WATER RENEWAL MECHANISMS OF THE BAY OF ALGECIRAS IN THE STRAIT OF GIBRALTAR

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1. Motivation & Goal

The **Bay of Algeciras** (BA) is at the northeastern end of the Strait Of Gibraltar (SoG; Fig. 1) and therefore within one of the **busiest marine routes on Earth** (> 100.000 ships/year). It is an attractive spot for refueling (Fig. 2) and its shoreline is home of numerous industrial plants. All these factors, together with the **severe windstorms** that frequently occur in the area, make of the BA a **disaster waiting to happen**, as claimed in the header of the newspaper article of Fig. 2. Despite of the environmental issue our knowledge of the physical setting is very poor, and **basic questions regarding the circulation of the BA**, its variability, and how and at what rate it exchanges water with the adjacent SoG has remained unexplored. The objective of this work is exactly to do so.

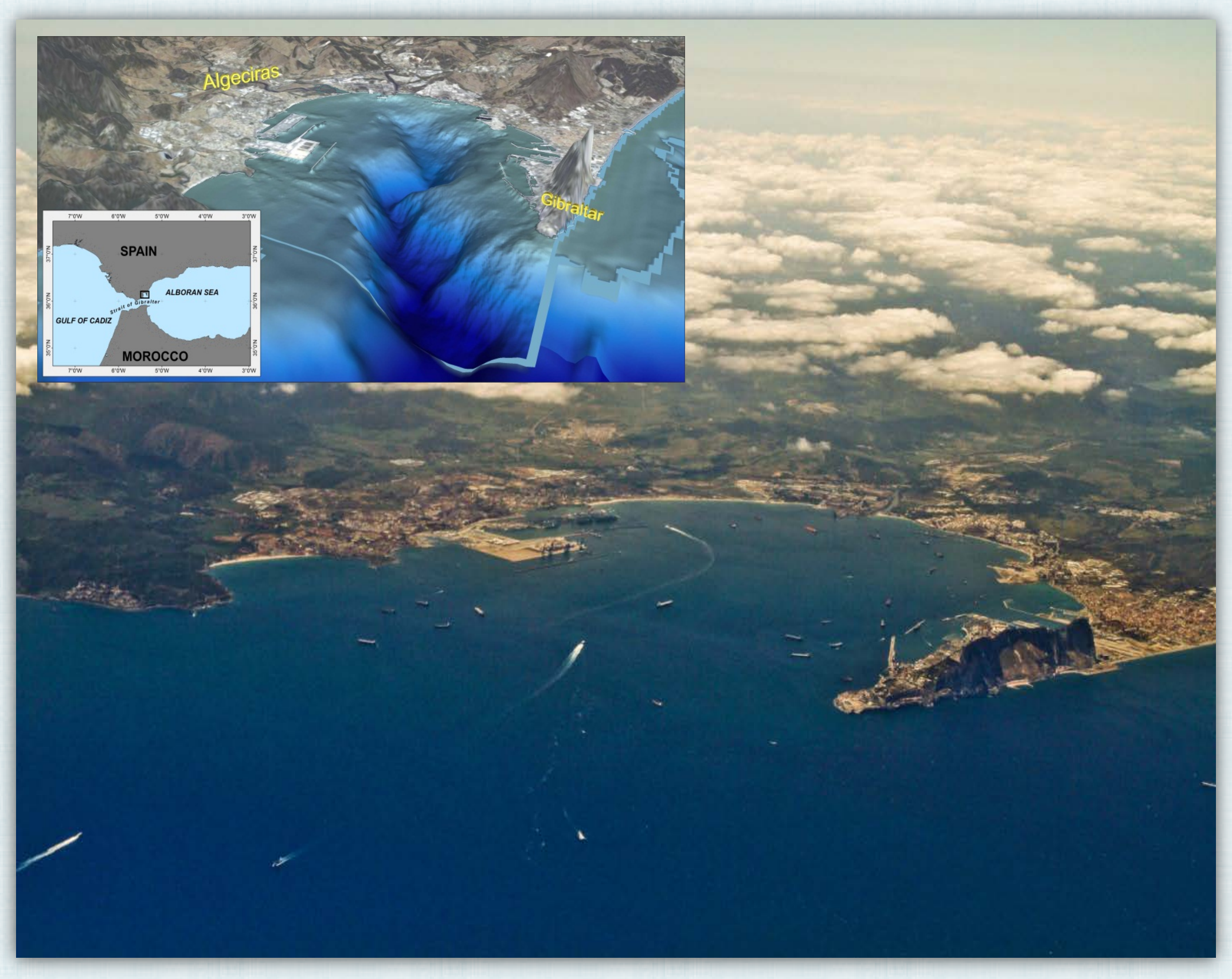
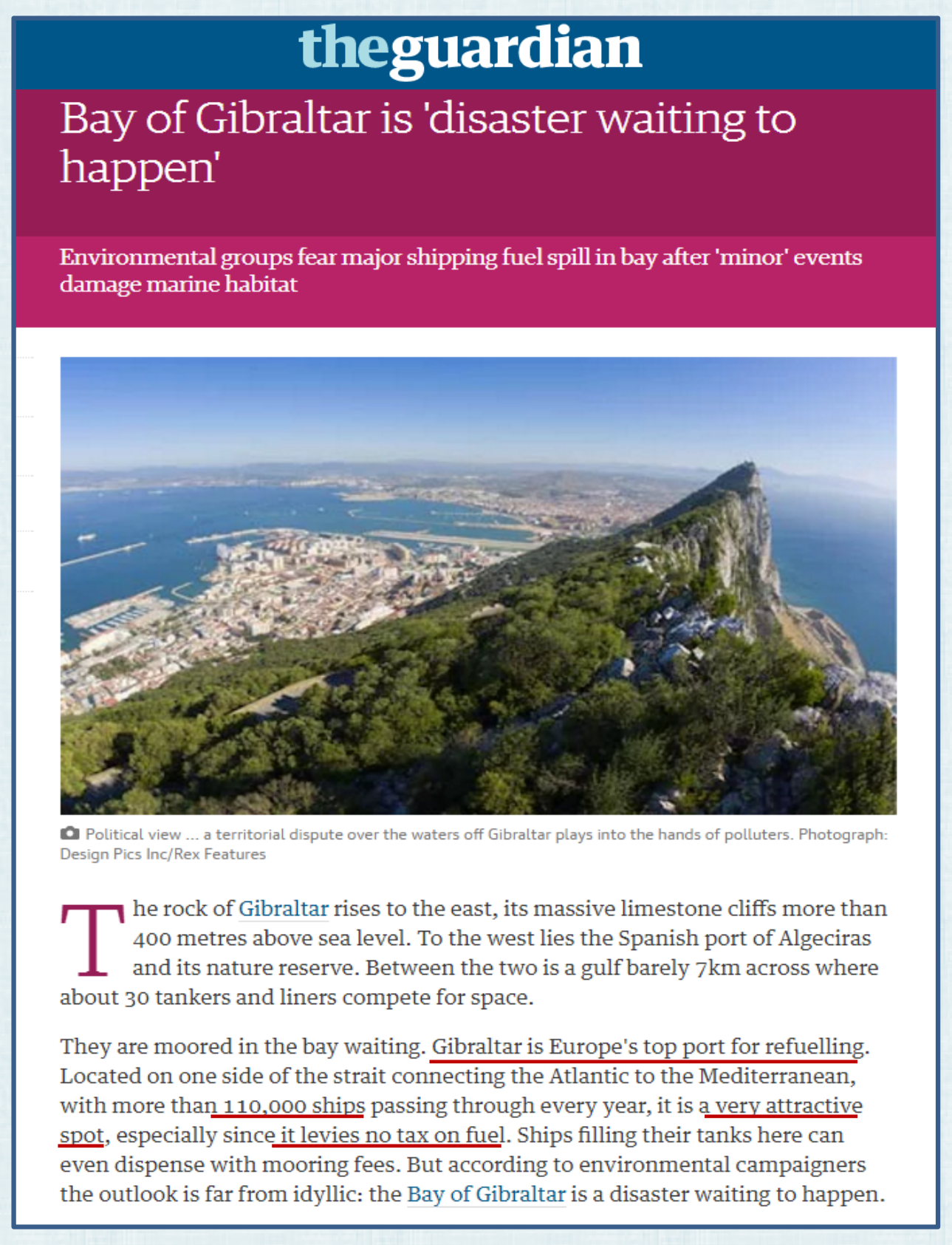


Fig.1 Aerial photography of the BA with its bathymetry and location in the inset.



theguardian

Bay of Gibraltar is 'disaster waiting to happen'

Environmental groups fear major shipping fuel spill in bay after 'minor' events damage marine habitat

Political view ... a territorial dispute over the waters off Gibraltar plays into the hands of polluters. Photograph: Design Pics Inc/Rex Features

The rock of Gibraltar rises to the east, its massive limestone cliffs more than 400 metres above sea level. To the west lies the Spanish port of Algeciras and its nature reserve. Between the two is a gulf barely 7km across where about 30 tankers and liners compete for space.

