# Oceanographic Observations Off the Pacific Northwest Following the 1982 El Niño Event

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## Introduction

In early 1983 a series of meetings was held by managers and researchers of the National Marine Fisheries Service (NMFS), Pacific Marine Environmental Laboratory (PMEL), and University of Washington. These discussions were prompted by the realization that the ocean off Oregon and Washington had warmed appreciably following the El Niño event that reached the eastern tropical Pacific in fall 1982. A consensus emerged from the discussions that special efforts should be made to obtain oceanographic observations off Oregon and Washington during the warm event, which was expected to affect various fisheries. Consequently, additional observations were planned for a cruise of a fishery research vessel of the Soviet Union in April-May, and PMEL researchers agreed to make extra measurements on cruises of the NOAA ship *Discoverer*. These data, plus routine sea surface temperature information, have been used in an effort to provide a timely description of the warming off the Pacific Northwest. Additional studies will also include previous events, and impacts on the biota will be examined.

*ABSTRACT—The evolution of sea surface temperature anomalies off the Pacific Northwest during the 1982-83 El Niño seems to be in general agreement with their formation through poleward advection by a long wave. Oceanographic observations in May 1983 indicated significant positive thermal anomalies above 500 m; salinity anomalies showed a reversal in sign which implied both sinking of upper water and northward advection. Geostrophic flow along 47°N revealed no evidence of the California Undercurrent.*

## Background

It is now clear that El Niño events in the equatorial Pacific are frequently accompanied by significant warming and rising sea level over a vast area of the Pacific (Enfield and Allen, 1980; Chelton and Davis, 1982). These sporadic changes are thought to be at least partially the result of equatorially trapped long waves which initiate the warming in the eastern tropical Pacific and then propagate poleward as coastally trapped waves (Wyrtki, 1975; McCreary, 1976). However, all anomalous temperature events along the west coast of North America do not appear to be caused by this process, and large-scale variations in wind forcing may also be important (Chelton and Davis, 1982).

The El Niño events do produce striking visual coherence in sea level and temperature records (Enfield and Allen, 1980); however, considerable variation in these effects seems to exist, which is not obviously related to the magnitude of warming in the eastern tropical Pacific. For example, the 1972 El Niño appeared to affect tropical sea level at least as much as did the 1957-58 event, but the 1972 El Niño was not apparent north of California, whereas sea level rose in a dramatic and coherent manner in early 1958 as far north as Yakutat, Alaska. Although a complete set of sea level data for the 1982 El Niño is not yet available, initial impressions are that the present El Niño is certainly a major one (Wooster, 1983), and the temperature anomalies in the tropics and along the west coast of North America are readily apparent.

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## Surface Temperature Anomalies

A time series of coastal sea surface temperature anomalies (from the long-term monthly means; taken from NOAA's *Oceanographic Monthly Summary*) is shown for July 1982-June 1983 in Figure 1. The maximum averaged anomalies were 1.6°-1.7°C for the three sites shown, but all locations had negative values prior to the warming. At lat. 35° and 41°N maximum anomalies occurred in January-February 1983, but at lat. 47°N the anomalies increased until April 1983. By June 1983, the anomalies at all sites had decreased significantly.

Preliminary results indicate that the maximum rate of warming off Peru probably occurred in early October 1982 (Wyrtki, 1983). From the theory of internal Kelvin waves and evidence from sea level data, Enfield and Allen (1980) suggested a phase speed of roughly 100 km/day; consequently one might expect to see the maximum change in anomaly off Oregon-Washington about 2 months after the wave reached Peru. None of the plots in Figure 1 are in exact agreement with this figure; large rates of warming did

