GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO. 9, PAGES 1341-1344, MAY 1, 1999

Prediction of seasonal mean United States precipitation based on El Niño sea surface temperatures

Hui Wang[1] and Mingfang Ting

Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana, Illinois

Ming Ji

Environmental Modeling Center, NCEP/NWS/NOAA, Washington, D.C.

Abstract. A method for seasonal predictions of U.S. precipitation based on tropical Pacific sea surface temperature (SST) anomalies is developed in this letter with the singular value decomposition (SVD). This method was applied to the 1997/98 El Niño. The 1997 summer and 1997/98 winter precipitation over the United States were predicted using forecast SST from the National Centers for Environmental Prediction (NCEP) coupled ocean-atmosphere model. A cross validation, based on the percentages of hit between the hindcast and observed precipitation for the past El Niño and La Niña events, indicates a certain degree of predictability in both winter and summer seasons. During El Niño, significant predictability of summer precipitation is found over the Northern Plains and Atlantic States, while during La Niña it is in the Midwest. Above normal precipitation in the Northern Plains and the Midwest and below normal precipitation in the Atlantic States is associated with a warm phase of the El Niño-Southern Oscillation (ENSO) in summer. For winter precipitation, significant predictability is detected over the Gulf Coast States, the Southern Plains and California. Over these regions, wetter conditions are generally associated with the warm phase of ENSO.

Introduction

A strong El Niño event occurred over the tropical Pacific from the spring of 1997 to the winter of 1997/98. This event was well predicted by the National Centers for Environmental Prediction (NCEP) coupled ocean-atmosphere model. A detailed description of the model can be found in *Ji et al.* (1996). For winter 1997/98, the model predicted sea surface temperature (SST) anomalies well over 4°C in the eastern Pacific. El Niño SST anomalies can alter the large-scale atmospheric circulation and lead to anomalous weather over the United States. One of the challenges is to predict the anomalous precipitation associated with the El Niño SST. The Climate Prediction Center's (CPC) statistical forecasting tool, i.e., canonical correlation analysis (CCA), presently uses observed SST and relies on lagged correlations between SST and U.S. precipitation to forecast anomalous rainfall associated with the El Niño-Southern Oscillation (ENSO) (*Barnston* 1994). *Ting and Wang* (1997, referred to as TW hereafter) and *Wang* (1997) established an empirical instantaneous relationship between U.S. precipitation and Pacific SST using the singular value decomposition (SVD) analysis (*Bretherton et al.* 1992; *Wallace et al.* 1992). Their study is extended in this letter to make seasonal precipitation forecasts based on tropical Pacific SST and the simultaneous relationship between the SST and U.S. precipitation. However, an application of this empirical relationship for forecast requires predicted SST anomalies for the target season. The successful prediction of the 1997/98 El Niño by the NCEP coupled model provides an unique opportunity for testing this method in real time, for both winter and summer seasons. The purpose of this study is to develop a method for forecasting U.S. precipitation, to assess the validity of the prediction, and to predict U.S. precipitation for summer 1997 and winter 1997/98 based on the NCEP coupled model forecasts of the tropical Pacific SST.

Data and Methodology

The data consist of observed monthly mean precipitation over the United States and SST in the tropical Pacific (20°S-20°N), from 1950-94. The precipitation data were taken from the Global Historical Climatology Network (*Vose et al.*, 1992) and the SST from the Reconstructed Reynolds Data (*Smith et al.* 1996). A seasonal mean is obtained by averaging monthly means over June, July and August (JJA) for summer, and over December, January and February (DJF) for winter. The tropical Pacific SSTs for summer 1997 and winter 1997/98 were taken from the coupled model forecasts.

The method of making the U.S. precipitation prediction based on the tropical Pacific SST, either from the observed or from the coupled model forecast, involves three steps. The first step is to perform an SVD analysis between the observed tropical Pacific SST and U.S. precipitation to establish a relationship between the two fields, with the target year removed from the SVD calculation. Second, the observed or forecast SSTs for the target year are projected onto the SVD SST modes. For each SVD mode, the SST projection coefficient is multiplied by the correlation coefficient between the corresponding SVD SST and precipitation time series to obtain a precipitation projection coefficient. Finally, the predicted precipitation anomalies associated with that SVD mode is obtained from a regression precipitation pattern against the SVD precipitation time series, multiplied by the precipitation projection coefficient.

