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RAPID-MOC time series April 2004 to February 2017

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Thank you for downloading the RAPID time series of the **Atlantic Meridional Overturning Circulation at 26.5°N**. The data files are updated from time to time, usually when time series can be extended and occasionally when changes are made to the processing of data. If you would like to be informed when changes are made please email the Principal Investigator.

The time series of the corresponding heat transport is available from: http://www.rsmas.miami.edu/users/mocha/

Data policy

Data from RAPID MOC monitoring project are made freely available to the public. Continued funding of this project depends on us being able to justify the usefulness of the data to the Natural Environment Research Council. The project scientists would appreciate it if you would use the data DOI (details below) and add the following acknowledgment to any publications that use this data:

"Data from the RAPID MOC monitoring project are funded by the Natural Environment Research Council and are freely available from www.rapid.ac.uk/rapidmoc."

The observational program is part of the UK RAPID-AMOC program and full data policy is available online at: http://www.bodc.ac.uk/projects/uk/rapid/data_policy/

Citations

Details of the calculation of the AMOC from the RAPID data are given in the following publications (and the online supporting material).

McCarthy, G.D., and Co-authors, 2015: Measuring the Atlantic Meridional Overturning Circulation at 26°N, *Prog. Oceanogr.*, 130, 91–111. doi:10.1016/j.pocean.2014.10.006.

Cunningham, S. A. and Coauthors, 2007: Temporal variability of the Atlantic Meridional Overturning Circulation at 26.5°N. *Science*, **317**, 935–938.

Kanzow, T. and Coauthors, 2007: Observed flow compensation associated with the MOC at 26.5°N in the Atlantic. *Science*, **317**, 938–941, doi:10.1126/science.1141293.

Digital Object Identifier (DOI) for this release

The full DOI for this data set is: 10.5285/5acfd143-1104-7b58-e053-6c86abc0d94b

The data citation that should be used in journals is: Smeed D.; McCarthy G.; Rayner D.; Moat B.I.; Johns W.E.; Baringer M.O.; Meinen C.S. (2017). Atlantic meridional overturning circulation observed by the RAPID-MOCHA-WBTS (RAPID-Meridional Overturning Circulation and Heatflux Array-Western Boundary Time Series) array at 26N from 2004 to

2017. British Oceanographic Data Centre - Natural Environment Research Council, UK. doi: 10.5285/5acfd143-1104-7b58-e053-6c86abc0d94b

Changes made when releasing data

October 2017

The time series is extended to 28th February 2017.

The coefficients used for extrapolation above the shallowest instruments have been updated.

Previously unused temperature and salinity measurements from MicroCATs at depths of about 400m on EBH4 since October 2012 have been included.

Previous time series have had a 10-day low-pass filter applied. This leads to spurious values in the first and last 5 days of the time series. In this release the same filter is applied, but the first and last 5 days of the time series have been set to absent data.

Each time the time series is updated the series mean and standard deviation change. These statistics affect interpolation and quality control of the data and so cause some minor changes to the calculated MOC.

In the mooring gridded-data files we have added a flag to indicate where climatological data has been used to fill gaps in the data. These gaps typically occur between deployments, or when gridded data are removed during quality control.

June 2016

The time series is extended to 11th October 2015.

The coefficients used for extrapolation above the shallowest instruments have been updated.

December 2014

The time series is extended to 22nd March 2014.

The calculation of the MOC has been modified as follows:

- The temperature and salinity gradients used for the interpolation of moored instrument data onto a high-resolution grid are now based on the Hydrobase3 climatology
- The coefficients used for extrapolation above the shallowest instruments have been updated leading to differences with the previous release of <0.1 Sv standard deviation.

These changes are detailed in McCarthy et al., 2015. The mean change from the previous release is a reduction of 0.2 Sv.

In addition an updated version of the Florida Straits transport time series was used.

May 2013

The time series is extended to October 2012

The calculation of the MOC has been updated to:

- Change equation of state to TEOS-10
- Improve extrapolation of near surface data and use seasonal climatology
- Modify the transport of AABW
- Change the wind product from CCMP to ERA interim

Description of the data

Three data files are provided here:

1. moc_transports (available in Matlab, NetCDF and ASCII format)
2. moc_vertical (available in Matlab format)
3. ts_gridded (available in Matlab format)

All times are in days since 1st April 2004.

The order of variables in the ascii file is:

JD YY	MM DD	HR		
t_therm10	t_aiw10	t_ud10,	t_ld10	t_bw10
t_gs10	t_ek10	t_umo10	moc_mar_hc10	

See below for a description of the variables.
Original instrument records form the moorings are available from the BODC.

1. MOC transport, components transports and transports in layers

The file *moc_transports* contains a 12.9-year time series of

- MOC transports (moc_mar_hc10)

for the period 2nd April 2004 to 28th February 2017 and the components:

- Upper mid-ocean transport (t_umo10),
- Florida Straits transport (t_gs10)
- Ekman transport (t_ek10).

Layer transports are also given for

- 0-800 m, “thermocline recirculation” (t_therm10)
- 800 to 1100m “intermediate water” (t_aiw10),
- 1100 to 3000m “upper North Atlantic Deep Water “ (t_ud10),
- 3000 to 5000m “lower North Atlantic Deep Water” (t_ld10),
- > 5000m “Antarctic Bottom Water” (t_bw10).

