Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
33rd NOAA Annual Climate Diagnostics and Prediction Workshop
Lincoln, NE, 20-24 October 2008

Intensification of Summer Rainfall Variability in the Southeastern United States in Recent Decades

Hui Wang[1], Rong Fu[2] and Wenhong Li[3]
[1]NOAA Climate Prediction Center
[2]University of Texas at Austin
[3]Georgia Institute of Technology

1. Introduction

The Southeastern United States is one of the fastest growing regions in the nation. Water supplies in this area are increasingly stressed especially during summer. The year-to-year fluctuations in summer rainfall over the Southeast thus have vital influence on regional hydrology, agriculture, and related industries. In the past three decades, summer droughts repeatedly struck the Southeast and had a devastating impact on this region socially and economically. For example, the 1986 Southeast summer drought caused billions of dollars of damage in agriculture. The 2007 drought, the most recent one, ranked as the worst in 100 years and pushed water shortages to a crisis point.

The recurrence of these severe droughts raises a question as to whether the magnitudes of anomalous rainfall, especially droughts, in the Southeast have been intensified in recent decades. If so, what might have caused such intensification? This study aims to characterize the change in summer rainfall variability in the Southeast and to explore possible causes of the shift of rainfall variability. In this report, we will present observational evidence that the intensification of Southeast summer rainfall variability closely ties to the variation of tropical Atlantic sea surface temperature (SST). The strong co-variability between the rainfall and SST also suggests some predictability of Southeast summer precipitation based on the tropical SST.

2. Data and method

The data used in this study consist of precipitation, atmospheric wind field, and SST from 1948 to 2007. Summer seasonal mean precipitation is an average of June, July and August (JJA) monthly rainfall. The precipitation data are taken from the NOAA Climate Prediction Center (CPC) U.S. Unified Precipitation for 1948–98 and from the realtime U.S. Daily Precipitation Analysis for 1999–2007. The atmospheric winds are the NCEP–NACR Reanalysis product (Kalnay et al. 1996). The SSTs are the NOAA Extended Reconstructed SST (ERSST v3, Smith et al. 2008).

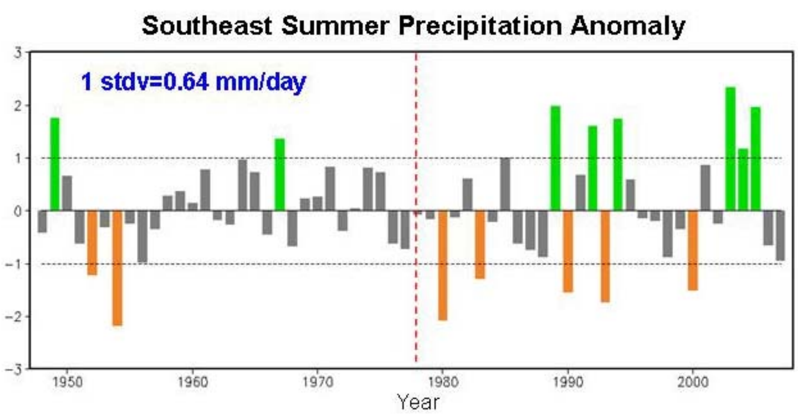

Fig. 1. Normalized time series of June–August mean precipitation anomalies averaged over the Southeastern United States (25N–36.5N, 76W–91W). Color bars indicate the summers with rainfall anomalies exceeding one standard deviation.

The relationship between the Southeast summer precipitation and tropical SST is examined by using the singular value decomposition (SVD; Bretherton et al. 1992). This statistical technique is able to objectively identify pairs of spatial patterns with the maximum temporal covariance between precipitation and SST (e.g., Ting and Wang 1997).

