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Seasonality of the circulation in the Ría de Muros (NW Spain)

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ABSTRACT

In the Ría de Muros, the northernmost of the four large coastal embayments on the NW coast of the Iberian Peninsula known as Rías Baixas, river discharges, winds and tides are the main agents driving the circulation. Both river discharges and winds present a high degree of seasonality: river flows are typically low in summer and high in winter, and the direction of prevailing winds is N–NE in spring–summer and S–SW in fall–winter. This seasonality may be expected to affect the circulation in the ría. To investigate this, a 3D, baroclinic model is implemented with an unconventional mixed boundary condition at the open (ocean) boundary. Once validated by comparing simulated and observed data of water level, current velocity and salinity, the model is applied to computing the circulation in four cases representative of typical summer and winter scenarios. In each case the model is forced by a specific combination of driving agents, including river runoff, tide and, in some cases, wind. A two-layer circulation pattern with bottom inflow and surface outflow (positive estuarine circulation) exists in the summer cases as well as in the winter case without wind, but its intensity varies greatly. It is weak in typical summer conditions in the absence of wind, but very strong in typical winter conditions also in the absence of wind due to the increase of baroclinic effects brought about by the high river discharges. Moreover, the winds characteristic of summer (N–NE) and winter (S–SW) have markedly different effects when added to the hydrodynamic forcing characteristic of the respective season. While the N–NE wind strengthens the summer no-wind circulation, the S–SW wind transforms the winter no-wind circulation into a three-layer pattern—previously undescribed in the Rías Baixas—in which the surface layer is mostly at rest, outflow resumes immediately underneath, and inflow continues at lower levels. The fact that the S–SW wind is incapable of triggering a negative estuarine circulation in the face of winter average river flows is indicative of the fundamental importance of baroclinic effects in the Ría de Muros. In sum, the seasonal variability of river discharges and winds is found to have a substantial effect on the circulation in the ría.

1. Introduction

The Ría de Muros is the northernmost of four flooded tectonic valleys between 42° N and 43° N on the Atlantic coast of Galicia (NW Spain) known as Rías Baixas (Fig. 1). Like the other Rías Baixas, it behaves as a partially mixed estuary with positive residual circulation—a two-layer pattern with outflow of surface water and inflow of bottom water (Fraga and Margalef, 1979; Prego and Fraga, 1992). This circulation is episodically enhanced—especially from April to October—by coastal upwelling events induced by northerly shelf winds, during which cold and nutrient-laden Eastern North Atlantic Central Water (ENACW) ascends to the shelf and eventually enters the rías (Wooster et al., 1976; Ríos et al., 1992; Fiúza et al., 1998). Indeed the Rías Baixas region forms part of the Eastern North Atlantic Upwelling System (e.g. Wooster et al., 1976), one of the major upwelling systems in the world along with the Benguela upwelling system (Fennel, 1999; Monteiro and Largier, 1999), the Peru-Humboldt Current (Nixon and Thomas, 2001; Di Lorenzo, 2003; Mesias et al., 2003) and the California Current System (Di Lorenzo, 2003).

With a surface area of some 90 km^2 and a mean volume of 2060 Hm^3, the Ría de Muros is one of the largest coastal embayments of the Iberian Peninsula. Its surface:volume ratio is 0.04, a typical value for a V-shaped basin where depth and width increase gradually towards the mouth. Its main axis stretches over 13 km in a NE–SW direction (Fig. 1). The general orientation of the northern margin is ENE–WSW while the southern margin follows a NE–SW line; as a result, the width of the ría increases from ~0.9 km at the inner ría to more than 6 km at its mouth. The northern margin forms a succession of bays from the upper ría to the mouth (Freixo, Esteiro, Bornalle, Muros and San Francisco) whereas the southern margin is more regular. The bathymetry (Fig. 2) presents roughly triangular cross sections in the middle and outer ría; maximum depths, of the order of 50 m near the mouth, decrease steadily towards the head. The inner ría is very shallow—from the cross section between Pt. de la Batuda and Pt. Cotarín (Fig. 1) upward water depths are below 10 m everywhere, and extensive tidal flats lie exposed at low tide.

The main forcing agents are river discharges, winds and tides. With a form number of 0.09, tides are clearly semidiurnal. The maximum tidal range is 4 m, and the average range 2.5 m (mesotidal). Tidal harmonics

