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The 1982–83 El Niño Event off Baja and Alta California And Its Ocean Climate Context

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Introduction

The 1982-83 El Nino brought extremely warm water to the coast of Alta and Baja California as part of one of the most intense ocean-atmosphere events of the century. This report describes this event in terms of surface and subsurface temperature, sea level, and large scale atmospheric pressure changes. The 1982-83 event is examined as part of the continuum of events occurring over the past 13 years (1971-83), a period containing two other tropical El Ninos (1972-73, 1976-78) and two California warming events seemingly unrelated to tropical warmings (1979-80, 1980-81). The 1976-77, 1977-78, 1979-80, 1980-81, and 1982-83 winters have been warmer than normal. Consequently, the period before 1976 was anomalously cool compared to the 13 year mean. These interannual variations are discussed in terms of physical characteristics of the California Current System and associated coastal upwelling, which are the predominant ocean features within 1000 km of the coast. The extreme nature of the 1982-83 event is examined by comparison with other winters of the series. Time-distance contour plots are used to graphically interpret interannual variations over the 13 year period and over the 2123 km distance from the southern tip of Baja California to the Alta California northern border.

The oceanographic term "El Nino", historically, has been applied to ocean surface warming events in the equatorial Pacific off the coasts of Peru and Ecuador. These events generally begin during the Christmas season. Hence, the Spanish words El Nino refer to the Christ Child. Since El Nino lasts through the northern winter, common terminology refers to two or more calendar years. More recently, El Nino became a generic term describing anomalous warm events in eastern boundary current regions of the world's ocean (Wooster 1960). Current understanding is that El Nino is part of a global ocean-atmosphere perturbation called "El Nino-Southern Oscillation" (ENSO) (Quinn 1974, Rasmusson and Wallace 1983). The Southern Oscillation is a quasi-periodic cycle (2-10 years) observed in the atmospheric pressure differences between Pacific and Indian Oceans and the Tahiti minus Darwin, Australia sea level pressure difference is a commonly used Southern Oscillation Index (SOI). Bjerknes (1969) found that El Nino events occur as the trade winds relax and the SOI drops sharply.

ENSO may include the tropical El Nino (TEN) and a California El Nino (CEN). Like the TEN, the CEN is characterized by warming in the coastal ocean's surface layers and both warm events may be synchronous. Other oceanic warming events also occur along the greater California coast (see below). These are mid-latitude warm (MLW) events. CEN events occur in concert with the TEN events: MLW events do not.

Major Geographic and Oceanic Features

The coast of Baja and Alta California extends 19.1 degrees of latitude from Cabo San Lucas at 22.9°N, to the northern California border at 42°N. East to west, the distance from Cabo San Lucas at 109.9°W to Cape Mendocino at 124.4°W is 14.5° (1363 km). In the following "California" refers to Alta California (USA).

The California Current transports cool, low salinity subarctic water southward along the greater California coast (Sverdrup, et al. 1942, Reid et al. 1958). Warmer, more saline, eastern North Pacific Central Water lies west of the California Current creating a positive temperature gradient from east to west as well as north to south. Consequently, warming along the coast can result from local heating and/or increased transport from the south and/or west.

Off central, southern and Baja California, a countercurrent flows northward inshore of the southward flowing California Current where it frequently becomes the dominant nearshore circulation feature (Wooster and Jones 1970, Wickham 1975). North of Pt. Conception, the surface countercurrent is generally most intense in late fall and winter (34.3°N). However, recent studies by Wickham and Tucker show countercurrent activity throughout the year during the warm 1978-80 period (Bird et al. 1984). South of Point Conception, the countercurrent is an important nearshore feature throughout the year, but it is not necessarily continuous with the surface Counter Current to the north (Reid 1960). The California Current System is characterized at depth by a weak poleward countercurrent having maximum speed and persistence over the continental slope. The California Current thickens seaward of 200 km resulting in a deeper countercurrent (Reid 1965, Hickey 1979).

The California Current System's western edge is a broad complex transition zone joining the subarctic transition on the north to the subtropical transition on the south as shown in Figure 1 (Saur 1980, Bernal and McGowan 1981).

Upwelling, caused by northerly winds and resulting offshore Ekman transport is a dominant oceanographic process in spring and summer along the entire California and Baja California coast (Sverdrup et al. 1942). Cooler, higher salinity subsurface waters are brought to the surface in a relatively narrow coastal band and then mixed and carried offshore by other advective processes (Smith 1968, Hickey 1979). The resulting density distribution enhances southward California Current flow. Upwelling occurs year-round off Baja California under the influence of the North Pacific High pressure system. Off central and northern California, however, the atmospheric high weakens and moves south in the winter as the Aleutian Low pressure system intensifies. The winds off central and northern California reverse as these pressure systems change. Downwelling occurs in winter under southerly winds asso-

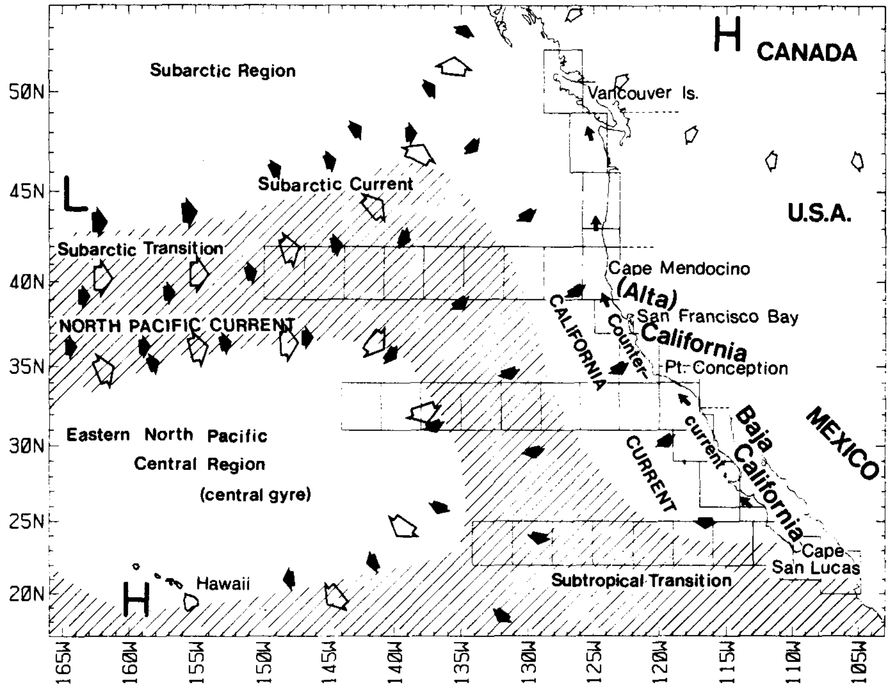

Figure 1. Schematic representation of northeastern Pacific Ocean climatology showing surface winds (open arrows), surface currents (solid arrows), and dominant atmospheric pressure systems: Aleutian Low, North Pacific High, and North American High. Letters "H" and "L" are near centers of action defined by Wallace and Gutzler (1981). Subarctic, California Current and Subtropical transition zones are indicated by hatching. Also shown are locations of $3^\circ x 3^\circ$ areas where surface and subsurface temperature are summarized.

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ciated with intensified Aleutian Low, deepening the mixed layer and facilitating poleward flow along the coast.

Connections Between Tropical and California El Niños

El Nino years on the California coast coincide with El Nino years along the South American coast because of energy transfer from the tropics to mid-latitudes by both oceanic and atmospheric processes. Each process has received considerable attention in the literature (McCreary 1976, Picaut 1984, Rasmusson and Wallace 1983, Wallace and Gutzler 1981).

Tropical El Nino's are associated with slackening of trade winds blowing from east to west over the tropical Pacific. As the trade winds relax, the Southern Oscillation Index (SOI) falls, and even reverses, resulting in a downwelling disturbance which propagates eastward toward South America with characteristics of an equatorially trapped Kelvin wave (Halpern et al. 1983, Cane 1983). The energy transfer that occurs along the equator is the result of the radiation of many Kelvin waves that superimpose to form a beam of energy that propagates eastward and downward (Picaut 1984). When the eastern boundary is reached, poleward and downward-propagating, coastal Kelvin waves are formed. These Kelvin wave packets bring downwelling perturbations to the California coast. This wave energy with subsequent advective adjustment can produce a remotely forced CEN event. This is consistent with subsurface temperature observations from the California coast shown below.

The atmospheric connection to mid-latitudes involves a mechanism originally postulated over fifty years ago by Walker (Rasmusson and Wallace 1983). As the Kelvin wave propagates eastward along the equator, it is accompanied by anomalously high sea surface temperature (SST). Through evaporation and condensation processes, the warm water transfers increased energy to the atmosphere. This energy appears to set up a quasi-stationary tropospheric wave pattern as it propagates northward in great circle arcs (Wallace and Gutzler 1981, Horel and Wallace 1981). In this way, extensive tropical SST anomalies can be teleconnected to mid-latitudes through the atmosphere, altering wind forcing on the eastern subtropical Pacific, thousands of miles to the north (Bjerknes 1969, Quiroz 1983, Pan and Oort 1983). These teleconnections appear most significant in winter and their impact at mid-latitude depends upon ongoing subtropical processes (Wallace and Gutzler 1981, Rasmusson and Wallace 1983, Haney 1984).

The Pacific/North American (PNA) Index was developed to measure tropical to mid-latitude teleconnection (Wallace and Gutzler 1981). This index is derived from a linear combination of 500 millibar atmospheric height anomalies at "centers of action" along the great circle standing wave pattern from the tropics through the North-Pacific High, Aleutian Low, North American Continental High and Florida Low pressure systems. Each is intensified by the standing wave, so that higher highs and deeper lows will contribute positively to the index value. Three of these pressure systems are indicated schematically in Figure 1.

