Comparison of Profiling Current Meter and Shipboard ADCP Measurements in the Western Equatorial Pacific

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ABSTRACT

Profiling current meter (PCM) measurements under a drifting buoy are compared with concurrent shipboard acoustic Doppler current profiler (ADCP) measurements carried out in the western equatorial Pacific in March 1991, from 10°S to 7°N along the 165°E meridian. The mean (ADCP minus PCM) ± rms differences between zonal and meridional velocity components are 5.7 ± 11.2 cm s^{-1} and 0.0 ± 8.8 cm s^{-1}, respectively, when PCM measurements are relative to 600 m. The mean ± rms differences decrease to 2.3 ± 7.8 cm s^{-1} and 0.0 ± 6.3 cm s^{-1} when the PCM and ADCP data are both referenced to the same layer (on a mean, 16–240 m). As compared with ADCP, it is found that PCM underestimates velocities of less than 20 cm s^{-1} by about 25%.

1. Introduction

Understanding the physical mechanisms responsible for sea surface temperature (SST) changes is a major objective of the decade-long international Tropical Ocean and Global Atmosphere (TOGA) program (WCRP 1985). Changes in SST are governed essentially by three processes: heat advection, balance of surface heat flux, and turbulent heat transport in the ocean. In equatorial regions, heat advection by upper-ocean currents may play a more important role than the two other processes in SST variability (e.g., Liu and Gautier 1990). Thus, measuring the current system in these regions is of major importance for attainment of TOGA objectives.

Quantitative information about currents in the ocean is being obtained by either indirect or direct measurements. Indirect measurements rely on the geostrophic approximation. Geostrophic currents deduced from dynamic height are relative to an assumed level of no motion. Near the equator and/or in the presence of strong Ekman drift, they may not be representative of real currents. In the past, direct current measurements were rather sparse because they called for specific, complicated techniques. In the last 20 years, instruments consisted mainly of profiling current meters (PCMs), moored vector-averaging current meters (VACMs), and vector-measuring current meters (VMCMs), and more recently of acoustic Doppler current profilers (ADCPs). The principles of the aforementioned current measurements are different. PCM freely fall down along a cable attached to a ship (Duïng and Johnson 1972) or a drifting buoy (Hénin and Hisard 1987); results are generally relative to a given reference level. VACM and VMCM are suspended beneath a surface-following moored buoy (e.g., Halpern et al. 1981), while ADCP are mounted on board a moving ship (e.g., Joyce et al. 1982) or a surface-following moored buoy (McPhaden et al. 1991). VACMs, VMCMs, and moored ADCP systems yield absolute current measurements, as do shipboard ADCPs, provided precise navigation data are available.

In equatorial regions, comparisons between different systems of current measurements have been made by various authors. To name a few, Freitag and Firing (1984) compare PCM and VACM in the central equatorial Pacific (153°W); Halpern (1987) evaluates the similarity of upper-ocean VACM and VMCM observations at 0°–110°W and 0°–140°W for 6-month intervals, and Chereskin et al. (1987) compare shipboard ADCP versus VACM near 0°–140°W during a 12-day interval. Interested readers can refer to these articles and their references for a detailed bibliography dealing with the quality of current measurements. It is worth mentioning, however, that previous quality estimates cannot automatically be applied to any new data. For example, PCM results are very much dependent on weather conditions during profiling, and ADCP techniques have improved very rapidly. For instance, results of a comparison between PCM and Doppler acoustic log data gathered during the Hawaii–Tahiti Shuttle

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Experiment (Johnson et al. 1988) cannot be readily extended to modern ADCP results.

Current measurements from a PCM under a drifting buoy and a shipboard ADCP were both conducted in March 1991 during part of the SURTROPAC 14 cruise running from 20°S to 8°N and back along the 165°E meridian (cf. Delcroix et al. 1987, 1991). The purpose of this note is to compare the results yielded by these two methods.

