Temperature, salinity and steric height variability in the Northern Atlantic on seasonal and interannual scales

***Heat and salinity content in the North Atlantic in 1999-2007**

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***Steric height variability in the Northern Atlantic on seasonal and interannual scales**

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Introduction

- ***Whether the North Atlantic is warming or cooling is an important question both in physical oceanography and climate change. The Argo profiling buoys provide an accurate and stable instrument for determing the tendencies in heat content from surface to 2000m from 1999 to 2007. However there are both spatial and temporal gaps in this data set. For this reason we combine these observations with a climatology. The climatologies used are well known Levitus-2001 climatology and WOCE Global Hydrographic climatology (Gouretski and Koltermann, 2004). By this method we can estimate the anomaly of heat content in the North Atlantic and all of its smaller sub-domains for the period 1999 to 2007.***

Current advances in satellite altimetry (SA) made practical monitoring trends and variability in the sea surface height (SSH), and in particular estimates of the sea level rise over last decade. The closely related topic of trends and variability in the ocean heat content, which is increasingly discussed in the context of climate change is linked to the variability of the SSH only approximately (Gill and Niiler,1973). Changes in steric height (SH) are caused by changes in the density of the column which imply an expansion or contraction of the column.

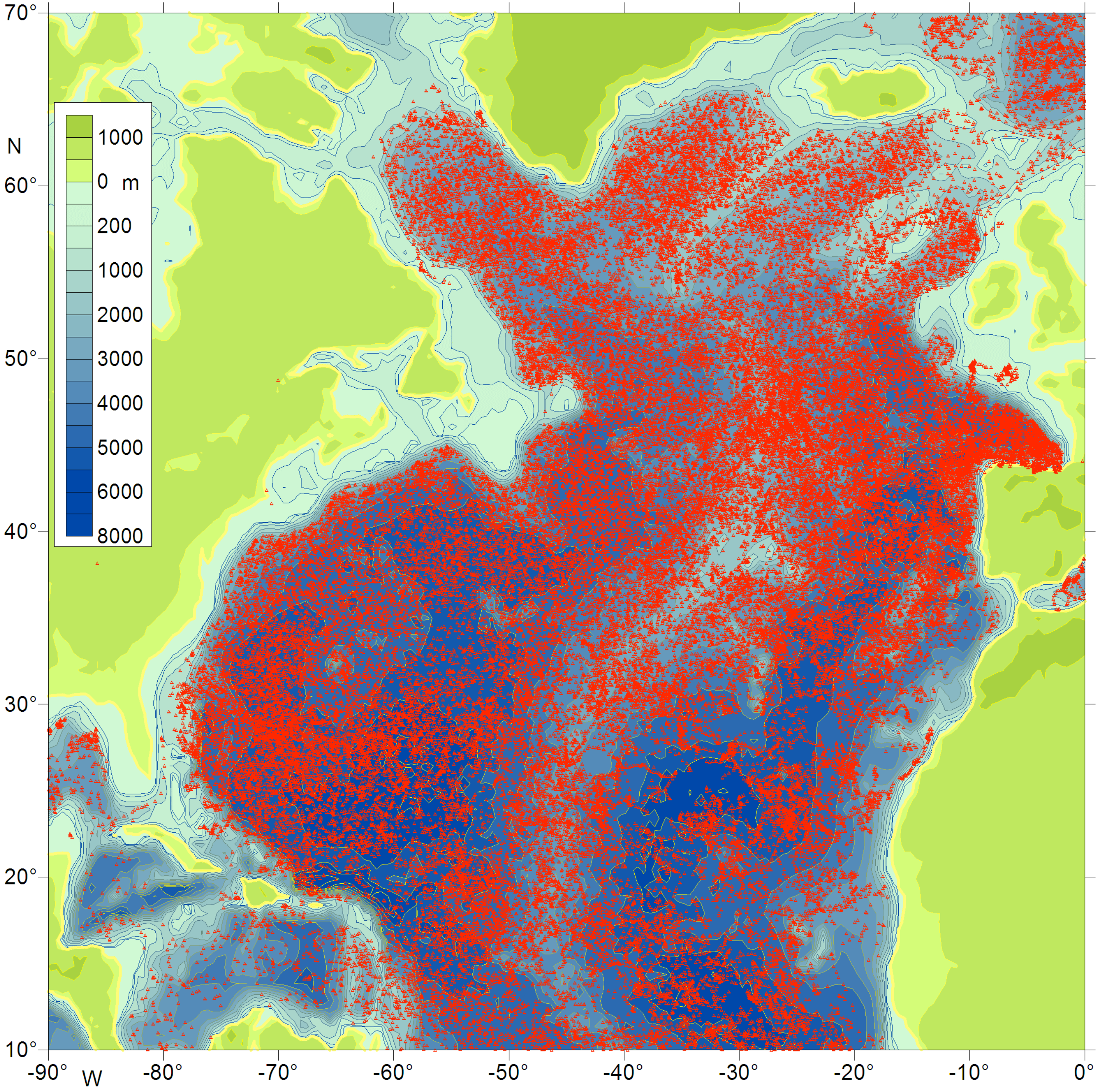
$$\zeta = \zeta_a + \zeta_{st} + \zeta_{bot},$$

