Correction of buoy contaminated Coastal Observatory ADCP data.

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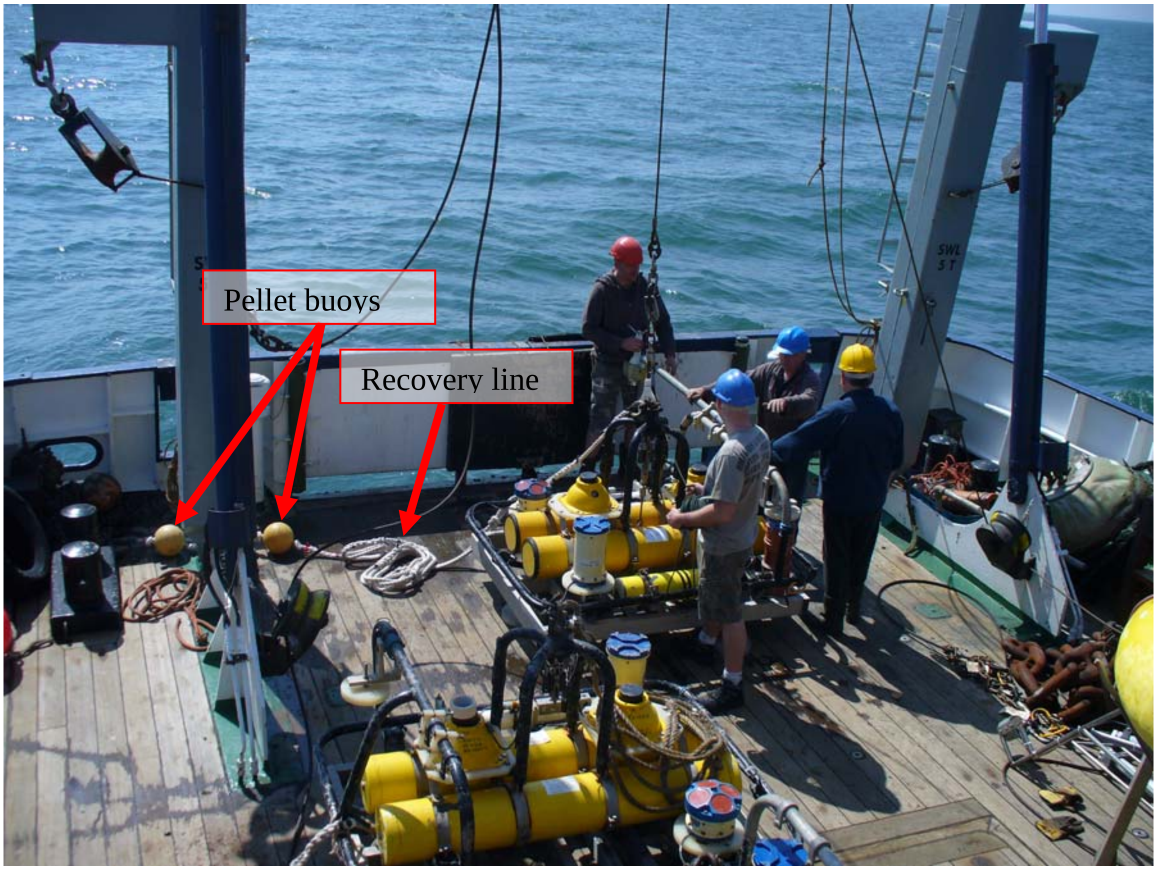
1. Problem:

Following analysis of ADCP data collected from both long term Coastal Observatory (CObs) stations (1 & 21) errors were identified in some mid-water positions suspected to be caused by contamination of individual acoustic beams by the recovery line attached to the respective ADCP lander frame. The recovery lines are ~10m in length and include two pellet buoys to maintain buoyancy for easy recovery of instrumentation at the surface (figure 1).



figure(1): A typical Coastal Observatory lander frame prior to deployment. The recovery line and attached pellet buoys are labelled.

Due to the strong tidal currents in Liverpool Bay, regularly exceeding 1ms^{-1} during spring tides, the pellet buoys and rope regularly cross the path of the acoustic beam path, most visibly in the dominant East/West component of flow (figure 2).

