EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION
VOLUME 90 NUMBER 11
17 MARCH 2009
PAGES 89–100

Early 21st-Century Drought in Mexico

PAGES 89–90

Prolonged drought conditions have persisted over western North America since at least 1999, affecting snowpack, stream discharge, reservoir levels, and wildfire activity [*Mote et al.*, 2005; *Westerling et al.*, 2006; *MacDonald et al.*, 2008]. Instrumental precipitation, temperature, and Palmer Drought Severity Indices (PDSI) indicate that severe and sustained drought began in 1994 in Mexico, where it has continued with only limited relief for the past 15 years. This late twentieth- and early 21st-century Mexican drought (referred to below as the "early 21st-century drought") has equaled some aspects of the 1950s drought, which is the most severe drought evident in the instrumental climate record for Mexico (1900–2008). Large-scale changes in ocean-atmospheric circulation have contributed to the lower than normal precipitation that has led to the current drought [*Seager*, 2007], but global warming and the sharp regional warming across Mexico, which appears to have been aggravated by land cover changes [*Englehart and Douglas*, 2005], may have added an anthropogenic component to the early 21st-century drought.

Comparison of the 1950s and Early 21st-Century Droughts in Mexico

The spatial pattern of winter-spring (January–May) and summer (July–September) drought was similar between the 1950s and early 21st-century droughts, but below-normal precipitation appears to have been more widespread and regionally more intense during the 1950s drought, especially during the summer (Figures 1a–1d [from *Zhu and Lettenmaier*, 2007]). Similar conclusions regarding the pattern and intensity of drought during the 1950s and early 21st-century events can be drawn from the precipitation data compiled by A. V. Douglas (personal communication, 2008). However, mean maximum temperatures were higher across most of Mexico during the current drought for both the winter-spring and summer seasons (Figures 1e–1h), which appears to have contributed to the severity, persistence, and spatial impact of the early 21st-century drought, and which has elevated it into the category of historic drought.

This conclusion is supported by the comparison of the 10 hottest and driest consecutive years of the 1950s and early 21st-century droughts, using the new 1/2° grid of instrumental PDSI for the summer season (June–August average for the 1948–1957 versus 1994–2003 drought periods; National Climatic Data Center, National Oceanic and Atmospheric Administration (NOAA)). The 1950s drought appears to have been more intense than the current event across Texas and northern Mexico, but most of Mexico and the southwestern United States were seriously affected during both the 1950s and early 21st-century droughts (Figures 2a and 2b).

The all-Mexico average of the gridded precipitation and maximum temperature data compiled by *Zhu and Lettenmaier* [2007] provides a time series perspective on winter-spring and summer season droughts during the 1950s and the early 21st century (Figures 2c and 2d). *Zhu and Lettenmaier* [2007] screened meteorological data compilations from the National Water Commission of Mexico for errors and outliers, but issues of data quality and urban heat island effects may not have been entirely eliminated, especially before 1950 and after Mexico's economic crisis of the 1980s, when many of that nation's meteorological stations had to be closed for financial reasons.

Nevertheless, the precipitation data indicate that the early 21st-century drought during the winter-spring season has reached historic proportions (Figure 2c). Mean maximum temperature across Mexico for the winter-spring season also reached record levels during this recent drought, and the cumulative temperature departure for the 11-year period from 1994 to 2004 exceeds the warmest consecutive period during the 1950s drought (Figure 2d). Precipitation during the summer rainy season has not been as low as in the 1950s during the current drought (Figure 2c), but summer temperatures were elevated, especially in 2004 (Figure 2d).

