the different SST products. However, the long-term behavior of the two reconstructions is different between the products over two periods of time, around the 1930s and 1980s. These periods are roughly coincident with the period of greatest change in "bucket-to-intake" correction of SST measurements (a correction that differs between the products, which is applied to account for changes in measurement techniques at sea, from using buckets lowered into the water to using ship engine room water intake) and the beginning of satellite infrared SST retrievals (satellite data are used in HadISST but not in ERSST), respectively. Effort should be concentrated toward identifying the specific sources of this discrepancy and the appropriate corrections.

Proxy Data

Another way forward to assess whether century-scale changes in Pacific conditions have been El Niño- or La Niña-like may be through reconstructions of local temperature and salinity using coral skeletons from the tropical Pacific over the historical record. Currently, there are only a handful of published data sets that can address this issue. Some coral records suggest a trend toward warmer and wetter conditions in the central Pacific at the end of the twentieth century [e.g., *Cobb et al.*, 2003; *Urban et al.*, 2000]. Taken at face value, these records would suggest an eastward shift of warm pool convection and more El Niño-like conditions. However, coral records from the region of the South Pacific convergence zone suggest that since the mid-1880s there has been an eastward expansion of rainfall, as occurs during La Niña events [*Linsley et al.*, 2006].

A more complete picture of the evolution of tropical Pacific climate in the twentieth century will emerge from additional records from various locations incorporated into a multiproxy, synthesized approach. For example, *Evans et al.* [2002] have constructed a framework for analyzing numerous coral records to extract spatially and temporally coherent signals. Because the discrepancies in the reconstructions of δ_xSST arise primarily in two discrete periods (see supplementary Figure 2), proxy observations spanning these periods could prove particularly useful.

Theory, models, and observations present diverging views of the Pacific response to global warming. It may be possible to reconcile the different theoretical frameworks for understanding the Pacific response to increased CO_2 within state-of-the-art coupled GCMs. However, the test of whether the tropical Pacific has become more El Niño- or more La Niña-like is in the hands of the observationalists, and the consequences for our understanding of the climate in the tropical Pacific and in all the regions affected by El Niño/La Niña are great.

Acknowledgments

We are grateful for comments and suggestions from T. Delworth, T. Knutson, A. Wittenberg, and B. Linsley. This work has been funded in part by the NOAA Office of Global Programs and the U.S. National Science Foundation's Paleoclimate program. The CMIP3 model data were made available by the Program for Climate Model Diagnosis and Intercomparison at the U.S. Department of Energy's Lawrence Livermore National Laboratory, Calif.

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Author Information

Gabriel A. Vecchi, NOAA Geophysical Fluid Dynamics Laboratory, Princeton, N. J.; E-mail: gabriel.a.vecchi@noaa.gov; and Amy Clement and Brian J. Soden, Rosenstiel School for Marine and Atmospheric Science, University of Miami, Florida.

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

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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

