VARIATION OF THE PACIFIC NORTH EQUATORIAL COUNTERCURRENT OBSERVED BY SHIPS-OF-OPPORTUNITY

by

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Approximately 17 merchant vessels were used during 1979 to monitor the tropical Pacific subsurface temperature by expendable bathythermograph (XBT). The ships' routes are shown in Figure 1. The number of equatorial crossings on each route is indicated within parentheses. The supporting institutions and responsible oceanographers are given in Table 1. Baroclinic structure observed by these ships in the vicinity of the Pacific North Equatorial Countercurrent is discussed in this paper. One ship provided approximately bi-monthly sections across the current in the western Pacific on the route between Noumea and Japan. Nine ships provided approximately weekly sections across the current in the central Pacific south of Hawaii. The temporal evolution in strength of the Countercurrent is described in this paper and its variability in the western and central Pacific is compared.

TABLE 1

ROUTE	INSTITUTION	OCEANOGRAPHER IN CHARGE
New Caledonia/Tahiti to Hong Kong/Japan/Panama California	ORSTOM-Noumea	J. R. Donguy
Australia/New Zealand to U.S. West Coast	FNOC-Monterey	P. Stevens
Australia/Samoa/Tahiti to U.S. West Coast	NOAA-Monterey*	D. McLain

Table 1. Institutions and oceanographers in charge of the merchant ships taking XBT observations on routes shown in Figure 1.

* Scripps Institution of Oceanography since 1980.

WESTERN PACIFIC - NOUMEA/JAPAN SECTION

Sixteen meridional temperature sections were obtained by the merchant vessel *Hachiyo Maru* near 157°E from June 1979 to May 1980. Four sections (Fig. 2) show the major changes in baroclinic structure observed during the year. The North Equatorial Countercurrent appears in these sections between a trough in the thermocline topography near 3°N and a ridge near 8°N. The trough and ridge are weakly developed in the section of 27 July - 2 August 1979 and strongly developed in the section of 8-16 February 1980. The latitude of each XBT drop is marked at the bottom of each section and shows that the typical spacing between drops is approximately 1 latitude.

The strength of the Countercurrent was monitored by the meridional slope of the 20°C isotherm between the trough and ridge, using a simple two-layer approximation (Wyrtki and Kendall, 1967). The depth of this isotherm at the ridge (D_n) or trough (D_s) was determined from the 16 temperature sections, as well as the mean depth $\bar{D}$ and the difference ΔD (Fig. 3). A low frequency signal has been observed by the *Hachiyo Maru* in spite of the data gap from December to February. Depth at the trough and ridge vary almost exactly out of phase, while the mean depth remains nearly constant. The current strength as indicated by ΔD varied from weak during June-July 1979 to strong during December-February 1979/80, then weak again during April-June 1980.

Although the South Equatorial Countercurrent (5°-10°S) is beyond the scope of this study, it is interesting to contrast it with its northern counterpart. The eastward contercurrent shear in the southern hemisphere appears distinctly in the thermocline above 20°C (Fig. 2), while in the northern hemisphere the shear involves virtually all the main thermocline down to 11°C. The southern current strengthens after February while the northern current weakens.

CENTRAL PACIFIC
AUSTRALIA (VICINITY) TO U.S. WEST COAST

The same technique was used to analyze 35 temperature sections obtained by 9 ships in the central Pacific between January 1979 and April 1980. The index ($\triangle D$) of Countercurrent strength indicates a weak current during April-June 1979, followed by a strong current during September-December, then weak again after March, 1980 (Fig. 4). It is remarkable that there is almost no difference in phase of Countercurrent strength between the central and western Pacific. The west appears to lag by 1 or 2 months, but this difference may not be significant due to the poorly resolved peak in the west and the large scatter of values near the peak in the central region. Note that the central Pacific sections are taken over a wide band of longitude from 130°W to 170°w (Fig. 4, bottom). The mean east/west slope of the thermocline during 1979/80 was used to project all the estimates to 155 W. This projection alters D_n and D_s by 1 to 20 m but does not change the estimate of $\triangle D$.

Temperature sections taken by merchant vessels have the deficiency that XBT drops are taken at someshat irregular intervals. The number of drops per day ranges from 2-6, depending on the agreement between ships' officers and the oceanographer in charge. The central Pacific sections were divided into two groups having a latitude spacing of approximately 1° - or 2° - latitude, and plotted in Fig. 4 with different symbols. Nearly half of the sections have 2° spacing, which does not always adequately resolve the Countercurrent. These sections give a slightly smaller estimate of Countercurrent strength than the sections with 1° - spacing during the time of peak strength from October to December, because the thermocline ridge or trough falls between drops.

