Project: **975**

Project title: **OCTANT – Modeling the chronology of deep ocean circulation changes during abrupt climate transitions**

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The main objective of OCTANT is investigating to what extent the temporal evolution of the ocean circulation during abrupt events may be inferred from deep-sea sediment cores. In that purpose we implemented in MPIOM isotopic ratios commonly measured in sediment cores ($\delta^{13}C$ and $\Delta^{14}C$) as well as several age tracers allowing tracking water masses and their role in ventilation. Several results of interest were obtained and are at the core of submitted or planned publications. Experiments with the fully coupled model have been delayed due to several technical problems. Among them, a conservation issue prevented the use of the full set of implemented tracers. Now that the reason for such misbehavior is identified we will resume with our initial plan and address ocean ventilation by means of transient experiments with MPI-ESM starting at the LGM.

**Radiocarbon and the record of ocean ventilation**

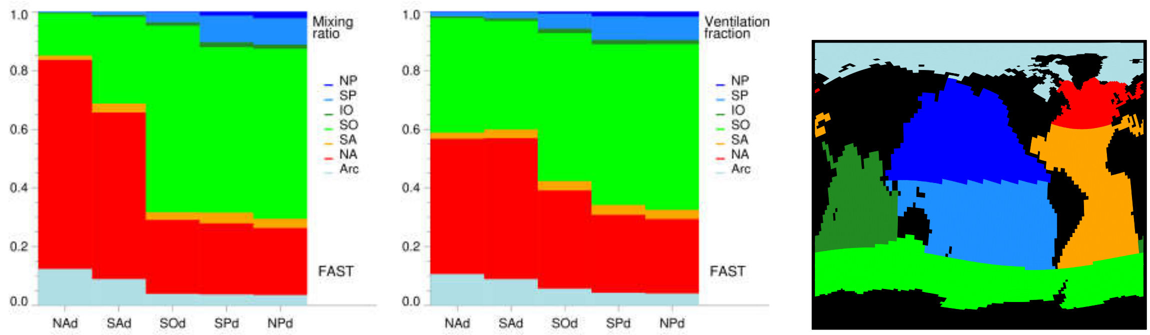
Ocean ventilation is defined as the renewal of interior waters by seawater that has been in contact with the atmosphere [1]. In models, this rate is obtained by computing the ideal age. On the other hand, radiocarbon anomalies ($\Delta^{14}C$) measured either in the water column or in deep sea cores offer one of the few ways to get estimates of present or past ocean ventilation rates. However, the interpretation of these field data is hindered by the complexity of processes controlling radiocarbon in the ocean. While ventilation age is immediately set to zero at the sea surface, radiocarbon is characterized by a slow air-sea exchange rate. The interplay between slow sea surface adjustment and transit pathways in the ocean interior results in significant differences between radiocarbon and ventilation ages [2]. By means of modeling studies with idealized age tracers we investigate the implications of such departures for the use of $\Delta^{14}C$ as a ventilation proxy.

We attribute a dye tracer to 7 ocean regions (Fig. 1). Each dye is characterized by a concentration and an age. Two experiments are conducted. In the first we impose a very large restoring coefficient at the sea-surface (FAST) as for computing the ideal age. In the second the restoring at the sea-surface is much weaker (SLOW); it is equivalent to imposing an air-sea exchange velocity of 7.5 m/yr (the global mean obtained from real radiocarbon experiments). It is worth mentioning that the distribution of the total dye age at depth obtained with this second experiment is very similar to that of the actual radiocarbon age computed with the same model. We may then be confident that dyes in this experiment may be used to interpret radiocarbon signal in the ocean.

These two experiments lead to contrasted results (Fig. 1). With FAST air-sea exchange, deep waters are mostly composed of and ventilated by two sources: the North Atlantic and the Southern Ocean. This corresponds to the classical view of the deep ocean ventilation. The picture is totally different with SLOW air-sea exchange rate. In this case, all surface regions contribute significantly to the deep water composition and ventilation. Further, the contrast between the deep Atlantic and Pacific is significantly reduced. Additional experiments with partial ages (see below) show that radiocarbon-like tracers have a larger life span in the upper ocean layers than the ideal age. This is a direct consequence of the slow air-sea exchange rate which reduces the probability that the radiocarbon clock is reset to zero in surface layers. These results put strong limitations on the practice consisting in interpreting radiocarbon signals in terms of a limited number of end-members.

**Partial ages and tracking the ocean ventilation**

Partial ages [3] record the time spent in specific ocean regions. They are of help in assessing contributions to the local ventilation. For example, Fig. 2 reproduces the age fractions or the relative contributions from the Atlantic, Pacific and Southern Oceans to the age in the Atlantic and the Pacific. Due to mixing processes there is a multiplicity of pathways. Hence, any location contributes, even slightly, to the ventilation anywhere in the ocean. Partial ages also yield information on regional flow rates. At steady-state they provide an upper limit of the mean residence time in interior regions. They also allow estimating the flushing time of these regions [4].



