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RESEARCH ARTICLE

Identifying the Best Microphysics Option to Improve Accuracy of Medium Range Rainfall Forecast for Tamil Nadu

Mehala, M[1], Dheebakaran, Ga, Panneerselvam, S, Patil Santosh Ganapati*, and Kokilavani, S.
Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore – 641 003.
* Department of Physical Sciences and Information Technology, Tamil Nadu Agricultural University, Coimbatore – 641 003.

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ABSTRACT

Weather Research and Forecasting (WRF) model is a numerical weather prediction system and having wide range of applications.It offers multiple physics options that could be combined in any way to improve the accuracy of forecast suitable to particular region.Each physics option has it's own individuality and no single scheme could perform better in all locations. In this context, a study was carried out to identify the best WRF microphysics scheme for improvingmedium range rainfallforecastissued by Tami Nadu Agricultural University at block levelforTamil Nadu. Based on the review of previous studies, the present study was restricted to three microphysics options which are suitable for tropical conditions viz. Kessler scheme, WSM3 and WSM6 class schemes. Forecast wasdeveloped daily at 3 km resolution with a lead time of six days for 32 locations of Tamil Nadu and for the first fortnight of November 2017. The simulated forecast values were verified with the observed data collected from the Automatic Weather Stations of TamilNadu Agricultural Weather Network (TAWN) using skill score and root mean square error verification methods. Input data resolution and microphysics option had huge impact on model performance. Data resolution of 0.25 degree performed better than 0.50 degree in all microphysics schemes considered for the study. Among the three microphysics options, the Kessler scheme had higher rainfall forecast accuracy than WSM 3 class scheme and WSM 6 class scheme. Root mean square error was also low in Kessler scheme compared to other two schemes. Kessler scheme produced highly usable forecast than WSM 3 and 6 class schemes. Hence, it is concluded that the Kessler scheme with 0.25^{o} input data resolution produced higher rainfall forecast accuracy for Tamil Nadu region.

Keywords: *Weatherforecast, WRF, Microphysics,Accuracy, Verification*

Agriculture is the major component of Indian economy, sharing 18 per cent of gross domestic product and supports livelihood of more than 50 per cent of Indian population. Agriculture and allied sectors are highly reliable on weather for their prosperity(Hardaker *et al.*, 2004). Among all the weather variables such asrainfall, temperature, relative humidity, wind speed and solar radiation, the rainfall has huge impact on crops(Selvaraju *et al.*, 2011). Weather forecast plays an important role in impact assessment in addition to the proper management of farm operations(Mase and Prokopy, 2014).Rainfall anomalies in recent years have led to flood and droughts and also undesirable effect on cropsand perfect rainfall forecast helps to minimize the crop loss to greater extent(Crane *et al.*, 2010; Ndamani and Watanabe, 2015).Presently, Numerical Weather Prediction (NWP) models are used for developing weather forecast, which involves complicated mathematical calculations on atmospheric processand no single scheme can give better results in all locations and every scheme has its own predicting powers (Gallus Jr and Bresch, 2006; Duan *et al.*, 2017).

Among the different numerical weather forecasting models, the Weather Research and Forecasting (WRF) model is used for operational forecasting and atmospheric research. WRF model includes the advanced numerical options, which solve complex equations, cutting edge data assimilation method, and numerous physics options mainly for dealing with convection and mesoscale precipitation (Skamarock, 2008;Bauer *et al.*, 2015). Microphysics options are considered as a key parameter in environment, meteorology and hydrology field, because it merges energy fluxes

*Corresponding author's e-mail: mehalaisha@gmail.com

from earth and atmosphere. Microphysics options are mainly used for the purpose of eliminating the moisture from the atmosphere based on the kinematic and thermodynamic fields, which is represented within numerical models (Kirtman and Min, 2009; Eltahan and Magooda, 2017).