COMPARISON TO HAWAII/TAHITI SHUTTLE

Temperature sections across the Countercurrent at approximately weekly intervals were obtained near 155°W by research vessels and aircraft during the Hawaii/Tahiti Shuttle Experiment. Preliminary results have been described in a recent article by Wyrtki et al (1981). The index of Countercurrent strength ΔD averaged monthly from the Shuttle observations is compared to the similar index from ships-of-opportunity in Fig. 5. A number in parenthesis by each plotted point indicates the month of 1979 for the averaged values. The monthly averages of Shuttle and ship-of-opportunity observations are highly correlated (0.94). A comparison of individual ship-of-opportunity sections to weekly averages of the Shuttle data (not presented) was also highly correlated (0.81). The high correlation clearly is due to the regular annual signal (Meyers, 1975, 1979) in both data sets. Past studies have shown that interannual fluctuations in the equatorial current system (Wyrtki, 1978, 1979; Donguy and Henin, 1981) are generally more energetic than the annual signal. The RMS deviation between monthly averaged ΔD from Shuttle and ship-of-opportunity observations is small error increases our confidence that XBT ships-of-opportunity can be used to economically monitor both annual and interannual variation in baroclinic structure of the tropical Pacific.

OBJECTIVE ANALYSIS
XBT DATA RECEIVED AT FNOC BY RADIO

Some ($\approx$50%) of the XBT observations from.ships-of-opportunity during 1979/80 were sent to FNOC, Monterey by radio on the global telecommunications system. They were merged at Monterey with radio reports from naval and research vessels. A linear, least-squares interpolation scheme (objective analysis) was used to map subsurface temperature throughout the tropical Pacific using the radioed data. Data from the Hawaii/Tahiti Shuttle Experiment were first eliminated and held out as a high quality control case to test the effectiveness of the interpolation scheme and ship-of-opportunity network.

Interpolated results are shown for the temperature anomaly at 160m. The anomaly is the departure from the longterm annual mean temperature. This allows annual variations, if present, to appear in the interpolated data. The mean was estimated from all XBT and MBT observations in the FNOC archives as of 1975, the majortiy of drops taken during 1950 to 1970. After removing the mean from the temperature at 160m for each XBT cast, the sesiduals for each month were interpolated to a 2°-latitude by 10°-longitude grid between 30°N and 20°S, using a Gandin-type objective analysis scheme. The scan dadius for accepting observations at a grid point was ± 15°-longitude, ± 3°-latitude, and ± 0.5 month. The objective analysis was not attempted at grid points with less than 2 observations within the scan radii. The spatial autocorrelation function used was an exponential decay with e-folding length of 1500 km east/west and 500 km north/south. The temporal autocorrelation function was assumed to be unity, which is conservatively small estimate. This permits a considerable amount of smoothing of the data.

TEMPERATURE ANOMALY AT 160 M

The mapped anomaly for each month shows coherence in sign over very large areas (Fig. 6), much larger in fact, than the scan radii. There are two possible explanations for these large scale anomalies. The first possibility is that the mean value used to remove climatology from the observations has a bias of large spatial scale. We do not think this is the case, but it will not be proven until the mapped anomalies show oscillations in sign throughout the region during the course of several years. The second possibility is that the large scale anomalies are truly an indication of ocean variability. This will become more believable as reasonable, physical interpretation of them is achieved.

The preliminary analysis is encouraging. Some of the anomalies evolve slowly in time. For example, variation of the North Equatorial Countercurrent already discussed in the analysis of the temperature sections appears on the maps. The weak current (westward anomaly) in June 1979 (Fig. 6, top) has warm water on its northern side near 10°N, in accordance with the "thermal wind" relation. The strong current (eastward anomaly) in November 1979 (Fig. 6, middle) has warm water on its southern side south of 3° to 7°N. An interesting evolution of the anomaly begins in November 1979, with the warm zone on the equator in the central Pacific near 140°W. An earlier map (not presented) shows it entering the region from the east. Lack of data in the radio reports does not allow connecting it to the region off Central and South America during earlier months, as seen on the June 1979 map. From the Central Pacific this warm zone progresses westward and southward across the equator until it reaches New Guinea in February 1980 (Fig. 6, bottom). We hope that a more complete description of this evolution of the temperature field, particularly in the eastern Pacific, will be possible after all the observations from the ORSTOM, FNOC, and NOAA (PEG) programs, as well as data from the Shuttle and EPOCS programs are merged with the other radio reports.

FUTURE RESEARCH PLANS

Our future research plans are: 1) Make a careful comparison of these preliminary maps with results from the Shuttle, in order to fine-tune the statistical structure used in the interpolation scheme. 2) Map the heat content of 0/400m, sea surface temperature and mixed layer depth throughout the tropical Pacific using the largest possible merger XBT data. 3) Relate the variability to the wind field.

In the longer run, we intend to merge the analysis of the XBT records with sea level records. Historical data indicates that sea level and dynamic height are highly correlated (Fig. 7), at least in the tropical Pacific. Dynamic height in turn can be accurately estimated from the vertical heat integral in this region because of the tight T-S relationship. Ultimately, we hope that this sea level mapping effort can be extended into the realm of smaller, synoptic space and time scales through the inclusion of new observations becoming available in the satellite ara, such as current and temperature monitored with tracked drifters, (Patzert, 1981) and sea level with the satellite altimeter.

