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Estimates of Equatorial Upwelling Between 140° and 110°W During 1984

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The equation of continuity is used to estimate profiles of vertical velocity between 25 and 120 m from moored current measurements in arrays nested within the triangle with vertices located at 1°30′S, 140°W and along the equator at 140° and 110°W during December 1983 through March 1984 and May–September 1984. All directions of the 4- to 5-month mean values were upward. The ensemble averaged mean vertical velocity was 2.2×10^{-5} m s^{-1}. Upwelling speeds decreased eastward.

1. INTRODUCTION

The existence of equatorial upwelling has long been a tenet of faith among oceanographers. Since the last century it has been known that lower sea surface temperature (SST) and higher biological productivity and plankton biomass exist in the surface layer in a narrow equatorial zone of the Pacific Ocean. The predominantly westward surface wind in this region should drive a poleward Ekman transport in both hemispheres, with compensating upwelling of nutrient-rich water from below the mixed layer. This scheme is consistent with the observed biological and SST distributions. Vertical motion in the ocean is extremely difficult to measure because of its low speed, which seldom exceeds 10^{-5} m s^{-1} for monthly time scales. Estimates are computed instead from physical principles or inferred from variations of conservative and nonconservative parameters. This short note presents estimates of vertical motion in the uppermost 125 m of the equatorial Pacific computed from the continuity equation with data from triangular arrays of moored current meters.

Using data from moored current meters, vertical velocity is computed from a finite difference approximation to the continuity equation:

$$\partial w/\partial z = -(\partial u/\partial x + \partial v/\partial y)$$

where distances x, y, and z are positive eastward, northward, and upward from the sea surface, respectively, and velocity components u, v, w are positive eastward, northward, and upward, respectively. The u and v components were recorded with EG&G Sea-Link vector-averaging current meters (VACM) throughout the current meter arrays, except for vector-measuring current meters (VMCM) at 80- and 120-m depths at the TH3 and TH6 moorings located at different times at 1°30′S, 140°W. *Halpern* [1987] showed that VACM measurements made in the upper ocean at the equator were nearly identical to those from VMCM, which *Weller and Davis* [1980] consider to be more accurate in laboratory tests.

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The computational procedure is identical to the method described by *Halpern and Freitag* [1987]. A zero vertical velocity is defined at the surface. At each current meter level where simultaneous measurements were recorded in a triangular array, the vertical velocity is computed from the continuity equation vertically integrated in the layer immediately above the selected depth. Each layer corresponds to the interval between current meters.

2. RESULTS

Vertical velocities were computed within nested triangles (Figure 1) on two occasions, neither of which was during an El Niño episode. During December 1, 1983, through March 31, 1984, the 25- to 125-m depth-averaged w mean values at 137° and 125°W were 2.5 and 2.0×10^{-5} m s^{-1}, respectively; the nominal location is the midpoint between the equatorial moorings. Similarly, during May 1 through September 30, 1984, the w mean values at 132° and 125°W were 2.2 and 1.9×10^{-5} m s^{-1}, respectively. The 25- to 125-m depth-averaged w mean value was 10% smaller during May–September than during December–March, while the 50% larger westward wind speed occurred in May–September at 124°W. At each depth the mean values decreased from west to east (Figure 1), which is consistent with the longitudinal distribution of the strength of the zonal surface wind component [*Halpern*, 1988].

The ratio of w standard deviations to w mean values increased with depth: it was typically 2–4 above 80 m and reached 10 at 160 m. The standard error (calculated by $(2ts^2/T)^{1/2}$, where t is the integral time scale of 15 days [*Hansen and Paul*, 1984]; s is the typical standard deviation of mean value, equal to 5×10^{-5} m s^{-1}, and T is the record length of 4 months) was approximately 2.5×10^{-5} m s^{-1}. To achieve statistically reliable estimates accurate to 1×10^{-5} m s^{-1} would require a record length of 750 days, which is not a likely occurrence because of limited resources for moored current measurements. An additional source of error is

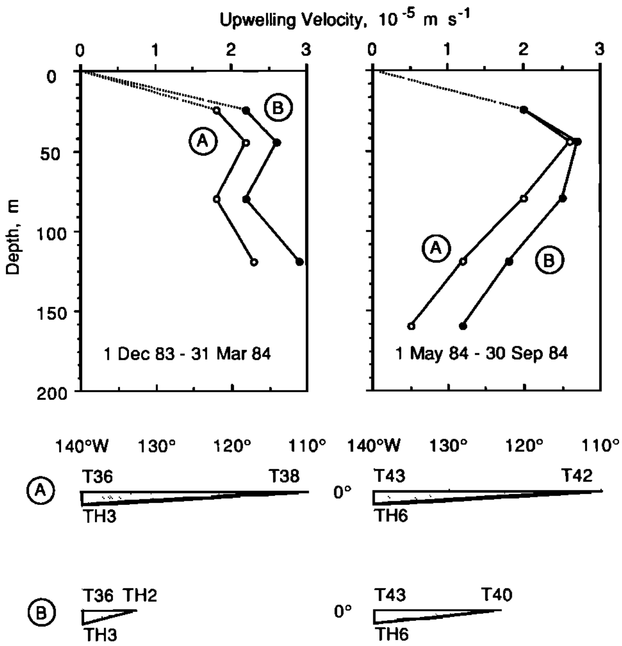

Fig. 1. (top) Profiles of mean upwelling velocity computed for different time intervals and (bottom) triangular arrays. Locations of vertical velocity profiles are designated with circled letters which are described in the lower panel. Buoy positions are listed by *Halpern et al.* [1988].

