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Anomalous behavior of Indian summer monsoon in the warming environment

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ABSTRACT

The variability of Summer Monsoon (SM) rainfall over India using the gridded rainfall data as well as subdivisional rainfall data is studied for the period 1951–2008. The total length of period is divided into two parts, 1951–1969 (Pre-Global Warming (PGW) period) and 1970–2008 (Global Warming (GW) period) as the Earth shows rise in the temperature since the beginning of 1970s. The differences in the mean rainfall of these two periods are tested using the Z-statistic. Further, the mean zonal wind differences at different grid-points at 850 hPa and 150 hPa of the above two periods for the domain 30°E–120°E, 40°S–40°N are calculated and tested using the Z-statistic. The results indicate that the reduced rainfall activity over India in the global warming is associated with a weakened SM system. Next, the differences in the frequencies of the days having different limits of rainfall are obtained by subtracting the frequencies of the PGW period from those of the GW period. The results pinpoint an increase in the no rainfall (dry) days as well as the extreme rainfall events in the warming environment.

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1. Introduction

In the warming environment, more moisture supply to the atmospheric system from the oceanic water mass, high amounts of cloudiness and abundant amount of rainfall as the ultimate product may be expected. But, the monsoon system is a wind phenomenon which arises basically due to uneven distribution of thermal patterns that is the differential heating between the land and the ocean. The importance of the temperature gradient between the northern latitudes and southern latitudes in the Indian/Asian summer monsoon regime is already pointed out by Chung and Ramanathan (2006), Naidu et al. (2009) and Naidu et al. (2015). Chung and Ramanathan (2006) reported the following points. (i) The Sea Surface Temperatures (SSTs) in the equatorial Indian Ocean have warmed by about 0.6 to 0.8 K since the 1950s, accompanied by very little warming or even a slight cooling trend over the north Indian Ocean. (ii) This differential trend has resulted in a substantial weakening of the meridional SST gradient from the equatorial

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region to the south Asian coast during summer, to the extent that the gradient has nearly vanished recently. (iii) On the basis of simulation with the Community Climate Model version 3, the summer time weakening in the SST gradient weakens the monsoon circulation, resulting in less monsoon rainfall over India and excess rainfall in sub-Saharan Africa. Now-a-days, the North Atlantic Oscillation is also considered as another important factor. According to Goswami et al. (2006a), (i) the Atlantic Multi-decadal Oscillation (AMO) produces persistent weakening or strengthening of the meridional gradient of tropospheric temperature by setting up negative or positive tropospheric temperature anomaly over Eurasia in the Northern late summer/autumn, (ii) AMO modulates the Indian summer monsoon through persistent tropospheric temperature anomalies over Eurasia and a positive AMO produces stronger monsoon by producing positive temperature anomaly over Eurasia, (iii) it is also associated with enhanced La Nina type Pacific SST anomalies that induces stronger regional monsoon Hadley Circulation and stronger monsoon and (iv) on inter-annual time scales, strong North Atlantic Oscillation (NAO) or North Annular Mode (NAM) influences the monsoon by producing similar tropospheric temperature anomaly over Eurasia, and the AMO achieves the inter-decadal modulation of the monsoon by modulating the frequency of occurrence of strong NAO/NAM events.

The positive relationship between the Indian SM rainfall and the southern oscillation is an established fact (Pant and Parthasarathy, 1981; Mooley et al., 1985). But, the relationship between Indian SM rainfall and El-Nino Southern Oscillation (ENSO) has weakened since the mid-1970s (Krishna Kumar et al., 1999). The weakened ENSO-monsoon teleconnection in recent decades in the observations might be caused by other factors such as the decadal change in SST pattern associated with ENSO (Krishna Kumar et al., 2006) or the decadal fluctuation of interannual SST anomalies in south equatorial Atlantic concurring with ENSO (Kucharski et al., 2007) rather than ENSO intensity (Chen et al. (2010)).

There is a significant relationship between the subtropical ridge position at 500 hPa in April at 75°E and Indian SM rainfall activity (Banerjee et al. (1978)). If the ridge position in April lies to the north/south of normal position (14°.25′N), active/poor monsoon is expected. According to Hastenrath and Greischar (1993), the SM rainfall trends are to be enhanced with more northerly ridge position at 500 hPa along 75°E in April, small Darwin pressure tendency from January to April, warmer pre-monsoon conditions over west-central India and reduced winter Eurasian snow cover (January). These relationships have varied considerably with strongest association during 1950–80 and drastic weakening in the 1980s.

