TECHNICAL MEMORANDUM

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Prediction of monsoon rainfall over India by the ECMWF model

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1. INTRODUCTION

There have been a number of studies to evaluate the forecast errors of tropical circulation features using operational ECMWF forecast models (Heckley, 1985; Kanamitsu, 1985), but all these studies considered the tropics in general.

Hollingsworth, et al. (1985) evaluated the ECMWF analysis/forecast for a few typical synoptic weather situations over the Indian subcontinent and concluded that

i) during winter, forecast movement of large scale features like troughs and areal coverage of precipitation is satisfactory,

ii) the forecasting of tropical cycle and monsoon depression was partially successful (forecast direction of movement was closer to the actual, but the speed was not) though precipitation forecast was not good.

Recently Datta et al. (1986) carried out an analysis to evaluate the performance of the ECMWF model to predict the monsoon flow pattern over India. A detailed study was carried out on the systematic errors during the monsoon period of 1985 (June-August, 1985). The performance of the model in cases of typical monsoon situations in 1985 was also examined. Important conclusions were:

i) The significant errors are generally over the regions of sparse data. The structure of error pattern is such that there is a tendency of development of anti-cyclonic vorticity over the bay of Bengal and cyclonic vorticity over the northern region of the west coast of India and the adjoining Arabian Sea. The model also has a tendency to increase the speed of low level jet (west to southwesterly winds at 850 mb) and weaken the tropical easterly jet (TEJ) at 200 mb.

ii) The ECMWF forecast could in general be used operationally for forecasting the monsoon flow pattern for a period of 1-3 days.

Systematic errors and use of operational rainfall forecasts were also studied by various workers for different regions. Åkesson (1981), Åkesson et al. (1982) and Johannessen (1982) studied the prediction of rainfall over Europe. Heckley (1981) carried out a similar study for the tropical region. Recently

Molteni and Tibaldi (1985) studied the climatology and systematic errors of rainfall forecasts at ECMWF for 4 representative months, January, April, July and October for three years 1981 to 1983. The area considered by them was Europe. Some of the salient conclusions of their study are:

a) The forecasts underestimate mean global rainfall during the whole year, the error ranging form 5 to 15 percent. The magnitude of error decreases from 24 to 168 hr forecasts in January, increases during July and remains nearly constant in the intermediate season.

b) Too much rainfall is forecast over the continents both in the tropics and in northern mid-latitudes in summer.

c) The main errors in the geographical distribution are strongly related to the orography. In January, too little rainfall is generated on the windward side of the mountains and too much on the lee side, in July, there is excessive convective activity over the mountains.

The present study critically examines the error structure of the operational (ECMWF) rainfall forecasts over the Indian region during the monsoon of 1985.

2. DATA USED

The data used in the study are the operational grid point precipitation forecasts for 24 to 120 hrs from ECMWF for the period June to August, 1985. The forecast model used was the global spectral model with horizontal resolution of T106 and 15 levels in the vertical. The details are given by Simmons and Jarraud (1984) and Tiedtke and Slingo (1985).

For validation of the forecast, we used district average daily rainfall data collected from the various Meteorological Centres of the India Meteorological Department. Average district (total number of districts in the order of 400) rainfall is based on a number of raingauge stations in the district.

The ECMWF rainfall forecast is interpolated to the district location for comparison and evaluation of the forecast errors.

Specifically we considered the following features:

i) Occurrence of rainfall and its prediction at district level.

ii) Root mean square error for district, subdivision and country as a whole.

iii) Errors in forecasting rainfall associated with a monsoon depression.

iv) Systematic errors over various geographical locations for 24 to 72 hour forecasts.

v) The capability of the model to simulate total monsoon rainfall.

In Fig. 1(a) we present the district location and approximate boundary of the subdivision and in Fig. 1(b) we show a sample rainfall forecast by ECMWF.

3. ANALYSIS AND RESULTS

To illustrate the rainfall distribution in the country, in Figs. 2 and 3 we present normal rainfall during June and July respectively. June is the month of onset of the monsoon, the rainfall activity starts over Kerala coast by 1st of June and progresses northward so that by the end of June, most of the country outside west Rajasthan is under the grip of the monsoon rainfall. Thus during June, the main region of rainfall with more than 30 cm in the month is confined to the west coast of India south of 20°N and northeastern parts of the country.

During July, however, most of the country gets more than 30 cm rainfall, except the plateau region of Peninsular India and western parts of the country. The main centres of heavy rainfall over 150 cm are the west coast, and northeaster parts of India. There are other regions of lesser (greater than 50 cm) rainfall over central India: Himachal Pradesh and Hills of Uttar Pradesh. The distribution of rainfall during August is generally similar to the month of July.

3.1 Systematic errors (observed-predicted)

To compute the systematic errors, we worked out the mean forecast errors of precipitation for 24, 48 and 72 hour forecasts for the months of June to August, 1985. The isopleths for the errors for the months of June and July are presented in Figs. 4 to 9. Since features during August, 1985 were not significantly different than July, 1985, we will confine our discussion for the month of June and July only.

i) The distribution of systematic errors is generally similar in June and July. The area of negative error is more prominent and vast in July.

ii) The pattern of systematic errors is similar for the ensemble of forecasts for 24, 48 or 72 hours. The order of magnitude of error is greater for the 48 hour forecast than the 24 hour or 72 hour.

iii) The rainfall is overestimated in most regions, except over coastal parts of the country and states of Jammu and Kashmir and along the foothills of the Himalayas where rainfall is underestimated. 24 hour forecasts for all months and 48/72 hour forecast for the month of June, also depict underestimated of rainfall (+ve errors) over small pockets on west coast of India.

The main errors thus seem to be geographically distributed, that is in the regions of monsoon trough and along the west coast of India.

3.2 Root mean square errors

The order and pattern of RMSE is different in June and July, being smaller during June over most of the country. Exception is the coastal Maharashtra and Konkan area where more errors are observed during June than July. It may be recalled that June is the month when the monsoon is advancing in the country from the Kerala coast. In early June, most of the northern parts of the country is free of monsoon rain. By July, however, the whole country gets under the grip of the monsoon current. RMSE values are higher in July when the monsoon is active throughout the country. Moreover, during July the RMSE values of 20 mm and above are confined (for all validity 24, 48 and 72 hour) to the region of steep orography and the eastern part of the monsoon trough zone. One is tempted to guess that the errors are probably related to representation of orography in the model as well as parametrization of convection processes which dominate rainfall forming processes especially over and near the monsoon trough zone. For illustration in Table 1, we present RMSE values for the month of July, 1985.

3.3 Correlation between observed and forecast rainfall

We also computed correlation coefficients between the observed and predicted rainfall both at the district as well as the meteorological subdivision level. The results are not conclusive, because correlation coefficient values are generally low, even negative in some cases.

In order to further assess the quality of the rainfall forecast, we also computed (at district level) the accuracy of the prediction in the form of rain or no rain. Generally, it is found that in more than sixty percent of the cases, the prediction is correct. But how far these predictions have better skill than persistence? To understand we did hit and no hit skill analyses with respect to persistence. The results show that 48 and 72 hour forecasts have better skill than 24 hour forecast compared to the subdivision of Punjab, Himachal Pradesh, Jammu and Kashmir, Gujarat, Saurashtra, Rayalseema and Tamilnadu persistence gives better prediction than the model especially for 24 hours. This may be because most of these subdivisions have no or little rainfall during this period. July is apparently more predictable than June for all periods of validity. Persistence has better skill for 24/48 hour forecast only in the subdivisions which have a few days of rain during the period.

