North Atlantic sea level, heat content and MOC variability over the last 60 years estimated from hydrographic data

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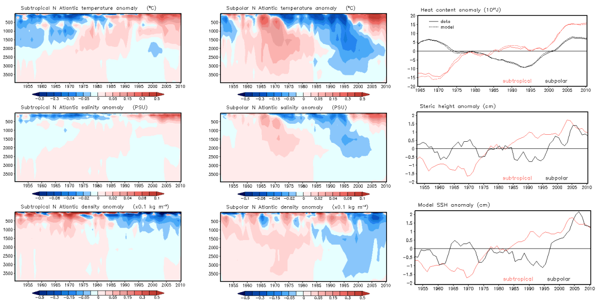
1. Historical data analysis

There have been marked gyre-scale property changes over the North Atlantic from 1950 to 2000: the subtropics warmed and became more saline, whereas the subpolar ocean cooled and freshened. However, increasing upper ocean temperatures and salinities across the whole basin dominate the recent period from 1995 to 2010. Temperature increase dominates the density change leading to a gradual decrease of the density. The analysis is based on the the UK Met Office hydrographic data set compiled by an advanced objective analysis of ocean T and S using covariances from a global climate model (Smith and Murphy, 2007) for the period 1950 to 2010.

Met Office temperature, salinity and density anomalies

Subtropical N Atlantic   *Subpolar N Atlantic*   *Heat content, steric height and sea surface height anomalies*



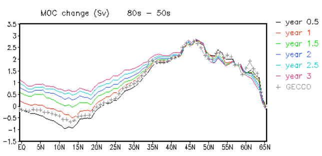
Upper 2000m temperature increase since 1995 is reflected by the heat content increase across the basin. The decreasing density leads to corresponding increase of the sea level dominated by the increase in the steric height.

2. Methodology

The overturning, heat transports and SSH are diagnosed using a dynamical adjustment in the MITGCM (global 1°x1° set-up and 23 vertical levels). The model is initialised from gridded hydrographic T/S data and integrated for few years to allow the density field to dynamically adjust and to spin-up the wind driven circulation. The model is forced by monthly NCEP winds. Weak internal 3D T/S relaxation towards initial fields has been applied in order to reduce the model drift.

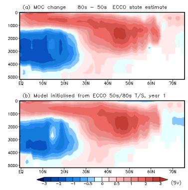
As a test case we use T/S from GECCO averaged over two 20 year periods: 1950-1970 and 1980-2000 and compare the model MOC with the transports directly calculated from GECCO monthly velocities.

Upper 1300m transport difference (Sv)



coloured lines - 12 month running mean transport difference
++++ transport difference from GECCO velocity field

GECCO MOC difference 1990s – 1960s ('model truth')



Model MOC difference

Similar approach has been used to adjust dynamically T and S from the HYDROBASE data set for the same two 20 year periods and estimate the MOC changes, see Lozier et al. (2010) for more details. Same procedure has been repeated with the Met Office global data on annual basis for the period 1950 to 2010 using inter-annually and monthly varying NCEP winds. The heat and volume transports have been diagnosed from the model annual mean fields.

3. MOC and heat transport variability

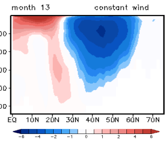
The heat transport (HT) has been split into components as follows:

$$\rho_0 C_P \int_{-D}^{0} \overline{v\,\theta}^{x} dz = \rho_0 C_P \left\{ \underbrace{\left(\int_{-D}^{0} \overline{v}^{x}\overline{\theta}^{x} dz - \overline{V}^{x}_{ek}(\overline{\theta}^{x}_{ek} - \overline{\theta}^{x,z}_{r}) \right)}_{\text{MOC-Ekman}} + \underbrace{\overline{V}^{x}_{ek}(\overline{\theta}^{x}_{ek} - \overline{\theta}^{x,z}_{r})}_{\text{Ekman}} + \underbrace{\int_{-D}^{0} \overline{v'\,\theta'}^{x} dz}_{\text{horizontal}} \right\}$$

