

## Chapter 2

# Monthly and Seasonal Indian Summer Monsoon Simulated by RegCM3 at High Resolutions

S.K. Dash, Savita Rai, U.C. Mohanty, and S.K. Panda

**Abstract** The purpose of this study is to examine the advantages of using higher resolution regional model in simulating the temperature and precipitation over India. The Regional Climate Model version 3 (RegCM3) has been integrated to simulate the Indian summer monsoon rainfall for a number of years at two horizontal resolutions 55 and 30 km. The characteristics of interannual variations in the contrasting monsoon years 2002 and 2003 have been examined in details at these resolutions. Comparison shows that the model simulated area weighted average magnitudes and spatial distribution of rainfall over India during June to September months reasonably compare with the respective gridded rainfall values of India Meteorological Department (IMD). Model simulated rainfall values with 30 km resolution are closer to the IMD values as compared to the simulated precipitation at 55 km model resolution. Also the spatial distribution of rainfall in RegCM3 with 30 km is more realistic than that of 55 km resolution. Comparison with NCEP/NCAR analysed fields shows that RegCM3 with 30 km resolution performs better than that with 55 km resolution in simulating the upper and lower level winds over India. It may be noted that both temperature and rainfall are important weather parameters for the farmers in terms of agricultural productions. Dynamical down-scaling of the high resolution model simulated weather parameters will eventually help in agricultural risk management.

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## 2.1 Introduction

The spatial variability of monsoon rainfall is observed to be large and there were several occasions when some parts of the country received heavy rainfall while at the same time some other parts had serious rainfall deficiency. In the recent past, the monsoons of 2002 and 2003 have exhibited very contrasting characteristics so far as rainfall over India is concerned. Large deficient rain in July 2002 over most of the country was reported in the year 2002. On the other hand, 2003 has been reported as a normal monsoon year. In 2002, the seasonal rainfall over the country as a whole was 81% of its long period average and hence it was declared as an All India drought monsoon year (Kalsi et al. 2004). The most important aspect of 2002 monsoon was that the rainfall in July was the lowest in the past 102 years. Month wise, the rainfall was normal in June, extremely subdued in July, normal in August and nearly normal in September. On the other hand in the year 2003, total seasonal monsoon rainfall over the country as a whole was 102% of its long term average. The rainfall activity in 2003 was very good during the months of June and July, though August and September were little subdued. Rajeevan et al. (2004) using 8-parameter and 10-parameter power regression models could not predict the large deficiency of rainfall of July 2002. Based on the model forecasts of European Centre for Medium range Weather Forecasts (ECMWF), Gadgil et al. (2002) summarised that June, July and August rainfall was deficient only over the southwestern peninsular and near normal over rest of the country.

It has been demonstrated that for examining the weather features in greater detail, regional models are more suitable than the global models. Today computationally it is affordable to increase the resolution of regional models so as to resolve regional climatic features reasonably well. There have been some attempts in the past to simulate monsoon features and extreme weather events over India by regional models. Bhaskaran et al. (1996) simulated the Indian summer monsoon using a regional climate model with a horizontal resolution of 50 km nested with global atmospheric GCM. Their study showed that regional model derived precipitation is larger by 20% than GCM. Ji and Vernekar (1997) simulated the summer monsoons of 1987 and 1988 by using the National Centers for Environmental Prediction (NCEP) Eta model nested in the Center for Ocean-Land-Atmosphere (COLA) GCM. Their comparative studies showed that for 1987, the Eta model simulates deficient summer monsoon rainfall over northern and peninsular India and the Indonesian region and excess rainfall over southeast China, Burma and the sub-Himalayan region compared to 1988. Azadi et al. (2001) used MM5 to simulate western disturbances during January 1997 over the Indian region and to predict precipitation associated with it. Bhaskar Rao et al. (2004) simulated many observed features of the Indian summer monsoon such as sea level pressure, 925 hPa temperature, low level wind and precipitation using MM5. The Regional Climate Model version 3 (RegCM3) has also been successfully integrated to simulate the salient features of Indian summer monsoon

circulation and rainfall (Dash et al. 2006; Shekhar and Dash 2005). They found that the RegCM3 successfully simulate the 850 hPa westerly flow and the 200 hPa easterly flow. Also the seasonal mean summer monsoon rainfall simulated by the model is close to the GPCC values. They have also found that RegCM3 successfully simulates the temperature pattern at 500 hPa over the Indian Peninsula and Tibet. In their study it was inferred that RegCM3 can be effectively used to study monsoon processes over the South Asia region. Shekhar and Dash (2005) have examined the effect of Tibetan snowfall in the month of April on the Indian summer monsoon circulation and associated rainfall using RegCM3 with 55 km resolution. Model simulations show that when 10 cm of snow-depth in April is prescribed over Tibet, summer monsoon rainfall in entire India reduces by about 30%. Singh et al. (2006) used RegCM3 over East Asia regions and showed promising performance of this regional model in simulating important characteristics of monsoon circulations.

The objective of the current paper is to examine the performance of RegCM3 at two different resolutions 55 and 30 km so as to compare the important features of simulated summer monsoon in the contrasting years 2002 and 2003. A brief description of RegCM3, experimental design and data used are given in Sect. 2.2. Sections 2.3–2.6 discuss the characteristics of upper level wind, lower level wind, temperature at 500 hPa and rainfall for both the resolutions of RegCM3 respectively and the conclusions are summarized in Sect. 2.7.

## 2.2 Model, Initial Data and Experimental Design

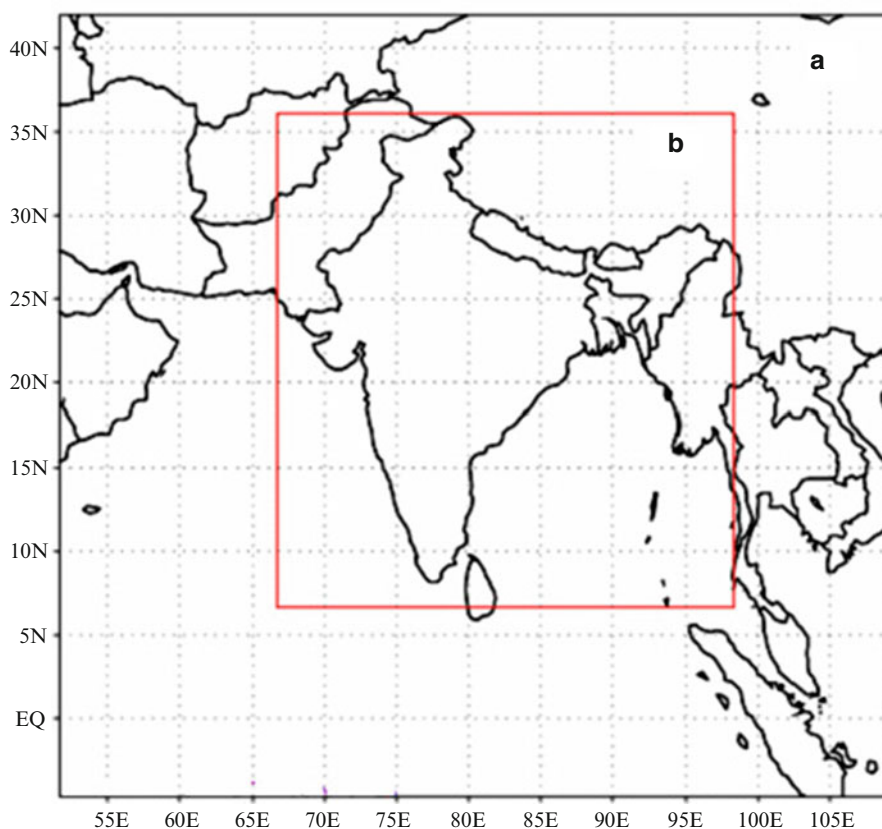
RegCM3, an upgraded version of the Abdus Salam International Centre for Theoretical Physics (ICTP) regional climate model RegCM2 originally developed by Giorgi et al. (1993a, b), is a compressible, grid point model with 14 vertical layers and hydrostatic balance. There are two categories of landuse such as MM4 vegetation and Global Land Cover Characterization (GLCC) which determine surface properties like albedo, roughness, moisture etc. at each grid point. MM4 vegetation has 13 different types and GLCC has similarly 20 types of lands. The model dynamical core is essentially the same as that of the hydrostatic version of MM5 (Grell et al. 1994). The model includes cumulus parameterization schemes, large scale precipitation scheme, planetary boundary layer (PBL) parameterization, state-of-the-art surface vegetation/soil hydrology package, the Biosphere-Atmosphere Transfer Scheme (BATS), Ocean flux parameterization, pressure gradient scheme, explicit moisture scheme, the radiative transfer scheme and the ocean-atmosphere flux scheme.

