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High resolution modelling of the Bay of Algeciras (Strait of Gibraltar) with application to biogeochemical processes

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INTRODUCTION

The Western Alborán Sea is an eutrophic sub-basin within the Mediterranean Sea, typically oligotrophic. It is especially eutrophic in the north-western coast, where we found the Algeciras Bay, a semi-enclosed inlet of about 9x11 km, opened in its south margin. As part of the Strait of Gibraltar system, it has a high energetic dynamics and presents flushing times of a few days.

The analysis of Chl images from satellite in the area Strait of Gibraltar-Western Alborán Sea, reveals that primary productivity of the Alborán Sea follows an annual cycle with maximum chlorophyll concentrations in winter and minimum in summer, which has been already addressed by several authors. On the contrary, surface Chl in the Algeciras Bay shows several blooms both, in spring and autumn. Despite this apparent disjunction between the two close systems, most of the time the Bay and the north-western Alboran Sea belong to the same upwelling system, but satellite images reveals that occasionally the Bay behaves as a source of primary productivity for the north-western Alborán Sea.

This work presents the preliminary results of the coupling of a biogeochemical (NPZD) and a hydrodynamic model, both broadly validated with several sources of observations (MODIS-aqua satellite and moorings). Main results show that the Bay of Algeciras has great primary productivity, and despite being linked to the upwelling system of the north-western Alborán Sea, occasionally behaves as a separate system, with high blooms occurring within the Bay, but low chlorophyll in the nearby basin. When the latter occurs, it results in the export of primary productivity from the Bay to the Alborán Sea.

METHODOLOGY

Geographical location:

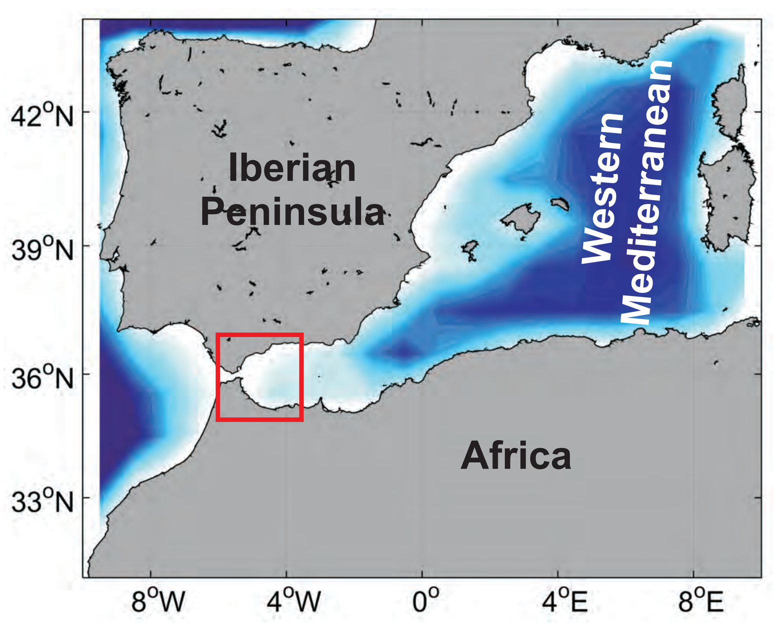


Fig. 1. Location of the area of interest, in the Westernmost part of the Alboran Sea. Red rectangle mark out this area, which include the Strait of Gibraltar and part of the Alboran Sea (enlarged in Figure 2).

