

Steric contribution to the long-term sea level variations within the Gulf of Cadiz continental shelf

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The response of the long-term coastal sea level variations to the steric contribution has been explored within the **Gulf of Cadiz (GoC)** (Figure 1) for the period 1997–2008 using **tide gauge data** as well as **altimeter-derived sea level anomaly maps (AVISO)**. In order to remove the atmospheric pressure contribution, tide gauge data were corrected using the inverted barometer (IB) method (*ASLA* hereinafter). The AVISO maps were initially de-corrected using the Dynamic Atmospheric Correction product and then corrected using the same IB method (*Alt_ASLA*, hereinafter). A high resolution TS climatology (0.1° x 0.1°) was combined with monthly maps of AVHRR sea surface temperature in order to improve spatial resolution of the sea surface temperature near the coast. Steric height (*ssh*) time series were computed from the combined datasets considering a reference depth of 500 m at the open ocean and the bottom depth for shallower areas using the following equation:

$$ssh = ssh_T + ssh_S = -\frac{1}{\rho_0} \int_{-H}^0 \frac{d\rho}{dT} T dz + \int_{-H}^0 \frac{d\rho}{dS} S dz$$

where T' and S' are the monthly temperature and salinity deviations referenced to their climatic annual mean values; ρ is water density; ρ_0 is the sea surface density; H is the reference depth; ssh_T is the thermal expansion term and ssh_S is the haline contraction term.

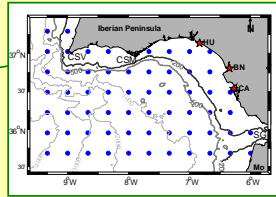
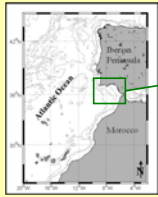


Figure 1. Map of the Gulf of Cadiz showing the position of Cape San Vicente (CSV), Cape Santa Maria (CSM), and the Strait of Gibraltar (SG). Mo stands for Morocco. Solid red stars mark the location of the three tide-gauge stations mentioned in the text, namely, Huelva (HU), Bonanza (BN), and Cadiz (CA). Blue dots mark the position of the AVISO grid points. The 200 (thick black line) 500 (thick grey line), 1,000, 2,000, and 3,000 m isobaths are shown for reference (Smith and Sandwell 1997).

The potential contribution of each of the defined steric effects on the pressure-adjusted sea level was evaluated as follows:

- (1) The *Alt_ASLA* time series at each grid point were corrected with the corresponding *ssh* time series in order to assess the contribution of the *local steric effect*. As for the tide gauges, the in-situ *ASLA* time series were corrected with the nearest *ssh* time series.
- (2) The contribution of the *open ocean steric effect* was estimated by correcting the *Alt_ASLA* and *ASLA* time series with the *ssh_O* values.
- (3) The *Western continental shelf steric contribution* was addressed by correcting only those *Alt_ASLA* time series located within the western shelf with the *ssh_{WS}* time series (no tide gauge data could be retrieved for this region).
- (4) The *Eastern continental shelf steric contribution* was evaluated by correcting those *Alt_ASLA* time series located within the eastern shelf as well as the three *ASLA* records with the *ssh_{ES}* time series.
- (5) The contribution of the *basin-wide steric effect* was examined by correcting all the *Alt_ASLA* and *ASLA* time series with the *ssh_B* values.

The performance of each of the steric contributions was determined in terms of the percentage of variance explained:

$$\%var = 100 \left(1 - \frac{\sigma_{residual}^2}{\sigma_{original}^2} \right)$$

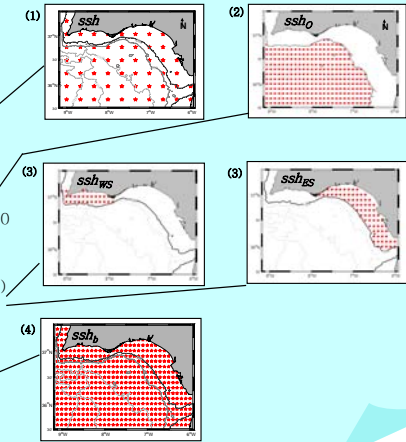
where σ is the standard deviation, "original" refers to the pressure-adjusted sea level time series (*ASLA*, or *Alt_ASLA*) and "residual" refers to the pressure-adjusted sea level time series corrected by each of the steric contributions.

Some references:

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4. Laiz, I., Gómez-Enri, J., Tejedor, B., Aboitiz, A., Villares, P., "Seasonal sea level variations in the gulf of Cadiz continental shelf from in-situ measurements and satellite altimetry". *Continental Shelf Research* 33, 77–88 (2013).
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6. Miller, L., Douglas, B.C., 2004. Mass and volume contributions to twentieth-century global sea level rise. *Nature* 428, 406–409.
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In order to evaluate the steric effect on the long-term sea level changes, four types of steric contribution were defined:

- (1) The *ssh* values interpolated to the AVISO grid resolution were considered as the *local steric effect (ssh)*.
- (2) The *open ocean steric effect (ssh_O)* was computed by averaging all the steric heights corresponding to grid points located over the 500 m isobath and deeper.
- (3) The *Eastern / Western continental shelf steric effect (ssh_{ES} / ssh_{WS})* was obtained by averaging over those grid points located within each continental shelf.
- (4) A *basin-wide steric effect (ssh_B)* was computed by averaging the steric heights all over the GoC.



Results and conclusions:

- The *open ocean steric effect* explained the highest percentage of variance all over the basin with the exception of the area located west of Cape Santa Maria (CSM).
 - This corroborates the fact that the long-term dynamics of both the offshore part of the Gulf of Cadiz and its eastern continental shelf are linked to the large scale circulation system of the North Atlantic Subtropical Gyre.
 - In terms of the eastern continental shelf, these results also suggest that the deep ocean thermosteric anomalies transfer onto the shelf region.
- In the region located west of CSM, the best results were obtained with the *local steric effect*, supporting the idea that the cell of cyclonic circulation found there is a local quasi-permanent feature.

- This also suggests that the deep ocean thermosteric anomalies do not transfer onto the shelf area in this region.

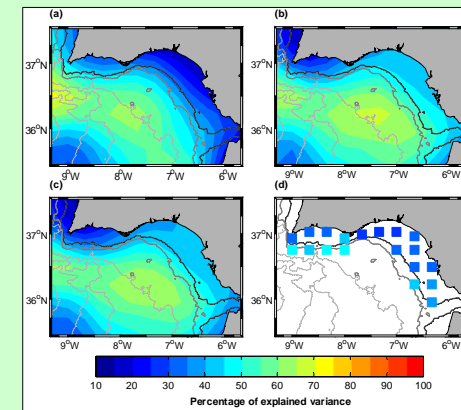


Figure 2. Maps of the percentage of pressure-adjusted sea level variance explained by the *local (ssh)* (panel a), *open ocean (ssh_O)* (panel b), *basin-wide (ssh_B)* (panel c), and *Eastern / Western continental shelf (ssh_{ES} / ssh_{WS})* (panel d) steric effects, respectively. The latter shows coloured dots at each altimeter point because there were not enough data to perform a contour plot.