They are moored in the bay waiting. Gibraltar is Europe's top port for refuelling. Located on one side of the strait connecting the Atlantic to the Mediterranean, with more than 110,000 ships passing through every year, it is a very attractive spot, especially since it levies no tax on fuel. Ships filling their tanks here can even dispense with mooring fees. But according to environmental campaigners the outlook is far from idyllic: the Bay of Gibraltar is a disaster waiting to happen.

Fig.2 First page of a newspaper article (the guardian), highlighting environmental concerns in the BA.

2. Methods

Numerical modeling was employed in order to simulate the circulation of the BA. A hindcast simulation corresponding to spring 2011 was carried out with the **MITgcm** [1] using the configuration and set-up described by [2]. The grid of the model in question features enhanced resolution in the SoG and in the BA in particular (Fig. 3), where horizontal cell sizes are 400m approx. In the vertical the models has 46 z-levels. Numerical results were satisfactorily compared with a set of *in situ* observations collected in the Bay (Fig. 4a,b). The variability of the time series are dominated by the tides (Fig. 4b), whose dynamics was already analyzed by [3]. Here we **focus on the subinertial variability** of the circulation. As such, prior to the analysis, a low-pass filter was applied to the model outputs in order to remove tidal fluctuations. An example of a tidal-free time series is shown in Fig. 4c.

