# MOVE
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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 Mid-Atlantic 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, data are available from early 2000 until mid 2013. Interannual and long-term changes in the circulation and its vertical distribution are clearly visible now. Joint analyses with other arrays like RAPID, with projects in the Labrador Sea, and also with modeling teams are under way, in order to inter-relate the changes, assess the basin-scale significance of the data and understand the 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 highly suitable. 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:
- the longest record of transports in the southward branch of the Atlantic thermohaline circulation (AMOC)
- data sets to validate and constrain ocean circulation and coupled climate models
- integration of the data at this latitude with Atlantic-wide observing efforts via US-AMOC and international collaborations
- connections between observations at high latitudes (Labrador Sea) and the MOVE transports.

The users/applications include climate modelers and forecasters, climate impact studies, IPCC assessments, and the observational and modeling and data assimilation research community. The 2013 IPCC assessment showed the MOVE transport timeseries.

2. Scientific and Observing System Accomplishments

Field Work

In the beginning of the performance period, instruments from prior field work in May 2013 were received and refurbished. The May 2013 work had swapped the complete mooring array, recovering the old moorings and re-deploying identical new ones. The next complete mooring swap is planned for 2015.

In fall 2013, the MOVE project participated in a joint expedition with the NTAS project (also funded by the NOAA Climate Observation Division) under leadership by Al Plueddemann. NTAS serviced their buoy in the tropical Atlantic, and the MOVE part of the expedition was to acoustically retrieve data from all deployed assets (two PIES near the MOVE1 site, two PIES near the MOVE3 site, one mooring each at MOVE1, MOVE3, and MOVE4). With the exception of one PIES, these data retrievals were successful. This work resulted in the MOVE data records to be extended through October 2013.

During summer and fall, preparations were started for a December 2014 expedition, again together with NTAS, to repeat the acoustic downloads and to recover/re-deploy one PIES at each of the sites MOVE1 and MOVE3. At the time of writing, the to-be-deployed PIES have been assembled in the lab, successfully completed testing, and are ready for deployment.
Scientific Analyses

Analyses of MOVE data in the 2013-14 performance period focused on two science questions:

1. How does the long-term signal seen in the MOVE data compare to other observations and simulations?
2. What are mechanisms of short-term variability seen in the MOVE mooring data?

MOVE NADW transport relative 4950db, lower-frequency view

![Figure 1: Water volume transport as measured from the MOVE moorings, low-pass-filtered to show long-term variability.](image-url)
Figure 1 shows the water volume transport observed by the MOVE moorings, including the data acoustically retrieved in late 2013. The data have been filtered with a low-pass to highlight the interannual-to-decadal variability that underlies the first scientific question. The period 2000 to 2006 sees primarily a reduction in the circulation (trend from larger negative numbers to smaller negative indicating the southward flow). Following this until 2013, the long-term trend seems to reverse and end at about the same current strength as 2000. These data were prominently included in the 2013 IPCC report, and more recently, the “State of the Climate” report. As discussed in the latter report, there remains some disagreement between these MOVE findings and observations at the 26N array, and the latitudinal coherence of these patterns of variability throughout the Atlantic. MOVE results have been presented at the 2014 US AMOC conference in context with observations in the Labrador Sea (courtesy I. Yashayaev, J. Fischer) and Line W off the US east coast. Based on these analyses and presentations, the trend towards faster circulation in the second half of the MOVE record coincides with decreasing densities in the Labrador Sea Water (mid-depth), increasing densities in the Denmark Strait Overflow Water (deep), and possibly increasing flow at depth in the exit region of the Labrador Sea. Figure 2 shows long-term trends in layer thickness observed by MOVE and at 26N. At MOVE, the layer thickness appears to remain roughly steady for the first few years at the western site (MOVE3), and increases during the later years. At the eastern site (MOVE1), the earlier years have a stronger increase than the later years. These changes in layer thicknesses are the drivers of the long-term behavior of the derived water volume transport. Comparing with the mooring data from the 26N array, we find similar behavior of layer thickness at their western and eastern moorings (also shown in Figure 2).

The second science question (about short-term variability) is examined by investigating the interaction between internal tides and eddies. As cyclonic or anticyclonic eddies pass by the MOVE3 mooring, they carry typical density structures. The nearby topography is a source of internal tides, which then propagate through the ocean. These propagation paths in turn are affected by the density structure. A process study (Nam and Lankhorst, submitted 2014) using the MOVE mooring data reports on which eddy density structures tend to reflect or to retain the propagating internal wave field, explaining variability in density and velocity observed in the data. Figure 3 shows typical density and stratification profiles for cyclonic and anticyclonic
circulation, and the MOVE data have been shown to contain weaker internal waves under anticyclonic conditions.

Figure 3: Vertical profiles of (a) density and (b) buoyancy frequency, estimated using the data from the MOVE3 mooring (open squares and open circles) and profiling floats (open triangles) for cyclonic (blue) vs anticyclonic (red) circulation. Mean profiles are shown in thick lines.

