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Trends and variability of droughts over the Indian monsoon region

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ABSTRACT

Drought characteristics for the Indian monsoon region are analyzed using two different datasets and standard precipitation index (SPI), standardized precipitation-evapotranspiration index (SPEI), Gaussian mixture model-based drought index (GMM-DI), and hidden Markov model-based drought index (HMM-DI) for the period 1901–2004. Drought trends and variability were analyzed for three epochs: 1901–1935, 1936–1971 and 1972–2004. Irrespective of the dataset and methodology used, the results indicate an increasing trend in drought severity and frequency during the recent decades (1972–2004). Droughts are becoming more regional and are showing a general shift to the agriculturally important coastal south-India, central Maharashtra, and Indo-Gangetic plains indicating higher food security and socioeconomic vulnerability in the region.

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1. Introduction

Droughts in the monsoon dominated regions have gained greater importance in the recent past, as monsoons not only define the unique features of the climate, but also affect the socio-economic well-being of more than two third of global population (Niranjan Kumar et al., 2013; Rajeevan et al., 2008). Recent changes in Indian monsoon precipitation have received wide attention (Kripalani et al., 2003; Mishra et al., 2012; Rupa Kumar et al., 2006) with some plausible uncertainty on whether trends associated with summer monsoon precipitation are related to global warming or those due to regional changes (Chung and Ramanathan, 2006; Kishtawal et al., 2010; Niyogi et al., 2010). A number of studies (Kumar et al., 1992; Rajeevan et al., 2008; Stephenson, 2001) have indicated that the mean precipitation during the monsoon season may be unaltered over the Indian monsoon region (IMR), however the extreme precipitation events have shown statistically significant increasing trends in last five decades resulting in modification of drought characteristics over IMR (Goswami et al., 2006; Mishra et al., 2012). Trends associated with the Indian summer monsoon rainfall (ISMR) have also shown a great regional variability where some parts of India have seen an increase in precipitation while others show a reduction in precipitation during the monsoon season (Guhathakurta and Rajeevan, 2008; Niyogi et al., 2010; Roxy et al., 2015). Significant interannual, decadal and long term trends have been observed in the monsoon drought time series over IMR influenced by El Nino Southern Oscillation and global warming (Niranjan Kumar et al., 2013).

Recently, contrasting conclusions were drawn about global drought climatology by two synthesis studies (Sheffield et al., 2012; Dai, 2013). While Sheffield et al. (2012) showed that there was little change in drought climatology in recent years, the study by Dai (2013) concluded that droughts were intensifying as a result of a warming climate. Building off these assessments, Trenberth et al. (2014) summarized that the choice of precipitation dataset and other forcing datasets could influence drought analysis in addition to the choice of model parameterizations being used in deriving the drought indices [e.g. potential evapotranspiration calculations while estimating PDSI as reported in Sheffield et al. (2012)]. These studies highlight the need for using multiple drought indices and datasets for drought climatology, and form the basis for reassessing the drought of the Indian Monsoon Region.

Evaluation of trends and variability associated with retrospective drought events provides a basis to understand regional patterns of severity, duration, and areal extent of droughts. It also enables an understanding of the nature of possible future droughts and potential vulnerabilities. Building off the findings of drought assessments over the IMR in recent years and the recommendations cited in Trenberth et al. (2014) the aims of this paper are

