Use of a hydrodynamic model for the management of the water renovation in a coastal system

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Abstract. In this contribution we investigate the hydrodynamic response in Alfacs Bay (~~Delta~~ Ebro Delta, NW Mediterranean Sea) to different anthropogenic modifications in freshwater flows and inner bay-open sea connections. The fresh water, coming from rice field irrigation, contains nutrients and pesticides and therefore affects in multiple ways the productivity and water quality of the bay. The application of a nested oceanographic circulation modelling suite within the bay provides objective information to solve water quality problems that are becoming more acute due to temperature and phytoplankton concentration peaks during the summer period, when sea water may exceed 28ºC leading to high rates of mussels mortality and therefore a significant impact on the local economy. The effects of different management “solutions” (like a connection channel between the inner bay and open sea) are hydro-dynamically modell~~l~~ed in order to diminish residence times (e-flushing time) and water temperatures. The modelling system, based on the Regional Ocean Modelling System (ROMS), consists ~~in~~of a set of nested domains using data from CMEMS-IBI for the initial and open boundary conditions (coarser domain). One full year (2014) of simulation is used to validate the results showing low errors with SST and good agreement with surface currents. Finally, a set of twin numerical experiments during the summer period (when water temperature reaches 28˚C) are used to analyse the effects of proposed nature-based interventions. Although these actions modify water temperature in the water column, the decrease in SST is not high enough to avoid high temperatures during some days preventing eventual mussel mortality during summer in the shallowest regions. However, the proposed management actions reveal their effectiveness in diminishing water residence times along the entire bay, thus preventing the inner areas to have ~~low renovation~~poor water renewal and the corresponding ecological problems.

1 Introduction

Coastal lagoons are highly productive areas,~~–~~ for instance regarding aquaculture,~~-~~ and are subject to multiple anthropogenic pressures. Due to the specific characteristics of these environments - e.g. ~~-~~small dimensions, calm inner waters, constrained ~~communication~~ exchange with open sea, heavy load of nutrients- there is usually a wide variety of problems related to water quality that can strongly limit their use and exploitation (e.g., HABs, anoxia/hypoxia events, water renovation or high seawater temperatures - i.e. Smith, 2003).

This problem is illustrated by the Ebro Delta coastal bays (NW Mediterranean) in which, for most of the year, there is an interaction between incoming salt water from the coastal sea and freshwater discharged into the bays through the irrigation system from the surrounding rice fields. These discharges are rich in nutrients and pesticides (Köck et al., 2009), therefore affecting in multiple ways the productivity and water quality of the bays (Loureiro et al., 2009), in which residence times can be large depending on the prevailing met-ocean conditions (Artigas et al., 2014).

These bays (Alfacs in the south and Fangar in the north hemidelta) constitute the most important shellfish aquaculture area in the Spanish Mediterranean coast. They are considered very productive coastal areas as compared to the oligotrophic western Mediterranean Sea; the primary production per volume unit is one order of magnitude greater than in the adjacent open sea (Delgado, 1989) and their waters support important fisheries and mussel and oyster cultures. Moreover, the economy of the ~~Ebro delta region~~area is largely based on activities that depend on primary production, such as agriculture, fisheries and aquaculture. The shellfish aquaculture in the region has to face different types of risks: shellfish pathogens (López-Joven et al., 2015), extreme warm events in the last years (Fernández-Tejedor et al., 2010), contamination (Köck et al., 2010), HABs and toxin accumulation (Loureiro et al., 2009), and the proliferation of invasive alien species, as for example tunicates (Ordóñez et al., 2015). Water mass transport in marine systems has been demonstrated to be a decisive factor controlling the behaviour of chemical and biological variables of the ecosystem (i.e. Wolanski,, 2007). In this sense, the evolution of the ecological status of the bays is highly related to water renewal and substances dispersion. Wind or wave induced re-suspension processes may also affect the ecological status by inducing the vertical transport of substances from the sea bottom to the inner water column (Umgiesser et al., 2004).

The application of a nested oceanographic model with enough resolution to solve the inner dynamics of this kind of environment provides objective information to address water quality problems. These are becoming more relevant in the Ebro Delta bays due to increasing peaks of temperature and nutrient concentrations during the summer, when seawater may exceed 28ºC leading to high rates of shellfish mortality and therefore having a significant impact on the local economy.

In this contribution, focused on Alfacs B~~b~~ay, we explore the suitability of land boundary conditions and the controlling effect of different management actions on the resulting 3D circulation patterns, based on the renewal times. In this ~~sense~~context, we also discuss the implications of opening a connection between the open sea and the inner bay dredging the sand bar and how it affects water temperature and concentrations. This has been a long-standing proposal by local fishermen to enhance water renovation rates and improve the water quality within the bay. A set of 3D numerical model simulations spanning one year (2014), with outer boundary conditions from Copernicus Marine Environment Monitoring ~~Systems~~ Service (CMEMS) models, is compared to intensive field campaigns and discussed in terms of water renovation and temperature. The implications of a hydraulic connection to the outer sea is analysed, as a natural and sustainable type of intervention. From here, a set of conclusions on the models' performance and on the effectiveness of such sustainable intervention are presented.

2 Methods

2.1 Study Area

Alfacs Bay is part of the Ebro Delta, which extends about 25 km offshore and forms two semi-enclosed bays on its lateral margins, Alfacs to the south and Fangar to the north. Both bays receive direct freshwater input from the drainage channels of nearby rice fields. In Alfacs B~~b~~ay, these freshwater inputs are distributed in two dominant periods: from April to December with mean flows estimated by Canicio (1996) of around 10 m3·s-1 and from January to March with channels closed and flows around 1 m3·s-1 (hereinafter referred as wet and dry periods, respectively), due to rain and groundwater sources. Alfacs Bay is about 16 km long and 4 km wide, with a 2.5 km wide mouth, an average depth of about 4 m and a maximum of 6.5 m in the middle of the bay. Fig. 1 presents the location and bathymetry of the bay. The bay is closed i~~o~~n the east by a sand bar beach called Trabucador bar. This coastal barrier linking the main lobe of the Ebro Delta with its southern spit has suffered various breaching events associated to storms, opening an ephemeral connection between the bay and the open sea (Sánchez-Arcilla and Jimenez, 1994, Gracia et al., 2013). The bed is mostly muddy (largest percentages in the middle of the bay) with silty sediments present close to the freshwater outflows (Palacín et al., 1991).

The bay has been defined as a salt-wedge estuary with an almost year-round stable stratification, alternated with well-mixed periods directly related to strong wind (Camp and Delgado, 1987) or seiche events (Cerralbo et al., 2015). Solé et al.(2009) found that drainage discharges were the main factor controlling the observed stratification. Cerralbo et al. (2015) found that during warm periods the salinity distribution shows strong vertical gradients, coinciding with isopycnals, with the saltiest water (almost 38) from outer sea in the deepest mouth layers and the freshest water (35–36) at the surface. Stratification is weaker in the inner bay, with lower salinity values in the water column. Within the bay, freshwater at the surface layer extends from the northwest to the southeast with a pycnocline at 3-4 m depth (Camp, 1994; Llebot et al., 2013). The water temperatures during summer show a clear diurnal pattern, with a clear stratification. This pattern occurred until the end of summer, when strong, dry and cold winds from NW mix and cool the water column (Cerralbo et al., 2015, Grifoll et al., 2016).

In Llebot et al. (2011), annual cycle (and inter-annual) analyses of temperature, salinity and some ecological indicators are described. Moreover, Llebot et al. (2014) use the Wedderburn number to identify wind events with enough energy to modify stratification, defining the mixed layer deepening response to wind events. Cerralbo et al. (2014) studied the tidal characteristics of the bay noticing the importance of the 3-h seiches and describing the 1-h seiches (corresponding to the 1st seiching mode). The subtidal patterns have been related to estuarine circulation (Llebot et al., 2014) and wind influence through EOF analysis (Cerralbo et al., under review). On the other hand, several ecological studies noticed the presence of harmful algal blooms (HABs) in some periods and their relation to nutrients and waters from the open sea (Loureiro et al., 2009). Ramon et al. (2007) and Fernández-Tejedor et al. (2010) have reported mussel mortalities associated to high seawater temperature in the Ebro delta bays.

2.2 Observations

~~Cerralbo et al. (2015) found that during warm periods the salinity distribution shows strong vertical gradients, coinciding with isopycnals, with the saltiest water (almost 38) from outer sea in the deepest mouth layers and the freshest water (35–36) at the surface. Stratification is weaker in the inner bay, with lower salinity values in the water column. Within the bay, freshwater at the surface layer extends from the northwest to the southeast with a pycnocline at 3-4 m depth (Camp, 1994; Llebot et al., 2013). The water temperatures during summer show a clear diurnal pattern, with a clear stratification. This pattern occurred until the end of summer, when strong, dry and cold winds from NW mix and cool the water column (Cerralbo et al., 2015, Grifoll et al., 2016).~~

~~On the other hand, w~~Weekly CTD profiles were conducted in the frame of the monitoring program of toxic phytoplankton in shellfish growing areas during the years 2013-2014. The location of one sampling station is shown in Fig.1 (T). The water temperature in different locations (and representing different kinds of water bodies) of the region is summarized in Fig.2. The water temperature inside the bay (T) and in the drainage channels are very similar (low gradients between them). Lowest temperatures (~10ºC) occur during winter season (December to March). After this, a gradual rise in water temperature is observed, with maximum values around 29ºC during summer (June to August). Finally, the water temperature decreases, affected by the influence of NW strong, dry and cold winds. On the other hand, the water temperature from the river does show remarkable differences (mainly during summer), with gradients around 2-3ºC (similar to the coastal waters measured at the Tarragona coastal buoy) as compared to inner-bay waters. All the observations are summarized in Table 1.

2.3 Numerical Model

The three-dimensional hydrodynamic model used in this study is the Regional Ocean Modeling System (ROMS). Numerical aspects are described in detail in Shchepetkin and McWilliams (2005), and a complete description of the model, with documentation and code is available at the ROMS website: http://myroms.org. Previous implementation for the model in Alfacs Bay showed a good skill assessment compared to currents, sea level and water temperature variables (Cerralbo et al., 2016).

The model applications consist of two nested regular grids with spatial resolution of ~350 m and ~70 m for the coarser (D-A) and finer domains (D-B), respectively (Fig. 1). The nesting ratio (~5) between both domains is defined to get enough resolution to reproduce the circulation in the inner bay allowing the transfer~~ence~~ of large-scale dynamics into the nested domain. The nesting is off-line, first D-A simulation is performed and the hourly results are used for the boundary conditions of D-B. The chosen vertical discretization consists in 20 and 15 sigma levels for the coastal and bay domains, respectively. Bathymetries of the coastal system are built by combining bathymetric data from GEBCO (www.gebco.net) and specific local high-resolution sources. The bottom boundary layer is parameterized with a logarithmic profile using a characteristic bottom roughness height of 0.002m. A surface stretching parameter (= 7.0) and bottom stretching parameter (= 0.4) for the Song and Haidvogel (1994) stretching function is used. This configuration allows to increase the resolution in the upper layer where the surface boundary layer takes place due to the wind action. The transformation function used is described in Shchepetkin and McWilliams (2005) denoted as an unperturbed coordinate system. In order to represent the processes at scales smaller than the grid resolution we selected anisotropic horizontal and vertical turbulent schemes based on a Generic Length Scale (GLD) formulation (Warner et al, 2005). K-Ɛ parameters are choosed for GLS formulation. Also Kantha and Clayson stability function formulation is used (Kantha and Clayson, 1994). For advection scheme a third-order upstream horizontal fluxes is selected. For heat and mass tracers, a biharmonic mixing scheme along geopotential surfaces is used. ~~The turbulence closure scheme for the vertical mixing is the generic length scale (GLS) tuned to behave as k-epsilon (Warner et al. 2005).~~

A one year long base simulation (hereafter referred to as BS, from 1st January to 31st December 2014) has been performed in order to validate the model and obtain the initial and boundary conditions for the 3-month simulations in the analysis period (summer 2014) in the smaller domain. The BS is done using the first 24h of the CMEMS-IBI (Sotillo et al., 2015) daily forecasts for the initial and open boundary conditions. Hourly ~~barotropic~~ depth-averaged water currents and sea level are provided by CMEMS-IBI and consistently accommodated to the open boundaries (OBC) with Chapman and Flather algorithms (Carter and Merrifield, 2007). The variability of currents along the water column (~~baroclinic~~ 3D component), temperature and salinity are imposed from CMEMS-IBI daily average values with clamped conditions.

At the sea surface, the models are driven by high frequency (hourly) wind components (with 0.05º resolution) ~~wind components~~, atmospheric pressure, humidity, precipitation and solar radiation derived from the Spanish Meteorological Agency (AEMET) forecast (model HARMONIE). The wind stress, sensible and latent heat are computed internally by the model using aerodynamic bulk formulas. To avoid land contamination of the atmospheric forcing on coastal areas (e.g. heat fluxes and winds), a prior land mask is applied to the forcing data, and then variables over the sea are interpolated on the land.~~.~~ The freshwater flows are 1 m3·s-1 during January-March (dry season), and 10 m3·s-1 during April-December (wet season) distributed in the three channels (see Fig. 1c). Salinity is set to 18, and water temperature is defined from climatological water temperature in the Ebro River (Fig. 2).