2. Instruments and methods

During the SURTROPAC 14 cruise, PCM measurements were made in the upper 600 m at every 1° of latitude between 10°S and 7°N. Out of 18 current profiles, 15 were successfully recorded: 12 during the northward leg and those at 5°N, 2°N, and 0° during the southward leg. PCM measurements at 8°S, 6°S, and 6°N failed for technical reasons. Time–space separations between PCM casts thus prohibited drawing a synoptic picture of the velocity field. The PCM system consisted of a profiler originally designed at the Institut für Meereskunde in Kiel, Germany, modified at the Université de Bretagne Occidentale in Brest, France (Fig. 1) (Meincke 1978; Girardot 1985), and fitted with an Aanderaa recording current meter model 7 (RCM7; Aanderaa 1987). For the RCM7, accuracies of pressure, direction, and velocity are ±1% of full range (i.e., ±7 db), ±5° for speeds from 5 to 100 cm s^{-1}, and ±1 cm s^{-1} or ±2% of actual velocity, whichever is greater, respectively. The starting velocity is 2 cm s^{-1}. The RCM7 profiler system is ballasted to remain vertical while sinking at 7–10 m min^{-1} along a 600-m cable. The upper part of the cable is lashed to a drifting buoy, and the lower end comprises a RCM7 vane system used to correct the PCM data from drift. PCM measurements are thus relative to the 600-m depth. Temperature and pressure are sampled every 30 s, rotor revolutions and direction are sampled every 12 s. All these measurements are aligned in time using linear interpolation. Details about data acquisition and processing are given in Masia (1990).

The ADCP system installed on the R/V *Le Noroit* is a model RDVM-150 from RD Instruments (San Diego, California) of 153.6-kHz nominal frequency. Version 2.48 of RDI Data Acquisition Software (DAS) was used. During the SURTROPAC 14 cruise, the DAS was programmed for a bin width of 8 m, a pulse length of 8 m, and a 4-m blanking interval below the transducer head mounted about 4 m below sea surface. The shallowest bin was thus centered at the 16-m depth. Profiles were vector-averaged in 5-min ensembles (about 300 pings per ensemble), leading to a random error in ensemble velocity components of less than 1 cm s^{-1}. An echo intensity signal-to-noise ratio of 6 dB was used to screen good quality pings inside each ensemble. A lower limit of 30% good pings per ensemble delimited maximum range. In these conditions, the deepest bin varied from 216 to 280 m, depending on acoustic conditions and other factors. Given that the depths of ADCP bins had not been corrected for actual sound speed profiles, an underestimation of 10–15 m can affect the deepest bins. A complete database and processing software, the Common Oceanographic Data Access System, version 3 (CODAS3), was generously provided by E. Firing of the University of Hawaii (see Bahr et al. 1989). To yield absolute current velocities, ship speed obtained from GPS navigation was added to ship-relative ADCP measurements. This was performed through calculation of the absolute velocity of a reference layer, smoothed by a 2-h-wide Blackman window.

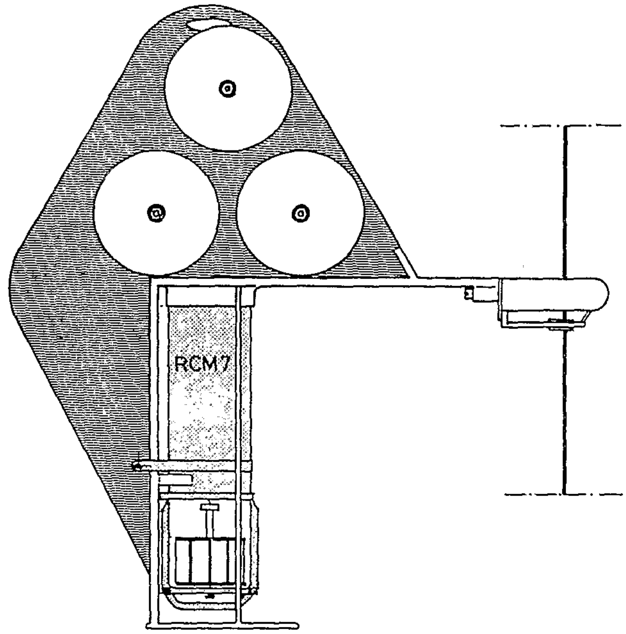

FIG. 1. Current profiler assembled. The Aanderaa RCM7 is fixed to a stainless frame equipped with a snatch block and attached to a PVC plate (shaded area) with six flotation spheres (Nokalon type 577). Scale is given by the RCM7 of overall length 49 cm.

For the purpose of comparison, PCM data were linearly interpolated to 8-m vertical spacing, and pressure was converted to depth units (600 db ≡ 595.8 m). ADCP measurements were selected to enclose PCM measurements in the time domain. As a result, each PCM measurement was compared to the mean of 12–15 5-min ADCP ensembles taken within 1–2 nmi. Standard deviations of these ensembles stay within 1–4 cm s^{-1} at all depths. Note that ADCP data were obtained in stations, thereby considerably reducing errors caused by imperfect navigation data or transducer misalignment.

