Relationships between ENSO and drought over the southeastern United States

Kingtse C. Mo[1] and Jae E. Schemm[1]

Received 12 May 2008; revised 20 June 2008; accepted 24 June 2008; published 1 August 2008.

[1] A long term precipitation (P) data set over the United States and the sea surface temperature (SST) data from 1915 to 2006 were used to examine the impact of El Nino Southern Oscillation (ENSO) on drought and persistent wet spells over the southeastern United States. The meteorological droughts and wet spells were identified based on the 6-month standardized precipitation index (SPI 6) calculated from P averaged over the Southeast. These events indicate that a drought (or wet spell) over the Southeast is more likely to start during a cold (warm) ENSO winter or early spring. The influence of ENSO on P is seasonally dependent. The P composites for cold ENSO events show positive P anomalies over the Southeast in winter but negative anomalies in summer. For warm ENSO events, the situation reverses. Therefore, a persistent cold (warm) ENSO from winter to summer does not create favorable conditions for drought (wet spells) to persist over the Southeast. While cold ENSO events are more likely to initiate droughts, droughts are likely to persist if the cold (warm) ENSO winter is followed by an ENSO neutral summer. **Citation:** Mo, K. C., and J. E. Schemm (2008), Relationships between ENSO and drought over the southeastern United States, *Geophys. Res. Lett.*, *35*, L15701, doi:10.1029/2008GL034656.

1. Introduction

[2] The current drought in the southeastern United States has caused water shortages and devastating economic effects on people and ecosystems. The water level in the Lake Lanier has reached its lowest level on the record. *Ropelewski and Halpert* [1986, 1989] demonstrated that warm (cold) ENSO events favor rain (dryness) over the Southeast in winter. Drought usually means persistent dryness. The question is whether persistent cold ENSO events will enhance and maintain drought over the Southeast. In this note, evidence will show that persistent ENSO conditions from winter to summer do not favor persistent drought or wet spells over the Southeast. Droughts (persistent wet spells) over the Southeast are likely to occur during a cold (warm) ENSO winter or early spring. However, droughts are likely to persist if the cold ENSO is followed by an ENSO neutral or a warm ENSO event in summer.

2. Data and Procedures

[3] The monthly mean precipitation (P) data set was obtained from the University of Washington. It is based on the cooperative observer station meteorological daily data with the Precipitation Regression on Independent Slopes Method (PRISM) correction. Station data are gridded using the method described by *Maurer et al.* [2002]. The data set covers the period 1915–2006. The data set is compared with the P derived from the Climate Prediction Center (CPC) unified gridded analysis [*Higgins et al.*, 2000] for the common period 1950–2006. Over the Southeast, the two data sets are similar. The SST data are the monthly reconstructed SSTs from *Smith et al.* [1996]. The data set covers the period from 1915-present. The horizontal resolution is 2°. Climatological monthly means for the period from 1915 to 2006 are removed from each data set to obtain anomalies.

[4] Composites were used to establish the relationships between ENSO and drought and wet spells over the Southeast. The statistical significance of a composite map was assessed by the Monte Carlo test. To test the statistical significance of a composite map of SST anomalies (SSTAs), composites were computed from randomly selected maps from the same SSTA time series. The process was repeated 500 times. The statistical significance of the tested map can be determined from these 500 cases at each grid point. The SST anomaly composite should be within 5 percentiles of the distribution function determined by composites of randomly selected maps. The areas in which values of the composite field are statistically significant at the 5% level are shaded. The composites of P and SPI 6 can be tested the same way.

3. Influence of SST Anomalies on the Southeast Drought

[5] Meteorological drought is measured by persistent precipitation deficits. The index used to define drought here is the 6-month standardized precipitation index (SPI 6) [*Hayes et al.*, 1999; *McKee et al.*, 1993, 1995]. Precipitation area means (P_{se}) were obtained for the Southeast from the P data set from the University of Washington. The area is marked on the map (Figure 1). To obtain SPI 6, 6 month P_{se} means were calculated. A transformation from Gamma to Gaussian distribution was performed on the 6-month P_{se} mean time series. Thus, SPI 6 was determined according to the distribution of the transformed data set (Figure 1, red crosses). The SPI 6 can also be calculated from the CPC gridded data (Figure 1, blue line). For the common period, they are very similar with a correlation of 0.95. Therefore, drought and wet spells from 1915–2006 were identified from the P data from the University of Washington (Figure 1).

