Atlantic Meridional Overturning Circulation:
Variability of the Deep Western Boundary Current at 26.5°N during 2004-2009

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Study description

In 2004 the confluence of three programs, the US/NOAA funded Western Boundary Time Series project, the US/NSF funded Meridional Overturning Circulation and Heat-flux Array project, and the UK/NERC funded RAPID-Meridional Overturning Circulation project, led to the first-ever basin-wide observing system capable of providing in situ estimates of the daily variability of the Meridional Overturning Circulation (MOC).

In addition to providing basin-wide MOC measurements, the combined array provides better resolution of crucial MOC components than has ever been available before. One such component is known as the Deep Western Boundary Current (DWBC), which carries the bulk of the cold deep limb of the MOC at 26.5°N. The focus of this poster is on the variability of the DWBC observed during 2004-2009 and its relationship to the MOC.

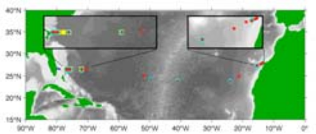


Figure: Map with two zoomed insets illustrating the locations of the moorings associated with the collaborative WBTS, MOCHA, and RAPID-MOC programs. Yellow squares denote PIES, cyan diamonds denote BPR, and red circles denote tall moorings. Also shown (blue line) is the approximate location of the cable used for monitoring the Florida Current. Gray-scale denotes the bottom topography from Smith and Sandwell (1997), while green indicates land.

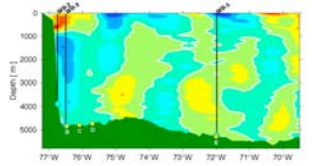
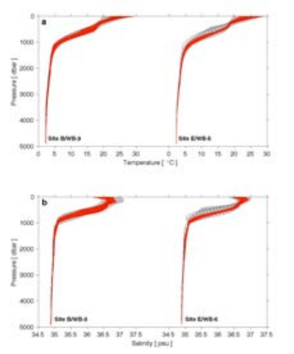


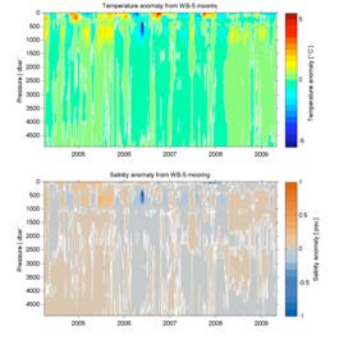
Figure: Vertical section plot illustrating the locations of the moored instruments used herein for estimating the DWBC in relation to the bottom topography (green). PIES, BRP, and tall moorings are denoted by yellow squares, cyan diamonds, and vertical lines, respectively. Contour field is a crude smoothing of all available historical meridional velocity sections with yellows and reds indicating northward flow and blues denoting southward flow.

Water property variability

The DWBC in this region is perhaps one of the most sampled open ocean currents, with more than 30 hydrographic sections collected since 1984.

Despite this, in just five years the combined WBTS/MOCHA/RAPID array has demonstrated (figure at right) that the range of temperatures (a) and salinities (b) observed by the moorings (gray shading) and by the PIES-GEM (cross-hatch) greatly exceeds that of all of the historical CTD observations, particularly within the 300-1000 m range.





The time series of water properties observed by the tall moorings illustrate never-before-seen events as well, such as the extremely cold (~ 5°C) and fresh (~1 psu) event that occurred in late spring 2006 at Site E/WB-5 (see anomaly plots at left).

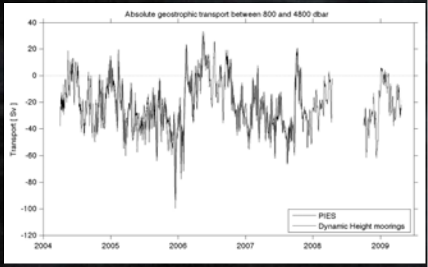
This event is also observed by the PIES at this site, and similar events are observed at other PIES sites (not shown).

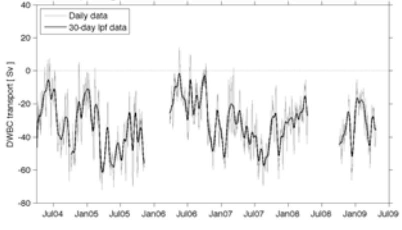
This illustrates one risk of analyzing 'snapshot' hydrographic sections.

Absolute transports from the combined array

Absolute transport estimates are made by calculating the geostrophic relative velocities from gradients between either the PIES-GEM profiles or the DHM profiles and then adding an absolute velocity reference determined from gradients in bottom pressure.