Horel and Wallace (1981) have presented important correlations between the PNA pattern and TEN activity. However, Douglas et al. (1982) point out that PNA type circulation can occur without TEN as it did in the winters of 1958-59, 1960-61, 1962-63, 1967-68, 1979-80 and 1980-81. Conversely, the intense TEN of 1972-73 occurred without a fully distinctive PNA pattern. It is probable that tropical forcing through the PNA pattern has maximum effect when in phase with pressure patterns brought about by complementary subtropical processes (Rasmusson and Wallace 1983). There also seems to be a time lag in the atmosphere's response to equatorial SST forcing (Pan and Oort 1983). The 1982-83 ENSO brought extreme El Nino conditions to the eastern tropical Pacific and the characteristic PNA pattern was formed over the North Pacific (Rasmusson and Wallace 1983, Halpern et al. 1983, Toole 1984).

Data Sources and Methods

El Nino is of large space and time scale and thus we based our analyses on historical data files of weather observations and ocean temperature profiles. The data were averaged by month for 3^{o} longitude-latitude areas.

Surface and subsurface temperature and atmospheric pressure data were obtained from the archives of the U.S. Navy Fleet Numerical Oceanography Center in Monterey, California (FNOC). Sea surface temperatures (SST) were obtained from the file of surface marine weather observations received in real-time at FNOC. The wind speed and upwelling index data were derived from the 6-hourly northern hemisphere pressure analyses (Bakun 1973, 1975).

The SST data were averaged by month in 1^o latitude-longitude areas and then further aggregated to provide means for the 3^o latitude-longitude areas in transects along the coast and westward from the coast (Figure 1). The total number of observations in the study area for the 1971-83 period exceeded 300,000. Over half of the observations were taken within 100km of the coast. Monthly means for SST may represent several thousand values depending on location.

Subsurface temperature profiles were taken from the FNOC Master Oceanographic Observations Data Set, which is an archive of bottle casts, mechanical and expendable bathythermographs, and CTD casts. Although the number of subsurface observations is an order of magnitude less than that of surface observations, the improved accuracy of the individual observations yields a more accurate data set.

Sea level data for tide stations along the west coast of the United States were obtained from Mr. Ray Smith of the National Ocean Survey, Rockville, Maryland. Sea level data for two Canadian stations were obtained from Dr. S. Tabata, Institute of Ocean Science, Sidney, British Columbia and data from Baja California were obtained from Ing. Francisco Grivel Pina, Instituto de Geofisica, Mexico, D.F. Monthly means of sea level were computed from daily values.

Time-distance plots of the variables under study were produced to display large-scale fluctuations in time and space (e.g., Figure 2a). In each plot, time is on the horizontal axis with years and months indicated. The vertical axis is distance, either along the coast (as in Figure 2a) or offshore (as in Figure 4a). The monthly mean values are contoured allowing objective assessment of major patterns. Each contour line is interpreted as the excursion of an isopleth through time and space. Areas north of California and south of Baja California are often included in alongshore plots to allow greater spatial continuity of features. Anomalies of variables from the long-term mean were computed and plotted in time-distance form (as in Figure 2b) to show interannual changes.

Sea Surface Temperature

Figure 2a is a time-distance plot of sea surface temperature along the coast from south of the tip of Baja California to Vancouver Island. A pronounced annual cycle is shown by the large excursions of each contour line (isotherm). Farthest northward isotherm extension or maximum SST occurs in summer and fall. Minimum SSTs, as shown by farthest southward isotherm excursions, occur in winter or spring. Isotherms at higher latitude have larger annual excursions, eg. the 12^oC isotherm crosses 12-18 degrees of latitude while the 20^oC isotherm has about half this latitudinal excursion. The subtropical transition zone off southern Baja California is shown by the denser packing of isotherms south of 29^oN. Interannual spatial variation in SST is weak south of 23^oN.

The extreme nature of the 1982-83 CEN is reflected in the 16^oC isotherm which extended as far north as San Francisco (37.8^oN) in October 1983. This extension was unprecedented in the previous 11 years and represents an anomaly of 1.2-2.0^oC or 2 to 2.2 times the between-year standard deviation (sdu) for that month and latitude. The minimum SST

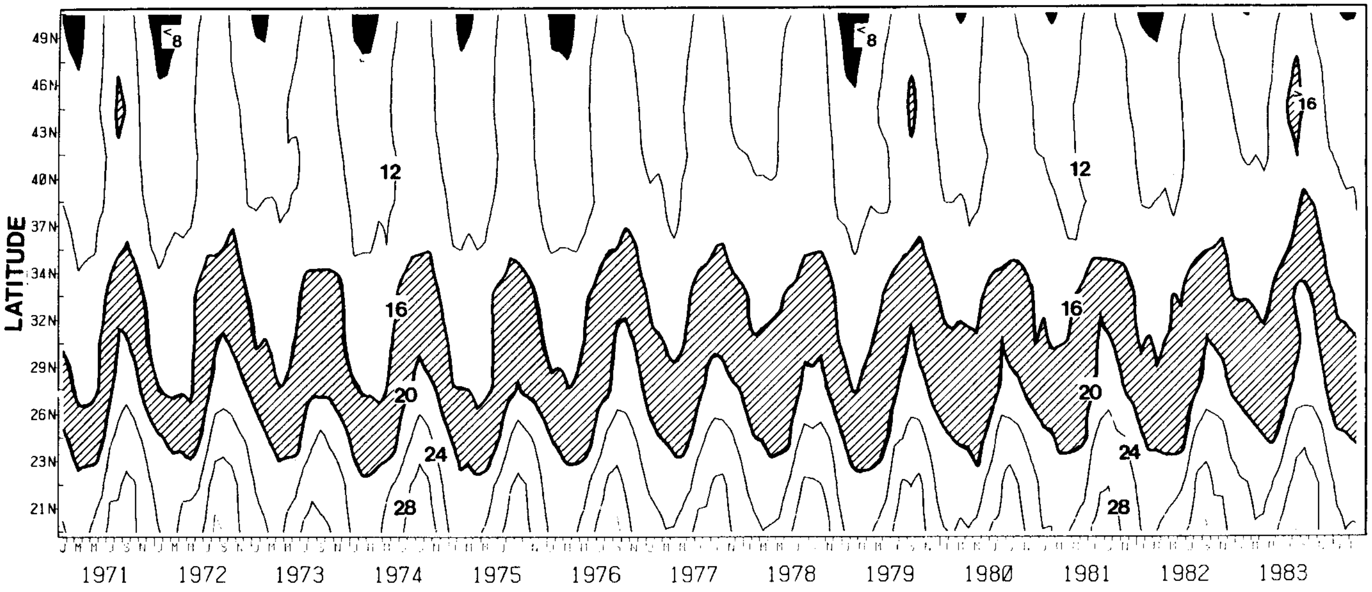

Figure 2a. Time-distance contour plot of monthly mean sea surface temperature (^{0}C) at 12 $3^{0}x3^{0}$ blocks of latitude and longitude on the alongshore transect from Baja California to Vancouver Island. Values are mean SST for $3^{0}x3^{0}$ blocks of sub-means for 1^{0} blocks. Contour interval is $4^{0}C$.

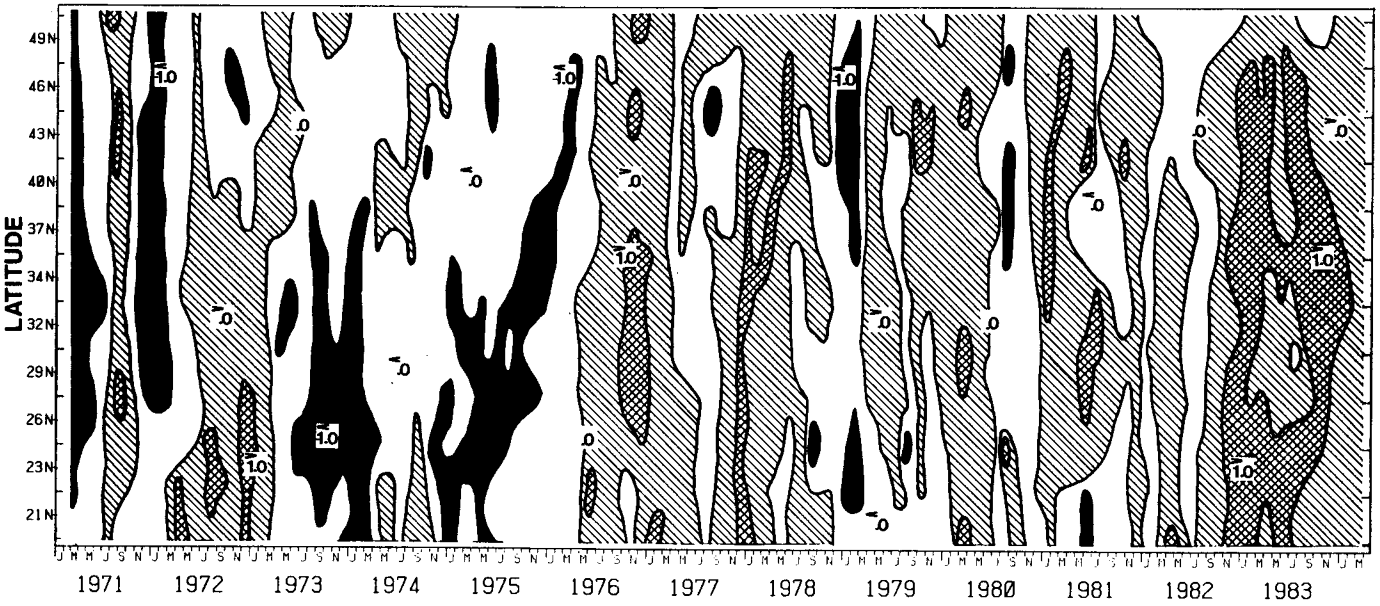

Figure 2b. Anomaly of monthly mean sea surface temperature on alongshore transect from Baja California to Vancouver Island. Hatched areas indicate anomaly between 0 and +1°C and cross-hatched areas greater than +1°C. Unshaded areas indicate anomaly between 0 and -1°C and areas shaded black anomaly less than -1°C. Block locations are the same as in Figure 2a.

during the previous spring was much warmer than usual. The maximum SST during fall 1982 was unusually high, equalled only by the fall seasons of 1979, 1976 and 1972, a MLW and two CEN years, respectively. Water of greater than 16°C was also present in an unusually large closed cell near 43°N. Warmer winters since 1976 are indicated by the reduction in areas less than 8°C near 49°N and by the greater distance between the 16°C and 20°C isotherms off Baja and southern California (23° -34°N). The maxima of the 20°C isotherm tend to follow those of the 16°C isotherm, but the 20°C minima are much more stable, causing the 16°-20°C band to widen in winter (Figure 2a).

