Responses to the Reviewers' Comments – Reviewer 1

Manuscript egusphere-2026-1549 — "Evaluation of a Coupled Regional Reanalysis for the Mediterranean Region Covering the Period 1993–2024"

We thank the Editor and the Reviewer for their careful reading and constructive comments. We have revised the description of the ocean analysis, atmospheric spectral nudging, open-boundary treatment, coupling strategy, verification datasets, and interpretation of the sensitivity experiments. We have also prepared a new Appendix A containing the principal ocean 3DVAR and atmospheric spectral-nudging equations. Terminology has been revised throughout to distinguish ocean data assimilation from the scale-selective large-scale constraint applied to the atmosphere.

Reviewer 1

We thank Reviewer 1 for the positive assessment of MESMAR-R and for the detailed suggestions, which have helped us improve both the methodological description and the interpretation of the results.

Major points

1. Since this study is primarily based on an air-sea coupled data assimilation method, there is not much methodological innovation. Nevertheless, I still think that Section 2.2 should provide a more detailed description of the assimilation method used, rather than merely citing previously published literature.

We agree. Section 2.2 was not exhaustive, and a new Appendix A now gives the principal equations for the standard ocean 3DVAR and atmospheric spectral nudging. We clarify that MESMAR-R uses the three-dimensional configuration of the OceanVar analysis framework: the analysis is performed as a 3DVAR/FGAT algorithm. Storto et al. (2018) is retained only as a reference to the broader analysis framework, while the present implementation is explicitly identified as 3DVAR. The citation "Storto et al. (2013)" was a typographical error and has been changed to Storto et al. (2023).

2. Regarding the MEDREA24 reanalysis dataset

We agree and have added a discussion on the comparison of MEDREA24 and UOA in section 2.4. Although both are NEMO-based ocean reanalyses using variational assimilation, they differ in model version, horizontal and vertical resolution, atmospheric forcing and bulk formulation, open-boundary data, river discharge, and covariance/analysis settings. Identifying the features most responsible for the differences is difficult and beyond the scope of the present study; please note also that the authors of MESMAR-R have no connection with the producers of MEDREA24, so we speculate on the differences based on published material. We expect that all differences contribute significantly to the different ocean state evolution. We have also adopted the strict common overlap 2000–2019 for all statistics and figures that include MEDREA24, also for consistency with all other datasets we compare our reanalysis with. Comparisons that do not involve MEDREA24 may retain the 2000–2020 period, and this distinction is now stated explicitly in each caption.

3. Identical MEDREA24 SST and SSS RMSE values in Table 2

Thank you for identifying this. We have rechecked the underlying calculation and coincidentally the values are correctly the same, differing at the 4th digit, so the Table remains unchanged.

4. The difference near the Po River mouth is evident…

We have clarified in the text that the localized signal is more directly associated with differences in river-discharge forcing and coastal mapping than with the coupled analysis itself. Data assimilation can redistribute or damp the resulting salinity anomaly, but the present experiment set does not isolate these effects uniquely; we therefore avoid a single-cause attribution.

5. Use of E-OBS and interpretation of atmospheric RMSE. The larger MESMAR-R RMSE against E-OBS does not necessarily demonstrate poorer performance because of resolution and representativeness differences. The E-OBS release, temporal coverage, resolution, and processing after 2006 should be described.

We agree. The verification subsection now identifies the exact E-OBS release, grid, common period, masking, temporal averaging, and interpolation procedure (see section 2.4 when e-OBS is first introduced). We also comment on the results in section 3, as suggested by the Reviewer, adding mention to the representativeness uncertainty.

6. Fine-scale atmospheric differences, marine coverage, and Figure 3 readability.

We agree on the points raised by the Reviewer. The wording has been made more cautious, Figure 3 has been enlarged and now can be visualized properly; the data masks are now explained. E-OBS is land-only, whereas marine precipitation is verified against GPCP (we added this explicitly in the figure label and in section 2.5); this accounts for the different spatial coverage. The new discussion identifies plausible mechanisms, namely coastline and orography representation, surface/PBL physics, coupled SST feedback, and scale-selective nudging, while explicitly stating that causality cannot be established without an atmosphere-only control experiment.

7. Spatial distribution of COS–COA differences: The basin-mean COS–COA differences are intriguing, but their spatial distribution is not shown.

We agree and add a new Figure on the principal COA–COS differences for atmospheric near-surface variables. The impact is confined to marine areas with occasional teleconnection mechanisms. We have thus changed the comments in the text accordingly.

8. Treatment of tides

We agree and have added an explicit statement. The present NEMO configuration does not include astronomical tidal forcing; consequently, tide-induced residual circulation and explicit tidal mixing are not represented, and we deleted the over-statement about possible impact of tides. The assimilated altimetry observations inherit the standard geophysical and tidal corrections of the upstream CMEMS/DUACS processing, and no additional tidal-period filter is

applied within the MESMAR-R 3DVAR. We have consequently excluded the tidal forcing from possible causes of enhanced variability near Gibraltar (it was obviously a mistake).