3.4 Simulated seasonal rainfall

It is interesting to also examine how the model performs in simulating the rainfall climatology of the area. In Figs. 10-12 we present total seasonal accumulated rainfall (June-August, 1985) based on 24, 48 and 72 hour forecasts respectively. For comparison, we also present in Fig. 13 the corresponding observed rainfall. The comparison brings out the following interesting points:

i) The general distribution of the rainfall is well simulated.

ii) The simulated rainfall, especially when based on 24 hour and 72 hr forecasts, shows smaller gradient than the actual rainfall over the region of Western Ghats, the extreme north-east region, Himachal Pradesh and adjoining foot hill areas.

iii) The centre of maximum rainfall over west coast areas agrees well with the 24 hr simulation (300 cm). 48 hr and 72 hr simulation rainfall is much higher, being 500 and 400 cm respectively.

3.5 Error statistics of rainfall associated with a monsoon depression (6-11 August, 1985)

In order to assess the accuracy of the forecast in case of rainfall associated with a typical monsoon depression, we present in Table 2, the mean error (difference) in rainfall forecast for 24 hr, 48 hr and 72 hr for the subdivisions which were under the influence of the monsoon depression. The track of the depression is presented in Fig. 1(b). The interesting points which emerge are:

i) In Orissa and Bihar Plains, the forecast rainfall is highly underestimated. It is also underestimated in Madhya Pradesh from 7 August onwards.

ii) It is overestimated in Vidarbha from 7 August onwards.

iii) In West Bengal the forecast is generally good during the first 3 days. It being overestimated from 9 August onwards.

It is difficult to interpret these variations, but can only indicate the limitation of the model to simulate the rainfall associated with a monsoon depression.

4. CONCLUDING REMARKS

The error analysis of the rainfall forecasts by the ECMWF model for the period of validity 24-72 hr over Indian area for the monsoon of 1985 leads us to the following tentative conclusions:

i) The total simulated rainfall for the season by the model is quite encouraging. The distribution and the area of maximum and minimum are well depicted.

ii) The error pattern has a geographical distribution related to orography and monsoon trough zone.

iii) The model is not able to simulate the high rate of precipitation associated with a monsoon depression. For example the model highly underpredicted the heavy rainfall over Bihar Plains during 6 to 8 August, 1985 and Orissa on 6 and 7 August, 1985.

iv) 72 hour forecasts seem to have better skill for hit or miss type of forecasts than 24 hr rainfall forecasts.

v) The error structure shows that the improvement in parametrization of convection and rainfall processes may help in considerably improving the rainfall forecasts.

Acknowledgements

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TABLE 1

Root mean square error (in mm) for July 1985

S. No.	Name of sub-division	RMSE for 24 hr F/C	RMSE for 48 hr F/C	RMSE for 72 hr F/C
(1)	(2)	(3)	(4)	(5)
1.	Arunachal Pradesh	40.5	40.5	41.0
2.	Assam and Meghalaya	35.8	35.0	37.4
3.	Naga., Mani., Mizo., Tripura	16.1	17.5	16.5
4.	SHWB and Sikkim	44.4	40.9	41.4
5.	Gangetic West Bengal	16.9	19.2	15.6
6.	Orissa	14.2	15.4	13.4
7.	Bihar Plateau	17.5	18.2	15.9
8.	Bihar Plains	27.1	24.9	24.3
9.	East Uttar Pradesh	17.8	13.9	17.0
10.	Plains of West U.P.	18.2	13.3	12.8
11.	Hills of West U.P.	16.1	16.6	17.8
12.	Haryana, Chandigarh and Delhi	13.8	15.2	14.3
13.	Punjab	22.0	24.2	23.9
14.	Himachal Pradesh	20.0	21.0	21.8
15.	Jammu and Kashmir	23.3	23.0	23.2
16.	West Rajasthan	10.0	11.0	12.0
17.	East Rajasthan	12.1	13.0	15.4
18.	West Madhya Pradesh	20.0	20.8	21.5
19.	East Madhya Pradesh	21.7	22.5	22.5
20.	Gujarat region	27.5	29.2	29.4
21.	Saurashtra, Kutch and Diu	24.6	24.2	22.4
22.	Konkan and Goa	47.9	57.1	43.6
23.	Madhya Maharashtra	21.4	35.8	26.4
24.	Marathwada	9.7	12.7	15.9
25.	Vidarbha	15.3	16.1	18.5
26.	Coastal Andhra Pradesh	8.9	10.6	13.7
27.	Telangana	10.6	12.3	16.6
28.	Rayalseema	8.6	14.5	17.0
29.	TamilNadu and Pondicherry	8.8	11.8	11.3
30.	Coastal Karnataka	31.1	47.3	32.9
31.	North Int. Karnataka	12.7	22.6	23.1
32.	South Int. Karnataka	12.1	24.8	21.7
33.	Kerala	16.2	20.8	18.3

TABLE 11

Mean errors in mm for a case of monsoon depression 6-11 August 1985

Sub-division	Date/ information type		6/8			7/8		9/8			10/8		11/8
			Err		Err		Err		Err		Err	Err	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
West Bengal	OBS	7.9	-	12.3	-	4.1	-	0.5	-	0.4	-	0.0	-
Based on 24-hr	F/C	10.9	-3.0	41.4	29.1	4.1	0.0	20.4	-19.9	0.8	-0.4	4.6	-4.6
28-hr	F/C	14.4	-6.5	8.2	4.1	12.1	-8.0	15.1	-14.6	6.9	-6.5	2.6	-2.6
72-hr	F/C	7.9	0.0	7.3	5.0	20.7	-16.6	2.1	-1.6	2.3	-1.9	2.4	-2.4
Orissa	OBS	65.2	-	60.7	-	12.3	-	4.2	-	2.0	-	2.4	-
Based on 24-hr	F/C	15.6	49.6	13.7	47.0	10.1	2.2	0.7	3.5	2.5	-0.5	7.4	-5.0
48-hr	F/C	15.6	49.6	25.5	35.2	22.0	-9.7	6.0	-1.8	3.3	-1.3	7.9	-5.5
72-hr	F/C	5.1	60.1	5.2	55.5	9.3	3.0	2.9	1.3	6.1	-4.1	3.9	-1.5
Bihar Plains	OBS	171.7	-	45.4	-	74.6	-	26.2	-	19.6	-	7.3	-
Based on 24-hr	F/C	11.4	160.3	5.2	40.2	9.3	65.3	8.8	17.4	17.3	2.3	12.7	-5.4
48-hr	F/C	11.7	160.0	6.1	39.3	5.3	69.3	12.8	13.4	18.3	1.3	12.5	-5.2
72-hr	F/C	11.8	159.9	10.1	35.3	8.4	66.2	13.1	13.1	7.8	11.8	12.1	-4.8

