Atlantic Meridional Overturning Circulation Slowdown Causes Widespread Cooling In The Atlantic

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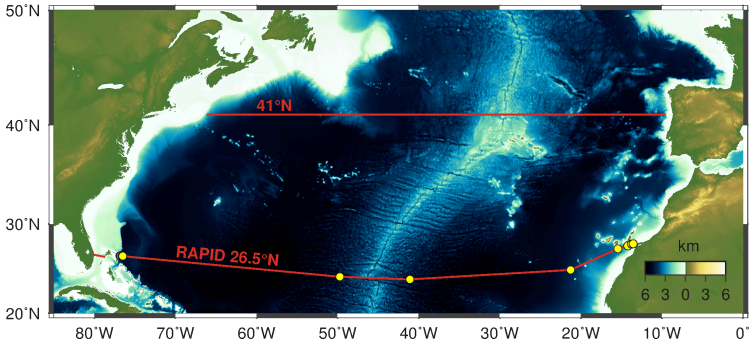
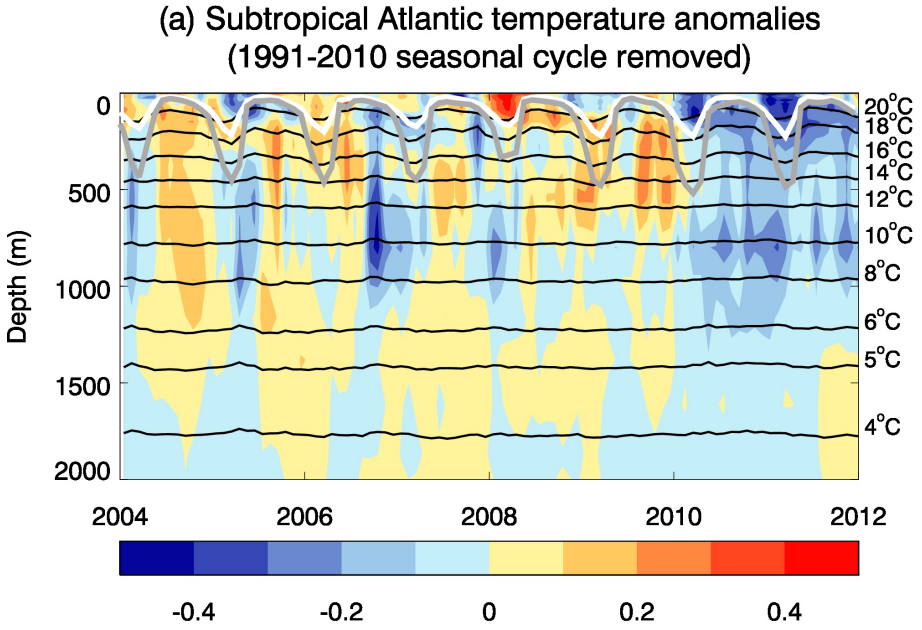
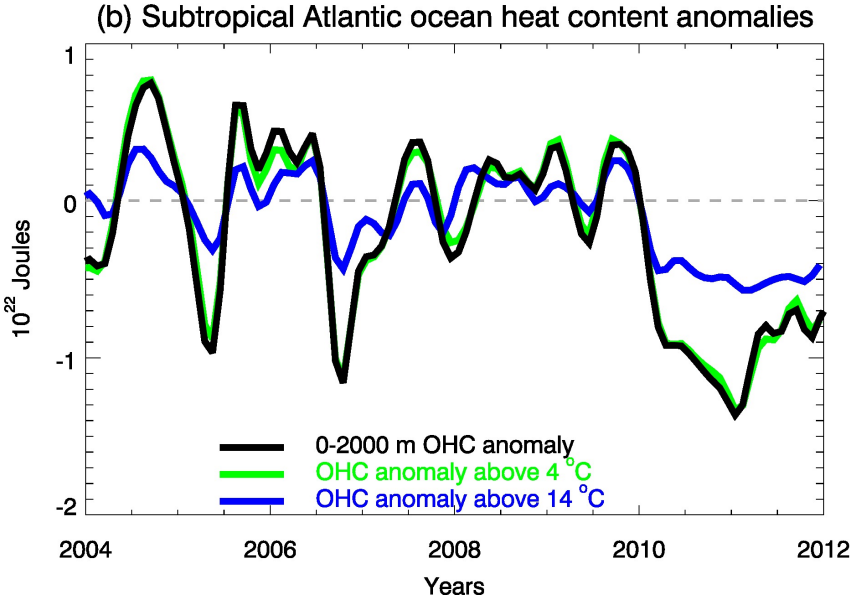
A cold subtropical North Atlantic



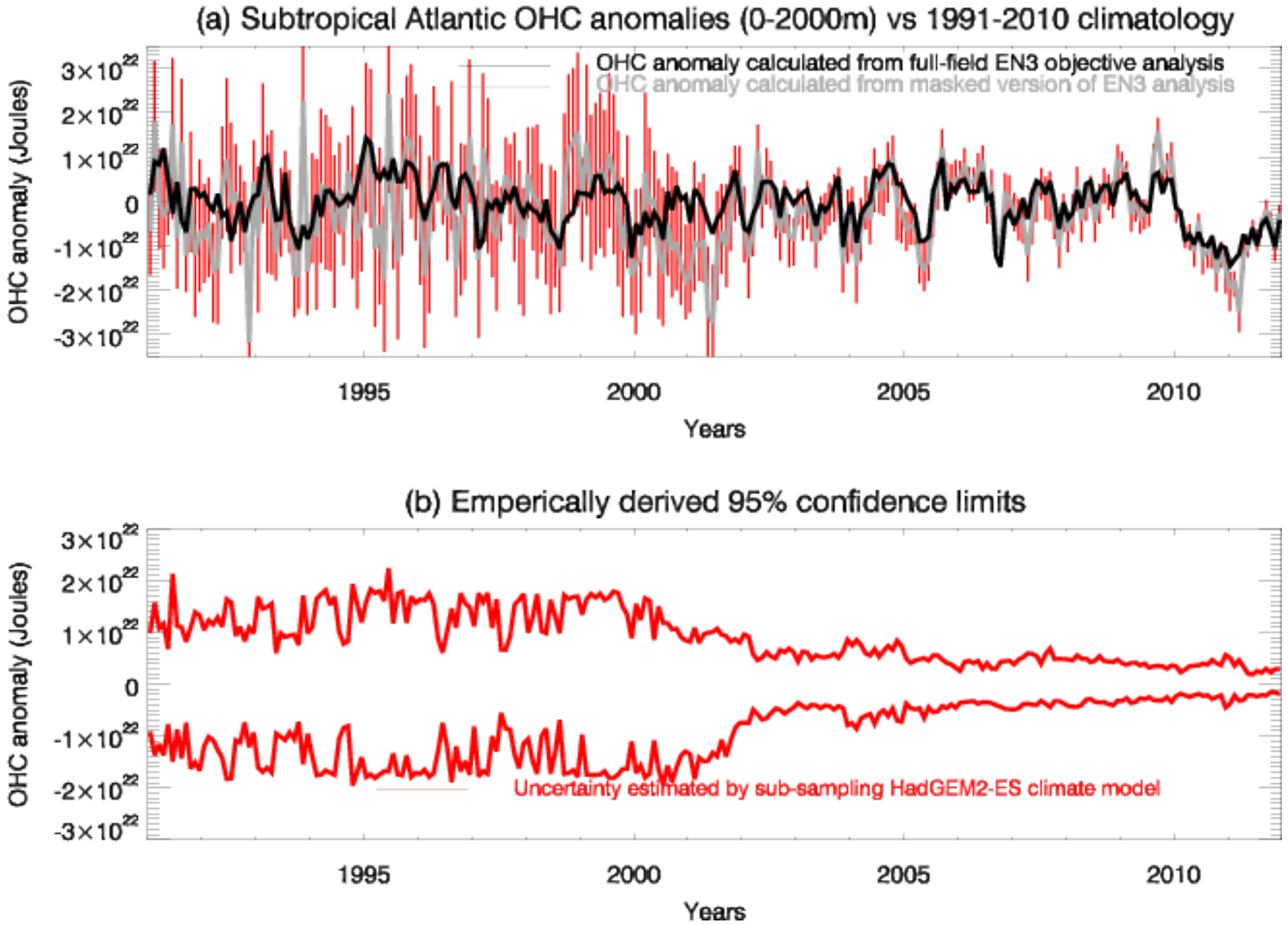




EN3 (UK Met Office product) gridded objective analysis of quality-controlled sub-surface temperature anomalies relative to a seasonal climatology.

