Variable Currents in the Western Pacific Measured During the US/PRC Bilateral Air-Sea Interaction Program and WEPOCS

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Abstract

As the ensemble of current profile sections in the western tropical Pacific increases, we begin to get a picture of the annual and interannual variability of circulation in the region. The data sets considered here—ADCP sections from two WEPOCS cruises and 4 US/PRC TOGA cruises—do not resolve the seasonal cycle, but they do span the 1986-87 El Niño event and show some of the current variability associated with it. The most striking result is the contrast between the ever-present New Guinea Coastal Undercurrent and equatorial undercurrent on 141°E, and the lack at 165°E of any persistent currents other than the Tsuchiya jets. The net transports across 165°E of water warmer than 26° were 77×10^6 m^3 s^{-1} to the east in December 1986, early in the El Niño event, and 50×10^6 m^3 s^{-1} to the west in May 1988, following the event. There was little net transport in October 1987.

1 Introduction

The US/PRC Bilateral Air-Sea Interaction Program (a contribution to TOGA: Tropical Ocean—Global Atmosphere) is a cooperative China-US meteorological and oceanographic study of the western tropical Pacific. Emphasis is on annual and interannual variability associated with El Niño and the Southern Oscillation. Five of the eight cruises planned have been completed, and a sixth is underway (as of mid-May, 1989). An acoustic Doppler current profiler (ADCP) was installed before the second of these cruises. Current measurements made with this instrument on cruises 2–4 and 6 show moderate variations in currents such as the Kuroshio, the Mindanao Current, and the New Guinea Coastal Undercurrent. In other areas the currents varied greatly in connection with the 1986-87 El Niño, which occurred during this series of cruises (McPhaden *et al.*, 1989). Cruise 2, November–December 1986, took place during the early stages of the event. Cruise 3, September–October 1987, was late in the El Niño. Cruise 4, April–May 1988, closely followed the end of the event.

The intersection between the equatorial waveguide and the western boundary, the north coast of New Guinea, is a particularly fascinating part of the western tropical Pacific. The growing ensemble of current surveys there includes ADCP measurements from three cruises of the Western Equatorial Pacific Ocean Circulation Study (WEPOCS; Lindstrom et al., 1987). Meridional sections from the second and third WEPOCS cruises (January–February 1986 and June–July 1988) are included here for comparison with the US/PRC sections.

2 Data

All data shown here were obtained with standard 150-kHz profilers made by RD Instruments. The profilers have been improved since the WEPOCS II, and areas of possible bias in the early cruises (WEPOCS II and US/PRC 2 and 3) have been identified (Chereskin et al., 1989). The magnitude of the bias cannot be predicted accurately enough to be removed, so regions where the bias may exceed about 10 cm/s have been edited out. This reduces the depth range of the earlier sections.

Navigation for the calculation of absolute velocities was provided by a single-channel Transit receiver (Magnavox 1105) on the PRC ships (Xiangyanghong #5 for cruise 2, Xiangyanghong #14 for the others), and by a dual channel Transit receiver (Magnavox

1107 on WEPOCS II, Magnavox 1157 on WEPOCS III) combined with a GPS receiver (Trimble) on the Moana Wave. In WEPOCS III and in the US/PRC cruises starting with 4 the Transit fix quality was improved by using the ADCP as a speed log. The GPS receiver was also upgraded between WEPOCS II and WEPOCS III. The quality of the navigation is correspondingly highest on WEPOCS III and lowest on US/PRC 2.

Absolute velocities were calculated using a reference layer from about 50–170 m. (See Kosro, 1985, for a good explanation of the method of calculating absolute currents from ADCP measurements and position fixes.) For US/PRC 2–4 the absolute velocity of this reference layer averaged between Transit fixes was smoothed with a 12-hour Blackman filter. With the ship travelling at a maximum speed near 10 m/s, this causes wavelengths less than 200 km along the cruise track to be reduced in power by half or more. On sections with CTD stations the average speed of the ship was reduced to about 4 m/s, so the half-power wavelength was about 80 km. These limitations in horizontal resolution, imposed by the infrequency and inaccuracy of Transit fixes, cause the most serious distortions of our estimates of circulation in regions of large horizontal gradients, such as near the Philippines and Papua New Guinea. A narrower filter (typically 6 hours) was used to smooth the reference layer velocity on the cruises with better navigation, permitting finer horizontal resolution.

Various approaches have been used to calibrate the transducer orientation and amplitude factor for each of the cruises, depending on available navigation and other conditions (Pollard and Reed, 1989; Joyce, 1989). Calibration of the orientation averaged over several days appears to be good to something like 0.1° on the WEPOCS cruises, but could be uncertain to as much as 1.0° on US/PRC 2, the worst case. This would lead to a systematic 7-cm/s error in speed on the 165°E section, assuming an average ship speed of 4 m/s. The error in transport in a 100-m depth interval would then be 0.8×10^6 m^3 s^{-1} per degree latitude.

