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Climate of the Past Discussions

Interactive comment on "A simple mixing explanation for late Pleistocene changes in the Pacific-South Atlantic benthic δ^{13}C gradient" *by* L. E. Lisiecki

Anonymous Referee #2

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Lisecki presents a nice analysis of the deep water carbon isotope records over the past 800,000 years. While the fact that there is a reversal in the d13C values between the Pacific and Southern Ocean during glacial times has been known for quite some time, Lisecki presents a compelling argument that the Pacific record can be explained as a relatively constant proportion of low nutrient (presumably NCW) and high nutrient (presumably SCW) end members accompanied by a relatively constant offset due to subsurface regeneration of carbon. I think this analysis was carefully done and should be published in Climate of the Past. However, I think the focus on refuting a North Pacific circulation change is a bit of a straw man argument. Most now would call on an isolated Southern Ocean deep water mass rather than North Pacific Deep Water

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formation in order to explain the reversal. I would like to see a more detailed discussion of this prevailing paradigm and how the data analysis presented here supports/refutes it. I would also like to see a more thorough discussion and justification of the possibility of Intermediate/Deep water mixing in both the Atlantic and Pacific.

A. Can GNAIW be the NCW end member?

If there is deep water mass divide in the glacial ocean at around 2 km, can GNAIW be considered the NCW end member for deep waters? Curry and Oppo (2005) argue that there is sufficient mixing down of GNAIW to explain why deep waters in the glacial North Atlantic are so isotopically enriched (-.2 per mil) relative to pure (-0.8 per mil) SCW. Matsumoto and Lynch-Stieglitz [1999], Raymo et al [2004] and Millo et al [2006] suggest there may have been contributions of overflow waters from the GIN sea directly ventilating the deeper waters (>2 km) in the N. Atlantic. I really don't think there's enough information to distinguish between the two possibilities at present. The author seems to implicitly favor the first interpretation for ventilating the deep Atlantic but doesn't like the idea of such intermediate/deep mixing occurring in the Pacific.

Specifically, on P 2612 Line 11-15. The author says she will focus on Pacific Deep Waters >2.5 km where GNAIW is unlikely to be a contributing factor. Then why is the NCW end member taken to be GNAIW? It seems like this is completely contradictory statement. In fact she concludes that GNAIW is indeed a big contributer (60%)! Clearly I'm misreading this paragraph... but I can't imagine another interpretation.

More generally, the author mentions the sharp d13C/d18O gradient in the mid-depth Pacific (p 2616 lines 20-25), and uses it to argue against an intermediate water source for the high d13C component of the deep Pacific. However, a similar water mass divide exists in the Atlantic (Curry and Oppo, 2005), and indeed the Indian Ocean. The author has to explain why she feels this is a barrier to mixing in the Pacific, but not in the Atlantic where the GNAIW NCW is introduced to the deep ocean.

It also appears that when all tracers are accounted for (not just d13C), intermediate

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waters make up a very significant portion of today's deep water in the Pacific (See Johnson [2008]and references therein).

Of course, it is possible that the glacial ocean was more stratified, and GNAIW and other intermediate waters could not mix into the deep ocean and form a significant component of deep water. In that case, it seems that the possibility of continued deep water formation in the North Atlantic should be considered (eg. Matsumoto, Millo, Raymo papers cited above). The analysis could be then repeated with GIN Seas cores or perhaps cores > 2.5 km in the Atlantic for a NCW end member.

So the author seems to be having it both ways–deep and intermediate water can mix in the Atlantic but not in the Pacific. I think this choice either has to be justified (more Atlantic mixing because of basin geometry? Weaker stratification? Longer residence time? Other?), or one has to allow for mixing down of intermediate waters in both basins (consider AAIW and NPIW) or in neither (use overflow water as the NCW end member not GNAIW and only consider the deepest waters).

B. What is the Nature of the SCW End Member?

The whole set up of the paper is that the assertion that the lowest d13C values in the glacial ocean are usually explained by ventilation in the North Pacific. This may have been true at some point and indeed is suggested in some papers that are referenced. But I would say that at this point the prevailing paradigm to explain the reversal is not that the Pacific ventilation changed, but rather that the Antarctic ventilation changed, i.e. the postulation of a very isolated, dense, low d13C, low radiocarbon, high salinity water mass of Adkins et al [2002], Hodell et al. [2003], Marchitto et al [2007], Toggweiler et al [2006], etc. I was surprised to find this idea mentioned only at the end of the discussion. It should be right up front in the introductory material.

Because this prevailing paradigm relies so heavily on the data presented in Adkins et al., 2002, I think you need to specifically address how your components of deep water relate to theirs. In other words does 60% GNAIW + 40% deep southern ocean water produce the deep water below 2.5 km in the Pacific this study? It seems from their Figure 2 that a much weaker SCW contribution is implied. I'm not sure this data is more reliable than yours, but the contradiction should be noted.

To me, the data presented here seem to require two conclusions (1) Not much of change in Pacific contributions and aging and (2) Big changes in aging of SCW. To me these are both equally important. Why emphasize (1) but not (2)?

Today, AABW forms from upwelled CDW, a mixture of NADW and aged returning deep waters from the Pacific. It gets a boost in d13C due to air-sea exchange without much change in nutrients.

The d13C balance for the Pacific is written as if it is a one way street:

NCW + SCW + remineralization => Pacific.

In reality the arrow goes both ways, with the Pacific contributing to the Antarctic balance:

Pacific + NCW + remineralization/uptake (not much today)+ Airsea xchange => SCW.

If you keep the remineralization and air-sea exchange terms constant, this doesn't work for the glacials! So you are really stuck explaining WHY the SCW has such low d13C values. Two scenarios are proposed in the paper–increases in productivity and stagnation of AABW (both leading to a bigger remineralization term during glacials). If you accept the d13C at face value (as opposed to a productivity overprint) in my mind there's no way to do this without invoking a deep ocean circulation change. Maybe not NPDW formation, more likely an isolated dense water mass in the SO. This is considered in the last paragraph of the discussion. But why not bring it up front? It is a first order result that must follow if the stacked records are truly representative.

C. "Old" vs. "Young" definition

On p. 2609 Line 6 and Bottom of p 2619, top of 2620 it is not clear how "age" "old"

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and "young" are defined. In your definition are the SCW "old" because they haven't exchanged carbon isotopes (and presumably radiocarbon as well) with the atmosphere? Or are they "young" because they exchanged heat with the atmosphere? Is the age defined as time since the water saw the surface? Or radiocarbon age (time since it fully exchanged carbon isotopes w/ atmosphere)? It would also help if "c" was consistently referred to as a remineralization offset not an "age offset". I think I understood what was meant in most circumstances, but sometimes I first read the sentence wrong until it was later made clear that the author was using a different definition of "age" than I was.

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