable future. This means that future climate maybe a blend of significant portions of greenhouse-gas induced trends as well as climate regimes that shift over multi-year or longer periods. This combination expands the potential range of conditions agricultural producers may face (Figure 2). This outcome is important when one considers how inherent variability has the capacity to amplify anthropogenic trends (or vice versa).

Consider a general trend towards increasing summer aridity and inherent D2M variability leading to a major drought-prone phase. The consequences would likely include severe, sustained droughts outside the range of anything in the historical record or most climate-change projections. Conversely, D2M variability that moves toward the wet end of the spectrum for 5, 10 or 15+ years might serve to temporarily mask the overall impacts of broader scale climatic changes.

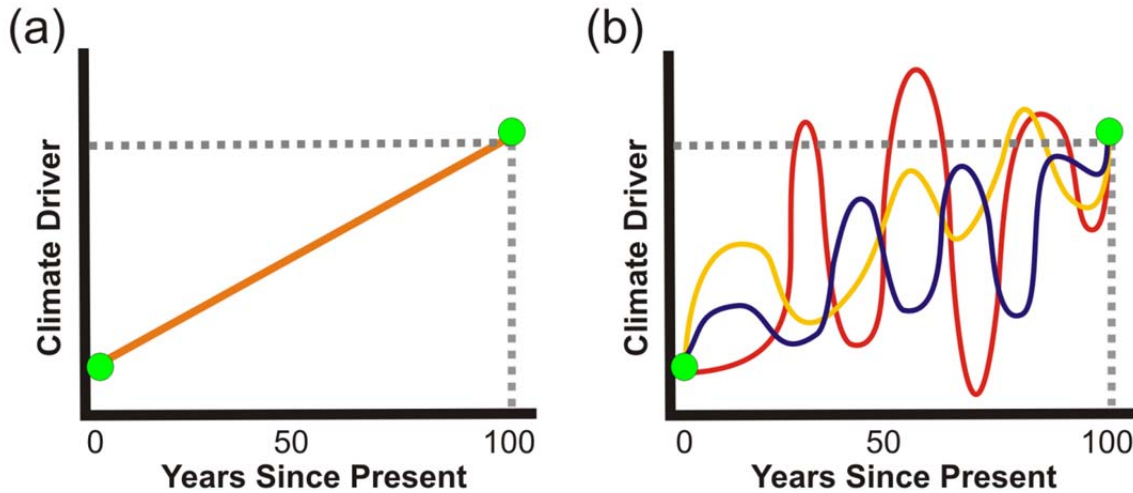


Figure 2. Conceptual diagrams showing a) future climate as a simple trend through time and b) future climate as a combination of greenhouse gas induced trend and inherent decadal to multidecadal (“D2M”) variability (after Gray et al. 2006). As shown on the right, adding different manifestations of D2M variability to the long-term anthropogenic trend greatly expands the range of potential climates that producers might face.

Further complicating matters is the fact that climate change projections themselves are associated with a tremendous amount of uncertainty. Climate predictions indicate, unequivocally, that the Earth will continue to warm for the foreseeable future (IPPC 2007). However, accurately estimating the rate and magnitude of potential warming at finer scales is exceedingly difficult. Consider the case of southeastern Wyoming. Comparisons between 16 different climate models running under various emissions scenarios, which are impacted by differing population and economic assumptions, yield a  $12^{\circ}$  F divergence between projections for low- and high-end warming by 2050 (Figure 3).

Ongoing warming will have significant impacts on processes that control storm tracks and other key aspects of precipitation delivery (e.g., El Niño/La Niña). Uncertainties multiply rapidly reducing confidence in the sign of future precipitation changes. Additional heating may alter the frequency and intensity of precipitation, storms and extreme events such as heat waves and cold-air outbreaks (Diffenbaugh et al. 2005; Trapp et al. 2007, 2009). Until models can better resolve storms, cloud formation processes and local land-surface to atmosphere feedbacks, the specifics of these changes remain highly tenuous.

