MOVE

(Meridional Overturning Variability Experiment)

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1. Project Summary

The meridional overturning circulation (MOC) in the Atlantic Ocean is one of the major oceanic climate drivers of the globe since it is the mechanism for most of the large heat transport carried by the Atlantic Ocean, with demonstrated impacts and control on northern hemisphere and global climate. Variations in this circulation and the associated heat transport, both due to natural or anthropogenic effects, are of utmost importance but have been impossible to observe directly to date. MOVE is the first program which tackled this problem, starting in the year 2000, by installing and sustaining an observing system for the lower branch (deep, cold return flow) of the overturning circulation in the Atlantic.

MOVE operates the circulation monitoring array in the subtropical west Atlantic along 16N, with the objective to observe the transport fluctuations in the North Atlantic Deep Water layer. Two "geostrophic end-point moorings" and bottom pressure sensors, plus one traditional current meter mooring on the slope have been used to cover the section between the Lesser Antilles (Guadeloupe) and the Midatlantic Ridge. The geostrophic transport fluctuations through this section are determined using dynamic height and bottom pressure differences between the moorings. It has been shown that on long timescales this is a good approximation to the total southward (and by mass balance also northward) MOC transport.

To date, the array has been collecting 13 years of temperature/salinity data (for relative geostrophic transports), 13 years of current meter data (for boundary slope transports), and 11 years of bottom pressure data (for barotropic transports, a data gap exists from 2005-2007). Due to the built-in redundancy, transports are available now for the complete period observed by instruments recovered in December 2010 (nearly 11 years), while the next two years of data are expected after mooring recovery in May 2013. Interannual and long-term changes in the circulation and its vertical distribution are starting to be visible. Joint analyses with other arrays like RAPID and also with modeling teams are under way, in order to assess the basin-scale significance of the data and understand differences.

The MOVE array also contributes to closing one of the gaps in the sustained ocean climate observing system which was identified by the global community at OceanObs09: techniques and programs for monitoring the circulation and mass/heat/freshwater transports of major current systems. For broad-scale and deep-reaching circulations, the MOVE approach of fixed-point horizontally integrating installations is promising. MOVE is one of the first sustained sites which are aimed at filling this gap in the global ocean observing system.

The supported activities include operation of three moorings and several bottom pressure sensors along 16N and processing of the data. This includes construction of moorings, execution of cruises, servicing and calibration of sensors with extreme accuracy, upgrading of technology, and participation in the OceanSITES effort.

The anticipated products and outcomes include:

- long records of the deep transports in the southward branch of the Atlantic thermohaline circulation (AMOC) at this latitude
- data sets to validate and constrain circulation and climate models
- integration of the data at this latitude with Atlantic-wide observing efforts via US-AMOC and international collaborations.

The users/applications include climate modelers and forecasters, climate impact studies, IPCC assessments, and the observational and modeling and data assimilation research community.

2. Scientific and Observing System Accomplishments

a) Field Work

As explained in the last annual report, the instruments from the last deployment cycle could only be recovered piece by piece due to ship time shortage and diplomatic clearance delays. Most of the moorings had been recovered, and all moorings and PIES were re-deployed, in December 2010. The remaining mooring had then been recovered in May 2011 with a small chartered boat out of Guadeloupe which gave us 11 years of temperature/salinity and current meter data for internal-plus-boundary transport estimates. The older PIES, which are needed for the internal (barotropic) transport, were then recovered in December 2011 with the exception of one near the site M3 which was located in French territorial waters. This one could only be recovered in December 2012 but it contains the bottom pressure data needed to complete the analyses of transports until the recovered mooring period (December 2010). Therefore we only now have in hand a complete set of data for transport calculcations until that time.

The newly deployed moorings and PIES (in the water since December 2010) have our new acoustic modem technology installed and would have allowed retrieval of the data during the recent NOAA cruise on the “R/V Pisces”, but again not enough ship time was available for this and in addition the ship developed engine problems and had to cut short the scientific work. While this is frustrating, in this particular case the impact is small since the moorings will be recovered in May 2013 from a German “Meteor” cruise, which will also allow acoustic data retrieval from the PIES.