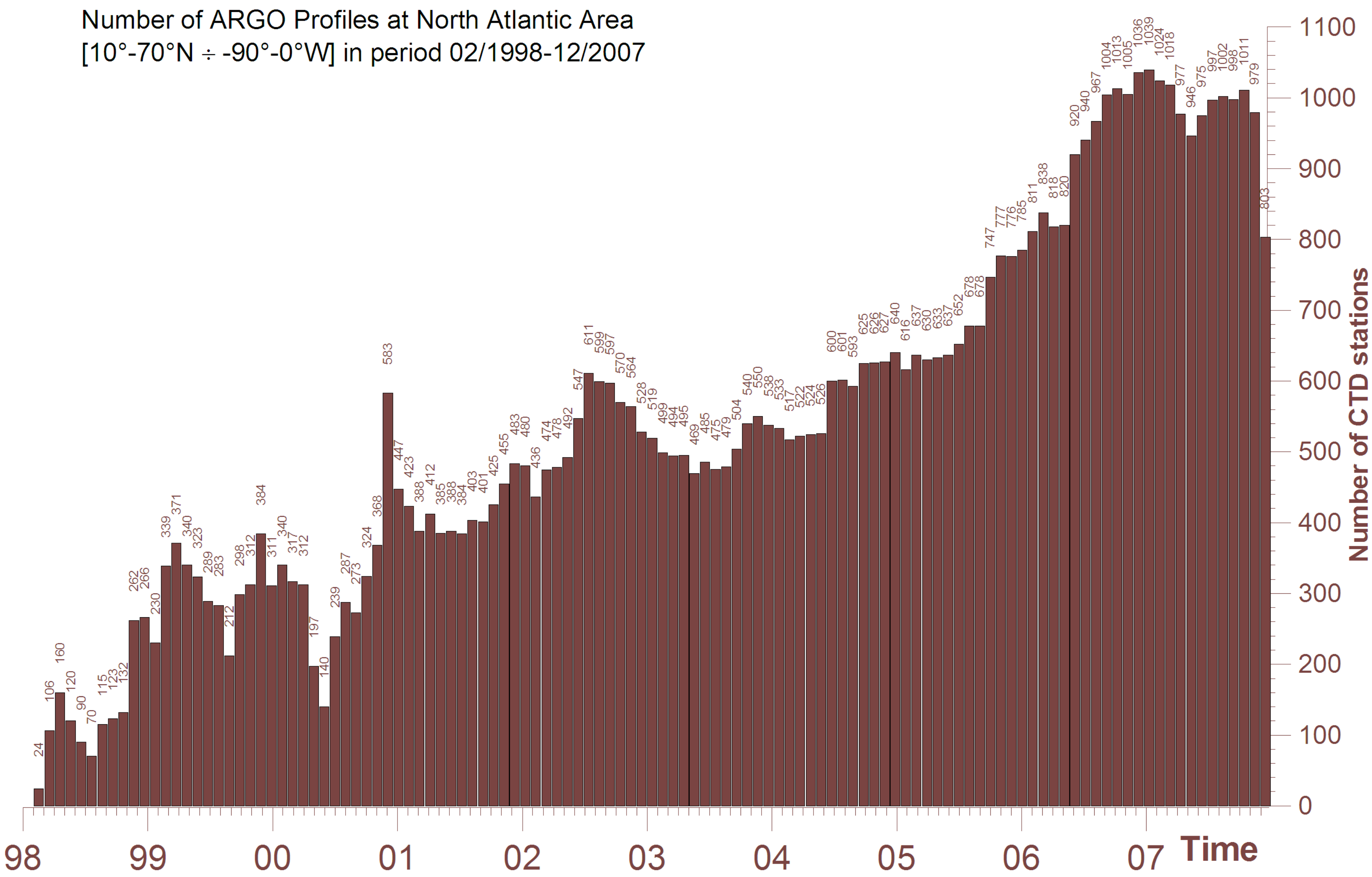
$$\zeta_a = -\frac{p_a}{g\rho_0}$$

$$\zeta_{st} = -\frac{1}{\rho_0}\int_{-H}^{0} \rho dz$$

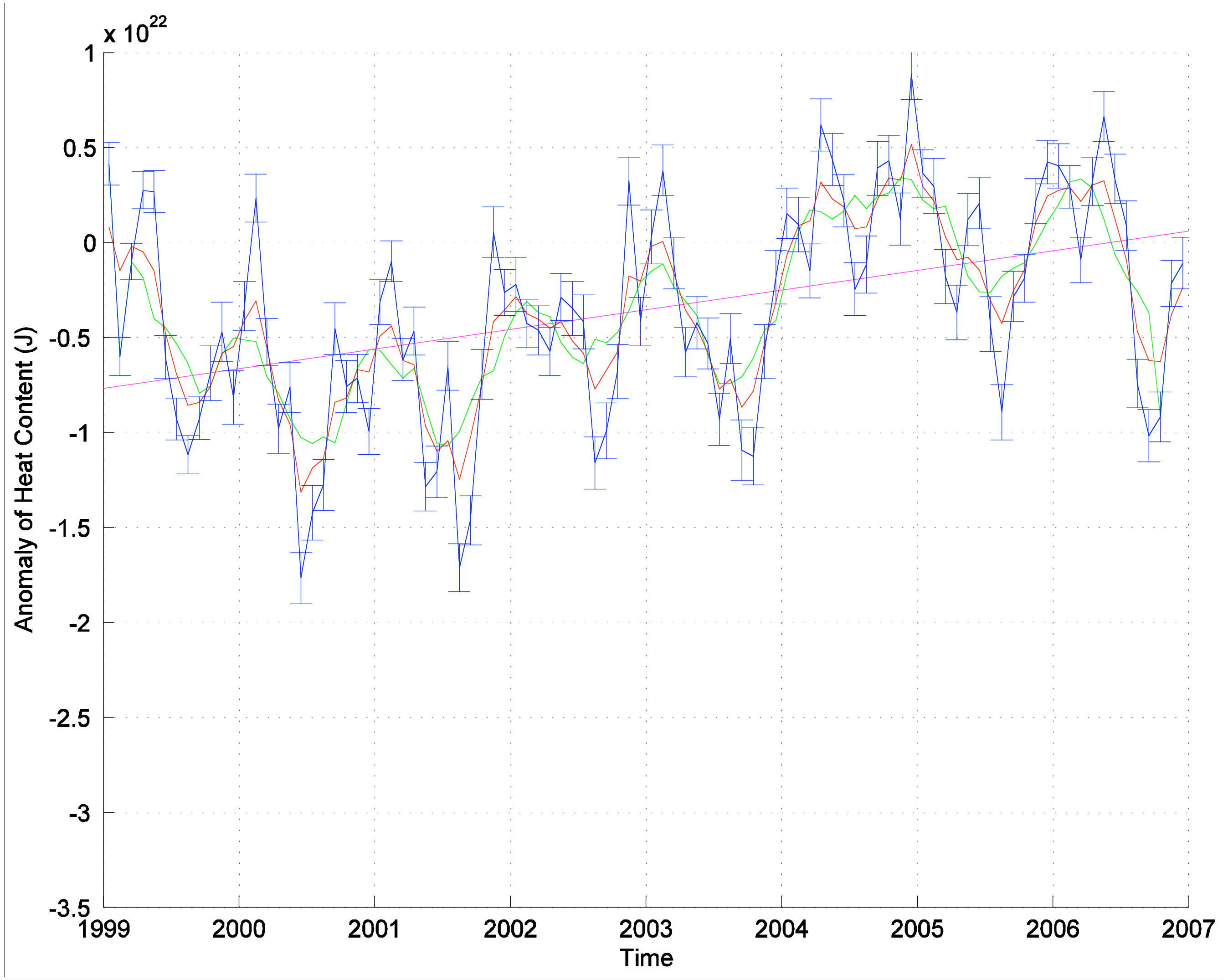
$$\zeta_{bot} = -\frac{p_b}{g\rho_0}$$

- ***We are using the Argo gridded data to asses the SH variability and its thermosteric and halosteric components. We are comparing the results with those derived from the SSH variability based on the TOPEX/Poseidon and Jason SA.***
- ***How good is a link between SH and SSH on various time scales in different regions of the ocean (tropical, subtropical, subpolar and polar)?***
- ***Our analysis is limited to the North Atlantic basin between the latitudes from 10°N to 70°N. It is complemented by analysis of a coarse resolution global ocean circulation model employed to estimate the variability of bottom pressure***
- ***We analyse variability in SH on seasonal and interannual scale.***

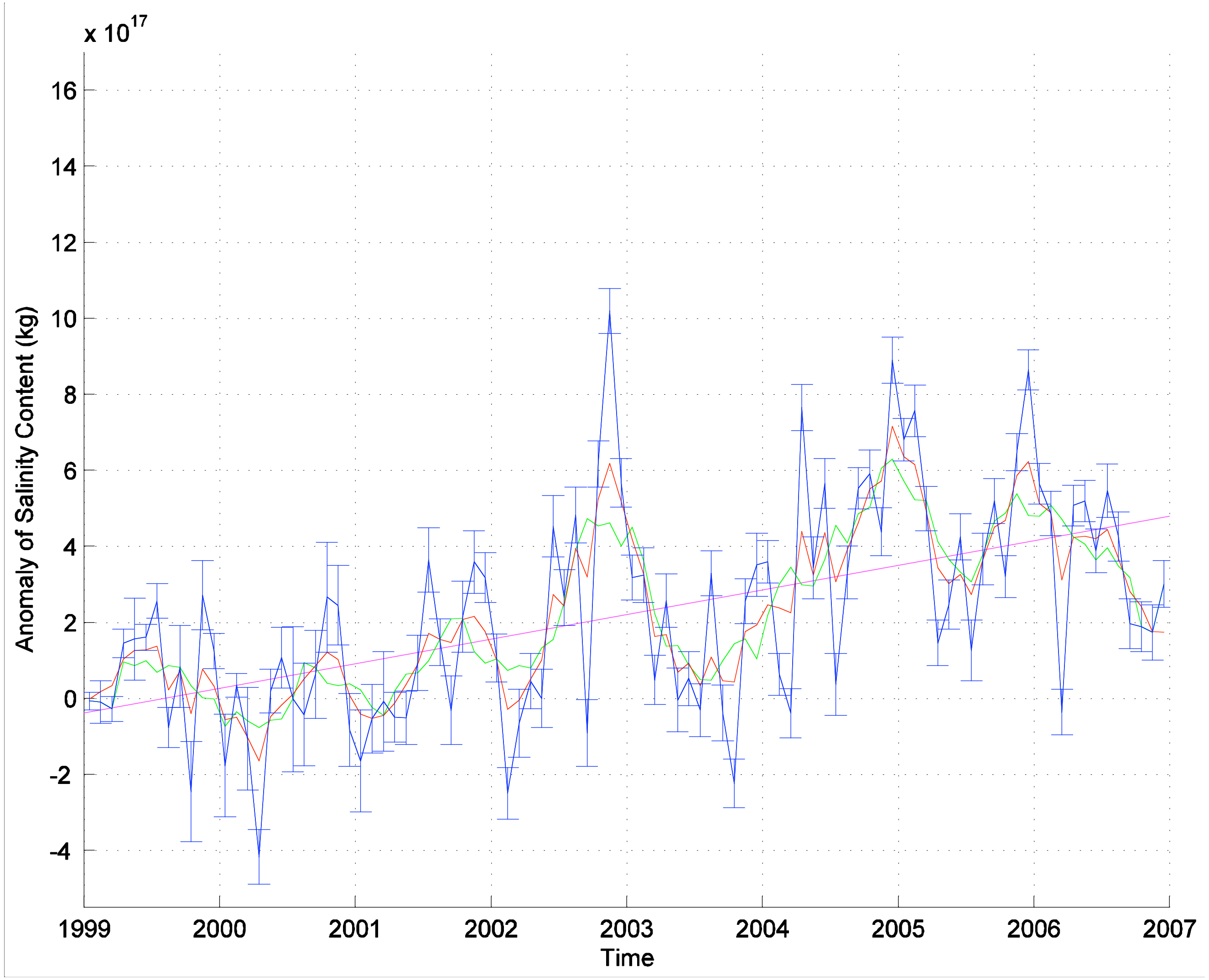

70°
60°
50°
40°
30°
20°
10°
N
1000
0 m
200
1000
2000
3000
4000
5000
6000
8000
-90°
W
-80°
-70°
-60°
-50°
-40°
-30°
-20°
-10°
0°

