CHANGES IN THE TEMPERATURE TENDENCIES OFF THE UPPER SUBTROPICAL NORTH ATLANTIC OCEAN

Argo - España
Parte de la estrategia de observación global

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Abstract

The **Atlantic Meridional Overturning Circulation** contributes to the moderation of the climate in Europe through the northward transport of 25% of the global heat flux, reaching its maximum of 1.5 PW[1] at around 24.5ºN. Consequently, the transatlantic oceanographic sections at this latitude, since the first occupation during the International Geophysical Year in 1957[2], have become a benchmark to monitor long-term changes in temperatures in the Atlantic[3], in order to understand the nature and causes of climate change[4].

In this study, **temperature data from the** Argo[5] network and five oceanographic sections at 24.5ºN are used to show here that **1)** a mean warming of 0.26 ºC occurred in the upper ocean (600-1800 dbar range) during the 1998-1957 period; **2)** a mean cooling of -0.15ºC of the upper ocean is found for the 2005-1998 period and; **3)** this cooling significantly decreases the maximum upper-ocean warming found in 1998 to only 0.11ºC for the period 2005-1957, less than half that found during the 1998-1957 period**.**

Figure 1. Station positions for transatlantic hydrographic section at 24.5ºN and Argo data. a) Locations of the hydrographic sections at 24.5ºN in 1957[2] during the International Geophysical Year (October), in 1981[9] (August), during the World Ocean Circulation Experiment in 1992[3] (A05, July-August) and 1998[10] (AR01, January-February), and finally in 2004[11] (April-May).
b) Locations of every Argo profile in the period between January 2003 and October 2007. From a total of 1448 profiles, 158 profiles belong to 2003, 263 to 2004, 210 to 2005, 317 to 2006 and 501 to 2007. The 2005 Argo 'zonal' synthetic section obtained is also shown. The grey lines, at 23ºW and 70ºW, bound the area where the 24.5º Atlantic was sampled during the fifth occupation.

