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River plume dispersion in response to flash flood events. Application to the Catalan shelf

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ABSTRACT

The dispersal of freshwater inflow from a flood event is studied using a three dimensional flow model (ROMS). The model domain includes a small part of the Catalan shelf where the combination of local land topography with torrential rainfall can cause high local runoff during a short period but with a large impact on the receiving coastal waters. Both steady, low river discharge, typical of normal (low-discharge) conditions and a high discharge representative of post-rain conditions are considered. Simulated salinity profiles on the shelf near the river mouth are compared with records from CTD measurements with quite good correspondence. A strong correlation between local wind and plume response was observed. Local winds affect the trajectory of the freshwater plume that enters the Catalan shelf waters. During post-rain conditions, northerly and westerly winds exported the plume further away from the coast, whereas southerly and easterly winds confine the plume closer to the coast. During low discharge conditions, the plume remained closer to the coast due to the weak wind stresses. Results show that freshwater spread, shape and dilution are mainly controlled by local wind forcing at relatively short time scales.

1. Introduction

Freshwater discharge into the coastal ocean represents a major link between terrestrial and marine systems, produces strong effects on the physical, chemical, and biological processes in coastal waters, induces circulation patterns and modifies mixing processes (Milliman and Farnsworth, 2011). Most studies on freshwater influence into the coastal sea have been developed in estuarine environments and continental/urban runoff more in particular combined sewer overflows (CSOs) have been rarely considered in coastal circulation models even though we know that they can play a crucial role for assessment and prediction of the dynamics and water quality at the local scale.

Idealized numerical simulations of freshwater plumes are typically formulated with different factors and forcings that modify the pathways of the freshwater plume. Examples are outflow angle (Avicola and Huq, 2003a, 2003b; Garvine, 1999), wind forcing (Fong and Geyer, 2001; García-Berdeal et al., 2002; Lentz and Chapman, 2004; Whitney and Garvine, 2005; Choi and Wilkin, 2007; MacCready et al., 2009; Xia et al., 2010; Schiller et al., 2011; Osadchiev and Zavialov, in press), nearshore current (Fong and Geyer, 2002; García-Berdeal et al., 2002; Hickey et al., 2005), tides (Rong and Li, 2012; Moon et al., 2012), and local topography (Schiller et al., 2011). Idealized simulations often use a straight coastline and a river represented by a point source at the wall or as a short channel (Fong and Geyer, 2001, 2002; García-Berdeal et al., 2002; Hetland R.D., 2005), possibly with the addition of time variability in either the river flow (Yankovsky and Chapman, 1997) or winds (Hetland, 2005; Choi and Wilkin, 2007). Other plume modeling studies have employed realistic geometry and imposed observed river flow, wind forcing (Pullen and Allen, 2000) and tides (Whitney and Garvine, 2005) to analyze the dispersal of a particular river plume in comparison with observations.

For the small and medium scale, local wind forcing and freshwater runoff have been identified as two primary factors which determine plume behavior and orientation (Xia et al., 2010). From this perspective, in spite of the many studies mentioned above, some processes still need investigating because of the wide range in wind climate, shelf dynamics and/or the temporal scale of the water discharge load. In this sense, there are not many detailed studies that summarize the plume transition under wind induced external forcing, including how the plume direction changes in response to different wind directions.

The variability of the different factors results in a variety of behaviors and time scales in river plumes. Among the factors affecting river plumes, the freshwater discharge and its temporal variation are particularly important. This discharge varies over many time scales. Practical time scales can be as long as interannual or seasonal and as short as a few days, such as during and after a flash flood events. In this sense, "flash-flood" events are characterized by sudden and

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abrupt freshwater discharge (lasting from hours to few days) and are common for rivers with relatively small catchment areas in the Mediterranean climate. Hereafter, we refer to the short time scales as abrupt changes in river discharge. Compared to the interannual or seasonal variations in river discharge, it is more difficult to understand the influence of abrupt changes in river discharge on salinity distributions from field observations. Abrupt changes in river discharge are usually caused by a heavy precipitation event accompanied by stormy conditions. The strong winds that coincide with storm conditions not only strongly affect the evolution of a plume, they also hamper field surveys.

The Catalan Coast has the same orographic and climatic characteristics as most Mediterranean regions, which leads to irregular rainfall patterns, both in time and in space. The annual rainfall of 400–600 mm is not very high, but the rainfall showers are very intense and irregular. The rainfall pattern is complex with two different kinds of rainfall storms that occur mainly during spring and fall. On the one hand there are showers that are caused by Atlantic fronts resulting in a slow and rather weak river response; on the other hand there are convective storms of very short duration but very high intensity which result in a very fast river response and larger discharge. These “flash flood” conditions occur during short (hours to days of duration) and intense storm events, typical of the Mediterranean climate, in small river mountainous drainage basins (Bourrin et al., 2008). Within thirty to sixty minutes, one quarter of the total annual precipitation can be recorded causing “flash floods” to be discharged into the ocean (Entitat Metropolitana del Medi Ambient, 2005). Land discharge (river and urban) is considered to have the largest influence on the results of the local scale coastal model.

