Authors point-to-point responds Community Comment #1 to egusphere-2025-2665

Please find the author's responses in black below the reviewer's comments in blue. The italicized text within quotation marks indicates the proposed revisions in the revised manuscript.

The main comment is about the state of the E3SMv2-MPAS simulations described and evaluated in this manuscript. The authors mentioned (lines 152-156) that they used the file 'ocean.ARRM60to10.180715.nc' as the MPAS initial condition for E3SMv2-MPAS. That initial condition came from a very short adjustment run (5 days only) with standalone MPAS-ocean that in turn started from rest and Polar science center Hydrographic Climatology (PHC) climatological temperature and salinity, and therefore does not represent a spun-up ocean state. For E3SM-Arctic-OSI, we ran 3 consecutive JRA-55 cycles to achieve a more adjusted state for the ocean and sea ice models, and we analyzed the climatological results over the third cycle only, specifically over the last 12 or 30 years of the simulation (years 148-177 or 166-177; see Figs. 3, 4, 5a, 6, 10-15, 16c,d in Veneziani et al. 2022). Our understanding is that the E3SMv2-MPAS was run for, and evaluated over only one JRA-55 cycle. If that is the case, we wonder 1) whether the analyzed fields are adjusted or not, and also possibly too close to the PHC climatology for a fair evaluation of model performance, and 2) whether it is fair to compare the E3SMv2-MPAS results with more adjusted model states (as done in Figs. 8-10 and 16).

Thank you very much for your valuable feedback and for pointing out the issue regarding the initial state in the E3SMv2-MPAS simulation. In response to your comments and those of the other reviewers, we have revised the manuscript to correct the description of the initial conditions and have provided more detailed simulation configuration information. Please refer to (P6, L169-173): "*The MPAS-Ocean component was initialized from a pre-processed state (ocean.ARRM60to10.180715.nc). This state was derived from a prior short-term (5-day) adjustment run of the standalone ocean model, which itself started from a state of rest with three-dimensional temperature and salinity fields prescribed from the PHC. Consequently, this initial condition provides a dynamically adjusted and physically consistent starting point for our coupled simulation, mitigating the initial shock that would otherwise occur from a purely cold start.*"

We fully agree that completing three cycles of JRA55 forcing and using the results from the last few decades for evaluation would be an ideal approach to obtain a sufficiently equilibrated model state. However, due to constraints in computational resources and funding, we are currently unable to perform such long-term simulations. In response to the two specific questions you raised, we provide the following clarifications:

1. Regarding your second question, i.e., "whether it is fair to compare the E3SMv2-MPAS results with more adjusted model states (as done in Figs. 8–10 and 16)": We agree that such a comparison may indeed be problematic. Accordingly, we have removed the comparative analyses involving Figures 8, 10, and Table 1 from the original manuscript.

2. Regarding your first question, i.e., "whether the analyzed fields are adjusted or not, and also possibly too close to the PHC climatology for a fair evaluation of model performance": Multiple previous studies have indicated that when using the PHC initial field along with CORE-II or JRA55 forcing in ocean simulations, surface and upper-ocean variables can reach a quasi-equilibrium state within a relatively short time period. For example:

    - Wekerle et al. (2013), using FESOM with CORE-II forcing for a 1958–2007 simulation starting from PHC conditions, analyzed surface variables and freshwater content in the 0–500 m layer after a 10-year spin-up, focusing on the subsequent 40 years.

    - Wang et al. (2018) found that the temperature and salinity structures within the 0–1000 m layer largely reached equilibrium within 20–30 years in a simulation spanning 1950–2009.

    - Wang, Shu, Bozec, et al. (2024) noted that due to computational constraints, many high-resolution OMIP2 models completed only one JRA55 cycle (1958–2018), with their evaluation periods often centered on 1971–2000—i.e., approximately 14 years after initialization.

    Our simulation covers the period 1958–2020, with the main evaluation focused on 1995–2020. The initial conditions for this period were taken from the December 1981 output, meaning the model had already been integrated for 24 years. Although the deep ocean is far from equilibrium, the surface variables (sea ice, sea surface temperature, and salinity) and the upper Atlantic Water layer (above 1000 m), which are the focus of this study, had largely stabilized during this interval, supporting the robustness of our analysis.

