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Impact of initial and boundary conditions on regional winter climate over the Western Himalayas: A fixed domain size experiment

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ABSTRACT

The Western Himalayas during winter receives precipitation due to the eastward moving low pressure synoptic weather systems, called Western Disturbances (WDs) in Indian meteorological parlance. The complex Himalayan topography, sparse observational data, less understanding of physical processes, etc. form many interesting research questions over this region. One of the important research goals is to study the change in the winter (Dec., Jan. and Feb. — DJF) climate over the Himalayas. In the presented study with modelling efforts having varying initial and boundary conditions (ICBC) with same model physics option is attempted to provide a comment on important physical processes pertaining to precipitation and temperature fields. A 22 year (1980–2001) simulation with Regional Climate Model version 3 (RegCM3) forced with National Centre for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) reanalysis 1 (NNRP1), NCEP/NCAR reanalysis 2 (NNRP2) and European Centre for Medium Range Weather Forecast 40 Year reanalysis (ERA40) as three different ICBC is carried out. The present study focuses on the winter climatology of the main meteorological parameters viz., temperature, precipitation and snow depth and interannual variability of winter seasonal precipitation. The model shows overestimation of seasonal average precipitation and underestimation of seasonal average temperature fields over the Western Himalayas in all the three model simulations. The interannual variability of precipitation and temperature over this region is nicely captured by the model. The model simulation with NNRP2 as the ICBC shows more realistic results. In addition the ensemble mean of the three simulations has shown improved results and is closer to the abovementioned simulation. Precipitation bias explained in terms of the higher vertical integrated moisture flux and transport shows strong convergence zone over and along the southern rim of the Indian Himalayas. The energy balance over the Western Himalayas explains the cause of lower temperature in the model simulation and the cause of lesser convective precipitation and evaporation.

1. Introduction

The Himalayas are characterized by complex cascading ranges of mountains having west to east stretches starting from near Afghanistan in west to the northeast India in the east. The altitudinal variation and orientation of these mountain ranges make their role complex and define the climate of the region. Also, the precipitation characteristic is not uniform along the stretch; the Western Himalayas (WH) gets the precipitation during winter due to the WDs and the eastern Himalayas (EH) gets the precipitation mainly during the Indian summer monsoon (ISM). The Himalayan region is termed as the third pole (Schild, 2008) and water tower of Asia (Xu et al., 2009). This is because the Himalayas are the source of fresh water to many rivers of many countries surrounding it and hence influence lives of the millions of people in Indian subcontinent. So the study of the regional climate of the Himalayan region becomes important. Due to heterogeneous topography and variable landuse, it is very difficult to establish many weather stations over these regions and to maintain it subsequently. Hence these regions are data sparse. The climate modelling/downscaling could be one of the options to understand the meteorological processes which are taking place over this complex topographic terrain. Fowler et al. (2007) showed that the dynamical downscaling provides far better results than the statistical methods. Generally the global climate models (GCMs) are integrated at a very coarser resolution in the order of 250 to 300 km horizontal resolution. This results in the loss of the climatic information over a small topographically complex region and subgrid processes. GCMs take longer time period for the simulation and huge computational resources. So regional climate models (RCMs) are widely used as they provide high resolution regional climate information from the GCMs or reanalysis (Giorgi, 2006) for the impact assessment of the climate and the detailed study of the atmospheric processes (Bhaskaran et al., 2012). The higher resolution information from the RCMs improves the understanding of the atmospheric processes associated with mountain orography, land cover and land–sea contrast (Rupa Kumar et al., 2006; Lucas-Picher et al., 2011). The problem of dynamic downscaling is that systematic

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error in the GCM or reanalysis may be transmitted to the RCMs (Giorgi et al., 1992) because the input to the RCMs comes from the GCMs or reanalysis.

While dealing with the RCMs it is necessary to determine a suitable domain for proper representation of the mesoscale processes. Various scientists have worked to find out a suitable domain for a regional climate model simulation over their region of interest. Bhaskaran et al. (1996) took three different domains for RCM simulation forced from a single GCM over the Indian region to study the ISM. Their study shows that the precipitation in the RCMs is higher due to string vertical motion arising in the RCM due to finer resolution and the RCMs are relatively insensitive to domain size over the Indian monsoon region. Bhaskaran et al. (2012) found out that a model could have uncertainty in downscaling over two different domains although they have similar large scale flow and no single domain is suitable for regional model application for climate change for all relevant sub regions within the model domain. Yang et al. (2011) used different ICBCs but over a fixed domain to study the East Asian summer monsoon. They found that the precipitation bias is mainly due to the different characteristic of the moisture information or the uncertainty in the reanalysis dataset. Browne and Sylla (2011) showed that the domain size has a significant effect on the RCM simulation and for West Africa they suggested that the user must include large portion of the tropical Atlantic Ocean and regions upstream of Sudanese highland for better representation of zonal moisture advection and African easterly waves in the RCMs.

