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The Signature of El Niño off Oregon, 1982–1983

ADRIANA HUYER AND ROBERT L. SMITH

College of Oceanography, Oregon State University, Corvallis

Current and conductivity, temperature, and depth (CTD) measurements were made over the Oregon shelf near 43°N between February 1981 and April 1984 as part of a large-scale west coast shelf experiment (SuperCODE). The data set includes a nearly continuous record of current velocity and temperature over the continental shelf off Coos Bay from May 1981 through January 1984, CTD sections off Coos Bay in January or February of each year from 1981 to 1984, and CTD sections off Newport (44.6°N) in April 1983, July 1983, and April 1984. The latter are compared with sections off Newport made during the previous two decades. Sea level from the Newport tide gage, daily sea surface temperature at Charleston (43.3°N), the alongshore component of the wind stress at 45°N and the large-scale North Pacific atmospheric pressure pattern provide a climatological perspective. The initial manifestation of El Niño off Oregon was in October 1982: anomalously high sea level, high coastal sea surface temperature, and increased poleward flow. These effects occurred within 1 month of the onset of El Niño off Peru and preceded any local (North Pacific) atmospheric effect by 2–3 months. The anomalous local meteorological conditions, which became manifest in December and January, greatly enhanced the initial effects and inserted their own signal. The first signals of El Niño probably arrived by an oceanic path, but there is no doubt they were subsequently reinforced by anomalous atmospheric conditions.

INTRODUCTION

Current and conductivity, temperature, and depth (CTD) measurements were made over the Oregon shelf near 43°N between February 1981 and April 1984 as part of a large-scale west coast shelf experiment with the nickname "SuperCODE" [*Allen et al.*, 1981]. These measurements serendipitously included the onset of the 1982–1983 El Niño. After its first effects on the U.S. west coast were recognized in early 1983, some measurements were deliberately extended beyond the planned termination date of April 1983 in order to observe the duration and decline of El Niño. The midshelf current meter mooring (point Q3 in Figure 1) near Coos Bay was continued through January 1984, and the CTD surveys [e.g., *Fleischbein et al.*, 1982] were expanded to include the Newport hydrographic line, for which there is a good historical data base [*Huyer*, 1977]. The resulting data set includes a nearly continuous record of current velocity and temperature over the continental shelf off Coos Bay [*Denbo et al.*, 1984] from May 1981 through January 1984, CTD sections off Coos Bay in January or February of each year from 1981 to 1984, and CTD sections off Newport in April 1983, July 1983, and April 1984.

MONTHLY ANOMALIES

The only two oceanographic measurements on the Oregon Coast that were made for the entire decade preceding the 1982–1983 El Niño are the sea level measured continuously at the Newport (44.6°N) tide gage [*Pittock et al.*, 1982] and the sea surface temperature at Charleston (43.3°N) measured at high tide on normal working days (A. McGie, personal communication, 1984). Local atmospheric conditions are represented by the alongshore wind stress calculated from the coastal upwelling index at 45°N, 125°W [*Bakun*, 1975], which is computed from the 6-hourly synoptic pressure charts. Large-scale atmospheric conditions are represented by an index computed by D. Chelton (personal communication, 1984); this index is the amplitude of the principal pressure pattern computed from 37-year (1947–1983) records of the monthly sea level pressure anomalies on a 113-point grid covering the entire Pacific north of 20°N with a spacing of 5° latitude and 10° longitude. The method and data base are the same as that used by *Davis* [1976], except that the longer series now available were used. The principal pressure pattern (first empirical orthogonal function) is almost identical to that obtained by *Davis* [1976] (shown in his Figure 3 as P_1). This pattern accounts for 36% of the variance and represents variations in the intensity of the Aleutian Low.

In Figure 2 we display the monthly anomalies of each of these variables relative to their 10-year monthly means (1971–1980; except 1947–1983 for P_1) along with the equivalent anomalies of the sea level at Callao, Peru (12.0°S). The Newport sea level anomaly has been adjusted for atmospheric pressure fluctuations (the standard deviation of the monthly atmospheric pressure anomaly at Newport was 2.4 mbar); data were not available to adjust Callao sea level, but the atmospheric pressure fluctuations there are small and generally insignificant (the standard deviation of the monthly atmospheric pressure anomaly at Callao during 1950–1974 was 0.7 mbar [*Enfield and Allen*, 1980]). The 1982–1983 El Niño shows up very clearly in the Callao sea level: monthly anomalies exceed 15 cm from October 1982 through June 1983. Beginning in the latter half of 1982, the behavior of the Newport sea level is strikingly similar to the Callao sea level. The gradual increase in the sea level anomaly becomes a jump in October: the October 1982 anomaly for Callao was greater than that for any previous month; the October 1982 anomaly for Newport exceeded that for any previous autumn (September–December) month. The sea level anomalies at both Callao and Newport continued increasing and reached record maxima in January 1983. The monthly mean anomalies of coastal temperatures at Callao [*Smith*, 1983] and Charleston both began to increase in October 1982. However, the monthly mean temperatures at Charleston during 1982–1983 did not exceed all previous values, whereas the monthly mean temperatures at Callao reached record highs in January 1983. By September 1983, El Niño was apparently over: the anomalies were similar to or less than those of September 1982.

The sea level anomaly (Figure 2) at Newport suggests El Niño began to affect Oregon waters in October 1982, the same