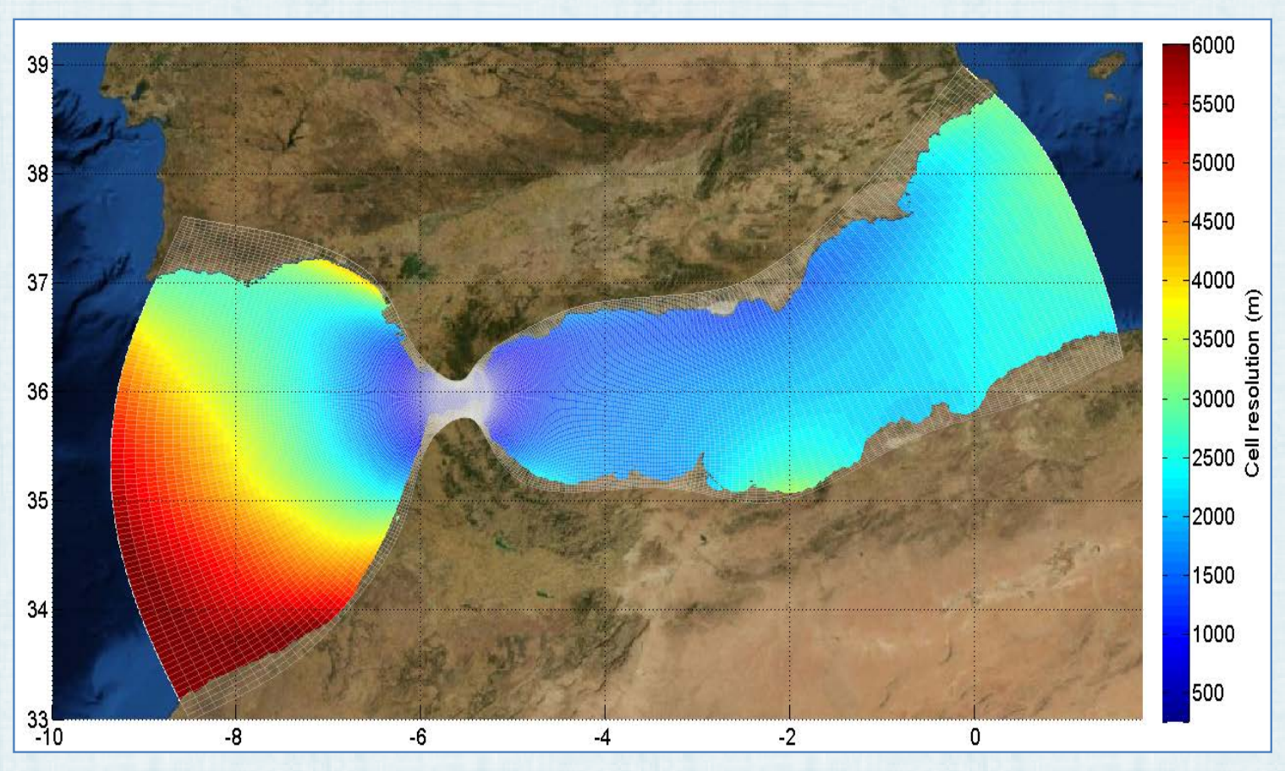


Fig.3 Model domain and resolution.