[6] Drought is defined as the SPI 6 index (Figure 1) being less than −0.8 [*Svoboda et al.*, 2002] for 4 consecutive

[1]Climate Prediction Center, NCEP, NWS, NOAA, Camp Springs, Maryland, USA.

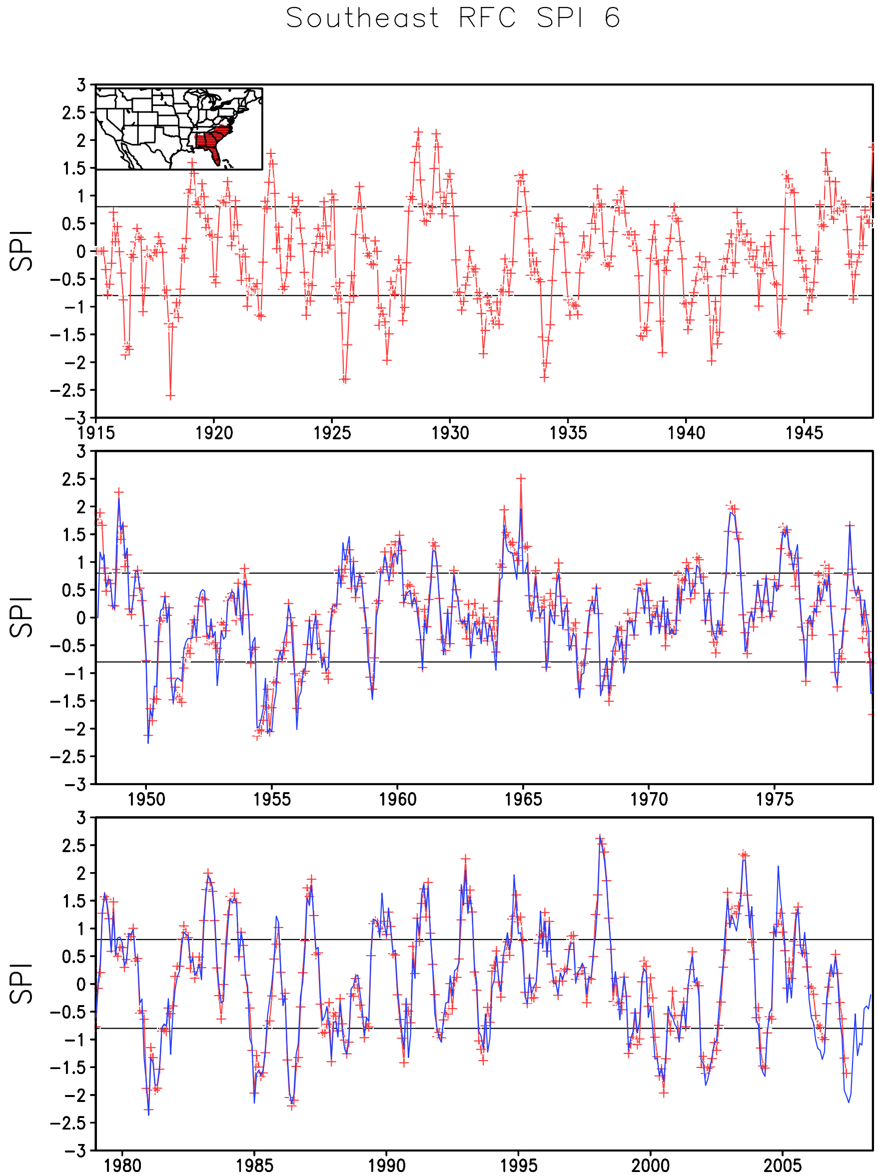

Figure 1. Six-month SPI for precipitation averaged over the Southeast (shaded area on the map) based on P data from the University of Washington (red crosses) and the CPC gridded P (blue line).

months. The wet spell can be defined similarly as the SPI 6 being greater than 0.8 for 4 consecutive months. There were a total of 19 drought events during the period 1915–2006. On average, drought over the Southeast lasted 7 months. Of these 19 drought events, 14 started in December–February and 4 started in spring (March–April). Twelve drought events ended in summer (June–September). There were a total of 20 wet events, and on average they lasted 7.8 months. Of these 20 events, 14 events started in December–May. Unlike droughts over the western United States, there were no multiyear or decadal dry or wet events over the Southeast. The longest dry or wet event lasted for 13 months.

