ESTIMATION OF TURBULENT PARAMETERS FROM A 5-BEAM ADCP OPTIMISED FOR WAVE MEASUREMENTS

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Abstract Acoustic Doppler Current Profilers (ADCPs) can simultaneously measure waves and currents, though the sensor is usually optimised for one application only. This study explores the use of collected current velocity data to estimate profiles of mean current, turbulence intensity, Reynolds stresses, and turbulent kinetic energy (TKE) when the ADCP's setup is optimised for waves. Non-intrusive measurements of waves and current were obtained by a new, high frequency 300 kHz Teledyne RDI 5-beam ADCP, with a vertical beam, sampling continuously at 2Hz at a marine energy site in the Bristol Channel, UK, of 40 m mean water depth. Accurate estimates of surface elevation were provided by the vertical beam, while four inclined beams (at 20° from vertical) characterise directional spectra using large 4 m bins with reduced velocity variance. It is not uncommon with these setups that current velocity data is not investigated further. In this paper it is shown that even when the ADCP's setup is optimised for wave measurements it is possible to use current velocity data to derive useful information on the characteristics of the mean current profiles and turbulence parameters along the water column. Measurements of turbulence parameters, which start at 6.2 m from seabed, are derived from the variances of the along-beam velocities of the four inclined beams. Obtained mean velocity profiles, vary according to theoretical and empirical predictions, showing the different shearing effects over the tidal cycle (peak flows of 1 m/s) and those due to the action of waves towards the upper part of the profiles. Reynolds stress profiles, representing the distribution of momentum flux within the flow, show familiar trends seen in other studies. Using a value of 0.17 for the turbulence anisotropy ratio, vertical profiles of TKE have been computed; these increase with height above seabed, but exhibit dramatic increases near the top surface. Although limited by the setup for wave measurements, the derived turbulence information is important when investigating wave current interactions, in which waves can significantly affect the turbulence parameters; this is crucial in the design and optimisation of marine energy converters as well as in turbulence modelling and analysis. These turbulence estimations can serve as powerful tools for planning more advanced turbulence investigations that require an optimised ADCP setup for current velocity, and provides insight on the large-scales of turbulence. The analysis is based on expensively obtained field data which may offer more details than controlled tank tests or numerical simulations. This might be a cost effective approach for collecting multi-scale data of interest to wave and tidal energy industries. The paper also discusses the merits of using a vertical beam for upcoming turbulence measurements.

SENSOR, DATA COLLECTION AND PROCESSING

Compared to the standard "Janus" four beam configurations, the Teledyne RDI 5-beam ADCP used in this study has, as a unique feature, a vertical 5th beam. The vertical beam was optimised to measure surface elevation directly using high resolution small bins near the surface (20cm), while the four inclined beams use larger (4m) low variance bins, to estimate directional wave spectra from orbital velocities. The current velocity data, collected continuously at 2Hz, was sampled at 15 bin locations throughout the water column; the bin size was dictated by the wave measurements. Quality control procedures were applied to the raw data to remove outliers, and spline interpolation to account for missing data (typically < 1%). The instantaneous current velocities, recorded in beam coordinates, can be transformed into the Cartesian (Earth) system (u, v, w) of horizontal velocities u (East) and v (North) and the vertical velocity w (Up). These velocities represent the dominant modes of motion. The measurements start at 6.2m from seabed to avoid transducer ringing but at the cost of not measuring closer to the bottom boundary. With the four inclined beams (at 20° from vertical), each pair of opposing beams resolves a horizontal velocity and the vertical component, thus giving redundant estimates for w, i.e., an "error velocity" that can be used to assess the accuracy of velocity measurements.

Due to the random nature of turbulence, statistical descriptors are usually based on velocity time series similar to what was collected by the 5-beam ADCP; each velocity component is decomposed into a mean and a fluctuating part, e.g., $u = \overline{u} + u'$. Ideally, turbulence measurements require that the measured velocities resolve the smallest temporal and spatial scales of the flow. However, the ADCP uses large (4m) bins for velocity measurement as dictated by wave estimates, the flow is inhomogeneous between the beams especially at larger beam spreads, sampling is limited to 2 Hz, and there is Doppler noise associated with velocity measurement. Currently available ADCPs are not able to resolve the smallest eddies in the flow, so turbulence parameters from ADCPs are generally based on large-scale structures [1]. Using a 10-minute window, mean current velocity profiles were computed over the tidal cycles assuming that the mean flow is statistically homogeneous in horizontal space over the distances separating the beams. From the variances of the along-beam velocities, two components of the Reynolds stress, $-\overline{u'w'}$ and $-\overline{v'w'}$ were calculated using the variance method assuming the second order moments of fluctuating velocities to be horizontally homogeneous [3], i.e., $\overline{u_1'} = \overline{u_2'}$, $\overline{u_1'w_1'} = \overline{u_2'w_2'}$, etc. Assuming a value of 0.17 for the large-scale anisotropy ratio $\alpha = \overline{w'^2} / \left(\overline{u'^2} + \overline{v'^2}\right)$ as in [2], profiles of TKE $q^2/2 = \left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)/2$ were computed. Turbulent intensity profiles and time series were also estimated.

