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Rainfall forecast in the Upper Mahaweli basin in Sri Lanka using RegCM model

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Abstract. The Upper Mahaweli basin is the upper most sub basin of 788 km2 in size above Polgolla barrage in the Mahaweli River, the longest river in Sri Lanka which starts from the central hills of the island and drains to the sea at the North-east coast. Rainfall forecast in the Upper Mahaweli basin is important for issuing flood warning in the river downstream of the reservoirs, landslide warning in the settlements in hilly areas. Anticipatory water management in the basin including reservoir operations, barrage gate operation for releasing water for irrigation and flood control also require reliable rainfall and runoff prediction in the sub basin. In this study, the Regional Climate Model (RegCM V4.4.5.11) is calibrated for the basin to dynamically downscale reanalysis weather data of Global Climate Model (GCM) to forecast the rainfall in the basin. Observed rainfalls at gauging stations within the basin were used for model calibration and validation. The observed rainfall data was analysed using ARC GIS and the output of RegCM was analysed using GrADS tool. The output of the model and the observed precipitation were obtained on grids of size 0.1 degrees and the accuracy of the predictions were analysed using RMSE and Mean Model Absolute Error percentage (MAME %). The predictions by the calibrated RegCM model for the basin is shown to be satisfactory. The model is a useful tool for rainfall forecast in the Upper Mahaweli River basin.

1. Introduction

Extreme weather events, especially heavy rainfall adversely affect the people, services and properties to hinder the societal development. Climate projections show that changing extreme weather patterns are very likely and will have significant consequences for the society and the economy [1]. Prediction of weather phenomenon with higher reliability under changing climate has become a major focus in the world.

The Upper Mahaweli basin is the upper most sub basin of 788 km^2 in size above Polgolla barrage in the Mahaweli River, the longest river in Sri Lanka which starts from the central hills of the island and drains to the sea at the North-east coast. There are two large reservoirs to regulate water and to generate hydropower in this sub basin, and Polgolla barrage in the Central Province diverts part of Mahaweli river water to the North Central Province of Sri Lanka while harnessing hydropower [2]. Rainfall forecast in the sub basin is important for issuing flood warning in the river downstream of reservoirs, landslide warning in the settlements in hilly areas. Anticipatory water management in the basin including reservoir operations, barrage gate operation for releasing water for irrigation and flood control also require reliable rainfall and runoff prediction in the sub basin. Figure 1 shows the location of the basin.

The Upper Mahaweli basin is characterized by predominantly mountainous topography elevations ranging from 400m to 2000m MSL (Figure 2). The basin receives an average annual rainfall of about 2500mm, western slopes in the basin receives higher rainfall up to 6000mm in some years with high intensity causing floods [3 & 4]. Therefore rainfall forecast is important to understand its accompanied impacts and necessary adaptation to minimize its adverse effects and for planning adaptation strategies.