Correspondence to: Hui Wang, NOAA Climate Prediction Center;
E-mail: Hui.Wang@noaa.gov

3. Variability of Southeast summer rainfall

To examine rainfall variability in the Southeast, a precipitation index is constructed by averaging JJA seasonal mean precipitation anomalies in an area from 76oW to 91oW and from 25oN to 36.5oN. The area covers seven southeastern states, including Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee. The normalized index time series for 1948–2007 is shown in Fig. 1, with one standard deviation corresponding to 0.64 mm day-1. The precipitation index displays higher interannual variability with more wet and dry extremes in the second half of the period (1978–2007). In the first 30 years (1948–77), there were four summers with rainfall anomalies exceeding one standard deviation while in the second 30 years, there were 11 summers. The summer precipitation in the second 30 years contributes to the total rainfall variance by 68%, in contrast to 32% in the first 30 years. The change in the rainfall variability is consistent with the shift of rainfall probability distribution in the second period. Composite analysis (not shown) indicates that there were coherent decreases (increases) of rainfall frequency and intensity in dry (wet) summers in the second 30 years. Evidently, the Southeast summer rainfall variability has been intensified in the recent three decades.

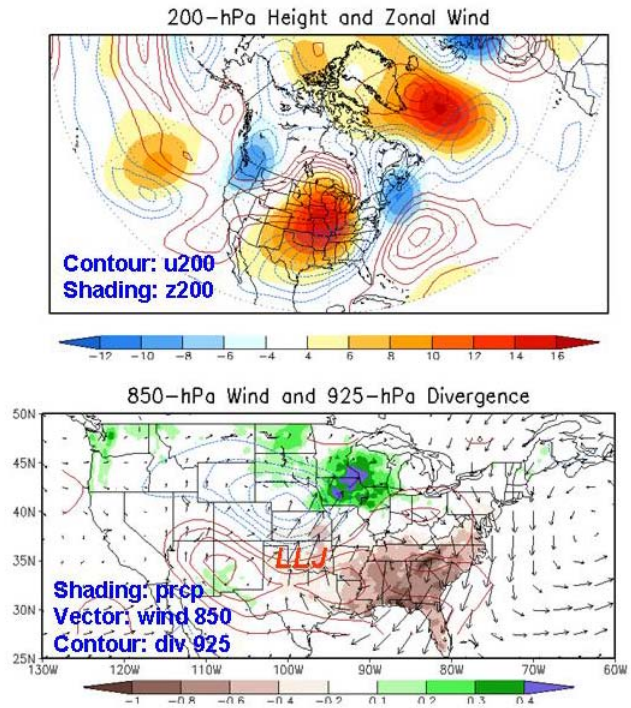

Fig. 2. Composite anomalies of 200-hPa height and zonal wind (upper panel) and 850-hPa wind, 925-hPa divergence and precipitation (low panel) associated with the Southeast summer droughts. The anomalies are obtained with linear regressions vs. the 60-year Southeast summer precipitation index.

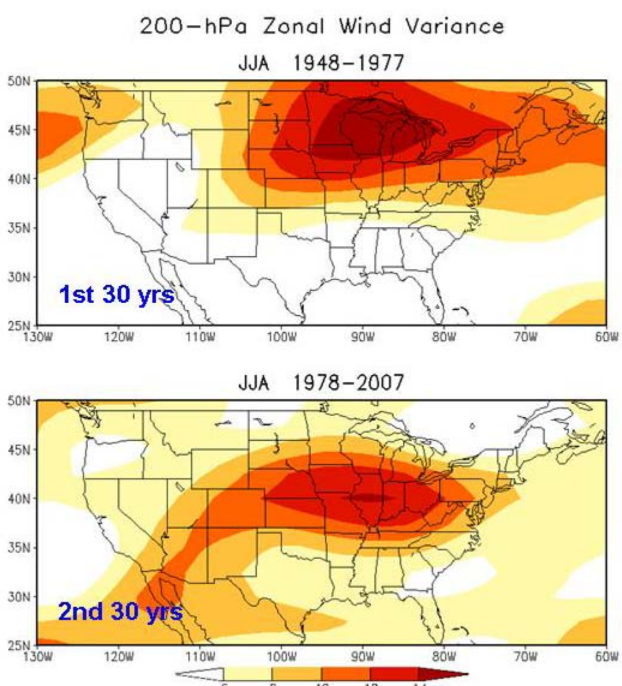

Fig. 3. 200-hPa zonal wind variance for the two 30-year periods.