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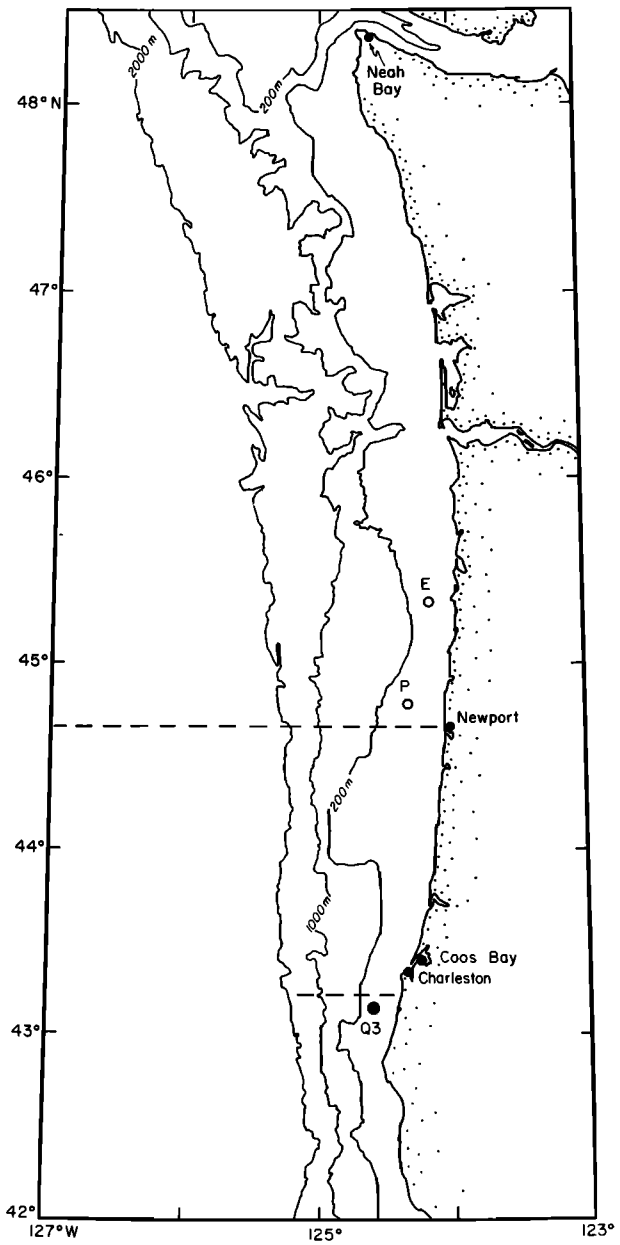

Fig. 1. Location of current meter mooring Q3 off Coos Bay, CTD sections (dashed lines) off Coos Bay and Newport, the tide gage at Newport, and the site of the surface temperature measurements at Charleston. Also shown are the sites (open circles) of previous winter current meter measurements on the Oregon shelf.

month it manifested itself off Peru. The strength of P_1, the large-scale atmospheric pressure pattern, which would be associated with increased poleward winds offshore of Oregon, was not anomalous until December 1982. The coastal winds off Oregon (wind stress anomaly in Figure 2) were not anomalous until January 1983 nor were they anomalous much earlier anywhere along the coast [*Fiedler*, 1984]. This suggests that the first signal of El Niño arrived by an oceanic path. During January–March 1983 the weather along the coast was anomalous, reflecting the altered atmospheric circulation that was part of El Niño [*Rasmusson and Wallace*, 1983]. The greatly increased poleward wind stress along the coast (negative coastal upwelling index) causes enhanced poleward current, increased sea level, and warmer coastal surface temperatures. (The post-El Niño month of November 1983 is another example of this.) Thus the effects of El Niño that began in October 1982 were greatly augmented by the anomalous weather (itself due to El Niño) in January–March 1983.

Calculations of the cross-correlation function between each pair of monthly anomalies (Table 1) show that the connections between the Newport sea level and other variables observed during the 1982–1983 El Niño are generally valid. Because of differences in inherent time scales and slight differences of record length (i.e., in the effective number of degrees of freedom) the correlation coefficients were divided by σ, the large-lag standard error of each comparison [*Sciremammano*, 1979]; quotient values of 2.6, 2.0, and 1.7 correspond to significance levels of 99%, 95% and 90%, respectively. Over both the 140-month period (January 1971 to August 1982, i.e., excluding the 1982–1983 El Niño period) and the entire time series, the Newport adjusted sea level anomaly is most strongly correlated with the local alongshore wind stress, and least correlated with the strength of the large-scale Pacific pressure pattern; these results are consistent with the analysis of *Chelton and Davis* [1982]. Including the 1982–1983 El Niño data improves all correlations considerably. The Charleston temperature anomaly is best correlated with the local wind stress and least correlated with the Callao sea level; again, including the 1982–1983 data improves the correlations. The Callao sea level is better correlated with the Newport sea level than with any of the other variables; this supports the idea that there is an oceanic connection between them. (Only if the 1982–1983 El Niño data are included, is there a significant correlation above the 90% level between the Callao sea level and the atmospheric variables used here.) Thus it appears that the local alongshore wind stress generally affects both the coastal sea level and the coastal temperature off Oregon; Callao sea level is related to the sea level on the Oregon coast; the large-scale North Pacific pressure pattern generally affects the temperature but not the sea level along the Oregon coast.

SUBSURFACE CURRENT AND TEMPERATURE

The subsurface mooring on the continental shelf (43.1°N, 124.6°W) provided a nearly continuous record of current velocity and temperature at about 70-m depth (25–30 m above the bottom) from April 29, 1981, to January 31, 1984, including the entire El Niño period. The time series of the temperature and the north-south (alongshore) component of the velocity are shown in Figure 3 along with the sea level (adjusted for atmospheric pressure fluctuations) from the Newport tide gage and the alongshore component of wind stress at 45°N (calculated from Bakun's daily coastal upwelling index). (The current meter and temperature time series are a composite from seven mooring installations which varied slightly in position. Because of dropouts in the speed record during the period 1800 UT, September 20, 1981, to 0600 UT, October 29, 1981, the velocity during that period was replaced by the velocity from the current meter 25 m above the bottom on a mooring 5 km farther offshore and in 40-m-deeper water. The velocity records from both meters were nearly identical during the months immediately preceding and following the questionable period.) The temperature, current, and sea level time series have been low-pass filtered (half amplitude is passed at 40 hours) to remove diurnal and higher frequency fluctuations; the daily wind stress values have been smoothed with a running three-point filter (1/4, 1/2, 1/4).

