



## **Performance of WRF'S Microphysics Options to Increase the Medium Range Rainfall Forecast Accuracy in Tamil Nadu Cauvery Delta Zone**

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### **Authors' contributions**

*This work was carried out in collaboration among all authors. Author SPS carried out the verification of output, wrote the protocol and the first draft of the manuscript. Author GAD generated the forecast outputs. Authors SK and VG defined the methodology of research and verification part. All authors read and approved the final manuscript.*

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### **ABSTRACT**

Weather plays a significant role in agricultural sector and the favourable weather enhance the opportunities and sustainability for crop production. Agriculture oriented Medium Range Weather Forecasts (3 – 10 days), particularly rainfall information in a week advance helps the farmers to overcome the aberrant weather conditions, reduces both input and output loss, thereby warranted higher benefit – cost ratio and net income. An attempt was made to improve the accuracy of medium range rainfall forecast (6 days) at Cauvery Delta Zone, the rice bowl of Tamil Nadu state, during South West Monsoon (June – Sep. 2020) and North East Monsoon (Oct. – Dec. 2020). The performance study of four microphysics schemes in WRF viz., Kessler, WSM3, WSM5 and WSM6 concluded that the WSM3 scheme produced more accurate forecast in Tamil Nadu's Cauvery Delta Zone (CDZ) during both the South West Monsoon (SWM) and North East Monsoon (NEM). The 2<sup>nd</sup> better choice was the Kessler scheme, where the WSM5 and WSM6 were bad performers in CDZ. The forecast usability was decreased with increasing lead time, irrespective of season and microphysics. Among the seasons forecast accuracy and usability were higher in NEM than SWM.

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## 1. INTRODUCTION

Agriculture has been the cornerstone of our Indian economy since 9000 BC and accounts for 14 per cent of gross domestic product and provides 42 per cent employment to the Indian population (Trading Economic, 2020). Tamil Nadu is having about seven million hectare of cultivable area and about 45 per cent comes under rainfed agriculture (3 mha), in which farming is the gamble of weather. Weather plays a significant role in agriculture and the optimum during the cropping season brings a positive relationship on yield. In developed countries, weather forecasting information become major factor to be considered for making decision on agriculture [1]. To resolve problems by changing weather, much efficient and upgraded methods are required for forecasting of weather [2].

Numerical Weather Prediction models are currently used for the development of weather forecasts, which include complicated atmospheric process mathematical calculations and no single scheme can produce better results in all locations and each scheme has its own predictive powers [3]. Weather Research and Forecast (WRF) model is anregional mesoscale advanced research model that provides Medium Range Weather Forecast (MRWF) at higher resolution [4]. The accuracy, reliability and compatibility of the MRWF should be checked for the benefit of farmers [5]. Microphysics plays an important role in Numerical Weather Prediction. These perform differently with different cloud and weather system. Thus validation of microphysics with different cloud types and regions is important [6].

In Tamil Nadu, the Cauvery Delta Zone is a lower riparian and heavily reliant on neighbouring states for water. A timely and detailed rainfall forecast enables farmers to make correct decisions about farm operations. Since 2011, the numerical weather prediction model "Weather Research and Forecast (WRF)" has been used by Tamil Nadu Agricultural University (TNAU) to produce medium range forecasts at the block level (approx. 25 km) of Tamil Nadu and the accuracy of the model varies between 60 and 80 percent spatially and temporally. Reviews on previous researches in similar line indicated that altering microphysics options could improve the

forecast output accuracy of WRF model [7]. Hence, an experiment was carried out at the Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore to assess the performance of microphysics options available in WRFv4.2.1 on the accuracy of MRWF rainfall output @ 3km resolution in seven Agro Climate Zone in Tamil Nadu. In this paper, the results pertaining to the Cauvery Delta Zone alone presented and discussed.

## 2. MATERILAS AND METHODS

### 2.1 Experimental Location

Cauvery Delta Zone is located in the central part of Tamil Nadu, geographically spread from 10° 02' N to 11° 30' N latitudes and from 78° 15' E to 79° 45' E Longitudes comprising of seven districts viz., Cuddalore, Nagapattinam, Perambalur, Pudukottai (Part), Thanjavur, Tiruchirappalli, Thiruvarur districts, receiving a mean rainfall of 984mm in 45 days and is mainly benefited from NEM rainfall. The mean annual PET of this zone is 1932mm compared to the normal annual precipitation of 984mm. The mean maximum and minimum temperature prevailing in this zone are 27°C to 38°C and 19°C to 27°C. The altitude ranges between 100-200m above mean sea level. Rice is the most predominant crop cultivated in this zone, the other crops are sugarcane, banana Sorghum and groundnut. Red Loamy and alluvium soils are the major soils found in this zone.

