Climate Warming and 21st-Century Drought in Southwestern North America

Since 2000, southwestern North America has experienced widespread drought. Lakes Powell and Mead are now at less than 50% of their reservoir capacity, and drought or fire-related states of emergency were declared this past summer by governors in six western states. As with other prolonged droughts, such as the Dust Bowl during the 1930s, aridity has at times extended from northern Mexico to the southern Canadian prairies. A synthesis of climatological and paleoclimatological studies suggests that a transition to a more arid climate may be occurring due to global warming, with the prospect of sustained droughts being exacerbated by the potential reaction of the Pacific Ocean to warming.

An analysis of 19 climate models by *Seager et al.* [2007] concluded that the transition to a more arid climate in southwestern North America is imminent due to increased air subsidence in the subtropics as the tropics warm and as equatorial convection increases. The Pacific Ocean may play an important role in generating prolonged droughts as warming continues.

Paleoclimatic studies provide insights into how the Pacific Ocean and North American hydrometeorology have responded to past climate warming. A pertinent lesson comes from the Medieval Climate Anomaly (MCA; 800–1300 A.D.). During the MCA, increased irradiance coupled with a lull in volcanic activity produced increased radiative forcing (Figure 1a) and climate warming. The MCA is associated with widespread aridity and increased fires in western North America [*Cook et al.*, 2004]. A pronounced confluence of increased solar forcing and decreased volcanic activity occurred during the twelfth century (Figure 1a). This peak of radiative forcing appears associated with a multidecadal persistence of La Niña-like conditions and a negative Pacific Decadal Oscillation (Figure 1a). These are phenomena typified by cool surface temperatures in the eastern tropical Pacific and eastern North Pacific that promote arid conditions in southwestern North America.

A synthesis of Palmer Drought Severity Index (PDSI) reconstructions from northwestern Mexico to the prairies of Canada shows a persistent state of aridity during the twelfth century (Figure 1a). River discharge reconstructions for the North Saskatchewan, Colorado, and Sacramento rivers also show a consistent response of decreased flow (Figure 1a). Mapped PDSI for the central period of the drought (1130–1180 A.D.) displays a spatial pattern broadly similar to the 21st-century drought (Figures 1b and 1c). Climate model experiments indicate that this spatial pattern is consistent with decreased temperatures in the eastern tropical Pacific promoting increased aridity in southwestern North America [*Herweijer et al.*, 2006].

Taken together, climatological and paleoclimatological evidence does not provide any reason to conclude that events such as the early 21st-century drought could not persist longer than the 5- to 8-year duration of historical droughts of the twentieth century. Prolonged episodes of aridity persisting for a decade or more are apparent in many paleohydrological records, and conditions in the Pacific appear to have played a key role in these episodes.

In addition to the Pacific Ocean, North Atlantic sea surface temperature variability has also been linked to recent and prehistoric droughts in Mexico and regions of the United States and Canada [*Enfield et al.*, 2001; *McCabe et al.*, 2004]. The response of the Atlantic to warming and that ocean's impact on North American hydrometeorology remain critical questions in anticipating the impacts of climate change.

The widespread twelfth-century megadrought appears to have developed due to increased radiative forcing and climate warming, suggesting that ongoing radiative forcing and warming could be capable of locking much of southwestern North America into an era of persistent aridity and more prolonged droughts. Indeed, the early 21st-century drought could potentially signal the transition to such a state.