OHC error ~=0.2x10^{22} J

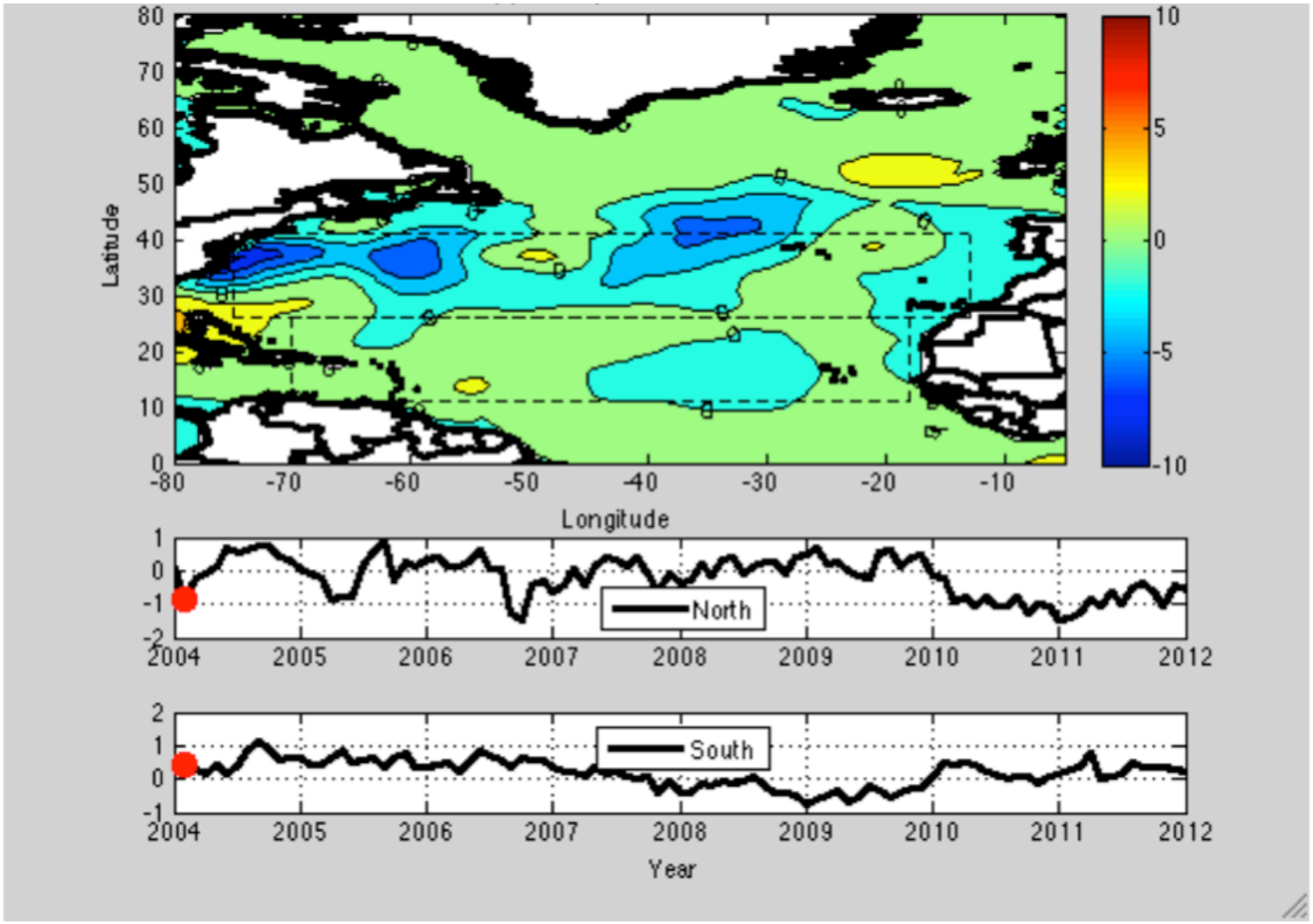
OHC Uncertainties



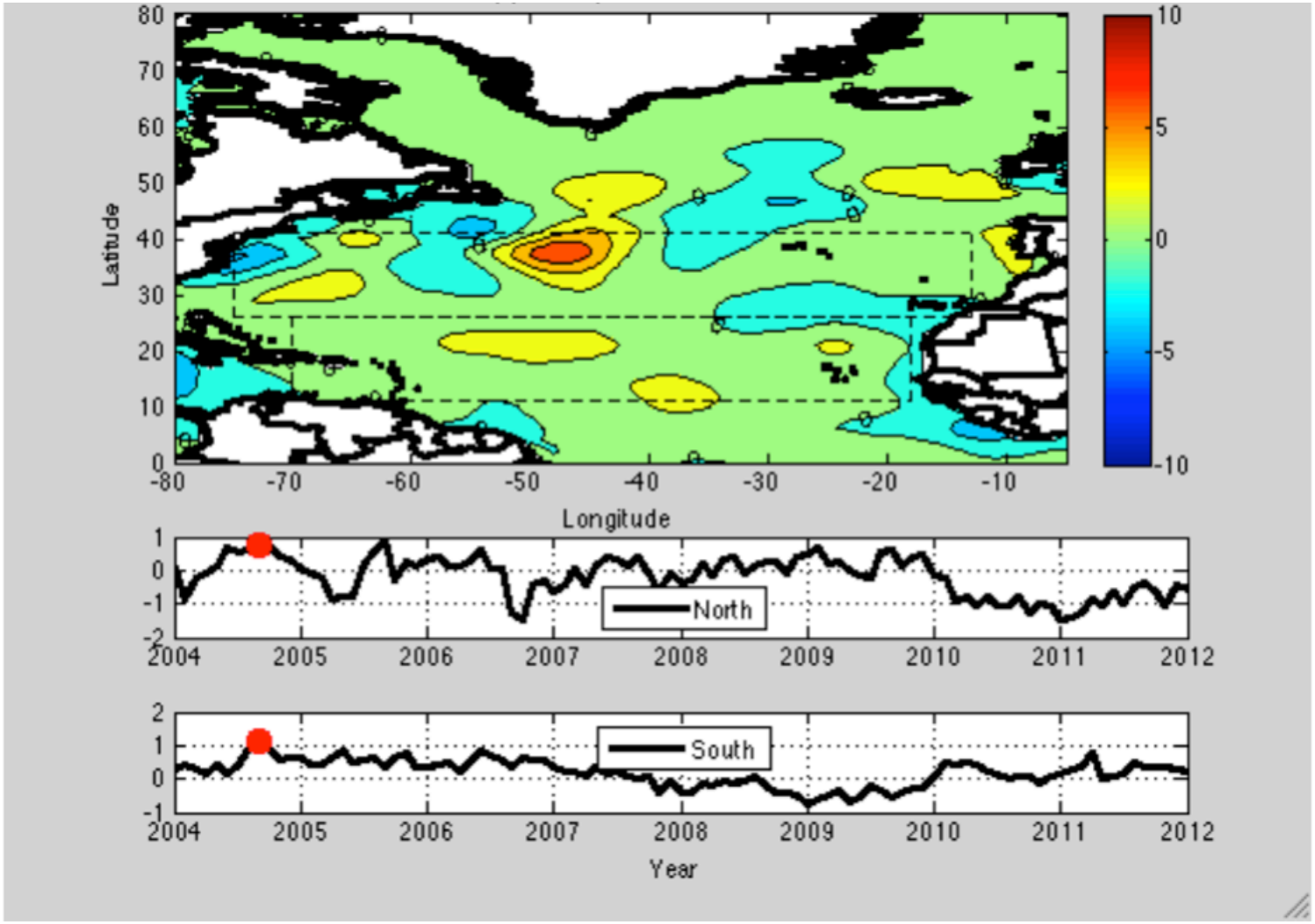
Spatial and Temporal Pattern of Ocean Heat Content in the North Atlantic

(**1991-2010 seasonal cycle removed & 0 to 2000 m**)

