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Value addition in district level dynamical forecast during monsoon depressions and storms

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सार – वर्ष 2005 की मानसून ऋतु के दौरान जिला स्तर के पूर्वानुमानों के परीक्षणों से उत्साहवर्धक परिणाम प्राप्त हुए हैं। इस शोध–पत्र का उद्देष्य मानसून अवदाबों और तूफानों की अवधियों के दौरान पूर्वानुमान की गुणवत्ता बढ़ाने के लिए अपनाई जाने वाली पद्धति का प्रलेखन करना है। विभिन्न मॉडल केन्द्रों, विषेष रूप से यूरोपीय मध्यावधि मौसम पूर्वानुमान केन्द्र (ई. सी. एम. डब्ल्यू. एफ.) द्वारा पूर्वानुमानित औसत समुद्र सतह (एम. एस. एल.) की स्थितियों और 850 हैक्टापास्कल परिसंचरण लक्षणों के उपयोग पर इस अध्ययन में विषेष ध्यान दिया गया है। ई. सी. एम. डब्ल्यू. एफ. द्वारा पूर्वानुमानित मानसून अवदाब केन्द्र की 72 घंटे की एम. एस. एल. स्थिति का इस तंत्र की वास्तविक स्थिति तथा इस तंत्र के साथ संबद्ध वास्तविक वर्षा के क्षेत्र की केन्द्रीय स्थिति के साथ महत्वपूर्ण सहसंबंध पाया गया है। ई. सी. एम. डब्ल्यू. एफ. द्वारा 850 हैक्टापास्कल पर इस तंत्र की पूर्वानुमानित स्थिति भी मानसून तंत्रों के कारण होने वाली भारी वर्षा वाले जिलों की पहचान करने में उपयोगी पाई गई है।

एम. एम. 5 और टी.–80 द्वारा 850 हैक्टापास्कल पर तंत्र के पूर्वानुमानित स्थानों का तंत्र से संबद्ध वास्तविक वर्षा के क्षेत्र की स्थिति के साथ निम्न सहसंबंधों का पता चला है। चूँकि ई. सी. एम. डब्ल्यू. एफ. द्वारा पूर्वानुमानित वर्षा के आँकड़े उपलब्ध नहीं थे अतः एम. एम. 5 और टी.–80 द्वारा पूर्वानुमानित वर्षा के आँकडों का मानसून अवदाबों और तूफानों से संबद्ध वास्तविक वर्षा की मात्रा के साथ सहसंबंधों का आकलन करने के लिए उपयोग किया गया है। एम. एम. 5 और टी.–80 के बीच सहसंबंधों से तंत्रों के साथ संबद्ध औसत और अधिकतम वर्षा का पूर्वानुमान लगाया गया तथा उसके अनुरूप वास्तविक वर्षा कम रही। यद्यपि मानसून अवदाबों/तूफानों से संबद्ध भारी वर्षा द्वारा प्रभावित होने वाले संभावित जिलों की पहचान करना कठिन कार्य नहीं है तथापि मॉडलों से प्राप्त आँकड़ों से प्रत्येक जिले (भारी वर्षा से अधिक, बहुत भारी अथवा विषेष भारी श्रेणियाँ) के लिए वास्तविक वर्षा की मात्रा का पूर्वानुमान लगाना कठिन कार्य है जो इस तरह के पूर्वानुमान के कार्य को चुनोतीपूर्ण बना देता है। अतः उपग्रह से प्राप्त सूचनाओं, सिनॉप्टिक चार्ट, जलवायु विज्ञान आदि जैसी अन्य सूचनाओं का उपयोग गुणवत्ता बढ़ानें के लिए मानसून तंत्रों से संबद्ध वर्षा की मात्रा का पूर्वानुमान करने हेतु अत्यंत उपयोगी है।

ABSTRACT. The trials of district level forecasts yielded encouraging results during 2005 monsoon. The purpose of this paper is to document the methodology followed in the value addition during the periods of monsoon depressions and storms. The focus is on the use of Mean Sea Level (MSL) positions and the 850 hPa circulation features predicted by different model centres, especially the European Centre for Medium-Range Weather Forecasts (ECMWF). The ECMWF-predicted 72 hr MSL position of the monsoon depression centre was found to be significantly correlated to the actual position of the system and the central location of the realized rainfall zone associated with the system. Even the predicted location of the system at 850 hPa by the ECMWF has been found useful in identifying the districts that received heaviest rainfall associated with the monsoon systems.

