Performance of Regional Climate Model (WRF 4.3)in Medium Range Rainfall Forecast (MRRF) for Tamil Nadu

ABSTRACT

The weather events are highly dynamic and fluctuating for the next few days due to enormous processes carried out by nature and physics and it is even more highly variable in tropics. The Medium Range Weather Forecast is incredibly helpful and trustworthy for agricultural purposes and rainfall is one of the most imminent events determining productivity. TheMedium Range Rainfall Forecast (MRRF) given by Weather Research and Forecast model (WRF v 4.3)is verified using forecast verificationscoresincluding Ratio of Root Mean Square Error (RMSE) to the standard deviation of the observations (RSR), Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), Kling-Gupta Efficiency (KGE), and Root Mean Square Error (RMSE). Scores were computed by comparing forecast generated using two microphysics options viz., WRF Single Moment scheme (WSM-3) and Kessler scheme during South West Monsoon (SWM) and North East Monsoon (NEM)of the year 2021 for five different physiographic regions of Tamil Nadu. WSM-3 microphysics scheme outperformed in predicting MRRF for all the five regions and during both the monsoons.

Keywords: Medium Range Rainfall Forecast, Numerical Model,WRF,Microphysics, Forecast VerificationScores, accuracy.

1. INTRODUCTION

Success of crop productionis highly reliant on weather magnitudes and credible advanced weather information raises the likelihood of success. In addition to effective farm management, weather forecasting is playing a significant role in higher productivity[1]. Rising temperatures and changing monsoon rainfall patterns due to climate change could cost India, 2.8 percent of Gross Domestic Product (GDP)[2]. Of all the weather parameters,rainfall patterns are projected to have a severe impact on global productivity [3] and one per cent increase in rainfall relative to its mean is correlated with a 0.16 per cent increase in GDP growth [4]. The southwest monsoon(June to September), which is wet, unstable, and has a large vertical extension provides rainfall to a certain region of Tamil Nadu. The Northeast monsoon(October to December),which is a component of the northeast trades, is relatively dry, consistent, and has a smaller vertical extent, around 1 to 2 kilometres holds the major responsibility for the rainfall over Tamil Nadu [5].

Timely prediction of rainfall during monsoon will support agriculture in a substantial way. Because of providing three to seven days of lead time, the Medium Range Weather Forecast (MRWF) is highlyusable and trustworthy for agricultural purposes.Possibility is there to improve rainfall prediction accuracy and thereby giving better MRWF by enhancing model elements such as physics, resolution, and atmosphere-land-ocean interactions[6]. The evolution of the Numerical Weather Prediction (NWP) model has gained prominence throughout the years, owing to the constant accumulation of scientific and technological advances [7].

WRF model is a Regional Climate model (RCM) that provides Medium Range Weather Forecastwith greater data precision [8]. The newer improved versions of WRF model showed its improvement than the previous versions by its capabilities [9]. The WRF model showed different accuracy with different schemes imparted [10]. From the earlier research works of Tamil Nadu Agricultural University (TNAU), it was found that the accuracy of WRF output varied with microphysics options and location specific. In this context, the WRF 4.3 model with two microphysics schemes in the Medium Range Rainfall Forecast (MRRF) was subjected to a performance analysis by the Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, India.The output was evaluated and compared using forecast verification scoresfor the two monsoonsviz.,SWM and NEM. By evaluating the model performance with different microphysics schemes and finding the suitable scheme the scope of providing accurate rainfall forecast can be enhanced.

2. METHODOLOGY

2.1 Study area

The study was carried out to assess the performance accuracy of MRRF in varied physiographic regions of Tamil Nadu under high resolution of 3km. Latitudes of 8^{o} 5' N and 13^{o} 35' N, and longitudes of 76^{o} 15' and 80^{o} 20' E, define the complete geographical area of Tamil Nadu. Five different locations of Tamil Nadu namely Panruti, Rajakkamagalam, Conoor, Gobichettipalayam and Vellore regions representingfive different physiography viz., Plain, Coastal Plain, Hills, Western Ghats influencing area (WGIA), Eastern Ghats influencing area (EGIA)were chosen as the study area for research.

