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Simulation of anomalous Indian Summer Monsoon of 2002 with a Regional Climate Model

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Abstract

The Indian summer monsoon behaved in an abnormal way in 2002 and as a result there was a large deficiency in precipitation (especially in July) over a large part of the Indian subcontinent. For the study of deficient monsoon of 2002, a recent version of the NCAR regional climate model (RegCM3) has been used to examine the important features of summer monsoon circulations and precipitation during 2002. The main characteristics of wind fields at lower level (850 hPa) and upper level (200 hPa) and precipitation simulated with the RegCM3 over the Indian subcontinent are studied using different cumulus parameterization schemes namely, mass flux schemes, a simplified Kuo-type scheme and Emanuel (EMU) scheme. The monsoon circulation features simulated by RegCM3 are compared with the NCEP/NCAR reanalysis and simulated precipitation is validated against observation from the Global Precipitation Climatology Centre (GPCC). Validation of the wind fields at lower and upper levels shows that the use of Arakawa and Schubert (AS) closure in Grell convection scheme, a Kuo type and Emanuel schemes produces results close to the NCEP/NCAR reanalysis. Similarly, precipitation simulated with RegCM3 over different homogeneous zones of India with the AS closure in Grell is more close to the corresponding observed monthly and seasonal values. RegcM3 simulation also captured the spatial distribution of deficient rainfall in 2002.

Key Words: Summer monsoon, parameterization, Precipitation, reanalysis Homogeneous zones.

1. Introduction

The summer monsoon rainfall over India during four months from June to September is very important because approximately 80% of annual rainfall over large parts of India is accounted by these four months. Therefore, the Indian summer monsoon rainfall is inarguably an important factor of life, whether the aspect is economic (Webster et al. 1998) or cultural (Zimmermann, 1987). The Indian summer monsoon occurs every year from June to September is one of the important spectacular seasonal phenomena on the globe. Despite the remarkable consistency in the seasonal reversal of the wind patterns, it is well known that Indian summer monsoon rainfall (ISMR) exhibited a significant temporal and spatial

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variability (Parthasarathy et al. 1995). Best example is the drought of 2002 over the Indian sub-continent. The ISMR exhibited some interesting features, which are worth considering for present study. The seasonal ISMR over the country as a whole was 81% of its long term average. Rainfall was lowest (−51%) in the month of July during the past 102 years. ISMR set in over Kerala 3 days prior to normal date. Even though the onset was in time, monsoon trough got established only by 15th August, a delay of almost one month (in accordance with the late coverage of monsoon over the country). Also for the first time in last 133 years there was not even a single depression during the monsoon season of 2002. It resulted in a large deficiency in monsoon rainfall (Kalsi et al., 2004). Rajeevan et al. (2004) using 8-parameters and 10 parameters power regression models could not predict the large deficiency of ISMR in 2002. Based on the European Centre for Medium Range Weather Forecasts (ECMWF) model, Gadgil et al. (2002) concluded that forecast of ISMR from June to August with initial condition of May indicated some deficiency in ISMR only over the southwest peninsular India and near normal ISMR over rest of the India. A large deficit in ISMR during 2002 was not anticipated. It naturally leads a lot of interest to select the case of 2002 in this study.

Several results based on the GCMs simulation have suggested that GCMs capture the main features of the general circulation reasonably well (Simmons and Bengtsson, 1988) but GCMs performance in representing the regional climate details is not up to the mark (Rind et al. 1989, Mearns et al., 1990). Most of the studies based on the Regional Climate model (RCM) have shown that the nested RCM consistently improves the simulation patterns of precipitation compared to the driving GCMs. RCM has proved to be able to improve climate simulation at the regional scales, especially in the regions where forcings due to complex orographic effect, land sea contrast and land use regulate the regional distribution of climate variables and variations. The RCM approach has also been shown to be useful tool for improving our understanding of various climate processes such as land-atmosphere interaction, topographic forcing and land use change. Bhaskaran et al. (1996) simulated the Indian summer monsoon rainfall (ISMR) using a regional climate model (Hadley Centre) with a horizontal resolution of 50㎞ nested with global atmospheric GCM. Their results show that the regional model simulated precipitation is higher by 20% than that of GCM. Ding et al. (2003) nested the NCAR RegCM2 within the NCC-AOGCM to verify the performance of nested RegCM2. Their results show that the RegCM2 has some skill in predicting the seasonal rain belts, showing more area of positive precipitation than the AOGCM simulation. Recently, Singh et al. (2006) have tested the performance of RegCM3 over the South Korea and found RegCM3 simulated precipitation is close to the observed precipitation of Korea Meteorological Administration (KMA). NCAR regional climate model (RegCM3) has been widely used for various mesoscale studies (Qian and Giorgi, 1999, Giorgi et al. 2003, especially over the Europe, America, Africa and the East Asia. But the model has not been tested in detail to study monsoon circulation features and associated precipitation with suitable cumulus parameterization schemes over the South Asia.