Results

The homogeneous correlation patterns (*Wallace et al.* 1992) of the leading SVD mode between tropical Pacific SST and U.S. precipitation for both summer and winter are shown in Fig. 1.

[1]Now at the University of Arizona, Tucson, AZ.

Paper number 1999GL900230.
0094-8276/99/1999GL900230$05.00

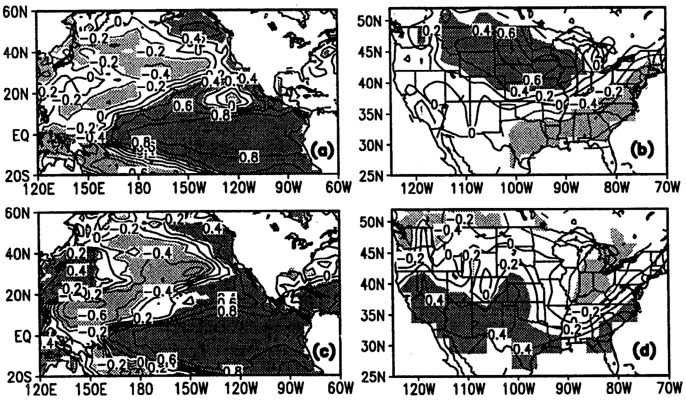

Figure 1. The first SVD mode in homogeneous correlation for summer (a, b) and winter (c, d) SST and precipitation. Contour interval is 0.2. Dark (light) shading indicates positive (negative) correlations exceeding 95% significance level, estimated by the Monte Carlo tests.

Due to difficulties in obtaining North Pacific SST anomalies in a long-lead time, this study is restricted to the tropical Pacific SST. The SST patterns in Fig. 1 are shown for the Pacific domain (20°S-60°N), though the SVD analysis is only applied to the tropical Pacific (20°S-20°N). The first mode in both seasons is a typical El Niño SST pattern. For summer precipitation (Fig. 1b), there is a northwest-southeast dipole with more precipitation over the northwest and less precipitation over the southeast associated with El Niño SST. For the winter season (Fig. 1d), the first mode shows above normal precipitation in the Southeast coastal regions and the Southwest associated with an El Niño condition. Table 1 lists the percentage of total squared covariance (CVR) and variance (VR) in each field explained by the first three SVD modes and correlation (r) between the SVD SST and precipitation time series. Those in parentheses are the values when only 17 ENSO summers (7 El Niño and 10 La Niña) and 14 ENSO winters (7 El Niño and 7 La Niña) are taken into account, which are chosen with amplitudes in the first SVD SST time series exceeding one standard deviation. In both seasons, the first mode is predominant in terms of the explained percentage of squared covariance between SST and precipitation and the SST variance. The percentages of both SST and precipitation variance explained by the first mode are higher for the ENSO years.

The second and third modes (not shown) in both winter and summer show large SST amplitudes away from the tropics and are linked to the North Pacific SST. For example, the third mode in summer is very similar to the second mode in TW (see their Figs. 7c and 7d) when North Pacific SST is taken into account. The squared covariance explained by these modes in current study differs considerably from that in TW, due to different SST domains used (tropical Pacific here versus the whole Pacific basin in TW). The first mode explains 63% of squared covariance between tropical Pacific SST and U.S. precipitation, while it only explains 34% of squared covariance between Pacific SST and U.S. precipitation in TW. On the other hand, the third mode in this study explains much less squared covariance (7%) than the corresponding mode in TW (21%), due to the lack of North Pacific SST in this case. Together, the first three modes in summer explain about 20% of the total summer precipitation variance. During winter, the SSTs in the second and third modes are North Pacific and subtropical modes, coupled with precipitation variability in the Pacific Northwest and Southeast. The two modes are almost identical to the second and third modes in *Wang* (1997) when North Pacific SST is included in the SVD analysis. The squared covariance explained by the second (16%) and third mode (9%) in *Wang* (1997) is much higher than in the absence of North Pacific SST in this study.