The complete RegCM3 modelling system consists of four modules: Terrain, ICBC, RegCM and Postprocessor. Terrain and ICBC are the two components of RegCM preprocessor. These program modules are run in sequence. Following Dash et al. (2006) in this study, Grell convective precipitation scheme with Arakawa-Schubert (AS) closure has been used. It has been widely used within both MM5 and

RegCM modeling frameworks. It is a mass flux scheme that includes the moistening and heating effects of penetrative updrafts and corresponding downdrafts.

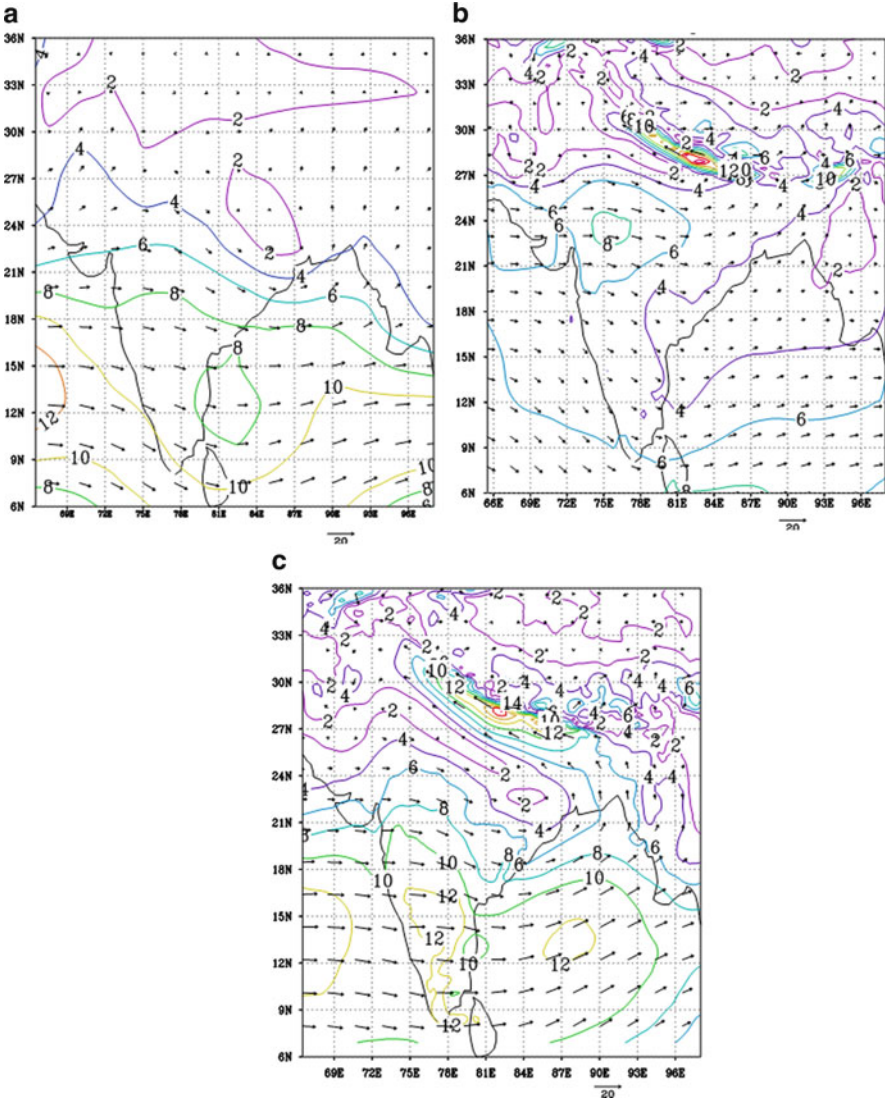
For simulating the monsoon circulation features the central grid point for model domain is chosen at  $80^{\circ}\text{E}$  and  $20^{\circ}\text{N}$ . In the 55 km resolution domain chosen is  $50^{\circ}\text{E}$  to  $109^{\circ}\text{E}$  and  $4^{\circ}\text{S}$  to  $41^{\circ}\text{N}$  and there are 101 grid points along a latitude circle and 120 points along the longitudinal direction. In case of 30 km resolution there is one-way nesting with a larger domain at 90 km resolution as shown in Fig. 2.1. In the 90 km resolution the domain chosen is  $51^{\circ}\text{E}$  to  $109^{\circ}\text{E}$  and  $4^{\circ}\text{S}$  to  $42^{\circ}\text{N}$  and there are 64 grid points along a latitude circle and 72 points along the longitudinal direction. While in case of 30 km resolution the domain chosen is  $66^{\circ}\text{E}$  to  $98^{\circ}\text{E}$  and  $6^{\circ}\text{N}$  to  $36^{\circ}\text{N}$  and there are 120 grid points along both the latitude circle and the longitudinal direction.

The elevation data used are obtained from the United States Geological Survey (USGS). Terrain heights and land use data are used at 30 min resolution. In both the years 2002 and 2003, simulations at 55 and 30 km resolutions cover the months



**Fig. 2.1** One way nesting of domains at (a) 90 km and (b) 30 km for the Indian region

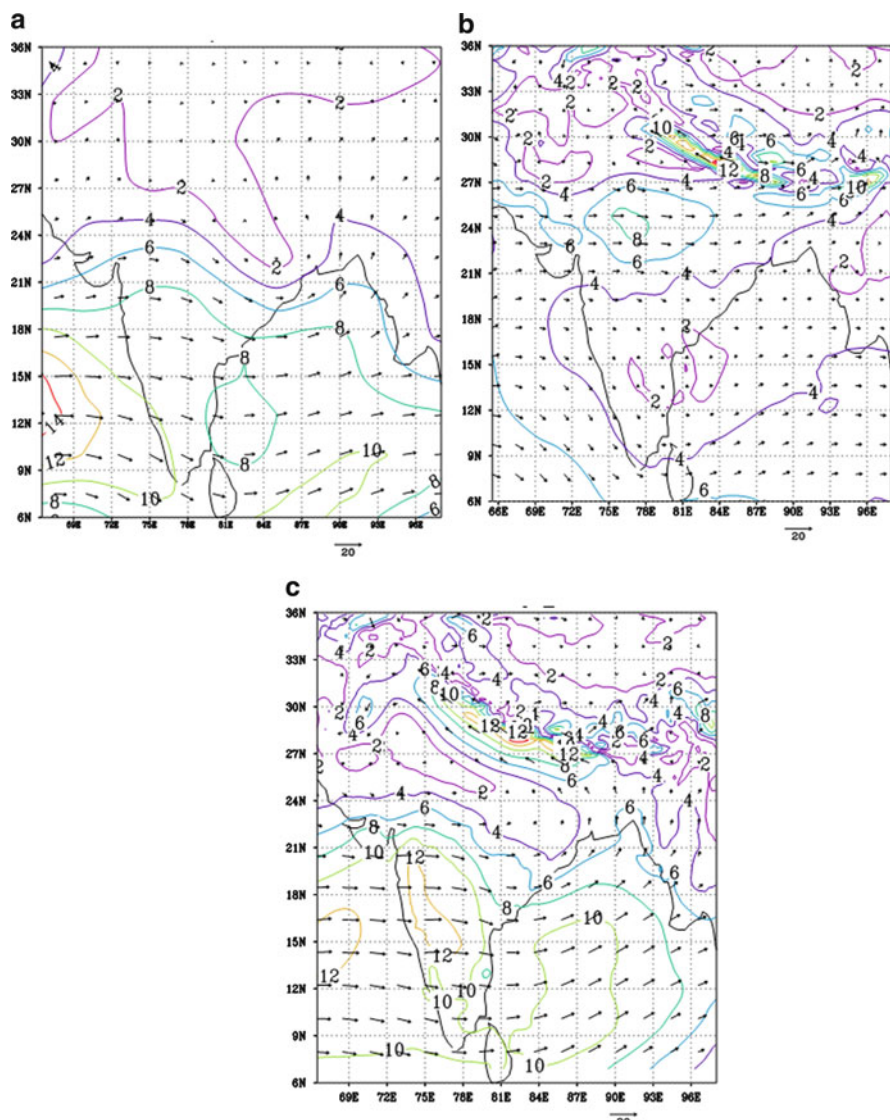
from April to September in the ensemble mode with nine-members starting from 25th April to 3rd May. The data for initial and lateral boundary conditions have been obtained from the National Centers for Environmental Prediction (NCEP) Reanalysis (NNRP1) and Sea Surface Temperature (SST) that are collected from the National Oceanic and Atmospheric Administration (NOAA) 4-times daily and weekly datasets respectively.