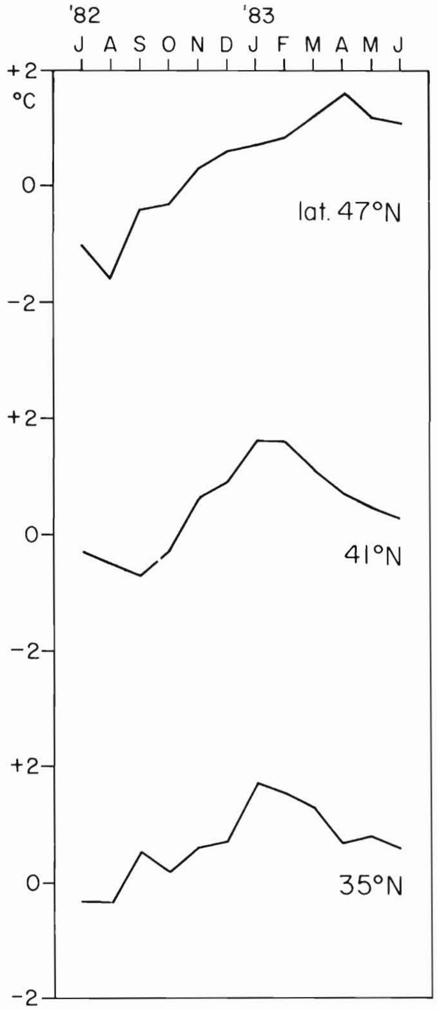


Figure 1.—Time series of monthly mean, spatially averaged, sea surface temperature anomalies (from the long-term monthly means) between the Pacific Northwest coast and long. 125°W at lat. 35°N and between the coast and long. 127°W at lat. 41° and 47°N.

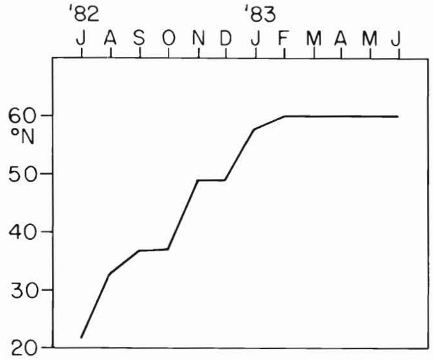


Figure 2.—Time progression of the latitude of the northern edge of the positive sea surface temperature anomaly.

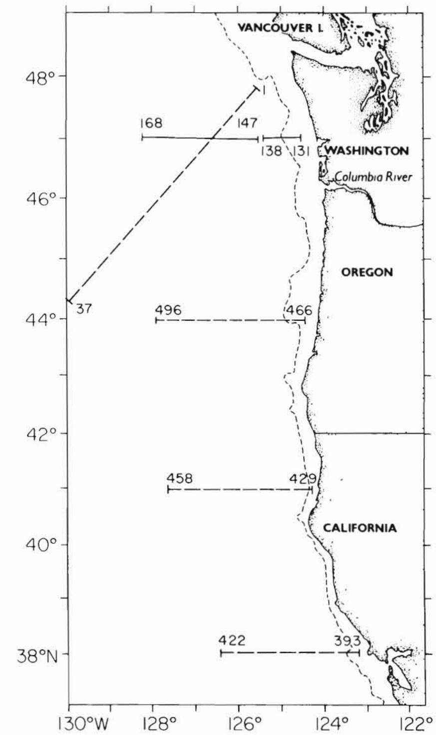


Figure 3.—Location of XBT sections (dashed lines) and a CTD section (solid lines) obtained by the NOAA ship *Discoverer*, 15 May-3 June 1983.

occur at lat. 35° and 41°N during December-January, which suggests a travel time of 3 months, but the increase at lat. 47°N was quite gradual. Figure 2 shows a time plot of the latitude of the northern boundary of the coastal positive anomaly. It shows rapid rates of movement of the anomaly during October-November and again in December-January; however, a peculiar lack of movement was present during November-December. It should be stressed that these data (from ships-of-opportunity and buoys) are not highly accurate, and the anomalies can vary as a result of air-sea energy exchange or upwelling that is different from the climatological mean. Thus it would be surprising if the results were entirely consistent with only an advective process.