For the sake of understanding the influence of land discharges and layout modifications on the water dynamics, a set of 3-month long numerical experiments is done (1st June-30th September). In all of them, a passive tracer with a 1 kg·m-3 concentration is initially released at all the computational nodes inside the bay. The BS simulation is re-started on 1st June with the passive tracers and is used as a control simulation (called C) to compare all the numerical tests. A second set of three tests has been prepared to understand the effects of establishing an artificial connection with the open sea through the

Trabucador bar (see Fig. 1). This is an engineering action proposed in the last years by the local authorities to consolidate the ephemeral connection between the bay and the open sea that occurs occasionally due to storm-related bar breaching. The purpose of a permanent open sea connection is to solve the problems of the bay linked to long residence times and overheating, and similar solutions have been studied in other coastal lagoons with water quality issues (Netto et al., 2012; Lill et al., 2012). These simulations consist in opening the bar using different widths: from 200m to 800m, and studying the effects on the water renewal and sea surface temperature. Finally, two more numerical tests are performed in which the freshwater input flows were modified. Considering that the gravitational circulation in the bay has been related previously to the hydrodynamics of the bay (Cerralbo et al., under review), it is expected to find variability on the water renewal times when the freshwater flows are modified. These numerical tests are designed to understand their effects on current patterns. In test R1 the usual flow (10 m3·s-1 in C) is doubled, keeping the proportion in the three channels. In test R2, the total discharged flow is doubled, but the flow increment is only applied to the innermost channel, while the outflow through the drainage channels closest to the bay mouth is kept the same as in C. Thus, R1 test doubles the freshwater input along the three channels, and R2 only modifies the innermost channel. All the numerical tests are summarized in Table 2~~1~~.

2.4 Validation

Data from CMEMS-IBI,~~ and~~ atmospheric models, and field observations~~ (-~~ High Frequency~~-~~ Radar (HF-R) from Puertos del Estado (PdE), SSS and SST data from Institute of Agriculture and Food Research and Technology (IRTA)~~-~~ were available for the year 2014. The modeled and observed SST are shown in Fig. 3. A qualitative and quantitative comparison shows good agreement between both variables (correlation of 0.99), with a small overheating in the modeled results (see some statistics in Fig.3). The errors in modeled SSS are mainly related to the uncertainty associated to the flows and the exact location of the discharge points. However, the results of the coastal model (D-A), which considers the inner bay freshwater flows, show a closer agreement with the observed values than the CMEMS-IBI results, which do not account for the inner discharges. The variability of SSS in the CMEMS-IBI fields is related to the Ebro River plume, not to the influence of inner bay freshwater inflows. Water surface currents are validated for the coastal model (D-A) considering the information from a ~~High-Frequency Radar~~HF-R in the area (Lorente et al., 2016). The HF-R (CODAR SeaSonde Standard-range) was deployed at the Ebro delta in 2013 within the framework of the RIADE (Redes de Indicadores Ambientales del Delta del Ebro) project. The network consists in three remote shore-based sites providing hourly radial measurements with a cut-off filter of 100 cm s−1 and representative of current velocities in the upper first meter of the water column (Lorente et al. 2015). The total current vectors are hourly averaged on a predefined cartesian regular grid with 3 × 3 km horizontal resolution. The parent model (CMEMS-IBI) has been validated in region using HF-R in Sotillo et al. (2015). Their results shows zonal and meridional RMSE (correlation) values in the range of 6–10 cm·s-1 (0.4–0.8) over central areas of HF-R radar domain, with higher errors detected in far edges of the radar spatial coverage (Sotillo et al. 2015). For D-A domain ~~B~~both eastward and northward components of the surface currents are shown in Fig. 3 (a and b) (at point *HF*, location shown in Fig. 1). Validation is performed for the entire 2014 in one point close to the bay and with optimal temporal coverage (more than 85% of 2014 with data). The gaps in the HF-R data are not considered. The agreement and correlation between modeled and observed currents are very high (~~>~~~0.7), both in intensity and phase, and in both components. The daily oscillations correspond to the inertial period in the region (~19h) and are well reproduced by the model. Some currents intensifications, probably related to energetic wind events, are also well described by the model (for instance on 10th February and 16th March).

2.5 Water Residence Times

There are multitude of different methods and concepts to calculate the water renovation in the literature. For any given domain, the simplest way to assess the water renovation is to obtain the water exchange time through the ratio between its total volume (V) and the daily flux (Q) -entering or leaving- through its open boundaries. It represents the time required for the entire mass of water to be replaced by input water (Takeoka, 1984; Jouon et al., 2006). On the other hand, the e-flushing time (Thomann and Mueller, 1987) assumes that a passive tracer is injected into a homogenous water mass at time t with an initial concentration C0. The e-flushing time is the time required for the tracer mass initially contained within the whole domain to decrease by a 1/e factor. A fair adaptation to this parameter, the local e-flushing time, is presented in Jouon et al. (2006), by considering the spatial variability of the e-flushing time and taking into account the evolution of the tracer in each cell of the computational mesh.

The integral water exchange time in Alfacs Bay can be grossly estimated using simple approaches. A first approximation can be done by considering the residual circulation presented in Cerralbo et al. (~~under review~~2018), where through an analysis of the mean circulation the authors obtain residual velocities at the bay mouth. Using the mean residual currents and the bay's volume and typical cross-section at the mouth leads to water exchange times (θ) of around 20 and 70 days for the wet and the dry season, respectively. Similar results can be also obtained using a box model approximation (Officer 1980) based on the salinity variations between the bay water and the open sea ~~(~~with four layers: sea side surface and bottom (salinity of 36.35 and 37.82 respectively) , and inner bay surface and bottom layers (with salinities of 35.7 and 36.94). The box model is described by equations (1-4):

$$S_2 \cdot (Q_{21} + E_{12}) = S_1 \cdot (Q_{13} + E_{12}) \tag{1}$$

$$S_0 \cdot Q_{02} + S_1 \cdot E_{12} = S_1 \cdot (Q_{21} + E_{12}) \tag{2}$$

$$Q + Q_{21} = Q_{13} \tag{3}$$

$$Q_{02} = Q_{21} \tag{4}$$

where Q is the total freshwater input, Si is the salinity in layer i, and Qij and Eij are the advective and turbulent fluxes between layers i and j. In this model, Q is set to be 10 m3·s-1, and the salinities are given by the mean values obtained in the field campaigns described in 2.2. Solving the system with these values yields residence times of ~13 and ~40 days for the wet and the dry season, respectively. However, these methods are not useful when large variations in hydrodynamics occur (Jouon et al., 2006). In this sense, previous studies on the Alfacs Bay hydrodynamics have highlighted the relevance of hydrodynamic spatial variability associated with seiches (Cerralbo et al., 2014), winds (Llebot et al., 2014, Cerralbo et al., 2016) and gravitational circulation (Artigas et al., 2014).

An approximation to ~~T~~the spatial variability of the residence times is addressed for the first time in this work by analysing the space distribution of the local flushing time (LFT) for the entire waterbody. The methodology applied is based on the numerical deployment of an Eulerian conservative tracer, within the inner domain of the bay, to compute the time required for its concentration in each grid cell to decrease by a factor e−1 from the initial value. This definition represents the sum of the Flushing Lag and Local e-Flushing Time, in Jouon et al. (2006). Thus, an Eulerian passive and conservative tracer with a concentration equal to Co=1 kg·m-3 was deployed in the different sigma layers of the inner bay. Considering that the pycnocline is around 3-4 m depth (Camp, 1994) and mussels farms are mostly above this depth, ~~T~~the analysis focuses on the surface layers. The freshwater inflows are considered clean of the tracer. An example of the time-evolution of the surface tracer concentration at two points is shown in Fig. 4a. The LFT is defined at each grid cell based on the concentration decrease between Co and C_o~~o~~*e-1, using the best correlated exponential regression (Jouon et al., 2006).

3 Results

The results for the LFT in C simulation reveals a high spatial variability (Fig. 4b), with short values between 5 and 20 days in the region close to the bay mouth and near the freshwater discharges. These are similar to those presented in Camp (1994), and Llebot et al (2011). On the other hand, longer times are found in the inner regions (30-47 days). When the total flushing time (TFT) is considered ~~– averaging~~ being TFT equal to the period necessary to the average concentration of the entire Bay to go from C_o to C_o*e-1~~the LFT~~ ~~for the entire bay~~-, values of about 28~~7~~ days for C are found.

As mentioned before, the hydrodynamics of Alfacs Bay are particularly affected by the freshwater inputs. Both R1 and R2 reveal (not shown) maximum LFT values of 34 and 29 days, respectively (shorter than C, with 47 days). The anomaly -in days- of these patterns in relation to the distributions obtained for C is shown in Fig. 5 (a and b). R1 shows shorter residence times than the C test in the innermost of the bay. The clearest effects of freshwater increment are observed in the area closest to the drainage points (with LFT under 10 days). However, the inner areas still present residence times higher than 30 days. The R2 results also show remarkable differences as compared to the control case, with shorter times in the area close to the inner channel and values around 20 days in the innermost region. In both tests, the area of mussel farms shows similar differences, with LFT values almost 10 days smaller in the results obtained with modified freshwater flows. In Table 3~~2~~ the TFT for the entire bay is summarized for all the cases. It is interesting to note that the TFT for test C is around 28~~7~~ days, similar to the values obtained through the simple relation between the mean residual circulation and the volume of the bay. Tests R1 and R2 show a noticeable decrease in the average e-flushing time, with reductions of ~8 and ~11 days, respectively. Regarding the SST (Fig. 6) the differences are evident, but not significant. In general, there is a cooling of the surface water over the entire bay of about 0.5ºC, being more evident in the vicinities of the drainage points. However, in the region near to the Trabucador bar, the surface waters show an increase in temperature. This area is very shallow and probably the effects of higher stratification (induced by the highest freshwater inputs) and longer residence times in this region contribute to increase the SST. Considering the integrated SST values for the entire bay, the R1 and R2 tests show a decrease of 0.07ºC and 0.08ºC in relation to the control test.

To evaluate the effect of bar breaching, a set of three numerical tests (B1, B2 and B3) with different widths of sand bar breaching (200 m, 500 m and 800 m, respectively) has been implemented. In all the cases, the depth of the channel is equal to the minimum depth considered in the model (1 m). Fig. 1 shows the region of the sand bar modified for these simulations.

The results are summarized in Figs. 5 and 6. Test B1 (200 m) shows shorter LFT mostly in the region close to the sand bar. However, no remarkable differences are observed in the mussel farm region (differences of about 5 days respect C). Tests B2 and B3 (500 m and 800 m) reveal a higher variation in the residence times than B1, but with similar spatial variability patterns. In general, a wider connection with the open sea implies a larger area with lower LFT in the vicinities of the sand bar and inner region. Moreover, the effects are also observed in the region of the mussel farms, with a decrease of the residence time to less than 10 days. The TFT for the entire bay and the differences relative to the C test are summarized in Table ~~2~~3. There is clearly a direct relationship between the width of the channel and the residence times, with those for B3 (widest channel) being almost 14 days shorter than those for the control case C.

The analysis of SST differences does not show relevant discrepancies with the C case almost anywhere in the entire bay. Only the region closest to the open channel in the bar shows a decrease of the inner-bay SST (due to mixing with the cooler open seawater, as observed in Fig. 2), and also an increase of SST in the open sea side of the bar. The integrated values over the bay do not show significant variations between the tests and the control case, with differences smaller than 0.07 ºC.

4 Discussion

Previous studies had applied numerical models in Alfacs Bay (Llebot et al., 2014, Artigas et al., 2014, Cerralbo et al., 2014, 2015 and 2016), trying to characterize the main hydrodynamic features of the bay: wind, sea level, seiches, mixing, and gravitational circulation. However, none of them faces one of the most relevant problems inside the bay related to the low water renovation and the warm water temperatures during summer periods. For this, a high resolution numerical model able to simulate interventions and impacts has been implemented for the first time in the bay using the available data from CMEMS numerical models (as initial and boundary conditions) and following the nesting scheme designed in SAMOA initiative (Sotillo et al., 2018). The validation of such implementation with the available data in the coarser domain has been done through comparison with HF-R~~adar~~ water surface currents, revealing very good performance and agreement. The validation of the higher resolution domain –local- has been performed using SST and SSS from in-situ field campaigns, revealing a ~~remarkable~~ good agreement between observed and modell~~l~~ed data for the SST. Errors in salinity could be related to the lack of accurate data of the freshwater flows (total volume, spatial and temporal distribution) and the salinity of these waters (freshwater from rice fields mixed with brackish waters from coastal lagoon). The model presented in this paper could be also considered as the first attempt towards the implementation of an operational system in the bay as a local downscaling of CMEMS products, which could be used by local authorities to improve the management of the bay. However, this study has revealed the scarcity of information about the bay, which may influence the robustness of modelling results. For instance, lack of accurate information on bathymetry -which is expected to improve with new products derived from Sentinel 2- and the correct characterization of the freshwater flows (i.e. number and spatial distribution of sources, water flows and temperature).