3 Maps of circulation

Maps of currents averaged from 30–75 m and 175–225 m show the general pattern of the circulation in the cruise region (Figure 1). Some points to note:

- The Mindanao current is consistently strong and deep, while the currents at comparable latitudes to the east are generally more variable and decay more rapidly with depth.
- Variability in the equatorial zone is much greater at the shallower level than near 200 m. For example, the shallow currents along the equator between 145°E and 157°E during May 1989 (US/PRC cruise 6) differ in direction by 90–180° from those one year earlier (US/PRC cruise 4).
- Currents are much more variable at 165°E than at 141.5°E at both levels shown here. At 141.5°E the NECC, the EUC, and the New Guinea Coastal Undercurrent (NGCUC) are present in all sections. There appears to be no major current common to all sections at 165°E.
- The region of high variability includes the NECC and the SECC, which are absent from 165°E in cruise 4 (May 1988).

The difficulty of distinguishing short-term temporal variations from spatial gradients is ever-present in the interpretation of data from cruise tracks at low latitudes. The US/PRC cruise tracks include three approximately meridional sections with equator-crossings between about 157°E and 165°E. The coherence of features among these sections on cruises 3 and 4 suggests that each map shows real spatial patterns, not just aliased temporal changes. For example, consider the 175–225-m layer during cruise 3. The zonal velocity component on the equator is eastward at 141°E (in the EUC), decreases toward the east to a null at about 157°E, and reverses to westward in the 165°E section. The null at 157°E is found both at the end of the section along the equator on October 7, and again on October 23 during the northwestward transit to Guam.

4 Meridional sections

The vector maps (Figure 1) show some current reversals near 141°E from one cruise to the next in the 30–75-m layer, but in the deeper layer the EUC and the NGCUC were always present. Looking at a series of meridional sections from January 1986 to May 1989 (Figure 2), we see that the strength of the NGCUC varied by about a factor of two, from just over 40 cm/s in early May 1988 to more than 80 cm/s in late June of the same year. The core depth was usually near 200 m. An exception is US/PRC 3, October 1987, when the NGCUC might be described as having "surfaced", and a core with 100 cm/s was found at 70 m.

The EUC near 141°E also varied in strength from one section to the next. The minimum in this series was about 40 cm/s in June 1988 and May 1989, and the maximum was 70 cm/s in October 1987. The

