Evaluation of Downscaled Climate Projections over Sri Lanka

A. Thevakaran[1], J.L. McGregor[2], J. Katzfey[2], M.Thatcher[2], R. Suppiah[2] and D.U.J. Sonnadara[3,*]

[1]*Department of Physics, University of Jaffna, Thirunelvely, Jaffna-Sri Lanka*
[2]*CSIRO Marine and Atmospheric Research, Aspendale VIC -Australia*
[3]*Department of Physics, University of Colombo, Colombo 3- Sri Lanka*
[*]*upul.sonnadara@gmail.com*

ABSTRACT

This study presents an assessment of the Conformal Cubic Atmospheric Model downscaled climate projections at 8 km spatial resolution which are forced by sea surface temperature and sea ice concentration of three global climate models centred on Sri Lanka. Model simulations were compared with observed daily gridded precipitation and temperature data for the period from 1981 to 2005 over Sri Lanka. Statistical measures such as pattern correlation, mean biases and root mean square errors are calculated using observed and simulated data. The results show that the temperature biases range between -1.4 and -2.4 °C and pattern correlations vary among the seasons between 0.92 and 0.96. The model underestimates the temperature over the selected domain. The pattern correlation of rainfall varies among the seasons and it is relatively low for the southwest monsoon season which is 0.67 with RMSE about 3.8 mm/day. Simulations show small bias values during the northeast season with a strong pattern correlation of 0.76 and RMSE of 1.7 mm/day.

1. INTRODUCTION

Climate models are widely used to regenerate climate system of the global as well as regional scale and the model projections are used for variety of purposes. For example, climate change projections are used for planning of infrastructure, ecosystem and species distribution, agriculture and forestry as well as urban designs. Since the projections from global climate models (GCMs) are derived from coarse horizontal resolutions and most of the climate impacts occur on regional and local scales, the dynamical and statistical downscaling techniques are used to regenerate the climate system of small countries like Sri Lanka.

In this study, we used Conformal Cubic Atmospheric Model (CCAM) to produce regional climate system at high resolution (8 km) over the Sri Lankan region. A number of simulations were carried out using the present generation of GCMs that were performed for the IPCC AR5 assessment report. Preliminary study on 50 km spatial resolution CCAM simulations show that, the resolution is not adequate to capture the regional climate features over Sri Lanka especially the effects due to the topographical nature of the country. Therefore the 50 km spatial resolution CCAM simulations were further downscaled to get the right spatial patterns in climate variables at 8 km spatial resolution. CCAM is a global climate model which is developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. It can simulate the regional atmosphere using a stretched conformal cubic grid where the grid is focused on the area of interest [1]. A number of simulations were performed in the past to regenerate the regional climate systems especially over Australia and surrounding countries by using CCAM [2]. These studies reveled that CCAM fairly well capture the spatial pattern of the temperature and rainfall with reasonable biases.

2. METHODOLOGY

2.1 Experimental Designing of CCAM

The dynamical formulation of CCAM includes a number of distinctive features. It employs semi-Lagrangian horizontal advection with bi-cubic horizontal interpolation [3], in conjunction with total-variation-diminishing vertical advection. The grid is unstaggered, but the winds are transformed reversibly to/from C-staggered locations before/after the gravity wave calculations, providing improved dispersion characteristics [1]. Three-dimensional Cartesian representation is used during the calculation of departure points, and also for the advection or diffusion of vector quantities. CCAM may be employed in quasi-uniform mode or in stretched mode by utilising the Schmidt [4] transformation. The current version of the model is non hydrostatic and this includes mass flux cumulus convection scheme to resolve vertical advection. Further details of the model dynamical formulation are provided by McGregor [1].

The high-resolution domain was centered on latitude 7.77° N longitude 80.77° E to cover Sri Lanka. The Schmidt factor was set as 25 to get the finer scale model results at 8 km spatial resolution. The time step between each grid point was set to 180 sec and the number of vertical levels was selected as 27. CCAM can be used in ocean coupled mode or interpolated Sea Surface Temperature (SST) mode. In this study, interpolated SST mode is used to simulate the regional climate of Sri Lanka. The results were obtained in six hourly frequencies over the area covered by latitude between 0° N to 20° N and longitude between 70° E to 90° E.

2.2 Data Analysis

The topographical features and regional scale wind regimes associated with rainfall have provided the basis for demarcating climatic seasons of Sri Lanka. There are two monsoon seasons and two inter-monsoon seasons. The southwest monsoon (SWM) prevails from May to September while the Northeast monsoon (NEM) lasts from December to February. In between these two monsoon seasons, two inter-monsoon periods exist: March to April - first inter-monsoon season (FIM) and October and November – second inter-monsoon season (SIM) [5]. Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of Water Resource (APHRODITE) daily gridded precipitation and temperature data for the period from 1981 to 2005 were used to evaluate how well the model captures the observed average climate over the selected domain.

