TECHNICAL MEMORANDUM

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Prediction of monsoon flow over the Indian subcontinent by the ECMWF model

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Abstract

This study examines the ability of the ECMWF operational model to forecast the monsoon flow over the Indian subcontinent. Also there is a limited investigation of the impact of changes to the humidity analysis and the convection scheme on the monsoon.

The study consists of three parts, i) evaluation of systematic errors in the operational forecasts during June, July and August, 1985; ii) study of the performance of the model in three typical cases during August, 1985; and iii) simulation of the onset processes of the monsoon of 1979 (MONEX period).

The ECMWF operational model clearly shows skill in forecasting significant monsoon features in spite of the existence of systematic errors. Possible problems due to imbalances in the initial field over and around the Himalayas are also noted.

CONTENTS

1. INTRODUCTION

There have been a number of studies of the ECMWF tropical forecast errors, but in the main they have concentrated on the very large scales. For example Heckley (1985) gives a broad picture of these errors and their structure.

The practical predictability of the tropical atmosphere has been examined by Kanamitsu (1985). He analysed the forecast errors of a large number of operational forecasts made at ECMWF during 1983-84, by separating the very large scales from the synoptic scale transient motions. He found that i) the predictability (measured by the time taken for the rms forecast errors to reach the climatological standard deviation) is about 1-2 days for the mass field, 1 day for the low level winds and 2-2½ days for the upper level winds; the error grows quickly in the first 24 hours, ii) in the tropics the mean error (systematic error) forms a very large part of the total error in the 24 to 164 hour forecasts, iii) the transient waves are predictable up to or beyond 4 days, iv) the seasonal variation of the predictability is not very large, and v) the systematic errors grow without propagation.

Very few regional studies have so far been carried out. However Hollingsworth and Datta (1985) did examine the performance of the ECMWF model over the Indian subcontinent and demonstrated useful skill in predicting significant synoptic systems.

The present study deals with the predictability of the ECMWF operational model, specifically for summer over the Indian subcontinent. The first part consists of a general discussion of model performance in forecasting significant monsoon flow during June, July, August, 1985 and the error structure in the forecasts. The second part considers a few specific cases of forecasts during August, 1985. The last part discusses experimental integrations of the 11 June 1979 monsoon onset case with various data assimilation and parameterization schemes. These experimental integrations have been included because there is known sensitivity of tropical forecasts to the parameterization of cumulus convection (e.g. Mohanti et al., 1984) and also to the analysis of humidity.

2. DATA

The data used in the study are the operational initialized analyses and forecasts from ECMWF. The analysis scheme is discussed by Bengtsson et al. (1982) and its subsequent revision by Shaw et al. (1984). The model details are given by Tiedtke et al. (1979), Simmons and Jarraud (1984), and Tiedtke and Slingo (1985).

In this study special attention is given to the verification of forecasts of the wind field, although some consideration is also given to the temperature and vertical motion fields. The following fields were used:

i) The analysed wind field and the 24 hour and 48 hour forecasts for the tropical belt 30°S to 30°N for the 850 mb and 200 mb levels.

ii) The monthly mean analyses for various levels (850, 700, 500, 300, 200mb) over the Indian area and monthly mean forecast error fields for 24, 48, and 72 hours. The variables considered were the horizontal wind field, temperature and ω field.

iii) Similar information as in ii) above but for individual cases.

The above analyses used conventional data, AIREPS from Gulf-India and India-Singapore routes, and SATEM data; INSAT-Ib data could not be used because of strong biases. Most of the Indian Ocean therefore continues to be data void.

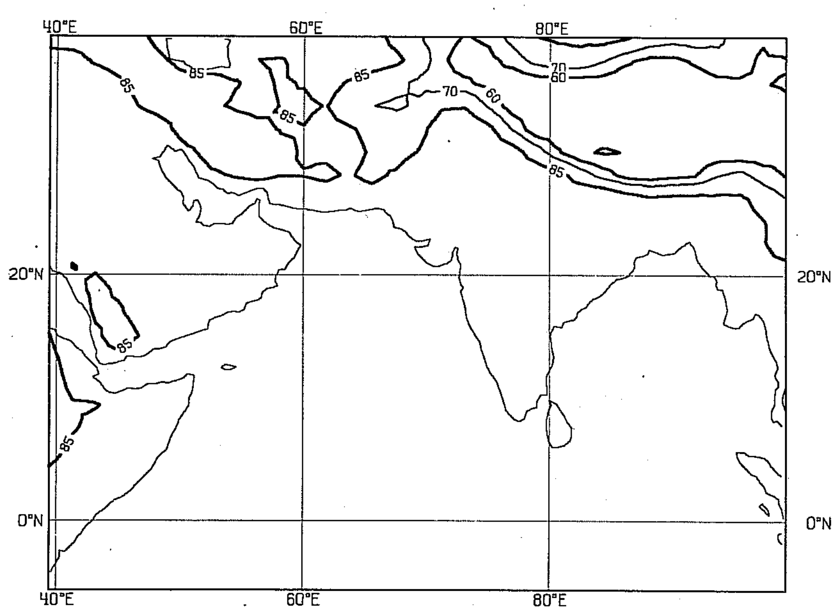

Fig. 1 Surface pressure distribution for 12 GMT 1/8/85. Units 10^3 pascals.

3. EVALUATION OF THE FORECAST ERRORS

A forecast of the monsoon may be considered as good if the significant features associated with the monsoon circulation are predicted properly. These are: the position and intensity of the monsoon trough; the formation and movement of monsoon disturbances, mid-tropospheric cyclones (MTC) and the low level jet (LLJ) in the lower troposphere; the position and intensity of the subtropical high and its associated ridge; the position and intensity of tropical easterly jet (TEJ) in the upper troposphere.

In order to examine these features in more detail, following Heckley (1985), the mean forecast errors of 24, 48 and 72 hour forecasts were examined for June, July and August, 1985. However, since the systematic errors are similar for these months the discussion will concentrate on August, 1985.

The region under consideration has some very large mountains. Therefore, in order to aid interpretation of the following figures, a typical surface pressure distribution is shown in Fig. 1 (12 GMT 1/8/85). Large areas of the 850 mb and 700 mb surfaces are below ground.

3.1 The mean flow

The mean analysed fields at 850, 700, 500 and 200 mb for August 1985 are presented in Fig. 2. The significant features are as follows:

i) 850 mb. There is a marked cyclonic circulation near 23°N, 87°E, a ridge with its axis along 70°E, a LLJ with speed >20 ms^{-1} in the SW Arabian Sea with most of India south of 20°N having winds > 10 ms^{-1}, and a cyclonic circulation centred near 32°N, 66°E.

ii) 700 mb. At this level the flow pattern is controlled by the monsoon trough running east-west at about 22.5°N.

iii) 500 mb. The flow is mainly controlled by two cyclonic circulations, one located over Orissa (near 20°N, 84°E) and another over the Arabian Sea off the Gujarat coast, (near 21.0°N, 70°E); there is also a weak subtropical ridge around 30°N.

iv) 200 mb. In the upper troposphere there is a marked anticyclone with ridge axis running generally east-west along 30°N. South of 20°N there are strong easterlies with speeds greater than 30 ms^{-1} over the Arabian Sea (TEJ).

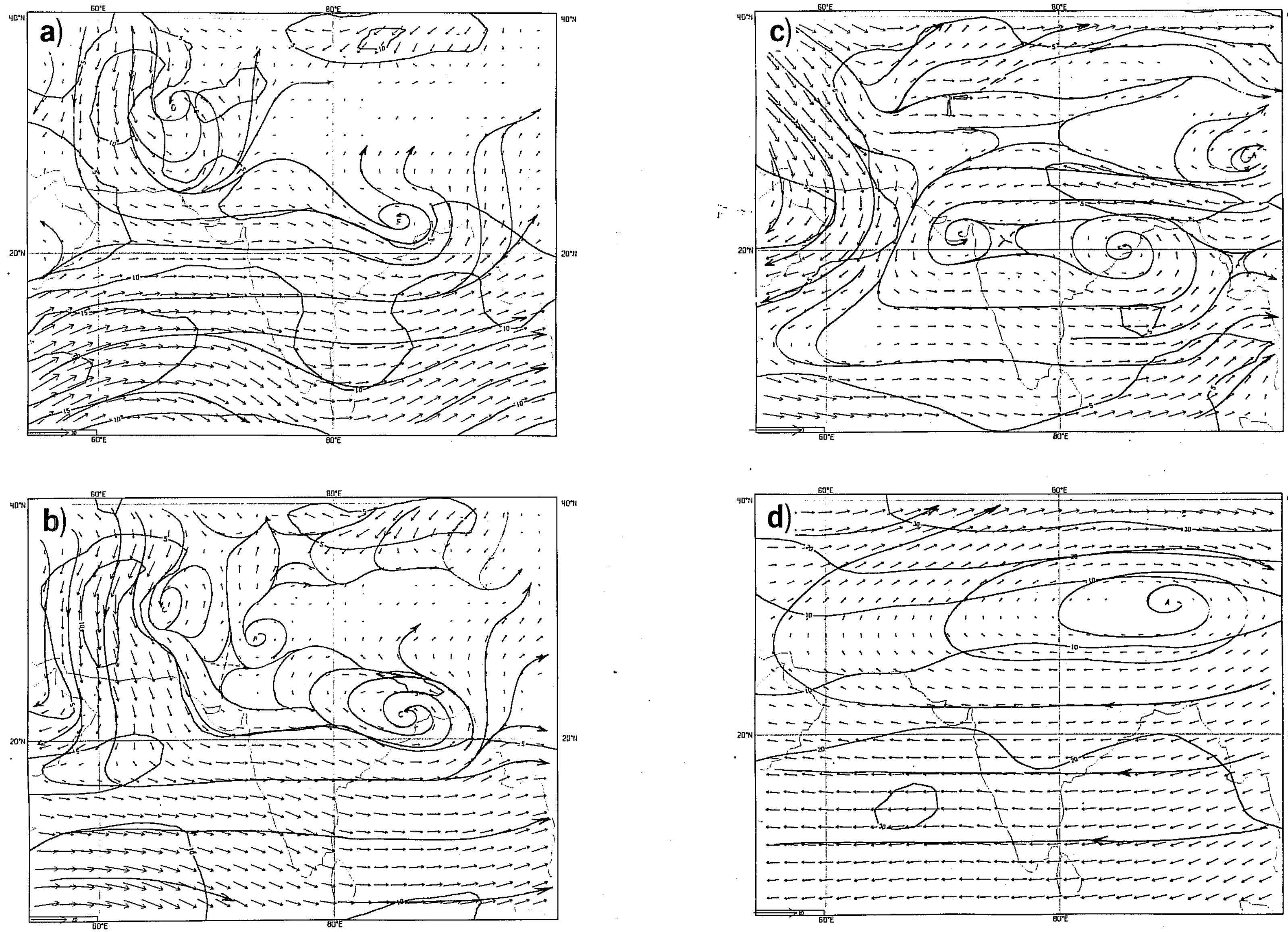

Fig. 2 Mean wind field for the month of August, 1985. For 850 mb (a), 700 mb (b), 500 mb (c) and 200 mb (d).

