The impact of EN3 and RAPID data assimilation on the change of heat balance in the Atlantic

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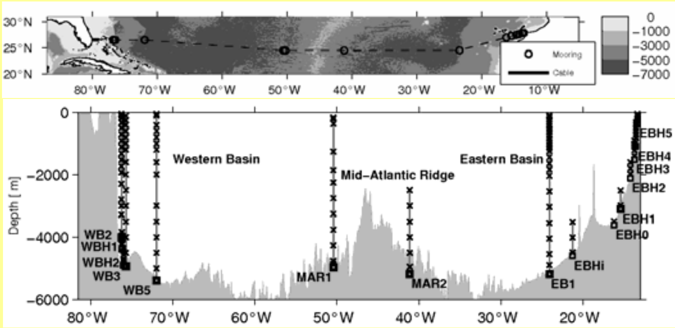
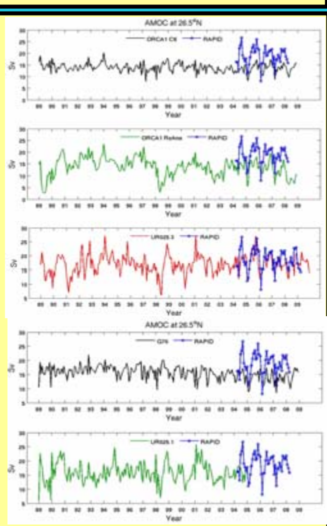
1. The Rapid Array Observations

The RAPID array at 26.5N is designed to monitor the geostrophic flow between Bermuda and Africa. The northward flowing Gulf Stream (~32Sv) is confined to the Florida straits where it is separately monitored by cable voltage measurements. Thus the Rapid array shown below does not provide direct information about the northward Gulf stream, but instead detects the southward return flow (~18Sv of which is below 1000m, thus representing the AMOC) and its variability, see Bryden et al (2009).



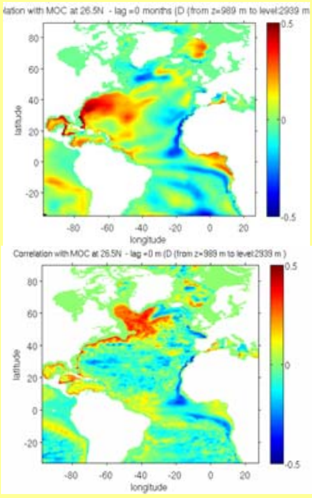
2. AMOC variability in models and ocean syntheses (EN3)

All runs use the NEMO 2.3 model with or without the assimilation of EN3 hydrographic data globally. The ORCA1° and UR025.3 ¼° runs use ERAInterim while G70(Ctl) and UR025.1 are ¼° runs using DFS3 Met forcing, based on CORE. Low frequency AMOC variations through the 1990's can be seen in ORCA1 and 025 reanalyses forced with ERAInterim, but not in the ORCA1 control forced with Interim, nor in the older UR025.1 reanalysis forced with DFS3. The UR025.3 product matches best the mean amplitude (17.5Sv) and variability during the RAPID monitoring period 2004-09.



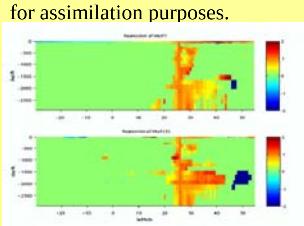
3. AMOC correlations: 1° and ¼°

The control run correlations of the monthly AMOC-Ekman at 26N with the 1000-3000m averaged and detrended density anomalies in ORCA1 (20yr) and ORCA025 (45yr) models. The high densities along the western boundary at 26N indicate stronger vertical shear and hence AMOC. Similarly for the lower densities on the eastern boundary. While the eastern spatial patterns are similar the western correlation patterns are quite different.



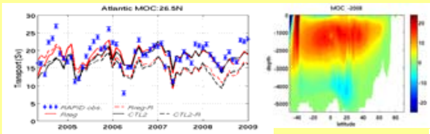
At 1° density correlations are confined to the subtropical gyre reaching up to 35-40N on the western boundary, and extending well into the basin interior. These are consistent with Ekman pumped density anomalies in the subtropical gyre propagating down to influence the 26N. At ¼° density correlations are confined to a narrow strip at the western boundary which reaches up to and fills the Labrador and Irminger seas. These correlations are associated with dense water formation. Further work is underway to determine how such different signals could be distinguished based on observational data from the RAPID array. These correlations can also be used to help assimilate the RAPID observational data more effectively.