MM5 and T-80 – predicted locations of the system at 850 hPa yielded lower correlations with the location of the actual rainfall zone associated with the system. As ECMWF – predicted rainfall was not available the rainfall predicted by MM5 and T-80 were used in the computations of the correlations with actual rainfall amounts associated with monsoon depressions and storms. The correlations between MM5 and T-80 – predicted average and maximum rainfall associated with systems and corresponding actual were poor. Though it is not difficult to identify the districts that are likely to be affected by the heavy rainfall associated with monsoon depressions/storms, the prediction of exact rainfall amount for each district (beyond heavy, very heavy or exceptionally heavy categories) is difficult from the model outputs which makes such forecasts a very challenging task. Therefore, the value addition using other inputs such as satellite information, synoptic charts, climatology etc. are very useful in the prediction of rainfall amounts associated with monsoon systems.

Key words – Value addition, Model Output Statistics (MOS), Monsoon Depression (MD), District level dynamical forecast, Predictor, Ensemble, European Centre for Medium Range Weather Forecasts (ECMWF).

1. Introduction

Monsoon Depressions and storms are important synoptic systems of the summer monsoon season. These systems generally form over the north and adjoining central Bay of Bengal at the eastern end of the Monsoon Trough (MT) and move along the MT and produce copious rainfall over the central parts of the country. (Pisharoty and Asnani, 1957; Rao, 1976, Saha *et al.*, 1981 Chang and Krishnamurti, 1987; Jadhav, 2002). The prediction of district level rainfall associated with these systems is a challenging task due to uncertainty involved in the prediction of their track of movement and the maximum rainfall amounts associated with these systems. Numerical Weather Prediction (NWP) models have their own limitations in predicting the quantity of rainfall associated with these systems for smaller spatial resolutions such as district level. The value-added district level dynamical-synoptic system for rainfall being developed in the India Meteorological Department [Lal *et al.*, 2006(a&b)] utilizes several inputs such as different model outputs other than rainfall (*i.e.*, circulation features at 850 hPa, sea level pressure, vertical velocity etc.), synoptic charts, climatology, satellite information etc. in addition to the rainfall predictions. The trials during 2005 monsoon have shown that it is difficult to arrive at an accurate district level forecast of rainfall associated with monsoon depressions and storms using the model-predicted rainfall alone even if the ensemble consists of a large number of models (Lal *et al*, 2006a). The value-addition using the above-mentioned inputs yielded considerable improvement in the forecast skill. The main aim of the present paper is to describe the methodology used in the value addition during the periods of monsoon depressions and storms.

2. Data and methodology

ECMWF-predicted 72 hr MSL positions of the centre of the monsoon system (depression or storm) and corresponding 850 hPa locations of the cyclonic circulation have been used to determine the districts that were likely to be severely affected by the system. The outputs of MM5 and T-80 were also examined but ECMWF outputs yielded better correlations with actual rainfall zones associated with the systems. As far as rainfall amount is concerned it was found that the satellite imageries, climatologies and the previous day realized rainfall associated with the systems were very useful in the value addition as the constituent models generally underestimated the heaviest rainfall amounts. Thus the realized rainfall data pertaining to all four monsoon depressions/storms formed during 2005 and the satellite imageries along with different model outputs have been used in the present work.

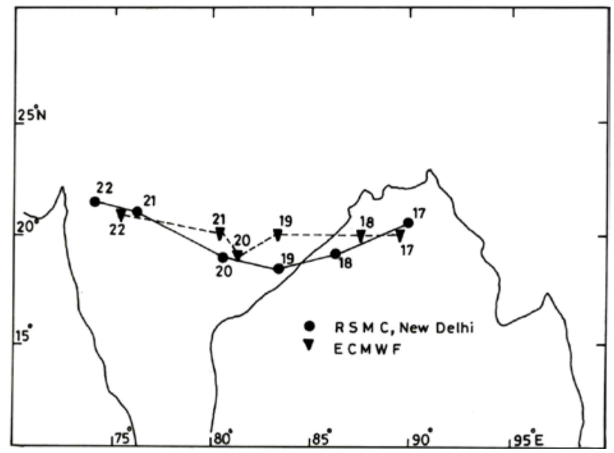

Fig. 1. ECMWF-predicted mean sea level positions (1200 UTC) of the centre of the system (cyclonic storm, 17-22 September, 2005) along with the actual positions given by RSMC, New Delhi