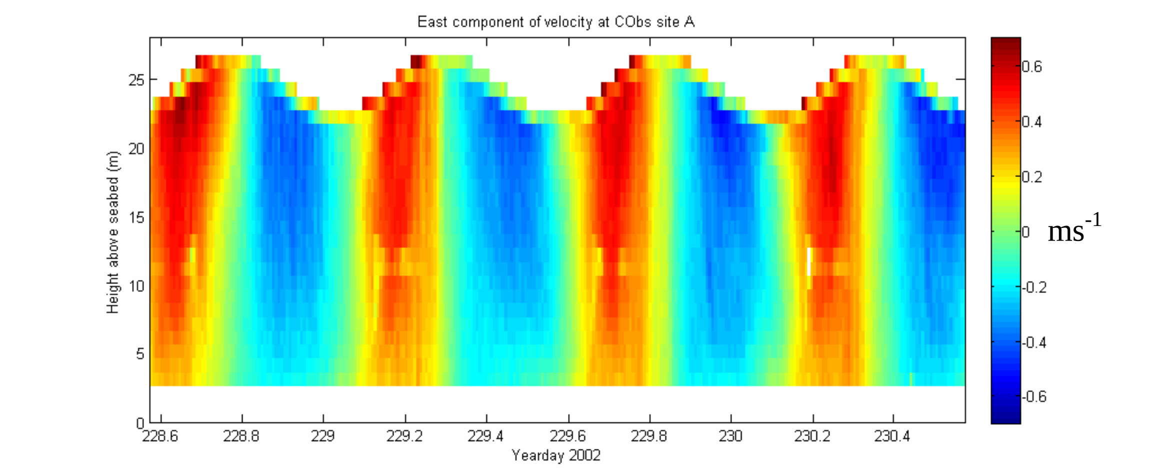


figure 2: The consequences of beam contamination are most evident at 10 to 12m above the seabed, most likely due to interference from the pellet buoys. The recovery line is also shown to have a significant effect, evident from the unnatural appearance of the current profile down to 5m from the bed during positive easterly flow in this example.

2. Solution:

2.1 Deriving velocity components from an ADCP

What the ADCP actually measures is the radial speed of flow along each of its four inclined acoustic beams from which the velocity vector is derived. Figure 3 shows typical 3rd and 4th beam geometry of a standard 4 beam RDI ADCP where θ is the declination angle of the beams, typically 20 or 30^{o}, and the horizontal angle between beams is 90^{o}. Along beam velocities, b_i, where subscript i refers to the beam number (i=1 to 4) are the product of horizontal velocities u_i or v_i and vertical velocity w_i.

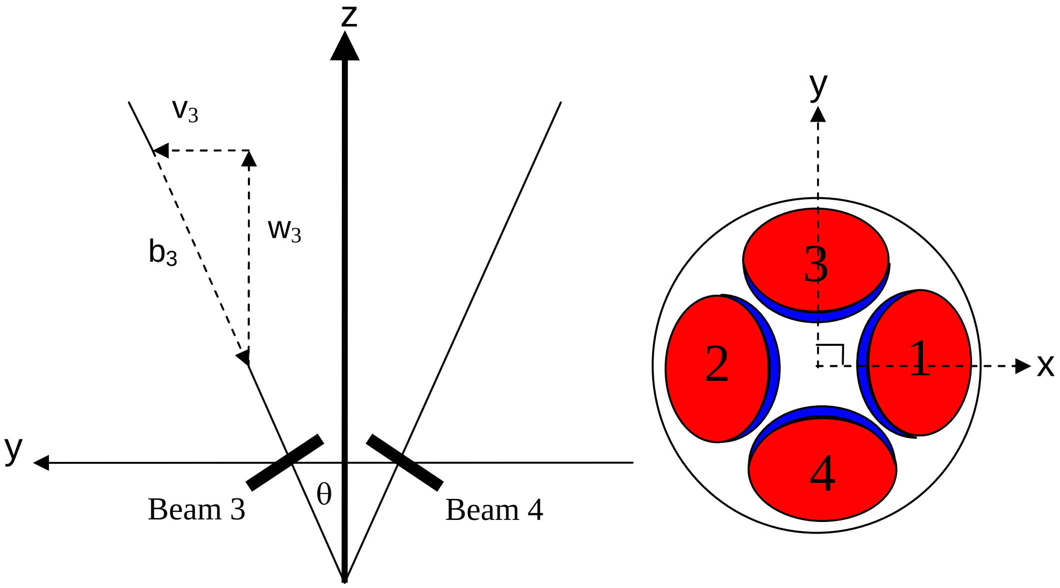


Figure 3: beam orientation of a four beam ADCP

A four beam ADCP obtains perpendicular horizontal velocity components and two independent vertical velocity components (from beams 1&2, w_{12}, and 3&4, w_{34}). This provides a means of evaluating data quality by calculation of the *error velocity*, equal to the difference between the two vertical velocity components. This provides a test to the assumption of horizontal homogeneity, equipment malfunction or beam contamination.

