East Asian climate during ENSO simulated by a linear model with interacting convection

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1 Introduction

It is well known that the El Niño–Southern Oscillation (ENSO) phenomenon has a global impact on the atmospheric general circulation. During the mature phase of ENSO, which is locked in boreal winter, convective activity tends to be enhanced over the central equatorial Pacific while suppressed over the western Pacific near Philippines. Associated with the latter, it has been reported that anticyclonic anomalies appear in the low–level circulation over the east of Philippines (Wang et al. 2000), which may be considered to link ENSO with milder winter over Japan. In this study, we attempt to investigate processes which generate and maintain the convection and circulation anomalies over the western Pacific and East Asia, using a linear dynamical model.

While linearized atmospheric models, in particular linear baroclinic models, are a useful tool to diagnose how the atmosphere responds to a forcing (Hoskins and Karoly 1981; Held et al. 1989 , among others), the forcing, anomalous diabatic heating in many cases, has been prescribed in most of the linear model diagnoses except for theoretical CISK studies (e.g. Hayashi 1971; Stevens and Lindzen 1978). However, convective activity which causes the anomalous diabatic heating is itself driven by the atmospheric circulation. Taking the above argument that constrains a relationship between the dynamics and cumulus convection into account, we incorporated interacting moist processes of the convection and surface heat fluxes into the linear baroclinic model in order to examine the anomalous climate over East Asia associated with ENSO. In the following sections, a brief description of the model is given, then results of the model diagnoses are presented.

2 Model

The model used here consists of primitive equations linearized about the winter (DJF) climatology obtained from the NCEP reanalysis. It has a horizontal resolution of T21 and vertical 20 levels. Details of the model formulation are given in Watanabe and Kimoto (2000). To obtain the linear atmospheric response to forcing, we adopt a time integration method in this study. An extention of the linear model which includes an interacting convection is symbolically explained as follows.

A linearized form of the primitive equations is written as

$$d_t\mathsf{X} + \mathsf{L}\mathsf{X} = \mathsf{F} \quad , \tag{1}$$

where X is a vector containing perturbations $(\ )'$ for prognostic variables, i.e., $\mathsf{X} \equiv \mathsf{X}(\zeta', D', T', \ln Ps')$, while F and L denote a prescribed forcing and linear dynamical operator, respectively. When we consider the forcing solely due to anomalous cumulus convection, Eq. (1) can be solved with a given diabatic heating as F (referred to as the conventional linear model). The forcing F, which is a function of both X and a SST anomaly T_s', may be decomposed into two components, $\mathsf{F}_i(\mathsf{X})$ and $\mathsf{F}_e(T_s')$ ('i' and 'e' stand for internal and external, respectively). Then Eq. (1) is modified as

$$d_t\mathsf{X} + (\mathsf{L} - \mathsf{F}_i)\mathsf{X} = \mathsf{F}_e \quad . \tag{2}$$

This equation indicates that the heating due to anomalous convection is internally determined such as to satisfy a constraint between large–scale circulation and the convective anomaly. Note that X in Eq. (2) now includes perturbation in the specific humidity q'. In the linear model represented by Eq. (2) (referred to as the moist linear model), a forcing F_e is composed by terms in linearized surface Bulk fluxes that depend on T_s' and the basic state but not on the perturbation X.

The convection in the moist linear model is actually calculated by a linearized Betts–Miller scheme (Neelin and Yu 1994) with some modifications. Both for the conventional and moist linear models, the time integration is continued up to 30 days, while the responses at day 15 are only shown because the response approaches steady state after day 10.

3 Results of linear model experiments

The anomalous forcing to the atmosphere during ENSO was first identified by composites for observed winter OLR and SST anomalies based on the Niño 3 SST time series (difference between 5 El Niños and 6 La Niñas). The SST composite shows a large warming in the eastern equatorial Pacific with the maximum of about 3K, and additionally weak warming (cooling) in the Indian Ocean (western Pacific). The eastern Pacific warming is associated with a negative OLR anomaly over the central equatorial Pacific, which is known as a heat source for Rossby waves emanating to the North Pacific/North America. The OLR composite also reveals a positive anomaly near Philippines that accompanies a low–level, anticyclonic circulation anomalies as visible in the corresponding 850 hPa wind and stream function (ψ) composites (Fig. 1a).

