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Reappraisal of Relationships between Historical Soviet Daily Snow Depth and Asian Summer Monsoon Circulation and Rainfall

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1. Introduction

Several observational and modeling studies have shown that there is an inverse relationship between the extent of Eurasian snow cover in the preceding season and strength of Indian summer monsoon rainfall (ISMR). Studies of Hahn and Shukla (1976), Dickson (1984) and Sankar-Rao et al. (1996) based on observed data are some of the examples. Also Kripalani & Kulkarni (1999) using Historical Soviet Daily Snow Depth (HSDSD) version I data for the period 1881-1985 found that wintertime snow depth over the west Eurasia surrounding the Moscow shows a significant negative relationship with following ISMR whereas, that over the eastern Eurasia in central Siberia has significant positive relationship with ISMR. Bamzai and Shukla (1999) found that ISMR had the highest correlation of -0.63 with the western Eurasia snow cover whereas it was -0.34 with the snow over the whole of Eurasia. The winter and spring snow covers over the southern Eurasia and the Himalayas have high interannual variability but are poorly correlated with the subsequent ISMR. Recently a detailed study on the relationship between number of days of snow of varying depths over different parts of Eurasia with ISMR was carried out by Dash et al. (2003a). In this study, the evolution of midlatitude circulation features such as temperature, wind and velocity potential in response to number of days of snow of varying depths over the Eurasia in winter/spring has been examined. Analysis of the characteristics of atmospheric circulation during two contrasting years of high(low) winter/spring snow depth followed by deficient(excess) monsoon rain over India was conducted in order to identify the signal of excess or deficient monsoon rainfall a season in advance (Dash et al. 2003b). The above two studies show that there is a complete phase reversal in the dipole structure of the upper tropospheric velocity potential anomaly from the deficient to excess ISMR.

In the present study, based on Soviet snow data and rainfall data of India Meteorological Department (IMD) during the period 1951-1994, two years have been identified with low Eurasian snow followed by excess ISMR and three years have been identified with high snow followed by deficient ISMR. It has been verified that in these years, there are no significant influence of the Pacific and Indian Ocean SST. The difference fields of temperature, wind and velocity potential between the above two groups of extreme cases have been examined with a view to study the relationship between the Eurasian snow, midlatitude circulation and the Indian summer monsoon circulation features.

2. Selection of contrasting Snow Years

ISMR data from June to September for the period 1881-1994 from Parthasarthy et al. (1995) have been used in classifying the excess, normal and deficient rain years. We have also used NCEP/NCAR reanalysed data for the period 1948-1994 which include temperature, wind, velocity potential, stream function and geopotential fields at upper and lower atmospheric levels. A detailed description of the reanalysed data has been given by Kalnay et al. (1996). The HSDSD version-II data set provides a long-term climatological data (1881-1995) and updates and replaces the original HSDSD version 1 data set that was previously available from National Snow and Ice Data Center (NSIDC) on CDROM. Using the seasonal DJF snow depth data for the years 1951-1994, mean values for each year over the western Eurasia are computed and the mean of the series and the standard deviations are also calculated. The snow depth of each year for the period 1951-1994 is expressed as a standardised snow depth anomaly by dividing the departure of each year from normal by standard deviation. The years having snow depth anomaly between ±0.5 standard deviations are considered as normal snow years. Similarly the years having snow depth anomaly equal to or above +0.5 standard deviation are taken as high snow years and those having equal to or less than -0.5 standard deviation snow depth anomaly are identified as low snow years. Based on this criterion it is found that the years 1951, 1952, 1954, 1955, 1960, 1961, 1962, 1963, 1964, 1971, 1972, 1973, 1975, 1977, 1980, 1983 and 1988 are low snow years and 1957, 1966, 1968, 1974, 1976, 1979, 1981, 1982, 1985, 1986, 1987, 1989, 1993 and 1994 are high snow years. Rest of the years in the period 1951 to 1994 had normal snow depth anomaly.

