RESEARCH ARTICLE

Performance of High-Resolution Rainfall Forecast from Weather Research Forecast Model Over Southern Agro Climatic Zone of Tamil Nadu

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ABSTRACT

Weather forecasting become important tool for the planning of everyday farming activities, particularly the medium range weather forecast is highly required to reduce both input and production loss. Tamil Nadu Agricultural University is providing block level medium range weather forecast for next six days with Weather Research Forecast (WRF) Model and having accuracy of 50 -70 per cent, varies with season. An attempt was made at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore during 2019-21 to improve the accuracy of medium range rainfall forecast over different Agro Climate Zones of Tamil Nadu state by increasing the resolution from block level (9 km) to village level (3km) and altering the microphysics options in WRF v 4.2.1. The performance study tested four microphysics schemes *viz*., Kessler, WSM3, WSM5 and WSM6 for all the four seasons of 2020. The results obtained for the Southern Zone (SZ) is discussed in this paper and study concluded that the performance of high resolution village level (3km) rainfall forecast at Southern Agro Climatic Zone of Tamil Nadu generated from WRFv4.2.1 model was best with the WSM3 microphysics scheme followed by Kessler scheme, WSM5 and WSM6. Between the major rainfall seasons, Forecast Accuracy Index (FAI) was higher in NEM (0.56 to 0.73) than SWM (0.38 to 0.70), whereas the Forecast Usability Percent (FUP) was almost similar during both the South West Monsoon (SWM, 53.0 to 81.4) and North East Monsoon (NEM, 52.9 to 85.9). There was over estimation observed irrespective of season and microphysics options.

Keywords: *Medium range weather forecast; WRF; Microphysics; Accuracy; Verification*

INTRODUCTION

Crops require favourable weather conditions to grow and develop normally. The weather during the cropping season has a significant impact on food production unpredictability. In comparison to other sectors of the Indian economy, the agriculture industry is at a high risk to weather. Weather-based response farming is an intellectual decision that reduces the risk of crop production due to weather conditions while also increasing output. Weather forecasting, particularly medium-range forecasting, has become an essential input for daily farm choices in recent years. The numerical weather prediction modelling that almost perfectly mimics atmospheric processes and reduces false alarms and missing. NWP models play a significant role in predicting the global weather forecasts and catastrophic events. There is still scope for enhancing prediction performance by enhancing model aspects such as physics, resolution, and atmosphere-land-ocean coupling.

Presently, numerical weather prediction model "Weather Research and Forecast (WRF)" being used by Tamil Nadu Agricultural University (TNAU) to produce medium range forecasts at the block level of Tamil Nadu and the accuracy of the model varies between 50 and 70 per cent over season and topography. Many reviews in similar line indicated that choosing best microphysics options would improve the forecast performance of WRF model in different season and topography (Mehala *et al*., 2019). In this context a study was carried out during 2019 – 2021 at the Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore

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to identify the best microphysics option in WRF model v 4.2.1 to produce more accurate Medium Range Rainfall Forecast (MRRF) output @ 3km resolution in seven Agro Climate Zone in Tamil Nadu. In this paper, the results pertaining to Southern Agro Climate Zone alone was presented.

MATERIAL AND METHODS

Study Area

Southern Zone (SZ) is one of seven Agro Climatic Zone (ACZ) in Tamil Nadu, located down south of peninsular India, comprising of seven districts *viz*., Dindigul, Madurai, Pudukkottai, Ramanathapuram. Sivagangai, Tenkasi, Tirunelveli, Theni, Tuticorin and Virudhunagar. It is the biggest ACZ of Tamil Nadu, mostly plain in topography, except bordering with western Ghat on the west and coastal area of Bay of Bengal on the East.

The SZ has an average annual rainfall of 776mm received in 43 rainy days and the major rainfall season is NEM. Major crops in this SZ are rice, millets, groundnut, pulses, chillies and coriander. Agriculture in Southern Zone of Tamil Nadu is highly dependent of rainfall, having more than 60 per cent area under rainfed agriculture. North East Monsoon is the chief cropping season and more than 50 per cent of total rainfall is from few unpredictable high intensity rains of cyclone events, where the frequency of drought has shortened almost once in every three years.

