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THE RELATIONSHIP BETWEEN CALIFORNIA RAINFALL AND ENSO EVENTS

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Introduction

The El Nino/Southern Oscillation (ENSO) event is one which has undergone much study over the last 50 years. Many people have tried to determine correlations between ENSO events and temperature and precipitation patterns across the world. Schonher and Nicholson (1989) have examined the annual rainfall pattern over California during 11 ENSO events within the period 1950 to 1982 to determine if any patterns could be discerned. This paper summarizes their findings and conclusions regarding their investigation.

Residents of California typically expect ENSO events to be associated with above average precipitation during that water year. However, as will be discussed, various areas of California respond differently to the forcings caused by ENSO events. Both theoretical studies and general circulation models have been very important in determining the conditions under which a strong midlatitude response to ENSO occurs. Diagnostic studies have identified three primary features of midlatitude response due to ENSO. One is a fixed and enhanced stationary wave pattern in the midtroposphere extending from low to subpolar latitudes over the central and north Pacific and then equatorward to midlatitudes over the eastern United States. This pattern strongly resembles a teleconnection pattern identified by Wallace and Gutzler (1981) as the Pacific-North America, or PNA, pattern.

Theoretical studies have indicated that this pattern can be interpreted in terms of the creation of a dispersive long-wave pattern originating from a localized vorticity source, i.e., heating anomaly, on the equator (Rasmusson and Wallace, 1983). Wave propagation is initiated by latent heat release and divergent outflow from a region of tropical convection, which is intensified and displaced eastward during ENSO events. The perturbations to the stationary wave pattern are associated with barotropic instability of the climatological upper-level mean wintertime flow and can be excited by anomalous equatorial rainfall patterns, which influence upper-level divergence patterns.

The two other common midlatitude responses to ENSO involve a deepening of the Aleutian low and a strengthening of the subtropical jet and zonal westerlies. The intensification of the Aleutian low is probably associated with the development of the PNA pattern, while the ENSO-related strengthening of low-latitude westerly flow is related to an increased northward flux of angular momentum, resulting from the enhanced Hadley circulation during ENSO years (Schonher and Nicholson, 1989).

Although clear patterns of extratropical circulation response to ENSO forcing have been established, fewer associations with weather patterns have been discovered. A large portion of western Canada and Alaska experience above average temperatures during ENSO events, while cooler than normal temperatures are found in the southeastern United States (Ropelewski and Halpert, 1986). The frequency of tropical storms influencing the southwestern United States also increases. This is likely due to the above average offshore sea surface temperatures (SST) along the west coast of Mexico and to an anomalous trough of low pressure off the southern California coast, which results from weaker trade winds in the eastern Pacific (Douglas and Englehart, 1983). ENSO also consistently enhances rainfall in two sectors of North America; the Great Basin during the April-October rainfall season in the ENSO year and in the Gulf of Mexico region beginning October of the ENSO year to the following March (Douglas and Englehart, 1981; Ropelewski and Halpert, 1986).

California ENSO Events

The dataset consisted of rainfall observations for over 500 California stations of varying record length. All stations that did not have complete records for the 28 year period of 1951-1983 were eliminated. Then, stations were randomly eliminated in an attempt to balance the need for a relatively even distribution of stations with the scarcity of stations in more remote areas. This resulted in 55 stations as shown in Fig. 1.

For each station, a normalized time series of annual rainfall was calculated. Since in most of the state, the winter rainy season is dissected by the calendar year, totals for 1 July to 30 June were calculated. For each year and station, a normalized annual departure was derived by subtracting the annual total from the 29-year station mean and dividing this difference by the standard departures of annual totals at that station. This was necessary due to the highly diverse rainfall patterns across California.

In addition, regionally averaged series were calculated for 13 districts as shown in Fig. 2. The regionalization was subjectively determined, based on annual average rainfall and its seasonality and geographical and topographical considerations. These regions are climatically diverse with mean annual rainfall ranging from 1400 mm in region 1 to 130 mm in region 13.

Within the period 1951-1983, 11 ENSO events occurred. These years were 1951-52, 1953-54, 1957-58, 1963-64, 1965-66, 1968-69, 1969-70, 1972-73, 1976-77, 1977-78, and 1982-1983. Strong positive departures in precipitation throughout the state characterize 6 of the 11 events: 1951-52, 1957-58, 1968-69, 1972-73, 1977-78, and 1982-83. Of the remaining five events, none show anomalies of a consistent sign throughout California and in four of them, departures were near normal everywhere. Only during the 1976-77 event, when rainfall was below normal throughout most of the state, did strong negative departures prevail in any area. Clearly, during an ENSO year, California as a whole is unlikely to experience abnormally dry conditions but wet conditions are fairly probable.