Temperature regressions against 26N along the deep western boundary in the ORCA1 model are shown below. These regressions were used to produce quasi-observational Rapid array western boundary data up to 35 N for assimilation purposes.



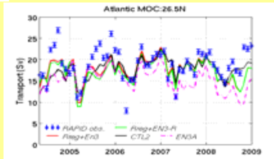
4. Assimilation of Rapid Array data

RAPID data has first been assimilated in the ORCA1 model, Stepanov et al (2011). The mooring data on the eastern and western boundaries are consolidated into single end profiles. If these are assimilated with standard isotropic covariances then the overturning circulation streamfunction is strongly distorted at latitudes around 26N. This was largely overcome using the western boundary regressions on *T*, *S* shown in box 3 to spread the 26N increments within the subtropical gyre as in the ORCA1 covariance region in box 3. Assimilation of Rapid moorings alone, experiment Rreg below, gives an increase in the AMOC over a control CTL2 without any assimilation.

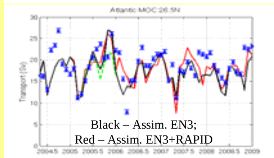


Rreg and CTL2 are RAPID assimilation and control experiments from the same initial states. Rreg-R and CTL2-R are recycled experiments from the end of 2008 starting with 2004 forcing again. The streamfunction is Rreg in 2008.

However Rreg gives only a temporary effect on the overturning. When the 2004-2008 forcing and assimilation is re-cycled and run again the AMOC decreases. When RAPID array data are assimilated together with basin-wide EN3 data (right, above) a stronger overturning is maintained for longer periods.

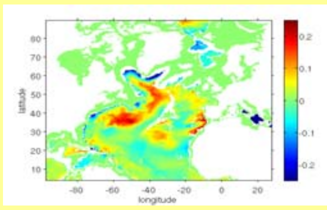


A first ¼° NEMO model run with Rapid data assimilated (right, below) demonstrates similar improvements in the AMOC (black line – UR025.3 in box 2), however the new ¼° covariances (box 3) have not yet been used.

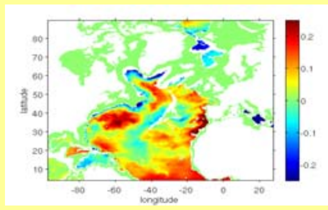


5. The change of the ocean heat content due to assimilation of RAPID data

Below the mean temperature difference between WOA09 (Levitus climatology) and the UR025.3 ¼° reanalysis averaged between 2000 and 3000 m are shown. These depths are below the level of the Argo array and there is very little observational data available. The difference is presented for two periods: 1989-2008 and 2005-2008. The reanalysis is slightly colder than the climatology (~0.2°C) in the mid-latitude basins in both periods, including the central Labrador sea, but there is a band down the western boundary where the model is always too warm. This suggests an inability to maintain strong enough

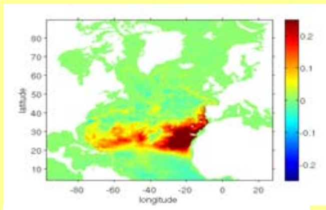


2000-3000m averaged T difference for 1989-2008 (WOA09 – EN3)



2000-3000m averaged T difference for 2005-2008 (WOA09 – EN3)

boundary gradients associated with the deep western boundary current, although the correlation pathway is still clearly visible in box 3. Assimilating the RAPID data (again note non-optimal covariances) leads to a decrease of the cold bias in the eastern subtropical gyre off west Africa (right above). This warming is due to a change of ocean circulation in the region of the North Atlantic between 20 and 40N (right below): the anticyclonic circulation becomes more intensive in this area with the assimilation of the RAPID array data, which then results in a warming. The intensification of the ocean circulation is mainly caused by barotropic (gyre) component changes.



2000-3000m averaged T (upper) and velocity (lower) difference for 2005-2008 (EN3+RAPID – EN3)

Bryden, H.L., A. Mujahid, S. A. Cunningham, and T. Kanzow (2009) Adjustment of the basin-scale circulation at 26 N to variations in Gulf Stream, deep western boundary current and Ekman transports as observed by the Rapid array; Ocean Science 5, 421–433, 2009.
Stepanov V., K. Haines and G.C. Smith (2011) Assimilation of RAPID observations into an ocean model; Submitted paper

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