TROPICAL PACIFIC THERMOCLINE TOPOGRAPHY DURING THE PERIOD MID-1979 THROUGH MID-1983

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During 1982 and 1983 the shape of the thermocline in the tropical Pacific Ocean changed dramatically from its climatological norm. Because the thermocline topography reflects sea level topography, some of these changes were to be expected on the basis of Wyrtki's (1979) studies of sea level variations during previous El Nino Southern Oscillation (ENSO) episodes. He determined that, during those episodes, sea level fell over a broad area in the western tropical Pacific and rose in the eastern tropical Pacific. From a pair of island sea level gauges spanning the NECC (North Equatorial Countercurrent) Wyrtki also found that the meridional slope of sea level between gauges increased indicating an intensified eastward flow. Repeated temperature/depth sections across the current during the last ENSO episode indicate similar changes in thermocline depth, as well as changes in the latitude of the thermocline ridges and troughs on either side of the current.

The depth of the thermocline in the tropical Pacific has been monitored continuously for the last several years through the deployment of XBTs from volunteer merchant ships. For the most part, the data presented here were obtained via a network of about 15 ships serviced cooperatively by the ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer) laboratory in New Caledonia and SIO (Scripps Institution of Oceanography). Since mid-1979 these ships regularly have made XBT temperature observations along three major merchant ship routes crossing the equator. These routes are: Australia/New Caledonia to Japan, Australia/New Caledonia to the west coast of the U.S., and

Tahiti to the Panama Canal. XBT sampling along these routes and other routes is still in progress and, hopefully, will continue during TOGA.

In the October 1983 issue of TOANL, Meyers and Donguy (1983) presented an analysis of the East-West slope of the thermocline along the equator during 1981, 1982 and the first quarter of 1983. Their Figure 1 (not reproduced here) shows that the annual cycle for the depth of the 14°C isotherm during a normal year, 1981, had a relatively small amplitude, about 10 m in the west and 30 m in the east. During the final quarter of 1982 and the first quarter of 1983, the 14°C isotherm in the eastern equatorial Pacific was about 100 m deeper than normal. During early 1983 the 14°C isotherm in the western Pacific was 30 m above the highest of all observations taken prior to 1975. The normal downward slope of the thermocline to the west leveled out, then reversed!

Western Tropical Pacific Sections

We will proceed by first examining the 1982-83 thermocline topography along the westernmost ship route, i.e., New Caledonia to Japan. During a December 1981 cruise the surface warm water layer was thick and the thermocline was deep (Figure 1). As EL Nino matured into December 1982, the warm water layer was drastically reduced in volume and the thermocline was about 50 m higher than in December 1981.

The temperature/depth sections in Figure 1 and all the temperature/depth sections represent the data from individual merchant ship cruises and not averages over the cruises made during a month or a season. Also, the data are all presented in "absolute" form, i.e., not in the form of anomalies with

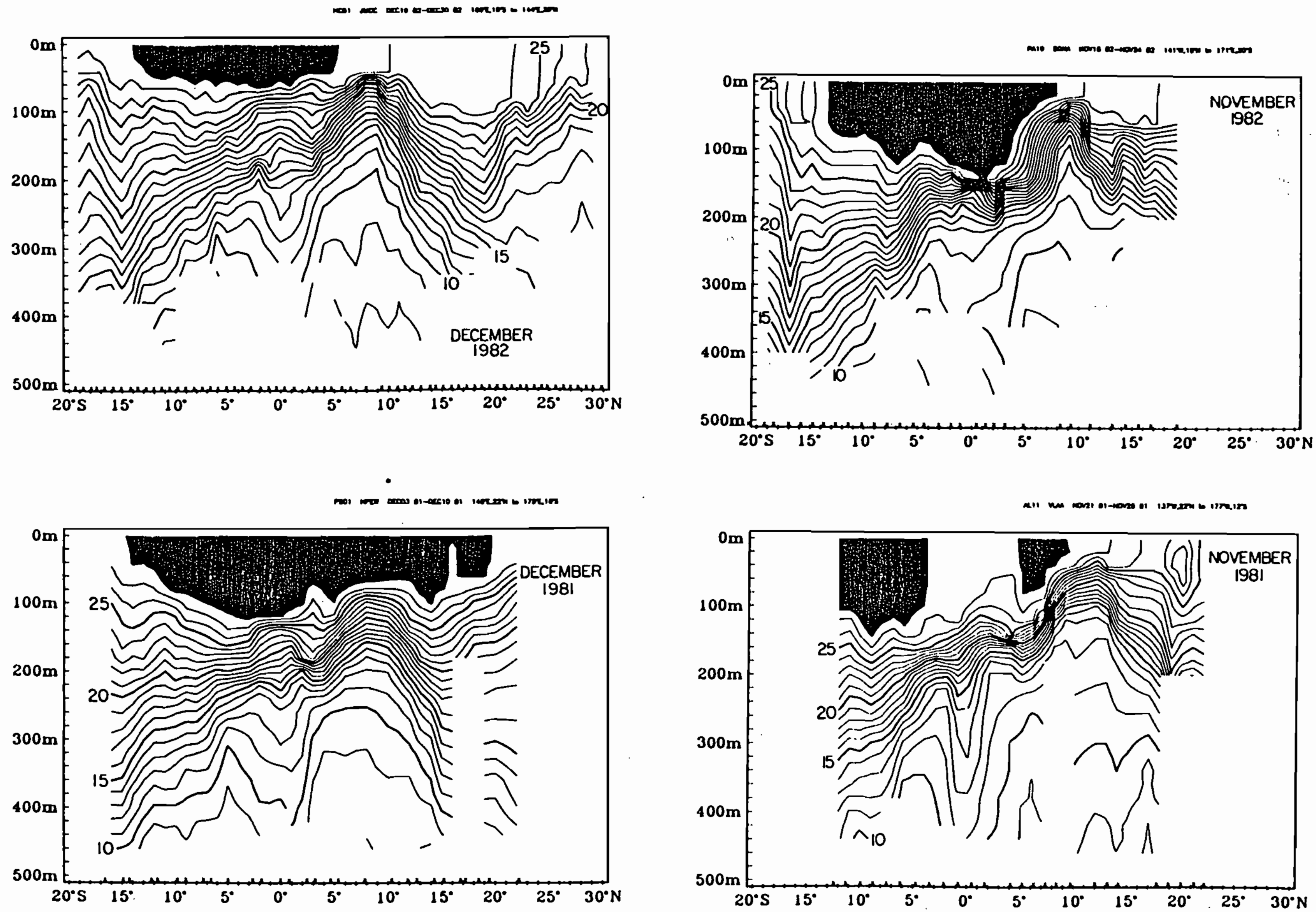

Fig. 1. Temperature/depth data sections between New Caledonia and Japan taken during Novembers and Decembers of 1981 and 1982. Shaded areas indicated water warmer than 28°C.

respect to any climatology. In this case the interannual variability was so strong that it stood out clearly above the annual signal and the shorter scale noise. Averages and anomalies will be computed as part of the continued analysis of the data.

