Review of “Resolving the mesoscale at reduced computational cost with FESOM 2.5: efficient modeling approaches applied to the Southern Ocean” by Nathan Beech et al.

This paper explores the eddy activity in a variable-resolution Southern Ocean configuration with up to 3km gridcells (SO3), using FESOM2.5, using atmospheric forcing data from three different five-year periods. The comparison data set of simulations is AWI-CM-1 medium-resolution configurations with nominally ¼ degree (~25km) gridcells. Three central questions are explored: (1) How does the SO3 configuration alter eddy activity over medium resolution; (2) How do both of those compare to satellite altimetry for the present-day simulations; and (3) How do the medium-resolution and SO3 change with climate change.

A major challenge of running at 3km resolution is the computational requirement. This experimental design makes the best use of available compute time by studying the eddy kinetic energy, which adjusts quickly, rather than ocean climatology which may take over 100 years to adjust (ocean water mass temperature and salinity, mixed layer depth, frontal location). The authors clearly explain this strategy, and I think they make the best possible use of 18 years of high-resolution simulations for a scientific study. Other modeling centers also struggle with the computational cost of long spin-up times at high resolution. The authors downscale their initial conditions from lower resolution FESOM runs for each period (“a semi-cold start-up”) to assist the spin-up process, which is only one year.

This paper very well written. The introduction and methods provide sufficient background, detail, and references. The analysis can be improved with the two major points below, but the included plots are well organized and nicely labelled. The English writing is excellent. This paper will be of interest to GMD readers, and ocean modelers more generally. I am happy to see a publication with scientific results from variable-resolution ocean models, down to 3km resolution!

Major Comments

1. In my view, the big missing piece of analysis for this study is the magnitude of the westerlies in the atmospheric forcing data. Figure 1 is a wonderful, clear summary of the model behavior, and shows that eddy activity increases substantially in the 2090s simulations for all resolutions and shows higher EKE at high resolution. The presumable cause of the gains from present day to 2090s is stronger westerly winds, as referenced in the Munday et al 2013 and Marshall 2003 papers. Please add a figure with violin plots or similar analysis of the distribution of Southern Ocean westerly winds used in the model atmospheric forcing data. This could look like Fig 1 panel c for the different time simulations, plus winds from AWI-CM-1 simulations, which had an active atmosphere.
2. There is no mention of the sea ice, other than that it is included in the model. Given that the sea ice covers part of the Southern Ocean every winter, presumably it has some modulating effect on the eddy kinetic energy. For example, “Generally, EKE is stronger when sea ice concentration is low versus times of dense ice cover.” and “Consolidated sea ice dampens eddy kinetic energy by reducing the atmosphere-ocean momentum transfer that drives part of the mesoscale variability, for example, along Arctic shelf

breaks” in Wilken-Jon von Appen et al. 2022, although that was specifically an Arctic study. So a second hypothesis is that sea ice cover is substantially reduced in 2091, leading to higher EKE. Which is it, increased winds or reduced sea ice? It may be beyond the scope of this paper to nail that down completely, but I think it is worth a literature search and discussion on this point. Like point 1, you could include the winter and summer Southern Hemisphere sea ice area (and perhaps volume) from the different simulations. I’m sure the sea ice for the 2090s simulations is greatly reduced. Then you have two potential culprits for the increased EKE. They probably work together – in the 2090s there is (presumably) both stronger winds *and* a more direct influence by the winds due to less sea ice.

Minor comments

L14 “eddy-present” is a new adjective for me. Is that standard? I’ve heard “eddy permitting” for 1/10 degree, but not “eddy-present” for ¼ degree. I see it appears in Moreton et al. 2020 for ¼ degree, so I must just be behind the times.

L179 Please add the range of core counts you typically run on, and the core count for the 0.65 SYPD.

L361 Is -> is (the only grammatical or spelling mistake I found in the whole paper!)