    We have added relevant clarifications in the manuscript. Please see (P7, L178-190):

    "*To begin the simulation for our main analysis period (1995–2020), we used the model state from December 1981 as the initial conditions for January 1995. This 13-year gap (1982–1994) was a strategic choice to conserve computational* *resources while ensuring physical consistency in the key variables of interest. This computational strategy is motivated by the fact that, under forcings such as CORE-II or JRA55 and when initialized with PHC hydrography, upper-ocean and surface variables are known to reach quasi-equilibrium within a few decades, as demonstrated in several previous studies. For instance, Wang et al. (2018) reported that temperature and salinity in the upper 1000 m reached near-equilibrium within 20–30 years. Wekerle et al. (2013) began their analysis of surface variables and freshwater content in the 0–500 m layer after a 10-year initialization in a 1958–2007 simulation using FESOM under CORE-II forcing. Likewise, in the analysis of multiple high-resolution OMIP2 models simulating the full 1958–2020 period under JRA55 forcing, Wang, Shu, Bozec, et al. (2024) focused their evaluation on the period 1971–2000—commencing approximately 14 years after the model initialization. In our simulation, the 24-year spin-up from 1958 to 1981 is largely sufficient for the adjustment of surface fields (e.g., sea ice, surface temperature, and salinity) and Atlantic Water layer (above 1000 m), which are the focus of this study. Although the deep ocean remains far from equilibrium, the targeted variables had largely stabilized by 1981.*"

3. Regarding the comparison with OMIP2 model results (original Figs. 9, 16, and Table 2), we note that these models also completed only one JRA55 cycle, with evaluations typically starting around 14 years after initialization (e.g., 1971–2000). To ensure a fair comparison, we have moved the relevant comparative content to the Discussion section (Section 5.1: Comparison with OMIP2 Models under Diverse Grid Configurations and Resolutions) and restricted the comparison period to 1995–2020. For details, please refer to (P34-35, L732-773).

4. Furthermore, in the Discussion section (Section 5.3: Limitations of the Experimental Design), we have elaborated on the limitations of not completing three full JRA55 cycles (P38, L808-813): "*Furthermore, since only a single JRA55 forcing cycle was applied, the deep ocean and some physical quantities may not have fully departed from the influence of the initial PHC hydrographic fields or reached complete equilibrium. This could potentially affect the stability and initial-condition independence of the simulation results. In subsequent work, given sufficient resources, we plan to carry out at least three full JRA55 forcing cycles to promote more complete adjustment of the ocean state, reduce dependence on initial conditions, and thereby enable a more comprehensive and robust evaluation of the climate performance of the E3SMv2-MPAS.*"

We deeply appreciate your insightful comments, which have significantly improved the quality of our manuscript.

References:

Wang, Q., Wekerle, C., Danilov, S., Wang, X., and Jung, T.: A 4.5 km resolution Arctic Ocean simulation with the global multi-resolution model FESOM 1.4, Geosci. Model Dev., 11, 1229–1255, https://doi.org/10.5194/gmd-11-1229-2018, 2018.

Wang, Q., Shu, Q., Bozec, A., Chassignet, E. P., Fogli, P. G., Fox-Kemper, B., Hogg, A. McC., Iovino, D., Kiss, A. E., Koldunov, N., Le Sommer, J., Li, Y., Lin, P., Liu, H., Polyakov, I., Scholz, P., Sidorenko, D., Wang, S., and Xu, X.: Impact of increased resolution on Arctic Ocean simulations in Ocean Model Intercomparison Project phase 2 (OMIP-2), Geosci. Model Dev., 17, 347–379, https://doi.org/10.5194/gmd-17-347-2024, 2024.

Wekerle, C., Wang, Q., Danilov, S., Jung, T., and Schröter, J.: The Canadian Arctic Archipelago throughflow in a multiresolution global model: Model assessment and the driving mechanism of interannual variability, J. Geophys. Res.-Oceans, 118, 4525–4541, https://doi.org/10.1002/jgrc.20330, 2013.