Figure 3 illustrates that with the use of simple trigonometry the along beam radial speed b_i at the j^{th} level can be related to the instantaneous true velocity vector (u_{ij}, v_{ij}, and w_{ij}), after Lohrmann et al (1990), by:

$$\begin{aligned}
b_{1j} &= -u_{1j}\cos\theta - w_{1j}\sin\theta \\
b_{2j} &= u_{2j}\cos\theta - w_{2j}\sin\theta \\
b_{3j} &= -v_{3j}\cos\theta - w_{3j}\sin\theta \\
b_{4j} &= v_{4j}\cos\theta - w_{4j}\sin\theta
\end{aligned}$$

(1)

By applying the average operator and making the assumption of homogeneity between beam spread it follows that:

$$\begin{aligned}\overline{b}_1 &= -\overline{u}\cos\theta - \overline{w}_{12}\sin\theta\\ \overline{b}_2 &= \overline{u}\cos\theta - \overline{w}_{12}\sin\theta\\ \overline{b}_3 &= -\overline{v}\cos\theta - \overline{w}_{34}\sin\theta\\ \overline{b}_4 &= \overline{v}\cos\theta - \overline{w}_{34}\sin\theta\end{aligned}$$

(2)

The mean velocity vector is therefore derived by solving the previous simultaneous equations by:

$$\overline{u} = \frac{\overline{b_2} - \overline{b_1}}{2\cos\theta},\ \overline{v} = \frac{\overline{b_4} - \overline{b_3}}{2\cos\theta},\ \overline{w} = -\sum_{i=1}^{4}\frac{\overline{b_i}}{4\sin\theta}$$

(3)

When one of these beams is contaminated as in the CObs scenario, we may estimate the undetermined horizontal velocity component using the vertical velocity derived from the beams perpendicular to the contaminated component and the unaffected beam in said component. For example; if the beam radial speed in beam 3, b_3, is contaminated the horizontal velocity component, v is also contaminated by (2) but can be derived from the so-called 3 beam solution:

$$\overline{v} = \left[\overline{b}_4 + \overline{w}_{12}\cos\theta\right]/\sin\theta$$

(4)

2.2 Application of the 3 beam solution

Due to natural inhomogeneity in the flow and instrument errors it is unlikely that w_{12} is always equal to w_{34}, i.e. the ‘error velocity’ is non zero. The three beam solution is therefore likely to increase error in derivation of the respective horizontal velocities and therefore should be used only when necessary. The following method was developed by *trial and error* and found to be the most effective in replacing buoy contaminated data.

i) Identify the contaminated beam: the previously explained ‘error velocity’ was determined as the best indicator for when the beams are obstructed. Natural inhomogeneity in the flow however makes the choice of a suitable and universal threshold difficult and ambiguous. When this threshold has been decided however identification of the offending beam is still not trivial. A clear and simple example is shown by examining a single vertical profile of horizontal velocity in figure 4.

The problems caused by using a universal threshold can be observed using a less clear example in figure 5.

To decrease the likelihood of data being erroneously identified as contaminated a horizontal velocity threshold was applied below which data was not replaced. This is justified since it is only during strong flows that contamination is likely to occur since the pellet buoys are highly buoyant and maintain verticality of the recovery line during low flow conditions. The velocity threshold of $0.3ms^{-1}$ was chosen as a suitable cut-off point.

A further restriction of only checking for errors in the first 15 bins ($\Delta z = 1m$) since the recovery line was always shorter than 15m in length.