Fig. 1. Geographical positions of the study sites used for forecast verification

2.2 Input data and model specifications

WRF model is a regional scale Numerical Weather Prediction model that is mostly used for research and operational forecasting and the WRF v 4.3 was used for the study. The six hourly intervalGlobal Forecast System (GFS) data of 12hour UTC time stepat0.25^o resolution were downloaded daily during the study period (SWM, NEM 2021) and used as input. The WRF model was constructed on two Linux-based high-performance computing servers, each of which was run in batches to produce output with two microphysics options.Two nested domains covering all the study area with 200 grids on both NS and EW at 9 km intervals (1800 x 1800 km) as parent and 225 (NS) x 165 (EW) grids at 3 km intervals as nested domain (645 x 498 km) was created in both the machines. The MRRFfor the selected five locations was chosen from the total output of 35640 locations. Forecasts with six days of lead time wasgenerated for every day of the SWM and NEM 2021.

2.3 Microphysics

Based on the reviews, the Kessler scheme (Kessler, simple rain) and WRF single moment 3 class scheme (WSM-3, rain, snow and graupel that suitable for mesoscale grid sizes) were considered as suitable microphysics schemes for tropical conditions [11].

2.4 Forecast Verificationscores

Forecast verification is a crucial aspect of any scientific forecasting system since it evaluates forecast accuracy [12]. The forecast accuracy of WRF's Medium Range Rainfall Forecast during two monsoons of 2021 was tested with five forecast verification scores namely Root mean square error (RMSE), Nash-Sutcliffe efficiency (NSE), Ratio of the RMSE between simulated and observed values to the standard deviation of the observations (RSR), Kling-Gupta efficiency (KGE), Percent Bias (PBIAS).

2.4.1 Nash-Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) is a normalised statistic that describes the degree of residual variation against measured data variance(Nash and Sutcliffe, 1970). For analysing the goodness of fit of hydrologic models, this is widely used and potentially reliable statistic.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs} - \overline{Q_{obs}})^2}$$

The Nash-Sutcliffe efficiency ranges from - ∞ to 1 and perfect is 1.

2.4.2 Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) is the standard deviation of the residuals (prediction errors). Residuals are a measure of how far from the regression line data points are; RMSE is a measure of how spread out these residuals are. It tells how concentrated the data is around the line of best fit.The lower values indicate a better fit.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)^2}$$

Where:

- ∑ is the summation of all values
- f is the predicted value
- o is observed or actual value
- $(f_i — o_i)$ 2 are the differences between predicted and observed values and squared
- N is the total sample size

2.4.3 Ratio of the RMSE between simulated and observed values to the standard deviation of the observations (RSR)

The ratio of the RMSE and standard deviation of observed data is determined as the RMSE observations standard deviation ratio (RSR). RSR can range from optimum of 0 to a significant positive number. The smaller the RSR, the lower the RMSE, and the more accurate the model simulation.

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(|Q_{obs} - Q_{sim}|)^2}}{\sqrt{\sum_{i=1}^{n}(|Q_{obs} - \overline{Q_{obs}}|)^2}}$$

When the RMSE equals 0 (zero), the observed and predicted values are perfectly aligned, while increasing RMSE values imply an increasingly poor fit. Low RMSE levels of less than half the standard deviation of the observed (measured) data may be deemed good model prediction.

2.4.4 Percent Bias (PBIAS)

The average tendency of simulated values to be overestimated or under estimated than their observed values is measured by percent bias (PBIAS).

$$PBAIS = 100 \times \frac{\sum_{i=1}^{n} Q_{obs} - Q_{sim}}{\sum_{i=1}^{n} Q_{obs}}$$

PBIAS has an ideal value of 0.0, and low magnitude values indicate accurate model simulation. Model overestimation bias is indicated by positive values, whereas model underestimation bias is indicated by negative values.

2.4.5 Kling-Gupta efficiency (KGE)

In recent years, the Kling-Gupta efficiency (KGE), which more evenly balances the three components of the Nash-Sutcliffe efficiency (NSE) of model errors (i.e., correlation, bias, ratio of variances or coefficients of variation), has been widely used for calibration and evaluation of hydrological models. The KGE is a model evaluation criterion that may be broken down into three components: mean, variance, and correlation.

In this implementation, the Kling-Gupta efficiency is defined as following:

$$KGE = 1 - eTotal$$

eTotal is the euclidean distance of the actual effects of mean, variance, correlation and trend (optional) on the time series: eTotal = sqrt (eMean + eVar + eCor + eTrend) eTotal can be between 0 (perfect fit) and infinite (worst fit). The efficiencies of Kling-Gupta range from -∞ to 1. In other words, the closer the model is to 1, the more accurate the model.