[7] Contributions to P over the Southeast come primarily from the vertically integrated moisture flux convergence. Soil moisture does not play a major role [*Koster et al.*, 2004; *Luo et al.*, 2007]. The low level winds and humidity are likely to be responses to SSTAs [*Mo and Schemm*, 2008]. To examine the relationships between drought (wet spells) and SSTAs, composites of SSTA were obtained for the winter (December– March) and summer (June–September) months under drought or wet spells respectively (Figure 2). Monte Carlo testing was used to assess the statistical significance. Areas over which anomalies are statistically significant at the 5% level are shaded.

[8] The winter composite for months under drought (Figure 2a) shows negative SSTAs in the tropical Pacific with positive SSTAs in the North Atlantic and along the East Coast of North America. The suggestion that a cold ENSO winter is in favor of drought over the Southeastern United States is consistent with the findings by *Ropelewski and Halpert* [1986, 1989]. However, the composite for summer months under drought (Figure 2c) indicates an ENSO neutral condition with warm SSTAs along the West Coast. In addition to the Pacific SSTAs, the warm SSTAs in

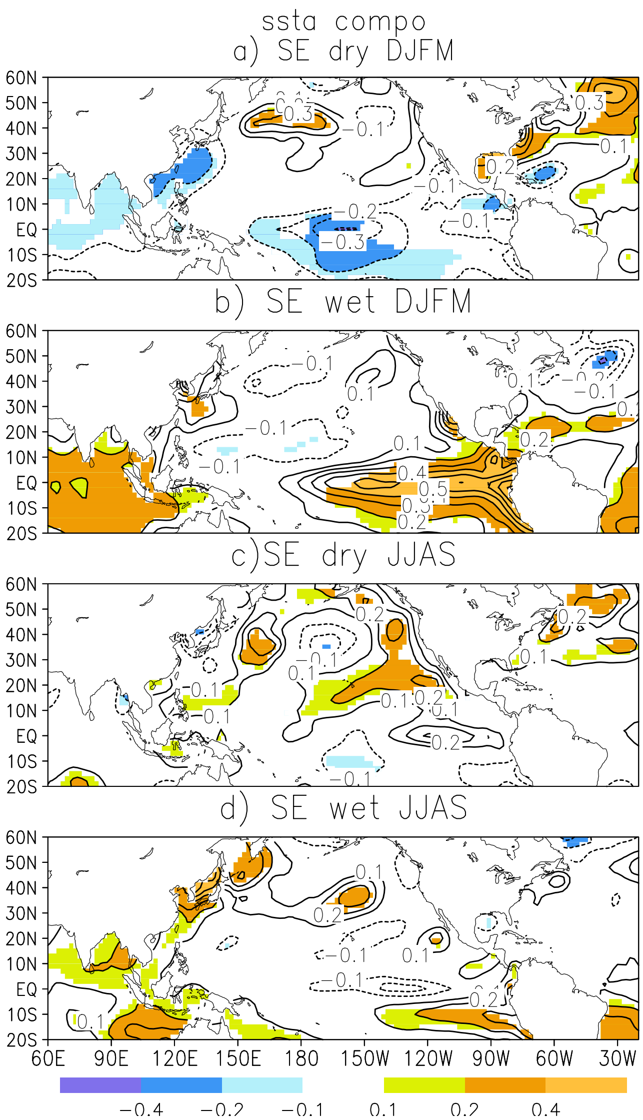

Figure 2. (a) SSTA composite for winter (December–March) months under drought over the Southeast. Contour interval is 0.1 C. Zero contours are omitted. Areas where positive (negative) anomalies are statistically significant at the 5% level based on the Monte Carlo test are shaded red (blue), (b) same as (a) but for persistent wet spells over the Southeast, (c)–(d) same as (a)–(b), but for summer (June–September) months under drought.

the Atlantic persist from winter to summer. These composites suggest that persistent cold ENSO events from winter to summer do not favor persistent drought over the Southeast. The conditions for drought are cold SSTAs in the tropical Pacific in winter and a neutral ENSO summer with warm SSTAs over the West Coast of the United States and in the North Atlantic.

