National Oceanography Centre, Southampton

Research & Consultancy Report No. 59

Monitoring the Atlantic Meridional Overturning Circulation at 26.5°N: RAPID-WATCH

S A Cunningham

2008

National Oceanography Centre, Southampton
University of Southampton, Waterfront Campus
European Way
Southampton
Hants SO14 3ZH UK

Author contact details:
Tel: +44 (0)23 8059 6436
Email: scu@noc.soton.ac.uk

DOCUMENT DATA SHEET

AUTHOR CUNNINGHAM, S A	*PUBLICATION DATE* 2008

TITLE

Monitoring of the Atlantic Meridional Overturning Circulation at 26.5°N: RAPID-WATCH.

REFERENCE

Southampton, UK: National Oceanography Centre, Southampton, 18pp.
(National Oceanography Centre Southampton Research and Consultancy Report, No. 59)
(Unpublished manuscript)

ABSTRACT

The Atlantic Meridional Overturning Circulation (AMOC) at 26.5°N carries a northward heat flux of 1.3 PW. Northward of 26.5°N over the Gulf Stream and its extension much of this heat is transferred to the atmosphere and subsequently is responsible for maintaining UK climate about 5°C warmer than the zonal average at this latitude. However, previous sparse observations did not resolve the temporal variability of the AMOC and so it is unknown whether it is slowing in response to global warming as suggested by recent model results. In 2004 NERC, NSF and NOAA funded a system of observations in the Atlantic at 26.5°N to observe on a daily basis the strength and structure of the AMOC. Two papers ([*Cunningham, et al.*, 2007] & [*Kanzow, et al.*, 2007]) demonstrated that not only does the system of observations achieve a mass balance for the AMOC, it reveals dramatic and unexpected richness of variability. In the first year the AMOC mean strength and variability is 18.7±5.6 Sv. From estimates of the degrees-of-freedom the year-long mean AMOC is defined with a resolution of around 1.5 Sv so abrupt changes would be readily identified and long-term changes will be measured relative to the 2004-2005 average.

The NERC contribution to the first four years of continuous AMOC observations was funded under the directed programme RAPID Climate Change. Following an international review of the system NERC will continue funding to 2014 under the programme RAPID-WATCH. The NSF and NOAA have also continued funding and commitments so that the system can continue operating at the same level of activity as during the period 2004-2008.

The objectives of RAPID-WATCH are: To deliver a decade-long time series of calibrated and quality-controlled measurements of the Atlantic MOC from the RAPID-WATCH arrays and; To exploit the data from the RAPID-WATCH arrays and elsewhere to determine and interpret recent changes in the Atlantic MOC, assess the risk of rapid climate change, and investigate the potential for predictions of the MOC and its impacts on climate.

Statements of contribution from the NSF and NOAA are included in Appendix A.

KEYWORDS

ISSUING ORGANISATION **National Oceanography Centre, Southampton**
University of Southampton, Waterfront Campus
European Way
Southampton SO14 3ZH
UK

Not generally distributed - please refer to author

Monitoring the Atlantic Meridional Overturning Circulation at 26.5°N

RAPID-WATCH

> **“There must be a beginning of any great matter, but the continuing unto the end until it be thoroughly finished yields the true glory’. Sir Frances Drake, 1587.**

Dr Stuart A. Cunningham (Project Leader and PI), NOCS

June 16, 2008

Background

The Atlantic Meridional Overturning Circulation (AMOC) at 26.5°N carries a northward heat flux of 1.3 PW. Northward of 26.5°N over the Gulf Stream and its extension much of this heat is transferred to the atmosphere and subsequently is responsible for maintaining UK climate about 5°C warmer than the zonal average at this latitude. However, previous sparse observations did not resolve the temporal variability of the AMOC and so it is unknown whether it is slowing in response to global warming as suggested by recent model results. In 2004 NERC, NSF and NOAA funded a system of observations in the Atlantic at 26.5°N to observe on a daily basis the strength and structure of the AMOC. Two papers ([*Cunningham, et al.*, 2007] & [*Kanzow, et al.*, 2007]) demonstrated that not only does the system of observations achieve a mass balance for the AMOC, it reveals dramatic and unexpected richness of variability. In the first year the AMOC mean strength and variability is 18.7±5.6 Sv. From estimates of the degrees-of-freedom the year-long mean AMOC is defined with a resolution of around 1.5 Sv so abrupt changes would be readily identified and long-term changes will be measured relative to the 2004-2005 average.

The NERC contribution to the first four years of continuous AMOC observations was funded under the directed programme RAPID Climate Change. Following an international review of the system NERC will continue funding to 2014 under the programme RAPID-WATCH. The NSF and NOAA have also continued funding and commitments so that the system can continue operating at the same level of activity as during the period 2004-2008.

The objectives of RAPID-WATCH are: To deliver a decade-long time series of calibrated and quality-controlled measurements of the Atlantic MOC from the RAPID-WATCH arrays and; To exploit the data from the RAPID-WATCH arrays and elsewhere to determine and interpret recent changes in the Atlantic MOC, assess the risk of rapid climate change, and investigate the potential for predictions of the MOC and its impacts on climate.

Statements of contribution from the NSF and NOAA are included in Appendix A.

The AMOC system

The 26.5°N Atlantic section is separated into two regions: a western boundary region, where the Gulf Stream flows through the narrow (80km), shallow (800m) Florida Straits between Florida and the Bahamas, and a transatlantic mid-ocean region, extending from the Bahamas at about 77°W to Africa at about 15°W (Figure 1). Variability in Gulf Stream flow is derived from cable voltage measurements across the Florida Straits, and variability in wind-driven surface-layer Ekman transport across 26.5°N is derived from QuikScat satellite-based observations. To monitor the mid-ocean flow we deployed an array of moored instruments along the 26.5°N section. The basic principle of the array is to estimate the zonally integrated geostrophic profile of northward velocity on a daily basis from time-series measurements of temperature and salinity throughout the watercolumn at the eastern and western boundaries. Inshore of the most westerly measurement of temperature and salinity, the transports of the Antilles current and deep western boundary current are monitored by direct velocity measurements.