The increase in positive surface temperature anomaly which apparently reached a peak off the Pacific Northwest during February-April continued northward into the Gulf of Alaska and then westward to the Bering Sea and Aleutian Islands. An examination of the anomaly maps (*Oceanographic Monthly Summary*), however, argues against the cause of this warming being solely an extension of the long wave off our west coast. In fact, the movement of anomalies into the Bering Sea seems to be mainly from the west; by November 1982 a vast area in the northwest Pacific (including Japan and the Kamchatka Peninsula) was abnormally warm, and by December this pattern seems to have spread eastward into the central Bering Sea somewhat before warming from the southeast occurred. Also, the maximum values in the Bering Sea were slightly greater than those off the Pacific Northwest. Blaha and Reed (1982) concluded that the equatorial Kelvin waves associated with Los Niños did not penetrate poleward into mid-latitudes along the western margin of the Pacific. Thus the large-scale warming in the northwest Pacific must result from a different mechanism than that along the eastern margin of the ocean.

## Subsurface Conditions

### NOAA Data

The principal observations made by the NOAA ship *Discoverer* in May-June 1983 are shown in Figure 3. These closely spaced XBT (expendable bathythermograph) drops and CTD (conductivity/temperature/depth) casts can be used to infer several features of the subsurface thermohaline properties as well as baroclinic flow. The XBT sections at lat. 38°, 41°, and 44°N are presented in Figure 4. The only indication of active coastal upwelling was on the section at lat. 41°N where the

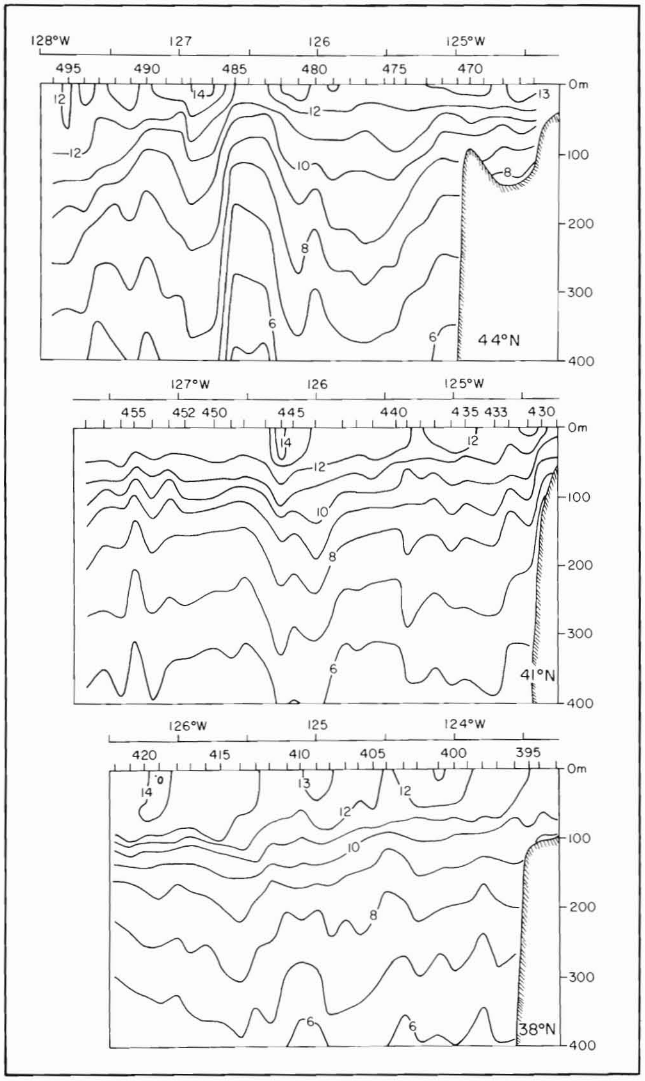


Figure 4.—Vertical XBT sections of temperature (°C) at lat. 38°N (15-16 May 1983), lat. 41°N (16-17 May 1983), and lat. 44°N (18 May 1983).

