The Effects of El Niño on Rainfall and Fire in Florida

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El Niño is only one phase of a larger ocean-atmosphere circulation termed the Southern Oscillation (SO). A complementary phase of El Niño known as La Niña or El Viejo constitutes the other phase of the SO. The SO is the dominant mode of interannual variability in the tropics. Several parameters exhibit interannual variability and all have a center region in which the SO accounts for the major portion of the parameter's variance (Philander 1990). Surface pressure, sea surface temperatures and convective zones are such parameters. Interannual fluctuations in the sea surface temperature (SST) are noted to be a maximum between 10 degrees north and south in the central and eastern equatorial Pacific.

An El Niño event, or warm anomaly, is referred to as a low SO. Meanwhile, a high SO, known also as a cold anomaly, constitutes La Niña. This phase is characterized by lower than normal SST due to intense trade winds which upwell cold water to the surface in the eastern tropical Pacific (Philander 1985). The Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ) diverge on either side of the equator and less rainfall is observed over equatorial South America and the eastern Pacific. This cold anomaly is a relatively new discovery and the specific years of La Niña are not agreed upon. On the other hand, general criteria exist for warm anomalies and these events are agreed upon. For the purpose of this study, the classification of warm and cold anomalies is taken from Yuri Volkov and Boris Kalashnikov's list (1990) and from the Galapagos Islands sea level data since sea level data is

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directly related to temperature anomalies. Warm temperature anomalies are indicative of high sea level pressures and conversely, cold anomalies indicate low sea level pressure. By this classification, warm anomalies exist when sea surface temperature and precipitation increase in the eastern equatorial Pacific, sea surface level differences between the eastern and western equatorial Pacific decreases, and the zonal component of the southern trade winds decreases in the Pacific.

The term El Niño originally implied an annual weak warm current running southward annually off the coast of Ecuador. Currently the term is associated with extended periods of unusually warm SST's occurring periodically off the western coast of South America and in the central and eastern tropical Pacific. These events occur approximately every three to seven years off the western coast of Peru and Ecuador and exhibit temperatures several degrees above normal (O'Brien 1987). Major ocean currents regulate the transport of heat. Busalacchi and O'Brien (1980) investigated the seasonal response to surface currents in the tropical Pacific. Similarly, Wrytki (1975) described the seasonal traits of the equatorial currents in the tropics. A basic comprehension of the seasonal variations of equatorial currents, specifically in the eastern tropical Pacific, is essential to better understand El Niño events which involve intense disturbances of those seasonal variations.

As stated previously, ocean heating plays a significant role in the generation of warm anomalies referred to as El Niño. The western equatorial Pacific Ocean is the source of an El Niño event. In the Pacific Ocean the ITCZ, the SPCZ and the convective zone across the maritime continent in the western tropical Pacific are important regions of heating (Philander 1985). During an El Niño event, the ITCZ and the SPCZ are displaced toward the equator. Philander claims SST's influence the movement of the convergence zones. The summer season of the western Pacific in the Northern Hemisphere, where SST's are the warmest, is witness to a strong ITCZ while the winter season in the Northern Hemisphere (summer in the Southern Hemisphere) experiences a strong influence of the SPCZ and a weak ITCZ. The ITCZ is at the southernmost position in March and April and at the northernmost position between August and September at approximately 10 - 15 degrees of latitude north. The occurrence of warm anomalies is most favorable early in the year, when the ITCZ is in its southern most position and the SST's are generally at a seasonal maximum. Even small variations in the position of these convergent zones can heavily affect the rainfall in certain areas.

Likewise, the convective zones around equatorial Africa and Central and South America, again under the influence of SST, somewhat control rainfall patterns. Given high SST's, warm, moist air rises and creates greater convection around the equator which produces more rainfall.

Another trait of El Niño also related to the SST is the fluctuation of the trade winds. A relationship between equatorial ocean currents and the trade winds is important when forecasting El Niño events. Most knowledge of this correlation is obtained from dynamic height and sea level analyses within the tropics (Busalacchi and O'Brien 1985). A large change in atmospheric pressure between the eastern subtropical Pacific and the maritime lands of Australia and Indonesia generate easterly trade winds (McPhaden and Picaut 1990). Warm surface waters are generally related to a lessening of the trade winds. Westerly wind stress anomalies, caused by the relaxation of the trades in the central and eastern equatorial Pacific, generate Kelvin waves (Graham and White 1988). These Kelvin waves reinforce the SST anomaly in this region by decreasing the depth (thickness) or the warm water in the western tropical Pacific and by increasing the depth in the eastern tropical Pacific. A clash of the trades over the warm water produces a line of heavy convection and clouds, thereby influencing precipitation patterns.