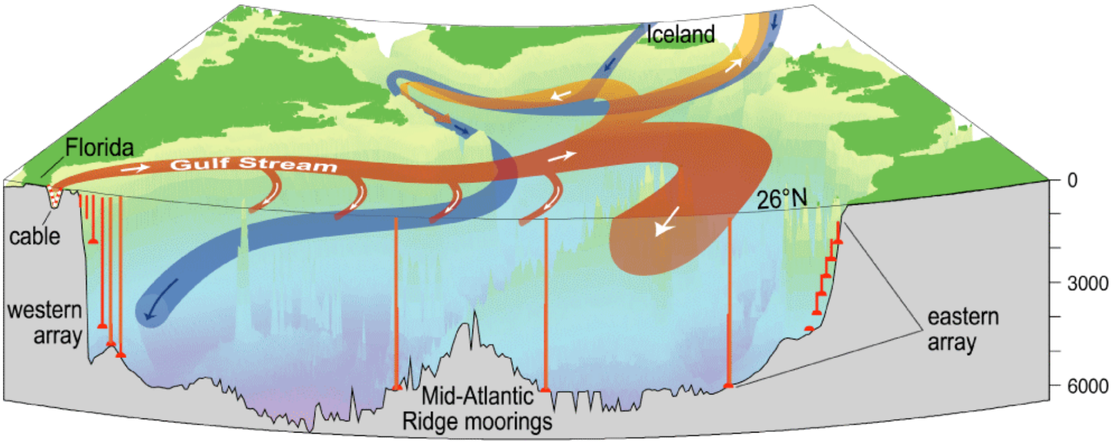

Figure 1: Schematic of the principal currents of the Atlantic Meridional Overturning Circulation. The vertical red lines across the Atlantic at 26.5°N indicate the main areas where moorings instrumented to measure the vertical density profile are located. The Gulf Stream transport is measured by submarine cable and the western boundary array includes current meters to directly measure transports of the shallow and deep western boundary currents. Bottom pressure recorders are located at several sites across the Atlantic to measure depth-independent fluctuations of the basin-wide circulation. Figure courtesy of Louise Bell & Neil White, CSIRO.

Array Specification

The array as deployed in 2007-2008 consists of a total of twenty one moorings and twelve landers. The following text assumes the array will continue in this form for RAPID-WATCH, but also allows for design changes as the array further evolves. Figures 2a,b and c are schematics showing each mooring and instrumentation in 2007-2008. Mooring naming convention: Moorings are named in three sub-arrays. Western boundary **WB#** with mooring number increasing to the east; Mid-Atlantic Ridge **MAR#**; Eastern Boundary **EB#**. The letter **H** is a historical reference to moorings originally intended to be HOMER profilers. **M** indicates a mini-mooring consisting of a 10m length mooring with one CTD instrument. Bottom landers instrumented with pressure recorders are indicated by **L** in the name. **ADCP** indicates an acoustic Doppler current profiler.

Eastern Boundary sub-array

The Eastern Boundary sub-array consists of two principal tall moorings **EB1** and **EB2** consisting of 30 CTDs. These moorings record the density profile at the Eastern boundary and act as a backup to each other. The eastern array further comprises a series of shorter CTD moorings **EBHi**, **EBH1**, **EBH2**, **EBH3** and **EBH4,** that step up the slope reducing the influence of bottom triangles when combined with the more offshore EB1/EB2 moorings, but they also can be used to reconstruct a single full depth density profile if required. Inshore of EBH4 there are a series of four “mini-moorings”, **EBM1**, **EBM4**, **EBM5** and **EBM6** that each consist of a single CTD and are relatively inexpensive meaning likely losses in this heavily fished area have less of an impact on the array. Finally the Eastern array includes four bottom pressure landers; **EBL1** and **EBL3** – comprising two bottom pressure recorders (BPRS) each – at the site of EB1/EB2, and **EBL2** and **EBL4** – comprising one bottom pressure recorder each – at the site of EBH1. The landers are serviced in alternate years so that each recovery provides a two-year record with a year's overlap with the previous lander to remove instrument drift. There are also two Inverted Echo Sounders with pressure sensors (PIES) deployed in the eastern boundary sub-array, **EBP1** at the site of EB1/EB2 and **EBP2** at the site of EBH4. These are not due for recovery until 2008, with the data being regularly downloaded through acoustic telemetry, and it is not presently known if replacements will be deployed.

