Western Iberia sea surface salinity patterns due to land inputs

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Abstract: An original methodology integrating the water cycle from rain water to the open ocean by numerical models was set up using an offline technique. The different components of the system, including watersheds, estuaries and regional ocean, for Western Iberia were reproduced using numerical models of the MOHID Water Modelling System (http://www.mohid.com). 44 estuarine and river fluxes were implemented as land-ocean boundary conditions in a regional ocean model. The performance of the methodology was evaluated aided by *in situ* cruises and observations. The modelling results served to study seasonal and interannual evolution of the sea surface salinity patterns, including the Western Iberia Buoyant Plume (WIBP), and to describe a new feature named as the Western Iberia Central Plume (WICP) resulting from the Tagus-Sado estuaries contribution. Modelling results were used, in combination with observed data, to analyse an extreme runoff event during April 2013.

Key words: Western Iberia, salinity, PCOMS, MOHID, Estuary, Watershed

1. INTRODUCTION

In western Iberia, the relatively recent detection and description of a significant regional feature associated to fresh water inputs increased the attention to this subject from the oceanographic point of view. The Western Iberia Buoyant Plume (WIBP; Péliz *et al.*, 2002) is an all-year-round low salinity water lens that extends along the Northwest Iberia coastal area due to the accumulation of several fresh water sources, such as the Douro, Minho and Mondego rivers along with other smaller rivers and the Galician Rias. According to Brito *et al.* (2015), the area comprised between the Mondego and the Minho River (Fig. 1) receives around 45000 Hm3year-1 corresponding to 55% of the total volume of water discharged in the Portuguese coast. Since its first description, the WIBP has been subject of the several research studies related to ocean productivity (i.e. Ribeiro *et al.*, 2005; Picato *et al.*, 2014) and larvae and eggs dispersal (i.e. Queiroga *et al.*, 2007).

The main objective of the present research and of the methodology described in Campuzano *et al.* (2016) was to explore the capacity to improve the thermohaline circulation in coastal areas by a better characterisation of the land-ocean boundary conditions, with special regard to the salinity fields. This is the final chapter of a set of research publications where the different components of the methodology (Campuzano *et al.*, 2016) were analysed including the adaptation and implementation of state-of-the-art hydrological models to multi-catchment modelling domains (Brito *et al.*, 2015) and the off-line extraction and analysis of estuarine fluxes properties in order to be integrated, including their temporal evolution, into regional mesoscale grids (Campuzano *et al.*, 2018). In this work, the impact of the numerical implementation of 44 rivers, eight of them using estuarine model applications, in a regional model for western Iberia will be analysed for the period 2011-2015.

2. METHODS

2.1 Numerical modelling

In this work the regional ocean model for western Iberia PCOMS (Portuguese Coast Operational Modelling System; Campuzano, 2018) was coupled in an offline mode with estuarine and watershed modelling applications in order to evaluate their impact in the thermohaline circulation fields. The PCOMS is a 3D full baroclinic hydrodynamic and ecological regional ocean model application that downscales the Mercator-Océan PSY2V4 North Atlantic solution (Drillet *et al.*, 2005) using the MOHID Water model (http://www.mohid.com; Neves, 2013).

The main objective of this work was to evaluate the land-ocean boundary implementation following the methodology described in Campuzano *et al.* (2016) in Western Iberia. A total of 44 rivers were implemented: 8 of them, ordered from North to South: Minho, Lima, Douro, Vouga (Ria de Aveiro), Mondego, Tagus, Sado and Guadiana, were included as estuarine fluxes in the regional ocean application. Detailed information related to the estuarine models, their forcing and the cross-section location where fluxes were obtained can be found in Campuzano *et al.* (2018). The other 36 rivers were imposed directly as continuous discharges using flow and temperature from the MOHID Land watershed model application (Brito *et al.*, 2015) and a constant salinity value of 32. This approach was adopted to take into consideration the tendency of watershed models to overestimate flows and avoid the excess of fresh water. For this reason, the salinity signature from some large rivers in the regional model, such as the Guadalquivir River, could be underrepresented.