More specific comments are included in the following.

1. Line 99: Please add reference to our most recent paper on the E3SM-Arctic fully coupled configuration with E3SMv2.1: Huo et al. 2025 (https://doi.org/10.1029/2024MS004726).

   Thank you for your suggestion. We have cited the relevant literature at the recommended location. Please see P3, L97: "(Huo et al., 2024; Ringler et al., 2013)".

2. Line 126: it seems that E3SMv2-MPAS uses the same MPAS mesh configuration as in Veneziani et al. 2022. Here, it would be good to clarify whether that is the case or whether the mesh is different.

   You are absolutely correct—the grid used in E3SMv2-MPAS is the same as that used in Veneziani et al. (2022). A clarification has been provided at P4, L128-129: *"... a meridional transition from 60 km resolution in the Southern Hemisphere to 10 km in the Arctic domain (hereafter 60to10 km, same as Veneziani et al. (2022); Fig. 1a).*"

3. Line 141: the 'spatially varying GM' was actually implemented prior to the development of the E3SM-Arctic-OSI configuration. Nevertheless, the current manuscript does not set GM=0 in the Arctic as we did in Veneziani et al. 2022, so maybe here one could say: "Similarly to what was done in Veneziani et al. 2022, we adopt a spatially varying…" and then include the sentence that is now on lines 212-215.

   Thank you for your suggestion. We have revised the text accordingly (P5, L143-146): "*For mesoscale eddy representation, similarly to what was done in Veneziani et al. (2022), we implement a spatially varying Gent-McWilliams (GM) parameterization, incorporating both bolus advection and Redi isopycnal diffusion components (Gent and Mcwilliams, 1990).*"

   Additionally, since we have now removed the comparative evaluation between E3SMv2-MPAS and E3SM-Arctic-OSI, the sentence originally numbered L212–215 does not appear in the revised manuscript.

4. Line 146: Huo et al. 2025 mentioned above could also be cited here.

   We appreciate you bringing the recent literature to our attention. We have now cited this work at the suggested location. Please see P6, L156-157: "... *have been comprehensively documented in Turner et al. (2022), Golaz et al. (2022) and Huo et al. (2024).*"

5. Line 159: Please clarify how the simulation was restarted after the 1981–1994 gap. What initial condition was used?

   Thank you for highlighting this key point, which was not clearly stated in our original manuscript. We have added a detailed description of the simulation design at the end of Section 2.1 (P7, L178-204).

   To begin the simulation for our main analysis period (1995-2020), we used the model state from December 1981 as the initial conditions for January 1995. This 13-year gap (1982–1994) was a strategic choice to conserve computational resources while ensuring physical consistency in the key variables of interest.

   The validity of this strategy is supported by the following considerations:

   1) Previous modeling experience: Under forcing such as JRA55, upper-ocean and surface variables typically reach quasi-equilibrium within a few decades. Our 24-year spin-up (1958–1981) is consistent with or longer than the adjustment periods used in many published studies, ensuring that the upper ocean and sea ice—the focus of this work—are adequately equilibrated.
   2) Physical rationale: The upper ocean and sea ice adjust much more rapidly than the deep ocean and are primarily governed by contemporary atmospheric forcing rather than initial conditions. Thus, any initial imbalance due to the 13-year gap is quickly overcome by the realistic forcing applied from 1995 onward.
   3) Model validation: The output from the 1995–2020 simulation shows physically consistent behavior, with key variables such as sea surface temperature and sea ice concentration aligning closely with observations and reanalysis products shortly after initialization, showing no persistent bias.

6. Line 205 (and more generally for the manuscript): the comparison with CMIP6 experiments seems unfair to us because those simulations are fully coupled. In addition, the comparison with the OMIP models and E3SM-Arctic-OSI should be done over similar (more adjusted) oceanic states. Finally, for the Veneziani et al. 2022 paper, we also provided data from a E3SMv1-LR-OSI simulation, which could be used for comparison to the E3SMv2-MPAS simulations here.

