Manuscript " Modelling the water isotopes distribution in the Mediterranean Sea using a high-resolution oceanic model (NEMO-MED12-watiso-v1.0): Evaluation of model results against in-situ observations”

Mohamed Ayache[1], Jean-Claude Dutay[1], Anne Mouchet[2], Kazuyo Tachikawa[3], Camille Risi[4], and Gilles Ramstein[1]

[1]Laboratoire des Sciences du Climat et de l’Environnement, CEA-CNRS-Université Paris Saclay, 91191, Gif-sur-Yvette, France
[2]Freshwater and OCeanic science Unit of reSearch (FOCUS), Université de Liège, B-4000 Liège
[3]Aix Marseille Univ, CNRS, IRD, INRAE, Coll France, CEREGE, 13545, Aix-en-Provence, France
[4]Laboratoire de Météorologie Dynamique, IPSL, CNRS, Sorbonne Université, Paris, France Correspondence: Mohamed Ayache (mohamed.ayache@lsce.ipsl.fr)

Reply to reviewers’ comments

Dear Pr. I., Andrew Yool

We would like to thank you for providing us the opportunity to revise our manuscript, and we are extremely grateful to Pr. Antje Voelker, Pr. Allegra N. LeGrande and the anonymous reviewer for their careful reading and comments that helped to improve our manuscript significantly.

We have revised our manuscript and provided a detailed response to each reviewer's comment and request below.

Color code
Reviewer comments
Authors response
The modifications performed in the manuscript appear in red above and in the revised manuscript with Changes Marked.

#1: Review by Antje Voelker:

Ayache and co-authors present the first high-resolution modeling study for water isotopes in the Mediterranean Sea. As a first attempt to relate their results to future paleoceanographic applications, they apply their water isotope model outcomes to calculate ∂^{18}O in marine carbonate. Overall, this is an interesting and novel study and, in my opinion, fits well into GMD. As someone working with water isotopes in sea water, I am very happy to see such studies advancing our knowledge. The manuscript is well written and the figures all informative and needed. The results are relevant and future attempts to go towards a fully coupled ocean-atmosphere model should be of great interest for the scientific communities interpreting speleothem and lacustrine paleo-records in the Mediterranean region.

The science presented is sound, although I am not an expert in climate models and therefore cannot fully judge if the model description is sufficient and can be reproduced based on the information given. From my reading I would say both criteria are sufficiently fulfilled.

I do not have major comments for the manuscript and believe minor revision will address the points I am making below. Some relevant changes might arise from the additional in-situ data I am pointing out in the specific comments, but those will not change the overall outcome of the study. One caveat I see in the manuscript is that Nile river run-off is never mentioned and discussed. For the sapropel research (mentioned in the manuscript) and tracing influences of NW African monsoon rainfall in paleoclimate studies, but also in the modern hydrological cycle that is an important process.

We thank Pr. Antje Voelker for the summary of our paper, and the positive assessment of its significance. Historically, the Nile played a crucial role in freshening surface water during sapropel events. However, following the construction of the Aswan High Dam in 1965, its influence has decreased (ElElla, 1993; Nixon, 2003). As a result, the Nile is no longer a primary factor contributing to the present-day state of the Mediterranean Sea.

Therefore, in the revised manuscript, we have included the following sentences to clarify this point.

"The Nile played a crucial role in freshening surface water during sapropel events. However, since the construction of the Aswan High Dam in 1965, its influence has decreased (ElElla, 1993; Nixon, 2003). As a result, the Nile is no longer a major contributor to the current state of the Mediterranean Sea."

(see section 2.3, lines 186-189 in the track changes version).

Moving forward, we will address each of the reviewer's comments in detail.

Specific comments:

Line 10: as a paleoceanographer I understand where you want to go with the phrase "$CaCO_3$ shell" but not every reader will be aware that you referring to planktonic foraminifera shells here. So, the text needs to be amended here to be understandable for every reader.

