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Dynamic downscaling over western Himalayas: Impact of cloud microphysics schemes

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ABSTRACT

Due to lack of observation data in the region of inhomogeneous terrain of the Himalayas, detailed climate of Himalayas is still unknown. Global reanalysis data are too coarse to represent the hydroclimate over the region with sharp orography gradient in the western Himalayas. In the present study, dynamic downscaling of the European Centre for Medium-Range Weather Forecast (ECMWF) Reanalysis-Interim (ERA-I) dataset over the western Himalayas using high-resolution Weather Research and Forecast (WRF) model has been carried out. Sensitivity studies have also been carried out using convection and microphysics parameterization schemes. The WRF model simulations have been compared against ERA-I and available station observations. Analysis of the results suggests that the WRF model has simulated the hydroclimate of the region well.

It is found that in the simulations that the impact of convection scheme is more during summer months than in winter. Examination of simulated results using various microphysics schemes reveal that the WRF single-moment class-6 (WSM6) scheme simulates more precipitation on the upwind region of the high mountain than that in the Morrison and Thompson schemes during the winter period. Vertical distribution of various hydrometeors shows that there are large differences in mixing ratios of ice, snow and graupel in the simulations with different microphysics schemes. The ice mixing ratio in Morrison scheme is more than WSM6 above 400 hPa. The Thompson scheme favors formation of more snow than WSM6 or Morrison schemes while the Morrison scheme has more graupel formation than other schemes.

1. Introduction

The climate of the Himalayas is quite complex and a number of studies have been carried out on the large-scale and regional aspects of the Himalayan hydroclimate using observed data (Negi et al., 2009; Kar and Rana, 2014; Shekhar et al., 2010; Tiwari et al., 2016a, 2016b, 2017). However, very few modelling studies have been carried out to simulate the weather and climate processes in the western Himalayas (e.g. Dimri et al., 2004; Dimri and Chevuturi, 2014; Tiwari et al., 2015; Kar and Tiwari, 2016). Tiwari et al. (2014) examined the skill of precipitation predictions from several global climate models (GCMs) over north India during winter season and found that the coarse resolution GCMs have difficulty in predicting rainfall amount especially over the region with sharp gradient in orography. Therefore, dynamic downscaling using high-resolution regional models is necessary to understand the climate and its variability over such regions. However, the main challenges in weather and climate models lie in the selection of proper cumulus parameterization and cloud microphysics schemes for the Himalayas.

Dynamic downscaling studies are mostly carried out using either Regional Climate Model (RegCM) or the Weather Research and Forecast (WRF) model. Several sensitivity studies using the WRF model with different microphysics options, land surface schemes and convection schemes have been performed over many regions including over India (Flaounas et al., 2010; Kim and Wang, 2011; Raju et al., 2011 and Crétat et al., 2012). However, most of the sensitivity studies using high-resolution regional models are to simulate the extreme events over the Indian region. Patil and Kumar (2016) examined the sensitivity of the WRF model to different physical parameterization schemes to identify a combination of the best physics options suited for this region during the passage of a western disturbance (WD) over northwest India. Rajeevan et al. (2010) found that there are major differences in the simulations of a severe thunderstorm in southwest India among the cloud microphysics schemes, in spite of using the same initial and boundary conditions and model configuration. Kar and Tiwari (2016) have simulated the extreme rainfall events of September 2014 over Jammu and Kashmir; India using the WRF model. Dimri and Chevuturi (2014) have studied the model sensitivity with five microphysics options during

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Table 1
Configuration for the model experiments.

Experiment	Microphysics	Convection scheme
CNTL	WRF single-moment 6-class (WSM6) (Hong and Lim, 2006)	Grell-Devenyi (Grell and Devenyi, 2002)
Morrison	2-moment (Hong and Pan, 1996)	Grell-Devenyi
Thompson	Single moment and mixed phase (Thompson et al., 2008)	Grell-Devenyi
KF	WSM6	Kain Fritsch (Kain, 2004)

western disturbance over northwest India. The above studies refer to model simulation in the scale of days and pertain only to the specific events considered.

Kar et al. (2014) used the WRF model to examine the impact of land surface processes on the south Asian monsoon simulations and found that the model with NOAH land surface scheme was able to simulate the main features of the monsoon hydroclimate. Tiwari et al. (2015) used a regional climate model (RegCM) and examined the influence of land surface processes on the simulated climate of the western Himalayas. Sinha et al. (2013) and Sinha et al. (2015) have carried out sensitivity studies of convective schemes in simulations of summer and wintertime precipitation over the western Himalayas respectively using the RegCM. Dutta et al. (2009) have investigated the impact of vegetation parameters on the simulation of seasonal monsoon rainfall over the Indian subcontinent using the MM5 model. The WRF model was successfully used for regional climate downscaling by Givati et al. (2012). Systematic improvement in physical parameterization schemes have been made to utilize the WRF model for climate simulation (e.g. Climate WRF, Liang et al., 2012). Cossu and Hocke (2014) have examined the impact of different microphysical parameterization schemes in the WRF model on orography induced precipitation and the distributions of hydrometeors and water vapor.

