Climate change projections over Sri Lanka

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Abstract
This paper investigates the future climate of Sri Lanka using the variable-resolution Conformal Cubic Atmospheric Model (CCAM) developed at CSIRO, Australia. Bias corrected sea surface temperatures (SSTs) and sea ice concentration from a few global climate models (GCMs) such as CNRM-CM5, GFDL-CM3 and ACCESS1-0 from the CMIP5 simulations were used as boundary conditions for simulations at 8 km horizontal resolution. Mean biases, root mean square errors (RMSE) and pattern correlations have been calculated by comparing with observations to assess the performance of the model. The results show that the temperature biases range between 0^{0}C and -3^{0}C. Pattern correlations vary among the seasons between 0.96 and 0.92. The model tends to underestimate the observed values over the selected domain. The CCAM simulations show small bias values during the northeast season with strong pattern correlations of 0.75 and RMSE values of 1.7 mm/day. The pattern correlation of rainfall is relatively low for the southwest monsoon season with 0.68 and RMSE about 3.9 mm/day. Projected changes in mean temperature and rainfall are presented for 2050. Area average temperature is expected to increase by 1^{0}C under the high level emission scenario (RCP 8.5). The rainfall changes show increase of about 40% in the northern part of the country during the first inter-monsoon season and about 20% in the south eastern part of the country during the northeast monsoon season by 2050.

Keywords: **climate change; Indian Ocean; precipitation change; temperature change**

I. INTRODUCTION

Due to the high variability of the Asian monsoon climate, most global climate models (GCMs) find it difficult to simulate different aspects of the monsoons and, in particular, the climate variability on various time scales for smaller regions such as Sri Lanka. However, climate change projections for Sri Lanka at high resolution tailored specifically for the local climate conditions are important to mitigate natural disasters. The climate change projections will help in the decision making process at all sectors of government, industries, business and community in Sri Lanka.

Dynamical downscaling is the process that produces high resolution climate data from the results of coarse spatial resolution global climate models (GCMs) [1]. Generally, the GCMs have low resolution, which is close to 200 km. Therefore, it is difficult to get a detailed picture of the climate conditions that exist over Sri Lanka and their spatial and temporal variability. In this study, we used the CSIRO Conformal Cubic Atmospheric Model (CCAM) to produce regional climate change projection at high resolution (8×8 km^2) over the region of Sri Lanka. CCAM is a global climate model that can simulate the regional atmosphere using a stretched conformal cubic grid where the grid is focused on the area of interest. Further details of the dynamical formulation of the model are provided by McGregor 2005 [2]. Increasing trends in greenhouse gases and changing aerosol emissions have profound effects on global temperature and hence circulation and rainfall patterns. Therefore, choosing the emission scenario is another important task for producing future climate projections over the region of interest and also the simulation period. Representative Concentration Pathways (RCPs) provide a set of greenhouse gas concentration and emission pathways recommended by IPCC to produce the fifth assessment report. In this work, we have produced a range of climate change projections under two emission scenarios RCP 4.5 and RCP 8.5 for Sri Lanka, which has not been attempted before.

II. CONFORMAL CUBIC ATMOSPHERIC MODEL

The dynamical formulation of CCAM includes a number of distinctive features. The model uses two-time-level semi-implicit time differencing. 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 [2]. 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 transformation [4].

The C48 quasi uniform grid is derived by projecting a grid on the panels of a cube onto the surface of the Earth. The grid can be stretched to produce a high resolution panel over the selected region by using the Schmidt transformation, so that total number of grids will remain constant and the conservation laws are applicable. The grids inside the zoomed panel are finer than the grids on the other panels of the cube. The high-resolution domain was centered on latitude 7.77°N longitude 80.77°E to cover the Sri Lankan region and 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 s and the number of vertical levels was selected as 27. The non-hydrostatic option was used to simulate the climatic conditions of the country. CCAM can be used in ocean coupled mode or interpolated 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.

III. 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 to November – second inter-monsoon season (SIM) [5]. The analysis was carried out for the four seasons, FIM, SWM, SIM, NEM as well as for annual. Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of Water Resource (APHRODITE) daily gridded precipitation and temperature data were used to estimate the spatial correlation, mean biases and root mean square error (RMSE) for the four seasons separately to evaluate how well the model captures the observed average climate over the selected domain.

IV. RESULTS AND DISCUSSION

The spatial pattern of seasonal mean temperature and rainfall produced by ensemble means of three CCAM runs were evaluated by comparing with observations. The results show that the temperature bias is between 0 and -3^{0}C with significant differences among the seasons. The model tends to underestimate the observed temperature over the Sri Lankan region. Table 1 shows mean bias, RMSE and pattern correlations (R) based on the spatial patterns of observed and CCAM simulated temperatures and rainfall for the four seasons.