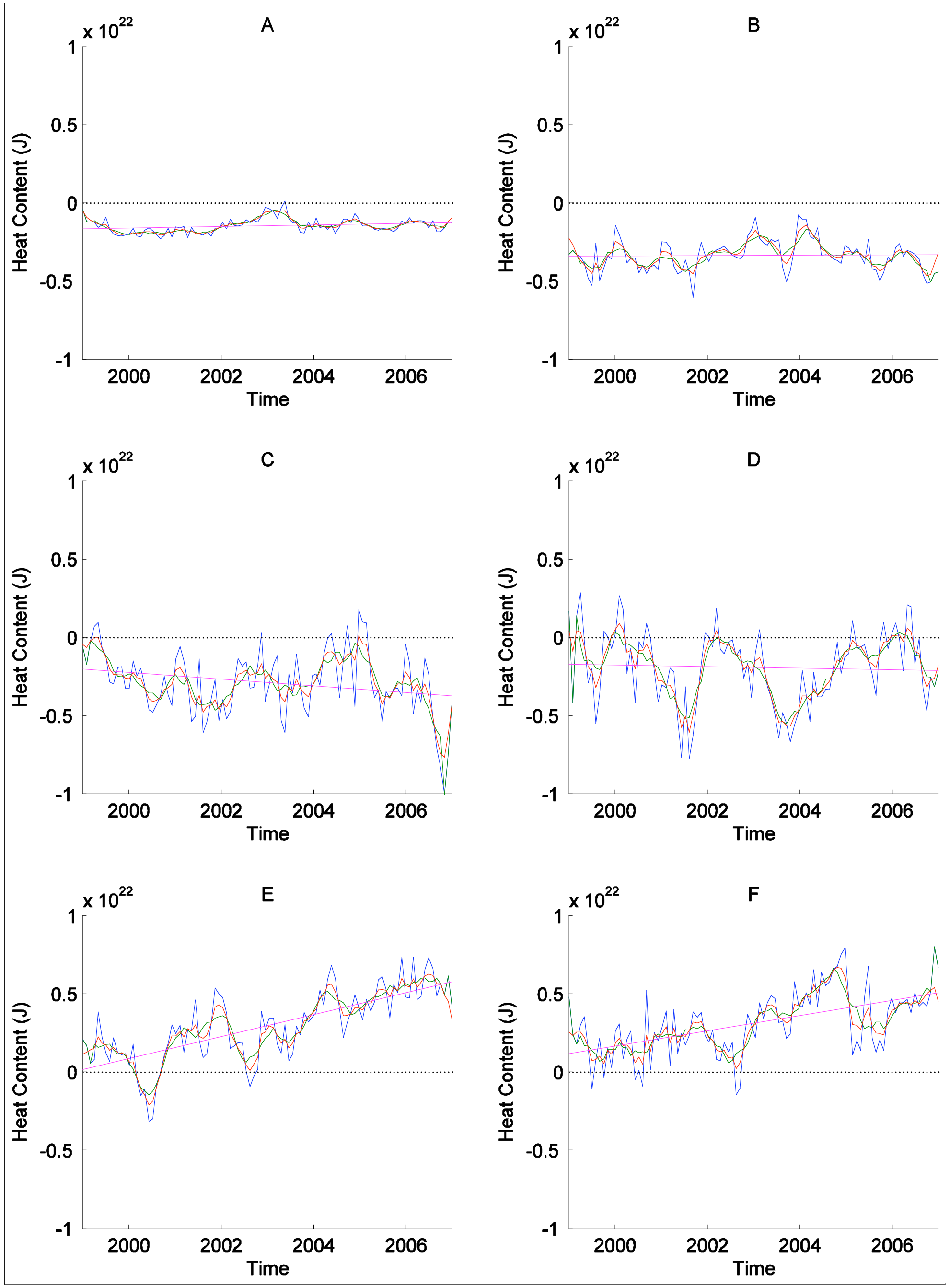


Number of ARGO Profiles at North Atlantic Area
[10°-70°N ÷ -90°-0°W] in period 02/1998-12/2007
Number of CTD stations
Time
98
99
00
01
02
03
04
05
06
07
0
100
200
300
400
500
600
700
800
900
1000
1100

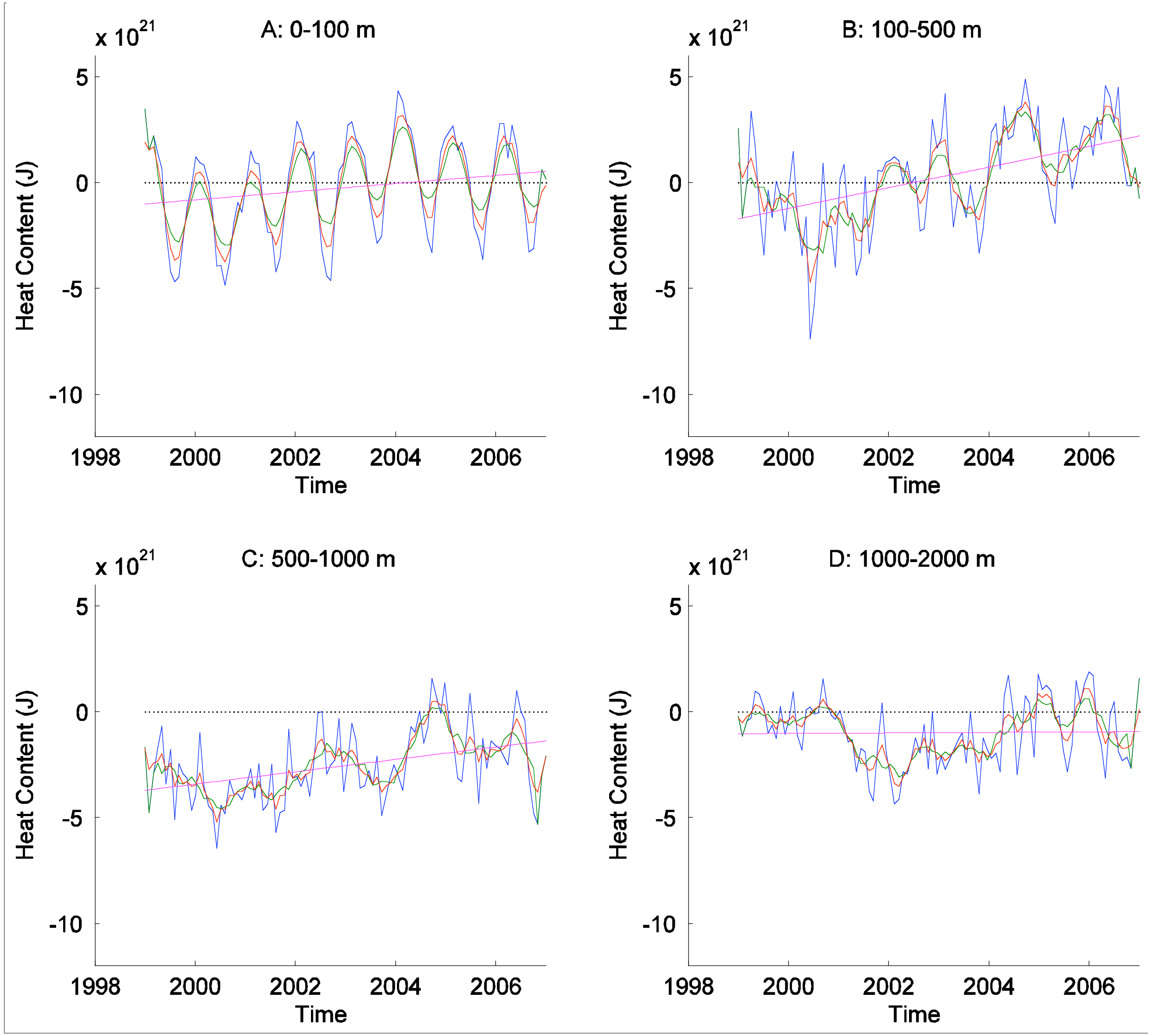


x 10^22
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
Anomaly of Heat Content (J)
1999
2000
2001
2002
2003
2004
2005
2006
2007
Time

