6.2 SPATIAL RELATIONSHIPS BETWEEN SST AND U.S. WILDFIRES

Yongqiang Liu*
Forestry Sciences Laboratory, USDA Forest Service

1. INTRODUCTION

Sea surface temperature (SST) anomalies can affect interannual variability of wildfire in the U.S. through their teleconnections with the North American atmospheric processes. SST anomalies usually maintain for seasons or even years, often leading to droughts and other favorable environmental conditions for the ignition and spread of intense wildfires. The strong La Nina event in 1988, for example, caused the northern U.S. drought (Trenberth et al. 1988), which was among the driest events of the 20th century in the continental United States (Karl et al. 1988). Numerous wildfires broke out in the northern Rocky Mountains, including the catastrophic Yellowstone National Park fires (Romme and Despain 1989).

The studies on SST-U.S. fire relations have been focused on the SST anomalies in the tropical Pacific during El Nino / La Nina events, which can contribute to variations of the U.S. weather patterns (e.g., Rasmusson and Carpenter 1982, Ropelewski and Halpert 1986, Harrison and Larkin 1998). Simard et al. (1985) found a statistically significant relation between El Nino and decreased fire activity in the South using 53 years of annual wildfire statistics. The finding was supported by a strong relation between La Nina and large Florida fires (Brenner 1991). Swetnam and Betancourt (1990) found large areas burn connected to La Nina events in Arizona and New Mexico using longer fire records. Hess et al. (2001) and Chu et al. (2002) recently reported the effects of El Nino/La Nina events on fires in Alaska and Hawaii, respectively. Long-range fire activity predictions for these regions have been attempted based on the fire-El Nino/La Nina relations (e.g., O'Brien et al. 2002, Chu et al. 2002).

Average fires are much more intense in a northwestern region (North, Pacific North, Rocky Mountains, or Inter-Mountain) than in a southern region (Southeast or Southwest). But no evidence for relations between El Nino events and fires in these regions was found (Simard et al. 1985). Unlike the two southern regions where fires occur mainly during spring, summer is the season of major fire activities for the northwestern regions (Liu 2004). The least effects of SST anomalies in the Pacific, particularly in the El Nino region, on North American air temperature were found for summer among various seasons (Barnett 1981).

It was found in a number of studies in the 1990s that SST anomalies in the northern Pacific can impact climate in the mid-latitude U.S. regions (Wallace et al. 1990, Ting and Wang 1997). Ting and Wang (1997), for example, showed that the Great Plains summer precipitation fluctuations are correlated with SST variation in North Pacific with certain statistical significance. This result suggests possible importance of SST in the northern Pacific to fire activities in the northern U.S. regions.

This study seeks to understand the relations between SST anomalies in the northern Pacific, independently and coupled with SST anomalies in the tropical Pacific, and wildfires in the contiguous U.S. Their implications for improving fire prediction skills will also be explored.

2. METHODOLOGY

a. Statistical analyses

The singular value decomposition (SVD) is used to identify the important regions and spatial patterns of Pacific SST anomalies connected to U.S. fire variations. Correlation and regression methods are sued to examine relations between SST in these regions and fires in various U.S. regions.

SVD is a technique to identify coupled spatial patterns with the maximum temporal covariance between two fields. It separates each of two fields into spatial patterns (principal components) and time series (expansion coefficients). The largest response occurs between the first pair of spatial patterns, the second largest response between the second pair, and so on. The first few pairs of patterns and the associated time series are regarded as SVD leading modes. The contribution of a pattern to the total covariance of the two fields is measured by squared covariance function (SCF).

* *Corresponding author address*: Dr. Yongqiang Liu, Forest Sciences Laboratory, 320 Green St, Athens, GA 30602; e-mail: yliu@fs.fed.us

SVD has been applied to analyzing relations between sea surface temperature (SST) and meteorological fields such as air temperature, precipitation, geopotential height, or atmospheric heat energy (Wallace et al. 1992, Ting and Wang 1997, Wang and Ting 2000, Trenberth et al. 2001, Liu 2004). A detailed description of SVD was presented in Bretherton et al. (1992). A similar technique called Canonical Correlation Analysis (CCA) was used for identifying spatial pattern relations between Palmer drought severity index and the western fires (Westerling et al. 2002).

b. Data

The monthly, global 2-degree extended reconstructed sea surface temperature (ERSST version 2) was constructed using the most recently available International-Comprehensive Ocean-Atmosphere Data Set (Smith and Reynolds, 2003). The ERSST over the area of 140E–90W, 20S–60N during 1980-2002 was used in this study. Seasonal series was constructed using monthly series.

