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District-level forecast of northeast monsoon rainfall over Tamilnadu using Indian Ocean dipole mode index

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सार – तमिलनाडु में उत्तर पूर्वी मानसून ऋतु (अक्तूबर से दिसम्बर) के दौरान हुई वार्षिक वर्षा के प्रतिशत का काफी योगदान रहता है। इस शोध पत्र में पर्याप्त आगे आने वाले समय तक छोटे स्थानिक मान अर्थात् जिला स्तर पर तमिलनाडु में उत्तरपूर्वी मानसून वर्षा (एन.ई.एम.आर.) का पूर्वानुमान लगाने की पद्धति को प्रस्तुत किया गया है। पूरे तमिलनाडु को एक समान दस जिलों के समूहों में बांटा गया और प्रत्येक समूह के लिए भारतीय समुद्री द्विध्रुव पद्धति (आई.ओ.डी.एम.) का उपयोग करते हुए दो और एक महीने के आगे आने वाले समय तक के लिए पूर्वानुमान लगाया गया। तमिलनाडु के अधिकांश जिलों में अगस्त–सितम्बर के दौरान आई.ओ.डी.एम. का प्रबल पश्चिमी ध्रुव उत्तरपूर्वी मानसून गतिविधि से व्यापक रूप से संबंधित होता है। एन.ई.एम.आर. और आई.ओ.डी.एम. सूचकांक के आँकड़ों से विकसित किए गए समाश्रयणों के आधार पर ये पूर्वानुमान वर्ष 1997–2002 तक 6 वर्षों के लिए मान्य होते हैं। अधिकांश जिलों में वास्तविक (प्राप्ति) और पूर्वानुमानित वर्षा के मध्य मान की त्रुटियाँ 10 प्रतिशत की घट–बढ़ के साथ रहती है। तथाति केवल कन्याकुमारी में एन.ई.एम.आर. के अपवाद को छोड़कर, क्योंकि वहाँ पर ये आई.ओ.डी.एम. परिघटना के साथ विशेष रूप से जुडे हुए नहीं हैं, तमिलनाडु के अधिकाँश जिलों में दो महीने आगे आने वाले समय तक के लिए आई.ओ.डी.एम. सूचकांक का उपयोग करते हुए एन.ई.एम.आर. की गतिविधि का पूर्वानुमान लगाना संभव है।

ABSTRACT. The northeast monsoon season (October-December) contributes a substantial percentage of annual rainfall over Tamilnadu. The present paper describes a method for prediction of northeast monsoon rainfall (NEMR) over Tamilnadu on smaller spatial scale, *i.e*., district-level with sufficient lead time. Tamilnadu has been divided into ten homogeneous clusters of districts and the predictions are made for each cluster with lead times of two and one months using Indian Ocean dipole mode (IODM) index. A stronger western pole of IODM during August-September is associated with enhanced northeast monsoon activity over most of the districts of Tamilnadu. The predictions on the basis of regressions developed from NEMR and IODM index data have been validated for six years from 1997-2002. For many districts the mean errors between actual (realized) and predicted rainfall are within ±10%. Hence, using IODM index, it is possible to predict the NEMR activity over most of the districts of Tamilnadu with a lead time of two months, with only exception of NEMR over Kanyakumari which is not significantly correlated to IODM phenomenon.

Key words – Northeast monsoon rainfall (NEMR), Indian Ocean dipole mode (IODM), Cluster, Sea surface temperature (SST), Validation, Forecast skill.