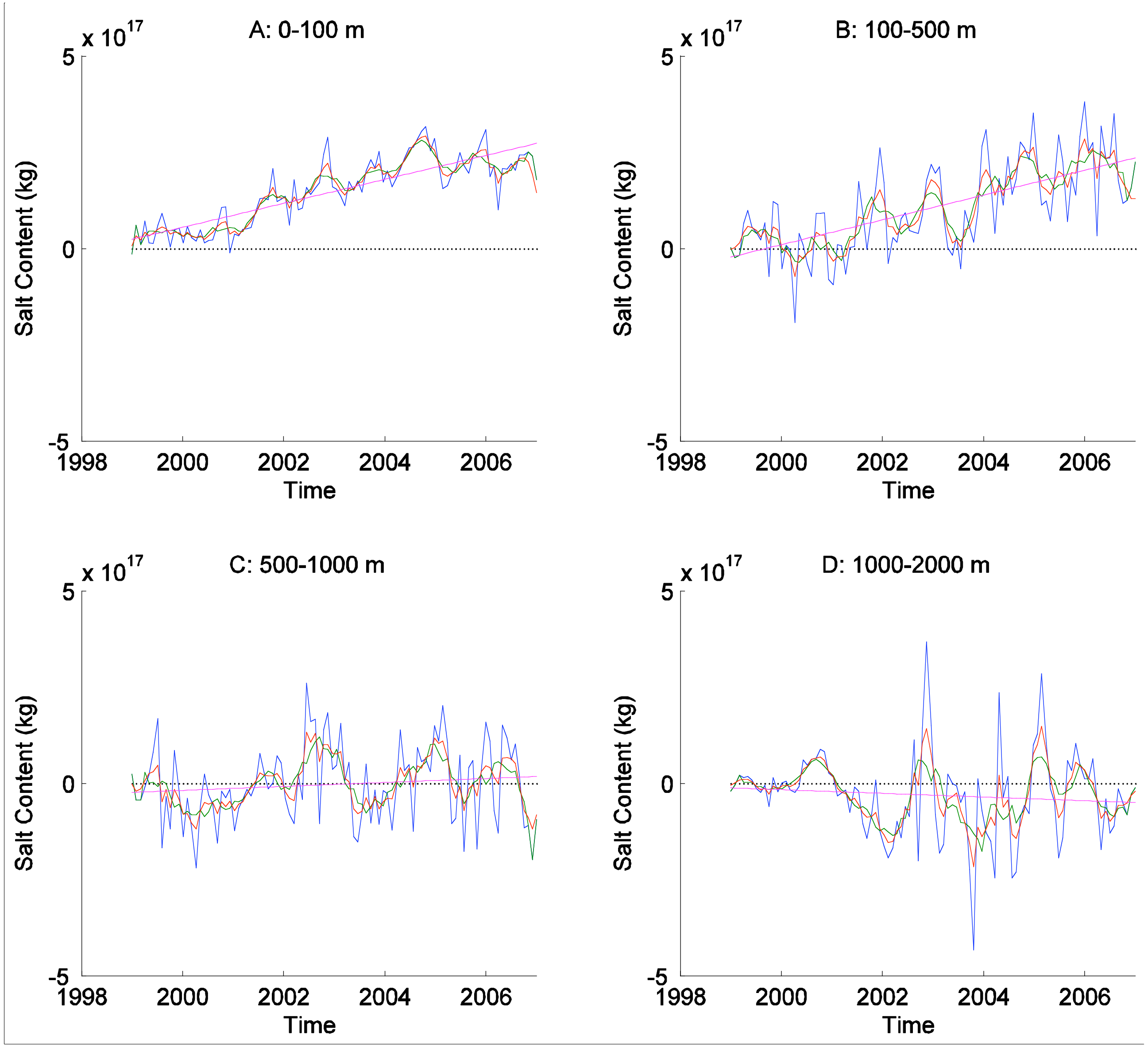

x 10^17
16
14
12
10
8
6
4
2
0
-2
-4
Anomaly of Salinity Content (kg)
1999
2000
2001
2002
2003
2004
2005
2006
2007
Time



A
B
C
D
E
F
x 10^22
Heat Content (J)
Time
1
0.5
0
-0.5
-1
2000
2002
2004
2006



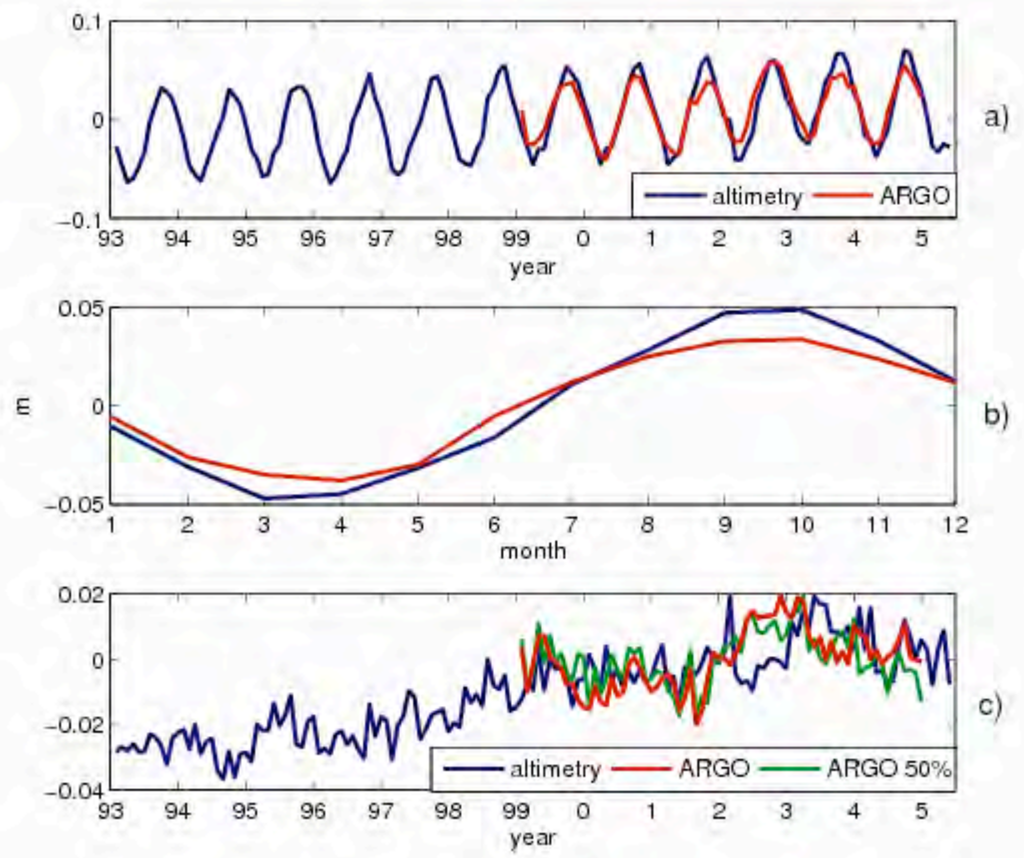
A: 0-100 m
B: 100-500 m
C: 500-1000 m
D: 1000-2000 m
x 10^21
Heat Content (J)
Time
5
0
-5
-10
1998
2000
2002
2004
2006

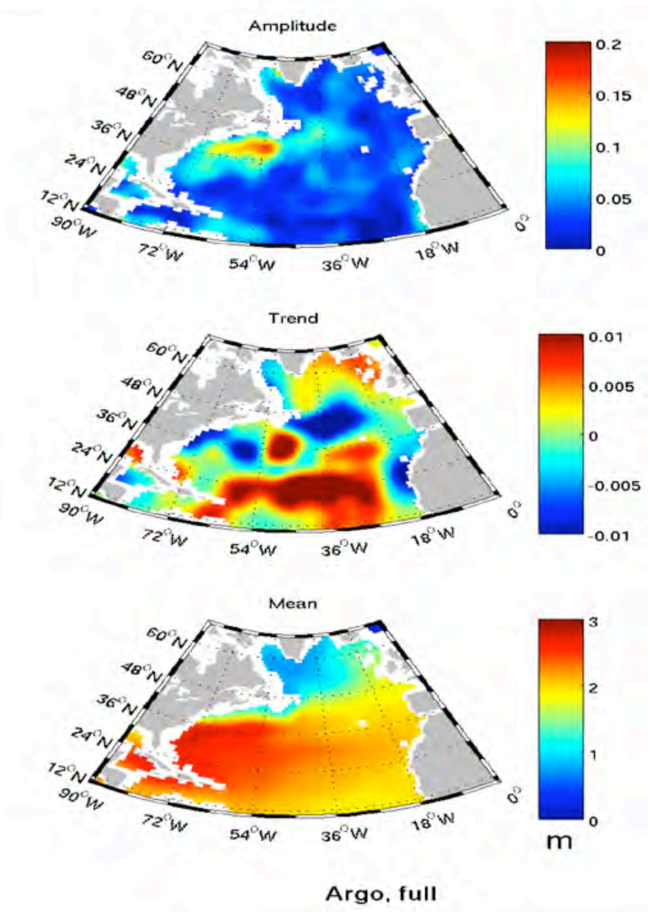

A: 0-100 m
B: 100-500 m
C: 500-1000 m
D: 1000-2000 m
x 10^17
Salt Content (kg)
5
0
-5
1998
2000
2002
2004
2006
Time