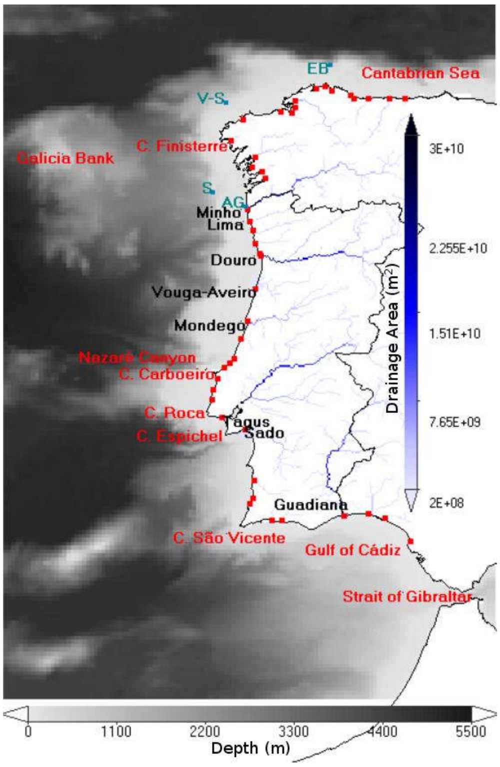

Fig. 1. Portugal domain bathymetry from the PCOMS application and drainage area from the MOHID Land WI domain. The location of the 44 river discharges implemented are marked with red squares and the rivers implemented with estuarine applications have their name next to its discharge location. Some ocean and coastal features from the Western Iberia region are displayed in red. The monitoring buoys used for model validation are displayed in light blue using an acronym: EB - Estaca de Bares, V-S – Villano-Sisargas, S - Silleiro Buoy and AG - A Guarda.

2.2 *In situ observations*

CTD surface data from two spring cruises in 2011 and 2015, hereafter referred as PELAGOS11 and PELAGOS15 cruises respectively, performed by the Portuguese Institute for Sea and Atmosphere, I.P. (IPMA) were made available for this study. Multiparametric buoys equipped with salinity sensors in Spanish waters, near the northern Portuguese boundary, were also used for validation since permanent monitoring stations observing salinity were absent/unavailable in the Region of Fresh Water Influence (ROFI) in Portugal.

3. RESULTS

3.1 *Model comparison with cruise data*

The PCOMS salinity results presented a similar salinity pattern than the PELAGOS11 CTD data where a meridional SSS gradient was interrupted by the two low salinity areas corresponding to the Tagus estuary plume, including its northward transport, and the WIBP in the northern sector.

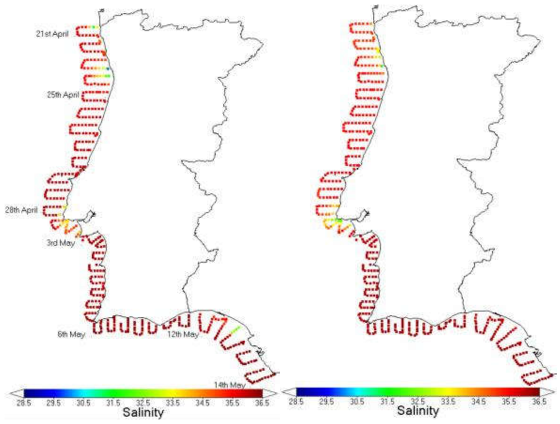

Fig. 2. Surface salinity observed with CTD during the PELAGOS11 cruise (left) and the PCOMS (right) modelling results.

3.2 *Extreme event case study: April 2013*

On early spring of 2013, a severe rain event affected the Western Iberia territory reaching maximum peak flows around 4500 m^3s^{-1} in the Douro River on the 30th of March and around 5400 m^3s^{-1} in the Tagus River on the 2nd of April (Campuzano *et al.*, 2018).

