Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
40th NOAA Annual Climate Diagnostics and Prediction Workshop
Denver, CO, 26-29 October 2015

Simulated U.S. Drought Response to Interannual and Decadal Pacific SST Variability

Robert Burgman, Youkyoung Jang
Department of Earth and Environment, Florida International University, Miami, FL

1. Introduction

Recent multiyear droughts in California and the Great Plains coincide with an extended period of arid conditions over much of the contiguous United States that began in 1999, with severe regional droughts occurring in 1999, 2002, 2006, 2008, and 2011. Understanding the mechanisms and probability for drought onset, persistence, and intensity is paramount for decision makers, who must assess potential impacts and management options. If there is long-term predictability for drought, the "memory" for this predictability resides with the global oceans, but precisely how the global oceans influence observed North American drought remains unresolved. In this study, we expand on previous studies by focusing on AGCM simulations where the decadal and interannual signals are effectively separated in order to examine how the cold phase Pacific SSTA patterns associated with different time scale variability impact hydroclimate over the contiguous United States, with a particular focus on the differences in amplitude of the equatorial and midlatitude SST anomalies and precipitation over the Great Plains region.

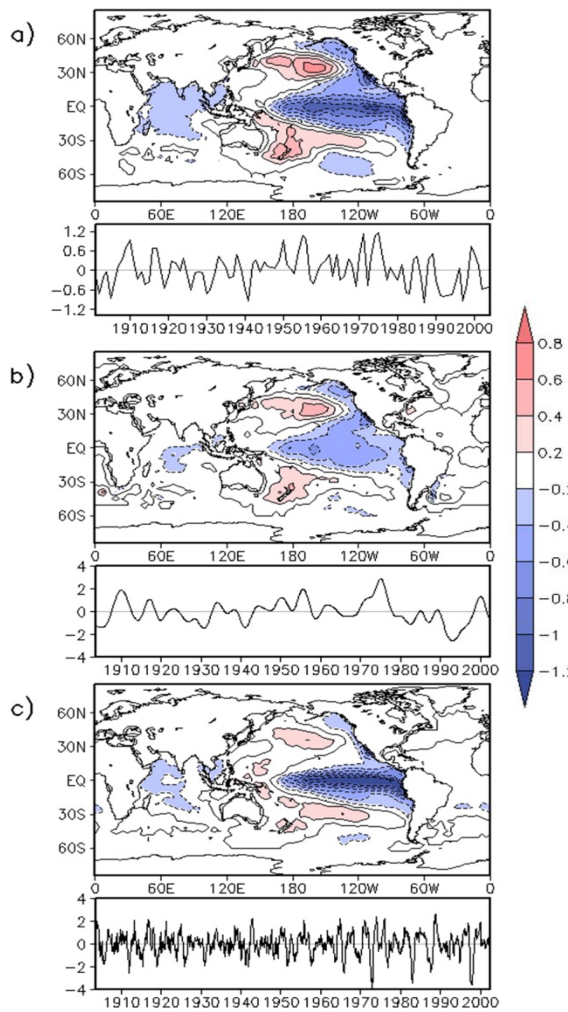

Fig. 1 The SST anomaly patterns (°C) used in forcing for experiments with principal components: (a) PcAn, (b) LFc, and (c) HFc. The top panels are the idealized anomaly patterns of each type and the bottom panels are the climatologically varying SSTs by years.

2. Models, modeling methodology, and data

Idealized AGCM simulations performed by members of the U.S. CLIVAR Drought Working Group (DWG) were used in this study. The low-frequency (LF) and high-frequency (HF) AGCM simulations of interest for this study were carried out by three of the five agencies that contributed AGCM data to the DWG in addition to the baseline simulations noted above. The three models are:

1. The NASA Global Modeling and Assimilation Office (GMAO) NSIPP, version 1 (NSIPP1) AGCM at 3° × 3.75°, L34 resolution (Bacmeister *et al.* 2000; Schubert *et al.* 2002).
2. The National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center Global Forecast System (GFS) AGCM at 2° × 2°, L64 resolution (Campana and Caplan 2005).

Correspondence to: Robert Burgman, AHC5-Ste 360, 12000 SW 8th Street, Department of Earth and Environment, Florida International University, Miami, FL 33199; E-mail: rburgman@fiu.edu.

3. NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) Atmosphere Model, version 2.1 (AM2.1), AGCM at 2° × 2.5°, L24 resolution (Delworth *et al.* 2006).