3. Results and discussion

During the southwest monsoon season-2005 four monsoon depressions/storms formed over the Bay of Bengal and crossed east coast of India. The ECMWF-predicted MSL positions along with actual positions (given by RSMC, New Delhi) pertaining to all the four systems have been presented in Table 1. The ECMWF and MM5-predicted positions and maximum winds at 850 hPa are also given in the same Table. Out of these four systems one intensified into a cyclonic storm. This system was located over the northeast Bay of Bengal near Lat. 20.5° N / Long 90.5° E on the morning of 17 September as a depression and intensified into a cyclonic storm in the evening of 17th itself and subsequently crossed Andhra Pradesh coast near Kalingapatnam in the morning of 19th. The system produced widespread rainfall with heavy to very heavy falls in several districts of a number of meteorological sub-divisions which led to a significant improvement in the seasonal monsoon rainfall scenario over the country.

3.1. *ECMWF-predicted and actual MSL positions of the centre of monsoon cyclone*

The predicted and actual MSL positions of the centre of the cyclone have been depicted in Fig. 1. It can be seen from Fig. 1 that from the time of formation (*i.e.*, 17th) to the time of landfall (19th) the 72 hr positions predicted by the ECMWF were very close to the actual positions. The ECMWF predicted a slight southerly movement between 17-19 September whereas RSMC, New Delhi kept a westerly movement till 19th. The 72 hr predicted and actual positions on 20th were remarkably close but on 21st

TABLE 1

Position and Intensity related predicted parameters *i.e.*, 72 hr predicted positions of depression/storm centres at MSL & 850 hPa and associated max. winds at 850 hPa along with actual MSL positions during 2005 monsoon

S. No.	Date	Actual MSL Position of centre (RSMC, New Delhi)		ECMWF-predicted 72 hr position of centre at MSL		ECMWF-predicted SLP of closest Isobar	ECMWF-predicted 72 hr position of centre and max. winds at 850 hPa				MM5- predicted 72 hr position of centre and max. winds at 850 hPa			
							Position of centre		Max. wind (kts)		Position of centre		Max. wind (kts)	
		Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)	(hPa)	Lat. (°N)	Long. (°E)	Northern Sector	Southern Sector	Lat. (°N)	Long. (°E)	Northern Sector	Southern Sector
1	27 Jun	21.5	88	-	-	-	21.8	88.6	20	35	23.3	90.9	26	37
2	28 Jun	23	86	-	-	-	22.1	87.9	30	45	21.4	90.7	29	45
3	29 Jun	23.5	85.5	-	-	-	22.4	83.8	20	25	22.8	87.4	29	42
4	30 Jun	24	82	22	83.3	995	22.7	82.4	20	35	22.5	88.3	21	39
5	1 Jul	24.5	80.5	24	81.3	995	23.3	82.4	30	35	23.3	88.3	14	32
6	2 Jul	24.5	80.5	24	81.3	995	23.6	81	20	30	-	-	-	-
7	3 Jul	24.5	80.5	-	-	-	24.8	78.6	25	30	26.7	80.7	16	32
8	4 Jul	25	79.5	25.3	80.6	995	26.1	81.3	30	25	25.8	77.5	37	45
9	5 Jul	26	80	26	80.6	990	28.2	77.2	30	30	28.3	76.9	32	18
10	6 Jul	25.1	78.2	26	78	995	27.3	76.5	40	30	28.3	77.9	29	13
11	28 Jul	21.7	88.7	-	-	-	-	-	-	-	21.9	87.6	25	25
12	29 Jul	21.5	87.5	22	82.7	995	22.4	80.7	10	40	22.5	89.8	20	35
13	30 Jul	21.5	85.5	21.3	88	995	20.9	88.5	15	30	20.3	90	25	40
14	31 Jul	22	82.5	-	-	-	20.9	86.2	30	40	23.1	88.6	20	25
15	1 Aug	23.3	79.3	-	-	-	22.1	79.3	30	45	-	-	-	-
16	2 Aug	24.3	76.6	-	-	-	23	78	20	35	23.3	73.3	10	20
17	11 Sep	18.6	86	17.3	84	1000	19	82.5	25	20	22.5	85.5	30	20
18	12 Sep	21	85	20	84	990	18.5	86.5	25	35	21	83	40	25
19	13 Sep	22	82.5	20	84.7	1000	19	86.2	40	45	21.7	81.7	50	35
20	14 Sep	23	80	21.5	83.5	1000	20.9	85.2	45	35	22.2	81.7	35	30
21	15 Sep	25.5	78	22.5	79	1000	22.5	83	30	30	27.5	82.1	20	15
22	16 Sep	28	78	-	-	1000	-	-	-	-	25.8	76	15	40
23	17 Sep	28.8	78.2	-	-	-	27	75	30	30	-	-	15	20
24	16 Sep	19.3	93.1	-	-	-	-	-	-	-	18.5	93	30	30
25	17 Sep	20.5	90	20	89.5	1000	18	92	25	35	26.1	76.7	20	25
26	18 Sep	19.5	86.5	20	87.5	995	-	-	-	-	24	84.3	25	10
27	19 Sep	18.5	83.5	21	83	1000	20	83.5	30	30	16	89.5	25	40
28	20 Sep	19	80.5	19	82	995	-	-	-	-	20	86	30	45
29	21 Sep	21	76	20.5	80.5	1000	20	81	20	25	20.8	83	15	25
30	22 Sep	21.7	74.8	17	78	1005	21	78.5	10	15	23	78	15	25