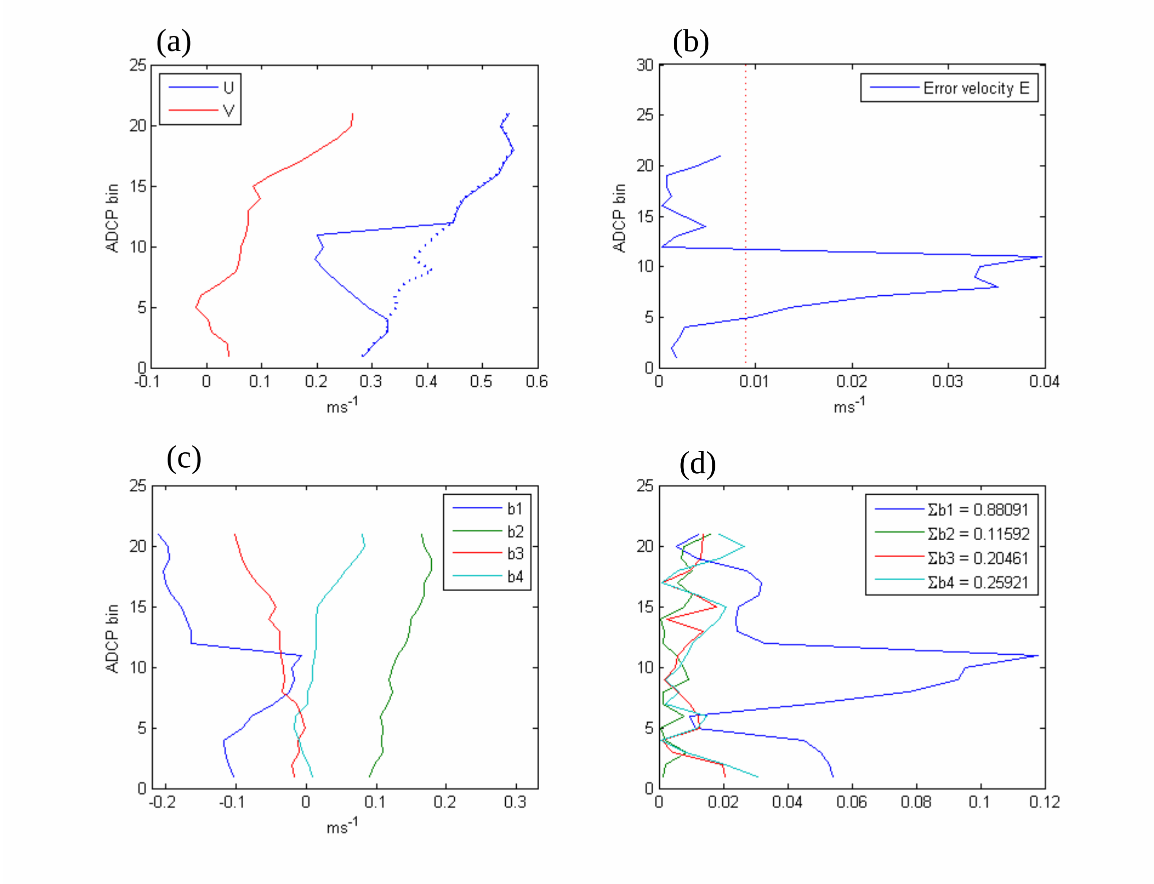


figure 4: (a) the solid lines show the U and V components of velocity derived from (3). There is a significant deviation from what may be considered a typical barotropic profile in the U component (b) consistent with a region of high 'error velocity', E. (c) Examination of the individual beam radial speeds shows the most likely error in beam 1 (b_1) which when linearly detrended (d) has a significantly higher depth integral than the remaining three beams which allows us to make an automated selection for correction. Choosing a threshold 'error velocity' of 0.009 ms^{-1}, beyond which the 3 beam solution (4) is applied we may replace the offending values in U, shown in (a) by the dashed line.

