SCALE-DEPENDENT RELIABILITY OF THE PRECIS MODEL IN RAINFALL PROJECTION FOR COASTAL AREAS IN BANGLADESH

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ABSTRACT

The regional climate model, PRECIS, has been widely used throughout the world to generate climate change projection for impact studies and adaptation. In spite of its wide application, a stringent validation of the model is yet to be reported. In this study, we assessed the performance of the model in simulating annual, monthly and extreme rainfalls over southwest coastal regions of Bangladesh by using a number of statistical techniques. The results indicated that the PRECIS model could capture the overall spatial pattern of mean annual and monthly rainfalls very well. However, the inter-year variability was poorly simulated by the model. In addition, the model could not capture the rainfall extremes. Even spatial aggregation of rainfall data did not improve the reliability of the model. Therefore, further improvements of the model and/or its driving GCM are warranted for its practical use in generation of rainfall scenario.

Keywords: Rainfall variability and extremes; PRECIS; reliability; and spatial and temporal scales

INTRODUCTION

Bangladesh is one of the most climate change vulnerable countries in the world. Along with a small geographical area and a huge population, the country is located at the confluence of the three mighty rivers – the Ganges, the Brahmaputra and the Meghna. To assess the potential impacts of climate change on different socioeconomic sectors, climate change scenarios are developed. Global Climate Models (GCMs) and Regional Climate Models (RCMs) are used to derive future scenarios of different hydro-climatic variables. RCMs are used to dynamically downscale coarser resolution climatic variables into finer resolution ones and to better represent meso-scale climatic phenomena. These models involve complex interactions between atmospheric, oceanic and land processes and as such exhibit a lot of uncertainties in projected climates. The regional models can add value to GCM projections, but only for certain variables and locations (Feser et al., 2011) as RCMs develop their own climatology which is not consistent with the driving global datasets precipitation (Syed et al., 2013). The downscaling strategy also involves the introduction of uncertainties associated with model physics (Stainforth et al., 2005). Providing Regional Climates for Impacts Studies (PRECIS) is a RCM developed by the Hadley Center of the United Kingdom. It is a hydro-static, primitive equation grid point model containing 19 levels described by a hybrid vertical coordinate. Since its release, the model has been extensively used in different parts of the world to generate climate change scenarios. (Islam et al., 2008; Islam, 2009) generated rainfall and temperature scenarios of Bangladesh by running the model at a horizontal resolution of 50 km. It was reported that the model overestimated the pre-monsoon season rainfall and underestimated the monsoon season rainfall and the model generated rainfall is not directly useful in application purposes. A regression-based approach was also proposed to adjust the model generated rainfall. (Nowreen et al., 2015) studied the changes in rainfall extremes in the northeastern part of Bangladesh using the PRECIS generated rainfalls. Though they mention that the model 'nicely capture the long-term rainfall' of the northeastern part, a visual comparison of the monthly average observed and model rainfalls reported in their Figure 2 did not provide such indication. The PRECIS model was used to develop high resolution climate change scenarios over India (Kumar et al., 2006). The model was found to be overestimating the all-India summer monsoon rainfall and underestimating the variability. There was significant positive bias in the rainfall during the onset phase of the monsoon (May and June). (Revadekar et al., 2011) studied precipitation extremes over India based on a comparison of baseline and future simulations of PRECIS. The authors, however, did not report the performance of the model in simulating baseline extremes which could be done by a comparison of observed and simulated rainfall extremes during the base period. (Zacharias et al., 2015) reported that the PRECIS generated rainfalls across India had a bias of +34% to -89% in annual scale, indicating 'poor performance of the model in simulating the baseline rainfall patterns'. The model also simulated more rainy days in the baseline period than observed. The PRECIS simulation was found to capture the shape of the annual rainfall cycle over the western and central Himalayas (Kulkarni et al., 2013). However, for the eastern Himalayas where Bangladesh is located, the peak of the rainfall hydrograph was simulated two months earlier in May or June. In this study, the performance of the model in simulating the rainfall over coastal areas in Bangladesh is evaluated. The selection of the coastal region is guided by the fact that the region is the most vulnerable within the country to climate change, and a number of vulnerability studies are currently being conducted for the region using the PRECIS projection (for example, the Ecosystem Services for Poverty Alleviation (ESPA) project funded by the Department for International Development [DfID], and the DEltas, vulnerability and Climate Change: Migration and Adaptation (DECCMA) project funded jointly by DfID and International Development Research Center [IDRC] are using the PRECIS projection).

