Performance of RegCM4.3 in Simulating Summer Monsoon Onset over India using Different Convection Schemes

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ABSTRACT

In the present study, the latest version of the Abdus Salam International Center for Theoretical Physics (ICTP) Regional Climate Model version 4.3 (RegCM4.3) is used to simulate the onset phase of summer monsoon over India during 2001-2005. The different cumulus convection schemes viz. Kuo, Mix98, Mix99, Emanuel, Grell and Tiedtke of RegCM4.3 are evaluated at 50 km horizontal resolution. The simulated precipitation is systematically evaluated with actual onset dates over 14 stations using six convection schemes, out of which Mix98 (Grell over land and Emanuel over the ocean) scheme performs well as compared to the other schemes.

Keywords: *RegCM4.3, Convection schemes, Onset of rainfall, Taylor diagram.*

1. Introduction

The onset of summer monsoon to the Indian subcontinent is anxiously awaited and it represents significant transitions in atmospheric and oceanic circulation. It produces more than 70% of the total annual rainfall over India. Therefore, any failure or even the late arrival of monsoon rains has a strong impact on the economy of the country.

Over the past few decades, Regional Climate Model (RegCM) has become significantly advanced and is extensively used in studies of climate simulation over various regions. It has been demonstrated that regional climate models have a quite reasonable skill to simulate or predict the summer monsoon circulation over the India (Dash et al., 2006, 2014). The parameterization schemes have been developed in specific convective environments and evaluated in a limited number of cases. Several studies have shown that regional climate simulations are very sensitive to the physical parameterization schemes, employed particularly over the tropics, where convection plays a major role in monsoon dynamics (Dash et al., 2006; Singh et al., 2011; Srinivas et al., 2013). RegCM was customized with the Emanuel scheme for the precipitation simulation by Davis et al. (2009). This model configuration predicted the rainfall over eastern Africa and the tropical Indian Ocean more realistically, but overestimation of precipitation also occurred. Segele et al. (2009) concluded that the Emanuel scheme performs better when selecting 1984 as a dry year and 1996 as a wet year. Octavian and Manomaiphiboon (2011) demonstrated that the Emanuel scheme performs well; followed by the Anthes–Kuo scheme, when a double nested 60 and 20 km resolution domain is used. Raju et al. (2015) reveal the better simulation of summer monsoon characteristics by RegCM4.3 with the combination of the mixed convection scheme over South Asia Coordinated Regional Climate Downscaling Experiment (CORDEX) domain. According to Basit et al. (2012), the Grell scheme captures well the monsoon phenomenon. Slingo et al. (1988) studied the effects of changes to the Kuo (1974) cumulus parameterization scheme in the operational European Centre for Medium Range Weather Forecasting (ECMWF) model for the onset of the Indian summer monsoon. Dash et al. (2006) showed that the Grell scheme performed better in simulating the summer precipitation over India.

In the present study, sensitivity experiments using Kuo, Emanuel, Grell, Mix98 (Grell over land and Emanuel over the ocean), Mix99 (Grell over the ocean and Emanuel over Land) as well as Tiedtke convection schemes of RegCM4.3 are used to simulate the onset of Indian summer monsoon over Kerala for the period 2001-2005.

2. Data and Methodology

Latest version of International Centre for Theoretical Physics (ICTP) regional climate model (RegCM4.3) data is used throughout this study. The initial conditions and lateral boundary forcing for RegCM4.3 simulations are derived 6 hourly feeds from ERA Interim reanalysis, available with a horizontal grid of 1.5^{O} latitude/longitude and 37 levels in the vertical. It uses 12 hourly 4D-Var data assimilation and improved model physics. Cumulus convection schemes, namely Kuo, Emanuel, Grell, Mix98, Mix99 and Tiedtke convection schemes are used to simulate the onset of Indian summer monsoon over Kerala by following one of the IMD criteria to declare the onset over India (i.e. 2.5 mm or more rainfall on two consecutive days after 10th may should be reported over 60% station) (Monsoon, 2008).