Precipitation is recognized as one of the most difficult parameters to forecast in the numerical weather prediction. Main difficulties exist in the representation of resolved and sub-grid scale precipitation processes in a regional climate model. The latter is known as cumulus parameterization problem, and its challenge and complexity have been acknowledged for many years (Emanuel and Raymond 1993). Because of the difference between the resolution of regional models and scale of a cumulus cell, regional models require the use of cumulus parameterization (CP) schemes. These schemes must define the trigger of convection, how convection modifies moisture and temperature in a column and how convection interacts with grid scale dynamics using the grid-scale information of the models, many of which are still used today (Kuo, 1965; Arakawa and Schubert, 1974; Anthes, 1977; Fritsch and Chappell , 1980, Grell, 1993 etc.). RegCM3 model usually run with nested grids and have the ability to use different parameterization schemes at different grid scales. The assumption and simplification that a scheme makes will limit its effectiveness, and since there is no universal framework for CP, it is not obvious what is the best approach is (Arakawa, 1993).

The purpose of this study is to evaluate the influence of the choice of CP schemes in RegCM3 model on the simulated precipitation with an emphasis on the accuracy of simulated precipitation in terms of spatial distributions. A brief description of the model and experimental design are given in Section 2 and model results are discussed in Section 3. Main conclusions are given in Section 4.

2. Model descriptions and experiment design

The model used in the present study is the National Centre for Atmospheric Research (NCAR) third generation regional climate model (RegCM3), which is an upgraded version of RegCM2. RegCM2 is an incremented version of NCAR/Pen State mesoscale model version MM4 (Anthes et al., 1987) and it is documented in the several publications in detail by Giorgi et al. (1993a, b). In this paper, we have analysed the model results using three convective parameterization schemes. The first one is the Emanuel convective scheme. In this scheme, fundamental entities are sub-cloud scale draft rather than the cloud themselves. The transport of small scale drafts are idealized as follows. The air from sub-cloud layer is lifted to each level between cloud base and the level of neutral buoyancy for diluting the air. A fraction of condensed water is then converted into precipitation which precipitates and partially or completely evaporates in an unsaturated downdraft. The remaining cloudy air is then assumed to form a uniform spectrum of mixtures with the environment. These then ascend or descend according to their buoyancy. Detail descriptions of this scheme are given in Emanuel (1991). The second scheme used is a simplified Kuo-type cumulus parameterization described in Grell et al (1994) and has been widely used in many years. This scheme uses the convective instability and moisture convergence as a measure of cumulus convection. The precipitation is initiated when the moisture convergence in vertical exceeds a certain threshold and the vertical sounding is convectively unstable. Once the convection is initiated, a fraction of the moisture convergence goes into precipitation while the remaining fraction moistening the atmospheric column following a prescribed vertical profile. The vertical moistening depends on the local relative humidity i.e. more moisture is allowed at drier points. This scheme produces much convective rainfall but less resolved scale rainfall. Third scheme used in this study was developed by Grell (1993). This is mass flux scheme that includes the moistening and heating effects of penetrative updrafts and corresponding downdrafts. Due to the simplicity of the mass flux scheme, any closure assumption can be adopted to complete the scheme. This scheme has two closure assumptions namely Arakawa and Schubert (hereafter referred to as AS) and Fritsch and Chappell (hereafter referred to as FC) type closures. In AS scheme, available buoyant energy is assumed to be released by the cumulus cloud systems instantaneously at each time step. While in FC, the buoyant energy release occurs with a temporal scale of 30 minutes. For planetary boundary layer computation, the non local eddy diffusion formulation of Holtslag et al. (1990) is used in RegCM3. Surface physics is described via the latest version of the Biosphere−Atmosphere Transfer Schemes (BATS) (Dickinson et al., 1993).