Thanks! Changed to "planktonic foraminifera shells ($\delta^{18}Oc$)". A table containing all abbreviations used in this manuscript has been added to the revised manuscript (see new Table. 1).

Line 83: if you just want to focus on paleoceanography, you need to add Sea after Mediterranean. However, I believe you can go further and say Mediterranean (region) paleoclimate as the modeling results should also be relevant for studies of speleothems and lacustrine sediments, besides paleoceanographic studies (that would also go beyond foraminiferal calcite shells). You actually hint to the broader potential impact in line 319!

Thank you for this synthesis and we fully agree. We are currently working with other teams on the IPSL coupled climate model, including the land surface model 'ORCHIDEEiso' and the atmospheric model 'LMDZiso', to implement water isotopes. This will enable further paleoclimate applications in the future across the entire Mediterranean region.

Line 121: verify bouquin AIEA; this reads like a placeholder text for a missing reference. It might also be IAEA.
Corrected (it was the French abbreviation).

Line 141: please provide reference for the standard isotopic values.

In models, the standard isotopic value is set arbitrarily, usually motivated by practical or computational constraints. Previous model-intercomparison projects of isotope-enabled models have shown that standard isotopic values could widely vary across models (Risi et al 2012).
"In reality, this value isn't standard; rather, it represents an average for the Mediterranean basin. We've set the simulations with these values to expedite computation time on the machine, as opposed to using the VSMOW value (i.e. The Mediterranean basin is largely more enriched as compared to the global scale)."
Changed in the revised ms (see section 2.2, lines 147-149 in the track changes version): “The ocean isotopic ratios are initially set to an average value for the Mediterranean basin of $\delta^{18}O_w$ = 1.5 ‰, δD_w =8 ‰, and the pseudo-salinity tracer is set to 37 (we have initialized the simulations with these values to save a little computing time on the machine)”.

Line 199: there exist additional/newer in-situ observations in the buffer zone west of the Strait of Gibraltar and one additional station in the Alboran Sea:

- Voelker, A.H.L., Colman, A., Olack, G., Waniek, J.J., Hodell, D., 2015. Oxygen and hydrogen isotope signatures of Northeast Atlantic water masses. Deep Sea Research Part II: Topical Studies in Oceanography 116, 89-106, doi: 1016/j.dsr2.2014.11.006.
- With the raw data available in Pangaea, e.g. Voelker, Antje H L; Colman, Albert Smith; Olack, Gerard; Waniek, Joanna J; Hodell, David A (2015): Oxygen and hydrogen isotopes measured on water bottle samples during EUROFLEETS cruise Iberia-Forams. PANGAEA, https://doi.org/10.1594/PANGAEA.831462
- Benetti, M., Reverdin, G., Aloisi, G., Sveinbjörnsdóttir, Á., 2017. Stable isotopes in surface waters of the Atlantic Ocean: Indicators of ocean-atmosphere water fluxes and oceanic mixing processes. Journal of Geophysical Research: Oceans 122, 4723-4742, doi: 1002/2017JC012712.
- With the data included in Reverdin, G., Waelbroeck, C., Pierre, C., et al., 2022. The CISE-LOCEAN seawater isotopic database (1998–2021). Earth Syst. Sci. Data 14, 2721-2735, doi: 10.5194/essd-14-2721-2022. https://www.seanoe.org/data/00600/71186/
- Voelker, A.H., 2023. Seawater oxygen and hydrogen stable isotope data from the upper water column in the North Atlantic Ocean (unpublished data). Interdisciplinary Earth Data Alliance (IEDA), doi: https://doi.org/10.26022/IEDA/112743
- and in the Alboran Sea itself: Voelker, Antje H L (2017): Seawater oxygen isotopes for Station POS334-73, Alboran Sea. Instituto Portugues do Mar e da Atmosfera: Lisboa, Portugal, PANGAEA, https://doi.org/10.1594/PANGAEA.878063

We appreciate the references and new data. The data from the Mediterranean Sea has been added to the model evaluation figures and will aid in future analysis. The data from the Strait of Gibraltar (i.e. in Voelker., et al 2015, 2023) will be valuable for setting boundary conditions in upcoming simulations.