METHODOLOGY

The reliability of the PRECIS model in simulating rainfall over coastal areas of Bangladesh was assessed by employing a number of statistical techniques. Among the techniques, a pattern similarity statistic suggested by (Santer et al., 1995) is widely used to compare observed time-evolving change patterns of a climatic variable with the model-predicted signal patterns. Such pattern/map correlation between the model-simulated and observed rainfalls was computed for a base period of 1986-2005. The same period was used in the fifth assessment report of IPCC (2013) as the base period. The pattern correlation was computed for annual, seasonal, monthly, annual maximum, 99^{th} percentile and 95^{th} percentile rainfalls. The pattern correlation method was used by IPCC in its second and third assessment reports. In addition to the spatial-pattern correlation, temporal correlation, root mean square difference (RMSD) and mean absolute difference (MAD) between the model and observed rainfalls were computed to check the adequacy of the model projections. For each grid, yearly rainfall time series was generated first for each rainfall variable. Then the presence of temporal trend in each variable was investigated and, where present, it was removed by detrending. The correlation between the detrended model and observed rainfalls was then computed. The detrending was done to avoid spurious correlation solely due to the presence of trends in the series. The statistical significance of the correlation was determined by applying the standard Student's *t*-test. From the 20 yearly values of a variable corresponding to a grid point, a grid point average value of the variable was obtained. The pattern correlation was obtained from the different grid point average values between the model and observed series. The simulated daily rainfall was available from the Met Office, UK for a period of 1971-2099 at an approximate horizontal resolution of 0.22°×0.22° (25 km×25 km). The data was generated from the PRECIS regional climate model driven by atmosphere-ocean coupled HadCM3 boundary conditions. Measured daily rainfall data were collected from the Bangladesh Meteorological Department (BMD), Dhaka. There are 13 observational stations of BMD within and around the study area. The BMD rainfall data is considered reliable and is widely used in scientific studies (Mondal et al., 2008; Mondal et al., 2012) and government documents. We used data from 7 stations within the study area for the purpose of generation of baseline map.

RESULTS AND DISCUSSIONS

The average annual rainfall over the study area for the base period (1986-2005) was found to be 1857 mm from the model simulation. The same rainfall was found to be 2171 mm from the observed data. Thus, the average rainfall from the model simulation was about 15% less than the observed rainfall. The spatial distribution of both the model and observed mean annual rainfalls are given in [Fig. 1]. Both low and high rainfall areas are overestimated in the model. However, if we find the pattern correlation in mean annual rainfalls between the observed and simulated rainfalls, a high correlation coefficient of 82% appears. This high correlation may be spurious and is probably due to the similar spatial variation pattern in the two data sets. The MAD and RMSD were found to be 17% and 19%, respectively.