3. RESULTS AND DISCUSSION

The forecast verificationscoresofMRRF generated for the five physiographic regions of Tamil Nadu in the WRF v 4.3 model with two microphysics options namely WSM-3 and Kessler scheme during the SWM,2021 and NEM,2021 were presented in the Table 1 and 2, respectively.

Table 1. Performance of two microphysics schemes in the WRF v.4.3 model in MRRF for different physiographic regions of Tamil Nadu during South west Monsoon of 2021.

Location	RMSE		NSE		RSR		KGE	
	WSM-3	Kessler scheme	WSM-3	Kessler scheme	WSM-3	Kessler scheme	WSM-3	Kessler scheme
Hills	7.9	10	0.3	-0.2	0.8	1.1	0.5	0.2
Coastal Plain	17.4	18	0.3	0.2	0.8	0.9	0.02	-0.02
WGIA	3.3	4.1	0.5	0.2	0.7	0.9	0.4	0.2
Plain	5.7	7.5	0.7	0.4	0.6	0.8	0.5	0.3
EGIA	7.2	8.9	0.6	0.4	0.7	0.8	0.5	0.4

Table 2. Performance of two microphysics schemes in the WRF v.4.3 model in MRRF for different physiographic regions of Tamil Nadu during North East Monsoon of 2021.

Location	RMSE		NSE		RSR		KGE	
	WSM-3	Kessler scheme	WSM-3	Kessler scheme	WSM-3	Kessler scheme	WSM-3	Kessler scheme
Hills	8.7	10.5	0.6	0.4	0.8	0.8	0.7	0.5
Coastal Plain	5.8	9.9	0.9	0.6	0.7	0.8	0.9	0.6
WGIA	5.8	9	0.7	0.3	0.8	0.9	0.7	0.5
Plain	6.6	12.2	0.9	0.5	0.7	0.8	0.9	0.7
EGIA	5.2	9.5	0.8	0.4	0.7	0.8	0.8	0.5

3.1 Kling-Gupta efficiency (KGE)

Among the microphysics options, for both the monsoon (SWM and NEM), WSM-3 performed comparatively better than Kessler Scheme. When comparing the two monsoons, WRF model outperformed for NEM when compared with SWM. During SWM, WRF model output is analogues with observed values in plains followed by rest of the places. During NEM, WRF model forecast is appreciable in plains followed by rest of the regions.

3.2 Nash-Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe efficiency for the two microphysics options WSM-3 performance was better in all the five regions and in both SWM and NEM compared with Kessler scheme. All the five regions were having acceptable NSE values with both schemes during both monsoons. However, hilly regions had unacceptable values during southwest monsoon with Kessler scheme. The WRF model had given forecast with better accuracy during NEM comparing with SWM and provided good prediction for coastal plain region followed by rest of the regions during NEM under NSE score. During SWM it gave better prediction for plain followed byrest of the regions.

3.3 Ratio of the RMSE between simulated and observed values to the standard deviation of the observations(RSR)

Having the lower RSR value WSM-3 performed well in all the five regions and in both the monsoons than Kessler scheme. All the five regions were having acceptable RSR values with both schemes during both monsoons. The WRF model gave forecast with better accuracy during NEM comparing with SWM and provided good prediction for plain region followed by rest of the regions during NEM under RSR. During SWM it gave better prediction for plain followed byrest of the regions.

3.4 Root Mean Square Error (RMSE)

WSM-3 performed well in all the five regions and in both the monsoons by having lower RMSE value than Kessler scheme. All the five regions were having acceptable RSR values with both schemes during both monsoons. The WRF model provided good prediction for Eastern Ghats influencing area region followed byrest of the regions during NEM under RMSE score. During SWM it gave better prediction for Western Ghats influencing area followed by rest of the regions.

