# cean circulation - Does large-scale

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Earth's oceans undergo a relentless churning as water responds to the interplay of temperature, salinity and prevalent winds. In the Atlantic Ocean, roughly 18 Sv[1] of warm, saline near-surface water is carried northward by the Gulf Stream/North Atlantic Current system (Cunningham et al. 2007). An equivalent amount of cold, deep water from the Nordic and Labrador Seas is guided by topography to the Southern Ocean. Here, it returns to the upper ocean more slowly via the mixing of deeper and shallower waters and/or the upwelling of deeper water in response to the strong westerly winds. This global-scale Meridional Overturning Circulation (MOC) is responsible for the observed temperature contrast of 15°C at low-latitudes in the Atlantic between the upper ocean and the deep ocean. In contrast, the absence of deep water formation in the Northern Pacific and Indian Oceans means that oceanic northward heat transport is significantly less than in the North Atlantic (Lumpkin and Speer 2007).

In its fourth assessment report the Intergovernmental Panel of Climate Change considers it "very likely" that the MOC will have gradually slowed by the end of the 21st century as a consequence of global warming. Climate model projections predict a slowdown between 0 and 50% by the year 2100, although complete shutdown is considered "unlikely" for this time horizon. The reasons for the slowdown include factors that impede deep-water formation – warming of surface waters and salinity reduction at high latitudes due to the melting of continental ice sheets and the intensification of the hydrological cycle. Uncertainties regarding the freshwater fluxes and the locations of deep-water formation at high latitudes are the primary causes of the large uncertainties in the model projections.

Future changes to the MOC will also be determined by changes in the mechanisms leading to the upwelling of warmer waters. Winds have intensified by 30% over the Southern Ocean during the second half of the last century (Huang et al. 2006), possibly due to decreasing stratospheric ozone concentrations. This trend is expected to prevail until 2100 (Shindell and Schmidt 2004). Beyond the end of this century, in what will be a different climate, upwelling in the Southern Ocean might gain in importance relative to sinking in the North Atlantic. Other long-term influences on the overturning in the North Atlantic Ocean are related to increased surface saltwater exchanges between the Indian and South Atlantic Oceans in the Agulhas Current System.

At present, there is no convincing observational evidence for a long-term weakening of the Atlantic MOC. This absence of evidence should not be mistaken as evidence of absence of a slowdown, especially when there is a lack of adequate long-term and sustained monitoring. Discontinuous historic observations do not capture the large intraseasonal-to-interannual variations, thereby reducing the reliability of the projections of the long-term changes in the MOC. Continuous measurements spanning the past decade or so are not indicative of a "strong" MOC decline. But on decadal time scales, natural variations have considerably larger amplitudes than the anthropogenic signature (on the order of 0.5 Sv per decade). Thus, observations sustained over several decades are required to distinguish between natural and anthropogenic changes.

Monitoring of the MOC has improved since the beginning of this century (Kanzow et al. 2010; Send et al., in press). Methods include those based on ocean state estimates and those using numerical models to identify observable variables (indices) that correlate well with the MOC strength in the models. Careful validation against the existing direct observations is now required to establish the robustness of state-estimate-based and index-based changes to the MOC. In principle these methods could also be applied to paleo-oceanographic proxies, to open a window to ocean-induced changes in past climate.

[1] *1 Sv= $10^6\ m^3 s^{-1}$, unit for volumetric transport. For comparison, the Amazon River discharge in the Atlantic is about 0.2 Sv*

## Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2012_1.pdf

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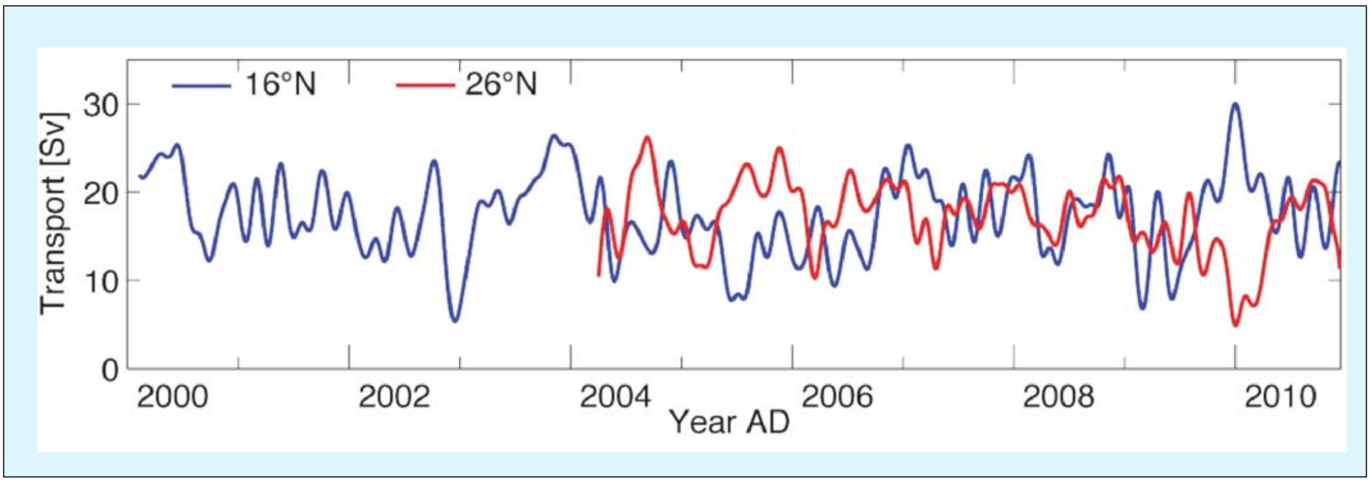


*Figure 1: Southward Deepwater Transport at 16°N (**blue** line) and Strength of Meridional Overturning at 26°N (**red** line) for the period 2000-2010 AD.*