The areas burned by wildfires on the federal lands in the contiguous U.S. during 1980-2002 (BLM 2003) were used. This data has been used to understand fire-weather realtiohsips (e.g., Westerling et al. 2003) and fire emissions (e.g., Liu 2004). Note that the BLM data does not include burnings on state and private lands, which contribute to a substantial portion of the acres burned in the South. Values of each of the 48 contiguous states are interpolated to a 60-km resolution grid for the SVD analysis. Averages over the 10 Forest Service regions (Fig.1) are made for correlation and regression analyses with SST.

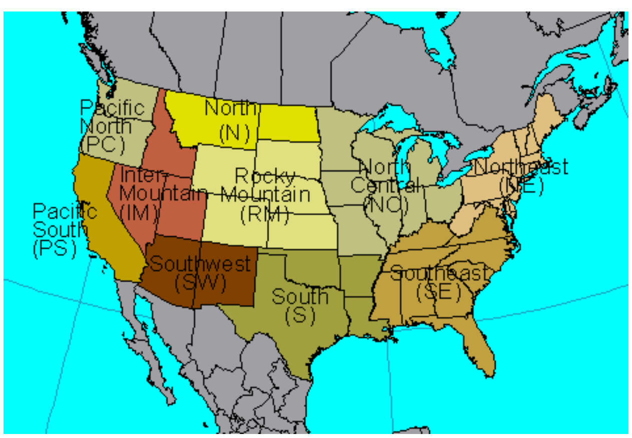

Fig.1 The USDA Forest Service regions (old division)

Precipitation and temperature at each state, to be used to interpret the SST-fire patterns, were obtained from the U.S. National Climate Data Center of the National Atmospheric and Oceanic Administration (NOAA).

3. RESULTS

a. Fire variability

The mean of acres burned during summer (Fig.2a) generally increases from the east to west with a value of 0.8 acre km^{-2} in Pacific North. Standard deviation (SD) of acres burned (Fig.2b) has a similar geographic distribution. The magnitude of SD is a factor larger than that of the mean in the west, indicating significant interannual variability at specific grid points.

Fire activities occur mainly during summer in most regions (Fig.3). Large areas were burned in 1988, 1994, 1996, 1999, 2000, and 2002.

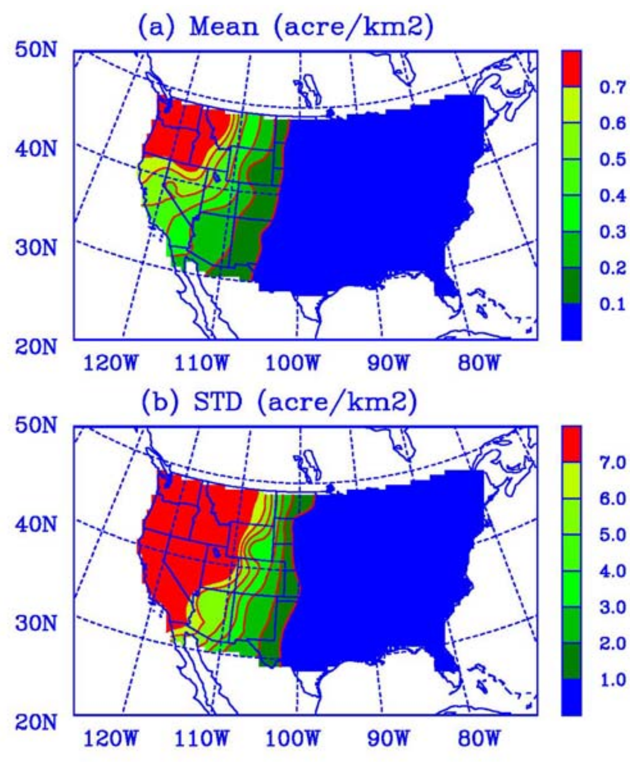

Fig.2 Mean and standard deviation of area burned during summer.

