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Research Paper

WRF's microphysics options on the temporal variation in the accuracy of cluster of village level medium range rainfall forecast in Tamil Nadu

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ABSTRACT

Timely and accurate medium range weather information is critical to conquer the impact of highly dynamic next few days' weather on the farming. Advances in weather forecast models, as well as their increased resolution, have resulted in more accurate and realistic forecasts. An attempt was made during 2019 – 2021 at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore to develop cluster of village level (@ 3km resolution) Medium Range Weather Forecast (MRWF) for Tamil Nadu with higher accuracy. In this study, Weather Research and Forecast Model (WRF v4.2.1) with four microphysics *viz*., Kessler, WSM3, WSM5, WSM6 schemes were tested for Tamil Nadu during CWP, HWP, SWM and NEM 2020. The MRWF generated from the WRF model v4.2.1 with WSM3 had better BSF, higher Forecast Accuracy Index (FAI) and Forecast Usability Percent (FUP) for Tamil Nadu followed by Kessler scheme. The WSM5 and WSM6 were poor performer during the study. In general, CWP had higher FAI followed by HWP, NEM & SWM. The FAI from WSM3 was 0.65 - 0.74 during NEM and 0.55 - 0.69 during SWM. Among the season, the MRWF generated during SWM were over forecasted the rainfall quantity, where the NEM and HWP had better rainfall forecast nearing actuals. The FUP was higher in NEM followed by CWP, SWM & HWP, which was 57 – 88 per cent during NEM and 46 – 82 per cent during SWM. A decreasing trend in the quantitative FUP was observed with increase in lead times, irrespective of the microphysics and seasons. Finally, the study concluded that the accuracy of village level medium range rainfall forecasts from WRF model v4.2.1 varied temporally by season and the WSM3 microphysics option having superiority in all seasons.

Keywords: Medium range weather forecast; WRF; microphysics; accuracy; verification.

Weather plays a major role in agriculture and the magnitude of weather events decide the success of the crop production. Weather based response farming promises sustainable productivity and net return by lowering input loss risk and increasing input use efficiency. The response farming is highly dependent on the accurate weather information in advance, at least for a week. Though every region has a unique seasonal climate pattern, the weather over the next few days is highly dynamic, depending on geographical location, topography, and green fractions and other factors. Timely and accurate medium range weather information become critical information for the planning of day today farm activities.

In the era of supercomputing, an operational Numerical Weather Prediction (NWP) model can now reliably predict different seasonal events, especially for homogeneous terrain, with the inclusion of different physical processes and better parameterization techniques. In developed countries, weather forecasting information become a major factor to consider while making agricultural decisions (Ireri & Daisy Mbucu, 2020).

Since 2011, Tamil Nadu Agricultural University (TNAU) is using the "Weather Research and Forecast (WRF)" model to provide medium range forecasts to the farmers at the block level (about 25 km) in Tamil Nadu and the forecast accuracy varies between 50 and 70 per cent, spatially and temporally.

Reviews on previous researches in similar line indicated that altering microphysics options could improve the forecast output accuracy of WRF model (Mehala *et al*., 2019). In this context, an attempt was made during 2019 – 2021 at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore to assess the performance of microphysics options available in WRF model on the accuracy of Medium Range Rainfall Forecast (MRRF) output @ 3km resolution over the different seasons and seven Agro Climatic Zones (ACZ) of Tamil Nadu.

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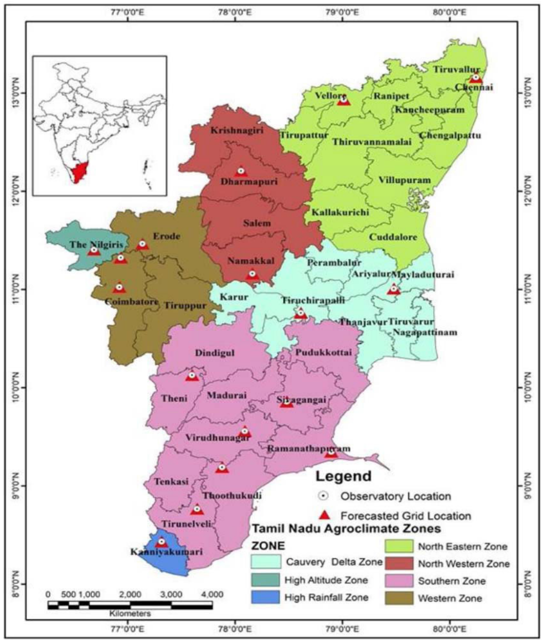

