Meridional Overturning Variability Experiment

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1. PROJECT SUMMARY

A present gap in the sustained ocean climate observing system are techniques and programs for monitoring the circulation and mass/heat/freshwater transports of major current systems. Depending on the intensity, width, and depth extension of the current to be observed, different approaches and technologies exist now which allow implementation and maintenance of such "transport reference sites". For broad-scale and deep-reaching circulations, a recently demonstrated method consists of fixed-point installations with moored and bottom-mounted instruments to obtain horizontally and vertically integrated measurements throughout the watercolumn. The MOVE project intends to maintain the developed elements of the first such system by taking over partial operation of a moored transport array in the Atlantic.

In the year 2000 the German CLIVAR programme initiated the circulation monitoring array (MOVE) in the subtropical west Atlantic along 16N, in order to observe the transport fluctuations in the North Atlantic Deep Water layer. Since then, three "geostrophic end-point moorings" 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 goal is to determine the transport fluctuations through this section, using dynamic height and bottom pressure differences between the mooring for estimates of the geostrophic transport.

To date, the array has delivered over 90% data return, and due to the built-in redundancy, transports are available for the full 8-year deployment period including the German funded period. The goal of the NOAA project is the continuation of the MOVE transport array in a reduced form (2 endpoint moorings plus current meter mooring on the slope), while complementing it on the eastern side of the Atlantic with a German-funded and operated mooring (near the Cape Verde islands). Numerical simulations by T.Kanzow (Ph.D. dissertation) have shown high skill of such an ocean-wide system for capturing the total meridional NADW transport across the latitude line, and IFM-GEOMAR/Kiel has committed to cooperate by providing the eastern end-point mooring.

With the new MOVE project, SIO will operate the two geostrophic endpoint moorings between the western boundary and the Midatlantic Ridge, plus the small current meter mooring on the slope. In the first years, the acquisitions for complete configuration of the moorings will take place, and the array will gradually be built up to its full implementation. In later years, routine operation will be achieved, and routine delivery of indicators about the state of the thermohaline overturning circulation at this latitude will be enabled.

2. PROGRESS

In the reporting period, the MOVE mooring array was serviced on a research cruise which was originally supposed to take place on the RV "Ron Brown" in May 2008. Due to technical problems with the ship the cruise was cancelled at short notice and alternate ships had to be sought. Fortunately, it was possible to arrange usage of the "Oceanus" departing from Woods Hole on 14 July. All shipments already had been on the way to or arrived in Barbados and needed to be re-routed to Woods Hole. The ship was smaller than needed and could barely take all the equipment and provide the lab space needed for the combined MOVE and NTAS cruises. However, with appreciable effort and compromises everything could be accommodated. Figure 1 shows the cruise track in the work area, with final port in Barbados. Moorings MOVE4, MOVE3, and MOVE1 were recovered successfully and data from the PIES at locations MOVE3, MOVE2, and MOVE1 were retrieved acoustically. The data from the moored instruments are complete (except for one current meter record) and of good quality. The PIES at location MOVE3 was behaving abnormally (probably a transducer arcing problem) and a spare/duplicate one was deployed next to it for safety. Raw data processing has been performed, and scientific data analysis is now possible with the data, some preliminary results are shown below.

