Authors' Response to Reviews of

The tidal effects in the Finite-volumE Sea ice–Ocean Model (FESOM2.1): a comparison between parameterised tidal mixing and explicit tidal forcing

Pengyang Song et al.
Geosci. Model Dev. Discuss., 10.5194/gmd-2022-25

RC: ***Reviewers' Comment***, AR: Authors' Response, ☐ Manuscript Text

1. Reviewer #1

1.1. General comments

RC: ***This manuscript compares three different simulations with an ocean general circulation model: a control simulation without the effect of tides (NOTIDE), a simulation with parameterised tidal mixing (CVTIDE), and a simulation with explicit tidal forcing (LSTIDE). The differences are in general rather small. Perhaps the most interesting and significant ones are seen in the meridional overturning in Fig 11. CVTIDE has a stronger deep cell involving AABW, while LSTIDE has a stronger AMOC and a stronger cell in the North Pacific, with upwelling around 50° N.***

There are major problems, both with the setup of the simulations and with the analysis of the results, and I therefore do not recommend publication of this manuscript.

AR: Thank you for reviewing this article and leaving the comments. Responses to your comments are listed below.

1.2. Detailed comments

RC: ***The tidal parameterisation in CVTIDE is very crude. It is based on a simple scaling estimate of the tidal generation of internal waves, but, for example, does not distinguish regions where these waves are trapped or propagating. There are more serious calculations of the tidal generation of internal waves by, for example, de Lavergne et al. (2019), with data available at https://www.seanoe.org/data/00470/58153/.***

de Lavergne, C., S. Falahat, G. Madec, F. Roquet, J. Nycander and C. Vic, 2019: Toward global maps of internal tide energy sinks. Ocean Model., 137, 52–75.

AR: In our research, we have found modern databases which feature either higher resolution or better dynamic processes. However, the approaches these databases implemented into the model are the same. That is via changing the vertical diffusivity. In our work, we mainly focus on the comparison between changing model vertical diffusivity and adding real tidal motions. Thus, we use the "basic" Simmons' data for two reasons: (1) to make our CVTIDE model results comparable to other models which also implemented the CVMIX_TIDAL parameterisation. (2) to compare the two approaches of considering tidal effects in a model. As to the new databases, we consider applying them in the future to perfect the expression of tide-induced mixing in an ocean model.

RC: ***As noted in the manuscript, the horizontal resolution is insufficient to resolve the internal tides in most of the ocean. It is therefore clear already from the outset that the tidal mixing can not be captured correctly. It should also be remembered that resolving the generation of internal tides is a necessary but not sufficient condition to describe tidal mixing. To do that, you must also describe the breaking of***

the internal waves, not just their generation. If, because of insufficient resolution, they decay by viscous dissipation instead of by breaking, the mixing is not captured.

AR: In our research, we cannot describe the breaking of internal waves in the model. We believe this is a common challenge to an Ocean General Circulation Model (OGCM). Klymak and Legg (2010) raised a parameterisation of internal wave breaking. However, this is not generally applied in an OGCM simulation. In our research, the mixing of tides is considered by the vertical shear of baroclinic tides.

Klymak, J. M., & Legg, S. M. (2010). A simple mixing scheme for models that resolve breaking internal waves. Ocean Modelling, 33(3-4), 224-234.

RC: ***It is unclear how the tidal motion in LSTIDE leads to vertical mixing, i.e. larger vertical diffusivity.***

AR: The model applies the KPP scheme (Large et al., 1994), in which vertical shear is decisive to the mixing in the interior of the ocean. Thus, the vertical mixing in LSTIDE is considered by the vertical shear of baroclinic tides.

Large, W. G., McWilliams, J. C., & Doney, S. C. (1994). Oceanic vertical mixing: A review and a model with a nonlocal boundary layer parameterization. Reviews of geophysics, 32(4), 363-403.