Tamil Nadu has agriculture as the major income source, lower riparian and heavily depend on water from neighboring states. Rainfall is the major source of water for agriculture and groundwater recharge. Timely and accurate weather forecast helps the farmers in making better decision on farm operations. Presently, block level medium range weather forecast for all the 385 blocks of Tamil Nadu are being developed at Agro Climate Research Centre, Tamil Nadu Agricultural University (TNAU) for next six days with WRF model using 0.50 degree GFS data (12 hours UTC) and microphysics of WRF single moment 6 class scheme. The accuracy of the rainfall forecast is around 50 – 70 per cent. Increasing the forecasting accuracy and reducing the false alarms not only increase the productivity but also could safeguard the poor resourced farmer from input loss. In this context, a study was taken up at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, India,to assess the possibility of increasing the accuracy of the TNAU's block level medium range weather forecast by altering the input data resolution and microphysics options and is presented here.

MATERIAL AND METHODS

Study area

Study was specific to Tamil Nadu, spread between 8^{o} 5' N and 13^{o} 35' N latitude and 76^{o} 15' and 80^{o} 20' E longitudein southern peninsular part of India. By averaging the results from22 districts well spread over Tamil Nadu was done to minimize the spatial variability of this weather forecasting study.The other 10 districts of Tamil Nadu were not taken for the study due to lack of observed data during the study period.

Model configuration and input data

WRF model is a mesoscale weather prediction system used for operational forecasting and atmospheric research. WRF Model Version 3.9.1.1 was used in this study. Forecast was generated for every day with the lead time of 6 days and 18 hours during1st to 15thNovember, 2017.Platform used for model compilation and running was Linux (CentOS 6.9) operating system. The data used in this study was 0.50 and 0.25 degree resolution (12 UTC) Global Forecast System (GFS) data of National Centre for Environmental Prediction (NCEP), downloaded at 6 hourly interval for the month of November 2017. Two nested domain viz., 9 km and 3 km were used for 0.25 degree (27 km) input data resolution, where as three nested domain viz., 27 km, 9km and 3km were used for 0.50 degree (55 km) input data resolution. The final output of both the run were 3 km.

Microphysics options

Important step in the weather simulation process is to choose the correct set of physics option suitable to that particular location.Based on the earlier reviews and as suggested in WRF User's forum for tropical climate, three microphysics options viz., Kessler scheme (warm rain scheme -mp1), WRF single moment 3 class scheme (suitable for mesoscale grid sizes - mp3), and WRF single moment 6 class scheme (suitable for high resolution simulation - mp6) were studied in this research.

Forecast development

Medium range weather forecast for 22 locations, two input data resolution (0.25 and 0.50), three microphysics options and 6 days of lead time for first fortnight of November 2017 were developed at daily interval. Though the developed forecast included weather parameter viz., rainfall, minimum temperature, maximum temperature, wind speed (8.30 and 14.30) and relative humidity (8.30 and 14.30), thispaper is concentrated only on rainfallforecast.

Forecast verification methods

Forecast verification is the process of assessing the accuracy and skill of a forecasting system. The accuracy of the forecasts developed at daily interval were verified with observed data obtained from Tamil Nadu Agricultural Weather Network (TAWN) of Tamil Nadu Agricultural University. Forecasts accuracy were verified for different microphysics options, input data resolution and lead times using the different scores (Ebert, 2013) and RMSE method.

Hit score or forecast accuracy ratio

Hit score is used in rainfall forecast verification, which is the ratio of correct forecast to the total number of forecast. It varies from 0 to 1 and 1 indicates the perfect forecast.

$$\text{Forecast accuracy ratio} = \frac{\text{Correct Forecast (CF)}}{\text{Total Forecast (N)}} = \frac{YY + NN}{NN + NY + YN + YY}$$

Bias score frequency (BSF)

Bias score is used in rainfall forecast verification, which is a measure of similarity from the mean forecast and observation. The Bias score frequency measures the ratio of the frequency of forecast events to the frequency of observed events. This indicates whether the forecast system has a tendency to under forecast (*BIAS*<1) or over forecast (*BIAS*>1) events. Perfect score is 1.