The Drought Area Index (DAI) for Mexico indicates that the early 21st-century drought has nearly equaled the severity and persistence of drought during the 1950s, based on instrumental data (Figure 2e). The continent-wide network of tree ring chronologies has been used to develop gridded summer PDSI reconstructions for North America, including most of Mexico [*Cook et al.*, 2007]. The North American network now includes 1450 tree ring chronologies, which have been used to update the summer PDSI reconstructions of *Cook et al.* [2007] for 11,696 grid points (1/2°) extending across the continent from southern Mexico to the Arctic. The calibrated and verified estimates of summer PDSI were also used to compute the DAI for Mexico for the past 500 years (excluding southeastern Mexico, where no long tree ring chronologies are available). The 20-year smoothed version of the DAI reconstruction indicates that the ongoing drought was exceeded only by the decadal extremes of the 1950s and 1560s (Figure 2f). The Mexican tree ring record is well replicated back to A.D. 1750, but before 1500 it is based on only 11 chronologies. Nonetheless, the available evidence suggests that the early 21st-century drought has become one of the worst in Mexico's history.

Socioeconomic impacts during the recent drought may not have been as serious as those suffered in the 1950s, given the dramatic improvements in water resource development, transportation, crop price support, and food relief in Mexico. But drought remains a factor that can contribute to emigration to the United States [*Schwartz and Notini*, 1994], and the string of early 21st-century droughts during the winter-spring season in Mexico may not be over. The North American Drought Monitor indicates that abnormal drought affected large portions of Mexico during the summers of 2006 and 2007 and that by 30 June 2008, most of Mexico was under drought,

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including extreme drought over portions of west central Mexico. Heavy rain alleviated drought across portions of northern Mexico during late summer 2008, but drought persisted into February 2009 across central and northwestern Mexico (see http://www.ncdc.noaa.gov/oa/climate/monitoring/drought/nadm/).

Possible Anthropogenic Influences on Early 21st-Century Drought in Mexico

These results indicate that persistent and widespread drought over western North America began 15 years ago in Mexico, starting in 1994. This early 21st-century drought appears to have been most severe, sustained, and widespread across Mexico, and the significant recent warming over Mexico [*Cortez Vazquez*, 2006] has contributed to this increasing aridity. The intense warming is dominated by a rise in maximum daily temperatures and may be a partial consequence of land cover change in Mexico [*Englehart and Douglas*, 2005]. Extensive land conversion for human activity is believed to have reduced evaporative cooling and to have sharply increased the sensible to latent heat flux, favoring higher daily temperature maxima and overwhelming the potential cooling effects of increased surface albedo following land cover change [*Englehart and Douglas*, 2005]. Precipitation across Mexico is negatively correlated with maximum temperature during the winter-spring season ($r = -0.50$, using the Zhu-Lettenmaier data for the period 1942–2004), so any regional or global escalation in seasonal temperature may therefore contribute to further drought across Mexico, which is already at the limit of its water supply system.

The early 21st-century drought may also be part of an aridity trend predicted for the subtropics of both hemispheres based on anthropogenic global warming and the poleward expansion of the Hadley circulation (i.e., the planetary-scale overturning circulation of the atmosphere centered over the equator). Climate model experiments indicate that the southwestern United States and Mexico will experience progressive drying during the 21st century, and that Dust Bowl–like droughts will "become the new climatology of the American Southwest" [*Seager et al.*, 2007]. The potential convergence of natural and anthropogenic drought provides compelling justification to improve and expand the climate observation network in parallel with enhanced drought planning and water conservation efforts in Mexico and the southwestern United States.

Acknowledgments

This research was supported by the U.S. National Science Foundation (ATM-0400713 and ATM-0753399), NOAA, and the Inter-American Institute for Global Change Research. We thank Chunmei Zhu, Art