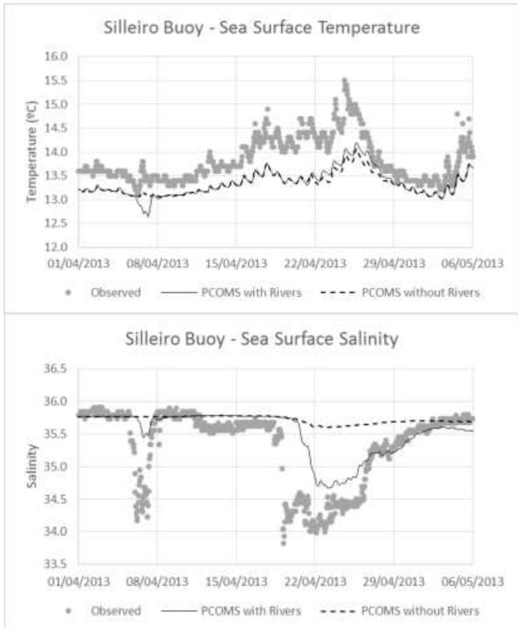

Fig. 3. Sea surface temperature (top) and sea surface salinity (bottom) at Silleiro buoy for the period 1st of April-6th of May 2013. Modelling results are displayed with (PCOMS with Rivers) and without rivers (PCOMS without Rivers) forcing.

During this period, the Silleiro buoy (Fig. 1) recorded salinity values below 34 (Fig. 3). On the 6th of April the observed salinity and temperature decreased by the arrival of WIBP waters. On the 19th of April, a second decrease in salinity was observed along with a SST increase. This temperature increase was reproduced by the PCOMS with and without river implementation while salinity decrease could only be reproduced by the PCOMS version including the river discharges. For this reason EO SST can be regarded as an inadequate tool to monitor the WIBP since the shallow and stable plume acquires rapidly the thermal signature of the surrounding waters (Ribeiro *et al.*, 2005). Correspondence between observed and the modelling results can be observed though there is room for improving the timing and intensity in the salinity field (Fig. 3).

3.3 Climatologic and seasonal analysis

The mean annual salinity distribution in the Western Iberian regional ocean for the period 2011-2015 is illustrated in Figure 4. Two areas influenced by fresh water inputs can be clearly distinguished: the WIBP that includes the coastal area from the Mondego estuary mouth up to the Galician rias and the Tagus-Sado estuarine plumes area, hereafter referred as West Iberia Central Plume (WICP) that extends from Cape Espichel until Cape Carvoeiro. Between these two areas, in the neighbouring waters of the Nazaré canyon, mean salinity values slightly saltier than open ocean waters, though this area present a high seasonal variability.

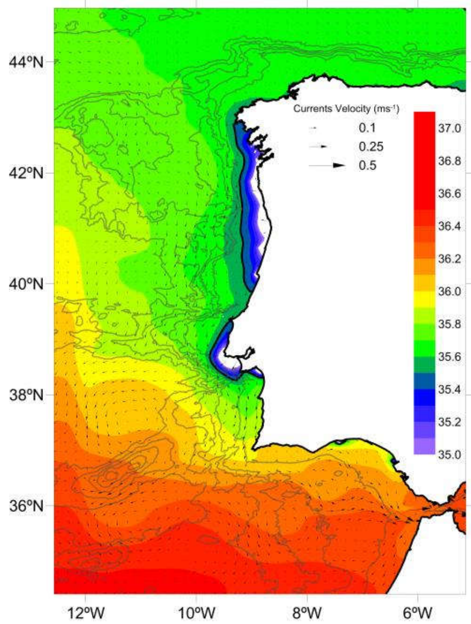

Fig. 4. Mean sea surface salinity for the period 2011-2015. The thick black line indicates the WIBP salinity upper limit (35.5) and white values indicate salinity values below 35. Vectors represent mean current intensity and direction every third cell.

