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Projected changes in mean and extreme precipitation indices over India using PRECIS

K. Koteswara Rao *, S.K. Patwardhan, Ashwini Kulkarni, K. Kamala, S.S. Sabade, K. Krishna Kumar

Indian Institute of Tropical Meteorology, Pune, India

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A B S T R A C T

The impact of global warming on the characteristics of mean and extremes of rainfall over India is investigated using a high resolution regional climate model PRECIS developed by Hadley Centre, UK. Five simulations of PRECIS made using the lateral boundary conditions from a suite of Perturbed Physics Ensembles (PPE) generated using Hadley Center Coupled Model (HadCM3) for Quantifying Uncertainty in Model Predictions (QUMP) project corresponding to IPCC A1B emission scenario have been analyzed here for this purpose. The projected changes depict seasonally dependent fine scale structure in response to the topographic forcing and changes in circulation, especially along the west coast and North East (NE) region of India towards the end of the 21st century i.e. 2080s (2071–2098). Analysis of the extreme precipitation indices indicates an increase in the intensity of rainfall on wet days towards 2080s under A1B scenario. Changes in extreme precipitation events and dry spells suggest not only shifts, but also a substantial increase in the spread of the precipitation distribution, with an increased probability of the occurrence of events conducive to both floods and droughts. The projected changes in various precipitation extremes show a large regional variability. Total rainfall on very heavy rainy days (R95p) is projected to increase by around 40–50% over the central parts of the country. The number of rainy days >10 mm (R10) may increase by 10–20% over west coast, east central India and northeastern parts while over northwest and rain shadow region they may increase by 40–50%. The consecutive dry days (CDDs) may decrease by 10–20% over Indo-Gangetic plain, however over west coast there may not be any significant change. The CDDs are projected to rise by 10–20% over west central and peninsular India. The precipitation per wet day (SDII) may be more intense by 10–40% over the entire land mass, however there may not be any significant change over south peninsular India.

1. Introduction

Climate change studies over the past few decades have been largely focused on the changes in the seasonal mean values. However, it is now being increasingly recognized that the manifestation of changes in the occurrence of extreme weather and climatic events, particularly on the regional and local scales, is of paramount importance in assessing the socio-economic impacts of climate change. The impacts of heavy precipitation on ecosystems, agriculture, and infrastructure are particularly important for a society. The impacts of climate change are manifold and vary regionally. However, the immediate damages to human lives and their properties are not obviously caused by gradual changes in precipitation but mainly by the changes in the so-called extreme weather events. The frequent occurrence of extremes makes it necessary to examine long data records to detect significant changes in the frequency and intensity of extreme events over a region and also their expected future changes using model simulations.

Global Climate Models (GCMs), because of their relatively coarse resolution, have difficulties in simulating extreme weather events, particularly the precipitation extremes. RCMs (Regional Climate Models) represent an effective method of adding fine-scale details to simulated patterns of climate variability and change as they better resolve the local land-surface properties such as orography, vegetation and the other internal regional climate variability through their better resolution of atmospheric dynamics (Alley et al., 2007; De Sales and Xue, 2010; Di Luca et al., 2011; Feser, 2006; Jones et al., 1995; Prömmel et al., 2010; Seth et al., 2007). This improved representation of severe weather phenomena in RCMs has motivated various studies on projected changes in heavy precipitation events on the basis of RCM simulations for different parts of the world (Beniston et al., 2007; Christensen and Christensen, 2003; Fowler et al., 2005; May, 2008; Mladjic et al., 2011; Nikulin et al., 2011). Thus, RCMs are able to generate long time series that can be used for model evaluation and also for analyses of possible future changes in extreme events. An increase in intense precipitation is projected under greenhouse warming conditions over large parts of the globe by most of the CMIP3 models (Kharin and Zwiers, 2000; Wehner, 2004) and CMIP5 models (Sillmann et al., 2012a, 2012b; A.Kitoh et al., 2013). Most of these models show an

* Corresponding author at: Climatology & Hydrometeorology Division, Indian Institute of Tropical Meteorology, India. Tel.: +91 20 25904363; fax: +91 20 25865142.
E-mail address: koti.meteo@gmail.com (K.K. Rao).

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increase in extreme daily precipitation despite the decrease in mean precipitation in some places. Much larger changes are expected in the recurrence frequency of precipitation extremes than in the magnitude of extremes (Barnett et al., 2006; Frei et al., 2006; Huntingford et al., 2003).

The expected consequences of global warming are the perturbation and possible intensification of the hydrological cycle. In very broad terms this is expected to increase the frequency and intensity of extreme rainfall events and also the length of dry spells (Intergovernmental Panel on Climate Change IPCC, 2007) though significant regional and local deviations are likely (Christensen et al., 2007). Alexander et al. (2006) studied the comprehensive global picture of the observed trends in precipitation extremes and found a general increase in the heavy precipitation indices. Their analysis showed the largest declining trends, over the Indian region, in the annual number of consecutive dry days. But the analysis suggests that changes in precipitation extremes are spatially less coherent and significant at lower level of statistical significance compared to the changes in temperature extremes. Goswami et al. (2006) suggest that the seasonal mean of all India rainfall (1951–2000) is trendless, because the contribution from increasing heavy events is offset by decreasing moderate events. Analyzing daily gridded rainfall observations also revealed a decrease in moderate rainfall events (of 5–100 mm/day) and an increase in extreme events over central India since 1950s (Gautam et al., 2009; Rajeevan et al., 2006). Moisture availability increases in a warmer world, leading to stronger extreme events, yet mean precipitation increases more slowly owing to energy constraints. Thus the frequency of large-scale convection must decrease, or the strength of more moderate rainfall events must decline (Chou et al., 2009; Trenberth et al., 2003). Consistent with this picture, model projections suggest increased intensity of South Asian monsoon rainfall (total precipitation summed over the number of wet days) as the number of wet days decreases (Krishna Kumar et al., 2011). The limitation, however, is that smearing of convection over the coarse grid scale of GCMs biases the intensity of rainfall downwards and increases its frequency. Furthermore, projections of the heaviest monsoon rainfall suggest generally large positive increases, potentially beyond those predicted by thermodynamic arguments alone.