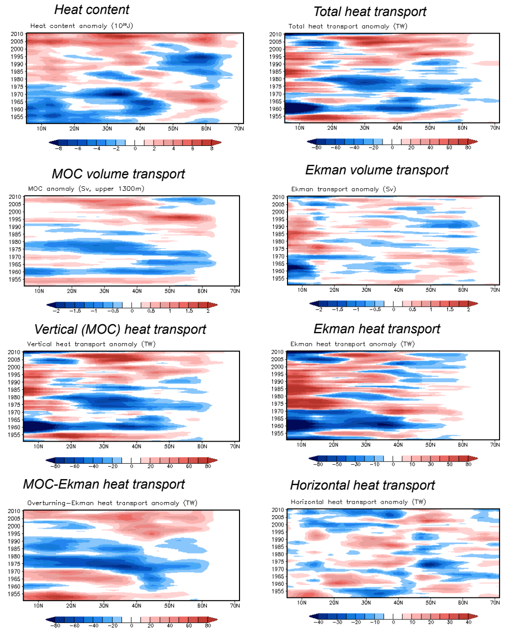
Total   *MOC-Ekman*   *Ekman*   *horizontal*

V_{ek} is calculated from the difference between wind and no wind runs performed for each year. Note the shallower Ekman return flow at low latitudes.

Ekman overturning cell (wind) – (no wind)



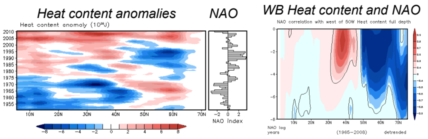
Anomalies of volume and heat transport components



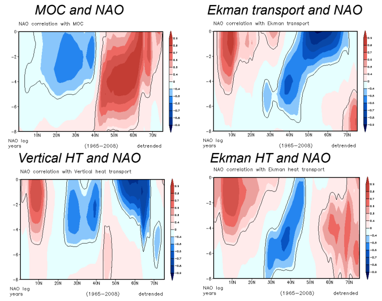
The subtropical heat content anomalies are mainly controlled by wind-induced changes in the Ekman heat transport, while the MOC-Ekman heat transport controls the subpolar heat content changes; the horizontal heat transport is generally weaker, only becoming significant within the subpolar gyre. The heat content anomalies often have an opposing sign between the subtropical and subpolar gyres, associated with opposing changes in the meridional volume transport driving the Ekman and MOC-Ekman heat transports.

4. Correlations with NAO

Lagged correlations with DJFM NAO index; contours of ±0.37 correspond to 99% confidence limit



NAO+ : stronger winds wormer on the western boundary in subtropicacs colder in the subpolar



Wormer western boundary in subtropical gyre – weaker MOC; colder on the west in subpolar – stronger MOC

NAO+ : stronger winds greater northward Ekman in tropics, greater southward transport at 45°N - 55°N

Ekman heat transport reflects the stronger Ekman volume transport and dominates variability in the subtropics; vertical heat transport dominates subpolar variability

5. Conclusions

- different responses in the long term property changes in the subtropical and the subpolar gyres: freshening and cooling in the subpolar gyre; warmer and saltier waters in the subtropical gyre
- density compensation of T and S changes reflected by reduced density changes
- T and S not completely compensated leading to a decrease of the density since 1995, reflected by an increase of heat content, SSH and steric height across the whole basin
- opposing MOC anomalies in the subtropical and subpolar gyre followed by coherent response over the basin
- subtropical heat content change is mainly controlled by the Ekman heat transport, while the vertical heat transport drives the heat content changes in the subpolar region, reinforced by the horizontal heat transport

References:

Lozier, MS, V Roussenov, MSC Reed and RG Williams 2010. On the spatial pattern of meridional overturning changes in the North Atlantic, Nature Geoscience, , DOI: 10.1038/NGEO94.

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