TABLE I
BIAS, RMSE AND R IN TEMPERATURE AND RAINFALL FOR FOUR SEASONS

	Temperature			**Rainfall**		
	Bias	RMSE	R	Bias	RMSE	R
FIM	-1.41	1.50	0.96	-1.19	1.66	0.76
SWM	-2.08	2.21	0.94	1.96	3.84	0.67
SIM	-1.74	1.82	0.95	-1.75	2.71	0.81
NEM	-1.69	1.79	0.93	0.16	1.73	0.75

The results show that the model captures the observed spatial patterns of temperature (as indicated by high pattern correlations). The pattern correlations among the season vary between 0.96 to 0.92. The RMSE values and mean biases of mean temperature are slightly higher (which is about -2^{0}C) with RMSE 2.2^{0}C for the SWM season compared to other seasons.

The spatial pattern of the rainfall bias ranges between -5 and +5 mm/day and significant differences in rainfall bias are noted among the seasons (figure not shown). The model tends to underestimate observed rainfall over south-western part of Sri Lanka during two inter-monsoon seasons. On the other hand, the model overestimates observed rainfall over the north and western coastal region of Sri Lanka during the SWM season. The pattern correlation of rainfall varies seasonally and it is relatively low for the SWM season which is 0.68 with RMSE about 3.9 mm/day. The CCAM downscaling results show low bias values during the NEM season with strong correlations (R=0.75 and RMSE=1.7 mm/day), indicating that the CCAM simulations capture the observed pattern well during the NEM season. The correlations are strong during the SIM season with high RMSE values and the model underestimates the mean rainfall on average (about 1.75 mm/day). Overall, the CCAM downscaling performs better during NEM, SIM and FIM seasons compared to the SWM seasons.

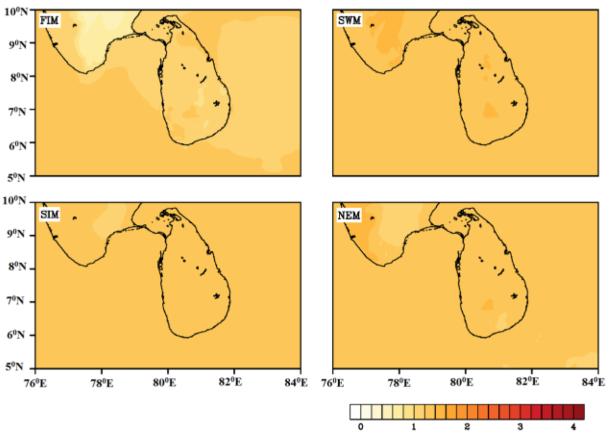

FIG. 1 Projected changes in ensemble mean temperature of three CCAM simulations for the four seasons in 2050 for RCP 4.5

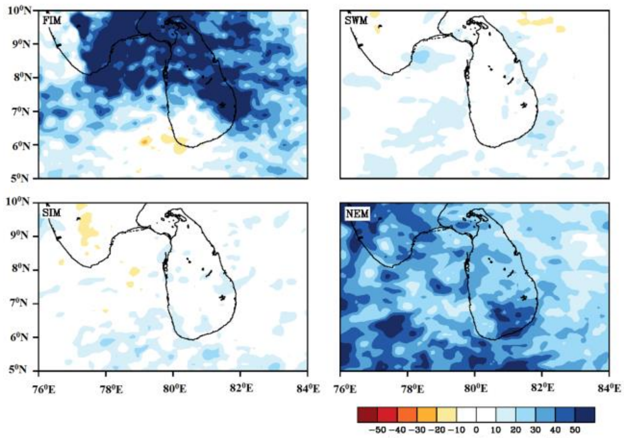

FIG. 2 Percentage changes in mean rainfall of ensemble means of three CCAM downscaling simulations in 2050 for RCP 4.5

Figure 1 depicts the ensemble means of seasonal mean temperature changes by 2050 for emission scenario RCP 4.5. Projected temperature changes are heavily dependent on emission scenarios. Changes are slightly low for RCP 4.5 compared to RCP 8.5. Although the ensemble spatial patterns of changes for both scenarios are similar, there are some differences in seasonal changes among the model simulations. Increases are up to 0.8^{0}C over inland regions especially during the SWM season for RCP 4.5. Increases are slightly lower in other seasons over eastern and south eastern coastal areas. For the high emission scenario RCP 8.5, the increase is about 1.0^{0}C over inland regions. The spatial patterns of increases are very similar for these two emission scenarios.