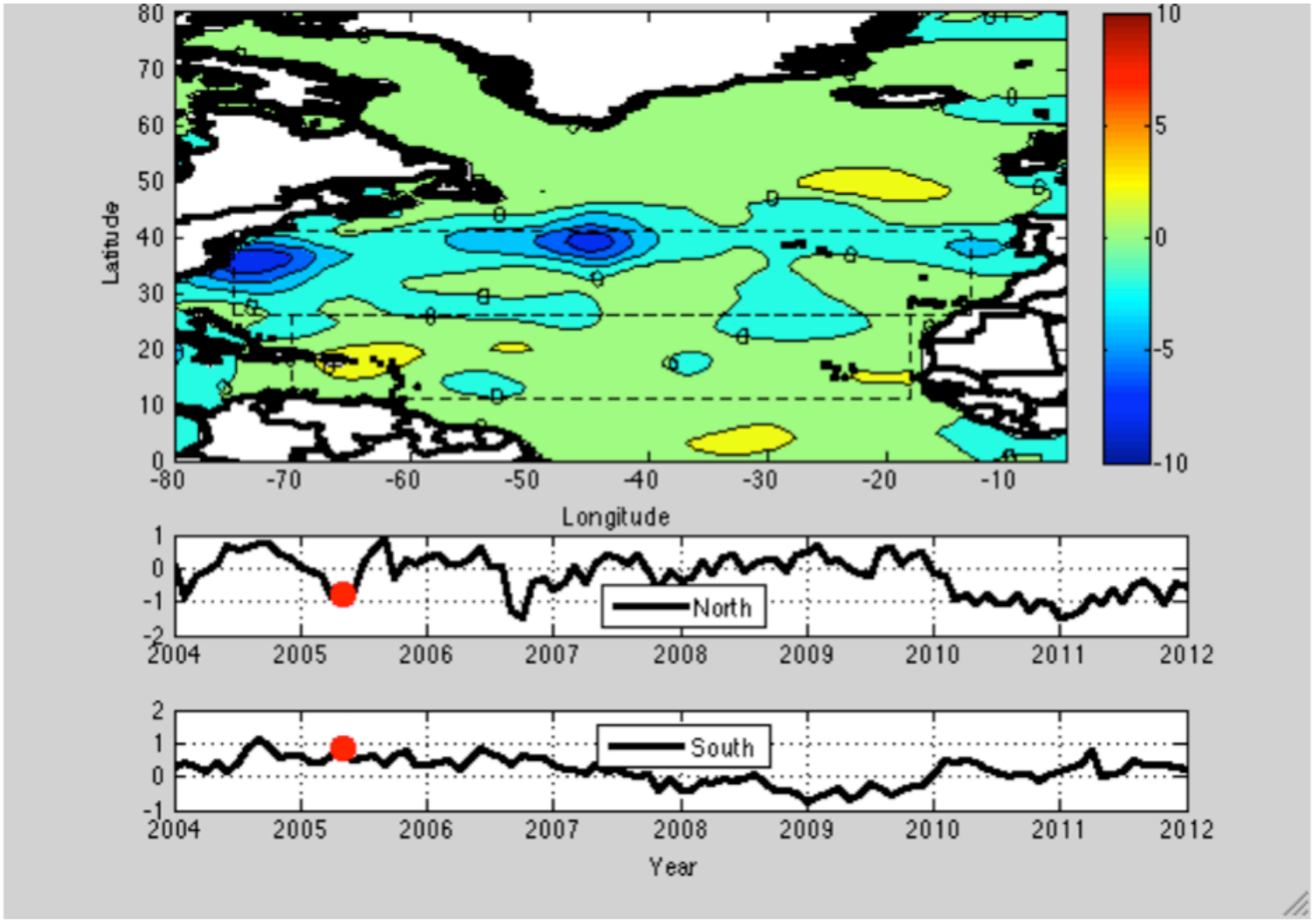
OHC (10^{22} J) : Feb 2004



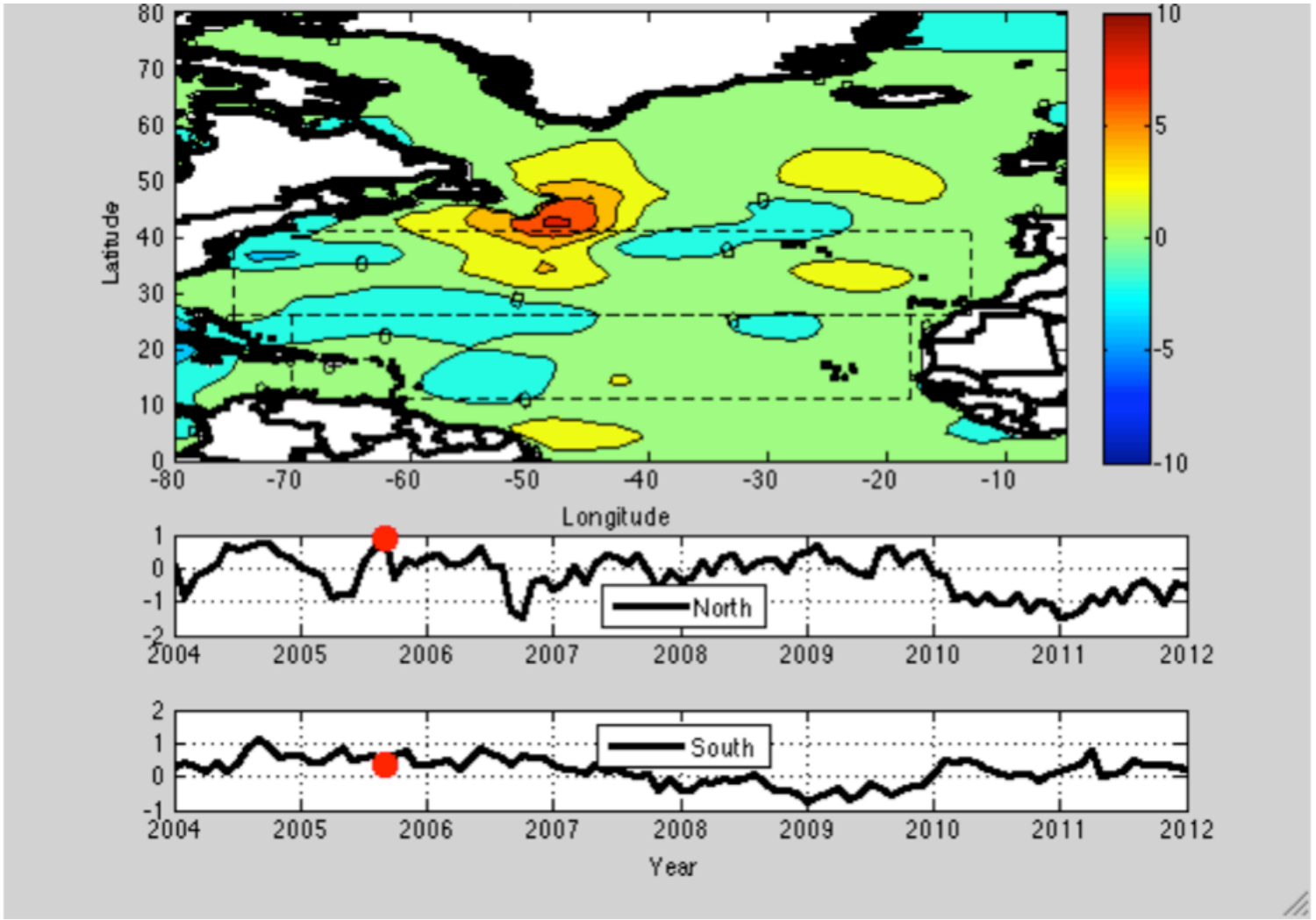
OHC (10^{22} J) : Aug 2004



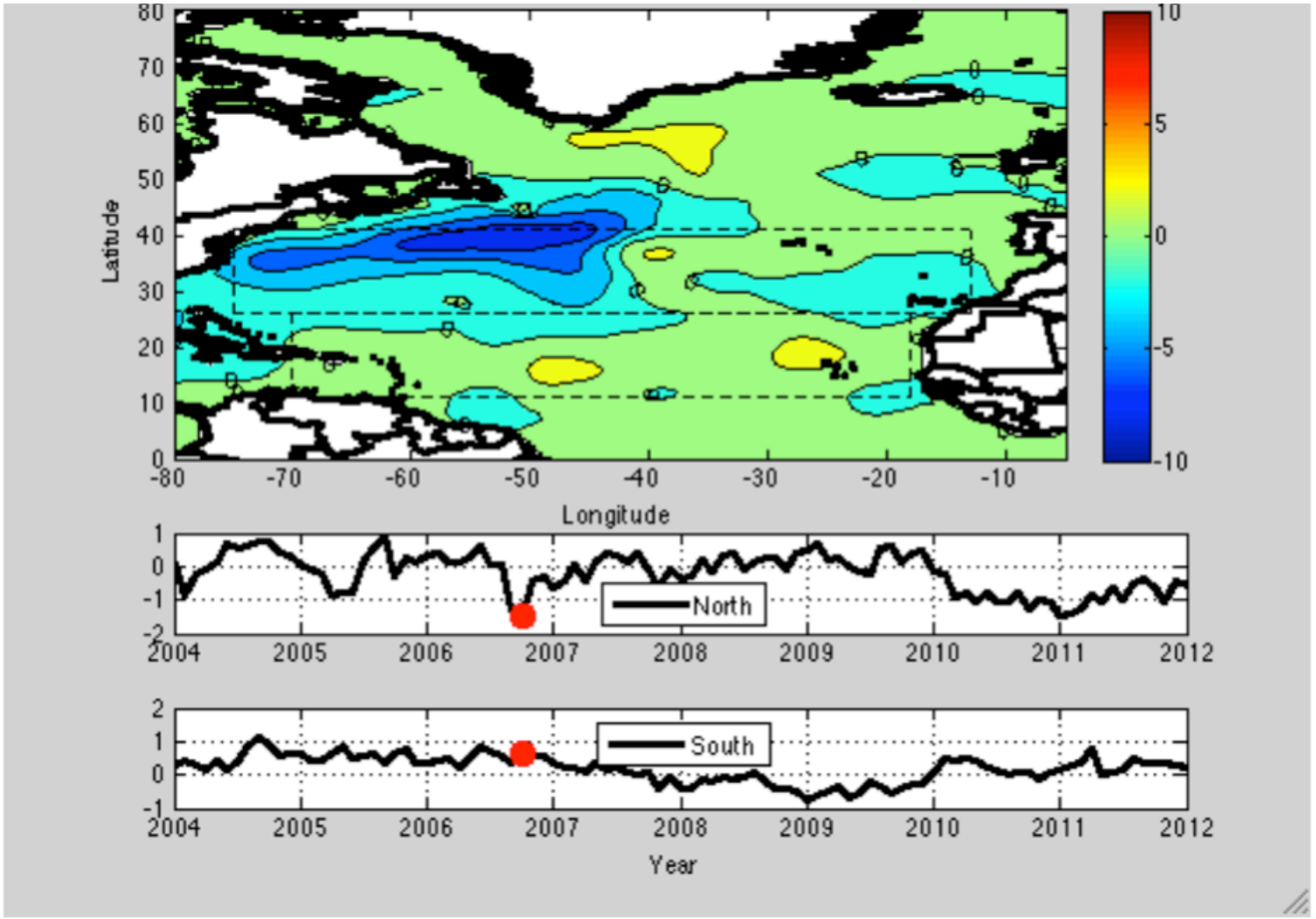
OHC (10^{22} J) : April 2005



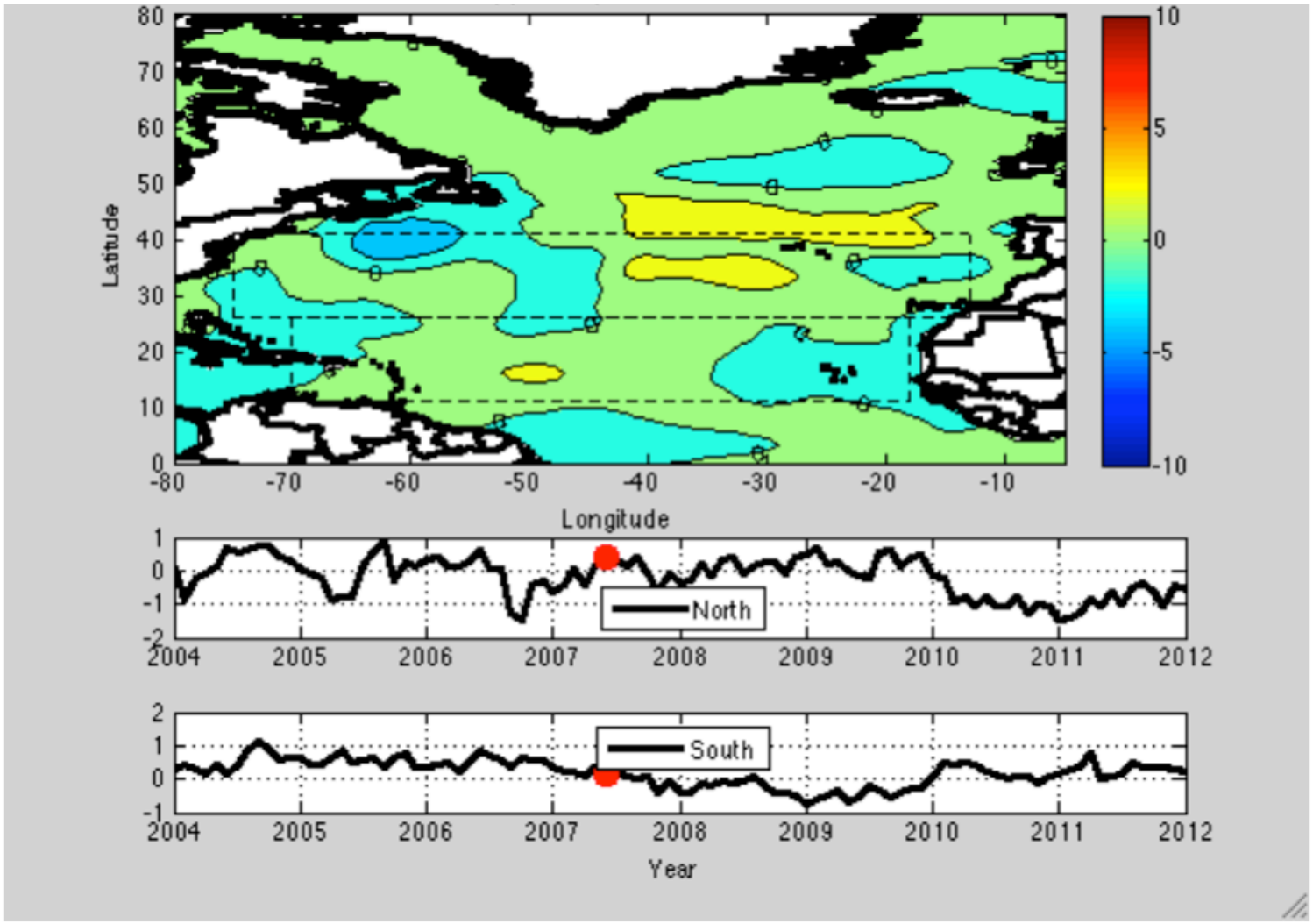
OHC (10^{22} J) : Aug 2005



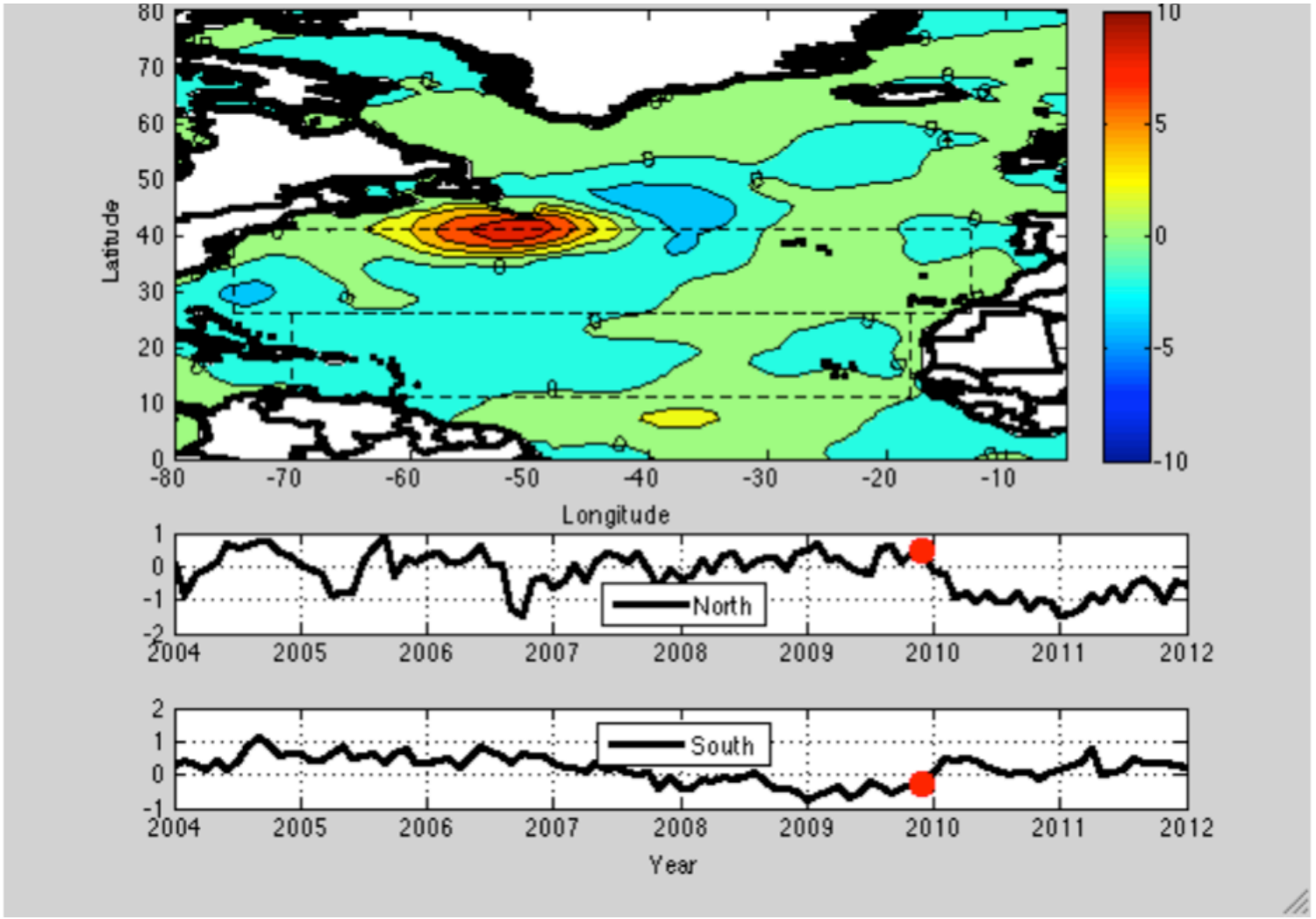