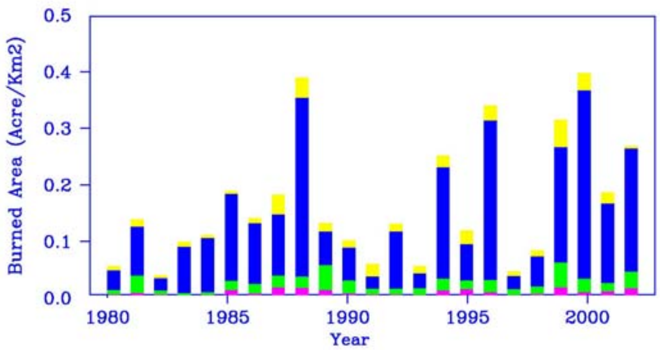

Fig.3 Annual variations of area burned averaged over the contiguous U.S. during winter (pink), spring (green), summer (blue) and fall (yellow).

b. Regions and spatial patterns of SST anomalies connected to U.S. fires

Fig.4 shows the two leading SVD modes. The left panels display SST patterns weighted by their corresponding singular value. The values measure correlation between SST field and *k*th SVD time series of the U.S. fires. The 1*st* mode (Fig.4a) is characterized by large negative anomalies in the central and eastern tropical Pacific, typically seen during a La Nina event. To the northwest and west are large positive anomalies, which may or may not occur during a La Nina event. The correlation coefficients reach the 1% statistical significance level (the corresponding critical correlation coefficient of 0.526) in a large portion of each of the anomalous SST regions. The 2*nd* mode (Fig.4b) is characterized by opposite SST anomalies in the tropical Pacific: negative in the central and positive in the eastern. The correlation coefficients in some areas reach the 5% statistical significance level (the corresponding critical correlation coefficient of 0.413). The SCF of the two modes is 24.8 and 13.9%, respectively.

The corresponding 1st SVD mode of the U.S. fires (Fig.4c) shows large positive anomalies from Pacific North to North Central, and to Southeast, reaching the 1% statistical significance level in a large area. Negative anomalies are found in Southwest, South, and Northeast. The 2*nd* mode (fig.4d) shows significant anomalies in the low latitudes, featured by large negative values in Southwest and South, and positive in Southeast. The SCF of the two modes is 37.9 and 20.0%, respectively.

Because Pacific SST anomalies usually last for over a few seasons, the SST SVD patterns connected to U.S. summer fires could initiate earlier (Fig.5).

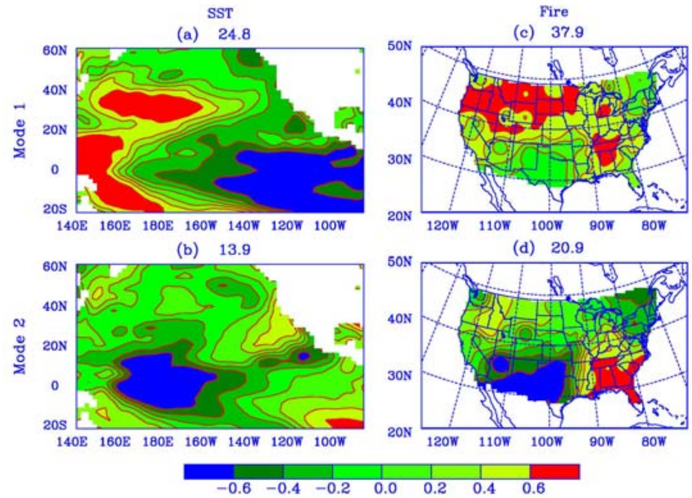

Fig.4 Two leading SVD for SST (a and b) and fire (c and d). The squared covariance function (SCF) is given on top of each panel.