Variations of thermocline topography along the New Caledonia-Japan route are shown over a four-year period (Fig. 2). The 20°C isotherm has been chosen as a representative tracer of the depth of the maximum vertical temperature gradient. The NECC (North Equatorial Countercurrent) ridge and trough system is clearly evident between approximately 10°N and 3°N. There are data gaps along the western ship route in middle and late 1981, so it is not possible to follow the ridge/trough system throughout the period before the onset of the ENSO episode. However, the seasonal steepening of the ridge/trough topography seen in December 1981 was weaker than during the previous two years. Similar interannual variations in seasonal cycle have been observed in sea level at Truk Island (Meyers, 1982). In July and August 1982 the ridge rose dramatically to heights which, in December, reached 40 m above the seasonal peaks for 1979 and 1980. This rise was different from earlier years because the thermocline rose everywhere throughout the band 16°N to 12°S. The progression was such that the thermocline in the equatorial region rose earliest and the higher latitudes followed by greater and greater lags.

By April and May 1983 the height of the NECC ridge had dropped to the 120-140 m level, where it was prior to El Nino. At the same time the shallowest thermocline was to be found at the equator. This shallow equatorial "ridge" was flanked by an approximately symmetrical trough and ridge to the north and to the south. The NECC and the SECC (South Equatorial Countercurrent) were, therefore, of approximately equal strength. The authors are not aware of any other observations which show this symmetry of the thermocline topography around the equator.

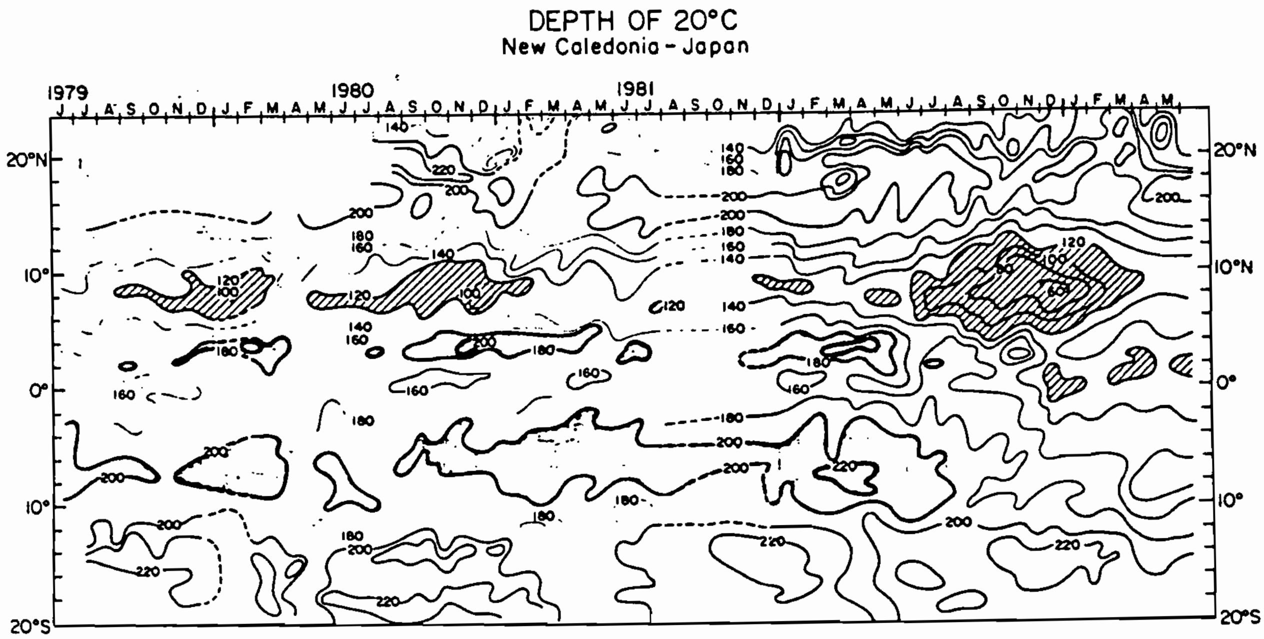

Fig. 2. Depth of the 20°C isotherm between New Caledonia and Japan during the period June 1979-June 1983.

Figure 3 shows a more detailed analysis of the strength of the NECC in the western Pacific at the point where the current crosses the New Caledonia to Japan shipping route. The differences in the depths of the 20°C isotherm in the trough and on the ridge on either side of the NECC were computed and then averaged by months to form an index of the current strength (see Wyrtki et al., 1981). Four seasonal cycles are shown, with the cycle phase selected to place the current strength peak, on average, in the middle of the cycle. The peak in the 1979/80 cycle occurred during one of the data gaps (indicated by dashed contours in Figure 2). The timing and amplitude of the peak were inferred from Wyrtki's sea level measurements at Truk. The NECC strength index during the other XBT data gap, July through October 1981, was linearly interpolated.

In comparing the four seasonal cycles of the NECC, it is apparent that the cycle-to-cycle variability is great, not only during the ENSO episode but

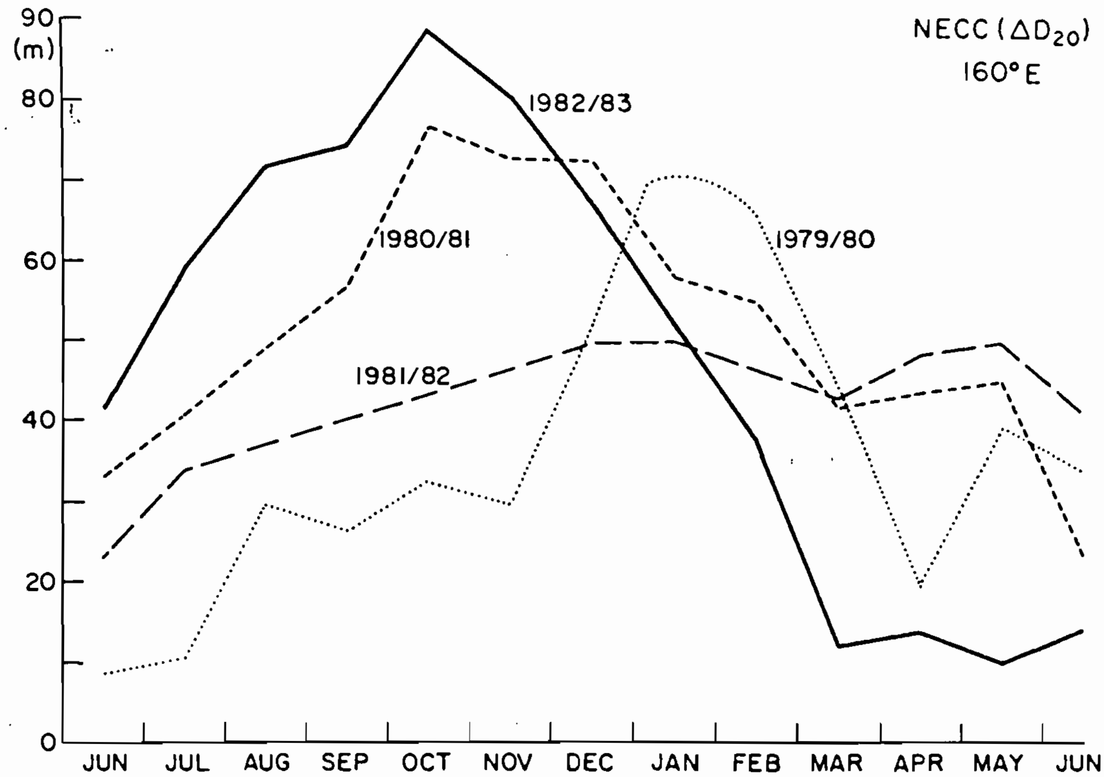

Fig. 3. Depth differences of the 20°C isotherm across the NECC ridge/trough system near 160°E for the period June 1979-June 1983. Data are averaged over individual months and smoothed over adjacent months with a 1/4, 1/2, 1/4 filter.

for all of the years. The significance of this consistently high interannual variability should properly be judged in the context of data series longer than the present XBT data series. From Figure 3, however, it is still clear that the NECC was relatively strong during the first half of the 1982/83 cycle and then relatively weak during the second half. The peak-to-peak amplitude of the 1982-83 ENSO cycle was much higher than for any of the other cycles.