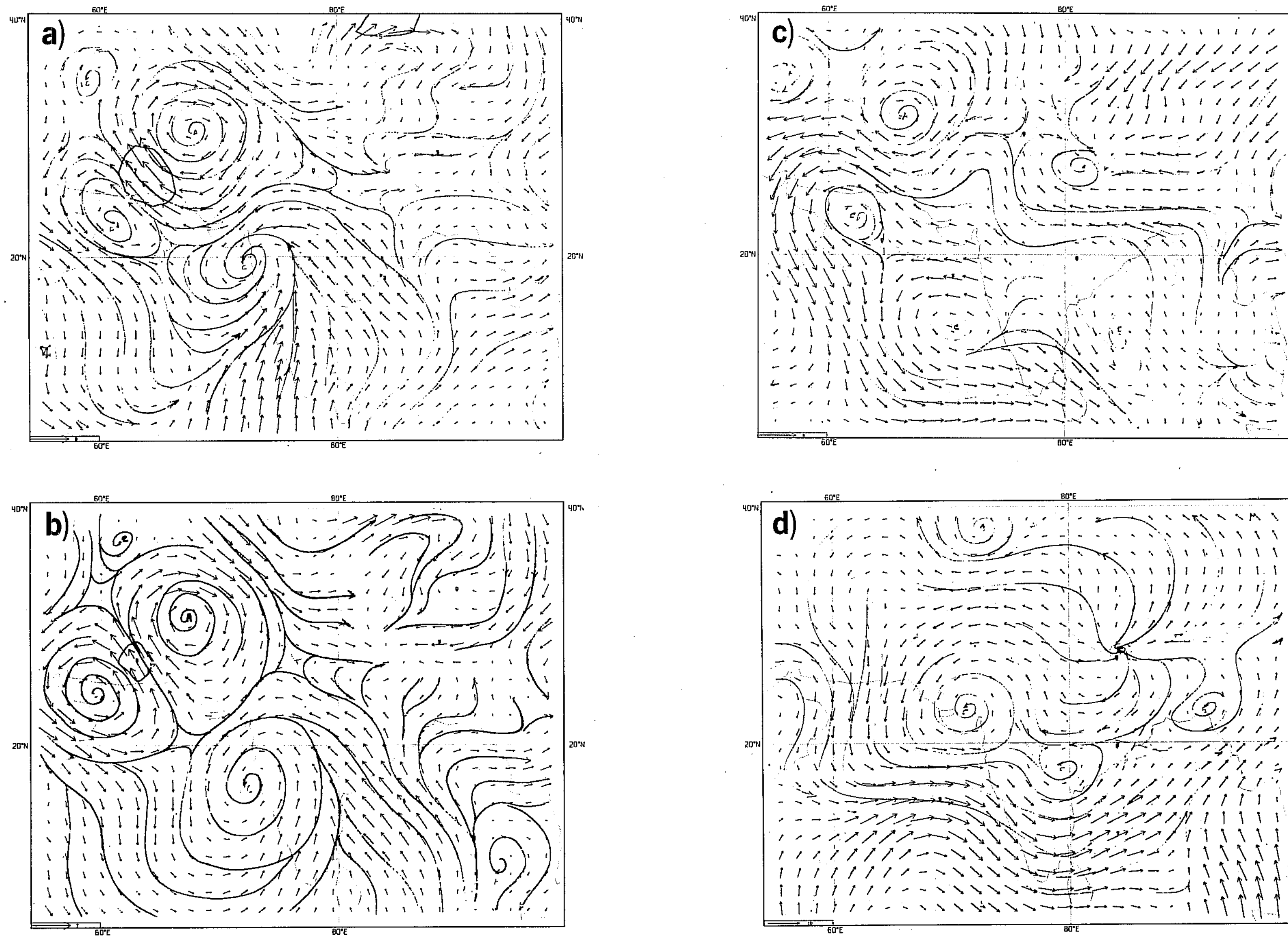

Fig. 3 Mean error of winds of the 24 hr forecast for August, 1985
for 850 mb (a), 700 mb (b), 500 mb (c) and 200 mb (d).

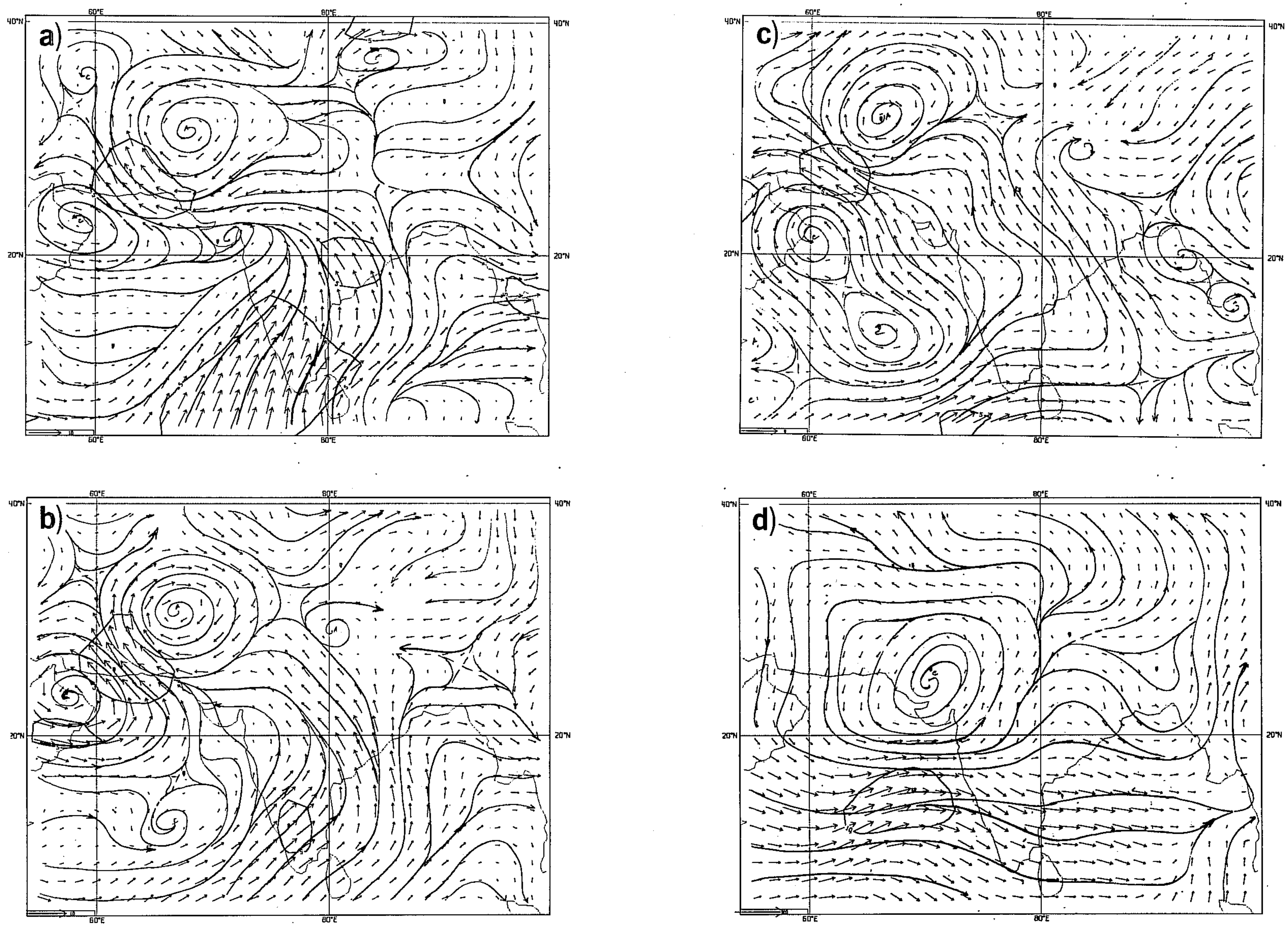

Fig. 4 Mean error of winds of the 48 hr forecast for August, 1985 for 850 mb (a), 700 mb (b), 500 mb (c) and 200 mb (d).

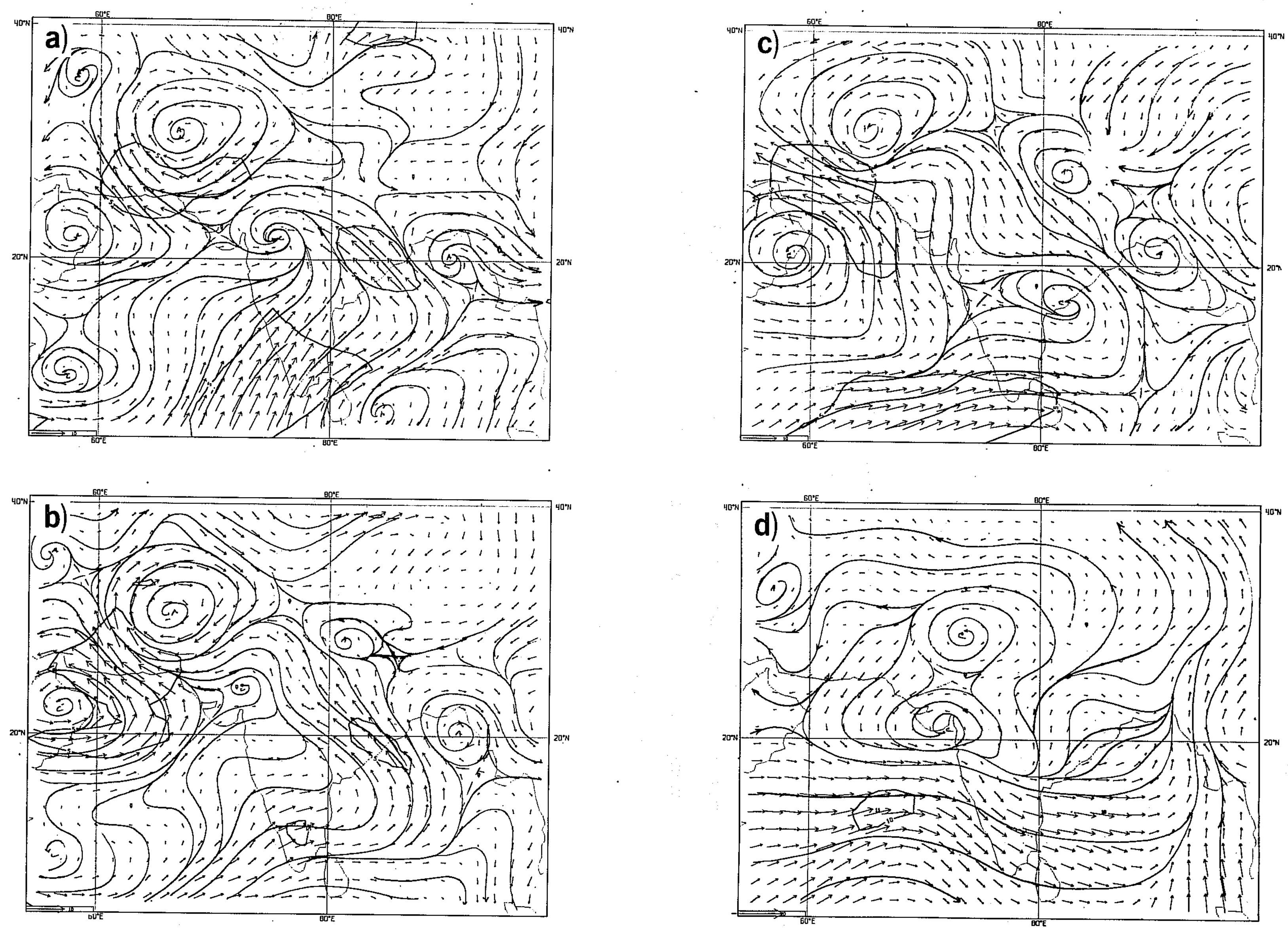

Fig. 5 Mean error of winds of the 72 hr forecast for August, 1985 for 850 mb (a), 700 mb (b(, 500 mb (c) and 200 mb (d).

3.2 The mean forecast errors

With the mean flow in mind, the errors in the forecasts are now considered. These are presented in Figs. 3-5 for the 24, 48, and 72 hour forecasts for 850, 700, 500 and 200 mb.

The error pattern in the wind field can be conveniently studied by splitting the region into two zones. One north of 25°N and the other to the south.

North of 25°N

In the north, at 850 and 700 mb, the major error pattern has anticyclonic flow centred near 30°N, 68°E with weak cyclonic flow northeast and northwest of it. This error pattern remains almost unchanged throughout the forecast, though there is a slight increase in wind error. At 500 mb, the anticyclonic flow lies slightly further west (centred approximately at 30°N, 65°E) with two other weaker anticyclonic regions east-southeast and west-northwest of it. The main anticyclone remains stationary whereas the other two change in intensity without any appreciable propagation throughout the range of the forecast. In the upper troposphere north of 25°N, over the Himalayas, the effect of orography is clearly seen near 28°N, 84°E with a diverging flow in the 24 hour forecast. The marked 200 mb divergence in the 24 hour forecast weakens by 48 hours; this adjustment in the divergence field is probably a consequence of an initial imbalance in the initialised fields, perhaps through inadequate representation of orography. The rest of the region has a weak and diffuse error structure, without any appreciable propagation with time.

South of 25°N

The region south of 25°N can be further broken into two zones, one east of 80°E and the other west of it.

In the eastern zone, which consists of the Bay of Bengal and adjoining parts of India and Burma, the anticyclonic flow with its associated ridges is a prominent feature in the error pattern at 850 and 700 mb. However there are some minor variations in the intensity and position, but they are not very significant. At 500mb, there are ridge/anticyclone - cyclone systems which clearly show propagation north-westwards with time. For example, the cyclonic circulation travels at almost 250 km per day for several days into the forecast. The propagation of the anticyclone, however, is not as systematic.

In the upper troposphere, there are no consistent synoptic scale patterns in the systematic errors.

In the zone west of 80°E and south of 25°N, the changes are more noteworthy. At 850 mb, there are two cyclonic circulations both of which show clear propagation westward from the 24 to 48 hour forecast; in the 48-72 hour period their propagation over Arabia is arrested, but the circulation off the west coast of India propagates eastwards and then weakens. From 48 hours onwards there is an eastwards propagation of a cyclonic system near 10°N, 56°E. In addition to these changes, there is also an intensification of the errors northwest of the cyclonic circulation, and the errors also grow over most of India.

General

At 850 mb, the errors in the 24 hour forecasts in most parts of the region are less than 5 ms^{-1}, except over the southern part of the west coast of India and the extreme north-west of the region. The Arabian Sea and most of the Indian area east of 70°E has southerly wind errors of the order of 5 ms^{-1}. West of 70°E, however, errors are northerly winds of the order 2-3 ms^{-1}. The errors grow, reaching 5-8 ms^{-1} in the 72 hour forecast, but show a slight decrease beyond 72 hours. At 700 mb the errors are generally in the same direction but of lower magnitude. The errors at 500 mb are similar to those at 700 mb, but are less than 5 ms^{-1} over the forecast range considered. Also both error patterns at these levels show a systematic propagation in the 24 to 72 hour forecasts.