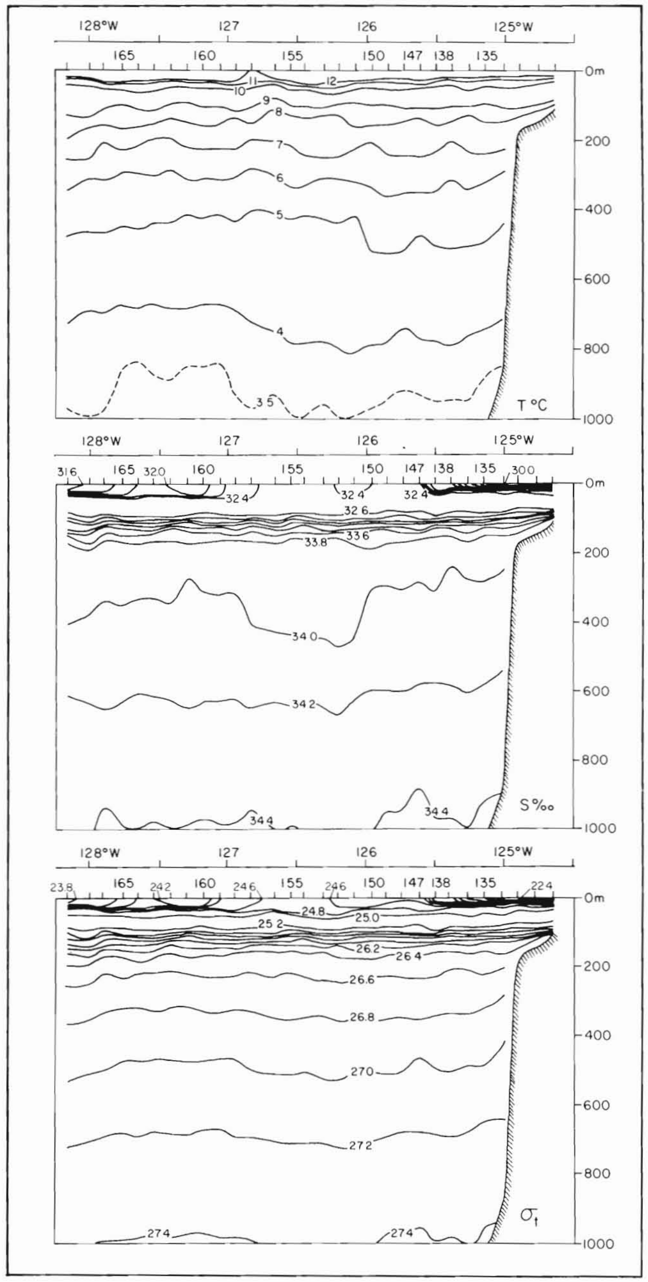


Figure 5.—Vertical CTD sections of temperature (°C), salinity (‰), and sigma-*t* density along lat. 47°N, 19-22 May 1983.

isotherms inshore of station 433 slope steeply upward. Elsewhere, this section suggests weak southward flow (isotherms tilted up to the east) east of long. 126°W, with a zone of northward flow between long. 126.0° and 126.5°W. The lat. 38°N section implies mainly southward flow except west of long. 125.5°W. At lat. 44°N the thermal structure was quite complex; the large domelike feature between stations 481 and 486 may be a counterclockwise eddy. Elsewhere the data suggest more intense baroclinic structure than at the other sites along the coast. In general, the isothermal slopes are quite coherent vertically, which implies the lack of any major counterflows below the surface.

Vertical sections of temperature, salinity, and sigma-*t* density (density minus one times $10^3$) for the CTD line along lat. 47°N are shown in Figure 5. It is apparent that salinity slopes are quite important to the density structure in these subarctic waters (Dodimead et al., 1963); farther south, thermal effects begin to dominate the baroclinic structure. The sigma-$t$ slopes are vertically coherent and suggest alternating zones of southward, northward, and southward flow proceeding offshore.