For representing different cumulus convection schemes, Raju et al. (2015) reveal a number of options in RegCM4.3, such as simplified Kuo (Anthes et al., 1987), Grell (Grell, 1993), MIT-Emanuel scheme (Emanuel, 1991), Tiedtke (Tiedtke, 1989) and the Mixed scheme. Kuo scheme activates the convection when the moisture convergence exceeds a threshold value and is occasionally used in lower precipitation simulations only (Dash et al., 2006; Singh et al., 2011). The Grell scheme is a mass flux deep convection parameterization in which clouds are considered as two steady state circulations including an updraft and a downdraft. This scheme is triggered when a parcel lifted in the updraft eventually reaches the moist convection level. Similarly, the Tiedtke scheme is a comprehensive mass flux convection scheme (Tiedtke, 1989); albeit it considers a number of cloud types as well as cumulus downdrafts that can represent deep, mid-level and shallow convection. The closure assumptions for the deep and mid-level convection are maintained by large-scale moisture convergence, while the shallow convection is sustained by the supply of moisture derived from surface evaporation. In the MIT-Emanuel scheme, convection is initiated when the level of buoyancy is higher than the cloud base. RegCM4.3 has the capability of running different combinations of convection schemes over land, and ocean referred to as mixed convection schemes. A preliminary study for mixed convection approach (Emanual over the ocean and Grell over land) is done by Giorgi et al. (2012) to simulate better performance in climate scale over a number of CORDEX domains.

The rainfall plots are considered over the station locations in Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore. In each experiment, the data are initialized on 1st May 2001 and integrated continuously up to 30th September for each year of 2001-2005 with a horizontal resolution of 50 km and 18 sigma levels in the vertical over South Asian CORDEX domain (22^{0} S- 50^{0} N; 10^{0}-130^{0} E).

In order to evaluate the performance of RegCM4.3 over a particular region and to reproduce its successful simulation with observed regional climate characteristics, it is important to check the accuracy of the six convection scheme. Therefore, Taylor diagram (Taylor, 2001) is employed in summarizing the statistical measures for the gradation of a well performed convective scheme. It's a concise statistical summary of good patterns matching in terms of the correlation, root-mean-square difference and the ratio of variances with observation.

3. Results and Discussion

Figs 1 to 5 illustrate the nature of simulated rainfall transition associated with the onset of the monsoon over Kerala for five years (2001-2005) during the time span 11th May to 10th June. These Figs indicate the rainfall pattern of the 30 days model-simulated data with the dates of actual and simulated onset as the condition mentioned above. Red dotted lines Indicate Actual Onset date and green dotted lines show the model simulated onset arrival over India.

In Fig.1 to Fig.5, all convection schemes are indicating good fitness with more or less early or late onset. In 2001 (Fig.1), it is clearly represented that, the actual onset date for 2001 is 23rd May. Most of the convection scheme simulates the onset date in difference of more or less ± 7 days, i.e. Emanuel