As stated by several authors (i.e. Braunschweig et al. 2003, Jouon et al., 2006, Dabrowski et al., 2012, Grifoll et al., 2013) there are various ways to obtain the residence time of a given waterbody. In this contribution, we have followed different approximations, from a simplistic scheme using the observed residual velocities or the application of a box model that uses the salinities and freshwater flows to obtain the gravitational circulation, to the most complete scheme using the depletion of eulerian conservative tracers in a numerical model (LFT and TFT). The analysis has focused on surface layers (above the pycnocline, at 3-4m), where the water column is entirely mixed. The Water Exchange Times reveal values of 13 and 40 days for wet and dry periods, respectively using the box model, similar to those obtained using residual currents (20 and 70 days). These results are in agreement with previous studies (Camp y Delgado, 1987; Llebot et al., 2011) presenting residence times for the Alfacs Bay between 10 (wet period) and 25 days (dry period). The differences between these results and previous studies may be due to the arbitrary selection of the bay mouth section, sensitivity to salinity and freshwater flows used in the box model and the location of the ADCP. In this sense, the variability of the flow through the mouth section has been demonstrated to be high in Cerralbo et al. (2016). However, the simple methods consider that all water particles have the same transit time through the entire control volume (Takeoka, 1984). In Alfacs Bay several authors (Llebot et al., 2011, Cerralbo et al., 2014, 2015, 2016) have observed the remarkable variability in spatial distribution of the hydrodynamics fields. Thus, the application of LFT allows understanding the spatial variability of the residence time inside the bay and offers a proper information tool for the local authorities. The results of the LFT method reveals differences in renewal times among different areas (for instance, where the mussel farms are located) with residence times (LFT) around 15-20 days, and regions inside the bay with much larger residence times (~40-45 days). According to these data, the location of the mussel's farms could be considered as optimal when the residence time is considered. Only locations closer to the bay mouth show higher ratios of renovation. These results agree with an approximation done by Artigas et al. (2014).

Once the numerical model is implemented, calibrated and validated, it can be used to test different interventions directed to improve the water quality of the bay. Hereof, and considering that some of the main problems of the bay are related to the long residence times (i.e. anoxia as observed by Camp et al., 1992) and the high values of water temperatures during summer, several management options have been tested to find the best option to mitigate these negative effects. Two actions are proposed and analysed here: the modification of freshwater flows (both volume and spatial distribution), and the artificial connection with open sea through the El Trabucador bar. Both actions show a remarkable reduction on the LFT (and corresponding TFT), mostly concentrated in the inner area of the bay, with almost LFT in B3 and R2 half of the observed in C case -as observed in similar studies by Netto et al., (2012); Lill et al., (2012)-. Previous studies have pointed out the presence of a region in the northeast of the bay with low residence times (Cerralbo et al., under review), also described as a nutrient accumulation area (Artigas et al., 2014). The LFT shows noticeable spatial variability, with highest diminution in the region close to the artificial channel (in B1, B2 and B3) and the freshwater discharge points (R1 and R2). The region where the mussel farms are located shows also lower LFT than in the control case (reductions ranging from 20% in B1 and R1, to 30% in B3 and R2), but the differences are not as high as those observed in the inner bay. The effects of opening a ~1 km-wide channel (B3) are negligible in comparison to modifying the freshwater flows in R2 (increase of freshwater mainly concentrated in the inner channel). In that sense, the modification of the freshwater flows seems more feasible both economically and technically as compared to artificially opening and maintaining a new connection with open sea. Moreover, the opening of the sand bar would imply high economic (dredging, jetties) and environmental costs (breaking of alongshore circulation and transport of sediments and nutrients) that must be evaluated cautiously.

The water temperature from the drainage canals used in the simulations corresponds to the climatological values observed in the Ebro river, not to the observations in the drainage channels, which is similar to the temperature of the water inside the bay (see Fig. 2). This is because the channel freshwater input would not decrease the temperature of the bay water, but there is the possibility of doing this by conducting cooler water from the river directly to the bay using the irrigation system. However, none of the analysed scenarios shows significant differences on the evolution of water temperature, and only the tests R1 and R2 show decreases of ~0.5ºC in the regions closest to the freshwater input points. The shallowness of the bay implies that the effects of solar heating, which is significant during the summer in these regions, influences the entire water column and counterbalances the analysed solutions. An example of this is the temperature of the open seawater, which is originally colder, but heats up rapidly upon entering the bay.

The comprehensive analysis of the complete set of simulations reveals the complexity of the area under study, and suggests that the effort must be invested on the regulation of the freshwater flows. For instance, by modifying the flows, the residence times and water temperatures are affected, and also by regulating the nutrient (and contaminants, suspended matter) load of the freshwater flows the productivity of the bay may also be controlled. However, the effects of increasing the freshwater sources could lead to some disturbances over the bay: e.g. stress over the marine biota and nutrient enrichment (increasing the risk of HABS under some conditions). For that reason, future works should consider the application of biogeochemical models (e.g Nash et al. 2011) in the bay characterizing the ecological behavior of the bay and performing numerical simulations in order to understand the effects of such modifications. All these actions should also be considered to avoid some of the climate change effects expected in the region: sea level rise (promoting marine intrusion in the rice fields and blocking the freshwater discharges) and the increase in water temperature (increasing the probability of mussels' mortalities).

5 Conclusions

The management actions proposed for Alfacs Bay (i.e. bar breaching and modification of freshwater flows) revealed the effectiveness in increasing~~e~~ the water renovation within the entire bay, thus preventing the innermost areas of the bay to have long residence times and the corresponding ecological problems (i.e. anoxia events). Both proposed actions show similar results. However, only the modification of freshwater flows ~~is recommended~~could be useful due to its lower impact on the environment and associated economic costs. On the other hand, none of the proposed solutions solve one of the main problems of the bay, related to occasional extremely high temperatures ~~water temperature peaks during some days~~ in summer (>28˚C). In this sense, the shallow depths of the bay and the warm water temperature from the rice fields restrict solving the events of mussels' higher mortality. The application of a set of validated numerical models in a pre-operational mode, nested into a CMEMS regional model, has allowed for ~~the~~ first time to provide objective high-resolution predictions for stakeholders and final users of the bay (fisheries and tourism) and to investigate the effects of the proposed actions to enhance the ecological problems of the bay. Future works should include the analysis of the effects of waves effect on water circulation, application of biogeochemical models, as well as the consideration of different initial conditions and met-ocean conditions on the determination of water renewal in Alfacs Bay.

Acknowledgments

The authors are grateful for the collaboration IRTA staff for the participation in the field campaigns carried out within the framework of the monitoring program of water quality at the shellfish growing areas in Catalonia. Thanks to the data provided by Puertos del Estado and AEMET. This work received funding from the EU H2020 program under grant agreement no. 730030 (CEASELESS project). The authors also acknowledge the economical funding and support received from the "Direcció General de Pesca I Afers Marítims" in the framework of the project "Anàlisi ambiental de les Badies del Delta de l'Ebre i el seu entorn. Cap al desenvolupament d'una eina per a la seva gestió integrada" and project ECOSISTEMA (CTM2017-84275-R). We also want to thank to Secretaria d'Universitats i Recerca del Dpt. d'Economia i Coneixement de la Generalitat de Catalunya (Ref 2014SGR1253) who support our research group.

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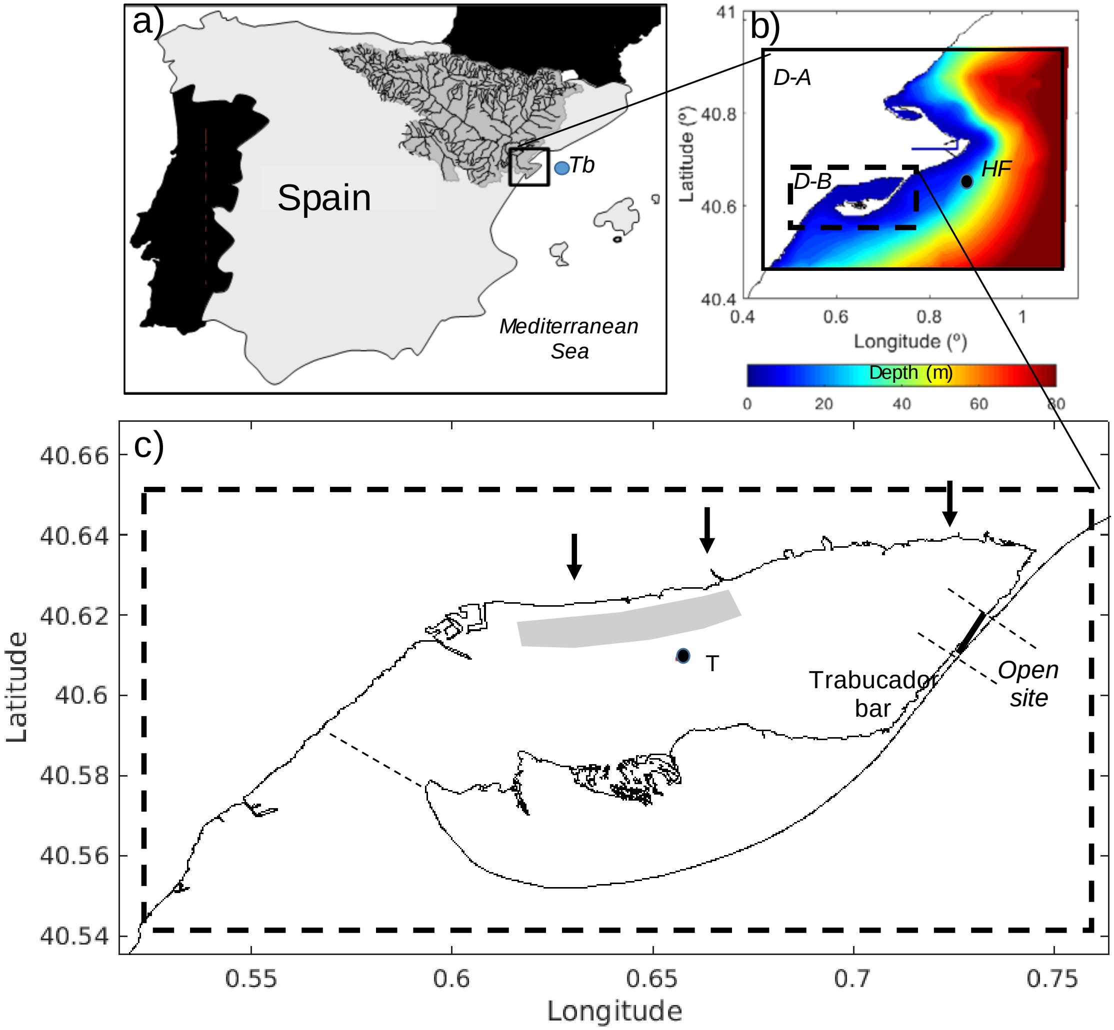


Figure 1: Location of ~~Delta~~ Ebro Delta and Alfacs Bay and Pd~~e~~E Tarragona buoy (blue point, Tb) (a). b) shows the nesting scheme, with the coastal (D-A) and bay (D-B) domains and bathymetry. Data from ~~High frequency Radar~~HF-R used to validate the system is indicated as "HF" (0.91° East, 40.31° North). In c) the location of the weekly CTDs is indicated (T). The opening area of the Trabucador bar modified in the numerical experiments is also shown. The dashed line in the bay mouth indicates the separation between the inner bay and open sea for the salinity box model. The grey rectangle indicates the mussel farm area. The freshwater drainage channels locations are indicated with arrows.

