Authors point-to-point responds Referee Comment #2 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.

1. I concur with CC1's comments. It is not entirely appropriate to compare the E3SMv2-MPAS results with those from E3SM-Arctic-OSI, CMIP6, and OMIP models, due to significant differences in integration lengths and associated model drifts. These discrepancies undermine the fairness of direct comparison. I recommend that the authors remove the model intercomparison from the main text and instead address relevant points briefly in the discussion section.

Thank you very much for your comments. We have revised the manuscript accordingly, shifting the focus of the analyze to the evaluation and comparison between E3SMv2-MPAS and observations/reanalysis data. And we have removed the comparisons with CMIP6 and E3SMv1 (formerly in Figs. 8, 10, and Table 1).

Furthermore, as noted by Wang et al. (2024), due to the substantial computational resources required for high-resolution simulations, high-resolution studies within the OMIP2 framework have typically considered only one JRA55 cycle (1958–2018). Therefore, in the Discussion section, we have briefly compared and evaluated E3SMv2-MPAS against these high-resolution OMIP2 models that also completed only one JRA55 cycle. For details, please refer to Section 5.1, titled "Comparison with OMIP2 Models under Diverse Grid Configurations and Resolutions" (P34-36, L732-773).

Reference:

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.

2. The model configuration requires further clarification. As the simulations do not adhere to the standard OMIP protocol, more detailed information regarding the model integration setup should be provided.

We sincerely appreciate your suggestion. We have primarily supplemented the detailed design of the simulation period in Section 2.1 (P6-7, L165-207):

"*Given the prohibitive computational cost of a continuous high-resolution simulation from 1958 to 2020, we adopted a strategic two-period integration scheme to prioritize computational resources for our core analysis period (1995–2020). The model's climatological fidelity during this satellite era is verified using multi-source observational data, ensuring a reliable assessment of both sea ice and ocean variability.*

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. In contrast, the MPAS-Seaice component was initialized from an idealized, uniform ice cover. A 1-meter thick ice layer with 100% concentration was prescribed on all ocean grid points between 60°S and 70°N, with zero initial snow depth and stationary ice velocity. This simple state allows the sea ice cover to evolve self-consistently in response to the model's atmospheric forcing and ocean coupling from the beginning of the simulation. Following this spin-up phase, the full interannual JRA55 forcing was applied from 1958 to 1981.

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.*

From a physical perspective, the potential impact of this initialization approach for the 1995–2020 simulation is expected to be short-lived. The upper ocean and sea ice (the primary focus of this study), adjust much more rapidly than the deep ocean, and their evolution is predominantly governed by contemporaneous atmospheric forcing rather than by the initial conditions. Therefore, the disequilibrium introduced by the initial condition from 1981 would be rapidly overwritten and adjusted by the realistic, synchronous atmospheric forcing applied from 1995 onward.

Therefore, initializing the 1995 run from the 1981 output allows a computationally efficient hot start and ensures that the model is in an appropriate state for evaluating the 1995–2020 period.

The model output initialized from the 1981 state also demonstrates physically consistent behavior during the 1995–2020 period, further supporting the validity of this approach. The temporal evolution of key diagnostic variables—including sea surface temperature (Fig. 8d) and sea ice-related variables (Fig. 7)—shows that the simulation quickly aligns with the observed/reanalysis trajectory after 1995, with no persistent systematic bias. Spatial distributions of these variables are also in good agreement with evaluation datasets (Figs. 3–5, 8a–c), and the long-term trends from 1995 to 2020 closely match those in the references (Fig. 7). These results, which will be discussed in detail in the following sections, indicate that the initialization from 1981 did not adversely affect the simulation of central climate features during the study period.

Accordingly, our primary evaluation focuses on the performance of E3SMv2-MPAS during the period 1995–2020. In addition, a comparative assessment of the 1960–1980 period is also included to briefly examine the decadal variability of key ocean and sea ice variables and to verify the model's capability under distinctly different climatic backgrounds."

3. Regarding sea ice validation, while sea ice concentration and thickness are evaluated, I encourage the authors to also include assessments of sea ice extent, volume, and their long-term trends.

We are grateful for your recommendation. In the revised manuscript, we have added analysis on the evaluation of sea ice extent and volume. Please see Figure 7 and the related content on P13-15, L333-365.

4. Given that this is a model evaluation study, I suggest a more comprehensive evaluation of the Arctic Ocean simulations. Key metrics should include Arctic Ocean freshwater content and its trend, as well as volume, heat, and freshwater fluxes through major Arctic gateways. These aspects are critical for assessing the model's performance in simulating Arctic Ocean climate.

Following your advice, we have added two new sections of the main text: Section 3.4 "Freshwater Content Spatiotemporal Variability" (P24-26, L529-565) and Section 3.5 "Gateway Transports: Volume, Heat, and Freshwater" (P26-29, L567-639). These sections present a comparative evaluation between E3SMv2-MPAS results and observational data.

The added analyses demonstrate that E3SMv2-MPAS faithfully reproduces both the spatial distribution and long-term trend of Arctic freshwater content (Fig. 15). Furthermore, it accurately simulates volume, heat, and freshwater transports through key Arctic gateways, capturing their observed magnitudes and essential variability trends (Fig. 16).