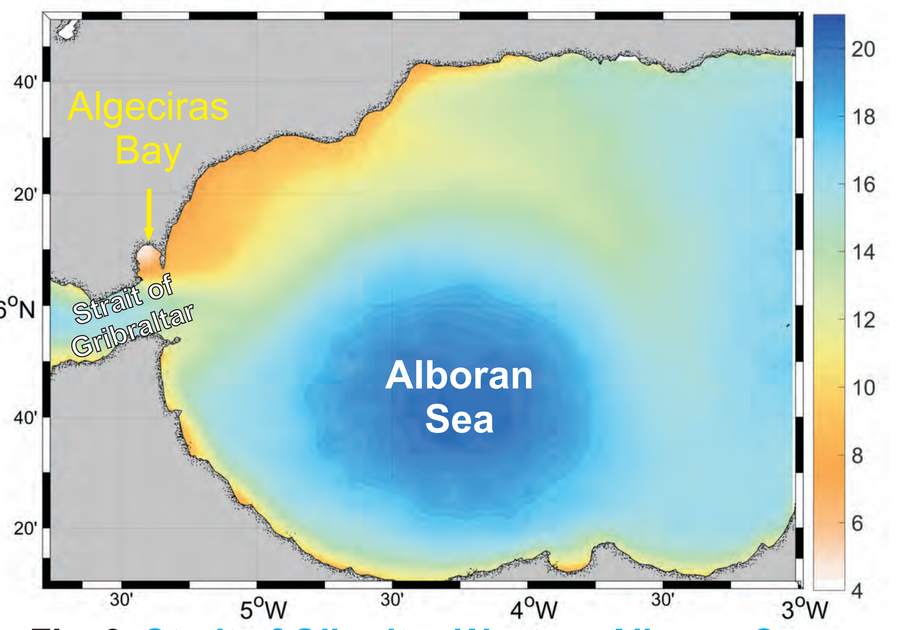


Fig. 2. Strait of Gibraltar-Western Alboran Sea basin. Algeciras Bay is located in the North-Western area, it is marked in the map with a black arrow. Colors indicate the ZSD depth estimated by satellite.

Physical Model:

A regional circulation model of the Strait of Gibraltar and Alborán Sea has been used on the basis of the MITgcm source code (Marshall et al., 1997). The model domain covers the Gulf of Cádiz and Alborán Sea, and was discretized with an orthogonal curvilinear grid of variable horizontal resolution. Maximum **resolution is set within the Bay of Algeciras (~400m)**. In the vertical the model has 46 levels with maximum resolution at the surface level (2.5m).

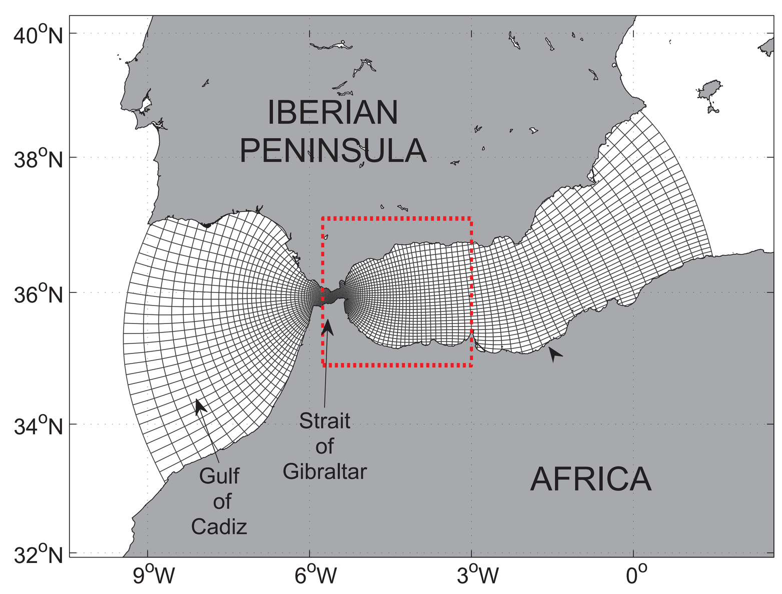


Fig. 3. Detail of the model domain and the grid design (in this figure the grid has been represented one in every two grid-points)