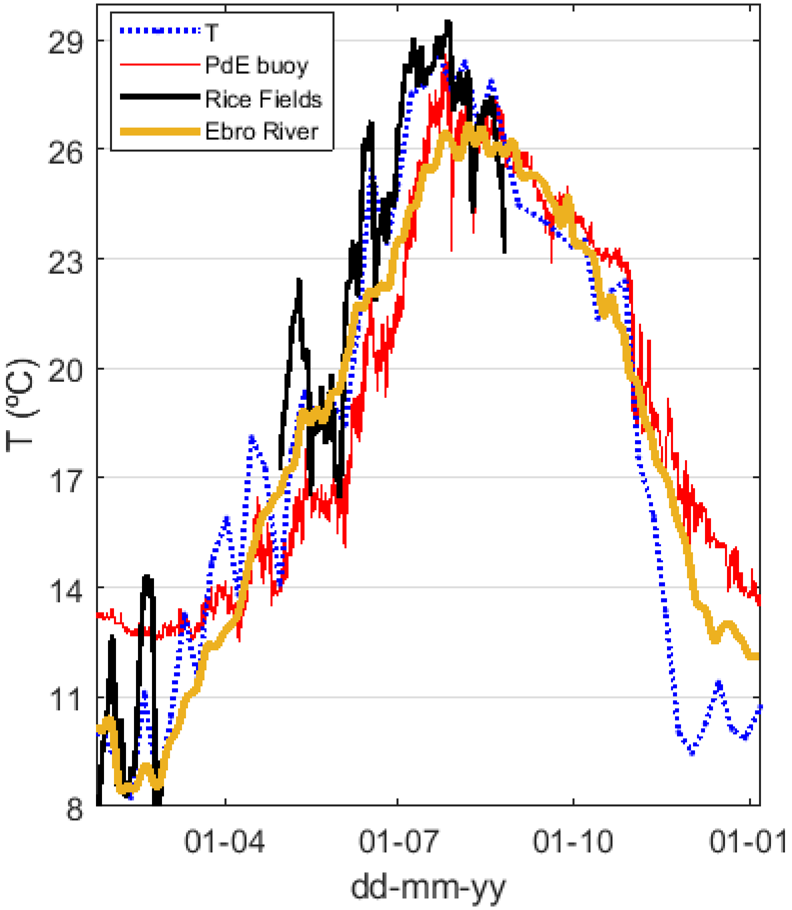
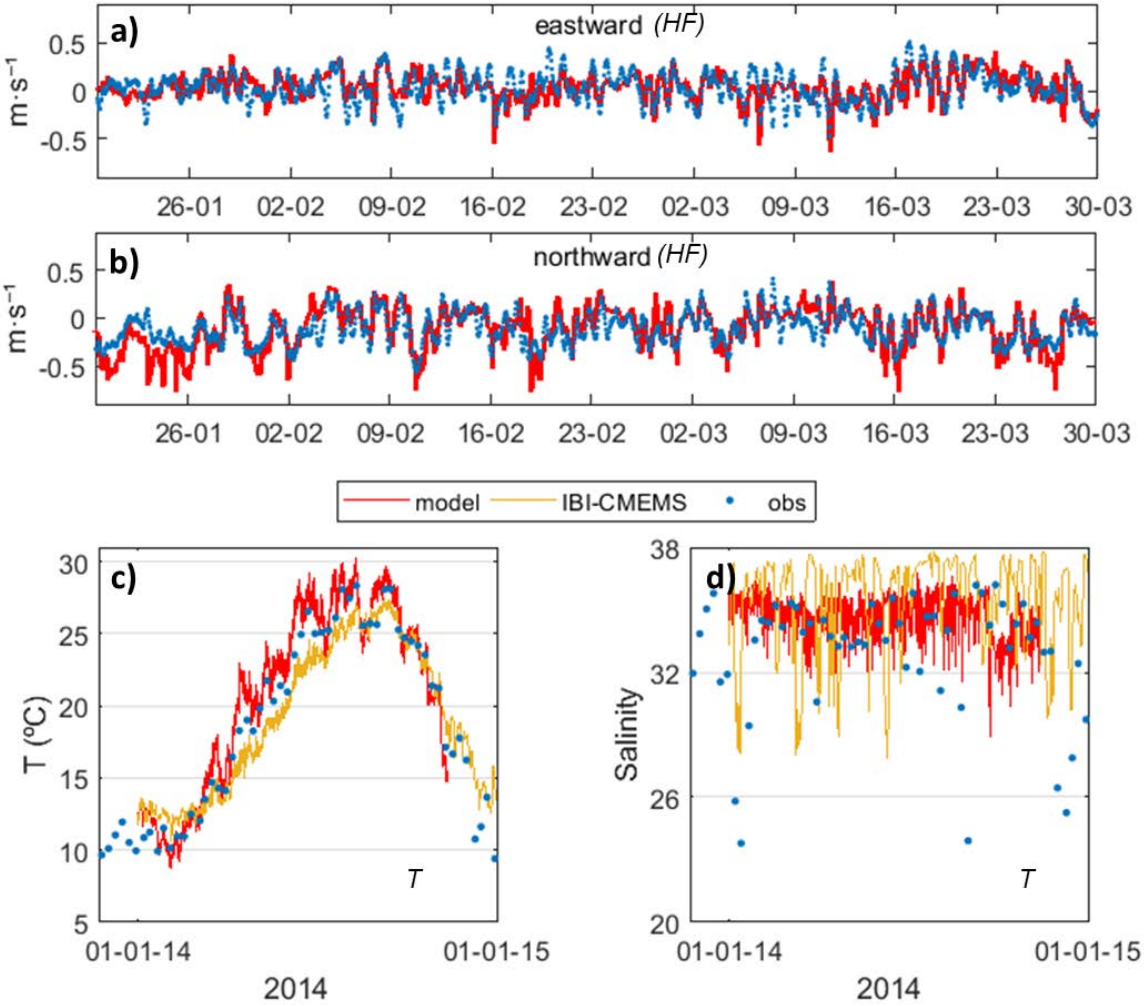


Figure 2. Water temperatures in Alfacs Bay at point *T* (year 2014), drainage-channels (Rice fields, from climatological observations -2002-2010- in a nearby coastal lagoon by the staff of the ~~Delta~~ Ebro Delta Natural Park), Tarragona buoy (Tb) for open sea water conditions (*Puertos del Estado*, PdE) and climatological data from Ebro River (*Confederación Hidrográfica del Ebro*).


a)
eastward (HF)
m·s⁻¹
0.5
0
-0.5
26-01
02-02
09-02
16-02
23-02
02-03
09-03
16-03
23-03
30-03
b)
northward (HF)
m·s⁻¹
0.5
0
-0.5
26-01
02-02
09-02
16-02
23-02
02-03
09-03
16-03
23-03
30-03
model
IBI-CMEMS
obs
c)
T (ºC)
30
25
20
15
10
5
T
01-01-14
01-01-15
2014
d)
Salinity
38
32
26
20
T
01-01-14
01-01-15
2014

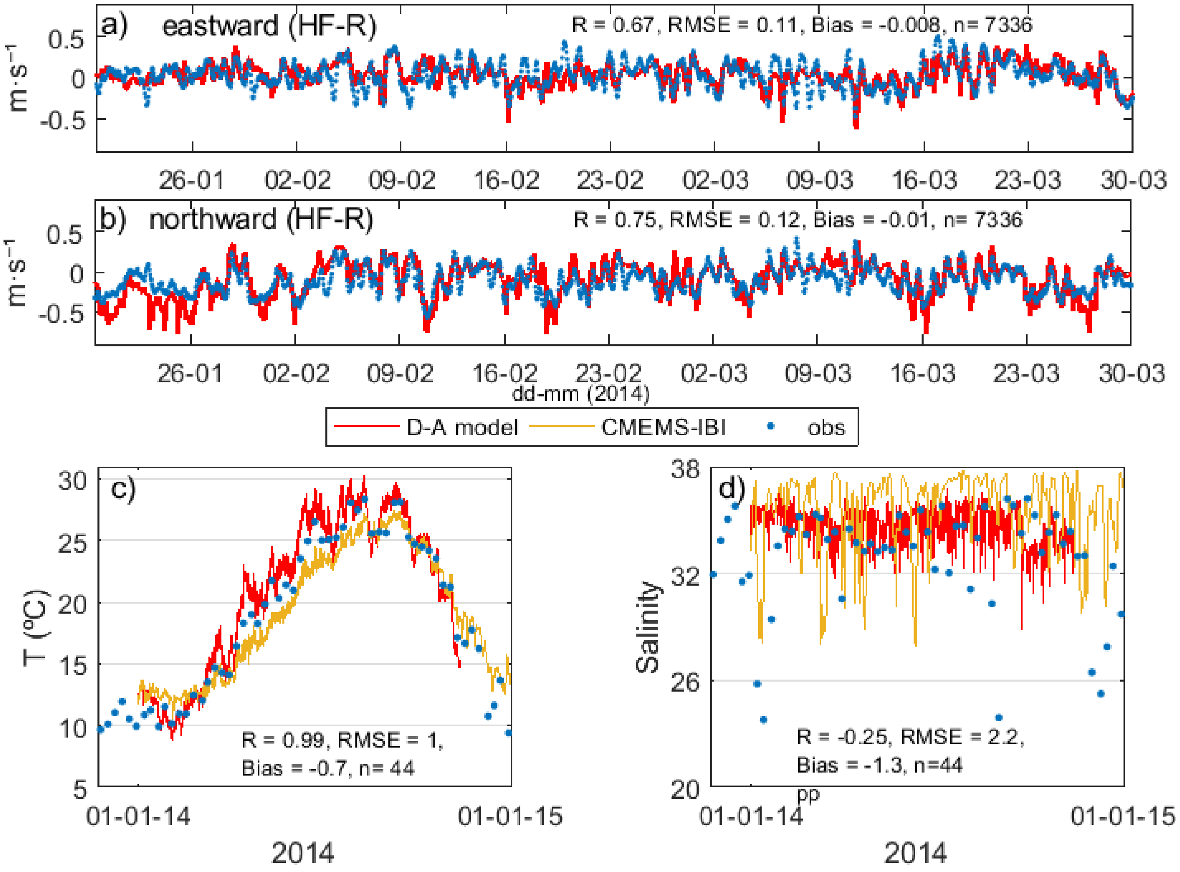


Figure 3. Eastward (a) and northward (b) water surface currents for D-A model and HF-R~~adar~~ at HF (Fig.1) are shown. SST (c) and SSS (d) validation of the local model D-B (red), CMEMS-IBI (yellow) and observations (blue) at T (Fig.1).

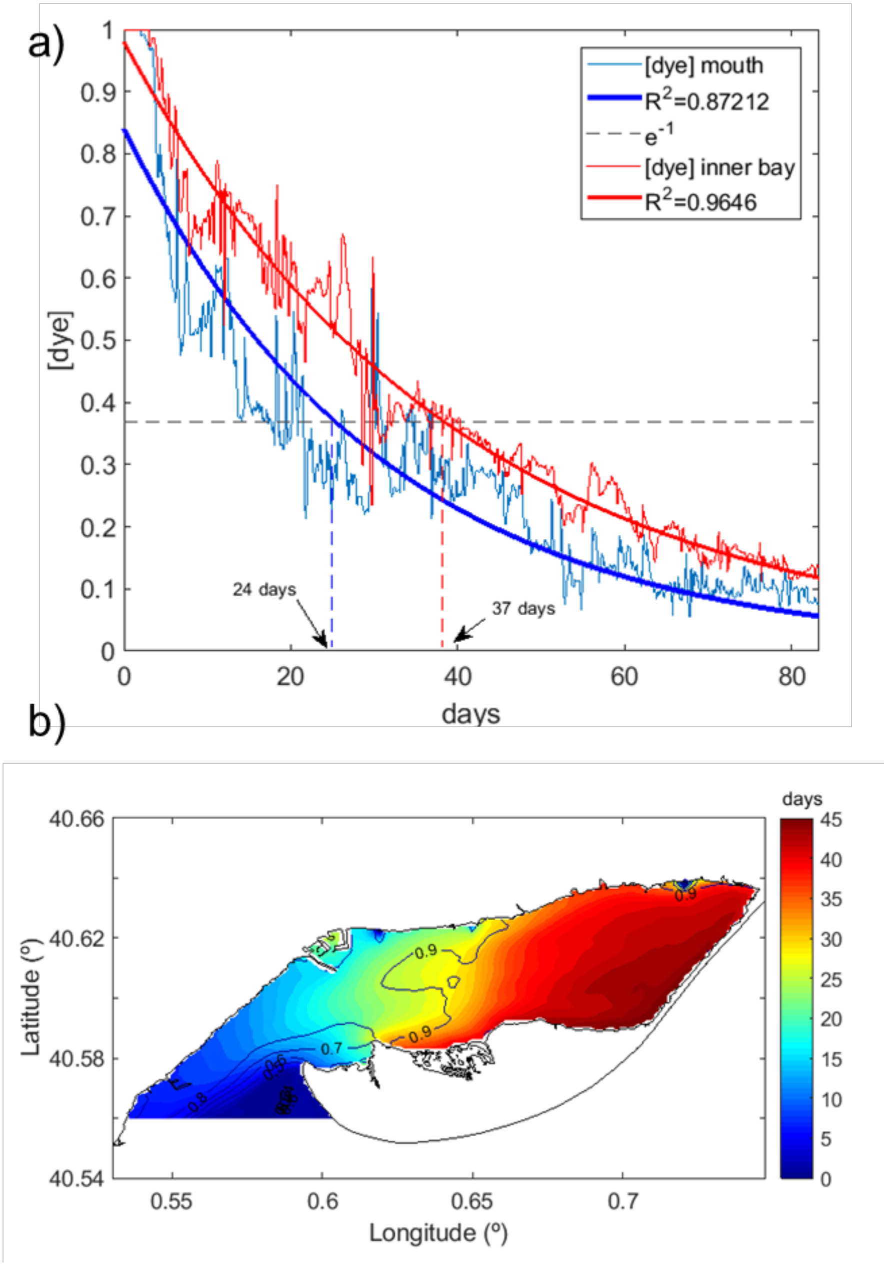


Figure 4. a) ~~Shows the t~~Time-evolution of the dye concentration at two points -at the bay mouth and inside the bay- and the corresponding exponential fitting (with the squared correlation shown in the legend) used to obtain the *LFT* for the C case. b) shows the local e-flushing time for the C case (color). The black contour shows the squared correlation obtained at each of the grid points.