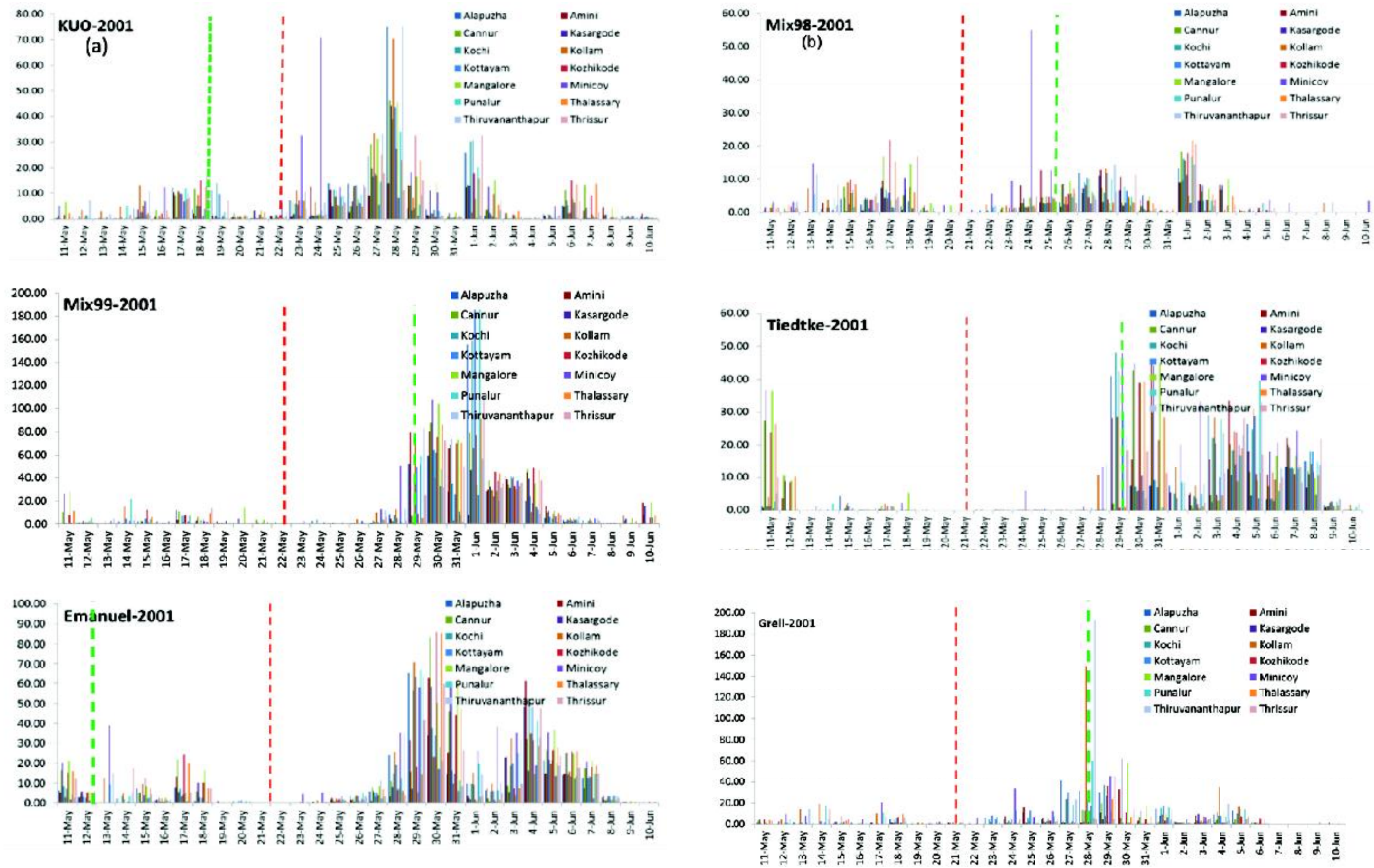

Fig.1a-f: Daily rainfall of fourteen stations, namely: Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore from 11th May to 10th June of 2001 for six cumulus convection schemes (a) KUO; (b) Mix98; (c) Mix99; (d) TIEDTKE; (e) EMANUEL; (f) GRELL of RegCM4.3. Red dotted line shows the actual date of onset and green dotted line shows the model simulated onset date.

