MAUSAM, **67**, 4 (October 2016), 829-840

551.509.313.5

Verification of district level weather forecast

N. CHATTOPADHYAY, S. K. ROY BHOWMIK*, K. K. SINGH*, K. GHOSH and K. MALATHI

India Meteorological Department, Pune – 411 005, India

**India Meteorological Department, New Delhi – 110 003, India*

(*Received 21 April 2015, Accepted 22 January 2016*)

e mail : nabansu.nc@gmail.com

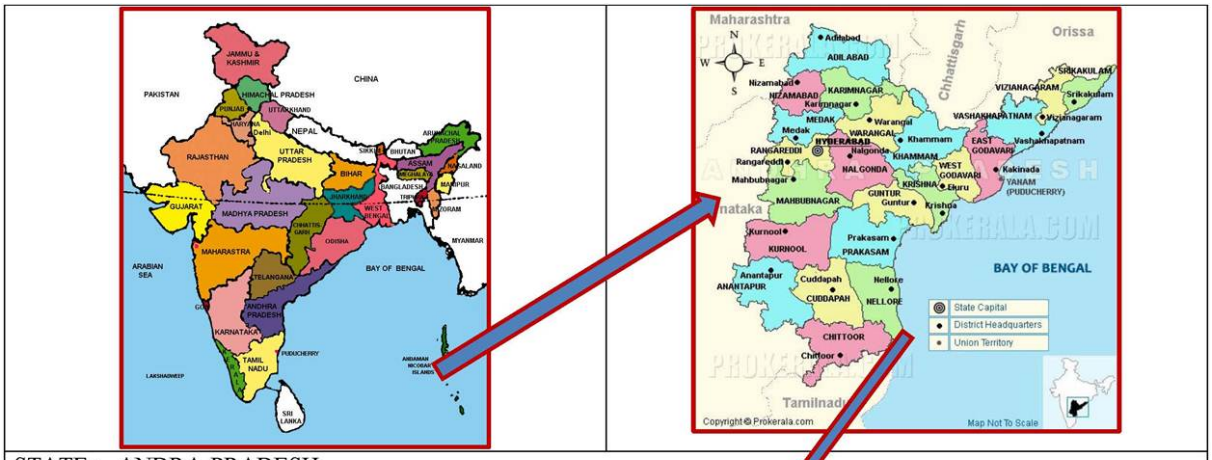
सार – भारत मौसम विज्ञान विभाग ने 1 जून, 2008 से प्रचालनात्मक आधार पर 5 दिनों का मात्रात्मक जिला स्तर मौसम पूर्वानुमान देना प्रारंभ कर दिया है। इन उत्पादों में सात मौसम प्राचलों अर्थात वर्षा, अधिकतम और न्यूनतम तापमानों, पवन गति और दिशा, सापेक्षिक आर्द्रता और मेघमयता के लिए मात्रात्मक पूर्वानुमान शामिल है। बहु निदर्श-समुच्चय तकनीकों (MME) के आधार पर वर्षा के पुर्वानुमान तैयार किए जाते हैं। अन्य प्राचलों के लिए ECMWF पूर्वानुमानों (वर्तमान में IMDGFS) का उपयोग किया गया। इन पूर्वानुमान उत्पादों को MCs/RMCs द्वारा वेल्यू एडिड किया गया और मौसम आधारित जिला कृषि मौसम परामर्शी सेवा बुलेटिन तैयार करने के लिए 130 कृषि मौसम वैज्ञानिक फील्ड एककों (AMFUs) को भेजे गए। यह मौसम वैज्ञानिक मोनोग्राफ वर्ष 2012-14 के शीतकाल और ग्रीष्मकाल में मॉनसून और तापमान के दौरान भारत के विभिन्न भागों में हुई वर्षा के प्रचालनात्मक जिला स्तर मौसम पूर्वानुमानों के निष्पादन कौशल को बताता है। यह मोनोग्राफ MME मॉडलों के आगे और सुधार के लिए भावी उद्देश्य और सीमा नियंत्रण की विशेषताओं को भी बताता है। सत्यापन परिणामों से पता चलता है कि मौसम पूर्वानुमान पर्याप्त रूप से सही है और वैल्यू एडिशन से मॉडल पूर्वानुमान की सटीकता में सुधार हुआ है। हालांकि MME मॉडल उत्तर के पर्वतीय क्षेत्रों में मौसम की प्रागुक्ति कर सकता है किन्तु पर्वतीय क्षेत्रों वाले अन्य भागों में तापमान का सही पूर्वानुमान नहीं लगा पाते हैं। देश के उत्तर पूर्वी क्षेत्र से गर्म, आर्द्र ग्रीष्मकाल, प्रचंड मॉनसूनों और सुहावने शीतकाल मौसम के साथ इनके प्रबलीय आर्द्र उप - उष्णकटिबंधी जलवायु के कारण मौसम की बहुत कम सटीकता दर्शाता है।

ABSTRACT. IMD started issuing quantitative district level weather forecast upto 5 days on operational basis from 1st June, 2008. The products comprise of quantitative forecasts for seven weather parameters, *viz*., rainfall, maximum and minimum temperatures, wind speed and direction, relative humidity and cloudiness. The rainfall forecast is generated based on multi model-ensemble techniques (MME). For other parameters, ECMWF forecasts (presently IMDGFS) are used. These forecast products are further value added, by the respective MCs/RMCs and forwarded to 130 Agrometeorological Field Units (AMFUs) for preparation of weather based District Agromet Advisory Service bulletin. This Meteorological Monograph describes the performance skill of the operational district level weather forecasts over different parts of India rainfall during monsoon and temperature during winter and summer from 2012-14. The Monograph also highlights limitations and future scope for further improvement of the MME models. The verification results show weather forecasts are reasonably accurate and value addition has improved the accuracy of model forecast. Though the MME model could predict the weather in hill regions in the North but in other regions having some hilly areas, the same could not come true in respect of temperature. North East region of the country shows very less accuracy due to its predominantly humid sub-tropical climate with hot, humid summers, severe monsoons and mild winter.