Central Tropical Pacific Sections

In the central tropical Pacific the principal merchant ship routes run from Australia, Noumea, and Fiji to Hawaii and the west coasts of Canada and the U.S. Because the end points of the possible routes are so spread out, the XBT data obtained from the volunteer ships are also dispersed over a wider range of longitudes than in the western and eastern tropical Pacific. Also, merchant ship routes cross the central tropical Pacific at a skewed angle of roughly 45° to the meridians. The temperature/depth XBT sections are a combination of zonal and meridional sections.

The vertical temperature sections for individual cruises may be used to construct an historical narrative of major changes in the central Pacific. From January through April 1982, the sections (not shown here) indicate that the ocean did not vary much from corresponding months of 1981. In retrospect, however, we can see that in May 1982 an important difference did develop (Fig. 4). An enormously large pool of warm water occupied the surface all the way from 5°N to beyond 15°S. Signs of equatorial upwelling disappeared and didn't return for over a year. With this exception, however, the thermocline topography had much the same general shape in May 1982 as in May 1981. In June 1982 normal upwelling was still absent and the NECC ridge/trough system started to steepen (Fig. 5). In August and September 1982 (Fig. 6) a large body of 28°C water had pooled onto the equator and there were indications of a powerful NECC covering a band from 10°N to 3°N. No equatorial upwelling was evident, in spite of the fact that this was the time of year when one normally would expect upwelling to be most vigorous. By late November (Fig. 7), the thermocline topography indicated a powerful eastward flow spanning the equator in the region 5°S to 10°N. Vertical spreading of isotherms around the core of the EUC (Equatorial Undercurrent) had virtually disappeared, as flow of the current ceased (Firing and Lukas, 1983). The NECC trough, usually located near 5°N, had shifted onto the equator. The small slope of the thermocline

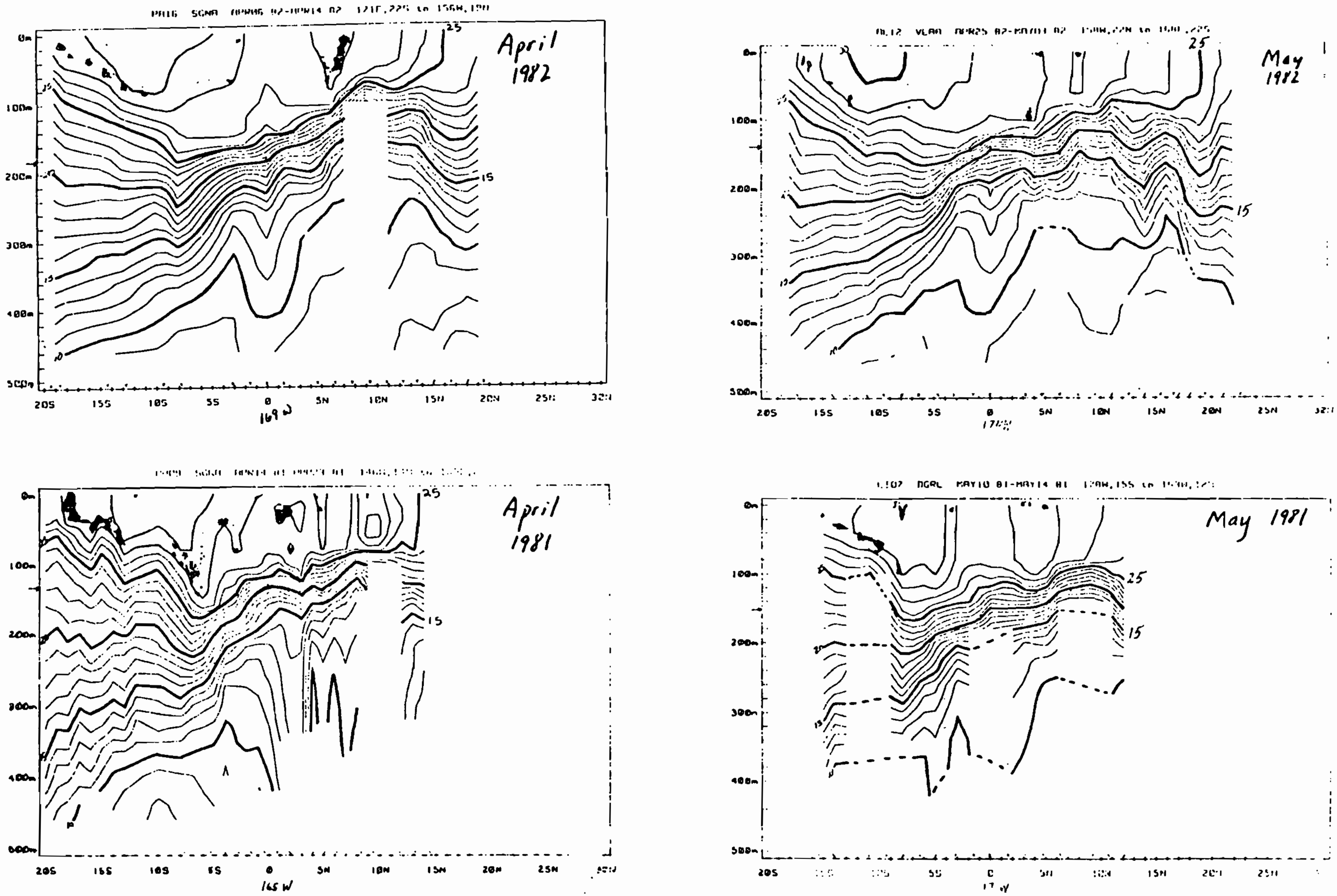

Fig. 4. Central tropical Pacific temperature/depth data sections in Aprils and Mays of 1981 and 1982.

