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Research papers

A novel approach for statistical downscaling of future precipitation over the Indo-Gangetic Basin

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ABSTRACT

We propose a novel statistical downscaling method using Global Circulation Model (GCM) rainfall and satellite based precipitation estimate Tropical Rainfall Measurement Mission (TRMM; 3B43v7) to generate a high-resolution rainfall ($0.25^\circ \times 0.25^\circ$) estimate over the Indo-Gangetic Basin (IGB) for 9 GCM and 4 Special Report on Emissions Scenarios (SRES) combinations. These precipitation values, along with the precipitation dataset from the APHRODITE's Water Resources project are then seasonally segregated (winter, pre-monsoon, monsoon and post-monsoon) and combined into a Bayesian framework to generate probability distribution of future precipitation change at regional scale. We considered present time as 2001–2010, and 3 non-overlapping time slices 2011–2040, 2041–2070, and 2071–2100 as future. The precipitation trends are heterogeneous in space and seasons, but there is an overall consistency in trends for different future time slices. The shapes of the final probability density functions given by the kernel density estimators show varying characteristics. Compared to traditional transfer function based statistical downscaling methods our framework allows downscaling to basin level gridded rainfall rather than station specific precipitation. It also allows an integrated estimate of uncertainties arising from different sources which is an essential diagnostic when datasets from various sources are considered. Furthermore, the Bayesian framework allows the analysis of means and precisions of precipitation, even when they reveal characteristics, such as multi-modality and long tails.

1. Introduction

Climate being a highly non-linear chaotic system, the prediction of future climate involves high uncertainty. Despite these uncertainties, available evidence suggests prominent changes and impacts on environmental and ecological system (Fischlin et al., 2007; NRC, 2008). Changing of climatic distribution will affect the hydrological cycle (Minville et al., 2008; Srikanthan and McMahon, 2001; Xu and Singh, 2004; Ghosh and Majumdar, 2007) of a region by changing the pattern of precipitation, evaporation, transpiration rates, and soil moisture, which in turn may also affect the water resource characteristics in that region. Precipitation over India during late 20th century shows a statistically significant trend in different aspects (Kumar et al., 2006; Ghosh et al., 2012). The trends are prominent from seasonal precipitation to extreme precipitation. Analysis of seasonally accumulated rainfall during different seasons over India shows statistically significant trend, especially over the Indo-Gangetic Basin (IGB) (Fig. 1). Recent studies have identified anthropogenic emissions as the major cause of these trends over Central-India (Ramaswamy, 2009; Turner and Annamalai, 2012; Loo et al., 2015).

Assessment of climate change impacts on water resources consists of estimating a climatic variable projection on a global-scale, downscaling the global synoptic-scale climatic variables to local regional-scale hydrological variables, and computation of possible patterns of changes in hydrological variables for future water resource management or planning. Spatio-temporal behavior of synoptic-scale climate variables under the effect of variable concentration of greenhouse gases (GHG) in the atmosphere are commonly simulated by Coupled Atmosphere-Ocean Global Climate Models (AOGCMs) (IPCC, 2007; Prudhomme et al., 2003).

Statistical downscaling is relatively more popular in the studies of climate change impacts due to its straightforward design methodology, computational ease and ability to produce synthetic datasets of any desired length. Statistical downscaling uses statistical relationships between the predictors (AOGCMs) and regional scale predictants (variables of interest) to construct local-scale features from large-scale patterns. Hewitson and Crane (1992) explained the underlying assumptions which build the foundation of statistical downscaling methods. As the methodology incorporates historical observations of the variables of interest, it can carry