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
East Madhya Pradesh	OBS	10.5	-	13.1	-	49.0	-	63.5	-	10.6	-	8.1	-
Based on 24-hr	F/C	7.1	3.4	5.7	7.4	11.2	37.8	20.2	43.3	13.4	-2.8	5.9	2.2
48-hr	F/C	6.0	4.5	11.9	1.2	8.8	40.2	19.7	43.8	15.7	-5.1	7.6	0.5
72-hr	F/C	7.9	2.6	8.8	4.3	9.7	39.3	23.4	40.1	7.9	2.7	8.8	-0.7
West Madhya Pradesh	OBS	25.8	-	23.7	-	40.7	-	9.2	-	5.9	-	1.8	-
Based on 24-hr	F/C	12.9	2.9	10.3	13.4	17.9	22.8	13.6	-4.4	4.5	1.4	9.9	-8.1
48-hr	F/C	7.4	8.4	12.9	10.8	20.7	20.0	16.0	-6.8	8.1	-2.2	8.7	-6.9
72-hr	F/C	6.2	9.6	8.3	15.4	17.0	23.7	14.3	-5.1	5.4	0.5	6.3	-4.5
Vidarbha	OBS	3.5	-	14.2	-	18.2	-	4.9	-	0.0	-	5.7	-
Based on 24-hr	F/C	6.0	-2.5	10.6	3.6	13.4	4.8	6.7	1.8	19.5	-19.5	4.1	1.6
48-hr	F/C	8.7	-5.2	16.5	-2.3	12.0	6.2	13.3	-8.4	6.4	-6.4	8.9	-3.2
72-hr	F/C	8.2	-4.7	14.4	-0.2	16.9	1.3	20.1	-15.2	9.1	-9.1	9.5	-3.8

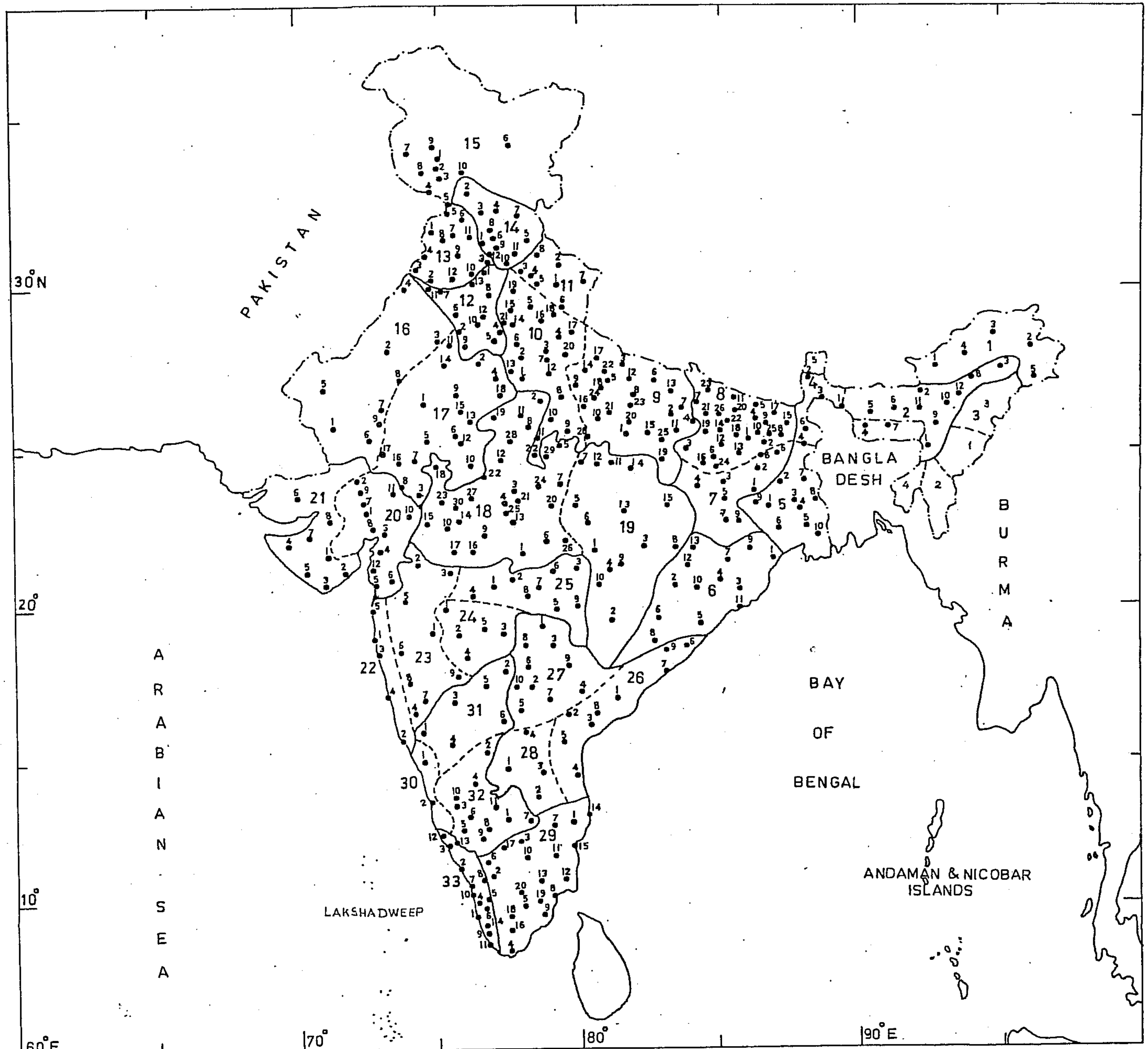
PAKISTAN
BANGLA DESH
BURMA
ARABIAN SEA
BAY OF BENGAL
LAKSHADWEEP
ANDAMAN & NICOBAR ISLANDS
30°N
20°
10°
60°E
70°
80°
90°E

FIG. 1(a)

