Roles of the SST and Land-Sea Heat Contrast in the Onset of the South Asian Summer Monsoon

Rosbintarti Kartika Lestari[1) and Toshiki Iwasaki[1)

(1: Graduate School of Science, Tohoku University)

Department of Geophysics, Graduate School of Science, Tohoku University, Aramaki-Aoba, Sendai, Japan 980-5578. Email: kartika@wind.geophys.tohoku.ac.jp

Abstract

1. Introduction

It has been recognized that the solar heating forms the land-sea heat contrast between the Eurasian continent and the Indian Ocean, and triggers of the Asian summer monsoon onset. The land-sea heat contrast induces heat low over the continent and westerly geostrophically in the surrounding coastal region (Yanai et al, 1992; Ueda and Yasunari, 1998; Minoura et al, 2003).

Except for the land-sea heat contrast, the other studies mentioned the influence of the SST on the Asian summer monsoon. Murakami and Wang (1992) showed that the high SST in the Indian Ocean enhances the Asian summer monsoon westerly. The similar conclusions were obtained by the some previous studies, e.g. Shukla (1975) and Yamazaki (1988).

In the present study, we separately the influences of the SST and the land-sea heat contrast on the onset of the South Asian summer monsoon by using global model, GSM T63L40. One experiment is the fixed SST run where the model is run from April 1st until June 30th for five cases under the SST fixed on April 1st. Hereafter, we refer this experiment as the SST fixed run. Another is the solar fixed run, where the model is run from April 1st until June 30th for five cases under the solar condition fixed on April 1st.

2. Model

We use a T63L40 version of the Global Spectral Model which is in operation for long-range forescasts at Japan Meteorological Agency (JMA). Spectral triangular 63 (T63) truncation is a roughly equivalent to the resolution 1.875 x 1.875 degrees latitude-longitude grids. There are 40 unevenly spaced hybrid levels from the surface to 1 hPa. The orography is truncated at the model's spectral T63 horizontal resolution. Parameterization schemes for radiative processes are described by Sugi et al. (1990) and the cloud diagnostic scheme is modified by Iwasaki and Kitagawa (1998). An economical version is implemented (Arakawa - Schubert scheme, 1974; Moorthi and Suarez, 1992; Randall and Pan, 1993).

3. Results

3.1. Performance of the control run

The model is run for five years from the initial condition of the global objective analysis of Japan Meteorological Agency (JMA) on January 1st, 2000 with the climatological monthly mean SST data. The results are referred as the control run and compared with the NCEP/NCAR reanalysis data for the low-level wind field and the CMAP for the precipitation (not shown). Both the NCEP (Fig.1 upper panel) and the GSM (Fig.1 lower panel) show that the easterly in April (Fig.1 left panels) drastically changes to be westerly in June (Fig.1 right panels). It indicates that the low-level wind of the GSM can describe the onset of the Asian summer monsoon well. On the other hand, in comparison with the CMAP data, the precipitation performance of the GSM has some climatic errors, e.g. GSM tends to take double ITCZ (not shown).

