The Atlantic Contribution to Global Ocean Heat Content (OHC) variability on isopycnal layers

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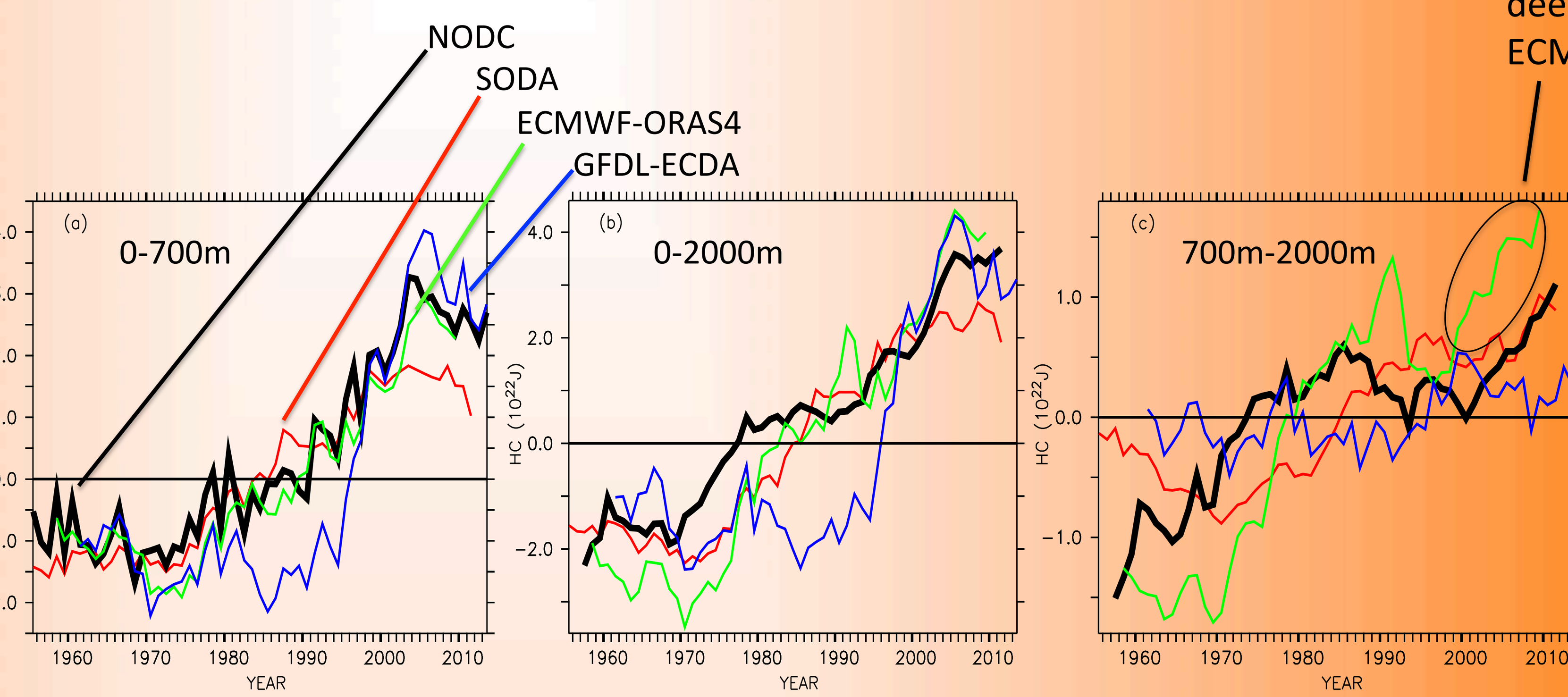
Abstract

Warming of the North Atlantic Ocean from 1950s to 2012 is analyzed in NODC observational data and three data reanalysis products, on potential density surfaces and vertical levels. The net North Atlantic gain of 5 x 10^{22} J in the upper 2000m is about 20%-30% of the global ocean gain over this period and the North plus South Atlantic has 40-50% of the global heat gain.