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Wyrtki, K., 1978: Monitoring the strength of equitorial currents from XBT sections and sea level. J. Geophys. Res. 83, 1935-1940.

Wyrtki, K., E. Firing, D. Halpern, R. Know, G.J. McNally, W.C. Patzert, E.D. Stroup, B.A. Taft, R. Williams, 1981: The Hawaii to Tahiti Shuttle Experiment. Science 211, 22-28.

FIGURE CAPTIONS

Figure 1. XBT sections by ships-of-opportunity January 1979 to June 1980. Number of sections obtained given in parentheses (). The start date is indicated on sections which did not begin prior to January 1979. Dashed lines give routes serviced by ORSTOM-Noumea, solid lines routes serviced by FNOC or NOAA, Monterey.

Figure 2. Meridional temperature sections (°C) near 157°E obtained by *Hachiyo Maru* between Noumea, New Caledonia and Japan. Temperature exceeding 29°C is stippled. Latitude of XBT drops indicated by x at bottom.

Figure 3. Development of the slope of the 20°C isotherm across the North Equatorial Countercurrent-Western Pacific. The depths of the 20°C isotherm at the northern and southern flanks of the current are indicated by D_n and D_s respectively. The mean depth is $\overline{D}$ and the difference is $\triangle D$. All temperature sections crossed Countercurrent near 157°E.

Figure 4. Same as Fig. 3 - Central Pacific. Temperature sections crossed Countercurrent between 130°-170°W (bottom).

Figure 5. Slope of the 20°C isotherm across the North Equatorial Countercurrent observed by ships-of-opportunity and by research ships and aircraft during the Hawaii-to-Tahiti Shuttle (Wyrtki et al, 1981). Month of 1979 indicated for each data pair.

Figure 6. Deviation (δ_A) from annual longterm mean temperature at 160 m. Cold anomaly shaded, warm anomaly clear, insufficient data blank. Distribution of XBT stations received by radio at FNOC given by inset at lower left.

Figure 7. Winter mean sea level observed at islands compared to dynamic height 0/1000 db observed during the January cruise of *R/V Ryofu Maru* along 137°E, 1967 to 1977.

