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Analysis of current intensification in the Northwest Mediterranean shelf

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ABSTRACT

Flow intensification episodes lasting more than 12 h are observed occasionally at different locations along the Northwestern Mediterranean coast. In the last years, these pulses have hindered ship operations outside the Barcelona harbour, thus attracting the attention of the port authorities. In this paper, the strongest intensification events in the Barcelona coast area are quantified and characterized in order to identify the mechanisms which generate them. For this, current, sea level and meteorological measured and modelled data, at local and regional scale, are analysed. The results show that the flow accelerations are due to the combination of a narrow coastal shelf and the prevalence of a strong and sustained wind from the NE to SE. The synoptic atmospheric conditions that lead to this meteorological scenario are described. For one of the events, the presence and contribution to the current fluctuations of a coastal trapped wave, likely generated at the Eastern edge of the Gulf of Lions shelf, and other factors such as a freshwater discharge are also identified and discussed.

1. Introduction

Traditionally, the scientific and engineering interests on the hydrodynamics of a specific region has been focused on the mean hydrodynamic behaviour, but the importance of local ("extreme") current pulses cannot be ignored. Strong current events are of concern for maritime industries such as gas and oil related activities (Ivanov and Magnell, 2012), aquaculture practices (Kumar and Karnatak, 2014) or harbour operativeness (Sánchez-Arcilla et al., 2010). The coupling of meteorological phenomena and local topographic features are also a probable source for flow pulses. Locally energetic or persistent wind events with a strong alongshore component lead to Ekman transport of surface water, thus enhancing (or dampening) the underlying currents. The combination of atmospheric pressure gradients and winds might generate strong storm surges, with an evident increase of the coastal water motion.

Intense water flows have been observed at different locations along the Catalan coast (NW Mediterranean Sea), usually associated to strong local wind events (e.g., Palanques et al., 2002; Jordà, 2005; Grifoll et al., 2015), even during energetic events the depth-averaged current magnitudes do not exceed 50 cm/s. However, and coinciding with the southward development of the Barcelona harbour (Fig. 1), the Port Authority has become aware during the last years of the existence of occasional current intensification episodes near the south port mouth that can hinder the manoeuvrability, approach and entrance of ships into the harbour through this access.

The presence of a permanent southwestward slope current is modulated on the shallowest part of the shelf by numerous physical processes at different temporal and spatial scales, including wind-forced motion (Grifoll et al., 2012), density-driven currents (Liste et al., 2014) and the propagation of barotropic long waves (Jordi et al., 2005). The inner and mid-shelf shelf circulation is characterized by a marked seasonal variability due to the heat and freshwater fluxes and the wind characteristics (Grifoll et al., 2013). Low-frequency motion in this region is controlled essentially by frictional forcing (wind and bottom stresses) and pressure gradients (both barotropic and baroclinic) in shallower waters, and by inertial-scale processes in the outer shelf (Palanques et al., 2002; Grifoll et al., 2012, 2013; Liste et al., 2014). However, Grifoll et al. (2012, 2013) suggest an eventual prevalence of the remote forcing – associated to regional bathymetric features or to the spatial gradients of wind and atmospheric pressure – in water motion but they did not clarify its link with the short-term current intensification (i.e. order of few days).

Following the concern of the Barcelona Port Authority with strong flow events sporadically observed near the south harbour mouth, Espino et al. (2011) undertook a first analysis of these currents, correlating three intensification events with local wind and wave forcings. They found a clear connection between the

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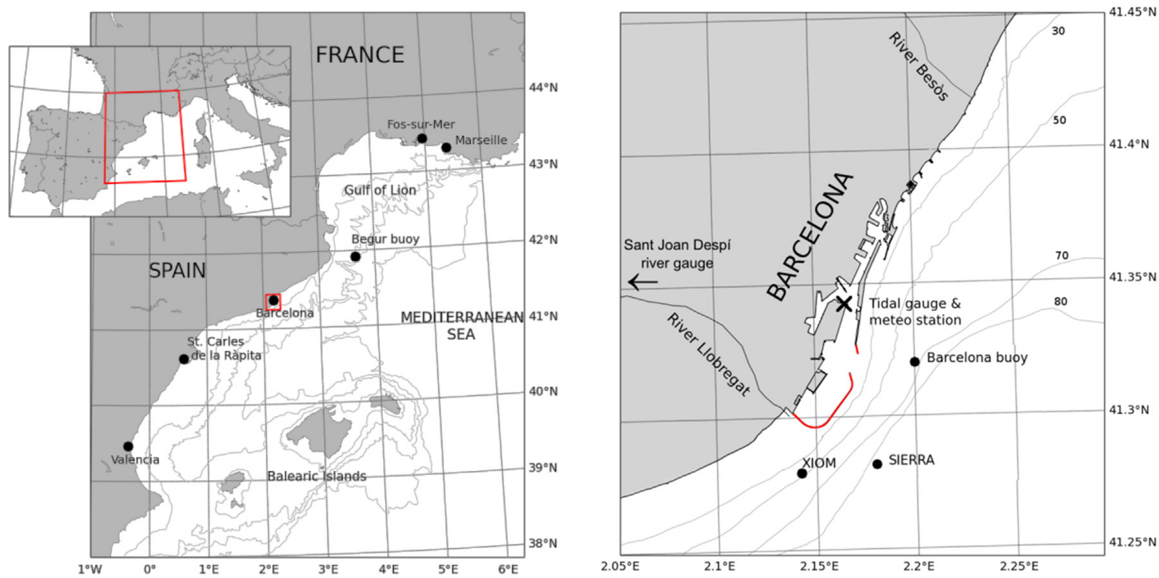