OHC (10^{22} J) : Sept 2006



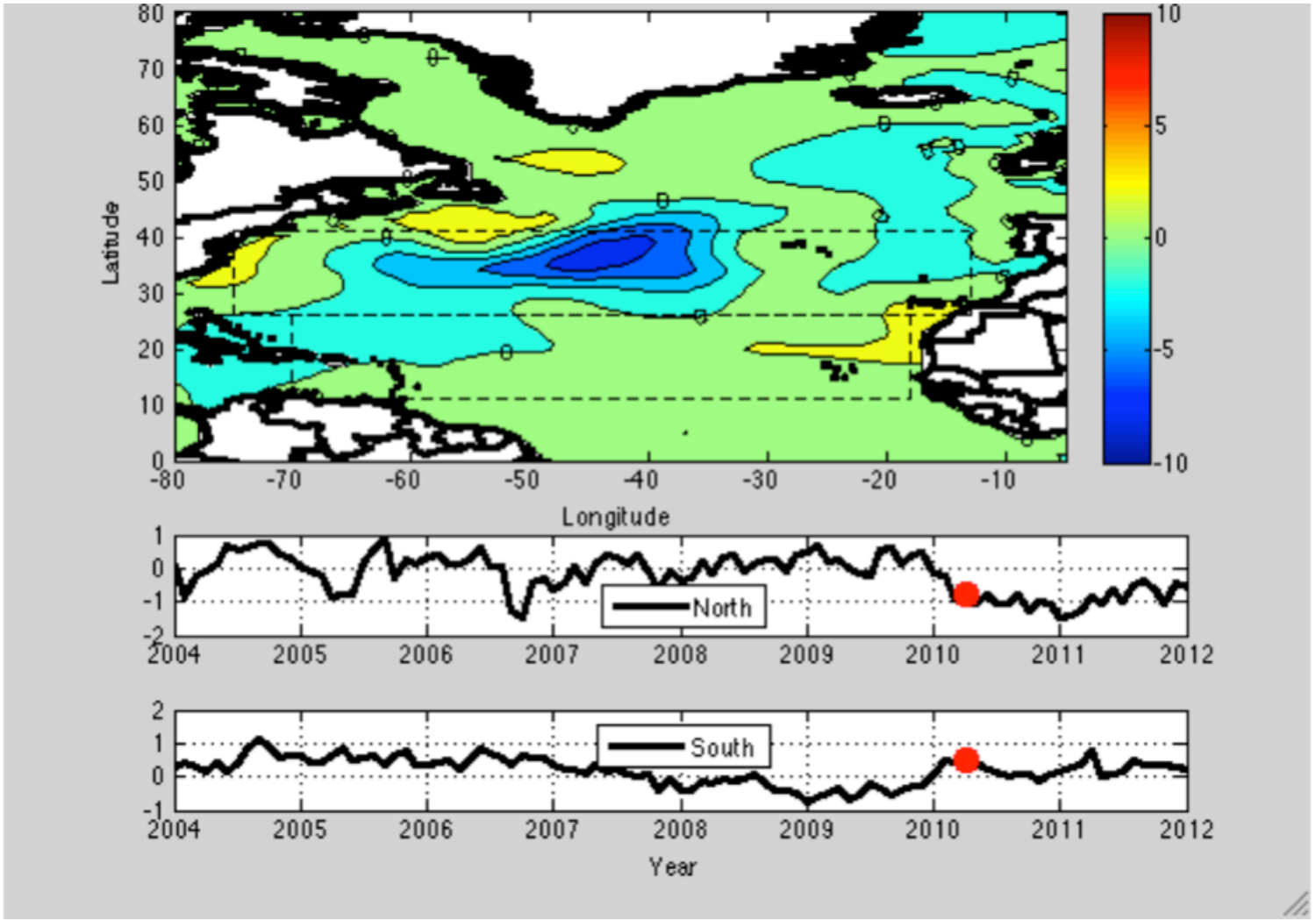
OHC (10^{22} J) : May 2007



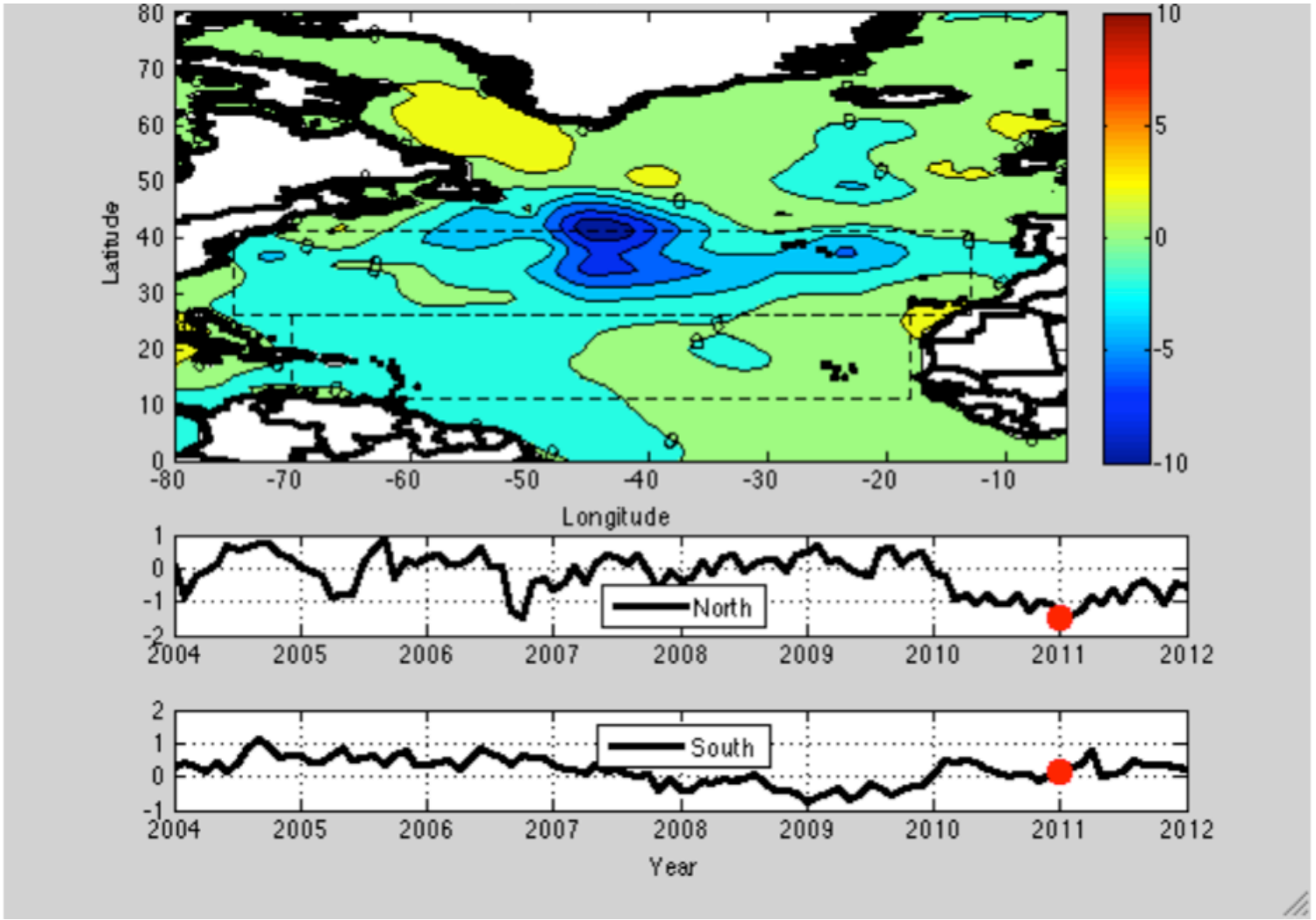
OHC (10^{22} J) : Oct 2009



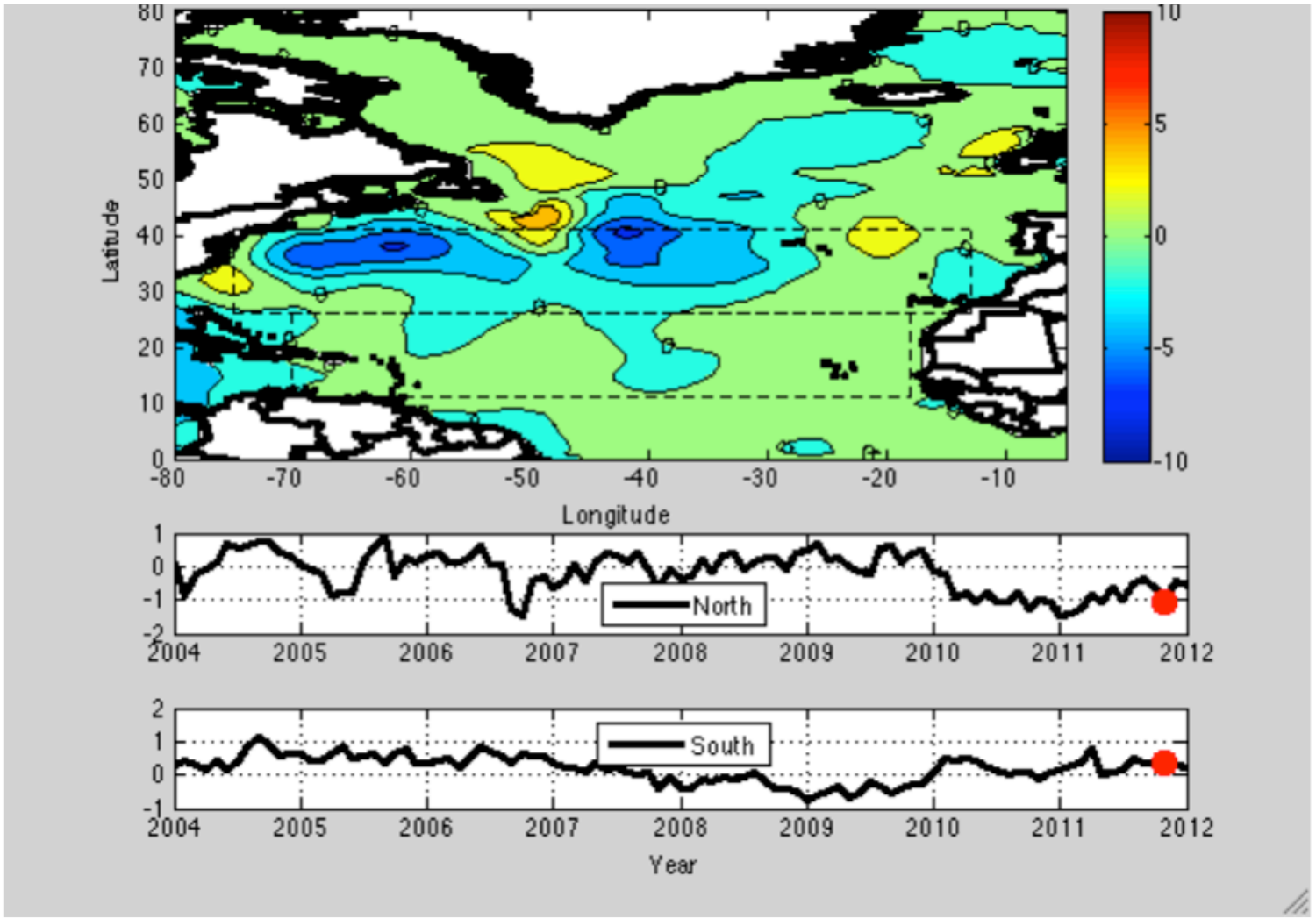
OHC (10^{22} J) : March 2010



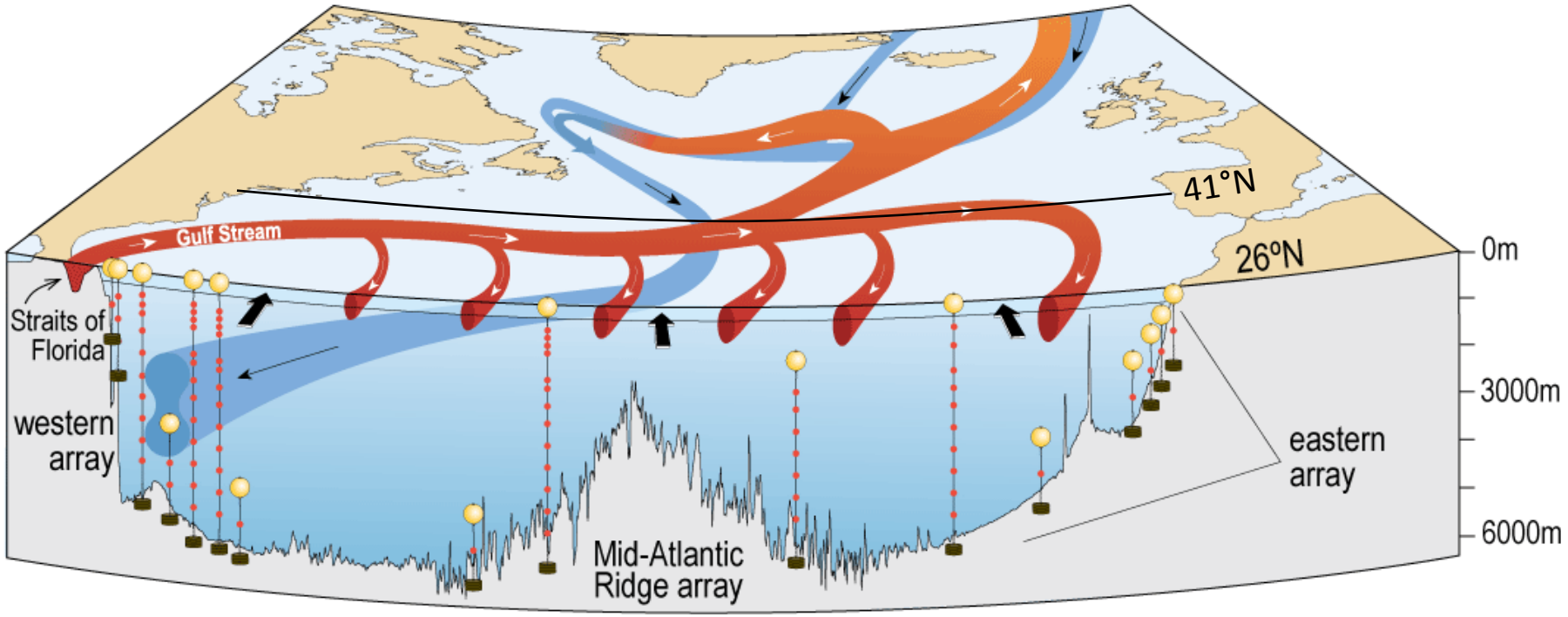