Experiments

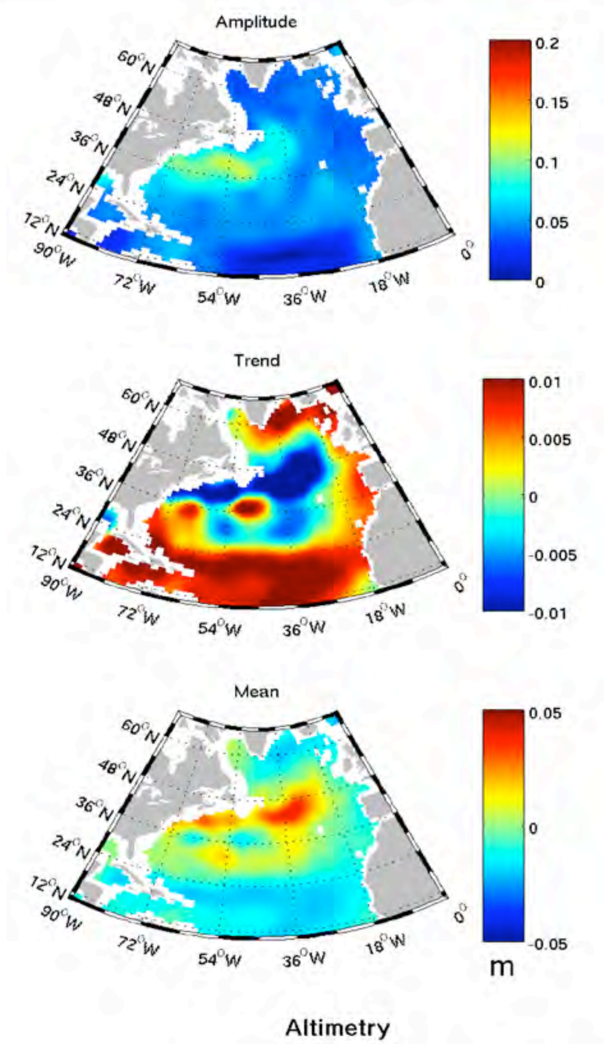
- *1.The Argo data for T and S . RL=1000m.*
- *2.The Argo T data; climatological annual S mean. RL=1000m.*
- *3.The Argo S data; climatological annual T mean. RL=1000m.*
- *4.The Argo T data; climatological monthly S. R=1000m.*
- *5.The Argo S data; climatological monthly T. RL=1000m.*
- *6.The Argo T and S data. RL=1500m.*
- *7.The Argo T data; climatological monthly S. RL=1500m.*
- *8.The Argo S data; climatological monthly T. RL=1500m.*

The steric height and satellite altimetry. a-the SH and SA averaged over the Northern Atlantic. b- the seasonal cycle of the SH and SA; the averaging time is between 1999 and 2005 and between 1993 and 2005 for the SH and SA, respectively; c-the anomalies of the SH, SA and the SH for the experiment with the half of the data.

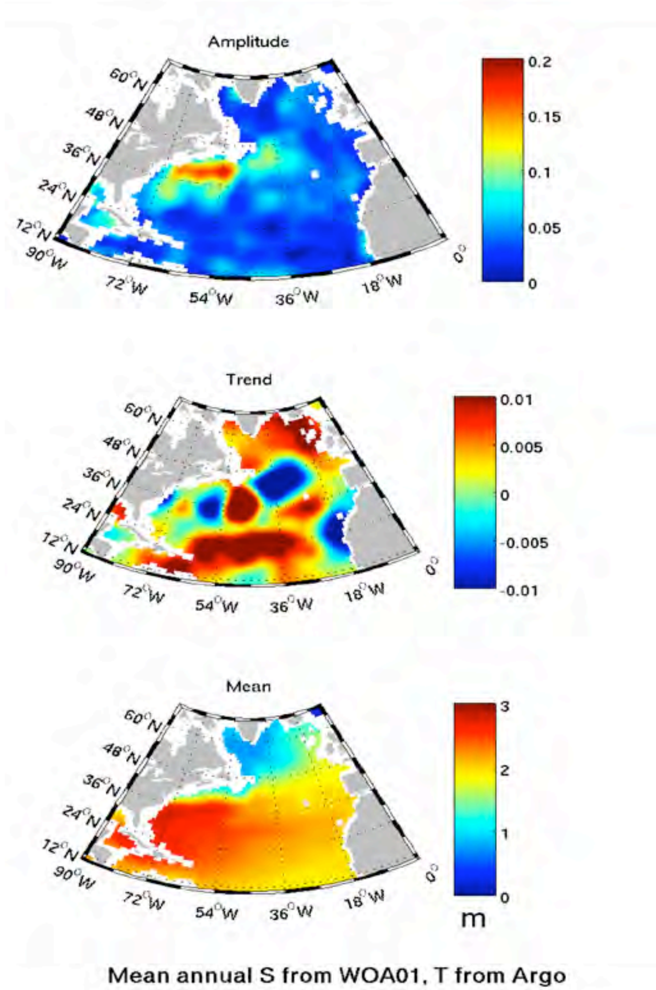




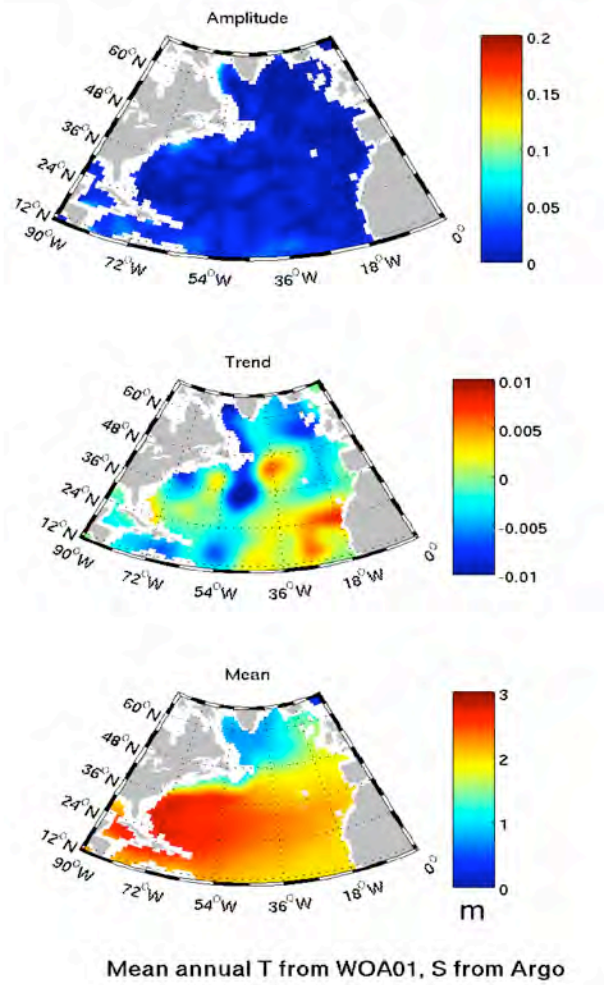
Steric height: amplitude, trend and mean state. Argo data. RL=1000m



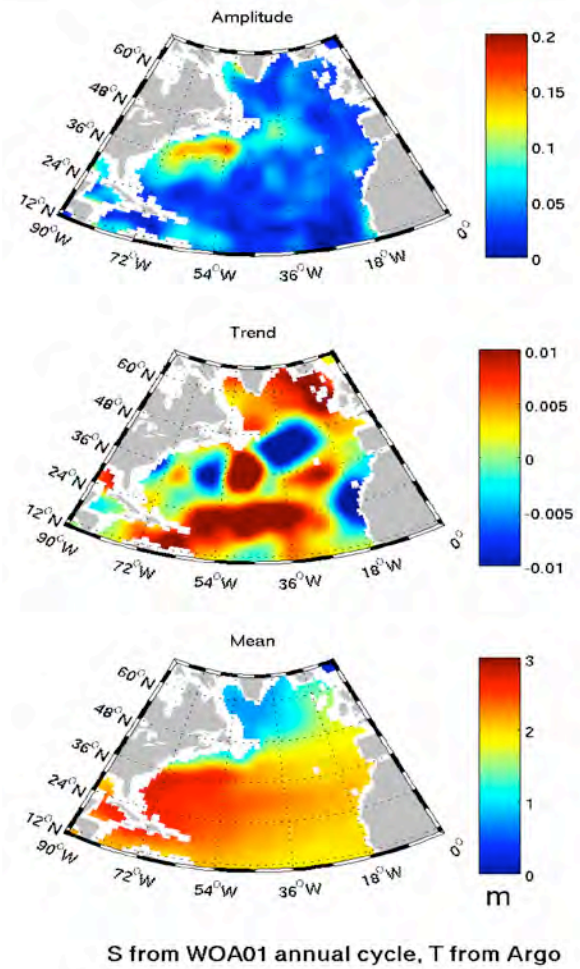
- Sea surface height: amplitude, trend and mean state (satellite altimetry)