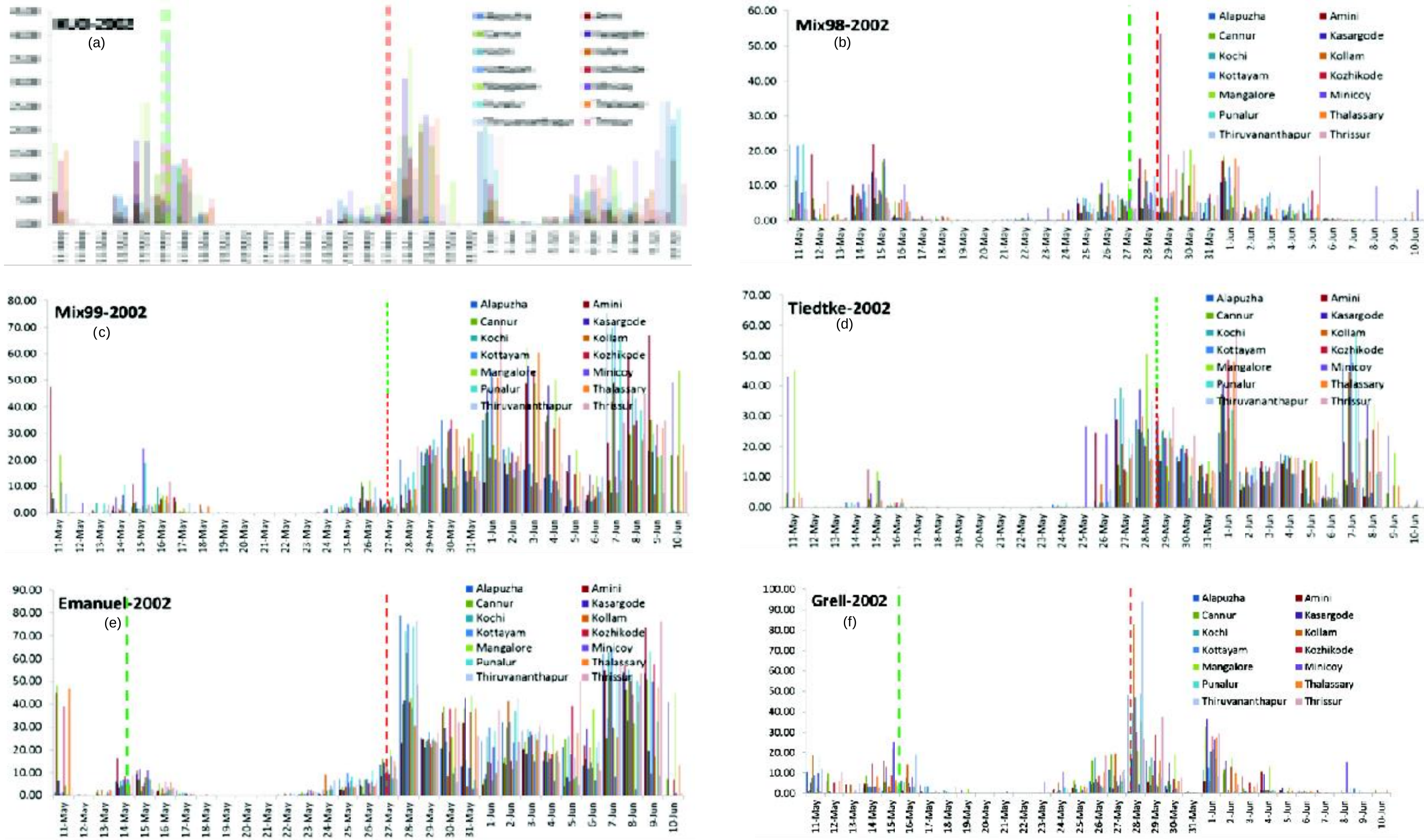

Fig.2a-f: Daily rainfall of fourteen stations, namely: Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore from 11th May to 10th June of 2002 for six cumulus convection schemes (a) KUO; (b) Mix98; (c) Mix99; (d) TIEDTKE; (e) EMANUEL; (f) GRELL of RegCM4.3. Red dotted line shows the actual date of onset and green dotted line shows the model simulated onset date.