$$\text{Bias score frequency} = \frac{\text{Hit + False alarms}}{\text{Hit + Misses}} = = \frac{YY + YN}{YY + NY}$$

False alarm ratio (FAR)

False alarm ratio is used in rainfall forecast verification, which ignores misses but sensitive to false alarms and climatological frequency of the events. It can be used in conjunction with the POD. Range is 0 to 1 and 0 is the perfect score.

$$\text{False Alarm Ratio (FAR)} = \frac{\text{False Alarms}}{\text{Hit + False alarms}} = \frac{YN}{YY + YN}$$

Root Mean Square Error (RMSE)

RMSE is used in rainfall, minimum and maximum temperature forecast verifications. RMSE is the square root of the average of the squared differences from forecasts and observations. Because it is a squared quantity, RMSE is influenced more strongly by large errors than by small errors. Values ranged from 0 to ∞ and 0 is perfect score.

$$\text{RMSE} = [1/N\sum (F_i - O_i)^2]^{1/2}$$

where, N- Total number of observations/forecast; F_i-Forecast value; O_i-observed value

RESULTS AND DISCUSSION

Kessler scheme with 0.25° and 0.50° data resolution

Skill score for the rainfall forecast developed in WRF model with Kessler scheme and input data resolution of 0.25° and 0.50° were depicted in Table 1. The hit score for 0.25°resolution werebetween 0.6 and 0.7, in whichDay1 to Day5 had 0.6, whereas Day6 had 0.7. The hit score for the 0.50° input data resolution showed the same value of 0.6 for all the six Days. BSF werebetween 0.6 and 1.2 with lowest value on Day6 and highest value on Day1 in 0.25°resolution and the BSF values were between 0.4 and 1, the highest value on Day1andthe lowest value on Day4 to Day6with 0.50° resolution input data. FAR values were between 0.4 and 0.8, showed a lowest value onDay1and highest value on Day6with 0.25°data resolution input data.In case of 0.50°resolution, Day1and Day2 showed FAR score of 0.5 and Day3 to 6 showed 0.6. RMSE was ranged from 10.8 and 17.3, showed a lowest value on Day6 and highest value on Day4with 0.25°data resolution. Similarly in 0.50°data resolution, the RMSE values were ranged from 12.4 to 17.9 and showed the highest value on Day4 and the lowest on Day5. In comparing different lead times from Day1 to Day6 under Kessler scheme, the Day1 showed low FAR, whereas Day6 showed low RMSE value with 0.25° data resolution. In case of 0.50° data resolution,Day1 to Day6 showed the same hit rate but FAR values were less in Day1 and Day2.The BSF had the perfect score of 1 on Day1 but decreased fromDay2 to Day6.Interestingly, the usability (Correct + Usable) of forecast data was increased from Day1toDay5 with 0.25°data resolution and it was increased from Day2 to Day5under 0.50°data resolution. In both cases, the usability was decreased after 5th day. Among the two input data resolutions, usability of forecast in 0.25°dataresolution (76 to 89 %) washigher than 0.50°data resolution (75 to 79 %).In an earlier study, the same had been noted that density of data in 0.25°was four times higher than that of 0.50° model and this will undoubtedly leads to increase in forecast accuracy (Francis, 2018).