**Fig. 2.2** Mean winds (JJAS) at 850 hPa in 2002 (a) NCEP/NCAR reanalysis, (b) RegCM3 at 55 km and (c) RegCM3 at 30 km

## 2.3 Lower Level Wind

The averages of seasonal mean winds of the nine ensemble members simulated by RegCM3 in 2002 and 2003 with 55 and 30 km resolutions at 850 hPa levels are depicted in Figs. 2.2 and 2.3 respectively. In the year 2002, the maximum

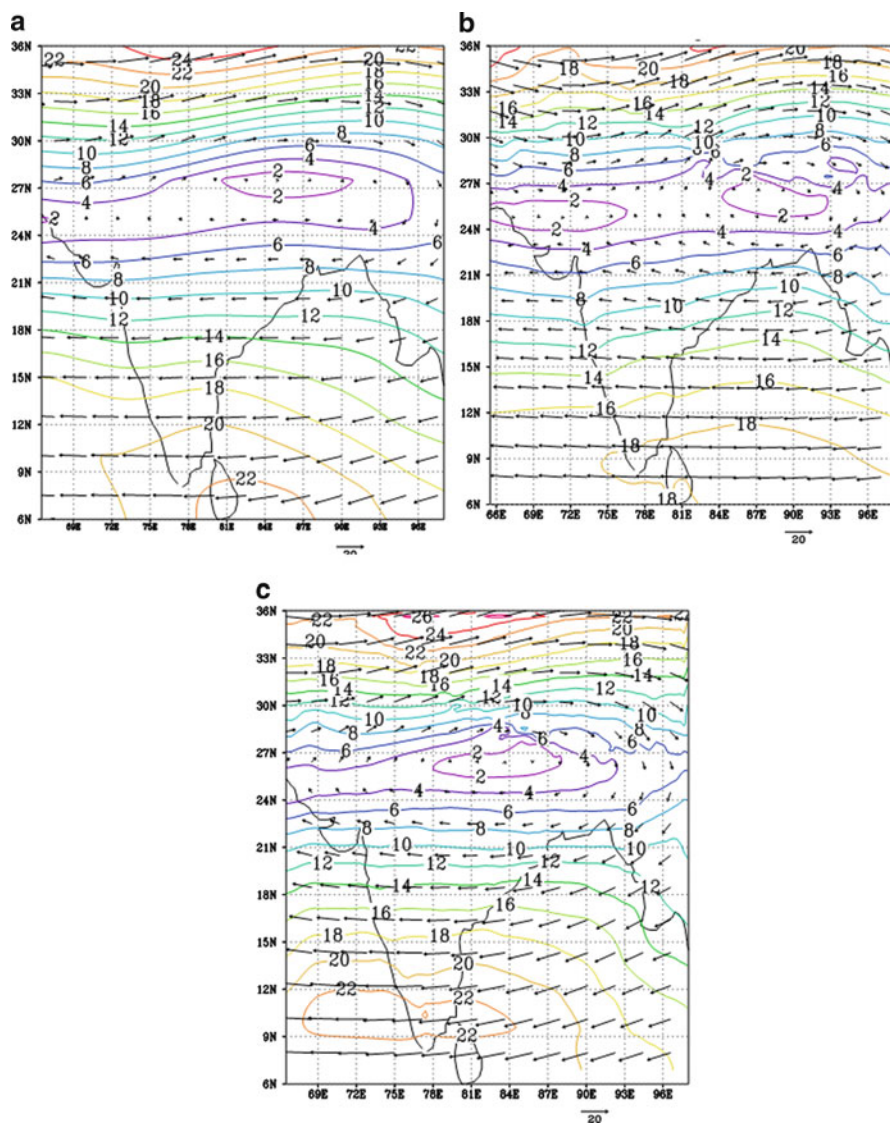


**Fig. 2.3** Mean winds (JJAS) at 850 hPa in 2003 (a) NCEP/NCAR reanalysis, (b) RegCM3 at 55 km and (c) RegCM3 at 30 km

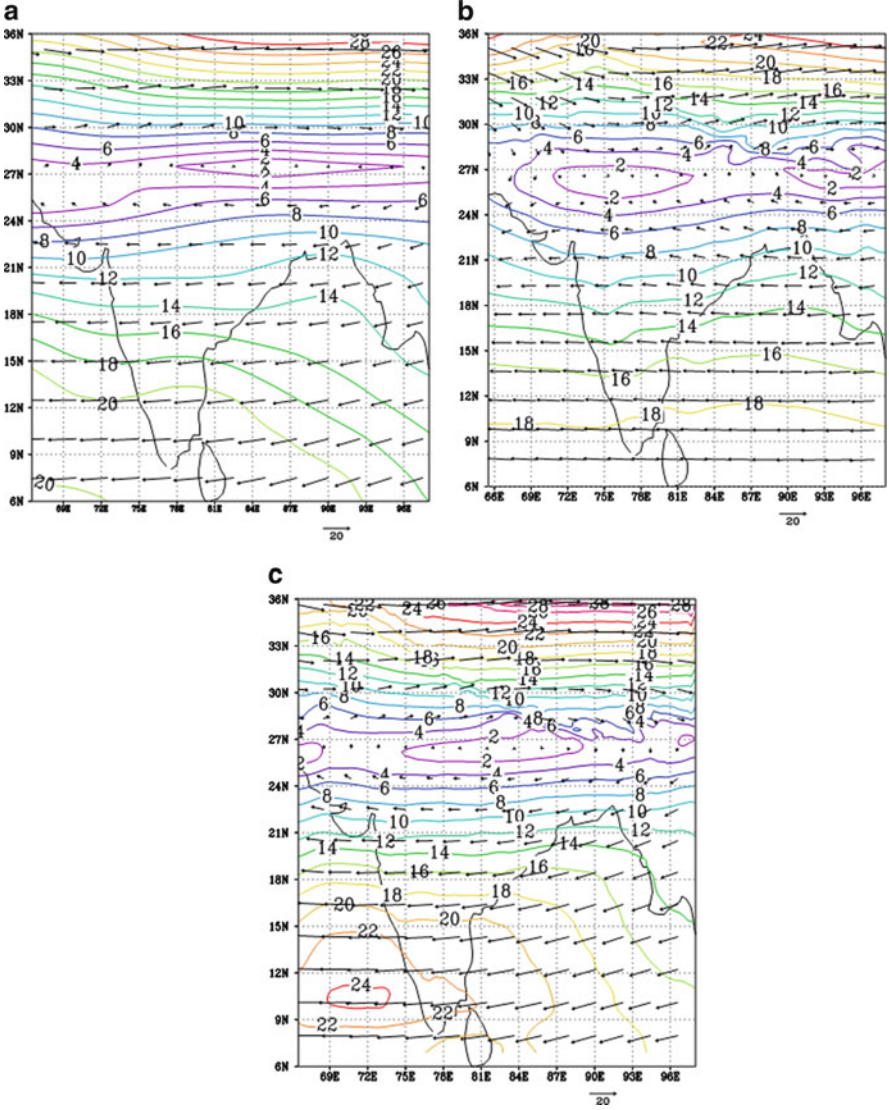
strength of the Somali jet at 850 hPa is 12 m/s at 30 km resolution which is closer to NCEP/NCAR reanalysis while in case of 55 km the difference is more. Across the monsoon trough the maximum values are 8 m/s and 4 m/s in case of 30 and 55 km respectively. The westerly wind over the peninsula has the speeds of 10–12 m/s, 4–6 m/s and 8–10 m/s in case of 30 km model resolution, 55 km model resolution and NCEP-NCAR respectively. Similar pattern is seen for the year 2003. The maximum strength of the Somali Jet at 850 hPa level in case of 30 km resolution is 12 m/s which is very close to the NCEP/NCAR reanalysis value of 14 m/s. While in 55 km resolution the corresponding wind strength is 6 m/s, along the west coast the wind speeds are 12 m/s, 4 m/s and 10 m/s for resolutions 30, 55 km of RegCM3 and NCEP/NCAR respectively. The westerly wind simulated by RegCM3 over peninsula has the same speed of 10–12 m/s for both the years 2002 and 2003.

