Effects of Climate Change on Weather and Water

by Ellen Cooter, Brian Eder, Cynthia Rosenzweig, Barry Lynn, Richard Goldberg, Cody Knutson, Michael Hayes, Donald Wilhite, Joseph DeCarolis, and Tim Barnett

Other articles in this issue summarize the value of regional climate models (RCMs) in translating surface temperature and transport processes to regional or local scales for air quality applications.[1] While temperature is often a determining factor for air quality, there are other weather variables deserving of careful consideration. In this article, we review the direct and indirect role of hydrological variables in air quality processes, provide specific examples of the relationship between water supply and subsequent air quality, and suggest ways in which a changing climate may affect these important interactions.

One climate variable vital to the prediction of both water supply and air quality responses to future climate is atmospheric water vapor content. The reaction rates of many chemical species important to downstream air quality depend directly upon ambient water vapor content as well as temperature. Recent studies based on satellite and radiosonde data indicate an increase in lower tropospheric water vapor over the past few decades. More specifically, one study indicates that total atmospheric water vapor has increased several percent per decade over many regions of the Northern Hemisphere since the early 1970s.[2] Over the same period, global mean surface temperature has trended upward at a rate of 0.18 °C per decade.[3] Warmer global temperatures increase the water-holding capacity of the atmosphere, which, in turn, can lead to hydrologic cycle enhancement and subsequent changes in cloud and precipitation patterns.[3] Cloud cover can affect air quality through actinic flux and photolysis rates. For instance, increased cloud cover is associated with a greater attenuation of actinic flux, which reduces the photolysis rates of many chemical species important to air quality. Changes in temporal and spatial patterns of precipitation delivery can directly affect air quality through the wet deposition of various chemical species. In combination with temperature, changes in precipitation can affect the frequency and severity of drought-related particulate concentrations and regional water resource management decisions.

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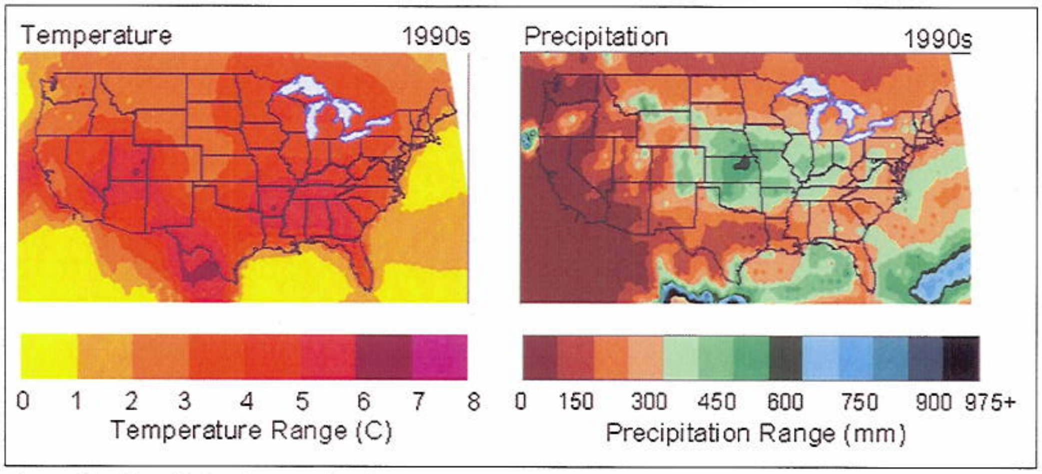

Figure 1a. Sensitivity of mean simulated present-day (1990s) summer season surface temperature and precipitation to five RCM boundary layer, radiation, and cumulus precipitation configurations. *Note:* Range is the highest mean season temperature (precipitation) minus the lowest mean season temperature (precipitation) of the five simulations at each individual grid.

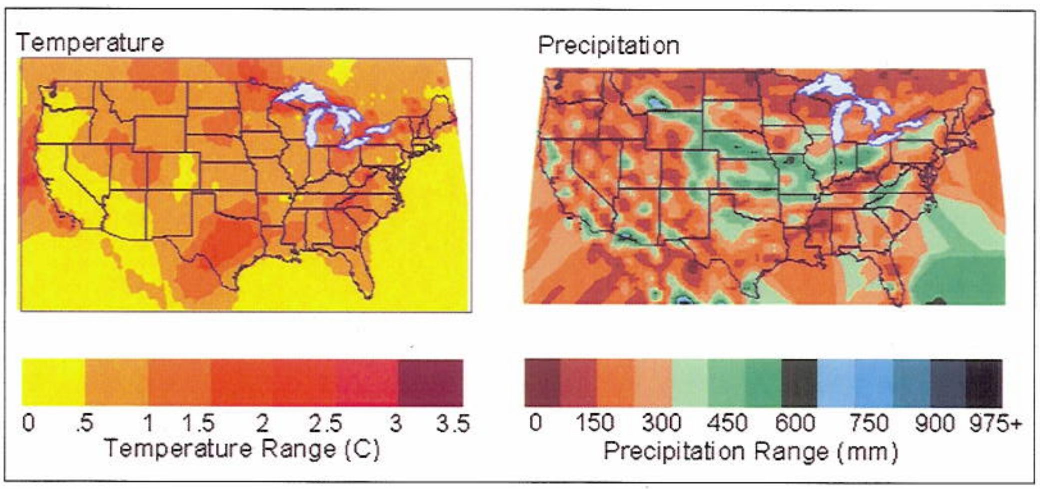

Figure 1b. Range of estimated climate change (1990–2050) using the most extreme maximum and minimum mean summer season values across the five RCM configurations. *Note:* Temperature range is the highest temperature anomaly minus the lowest temperature anomaly at each individual grid point. Precipitation range is highest precipitation change in mm minus the lowest precipitation change in mm at each grid point.

