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Trends in seasonal precipitation extremes – An indicator of 'climate change' in Kerala, India

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SUMMARY

Recent news on the occurrence of off-seasonal natural disasters, such as pre-monsoon drought and post-monsoon flooding in India and particularly in the peninsular region, highlight the urgent need to look at the patterns of change in seasonal extremes at the local level. Kerala, the south-western state of the Indian peninsula, comprising of a total of six gridded areas, was chosen for this study focusing on the variability and changes in rainfall extremes in the different seasons. Since other studies by the authors have focused on the monsoon season, this paper considers the winter, spring and autumn seasons only. A set of indices derived from the daily rainfall time series is defined and used to examine the changes in extreme rainfall through assessing long-term trends by non-parametric Mann–Kendall technique. The trends are determined over the period of 1954–2003, which are also tested for significance. The results show that there are large intra-regional differences in the trends in different seasons. Local changes were found different from the large spatial scale averages in Kerala. Winter and autumn extreme rainfall were found having an increasing tendency with statistically significant changes in some regions indicating more occurrences of winter and autumn floods. On the other hand the spring seasonal extreme rainfall showed decreasing trends, which together with increasing frequency of the dry days is mainly affecting the total seasonal precipitation, which mainly point towards the vulnerability of Kerala to increasing probability of water scarcity in the pre-monsoon time and a delaying monsoon onset. Overall, the results of this study are good indicators of local climate changes over the five decades that will assist in seasonal forecasting and risk management.

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Introduction

Temporal changes in discrete random extreme events are becoming important in climate change scenario studies because of their socio-economic impacts. The risk of extreme events is difficult to predict but their impacts could be severe. To outline the change in rainfall extremes in a certain region, it is necessary to look at the historical trends of statistical properties of seasonal rainfall extremes. An increase of extreme events has been reported in the monsoon season over central India (Goswami et al., 2006). Also, rainfall with more than 10 years and up to 50 years of return periods has been reported occurring in Kerala, the south-western state of Indian peninsula (Pal and Al-Tabbaa, 2007). Kerala is a very important region for India since a large part of India's agro-economy is concentrated there. Although Kerala is one of very few highest monsoon rainfall regions in India, along with the North-Eastern Indian states, and receives the first monsoon showers every year, significant amount of precipitation in the other seasons is also important from an agricultural point of view. Furthermore, increasing off-monsoon seasonal floods and thunderstorms in some parts of Kerala, and also in the neighbouring state of Karnataka in peninsular India (De et al., 2005), make it important to look at the change in extreme rainfalls in the other seasons as well.

Assessment of other seasonal extreme rainfall changes in Indian region is scarce in the literature. Only Revadekar and Kulkarni's (2007) recently published work on winter monsoon extremes and their relation with ENSO in South–East peninsular India in the months of October–December provides some information. However, they did not consider other important seasons such as spring (March–May) and autumn (October–November) in their study. The authors have found that spring precipitation makes a very important contribution to annual rainfall variabilities and changes in India and that extreme rainfall plays a dominant role in deciding the seasonal rainfall strength (Pal and Al-Tabbaa, submitted for publication). Therefore, in addition to the winter season (December–February), spring and autumn seasonal precipitations are also considered in this study to investigate whether there have been any significant changes in the extreme rainfall in Kerala over the second half of the 20th century. Previous analyses by the authors found that the average autumn and winter rainfall in Kerala does not seem to show any significant trends but that the

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spring rainfall does (unpublished work). Since the changes in short-duration extreme events do have the potential to indicate long-term seasonal climatic changes (Keim and Cruise, 1998), winter and autumn extremes are also examined here. Six separate gridded regions comprising of the whole state of Kerala are studied. Fig. 1 shows the position of the Kerala state in India and the gridded regions in Kerala (orange colour) considered in this study. Gridded regional analysis will help us to identify the spatial changes at very small scales, which will provide the local information on the changing climate that is not usually extracted from the aggregated spatial mean (Bardossy and Hundecha, 2003). Collectively, this work aims at characterising the singular events that have the potential to help in defining and assessing the associated risks, and developing mitigation and adaptation strategies in the state of Kerala.

Database and methodology

Lack of long-term daily precipitation time series restricts the empirical analysis of the extreme precipitation changes in the precipitation distribution. High resolution ($1^\circ \times 1^\circ$ Lat/Long) gridded daily rainfall datasets comprising of 53 years of data (1951–2003) covering the whole Indian region was collected from the National Climate Center, Indian Meteorological Department, Pune (http://www.imdpune.gov.in/). The daily time series for the six grids of Kerala was then extracted from this database for the 50 years (1954–2003) of analysis done here. Gridded rainfall data sets are useful for regional studies on the climate variability and changes. The high resolution gridded daily rainfall data base for India was developed based on interpolation of the daily rainfall data from 1803 stations in India having at least 90% data availability during the period of 1951–2003 (Rajeevan et al., 2005,2006). Standard quality control was performed in order to minimise the risk of generating spatial or temporal inhomogeneities in the gridded data. A comparison with similar global gridded rainfall revealed that this database is better in accurate representation of spatial and temporal rainfall variations in India (Rajeevan et al., 2006).

