Earth's oceans undergo a relentless change in response to the interplay of temperature, salinity and precipitation. In the Atlantic Ocean, roughly 18 Sv of warm, saline near-surface water is carried northward by the Gulf Stream and North Atlantic Current system (Cunningham et al. 2007). An equivalent amount of cold, deep water from the Nordic and Labrador Seas is pulled up 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 on 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 of the MOC is not expected until some time after the year 2100, although complete shutdown of the MOC is not expected until some time after the year 2100. The reasons for the slowdown in the MOC include changes in the thermohaline properties of the water, changes in the wind field, and changes in the topography of the ocean basin (Mason et al. 2002; Jungclaus et al. 2006; Menviel et al. 2006). The evidence for circulation changes is derived from paleoclimate records, such as isotopic composition of deep-sea sediments, and from numerical models.

Monitoring the MOC has improved significantly 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.

**Figure 1: Changes in the ocean-climate system over the past 60 ka, showing climate anomalies over Greenland (A) and Antarctica (B).** (Lemieux-Dudon et al., 2010) compared with evidence for ocean circulation changes (Lumpkin et al., 2007). The evidence for circulation changes is derived from benthic foraminiferal stable carbon isotopes, which are interpreted here to represent primarily the preformed macroscale nutrient content of deep waters. (C) Ratio of northward transport to poleward transport (from 1850 to 2000 AD) in the North Atlantic and Pacific seas. (D) Ratio of northward transport to poleward transport (from 1850 to 2000 AD) in the North Atlantic and Pacific seas.

**Selected references**