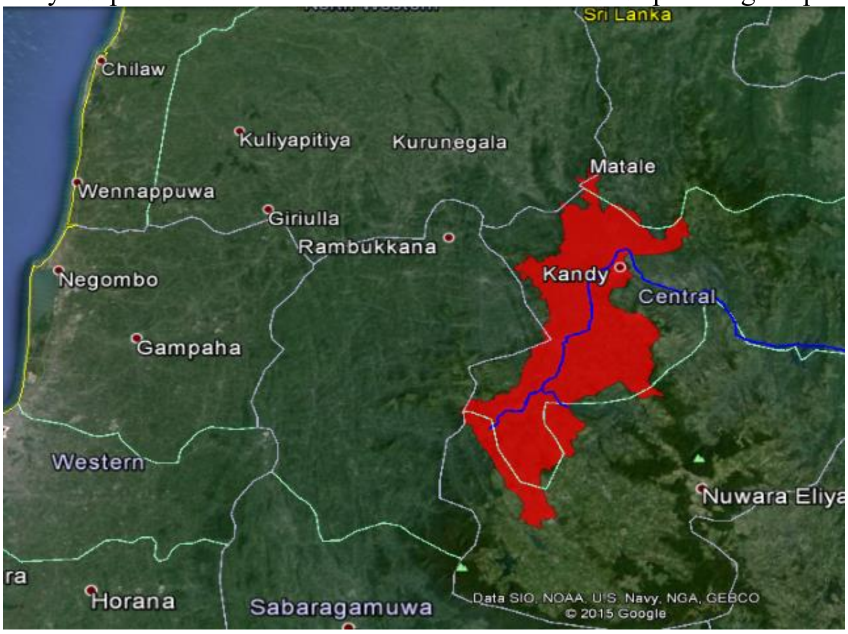

Figure 1. Location of Upper Mahaweli River basin in Sri Lanka

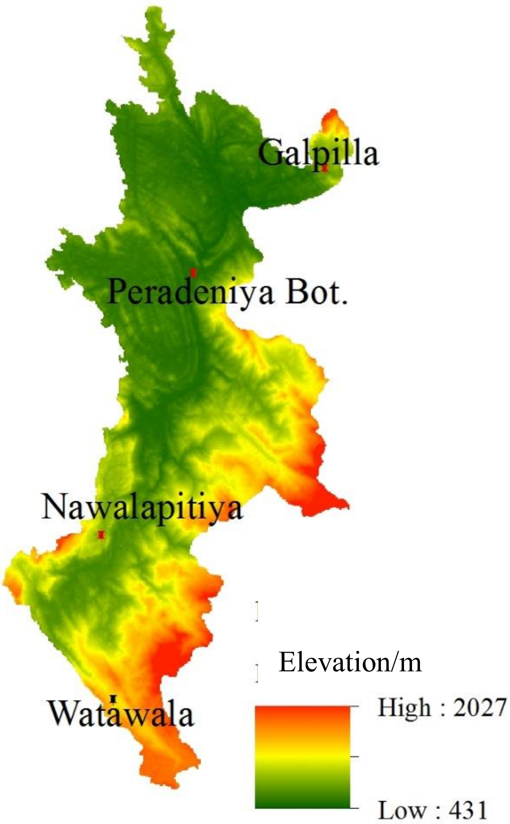

Figure 2. Topography of the basin showing selected rainfall gauging station

Numerical weather prediction (NWP) is based on the solution of atmospheric state variables including temperature, wind, humidity and pressure derived by the numerical solution of mathematical models formed by physical equations describing motion, thermodynamics, continuity, hydrostatic equation together with closure modes [5]. Global Circulation Models (GCM's) and Limited Area Models are two groups of models used for NWP. Global weather simulation, which is computationally expensive, provides predictions at a coarse scale (250 km by 250 km grid) in most cases [6]. GCMs fail to capture sufficient basin properties to provide an accurate description of weather at local or basin scale. Thus, the process of dynamic downscaling of GCM predictions is used to produce the basin-scale weather predictions of the Upper Mahaweli basin. Dynamical downscaling is a computationally intensive technique which makes use of the lateral boundary conditions from GCMs combined with regional-scale forcings such as land-sea contrast, vegetation cover, etc., to produce regional climate models (RCMs) [6]. There are number of dynamic downscaling models and each model has its advantage/disadvantage over the counterparts. WRF [7], RegCM [8], CCSM [9], etc., are among the popularly used RCMs.

RegCM developed and maintained by the Abdus Salam International center for Theoretical Physics (ICTP) is used in this study due to its successful and increase use in Asian countries, and that it has not been used yet in Sri Lanka. The RegCM has been the first limited area model developed for long term regional climate simulation, and it has been applied by a large community for a wide range of regional climate studies, from process studies to paleo-climate and future climate projections [10].

1.1. Model description

RegCM simulation system consists of four modules, including the terrain, the initial / lateral boundary condition (ICBC), the main program (Main) and post-treatment (Post-proc) module (Figure 3). The entire technological process can be divided into pre-processing, simulation and post-processing. The pre-processing stage includes topographic parameters, parameters of the study area as well as the mode setting of the initial and boundary conditions for the setting. Terrain and ICBC are two parts in the pre-processing stage. The main module (Main) is the master control program in the model; post-processing module is to convert the output results for the needs of the average type and data format [11].