FY12 funds have also been used to acquire instruments and mooring hardware for the May 2013 Meteor cruise with a planned full deployment of all moorings and PIES. All required sensors and mooring equipment is in hand, the wire has been ordered, and the subsurface controllers have begun bench-testing in the lab. Containers will be shipped to Guadeloupe, where we can also retrieve our remaining mooring gear still stored there since the May 2011 recovery (due in insufficient funds for shipping back to San Diego). The Meteor cruise will end in the Cape Verde Islands, from where we will ship containers back to San Diego.

b) Scientific Analyses

The last annual report had already shown the full 11 year internal-plus-boundary transport timeseries (until December 2010) which is still the longest record we have available. Figure 1 now presents a different version with less filtering for better comparison with later bottom-pressure analyses. Most prominent is large event of strong southward transport at the end of 2009/beginning of 2010, which counteracts the weakening trend observed until then.

This observation had caused a lot of discussion and some concern in the international AMOC community, since the RAPID measurements at 26N did not observe this change, and in fact a weakening event was detected at the same time there (related to Ekman transports requiring a northward compensation flow). Speculation resulted that maybe the assumption in MOVE of a fixed reference level at 4950db for the internal transport was not appropriate, meaning that the actual transports if referenced "properly" would not show the strengthening seen in the MOVE as referenced to 4950db. With the new recovered bottom pressure data from the PIES we can finally put this discussion to rest: referencing the transports to the actual bottom pressure fluctuations shows the same strengthening MOC event, and possibly even larger amplitude, see figure 2.

RAPID and MOVE use very different approaches for determining the reference level flow – MOVE uses a mix of a fixed reference level (on long timescales) and actual bottom pressure reference data (on timescales of up to 2 years), while RAPID determines the reference level flow from postulating mass conservation over the whole water column by adding (to the internal geostrophic transport) the Ekman transport, the Gulf Stream transport, and the western boundary transport. Joint analyses have been performed between MOVE and RAPID to compare equivalent types of data processing, and U.Send presented some of these initial results at a European/German THOR conference in Hamburg in September 2012. An example is shown in figure 3, where only the western boundary component of MOVE and RAPID are compared, and where both use geostrophic transports referenced to a fixed pressure level. In this view, some coherence at long timescales appears to be visible. However, different types of processing reveal a divergence between RAPID and MOVE.

These are topics of ongoing analyses and collaborations, also with the modeling teams at Geomar Kiel. One result of the Kiel ORCA model addressing such questions is shown in figure 4. It shows the difference of MOC transports between 16N (MOVE) and 26N (RAPID). There are periods with coherent transports (e.g. 1994), and other periods when the transports are incoherent (e.g. 2001).

Apart from these individual national and international collaborations, we participate actively in US AMOC, international AMOC, and in OceanSITES. In particular, Scripps Institution hosted an international OceanSITES meeting in La Jolla in December 2011. Some of the FY12 MOVE funded helped to organize and run this meeting, which was highly productive (and by some attendees deemed to be the best OceanSITES meeting so far).

c) Data Management

Within the available resources we make a best effort at quality controlling the MOVE data set and providing it to OceanSITES. The complete set of microcat data since 2000 has finally been re-processed to make sure it is of uniform quality, and is now available in OceanSITES format via OceanSITES. The current meter data from the M3/M4 (and earlier also M5) moorings were re-processed during 2011 and have also been delivered now. The bottom pressure and inverted echosounder data will take more time, since this is also a complicated data set, and we would like to learn more from the now overlapping and staggered side-by-side deployments of PIES. We hope to be able to work on that data set in more depth in the coming year.

Summary Information:

a. Project deliverables serving the observing system's program deliverables
- Longest directly observed timeseries of the strength of the southward limb of the AMOC
- Quantification of variability in the AMOC strength and vertical structure
- Relation between NADW variability at 16N and at other latitudes / assessment of meridional coherence

b. Achievements during FY2012
- Field work to recover remaining PIES and test data telemetry from new moorings/PIES
- Newly recovered PIES allowed bottom-pressure referencing of recent transports
- New comparisons of MOVE results with RAPID and model outputs

c. Scientific advances made and/or facilitated through the project activities
- Observational proof of interannual and decadal-scale variability in southward AMOC flow
- First studies initiated about meridional coherence based on observational data
- Developments will be enabled to constrain or initialize circulation and climate models with the observational MOC data

d. Significance of these advances
- Knowledge of the existence and sense of AMOC changes will allow climate forecasts
- Circulation and climate models can be tested/validated
- Comparing MOC observations at several latitudes and with models will allow design of better future observing systems

e. Information jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work
- Due to the financial losses in FY11 resulting from lack of ship time (requiring vessel charter and staging in Guadeloupe) we are still recovering from that deficit and cannot afford enough data processing and hardware upgrades
- The new moorings have inductive communication and acoustic modems, so we could download the data more regularly by deploying gliders and using the technology developed in CORC, but we do not have the funds available for glider operations in MOVE.
- Data management is far behind and lacking funding, especially the QC and dissemination of bottom pressure data has not been possible yet.