[9] For wet spells, the winter composite (Figure 2b) shows a typical warm ENSO pattern with positive SSTAs in the tropical Pacific and the Indian Ocean and negative SSTAs in the North Atlantic. For summer, the composite shows a weakening of the warm ENSO with weaker warm SSTAs in the eastern Pacific. Similar to the drought events over the Southeast, a warm ENSO event may initiate wet spells in winter or spring, but wet spells are more likely to persist over an ENSO neutral summer. The physical mechanisms are explored in the next section.

4. Physical Mechanisms

[10] *Mo and Schemm* [2008] demonstrated that rainfall over the Southeast has a very weak seasonal cycle. This means that rainfall for all seasons can contribute to SPI 6 or other measures of persistent rainfall. Persistent ENSO events do not favor persistent drought or wet spells over the Southeast because the influence of ENSO on rainfall over the Southeast is seasonally dependent. Winter and summer ENSO events have the opposite influence on P over the Southeast.

[11] To demonstrate that, ENSO events were selected according to the first rotated empirical orthogonal function (REOF 1) of annual mean SST anomalies (Figure 3a). The REOF explains about 14% of the total variance. It shows a typical SST pattern for cold ENSO events. Negative SSTAs extend from the central Pacific to the eastern Pacific with positive SSTAs in the North Pacific. The seasonal mean SSTAs for DJFM and JJAS were projected onto REOF 1 to obtain the rotated principal component RPC1. Cold (warm) ENSO events were selected when RPC 1 was greater than 1 (less than −1) standard deviation. When REOFs are obtained for summer and winter separately, the first REOFs had similar patterns, but the percentages of explained variances differ. Composites of P and SPI6 were obtained for warm and cold ENSO events separately. The results are displayed as the differences between cold and warm events. The statistical significance was accessed using the Monte Carlo method.

[12] During a cold ENSO event, the atmospheric response to tropical SSTAs is a Pacific North American type wave train with negative height anomalies over the western-central United States and positive height anomalies over the Southeast [*Mo and Livezey*, 1986]. That pattern supports dryness over the Southeast as indicated by the winter P composite (Figure 3b). Figure 3b shows negative rainfall anomalies over the Southeast, the Southwest and the Southern Plains with positive anomalies over the Ohio Valley and the Pacific Northwest. The important feature is that the Southeast is dry during a cold ENSO event. The composite for summer shows positive P anomalies over the Southeast and the East Coast with negative anomalies over the north central United States (Figure 3b). Results are consistent with composites based on different data sets over shorter periods and with different criteria for ENSO [*Mo and Schemm*, 2008]. The positive P anomalies over the Southeast and the East Coast may be due to tropical storms. During summer, one of the major atmospheric responses to cold ENSO events is the decrease of wind shear in the tropical North Atlantic. Lower vertical wind shear is conducive to the occurrence of tropical storms [*Gray*, 1984; *Chelliah and Bell*, 2004]. The situation reverses for warm ENSO events. Because the influence of ENSO on rainfall anomalies over the Southeast is seasonally dependent, a persistent cold (warm) event may initiate drought (wet spells) in winter or spring but it will bring relief in summer. In addition to