Key words – NWP model, Multi-model ensemble, District level weather forecast, Indian summer monsoon, Medium range quantitative forecasts, Gramin Krishi Mausam Sewa.

1. Introduction

There has been long demand from the user community for district level quantitative weather forecasts in short to medium range time scale. Considering need of farming sector, India Meteorological Department (IMD) has upgraded the Agro-Meteorological Advisory Service from agro climate zone to district level because of high spatial variability of different weather parameters at district level which have direct impact on crop growth and to generate crop and location specific advisories. As a major step, IMD started issuing quantitative district level weather forecast upto 5 days from 1st June, 2008 based on multi model-ensemble (MME) technique upto 5 days [Rathore, *et al*., 2011; Roy Bhowmik, *et al*., 2012] for preparation of District Level Agromet Advisories. The



STATE : ANDRA-PRADESH

PARAMETERS — ENSEMBLE FCST

	DAY-1 29/12	DAY-2 30/12	DAY-3 31/12	DAY-4 01/01	DAY-5 02/01
DISTRICT : SRI-KAKULAM					
Rainfall (mm)	0	0	0	0	0
Max Temperature (deg C)	27	28	27	27	27
Min Temperature (deg C)	9	10	10	10	10
Total cloud cover (octa)	3	2	2	0	0
Max Relative Humidity (%)	63	73	73	86	85
Min Relative Humidity (%)	27	27	28	30	34
Wind speed (kmph)	004	004	002	003	004
Wind direction (deg)	331	233	31	56	296

Fig. 1. District level weather forecast

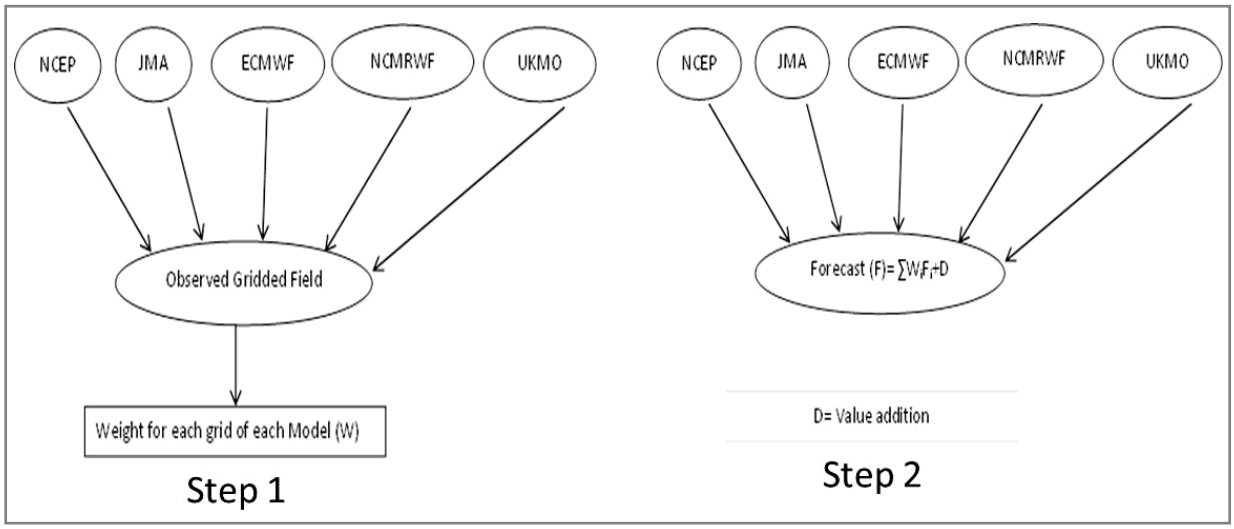


Fig. 2. Generation of forecast using MME model

products comprise of quantitative forecasts for 7 weather parameters, *viz*., rainfall, maximum and minimum temperatures, wind speed and direction, relative humidity and cloudiness. These forecast products are generated by National Weather Forecasting Centre, IMD, New Delhi and further value added by the respective RMCs / MCs and communicated to 130 Agrometeorological Field Units for preparation of district level advisories. The value

addition to the MME forecast is done manually by considering the climatology of the region, products of other NWP models, prevailing synoptic condition of the region & neighbourhood, satellite imageries on the day of forecast, DWR products on the day of forecast and knowledge gathered by comparing MME forecast with the observed data in the previous years. As the quality of agromet advisories depends on accurate weather forecast, there is a need to verify the forecast. Forecast verification serves the role of identifying the accuracy of forecasts, with the goal of improving future predictions and also emphasizes accuracy and skill of prediction. The issue of district level weather forecast particularly in respect of rainfall and other parameters are extremely challenging particularly in the monsoon period and minimum temperature in the winter months. IMD issues 647 district level weather forecasts daily for different weather parameters as shown in Fig. 1. The flow diagrams of forecast preparation and subsequent dissemination to AMFUs are given in Fig. 1.