The Southeast summer precipitation is an important part of the continental-scale warm season rainfall in the United States. As shown in Fig. 2, the drought-related circulation is dominated by positive height anomalies over the Central United States. The upper-level jet stream thus shifts towards the north. In the lower level, the anticyclonic circulation enhances the Great Plains' low-level jet and moisture transport from the Gulf of Mexico to the Midwest, and also causes deficit of moisture flux from the Gulf to the Southeast. The circulation pattern and associated lower-level divergence field are consistent with dry conditions in the Southeast and wet conditions in the Midwest.

The intensification of the summer rainfall variability in the Southeast is accompanied by a change of zonal wind variability at the jet-stream level. Figure 3 shows the 200-hPa zonal wind variance for the two 30-year periods. The center of maximum zonal wind variability experienced a significant southward shift from 45ºN in the early period to 40ºN in the late period.

4. Co-variability with SST

To explore possible links between the Southeast precipitation and Pacific and Atlantic SST, two SVD analyses were performed by analyzing the covariance matrices of summer season U.S. rainfall and SST from each ocean basin. The results are shown in Fig. 4 with homogeneous correlation maps (Wallace et al. 1992). For the Pacific SST, the first SVD mode is characterized by the El Niño SST pattern. The corresponding precipitation displays wet conditions in the Northern Plains and the Midwest and dry conditions in the Southeast. This is the canonical summer precipitation pattern associated with El Niño (e.g., Ting and Wang 1997). For the Atlantic SST, the first mode features warm SST anomalies across the tropical and North Atlantic. These warming anomalies are also correlated with warming anomalies in the Indo-Pacific warm pool. Associated with the Atlantic warming, precipitation in the Southeast and the Southern Plains, especially Texas, is above normal. The second SVD mode of the Atlantic SST closely resembles the Atlantic zonal mode (Zebiak, 1993), with warm SST anomalies along the equator. The associated precipitation pattern shows a large deficit of rainfall in the Southeast.

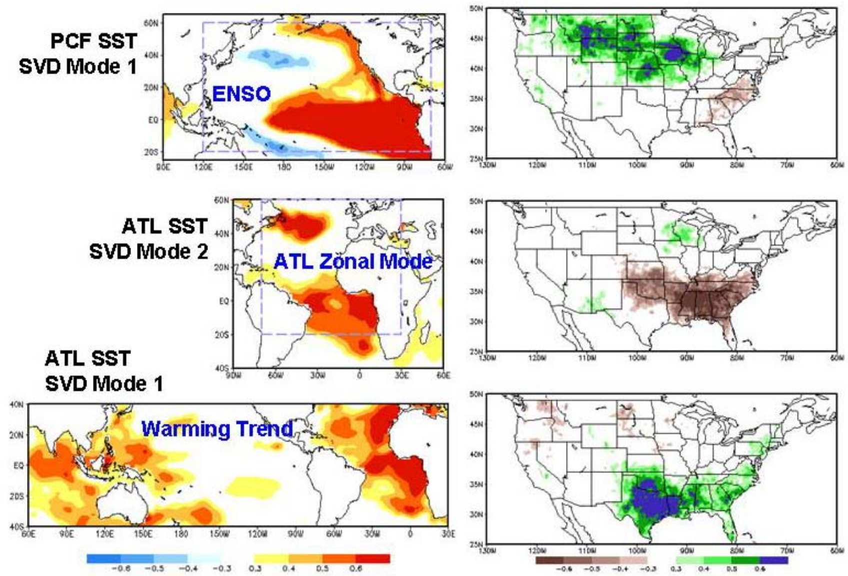

Fig. 4. Homogeneous correlation maps of the first SVD mode of the Pacific SST and U.S. precipitation (top), the first (bottom) and second (middle) SVD modes of the Atlantic SST and U.S. precipitation.