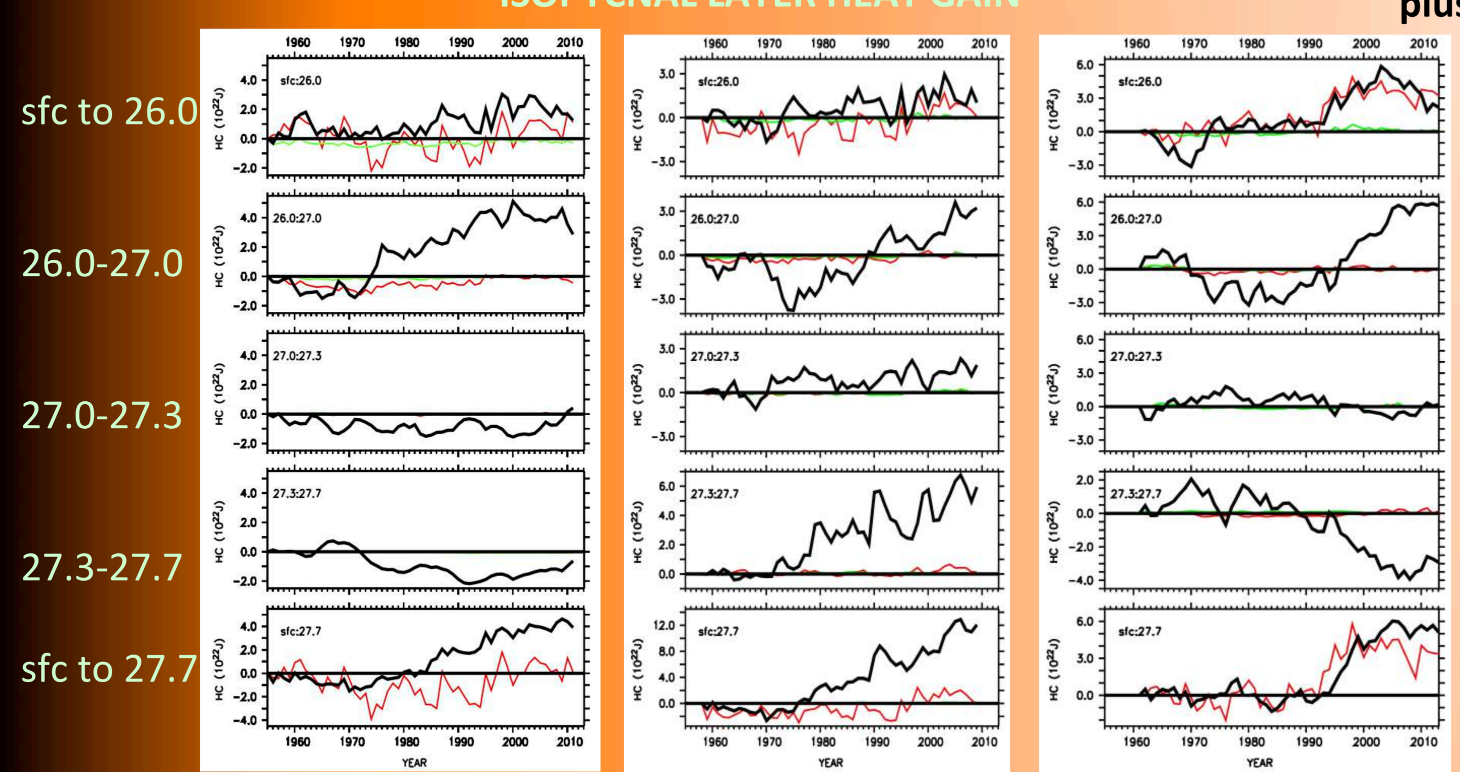
Isopycnal layers vary in heat content mostly through their thickness and lateral extent, rather than variability of temperature/salinity 'spice'. The layer σ_0 = 26.0-27.0 including subtropical mode water layer expresses more than 1/2 the 50-year heat gain. Yet Atlantic Multidecadal Variability makes this trend unrepresentative of the spatial structure of warming. Three ocean state reanalyses and the NODC database differ greatly in the deeper layers (σ_0= 27.0 to 27.7). The 'hiatus' in Atlantic warming during 2000-2010 occurs in two of the reanalyses whose mid-depth waters cool, while the other two datasets show deep warming and reduced hiatus.



Heat content evolution integrated over z-levels: 0 - 700m (a) and 0 - 2000m (b) and (c) 700m-2000m from NODC (black), SODA (red), ORAS4 (green) and ECDA (blue) for 0-65N. Units are 10^{22}J.