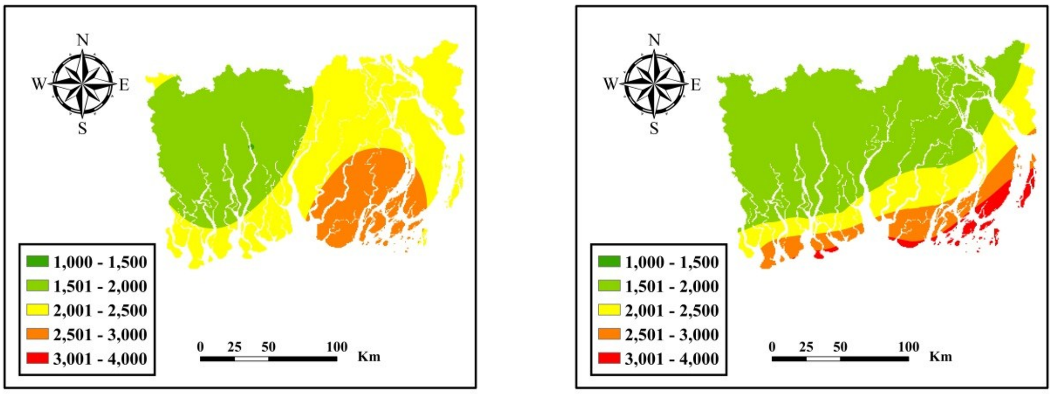

Fig. 1: Comparison of spatial distribution of observed (left) and simulated (right) mean annual rainfalls over the base period (1986-2005)

The point-to-point correlation between the observed and corresponding simulated annual rainfalls is given in Table 1. It is seen from the table that the correlation coefficient varies widely – from -8% at Satkhira to +61% at Patuakhali. The MAD and RMSD of the simulated rainfalls vary from 16-30% and 20-31%, respectively. Thus, there is a large error in simulated annual rainfall over the study area.

Table 1: Performance of the PRECIS model in simulation of annual rainfall in coastal areas of Bangladesh

Station	Correlation coefficient	MAD (%)	RMSD (%)
Satkhira	-0.08	21	28
Khulna	0.16	20	24
Barisal	0.19	21	27
Bhola	-0.08	24	30
Mongla	0.21	24	26
Patuakhali	0.61	30	31
Khepupara	0.22	16	20

Comparisons of probability density functions (pdfs) between observed and simulated rainfalls over the base period at different locations of the study area were made. Such comparisons for two locations (Khulna and Barisal) are shown in [Fig. 2]. It is seen from the figure that neither the location parameter nor the shape parameter of the observed rainfall is captured by the simulated rainfall. The location parameter is underestimated in model simulation and the shape parameter always has a higher peak and smaller base in simulated rainfall. Also, the pdfs from the observed rainfalls appear to be about symmetric, whereas that from the simulated rainfalls appear to be either negatively (Khulna) or positively (Barisal) skewed.

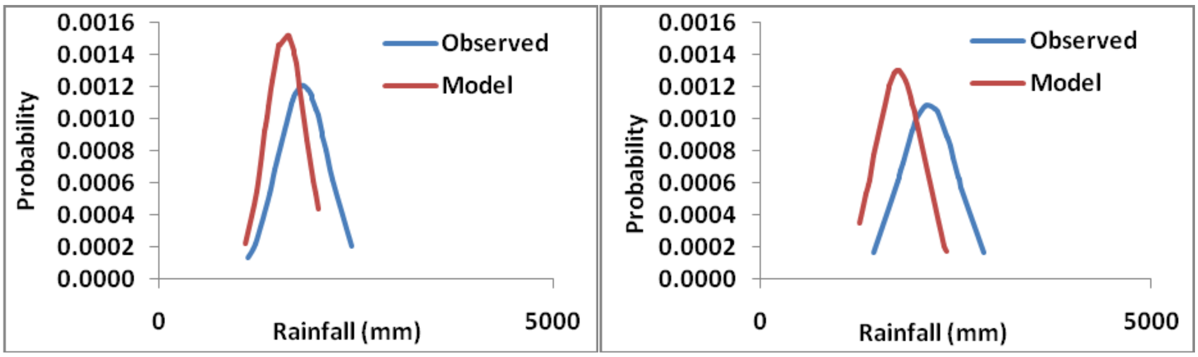

Fig. 2: Comparison of probability density functions between observed and simulated annual rainfalls at Khulna (left) and Barisal (right) during the base period (1986-2005)