## 2.4 Upper Level Wind

The observed NCEP/NCAR reanalysed wind and the ensemble averages of the seasonal mean winds simulated by RegCM3 at 200 hPa level in the years 2002 and 2003 are shown in Figs. 2.4 and 2.5 respectively. In the year 2002 maximum strengths of the easterly jet across the peninsula are 22 m/s and 18 m/s at 30 and 55 km model resolutions respectively. Both the values are close to the NCEP/NCAR reanalysis value of 20 m/s. Upper level easterly wind strength over Tibet is 20 m/s at both 30 and 55 km model resolutions. In 2003, the wind speed ranges over the peninsula are 20–22 m/s, 18–20 m/s and 16–18 m/s in case of 30 km model resolution, NCEP/NCAR reanalysis and 55 km respectively. Upper level wind strength over Tibet is 24 m/s in the 30 km model resolution whereas both in NCEP/NCAR reanalysis and 55 km resolution the corresponding strength is 20 m/s. At 30°N and 85°E, the wind strength is 12 m/s at both 30 and 55 km model resolutions.



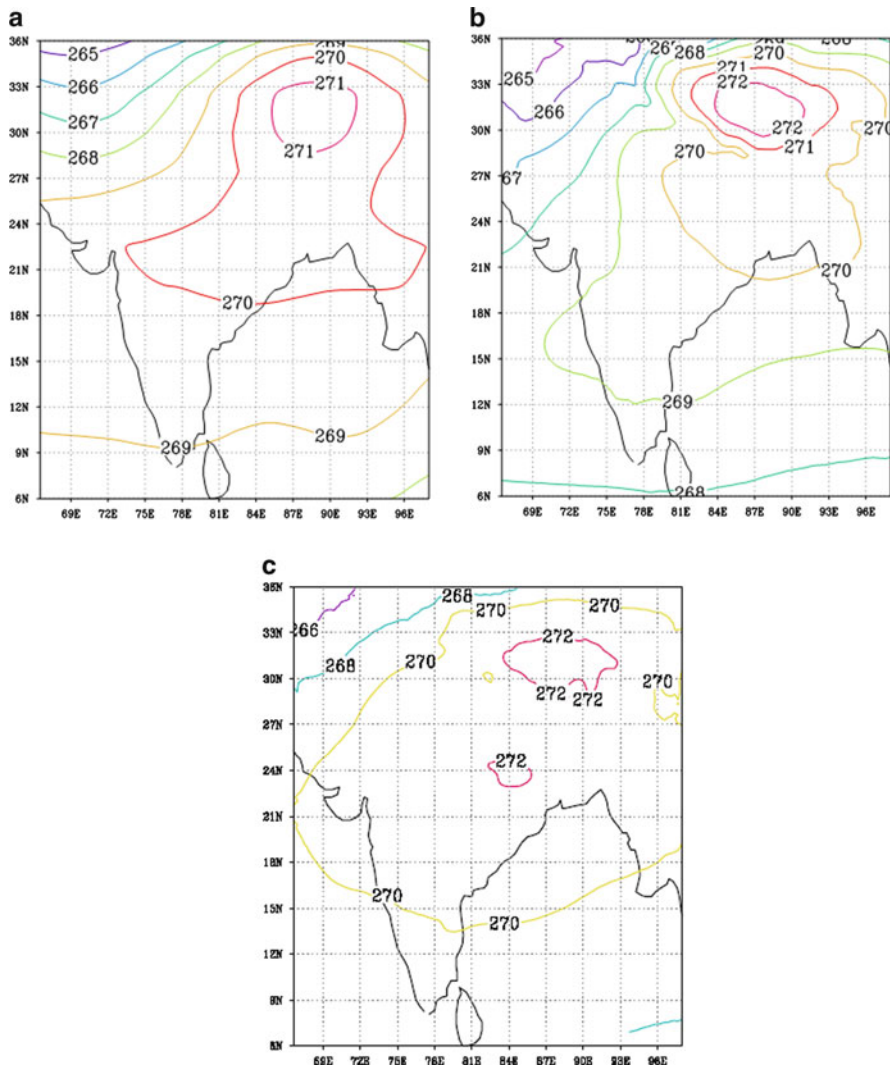
**Fig. 2.4** Mean winds (JJAS) at 200 hPa in 2002 (a) NCEP/NCAR reanalysis, (b) RegCM3 at 55 km and (c) RegCM3 at 30 km



**Fig. 2.5** Mean winds (JJAS) at 200 hPa in 2003 (a) NCEP/NCAR reanalysis (b) RegCM3 at 55 km (c) RegCM3 at 30 km

## 2.5 Temperature at 500 hPa

Depict the NCEP/NCAR reanalysis and RegCM3 simulated JJAS mean temperatures at 500 hPa with 55 and 30 km resolutions respectively for the years 2002 and 2003. As shown in Fig. 2.6 the mean maximum temperature over Tibet is 272 K at both 30



**Fig. 2.6** Mean temperatures (JJAS) at 500 hPa in 2002 (a) NCEP/NCAR reanalysis, (b) RegCM3 at 55 km and (c) RegCM3 at 30 km

and 55 km model resolutions in 2002. The corresponding mean temperature at 500 hPa in the NCEP/NCAR reanalysis is 271 K. Over the Indian Peninsula the mean simulated temperature in the 55 km resolution is similar to that of NCEP/NCAR but it is more in case of 30 km model resolution for both the years 2002 and 2003. The corresponding value in NCEP/NCAR reanalysis is 272K Figures 2.6 and 2.7.

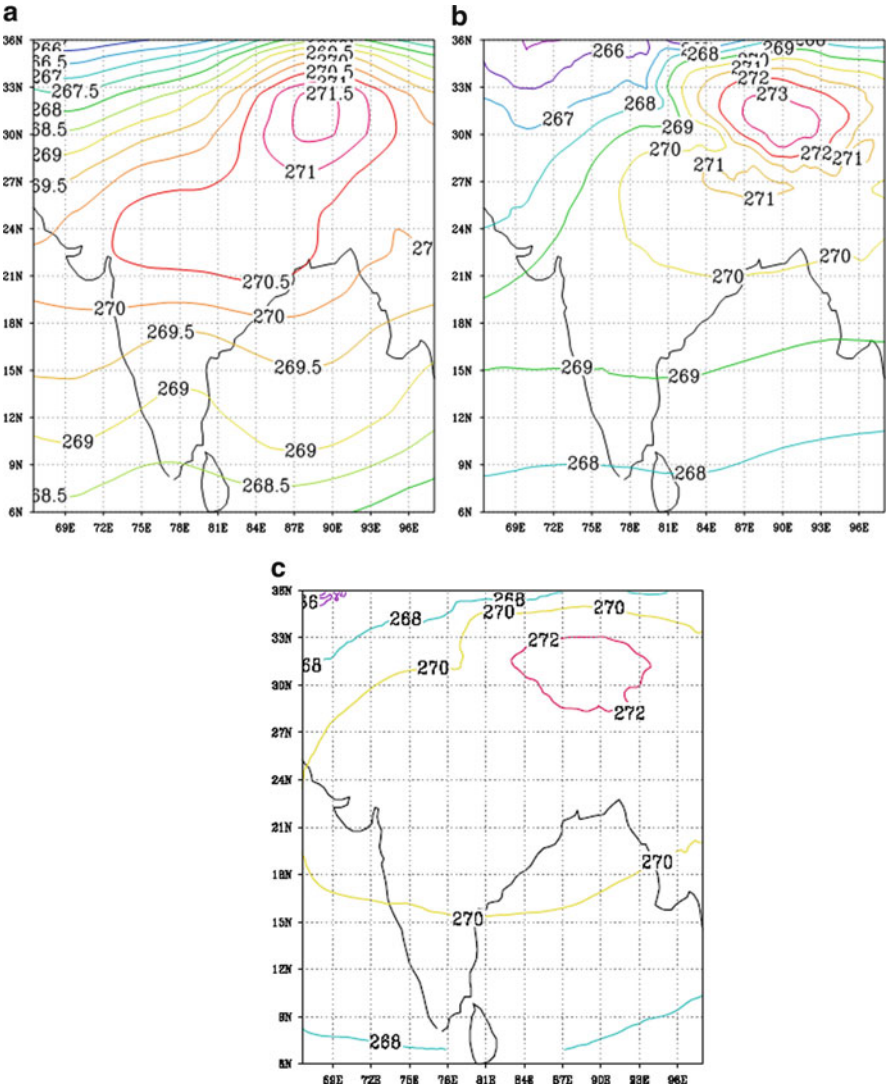
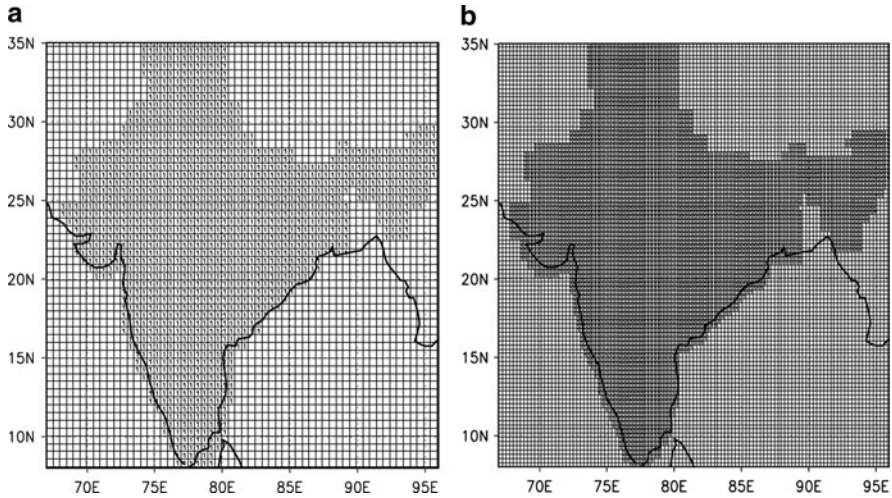