The period chosen for the RegCM3 integration is from 1st March to 1st October, 2002. Several tests of simulation were performed to determine the appropriate horizontal resolution and size of the computational domain. The computational domain of the present study is centered at 750E longitude and 250N latitude with 100 grid points along the latitude circle and 105 points along the longitudinal direction. The computation domain covers the area approximately 400E−1100E along longitude circle and 50S−530N along the latitude with horizontal grid distance of 60㎞. Lamberts Conformal Projection has been used in this study. The terrain height and land use data are generated from a global dataset produced by the United States Geological Survey (USGS) global 30 minute resolution. Monthly averaged optimum interpolation sea surface temperature (OISST) available from the National Oceanic and Atmospheric Administration (NOAA) for the whole year is horizontally interpolated into the specified domain and also in each time step for the model integration. The lateral boundary conditions necessary to run the model were obtained from the NCEP (NNRP2 data sets). The lateral boundary conditions are updated and supplied in every 6 hours into the model and the time step of the integration is kept 150 second. The experiments are conducted for Emanuel, Kuo and Grell cumulus parameterization schemes.

3. Simulation of Mean Monsoon Features

The observational features show that during summer monsoon season, south westerlies at the surface and easterlies at upper levels prevail over the monsoon regions. At 850 hPa, winds from the Southern Hemisphere cross the equator mainly near the African coast and forms the Somali Jet. At 200 hPa, the most outstanding feature is a huge anticyclonic circulation, the Tibetan High centered over the southern part of the Tibetan Plateau. Several studies have shown that monsoon rain over India has significant temporal as well as spatial variability. India as whole is too large to be treated as a single unit. Even in early days, Walker (1928) suggested that the precipitation over different subdivisions of India should be grouped together to define area average far large homogeneous regions on the basis of uniformity of correlation coefficients between the anomalies and geographical distant atmospheric parameters. It is not uncommon to find some area of excessive rainfall even with the worst all India monsoon year and vice−versa. Therefore, it is always advisable to consider some homogeneous zones for better understanding of ISMR. In the present study, we have considered the area average monthly (July) and seasonal precipitation over six homogeneous zones of India namely the northwest India (NWI), the west peninsular India (WPI), the south peninsular India (SPI), the north central India (CNI), the east peninsular India (EPI) and the northeast India (NEI). The criteria for selection of six homogeneous zones are described in Singh and Sontakke (1996). For detail understanding of drought over India, we have shown the results of RegCM3 simulated precipitation in July as well as the season as a whole (June-September) over different homogeneous zones of India and compared the simulated precipitation with the observed precipitation of GPCC.