1. Introduction

As the Indian Ocean (IO) is the main source of moisture for monsoon rains over the Indian subcontinent, it is reasonable to assume that the sea surface temperature (SST) and sea level pressure anomalies over the Indian Ocean would have profound influence over the weather and climate of the subcontinent (Suppiah, 1988; Singh, 1995 and Ashok *et al.*, 2001). Recent studies by Saji *et al.*, 1999 and Webster *et al.*, 1999 have established the existence of an ocean-atmosphere mode in the Indian Ocean known as IODM. As the IODM generally peaks during September-November, it seems to modulate the northeast monsoon rainfall (NEMR) over India and Sri Lanka (Saji and Yamagata, 2003a; Zubair *et al.*, 2003; Kripalani and Kumar, 2004). Warmer SST anomalies in the western pole (50° - 70° E, 10° S - 10° N) and the colder SST anomalies in the eastern pole (90° - 110° E, 10° S - Equator) are associated with enhanced NEMR activity.

The wind pattern associated with positive phase of IODM suggests easterly anomalies over the equatorial

TABLE 1

Clusters of districts in Tamilnadu

S. No.	Name of the district	Cluster No.
1	Chennai	1
2	Kanchipuram	
3	Tiruvallur	
4	Tiruvannamalai	2
5	Vellore	
6	Villupuram	
7	Cuddalore	3
8	Nagapattinam	
9	Tiruvarur	
10	Pondicherry	
11	Dharmapuri	4
12	Salem	
13	Namakka	
14	Karur	5
15	Pudukottai	
16	Perambulur	
17	Tiruchimpalli	
18	Thanjavu	
19	Coimbatore	6
20	Erode	
21	Madurai	7
22	Theni	
23	Virudhunagar	
24	Dindigul	
25	Sivaganga	
26	Nilgiri	8
27	Ramanathapuram	9
28	Tuticorin	
29	Tirunavelli	
30	Kanyakumari	10

Indian Ocean and enhanced transfer of moisture from the eastern equatorial Indian Ocean to the southern parts of India which is favourable for good NEMR activity.

The prediction of monsoon rains on smaller spatial scales, *i.e.*, district-level or for cluster of districts is very much required for a variety of user application (Lal *et al.*, 2006). As the northeast monsoon rainfall is very important for Tamilnadu, it would be desirable to have NEMR forecast for each district of Tamilnadu one or two months in advance. The present study has shown that IODM indices of August-September have useful predictive applications for this purpose. A watch on the evolution of IODM phenomenon during August-September can provide predictive indications of NEMR over Tamilnadu on district/cluster level.

It is interesting to note that a large-scale phenomenon like IODM can influence the northeast monsoon rainfall over homogeneous clusters of districts differently. The characteristic features of rainfall over coastal districts of Tamilnadu are entirely different from those over its western interior districts. Due to this there was a need for clustering of districts according to the rainfall characteristics. The impact of IODM varies from cluster to cluster due to location and local peculiarities. However, there is uniformity in the impact in the sense that correlations for all clusters are positive. In other words, positive phase of IODM is conducive for enhanced rainfall over all the districts. The percentage of enhancement may vary from cluster to cluster. The main aim of the present work is to determine that.

2. Data and methodology

For the preparation of district level NEMR time-series, the NEMR data for each district of Tamilnadu has been processed and analysed for the 33-year period from 1972-2004. Ten homogeneous clusters of districts have been identified on the basis of NEMR characteristics. Clustering of districts has been made on the basis of inter-correlations between NEMR rainfall of different districts. The districts falling in a particular cluster have similar NEMR characteristics in the sense that their rainfall are highly inter-related (correlation coefficient more than +0.9). Cluster-wise distribution of districts has been shown in Table 1.

The time-series of monthly IODM indices derived from GISST data have been used (Saji and Yamagata, 2003b). The IODM index is defined as the difference in the SST anomaly between tropical western Indian Ocean (50° - 70° E, 10° S - 10° N) and tropical southeastern Indian Ocean (90° - 110° E, 10° S - Equator). The