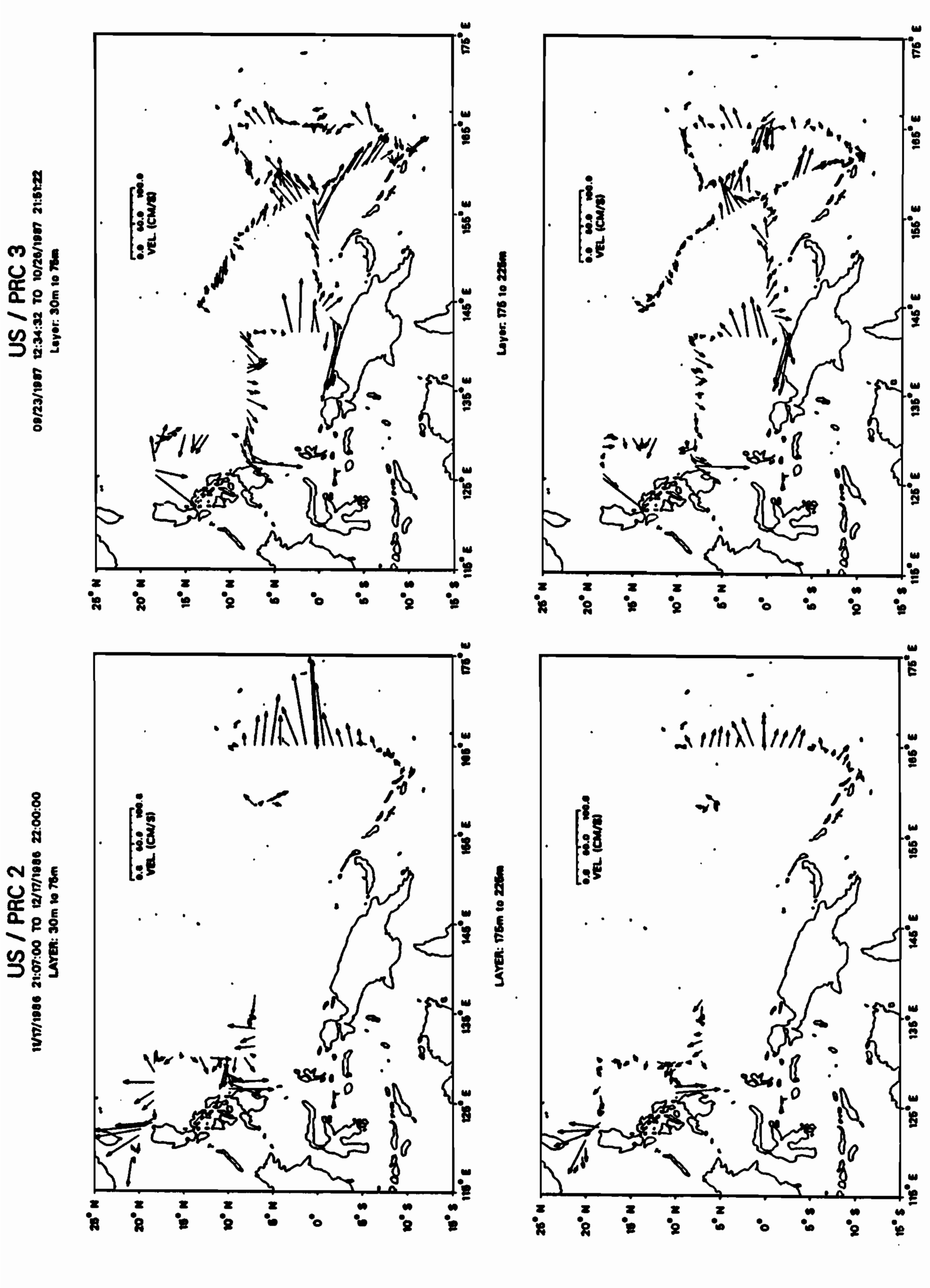
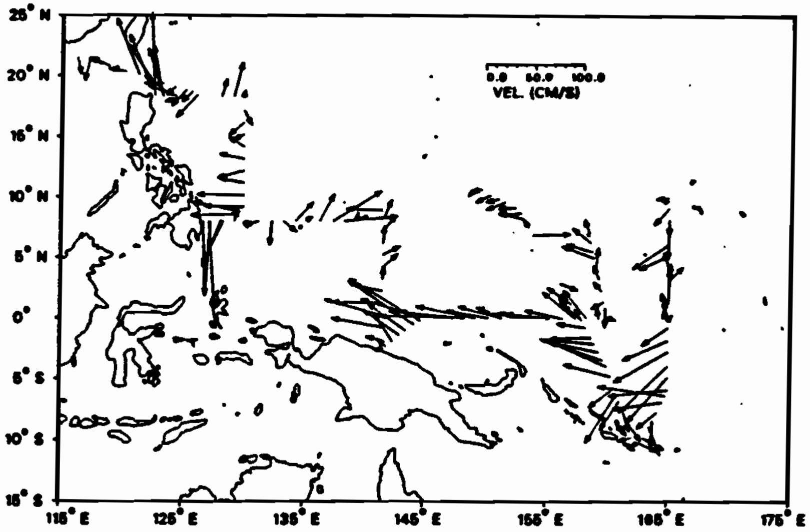
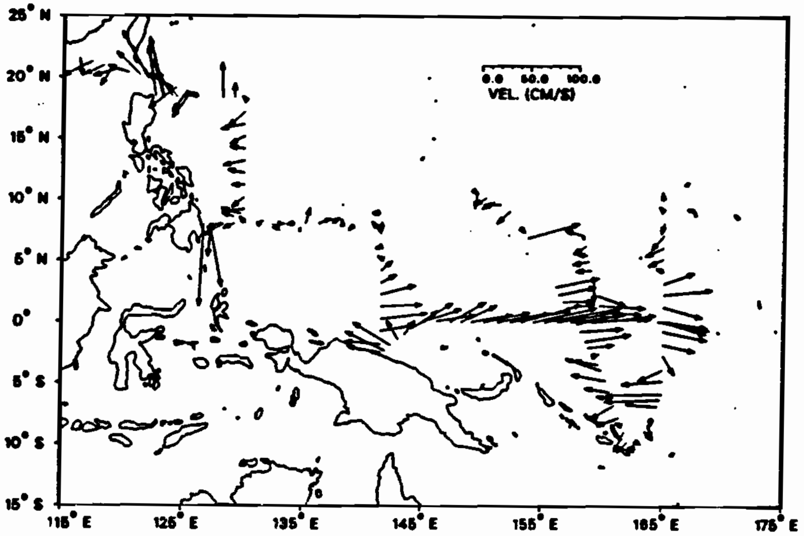


Figure 1: Currents averaged from 30–75 m (top) and 175–225 m (bottom) on the US/PRC cruises.

