THE RAPID-MOC/MOCHA MOORING ARRAY AT 26ºN IN THE ATLANTIC

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ABSTRACT

The Atlantic Meridional Overturning Circulation (AMOC) at 26.5°N carries a northward heat flux of 1.3PW. Northward of 26.5°N much of this heat is transferred to the atmosphere.

The Rapid-MOC/MOCHA array measures: 1. The Gulf Stream transport through the Flordia Straits by use of a disused telephone cable; 2. Ekman transports by satellite scatterometry; 3. Deep western boundary currents by direct velocity measurements; 4. The basin-wide interior baroclinic circulation from moorings measuring vertical profiles of density at the boundaries, and; 5. Barotropic fluctuations using bottom pressure recorders.

These components are combined to produce an overall estimate of the AMOC, which is taken as the maximum northward flow of upper waters, including the Gulf Steam and Ekman transports.

Here we describe the array as it was deployed from the Autumn 2008 and Spring 2009 service cruises, and present a three-and-a-half-year timeseries of the AMOC and the component parts from the start of the array in Spring 2004 to Autumn 2007. The mean AMOC for this period was 18.5 Sv, with the mean Gulf Stream, Ekman and Upper mid-ocean components measured as 31.7 Sv, 3.5 Sv and -16.6 Sv respectively.

1. INTRODUCTION

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 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.

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.

2. THE ARRAY DESIGN

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 (Fig. 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 water column 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.

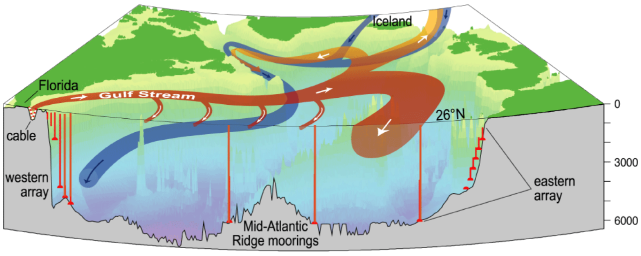

Figure 1: Schematic of the principal currents of the Atlantic Meridional Overturning Circulation. The vertical red lines across the Atlantic at 26.5°N indicate the main areas where moorings instrumented to measure the vertical density profile are located. The Gulf Stream transport is measured by submarine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

2.1 History of the Array

The array was first deployed in Spring 2004 and has since been refined in response to our experiences. It is funded by the Natural Environment Research Council, with additional moorings in the west deployed by the Rosenstiel School for Marine and Atmospheric Science, funded by the National Science Federation.

The Eastern Boundary and Mid-Atlantic Ridge sub-arrays are serviced in the Autumn with the Western Boundary sub-array serviced in Spring. There have been a total of 17 cruises involving mooring operations for the UK contribution to the array, with the most recent in Spring 2009.

2.2 Most recent configuration

The array as deployed in 2008-2009 consists of a total of twenty-one moorings and twelve landers in three sub-arrays (Fig. 2). The principal moorings measure the density profile at the eastern and western boundaries through use of CTDs. In the west the continental shelf forms a “wall” whereas in the east a series shorter moorings step up the slope reducing the influence of bottom triangles. Each sub-array also includes four bottom pressure landers that 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.

The Mid-Atlantic Ridge moorings provide full depth density profiles either side of the ridge to allow separation of the eastern and western basin MOC contributions. The western boundary sub-array includes current meters to directly measure the currents in the western boundary wedge. The contribution of the Antarctic Bottom Water is captured through an offshore mooring in the western boundary combined with a mooring on the western flank of the mid-Atlantic ridge. 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 that act as a backup to the density profile moorings and also provide the thermal-wind shear and measured velocities of the deep western boundary current [1].

2.3 Instrumentation Used

Table 1 show shows the numbers of different instrument types as deployed on the UK-deployed moorings.

Table 1: Summary of Instrumentation used on the UK moorings

Instrument	Instrument Type	No. in WB	No. in EB	No. in MAR
SeaBird SBE37 MicroCAT SMP/IMP	CTD	54	44	39
SeaBird SBE26	BPR	0	5	1
SeaBird SBE53	BPR	7	1	6
Aanderaa RCM11	Current meter	14	0	0
Nortek Aquadopp	Current meter	9	0	0
InterOcean S4	Current meter	0	0	3
RDI 75kHz Longranger ADCP	Current profiler	1	0	0
URI - PIES	Inverted Echosounder	0	2	0
Ixsea Oceano AR861	Acoustic Release	17	14	12
Sonardyne LRT	Acoustic Release	0	4	0

3. RESULTS

Two papers ([2] & [3]) demonstrated that not only does the system of observations achieve a mass balance for the AMOC, it reveals dramatic and unexpected richness of variability (Fig. 3): the AMOC mean strength and variability is 18.5±4.9 Sv. The component parts were found to have mean strength of 31.7 Sv for the Gulf Stream transport, 3.5 Sv for the Ekman transport and -16.6 Sv for the Upper mid-ocean transport.

