Western water resources in a changing climate

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Introduction

In most river basins of the West, especially in California, Oregon, and western Washington, snow (rather than man-made reservoirs) is the largest component of water storage. Most precipitation falls in the winter but about 70% of annual flow is snowmelt; snow provides a roughly half-year delay in runoff. Furthermore, a significant portion of the mountainous West receives much of its annual precipitation as warm snow, with temperatures above -3°C (Bales et al. 2006). Hence, the West is (to varying degrees) vulnerable to climatic variations and changes that influence snowpack. This document updates the testimony I gave to the U.S. Senate Committee on Commerce, Science, and Transportation (Mote 2004).

Observed changes

What changes have been observed in the West since the mid-20th century?

1) The West has warmed by roughly 0.8°C in the November-March season (Mote et al. 2005).

2) Snowfall has diminished at most weather stations; these changes are large and statistically significant in California, Oregon, and Washington (Knowles et al. 2005).

3) Spring snowpack has declined at roughly 75% of sites and the magnitude of declines is largest at low elevations (Mote et al. 2005).

4) Spring snowmelt is generally occurring earlier, roughly 2 weeks (Stewart et al. 2005) and these shifts are larger at lower elevations than at higher elevations (Regonda et al. 2005).

5) In most snowmelt-dominated basins, winter flows have increased and late spring-early summer flows have decreased as flows shift (Stewart et al. 2005).

6) The timing of biological events like flowering of lilacs have also shifted in response to springtime warming (Cayan et al. 2001).

7) Flood risk appears to have changed in many river basins, decreasing in snow-dominant basins and increasing in those with some snow storage.

In several of these studies, a clear quantitative link was established between the observed change and temperature in winter or spring. The warming in the West can now confidently be attributed to rising greenhouse gases and are not explained by any combination of natural factors (Stott 2003).

These hydrologic shifts in response to warming – elevation-dependent losses in snow storage, with concomitant increases in winter flow and decreases in summer flow – are a harbinger of changes to come.

Predicted future changes

The starting point for future changes are the physically consistent global simulations of climate from climate models (e.g., IPCC 2007 Chapters 8, 10, and 11). Such projections typically are reported as seasonally averaged changes in temperature and precipitation (see Figure below, for the A1B socioeconomic scenario). Modeling centers around the world have contributed hundreds of climate simulations to a database maintained by the Program for Climate Model Diagnostics and Intercomparison at the Lawrence Livermore National Laboratory. From such simulations one can construct average changes or produce also a range of changes. The projected warming in North America is greatest in high latitudes in winter, but is greatest in midlatitudes in summer owing partly to a soil moisture feedback. For much of the Lower 48 states, warming is projected to be roughly 0.3°C/decade for winter and 0.4°C/decade in summer for the A1B scenario. Precipitation changes globally tend to be positive in the tropical rainy belt and also in high latitudes, and negative in low latitudes. For North America, models are divided over whether precipitation will increase or decrease for a swath (white area in the bottom row of the Figure) of the Lower 48, but tend to agree on increases in the northern tier of states and tend to agree also that precipitation in the Southwest will decrease.

