Evaluation of an ADCP Fish-Bias Rejection Algorithm

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Abstract—Downward-looking surface-moored Acoustic Doppler Current Profiler (ADCP) data is at times biased towards lower values when compared to mechanical current meters (MCM). This bias has been shown to be caused by the attraction of large pelagic fish to surface moorings. RD Instruments ADCPs have an optional algorithm which attempts to limit velocity bias due to fish. The algorithm compares echo intensity amplitude among the four beams of the instrument and rejects samples in which the highest and lowest echo intensity amplitude differ by more than a given level. The performance of the algorithm was evaluated at deployments in the eastern and western equatorial Pacific. Bias was found to be reduced in some cases, but remained in others. The cause of residual bias is shown to be the presence of fish in all four acoustic beams—a condition not considered by the algorithm. A post-processing method of correcting fish bias in ADCP velocity data is presented. The method involved computing vertical modes of the bias from ADCP-MCM differences using empirical orthogonal functions (EOFs). The vertical structure of the EOFs was interpolated to the higher vertical resolution of the ADCP and then applied as a correction to the ADCP data. The quality of ADCP data was significantly improved by this correction.

INTRODUCTION

The Tropical Atmosphere Ocean (TAO) Array of moored buoys spans the tropical Pacific from longitudes 137°E to 95°W between latitudes of approximately 8°S and 8°N [1,2]. Within the array, 65 moorings measure surface winds and water temperatures to a depth of 500 m and transmit the data in near-real time via satellite to shore. The array is part of the in-situ measurement portion of the Tropical Ocean-Global Atmosphere (TOGA) Program, a 10-year study (1985-1994) of climate variability on seasonal to interannual time scales, the most pronounced mode of which is the El Niño/Southern Oscillation (ENSO) phenomenon. The TAO array is presently supported by the United States, France, Japan, Korea, and Taiwan.

There are four PROTEUS (Profile Telemetry of Upper Ocean Currents) equatorial moorings within the TAO array from which Acoustic Doppler Current Profilers (ADCPs) measure and transmit ocean currents within 300 m of the surface. The ADCPs on these taut-line moorings are mounted on surface following toroidal buoys [3]. The downward-looking 153.6 kHz ADCPs are programmed for 8-m bin widths and pulse lengths and sample at a 1-second rate for 6 minutes per hour. Daily mean current profiles are computed on the buoy and transmitted via Service Argos. For backup and verification, mechanical current meters (MCMs) are placed on the mooring line at depths typically between 3 and 300 m. The MCMs are either EG&G Vector Averaging Current Meters (VACMs) or EG&G Vector Measuring Current Meters. PROTEUS moorings are recovered and redeployed on an approximate 6-month schedule.

To first order, current profiles measured by the ADCP and MCMs are quite similar (Fig. 1). Temporal variability in the zonal current structure is dominated by changes in the strength and depth of the Equatorial Undercurrent (EUC) near 100 m and by changes in the strength of the South Equatorial Current.

Fig. 1. Contour plot of MCM (upper) and ADCP (lower) zonal velocity. Contour interval is 30 cm s⁻¹ with westward contours dashed and lightly shaded. Regions of eastward flow greater than 90 cm s⁻¹ are heavily shaded. Daily averaged data have been smoothed with a 15-day Hanning filter. Symbols on the right axis of the MCM plot indicate the depth of instruments from which this plot was based.
(SEC) at the surface. Some small differences are due to the ADCP data having a finer vertical resolution and at the same time being averaged over 8 m. Other small differences may be due to MCMs overestimating current speed in the presence of mooring motion [4].

More significantly, larger (order 50 cm s⁻¹) differences also occur in the SEC and upper EUC. These large differences are due to bias induced in the ADCP data by acoustic energy reflected from fish [5] and are the subject of this paper. Large pelagic fish (e.g., tuna) are known to be attracted to moorings. Buoys known as fish aggregating devices (FADs) are used by commercial and sport fisheries and the behavior of some tuna species around FADs has been documented [6].

Previous examination of PROTEUS data indicated that large differences in echo intensity (EI) were coincident with large negative ADCP-MCM speed differences [5]. We define echo intensity range (EIR) as the difference between highest beam EI and lowest beam EI. EIR increased during daylight hours as did speed differences. In addition, the beam in which the highest EI was present was typically aimed in the upstream direction. These relationships are consistent with the idea of fish bias in that some species of tuna tend to remain near and upstream of FADs during the day [6].

The manufacturer of the ADCP, RD Instruments, added an algorithm to the instrument software (versions 17.09 and above) which checked the EIR for every ping of an ensemble average. If it exceeded a preset level, the lowest of the 4-beam EI was rejected and the EIR recomputed. If the EIR of the three remaining beams was also large then all data from that ping were rejected. This two-step process was included in order to insure that the fish rejection algorithm would not flag all data as bad in the event of one beam failing. This algorithm would work properly when elevated EI is present in one or two beams. In the event that EI is larger than normal in three or four beams the data will be passed along as good. PROTEUS moorings deployed after March 1992 had this algorithm included in the ADCP software.

**DISTRIBUTION AND CHARACTERISTICS OF SPEED DIFFERENCES**

Daily mean speed difference, mean EI and EIR over a 2-year period from PROTEUS moorings on the equator at 110°W, 140°W and 165°E are shown in Fig. 2. Four separate moorings were included within the 2-year period at each site. Dates of mooring deployment and recovery are indicated on the date axes with each mooring name indicated at the top of each panel. Regions where speed differences are not plotted are mainly due to loss of MCM data which in turn was caused by either instrument failure or instrument loss due to vandalism of the mooring.