In the upper troposphere, 300 mb (not presented) and 200 mb, the significant errors are south of 20°N, where there are errors of 5-10 ms^{-1} in the westerly winds at 24 hours, growing to greater than 10 ms^{-1} with an increase in the range of the forecast.

In general the errors are such as to increase the speed and extent of the LLJ at the lower levels and decrease the speed of the easterly jet at 200 mb.

3.3 Systematic 'errors' in the vertical motion field

The 'error' in the vertical motion is shown in Fig. 6 for the ensemble of 24 and 72 hour forecasts. This is not strictly an error field due to uncertainty in the analysis of divergence and the effect of initialisation on the analysed field. However the fields should be reasonable in terms of geographical distribution, if not in magnitude.

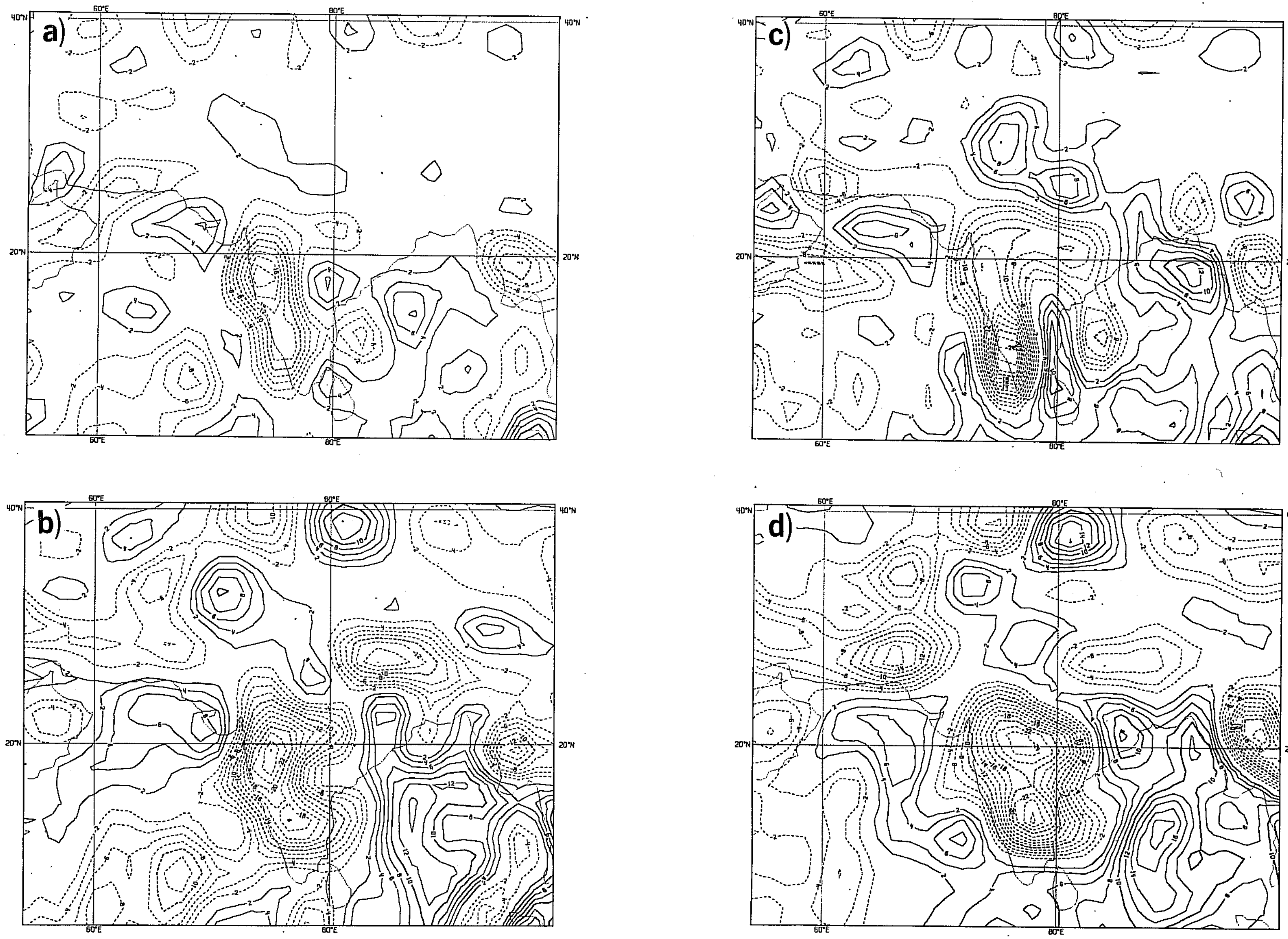

Fig. 6 Mean 'error' of the 'ω' field of the 24 hr forecast for August, 1985 for 850 mb (a) and 500 mb (b); the corresponding results for the 72 hr forecast in (c) and (d).

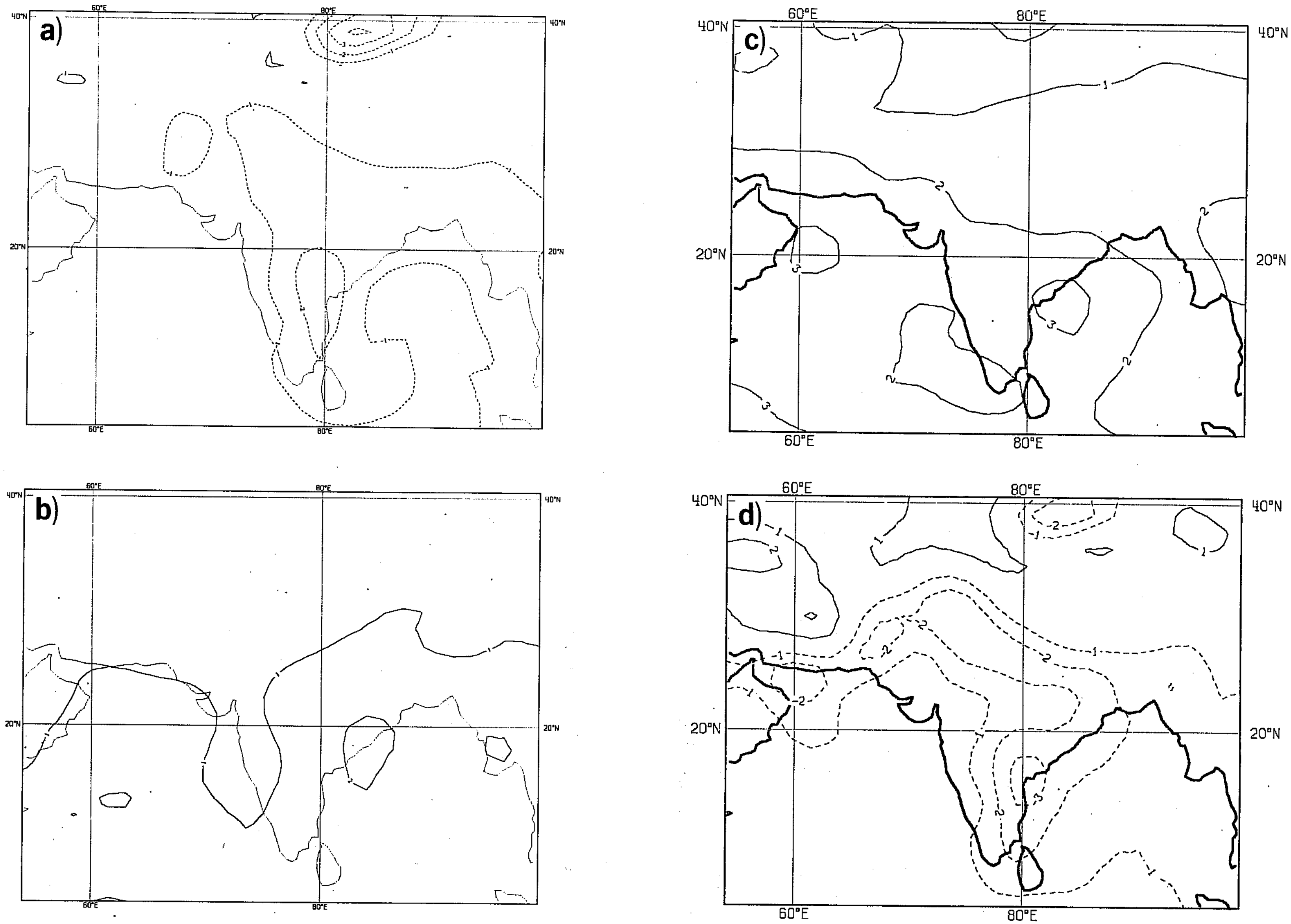

Fig. 7 Mean error of temperature field of the 24 hr forecast for August, 1985 for 850 mb (a) and 200 mb (b); the corresponding results for the 72 hr forecast in (c) and (d).

The 24 hour error structure of the ω field seems to be organised on a fairly large scale. From the west coast of India extending far inland there is a region of large errors in ω values, with the maximum at 700 mb. Correspondingly there is a region of subsidence over the Bay of Bengal and the approximate surface position of the monsoon trough; the subsidence is equally intense at 700 and 500 mb, and least at 850 mb. Another region of significance is the South Arabian Sea where there are large errors in the ω field at all levels, being most intense at 300 mb.

These errors appear to be consistent with the errors in the wind field, notably the tendency for erroneous anticyclonic flow over the Bay of Bengal. The larger region of ascent in the vicinity of the west coast of India may be a consequence of the poor representation of the Western Ghats in the model.

The 200 mb errors in the ω field are very small, but there is weak ascent over most of the Indian subcontinent and the Himalayas.

The 72 hour forecast error structure is generally very similar to that at 24 hours. Significant differences are:

i) an increase in magnitude and extent of the ascent over the west coast and adjoining region,

ii) the organisation of a large subsidence error field over the monsoon trough region and a decrease of negative error maxima over the Arabian Sea.

3.4 Systematic errors in the temperature field

Fig. 7 shows the temperature error for the ensemble of 24 and 72 hour forecasts, for the 850 and 200 mb levels. In the model there is cooling at 850 mb over most of the Indian subcontinent by 1-2°C in 24 hours, increasing to 3°C by 72 hours. Errors at 700 and 500 mb are generally of the order of 1°C or less. In the upper troposphere, there is warming over most of India of 1-2°C, becoming 2-3°C after 3 days. The temperature and wind errors, as discussed earlier, are generally consistent.

3.5 Summary and interpretation of systematic errors

Examination of daily 24-48 hour operational forecasts for the period June to August 1985 and the study of the mean forecast error from ensembles of 24, 48 and 72 hour forecasts leads to the following conclusions:

i) In the lower troposphere the forecasts have a tendency to increase winds with southerly components south of 25°N. The errors grow with time up to 72 hours.

ii) In the upper troposphere (300 and 200 mb) the model predicts easterlies which are too weak south of 20°N. The error does not grow appreciably with time beyond 48 hours. Also the error pattern is diffuse. In the errors of the 24 hour forecast and sometimes the 48 hour forecast, divergent type of flow from a single point is quite evident. This might be due to the steep topography. The forecast flow generally becomes smooth beyond 72 hours.

iii) North of 25°N, the significant error pattern is one of anticylonic flow near 30°N, 68°E in the lower troposphere. The position changes slightly with month and level, but there is no appreciable propagation during the forecast.

iv) Over the Bay of Bengal, in the lower troposphere, there is a predominantly anticyclonic error which expands to cover a large area with time, but there is no appreciable propagation at 850 mb and 700 mb. At the 500 mb level, besides the anticyclonic error to the east of the Bay of Bengal, there is also a cyclonic error which propagates west-northwestwards by as much as 250 km per day. However the anticyclonic circulation does not show any systematic propagation. In the upper troposphere the 300 mb error pattern is very similar to that at 500 mb, but at 200 mb there is no well defined pattern.

v) In the Arabian Sea off the west coast of India the error structure is predominantly cyclonic with a systematic propagation in the forecast, at least up 72 hours. This is true for all the levels up to 300 mb.

vi) The present study shows that the errors generally propagate westwards in the lower troposphere south of 25°N. The general pattern of systematic errors is similar to the large scale errors discussed by Heckley (1985) and Kanamitsu (1985).

vii) ω field 'errors' are organised on the large scale.

Explanation of the causes for these errors is beyond the scope of this study, however the major error fields and propagation of errors seem to be in the region of sparse data. This is specially true over the Arabian Sea where there are major errors, as well as near 30°N, 65°E (Middle East) which is the centre of the main anticyclonic error. Also, since the orography of the Himalayas, the Western Ghats, the Khasi-Jaintia hills and Africa high land plays a significant role in the monsoon circulation, their proper representation in the model is very important.

4. PERFORMANCE IN INDIVIDUAL CASES

From August 1985 three interesting cases have been picked for individual study, but before considering these in detail, the general synoptic development in the first part of August is discussed.

