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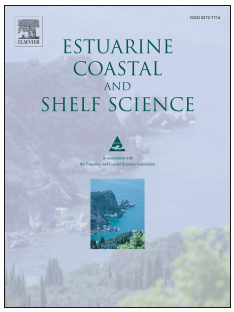

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Intermittent large amplitude internal waves observed in Port Susan, Puget Sound

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Abstract

A previously unreported internal tidal bore, which evolves into solitary internal wave packets, was observed in Port Susan, Puget Sound, and the timing, speed, and amplitude of the waves were measured by CTD and visual observation. Acoustic Doppler current profiler (ADCP) measurements were attempted, but unsuccessful. The waves appear to be generated with the ebb flow along the tidal flats of the Stillaguamish River, and the speed and width of the resulting waves can be predicted from second-order KdV theory. Their eventual dissipation may contribute significantly to surface mixing locally, particularly in comparison with the local dissipation due to the tides. Visually the waves appear in fair weather as a strong foam front, which is less visible the farther they propagate.

Keywords: internal waves, Korteweg de Vries equation, mixing processes, coastal waters, tidal effects

1. Introduction

Internal waves are now well known phenomena throughout the oceans (Jackson and Apel, 2004), and particularly large amplitude nonlinear internal waves are known to be formed when tidal currents interact with topography, such as a continental shelf break (e.g., Stanton and Ostrovsky, 1998), islands (Wolanski et al., 2004), or even can be generated by a river plume (e.g., Nash and Moum, 2005). See Apel et al. (2006) for a recent review. The presence of internal waves in estuaries has also received particular attention (e.g., Wang, 2006). In terms of hydrodynamics, large amplitude internal waves could be significant in dissipating tidal energy by mixing stratified environments (Chioua et al., 2013), and are known for being unpredictable (Nash et al., 2012).

Although moored installations are perhaps best to monitor internal waves (Cudaback and McPhee-Shaw, 2009), the simplest way to observe, albeit indirectly, internal waves are from a surface feature of converging and diverging flows that appear as slicks (e.g., Groeskamp et al., 2011). From this sort of surface expression, internal solitary waves were first suspected to exist in Port Susan, a basin of the Puget Sound estuary along the northeast of the Pacific Ocean (Fig. 1). Surface expressions of six wave fronts appeared in the south end of the basin about an hour after low tide on 29 April 1999, traveling south (A. Chiodi, pers. comm.), during Seaglider (autonomous CTD profiler) testing (Eriksen et al., 2001). Although internal solitary waves have been observed on the continental shelf and in the nearby Strait of Juan de Fuca, to the authors knowledge, there have been no published measurements of internal waves within Port Susan yet.

The Port Susan basin is calm, with weak currents, and is bordered by Camano Island on the west and by the mainland on the east. Due to the geography of the area, Port Susan is effectively a small bay. The area has two freshwater inputs; the Stilliguamish River to the north, with a large tidal flat (with a tidal range around 3 m), and the Snohomish River to the south. The stratification of the Port Susan basin is determined almost entirely by these rivers, resulting in a surface layer which varies significantly over the year, but often can be 5 to 10 m deep. We

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