By grouping the 11 events into "wet", "normal", and "dry" categories, the spatially differential response to ENSO becomes more evident. The strongest and most consistent response appears to be in southern California, which is generally the driest sector as well. That area experienced predominately above average rainfall during 9 of 11 ENSO events. Northern

California appears to be least influenced by ENSO. These results suggest three conclusions concerning ENSO and California rainfall: 1) the response to ENSO is not the same in all years; 2) responses are regionally specific; and 3) ENSO events are likely to be linked with relatively wet conditions throughout much or all of the state.

Despite the tendency for ENSO events to enhance rainfall throughout California, the regionally specific nature of the response is quite evident. The most consistent response was in southern California which had a high correlation for wet years during ENSO events. The probability of wet conditions being linked with ENSO decreased from south to north.

A more complex pattern exists in central California. In western sectors (regions 5, 6, and 8) the pattern shows that ENSO years are those with highly anomalous rainfall, but they can be *wet* **or** *dry*. In regions 4 and 9, nearly all extremely wet years are ENSO, thus, the likelihood of an ENSO year being wet is about the same as that for the other regions of central California. Thus, only regions 5, 6, and 8 show a dichotomy between wet ENSO events and dry ones, with only one of the 11 ENSO cases being near normal in terms of precipitation.

In order to diagnose the conditions under which ENSO is likely to influence California rainfall, Schonher and Nicholson (1989) examined various characteristics of the events along with patterns of SST anomalies determined by Fu et al. (1986). Fu et al. (1986), examining the zonal SST distribution in the equatorial Pacific during June-August, differentiate between three types of ENSO patterns (Fig. 3). The attributes of Type 1 are: (i) much warmer water east of the dateline, (ii) near normal in the west and (iii) warmest water extending to about 150° - 160° E, well east of its climatological mean position. In Type 2, water is warmer than normal almost everywhere and the warmest areas extend east of the dateline, but not as far east as in Type 1, and is still near the climatological mean. Type 3 is warmer than normal in the east, slightly below normal in the west and near normal in the central zone; the warmest water is near its climatological position in the central Pacific. Additionally, in Type 1 years, the SST anomalies tend to persist well into the winter season (December-February); in Type 2 years, anomalies are weak by the following winter, and in Type 3 years, SSTs have returned to near normal in most of the Pacific by December. According to Fu et al. (1986) and Schonher and Nicholson (1989), Type 1 includes 1957, 1965, 1972, 1982; Type 2 includes 1953, 1963 and 1969; and Type 3 includes only 1976. They did not analyze the 1951 event due to the sparseness of data.

Based on the above information, "wet" years in California are invariably those of Type 1, in which convective activity and warmest water are displaced markedly eastward. Years of near normal rainfall in California, with the exception of 1965-66, fall into Type 2; and the only dry year, 1976-77, is the only year in Type 3.

Schonher and Nicholson (1989) go on to suggest that these results are compatible with the current theory of extratropical response being manifested as a wave train emanating from the region of the tropical heat source. The location of the warm anomaly in SST may determine the precise nature of the normal mode response. Depending on the characteristics of the equatorial SST anomalies, the Aleutian low, and midlevel low pressure cell may extend their influence to the West Coast, or may remain somewhat to the north and west, allowing for the development of a high over California. The former pattern generally enhances rainfall in California while the latter reduces rainfall over the state. This is consistent with California being a node in the typical PNA response, so that small changes in the pattern can produce abnormally high or low rainfall. This dichotomy could explain the tendency for ENSO years to produce highly abnormal rainfall with either large positive or large negative anomalies over much of California.

Modulation of rainfall in central and northern California, where rainfall is mainly confined to the cold season, requires that ENSO evoke a response in the extratropical circulation. Since that requires the presence of equatorial westerlies, an occurrence generally limited to the winter season, a strong influence on rainfall requires the persistence of ENSO-induced SST anomalies into the winter season. Strong anomalies persist into winter only in Fu et al. (1986) Type 1 years; weak anomalies persist into winter in Type 2, but conditions return to near normal by winter in Type 3. This is a likely explanation for the coincidence of Types 1, 2, and 3 with wet, normal, and dry conditions over California, respectively.

