



Role of Anthropogenic Forcing and Decadal Oscillations on the Delayed Withdrawal of Indian Summer Monsoon

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The mean Indian summer monsoon (ISM) rainfall as well as the duration of monsoon spell have a profound impact on the agriculture practice in the country. Due to the recent increase in surface temperature, global circulation patterns exhibit considerable changes which also affects the characteristics of ISM. The present study aims to find out any long-term changes in the monsoon onset and withdrawal dates over different parts of India and the possible mechanisms behind it. During the last four decades, the trend analysis of ISM onset dates over south India and north-west (NW) India shows an early onset in both regions. However, the trends are statistically less significant. In the case of the monsoon withdrawal dates, trends over NW India and south India show a statistically significant delay of about 6 days/decade and 3.25 days/decade, respectively. As a result, the monsoon season over NW India and south India shows a lengthening of about 7.8 days/decade and 3.5 days/decade, respectively. During the withdrawal phase of the ISM, a stronger monsoon low-level jet and an enhancement of the ISM rainfall have been observed in recent decades. The enhancement in rainfall activity and the strengthening of the low-level jet in the withdrawal phase reaffirms the delayed withdrawal of the ISM in recent decades.

The role played by factors such as Indian Ocean warming, Atlantic Multidecadal Oscillation (AMO) and Pacific Decadal Oscillation (PDO) on the ISM withdrawal is examined. The AMO has changed its phase from negative to positive in recent decades, particularly after about 1998, which might have played a key role in enhancing the meridional tropospheric temperature gradient. The stronger meridional tropospheric temperature gradient and the Eurasian surface warming observed in recent decades might played a key role in the delayed monsoon withdrawal over NW India. The CESM2 large ensemble data analysis shows that both the external forcing as well as the decadal phase shift of the AMO and PDO, favour the delayed withdrawal, while the latter plays a dominant role.