2. Multi-model ensemble technique

Multi-model ensemble samples the uncertainty in the model initial condition (*via* the different observational data, assimilation and initialization methods, lateral boundary conditions for the regional models) and model formulation (*via* the variety of model physical parameterization, numeric and resolution). It avoids the problem of systematic bias that occurs when a single model is used. (Krishnamurti, *et al*., 1999) Due to the differences in model formulation, each model has its own relative strength and weakness in respect to prevailing synoptic, geographic and orographic conditions, with no model clearly superior to the others. Five NWP models were considered for this development work are: (*i*) National Centre for Medium Range Weather Forecasting (NCMRWF) (presently it uses IMD GFS T-574/L64), (*ii*) European Centre For Medium Range Weather Forecasting (ECMWF T-799), (*iii*) Japan Meteorological Agency (JMA T-959), (*iv*) United Kingdom Meteorological Office (UKMO) and (*v*) National Centre for Environmental Prediction Global Forecast System (NCEP GFS).

3. Data and methodology

Verification in most of the states have been carried out using one representative district in agroclimatic zone taking departmental observatory (around 300 surface observatories spread over 200 districts) as the representative for the district for temperature and area weighted average of rainfall for all the districts (Both surface observatories and Daily rainfall Monitoring stations) (Rajeevan, *et al*., 2005; Roy Bhowmik and Das, 2007) was considered for verification. The accuracy of a forecast is some measure of how close to the actual weather the forecast was. Here, accuracy of a forecast is defined as how many days in the season the forecast was close to the actual weather (correct and usable) based on error structure.

3.1. Error structure for verification of quantitative district level weather forecast, if the forecast parameter is out by one stage compared to observed, it is considered as correct forecast and if the same is out by two stages and more than that it is considered as partially correct and wrong forecast respectively. The forecast has been verified with the help of observed data using the following error structure for rainfall and temperature for different districts in the state and inter-comparison between the states to observe the trend of value added forecast.

(A). The error structure considered for verification of ttemperature forecast:

Correct	Diff ≤ 1 °C
Usable	1 °C < Diff ≤ 2 °C
Unusable	Diff > 2 °C

(Diff is the absolute difference between observed and forecast temperatures).

(B). The error structure considered for verification of rainfall forecast:

Correct	Diff ≤ 25% of observed
Usable	25% of observed < Diff ≤ 50% of observed
Unusable	Diff > 50% of observed

(Diff is the absolute difference between observed and forecast rainfall).

Thus, for better interpretation of the results in different categories, following criteria was made to observe the worthiness of the forecast.

Good	:	Correct and usable forecasts for >70% days in the district.
Moderate	:	Correct and usable forecasts for 50-70% days in the district.
Poor	:	Correct and usable forecasts for <50% days in the district.

Besides, various skill scores like Probability of Detection (POD), False Alarm Rate (FAR), Missing Rate, Correct Non-Occurrence (C-Non), Critical Success Index (CSI), Bias for Occurrence (Bias), Percentage correct (Pc), True skill score (Tss), Heidke skill score (Hss) (WMO Technichal Circular No. – WMO/TO No.1023 Guidelines on Performance Assessment of Public Weather Services) have also been used to verify the forecast using the following formulae based on the matrix (2 × 2) given below:

Forecast / observation	*Rain*	*No Rain*
Rain	A (YY)	B (YN)
No Rain	C (NY)	D (NN)

A = No. of Hits (predicted and observed)

B = No. of False Alarms (predicted but not observed)

C = No. of misses (observed but not predicted)

D = No. of correct predictions of no rain. (neither predicted nor observed)

(*i*). *Forecast Accuracy (ACC) or Ratio Score or Hit Score* : It is the ratio of correct forecasts to the total number of forecasts.

$$\text{ACC} = \frac{\text{Correct Forecast}}{\text{Total Forecast}} = \frac{\text{A} + \text{D}}{\text{N}} = \frac{\text{YY} + \text{NN}}{\left(\text{YY} + \text{NN} + \text{YN} + \text{NY}\right)}$$

(*ii*). *Hanssen and Kuipers Scores or True Skill Score (HK score)*: It is the ratio of economic saving over climatology due to the forecast to that of a set of perfect forecasts

$$\text{HK} = \frac{\text{Correct Forecast} - \left(\text{Correct Forecast}\right)_{\text{random}}}{\text{N} - \left(\text{Correct Forecast}\right)_{\text{random, unbiased}}}$$

$$HK = \left(Acc\right)_{events} + \left(Acc\right)_{non-events} - 1 = \frac{AD - BC}{\left(A + C\right)\left(B + D\right)}$$

Range : -1 to +1

Perfect : 1

Advantage : equal emphasis to yes/no events

(*iii*). Probability of detection (POD)

$$\text{POD} = \frac{\text{Correctrain forecast}}{\text{rain observation}} = \frac{\text{A}}{\text{A} + \text{C}}$$

Range : 0 to 1; Perfect Score 1

(*iv*). False alarm ratio = $\dfrac{\text{False alarms}}{\text{Hots} + \text{False alarms}}$

$$\text{FAR} = \frac{\text{B}}{\text{A} + \text{B}}$$

(*v*). BIAS score = $\dfrac{\text{Rain forecast}}{\text{Rain observation}}$

$$\text{BIAS} = \frac{\text{A} + \text{B}}{\text{A} + \text{C}}$$

3.2. *Verification procedure*

Verification of forecast has been done on day basis, *i.e*., first day, second day, third day, fourth day and fifth day from the date of issue of forecast.