Totally seventeen locations where continuous observed data is available for hindcast verification had selected for the WRF forecast performance study in TN, of which spatially well distributed six 6 locations were chosen and pooled for Southern Zone (Figure 1).

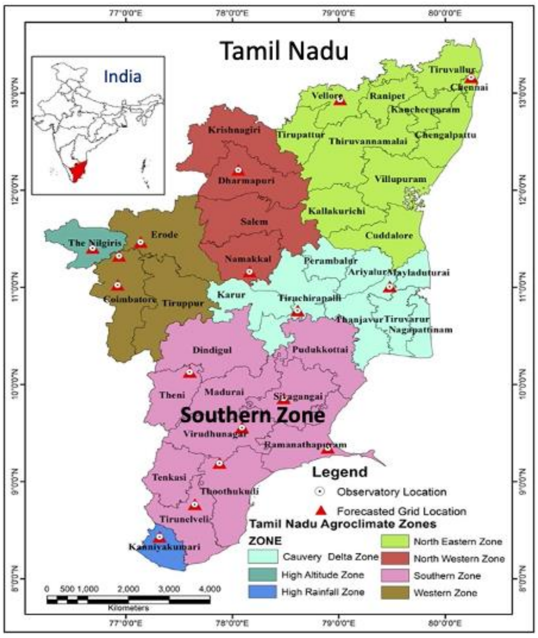
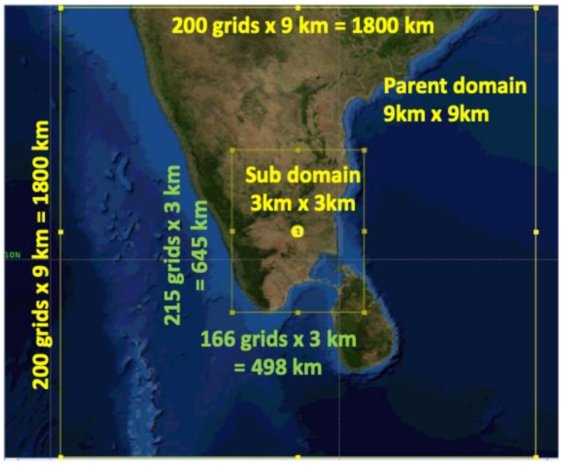


Figure 1. Study area for the medium range rainfall forecast

Forecast model, input and output

The high resolution mesoscale NWP model Weather Research and Forecast (WRFv4.2.1) was used in this study. The six hourly, 12^{tz} and 0.250 GFS data was used as input for the model to generate the forecast for next six days on daily basis. The WRF model was compiled in Linux operating system and run in two nested domain (Figure 2). The parent domain had 200 grids on both NS and EW @ 9 km interval (1800 x 1800 km) and the nested domain had 225 (NS) x 165 (EW) grids @ 3 km interval (645 x 498 km). The final output had generated for 35,640 points (Figure 2), of which six selected locations representing Sothern Zone (SZ) were considered for this paper.

The MRRF was generated daily for all the four season *viz*., Cold Weather Period (CWP, Jan–Feb 2020), Hot Weather Period (HWP, Mar–May 2020), South West Monsoon (SWM, Jun–Sep 2020) and North East Monsoon (NEM, Oct–Dec 2020).



Parent domain - 81 sqkm – 10000 locations – South India
Sub domain - 9 sqkm – 35640 locations – Tamil Nadu

Figure 2. Two nested domain used for WRF model to generate medium range rainfall forecast

Microphysics tested in WRF

The four microphysics options suitable for tropical conditions *viz*., Kessler scheme (warm rain scheme - mp1), WRF single moment 3 class scheme (suitable for mesoscale grid sizes - mp3), WRF single moment 5 class scheme (mixed-phase process and super-cooled water – mp5), and WRF single moment 6 class scheme (suitable for high resolution simulation - mp6) were tested during the study for their performance.