The dominant signal throughout the entire record is "event" scale variability due to "weather" superimposed on the seasonal cycle. The signature of El Niño is far more subtly dis-

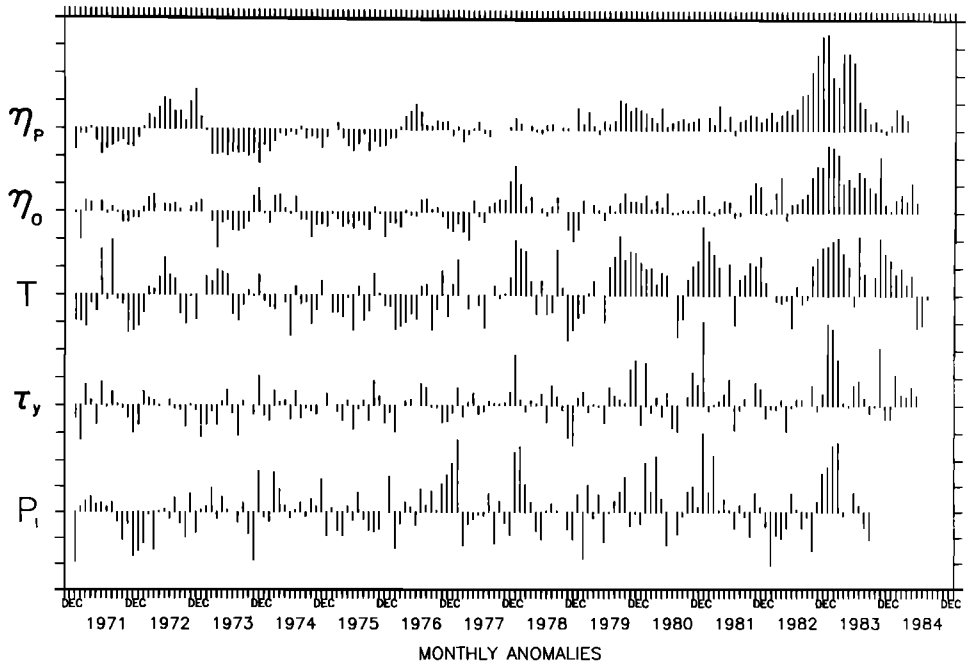

Fig. 2. (Top to bottom) Monthly anomalies of sea level at 12°S on the Peru coast (η_P), sea level at 44.6°N on the Oregon coast (η_O), sea surface temperature at 43.3°N on the Oregon Coast (T), alongshore wind stress at 45°N, 125°W (τ_y), and the amplitude of the large-scale North Pacific atmospheric pressure pattern (P_1). Ticks are 10 cm for sea level, 1°C for temperatures, and 0.5 dyn cm^{-2} for wind stress. One tick corresponds to a pressure anomaly of 5 mbar at the center of the Aleutian Low.

played in the Oregon data than in comparable data from 100-m depth off Peru [*Smith*, 1983]. Off Peru, the arrival of El Niño in October 1982 could be identified by strong poleward acceleration of the current and a rapid rise of temperature (5.7°C in 64 days) during continued strong poleward flow (25 cm s^{-1}); the temperature far exceeded values normally reached during any season. Off Oregon, El Niño is apparent in the low-passed data (Figure 3) only by the repeated occurrence and occasional persistence of high temperature, poleward flow, and high sea level during the winter of 1982–1983 as compared with the winters of 1981–1982 and 1983–1984. Although the monthly averaged sea level data clearly reveal the presence of El Niño off Oregon (Figure 2), the 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 [e.g., *Huyer et al.*, 1978]. Averages over a month or season more clearly reveal the presence of El Niño off Oregon.

Because the alongshore component of the current is nearly in geostrophic balance [*Huyer et al.*, 1978], anomalously high sea level should be associated with anomalously strong poleward flow. In Figure 4 we show the progressive vector diagram (a convenient means of displaying the vector mean velocity) for the current meter record displayed in Figure 3. The current was indeed more strongly poleward during the period of El Niño (October 1982 to September 1983). Specifically, we may compare equivalent periods (93 days: October 29 to January 30) for 3 years; the mean alongshore flow was poleward in all three periods, but the magnitude was 5.8, 13.0, and 7.0 cms^{-1} for the periods beginning in late October 1981, 1982, and 1983, respectively. Previous current measurements from other locations over the midshelf off Oregon also show weaker

TABLE 1. Maximum Lagged Correlation Coefficients Expressed as Multiples of the Standard Error at Large Lag (With the Lag in Months, Callao Leading) Between the Monthly Anomalies Shown in Figure 2

	Callao Sea Level	Newport Adjusted Sea Level	Charleston Temperature	Alongshore Wind Stress	Pacific Pressure Pattern P_1
Callao sea level		3.83 (1)	2.38 (1)	2.83 (1)	2.35 (1)
Newport adjusted sea level	2.28 (0)		4.59 (0)	7.23 (0)	2.32 (0)
Charleston temperature	0.68 (0)	3.90 (0)		6.02 (0)	4.62 (0)
Alongshore wind stress	0.78 (0)	6.21 (0)	5.81 (0)		5.06 (0)
Pacific pressure pattern P_1	1.25 (2)	1.44 (0)	4.38 (0)	4.38 (0)	

Values above the diagonal are for all available data (1971–1984); values below the diagonal include only data through August 1982.

