Downscaling Ability of PRECIS over Snow-Covered Areas of Pakistan

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Abstract

The regional climate models are being used to investigate the future projections of climate change and their impacts in developing and developed countries of the world in the recent era. The present study is carried out to study the downscaling ability of a regional climate model named PRECIS (Providing Regional Climates for Impacts Studies) of Hadley Centre, Meteorological Office, U. K in mountainous regions of Pakistan. The model is applied to the Snow-covered areas of Pakistan with two different horizontal resolutions of 25 km and 50 km to study its ability to simulate the climate of regions of complex topography. The simulations of the model are compared with the observed meteorological data and CRU (Climate Research Unit) gridded data set. The results show that both simulations of PRECIS overestimate mean temperature for the Snow-covered areas of Pakistan. However, the difference between the model's simulated temperature and the observed temperature is less for the 25 km simulation as compared to that of 50 km simulation. The comparison of the model used altitudes and actual altitudes shows that the main factor for these large biases is the topography of the model. The bias in the model may be decreased by updating the topography of the model which will enhance the confidence in the future predications provided by the model.

Key Words: RCM, PRECIS, baseline, mean temperature, altitude, Snow-covered areas of Pakistan.

Introduction

Global Climate Models (GCMs) are considered as the best tools to study the future climate change. But when it comes to study the climate change for adaptation and impact studies the GCMs fail to provide the detailed information of a region at finer scale, hence Regional Climate Models (RCMs) which allow the climate change studies at finer scale are used instead of GCMs (Hudson et al., 2002). Providing Regional Climates for Impacts Studies (PRECIS) is a regional climate model developed by the Hadley Centre of Meteorological Office, U.K.

Pakistan is an agrarian country with different types of climates ranging from Humid to extremely Arid zones. Two third of the whole country has arid type of climate while in northern areas of Pakistan have various belts of similar climatic characteristics varying from very humid to extremely arid (Chaudhry et al., 2004). The high mountainous regions in the north of Pakistan are very important for the climate and economy of Pakistan. These mountainous regions include the famous Himalya-Karakorum-Hindukush (HKH) region and other high mountains. These regions protect the inhabitants from the cold surges in the winter and in summer they confine the monsoon precipitation to the south Asian region and also they are the life line of our rivers especially the Indus river (Rasul et al., 2008).

The northern areas of Pakistan have very complex topography. Regional climate model PRECIS is being applied throughout the world for impact studies like in South America (Lincoln et al, 2009), China (Yinlong et al., 2006) and India (Kumar et al., 2006). In Pakistan the RCM PRECIS is also being used for impact studies. Islam et al., (2009) have performed the validation of the PRECIS with both observed and CRU data for whole Pakistan. They selected 17 meteorological stations and compared the output of baseline period. The findings of this study describe that as a whole the model possess strong capacity to simulate the baseline period climate. However the study suggests the lack of ability of the model to simulate the climate of regions with complex topography like in the northern parts of Pakistan, however no effort is made to study the reason of these large biases.

The aim of this study is to focus only to the Snow-covered areas of the country to investigate the performance of the model at different horizontal resolutions. Two simulations are performed for the analysis: simulation-A refers to the experiment of PRECIS run with the horizontal resolution of 50 km

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and the simulation-B refers to the experiment of PRECIS run with the horizontal resolution of 25 km. An effort has also been made to explore the possible reasons of the large biases in the model for the complex topographic regions. The large biases may be reduced if the altitudes used by the model are corrected.

Data and Methodology

Surface air mean temperature provides essential input to different spatially distributed models which determine evapotranspiration, snowmelt and more processes from the surface air mean temperature (Dodson et al., 1997). Surface air mean temperature is the parameter selected for the study. The behavior of regional climate model PRECIS over the Snow-covered areas of Pakistan have been observed using the data of 6 meteorological stations; Astore, Gilgit, Bunji, Gupis, Chitral and Skardu. The baseline period of 1961-1990 has been selected for the analysis. The daily mean temperature data for the above mentioned meteorological stations has been taken from Pakistan Meteorological Department for the baseline period 1961-1990.