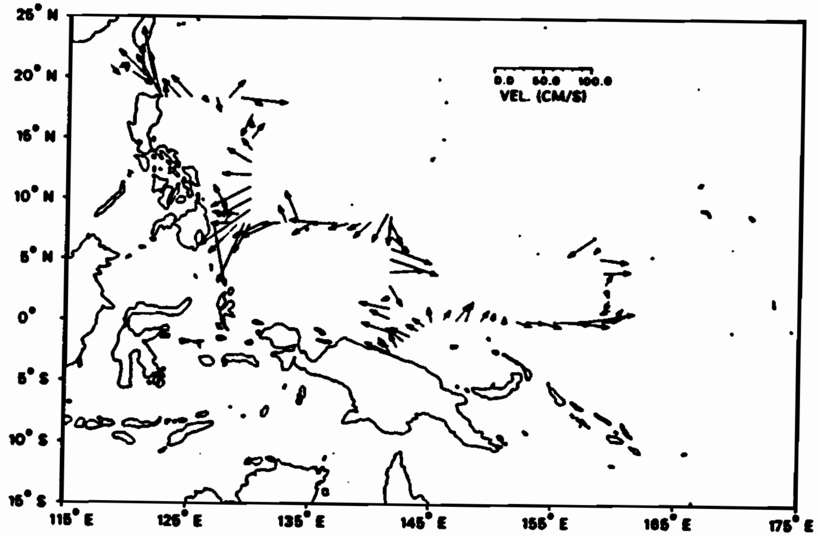
US / PRC 4
04/21/1988 09:15:00 TO 05/26/1988 20:12:00
LAYER: 30m to 75m



LAYER: 175m to 225m



US / PRC 6
04/20/1989 16:58:21 TO 05/09/1989 20:27:14
Layer: 30m to 75m



Layer: 175m to 225m

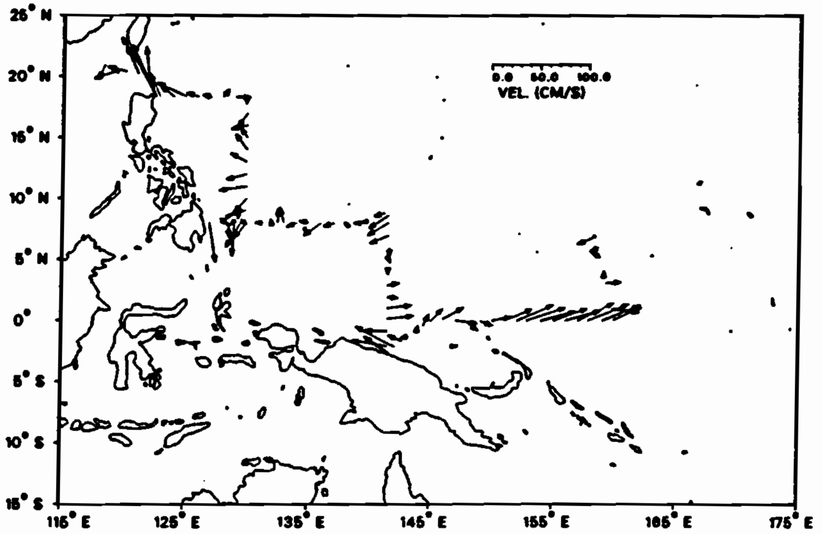
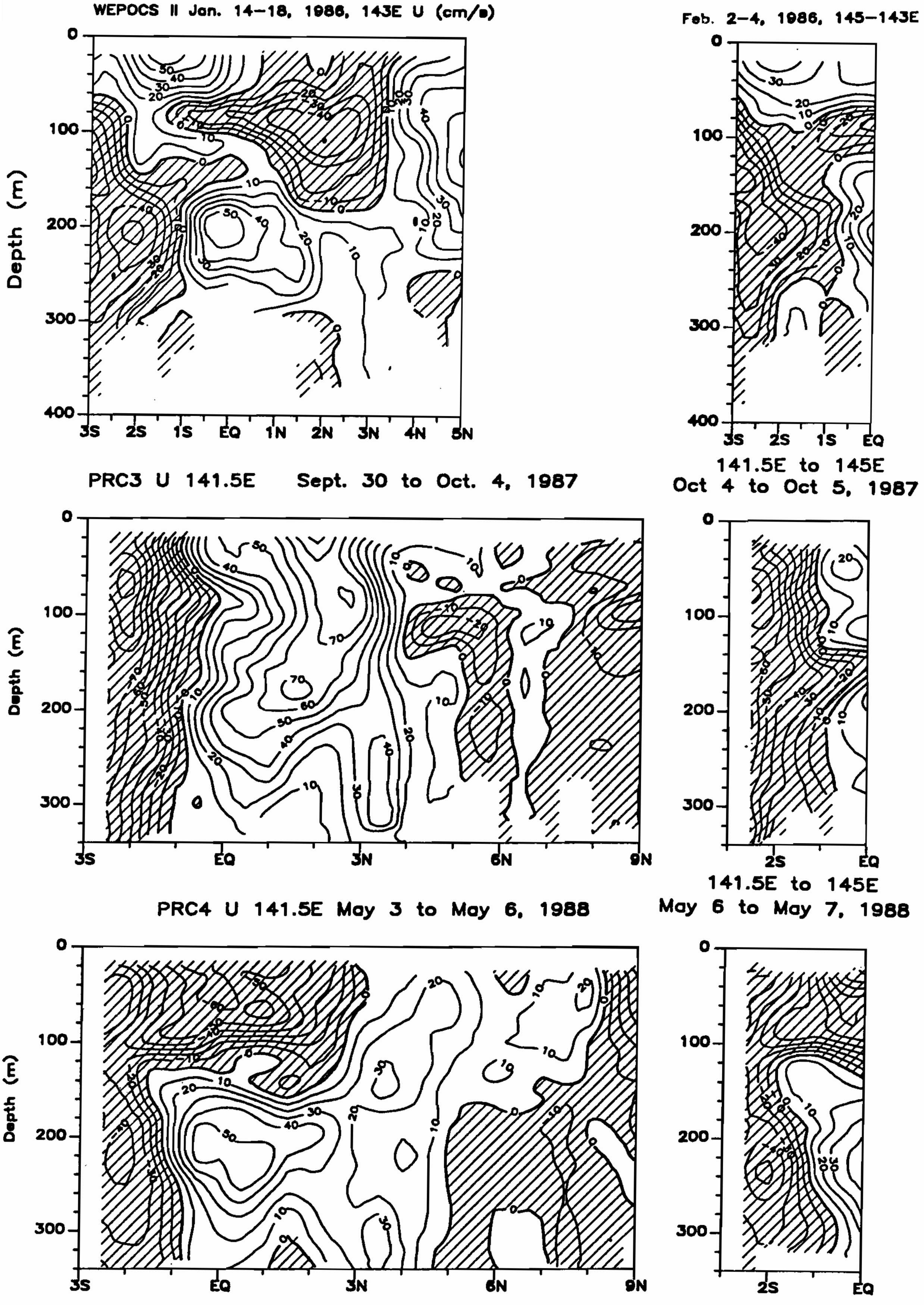