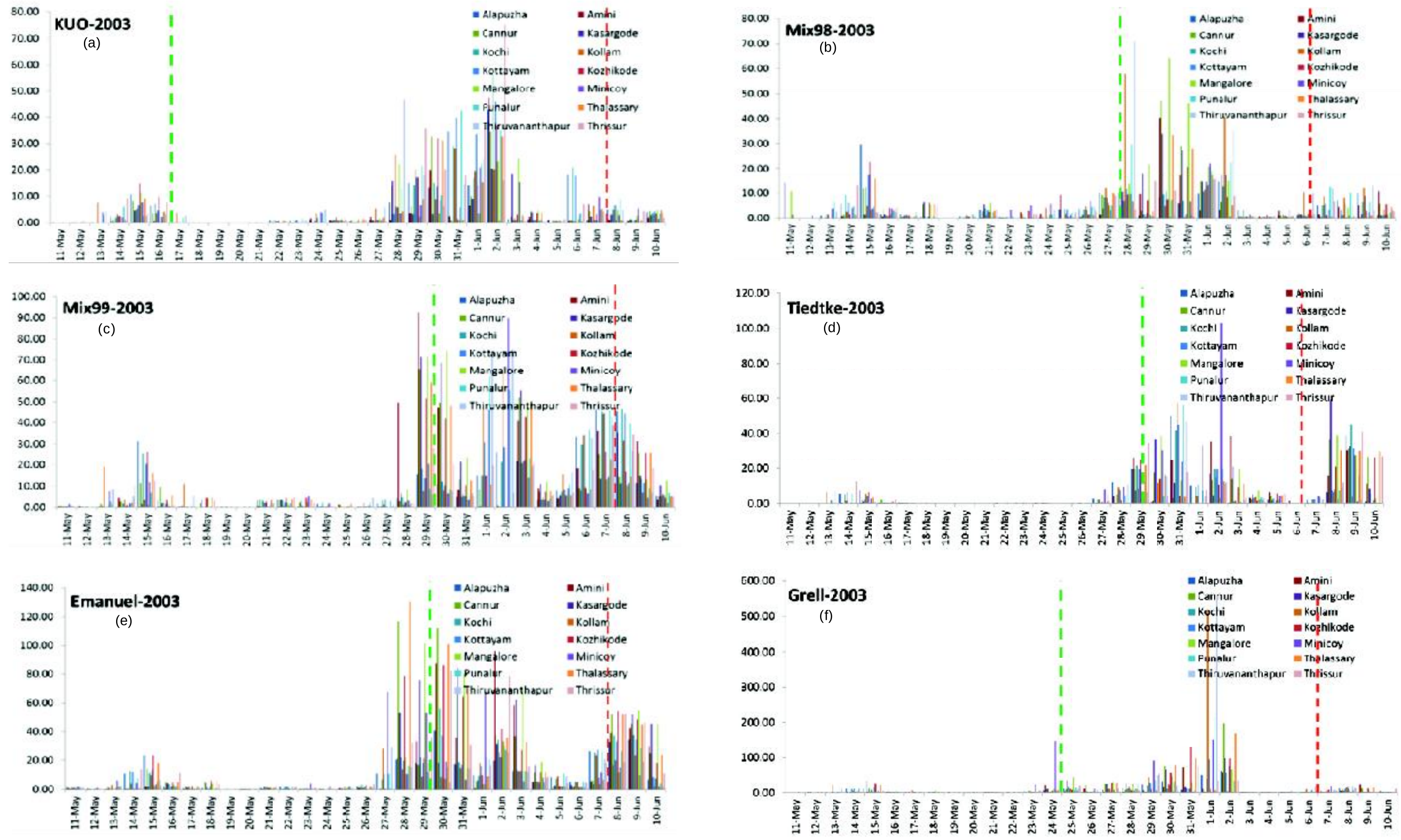

Fig.3a-f: Daily rainfall of fourteen stations, namely: Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore from 11th May to 10th June of 2003 for six cumulus convection schemes (a) KUO; (b) Mix98; (c) Mix99; (d) TIEDTKE; (e) EMANUEL; (f) GRELL of RegCM4.3. Red dotted line shows the actual date of onset and green dotted line shows the model simulated onset date.

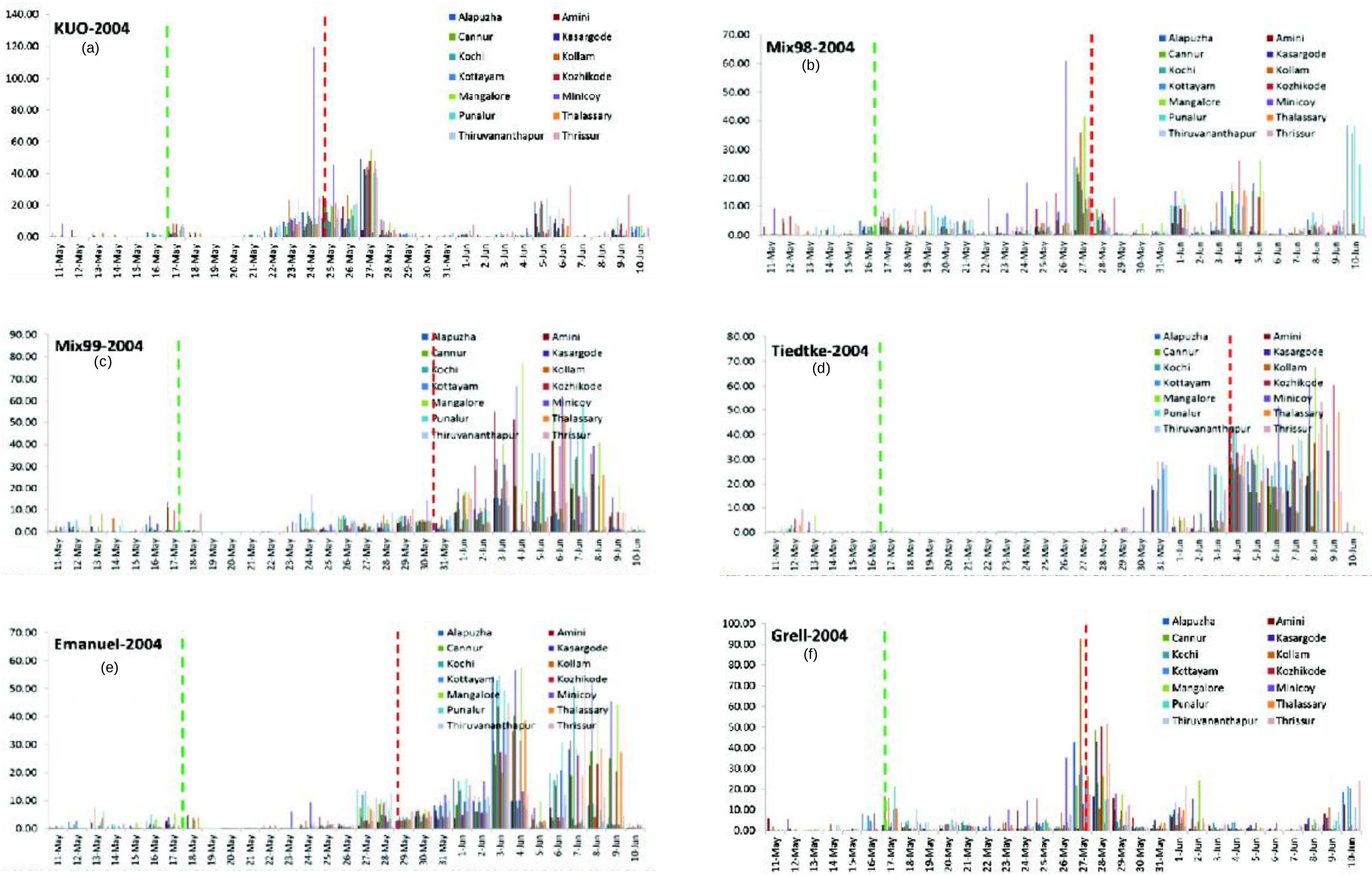

Fig.4a-f: Daily rainfall of fourteen stations, namely: Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore from 11th May to 10th June of 2004 for six cumulus convection schemes (a) KUO; (b) Mix98; (c) Mix99; (d) TIEDTKE; (e) EMANUEL; (f) GRELL of RegCM4.3. Red dotted line shows the actual date of onset and green dotted line shows the model simulated onset date.

