Simulation of Indian Summer Monsoon Circulation and Rainfall using Mesoscale Models

S. K. DASH
Centre for Atmospheric Sciences
Indian Institute of Technology Delhi
Hauz Khas, New Delhi, India

1. Introduction

General Circulation Models (GCMs) have been extensively used for research in weather and climate studies and the forecast of weather and climate at different spatial and temporal scales. However, for studying the regional weather/climate features in greater details, regional models are more suitable, mostly because of the integration of such models at high resolutions. Various regional climate models have been used for a wide variety of applications, including studies of present-day climate characteristics and possible future climates over a number of regions throughout the world. Regional models have been used for operational weather forecasting in the range of several hours to about 2-3 days into the future. The Eta model, developed by the National Center for Environmental Prediction (NCEP) is very useful to examine and diagnose sub-synoptic weather phenomena (Mesinger 1984). The Fifth-Generation NCAR/Penn State Mesoscale Model (MM5) has been extensively used for the simulation of air-sea interaction (Bao et al. 2000) and precipitation over the Pacific (Colle et al. 2000). Chen and Dudhia (2001) coupled an advanced land-surface hydrology model with the MM5. The effects of different cloud parameterization schemes in MM5 have been studied by Zhang et al. (1994). Simulation of the Indian summer monsoon circulation features and the associated rainfall by a numerical model have been the most challenging problems so far. There have been some attempts 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. Bhaskar Rao et al. (2004) simulated many observed features of the Indian summer monsoon such as sea level pressure, 925hPa temperature, low level wind and precipitation using MM5. Prasad et al. (1997) studied the impact of humidity field on the track and intensity of cyclones using India Meteorological Department's (IMD) regional model. Rama Rao et al. (2001) studied the impact of satellite derived moisture profiles on precipitation forecast by using the same IMD model. Mandal et al. (2003) examined the performance of a regional atmospheric model, which is the modifed version of the regional model developed in collaboration with the Naval Research Laboratory (NRL) and North Carolina State University in forecasting tropical cyclones over the Bay of Bengal and its sensitivity to horizontal resolution. The structure, intensity and track of the cyclones were found to be well simulated in the model for finer resolution compared to the coarse resolution. The Pennsylvania State University (PSU) / National Center for Atmospheric Research (NCAR) mesoscale model MM5 has been used in a number of studies for the simulation of tropical cyclones. Patra et al. (2000) made a comparative study on the performances of MM5 and Regional Atmospheric Modelling System in simulating the Bay of Bengal cyclones. Trivedi et al. (2002) used MM5 to examine the impact of initial conditions on the simulation of Orissa supercyclone in 1999. Azadi et al. (2001) used MM5 to simulate western disturbances during January 1997 over the Indian region and to predict precipitation associated with it.

The main objective of this study is to integrate MM5 and RegCM3 over the Indian region with different convective schemes so as to simulate the mean features of Indian summer monsoon and the track of the Orissa supercyclone over the Bay of Bengal with a view to examine the suitability of using MM5 / RegCM3 over the Indian region. Section 2 deals with the model integrations and results for simulation of monthly mean monsoon circulation features and Orissa supercyclone using MM5. Section 3 describes the model integrations and results obtained by RegCM3. Summary and conclusions are given in the last Section 4.

2. Monsoon Simulations by MM5

MM5 version 3 is a LAM to simulate and predict mesoscale systems and regional atmospheric circulations. Its vertical coordinate system is terrain following sigma with options for either hydrostatic or non-hydrostatic approximations. There are various options for the physical parameterization schemes for inclusion of processes such as the precipitation, Planetary Boundary Layer (PBL), explicit moisture, atmospheric radiation and ground temperature. The model has been integrated over a season to (i) examine some of the salient features of monthly mean monsoon circulation and rainfall and to (ii) predict the track of

Orissa supercyclone in 1999 over the Bay of Bengal using different convection schemes. For simulating the mean monsoon features, the domain chosen is 40^{O}E to 110^{O}E and 10^{O}S to 40^{O}N with horizontal grid distance of 55 Km. The domain has its centre at the co-ordinate 15^{o}N, 75^{o}E with 141 grid points along the latitude circle and 101 points along the meridian direction. The extended domain has 155x115 grid points. The model has 28 vertical sigma levels. The experiments are conducted for three cumulus parameterization schemes such as Anthes-Kuo (Kuo), Betts-Miller (BM) and Grell for the months of August and September starting with 1st August 1998 NCEP analysis. The model output results are saved every 24 hours. MM5 has also been integrated from the initial condition of 00Z on 25th October 1999 in three stages of 48 hours each to simulate the characteristics of the supercyclone with the above three convective schemes. The domain of integration is 80^{O}E to 100^{O}E and 5^{O}N to 25^{O}N with horizontal grid distance of 27.5 Kms. Thus there are 81 grid points both along the latitude circle and the meridian direction with the centre of the integration domain at 90^{O}E, 15^{O}N. However, the extended domain has 109X109 grid points. The output results are analysed 12 hourly.