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.

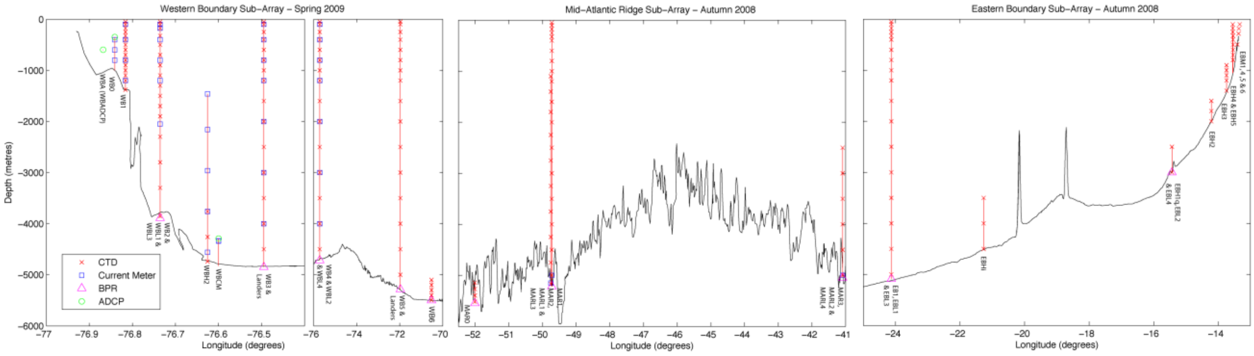

Figure 2: Schematic of the mooring array spatial resolution and instrument usage. The Western Boundary sub-array is serviced in the Spring of each year and so the configuration of the Western Boundary sub-array is as deployed from the Spring 2009 service cruise. The Mid-Atlantic Ridge and Eastern Boundary sub-arrays are serviced by a cruise each Autumn so the configuration shown here is as deployed from the Autumn 2008 service cruise.

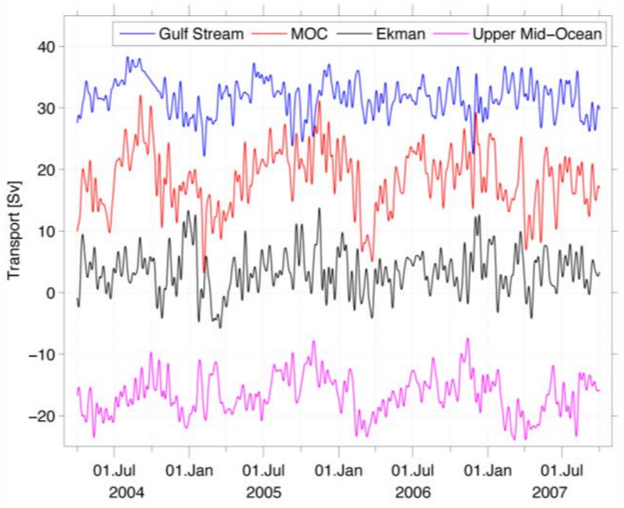

Figure 3: Three and a half year timeseries of the Atlantic Meridional Overturning Circulation as recorded by the 26.5°N mooring array showing the high degree of variability along with the component parts.

The Mid-Atlantic Ridge (MAR) sub-array was included in the array design to allow separation of the eastern and western basin MOC contributions (Fig. 4). The mean difference between including the MAR moorings and not including them in the calculation of the MOC is 0.68 Sv, with the MOC being stronger when the MAR moorings are not included.

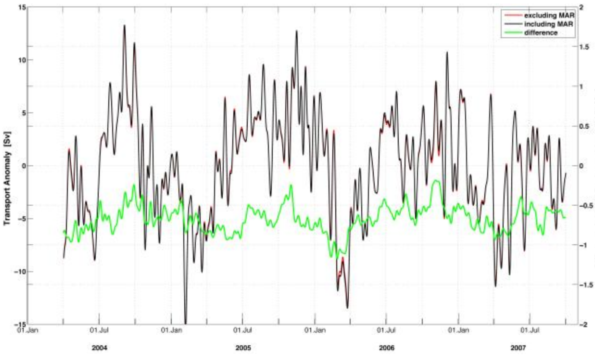

Figure 4: The impact of including or excluding the MAR moorings on the estimate of the MOC. Mean difference = -0.68 Sv ("with MAR" minus "without MAR"). Standard deviation of difference = 0.17 Sv.

4. REFERENCES

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