120 HOUR FORECAST, 15/ 8/1985 12GMT INITIAL DATE(S)
1.121 1.125 LAT/LON GRID
TOT RAIN, SURFACE, MEAN (-24 TO 0 H) MM

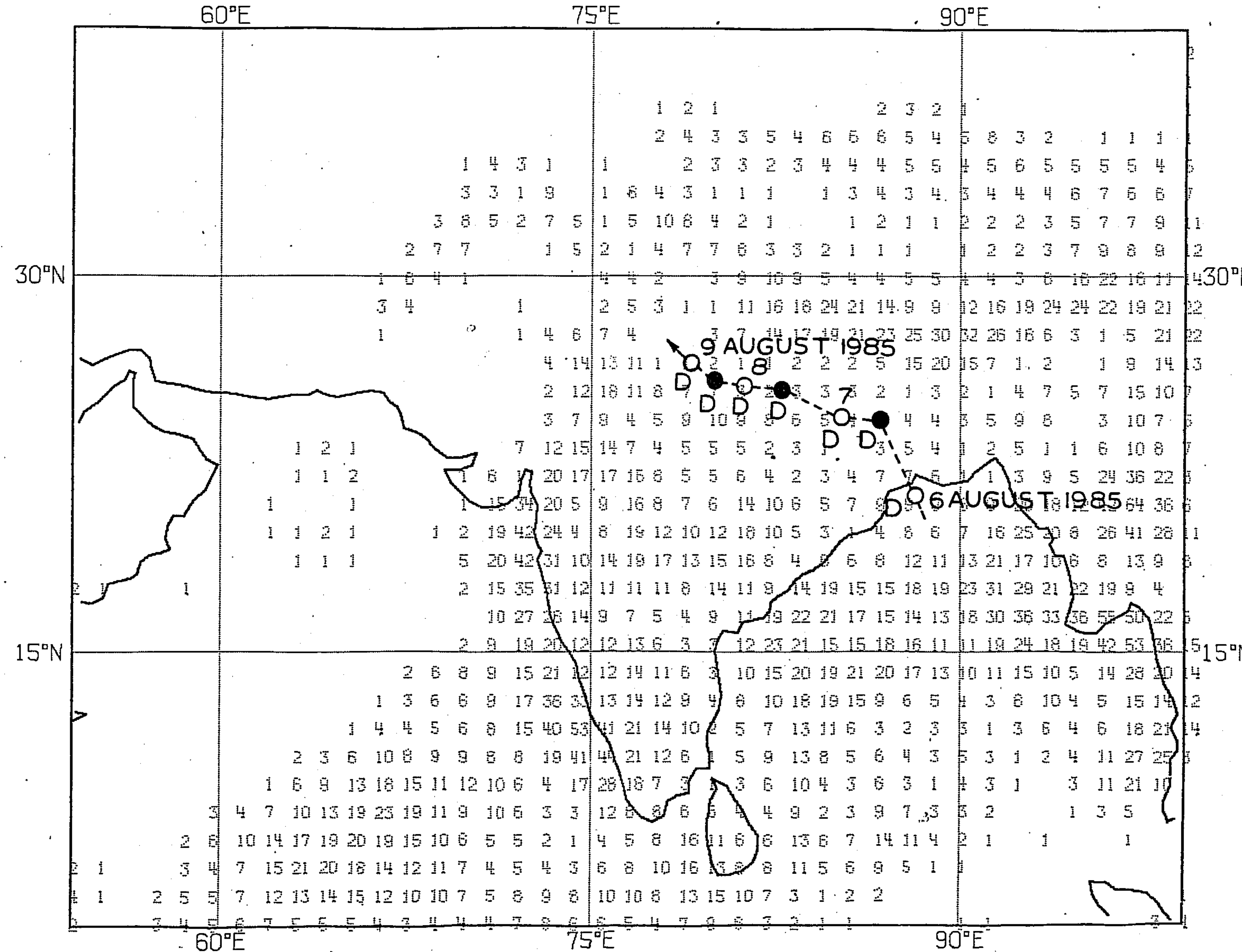

FIG. 1 (b)

NORMAL RAINFALL (Cm)

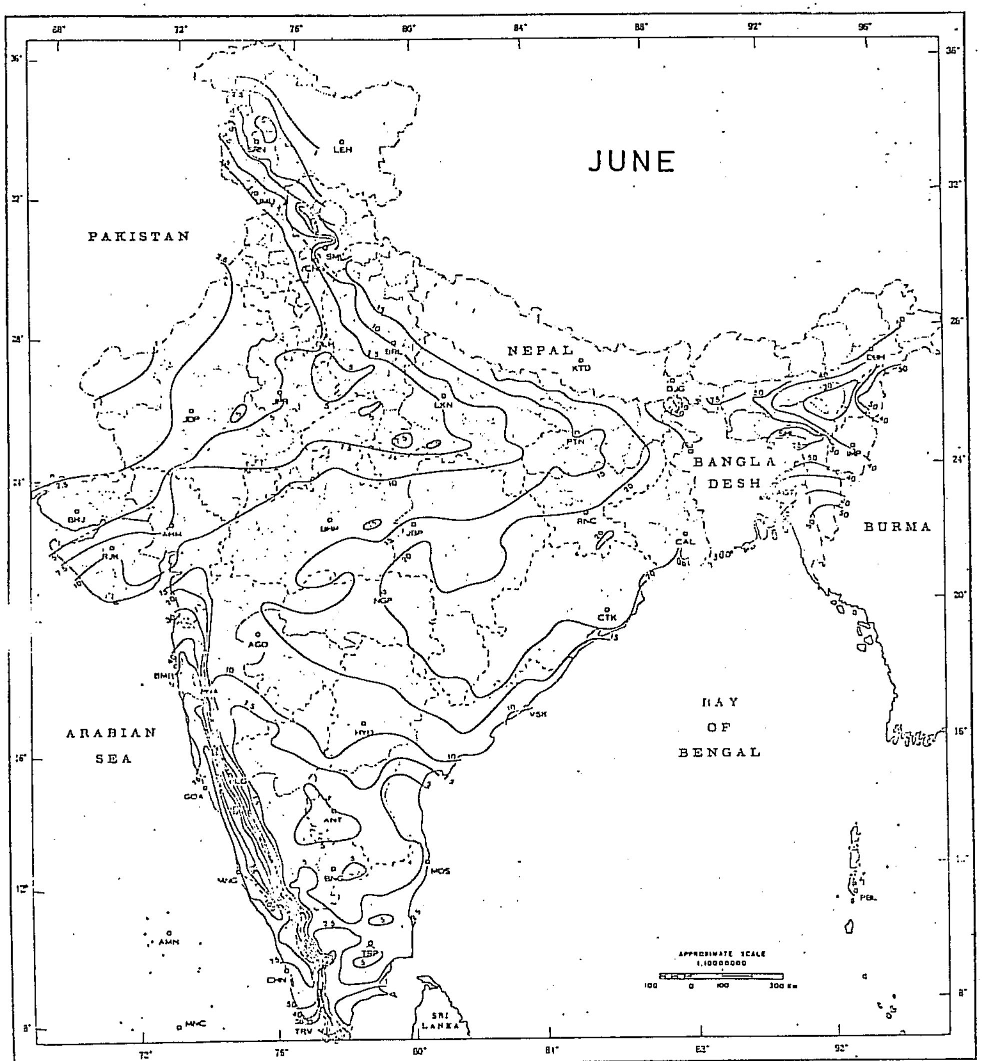

FIG. 2.

NORMAL RAINFALL (Cm)

