Mixing and turbulence sources during the summer upwelling season in the Ría de Vigo (NW Spain)

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ABSTRACT

High-frequency observations of microstructure turbulence were carried out in the Ría de Vigo in August 2013 during two 25-hours cycles corresponding to spring (CHAOS 1) and neap (CHAOS 2) tides. This presentation describes the variability observed in turbulence levels at different time scales, and investigates the mechanisms driving this variability. Our results revealed enhanced levels of turbulent kinetic energy dissipation and turbulent mixing during CHAOS 1. Within cruise variability was relevant during both periods. In particular, strong bursts of turbulence occurred during the ebb, associated with enhanced vertical shear of tidal currents. The shear enhancement, which was more intense during spring tides, could be related to the interaction between tidal and upwelling driven circulation. Furthermore, the analysis of the potential energy involved in isopycnal displacements supports that internal wave activity was more intense during CHAOS 1, which could contribute to the enhanced levels of mixing observed during this period.

INTRODUCTION

The Ría de Vigo (NW Spain) is a highly dynamic partially mixed estuarine-like coastal environment where the variability of the relevant physical processes (upwelling-downwelling, tides, etc.) occurs at a wide range of temporal scales (i. e. seasonal, fortnightly, weekly, daily or shorter). During spring-summer months (April to September) the NW Iberia is characterized by intense and intermittent upwelling pulses [1]. Although the circulation of the Ría de Vigo is relatively well characterized [2], a description of the different scales involved in the variability of turbulence field is lacking. For both physicists and biologists, ocean turbulence is a relevant mechanism by which energy is dissipated and solutes, including dissolved nutrients, are transported. With the aim of characterizing different scales of variability in turbulence and their driving mechanisms, high-frequency observations of microstructure turbulence were carried out in the Ría de Vigo (NW Spain) in August 2013.

MATERIAL AND METHODS

Two cruises were conducted on board the R/V Mytilus in the outer part of the Ría de Vigo (42.174ºN, 8.890ºW) during spring (20-21 August 2013, CHAOS 1) and neap (27-28 August 2013, CHAOS 2) tides. During each cruise, by using a microstructure turbulence profiler (MSS), an intensive sampling (yo-yo) of measurements of turbulent kinetic energy (TKE) dissipation rates (ε) was carried out covering a complete diurnal tidal cycle (ca. 25 hours). Temperature and salinity values were measured by the CTD sensors incorporated into the MSS profiler, and used to calculate seawater potential density (σ_T) and buoyancy frequency (N^2). Diapycnal diffusivity (K_ρ) was calculated as $K_\rho = 0.2\varepsilon N^{-2}$.
Currents were measured with a vessel-mounted Acoustic Doppler Profiler (vmADCP). Vertical shear (S) was calculated as the vertical derivative of horizontal velocities. Gradient Richardson number (Ri) was calculated as $Ri = N^2/S^2$.
Internal wave potential energy was calculated from the vertical displacements of the isopycnals (η) as $E^{IW} = 0.5N^2\langle\eta^2\rangle$, where $\eta = (\sigma_T - \langle\sigma_T\rangle)/\partial_z\langle\sigma_T\rangle$ [3] and $\langle\sigma_T\rangle$ is the averaged density profile during the tidal cycle.

RESULTS AND DISCUSSION

Turbulence microstructure measurements indicated that TKE dissipation rates ($\langle\varepsilon\rangle$) and diapycnal diffusivity ($\langle K_\rho\rangle$), averaged in the main thermocline (12-32 m) away from boundary influence, were more than 2-fold higher in spring compared to neap tides (Table 1). Both variables showed significant variability along the semi-diurnal tidal cycle, and this variability was more evident during spring compared to neap tides (see Fig. 1 and Table 1). $\langle\varepsilon\rangle$ varied up to two orders of magnitude during the sampling period in spring tides. Minimum values of ca. 10^{-8} W/Kg occurred during high tides and then <ε> sharply increased during the ebb reaching ca. 10^{-6} W Kg^{-1} 1-2 hours before low tides (Fig. 1). As the result of this, <ε> and <K_ρ> averaged in a 6-hour window around the low tide, were more than 2-fold higher compared to high tides (Table 1). Although weaker, this pattern was also observed during neap tides.

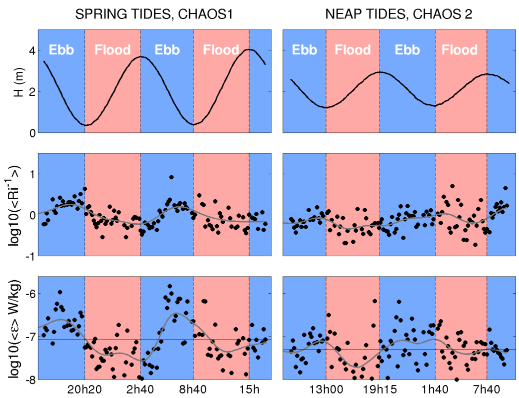

Fig. 1. Time evolution of tidal height (H), and averaged (12 – 32 m) inverse Richardson number (<Ri^{-1}>) and TKE dissipation rates (ε) for the 25-hour sampling cycles carried out during spring (CHAOS 1) and neap (CHAOS 2) tides. Grey lines are running averages.

Table 1. Averaged values (±se) of TKE dissipation rates (ε), turbulent diapycnal diffusivity (K_ρ), gradient Richardson number (*Ri*) and internal wave energy (E^{IW}) computed during spring (CHAOS 1) and neap (CHAOS 2) tides. Averages were calculated for the whole tidal cycle (average), and for 6-hous periods centered at low and high tides.

	<ε> 10^{-7} (W/kg)	<K_ρ> 10^{-4} (m^2/s)	<Ri>	$\int E_{IW}$ (J/m^2)
Spring tides (CHAOS 1)				
Average	1.76±0.23	4.09±0.74	5.2±1.0	59
Low	2.26±0.34	6.0±1.3	3.18±0.63	
High	1.22±0.26	2.05±0.42	7.4±2.1	
Neap tides (CHAOS 2)				
Average	0.68±0.07	1.70±0.20	11.2±2.3	44
Low	0.71±0.90	2.03±0.39	8.6±1.7	
High	0.67±0.09	1.55±0.22	12.3±3.2	

The observed enhanced values of TKE dissipation during the ebb were associated with reduced values of *Ri*. During spring tides *Ri* ranged between supercritical and subcritical values along the tidal cycle (Fig. 1). This decrease in *Ri* was caused by a significant increase of shear during the ebb, when the tidal current showed a sheared pattern, with circulation towards the ocean predominantly occurring in the upper 20 m (data not shown). We hypothesize that this pattern was driven by the interaction with positive upwelling circulation, which was active during the sampling period. Enhanced internal wave activity during the more energetic spring tide period could contribute to explain the observed differences, as internal wave energy was ca. 35% higher during this period (Table 1)

It has been proposed that tidal [4], and wind induced positive circulation [5] of surface waters towards the open ocean, can result in a net increase in stratification in estuaries, due to the straining caused along the channel density gradient. Our observations suggest that a different mechanism could be at work during the upwelling season, when freshwater input into the Ría is relatively weak. Sheared ebb tidal current, likely caused by the interaction of the tidal wave with the upwelling circulation, results in a net increase of bulk shear and TKE dissipation, which peaks before the low tide. This mechanism could have important ecological implications in this region. Complementary observations carried out during the CHAOS cruises showed that enhanced nutrient diffusive supply during spring tides could contribute to the continuous dominance of large-sized phytoplankton during the upwelling favorable season (Villamaña et al., this issue) [6].

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