Dynamic coupling between NAO and North Atlantic SSTA tripole

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Introduction

In the North Atlanitc region, the North Atlantic Oscillation (NAO) is the most prominent and recurrent pattern of atmospheric low-frequency variability (Fig. 1) (Walker and Bliss, 1932; Hurell 1995; Hurell et al 2003), and a tri-polar pattern dominates sea surface temperature anomaly (SSTA) in the ocean (Deser and Blackmon, 1993) . A NAO (or tripole) index can be defined according to the time series of the first EOF mode of sea level pressure anomaly (or SSTA) in the North Atlantic region. Observations showed that covarying patterns exist in the atmospheric and oceanic variability (Deser and Blackmon, 1993 ; Sutton and Allen, 1997). With the observed SSTA, a portion of the low-frequency variability of the NAO during the last decades can be reproduced (Rodwell, 1999). A positive feedback between a tri-polar North Atlantic SST anomaly pattern and the NAO may be responsible for this oceanic influence (Rodwell et al., 1999; Watanabe and Kimoto 2000; Robinson, 2000; Czaja and Frankignoul, 2002; Peng et al., 2003). However, given an extratropical warm SSTA, different GCMs may have different responses (Ting, 1991; Kushnir and Held, 1996; Peng and Robinson, 2001; Kushnir, 2002). The diversity of responses may be due to GCM's sensitivity to the characteristics of the climatological storm track and the locations of the SSTA relative to the storm track (Peng and Robinson, 2001).

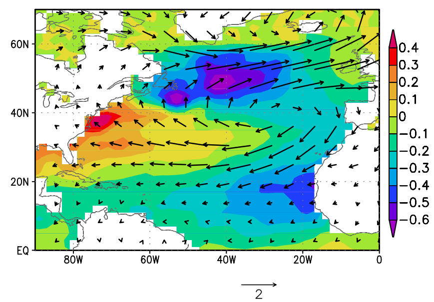

Fig. 1 Wind anomaly at 500 hpa regressed on the NAO index, and SSTA regressed on the tripole index. Units are m/s for wind and K for SSTA

Therefore, a new atmospheric model is used in this study (Pan, 2003; Jin et. al., 2005a, b, c; Pan et al., 2005). In this model, the climatological features of the storm track are characterized using observational data with no bias. We coupled this atmospheric model with an ocean mixed-layer model to investigate the air-sea interaction in the North Atlantic region.

Model

The atmospheric model is a five-layer linearized primitive equation model with SELF interaction. Using X to represent the variable group of vorticity, divergence, temperature and logarithm of surface pressure, the linearized equation for low-frequency variability $\bar{X}_a$, with transient eddy and mean flow interaction, can be symbolically written as:

$$L(\bar{X}_c)\bar{X}_a + L_D\bar{X}_a = f, \qquad (1)$$

here steady state is assumed because the time scale for atmosphere to reach steady state is much shorter than that for ocean. $\bar{X}_c$ represents the climatological basic state and L denotes the linear matrix related to the climatological basic state. $L_D\bar{X}_a$ is related to the interaction between transient eddy and low-frequency flow and L_D is SELF interaction operator. Here the climatological characteristics of the storm track variability are parameterized in terms of the spatial patterns, variances, decay time scales, and propagation speeds through the Complex Empirical Orthogonal Function (CEOF) analysis on the bandpass (2-8 days) data (Figs. 2). Based on that, L_D can be obtained through the dynamic equation of high-frequency anomaly. f represents forcing related to surface heat flux anomaly. Without $L_D\bar{X}_a$, equation (1) is the same as the normal linear baroclinic model.

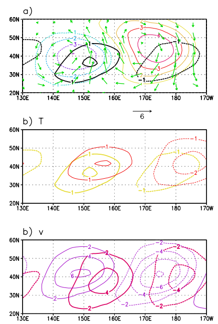

Fig. 2 Spatial structure of the real part of first CEOF. (a) surface pressure (color line), temperature (black line) and wind anomalies (arrow) at σ=0.8987. (b) temperature anomaly at the first layer (yellow line) and the third layer (thin line). (c meridional wind anomaly at first layer (red line) and the third layer (purple line). Units are hpa for pressure, K for temperature and m/s for meridional wind.

The ocean model is a mixed-layer model:

$$\frac{\partial T'_m}{\partial t} + L_o T'_m = F_{o1}(T'_m, \bar{X}_c, \bar{T}_m) + F_{o2}(\bar{X}_a, \bar{X}_c, \bar{T}_m) = \frac{\partial F_{o1}}{\partial T'_m}T'_m + \frac{\partial F_{o2}}{\partial \bar{X}_a}\bar{X}_a, \qquad (2)$$

$\bar{T}_m$ is climatological basic state of mixed-layer temperature, T'_m denotes mixed-layer temperature anomaly,and L_o represents linear matrix.

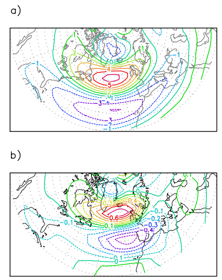

Fig. 3 Regressed pattern of zonal wind anomaly to NAO index at 500 hpa and (b) model simulated zonal wind anomaly associated with SSTA tripole pattern forcing. Units are m/s.

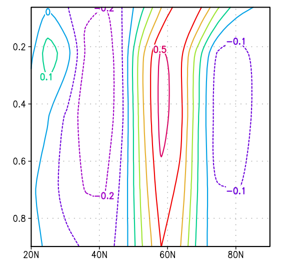

Fig.4 As in fig. 3 (b) but for latitude-height cross section at 45°W.

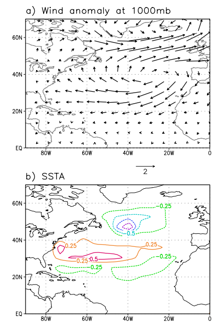

Fig. 5 (a) Regressed pattern of wind anomaly to NAO index and (b) mixed layer ocean temperature anomaly forced by NAO associated atmospheric anomaly. Units are (top) m/s per standard deviation of the NAO index time series and (bottom) K.

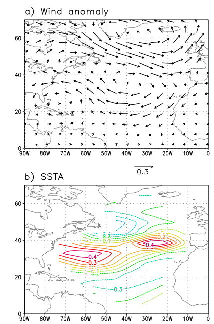

Fig. 6 Wind and SST anomalies of the leading mode in the coupled system. Units are m/s for wind and K for SSTA, respectively.

Results

The tripole-like SST anomalies can excite a NAO-like dipole with an equivalent barotropic structure in the atmospheric circulation (Figs. 3, 4), and the NAO-like atmospheric circulation anomalies can produce tripole-like SST anomalies in the North Atlantic (Fig. 5). The dominant mode of the coupled dynamic system has tripole-like SST anomalies in the ocean part and NAO-like circulations in the atmosphere part (Fig. 6). The SELF feedback plays essential role in the origin of this covarying pattern. Without SELF feedback, this covarying pattern can not exist.