TABLE 2

Predicted and realized rainfall parameters associated with monsoon depressions/storms during 2005

S. No.	Date	MM5-predicted 72 hr rainfall				T-80-predicted 72 hr rainfall				Realized rainfall			
		Central location of max. rainfall zone		Average rainfall	Maximum rainfall	Central location of max. rainfall zone		Average rainfall	Maximum rainfall	Central location of max. rainfall zone		Average rainfall	Maximum rainfall
		Lat (°N)	Long (°E)	(cm)	(cm)	Lat (°N)	Long (°E)	(cm)	(cm)	Lat (°N)	Long (°E)	(cm)	(cm)
1	28 Jun	24.1	89.9	1.3	4.3	22.8	87.7	1.9	4.3	21	86.6	8.3	11
2	29 Jun	22.5	86.4	1.2	4.3	21.4	85	2.5	4	21.8	83.5	5	5
3	30 Jun	22.4	84.4	1.8	5.3	22.8	84.2	2.2	4.4	23.1	83.4	6	6
4	1 Jul	23.3	82	1.9	5.4	23.4	81.4	2.8	6.7	23	80.8	2	2
5	2 Jul	22.4	81.9	1.81	3.5	23	80.7	1.6	2.6	24	80.2	13	19
6	3 Jul	-	-	-	-	22.5	82.7	1.8	3	24	78.5	11.25	19
7	4 Jul	24	79	1.4	3	24	83.5	2	5.5	23	78.9	18.4	48
8	5 Jul	27	81.1	1.9	6.1	29.5	77.5	4.5	9.9	23.3	78	11.5	19
9	6 Jul	27.4	80	2	3.9	28.4	78	3.3	8.5	24.4	77.8	9.2	13
10	7 Jul	30.3	77.9	1.8	5.3	28.8	76.8	1.7	2.7	25.8	76.2	9.6	15
11	29 Jul	22.9	88.4	2.5	6.4	23.1	88.3	0.4	0.6	20.9	86.8	13.6	25
12	30 Jul	22.5	87.5	2.1	3.7	22	81	2.1	3	21	86.2	16	31
13	31 Jul	23.2	85.9	1.9	3.7	21.5	79.6	1.92	3	20.5	85.6	13.3	31
14	1 Aug	21.7	83.7	1.19	3	20.5	81.2	1.8	3.5	22.8	79	5	8
15	2 Aug	22.5	78	1.3	5.3	22	79	1.6	2.4	22	77	1.8	3
16	3 Aug	23.2	77.6	0.9	3.0	21.1	79.5	1.6	2.2	22.5	73	3.1	7
17	12 Sep	22.5	86.5	3.5	11.4	22.5	86	0.6	1	18.8	84.4	10.2	30
18	13 Sep	22	84.2	2.8	7.5	22	82	1.7	2.8	20	83	11.9	27
19	14 Sep	22	82	1.5	3.8	22.5	83	4.5	8.3	20.8	81	11	27
20	15 Sep	22	85	2.2	6.3	23.5	82	3.7	6.5	22.3	78.4	10.7	19
21	16 Sep	26.5	82	1.2	4	-	-	-	-	23.8	78	10.6	20
22	17 Sep	27.5	78.5	3.2	6.1	-	-	-	-	29.4	77.6	13.3	27
23	18 Sep	25.9	76.7	2.2	8.0	-	-	-	-	29.8	78.5	9	13
24	17 Sep	24	82.8	1.6	3	-	-	-	-	19.7	84	1.7	5
25	18 Sep	-	-	-	-	-	-	-	-	20.8	87.1	9.7	15
26	19 Sep	24	86	1.1	3.6	-	-	-	-	19	84.8	12.6	35
27	20 Sep	-	-	-	-	-	-	-	-	17	82	19	49
28	21 Sep	-	-	-	-	16.5	80.5	1.4	2	18.3	78	7.9	19
29	22 Sep	21.1	84.4	1.2	6.6	21.8	86.4	2.5	6.4	20.2	75.3	6	17
30	23 Sep	23.5	78	0.8	1.9	23	78	1.5	2.7	20.2	74.2	1.5	5