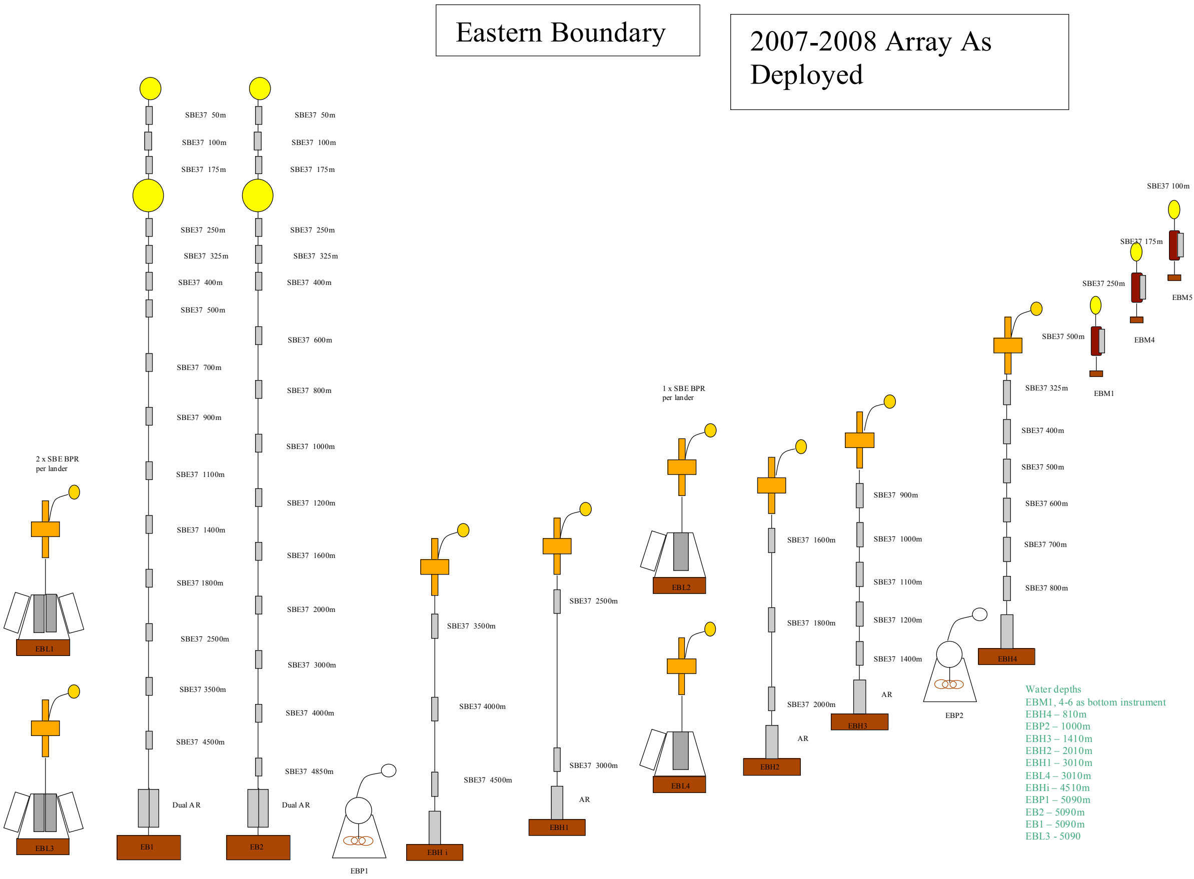

Figure 2a: Schematic of the Eastern Boundary mooring array for 2007-2008.

Mid-Atlantic Ridge sub-array

The sub-array at the Mid-Atlantic Ridge consists of one full depth mooring (**MAR1**), three shorter moorings (**MAR0**, **MAR2** and **MAR3**), and four landers (**MARL1**, **MARL2**, **MARL3** and **MARL4**). **MAR0** is a recent addition to the array and consists of three CTDs and a BPR to capture the Antarctic Bottom Water (AABW) to the west of the ridge. **MAR1** provides a full depth density profile through sixteen CTDs, with MAR2 acting as a backup to 1000m on the west of the ridge. MAR3 is sited to the east of the ridge and allows separation of the eastern and western basin MOC contributions. The landers are deployed as per those for the Eastern Boundary, with two at the site of MAR1, and two at the site of MAR3.

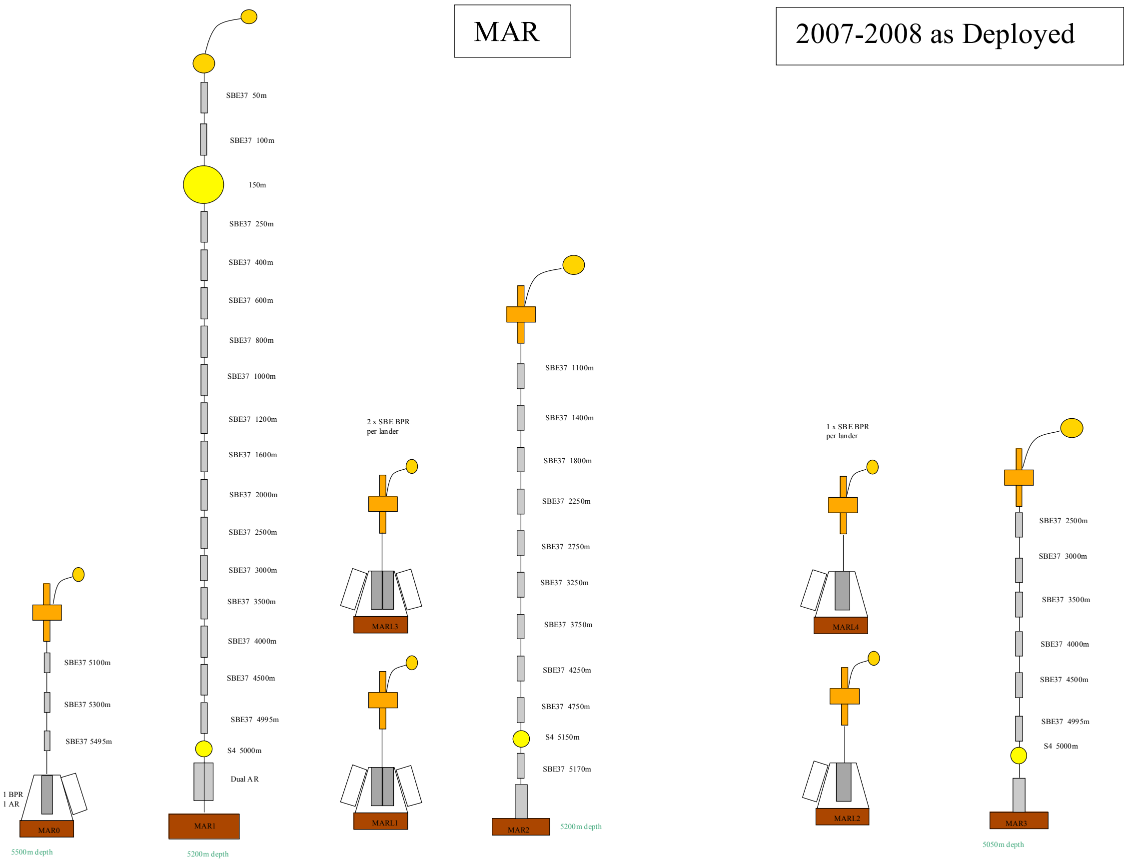

Figure 2b: Schematic of the Mid-Atlantic Ridge mooring array for 2007-2008.

Western Boundary sub-array

At the western boundary, **WB2** is the pivotal mooring and provides a full depth density profile very close to the western boundary "wall". The resolution of the profile can be improved by merging data from the nearby **WB1**. WB2 comprises sixteen CTDs and six current meters, whereas WB1 comprises fifteen CTDs and four current meters. WB2 will be made a telemetry mooring if possible. Inshore of WB1 there is **WBADCP** that comprises a Longranger ADCP at a depth of 600m to measure the shallow Antilles current. At the normal offshore extent of the Deep Western Boundary Current (DWBC) is **WB4**, which comprises fifteen CTDs and seven current meters. Further offshore is **WB6** – comprising three CTDs and a bottom pressure recorder – which combined with MAR0 measures the contribution to the MOC of deep water below 5200m including the Antarctic Bottom Water. There are again four landers in this sub-array; **WBL1** and **WBL3** (two BPRs each) at the site of **WB2**; and **WBL2** and **WBL4** (one BPR each) at the site of WB4.