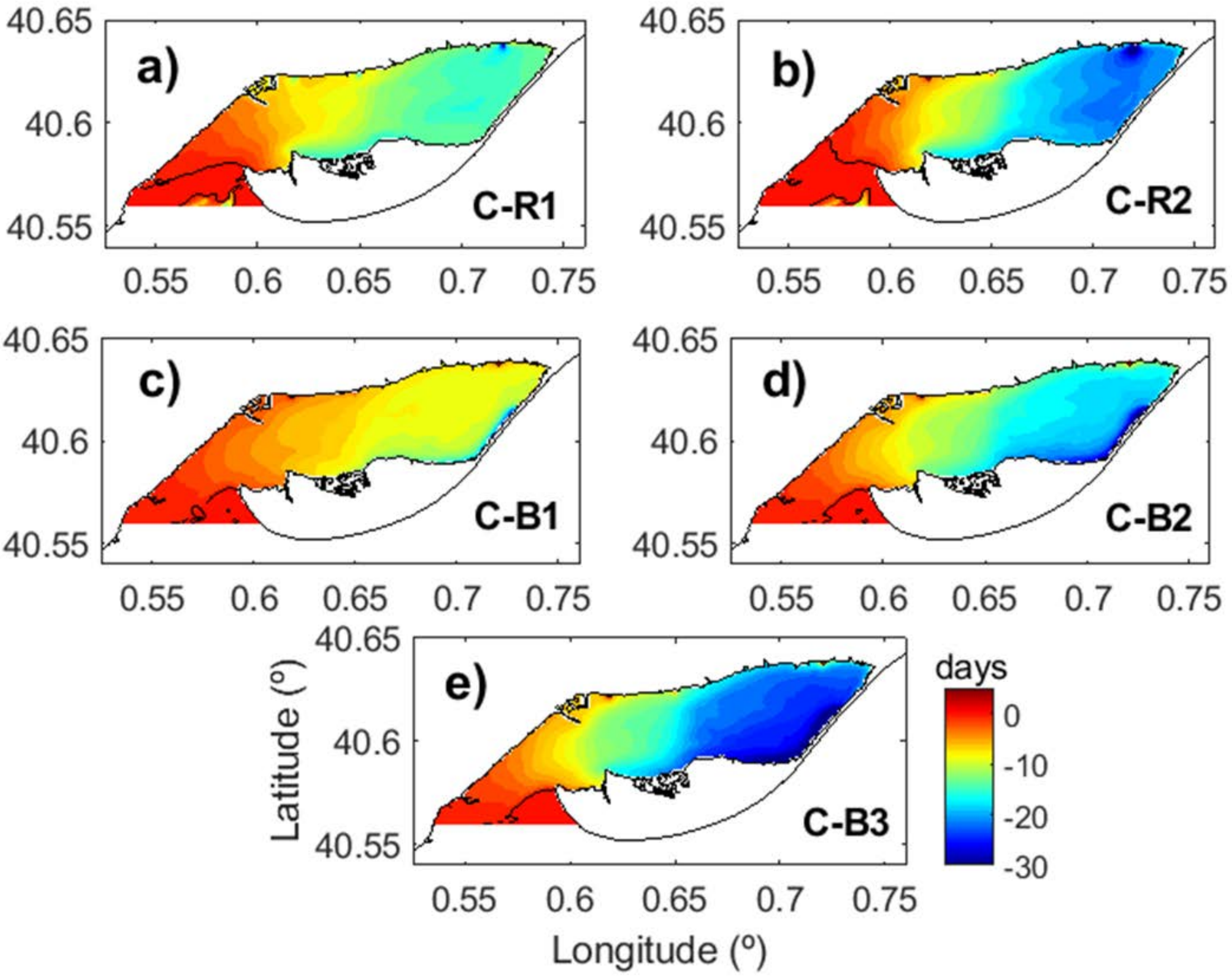
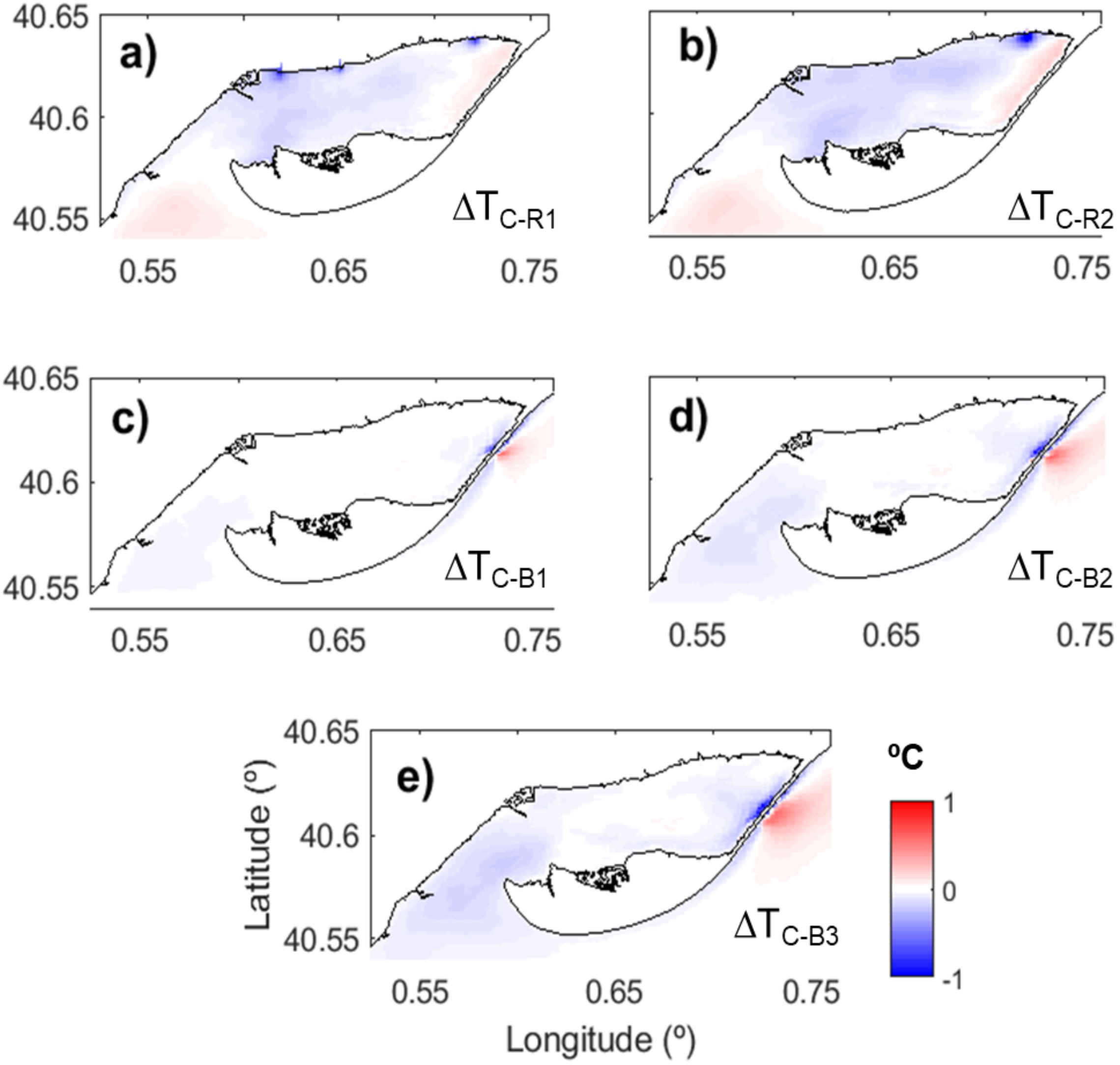


Figure 5. Differences (in days) for the water e-flushing times between each test case and Control Simulation (C). negative (positive) indicates shorter (longer) local e-flushing times for the corresponding test compared with *C*.


a)
ΔT_C-R1
b)
ΔT_C-R2
c)
ΔT_C-B1
d)
ΔT_C-B2
e)
ΔT_C-B3
40.65
40.6
40.55
0.55
0.65
0.75
Latitude (º)
Longitude (º)
ºC
1
0
-1

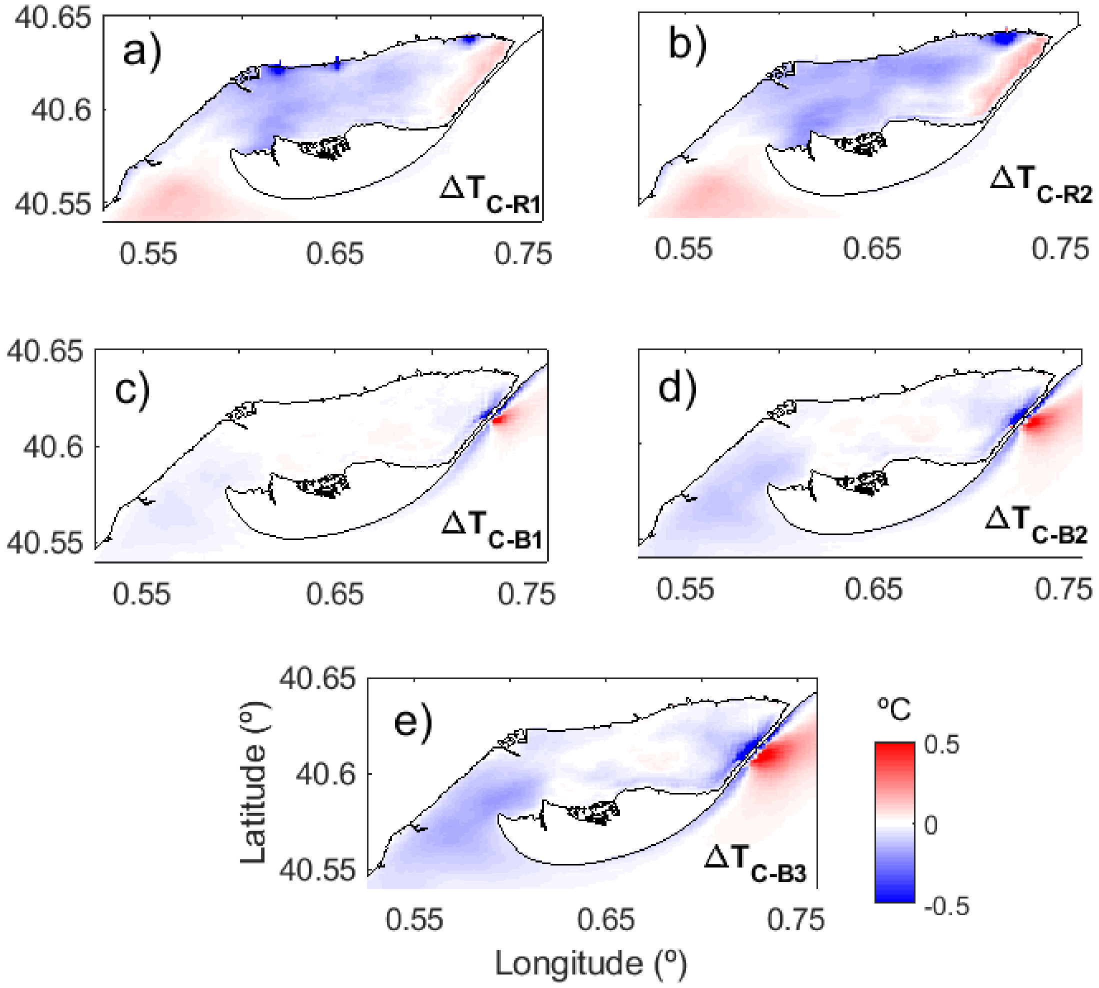


Figure 6. Differences for the SST between each test case and Control Simulation (C). Blue color indicates lower SST for the corresponding test compared with *C* (red colors indicates lower SST for the Control Simulation).

5

Table 1. Summary of observations (see Fig.1 for identifications)

	Identification	Location	Frequency	Period
CTDs	T	Inner bay	weekly	2013-2014
PdE buoy	-	Shelf	hourly	2004-2015
Ebro River	-	Amposta city	daily	2004-2015
Drainage channel	Rice Fields	drainage channel	daily	2012-2015
High Frequency Radar	HF	Selected point (HF)	hourly	2014 (entire year)

Table ~~1~~2. Numerical experiments and main characteristics

Test	Trabucador bar	Freshwater inputs ($m^3 \cdot s^{-1}$)	Long name
C	Closed	10 (4,2,4)*	Control Simulation
B1	Opening: 200 m	10 (4,2,4)	Bar breaching 1
B2	Opening: 500 m	10 (4,2,4)	Bar breaching 2
B3	Opening: 800 m	10 (4,2,4)	Bar breaching 3
R1	Closed	20 (8,4,8)	Freshwater 1
R2	Closed	20 (4,2,14)	Freshwater 2

* The order inside the brackets indicates the location of drainage channel from west to east (see Figure 1).

Table 3~~2~~. TFT values for the surface e-flushing time in the Alfacs Bay

Numerical Test	*TFT* (Total Flushing Time)	Difference in relation to *C*
	Days	**Days**
C	~~27~~28,2	-
B1	2~~1.3~~2.7	**-5.5~~7~~**
B2	1~~6~~7.6~~1~~	**-10.6~~9~~**
B3	14~~3~~.6~~1~~	**-13.6~~9~~**
R1	20.3~~18.7~~	**-7.9~~8.3~~**
R2	17.6~~6~~	**-10.6~~1~~**

--------------------------------- REVIEWER 1--

GENERAL COMMENTS

In this contribution, the authors describe the operational implementation of a very high-resolution coastal ROMS-based model, nested to CMEMS-IBI regional system, in order to monitor water quality within Alfacs Bay (NW Mediterranean Sea). 1-year validation exercise is presented along with two numerical simulations to analyze the impact of proposed interventions. This work addresses an interesting topic. I particularly appreciate the development of tailored CMEMS downstream services in coastal and port-approach areas with subsequent societal benefits. The paper is mostly well written and organized, just a few English slips, and will be of interest to readers of this journal. The results of water residence times are consistent and nicely interpreted. However, the overall impression is that the paper, although adequately conceived, is too short in some sections. My main concern is that sections 2.2 (Observations) and 2.4 (Validation) are not well resolved and therefore should be improved. In summary, I believe that the paper can be made acceptable for publication **upon minor revision**. In the following lines I provide some comments, which should hopefully strengthen the manuscript.

Dear Referee, Thank you very much for your insightful comments and suggestions. These are very valuable and helpful for revising and improving our paper. A revision has been made to our manuscript in accordance with these recommendations. The response to each one of the reviewer’s comments and the corresponding correction to the paper are explained in detail. Once again, thank you very much for all your help in reviewing our paper. Kind regards,

SPECIFIC COMMENTS

-Section 2.2: Observations

1. I definitively do not understand why the first paragraph was placed in this section. It should be better moved to other section, perhaps to “Results”.

Thanks, we agree with the referee that the way it is written and placed could lead to confusion. We have moved the text to the study are description.

2. I miss a brief description of the most basic technical features of the in situ and remote-sensing instrument used in this work: CTD, moored buoy, HFR, etc… Maybe a table summarizing those details would be useful (together with the time periods used in the validation exercise), similar to Table 1 where information about the different simulations was gathered.

OK, we agree. We have added a table summarizing all the instrument used for the validation. (Table 1). A sentence have been added in page 4: *All the observations are summarized in Table 1*

3. Most of the audience will not be familiarized with HFR shore-based technology. Please add a brief paragraph describing basic characteristics: frequency at which it operates, time sampling (1 hour?),

horizontal resolution of the grid, spatial coverage, number of radar sites, date of deployment, sources of uncertainties in the remotely-sensed observations, etc.