### 2.2 Model Specification and Input Data

The Weather Research and Forecast (WRF) model is a numerical weather prediction (NWP) system designed to serve both atmospheric research and operational forecasting needs. The latest WRF model version 4.2.1 is used in this study. Numerical Weather models require real time data from AWS for accurate forecast [8]. In this study, 12 hour UTC time step GFS data at six hourly interval (0 to 162 hours, totally 28 files, approximately 330 MB each) was downloaded daily for the two monsoon seasons, SWM (Jun – Sep 2020) and NEM (Oct – Dec 2020). Two Dell Servers (R 820) installed with Centos (version 8.1) operating system were used for the running and compilation of the model.

## 2.3 Selected Microphysics

Based on the previous research reviews the best four microphysics options suited 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 used in this study.

## 2.4 Medium Range Rainfall Forecast

During the study, WRF forecast output was generated and verified for two locations in CDZ viz., Tamil Nadu Rice Research Institute (TRRI), Aduthurai, Thanjavur district and Agricultural Engineering College and Research Institute (AEC&RI), Kumulur, Tiruchirappalli district, where continuous observed daily rainfall data is available.

## 2.5 Forecast Verification Methods

Forecast Verification is the process and practice of determining the quality of forecasts, and it represents an essential component of any scientific forecasting system. These methods serves for different purposes like assessing the state of art of forecasting, recent trends in forecasting and improving the forecasting quality [9]. Forecast generated for next six days were pooled seasonally viz., SWM and NEM 2020and the temporal variation in the accuracy of the forecast for each lead day (1 to 6 days) is verified for two location separately. Then the results of both the locations were pooled and presented as single value for CDZ in this paper.

Contingency table cum scoring method was used for the forecast verification. Contingency table showed the frequency of "yes" and "no" forecasts and occurrences. The scores adopted for this study were viz., FAI, BSF, POD, FAR, POFD, CSI, RMSE, HKD and usability percentage. The forecast can be validated by calculating the error structure [10].

### 2.5.1 Forecast accuracy index (FAI) or hit score

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

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

### 2.5.2 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.

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

### 2.5.3 Probability of Detection (POD)

POD ignores the false alarms but is sensitive to hits. The POD value ranges from 0 to 1 and 1 indicates perfect score.

$$\text{Probability of detection} = \frac{\text{Hit}}{\text{Hit} + \text{Misses}} = \frac{YY}{YY + NY}$$

### 2.5.4 False Alarm Ratio (FAR)

FAR excludes misses but more sensitive to false alarms and events of climatological frequency. This can be used along with POD. The ratio value ranges from 0 to 1 where, 0 represents perfect score.

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

### 2.5.5 Probability of False Detection (POFD)

POFD ignores misses and sensitive to false alarms. It can be artificially improved by giving fewer "yes" forecasts in order to reduce the number of false alarms. The POFD value ranges from 0 to 1 and 0 indicates perfect score.

$$\text{Probability of False Detection (POFD)} = \frac{\text{False Alarms}}{\text{Correct Negatives} + \text{False alarms}} = \frac{YN}{NN + YN}$$

**Table 1. Contingency table**

Contingency table		Forecast	
		Yes	No
Observed	Yes	YY <i>Hit</i>	NY <i>Miss</i>
	No	YN <i>False Alarm</i>	NN <i>Correct Negative</i>

**2.5.6 Critical Success Index (CSI) or threat score**

CSI is a verification measure of categorical forecast performance equal to the total number of correct event forecasts (hits) divided by the total number of forecasts plus the number of misses (hits + false alarms + misses). The index value ranges from 0 to 1, where 0 indicates no skill and 1 indicates perfect score.

$$\text{Critical Success Index} = \frac{\text{Hit}}{\text{Hit} + \text{False Alarm} + \text{Misses}} = \frac{YY}{YY + YN + NY}$$

**2.5.7 Hanssen and Kuiper’s Discriminant (HKD) or true skill statistic or peirce’s skill score**

HKD utilizes all the components in the contingency table. The expression is similar to HK = POD - POFD, but it is also feasible to represent the HK score as (event accuracy) + (non-event accuracy) - 1. This score could be more useful for more frequent occurrences. The value of HK score ranges between -1 to 1, where 0 indicates no skill and 1 indicates perfect HK score.