The extreme nature of the 1982-83 event becomes more evident when the annual cycle is removed by taking anomalies from monthly mean values (Figure 2b). Areas representing anomaly greater than 1°C have wider meridional distribution and persist longer during the 1982-83 event than in any of the other warm events during 1971-83. The CEN winter of 1976-77 shows a comparable pattern. Figure 2b shows that during 1982-83, anomaly exceeding 1°C appears as two vertical bands connected at 24°N and 36°N by persistent periods lasting from November 1982 through November 1983. These vertical bands represent almost simultaneous occurrence of the anomaly over the range from 29°N to 49°N. Anomalies greater than 1°C occur first in the subtropical transition. The extreme anomaly (2.0°C or 2.0 sdu) south of 29°N represents a northward shift of the 20°C isotherm due to decreased or displaced input of cooler California Current water. Because of the steep SST gradient in the subtropical transition, a small geographical change in isotherm position will create relatively large anomalies. The area of anomaly persistence near 36°N on the central California coast probably reflects a relatively large decrease in seasonal upwelling and climatological tendency toward negative wind stress curl at these latitudes (Nelson 1977). Increased input of offshore water into the coastal region north of 46°N may have been responsible for persistence of the anomaly greater than 1°C in these areas.

CEN warming effects were partially negated in spring and summer 1983 by spring upwelling when anomalies remained positive but less than 1°C. Maximum SSTs normally occur in the inshore California Current System in the fall when both the California Current and the countercurrent are near minimum intensity and insolation has had maximum effect (Sverdrup et. al. 1942, Reid et al. 1958). The second period of extreme anomaly corresponds to this period of maximum seasonal SST. The tropical El Nino of this period also had two maxima in temperature (Smith 1984).

Generally warmer SSTs since mid-1976 are indicated by Figure 2b. Much of the period after 1976 had positive SST anomaly and much of the period before 1976 had negative SST anomaly. Extensive periods with positive anomaly during the 1979-80 and 1980-81 winters indicate MLW events, since there was no corresponding TEN activity.

The SST anomalies were summed for the entire coast for each 6 month period during 1971-84 to show large-scale features of the alongshore anomalies. Scaled values are plotted in Figure 3. A succession of warm events after the first half of 1976 produced a positive shift in SST involving the entire California Current System's inshore component. In the winter of 1976-77, there was a California El Nino accompanied by a tropical El Nino. In 1977-78, CEN and ENSO conditions reoccurred. Winter and spring of 1978-79

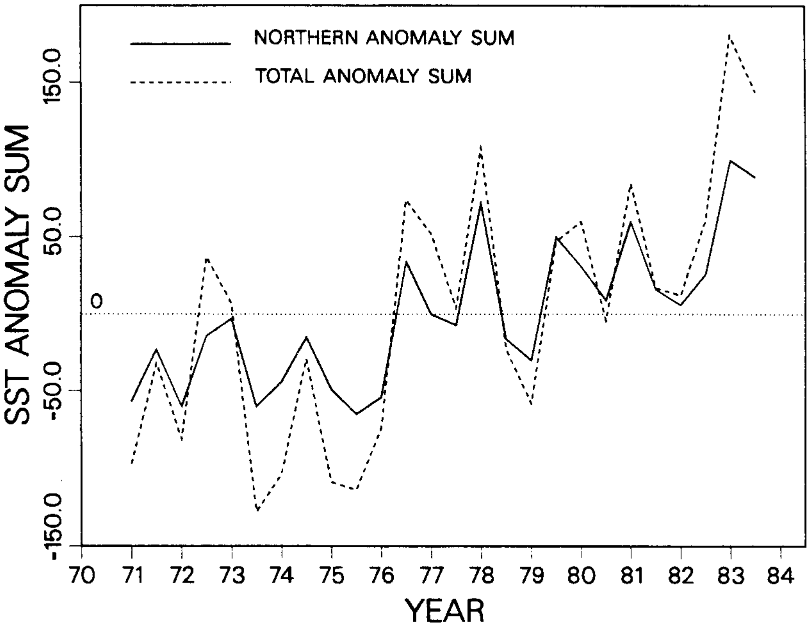

Figure 3. Six-month sums of SST anomaly on alongshore transect from Baja California to Vancouver Island. Abstract of data presented in Figure 2b. Northern Anomaly Sum is for northernmost 7 blocks of transect and Total Anomaly Sum is for all 12 blocks of transect.

were relatively cool, but temperatures remained above pre-1976 levels. In 1979-80, a MLW event occurred off California and Baja California. Similar though less extreme atmospheric and oceanic conditions occurred in 1980-81. The 1981-82 winter temperatures were near normal for the 13 year period. More recently, the extreme CEN and TEN 1982-83 season elevated coastal temperature to a 13 year high. In 1983-84 SSTs remained above normal through fall 1984. Note that during CEN years, the northern and southern portions of the transect both contribute to the total but during MLW years, the northern portion is dominant.

To examine the offshore extent of SST fluctuations, the data were abstracted to form three transects of nine 3^{o} blocks extending from the coast 3000 km westward (Figure 1). A time-distance plot for the transect off Southern California (Figure 4a) shows warm fingers reaching in from offshore during summer and fall and cold fingers of California Current water extending offshore to near 126^{o}W during the winter months.

Regions of cool water (less than 14^{o}C) are prominent features from February through May in 1971, '72, '74, '75, '76, but appear in only one year after 1976 and this occurrence in 1979 is minor compared to the previous years. Cool water is brought into the coastal area from the north by the California Current. Upwelling is less important at the one month-3^{o} scales. Lack of water less than 14^{o}C since 1976 suggests a diminished California Current since 1976. During the third quarter of 1972, '76, '78, '79, '82 and '83 SSTs of greater than 18^{o}C occurred over the entire zonal range (Figure 4a). In general these events precede MLW and CEN winters, and probably represent early surface countercurrent influence. Normally the areas within the 16°C isotherm are broken into inshore and offshore regions by the cool California Current maximum which occurs 200 - 400 km offshore. The absence of persistently strong California Current flow since 1976 has allowed the area greater than 16°C to become zonally continuous in summer and fall during five of the last eight years.

In 1980 and 1983 offshore water was cooler than in other years; SSTs greater than 22°C were absent at the western end of the Southern California transect (Figure 4a). Negative SST anomalies were widespread offshore in fall (Figure 4b). Both events followed winters of intense PNA-type atmospheric circulation. In both preceding winters, a deep Aleutian Low created high winds of long fetch blowing eastward across the Pacific. These intense and persistent winds may have redistributed the warm surface water of the central gyre and transition zone, decreasing horizontal density gradients in the upper layers and thereby decreasing the baroclinicity of the California Current Region. The warm water displaced onshore by southwesterly winds near the coast would tend to increase poleward countercurrent activity which would in turn bring more warm water into the coastal zone from the south. Comparison of Figures 4a and 4b shows that the absence of 22°C water offshore in 1980 and 1983 represents extreme negative anomaly (to -1.8°C, sdu to 2.4). Nearshore, positive SST anomaly is associated with each event. During 1983, the shoreward extension of the 20°C isotherm was the most extreme of the series, as shown by anomalies to 1.2°C (sdu to 2.5) in fall 1983 (Figure 4b).

The SST anomalies along the offshore transect tend to be of opposite sign in nearshore and offshore areas (Figure 4b). Note similarities among 1971, 1973, 1974 and 1975, which were cool years. Negative anomaly occurred in nearshore areas from 1971 through 1976, accompanied by positive anomaly offshore; producing horizontal density structure conducive to an enhanced California Current. In 1976 and the years following, negative anomaly commonly occurred offshore, accompanied by positive anomaly nearshore; opposing California Current baroclinicity.

Warm winters since 1971 were compared by summarizing the three offshore transects (Table 1). Offshore areas were divided into three 1000 km zones, with the nearshore zone containing most of the California Current System and the middle zone in the transition region (Figure 1). The outer zone of the northern transect extends into and sometimes through the northerly meander in the North Pacific and Subarctic Currents (Kirwan et al. 1978) where temperatures are more characteristic of the Subarctic Region. The transect off southern California reaches into the central gyre and the offshore zone of the Baja California transect remains in the subtropical transition.

In Table 1, the 1982-83 winter is shown to have the warmest SSTs of the series inshore and the coolest offshore. If the full length of each transect is considered, the 1982-83 CEN must be considered a cool SST event. In the inshore zone, the 1976-77 and 1983-84 winters were as warm as in 1982-83. Winter 1983-84 probably represents residual warming of the 1982-83 CEN. Note, the inshore zone remained warm in 1983-84, but offshore the cool anomaly of the previous year was lost in the southern and Baja California transects.