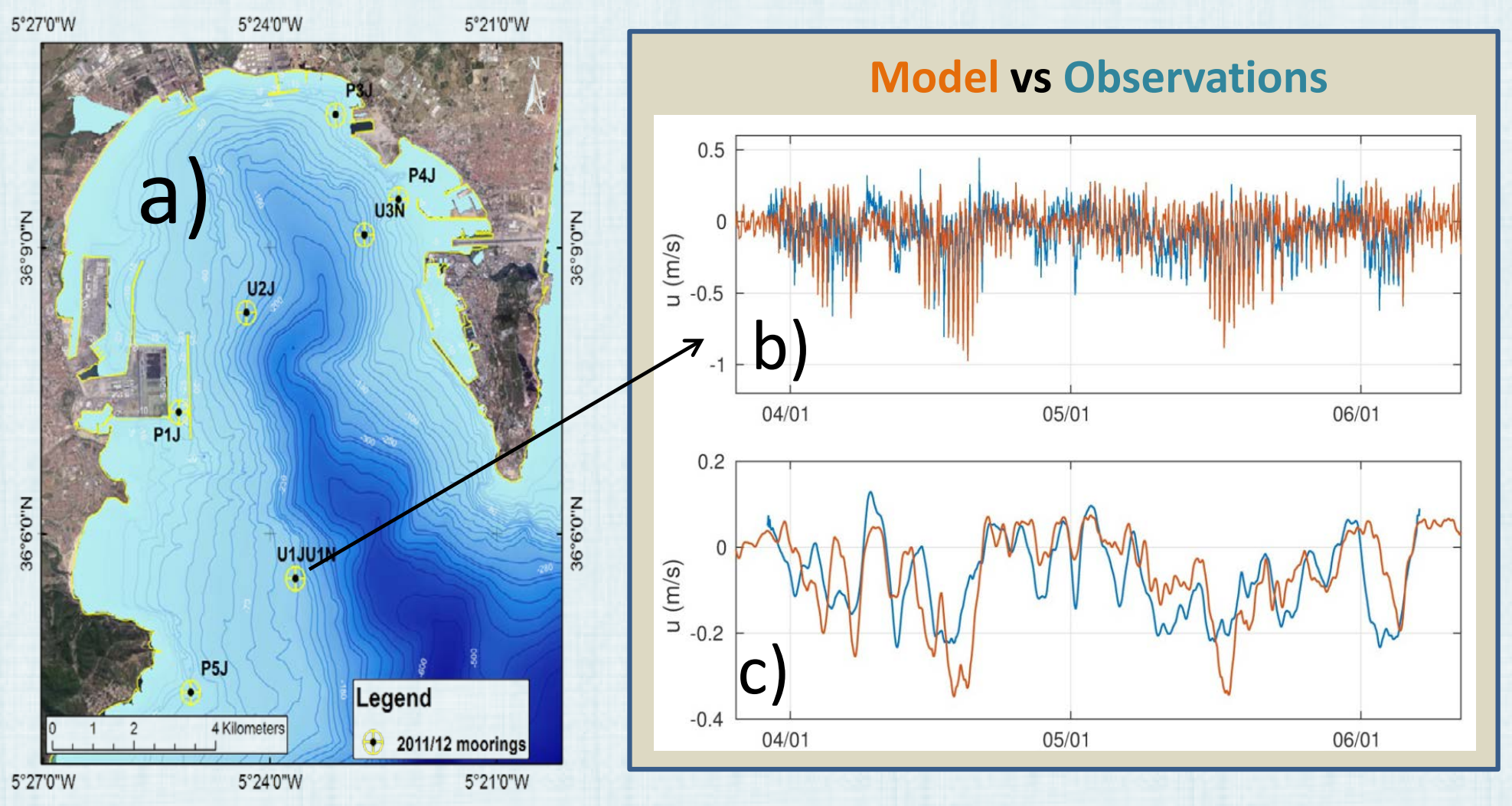


Fig.4 a) Locations were mooring lines were deployed; all equipped with ADCP and CT sensors. b) Model versus ADCP near-surface velocities. c) filtered (tidal free) series.

3. Results

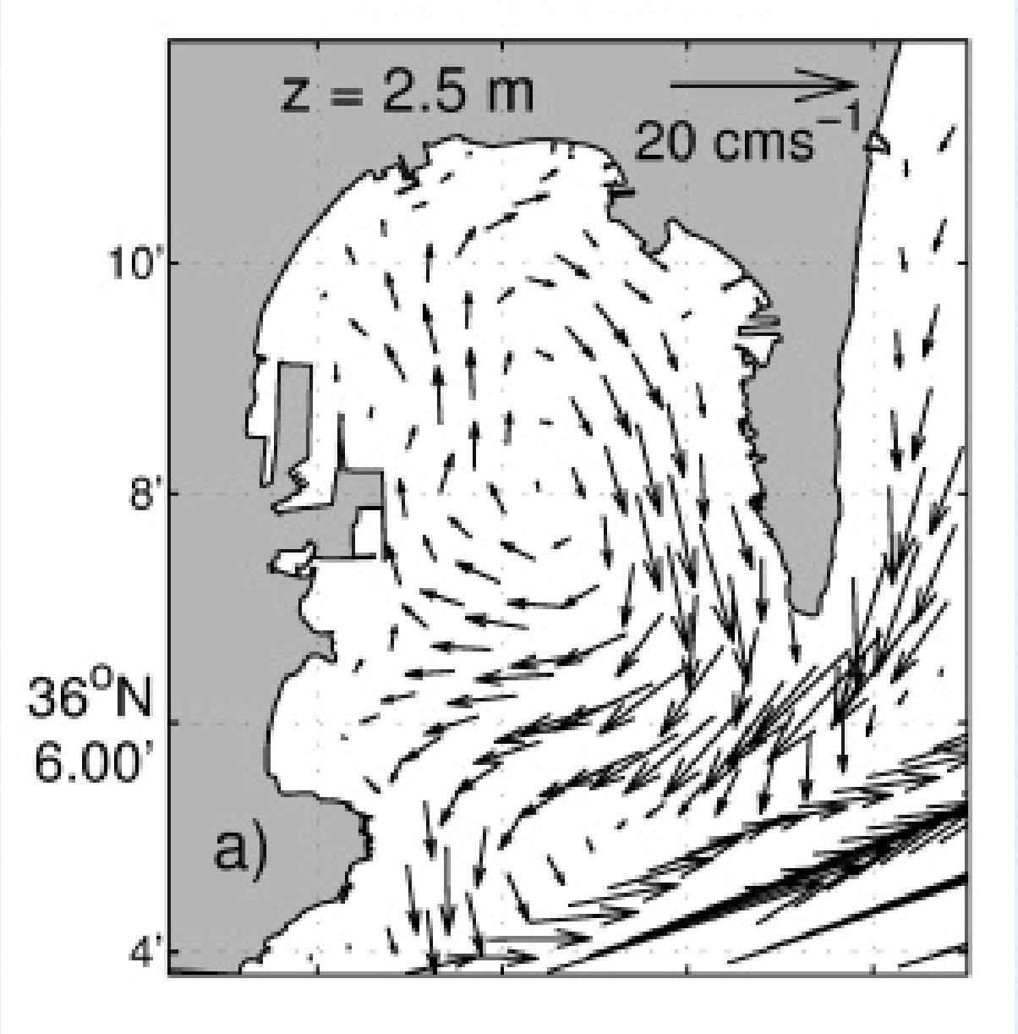


Fig.5 Mean surface circulation derived from the model, consisting of a single anticyclonic cell.