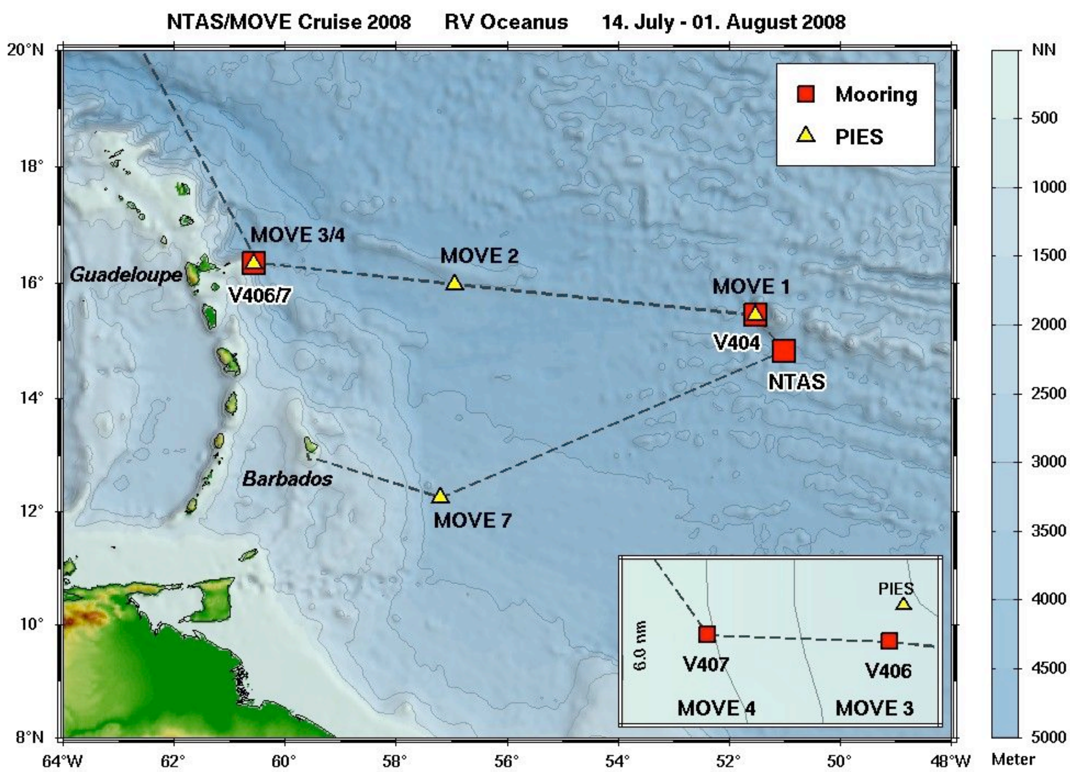

Figure 1. Map of cruise track, moorings MOVE1, MOVE3, MOVE4, and pressure sensors/inverted echosounders (PIES) at locations MOVE1, MOVE2, MOVE3, MOVE7. Shown also is the location of the NTAS mooring which was deployed by Woods Hole Oceanographic Institution.

Much of the raw data processing and calibration was carried out during the cruise. Figure 2 shows an example of processing the time-coded acoustic telemetry data from the PIES, cleaning them up and converting them to bottom pressure anomalies. The RCM current meters which still belonged to IFM-GEOMAR in Kiel/Germany were also processed, one example is shown in Figure 3.

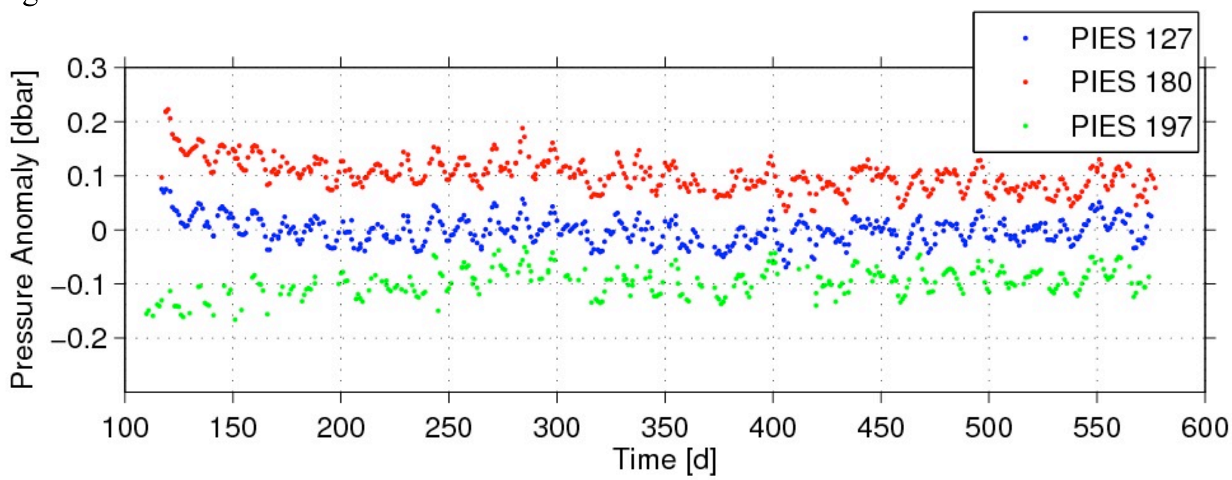

Figure 2. Daily average pressure anomalies from the 3 PIES along the MOVE section, retrieved acoustically and converted to pressure units.