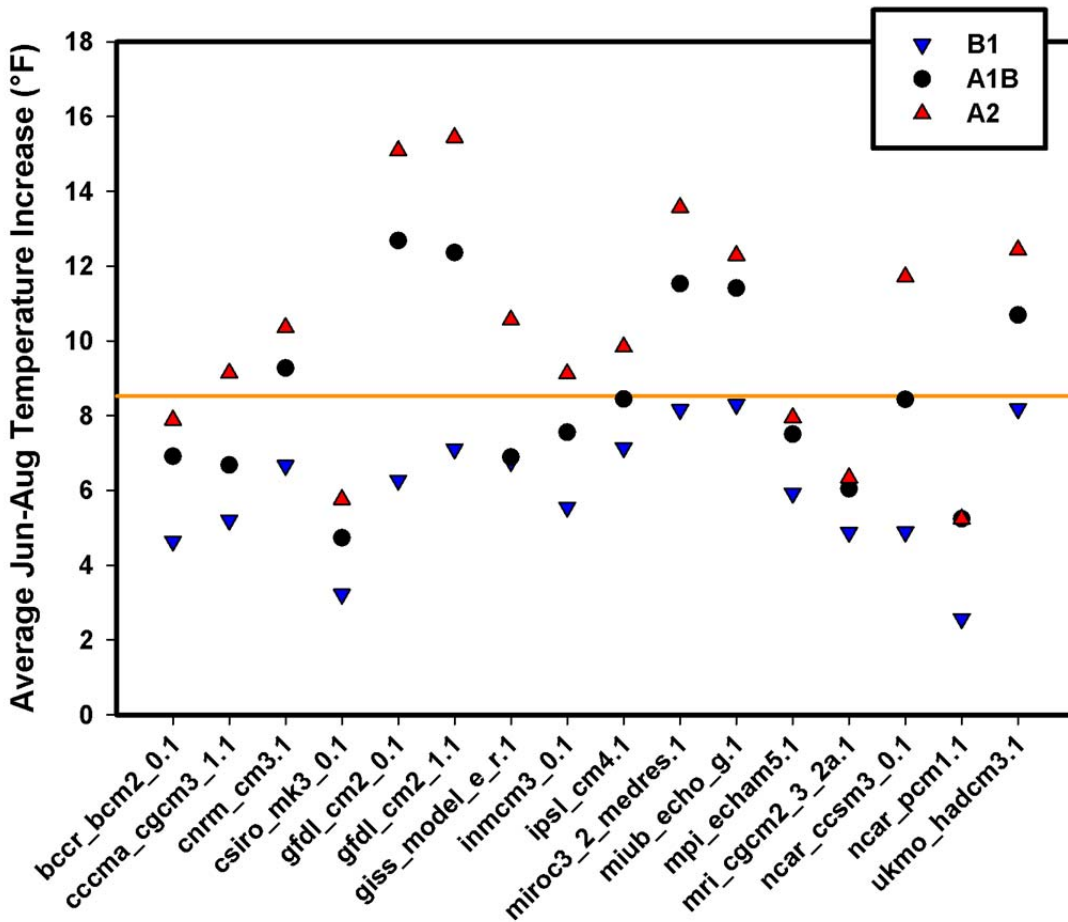


Figure 3. Range of future temperature projections for southeastern Wyoming (after Maurer et al. 2007). Projections are drawn from a set of 16 global circulation models, and results have been downscaled to 4 km resolution. Each model is also run under three different emission scenarios (IPCC 2007), with the B1, A1B and A2 scenarios representing low, medium and high emissions, respectively.

Emissions scenarios—the very foundation of future climate projections—are themselves highly uncertain. The underlying economic, political and demographic factors that control the consumption of fossil fuels are immensely complex and interconnected. At the same time, releases of greenhouse gases from melting permafrost, logging of tropical forests, and other terrestrial sources of carbon are not fully accounted for in these scenarios. Other issues such as the capacity for the world’s oceans to serve as sinks and sources for carbon remain unresolved.