Fig. 1: Study area of cluster of village level weather forecast

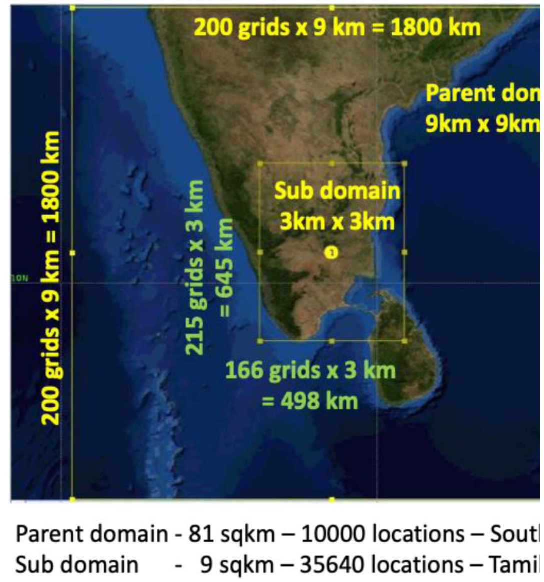

Fig. 2: Two nested domain used for WRF model run to generate medium range rainfall forecast for Tamil Nadu.

MATERILAS AND METHODS

Study area

The focus of the research was to improve the accuracy of high resolution (3km) medium range rainfall forecasting in Tamil Nadu, which is located in southern peninsular India. Agriculture continues to be the primary source of employment in Tamil Nadu, as it is throughout the Indian subcontinent, and a diverse range of crops are grown to take advantage of the varied climate and geography. Tamil Nadu's total geographical area is bounded by latitudes of 8^o 5' N and 13^o 35' N, and longitudes of 76^o 15' and 80^o 20' E.

The state of Tamil Nadu is divided climatically into seven Agro Climate Zones (ACZ), namely the Cauvery Delta Zone (CDZ), High Altitude Zone (HAZ), High Rainfall Zone (HRZ), North Eastern Zone (NEZ), North Western Zone (NWZ), Southern Zone (SZ), and Western Zone (WZ), as well as administratively into 38 districts and 385 blocks. It is surrounded by the Western Ghats, Deccan plains, Bay of Bengal and the Indian Ocean. The main source of water for agriculture and groundwater replenishment is rainfall. During the study, MRRF was generated and verified for seventeen locations at least two in every ACZ of Tamil Nadu (Fig. 1).

Model specification and input data

Weather Research and Forecast (WRF) model is a numerical weather prediction (NWP) system that can be used for atmospheric research as well as operational forecasting. The WRF model version 4.2.1 was used in this study and the GFS data of 0.25^0, 12 hour UTC time step and six hourly interval (0 to 168 hours, totally 28 files, approximately 330 MB each) were downloaded daily and used as input. The WRF model was compiled in two high performance computing servers having Linux operating system and each server was run in two batches to get output with four microphysics options. The WRF model was 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 was generated for 35,640 points, of which seventeen locations distributed over Tamil Nadu were selected and the results were averaged for the study. Forecast were generated for all the days of the year 2020 and grouped in to four seasons viz., CWP (Jan – Feb.2020), HWP (Mar. to May 2020), SWM (Jun. – Sep. 2020) and NEM (Oct. – Dec. 2020). Every day forecast was generated for six lead days.

Microphysics

Based on the reviews, the best four microphysics options suited for tropical conditions viz., Kessler scheme (Kessler), WRF single moment 3 class scheme (suitable for mesoscale grid sizes, WSM3), WRF single moment 5 class scheme (mixed-phase process and super-cooled water, WSM5), and WRF single moment 6 class scheme (suitable for high resolution simulation, WSM6) were used in this study. The Kessler scheme is a warm-rain (i.e., no ice) scheme, WSM3 is an efficient scheme with ice and snow processes, WSM5 is having mixed-phase process with super-cooled water in WSM3 and the WSM6 is having Ice, snow and graupel processes (snow to crystal)

Forecast verification

Forecast verification is the process of assessing the accuracy of forecasts and is an important part of any scientific forecasting system (Lunagariya *et al*., 2009). The temporal variation was tested with the performance of WRF's MRRF during four seasons, CWP, HWP, SWM, and NEM 2020, as well as each lead day (1 to 6 days). Contingency table cum scoring method was used for the forecast verification. Contingency table showed the frequency of "yes" and "no" forecasts and occurrences. The four combinations