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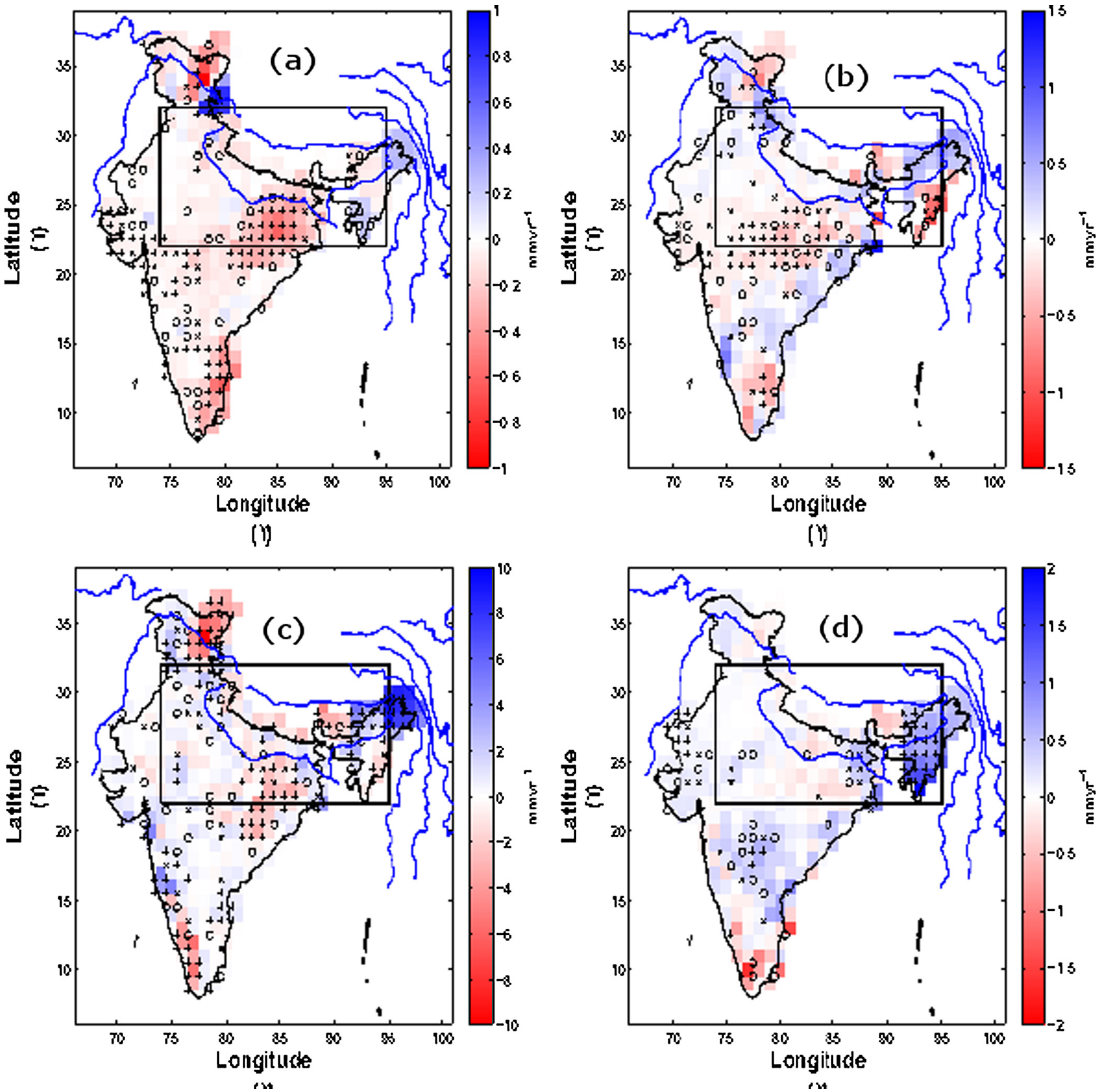

Fig. 1. Trends of Total (a) winter, (b) pre-monsoon, (c) monsoon and (d) post-monsoon rainfall over different grid points over India during 1901–2005.+ denotes trend with significance level less than 0.05, x denotes trend with significance level 0.1–0.05 and ○ denotes trend with significance level 0.2–0.1 in 2 tail t-test. CRU TS v3.00 data has been used to compute these trends.

the site-specific climatic signature inherently. This in turn makes it very robust in the study of climate change impact of any location.

Our limited understanding of geo-physical or bio-physical processes, together with incomplete knowledge of relevant processes and indefinite nature of future green-house gas emission scenarios (SRES), introduces uncertainties in the outputs of AOGCM. Uncertainty resulting from the ensembles of projections generated with multiple AOGCMs and scenarios is known as GCM-scenario uncertainty. For example, simplification during the parameterization of complex processes involved in atmospheric and oceanographic interactions, restrictive assumptions regarding climatic processes, inadequate spatial and temporal resolution result in a disagreement between AOGCMs over quantification of climate change at regional scale. Besides, performance of different AOGCMs for the estimation of future climate depends on the metric that is used to assess the strength and weakness of the model. A metric without proper generality can introduce large uncertainty in the future estimates of climatic variables (Wilby and Harris, 2006; Ghosh and Majumdar, 2007; Tebaldi and Smith, 2010). Considering these different uncertainties, output from a single AOGCM driven by a single Special Report on Emission Scenarios (SRES) storyline can only represent a single sample in a complex uncertain distribution. Thus, using a single AOGCM output to study the future impact of climate change can be misleading and unreliable as it cannot give