Day of issue of forecast	*Ist Day*	*2nd Day*	*3rd Day*	*4th Day*	*5th Day*
Tue	Tue	Wed	Thu	Fri	Sat
Fri	Fri	Sat	Sun	Mon	Tue

- If the district has more than one observatory temperature should be an arithmetic mean of total number of observatories.
- Rainfall should be area weighted average

4. Results & discussion

It is observed that the weather parameters show a good accuracy with the value added forecast during non-rainy / less rainfall seasons, *i.e*., winter, pre monsoon and post monsoon. In the present verification report extensive analysis has been made in the monsoon followed by minimum temperature particularly in the winter season and maximum temperature for the pre monsoon season. Results have been discussed region wise covering all the states of the country. The forecast verification has been carried out day wise for forecasted weather parameters, *viz*., rainfall, maximum and minimum temperature both qualitatively and quantitatively. Correct forecast plus usuable forecast together represents the total accuracy of the forecast. The average value of the verification is given below:

(A). Rainfall verification

Based on the criteria mentioned above verification has been carried out for the monsoon season region wise. Qualitative rainfall skill score for all the regions is shown

TABLE 1

Skill score of rainfall

S. No.	State	DAY-1					DAY-2					DAY-3					DAY-4					DAY -5				
		PC	HK	POD	FAR	BAIS	PC	HK	POD	FAR	BAIS	PC	HK	POD	FAR	BAIS	PC	HK	POD	FAR	BAIS	PC	HK	POD	FAR	BAIS
1.	A & N	77	-	-	-	-	85	-	-	-	-	75	-	-	-	-	81	-	-	-	-	75	-	-	-	-
2.	Bihar	60	-	-	-	-	75	-	-	-	-	72	-	-	-	-	71	-	-	-	-	66	-	-	-	-
3.	Delhi	91	0.2	0.4	0.71	1.4	79	0.43	0.78	0.56	1.8	68	0.45	0.75	0.44	1.3	92	0.56	0.75	0.63	2	87	0.35	0.67	0.69	2.2
4.	Gujarat	68	0	0.8	0.5	0.5	65	0	0.8	0.4	0.5	65	0	0.8	0.5	0.5	67	0	0.8	0.5	0.5	70	0	0.6	0.4	0.5
5.	Haryana	45	0.62	0.9	0.44	1.6	64	0.68	0.86	0.45	1.57	71	0.22	0.54	0.5	1.08	58	0.33	0.56	0.29	0.78	49	0.34	0.56	0.29	0.8
6.	HP	90	-	-	-	-	93	-	-	-	-	80	-	-	-	-	80	-	-	-	-	-	-	-	-	-
7.	J & K	67	-	-	-	-	64	-	-	-	-	63	-	-	-	-	63	-	-	-	-	68	-	-	-	-
8.	Jharkhand	69	-	-	-	-	54	-	-	-	-	54	-	-	-	-	54	-	-	-	-	-	-	-	-	-
9.	Kerala	90	-	-	-	-	88	-	-	-	-	88	-	-	-	-	88	-	-	-	-	87	-	-	-	-
10.	MP	83	-	0.28	0.67	0.15	84	-	0.04	0.98	0.12	90	-	0.38	0.81	0.09	85	-	0.38	0.87	0.16	87	-	0.19	0.79	0.15
11.	Maha and Goa	73	0.18	0.81	0.21	1.1	68	0.09	0.8	0.27	1.22	76	0.34	0.83	0.2	0.99	71	0.19	0.82	0.24	1.11	70	0.16	0.84	0.27	1.14
12.	Odisha	87	-	-	-	-	81	-	-	-	-	81	-	-	-	-	82	-	-	-	-	87	-	-	-	-
13.	Punjab	68	0.4	0.74	0.47	1.42	62	0.36	0.54	0.36	0.85	48	0.52	0.67	0.23	0.87	74	0.56	0.78	0.22	1	52	0.56	0.68	0.23	1
14.	Rajasthan	74	0.46	0.49	0.06	0.52	66	0.33	0.39	0.13	0.45	69	0.3	0.43	0.29	0.61	71	0.26	0.47	0.57	1.09	74	0.16	0.34	0.74	1.28
15.	Tamil Nadu	58	-	0.78	0.52	1.17	57	-	0.78	0.53	1.16	57	-	0.77	0.54	1.15	57	-	0.78	0.54	1.15	59	-	0.79	0.5	1.18
16.	Vidarbha	-	0.92	0.63	0.12	0.15	-	0.64	0.56	0.11	0.12	-	0.76	0.61	0.14	0.09	-	0.19	0.49	0.29	0.16	-	0.4	0.57	0.27	0.15
17.	Utt	85	-	0.93	0.11	1	79	-	0.83	0.08	1	85	-	0.88	0.08	0.89	82	-	0.89	0.11	1	76	-	0.8	0.08	1.04
18.	UP	66	-	-	-	-	70	-	-	-	-	68	-	-	-	-	63	-	-	-	-	69	-	-	-	-
19.	WB	81	0.3	1	0.2	1.1	85	0.4	1	0.5	1	83	0.4	0.9	0.1	1	79	0.3	1	0.2	1.1	79	0.1	1	0.2	1.2

Note : PC : percentage correct, HK : Hanssen and Kuipers Scores or True Skill Score , POD : Probability of Detection, FAR : False Alarm Ratio

in the Table 1 and individual state is described in the Table 2.

Eastern Region : Orissa, Bihar, West Bengal, Jharkhand, Sikkim and Andaman & Nicobar

In this region, it is observed that qualitatively the rainfall forecast during past three years was >70% in most of the districts in West Bengal, Odisha, Sikkim and Andaman & Nicobar for all the five days whereas, qualitative forecast in Bihar and Jharkhand showed skill in the range of 50 - 70%. However, quantitatively the forecast accuracy has been noticed as moderate in Bihar, West Bengal and Andaman & Nicobar and poor in Jharkhand in 2014 as compared to good in 2012 and 2013. In Odisha, accuracy of rainfall forecast improved moderately during 2014 as compared to 2012 and 2013. In Sikkim, even though, rainfall forecast was moderately accurate for most of the districts in 2014, there was marginal improvement in accuracy level in 2014 compared to 2012 and 2013. As observed, the accuracy level of rainfall forecast in Jharkhand needs improvement. Results for the six states are presented in Tables 1 and 2.