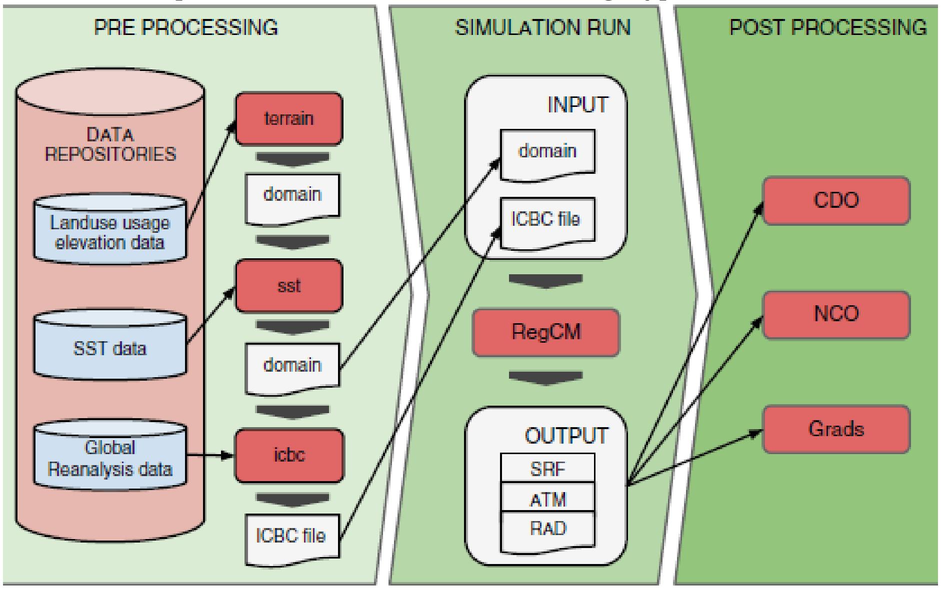

Figure 3. Different components of RegCM modelling system [12]

The RegCM has number of physics options which can be changed to fine-tune the model in order to calibrate the model to the given region. These models include the Biosphere-Atmosphere Transfer scheme(BATS) for surface process representation, The Radiative Transfer scheme of the NCAR Community climate Model, A medium resolution local Planetary boundary layer scheme, the Kuo-type cumulus convection scheme and the explicit Moisture scheme [13]

2. RegCM model application

2.1. Setting up of the model

RegCM model was set up with the centre longitude 80.952, the centre latitude 7.519, resolution of 10 km, which is the lowest grid size possible (RegCM Version 4.4.5.11), and the grids, to cover the Upper Mahaweli basin.

Observed daily rainfall data at four rainfall gauging stations in the basin were obtained from the Department of Meteorology of Sri Lanka to select extreme events for model calibration and validation

GIS based Thiessen polygon method was used to generate average rainfall over the study area and two highest rainfall events were selected as extreme events for model calibration and validation. Table 1 illustrates the details of selected rainfall events. The reanalysed datasets EIN15 at $1.5^0 \times 1.5^0$ resolution (≈ 167 km × 167 km) corresponding to the selected events in 2002 and 2004 were downloaded from the ICTP website: http://clima-dods.ictp.it/data/Data/RegCM_Data/ and used as the initial values and lateral boundary values in the simulation

Table 1. Selected extreme events

Process	Date	Daily Rainfall/(mm)
Calibration	25/03/2004	60
Validation	10/05/2002	74

2.2. Post processing

GrADS tool is used to view the daily rainfall obtained from RegCM model and the observed rainfall. The observed was spatially distributed using GIS Inverse Distance Weighing tool (IDW) in the same grid size of 0.1 degree of the RegCM results using GIS Point to Raster tool. For the purpose of comparison grids in the basin were numbered as shown in Figure 4.

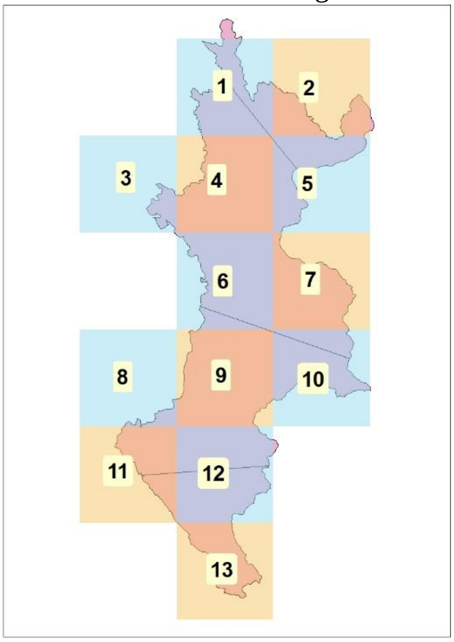

Figure 4. Grid numbering

The Mean Absolute Model Error Percentages (MAME %) and Root Mean Square Error (RMSE) were used to compare the simulated (SR) and observed (OR) rainfall values.

$$\text{MAME \%} = (\text{SR} - \text{OR}) / \text{OR} \; x \; 100 \; \% \quad (1)$$

3. Model calibration and validation

3.1. Model calibration

The RegCM Model was calibrated to forecast the rainfall for the selected rainfall event on 25 March 2004 over the Upper Mahaweli basin by selecting appropriate physics options. Microphysics, Lateral Boundary conditions scheme, Semi-Lagrangian advection scheme for tracers and humidity, Boundary layer scheme, Cumulus convection scheme, Grell Scheme Cumulus closure scheme, Moisture scheme, Ocean Flux scheme were the physics options considered under model calibration.