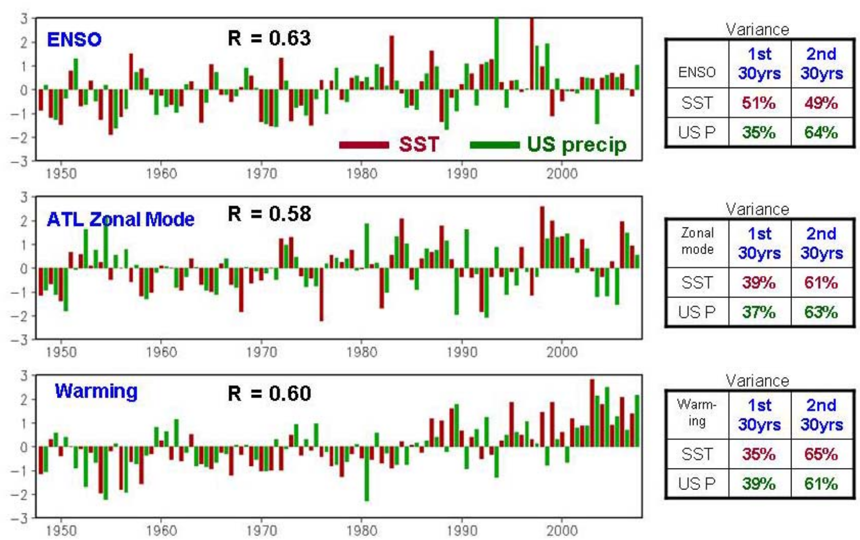

Fig. 5. Times series of the three SVD modes shown in Fig. 4, with the correlation coefficients (R) between each pair of SST and US precipitation time series. The tables on the right side list the percentages of SST and US precipitation variance over the two 30-year periods.

The corresponding time series of each pair of SVD modes are show in Fig. 5, together with the percentages of SST and precipitation variance explained by each mode over the two 30-year periods. The increase of the Atlantic SST variability in the recent 30 years in both the zonal mode and the warming trend is consistent with the increase of the precipitation variability in the same period. Both SVD modes have strong loadings over the Southeast in the precipitation field (Fig. 4). Therefore, the intensification of the Southeast summer rainfall variability is strongly coupled with the higher Atlantic SST variability in the last three decades. This is also supported by the evidence that the changes in the upper-level zonal wind variability associated with the two Atlantic SST modes (Fig. 6) contribute to the observed shift of the zonal wind variability between the two periods (Fig. 3).

The SVD analyses separate the relation of the U.S. precipitation to the Atlantic SST from that of the Pacific SST. How the SST-coupled precipitation contributes to the Southeast rainfall variability is assessed by reconstructing the Southeast precipitation index based on the three SVD precipitation time series. As shown in Fig. 7, the reconstructed total rainfall anomalies well reproduce the observed precipitation variation with a correlation of R=0.92. Among the three SVD modes, the Atlantic zonal mode-related precipitation contributes most to the Southeast rainfall variability (R=0.87). The warming trend also has a significant contribution (R=0.63), whereas the ENSO mode has contributed less (R=0.39). The threshold for the correlation coefficients at the 1% significance level is 0.29 based on the Monte Carol tests.