OHC (10^{22} J) : Jan 2011



OHC (10^{22} J) : Sept 2011

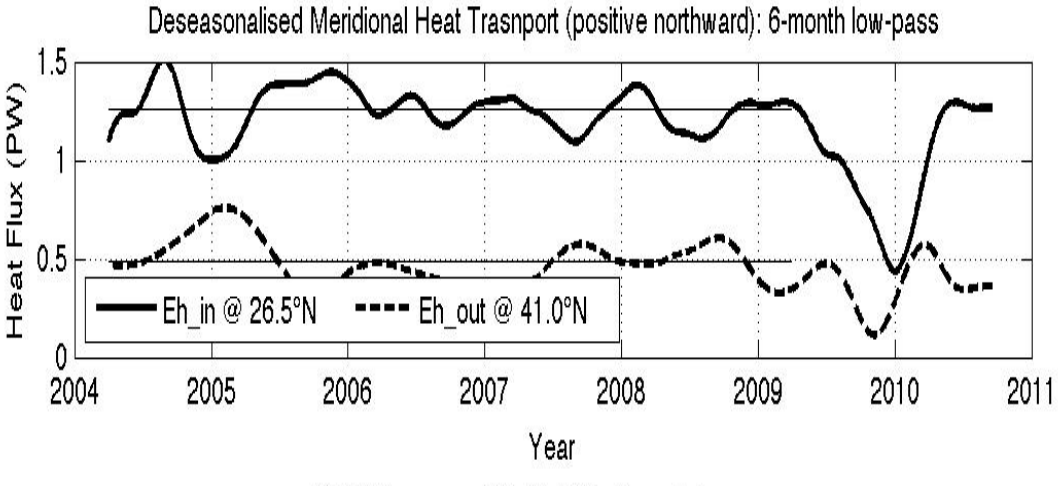


A Heat Budget for the Sub-Tropical Atlantic



Johns, W. E., et al., (2011). "Continuous, array-based estimates of Atlantic Ocean heat transport at 26.5°N." J. Clim. **24**(10): 2429-2449.

