Observations for Climate: Sustained observations that contribute to understanding the Meridional Overturning Circulation

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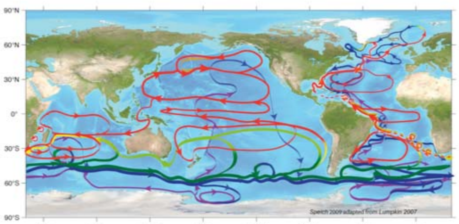
What is the Meridional Overturning Circulation (MOC)?

The Meridional Overturning Circulation (MOC) is a vertical-horizontal circulation cell in the ocean that exchanges waters between nearly all of the major ocean basins through thermohaline and wind-driven processes. In the Atlantic, there are two main cells of the MOC; a larger cell dominated by sinking in the northern North Atlantic, and a weaker deep cell dominated by sinking near Antarctica. The MOC is a major mechanism controlling the oceanic meridional heat transport, and may fluctuate on a broad range of time scales with significant climate implications. The upper limb of the MOC transports ~1.2 Petawatts of heat northward at around 24°N in the Atlantic, between 30-50% of the total heat transport within the ocean-atmosphere system globally at this latitude. This heat is released to the atmosphere primarily at subpolar latitudes.



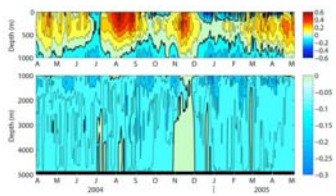
Left: A schematic of the global MOC. Northward flow in the Atlantic at the surface (red) and intermediate (yellow) depths ultimately reaches the Labrador, Irminger and Greenland/Iceland/Norwegian seas where it is converted to bottom (blue) dense water by loss of buoyancy due to intense air-sea heat fluxes. En-route, buoyancy is also lost due to evaporation. The deep water returns southward in a deep western boundary current. Regions where currents break apart, and transport is primarily done by eddies, are indicated by small rotating circles.

Numerical climate studies have identified correlations between variations in the MOC and important climate variables including precipitation and surface air temperature over large regions in the northern hemisphere. Improving understanding of the MOC has been identified as one of the key near-term priorities in the U.S. interagency Ocean Research Priorities Plan.

NOAA maintains several different sustained observing programs aimed at capturing key components of the MOC in the Atlantic basin and contributes to several international initiatives. This poster highlights several of the programs.

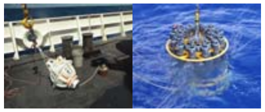
Observing the MOC in the North Atlantic

NOAA began measuring key components of the MOC in the North Atlantic as early as 1982 when Florida Current transport monitoring began as part of the STACS program. When the STACS program expanded to include monitoring of the Deep Western Boundary Current offshore of the Bahamas in 1984, both the warm upper and cold lower western boundary limbs were being observed, and this long-term time series, still maintained under the NOAA Western Boundary Time Series (WBTS) project, represents the only long-term transport and water mass time series of the MOC, with 25+ years of data.

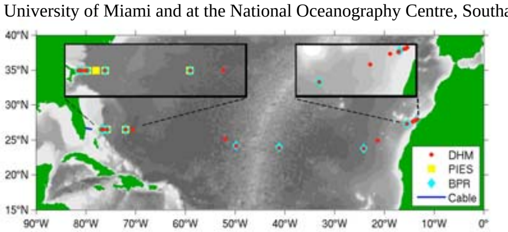


Above: Time series of the transport per unit depth profile (10^5 m^2/s) across 26.5°N in the Atlantic Ocean. The contour interval is decreased in the lower panel to better illustrate the deep variability. A notable reversal in the deep flow occurs during November 2004 (from Johns et al., 2008).

In 2004 an international program built upon the WBTS 'cornerstone' was started, deploying a line of moorings across the entire Atlantic basin along 26°N that will continuously observe the meridional mass and heat transport in the subtropical Atlantic. This system will document the variability of the subtropical Atlantic and its relationship to observed climate fluctuations, and the observations will help assess climate model predictions. This ambitious collaboration has three components: the continuing WBTS program, the Meridional Overturning Circulation and Heat-flux Array (MOCHA) funded by the U.S. National Science Foundation, and the Rapid Climate Change MOC project funded by the United Kingdom's Natural Environment Research Council. The programs involve investigators at NOAA/AOML, at the University of Miami and at the National Oceanography Centre, Southampton.



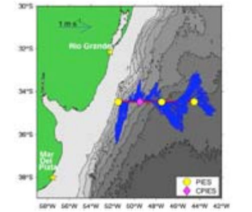
Above: A pressure-equipped inverted echo sounder (left) being prepared for deployment, and (right) a CTD being lowered; both are used for measuring the Deep Western Boundary Current.