A well marked low pressure area over the northwest and west-central Bay of Bengal developed into a monsoon depression on 1 August (Fig. 8). It moved rapidly westwards crossing the Orissa coast the next day (Figs. 9, 10); it then weakened as it travelled over the land, and continued to move in a northwest direction until it intensified again on 4 August, 1985. Moving slowly north to northeastward it became much weaker by August 6 (Fig. 15) and then became unimportant.

During the same period another low pressure area formed over the head of the Bay of Bengal on the 4 August and developed into a monsoon depression two days later. It influenced the monsoon flow until 10 August 1985, when the depression weakened over the central parts of India.

After 10 August 1985, the flow pattern was such that there was a possibility of the establishment of a break monsoon situation. To examine the skill of the model in this type of situation, results are presented from forecasts based on the analysis of 11 August 1985 (Fig. 16). Thus it is interesting to study the performance of the model:

i) starting 1 August 1985 to study the weakening of the monsoon depression and its movement;
ii) starting 3 August 1985 to study in situ development;
iii) starting 11 August 1985 to examine the revival of the monsoon.

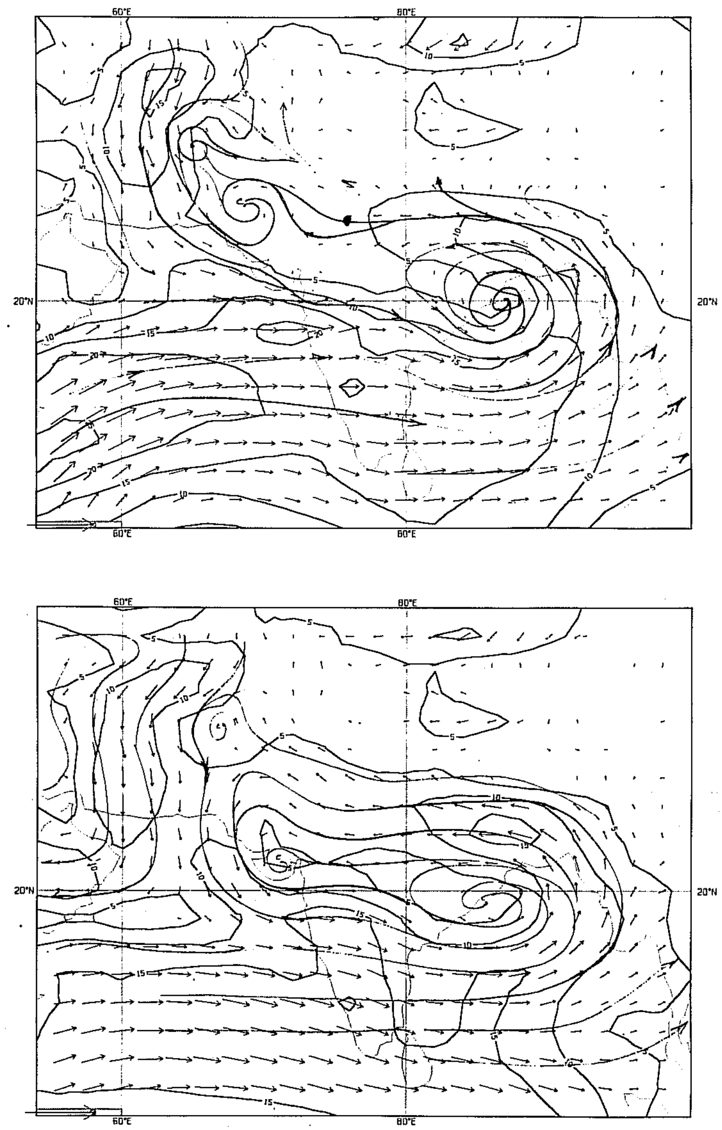

Fig. 8 Initial analysis of wind field for 12 GMT of 1 August, 1985 for 850 mb (top) and 700 mb (bottom).

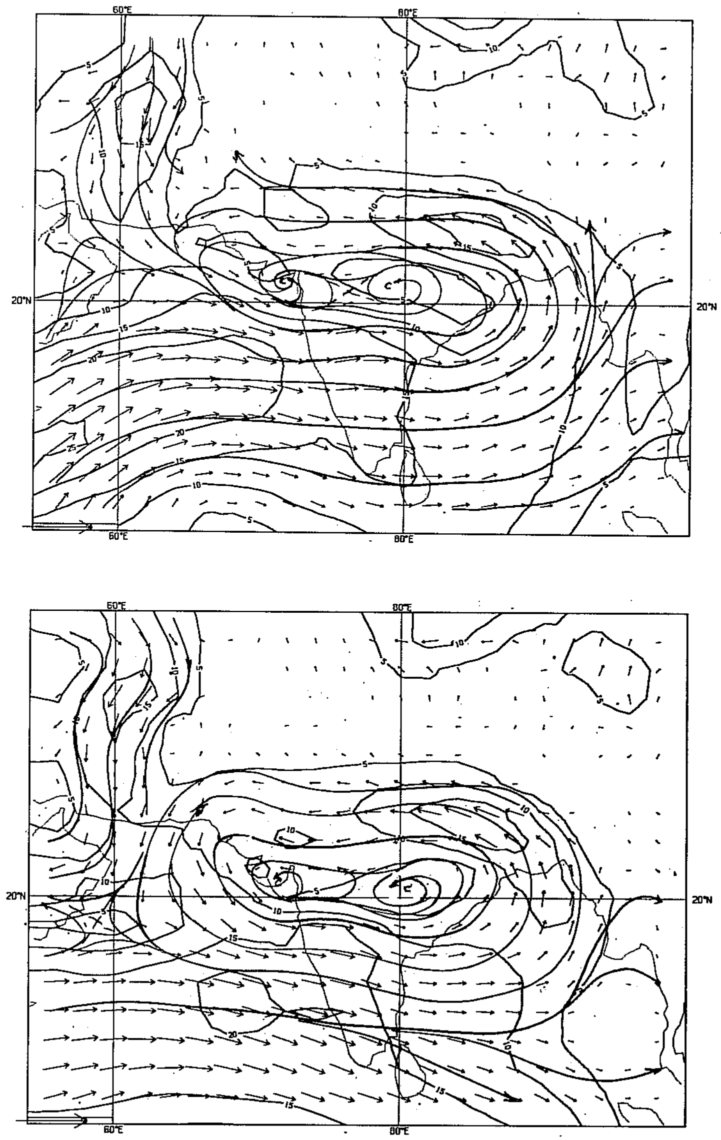

Fig. 9 Initial analysis of wind field for 00 GMT of 2 August, 1985 for 850 mb (top) and 700 mb (bottom).

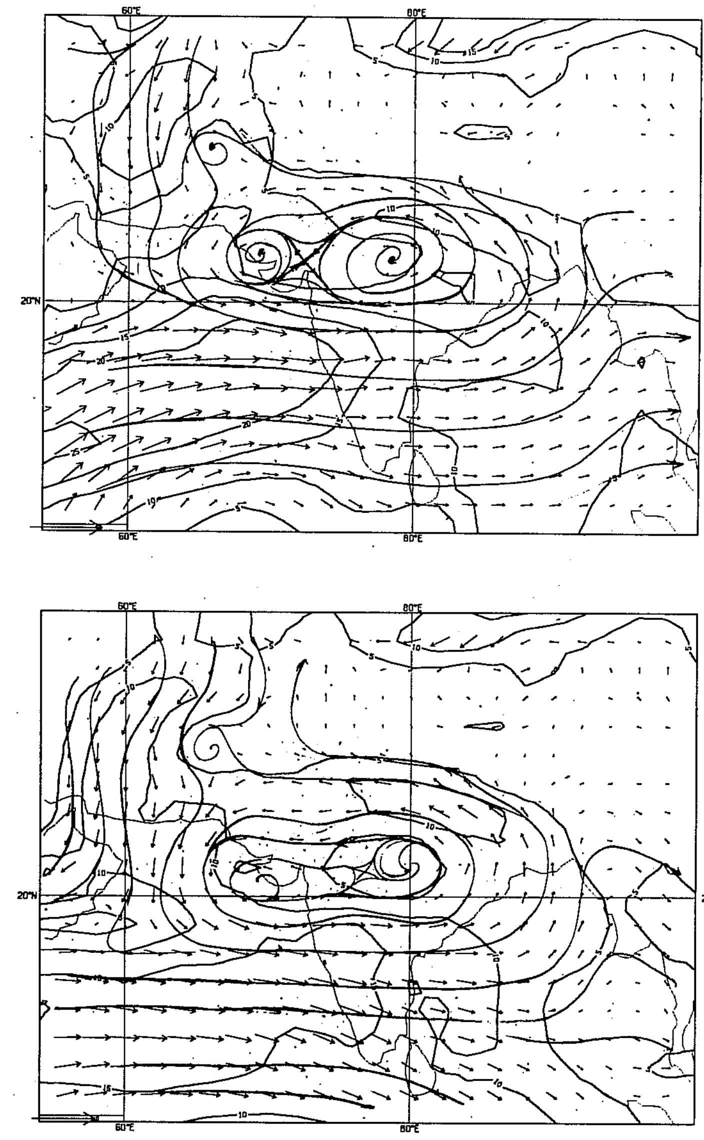

Fig. 10 Initial analysis of wind field for 12 GMT of 2 August, 1985 for 850 mb (top) and 700 mb (bottom).

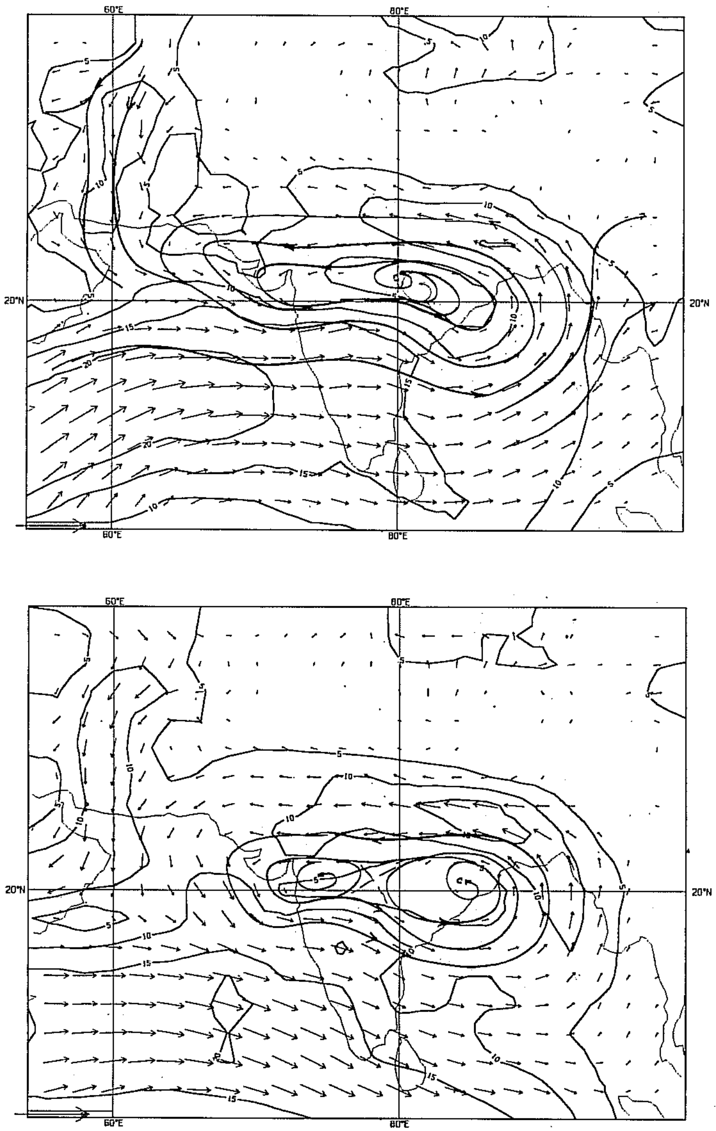

Fig. 11 12 hr operational forecast of wind field from initial analysis of 12 GMT of 1 August, 1985 for 850 mb (top) and 700 mb (bottom).