The analysis of the precipitation extremes was based on the indices developed under the World Climate Research Programme on Climate Variability and Predictability Working Group on Climate Change Detection (Peterson et al., 2002; Peterson, 2005). Some of these indices have been previously used in the analyses of the trends in global and regional climates (Bardossy and Hundecha, 2003; Alexander et al., 2006). Selective indices used here for the seasonal analyses are demonstrated in Table 1. Seasonal extreme indices were calculated on a yearly basis for the entire 50 years (1954–2003) of study for all the areas under investigation in Kerala. The base period considered here was 1961–1990. Before moving onto the extremes, changes in seasonal total rainfall in the wet days and changes in the frequency of the dry days are also examined and discussed in the first two sub-sections below.

All the trends for each index were determined using non-parametric Mann–Kendall test, which were also tested for significance at 95% level (Wilks, 1995; Onoz and Bayazit, 2003; Luo et al., in press). Since there are chances of outliers to be present as the extreme rainfall events, non-parametric Mann–Kendall test is useful because its statistic is based on the sign of differences, not directly on the values of the random variable and therefore the trends determined is less affected by the outliers. The Mann–Kendall test

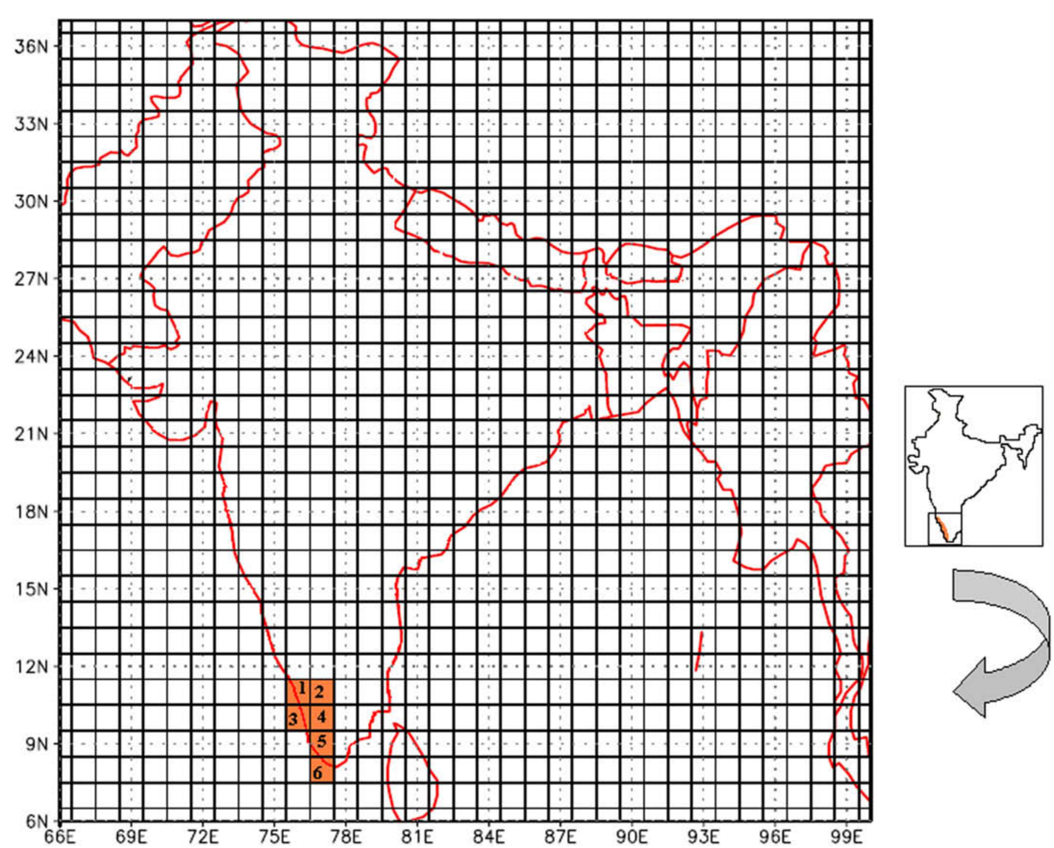

Fig. 1. Location of Kerala state in India (orange colour grids mark the study regions considered). The numerical numbers in the grid points represent $1^\circ \times 1^\circ$ grids as follows, 1 = 11.5N, 75.5E; 2 = 11.5N, 76.5E; 3 = 10.5N, 75.5E; 4 = 10.5N, 76.5E; 5 = 9.5N, 76.5E and 6 = 8.5N, 76.5E [from Rajeevan et al., 2006]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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