Source: Rosenszweig, C.; Goldberg, R.; Lynn, B., Climate Impacts Group, New York Climate and Health Project (NYHCP), grant R828733 from the U.S. Environmental Protection Agency's Science to Achieve Results (STAR) program.

REGIONAL CLIMATE MODELING FOR WEATHER AND WATER

Global climate model (GCM) experiments help scientists understand broad patterns of global warming,[3] but typically do not represent well day-to-day meteorology and extreme events such as droughts and heat waves. Regional-scale models typically have much higher grid resolution than the GCMs. Hence, they include more realistic topography and are able to simulate smaller temporal and spatial scale processes, such as convection, air–sea contrasts, and sea breezes. Regional models have been used to study potential climate change-related effects on the intensity of hurricanes;[4] California heat waves;[5] and, in combination with land-use change, air quality and health in the New York Metropolitan Region.[6] Of particular interest here, regional models have been used to simulate climate change impacts on precipitation and hydrology in the continental United States.[7]

Regional climate modelers have found that the choice of model parameterization for the boundary layer, cumulus clouds, and radiation is important for simulating current and future climate conditions.[8] One study used multiple physics configurations in an RCM to down-scale GCM present-day climate and climate change simulations (see Figure 1). Results show that using different physics options can lead to wide-ranging results in the present climate in some regions, but that projected climate changes appear to be more uniform. This implies that more confidence may be placed in climate change projections at regional scales than differences in the model simulations of current climate might suggest. The choice of cumulus parameterization can also play an important role in the simulation of surface temperature extremes and variability. Studies that identify relationships between observed temperature extremes and variability and precipitation frequency and timing (i.e., seasonal and diurnal precipitation patterns) help inform the choice of RCM cumulus parameterization.[8,9] In general, most GCMs simulate far too frequent rain,[10] which may lead to an underestimation of the positive feedback between precipitation and clouds at night and to an underprediction of surface temperatures.[9] Such underprediction could produce overly conservative estimates of how future climate change may affect air quality.

DROUGHT AND AIR QUALITY

During drought conditions, air becomes warm, dry, and dusty. The lack of precipitation, along with accompanying high temperatures and windy conditions, can increase the evaporation of water bodies and desiccate plants and soil.

Figure 2. The town of Colby, KS, was inundated by dust on May 29, 2004. Image courtesy of Weather Underground Inc., http://wunderground.com.

Under these conditions, it is easier for winds to scour particles from exposed landscapes and transport large amounts of the dust downwind. Dry vegetation also enhances the potential for wildfires and air pollution from smoke and ash.

Under certain climate change scenarios, drought-related air quality could become an even greater problem in the future for some regions. The combination of increased temperatures, evaporation, and variable rainfall causes models to suggest potential drying of mid-continent areas during summer months, which increases the likelihood of drought in these regions.[11,12] Any change in drought occurrence will, in turn, result in air quality responses.

In general, recent studies suggest that climate change is likely to increase the risk of wildfires, especially where precipitation remains the same or is reduced. For example, a recent climate change study of northern California estimated that in spite of more extensive utilization of current fire suppression capabilities, a doubling of atmospheric carbon dioxide (CO_2) levels would result in more frequent and intense fires because of warmer, windier, and drier conditions in portions of the region.[13] According to the U.S. National Interagency Fire Center, wildland fires have burned an annual average of nearly 4.2 million acres in the United States since 1960.[14] From 2000 to 2004, the average area burned increased nearly 45% to more than 6.1 million acres per year. More than 8.4 million acres were reported burned during the worst year on record, 2000. Many of these fires were caused by drought conditions that prevailed over much of the western United States during that time period. Not only do smoke and other particulates from these fires affect local air quality, but they also often travel far from their source, affecting air quality and visibility farther downwind. For example, Alaska experienced one of driest and warmest summers on record in 2004, which resulted in its worst fire season on record.[15] Smoke from the summer fires covered portions of the United States, Canada, and East Asia.

A dust storm is another drought-related phenomenon that can affect air quality and visibility. Dust storms can be caused by or exacerbated by drought and range from localized to large regional events. For example, during the 2004 drought, one localized dust storm in western Kansas caused a rapid visibility drop and several traffic accidents, including one resulting in the death of a state senator (see Figure 2).[16] On October 23, 2002, one of the worst dust storms in decades swept across Queensland, Australia, stripping an estimated 10 million tons of fine soil particles. The storm was exacerbated by a lack of vegetation cover caused by widespread drought, and resulted in severe reductions in visibility. Although there is great uncertainty in the future projections of dust storm occurrence, drought induced by climate change will undoubtedly affect air quality in many regions.