Thus, an El Niño event results from warm SST anomalies. These warm SST's are continuous for at least four months and at three or more coastal stations. El Niño events also result from a relaxation of the trade winds in the central and eastern tropical Pacific. This relaxation leads to the convergence of the ITCZ and the SPCZ around the equator. Low surface pressure over the southeastern tropical Pacific and large amounts of precipitation are also noticed during an El Niño event.

For many years, El Niño was viewed only as a destructive occurrence (Philander 1990). However, this research indicates an El Niño event actually brings relief to Florida while its counterpart, an El Viejo, or La Niña, event yields negative results in Florida. The authors will examine the relationship between the amount of rainfall in an El Niño event and the number of acres burned across Florida. Such a correlation could help prevent the destruction of land by better predicting the dryness or wetness of a season.

In addition to fire management, a correlation could be of ecological importance. Fires are a cause of economic loss and also of basic ecological processes which are likely to change with future climates. The impact of local ecological processes in ecosystems could diminish if a connection between fire and climate is substantiated since some systems are regulated by fire frequency and intensity. A relationship between fire and climate could also help predict future vegetation (Sweetnam and Betancourt 1990).

Douglas and Englehart (1981) concluded heavy rainfall events in the equatorial Pacific during autumn are frequently followed by wet winters in the southern United States. They also concluded that heavy precipitation in Florida is the result of a strong low-latitude flow across North America and an increase in frontal activity in the Gulf of Mexico. Meteorologists refer to this strong flow as the subtropical jet stream. When the subtropical jet stream is shifted, a low pressure center is located over Mexico and the convective zone is shifted to the Gulf of Mexico, and includes Gulf coastal states of the United States. Normally, a high pressure center sits off the western coast of Mexico and California, keeping Florida drier in the winter.

Sweetnam and Betancourt (1990) conducted a similar study of the southwestern United States using fire data from 1905 to 1989. Research showed that large areas of burn after dry springs were related to the high phase of the Southern Oscillation (SO), accepted as being associated with the La Niña phase of the SO. Meanwhile, small areas of burn after wet springs were associated with El Niño events. Sweetnam and Betancourt (1990) concluded the relationship to be the strongest during the extreme phases of the SO.

Brenner (1990) examined monthly wildfires in Florida and their relationship to anomalous SSTs and sea level pressures. A simple statistical analysis confirms such a relationship. Early personal contact by Brenner with the authors led to this paper. In this study, empirical orthogonal function analysis is applied to fire data from each Florida county and rainfall data in 22 cities in order to determine the variance of the spatial and temporal patterns in the data. The significant, repetitive patterns are compared to the sea level pattern off the Galapagos Island which is indicative of El Niño events.

Method

Empirical orthogonal function analysis (EOF) is a purely statistical method of examining data and is used frequently in handling meteorological and climatic data (Preisendorfer 1988). Physical interpretation of the results are necessary. An empirical orthogonal function is a linear function dependent in this case on space (the 67 counties in Florida) and time (108 months of fire data from the years (1981-1989). One linear separable function of the data set is:

$$D(s,t) = G(s)H(t)$$

Where G(s) represents the spatial function and H(t) represents the temporal function. The first principal component is the linear function which has the maximum possible variance. The second principal component is the linear function with the maximum variance subject to being uncorrelated with the first principal component and so forth (Joliffe 1981). The total data set is defined by the data matrix (D):

$$D = (dsT)$$

Where for example, s ranges from 1 to 67, representing the 67 counties throughout Florida, and t ranges from 1 to 108, representing the number of the month of data acquired. A space by space correlation matrix (C) is formed by collapsing the initial temporal components of the original function:

$$C = \frac{1}{N} DD^{T}$$

In order to calculate the variance, the correlation matrix is divided by the number of points (N). A twelve month moving average was later carried out to filter large twelve month variances and to isolate significant and repetitive modes. Only 97 temporal components remain after this statistical filter. The diagonal (trace) of the new correlation matrix now represents the variance for each of the 67 counties in Florida. The remaining values in the matrix represent the sample covariances for the various counties.