Figure 1, cont.



WEPOCS II Jan. 14–18, 1986, 143E U (cm/s)

Feb. 2–4, 1986, 145–143E

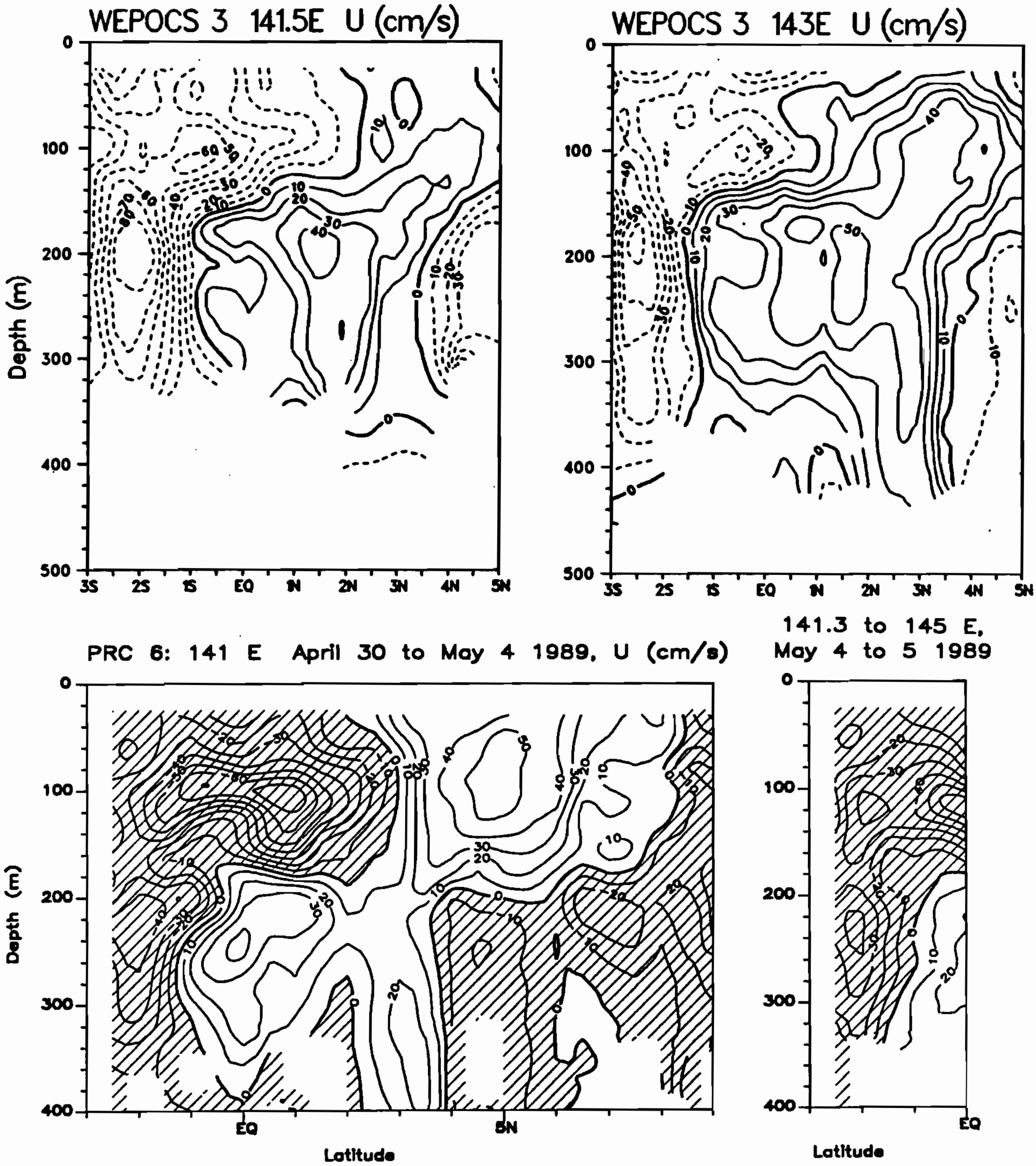
PRC3 U 141.5E Sept. 30 to Oct. 4, 1987

141.5E to 145E
