Preliminary Observation of the 1997 El Niño Signals Off California

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ABSTRACT

The variability of the California Undercurrent (CUC) due to the increased poleward flow related to El Niño events is investigated from two sets of ADCP data for the period of May 1997 to July 1997. Supporting temperature profile, sea level, and local wind data are presented for this period, as well as for January-July 1997 and January-July 1995 to serve as a comparison between El Niño anomalies and "normal" seasonal conditions. Biological impacts of El Niño are addressed through the calculation of acoustic backscatter strength as a measure of the amount of zooplankton and the inclusion of fluorometer data, which measures phytoplankton concentrations.

INTRODUCTION

El Niño Southern Oscillation (ENSO) is the coupled ocean-atmosphere cycle which causes global climatic variability. Among the observed effects of the atmospheric forcing in the western tropical Pacific is the eastward propagation of warm sea surface temperature (SST) anomalies, increased water levels, and a deepening thermocline via equatorial Kelvin waves (Chavez, 1996). Once these waves reach the western coast of South America, they travel poleward as coastally-trapped Kelvin waves, or waves which propagate forward with the boundary on the right in the northern hemisphere and on the left in the southern hemisphere (Pond and Pickard, 1995). Accompanying the coastally-trapped waves and often intensifying the effects they cause are significant changes in the motions of the atmosphere. There remains much debate over the role of local versus remote forcing in the appearance of El Niño effects along the coast of California (Chavez, 1996). Huyer and Smith (1985) found that the initial appearance of anomalous conditions off Oregon in 1982-83 probably arrived by an oceanic path and were "subsequently reinforced by the anomalous atmospheric conditions." Ramp et al. (1997) concluded that the 1991-92 El Niño event produced changes off California through both atmospheric and oceanic teleconnections which entered the area from opposite directions and were responsible for different anomalous conditions.

Among the changes associated with ENSO events which will be addressed in this paper are the effects on the current system off California, namely the northward-flowing California Undercurrent (CUC), which is centered at depths of about 200 m. Dominated by upwelling forces during the spring and summer months, the CUC is not usually detectable above depths of about 150 m, but through the winter months when upwelling forces relax, the CUC and the northward-flowing surface current, the Davidson current, may be indistinguishable (Breaker and Broenkow, 1994). Studies have shown the existence of considerable variability in the flow of the CUC along the coast of California, vet no conclusions have been made regarding the spatial continuity of the Undercurrent (Tisch et al., 1992). Wooster and Jones (1970) found the CUC off northern Baja to lie close to the continental slope, with a width of approximately 20 km, thickness of 300 m, and velocities approaching 30 cm/s (Tisch et al., 1992).

It remains unclear if coastally-trapped Kelvin waves cause upper layer warming by either thermocline depression or thickening the upper layer, or by transport of warmer equatorial water poleward in the form of an intensified CUC (Ramp et al., 1997). Comparative experiments have been conducted to determine the variability of currents during El Niño events off the western coasts of both North America and South America. Huyer and Smith (1985) observed that the poleward current signal revealed the presence of the 1982-83 El Niño off Oregon clearly when averaged over a month or a season. However, "magnitudes of the low-passed sea level, temperature, and current values on any given day did not exceed what would be occasionally observed during a ‘normal’ season off Oregon." Studies off the coasts of Peru and Chile during normal and El Niño conditions have been conducted extensively over the last couple of decades to determine the variability of nearshore circulation and the Peru-Chile current system. Results have confirmed that the poleward-flowing Peru-Chile Undercurrent centered at 150 m depth remains persistent over El Niño events (Shaffer et al., 1997).