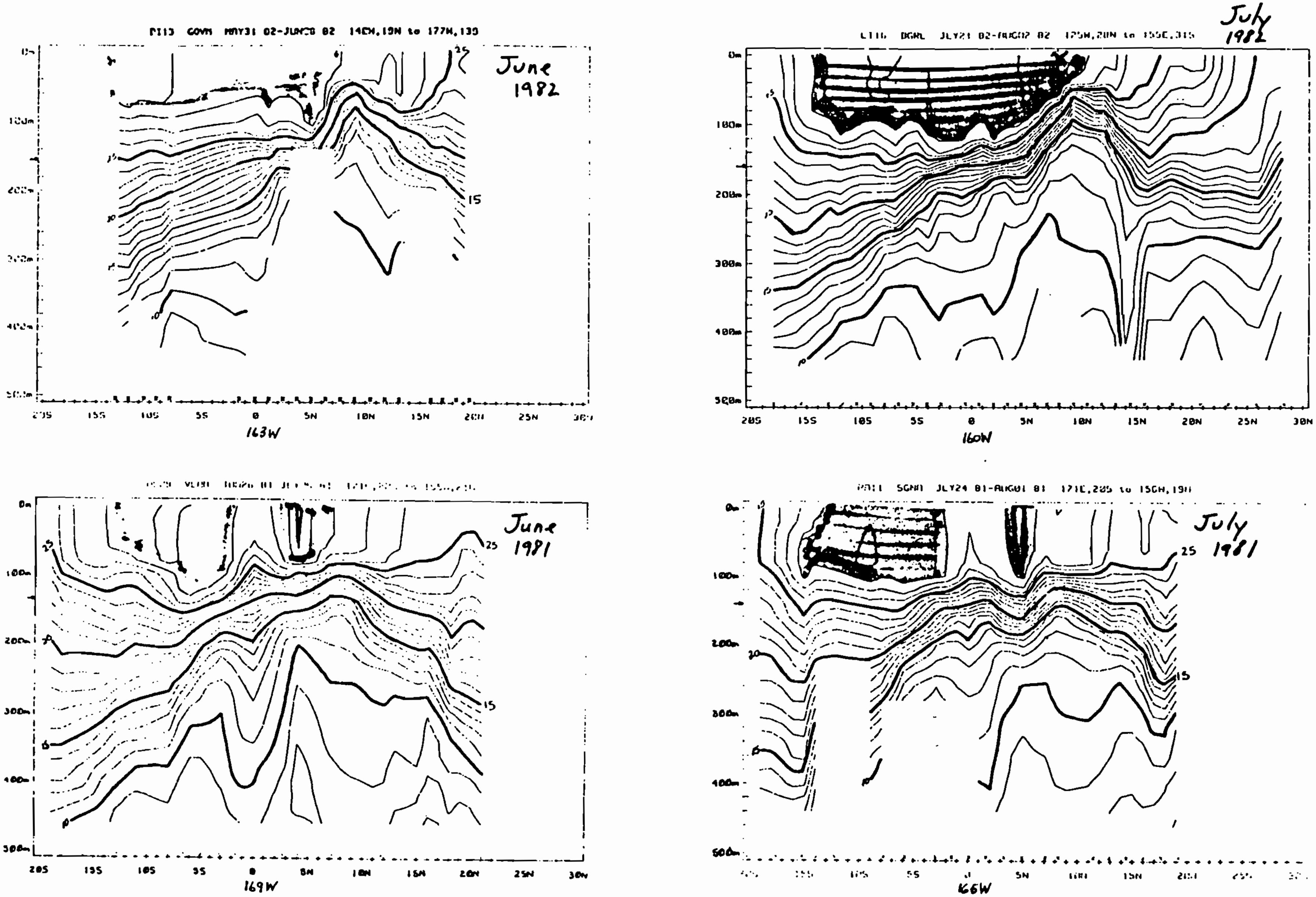

Fig. 5. Central tropical Pacific temperature/depth data sections in Junes and Julys of 1981 and 1982.

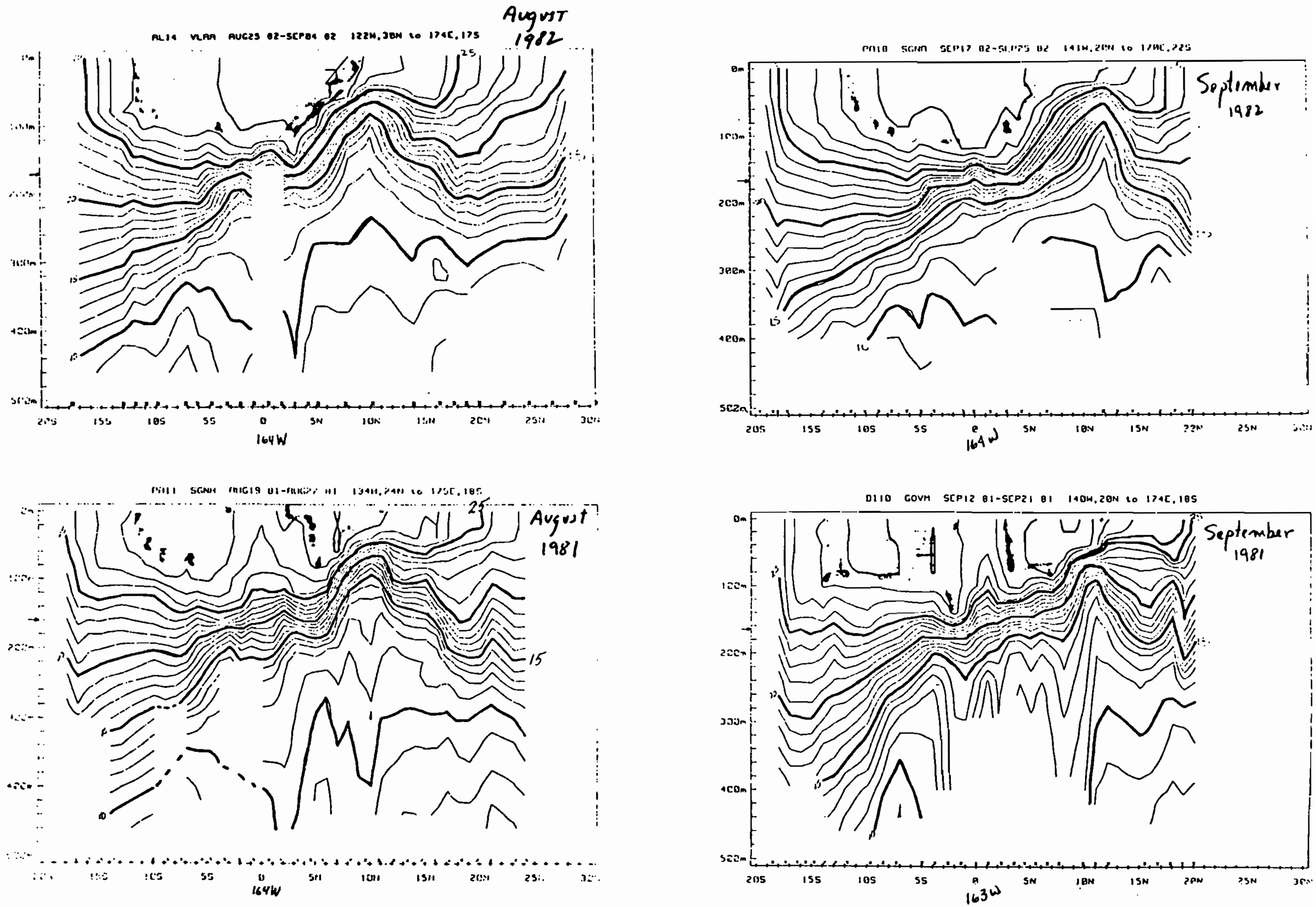

Fig. 6. Central tropical Pacific temperature/depth sections in Augusts and Septembers of 1981 and 1982.