3. RESULTS AND DISCUSSION

The spatial pattern of seasonal mean temperature and rainfall produced by ensemble means of three CCAM were evaluated by comparing observations (APHRODITE). Spatial pattern of the seasonal mean temperature produce by three ensemble mean of CCAM downscaling results and the biases compared to observations are illustrated in Fig. 1. It can be seen clearly that the spatial distribution of the temperature produce by CCAM over the country is unique and it is mainly controlled by the elevation rather than the latitude. The geographical location of the island results in small seasonal variations in temperatures. The central part of the country is a mountainous region with the elevation of the highest peak reaching more than 2,000 m and includes complex topographical features such as plateaus, ridges, peaks and valleys. Most of the surrounding areas of the central highlands are flat and the spatial temperature pattern is homogeneous at value about 28 °C. The temperature decreases drastically associated with the increase of altitude towards the central highlands and reaches the low temperature about 15 °C. The model fairly well captures the spatial pattern of temperature relating to complex topography at high resolution (8 km).

The temperature bias range is between -1.4 and -2.1 °C. There are significant differences in temperature biases among the seasons. The model tends to underestimate observed temperature over the Sri Lankan region. Table 1 shows pattern correlations based on the spatial patterns of observed and CCAM simulated temperatures and rainfall for the four seasons. It is clearer that the model captures the observed spatial patterns of temperature as shown by high pattern correlation. The pattern correlation among the season varies from 0.92 to 0.96. The RMSE values and mean biases of mean temperature are slightly higher (which is about -2 °C) with RMSE 2.2 °C for the SWM season compared to other seasons.

Table 1: Mean biases, RMSE and pattern correlations of mean temperature and rainfall for ensemble mean of model and observed data for the four seasons

	Temperature			Rainfall		
	Mean bias (ºC)	RMSE (ºC)	Pattern correlation	Mean bias (mm/day)	RMSE (mm/day)	Pattern correlation
FIM	-1.4	1.5	0.96	-1.2	1.7	0.76
SWM	-2.1	2.2	0.94	2.0	3.8	0.67
SIM	-1.7	1.8	0.95	-1.8	2.7	0.81
NEM	-1.7	1.8	0.93	0.2	1.7	0.75