Left: Illustration of the trans-basin moored array with clusters of dynamic height moorings (DHM), pressure-equipped inverted echo sounders (PIES), and bottom pressure recorders (BPR) at the eastern and western boundaries and Mid-Atlantic Ridge. Also shown is the cable used for Florida Current transport monitoring. Hydrographic observations are collected at varying times along each segment of the trans-basin array.

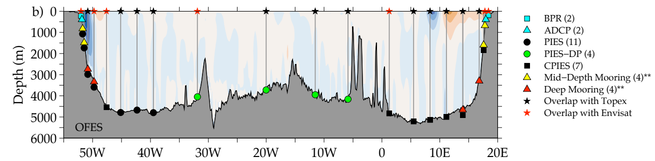
Observing the South Atlantic MOC

The SAM Program began in 2009, seeking to capture key western boundary components of the MOC in the subtropical South Atlantic Ocean. Numerical climate models have indicated that MOC flows undergo important water mass transformations in the South Atlantic, however little data has previously been available for the study of the transport and water mass changes of these flows in the real ocean. This pilot array initially involved a zonal line of pressure-equipped inverted echo sounders (PIES; including one current-and-pressure-equipped inverted echo sounder, CPIES) deployed near the western boundary at 34.5°S. The present array (since July 2011) has involved all PIES. Data from these instruments will be used to monitor the Brazil Current and the Deep Western Boundary Current as they carry components of the MOC along the western boundary of the basin. Coupled with annual or semiannual hydrographic observations collected on an Argentine or Brazilian research vessel, these data will produce better understanding of the processes involved in MOC variability in the South Atlantic.



Above: Locations of the four PIES/CPIES instruments deployed as part of the SAM project. Also shown (blue arrows) are the near-surface velocities observed by the shipboard-ADCP onboard the Brazilian Navy research vessel Cruzeiro do Sul during the March 2009 deployment cruise.

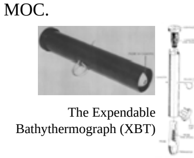
The pilot array also is the cornerstone of a major proposed international initiative to measure the trans-basin MOC at 34.5°S similar to the array at 26°N.



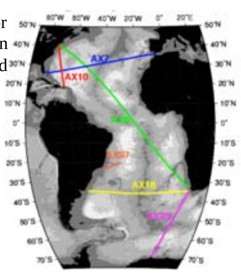
Left: Schematic showing the proposed international trans-basin array for measuring the MOC in the South Atlantic. Types of instruments are indicated in the legend. This array is a collaboration between the US, France, Brazil, South Africa, and Argentina. Color contours are the mean meridional velocity from a 27-year run of the OFES numerical ocean model.

Argo floats and Expendable Bathythermographs (XBTs)

NOAA also plays a key role in several international initiatives which benefit the study of the MOC. The Ship of Opportunity Program (SOOP) is a component of the Global Ocean Observing System, and SOOP's mission is to provide a global platform to deploy and operate and deploy oceanographic instrumentation from cargo ships or research vessels. This program enables the deployment of Argo floats and XBTs to help monitor the upper limb of the MOC. NOAA/AOML operates a global XBT program that uses approximately 50 ships of the SOOP to monitor the upper ocean thermal structure along 18 transects in all ocean basins, some of which are climate time series extending back more than 30 years. The high density lines are occupied approximately every three months, with XBTs deployed at ~25 km spacing in order to measure the mesoscale structure of the ocean, to diagnose the ocean circulation responsible for redistributing heat and other water properties. Three of these high density transects (AX7, AX18, and AX25) are of particular use for monitoring the upper limb of the MOC, collecting trans-basin sections across either the Atlantic (AX7 & AX18) or the Southern Ocean (AX25), while the other sections cross key boundary currents. Argo is an international program that oversees an array of 3,000 free drifting profiling floats, distributed over the global oceans, which measure the temperature and salinity in the upper 2 km of the ocean providing 100,000 T/S profiles and reference velocity measurements per year. This allows continuous monitoring of the upper limb of the MOC, with all data being relayed and made publicly available within hours after collection. Recent research using data and models has demonstrated the key role that Argo data can play in getting accurate estimates of the MOC and the meridional heat transport. Future deep-diving Argo floats are being designed to measure the deep bottom waters of the lower limb of the MOC for even further improvements.



The Expendable Bathythermograph (XBT)



Above: location of high-density Atlantic XBT lines maintained by NOAA/AOML

Below: the global Argo array, August 2011