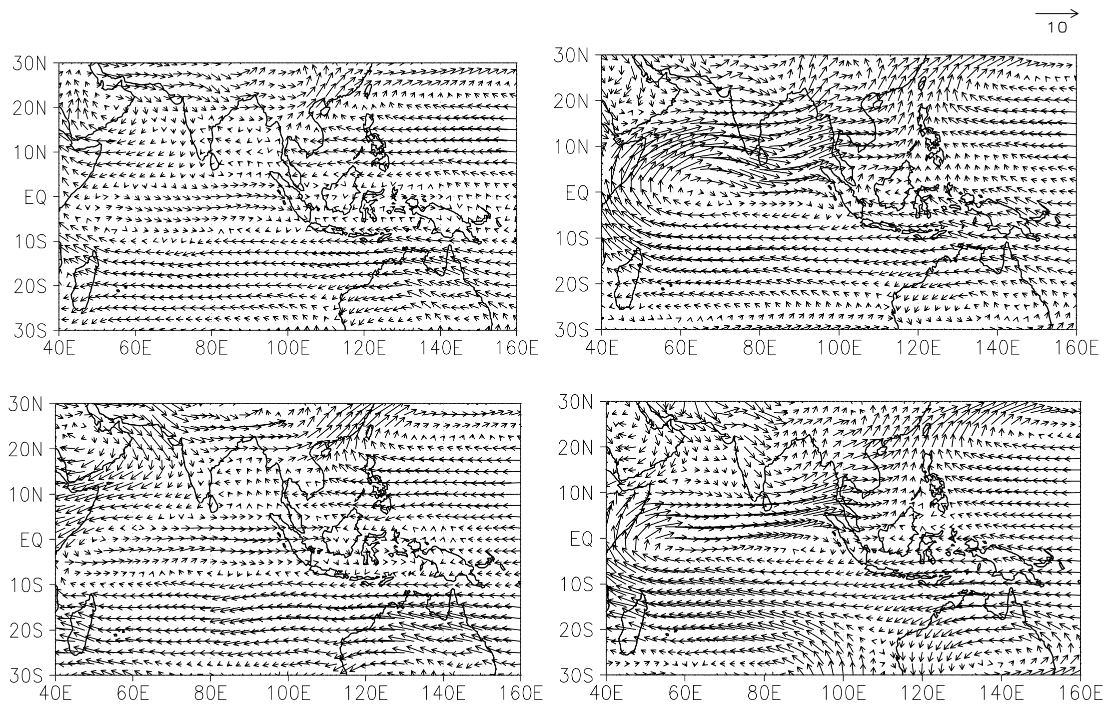

Fig.1. Wind fields at 850 hPa of the NCEP/NCAR reanalysis (upper panels) averaging over 10 years from 1990 to 1999 and the GSM (lower panels) averaging over five model years, in April (left panels) and June (right panels). Wind speed is indicated by an arrow above the panel in the unit of m/sec.

3.2. Impact studies

Our experiment shows that the SST fixed run (the solar fixed run) decreases the surface air temperature over the ocean (continent) in the northern hemisphere and increases it over the ocean (continent) in the southern hemisphere, respectively. Both of the SST fixed run and the solar fixed run change the mean sea level pressure (MSLP), in which the northern-hemispheric MSLP is increased and the southern-hemispheric MSLP is decreased (not shown). The change in the MSLP trough of the SST fixed run weakens the southern-hemispheric trade wind, cross equatorial northward flow in the east off the Africa (Somali jet) and Indian monsoonal westerly. The reduction of the Indian monsoonal westerly seems to suppress the South Asian summer monsoon, as depicted in Fig.2 (left panel). The solar fixed run reduces the land-sea thermal difference, weakens the low-level wind surrounding the Eurasian continent and suppresses the Indian monsoonal westerly, as shown in Fig.2 (right panel).

Fig.3. shows the impacts on the precipitation. The impact of the SST fixed run on the precipitation over the ocean is very different from that of the solar fixed run, although the two similarly reduce the precipitation around the monsoon Asia. The SST fixed run considerably suppresses the ITCZ jump from the southern hemisphere to the northern hemisphere in June. On the other hand, the solar fixed run increases the precipitation around the equatorial Indian Ocean and the western maritime continent regions, but decreases it in the northern hemisphere (Fig.3 right panel).

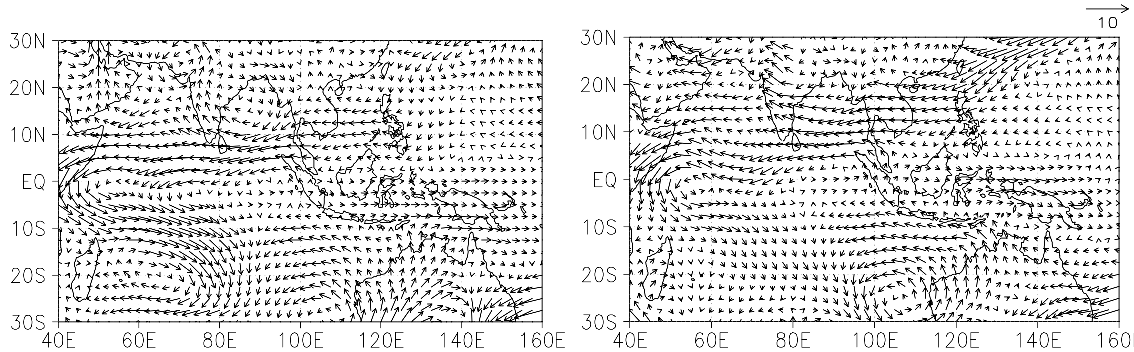

Fig.2. Impacts on the 850 hPa wind field in June. The left panel is the difference between the SST fixed run and the control run, and the right panel is the one between the solar fixed run and the control run, averaging over five cases. Wind field is indicated by an arrow above the panel in the unit of m/sec.

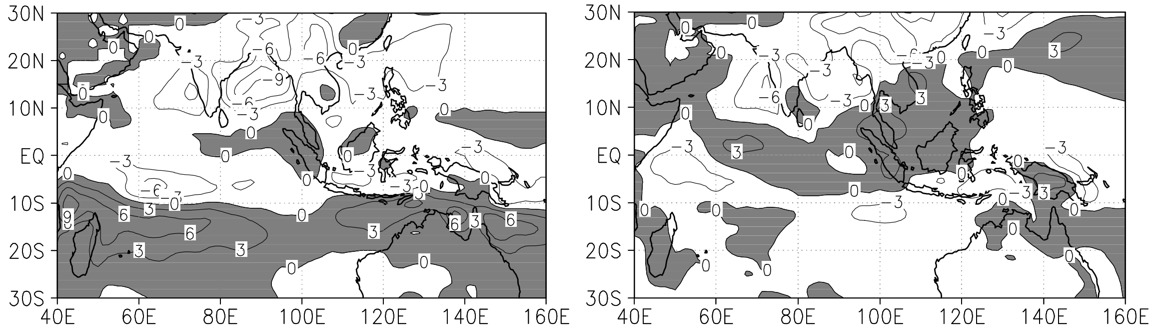

Fig.3. Impacts on the precipitation in June. The left panel is the differences between the SST fixed run and the control run, and the right panel is the one between the solar fixed run and the control run. The data is averaged over five cases. The contour intervals are 3 mm/day and the regions of positive difference are shaded.