The sum of the diagonal (the trace of C) is equal to the sum of the eigenvalues which is also equal to the sum of the squared variances (See Kim). Because C is symmetric, all of the values are real. Starting with the largest eigenvalue, the eigenvalue is divided by the trace of C to determine the percentage of total variance in the eigenvector associated with the maximum eigenvalue. The usefulness of this statistical method depends on how much of the total variance is accounted for by the first few eigenvalues (Moore 1974).

Eigenvalue coefficients are extracted from the two most significant modes and the temporal components were calculated (Figures 3 and 4). The 67 eigenvector coefficients are likewise extracted from

Table 1
Anomalous Years as Established by Volkov and Kalashnikov

Strong El Niño	Moderate El Niño	Moderate La Niña	Strong La Niña
1957	1951	1950	1973
1965	1953	1954	1985
1972	1958	1955	1988
1982	1963	1967	
1983	1969	1970	
	1976	1971	
	1987	1974	
		1975	
		1988	
		1989	

Figure 1
Galapagos Islands Sea Level

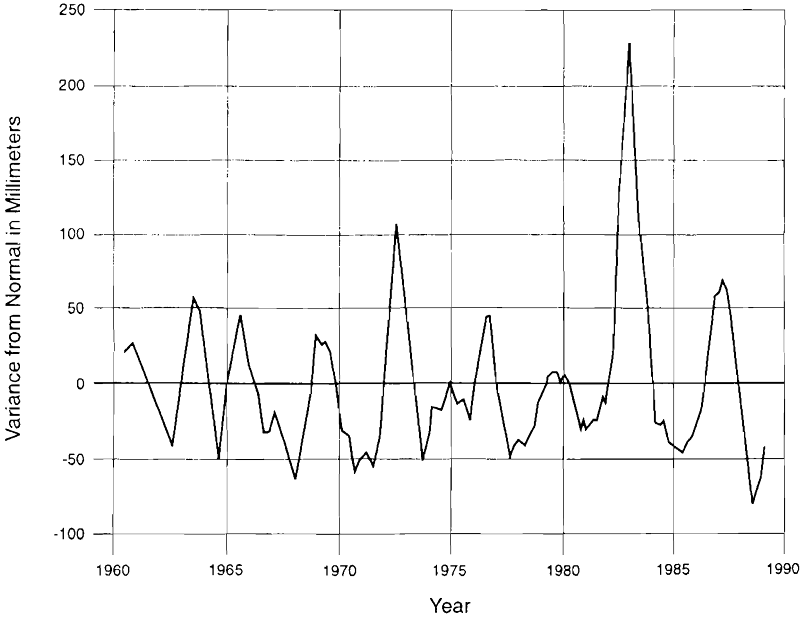
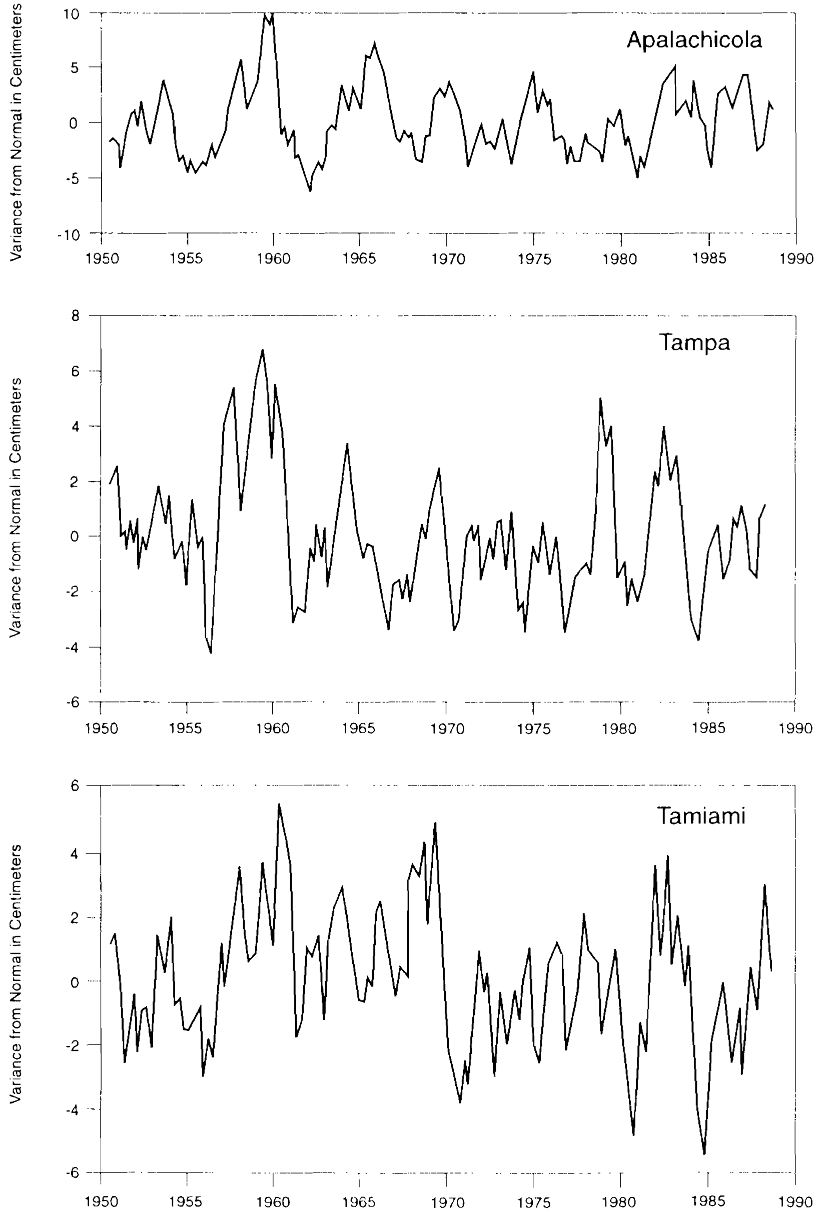