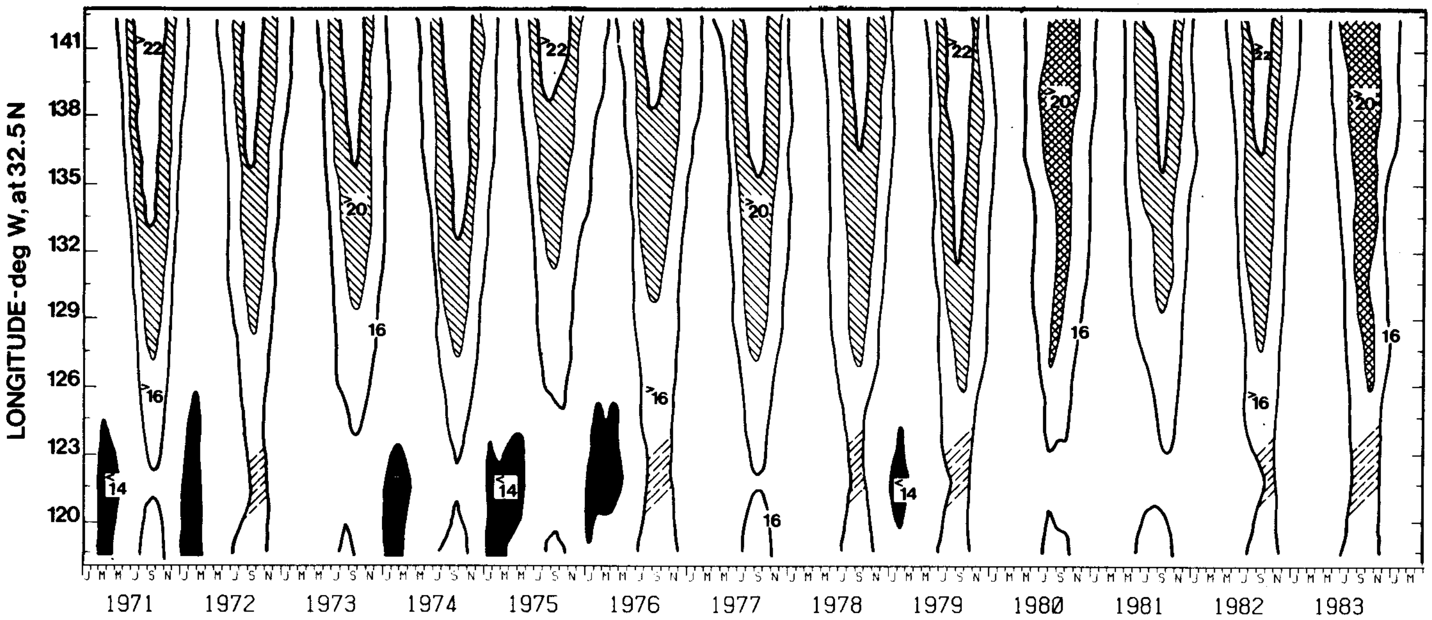

Figure 4a. Sea surface temperature of offshore transect west from southern California. The coast is at the bottom of the figure and the top of the figure is a point 2900 km offshore. The contour interval is 2°C except that the 18°C line is omitted. SSTs between 20°C and 22°C are hatched except for the two years 1980 and 1983 when SST greater than 22°C was not present offshore and the area greater than 20°C cross-hatched for emphasis (see text). Diagonal dashes near 122°W indicate years when SSTs greater than 16°C occurred continuously along the entire transect.

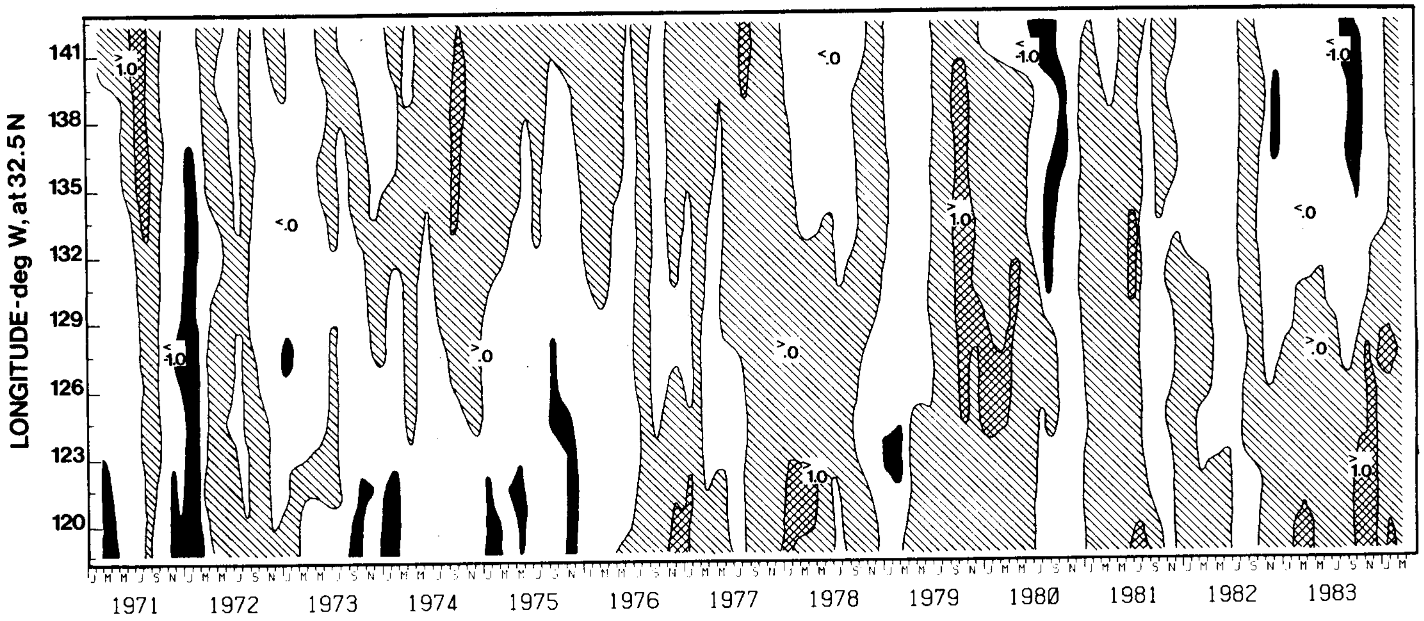

Figure 4b. Anomaly of sea surface temperature of offshore transect from southern California. Hatched areas indicate anomaly 0 to $+1^{0}C$ and cross-hatched areas anomaly greater than $+1^{0}C$. Unshaded areas indicate anomaly between 0 and $-1^{0}C$, and areas shaded black anomaly less than $-1^{0}C$. Block locations are the same as Figure 4a.

Table 1. Summary table of SST anomaly during warm event winters (Nov.-Feb.) since 1971 along the three offshore transects; Northern California, Southern California, and Baja California. SST anomalies are summarized for 1000 km zones along each transect. The symbols represent SST anomaly in each zone along a transect; "W" represents areas having more than 50% positive SST anomaly and "C" represents areas having more than 50% negative anomaly. The numbers under each column are weighted average SST anomaly indices in each zone for each of the three transects; positive numbers representing positive anomalies and negative numbers representing negative anomalies. The anomaly indices are summed by winter in the sixth column and compared to event type (see text).

Winter (Nov-Mar)	Transect	Offshore 2000-3000	Zone Middle 1000-2000	Inshore 0-1000 km	Event Type (Warm Index Total)
1972-73	North	W	W	C	CEN
	South	C (10)	C (-15)	W (-4)	(-9)
	Baja	W	C	W	
1976-77	North	W	W	W	CEN
	South	W (12)	C (15)	W (25)	(53)
	Baja	W	W	W	
1977-78	North	C	C	W	CEN
	South	W (1)	W (15)	W (19)	(35)
	Baja	W	W	W	
1979-80	North	C	W	W	MLW
	South	W (10)	W (20)	W (10)	(40)
	Baja	W	W	C	
1980-81	North	C	W	W	MLW
	South	W (-4)	W (19)	W (12)	(27)
	Baja	W	W	W	
1982-83	North	C	C	W	CEN
	South	C (-9)	C (-19)	W (27)	(-1)
	Baja	W	C	W	
1983-84	North	C	C	W	CEN
	South	W (2)	W (10)	W (26)	(38)
	Baja	W	W	W	

The 1976-77 CEN occurred at the end of a cool onshore - warm offshore period (McLain 1983). It appears that in this winter the central gyre remained warm from the previous period and that the inshore zone warmed under CEN influence. Overall, the SSTs of the 1976-77 CEN were the warmest of the series.

Since 1976-77, each warm winter has shown a tendency to negative SST anomaly offshore in the northern transect (Table 1). This could be the result of increased mixing by high winds in this area and/or a southward shift of the subarctic transition under the influence of basin-wide forcing due to persistent PNA circulation.

During the 1979-80 and 1980-81 MLW winters, warming occurred in the middle zone of all three offshore transects. Since this also occurred under

PNA pattern influence, the suggestion is that surface water is being transported from west to east under the influence of the intensified Aleutian Low. In the case of the MLW winters, warm surface water is moved from offshore into the middle zone. The Aleutian Low was even stronger in winter 1982-83 (Quiroz 1983). More water moved to the south and east in the offshore and middle zones bringing cooler water to the surface in the middle zone and extreme Ekman convergence at the coast. This is indicated by the 1982-83 pattern shown in Table 1. When extreme wind forcing relaxed in 1983-84, a more stable pattern returned offshore even though the inshore zone remained warm.

Subsurface Temperature

Mean monthly temperature time-distance plots at 100 and 200m depths for the same alongshore transect used for SST are shown in Figure 5. The seasonal cycle at 100m is influenced by vertical motion of the thermocline, especially off northern California where turbulent mixing causes mixed layer depths greater than 80m in winter (Husby and Nelson 1982). As with SST, subsurface isotherms make greater latitudinal excursion in the north (see Figure 2a). Isotherms are also more closely packed in the south, but the temperature gradient of the subtropical transition is not as large at 100m as it is at the surface.