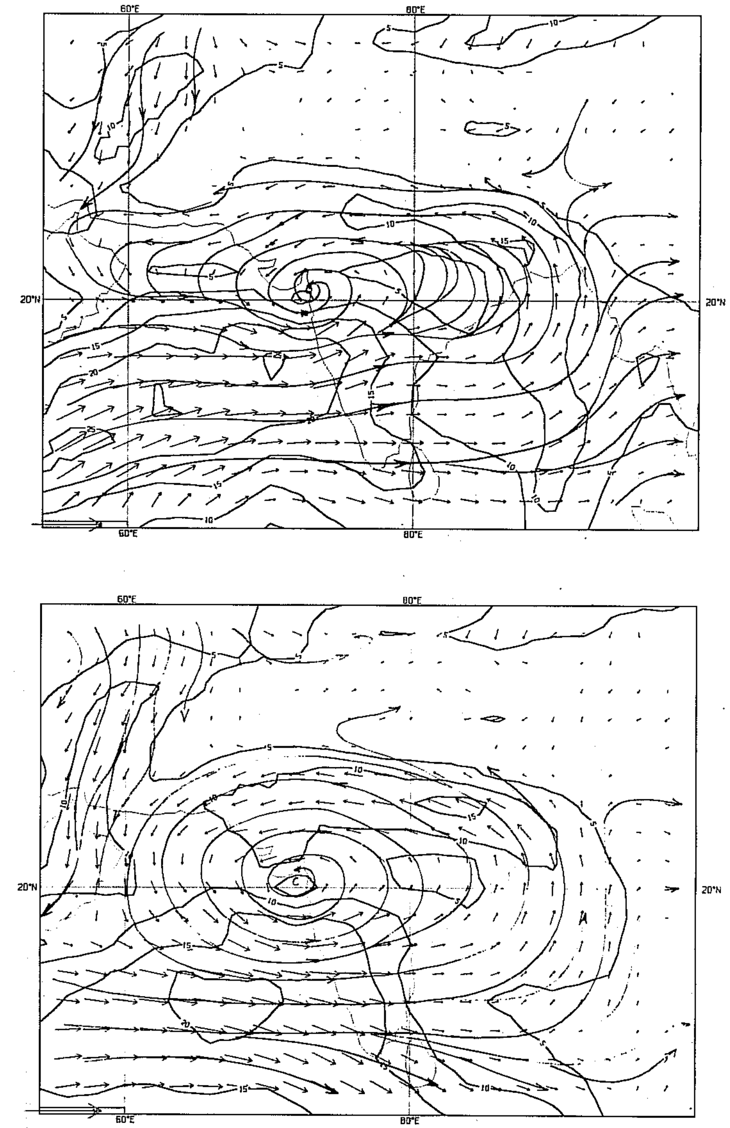

Fig. 12 24 hr operational forecast of wind field from initial analysis of 12 GMT of 1 August, 1985 for 850 mb (top) and 700 mb (bottom).

4.1 Case of 1 August 1985 (weakening and movement)

In Figs. 8-10, the 850 and 700 mb analyses are presented for 12 GMT on 1 August, and 00 GMT and 12 GMT on 2 August 1985. The corresponding 24 hour forecast fields verifying at 12 GMT 2 August are shown in Fig. 12. It may appear that the monsoon depression of 1 August has been predicted to move very fast over to the west coast of India. This did not happen in reality.

The depression no doubt weakened and moved rather fast inland but remained as a separate entity. As it stands, it appears that the forecast is a failure. To assess this more critically, it is necessary to examine the 12 hour forecast based on the same initial data (Fig. 11). This forecast is excellent, as it predicts both the direction of movement and intensity correctly.

How the does one explain the failure of the 24 hour and extended period forecast? As discussed in the previous section, the ECMWF model systematically weakens systems moving from the Bay of Bengal in the lower troposphere, so the model predicted the correct direction of movement, but exaggerated the weakening. The system in its weak stage could not be resolved because of the limit of resolution of the model; it apparently merged with a cyclonic circulation forming off the Bombay coast, where the model has a tendency to intensify cyclonic systems.

The 72 hour forecast, however, did not show in situ development of cyclonic circulation in the Bay of Bengal; this is also interesting because between the 3 and 4 August a circulation developed in the Bay of Bengal.

The model apparently did not produce an operationally useful forecast after 12-18 hours, but if the systematic errors could be reduced and data coverage improved to delineate such weak and short wave systems, it could be a very useful operational forecast.

4.2 Case of 3 August 1985 (development)

In this case it is interesting to examine if the operational forecast based on 3 August develops a monsoon depression by 6 August. The analysis for 12 GMT 3 August 1985 (Fig. 13) shows that initially no circulation exists. Comparison of the 72 hour forecast (Fig. 14) with the corresponding analysis of 6 August (Fig. 15), indicates that the forecast does bring about a development of the system in the proper position, though it is not as intense as it should be.

4.3 Case of 11 August 1985 (change from poor to active conditions)

Fig. 16, shows an analysis of the 850 and 200 mb flow at 12 GMT 11 August 1985. The flow pattern on 11 August shows that the monsoon trough at the surface and 850 mb has shifted northward. The trough was also weak at 700 mb, with an anticyclone and associated ridge in the north-west. In the upper troposphere, the subtropical ridge showed a marked southward shift in the west with a trough in the westerlies along 58°E. This is one of the situations which can lead to a break of the monsoon. The 72 hour forecast based on 11 August 1985 presented in Fig. 17, clearly shows a revival of the active phase of the monsoon which is quite similar to the analysis of 14 August 1985 (Fig. 18); this is encouraging.

4.4 General assessment of forecasts

This study which is confined to the assessment of forecasts for a very small region, reveals some interesting results, despite the following factors:

i) significant systematic errors in the model forecast,
ii) sparse data zones, especially over the oceans and middle east Asia,
iii) a poor representation of significant topographic features in the region,
v) deficiencies in the humidity analysis.

The cases discussed above clearly show that the ECMWF model can skilfully forecast significant monsoon features at short range.

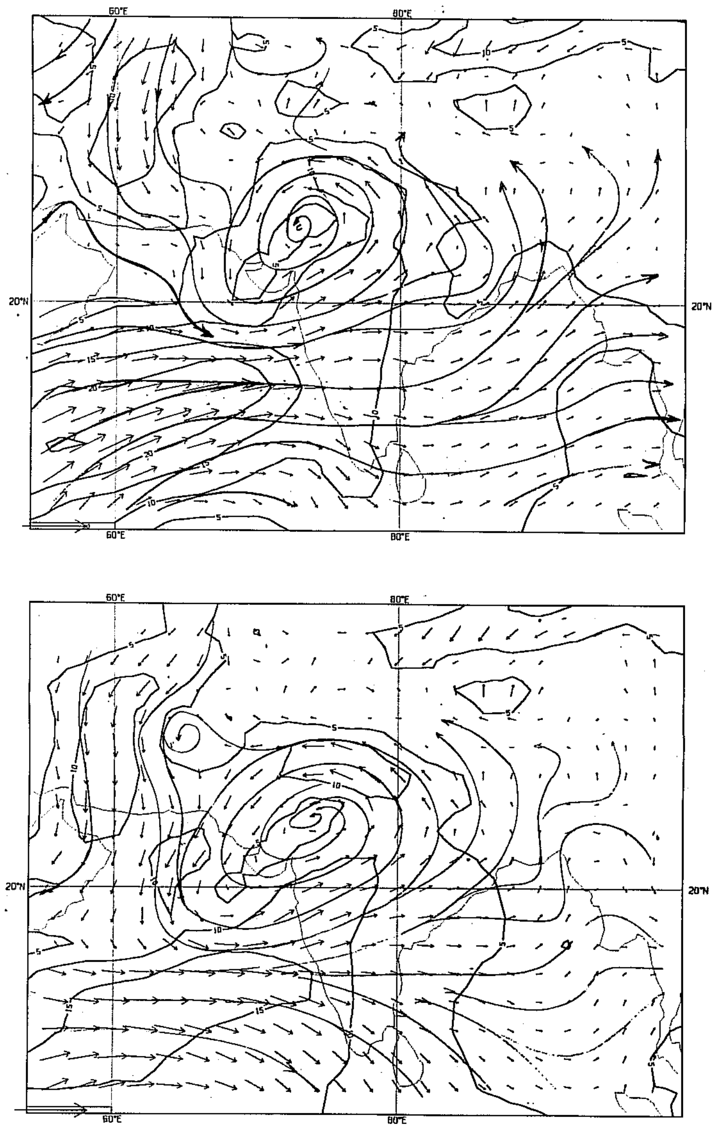

Fig. 13 Analysis of the wind field for 12 GMT of 3 August, 1985 for 850 mb (top) and 700 mb (bottom).

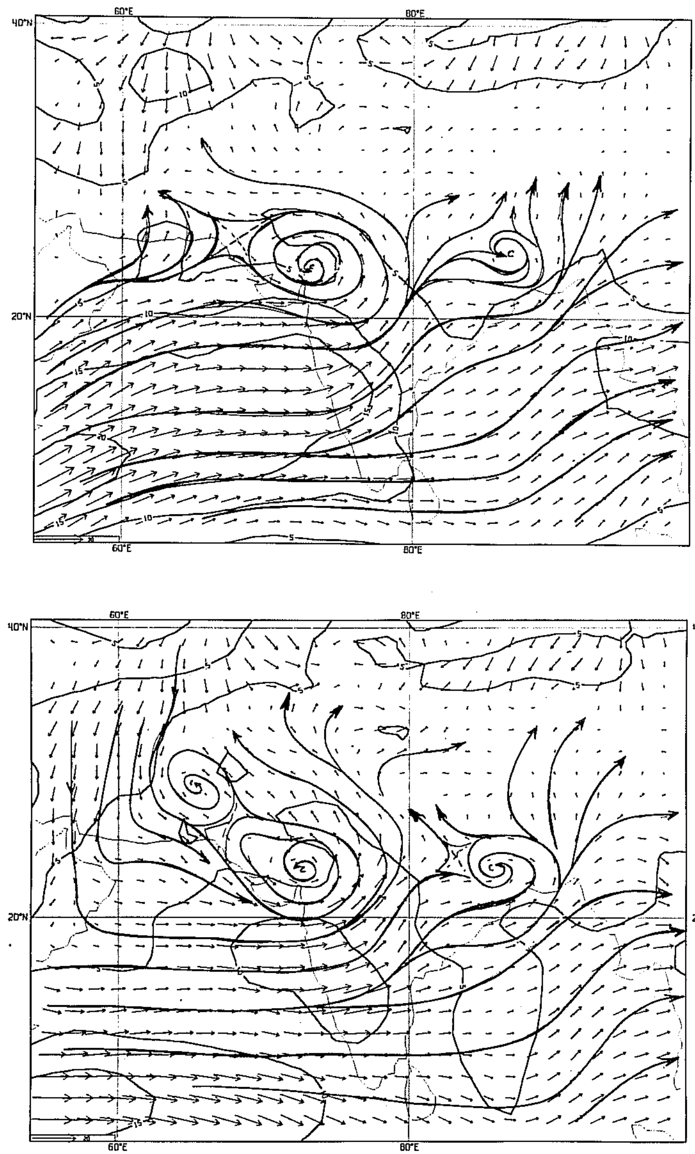

Fig. 14 72 hr forecast of the wind field from the 12 GMT 3 August, 1985 for 850 mb (top) and 700 mb (bottom).

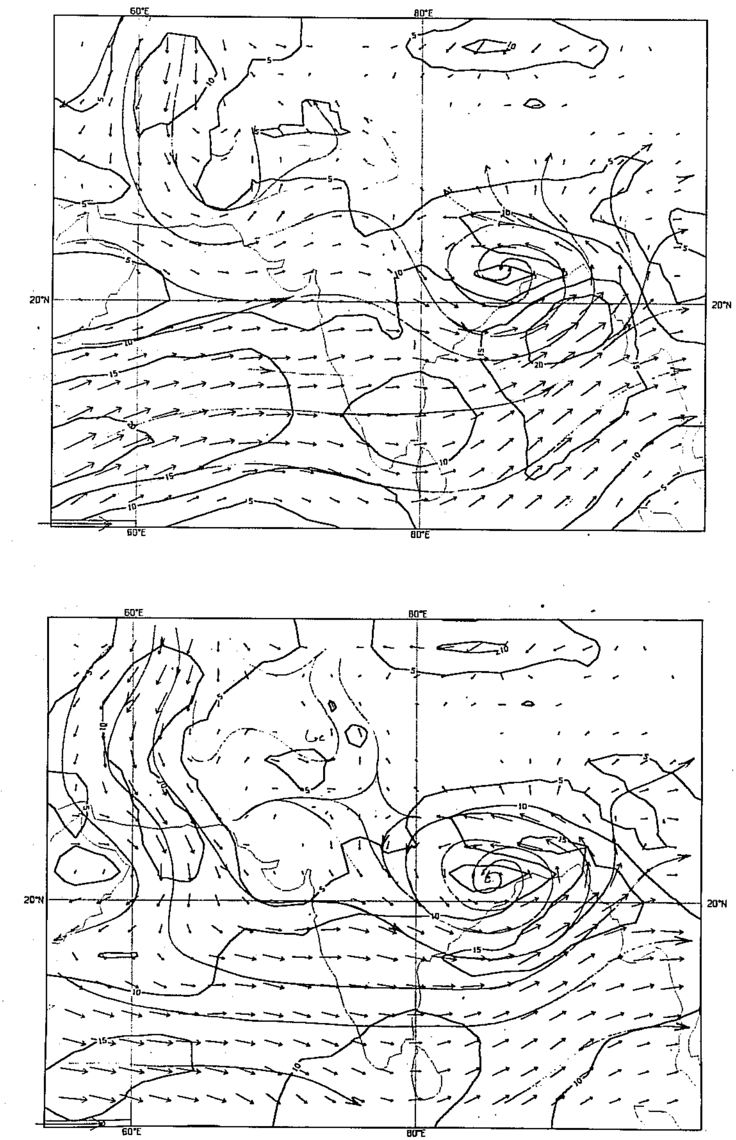

Fig. 15 Analysis of the wind field for 12 GMT of 6 August, 1985 for 850 mb (top) and 700 mb (bottom).