The correlations between large negative speed differences and increased mean EI and EIR occurred at all three sites, but were highly variable in longitude, depth and time. These fish-bias events occurred more often and were of larger magnitude at 110°W and 140°W than at 165°E. While there was a strong link between onset and duration of large speed differences with increased EI and EIR, the relative magnitude of each were not necessarily related, i.e., a given EIR was not always associ-
increases in EIR were often associated with even larger increases in mean E1, indicating that the assumption that E1 increases are in one or two beams only was often not the case.

At 110°W speed differences were relatively small for at least 3 months (in one case 5 months) after the deployment of each mooring; thereafter speed differences generally increased at the depths of the uppermost MCMs. In some cases the onset of large speed differences was sharp, while at other times it was gradual. At 120 m and below there was no indication of major speed bias due to fish. For moorings PRO4 and PR08 speed differences were largest at 10 m and decreased with depth, while for mooring PR06 differences were at times as large as 80 m as they were above.

As at 110°W, negative speed differences at 140°W were generally largest near the surface, but extended deeper, to 120 m. The onset of fish bias was at times sooner after deployment at 140°W than at 110°W, e.g., evidence of fish bias was present in the first or second month of mooring PR09.

Fish bias was much less evident at 165°E than at the other two sites (although more gaps were present in the MCM speed data at 165°E). Large negative speed differences and coincident increased EIR were mainly found in the upper 100 m of mooring FU3. It is of interest to note that increased mean E1 in the upper 50 m of mooring FU5 in April 1992 was not accompanied by an increase in EIR nor by speed bias at 10 m. This suggests that the increase in E1 may have been from an increase in the concentration of planktonic organisms rather than free-swimming fish.

EVALUATION OF ALGORITHM

The fish-bias rejection algorithm was used in the last two moorings at 110°W (PR08, PR10) and 140°W (PR07, PR09), and in the last mooring at 165°E (FU7). A decrease in the percentage of good pings per ensemble average in regions of high EIR indicated that some rejection was occurring, but was not sufficient to remove large negative speed differences. This failure was due to the assumption that, in general, high EIR would occur in only one or two beams. When only one or two beams were affected the algorithm did improve the quality of the data, but often all four beams showed high EIR values.

The fish-bias rejection algorithm could be modified so that data were rejected whenever E1 exceeded a given level, but this would require previous knowledge of the sensitivity of individual ADCPs when fish were not present. It would also require the assumption that all E1 increases were due to pelagic fish, a condition apparently not always applicable at 165°E.

AN EOF METHOD OF BIAS REMOVAL

It appears that adequate rejection of fish bias can not be made while the data are being taken, so an attempt has been made to remove the bias using MCM data. The method of empirical orthogonal functions (EOFs) was used to separate daily averaged time series of MCM-ADCP speed differences into vertical modes. It was assumed that the majority of the variability would be contained in the first few vertically-coherent modes. Each mode has an associated amplitude (eigenvector) at the depth of the input time series. The advantage of this method lies in that these amplitudes may be interpolated onto the higher resolution grid of ADCP depths. From the dominant vertical modes and vertically-interpolated amplitudes, a time series of speed differences were generated for each ADCP depth, and these differences were then used to correct the original biased ADCP data.

For mooring PR07 at 140°W, 97% of the total energy was contained in the first three modes (Fig. 3). The amplitudes for these modes were vertically interpolated using a cubic-spline technique and extrapolated to 250 m where the differences were assumed to be zero. The mean differences were likewise vertically interpolated and extrapolated. Time series of speed differences at each ADCP depth were generated from these first three modes and applied to the original data. Profiles of means and standard deviations of speed differences for the original and corrected ADCP data sets show the EOF corrections are quite effective (Fig. 4). Mean differences, which were as large as -17 cm s⁻¹ for the uncorrected data, were zero (by definition) after correction. Standard deviation of the differences decreased from a maximum of 19 cm s⁻¹ (at 25 m depth) to 2–3 cm s⁻¹ over the range of depths affected by fish bias.

![Fig. 3. Time series and eigenvectors for the first three EOF modes of ADCP-MCM speed differences at mooring PR07 (140°W). Numbers in the upper right of the time series panels are the percent of the total variance contained in that mode.](image-url)
The EOF correction scheme described above must be carefully applied on a case-by-case basis. Sufficient high quality MCM data must be available to adequately characterize the vertical structure of the fish bias. In addition, speed differences must be carefully analyzed since not all differences are necessarily the result of fish bias. Increases in EIR and EI can generally be used as indicators of fish presence to guide the EOF analysis, recognizing however that there may be times and locations where these indicators do not correlate with speed differences.

CONCLUSION

Downward looking ADCPs mounted on moored surface buoys are at times biased by the return of acoustic energy from fish attracted to the mooring. An algorithm designed to reject biased data provided some improvement in data quality. Unfortunately, a significant amount of biased data remained after implementation of the algorithm because the assumptions on which it was based were not generally applicable.

An EOF analysis method was presented that used daily averaged ADCP-MCM speed differences at a few depths to significantly decrease fish bias in the ADCP profiles. The resultant merged ADCP/MCM data set has a combined accuracy and vertical resolution superior to either data set alone. This correlation procedure is presently being applied to the entire ADCP time series at 110°W, 140°W and 165°E.

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REFERENCES