Oct 4 to Oct 5, 1987

PRC4 U 141.5E May 3 to May 6, 1988

141.5E to 145E
May 6 to May 7, 1988

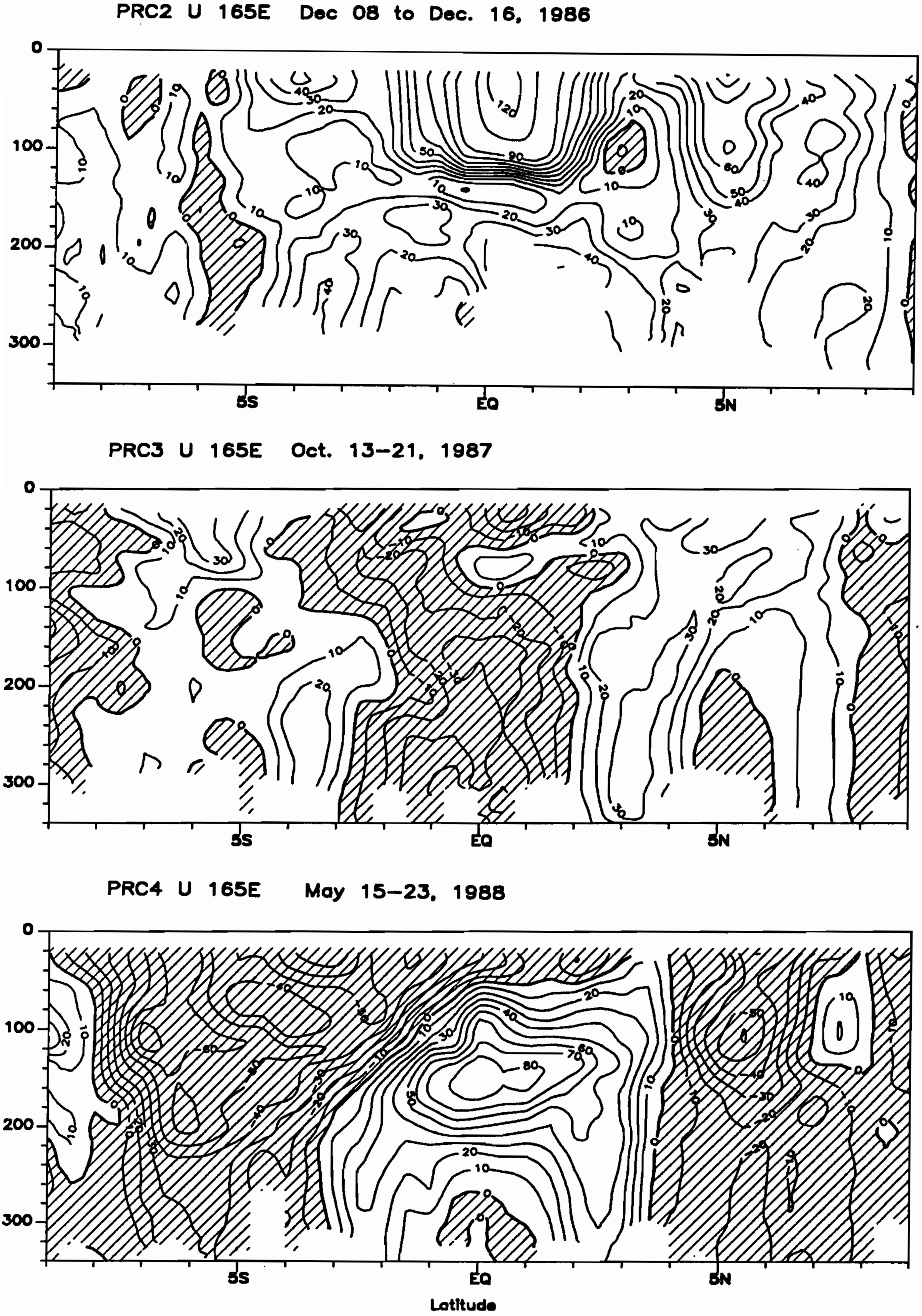
Figure 2: Zonal currents, 141°E to 143°E.