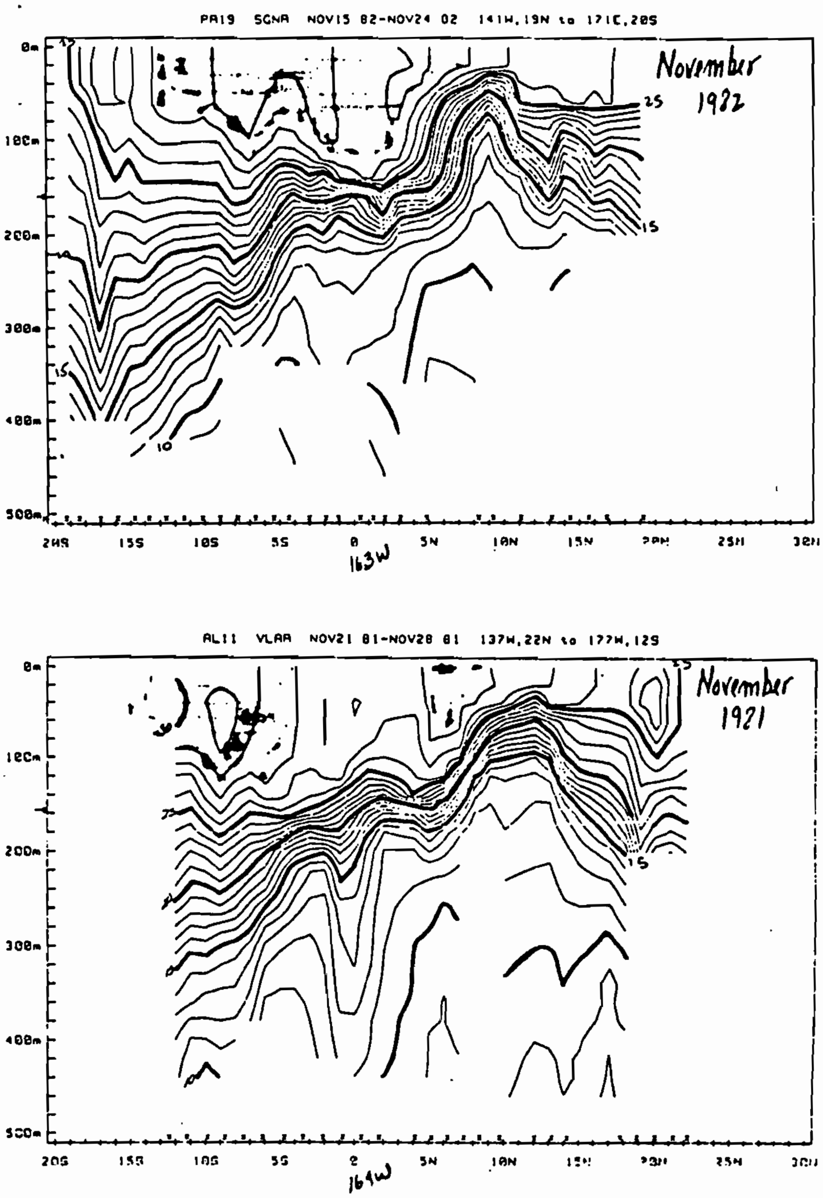

Fig. 7. Central tropical Pacific temperature/depth data sections in Novembers of 1982 and 1981.

between the equator and 5°N indicated a substantial increase of the NECC transport. Near the equator even a small slope is important because the Coriolis parameter is also small.

Relaxation back toward a more normal configuration (Fig. 8) began in January 1983. The 28° water retreated southward and the isotherms around the EUC spread vertically. By May 1983 the equatorial upwelling again broke the surface (Fig. 9). For the period February 1983 through at least May 1983 the

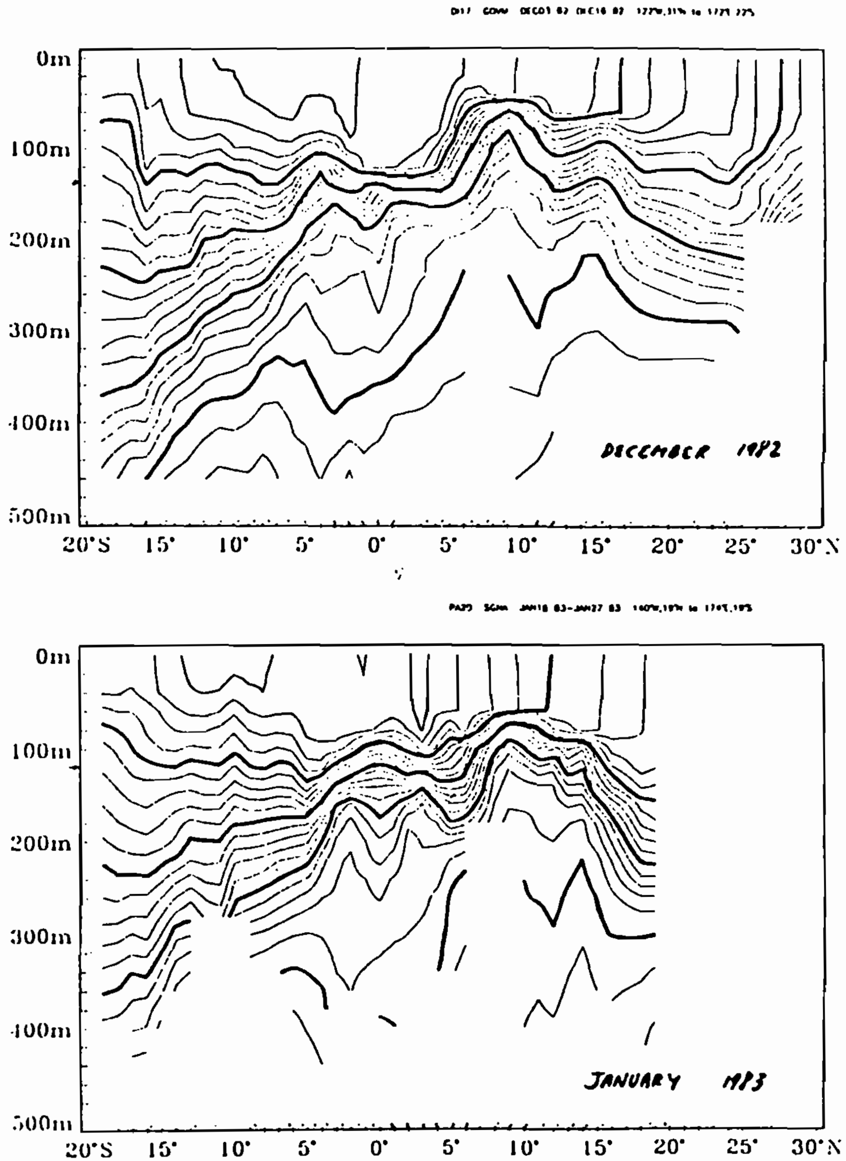

Fig. 8. Central tropical Pacific temperature/depth data sections in December 1982 and January 1983.