Summary

Of the 11 ENSO events occurring between 1951 and 1982, six were associated with abnormally high rainfall throughout California, four with normal to moderately dry conditions, and one with intense statewide drought. The response to ENSO appears to be regionally specific. The influence is weakest in northern California, while ENSO consistently produces heavy rainfall in southern California, an area influenced by several ENSO-related circulation changes. Unlike the rest of the state, where modulation of the rainfall regime requires a strong midlatitude response to the equatorial heating anomaly, southern California is influenced by low-latitude circulation changes directly linked to ENSO. The ENSO-induced increase of the subtropical jet along with increased tropical storm frequency in the eastern Pacific are both likely causes of this anomaly.

By contrast, in northern California, rainfall is solely associated with midlatitude systems and can be influenced only by those ENSO events provoking strong midlatitude response. This limits ENSO influence on rainfall to the winter season, or about half the northern California rainy season. This leads to northern California having the weakest rainfall response to ENSO.

In central regions of California, ENSO events are consistently linked with abnormal rainfall, but may be unusually wet or dry. This dichotomy appears to relate to California's position as a node in the typical PNA pattern. Rainfall is enhanced when the Aleutian low and midlevel trough intensify and extend to the West Coast. If theses features remain to the north and west, a high pressure cell develops over central and northern California, reducing rainfall. This primarily occurs in Fu et al's. (1986) Types 2 and 3.

The results of Schonher and Nicholson (1989) in conjunction with Fu et al's. (1986) suggest that ENSO is a potentially useful prognostic tool for California rainfall. In southern California the consistent and direct association between ENSO and unusually high rainfall provides a basis for a forecast. Elsewhere, the degree to which rainfall is modulated by ENSO depends on spatial and temporal characteristics of the Pacific SST anomalies. Further research into this will likely provide a better idea of how ENSO and the SST's affect California rainfall.

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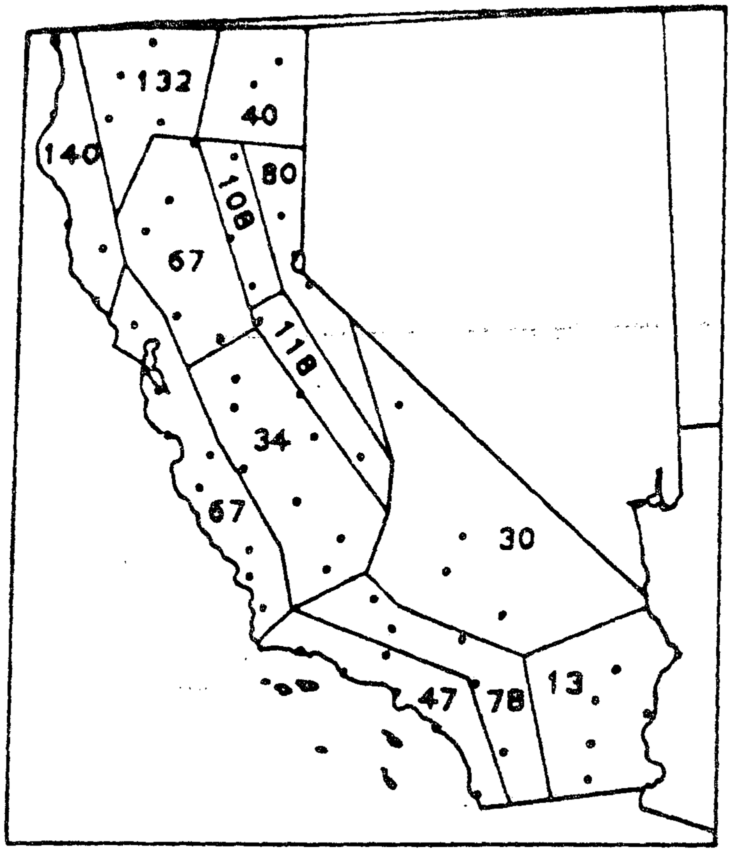

FIG. 1. Map of network of 55 rainfall stations and mean annual rainfall in cm for the regional divisions in Fig. 2.