The output of HadAM3P (Third Generation GCM of Hadley Centre) model (with a horizontal resolution of 150 km) of UK Met Office has been used as the boundary condition for the PRECIS, for both simulations i.e. Simulation-A and Simulation-B. The gridded data set of Climate Research Unit (CRU) from the climate and research unit of the University of East Anglia has been used for the period1961-1990 on monthly basis with the horizontal resolution of 0.5˚ x 0.5˚ (~50 km).

PRECIS is a regional climate model developed by Hadley Centre of UK Met Office and it can be run on a simple Personal Computer (PC) under the Linux operating system (OS). It is a hydrostatic, primitive equation grid point model. There are 19 vertical levels of pressure and 4 levels in the soil (Jones et al., 2004). The model uses the output of HadAM3P of Hadley Centre, UK for its lateral boundary conditions. The horizontal resolution of the global model is 150 km. Domain for the experiment is South Asia. The experiment is set from 1960-1990 as the model takes one year as spin-up time to allow the land and atmosphere processes to adjust and reach a mutual equilibrium state. Time to complete the experiment depends on the computing capacity of the computer on which the model is run.

The output from the model PRECIS is in post processing (PP) format under the $ARCHIVE/runid/stash-code directory, where runid is the name of the experiment and stash code is a five digit number used by PRECIS model to represent the different parameters for example the stash code for mean temperature is 03236. Naming convention of files is studied to get the desired annual files of temperature from the output. These pp format output files are first regrided to regular latitude longitude grid, and then converted to Network Common Data Format (NetCDF). The GrADS software and GrADS scripting is used to obtain the point data for all considered stations for the period 1961-1990. Microsoft Excel is used to arrange the data, making graphs and finding the bias between the model and the observed data sets.

Method of Comparison

The daily data of mean temperature obtained from the meteorological stations was calibrated for errors and missing values. This observed data was then averaged on annual basis in Microsoft Excel. Monthly data from Climate Research Unit (CRU) was also extracted through GrADS and averaged for generating annual time series of all the stations used in the study. All the three data sets (Observed data, CRU data and PRECIS/Model data) were compared in order to find the relation among these data sets. The difference between the observed and the model value i.e. bias was calculated for all 6 stations.

Results and Discussion

Graphs show the annual mean temperatures plotted among the observed, CRU, PRECIS_25 km (biased) and PRECIS_50 km (biased) for the snow-covered areas of Pakistan. The biases calculated for CRU, simulations A and B are shown in the Table 1 along with the details of latitude and longitude used by both simulations. For the meteorological station of Astore all the three data sets have shown almost same increasing and decreasing trends in the annual mean temperature when compared with the observed annual temperature values as shown in Figure 1. The curves produced by simulation-A and simulation-B are almost same which is because of the latitudes and longitudes used by both simulation as shown in Table 1. The longitude is same but the latitude is 0.25 degrees more in case of simulation-A. The girded data set CRU is also having bias for these regions but less than that of PRECIS for both simulations. All these three data sets have underestimated the mean annual temperature.