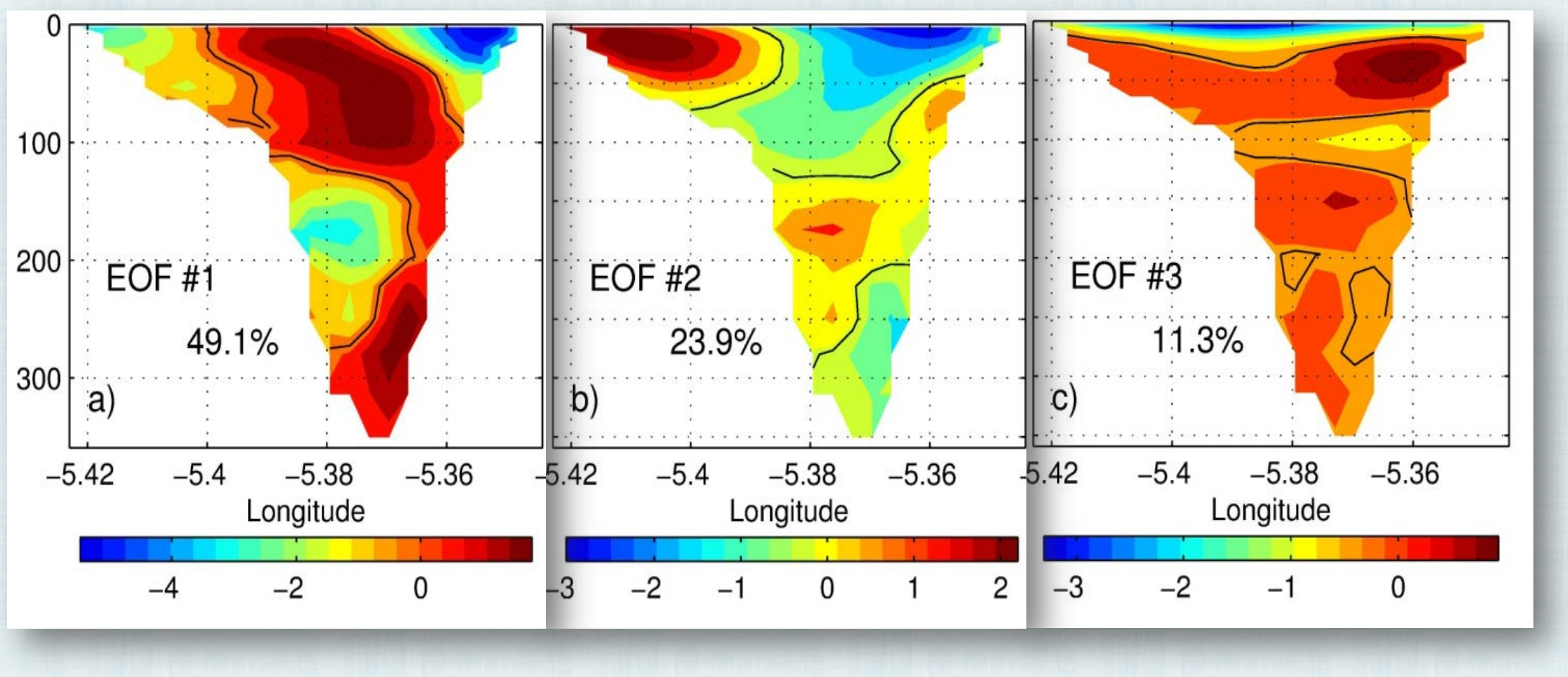


Fig.6 In order to obtain spatial patterns of variability, the PCA technique was applied to the velocity component across the Bay mouth. EOF #1 (a) essentially corresponds to the mean field (note the matching with Fig. 5) as the original data was not detrended prior to the analysis. EOF #2 (b) is a mode of variability with a marked horizontal renewal pattern of Atlantic Water (AW; 0<z<100), while EOF #3 (c) exhibits a vertical circulation cell within those depths.