Figure 6 shows the geopotential anomalies of the 0-, 200-, and 500-db (decibars pressure; 1 db $\cong$ 1 m) surfaces, all referred to 1,000 db (maximum cast depth). The slopes of the surfaces are proportional to geostrophic flow, with line segments sloping downward to the east representing southward flow. The greatest computed speed (35 cm/second) was for the 0/1,000-db surface between stations 166 and 167; speeds elsewhere were generally much less than this. Although the 1,000-db surface may not be entirely level, the amount of baroclinic structure below this level off the Pacific Northwest is quite small (Reid and Arthur, 1975; Reed and Halpern, 1976). Ignoring small-scale features, the surface circulation consisted of southward flow between stations 134 and 152, northward flow from station 152 to 162, and southward flow west of station 162. Although this was suggested by the sigma-$t$ section, Figure 6 presents striking evidence that the flow was vertically coherent. There is simply no evidence for any subsurface counterflow or undercurrent, and the only suggestion of any northward flow along the continental slope is a 9 km band rather far offshore between stations 138 and 147.

Thus the California Undercurrent normally present along the slope (Hickey, 1979) was absent in mid-May 1983. Ingraham (1967) presented data for May 1963 which also showed flow that was generally vertically coherent, but the nearshore flow was more northerly than across the section here. Data are simply inadequate to indicate if the undercurrent may typically be absent in spring (Hickey, 1979). If the warm water was advected into this region by a long, coastally trapped wave (with a strong current pulse) a few months before this cruise, there would not necessarily be any evidence for it in these data. Intuitively, however, one might have expected some intensification of the California Undercurrent, but such

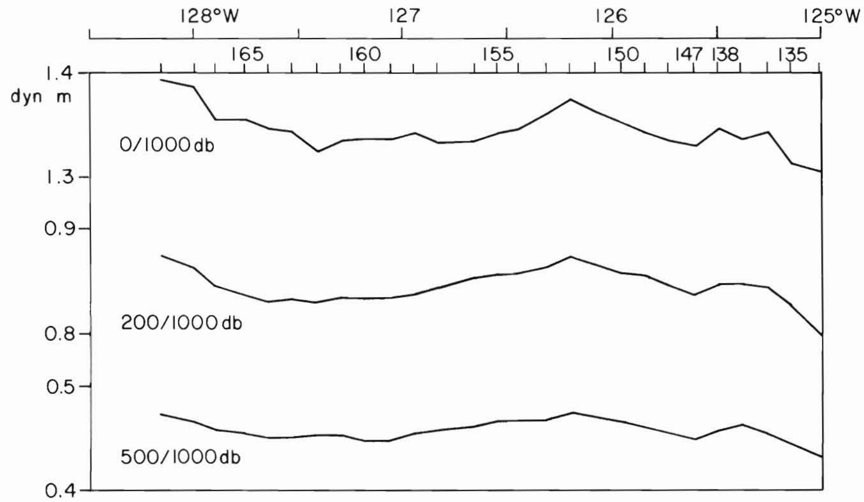


Figure 6.—Variation of geopotential anomaly (dyn m) of the 0-, 200-, and 500-db surfaces, referred to 1,000 db, along lat. 47°N, 19-22 May 1983.

does not appear to be the case.

The CTD section at lat. 47°N is quite close to one (at lat. 47.5°N) in September 1973 from which Reed and Halpern (1976) derived the percentage of Pacific Equatorial water, using temperature-salinity curves, as an index in examining the California Undercurrent. September 1973 was a period with essentially normal sea level and coastal water temperatures off Washington (Enfield and Allen, 1980). At levels of 200-300 m the percentage of equatorial water in May 1983 was about 40 percent, rather than roughly 30 percent in September 1973; however, below this level the differences were smaller and less systematic. The equivalent thickness (integral of the area under a depth-percentage curve) of the equatorial water from 200 to 1,000 m, however, was only 4 percent greater in May 1983 than the value in September 1973. This analysis suggests that the water properties associated with the 1982 El Niño in the upper 300 m were more characteristic of equatorial water than in a normal year, but that they differed little below this level.