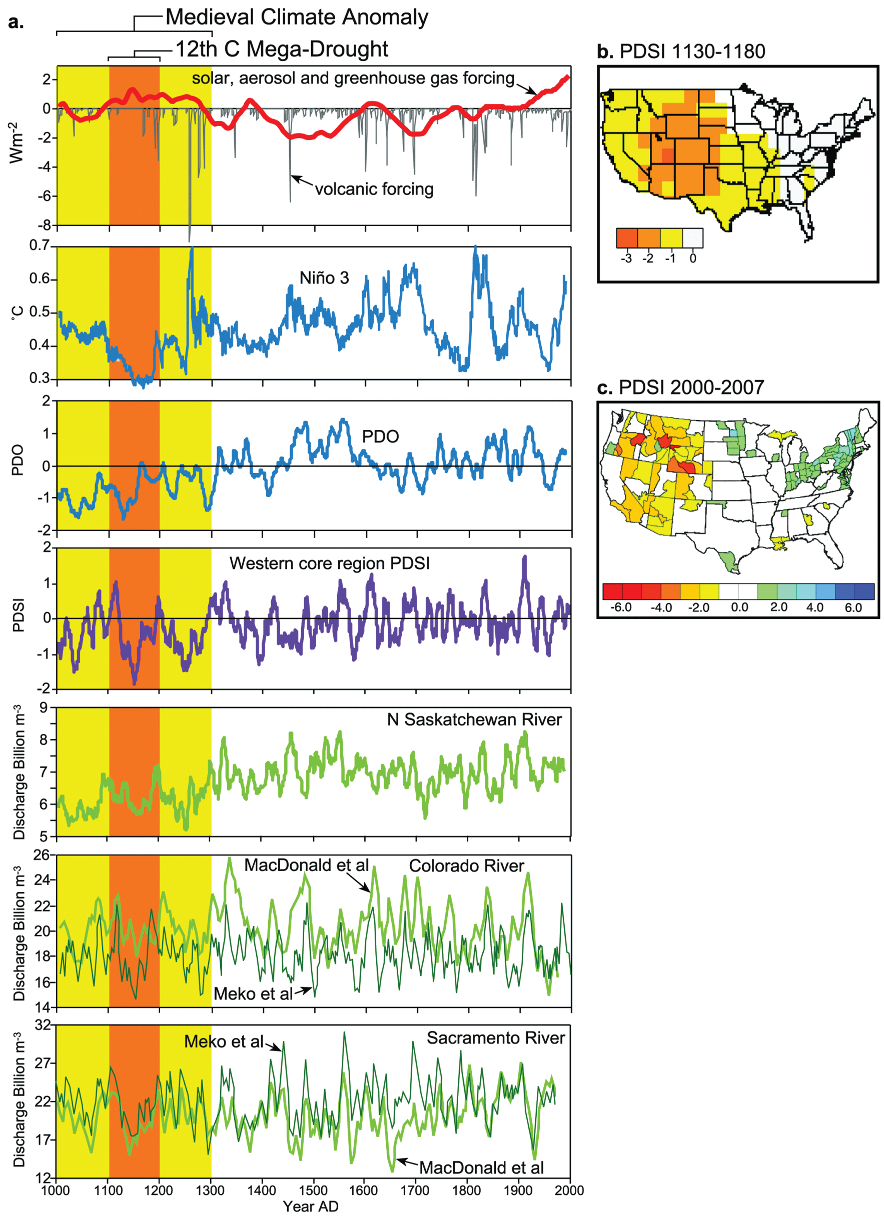

Fig. 1. (a) The relationship between increased radiative forcing, cooling of the eastern Pacific Ocean, and evidence for widespread drought in western North America during the twelfth century. The evidence for positive radiative forcing and decreased volcanic negative forcing is from Crowley *[2000]. 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 90ºW to 150ºW. 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).*

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.

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—GLEN M. MACDONALD, University of California, Los Angeles; E-mail: macdonal@geog.ucla.edu; DAVID W. STAHLE, University of Arkansas, Fayetteville; JOSE VILLANUEVA DIAZ, Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP), Durango, México; NICHOLAS BEER, Liverpool John Moores University, U.K.; SIMON J. BUSBY, University of East Anglia, U.K.; JULIAN CERANO-PAREDES, INIFAP; JULIE E. COLE, University of Arizona, Tucson; EDWARD R. COOK, Lamont-Doherty Earth Observatory of Columbia University, Palisades, N.Y.; GEORGINA ENDFIELD, University of Nottingham, U.K.; GENARO GUTIERREZ-GARCIA, University of Arizona, Tucson; BETH HALL, University of Nevada, Reno; VICTOR MAGANA, Centro de Ciencias de la Atmosfera, Universidad Nacional Autonoma de México (UNAM), México City; DAVID M. MEKO, University of Arizona, Tucson; MATIAS MÉNDEZ-PÉREZ, UNAM; DAVID J. SAUCHYN, University of Regina, Canada; EMMA WATSON, Environment Canada, Toronto, Canada; and CONNIE A. WOODHOUSE, University of Arizona, Tucson