EL NIÑO AND RELATED VARIABILITY IN SEA-SURFACE TEMPERATURE ALONG THE CENTRAL CALIFORNIA COAST

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Abstract. Sea-surface temperature along the central California coast ontains interannual variability primarily associated with El Niño episodes. Sea-surface temperatures at Granite Canyon from 1971 to 1985 reveal four periods of sea-surface warming which coincide with tropical El Niño occurrences. El Niño related increases in sea-surface temperature at Granite Canyon are examined using two-way layouts of the monthly means and standard deviations, an anomaly analysis, and empirical orthogonal functions. These techniques were well-suited to the task of isolating and enhancing the El Niño influence. Two-way layouts of the monthly means and standard deviations, the mean annual anomaly for the El Niño years, and empirical orthogonal functions indicate that El Niño related warming is seasonal, being strongest in the fall and winter and weakest during the spring. Analysis of shorter term variability suggests that a recently discovered 40- to 50-day oscillation in sea-surface temperature along central California, and spring transitions to coastal upwelling may be related to, or at least influenced by, El Niño episodes at mid-latitudes. Finally, sea-surface temperatures at Pacific Grove, inside Monterey Bay, are not as representative of oceanic conditions along central California as are the observations acquired at Granite Canyon. However, sea-surface temperature at Pacific Grove is a useful indicator of events and processes that occur in and around Monterey Bay.

Introduction

Oceanic variability on interannual time scales is of major importance along the west coast of North America [Hubbs, 1948; Roden, 1963]. El Niño episodes contribute strongly to this variability at mid-latitudes along the California coast [Enfield and Allen, 1980; Chelton and Davis, 1982; Chelton et al., 1982]. This variability is manifested in the California Current System (CCS) at the surface and at subsurface levels to depths of several hundred meters [Rienecker and Mooers, 1986]. It is clearly revealed in a number of physical properties including coastal wind [Norton et al., 1985], sea level [e.g., Enfield and Allen, 1980], alongshore currents [Huyer and Smith, 1985], salinity [e.g., McGowan, 1984], and sea-surface temperature [e.g., Breaker and Mooers, 1986].

Sea-surface temperature at various coastal locations has been examined in a number of studies of long-term variability in the CCS. From spectral analysis of multiyear records of sea-surface temperature (and salinity) Roden [1961] found that most of the nonseasonal variance in these properties is concentrated at frequencies below one cycle per year. Based on a statistical analysis of 26 years of sea-surface temperature acquired along the west coast of the United States, Roden [1963] concluded that (1) the only significant periodicity in sea-surface temperature was due to the annual cycle, (2) non-annual fluctuations of extreme temperatures were reasonably coherent over distances of several hundred km, and (3) the magnitude of the largest extremes in temperature increased with increasing return period. More recently, McLain et al., [1985] concluded that El Niño related anomalies in sea-surface temperature are often spatially coherent from Chile, in the southern hemisphere, to British Columbia, in the northern hemisphere. These anomalies may occur quasi-simultaneously off Peru and California.

Based on 12 years of daily sea-surface temperatures acquired in Granite Canyon along the central California coast (Figure 1), Breaker et al., [1984] found that (1) El Niño influence on coastal sea-surface temperature produces higher-than-average temperatures during the fall and winter, (2) during El Niño episodes, mean annual sea-surface temperature are significantly

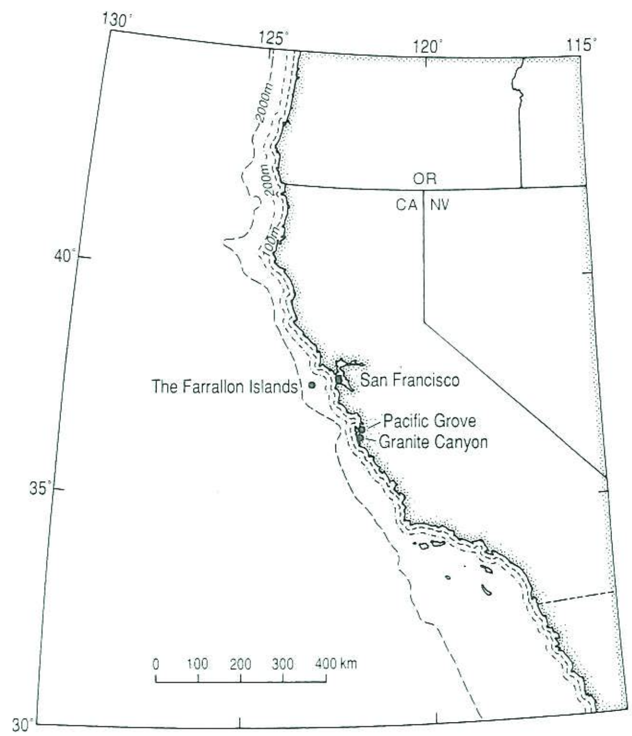

Fig. 1. Locations of the sea-surface temperature acquisition sites at the Farallon Islands, Pacific Grove, and Granite Canyon along the central California coast.

higher than normal (0.5–1.0 °C), and (3) because of their frequency of occurrence, duration, and intensity these episodes must be considered a major contributor to interannual variability in sea-surface temperature at mid-latitudes along the California coast. Breaker and Mooers [1986] found over the 12-year period from 1972 through 1983 that El Niño influence along the central California coast was present approximately 30 percent of the time.