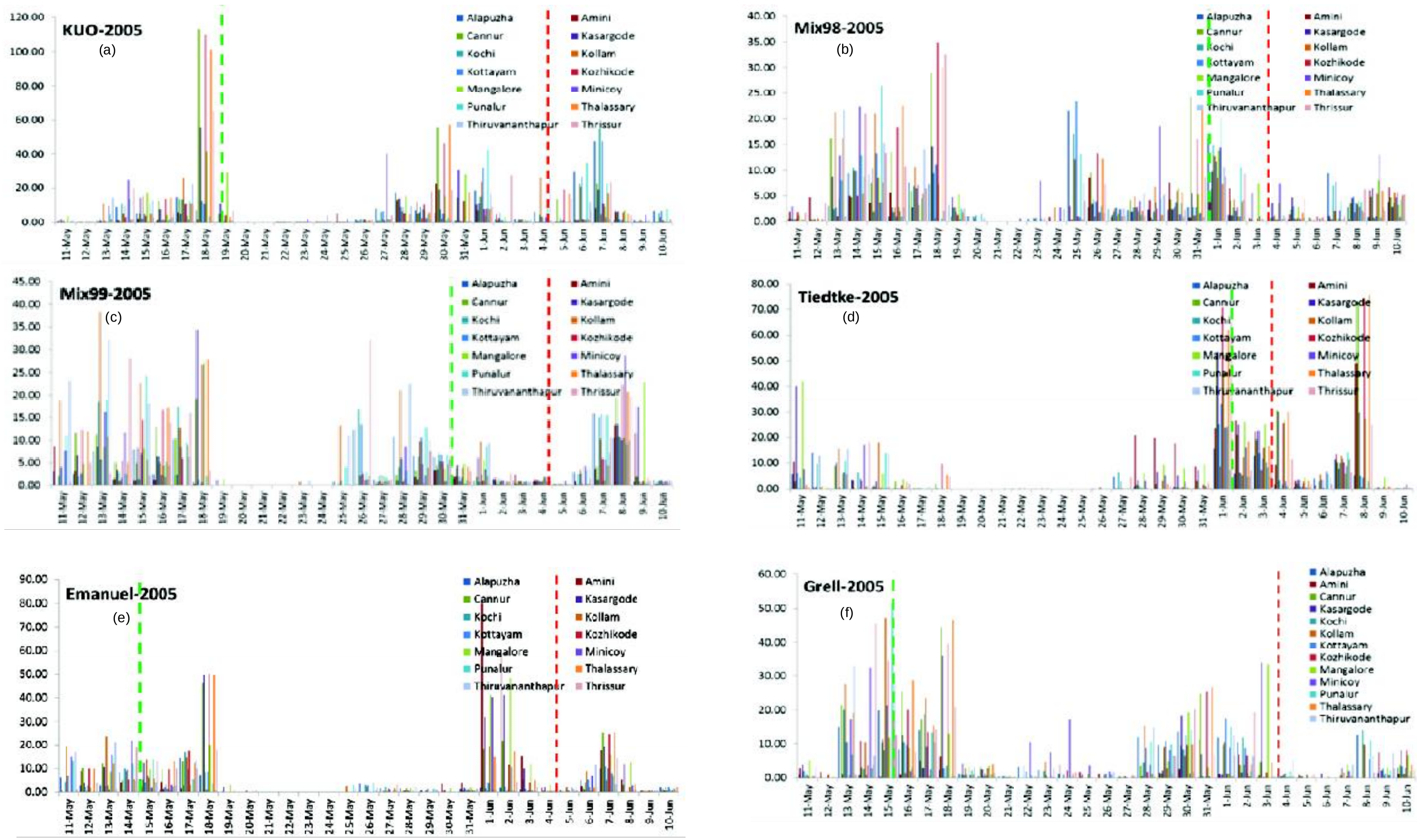

Fig.5a-f: Daily rainfall of fourteen stations, namely: Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore from 11th May to 10th June of 2005 for six cumulus convection schemes (a) KUO; (b) Mix98; (c) Mix99; (d) TIEDTKE; (e) EMANUEL; (f) GRELL of RegCM4.3. Red dotted line shows the actual date of onset and green dotted line shows the model simulated onset date.

