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Assessment of regional downscaling simulations for long term mean, excess and deficit Indian Summer Monsoons

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ABSTRACT

This study undertakes a comprehensive assessment of dynamical downscaling of summer monsoon (June–September; JJAS) rainfall over heterogeneous regions namely the Western Ghats (WG), Central India (CI) and North-Eastern Region (NER) for long term mean, excess and deficit episodes for the historical period from 1951 to 2005. This downscaling assessment is based on six Coordinated Regional Climate Downscaling Experiments (CORDEX) for South Asia (SAS) region, their five driving Global Climate Models (GCM) simulations along with observations from India Meteorological Department (IMD) and Asian Precipitation Highly Resolved Observational Integrated Towards Evaluation for Water Resources (APHRODITE). The analysis reveals an overall reduction of dry bias in rainfall across the regions of Indian sub-continent in most of the downscaled CORDEX-SAS models and in their ensemble mean as compared to that of driving GCMs.

The interannual variabilities during historical period are reasonably captured by the ensemble means of CORDEX-SAS simulations with an underestimation of 0.43%, 38% and 52% for the WG, CI and NER, respectively. Upon careful examination of the CORDEX-SAS models and their driving GCMs revealed considerable improvement in the regionally downscaled rainfall. The value addition of dynamical downscaling is apparent over the WG in Regional Climate Model (RCM) simulations with an improvement of more than 30% for the long term mean, excess and deficit episodes from their driving GCMs. In the case of NER, the improvement in the downscaled rainfall product is more than 10% for all the episodes. However, the value addition in the CORDEX-SAS simulations for CI region, dominantly influenced by synoptic scale processes, is not clear. Nevertheless, the reduction of dry bias in the complex topographical regions is remarkable. The relative performance of dynamical downscaling of rainfall over complex topography in response to local forcing and orographic lifting depict the value addition (30% over WG and 10% over NER, with a statistical significance of more than 5% level), when compared with the synoptic scale system induced rainfall over the plains of central-India.

1. Introduction

The occurrence of boreal summer monsoon rainfall, during June to September (JJAS), has various socio-economic impacts across south-Asia particularly over Indian sub-continent (Webster et al., 1998; Gadgil and Gadgil, 2006; Rajeevan and Nanjundiah, 2009). The southwest monsoon rainfall has large variability in spatio-temporal domains which can impact the economic growth of the country (Mooley and Parthasarathy, 1984; Kripalani et al., 2003). The frequent droughts and floods in the Indian subcontinent is the manifestation of the year to year variability of Indian Summer Monsoon Rainfall (ISMR, Krishnamurthy and Shukla, 2000). The studies of mean features and their variabilities in terms of excess and deficit monsoon episodes are of great importance especially based on the dynamically downscaled models.

Importantly, south-Asian summer monsoon evolves from inter hemispheric mass exchanges. The tropical and extra-tropical interactive feedback processes, among ocean, atmosphere and land, greatly modulate the moisture transport and monsoonal convection (Mohtadi et al., 2016). Interestingly, regions with high and complex topography such as the Himalaya and Western Ghats also modulate the spatio-temporal pattern of ISMR (Grossman and Durran, 1984; Priya et al., 2016). Earlier studies have brought out the crucial influence of strong (Goswami et al., 2006; Ghosh et al., 2012) and weak (Mishra and Singh, 2010) ISMR, particularly under climate change scenario as the extreme manifestations of the year to year variability. It is worth mentioning that various climate factors, such as ENSO (El Nino Southern Oscillation) and non-ENSO, are attributable to the strong and weak ISMR

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(Varikoden and Preethi, 2013; Varikoden et al., 2014). Modelling the climate processes, for accurately representing the complexities of south-Asian summer monsoon, is challenging and therefore, it has limitations (Kripalani et al., 2007). Particularly, the poor skills of the seasonal simulation, using current Global Climate Models (GCMs), of mean precipitation over intense convective regions such as the northern Bay of Bengal, northeast regions of Indian subcontinent and Western Ghats is attributable to inappropriate representation of complex topographies (Krishna Kumar et al., 2005; Kumar et al., 2006; Raju et al., 2015; Kumar et al., 2013; Kulkarni et al., 2013; Sabin et al., 2013).

Recent studies, using CMIP5 (Coupled Model Inter-comparison Project Phase 5) models, found that the coarser horizontal resolution fails to appropriately represent the coupling between regional convection and circulation, one of the key processes, in simulating regional mean climate (Byun and Hong, 2004; Sabin et al., 2013; Jayasankar et al., 2015; Sooraj et al., 2015). Also, the large spread among the CMIP5 simulations leads to uncertainty in capturing regional climate features (Huang et al., 2013). Sabin et al. (2013) reported that the finer resolution of space grids, zooming over desired region in the GCMs improved the representation of monsoon dynamics and heavy precipitation patterns over complex topographies. Ramu et al. (2016) also pointed out that the CFSv2 (Climate Forecast System version 2) with high resolution provide better skill in representing mean features of rainfall, its variance and its prediction while comparing to its version having coarse resolution.

The above discussed limitations of GCM simulations, using CMIP5 datasets to get insight into regional atmospheric characteristics, motivated us to look into dynamical downscaling as an investigative tool. The higher resolution climate simulations using appropriate combination of Global and Regional Climate models generate downscaled regional climate features which are useful for planners, hydrologists, farmers and fisherman. In this dynamical downscaling process the better representation of small scale topography and better physical processes is crucial. The idea behind using Regional Climate Models (RCMs) is to improve the regional features by allowing resolved convective processes of Indian Summer Monsoon (ISM) simulated by global models. A number of studies have been carried out to test the ability of RCMs to simulate annual and seasonal mean ISM features using GCMs/reanalysis data as lateral boundary conditions (e.g. Bhaskaran et al., 1996; Vernekar and Ji, 1999; Ratnam and Kumar, 2005; Dash et al., 2006; Raju et al., 2015). The above studies indicate that the improvement in the simulation of spatial and temporal distribution of mean monsoon precipitation characteristics is due to better representation of orography, land cover and land-sea contrasts in regional models.

