Summer Monsoon Variability over South and East Asia: Understanding Tele-connections through NCEP/NCAR Reanalysis data

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INTRODUCTION

The authors have extensively used the Reanalysis data sets to examine the monsoon variability over South and East Asia vis-à-vis the Soviet snow depth, satellite derived snow cover (Kripalani et. al., 2002, 2003; Kim et. al., 2002)), El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole Mode (IODM: Kripalani et. al. 2004, 2005, 2008; Kulkarni et. al., 2007) and evaluating coupled climate simulations under IPCC AR4 (Kripalani et. al. 2007a, b). The above studies reveal that the NCEP/NCAR data sets are consistent with all the above independent data sets. Here we demonstrate the usefulness of the Reanalysis data sets in bringing out the delayed impact of the IODM (over the South Asian domain) on the East Asian Summer Monsoon.

INDIAN OCEAN DIPOLE MODE AND MONSOON VARIABILITY

Saji et. al. (1999) identified a unique ocean-atmosphere mode over the Indian Ocean, with anomalous warm sea surface temperatures (SSTs) over the western Indian Ocean and anomalous cool SSTs in the eastern Indian Ocean. They termed this phenomenon as the positive phase of the Indian Ocean Dipole Mode, which develops in boreal summer and peaks in autumn. This mode has been associated with climate and monsoon variability over India, Sri Lanka, East Africa, Australia and other parts of the globe. Most of these studies have focused on the simultaneous relationship between the Indian Ocean and the monsoon variability on the countries surrounding the rim of the Indian Ocean. However, Kripalani et. al. (2005) have shown that the positive phase of this mode enhances summer monsoon activity over China, but suppresses monsoon activity over the Korea-Japan sector, 3 to 4 seasons later. The relationship is more consistent and stronger over the remote Korea-Japan region than over China or even India. They speculated that the memory for delayed impact, 3 to 4 seasons later, could be carried by the surface boundary conditions of the Eurasian snow cover and/or the SSTs through the Indonesian Through-Flow sector. Guan and Yamagata (2003) have explained the simultaneous IODM induced circulation changes over East Asia during the positive event of 1994 through these two channels. However such delayed impact 3 to 4 seasons later has not yet been reported. Hence the primary focus here is to examine possible mechanism scenarios of the delayed IODM impact on East Asian monsoon with the help of NCEP/NCAR data.

DATA

Following data sets have been used:

(i) The historical Soviet snow depth data product (Kripalani and Kulkarni 1999) for the 1961-1995 period
(ii) NCEP/NCAR Reanaysis data sets (Kalnay et al. 1996) for the 850 hPa vector winds and the sea surface

temperature for the 1958-2000 period

(iii) An index to quantify the IODM has been proposed by Saji et al. (1999). This is the difference in SST anomaly between the tropical western Indian Ocean and the tropical Southeast Indian Ocean and is denoted as Dipole Mode Index (DMI). Based on this index the years 1961, 1963, 1967, 1972, 1982, 1983, 1991, 1994, 1997 and 2000 are identified as extreme positive events and the years 1964, 1973, 1974, 1980, 1981, 1984, 1989, 1992, 1996 and 1998 are identified as extreme negative events

RELATION: SOVIET SNOW DEPTH AND DIPOLE MODE

During the period 1961-1995, 8 positive and 8 negative IODM events are identified (see DATA section). The composite snow depth differences between these two sets of extreme dipole events during the following winter and spring are determined (Fig.1). Significant positive snow anomalies indicating heavy snow are noted north of Korea-Japan (50^0-70^0 N, 120^0-140^0 E) in particular during the spring season. This suggests that the IODM plays a dominant role in the winter and spring snow distribution over the Eurasian region. In particular the positive phase of the dipole during summer / autumn induces heavy snow during the following winter / spring over eastern Eurasia north of Korea-Japan peninsula.