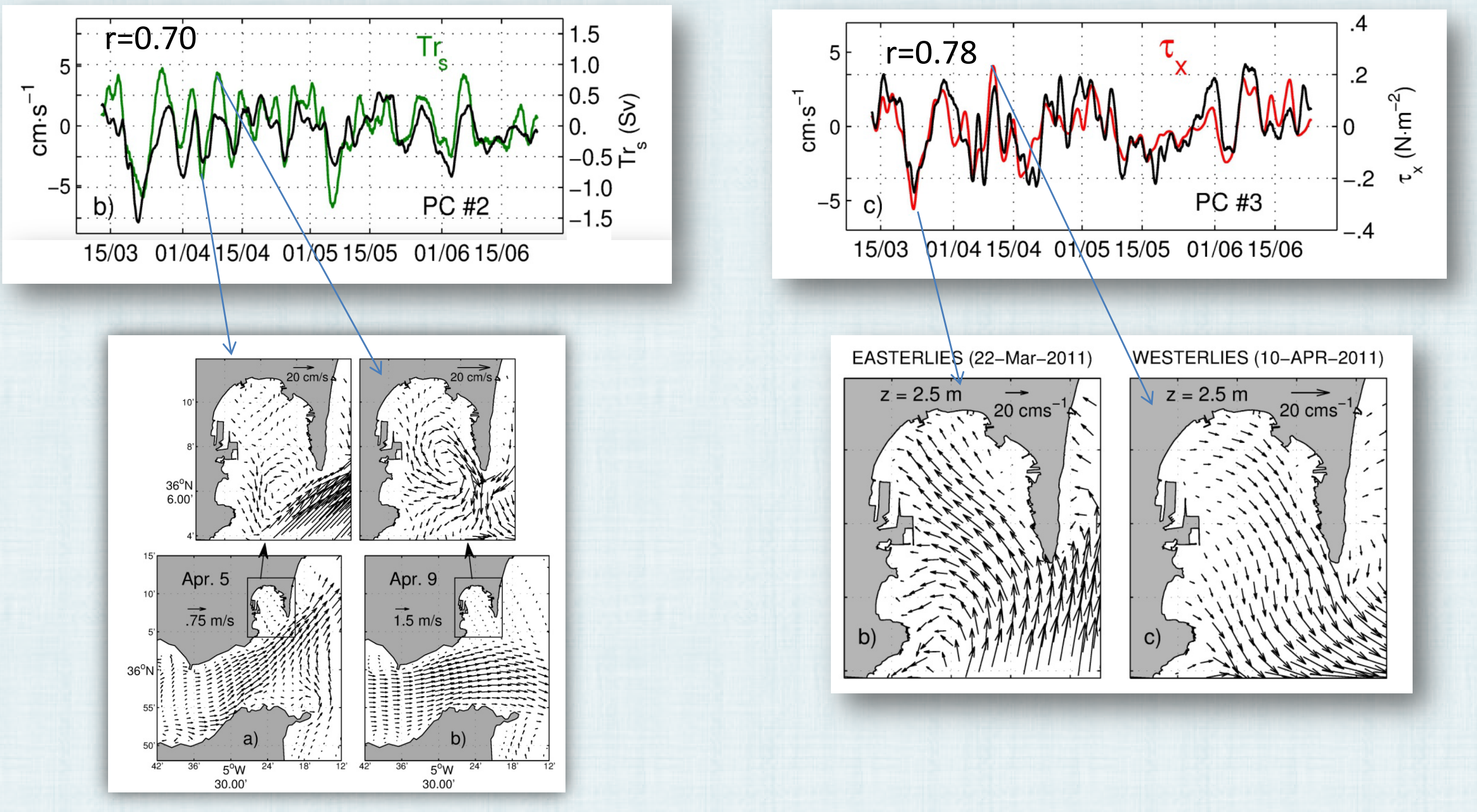


Fig.7 Cause-effect relationships were established by correlating the PCs with the model forcing. EOF #2 is driven by meridional displacements of the jet of AW entering through the SoG (bottom-left panel); which in turn are due to fluctuations of the incoming volume transport (Tr_s; top-left) via internal hydraulics [4]. PC #3 is highly correlated with the zonal wind stress (top-right), from which the 3rd mode of variability is associated with the dynamics of the surface Ekman layer.