f. Web sites for the program
- http://mooring.ucsd.edu/MOVE

g. Data Management
- Data not distributed on GTS since not in real-time
- Delayed-mode data is on institutional computer with backup system, plots are provided on the website. Processed data are made available through OceanSITES ftp servers up to most recent field operations and this implemented for microcat (T/S) and current meter data so far.
- Archival on institutional backup system happens daily; transfer of newly processed data to OceanSITES repository approx yearly.
- Data plots are shown on http://mooring.ucsd.edu/MOVE

2.1. Outreach and Education

MOVE is regularly presented to the next generation of researchers at the national and international AMOC and RAPID meetings, and this time also at the THOR conference in Hamburg. These events are heavily attended by students and post-docs. MOVE is communicated to the public via various websites (see above).

One postdocs and one graduate student were partially supported by MOVE. Wherever possible, we invite students to participate in MOVE cruises. One student (Samuel Wilson) has been carrying out MOVE PIES work by himself on the recent NTAS/MOVE cruise. In my teaching, and during visits of prospective students, MOVE is used as a demonstration of exciting and relevant research.

3. Publications and Reports

3.1. Publications by Principal Investigators

Baringer, M. O., S. A. Cunningham, C. S. Meinen, S. Garzoli, J. Willis, M. Lankhorst, A. Macdonald, U. Send, W. R. Hobbs, E. Frajka-Williams, T. O. Kanzow, D. Rayner, W. E. Johns, and J. Marotzke (2011): Meridional overturning circulation observations in the subtropical North Atlantic. In "State of the Climate in 2011", chapter "Global Oceans". Bulletin of the American Meteorological Society, 93 (7), S78-S81.

Lankhorst, M. and H.-J. Kim (2012): Comparing Automatic versus Human-Created QC Flags of Oceanographic Mooring Data and Applicability to the OOI. 2012 Ocean Sciences Meeting, Salt Lake City, UT. American Geophysical Union [and others], Conference Proceedings.

Kanzow, T., M. Lankhorst, E. Frajka-Williams, U. Send, S. A. Cunningham, R. Bingham, J. Karstensen, and C. W. Hughes (2012): Meridional coherence and divergence of the Atlantic Meridional Overturning Circulation (AMOC). Conference Proceedings. European Geosciences Union. 2012 EGU General Assembly, Vienna, Austria.

Elipot, S., E. Frajka-Williams, C. Hughes, S. Olhede, M. Lankhorst (2012): Basin-wide response of the North Atlantic Meridional Overturning Circulation to wind stress forcing. Conference Proceedings. European Geosciences Union. 2012 EGU General Assembly, Vienna, Austria.

Kanzow, T., M. Lankhorst, E. Frajka-Williams, U. Send, S. A. Cunningham, R. Bingham, J. Karstensen, and C. W. Hughes (2012): Meridional coherence and divergence of the Atlantic Meridional Overturning Circulation (AMOC).Conference Proceedings. 2012 US AMOC PI Meeting, Boulder, CO. Sponsored by U.S. CLIVAR Project Office.

Kanzow, T., U.Send, M. Lankhorst, A.Biastoch, C.Boening (2012): Comparison of the Atlantic Meridional Overturning Circulation (AMOC) at two latitudes - 16°N and 24°N. Abstract THOR/AMOC conference, Hamburg, September 2012.