In addition to the moorings listed above, the western boundary sub-array also contains three full depth moorings and four landers from the University of Miami. **WB0** comprising 4 CTDs and current meters and an upward looking ADCP. **WB3** is 22 km west of WB2 and so acts as a critical backup in case of loss of WB2. WB3 consists of 7 CTDs and current meters. Combined with the other inshore moorings it provides the thermal-wind shear and measured velocities from the core of the deep western boundary current. **WB6** is located 500 km offshore and is instrumented with 17 CTDs and provides the thermal-wind shear across the full width of the boundary

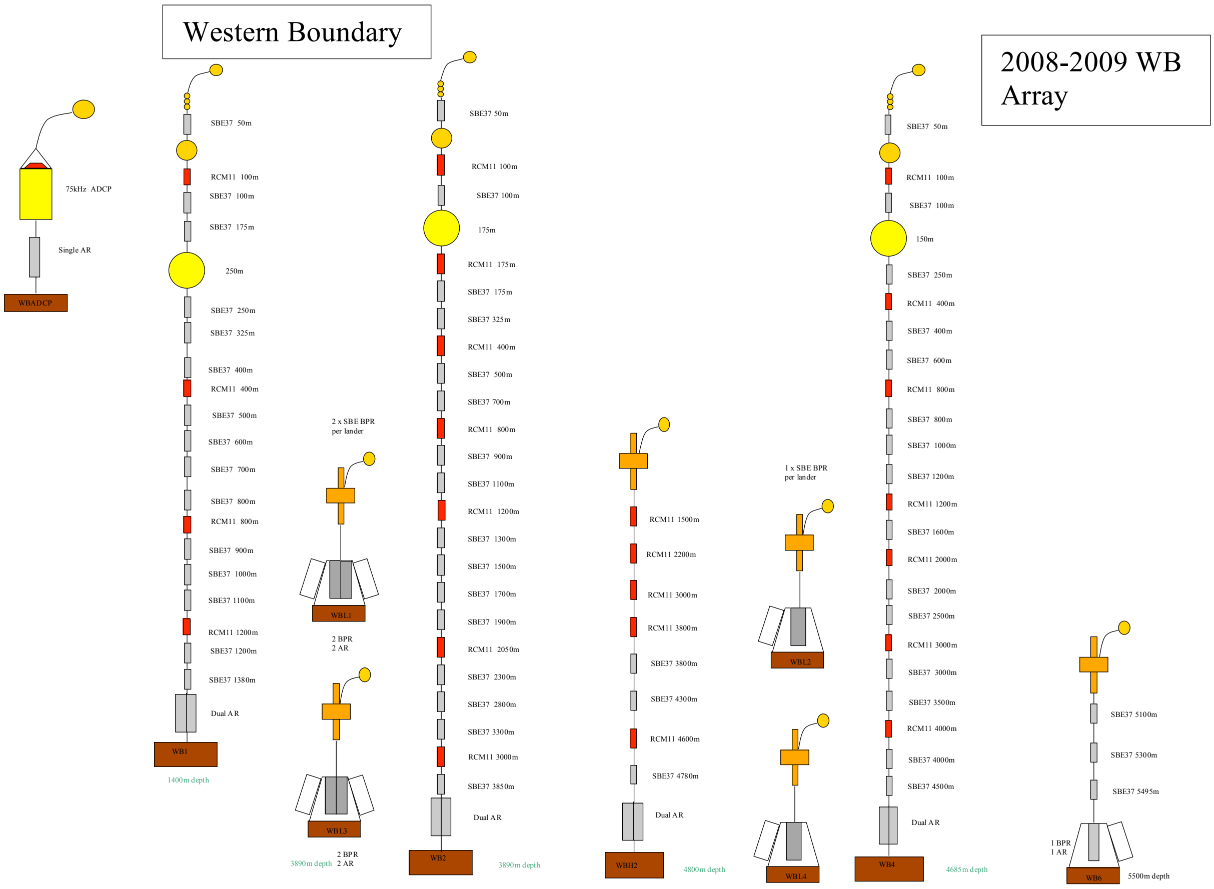

Figure 2c: Schematic of the Western Boundary mooring array for 2007-2008.

Hydrographic section

As part of the NOCS Oceans 2025 core programme the Ocean Observing and Climate group will conduct a repeat hydrographic section along 26.5°N in early 2010 as per the section completed on cruise D279 in 2004. This cruise is not part of the RAPID-WATCH budget but the data will be used to compare the array observations with the traditional hydrographic method and to provide basin-wide property distributions for flux studies.

Cruise Schedule

The schedule of cruises is outlined in Tables 1 and 2. For logistic and planning the NERC western boundary cruises are scheduled in the spring and the eastern boundary and mid-Atlantic Ridge cruises are scheduled in the autumn. NERC will lead two western boundary mooring cruises: One in autumn 2009 to refurbish the moorings and complete the NOAA Western Boundary CTD sections, the second in spring 2014 is the final mooring recovery cruise at the end of RAPID-WATCH. In total NERC will lead seven eastern boundary and mid-Atlantic Ridge cruises, two western boundary cruises and one transatlantic hydrographic section.

Table 1: Schedule of cruises for the refurbishment of the *western boundary array* from spring 2008 to spring 2014. The Sponsor provides ship-time and leads the cruise. NERC cruises are highlighted. Approximately 50 CTD stations (Hydro) will be occupied on each cruise. During RAPID-MOC cruises mobilise from a variety of ports on the eastern US and in the Carribean.