   We are grateful for this important comment. We fully agree that a direct comparison between E3SMv2-MPAS and either fully coupled CMIP6 models or a well-spun-up E3SM-Arctic-OSI would be scientifically unfair. As mentioned in our response to the main comment, we have therefore removed all comparative analyses involving CMIP6 and E3SM-Arctic-OSI (including the original Fig. 10).

We recognize that a rigorous comparison should be conducted over equivalent time periods after completing simulations of the same length (e.g., three JRA55 cycles). Should computational resources allow in the future, we plan to carry out the full simulation and perform a comprehensive and equitable comparison of E3SMv2-MPAS results with E3SM-Arctic-OSI and the E3SMv1-LR-OSI you mentioned.

7. Line 230 (and Figs. 3-4): We assume these are annual sea ice quantities. Wouldn't it be better to show seasonal sea ice climatologies?

   You are entirely correct—the original Figures 3 and 4 depicted annual sea ice quantities. Following your suggestion, we have now separated the evaluations of sea ice concentration and thickness into winter (December–February) and summer (June–August). Please refer to the revised Figures 3–5 and the related analysis (P10-12, L284-307).

8. As mentioned above, the comparison with E3SM-Arctic-OSI in section 3.3 (Fig. 10) should be over the same time period. For the Veneziani et al. 2022 paper, we provided climatologies for both E3SM-Arctic-OSI and E3SM-LR-OSI over years 148-177 and 166-177 (end of third JRA-55 cycle). A similar time frame should be used for E3SMv2-MPAS.

   Thank you for reiterating this point. We strongly concur with your view that any inter-model comparison should be conducted over the same time period to be scientifically valid.
   Given the current computational constraints, which prevent us from completing three full JRA55 cycles, we agree that such a comparison in the original Section 3.3 was not appropriate. We have therefore decided to remove the original Figure 10 and all associated comparative analysis.
   We have also explicitly acknowledged this limitation in the Discussion section of the paper (P38, L808-813).

9. Similarly to other reanalysis products, JRA55 is known to overestimate surface air temperatures over Arctic sea ice (e.g., Batrak and Müller 2019, https://doi.org/10.1038/s41467-019-11975-3; see their Fig. 3d). These warm biases can propagate into the ocean component by modifying surface fluxes—particularly enhancing downward longwave radiation and reducing sensible heat loss—potentially leading to underestimated sea ice growth and overestimated upper-ocean temperatures. A brief discussion on how such forcing biases might influence ocean stratification, mixed layer depth, or Atlantification could be included in the Conclusions section.

We greatly appreciate your suggestion. A new subsection (Section 5.4: Limitations from the Atmospheric Forcing: The JRA55 Warm Bias) has been added, specifically addressing the limitations arising from the warm bias in JRA55. This addition significantly enhances the academic rigor of the paper. For details, please see (P38, L815-827):

"*The JRA55 reanalysis forcing data employed in E3SMv2-MPAS exhibits a known warm bias over the central Arctic deep basin (Batrak & Müller, 2019). This bias may systematically suppress sea ice growth and induce upper-ocean warming in the simulation by enhancing downward longwave radiation and reducing oceanic sensible heat loss. Therefore, the overestimated SST (Fig. 8c) and underestimated summer SIC (Fig. 4e–g) simulated in the central Arctic basin may be partially attributable to the inherent bias in the forcing data, rather than solely to inaccuracies in the model's physical processes.*

The enhanced ice melt driven by this warm bias releases additional freshwater, leading to a stronger and shallower freshwater layer (a more pronounced halocline) in the surface ocean, which significantly strengthens the stratification stability of the upper ocean. This inhibits vertical mixing between layers and impedes the upward heat transfer from the warmer, saltier AW below. This bias may partly explain the overestimation of the intermediate Atlantic Water layer temperature alongside the underestimation of the mixed-layer temperature (Fig. 12e). Future work will consider employing alternative reanalysis products or applying bias-correction methods to better constrain the impact of forcing uncertainties on simulation results."