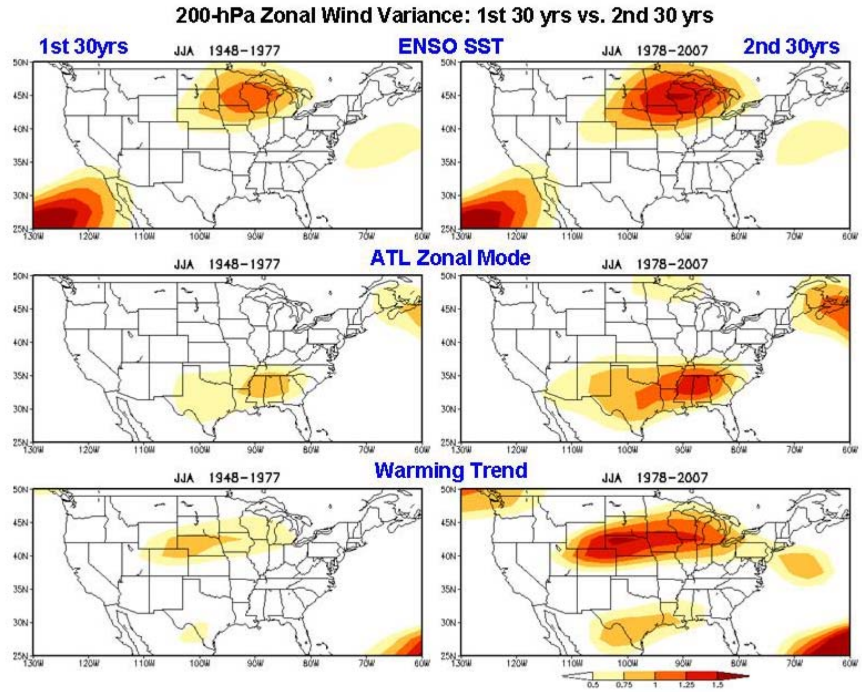

Fig. 6. 200-hPa zonal wind variance for the two 30-year periods reconstructed with each SVD SST time series.

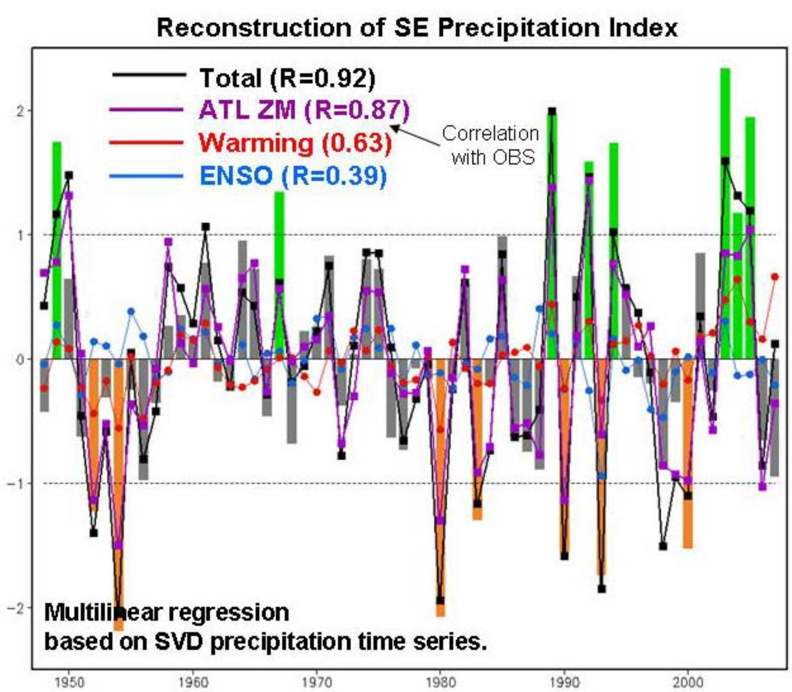

Fig. 7. Reconstructed Southeast summer precipitation index based on the time series of precipitation for the first three SVD modes and multiple linear regressions.