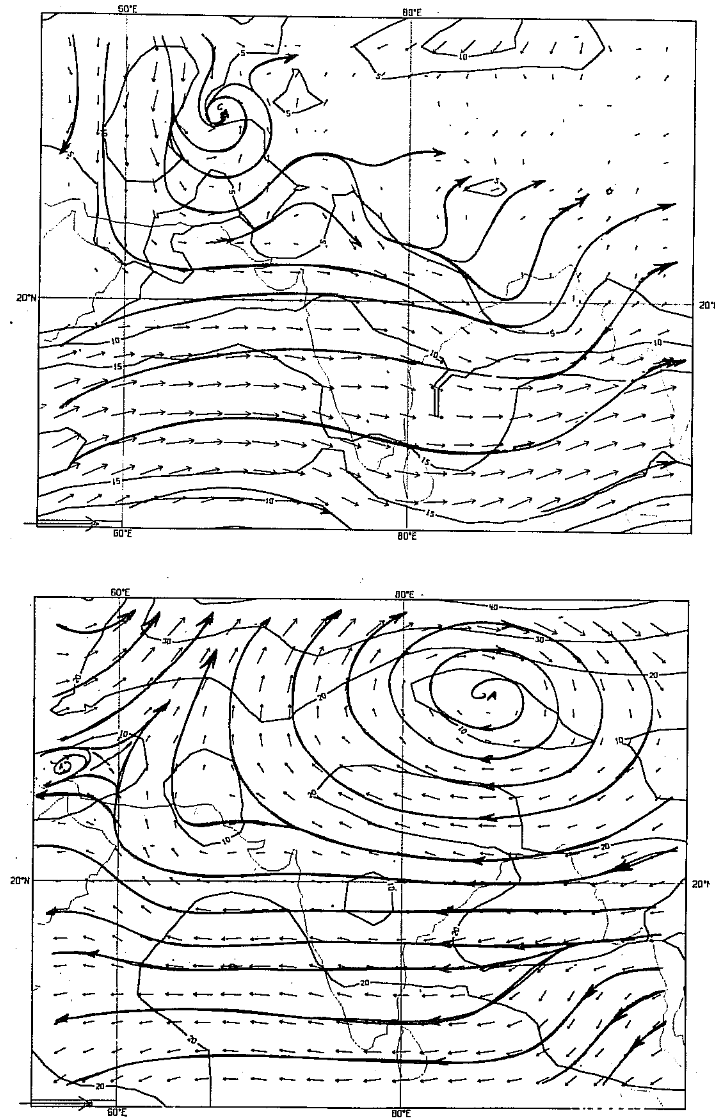

Fig. 16 Analysis of the wind field for 12 GMT of 11 August, 1985 for 850 mb (top) and 700 mb (bottom).

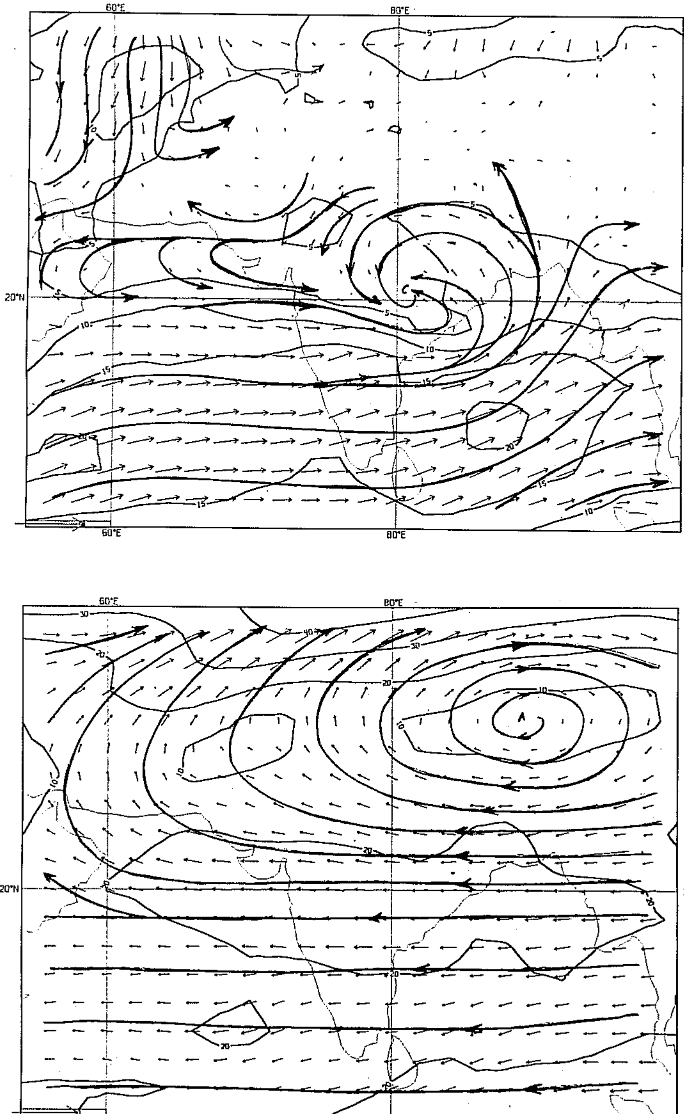

Fig. 17 72 hr forecast of the wind field from of 12 GMT 11 August, 1985
for 850 mb (top) and 700 mb (bottom).

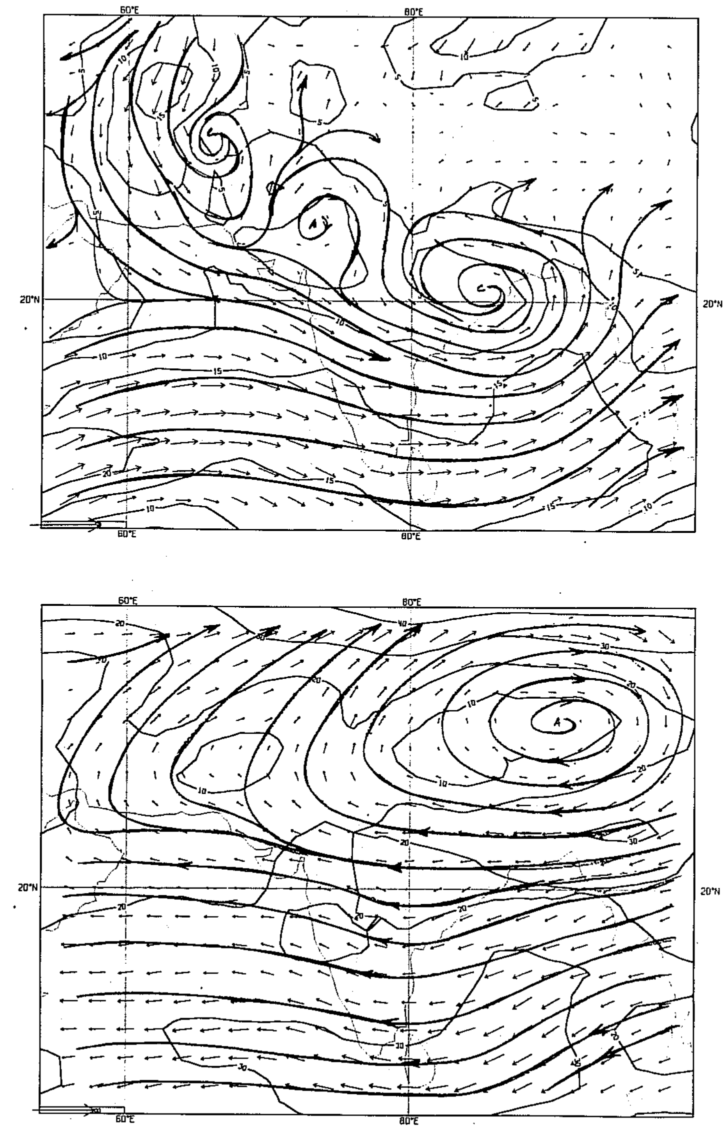

Fig. 18 Analysis of the wind field for 12 GMT 14 August, 1979
for 850 mb (top) and 700 mb (bottom).

5. SIMULATION OF ONSET PROCESSES OF SUMMER MONSOON DURING JUNE, 1979

The monsoon experiment (MONEX-79) formed an important subprogramme of FGGE; during MONEX special observing systems were launched to monitor the various phases of the summer monsoon. The monsoon onset was delayed during 1979, and when it arrived 11 days later than normal, it was quite dramatic. In view of the known sensitivity of tropical forecasts to the parameterization of cumulus convection and to the analysis of humidity, it is of interest to examine how well some of the experimental schemes under development at ECMWF compare with the operational scheme. In this section the results of three different simulations at a T63 resolution are presented starting from 12 GMT 11 June 1979. It should be noted, however, that such a limited study can give no more than an indication of sensitivity. The three simulations are listed below.

KUO: Data assimilation and forecast using a modified Kuo parameterisation. This convection scheme has been used operationally at ECMWF since May, 1985 (Tiedtke and Slingo, 1985).

ADJ: A convective adjustment scheme for data assimilation and forecast (Betts and Miller, 1984).

HUM: Using the same procedure as in KUO, but with a revised analysis of the humidity field (Illari, 1985).

Before discussing the results of the above simulations, it is useful to briefly state some of the significant synoptic conditions before and during the monsoon onset besides increases in rainfall. These are given below:

- Formation of a trough (the equatorial trough) in the upper air circulation usually appearing first at 700 mb over the Arabian Sea or the Bay of Bengal or in both these regions, and its northward propagation. (Riehl, 1959; Datta et al., 1981).
- Significant cross-equatorial flow in the lower troposphere (most significant at 850 mb).
- Change of winds at the southern tip of the west coast of India from northwesterlies to westerlies or southwesterlies.

- Establishment of an intense high pressure area over the southern hemisphere, known as the Mascarene High.

- Appearance of the TEJ and shift of the trough in the upper tropospheric westerlies from its winter position of 85-90°E to 75-80°E.

- Weakening of the subtropical westerlies south of the Himalayas.

During 1979, as described by Krishnamurti et al. (1980), a weak equatorial trough (ET) oriented northeast to southwest appeared at the beginning of June near 3-5°N at 700 mb. This did not show steady northward progression until between 8 and 9 June. During its northward progression it brought a good monsoon flow to the Kerala Coast and the monsoon onset was declared on 12 June. This was associated with a strengthening of the equatorial westerlies. During the further northward propagation of the equatorial trough, a well marked circulation formed on 14 June which concentrated into a tropical depression centred at 14N, 7°E on 16 June.

In view of the above synoptic changes, what one would look for in a simulation experiment is the strengthening of low level westerly flow, and the formation and northward propagation of ET leading to the formation of a cyclonic circulation on the 14 June.

5.1 Results of experiments

Only the flow for 850 and 700 mb are presented for the various experiments. In Figs. 19-20 the analysed flow pattern is shown for 11 June 1979 and 14 June 1979 at 12 GMT. In Figs. 21-26 the 24 and 72 hour forecasts are presented for the three experiments. The analysis of 11 June, 1979 is based on the main FGGE level II-b data which is still devoid of drop sondes data; this is omission could have a significant effect on the analysis over the Arabian Sea.

i) KUO Results

In this experiment, the data assimilation (6 hourly cycle for analysis) as well as the forecast used the current operational scheme for convective parameterisation, which is based on the Kuo scheme.

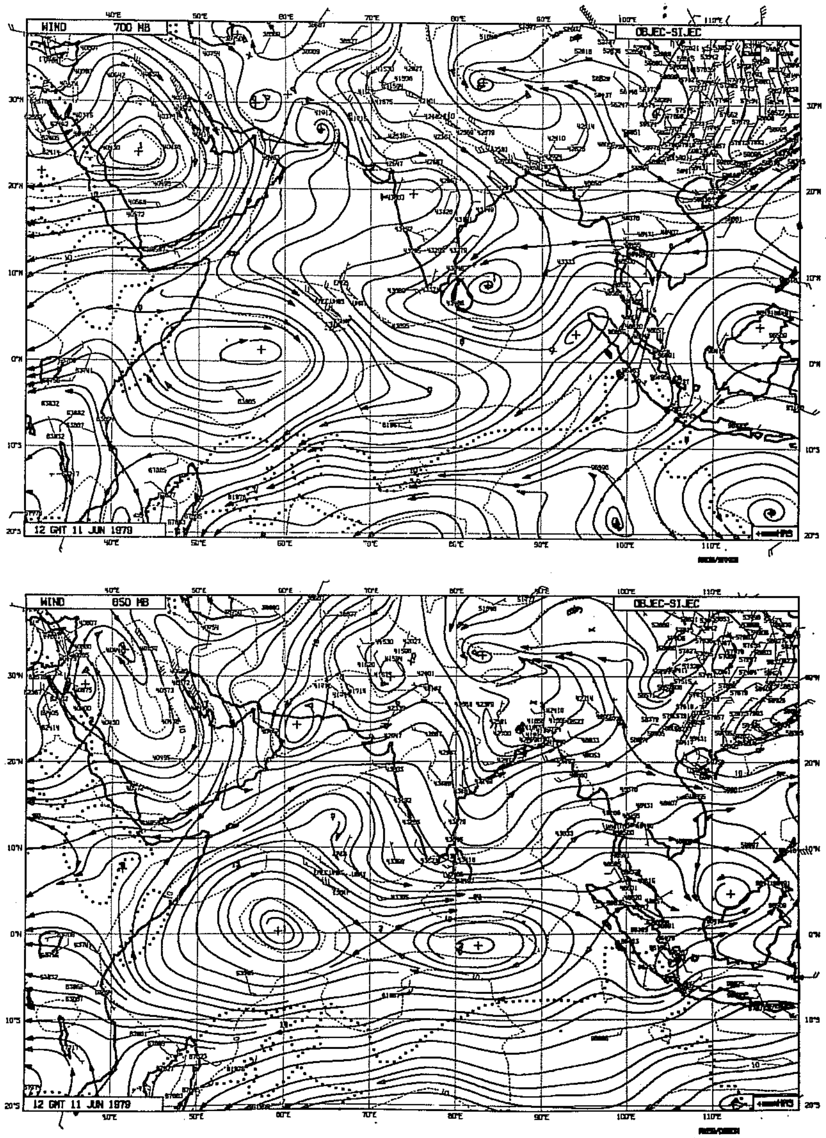

Fig. 19 Analysis of the wind field for 12 GMT of 11 June, 1979
for 850 mb (top) and 700 mb (bottom).