In addition to the effects on the current systems off North and South America and in the global climate system, El Niño also brings with it many impacts to the biological communities of the waters it intercedes. Not only are there noticeable changes in the populations of fish, seabirds, and marine mammals, but also in the productivity levels of the smaller life which some of them feed on (Chavez, 1996). F. Chavez (1996) found that in contrast with the normal, productive spring conditions caused by coastal upwelling in March 1990, his study in March 1992 showed greatly decreased phytoplankton productivity due to the reduced concentrations of nutrients in the upwelling source water. The lack in nutrients occurred because the deepening thermocline placed nutrients below the euphotic zone, or the region from the surface to a depth at which there is not enough light to support photosynthesis. Zooplankton inhabit the outer waters of the bay and graze on the phytoplankton which upwelled waters produce. Decreasing levels of phytoplankton due to El Niño events may also be causally linked to the concentration of zooplankton, although the relationship of zooplankton and El Niño events is relatively new and studies are fewer in number (F.Chavez, personal communication).

MATERIALS AND METHODS

MOORED DATA

An RD Instruments 300-kHz broadband Acoustic Doppler Current Profiler (ADCP) was deployed at 36°

4l.42' N and 122° 23.20' W (M2 ATLAS mooring) on 6 May 1997 in the Monterey Canyon at 1800 m depth and 38 km offshore (Figure 1). The ADCP is an instrument that transmits acoustic pulses, then measures backscattered sound received from zooplankton and other small particles which move at approximately the speed of the water particles. The ADCP then converts this backscattered sound into components of current velocity using the Doppler Principle. The broadband ADCP at M2 collected velocity data in ensembles, each consisting of 25 pings and averaged every 30 minutes for the 30 bins. Each bin was four meters in length and used a 3.98 m pulse length. Although the ADCP operated to a depth of 120 m, the velocity plots for M2 are shown to only 100 m because the quality of the data below this depth decreased significantly. Data was also collected from an RD Instruments 153-kHz narrowband ADCP which has been located at the Ml ATLAS mooring (36° 45.19' N and 122° 01.32' W) at 1000 m depth and 15 km offshore since January 1992. The narrowband ADCP at Ml also collected data in ensembles, each consisting of 110 pings and averaged everv 15 minutes for the 30 bins. Each bin was eight meters in length and used an eight meter pulse length, thus the instrument operated to a depth of 240 m. However, this instrument was recovered on 1 July 1997 for maintenance and redeployed on 31 July 1997, therefore no data could be collected during this time period.

In addition to the current profilers, the ATLAS moorings also contain several instruments for obtaining meteorological and oceanographic data. Temperature profiles were compiled using ten minute data recorded by the thermistors on the temperature sensor cable from the surface to 300 m. Local surface wind speeds were collected, also at ten minute intervals, from the wind sensor on the mooring. Temperature and wind data was collected for the months of January-July in 1995 and 1997 to allow a comparison between the "normal" conditions of 1995 with the anomalous conditions caused by the onset of an El Niño event in 1997. The year 1995 was selected because data was not collected at the M2 mooring for the duration of 29 May 1996 to 23 July 1996. The study concentrates on the period of May-July 1997, therefore more than half of the comparative temperature and wind data would be unobtainable for 1996.

ANCILLARY DATA

To determine if the events occurring off the California coast were possibly linked to strong westerly winds from the western Pacific, wind and sea surface temperature means and anomalies were plotted with data obtained from the NOAA Pacific Marine Environmental Laboratory (PMEL) buoys. PMEL maintains 70 ATLAS and current meter moorings in the Tropical Pacific, called the TAO (Tropical Atmosphere Ocean) array, which collect data in realtime via the Argos satellite system with the primary motivation of investigating the forces behind El Niño events (PMEL, 1997). In addition, sea level data was obtained at six sites along the coast of California (Figure 1) to illustrate the northward propagation of the Kelvin waves. Historic water level data is from the National Oceanic and Atmospheric Administration’s Ocean & Lake Levels Division (OLLD). Sea level data was only available until the end of June and atmospheric pressure data was not available for any of the sites for the months of May-July 1997, so the sea level data is not adjusted for atmospheric pressure.

COMPILATION OF ADCP DATA

Prior to the analysis of the ADCP and other data, the software for unpacking the raw data was modified to account for the differences in the format of the 153-kHz narrowband model for which the software was originally created and the 300-kHz broadband model at M2. Once this software, created with the ‘C’ programming language, was revised, velocity data and echo intensity data, which was converted to acoustic backscatter strength, could be stripped from the output files and processed.