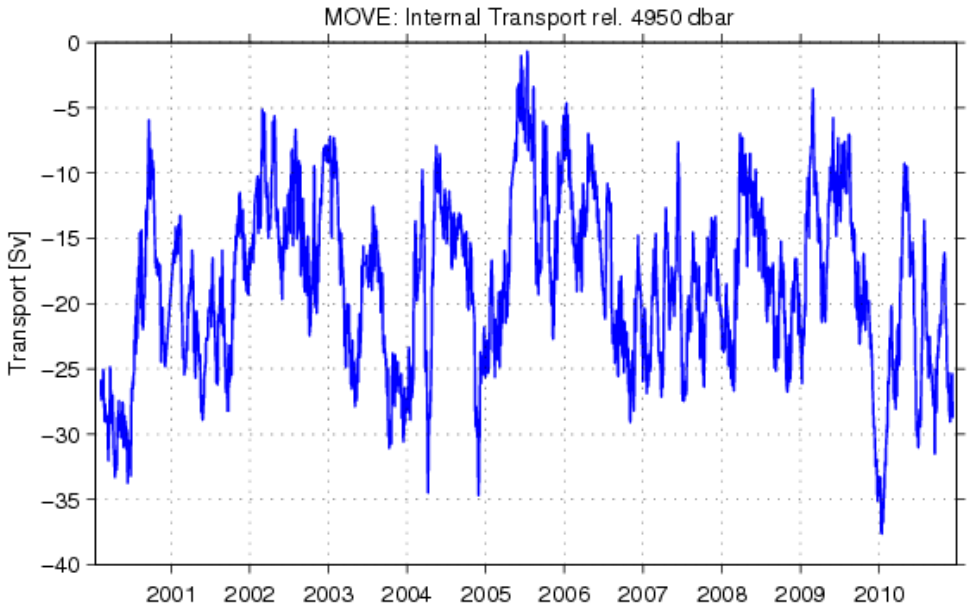

Figure 1: *Full data set of internal transports until December 2010, showing the large southward transport event at the end of 2009/beginning of 2010.*

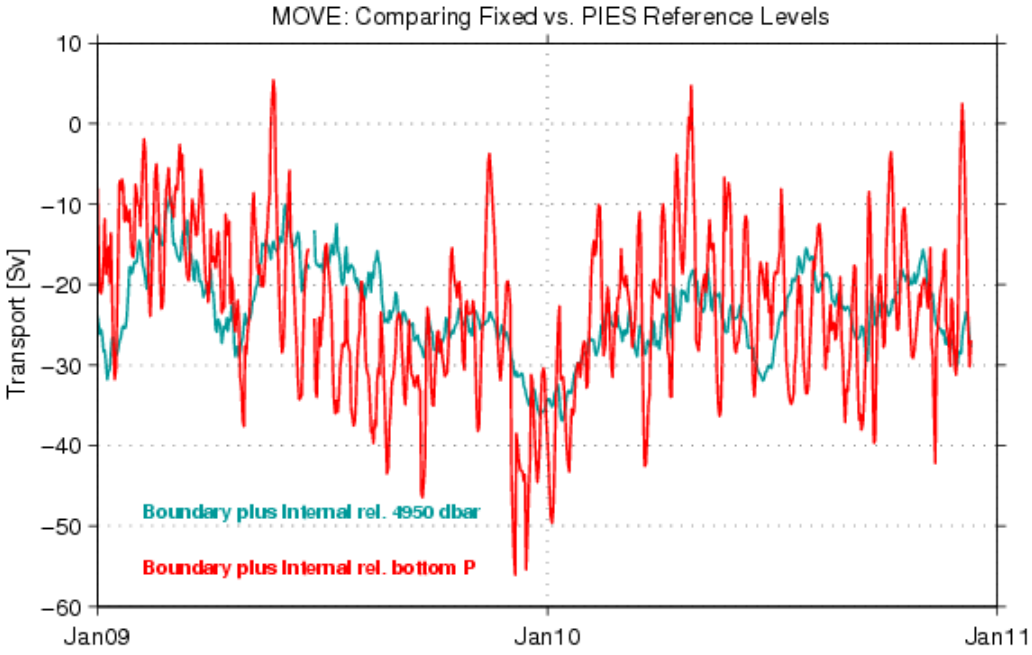

Figure 2: *Internal-plus-boundary transport for the last 2 years available referenced to 4950db is shown in blue-green, showing the large negative amplitude of -35Sv at the end of 2009. This is the only record that was available until December 2012. With the recovery of the last missing PIES, the same can now be referenced to the actual bottom pressure fluctuations, shown in red. The large southward transport event remains, and may in fact be even stronger.*