In the present study several analyses of sea-surface temperature data acquired at Granite Canyon are presented in an effort to provide better resolution of the El Niño episodes that occur. Also of major interest is the seasonal dependence associated with the El Niño signal. Primarily because El Niño related variability is inherently nonperiodic, but also because our data span only four El Niño episodes, the data used in this study are not well suited to standard spectral analysis techniques. Consequently, we consider alternate analysis methods to accomplish our objectives. These analyses include (1) two-way layouts of the monthly means and standard deviations, (2) an anomaly analysis, and (3) empirical orthogonal functions (EOFs). Possible connections between El Niño episodes and shorter term variability, including (1) the recently discovered 40- to 50-day oscillation in sea-surface temperature [Breaker and Lewis, 1988] and (2) the often abrupt spring transition to coastal upwelling, are considered. Finally, the representativeness of sea-surface temperature acquired at Pacific Grove is considered through comparisons with the data from Granite Canyon.

The Data

Daily sea-surface temperatures have been acquired by the California Fish and Game Commission's Marine Culture Laboratory at Granite Canyon, located 11 km north of Point Sur and about 25 km south of Pacific Grove (Figure 1), since March 1, 1971. Granite Canyon has an excellent exposure to the deep ocean with the Continental Shelf extending only 6 km offshore at this location. Because of its proximity to deep water the influence of the predominant semidiurnal tide is expected to be small. The daily observations are taken at approximately 1600 UT.

Daily sea-surface temperatures have been acquired since January 1, 1919 (except for 1940), at the Hopkins Marine Station in Pacific Grove. This monitoring site is located inside Monterey Bay in relatively shallow water.

Temperatures at both locations are read to the nearest 0.1 °C using a calibrated immersion thermometer. Mesurement accuracy is reported to be plus or minus 0.2 °C [Scripps Institution of Oceanography Reference 81–30, 1981]. Leap days that occurred during 1972, 1976, 1980, and 1984 have been removed from the data at both locations. Because the calculations contained herein have been performed over the past 4 years, a period over which the Granite Canyon time series itself has increased in length, the record lengths for the various analyses presented vary slightly. However, it is felt that these slight differences in record length (12 versus 15 years, in the extreme) should not significantly affect the results.

Interannual Variability at Granite Canyon

The time series of daily sea-surface temperature at Granite Canyon starting on March 1, 1971, and ending on Febraury 28, 1985. is shown in Figure 2. Each El Niño episode occurring between 1971 and 1985 is indicated by a vertical arrow (1972–1973, 1976–1977, 1979–1980, and 1982–1983). The 1972–1973 El Niño was classified as a strong episode based on a variety of environmental indicators off the Peruvian coast [Quinn et al., 1978]. According to the same indicators, the 1976–1977 El Niño was classified as an episode of moderate intensity. By any standard the 1982–1983 El Niño episode was exceptionally strong. Even the relatively weak El Niño of 1979–1980, which was mainly observed in the western and northeastern Pacific [Donguy et al., 1982], can be identified in the raw data.

Abrupt decreases in temperature also occurred in 1973, 1977, 1980, 1981 and correspond to the spring transition to coastal upwelling. The spring transition is a major event along the coasts of California and Oregon in certain years that signals the seasonal change from nonupwelling to upwelling conditions [Huyer et al., 1979]. A discussion of the spring transition in sea-surface temperature along the central California coast was presented previously [Breaker and Mooers, 1986].

To examine El Niño influence on sea-surface temperature on a seasonal and an annual basis two-way layouts of the monthly mean values and the corresponding standard deviations within each month were calculated for the period from March 1, 1971, to March 1, 1983 (Figures 3 and 4). These two-way layouts were constructed as follows: The distribution of monthly means (standard deviations) by month and year are plotted along each of the two horizontal axes and their magnitudes along the vertical axis, yielding a three-dimensional display. Relatively high values of the monthly means generally coincide with each of the El Niño episodes (indicated by large dots). These higher monthly means also tend to occur during the fall and winter between September and February. The monthly means were also

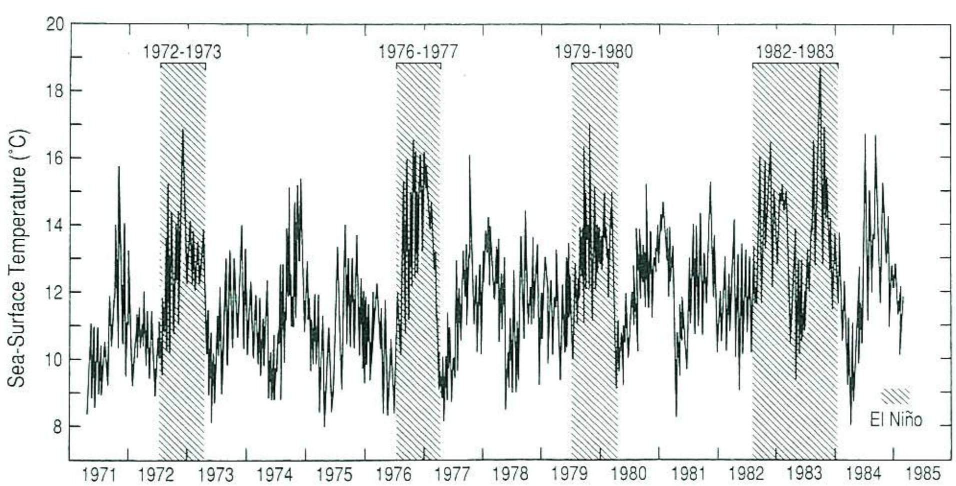

Fig. 2. Daily sea-surface temperatures at Granite Canyon from March 1, 1971, to March 1, 1985. El Niño episodes occcurring during this period are indicated by vertical arrows.