RESULTS

The vertical beam surface tracking accurately measures waves up to 1 Hz and the directional spectra were accurately estimated, but only within a small frequency band due to the spatial Nyquist limitation inherent in ADCP array processing. Examples of current velocity profiles are shown in Figure 1, clearly demonstrating the neap and spring tides (Figure 1(a)). Also, as expected higher velocities occur towards the surface. Figure 2 shows the profiles of Reynolds stresses and TKE over a tidal cycle. The profiles in Figure 2(a) and (b) show generally that away from the bottom the magnitude of Reynolds stress decreases, but then close to the top surface dramatic changes occur, presumably as a result of wave action, though such changes seem to depend on the phase of the tide. The increase in Reynolds stress activity for $-\overline{u'w'}$ during the deceleration phase of the tide as in Figure 2(a) was also noted by Stacey et al. [2]. Just below the sea surface, the profiles of $-\overline{u'w'}$ and $-\overline{v'w'}$ are opposite to each other. The TKE profiles increase with height above seabed and, again, significant increases near the top surface occur over the tidal cycle, presumably due to increased perturbations from orbital velocities caused by the passage of waves over the mean current field.

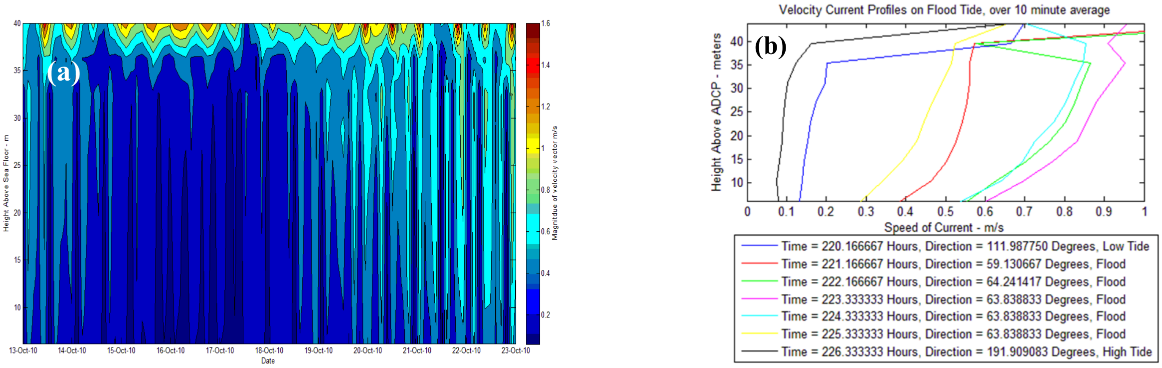

Figure 1. Current data: (a) Depth-time series of velocity profiles, (b) velocity profiles over a flood tide.

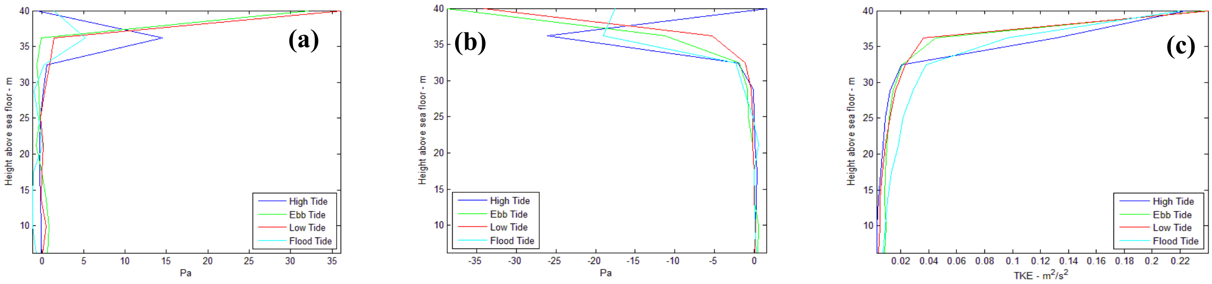

Figure 2. Turbulence profiles over a tidal cycle: (a) $-\overline{u'w'}$, (b) $-\overline{v'w'}$, (c) TKE.

Results show that even with ADCP set up for waves it is possible to obtain valuable insight into the behaviour of some bulk turbulence parameters particularly in a site with strong waves that seem to affect the mean and turbulence profiles. Here, the vertical beam was only setup to measure waves; the vertical velocity was only resolved from the slant beams. In future deployments at Pentland Firth in Scotland (start of February 2013), the vertical beam will measure the vertical velocity directly, and thus eliminating errors associated with its estimation, partly relaxes the issue of flow inhomogeneity, and improves estimates of higher moment parameters. The Reynolds stresses will be linked to empirical estimates of shear velocity and bottom drag coefficient and compared to estimates from mean current. Issues of statistical uncertainty, bias, error sources (e.g. Doppler noise), and spectra will be addressed in the full paper. Ongoing work is investigating the use of ADCP velocity data to compute the TKE dissipation rate via the "structure function" method, the characteristic length scales, and parameters important in turbulent modelling such as turbulent viscosity.

References

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