9. Interpretation of COS–UOS as a coupling effect: COS–UOS is not a pure coupling comparison because UOS is forced by an observation-constrained atmospheric reanalysis.

We agree. We no longer refer to COS vs UOS as a pure coupling effect assessment. It is now described as a composite contrast between an interactive coupled simulation and an ocean-only simulation forced by ERA5, including differences in forcing source, bulk formulation, temporal adjustment. The OHC discussion has also been revised to avoid attributing the time-varying divergence to a single mechanism. This is also mentioned in the experimental description.

10. Open-boundary conditions and basin volume

We agree. The model description now distinguishes the atmospheric lateral sponge from the ocean open boundary and explains the barotropic, baroclinic, and tracer constraints. We also state explicitly that no separate basin-wide volume correction is imposed. Basin volume evolves from the free-surface equation under surface freshwater fluxes and net transport through the Atlantic and Dardanelles boundaries; the Flather condition provides the fast barotropic adjustment to the external sea-level and transport signal.

11. Figure 15 title and precipitation-trend comparison. Part of the Figure 15 title is cut off.

The panel titles have been corrected, and the Figure is now enlarged to improve readability. We have compared the DJF precipitation trend between MESMAR-R and ERA5 (see Figure R1 below) and found a very similar patterns (beside ERA5 being somehow smoother), which confirms the consistency of the trends; as the section is mostly devoted to climate trends from MESMAR rather than their comparison with other datasets, we prefer to only mention briefly the issue without adding figures.

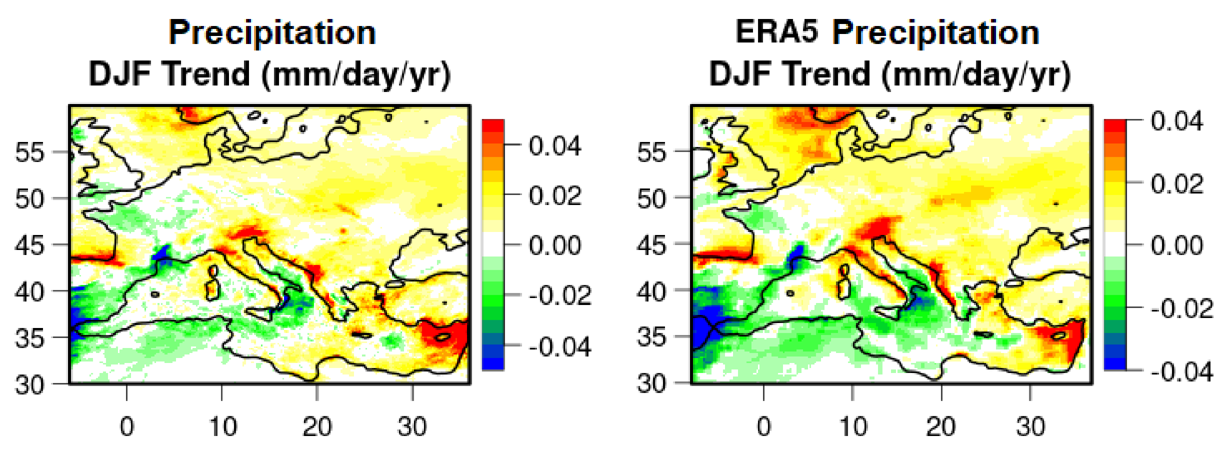

Figure R1: Comparison of DJF Precipitation Trend between MESMAR-R (left) and ERA5 (right). Period is 1993-2024.

12. Purpose of Table 5

We partially agree. While the sub-regional analysis can offer a more detailed view (which can however be inferred by the trend map figures), Table 5 provides basin-integrated assessments

that are important for monitoring changes in a climate change hotspot as the Mediterranean basin. We prefer to keep the table with basin-average values, and the region's definition following well-known literature.

13. Evolution of the observing system from 1993 to 2024

We agree and have added a discussion, which now highlights the transition from XBT/CTD and mooring dominance toward broad Argo coverage after the early 2000s, together with changes in altimeter constellation and also in atmospheric observing networks, which all could affect both the reanalysis accuracy and the reliability of the verification metrics. Added in the Discussion and Conclusions section.

14. Assessment of strongly coupled events

We agree that such events are important applications of MESMAR-R. A comprehensive event-based assessment would require dedicated object definitions, event matching, and high-frequency verification and is beyond the scope of this first dataset paper. We have made this limitation explicit and added a short discussion of the relevant high-frequency fields and planned follow-up analyses, while citing the existing MESMAR medicane evaluation (2023's article) as proof of concept. This is added at the very end of the manuscript.