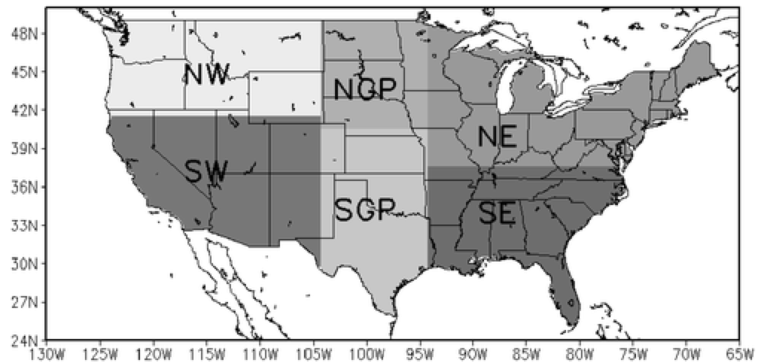

Fig. 2 The regions of the United States used to form averages in Figs. 3 and 4

For the DWG AGCM simulations, idealized SST anomaly patterns are fixed in time and superimposed on climatologically varying SSTs derived from the Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST; Rayner *et al.* 2003) for the period 1901–2004. The SST pattern for the Pacific (PcAn; Fig. 1a) comes from the baseline experiments. (See Schubert *et al. 2009* for methodology and derivation of SST patterns). Note that the principal component (PC) time series associated with the PcAn pattern in Fig. 1a captures the interannual variability of ENSO in addition to variability on decadal time scales. The Drought Working Group also produced patterns of SST anomalies associated with the low-frequency (LF) and high-frequency (HF) tropical Pacific SST variability. The low-frequency cold (LFc) and high-frequency cold (HFc) patterns are shown in Figs. 1b and 1c, The patterns of the anomalies are similar in a broad sense (spatial correlations for PcAn and LFc, r = 0.93; PcAn and HFc, r = 0.9; and LFc and HFc, r = 0.79); however, the amplitude of the equatorial (midlatitude) anomalies differ by up to 1°C (0.3°C) between the different patterns. The GFDL AM2.1 and NASA NSIPP1 simulations were run for 50 yr and the NCEP GFS for 35 yr. For the purposes of the regional analysis in this study, the contiguous United States is divided into six subregions (see Fig. 2); the northern–southern western United States, the northern–southern Great Plains, and the northern–southern eastern United States.

3. Research highlights

Overall, there is agreement with previous results using the DWG model data, as all of the models simulated drought conditions over large portions of the contiguous United States for the La Niña–like PcAn SST forcing pattern. Building on previous results of the DWG, the current study finds differing levels of sensitivity to regional differences in prescribed Pacific SST forcing patterns with respect to internal atmospheric variability in the three AGCMs. The coherence of the AM2.1 responses for all forcing patterns and across all seasons (Fig 3a and d) suggests the model is overpredicting the strength of the tropical SST signal. Internal atmospheric variability and land–atmosphere interactions were shown to influence the GFS model response, though the shorter simulations also play a role in the reduced significance of the results presented (Fig. 3c and f). The SST forced response in the NSIPP1 AGCM (Fig 3b and e) is a function of the relative amplitude of the SST forcing in the tropics and middle latitudes, with detectible constructive interference between the two signals, similar to that seen between ocean basins (McCabe *et al.* 2004; Schubert *et al.* 2009). The current study points to a more significant role for the extratropical component of the SST in forcing the precipitation response; particularly over the western United States and northern Great Plains, via distinctly different teleconnections. In light of the results presented, it is certainly reasonable that the amplitude of the Pacific (PcAn) pattern dominated the drought response in the earlier works by the U.S. CLIVAR Drought Working Group (Schubert *et al.* 2009), when compared to the multidecadal Atlantic and warming trend patterns.

While the large equatorial component of the PcAn forcing may not be appropriate for comparison with the decadal- and century-scale Atlantic multidecadal oscillation (AMO) and global trend pattern, it is critical in the context of understanding the observed variability of the Pacific. The PcAn pattern can be seen as a "worst case" scenario for drought that is all the more relevant considering the recent occurrence of multiyear La Niña events (1998–2001, 2007–09, and 2010–12). The amplified response to the combined PcAn pattern seen in the NSIPP1 AGCM suggests that the severity of several recent droughts, particularly in the U.S.