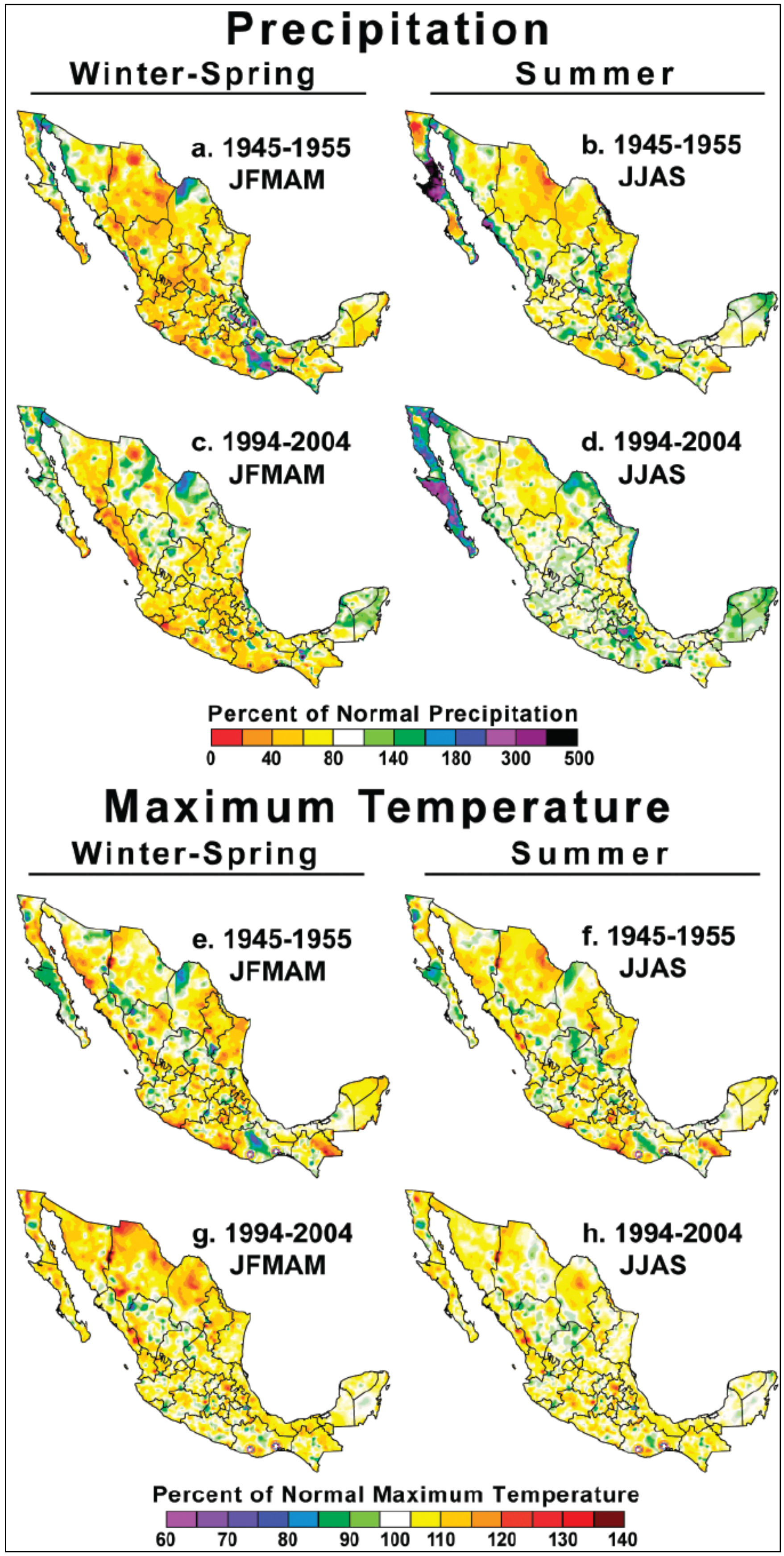

Fig.1. Seasonal precipitation and maximum temperature anomalies are averaged and mapped for 11-year episodes during the 1950s and early 21st-century droughts (as a percent of the 1961–1990 normal [from Zhu and Lettenmaier, *2007]). The winter-spring season was January–May (JFMAM), and summer was June–September (JJAS). The fall months of October–December (not shown) were also warm and dry during both 11-year episodes.*

Douglas, and contributors to the International Tree-Ring Data Bank (http://www.ncdc.noaa.gov/paleo/treering.html). This is Lamont-Doherty Earth Observatory contribution 7232.