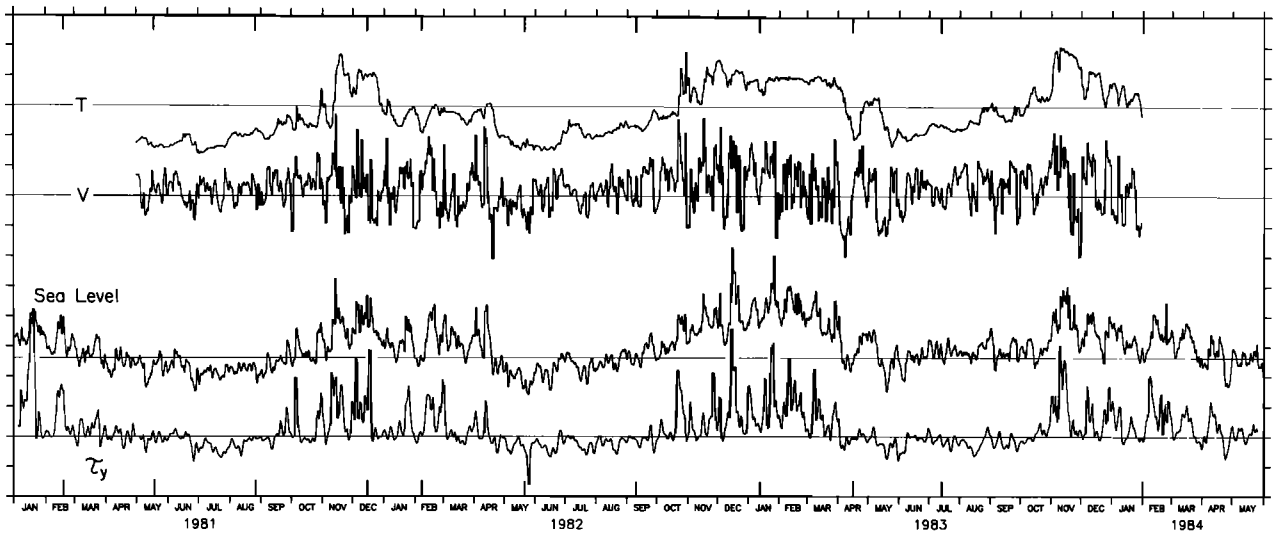

Fig. 3. Time series of 70-m temperature (T) and alongshore component of velocity (V) at 43.1°N, coastal sea level at 44.6°N, and the alongshore component of the wind stress at 45°N from Bakun's coastal upwelling index. Ticks on the vertical axis represent 2°C, 20 cm s^{-1}, 20 cm, and 1.5 dyn cm^{-2}. The horizontal axis for T is at 10°C and for sea level is at 292.1 cm (the mean sea level from the 10 years 1971–1980. The vertical ticks on the time axis indicate times of CTD sections along 43.2°N.

mean alongshore currents during the October 29 to January 30 period: 10.1 cm/s at a depth of 40 m and 7.5 cm/s at 80 m at Poinsettia (44.6°N, 124.3°W; bottom depth 100 m) in 1973–1974 [*Huyer et al.*, 1979] and 10.1 cm/s at 90 m at Elephant (45.3°N, 124.15°W; 110 m) in 1978–1979 [*Huyer et al.*, 1984]. The latter occurred during a relatively high sea level anomaly at Newport and thus is almost certainly an overestimate of the normal mean.

The increased poleward advection observed at 70 m should affect the water temperature at that depth. Although the temperature during the fall of 1982 did not exceed the temperatures during 1981 or 1983, temperature remained near 12°C throughout the winter of 1982–1983 instead of cooling in December and January to less than 10°C as is usual (e.g., 1981–1982 and 1983–1984 in Figure 3). The coastal ocean near 43°N loses heat during November–February [*Nelson and Husby*, 1983] with the strongest cooling in December and January. The maintenance of warm subsurface temperatures throughout the winter of 1982–1983 is the most obvious anomalous feature of Figure 3 and is consistent with the strong poleward flow during that period.

CTD SECTIONS

The SuperCODE CTD sections across the continental shelf and upper slope at 43.2°N near Coos Bay were made at intervals of several months (Figure 3). Each section was about 70 km long and consisted of eight stations, of which the two outer extended down to 1000 dbar. Three of these sections were made within the time period of high monthly sea level anomalies that began in October 1982: in January 1983, April 1983, and July 1983. Winter sections in either January or February were also made in 1981, 1982, and 1984, and an additional winter section was made in December 1981. Spring sections were also made in May 1981 and May 1982, but at this time of year the seasonal rate of change is too large [*Huyer*, 1977] to allow direct comparison between these sections and the April 1983 section. Similarly, the July 1983 Coos Bay section could not be compared directly with the August 1981 and September 1982 sections. Because of the strong interest in El Niño effects and because of the likelihood of such seasonal aliasing, additional CTD sections were made in April 1983, July 1983, and April 1984 along the Newport hydrographic line, which was occupied repeatedly from 1961 through 1970. Thus for comparison between 1982–1983 El Niño conditions and normal conditions, we will use the winter Coos Bay sections and the spring and summer Newport sections.

The January 1983 section off Coos Bay was made during the peak of the monthly sea level anomalies associated with the 1982–1983 El Niño. At first glance, however, this section seems to be similar to the other winter sections (Figure 5): the 8–9°C temperature band is still at about 100–200 m, and the permanent halocline (~32.8–33.6‰) still lies between 50 and 150 m. Although surface temperatures near shore are warmer than on February 5–6, 1982, and January 31, 1984, they are cooler than on February 17, 1981. Some of the differences and similarities between the winter sections can be explained by variations in the weather. The sections of February 17 and December 15–16, 1981, which show a downward sloping pycnocline and warm surface waters, were preceded by 7-day mean onshore Ekman transports of 2 and 1.2 m^2/s, respectively; the sections of February 5–6, 1982, and January 31, 1984, which show the pycnocline sloping up toward the coast, were preceded by 7-day mean offshore Ekman transports of 0.1 and 0.02 m^2/s. The January 11, 1983, section was preceded by onshore transport (a 7-day mean of 0.8 m^2/s).

The January 1983 section differs from the other winter sections in one important qualitative respect. In the four other sections, the permanent halocline is approximately parallel to the 8° and 9°C isotherms: the upper halocline (~32.8‰) has a temperature of 9–10°C, and the bottom of the halocline (~33.8‰) has a temperature of about 8°C. In contrast, in the January 1983 section, the halocline actually intersects the 9°, 10°, and 11°C isotherms: the halocline is much warmer near shore than at the most offshore station. TS diagrams indicate that two distinct water masses were present at this time, while the other sections each show only a single water mass. Both temperature and salinity decrease from south to north along the U.S. west coast [*Tibby*, 1941], but the meridional gradients vary with location as well as with time, on both seasonal

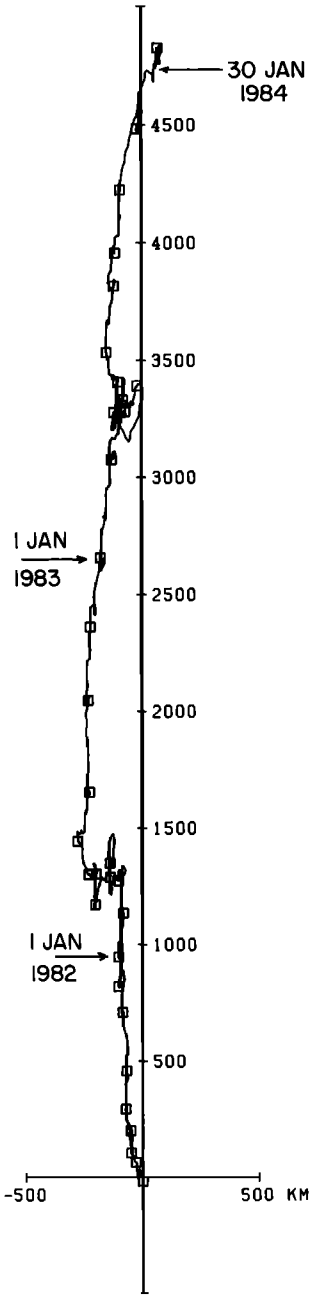

Fig. 4. Progressive vector diagram from current at 70-m depth (25–30 m above bottom) at 43.1°N, from May 1, 1981, to January 30, 1984. Open squares mark beginning of each month.

and interannual time scales. The warmer, more salty water mass inshore must have originated farther south, but we cannot say exactly where.

