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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

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This paper addresses a mystery regarding the way that the Earth's climate varies between its glacial and interglacial states. The mystery in this case concerns the location of the d13C minimum, a marker for the part of the deep ocean that is most isolated from the atmosphere. The d13C minimum in today's ocean is found in the deep North Pacific. During the Last Glacial Maximum (LGM) the d13C minimum was located in the deep South Atlantic and southern Indian.

The modern location of the d13C minimum is easy to understand because the deep North Pacific is the part of the ocean that is most remomte from the regions of ventilation in the North Atlantic and the perimeter of Antarctica. The fact that the d13C minimum shifted to the South Atlantic/southern Indian during the LGM is not easy to understand because the deep North Pacific remained isolated. To be sure, the ventilation around the perimeter of Antarctica was weakened or was cut off entirely. But how did the deep North Pacific manage to become less isolated than the South Atlantic and southern Indian, which are so much closer to the North Atlantic?

This conundrum has led some to postulate that ventilation must have been going on in the glacial North Pacific that has either not been detected or that differs substantially from the kind of ventilation seen today. Here, Lisiecki makes a detailed comparison between stacked d13C records in the North Pacific, Southern Ocean, and North Atlantic and argues that there has been no extra ventilation in the North Pacific at any time over the last 800,000 years because the fractions of northern component (i.e. North Atlantic) and southern component water in the deep Pacific seem to have been the same through this entire time period.

Figures 1 and 2 show that southern deep water became depleted in 13C by 1 per mil or more during all the glacial stages of the last 800,000 years. This depletion makes Lisiecki's southern component water lighter in 13C than the water in the deep Pacific. Nevertheless, the deep Pacific seems to have been filled with the same fractions of northern and southern water. This means that Lisiecki's southern component water continued to act as a source of water to the deep Pacific even when it was not being ventilated. This, it seems to me is the real problem, as oceanographers tend to assume that a source of deep water is always a ventilated source.

A couple of years ago, I published a paper (with co-authors J. Russell and S. Carson – Toggweiler et al., Paleoceanography, 2006) in which we described an idealized ocean GCM that, among other things, simulated the d13C shift from the North Pacific to the South Atlantic. The model, it seems to me, did what Lisiecki calls for and it yields, perhaps, a bit more insight as to the nature of the unventilated southern component water during glacials.

The model generates a ventilated source of deep water in its "Weddell Sea" that turns on and off over the course of a model run. We equate the 'on' state with the modern ocean and the 'off' state with the glacial ocean. Figure 10 in our paper shows maps of the mid-depth d13C distribution in the model in the "modern" and "glacial" states. It shows that the water in the South Atlantic near Antarctica is 1 per mil lighter in d13C when the source of ventilated water in the Weddell Sea is off and is also 0.2 per mil lighter than the water in the d13C minimum zone of the North Pacific. Thus, the model managed to reproduce the observed shift of the d13C minimum with a simple on-off switch.

The key to this result is that dense water continues to form near Antarctica when the ventilated source in the Weddell Sea turns off. Indeed, the model would seem to have no choice in the matter, as the ocean has to have a supply of dense water somewhere around Antarc- tica so that the Antarctic Circumpolar Current (ACC) can continue to flow toward the east in the same direction as the wind. The glacial source in our model consists of deep convection in a single grid cell in the Pacific sector. The convection, in this case, allows the subsurface water around Antarctica to give up heat to the atmosphere but the area of convection is too small to allow the gas exchange in the model to alter the CO2 and d13C contents of the convecting water.

Thus, the southern component water in the model remains denser than the water north of the ACC but is essentially unventilated with respect to CO2 and d13C. The real ocean did not solve the problem in exactly this way but it did apparently do something similar by producing dense water that had little or no contact with the CO2 in the atmosphere.

As is fairly clear in our Figure 10, mid-depth water north of the ACC in the South Pacific remains quite a bit heavier in d13C than the water around Antarctica because high-d13C NADW continues to flow into the Pacific around the tip of Africa along the northern edge of the ACC. Mid-depth water in the North Pacific remains a bit heavier because it has some contact via mixing with high-d13C intermediate waters that form

locally in the North Pacific. This level of intermediate-deep contact remains the same in the model whether the ventilated source in the Weddell Sea is active or not. It is simply not as apparent in the 'on' state when the Southern Ocean is also supplying high-d13C water to the deep Pacific.

Intermediate waters are similar to NADW in having a relatively high d13C content. If the intermediate influence in the North Pacific remains constant with time in the real world, as it does in the model, it would not be distinguishable in the kind of analysis being performed by Lisiecki in this paper.

In summary, Lisiecki is giving us an important new result in carrying the d13C-minimum story back 800,000 years. I would submit, however, that the discussion in her paper is rather unfair in regard to the insights that Russell, Carson, and I pulled out of our idealized model back in 2006.

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