**Rocky Mountain West as a Case Example**

In the early 2000’s coarse-scale general circulation models (GCMs) provided output with a resolution measured in degrees of latitude and longitude. This meant that major topographic features such as the Sierra Nevada and Rocky Mountains were not adequately depicted creating an inability to differentiate between valley bottoms and the high country. Efforts since the IPCC Fourth Assessment Report (2007) have brought some improvements in the resolution

of GCMs. Recent years have featured major advances in downscaling which is a family of techniques that translates GCM output into finer-resolution projections. These advances include the use of regional scale, process-based models that can be used to better explore the interactions between climate and local topography (e.g., Salathe et al. 2010), as well as, efforts aimed at understanding future climatic extremes such as heat waves or flood-inducing precipitation events (e.g., Rosenberg et al. 2010). As such, downscaling and related research is beginning to provide a glimpse into climate change processes at scales, and of the types, most relevant to producers. However, these techniques do not necessarily improve the accuracy of long-term projections. Downscaling cannot necessarily correct inherent problems in the global models. The potential resulting “multiplication of errors” can lead to additional uncertainty in-and-of itself. While downscaling offers one of the best means for exploring how climate change might play out over “real world” terrain, such processes still have many important limitations. This is especially true for the Rocky Mountain West. Despite these limitations, predictions from these downscaling techniques provide the best available climate forecasts for the region.

While future warming is considered to be virtually certain in the Rocky Mountain West, precipitation projections are still highly uncertain for reasons discussed (Mearns et al. 2005). Median estimates from the 21 climate models used in the IPCC’s (2007) Fourth Assessment Report suggest 2 to 5% increases in winter precipitation over the area while spring and summer precipitation may decrease by 3.5 to 7% by 2050. However, regional downscaling exercises (e.g., Maurer et al. 2007) show that the range on these predictions is very large, with winter wetting sometimes increasing by 10%, and summer conditions ranging from no change to a 15-20% reduction in spring and summer precipitation. A growing number of studies also suggest that climate change may bring increased variability in precipitation that might be manifested as changes in storm frequency and severity (e.g. Trapp et al. 2007), as well as enhanced interseasonal and interannual variability (Leung et al. 2003). Significant model uncertainty remains (IPCC 2007), and the potential magnitude of such changes is likely to vary significantly at the sub-regional level (Trapp et al. 2009). Moreover, this uncertainty in outcomes regarding model predictions and magnitude of change is exacerbated by the potential variability in microclimates across the region. Changes in the amount, timing, frequency and duration of precipitation are likely to have profound implications for agricultural production in the region.

Increasing temperatures will likely bring a suite of consequences for water users in the Rocky Mountain West, including earlier and faster spring runoff, and diminished late-season flows (Stewart et al. 2004). Among these impacts, warmer temperatures could have some of the greatest effects on water supply vulnerability by altering the timing of snowmelt. When compared to historical averages, a clear trend toward earlier spring runoff has already been recorded in the Sierra Nevada Mountains of California, as well as the Cascade ranges in Oregon and Washington (USGS 2005, Stewart et al. 2004). During recent drought years in Wyoming, runoff was earlier and faster in many parts of the state. If early runoff becomes commonplace in the future, storing water for the Rocky Mountain West and downstream users could become more challenging. In short, a rapid or “flashy” runoff could limit the ability of reservoir managers to balance flood control and storage. Moreover, an early runoff inevitably leads to diminished late-season flows, which are crucial to a wide variety of agricultural users, as well as municipal, industrial, and environmental uses.

Increasing temperatures will also bring increased evaporative losses from lakes, streams, wetlands and from terrestrial ecosystems (Arnell 1999). This aspect of climate-change may be especially difficult for water users to cope with because it would occur at the same time agricultural producers require more water for irrigation (Brikowski 2007). Increasing temperatures will also significantly intensify the types of dry events seen in the historical record,



and might even bring about a new type of climate where conditions we previously thought of as “drought” become the norm (Seager et al. 2007).

### **Implications for Economic Analyses and Outreach Education**

Climate change predictions for the Rocky Mountain West indicate potential for increased temperatures, variability in precipitation and irrigation supplies, and frequency in drought events. The variability in these projections relevant to the region is significant. Thus, to be relevant at the finer regional or localized scale, economic analyses will need to incorporate a relevant suite of climate alternatives rather than a predicted “average” scenario as the uncertainty of the average occurring may provide erroneous information for decision making. Climate science scenarios will have to be developed that can provide a broad range of potential outcomes that will define constraints such as water for irrigation, yields, growing seasons, and grazing days. This will be exacerbated by the inability of climate science predictions to provide reasonably accurate probabilities associated with potential outcomes. Thus, agricultural economists will need to further develop techniques being reported in the recent literature designed to capture non-linear trends (see for example Schlenker and Roberts 2006) and/or simulation techniques coupled with stochastic programming (see for example Peck and Adams 2010; Ritten et al. 2010) to capture uncertainty in key parameters or constraints and a range of possible outcomes.