Fig. 2.7 Mean temperatures (JJAS) at 500 hPa in 2003 (a) NCEP/NCAR reanalysis, (b) RegCM3 at 55 km and (c) RegCM3 at 30 km

2.6 Rainfall

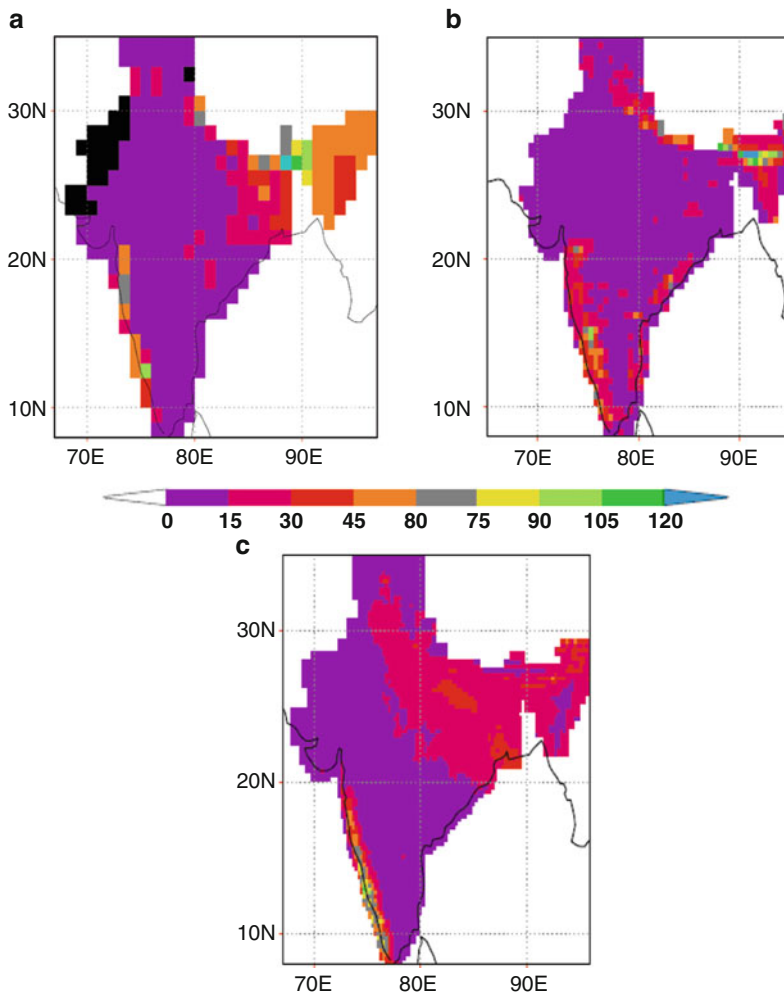
The monthly and seasonal rainfall simulated in two consecutive years 2002 and 2003 with two different model resolutions of 55 and 30 km are discussed here. For better and close comparison of rainfall simulated by the model and the IMD observed rainfall, area weighted averaging has been done at the model grids. This



**Fig. 2.8** Grid boxes used for calculating rainfall over Indian landmass in RegCM3 simulations at (a) 55 km and (b) 30 km resolutions

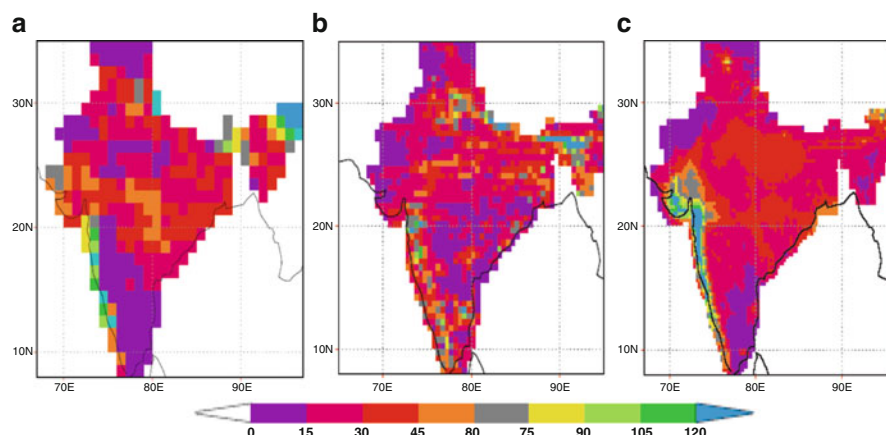
method is similar to that used by IMD with the observed sub-divisional rainfall. It is known that IMD calculates ISMR based on the area weighted average sub divisional rainfall. As mentioned earlier RegCM3 at 55 km has  $118 \times 99$  grids across the Indian landmass and at 30 km it has a total of  $118 \times 118$  grids. The grid boxes marked '1' in Fig. 2.8a, b are those, which cover all the meteorological subdivisions of IMD as closely as possible. In this study, the model simulated monthly and seasonal rainfall are computed at the grids over Indian landmass. Figures 2.9 and 2.10 show the grid averaged rainfall of IMD and those simulated by RegCM3 with 55 and 30 km resolutions in July of both the years 2002 and 2003 respectively. Figures 2.11 and 2.12 show corresponding values for JJAS.

IMD has generated monthly mean rainfall at regular  $10 \times 10$  grids over the India landmass (Rajeevan et al. 2005). For the analysis, daily rainfall data of 6,329 stations were considered during 1951–2003. There were only 1,803 stations with a minimum 90% data availability during that period. In their analysis, the interpolation method proposed by Shepard (1968) has been followed. This method is based on the weights calculated from the distance between the station and the grid point and also the directional effects. Standard quality controls were performed before carrying out the interpolation analysis. Quality of the present gridded rainfall analysis was also compared with similar global gridded rainfall data sets. Comparison revealed that the present gridded rainfall analysis is better in more realistic representation of spatial rainfall distribution. The IMD gridded rainfall dataset is being extensively used for many applications in validation of climate and numerical weather prediction models and also for studies on monsoon variability (Rajeevan et al. 2006; Dash et al. 2009).