Reanalysis Datasets: SODA 2.2.8 *Carton & Giese MWR 2008*
ECMWF-ORAS4, *Balmaseda & Trenberth GRL 2013*
GFDL-ECDA, *Chang et al. Clim.Dyn 2013*
plus NODC data, *Levitus GRL 2012*

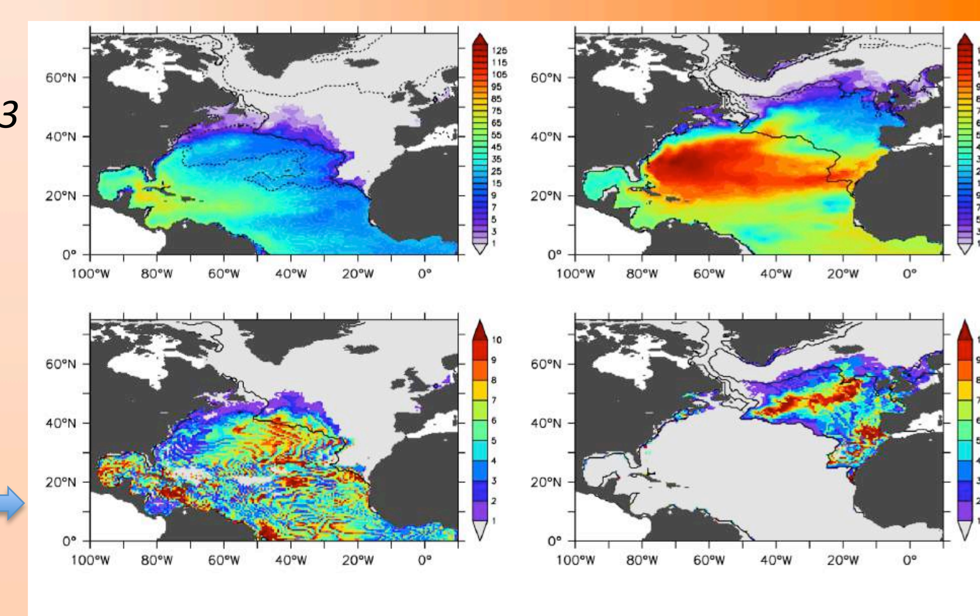
ISOPYCNAL LAYER HEAT GAIN



(a), SODA (b), ECMWF ORAS4 (c), GFDL-ECDA

Fig. 2a-c. Total OHC (**black** lines) integrated from the Equator to 65N excluding the Mediterranean for each sublayer and the sum of the sublayers for SODA (a), ORAS4((b) and ECDA (c). Isopycnal migration HC contribution in the ventilated area **(red)**; HC contribution from migration outside the static layer bottom (**green**). Each HC is plotted as an anomaly from the first year of the respective data set. All quantities referenced to their value at 1955. All HC units are 10^{22} J.