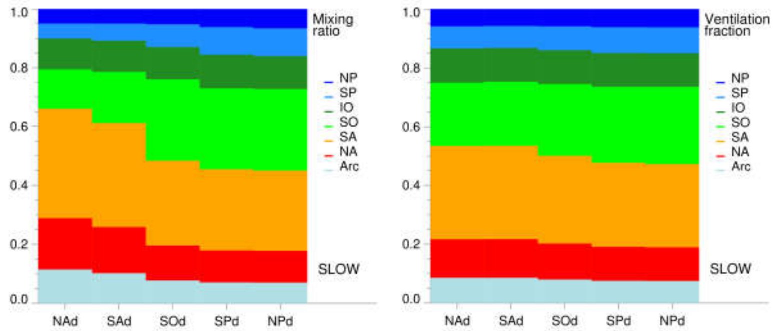




***Figure 1*** *Mixing ratio (left) and ventilation fraction (middle) in 5 deep ocean basins (X-axis) for FAST (top) and SLOW (bottom) air-sea exchange. Colors correspond to the 7 source regions outlined in the map above: Arctic (Arc), North Atlantic (NA), Subtropical and South Atlantic (SA), Southern Ocean (SO), Indian (IO), South Pacific (SP), and North Pacific (NP).*

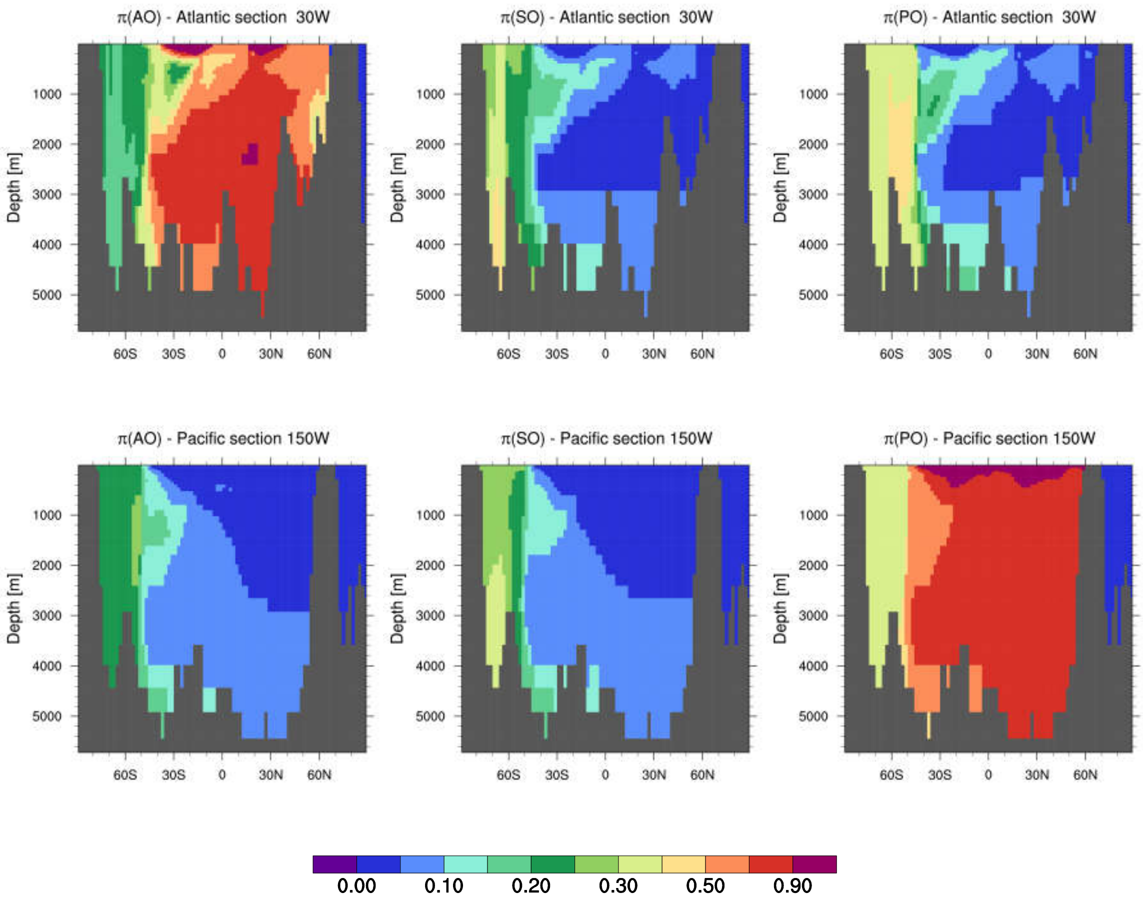



***Figure 2*** *Age fraction in the Atlantic (top) and in the Pacific (bottom).Total contribution from the Atlantic, Southern, and Pacific Oceans, from left to right, respectively. The color scale is non-linear; transitions occur at $\pi$= 0., 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.4, 0.5, 0.75, 0.9, with $\pi \leq 1$.*

**Notes and references**

All results presented here are obtained with a version of the Max Planck Institute Ocean Model (MPIOM-GR30L40) optimized for deep ocean $\Delta^{14}C$, salinity and temperature. Experiments were performed over 10 kyr with climatological (OMIP) forcing.

[1] England (1995) Journal of Physical Oceanography, doi: 10.1175/1520-0485(1995)025<2756:TAOWAV>2.0.CO;2.
[2] Campin et al. (1999) Earth and Planetary Science Letters, doi: 10.1016/S0012-821X(98)00255-6.
[3] Mouchet et al. (2016) Ocean Dynamics, doi: 10.1007/s10236-016-0922-6.
[4] Mouchet et al., Ocean Modelling, to be submitted.