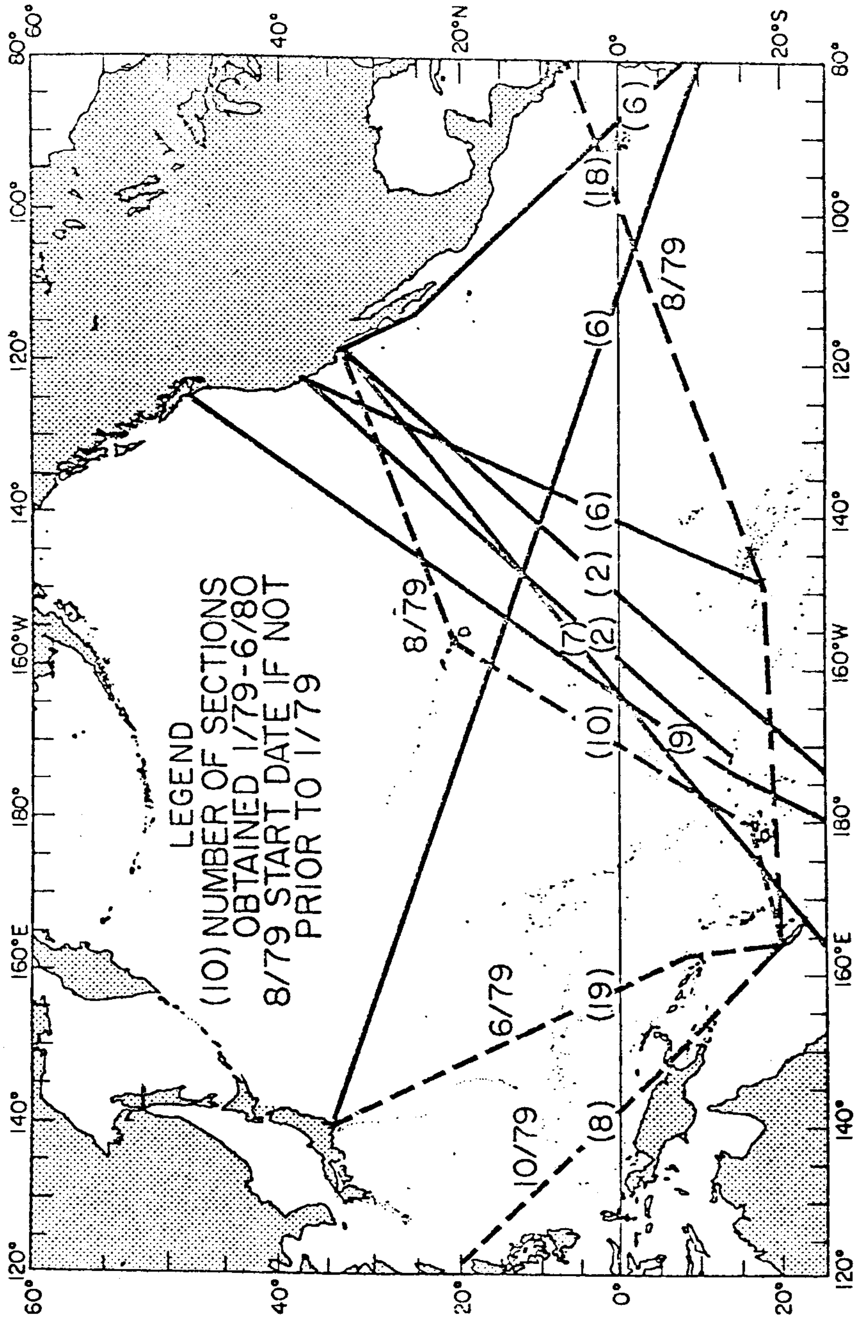

LEGEND
(10) NUMBER OF SECTIONS
OBTAINED 1/79-6/80
8/79 START DATE IF NOT
PRIOR TO 1/79
(6)
(18)
(6)
8/79
(6)
(2)
(7)
(2)
(10)
(9)
8/79
6/79
(19)
10/79
(8)
60°
40°
20°N
0°
20°S
20°
0°
20°
80°
100°
120°
140°
160°W
180°
160°E
140°
120°

FIGURE - 1

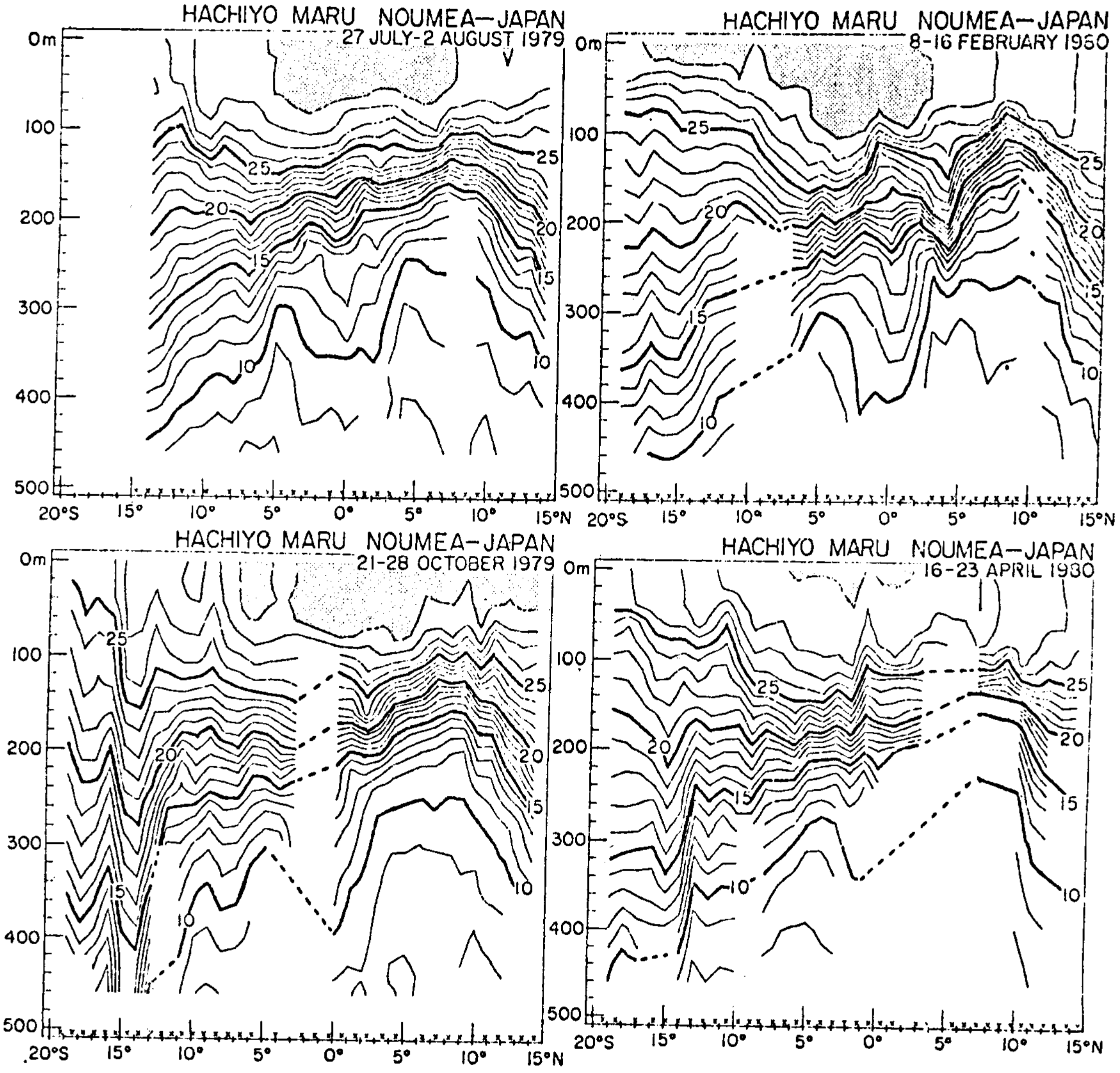

HACHIYO MARU NOUMEA–JAPAN
27 JULY-2 AUGUST 1979
HACHIYO MARU NOUMEA–JAPAN
8-16 FEBRUARY 1980
HACHIYO MARU NOUMEA–JAPAN
21-28 OCTOBER 1979
HACHIYO MARU NOUMEA–JAPAN
16-23 APRIL 1980
0m
100
200
300
400
500
25
20
15
10
20°S
15°
10°
5°
0°
5°
10°
15°N