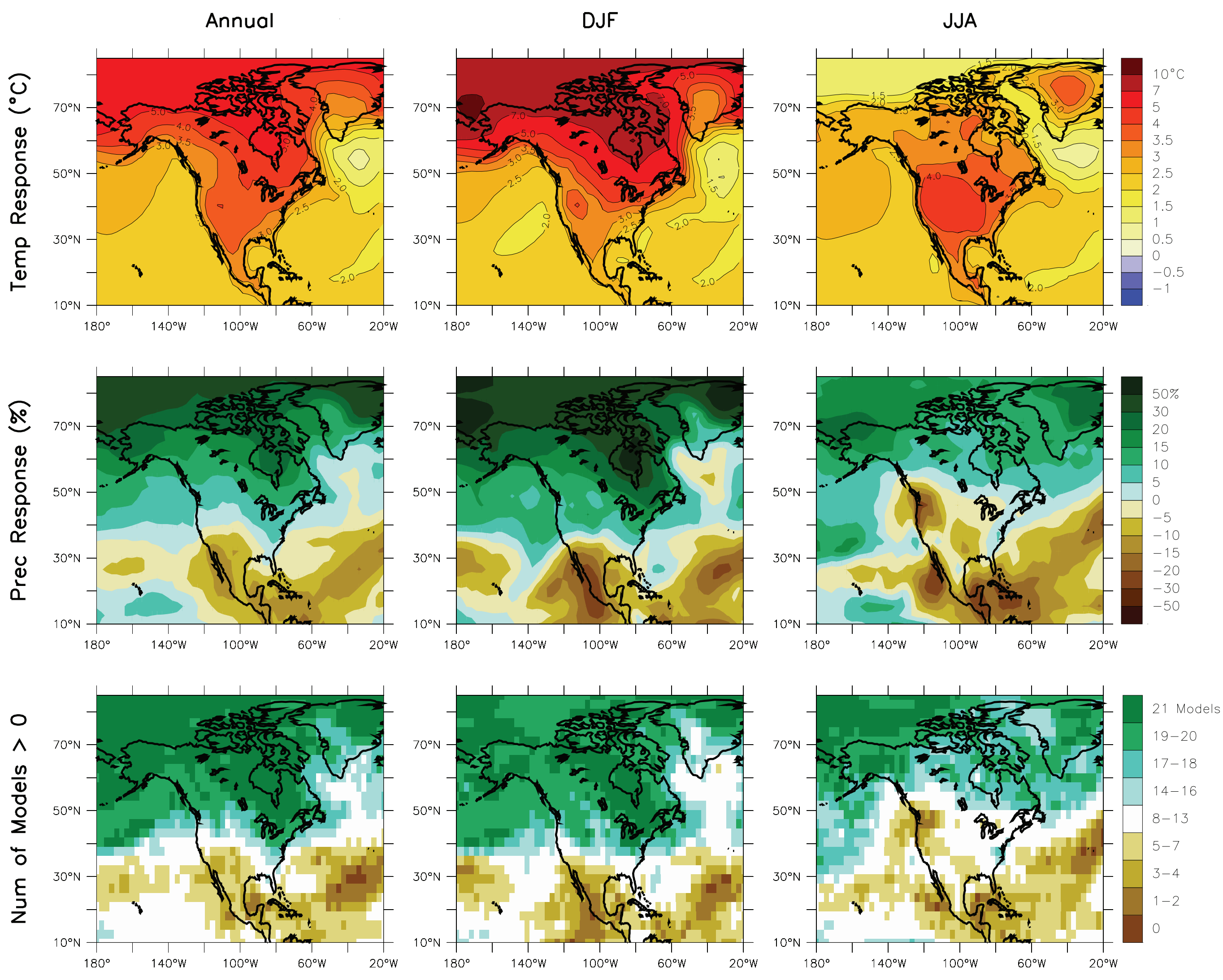

Figure . *Temperature and precipitation changes over North America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation.*

From IPCC 2007, Figure 11.12

Physically-based models of hydrology can be used to translate such changes in climate into future changes in snowpack, soil moisture, streamflow, and so forth. Studies with such models are still relatively new, but it is clear that projected future hydrologic changes (e.g., Payne et al. 2004 for the Columbia River Basin, Christensen et al. 2004 for the Colorado, Maurer and Duffy for California) produce the same types of changes in snowmelt-driven basins as have been observed. For low-end scenarios of future temperature change, the reductions in summer flow, shifts in timing of spring snowmelt, and increases in winter flow over coming decades would be as large as those observed in recent decades, whereas for high-end scenarios of future temperature change the projected hydrologic changes are extremely large.

Management and policy implications

Few water management agencies have begun to explore what these changes would mean for their ability to meet management objectives, let alone proactively address the changes. Some academic studies (e.g., Payne et al. 2004) have attempted to estimate changes in reliability of various water supply systems, and to explore adaptation options.

Federal policy responses could include:

a) directing federal agencies involved in water management to study future streamflow

b) ensuring that existing observation networks (e.g., the USGS stream gauge network and the National Weather Service cooperative network) do not suffer further neglect and decline but instead are upgraded to effectively monitor changes

c) catalyze river basin-scale policy planning, using reservoir optimization models that optimally balance management objectives.

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