Complex topography and scarcity of observed data over the Himalayas is a serious challenge for the modelling community to model and to predict the weather and climate over Himalayan region. Due to lack of our understanding of complex precipitation processes (snowfall and rainfall) over the region with high mountains (> 5000 m or 6000 m), only few attempts to dynamically downscale the observed climate to higher resolution for this region have been made. There is a need to make systematic dynamic downscaling studies of the Himalayan hydroclimate using high-resolution regional models. However, before such a study is undertaken, it is important to identify optimum configuration of the regional model and identify suitable physics options.

The main purpose of present study is to examine and document the sensitivity of the WRF model with different convection and microphysics schemes and to choose the best physics options for the western Himalayan region and Satluj river basin. Section 2 of the paper explains data used, the model configuration and sensitivity experiments. Simulations of hydroclimate are described and compared with available observation in Section 3. Results of the sensitivity experiments using the WRF model are presented in Section 4. The study is concluded in Section 5.

2. The data and model used

2.1. Data

Six hourly high resolutions (0.75° × 0.75°) European Centre for Medium-Range Weather Forecast (ECMWF) Reanalysis-Interim (ERA-I) data (Dee et al., 2011) have been used as initial and boundary conditions of the WRF model as well as for model diagnostics. The observed gridded India Meteorological Department (IMD) precipitation data at 0.25° × 0.25° spatial resolution (Pai et al., 2013) is used to compare model simulations over the Indian area. In situ observed snowfall and rainfall data of Bhakra Beas Management Board (BBMB) observing stations have also been used. BBMB is one of the nodal agencies in India that maintains the snowfall rainfall and temperature stations over higher elevation region in Satluj basin (shown in Fig. S1b in Supplementary material). Tiwari et al. (2016a) have used data of 17 snowfall stations of BBMB to study the snow accumulation and melt in Satluj basin. This study also utilizes gridded temperature data (1° × 1°) from IMD (Srivastava et al., 2009) over the Indian region.

2.2. The model configuration

The model used for the present study is the WRF model version 3.4.1 (Skamarock et al., 2005). The microphysics scheme of the model controls the formation of cloud droplets and ice crystals, their growth and fall down as precipitation. Out of many microphysics schemes

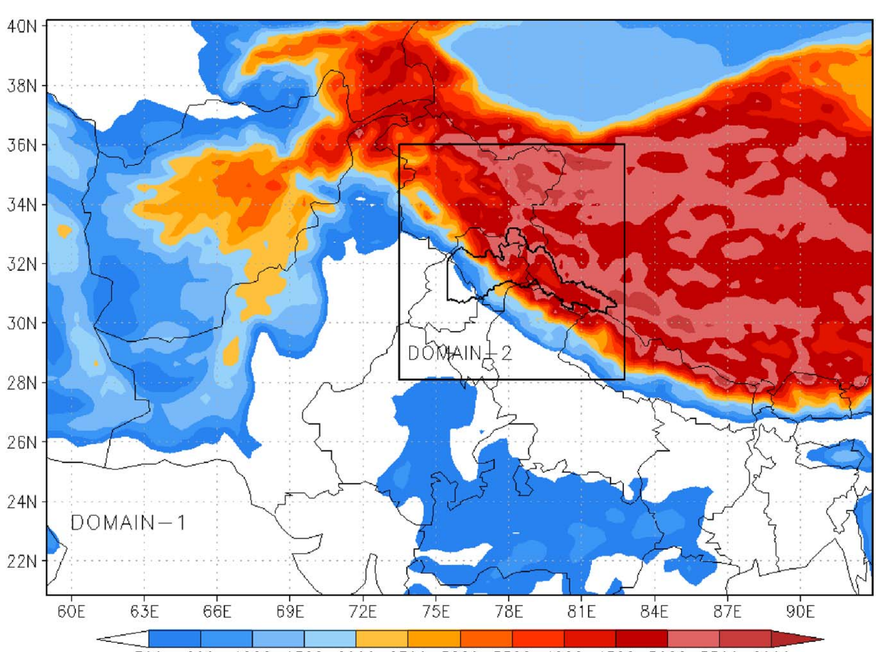

Fig. 1. Two nested domains (Domain-1 and Domain-2) of the WRF model used in the present study. The topography of the domain-1 at 24 km and domain-2 at 8 km horizontal resolution is also shown.