Perhaps a more straightforward comparison is to derive temperature differences at specific depths between data on the section at lat. 47°N and stations at the same longitude at lat. 47.1°N in September 1973 (Holbrook, 1975). The mean results, based on a comparison at six stations, are given in Figure 7. At 100 m the water in spring 1983 was 1.6°C warmer than in fall 1973; at 200, 300, 500, and 1,000 m the differences were +0.6°, +0.4°, +0.1°, and −0.1°C, respectively. The standard deviations from the means in this data set are relatively small. In May the sea surface anomaly was +1.2°C (Fig. 1), slightly less than the difference at 100 m. Comparable differences in salinity varied from −0.39‰ at 100 m to slightly positive at 300 m and below; only the differences at 100 and 300 m were statistically significant from zero, however. The negative salinity difference at 100 m, which is also present but much smaller in the Soviet data discussed below, suggests that the upper part of the water column had been depressed, perhaps through downwelling associated with the long wave, whereas the positive differences below are in agreement with northward advection of equatorial water.

## Soviet Data

A fishery vessel of the Soviet Union has conducted resource surveys in cooperation with the NMFS Northwest and Alaska Fisheries Center (NWAFC) during April-June in each of the last 4

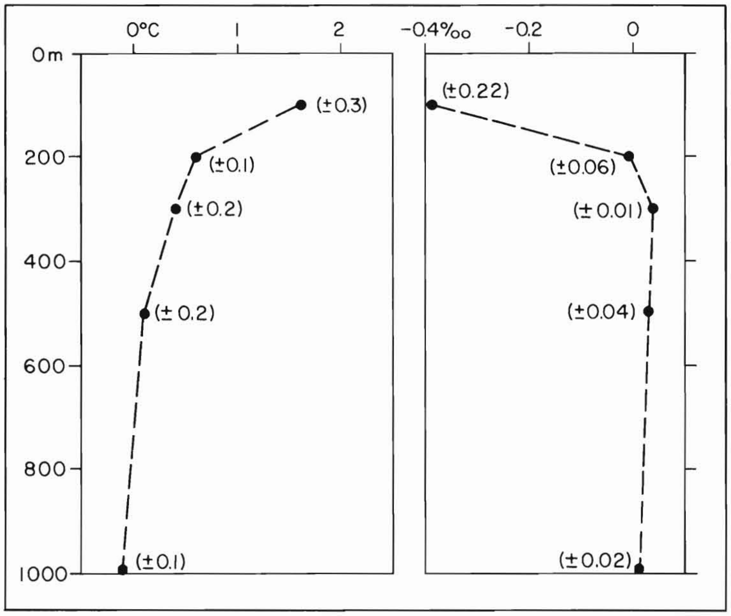


Figure 7.—Vertical structure of the differences in temperature and salinity between 19-21 May 1983 (along lat. 47.0°N) and 20 September 1973 (along lat. 47.1°N). Values in parentheses indicate the standard deviations from the mean differences.

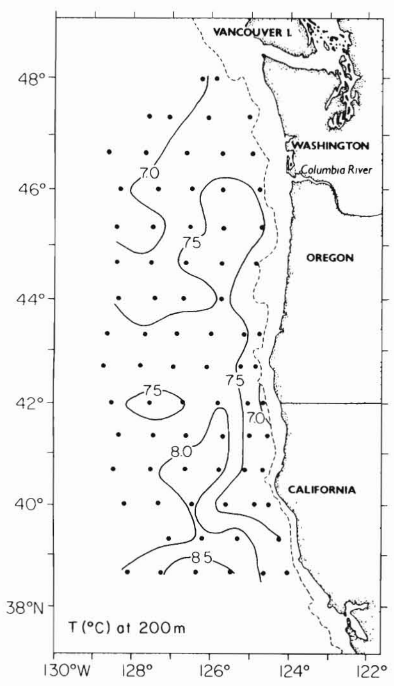


Figure 8.—Distribution of mean temperature (°C) at 200 m from Soviet cruises during April-May 1980, May-June 1981, and May-June 1982.