CALCULATION OF ACOUSTIC BACKSCATTER

The backscatter strength at M1 was calculated using the equation provided in the 1991 RDI Self-Contained ADCP Technical Manual.

$$S_V = \frac{l0\log (4.47 \times 10^{-20} K_2 K_S (T_x+273)(l0^{KcE10} - l)R2)}{cPK_1\, 10^{-2R\alpha/10}}$$

K_2 = system noise factor (dimensionless)
K_S = system constant (depends on frequency)
T_X = water temperature at the transducer head (° C)
K_C = conversion factor for echo intensity (dB/counts)
E = echo intensity (counts)
R = slant range to depth cell (in)
c = speed of sound at each depth cell (m/s)
P = transmit pulse length (in)
K_1 = real-time power into the water (XV)
α = sound absorption coefficient (dB/m)

The calculation of backscatter strength at M2, however, lacked the inclusion of K_1, K_2, and K_S because these system values were unable to be obtained for the broadband instrument. For this reason, the backscatter data for M2 is fairly rough. However, it is useful as a qualitative inspection of the distribution of biomass in the water column and its variability throughout the study period.

RESULTS

Two particularly notable eastward wind bursts originating at a longitude of 165° E, which can be seen in Figures 2a, 2b, and 3, are the focuses of this paper. The first occurs in the beginning of March and the second in the middle of April. Following the present knowledge that Kelvin waves travel at speeds of 200-250 km/day (Chavez, 1996), the effects of these wind bursts would reach the M2 mooring after a lag of 77-97 days. The mean sea levels for the six stations along the California coast for 1997 are shown in Figures 4a and 4b. Because these values could not be adjusted for atmospheric pressure, the plot is rough and includes some noise that would likely be filtered out by further processing. There is a clear increase in sea levels around May 20 at the sites north of Santa Monica, indicating the possibility, based on the observed time lag, of a propagating sea level signal which correlates with the first westerly burst.

The east and north velocity components for M1 and M2 are plotted as daily-averaged contours for the period of 7 May 1997 to 31 July 1997 in Figures 5a, 5b, and 6. As can be seen from Figure 5b, there was a significant increase in northward current velocities at M2 beginning on May 18 with a duration of about 10 days. The strong velocities, reaching speeds of more than 40 cm/s, are seen all through the water column to 100 m. Another episode of comparably high velocities at M2 begins July 7 and again lasts for about 10 days. If the first increase is linked to the March 1 wind burst, then the Kelvin wave traveled at a speed of 249 km/day, or 2.9 m/s. Additionally, if the second rise in velocities was caused by the April 15 wind burst, the corresponding Kelvin wave propagated at a speed of 234 km/day, or 2.7 m/s. Both of these phase speeds are consistent with those observed during past El Niño episodes (Table 1).

The north/south velocities at M1 (Figure 6b), however, do not show a significant increase corresponding with the first event at M2, and the second event occurred while M1 was not recording data. A noticeable pattern in the M1 velocities is that the east/west velocities (Figure 6a) are consistent in being predominantly eastward when the north/south flow is southward and predominantly westward when the north/south flow is northward. This is consistent with past observations of the current characteristics at M1 during the summer months, namely those corresponding to a clear circulation pattern found within the bay which deflects southward waters at the outer part of the bay eastward in a cyclonic motion (Paduan and Rosenfeld. 1996). Figures 7a and 7b serve as a comparison between velocities at M1 for the study period and throughout the rest of the year. It can be seen that there is not a significant increase in velocities at Ml within the period of 7 May 1997 to 31 July 1997 on the order of the 10-day period observed at M2.

Table 1. Summary of selected past observations of Kelvin wave propagation speeds.

