

Interactive comment on “Exploring the isopycnal mixing and helium-heat paradoxes in a suite of Earth System Models” by A. Gnanadesikan et al.

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We thank the reviewer for very thoughtful comments which we believe will certainly help to clarify and improve the manuscript.

The isopycnal mixing paradox: theory suggest that isopycnal mixing is small ($O(10^2)$ m^2/s) in the ocean interior, but direct observations suggest values closer to $O(10^3)$ m^2/s . Calling this a paradox is a bit of a stretch, but okay.

The common thread here is that there is a contradiction between the constraints placed by large scale budgets and underlying geophysical understanding (geothermal heat flux/radiative heating, water mass transformation rates/relationship between A_{GM} and A_{Redi}) and the actual measurements. We thank the reviewer for pointing out that this

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could be more explicit.

pg 2534, In 11-14: This sentence, "Because helium isotopes equilibrate rapidly with the atmosphere, but radiocarbon equilibrates slowly, it might be thought that resolving the isopycnal mixing paradox in favor of the higher observational estimates of A_{Redi} might also solve the helium paradox", is problematic. First, the second clause does not logically follow from the first?unless, perhaps, one invokes several unstated assumptions. It would be helpful to state the logical chain more explicitly

We will replace the sentence with the following.

Helium isotopes equilibrate rapidly with the atmosphere and thus exhibits large gradients along isopycnals while radiocarbon equilibrates slowly and thus exhibits smaller gradients along isopycnals. Thus it might be thought that resolving the isopycnal mixing paradox in favor of the higher observational estimates of A_{Redi} might also solve the helium paradox, by increasing the transport of mantle helium to the surface more it would radiocarbon.

p2537, In 16: the isotopic equilibration is further slowed beyond just CO_2 because it depends on gross, not net, gas exchange.

Agreed. This sentence will be added in the final version.

p2537, In 25-26: "The [highest] radiocarbon is found in the North Atlantic...", i.e. the most freshly ventilated waters.

Actually equilibration is as important as ventilation here. Ideal age shows a much smaller difference between the Atlantic and Southern Ocean. We will add the following statement to the end of the sentence.

"where freshly ventilated waters have also equilibrated with the atmosphere."

p2546, In 10: change "data" to "observations" or similar?use of data to mean observations is a colloquialism and confusing (apply this change throughout). I am not sure I

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understand the statement, "The plot is cut off above 1000 m as all the models overlie the data for these depths." Is the cut-off at 100 m?

We will change "data" to "observations" as suggested. The reviewer is right that this sentence is incorrect. It should read

"The horizontal axis is cut off at 12C (corresponding to a depth of around 200m) are not shown in order to highlight the differences at depth, as all the models agree with observations at warmer temperatures and shallower depths."

Fig. 4: How close to equilibrium are these tracer profiles? OCMIP specifies a criterion for radiocarbon equilibration; do the experiments (both the control and branches) meet this? Add a statement quantifying drift.

This is a good point, see language that will be added above for point 2 of reviewer 1. However, it should also be noted that the OCMIP criterion will in general not be met for coupled climate models as the OCMIP2 runs tended to use surface forcing which did not include climate variability. Unfortunately, running the models for 10,000 years is not something that is feasible for coupled climate models (our spinup is already longer than the majority of experiments in the IPCC).

p2547, In 3-5: What about diapycnal mixing?

"Vertical overturning" was meant to include both advective and diffusive exchange. We will replace it with "vertical advective and diffusive exchange".

p2547, In 19-20: Is 14C tracer being directly mixed down by isopycnal mixing, or does the increased isopycnal mixing reduce stratification, thereby removing the surface diapycnal mixing bottle-neck?

It depends on the simulation. We will add the following sentences.

The differences between the AREDI400 and AREDI800 run are largely due to an increase in the gradient between the Southern Ocean and North Pacific, with the South-

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ern Ocean values of radiocarbon remaining relatively unchanged, suggesting that lateral transport is important here. However, the differences between AREDI1200 and AREDI2400 and AREDI800 show the impact of decreases in high-latitude stratification (particularly in the North Pacific) as well.

Fig. 5: there is an inconsistency between the caption (little delta) and figure labels (cap delta).

Thanks for catching this. We will fix the caption.

p2551, near In 25: do all passive tracers have the same (eddy) diffusivity?

This is generally assumed to be the case, though it is not clear that it should be in the presence of spatially distributed sources and sinks. A statement to this effect will be added to the final version.

Interactive comment on Ocean Sci. Discuss., 11, 2533, 2014.

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