WSM3 class scheme with 0.25° and 0.50°data resolution

Skill score for rainfall forecast developed in WRF model with WSM3 class scheme and input data resolution of 0.25° and 0.50°was depicted in the Table 1. The hit score was ranged from 0.5 to 0.7 and 0.5 was recorded on Day1 to Day3, and 0.7 on Day6with 0.25° resolution. The hit score was ranged from 0.5 to 0.6 with 0.50° dataresolution. BSF was ranged fromfrom 0.6 to 0.8, the lowest value was on Day6 and the highest value was on Day1 to Day3 in 0.25° data resolution. BSF values were ranged from 0.9 to 1.4 with lowest on Day4 and highest on Day1 in 0.50° data resolution. Interestingly, the 0.25° data resolution input produced under forecast,whereas the 0.50° data resolution produced over forecast in all Days. FAR values rangedfrom 0.3 to 0.5 in 0.25° data resolution and in case of 0.50°data resolution Day1 and Day6 showed 0.6 and Day2 to Day4 showed 0.5. FAR was increased from Day1 to Day6 in both the cases, which indicated that the perfectness in the forecast was decreased with theincrease in lead time.RMSEwas rangedfrom 15.1 to 22.8 per cent with 0.25° data resolution and ranged from 16.8 to 24.3 with 0.50° data resolution. In both the cases, lowest value was on Day3 and highest value was on Day6. The Day1and Day2 were also shown lesser RMSE values (around 16) in 0.25°data resolution. In comparing different lead time from Day1 to Day6 under WSM3 class scheme, theDay6 showed higher hit rateand high false alarm ratio, whereas the Day1 showed low FAR in 0.25° data resolution. In case of 0.50° data resolution,Day1 and Day2 showed the low hit rate with high FAR value.Similar to the Kessler scheme, in WSM 3 class scheme also, the usability was increased from Day 1 to 5 and decreased on Day 6in both 0.25°and 0.50°input data resolutions. Usability of forecast was from 64 to 77 per cent in 0.25° data resolution whereas it was 58 to 65 per cent in 0.50° data resolution.

Table 1. Skill scores of rainfall forecast developed in WRF with microphysics schemes and 0.25° and 0.50° GFS data resolutions

Forecast verification scores		Kessler scheme with 0.25°GFS data						Kessler scheme with 0.50°GFS data					
		Day1	Day2	Day3	Day4	Day5	Day6	Day1	Day2	Day3	Day4	Day5	Day6
Hit score	SR	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6
Bias score frequency	BSF	1.2	0.8	0.8	0.7	0.8	0.6	1.0	0.7	0.5	0.4	0.4	0.4
False alarm ratio	FAR	0.4	0.6	0.7	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.6	0.6
Root mean square error	RMSE	14.7	14.1	14.3	17.3	13	10.8	15.1	14.5	14.8	17.9	12.3	12.4
Error structure for rainfall (for matching cases)	Correct	67.0	75.4	85.1	86.3	88.6	85.7	69.1	67.3	71.2	70.1	72.3	69.1
	Usable	8.5	5.0	2.3	3.9	1.7	2.4	10.6	8.6	6.7	9.2	7.3	7.3
	Unusable	24.4	19.6	12.6	9.9	9.7	11.8	20.3	24.1	22.1	20.7	20.4	23.6
		WSM3 class scheme with 0.25°GFS data						WSM3 class scheme with 0.50°GFS data					
Hit score	SR	0.6	0.6	0.6	0.5	0.6	0.7	0.5	0.5	0.6	0.6	0.6	0.6
Bias score frequency	BSF	0.8	0.8	0.8	0.8	0.7	0.6	1.4	1.3	1.3	1.1	0.9	1.1
False alarm ratio	FAR	0.3	0.3	0.3	0.4	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6
Root mean square error	RMSE	16.5	16.0	15.1	17.1	19.8	22.8	16.9	17.5	16.8	17.6	20.7	24.3
Error structure for rainfall (for matching cases)	Correct	54.2	56.2	59.3	61.7	65.6	65.4	50.1	50.3	52.1	55.3	59.1	57.1
	Usable	7.6	6.8	10.0	9.1	12.1	6.7	8.6	10.2	7.3	9.6	7.1	8.0
	Unusable	38.3	37.0	30.7	29.1	22.2	27.9	41.3	39.5	40.6	35.1	33.8	34.9
		WSM6 class scheme with 0.25°GFS data						WSM6 class scheme with 0.50°GFS data					
Hit score	SR	0.6	0.6	0.6	0.6	0.6	0.7	0.5	0.6	0.6	0.5	0.6	0.6
Bias score frequency	BSF	0.8	0.8	0.7	0.7	0.7	0.6	1.5	1.6	1.5	1.1	1.0	1.0
False alarm ratio	FAR	0.2	0.2	0.3	0.6	0.5	0.4	0.6	0.5	0.6	0.6	0.6	0.5
Root mean square error	RMSE	15.5	16.5	15.3	17.3	19.8	27.3	15.9	17.1	16.8	17.9	21.3	20.4
Error structure for rainfall (for matching cases)	Correct	50.6	47.7	62.2	86.3	65.6	62.5	51.7	45.3	49.1	50.3	53.1	52.1
	Usable	10.3	9.4	9.0	3.9	12.1	6.2	10.6	10.2	7.5	8.9	7.1	8.0
	Unusable	39.1	42.8	28.8	9.9	22.2	31.3	37.7	44.5	43.4	40.8	39.8	39.9