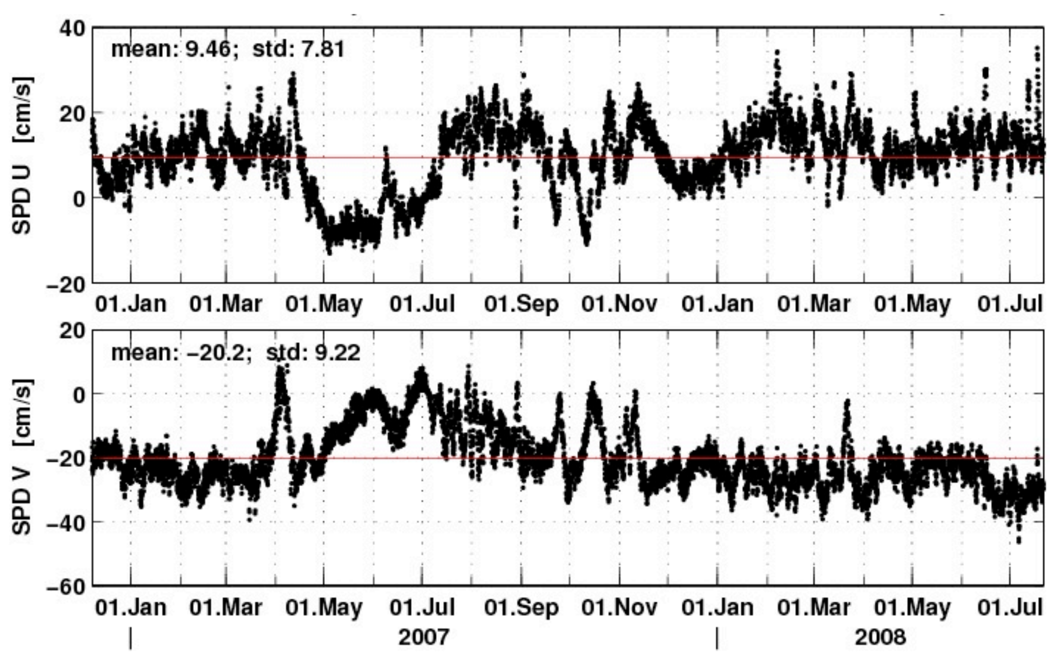

Figure 3. Example of the currents recorded by RCM rotor current meters on moorings M3 and M4. Shown here is the southward flow component in the core of the western boundary current, on mooring M3 at a depth of 2250m. Vertical mooring excursions by up to 400m were observed due to knock-down by strong current.

Extreme care is required for the calibration of the 36 microcat temperature/conductivity sensors, since the accuracy of the density, dynamic height, and geostrophic transport estimates is very sensitive to any offsets in those sensors. All microcats that were recovered (and also those which were going to be deployed) were attached to the CTD rosette and simultaneous vertical profiles were recorded with the CTD system and the attached microcats. In addition, the CTD conductivity probe was calibrated with water samples and high-precision salinometry carried out on board during the cruise. Careful processing of the entire data ensembles then allows calibration of T, C, and S to the required accuracy.

Each mooring was re-deployed within less than 24 hours of recovery, due to the short time at sea available. This was only possible by having enough equipment at hand to deploy at least one complete mooring without "turning around" any recovered instruments. This had required purchases of new microcats. Later during the cruise, instruments from the first recovered moorings could be re-used for new deployments. New acoustic releases had also been purchased since for the previous deployments releases loaned from Germany and other groups at SIO had to be used.

Another new instrument used in the new deployment was the Nortek Aquadopp current meter. This will replace the rotor RCM instruments used until now to capture the near-shore part of the boundary current not covered by the geostrophic estimates between the deep moorings. Seven newly purchased Aquadopps were used, but in parallel with a set of borrowed RCM current meters, since the Aquadopps are still unproven (in our applications) and cross-calibration with the long existing timeseries is desirable.