In this contribution, we focus on the freshwater dispersal from a flash-flood event in response to the local wind forcing in a small part of the Catalan Coast (The Catalan inner-shelf, NW Mediterranean Sea) based on observations and modeling efforts during the Field_AC project (www.field_ac.eu). This paper provides an analysis of the behavior of the freshwater plume in low-discharge and post-rain conditions (after a flood event) and discusses the influence of the discharge temporal scales (short-term response) on the plume evolution. Both urban runoff (from combined sewer overflows) and river runoff are included in the simulations.

The model presented here takes into account variable wind forcing, river (Llobregat and Besòs; see Fig. 1) and urban runoff discharge, initial ocean stratification and boundary forcing of the Catalan shelf waters (Fig. 1). The model was previously calibrated, in terms of water circulation, using observed data from three ADCP deployments (Grifoll et al., in preparation). The model results are compared here with hydrographic measurements (temperature and salinity observations) around the Besòs River mouth.

This contribution is organized as follows: in Section 2 we introduce the study area, the hydrographic measurements and the numerical model. In addition, we summarize the numerical model setup. In Section 3 the results are described. Section 3 is divided into three different subsections: Hydrographic measurements and flash flood events, comparison of model with field measurement (where model results and observations are compared) and plume dispersion modeling (where we carry out model runs the examine the effect of different processes). Within the plume dispersion modeling section, we show results for the impact of freshwater, the influence of the CSOs and the river plume response to local wind forcing. Section 4 provides the discussion and future work. Conclusions can be found in Section 5.

2. Data and methods

2.1. Study area

The Catalan coast is located in the north-western Mediterranean at the latitude 40° 45′ N to 42° 25′ N and longitude 0° 45′ E to 3° 15′ E (Fig. 1, A panel). The Catalan inner-shelf exhibits microtidal fluctuations and is relatively narrow. The shelf width corresponding to the Barcelona shoreface is around 20 km. The shelf break is approximately located at the 150 m isobath and the averaged slope is of the order of 10^{-2}. The wind regime is characterized by small inter-annual variability (Font J., 1990). The predominant winds come from the north and northwest, primarily during fall and winter, with energy concentrated in low frequencies (periods over 3 days) associated with synoptic low-pressure systems (Salat et al., 1992). In summer and spring, the dominant winds are southwesterly, with the dominant frequencies being the synoptic and diurnal (sea breeze) bands (Font J., 1990). Torrential rainfall in this area acts in a short-time scale and is considered to have a high impact on the quality of coastal waters and it is thus important to be able to predict the land discharge adequately such that it can be incorporated into the coastal scale oceanographic models (Keupers et al., 2011).

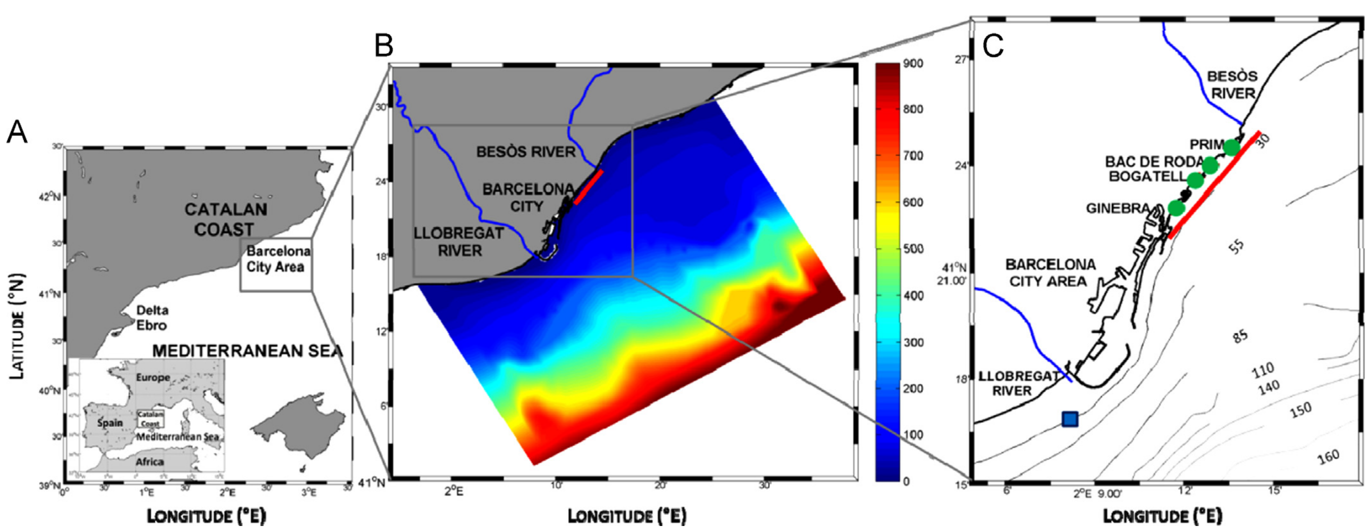

Fig. 1. Map of the Catalan Coast (A panel), bathymetry in the numerical grid (B panel), bathymetry of a portion of the Catalan inner-shelf showing four combined sewer overflows (CSOs) location (green dots, C panel). Blue rectangle (C panel) shows the position of buoy (part of the XIOM network www.xiom.net). Red line (C panel) indicates the position of the transect shown in Fig. 8. Note: For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.