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# Evolution of the Western Pacific Ocean During the 1986–1987 El Nino

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**Abstract**—A series of 12 meridional transect along longitude 165 ° E in the western equatorial Pacific Ocean were made between mid-1986 and mid-1988: a time interval spanning an El Nino / Southern OScillation (ENSO) event. Data collected on these cruises provide a detailed (albeit temporally sparse) view of the oceanic changes which occur in the western Pacific during an ENSO event. The present work focuses on the evolution of the upper ocean thermohaline and zonal velocity fields as revealed by high resolution hydrographic casts and direct near surface velocity measurements. Onset of the El Nino was characterized by anomalous eastward transport of warm surface waters equatorward of 10 ° latitude (where anomalies are relative to a mean state defined by historical hydrographic data and recent observations during non-ENSO periods). The thermocline in the western Pacific shoaled in response to this export of surface water; near-equator surface dynamic height relative to $10^5$ hPa at event peak was 20 dyncm below historical non-El Nino levels. Vertical displacements of the water column which resulted in the dynamic height changes were confined to the upper 300–400 m of the ocean . Later in time, strong westward transport anomalies were observed and by mid-1988, sea level had recovered to its historical mean level.

## Introduction

The western equatorial Pacific Ocean has become the focus of intensive study in recent years in connection with the El Nino / Southern Oscillation problem. In this region, surface ocean temperatures approach and often exceed 30 ° C, leading to enhanced air-sea exchange of heat by evaporation. The spatial extent of the warm water pool, which is dictated by a complicated and poorly understood interaction of the ocean large-scale circulation and local processes, is intimately related to the evolution of the coupled ocean-atmosphere system (e.g., Cane, 1983;Rasmusson and Wallace, 1983). In an effort to better understand the circulation in the western Pacific and the characteristics of the oceanic variability there, hydrographic sections along longitude 165 ° E have been occupied repeatedly over the past four years (Fig.1). This intensive sampling program

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spanned the period June 1986 to June 1988, when the pacific experienced an El Nino event. Consequently, a detailed view of the evolution of the western Pacific Ocean during El Nino, comparable to that compiled by leetmaa et al. (1987) for the eastern Pacific, is now available.

## Observations and Analysis

Regular sampling between 20 ° S and 10 ° N was initiated on a biannual basis in 1984 by investigators from Noumea, New Caledonia. The cooperative research program between the United States and the People's Republic of China began twice yearly sampling between 10 ° N and 10 ° S in 1986. Last year the Nomea effort was expanded to quarterly sampling. 1987 also saw two additional cruises sample meridionally on or near 165 ° E. This work has resulted in a total of 12 sections along 165 ° E during the recent El Nino period(Table 1).

