ATMOSPHERE-OCEAN FEEDBACK PROCESSES IN THE NORTH ATLANTIC

Masahiro Watanabe *
Center for Climate System Research, University of Tokyo, Tokyo, Japan

1. INTRODUCTION

It is well known that the sea surface temperature (SST) variability in midlatitudes can be approximatedly modeled as an one-dimensional heat reseavoir driven by the stochastic atmosphere (e.g. Frankignoul 1985). On one hand, recent atmospheric general circulation model (AGCM) experiments show that the midlatitude SST anomalies have a weak, but significant impact on the atmospheric circulation (Rodwell et al. 1999, among others). A combination of the above two processes suggests a coupled feedback via the surface heat fluxes; if a SST anomaly, generated by specific atmospheric circulation anomalies, in turn effectively forces the initial circulation anomalies, it represents a positive feedback loop although the SST anomaly is in reality the subject to a local thermal damping.

The results presented below, based on Watanabe and Kimoto (2000b,2001), are motivated by the above question. We especially focused on the North Atlantic, and performed a series of coupled GCM and linear model experiments in order to elucidate the physics of the air-sea thermal coupling. Please refer to the above papers for more detail.

2. COUPLED GCM EXPERIMENTS

The model used here is a global AGCM developed at the Center for Climate System Research, referred to as the CCSR/NIES AGCM, coupled to a 50m motionless mixed layer ocean. The resolution of the model is T21, and integrated for 60yr with a flux correction to ensure the SST climatology close to observations.

In addition to the coupled run (CTL), two uncoupled experiments were conducted: one using SST climatology of CTL to force the AGCM, while another using daily SSTs of CTL. In these runs (called PS1 and PS2, respectively), the atmosphere drives another mixed layer ocean as in CTL. Prescribed and predicted SSTs in PS1 and PS2 are hereafter denoted as the 'forcing' and 'response' SSTs. Variances of monthly SST and 500hPa height (Z500) in CTL are generally larger than those in uncoupled runs, indicating a reduced thermal damping mechanism (cf. Barsugli and Battisti 1998) at work.

A principal mode of variability over the North Atlantic is identified using the singular value decomposition (SVD) between winter (DJF) SST and Z500 anomalies. A well-known set of the leading SVD patterns is detected in all the above integrations: the North Atlantic Oscillation (NAO)-like Z500 anomalies and a 'tripole' SST anomaly pattern. The result that such a leading mode was obtained even in PS1 confirms a primaly role of the atmospheric (i.e. NAO's) forcing of the ocean (i.e. tripole SST anomalies). On the other hand, the 'forcing' and 'respone' SST anomalies in PS2 reveal high coherence in low freqency timescales, suggesting that the SST anomalies also affect the temporal behavior of the atmosphere. To detect a SST forcing pattern which is the most effective in exciting the NAO-like atmospheric anomalies, we replicated the SVD analysis but using three variables of the Z500, forcing and response SST anomalies in PS2. The leading patterns for Z500 and response SST anomalies are quite similar to the conventional counterpart, namely, the NAO and tripole anomalies. Interestingly, the forcing SST anomalies associated with them represent a monopole pattern around 40N, having the same polarity as the central portion of the tripole. This mode is, in a statistical sense, quite robust and thus suggests that the following feedback works; the NAO drives the tripole SST anomalies while the midlatitude part of the tripole in turn enhances the NAO. We confirmed that the SST anomaly pattern shown as the forcing SST anomalies of the above SVD mode can excite the NAO-like circulation anomalies using nine-member ensemble of the AGCM experiments.

* *Corresponding author address:* Masahiro Watanabe, CCSR, Univ. of Tokyo, 4-6-1 Komaba, Meguro, Tokyo 153-8904; e-mail: hiro@ccsr.u-tokyo.ac.jp

3. POSITIVE FEEDBACK LOOP

The above results suggest a positive thermal feedback between the NAO and tripole SST anomalies. To further examine the possibility of the positive feedback, we carefully looked at the surface flux and precipitation fields in CTL and PS2. In most part of the North Atlantic, heat flux anomalies associated with the SVD mode tend to force the SST tripole, consistent with the atmospheric

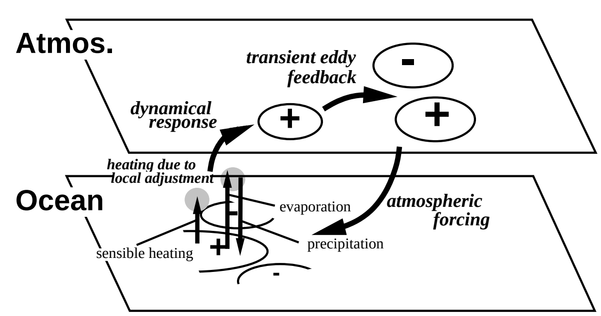

Fig. 1 Schematic showing the positive feedback loop between the NAO-like anomalies and the tripole SST anomaly pattern.

driving of the ocean. However, we found a positive latent and sensible flux anomalies over the positive forcing SST anomalies around 40N, indicating an opposite sense. A richer precipitation also occurs at the same region, which implies an enhanced local recycling of the water vapor as reported by Rodwell et al. (1999). Note that the positive heat flux anomalies force the atmosphere as well as damp the SST anomaly itself.