RC: ***In Figs 3-6 the hydrography in the simulations is compared to the observationally based data set WOA18. The results are mixed, and the differences between the different simulations are generally small compared to the bias of the control simulation. It is clear that neither CVTIDE nor LSTIDE gives any decisive improvement, and the improvements that exist in some regions may well be for the wrong reason. For example, biases caused by the background diffusivity, the K-profile parameterisation or the GM-parameterisation might be compensated by the parameterisation of tidal mixing. It is therefore difficult to draw any conclusion at all from these figures. CVTIDE and LSTIDE should instead be regarded as sensitivity tests, and the interesting question is not whether they decrease the bias, but how they modify the hydrography compared to NOTIDE.***

AR: Thanks for this comment. We agree that KPP and GM might be compensated by either CVMIX_TIDAL scheme or tidal motions. We will change this expression and focus more on how they modify the model results instead of decreasing the biases.

RC: ***The key to understanding the effect on hydrography is the vertical diffusivity. Its geographical distribution is shown in Fig 12, but this should be complemented by plots with the vertical profile of the diffusivity, along with the vertical hydrographic profiles.***

AR: Thanks for this comment. We will add the vertical profile figures in our revision.

RC: ***In my view, the clearest and most interesting effect in LSTIDE is the strongly increased strength of the overturning cell in the North Pacific seen in Fig 11f. What evidence shows that this is an improvement?***

AR: Figure 3 shows that LSTIDE improves the temperature results because of the PMOC cell in the North Pacific. By comparing Fig. 3d and 3f, the intermediate layer of the North and Equatorial Pacific shows model biases in NOTIDE are reduced. By comparing Fig. 3g and 3i, the cold biases in the Pacific Ocean are reduced in LSTIDE. In Fig. 5c, the temperature biases in the Pacific Ocean is reduced at 1000–3500 m. Fig. 6e also shows significant temperature bias reducing below 1000 m.

RC: ***To explain the increased strength of the overturning cell in the North Pacific, the authors invoke the increased vertical diffusivity at the Kuril Ridge and Aleutian Ridge seen in Fig 12l and probably caused by trapped internal tides. This might be correct, but no strong support for this explanation is shown. Here***

are some problems. i) According to Fig 12 the vertical diffusivity in the Northern Pacific increases much more in CVTIDE than in LSTIDE, and yet there is much less upwelling in CVTIDE. In order to make the explanation credible, the pattern of vertical diffusivity (geographical and vertical) in the Northern Pacific should be studied in detail. ii) The strong diffusivity could be caused by resonant trapped waves, but it could also be caused simply by strong shear of the barotropic tide caused by bottom friction on the continental shelf. It should be possible to check which alternative is correct.

AR: Thanks for this comment. As to point (1), we think that changing vertical diffusivity in the model has a much slower response compared to the tidal dynamics itself. Three hundred years might be long enough for dynamic processes, but not for thermodynamic processes. This is also why CVTIDE does not show mixing as strong as LSTIDE in the North Pacific. As to point (2), we cannot distinguish the two factors now and our research needs more add-on work.

RC: ***In section 5.2 it is argued that the stronger AMOC in LSTIDE is caused by increased upwelling in North Pacific and the Indonesian Archipelago. This seems far-fetched. An alternative explanation is that it is caused by increased vertical diffusivity in upper 3000 m of the Atlantic itself, but this is difficult to judge since vertical diffusivity profiles are not shown.***

AR: Thanks for this comment. We will add the diagnostic of vertical profile in the Atlantic Ocean in our revision.

RC: ***The energy diagnostics in Table 3 are potentially interesting, but unfortunately incomplete. The surface energy input, bottom drag, viscous dissipation, buoyancy flux and barotropic tide power are terms in the budget for kinetic energy. However, the budget is far from closed, particularly in LSTIDE. (Note that the sign of the buoyancy flux should be changed when calculating the budget, since a positive*** ρw ***is a conversion from kinetic energy to potential energy, i.e. a sink of kinetic energy.) It is striking that the barotropic tide power in LSTIDE is much larger than the increase of the sinks. The main missing term is probably energy loss due to horizontal viscosity, which should therefore also be diagnosed. If there are no more missing terms, the remaining residual will then be due to numerical errors. This is essential to know.***

AR: Thanks for this comment. We will complete the energy diagnostic parts in our revision, especially horizontal viscosity and kinetic–potential energy conversion.