4. Discussions

As shown in the left panel of Fig.3, in the SST fixed run, the ITCZ tends to stay in the southern hemisphere in June. It probably suppresses the Hadley circulation that exerts eastward acceleration in the summer hemisphere and enhances westerly in the South Asian summer monsoon. In order to observe this mechanism, we consider the zonal momentum equation for the low-level wind in an equatorial β -plane,

$$\frac{\partial u}{\partial t} \approx \left(f - \frac{\partial \bar{u}}{\partial y}\right)\bar{v} - k\bar{u}, \qquad (1)$$

where u, v, y, f ($=\beta y$) and k represent zonal wind speed, meridional wind speed, latitudinal distance, Coriolis and friction, respectively.

Derivation of Eq.(1) under the assumptions of steady states $\frac{\partial \bar{u}}{\partial t} = 0$ and constant meridional velocity $\bar{v}$,

results in:

$$\bar{u} \approx \frac{\beta y}{k}\bar{v}, \quad \text{for} \quad \frac{ky}{\bar{v}} >> 1, \qquad (2)$$

where k is constant.

The Eq.(2) indicates that the frictional forcing zonal mean low-level westerly almost balances with the Coriolis force due to the mean-meridional wind away from the equator ($|y| >> \bar{v}/k$). This solution explains that the low level wind becomes easterly in the winter hemisphere and westerly in the summer hemisphere.

Return to the model result, it is confirmed that the SST fixed run suppresses the Hadley circulation (Fig.4 left panel.) because of the decrease of the northern-hemispheric cumulus convection, ITCZ (Fig.3. left panel.). The weakening of the Hadley circulation corresponds to the weakening of southerly. Then, according to the Eq.(2), the weakening of southerly ($\Delta\bar{v} < 0$) induces easterly anomaly ($\Delta\bar{u} < 0$) in the low latitude of the northern hemisphere (Fig.4. right panel). The easterly anomaly in the northern hemisphere indicates the weakening of the Indian monsoonal westerly. It indicates the suppression of the South Asian summer monsoon.

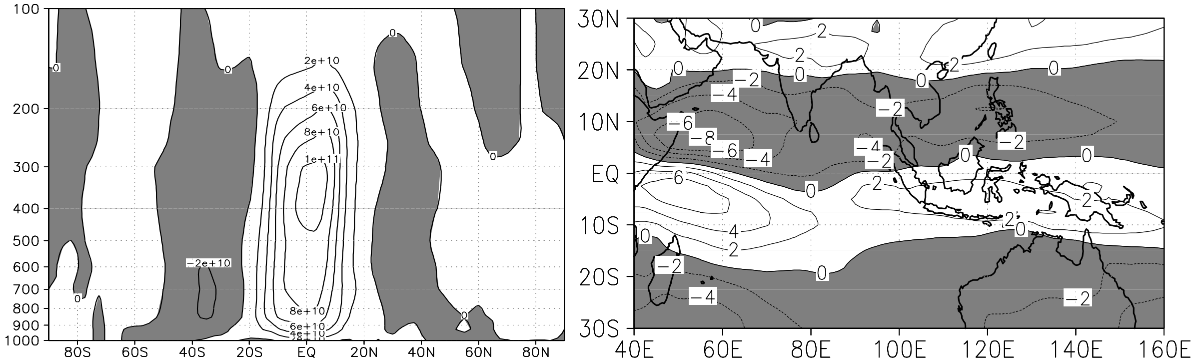

Fig.4. Meridional wind circulation (left) and time-averaged zonal wind speed (right) differences between the SST fixed run and the control run (SST fixed – control) in June of GSM T63L40. The data are averaged over five cases. The regions with the negative difference are shaded.

The solar fixed run directly weakens the South Asian summer monsoon. The Asian monsoon westerly is strong in June when the land-sea heat contrast between the Eurasian continent and the Indian Ocean is large (not shown). The solar fixed run reduces the land-sea heat contrast and suppresses the heat low over the Eurasian continent. Therefore, the low-level wind surrounding the Eurasian continent is geostrophically weakened (not shown).

5. Conclusions

We confirmed that the seasonal marches of the SST and land-sea heat contrast contribute to the Asian summer monsoon onset by the same order of magnitude. The SST has an indirect impact on the strengthening of the South Asian summer monsoon. The SST controls the seasonal march of the ITCZ jump between the southern and northern hemispheres, strengthens the Hadley circulation, and then enhances the monsoon westerly. The land-sea heat contrast has a direct impact on the activation of the South Asian summer monsoon. The strong land-sea thermal difference in June induces the low level wind surrounding the Eurasian continent. Therefore, the Asian monsoon westerly is strengthened.

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