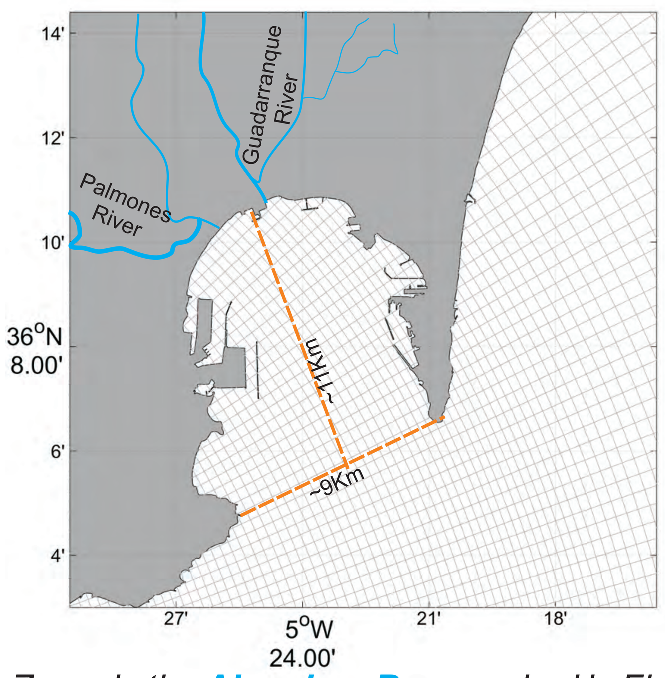


Fig. 4. Zoom in the Algeciras Bay, marked in Fig. 2 with an arrow. Two main rivers flow into the Bay, the Palmones and Guadarranque rivers, indicated with blue lines.

BiogeochemicalModel:

The ecosystem model of Follows et al (2007), has been coupled to the circulation model. We use a simplified configuration consisting of **two phytoplankton** functional types, one representing small phytoplankton better adapted to oligotrophic waters (representing for example Synechococcus or prochlorococcus) , and one larger phytoplankton better adapted to nutrient rich water within intermittent upwelling areas (for example dinoflagellates species). Zooplankton is also modeled following the same scheme, **two zooplanktons** types representing the large and the small types that graze respectively on the large and small phytoplankton.

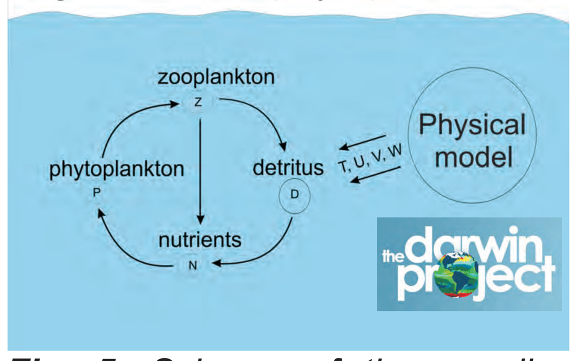


Fig. 5. Scheme of the coupling between Physical and Biogeochemical model.

Nutrients, phytoplankton, zooplankton and detritus are determined solving a system of partial differential equations

$$\frac{\partial B}{\partial t} = -\mathbf{u}\cdot\nabla B + \nabla\cdot(\mathbf{k}\nabla B) - \frac{\partial (w^B B)}{\partial z} + R$$

Initialization was set followin Losch et al.(2014). MEDAR/MEDATLAS database was used to set the initial conditions of the biogeochemical tracers (Maillard, 2002).

The simulation period covers one complete year from March 2010 to March 2011.

Model outputs:

The model uses phosphorus for phytoplankton growth and biomass. Model gives phytoplankton as mmolP/m3, but for consistency with the rest of biobliography we express it in mgChl/m3. To do this conversion we use the Redfield ratio C:N:P=106:16:1 and, then we apply the ratio Chl:C=1:50 to calculate the content of Chlorophyll in each carbon molecule of phytoplankton (Echevarrıa et al., 2009). Nevertheless this ratio could vary among species (Geider et al., 1997), thus dissimilarities between satellite observations and modeled phytoplankton are expected.

Comparison between Satellite and Modeled surface Chlorophyll:

Surface mean modeled Chl is compared with satellite stimations of Chl. We use a multy platform avalaible through Copernicus website (*marine.copernicus.eu*) and produced by GOS Group from CNR-Roma (Volpe et al., 2012).

