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Investigation of the snow-monsoon relationship in a warming atmosphere using Hadley Centre climate model

S.K. Panda [a,*], S.K. Dash [a], B. Bhaskaran [b,1], K.C. Pattnayak [a,2]

[a] Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110 016, India
[b] Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK

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ABSTRACT

Several studies based on observed data and models show that there is an inverse relationship between the strength of the Indian summer monsoon and the extent/depth of Eurasian snow in the preceding season. Perturbed Physics Ensemble (PPE) simulations of Hadley Centre Coupled Model version 3 (HadCM3) have been used in this study to re-examine the snow-monsoon relationship in the longer time scale. The PPE monthly precipitation values during June, July, August and September (JJAS) have been compared with the corresponding values of Climatic Research Unit (CRU) of the University of East Anglia (UEA), UK for the period 1961–1990. The PPEs which simulated the Indian summer monsoon reasonably well have been used for examining snow-monsoon relationship. Atmospheric fields such as wind, geopotential height, velocity potential and stream function from the PPE simulations have been examined in detail. Results show that because of the west Eurasian snow depth anomalies, the mid-latitude circulation undergoes significant changes, which in turn lead to weak/strong monsoon circulation during deficient/excess Indian Summer Monsoon Rainfall (ISMR) respectively. The first Empirical Orthogonal Function (EOF1) of winter snow depth for the period 1961–1990 over the whole of Eurasia explains 13% variability. Thus the significant correlation patterns are consistent with the most dominant EOF of snow depth, in which the first mode describes a dipole type structure as observed. The study confirms that snow depth in the western part of Eurasia (20°E–65°E and 45°N–65°N) has negative correlation with the ISMR.

1. Introduction

The summer monsoon rainfall over the Indian sub-continent is found to be more significant in terms of its space and time variability. The Indian summer monsoon (also known as southwest monsoon) contributes about 80% of the annual rainfall over most parts of the country during the four months from June to September, while Tamil Nadu receives maximum rainfall during winter monsoon. Indian summer monsoon is part of a seasonally reversing wind system characterized by wet summers and dry winters. The wind during summer monsoon season are associated with a large scale vorticity at 850 hPa and the Low Level westerly Jet (LLJ) over the Arabian Sea and an anticyclone (the Tibetan anticyclone) at the upper level (200 hPa) with the monsoon easterly jet. The economical progress of India is mostly dependent on the behavior and changes in summer monsoon precipitation. Dash et al. (2013) examined the characteristics of extreme precipitation and temperature events during the Indian summer monsoon months with 9-member ensembles over the period 1982 to 2009 using the Regional Climate Model version 3 (RegCM3) of the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy. Their study shows that, the simulated extreme weather conditions like very wet days, extremely wet days, warm days and warm nights are more often as compared to those in India Meteorological Department (IMD) observed values in Central India. Ashfaq et al. (2009) simulated the dynamical features of the summer monsoon with 25 km resolution over south Asia region and found that enhanced greenhouse forcing resulted in the overall suppression of summer monsoon precipitation, delay in onset and an increase in the occurrence of monsoon break periods. Several authors (Dash et al., 2004, 2005 and 2006a; Shekhar and Dash, 2005; Parth Sarthi et al., 2011; Pattnayak et al., 2016; Kripalani and Kulkarni, 1999; Sankar-Rao et al., 1996) have examined the teleconnection of Indian summer monsoon with atmospheric and climatic parameters.

Long back Blanford (1884) suggested that the varying extent and thickness of continental snow cover exerts an influence on the land surface's thermal characteristics and in turn, influences the onset of the Asian summer monsoon. Because continental snow cover in the Asian region persists for a long time and snow-monsoon relationship is observed to be inverse, it has remained as one of the important parameters in empirical long range prediction of monsoon. Studies of Hahn and Shukla (1976), Kripalani and Kulkarni (1999), Bamzai and Shukla (1999), Fasullo (2004) based on observed data emphasized on

* Corresponding author at: Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110 016, India.
E-mail address: subrat75@gmail.com (S.K. Panda).
[1] Current affiliation: Fujitsu Laboratories of Europe, Hayes Park Central, Hayes, Middlesex, UK.
[2] Current affiliation: School of Geography, University of Leeds, Leeds LS2 9JT, UK.

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the inverse relationship between the Indian Summer Monsoon Rainfall (ISMR) and the Eurasian snow cover/depth in the preceding season. Kripalani et al. (2003) further reiterated that the summer monsoon over India and south Asia are primarily governed by large-scale atmospheric features like ENSO and Eurasian winter snow cover.

Barnett et al. (1989), Yasunari et al. (1991) and Vernekar et al. (1995) used a number of General Circulation Models (GCM) to examine and analyses the relationship between snow and monsoon. Their results clearly indicate that a positive snow anomaly over Eurasia in winter/spring does affect the monsoon circulation in the following summer in terms of weaker monsoon. Sankar-Rao et al. (1996) using data from National Environmental Satellite Data and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA) for the period 1967 to 1992 concluded that following the winters of more snow, stationary perturbations with higher pressures over central Asia north of India are produced in the lower atmosphere and the following Asian summer monsoon is weaker. Simultaneously, in the upper-atmosphere, lower anomalous pressure occurs during summer which weakens the upper level monsoon high.