Some of the important characteristics of the Indian summer monsoon circulation such as the Somali jet at 850hPa, the easterly jet at 200hPa and the subdivision wise rainfall simulated by MM5 using different convective schemes such as BM, Kuo and Grell are discussed here. Usually August is very active monsoon month so far as the circulation characteristics are concerned. Hence, the mean monsoon circulation features simulated in August of a particular year 1998 are examined and compared with those of NCEP reanalysed fields of the same year. The maximum strength of the southwesterly wind is 24 m/s for Grell, 22 m/s for BM and 26 m/s for Kuo schemes. These values indicate that MM5 simulated Somali jet at 850 hPa is overpredicted. However, BM scheme simulates the wind strength close to NCEP/NCAR reanalysis which is 18 m/s. The maximum strength of wind at 200hPa is 26 m/s for Grell, 30 m/s for BM and 32 m/s for Kuo schemes. The value of the monthly mean wind at 200hPa by NCEP/NCAR reanalysis is 30 m/s. Comparison of the wind strengths simulated by different convection schemes in the three identified regions show that BM scheme gives values close to the reanalysis. Comparison of rainfall shows that in case of BM scheme, the model simulated rainfall of about 50 Cm over northeast India, 100 Cm over foot hills of the Himalayas and about 50 Cm at the Western Ghats agree well with the observed rainfall of India Meteorological Department (IMD). For Kuo scheme, the simulated rainfall due to the Western Ghats is mostly over the ocean. At the foot hills of the Himalayas, the rainfall in Kuo scheme is somewhat close to the observed values of about 100 Cm. But the areas of maximum rainfall do not coincide with IMD observed rainfall. In the Grell scheme, most of the rain in the Western Ghats region is on the sea and there is little rainfall of about 30 Cm over the coast. At the foot hills of Himalayas, the maximum rainfall is close to the observed value of about 100 Cm. But the spatial distribution differs from the observed one. Thus BM scheme simulates reasonably good rainfall distribution pattern in comparison with that of Kuo and Grell. Since the August mean monsoon features are reasonably well simulated with the BM convection scheme, the September mean features are examined only with the same scheme. Results show that the maximum strength of wind at 850hPa is 18 m/s with BM scheme as compared to 12 m/s in NCEP. Similarly the maximum strength of wind at 200 hPa is 24 m/s for BM scheme against 26 m/s in NCEP. The corresponding climatological values of maximum strength of wind are 10 m/s and 20 m/s at 850 and 200 hPa respectively. The model simulated rainfall for the month of September 1998 for BM scheme as well as IMD actual rainfall have been compared in detail. The maximum value of rainfall near Western Ghats reaches 70 Cm for BM scheme as against the observed value of 60 Cm. Similarly, over the northeast part of the country (20^{o}N and 88^{o}E), the simulated rainfall with BM scheme is the same as the observed value of 30 Cm. The main land area in the country underpredicts the values of rainfall as compared to the actual observation.

The characteristics of the MM5 simulated supercyclone of October 1999 over the Bay of Bengal have been compared in detail by using the above mentioned three convective schemes. The Grell convective scheme gives the most organised cyclonic system compared to Kuo and BM schemes. Comparison of the tracks of the cyclone simulated by MM5 from 00Z on three different dates of integration such as 25 Oct 1999, 27 Oct 1999 and 29 Oct 1999 and the observed track based on IMD data shows that the tracks simulated by MM5 upto 2 days in all the three cases are close to the actual track. The simulation of the reasonably good track of the supercyclone by MM5 model is encouraging enough for designing a number of sensitivity studies in future with different physical parameterization schemes including the land-surface processes available in MM5.

3. Monsoon Simulations by RegCM3

RegCM3 is an upgraded version of the ICTP regional climate model RegCM2 originally developed by Giorgi et al. (1993a, b). The model dynamical core is essentially the same as that of the hydrostatic version of the mesoscale model MM5. For simulating mean monsoon circulations and rainfall, the domain chosen is 55^{O}E to 105^{O}E and 5^{O}S to 45^{O}N with a grid point spacing of 55 km using a Mercator projection. All simulations cover the period of 1st April to 30th September in the 4 years from 1993 to 1996. The mean monsoon circulation characteristics and the total amount of rainfall simulated during June, July, August and September (JJAS) over India are examined.