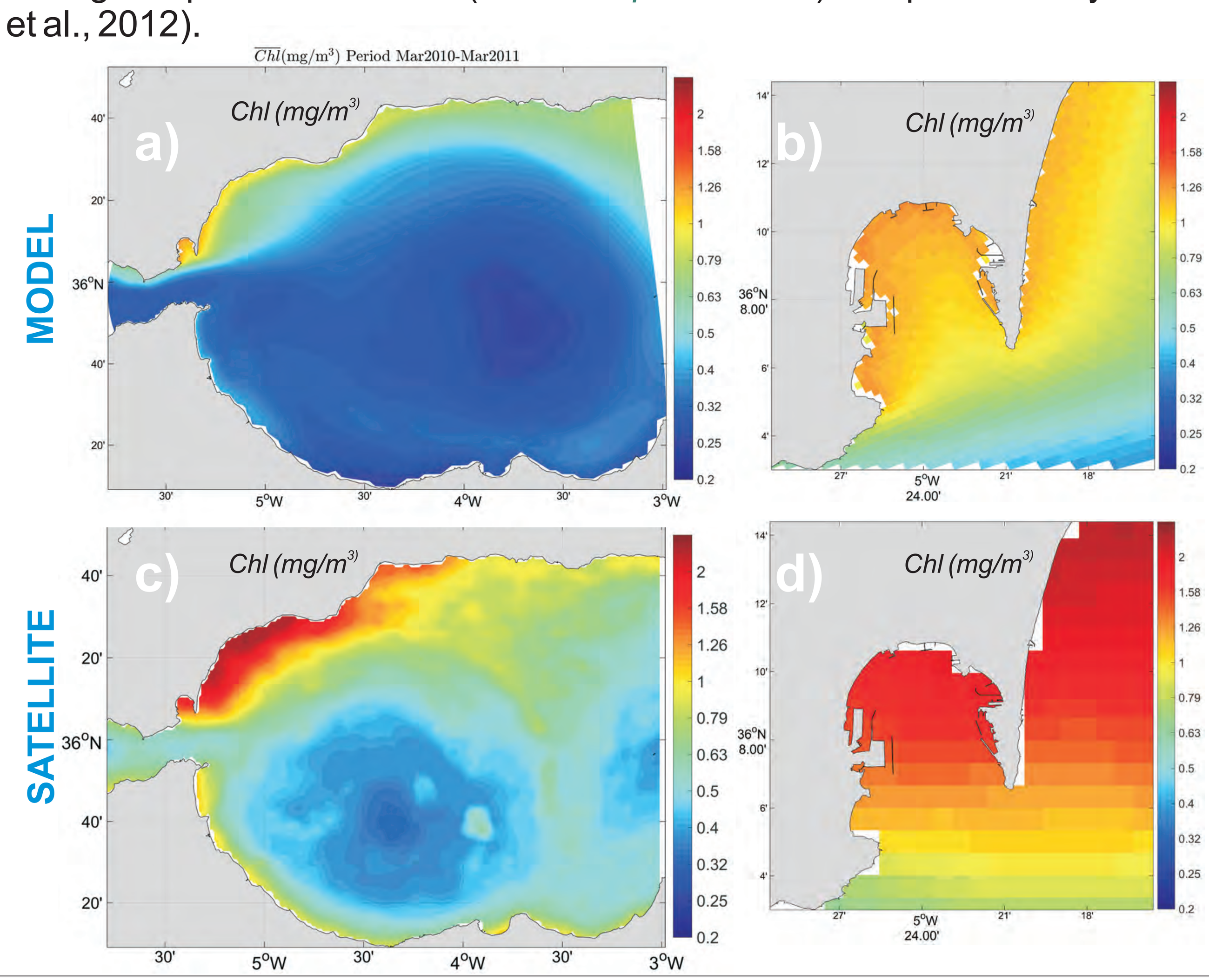