June 26-28, 1988

June 22-25, 1988

Figure 2, cont.



PRC2 U 165E Dec 08 to Dec. 16, 1986

PRC3 U 165E Oct. 13–21, 1987

PRC4 U 165E May 15–23, 1988

Figure 3: Zonal currents, 165°E.

core depth was usually near 200 m. The core was found on the equator in three of the sections, and at about 1.5°N in the other two (October 1987 and June 1988). These instances of large displacement from the equator suggest that a single equatorial mooring may give a poor index of EUC transport at this longitude. All sections near 141°E show the EUC connected by continuous eastward flow to the NECC and to the northern subsurface countercurrent (also known as a Tsuchiya jet; Tsuchiya, 1972, 1975).

On 165°E, the Tsuchiya jets are the only consistent features of the three sections shown (Figure 3). Otherwise these sections could hardly be more different. The outstanding features of US/PRC 2 in December 1986, early in the 1986-87 El Niño, are the preponderance of eastward flow throughout the section, and the intense eastward surface jet on the equator. The equatorial jet is very similar to one observed at 159°W in November 1982, early in the 1982-1983 El Niño. In October 1987 (cruise 3), late in the 1986-87 El Niño, currents were weak everywhere on this section, and westward almost everywhere within 3° of the equator. Following the El Niño, in May 1988 (cruise 4), the EUC was unusually strong for the western Pacific, and was embedded in an exceptionally strong and extensive westward flow with cores at 5–6° on either side of the equator.

5 Zonal transports at 165°E

Transports per unit width were calculated by integrating the velocity from the surface to 520 cl/t, from 520 to 450 cl/t, and from 450 to 300 cl/t. These isopycnals roughly correspond to the 26°, 23.5°, and 18° isotherms, respectively. The velocity was approximated as constant from the shallowest depth bin at about 20 m to the surface. Transports per unit width were then integrated trapezoidally in latitude to give a transport streamfunction (Figure 4).

Transports were weak in cruise 3, and eastward and westward transports were nearly in balance across the section. In cruises 2 and 4 the transports of warm water were predominantly of one sign; 77×10^6 m^3 s^{-1} to the east in cruise 2, and 50×10^6 m^3 s^{-1} to the west in cruise 4. Note that a sizeable fraction of the warm water transport, about 17×10^6 m^3 s^{-1}, was found north of the 4°N in cruise 2, and almost none was found south of 4°S. Most of the transport, 44×10^6 m^3 s^{-1}, was within 2° of the equator. In cruise 4 the distribution was different; most of the westward transport occurred south of the equator, and only about 10×10^6 m^3 s^{-1} occurred north of the equator.