Table 1. Summary of the Statistics of the SVD Analysis for Pacific SST and U.S. Precipitation

	CVR	r	SST VR	Precip. VR
JJA: SVD1	63%	0.58	59% (72%)	8% (11%)
SVD2	15%	0.73	16%	4 %
SVD3	8%	0.66	6%	7%
DJF: SVD1	86%	0.77	70% (80%)	10% (12%)
SVD2	5%	0.51	5%	23%
SVD3	4%	0.52	7%	13%

Given a tropical Pacific SST pattern, the seasonal mean U.S. precipitation can be predicted based on the relationship depicted by the SVD. The usefulness of this forecast method, especially for ENSO years, is evaluated by a cross-validation. First, we take both SST and precipitation of each year (1950-94) out from the data and perform an SVD analysis on the rest of the 44-year data. A precipitation hindcast is then made for the year taken out using the observed tropical SST of the same year. Similar to *Ropelewski and Halpert* (1986), the precipitation anomalies at each grid point are expressed by their percentile rank in the 45-year data for both hindcasts and observations, respectively. Three categories are divided based on the rank, i.e., dry (<33.3%), normal (33.3%-66.6%) and wet (>66.6%). A hit rate is then used to measure the forecast skill, which is simply the ratio of number of hit (both hindcast and observation fall into the same category) to the total number of events. Figure 2 shows the hit rates for the 17 ENSO summers and 14 ENSO winters, as mentioned earlier in this section. Note the percentage of hit by a pure guess is 33%, Figure 2 indicates considerable forecast skills associated with the first SVD mode in both seasons. Significant forecast skill for summer precipitation associated with El Niño (Fig. 2a) is found over two regions, one from Colorado to Montana and from Idaho to Wyoming, and the other from the Ohio River Valley to the Atlantic coast. For La Niña summers (Fig. 2b), a region of high forecast skill is found in the Midwest. In winter (Figs. 2c and 2d),

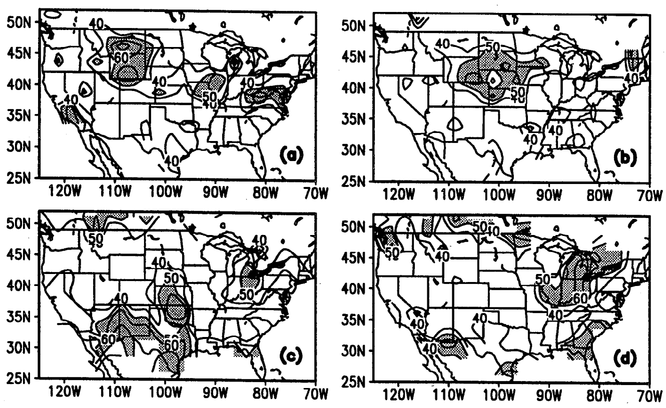

Figure 2. Percentage of the hit between hindcast precipitation and observations for 7 El Niño summers (a) and 10 La Niña summers (b), and 7 El Niño winters (c) and 7 La Niña winters (d) during 1950-94, using the first SVD modes. Shading indicates hit rates exceeding 50%.

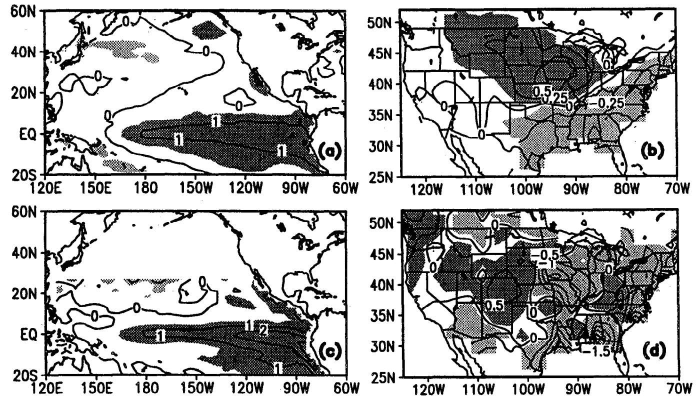

Figure 3. (a) Summer 1997 SST anomalies from model forecast projected onto the first SVD SST mode. (b) Predicted U.S. precipitation (JJA 97) using the first mode. (c) Coupled model forecast of JJA 97 tropical SST anomalies. (d) Observed precipitation (JJA 97). Contour intervals are 1°C in (a, c), 0.25mm/day in (b), and 0.5mm/day in (d). Dark (light) shading indicates positive (negative) anomalies.

