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Climate of the Past Discussions

Interactive comment on "Changes in the geometry and strength of the Atlantic Meridional Overturning Circulation during the last glacial (20–50 ka)" *by* P. Burckel et al.

Anonymous Referee #1

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In their manuscript "Changes in the geometry and strength of the Atlantic Meridional Overturning Circulation during the last glacial (20-50 ka)", Burckel et al. use 231Pa and 230Th ratios and 13C to assess the past state of deep ocean circulation in the Atlantic Ocean at several intervals during the past glaciation. After attempting to assess the geometry and strength of the overturning cell of the Atlantic, they conclude that the deep ocean circulation was very different from the modern in all four of their study intervals. The interstadial circulation was different in being relatively shallow, with a deep inflow from the south. Southward flowing waters at mid-depth would therefore have been the return flow of southern-sourced waters. At the time of Heinrich Stadial 2, yet another different circulation is inferred, with southern waters filling the deep Atlantic

and a slow, southward-flowing water mass occupying the intermediate depths.

This is a potentially valuable contribution to the literature on past states of the ocean circulation. It presents new geochemical data in a spatial array that may provide insights into changes at different depths and locations. The isotopic method is a promising and exciting approach, although it seems still in development in comparison to modern measurements. The data are compared to model output, which although limited in resolution and lacking a third dimension, nevertheless provides useful constraints on potential interpretations. The conclusions are not inconsistent with the relatively limited data presented.

In terms of the specific criteria, the paper certainly addresses relevant questions within the scope of CP. It does not present novel approaches, but builds well upon existing techniques, data, and ocean modeling output. Substantial conclusions are reached regarding the configuration and rate of ocean circulation. The conclusions are not inconsistent with the data, although there are too many gaps at relevant locations and depths for them to be any more convincing than many alternatives which are not discussed. Figures are relatively clear, and text is a reasonable length. The text is fluent and the authors give adequate credit to the previous studies that they utilize and discuss.

The two largest issues with the paper in its present form are related to its justification and chronology. This is a study of four time slices that are widely distributed within the last glacial. They are neither the most extreme, nor the most characteristic. Nor do they include important transitions or intervals of special climatic interest. It is therefore not clear to the reader why this seemingly arbitrary assortment of time slices was chosen. The authors should provide a much better explanation of the rationale for their selection. It is possibly related to what may be understandable difficulties with a challenging geochemical method, although others, notably Hall, also Negre, McManus, Lippold and Böhm have demonstrated that it is possible to produce continuous highly resolved records of the same isotope systems for specific intervals. Or it may be related to the

quality or continuity of the sediment cores. These are acceptable reasons if they are confronted and explained, although it would be most satisfactory if some greater level of scientific rationale were presented. This is currently inadequate, beyond the mention of an interval that was not included. A section of a paragraph or two that would better explain the reasons for the scattered data intervals might seem to the authors to be an acknowledgement of a shortcoming, but in the end it would increase the interest and potential impact of the published study.

The issue of chronology may be even more crucial, as the authors draw potentially important conclusions about intervals that do not appear to coincide with their data exactly, or in one crucial instance, at all. Figure 3 makes this very clear. None of the shaded intervals truly represent interstadials. The red shaded intervals all cover some portion of one interstadial or another, but the oldest begins at the peak of GI10 and extends beyond the peak of the next stadial, the subsequent shading covers solely a portion of the transition from GI 8 to the next stadial, without including the interstadial peak at all, and the youngest of the three is the only one to cover the entire interstadial GI3, but also includes two times as much duration of full stadial conditions. This does not appear to be just a drafting issue, which might be easily remedied. The shading is well aligned with the sediment data, which largely do not coincide with the ice core evidence. In the case of the fourth time slice, HS2, the blue shading in Figure 3 aligns well with the new data, until there is an abrupt data gap above the most extreme values, apparently due to a turbidite layer. But the shaded interval is centered on 26 ka, when the published age for HS2 is more than one to two thousand years younger (Naafs et al., 2013, Hodell et al., 2008, Hemming, 2004). Because this interval is well dated, it seems that the new data are older than HS2, which might instead correspond and even be related to the turbidite interval. A related question is how there appear to be data from this same interval, which is presented as a several thousand year gap in the supplemental figure S2.

The authors very reasonably identified intervals of stability in the circulation based

on their data, to make the most informative comparison with the model results. These choices did not lead to direct comparisons with the Greenland climate variations, which they accurately describe as important intervals for which the past circulation is not fully or well understood At the very least these chronological issues should be confronted. If they can be adjusted or adequately explained, it will greatly enhance the significance of this study.

Specific comments-

As mentioned in the introduction, the 13C data should have complications due to carbon cycling as well as ocean circulation. These can also be better addressed when interpreting the different time slices, and may help to explain differences in the data not due to circulation.

The authors describe an important change at the onset of HS2. Aside from the chronological issues, do they infer that the observed changes relate only to the HS2 interval, or do they establish the LGM condition that is the focus of so many studies?

If it was only during HS2, was the configuration and strength then different from LGM?

The changes at various depths appear to be under-constrained by the data, in particular because some time slices utilize four sites and others more, but never more than six locations, and no two time slices utilize the same set of locations. This limits the confidence bounds possible in the interpretations, and must allow other consistent alternatives, which should be mentioned and possibly discussed.

The contrast between the inferred interstadial mode and HS2 mode appears to be related to which direction the waters were moving below 2500 meters. Does that mean that the deep Atlantic was influenced by southern source waters below 2500 in both scenarios?

Many schematic and model representations of the deep Atlantic display a boundary between northern and southern waters that is inclined as a function of latitude. Do the

authors consider that also to be possible in their reconstructions?

The presented model shows that boundary to slope deeper to the south in the Holocene, which might suggest that northern waters influence more of the volume of the south Atlantic than the north. Perhaps this can be explained and clarified for those less familiar with this type of geochemical modeling.

Is the southward flowing mass at intermediate depth GNAIW? Several studies mentioned have inferred a vigourous circulation by this water mass, at least at the LGM. The contrasting conclusion of a sluggish intermediate circulation here is largely based on 13C from the productive equatorial region. Nevertheless, it would be useful to have a more direct discussion in the context of previous interpretations.

Technical points with page and line numbers-

p4 l4 THE GeoB3910 age model

p10 l25 values measured in the deep equatorial core during HS2 ARE consistent

Fig S4 Two panels compare similar data, yet are presented in very different ways.

Fig S4, S5 Should show r2 values.

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