Characteristics of Findlater jet at 850hPa, the easterly jet at 200hPa and the temperature at

500hPa are compared with corresponding fields from the NCEP/NCAR reanalysis. The composites of the four years of winds show that the maximum strength of the JJAS mean westerly wind at 850hPa is 16 m/s for Grell scheme and 14 m/s for Kuo scheme. Similarly, the maximum strength of the JJAS mean wind at 200 hPa over the Indian Ocean is 18 m/s for Grell scheme and 14 m/s for Kuo scheme. The difference (Grell – Kuo) fields indicate that the lower level winds simulated with the Kuo scheme are generally weaker than those obtained using the Grell scheme. At 850 hPa, the westerlies over the Arabian Sea and Indian peninsula are stronger with the Grell scheme than the Kuo scheme by 2.4 m/s. The Grell scheme simulates mean monsoon wind values at 850hPa in line with the NCEP/NCAR reanalysis, which shows a jet core of 16 m/s. A similar agreement is found for the 200 hPa easterlies over the Arabian Sea and Indian Peninsula, with maximum values of about 20 m/s. The maximum value of model simulated JJAS mean temperature at 500hPa over Tibet is 274^{o}K for the Kuo run and 272^{o}K for the Grell run. The corresponding mean temperature at 500hPa in the NCEP/NCAR reanalysis is 272^{o}K. Four year composite JJAS accumulated rainfall simulated by the Kuo and Grell convection schemes indicate that in the Kuo run, the model simulates rainfall of about 80 cm over northeast India, 120 cm over foothills of the Himalayas, 40 cm over the east coast of India and about 150 cm over the Western Ghats. When using the Grell scheme, the model simulates rainfall of about 120 cm over northeast India, 140 cm over foothills of the Himalayas, 80 cm over the east coast and about 260 cm over the Western Ghats. The corresponding observed values in the GPCC dataset are 120 cm, 150 cm, 90 cm and 270 cm, respectively. The difference (Grell – Kuo) of rainfall shows that the Grell scheme simulates greater precipitation amounts over the Western Ghats (120 cm), the foothills of the Himalayas (40 cm), the east coasts of India (50 cm) and northeast India (60 cm). Comparison of GPCC and simulated rainfall with the two convection schemes shows that the amount and distribution of rainfall simulated by RegCM3 when using the Grell parameterization is closer to observations. Comparison of the simulated JJAS mean rainfall over All India and its five homogeneous zones such as North West India (NWI), West Central India (WCI), Central Northeast India (CNI), North East India (NEI) and South Peninsular India (SPI) (Parthasarathy et al., 1995) for the years 1993 to 1996, along with the composite of the four years, with the corresponding observed values in the IMD dataset shows that there is a good agreement between the rainfall simulated with Grell scheme and the IMD observed rainfall over All India, NWI, WCI and SPI in all four years. Conversely, precipitation is underestimated over CNI and NEI. In addition, the Grell scheme consistently simulates more rainfall than the Kuo scheme in all years for All India and its five homogeneous zones.

4. Summary and Conclusions

The fifth generation National Centre for Atmospheric Research (NCAR)/Penn State Mesoscale Model (MM5) has been successfully integrated over a season to simulate the monthly mean features of Indian Summer monsoon as well as an extreme weather event over the east coast of India. Considering the importance of convective process in the Indian summer monsoon circulation, a number of simulation experiments have been conducted with different parameterization schemes such as Anthes-Kuo (AK), Betts-Miller (BM) and Grell. Results show that monthly mean circulation features and rainfall are better simulated by the BM cumulus parameterization scheme. Comparison of the wind strengths simulated by different convection schemes in the model show that, BM scheme gives values close to the National Center for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) reanalysis. Similarly, the model simulated rainfall with BM scheme compares reasonably well with the observed rainfall of India Meteorological Department (IMD). The same mesoscale model simulated the track of the Orissa supercyclone of October 1999 reasonably well using the Grell convection scheme. Similarly, Results of RegCM3 simulations indicate that, the model successfully simulates some important characteristics of the Indian summer monsoon circulation, such as the 850hPa westerlies and the 200hPa easterly flow. Also, the seasonal mean summer monsoon rainfall simulated by RegCM3 is close to the corresponding GPCC values when the Grell convection scheme is used, although the observed precipitation is underestimated over Central North India and North Eastern India. In general, the Grell scheme performed better than the Kuo scheme in simulating both the monsoon circulations and rainfall. Thus the performance of the different convective schemes depends on the spatial and temporal scale of the weather phenomenon to be simulated in the tropical monsoon atmosphere. Such sensitivity studies are proposed to be conducted using current generation mesoscale model such as the Weather Research and Forecasting (WRF) model. Attempts are being made to use WRF in wide range of applications such as the mean monsoon circulation features, precipitation forecasting, extreme weather events, and regional climate studies over India with horizontal grid size of 1 to 10 Km.