North Eastern Region : Assam and Tripura

During 2014, District level weather forecast was good for most of the districts in Tripura, and it was moderate for most of the districts in Assam. Tripura maintained good accuracy level for the past three years, whereas, Assam showed considerable improvement during this period. Forecast accuracy was more for first three days in Tripura and for first four days in Assam as compared to later parts of the forecast period. The rainfall

TABLE 2

Verification of district level weather forecast : Rainfall

States	Day 1			Day 2			Day 3			Day 4			Day 5		
	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor
A P	5	4	2	2	8	1	2	8	1	4	5	2	3	5	3
A & Nicobar	0	2	1	0	3	0	0	2	1	0	1	2	0	1	2
Assam	3	18	6	3	18	6	2	19	6	3	20	4	2	11	14
Bihar	0	2	1	1	1	1	0	2	1	0	2	1	1	0	2
Chatt.	0	14	4	0	7	11	1	5	12	2	7	9	0	9	9
Delhi	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
Haryana	0	0	3	0	3	0	0	3	0	0	3	0	0	0	3
HP	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Gujarat	2	3	3	4	4	0	4	3	1	4	3	1	4	3	1
Jharkhand	0	1	2	0	0	3	0	0	3	0	0	3	0	4	3
J and K	0	3	4	0	2	5	0	2	5	0	2	5	0	2	16
Karnataka	0	1	17	0	2	16	0	3	15	0	1	17	0	0	10
Kerala	0	0	10	0	0	10	0	0	10	0	0	10	12	2	10
Maha & Goa	15	6	3	12	9	3	8	11	7	9	10	5	0	2	7
MP	0	2	7	0	9	0	0	1	8	0	2	7	1	20	9
Odishha	1	2	3	0	24	6	20	10	0	2	22	6	0	3	0
Punjab	0	3	0	0	3	0	0	0	3	3	0	0	6	4	0
Rajasthan	2	8	0	0	7	3	1	7	2	6	2	2	0	2	0
Sikkim	4	4	0	0	3	1	0	3	1	0	2	2	3	1	0
Tripura	4	0	0	4	0	0	4	0	0	3	1	0	0	1	18
Tamilnadu	4	3	16	0	2	17	0	1	18	0	1	18	6	4	0
Telangana	1	6	0	3	7	0	5	3	2	4	6	0	1	0	0
Uttar Pradesh	0	6	0	1	0	0	1	0	0	1	0	0	4	2	1
West Bengal	1	10	7	4	3	0	5	1	1	6	1	0	0	8	9
Uttarakhand	1	0	0	0	11	6	0	9	8	0	9	8	0	5	5
Vidarbha	0	2	8	0	1	8	0	4	6	0	7	3	-	-	-

Note : Figures in the Table indicate the number of districts in the respective category of forecast accuracy

events could also be captured qualitatively by the model in this region.

Western Region : Maharashtra (except Vidharbha), Gujarat and Goa

The states of Maharashtra and Goa showed moderate skills for all five days during 2012 and 2013 but accuracy improved considerably during 2014 and forecasts were good for first two days for majority of the districts. Forecasts were even good for many districts of the state for subsequent three days. Forecast skill varied mostly between 60 - 80% for all five days for these States. In the state of Gujarat forecast was good to moderate on all five days and accuracy level improved from 2012.

Northern Region : Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Uttar Pradesh, Punjab, Haryana, Rajasthan and Delhi

In Delhi, there was marked improvement in quality of rainfall forecast in 2014 and forecast was more

TABLE 3

Verification of district level weather forecast : Minimum temperature

States	Minimum temperature distribution														
	Day 1			Day 2			Day 3			Day 4			Day 5		
	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor
A P	9	2	0	10	1	0	8	3	0	9	2	0	9	2	0
A & Nicobar	2	1	0	2	1	0	0	1	2	2	0	1	0	2	1
Assam	11	0	0	11	0	0	11	0	0	11	0	0	11	0	0
Chatt.	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Delhi	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0
Gujarat	8	0	0	2	3	3	0	7	1	2	4	2	3	0	5
Haryana	0	3	0	2	1	0	2	1	0	1	2	0	0	3	0
HP	1	0	0	1	0	0	0	0	1	0	1	0	0	1	0
J and K	1	4	2	2	4	1	4	3	0	4	3	0	1	6	0
Karnataka	15	1	0	16	0	0	13	2	1	13	3	0	10	4	1
Kerala	9	1	0	10	0	0	10	0	0	10	0	0	10	0	0
Maha	3	0	0	3	0	0	2	1	0	0	3	0	0	3	0
Punjab	0	3	0	1	2	0	1	2	0	1	2	0	1	2	0
Rajasthan	8	2	0	2	6	2	1	8	1	0	9	1	0	8	2
Sikkim	3	1	0	4	0	0	4	0	0	4	0	0	3	1	0
Tripura	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0
Tamilnadu	15	2	2	12	6	1	14	4	1	11	7	1	13	5	1
Telangana	8	2	0	9	1	0	7	2	1	6	4	0	8	2	0
Uttakhand	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Uttar Pradesh	1	6	0	0	4	3	0	2	5	0	4	3	0	2	5
West Bengal	15	2	0	10	7	0	9	7	1	4	12	1	5	9	3
Goa	1	0	0	1	0	0	1	0	0	0	1	0	0	0	1
Vidarbha	4	6	0	6	3	1	2	5	3	1	8	1	3	4	3

