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Decadal Variability in the North Atlantic

Kurzfassung

Die Jahrzehnte-Veränderung im Nordatlantik wird auf der Basis von numerischen Modellresultaten diskutiert, die den meridionalen Wärmetransport (näherungsweise ermittelt an der meridionalen „overturning rate") und die Meeresspiegelhöhe (SSH) erfassen. Die Altimeter-Daten der TOPEX/Poseidon-Mission (1992–2000) entsprechen sehr gut den Modellergebnissen, die folglich die Modellsimulation bestätigen. Das Modell zeigt, dass die Modifikationen der SSH entlang des Golfstroms sehr gut die Schwankungsveränderungen wiedergeben. Bedeutende meridionale „Overturning"-Perioden gemäß unserem Modell lassen sich nachweisen für die Zeit um 1960, für die Mitte der siebziger Jahre und um 1990. Die gravierendste Veränderung in der Modellsimulation ist das Abnehmen der „overturning rate" im Jahr 1996.

Abstract

Decadal variability in the North Atlantic is discussed based on numerical model results focusing on meridional heat transport (a proxy for meridional overturning rate) and sea surface height (SSH). Altimeter data from TOPEX/Poseidon (1992–2000) mission compares well with the model results giving the confidence to the model performance. Model indicates that low-frequency variations of SSH along the Gulf Stream reflect predominantly overturning changes. Strong meridional overturning periods according to the model occurred around 1960, in the mid 1970's and around 1990. The most significant change in the model record is the weakening of the overturning in 1996.

Résumé

La variabilité pendant des dizaines d'années dans l'Océan Atlantique est discutée sur la base des résultats numériques modèles qui enregistrent le transport thermique méridional (qui est déterminé approximativement à l'aide d'un „meridional overturning rate" et l'altitude du niveau de la mer (SSH). Les données – altimètre de la mission TOPEX/Poseidon (1992–2000) correspondent très bien aux résultats modèles qui vérifient par conséquent l'enregistrement modèle. Le modèle montre que les modifications du SSH le long du Gulf Stream reflètent bien les variations. Selon notre modèle, on peut prouver d'importantes périodes de „overturning" aux environs de l'année 1960, au milieu des années soixante-dix et aux environs de l'année 1990. Le changement le plus grave de l'enregistrement modèle est la diminution de „overturning rate" en 1996.

Keywords

Meridional Overturning, Altimeter Data, Numerical Modeling

1. Introduction

The North Atlantic ocean and atmosphere exhibit apparent long term climate variations, some of which might arise from coupled interactions. Existence of such coupled modes could provide significant potential for dynamical climate prediction as exemplified by the best known coupled phenomenon, El Niño. Several studies on the observed North Atlantic sea surface temperatures (SST) report an oscillatory mode of a period of 12–14 years (DESER & BLACKMON 1993; SUTTON & ALLEN 1997). UNAL & GHIL (1995) find 10–13 year period in sea level around the North Atlantic coasts. Decadal variability is found also in the subsurface temperatures (LEVITUS, 1989; MOLINARI et al. 1998; CURRY et al. 1998). As a non-scientific evidence, an indication of a 14 year variability is also recorded in the Old Testament, Genesis 41, in a description about '7 years of plenty and 7 years of famine' in the dream of the pharaoh and its interpretation by Joseph.

The observations, especially the SST variability, show that the decadal periodicity can hardly be separated from the red noise (DESER & BLACKMON, 1993). Nevertheless, several phenomena such as the freshening of the subpolar gyre occurs nearly once a decade (BELKIN et al. 1997), and appears as a very significant modification of the oceanic surface (and subsurface) conditions. Here we concentrate on exploring the thermal variability which is reflected strongly in the sea surface height variability. The SSH variations can be measured from satellites using altimeters as used in the TOPEX/Poseidon mission which is a joint effort of the US and French space agencies.