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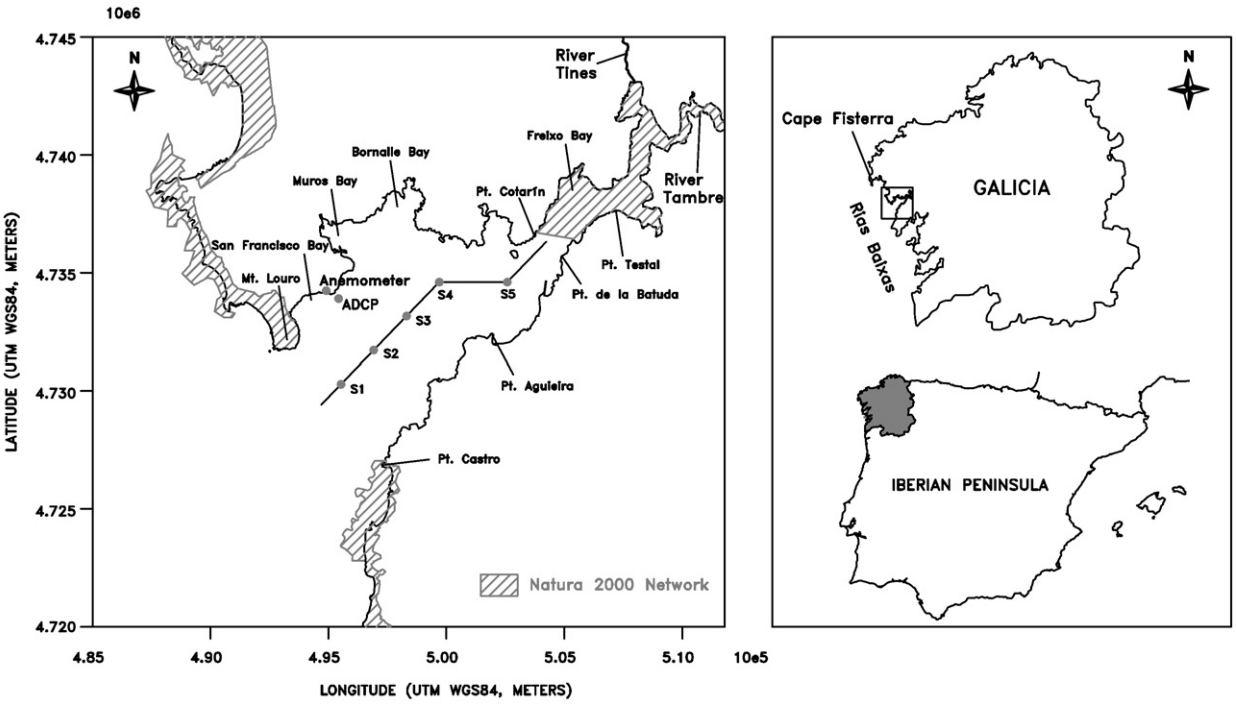

Fig. 1. Ría de Muros. The locations of the ADCP and anemometer are marked on the map, along with the stations along the ría axis where CTD profiles were taken (S1 to S5). Hatched areas indicate special protection areas included in the Natura 2000 Network.

propagate as Kelvin waves along the shelf, from south to north, with increasing amplitude towards the coastline (Alvarez-Fanjul et al., 1997). Typical tidal velocities are 0.05–0.2 m s^{-1} in the outer and middle ría and 1.5 m s^{-1} in the inner ría (Iglesias et al., 2008).

Both river discharges and winds present a high degree of seasonality, related to the seasonal evolution of the two centres of action that govern the large-scale meteorological dynamics of NE Atlantic: the Azores High and the Iceland Low. In typical summer conditions the Azores High is strong and at its highest latitude while the Iceland Low is weak; consequently, low-pressure centres cross the Atlantic at relatively high latitudes so their influence barely (if at all) reaches the Rías Baixas. The proximity and strength of the Azores High together with the thermal low over the Iberian Peninsula create a pressure gradient that leads to northerly shelf winds and fine weather in the region. Conversely, in

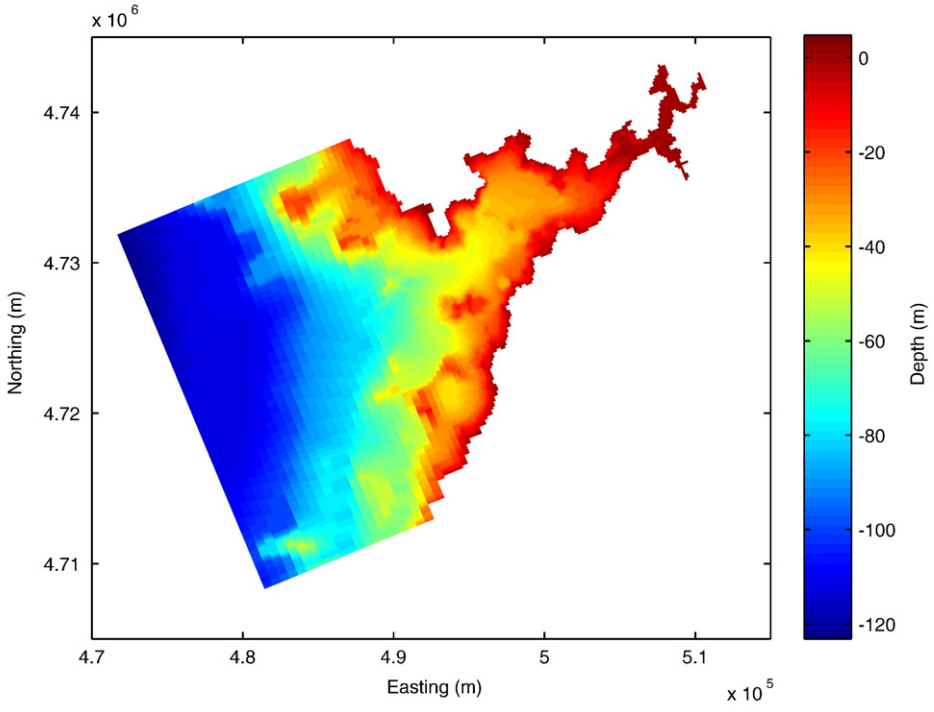

Fig. 2. Bathymetry of the Ría de Muros. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).