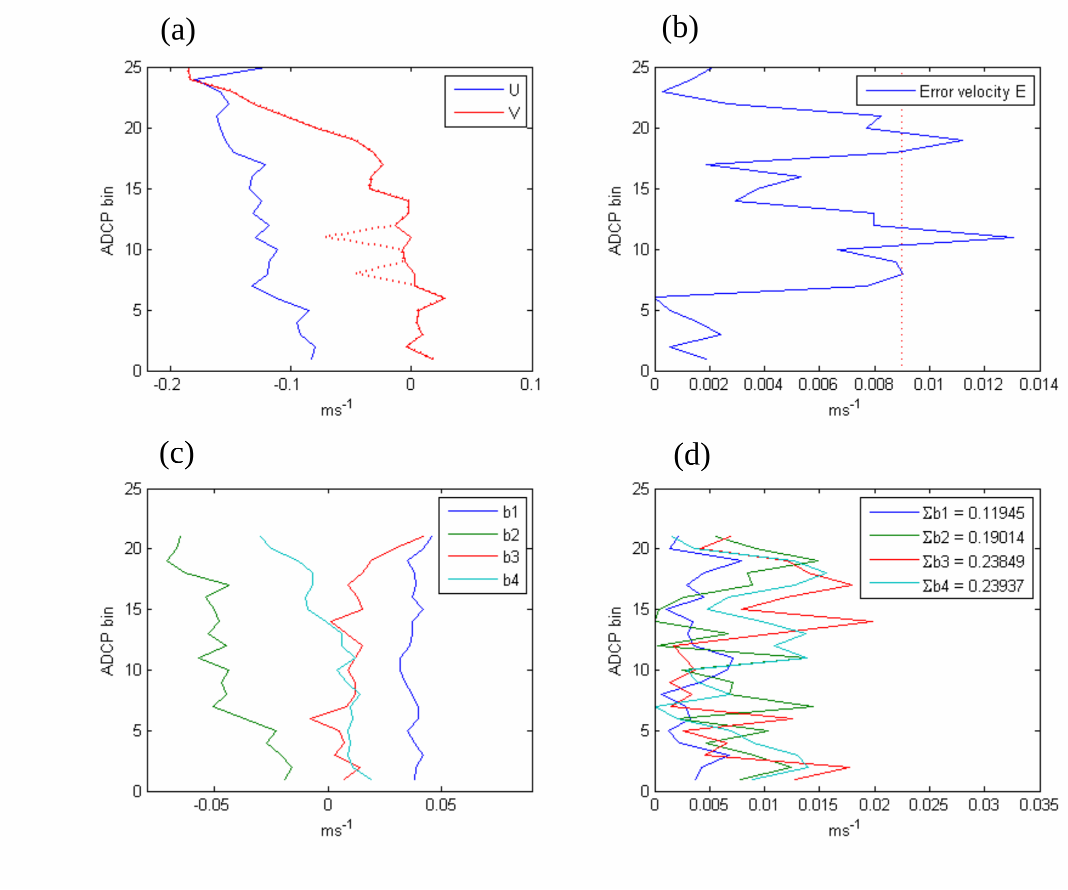


figure 5: (a) there are no clear anomalies evident in the U and V velocity components derived from (3) however the previously used 'error velocity' threshold of 0.009 is exceeded three times. (c) Examination of the individual beam radial speeds shows the no clear contamination in any of the beams. Replacing the identified 'erroneous' values in the beam with the largest depth integral in this case results in likely detrimental results, indicated by the unnatural change to the profile in (a) shown by the dashed lines.

ii) Apply the 3-beam solution to contaminated bins only: The decision was made to only use the 3-beam solution for identified contaminated bins rather than replacing the entire profile. The decision for this was based on the size of the pellet buoys and recovery line make up only a small percentage of the volume of water used to derive a bin velocity and are therefore unlikely to affect measurements made beyond the range of the contaminated bins.

iii) Produce a matrix of replaced values for identification of contaminated cells.

Following a review of all ADCP data collected by the Coastal Observatory to date all ADCP deployments were observed to have significant levels of contamination. Due to automatic derivation of 'earth' velocities during the first 7 Observatory cruises these datasets can not be corrected using the 3-beam solution as individual along beam velocities are not available. A corrective modification to the bedframes was applied from cruise number 55 (MA2308), deployed 30th July 2008, which secured the recovery line and pellets in a protective cage until the acoustic releases on the bedframe are fired during recovery. Following 6 successful recoveries this method has been shown to be 100% effective in eradicating the beam contamination errors presented in this report.

Reference:

Lohrmann, A., B. Hackett and L.P. Roed, 1990: High resolution measurements of turbulence, velocity and stress using pulse-to-pulse coherent sonar. *Journal of Atmospheric and Oceanic Technology (7), 19-37.*