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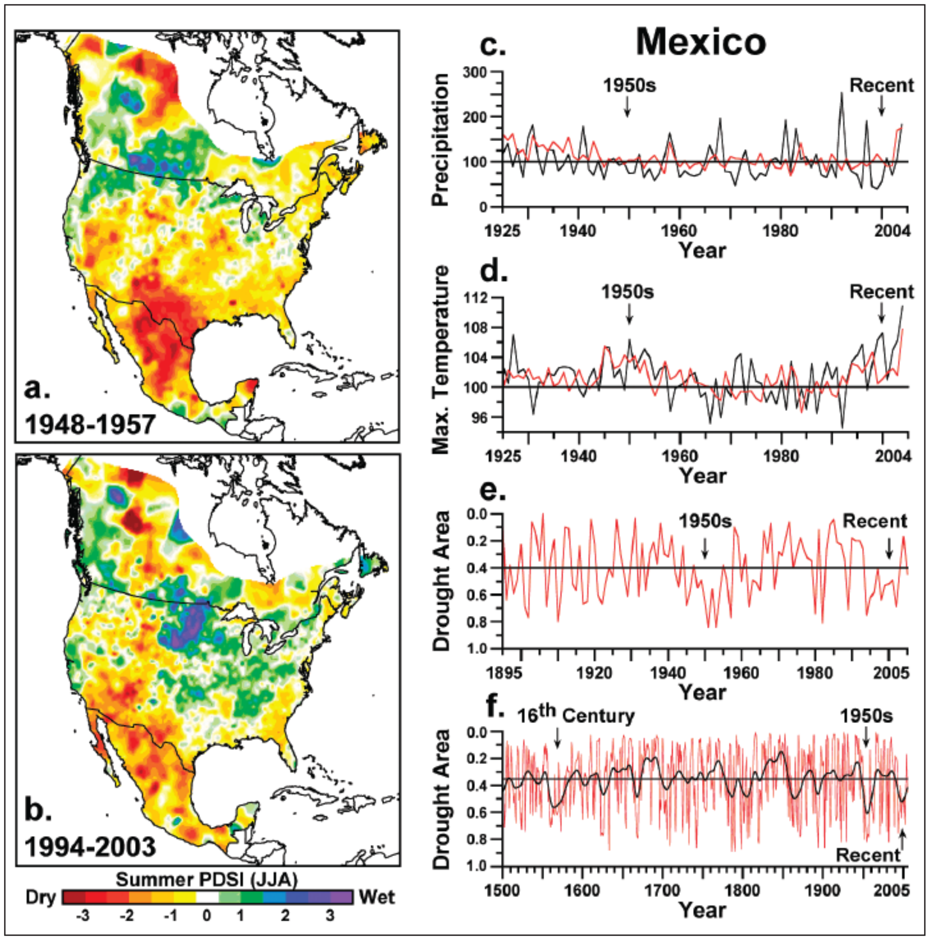

Fig. 2. The gridded instrumental summer Palmer Drought Severity Indices (PDSI) have been averaged and mapped for the driest consecutive 10 years of (a) the 1950s and (b) early 21st-century droughts (i.e., "recent"). The all-Mexico average of (c) percent of normal precipitation and (d) maximum temperature are plotted from 1925 to 2004 during the winter-spring (black curves) and summer seasons (red curves; as a percent of 1961–1990 average; data from Zhu and Lettenmaier *[2007]). (e) The Drought Area Index (DAI) averaged for 605 grid points in Mexico from 1895 to 2005 based on the NOAA 1/2° instrumental summer PDSI (east of 95°W excluded; drought area scale inverted (in percent)). (f) Tree ring reconstructed DAI for Mexico from 1500 to 2005 based on the 1/2° grid (tree ring estimates from 1500 to 1979 and the instrumental DAI from 1980 to 2005, east of 95°W excluded; drought area scale inverted (percent)). The sixteenth-century, 1950s, and "recent" early 21st-century droughts are highlighted.*

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