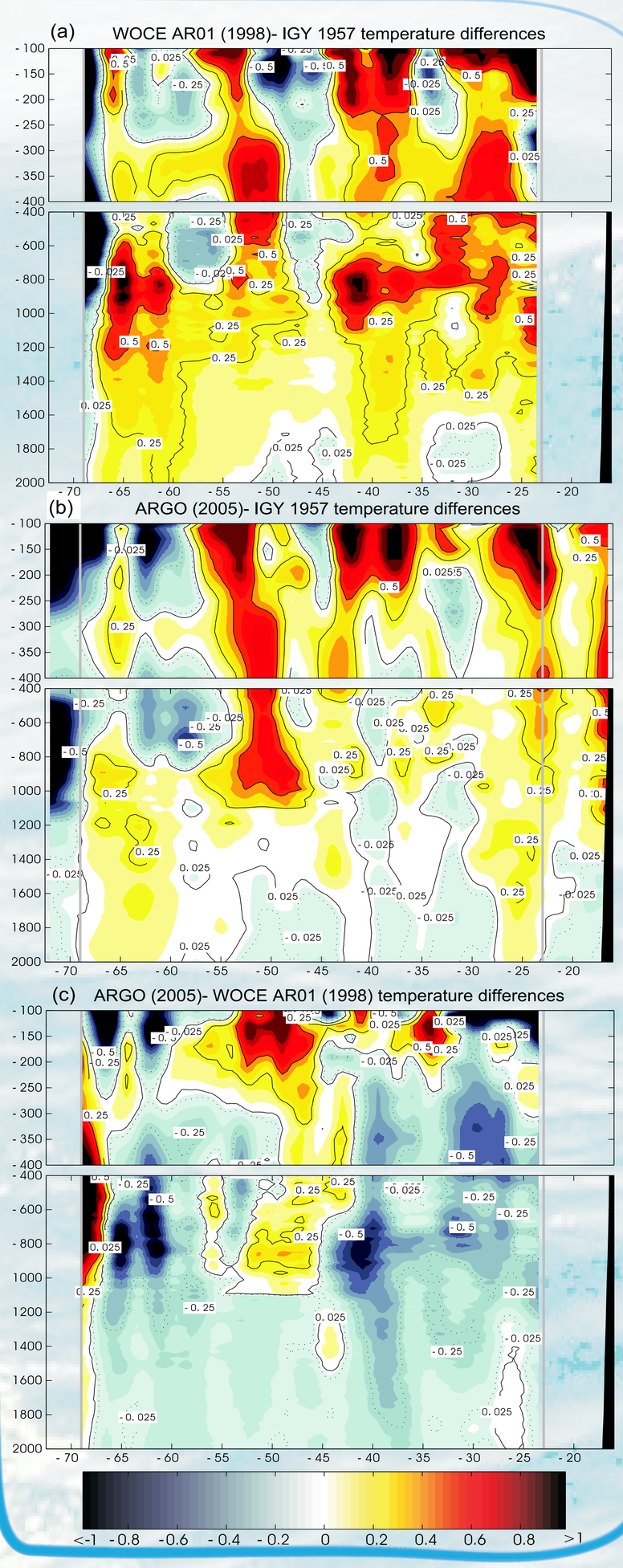
Data

The first oceanographic section along 24.5ºN, bisecting the North Atlantic Subtropical Gyre, was carried out during the 1957 International Geophysical Year (IGY). Since then, four additional occupations of this transatlantic section have been done **(Fig 1a)**.

In addition to these five oceanographic sections, the broad-scale global array of temperature/salinity drifting profiling floats, known as Argo[5], provide continuous monitoring of the temperature and salinity of the upper 2000 dbar**.**

All available good quality Argo data[12] from almost five years (January 2003 to October 2007) in the North Atlantic have been examined, edited, and objectively interpolated onto a hypothetical zonal 'section' at 24.5ºN, following a method employed previously[13] **(Fig.1b)**. The statistical approach used, optimal statistical interpolation, is commonly used to obtain climatological fields, since it has been designed[14] to minimize the signal to noise ratio, the noise being mainly due to eddies in transoceanic sections. For objectively interpolated temperature and salinity, the annual climatological temperature and salinity data from the World Ocean Atlas (1994) is used as a first guess[15,16]**.** The large amount of data and the 5 year span of the observations allow the ocean 'eddy' noise, always present in single hydrographic sections, to be greatly reduced**.** The obtained Argo 'zonal' section is composed of temperature and salinity profiles at 101 pressure levels, each 0.5º degree between 16ºW and 72ºW, with a mean date equivalent to 2005**.** This synthetic Argo section will be considered as the **sixth occupation of 24.5ºN**.

In order to examine the differences between the surveys and the synthetic Argo section given the different sampling grid in each trans-oceanic section, temperature and salinity data from each section have been interpolated to the positions used by the Argo 'zonal' section. Contoured sections of the temperature differences on isobaric levels for the periods 1998-1957, 2005-1957 and 2005-1998 are presented in **Fig. 2**. The temperature sections have been smoothed, using a 300 km low-pass Gaussian filter, to eliminate eddy variability from the cruise sections.



