Three dimensional dynamics of baroclinic tides in the Celtic Sea on the results of in-situ observations and numerical modelling

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Three dimensional dynamics of baroclinic tides in the shelf-slope area of the Celtic Sea (CS) was investigated numerically and using observational data collected in 376-th cruise of the R/V "Discovery" in June 2012. The field campaign was conducted in the framework of the FASTNEt NERC grant on investigation of the processes controlling the cross shelf transport on the NE Atlantic Ocean margin.

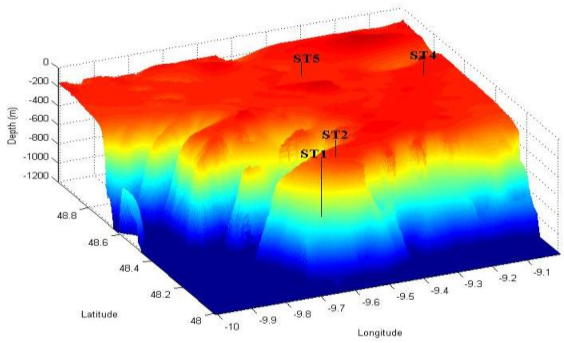

Figure 1. The bottom topography with location of four moorings.

The bottom topography in the observational domain is quite complicated. A number of canyons and headlands makes it highly corrugated (see Figure 1) suggesting a substantial three-dimensionality of the baroclinic wave fields. The baroclinic tide data were collected at four moorings ST1, ST2, ST4, ST5 shown in Figure 1. ST1 and ST2 were deployed at the slope (ST1) and in the shelf break area (ST2) in order to quantify the characteristics of baroclinic tides close to the sites of their generation.

The most interesting fragment of the time series at moorings ST1 is shown in Figure 2. It represents an example of a spring tidal response. The vertical scope of thermoicline displacements (shown by dashed line in the left panel) reaches 40 m. In addition to the semidiurnal tidal signal a number of spikes short-period internal solitary waves (ISW) are clearly seen. The amplitude of the largest ISW exceeds 100 m, is the largest ISW ever recorded in the CS.

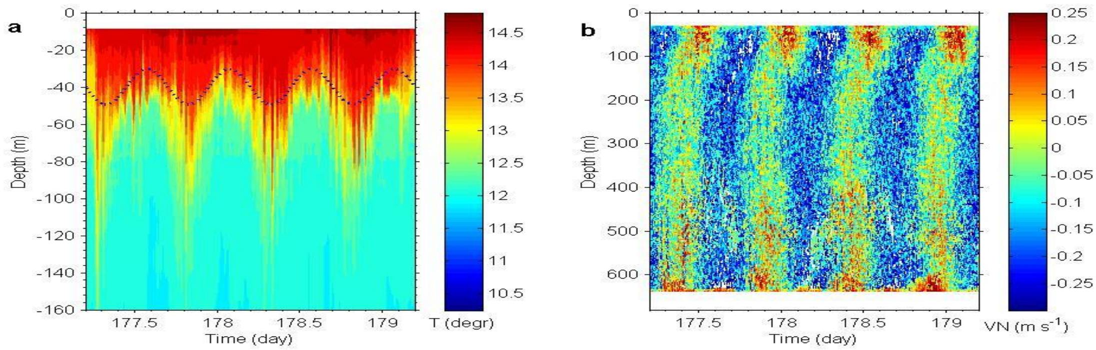

Figure 2. Temperature time series (left) and horizontal northward velocity (right) recorded at ST1.

The horizontal velocity at the mooring ST1 (right panel) reveals quite a strong semidiurnal tidal periodicity with the typical velocity in the range (-0.3, +0.3) m sec^{-1}. The most exciting feature of these currents is their intensification near the bottom that cannot be explained in terms of a standard approach considering internal tide as a progressive internal wave with the maximum of horizontal velocity at the free surface. It is interesting that the mooring ST2 deployed just 13 km further to shelf does not reveal any tidally induced bottom intensification. The latter suggests a great level of spatial variability of the baroclinic tidal wave fields.

The detailed spatial structure of the tidally generated internal waves as well as the place of their generation cannot be retrieved just from the available observations. However, the baroclinic wave fields can be reconstructed based on a joint analysis of the observational and model data. In doing so numerical modelling of baroclinic tides was conducted using the Massachusetts Institute of Technology general circulation model (MITgcm) on a fine-resolution grid with the horizontal step of 115 m in meridional and zonal directions. The calculational domain is shown by a rectangular in Figure 1. In vertical direction the grid step was equal to 10 m.