The red line in Fig. 2a represents OHC contributed by density outcrop migration



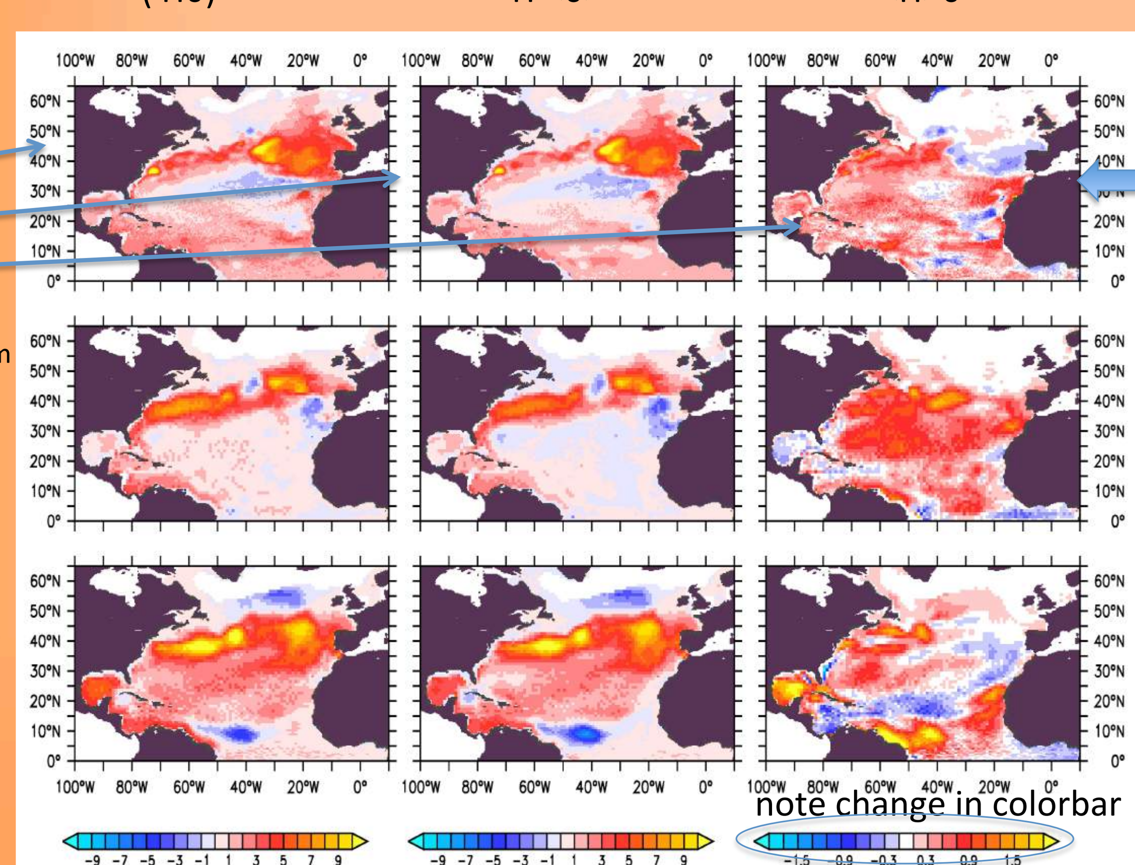
TOP: **Total OHC in σ_0 = 0-26 (top left) and 26-27 (top right)** sublayers for year 2000 from SODA. On left the static 26.0 density outcropping line marked by heavy line (where the layer is present all years of the record), on the right both static 26.0 (southern) and 27.0 (northern) outcropping boundaries are marked. Year 2000 March and September outcropping lines are marked by dotted lines (only for the 27.0 surface on the right). BOTTOM: **OHC contribution from migration of isopycnals within ventilated area s**hown for the 0-26 sublayer (bottom left; lighter isopycnals in the sublayer appear and disappaer above the static isopycnals that exist all years) and 26-27 sublayer (bottom right; migration of isopycnals within the ventilated area and/or decreasing or expanding their volume). Migration outside (northward) the static layer bottom is also shown in all cases. Units are 10^{18} J m^{-2} .