Although coastal sea levels during January 1983 were obviously anomalous (Figure 2), the near-surface water properties observed during the January 1983 section were not outside the ranges of the other winter sections: at 50 m, both temperature and dynamic height were above average, but salinity was normal (Figure 6). Subsurface water properties, however, were clearly anomalous: at 150 m the water within 50 km from shore was about 1°C warmer in January 1983, and dynamic height was higher, than in any of the other winter sections. Geostrophic velocities (relative to 600 dbar) calculated from the sections show a definite undercurrent was present in January 1983 but not in the other winter sections. The core of this undercurrent was at a depth of about 130 m, with maximum poleward velocities of 10–15 cm/s. The 150-dbar dynamic height profile (Figure 6) indicates that this undercurrent was narrow, with an offshore decay scale of about 20–30 km; this would account for the presence of warm, salty water adjacent to the extreme upper slope and cooler, fresher water offshore, i.e., for the offshore temperature gradient in the permanent halocline. This is consistent with the strong poleward flow measured by the current meter at 70 m, 15 km offshore, during late fall and winter 1982–1983.

The April 1983 CTD section off Newport was also made within the period of high monthly sea level anomalies associated with the 1982–1983 El Niño. However, this section was preceded by 2 weeks of upwelling, favorable winds (14-day mean offshore Ekman transport of 0.3 m^2/s) and the associated large drop in the coastal sea level at Newport (Figure 3), which normally signals the onset of the spring regime over the Oregon shelf [*Huyer et al.*, 1979]. Although the low sea level did not persist (Figure 3), the April CTD section (Figure 7) has the structure typical of the spring regime: isotherms, isohalines, and isopycnals over the continental shelf slope generally upward toward the coast, and surface waters are considerably more saline inshore than just beyond the shelf [*Huyer et al.*, 1979]. In the tradition of the historical Newport line, this section was extended to 330 km from the coast. Comparison of the April 1983 section with the average April (Figure 7) computed from sections in six different years (1962, 1964, 1966–1969) shows that near-surface temperatures were much warmer than normal (by >2°C), that the 9°C isotherm was much deeper than normal (by ~100 m), and that the permanent halocline (33.0–33.8‰) and pycnocline (25.5–26.0) were also deeper than normal (by ~40 m). There is no obvious systematic difference below ~300 m. In both the April 1983 section and the average April section, halocline waters within 150 km from shore are warmer than farther offshore, but near the continental slope the halocline is parallel to the local isotherms in both sections. Thus there is no evidence that the narrow undercurrent observed in January 1983 was still present. This is substantiated by the current meter observations which show that the flow on the shelf became strongly southward during the first half of April 1983 (Figure 3), and is consistent with the onset (albeit temporary) of the spring regime.

Figure 8 shows the offshore profiles of water properties at 50 and 150 m. As well as the six previous Newport line sections, these profiles include sections along 45.0°N in April 1975 and along the Newport line in April 1984. The profiles at 50 m show that near-surface waters in April 1983 were 1.5°–2.0°C warmer than normal, not only near shore, but out as far as 300 km from the coast. Between 50 and 150 km from shore, the 50-m temperature was more than 1°C higher than in any previous April section (Figure 8). Salinity at 50 m in April 1983 was within the normal range, and thus density was lower than normal. At 150 m, the anomalous zone was much narrower: between 80 and 150 km from the coast, the April 1983 temperature was well above the normal range (by 0.5°C), and salinity was well below normal (by 0.4‰): elsewhere, values were very near or within the normal ranges. Dynamic height profiles were slightly higher than normal at 50 and 150 dbar, but they barely exceeded the normal range. Note that April 1984 profiles were generally near normal within 200 km of the coast but farther offshore the temperatures at 50 and 150 m were well above normal, and even above the April 1983 temperatures there; near-surface salinities were near normal