In 1982-83, two northward excursions of the 10°C isotherm mark anomalous warming at 100m associated with the 1982-83 CEN (Figure 5). The first warming occurred in winter 1982-83 and after cooling in spring and summer, the second major warming occurred in late summer, fall and winter 1983. Resulting positive anomalies of up to 1.5°C (3.1 sdu) occurred between 46°N and 49°N in the first warming episode. The extreme excursions of the 10°C isotherm off central California in 1982-83 caused anomalies to 1.5°C (3.0 sdu) and 1.4°C (2.8 sdu) for the 1982-83 winter and 1983 fall respectively. Farther south between 29°N and 34°N, anomalies were 2.3 to 3.0°C (2.8 to 3.0 sdu) in winter 1983 and to 1.8°C (3.6 sdu) the following fall. These were the most extreme positive anomalies encountered in the study. The 8°C isotherm was depressed below the 100m level for the entire 1982-83 event (Figure 5). Relative extent of the two northward isotherm excursions varies with latitude and depth. The TEN associated first peak is more persistent with depth and distance south. This persistence is clearly suggestive of oceanic connection between tropical El Nino and California El Nino.

Extreme excursions of the 10°C isotherm at 100m are also seen during the 1972-73 CEN and the 1979-80 MLW winters. If northward excursion of this isotherm is considered alone, the 1979-80 winter is the most extreme, producing an anomaly of 1.6°C (2.7 sdu) at 43°N. The extremity of this winter was also evident at the surface (Figures 2a,b and 4a,b). These two events represent extremes of quite different forcing processes. The 1972-73 CEN was unaccompanied by a fully developed PNA pattern and the 1979-80 MLW event was unaccompanied by anomalous equatorial Kelvin wave activity (Douglas et al. 1982, Cane 1983).

The excursions of the 8°C isotherm during the 1972-73 CEN were as large at 200m as they were at 100m in the 10°C isotherm (Figure 5). The 1972-73 signal was also strong to the south in the subtropical transition, where

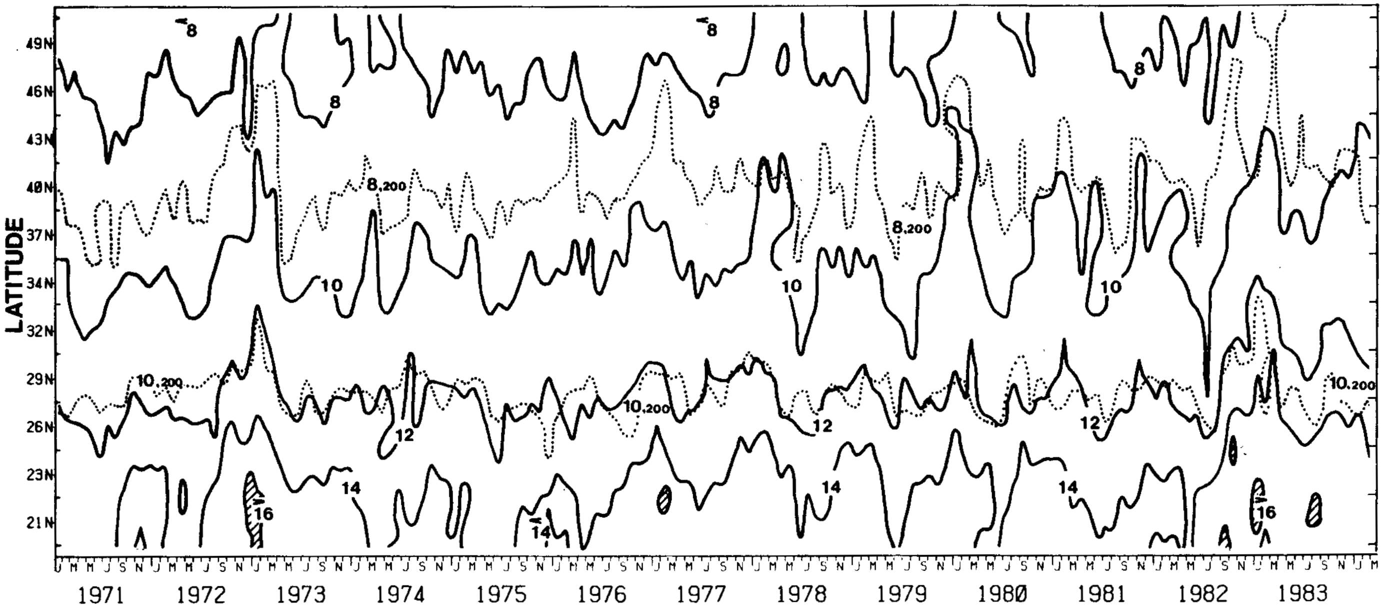

Figure 5. Monthly mean temperature at 100 m depth (solid lines) of alongshore transect from Baja California to Vancouver Island. Contour interval is 2°C. The 8° and 10°C isotherms at 200m (dotted lines) are also shown for comparison.

Table 2. Summary table of temperature at 100 m during warm event winters since 1971 along the three offshore transect. Symbols and numbers are the same as in Table 1.

Winter			Zone		Event Type
(Nov-Mar)	Transect	Offshore	Middle	Inshore	(Warm Index)
1972-73	North	W	W	W	CEN
	South	W (8)	C (0)	W (19)	(27)
	Baja	C	-	W	
1976-77	North	W	C	C	CEN
	South	W (16)	C (-16)	C (-7)	(-7)
	Baja	-	-	C	
1977-78	North	W	C	C	CEN
	South	C (-6)	C (-4)	C (-12)	(-22)
	Baja	-	-	C	
1979-80	North	W	W	W	MLW
	South	C (1)	C (2)	C (-14)	(-11)
	Baja	W	W	C	
1980-81	North	C	W	W	MLW
	South	C (-3)	W (17)	C (-9)	(5)
	Baja	W	-	C	
1982-83	North	C	C	W	CEN
	South	C (-2)	C (-4)	W (20)	(14)
	Baja	W	-	W	
1983-84	North	C	C	W	CEN
	South	C (-1)	W (-5)	W (16)	(10)
	Baja	W	-	-	

the extent of 16°C water at 100m was as great in this period as at any other time in the series.

In contrast to the 1972-73 CEN, the 1979-80 MLW event's signal was halved at 200m and it appears not to have had pronounced influence in the south. This mid-latitude warming event is an example of locally forced coastal warming. Its signal is attenuated with depth and distance from areas of direct energy transfer.

The 100m and 200m alongshore temperature data for the 1972-73 CEN clearly suggest remote forcing from the south. The persistence of signal with depth without apparent attenuation indicates poleward and downward propagating coastal Kelvin waves (McCreary 1976). Although strong MLW events affect temperature at 200m, attenuation occurs with depth. Anomaly computations show the signal for the 1972-73, 1976-77 and 1982-83 CEN events to be stronger in terms of sdu below the thermocline than above. This trend is also shown in Figure 5 where the 1976-77 CEN appears stronger at 200m in the 8°C isotherm than at 100m in the 10°C isotherm. These are the years when a strong Kelvin wave signal would be expected (Cane 1983, Picaut 1984).

Table 2 summarizes the offshore 100m temperature anomaly in the same form as Table 1. The 1982-83 event produced a temperature anomaly pattern at 100m similar to that observed at the surface. The patterns at the surface and 100m were also similar during the following warm winter, 1983-84.

In contrast to the 1982-83 CEN, the inshore zone was cool at 100m during the 1976-77, 1977-78, 1979-80 and 1980-81 warming events. This may represent a large scale density adjustment with depth. Presumably similar adjustment occurred below 100m during the 1982-84 period.

Figure 5 shows conspicuous coastal warming at 100m during the 1976-77, 1977-78, 1979-80 and 1980-81 winters in the alongshore 3° blocks. However, the 3° latitude by 9° longitude areas summarized in Table 2 show that these winters have predominantly negative anomaly at 100m. Quite possibly, this points to the distinction between the coastal countercurrent, which appears instrumental in increased coastal warming in warm winters, and the diffuse offshore countercurrent or undercurrent. Kelvin wave influence would be expected to occur first in the region of the countercurrent. Offshore, it appears that the undercurrent becomes weaker as the California Current weakens (Table 1, Figure 4a) during warm events, leading to cool anomalies at depth in the inshore zone (Table 2).

The persistence of negative winter SST anomaly offshore on the northern transect as shown in Table 1 may represent a southward shift of the subarctic transition. It appears that a similar shift occurs in the 100m index four years later in winter 1980-81 and persists through winter 1983-84. This is shown by negative anomaly index in the offshore zones of the two northern transects. Examination of more detailed data shows that the cooling in this region began in 1977. This trend to cooler water in the offshore zone may represent a time-dependent deepening of the mean oceanic circulation brought by increased frequency of the PNA atmospheric pattern over the north Pacific. This climatic shift, which apparently favors warmer coastal water, undoubtedly contributed to the extremity and persistence of the 1982-83 CEN.

Sea Level

To examine the effects of the 1982-83 California El Nino on sea level, 6-month sums of sea level anomaly for Neah Bay, Washington and for Crescent City, San Francisco, Monterey, Los Angeles and San Diego, California were added together to give a value for the entire west coast of the United States. These scaled values are plotted with the corresponding scaled SST anomaly sum in Figure 6. The extremely high sea level anomaly values that occurred during the 1982-83 CEN event suggest an anomalously warm water column as the result of atmospheric and oceanic forcing of convergent ocean currents along the greater California coast.