The performance of the model in simulating monthly rainfalls was assessed. The assessment was made only for those months which have monthly rainfalls greater than zero in all the years. Presence of zero rainfalls makes the computed statistics, such as correlation coefficient, unreliable. The model fails to capture the monthly rainfall characteristics at individual stations as the correlation coefficients are often low or negative, and MADs and RMSDs are high. As an example, the correlation coefficients are negative for the month of September at all the seven stations of the study area. This indicates that the model is not able to capture the inter-year rainfall variability of September, the last month of the monsoon season. This could be due to the failure of the model in capturing the monsoon recession from the coastal region adequately. The MAD varies from 44-51% and RMSD from 55-82% for September. The inter-year variability of rainfall is poorly captured for the months of July and August of the monsoon season. However, it is interesting to note that the pattern correlations are quite high for these months. For example, the pattern correlations for the months of June, July, August and September were found to be 86, 87, 87, 76% respectively, which are very high. Thus, it appears that the pattern correlation may not be a good indicator to judge the performance of a climate model. Comparisons of pdfs between observed and simulated rainfalls for different months at different locations were also done. The results were more or less similar for different months. As an example, the comparison for the month of June indicated that there were a negative bias in scale parameter and a positive bias in shape parameter. A further comparison was made between observed and simulated annual maximum rainfalls with their pdfs. The shape parameter of the pdf for Mongla and the scale parameter of the pdf for Barisal are poorly simulated by the model. The underestimation of the scale parameter and shape parameter was found to be almost universal throughout the study area. This indicates that the annual maximum rainfall was underestimated by the model. The correlation coefficients were negative in 5 out of 7 locations for which observed data were available. It thus appears that the uncertainty in simulated annual maximum rainfall is higher than that of annual average rainfall.

Consistency, and hence reliability, of the model results are also assessed by comparing the simulation results among different future time periods. The results for mean annual rainfall are shown in [Fig. 3]. It is seen from the figure that the rainfall is projected to be mainly increased during the period of 2021-2040. The major increase is expected to be over the Barisal-Bhola-Jhalakathi region. The pattern of increased rainfall is also evident for the period of 2041-2060. However, there is a shift in the zone of maximum change. For 2021-2040, the zone of maximum change is near the north-east side, whereas for 2041-2060, it is near the north-west. The reason for this east to west shift of the zone is not understood. Moving to the period of 2061-2080 in the figure, we see that a decrease in rainfall manifests over the entire region. The same is also true for the period of 2081-2100. Thus, one can deduce that the rainfall would decrease in the long term. Again, it is not clear whether there is any physical basis of this decrease or it is simply the result of the incapability of the model to simulate the rainfall.