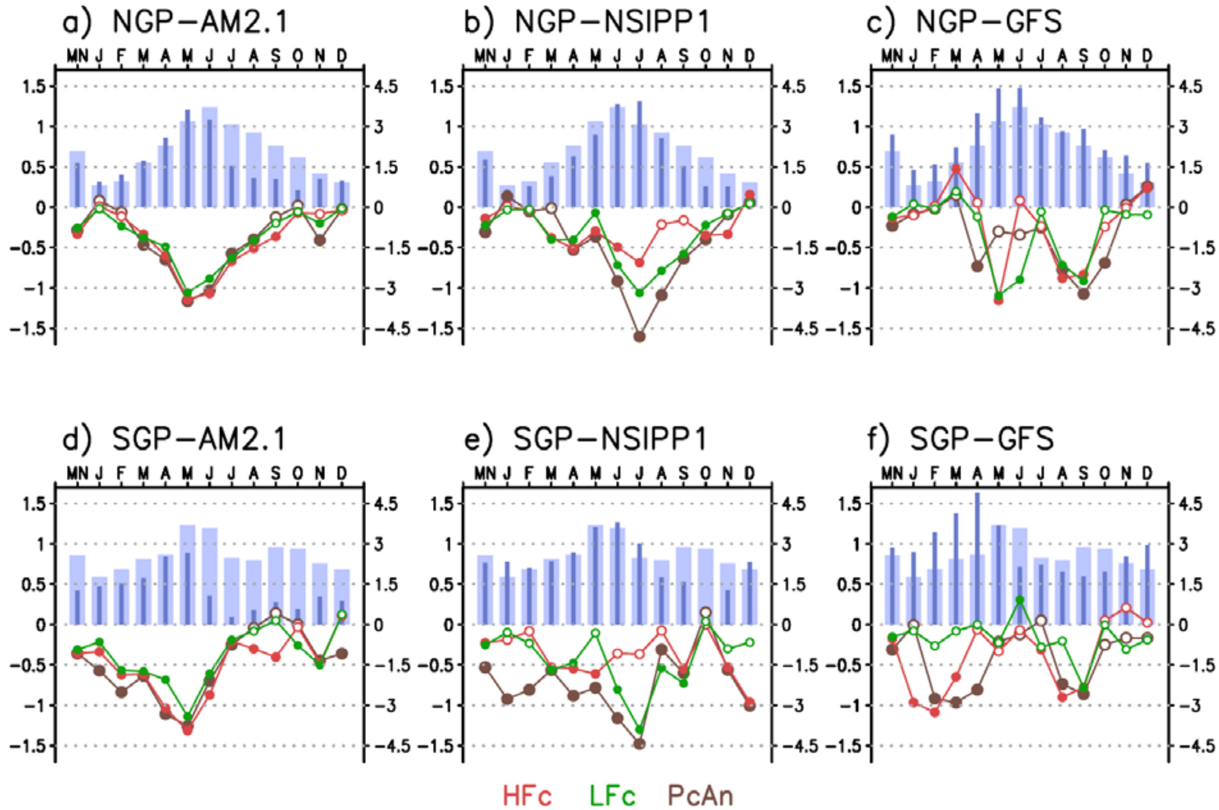

Fig. 3 Annual mean (labeled MN in the top far left of each panel) and monthly precipitation climatology and simulated precipitation response with respect to control (PnAn) averaged over (a)–(c) the northern Great Plains and (d)–(f) the southern Great Plains. Model annual mean and monthly mean climatology is shown with dark blue bars for each case; and observed annual mean and monthly climatology are shown with light blue bars (right-hand side *y* axis; mm month^{-1}). Annual mean and seasonal response of HFc (red), LFc (green), and PcAn (brown) compared to climatology control run. Solid circles indicate confidence at 90% (left-hand side *y* axis; mm day^{-1}).

Southwest and Great Plains, is likely influenced by the combined cold decadal pattern that has prevailed since the late 1990s (Burgman *et al.* 2008, Clement *et al.* 2009) and the large number of individual La Niña events.

This work has been published in *Journal of Climate* in 2015.

References

Bacmeister, J., P. J. Pegion, S. D. Schubert, and M. J. Suarez, 2000: Atlas of seasonal means simulated by the NSIPP 1 atmospheric GCM. NASA Tech. Memo. 104606, Vol. 17, Goddard Space Flight Center, Greenbelt, MD, 194 pp.

Burgman, R. J., A. Clement, C. Mitas, J. Chen, and K. Esslinger, 2008: Evidence for atmospheric variability over the Pacific on decadal timescales. *Geophys. Res. Lett.*, **35**, L01704, doi:10.1029/2007GL031830

——, and Y. Jang, 2015: Simulated U.S. drought response to interannual and decadal Pacific SST variability. *J. Climate*, **28**, 4688–4705, doi: http://dx.doi.org/10.1175/JCLI-D-14-00247.1

Campana, K., and P. Caplan, Eds., 2005: Technical procedures bulletin for the T382 Global Forecast System. Available online at http://www.emc.ncep.noaa.gov/gc_wmb/Documentation/TPBoct05/T382.TPB.FINAL.htm

Clement, A. C., R. Burgman, and J. R. Norris, 2009: Observational and model evidence for positive low-level cloud feedback. *Science*, **325**, 460–464, doi:10.1126/science.1171255

Delworth, T. L., and Coauthors, 2006: GFDL’s CM2 global coupled climate models. Part I: Formulation and simulation characteristics. *J. Climate,* **19**, 643–674, doi:10.1175/JCLI3629.1

McCabe, G. J., M. A. Palecki, and J. L. Betancourt, 2004: Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. *Proc. Natl. Acad. Sci. USA*, **101**, 4136–4141, doi:10.1073/pnas.0306738101

Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan, 2003: Global analyses of SST, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res.*, **108**, 4407, doi:10.1029/2002JD002670

Schubert, S. D., and Coauthors, 2009: A U.S. CLIVAR project to assess and compare the responses of global climate models to drought-related SST forcing patterns: Overview and results. *J. Climate*, **22**, 5251–5272, doi:10.1175/2009JCLI3060.1

Schubert, S. D., M. J. Suarez, P. J. Pegion, M. A. Kistler, and A. Kumer, 2002: Predictability of zonal means during boreal summer. *J. Climate*, **15**, 420–434, doi:10.1175/1520-0442(2002)015<0420:POZMDB>2.0.CO;2