One physics scheme was changed while keeping other physics schemes at default options. Once the best option was selected, it was kept unchanged for the remaining simulations. This procedure was followed in selecting all physics schemes.

The appropriate physics options that were selected for the Upper Mahaweli basin during calibration are shown in Table 2. Figure 5 shows the RegCM output and the Figure 6 shows the observed rainfall data on same grids for the rainfall event of 25/03/2004.

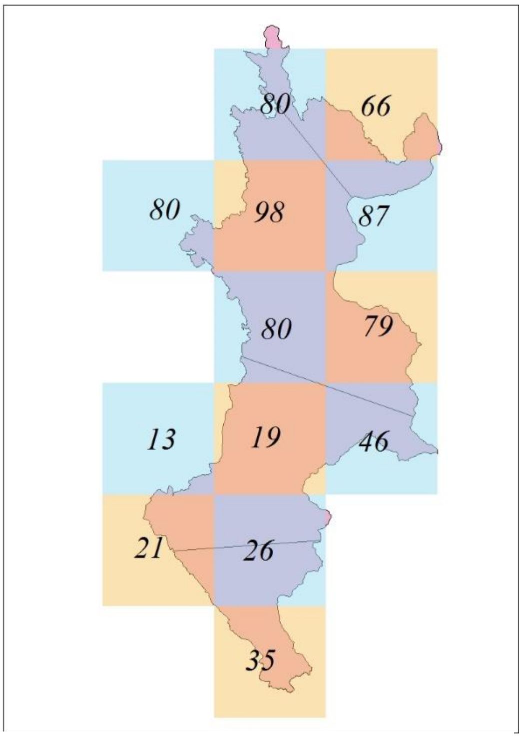

Figure 5. Gridded output of observed rainfall in millimetres on 25/03/2004

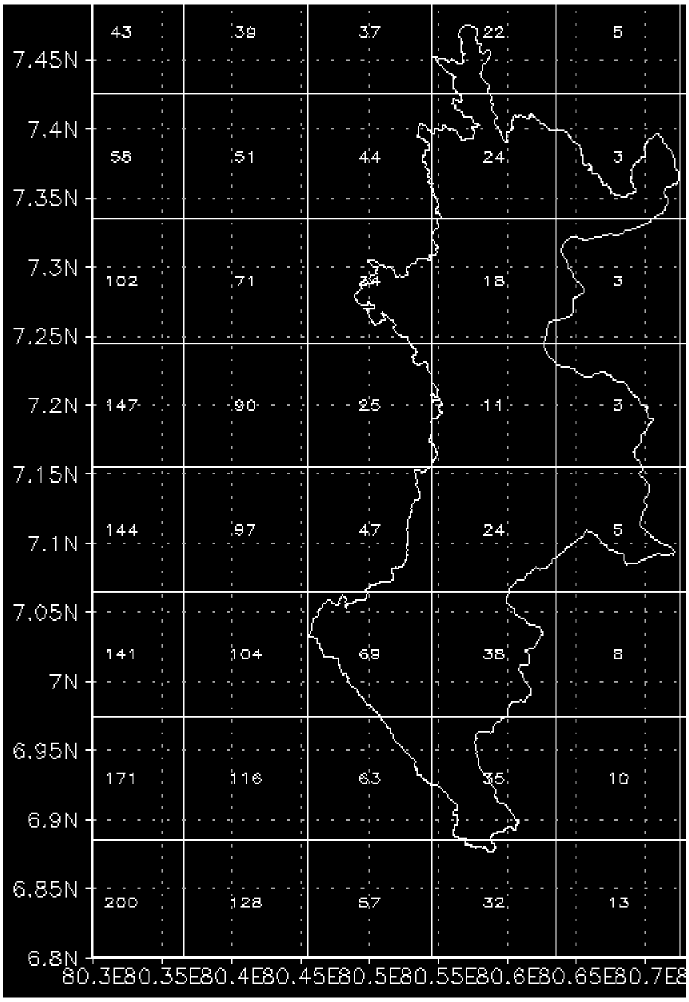

Figure 6. RegCM output of precipitation in millimetres on 25/03/2004

Table 2. Selected physics options based on 25/03/2004 rainfall event

Physics Scheme	Selected options
Boundary layer scheme	Holtslag PBL
Cumulus convection scheme	Emanuel
Moisture scheme	Explicit moisture

Table 3 provides the area percentage corresponding to the MAME % and the cumulative area percentage for the rainfall event of 25/03/2004. It is observed that the MAME % is less than 50%, for about 40% of the basin area for the selected event for calibration.