	Phase speed
A.Huyer and R.Smith (1985)	≥ 140 km/day (1.62 m/s)
DEnfield (1989)	200-250 km/day (2.3-2.9 m/s)
F.Chavez (1996)	first event: 205 km/day (2.37 m/s) second event: 220 km/day (2.55 m/s)
G.Shaffer et.al. (1997)	266 ± 4 km/day (3.08 ± 0.04 m/s)
My observations	first event: 249 km/day (2.88 m/sec) second event: 234 km/day (2.71 m/sec)

Temperature profile plots for M2 are shown for the years 1995 and 1997 in Figures 8, 9, and 10. The contour plots in Figures 8a and 8b illustrate a deepening of the 8° isotherm corresponding to the M2 current velocity increases. Figure 8b illustrates the temperature distribution observed during a non-El Niño year, with cold, upwelling waters pushing the isotherms upward through the months of March-May. When compared with Figure 8c, it is obvious that upwelling forces have not affected the isotherms in this way in 1997.

The temperature curves below 100 m shown in Figures 9a-9b represent the depression of warmer waters at times which correspond to the current velocity increases. In comparison with the plot from 1995 (Figure 8b), upwelling forces again appear much more apparent in 1995 than in 1997. The final temperature plot (Figure 10) illustrates the increase of temperatures at all depths, but most noticeably below 100 m. By the third week of May, temperatures at 250 m have increased by almost 2 degrees. Throughout June and the first week of July, temperatures remain fairly constant, then increase again through the end of the study period.

Temperature contours at M1 for the years 1995 and 1997 are also plotted in Figures 11a and 11b. Unfortunately, the temperature sensors were not transmitting data for the period of 7 May 1997 to 31 July 1997, thus the temperature data at M1 during the study period was unobtainable. The spring upwelling conditions of 1995, which can be seen in Figure 11a, are stronger at this site than at M2. Figure 11b again illustrates the lack of the usual steadily decreasing temperatures caused by spring upwelling

Local wind data was obtained to better understand the role of oceanic versus atmospheric forces. Figure 12a shows the daily-averaged data from M2 for the months of May-July 1997. The dominant alongshore direction for the wind vectors is southward, which is expected at this time period as the winds are deflected offshore due to the earth's rotation and serve as the force behind coastal upwelling. However, a significant reversal with speeds of up to 8 m/s occurs from about May 16-21, around the same time as the first strong undercurrent velocity increase. Another strong reversal of the same eight-day period as the first occurs from about July 12-July 17. This reversal is also during a strong signal in the current record, although lagging behind the start of the second velocity event by a few days. Figures 12b and 12c display the wind vectors for the years of 1997 and 1995, respectively. Note that even though the upwelling winds do prevail in the spring months of 1995, they do not appear to be as dominant as in 1997.

Wind vectors at M1 are plotted in Figures 13a, 13b, and 13c. The study period contained upwelling-favorable winds, although with a stronger eastward component than was observed at M2. A reversal with a period of about 3 days occurs in mid-May and another of less magnitude, but longer duration, occurs in mid-July, both of which correspond to the reversals observed at M2. Again the alongshore wind component does not appear quite as dominant in 1995 as in 1997 even though the upwelling conditions of 1995 were apparent in the temperature profiles.

Acoustic backscatter strength is plotted as a composite of daily averages for the study period in Figures 14a and 14b. As a measure of daily patterns in zooplankton distribution, this time scale is not very useful because the changes in concentration throughout the day are averaged out. However it is easy to see in Figure 14a that higher concentrations of zooplankton (indicated by the red and orange areas) are present near the surface for the first and last few weeks of the study period. In comparison with the backscatter data from M1 shown in Figure 14b, the concentrations around 120 meters appear to be much higher at M1. This is a difficult comparison to make, however, because the M1 data covers an additional 120 meters of water, and thus the depth scale is greater by a factor of two in Figure 14b. The measurement of backscatter in decibels (dB) is also different in the two plots due to the difference in the calculations used for the estimate, which were described previously.