3. Comparisons

Figure 2 illustrates vertical current profiles measured at the equator (165°E), with ADCP and PCM. Between

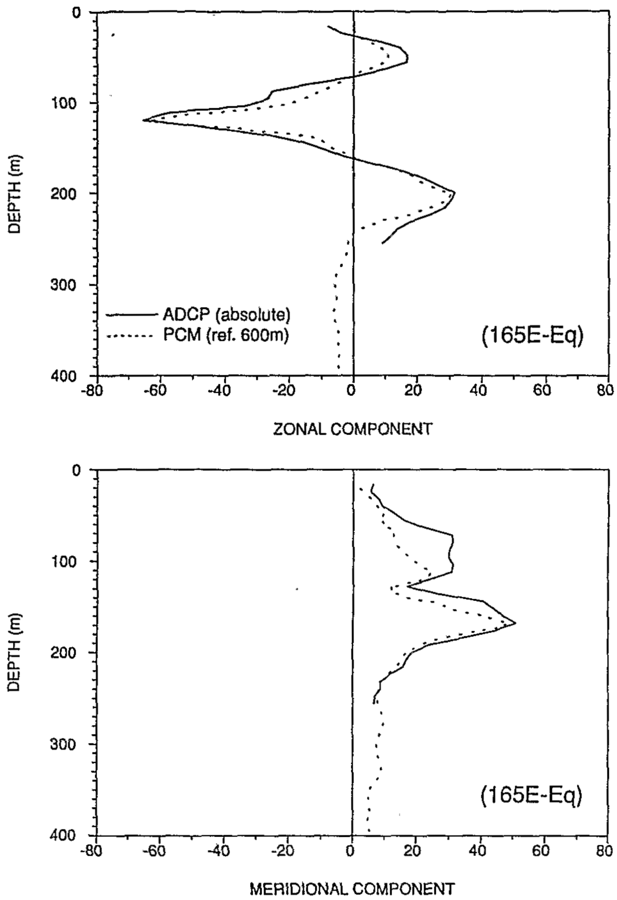

FIG. 2. Comparison of zonal (U) and meridional (V) velocity ($\mathrm{cm\ s^{-1}}$) measured by the ADCP (full line) and PCM (broken line) system at 0°–165°E on 28 March 1991.

30 and 70 m there is an eastward-flowing component that is the remnant of a well-marked Yoshida jet observed 10 days before and is in the upper 70 m and within about 2°N and 2°S (not shown here). The eastward jet splits the westward-flowing South Equatorial Current (SEC) into a weak newly reconstructed upper part (16–30 m) and a strongly developed lower part reaching as much as $-65\ \mathrm{cm\ s^{-1}}$ at 120 m. Further below is the eastward-flowing equatorial undercurrent (EUC) with a maximum speed of $35\ \mathrm{cm\ s^{-1}}$ at 200 m. Depicted only by the PCM is the equatorial intermediate current (EIC) flowing westward below 250 m. Visual agreement between PCM and ADCP profiles is remarkable. For this particular equatorial station, correlation coefficients between PCM and ADCP for zonal and meridional components are .96 and .92, respectively. Corresponding mean ± rms differences (ADCP minus PCM) are $-0.2 \pm 7.6\ \mathrm{cm\ s^{-1}}$ and $5.8 \pm 5.5\ \mathrm{cm\ s^{-1}}$.

Scatter diagrams of zonal and meridional velocities from PCM versus ADCP are shown in Fig. 3 for all 15 stations. The ADCP and PCM zonal and meridional velocities are well correlated with a correlation coefficient of .86, significant at the 95% confidence level. Mean ± rms differences (ADCP minus PCM) are $5.7 \pm 11.2\ \mathrm{cm\ s^{-1}}$ and $0.0 \pm 8.8\ \mathrm{cm\ s^{-1}}$ for zonal and meridional components, respectively. A comparison of 50-m depth-interval averages (Table 1) indicates a tendency for correlation coefficients to decrease with standard deviations of ADCP and PCM velocities. This probably reflects the fact that signal quality decreases for low-amplitude velocities.

