

Decadal variability in the Eastern and Western Mediterranean sea level trends

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Below is the reviewer comment written in *blue italics*, while our response is in **black** and the inserted text in the revised manuscript is in **red**.

Comment in Report #1

The authors have addressed all my previous concerns, and I am happy to recommend publication of the manuscript after a minor remaining issue is addressed. Specifically, the reply to my point 4) is not completely satisfactory; this is because the use of alpha and beta is already a very crude approximation of the EOS (they are basically the linear Taylor truncation of the truly non-linear EOS), plus the use of constant Climatological T and S may decrease the accuracy of the steric sea level computation. I recommend that the authors assess the impact of using non-linear EOS + spatially varying T/S versus the simplified formula they use. In cases of non-linear relationships, the basin average should be performed on the steric fields. Mentioning the limitations (if any) of their formulations will be generally useful to others interested in diagnosing steric fields.

R: We agree with the reviewer that the use of a linear approximation of the EOS, combined with constant climatological temperature and salinity, represents a simplification that deserves further assessment. To quantify its impact, we evaluated the sensitivity of steric sea level estimates to different EOS formulations at a set of representative open-ocean locations in both the WMED and EMED from MEDREA24 data. Specifically, we compared:

- a linear EOS with constant thermosteric and halosteric coefficients (as used in this study)
- a linear EOS with spatially and temporally varying coefficients
- the full non-linear EOS-80 formulation.

The resulting density profiles were used to compute steric sea level and its decadal trend. Two representative examples are shown in Fig. S1 and Fig. S2, where relative trend differences between EOS cases are reported in the captions.

Results indicate that differences between the linear and non-linear formulations vary in time and across regions. Although the linear approximation introduces non-negligible discrepancies, no systematic difference in sensitivity is found between WMED and EMED subbasins. Despite these limitations, the linear framework allows for a straightforward separation between thermosteric and halosteric contributions, which is central to the objectives of this study. In addition, the use of constant versus variable thermosteric and halosteric coefficients has a comparatively smaller impact on steric sea level trend estimates. The magnitude of these differences is comparable to uncertainties associated with temperature and salinity fields from model data, indicating that the simplified formulation is adequate for the scope of this analysis.

Following the reviewer's suggestion, we have modified the manuscript in the Methods section as follow:

"The same approach is used to evaluate the decadal trend associated with thermosteric (η_T) and halosteric (η_H) sea level components, whose sum defines the total steric sea level (η_S):

$$\eta_S = \eta_T + \eta_H = \int_{-H}^0 \alpha (T - T_f) dz - \int_{-H}^0 \beta (S - S_f) dz \quad (1)$$

where T_f and S_f are reference temperature and salinity values, α and β are constant linear coefficients of thermal expansion and haline contraction, and H is the spatially varying ocean depth. Both reference values and steric coefficients are taken as spatially constant basin-mean values, consistent with previous studies and suitable for a basin-averaged steric sea level analysis (Borile et al., 2025; Pinardi et al., 2014). The proposed formulation (1) is based on a simplification of the non-linear equation of state, enabling the separation of thermosteric and halosteric sea level contributions. Although this linear approximation introduces region-dependent differences, these are consistent with uncertainties in model temperature and salinity fields, supporting its use for the present analysis.”

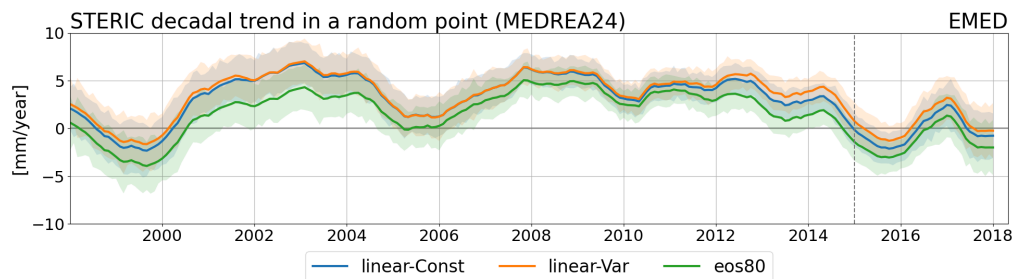


Fig. S1: Total steric sea level **decadal trend** in a random point of the Ionian Sea (18.54E / 35.60N) using: linear approximation of the EOF with constant coefficients (submitted case, linear-Const), with variable coefficients (linear-Var) and full EOS-80 (eos80). Trend is computed on decadal windows monthly shifted. Mean relative difference between linear-Const and linear-Var is 2%, between linear-Const and full-EOS80 is 23%.