In order to analyze the daily migration patterns of zooplankton throughout the study period, the backscatter strength is also plotted at M2 on a weekly time scale with no averaging in Figures 15a and 15b. It can be seen by comparing these plots that during a week of strong northward velocities recorded at M2, the zooplankton concentrations are higher near the surface than during the week of relatively weak northward velocities. The same results are apparent at M1 in Figures 16a and 16b. The cycle of zooplankton movement through the water column is very clear in Figure 16b. It resides on the surface at night and then submerges to deeper depths during the daytime to escape its predators (T. Anderson, personal communication). This pattern is not as easily noticed at M2 most likely because the ADCP does not record to great enough depths to receive backscatter data from the depth region where the zooplankton migrate.

Fluorometer voltage data for the years 1995 and 1997 at M2 and M1, are provided in Figures 17, and Figures 18 respectively. Figure 17a shows that for the months of April-July, 1995, surface phytoplankton levels at M2 are high due to upwelling. However, April and the first part of May, 1997 (Figure 17b) indicate fairly high concentrations, then a sharp decrease occurs and the remaining portion of the study period experiences levels comparable to the winter months of 1995. At M1 the levels in May-June, 1997 (Figure 18b) are higher than those recorded at M2. In comparison with the spring of 1995 (Figure 18a), it is obvious that the upwelling conditions during a non-El Niño year provided not only greater voltage readings, but also much more consistency in the resulting high levels of phytoplankton.

DISCUSSION

The two events of increased northward flow at M2 appear to be causally linked to the westerly wind bursts in the Western Pacific. The time lag of observed effects produces a Kelvin wave propagation speed, which corresponds to those documented in past studies. The velocity increases have a duration of about 10 days and a separation of about 50 days, the same separation observed between the two wind events.

Based on the poorly correlating current record at M1, I believe the ADCP is located too close to shore to capture the increasing velocity signal from the propagating Kelvin wave. Many other dynamics of the circulation in Monterey Bay most likely play a role in the currents recorded at M1. Past studies have shown the temperatures below 100 m at M1 to increase sharply in response to coastally trapped wave propagation (Chavez, 1996). Therefore, the site at M1 is able to record the anomalous conditions associated with El Niño, but the undercurrent is probably affected by other forces which act to decrease its poleward signal at this site.

The temperature data observed at M2 support the time lag of the current velocity increases and allow conclusions to be drawn as to the link between the Kelvin wave and deepening thermocline and the propagation speed of the Kelvin wave. Typical spring upwelling conditions were not nearly as apparent in 1997 as in the "normal" year of 1995. The isotherms deeper than 100 m, where local winds do not play a significant role, from May-July 1997 are characteristic of those observed off the central California during El Niño events.

Local winds do not exhibit any highly anomalous reversals with of duration of more than a few days. It has been shown that local wind reversals can deepen the isotherms by only 10’s of meters (Chavez. 1996), whereas the observed depressions were on the order of 100 m and occurred deep in the water column. Winds also maintain an upwelling-favorable direction throughout the course of the study, showing that the deepening layer of warm water must affect upwelling conditions significantly.

Few conclusions can be reached from the observed backscatter strength data, especially of the forces at M2 since only three months worth of data is available at this site. It appears that the weeks corresponding to strong northward flow (Figures 15a and 16a) bring higher levels of zooplankton at all depths. This is not the expected result since phytoplankton levels were decreasing at this time. However, studies on the relationship between El Niño events and zooplankton concentrations are new and much is still not known about the all the forces in action.

Figure 19 is a composite of the major types of data collected for the site of M2. It is easy to recognize the correlating signal between the declining isotherms and the increasing northward current velocities, as well as the time of the wind reversals. In the future, much more data needs to be collected from the instruments at M2 in order to allow comparative studies of the effects of El Niño events and "normal" seasonal fluctuations in current velocities. The time period of three months allows little more than a qualitative investigation as to the possibility of a link between events observed off the central California coast and westerly wind bursts observed in the Western Pacific, but it is a good place to start.

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- The Tropical Atmosphere Ocean (TAO) Array