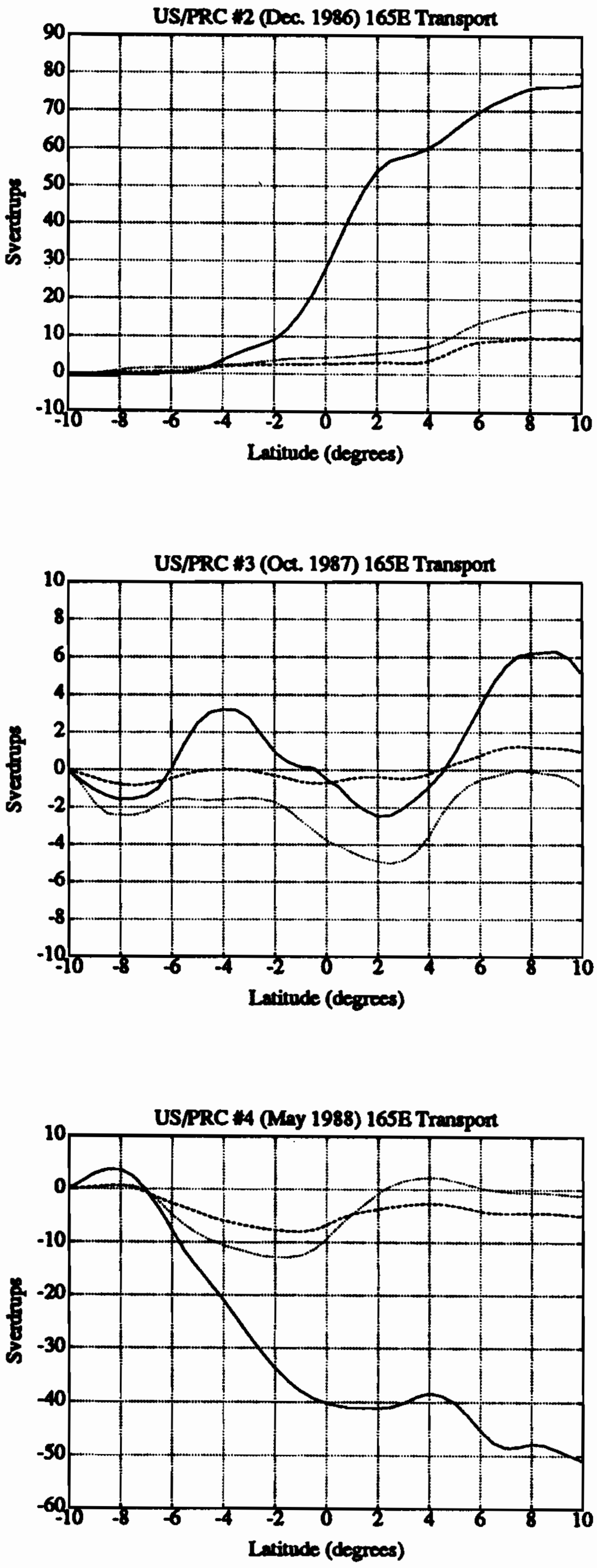


Figure 4: Transport streamfunction, 165°E.

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References

Chereskin, T., E. Firing, and J. Gast. 1989. On identifying and screening filter skew and noise bias in acoustic Doppler current profiler measurements. J. Atmos. Oceanic Technol., accepted.

Joyce, T. M. 1989. On in-situ "calibration" of shipboard ADCPs. J. Atmos. Oceanic Technol., 6, 169–172.

Lindstrom, E., R. Lukas, R. Fine, E. Firing, S. Godfrey, G. Meyers, and M. Tsuchiya. 1987. The Western Equatorial Pacific Ocean Circulation Study. Nature, 330, 533–537.

McPhaden, M. J., S. P. Hayes, L. J. Mangum, and J. M. Toole. 1989. Variability in the western equatorial Pacific Ocean during the 1986–87 El Niño/Southern Oscillation event. Submitted to J. Phys. Oceanogr.

Pollard, R., and J. Reed. 1989. A method for calibrating shipmounted acoustic Doppler profilers, and the limitations of gyro compasses. J. Atmos. Oceanic Technol., in press.

Tsuchiya, M. 1972. A subsurface north equatorial countercurrent in the eastern Pacific Ocean. J. Geophys. Res., 77, 5981–5986.

Tsuchiya, M. 1975. Subsurface countercurrents in the eastern equatorial Pacific Ocean. J. Mar. Res., 33 (Suppl.), 145–175.

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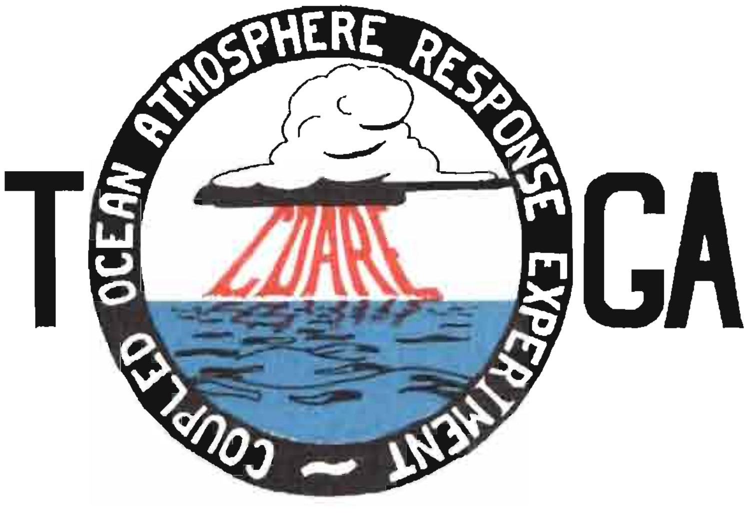

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