Global warming is well known for the facets like shifting of rainfall patterns, weakening of jet streams, rising of tropospheric temperatures, rising of sea levels etc. (Ahrens, 1993). At the same time, the monsoon system is well influenced by the rising of temperature and uneven warming rates at different latitude belts in the warming environment. The Indian summer monsoon rainfall is connected with the variations of the intensity of the tropical easterly jet stream which is a fascinating feature of summer monsoon. The rainfall activity of Indian SM shows a decline in the global warming which seems to be associated with the decrease of north–south temperature gradient over the Indian Ocean, weakening of easterly jet and the relaxation of the southern oscillation (Naidu et al., 2009, 2011a,b).

Indian SM is associated with the break and active phases. Krishnamurthy and Shukla (2000) found that the major drought years are characterized by large-scale negative rainfall anomalies covering nearly all India persisting for the entire monsoon season. The intraseasonal variability of rainfall during the monsoon season is characterized by the occurrence of active and break phases. In active phase, the rainfall is above normal over central India and below normal over northern India (foothills of the Himalayas) as well as southern India. This pattern is reversed during the break phase. Ashfaq et al. (2009) used a high-resolution nested climate modeling system to investigate the response of South Asian SM dynamics to anthropogenic increases in greenhouse gas concentrations, and the simulated dynamical features of the SM agreed well with reanalysis data and observations. Further, they found that the enhanced greenhouse forcing resulted in overall suppression of summer precipitation, a delay in the monsoon onset, and an increase in the occurrence of monsoon break periods. Weakening of the large-scale monsoon flow and suppression of the dominant intraseasonal oscillatory modes were instrumental in the overall weakening of the South Asian SM. Such changes in monsoon dynamics could have substantial impacts by decreasing summer precipitation in key areas of South Asia.

According to Naidu et al. (2012), the enhanced rainfall activity of the northeast monsoon over South Peninsular (SP) India during global warming period was closely associated with (i) the intensification of easterly belt in the lower troposphere over the major part of northeast monsoon region of India, (ii) an increase in low rainfall events as well as extreme rainfall events and (iii) a decrease in the no rainfall events as well as moderate rainfall events. The overall contribution of all types of events results in a net increase of rainfall activity over SP India.

Increasing moisture in the atmosphere as a result of increasing global temperature makes the tropical atmosphere increasingly more unstable (Trenberth et al., 2005). In general, the frequency of occurrence as well as the intensity of extreme rainfall events have shown a significant increasing trend in the tropics (Hegerl et al. (2007)) in the warming environment. Further, Goswami et al. (2006a,b) have mentioned that there is a significant positive trend in the frequency and the magnitude of extreme rain events and a significant negative trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events. A substantial increase in hazards related to heavy rain is expected over central India in the future (Goswami et al., 2006a,b).

According to the analysis of high resolution gridded rainfall data (Rajeevan et al. (2008)), the frequency of extreme rainfall events over central India during 1901–2004 shows significant interannual as well as interdecadal variations with a significant long term trend. The interannual, interdecadal and long term trends of extreme rainfall events are modulated by the SST variations over the tropical Indian Ocean. In the global warming scenario, the coherent relationship between Indian Ocean SST and extreme rainfall events suggests an increase in the risk of major floods over central India.

Global Greenhouse Gas (GHG) emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. The observed pattern of tropospheric warming and stratospheric cooling is very likely due to the combined influences of GHG increases and stratospheric ozone depletion. An increase in GHG concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. Some extreme weather events have changed in frequency and/or intensity over the last 50 years. It is likely that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas (IPCC-2007).

The episode happened in the year 2013 in the Uttarakhand, India is an example of the extreme event. Hundreds of people have lost their lives. It is the most pathetic situation. The monsoon arrived early in the northern state of Uttarakhand, bringing with it 375% more rain than those of previous years. The sheer weight of water that hit an area known as India's 'Holy Land' is hard to overstate. It suffered 60 h of continuous and heavy rains coupled with cloudbursts during 14–17 June 2013. This resulted in increasing water level and floods in the Alaknanda and Bhagirathi rivers causing the massive devastation of infrastructure and loss of lives (http://www.rtcc.org/climate-adaptation-planning-could-have-prevented-uttarakhand-deaths/). The unusual high rainfall in Dehradun (capital of Uttarakhand) on 16 and 17 June