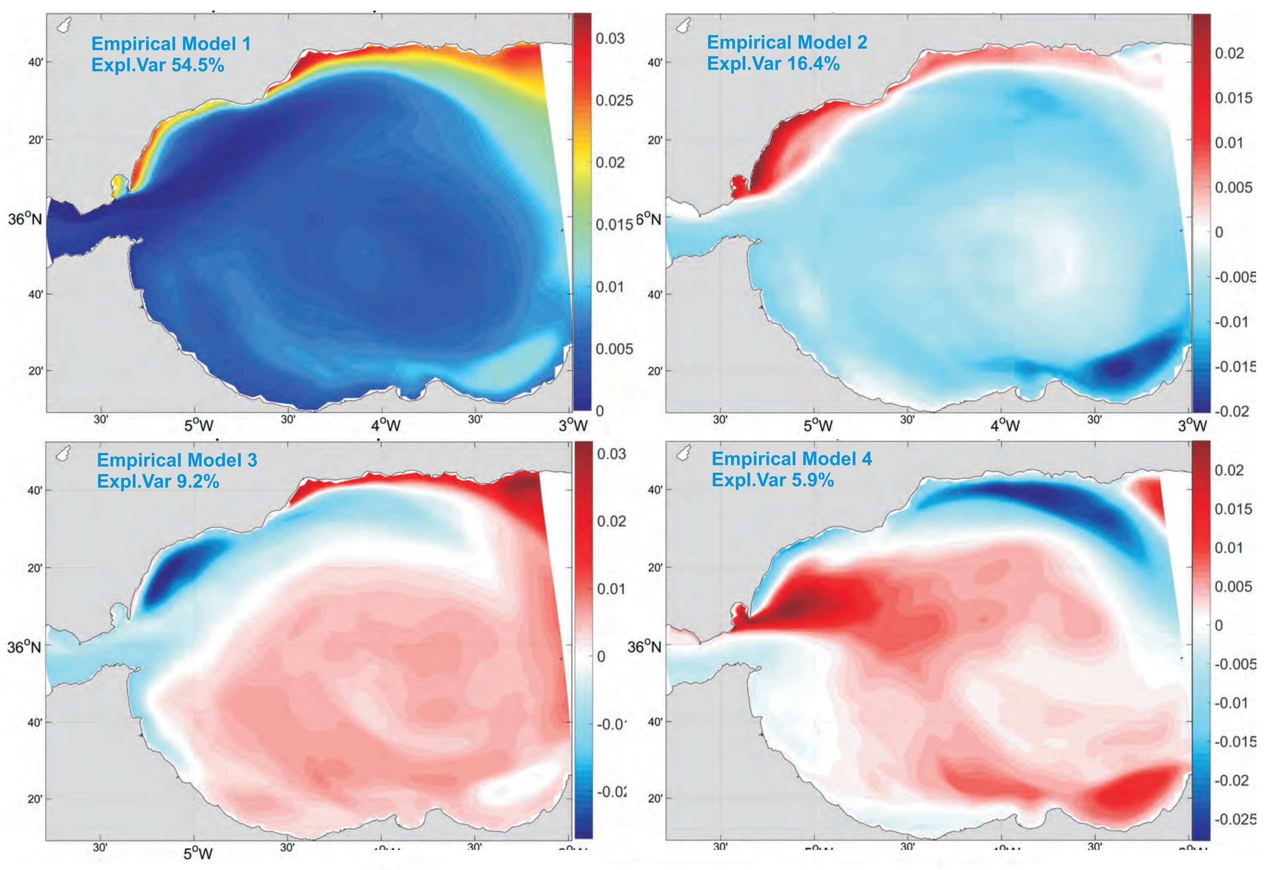