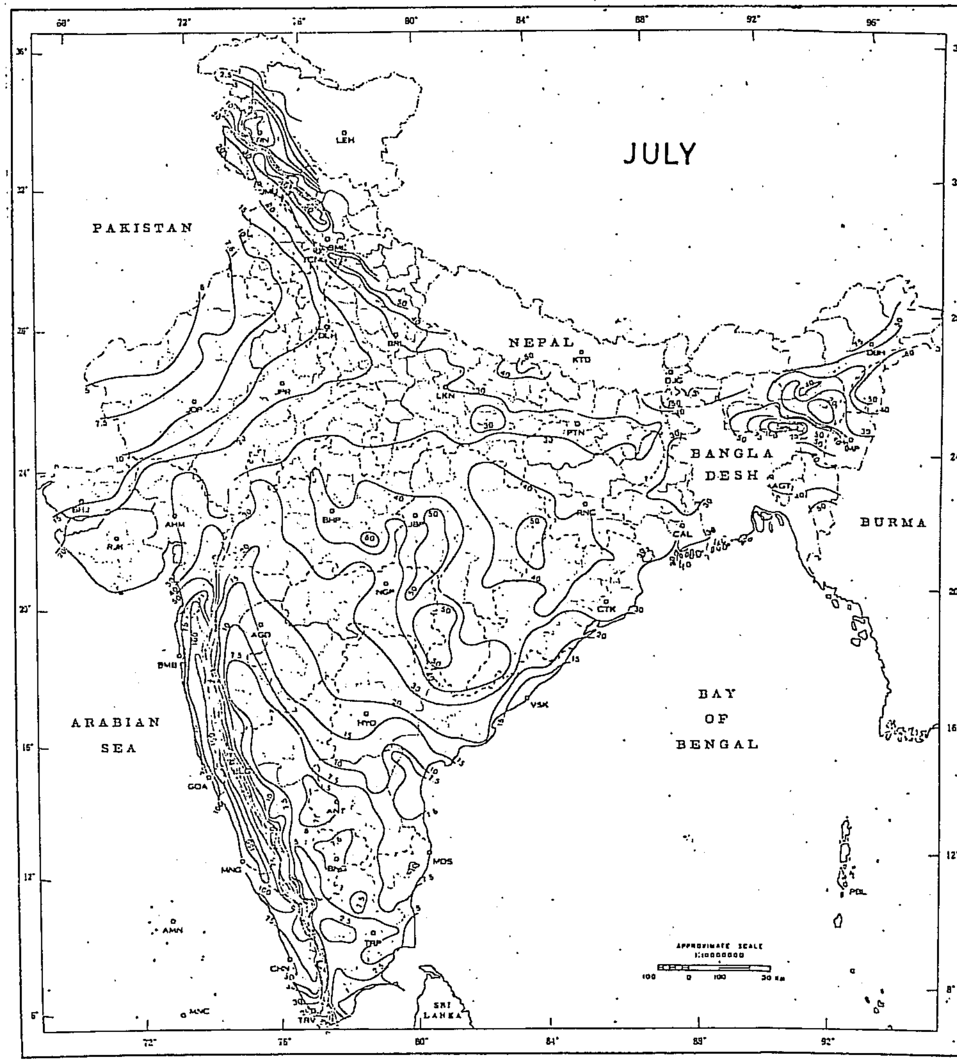

FIG.3.

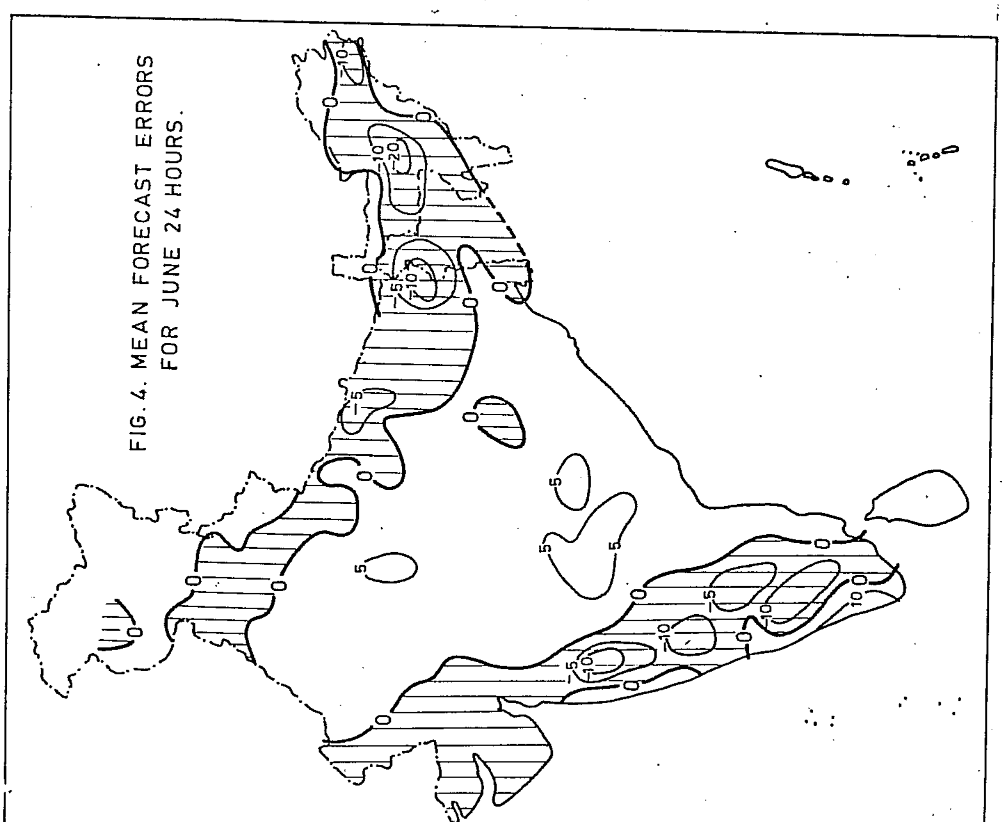

FIG. 4. MEAN FORECAST ERRORS FOR JUNE 24 HOURS.

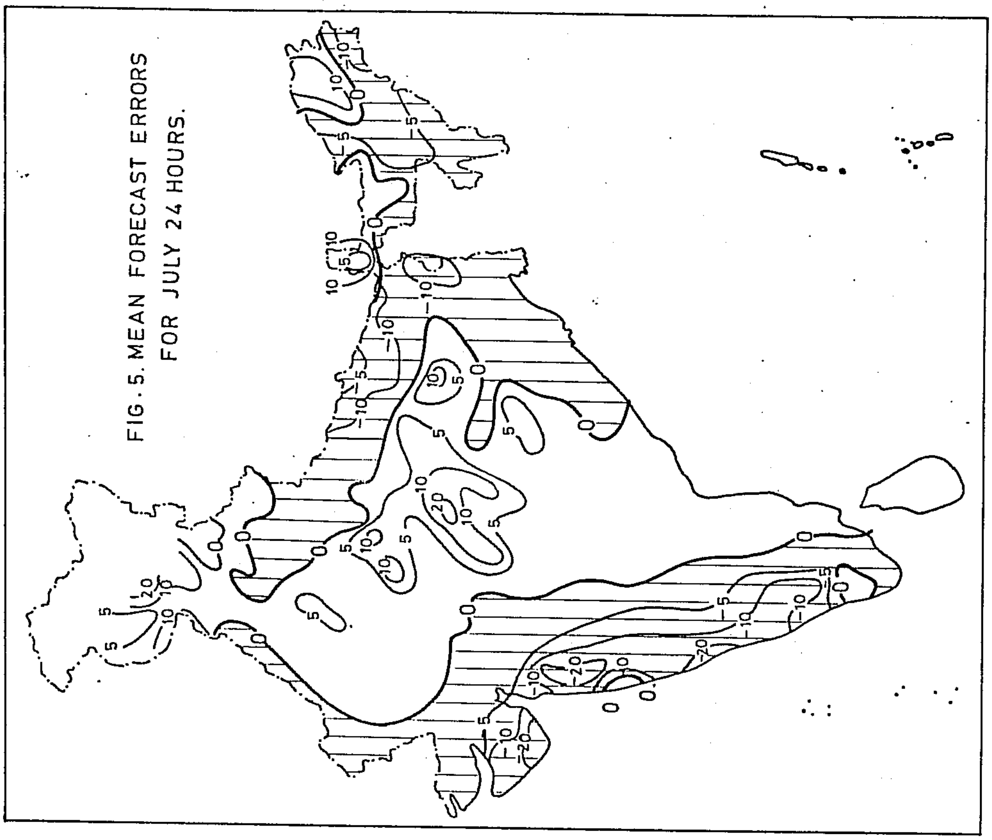

FIG. 5. MEAN FORECAST ERRORS FOR JULY 24 HOURS.