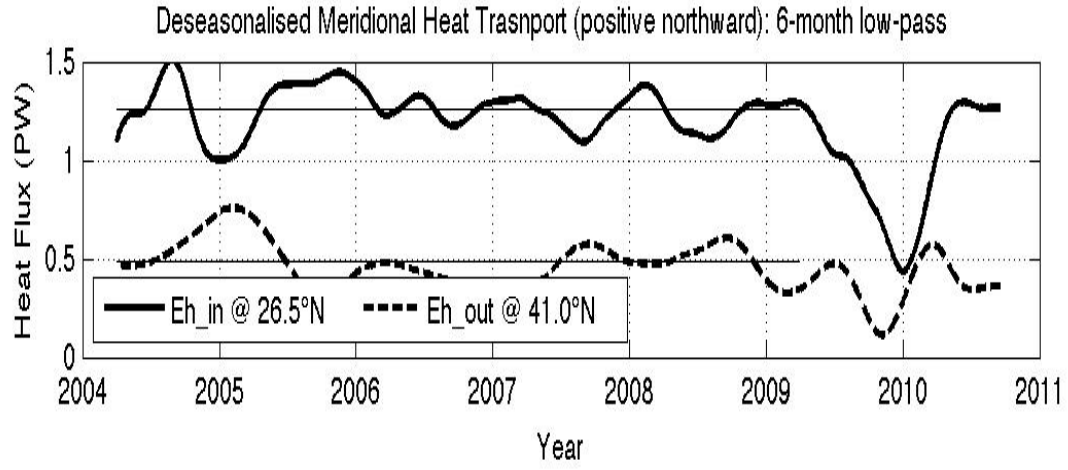
Hobbs, W. R. and J. K. Willis (2012). "Midlatitude North Atlantic heat transport: A time series based on satellite and drifter data." J. Geophys. Res. **117**(C01008): doi:10.1029/2011JC007039.

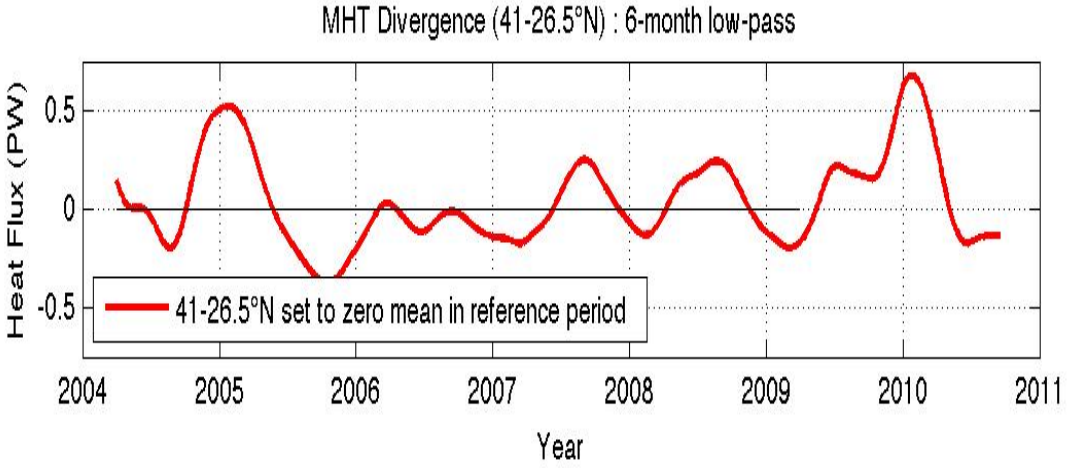


Meridional Heat Transport and Divergence (PW)

