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The accuracy of acoustic vertical velocity measurements: instrument biases and the effect of Zooplankton migration

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Abstract

Doppler velocity and backscatter intensity records from an energetic estuarine flow in which backscatter reveal a significant diel migration of zooplankton are used to examine the reliability of the vertical velocity measurements. During periods when zooplankton were not migrating, the measured value is shown to be an accurate representation of the actual vertical velocity. At depths and times of active migration, with large increases in backscatter intensity, it is expected that vertical velocity measurements should be strongly affected by zooplankton motion. This does not appear to be the case, however, as the effect is much smaller than expected at sunset, and non-existent at sunrise.

Keywords: Current velocity; Acoustic current meters; Zooplankton; Vertical migrations; Canada; British Columbia; Juan de Fuca Strait

1. Introduction

Traditional rotary current meters have generally measured only the horizontal component of the flow. More recently, acoustical techniques, such as acoustic Doppler current profilers (ADCPs), have permitted the quantification of w, the vertical velocity. Measurements of w are invaluable in a wide range of dynamical studies, such as those involving turbulent mixing, Reynold stress, and upwelling of nutrients.

Although generally only the horizontal contributions ($\overline{u'u'}$ and $\overline{v'v'}$) of the turbulent kinetic energy are diagnosed, Gargett (1994) has used ADCPs to measure $\overline{w'w'}$ as a basis for an estimate of vertical mixing. In the past decade, direct measurements of Reynolds stresses have also been made (e.g. Lohrmann et al., 1990; van Haren et al., 1994; Lu and Lueck, 1999; Stacey et al., 1999a, b; Ott et al., 2002). Turbulence obtains its energy from the tides, solar irradiation, and wind stress and affects the distribution of scalars such as nutrients upon which biological activity depends,

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while Reynolds stresses act to directly modify currents at longer timescales.

Upwelling and vertical mixing are also important in drawing nutrients into the euphotic zone, where they can be used by phytoplankton. In an estuary, for example, the dynamic head resulting from river runoff drives a seaward flow in the upper layer. Through vertical mixing, the surface layer becomes more brackish, causing isopycnals at mid-depths to shallow in the oceanward direction, eventually reversing the pressure gradient and driving a return flow in the bottom layer. This draw nutrients from offshore into the estuary, and the amount transported back out of the estuary and thus lost to primary productivity within the estuary is related to the amount of entrainment into the upper layer. Box model budgets of Juan de Fuca Strait, for example, show that "up to 90% of the deep nutrient inflow is entrained into the upper layer and returns to the Pacific" (Pawlowicz, 2001).

Despite the importance of measurements of w, there is some question as to the accuracy of these observations, particularly in energetic regions such as the coastal ocean. The vertical velocity component is much more sensitive than the horizontal components to biases inherent in the measurement process itself, such as spatial inhomogeneity of the flow field and errors in the ADCP tilt angles, owing to the fact that w is typically an order of magnitude smaller. In order to use estimates of the vertical velocity confidently, it is important to examine the uncertainties associated with these biases.

The use of the ADCP to measure water movement also requires that sound-reflecting particles be passively advected by the background current; coherent relative movement by zooplankton may lead to erroneous current measurements. While horizontal movement among individual zooplankton is generally uncorrelated, horizontal biases may be present in regions of shallow topographic features (with zooplankton avoiding bottom-associated predators) or in regions of strong vertical shear of horizontal current (Wilson and Firing, 1992). Although the focus of the present study is on the vertical velocity, the relationship between horizontal velocity and backscatter intensity was examined and the results (not shown) indicate no bias in the data presented here.

On the other hand, many species of zooplankton descend from the euphotic zone, where they feed during the night, to escape predation from fish during daylight hours (Gliwicz, 1986; Neill, 1990; Hays, 1995; De Robertis, 2002). While burst speeds of about 5 body lengths per second are possible (Torres and Childress (1983) measured $0.1\,\mathrm{m\,s^{-1}}$ for *Euphausia pacifica* in the lab), typical swimming speeds are an order of magnitude smaller in the field. For example, Pinot and Jansa (2001) found euphasid migration speeds of $0.03–0.04\,\mathrm{m\,s^{-1}}$ in the western Mediterranean Sea for both ascent and descent, and Rippeth and Simpson (1998) found $0.02–0.03\,\mathrm{m\,s^{-1}}$ speeds on the Hebridean continental shelf, while Robinson and Gomez-Gutierrez (1998) found *E. pacifica* migration speeds of $0.005–0.007\,\mathrm{m\,s^{-1}}$ for descent and less than $0.0025\,\mathrm{m\,s^{-1}}$ for ascent, in Baja California. In Juan de Fuca Strait, sustainable swimming speeds are typically 1 to 2 body lengths per second, with body lengths varying from 0.001 to 0.02 m (Dave Mackas, personal communication, 1999). The maximum expected migration speeds are therefore approximately $0.02–0.04\,\mathrm{m\,s^{-1}}$, although smaller zooplankton do not migrate as much.

Considerable work in both the laboratory and field has been done on assessing the ability of ADCPs to estimate biomass in the ocean (e.g. Flagg and Smith, 1989; Stanton et al., 1993; Griffiths and Diaz, 1996; Brierley et al., 1998). There are many factors affecting backscatter intensity which make this proposition very difficult, including the large number of species and their relative distributions, the effect of zooplankton orientation, and possibly even the amount of undigested food inside the animals (McGehee et al., 1998). The focus of the present study, however, is to determine the degree to which the measured vertical velocity accurately represents the true, or background, water velocity. The diel migration is therefore considered a source of error, which eliminates the need to accurately estimate the biomass itself.

The data used in this study are described in Section 2. Section 3 examines errors in the