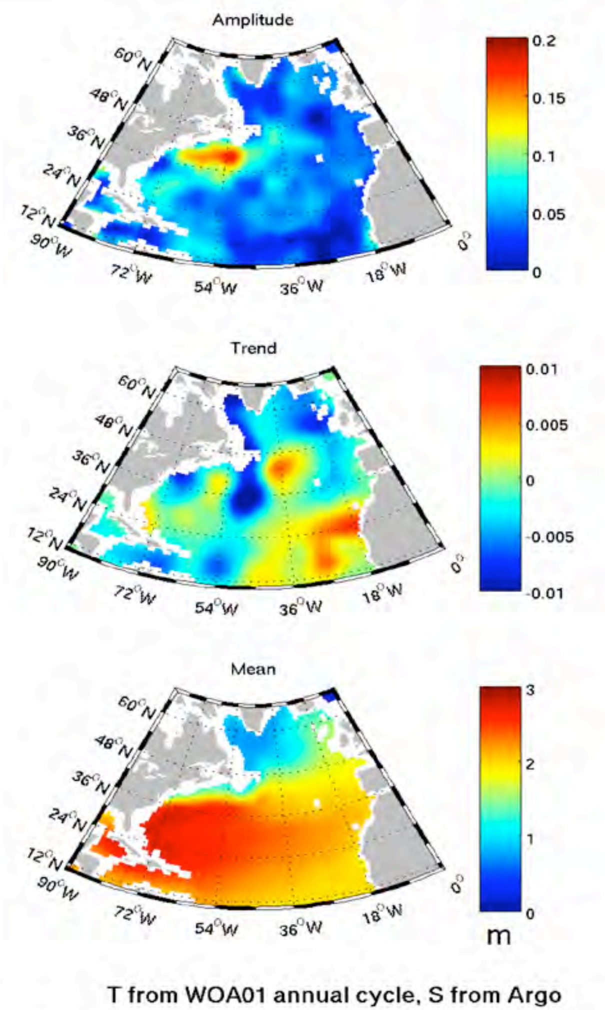
Steric height: amplitude, trend and mean state. RL=1000m.Mean annual S from WOA2001, T from Argo



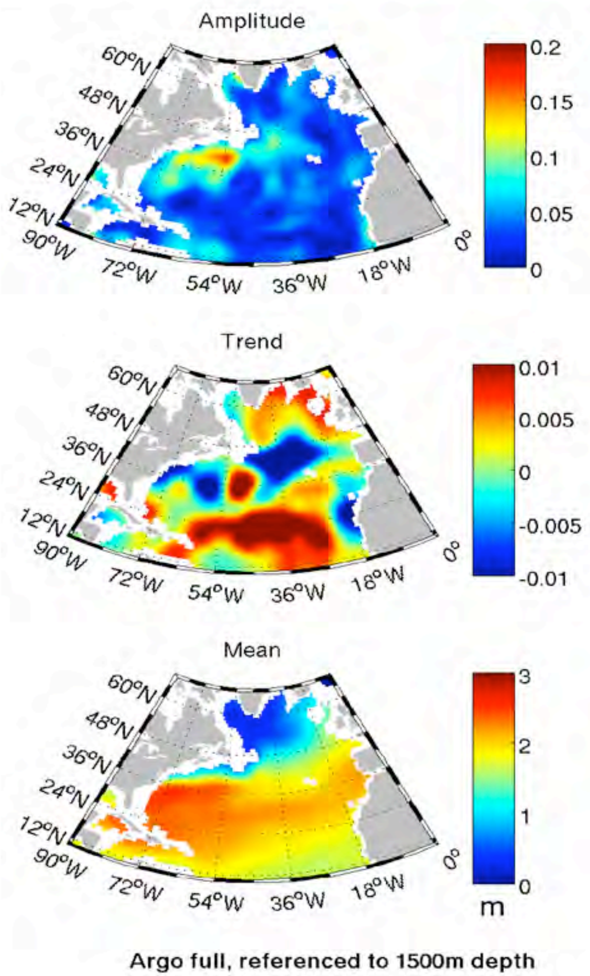
Steric height: amplitude, trend and mean state. RL=1000m. Mean annual T from WOA2001, S from Argo



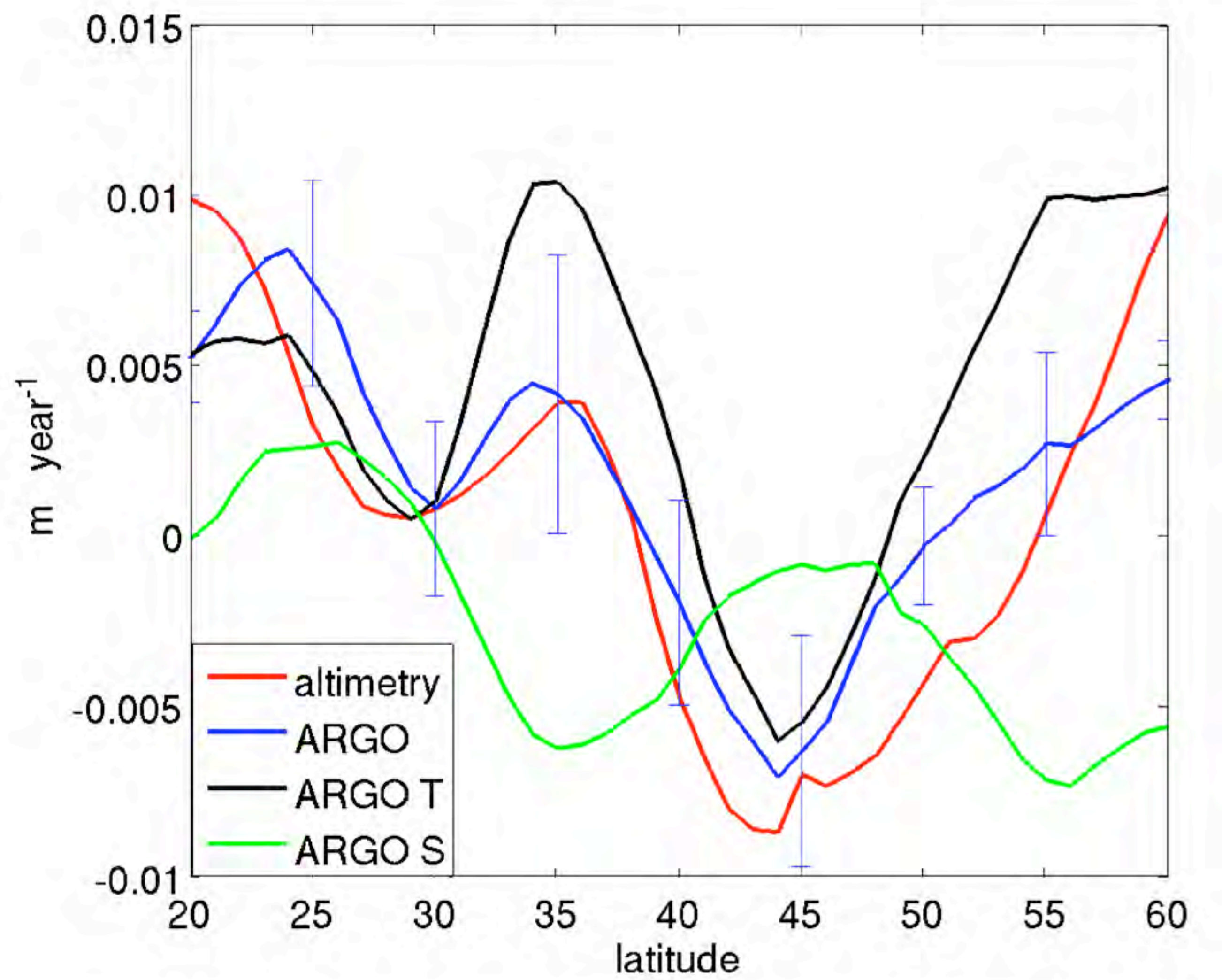
Steric height: amplitude, trend and mean state.
RL=1000m.S from WOA2001 seasonal cycle, T from Argo