FIGURE - 2

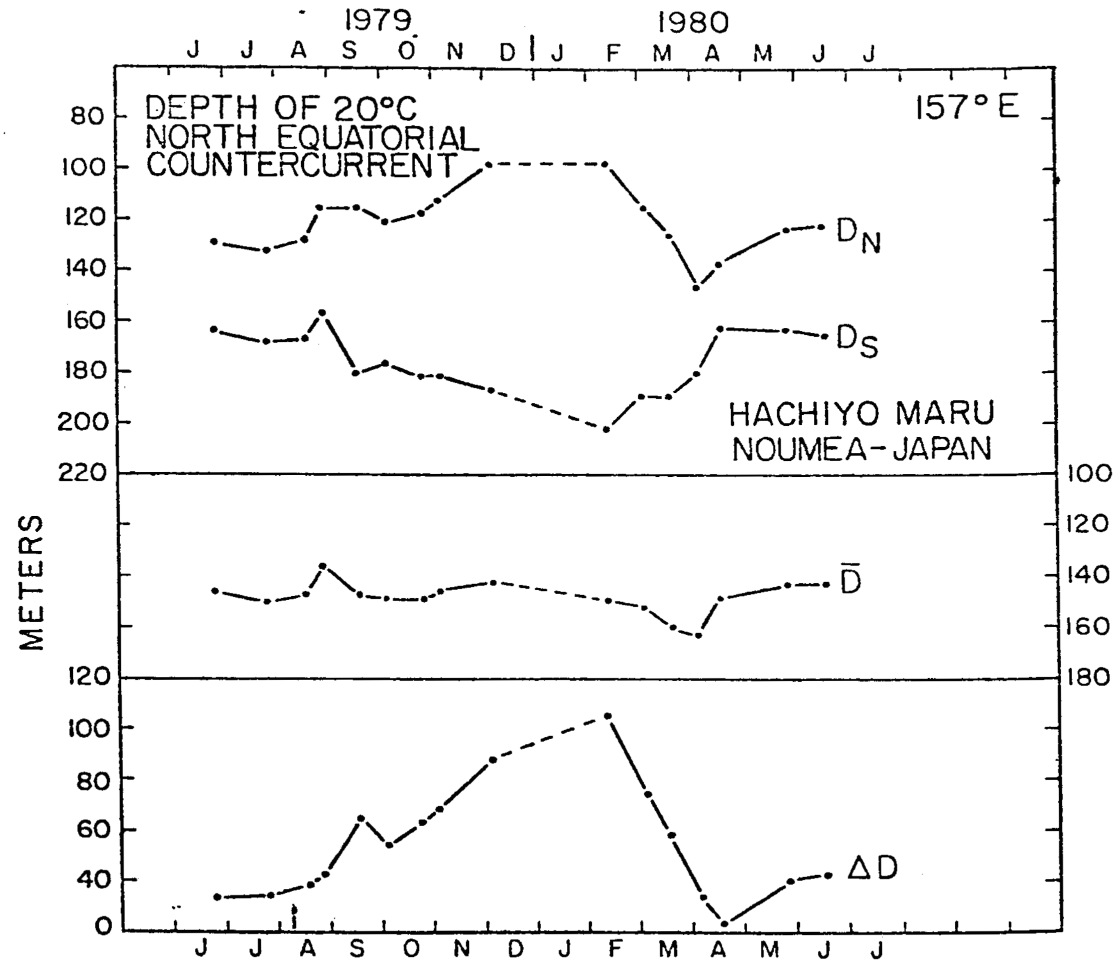

1979
1980
J J A S O N D J F M A M J J
DEPTH OF 20°C
NORTH EQUATORIAL
COUNTERCURRENT
157° E
80
100
120
140
160
180
200
220
D_N
D_S
HACHIYO MARU
NOUMEA-JAPAN
METERS
100
120
140
160
180
$\bar{D}$
120
100
80
60
40
0
ΔD
J J A S O N D J F M A M J J