$$\text{HK score} = \frac{\text{Hit}}{\text{Hits} + \text{Misses}} + \frac{\text{False Alarms}}{\text{False Alarms} + \text{Correct Negative}} - \frac{YN}{YY + YN}$$

**3. RESULTS AND DISCUSSION**

Skill scoring results for the medium- range rainfall forecast produced with four microphysics schemes in the WRF model, viz., Kessler, WSM3, WSM5, WSM6 during the SWM and NEM for Cauvery Delta Zones (CDZ) are shown in Table 2.

**3.1 Forecast Accuracy Index (FAI)**

The FAI of rainfall forecast generated during the study was ranged between 0.44 – 0.79, which was 0.44 to 0.77 during SWM and 0.59 to 0.79 during NEM. Between the season, the FAI was higher in NEM (0.78) than SWM (0.71). Among the microphysics schemes, highest average FAI was observed with WSM3 scheme (0.78) followed Kessler scheme (0.74). The WSM5 and WSM 6 had poor performance in all spatial and temporal verification. Compared to day 1 forecast the day 6 forecast had higher FAI due to more number NN (Not forecasted and not observed).

**3.2 Bias Score Frequency (BSF)**

The BSF indicated that the forecast generated during SWM had both under forecast (0.86) and over forecast (3.19), whereas the NEM forecast were completely over forecasted (1.15 to 2.37). The upper limit of over forecast was very high in SWM than NEM. Among the selected microphysics, highest average BSF was observed with WSM6 (2.71) followed by WSM5 (2.46). Kessler scheme (1.54) and WSM3 (1.46) schemes showed lesser BSF during both the seasons, which is required character of a forecast. Moving from day 1 forecast trend. The results indicated that the WSM3 scheme may produce better forecast followed by Kessler scheme and the rainfall forecast for NEM was more reliable than SWM.

**3.3 Probability of Detection (Hit Rate)**

During SWM, the POD values of forecast verification was ranged between 0.46 and 1.00, while they ranged between 0.72 and 1.00 during NEM. The highest average POD rate was observed with WSM6 followed by the WSM5. The POD values of Kessler scheme and WSM3 were lesser during both the seasons. The

Table 2. Forecast verification scores for different microphysics schemes in WRF 4.2.1 over Cauvery Delta Zone of Tamil Nadu