Fig. 6. Average surface Chl in the Alboran Sea computed for the period March 2010-March 2011. Right panels show a detailed view of the Algeciras Bay area (Fig.1 for location). Panels a) and b) correspond with the modeled surface Chl in the Alboran Sea and Algeciras Bay, while panels c) and d) shows the Chl estimated from satellite (Copernicus database).Colorbar indicates Chl in mgChl/m³ Satellite shows greater values of Chl, especially in the north coast, than the model. A feasible reason could be the different depth of integration. Satellite see about the Secchi Disc Depth while in the model we represent only the 2.5 first meters.

MAIN RESULTS

EOF Analysis:

Fig. 7. Spatial four first modes of the EOF applied to the modeled surface total Chl ($Chl_{small\ phyto}$+$Chl_{large\ phyto}$). First mode indicates the main situation with high Chl in almost all the Alboran Sea and specially in the edge of the anticyclonic gyre while the second mode represent an upwelling situation that highlight the high Chl of the north-western coast against the oligotrophic center of the gyre. Third and four modes represent less frequent situations, but more interesting as both of them imply high productivity in the Algeciras Bay. We will focus here in these two modes.



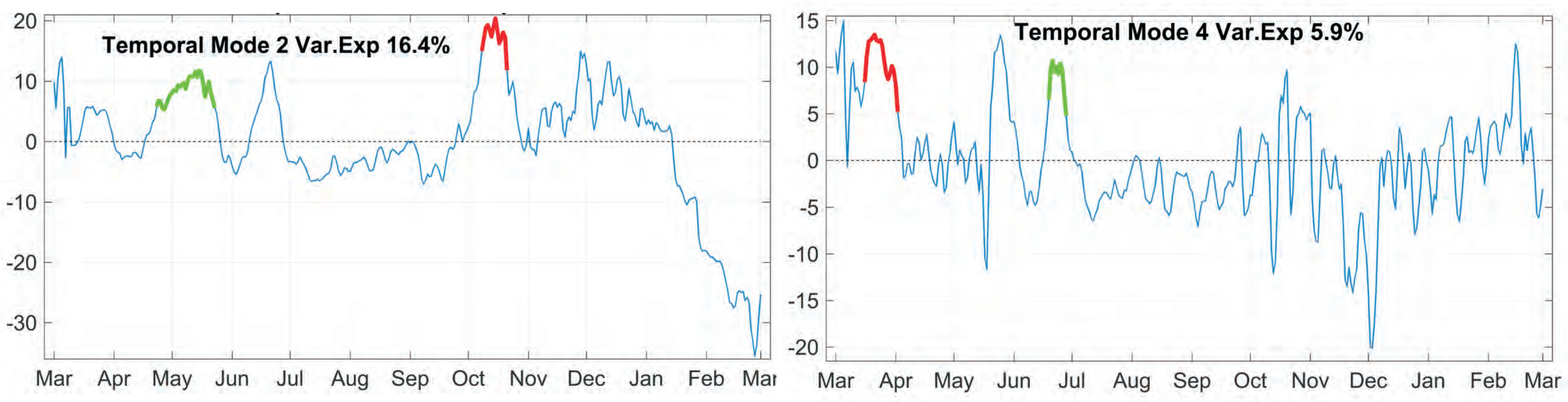


Fig. 8. Second and forth temporal mode, which show high Chl values inside the Bay of Algeciras (Fig.7). Red and green highlighted periods indicate two periods of positive temporal mode, which will be used to evaluate the circulation and wind conditions that favors a high productivity in the Bay of Algeciras.

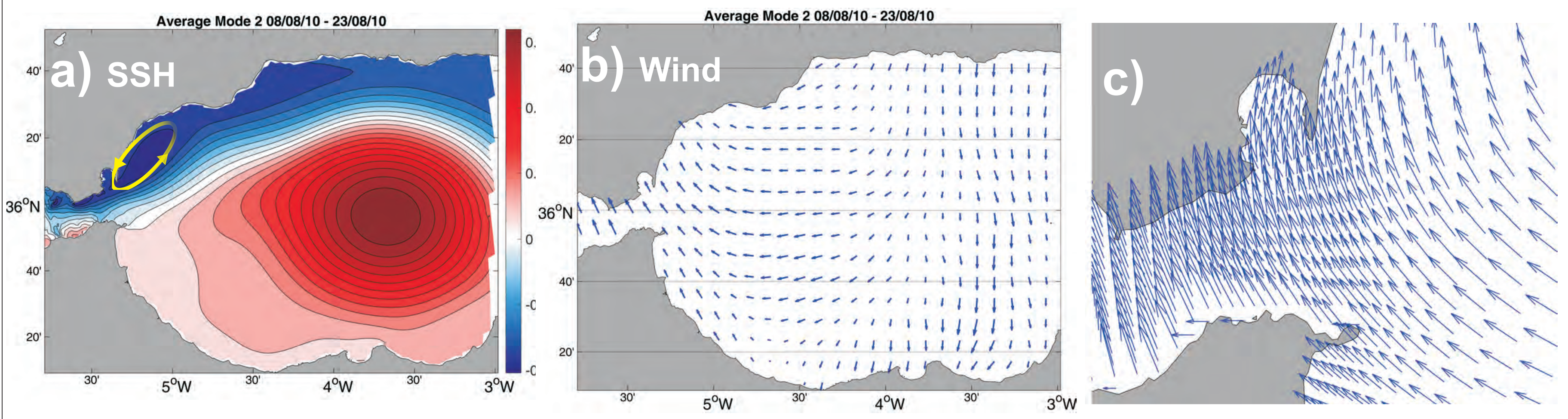


Fig. 9. a) shows the mean SSH (cm) corresponding with the positive period of Mode 2 (red line in Fig. 8a), b) is the same for the wind velocity, and c) highlight de wind in the Algeciras Bay-Strait of Gibraltar area.