Ok, we have added a brief paragraph with some more information about the HFR (as well as some new references):

"The HF-R (CODAR SeaSonde Standard-range) was deployed at the Ebro delta in 2013 within the framework of the RIADE (Redes de Indicadores Ambientales del Delta del Ebro) project. The network consists in three remote shore-based sites providing hourly radial measurements with a cut-off filter of 100 cm s−1 and representative of current velocities in the upper first meter of the water column. The total corrent vectors are hourly averaged on a predefined Cartesian regular grid with 3 × 3 km horizontal resolution (Lorente et al. 2015)."

Lorente, P., Piedracoba, S., Soto-Navarro, J., and Alvarez-Fanjul, E.: Evaluating the surface circulation in the Ebro delta (northeastern Spain) with quality-controlled high-frequency radar measurements. Ocean Science, 11(6), 921-935, 2015.

4. Likewise, no information about the data treatment was provided. There were gaps in observational time series? If so, small gaps (let´s say, < 6 hours) were linearly interpolated?

Ok, we have added some information about the data treatment:

"Validation is performed for the entire 2014 and the gaps in the HF-R data are not considered (it represents less than 15% of raw data)."

- Section 2.4: Validation

1. As previous step to validate your model, you must be sure that the parent system is consistent and accurate enough, able to provide coherent open boundary conditions to the nested system you are implementing. In this context, has CMEMS-IBI system been previously validated in Ebro Delta area using a multi-platform approach? If so, please add the reference and briefly mention the statistical results derived from IBI validation in this coastal area.

OK. We have added a paragraph addressing this question:
"The parent model (CMEMS-IBI) has been validated in Region using HF-R in Sotillo et al. (2015). Their results shows zonal and meridional RMSE (correlation) values in the range of 6–10 cm/s (0.4–0.8) over central areas of HF-R radar domain, with higher errors detected in far edges of the radar spatial coverage (Sotillo et al. 2015)."

2. The validation is performed on a very basic level, only form a qualitative perspective. The conclusions are drawn according to the visual resemblance of time series. I miss the number of hourly observations and some skill metrics such as the (relative) bias, (normalized) root mean squared error (RMSE), temporal correlation, complex correlation, mean percentage error, scatter and quantile-quantile plots, current roses, Taylor diagrams, percentiles, etc. in order to provide a quantitative

perspective of the model performance. I am not asking to compute all of them, but a deeper insight should be welcome. You could add some skill metrics to Figures 2 and 3, for instance.

Ok, we agree. For that reason, we have modified Figure 2 and 3 adding some skill scores.

3. Why both SST and SSS validations were performed on an annual basis (2014), but the validation against the HFR was only performed from approximately mid-January to end of March? Please provide and explanation. There was a radar break down?

It is only a graphical recurse. Using all the data for 2014 for Figure 3 does not allow to correctly see the fitting between the model and the data. The validation (statistical values) have been done for the entire 2014. In the text now is reflected that validation is done for the entire 2014.

4. A specific HFR grid point was selected to conduct the comparison against modeled currents. Which one? Please provide longitude and latitude. Why this grid point was selected and no other one? Maybe because the data temporal coverage was optimal? If so, explain it please.

Ok. Longitude and latitude are now provided in the Figure 1 caption.
This point was selected because the data temporal coverage was optimal and also it is located close to the Ebro Delta but far from the coast to avoid land-mask effects. We have added a sentence explaining it:

"Validation is performed for the entire 2014 in one point close to the bay and with optimal temporal coverage (more than 85% of 2014 with data). The gaps in the HF-R data are not considered."

5. The time series of zonal and meridional currents shown in Figure 3 (a-b) were raw or low-pass filtered?

Raw data, without filtering.

6. As far as I know, the HFR deployed in Ebro Delta operates at a nominal frequency of 13.5 MHz and provides hourly current estimations which are representative of the first meter of the upper water column. In this context, the current meter installed in PdE buoy provides in situ measurements of currents at which depth? This was not explicitly described in the manuscript and could partially explain some of the HFR-model discrepancies observed. I think it is worthwhile mentioning this in the Discussion section.

We are sorry but we believe there is a misunderstanding here. Data from PdE buoy is used here only to compare it with SST with data from Ebro River and discharge channels. The PdE buoy is located outside the CSTDEL domain, so no validation is possible to realize.

Conclusions

1. Future prospects are not provided in the conclusions.

Ok,we agree. In this sense we have added the following text:

"Future works should include the analysis of the wave effects on water the circulation, as well as the consideration of different initial conditions and met-ocean conditions on the determination of water renewal in Alfacs Bay."

2. Besides, in "future work" section I miss a mention to the inter-comparison of the high-resolution coastal model against its parent regional system (IBI) in order to thoroughly quantify the potential added value of the dynamical downscaling approach adopted.

Yes, we agree and we have added a sentence in the discussion to this end.

Figures

1. I suggest splitting Figure 3 into two different Figures, adding also the skill metrics derived from the comparison.

We prefer to keep the figure as it is (not splitting). However, we have added the skill metrics following the reviewer suggestion.

2. It could be useful to show the mean surface circulation patterns in D-B domain during inflow/outflow phases. This is also partially related to the residual and mean circulation (last paragraph, page 6) you mentioned in the text: since only six figures were provided in the manuscript, an additional image showing this could enrich the work.

We agree with the reviewer that the residual (mean circulation) is important and could improve the knowledge of the bay. For that reason, we have added the reference of an article (just published, Cerralbo et al. 2019) where the subtidal and mean circulation of Alfacs Bays is analyzed in detail. However, we prefer not to add any new figure in this article in order to not blur the main results and scope of this manuscript.

TECHNICAL CORRECTIONS:

I am fully aware that the authors are not English native speakers (neither am I) and therefore I appreciate the considerable effort made to write down a research paper. However, I would suggest some professional English editing to improve the quality of the manuscript.

OK, we have done some English-editing.

Abstract

- For consistency reasons, please replace “Delta Ebro” by “Ebro Delta”
Ok, done.

- Replace “leading high rates” by “leading to high rates”
Ok, done.

- For consistency reasons, please replace “modelled” by “modeled”
Ok, done

1. Introduction:

- Wrong definition of CMEMS acronym: it should be “Copernicus Marine Environment Monitoring Service” instead of “Copernicus Marine Environment Monitoring System”.
Ok, thank you.

2.3. Numerical model

- Please specify the atmospheric model, implemented by AEMET, used to force the coastal ocean model: HIRLAM, HARMONIE-AROME, etc?
Ok. Done. The model used has been HARMONIE

2.4. Validation

- Replace “Ebro plume” by “Ebro River plume”.
Ok. Done.

- **“**HF-radar” and “High-Frequency radar” are found in the text, “HF” in Figure 1-b. Please use an unified nomenclature: Define firstly “High-Frequency radar (HFR)” and use the acronym afterwards.
Ok, Done.

- Please define the acronym IRTA in the text since it was only previously described in the list of institutions involved in the present manuscript.
Ok, Done.

4. Discussion:

- For consistency reasons, please replace “modelled” by “modeled”
Done.

5. Conclusions:

- It should be “effectiveness in increasing” instead of “effectiveness in increase”.
OK.

- Replace “related to water temperature peaks during some days” by “related to occasional extremely high temperatures”
OK.

- Replace “allowed for the first time” by “allowed for first time”
OK.

Figure 1, caption:
- For consistency reasons, please replace “Delta Ebro” by “Ebro Delta”
OK
- Replace “Pde” by “PdE”
OK
-Replace “Data from High frequency Radar used to…” by “Location of the HFR grid point used to…”
OK

Figure 2, caption:
- You mention “Puertos del Estado” and define here the acronym PdE. Such acronym, used several times along the document, should be defined in the main body of the text, not in a Figure caption.
OK. Done

Figure 3:
- In the text, you defined CMEMS-IB but in the legend “IBI-CMEMS” is shown. Please correct this inconsistency.
Ok, done
- Specify that model (red line) represent DA model
Ok, done
- Which is the frequency of observations (blue dots)?
Hourly. It has been added in the Figure 3 caption.

Figure 4, caption:
Replace “a) Shows the time-evolution” by “a) Time evolution”
OK, done.

Figure 6:
Please redefine the color palette (maybe from -0.5 to 0.5) because the details can not be readily inferred.
Ok, we agree. Thanks for the suggestion. It ha

---------------------------------- REVIEWER 2--

GENERAL COMMENTS

This paper is an excellent example how the CMEMS hydrodynamic solutions (or similar) can be useful to support coastal management. A lot of consultancy work is done assuming that the coastal areas do not present relevant 4D hydrodynamic variability. In some cases this can be valid but not in the case of Alfacs Bay and many other. As a consequence, the scientific community should not only be proposing new concepts (e.g. numerical discretizations, different methodologies on quantify the general concept of “water residence time”) but also present methodologies on how these “new methods” should be applied in efficient way and with controlled costs to support complex decisions in highly socio-economic sensitive coastal areas. This paper is an excellent effort in this direction. This paper address areas where some guidance should be given to coastal marine modelers:

How to define realistic boundary conditions? In this paper the focus is in the open boundary conditions but land/surface/bottom boundaries are also properly addressed: how to improve open boundaries integrating regional scale operational model results (e.g. CMEMS); when realistic boundary conditions should be used and when it is acceptable the use of schematic ones. In this paper the authors are also faced with the problem of imposing a freshwater flux along the land boundary based in generic seasonal data: which simplifications can be assumed and how this can influence the model results.

Which valid methods should be followed to have a hydrodynamic model forced with realistic conditions with a proper spatial discretization? In this case a one-way nesting approach was assumed with two nesting levels; How should it be validated a 4D hydrodynamic model? How hydrodynamic model results can be used to support water quality problems? Is it required to implement also a 4D biogeochemical model or computing “hydrodynamic time parameters” based in the model hydrodynamic results can be a good option? How about sub-grid parametrization. How can this impact the “hydrodynamic time parameters” results? In a complex model implementation like the one described in this paper a lot of options must be adopted.

In my opinion the paper will be improve if some of these options are better explained: Why 12 layers and not more or less? Open boundary condition: Clamped vs Flow Relaxation. Options related with the subgrid parametrization (e.g. what values were assumed for the turbulent viscosity and

diffusion of heat and mass coefficients?);

Why an eulerian approach to compute the “hydrodynamic time parameters” and not a lagrangian one that is able to avoid numerical diffusion problems associated with the advection term?

Dear Referee, Thank you very much for your insightful comments and suggestions. These are very valuable and helpful for revising and improving our paper.

Most of the proposed questions by the referee are extremely interesting and useful in order to conduct modeling works in coastal areas. In this sense, the improvement of CMEMS products to nest high resolution coastal models, the impact of the boundary conditions or the influence of spatial resolution will deserved a paper for itself. Therefore, many of the specific comments face these points and we reply properly trying to avoid an enlargement of the manuscript. As we explain in the point-by-point reply some of the decisions made (e.g. spatial/vertical resolution) in the modelling effort are based on our extensive background in to modelling the Bay including calibration and validation excises (see Cerralbo 2014, 2016 and 2018). However many of the questions may involve extensive sensitivity tests, which is out of the focus of our manuscript. In this sense, a revision has been made to our manuscript in accordance with these recommendations.

The response to each one of the reviewer’s comments and the corresponding correction to the paper are explained in detail. Once again, thank you very much for all your help in reviewing our paper. Kind regards,

Scientific significance: The scientific contribution of this paper is focused in the methods. There is a vast variety of concepts, ideas and data being produced by the scientific community focused in the transport of heat, mass and momentum in coastal environments but there is a lack of papers presenting clear methods to support decision making in which concerns the numerical modelling of the momentum, mass and heat transport in coastal areas that I’m more familiar. I rate this paper scientific significance as good. Scientific quality

Specific comments

Page 2 - line 16 – “. . . based on activities that depend on primary production, such as agriculture, fisheries and aquaculture.” The link between marine primary production and agriculture it is not fully clear. In the North of Portugal there was an antient practice of use seaweed as a fertilizer in agriculture. Are the authors referring to something similar?

In this point, the authors are referring to the economy of the area (not only the primary production.). We believe there was a misunderstanding here. For that reason, we have done some minor changes in the text. We believe now it is clearer.

Page 4 – Line 1 – “ Cerralbo et al. (2015) found that during warm periods the salinity distribution shows strong vertical gradients . . .”. The way this is stated may be a little bit misleading. In fact this happens in periods of low wind intensity that are more frequent in warm periods.

Yes. Thanks. We agree that the way it was written and the place in the text could induce to some errors of comprehension. For that reason, the changed text has been moved to the description of Study Area.

Page 4 – Line 24 – It would be interesting to detail how the nesting it is done between the two ROMS models: the two models run at the same time and every time step the “father model” solution is interpolated for the “son grid” boundary cells or the “father model” runs first and the data is stored every X seconds in a file and the “son model” runs in a second step?

Ok. We agree and a sentence has been added:
“The nesting is off-line, first D-A simulation is performed and the hourly results are used for the boundary conditions of D-B.”

Page 4– Line 25-26 – The justification for the adopted spatial discretization (_70 m horizontally and 12 sigma layers vertically) could be improved. Usually this is a critical point when implementing a 3D (in space) hydrodynamic model. Why dx _70 m is necessary to capture correctly the variability in the inner bay? The same question can be raised for the number of sigma levels. Why 12? They have the same relative thickness?
It was done any sensitive analysis to check if the model results change significantly for different horizontal or vertical discretizations? I’m not familiar with the ROMS model implementation details but I know that it allows the user to do some “vertical stretching” (S coordinate). This way it would be possible to increase the resolution where stratification is more intense (e.g. halocline depth) by aligning the sigma layers with the isopycnic lines and minimize the numerical diapycnal mixing. Was this option considered?