Apart from the Aquadopp additions, the moorings were re-deployed in a nearly equivalent configuration as in the previous period, but now with purely NOAA funded equipment (except for the co-located RCM current meters). The configuration is still sparser than desirable, so that more instruments will need to be purchased from future funds. The tables below give information about the PIES and moorings deployed and the material contained in them. The mooring designs are shown in Figures 4-6. Note that PIES remain deployed for nominally 4 years.

Table1. PIES Deployments during cruise RB-07-02, April 2007, and OC 449/1, July 2008.

Site	*PIES s/n*	*Position*	*Water Depth*	*Depl. Date*
MOVE 3	197 SIO	16N21.36 60W29.33	4955m	15-Apr-2007
MOVE 3	200 SIO	16N20.29 60N29.31	4900m	22-Jul-2008
MOVE 2	127 IFM	15N59.28 56W56.29	4943m	23-Apr-2007
MOVE 1	180 SIO	15N27.04 51W31.62	4965m	24-Apr-2007
MOVE 7	128 IFM	12N15.47 57W12.07	4454m	17-Apr-2007

Table 2. Mooring Deployments during cruise OC 449/1, July 2008.

Site	*Mooring ID*	*Position*	*Water Depth*	*Depl. Date*
MOVE 4	MOVE4-08	16N20.00 60W36.45	3005m	22-Jul-2008
MOVE 3	MOVE3-08	16N20.30 60W30.30	4960m	22-Jul-2008
MOVE 1	MOVE1-08	15N26.60 51W30.85	4990m	25-Jul-2008

Table 3. Mooring Instrumentation and Equipment.

Site	*Aanderaa RCM*	*Nortek Aquadopp*	*Seabird 37 MicroCat IM*	*Acoustic Release*	*17" Float*
MOVE 4	4	4	-	2	40
MOVE 3	3	3	21	2	67
MOVE 1	-	-	15	2	45

The Aanderaa RCM are loaned by collegues at Ifremer in Brest/France and at IFM Hamburg/Germany.
Each Mooring is equipped with 2 Elkins Titanium Swivel, in total 6 swivel are deployed.
Each Mooring has a Top-Float (Aluminum Frame with 2 Benthos Floats), equipped with an Argos-Beacon, a VHF-Radio-Transmitter and a Xenon-Flasher.

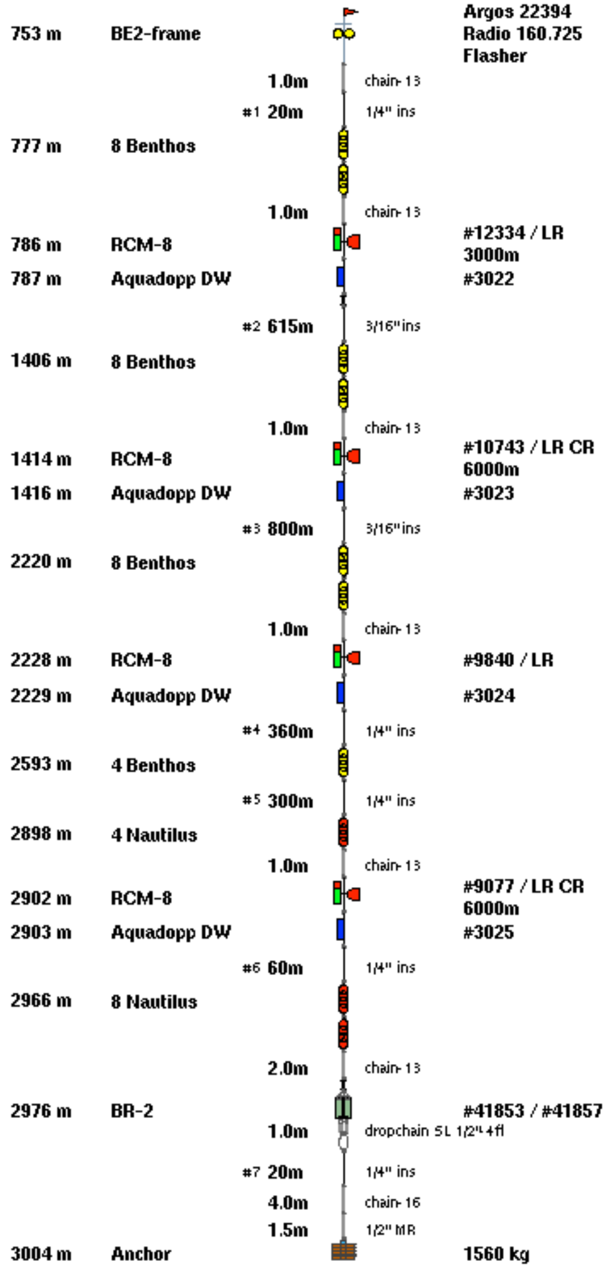

Figure 4. Design of mooring MOVE4 with each instrument and its depth noted.