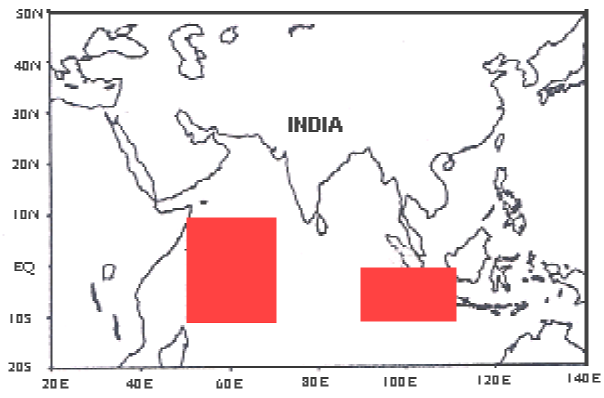

Fig. 1. Western and eastern poles of Indian ocean dipole

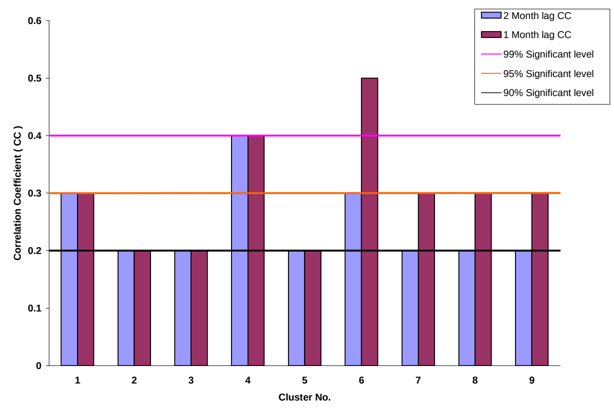

Fig. 2. Lag correlations between IODM index and cluster-wise seasonal NEMR over Tamilnadu

locations of western and eastern poles of IODM are shown in Fig. 1.

The lag correlation between IODM indices and NEMR for each cluster have been computed. The relationships between August-September IODM indices with seasonal NEMR over each cluster have been used to develop regressions for individual clusters.

3. Results and discussion

3.1. *IODM-NEMR relationships*

The results show that a positive phase of IODM prior to northeast monsoon season is conducive for enhanced NEMR over Tamilnadu. The relationship is quite consistent in the sense that even monthly NEMR over Tamilnadu during each month of the season *i.e*., October, November and December has positive correlations with past one-two months IODM indices. But the focus of the present work is to explore the feasibility of applicability of such relationships for forecasting of district-level seasonal rainfall over Tamilnadu with one-two months leadtime.

The lag correlations between IODM indices during August-September and cluster-wise seasonal NEMR alongwith significant levels are shown in Fig. 2 and Table 3. The correlations range from 0.2 to 0.5. For some clusters one-month lag correlations are higher than two-month lag correlations. For clusters 1, 4 and 6-9 comprising of 18 districts one-month lag correlations are significant at the 95% level. Highest correlations have been found for clusters 4 and 6 comprising 5 districts. For NEMR over the districts falling in clusters 1, 4 and 6 the IODM index has useful predictive indications even 2 months in advance. For the districts in three clusters, *i.e.*, 2, 3 and 5 the IODM-NEMR correlation do not improve with the reduction of leadtime, *i.e*., from two-months to one-month.

The NEMR over Nilgiri and Kanyakumari district have unique characteristics. Hence these districts are put separately in cluster numbers 8 and 10. The NEMR over Kanyakumari is not significantly correlated to the IODM index. The lag correlation (one/two months) of NEMR over Kanyakumari with IODM indices is only +0.1. Therefore, the validation results have been presented for 9 clusters only and Kanyakumari has been excluded.

It is true that most of the correlations range from 0.2-0.3 only (Fig. 2 and Table 3). But these are robust due to sufficiently large number of years considered, *i.e*., 33 years. The present work has shown that it is possible to predict the category of rainfall, *i.e*., Excess, Normal, etc. accurately with these type of correlations. Let us recall that the rainfall departure from –19% to +19% is considered Normal. However, it may be admitted that it would be difficult to predict the exact percentage with such correlations. But that is not the aim of our work. The prediction of rainfall category for each cluster with lead time of one/two months is the objective.

