

Warmer Led to Drier: Dissecting the 2011 Drought in the Southern U.S.

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When prolonged high temperatures combine with scant precipitation, droughts intensify. This potent combination struck the southern U.S. in spring and summer of 2011—and may again in coming months—causing crops to wither and turning trees and shrubs into tinder. Record-setting wildland fires raced across parts of the Southwest and southern Plains. By the end of September, exceptional drought covered about half of Arizona, New Mexico, Texas, and Oklahoma combined. When all was said and done, damages exceeded \$1 billion, according to the National Oceanic and Atmospheric Administration (NOAA).

Research has shown that unusually warm temperatures can conspire with low precipitation to intensify droughts and worsen their impacts (Breshears et al. 2005; Weiss et al. 2009). We set out to assess how much temperatures exacerbated the dry spell in 2011, and our analysis showed that the widespread warmth experienced in the southern U.S. substantially compounded conditions brought about by the shortfall of moisture.

With the expectation that warmer temperatures will be a mainstay of future climate, our results highlight the potential that the Southwest will experience intensified droughts. Warmer temperatures, in other words, can lead to drier conditions.

Vapor Pressure Deficit: The Roles of Temperature and Moisture

We distinguished the roles of low moisture and high temperatures during the April–September 2011 period by determining the moisture- and temperature-dependent contributions to vapor pressure deficit, or VPD. VPD is an estimate of the atmospheric demand for both evaporation and transpiration, or

evapotranspiration, and can be thought of as the atmosphere's ability to act like a sponge and wick moisture from soils and vegetation.

VPD is the difference between saturation and actual vapor pressure (Campbell and Norman 1998). Larger differences signal greater evapotranspirational demand and can lead to more intense drought conditions. While air temperature controls saturation vapor pressure (SVP), the maximum water vapor that the atmosphere can hold, atmospheric moisture sets the dewpoint that governs actual vapor pressure (AVP). VPD can increase from either higher SVP—driven by warmer temperatures—or decreases in AVP, which results from lower dewpoints.

Extreme Conditions in 2011

From April through September 2011, warmer temperatures extended from southern Arizona to the southern Atlantic coast, with temperatures greater than 1.5 degrees Celsius above average for many parts of the Southwest and southern Plains (*Figure 1a*). Several areas in these regions experienced relatively extreme temperatures, ranked in the highest one percent (*Figure 1b*).

At the same time, below-average dewpoints occurred almost exclusively over the Southwest and southern Plains, reflecting the shortage of moisture in these regions. Most areas from central Texas westward experienced dewpoints that were greater than 1.5 degrees C below average (*Figure 1c*). In many of these areas, dewpoints were also relatively extreme, falling in the lowest 1 percent (*Figure 1d*).

VPDs in the highest 1 percent blanketed almost all of Texas, western Oklahoma, and eastern New Mexico and covered substantial parts of several adjacent states

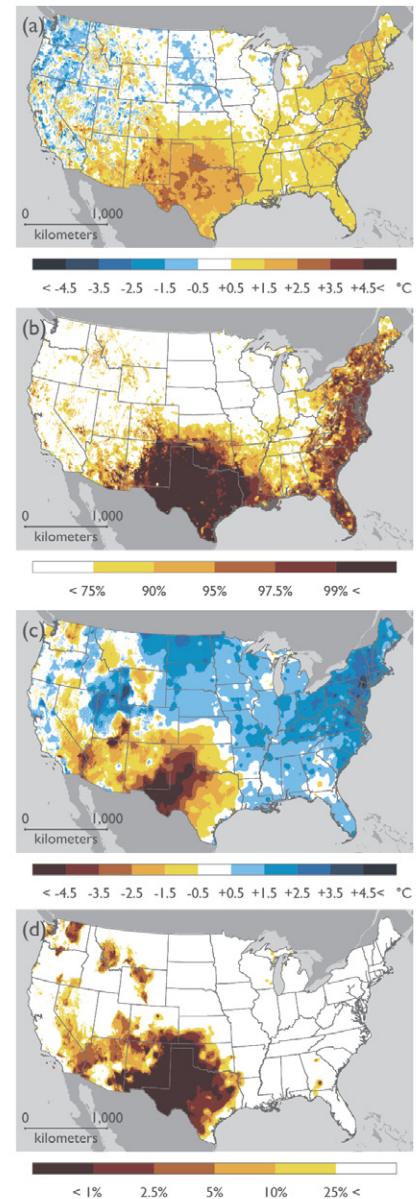


Figure 1. (a) Temperature anomalies ($^{\circ}\text{C}$) in the U.S. for 2011 April–September. (b) Areas with temperatures above upper percentiles. (c) Dewpoint anomalies ($^{\circ}\text{C}$) for 2011 April–September. (d) Areas with dewpoints below lower percentiles. Anomalies are relative to and percentiles are derived from the 1951–1980 April–September average. The PRISM Group at Oregon State University provided gridded observational data for temperature and dewpoint.

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during this period, including Arizona (Figure 2a). The geographic extent of relatively extreme VPD matches areas that experienced the most severe drought impacts during this time.