1/4/04 to 31/3/09	Mean	SD
26.5°N	1.26	0.11
41°N	0.48	0.11

1/4/09 to 31/3/10	Mean	SD
26.5°N	0.85	0.26
41°N	0.35	0.14

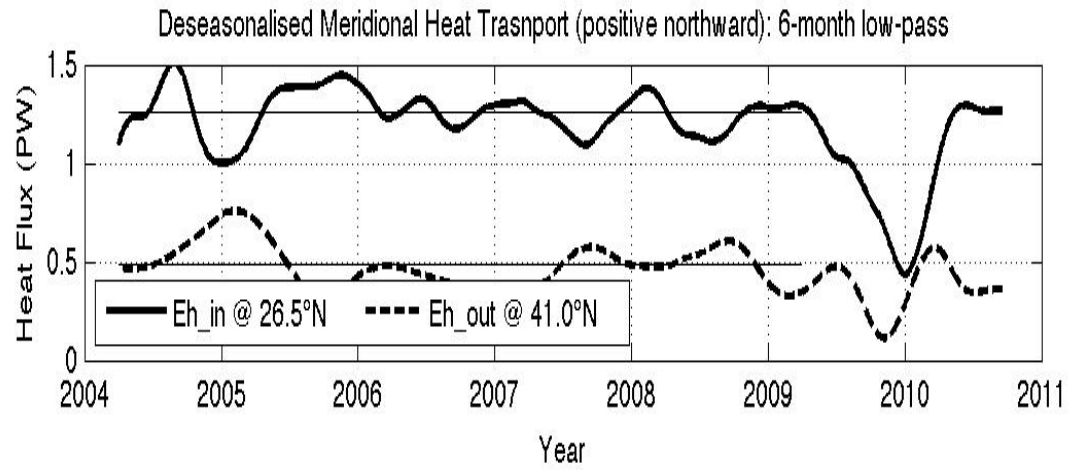


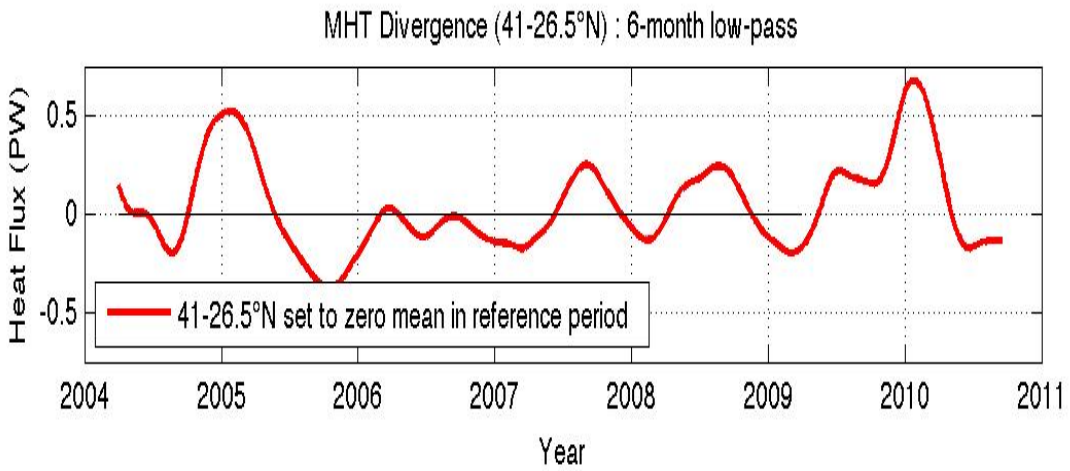


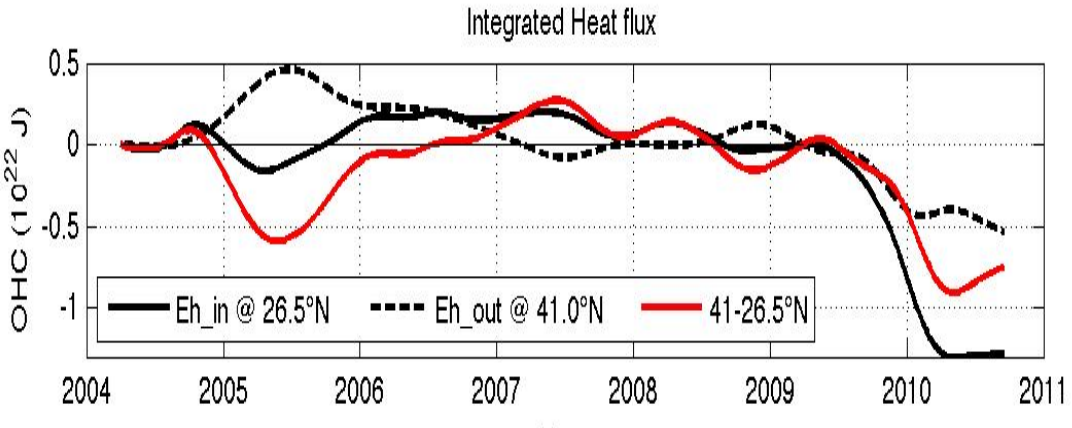
Meridional Heat Transport and Divergence (PW)

1/4/04 to 31/3/09	Mean	SD
26.5°N	1.26	0.11
41°N	0.48	0.11
41-26.5°N	-0.77	0.2
1/4/09 to 31/3/10	**Mean**	**SD**
26.5°N	0.85	0.26
41°N	0.35	0.14
41-26.5°N	-0.5	0.23