3.2. *Validation results*

3.2.1. *Two months leadtime forecasts*

Fig. 3 depicts the errors in predicted NEMR over different clusters using IODM index for August (*i.e*., two-

TABLE 2

Forecast validation results for clusterwise forecast for the period 1997-2002

Cluster No.	Based on August IODM Index			Based on September IODM Index		
	Very Good (0)	Skillful (%) (±1)	Not Skillful (±2)	Very Good (0)	Skillful (%) (±1)	Not Skillful (±2)
1	50	50	0	50	50	0
2	50	50	0	50	50	0
3	50	50	0	67	33	0
4	17	83	0	33	67	0
5	50	50	0	50	50	0
6	33	67	0	33	67	0
7	50	50	0	50	50	0
8	50	33	17	50	33	17
9	50	50	0	50	50	0

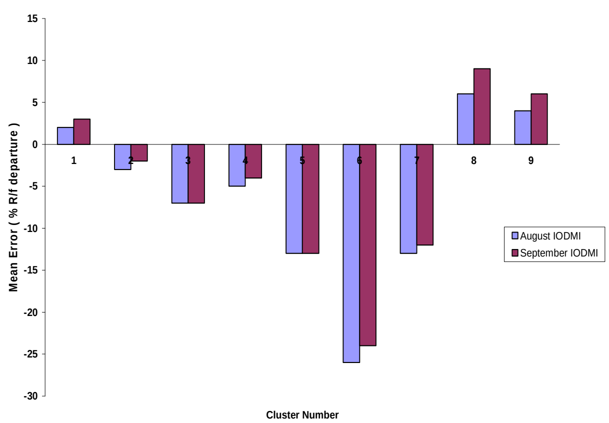

Fig. 3. Clusterwise forecast skill for seasonal northeast monsoon rainfall over Tamilnadu using Indian Ocean Dipole Mode (IODM) index

TABLE 3

Significant correlations between IODM index and seasonal NEMR over different district clusters of Tamilnadu

Cluster No.	Correlation Coefficient		*Significance level (%)
	One month lag	Two month lag	
1	0.3*	0.3*	95
4	0.4*	0.4*	99
6	0.5*	0.3*	99 & 95
7	0.3*	0.2	95
8	0.3*	0.2	95
9	0.3*	0.2	95

months leadtime). Cluster-wise mean errors (predicted minus actual) for the 6-year validation period (1997-2002) are +2%. -3%, -7%, -5%, -13%, -26%, -13%, +6% and +4% respectively (Fig. 3.). Thus the mean error for all the districts of Tamilnadu (except Kanyakumari) would be about -6% which shows that the model generally predicts less rainfall than the actual. For instance, during 1997 the actual (realized) NEMR was excess (+20% to +59%) over the clusters 1 and 3-9 whereas it was normal (-19% to +19%) over cluster 2. The predicted rainfall was excess over clusters 1, 6 and 8-9 only whereas it was normal over the clusters 2-5 and 7. Hence the category-wise skill of NEMR was 100% over five clusters. Over remaining four clusters it was out by only one stage, *i.e.*, predicted rainfall was normal whereas actual rainfall was excess. Barring few exceptions this type of trend was observed during remaining years of validation, *i.e.*, 1998-2004. Total validation period of six years comprises 54 cluster-wise forecasts, out of which 24 category-wise forecastsare 100% accurate (*i.e.*, predicted and actual rainfall are in the same category) whereas 30 forecasts are out by only one stage. No forecast is out by more or equal to two stages. Hence so far as district/cluster level forecast of rainfall category is concerned, *i.e.*, excess, normal etc., it is possible to make reasonably accurate prediction with a leadtime of two months using August IODM SST index.