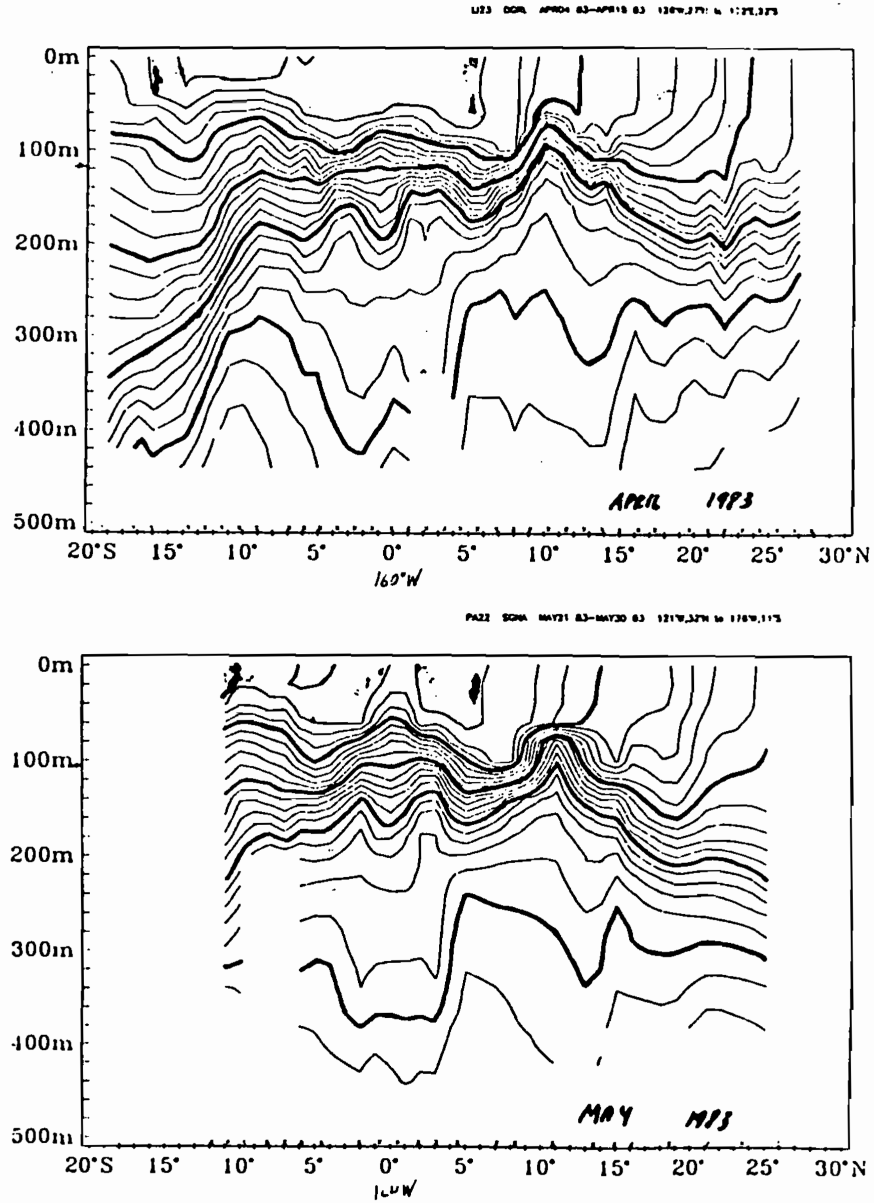

Fig. 9. Central tropical Pacific temperature/depth data sections in April and May 1983.

central Pacific thermocline assumed an atypically symmetric shape about the equator, indicating approximately equal strengths of the North and South Equatorial Countercurrents. This unusual symmetry was also noted as a characteristic of the western Pacific XBT data. Studies of the wind stress and the curl of the stress during previous El Nino events have demonstrated that the most important forcing functions also assumed a more hemispherically symmetric shape (Pazan and Meyers, 1982).

Figure 10 shows a four year time series of the depths of the NECC ridge and trough in the central tropical Pacific, as observed on individual temperature sections. The ridge data points and the trough data points in Figure 10 form two easily identifiable groups or "chains." The (vertical) separation of these chains is an index of the strength of the NECC. The annual and interannual variability exhibited by the data are clearly visible in spite of the presence of some high frequency flutter.

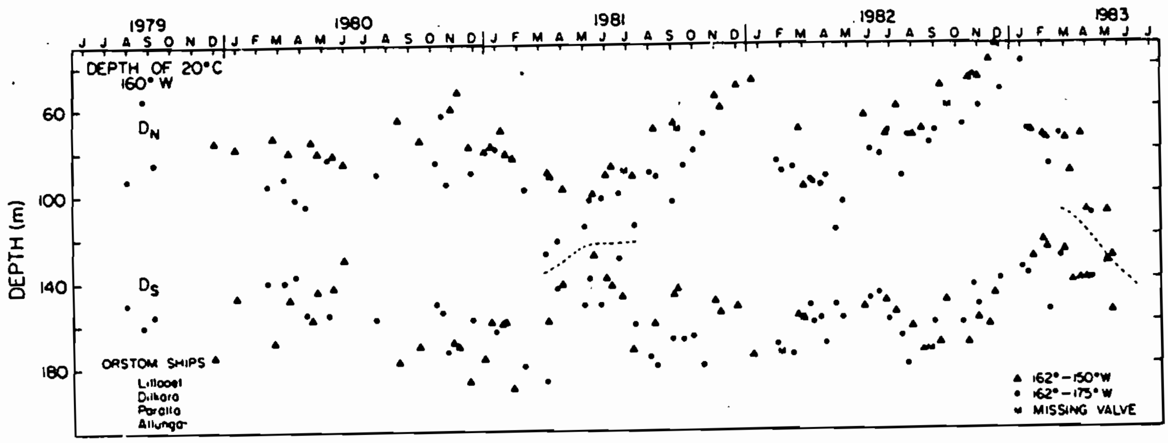

Fig. 10. Central tropical Pacific depths of the NECC trough and ridge (as indicated by the depths of the 20° isotherm) for the period August 1979 through May 1983.

Figure 11 presents four annual cycles of an index of the strength of the NECC in the central tropical Pacific. The index was computed from the slope of the 20°C isotherm in the same manner as that used to compute the western tropical Pacific NECC cycles (Figure 3). The central tropical Pacific cycles are remarkably similar from year to year, much more so than in the western Pacific. This is consistent with the greater stability of the annual cycle in wind stress fields of the central, near-equatorial Pacific. In the central Pacific the annual variability is dominated by the regular, north-south migration of the ITCZ.

