Improved Estimates of AMOC and Global Meridional Circulation Using Altimetry with *In Situ* Tracers

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Warming of the North Atlantic Ocean from 1950s to 2012 is analyzed on potential density surfaces and vertical levels, using three data reanalyses and NODC direct observations. The half-century net gain of 6.7 x 10^{22} J estimated in the upper 2000 m is about 30% of the global ocean warming over this period. Isopycnal layer heat content varies mostly through layer thickness and lateral extent (through heat transport convergence, rather than variability of temperature/salinity 'spice'). The subtropical mode water layer $\sigma 0$ = 26.0-27.0 expresses more than 50% of the 50-year heat gain.

The observed ocean heat content and reanalysis subsurface temperature are dominated by two modes accounting about 50-60% of all variability. The dominant mode is a trend, with a strong positive center over the Gulf Stream-North Atlantic Current (GS-NAC) region, and a weaker negative signal in the subpolar gyre. The second mode of variability is associated with the Atlantic multidecadal variability (AMV), exhibiting a negative center over the GS-NAC, and strong positive anomalies over the subpolar gyre and in the eastern basin extending to the tropics. These modes can be found also at deeper density levels, but their spatial appearance is quite different.

By dividing the upper ocean into density layers between the surface and permanent thermocline we find that the subducting subtropical mode waters ($\sigma\theta$ = 26.0 to 27.0) have gained the most heat over the 57 years, with an abrupt downturn after 2008. A significant portion of this heat gain has come from northward migration of the density surfaces. The 'hiatus' in warming during 2000-2010 occurs in the surface and subtropical mode water layers but the four datasets disagree greatly in the deeper layers. The 50-year warming corresponds to only 10-20 m of subsidence of potential isotherms, which challenges the objectively mapped data. AMV complicates trend analysis: The North Atlantic 0-30°N gains heat rather steadily while the latitudes 30-65°N have large fluctuations due to AMV variability.

Our earlier study of the association of atmospheric jet-stream blocking with warm AMV has led to a diagnosis of the acceleration of Greenland's ice-melt in mid 2000s: persistent blocking highs during summer brought warm air to the region, causing rare episodes of summer melt at the summit of the ice cap, and across southern Greenland.

A collaborative investigation is continuing, of AMOC connections between subtropics and subpolar gyre with the HYCOM Atlantic model, with Xu, Chassignet and Schmitz at Florida State University. The project is analyzing the warm water pathway through the North Atlantic Current and just below the southward dense AMOC branches flowing from the Greenland-Scotland Ridge and Labrador Sea. Atlantic model simulations, with lateral resolution as fine as 1/50 degree, are being carried out to explore mesoscale and submesoscale contributions to AMOC, particularly involving the western boundary current system.

In the subtropical Atlantic there are intricate interactions between layers of the deep circulation. North Atlantic Deep Water and Antarctic Bottom Water, for example, experience fine-scale diapycnal mixing at the Mid-Atlantic Ridge (Curry & Polzin 2013), which drives a newly discovered deep cyclonic recirculation in the