**Questionnaire**

- How did your project deliverables address the program’s priorities to provide information about the state of the world’s ocean and its regional variations to address important societal needs related to the Earth’s climate, including delivering continuous instrumental records for global analyses of:
  - sea surface temperature and surface currents,
  - ocean heat content and transport,
  - air-sea exchanges of heat, momentum, and freshwater,
  - sea level, and
  - ocean carbon uptake and content?

MOVE data continue to deliver a reference time series of temperature and salinity, derived currents, and seafloor pressure, which now spans the 2000-2013 time frame. The primary topic addressed by these is the large-scale ocean current, and the data continue to be used in climate assessments (“State of the Climate” and IPCC 2013).

- What were your primary achievements during FY 2014?

Extending the data holdings through October 2013 was the primary achievement of the field work, and finding coherences between long-term signals in MOVE data and in other hydrographic data (e.g. Labrador Sea) was the primary achievement of the analysis work.

- What scientific advances were made and/or facilitated through your activities? (For multi-institution proposals, provide your top 2 or 3 advances.)
  - Coherent signals between MOVE and data from higher latitudes were found
Interaction between internal waves and the eddy field shows reflection/trapping of wave energy by thermocline anticyclones/cyclones

- **What is the significance of these advances?**
  The coherence of long-term signals between MOVE data and higher latitudes is expected to be a signal of the Atlantic Meridional Overturning Circulation, which is the primary science driver behind MOVE. This is the climate signal that the project intends to detect. The internal wave / eddy study is a process study that explains local circulation features.

- **What, if any, impediments were encountered and what information was jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work?**
  MOVE would like to retrieve the data in a more autonomous fashion using gliders, but this is presently not funded. Doing more frequent downloads would secure the data as well as provide data updates on a more regular schedule.

  Processing of PIES data has progressed slower than expected. The OceanSITES data format is still awaiting a metadata naming convention for the travel time data from CF, and there are still several options for filtering of the data that MOVE is considering.

- **What is the website for your program?**
  [http://mooring.ucsd.edu](http://mooring.ucsd.edu) (Then click on PROJECTS - MOVE in the left menu.)

- **Are your data distributed in real time on the Global Telecommunications System?**
  There are no real-time data.

- **Where do your real time data reside? Are the data available online?**
  The data telemetered from the moorings are online at OceanSITES. The PIES data are intended to be there, but still pending.

- **Where do your delayed mode data reside? Are the data available online?**
  The data from the moorings are online at OceanSITES. The PIES data are intended to be there, but still pending.

- **When did you make your most recent data publicly available?**
  After the acoustic download, late 2013.

- **Where are your data archived and with what frequency?**
  OceanSITES is presently developing an archival system for their data holdings, which will include the MOVE data uploaded there. The data are also archived at an institutional server within Scripps Institution of Oceanography.

- **What is the website where the data for your program can be accessed? If you haven’t updated your website recently, please do so now.**
  [ftp://data.ndbc.noaa.gov/data/oceansites/DATA/](ftp://data.ndbc.noaa.gov/data/oceansites/DATA/)

- **Have you successfully retrieved your program’s data from the website or Data Assembly Center where your data reside to ensure the accessibility of the data? If not, please do this now and address any problems with data access.**
  Yes.

- **Do you have a publications supported through COD funding? We encourage your bibliographies to be posted online.**
  MOVE is maintaining a bibliography on the above website.

- **How are you tracking uptake and use of the data and products produced by your project?**
  Some have found it helpful to establish a standard and recognizable name (e.g., Argo, OceanSITES)? We encourage this approach to improve the recognition, discoverability, and visibility of your project.
Colleagues we know usually inform us about publications and data requests in person. OceanSITES is developing tools to track download of the data from the ftp servers.

- **How do you direct users of your data to acknowledge its use?**
  The OceanSITES data files contain a request to this effect in the metadata.

- **Do web pages that provide data and products from COD support acknowledge CPO/COD support?**
  The above MOVE website does.

### 3. Outreach and Education

MOVE maintains a project website that contains relevant information for both a layperson audience (e.g. project summary) as well as for professionals (e.g. bibliography). MOVE data are used in assessment reports (cf. previous section), which target a broader audience of science professionals than single-project publications.

MOVE results were presented by the project team in three presentations at two scientific conferences:


In the 2013-2014 performance period, two graduate students in our group have used MOVE data (I. Arzeno and J. Koelling) as part of their work. In addition, M. Lankhorst gave one informal presentation about oceanographic work to a local middle school, which included showing instrumentation and pictures from the MOVE moorings.

### 4. Publications and Reports

#### 4.1. *Publications by Principal Investigators*


#### 4.2. *Other Relevant Publications*

IPCC, 2013 (section 3.6.3):


5. Slides
Slides from the current science analyses are available online at the following address:

http://usclivar.org/sites/default/files/meetings/2014/amoc-presentations/Send_USAMOC14_MOVE.pdf