Technical corrections

T1. First definition of MESMAR-R

Corrected. The first occurrence now reads: "Mediterranean Earth System Model at ISMAR Reanalysis (MESMAR-R)."

T2. Definition of REA in Figure 4

Corrected. "REA" is now defined as "MESMAR-R" in the Figure 4 caption, and the experiment names are used consistently thereafter.

T3. Heat- and freshwater-flux sign convention

Corrected. The caption now states: "Positive net heat flux is directed downward into the ocean and therefore represents ocean heat gain. Positive net freshwater flux is directed upward out of the ocean and therefore represents net freshwater loss through evaporation minus precipitation and runoff."

Responses to the Reviewers’ Comments – Reviewer 2

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Reviewer 2

We thank Reviewer 2 for the positive assessment and for the three focused suggestions. They have led to substantial clarification of the model-coupling and atmospheric-constraint choices.

1. Definition of MESMAR-R in the Abstract

Corrected. The acronym is now expanded at first occurrence.

2. Why the air–sea bulk fluxes are computed in WRF

We agree and have added a dedicated paragraph. The choice is motivated by physical and numerical consistency rather than horizontal resolution alone. WRF supplies the near-surface gradients, stability, roughness, and boundary-layer closure needed by the bulk formulation; the resulting surface fluxes also constitute the lower boundary condition for the atmospheric vertical turbulent-diffusion solve, which is treated implicitly in the PBL implementation. Computing the same fluxes in WRF therefore keeps the atmosphere’s surface tendency and the flux passed to NEMO consistently and avoids using a second, potentially inconsistent, bulk algorithm. The atmospheric time step is much shorter than the ocean baroclinic time step (60 s versus 450 s), so WRF resolves the rapid boundary-layer and diurnal adjustment and accumulates the fluxes over the 30 min coupling interval before conservative remapping to NEMO. The finer ocean grid does not create additional atmospheric information; calculating fluxes there would first require interpolation of the 15 km atmospheric state. We also cite Marti et al. (2021) and Schüller et al. (2025), which show that using temporally synchronized atmospheric fluxes reduces splitting and solar-radiation phase errors. We clarify that MESMAR-R does not implement their iterative Schwarz solution, so residual non-iterative coupling error may remain.

3. Why spectral nudging is used instead of full atmospheric data assimilation

The revised text explains in section 2.2 that MESMAR-R is designed as a multidecadal regional coupled reconstruction rather than a stand-alone operational atmospheric reanalysis. Spectral nudging provides a computationally affordable and temporally homogeneous large-scale constraint from ERA5 while preserving regional mesoscale development. It avoids observation processing, cycling, changing observing-system effects, and additional imbalance risks

associated with a full regional atmospheric analysis. The choice is supported by the sensitivity tests in Storto et al. (2023), where spectral nudging preserved effective regional resolution and performed better than full-field/grid-point nudging for several coupled ocean and medicane diagnostics. We have also added the formulation in Appendix A.

Responses to the Reviewers' Comments – Reviewer 3

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Reviewer 3

We thank Reviewer 3 for the positive assessment and the precise scientific and technical comments. We have revised the manuscript accordingly.

1. State the spatial resolution early in the manuscript

We agree and now state both resolutions in the Introduction.

2. More detail on assimilation and boundary conditions

We agree. Section 2 has been expanded, Appendix A provides the equations, and the atmospheric and ocean boundary treatments are now described with more details. See also the response to Reviewer 1, Comments 1 and 10.

3. Distinguish atmospheric spectral nudging from data assimilation

We agree. Throughout the manuscript, "atmospheric data assimilation" has been often replaced by "large-scale atmospheric constraint by spectral nudging," except where the broad, weakly coupled framework is being described and immediately qualified. We now state explicitly that only the ocean component performs an observation-space variational analysis. The abstract, experiment table, validation discussion, sensitivity interpretation, and conclusions have all been revised accordingly.

Reviewer 3 — Technical corrections

T1. Line 489

Corrected.

T2. Line 131

Corrected. XIOS 2.5 is now cited.

T3. Section numbering and cross-references

Corrected throughout.

T4. Line 181

We checked the comparison and "advantage" was intended because MEDREA24 has the lower RMSE in those layers. To remove ambiguity, the sentence has been rephrased as: "Below 210 m, MEDREA24 generally yields slightly lower RMSE than MESMAR-R, particularly for temperature between 210 and 600 m."

T5. Figure 9 units

Corrected.

T6. Figures 13- and 14-time axes

Corrected; both time axes now end in 2024.

T7. Lines 491–492

Corrected. The text now distinguishes trend from variability: "The eastern basin exhibits the stronger long-term warming trend, whereas the western-basin time series shows the larger seasonal-to-interannual amplitude."