Forecast Verification Methods

Forecast Verification is one of the important methodologies to assess the performance of both the quality and quantity criteria of the forecast. During the study, forecast were generated using all the four microphysics and every day with six lead days for the 366 days of 2020. The forecasts were verified with observed value and the results were pooled seasonally *viz*., CWP, HWP, SWM and NEM 2020. The contingency table with skill scoring method was used for the forecast verification (JWGFVR, 2017). Contingency table showed the frequency of "yes" and "no" forecasts and occurrences. The four combinations of forecasts (yes or no) and observations (yes or no), called the joint distribution, are YY (Hit), NY (miss), YN (False Alarm) and NN (Correct negative) (Table 1).The scores used in this study were viz., Forecast Accuracy Index (FAI), Bias Score Frequency (BSF) and Forecast Usability Percentage (FAP).

Forecast Accuracy Index (FAI) or hit score

FAI is the ratio of correct forecast to the total number of forecast. It varies from zero to one and the one indicates perfect.

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

Bias Score Frequency (BSF)

BSF measures the similarity seen between the mean and observational forecast. Bias score frequency is the ratio between the forecast event frequency and the observed event frequency, which shows whether there is a bias for the forecast system to underestimate the forecast (BIAS<1) or else to overestimate the forecast events (BIAS>1). 1 indicates perfect score. Bias score only measures the relative frequency, but it doesn't evaluate how better the forecast matches the observed one.

$$\text{BSF} = \frac{\text{Hit + False alarms}}{\text{Hit + Misses}} = \frac{\text{YY + YN}}{\text{YY + NY}}$$

Forecast Usability Percentage (FUP)

Daily rainfall of 10mm was taken to be the threshold for differentiating between light and heavy rainfall. If observed rain is less than 10mm then the forecast is found to be correct if the absolute difference (observed – forecast) between the two is less than or equal to 0.2mm. Forecast is usable but not correct if the absolute difference lies between 0.2 and 2.0mm. The forecast is unusable otherwise. If the observed rainfall is more than 10mm then forecast is found to be correct if the absolute difference is less than or equal to 2 per cent of the observed, it is usable but not correct if the absolute difference lies between 2 per cent of the observed and 20 per cent of the observed and is unusable otherwise (Table 2). The results of forecast usability were calculated as below.

$$\text{FUP} = \frac{\text{No. of events with “Correct + Usable”}}{\text{Total number of events}} \times 100$$

RESULTS AND DISCUSSION

Skill scoring results for the performance of village level MRRF produced for next 6 days in the WRF v 4.2.1 model with four microphysics schemes viz., Kessler, WSM3, WSM5, WSM6 during the CWP, HWP, SWM and NEM 2020 for Tamil Nadu are shown in Table 3 and Table 4.

Forecast Accuracy Index (FAI)

In SZ, the FAI of rainfall forecast was ranged between 0.38 and 0.99, which was 0.77 to 0.99, 0.48 to 0.89, 0.38 to 0.70 and 0.56 to 0.73 during CWP, HWP, SWM and NEM, Respectively. Between the two main rainy seasons the FAI value was higher in NEM than SWM. Comparing the microphysics scheme, the higher FAI was with WSM3 followed by Kessler. The WSM3's ice and snow processes had produced perfect forecast for all over Tamil Nadu with mesoscale grid sizes and tropical conditions (Dheebakaran *et al*., 2022). This was also supported with the results of Venkata Rao *et al*. (2020), who suggested to use WSM3 scheme for the best prediction of post-monsoon tropical cyclones. Though the microphysics options produced variation during SWM, the FAI values were similar for Kessler scheme, WSM5 and WSM6 schemes during NEM. Irrespective of microphysics schemes and season, there was an increasing trend in FAI scores from day 1 forecast to day 4 forecast. The WSM5 scheme had lesser forecast accuracy than other microphysics schemes.