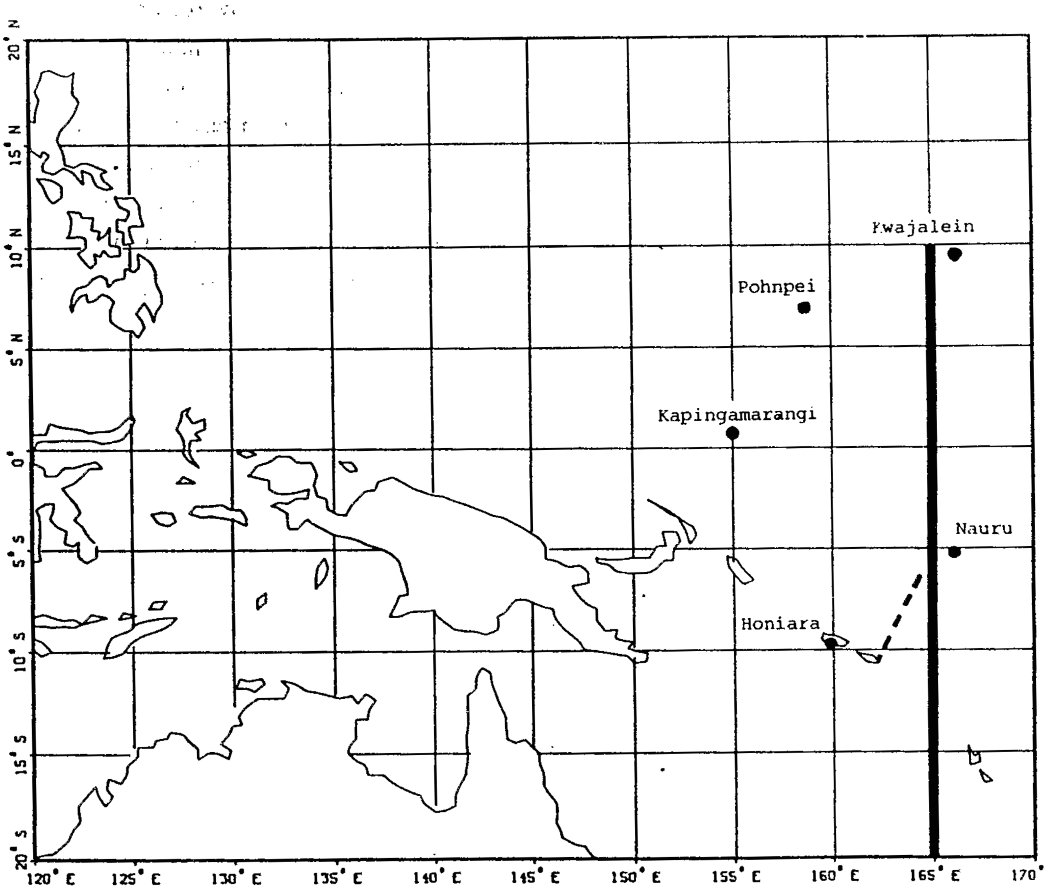


**Fig. 1.** Map of the western pacific ocean showing the section along 165 ° E. The dashed line marks the track of the US / PRC section. Also shown are the location of island sea level station used in the analysis

**Table 1.** the Sections Collected Along 165° E During 1986–1988

| Time | Cruise | Institution | Comments |
|---|---|---|---|
| 17–27 June 1986 | Surtropac 6 | ORSTOM[1] | 20° S to 10° N |
| 8–16 December 1986 | US / PRC 2 | WHOI / SOA[2] | 10° N to 6° S on 165° E,then to 10° S–160° E |
| 10–27 January 1987 | Surtropac | ORSTOM | 20° S to 10° N |
| 23 May–6 June 1987 | Saga II | SIO / IAG[3] | Section along 160° E to 5° 30′S then deflects east to be along 170° E south of 10° S |
| 2–21 July 1987 | Surtropac 8 | ORSTOM | 20° S to 10° N |
| 20–26 July 1987 | TEW–3 | PMEL[4] | Section from 5° S to 8° N |
| 9–20 September 1987 | Proppac 1 | ORSTOM | 20° S to 6° N |
| 13–22 October 1987 | US / PRC 3 | WHOI / SOA | Sampling as for US / PRC 2 |
| 16–28 January 1988 | Surtropac 9 | ORSTOM | 20° S to 10° N |
| 28 Mar–8 April 1988 | Proppac 2 | ORSTOM | 20° S to 6° N |
| 15–25 may 1988 | US / PRC 4 | WHOI / SOA | Sampling as for US / PRC 2 |
| 14–27 June 1988 | Surtropac 10 | ORSTOM | 20° S to 10° N |

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The present work focuses on the temperature and salinity profile data (and quantities derived from these) obtained on the 12 cruises. Meridional station spacing was typically 1° narrowing to 1 / 2° within 2–3° of the equator, and extended in depth to greater than 1000m. Primary attention is paid here to the upper kilometer of the water column.

The shipboard sampling, while relatively intensive in time, is nevertheless aliased by the energetic high-frequency variability of the equatorial ocean. Continuous sea level records from the region are used here to provide a complementary view of the evolution of the western Pacific. Records from 7–9° N,1–0° N and 9° S are discussed below (Fig.1).

Cruises which took place in January–February and June,1986 sampled the pre- El Nino conditions along 165° E. The surface dynamic height values (Fig.2) and sea level heights (Fig.3) at these times were comparable to or exceeded the historical mean levels as documented by Toole et al. (1988),(who also touch on the large differences between the nearly contemporaneous cruises in Jannuary–February,1986). Surface temperatures observed on these cruises were very warm, approaching and occasionally exceeding 30° C near the equator.

Sea level in the latter half of 1986 began to change significantly: falling at 7–9° N, rising slightly near the equator and falling slightly at 9° S. The result was an enhancement of the northward pressure gradient north of the equator and a relaxation (and possibly a reversal) of the northward gradient south of the equator. These changes were reflected in perturbations of the zonal geostrophic velocity,the sense of which was for increased eastward flow.