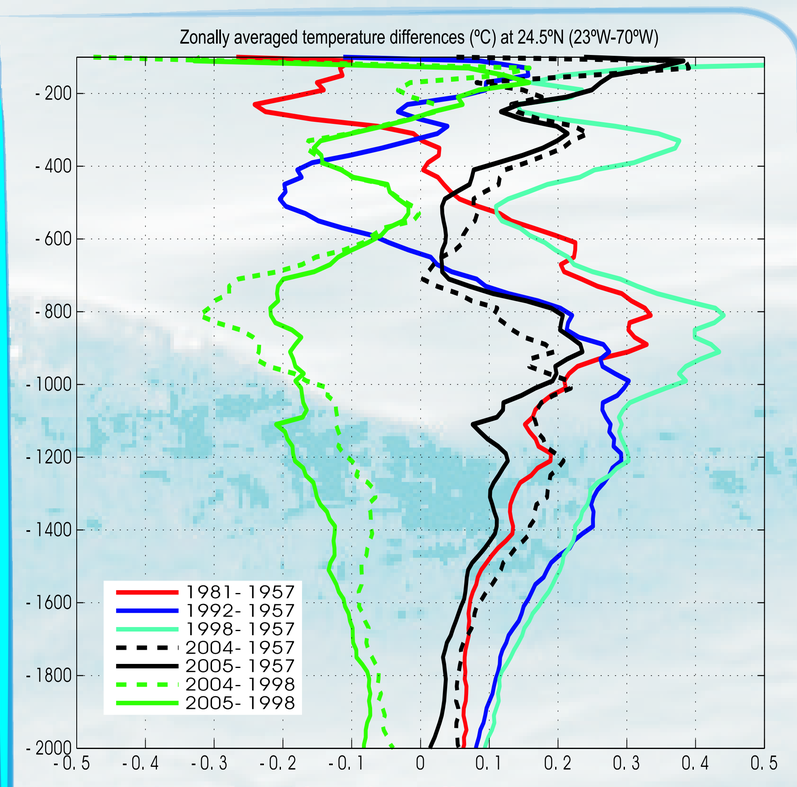
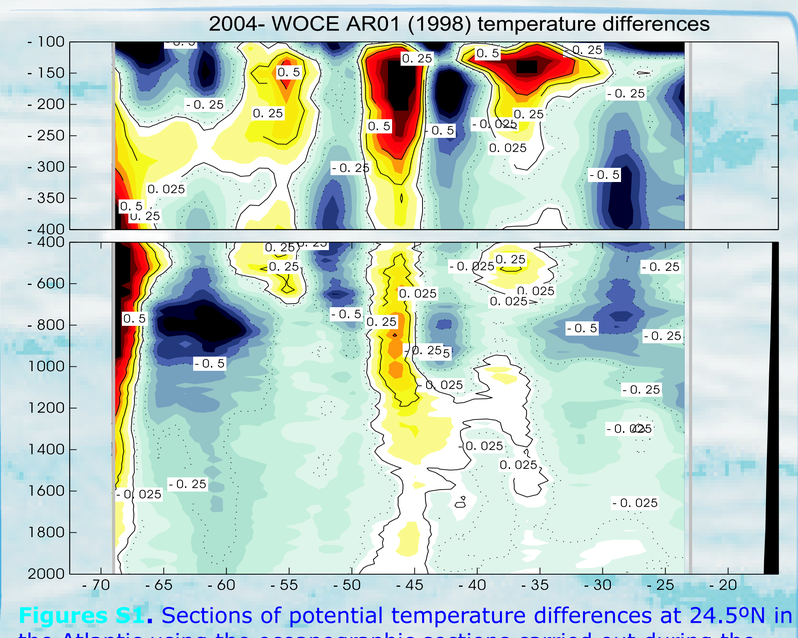


Figure 3. Vertical profiles of zonally averaged temperature on pressure surfaces. Mean zonal potential temperature differences in the 1981-1957, 1992-1957, 1998-1957, 2004-1957, 2005-1957, 2004-1998 and 2005-1998 periods. Each pair of sections has been compared where the data were effectively collected along 24.5ºN, between 23ºW-70ºW (bounded by gray lines in Figs. 1 and 2)**.**

Figure 2. Decadal-scale temperature changes in the subtropical North Atlantic Ocean at 24.5ºN. Sections of potential temperature differences at 24.5ºN in the Atlantic between the oceanographic sections carried out during: (a) 1998-1957, (b) 2005-1957 and (c) 2005-1998. The grey lines at 23ºW and 70ºW bound the area where the 24.5º Atlantic was sampled during the five occupations.



Figures S1. Sections of potential temperature differences at 24.5ºN in the Atlantic using the oceanographic sections carried out during the years 2004 and 1998. The colour scale is the same as for figure 2.

Results

Temperature differences between the WOCE AR01 **1998** and IGY **1957** surveys **(Fig. 2a)** reveal that the ocean in the subtropical north Atlantic at 24.5º N became warmer over this 41-year period, following the tendencies found in 1992. The maximum warming occurred between 800 and 1000 dbar, with values up to 1ºC. The warming occurred almost along the whole section.