is showing early arrival of onset in 13th May and Mix99, Tiedtke as well as Grell are simulating the late arrival on 30th, 31st and 30th May respectively. The cumulus convection scheme Mix98 and Kuo simulate the onset in ± 4 days with the actual onset summer monsoon of rainfall for 2001. Fig.2 and Fig.5 represent the years of 2002 and 2005 respectively. In both Figs, Mixed scheme and Tiedtke are performed well with the actual onset in more or less variation of ±3 day. In Fig.2, mixed schemes (Mix98 and Mix99) and Tiedtke scheme shows the difference of ±1 day except the convection schemes Kuo, Emanuel and Grell. The simulated onset date of Mix98, Mix99 and Tiedtke schemes are 28th, 29th and 29th May respectedly which is too close to the actual onset date 29th May 2002. The remaining three schemes Kuo, Emanuel and Grell are simulatinga large difference respect to the actual onset and showing the arrival of onset 18th, 16th and 16th May, respectively. In Fig.5, Mix98 as well as Tiedtke simulate the onset date with the variation of ±3 day on dates 2nd,3rd June 2005 where Kuo, Emanuel and Grell scheme indicates the early arrival on 19th,15th and 17th May with respect to actual Onset on 5th June 2005 respectively. The actual onset dates for the years 2003 and 2004 are 8th June (Fig.3) and 18th May (Fig.4) respectively. These two years are showing the late and early arrival of actual onset summer monsoon, compared to 2001-2005. Cumulus convection scheme Kuo for 2003 (Fig.3) and Tiedtke for 2004 (Fig.4) are performed poorer rather than remaining schemes. Remaining five convection schemes, namely, Mix98, Mix99, Tiedtke, Emanuel and Grell with simulated onset date 29th,30th, 31st,30th and 26th May for the year of 2003, and Kuo, Mix98, Mix99, Emanuel and Grell with simulated date of 25th,29th,31st,29th,29th for 2004 are performing well as compared to actual onset respectively. For early arrival of onset of monsoon in 2004, most of the schemes are simulated poor result (Fig.4) and a minimum ±7 day difference is indicated by convection scheme Kuo. From the above discussion, it may be summarized that Mixed scheme, compared to Kuo, Emanuel, Tiedtke and Grell scheme is simulates significant arrival of onset precipitation date over land and ocean during 2001 to 2005. The above discussion indicates the patterns of onset varies, which follow the actual onset date relatively well. Hence, it is slightly difficult to get information about a well performed scheme for onset simulation.To overcome this difficulty Taylor's diagram method (Taylor, 2001) is derived, which summarize multiple aspects in a single diagram by assessing the relative performance of different convection scheme with actual onset dates of monsoon.

Fig.6 shows the Taylor diagram to obtain all simulation option of correlation coefficient and normalized standard deviation for onset rainfall, with the six convection scheme and sub-regions of India. Fig.6 shows the minimum to large differences in terms of correlation, standard deviation and RMSE for different schemes. The correlation of the Mix98

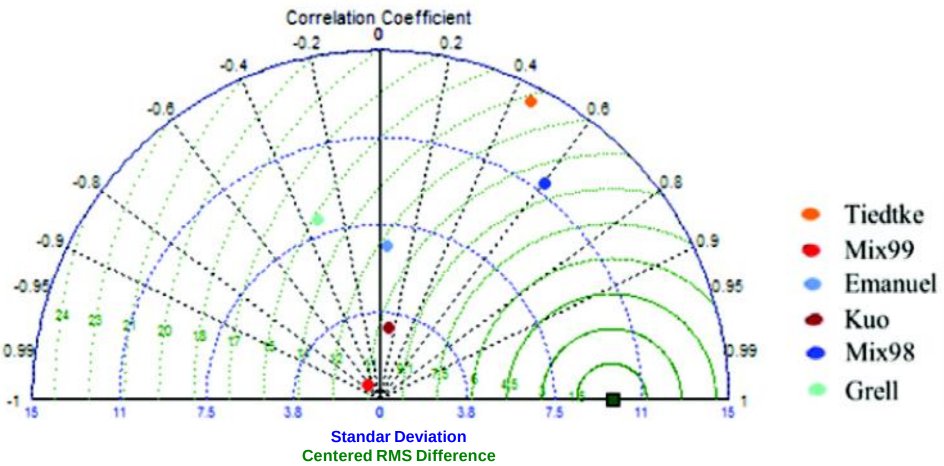

Fig. 6: Taylor diagram to display pattern of six Cumulus convection schemes with actual onset.

scheme of RegCM4.3 shows good simulation and the intensity, as well as the arrival time of onset over Kerala. Remaining convection schemes, namely Kuo, Mix99, Emanuel, Tiedtke and Grell are showing very weak correlation, standard deviation as well as RMSE for onset.

