ROLE OF TROPICAL/EXTRA-TROPICAL INTERACTIONS ON THE MONSOON/ATMOSPHERE-OCEAN SYSTEM (MAOS) IN THE TROPICS

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1. INTRODUCTION

The ENSO and the interanual variability of the Asian monsoon system has been identified as a modulation of a coupled land/ atmosphere/ocean system (MAOS) in the Asian monsoon region through the Indian and Pacific Ocean sector of the tropics, with basically a biennial cycle (Meehl, 1987; Yasunari, 1990; Yasunari and Seki, 1992; Webster and Yang, 1992 etc.). In this oscillation of the system, the Asian summer monsoon seems to have an active role on producing the anomalous state of the sytem. The seasonal evolution of one anomalous state of each monsoon year (Yasunari, 1991) starts in northern late winter through spring. In this paper, it is shown that the tropical/extratropical interactions in the northern hemisphere in different seasons contribute to initiate and change one anomalous state to another, through the modulation of northern winter monoon surges and the subtropical high, which may be closely related to land/atmosphere interaction over the continent.

2. THE MONSOON YEAR AND THE BIENNIAL CYCLE

The interanuual variability of MAOS tends to have a seasonal phase locking with the starting of one anomalous state in northern spring and the evolution of anomaly toward later seasons with the mature phase in winter (Yasunari, 1991). The one unit climatic year was named as "monsoon year" by Yasunari (1991), since the anomalous state is tightly linked with that of the Asian summer monsoon. Figure 1 shows one typical example of seasonal evolution of SST anomaly in the equatorial Pacific, which is closely associated with the anomaly of the Indian summer monsoon activity. Interestingly, correlations of monthly evolution of precipitation anomaly over the Indian monsoon region to seasonal total precipitation, SOI and snowcover over Eurasia (Table 1) shows that the interannual signals of monsoon rainfall come mostly from the later months (August, September) of the season rather than the early monsoon months (June, July). This suggests that some positive feedback process (mostly by the atmosphere/ocean interaction over the Pacific/Indian Ocean) is involved in the seasonal evolution of the monsoon activity itself (Meehl, 1987; 1993).

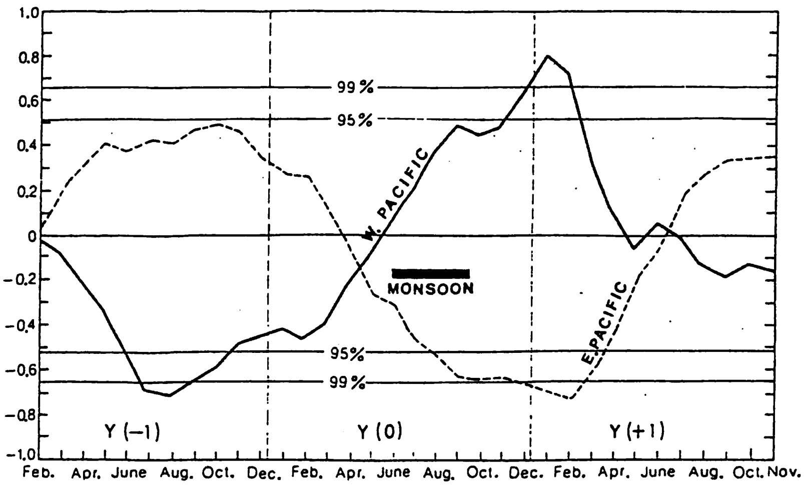

Figure 1. Lag-correlations between Indian Monsoon rainfall and sea surface temperature in the western (0° - 8°N, 130°E-150°E) and the eastern (0°-8°N, 170°W-150°W) Pacific. The reference monsoon season is shown with thick black bar. Y(0) denotes the year of reference monsoon and Y(-1) (Y(+1)) denotes the year before (after) the reference monsoon year. (Yasunari, 1990)

	AIMR	SOI	SNOW
JUNE	0.62	0.28	-0.41
JULY	0.67	0.21	-0.56*
AUG.	0.73	0.41**	-0.39
SEP.	0.83	0.51**	-0.49

Table 1. Correlations of monthly evolution of precipitation anomaly over the Indian monsoon region to seasonal total precipitation, SOI and snowcover over Eurasia .

This nature of the anomaly evolution of MAOS, inevitably, shows a biennial oscillation of the system, in which the anomaly tends to change its sign around the end of one monsoon year, e.g., in spring. The ENSO cyle or event is manifested as an amplification of this biennial oscillation, though it, at times, is modulated considerably to longer time-scale cycle (Tomita and Yasunari, 1992).

This paper focuses on the processes how the anomalous state of MAOS is changed from one sate to another in the northern late winter to spring.

