Heat Storage in the North Atlantic Ocean between 1992 and 1998 as Estimated From Satellite Altimetry

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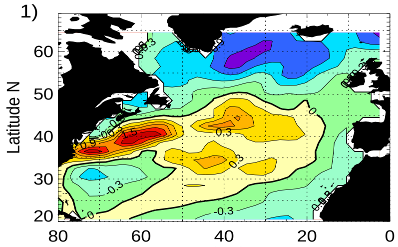
INTRODUCTION

Heat content deviations have been derived for the subtropical and the subpolar North Atlantic from sea level data measured by Topex/Poseidon, ERS-1, and ERS-2, from October 1992 to September 1998. Oceanic heat storage and its relation to the dominant mode of atmospheric variability in this region, the North Atlantic Oscillation (NAO), are investigated on the interannual time scale.

INTERANNUAL CHANGES IN SEA LEVEL

The 1st mode empirical orthogonal function (EOF) of sea level anomaly (Figure 1), accounting for 37% of the total variance, exhibits a dipole structure with centers in the subpolar and subtropical gyres. The corresponding time amplitude function (solid line, Figure 2) and the time integral of the NAO-Index (broken line, Figure 2) both change sign between summer 1995 and spring 1996 To highlight these changes, we define two periods: A -during positive NAO conditions, and B -during near zero NAO-conditions.

1)



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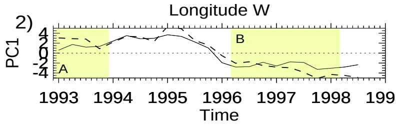

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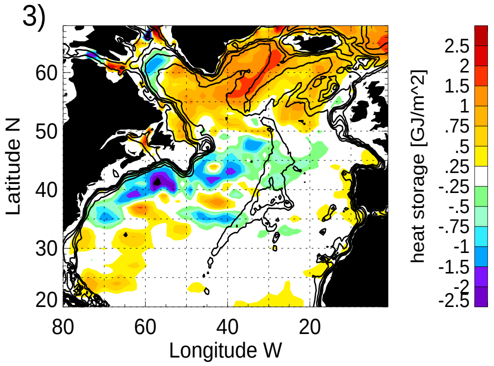

HEAT STORAGE CHANGE (Period B -Period A)

Figure 3 shows the heat storage difference periods B - A. Heat storage (ΔH) is calculated using the formula (Chambers et al., 1997): (α_{mix} = thermal expansion coefficient of oceanic mixed layer, c_p = heat capacity of sea-water, ρ_0 = density of standard sea water, $\Delta\zeta$ = sea level deviation). Between periods A and B the subpolar gyre gained 0.5 to 1.0 GJ/m^2, while the Gulf Stream region and the transition zone (40°N to 50°N) lost 0.5 to 2.5 GJ/m^2.

$$\Delta H = \frac{\rho_0 c_p}{\alpha_{mix}} \Delta\zeta$$

HEAT STORAGE CHANGE (Period B - Period A) RELATED TO OCEANIC ADVECTION

Figure 4 shows the heat storage change caused by oceanic heat advection. This is estimated by subtracting the time integrated air-sea heat flux deviations (NCEP/NCAR, Kalnay et al., 1996) from the total heat storage.

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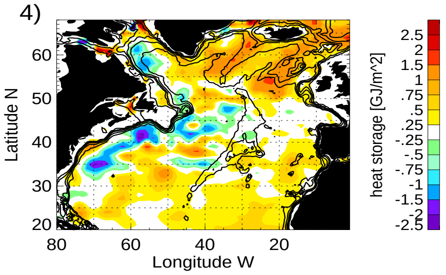


CHANGES IN MERIDIONAL EKMAN TRANSPORT

The changes evident in Figure 4 may be explained in part by anomalies in the wind driven heat transport associated with the downturn in the NAO. Figure 5 presents the anomalous meridional Ekman transports for the period July 1995 to June 1996 (negative NAO-Index) relative to period A, calculated from ERS scatterometer data. Based on these results, one would expect a heat gain in the subpolar region due to northward advection of the mean temperature gradient. Also, increased Ekman-pumping is observed, in the form of a divergence centered on 45°N, implying a heat loss in the 40° to 50° N region.

5)

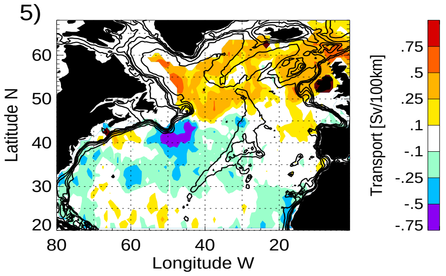


Table 1.