The mean (ADCP minus PCM) velocity differences are $5.7\ \mathrm{cm\ s^{-1}}$ to the east and near $0\ \mathrm{cm\ s^{-1}}$ to the south. On a mean, PCM thus underestimates the velocities when compared to ADCP. This is reflected in Fig. 3, where regression coefficients are less than unity ($a = 0.74$–0.76). A careful inspection of Fig. 3 suggests, however, that the underestimation does not apply to the fastest velocities that are located close to the di-

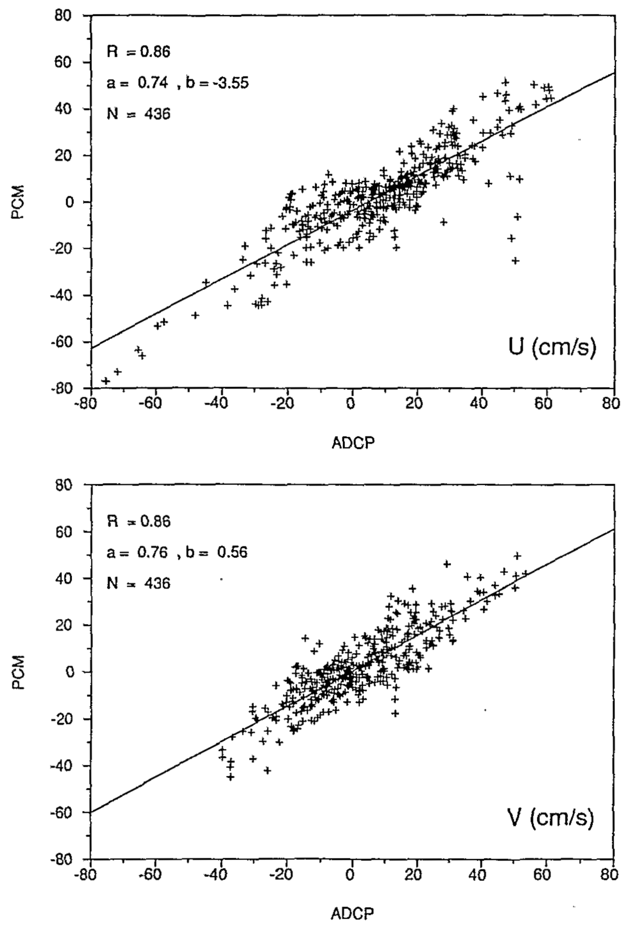

FIG. 3. Scatter diagram of zonal (U) and meridional (V) velocity measured by the PCM versus ADCP system. Measurements were made in March 1991, from 16 to 280 m, in between 10°S and 7°N along 165°E. PCM velocities are referenced to 600 m, ADCP velocities are absolute. The straight line is the least-squares fit to the data [PCM = aADCP + b]; N is the number of observations; and R is the correlation coefficient.

TABLE 1. Means and standard deviations of ADCP (absolute) and PCM velocities (relative to 600 m), mean (ADCP minus PCM) and rms differences between them, correlation coefficients, and number of observations N at each depth interval. Velocity units are centimeters per second. Data are gathered along 165°E, from 10°S to 7°N.

Depths (m)	N	ADCP Mean	ADCP Standard deviation	PCM Mean	PCM Standard deviation	Mean difference	rms difference	Correlation coefficient
				Zonal component				
0–50	74	23.7	21.2	14.2	22.3	9.5	15.5	.74
50–100	89	9.3	20.6	1.4	16.8	7.9	10.2	.87
100–150	86	−6.1	27.3	−10.2	24.3	4.1	9.0	.95
150–200	105	5.4	15.6	3.6	11.0	1.8	9.0	.82
200–250	85	12.1	15.0	6.5	10.4	5.6	10.7	.70
All	436	8.1	22.0	2.5	18.9	5.7	11.2	.86
				Meridional component				
0–50	74	5.9	19.1	7.0	19.9	−1.1	10.9	.84
50–100	89	4.1	18.6	3.5	14.1	0.7	8.7	.89
100–150	86	2.2	16.4	2.2	13.6	−0.0	8.3	.86
150–200	105	−1.8	16.4	−1.8	15.4	0.1	7.8	.88
200–250	85	−0.2	12.5	1.4	10.4	−1.5	8.1	.76
All	436	2.1	16.8	2.2	14.9	−0.0	8.8	.85

agonal ($a = 1$) of the scatter diagrams. Computation of the regression coefficients for different PCM minimum velocity thresholds confirms that PCM does not significantly underestimate the fastest velocities. For example, the regression coefficient a becomes 0.89 and 0.96 if only PCM velocities over 20 cm s^{-1} and 40 cm s^{-1} are kept, respectively. This tendency for the PCM system to underestimate low velocities, as compared to ADCP, might be related to particulars of the PCM measurement technique.

The ADCP–PCM differences may also stem from the use of a reference level (600 m) in obtaining PCM data and to some leftover error in integrating ship velocity to get absolute ADCP velocities. This is exemplified in Fig. 4. At 2°S, 165°E, the ADCP and PCM systems have measured very similar velocity profiles, with the notable exception that the mean PCM velocities are shifted 13.3 cm s^{-1} to the west and 11.6 cm s^{-1} to the north. The zonal shift is probably due to the presence at 600 m of the eastward-flowing south subsurface countercurrent (SSCC); the meridional shift is not consistent with an assumed equatorially convergent SSCC. These shifts are roughly constant on the vertical and therefore can be eliminated by comparing ADCP and PCM velocities both referenced to the same level (or layer).