Hit score (0 to 1, perfect is 1); BSF (>1 over forecast, <1 under forecast, perfect is 1),FAR (0 to 1, perfect is 0); RMSE (0 to ∞, perfect is 0, Acceptable up to 15).

WSM6 class schemewith 0.25° and 0.50° data resolution

Verification skill score for rainfall forecast developed in WRF model with WSM6 class scheme and input data resolution of 0.25° and 0.50°was depicted in the Table 1.Hit score of 0.25° data resolution input was ranged from 0.6 to 0.7 and 0.6 was recorded on Day1 to Day5 and 0.7 on Day6. Hit score of 0.50° data resolution ranged from 0.5 to 0.6 and lowest value on Day4 and remaining Days were numerically on par with each other. BSF was ranged from 0.6 to 0.8, lowest value on Day6 and highest value on Day1 in 0.25° data resolution. The BSF values were ranged from 1.0 to 1.6, showed the lowest value on Day5 and Day6 and highest value on Day2in 0.50°data resolution. FAR values were rangedfrom 0.2 to 0.6 showed a lowest value on Day1 and Day2 and highest value on Day4 in 0.25° data resolution. In case of 0.50°data resolution,Day2 and Day6 showed 0.5 and Day1,Day3,Day4 and Day5 showed 0.6. RMSE ranged from 15.5 to 27.3, lowest value on Day3 and highest value on Day6 in 0.25° data resolution. In 0.50° data resolution, RMSE values were ranged from 15.9 to 21.3 per cent, showed a lowest on Day1 and highest value on Day5. In comparing different lead time from Day1 to Day6 under WSM6 class scheme,Day6 showed higher hit rate but high RMSE value and high FAR. Whereas Day1 showed low FAR in 0.25°data resolution. In case of 0.50° data resolution Day2,Day3,Day5 and Day6 showed the same hit rate,The FAR values were less in Day1 and Day4 and the BSF showed perfect score 1 on Day4.In error structure of rainfall, unusable data were ranged from 9.9 to 42.8 per cent in 0.25° data resolution, where as it was ranged from 37.7 to 44.5 per cent in 0.50° data resolution. Similar to the other two microphysics schemes, the usability of forecast was increased fromDay1 to Day5 in 0.25°input data resolution and fromDay2toin 0.50° data resolution. Usability of forecast was from 60 to 80 per cent in 0.25 degree resolution and it was ranged from 55 to 62 % in 0.50° data resolution.

CONCLUSION

Input data resolution and microphysics option had huge impact on model performance. Data resolution of 0.25 degree performed better than

0.50 degree in all microphysics schemes considered for the study. Among the three microphysics options, the Kessler scheme had higher rainfall forecast accuracy than WSM 3 class scheme and WSM 6 class scheme. Root mean square error was also low in Kessler scheme compared to other two schemes. Bias score frequency was also near to 1 and false alarm ratio increases when the lead time get increased. These factors reflected in usability of forecast. Kessler scheme produced highly usable forecast than WSM 3 and 6 class schemes.Typically, the usability of forecast has to be decreased with lead time, whereas in our study the usability was increased from Day 1 to 5 and decreased after Day 5. Hence, it is concluded that the Kessler scheme with 0.25° input data resolution produced higher rainfall forecast accuracy for Tamil Nadu.

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