Table 1. Cost and operating emissions comparison for western hydropower alternatives.

Alternative Capacity Source	Production Cost[a] ($/kWh)	Operating Emissions (g/kWh)[b]		
		CO_2	SO_2	NO_x
Gas Turbines				
Combined cycle	5.1	350	0.0027	0.045
Simple-cycle	6.9	580	0.0031	0.45
Coal				
New pulverized coal	3.0	960	0.14	3.3
IGCC with CCS[c]	4.4	95	0.12	0.071
Wind	4.8	0	0	0
Advanced Nuclear	7.0	0	0	0
Photovoltaics (solar)	29.6	0	0	0
Large-scale hydropower	N/A[d]	0	0	0

[a]Cost estimates and heat rates for the levelized cost calculation are drawn from the literature.[24,25] All capital costs were amortized at a 10% discount rate, over an assumed 20-yr lifetime for gas turbines and wind and a 30-yr lifetime for coal-based technologies. To enable comparison, the capacity factor for all fossil-based technologies is assumed to be 90%. Wind is assumed to have a 30% capacity factor, a reasonable estimate for a modern wind turbine with an 80-m hub height in a windy area while solar is assumed to have 20% capacity factor based on national average insolation. The cost of natural gas was assumed to be $5/GJ for natural gas and $0.85/GJ for coal, both based on near-term projections in the 2005 Annual Energy Outlook. [b]Operating emissions for gas turbines and pulverized coal were drawn from the literature.[24] Operating emissions from wind, hydropower, nuclear, and photovoltaics were assumed negligible. [c]IGCC-CCS refers to integrated coal gasification combined cycle with carbon capture and sequestration. This technology utilizes coal as a feedstock to produce hydrogen, and the resultant CO_2 produced before combustion is sequestered underground. These emissions estimates are for a 500-MW Texaco plant with carbon capture and sequestration using a sour shift + Selexol process and running on low-sulfur Appalachian coal.[26] [d]In the United States, the best conventional hydro resources have already been utilized, making the development of new hydro capacity on the remaining marginal waterways prohibitively expensive. Smaller streams could be used to drive water turbines directly (no dam), but the potential for development in the near- to mid-term remains low.

WESTERN RESERVOIR STORAGE, HYDROPOWER PRODUCTION, AND AIR QUALITY

Examined uncritically, it would appear we could say little about future changes in regional water conditions because the estimates of local precipitation are so uncertain. What is often overlooked is that the hydrological cycle is affected by much more than just precipitation. It also includes the processes of snow/ice accumulation and melting and the influence these processes have on regional hydrology and the establishment of water supply and hydro-generation pools. In a warmer climate, even if precipitation amounts remain equal, more water will fall in the form of rain than snow and snow will melt earlier in the year.[17] A smaller snowpack and earlier melting are already being observed at statistically significant levels in the West. The Accelerated Climate Prediction Initiative (ACPI) demonstration project was launched in 2000 to investigate the effects of greenhouse warming on water supplies in the western United States through 2050.[18] ACPI results suggest that by 2050 reductions in snowpack and changes in the timing of snowmelt will reduce the hydropower production potential in the Central Valley of California (10% reduction),[19,20] the Columbia River system (which cannot be managed to accommodate both salmon runs and current levels of hydropower production for export to California),[21] and the Colorado River Basin (up to 40% generation reduction).[22]

The choice of energy generation alternative(s) to supplement the potential capacity reductions noted by the ACPI study could significantly affect present levels of CO_2, sulfur dioxide (SO_2), and nitrogen oxides (NO_x) emissions in regions that rely on reservoir storage to meet energy demands. Potential choices in the short- to mid-term (i.e., in the next 50 years) to replace lost hydropower resources include gas turbines, coal, advanced nuclear, photovoltaics, and wind (see Table 1). The type of new capacity deployed will depend largely on three factors: potential greenhouse gas policy, the price of natural gas, and where hydropower ranks in the system operator's order of dispatch. Such emerging considerations only add to the already complex task of devising regional air quality management strategies whose success can hinge on the way in which water resources are allocated and used.

SUMMARY

Information regarding weather and hydrological processes and how they may change in the future is available from a variety of dynamically downscaled climate models. Current studies are helping to improve the use of such models for regional climate impact studies by testing the sensitivity of climate change projections to different boundary layer, cumulus, and radiation parameterizations. Results to date suggest that regional-scale temperature projections are highly dependent on the choice of model precipitation physics and subsequent event frequency, timing (night/day), and associated cloud cover. Refinements in the quality of climate model precipitation predictions should be pursued in conjunction with studies on air quality characteristics that show significant linkages to precipitation. Changes in the patterns of these weather characteristics will likely be reflected in changes in atmospheric deposition; visibility; soil resuspension; wildfire-related emissions; and emissions associated with changing energy resources, technology, and demand.[1,23] **em**

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