Temperature differences between the Argo **2005** and IGY **1957** sections **(Fig. 2b**) show that the Atlantic interior in 2005 is warmer than in 1957, with a similar pattern to that found during 1998. However, the magnitude of the warming is lower than for 1998, especially at waters deeper than 400 dbar, where the values up to 1ºC found in 1998 have reduced to less than 0.5ºC, and even lower in the eastern central Atlantic (25ºW 45ºW). This cooling, that weakened the long-term warming of the North Atlantic, is clearly observed in the temperature differences between the Argo **2005** and the WOCE AR01 **1998** sections **(Fig. 2c)**. The cooling in the period 2005-1998 is homogenous, except for the central Atlantic (40ºW-55ºW), where a 0.70ºC warming in the upper levels (<200 dbar) is found. The cooling has maximum values of -0.5ºC at 800 dbar.
Temperature differences for the period 2004-1998 using CTD data from the 2004 cruise[11] **(Fig. S1)** show the same predominant cooling for the 2005-1998 period, supporting the validity of the Argo data for long-term studies, and confirming that the cool bias[17] found in the Argo data has been solveved. Salinity shows changes similar to those found in temperature, with the upper ocean becoming saltier until 1998 and freshening since then, with a net increase in salinity since 1957 half of that found in 1992. The CTD 2004 salinity data also confirm the results obtained with the Argo floats.

Vertical profiles of zonally averaged temperature differences between 1957 and the five occupations **(Fig. 3**) confirm and quantify the change in tendency observed in the contoured sections**.**

Table 1. Mean temperature differences (ºC), with respect to IGY 1957, between 23ºW and 70

	1981	1992	1998	2004	2005
Upper Ocean (600-1800 dbar)	0.16	0.20	0.26	0.12	0.11
Thermocline waters (300-800 dbar)	0.14	-0.07	0.19	0.08	0.08
Intermediate Waters (800-1800 dbar)	0.14	0.22	0.26	0.14	0.11

A warming between the first occupation in 1957 and the sections sampled in 1981, 1992 and 1998 is observed, although with an oscillation in the maximum warming level, from 900 dbar in 1981, to 1000 dbar in 1992 and back to 900 dbar in 1998. The warming reached a maximum of 0.26ºC for the upper ocean, 0.19ºC for the thermocline waters and 0.26ºC at the intermediate waters in 1998 **(Table I)**.
From 1998 to 2005 the zonally averaged temperatures decreased, with a maximum cooling of ~0.2ºC at 800 dbar. The thermocline waters (300-800 dbar) cooled by 0.11ºC, while the intermediate (800-1800 dbar) cooled by 0.15ºC, representing, in both cases, almost 50% of the warming found during the 1998-1957 period **(Fig. S3)**, this cooling being statistically significant. As a result, the 2005-1957 averaged temperature difference shows a weak warming of 0.08ºC in the thermocline waters, 0.11ºC in the intermediate waters, and 0.11ºC in the upper-ocean layer (600-1800 dbar) **(Table I)**. This statistically significant 0.11ºC temperature increase is less than half that found during the 1992-1957 period. The differences between the sections and the zonally averaged values (table 1) for the 2004 and 2005 datasets are smaller than the changes that occurred in the period 1992-1998.

The subtropical Atlantic along 24.5ºN was **reported to** warm at 0.65ºC/century[18], with a maximum of 1ºC/century at 1100 dbar[3], until 1992. This reported tendency is very similar to that obtained here for the same period, with minor differences a consequence of the slightly different layers and zonal limits. The present study shows that the upper-ocean (600-1800 dbar) warmed at a rate of 0.57ºC/century in the 1992-1957 period. However, in the 2005-1957 time period the warming decreased to 0.23ºC/century, less than half of that predicted in 1992.

Conclusions

The results presented here, together with those obtained in 2002 for the transIndian hydrographic section across 32ºS[6], which revealed an increase in salinity that almost reversed the freshening of mode waters observed from 1960 to 1987, and the results obtained in 2005 for the Western Mediterranean Deep waters[7], a proxy for climate change[8]**,** which illustrated a reversal of the long-term progressive warming after the 2004-2005 winter, **demonstrate** that there are still important unknown mechanisms of ocean variability that complicate the understanding of ocean climate change. **Moreover,** water mass changes are not necessarily unidirectional and substantial oscillations over decadal timescales can occur.

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