Year	Season	Sponsor	Activity
2008	spring	NSF	US+UK moorings, Hydro
2008	autumn	NOAA	Hydro
2009	spring	NOAA	UK moorings, Hydro
2009	autumn	NERC	US moorings, Hydro
2010	spring	NOAA	UK moorings, Hydro
2010	autumn	NOAA	Hydro
2011	spring	NSF	US+UK moorings, Hydro
2011	autumn	NOAA	Hydro
2012	spring	NOAA	UK moorings, Hydro
2012	autumn	NSF	US moorings, Hydro
2013	spring	NOAA	UK moorings, Hydro
2013	autumn	NOAA	Hydro
2014	spring	NERC	US+UK moorings (recover only), Hydro

Table 2: Schedule of cruises for the refurbishment of the *eastern boundary and mid-Atlantic Ridge array* from spring 2008 to spring 2014. The Sponsor provides ship-time and leads the cruise. Approximately 12 CTD stations (Hydro) will be occupied on each cruise. During RAPID-MOC these cruises usually mobilised from Santa Cruz de Tenerife, but occasionally mobilised directly from the UK.

Year	Season	Sponsor	Activity
2008	autumn	NERC	UK moorings, Hydro
2009	autumn	NERC	UK moorings, Hydro
2010	autumn	NERC	UK moorings, Hydro
2011	autumn	NERC	UK moorings, Hydro
2012	autumn	NERC	UK moorings, Hydro
2013	autumn	NERC	UK moorings, Hydro
2014	spring	NERC	UK moorings (recovery only) , Hydro

Data Delivery

Mooring array data is obtained from a variety of instrument types (Table 5). The main measurements are from SBE37 self-logging CTDs, providing measurements of conductivity, temperature and pressure from which vertical density profiles at the boundaries are calculated. The next most common measurement are the current meter direct velocities in the western boundary. The data processing report ([*Collins, et al.*, 2008]) details all data logging procedures and processing from raw to callilbrated data. Each mooring cruise is documented in a Cruise Report – part of our duty to NERC. These reports fully document all aspects of instruments recovered and deployed, their programming, data recovery rates and any other relevant information. They are also the meta data reports used by BODC for documenting the data they receive from the array.

Raw Instrument Data Files

Raw data files (all instrument types) downloaded direct from the instrument and converted from engineering units to physical units but without quality control or error checking are submitted to BODC immediately after each cruise – typically within a few weeks of cruise end.

Calibrated SBE37 microcat CTD Data

Microcat CTD data will be quality controlled and calibrated within three months of the end of each mooring refurbishment cruise. This work is carried out by the NOCS group for US and UK instrumentation.

Calibrated Current Meter Data

Direct velocity measurements are quality controlled and calibrated by the University of Miami, RSMAS group (Bill Johns). These are normally ready within six months of each mooring refurbishment cruise.

Calibrated Bottom Pressure Data

Although processing methodologies for these data are straightforward, there have been issues with varying stability of the pressure sensors that has required investigation by the manufacturer. A year timescale from recovery is a realistic timescale for delivery of these data.

Table 5: Summary of all instruments used in the array up to and including Spring 2008. Excludes US 2008 moorings

Instrument type	Model	Manufacturer	Number of deployments	Notes
CTD	SBE37 SMP MicroCAT	Sea-Bird Electronics	385	
	SBE37 IMP MicroCAT	Sea-Bird Electronics	190	
	XR420 CTD	RBR	5	
	OceanSeven 304 CTD	Idronaut	3	use discontinued in 2006
BPR	SBE26 SEAGAUGE	Sea-Bird Electronics	36	
	SBE53 BPR	Sea-Bird Electronics	8	
	SBE16 SEACAT	Sea-Bird Electronics	2	
	OT660C	IXSEA	2	
	WLR8	Aanderaa	2	
Single point current meter	Argonaut MD	SonTeK	24	
	RCM11	Aanderaa	75	
	S4A	InterOcean	38	
	Aquadopp 6000m	NorTek	1	single intercomparison trial
	RCM7	Aanderaa		
Current/CTD profiler	Moored Profiler (MMP)	McLane	8	use discontinued in 2006
Current profiler	150kHz BroadBand ADCP	RD Instruments	4	All units Lost
	75kHz Long Ranger ADCP	RD Instruments	4	
	150kHz NarrowBand ADCP	RD Instruments	2	
PIES	IES model 6.2	University of Rhode Island	2	Units under test

Science Deliverables

At the time of writing (June 2008) the calculation of scientific deliverables in the form of timeseries products is still an area of active research. A comprehensive account of the calculations is due to be submitted to the Journal of Physical Oceanography by late autumn 2008. We will develop routine methodologies that these calculations may be undertaken by a research assistant (under supervision) and produced more quickly. However, it is unlikely to be before autumn 2010 that we will reach this satisfactory state.

AMOC Timeseries

The science deliverable will be a 10-day filtered timeseries of the AMOC transports, its components (Gulf Stream, Ekman and Upper mid-ocean) and water mass layer transports as described by [*Cunningham, et al.*, 2007] and [*Kanzow, et al.*, 2007] (Figures 4 and 5). These products will be of particular use to those interested in the AMOC timeseries and for comparison to models.

Gridded temperature and salinity timeseries

We will also provide gridded files of temperature and salinity that will be of use for assimilation and for independent calculations of the AMOC. These will consist of the pressure gridded profiles of temperature and salinity versus time at the western and eastern boundaries and on either side of the mid-Atlantic Ridge and also the western boundary wedge pressure gridded velocities.

Delivery Schedule

The current delivery time for each additional year of timeseries is 1 year (Figure 3). The western boundary moorings are refurbished in spring each year and the mid-Atlantic Ridge and eastern boundary moorings in autumn. Therefore, a one year segment of MOC timeseries is constructed from two years of western boundary mooring deployments that are overlapped by one year of eastern boundary deployment. The data have first to be quality controlled and calibrated at RSMAS and at NOCS then brought together in a unified data set. There is a complication to this in that the western boundary US moorings are refurbished on an 18 month timescale and only in 2008, 2011 and 2014 are the US moorings recovered in spring synchronously with the UK moorings (Table 1). On other years the US moorings are recovered in autumn. This has the potential to add to the final delivery time (Table 1).

When the timeseries are ready they are delivered to BODC for distribution.