2. Results

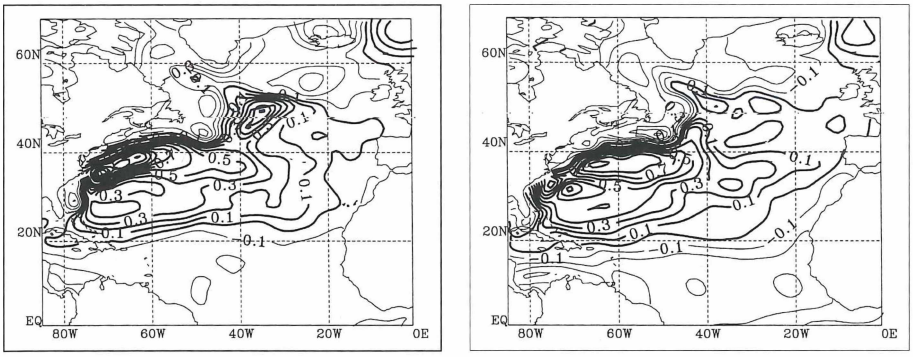
2.1. Overturning Variability

This summary of the North Atlantic decadal variability will rely on an uncoupled ocean model simulation (1951–1993) (HÄKKINEN, 1999) where the surface forcing anomalies are derived from COADS (DASILVA et al. 1994). Here results are also shown by means of the same model using surface forcing anomalies from NCEP/NCAR Reanalysis (1958–2000). In this model simulation for 1951–1993 of HÄKKINEN (1999), the meridional overturning cell (MOC) and heat transport (MHT) are shown to reflect predominantly, and to be driven by, the variability of the North Atlantic Oscillation (NAO) related heat flux. The northern center of the NAO related heat flux located in the subpolar gyre controls the strength of convection (and thus MOC). The MOC changes are result of variations in the volume in the Labrador Sea Water (LSW), as the simulated Nordic Sills overflow did not vary significantly during the same period. MOC and MHT changes in the subtropics lag typically 2 years the NAO heat flux changes. This intensified MOC appears as anomalously high sea level height in the Gulf Stream-North Atlantic Current region as a result from an enhanced heat content of the ocean. This heat content build-up in the Gulf Stream area occurs within one year from the maximum MHT at 25N. Thus, we can causally relate the leading heat flux mode to the strength of the overturning and heat content anomalies in the North Atlantic.

2.2. Analysis of Simulated and Altimeter SSH

EOF analysis of the SSH variance structure separates the monthly (detrended) SSH anomalies into orthogonal modes with a constant spatial structure and a temporal component. The shown spatial amplitude (EOF) multiplied by its time series (the principal component (PC)) describes the contribution of any particular mode (our main focus is on the first mode) to the detrended SSH anomaly. The variance explained by the first EOF mode is 13.4% and 12.8% in the COADS and NCEP experiments respectively (in the time series spanning 43 years). Both EOFs of SSH give a leading mode which has a large amplitude, elongated center along the Gulf Stream and North Atlantic Current with a weaker anomaly of opposite sign extending from the Labrador Sea along the Eastern

seaboard (Figs. 1a, 1b). The latter characteristics explain why the coastal sea level should display a strong decadal signal. The prominent center of variability in the Gulf Stream area may result from the changes in the Gulf Stream position, changes in the current speeds (leading to anomalous transport) or transport of warmer waters (anomalous heat content) or from all of them.



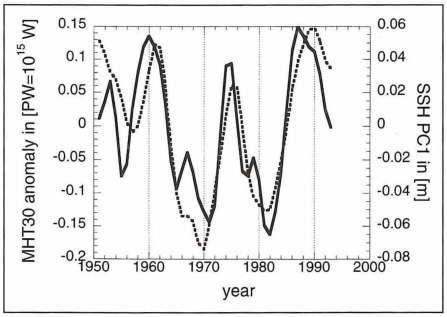
1a 1b

Fig. 1: EOF1 of SSH from (a) COADS experiment and from (b) NCEP experiment. Contour interval is 0.2 non-dimensional units, thick solid lines denote positive values, thin solid ones negative values.

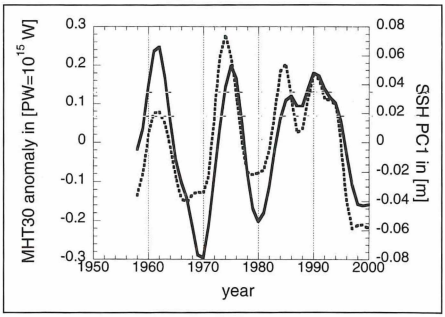
The principal coefficient (i.e. temporal coefficient) of the leading spatial pattern is depicted in Figs. 2a, 2b. A pronounced decadal low-frequency is present in the time series. The autocorrelation function of the SSH PC1 which can be used to determine whether any cyclic behavior is present, has minimum at +6–7 years suggesting a cyclically occurring phenomenon in the SSH variability.