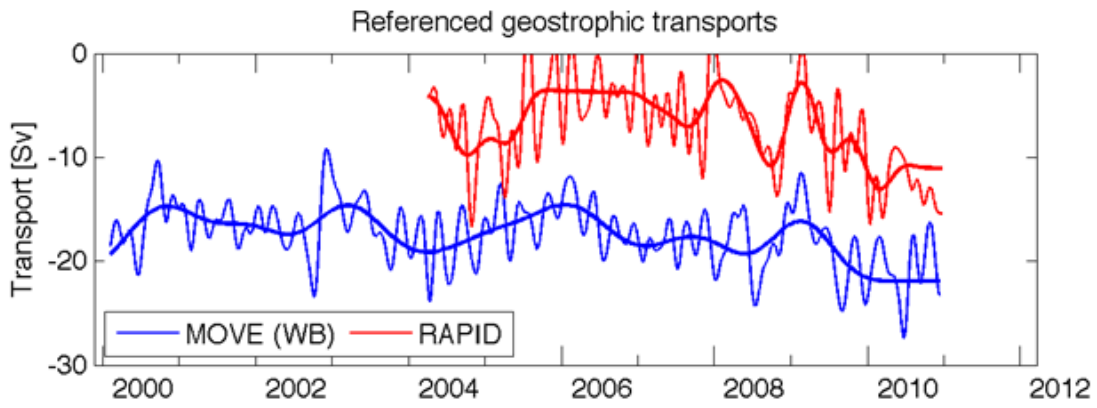

Figure 3: *Internal geostrophic transport from just the western boundary contribution, referenced to a fixed pressure level, for MOVE and RAPID.*

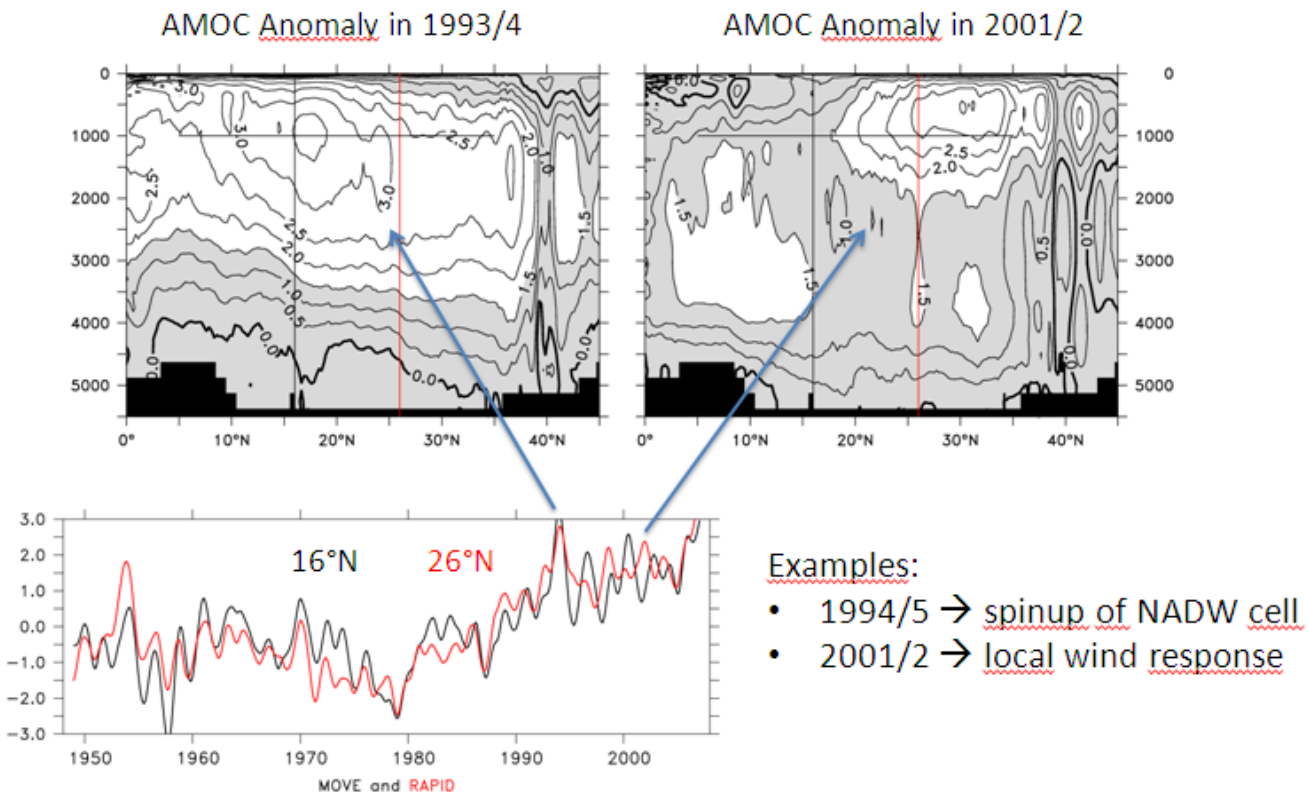

Figure 4: *MOC simulations with the Kiel ORCA model, showing the overturning streamfunction for two time snapshots in the upper panels, and a timeseries of MOC amplitude at 16N and 26N in the lower panel. The presence and absence of coherence between these two latitudes at different times is highlighted.*