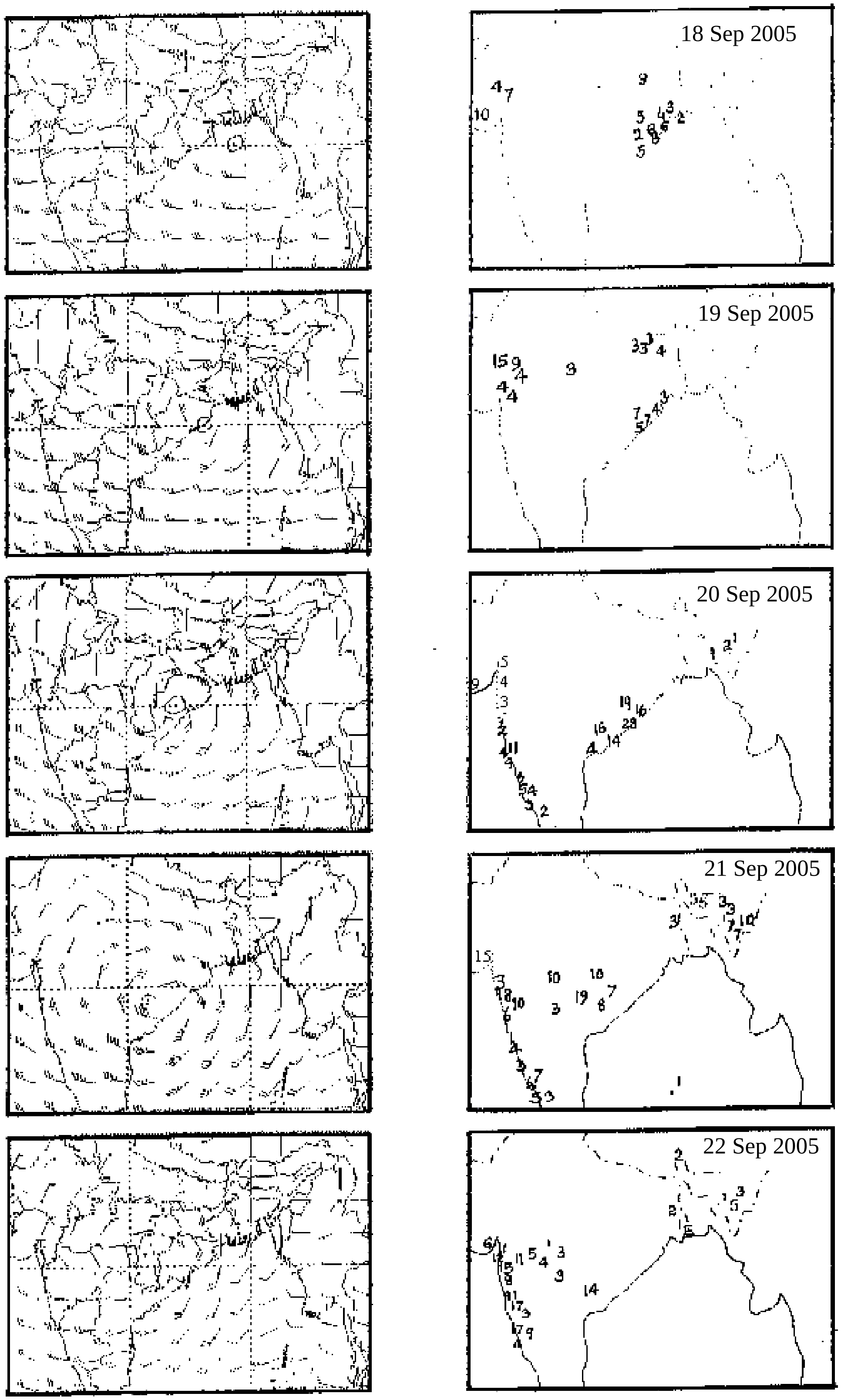

Fig. 2. ECMWF-predicted winds at 850 hPa (1200 UTC of previous day) along with realized rainfall associated with the cyclonic storm during 17-22 September, 2005

TABLE 3

Correlations between different predictors and the actual location of the system and realized rainfall

S. No.	Predictor (X)	Predictand (Y)	Correlation coefficient		Regression equation	
			Latitude	Longitude	Latitude	Longitude
1.	ECMWF-predicted 72 hr MSL position of centre of the system	Actual Position of the centre of the system	0.87	0.83	$Y = 0.90X + 2.76$	$Y = 1.03X + 2.84$
2.	ECMWF-predicted 72 hr MSL position of centre of the system	Actual central location of the realized rainfall zone associated with the system	0.77	0.84	$Y = 0.69X + 6.40$	$Y = 1.05X - 0.01$
3.	ECMWF-predicted 72 hr position of the centre of cyclonic circulation at 850 hPa	Do	0.76	0.61	$Y = 0.72X + 0.62$	$Y = 0.60X + 31.57$
4.	MM5-predicted 72 hr position of the centre of cyclonic circulation at 850 hPa	Do	0.68	0.47	$Y = 0.61X + 7.61$	$Y = 0.36X + 50.90$
5.	MM5-predicted 72 hr position of the centre of rainfall zone associated with the system	Do	0.62	0.77	$Y = 0.91X + 0.95$	$Y = 0.91X + 4.85$
6.	T-80-predicted 72 hr position of the centre of rainfall zone associated with the system	Do	0.60	0.44	$Y = 0.41X + 12.46$	$Y = 0.59X + 32.22$
7.	MM5-predicted average rainfall associated with the system	Actual average rainfall associated with the system	0.27			

the positions differed significantly. On 22nd again the predicted and actual positions were very close to each other. It may be mentioned here that Fig. 2 depicts only predicted and actual tracks of the system from 17-22 September and not the intensity and therefore, continuous and broken lines do not indicate the intensity. On 22nd September the system had weakened into a well marked low pressure area.