We have incorporated all the data from Benetti et al. (2017) and Reverdin et al. (2022) database, primarily situated in the Western Mediterranean (refer to new Fig 2a, below new data are shown in green in Fig. 2d), as well as the data from Voelker et al. (2017) localized in the Alboran basin (in bleu).

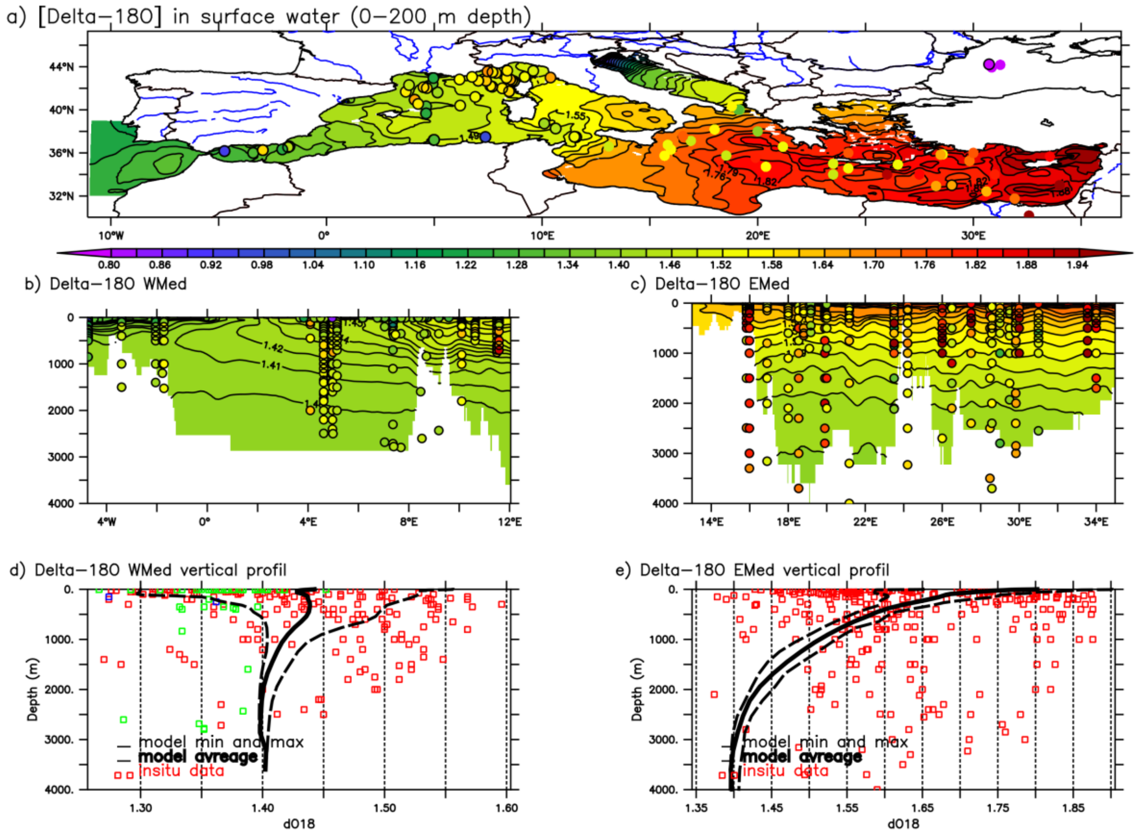


Figure 1 The model outputs against in-situ data for the present-day situation. a) $\delta^{18}O_w$ (in ‰) distribution in the surface water (50 m depth). b) E-W vertical section of $\delta^{18}O_w$ (in ‰) in the western Mediterranean basin d) Zonal mean comparison of $\delta^{18}O_w$ (in ‰) average vertical profiles in the western basin presenting model results against in-situ data. c) and e) the same as b) and d) but for the eastern basin. Colour-filled dots represent in-situ observations from (Epstein and Mayeda, 1953; Stahl and Rinow, 1973; Pierre et al., 1986; Gat et al., 1996; Pierre, 1999, Voelker et al. 2017, Reverdin et al. 2022). Both model and in-situ data use the same colour scale.