Dissecting the 2011 Drought

The combined effects of temperature and scant moisture are presented in figure 2b. We then calculated VPD under two scenarios to examine the relative contributions of temperature and atmospheric moisture to 2011 VPD during April–September (Figure 2b). In the first, we calculated VPD using 2011 temperature and the 1951–1980 average dewpoint (Figure 2c). In the second, we used the 1951–1980 average temperature and 2011 dewpoint (Figure 2d). These two scenarios represent the contributions of above-average temperature, or higher SVP, and below-average dewpoint, or lower AVP, respectively, to the observed 2011 evapotranspirational demand.

Splitting VPD into SVP and AVP anomalies shows that below-normal dewpoints in 2011 produced greater evapotranspirational demand over southern and eastern New Mexico, western Oklahoma, and most of Texas (Figure 2d). Above-average temperatures during the drought played a widespread role in exacerbating the influence of the lower moisture (Figure 2c). This one-two punch of lower moisture and higher temperatures created extraordinary evapotranspirational demand over many parts of the southern U.S.

The effect of feedbacks between the land surface and atmosphere in elevating temperature and lowering atmospheric moisture during drought in the Southwest and southern Plains is unclear in our study (Schubert et al. 2004). However, extensive warmth across much of the southern U.S. suggests that such feedbacks in these regions were not the sole reason for higher evapotranspirational demand.

This analysis illustrates the potent influence that higher temperatures can

have on current and future droughts in our region. Even though changes in future moisture are sometimes subject to notable uncertainty, particularly for the monsoon season, the potential for greater evapotranspirational demand and, as a result, intensified droughts, will grow as the Southwest continues to warm (Solomon et al. 2007; Karl et al. 2009).

Further Reading

Breshears, et al. 2005. Regional Vegetation Die-off in Response to Global-change-type Drought. *Proc. Natl. Acad. Sci. U.S.A.* 102, 15,144-15,148.

Campbell, G.S. and J.M. Norman. 1998. *An Introduction to Environmental Biophysics*. Springer.

Karl, T.R., J.M. Melillo, and T.C. Peterson. 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press.

Schubert, S.D., M.J. Suarez, P.J. Pegion, R.D. Koster, and J.T. Bacmeister. 2004. On the Cause of the 1930s Dust Bowl. *Science* 303, 1855-1859.

Solomon, et al. 2007. *Climate Change 2007: The Physical Science Basis. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Weiss, J.L., C.L. Castro, and J.T. Overpeck. 2009. Distinguishing Pronounced Droughts in the Southwestern United States: Seasonality and Effects of Warmer Temperatures. *J. Climate* 22, 5918-5932.

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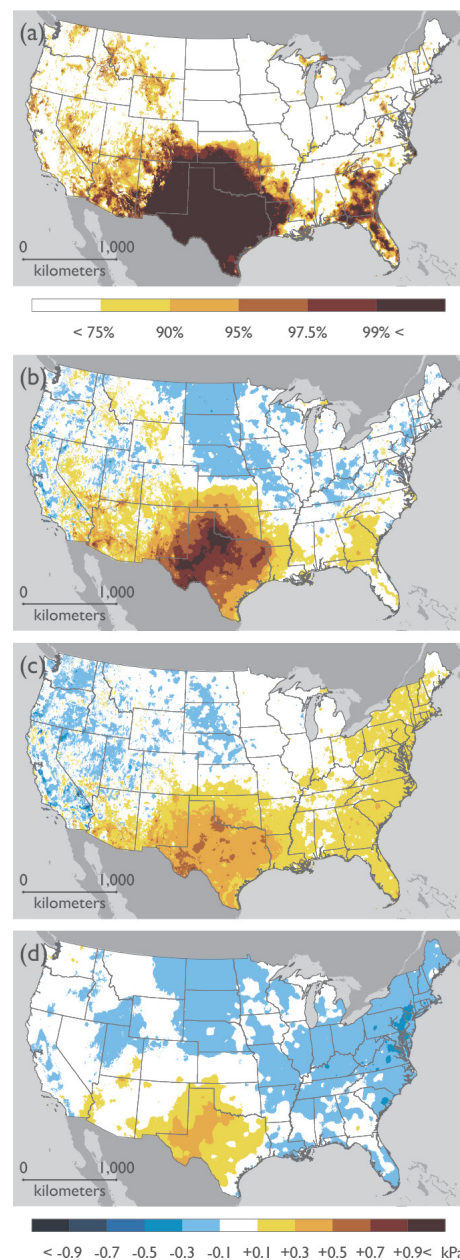


Figure 2. (a) Areas of the U.S. where 2011 April–September vapor pressure deficit (VPD) was above upper percentiles, derived from 1895–2011 April–September VPD. Panels b–d show VPD anomalies for April–September computed with (b) 2011 temperature and 2011 dewpoint; (c) 2011 temperature and 1951–1980 dewpoint (which represents the temperature contribution to 2011 evapotranspirational demand); and (d) 1951–1980 temperature and 2011 dewpoint (which shows the atmospheric moisture contribution to 2011 evapotranspirational demand). Anomalies are relative to the 1951–1980 average April–September VPD.