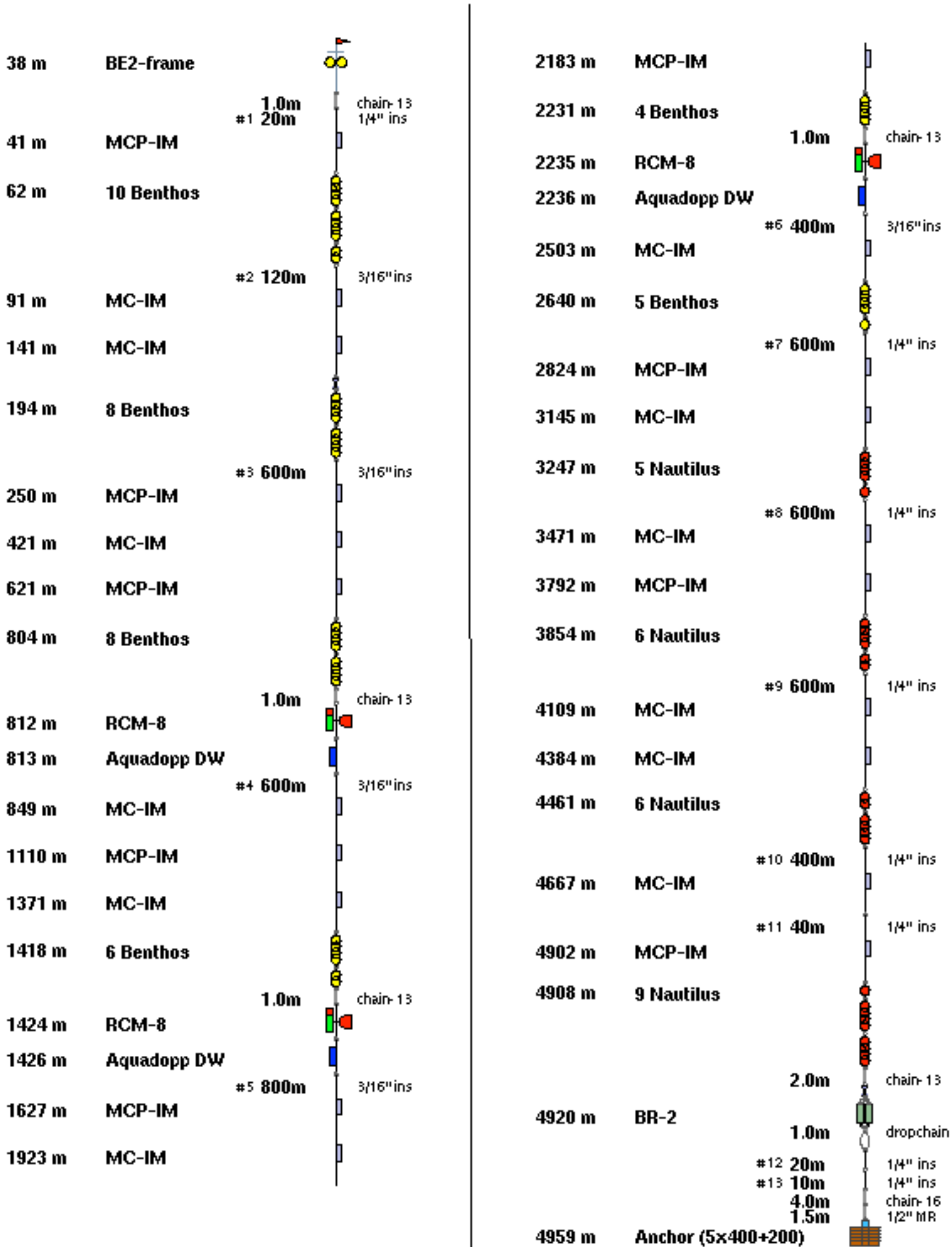

Figure 5. Design of mooring MOVE3 with each instrument and its depth noted.