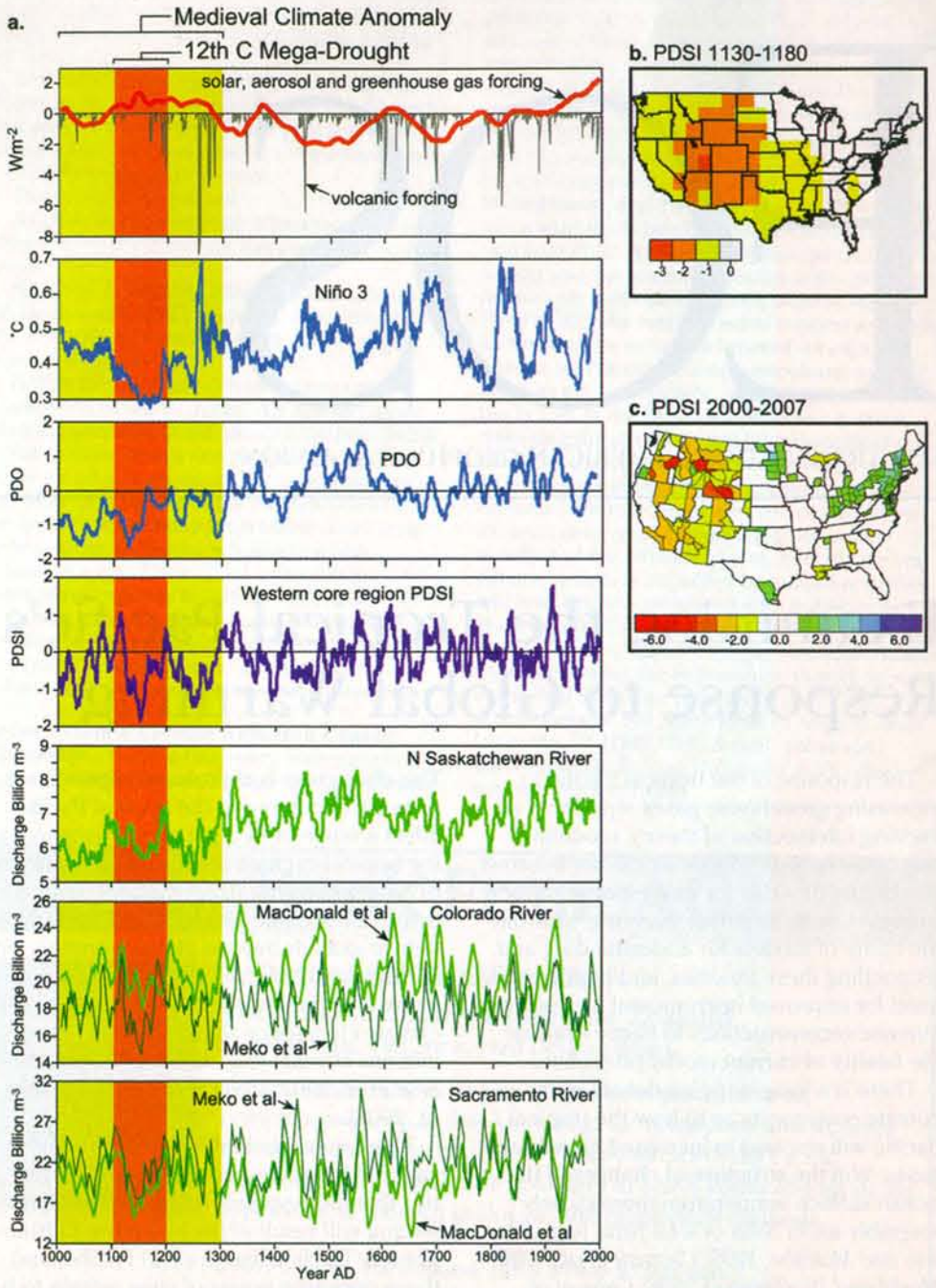

Fig. 1. (a) The relationship between increased radiative forcing, cooling of the eastern Pacific Ocean, and evidence for widespread drought in western North America during the twelfth century. The evidence for positive radiative forcing and decreased volcanic negative forcing is from Crowley *[2000]. The modeled cooling in the Niño-3 region of the eastern equatorial Pacific during the twelfth century is from* Mann et al. *[2005]. Niño-3 is the region of the equatorial Pacific from 90°W to 150°W. The tree-ring-based reconstruction of a prolonged negative state of the Pacific Decadal Oscillation (PDO) is from* MacDonald and Case *[2005]. The reconstruction of increased drought severity (Palmer Drought Severity Index, or PDSI) for the core area of the twelfth-century drought from the southwestern interior of Canada to northwestern Mexico is from tree rings (data from* Cook et al. *[2004] and World Data Center for Paleoclimatology). Negative PDSI values indicate arid conditions, and values of –3 or less represent severe drought. Evidence for decreases in river flow during the twelfth century comes from tree-ring-based reconstructions of annual discharge of the North Saskatchewan River [*Case and MacDonald, *2003], the Colorado River [*Meko et al., *2007;* MacDonald et al., *2007], and the Sacramento River [*Meko et al., *2001;* MacDonald et al., *2007]. All series are smoothed with an 11-year moving average. (b) PDSI map of the twelfth-century drought and (c) the early 21st-century drought (data in Figure 1b are from* Cook et al. *[2004] and World Data Center for Paleoclimatology, and data in Figure 1c are from National Climatic Data Center).*

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