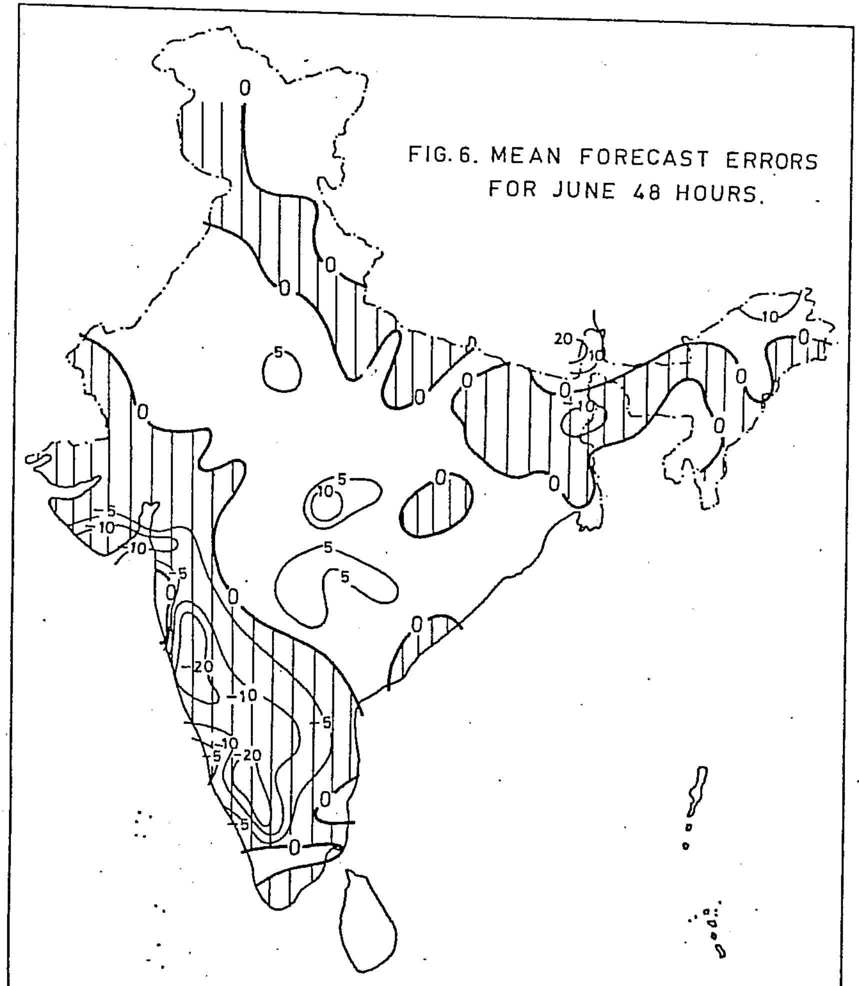

FIG. 6. MEAN FORECAST ERRORS FOR JUNE 48 HOURS.

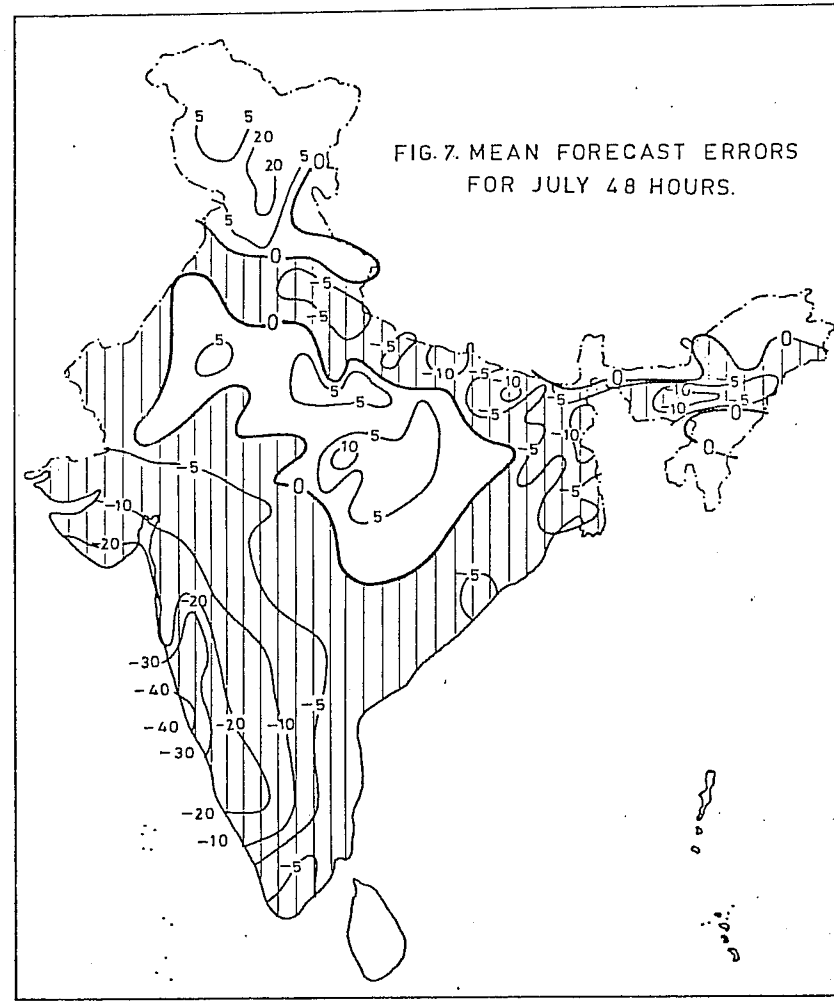

FIG. 7. MEAN FORECAST ERRORS FOR JULY 48 HOURS.

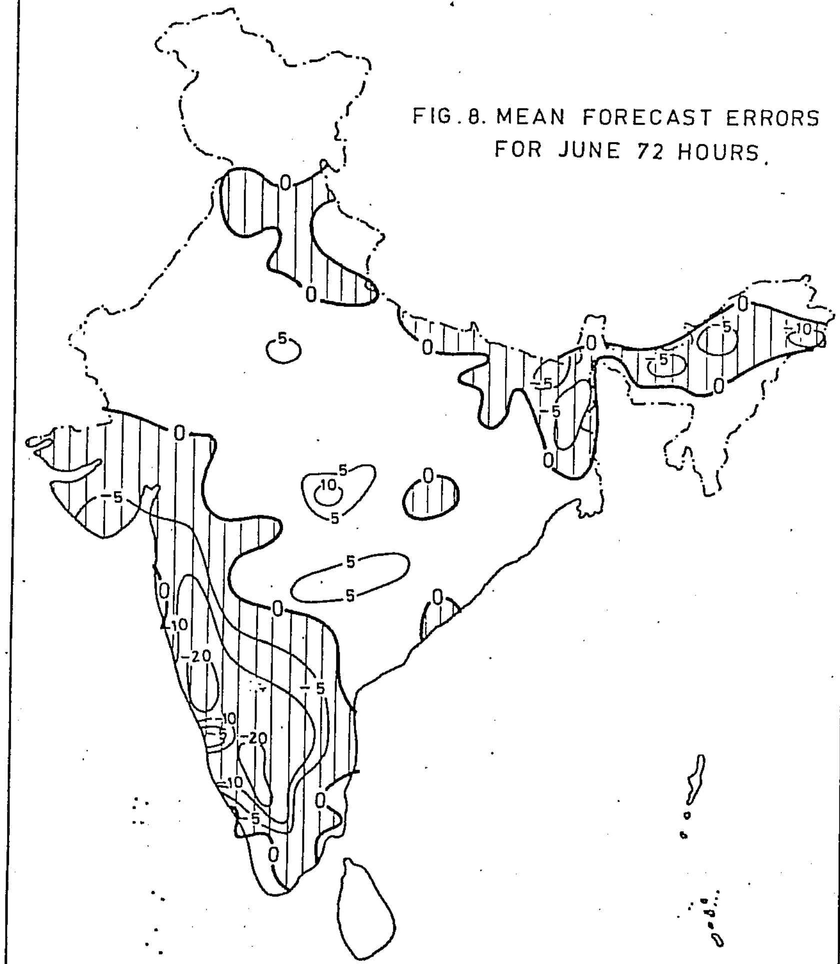

FIG. 8. MEAN FORECAST ERRORS FOR JUNE 72 HOURS.