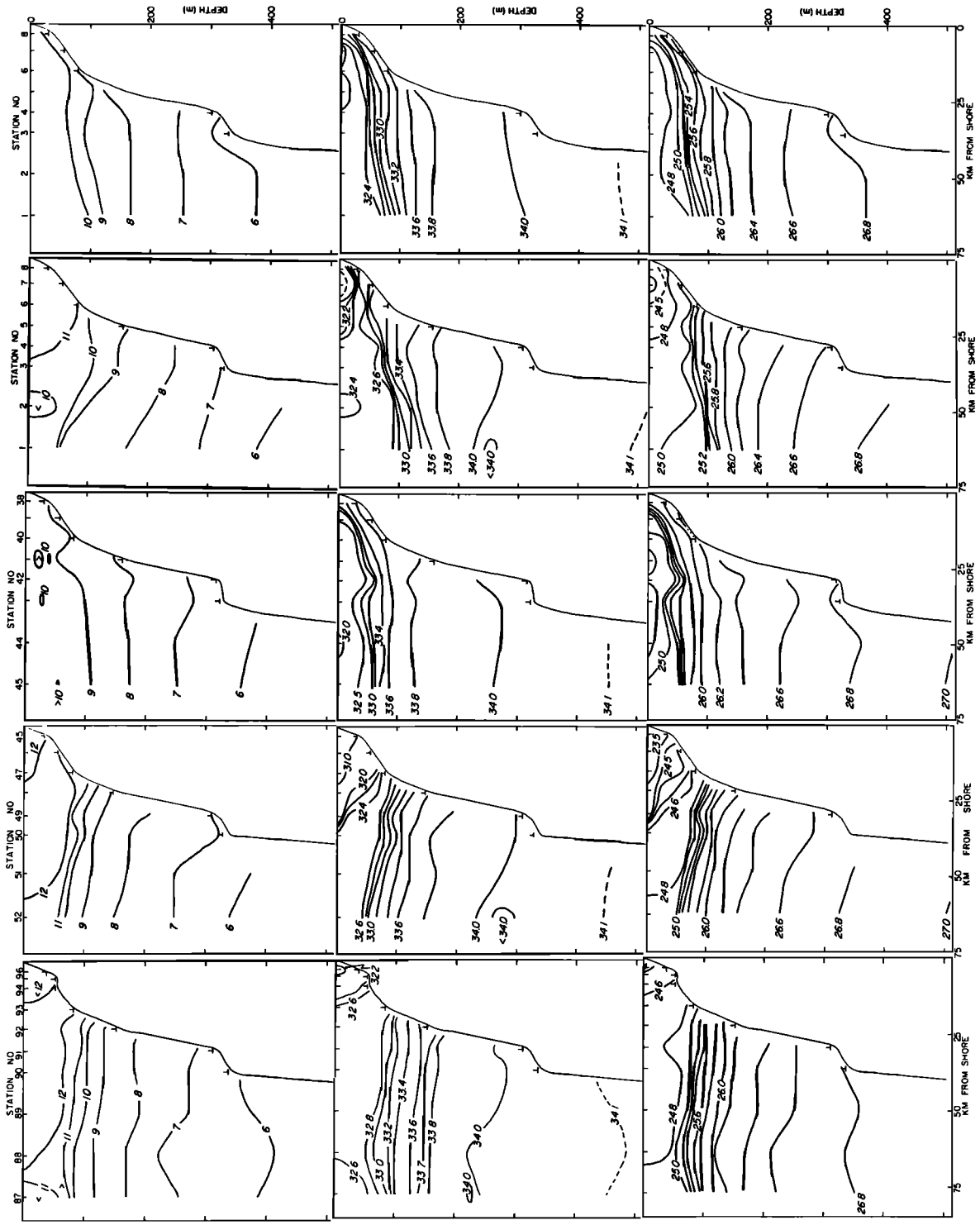

Fig. 5. Distributions of temperature, salinity, and sigma theta (top to bottom) off Coos Bay, Oregon, on February 17, 1981, December 15–16, 1981, February 5–6, 1982, January 11, 1983, and January 31, 1984 (left to right).

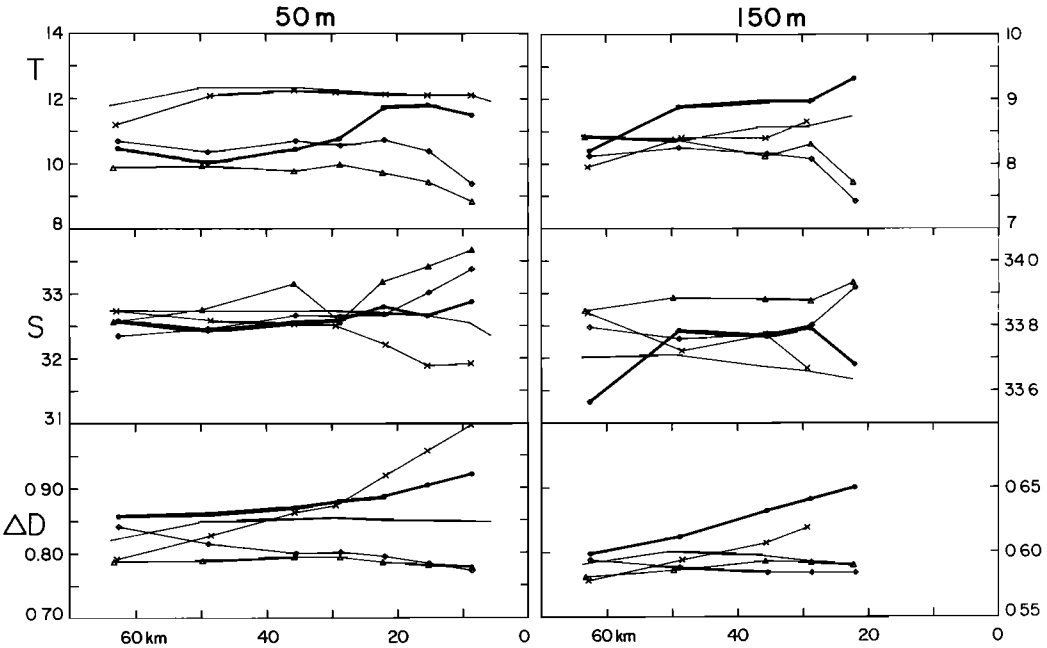

Fig. 6. Offshore profiles at 50 and 150 m of temperature, salinity, and dynamic height relative to 600 dbar for the winter sections. Solid curve, February 1981, crosses, December 1981; triangles, February 1982; circles, January 1983; and triangles, January 1984.

everywhere, but at 150 dbar, the offshore salinities were well below normal and also below the 1983 values.

The July 1983 Newport line section did not extend as far offshore as the earlier Newport sections, but it was longer than any of the Coos Bay sections. In comparison with the average July section calculated from seven different years (1962–1968), this section shows much stronger stratification over the continental shelf, and very warm temperatures and very low salinities much nearer shore than normal (Figure 9). Both of these features are consistent with weaker coastal upwelling during June and July 1983, which would result from the positive poleward wind stress anomalies in those months (Figure 2). The very low surface salinities (<30‰) and high surface temperatures (>18°C) at 50 km from shore indicate that the Columbia River plume axis was much nearer shore than usual because of this decrease in the offshore Ekman transport. Nevertheless, the subsurface structure of the temperature, salinity, and density fields is still fairly typical of the summer regime, with all isopleths above 200 m sloping generally upward toward the coast [*Huyer*, 1977]. Note, however, that even at depths between 100 and 350 m, the temperature at a given depth is systematically higher in the 1983 section than in the average section. Comparison of the offshore profiles at 50 and 150 m with the earlier sections (Figure 10) shows that the July 1983 temperature at these depths exceeded the normal range by as much as 1°C at 100 m. Salinities were within the previous range, but they seem to be below average. Dynamic height was near the maximum observed in the previous sections.