3. ROLE OF MAOS ON THE EXTRATROPICAL CIRCULATION

The role of the Asian summer monsoon on the interannual variability of the MAOS was comprehensively described in Yasunari (1990) and Yasunari and Seki (1992). A strong (weak) summer monsoon over India and southeast Asia tends to precondition a La Nina (El Nino) like condition over the equatorial Pacific in the succeeding autumn and winter with strong (weak) atmospheric east-west circulation over there. Associated with this strong (weak) state of MAOS, the atmospheric circulation in the extra-tropics changes considerably.

Figure 2 shows the result of time-lag correlation between the Indian monsoon rainfall index (IMR) and the teleconnection patterns deduced by the rotated EOF analysis of the seasonal mean 500 hpa anomaly field in the northern hemisphere. This diagram shows that in summer so-called PNA (and PNA-2) pattern significantly appear concurrently with the anomalous IMR. That is, with a strong (weak) Indian monsoon, + (-)PNA with - (+)PNA-2 is dominant, which implies that ovet the north Pacific through north America more zonal (meandering) flow is apparent. In autumn and winter after the strong (weak) Indian monsoon the WP (Western Pacific) pattern is dominated over east Asia through north Pacific with positive (negative) sign, which correspond to the height anomaly pattern positive (negative) in the north and negative (positive) in the south.

Figure 3 shows a more general feature of the anomalous circulation in December after the strong/weak Indian monsoon, which strongly suggests that the strong (weak) state of MAOS produces more zonal (meridional) flow over the western hemisphere and more meridional (zonal) flow over the eastern hemisphere. These anomalous seasonal circulation particularly over the north Pacific through north America is supposed to be forced by heating in the tropics associated with the anomalous state of MAOS.

The +(-) WP pattern is well identified as an index of strong (weak) winter monsoon cold surge over east Asia. That is to say, a strong (weak) summer monsoon in south/southeast Asia tends to be followed by the strong (weak) winter monsoon over east Asia. This signature in the eastern Pacific seems to be very important for changing the state of MAOS, or the biennial monsoon year cycle as shown in Figure 1.

4. ROLE OF EXTRATROPICAL FORCING ON MAOS

In the northern spring, when the interannual signals in the MAOS, as identified by SST anomaly or SOI, is weakest among the seasons (as shown in

WINTER→SPRING→SUMMER→AUTUMN→WINTER→SPRING

Indian Monsoon Rainfall

↕

STRONG E-ASIAN MONSOON

↕

⇒ -EP* ⇒ +PNA ⇒ +WP** ⇒ +WP** ⇒ +EP** ⇒

-PNA-2 + PNA-2

← 1 Monsoon Year →

Figure 2. Lag-correlation between IMR and teleconnection patterns.

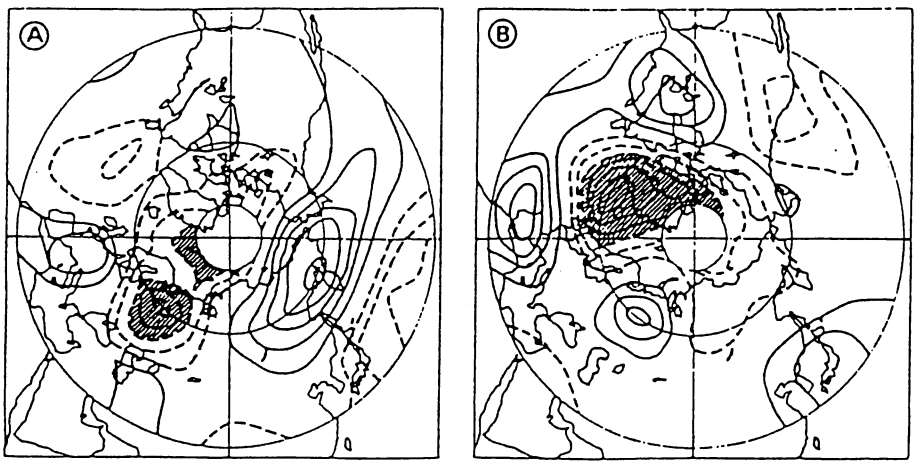

Figure 3. Composite anomalies of 500 mb geopotential height for December of (a) strong monsoon year and (b) weak monsoon year. Contours are 10 gpm and negative values are shown with dashed lines.
(Yasunari and Seki, 1992)

Figure 1). However, in the extratropics and subtropics, some significant anomalies appear both in the atmosphere and oceans. Lag correlations beteen the SST anomaly in the north Pacific in spring (March to May) and IMR anomaly in the following summer proved that a large area of positive correlations is noticeable in the subtropical western Pacific to the south of Japan islands, which implies that warmer (colder) SST anomaly is significant in spring immediately before the strong (weak) Asian summer monsoon. In contrast, in the warm water pool region of the equatorial western Pacific, negative correlations are remarkable.