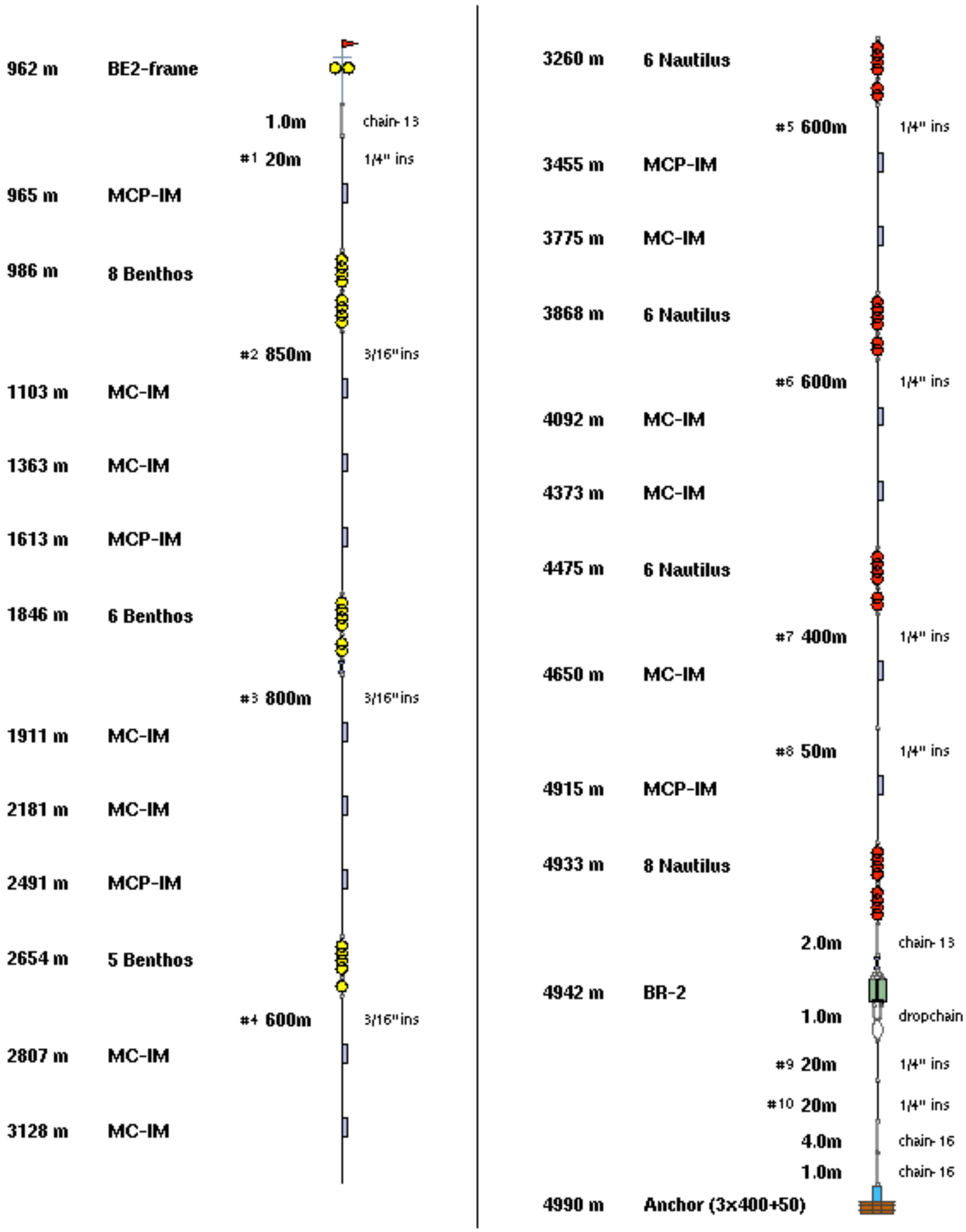

Figure 6. Design of mooring MOVE1 with each instrument and its depth noted.

After the cruise, work concentrated on analyzing the data in order to obtain useful and reliable estimates of the various transport components in the deep southward return flow of the meridional overturning circulation (MOC), i.e. the transport in the NADW (North Atlantic Deep Water). Since we now had an unprecedented 8-year timeseries at hand, a special effort was made to prepare a complete record of data for the annual NOAA system review meeting in Silver Spring.