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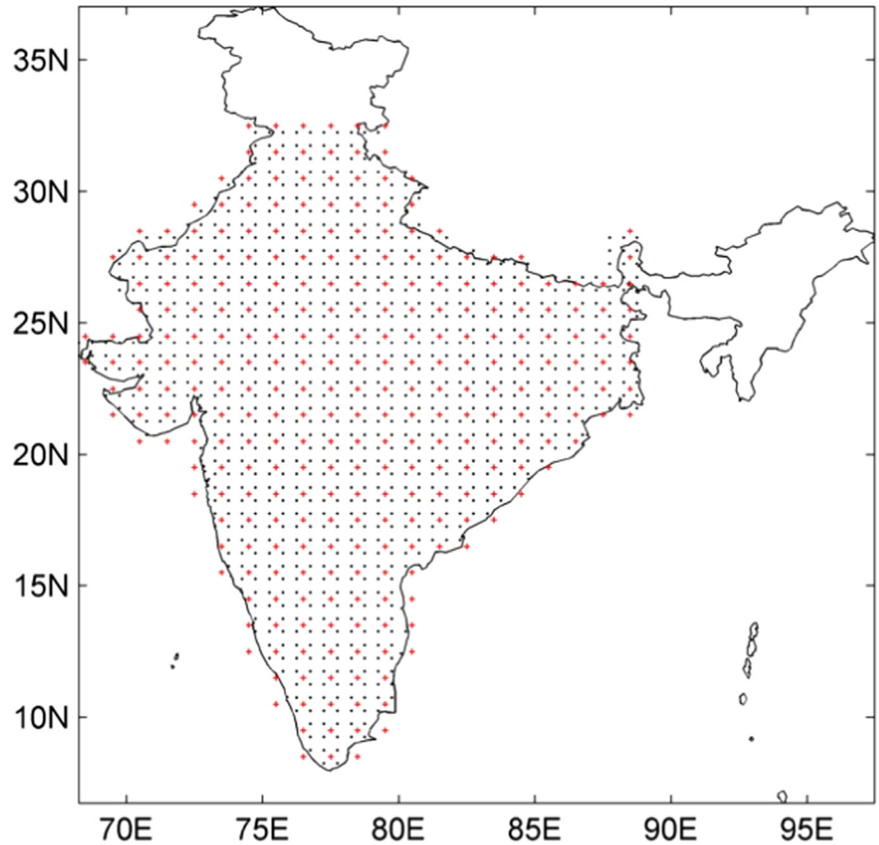

Fig. 1. Study domain showing 1° grid cell locations for India Meteorological Department precipitation dataset as cross-hairs, and 0.5° grid cell locations for University of Delaware precipitation dataset as dots.

(i) to study the retrospective droughts and associated trends over IMR using different precipitation datasets and drought indices, and (ii) to identify regions in IMR that are vulnerable to droughts.

2. Data and methods

We used gridded daily precipitation data from the India Meteorological Department (IMD) (Rajeevan, 2006) available for the period 1901–2004 at 1° spatial resolution (Fig. 1). The daily precipitation data obtained from IMD was then aggregated over monthly time scale. The second dataset used in this study was monthly precipitation data from University of Delaware (UD) available for the period of 1900–2004 (UDel_AirT_Precip data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at ⟨http://www.esrl.noaa.gov/psd/⟩) at 0. 5° spatial resolution (Fig. 1). The precipitation data from high-mountainous regions in northern and northeastern parts of the country were not used in the study.

Despite the differences in the spatial resolution, the precipitation datasets show similar patterns in the spatial distribution and variance of precipitation over the study region. Fig. A.1a and b shows the distribution of mean monthly precipitation over the study region, and Fig. A.1c and d compares the standard deviation in monthly mean precipitation between the two datasets. While the overall patterns are similar, the effects of resolution on the magnitudes are evident. For instance, the UD dataset provides more detail in the spatial distribution of precipitation statistics; and a comparison of monthly mean precipitation time series (Fig. A.2) between the two datasets shows that while the overall monthly time series pattern are similar, the precipitation magnitude for IMD grids are lower compared to UD grids during the months June to September, and relatively identical for the remaining months.

Standardized precipitation index (SPI; McKee et al., 1993), standardized precipitation-evapotranspiration index (SPEI; Vicente-Serrano et al., 2010; Niranjan Kumar et al., 2013), Gaussian mixture model-based drought index (GMM-DI; Mallya, 2011), and hidden Markov model-based drought index (HMM-DI; Mallya, 2011; Mallya et al., 2012) were calculated for drought characterization at multiple time scales ending in September (i.e. for 1-month, 4-month, and 12-month moving time-window) and December (i.e. for 7-month moving time-window). The results for 12-month moving time window accounts for precipitation events occurring over both the active monsoon and the non-monsoon months and 7-month time-window ending in December accounts for summer monsoon (JJAS) and winter monsoon (OND) months over the study area and are discussed here in detail. These indices differ in their mathematical formulation and the drought classification technique. While SPI relies on fixed thresholds for drought classification, GMM-DI and HMM-DI employ a probabilistic data-driven approach. SPEI uses temperature (UDel_AirT_Precip, ⟨http://www.esrl.noaa.gov/psd/⟩) for calculating evapotranspiration, thus accounting for any temperature rise in the study area during recent decades. The mathematical formulations of the drought indices are summarized in Appendix A.

The drought index values obtained were analyzed further to extract drought characteristics such as severity, duration, areal extent, and frequency. The drought impact index was then computed for each year, by normalizing the product of mean severity

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