The third US / PRC cruise sampled 165 ° E during this period. Surface dynamic height about the equator was approximately 5 dyn-cm above the historical mean in December, 1986 but was some 10 dyn-cm below the mean at 8 N and S (FIgure 2). Strong eastward transport anomalies for the surface waters were calculated for this section (Fig.4). Between 9 ° N and 9 ° S the net eastward transport of water above the 23.5 kg $m^{-3}$ potential density surface was $46 \times 10^6 m^3 s^{-1}$. This eastward export of the warm surface waters is a characteristic feature of the onset of El Nino (*e. g.*, Wyrtki,1975).

The sea level date indicate that the period of strong eastward flow persisted into 1987 (Fig.3). In mid-January, sea level at 7–9 ° N and 9 ° S began to rise while near equatorial levels fell, reducing net height differences along the section. The January, 1987 cruise dynamic height data offer a consistent view: heights were order 10 dyn-cm below the historical mean south of 6 ° N and there was little meridional variation (Fig.2). As a consequence, minimal net zonal geostrophic transport of surface waters occurred at this time. Sea level continued to evolve in early 1987 to a point where all island stations attained virtually the same height.

Throughout mid-1987, surface heights near the equator were consistently 10 to 20 dyn-cm below the historical mean, and there was little relief to the surface topography along 165 ° E. The major export of warm surface waters to the east occurred in late 1986. Comparison of the surveys conducted prior to the El Nino with that conducted in September–October, 1987 allows estimation of the net loss of western Pacific warm surface waters during this period. The change in volume of waters above the 23.5kg $m^{-3}$ potential density surface, equatorward of latitude 9, between 165 ° E and the western boundary was extimated as $-2 \times 10^{14} m^3$(the 23.5kg $m^{-3}$ surface shoaled an average of 42 m in the study region). For this to have occurred uniformly over a 6-month period, net eastward transport across the 165 ° E section would have had to have been $13 \times 10^6 m^3 S^{-1}$. The much larger September, 1987 transport estimate suggests the export was actually more episodic (only two months of eastward transport at the September, 1987 rate of $46 \times 10^6 m^3 s^{-1}$ is required to export $2 \times 10^{14} m^3$ of surface water).

Low surface dynamic height in the western Pacific during El Nino reflects shoaling of the thermocline. Comparison of sections before and during the El Nino documents the vertical extent of vertical displacements associated with the event. upward displacements appeared confined to the top 300–400m of the water column. Potential density profiles near the equator from mid-1987 were nearly identical to the historical mean profiles and pre-El Nino profiles below 400 m (Fig.5). This result contrasts with observations from the mid-and eastern Pacific during the 1982–1983 El Nino which exhibited sizable vertical motions down to at least 1000m depth (Toole and Borges, 1984; Toole, 1985; Leetmaa et al., 1987).