One component of the transport is the part shoreward of the geostrophic section spanned by the deep moorings M1 and M3. This component is captured with the current meters on moorings M3 and M4. Since there are some gaps, and in the last deployment much fewer current meters were available (all needed to be borrowed) than previously, statistical estimates were constructed for the more sparse phases, based on the long timeseries with the full array. It was found that the error was acceptably small, and an 8-year timeseries of this "boundary transport" could be calculated. It is shown in Figure 7.

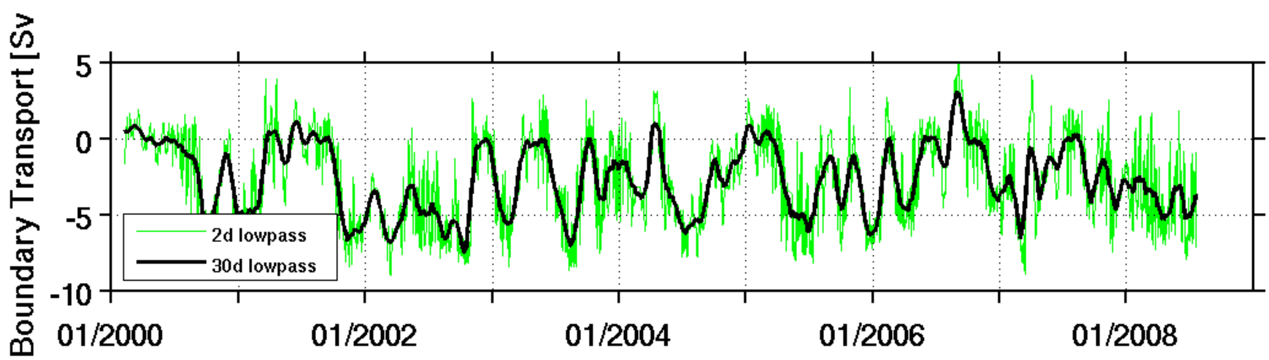

Figure 7. Transport (in Sv) of the boundary component of the NADW flow, i.e. the part between the continental shelf and mooring M3, estimated from the current meters in the moorings.

Another component is the "internal" transport calculated from the geostrophic pressure differences between moorings M1 and M3, derived from the density profiles at each mooring (from the T/S timeseries recorded by the microcats). This gives a transport relative to a pressure level, in our case initially 5000db. The excellent data set at hand now also allows an 8-year computation of this component, shown in Figure 8.

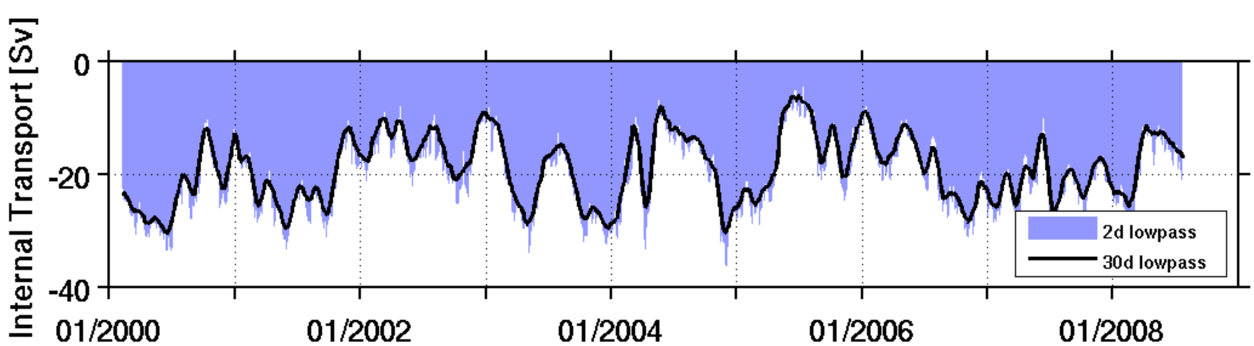

Figure 8. Transport (in Sv) of the internal (dynamic height derived) geostrophic transport of the NADW between moorings M1 and M3.

