DID HUMAN INFLUENCE ON CLIMATE MAKE THE 2011 TEXAS DROUGHT MORE PROBABLE?

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In 2011, the state of Texas experienced an extraordinary heat wave and drought. The 6-month growing season of March–August (MAMJJA) and the three summer months of June–August (JJA) were both, by wide margins, the hottest and driest in the record that dates back to 1895 (Fig. 8). (See also Nielsen–Gammon, Office of the State Climatologist Report: The 2011 Texas drought, a briefing packet for the Texas Legislature, Oct. 21, 2011).

As with other extreme events discussed in this volume, we pose this question: Was the likelihood of either the heat wave or the drought altered by human influence on global climate? This question is portentous because an affirmative answer implies that such events, with their severe impacts on ecosystems and economics, may become more frequent. Here we endeavor to quantify the change in the likelihood of the heat wave and drought since the 1960s to the present, a period during which there has been a significant anthropogenic influence on climate. We analyze a very large ensemble of simulations from a global climate model (GCM), with greenhouse gas concentrations and other climate forcings representative of the 1960s and present day (Pall et al. 2011; Otto et al. 2012). Through the use of public volunteered distributed computing (Allen 1999; Massey et al. 2006), we obtain an ensemble size that is large enough to examine the tails of the distribution of climate variables (see the later section on the changing odds of warm Novembers and cold Decembers in England for more details).

Along with anthropogenic greenhouse gases and other climate forcings, natural sources of interannual variability will result in differences in probability distributions between years. The El Niño–Southern Oscillation (ENSO), for one, is considered to be a key driver of drought conditions in the central United States (Trenberth et al. 1988; Palmer and Brankovic 1989; Atlas et al. 1993; Hong and Kalnay 2000). Hence, to assess the role of multidecadal trends on the 2011 heat wave and drought, we compared years with similar La Niña conditions, separated by four decades, to evaluate how the probability of hot/dry conditions differed between them. The years were 1964, 1967, 1968, and 2008, with 2008 serving as a proxy for 2011 because simulations for 2011 were not available.

Data and methods. Values of observed monthly temperature and precipitation for the years 1895–2011 and spatially averaged over the state of Texas were obtained from the U.S. National Climatic Data Center (NCDC) Climate at a Glance dataset (www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html).

The atmospheric and land surface climate of the decades 1960–70 and 2000–10 were simulated with the UK Meteorological Office's Hadley Center Atmospheric General Circulation Model 3P (HadAM3P) with SST and sea–ice fraction taken from the HadISST observational dataset (Rayner et al. 2003) and using observed greenhouse gas concentrations. A large ensemble of runs with varying initial conditions was completed, resulting in many plausible realizations of the climate of these decades. See the later section on the changing odds of warm Novembers and cold Decembers in England for more information on the modeling and the climate forcings used.

Because simulations under 2011 forcing conditions were not available, we chose 2008 as a proxy for 2011, and compared it to the years 1964, 1967, and 1968. The years 1964 and 2008 were similar with respect to sea surface temperature patterns in the tropical and northern Pacific, as given by the Niño-3.4 and Pacific decadal oscillation (PDO) indices, respectively. The years 1967 and 1968 were also La Niña years (though weaker than 1964) and had negative values of the PDO index. The inclusion of three La Niña years from the 1960s allows us to examine interannual variability not driven by ENSO alone. Moreover, any influence of the Mt. Agung volcanic eruption (Indonesia,

18 February 1963) on Texas climate would have been greatly reduced by 1967 (Robock 2000).

A spatial, weighted average was calculated from the 27 GCM grid boxes that fell within Texas, with weights proportional to the cosine of the latitude. Surface air temperature and cumulative precipitation were also averaged over MAMJJA and JJA and the return period for each value from each ensemble member was calculated. Totals of 171, 1464, 522, and 1087 ensemble members were analyzed for 1964, 1967, 1968, and 2008, respectively. We attempted no model bias correction because our objective was to examine changes in the entire modeled probability distribution between the 1960s and 2008, and not to estimate the actual return period of the 2011 heat wave in a nonstationary setting.