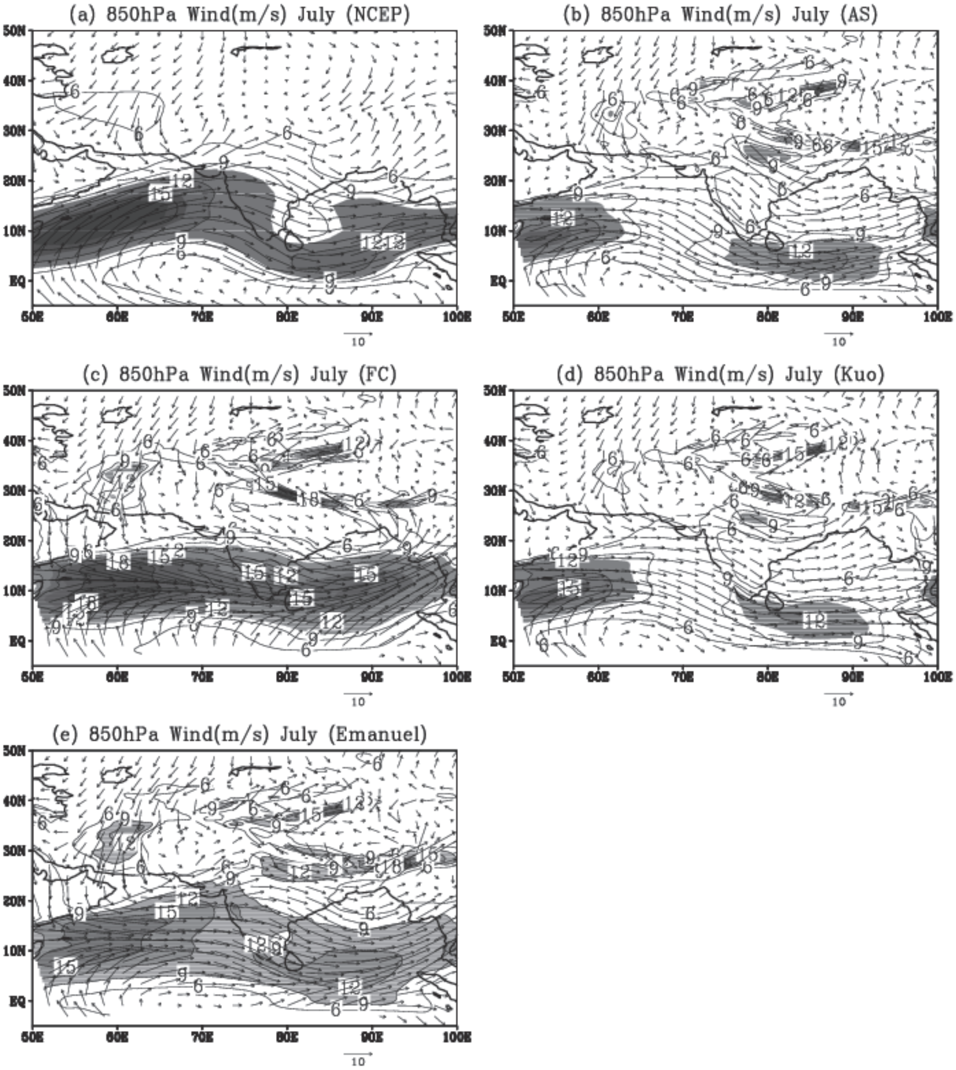

Fig 1. Wind (m/s) at 850 hPa in July for (a) NCEP (observed), (b) AS closure in Grell, (c) FC closure in Grell, (d) Kuo-type and (e) Emanuel convective schemes respectively. (Wind more than 9m/s are shaded)

For detail analysis of the performance of RegCM3, simulated wind fields at 850 hPa and 200 hPa are compared with observed wind fields of the reanalysis (NCEP) data. The anti-cyclonic circulation around the Arabian Sea is well captured in the model simulation. This anticyclonic circulation controls the strength of monsoon westerly and moisture flux over the southern peninsula. The main features of monsoon circulation such as anticyclonic flow over the Arabian Sea, low level westerly over the peninsula and westerly flow over the Bay of Bengal are well captured when compared with those of the NCEP fields. The NCEP wind field at 850 hPa shows the maximum wind strength of 15m/s during weak monsoon of July 2002 (Fig. 1). RegCM3 simulated wind fields also show the maximum wind speed of 15m/s when Emanuel, Kuo and AS convective schemes are used and 18m/s for FC (Fig. 1) (but arrear coverage of maximum wind strengths in RegCM3 are slightly smaller compared with the NCEP wind field).

At 200 hPa, RegCM3 simulation shows that large parts of the Indian subcontinent come under the influence of an anticyclone. The model also captured the upper level anticyclone well. The maximum wind strength (easterly) at 200 hPa over Indian Ocean is 24m/s for NCEP. The wind fields simulated with RegCM3 at 200 hPa also show the maximum wind strength of 24m/s for Emanuel, Kuo and AS schemes and 30m/s with FC. Thus, the analysis of wind fields show that Emanuel, Kuo and AS cumulus parameterization schemes simulate the monsoon wind strength at 850 hPa similar to that of the NCEP (observed) wind fields. A similar agreement is also found for upper air easterly (200 hPa) over the Indian Ocean. In sums, present study shows that the characteristics of the upper level monsoon winds are reasonably well simulated by the RegcM3 when using the Emanuel, Kuo and AS convective schemes, while the model performance deteriorated using the FC cumulus parameterization schemes.