In Cerralbo et al. (2016) there are explained in more detail some of the options (e.g. bottom rugosity height). But it would be beneficial to provide a more detailed explanation for the vertical discretization.

The horizontal resolution are associated at the compromise of the numerical resources and the physical process that we want to solve. The minimum horizontal discretization was established in order to simulate properly the mouth. In this case, the mouth section is discretized in x points and the vertical layers was 12. Also we use vertical stretching for the terrain following coordinates: surface stretching parameter = 7.0 and bottom stretching parameter = 0.4 using Song and Haidvogel (1994) stretching function. This configuration allows to increase the resolution in the upper layer where the surface boundary layer takes place due to the wind action. The transformation function used is described in Shchepetkin and McWilliams (2005) denoted as an unperturbed coordinate system since all the depths are not affected by the displacements of the free surface.

The paper has been improved adding the paragraph:

“A surface stretching parameter (= 7.0) and bottom stretching parameter (= 0.4) for the Song and Haidvogel (1994) stretching function has been used. This configuration allows to increase the resolution in the upper layer where the surface boundary layer takes place due to the wind action. The transformation function used is described in Shchepetkin and McWilliams (2005) denoted as an unperturbed coordinate system. “.

Page 4 – Line 31. It is described the turbulence closure scheme assumed vertically but not horizontally. Additionally it would be important to mention the advection scheme used horizontally and vertically for momentum, mass and heat transport.

Ok. We have changed the sentence in order to provide the aforementioned information:

In order to represent the processes at scales smaller than the grid resolution we used anisotropic horizontal and vertical turbulent schemes based on a Generic Length Scale (GLD) formulation (Warner et al, 2005). K-epsilon parameters are used for GLS formulation. Also Kantha and Clayson stability function formulation is used (Kantha and Clayson, 1994). For advection scheme a third-order upstream horizontal fluxes is used. For heat and mass tracers, a biharmonic mixing scheme along geopotential surfaces is used.

Page 5 – line 6-7. "The variability of currents along the water column (baroclinic component), temperature and salinity are imposed from CMEMS-IBI daily average values with clamped conditions". Two comments: It would be interesting to explain a little better how the baroclinic velocity required to the ROMS boundary condition is computed? U baroclinic (i,j,k,t)= U CMEMS (i,j,k,t) – U CMEMS barotropic (i,j,t) and both CMEMS are interpolated in time for each t instant ? Why had been choose clamped boundary conditions ? Was it also considered the use of nudging layers as an alternative to a clamped boundary condition? If not why? Usually in the literature for coastal and ocean 3D hydrodynamic implementations nudging layers is the methodology recommended. Marchesiello, P., J. C. McWilliams, A. Shchepetkin (2001): Open boundary conditions for long-term integration of regional oceanic models. Ocean Modelling 3, 1-20, 2001. Palma, E. D. and R. P. Matano, 2000: On the implementation of passive open boundary conditions for a general circulation model: The three-dimensional case. Journal of Geophysical Research, 105,. 8605-8627 (2000).

A lot of question here:

1. Ok. The way it was written lead to some confusion. Basically we are referring to baroclinic currents when using the 3D currents, and barotropic when using depth averaged water currents. No more treatment is done. In order to clarify this, we have re-written the text, specifying vertically depth averaged water currents (when saying barotropic) and 3D variables (T, S and water currents). We believe now everything is clearer.

2. 3D values in the OBC are imposed with daily mean values (is the only values CMEMS-IBI provides), and 2D values (depth integrated water currents and sea-level) is provided hourly.

3. We have done many numerical tests trying to define the best OBC for the system (we are not talking about them in the manuscript). Some tests have included nudging schemes as the reviewer proposes (also trying different ways to impose the nudging area and considering different time values). However, the best results (both in skill assessment) and preservation of the continuity with the parent solution (IBI-CMEMS) have been obtained with Clamped for the 3D variables. Other similar applications have used similar configurations (e.g. Penven et al. 2006, Costa et al. 2012.)

Penven, P., Debreu, L., Marchesiello, P., & McWilliams, J. C. 2006. Evaluation and application of the ROMS 1-way embedding procedure to the central California upwelling system. Ocean Modelling, 12(1), 157-187.

Costa, P., Gómez, B., Venâncio, A., Pérez, E., & Pérez-Muñuzuri, V. 2012. Using the Regional Ocean Modelling System (ROMS) to improve the sea surface temperature predictions of the MERCATOR Ocean System. Scientia Marina, 76(S1), 165-175.

Page 5 – line 13. Why was it assumed 18 for the freshwater salinity concentration? This is based in observations? This should be better explained.

The freshwater from the rice-fields is mixed in some areas with water from a coastal Lagoon (L'Encanyissada). The water in this lagoon are considered as brackish waters, but no receantly measurements allows the authors to know or even calculate the mean salinity of these waters. For that reason, an arbitrary value of 18 has been used. However, and considering that the main objective of the manuscript is the comparison between simulations with modification of selected variables (flows or connections with open sea), while keeping the rest immutable, the authors consider that the value of 18 is correct for the purpose of this research. However, some text have been added in the discussion according to the referee suggestion.

In discussion, first paragraph:
"Errors in salinity could be related to the poor knowledge of the freshwater flows (total amount, spatial and temporal distribution) and the salinity of these waters (freshwater from rice fields mixed with brackish waters from coastal lagoon)."

Page 6 – Validation. A table with the statistic parameters (bias, RMSE, R) resulting from the comparison of model results with observations for each water/flow property should be presented.

We agree. We have added some skill parameters to Figure 3.

Page 6 – line 10-11. Why HF radar is only compared for one point? What was the criteria to choose this specific point? Was it considered to compare all HF radar observations intersecting the model domain? See the methodology followed in the validation of IBI CMEMS http://cmems-resources.cls.fr/documents/QUID/CMEMSIBI-QUID-005-001.pdf You can also look in to a conference abstract where it is presented some validation of a model (in this case MOHID model) implemented in the Algarve coast following a methodology similar to the one used in this paper.
http://www.mohid.com/PublicData/Products/ConferencePapers/Leitao_etal_5JEH_2018.pdf

We agree that one option is to perform a 2D validation over the entire domain. In this sense, there is already a similar validation done in a manuscript already in publication process in Journal of Operational Oceanography (Sotillo et al. 2019) for a similar configuration presented here. However, in this manuscript we prefer to show part of the time series in one point in order to clearly observe the good behavior of the model close to the bay in a point with almost data for the entire period.

Page 6 – Water Residence Time. Jouon (2006) do a very good review of the different approaches proposed in the literature to compute what Jouon (2006) calls "Hydrodynamic Time Parameters". In my daily work I usually characterize the "Water Residence Time" based in the parameter that Jouon (2006) named "Water Export Time" using a lagrangian approach (particle tracking model). Braunschweig F, Martins F, Chambel P, Neves R. A methodology to estimate renewal time scales in estuaries: the Tagus Estuary case. Ocean Dynamics. 2003; 53(3): 137-145. Jouon (2006) also follows a lagrangian approach to compute this parameter. The advantage of the lagrangian approach is to avoid the numerical diffusion problems associated with the advection term in the eulerian methods. However, in the eulerian approach the turbulent diffusion parametrization is more straightforward. Additionally the no flux land boundary condition in the eulerian methods is quite simple to impose while in lagrangian case is not so trivial (this problem is also mentioned by Jouon, 2006).

We agree with the referee that lagrangian method could also be used in here. However, in our initial test cases, the utilization of the lagrangian model of ROMS lead us to some problems not so trivial to solve. After performing different tests and methods, the one that provide us with more intuitive and useful results were the ones presented in the manuscript. We have added the reference of Braunschweig et al (2003) in the text to explicitly refer to the lagrangian methods.

Page 7 – line 13-14. It would be important to describe the methods used to compute advection (e.g. TVD ???) and turbulent diffusion (e.g. values of the horizontal turbulent diffusion coefficient) horizontally and vertically in the transport of the conservative tracer. One of the goals of this paper is to compute "hydrodynamic time parameters" using an eulerian method. In this case numerical diffusion associated with: advection numerical discretization, over estimation of horizontal turbulence (e.g. very high turbulent viscosity/diffusion coefficients), numerical diapycnal mixing can have a have a strong impact over the results. The impact of the advection numerical diffusion is briefly discuss by Jouon (2006) (TVD vs Upwind).

Information about the advection scheme used for the mass and tracers are included in the new version of the manuscript (see also previous comment referred to numerical model implementation). These schemes are also selected in previous modelling efforts in Alfacs Bay with good results in terms of skill assessment (see Cerralbo et al.2014, 2016,) Page 7 – line 14. Why the focus was the surface layers? It is because the main source of stress over the mussel's production is high temperatures? I would aspect the bottom layers would be the ones presenting from a general point of view more intense water quality problems (e.g. oxygen depletion);

The main idea is to study the water quality parameters in the bay (both SST and water e-flushing times) in the well mixed surface layers (above the pycnocline at 3-4m, and where the most of the mussels production is located). For that reason, the analysis have focused on the surface layers.
We agree with the referee that problems like oxygen depletion (not covered by this manuscript) are more related with bottom circulation, and for that reason in the discussion we have added a sentence suggesting to do similar studies but considering the bottom circulation in the framework of problems related to oxygen depletion and turbidity.

Page 7 – line 22. If I understand correctly TFT (total flushing time) is compute averaging the LFT (local flushing time) for the entire bay (surface layer). For me is more consistent to average first the concentration in the entire control volume of interest (in this case the Alfacs bay – surface layer) and compute the TFT to be equal to period necessary to the average concentration to go from C0 to C0/e. This is the methodology proposed by Jouon (2006). Myself when I want to check if my lagrangian approaches are consistent I use a similar eulerian methodology.

We agree. We have re-done the analysis following the suggestion of the referee. In addition, we have changed the text *("(…) being TFT equal to the period necessary to the average concentration of the entire Bay to go from* C_o *to* C_o**e-1 (...)")* and corresponding values in the table.

Technical corrections

Page 19 - Figure 6. Maybe it could be considered another colormap. It is a little bit difficult analyse the figure. A rainbow or similar colormap could be preferable.

Ok. We have changed the color scale and now the analysis

-------------------------------- REVIEWER 3 ---

GENERAL COMMENTS

In this paper, the authors present an application of a numerical model ROMS to a small bay in NE Spain in order to study the water renovation times and possible implications on water quality. The model is used to examine several coastal zone management scenarios that can be undertaken in order to improve the exchange of water in the bay. These include increased freshwater inputs from rice fields and a construction of an artificial channel of various widths through the Trabucador Bar in order to connect the inner Alfacs Bay with the sea. It is a very interesting contribution and the paper is well structured and easy to follow. Presentation of the results is clear, especially the figures and tables. It is also a very nice demonstration of the usefulness of having the Copernicus Marine Environment Monitoring Service as an enabler of downscaling of numerical models to a coastal zone in order to assist with the coastal zone management. I would like to see this paper published, as I think it will be of wide scientific interest. However, I recommend the following revisions to be undertaken by the authors before this paper is accepted for publication, especially that there is still scope (in terms of the size of the paper) to expand the paper to include some more and important, in my opinion, details.

Dear Referee, Thank you very much for your insightful comments and suggestions. These are very valuable and helpful for revising and improving our paper. A revision has been made to our manuscript in accordance with these recommendations. The response to each one of the reviewer's comments and the corresponding correction to the paper are explained in detail. Once again, thank you very much for all your help in reviewing our paper. Kind regards,

Specific comments:

1. Validation: The quality of the paper will be strengthened if more validation results of the numerical model are presented. In particular:

a. Why validation against the HF Radar is only limited to the sampling station T and why validation is only limited to 3 months, whereas validation against temperature and salinity is presented for a full year?

We think that there is a misunderstanding here. The HF-R is validated in one point (HF-R, in Figure 1), and for the entire year 2014. However, the Figure only shows a period of three months in order to facilitate the understanding of the image (one year long does not allow to clearly observe the good behavior of the model compared with the HF-Radar). In order to clarify this point, some text has been modified in the validation paragraphs and figure captions.