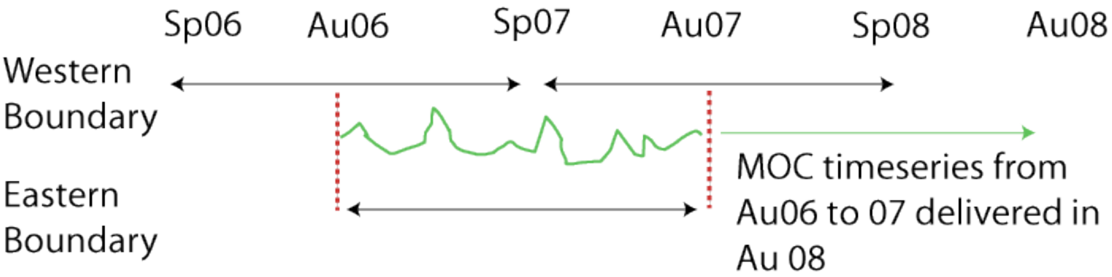

Figure 3: Illustration of the delivery schedule for each additional year of MOC timeseries. The western boundary moorings are refurbished in spring each year and the mid-Atlantic Ridge and eastern boundary moorings in autumn. Therefore, a one-year segment of MOC timeseries is constructed from two years of western boundary mooring deployments that are overlapped by one year of eastern boundary deployment.

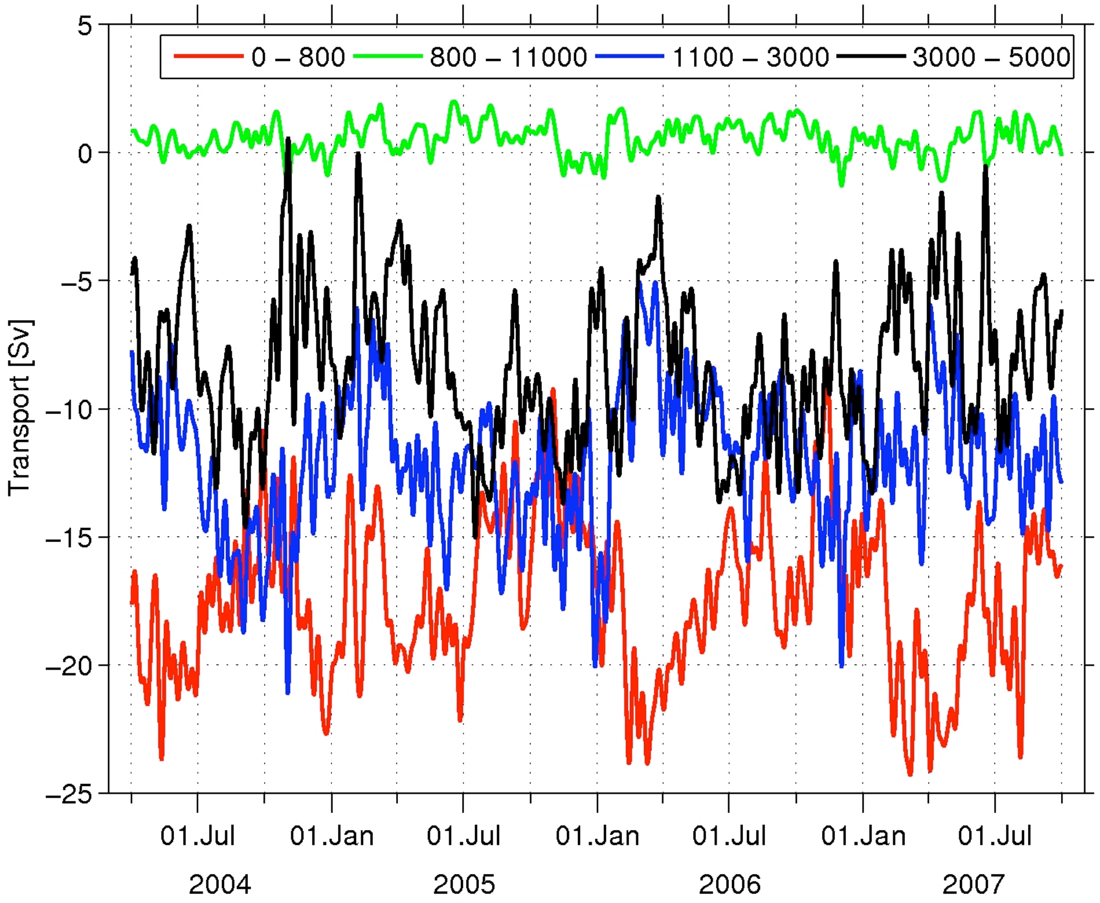

Figure 4: Three and a half year-long time series of 10-day filtered layer transports for thermocline recirculation (red), intermediate water (green), upper North Atlantic Deep Water (light blue) and lower North Atlantic Deep Water (dark blue). Negative transports correspond to southward flow.