The 72 hr predicted positions were used in the identification of districts that were likely to be affected by the heavy rainfall associated with the monsoon cyclone. It is seen from Table 3 that the correlation between the ECMWF-predicted 72 hr MSL position and actual position of the system is very high. The latitude correlation is 0.87 and longitude correlation is 0.83 (both significant at the 99% level).Therefore, the trials during 2005 monsoon have shown that the positions predicted by the ECMWF 3 days in advance is a potential input to the value addition during the periods of monsoon depressions/storms.

3.2. *Correlations between predicted positions and the location of realized rainfall*

The correlations between the 72 hr predicted positions (MSL and 850 hPa) and the location of realized rainfall have been presented in Table 3. Significant correlations were found between the ECMWF-predicted MSL position and the central location of the realized rainfall. The latitude correlation was 0.77 and the longitude correlation was 0.84, both being significant at the 99% level. Even the 72 hr ECMWF-predicted positions at 850 hPa could provide good indications of the districts which were severely affected by the system. The latitude correlation between ECMWF-predicted 72 hr 850 hPa position and the central location of realized rainfall was 0.76 and the corresponding longitude correlation was 0.61. The correlation between MM5 predicted position at 850 hPa and the location of the realized rainfall have also been presented in Table 3. The latitude and longitude correlations are 0.68 and 0.47, respectively which are lower than respective correlations of ECMWF outputs. The model output statistics presented here has shown that by the judicious use of ECMWF-predicted positions of the monsoon systems at MSL and 850 hPa it is not difficult to identify the districts that are likely to be severely affected by the systems 3 days in advance (Table 3 and Fig. 2).