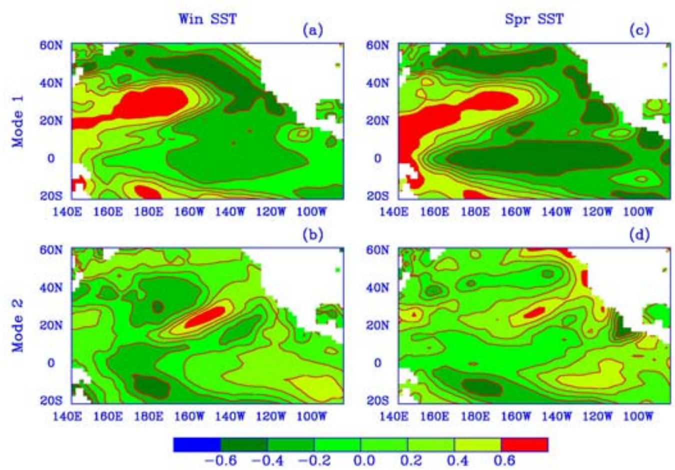

Fig.5 Correlation between summer fire SVD time series and previous seasons of SST. (a-b) 1st and 2nd summer fire modes and winter SST, and (c-d) 1st and 2nd summer fire modes and spring SST.

The negative tropical Pacific SST anomaly in the 1st SST SVD mode is a primary feature of La Nina. The evolution of the SVD time series (Fig.6) shows positive peaks in 1988, 1996, and 1999, which apparently correspond to the La Nina events defined using the Nino3.4 SST index (note that the peak years of the time series and La Nina years could be different because the SVD analysis is for summer, while a La Nina event is usually related to SST anomalies for a few seasons or longer). This result suggests a close relation of the U.S. fire with La Nina and therefore supports the previous finding about the important role of La Nina in fires in the southern U.S. regions.

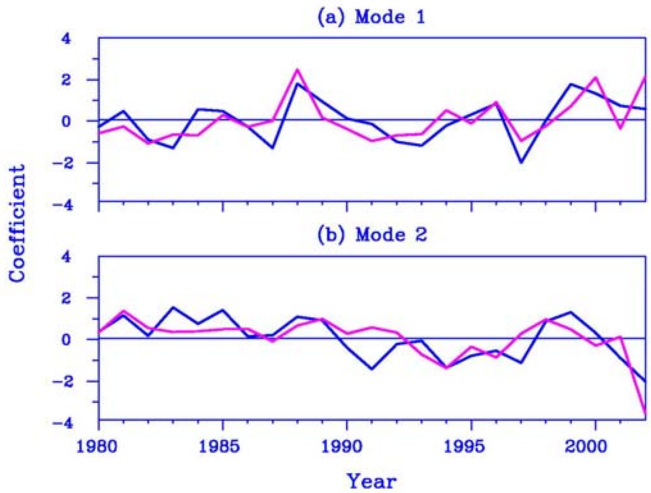

Fig.6 The time series for the two leading SVD modes for SST (blue) and fire (pink).

The most conducive atmospheric condition for strong wildfire in most U.S. regions is dry weather, and high temperature also contributes to strong emissions in some western regions (Liu 2004). The atmospheric anomalies related to the 1st SST mode are characterized by decreased precipitation in the northwestern and increased temperature in the western regions. (Fig.7). This explains the increased fire activities in the northwestern regions. Fires in Southeast become more intense due to slightly warming. The atmospheric anomalies related to the 2nd SST mode are characterized by wetting and cooling in the southwestern and drying and warming in the southeastern regions. This explains the weakened and intensified fire activities in the two areas, respectively.

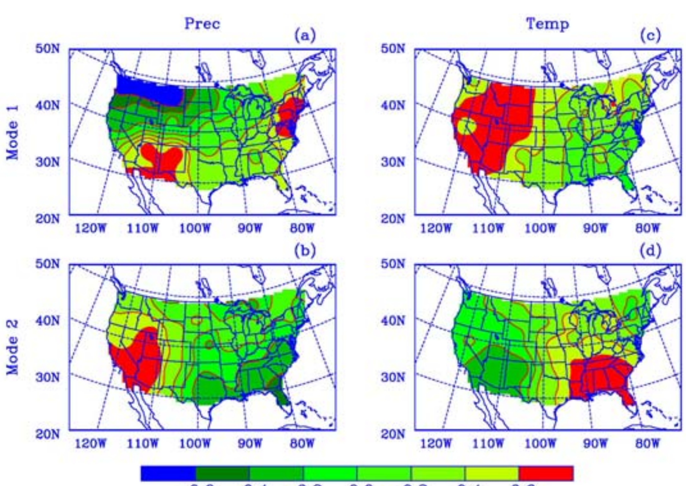

Fig.7 Correlation between SVD summer SST time series and summer U.S. weather of (a-b) 1st and 2nd SST modes and precipitation, and (c-d) 1st and 2nd SST modes and temperature.