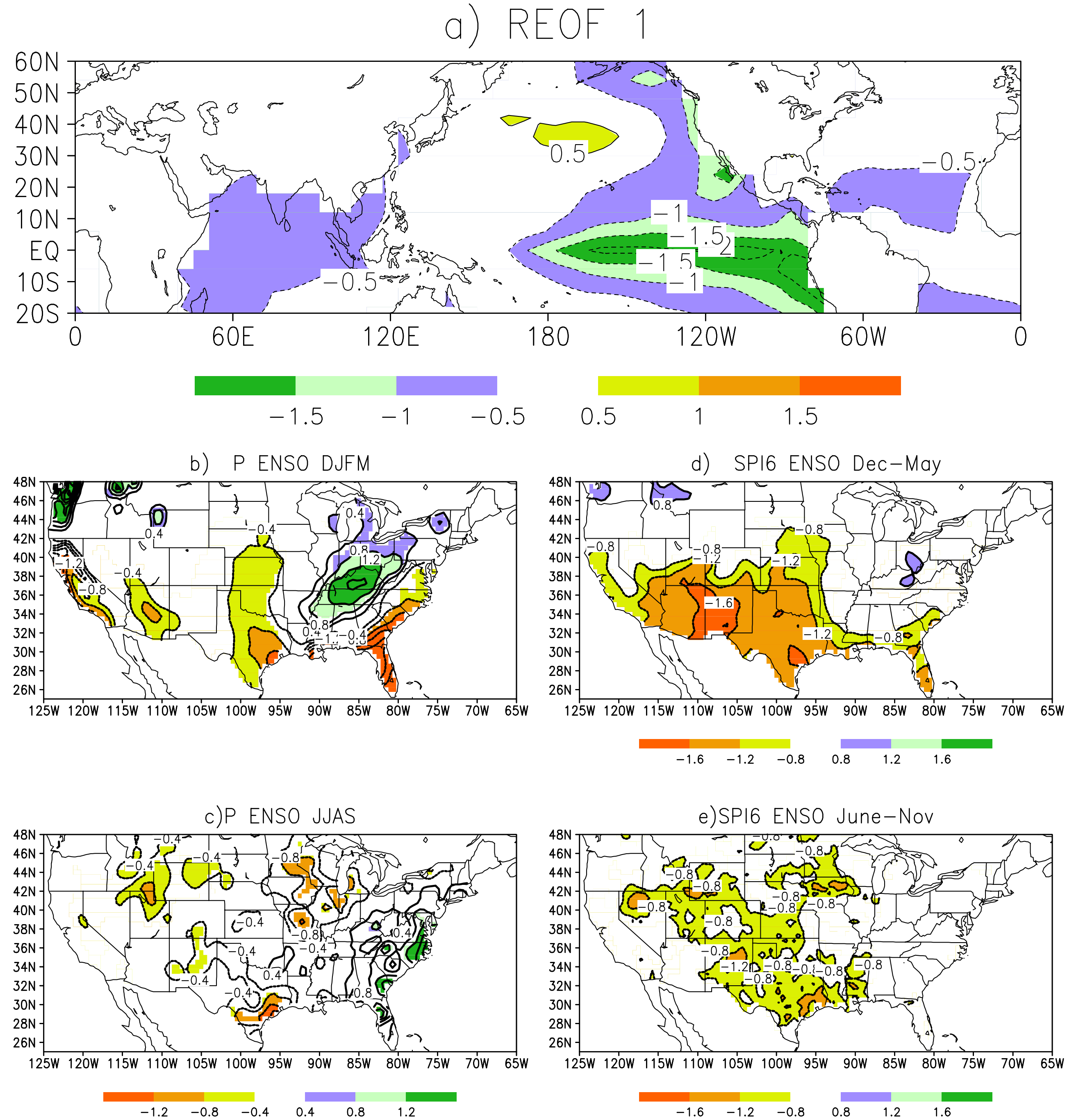

Figure 3. (a) Rotated EOF for annual mean SSTAs. Contour interval 0.5 non dimensional unit. Zero contour are omitted, (b) Precipitation composite difference between cold and warm ENSO events for winter. Contour interval is 0.4 mm day^{-1}. Zero contours are omitted. Areas where positive (negative) anomalies are statistically significant at the 5% level based on the Monte Carlo test are shaded red (blue), (c) same as Figure 2b, but for summer, (d) same as Figure 2b, but for SPI 6 for Dec–May and (e) same as Figure 2b, but for SPI 6 for June–November.

P composites, we also show composites of the drought index SPI 6. The composite of SPI 6 indicates that a drought is likely to start over the southern United States, the Southeast and the Great Plains during a cold ENSO winter and spring (Figure 3d). For summer, drought over the central United States and the upper Colorado region is likely to continue, but drought over the Southeast diminishes. This may explain why drought over the Southwest usually does not persist more than a year and why persistent ENSO events do not favor prolonged drought or wet spells.