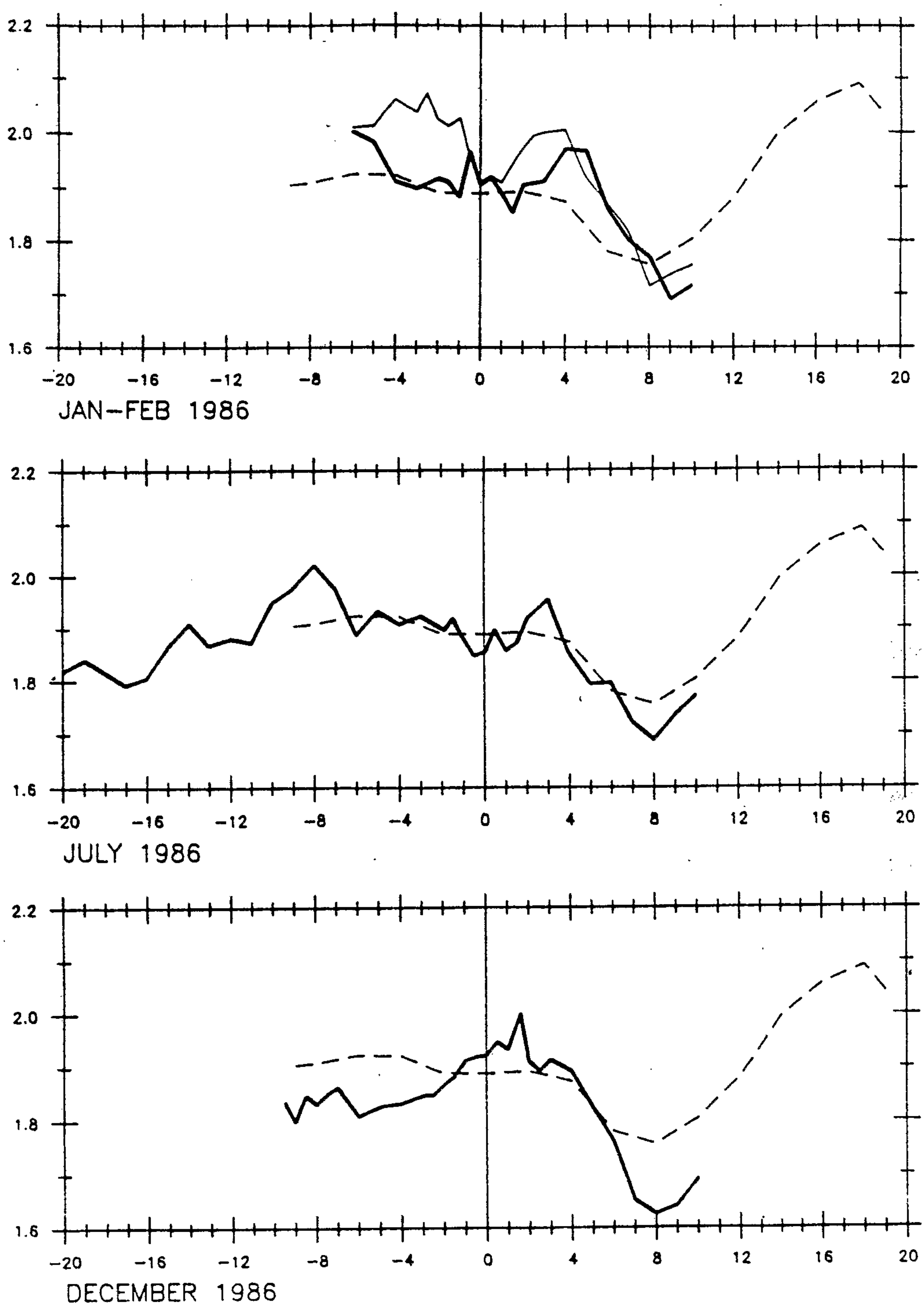



**Fig.2.** Meridional sections of surface dynamic height relative to $1000 \times 10^2$ hPa observed along 165 E in the 1986- 1988 time period