caused by measurement uncertainty. For a 0.03 m s^{-1} uncertainty of the moored current measurements, an estimate of the error in the computation of $\int(\partial v/\partial y)\, dz$ along 140°W would be about 1×10^{-5} m s^{-1} for a 50-m layer. While substantial errors are associated with the computed mean vertical velocities, the results are consistent with previous notions and are instructive for planning future experiments.

Caution is advised in the interpretation of the longitudinal variation of the vertical motion computed from these particular current meter arrays. For each time interval the $\partial v/\partial y$ term was computed from the same current measurements and only the $\partial u/\partial x$ term was computed from different moored data. Over the short distances associated with $\partial v/\partial y$ the v components were coherent at the 95% confidence level [*Halpern and Freitag*, 1987; *Halpern et al.*, 1988]. However, coherences between u fluctuations recorded at 110° and 140°W were not statistically significant at the 95% confidence level with current fluctuations at 124°W for 4- to 5-month periods [*Halpern et al.*, 1988]. The $\partial u/\partial x$ term was computed with uncorrelated zonal currents and represents an upper limit of the gradient computed from correlated currents. Thus computations of $\partial u/\partial x$ indicate the magnitude of the variability. Furthermore, it is noted that the absence of $\partial v/\partial y$ estimates at other longitudes presumes that this term is constant with longitude.

3. Discussion

Four vertical velocity profiles were estimated over longitudinal distances from about 6° to 30° and a constant latitudinal distance of about 1.5°, with each estimate appropriate to a 4- to 5-month interval. These particular time intervals may not yield unbiased estimates of very long term mean conditions. The ensemble averaged w mean value within the 25- to 125-m interval was 2.2×10^{-5} m s^{-1}, which is similar to other short-term estimates. Using the same kind of instruments and the same technique described herein, *Halpern and Freitag* [1987] determined a 25- to 120-m vertically averaged mean w value of 1.9×10^{-5} m s^{-1} during January 20 through April 24, 1979, within a 150-km triangle centered at 0°, 110°W. *Bubnov* [1987] reported a 28-day [February–March 1980], 25- to 125-m vertically averaged w value of 3.7 $\times$ 10^{-5} m s^{-1} in the region 1.5°S to 1.5°N, 167°–163.25W; the continuity equation method was used. *Hansen and Paul* [1984] used the average meridional gradient of the v component determined from satellite-tracked drifting buoys to estimate an upwelling velocity of 3×10^{-5} m s^{-1} at 50-m depth during June–October 1979 in the region 1.5°S to 1.5°N, 130°–100°W. In a subsequent study, *Hansen and Paul* [1987] found the average w value for November 1977 to June 1982 to be 1.7×10^{-5} m s^{-1} in the region 1.5°S to 1.5°N, 130°–80°W. These two studies by Hansen and Paul suggest a decrease of w toward the east, which is similar to our findings. *Bryden and Brady* [1985] conserved mass in three dimensions to find a 25- to 125-m averaged upwelling value of 1.9×10^{-5} m s^{-1} within the region 0.75°S to 0.75°N, 150°–110°W. In summary, for time scales of 1–5 months the vertical motion along the Pacific equator between about 165° and 90°W is directed upward above 125 m with a typical speed of 2.5×10^{-5} m s^{-1}, and the vertically averaged upwelling speed decreases eastward from 140°W.

Philander et al. [1987, Figure 4] simulated the climatological mean annual vertical motion field along the Pacific equator with an ocean general circulation model forced with *Hellerman and Rosenstein*'s [1983] surface wind stress field. The model simulation indicates that equatorial upwelling occurs at shallow depths and is most intense in the central Pacific. In the 140°–110°W region, where the EUC and thermocline depths decrease toward the east, the model result does not suggest a similar upward tilt of upwelling isolines, as might be expected if longitudinal divergence of the EUC flow contributed substantially to the vertical velocity distribution. Both model simulation and observations indicate a decrease of upwelling speed eastward of 140°W.

4. Concluding Remarks

Equatorial upwelling is ubiquitous in the upper ocean in the central and eastern Pacific and probably in the western Pacific. The longitudinal distributions of w and SST along the equator are not related in an intuitive fashion: SST increases continuously from east to west. Longitudinal distributions of w and an 18-month composite of phytoplankton pigment concentrations observed from the Nimbus 7 coastal zone color scanner (CZCS) [*Yoder et al.*, 1988] seem to be related because of a large patch of high phytoplankton occurring in the central Pacific; however, other CZCS images (e.g., a 12-month composite) portray different zonal patterns (G. Feldman, personal communication, 1988). Relationships between w, SST, and biological productivity along the Pacific equator are under investigation and will be reported elsewhere.

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