Note : Figures in the Table indicate the number of districts in the respective category of forecast accuracy

than 70% correct quantitatively as well as good qualitatively. Districts of Amritsar, Ludhiana and Patiala of Punjab and Ambala, Karnal and Hisar of Haryana have been considered as representative districts to study the performance of rainfall forecast. The state of Punjab maintained the same level of accuracy of forecast during past years. As observed in 2014, forecasts were good for all five days quantitatively. For Haryana, accuracy level reduced in 2014 as compared to 2012 and 2013. However, in 2014, forecasts were good for first three days, whereas, moderate for subsequent two days. Qualitatively forecast skill varied between 50-75% for Punjab and 45-70% for Haryana in 2014. Based on the verification carried out for six representative districts of Jammu and Kashmir, the State showed moderate accuracy of forecast quantitatively in 2014 as compared to good forecasts in 2012 and 2013. Qualitatively forecast skill varied between 55-75% in various districts on different days. Accuracy of forecasts in Himachal Pradesh was good quantitatively for all the five days during past three years. Qualitatively, forecasts were more than 80% correct. In Uttar Pradesh, considering seven districts for verification of forecasts, it is noticed that the skill of forecast improved qualitatively showing skill in the range of 60-80% for most of the districts in 2014 as compared to last two years. Accuracy of quantitative forecasts was also good in 2014 showing

TABLE 4

Verification of district level weather forecast: Maximum temperature

States	Maximum temperature distribution														
	Day 1			Day 2			Day 3			Day 4			Day 5		
	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor
A P	4	5	2	1	6	4	1	8	2	2	5	4	2	7	2
A & Nicobar	3	0	0	3	0	0	3	0	0	2	1	0	3	0	0
Assam	9	2	0	9	2	0	9	2	0	9	2	0	9	2	0
Chatt.	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0
Delhi	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Gujarat	2	5	1	1	5	2	1	5	2	0	6	2	1	4	3
Haryana	2	0	1	3	0	0	2	1	0	1	2	0	2	1	0
HP	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
J and K	1	3	3	1	3	3	0	4	3	1	4	2	1	4	2
Karnataka	15	0	0	15	0	0	12	3	0	13	2	0	10	4	1
Kerala	10	0	0	9	1	0	9	1	0	9	1	0	10	0	0
Maha	3	0	0	3	0	0	3	0	0	3	0	0	2	0	1
Punjab	0	3	0	3	0	0	1	2	0	0	3	0	2	1	0
Sikkim	3	0	1	1	2	1	0	3	1	1	3	0	0	4	0
Tamilnadu	19	0	0	17	1	1	17	0	2	15	3	1	18	1	0
Telangana	5	5	0	5	5	0	2	8	0	3	7	0	7	3	0
Uttakhand	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Uttar Pradesh	1	5	0	5	1	0	5	1	0	0	4	2	2	4	0
West Bengal	16	1	0	13	4	0	11	6	0	6	10	1	4	11	2
Goa	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Vidarbha	8	0	1	7	1	1	7	1	1	7	0	2	4	3	2

Note : Figures in the Table indicate the number of districts in the respective category of forecast accuracy

improvement as compared to 2012 and 2013. In Rajasthan, rainfall forecast showed moderate accuracy quantitatively in 2014.

Central Region : Chattisgarh, Madhya Pradesh and Vidharbha

The state of Madhya Pradesh maintained qualitatively the same skill of predicting rainfall nearly 80% on all five days during past 3 years, whereas the accuracy of quantitative forecast reduced in 2014 compared to 2012 and 2013. Quantitative rainfall forecast in 2014 was not upto the mark for 2014. In Chhattisgarh, value addition to the model output showed improvement in forecast skill in all the three years qualitatively. However, quantitatively rainfall forecast showed moderate accuracy only on first day, whereas for other four days, quality of forecast was not upto the mark. All the districts in Vidarbha showed marginal improvement in accuracy of forecast, both qualitatively and quantitatively, in 2014 compared to 2012 and 2013. However, quantitative rainfall forecasts were not upto the mark for most of the districts during 2014. Skill of forecast in all these regions needs improvement.

Southern Region : Andhra Pradesh, Karnataka, Kerala and Tamil Nadu

In the state of Tamil Nadu accuracy which was moderate in 2012 decreased in 2013 and 2014 alongwith