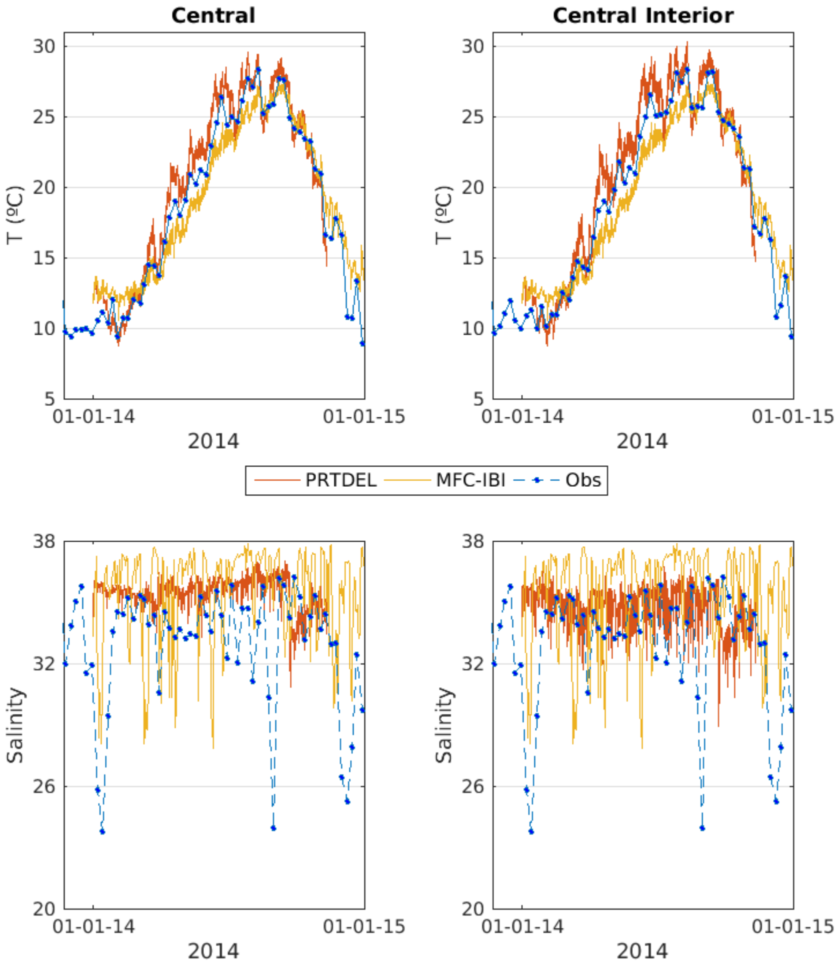
b. Some basic stats would be very useful, e.g. RMSE, for T, S and currents to accompany the results presented in Figure 3, especially that the authors claim a 'remarkable' agreement between the model and observations (p.9, ln. 2), which is a very firm statement and should be confirmed by very high values of stats. Otherwise, I recommend not to claim a remarkable agreement, or define the scale somehow. See Sutherland et al. (2004) for an example of a model skill assessment method: Sutherland, J., Walstra, D.J.R., Chesher, T.J., vanRijn, L.C., Southgate, H.N., 2004. Evaluation of coastal area modelling systems at an estuary mouth. Coastal Engineering 51, 119-142. The
standards of model skill assessment are not very well established and remarkable, vey good, poor, etc., model scores are too frequently used subjectively.

We agree with the reviewer. Some statistics have been added in the Figure 3 and text in order to explain the behavior of the model.

c. From section 2.5 I understand that some good salinity measurements exist across the Alfacs Bay, since it was possible to apply the Officer (1980) box model to it. If so, the authors should present validation of the model against salinity, not only at location T, but also at other available locations. The authors also state that there were weekly CTD casts taken, and location T is only one of them.

The field campaigns used for the calculation of the box model are for different years (2012-2013). For that reason, it was impossible to use it for the validation.

The other weekly CTDs casts taken during 2014 were performed close to the T point (not covering a wide area). For that reason, the authors consider that is enough with validation at T point. In the next figure it is shown the SST and SSS validation for another point inside the bay (note that the behavior is very similar).



d. I understand that there is no tide gauge in Alfacs Bay in order to validation the model against the water level?
Yes. There is no data for sea level.

<u>2. Numerical model:</u> I have three comments here that I would like to see addressed:

a. This comment is related to 1(d) above. From the description of the model set-up, I understand the model is forced with 1-hourly data from the CMEMS-IBI model. What is the amplitude of tides in the region? The high and low water levels can be cut-off when using 1-hourly forcing resulting in not so-good representation of tidal circulation in the bay. This information will be of wide interest to the scientists trying to force coastal models with 1-hourly data in strongly tidal regions.

Yes. The model is forced with 1-hourly data from CMEMS-IBI model. Although not presented in this contribution, we have done different tests trying different OBC (open boundary conditions) in similar configurations for differents Spanish harbours. One of the options was to use only the CMEMS-IBI for the water velocities, salinity and temperature, and use the tidal information from an atlas (amplitude, phase, ellipses) to allow ROMS to compute internally the tides. That method presented some inconsistencies at the contours due to the tidal currents from CMEMS-IBI and the tidal currents computed from the atlas. In the Mediterranean sea harbours no difference where observed.

b. Why is the salinity of incoming freshwater flows set at 18? I know that for stability reasons it is generally advised not to use salinity of 0 in ROMS, but some small value, e.g. 1-2. However, 18 seems excessive. Are the intended freshwater input 1m3/s and 10m3/s (p.5, ln. 12)? If so, prescribing the salinity of 18 implies much lower effective freshwater input. This needs to be clarified.

The freshwater from the rice-fields is mixed in some areas with water from a coastal Lagoon (L'Encanyissada). The water in this lagoon are considered as brackish waters, but no receantly measurements allows the authors to know or even calculate the mean salinity of these waters. For that reason, an arbitrary value of 18 has been used. However, and considering that the main objective of the manuscript is the comparison between simulations with modification of selected variables (flows or connections with open sea), while keeping the rest immutable, the authors consider that the value of 18 is correct for the purpose of this research. However, some text have been added in the discussion according to the referee suggestion.

In discussion, first paragraph:
"Errors in salinity could be related to the poor knowledge of the freshwater flows (total amount, spatial and temporal distribution) and the salinity of these waters (freshwater from rice fields mixed with brackish waters from coastal lagoon)."

c. It will also be of wide interest to the modelling community if the authors provided more details on 'to avoid land contamination of the atmospheric forcing . . ..' (p.5, ln.11).

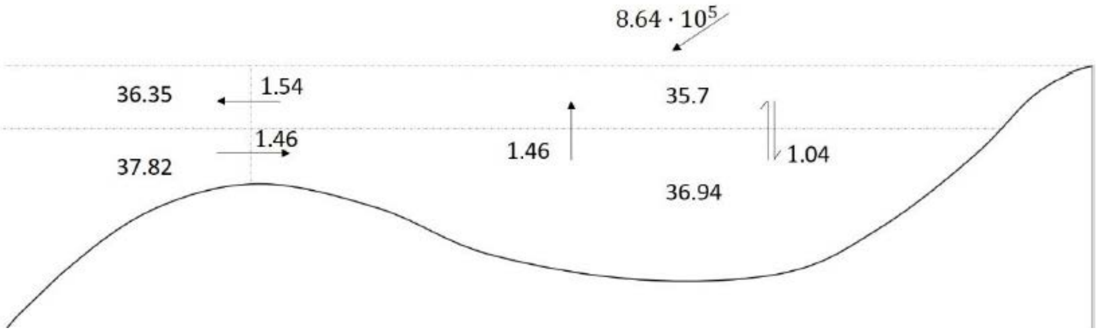
OK, the text has been modified in order to clarify this point.

" To avoid land contamination of the atmospheric forcing on coastal areas (e.g. heat fluxes and winds), a prior land mask is applied to the forcing data, and then variables over the sea are interpolated on the land. "

<u>3. Water residence times:</u>

a. Related to comment 1(c) it would be good if authors included a Table with the values of S, Q and E used in the Officer (1980) box model.

Ok. We have added the information of the salinities in the different layers in the manuscript, whilst the Q from the rice fields was already described (10m3/s). We also have added in the response the figure summarizing the salinities and the corresponding flows from the model.



b. It will also be beneficial if the authors provided more details on the definition of LFT and TFT for quick reference for the readers. I appreciate it is provided by Jouon et al. (2006), but a brief overview will be useful. There is a plethora of the definitions of the flushing, e-folding, residence, renewal, etc., times, and the reader will benefit of a precise definition of LFT and TFT in this paper, even if it entirely follows Jouon et al. (2006). See also my related comment 4(a) below.

This point has been addressed following the suggestion in 4.a (see below)

4. Results:

a. P.7, ln.21 'When the total flushing time (TFT). . . '. I am not convinced that TFT is simply an average of LFTs. We are dealing with exponential functions describing the decrease of tracer concentration in the bay or sub-region of the bay (see Figure 4(a)). If TFT is defined same way as LFT, e.g. as a time needed for tracer concentration to drop to 1/e of C0 then this time should be computed separately for the entire Alfacs Bay by finding the time needed for the average concentration in the entire Bay to drop to 1/e of C0. This will not be the same as averaging LFTs. This is one of the reasons I asked for precise definitions of LFT and TFT in my comment 3(b) above.

We agree. We have re-done the analysis following the suggestion of the referee. And changed the text *("(…) being TFT equal to the period necessary to the average concentration of the entire Bay to go from C_o to C_o*e-1 (...)")* and corresponding values in the table.

5. Discussion:

a. The authors say that there are many ways to compute residence times (p.9, ln.9) and further they claim that the most complete method is to compute LFT and TFT using a passive tracer simulations in a numerical model. Given that LFT and TFT are defined as e-flushing times (time needed for the concentration to drop to 1/e of C0) and we have a luxury of having a numerical model of the bay, there are actually more accurate methods. The e-flushing time approach as a representation of residence time is valid under the assumption of complete mixing in the bay at all times, i.e. tracer is evenly distributed in the bay at all times, which is simply not the case in a real situation, and in the Alfacs Bay. The residence time being equal to e-flushing time in the case of a fully mixed waterbody can be derived analytically. Having the numerical model in place and the predicted tracer decay in it, there is actually a more accurate method to calculate flushing (residence) time. This is the approach proposed by Takeoka (1984), whom authors actually quote. Residence time is an integral of a remnant function (from zero to infinity). The remnant function can be approximated by an exponential function proposed by Murakami (1991), r(t) = exp(-A*t)ˆB, which can be easily integrated to obtain residence time (Murakami, K., 1991. Tidal exchange mechanism in enclosed regions. In: Proceedings of the 2nd International Conference on Hydraulic Modelling of Coast Estuary and River Waters, vol. 2, 111-120.). This is certainly more complete than simply using the 1/e condition. It is still fine for the authors to use the e-flushing time, but precise definitions are needed and it is certainly not the most complete method and it should be discussed in the paper. E-flushing time is e-flushing time and it is not the same as residence time or water renovation time unless we are dealing with a fully mixed waterbody, as explained above. Several examples of the application of Takeoka and Murakami methods exist for the Irish Sea, e.g. Dabrowski et al. (2012). Determination of flushing characteristics of the Irish Sea: a spatial approach. Computers and Geosciences, 45: 250-260.

Ok, we agree with the reviewer. In order to clarify this point we have modified some text reflecting the concept that other methods are also adequate for environments like this, and the fully mixed water body constraints the e-flushing time related to residence times. However, we still believe that the e-flushing time, as it has been used here is a good proxy for the idea (or concept) of residence times. The referee affirms that the e-flushing times is only valid as a residence times when dealing with a fully mixed waterbody. For that reason, our analysis focuses on the surface layers, which is well mixed above the pycnocline at 3-4m. We have added some lines in both methods and discussion about this topic. The reference of Dabroswki et al. 2012 has been added.

6. Conclusions:

a. Conclusions can be expanded to include recommendations for the future research and developments in the area of research covered by the paper

Ok, we agree. In this sense, we have added the following text:

"Future works should include the analysis of the wave effects on water the circulation, as well as the consideration of different initial conditions and met-ocean conditions on the determination of water renewal in Alfacs Bay."

b. I am in doubt as to the following conclusion drawn in the paper, namely 'only the modification of freshwater flows is recommended due its lower impact on the environment. . .'. How about the impact of freshening of the bay? Surely it will exert some, possibly significant, stress on marine biota. Also, high temperature is identified as one of the stressors, and yet, as stated by the authors, the freshwater from rice fields is of high temperature and so it will make matters even worse? How about nutrient enrichment? Is the freshwater from rice fields not rich in nutrients? I think it deserves a more thorough discussion and more thoughts should be given to the conclusions drawn. Some discussion of a relationship between residence time and water quality is presented, for example, in Nash et al. 2011. Modelling phytoplankton dynamics in a complex estuarine system. Water Management, 164(1): 35-54.

Ok, we agree. For that reason we have added some new text.

However, the effects of increasing the freshwater sources could lead to some disturbances over the bay: e.g. stress over the marine biota and nutrient enrichment (increasing the risk of HABS under some conditions). For that reason, future works should consider the application of biogeochemical models (e.g Nash et al. 2011) in the bay characterizing the ecological behavior of the bay and performing numerical simulations in order to understand the effects of such modifications.

Technical comments: Overall the paper is well structured, easy to follow and English is good. Figures and Tables are nicely presented also.

p.1, ln.1: change "Delta Ebro" to "Ebro Delta"
Ok. Thanks. Done

p.1, ln. 15: leading "to" high rates
Ok. Done.

p.1, ln.19: change "consists in" to "consists of"
Ok. Done.

p.1, ln.26 change "low renovation" to "poor water renewal"
Ok. Thanks. Done

p.2, ln.1: change "-" to ","
Ok. Thanks. Done

p.2, ln.1: insert "and are" after "aquaculture"
OK.

p.2, ln.2: change "-" to "," and add "e.g." after the comma
We have added e.g. But we prefer to keep the '-'

p.2, ln.2: change "communication" to "exchange"
Ok

p.2, ln.16: "Ebro delta" should read "Ebro Delta" here and throughout the manuscript
Yes. done

p.2, ln.29: “Alfacs bay” should read “Alfacs Bay” here and throughout the manuscript
Ok. Done

p.2, ln.30: change “sense” to “context”
Ok. Done.

p.3, ln.13: change “on the east” to “in the east”
OK

p.4, ln.25: comma missing before “respectively” here and throughout the manuscript
Ok. done

p.4, ln.26: change “transference” to “transfer”
OK.

p.6, ln.6 expand IRTA (despite it being explained in the affiliation)
OK. Done

The remainder of the manuscript seems to be mostly free from the small errors like above, except: p.10, ln.18: insert comma after “regions”
OK. Done.

p.10, ln.30: change “increase” to “improving”.
We believe increase is more adequate here.