**Fig. 2.9** July 2002 mean rainfall (cm) at the grids over Indian landmass (a) IMD 1-degree, (b) RegCM3 55 km and (c) RegCM3 30 km

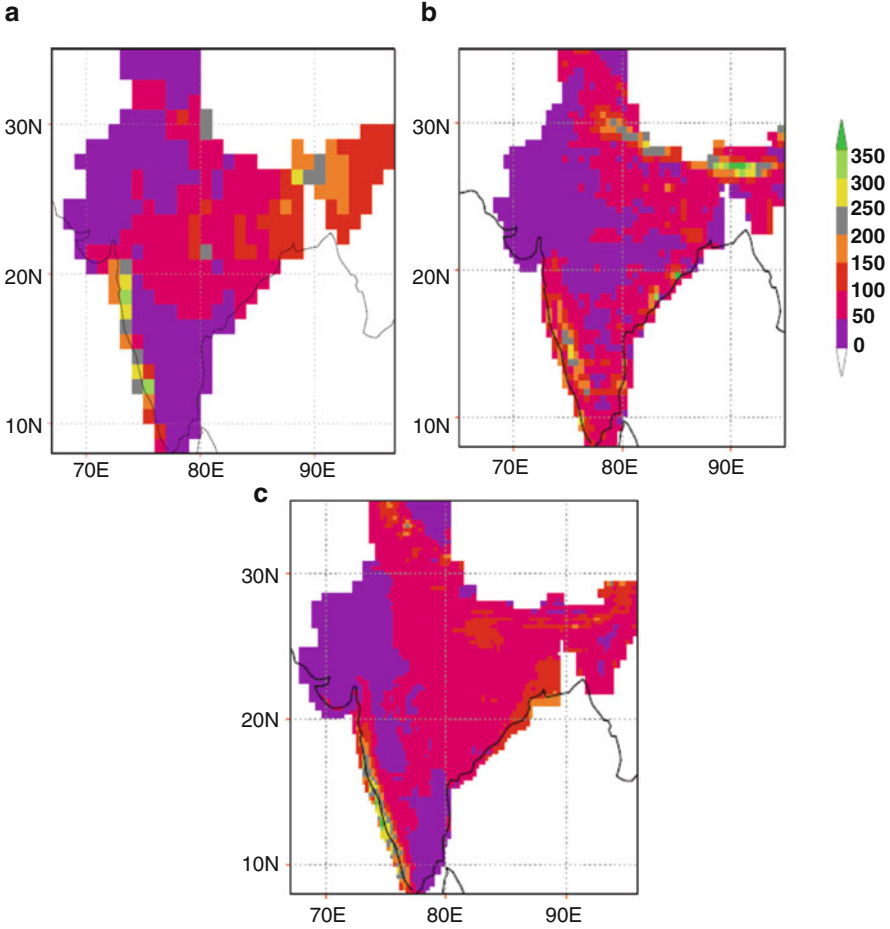
In July 2002 very little rain was observed except in the west coast and north-east of India (Fig. 2.9a) while in July 2003 good amount of rainfall was recorded throughout the country (Fig. 2.10a). This contrasting rainfall is clearly seen for higher resolution simulation of RegCM3 in comparison to resolution of 55 km. Figure 2.9a, c show that there is good amount of rainfall in west coast, some parts of coastal Andhra, coastal Orissa, along the foothills of Himalayas and north east India whereas there is very less rainfall in north-west and some parts of central India while Fig. 2.9b shows very less rainfall in coastal Orissa and north east India. On the other hand in 2003, most of the country received good amount of rainfall except north-west India as shown in Fig. 2.10.



**Fig. 2.10** July 2003 mean rainfall (cm) at the grids over Indian landmass (a) IMD 1-degree, (b) RegCM3 55 km and (c) RegCM3 30 km

Figure 2.9c shows that in the simulations with 30 km grid size maximum rainfall is 75–90 cm. The model with 55 km simulates maximum rainfall of 90–105 cm (Fig. 2.9b) over west coast whereas the corresponding observed value is 50 cm (Fig. 2.9a). Simulated rainfall over Bihar, West Bengal and Orissa is 1–15 cm which is less than the corresponding observed value of 10–25 cm. However, precipitation simulated by RegCM3 at 30 km exactly matches with the observed values. Simulated rainfall over North-West India at both 55 km and 30 km lies between 1 and 15 cm. These are close to the observed rainfall value of 0–15 cm for the year 2002. The observed and simulated mean rainfall in the month of July at 55 and 30 km resolutions in the year 2003 are depicted in Figs. 2.10a–c respectively. Over west coast of India, the simulated rainfall is 80–120 cm for all the three cases. Comparing with observed rainfall over the central India, we found that higher resolution of 30 km predicted much accurate rainfall than 55 km resolution.

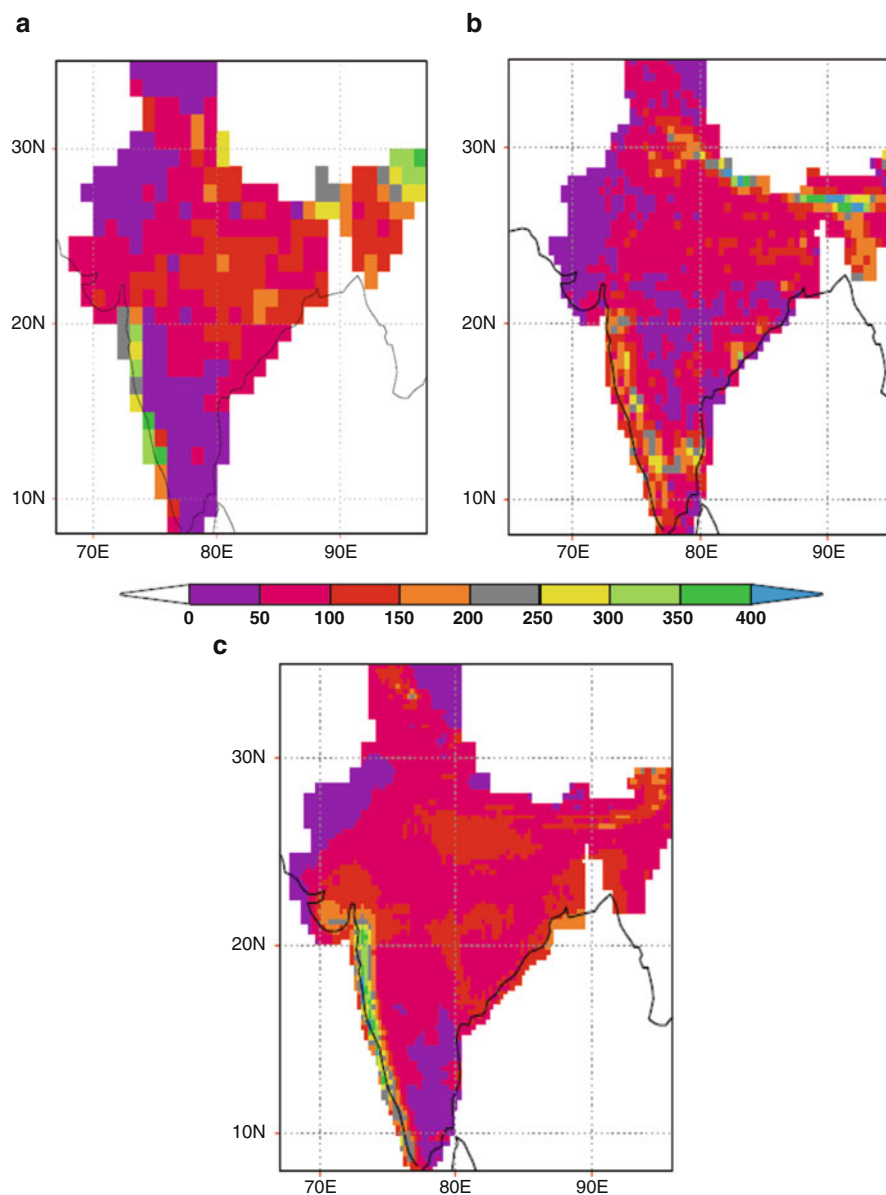
Figure 2.11a–c show the monthly mean rainfall of IMD and those simulated by RegCM3 with 55 and 30 km resolutions for the year 2002 respectively. The spatial distribution of rainfall shows differences in pattern for model simulated and IMD values, but some similarities exist in the zones of maximum and minimum. Simulated precipitation range rainfall for both of the resolutions over the west coast is 200–300 cm (Fig. 2.11b, c) which is similar to the corresponding observed value (Fig. 2.11a). Over Bihar and Gangetic west Bengal rainfall values lie between 100 and 200 cm for both the observed and RegCM3 simulated with 30 km resolution while with 55 km resolution these rainfall values lie between 50 and 100 cm. This shows that the RegCM3 simulated rainfall with 55 km is less than that observed over Gangetic plain. However, higher resolution of RegCM3 at 30 km depicts nearly same distribution of rainfall. Figure 2.12a–c show the monthly mean rainfall of IMD and RegCM3 simulated with 55 and 30 km respectively for



**Fig. 2.11** JJAS 2002 mean rainfall (cm) at the grids over Indian landmass (a) IMD 1°, (b) RegCM3 55 km and (c) RegCM3 30 km

the year 2003. Over west coast of India, the observed rain and that simulated by RegCM3 with 30 km resolution are more than 200 cm which is reasonably good in comparison to 55 km resolution value lying between 100 and 200 cm. Simulated rainfall values are up to 200 cm over Gangetic plain and up to 100 cm over the North-West India with both the resolutions of model.