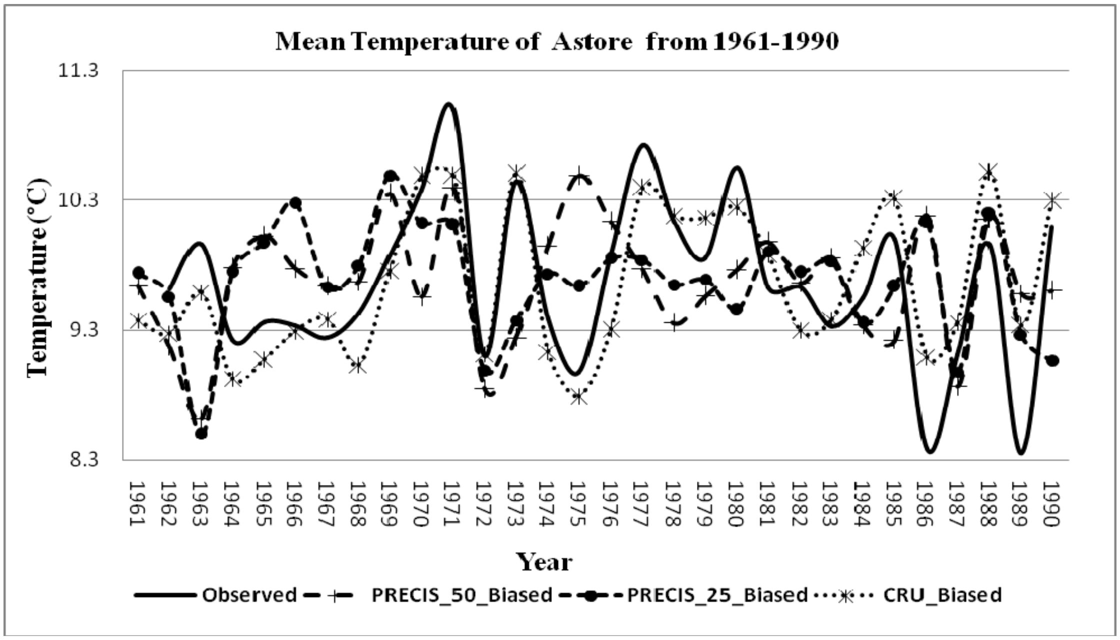

Figure 1: Mean Temperature of Astore from 1961-1990 and their comparison with the Observed, CRU, PRECIS (25 km resolution) biased and PRECIS (50 km resolution) biased

For meteorological station of Bunji, the annual mean temperature for the baseline period has been shown in Figure 2(a). Precis_25 and Precis_50 have almost same curves for the whole period of simulations however the comparison with the observed and CRU shows that there is no strong relation among these data sets and that's why the bias for this station is highest among all the stations. The station with the largest bias for CRU and Simulation-B is Bunji with the bias of 20°C and 15.54°C respectively.

Both simulations have successfully simulated the annual mean temperatures of Chitral as shown in Figure 2(b). Increasing and decreasing trends are very well captured by the model. The bias for Simulation-B and CRU for Chitral has been recorded minimum as shown in Table 1.

The results suggest that the annual variability in the mean temperature is well captured by the PRECIS for all the stations in most of the years of the baseline period but there are some years in the baseline when the behavior of the model is against the CRU and Observed data (for example the year 1975-76 for Astore and Chitral, year 1962-63 for Bunji, Gilgit, Gupis and Skardu); even there are years when the simulation-A and simulation-B are of different behavior (for example the year 1975-76 for Skardu).The station with the largest bias for CRU and Simulation-B is Bunji with the bias of 20°C and 15.54°C respectively. The reason for this large bias may be the altitude used by the Simulation-B as shown in Table 2. The station with the largest bias for the Simulation-A is Gilgit with the bias of 19.30°C as shown in Figure 3.

On the other hand the station with the minimum bias is Astore (Chitral/Skardu), for Simulation-A (Simulation-A/CRU).Figure 4 shows comparison of mean temperature for all the four data set used in this study. The model has successfully captured the increasing and decreasing trends of mean temperature but with the biases. The altitude seems to be the dominant factor for these biases. The higher resolution of the model has not reduced the error as a whole. To study this issue, we have considered two points 1: latitude and longitude of the stations, and 2: the altitude of the stations. The latitude and longitude of the stations in actual and for both the simulations are shown in Table2.It is clear that the latitude and longitude used by the model simulations are different by the actual one and this may increase the error as the regions of our study have complex topography and a small increase in either latitude, longitude or both may deviate the location point on a top hill or bottom of hill which effects the temperature so as a result the error is generated.