high hit rates are found in the Gulf Coast States, Southern Plains and Southwest. Differences in hit rates between El Niño and La Niña in Fig. 2 suggest that nonlinearity is significant between warm and cold phase atmospheric responses (*Hoerling et al.*, 1997). By including the second and third SVD modes in the hindcasts (not shown), there is no significant impact on the regions of high forecast skill. However, the hit rate is increased over other regions, such as the Pacific Northwest in both seasons, the Southeast in summer and the Mississippi River basin in winter. This suggests the importance of extratropical SST information in forecasting U.S. precipitation.

This forecast method is applied to the 1997/98 El Niño. For summer 1997, the coupled model forecast for JJA SST (Fig. 3c) made from May 1997 observations is used. The projection coefficients are 1.83, 1.06 and 0.05 for the three leading modes, respectively. The eastern Pacific SST anomalies in the first mode (Fig. 3a) are weaker than the model forecast (Fig. 3c), but of the same spatial structure. By adding in the second and third modes, the SST anomalies (not shown) are very close to the model forecast. The predicted rainfall anomalies based on the first SVD mode (Fig. 3b) show above normal precipitation in the Midwest

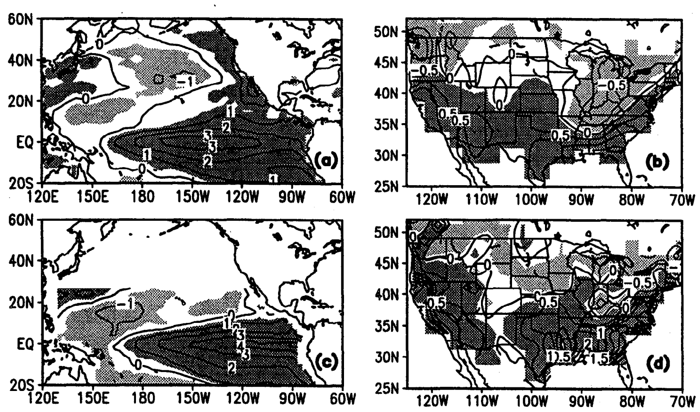

Figure 4. Same as Fig. 3, but for 1997/98 winter SST and precipitation. Contour intervals are 1°C in (a, c) and 0.5 mm/day in (b, d).

and Northern Plains and below normal in the East and Southeast. To verify the forecast for 1997 summer precipitation, the observed precipitation anomalies (Fig. 3d) are compared to the forecast. The agreement between the forecast (Fig. 3b) and observations (Fig. 3d) is rather poor over most areas. However, the observed above normal precipitation over the Rocky Mountain region and below normal precipitation over the East Coast and Gulf coast are in agreement with the forecast.

For winter 1997/98, the model predicted SST anomalies made from September 1997 observations are largely projected onto the first and third SVD SST modes, with projection coefficients of 3.02 and 3.38. The projection on the first SVD mode (Fig. 4a) reproduces the model forecast (Fig. 4c) reasonably well. The prediction of winter precipitation based on the first mode shows positive anomalies in the southern United States and negative anomalies in the Pacific Northwest, middle Mississippi River Basin and Ohio Valley (Fig. 4b). The gross features are very similar to the observed 1997/98 winter precipitation (Fig. 4d), especially in the Southern States.

As mentioned earlier, the CCA (*Barnston* 1994) is now being used for operational long-lead seasonal forecasts at CPC, based on lagged relationships between tropical Pacific SST and U.S. precipitation. Their forecasts for 1997 summer precipitation (*Barnston* 1997a) were wetter conditions in Great Lakes/Northern Plains, and for 1997/98 winter (*Barnston* 1997b), were dry northern Plains, Great Lakes and Ohio Valley; wet extreme south in Florida, southern Texas and Arizona. In general, the forecasts using the CCA agree with those using the SVD (Figs. 3b and 4b). The major difference between CPC's forecasts based on CCA and those in this study is that the CPC precipitation forecasts are based on observed tropical SST and lagged SST-precipitation relationship, while the forecasts made here are based on model predicted SST and instantaneous SST-precipitation relationship. Since the atmospheric response to the tropical SST is on a time scale less than a month, the simultaneous correlation between tropical SST and U.S. precipitation is stronger than their lagged correlation, using the seasonal mean data. Given a predicted SST pattern with sufficient accuracy, the precipitation forecast based on the instantaneous relationship should be more accurate than that based on the lagged relationship.