5. Conclusions

[13] The influence of ENSO on rainfall anomalies over the Southeast is seasonally dependent. The cold (warm) ENSO favors dryness (wetness) over the Southeast in

winter, but it is likely to bring rainfall (dryness) in summer. The seasonal cycle of precipitation over the Southeast is very weak, and rainfall for all seasons can contribute to long term measures of rainfall anomalies such as SPI 6. Therefore, persistent ENSO conditions do not favor persistent drought or wet spells over the Southeast. Favorable conditions for drought are cold ENSO conditions in winter followed by neutral ENSO conditions in summer. This also explains why there is no multiyear drought over the Southeast. ENSO events can last more than 6 months from winter to summer. This may explain why drought over the Southeast is likely to end in summer.

[14] **Acknowledgments.** We wish to thank Andy Wood and Dennis Lettenmaier for providing precipitation data. This work was supported by NCPO/CPPA project GC06-012.

References

Chelliah, M., and G. D. Bell (2004), Tropical multi decadal and interannual climate variability in the NCEP-NCAR reanalysis, *J. Clim.*, *17*, 1777–1803.

Hayes, M. J., M. D. Svoboda, D. A. Wilhite, and O. V. Vanyarkho (1999), Monitoring the 1996 drought using the standardized precipitation index, *Bull. Am. Meteorol. Soc.*, *80*, 429–438.

Higgins, R. W., W. Shi, E. Yarosh, and R. Joyce (2000), *Improved United States Precipitation Quality Control System and Analysis*, *NCEP/CPC Atlas 7*, Clim. Predict. Cent., Camp Springs, Md.

Gray, W. M. (1984), Atlantic seasonal hurricane frequency. Part 1: En Nino and 30 mb quasi biennial oscillation influences, *Mon. Weather Rev.*, *112*, 1649–1668.

Koster, R. E., et al. (2004), Regions of strong coupling between soil moisture and precipitation, *Science*, *305*, 1138–1140.

Luo, Y., E. H. Berbery, K. E. Mitchell, and A. K. Betts (2007), Relationships between land surface and near surface atmospheric variables in the NCEP North American regional reanalysis, *J. Hydrometeorol.*, *8*, 1184–1203.

Maurer, E. P., A. W. Wood, J. C. Adam, D. P. Lettenmaier, and B. Nijssen (2002), A long term hydrologically based dataset of land surface fluxes and states for the conterminous United States, *J. Clim.*, *15*, 3237–3251.

McKee, T. B., N. J. Doesken, and J. Kleist (1993), The relationship of drought frequency and duration to time scales, paper presented at Eighth Conference on Applied Climatology, Am. Meteorol. Soc., Anaheim, Calif.

McKee, T. B., N. J. Doesken, and J. Kleist (1995), Drought monitoring with multiple time scales, paper presented at Ninth Conference on Applied Climatology, Am. Meteorol. Soc., Dallas, Tex.

Mo, K. C., and R. E. Livezey (1986), Tropical extratropical geopotential height teleconnections during the Northern Hemisphere winter, *Mon. Weather Rev.*, *114*, 2388–2515.

Mo, K. C., and J. E. Schemm (2008), Drought and persistent wet spells over the United States and Mexico, *J. Clim.*, *21*, 980–994.

Ropelewski, C. F., and M. S. Halpert (1986), North American precipitation and temperature patterns associated with the El Nino/Southern Oscillation, *Mon. Weather Rev.*, *114*, 2352–2362.

Ropelewski, C. F., and M. S. Halpert (1989), Precipitation patterns associated with the high index phase of the Southern Oscillation, *J. Clim.*, *2*, 268–284.

Smith, T. M., R. W. Reynolds, R. E. Livezey, and D. C. Stokes (1996), Reconstruction of historical sea surface temperatures using empirical orthogonal functions, *J. Clim.*, *9*, 1403–1420.

Svoboda, M. D., et al. (2002), The drought monitor, *Bull. Am. Meteorol. Soc.*, *83*, 1181–1190.

K. C. Mo and J. E. Schemm, Climate Prediction Center, NCEP, NSW, NOAA, Camp Springs, MD 20746, USA. (kingste.mo@noaa.gov)