Table 2.1 shows monthly mean rainfall values simulated by RegCM3 with 55 and 30 km resolutions using 9-ensemble members and IMD rainfall values for the years 2002 and 2003. In 2002, the area weighted average JJAS rain amount are 70.9 cm, 69.0 cm and 70.6 cm in case of 30 km, 55 km and IMD respectively. In 2003 these values are 90.7 cm and 88.3 cm with 30 and 55 km resolutions respectively while the corresponding observed value is 89.4 cm. Simulated rainfall by RegCM3 with 30 km resolution shows an overestimate of about 0.4% while with

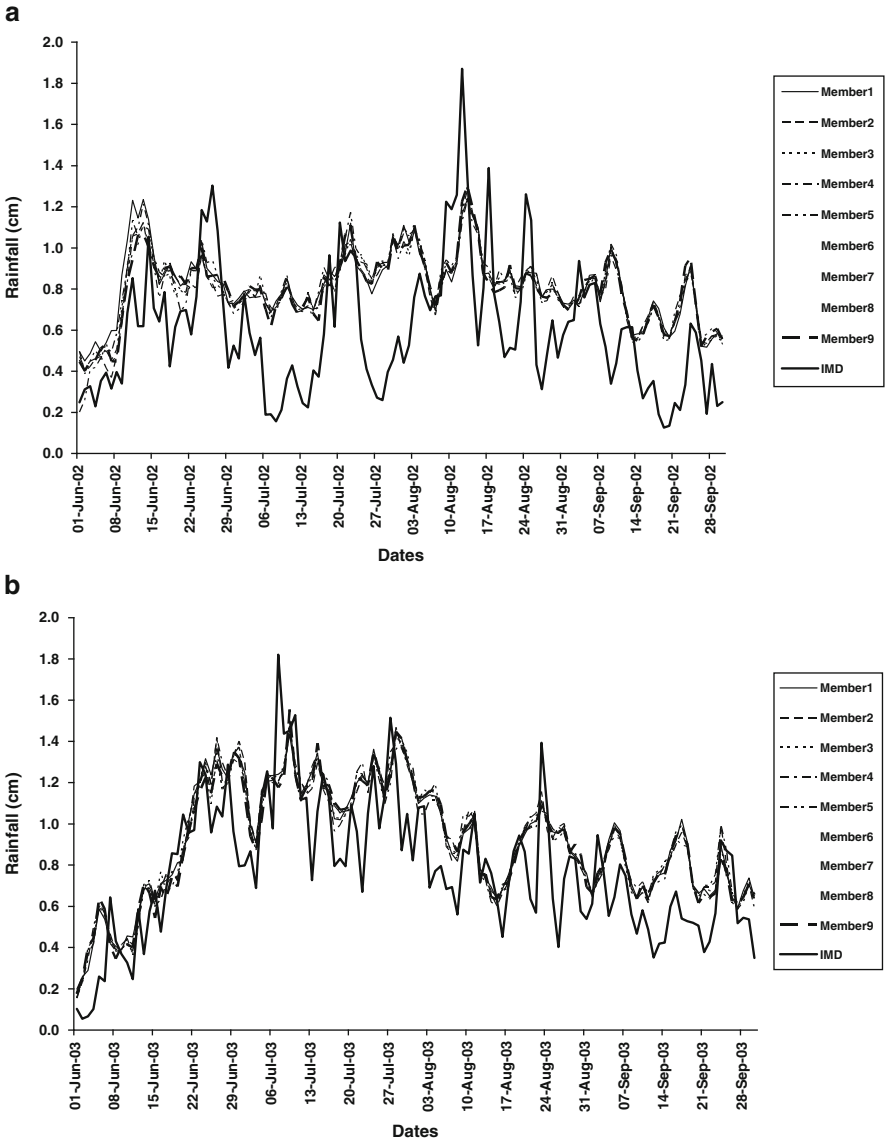


**Fig. 2.12** JJAS 2003 mean rainfall (cm) at the grids over Indian landmass (a) IMD 1°, (b) RegCM3 55 km and (c) RegCM3 30 km

55 km resolution rainfall value is underestimated by about 2.3% in 2002. While in 2003, simulated rain amount is overestimated by 1.4% and underestimated by 1.3% in 30 and 55 km model resolutions respectively. These results indicate that area

**Table 2.1** Comparison of RegCM3 simulated rainfall (cm) at resolutions 55 and 30 km with observed rainfall of IMD for the years 2002 and 2003

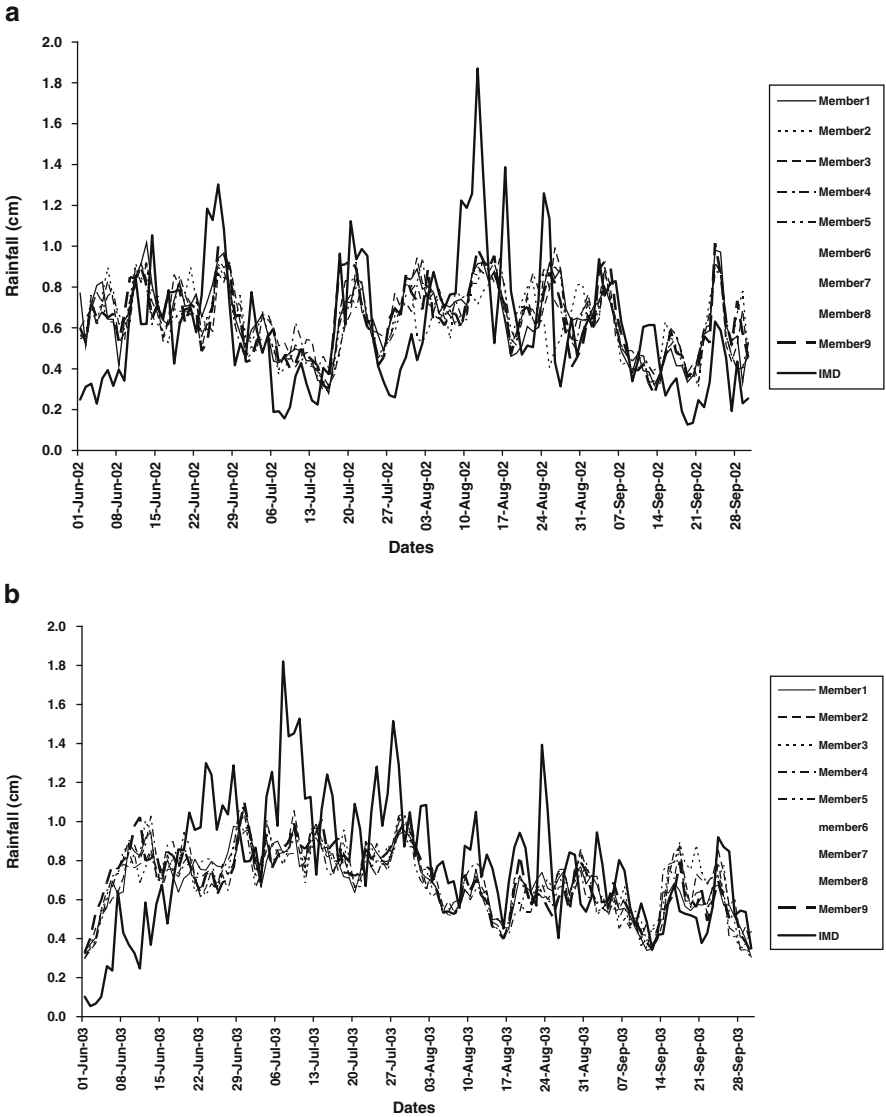
| 2002           |      |                       |      | 2003           |      |                       |      |                |      |                       |      |
|----------------|------|-----------------------|------|----------------|------|-----------------------|------|----------------|------|-----------------------|------|
| IMD            |      | RegCM3-55 km          |      | RegCM3-30 km   |      | IMD                   |      | RegCM3-55 km   |      | RegCM3-30 km          |      |
| Magnitude (cm) |      | departure from normal |      | Magnitude (cm) |      | departure from normal |      | Magnitude (cm) |      | departure from normal |      |
| Months         |      |                       |      |                |      |                       |      |                |      |                       |      |
| June           | 16.2 | 104.2                 | 15.9 | 102.2          | 16   | 102.6                 | 16.9 | 108.7          | 19.1 | 122.7                 | 18.3 |
| July           | 14.2 | 48.3                  | 13.9 | 47.3           | 14.9 | 50.5                  | 31.4 | 106.7          | 30.2 | 102.5                 | 30.9 |
| August         | 24.8 | 95.7                  | 23.1 | 89             | 24.3 | 93.7                  | 24.6 | 94.9           | 23   | 88.7                  | 24.6 |
| September      | 15.4 | 89.6                  | 16.1 | 93.4           | 16.9 | 98.2                  | 16.5 | 96             | 16.1 | 93.4                  | 16.9 |
| JAS            | 70.6 | 80.2                  | 68.9 | 78.3           | 72   | 81.7                  | 89.4 | 101.5          | 88.3 | 100.2                 | 90.7 |