	25°-40°N	40°-50°N	50°-65°N
Total Heat Storage	0.5	-1.4	3.1
Case 1: Advected Heat Storage	2.6	-0.3	2.8
Case 2: Advected Heat Storage	-0.1	-1.5	1.6

All in units of 10^{21} Joules

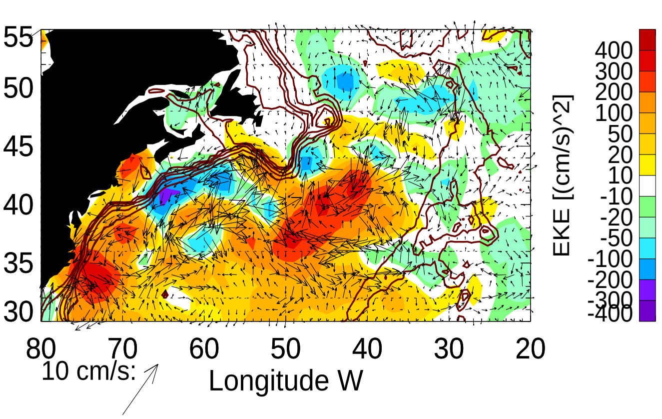
SHIFTS IN THE POSITIONS OF THE MAJOR ZONAL CURRENTS

Figure 7 shows the Period B - A changes in eddy kinetic energy (shaded) and geostrophic surface currents (arrows), calculated from T/P and ERS-1/2 data. Both parameters exhibit large signals in the Gulf Stream, south of the Grand Banks, and in the North Atlantic Current, east of the Grand Banks, which are indicative of meridional shifts in the zonally oriented currents. Figure 8 shows the Period B - A changes in the zonal component of the Sverdrup transport calculated from ERS-scatterometer data. Eastward transports appear related to strengthened currents and vice versa.

ZONALLY INTEGRATED HEAT STORAGE CHANGE

Table 1 gives the zonally integrated heat storage change for three regions: subtropics (20° to 40°N), transition (40° to 50°N), and subpolar (50° to 65°N). The advected component was estimated by subtracting the integrated air-sea heat flux deviations from the total heat storage (Case 1). Allowing for anomalous oceanic heat storage of air-sea heat fluxes of 2 W/m^2 during the study period, we get a closed system with no net heat advection into the area between 25° to 65° N (Case 2). Assuming that the changes took place between summer 1995 and spring 1996, we derive for Case 2 an anomalous heat tranport of 0.06 PW from the 40° to 50°N region to the subpolar region.

7)



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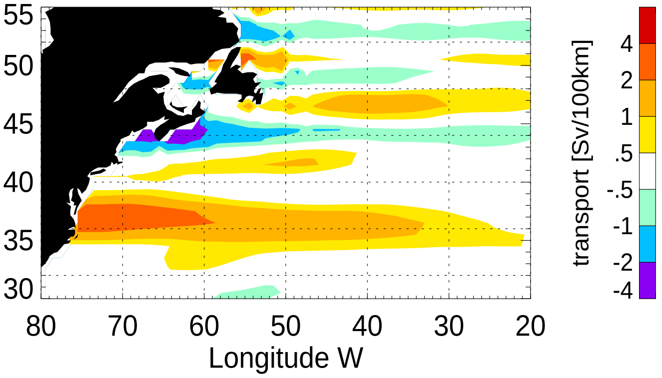

SUMMARY

Altimeter data suggests that large scale, interannual patterns of oceanic heat loss and gain in the North Atlantic are related to the NAO. Between Summer 1995 and Spring 1996, the subpolar region gained about 3.1x10^{21} J and the region between 40°-50°N lost about 1.4x10^{21} J. The present analysis shows that most of these changes reflect anomalous heat advection caused by changes in meridional Ekman transport and meridional shifts in the positions of the major zonal currents.

REFERENCES

Chambers, D.P., B.D. Tapley, and R.H. Stewart, Long-period ocean heat storage rates and basin-scale heat fluxes from TOPEX, *J. Geophys. Res*., 102, 10525-10533, 1997.

Kalnay, E., et al., The NCEP/NCAR 40-Year Reanalysis Project, *Bull. Amer. Meteor. Soc.*, 77, 437-471, 1996.