This anomalous SST pattern in the north Pacific seems to be consisitent with the dominant concurrent appearance of EP (Eastern Pacific) pattern in the atomsopheric circulation as shown in Figure 2. In spring prior to the strong (weak) monsoon, -(+)EP pattern is dominant with negative (positive) height anomaly over the Aleutian Low area and positive (negative) height anomaly over the subtropical high area. This negative pattern, for example, represents the stronger subtropical high with intensified mid-latitude westerly flow, which seems to correspond well with the SST anomalies mentioned above. The negative SST anomaly in the equatorial western Pacific in this case may be due to stronger easterly trade winds.associated with stronger subtropical high. The overall feature in the SST anmaly pattern is already apparent in the preceding winter. Namely, the high-index type circulation with more zonal westerly flow over the east Asia through the north Pacific in winter seems to be responsible for the stronger subtropical high with stronger trade wind in spring. This anomalous circulation is, in fact, favorable for producing warmer SST anomalies over the western Pacific, through the anticyclonic surface wind stress curl over there.

We should keep in mind that the overall atmospheric circulation in winter to spring mentioned above correpond to weak or mild winter monsoon over the east Asia and the western Pacific, which is just oppsite to the same season after the strong summer monsoon. Here, a basic mechanism of the biennial nature of the MAOS has been offered, based upon the tropical/extratropical interaction over the east Asia and the north Pacific.

The SST to the south of Japan and in the South China Sea in winter , thus, seems to be a good predictor for the following summer monsoon activity, or the state of MAOS. Fig. 4 shows the time series of the SST anomaly in winter averaged over this area (Tomita, 1994). It is noticeable in this diagram that the negative (positive) extreme anomalies signal weak (strong or normal) summer monsoons. This correspondency seems to be better in the neagative extreme cases.

Another predictor of the Asian summer monsoon widely discussed is the Eurasian snowcover in winter or spring (Hahn and Shukla, 1976; Dickson, 1984; Dey and Bhanukumar, 1983; Morinaga and Yasunari, 1992). The atmospheric circulation responsible for the snowcover anomaly is the low-index type ciruculation over the central/western Siberia with the extended trough over central Asia (Morinaga and Yasunari, 1987), which is also noted in Figure 3. That is, the low-index circuation over the eastern hemisphere, which frequently appear after the strong summer monsoon as mentioned in section 3, is mostly responsible both for the Eurasian snowcover and the intensity of the circulation

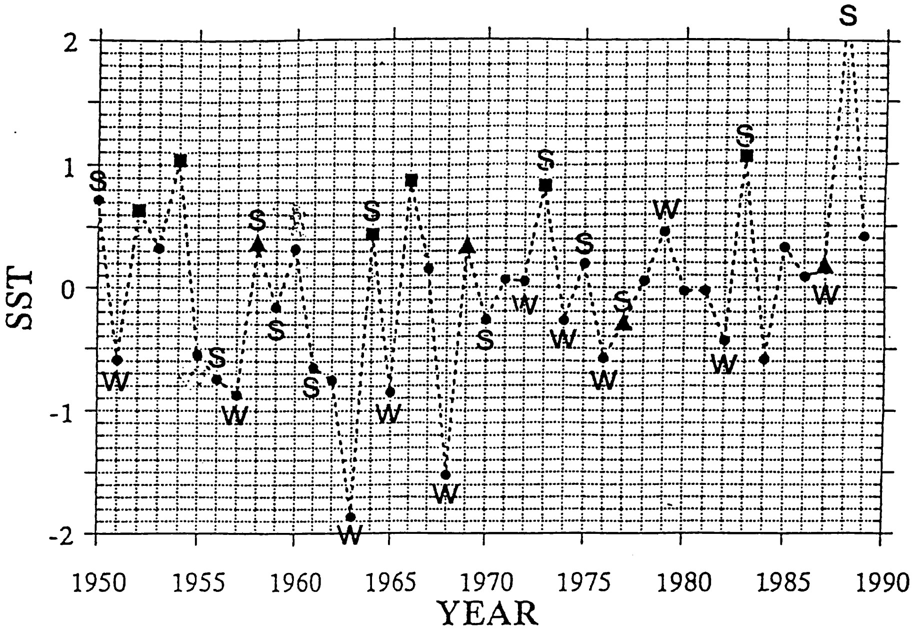

Figure 4. Time series of the normalized SST anomalies in the northern winter in South China Sea and the ocean region south of Japan. Weak (strong)Indian monsoon year is indicated with W(S).