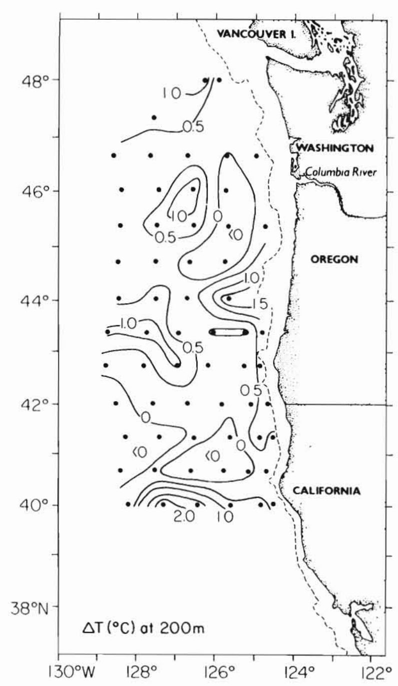


Figure 9.—Differences of temperature (°C) at 200 m during April-May 1983 from the mean temperatures at the same sites during April-June 1980-1982.

years. The area surveyed has been from lat. 38° to 48°N and from the coast to about long. 128°W. Oceanographic observations consisted of Nansen bottle casts to 500 m with bottles at traditional standard depths. The manuscript data were keypunched, and values were interpolated to standard depths under supervision of NWAFC personnel. The stations are rather widely spaced and are too shallow for reliable derivation of geostrophic flow. In addition, the salinity data appear to be of marginal quality, although they are useable for some purposes. On the other hand, the data set is quite nice in that essentially the same stations have been occupied for 4 years, and one can compare conditions during the present El Niño with "normal" conditions from the three previous years.

Temperature and salinity data at various levels for spring 1980, 1981, and 1982 were averaged, and the distributions were mapped. Figure 8 presents the averaged temperature at 200 m, which is in good general agreement with the distribution from long-term mean data in Favorite et al. (1976). The fact that the maximum temperatures are located some distance offshore probably reflects the normal coastal upwelling; the distribution at 500 m (not shown) shows the warmest water along the inner part of the continental slope. Figure 9 shows temperature differences at 200 m during April-May 1983 compared with the data in Figure 8. There is considerable variability over fairly small spatial scales, which might result from eddies or oscillations caused by internal waves. The water was generally warmer in spring 1983 than spring 1980-82, however, and there is a consistent band of higher temperatures along a portion of the continental slope. The differences have a mean value of +0.4°C, which is similar to the value at lat. 47°N (+0.6°C; Fig. 7), but the standard deviation in this data set (±0.56°C) is over four times larger than the value at lat. 47°N. The mean value of the temperature difference at 500 m is +0.1°C; the values north of lat. 43°N, however, average +0.2°C, while those to the south have a mean of zero. The salinity differences at 200 and 500 m average −0.03 and

−0.01‰, respectively, but only the first value is statistically significant from zero. The Soviet data do indicate warmer than normal temperatures during the El Niño at 200 m, while a spatial difference at 500 m was suggested.

## Discussion

The 1982 El Niño appears to have produced significant warming at high latitudes much like the event of 1957-58. However, the phase of the recent El Niño appears to be 2-3 months before that of the earlier, typical one, both in the tropics and to the north. The effect of this difference should be to produce maximum anomalies before the maximum seasonal rate of heating; thus absolute maximum temperatures, as opposed to maximum anomalies, might be somewhat less than during a more typical event. One can speculate, then, that the recent El Niño should have had less severe effects on the biota, at least in terms of the temperature tolerance of organisms, than events of comparable magnitude but more typical timing. However, this aspect of the problem will require a comprehensive examination of biological and fisheries data.

Evolution of the thermal anomalies and their apparent northward movement with time are at least suggestive of an advective process caused by a coastally trapped long wave. The data also appear to roughly agree with the expected phase speeds. On the other hand, the zone of warm water off the Pacific Northwest was several times wider than the Rossby deformation radius. Also, warming in the Bering Sea appears to have resulted from eastward movement of warm water in the northwest Pacific; this suggests some aspect of wind forcing there, rather than effects from long-wave propagation. The geostrophic flow across a section off Washington did not reveal any subsurface northward undercurrent; it is not known if its absence was a normal seasonal feature or was related to the El Niño or some other event.


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