Figure 2
Variance from Normal Monthly Rainfall

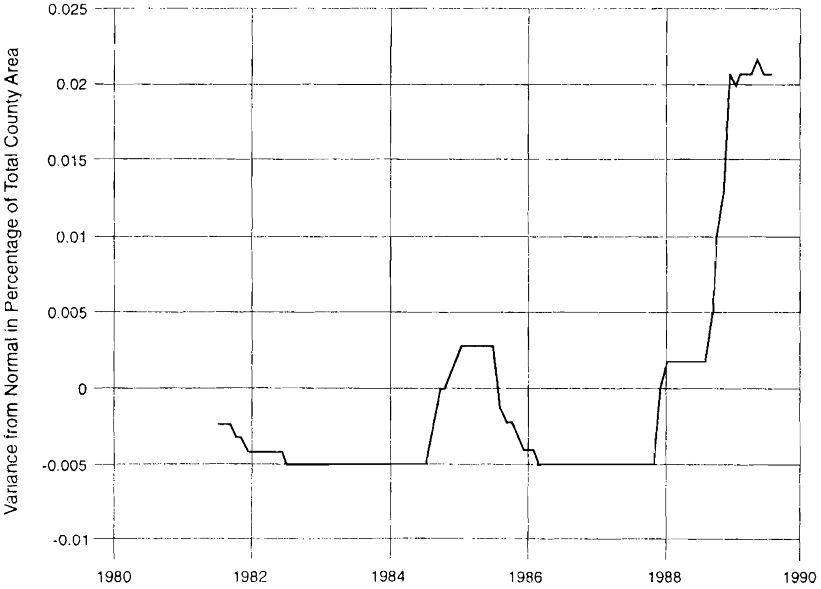


the two most significant modes, and are plotted to form the spatial components (Figure 5 and 6). Eighty-eight percent of the variance was detected within these two significant modes.

Rotational EOF analysis often follows the above process. Rotational analysis is based on a linear rotation around the axes. However, unrotated solutions are easier to extract maximal variance from the data; they have spatial and temporal orthogonality, and are also insensitive to the number of principal components (Richman 1986) The method of unrotated EOF's is good for situations in which pure data reduction is desired, but the method may hinder the ability to isolate individual modes of variation. Rotational analysis was not performed as rotation of the principal components would have altered the pattern very little.