Table 3. Area percentage corresponding to each MAME % of 25/03/2004

MAME %	Area %	Cumulative area %
0-10	8	8
10-20	8	16
20-30	15	31
30-40	0	31
40-50	8	39
50-60	0	39
60-70	8	47
70-80	0	47
80-90	23	70
90-100	30	100

3.2. Model validation

The calibrated model was applied to simulate the extreme event of 10/05/2002, for model validation. The MAME % and the area percentage respect to each MAME % were calculated to have an assurance about the result for validation. Figure 7 shows the observed rainfall and figure 8 shows the RegCM model predictions for this event

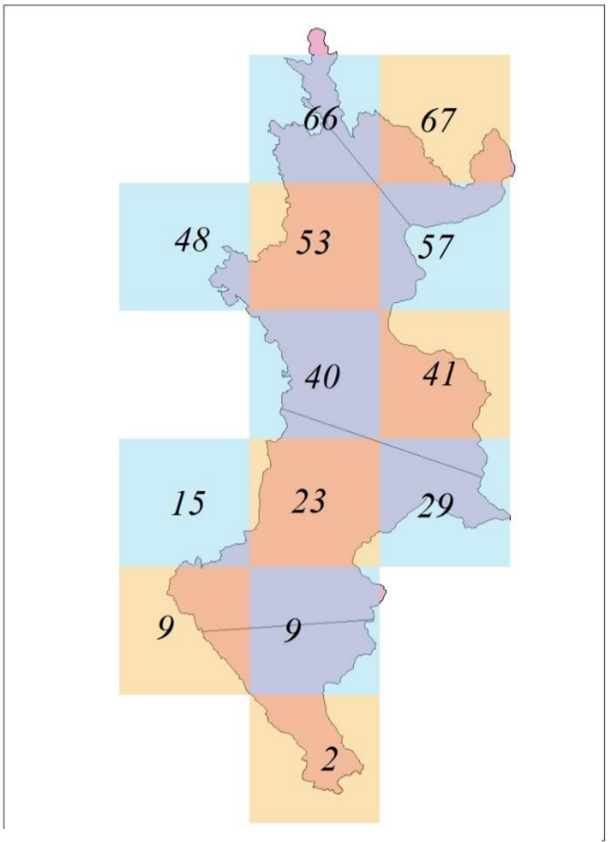

Figure 7. Gridded output of observed rainfall in millimetres on 10/05/2002

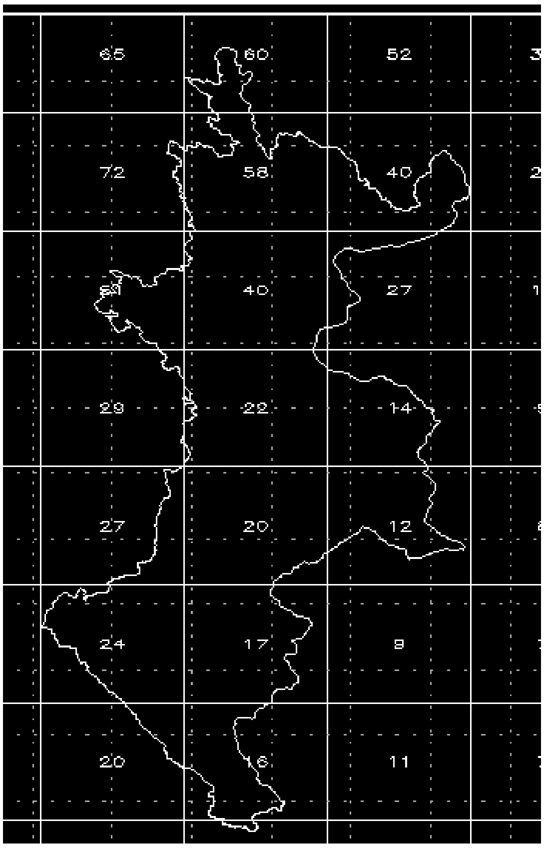

Figure 8. RegCM prediction in millimetres for 10/05/2002 event

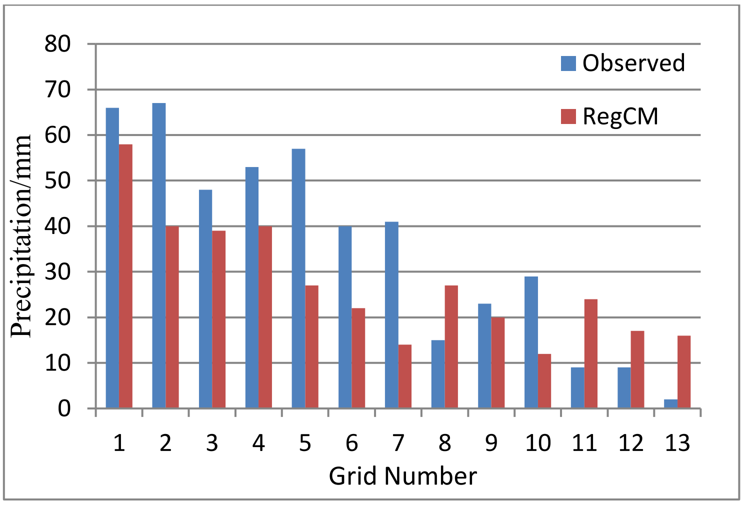

Figure 9. Comparison of RegCM predicted precipitation with the observed precipitation on 10/05/2002

Table 4. Area percentage corresponding to each MAME % of 10/05/2002

MAME %	Area %	Cumulative area %
0-10	0	0
10-20	23	23
20-30	8	31
30-40	8	39
40-50	23	62
50-60	8	70
60-70	0	70
70-80	8	78
80-90	8	86
90-100	14	100