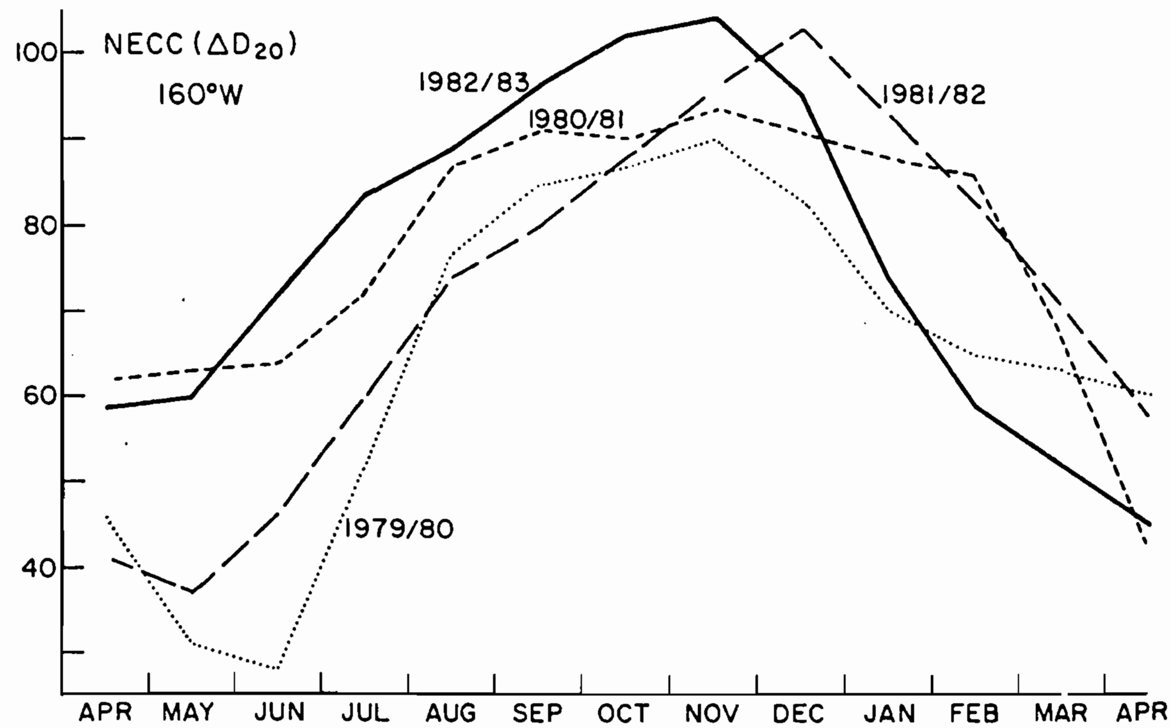

Fig. 11. Depth differences of the 20°C isotherm across the NECC ridge/trough system near 160°W for the period April 1979-April 1983. Data were averaged and smoothed in the same manner as employed for data in Figure 3.

During the ENSO episode of 1982/83 the NECC in the central Pacific (Figure 11), as in the western Pacific (Figure 3), was flowing strongly during the first half of the annual cycle and weakly during the second half. The possibly important implications of increased heat transport by the NECC during ENSO episodes have been noted (Wyrtki, 1973; Namias, 1973; Barnett, 1975), but are not really understood.

Eastern Tropical Pacific Sections

The merchant ship route from the Panama Canal to Tahiti and Noumea crosses the equator at approximately 100°W. XBT data taken along this route are somewhat more difficult to display and to analyze since the sections are along a heading of 70° from North. Some cruises sail to Mururoa, located approximately 1000 km east of Tahiti, prior to calling at Papeete.

During the first half of 1982 the thermal structure along this section was very similar to the structure observed during 1981 (Figures not shown here). A slight depression of the equatorial thermocline and an increase in SST, relative to 1981, began in May but it was not very prominent. By August these signs were more noticeable but the thermal structure was still generally the same in 1982 as in 1981. Then the changes increased dramatically so that by the first week of October the equatorial thermocline was more than 100 m deeper and SST was more than 4°C warmer than in 1981 (Figure 11). Increased SST was also observed around 10-15°S, near the climatological SST maximum for the southern hemisphere. The thermocline topography in August indicated eastward baroclinic flow of the surface layer between 5°S and 7°N counter to the westward flow usually observed.

By December 1982, water warmer than 26°C had completely blanketed any indications of equatorial upwelling (Figure 13). The eastward baroclinic flow spanning the equator had intensified. Figure 13, along with Figures 1 and 8, indicates a powerful NECC, spanning the equator, flowing all the way across the Pacific.

Figure 14 is a 16-month time series which focuses on the topography of the 15°C isotherm along the eastern tropical Pacific ship route. Each monthly panel within this figure contains two almost identical sub-panels. For the purposes of comparison, the left sub-panels contain the depth of the 15°C isotherm during the previous month and the right sub-panels contain the 15°C depth for the same month of the previous year. The panel for "early October" clearly shows a significant deepening of the thermocline, which first began to develop in May, 1982. This anomalously thick thermocline persisted through the end of the time series in May 1983. The anomaly spread into a wider band of latitude and longitude after May, 1982. It is not yet known if this development is consistent with the dispersion of waves reflected from the eastern boundary.

The subsurface temperature data presented here is only a small part of the total data taken by the ORSTOM/SIO XBT program and other programs. Many data have been taken in recent months and, obviously, a great deal of analysis and interpretation of the data remains to be done.

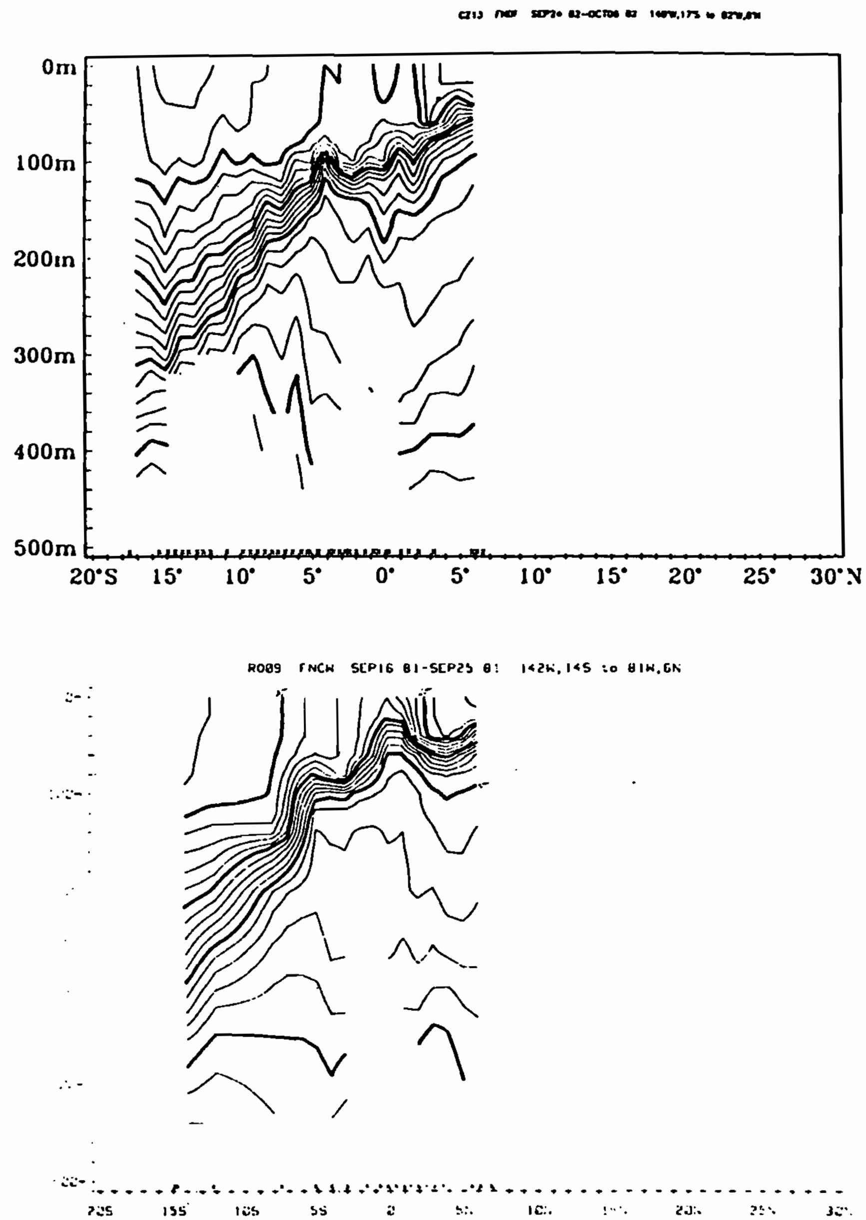

Fig. 12. Eastern tropical Pacific temperature/depth data section in September 1981 (bottom) and in September-October 1982 (top).