Fig. 1. (Left) Extended study area, comprising the NW Mediterranean. Focus is placed around the Barcelona area. Other sites from which measured data are used are also shown. Isobaths are drawn at 100, 1000, 1600 and 2400 m. (Right) Barcelona harbour, showing the position of the currentmeters, and isobaths up to 80 m. The recent harbour expansion is marked in red. (For interpretation of the references to colour in this figure legend,the reader is referred to the web version of this article.)

speed and direction of the wind and those of the currents, and attributed the flow intensification to the enhanced transfer of energy to the top water layers during long and intense wind periods.

The goal of this paper is to go a step further using the output from numerical models and oceanographic and meteorological field data, recorded during a three-year period near the south entrance of the Barcelona harbour and along the Northwestern Mediterranean coast. With this, we aim to characterize and quantify these flow intensifications, and shed some light on their probable causes, local or remote.

2. Study zone

In the northmost Spanish Mediterranean coast in which Barcelona is located, the general circulation pattern presents a relatively complex pattern largely determined by the bottom bathymetry (Sánchez-Arcilla and Simpson, 2002). Particularly important are the characteristics of the continental shelf and the slope. The shelf is broad in the north (about 70 km in the Gulf of Lions, GoL), narrows to less than 20 km in the central stretch of the coast (in front of Barcelona city), and then widens again abruptly to about 60 km further south, in the Ebro Delta Region. The end of the shelf is marked by a fairly steep slope, with a mean value of about 0.01

The focus of this work is placed on the coast off the city of Barcelona, at about 41.3°N, 2.15°E, in the Northwestern Mediterranean (Fig. 1). The general circulation in this area has been described in the previous section, and will not be repeated here. The continental shelf is approximately 20 km wide, in contrast to the much wider shelves to the North (Gulf of Lions) and South (Gulf of Valencia), and plays an important role in determining the local hydrodynamic patterns (Sánchez-Arcilla and Simpson, 2002). Furthermore, storm-related forcings acting at short timescales (Grifoll et al., 2012) and the freshwater input from two rivers (Llobregat and Besòs) can also influence the flow behaviour in the inner-shelf The water flow variability is strongly correlated with local wind pulses which tend to be south-westerly during summer and relatively variable during the rest of the year (Grifoll et al., 2013). The depth-averaged flow at depths shallower than 50 m tend to be aligned following the isobaths due to the coastal constrain and the importance of the bottom boundary layer. Eventual storms accelerates the along-shelf flow due to the increasing wind stress with a momentum balance dominated by the pressure gradient force (due to sea-level adjustment) that oppose the wind stress (Grifoll et al., 2015). In this case, advective terms may be relevant in the momentum balance during the relaxation period of the storm. The importance of the bottom friction and the proximity of the coastline restrict the development of inertial circulation at the mid and inner-shelf during storms. Stratification mainly occurs in the summer due to positive heat flux, and is broken in autumn and winter by water cooling and wind-induced mixing (Font, 1990; Grifoll et al., 2013). Due to the microtidal character of the Mediterranean Sea, tidal perturbations to the currents are not significant in this area (Poulain et al., 2013; Tsimplis et al., 1995).

The Barcelona coast is highly urbanised, dominated by the presence of a large commercial harbour which has undergone substantial evolution and development during the last decade, particularly with its southward expansion involving the construction of a new seawall and dock (Fig. 1). The new south configuration of the port has narrowed the coastal shelf locally by about 1.5 km which, in this particular area, can be up to 20% of its original width. Coinciding with these changes, the harbour pilots have become aware of the existence of occasional strong current pulses near the south mouth that affect the normal ship approach operations.

3. Methodology

The analysis of currents in the Barcelona harbour vicinity has been based on different datasets from two currentmeters. The currentmeter location and time windows are presented in Table 1 and Fig. 1. The more extensive dataset spans from June 2008 to July 2011 and was recorded by a buoy-mounted Aanderaa DCS 4100 currentmeter deployed approximately 1.9 km from the Llobregat rivermouth (Fig. 1). This buoy belongs to the XIOM network (Network of Oceanographic and Meteorological Instrumentation, Bolaños et al., 2009) and provided current data every 10 min at 1 m and 10 m depths, together with water temperature values. The XIOM time series is complemented with additional measurement