According to Table 4, the MAME is less than 50% over more than 60% of the basin area for the selected extreme event. Further the RMSE value for this date was 17mm, which is an acceptable error. Figure 10 shows the error percentage of the model of the validation results. Therefore the selected physics combination can be applied for the Upper Mahaweli river basin to provide reasonably accurate weather predictions by downscaling the global weather predictions available in coarse grid. However, verifying the model against more events and using more rain gauges would increase the confidence of predictions. Moreover, the resolution of RegCM can be reduced up to 1 km by using the new hydrostatic version of RegCM (version 4.5 of RegCM) which is under development.

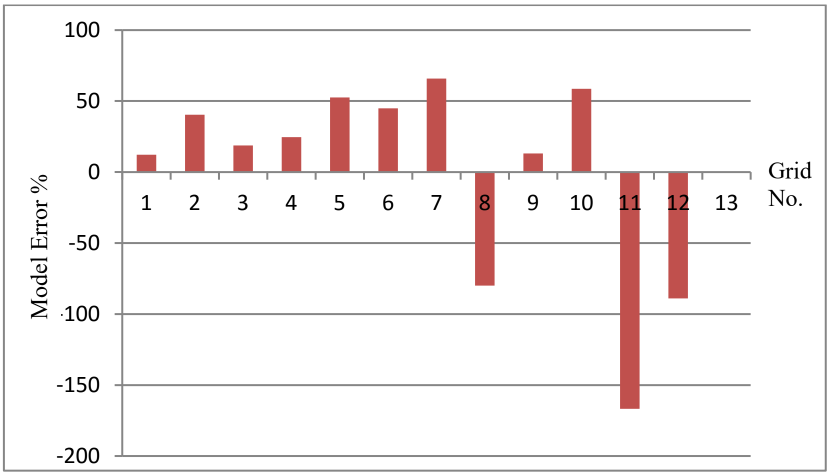

Figure 10. Error percentage of RegCM for 10/05/2002 simulation

4. Conclusion

The RegCM model is proven to be capable of predicting the weather over mountainous Upper Mahaweli River basin. The developed model is a useful tool for extreme rainfall prediction in the basin.

The combination of Relaxation, exponential technique Lateral Boundary conditions scheme, Holtslag PBL (Holtslag, 1990) Boundary layer scheme, Emanuel (1991) Cumulus convection scheme and Explicit moisture (SUBEX; Pal et al 2000) Moisture scheme with other default options were the most suitable physics combinations for the model applied to the Upper Mahaweli basin.

Acknowledgment
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