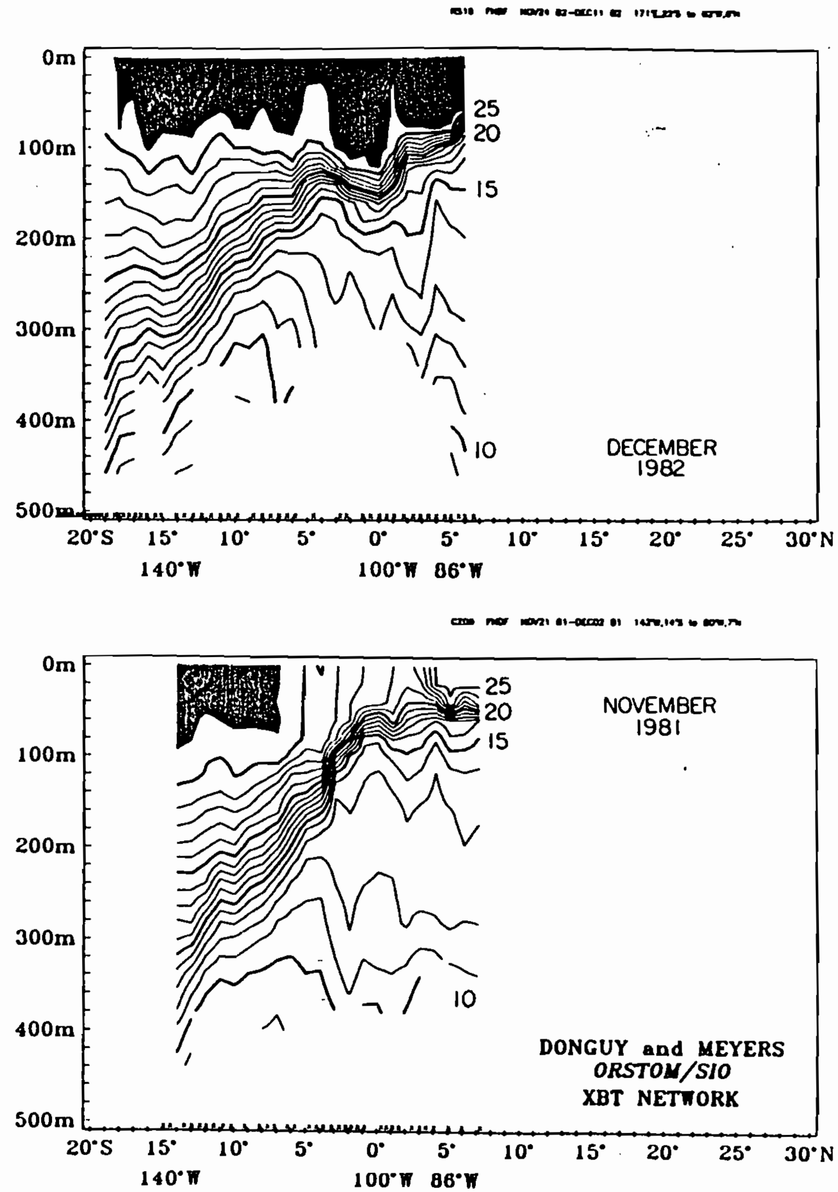

Fig. 13. Eastern tropical Pacific temperature/depth data sections in November-December 1981 (bottom) and in November-December 1982 (top)

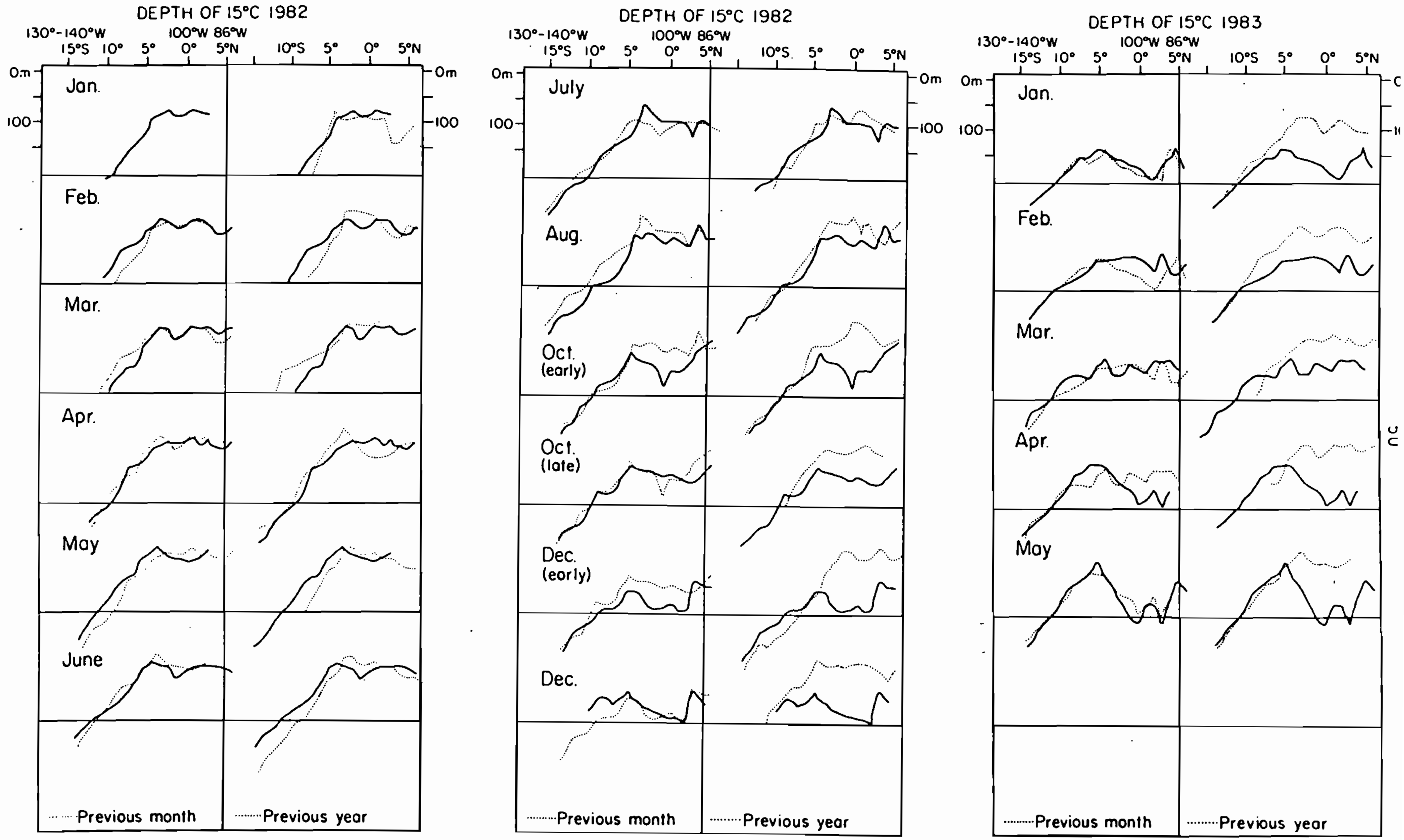

Fig. 14. 16-month time series of the depth of the 15°C isotherm along the eastern tropical Pacific ship route. Data are overlaid with data from previous month and same month of previous year.

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