THE ATLANTIC OVERTURNING CIRCULATION

More Evidence of Variability and Links to Climate

by James A. Carton, Stuart A. Cunningham, Eleanor FraJka-Williams, Young-Oh Kwon, David P. Marshall, and Rym Msadek

A unique feature of the Atlantic Ocean is the presence of regions in the Labrador Sea and Nordic Seas where surface water can convect and sink to deep levels. This process of deep water formation and the related northward transport of warm surface water are components of the Atlantic meridional overturning circulation (AMOC), which annually transports in excess of 1 PW of heat northward through the northern subtropics. Between 26°N and Greenland much of this heat flux enters the atmosphere where it is then transported eastward by the atmospheric circulation and is responsible for the mild U.K. and European climate. Coupled models suggest that one of the consequences of anthropogenic climate change will be a slowing of the AMOC and an alteration of the ocean’s role in climate (e.g., Cheng et al. 2013). Observing, quantifying, and understanding the detailed mechanisms controlling AMOC variability, its present circulation, and past behaviors, and the extent to which changes in the AMOC are predictable all remain preeminent scientific challenges for the twenty-first century.

The U.S. Atlantic meridional overturning circulation (U.S. AMOC) program was created in 2007 to promote research and provide direct observational estimates of the AMOC–climate connection. A central activity has been the development of an observing system building on the U.K. Rapid Climate Change (RAPID) program in the subtropical North Atlantic that began in April 2004. Now in its fifth year, U.S. AMOC, together with U.K. RAPID-
WATCH, have constructed a time series of the overturning circulation, as well as heat and salt transport across the equator, using RAPID observations. This time series, which is approaching 10 years long, reveals striking changes on time scales ranging from weekly to interannual with a hint of even longer time scales (Fig. 1). Following this successful deployment, a basin-crossing observing array is being developed for deployment across the subpolar gyre to the north, and another is being deployed in the Southern Hemisphere. These arrays should provide the observational understanding of subsynoptic, seasonal, and interannual variability that is necessary for assessing decadal climate predictions.

**WORKSHOP.** In 2011 the first joint workshop of U.S. AMOC–U.K. RAPID scientists was held in Bristol, United Kingdom. The continuing analysis of observations from the 26.5°N array, plans for further development of the observational arrays, and the high level of interest in the connection between AMOC and climate variability and change have provided ample motivation for this second U.S. AMOC–U.K. RAPID International Science Meeting, held in Baltimore, Maryland. The central feature of this 4-day workshop was a set of 50 oral science presentations divided into three sessions, followed by updates from the funding agencies and three “perspectives” talks. The agenda was also designed to allow long breaks for discussion and exploration of a set of 43 posters. The workshop was divided into three sessions:

1. **Observations and dynamics of seasonal to interannual time scales.** This session included results from recent instrument deployments and related observational studies and results from regional high-resolution modeling.

2. **Observations and dynamics on decadal to multidecadal time scales.** This session included results from proxy studies and coupled climate model simulations.

3. **Climate impacts and what the future may hold.** This session examined new evidence from coral isotope studies for the existence of Atlantic multidecadal variability (AMV) of climate in the Atlantic sector stretching back to the preindustrial era. This observational theme was continued in presentations by David Thornalley and Hali Killbourne raising, among other issues, the question of AMOC variability for SST and continental climate. The three speakers led a roundtable discussion that identified the following key research needs:

   - faster real time availability of rapid data;
   - adoption of new technologies as they mature (e.g., autonomous gliders) to sustain the monitoring for arrays over many decades;
   - development of proxies of AMOC variability using long records of sea level, SST, and paleo data;
   - development of data assimilation and other estimation techniques to combine available aerosol-climate and meteorological observations in ways consistent with the equations governing the two systems;

**Session 1. Observations and dynamics of seasonal to interannual timescales began with a review of the status of AMOC by Garth insights into the historical variability of AMOC and its role in future climate. The two speakers outlined plans for the extension of the observing system northward into the subpolar gyre (Monika Rhine and colleagues) and into the Southern Hemisphere (Christopher Meinen and colleagues). A key aspect of AMOC is the deep western boundary current, which transports much of the deep water into the Southern Ocean. In a modeling study carried out in preparation for the southern extension of the observing system, Sylvia Garzoli and colleagues showed evidence that this deep western boundary current may actually leave the boundary and transverse the basin as a result of eddy momentum flux convergence in the southern subtropics. The session also featured modeling results, in particular a presentation by Gokhan Danabasoglu of the Commonwealth Ocean–Ice Reference Experiments, highlighting the diversity of AMOC representations produced by different ocean models forced by the same surface meteorology.

**Session 2. Observations and dynamics of decadal to multidecadal timescales was led by a fascinating set of presentations describing some of the increasing quantity of proxy climate records. Delia Oppo described new evidence from coral isotope studies for the existence of Atlantic multidecadal variability (AMV) of climate in the Atlantic sector stretching back to the preindustrial era. This observational theme was continued in presentations by David Thornalley and Hali Killbourne raising, among other issues, the question of AMOC variability for SST and continental climate. The three speakers led a roundtable discussion that identified the following key research needs:

   - faster real time availability of rapid data;
   - adoption of new technologies as they mature (e.g., autonomous gliders) to sustain the monitoring for arrays over many decades;
   - development of proxies of AMOC variability using long records of sea level, SST, and paleo data;
   - development of data assimilation and other estimation techniques to combine available aerosol-climate and meteorological observations in ways consistent with the equations governing the two systems;

**Session 3. Climate impacts began with presentations by Jianjun Yin, Tal Ezer, and Joseph Park on the impacts of AMOC variability for SST and continental climate. These presentations also made an interesting comparison to the impacts of AMOC variability for SST and continental climate. The three speakers led a roundtable discussion that identified the following key research needs:

   - faster real time availability of rapid data;
   - adoption of new technologies as they mature (e.g., autonomous gliders) to sustain the monitoring for arrays over many decades;
   - development of proxies of AMOC variability using long records of sea level, SST, and paleo data;
   - development of data assimilation and other estimation techniques to combine available aerosol-climate and meteorological observations in ways consistent with the equations governing the two systems;
• understanding of the impact of ocean model biases on coupled models;
• identification of similarities and differences between the AMV in the historical record, the corresponding variability in coupled climate models, and their relationships to AMOC;
• exploration of the role of aerosol forcing in impacting the climate of the North Atlantic sector; and
• investigation of AMOC variability and biogeochemistry/carbon sequestration.

The research findings presented at the meeting and suggested future research needs from the final session will help guide future planning of the U.S. AMOC and U.K. RAPID programs. The benefit of international collaboration fostered by the meeting is acknowledged by the sponsoring programs with an expression of intent to convene a *Third International AMOC Science Meeting* in 2015 in the United Kingdom.

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**REFERENCES**