For all 15 stations, ADCP and PCM velocities are thus referenced to their respective average velocity calculated from the top to the bottom of the ADCP profile (16–240 m, on a mean). This is preferable to the use of a single reference level because the vertical average reduces sensitivity to small-scale fluctuations. In this case, the mean ± rms differences (ADCP minus PCM) decrease to 2.3 ± 7.8 cm s^{-1} and 0.0 ± 6.3 cm s^{-1}, and the correlation coefficient increases to .91 and .90 for zonal and meridional components, respectively. Also, the regression coefficient $a = 0.95 \pm 0.05$ (the second number is the standard error) becomes insignificantly different from unity when rejecting PCM velocities less than 20 cm s^{-1}. Variation with depth of mean and rms differences is similar to what was obtained in comparing raw velocities. These results show that referencing plays a major role in ADCP minus PCM differences summarized in Table 1.

A similar computation can be carried out on vertical velocity shears, taking into account that, without precise navigation devices, PCM and ADCP are inherently shear measuring systems. In this case, rms differences between PCM and ADCP zonal and meridional shear components are 0.4×10^{-2} and 0.3×10^{-2} s^{-1}, and the correlation coefficients are .82 and .81, respectively. Agreement between shears computed from PCM and ADCP is thus similar to the one computed from VACM and ADCP (Chereskin et al. 1987). Unlike our previous comparison cases, a significant variation with depth of correlation coefficients is observed, with a minimum $R = .53$ in the 0–50-m layer and a maximum $R = .91$ in the 100–150-m layer. This low surface R value may be explained by poor quality PCM data close to the surface, when the system is not yet in equilibrium. This effect is amplified here by the shear computation.

As compared with the ADCP, it can be concluded that the PCM has a tendency to underestimate by about 25% velocities of less than 20 cm s^{-1}. Also, PCM measurements in the upper 50 m may be degraded, probably on account of the time it takes for the profiler–buoy–cable system to reach its equilibrium position

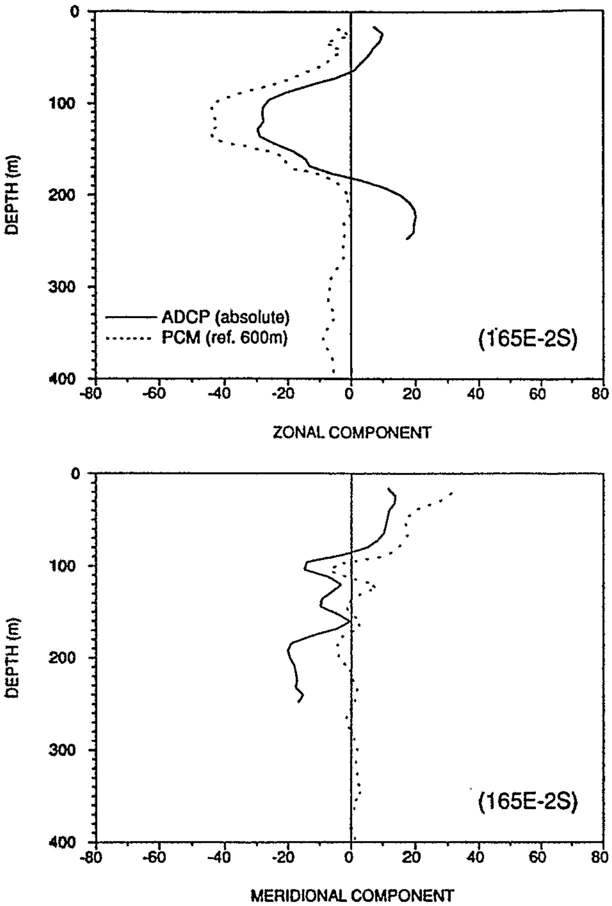

FIG. 4. Comparison of zonal (U) and meridional (V) velocity (cm s^{-1}) measured by the ADCP (full line) and PCM (broken line) system at 2S°–165°E on 18 March 1991.

after having been released from the ship. As shown in Fig. 4 and by comparison of relative velocities, the 600-db reference layer used in obtaining PCM velocities introduces a significant difference with ADCP data. This is specially embarrassing for the purpose of current transport calculation because this reference velocity error is constant in depth and may be uniform over large zonal or meridional bands.

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