Response to reviewers' comments for: An evaluation of the E3SMv1-Arctic Ocean/Sea Ice Regionally Refined Model

January 28, 2022

Response to Reviewer 2

We thank the reviewer for the helpful comments and the positive review of our manuscript. We believe we have addressed the reviewer's concerns and suggestions in our response below. Please note that the reviewer's original comments are in italics. Line numbers, as well as Figure and Table numbers, indicated in our responses refer to the new version of the manuscript.

Comments

1. *line 4: ...cost of high – resolution (HR)* ***regular gridded*** *global configurations...*

   We have clarified this sentence (lines 4-5) as follows: "...relative to the respective cost of configurations with high-resolution (HR) everywhere on the globe.".

2. *line 6: "...while employing data-based atmosphere, land and hydrology components..." If I understand well you run MPAS+Sea-Ice more or less in a standalone mode with a prescribed atmosphere. What are in this case the land and hydrology components? Maybe some rephrasing is necessary.*

   We do not run MPAS in standalone mode, but as the ocean and sea-ice components of E3SM. We run E3SM in data-atmosphere/data-hydrology and active ocean/sea-ice mode (so called G-case in E3SM/CESM lingo). The data used to forced MPAS is described in Section 2 of the manuscript: it's basically the JRA55 atmospheric data, which also supplies the river runoff data (only land-related feature that is needed for this ocean/sea-ice configuration).

3. *line 43: "...Wang et. al 2018...", Its fully OK here to cite Q. Wangs paper, but since you anyway run your configuration uncoupled it might be worth it to cite also the papers of C. Wekerle et. al 2013, 2017a and 2017b. Since they directly deal with mesh improvements in the Arctic realm (but in an uncoupled FESOM standalone configuration) and their consequences for the local ocean circulation down to an eddy resolving regime (C. Wekerle et. al 2017b).*

   We agree that we should have added the reference to the Wekerle et al. publications, and have done so on line 42.

4. *line 75: Why only 10 km was chosen for the Arctic refinement, considering the rossby radius for high latitudes, at this resolution the Arctic ocean will be barely eddy permitting. For example the standard higher resolved Arctic FESOM configuration goes down to a resolution of 4.5km using around 650k surface vertices. There exists an intentional similar paper to yours within the FESOM community (C. Wekerle et. al 2017a), maybe it's worth to be cited.*

   We agree completely with the reviewer statement about the need for higher resolution in the Arctic, in order to better resolve the local Rossby radius of deformation. We did run a simulation similar to the one described in the manuscript but using an Arctic regional refinement of 6 km instead of 10 km. Unfortunately that simulation, while being approximately 3 times more expensive than the 10-km refined mesh, did not produce any significant improvements in the Arctic and subarctic ocean and sea-ice representation. We concluded that a resolution of at least 3-4 km is necessary to really make a difference in the Arctic (and likely in the Southern Ocean as well). This very-high-resolution Arctic configuration of E3SM is in the planning stages at the moment, and we hope to have some results available over the next few years.

5. *line 88-89: Why is there no background diffusivity utilized?*

   We have tried using some background diffusivity in recent E3SM-Arctic runs, but the constant value of diffusivity everywhere does not work well for regionally refined meshes, because the model becomes unstable in the shallow regions with highest horizontal resolution. We have also tried background diffusivity in low resolution E3SM runs, but little change has been observed in the simulated T, S, and AMOC strength. We have concluded that more natural ways of representing deep ocean mixing, such as tidal mixing, should be instead used in MPAS-Ocean. We are working on having tidal mixing available in the next version of the model.

6. *line 110: I would like to know but also the community might like to know at which time-step the high and low resolution configuration perform.*

   We have now added the requested information (10 minutes baroclinic time step for the high resolution configuration and 30 minutes for the low resolution configuration) on lines 90 and 111.

7. *line 111-118: I haven't fully got the point why or for which purpose you bring the RAMS configuration into the comparison since it's also just another model that is not directly related to E3SM. Maybe you can clarify in a couple of sentences, also in the introduction, what's the benefit of RAMS in this comparison.*

   We thank the reviewer for suggesting this. We have now added the following sentence in the introduction (lines 56-59): "We also compare results with a high-resolution Regional Arctic System Model (RASM) simulation when observations are scarce or unavailable. Due to the higher number of constraints and its Arctic focus, we expect RASM to give a realistic representation of local processes, while obviously not directly accounting for the Arctic to mid-latitude exchange processes".

8. *line 132-136: For my own curiosity (doesn't need to be in the paper), can you say something to the "...recent improvements in the MPAS-Ocean eddy parameterisation scheme...".*

   Absolutely. The next release of E3SM (v2 version) will include a version of MPAS-Ocean with the following options for the mesoscale parameterization scheme: i) inclusion of Redi mixing, with Redi kappa constant as well as variable in space and time; ii) variable GM kappa (again in space and time) following a number of different algorithms; iii) the ability to transition from GM-on to GM-off based on the local Rossby radius of deformation and local horizontal resolution.

9. *line 145: Are there known causes why your AMOC in the high but especially in the low resolution are so weak?*

   Good question! We currently have a E3SM special working group that is trying to understand and untangle this very problem. The conclusion so far is that the ocean model is not fully able to mix or distribute the fresh water inputs/caps that form in the upper polar oceans at low resolution. Since the high-resolution simulation (Caldwell et al. 2019) displays a strong AMOC, we believe that vertical mixing is not the major culprit, but rather the implementation of the mesoscale parameterization must be at least partially responsible for the upper ocean fresh biases that we see in many E3SM low resolution simulations. We are hopeful that these investigations will be part of an upcoming publication.