Dash et al. (2004, 2005) tried to show the impact of Eurasian snow depth anomalies on the Indian Summer Monsoon Rainfall anomaly through the mid-latitude circulations. They used Soviet snow depth data and Indian rainfall data for the period 1951–1994 and showed that in winter through spring undergo significant changes in the upper and lower level winds, geopotential height, velocity potential and stream function fields. Such changes in the large-scale circulation pattern may be interpreted as precursors to weak/strong monsoon circulation and deficient/excess ISMR. Dash et al. (2006a) confirmed the inverse snow-ISMR relationship by using the actual observed values of snow depth of Historical Soviet Daily Snow Depth (HSDSD) version II data set in the spectral GCM of Indian Institute of Technology Delhi (IITD). RegCM3 has also been integrated from 1st April to 30th September in four years (Dash et al., 2006b, Shekhar and Dash, 2005) starting from 1993. Monthly snow depth data based on NIMBUS-7 SMMR satellite are used for conducting sensitivity experiments with RegCM3. Their simulations reveal that excess Tibetan snow in April decreases the rainfall over India in the following monsoon season. Their simulations also show that lower level westerlies and upper level easterlies are weakened in the snow experiment than in the control experiment.

From the global warming point of view, relation between Eurasian snow and ISMR is an important issue, some studies in the recent past show changes in the characteristics of summer monsoon rainfall in the warming atmosphere. The robust inverse relationship between Eurasian snow and ISMR is essential to be examined in the warming atmosphere. PPE simulations of Hadley Centre, UK Met Office have provided data over a large number of years and hence the objective of this study is to use those model scenarios to examine above. CRU rainfall data have been used for comparison. The PPEs which give better results in terms of ISMR have been selected for the study of snow monsoon relationship in a warming scenario. Finally, the characteristics of upper and lower-level mean monsoon circulations and midlatitude circulations during extreme snow depths years over Eurasia have been examined in detail. The model details and selection of PPEs have been described in Section 2. Section 3 discusses the results, while summary and conclusions are given in the last Section 4.

2. Description of the model and simulations

2.1. Model details

The PPE simulations are made mainly on an ensemble of variants of the slab version of HadCM3. HadCM3 is the third generation Hadley Centre model of UK Met Office. It is a coupled atmosphere-ocean GCM

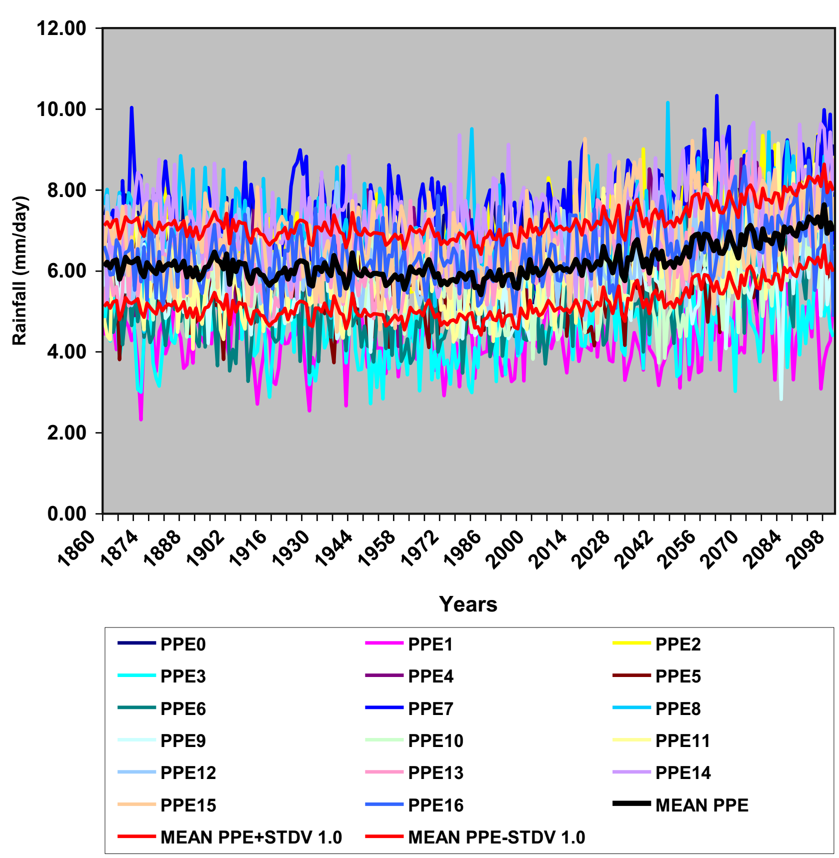

Fig. 1. Time series of simulated ISMR (mm/day) averaged over all the Indian land points for the period 1860–2098.