surface to σ_0=27.0 OHC trends 1995:2009 minus 1961:1975

total OHC trend = isopycnal layer thickening + Θ/S 'spice variability

$(H\theta)'$ = $H'\langle\theta\rangle$ + $\langle H\rangle\theta'$

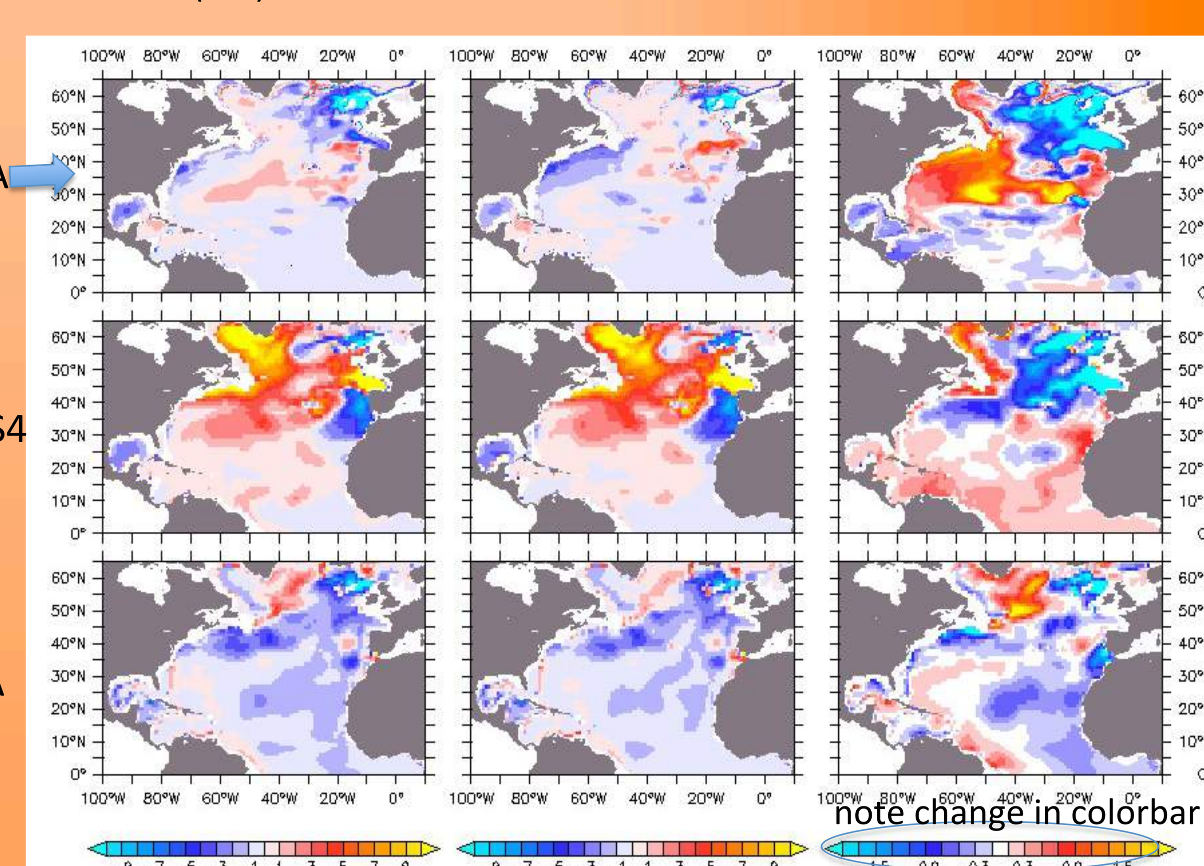
In each grid point we create mean and anomaly of the layer thickness (H) and potential temperature (θ) such that:
Heat content =
$\langle H\rangle\langle\theta\rangle$
$+ H'\langle\theta\rangle$
$+ \langle H\rangle\theta'$
$+ H'\theta'$ (small) ,
where bracketed quantities are long-term means, primed quantities are anomalies. The first term on the right is (minimum) water mass change anomaly (changes of θ/S properties on constant density surfaces), the second one is the heaving, or here volume change, contribution which includes both vertical and lateral expansion of the layer (as allowed by the variable outcrop mask). The third is a mixed term, usually negligible, by order of magnitude smaller than the first two terms.