The 1982-83 CEN resulted in the most extreme sea level anomaly in the 1971-83 record. If cool negative anomaly events are excluded, the 1972-73 CEN was next in extremity followed by the 1976-77 (CEN), 1977-78 (CEN) and 1979-80 (MLW) events. Greatest anomalies were in winter 1982-83 when anomalies greater than 20 cm occurred from San Francisco north to Sitka, Alaska. Anomalies of this magnitude and duration are unique in the National Ocean Survey's records for the west coast of the USA. A 90 year daily sea-level height maximum for San Francisco occurred on January 27, 1983. The 26 cm monthly anomalies for February and March 1983 at San Francisco were

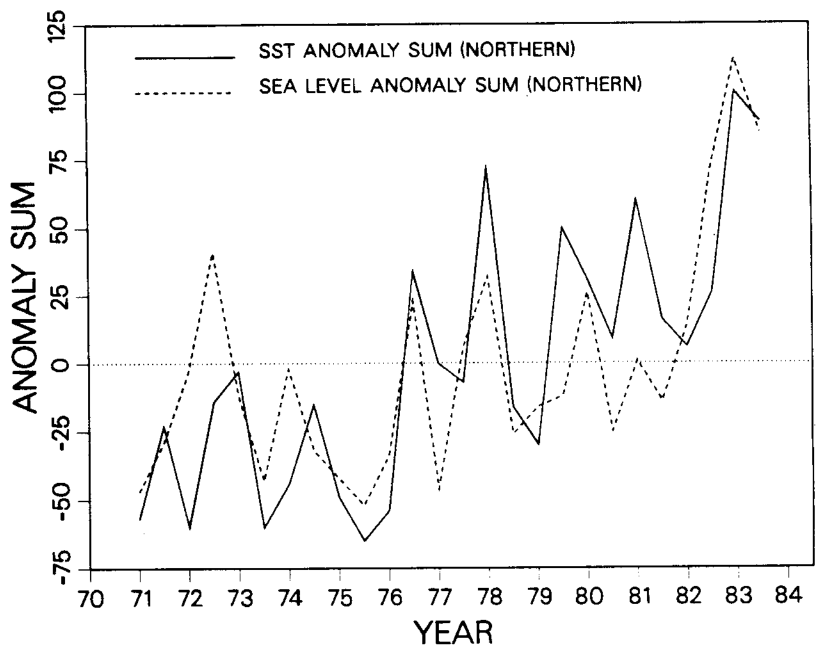

Figure 6. Six-month sums of anomaly of sea level at 6 tide stations along the northern portion of coast from San Diego, CA. to Neah Bay, WA. Six-month SST anomaly for the northern portion of coast are also included from Figure 1 for comparison.

without precedent in the 90 year record. High positive anomalies also made the 1983 yearly mean unique in the 90 year series. In southern California anomalies were less extreme with the largest monthly anomalies ranging from 10 to 15 cm.

Chelton and Davis (1982) related the first empirical orthogonal function of monthly sea level anomaly along the coast of North America to bifurcation of the North Pacific Current as it approaches the eastern boundary under the influence of basin-wide atmospheric forcing. When bifurcation favors northerly flow, there is sea level rise along the coast of Alta and Baja California. This represents the warm oceanic event response characterized by the years since 1976 (Figure 6). In the opposite extreme, the cool subarctic water flows south in an anomalously cool California Current and there are lower sea level heights.

This analysis agrees well with the implications of the above temperature data. Northerly winds in the western Pacific basin bring more cool subarctic water into the North Pacific Current allowing the subarctic transition to move south. This brings cool water to the offshore end of the northern transect (Tables 1, 2). The PNA-associated intensified Aleutian Low favors an increased northward flow of subarctic water. Consequently, the California Current System receives less cool water.

Wind Mixing and Upwelling Index

Wind stress on the sea surface mechanically mixes the ocean's surface layers and induces surface currents. The mixing effect of the wind is directionally independent and the rate at which turbulent kinetic energy becomes available to mix the upper ocean is proportional to the third power of the wind speed (Niiler and Kraus 1977).

An index of the turbulent wind events along the California coast was calculated from the 6-hourly northern hemisphere pressure/wind analyses of the Fleet Numerical Oceanography Center at six coastal locations from 24° to 39°N for the period 1974-84. The daily mean wind speed cubed was calculated from the mean of the four 6-hourly wind speed cubed values. To investigate the interannual variability in the atmospheric forcing, these daily time series of wind speed cubed were examined in terms of the number of daily means greater than a threshold value of 400 m^3/s^3 and the persistence of events above the threshold. It is emphasized that these wind speed values are representative of the large-scale wind forcing, characteristic of the approximate 3°x3° grid spacing of the northern hemisphere analysis.

Wind events for the central California coast (36°N) during the winter quarter (Dec. - Feb.) from 1974-75 to 1983-84 are described by the product of the number of daily means greater than the 400 m^3/s^3 threshold times the mean value of the wind speed cubed for these days (Table 3). This product is a relative index of the turbulent energy added to the water column during the various winters. The greatest turbulent mixing appears to have occurred in the CEN winters of 1977-78 and 1982-83. The third most turbulent winter was the mid-latitude warming event winter of 1979-80. These three winters occurred in winters when the PNA-type atmospheric circulation was strong (Wallace and Gutzler 1981, Quiroz 1983). This pattern was also observed at the other coastal locations, but with smaller magnitudes in the extreme events.

Equatorward winds blowing parallel to the California coast cause surface water to be moved offshore and subsurface water to rise in the upwelling process. Conversely, poleward winds cause surface water to be pushed toward shore, causing downwelling and northward flow. The upwelling index (Bakun 1973, 1975) provides a large-scale estimate of the onshore/offshore Ekman transport based on FNOC pressure/wind fields.

A time-distance plot of monthly mean upwelling index (Figure 7) shows that in the area south of 33°N, winds favoring coastal upwelling occur throughout most of the year. North of 33°N, winter winds favor onshore transport and resulting downwelling. These areas are seen in Figure 7 as cusps that extend southward to latitudes from 33° to 39°N. The hatched areas within the negative regions represent extreme downwelling of less than -200 cubic meters per second per 100m of coastline (m^3/s/100m). At 42°N the upwelling index exceeded this negative value for only two months in the entire 13 year record. These occurred during the anomalously warm 1982-83 winter. The shaded cells centered near 33°N represent periods of strong upwelling in spring and summer when the monthly values are greater than +200 (m^3/s/100m). Note the increase in upwelling at 21°N which occur in the spring and summer after 1976. These may be the result of a southward shift and/or intensification of the North Pacific High pressure center.

To examine the interannual variability in the upwelling index the consecutive positive values of the index greater than +200 at 33°N were summed for summer seasons during the 1951-84 period. The negative

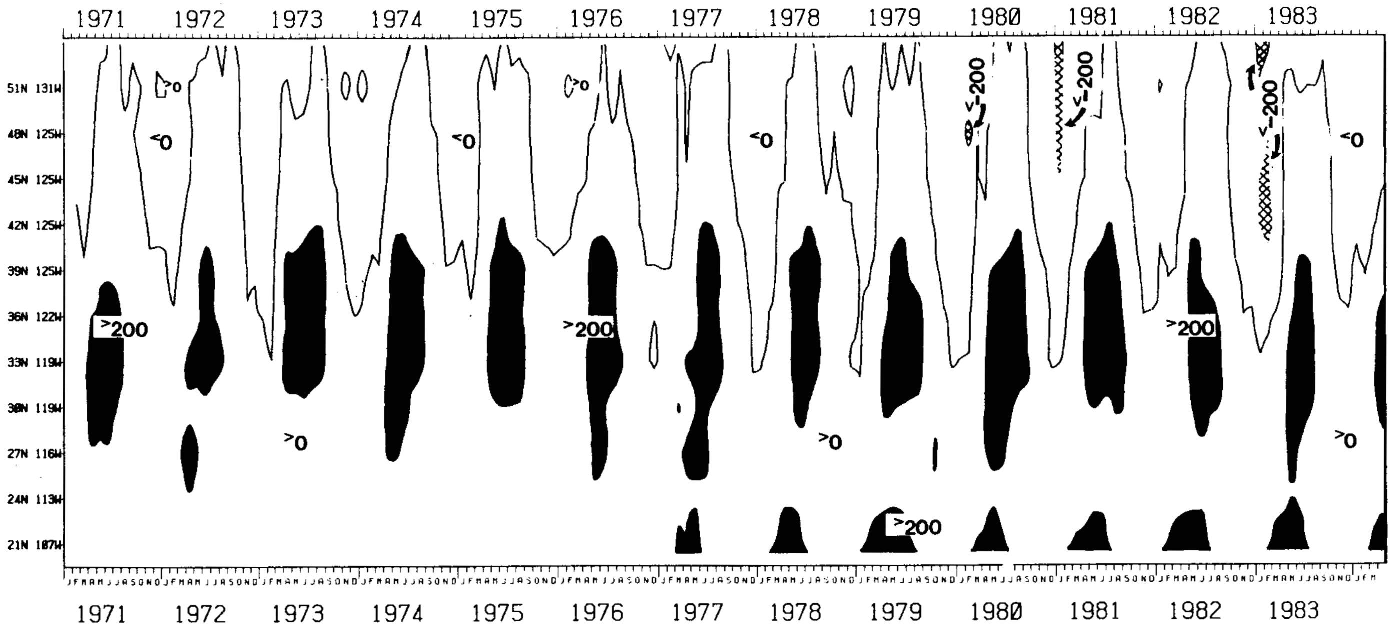

Figure 7. Upwelling Index computed by methods of Bakun (1973) for 12 locations along west coast from Baja California to Vancouver Island. Units are $m^3/s/100$ m of coastline. Solid lines represent zero upwelling index and enclose regions of negative upwelling or downwelling. Cross-hatched areas represent downwelling stronger than -200 upwelling index units. Areas shaded black represent cells of strong upwelling (greater than +200 units) along central and Baja California in spring and summer.

Table 3. Summary of severe winter (Dec.-Feb.) turbulent wind events off central California (36°N) during winters from 1974-75 to 1983-84. Computed from 6-hourly pressure fields from Fleet Numerical Oceanography Center. The first column gives the number of days when the daily mean wind speed cubed was greater than $400\ m^3/s^3$ and the second column gives the mean wind speed cubed value for those days. The third column gives the product of number of days times the mean wind speed cubed and indicates the amount of turbulent energy added to the water column. The last three columns summarize the turbulent energy transfer as events by giving the number of events of wind speed greater than $400\ m^3/s^3$, the mean duration of the events, and the standard deviation of the duration of the mean.