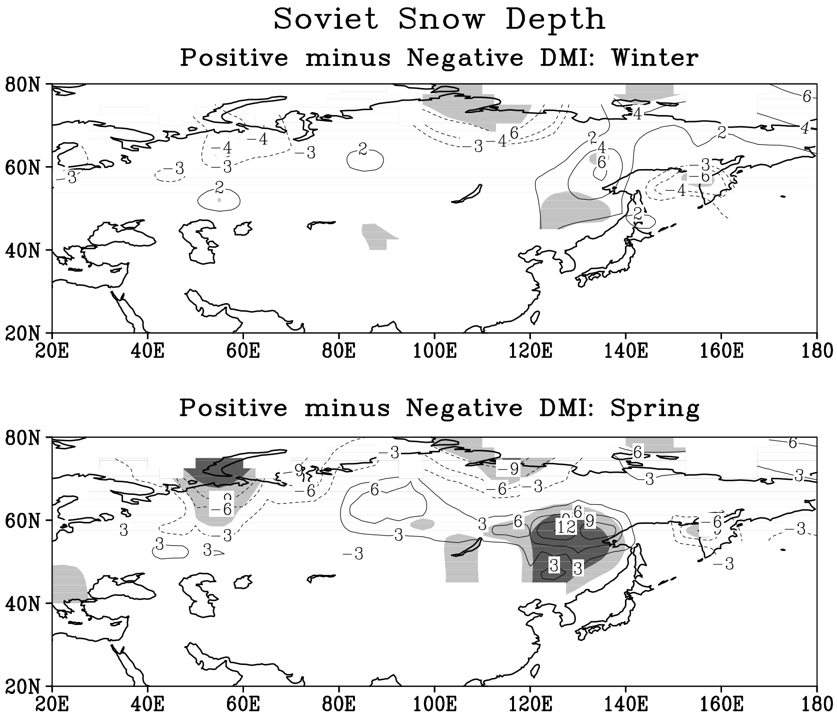

Figure 1: Composite snow depth anomalies in cm for the positive minus negative dipole events for winter (upper panel) and spring (lower panel)

NORTHERN CHANNEL: CIRCULATION ASSOCIATED WITH EXTREME SNOW DEPTH

Extreme winter and spring seasons with heavy snow (years 1962, 1970, 1978, 1979, 1980: standardized snow depth for these years during winter= +1.6, during spring= +1.1) and light snow (years 1961, 1963, 1966, 1973, 1987; standardized snow depth for these years: winter= -1.5, during spring= -0.6) over the region 50^0-70^0 N, 120^0-140^0 E are identified. To examine the impact of eastern Eurasia snow, composite differences for the 850 hPa vector winds during summer for the 5 extreme snow events are computed (Fig. 2). Composite differences are prepared for heavy minus light snow events.

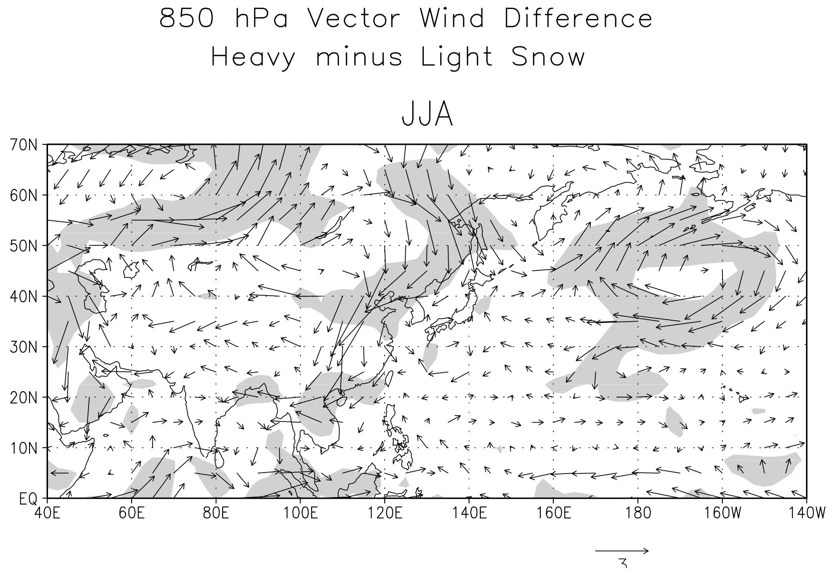

Figure 2: Composite differences for the 850 hPa vector winds for summer season following the extreme snow depth events (heavy minus light snow over eastern Eurasia). Gray shading illustrates the areas of significance at 95 % confidence level determined from two-tailed Student's t-test.