The same method was applied to the monthly rainfall data. The spatial components are the 22 sites across Florida while the temporal components are 360 months of rainfall totals. The first two significant modes comprised 55 percent of the variance as compared to 88 percent in the fire data.

Figure 3
Empirical Orthogonal Function Analysis of Fire Data for Time Series 1

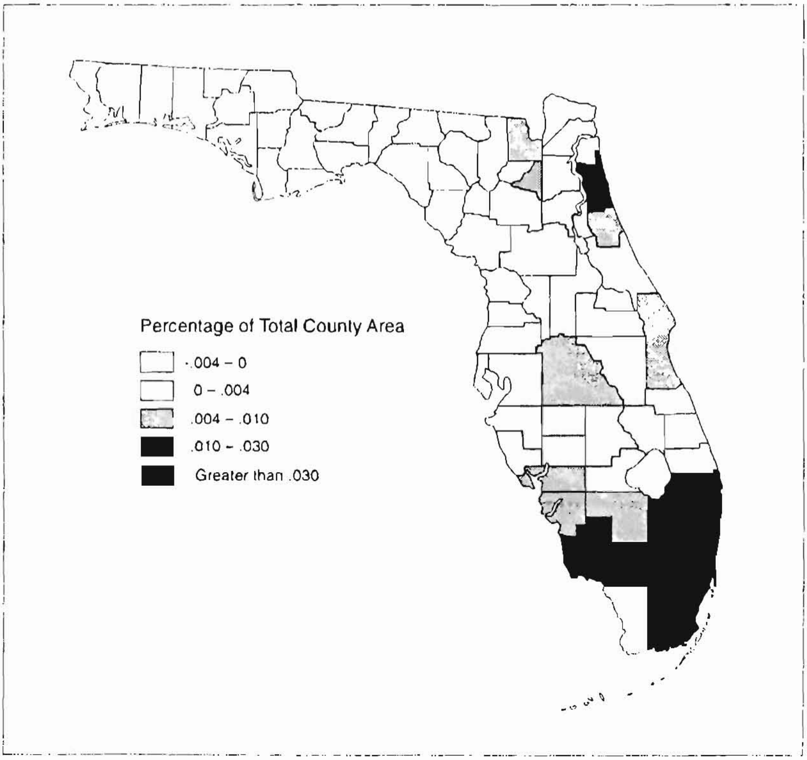


Data

The Galapagos sea level data were measured by several gauges put together by Klaus Wyrtki. The data encompasses the year 1959-1989. To highlight the interannual variability, a 12 month moving average was used. A comparison of Wyrtki's data and the list of cold and warm anomalies as classified by Volkov and Kalashnikov (Table 1) helps determine a relationship between the anomalous years and the Florida data.

The initial data set to be examined which included the number of fires and the number of acres burned in each county for a period of 108 months was provided by Florida's Division of Forestry. The data were normalized by county acreage so that the county size did

Figure 4
Variance from Normal of Total County Area Burned for Time Series 1

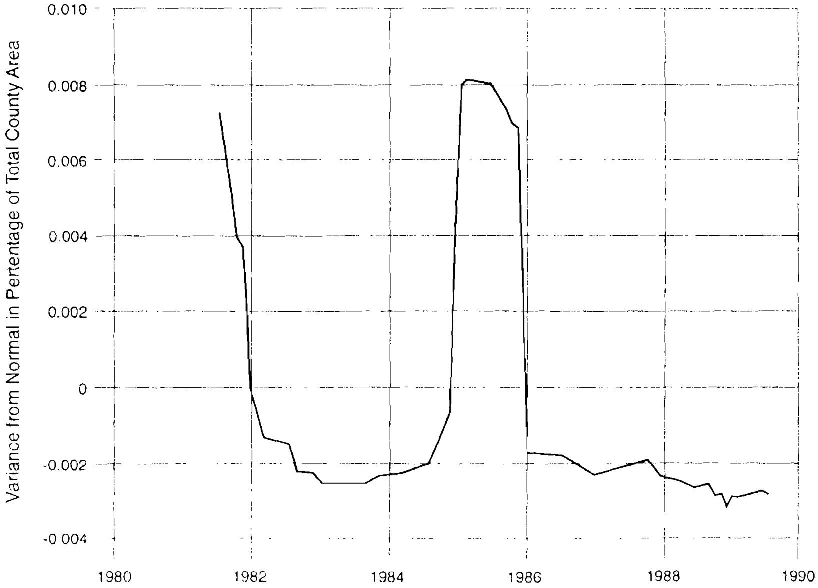


not bias the statistics. Rainfall data were obtained through the state climatologist for a 30-year period. Twenty -two sites were selected as an appropriate representation of the various regions in the state.