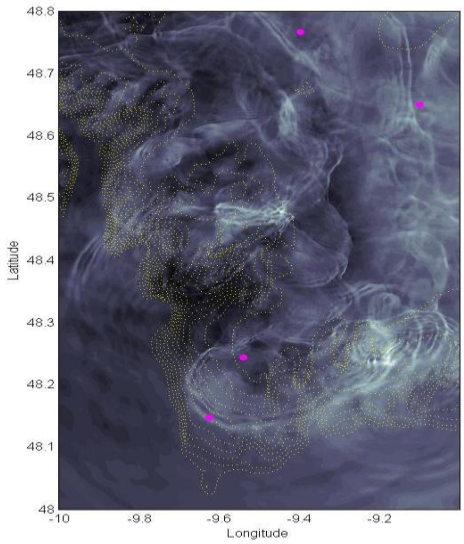

Figure 3. Free surface after 34 hours of the model run.

Corrugated bottom topography shown in Figure 1 suggests generation of substantially three-dimensional wave fields. The spatial structure of internal waves was investigated here based on the MITgcm output using elevation (light colour) and depression (dark colours) of free surface that produced by propagating internal solitary waves.

It is clear from Figure 3 that the structure of the wave pattern in the area is quite irregular. One can identify some circular wave systems radially spreading from the point sources of generation. The most powerful sources are located in the shelf break area, but some point sources are also visible on the shelf.

Comparing the frames taken every hour of the model run one can reproduce the spatial evolution of the wave fronts. Figures 4 represents overlaid signatures for one tidal cycle of all strongest wave systems. The positions of leading waves in every wave packet allows one to trace the place of their generation and reproduce their spatial evolution.

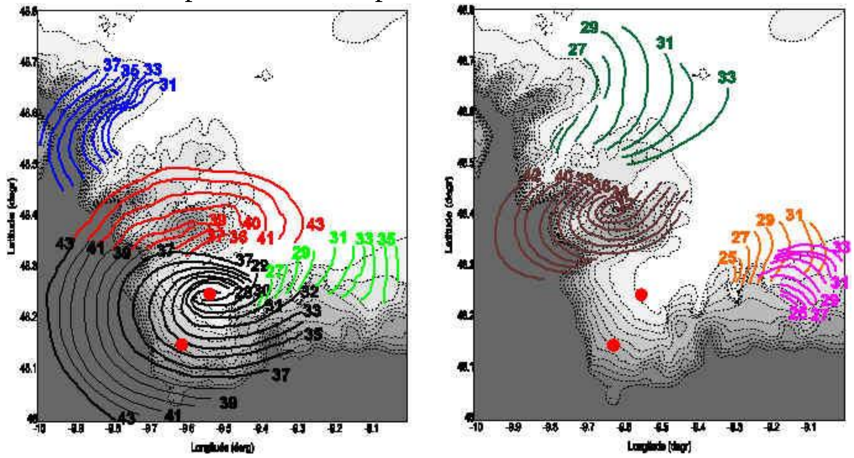

Figure 4. Model predicted spatial evolution of the strongest wave systems.

Eight wave systems are presented in Figure 4. One can identify two classes of generated internal waves that are different on the mechanism of their generation and spatial evolution. The first class reveals the properties of spiral-type waves typically generated over isolated underwater banks (find the wave families shown in black, red, and dark-brown colours). The second class of waves is generated in the areas of isolated canyons (a number of them are present in the area). For instance, the northern most canyon produces two system of waves: the strongest one propagates on-shelf (shown in forest-green in the right panel) and looks as a superposition of two radially spreading packets merged at t=29 h and moving further as a single wave packet.

Another interesting feature of the baroclinic tides revealed by the model is the bottom intensification of the tidal currents recorded at the mooring ST1. The basic reasons for that is the generation of a tidal beam. The bottom topography in the generation site is supercritical in terms of the bottom steepness and the inclination of the characteristic lines of the hyperbolic wave equation. As a result, the tidal beam is generated. It starts just at the top of the local topography (where by chance the mooring ST1 was deployed) and propagates downward to the abyss along the slope.