c. The importance of northern Pacific SST

Fig.8 shows SST anomalies for nine individual years, six with large U.S. fires (that is, 1988, 1994, 1996, 1999, 2000, and 2002), and six years (including three years overlapping with fires) with large negative SST anomalies in the Nino3.4 region (that is, 1984, 1985, 1988, 1998, 1999, and 2000). These years can be divided into three categories, each containing three years. For 1988, 1999, and 2000, large fires were accompanied by negative SST anomalies in the tropical Pacific and positive SST anomalies in the northern Pacific (140E-140W, 20-40N). For 1994, 1996, and 2002, large fires occurred, but there were no significant negative anomalies in the tropical Pacific. Overall positive SST anomalies, however, were found in the northern Pacific. For 1984, 1985, and 1998, negative SST anomalies in the tropical Pacific Ocean were found, but there were no large fires in the U.S. Thus, large fire occurred when there were significant positive SST anomalies in the northern Pacific, with or without significant negative SST anomalies in the tropical Pacific.

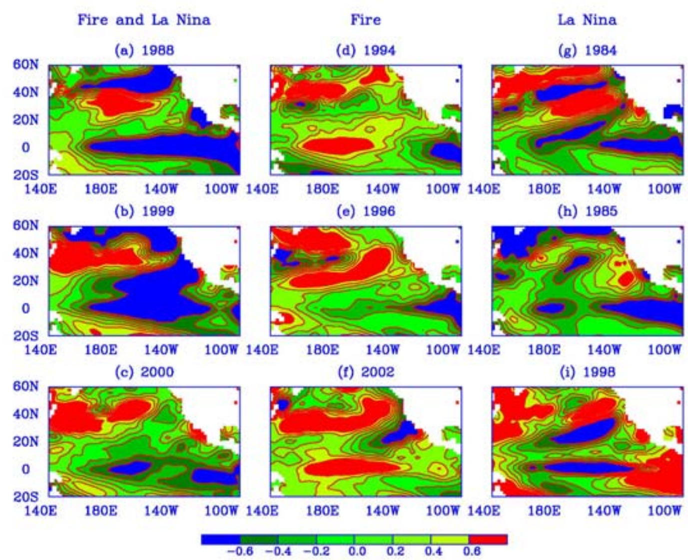

Fig.8 SST anomalies during summer (^{o}C) for the years with both large fire and La Nina (left column), large fire without La Nina (middle), and La Nina without large fire (right). Three cases are shown for each category from the top to bottom.

Fig.9 shows correlations between the northern Pacific SST and fires of various U.S. regions. Positive SST anomalies lead to intensified fires in all regions. The large impacts occur in five northern regions (that is, North, Rocky Mountain, Inter-

Mountain, Pacific North, and Northeast), where the correlation coefficients reach or close to the 95% significance level. In contrast, fires in all regions except Northeast become more intense in response to negative SST anomalies in the Nino 1 region. The correlation coefficients, however, reach the significance level only for Inter-Mountain.

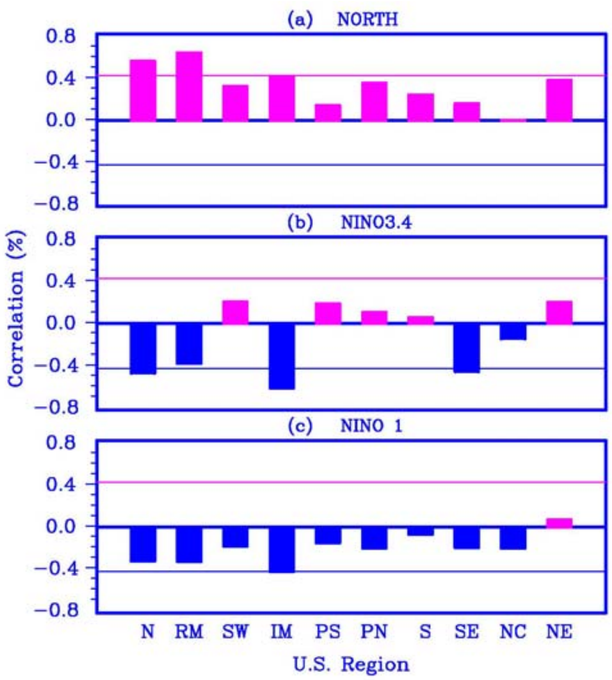

Fig.9 Correlation coefficients between SST and fires. (a-c) are for SST at North Pacific, Nino3.4, and Nino 1. Bars in each panel represent various U.S. regions (see Fig.1 for definition of symbol of each region). The horizontal lines indicate the 95% statistically significant levels.

