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Atlantic ocean circulation during the Last Glacial Maximum: What do we know?

W. Curry (1), **O. Marchal** (1), C. Wunsch (2), and P. Huybers (3)

1. Woods Hole Oceanographic Institution, USA (omarchal@whoi.edu / Fax +1 508 457 2187)
2. Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, USA
3. Department of Earth and Planetary Sciences, U. Harvard, USA

Marine sediment cores are the only avenue to extend the relatively short record of direct oceanographic measurements in the water column to the periods of climate change of the geological past. The ratio of carbon-13 to carbon-12 (hereafter δ^{13}C) in fossil shells of benthic foraminifera picked from surface sediments have been shown to reflect the δ^{13}C of dissolved inorganic carbon in the overlying bottom water (e.g., r = 0.94; n = 67 for the benthic genus *Cibicides*). A recent compilation of benthic δ^{13}C data for Atlantic sediments deposited during the Last Glacial Maximum (LGM, a time interval centered near 21,000 years ago) confirms an earlier inference, based on a less abundant data set, that the distribution of δ^{13}C during the LGM was very different from the modern one. Most notably, waters below a depth of ca. 2000 m were characterized by lower δ^{13}C values and waters above that depth were characterized by higher δ^{13}C values.

Here we use an inverse method in order to evaluate whether the δ^{13}C data for the glacial Atlantic require a circulation different from the modern one. More specifically, we test the null hypothesis (H0) that these data *are* consistent with an estimate of the abyssal circulation in the modern Atlantic based on (i) the WOCE hydrographic climatology, (ii) estimates of volume transport at specific locations, and (iii) the dynamical constraints provided by a nonlinear geostrophic finite-difference model of the time mean flow. We find that H0 must be rejected at the 5% confidence level, i.e., the δ^{13}C distribution in the glacial Atlantic as inferred from the isotopic composition of fossil shells of glacial age is inconsistent with our estimate of the modern flow. We identify geographic locations where the largest misfits of the glacial δ^{13}C values with the modern flow occur and thus where additional δ^{13}C measurements would increase the power of the test: the largest positive (negative) adjustments needed to bring into consistency δ^{13}C with the modern flow occur at 3750 m (1000 m) in the western North Atlantic. On the other hand, we find that the δ^{13}C distribution as inferred from the isotopic composition of fossil shells of more recent age (the last 3000 years) is consistent with the modern flow. It is argued that our approach provides a rigorous basis for the quantitative interpretation of paleoceanographic observations for the LGM – a climatic extreme of the recent geological past.