3.5Percent Bias (PBIAS)

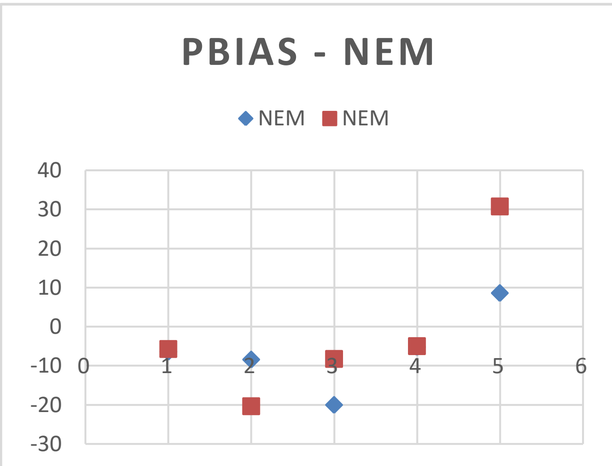

Fig.2.PBIASfor WSM-3 and Kessler Scheme during NEM 2021

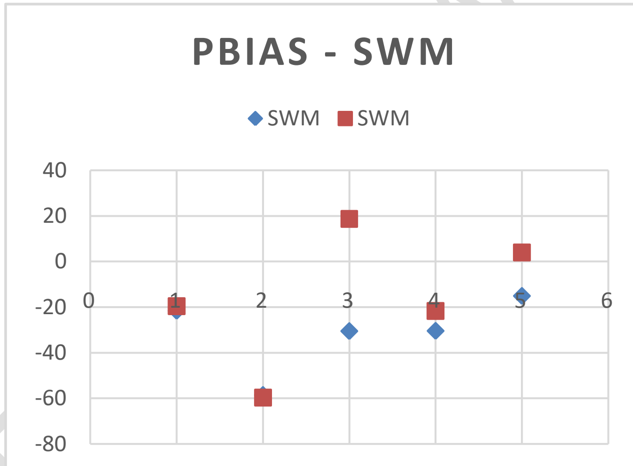

Fig.3.PBIASfor WSM-3 and Kessler Scheme during SWM 2021

For Eastern ghats influencing area the model overestimated rainfall and for all other regions it underestimated rainfall values during NEM. For SWM all the model underestimated rainfall forecast for all the five regions with WSM-3 scheme and with Kessler it underestimated in all regions except Eastern Ghats influencing area. The WSM-3 had shown lesser deviation and bias than Kessler scheme during both SWM and NEM.

WSM-3 performed comparatively better than Kessler scheme during both SWM and NEM, irrespective of all the regions. The WRF model gave forecast with better accuracy during NEM than SWM. Study showed that the Kessler and WSM-3 outperformed in 5km resolution [13], and the WSM-3 efficiently caught many essential aspects, despite certain spatial and temporal biases in its simulation [14].For bothSWM and theNEM, the WSM-3 method delivered better accurate forecasts in Tamil Nadu's Cauvery Delta Zone[15].WSM-3 scheme is found to have better values for all the scores RMSE, RSR, KGE, NSE and PBIAS used for the study.Weather Research and Forecasting model's WSM-3 microphysics scheme gave a best possible forecast for Tamil Nadu at 3km resolution, with relatively high Forecast Accuracy Index and Forecast Usability Percentage and virtually perfect Bias Score Frequency [16].

Operational forecasting and meteorological research operations both require verification. The forecast can be verified using RMSE and other methods. Calculating the error structure might be used to validate the forecast [17]. All the regions were having acceptable values for both Kessler and WSM-3 schemes during both SWM and NEM. Distinct regions saw variants, which might be attributable to shifts in the centres of precipitation cloud development, since convective clouds are impacted by adiabatic heating, orography, and moisture advection [18]. Model skill varies with different altitudes accordingly [19].

4. CONCLUSION

The verificationscores for newly released version of WRF model for the five physiographic regions of Tamil Nadu during the two monsoon of the year 2021 with two microphysics options clearly depicts that WSM-3 scheme is providing the better forecast with higher accuracy. All the scores taken for the study such as RMSE, RSR, NSE, KGE and PBIAS favours WSM-3 microphysics scheme. The performance of Kessler scheme wascomparatively lower than WSM-3 in all the five regions. The model gives comparatively better forecast during NEM than SWM and also the accuracy was more or less high in plain region to regions with higher altitude and regions having influence of hills.