It has been argued that transient eddy feedback may be crucial in understanding the atmospheric response to midlatitude SST anomalies. Therefore, how the anomalous heat flux excites the NAO was investigated using an iterative calculation of a linear baroclinic model in a similar manner to Peng and Whitaker (1999). Namely,

a. compute steady atmospheric response to a prescribed heating,
b. evaluate transient eddy feedback in response to the circulation change induced by the heating,
c. compute steady atmospheric response to the transient eddy feedback.

The process b. was implemented with the so-called storm track model, following Branstator (1995). A basic state for both the steady linear model and storm track model was employed by the winter climatology in CTL. The steady response to an idealized heating which mimics the heating anomaly in PS2 reveals downstream positive height anomalies, which lead to a northward deflection of the storm track.

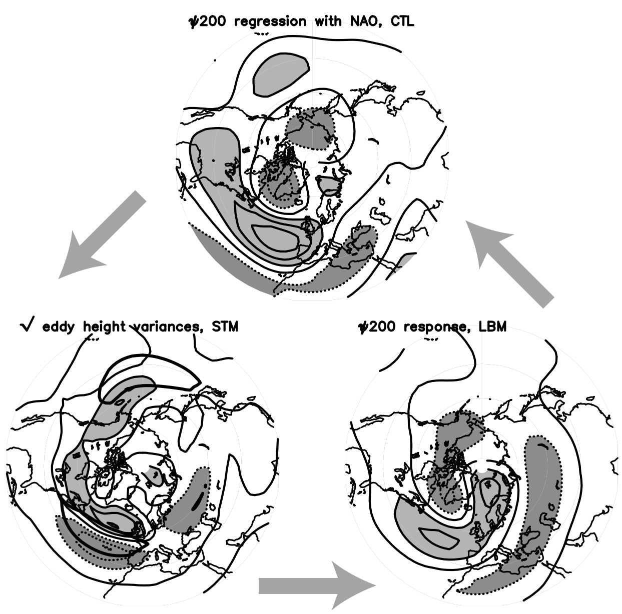

Fig. 2 (upper) NAO anomalies in CTL as shown by the 200 hPa stream function regressed on the leading Z500 EOF. (left) Change in the storm track activity in response to the NAO, obtained by the storm track model. The thick contour denotes a position of the mean storm track. (right) Steady 200 hPa stream function response to the heat and vorticity forcing due to transient eddy anomalies as shown in the left panel. Note that the contour interval is one-fifth of the upper panel.

The secondary response to the deflected storm track more resembles the NAO.

The results described above are summarized in Fig. 1, showing the positive NAO-tripole SST feedback. Since the interaction between the heat-induced atmospheric anomalies and storm track is nonlinear, it would be difficult to compare the magnitude with the negative feedback for SST anomalies due to local damping, having the timescale of several months. However, the amplitude of the NAO excited by the SST anomaly is much smaller than that internally generated in the atmosphere. It thus seems that the positive feedback presented here cannot overcome the local thermal damping, i.e. the midlatitude atmosphere-ocean system is hardly unstable.

Using the linear models, we could also show a positive feedback between the model NAO and the storm track, as displayed in Fig. 2. This may explain in part why the NAO dominates in the free atmosphere, but as emphasized by Branstator (1995), not all the circulation anomaly patterns show such a feedback. Thus it is conceivable that the heat-induced anomalies must project well on to the NAO in order for the positive NAO-tripole SST feedback at work.

4. REMARKS FOR EXTENDED PREDICTABILITY

Since both the NAO and tripole SST anomalies are only prevailing in winter, the positive feedback works at maximum during the wintertime. The SST anomalies may disappaer until summer due to stong local damping. On the other hand, reports have been made that a part of tripole produced in winter can be preserved below the summer mixed layer, and reappear in the following winter (Alexander and Deser 1995; Watanabe and Kimoto 2000a). If such a 'reemergence' process is coupled with the positive air-sea feedback, we may be able to expect that the climate predictability can be extended beyond a year by giving accurate subsurface conditions. We are currently investigating such a possibility using a coupled model.

References

Alexander, M. A., and C. Deser, 1995: *J.Phys.Oceanogr.*, **25**, 122-137.

Barsugli, J. J., and D. S. Battisti, 1998: *J.Atmos.Sci.*, **55**, 477-493.

Branstator, G., 1995: *J.Atmos.Sci.*, **52**, 207-226.

Frankignoul, C., 1985: *Rev.Geophys.*, **23**, 357-390.

Peng, S., and J. S. Whitaker, 1999: *J.Climate*, **12**, 1393-1408.

Rodwell, M. J., D. P. Rowell, and C. K. Folland, 1999: *Nature*, **398**, 320-323.

Watanabe, M., and M. Kimoto, 2000a: *J.Climate*, **13**, 3017-3028.

Watanabe, M., and M. Kimoto, 2000b: *Q.J.R.Meteorol.Soc.*, **126**, 3343-3369.

Watanabe, M., and M. Kimoto, 2001: *Q.J.R.Meteorol.Soc.*, **127**, 733-734.