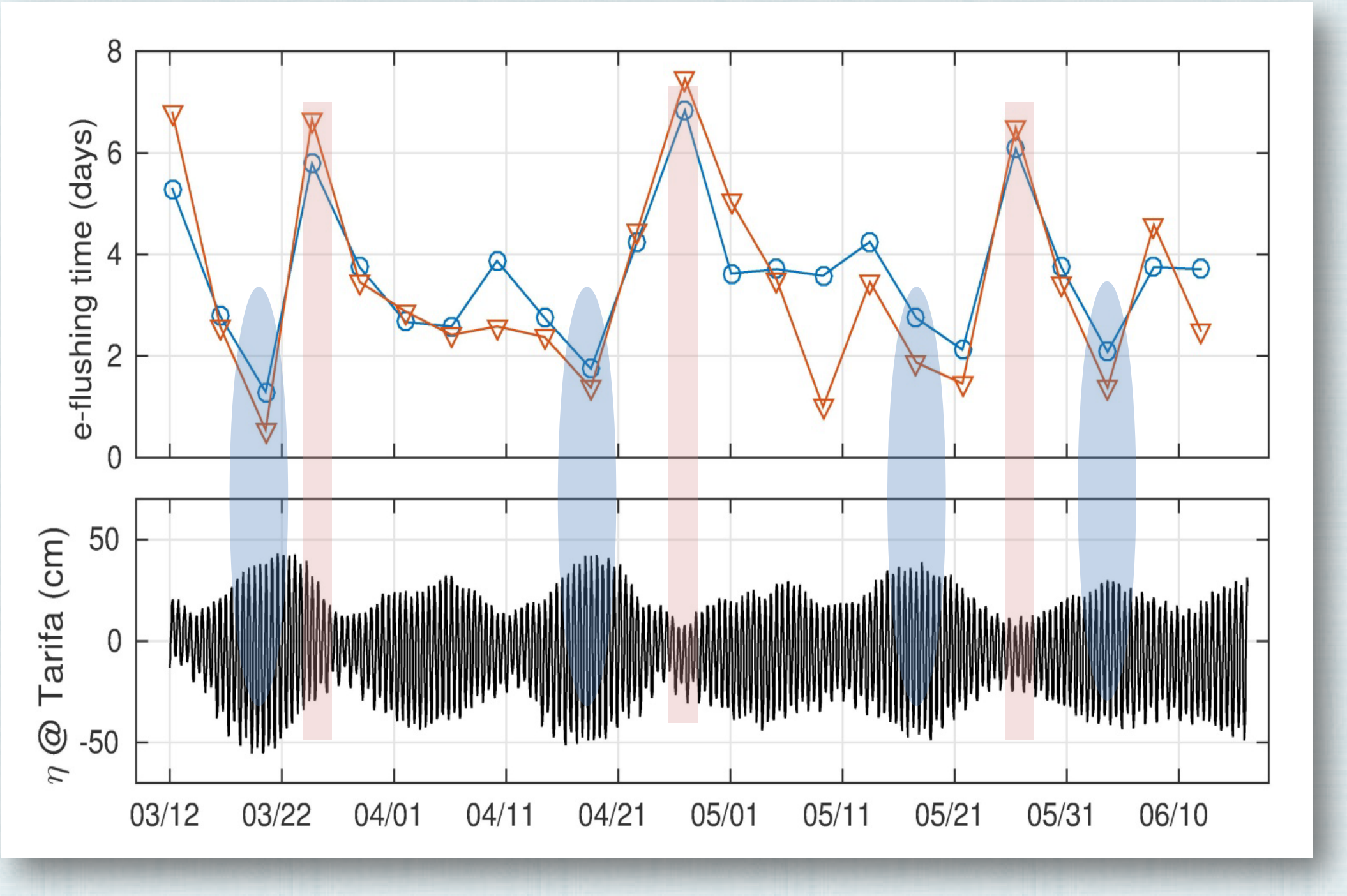


Fig.8 A series of additional model runs tracking the evolution of passive tracers (dye) released in the BA were carried out in order to determine the mechanisms involved in the water renewal of the Bay, and this way discern the most favorable scenario for its rapid flushing. Dye was released within the Atlantic layer (S<37.5) every 10 days and, for each release, the e-flushing time was computed by the exponential fitting the dye content curve within both, the Atlantic layer (blue line) and the very surface layer (0<z<5m; red line). Minimum (maximum) e-flashing times are obtained during Spring (Neap) Tides; suggesting that the ventilation of the Bay is largely determined by astronomical forcing. More details can be seen in [5].

References

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