Table 1 : Contingency table for forecast verification

Contingency table		Forecast	
		YES	NO
Observed	YES	YY *Hit*	NY *Miss*
	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	0.2-2.0mm	2-20%
Unusable	>2.0mm	>20%

Table 3: Forecast usability percentage (FUP) over the lead days of village level medium range rainfall forecast over 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	82.2	68.4	65.6	65.7	66.4	65.5	69.0
WSM3	84.7	69.1	66.3	66.0	65.2	64.9	69.4
WSM5	83.5	64.2	61.7	62.9	60.8	61.9	65.8
WSM6	83.4	62.8	59.5	60.7	59.0	59.5	64.2
Mean	83.4	66.1	63.3	63.8	62.8	63.0	67.1
			HWP 2020				
Kessler	69.5	54.1	49.3	49.3	47.5	48.3	53.0
WSM3	67.8	54.6	51.3	49.4	48.0	50.2	53.5
WSM5	66.0	47.7	44.1	42.1	41.1	41.5	47.1
WSM6	65.3	48.7	43.4	41.5	39.8	38.8	46.2
Mean	67.1	51.3	47.0	45.6	44.1	44.7	50.0
			SWM 2020				
Kessler	69.2	65.4	56.4	60.9	57.1	57.7	61.1
WSM3	83.3	68.0	64.1	60.3	59.0	61.5	66.0
WSM5	76.3	53.2	49.4	42.3	43.6	43.6	51.4
WSM6	79.5	57.1	52.6	42.3	44.2	43.6	53.2
Mean	77.1	60.9	55.6	51.4	51.0	51.6	57.9
			NEM 2020				
Kessler	77.7	62.0	61.4	59.2	58.2	58.7	62.9
WSM3	88.0	64.7	65.2	60.3	60.3	63.0	66.9
WSM5	77.7	60.9	52.7	57.6	54.4	52.2	59.2
WSM6	79.9	56.0	52.2	54.4	50.0	52.2	57.4
Mean	80.8	60.9	57.9	57.9	55.7	56.5	61.6

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 adopted for this study *viz*., Forecast Accuracy Index (FAI), Bias Score Frequency (BSF) and Forecast Usability Percentage (FUP) were based on the JWGFVR (2017).

Forecast accuracy index (FAI) or hit score

FAI is the ratio of correct forecast to the total number of forecasts. It varies from 0 to 1

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

Bias score frequency (BSF)

The BSF is a metric that assesses the similarity between the mean and the observed forecast. The ratio between the forecast event frequency and the observed event frequency is known as the bias score frequency, and it indicates whether the forecast system is biased to underestimate the prediction (BIAS<1) or overestimate the forecast events (BIAS>1). The 1 indicates perfect score. The bias score just assesses the relative frequency, not how well the forecast

Table 4: Performance of four microphysics options in WRF v 4.2.1 on the village level medium range rainfall forecast for Tamil Nadu

Scheme	CWP 2020	HWP 2020	SWM 2020	NEM 2020	Mean
Forecast accurace index (FAI)					
Kessler	0.93	0.72	0.66	0.68	0.74
WSM3	0.94	0.74	0.67	0.73	0.77
WSM5	0.89	0.70	0.63	0.67	0.72
WSM6	0.90	0.71	0.62	0.67	0.73
Mean	0.91	0.72	0.64	0.69	0.74
Maximum	0.96	0.76	0.69	0.74	0.96
Minimum	0.82	0.62	0.55	0.62	0.55
Bias score frequency (BSF)					
Kessler	1.28	1.18	1.68	1.45	1.40
WSM3	0.99	0.93	1.29	1.10	1.07
WSM5	1.25	1.30	1.87	1.49	1.48
WSM6	1.43	1.44	2.09	1.56	1.63
Mean	1.24	1.21	1.73	1.40	1.39
Maximum	1.87	1.85	2.68	1.99	2.68
Minimum	0.72	0.72	1.00	0.80	0.72
Forecast usable percent (FUP)					
Kessler	69.0	53.0	59.3	65.5	61.7
WSM3	69.4	53.5	63.9	71.8	64.6
WSM5	65.8	47.1	55.6	61.7	57.6
WSM6	64.2	46.2	54.9	61.8	56.8
Mean	67.1	50.0	58.4	65.2	60.2
Maximum	84.7	69.5	82.2	88.4	88.4
Minimum	59.0	38.8	45.9	56.8	38.8

fits the observed data.