Summary

The relationship between tropical Pacific SST and U.S. precipitation is examined using the SVD method on the 45-year observed tropical Pacific SST and U.S. precipitation. In both winter and summer, the first mode captures the precipitation associated with El Niño SST variation. The SST anomalies in summer 1997 and winter 1997/98 from the NECP coupled model forecasts are projected onto the leading SVD SST mode. Predictions of U.S. precipitation for the two seasons are made. Associated with this El Niño event, summer precipitation shows positive anomalies in the Central and Northern Plains, and negative anomalies in the East and Southeast. Winter precipitation is above normal in the southern part of the country and below normal to the north. A comparison between predicted and observed precipitation and cross-validation for both seasons indicate a certain degree of predictability of seasonal mean U.S. precipitation based on tropical Pacific SST.

Acknowledgments. We thank two anonymous reviewers for their constructive comments. This work was supported by NOAA Grants NA36GPO105 and NA56GPO150.

References

Barnston, A. G., Linear statistical short-term climate predictive skill in the northern hemisphere, *J. Climate*, *7*, 1513-1564, 1994.

Barnston, A. G., Summary of NCEP's canonical correlation analysis (CCA), optimal climate normals (OCN), and coupled model forecasts for U.S. climate, *Experimental Long-Lead Forecast Bulletin*, NOAA, *6*, No.2, 94, 1997a.

Barnston, A. G., Summary of NCEP's canonical correlation analysis (CCA), optimal climate normals (OCN), and coupled model forecasts for U.S. climate, *Experimental Long-Lead Forecast Bulletin*, NOAA, *6*, No.3, 62, 1997b.

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

Hoerling, M. P., A. Kumar and M. Zhong, El Niño, La Niña, and the nonlinearity of their teleconnections, *J. Climate*, *10*, 1769-1786, 1997.

Ji, M., A. Leetmaa and V. E. Kousky, Coupled model predictions of ENSO during the 1980s and the 1990s at the National Centers for Environmental Prediction, *J. Climate*, *9*, 3105-3120, 1996.

Ropelewski, C. F. and M. S. Halpert, North American precipitation and temperature patterns associated with the El Niño-Southern Oscillation (ENSO), *Mon. Wea. Rev.*, *114*, 2352-2362, 1986.

Smith, T. M., R. W. Reynolds, R. E. Livezey and D. C. Stokes, Reconstruction of historical sea surface temperature using empirical orthogonal functions, *J. Climate*, *9*, 1403-1420, 1996.

Ting, M. and H. Wang, Summertime United States precipitation variability and its relation to Pacific sea surface temperature, *J. Climate*, *10*, 1853-1873, 1997.

Vose, R.S., R. L. Schmoyer, P. M. Steurer, T. C. Perterson, R. Heim, T. R. Karl and J. Eischeid, The Global Historical Climatology Network: Long-Term Monthly Temperature, Precipitation, Sea Level Pressure, and Station Pressure Data, NDP-041, Carbon Dioxide Information Analysis Center, Oak Ridge Nat. Lab., Oak Ridge, Tenn., 1992.

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

Wang, H., An observational and modeling study of the relationships between United States precipitation and Pacific sea surface temperature, Ph.D. Thesis, University of Illinois at Urbana-Champaign, 136 pp, 1997.

H. Wang and M. Ting, Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana, IL 61801. (e-mail: huiwang@atmo.arizona.edu; ting@uiuc.edu)

M. Ji, Environmental Modeling Center, NCEP/NWS/NOAA, Washington, DC 20233. (e-mail: ming.ji@noaa.gov)

(Received November 6, 1998; revised January 28, 1999; accepted March 12, 1999.)