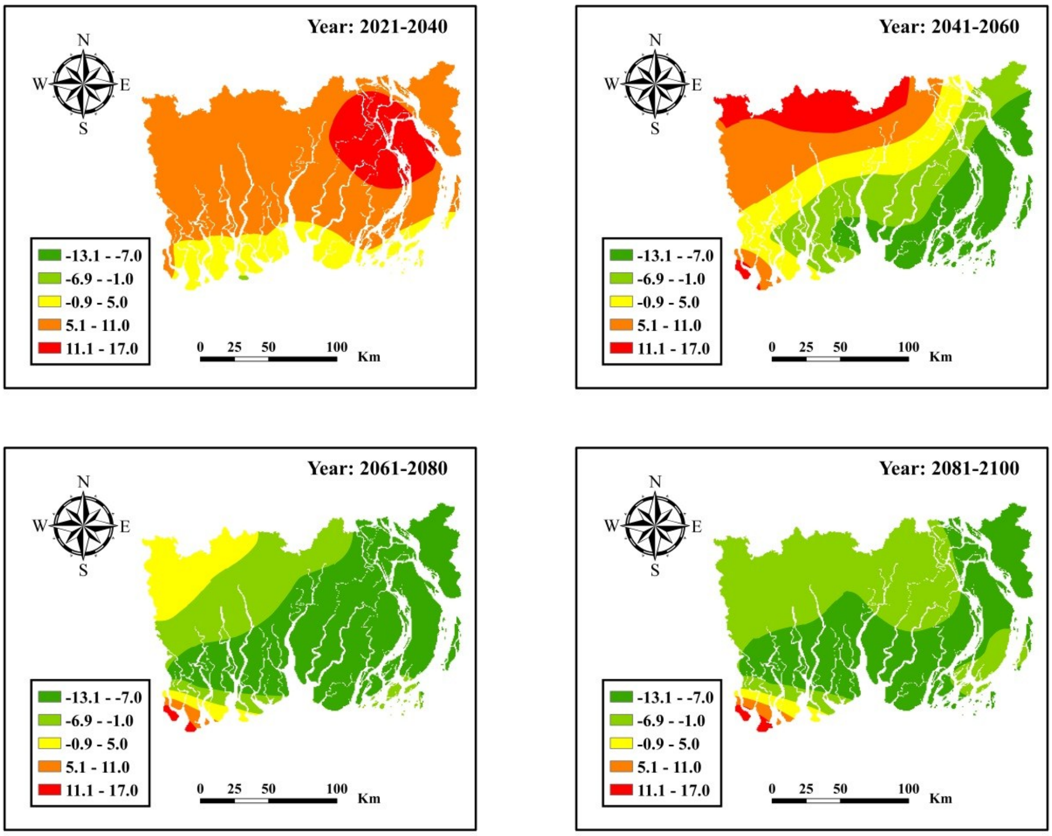

Fig. 3: Changes in mean annual rainfall (%) in different future periods over base period (1986-2005) from the PRECIS model simulation.

Spatial distribution of the linear trends and their statistical significance is calculated. It is seen that majority of the study areas have negative or no trends in annual rainfalls. The trends are positive only towards the northern margin. The p (significance level) values are also large (>0.05) which indicates that the trends are not statistically significant at the confidence level of 95%.The spatial distribution of the change in the 95th percentile (not shown) rainfall indicates that the change is entirely positive for the period of 2021-2040, mainly positive for 2041-2060, largely negative for 2061-2080 and mainly positive for 2081-2100. This temporal change in sign is difficult to understand physically and may simply be due to the inadequacy of the model in capturing the important rainfall processes and features. Overall, the trend is found to be small and statistically insignificant (not shown). Same analyses for the annual maximum rainfall, 99th percentile, 90th percentile and 80th percentile were carried out and the results were more or less similar to the above results in relation to the 95th percentile.As discussed earlier, there is a high pattern correlation between the observed and simulated rainfalls of the base period, but the correlation coefficient is small and sometimes negative at individual locations. This indicates that the model captures the overall spatial pattern of temporal mean rainfall, but fails to capture the inter-year variability of rainfall. To see if this failure is due to the spatial resolution of the model, the pdfs of annual rainfalls were estimated for each cell, for averaged rainfalls of five cells and for averaged rainfalls of nine cells. A visual comparison of the one-, five- and nine-cell pdfs (not shown) indicated that there was no significant difference among the three types of pdfs. This indicated that even after aggregation, the inter-year variability could not be captured. The problem could be due to the poor boundary condition of the PRECIS model obtained from the driving GCM, or due to the internal structure of the PRECIS which fails to capture the dynamic characteristics of the rainfall over the southern coastal Bangladesh. So, it is highly unlikely that it had captured the rainfall extremes.

CONCLUSIONS

The PRECIS climate model simulates the annual and monthly spatial rainfall patterns of the southwest coastal Bangladesh very well. The value of the spatial pattern correlation coefficient was found to be +0.82 for the average annual rainfall and the values were between +0.76 and +0.87 for the average monthly rainfalls. However, the model fails to capture the inter-year variability in both annual and monthly rainfalls. For annual rainfall, the temporal correlation coefficients were from -0.08 to +0.61 depending on locations. Such coefficients for monthly rainfalls were between -0.67 and +0.47 depending on locations and months. In case of annual maximum rainfall, the correlation coefficients were negative in most of the cases. Thus, the finer is the temporal scale of rainfall, the less reliable is the model simulated rainfall. The reliability also does not improve with spatial aggregation of the rainfall data. Thus, any projection of rainfall variability and extremes based on the PRECIS model is likely to be highly uncertain.

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