d. Prediction Implications

By using predicted SST in the northern Pacific with dynamical and statistical techniques (Goddard et al. 2003), summer fires in all northern regions except North Central can be estimated using uni-variate regression equations formed based on the correlations shown in Fig.9. By further using predicted SST in Nino3.4, bi-variate regression equations, which have more significant covariance coefficients (Fig.10), can be formed that would improve the fire estimate in these regions. The bi-variate equations would also be able to estimate fires in the two southern regions (that is, Southwest and Southeast) with significant level. The estimate of fires in the two regions, however, would not be improved much with an additional factor of SST anomalies in Nino1 region.

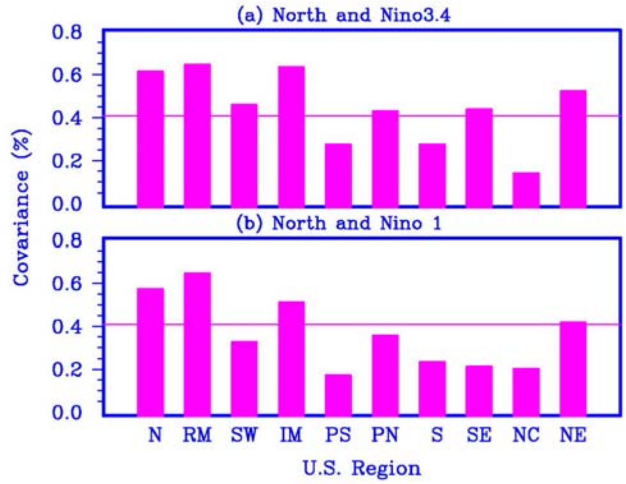

Fig.10 Covariance coefficients of bi-variate regression equations for fires. The factors used are SST at the SST in northern Pacific and Nino3.4 (a) and northern Pacific and Nino 1 (b). The horizontal lines indicate the 95% statistically significant levels.

e. Spring and fall

Similar analyses were made to spring and fall U.S. fires, respectively. The 1st SVD spring SST mode is similar to that of summer SST, but the corresponding spring fire mode shows a different feature, that is, increased fires in Southeast. The covariance coefficients of the bi-variate equations with SSTs in the northern Pacific and Nino3.4 as factors are significant only for fires in Southeast. Unlike the summer case, replacing SST in Nino3.4 with Nino1 results in some major changes. The 1st SVD fall SST mode, on the other hand, is characterized by large positive anomalies in the northern Pacific and moderate negative anomalies in the central tropical Pacific, which are connected to increased fires in North Central and the middle Atlantic. The covariance coefficients of the bi-variate equations with SST in the northern Pacific and Nino3.4 or Nino1 as regression factors are significant in North and close to significant in Southeast.

4. SUMMARY

Singular value decomposition (SVD) and correlation and regression analyses have been conducted to identify regions and spatial patterns of Pacific SST anomalies connected to the U.S. fire variations. The results emphasize the importance of the northern Pacific SST anomalies to the summer fires in the northern U.S. regions. The SST patterns connected to the U.S. summer fire variations are characterized by large positive SST anomalies in the northern Pacific and large negative SST anomalies in the tropical Pacific (La Nina). Statistically significant relations are found between the SST anomalies in the northern Pacific and summer fires in most northern U.S. regions. The relations between fires and the coupled SST anomalies of the northern Pacific and the tropical Pacific are more significant for fires in the northern regions, as well as those in the two southern U.S. regions. These relations might be useful for long-range predictions of wildfires in the contiguous U.S.

5. REFERENCES

Barnett, T.P., 1981, Statisitcal prediction of North American air temperature from Pacific predictors, *Mon. Wea. Rev*., **109**, 1021-1041.