The third component of the flow is more problematic, since we rely on bottom pressure measurements that are not absolute, and thus for each deployment cycle the mean needs to be removed. As a result, long-term multi-annual variability cannot be determined at present (we will address this in the future with longer overlapping deployment of PIES). In addition, the failure of the PIES during 2006-2007 (reported manufacturer-related battery problem) resulted in a 2-year gap in the bottom pressure data. The available timeseries of transport fluctuations resulting from this "external transport" is shown in Figure 9.

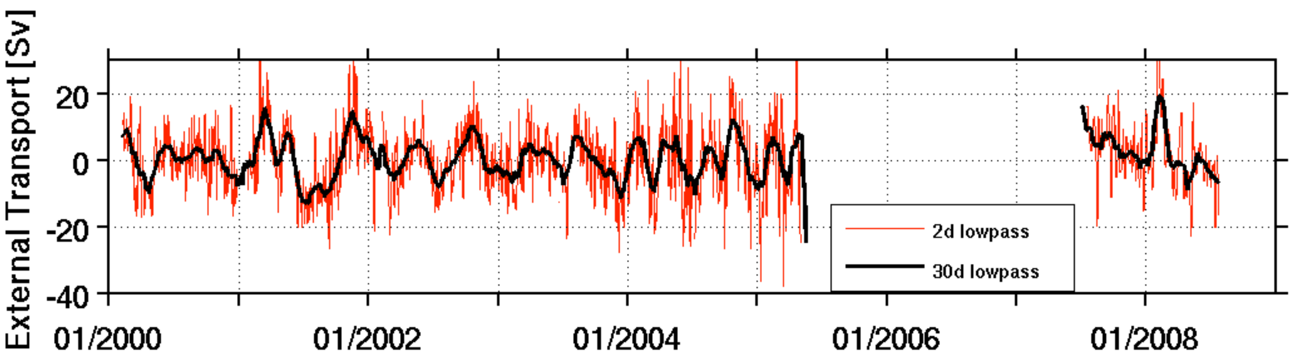

Figure 9. Transport (in Sv) of the "external" (bottom-pressure derived) component of the NADW flow, between moorings M1 and M3.

In order to obtain absolute transports, it was assumed that the long-term flow at the interface between the AAIW and the NADW is zero, since those water masses spread in opposite directions. This assumption had been shown to be valid in the initial phases of MOVE where 10 moorings with current meters were available from the joint deployment together with the GAGE project (M.McCartney). If this reference level is chosen to make the internal transports absolute, and the boundary transport is added, our current best estimate for the total absolute NADW transport over 8 years results, and is shown in Figure 10.

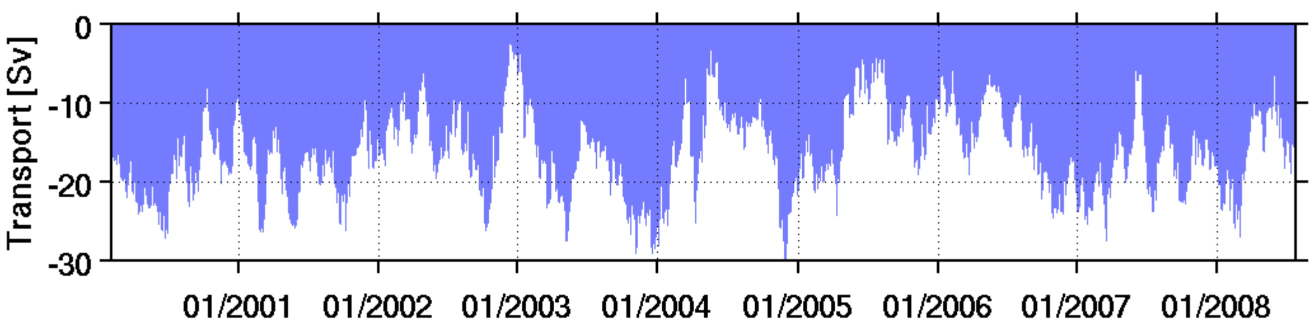

Figure 10. Absolute internal plus boundary transport through the MOVE section. The long-term mean is -14.9Sv (southward).

Careful trend analyses have been performed on the timeseries in Figure 10, and it appears that there is a significant decreasing transport intensity present with 80% certainty. However, there are still poorly understood sensitivities to the reference level chosen to make the internal transports absolute, and this a topic of ongoing work.