Report from Breakout Group: Temperature, salinity, oxygen isotopes and density

Present: Stephen Barker, Andrey Ganapolski, Joel Hirschi, Camille Levi, Jean Lynch-Stieglitz, Michael Sarnthein, Matthew Schmidt

This group assessed the methods and data necessary for reconstructing past ocean density. Seawater density combined with the assumption that the large-scale flow of the ocean is in geostrophic balance provides a powerful constraint for modern ocean circulation, and has the potential to play a similar role in a quantitative reconstruction of past ocean circulation. In particular, this group examined our ability to reconstruct large-scale ocean circulation from ocean margin density.

Stawman A: Reconstruct the strength of the large-scale meridional overturning circulation in the Atlantic at millennial timescales over the last 30 kyr with an estimate of the associated error

It was generally agreed that, in theory, if we had records of ocean density at millennial time resolution on both sides of the Atlantic ocean basin at a variety of latitudes, the strength of the overturning can be reconstructed with a fairly high degree of accuracy. It was also noted that if we were only able to obtain such detailed records for the top 2 km of the ocean basin, and at a limited number of locations, the strength of the overturning could still be constrained to some degree. Joel Hirschi plans further studies to assess the minimum data density necessary for such a reconstruction.

Density of seawater can be estimated from the $\delta^{18}O$ of foraminiferal calcite if the relationship between T-S- $\delta^{18}O_{water}$ is known. Mg/Ca ratios in foraminifera can potentially help constrain the T, and combined with $\delta^{18}O$ measurements can constrain the T- $\delta^{18}O_{water}$ relationship. T and $\delta^{18}O$ reconstructions for surface waters at a range latitudes can be used to help constrain these relationships through the thermocline. At present the only known way to constrain the relationship between salinity and $\delta^{18}O_{wate}$ is by measuring Cl and $\delta^{18}O$ in pore waters. This can provide and estimate of changes in this relationship between glacial and modern times, but the nature of diffusion prevents the direct assessment of this relationship on millennial timescales.

Is the current data coverage sufficient? No. There may be sufficient coverage to make an estimate at lower time resolution (LGM, for example), but there are not existing, well dated benthic $\delta^{18}O$ records at millennial timescales at a variety of depths along the Atlantic margins. A synthesis of existing LGM $\delta^{18}O$ data from the Atlantic is recommended.

Strawman B: Reconstruct large scale water mass distribution and circulation for the global ocean during LGM (19-23kyr)

Ocean margin density can potentially be used to reconstruct the world ocean circulation. Particular challenges in the Southern Ocean include the influence of sea ice formation on the T-S- $\delta^{18}O$ properties of the oceans densest seawater along the Antarctic margin and

the barotropic component of the ACC. Challenges in the Pacific include the greater role of the wind driven circulation relative to the surface to deep overturning in oceanic heat transport as well as the larger impact of the wind driven circulation on upper ocean margin density. However, it was concluded that the existing cores and the good potential for collecting additional sediment cores from critical locations make a global circulation estimate for the LGM a realistic goal. It was also noted that if we expect (and find) small changes in Pacific Ocean circulation, a more geographically limited sample set may be sufficient for confirming the lack of change vs. constraining a completely different circulation regime.

Is the current data coverage sufficient? No. There may be sufficient data in the Atlantic Ocean for a LGM reconstruction, but certainly not in the other ocean basins.

What method developments are necessary for wider/more effective coverage?

- Determine minimum data network for reconstruction of circulation from ocean margin density using forward and inverse modeling techniques
- Establish database for existing and future oxygen isotope and Mg/Ca measurements in foraminiferal calcite.
- Ensure proper inter-laboratory calibration of $\delta^{18}O$ and Mg/Ca measurements. This will be critical for reproducing the small gradients across the ocean basin.
- More widespread application of pore water methods to more fully constrain past T-S- $\delta^{18}O$ is necessary. It is not clear what needs to happen to make the collection of these samples routine. In particular, it is urgent that the high salinity of the LGM deep Southern Ocean be confirmed at an additional location.
- Further development of the Mg/Ca temperature proxy for benthic foraminifera. This will be particularly necessary if we want to infer the heat flux as well as the mass flux changes associated with the MOC