BLM (U.S. Department of Interior Bureau of Land Management), 2003, *Federal Fire History Internet Map Service User Guide*. (www.firehistory.blm.gov)

Brenner, J., 1991, Southern oscillation anomalies and their relationship to wildfire activity in Florida, *Int'l J.f Wildland Fire*, **1**, 73-78.

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

Chu P. –S., W.P. Yan, and F. Fujioka, 2002, Fire-climate relationships and long-lead seasonal wildfire prediction for Hawaii, *Int'l. J. Wildland Fire*, **11**, 25-31.

Goddard, L., A. G. Barnston and S. J. Mason, 2003: Evaluation of the IRI's "Net Assessment" Seasonal Climate Forecasts: 1997-2001. *Bull. Am. Meteor. Soc.*, **84**.

Harrison, D.E., and N.K. Larkin, 1998, Seasonal U.S. temperature and precipitation anomalies associated with El Nino: Historical results and coparison with 1997-98, *Geophy. Res. Lett*., **25** (21), 3959-3962.

Hess, J.C., C.A. Scott, G.L. Hufford, and M.D. Fleming, 2001, El Nino and its impact on fire weather conditions in Alaska, *Int'l J. Wildland Fire*, **10**, 1-13.

Karl, T.R. *et al.* 1988, The 1988 drought in the United States: Just another drought? *EOS, Trans. Amer. Geophys. Union*, **69**, 1069.

Liu, Y.-Q.,2003, Spatial patterns of soil moisture connected to monthly-seasonal precipitation variability in a monsoon region, *J. Geophy. Res*., **108** (D22), 8856, doi:10.1029/2002JD003124.

Liu, Y.-Q., 2003, Prediction of monthly-seasonal precipitation using coupled SVD patterns between soil moisture and subsequent precipitation, *Geophys.Res.Lett*.,**30**(15),1827,doi:10.1029/2003GL017709.

Liu, Y.-Q. Variability of wildland fire emissions across the continuous United States. *Atmos. Environ.*, **38**, 3489-3499, 2004.

O'Brien, J., D. Zierden, and M. Griffin, 2002, *Long-Term Forecasting of Wildfire Season Severity in Florida*, Center for Ocean-Atmospheric Studies Tech. Rep., The Florida State Uni., 44pp.

Rasmusson, E.M., Carpenter, T.H., 1982: Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño, *Mon. Wea. Rev.*, **110**,354-384.

Romme, W.H, & Despain, D.G. The Yellowstone fires. *Sci. Amer.* **261**, 36-44,1989.

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

Smith, T.M., and R. W. Reynolds, 2003: Extended Reconstruction of Global Sea Surface Temperatures Based on COADS Data (1854-1997). *J. Clim*., **16**, 1495-1510.

Simard, A.J., D. Haines, and W. Main, 1985, Relations between El Nino/Southern Oscillation anomalies and wild land fire activities in the United States, *Agri. Forest Meteor*., **36**, 93-104.

Swetnam, T.W., and J.L. Betancourt, 1990, Fire-Southern Oscillation relations in the southwestern United States, *Science*, **249**, 1017-1020.

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

Trenberth, K. E., G.W. Branstator,. and P.A. Arkin,. 1988, Origins of the 1988 North American drought. *Science*, **242**, 1640-1645.

Trenberth, K.E., D.P. Stepaniak, and J.M. Caron, 2001, Interannual variations in the atmospheric heat budget, *J. Geophys. Res*., **106**.

Wallace, J.M., C. Smith, and Q.-R., Jiang, 1990, Spatial patterns of atmosphere-ocean interaction in the northern winter, *J. Clim*., **3**, 990-998.

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

Wang, H. and M.F. Ting, 2000, Covariability of winter U.S. precipitation and Pacific sea surface temperatures, *J. Clim.*, **15**, 3711-3719.

Westerling, A. L., A. Gershunov, D.R. Cayan, and T.P. Barnett, 2002, Long lead statistical forecasts of area burned in western U.S. wildfires by ecosystem province, *Int'l J. Wildland Fire*, **11**, 257-266.

Westerling, A. L., T.J. Brown, A. Gershunov, D.R. Cayan, and D.R. Dettinger, 2003, Climate and wildfire in the western United States, *Bull. Amer. Meteor. Soc*. **84**.