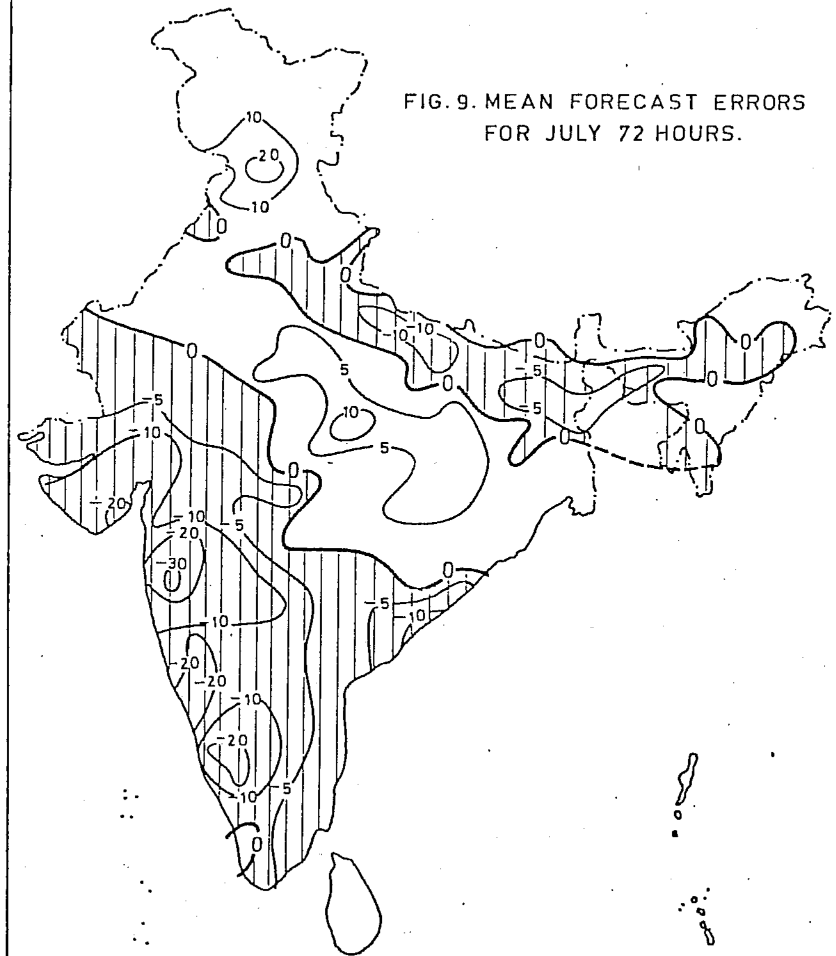

FIG. 9. MEAN FORECAST ERRORS FOR JULY 72 HOURS.