Line 251: Voelker et al. (2015, DSR II) obtained a lower slope of 0.32 for surface waters in the NE Atlantic with a strong bias towards subtropical waters (see their figure 11a). Craig and Gordon (1965) also observed a slope of 0.22 for the Atlantic's subtropical to tropical waters. So, your MedSea slopes fit well to those observations.

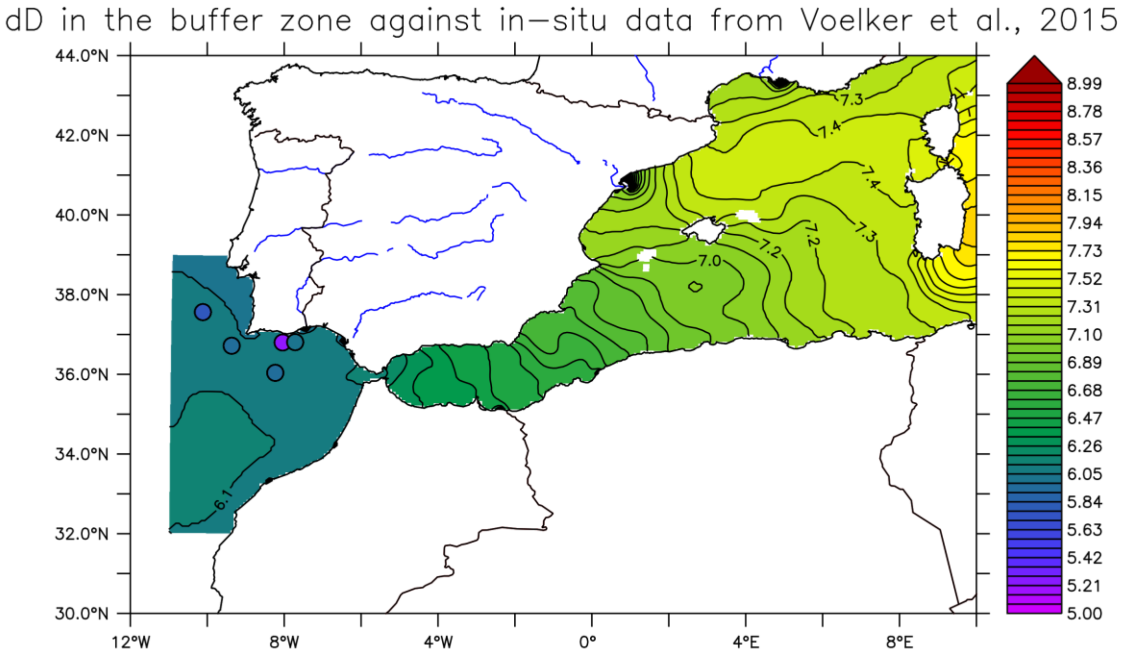
Thank you for alerting us to this. Indeed, Voelker et al. (2015) provided a thorough analysis of the $\delta^{18}O$-Salinity relationship. We have integrated the slope value calculated by Voelker et al. (2015) into our discussion and have included extra sentences in the revised manuscript's discussion section.
See section 3.2, lines 269-273 in the track changes version.
"The lower slopes reflect the impact of the evaporation surplus in the EMed (Voelker et al., 2015). High values of the slope are simulated in the western basin (> 0.5, Fig. 5a), especially in the Alboran basin which is influenced by Atlantic water characterized by a $\delta^{18}O_w$-S slope of 0.48 (Laube-

Lenfant, 1996; Pierre, 1999), and 0.32 obtained by Voelker et al. (2015) in the North East Atlantic with a strong bias towards subtropical waters.”