FIGURE - 3

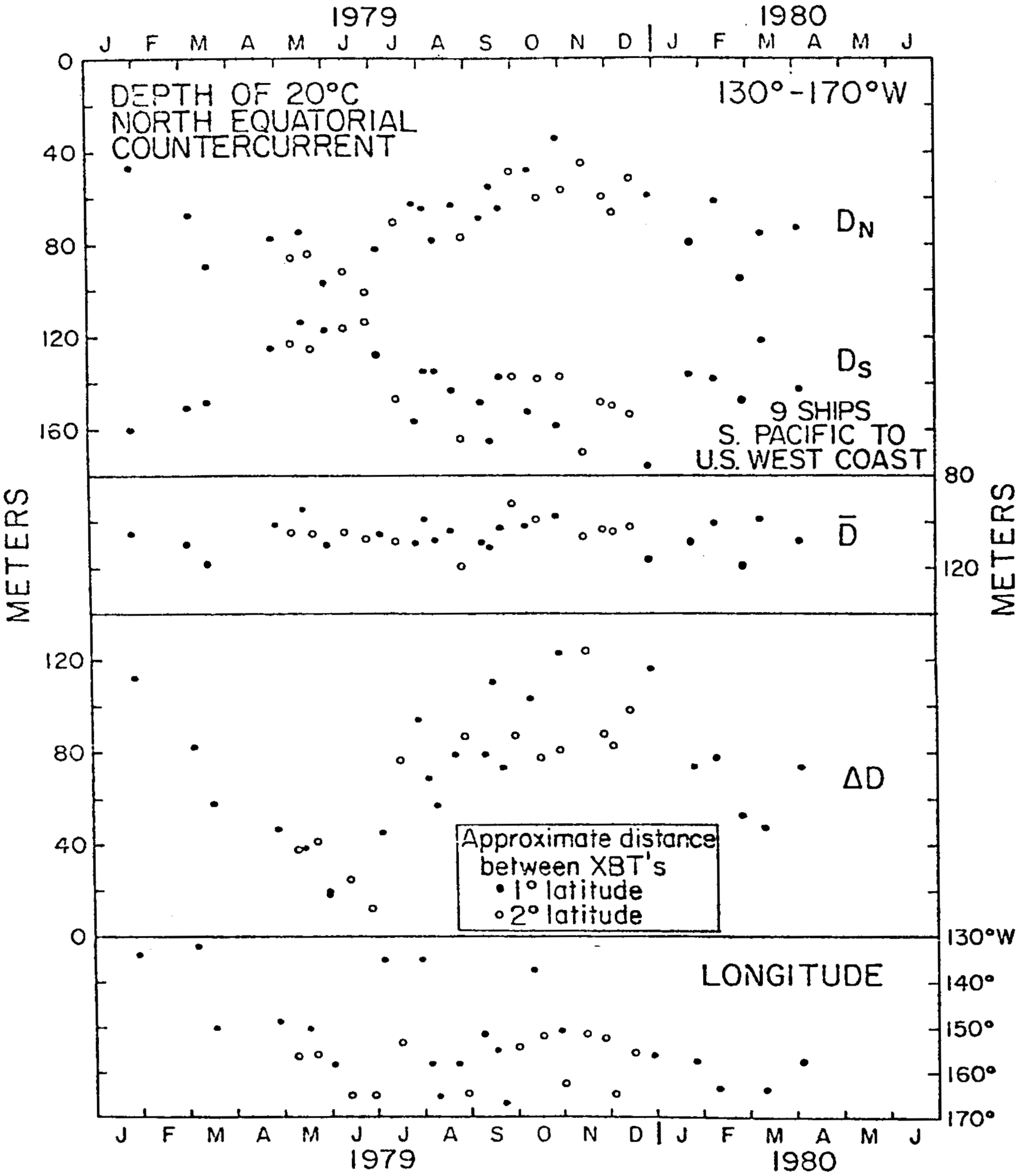

1979
1980
J F M A M J J A S O N D J F M A M J
DEPTH OF 20°C
NORTH EQUATORIAL
COUNTERCURRENT
130°-170°W
0
40
80
120
160
D_N
D_S
9 SHIPS
S. PACIFIC TO
U.S. WEST COAST
80
120
D̄
METERS
METERS
120
80
40
0
ΔD
Approximate distance
between XBT's
• 1° latitude
○ 2° latitude
LONGITUDE
130°W
140°
150°
160°
170°