Steric height: amplitude, trend and mean state. RL=1000m.
T from WOA2001 seasonal cycle, S from Argo

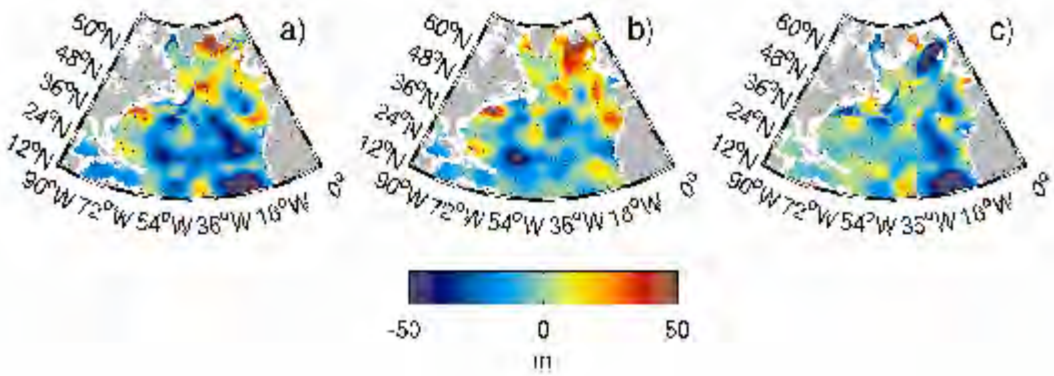


Steric height: amplitude, trend and mean state. RL=1500m. T and S from Argo



- Zonally averaged trends between 2000 and 2004 for satellite altimetry (red), steric height (blue), thermosteric (black, S is from WOA2001), and `halosteric (green, T is from WOA2001).

The variation of the depth of the neutral surface of 27.5 between 2004 and 2003; a- for the general case; b-without variation of salinity; c-without variation of temperature.

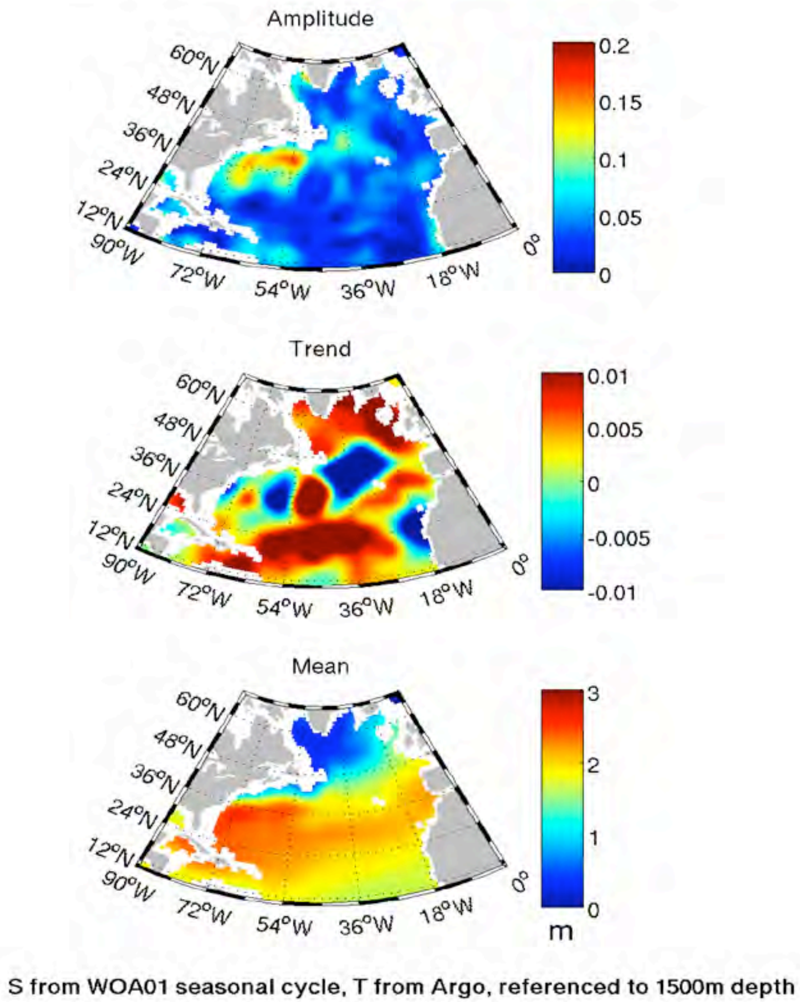


Discussion and Conclusions

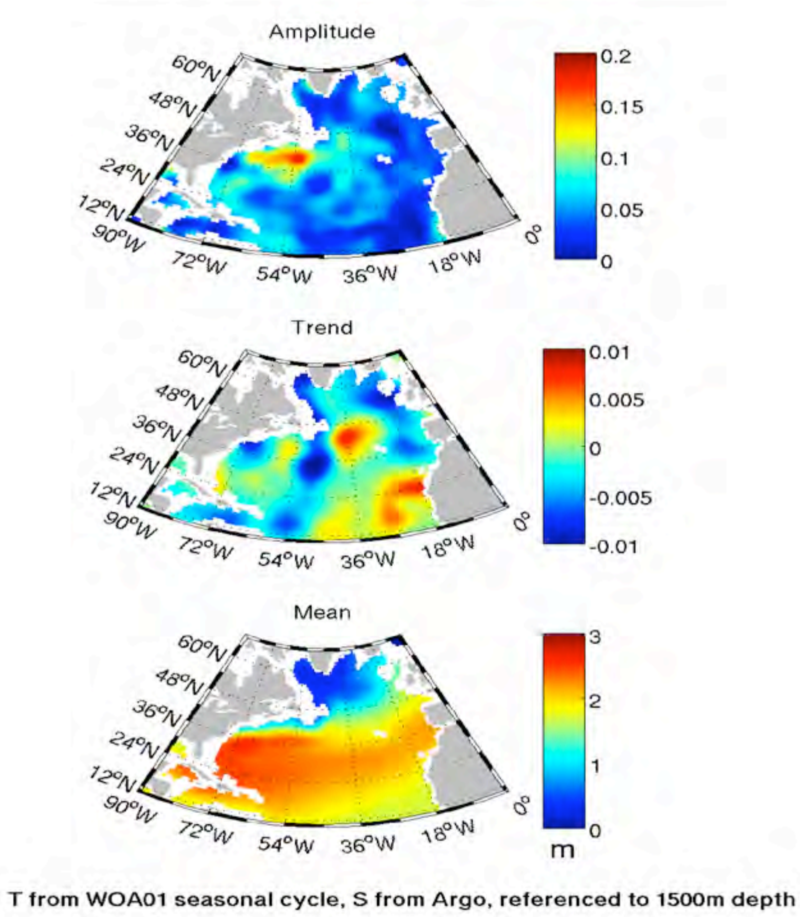
The AHC and ASC demonstrate positive trends in the last 8 years in the upper 2000m of the North Atlantic. The decisive contribution to the trend comes from the northern part of the basin between 50°N and 70°N. Is the number of Argo observations and their density population good enough for the estimations, based on such data? The correlations of monthly averaged values of AHC/ASC with the 50% randomly removed data are 0.84 and 0.72 and are statistically significant at 95% level of significance.

- ***The seasonal variability of temperature in the upper several hundred meters is the major contributor to the amplitude of seasonal cycle in the SH, while the variability of salinity is a minor importance on this temporal scale.***
- ***On the interannual time scale, however, the salinity input into the SH trend cannot be disregarded. The halosteric contribution to SH is usually in the opposite phase to the thermosteric one corrects the SH trend toward values which are closer to the SSH trend.***
- ***The RL at 1000m in the North Atlantic is deep enough to catch the most important features of not only the amplitude of annual harmonics but also the trend of SH.***

- ***With the increase in the period of observations one would need to take into account deeper anomalies.***
- ***However, the range of 2000m is seemingly deep enough to catch the trends of SH even on decadal time scales almost everywhere in the NA with exception, perhaps, of the Deep Western Boundary Current.***

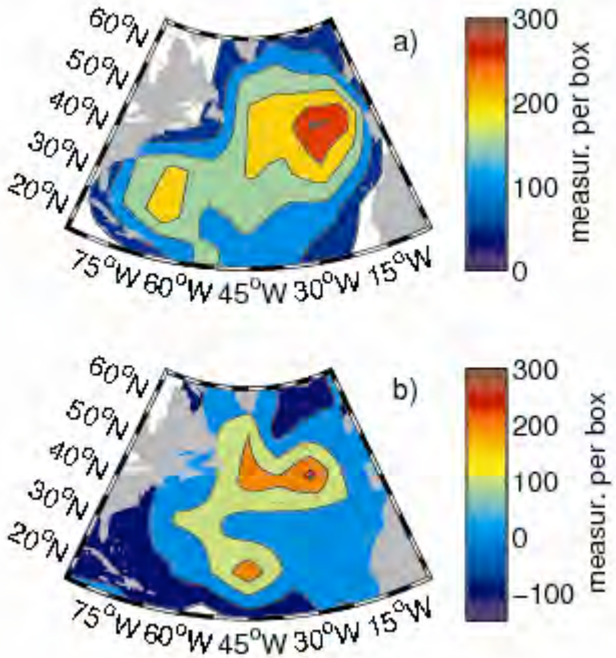


- Steric height: amplitude, trend and mean state. RL=1500m. S from WOA2001 seasonal cycle, T from Argo