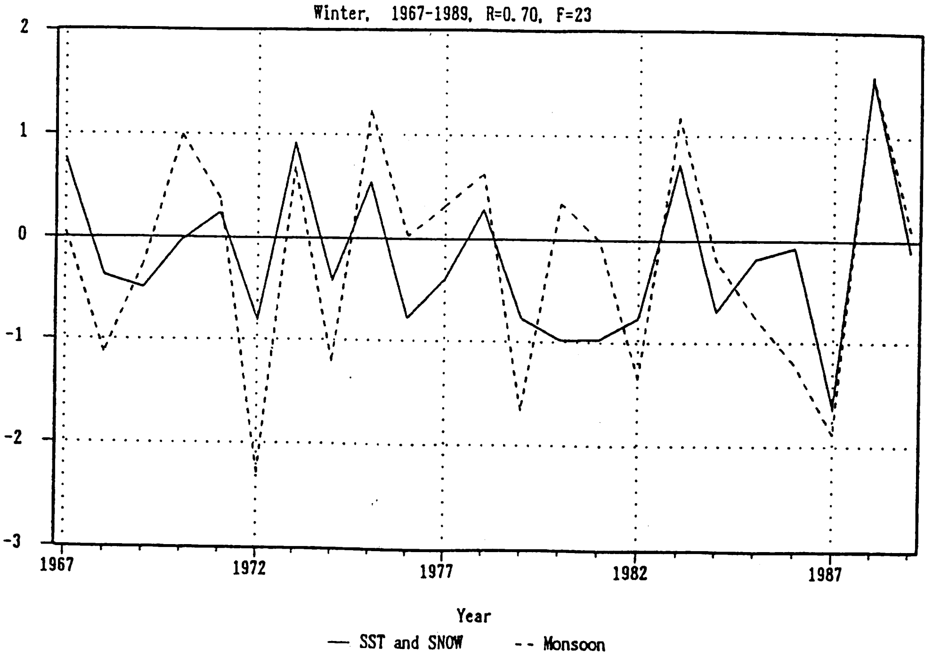

Figure 5. Reconstructed IMR anomaly (solid line) by the linear multiple regression of SST in South China Sea (Dec.-Feb.) and snowcover in Eurasia(April), and observed IMR anomaly (dashed line). IMR anomalies are normalized.

over the Pacific, though the chaotic nature of westerly flow regime in winter seems to disturb or modify relative importance of these two predictors. Finally, a series of the IMR anomaly is constructed as shown in Figure 5 by the linear multiple regression of these two predictors, though these two predictors are supposed to be, at least partly, dependent each other.

5. SUMMARY AND DISCUSSION

The interannual variability of MAOS, i.e., a coupled climate system with the Asiân monsoon and the atmosphere/ocean system in the tropical Pacific and Indian Ocean sector, shows a significant seasonal phase lock, with the initiation of one anomalous state in the norther spring, evolution from the Asian summer monsoon season with the mature phase in the winter monsoon season (or Australian summer monsoon season) and rapid decay to late winter and the next spring. Yasunari (1991) defined this unit climate year as the "monsoon year".

This seasonal evolution of MAOS involves a considerably large forcing to the extratropical flow regime, through the stationary Rossby wave propagation particularly over the north Pacific through the north American sector. One anomalous state with strong (weak) Asian summer monsoon and La Nina (El Nino) type condition produces a contrastive circulation pattern in the succeeding northern autumn through winter.; high (low)-index regime in the western hemisphere and the low (high)-index regime in the eastern hemisphere (over Eurasia and east Asia). The spatial distribution of anomalous heating in the tropical Pacific region may chiefly be responsible for this flow regime in the northern hemisphere. One prominent feature of this monsoon year cycle is that a strong (weak) Asian summer monsoon tends to produce a strong (weak) winter monsoon over east Asia.

The anomalous flow regime in the northern extratropics thus produced, in turn, affects MAOS in late winter and spring, basically through the modulation of the subtropical high over the Pacific and the snowcover (and possibly soil moisture) anomaly over Eurasia. The ample evidence has been shown that the anomalous westerly flow, cold surge from the continent, and trade wind intensity dynamically changes the SST anomaly over the western Pacific through the surface wind stress curl and Ekman pumping mechanism.

Another mechanism is a thermal effect of the Eurasian snowcover, which may affect the seasonal land/ocean heating contrast (and possibly controls the seasonal evolution of the subtropical high). Another adhoc effect of the low-index type circulation over the central Asia may be an equatorward propagations of wave energy flux to the Indian Ocean area, which sometimes trigger large-scale equatorial disturbances (Hoskins et al. , 1990). In the winters of 1991/92 and 1992/93, the disturbances of this type seem to have an essential role on the initiation of the ENSO event by accompanying the westerly wind bursts over the western Pacific.

The dynamical, thermo-dynamical and hydrological effect of winter monsoon surge and land surface conditions over Eurasia to the evolution of the anomalous state of MAOS need to be assessed further in detail. The forthcoming GEWEX Asian Monsoon Experiment (GAME) is expected from these points of view.

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