Scheme	South West Monsoon							North East Monsoon						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean
<b>Forecast Accuracy Index</b>														
Kessler	0.61	0.76	0.70	0.74	0.69	0.70	0.70	0.70	0.76	0.73	0.75	0.76	0.74	0.74
WSM3	0.63	0.77	0.72	0.74	0.68	0.72	0.71	0.73	0.78	0.78	0.79	0.79	0.79	0.78
WSM5	0.44	0.59	0.56	0.56	0.56	0.54	0.54	0.59	0.68	0.68	0.77	0.70	0.70	0.69
WSM6	0.46	0.58	0.58	0.56	0.54	0.58	0.55	0.65	0.64	0.67	0.74	0.68	0.69	0.68
Mean	0.54	0.68	0.64	0.65	0.62	0.64	0.63	0.67	0.72	0.72	0.76	0.73	0.73	0.72
<b>Bias Score frequency</b>														
Kessler	2.24	1.63	1.71	1.59	1.63	1.56	1.73	1.88	1.51	1.53	1.51	1.42	1.38	1.54
WSM3	1.76	1.24	1.19	1.05	0.86	1.00	1.18	1.89	1.51	1.50	1.39	1.33	1.15	1.46
WSM5	2.86	2.38	2.43	2.52	2.19	2.38	2.46	2.37	1.68	1.84	1.50	1.64	1.69	1.79
WSM6	3.19	2.71	2.62	2.71	2.57	2.48	2.71	2.20	1.72	1.94	1.72	1.79	1.79	1.86
Mean	2.51	1.99	1.99	1.97	1.81	1.86	2.02	2.09	1.61	1.70	1.53	1.55	1.50	1.66
<b>Probability of deduction (Hit rate)</b>														
Kessler	0.88	0.85	0.78	0.81	0.73	0.71	0.79	0.93	0.85	0.81	0.83	0.80	0.76	0.83
WSM3	0.98	0.70	0.68	0.71	0.46	0.56	0.68	0.98	0.89	0.87	0.83	0.81	0.72	0.85
WSM5	0.95	0.88	0.90	0.88	0.81	0.80	0.87	0.98	0.80	0.87	0.85	0.80	0.83	0.86
WSM6	1.00	0.93	0.95	0.93	0.83	0.88	0.92	1.00	0.74	0.91	0.92	0.85	0.87	0.88
Mean	0.95	0.84	0.83	0.83	0.71	0.74	0.82	0.97	0.82	0.87	0.86	0.82	0.80	0.85
<b>False Alarm ratio</b>														
Kessler	0.61	0.47	0.54	0.49	0.55	0.54	0.53	0.51	0.43	0.47	0.45	0.44	0.45	0.46
WSM3	0.56	0.45	0.50	0.47	0.57	0.52	0.51	0.48	0.41	0.42	0.40	0.39	0.38	0.41
WSM5	0.69	0.62	0.63	0.64	0.65	0.66	0.65	0.56	0.51	0.52	0.43	0.51	0.50	0.51
WSM6	0.67	0.61	0.62	0.63	0.65	0.63	0.64	0.55	0.57	0.53	0.46	0.53	0.51	0.53
Mean	0.63	0.54	0.57	0.56	0.61	0.59	0.58	0.53	0.48	0.49	0.44	0.47	0.46	0.48
<b>Probability of false detection</b>														
Kessler	0.49	0.28	0.33	0.28	0.32	0.30	0.33	0.40	0.28	0.30	0.29	0.26	0.26	0.30
WSM3	0.49	0.21	0.27	0.25	0.24	0.23	0.28	0.38	0.26	0.26	0.23	0.22	0.18	0.26
WSM5	0.75	0.51	0.56	0.55	0.52	0.56	0.58	0.57	0.36	0.40	0.27	0.35	0.35	0.38
WSM6	0.73	0.54	0.56	0.57	0.56	0.52	0.58	0.50	0.41	0.43	0.33	0.39	0.39	0.41
Mean	0.62	0.39	0.43	0.41	0.41	0.40	0.44	0.46	0.33	0.35	0.28	0.31	0.30	0.34
<b>Critical Success Index</b>														
Kessler	0.37	0.49	0.41	0.45	0.39	0.39	0.42	0.47	0.52	0.47	0.50	0.49	0.47	0.49
WSM3	0.43	0.45	0.41	0.42	0.28	0.34	0.39	0.51	0.54	0.54	0.53	0.53	0.51	0.53
WSM5	0.31	0.36	0.35	0.35	0.33	0.31	0.34	0.43	0.43	0.45	0.52	0.44	0.45	0.45

Scheme	South West Monsoon							North East Monsoon						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Mean
WSM6	0.33	0.38	0.37	0.36	0.33	0.36	0.36	0.45	0.37	0.45	0.52	0.44	0.45	0.45
Mean	0.36	0.42	0.39	0.40	0.33	0.35	0.37	0.47	0.47	0.48	0.52	0.48	0.47	0.48
<b>Hanssen &amp; Kuiper's index</b>														
Kessler	0.39	0.58	0.45	0.53	0.41	0.40	0.46	0.52	0.57	0.51	0.55	0.53	0.50	0.53
WSM3	0.49	0.50	0.41	0.46	0.22	0.34	0.40	0.60	0.62	0.61	0.60	0.60	0.54	0.60
WSM5	0.20	0.37	0.35	0.33	0.28	0.25	0.30	0.42	0.44	0.47	0.58	0.45	0.48	0.47
WSM6	0.27	0.39	0.39	0.35	0.27	0.35	0.34	0.50	0.33	0.48	0.59	0.46	0.48	0.47
Mean	0.34	0.46	0.40	0.42	0.30	0.34	0.37	0.51	0.49	0.52	0.58	0.51	0.50	0.52
<b>Usability percentage of forecast (Correct + Usable)</b>														
Kessler	69.2	65.4	56.4	60.9	57.1	57.7	61.1	77.7	62.0	61.4	59.2	58.2	58.7	62.9
WSM3	83.3	68.0	64.1	60.3	59.0	61.5	66.0	88.0	64.7	65.2	60.3	60.3	63.0	66.9
WSM5	76.3	53.2	49.4	42.3	43.6	43.6	51.4	77.7	60.9	52.7	57.6	54.4	52.2	59.2
WSM6	79.5	57.1	52.6	42.3	44.2	43.6	53.2	79.9	56.0	52.2	54.4	50.0	52.2	57.4
Mean	77.1	60.9	55.6	51.4	51.0	51.6	57.9	80.8	60.9	57.9	57.9	55.7	56.5	61.6

reason could be more YY (forecast and observed) than two other microphysics options due to more days with rainfall forecast in WSM 6 and WSM 5. The POD values were decreased with lead days, irrespective of microphysics schemes.