First, a mean plot of the total number of acres burned over the 108 months was constructed. This figure indicated areas of little burn in 1983 and in 1987, years of known El Niño events. Meanwhile, data for 1985 indicated an above normal fire year and data for 1989 showed a record year for acres being burned. These are years of anti-El Niño events according to the table from Volkov and Kalashnikov. The Galapagos sea level data (Figure 1) also indicates these years to be anti-El Niño years.

Anomalies of monthly rainfall plots of three particular cities, Apalachicola, Tampa, and Tamiami (Figure 2) are very similar to the Galapagos data. All three of the sites show a marked increase in rainfall during the years of strong El Niños - 1957, 1965, 1982 and 1983. Moreover, the strong El Viejo years of 1973 and 1985 are represented by below normal rainfall in each of these cities. Thus, the data appear believable on first examination.

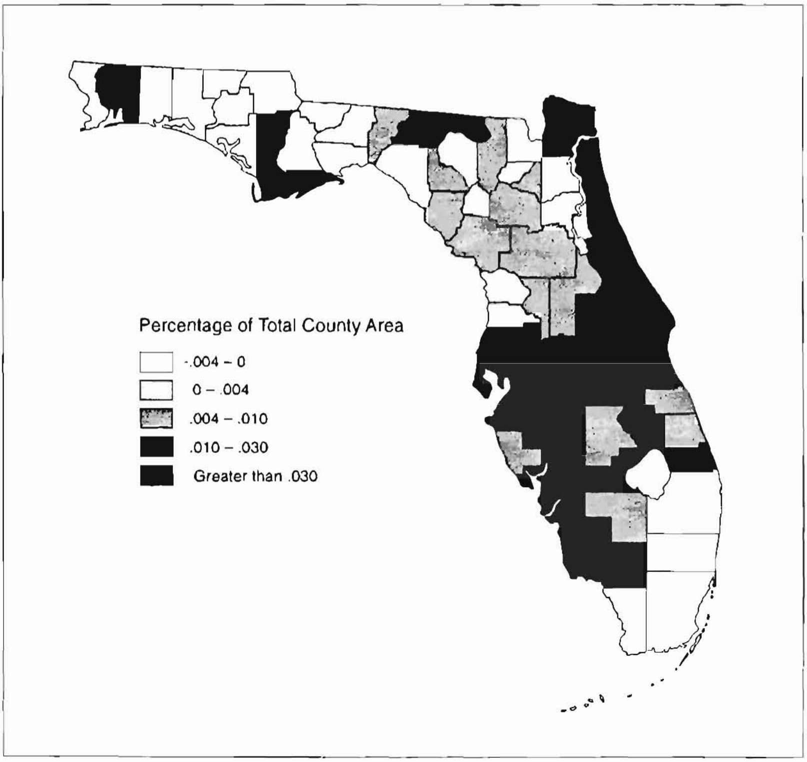
Figure 5
Empirical Orthogonal Function Analysis of Fire Data for Time Series 2



Although the first two rainfall eigenmodes represent about one-half the variance, it is sufficient to show the monthly totals of rainfall for these three cities. In essence, a combination of the spatial and temporal components is being displayed. The number of fires and acres burned is a consequence of the amount of rainfall received. By showing the eigenmodes of the fire data, readers should realize these patterns are indicative of the rainfall data as well.

Together, the first two statistical modes of fire data account for 88 percent of the variance. At first glance, a relationship appears evident. The first significant temporal mode (Figure 3) accounts for 72.62 percent of the variance in the data and is closely related to the Galapagos Island sea level plot. Peaks in the sea level correspond to

Figure 6
Variance from Normal of Total County Area Burned for Time Series 2



El Niño years (particularly 1982-83 and 1987), which correspond to a low number of acres burned.