Fig. 2 clearly depicts the China-Korea-Japan sector under the influence of significant anomalous northerly flow (100^0-140^0 E) bringing in dry air. These mid-latitude northerlies even penetrate up to 10^0 N weakening the cross-equatorial flow / low level jet resulting in the shift of the North Pacific Subtropical High (NPSH) eastward with its western edge around 170^0 E. Thus the dry anomalous northerlies and the weak southerlies from the Pacific will cut off moisture supply towards the South China-Korea-Japan sector leading to below normal rainfall activity, consistent with the relationships obtained above.

SOUTHERN CHANNEL: INDONESIAN THROUGH-FLOW SECTOR

The delayed impact through the southern channel is ascertained by examining the seasonal evolution of the SST fields from autumn through to summer. The SST anomaly patterns for the positive minus negative dipole index are illustrated in Fig.3 for autumn and winter and in Fig. 4 during spring and summer. Anomalous warming over the western Indian Ocean and cooling over the southeast Indian Ocean displays the positive phase of the dipole mode. On the other hand the positive anomalies over the equatorial central and eastern Pacific Ocean depict the warm phase (El Nino) of the ENSO phenomenon (Fig. 3 upper panel). During winter (Fig.3 lower panel) the warming over the western Indian Ocean only prevails south of the equator, while El Nino conditions still prevail over the Pacific. During spring (Fig. 4 upper panel) significant positive anomalies over the Indian Ocean, west Pacific and along the China coast prevail. El Nino over the Pacific has collapsed. A season later (summer: Fig.4

lower panel) significant positive anomalies prevail over west and north Pacific. The significant positive (negative) anomalies over the western (central) Pacific indicate the development of the La Nina phase. Positive SST anomalies over the west and north may have resulted in the displacement of the NPSH northeastwards. This La Nina phase is also not conducive for monsoon rainfall over Korea-Japan. Thus as the season's progress from autumn to summer the areas of significant positive SST anomalies shift from the western Indian Ocean to the eastern Indian Ocean to west Pacific and finally to the north Pacific. The Indonesian Through-Flow acts as a gateway for the SSTs over the eastern IO and west Pacific to interact. Thus SSTs have carried the memory.

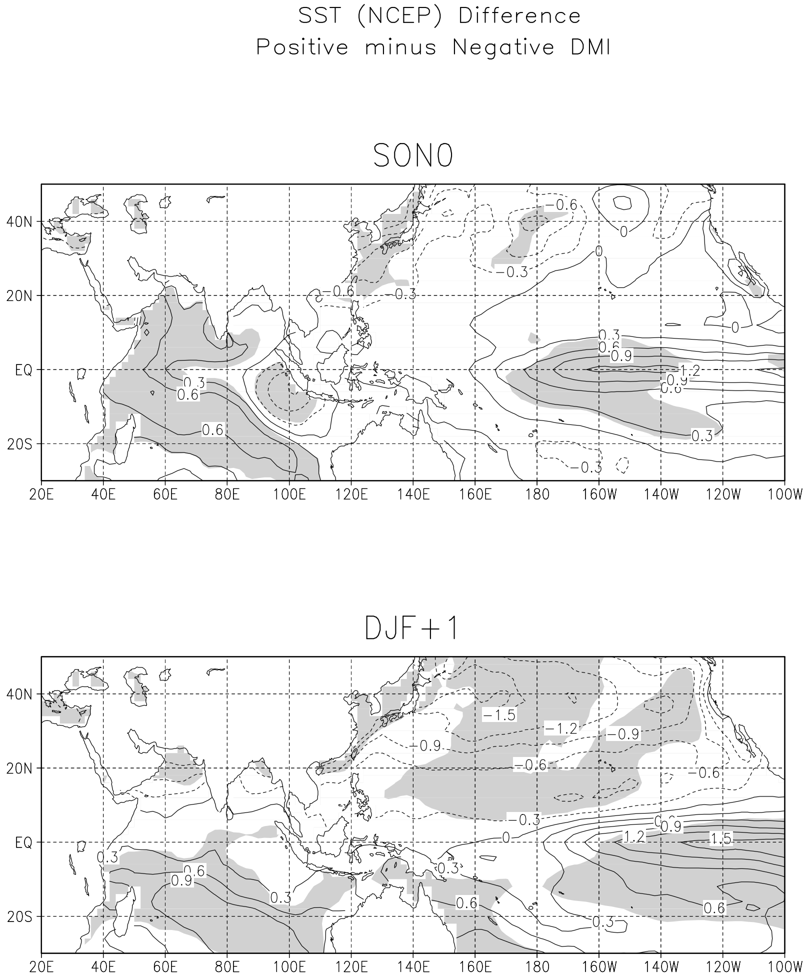

Figure 3: Composite SST anomalies in ^{0}C during autumn (SON0) and winter (DJF+1) associated with the positive minus negative phase of the dipole mode. Continuous (dashed) contours indicate positive (negative) anomalies. Shading illustrates the areas of significance at 95 % confidence level determined from two-tailed Student's t-test.