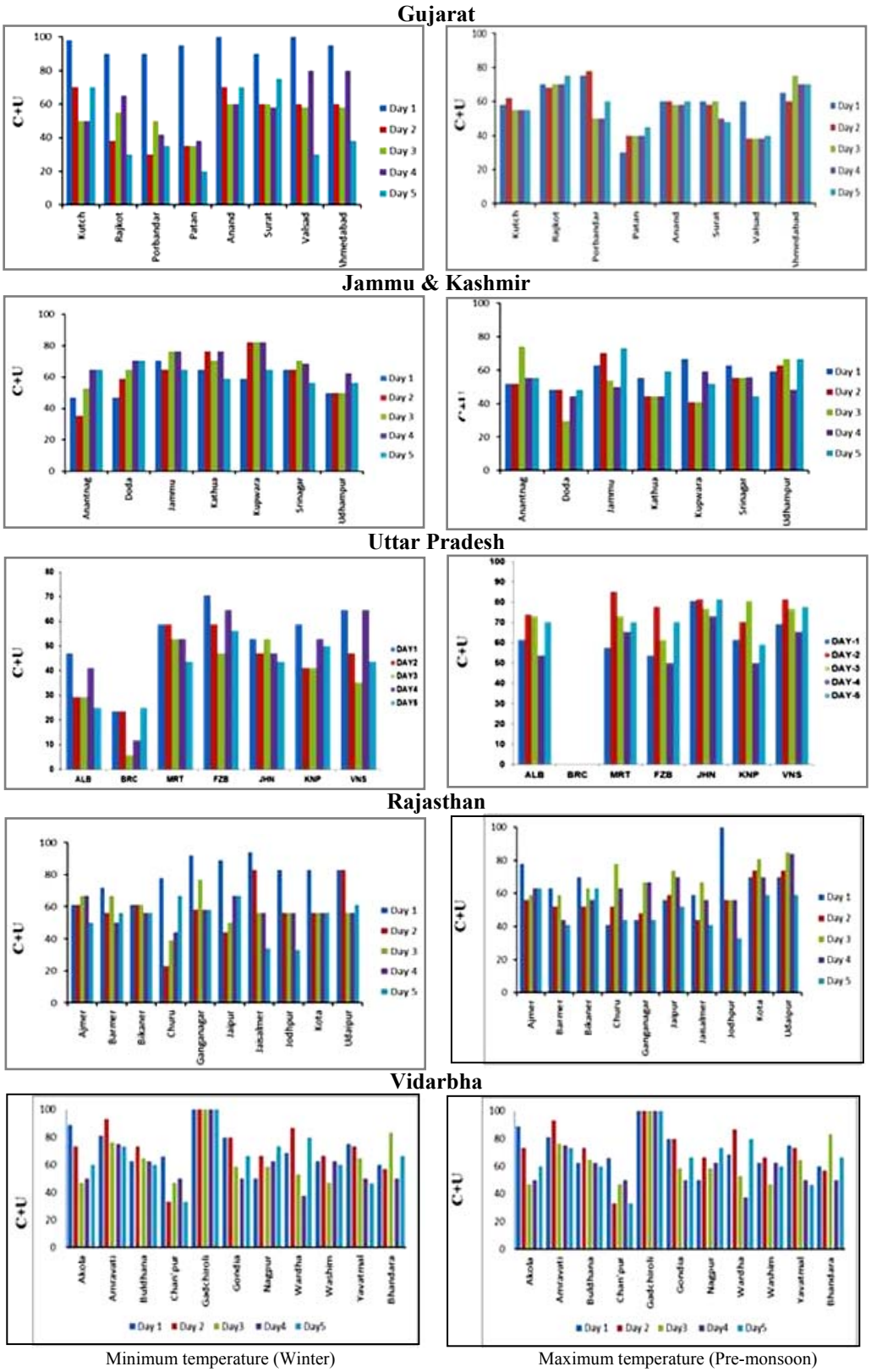


Fig. 3. Performance of temperature forecast in various districts in some of the states

the skill score of predicting rainfall. Kerala receives copious rain (average 3000 mm) each year, Southwest monsoon is the main rainy season of Kerala. The state of Telangana showed a moderate improvement in the skill of predicting the value quantitatively in 2014 compared to 2013 and 2012. The accuracy level in Kerala, Karnataka and Andhra Pradesh need improvement as it showed very less values during consecutive three years.

(B). Verification of temperatures

Based on the above criteria mentioned above verification has been carried out for the minimum temperature in winter and maximum temperature in Pre-monsoon season for 300 departmental observatories in 200 districts. Some of the district wise performance of temperature is shown in the Fig. 3. Further the performance of state as a whole are reported in the Tables 3 and 4.

Eastern Region : Orissa, Bihar, West Bengal, Jharkhand, Sikkim and Andaman and Nicobar

On an average the maximum and minimum temperature forecasts showed good accuracy level in the region. The value added forecast was good in all three years in the states of West Bengal and Andman and Nicobar. Sikkim also showed good accuracy level for minimum temperature forecast in winter season, whereas, skill was moderate for maximum temperature in pre-monsoon season. Temperature forecast verification results for Bihar, Jharkhand and Odisha are not available.

North Eastern Region : Assam and Tripura

Assam showed improvement in accuracy level showing good quality forecasts for both the minimum temperature in winter and maximum temperature during pre-monsoon season in 2014 compared to last two years. The accuracy of minimum temperature forecast for Tripura is also good in 2014 showing improvement over 2012 and 2013. Though district level forecast has been issued for other states in this region the verification could not be carried out due to sparse observatories.

Western Region : Gujarat, Maharashtra and Goa (except Vidarbha)

Maharashtra and Goa (except Vidarbha) showed good level of accuracy for both the minimum and maximum temperature during the past there years. Gujarat state minimum temperature was more accurate than maximum temperature. The accuracy of temperature forecast for Gujarat is also good in 2014 showing improvement over 2012 and 2013.

Northern Region : Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Uttar Pradesh, Punjab, Haryana, Rajasthan and Delhi

On an average the temperature both maximum and minimum showed a good accuracy in the region with improving trend for the past three years. Himachal Pradesh where more than 80% of the region fall under Himalayas the value added forecast minimum temperature was nearly equal to observed values. In Punjab the accuracy level of predicting maximum and minimum improved slightly compared to 2012 and 2013 whereas in Haryana the slight fall in prediction of minimum temperature was observed compared to 2012 whereas maximum temperature maintained the same level of accuracy in past three years. Delhi maintained on an average same accuracy level during the last three years for maximum and minimum. The state of Uttar Pradesh where more than 60% is in plain land the maximum temperature showed a better accuracy compared to minimum temperature and level of accuracy improved moderately compared to last two years in 2014. Dehradun district in Uttarakhand was taken as representative district to study the verification of forecast. All the three years it maintained same accuracy level falling in good category. In Jammu and Kashmir the moderate fall in accuracy level of forecast was observed during 2014 compared to 2013 and 2012.

Central Region : Vidarbha, Madhya Pradesh and Chhattisgarh

For Chhattisgarh value addition to model output showed improvement for both maximum and minimum temperature forecast. The forecast showed good skill and remained steady during all the three years. In Vidarbha accuracy level improved during 2014 compared to 2012 and 2013. But the accuracy level decreased for most of the districts from day 3 onwards for both the maximum and minimum temperature forecast.