FIGURE - 4

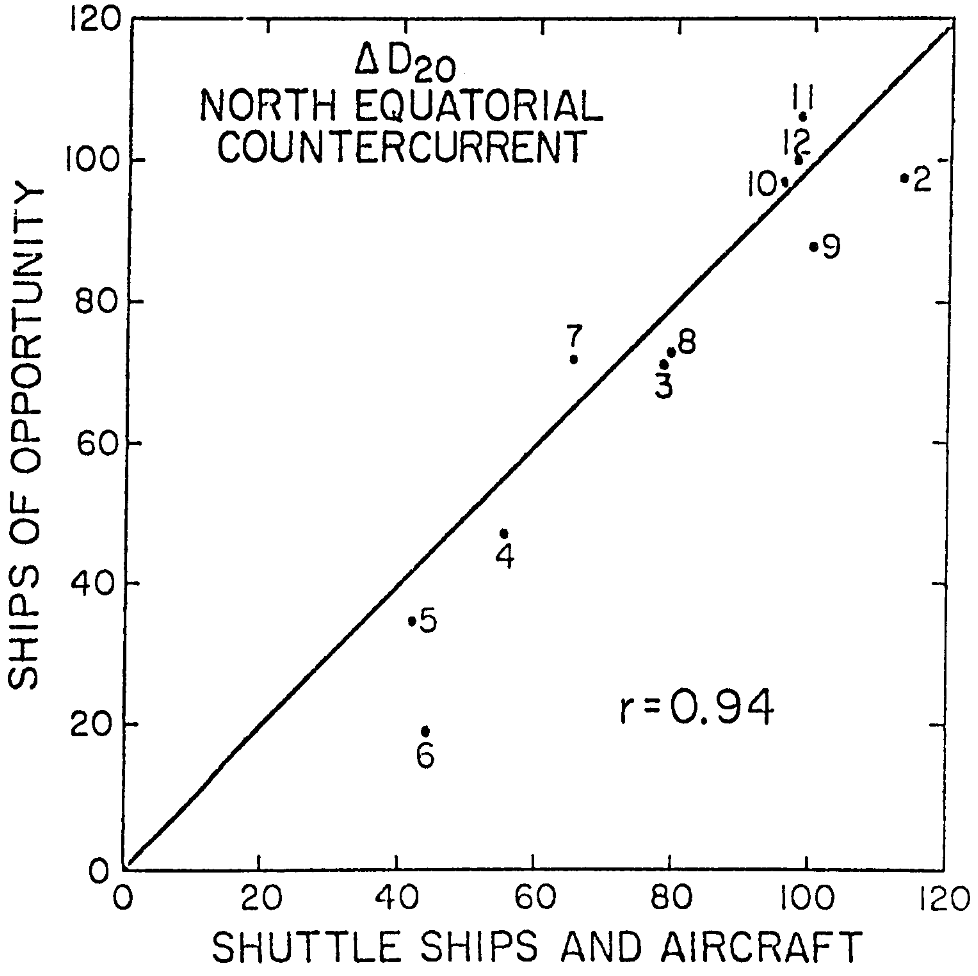
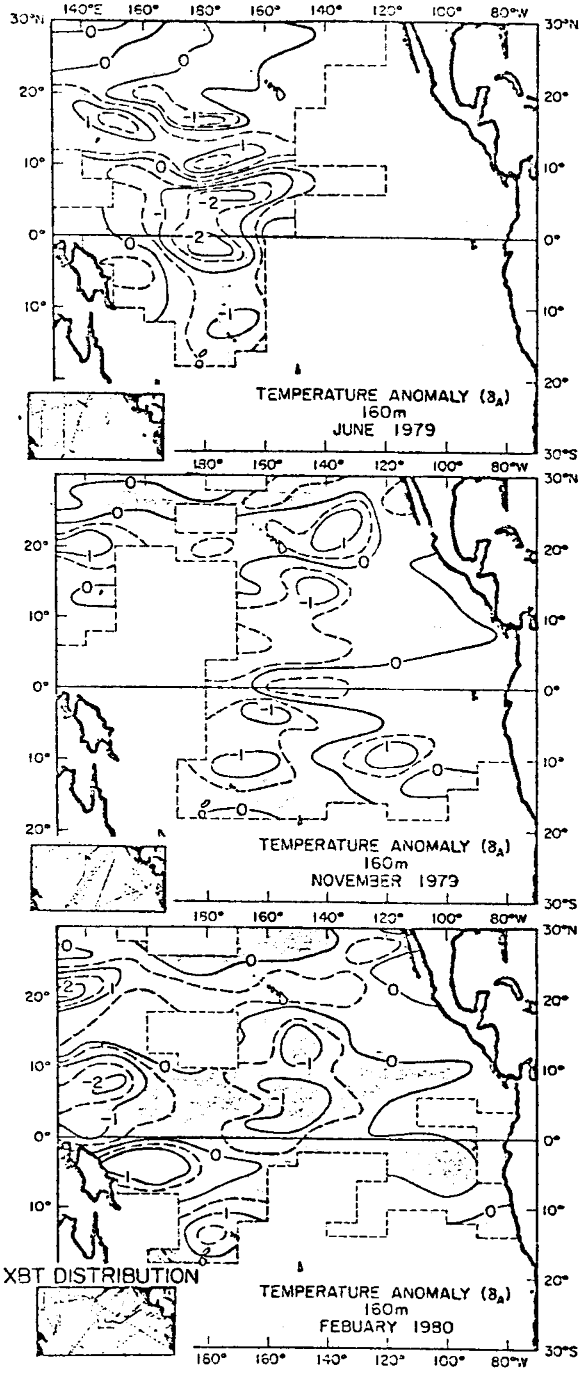

ΔD20
NORTH EQUATORIAL
COUNTERCURRENT
r=0.94
SHIPS OF OPPORTUNITY
SHUTTLE SHIPS AND AIRCRAFT
0
20
40
60
80
100
120
2
3
4
5
6
7
8
9
10
11
12