At present nearly eight years of altimeter data, May 1992 to July 2000 (as monthly averages in a 1x1 degree grid) are available from the NASA Pathfinder project. The EOF1 from altimeter data for a shorter period of 1992–1998 is published in REVERDIN et al. (1999) which greatly resembles the figures 1. Extending the altimeter time series gives a slightly different pattern where the largest amplitude spans the central Atlantic suggesting that the EOF1 is not completely stable for shorter periods. To compare the model and altimeter data (for the same 100 months), EOF analysis has been done with linear detrending as before for the 43 year time series. The altimeter and model EOF1 are shown in Figs. 3a, 3b.

Both data sets display remarkably similar patterns, but there are some differences, e.g., compared to the altimeter data, the model lacks in amplitude in the eastern portion of the subpolar gyre. The time series (PCs) of the two EOFs are shown in Fig. 3c where the most prominent events are the reversals of the sign between the winters of 1995 and 1996 and between 1998 and 1999. The detrended data for this short record emphasizes high-frequency variability as expected from Ekman transport changes. Coinciding with the sign changes in SSH PC1 there were shifts in the winter NAO index (Nov-Apr average) from a positive phase (1995) to a strongly negative phase (1996) (characterized by weak Icelandic Low and weak Azores High), and an opposite shift between 1998 and 1999. It is unlikely that the local heating contributes to the SSH PC1 reversals, because the NAO associated heat flux (CAYAN, 1991) or the leading heat flux mode in the North Atlantic (HÄKKINEN, 1999) do not influence area where the SSH has the maximum amplitude.

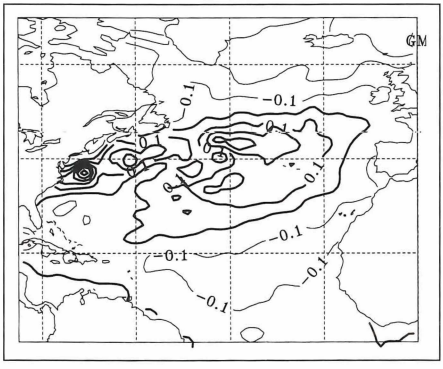


2a

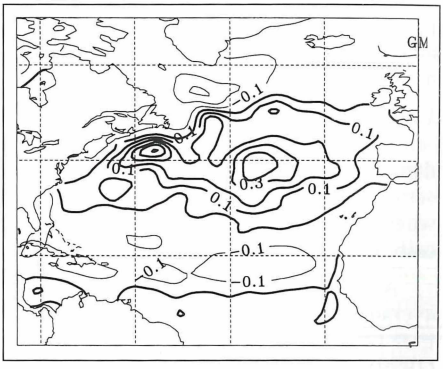


2b

Fig. 2: PC1 of SSH in units [m] (dotted) and detrended meridional heat transport anomaly at 30N in units [PW] (solid line) from COADS (a) and NCEP (b) experiments. The axis for PC1 on right and for meridional heat transport on left. All values are annual averages which are smoothed twice by a binomial filter retaining the end points with 50% weights.



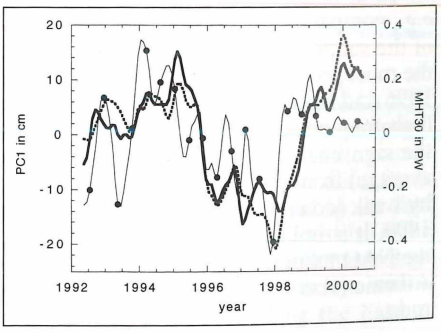
3a



3b

3c

Fig. 3: EOF1 of the sea surface height from TOPEX/Poseidon altimeter and from the model (using NCEP forcing anomalies) for period May 1992–July 2000: The altimeter (a) and model data (b) (both are detrended). EOF1 in non-dim. units, interval 0.1, thick solid lines denote positive values, thin solid ones negative values. (c) The corresponding PC1's of the sea surface height from TOPEX/Poseidon altimeter (thick solid) and from the model (dashed) along with the simulated meridional heat transport (MHT30) (thin line with dots). PC1 in units of cm, axis on the left and MHT30 in units of PW (petaWatts), axis on the right.