Revadekar (2010) has studied the observed changes in precipitation and temperature extremes and shown that climate over the Indian region is changing towards warmer and wetter climate. High resolution models are arguably better suited to investigate the variability in extreme weather conditions as they can better represent the spatial scales at which such systems develop (Diffenbaugh et al., 2005). However, not many studies are available on precipitation extremes over the Indian region. Revadekar et al. (2011) studied the characteristic features of precipitation extremes and their seasonal behavior using standardized indices based on PRECIS simulations over the Indian region and showed that the PRECIS simulations under both A2 and B2 scenarios indicate an increase in the frequency of heavy precipitation events and enhancement in their intensity towards the end of the 21st century. Recently published IPCC SREX report (2012) deals with the observed changes and future projections of extreme weather and climate events on global and regional scales. Between the late 20th and the late 21st century, the projected responses of extreme precipitation to future emissions show increased precipitation rates in most regions and decreases in return periods in most regions in the high latitudes and the tropics and in some regions in the mid-latitudes consistent with projected changes in several indices related to heavy precipitation.

Frich et al. (2002) defined the key indices, which are expected to be statistically robust with fairly short return periods and represent a wide variety of climate aspects. Several subsequent studies have focused on the analysis of this set of key indices. However, the definitions and usefulness of some of these indices, although meant to be globally valid, became the subject of discussion and, as a result, definitions of some indices as well as their calculations were reconsidered (Alexander et al., 2006; Zhang et al., 2005; Tebaldi et al., 2006; Kiktev et al., 2003; Haylock and Goodess, 2004, etc.). Several studies to date have concentrated on the analysis of indices for climate extremes based on observational data from weather stations (Frich et al., 2002; Klein Tank and Können, 2003), while others focused primarily on the changes in extremes in future climate projections (Meehl and Tebaldi, 2004; Meehl et al., 2000; Tebaldi et al., 2006).

India being a densely populated developing country is more vulnerable to climate change. Kitoh et al. (2013) have shown that the projected changes in extreme precipitation indices over South Asian region are larger than over the other monsoon domains. Hence the objectives of the present study are, first, to investigate whether the model simulations are able to capture the observed mean climate and spatial patterns of extreme precipitation events and, second, to analyze the changes in extreme indices in future climate projections. Based on these objectives the paper is organized as follows. The experimental deign and methodology are briefly described in Section 2, followed by a discussion of the climate indices considered in this study in Section 3. The results are presented in Section 4. A discussion of the main results in Section 5 concludes this paper.

2. Experimental design

PRECIS is a regional climate modeling system developed at the Met Office Hadley Centre, UK. The PRECIS model is based on the atmospheric component of Hadley Centre Climate Model (HadCM3) with substantial modifications to the model physics (Gordon et al., 2000). The model requires prescribed surface and lateral boundary conditions; surface boundary conditions are required only over water and needs time dependent sea surface temperature and ice extent. The lateral boundary conditions (LBCs) provide the dynamical atmospheric information at the latitudinal and longitudinal edges of the model domain. The lateral boundary conditions comprise the standard atmospheric variables of surface pressure, horizontal wind components and measures of atmospheric temperature and humidity.

Five simulations from a seventeen-member Perturbed Physics Ensemble (PPE) produced using fully coupled model, HadCM3 under the Quantifying Uncertainty in Model Predictions (QUMP) project of Hadley Centre Met Office, U.K., have been used as Lateral Boundary Conditions (LBCs) for the continuous 138 year simulations (1961–2098) of the regional climate model — PRECIS. The lateral boundary conditions have been used directly from the coarse resolution global coupled model. The perturbed physics approach was developed in response to the call for better quantification of uncertainties in climate projections (Chapter 14 of the TAR: Third Assessment report of IPCC). The basic approach involves taking a single model structure and making perturbations to the values of parameters in the model, based on the discussions with scientists involved in the development of different parameterization schemes. In some cases, different variants of physical schemes may also be switched in and out. Any number of experiments that are routinely performed with single model can then be produced in an “ensemble mode” subject to constraints on computer time. A significant amount of perturbed physics experimentation has been done with HadCM3 and variants, starting with the work of Murphy et al. (2004) and Stainforth et al. (2005).

The QUMP simulations comprise 17 versions of the fully coupled version of HadCM3, one with the standard parameter setting and 16 versions in which 29 of the atmosphere component parameters which are simultaneously perturbed are used in order to sample a range of surface and atmosphere feedbacks under climate change. The interactive sulfur cycle is activated. Flux adjustments are employed in these coupled model simulations to (i) prevent model drift that would result from perturbations to the parameters that lead to top-of-atmosphere net flux imbalances, and (ii) to improve the credibility of the simulations in simulating regional climate change and feedbacks. The sea-ice scheme in HadCM3 is contained in the atmosphere component and