Meridional Heat Transport and Divergence (PW) and OHC change

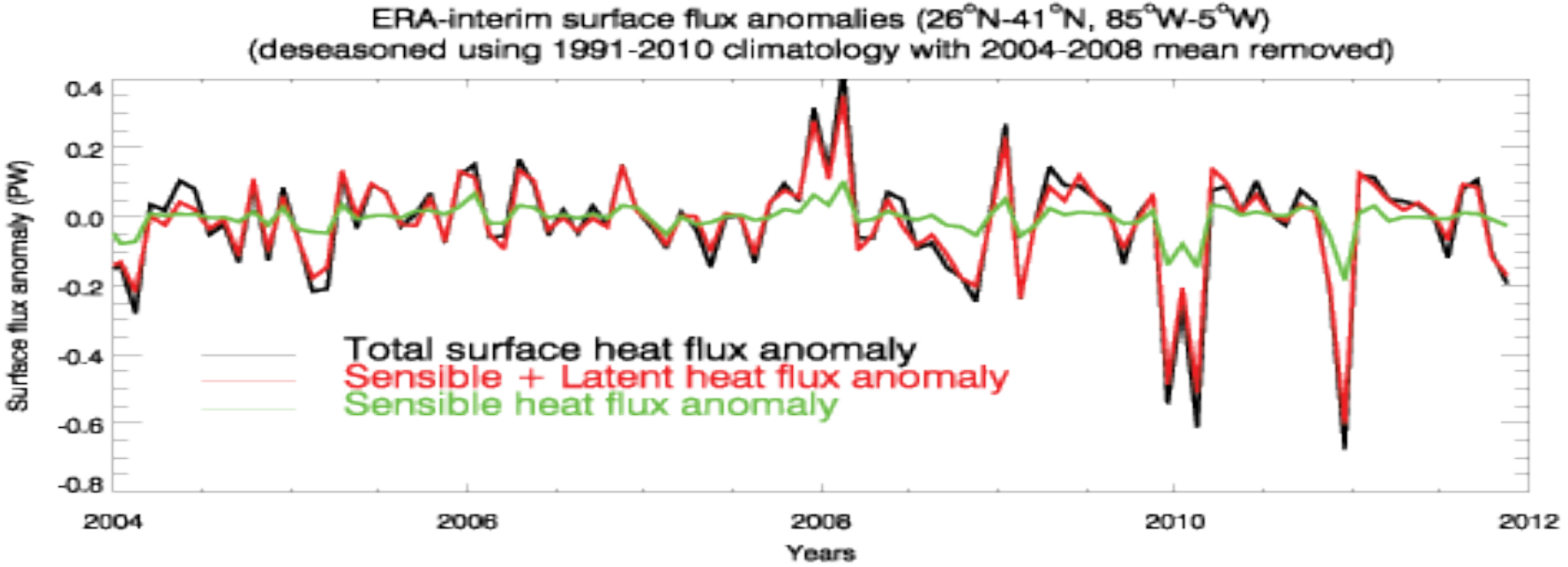


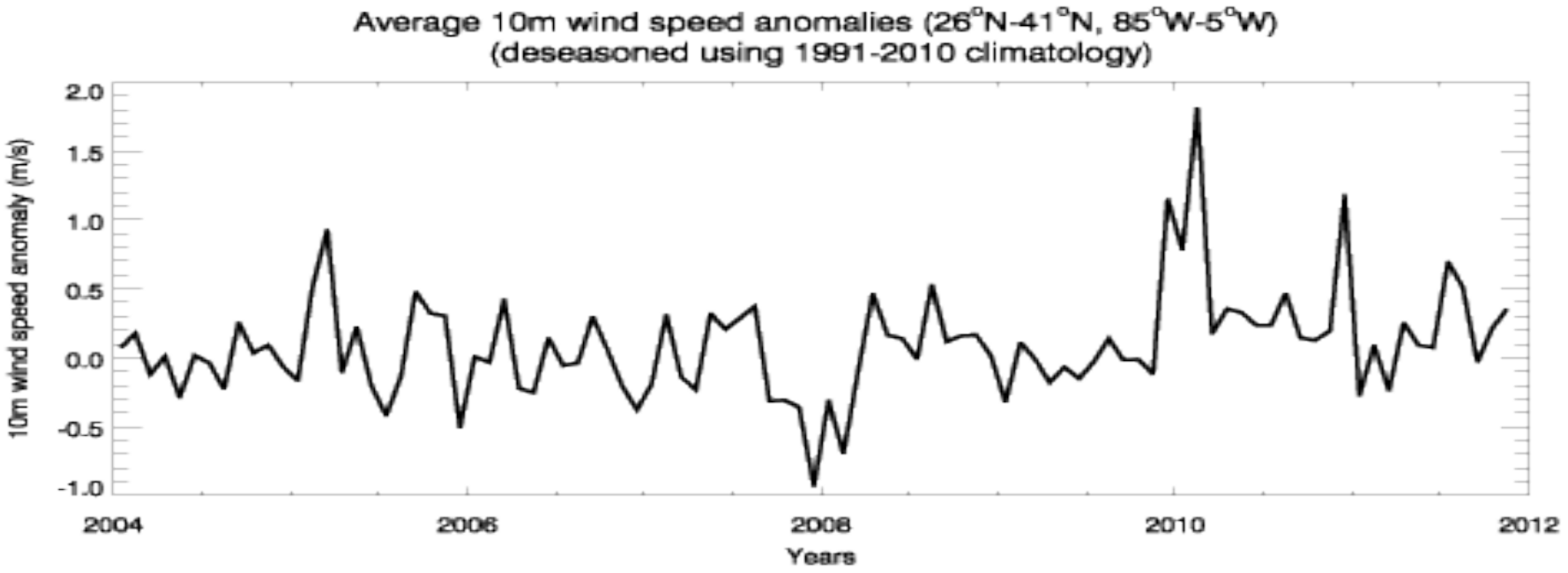




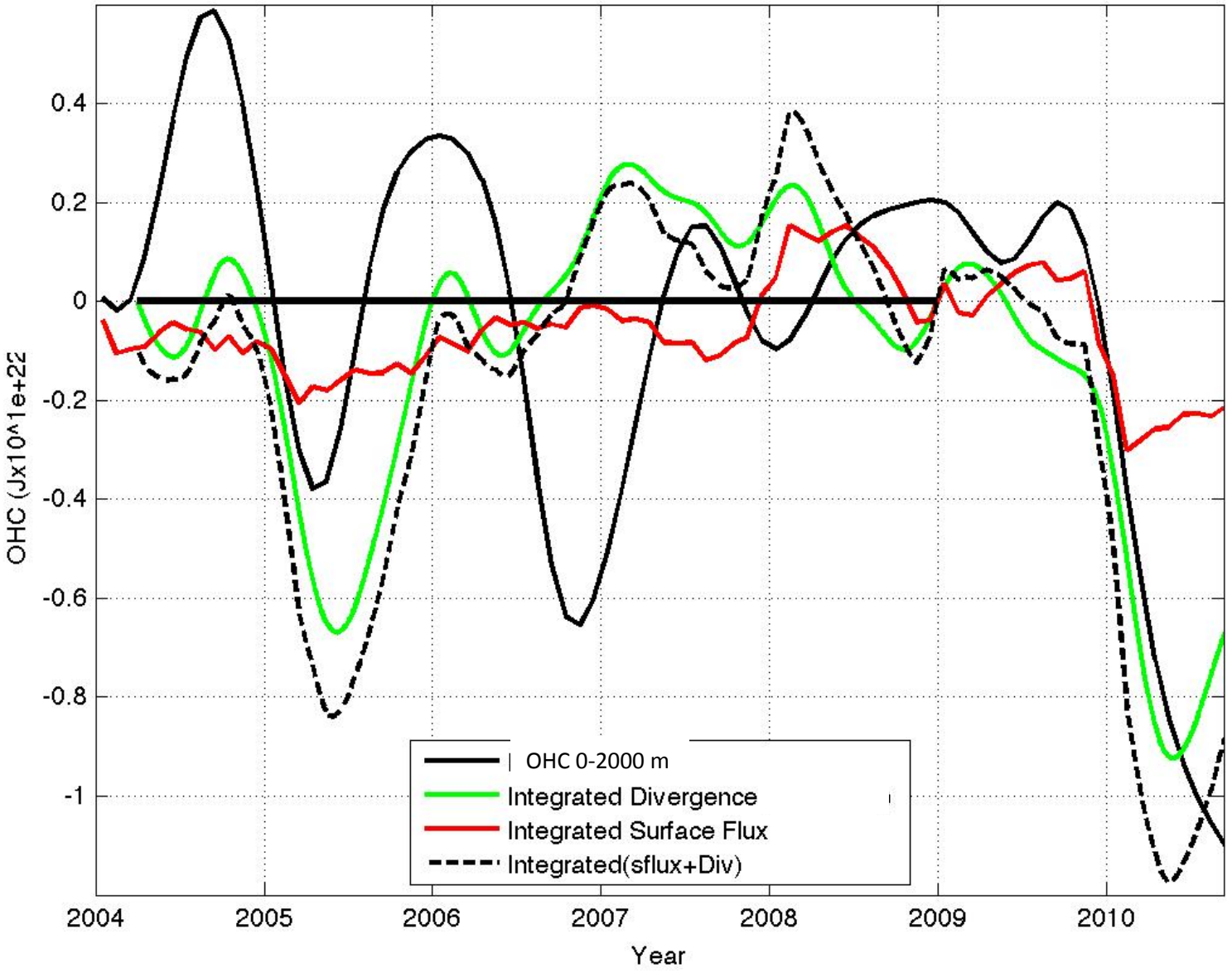
1/4/04 to 31/3/09	Mean	SD
26.5°N	1.26	0.11
41°N	0.48	0.11
41-26.5°N	-0.77	0.2
1/4/09 to 31/3/10	**Mean**	**SD**
26.5°N	0.85	0.26
41°N	0.35	0.14
41-26.5°N	-0.5	0.23

OHC_{error} in the range 0.09 to 0.28×10^{22}J


ERA-interim surface flux anomalies (26°N-41°N, 85°W-5°W)
(deseasoned using 1991-2010 climatology with 2004-2008 mean removed)
Surface flux anomaly (PW)
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Total surface heat flux anomaly
Sensible + Latent heat flux anomaly
Sensible heat flux anomaly
2004
2006
2008
2010
2012
Years

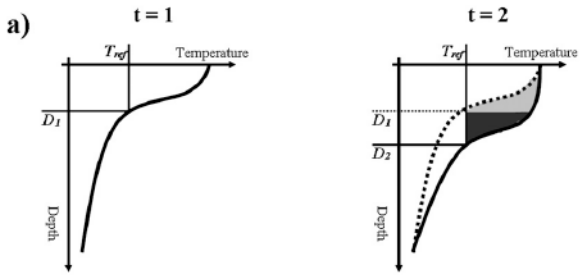

Average 10m wind speed anomalies (26°N-41°N, 85°W-5°W)
(deseasoned using 1991-2010 climatology)
10m wind speed anomaly (m/s)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
2004
2006
2008
2010
2012
Years

Ocean Heat Content



Relative OHC Changes in the Mixed Layer

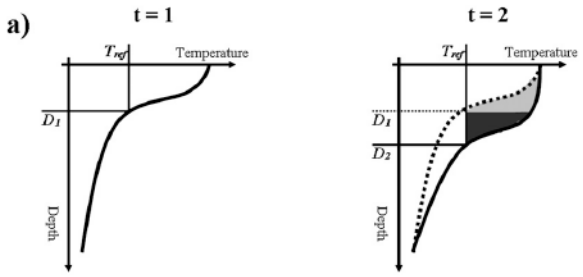
$$\Delta \mathrm{RHC} = C_p \rho_0 \{ D_1 (\langle T_2 \rangle - \langle T_1 \rangle) + (D_2 - D_1)(\langle T_2 \rangle - T_{\mathrm{ref}}) \} (\mathrm{J\,m^{-2}}). \quad (1)$$



Palmer & Haines (2009): Estimating oceanic heat content change using isotherms, J.Clim, 22,

Relative OHC Changes in the Mixed Layer

$$\Delta \mathrm{RHC} = C_p \rho_0 \{ D_1 (\langle T_2 \rangle - \langle T_1 \rangle) + (D_2 - D_1)(\langle T_2 \rangle - T_{\mathrm{ref}}) \} (\mathrm{J\,m^{-2}}). \quad (1)$$



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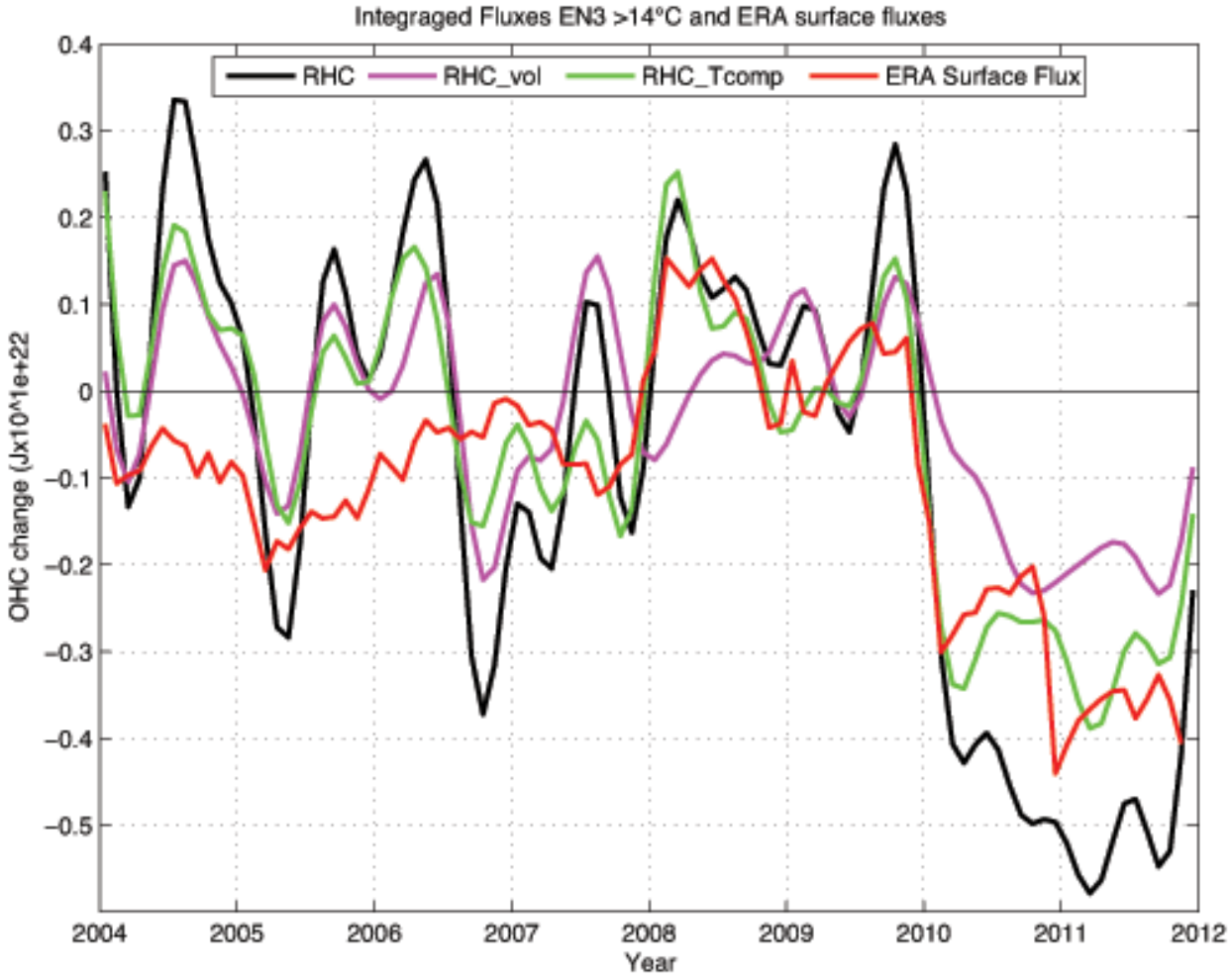

Summary

1. Sustained cooling in upper 2 km of subtropical Atlantic between 2010-2012.
2. OHC change partitioned equally between the seasonal mixed layer >14°C and top 2 km.
3. Reduced AMOC at 26.5°N is the largest contributor to reduced MHT divergence.
4. In seasonal mixed layer heat loss is due to atmospheric heat loss (60%) and MHT divergence (40%).
5. Results emphasise the role for the ocean in the North Atlantic climate system on seasonal to interannual timescales and suggest a role for the AMOC in setting sub-surface temperature anomalies.
6. These anomalies have previously been linked to re-emerging SST patterns and subsequent NAO anomalies.