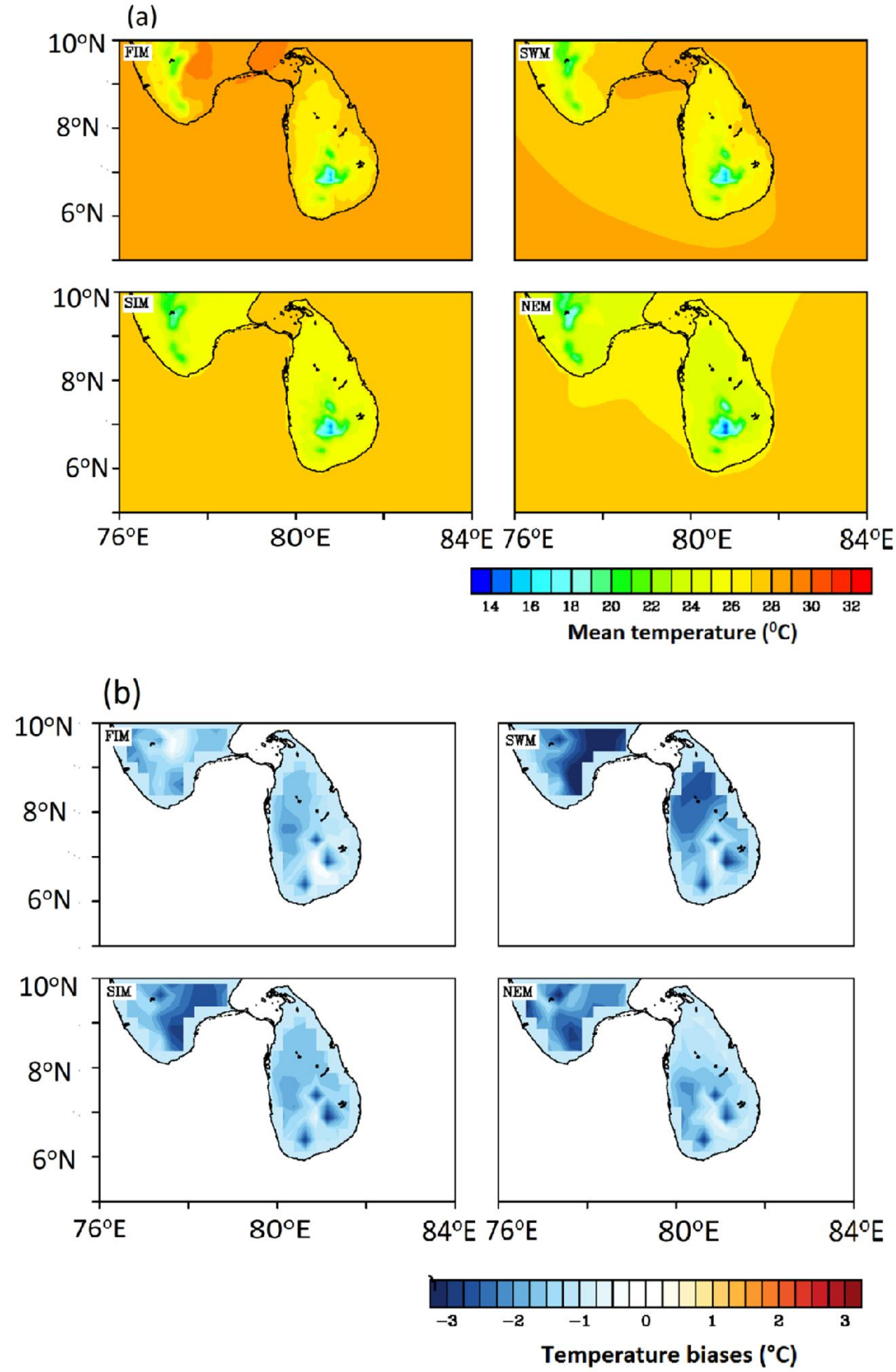

Fig. 1: Spatial pattern of (a) seasonal mean temperature produce by ensemble means of three CCAM downscaled simulations and (b) biases compare to observations.