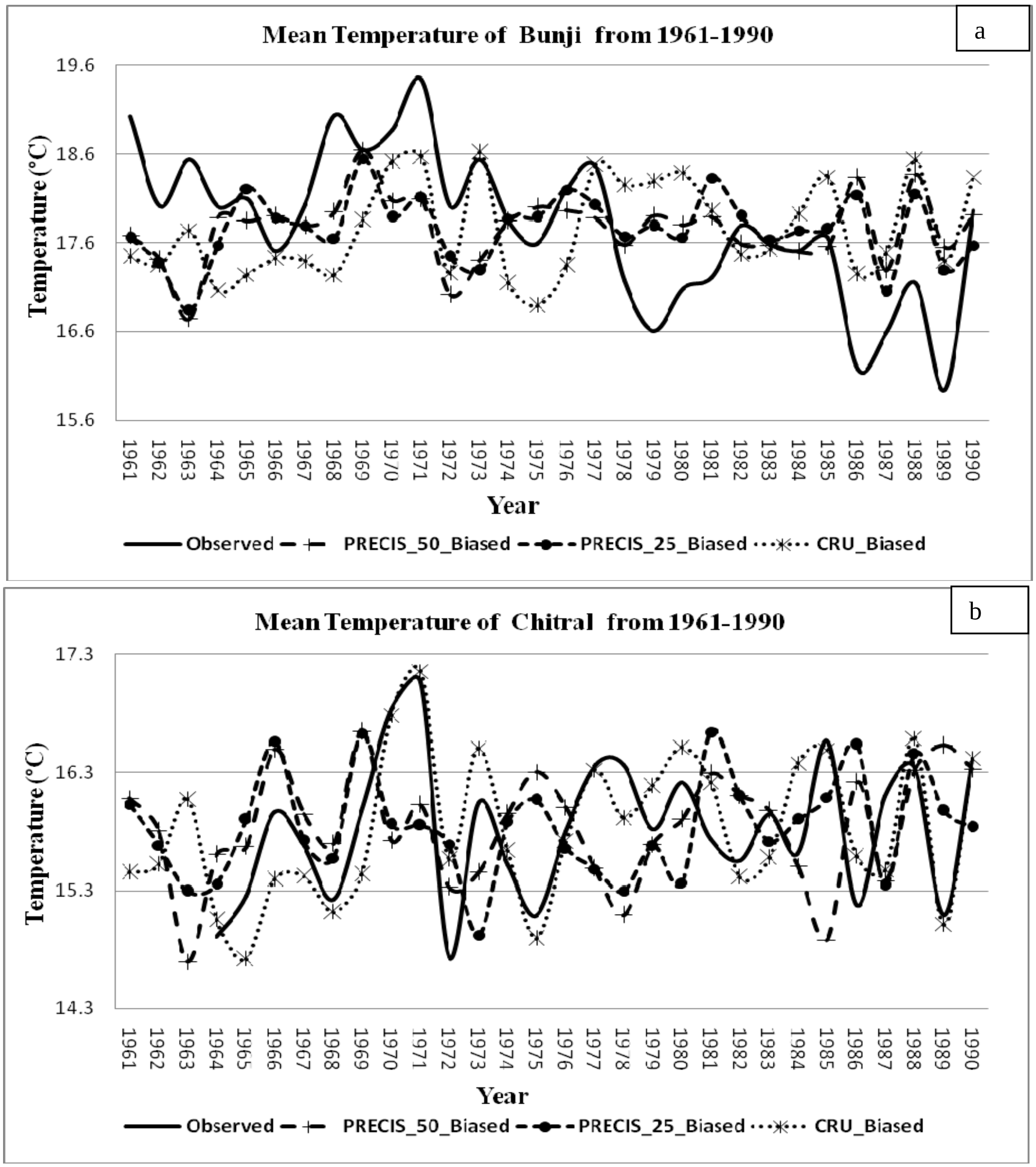

Figure 2 Mean Temperature of **(a)** Bunji and **(b)** Chitral from 1961-1990; and their comparison with the Observed, CRU, PRECIS (25 km resolution) biased and PRECIS (50 Km resolution) biased