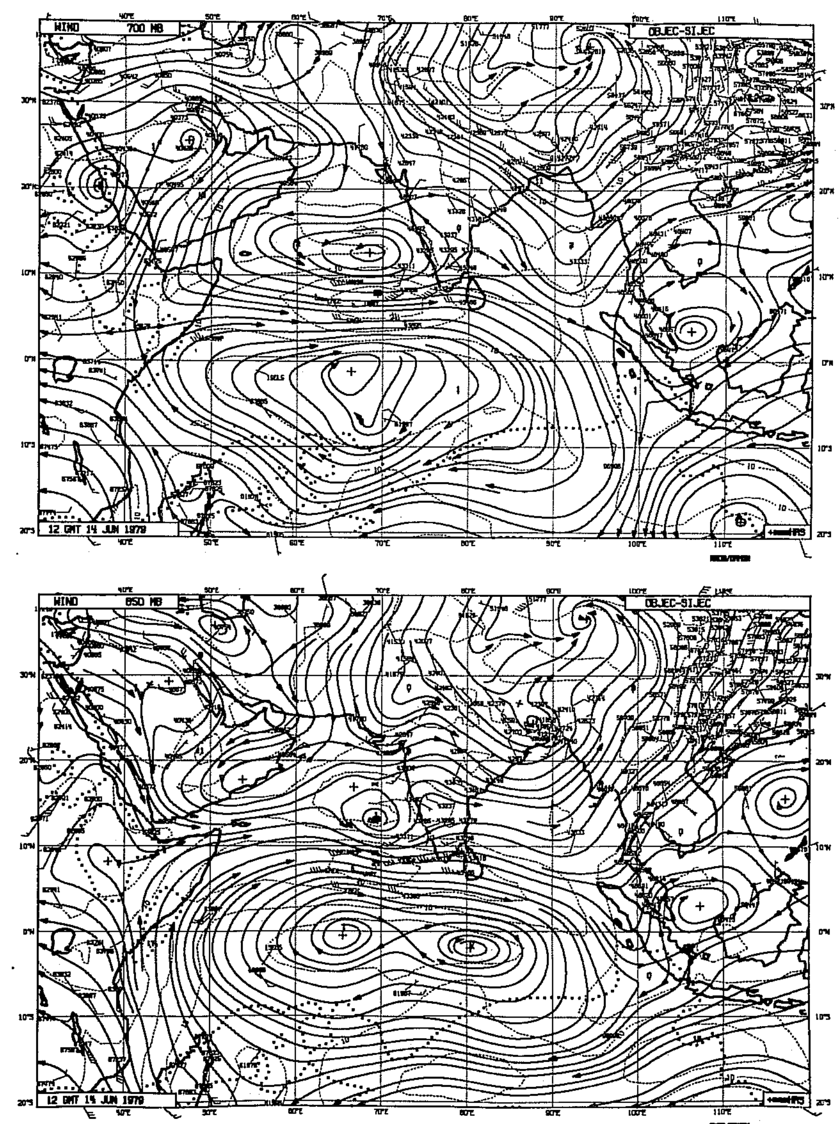

Fig. 20 Analysis of wind field for 12 GMT of 14 June, 1979
for 850 mb (top) and 700 mb (bottom).

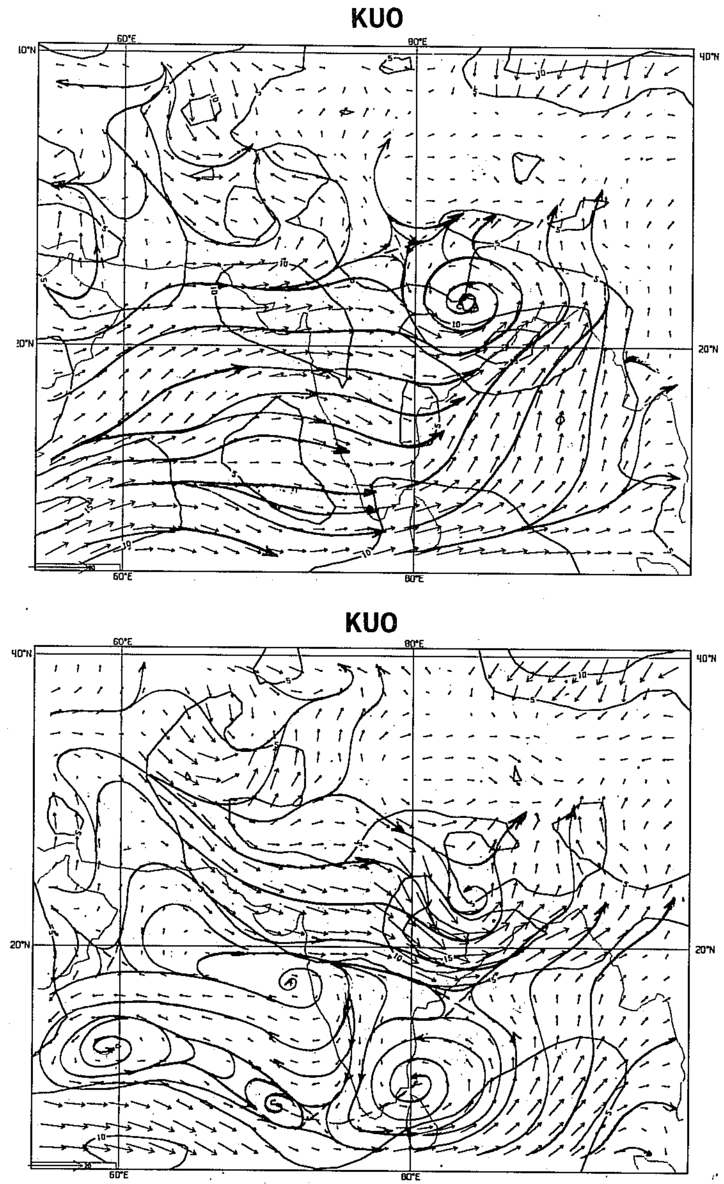

Fig. 21 24 hr forecast of wind field from 12 GMT of 11 June, 1979 using Kuo's modified method for data assimilation and forecast (ECMWF operational version) for 850 mb (top) and 700 mb (bottom).

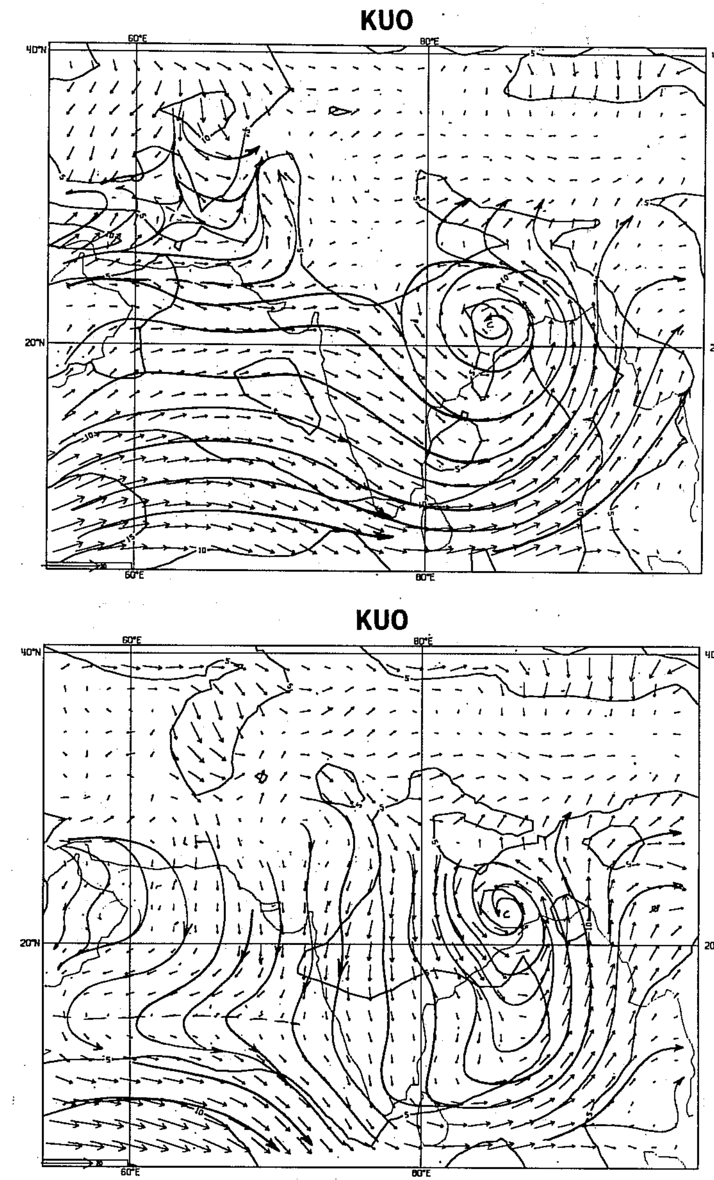

Fig. 22 72 hr forecast wind fields from 12 GMT of 11 June, 1979 for 850 mb (top) and 700 mb (bottom).

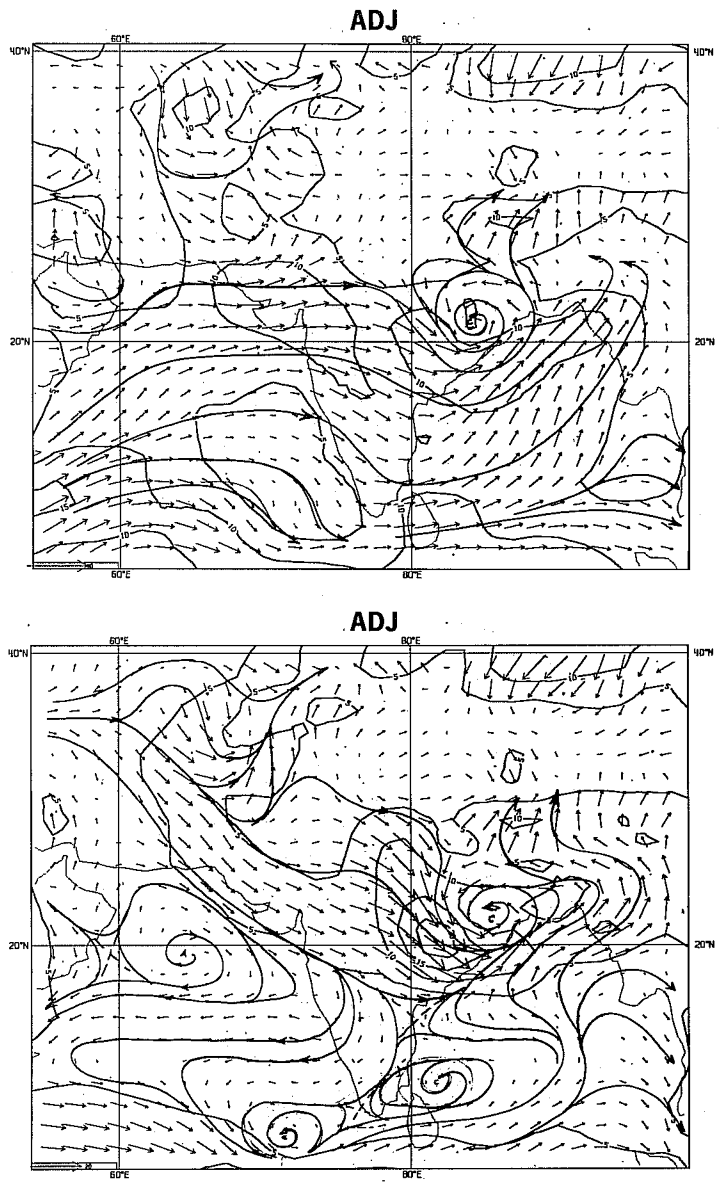

Fig. 23 24 hr forecast of wind field from 12 GMT of 11 June, 1979 using convective scheme of Betts and Miller (1984) both for data assimilation and forecast.