Results. The GCM captured the inverse correlation between temperature and precipitation that is evident in the observations (Fig. 8), though the model in general generated a climate that was too dry and too warm. Between 1964 and 2008, the simulated ensembles show shifts towards warmer and slightly drier conditions (Fig. 8). The relationship is similar between 1967–68 and 2008 (not shown).

The return period for a given low precipitation event was slightly longer for the years in the 1960s than for 2008 (Fig. 9, top; e.g., a simulated 100-yr return period MAMJJA precipitation under 1964 conditions has a 25-yr return period under 2008 conditions). This may indicate an increased contribution of precipitation deficit to drought conditions in 2008, but larger sample sizes and a more in depth analysis including looking at other years are required before firmer conclusions can be drawn.

For extreme heat events, the difference between the years in the 1960s and 2008 was much more pronounced, with the return period of a particular extreme heat event being more than an order of magnitude shorter for 2008 than for any of the 3 years from the 1960s (Fig. 9, lower panel). As an example, 100-yr return period MAMJJA and JJA heat events under 1964 conditions had only 5- and 6-yr return periods, respectively, under 2008 conditions.

Conclusions. We are assessing how the combined impact of changing atmospheric composition and surface temperatures have affected the risk of extreme hot and dry conditions in Texas: since most of the large-scale warming that has occurred over the past 50 years is thought to be attributable to the anthropogenic increase in greenhouse gas levels, this provides one component of a multistep attribution process (Hegerl et al. 2010) relating the 2011 event to human influence.

We found that extreme heat events were roughly 20 times more likely in 2008 than in other La Niña years in the 1960s and indications of an increase in frequency of low seasonal precipitation totals. With 2008 serving as our proxy for 2011, this suggests that conditions leading to droughts such as the one that

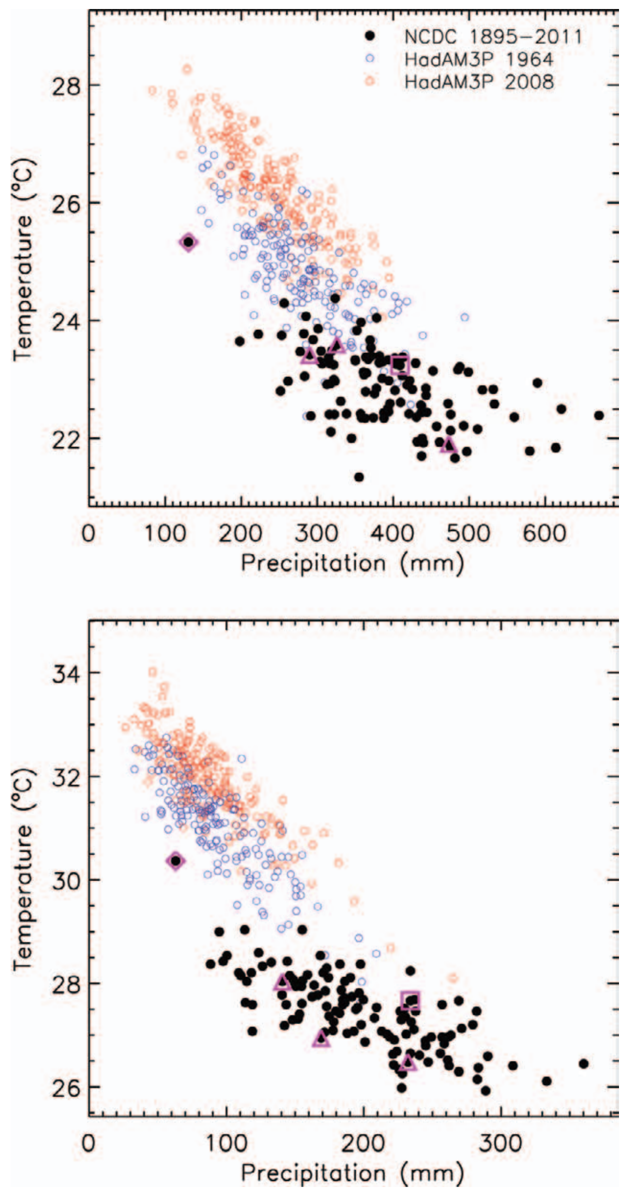

Fig. 8. Texas mean temperature against total precipitation for (top) MAMJJA and (bottom) JJA from NCDC and the HadAM3P ensembles. The observed years 1964, 1967, and 1968 are highlighted by the magenta triangles, and the observed years 2008 and 2011 are highlighted by the magenta square and diamond, respectively. To facilitate comparison between model years, only a random sample of the HadAM3P 2008 dataset, equal in size to the 1964 dataset, is shown.

