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Comparison of 4- and 5-beam acoustic Doppler current profiler configurations for measurement of turbulent kinetic energy

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Abstract

Acoustic Doppler current profilers (ADCPs) are commonly used to assess mean currents and turbulence at energetic sites. Since 2014, five-beam ADCP configurations have become more common, but conventional analysis of turbulence properties is still based on the four-beam Janus configuration. We use measurements from a single site to investigate improved estimates of turbulent kinetic energy (TKE) that are made possible by the addition of a fifth vertical beam. We conclude that four-beam estimates of TKE are suitable in most cases, and exhibit lower variance than five-beam estimates, but are more prone to contamination by wave activity.

Keywords: ADCP; Turbulence; Tidal energy; Ocean current

Nomenclature

B'_m	fluctuation velocity along the direction of the mth ADCP beam
H_S	significant wave height
k	turbulent kinetic energy density
k_4, k_5	estimates of k obtained with four- and five-beam ADCP configurations
u'_i	component of fluctuation velocity along the ith spatial dimension
θ	angle of inclination for off-vertical ADCP beams
ξ	fraction of turbulent kinetic energy contained in vertical fluctuations

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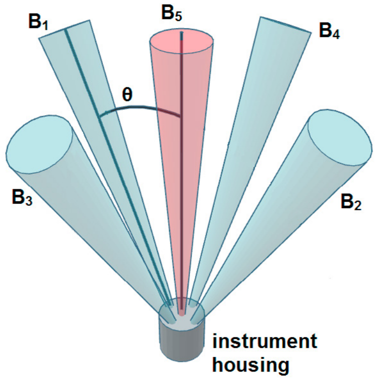

Fig. 1. Simplified diagram of upward-looking five-beam ADCP showing beam layout. Blue beams are also present in conventional four-beam Janus configuration.

1. Introduction

Tidal energy converters (TECs) are renewable energy devices that transfer the kinetic energy of tidal currents into electricity, with most designs using similar principles to conventional horizontal-axis wind turbines. However, the marine environment in which they are deployed and operated poses its own set of technical hurdles that must be addressed [1, 2, 3]. Tidal current turbulence, defined as the fine-scale fluctuations in mean flow manifesting as discrete eddies and vortices caused by topographic, bathymetric and frictional effects, is one of these challenges, and an important consideration for the development of TECs due to its impact on loading, reliability and fatigue [4, 5]. Ocean turbulence differs from atmospheric turbulence as the oceans surface acts as an upper-bound, where surface waves propagate, which can increase turbulence by introducing additional mass and momentum to the flow [6]. Therefore, knowledge of turbulence at tidal energy sites is of crucial importance for the design of resilient and efficient TECs.

Acoustic Doppler current profilers (ADCPs) are one of the most widely-used tools for measuring properties of marine flows, including turbulence characteristics. ADCPs use the Doppler shift in the echoes of pings along directed acoustic beams to measure flow velocities [7]. The specifics of an ADCP model and its deployment will vary according to the needs of a particular measurement campaign; however, for highly energetic sites suitable for TECs the standard is to use an upward-looking ADCP with three or four diverging beams [8, 9, 10]. Five-beam ADCPs are similar to the conventional four-beam Janus configuration (cf. figure 1), but with the addition of a vertical beam. Such devices have seen occasional use for approximately a decade [11], but have only recently become widely available as off-the-shelf instruments. In this paper, we examine how measurements of turbulence parameters may be improved by the additional data available from a fifth ADCP beam.

Each ADCP beam samples a single component of velocity from separate locations, so it is not possible to get direct measurements of the full turbulence velocity field at any given point. However, under certain assumptions regarding the flow statistics across the sampled area, it is possible to calculate some parameters of the turbulence.

1.1. Instrument deployment

All data presented in this paper is taken from a deployment of an RDI Sentinel V five-beam acoustic Doppler current profiler (ADCP) near the West Anglesey Demonstration Zone (WADZ) off the Welsh coast (UK) between 19/9/14 and 19/11/14; a map of the deployment zone is shown in figure 2. Concurrently with this deployment, a directional wave buoy measured significant wave height and period approximately 2 km to the south of the ADCP location. Water depth at the ADCPs location varied between 41.1 m and 46.2 m through the deployment period, and peak spring currents were 2.48 ms^{-1}. There was a blanking distance of 1.89 m between the instrument and the first bin, and subsequent bins had a vertical separation of 0.6 m. The ADCP collected fifteen minutes of data every hour; during