Bias Score Frequency (BSF)

In SZ, the BSF scores indicated that the forecast generated were completely over forecasted (1.00 to 4.46), except during HWP when 0.86 was recorded. The NEM showed a perfect forecast (1.00) and maximum over forecast of 2.32. The upper limit of over forecast was very high in SWM than NEM. Among the selected microphysics, the lowest average BSF was observed with WSM3 followed by WSM5, Kessler and WSM6. Hong *et al*. (2006) inferred that the WSM6 (graupel scheme) had overestimated the rainfall events in high resolution grid than low resolution grid.

Compared to the BSF observed with overall Tamil Nadu rainfall forecast by Dheebakaran *et al*. (2022), the BSF of Southern Zone rainfall forecast was higher in all the season i.e. all the four microphysics of WRFv4.2.1 had overestimated the rainfall events in Southern zone.

Table 1 Contingency table for forecast verification

Contingency table		Forecast YES	Forecast NO
Observed	YES	YY - *Hit*	NY - *Miss*
Observed	NO	YN - *False Alarm*	NN - *Correct Negative*

Table 2 Error Structure for verification of quantitative precipitation

Forecast Usability	Difference between forecast and observed value	
	Observed rainfall <=10mm	Observed rainfall > 10mm
Correct	≤ 0.2mm	≤ 2%
Usable	Between 0.2mmand 2.0mm	Between 2%and 20%
Unusable	>2.0mm	>20%

Table 3. Forecast Usability Percentage (FUP) for the lead days of MRWF over Sothern Agro Climatic Zone of Tamil Nadu with different microphysics schemes in WRF 4.2.1

Scheme	Lead Days						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean
CWP 2020							
Kessler	89.3	68.9	65.1	62.8	64.3	63.2	**68.9**
WSM3	95.9	72.6	65.9	66.5	69.6	67.8	**73.0**
WSM5	92.4	63.0	61.1	60.3	62.0	63.4	**67.0**
WSM6	91.9	62.8	59.4	61.0	61.4	61.6	**66.3**
Mean	**92.4**	**66.8**	**62.9**	**62.7**	**64.3**	**64.0**	**68.8**
HWP 2020							
Kessler	73.8	62.2	57.6	55.8	55.4	55.6	**60.0**
WSM3	74.2	62.2	57.1	55.9	57.5	60.8	**61.3**
WSM5	71.9	55.1	50.4	48.3	49.2	47.2	**53.7**
WSM6	72.5	57.4	52.8	52.6	52.0	50.3	**56.3**
Mean	**73.1**	**59.2**	**54.5**	**53.1**	**53.5**	**53.5**	**57.8**
SWM 2020							
Kessler	78.8	66.5	61.5	59.6	59.2	59.4	**64.2**
WSM3	81.4	68.2	62.6	61.3	63.0	66.7	**67.2**
WSM5	80.8	62.0	56.6	54.3	55.3	53.0	**60.3**
WSM6	76.3	60.5	55.6	55.3	54.7	53.0	**59.2**
Mean	**79.3**	**64.3**	**59.1**	**57.6**	**58.1**	**58.0**	**62.7**
NEM 2020							
Kessler	79.3	61.2	57.8	55.8	57.1	56.2	**61.2**
WSM3	85.9	65.0	59.1	59.6	62.3	60.7	**65.4**
WSM5	82.4	56.2	54.5	53.8	55.3	56.5	**59.8**
WSM6	81.9	56.0	52.9	54.3	54.7	54.9	**59.1**
Mean	**82.4**	**59.6**	**56.1**	**55.9**	**57.3**	**57.1**	**61.4**

Table 4. Performance of four microphysics options in WRF on the village level medium range rainfall forecast for the Sothern Agro Climatic Zone of Tamil Nadu Tamil Nadu