10. *line 145-148: I would be interested to know what the maximum March (NH) and September (SH) mixed layer depth in both configurations looks like.*

    We have not stored maximum mixed layer depth (MLD) for these particular simulations, but we have plotted the average MLD for March (NH) and September (SH) in Figure 1 below, as requested by the reviewer. It is interesting to note that some differences are even found in the Southern Hemisphere (where both configurations feature the same horizontal resolution), but the main differences are found in the Northern Hemisphere, with higher MLD found in the Greenland, Irminger, and Labrador Seas in E3SM-Arctic-OSI, as opposed to the Norwegian Sea in E3SM-LR-OSI.

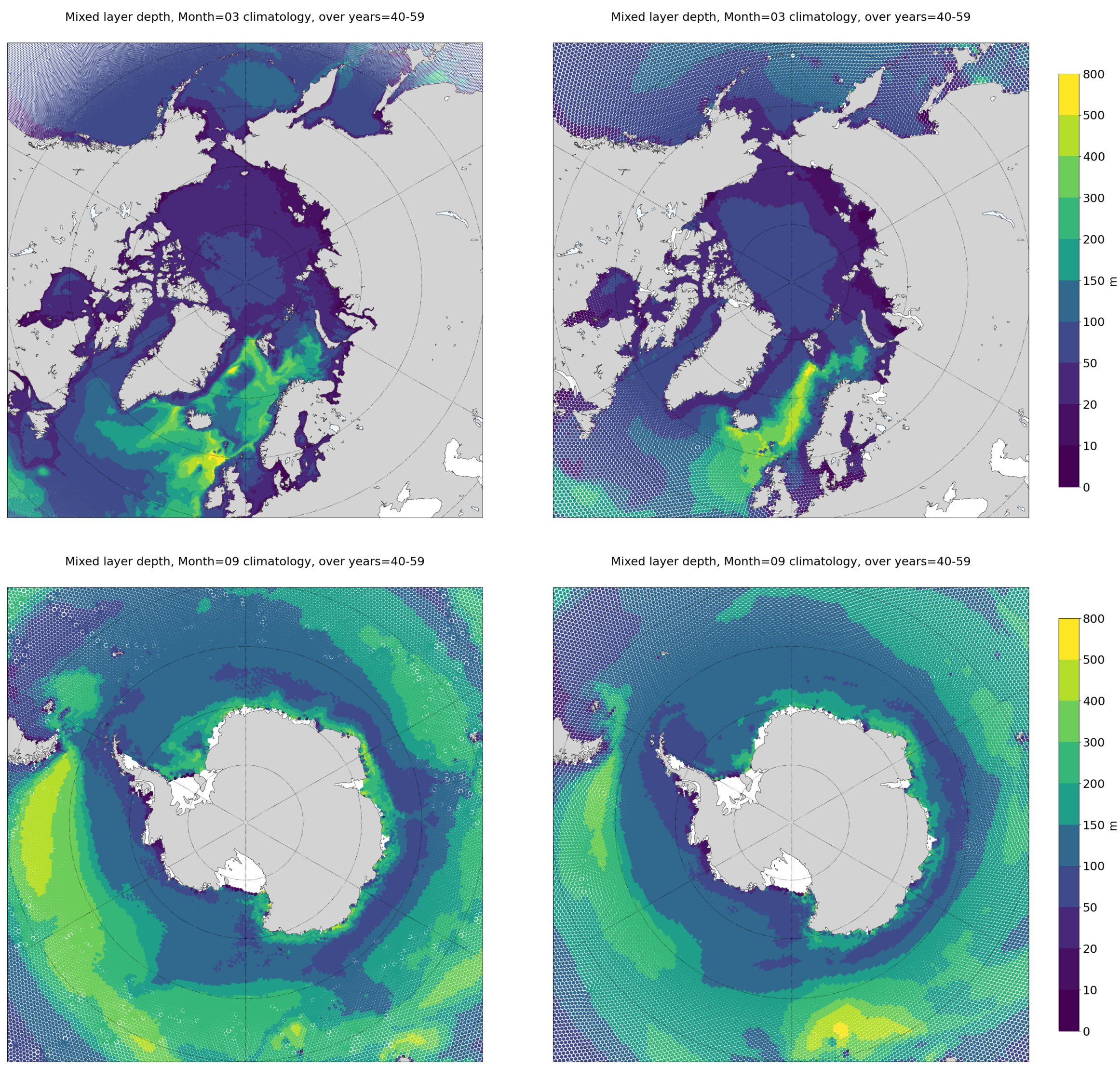

Figure 1: Average mixed layer depth for March (upper panels, Northern Hemisphere) and September (lower panels, Southern Hemisphere) for E3SM-Arctic-OSI (left panels) and E3SM-LR-OSI (right panels). Monthly climatologies are computed over years 40-59.

11. *line 211: ...heat flux through Davis Strait...*

    Fixed.

12. *line 320, Fig.14 and Fig.15: You compare the 3rd. cycle of your E3SM simulations with the 1st. cycle of the RAMS simulation. In my experience, there are usually considerable differences between the 1st. and the 3rd. forcing cycle. At least this is the case for the Atlantic and Southern Ocean. For the Arctic these differences might be not that large, but nevertheless it might be of benefit also to provide the temperature and salinity profiles of the 1st. forcing cycle of your E3SM simulation in Fig. 14 and Fig. 15 as a dashed line.*

    As suggested by the reviewer, we have now included the profiles for the last 12 years of the first JRA cycle as dark red dashed lines in Figures 14, 15, in addition to the profiles computed over the two periods of the third JRA cycle. They give a good idea of how the stratification changes from cycle to cycle over the whole Arctic and locally over the Canada Basin only.