### 3.4 False Alarm Ratio (FAR)

The overall FAR values ranged between 0.38 to 0.69, where the lowest value observed during NEM and highest value observed during SWM. Among the microphysics, highest average FAR was observed with WSM5 (0.65) followed by WSM6 (0.64), whereas Kessler scheme (0.46 – 0.53) and WSM3 (0.41 – 0.51) had lower FAR. Compared to day 1 forecast, the day 6 forecast had higher FAR. The FAR results confirmed that the NEM forecast was better than SWM and the WSM3 scheme performed better in generating reliable forecast.

### 3.5 Probability of False Detection (False Alarm Rate)

The overall POFD was between 0.18 and 0.75, which was 0.21 – 0.75 found during SWM, while the POFD values were between 0.18 and 0.57 for the NEM. Between the two seasons, POFD was higher in SWM than NEM. Among the microphysics options, highest average POFD was observed with WSM6 and WSM5 scheme. The lower POFD values of WSM3 scheme ensured the higher accuracy in rainfall forecast from WSM3 scheme. The increasing trend of POFD from day 1 to day 6 indicated the increasing false alarm with increasing lead time.

### 3.6 Critical Success Index (Threat Score)

The overall CSI was ranged between 0.28 to 0.54, which was 0.28 to 0.49 during the SWM, whereas ranged between 0.37 and 0.54 for NEM. CSI value. Comparing the season, CSI was higher in NEM (0.59) followed by SWM (0.42). The highest average CSI was observed with WSM3 (0.59) followed by Kessler scheme (0.49). The CSI value was highly fluctuated with the lead time.

### 3.7 Hanssen and Kuiper's Discriminant (HKD)

The overall HKD score was ranged between 0.20 to 0.62, which was 0.20 to 0.58 with SWM,

and varied between 0.33 and 0.62 in NEM. Between the season, the average HKD was higher in NEM (0.60) than SWM (0.46). The highest average HKD score was observed with WSM3 (0.60) followed by the Kessler scheme (0.53). Similar to CSI, the HKD also fluctuated widely with lead time and could not conclude better lead time.

### 3.8 Usability Percentage (Correct + Usable)

The overall usability of medium range rainfall forecast generated with the selected microphysics options were ranged between 42.3 and 88.0 per cent. During SWM, the usability of forecast was varied between 42.3 and 83.3, whereas it was little higher in NEM (50 to 88.0) and the average forecast usability per cent was higher in NEM (61.6) than SWM (57.9). Among the four microphysics, WSM3 scheme performed better and recorded higher usability per cent of 66.9 (SWM) and 66.0 (NEM) followed by Kessler scheme. Least usability were observed with WSM5 and WSM6 in both SWM and NEM seasons. The usability per cent was decreased from day 1 to day 6 in all the microphysics scheme irrespective of seasons. The results were deviated from previous study [10], 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 from July 15<sup>th</sup> to Dec.31, 2020 and specific to Cauvery Delta Zone. A study on the usability of rainfall forecast reported that the monsoon season when more rainfall was received recorded the lowest percent of usability varying from 29 per cent in 2007 to as high as 90 per cent in the year 2002 and concluded that the usability percentages were higher and RMSE values were lower in the low rainfall years and vice-versa at Junagadh [11]. But during this study, the NEM, which was major monsoon season of Tamil Nadu had higher usability than SWM.

## 4. CONCLUSION

The performance study of four microphysics schemes in WRF viz., Kessler, WSM3, WSM5 and WSM6 concluded that the WSM3 scheme performed better in Tamil Nadu's Cauvery Delta Zone (CDZ) during both the South West Monsoon (SWM) and North East Monsoon (NEM). The 2<sup>nd</sup> better choice was the Kessler scheme, where the WSM5 and WSM6 were bad

performers in CDZ. The forecast usability was decreased with increasing lead time, irrespective of season and microphysics. Among the seasons forecast accuracy and usability were higher in NEM than SWM.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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