The agreement between the two techniques is quite good for the lone pair of overlapping PIES/DHM at Sites B/WB-3 and E/WB-5 (figure at right: r=0.96; rms difference=6 Sv).



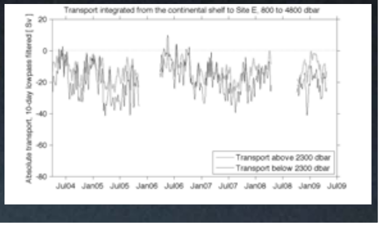


Combining all of the data together (including current meter data very near to the continental shelf) we can obtain a nearly continuous time series of transport integrated out to Site E/WB-5. The two large gaps result from a few instrument failures.

Variability is quite high, with a standard deviation of ~ 16 Sv.

Transport of LSW/DSOW/ISOW

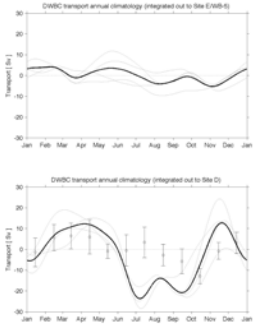
It is well known that the DWBC at this latitude is carrying both waters formed in the Labrador Sea (LSW) and waters that overflow the Demark Straits and Iceland-Scotland ridges after being formed in the Greenland, Iceland, and Norwegian Seas (DSOW, ISOW). The transport of these different waters appears to be highly correlated (r ~ 0.75).



Annual cycle

The observed annual cycle of the DWBC transport depends strongly on the integration range, being very weak if integrated out to Site E/WB-5 (right, top), and significantly stronger if integrated only out to Site D (right, bottom). The strong 'compensation' of the annual cycle out to Site E/WB-5 is somewhat surprising, as earlier theoretical/modeling studies suggested that such would occur only further offshore.

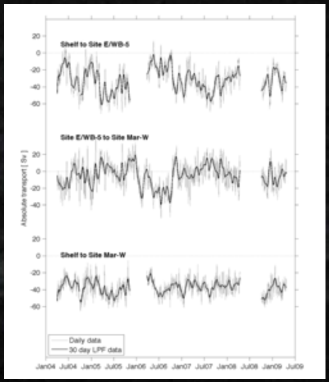
It must be noted, however, that the annual cycle is not statistically robust. Gray lines at right indicate annual climatologies determined with 4-year subsets of the 5 years. And the annual climatology from current meter data from 1987-1997 is also quite different and is similarly not robust statistically.



Comparing the DWBC and MOC transports

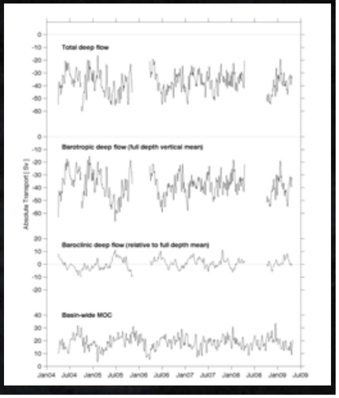
As is evident in analyzing the annual cycle, the existence of the well-known strong recirculation cell offshore of the DWBC complicates the interpretation of the observed transports. One way to address this is to integrate the transport all the way from the shelf out to the western side of the Mid-Atlantic Ridge (figure at right) using the DHM moorings at Sites WB-5 and Mar-W.

When integrated over this range the variability of the flow is smaller, and there are no reversals of flow (i.e. the flow is never northward). The variability, however, is still twice that of the MOC (a standard deviation of 10 Sv versus 5 Sv for the MOC).



Even if the deep flow is broken into baroclinic and barotropic components (barotropic defined here as the full water column average) there is no statistically significant correlation or correspondence between the deep flow and the total MOC integrated across the basin (figure at right).

Furthermore, neither the barotropic or baroclinic variability matches that of the total MOC – the barotropic variations are much larger and the baroclinic variations are significantly smaller. (Note: the baroclinic transport is non-zero because it is integrated only over 800-4800 dbar. If it had been integrated over the full water column it would be exactly zero by definition.)



Conclusions

- Variability observed by the array illustrates the need for continuous measurements
- The DHM and PIES are producing equivalent estimates of the deep volume transports
- The time variability of the DWBC is significantly higher than that of the total basin-wide MOC. This is true even if the deep flows are integrated across the recirculation cell to the Mid-Atlantic Ridge.
- The data presented here suggest there must be some compensation of the deep flows in the eastern basin of the Atlantic Ocean.
- Only with higher resolution of observations will we be able to attribute MOC changes.