Another challenge facing economists doing such analyses may be a lack of accurate data regarding production responses and economic variables across a broad range of climate scenarios. Crop scientists have been investigating production technologies and new cultivars for the Rocky Mountain West (see for example Krall et al. 2007), but yields for a broad range of climate scenarios may not be well understood. Performance of individual cultivars over a broad range of conditions may be especially important to understand if climate change causes temperatures and precipitation to become more variable (i.e., if extremes become more extreme, not just more frequent).

Adams and Peck (2008) explore the effects of changes in drought frequency versus drought severity. They assume farmers produce the same general suite of crops and simply adjust the proportion of various crops in their rotation as well as their irrigation technologies or management. The authors found more extreme drought (holding frequency constant) was more damaging than more frequent drought (holding severity constant). Thus, understanding how crops may perform under scenarios of increased extreme events may be more important than average events.

Ritten et al. (2010) find that stocking rates and resulting profitability are more impacted by variability in precipitation than changes in mean precipitation. They suggest their study is limited by not addressing the potential change in range forage species composition and quality under climate change. Other issues from climate change could impact livestock performance as well. Less severe winters, for example, could allow disease vectors, such as ticks and parasites (intestinal helminthes), to overwinter more successfully, leading to higher disease rates in livestock. Changes in runoff patterns and or flooding could change mosquito dynamics and influence diseases such as bluetongue and West Nile virus, for example.

Crops might also be impacted by similar disease issues brought on by climate change. Additionally, finding appropriate price data for alternative niche crops or crops new to an area may be difficult. As extreme weather such as long term drought events become more frequent, factor markets for both inputs (for example feed) and outputs related to agricultural production may change, impacting both variability and means of relevant price series for economic models.



Economic models will have to be dynamic. Many possible scenarios will have to be analyzed to capture a relevant range of potential outcomes for agriculture which may include changes in both variability and means of relevant production and economic variables. Analyses will have to be systems oriented to address most potential issues impacting production and economic outcomes. For example, irrigation water availability for crops or spring precipitation for range will likely be impacted. Thus, models relating precipitation or snowpack to resulting irrigation supplies may need to be developed to feed into production or yield models that then feed into economic models.

The ability of agricultural firms to adapt to climate change in a timely fashion is likely complicated by the fact that at local to regional scales, and on time frames of several years, natural climate variations can be relatively large and temporarily mask the progressive nature of global climate change (Karl et al. 2009). This masking of climate change phenomena at the local and regional level is likely coupled with potential skepticism of climate change by many agricultural producers. This will pose an additional challenge as agricultural economists offer regionally relevant outreach education from research that will likely provide an array of potential outcomes. Outreach efforts will have to engage producers as part of an initial assessment of beliefs and concerns regarding climate change as well as relevant alternatives given the broad suite of potential climate predictions at the local level. Thus, once engaged in the process, research results could help producers assess the following:

- 1) whether or not production strategies and policies in place today would be adequate under a wide range of potential climatic changes;
- 2) how changing production costs or shifting product demand might interact with climatic variability and change; and
- 3) how various adaptation strategies might (or might not) be viable across a wide range of potential climatic and economic futures.

This should help agricultural producers decide for themselves how best to adapt given their resources and assessment of potential outcomes for their operations.

### **References**

- Adams, R.M. and D.E. Peck. 2008. "Effect of climate change on drought frequency: potential impacts and mitigation opportunities." In Garrido, A. and A. Dinar (eds) *Managing water resources in a time of global change: mountains, valleys and flood plains*. New York: Routledge, pp. 117-130.
- Adams, R. M., B. H. Hurd, and J. M. Reilly. 1999. *Agriculture and global climate change: a review of impacts to U.S. agricultural resources*. The Pew Center on Global Climate Change, Arlington, VA, USA.
- Antle, J.M., and S.M. Capalbo. 2010. "Adaptation of agricultural and food systems to climate change: An economic and policy perspective." *Applied Economic Perspectives & Policy*, 32(3): 386-416.
- Arnell, Nigel W. 1999. "Climate change and global water resources." *Global Environmental Change*, 9:31-49.