On the basis of the CTD sections, we would infer that the onset of El Niño was accompanied by increased poleward flow in a narrow (~30 km) undercurrent at a depth of ~130 dbar, with an associated increase in subsurface temperature within ~50 km of the coast; the narrow width of this undercurrent accounts for the January 1983 occurrence of two distinct water masses within 70 km of the coast. As El Niño persisted through winter into spring, the undercurrent weakened or disappeared, and the temperature anomaly spread farther offshore: by April, near-surface temperatures were anomalous everywhere within 270 km of the coast, and subsurface temperatures were anomalous out to about 200 km. These temperature anomalies were still present in July 1983 and had penetrated to depths greater than 300 m. By April 1984, water properties seemed to be normal within 200 km offshore, but anomalously high temperatures and low salinities at depth were still observed far (~250 km) from the coast.

The large positive temperature anomalies were associated with negative salinity anomalies. They can therefore not be explained solely by anomalous northward advection, since both temperature and salinity generally increase from north to south along the coast [*Robinson*, 1976]. Indeed, toward the end of the period of the anomalously strong northward flow between October 1982 and January 1983, we did observe that salinities were higher nearshore than farther offshore. As El Niño continued, however, there were strong positive local wind stress anomalies in January–March and June–July (Figure 3); these would have induced increased onshore transport (or decreased upwelling) near the coast. This occurred in combination with increased rainfall along the California coast during fall and winter: in the fall (September to November 1982), much of the California coast experienced more than twice the normal rainfall, and in winter (December 1982 to February 1983) the precipitation along the California and Oregon coast was 150% of normal [*Quiroz*, 1983]. Anomalous rainfall continued through early spring, e.g., at San Francisco the monthly anomalies were 5.5, 6.8, 14.9, and 4.0 cm (corresponding to 147%, 190%, 322%, and 203% of normal) from January through April 1983 [*Anonymous*, 1983]. This combination of anomalous rainfall and anomalously strong downwelling would certainly contribute to a deeper-than-normal halocline and negative salinity anomalies.

CONCLUSIONS

In October 1982, monthly anomalies of coastal sea level rose sharply at both Newport, Oregon, and Callao, Peru. In both locations, sea level anomalies reached record values in

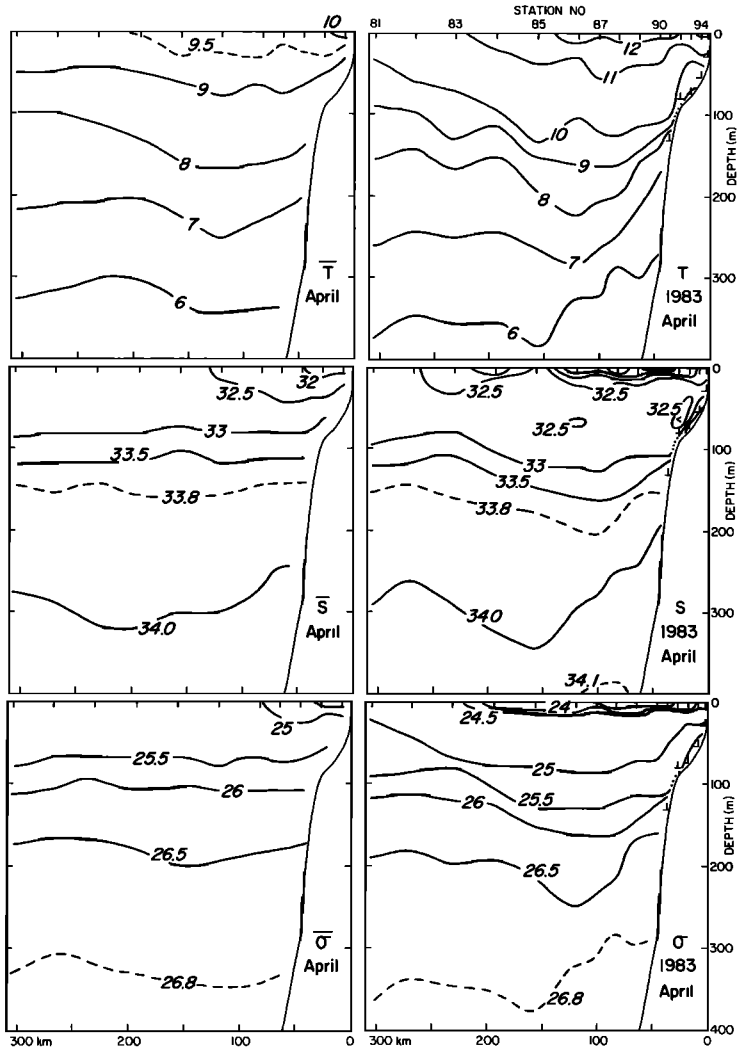

Fig. 7. April sections along the Newport Hydrographic Line. (Left) Average calculated from sections in six different years (1962, 1964, 1966–1969). (Right) April 17–18, 1983.

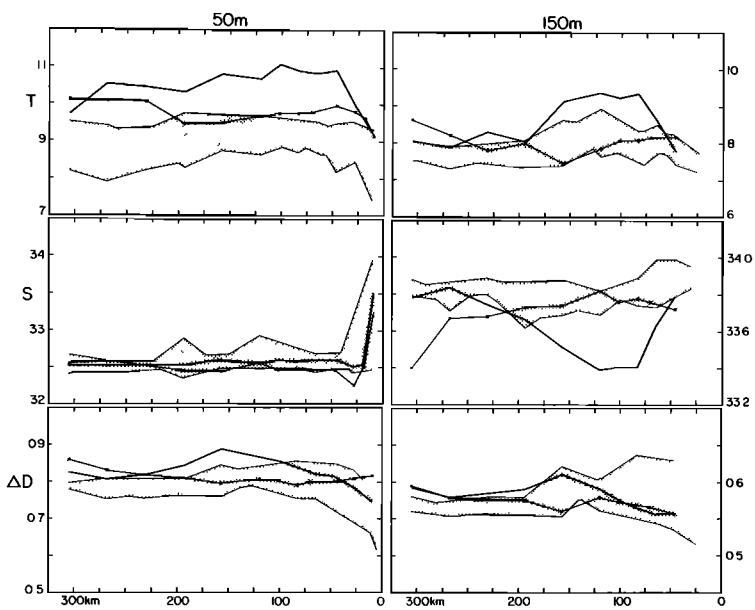

Fig. 8. Offshore profiles at 50 and 150 m of temperature, salinity, and dynamic height relative to 600 dbar for April 16–18, 1983 (heavy line), and April 4–5, 1984 (light line with crosses). The shaded area is the envelope of April observations along 44°40′N in 1962, 1964, and 1966–1969 and along 45°00′N in 1975.