To examine whether the enhanced convection near the dateline can generate the anticyclonic anomalies, the conventional linear model was integrated with a heating estimated from the negative OLR anomalies over the central Pacific (cf. Reed and Recker 1971). The low–level response, however, does not indicate the anticyclonic signals over Philippines (not shown). On the other hand, they are successfully reproduced when the in–situ diabatic cooling due to suppressed convection was incorporated into the forcing (Fig. 1b). This implies that the western Pacific anticyclone owes its presence to the convective activity suppressed over Philippines. An important question is; how and why the convection is suppressed? Referring to the SST anomaly pattern during ENSO, there may be, at least, three possibilities, namely, the weakened convection occurs due to (1) SST warming in the eastern equatorial Pacific, (2) in–situ negative SST anomalies, and (3) SST anomalies outside of the Pacific. The moist linear model experiments are the most relevant to answer this question.

As for the first hypothesis, one may simply expect that the ascending motion over the central Pacific accompanies a descent over the western Pacific through change in the Walker circulation. Alternatively, a low–level, equatorward horizontal flow associated with the Rossby waves excited to the west of the heating is compensated by a downward motion due to the Sverdrup balance, thus the convection may be suppressed over the western Pacific. However, the moist model driven only by the eastern Pacific SST anomalies captures neither the suppressed convection nor the anticyclone over