Brikowski, T. H. 2008. "Doomed reservoirs in Kansas, USA: Climate change and groundwater mining on the Great Plains lead to unsustainable surface water storage." *Journal of Hydrology*, 354:90-101.

Cook, E.R., C.A. Woodhouse, C.M. Eakin, D.M. Meko and D.W. Stahle. 2004. "Long-term aridity changes in the western United States." *Science*, 306:1015-1018.

Gray, S.T., C. Fastie, S.T. Jackson and J.L. Betancourt. 2004. "Tree-ring based reconstructions of precipitation in the Bighorn Basin, Wyoming since A.D. 1260." *Journal of Climate*, 17:3855-3865.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate change 2007: The physical science basis: Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate*. Cambridge Univ. Press, New York.

Karl, T.R., J.M. Melillo and T.C. Peterson (eds). 2009. *Global climate change impacts in the United States*. New York: Cambridge University Press.

Krall, J.M., R.W. Goose, M.J. Walsh, V. Nayighugub, J. Cecil, and B. Hess. 2007. "Registration of 'Laramie' annual medic." *Journal of Plant Registration*, 1:32-33.

Leung, L.R., L.O. Mearns, F. Giorgi, and R.L. Wilby. 2003. "Regional climate research: needs and opportunities." *Bulletin of the American Meteorological Society*, 84, 89–95.

Maurer, E. P., L. Brekke, T. Pruitt, and P. B. Duffy. 2007. "Fine-resolution climate projections enhance regional climate change impact studies." *Eos Trans. AGU*, 88(47): 504.

McCabe, G.J., J.L. Betancourt, S.T. Gray, M.A. Palecki, and H.H. Hidalgo. 2008. Associations of multi-decadal sea-surface temperature variability with U.S. Drought. *Quaternary International*, 188(1): 31-40.

McCarl, B. A. 2010. "Analysis of climate change implications for agriculture and forestry: An interdisciplinary effort." *Climatic Change*, 100: 119-124.

Mearns, L.O., et al., 2005: NARCCAP, North American Regional Climate Change Assessment Program, A multiple AOGCM and RCM climate scenario project over North America. American Meteorological Society 16th Conference on Climate Variations and Change. 9-13 January, 2005. Paper J6.10, American Meteorological Society, Washington, DC, pp. 235–238.

Peck, D. E., and R. M. Adams. 2010. Farm-level impacts of prolonged drought: is a multiyear event more than the sum of its parts? *Australian Journal of Agricultural and Resource Economics*, 54:43-60.

Ritten, J. P., W. M. Frasier, C. T. Bastian, and S. T. Gray. 2010. "Optimal stocking decisions under stochastic and climate-impacted weather," *American Journal of Agricultural Economics*, 92(4): 1242-1255.

Rosenberg, E.A., P.W. Keys, D.B. Booth, D. Hartley, J. Burkey, A.C. Steinemann, and D.P. Lettenmaier. 2010. Precipitation extremes and the impacts of climate change on stormwater infrastructure in Washington State. *Climatic Change* 102(1-2): 319-349.

Salathé, E.P., L.R. Leung, Y. Qian, and Y. Zhang. 2010. Regional climate model projections for the State of Washington. *Climatic Change*, 102(1-2): 51-75.

Schlenker, W. and M. J. Roberts. 2006. "Nonlinear impacts of weather on corn yields," *Review of Agricultural Economics*, 28(3): 391-398.

Seager, R., M.F. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H.P. Huang, N. Harnik, A. Leetmaa, N.C. Lau, C.H. Li, J. Velez and N. Naik. 2007. "Model projections of an imminent transition to a more arid climate in southwestern North America." *Science*, 316: 1181-1184.

Trapp, R.J., N.S. Diffenbaugh, H.E. Brooks, M.E. Baldwin, E.D. Robinson and J.S. Pal. 2007. "Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing." *Proceedings of the National Academy of Science* 104(50):19719–19723.

Trapp, R.J., N.S. Diffenbaugh and A. Gluhovsky. 2009. "Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations." *Geophysical Research Letters*, 36: L01703.

U.S. Geological Survey (USGS). 2005. *Changes in streamflow timing in the western United States in recent decades*. USGS Fact Sheet 2005-3018. Available at: <http://pubs.usgs.gov/fs/2005/3018/>.