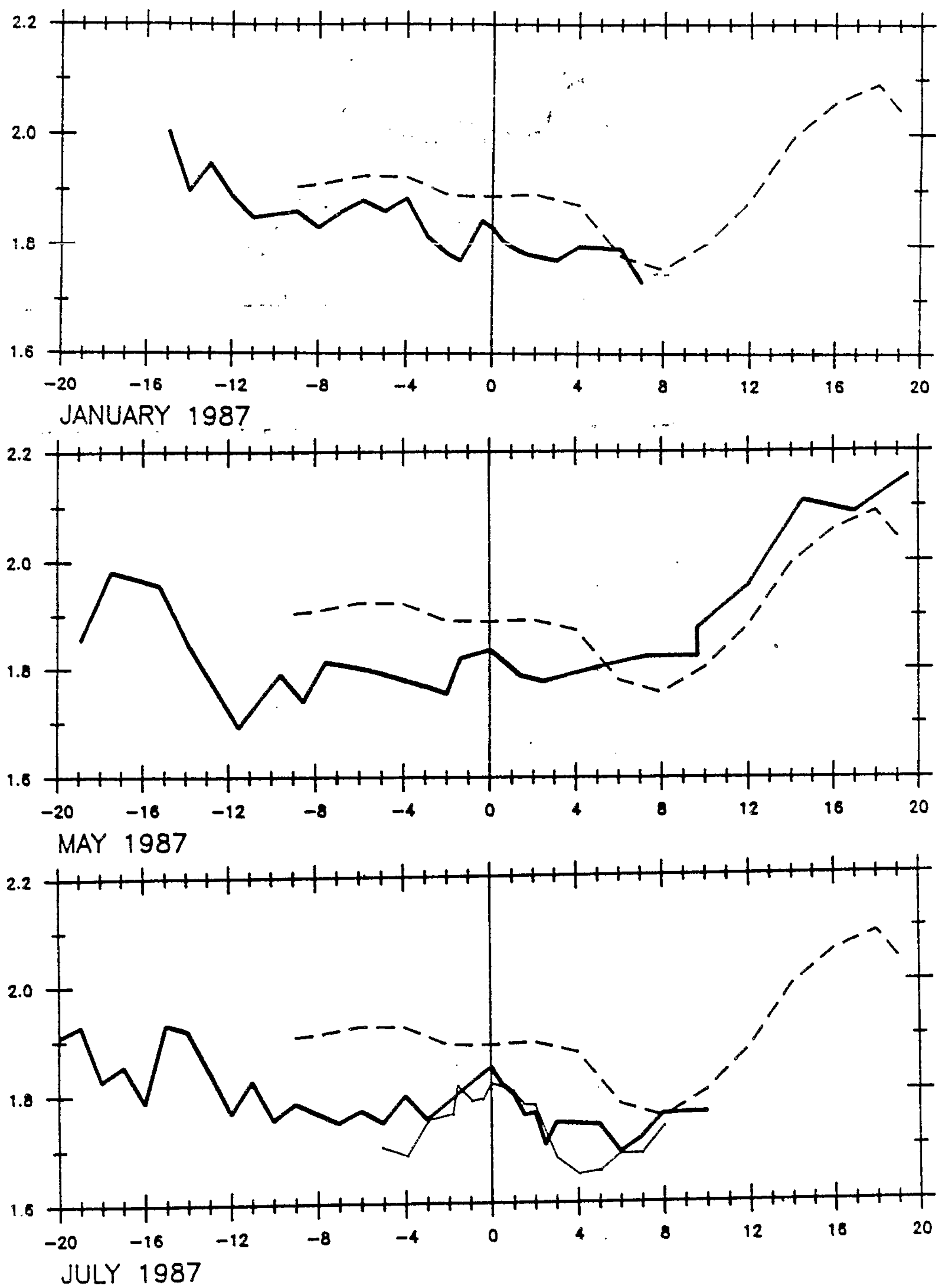



**Fig.2.** continued

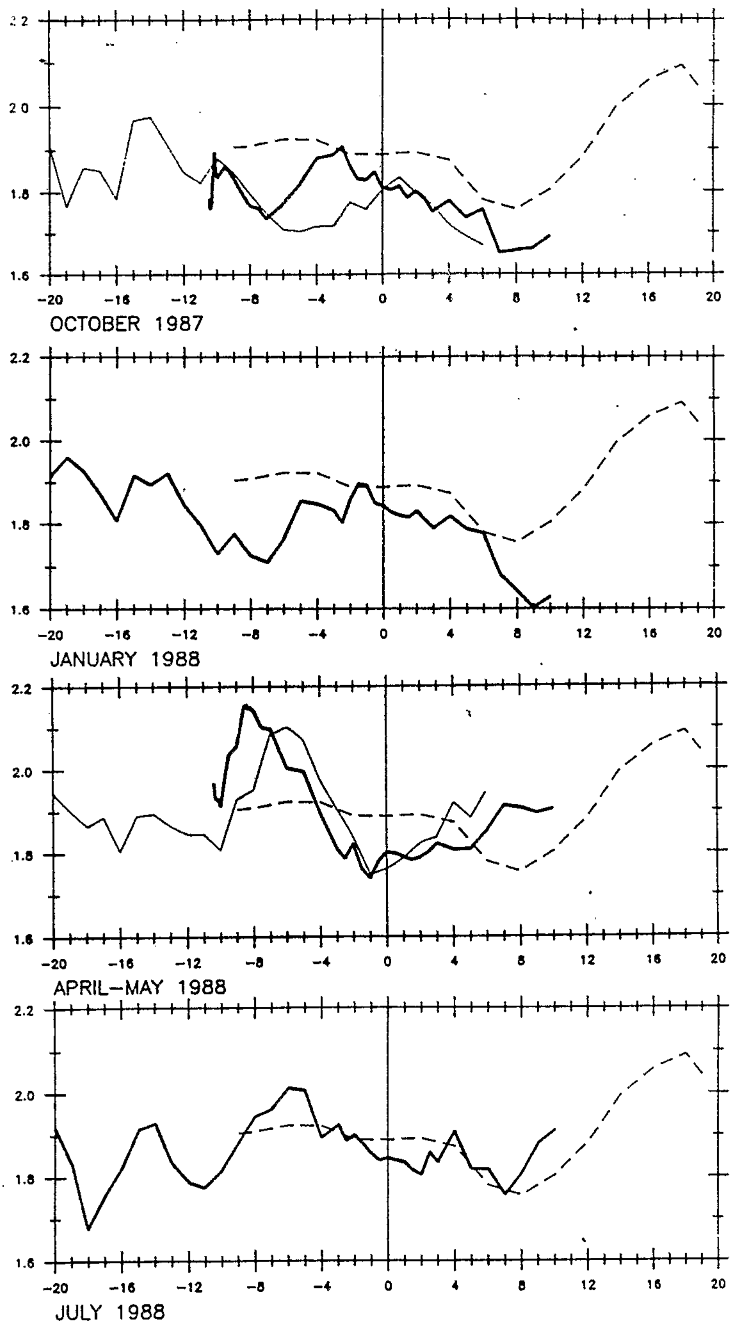


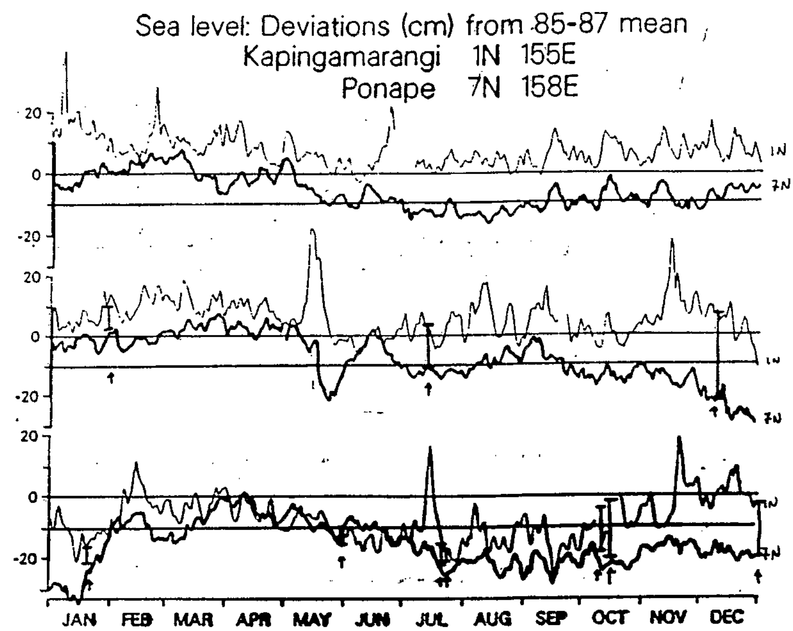

Fig.2.continued

Sea level near the equator and at 9 ° S began to recover in October, November 1987 (Fig.3). Levels at 7-9 ° N did not change significantly at this time, however, which lead to a sizable northward pressure gradient by year's end. Net eastward geostrophic flow north of the equator is implied by this gradient. The sea level data and section data in late 1987–early 1988 indicate only weak westward flow south of the equator (Fig.2,3). It is therefore not clear how near equatorial sea level (and the volume of warm surface water.) recovers during this period. Perhaps meridional redistribution of surface water was responsible rather than zonal convergence.

Significant westward transport of surface water was observed in boreal spring 1988. The sections in April and May observed depressed surface dynamic heights near the equator with higher levels poleward (Fig.2). Virtually no eastward geostrophic surface flow was found anywhere equatorward of 8 ° latitude (Fig.4). Net westward transport equatorward of 9 ° of water above the 23.5kg $m^{-3}$ surface in May was $26 \times 10^6 m^3 s^{-1}$. During this time, equatorial dynamic height at 141 ° 30′E was close to its mean value, and a significant eastward pressure gradient was sampled along the equator between 141 ° and 165 ° E. The signature of equatorial upwelling (outcropping of isotherms about the equator) was prominent on the 165 ° E section and the equatorial undercurrent was stronger than had ever been observed at this location (M. McPhaden, personnel communication). By June, 1988, near equatorial dynamic height at 165 ° E had returned to its mean level, the volume of warm surface water had recovered to the pre-El Nino level and the subsurface vertical density structure was indistinguishable from that sampled in early 1986. The upper layer heat content was below pre-El Nino values, however. The areal averaged temperature of the water along 165 ° E above the 23.5kg $m^{-3}$ surface and equatorward of 10 ° latitude was nearly 0.5 ° C colder in 1988 than in early 1986. Whereas surface temperatures at the equator in early 1986 were nearly 30 ° C, they fell below 29 ° C in 1988. Equatorial upwelling was probably responsible for the colder temperatures in 1988.