	WIND SPEED CUBED > $400m^3/s^3$					
	(1)	(2)	(3)	(4)	(5)	(6)
SEASON	NO. OF DAYS	MEAN FOR DAYS>400	(1)x(2)	NO. OF EVENTS	DURATION OF EVENT MEAN	S.D.
1974-75	26	1096	28496	9	2.8	0.7
1975-76	9	760	6840	3	2.3	0.3
1976-77	4	516	2064	2	2.0	0.0
1977-78	27	1462	39474	5	4.6	8.8
1978-79	19	836	15884	6	2.2	0.2
1979-80	24	1388	33312	6	3.3	3.9
1980-81	11	1548	17028	4	2.3	0.3
1981-82	16	854	13664	5	2.4	0.8
1982-83	31	1261	39091	8	3.3	0.8
1983-84	12	1610	19320	3	2.3	0.3

upwelling index values at 42°N were also summed for each winter downwelling season (Table 4). The most extreme downwelling of the last 33 years occurred during the 1957-58 and 1982-83 fall and winter seasons which were two and three times the mean, respectively. During the winters of 1979-80 and 1980-81, the PNA-type circulation occurred over the North Pacific. They also had higher than average downwelling values at 42°N. The 1979-80 and 1980-81 winters were probably important in maintaining the anomalously warm SST regime since 1976.

Large negative values of the downwelling at 42°N are associated with the occurrence of PNA atmospheric circulation. Upwelling in the following spring and summer appear decoupled from winter downwelling. However, upwelling can also influence the overall impact of warm anomalies. Note that in the 1982-83 two seasonal influences related to upwelling lead to high California coastal SSTs. First, there appears to have been unprecedented downwelling which promoted northward coastal flow and warming during winter 1982-83. This was followed by indication of below average upwelling during the following spring and summer. This, in turn, was followed by the highest SSTs and highest SST anomalies (in sdu.) during fall 1983 (see Figures 2a,b).

Table 4. Summary of monthly upwelling index for winter and summer seasons from 1951-52 to 1983-84. The second column is the sum of negative monthly mean upwelling index values at 42^{o}N during the winter downwelling season. Seasons with downwelling sums more negative than -300 units at 42^{o}N are marked with double minus (--). The third column is a similar sum of positive upwelling index values during the following spring and summer at 33^{o}N. These are the sum of consecutive monthly mean values greater than +200 units . Upwelling seasons with sums greater than +1500 units are marked with double plus (++). The fourth column indicates the occurrence of tropical El Nino (TEN) and Pacific/North American circulation (PNA).

MONTHLY MEAN UPWELLING INDEX ABSTRACT
1951-1984

SEASON	42N NEG.	33N POS.	EVENT
51-52	(194)	448	
52-53	(413)--	814	TEN
53-54	(215)	491	
54-55	(246)	1813++	
55-56	(230)	1656++	
56-57	(60)	1439	
57-58	(544)--	1535++	TEN, PNA
58-59	(139)	1955++	PNA
59-60	(101)	349	
60-61	(409)--	809	PNA
61-62	(64)	792	
62-63	(204)	1053	PNA
63-64	(168)	2261++	
64-65	(210)	1161	
65-66	(197)	1211	TEN
66-67	(165)	1319	
67-68	(189)	1511++	PNA
68-69	(269)	1584++	
69-70	(353)--	1404	TEN, PNA
70-71	(131)	1354	
71-72	(92)	1209	
72-73	(219)	1310	TEN
73-74	(198)	1383	
74-75	(121)	1217	
75-76	(54)	1055	
76-77	(128)	1266	TEN, PNA
77-78	(366)--	798	TEN, PNA
78-79	(99)	1446	
79-80	(369)--	1629++	PNA
80-81	(383)--	1546++	PNA
81-82	(215)	1157	
82-83	(765)--	984	TEN, PNA
83-84	(278)	1191	

DOWN 42:	MIN.	(60)
	MEAN	(251)
	MAX.	(765)
	--LT.	(300)
UP 33:	MIN.	349
	MEAN	1224
	MAX	2261
	++ MT	1500

Discussion and Conclusions

Our analyses suggest that the severity of the 1982-83 CEN was the result of several warming factors. Remote forcing occurred both through the atmosphere and through the ocean to cause warming in the California Current System which had already been warmed by remotely forced and local events of lesser, but similar nature.

Two maxima characterized 1982-83 warming that occurred within 300km of shore (Figures 2a,2b,4a,4b). The first maxima occurred nearly in phase with the tropical El Nino at all depth levels studied. At the surface the second peak which occurred in late summer and early fall 1983 was the most extreme. At the 100 and 200m depths, the first peak, which was most likely associated with coastal Kelvin wave activity, was the most extreme. The second maxima at 100m was reduced in expression south of 32°N and with depth (Figure 5).

Maximum temperature anomalies of 2°C, 3°C and 1.2°C occurred at the surface, 100m and 200m respectively. In terms of sdu, the highest value was 3.6 off Baja California with values to 3.0 throughout the alongshore transect at 100m. Anomalies with sdu values ranging to 2.0 and 2.5 at the surface and 200m, respectively, indicate a relatively unattenuated signal below the thermocline consistent with coastal Kelvin wave theory.

Comparison of the 1982-83 CEN with other warm events of the series has allowed considerable insight into the causes of its severity and persistence. The 1972-73 CEN occurred without the PNA atmospheric adjustment which occurred in 1976-77, 1977-78 and 1982-83. The 1972-73 CEN, which has a number of similarities to the 1982-83 event (Figure 5) provided an example of the oceanic tropical to mid-latitude connection. In contrast, the 1979-80 MLW event was accompanied by the distinctive PNA atmospheric pattern in a period without tropical El Nino activity. This coastal warming event also had several points of similarity to the 1982-83 CEN (Figures 4a,b). Overall, the 1977-78 CEN is similar to the 1982-83 event, though less extreme (Figure 4b, Table 3).

The 1982-83 event brought anomalous cooling in an area reaching from 1000-3000 km offshore. If the 3000 km area adjacent to the coast is considered, the 1982-83 CEN was a cool event rather than a warm one (Figure 4b, Table 1). This was the result of unprecedented development of the Aleutian low that occurred in winter 1982-83. As noted above, this low was probably the result of extra-tropical forces acting in concert with the tropical atmospheric connection. Cooling in the area 2000-3000 km offshore at 40.5N appears characteristic of years when anomalously warm water occurs at the coast (Tables 1, 2). However, no other offshore cooling event of the 13 year series was as extensive as the one that occurred during the 1982-83 CEN (Figure 4b, Table 1).

Coastal subsurface temperature patterns at 100m and 200m during the 1976-77, 1977-78 and 1982-83 CENs suggest downward and poleward propagating coastal Kelvin wave influences, since the signal at 200m appears stronger, in terms of sdu, than at the surface (Figure 5). The warming signal decreased with depth for the 1979-80 warm event, which appeared unrelated to tropical warming.

Coastal winds during 1982-83 winter were extreme (Figure 7, Tables 3,4). In terms of negative upwelling index, indicating a general tendency to Ekman convergence at the coast, the 1982-83 CEN winter was the most extreme of the 33 year series (Table 4). The 1957-58 CEN winter which also occurred with PNA atmospheric adjustment was second. Although the 1957-58 event is considered extreme, the accumulated seasonal downwelling index at 42°N was only 70% of that obtained for the 1982-83 winter. Extreme downwelling index or negative upwelling index is associated with the PNA atmospheric pattern, though not absolutely (Table 4).

Atmospheric and oceanic remote forcing appear to produce California El Ninos by enhancing normal processes that lead to warming, according to the following scenario. Coastal Kelvin wave activity depresses the thermocline along the coast. This in turn facilitates northward coastal countercurrent flow, which will bring anomalously warm water into the coastal zone, as indicated by Figures 2a, 2b, 3, 4a and 4b. Basin-wide forcing deflects subarctic water north away from the California Current. Consequently, more warm water reaches the California coast (Figure 6). Atmospheric patterns associated with mid-latitude adjustment to tropical influences may also cause local downwelling winds (Table 4) causing Ekman convergence at the coast, thereby inducing northward surface currents (Figure 6). These three warming processes contribute to positive temperature anomalies occurring at the coast during CEN years.

The data presented suggest that a climatic change occurred after the winter of 1976-77. The period before 1976 was characterized by positive SST anomaly offshore (Figure 4b), negative anomaly in the California Current System (Figure 3, 4a, b), negative sea level anomaly (Figure 6) and coastal winds favoring upwelling (Table 4). Four of the six winters since 1976 are classified as anomalously warm on the coast. These were accompanied by positive sea level anomaly and downwelling winds. The 1982-83 CEN occurred in an already warm period. This also contributed to its severity.

The 1972-73 CEN appears equal in positive anomaly to the 1982-83 CEN in subsurface temperature (Figure 5) and sea level (Figure 6). However, its expression, particularly at the surface (Figure 2b), was attenuated in the California Current System because it was opposed by locally forced processes rather than augmented by them.

Summary

1. Coastal ocean warming associated with the 1982-83 California El Nino was the most extreme of 1971-83 period. This warming appears to have been the result of at least two remote connections to the tropical El Nino, one through the ocean and the other through the atmosphere. Two major peaks of anomalous subsurface warming occurred. The earlier peak may primarily reflect oceanic propagation while the latter peak seems to be the result of the atmospheric tropical to mid-latitude connection.

2. Atmospheric patterns associated with the 1982-83 event brought extreme cooling in an area reaching from 1000 to 3000 km offshore. The 1982-83 period was a cool rather than a warm year if the entire 3000 km offshore area is considered. Offshore cooling is characteristic of

other coastal warming events (eg. 1979-80 and 1980-81) that can occur without tropical El Nino activity.

3. Persistence of warm anomaly below 100m during the 1982-83 event suggests the presence of oceanic propagation from the tropics consistent with coastal Kelvin wave activity. Similar strong persistence at depth occurred during the 1972-73 California El Nino, which was unaccompanied by atmospheric patterns associated with 1976-77, 1977-78 and 1982-83 California El Ninos. In contrast, the strong surface warming which occurred during 1979-80 unaccompanied by tropical El Nino activity, attenuated rapidly with depth.