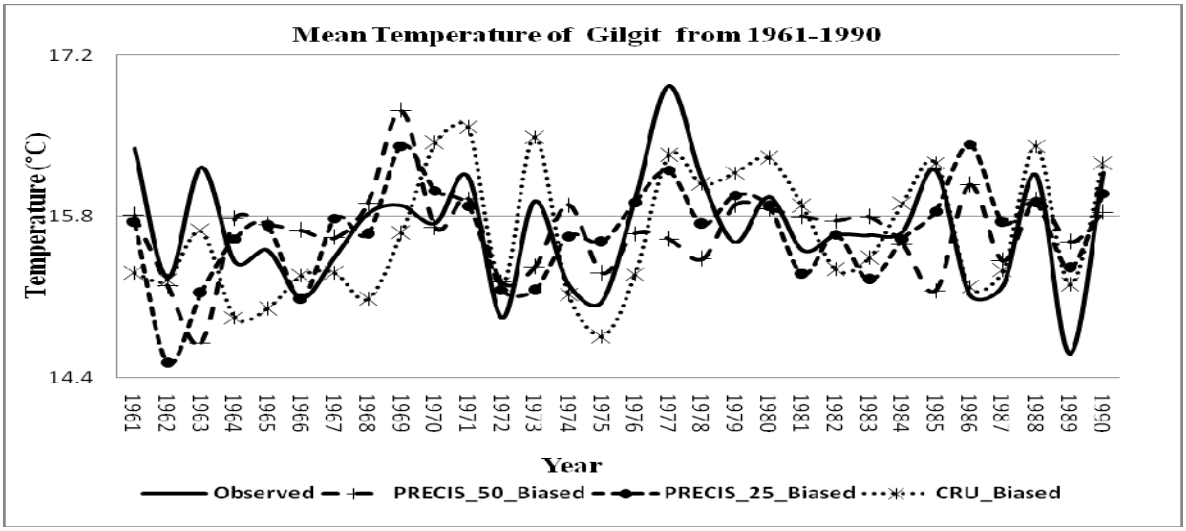

Figure 3. Mean Temperature of Gilgit from 1961-1990 and their comparison with the Observed, CRU, PRECIS (25 km resolution) biased and PRECIS (50 Km resolution) biased