Acknowledgements

The author wishes to thank UCAR, USA for providing computer facility to run MM5 and India Meteorology Department for providing the rainfall data and the documentation on the Orissa supercyclone of October 1999. The author also thanks Prof. F. Giorgi and Dr. X. Bi for their encouragement and initial help in the installation of RegCM3 in IIT Delhi.

References

Azadi, M., U. C. Mohanty, O. P. Madan and B. Padmanabhamurti, 2001, "Prediction of precipitation associated with a western disturbance using a high-resolution regional model - role of parameterization of physical processes", *Meteorol. Appl.*, **7**, 317-326.

Bao, J.-W., Wilczak, J. M., Chio, J.-K. and Kantha, L. H., 2000, "Numerical simulation of air-sea interaction under high wind conditions using a coupled model: A study of hurricane development", *Mon. Wea. Rev.*, 128, pp. 2190-2210.

Bhaskaran, B. R., G. Jones, J. M. Murphy and M. Noguer, 1996, "Simulations of the Indian summer monsoon using a nested regional climate model: Domain size experiments", *Clim. Dynamics*, 12, 573-578.

Bhaskar Rao, D., V., K. Ashok and T. Yamagata, 2004, "A numerical simulation study of the Indian summer monsoon of 1994 using NCAR MM5", *J. Meteorol. Soc. Japan*, 82(6), 1755-1775.

Chen, F., and Dudhia, J., 2001, "Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model implementation and sensitivity", *Mon. Wea. Rev*., 129, pp. 569-585.

Colle, B. A., Mass, C. F. and Westrick, K. J., 2000, "MM5 precipitation verification over the Pacific northwest during the 1997-99 cool seasons", *Weather and Forecasting*, Boston, MA, 15(6): pp. 730-744.

Giorgi, F., Marinucci, M., R. and Bates, G., T., 1993a, "Development of a second generation regional climate model (RegCM2). Part I: boundary-layer and radiative transfer processes", *Mon. Wea. Rev.*, 121, 2794-2813.

Giorgi, F., Marinucci, M., R., Bates, G., T. and De Canio, G., 1993b, "Development of a second-generation regional climate model (RegCM2). Part II: convective processes and assimilation of lateral boundary conditions", *Mon. Wea. Rev.*, 121, 2814-2832.

Ji, Y. and A. D. Vernekar, 1997, " Simulation of the Asian summer monsoons of 1987 and 1988 with a regional model nested in a global GCM", *J. Climate*, 10, 1965-1979.

Mandal, M., U. C. Mohanty, K. V. J. Potty and A. Sarkar, 2003, "Impact of horizontal resolution on prediction of tropical cyclones over Bay of Bengal using a regional weather prediction model", *Proc. Indian Acad. Sciences* (Earth and Planetary Science), 112 (1), 79-93.

Mesinger, 1984, "A blocking technique for representation of mountains in atmospheric models", *Riv. Meteor. Aeronaut*., 44, pp. 195-202.

Parthasarathy, B., Munot, A. A. and Kathawale, D. R., 1995, "Monthly and seasonal rainfall series for All India homogeneous regions and meteorological subdivisions: 1871-1994", *Contributions from Indian Institute of Tropical Meteorology*, India, Research Report RR-065, p113.

Prasad, K., Y. V. Rama Rao and Sanjib Sen, 1997, "Tropical cyclone track prediction by a high resolution limited area model using synthetic observations", *Mausam*, 48, 351-366.

Patra, K., M. S. Prabir Santhanam, K. V. J. Potty, M. Tewari and P. L. S. Rao, 2000, "Simulation of tropical cyclones using regional weather prediction models", *Current Science*, 79 (1)**,** 70-78.

Rama Rao, Y. V., K. Prasad and Sant Prasad, 2001, "A case study of the impact of INSAT derived humidity profiles on precipitation forecast by limited area model", *Mausam*, 52(4), 647-654.

Trivedi, D., K., J. Sanjay and S. S. Singh, 2002, "Numerical simulation of a super cyclonic storm, Orissa 1999: impact of initial conditions", *Meteorol. Appl*., 9, pp. 367-376.

Zhang, D. L., Kain, J. S., Fritsch, J. M. and Gao, K., 1994, Comments on: "Parameterization of convective parameterization in mesoscale numerical models: A critical review", *Mon. Wea. Rev*., 122, pp. 2222-2231.