FIGURE - 5



TEMPERATURE ANOMALY (δ$_A$)
160m
JUNE 1979

TEMPERATURE ANOMALY (δ$_A$)
160m
NOVEMBER 1979

TEMPERATURE ANOMALY (δ$_A$)
160m
FEBUARY 1980

FIGURE - 6

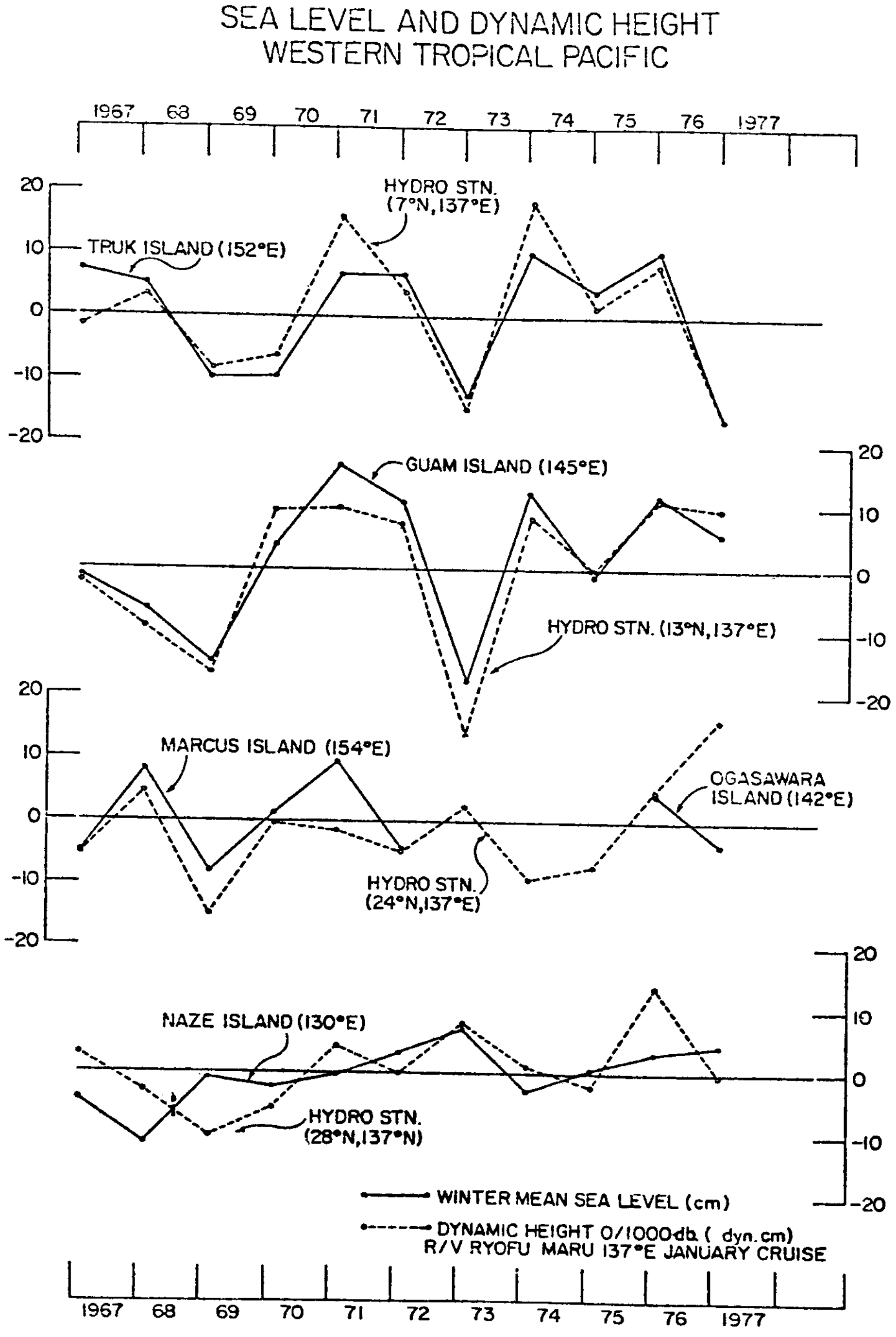

SEA LEVEL AND DYNAMIC HEIGHT
WESTERN TROPICAL PACIFIC
1967
68
69
70
71
72
73
74
75
76
1977
20
10
0
-10
-20
TRUK ISLAND (152°E)
HYDRO STN.
(7°N, 137°E)
GUAM ISLAND (145°E)
HYDRO STN. (13°N, 137°E)
MARCUS ISLAND (154°E)
HYDRO STN.
(24°N, 137°E)
OGASAWARA
ISLAND (142°E)
NAZE ISLAND (130°E)
HYDRO STN.
(28°N, 137°N)
WINTER MEAN SEA LEVEL (cm)
DYNAMIC HEIGHT 0/1000db. (dyn.cm)
R/V RYOFU MARU 137°E JANUARY CRUISE

FIGURE - 7