4. Conclusion

Through the use of six convective parameterization schemes in RegCM4.3, it is shown that many of them performed poorly in simulating on the simulation of rainfall over Kerala. The regional climate model with the mixed convection scheme Mix 99 simulates the onset of monsoon well in terms of Taylor diagram and distribution of rainfall with respect to actual onset dates (IMD).

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References

1. Anthes R.A., Hsie E.Y., Kuo Y.H., 1987, Description of the Penn state/NCAR mesoscale model version 4 (MM4). National Center for Atmospheric Research Technical Note TN-282, NCAR, Boulder, CO.
2. Basit A., S.R. Shoaib., N. Irfan., and R. Avila., 2012, Simulation of monsoon precipitation over South-Asia using RegCM3. ISRN Meteor., 12, 754902, doi: 10.5402/2012/754902.
3. Dash S.K., Pattnayak K.C., Panda S.K., Vaddi D., and Mamgain A., 2014, Impact of domain size on the simulation of Indian summer monsoon in RegCM4 using mixed convection scheme and driven by HadGEM2, Climate Dynamics, DOI 10.1007/s00382-014-2420-1
4. Dash S.K., Shekar M.S., Singh G.P., 2006, Simulation of Indian summer monsoon circulation and rainfall using RegCM3. Theor. Appl. Climatol. 86: 161–172
5. Davis N., J. Bowden, F. Semazzi, L. Xie, and B. O¨ nol., 2009, Customization of RegCM3 regional climate model for eastern Africa and a tropical Indian Ocean domain. J. Climate, 22, 3595–3616
6. Emanuel K.A., 1991, A scheme for representing cumulus convection in large-scale models. J. Atmos. Sci. 48: 2313–2335.
7. Giorgi F., Coppola E., Solmon F., Mariotti L., Sylla M.B., Bi X., Elguindi N., Diro G.T., Nair V., Giuliani G., Turuncoglu U.U., Cozzini S., Güttler I., O'Brien T.A., Tawfik A.B., Shalaby A., Zakey A.S., Steiner A.L., Stordal F., Sloan L.C., Brankovic C., 2012, RegCM4: model description and preliminary tests over multiple CORDEX domains. Clim. Res. 52:7–29.
8. Grell G.A., 1993, Prognostic evaluation of assumptions used by cumulus parameterization. Mon. Weather Rev. 121: 764–787.
9. Kuo H.L., 1974, Further studies of the parameterization of the influence of cumulus convection on large scale flow. Journal of the Atmospheric Sciences 31: 1232–1240
10. Monsoon 2008, A report. Edited by: Tyagi A., Hatwar H.R., and Pai D.S., 2009, IMD Met Monograph No: Synoptic Meteorology No: 7/2009
11. Octaviani M., and K. Manomaiphiboon., 2011, Performance of regional climate model RegCM3 over Thailand. Climate Research, 47(3), 171–186
12. Raju P.V.S., Bhatla R., Almazroui M. and Assiri M., 2015, Performance of convection schemes on the simulation of summer monsoon features over the South Asia CORDEX domain using RegCM-4.3.Int. J. Climatol. DOI: 10.1002/joc.4317
13. Segele Z.T., L.M. Leslie., and P.J. Lamb., 2009, Evaluation and adaptation of a regional climate model for the Horn of Africa: Rainfall climatology and interannual variability. International Journal of Climatology, 29(1), 47–65
14. Singh A.P., Singh R.P., Raju P.V.S., Bhatla R., 2011, Comparison of three different cumulus parameterization schemes on Indian

summer monsoon circulation. Int. J. Ocean Clim. Syst. 2(1): 27–43

15. Slingo J.M., Mohanty U.C., Tiedke M., Pearce R.P., 1988, Prediction of the 1979 summer monsoon onset with modified parameterization schemes. Monthly Weather Review 116: 328–346

16. Srinivas C.V., Hariprasad D., Rao D.V.B., Anjaneyulu Y., Baskaran R., Venkataraman B., 2013, Simulation of the Indian summer monsoon regional climate using advanced research WRF model. Int. J. Climatol. 33: 1195–1210

17. Taylor K.E., 2001, Summarizing multiple aspects of model performance in a single diagram. J. Geophys. Res. 106 (D7), 7183–7192

18. Tiedtke M., 1989, A comprehensive mass flux scheme for cumulus parameterization in large-scale models. Mon. Weather Rev. 117:1779–1800.