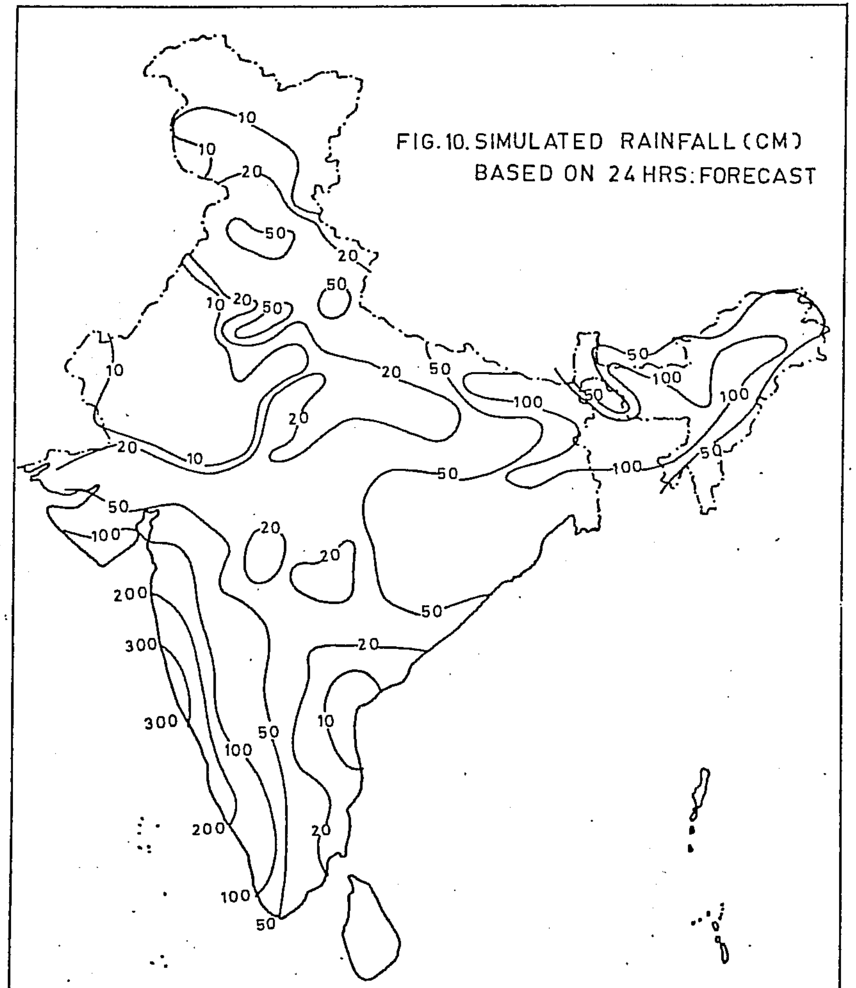

FIG. 10. SIMULATED RAINFALL (CM) BASED ON 24 HRS: FORECAST

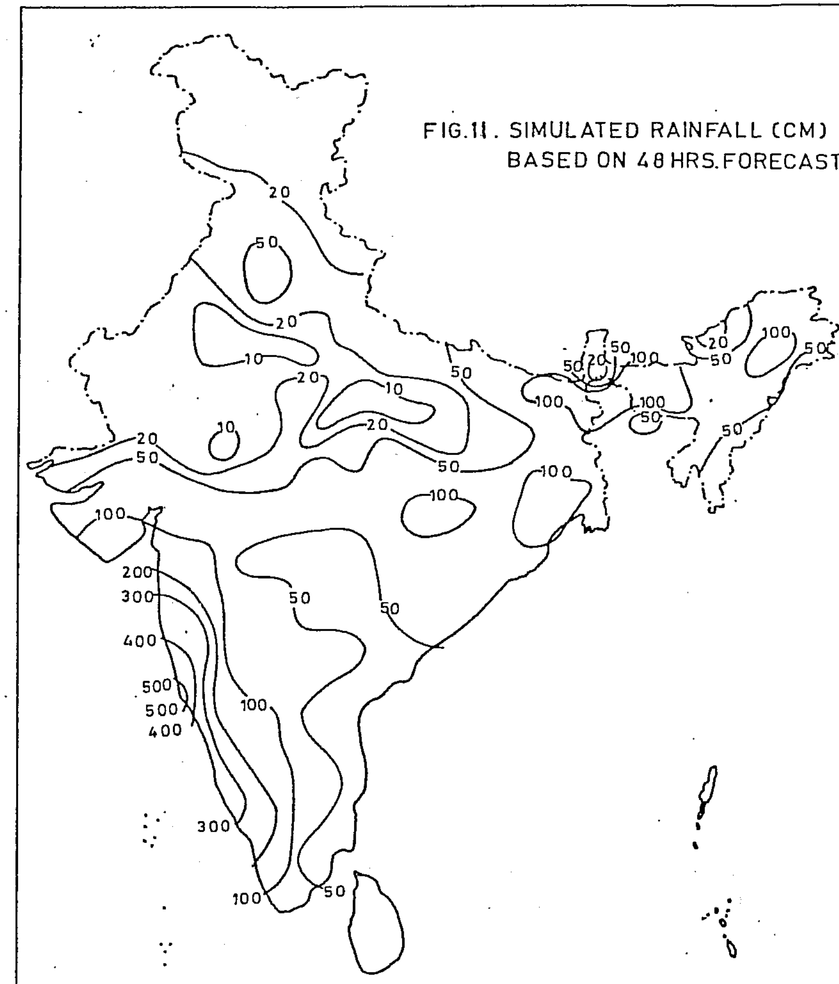

FIG. 11. SIMULATED RAINFALL (CM) BASED ON 48 HRS. FORECAST

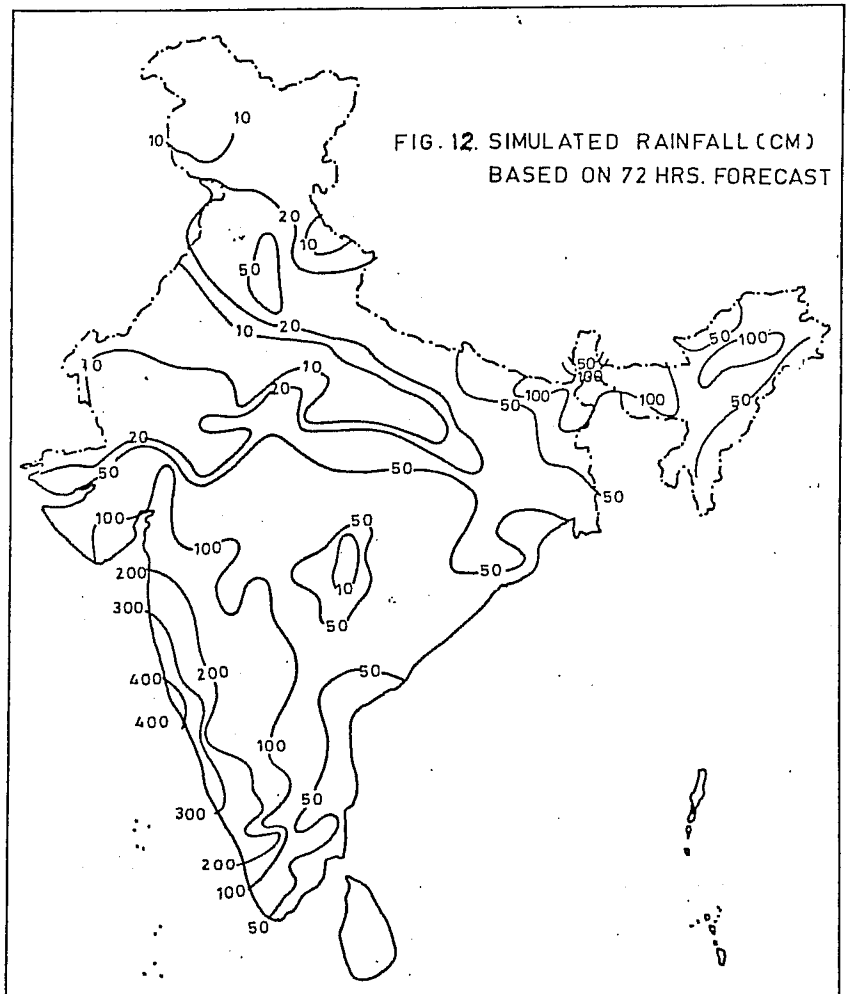

FIG. 12. SIMULATED RAINFALL (CM) BASED ON 72 HRS. FORECAST

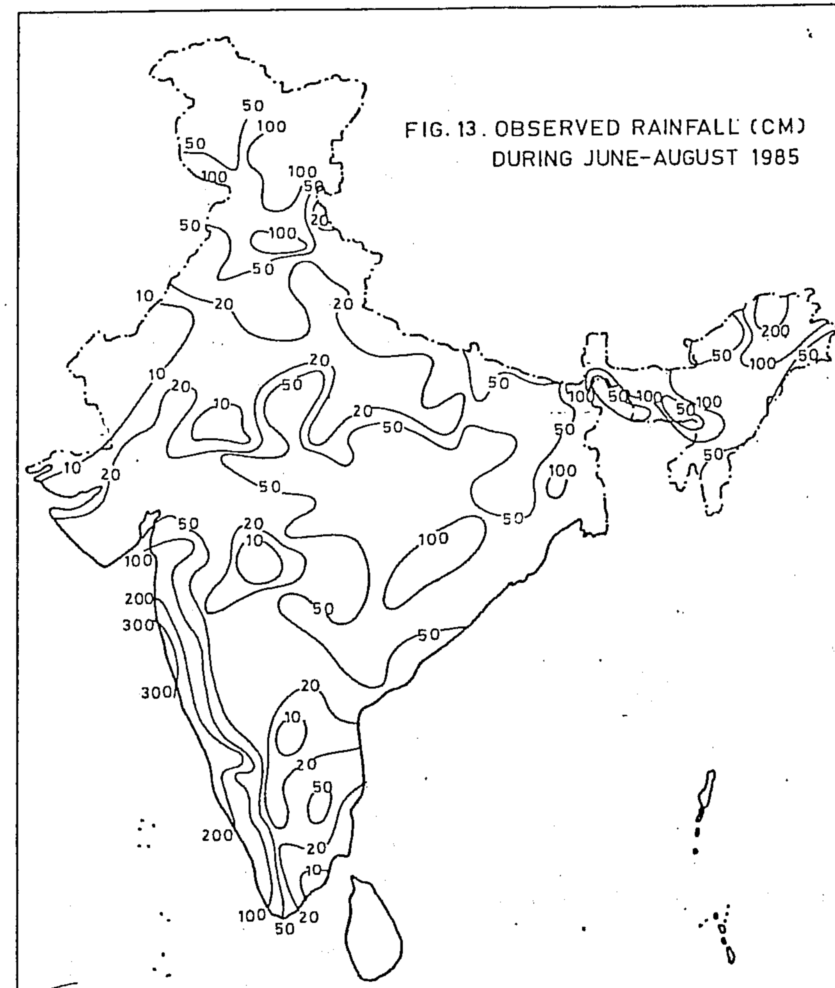

FIG. 13. OBSERVED RAINFALL (CM) DURING JUNE-AUGUST 1985