South Region : Andhra Pradesh, Tamilnadu, Kerala, Karnataka and Telangana

The states of Tamil Nadu, Kerala, Telangana and Karnataka the accuracy level for both minimum and maximum temperature fell in good category during the past there years. The state of Andhra Pradesh the accuracy for maximum temperature needs improvement during pre-monsoon season whereas minimum temperature prediction remained steady for the past three years.

(C). Day-wise performance and inter-state comparison of forecast

Rainfall (Monsoon season): Qualitatively the rainfall forecast was able to capture the event for most of the regions of the country. But quantitatively the accuracy still needs to be improved for some regions of the country, especially Southern (Karnataka, Kerala and Tamil Nadu) and Central India (Madhya Pradesh, Chhattisgarh and Vidarbha) as well as Jharkhand in eastern India. Some states like Delhi, Maharashtra (except Vidarbha), Goa, Assam and Uttar Pradesh showed a considerable improvement in quantitative rainfall forecasts and states like Jammu & Kashmir, Himachal Pradesh, Punjab and Tripura maintained accuracy level. In general the accuracy level in the country is more on the first three days and decreasing thereafter. Results for the inter-state comparison in country day wise are presented in Table 2.

Minimum temperature (Winter season) : It is observed that in the country as whole the minimum temperature accuracy, on an average, was 60% or more on all the five days in most of the districts. In general the accuracy level in the country is more for the first three days and decreasing thereafter. In Punjab, Haryana and Rajasthan, compared to other states, the accuracy level was less, falling in moderate category on most of five days. Mostly it is observed that on fourth and fifth day, many districts in the country observed reduced accuracy level. As compared to other regions, south region showed good accuracy in predicting the minimum temperature. Results for the inter-state comparison in country day wise are presented in Table 3.

Maximum temperature (Pre-monsoon season) : It is observed that in the country as whole the maximum temperature accuracy, on an average, was 50% or more on all the five days in many districts. In general the accuracy level in the country is more on the first two days and decreasing thereafter. In Andhra Pradesh, compared to other states, the accuracy level was less on all five days. Mostly it is observed that on fourth and fifth day, accuracy level decreased for many of the districts in the country. Comparative to other regions States of South region (except Andhra Pradesh), Maharashtra, Goa and Andaman & Nicobar showed a good accuracy in predicting Maximum temperature. Maximum Temperature forecast in Andhra Pradesh needs improvement. Results for the inter-state comparison in country day wise are presented in Table 4.

5. Conclusions

In view of importance of District Level Weather Forecast (DLWF) for preparation of good quality Agromet advisories, initiative has been taken by the Regional Meteorological Centres (RMCs) and Meteorological Centres (MCs) of IMD to verify the quality of DLWF for further improvement of accuracy of forecast. Initially three parameters namely rainfall for monsoon season, minimum temperature for winter season and maximum temperature for pre-monsoon season, have been considered for in depth verification. The verification report has been prepared based on three years data and extensive efforts have been made by the RMCs and MCs in collaboration with National Weather Forecasting Centre (NWFC) and Agricultural Meteorology Division, IMD, Pune for improvement of quality of forecast. The observations from the verification results of the above mentioned parameters are summarised below :

(*i*) Qualitatively the model forecast for rainfall is able to predict correctly and capture the event in most of the regions of the country. Quantitatively the accuracy level varied for different regions.

(*ii*) Quantitatively the accuracy level still needs to be improved for some regions of the country, especially Southern (Karnataka, Kerala and Tamil Nadu) and Central India (Madhya Pradesh, Chhattisgarh and Vidarbha) as well as Jharkhand in eastern India.

(*iii*) Compared to rainfall forecast, the accuracy level of Temperature forecast is better for most of the States. However, maximum temperature forecast in Andhra Pradesh needs improvement.

(*iv*) There is need to improve forecast skill for fourth and fifth day.

Acknowledgments

This report is prepared based on the verification results presented by heads of each Regional Meteorological Centres of India Meteorological Department in the Annual Review Meetings of Gramin Krishi Mausam Sewa. Authors are thankful to Director General of Meteorology, India Meteorological Department, New Delhi for his constant encouragement, guidance, suggestions and support given to them. European Centre for Medium Range Weather Forecasting, Japan Meteorological Agency, United Kingdom Meteorological Office and National Centre for Environmental Prediction Global Forecast System, USA are duly acknowledged for sharing their models in developing the district level weather forecast models. Authors are also thankful to National Centre for Medium Range Weather forecast for constant support. Authors are also grateful to officers and staff members of meteorological centres who are involved in this verification work.

References

Krishnamurti, T. N., Kishtawal, C. M., Larow, T., Bachiochi, D., Zhang, Z., Willford, E. C., Gadgil, S. and Surendran, S., 1999, "Improved weather and seasonal climate forecasts from multimodel super ensemble", *Science*, **285**, 1548-1550.

Rajeevan, M., Bhate, J., Kale, J. D. and Lal, B., 2005, "Development of high resolution gridded rainfall data for Indian Region", IMD Met. Monograph No. Climatology 22/2007.

Rathore, L. S., Roy Bhowmik, S. K. and Chattopadhaya, N., 2011, "Integrated Agro-advisory Services of India", *Challenges and opportunities of Agro-meteorology*, 195-205 (Spinger publication).

Roy Bhowmik, S. K. and Das A, K., 2007, "Rainfall Analysis for Indian monsoon region using the merged rain gauge observations and satellite estimates : Evaluation of monsoon rainfall features", *Journal of Earth System Science*, **116**, 3, 187-198.

Roy Bhowmik, S. K. and Durai, V. R., 2012, "Development of multi-model ensemble based district level medium range rainfall forecast system for Indian region", *Journal of Earth system Science*, **121**, 2, 273-285.

WMO Technichal Circular No. – WMO/ TO No.1023 Guidelines on Performance Assessment of Public Weather Services.