For several selected geographical locations in Sri Lanka the means and the standard deviations of projected annual mean temperature values were estimated from the ensemble mean of CCAM under two emission scenarios RCP 4.5 and RCP 8.5. The current trend of the annual mean temperature is quite close to the projected temperature trend for the low level emission scenario. For all locations considered in this study, the projected trend in temperature for emission scenario RCP 4.5 and RCP 8.5 is about 0.2^{0}C and 0.3^{0}C per decade, respectively. The projected temperature increase in the station located in the central mountain region is slightly higher, about 0.4^{0}C per decade for RCP 8.5 and 0.2^{0}C per decade for RCP 4.5. The model-predicted temperature changes are more sensitive in the central mountain region compared to the low land areas. It can be seen from the standard deviations that the temporal variation is slightly stronger for the high emission scenario compared to the low emission scenario.

Projected percentage changes in the ensemble simulated mean rainfall by 2050 for the four seasons under the emission scenario RCP 4.5 is shown in Figure 2. The results show increases in rainfall over most parts of Sri Lanka during FIM and NEM seasons, particularly in north, eastern and south-eastern parts of the country. CCAM tends to project decreases in rainfall in the northern region of Sri Lanka during SWM season and in the south-western part of the country during the FIM season for both emission scenarios. The spatial patterns of rainfall changes for both emission scenarios are the same, but percentage values are different between emission scenarios. Projected rainfall changes by 2050 are very high which is above 50% in the northern part during the FIM season and increases are 10% to 50% all over the country during the NEM Season. No decreasing patterns are projected during SWM for the low emission scenario. For the high emission scenario the percentage increases are slightly lower than the increases projected for RCP 4.5 during FIM and NEM seasons. About 10% decrease is projected in the northern part during SWM and in the south-western part during FIM and SIM seasons. Overall, NEM and FIM seasons show similar patterns of rainfall increases and in the SWM season the changes are small.

For different geographical regions of Sri Lanka, mean annual rainfall anomalies were derived from CCAM simulated annual rainfall of ensemble means for two emission scenarios. The projected rainfall anomalies were calculated relative to the mean rainfall produced by the ensemble mean for the current climate 1981 to 2010. Rainfall anomalies projected under two different emission scenarios show different fluctuations at different time intervals. In the eastern region, positive anomalies for projected ten years mean annual rainfall were seen for both emission scenarios which is particularly high for RCP

8.5 after 2060. In the central region, positive anomalies for RCP 8.5 and RCP 4.5 were also seen, except for 2040 under high level emission scenario. In the northern region, the annual mean rainfall anomalies values are negative up to 2040. After 2040, values are positive for RCP 4.5 but fluctuate around zero for RCP 8.5. In the southern and western regions, anomalies show different behaviour for both RCP 4.5 and RCP 8.5.

V. CONCLUSION

Regional aspects of climate system of Sri Lanka for current and future climate are studied at high resolution (8 km) by using CCAM to downscale dynamically, forced by sea surface temperature and sea ice concentration of the GCMs CNRM-CM5, GFDL-CM3 and ACCESS1-0 from the CMIP5 simulations. The downscaling experiments were performed for the period 1971 to 2099 and the ensemble mean of three downscaling results were analysed by separating the two periods 1981-2010 for current climate, and 2036-2065 for mean climate at 2050 under two emission scenarios RCP 4.5 and RCP 8.5. The high-resolution simulation shows good improvement on spatial pattern of temperature and rainfall compared to low resolution and it clearly captures effects due to the topographical nature of the country.

The performance of the model was evaluated by comparing the annual cycle of mean temperature and rainfall with the observed data. In general, the temporal correlation between observed and simulated mean temperature is strong for the selected stations except for the station in the high elevation area of the central mountain region of Sri Lanka. The character of the observed annual variation of rainfall is captured quite well by CCAM at the stations located in the dry zone of Sri Lanka which receives rainfall predominantly from the NEM season. The model performed weakly during the SWM and second inter monsoon period especially over the south-western and western part of the country. Mean biases in rainfall vary 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 experiences difficulties to simulate the rainfall over the central mountain region and the western part of the country during the SWM seasons.

Projections show the warming is high for the high-level emission scenario compared to the low-level emission scenario. The warming is larger over the inland region than the sea surface. The warming is slightly higher during the SWM seasons compared to other seasons. The projected changes in rainfall are widespread and they are high during the FIM and NEM seasons compared to other seasons. The spatial distribution of the projected rainfall changes vary for different emission scenarios and the changes are higher for low level emission scenario.

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REFERENCES

[1] Nguyen, K.C., McGregor, J.L, 2009, 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)

[2] McGregor, J.L 2005, C-CAM: Geometric Aspects and Dynamical Formulation. *CSIRO Atmospheric Research Technical Paper* 70, 43 pp

[3] McGregor ,J.L 1996, Semi-Lagrangian advection on conformal-cubic grids, *Monthly Weather Review* 124:1311-1322

[4] Schmidt, F 1977, Variable fine mesh in spectral global model. *Beitraege zur Physik der Atmosphaere*, 50: 211-217

[5] Thambyahpillay, G. 1954, The rainfall rhythm in Ceylon. *Univ. Ceylon. Rev.*, 17: 137-180