## Conclusions

Thanks to a series of ongoing sampling programs in the western Pacific Ocean, a detailed view of the evolution of the Pacific during the 1986–1987 El Nino event is now available. Shortly before the event, surface dynamic height near the equator was comparable to or exceeded slightly the historical mean levels. Surface temperatures approached 30 ° C about the equator. Onset of the event in late 1986 involved an export of warm surface waters to the east. Sea level near the equator did not change significantly at this time but levels 800 km off the equator were significantly depressed (leading to sizable eastward geostrophic flow). By early 1987, the eastward export of waters had slowed; equatorial sea level had fallen and little relief to the surface topography was



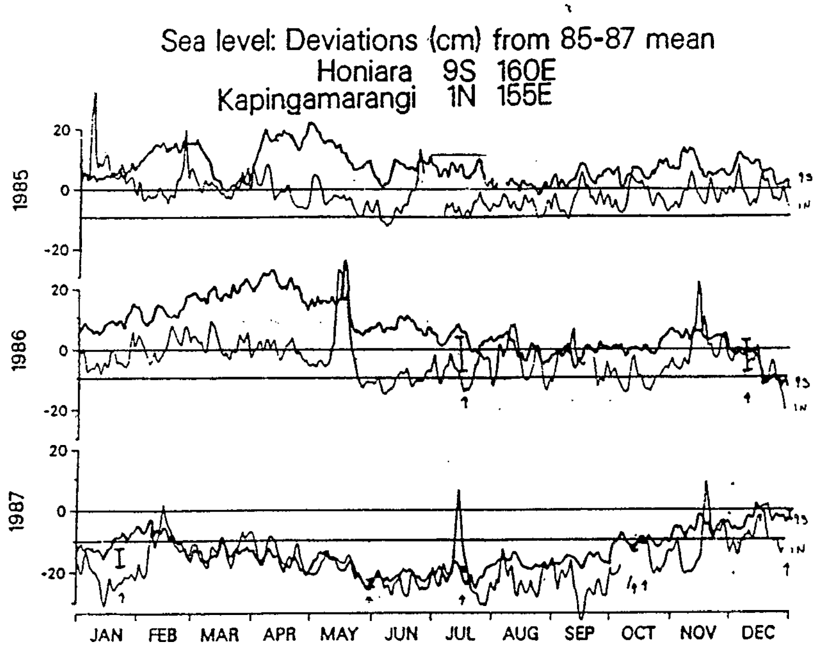




**Fig.3.** Sea level heights: Deviations (cm) from 1985–1987 mean

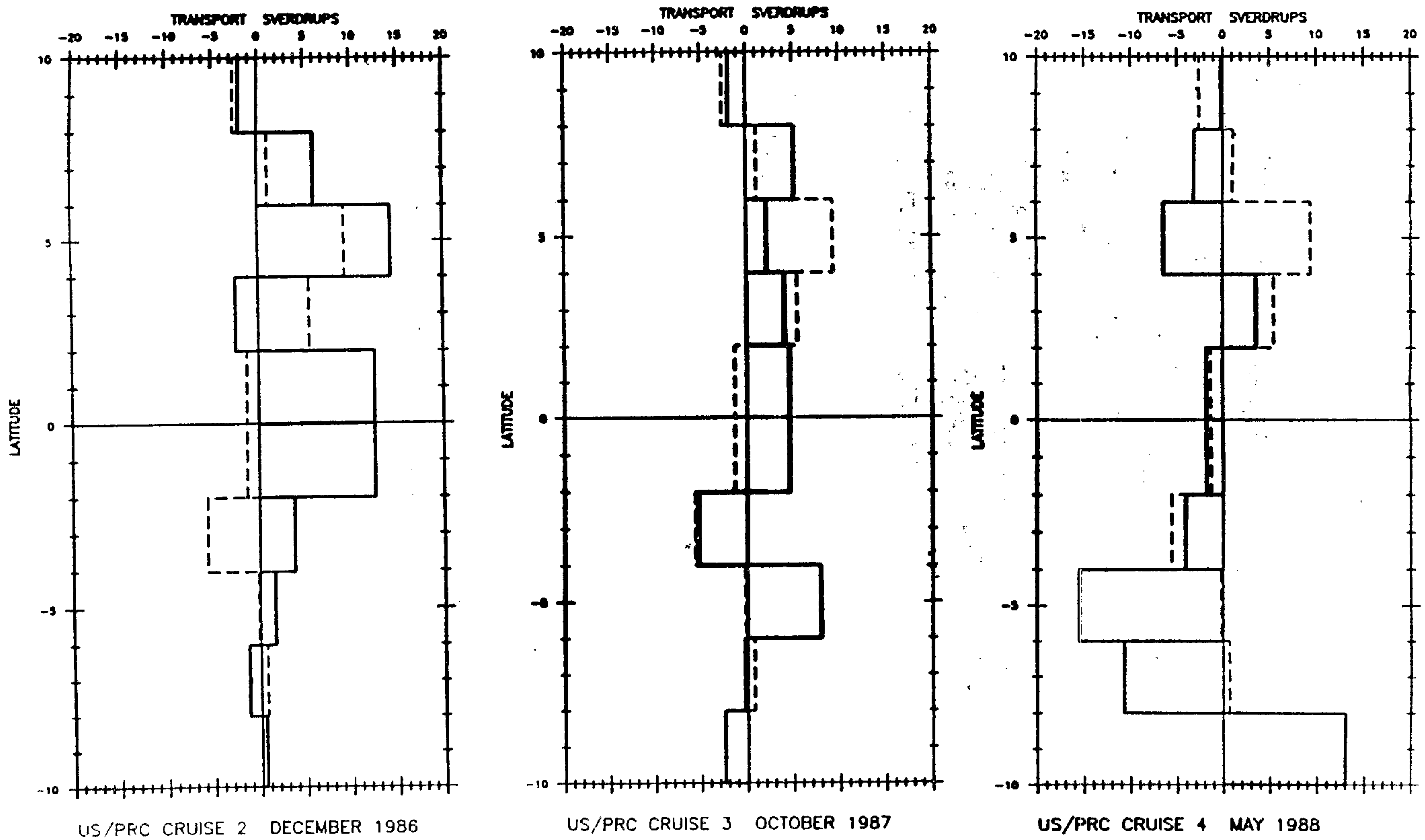