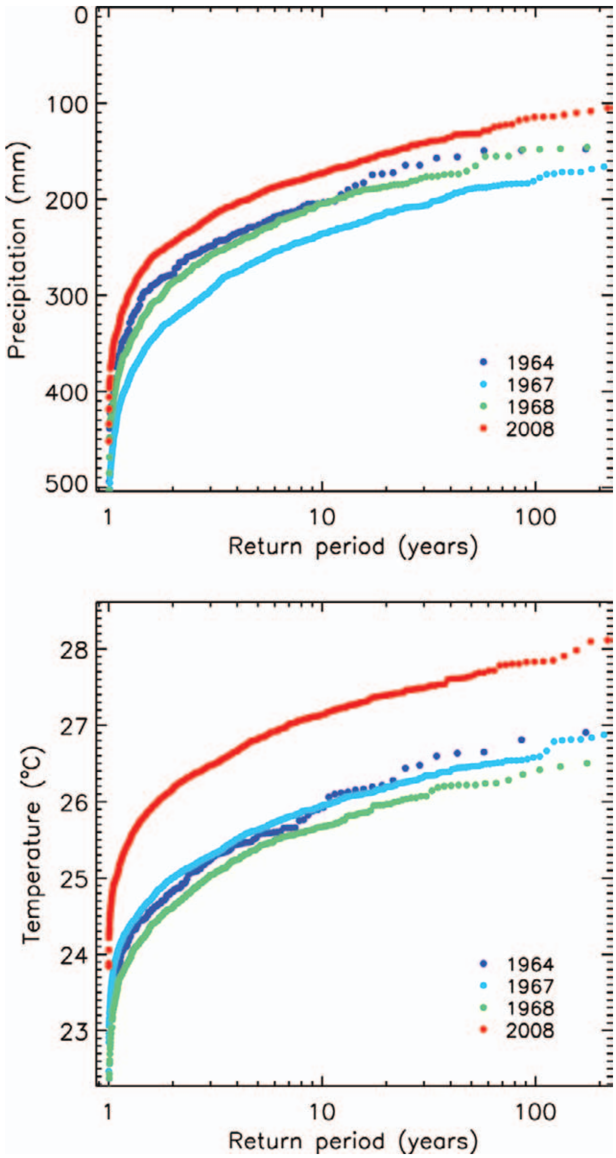

Fig. 9. Return periods of (top) total precipitation and (bottom) mean temperature, Texas, MAMJJA, 1964, 1967, 1968, and 2008, from HadAM3P ensembles.

occurred in Texas in 2011 are, at least in the case of temperature, distinctly more probable than they were 40–50 years ago.

However, there are two main factors in the model driving the differences in the 1960s and 2008 probability distributions of precipitation and temperature. One factor is the effects of external climate forcings, dominated by the increase in greenhouse gas concentrations due principally to anthropogenic emissions. The second factor is the difference in the SST/sea–ice-fraction fields between the years. However, the difference in SST/sea–ice-fraction fields itself has a contribution from increased anthropogenic greenhouse gases, and a second contribution that is due to natural variability. We chose to compare years with similar values of the Niño-3.4 and PDO in order to reduce the contribution due to natural variability; however, other SST patterns may have played significant roles (e.g. McCabe et al. 2004; Schubert et al. 2009).

Progress toward quantifying attribution will include analysis of more years to further evaluate the natural variability and test the robustness of the results presented here. Furthermore, we will explore uncertainty in atmospheric response using perturbed physics ensembles.

Modeling studies such as this allow us to quantify how much the probability of extreme hot and dry conditions in Texas has changed. Quantifying the absolute probability of such extreme conditions is much more difficult, since the models we use are subject to bias, particularly affecting tails of distributions, and data records are too short to quantify absolute probabilities empirically. Hence, while we can provide evidence that the risk of hot and dry conditions has increased, we cannot say that the 2011 Texas drought and heat wave was "extremely unlikely" (in any absolute sense) to have occurred before this recent warming.

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