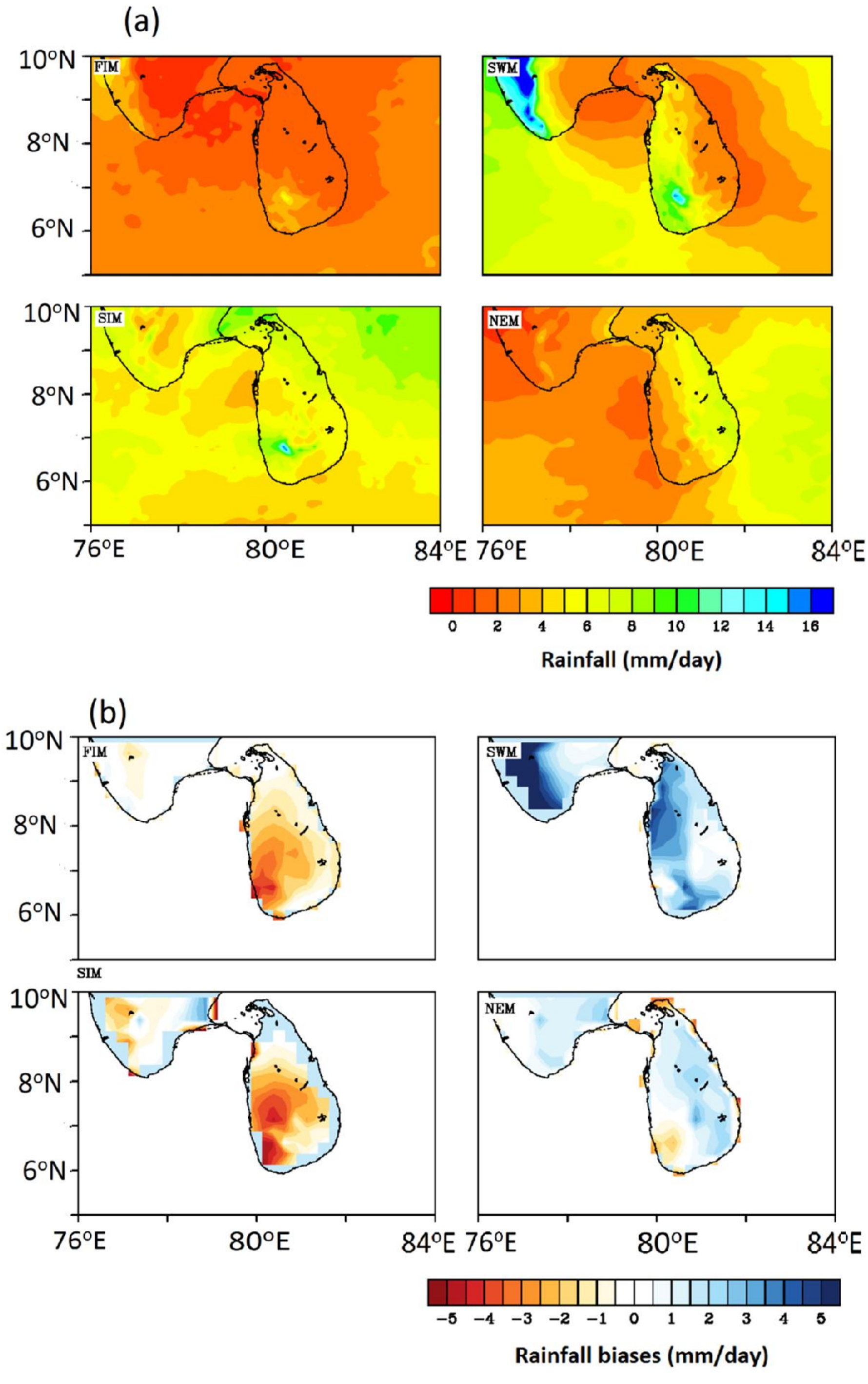

Fig. 2: Spatial pattern of (a) seasonal mean rainfall produce by ensemble means of three CCAM downscaled simulations and (b) biases compare to observations.

Fig. 2 shows seasonal rainfall produce by ensemble mean of three CCAM downscaling results and the biases between ensemble means of CCAM simulations and observations. The spatial distribution of seasonal rainfall produce by CCAM reveals distinguishable features and the amount of rainfall received throughout the country varies seasonally as well as spatially. The model results show that the southwestern slope of the central mountain region receives excess rainfall during FIM, SIM and SWM seasons compared to other areas of Sri Lanka. Hot humid air during FIM seasons provides one of the favorable conditions for thunderstorm activity over the country with the highest amount of rainfall observed over the southwestern part of the country where the rainfall amount varies between 2 to 8 mm/day. The mid altitude of the western slopes of the mountain region receives heavy rainfall during SWM season which is strongly influenced by uplifting of air in the mountain slopes. The amount of rainfall decreases as the altitude increases from the slopes due to the reduced water vapor content of the air. Therefore the top of the mountain and leeward side of the mountain region receive relatively low rainfall compared to the windward side of the mountain region. The eastern slopes of the mountain, eastern coastal and northern region receive maximum rainfall during NEM and the south western coastal region receives less rainfall in this season.

Overall biases range between -5 and +5 mm day. However, there are significant differences in rainfall biases among the seasons (see Table 1). In particular, the model tends to underestimate observed rainfall over the south-western part of Sri Lanka during the two inter-monsoon seasons. The model also overestimates observed rainfall over north and western coastal regions of Sri Lanka during the SWM season. The pattern correlation of rainfall varies seasonally and it is relatively low for SWM season which is 0.67 with RMSE about 3.8 mm/day. The CCAM downscaling results show low bias values during the NEM season with strong correlations (r =0.76 and RMSE=1.7 mm/day), indicating that the CCAM simulations are capable of capturing the observed pattern well during this season. The correlations are strong during the SIM seasons with high RMSE values and the model underestimates the mean rainfall on average (about 1.75 mm/day). Overall, the CCAM downscaling perform better during NEM, SIM and FIM seasons compared to the SWM seasons.

4. CONCLUSION

Regional aspect of current climate system over Sri Lanka is simulated by using CCAM and the performance of the model was evaluated by comparing the seasonal temperature and rainfall with the observed data. Comparatively, model seems to be less accurate in producing rainfall during the SWM and second inter monsoon period especially over south-western and western part of the country. Mean biases in precipitation varies between ±5 mm spatially and seasonally over Sri Lanka. The model predicts less rainfall over the south western part of the country during the two inter monsoon periods. Generally CCAM reproduce the climate condition well over the north and eastern part of the country during the NEM seasons. Results based on statistical tests indicate that the current CCAM simulations fairly well capture the observed spatial patterns of temperature and rainfall over Sri Lanka.

ACKNOWLEDGEMENT

Financial support provided by the HETC project assisted by the World Bank (IDA Credit 49190 –LK) and the work carried out at the CSIRO – Australia is appreciated.

REFERENCES

1. McGregor, J.L, C-CAM, *Geometric Aspects and Dynamical Formulation*, CSIRO Atmospheric Research Technical Paper, 70 (2005) 43
2. Nguyen, K.C, and McGregor, J.L, *Dynamical downscaling of the Mk 3.0 GCM simulation of the A2 scenario over the Australian region using CCAM*, CSIRO Marine and Atmospheric Research (2009)
3. McGregor, J.L, *Semi-Lagrangian advection on conformal-cubic grids*, Monthly Weather Review, 124 (1996) 1311-1322
4. Schmidt, F, *Variable fine mesh in spectral global model*, Beitraege zur Physik der Atmosphaere, 50 (1977) 211-217
5. Thambyahpillay, G, *The rainfall rhythm in Ceylon*, University of Ceylon Reviews, 17 (1954) 137-180