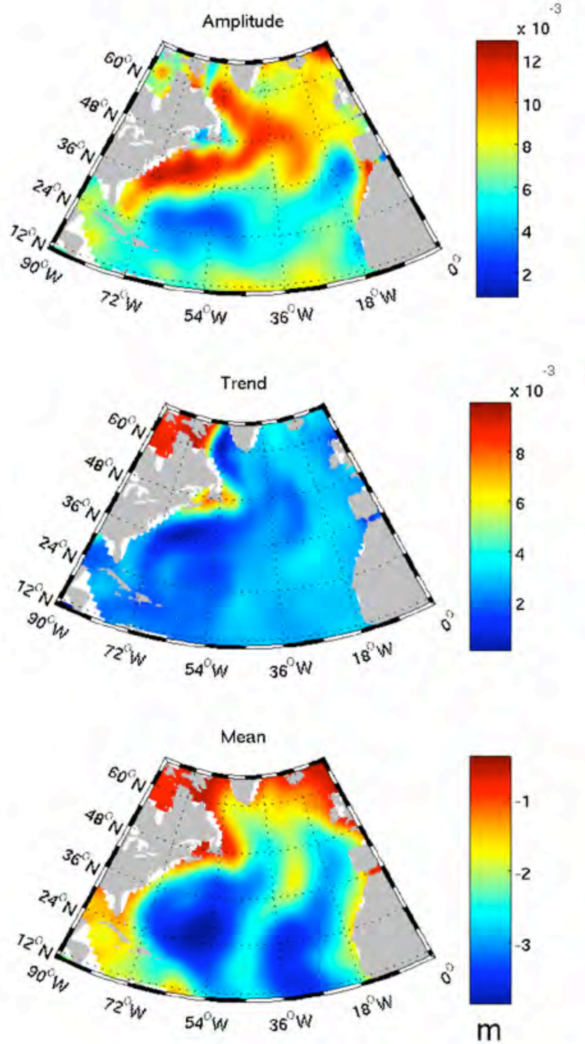
Steric height: amplitude, trend and mean state. RL=1500m. T from seasonal cycle of WOA2001, S from Argo.

The number of the temperature profiling data at the surface of the North Atlantik for the 10° boxes. a-for the 1999-2005;b-difference between 2005 and 1999



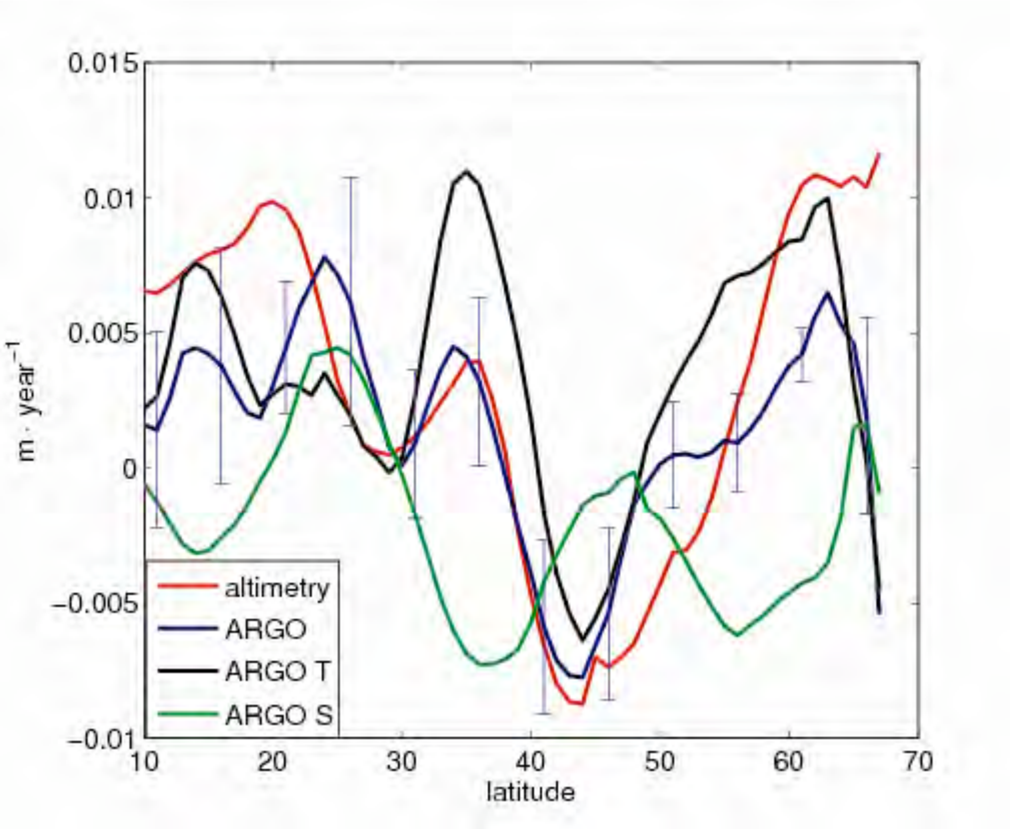
Correlation between AHC/ASC for the whole set and part of set

Depth (in m)	r(AHC) for whole and half	r(AHC) for whole and quarter	r(ASC) for whole and half	r(ASC) for whole and quarter
0-2000	0.88	0.61	0.82	0.67
0-100	0.98	0.96	0.96	0.92
100-500	0.86	0.69	0.86	0.72
500-1000	0.85	0.56	0.65	0.31
1000-2000	0.84	0.61	0.70	0.48



- Bottom pressure (Schodlock et al., 2007)

Zonally averaged trend between 2000 and 2004 of the satellite altimetry (red), steric height (blue), steric height when salinity is climatological (black), and steric height when temperature is climatological (green). The vertical bars represent error estimation for the consistently averaged trend.



Conclusions

- *The analysis shows that both temperature and salinity determine interannual variability of steric height in the Northern Atlantic. Leaving only temperature variability gives for the basin averaged trend more than two times larger than the total trend in steric height. On the local scale, the contribution from temperature and salinity are of similar magnitude. Usually the thermosteric and halosteric contributions into steric height anicorrelate, i.e. partly compensate each other.*
- *There is a different response of the steric height to the same anomaly of temperature in the north and south, or in the upper and middle layers of the ocean, due to strong nonlinearity of the thermal expansion coefficient.*

Discussion and Conclusions

- *Levitus et al. (2005) shown, that a substantial part of the global warming signal originates in the Atlanic Ocean. In contrast, we found a negative AHC for the upper 1500m for the period of time 1999-2005 relative to the Levitus climatology.*
- *Why is it negative? First of all, the space distribution of the AHC in the Northern Atlantic shows variability, with both positive and negative anomalies. In particular there is a dipole type distribution of the time averaged AHC with negative values concentrated in the southern and middle latitudes of the North Atlantic and positive values north of 50S. Secondly, despite the overall positive trend of the heat content in the North Atlantic, there were periods of several years when the heat content decreased substantially (Levitus et al., 2000). The climatology we used in this study contains the data even earlier than 1948. Thirdly, the climatology comprises observations from very different instruments, including XBT. It was shown by V.Gouretski (private communication, manuscript in preparation) that the XBT data has a positive temperature bias when compared to CTD data. The XBT data, since 1970s contributed substantially, to the total set of all data and therefore this bias may have a significant positive bias on the climatological tmperature.*

- *The upper 50m of the ocean has a positive time averaged AHC, that is the ocean surface layer is warmer, compared to the Levitus climatology. We found that the upper 1000m of the North Atlantic is getting warmer. The areas between 20N-30N and 40N -50N demonstrate cooling in the last 7 years, but the band between 30-40N and especially the northern part of the North Atlantic shows strong warming. This agrees with the recent observation (Bryden et al, 2005), that meridional overturning at 25N is slowing and the associated poleward heat transport is weakening. Also we did not find a significant contribution in the AHC of the upper North Atlantic Deep Water between 1000m and 1500m in the zonal belt 20-30N, which also agrees with observations. The exciting result is that the warming takes place in all studied layers in the northern part of the domain and the strongest signal is associated with the upper ocean.*