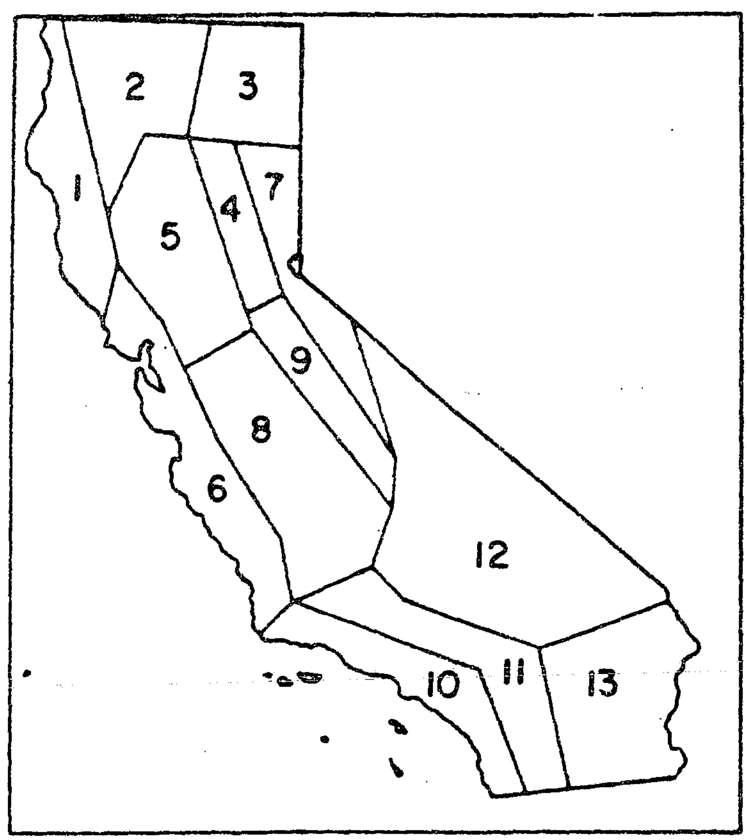

FIG. 2. Map of the 13 regional divisions used in this study.

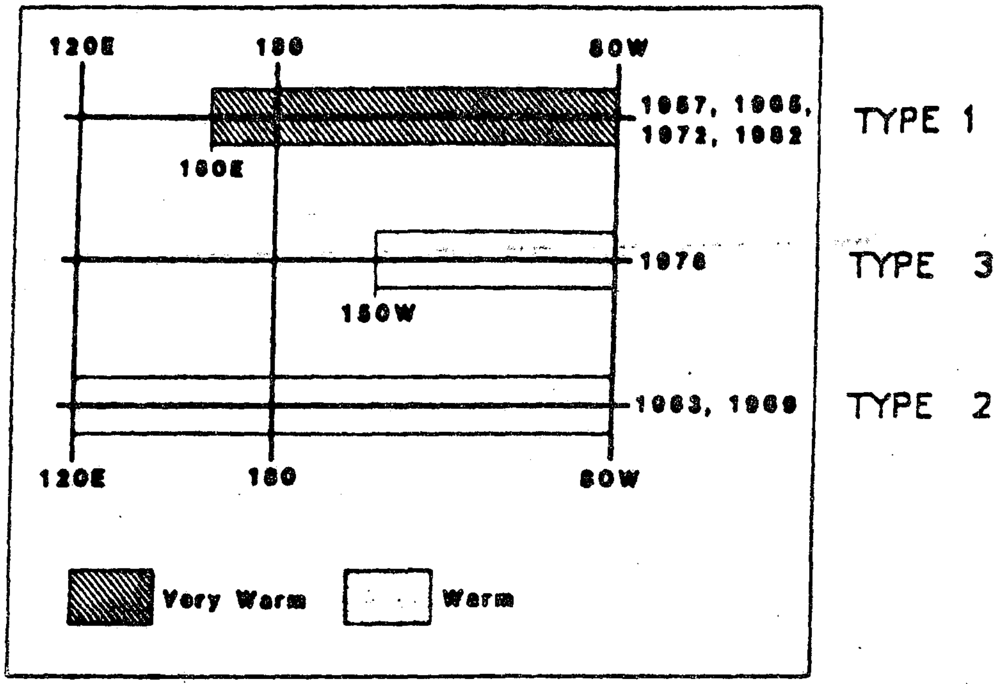

FIG. 3. Schematic east–west map of three patterns of equatorial warming associated with ENSO events and the years in which they occurred (from Fu et al. 1986). Top panel is associated with Type 1 ENSO events, middle with Type 3 and bottom with Type 2.