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Ocean Science Discussions

OSD

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Interactive Comment

Interactive comment on "Geothermal heating, diapycnal mixing and the abyssal circulation" *by* J. Emile-Geay and G. Madec

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Thank you very much for insightful reviews of our work. Following your suggestions, the manuscript has been extensively reworked to exclude the faulty sections (scaling law, Sverdrup balance) and expand on the uncertainties regarding geothermal heating.

Answer to General Comments : A) GH Uncertainty. You are asking for work in an area of solid Earth geophysics that has bred much controversy. We believe a proper error analysis should use a Bayesian hierarchical model and recognize the low-biased nature of crustal heat flow measurements, which is beyond the scope the paper. A new section has been added to discuss those uncertainties, but cannot get meaningfully quantitative without a much more in-depth study.

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B) Very good point. We followed your advice and only kept the subsection establishing the parity between geothermal heat flux and turbulent mixing.

C) This section was removed.

Answer to Specific Comments:

1. Unit consistency fixed

2. What matters is not so much the location of the heating but the residence time of seawater along regions of high heatflow, which explains why the thermal response is consistently higher in the North Pacific. (cf “In addition, the region exhibits a marked horizontal recirculation in the interior (not shown), allowing bottom water to feel the influence of geothermal heating for a long time”).

3. See new section 2

4. Replaced by “Their surface is quite large, though, especially East of Australia and Indonesia. Over such regions, the flux was nearest-neighbor interpolated”;.

5. This notation is defined in the text

6. fixed

7. Replaced by “Averaging on the global scale, a geothermal heating of 86.4 mW.m-2 is seen equivalent to a mean diapycnal mixing rate of $10^4 m^2.s^{-1}$ (the reason for the difference with the previous diagnostic is due to the non-commutability of the average and inverse operations). We are thus brought to the conclusion that, far from being negligible, geothermal heating is an essential term in the heat balance of the abyssal ocean”. 8. 9. 10. 11. irrelevant as the section was removed.

12. replaced by “An apt metaphor...”;

13. Yes, it is α_θ. Fixed in the text.

14. An OSD typesetting mistake...

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15. line now reads : Fig 5b displays the area of the seafloor that is covered by each isopycnal layer (i.e. water masses whose density falls between σ and $\sigma + \Delta\sigma$, with $\Delta\sigma$ the binning interval as before).

“Although it is seldom discussed, strong artificial temperature drift is ubiquitous with ocean circulation models, particularly those forced initially by a climatology. Did the Authors notice a difference in equilibrium time between the different model runs?”. This difference in equilibrium was not noticed, but the inclusion of geothermal heating does quite a bit to correct the ubiquitous cold bias in the climatological bottom water temperature of our GCM, and, we assume, many others. Re:eqn 4 re-arrangement : thank you for this sound explanation which we added to section 5.4.

16. fixed

17. geothermal “heating” : fixed

18. this explanation was added to the revised manuscript.

19. fixed

20. fixed

21. Replaced by “...enables quantification...”;

22. There is no bottom boundary-layer in this model: the heating is spread across the entire bottom layer, but this should not alter the essential physics of the problem, which do not rest on bottom intensification.

23. We respectfully disagree. Here we have considered diapycnal mixing as a deus ex machina that can be changed at will, independently of energetic constraints. It is important to point out that in nature, the mixing process will also depend on the amount of potential energy available, which is influenced by geothermal heating (Huang , 1999).

24. We now write “The case is hereby made that geothermal heating is an important actor of abyssal dynamics. We recommend its inclusion in every model dealing with the

long-term ocean circulation, for it substantially alters bottom water mass characteristics and generates a non-negligible circulation in the present-day climate. Recent results by Dutay et al (submitted) confirm its importance in correctly simulating tracer distributions in the deep ocean. The case corresponding to STD_Qvar appears to be the most relevant to most users, but it would be most interesting to prescribe in conjunction with state-of-the-art parameterizations of diapycnal mixing. Data for the spatially variable heatflux (Fig 1) are available upon request.";

25. fixed

26. fixed

27. fixed

28. See new Table 3

29. See new Table 3

30. It is a zonal average. The legend now makes it clear.

31. Fixed

32. Figure was cut out, as the rest of the section.

Interactive comment on Ocean Sci. Discuss., 5, 281, 2008.

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