SUMMARY

This study has identified possible mechanisms for the delayed impact of the dipole mode on the summer monsoon rainfall over the Korea-Japan sector. The positive phase of the dipole mode during autumn induces heavy snow just north of Korea-Japan during the following winter / spring. This results in an anomalous northerly flow which transports cold and dry air from north towards Korea-Japan and neighborhood. This results in the shift of the NPSH northeastwards, weakening the cross-equatorial flow / low level jet at its western periphery. This inhibits water vapor from the Pacific towards South China and the Korea-Japan sector. The net result is less precipitation over South China and Korea-Japan. The delayed impact 3 seasons later is carried by the snow distribution over Eurasia.

The influence of the SSTs associated with the dipole mode over the Indian Ocean is carried to the Pacific via the Indonesian Through-Flow as the season's progress from autumn through the following summer. As the seasons progress from autumn through summer the positive dipole mode over the Indian Ocean and the El Nino over the Pacific transforms into a weak negative dipole over the Indian Ocean and the La Nina phase over the Pacific. La Nina is also not favorable for monsoon activity over Korea-Japan. The delayed impact here is carried by the SSTs.

Thus the seasonal evolution from autumn through to summer of the NCEP/NCAR Reanalysis fields clearly brings out the remote tele-connections.

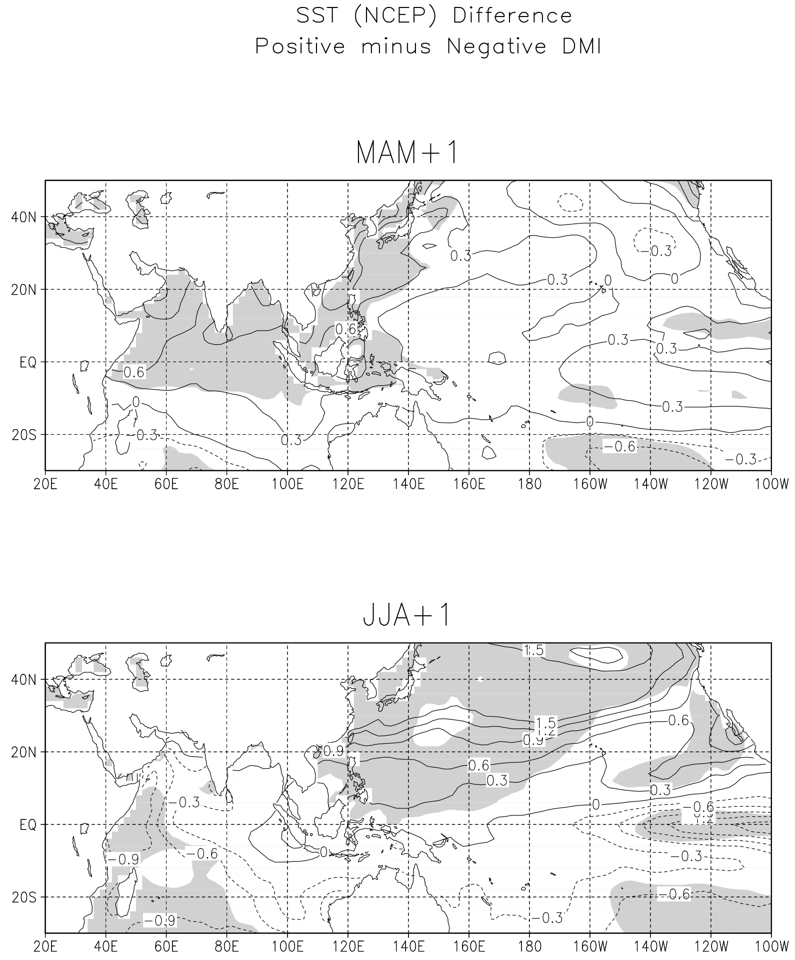

Figure 4: Same as Figure 3 but for spring (MAM+1) and summer (JJA+1)

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