Line 275: you could check the model’s performance in the buffer zone west of the Strait of Gibraltar as much of the new data listed above include dD measurements.

The NEMO-MED12 grid covers the entire Mediterranean Sea and a small portion of the Atlantic Ocean to the west of Gibraltar, serving as a buffer zone for open boundary conditions. In this zone, 3D $\delta^{18}O_w$ and ∂D_w are relaxed towards in-situ data fields (from Pierre, 1999; Craig and Cordon 1965), meaning that the tracer values are imposed as boundary conditions rather than being predicted by the model.

The comparison between the new ∂D_w measurements and our imposed boundary conditions in the buffer zone demonstrates good consistency, as shown in the figure below.



dD in the buffer zone against in–situ data from Voelker et al., 2015

Figure 2 Comparison between simulated and observed dD in the Buffer zone (west of Gibraltar strait)

Line 284: in a general sense, you could compare d-excess trends with Benetti, M., Reverdin, G., Pierre, C., Merlivat, L., Risi, C., Steen-Larsen, H.C., Vimeux, F., 2014. Deuteriu »m excess in marine water vapor: Dependency on relative humidity and surface wind speed during evaporation. Journal of Geophysical Research: Atmospheres 119, 2013JD020535,doi: 10.1002/2013JD020535. That reference might also fit in the discussion in line 377.

We appreciate your suggestion. We've now included a comparison between the simulated trends and the data published by Benetti et al. (2015). The following text has been incorporated into the revised manuscript:

"In a more recent study, Benetti et al. (2015) observed a d-excess ranging from -1.56 to -1.72 ‰ in the surface waters of the eastern subtropical Atlantic. Their findings reveal a contrasting trend between increasing $\delta^{18}O_w$, δD_w, and decreasing d-excess, which corresponds closely with our simulated values. The authors suggest that d-excess variations are predominantly influenced by humidity and wind speed rather than mixing effects".

See changes at the end of section 3.3, lines 314-317, and in the discussion section (lines 416-421).

Technical corrections:

Line 5: define what sw in $\partial^{18}O_{sw}$ stands for: sea water or surface water? If sea water, the more common practice is to just use "w" for water.

$\partial^{18}O_{sw}$ stands for seawater. We agree with this suggestion and we change this abbreviation to $\partial^{18}O_w$.

Line 14: O is missing

Corrected

Line 19: correct spelling to "include"

Corrected

Line 48: replace input with inflow

Replaced

Line 49: replace into with in. Later in the sentence, correct the word order to Levantine Intermediate Water.

Done

Line 142: salinity is nowadays only given as a number (as correctly, done, for example in line 234); so, PSU should be deleted here.

Corrected

Line 201: I assume you mean eastern and not western basin as all the Gat et al. (1996) data are from the eastern basin.

Corrected. Thank you for pointing this out.

Line 207: EMed and WMed as acronyms should be defined.

Done, already defined in the introduction section (and in the new table 1)

Line 209: if you write western Mediterranean instead of WMed, Sea should be added behind Mediterranean.

Done

Lines 228-229: check the longitudes given for the eastern and western Med, respectively. If referring to the WMed, there should also not be a negative sign before the 6°E.

Corrected (section 3.1, lines 248-249).

Lines 365-366: add the article the before EMed/WMed, respectively.
Added

Figures: chosen color scheme: many of the figures include a red to green color range with symbols overlain in such colors. So, for color blind people it will be impossible to correctly read some of the figures. The author might want to check, if plotting in a different color range would be possible.
The second reviewer also highlighted this concern. In the updated version of the paper, we have modified the color palettes accordingly (see the new version of our ms).

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