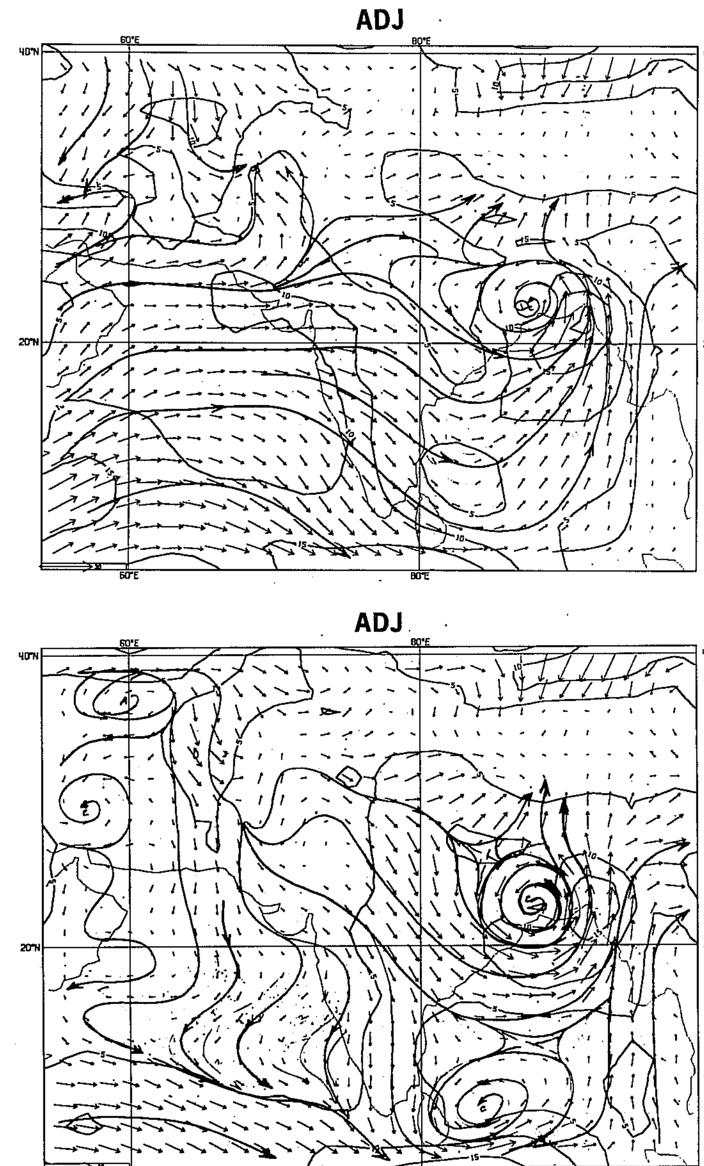

Fig. 24 72 hr forecast of wind field from 12 GMT of 11 June, 1979 using convective scheme of Betts and Miller (1984) both for data assimilation and forecast.

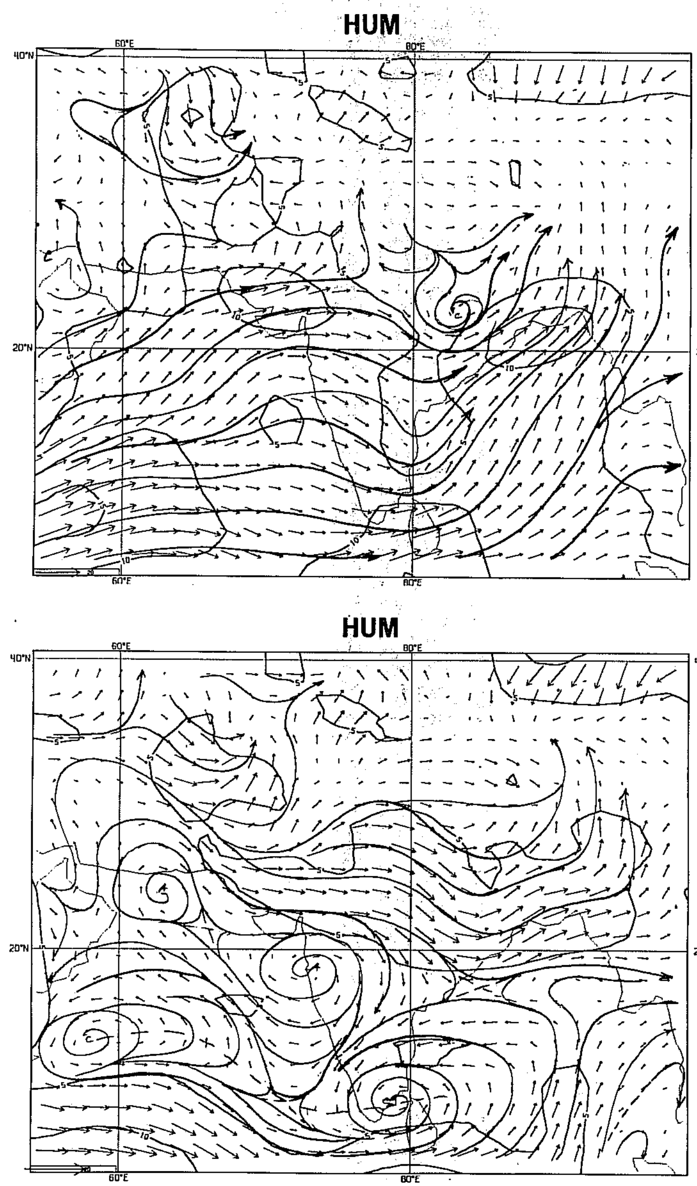

Fig. 25 24 hr forecast of wind field from 12 GMT of 11 June, 1979 using new humidity analysis (Illari, 1985).

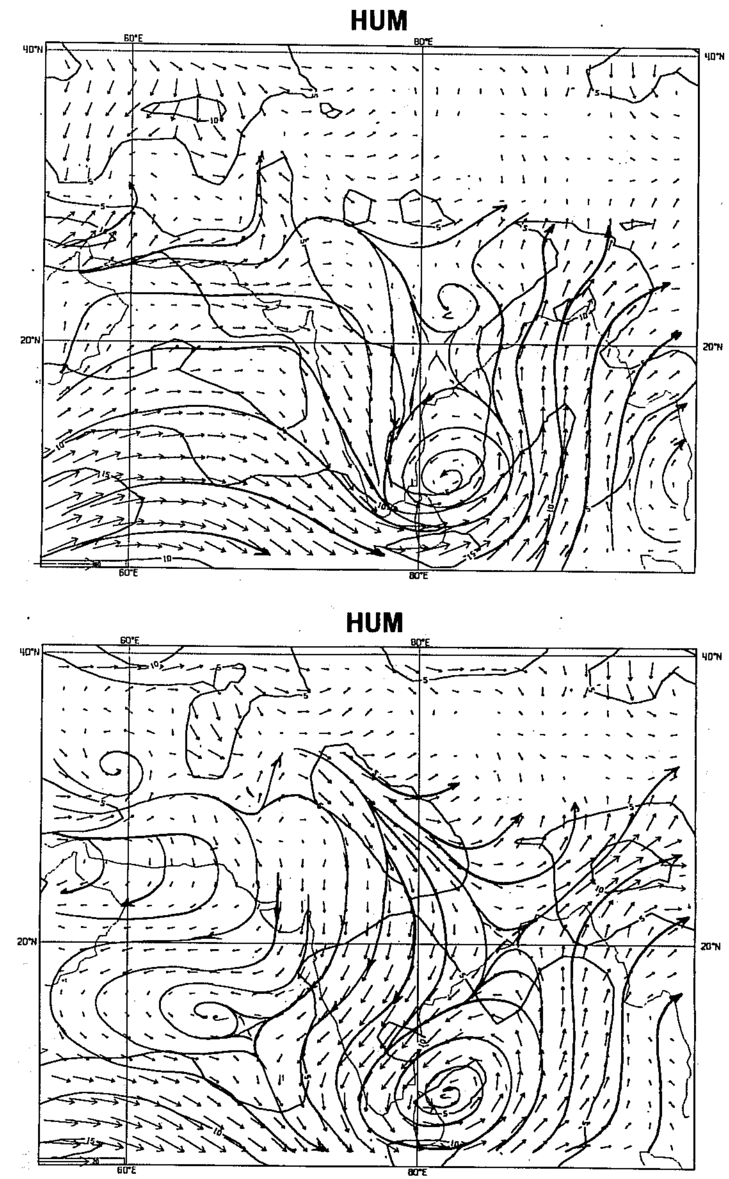

Fig. 26 72 hr forecast of wind fields from 12 GMT of 11 June, 1979 using new humidity analysis (Illari, 1985).

The forecast fields for 24 and 72 hours (Figs. 21,22) have the following significant features:

a) At 850 mb there are winds in excess of 5 ms^{-1} over the Kerala Coast, whereas the LLJ has speeds greater than 15 ms^{-1}. In the 72 hour forecast there is a further increase in wind speed, reaching speeds over 15 ms^{-1}. This is quite satisfactory in terms of the evolution of the LLJ, and the strong westerlies over Kerala Coast - conditions which are associated with the onset.

b) At 700 mb, the ET with embedded circulations move from the Bay of Bengal to the Arabian Sea in the 24 hour forecast, but it becomes very diffuse during the next 48 hours, whereas in reality it is quite marked. This shows that although there is a good 24 hour forecast, the model could not satisfactorily generate the ET and embedded vortex after 72 hours.

ii) <u>ADJ Results</u>

In this experiment, both the data assimilation as well as forecast use the adjustment scheme of Betts and Miller (1984). Although both 850 mb and 700 mb wind fields are generated satisfactorily in the 24 hour forecast (except over the Kerala Coast where the wind are northwesterlies rather than westerlies) this is not the case in the 72 hour forecast. (See Figs. 23-24). Instead of increasing winds over the Kerala Coast, there is a decrease at 850 mb and the ET at 700 mb has become rather feable.

iii) <u>HUM Results</u>

This experiment is the same as KUO except that it has an improved humidity analysis which is described by Illari (1985).

Significantly, by inclusion of an improved humidity analysis, there is a large improvement in the simulation of the onset processes (Figs. 25,26). The 24 hour forecast has stronger winds of the order of 10 ms^{-1} over the Kerala Coast, compared to 5 ms^{-1} in KUO. At 700 mb, the ET is well defined.

The 72 hour forecast, shows a further increase in wind speed, being greater than 10 ms^{-1} at 850 mb. It has an enhanced cyclonic circulation over the southwest Bay of Bengal. At 700 mb it has generated two circulations over the ET, one each over the Bay of Bengal and Arabian Sea. However the position of the circulation in the Arabian Sea is north of that observed. Out of all the experiments, this one has produced the best results.

5.2 Discussion of the results

From these experiments it is difficult to draw general conclusions, but it does seem that humidity has a large impact. It also appears that the modified Kuo method used for both the data assimilation and forecast produced better results than the adjustment scheme. However, this conclusion should be qualified since for the August case the adjustment scheme shows an improvement over the operational forecast (not shown).

As the initial analysis lacked some potentially crucial data, it will be interesting to repeat these experiments after re-analysis using the MONEX data set.

Simulation of the vortex on 14 June 1979 and its further intensification into a tropical depression is an interesting experiment which needs to be performed by running forecasts from 13 June 1979.

6. SUMMARY

i) It is found that there are systematic errors in the forecasts. North of 25°N, the predominant error pattern is one of anticyclonic flow which remains stationary, at least during the early part of the forecasts. South of 25°N, the Bay of Bengal region has predominant anticyclonic flow which shows some propagation with time, but the Arabian Sea region has predominant cyclonic flow which shows a systematic propagation in a westerly direction.

ii) The error patterns are such that there is a tendency for the LLJ to increase and extend eastwards and to lower levels, and a tendency of the TEJ at 200 mb to weaken and the maximum to shift westwards.

iii) The significant error patterns are generally over the regions of sparse data.

iv) The error structure in the 24 hour forecast in the upper troposphere shows significant divergent flow which suggests that there are adjustment processes in action in the model, probably related to an initial imbalance.

v) An improved humidity field can improve the monsoon forecast.

vi) In its present form, the ECMWF forecasts could in general be used operationally for forecasting monsoon flow for a period of 1-3 days.

7. POSTSCRIPT

During July 1985 the precipitation forecasts showed considerable rainfall in Arabia. This was found to be due to the use of erroneous SST for 31 May onwards; the SST being used was too warm by 3°C over the Arabian Sea. During August 1985, when the correctly analysed SST field was used, precipitation forecasts showed no rainfall over Arabia but still very high rainfall over the Arabian Sea, especially west of 65-70°E. This needs to be examined with reference to cloud imagery from INSAT (the Indian satellite). The SST in this region compared to other tropical oceans shows very significant day to day changes during the monsoon; use of 2 day mean or climatology in the model may not be adequate. It may be useful to experiment with improved SST and, if possible, to use some simple technique to forecast the changes during integration of the model. It is difficult to comment on the precipitation forecasts, since more quantitative assessment is necessary.

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