In addition to the runoff variation, the prevailing wind regime in each season influences the WIBP distribution since it is transported offshore with northerly winds and converges to the coast with southerlies (Peliz *et al.*, 2002; Ribeiro *et al.*, 2005). Nevertheless, during winter and spring conditions, Tagus and Sado estuary plumes were connected with salinity values below 35.5 (Fig. 5). The WICP influence during this period extended further than Cape Carvoeiro and entered the Nazaré Canyon area. During wet years, such as 2011 and 2013, the WIBP and the WICP joined forming a continuous plume (not shown; Campuzano, 2018).

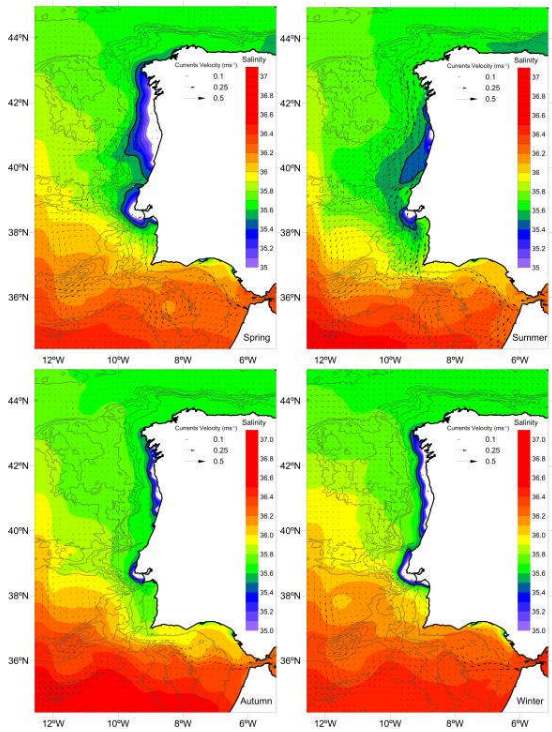

Fig. 5. Seasonal mean sea surface salinity for the period 2011-2015. The thick black line indicates the WIBP salinity upper limit (35.5)

During typical winter conditions, the prevailing downwelling favourable winds from the south-west generate convergent transport towards the coast and the WIBP remain in the inner shelf and rivers feed a coastally trapped branch of the poleward current advecting low salinity waters (Relvas *et al.*, 2007; Picado *et al.*, 2014). During the upwelling conditions, the Ekman surface plume is transported offshore and advected along the shelf (Santos *et al.*, 2004; Relvas *et al.*, 2007). During autumn several surface salinity minima are located around the estuarine mouth and poleward circulation dominates in the inner shelf reaching the Galician rias. The winter season increases the volumes discharged in the coastal areas and the salinity values below 35 occupy the inner shelf from the Mondego River up to the Galician Rias and the WIBP influence extends further than Cape Finisterre. During spring, the relaxation of northern winds, the abundance of less salty water in the coastal area and the beginning of upwelling-dominated wind conditions spread the WIBP off the continental shelf and equatorward, as part of the upwelling induced current, occupying a large area of the Portuguese continental platform near the Nazaré Canyon area.

4. CONCLUSIONS

Due to the *in situ* monitoring low frequency, numerical modelling is currently the only tool able to represent and estimate the temporal and spatial scale of coastal salinity fronts, such as the WIBP. Taking into consideration the numerical modelling limitations and assumptions, the salinity modelling results provided by the methodology described in Campuzano *et al.* (2016) improved significantly salinity fields and aid to the delimitation of region of fresh water influence and salinity fronts. Overall results were in agreement with the observed values and were able to represent WIBP features described in the bibliography.

A description of the temporal and spatial variability of the seas surface salinity was provided by generating an annual and seasonal climatology. The climatological analysis served to describe the WIBP evolution along all the year and its interannual variability since most of previous studies focused on particular seasons or field surveys.

On this work, the author noticed the presence in western Iberia of a second merged plume, along with WIBP, resulting from the contribution of the Tagus and Sado estuaries, named West Iberian Central Plume (WICP). According to the modelling results, the WICP could connect with the WIBP and generate a common salinity front covering most of the Western Iberian coasts.

In order to confirm the existence of the WICP and its influence, as the modelling results suggest, observations covering this area around the year would be needed.

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