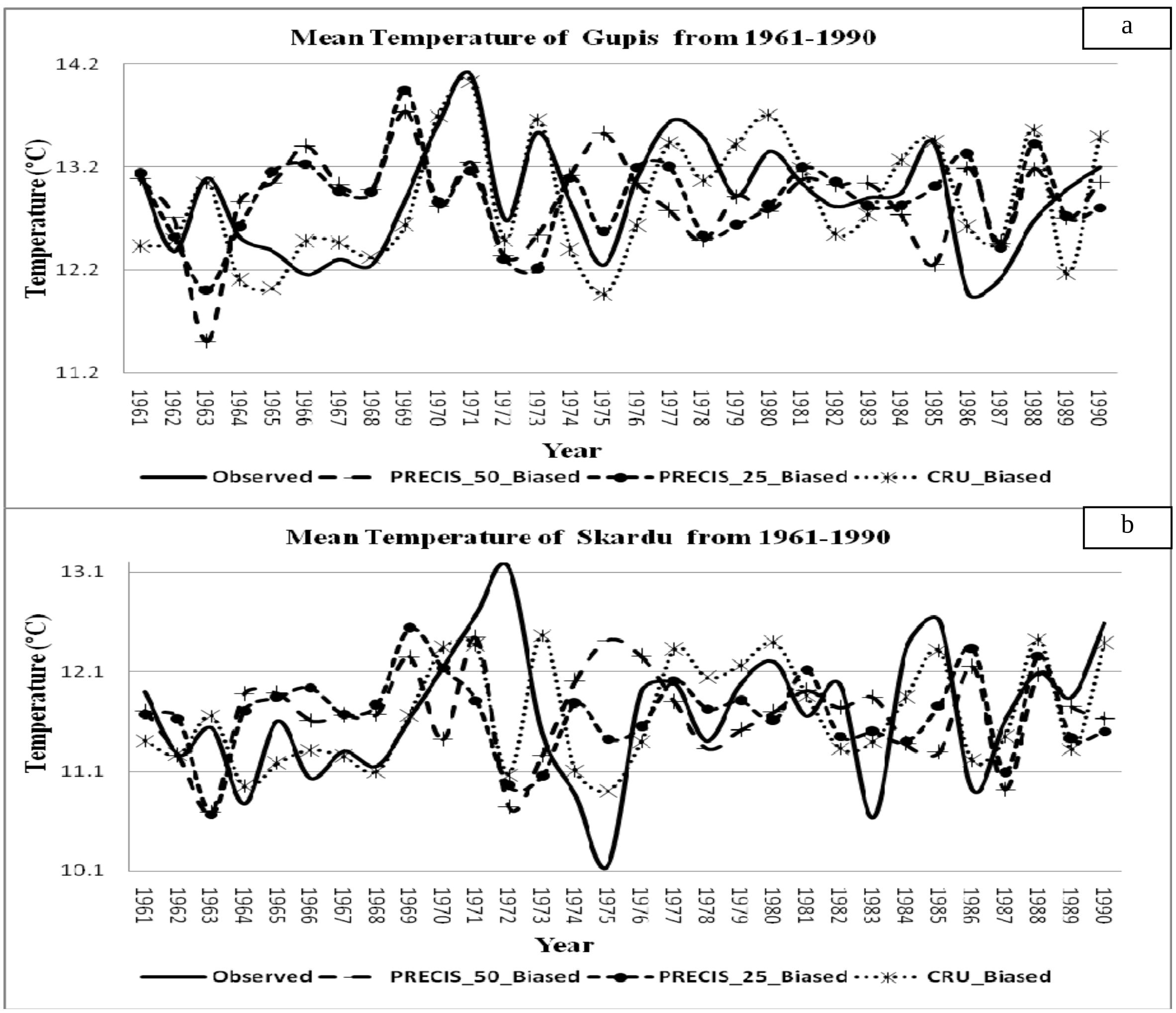

Figure 4: Mean Temperature of (a) Gupis and (b) Skardu from 1961-1990; and their comparison with the Observed, CRU, PRECIS (25 km resolution) biased and PRECIS (50 km resolution) biased

For the second point the altitude of the model; the model is given the topography information for each simulation. This information can be extracted from the output of the model in the $ANCILDIR/runid directory where the $ANCILDIR is the directory containing information of ancillary data files and runid is the experiment name given by the user. From this mention directory the topography information is extracted and the results show that the altitude used by the model at each station is very high than the actual. Despite the other factors influencing the climate system the height (altitude) is very important and it has a huge impact on the temperatures. The altitudes used in the simulation-B are even higher than those used in Simulation-A.

Table 1: Latitude-Longitude in degrees of stations (actual and PRECIS) and Bias of Snow-covered Areas of Pakistan

	Actual		Simulation-A		Simulation-B		Bias(Obs.-Model) (°C)		
Station	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**PRECIS (50 km)**	**PRECIS (25 km)**	**CRU**
Astore	35.34	74.90	35.50	75.00	35.25	75.00	14.03	14.13	9.08
Bunji	35.67	74.63	35.5	74.5	35.75	74.50	18.82	20.21	15.54
Chitral	35.85	71.83	36	72	35.75	71.75	17.43	11.56	8.89
Gilgit	35.92	74.33	36	74.5	36	74.25	19.30	16.71	11.62
Gupis	36.17	73.40	36	73.4	36.25	73.50	15.93	16.91	12.29
Skardu	35.30	75.68	35.5	75.5	35.25	75.75	16.65	13.10	8.87

Table 2: Altitudes (in meters) of the stations actual and the model

Station	**Actual (m)**	**Simulation-A (m)**	**Sim.A-Actual (m)**	**Simulation-B (m)**	**Sim.B-Actual (m)**	**Sim.B-Sim.A (m)**
Astore	2167	3973.49	-1806.49	4099.64	-1932.64	126.15
Bunji	1372	3607.06	-2235.06	3826.75	-2454.75	219.69
Chitral	1499	3489.05	-1990.05	2933.54	-1434.54	-555.51
Gilgit	1459	3666.88	-2207.88	3318.43	-1859.43	-348.45
Gupis	2155	3740.63	-1585.63	3923.03	-1768.03	182.40
Skardu	2317	4069.62	-1752.62	3812.28	-1495.28	-257.34

Conclusion

In this paper the analysis of annual mean temperature for the Snow-covered areas of Pakistan is preformed to test the downscaling ability the RCM PRECIS for two different horizontal domain sizes 25 km and 50 km respectively. The simulated temperatures are compared with the meteorological data and girded data set of CRU. An analysis is also performed on the latitude-longitude and altitudes for all the stations. The analysis performed brought about the following conclusions:

- The error is reduced on shifting the horizontal domain to a finer scale of 25 km but not for all stations like Bunji.
- Both simulations (i.e., with 25 km and 50 km) has underestimated the annual mean temperatures for all the station.
- CRU also has underestimated the annual mean temperature.
- PRECIS has a cold bias behavior for the Snow-covered areas of Pakistan.
- The downscaling ability of the model is good but needs modifications to improve the results.
- The altitude of the stations used by the model PRECIS is directly proportional to the resolution of the model.

It is highly recommended that the topography information used by the model may be modified to achieve the better results.

Acknowledgement

The authors are thankful to Hadley Centre of UK Meteorological Office for providing the PRECIS Model, Global Data and technical support.

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