Cluster-wise forecast skill for the period 1997-2002 has been presented in Table 2. The forecast is considered very good if the predicted and realized rainfall are in the same category *i.e*., excess, (+20% to 59%) normal (-19% to +19%), deficient (-20% to -59%) and scanty (-60% or less) implying that there is no difference in category (*i.e*., 0). Similarly, if the forecast is out by one category (±1) it is considered skillful, and it is not skillful if the forecast is out by two categories or more (±2 or more).

It is seen from Table 2 that for most of the clusters, *i.e*., for 7 clusters two-months lead forecast accuracy is 50% in very good category and 50% in skillful category. Unskilled or not skillful forecast percentage for these 7 clusters is zero. Very good forecast percentage is lowest for cluster 4 for which 17% forecast is in not skillful category. Thus for most of the districts it is possible to generate very good and skillful forecasts of NEMR category two-months in advance using August IODM index. When the leadtime is reduced from two months to one-month there is a slight improvement in the forecast skill for some clusters.

3.2.2. *One-month leadtime forecasts*

Validation results for one-month lead time are presented in Table 2 and Fig. 3. The results vary from cluster to cluster. For instance, for clusters 2, 4, 6 and 7 there is a slight reduction in the mean error between predicted and actual NEMR whereas for remaining clusters there is a slight enhancement in the mean error. However, for cluster 6 which has mean error more than -20%, there is a slight improvement in the forecast, *i.e*., a reduction from -26% to -24%. Also, there seems to be a general reduction in the bias towards lesser rainfall forecast when September IODM index is considered. The mean error for all 29 districts would come out to -5% against the corresponding value of -6% when August index was considered.

It is seen from Table 2 that the average percentage of one-month leadtime very good forecast for clusters 1-3, 5 and 7-9 is about 52% against 50% of two-months leadtime forecasts. The percentage of very good forecast for cluster 4 went up to 33% from 17% when leadtime reduced from two-months to one-month. Therefore, one-month leadtime forecasts are better for clusters 3 and 4 comprising the districts of Cuddalore, Nagapattinam, Tiruvarur, Pondicherry, Dharmapuri, Salem and Namakkal. For remaining districts two-months lead forecasts are as good as one month leadtime forecasts showing that IODM index of August holds useful signals for prediction of the seasonal NEMR over different districts of Tamilnadu.

It may be pointed out that the inter-annual variability of the predicted rainfall over most of the clusters is less than the variability observed in the actual rainfall, especially during the period 1999-2002. This may be due to relatively smaller inter-annual variability in the actual rainfall itself, especially during the period 2000-2002 (the actual rainfall over cluster 3 was around 80% during all the three years, over clusters 4 and 7 it was 60-80% and over cluster 5 it was 100-110%). However, it is true that the model is not able to capture large inter-annual variations well. The validation for some more extreme northeast monsoon years will bring out more definite conclusions in this regard when more district-level rainfall data becomes available in future.

4. Conclusions

The study has brought out the following results:

(*i*) A stronger western pole of the Indian Ocean dipole (warmer SST anomalies) during August-September is associated with enchanced subsequent northeast monsoon rainfall activity over most of the districts of Tamilnadu. The easterly anomalies over the equatorial Indian Ocean and enhanced transfer of moisture from the eastern equatorial Indian Ocean to the southern parts of India during stronger western pole periods is favourable for good NEMR activity.

(*ii*) It is possible to forecast the northeast monsoon activity (in terms of excess, normal etc.) over most of the districts of Tamilnadu with reasonable degree of accuracy with a leadtime of two-months using Indian Ocean dipole mode index of August.

(*iii*) The forecast using September Indian Ocean dipole mode index yields slight improvements over the districts of Cuddalore, Nagapattinam, Tiruvarur, Pondicherry, Dharmapuri, Salem and Namakkal. Over the remaining districts two months lead forecasts are as good as one-month lead forecasts.

(*iv*) It is interesting that northeast monsoon rainfall over Kanyakumari is not significantly correlated to Indian Ocean dipole phenomenon whereas the correlations for all other 29 districts are statistically significant.

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