Fig.4. Meridional distribution of zonal geostrophic transport of water above the 23.5 kg m$^{-3}$ surface. The dashed line gives the annual mean transport

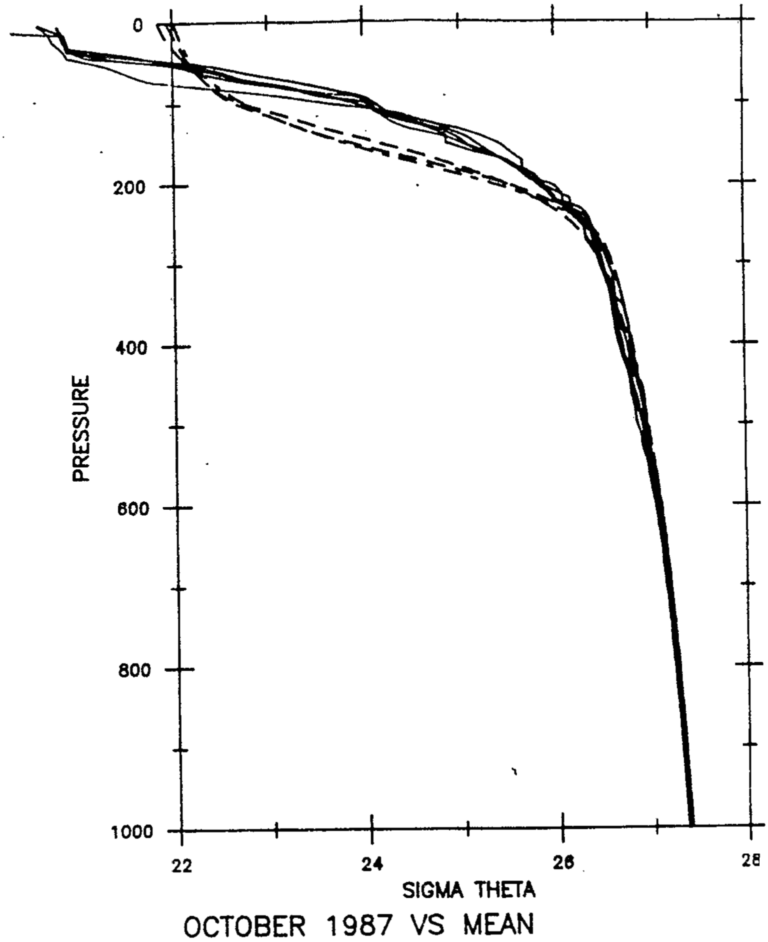



Fig.5. Profiles of potential density between 2 N and 2 S observed in October 1987 (solid lines) and the annual mean profiles (dashed lines)

found. Consequently, geostrophic currents were weak. At event peak, the thermocline in the west had shoaled approximately 40 m above normal conditions. The western Pacific surface height field began to recover in late 1987, but the zonal current field remained weak until boreal spring, 1988 when strong westward flow was sampled. By mid-1988, the hydrographic conditions along 165 ° E were comparable to those sampled before the event with the exception of somewhat colder surface layer temperatures.

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