**Fig. 2.13** Daily standardised rainfall series simulated by individual ensembles at 30 km resolution compared with that of IMD (a) 2002 (b) 2003

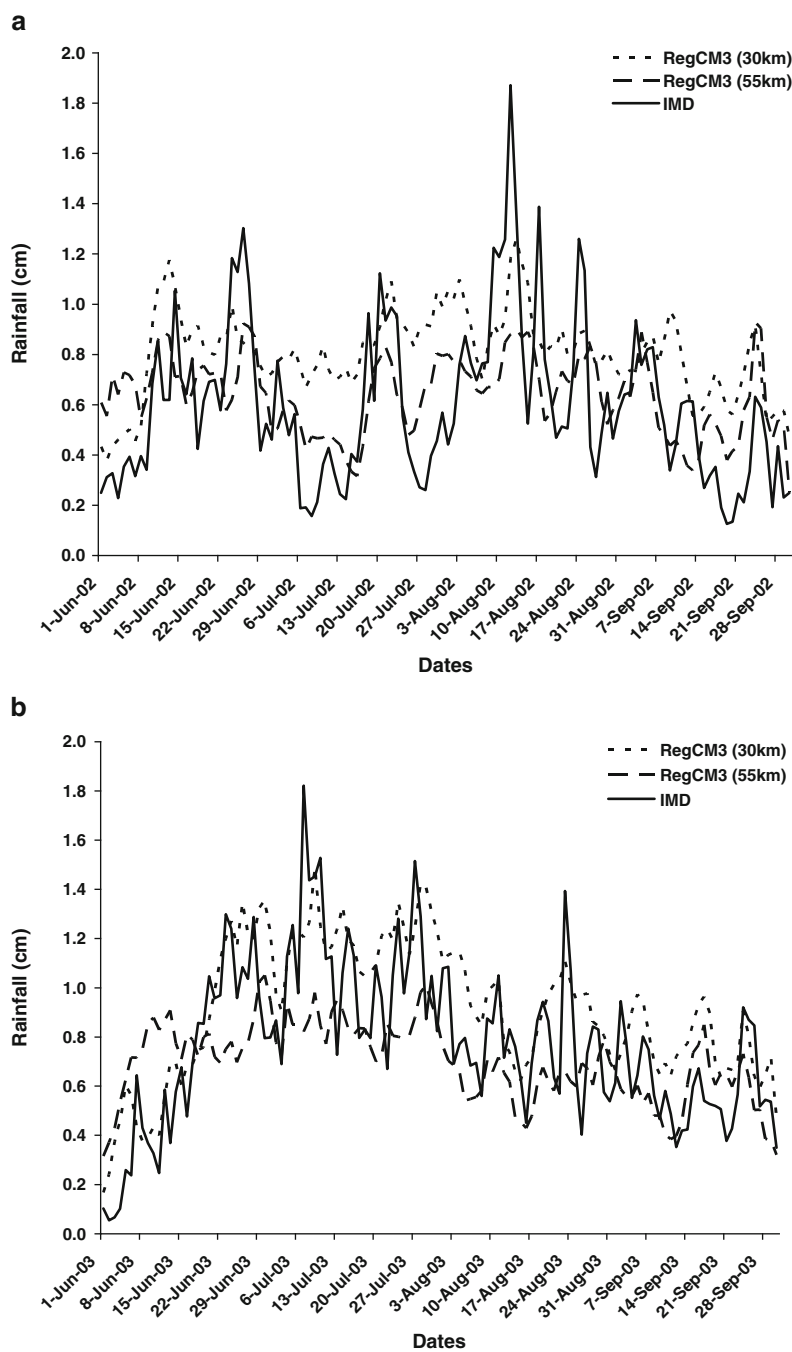
weighted average rainfall over India is better simulated by the RegCM3 at higher resolution of 30 km and are more accuracy in comparison to 55 km resolution.

Figures 2.13 and 2.14 show the daily standardised rainfall simulated by nine ensembles individually with 30 and 55 km resolutions respectively in the years



**Fig. 2.14** Daily standardised rainfall series simulated by individual ensembles at 55 km resolution compared with that of IMD (a) 2002 (b) 2003

2002 and 2003. Figure 2.15 shows the daily accumulated rainfall simulated by RegCM3 with 30 and 55 km along with IMD daily rainfall time series, starting from 1st June up to 30th September. These figures demonstrate the advantages of using higher resolution of 30 km compared to 55 km.



**Fig. 2.15** Daily ensemble mean rainfall simulated at 30 and 55 km of RegCM3 and IMD rainfall from 1st June to 30th September (a) 2002 and (b) 2003

## 2.7 Conclusions

In this study characteristics of summer monsoon circulation, rainfall and temperature simulated by RegCM3 at two different resolutions 55 and 30 km in the contrasting monsoon years 2002 and 2003 are compared in detail. The initial and boundary conditions for model integration are obtained from the analyses of NCEP/NCAR. Also the physical parameterization schemes of the two simulations are same. Results indicate that in both the years 2002 and 2003, higher resolution RegCM3 at 30 km predicts much closer wind to NCEP/NCAR reanalysis field at 850 hPa than that at 55 km model resolution. Also across the peninsula the strength of the easterly jet is well simulated by RegCM3 at 30 km resolution in both the years 2002 and 2003. In general, the maximum strengths of the Tibetan anticyclone and the easterly jet over peninsula are more in the year 2003 compared to those in 2002 in both the simulations of RegCM3 at 55 and 30 km. The temperatures at 500 hPa based on both the simulations of RegCM3 are close to NCEP/NCAR reanalysis in 2002 and 2003. Comparison of rainfall shows that higher resolution of RegCM3 at 30 km simulates much better rainfall magnitude and distribution close to that of IMD in both 2002 and 2003. The percentage rainfall departure from normal is minimum at 55 km model resolution in July of both the years 2002 and 2003. These percentage values are much closer to observed IMD at 30 km model resolution. Comparison of daily rainfall simulated by individual ensembles shows that at 30 km model resolution the time series are much closer to each other than in 55 km model resolution. In most of the months 55 km model simulation underestimates rainfall values in comparison to 30 km model simulation. In sum, results of this study demonstrate the advantages of using higher resolution RegCM3 in simulating the characteristics of summer monsoon over India. However, it is essential to conduct more detailed study by considering large number of contrasting years and also examining other important features of Indian summer monsoon including intra seasonal variabilities.

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