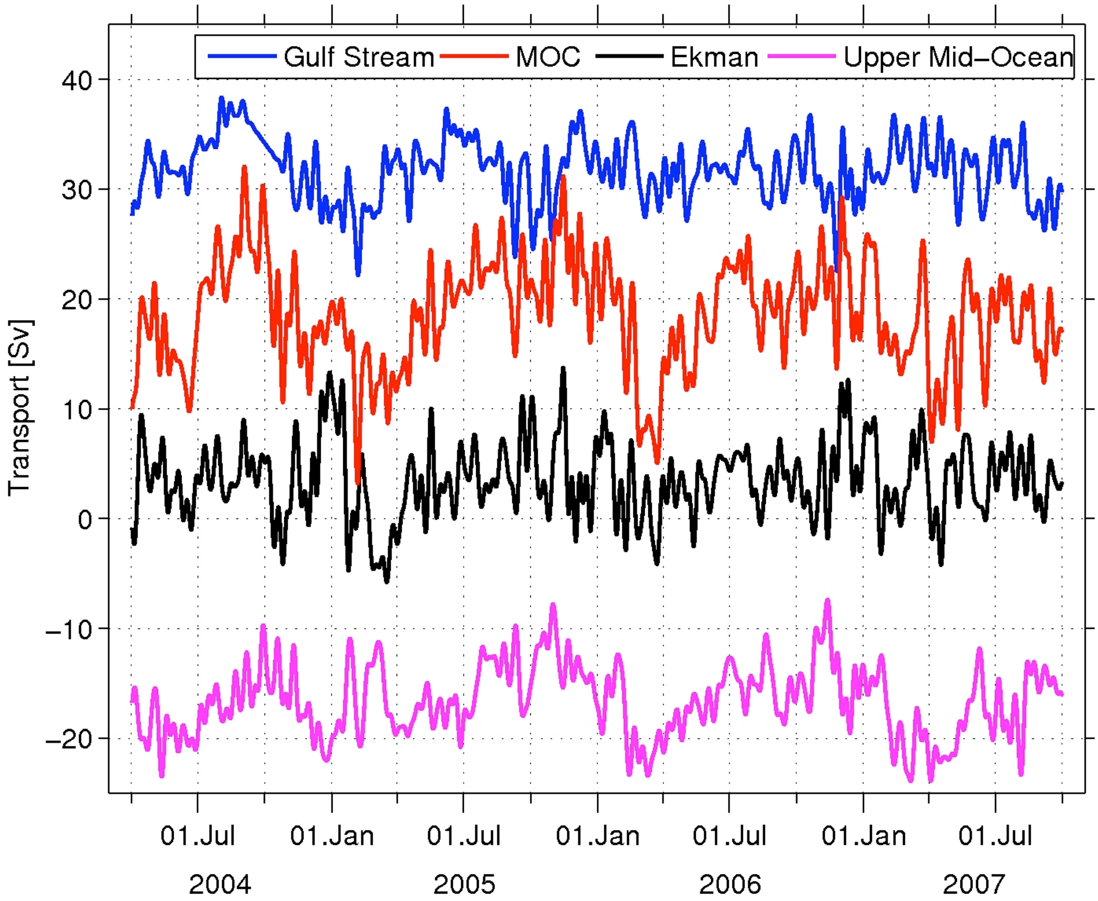

Figure 5: Three and a half year-long time series of 10-day filtered Gulf Stream transport (blue), Ekman transport (black), upper mid-ocean transport (magenta) and overturning transport (red). Gulf Stream transport is based on electromagnetic cable measurements. Ekman transport is based on QuikScat winds. The upper mid-ocean transport is the vertical integral of the transport per unit depth down to the deepest northward velocity (~1100 m) on each day. Overturning transport is then the sum of the Florida Straits, Ekman and Upper Mid-Ocean transports and represents the maximum northward transport of upper layer waters on each day.

Telemetry

There are three reasons for developing a telemetry system for remotely retrieving data from the moorings. 1. As soon as the data are taken and transferred they are then secure from subsequent loss through failure of the instrument (flooding for example) or mooring loss. The early retrieval of data also enables rapid response to failures in the system; 2. Receiving the data ashore will reduce the frequency of service intervals and hence significantly reduce the operating costs of the array and 3; increase the timeliness of data delivery to users and quicken the delivery of the AMOC and associated timeseries.

From 2004 to 2006 we developed and deployed a telemetry system (Risk Report – presented to the International review group in February 2007). A prototype and a functioning system were developed. The basic principal was to use electromagnetic inductive coupling of instruments to transfer data along the mooring wire to a surface buoy. Data were then sent ashore via the ORBCOMM satellite using off-the-shelf mobile phone technology. The inductive coupling and surface buoy worked well and reliably. However, we did not solve the problem of keeping the surface buoy attached to the subsurface mooring. Waves, winds, currents, ships/fishermen seemed to be responsible for detaching the surface buoy. A decision was made that the mooring security had a priority over further development of a tethered system and so no deployments took place after 2006. In tandem Bill Johns at RSMAS is continuing to develop a tethered system, but has also had very limited success.

At present we are conducting a desk-top-study with Professor Gywn Griffiths (National Marine Facilities Division – Underwater Systems Laboratory) of alternative methods. The most promising appears to be the use of sea-bed data capsules that receive data inductively and are released to the surface where they transmit data ashore. This would exploit the expertise (and instruments) we have for inductive data transfer. For this new development we could draw on the expertise of the Proudman Oceanographic Laboratory. They have been using for a number of years a pod system called MYRTLE for returning multi-year bottom pressure records. Our desk-top study is not yet complete so it may conclude differently to the above as our requirements and operating conditions differ from those for which MYRTLE was designed. Our goal is to have a fully demonstrated and operational system by 2011. Based on the costs of developing the first telemetry based system we have included a budget item for telemetry development and operational costs.

We have also initiated contact with the Woods Hole Oceanographic Institution moorings group. We will visit in September 2008 to seek advice on our proposals for telemetry and also in the area of moorings design.

References

Collins, J., et al. (2008), Processing and management of the RAPID-MOC/MOCHA mooring array data, NOCS Internal Report, in prep pp, NOCS, Southampton.

Cunningham, S. A., et al. (2007), Temporal variability of the Atlantic Meridional Overturning Circulation at 26.5°N, *Science*, *317*, 935-938.

Kanzow, T., et al. (2007), Flow compensation associated with the MOC at 26.5°N in the Atlantic, *Science*, *317*, 938-941.

Appendix A : Status of collaborations

Funding of the US components comes via NSF funding to Professor William Johns for direct velocity measurements of the deep western boundary currents, and for Molly Baringer from NOAA for sustained cable measurements of the Florida Current and also for tracer and property measurements of the deep western boundary currents. NSF are funding the Johns measurements now to 2014. NOAA have a long-term commitment to the western boundary. Jochem Marotzke provides a critical link to the field of coupled climate and ocean modelling which are expected to be the main users of RAPID observations. The scientific goals of the Johns and Baringer contributions are described below. Both are considered central to the RAPID monitoring programme.

Professor William Johns, RSMAS, University of Miami

MOC Estimate

The proposed U.S. contribution to the trans-basin array is focused on the western boundary region off Abaco, Bahamas. This region has a long history of measurements including moored time series observations that extend over nearly a decade. The moorings proposed for U.S. support (sites WB0, WB3, and WB5) are at sites where earlier time series records of 3-10 years duration have been obtained prior to this program. The proposed configuration of moorings has two primary purposes within the MOC/MHT monitoring system: (1) to monitor the volume transport, the volume transport profile, and the temperature transport over the shallow Bahamas escarpment, and (2) to monitor the total transport of the Antilles Current and DWBC across the entire Bahamas western boundary layer.