Meanwhile, the most notable valleys in the sea level plot (1985 and 1989) correspond to the peaks in the first time series. Cold anomalies with large numbers of acres burned occurred in these years. The spatial mode must be examined with the temporal mode in order to yield an overall picture. The product of the spatial and temporal modes produces the percentage the county burned. The first spatial pattern (Figure 6) shows a strong influence in southern Florida. The southwestern tip and two northeastern counties exhibit anomalous values relative to the rest of the pattern.

The second time series (Figure 4), which accounts for only 16.75 percent of the variance, also exhibits a peak in 1985 and two valleys in 1983 and 1987. However, another peak is noticeable in 1981 and a valley in 1989.

The first temporal mode accounts mostly for the El Viejo and the severe burning in 1989. This mode accounts only slightly for the El Viejo in 1985. The second temporal mode combined with the first mode shows the influence of a strong El Niño period in 1982-83 and a strong El Viejo in 1985. Since the variance percentages of the 67 modes should sum to one, some compensation is likely to be occurring in this second mode. For example, a large peak is observed in mode 1 in 1989, while a large valley is noticed in mode 2.

Examination of the second spatial mode (Figure 6) also indicates a relationship of acres burned to El Niño events. In this mode central Florida experiences the most burning while very little burning is observed in the Panhandle. Combined with the second temporal mode, twelve percent of each of the counties in central Florida which exhibited the strongest influence are burned. Again, the extreme southwestern and a couple of northeastern counties are outliers to the pattern. These counties are mostly unincorporated. For example, the southwestern region of Florida consists mainly of the Everglades National Park and the Big Cypress National Preserve. The northeastern counties are comprised mainly of forests and wetlands, including part of the Okefenokee National Wildlife Refuge.

When examining the temporal and spatial modes together, the first mode represents the 1989 El Viejo which is most apparent across southern Florida with some of the 1985 El Viejo noticeable in the northeast portion of Florida. The second mode represents the 1985 El Viejo across much of central Florida and in a few counties in the Panhandle. Southern and central Florida experienced the most burning while the Panhandle of Florida experienced little burning during both of these events in 1985 and in 1989. Baker and Monroe counties are anomalous in both modes. However, the overall pattern is strong enough to conclude a definite relationship exists between an El Niño/El Viejo event and the numbers of acres burned.

Possible anomalies in the aforementioned areas may be caused by the location. More moisture along the Panhandle counties of Florida from the Gulf of Mexico could prevent fires in these counties.

Summary

Statistical analysis of rainfall and fire data across Florida indicates two recurring spatial and temporal patterns which account for 88 percent of the variance in the number of acres burned per year and 55 percent of the variance in the amount of rainfall. In a strong El Niño phase, warm SST's exist off the coast of Ecuador while Florida experiences a cool, wet winter in which fewer acres are burned. In contrast, more acres are burned during an El Viejo phase which is related to warm, dry winters in Florida. This relationship is most prevalent during the extreme phases of the Southern Oscillation. Large anomalies existed in the years 1983, 1985, 1987, and 1989 in which strong or moderate phases of the SO occurred. The warm El Niño anomalies in 1983 and 1987 produced very little burning and extremely wet winters. Cool El Viejo anomalies in 1985 and 1989 produced a record number of acres burned in Florida as a result of little rainfall. Based on the two spatial patterns of the fire data, southern Florida exhibits the strongest relationship to El Niño/El Viejo events while the western panhandle indicates very little correlation. Spatially, northern Florida, particularly the Panhandle, received more rainfall than the other areas. However, all regions showed a significant increase in rainfall during the El Niño years.

Although the number of fires and acres burned are a result of the amount of rainfall, statistical analysis shows that the rainfall data is a good indicator of El Niño events, while the fire data is more significant to the El Viejo events.

The fire data do not cover an extensive period of time since prior to 1980 records were listed by districts. Analysis may change with a longer time series. However, the results are conclusive for the nine-year period analyzed with rainfall and fire data. A relationship exists among the amount of rainfall received, the number of acres burned in Florida, and El Niño events. Therefore, better prediction of such events will help prevent the destruction of wildlife areas and national forests.

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