The precipitations are shown only for the interior of the domain in order to clearly illustrate the fine scale topographically induced details. Figs. 2 (a-d) show precipitation rate (cm/month) in July simulated with RegCM3 using AS, Kuo, FC and Emanuel convective schemes respectively. Fig. 2 (e) shows observed precipitation rate (cm/month) from the Global Precipitation Climatology Centre (GPCC). In AS run, the model simulates the maximum precipitation of about 60cm over the foot hills of Himalayas, 20cm over the Western Ghat and 10cm over the east coast of India (Fig. 2a). When using FC schemes, model simulate the maximum precipitation of about 60cm near the foot hills of Himalayas, 80cm over the West Ghat and 20cm over the east coast of India (Fig. 2b), for Kuo run, the model simulate the maximum precipitation of 80cm and 40cm over the foot hills of Himalayas and the West Ghat (Fig. 2c). When Emanuel scheme is used, the maximum precipitation of about 80cm over the foot hills of Himalayas, 20cm near the West Ghat and 10cm over the east coast of India (Fig. 2d) are found with RegCM3 simulation. Observed precipitation of GPCC shows maximum precipitation of about 40cm over the foot hills of Himalayas and 10cm over the West Ghat (Fig. 2e). The precipitation patterns simulated with RegCM3 show that the GPCC underestimates the magnitude of orographyically forced precipitation over the northeast India and the west coast. RegcM3 simulation also shows higher precipitation over the oceans in comparison to that with GPCC. The precipitation over the oceans are generally caused by convective activity, therefore the high precipitation over the

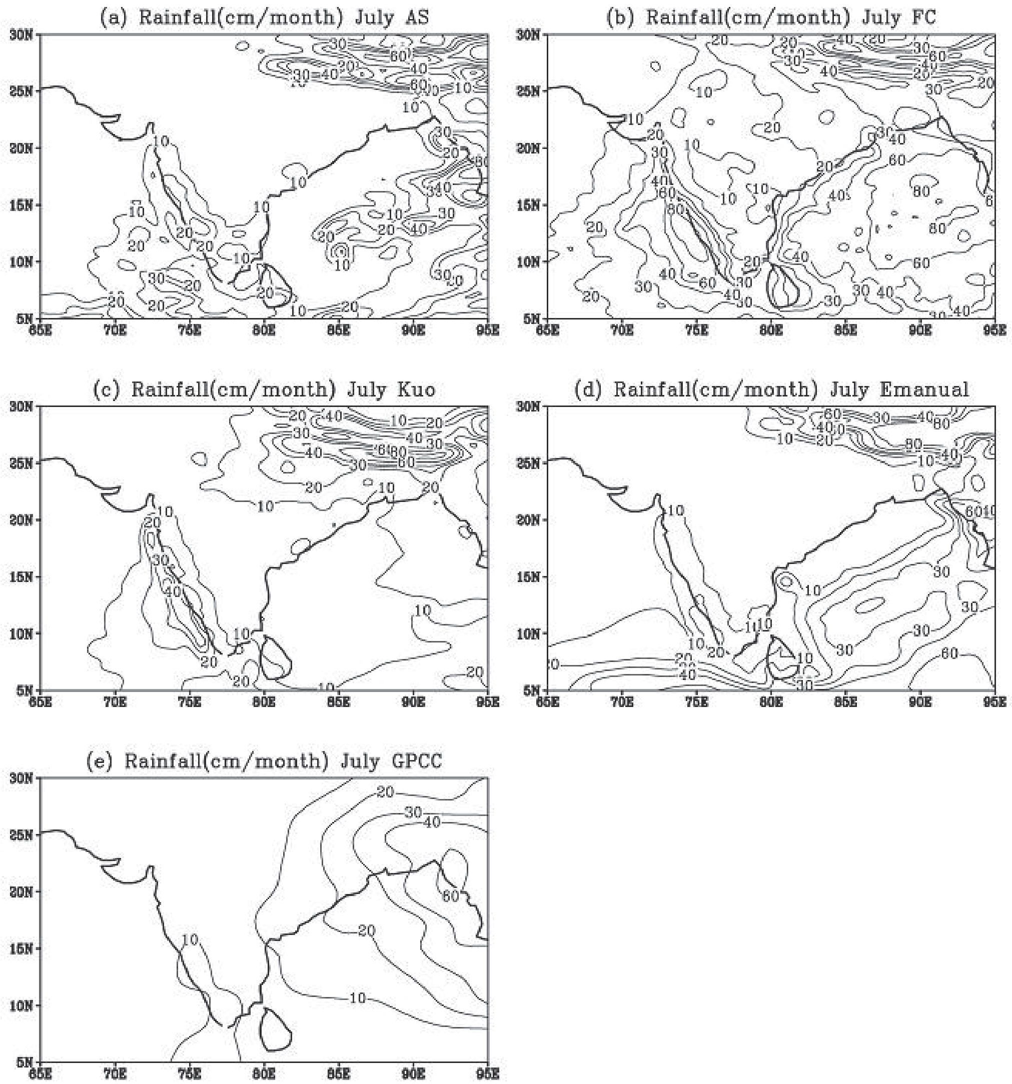

Fig 2. Precipitation (cm) in July for (a) AS closure in Grell, (b) FC closure in Grell, (c) Kuo-type, (d) Emanuel schemes in RegCM3 and (e) observed from GPCC

oceans is likely to be associated with the physical parameterization of convection in RegCM3 possibly in combination with parameterization of other related processes.