Site WB0 is a conventional current meter mooring with an upward looking ADCP at 300 m and three current meters below it. Together with the UK moorings WBA and WB2 it measures the shallow transport over the upper escarpment off Abaco. Sites WB3 and WB5 are configured as dynamic height' moorings that are capable of monitoring the integrated geostrophic transport profile between moorings through the use of high-quality T/S sensors on the mooring and precision bottom pressure gauges. Sixteen T/S measurement levels are included on the deep water moorings which produces accurate relative geostrophic transports. Precision bottom pressure gauges (leveled by repeat CTD/LADCP sections) monitor the variations in the barotropic flow.

Site WB2 is intended to serve as the western boundary endpoint dynamic height mooring for the trans-basin section and is therefore placed as close to the escarpment as practicable while still being in relatively deep water. Mooring WB3 serves as a backup dynamic height mooring for WB2 and also provides direct velocity measurements near the core of the DWBC. Mooring WB4 is placed near the offshore edge of the DWBC and with WB2 provides integrated geostrophic transport estimates across the typical domain of the DWBC. Finally, mooring WB5 is placed well offshore of the western boundary to capture transport variability associated with offshore meandering of the DWBC and localized recirculation cells adjacent to the western boundary.

We feel that it is important in the framework of this program to explicitly monitor the variation of the DWBC, since it plays a central role in the overturning circulation and implicitly in its variability and has a mean transport larger than the Gulf Stream. The DWBC off Abaco is known to exhibit several modes of variability, including offshore meandering of the velocity core to distances of 100 km from the boundary that can persist for relatively long periods of time. To adequately monitor its transport it is necessary to have a western boundary array which spans the width of the DWBC meandering envelope. In addition, the transport of the DWBC is locally affected by topographic Rossby waves and small scale eddies near the western boundary that can alias the determination of longer period variations. In view of these considerations, the western boundary array is designed to provide: (i) a record of typical DWBC velocities and vertical current structure at a site near the mean core of the DWBC (mooring WB3), (ii) an integrated transport estimate for the region between the western boundary and 90 km offshore (mooring WB4) where the DWBC is normally confined, and (iii) an integrated transport estimate from the western boundary to a distance of 500 km offshore, where the deep eddy energy levels decrease to near mid-ocean levels and the variability of the transport estimates by DWBC meandering and other mesoscale variations will be mimimized. The enhanced DWBC monitoring provided by this array is intended to provide a well documented record of the DWBC variability to correlate with other indices of DWBC variability around the basin being collected in other programs.

With respect to the MOC calculation, the main effort supported by this proposal has been in the western boundary wedge region (the region adjacent to the Bahamas lying inshore of the western boundary endpoint dynamic height mooring), where RSMAS haven taken primary responsibility for the analysis of both U.S. and U.K. current meter observations. We have combined the transport estimates in the western boundary layer from direct current meter observations with those from dynamic height moorings farther offshore, to estimate the time varying transports in the upper and deep ocean over the width of the western boundary layer to a distance of 500 km offshore of the Bahamas (Johns et al. 2007). In this way we monitor not only the near-boundary wedge transport that is required for the MOC calculation, but also the net transport of the DWBC and the overlying shallow Antilles current over the full width of the western boundary layer.

Meridional Heat Transport (MHT) Estimates

Although the MOC dominates the overall meridional heat transport (MHT) in the North Atlantic, the measurement of the MOC provided by the observing system does not translate directly into estimates of the heat transport. Our goal is to provide MHT estimates that have an accuracy of approximately 0.2 PW and a bias of less than 0.1 PW for monthly averages. We expect the heat transport estimates from the observing system to meet the CLIVAR requirements of constraining interannual air-sea heat flux estimates over the North Atlantic to 20 W/m2. These estimates should also be sufficient to resolve any variations in the MHT that have a large enough amplitude to produce a significant climate impact.

To extend the MOC observing system to provide estimates of the MHT there are several tasks to be accomplished, which will be a main scientific focus of the University of Miami and NOAA/AOML efforts:

1. The temperature transport of the Florida Current and the Bahamas western boundary wedge need to be measured in addition to the volume transport.

2. The zonal variation of velocity and temperature (and specifically their correlation) across the ocean interior need to be accounted for in the estimation of the basin-wide baroclinic heat flux.

3. The Ekman heat transport needs to be estimated, by combining Ekman transports derived from scatterometry (QuickSCAT) with surface mixed layer products (validated by the NOAA AX7 XBT sections).

Dr. Molly Baringer – NOAA/AOML

Since 1982 electromagnetic cables have been used to measure the transport of the Florida Current between Florida and the Bahamas near 27°N, calibrated by monthly cruises. The Florida Current project, part of the Western Boundary Timeseries Project funded by the NOAA Office of Climate Observations, provides calibrated time series of Florida Current transports to the community via a web site.

The Abaco time series began in earnest in August 1984 when NOAA extended its Straits of Florida program to include measurements of western boundary current transports and water mass properties east of Abaco, the Bahamas. To achieve the goals of NOAA's strategic plan in terms of understanding the Atlantic Ocean's role in decadal and longer time scale climate variability, these continued time series observations at Abaco are seen as serving three main purposes:
1. Monitoring of the DWBC for water mass and transport signatures related to changes in the strengths and regions of high latitude water mass formation in the North Atlantic. Monitoring water mass properties in the DWBC at key locations is one part of an effort to track decadal changes in large-scale water mass properties.
2. Serving as a western boundary endpoint of a subtropical Meridional Overturning Circulation (MOC)/heat flux monitoring system designed to measure the interior dynamic height difference across the Atlantic basin and the associated baroclinic heat transport.
3. Monitoring the intensity of the Antilles current as an index (together with the Florida Current) of inter-annual variability in the strength of the subtropical gyre. Variations in the strength of the subtropical gyre in relation to the North Atlantic Oscillation (NAO) has been proposed as an important mechanism in the atmosphere-ocean feedback within coupled models (e.g., Latif and Barnett, 1996).