Negative transports correspond to southward flow. Transports are given in Sv (10^6 m^3s^{-1}), low-pass filtered at 10-day cutoff at twice daily resolution. The dates in the ASCII file are given in both Julian days and the Gregorian calendar. Julian day 1 corresponds to 2nd April 2004 at 00:00:00.

In order to calculate a maximum overturning, the methods of Cunningham et al. (2007) are followed, the upper mid-ocean transport is computed in a way that minimises the amount of southward transport, thus maximising the overall amount of northward transport of upper waters when Florida Straits, Ekman and mid-ocean transports are added together. The mid-ocean flow is generally southward from the surface to about 800 m depth, but between about 800 m and 1100 m depth there is a region of northward flow, while below about 1100 m depth the deep flow is generally southward. To obtain the minimum value of southward upper midocean transport at each time, the depth above which there is intermediate northward flow if found and below which there is southward flow. The upper mid-ocean transport is then defined to be the transport from the surface down to this depth at each time. On days where there is no northward flowing intermediate water and the mid-ocean transport is summed down to only 800 m because this is the approximate depth of the Florida Straits, where northward flowing Gulf Stream waters extend to the bottom.

Florida Straits transport

Florida Straits transport is based on electromagnetic cable measurements (Baringer & Larsen 2001). The Florida Current cable and section data are made freely available on the Atlantic

Oceanographic and Meteorological Laboratory web page (www.aoml.noaa.gov/phod/floridacurrent/) and are funded by the NOAA Office of Climate Observations. A gap in the time series of approximately two months from 4th September to 28th October 2004 is due to hurricane Frances that destroyed the facility recording the voltage. Here linear interpolation is used to fill the gap.

Ekman transport

Our earlier MOC calculations used QuikScat [Seawinds] winds in order to calculate Ekman transport at 26.5°N. Following the demise of QuikScat in November 2009, a replacement wind product was required. The Cross-Calibrated Multi-Platform Product (CCMP) [Atlas et al., 1996; Atlas et al., 2011] provides an excellent replacement [Kent et al., 2013]. A comparison between four wind products over the time period of April 2004 to September 2009 was undertaken to validate our choice of a new wind product. The mean and standard deviation of Ekman transport derived from CCMP 10 m zonal winds 3.6 ± 3.3 Sv compared with 3.6 ±3.4 Sv for QuikScat. This was preferred to NCEP [Kistler et al., 2001] and ERA-Interim [Dee et al., 2011] winds, which had mean and standard deviation Ekman transports of 3.6 ± 2.7 Sv and 3.8 ± 2.9 Sv respectively. Due to the delayed availability of the CCMP, ERA-Interim winds are used for the MOC calculation when CCMP is not available.

Negative values of the MOC

Negative MOC values: From 20th – 24th December 2009 and on 6th January 2010, there was no northward transport of water across 26.5°N. Usually, when there is no northwards transport, the MOC is seen to have two depth modes. If northward flow of Antarctic Intermediate Water is present in the geostrophic transport per unit depth, the MOC depth is 1050m. This is the case in all but one of the anomalous profiles. If no northward flow of AAIW exists, then the Florida Straits transport dominates and the MOC depth is 655m. This is the case in one of the anomalous profiles. Thus for the anomalous profiles when no northward flow exists, the MOC is defined as the cumulative vertical integral of all transports either from the surface to 1050m, if northward flow of AAIW is present in UMO, or to 655m if there is no northward flow of AAIW in UMO. Full details are given in the supplementary online material for McCarthy et al. 2012.

2. Streamfunction

The file *moc_vertical* contains the vertical profile of the overturning stream function at each time.

3. **Gridded Mooring Data**

The file ts_gridded contains the temperature and salinity data used in the calculation of the MOC. To calculate the interior geostrophic flow data from the different moorings are combined to create four merged profiles of temperature and salinity, one each for the:

- the western boundary (TG_west, SG_west)
- the western Mid Atlantic Ridge, (TG_marwest, SG_marwest)
- the eastern Mid Atlantic Ridge (TG_mareast, SG_mareast)
- the eastern boundary. (TG_east, SG_east)

Each of these merged profiles is then mapped onto a regular depth grid using the methodology of Johns et al. (2005). The resulting gridded profiles are supplied in the file gridded_TS_profiles.mat

Data gaps

Data from the top 800 m of the mooring on the west flank of the MAR was lost from 10th October 2016 to the 28th February 2017 due to fishing activity. Data for this time period were replaced with a climatology based on previous deployments of the mooring.

From February to June 2006, data were lost on the eastern boundary due to a change in the firmware of the instruments. This gap was linearly interpolated over.

Data from the top 800m of the mooring on the west flank of the MAR was lost from 25th October to the 22nd December 2010 due to fishing activity. Data for this time period were replaced with a climatology based on previous deployments of the mooring.

The mooring on the eastern flank of the MAR was lost for the period 1st November 2009 to the 22nd December 2010. This time period was also replaced with a climatology based on previous deployments of this mooring.

In the western boundary, the primary mooring WB2 was lost from 7th November 2005 to the 26th March 2006. For this period, the calculation of transport in the Western Boundary Wedge was extended out to WB3 and WB3 temperature and salinity data were used instead of WB2.

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