REFERENCES

1. Mase AS, Prokopy LS. Unrealized potential: A review of perceptions and use of weather and climate information in agricultural decision making. Weather, Climate, and Society. 2014 Jan 1;6(1):47-61.
2. Topmiller A, Acharya A, Jabari E, Fitzgerald D. Impacts of Climate Change: Regional Increase in Flooding (due to rainfall).
3. Funk CC, Brown ME. Declining global per capita agricultural production and warming oceans threaten food security. Food Security. 2009 Sep;1(3):271-89.
4. Iyer T, Gupta AS. Nowcasting Economic Growth in India: The Role of Rainfall. Asian Development Bank Economics Working Paper Series. 2019 Oct 16(593).
5. Selvaraj RS, Aditya R. Study on Correlation between Southwest and Northeast Monsoon Rainfall over Tamil Nadu. Universal Journal of Environmental Research & Technology. 2011 Dec 1;1(4).
6. Goswami BN. The challenge of weather prediction. weather. 1997 Jan.
7. Bauer P, Thorpe A, Brunet G. The quiet revolution of numerical weather prediction. Nature. 2015 Sep;525(7567):47-55.
8. Chawla I, Osuri KK, Mujumdar PP, Niyogi D. Assessment of the Weather Research and Forecasting (WRF) model for simulation of extreme rainfall events in the upper Ganga Basin. Hydrology and Earth System Sciences. 2018 Feb 8;22(2):1095-117.
9. Sahu SK, Sharma S, Zhang H, Chejarla V, Guo H, Hu J, Ying Q, Xing J, Kota SH. Estimating ground level PM2. 5 concentrations and associated health risk in India using satellite based AOD and WRF predicted meteorological parameters. Chemosphere. 2020 Sep 1;255:126969.
10. Rodrigo C, Kim S, Jung IH. Sensitivity study of WRF numerical modeling for forecasting heavy rainfall in Sri Lanka. Atmosphere. 2018 Sep 28;9(10):378.
11. Mehala M, Dheebakaran G, Panneerselvam S, Ganapati PS, Kokilavani S. Identifying the Best Microphysics Option to Improve Accuracy of Medium Range Rainfall Forecast for Tamil Nadu. Madras Agricultural Journal. 2019 Jun 1;106.
12. Lunagariya MM, Mishra SK, Pandey V. Verification and usability of medium range weather forecast for Anand region. Journal of Agrometeorology. 2009;11:228-33.
13. Zeyaeyan S, Fattahi E, Ranjbar SaadatAbadi A, Azadi M, Vazifedoust M. Evaluating the effect of physics schemes in WRF simulations of summer rainfall in north west Iran. Climate. 2017 Jul 6;5(3):48.
14. Chutia L, Pathak B, Parottil A, Bhuyan PK. Impact of microphysics parameterizations and horizontal resolutions on simulation of “MORA” tropical

cyclone over Bay of Bengal using Numerical Weather Prediction Model. Meteorology and Atmospheric Physics. 2019 Oct;131(5):1483-95.
15. Poorani Selvi S, Dheebakaran G A,Kokilavani S,Geethalakshmi V. Performance of WRF'S Microphysics Options to Increase the Medium Range Rainfall Forecast Accuracy in Tamil Nadu Cauvery Delta Zone. International Journal of Environment andClimate Change. 2020 10 (12), 511-18.
16. DHEEBAKARAN G, GEETHALAKSHMI V, RAMANATHAN S, RAGUNATH K, KOKILAVANI S. WRF's microphysics options on the temporal variation in the accuracy of cluster of village level medium range rainfall forecast in Tamil Nadu. Journal of Agrometeorology. 2022 Apr 27;24(2):133-7.
17. Sridevi C, Singh KK, Suneetha P, Durai VR, Kumar A. Rainfall forecasting skill of GFS model at T1534 and T574 resolution over India during the monsoon season. Meteorology and Atmospheric Physics. 2020 Feb;132(1):35-52.
18. Mugume I, Waiswa D, Mesquita MD, Reuder J, Basalirwa C, Bamutaze Y, Twinomuhangi R, Tumwine F, Otim JS, Ngailo TJ, Ayesiga G. Assessing the performance of WRF model in simulating rainfall over western Uganda. J. Climatol. Weather Forecast. 2017;5(1):1-9.
19. Miglietta MM, Thunis P, Georgieva E, Pederzoli A, Bessagnet B, Terrenoire E, Colette A. Evaluation of WRF model performance in different European regions with the DELTA–FAIRMODE evaluation tool. International Journal of Environment and Pollution. 2012 Jan 1;50(1):83.
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