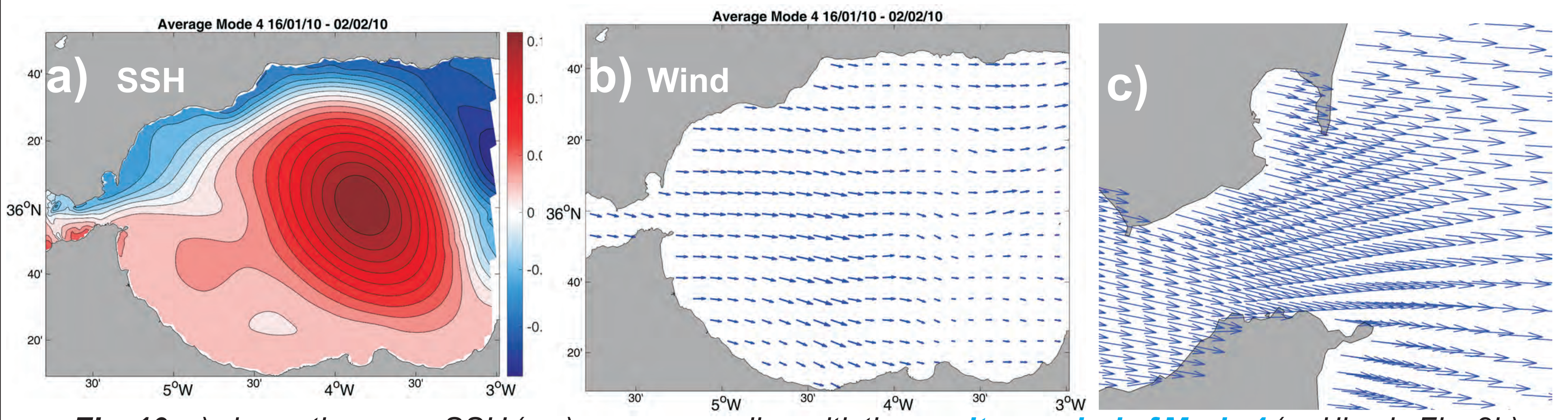


Fig. 10. a) shows the mean SSH (cm) coorresponding with the positive period of Mode 4 (red line in Fig. 8b), b) is the same for the wind velocity, and c) highlight de wind in the Algeciras Bay-Strait area.

CONCLUSIONS

- Figure 6 shows how the model captures the distribution of Chl in the Alboran Sea and Algeciras Bay, with higher values in the north coast and Algeciras bay, and minimum Chl concentration in the center of the gyre. Nonetheless, and despite that the mean Chl in the model is the same order of magnitude than in the satellite image, satellite shows greater values in the north coast.

- **Mode 2** are related with the SSH, this mode shows high Chl in the Bay of Algeciras when a **westward coastal countercurrent** flows in the North-Western Alboran Sea, which will result in the **input of Chl** in the Bay.

- **Mode 4** are not related with the SSH but with the wind circulation, this mode explains the **westerly** events (with north component), which help the **export of Chl from the Algeciras Bay** to the Alboran Sea.

NEXT STEPS

- Improve the Chl calculation from the mmolP output of the model to mgChl using two different C:Chl ratio for the small and large phytoplankton.

- Calculation of the flow of Chl from the Algeciras Bay to the Alboran Sea.

- Evaluation of the Primary Productivity, which will clarify if the high Chl of the Bay during the events marked in Fig.8 are produced inside the Bay itself or it comes from other source.

- Incorporate the river runoff to the biogeochemical model and study thieir effect in the Bay.

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