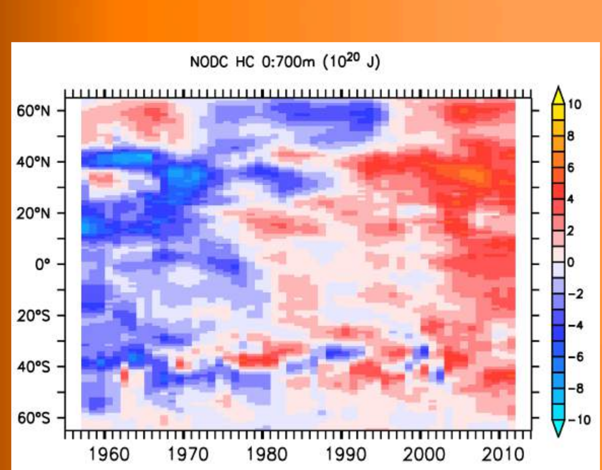


units: 10^9 Joules m^{-2}

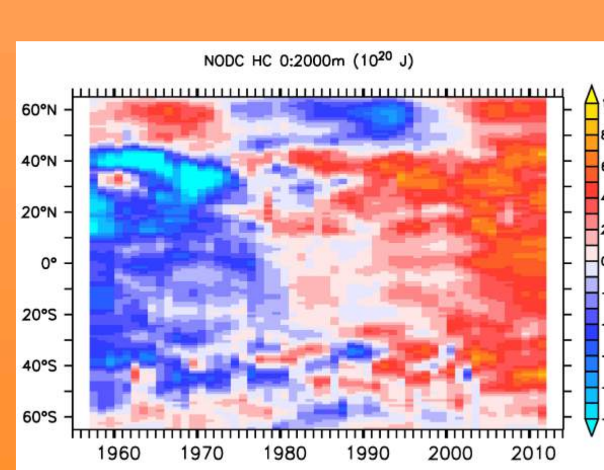
σ_0 = 27.3 – 27.7

$(H\theta)'$ = $H'\langle\theta\rangle$ + $\langle H\rangle\theta'$

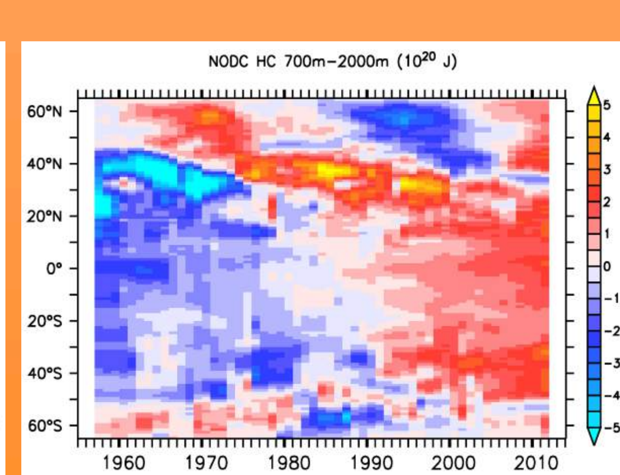




0-700m heat content



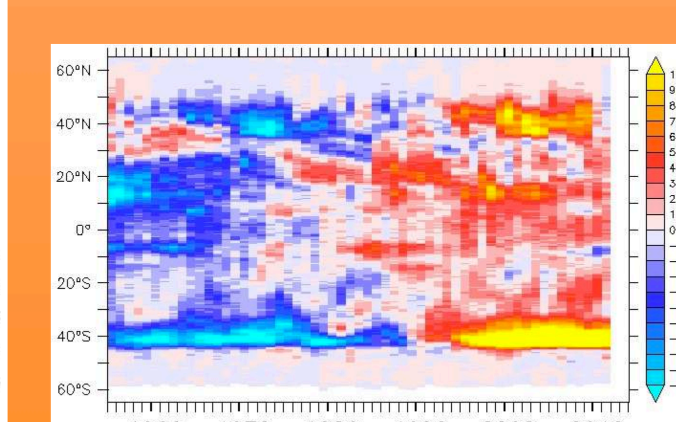
0-2000m heat content



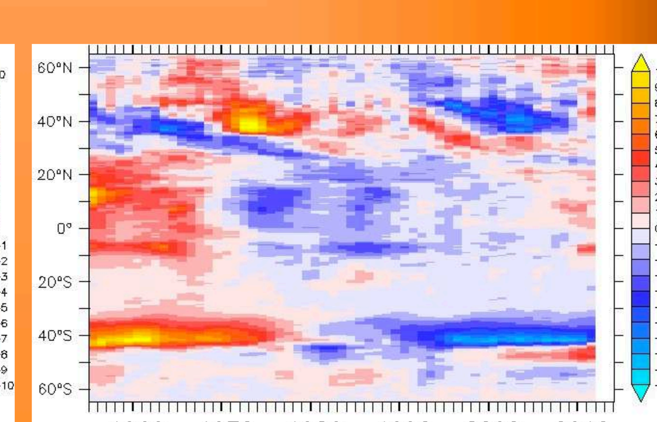
deep (700m-2000m) heat content

z-level evolution of NODC zonally integrated Atlantic OHC

(integrated zonally 10^{20} J per degree of latitude, 1955-2012).



surface to σ_0=27.0



27.0 – 27.7

SODA isopycnal layer heat content (10^{20} J per degree)

CONCLUSIONS

•Warming of the North Atlantic Ocean is investigated in isopycnal layers and z-levels, based on three ocean reanalyses and NODC observed ocean heat content (OHC) from the 1950s to present. Surface layer (σ_0<26) and subtropical mode water layer (σ_0=26-27) show more than ½ the heat gain, largely in the North Atlantic Current/Gulf Stream region. Two deeper layers (σ_0=27-27.3) and (σ_0=27.3-27.7) show widely differing geography of warming, ranging from the Labrador Sea to the Mediterranean Overflow tongue.]

•All 3 reanalyses show the layer thickness variability to determine the heat content changes, rather than 'spice'/ watermass variability of θ and S; SODA and ECDA show that the two upper layer volumes have varied inversely with the two lower ones.

• In the North Atlantic, one reanalysis (ECMWF-ORAS4) and NODC data (Levitus, JGR 2012) support the increase in deep heating (>700m) to remove the 'hiatus' in N. Atlantic warming while two of the reanalyses (SODA, GFDL-ECDA) show cooling in the σ_0 = 27.0-27.7 isopycnal layers waters. Related vertical migration of isopycnals during this OHC variability is only 10 to 20m, suggesting the level of accuracy required.

• The observed and reanalysis OHC show in-phase variability in North and South Atlantic with some tendency for equatorward migration; the geographic distribution of OHC variability differs between density space and z-space.