As mentioned in the beginning of Section 3 that ISMR is characterized by considerable spatial variability, hence it is essential to examine the RegCM3 simulated precipitation over different homogeneous zones of India. Table 1 presents an area averaged precipitation in July 2002 over six homogeneous zones of India.

There is a good agreement between RegCM3 simulated precipitation with the Emanuel scheme over the NWI, WPI and NCI

Table 1. Comparisons of RegcM3 simulated precipitation (cm) with observed precipitation of GPCC in July 2002 over six homogeneous zones of India. GPCC stands for Global Precipitation Climate Centre, AS for Arakawa and Schubert closure in Grell, FC for Fritsch and Chappell closure in Grell, Kuo for Kuo-type scheme and Eman for Enanuel scheme.

Homogeneous zones	GPCC	AS	FC	Kuo	Eman
NWI	7.2	4.4	26.5	12.4	7.1
WPI	6.1	5.9	11.6	5.9	6.2
SPI	17.6	27.3	57.0	21.4	21.3
NCI	16.4	13.3	28.4	26.4	13.3
EPI	44.3	17.4	53.7	19.3	11.5
NEI	110.3	100.8	96.2	108.3	163.5

and GPCC (observed). For AS closure in Grell, a good agreement can be seen over the NWI, WPI and NCI. While a Kuo-type scheme shows closer values of monthly precipitation over the WPI and NEI. When FC closure in Grell is considered, very high precipitation can be seen approximately over all zones of India except NEI. Table 2 shows area averaged precipitation (cm) of total monsoon period (June-September) in 2002 for GPCC and model simulated precipitation using AS and FC closure in Grell, Kuo and Emanuel convective schemes.

GPCC (observed) shows average precipitation of 11.5cm over the NWI, 16.9cm over the WPI, 32.3cm over the SPI, 15.8cm over the NCI, 63.2cm over the EPI and 78cm over the NEI. As far as RegCM3 simulated precipitation is concerned, Table 2 shows the precipitation of 12.1cm, 9cm, 33.7cm, 14.2cm, 29.8cm and 66.2cm over the NWI, WPI, SPI, NCI, EPI and NEI respectively when AS closure in Grell is used. A comparison of observed (GPCC) and RegCM3 simulated seasonal precipitation shows that AS closure in Grell convection is more close to the GPCC followed by Emanuel, a Kuo type and FC closure in Grell.

Table 2. Same as in Table 1 except for whole season (June-September)

Homogeneous zones	GPCC	AS	FC	Kuo	Eman
NWI	11.5	12.1	30.6	15.5	16.4
WPI	16.9	9.0	15.1	5.5	9.1
SPI	32.3	33.7	55.5	16.1	32.5
NCI	15.8	14.2	25.1	19.1	23.5
EPI	63.2	29.8	68.0	27.8	40.8
NEI	78.0	66.2	68.0	67.8	134.6

Overall, RegCM3 captured reasonably well the spatial distribution of monthly precipitation during drought of 2002. The spatial representation of precipitation over the whole domain is satisfactory. The low precipitation simulated in July over large parts of the Indian subcontinent is captured well by RegCM3.

4. Conclusions

Although, RegCM3 has been used widely for various meso scale studies, but it has not been tested in details for suitable cumulus parameterization schemes over the Indian sub-continent. We have tried for the first time using various convective schemes. Results show that RegCM3 has been successfully simulates the important characteristics of Indian summer monsoon circulation such as westerly at 850 hPa and easterly at 200 hPa and belt of high precipitation. The large deficiency in precipitation is simulated with RegCM3. The monthly and seasonal precipitation simulated with RegCM3 is more close to the corresponding GPCC when AS closure in Grell is used. In general, the Grell scheme (AS closure) performed better over the South Asia in summer monsoon season (June-September). In sum, present results indicate that the RegCM3 can be used to study the monsoon processes over the south Asia. In order to support above conclusion, we plan to consider the more cases of deficient and excess rain years to conclude the suitable cumulus parameterization schemes over south Asia in future.

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