Recently, World Climate Research Programme (WCRP) initiated Coordinated Regional Climate Downscaling Experiments (CORDEX), to assess the impact of regional climate change on human and natural systems (Giorgi et al., 2009) over various subcontinents. Mishra et al. (2014) analysed CORDEX South Asia (CORDEX-SAS) products and compared with driving CMIP5 simulations and they brought out the limitations of dynamical downscaling. Ghimire et al. (2015) studied the rainfall characteristics over Himalayan region using the CORDEX-SAS experiments and could illustrate the value addition. High altitude regions show a wet bias in CORDEX-SAS models while comparing with their driving GCMs (Dimri et al., 2013). In the back drop of global warming, depicting the weakening of global monsoon circulation and rainfall (Krishnan et al., 2016), would be very interesting to carefully analyse the CORDEX-SAS simulations over three regions WG, CI and NER to understand the relative influence of local and large-scale factors on dynamical downscaling. Particularly it would be challenging to understand this regional coupling during long term mean, excess and deficit monsoon episodes over Indian subcontinent. Section 2 describes the data and methodology while Section 3 presents the spatio-temporal characteristics of the observed and simulated monsoon rainfall over WG, CI and NER regions. Section 3 also highlights the value addition of the CORDEX-SAS simulations, relevant to local and large-scale processes. Section 4 discusses the major conclusions and future scope.

2. Data and methodology

The present study uses rainfall data from both the observation and the modelling experiments. The observational data set used in the study is APHRODITE (Asian Precipitation Highly Resolved Observational Integrated Towards Evaluation for Water Resources) for the evaluation of the model data set. The APHRODITE is a daily precipitation data available on $0.5^0 \times 0.5^0$ latitude-longitude grid from 1951 to 2007. This high resolution rainfall data developed from the rain gauge observations collected from a number of rain gauges varying from 5000 to 12,000 well distributed stations across Asia (Yatagai et al., 2009, 2012). The data set is generated using 2500 rain gauge stations widely distributed across India and the data set has undergone quality control check for errors and inconsistencies (Yatagai et al., 2012). Wind at 850 hPa are analysed using National Centres for Environmental Prediction/National Centres for Atmospheric Research (NCEP/NCAR) reanalysis data set. This data set has a spatial resolution of $2.5^0 \times 2.5^0$ latitude-longitude grid with daily temporal resolution (Kalnay et al., 1996). Daily gridded IMD (Indian Meteorological Department) rainfall data set with a spatial grid resolution of $0.25^0 \times 0.25^0$ from 1951 to 2007 during the monsoon period is also used in order to compare with APHRODITE rainfall data. The rainfall data from over 6955 rain gauge stations in India was considered for interpolating (Shepard, 1968) to gridded rainfall data (Pai et al., 2014).

In addition to the observational data, we used model simulation data sets for both the GCMs and the RCMs. The GCMs are driving models to the CORDEX RCMs over South Asian region. CORDEX is a programme under the aegis of WCRP to improve the regional climate representations under a changing climate (Fernández et al., 2010). The model details and their references are given in Table 1. Spatial resolution of CORDEX-SAS data is $0.44^0 \times 0.44^0$ latitude-longitude grid (∼50 km horizontal resolution) with a temporal resolution of a day. In the present study, the entire model data set have been regridded to match the APHRODITE data grid for better comparison. The model data set for the historical period are available from 1951 to 2005 except for the model REMO2009 (MPI). For this model, historical data is available from 1961 to 2005. We used five driving GCMs (ICHEC, GFDL, IPSL, LMDZ4 (IPSL) and MPI) and six CORDEX RCMs and they are RCA4 (ICHEC), RegCM4 (GFDL) LMDZ4 (IPSL), RegCM4 (LMDZ4), CCLM4 (MPI) and REMO2009 (MPI). In the nomenclature of the CORDEX models, the bracket represents the driving GCM. Here, the GCM MPI is given as the driving model for CCLM and REMO2009. The CORDEX model LMDZ4 (IPSL) is given as the driving model for another regional model RegCM4 in the CORDEX experiment.

The classification of excess and deficit JJAS rainfall episodes, for both the observations as well as model simulations, is carried out based on the area averaged rainfall over Central Indian region (75^0E–84^0E & 18^0N–26^0N). The excess and deficit episodes were categorised based on the rainfall departure of area averaged long term mean rainfall over Central India. The excess (deficit) year is considered when the percentage of rainfall departure is more than 10% (less than −10%). The statistics of the rainfall and number of episodes of the different models are given in Table 2. The table summarises that the number of excess and deficit episodes do not coincide with that of the observation because the models run in the virtual time frame without any external data assimilation. The CORDEX model RCA4 (ICHEC) and LMDZ4 (IPSL) show almost good agreement with the observation in average mean rainfall and its percentage of departure in both the excess and deficit episodes. Further, we selected three regions (marked in Fig. 1c) namely (i) the Western Ghats (WG) characterised by the interaction between large-scale flow with narrow, complex orography and the convection is dominantly influenced by orographic lifting (Grossman and Durran, 1984), (ii) plains of Central India (CI) influenced by large-scale synoptic system with stratified convection (Rao et al., 2010), and