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

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

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

RESULTS AND DISCUSSION

Skill scoring results for the 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)

The FAI score for Tamil Nadu (average of all seventeen locations) was 0.55 to 0.96 during the year 2020, ranging from 0.82 to 0.96 during CWP, 0.62 to 0.76 during HWP, 0.55 to 0.69 during SWM, and 0.62 to 0.74 during NEM (Table 4). The CWP had higher FAP followed by HWP, NEM & SWM. Between the major rainfall seasons, NEM had higher FAI than SWM. When comparing the four microphysics schemes, the WSM3 scheme (0.73) had the best average forecast accuracy, followed by the Kessler scheme (0.67), while the WSM5 and WSM6 schemes had the worst forecast accuracy for Tamil Nadu. The ice and snow processes in WSM3 microphysics are well suited to mesoscale grid sizes and tropical conditions. Venkata Rao *et al. (*2020) also supported that the WSM3 scheme can be used as the first best scheme for the prediction of post-monsoon tropical cyclones. The FAI value did not showed any trend over the lead days and fluctuating.

Bias score frequency (BSF)

In Tamil Nadu, the BSF was 0.72 to 2.68, ranging from 0.72 to 1.87 during CWP, 0.72 to 1.85 during HWP, 1.00 to 2.68 during SWM, and 0.80 to 1.99 during NEM (Table 4). The SWM forecast was completely overestimated in all of the four seasons and the NEM had better forecast and more reliable than SWM. Among the microphysics schemes, the average WSM3 was nearly perfect, which was 0.99, 0.93, 1.29 and 1.10 for CWP, HWP, SWM and NEM 2020 respectively. Mostly over forecast were observed with WSM6 in all the seasons. In a heavy rainfall event simulation, the graupel (WSM6) is similar to simple (WSM3) and mixed phase (WSM5) at low-resolution grid; however, in a high-resolution grid, the rainfall increases with strong intensity as the number of hydrometeors increases. (Hong *et al*., 2006). The BSF value showed decreasing trend with lead days from 1 to 6. Thus for overall TN the BSF was better performed with WSM3 scheme followed by the Kessler scheme and NEM rainfall forecast was more reliable compared to SWM.

Usability percentage (Correct + Usable)

The FUP of Tamil Nadu village level MRRF generated with selected microphysics was ranged between 38.8 and 88.4 per cent, ranging from 59 to 84.7 during CWP, 38.5 to 69.5 during HWP, 45.5 to 82.8 during SWM, and 56.8 to 88.4 during NEM (Table 4). Between the seasons, overall average FUP was higher in NEM followed by CWP, SWM and HWP. Report of Sahu *et al*., (2011) stated that the monsoon season recorded the lowest per cent of usability varying from 29 per cent in 2007 to as high as 90 per cent in the year 2002. But in this study, the NEM, which was major monsoon season of Tamil Nadu had higher usability than SWM. In Comparing the microphysics, FUP was better generated with WSM3 scheme (64 - 72%) and Kessler scheme (53 - 69%). Poor performance of FUP was found with WSM5 (47 - 56%) and WSM6 (46 – 64%) scheme. The results were deviated from previous study of Mehala *et al*., (2019), where the Kessler scheme performed better than WSM3 scheme (Nov. 1 to Nov. 15, 2017), may be due to short study period, whereas this study was done for long period of entire year 2020. Mahala *et al*., (2015) also reported that there was smaller track error in WSM3 scheme as compared to other schemes such as LIN, WSM5, FER, WSM6, TG, WDM5, WDM6 schemes. The FUP of village level MRRF in Tamil Nadu was decreased from day 1 to day 6 in all microphysics schemes irrespective of seasons.

CONCLUSION

The performance study of four microphysics schemes *viz*., Kessler, WSM3, WSM5 and WSM6 inferred that the WSM3 in WRF produced better forecast @ 3km resolution for TN with higher FAI and FUP and nearly perfect BSF, followed by Kessler scheme. The WSM 5 and WSM 6 were poor performer with low FAI, BSF and completely over forecasted. Among the seasons, forecast was better in CWP, NEM, SWM and HWP. A decreasing trend in FUP was observed with increase in lead times, irrespective MP and seasons. Finally, the study concluded that the accuracy of village level medium range rainfall forecasts from WRF model v4.2.1 varied temporally by season and the WSM3 microphysics option having superiority in all seasons.

Conflict of Interest Statement: The author (s) declares (s) that there is no conflict of interest.

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