Figs. 2a, 2b and 3c show both the SSH PC1 and the corresponding meridional heat transport at 30N (= MHT30). It is apparent that the two quantities share the same variability and thus the SSH variations over the Gulf Stream could be considered as a signal of the overturning changes, a quantity that would be otherwise very difficult to measure.

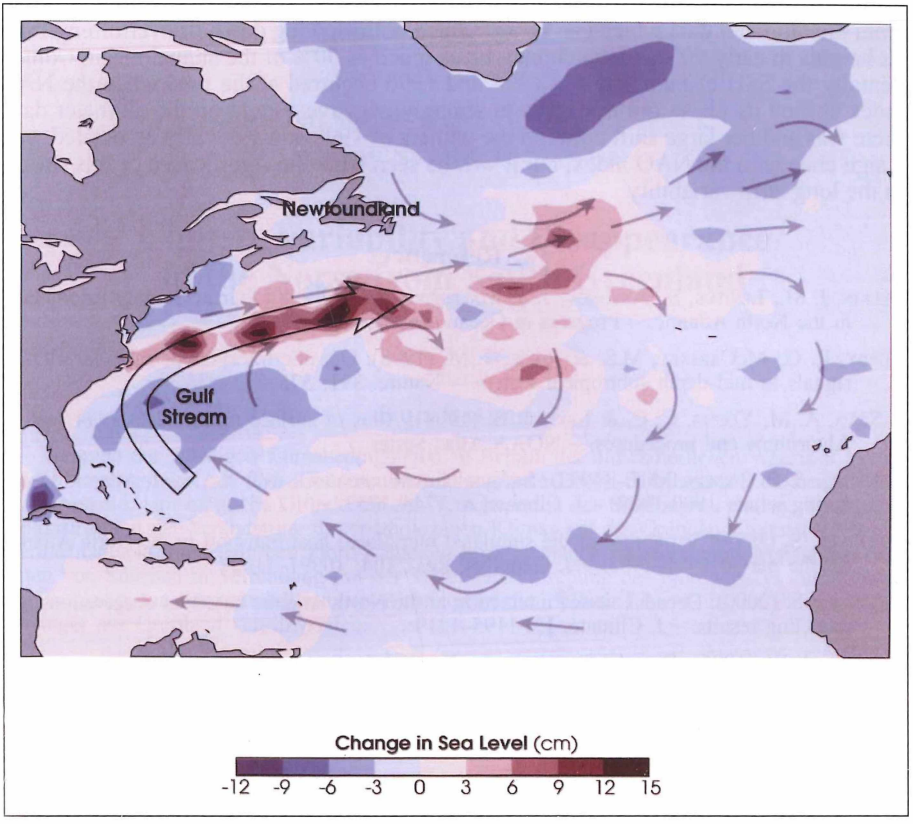


Fig. 4: The changes described by EOF analysis can be displayed by computing a difference between the late 1990's SSH and early 1990's difference: Sea level has increased along the Gulf Stream as a manifestation of increased oceanic heat content resulting from the intense overturning in the beginning of the 1990's.

3. Summary

Monthly atmospheric anomalies from COADS (1951–1993) and NCEP Reanalysis (1958–2000) are appended to a climatological surface forcing to produce numerical model hindcasts of the state of the North Atlantic (and Arctic) Ocean. Sea surface height variability is analyzed from ocean model simulations and from altimeter data because it reflects the distribution of heat content in the water column. It is reassuring that both simulations share similar leading SSH mode where the center of action is along the Gulf Stream and North Atlantic Current with opposite anomalies in the subpolar gyre.

A significant correlation between the time series of the SSH EOF1 and meridional heat transport provides a qualitative estimate of the state of overturning/meridional heat transport based on SSH. The time series of the leading mode is dominated by low-frequency variability which the model associates with decadal variations in the thermohaline circulation. The model results are interpreted that thermohaline circulation variations are manifested in the SSH/heat content in the Gulf Stream area and subpolar gyre.

There was a major SSH change in 1995–1996 as also reported by REVERDIN et al. 1999 from the altimeter data which can be associated with slowing down of overturning from its heights in early 90's and which may be as much as 30% of the annual mean. Coincidentally the SSH change between 1995 and 1996 occurred at the time when the NAO index shifted its phase from positive to strongly negative. Based on the altimeter data, there was another large shift between the winters of 1998 and 1999 also associated with a sign change in the NAO index, but it will be seen what the significance of this shift is in the long term variability.

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