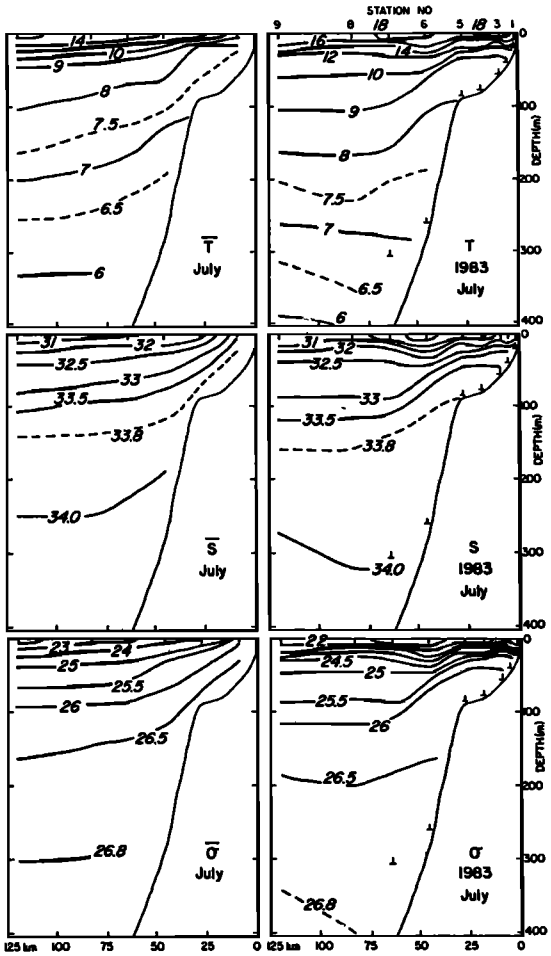

Fig. 9. July sections along the Newport Hydrographic Line. (Left) Average calculated from seven different years (1962–1968). (Right) July 11–12, 1983.

January 1983. A positive coastal sea surface temperature anomaly also began at Charleston, Oregon, in October 1982, but maximum surface temperature anomalies in 1982–1983 did not exceed previous record values. Large-scale winds over the North Pacific did not become anomalous until December 1982, and local winds off Oregon did not become anomalous until January 1983. These results suggest strongly that there is a direct oceanic connection between the sea levels at Newport and Callao. The most plausible explanation is coastal Kelvin waves. Assuming the waves travel southeastward from the equator to Callao at 12°S (~2000 km) and northeastward from the equator to Newport at 45° (~6000 km), and assuming that the signal arrived at Newport within about a month after arriving at Callao, this would indicate a phase speed of at least 140 km/d. In a study of monthly sea level anomalies along the Pacific coast of North and South America for a previous period (1950–1974), *Enfield and Allen* [1980] noted that "interannual events" occurred nearly simultaneously at most stations and that lagged cross-correlation analysis suggested poleward propagation of events in the northern hemisphere at a phase speed of 180 ± 100 km/d.

Although the first signals of anomalous conditions off Oregon probably arrived by an oceanic path, there is no doubt that they were subsequently reinforced by the anomalous atmospheric conditions. The anomalously strong poleward winds in January reinforced the poleward flow over the shelf, with the result that the 3-month mean, near-bottom current over the midshelf was stronger during the winter of 1982–1983 than during the four other winters with comparable measurements (1973–1974, 1977–1978, 1981–1982, 1983–1984).

In summary, the manifestation of El Niño off Oregon was associated with both distant and local causes. The initial manifestation (in October 1982) was that of high sea level and,

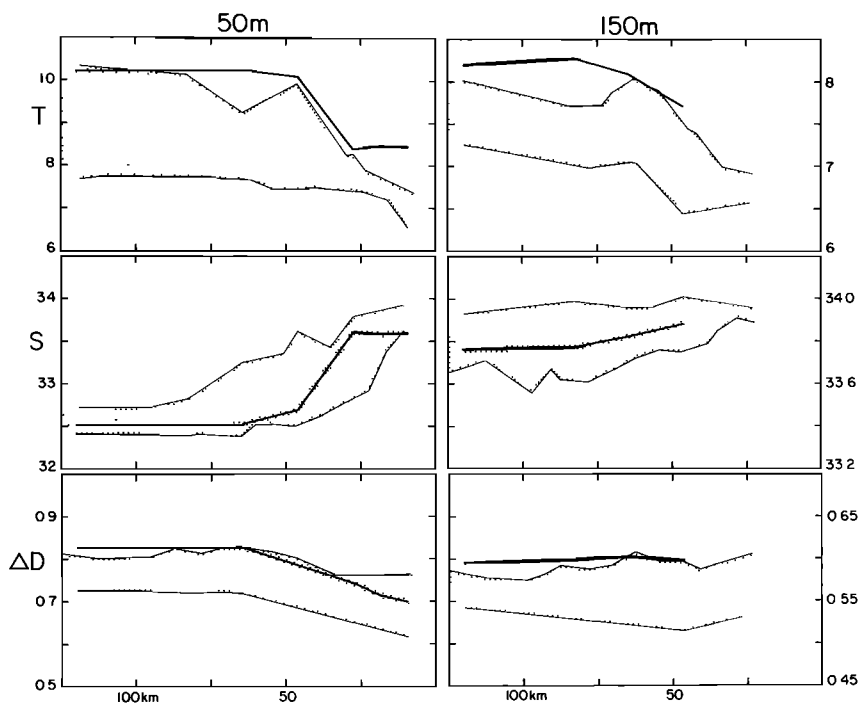

Fig. 10. Offshore profiles at 50 and 150 m of temperature, salinity, and dynamic height relative to 600 dbar, for July 11–12, 1983 (heavy line). The shaded area is the envelope of July observations along 44°40′N in 1962–1968, along 45°N in 1975, and along 45°N in 1977 and 1978.

consistent with that, an observed anomalously strong poleward flow. This preceded any local (extratropical North Pacific) atmospheric effect by 2–3 months. The anomalous local meteorological conditions that became manifest in December and January greatly enhanced the initial effects and inserted their own signal through excessive rainfall and through onshore transport caused by the strong northward winds.

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A. Huyer and R. L. Smith, College of Oceanography, Oregon State University, Corvallis, OR 97331.

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