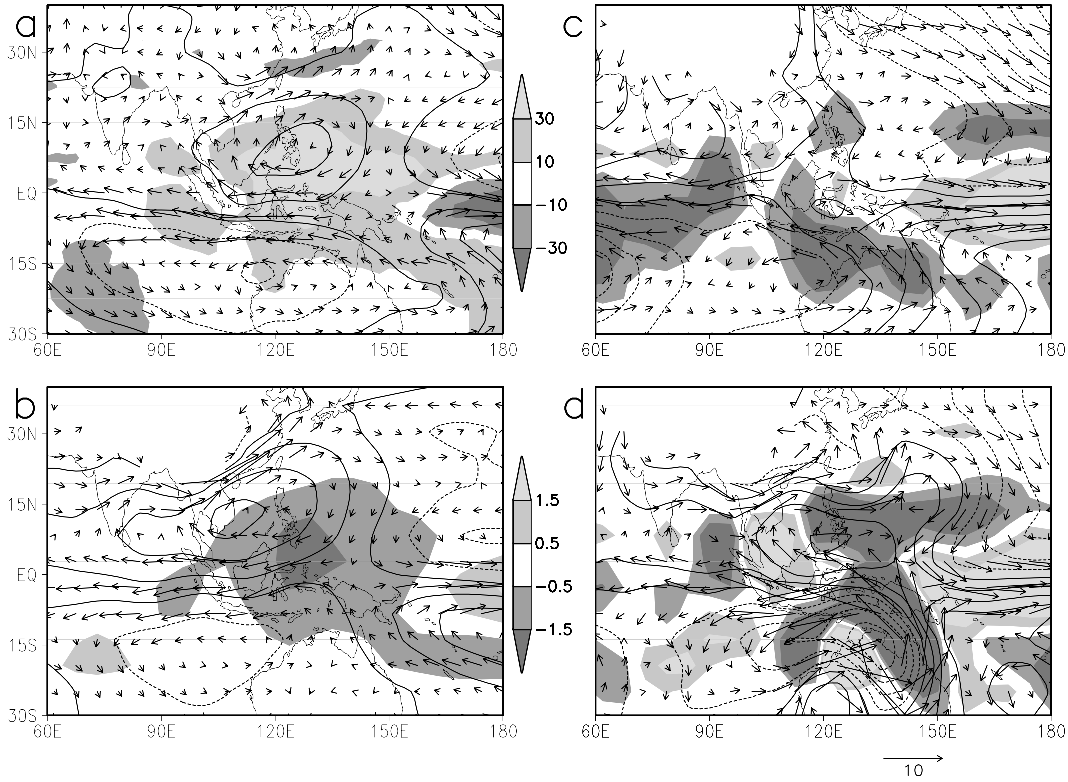

Fig.1 (a) Observed composite of winter OLR (shading), 850 hPa wind (vector) and ψ (contour) anomalies for EL Niño. The unit for OLR is W m^{-2} while the contour interval for ψ is 2×10^6 m^2 s^{-1}. (b) Vertically averaged heating (shading) and 850 hPa wind and ψ in the conventional linear model at day 15. The unit for the heating is K day^{-1}. (c) As in (b) but for the response in the moist linear model with given El Niño SST anomalies only in the central eastern Pacific. (d) As in (b) but for the response in the moist linear model with SST anomalies in the whole tropics. Note that the heating in (c)–(d) is internally computed in the model.

Philippines (Fig. 1c), indicating that the above hypothesis does not work in reality. Interestingly, the observed anomalous features (Fig. 1a) is well reproduced by the moist linear model driven by the ENSO SST anomalies in the whole tropics (Fig. 1d). We confirmed that a modest warming (<1K) of the Indian Ocean is the major source of the difference between Figs. 1c and 1d.

By comparing the anomalous Walker circulation in the moist linear model diagnoses, processes found in this study are schematically illustrated in Fig. 2, which shows an anomalous Walker circulation with and without the Indian Ocean warming. When El Niño does not accompany the warming in the Indian Ocean, the central Pacific is only the ascending blanch and the convection over the western Pacific is not strongly suppressed (upper panel). A concurrence of the Indian Ocean warming, however, induces another ascent and the convection hold between the two ascending blanches is now considerably weakened (lower panel). Although we cannot mention details, it turned out that the in–situ SST cooling and associated wind–evaporation feedback work to strengthen the convective cooling hence anticyclonic anomalies over Philippines, consistent with Wang et al.'s (2000) results.

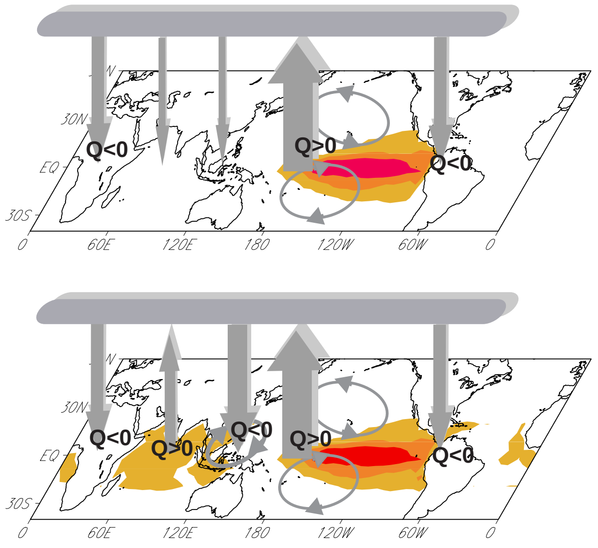

Fig.2 Schematic showing the importance of the Indian Ocean warming in suppressing the convection over the western Pacific.

4 Conclusions

We developed a linear baroclinic model which allows a convective interaction with dynamics, and applied it to examine the mechanism responsible for a set of weaker convection and low–level anticyclonic circulation anomalies over Philippines, both observed during ENSO. It was found that the warming in the Indian Ocean, which is accompanied with ENSO, is of importance for them since the Indian Ocean warming modifies the structure of the anomalous Walker circulation. While the cause of the Indian Ocean warming is beyond the scope of this work, it may be explained by a radiative warming induced by El Niño (Lau and Nath 2000). We need to elaborate the mechanism of the coupling between El Niño and the Indian Ocean warming.

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