Similarly the years having ISMR anomaly more than or equal to +1 standard deviation are termed as excess monsoon years and those less than or equal to −1 standard deviation are considered deficient monsoon years. The years having ISMR anomaly between -1 and +1 standard deviation are termed as normal monsoon years. Based on this criterion the years 1956, 1959, 1970, 1975, 1983 and 1988 are excess monsoon years and 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986 and 1987 are deficient monsoon years. Out of all the years of high and low snow which are related to below normal and above normal monsoon years respectively, we have cases (i) 1961 and 1975 where low winter snow is followed by excess monsoon rain and (ii) 1966, 1968 and 1979 where high snow is followed by deficient monsoon rain.

3. Difference in Circulation Characteristics between high and low Snow Years

Analysis of the composite mean snow depth of the above mentioned three years of high snow and two years of low snow indicates that the anomalies over the west Eurasia persisted through DJF up to MAM. It is found that the entire Eurasia north of 45^0N is cooler in high snow winter compared to low snow winter. In high snow year, the west region is cooler by about 5^0C at 850hPa whereas the east Eurasia is cooler by 4^0C. The cooling is there up to 500hPa level with magnitude of 2^0C in the west. This cooling of the atmosphere can be ascribed to the difference in snow depth. In high snow spring, the west and east Eurasia remain cooler by 2^0C and the temperature difference is even smaller at 500hPa. In spring, the atmospheric cooling has spread southwards up to the Caspian Sea. The cooling of the region around the Caspian Sea by about 2^0C might have played significant role in the weak monsoon circulation and deficient rain in the high snow years compared with low snow years. Even in JJAS, the Tibetan area is cooler by about 2^0C in the high snow year.

The composite seasonal wind difference fields at 850hPa during winter, spring and monsoon seasons show consistence circulation pattern corresponding to seasonal temperature difference fields. The wind difference field at 850hPa also gives anomalous anticyclonic circulation over the west Eurasia and anomalous cyclonic circulation over the east Eurasia corresponding to snow difference field. Correspondingly, the wind difference fields at 200hPa give anomalous cyclonic circulation at the upper level over the east and the west Eurasia during winter and the anomalous westerlies at the lower level over the Arabian Sea indicating weaker lower level monsoon wind in high snow compared to low snow in monsoon season. These anomalous winds at upper level correspond to weaker easterly in the deficient monsoon year in high snow compared to the excess rain year in low snow. Thus during the year of high snow easterly started weakening in spring to give rise to weak monsoon upper level easterly during JJAS.

The upper level seasonal tropospheric velocity potential difference fields in winter, spring and JJAS are also examined. It is well known that there is a strong upper level divergent centre (Krishnamurti et al. 1972) associated with the Asian monsoon. Normally the upstream side of TEJ is associated with the largest divergent centre and the downstream side, west of India is associated with convergence (Chen and Van Loon 1987). The positive difference field over the Indian subcontinent and the negative difference field to the east indicate that the upper level divergence centre was weaker over India in high snow compared to low snow. This divergent circulation changed in such a way that the intensity of easterly over the monsoon regions of southern Asia and Africa was weak in high snow. As shown by Chen and van Loon (1987), the anomalous divergent circulation during weak easterly year reduces the generation of kinetic energy on the upstream side of the jet and the destruction of kinetic energy on the downstream side of the jet.

4. Conclusions

Analysis of long term HSDSD data shows that lag CCs are significant from winter to spring season only over west Eurasia in the recent past from 1976 to 1994. For the west Eurasia, the antecedent DJF snow depth anomaly has highest CCs of −0.44 with the subsequent ISMR (at 0.1% significant level) while east Eurasia have CCs of 0.49 (at 0.1%) significant relationship in full period of study. The years 1961 and 1975 and 1966, 1968 and 1979 have been identified as less and more Eurasian snow respectively. The difference in the circulation pattern during these two sets of contrasting snow years have been examined carefully. Analysis of wind fields show that during the year of high snow, easterly started weaking in spring to give rise to weak monsoon upper level easterly during JJAS. The upper level divergence centre was weaker over India in high snow years compared to low snow years. This divergent circulation changed in such a way that the intensity of easterly over the monsoon regions of southern Asia and Africa was weak in high snow years. The anomalous convergence centre in winter over India gradually becomes weaker as spring comes and gives way to anomalous divergence which persists in JJAS. Also the anomalous divergence centre shifts from over the northern hemisphere and equator to the southern hemisphere over Australia.

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