FAI	CWP 2020	HWP 2020	SWM 2020	NEM 2020	Mean
Kessler	0.75	0.94	0.57	0.66	**0.73**
WSM3	0.78	0.93	0.61	0.69	**0.75**
WSM5	0.72	0.88	0.55	0.66	**0.70**
WSM6	0.74	0.94	0.54	0.66	**0.72**
Mean	0.75	0.93	**0.57**	**0.67**	**0.73**
Maximum	0.99	0.89	0.70	0.73	**0.83**
Minimum	0.77	0.48	0.38	0.56	**0.55**
BSF					
Kessler	1.57	1.67	2.85	1.73	**1.96**
WSM3	1.17	1.31	2.32	1.34	**1.54**
WSM5	1.28	1.50	2.65	1.48	**1.73**
WSM6	1.66	1.69	3.03	1.75	**2.03**
Mean	1.42	1.54	**2.71**	**1.58**	**1.81**
Maximum	2.32	2.44	4.46	2.32	**2.89**
Minimum	1.00	0.82	1.64	1.00	**1.12**
FUP					
Kessler	60.0	68.9	64.2	61.2	**63.6**
WSM3	61.3	73.0	67.2	65.4	**66.7**
WSM5	53.7	67.0	60.3	59.8	**60.2**
WSM6	56.3	66.3	59.2	59.1	**60.2**
Mean	57.8	68.8	**62.7**	**61.4**	**62.7**
Maximum	95.9	74.2	81.4	85.9	**84.4**
Minimum	59.4	47.2	53.0	52.9	**53.1**

Usability Percentage (Correct + Usable)

In SZ, The FUP of MRWF generated during overall study period was ranged between 46.2 and 95.9 per cent, which was 59.4 to 95.9, 47.2 to 74.2, 53.0 to 81.4 and 52.9 to 85.9 during CWP, HWP, SWM and NEM 2020, respectively. Between the seasons, the average FUP was higher in HWP (68.8) followed by SWM (62.7), NEM (61.4) and CWP (57.8). In comparing the microphysics, the highest average FUP of MRWF was observed with WSM3 (66.7) followed by Kessler (63.6). Moving from day 1 to day 6, the FUP was decreased in all microphysics schemes irrespective of seasons. The results were deviated from the previous study (Mehala *et al*., 2019), where the Kessler scheme performed better than WSM3 scheme (Nov. 1 to No. 15, 2017), may be due to short study period and averaging for whole Tamil Nadu, whereas this study was done for long period 1st Jan to 31st Dec. 2020 and at least minimum of 60 days. As inferred by Sahu *et al*. (2011), both the monsoon seasons (SWM & NEM) had lower average usability than the HWP. Between the major seasons of rainfall, the SWM had higher usability than NEM in SZ. The smaller track error in WSM3 scheme was reason for the best performance as compared to WSM5 and WSM6 schemes, reported by Mahala *et al*. (2015).

CONCLUSION

In all the four seasons, performance of high resolution village level (3km) rainfall forecast at Southern Agro Climatic Zone of Tamil Nadu generated from WRFv4.2.1 model was best with the WSM3 microphysics scheme followed by Kessler scheme, WSM5 and WSM6. Between the major rainfall seasons, Forecast Accuracy Index (FAI) was higher in NEM (0.56 to 0.73) than SWM (0.38 to 0.70), whereas the Forecast Usability Percent (FUP) was almost similar during both the South West Monsoon (SWM, 53.0 to 81.4) and North East Monsoon (NEM, 52.9 to 85.9). There was overestimation was observed irrespective of season and microphysics option.

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Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Originality and plagiarism

Authors should ensure that they have written and submit only entirely original works, and if they have used the work and/or words of others, that this has been appropriately cited. Plagiarism in all its forms constitutes unethical publishing behavior and is unacceptable.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required. If anything is required from the MS, certainly, this will be extended by communicating with the corresponding author through corresponding official mail; gadheebakaran@tnau.ac.in

Author contributions

Research Idea conceptualization-GD and KPR, Experiments –GD, KPR, SK and SP, Guidance– SPR and VG Writing original draft -GD, KPR, SK and SP, Writing- reviewing &editing -GD, SPR and VG.

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