5. Predictability of the Southeast summer precipitation

The results presented in Figs. 4, 5, and 7 suggest that the variability of the Southeast summer precipitation is strongly linked to the Atlantic and Pacific SST. The SST thus possesses potential predictive value for the Southeast summer precipitation. Given Atlantic and Pacific SST patterns, the Southeast precipitation can be predicted based on the relationship depicted by the SVD analyses (Figs. 4 and 5). The empirical forecast system involves three steps. First, seasonal mean SSTs of a target summer, either from observations or from climate model forecasts, are projected onto the SVD SST patterns (Fig. 4) to obtain the SST projection coefficients. The corresponding precipitation projection coefficients are then obtained based on the SVD SST–precipitation relationship (Fig. 5) and a linear regression. Finally, precipitation anomalies are predicted with multiple linear regression coefficients of historical rainfall data vs. the three SVD precipitation time series, multiplied by the precipitation projection coefficients for the target summer. The proposed forecast method is similar to Wang et al. (1999), in which the Pacific SST is the only predictor for U.S. precipitation.

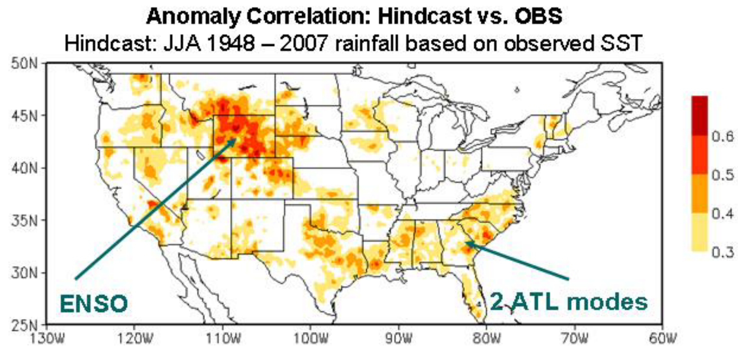

Fig. 8. Anomaly correlation between 60-year hindcasts and observations of summer U.S. precipitation.

The predictability of the Southeast summer precipitation is evaluated by a cross validation of the hindcasts of summer rainfall for the past 60 years (JJA, 1948–2007) based on the observed SST. Figure 8 shows the anomaly correlation between the hindcasts and observations of JJA U.S. precipitation. Considerable forecast skill is found in the Northern Plains and the Southeast. The former is primarily contributed by the Pacific ENSO mode, whereas the latter is contributed by the Atlantic zonal mode and the warming trend.

6. Summary

Our analysis of 60-year rainfall data reveals that the interannual anomalies of summer precipitation in the Southeast United States have been intensified in recent three decades (1978–2007) compared to the earlier period (1948–77), leading to stronger summer droughts and anomalous wetness. Such intensification of summer rainfall variability is consistent with the shift of daily rainfall probability distribution. It is also accompanied by a southward shift of the region of maximum zonal wind variability at the jet stream level and coupled with higher Atlantic SST variability in the late period. An empirical model for predicting Southeast summer precipitation was developed based on the SVD analyses, which link the Southeast rainfall variability to the Atlantic zonal mode, the SST warming trend, and the Pacific ENSO mode. A cross validation of 60-year hindcasts suggests considerable predictability of the Southeast summer precipitation with tropical SST.

References

Bretherton, C. S., C. Smith, and J. M. Wallace, 1992: An intercomparison of methods for finding coupled pattern in climate data. *J. Climate*, **5,** 541–560.

Kalnay, E., and Coauthors, 1996: The NCEP–NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, **77,** 437–471.

Smith, T. M., R. W. Reynolds, T. C. Peterson, and J. Lawrimore, 2008: Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880–2006). *J. Climate*, in press.

Ting, M., and H. Wang, 1997: Summertime U.S. precipitation variability and its relation to Pacific sea surface temperature. *J. Climate*, **10,** 1853–1873.

Wallace, J. M., C. Smith, and C. S. Bretherton, 1992: Singular value decomposition of wintertime sea surface temperature and 500-mb height anomalies. *J. Climate*, **5,** 561–576.

Wang, H., M. Ting, and M. Ji, 1999: Prediction of seasonal mean United States precipitation based on El Nino sea surface temperatures. *Geophys. Res. Lett.*, **26,** 1341–1344.

Zebiak, S. E., 1993: Air-sea interaction in the equatorial Atlantic region. *J. Climate*, **6,** 1567–1586.