Dimri and Ganju (2007) have provided the preliminary analysis of a winter season using regional climate over the WH. Dimri and Niyogi (2012) showed the better representation of subgrid scale processes within regional climate model framework during Indian winter monsoon (IWM) over the WH. The atmospheric water budget plays a major role in deciding the precipitation over a region. Dimri (2007) has provided comprehensive analysis on meridional transport of moisture over the WH during winter. The winter water balance over the WH region and the melting of the deposited winter snow in the spring time are the major sources of the water which feed the rivers (Thayyen and Gergan, 2010). The atmospheric water budget and its variability over the Western Himalayas are studied by Dimri (2012). Similar studies were conducted by Prasanna and Yasunari (2009, 2010) over different domains for different periods of study using different models. Dimri and Dash (2012) using station data showed that the surface air temperature over the WH is increasing as the percentage number of warm days is increasing in the last 30 years as well. Diodito et al. (2012) found an increasing trend of the temperature over the Himalayas. Many scientists and researchers have contributed to the understanding of the winter time WH climate, but still there are many grey areas to be understood over this region.

With reference to the above discussion and work by various researchers, the present study aims to understand the effect of the changing ICBCs on the winter (DJF) regional climate of the WH; also, to find out which reanalysis dataset as ICBC is showing more realistic results in simulating climatology and interannual variability of different meteorological parameters during IWM. This study also looks in to the explanation for the reason of the model biases which are inherent to the model simulated results. The analysis of surface energy balance is taken into account which plays a major role in defining the surface temperature, evaporation and convective activities which are similar to the study of Krishnamurthy and Biswas (2006) where they analysed the different phases of monsoon over central India. The WH is chosen as the study area because of its complexity in terrain and most of the RCMs are not able to capture the climatic processes over these regions. The climatic information from the RCM for DJF may contribute to the agricultural preparedness, tourism industry, transport, source of moisture to this region, defence as well as the water resources management over this region. The methodology consisting model detail, experimental design and data used is explained in Section 2. Section 3 provides results and discussion and the concluding remarks are given in Section 4.

2. Methodology

2.1. Experimental design and dataset used

The Regional Climate Model version 3 (RegCM3) model framework is used to carry out these three simulations with three different ICBCs (Pal et al., 2007). The dynamical core of the RegCM3 is similar to that in the hydrostatic version of the Mesoscale Model version 5 (MM5, Grell et al., 1994). The model uses CCM3 radiation parameterization scheme of Kiehl et al. (1998). Biosphere–Atmosphere Transfer Scheme (BATS1E) of Dickinson (1993), which includes the role of vegetation and exchange of water vapour, momentum and energy between land surface and atmosphere, surface scheme over the ocean of Zeng et al. (1997), planetary boundary scheme by Holtslag and Boville (1993) and convective parameterization scheme of Grell (1993) is used in the modelling framework. The United States geological Survey (USGS) elevation, USGS Global Land Cover Characterization (GLCC) landuse and vegetation data are used in the course of model simulation. Global Sea Ice and Sea Surface Temperature (GISST) analyses of the Hadley Centre for Climate Prediction and Research, U.K. (Rayner et al., 1996) are considered in model simulations.

Three suits of model simulation are made for 22 years (1981–2002) with RegCM3 using ERA40 at 2.5° × 2.5° horizontal resolution with 23 vertical pressure levels (Uppala et al., 2005), NNRP1 at 2.5° × 2.5° horizontal resolution with 17 vertical pressure levels (Kalnay et al., 1996) and NNRP2 at 2.5° × 2.5° horizontal resolution with 17 vertical pressure levels (Kanamitsu et al., 2004) as ICBCs. All the boundary conditions used in the simulations are updated in every 06 h. Model horizontal resolution is fixed at 60 km. The model domain is the same for all the three simulations and consists of 96 grid points along east–west direction and 94 grid points along north–south direction with centre at 20°N 75°E. 18 vertical model layers are chosen for the simulation. The model domain of simulation is shown in Fig. 1 and model details are provided in Table 1.

Climate Research Unit (CRU) (TS2.1; Mitchell and Jones, 2005) precipitation and temperature fields (0.5° × 0.5°) are used to validate the model outputs. The precipitation fields are also validated with the Asian precipitation highly resolved observational data integration towards the evaluation of the water resources (APHRODITE; Yatagai et al., 2009) gridded data (0.25° × 0.25°) (APH hereafter) and Global precipitation climatology centre (GPCC; Rudolf and Schneider, 2005) data (2.5° × 2.5°). The snow depth and the different energy fluxes data of the model are validated against snow cover data and energy flux data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA from their website http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.monolevel.mm.html#detail.

The model integration starts from 01 Nov. 1980 in all the simulations. The output of DJF is analyzed because during winter the WH; which is the area of interest (AOI) for the study (marked in rectangle over the model domain in Fig. 1), gets precipitation due to eastward moving WDs (Dimri and Mohanty, 2009). The domain of AOI ranges from 65°E to 85°E along longitude and 25°N to 39°N along latitude. The larger domain is selected for the study so that larger scale flow and small grid scale features over the AOI could evolve (Jones et al., 1994). Also the AOI is placed well outside the boundary to avoid the unrealistic responses to internal forcing (Seth and Giorgi, 1997).

2.2. Hydrological balance

The formula for the atmospheric water budget is given by Peixoto and Oort (1992) and this equation is used by many scientists and researchers to calculate the water balance over a region (Prasanna and Yasunari, 2009, 2010; Dimri, 2012).

$$\langle \partial W/\partial t \rangle + \langle \nabla . Q \rangle = \langle E - P \rangle \quad (1)$$