3.3. *Correlations between 72 hr predicted and actual locations of the rainfall zone*

Table 2 presented the predicted and realized rainfall parameters associated with monsoon depressions and storms during 2005. As ECMWF-predicted rainfall was not available the correlation of MM5 and T-80 predicted locations of rainfall with actual location were computed which are presented in Table 3. The correlation of MM5 output is better. The latitude and longitude correlations are 0.62 and 0.77 respectively. The corresponding correlations of T-80 outputs are 0.60 and 0.44 showing that T-80 could not predict the westward movement of the rainfall zone well. It is evident from Table 3 that the best model output for the identification of districts severely affected by the monsoon depressions/storms was ECMWF-predicted 72 hr MSL position of the centre of the system. The ECMWF-predicted position at 850 hPa faired not so well in anticipating the westward movement of the realized rainfall zone associated with the system as the longitude correlation between predicted 850 hPa position and the location of realized rainfall zone was only 0.61 against the corresponding correlation of MSL position of 0.84.

3.4. *Correlation between 72 hr predicted rainfall and actual rainfall amounts*

As mentioned earlier the identification of districts that were likely to be affected by the heavy rainfall associated with monsoon depressions and storms is not difficult provided that different model outputs are utilized properly. The most challenging task, however, is the prediction of maximum and average rainfall associated with these monsoon systems. The trials using the available rainfall predictions of different models showed that none of the models could predict the rainfall amounts accurately. As ECMWF-predicted rainfall was not available, the rainfall amounts predicted by MM5 and T-80 were used in the computation of correlations with actual rainfall amounts. It is seen from Table 3 that correlation between MM5-predicted (72 hr) average rainfall and the actual average rainfall associated with monsoon systems was only 0.27. The correlation of T-80 predicted rainfall amount with actual amount was insignificant. Similarly, the correlations between predicted maximum rainfall and actual maximum rainfall associated with monsoon systems were also very poor. Therefore, as far as forecast of rainfall amount associated with monsoon depressions and storms was concerned, none of the models could provide good predictions which shows that the value addition using other inputs like climatology, satellite information synoptic charts etc is very important in the forecast of actual rainfall amounts associated with monsoon systems.

4. Conclusions

(*i*) The ECMWF-predicted 72 hr MSL position of the centre of Monsoon Depression/Storm was found to be significantly correlated with the central location of the realized rainfall zone associated with the system. Even 850 hPa positions predicted by the ECMWF 3 days in advance could be used in value addition for the identification of districts that were likely to be affected by the heavy rainfall associated with monsoon system.

(*ii*) The correlation between the ECMWF-predicted MSL position of the centre and the actual MSL position of the centre was highly significant.

(*iii*) None of the model outputs like predicted maximum winds in the lower troposphere (at 850 hPa) or predicted rainfall amount (MM5 and T-80) could yield good correlations with the actual rainfall amounts associated with monsoon systems which shows that the value addition using other inputs like climatology, satellite and synoptic information is very important in the forecasting of rainfall amounts associated with monsoon depressions and storms.

(*iv*) The most difficult task is the forecasting of maximum rainfall associated with monsoon depressions and storms as none of the model outputs could provide good correlations with realized maximum rainfall. The forecasting of average rainfall associated with these monsoon systems in affected area is less challenging.

References

Chang, P. and Krishnamurti, T. N. (Eds.), 1987, “Monsoon Meteorology”, Oxford Monographs in Geology and Geophysics, No.7, Oxford Univ. Press.

Jadhav, S. K., 2002, “Summer monsoon low pressure systems over the Indian region and their relationship with the sub-divisional rainfall”, *Mausam*, **53**, 177-186.

Lal, B., Singh, O. P., Prasad, O., Roy Bhowmik, S. K., Kalsi, S. R. and Subramanian, S. K., 2006a, “District level value-added dynamical-synoptic forecast system for rainfall,” *Mausam*, **57**, 209-220.

Lal, B., Singh, O. P. and Prasad, O., 2006 b, "Value addition in district level dynamical forecast during intense rainfall spells over the west coast of India", *Mausam*, **57**, 3, 411-418.

Pisharoty, P. R. and Asnani, G. C., 1957, "Rainfall around monsoon depression in India," *Indian J. Met. & Geophys*., **7**, 333-338.

Rao, Y. P., 1976, "Southwest monsoon," India Meteorological Department meteorological monograph synoptic meteorology, No.1/1976, New Delhi, p367.

Saha, K. R., Sanders, F. and Shukla, J., 1981, "Westward propagating predecessors of monsoon depressions", *Mon. Wea. Rev*., **109**, 330-343.