4. In winter 1982-83 monthly anomalies based on 3^o latitude-longitude areas exceeded 2.5^oC at 100m with lesser magnitudes at surface and 200m.

5. Maximum alongshore SST warming occurred in fall 1983. During winter 1982-83 accumulated downwelling index at 42^oN was three times the average value indicating a tendency to extreme Ekman convergence. This is the largest accumulated downwelling index recorded (33 year series). Non-directional wind mixing parameter for winter 1977-78 was as great as for 1982-83, but the downwelling index value was only half that recorded for 1982-83. The extreme accumulated downwelling value for 1982-83 represents local expression of the PNA pattern circulation.

6. Indirect evidence points to weakening of the cool California Current, onshore transport of offshore water, increased downwelling and counter current intensification as primary local mechanisms through which the oceanic and atmospheric remote forcing bring warming to the California coast. Atmospheric and oceanic forcing of warming processes occurred together during the 1982-83 California El Nino.

7. The second half of the 1971-83 study period is warm relative to the first half. The change occurred rather abruptly in winter 1976. Since five of the next seven winters were characterized by warm coastal waters and characteristic atmospheric circulation, residual warm effects have accumulated so that the 1982-83 California El Nino occurred in an already warm period with an atmospheric circulation already favorable to coastal warming. This warm setting also contributed to the extreme nature of the 1982-83 event.

References

ARKIN, P.A.
1984. Tropical circulation anomalies associated with the 1982-83 ENSO Event. Proceedings of the Eighth Annual Climate Diagnostics Workshop, U.S. Dep. Commer., NOAA, pp. 111-121.

BAKUN, A.
1973. Coastal upwelling indices, west coast of North America, 1946-71. U.S. Dep. Commer., NOAA Tech. Rep., NMFS SSRF-671, 103 p.

1975. Daily and weekly upwelling indices, west coast of North America, 1967-73. U.S. Dep. Commer., NOAA Tech. Rep., NMFS SSRF-693, 114 p.

BERNAL, P.A. and J.A. McGOWAN
1981. Advection and upwelling in the California Current. In Coastal Upwelling, F. A. Richards, (Ed.), Coastal and Estuarine Science 1, Amer. Geophys. Union, Washington, D.C., pp. 381-399.

BIRD, A.A., R.J. KOOB, J.B. WICKHAM and C.N.K. MOOERS
1984. Hydrographic data from the slope waters off central California. 26 November 1978 - 26 June 1980., Dep. of Oceanography, Tech. Rep. NPS 68-84-010, Naval Postgraduate School, Monterey, CA.

BJERKNES, J.
1969. Atmospheric teleconnections from the equatorial Pacific. Mon. Wea. Rev., 97:163-172.

CANE, M.A.
1983. Oceanographic events during El Nino. Science, 222: 1189-1194.

CHELTON, D.B.
1981. Interannual variability of the California Current-physical factors. Cal. Coop. Ocean. Fish. Inv. Rep. 22: 34-47.

CHELTON, D.B. and R.E. DAVIS
1982. Monthly mean sea-level variability along the west coast of North America. J. Phys. Oceanog., 12: 757-784.

DOUGLAS, A.V., D.R. CAYAN and J. NAMIAS
1982. Large-scale changes in North Pacific and North American weather patterns in recent decades. Mon. Wea. Rev., 110: 1851-1862.

EMERY, W.J. and K. HAMILTON
1984. Atmospheric forcing of interannual variability in the Northeast Pacific Ocean, connections with El Nino. J. Geophys. Res. (In press) (see also this volume).

HALPERN, D., P. HAYES, A. LEETMAA, D.V. HANSEN and S.G.H. PHILANDER
1983. Oceanographic observations of the 1982 warming of the tropical eastern North Pacific. Science, 221: 1173-1175.

HANEY, R.L.
1984. Comment on "Seasonality in the associations between surface temperatures over the United States and the North Pacific Ocean". Mon. Wea. Rev., 112: 868-869.

HICKEY, B.M.
1979. The California Current System-hypotheses and facts. Prog. Oceanog., 8: 191-279.

HOREL, J.D. and J.M. WALLACE
1981. Planetary atmospheric phenomena associated with the Southern Oscillation. Mon. Wea. Rev., 109: 813-829.

KIRWAN, JR.,A.D., G.J. McNALLY, E. REYNA and M.J. MERRELL, JR.
1978. The near-surface circulation of the eastern North Pacific. J. Phys. Oceanog. 8: 937-945.

McCREARY, J.
1976. Eastern tropical ocean response to changing wind systems: with application to El Nino. J. Phys. Oceanog., 6: 632-645.

McLAIN, D.R. and D.H. THOMAS
1983. Year-to-year fluctuations of the California Countercurrent and effects on marine organisms. Cal. Coop. Ocean. Fish. Inv. Rep., 24: 165-181.

McLAIN, D.R.
1983. Coastal ocean warming in the northeast Pacific, 1976-83. In The Influence of Ocean Conditions on the Production of Salmonids in the North Pacific, A Workshop. W.G. Pearcy, (Ed.), Oregon State University, Sea Grant Program. Newport, OR. ORESU-W-001. November 8-10, 1983. 61-86.

McLAIN, D.R., R.E. BRAINARD, and J. NORTON
1984. Anomalous warm years in eastern boundary current systems. Cal. Coop. Ocean. Fish. Inv. Rep., (In press)

MOREANO, H.R.
1984. The weakening of the 1982-83 El Nino in Ecuadoran waters. Tropical Ocean-Atmosphere Newsletter, 28: 13-14.

NELSON, C.S.
1977. Wind stress and wind stress curl over the California Current. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-714, 87 p.

NIILER, P.P. and E.B. KRAUS
1977. One dimensional models of the upper ocean. In E.B. Kraus (Ed.), Modelling and Prediction of the Upper Layers of the Ocean. Pergamon Press, New York, pp. 143-172.

NORTON, J. and D.R. McLAIN
1984. Monitoring the California Current from daily sea surface temperature and salinity at shore stations. (Abstract) EOS Trans. Amer. Geophys. Union, 65(45): 970.

PAN, Y.H. and A.H. OORT
1983. Global climate variations connected with sea surface temperature anomalies in the eastern equatorial Pacific Ocean for the 1958-73 period. Mon. Wea. Rev., 111: 1244-1258.

PICAUT, J.
1984. Major dynamics affecting the eastern tropical Atlantic and Pacific Oceans. Cal. Coop. Ocean. Fish. Inv. Rep. (in press).

QUINN, W.H. and V.T. NEAL
1984. Recent climatic change and the 1982-83 El Nino. Proceedings of the Eighth Annual Climate Diagnostic Workshop, U.S. Dep. Commer., NOAA, pp. 148-154.

QUIROZ, R.S.
1983. The climate of the "El Nino" winter of 1982-83 - A season of extraordinary climatic anomalies. Mon. Wea. Rev., 111: 1685-1706.

RASMUSSON, E.M. and J.M. WALLACE.
1983. Meterological aspects of the El Nino/Southern Oscillation. Science, 122: 1195-1202. (see also this vol.)

REID, J.L., G.I. RODEN, and J.G. WYLLIE
1958. Studies of the California Current System. Cal. Coop. Ocean Fish. Inv. Progress Rep. 7-1-56 to 1-1-58, Marine Res. Comm., Cal. Dep. Fish and Game, Sacramento, Ca., p. 27-56.

REID, J.L.
1960. Oceanography of the Northeastern Pacific Ocean during the last ten years. Cal. Coop. Ocean. Fish. Inv. Rep., 7: 77-90.

1965. Intermediate waters of the Pacific Ocean. Johns Hopkins Oceanog. Stud., Number 2, Johns Hopkins Press, Baltimore, MD, 85 p.

SAUR, J.F.T.
1980. Surface salinity and temperature on the San Francisco-Honolulu route, June 1966-December 1970 and January 1972-December 1975. J. Phys.
Oceanogr., 10: 1669-1680.

SIMPSON, J.J.
1984. El Nino-induced onshore transport in the California Current during 1982-83. Geophys. Res. Let., 11: 241-242.

SKOGSBERG, T.
1936. Hydrography of Monterey Bay, California, thermal conditions, 1929-1933. Amer. Phil. Soc., Trans., M.S., 29, 152 p.

SMITH, R.L.
1968. Upwelling. Oceanog. Mar. Biol. Ann. Rev., 6: 11-46.

1983. Peru coastal currents during El Nino: 1976 and 1982. Science, 221: 1397-1398.

1984. Coastal Currents off Peru during El Nino of 1982-83: Prenatal to Senescent Conditions. Tropical Ocean-Atmosphere Newsletter, 28: 7-8.

SVERDRUP, H.U., M.W. JOHNSON and R.H. FLEMING
1942. The oceans, their physics, chemistry and general biology. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1087 p.

TABATA, S.
1984. Oceanographic conditions off the Pacific coast of Canada during the 1982-83 El Nino. Proceedings of the Eighth Annual Climate Diagnostics Workshop, U.S. Dep. Commer., NOAA pp. 92-99. (see also this vol.)

TOOLE, J.M.
1984. Near equatorial CTD observations at 85°W in October 1982. (Abstract) EOS. Trans. Amer. Geophys., 65(49): 1208.

WALLACE, J.M. and D.S. GUTZLER
1981. Teleconnections in the geopotential height field during the northern hemisphere winter. Mon. Wea. Rev., 109: 784-812.

WICKHAM, J.B.
1975. Observations of the California Counter Current. J. Mar. Res., 33: 325-340.

WOOSTER, W.S.
1960. El Nino. Cal. Coop. Ocean. Fish. Inv. Rep., 7: 43-45

WOOSTER, W.S. and J.L. REID
1963. Eastern Boundary Currents. In The Sea, 2, M.N. Hill, (Ed.), pp. 253-276., John Wiley and Sons, New York.

WOOSTER, W.S. and J.H. JONES
1970. California undercurrent off northern baja California. J. Mar. Res., 28: 235-250.