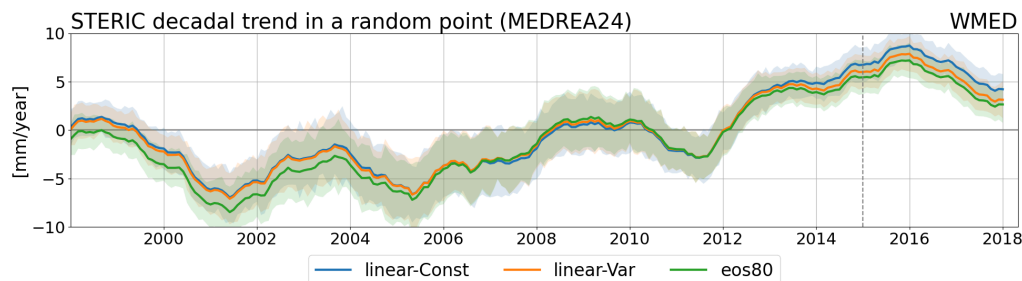


Fig. S2: Total steric sea level **decadal trend** in a random point of the Balearic Sea (6.04E / 39.77N) using: linear approximation of the EOF with constant coefficients (submitted case, linear-Const), with variable coefficients (linear-Var) and full EOS-80 (eos80). Trend is computed on decadal windows monthly shifted. Mean relative difference between linear-Const and linear-Var is 4%, between linear-Const and full-EOS80 is 8%.

Comment in Report #2

The manuscript presents simple yet robust estimates of sea level variability and trends in the Mediterranean Sea, focusing on similarities and differences between the western and eastern basins, and linking the results to key processes (e.g., the BiOS in the Eastern Mediterranean). Indeed, the effects of the BiOS on Eastern Mediterranean sea level variability may be perceived—when considering appropriate spatial and temporal scales—as analogous to the effect of El Niño on global estimates. For curiosity, this comparison could be briefly mentioned in the summary section.

R: We thank the reviewer for pointing out this analogy. The information is now included in the summary section as follow:

“In the Western Mediterranean (WMED), a sea level acceleration has been observed since the early 2000s, partially sustained by thermal expansion that exceeds haline contraction (Pisano et al., 2020). In contrast, the Eastern Mediterranean (EMED) displays stronger temporal variability, with halosteric contraction playing a major counterbalancing role (Meli et al., 2023; Borghini et al., 2014) correlated to the Adriatic–Ionian Bimodal Oscillating System mechanism (Civitarese et al., 2023). *This regional modulation is conceptually analogous to the influence of the El Niño–Southern Oscillation (ENSO) on global mean sea level variability (Nerem et al., 2010), though ENSO is more strongly linked to mass-driven fluctuations (Cazenave et al., 2012).*”

The manuscript is well written, and the data and methods are appropriate. The only minor revision I would suggest is to better connect thermosteric and halosteric sea level changes to actual variations in thermohaline properties. For example, Terzić et al. (2025, <https://doi.org/10.1002/lol2.70051>) estimated these changes locally and found an increasing thermosteric contribution in the most recent decade. Additional Mediterranean studies addressing similar analyses could also be discussed and referenced to strengthen this aspect of the manuscript

R:We thank the reviewer for this valuable suggestion. The corresponding modifications have been made in the 3.1 section as follow:

“Focusing on the steric contribution to sea level change, Fig. 2 shows the thermosteric and halosteric components of the mean sea level decadal trend. The concept of steric compensation in the Mediterranean Sea arises from the opposing behaviour of these two components: the thermosteric trend is positive and driven by seawater thermal expansion, while the halosteric contribution is negative and associated with the observed salinity increase. *Observational evidence of these processes has been reported at local and basin scales, affecting coastal and deep regions. Recent studies document a general warming and salinification of the Mediterranean (Aydogdu et al., 2023; Kubin et al., 2023; Borghini et al., 2014), alongside regional contrasts in the EMED, such as Ionian freshening and Levantine salinification (Grotsky et al., 2019). Together, these observations highlight the direct link between steric sea level components and changes in underlying thermohaline properties.*

[...] In the WMED (Fig. 1a) [...] Accordingly, the increasing decadal trend reported by satC3S is supported by thermal expansion that exceeds haline contraction, *consistent with reported sea surface temperature increases and long-term warming trends in the region (Pastor et al., 2018; Pisano et al., 2020).*

[...] The steric components in the EMED (Fig. 2b) help explain this behaviour: halosteric contraction persisted throughout the period, with a strengthening negative trend observed from the decade centered in 2014 onward, while thermal expansion has remained relatively stable since 2007, after a period of minimal contribution centered around 2004. The combined effect of these two components caused the total steric contribution to alternate between negative and positive trend values. In the most recent decadal windows (centered from 2015 onward), the observed EMED sea level trend increases as the total steric component's negative contribution weakens approaching negligible values, as shown in both MEDREA24 and GLORYS12. *These features are consistent with documented changes in thermohaline properties of deep waters in the Adriatic–Ionian system, including recent variations in both thermosteric and halosteric contributions and associated salinization signals (Terzić et al., 2025), as well as with broader EMED variability patterns (Mohamed and Skliris, 2022).*”