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Some results of the impact of additional data collected during MONEX - 79 on the performance of an objective analysis scheme and barotropic prediction*

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सार — मानसून अवदाबों की रचना तथा उनकी गति का विस्तृत अध्ययन ग्रीष्म कालीन मौनैक्स-79 कार्यक्रम का एक अंग था । वायुयानीय अन्वेषण मिशन के द्वारा क्षेत्रीय चरण में विस्तृत आंकड़े इक्ट्ठे दिये गए थे । इन अतिरिक्त आंकड़ों के विश्लेषण तथा वस्तुनिष्ठ तथा व्यक्तिनिष्ठ विधियों पर प्रभाव का अध्ययन करने के लिये इनका परीक्षण किया गया है। प्रेक्षित आंकड़ों में दाबघनत्वी अस्थायित्व की मौजूदगी के लिये आवश्यक परिस्थिति का भी पता लगाया गया है ।

इस अध्ययन से पता चला है कि कुछ मामलों में उचित पूर्वानुमान नहीं प्राप्त होते हैं हालांकि पर्याप्त मात्रा में आवश्यक आंकड़े उपलब्ध होते हैं ।

ABSTRACT. Detailed study on the formation and movement of monsoon depressions formed a part of the scientific objectives of the summer Monex-79 programme. During the field phase extensive data were collected by aircraft probing mission. This additional data have been examined to study its effect on the analysis, both objective and subjective methods. The necessary condition for the existence of barotropic instability in the observed data has also been investigated.

The study has revealed that good forecasts are not achieved in some cases even when good coverage of data is available.

1. Introduction

Monsoon depression is an important transient disturbance during southwest monsoon season. These disturbances mostly form over the Head Bay of Bengal and move towards west or westnorthwest over the Indian plain. A critical review of several studies on these disturbances has been presented by Rao (1976) and Sikka (1975, 1977).

The movement of monsoon depression has always been a puzzling problem. Although the disturbance is embedded in the westerlies it moves westward against the prevailing lower-tropospheric basic current. This aspect has been examined by Koteswaram and George (1960), Rao and Rajamani (1970), Daggupati and Sikka (1977) and several others. Prediction of movement of monsoon depression by numerical models has been attempted by Das and Bose (1958), Shukla and Saha (1970), Singh and Saha (1976), and Krishanamurti *et al.* (1976).

Detailed study on the formation and movement of monsoon depression formed a part of the scientific objectives of the summer Monex-79 programme. During the field phase of summer Monex between 3 & 8 July 1979, extensive data were collected by aircraft probing mission to study a monsoon depression in the Bay of Bengal. As a result, good data are available around this monsoon depression. In the present study we propose to examine the effects of additional data on the analyses— both objective and subjective methods. The necessary condition for the existence of barotropic instability in the observed data has also been investigated. Furthermore, it is also proposed to investigate whether additional data input to a barotropic model would yield better forecast on the movement of monsoon depression.

2. Model, data and analysis

The numerical model used for this experiment is a primitive equation barotropic model and its details and computational schemes are given by Singh and Saha (1976). As previous experiments have shown that the 700 mb is a proper reference level for using the model for the monsoon season, wind field at this level has been used as input for the present study.

The case chosen for the present study is that of a monsoon depression from 5 to 8 July 1979 which had formed during the Bay of Bengal field phase of Monex-79. Extensive data were collected through aircraft probing missions by the US Aircraft P3 and Electra on each day except on 6 July when only P3 probed the depression field.

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The streamline isotachs analyses were carefully done for 12 GMT observations at 700 mb on all the four days. In order to examine the effect of additional data (aircraft data), two sets of subjective analyses were made-one set (set 1) using all available data from pilot balloons, radiosonde and data from the ships and the other set (set 2) in addition included the aircraft data (dropsondes). Set 2 differs from the first only in the cyclonic domain (from 10°N to 24°N and 80°E to 100°E) where reanalyses were done after taking into account the aircraft data. Further, a third set (set 3) of data were analysed by objective technique following Cressman (1959) in which all data were included. Wind data were interpolated at 2° latitude-longitude intersections for the domain of integration which extended from 4° N to 36°N and 60°E to 100°E.

3. Influence of additional data on analyses

In order to study the influence of additional data on the analyses, objective analyses without aircraft data were also made for 5-7 July. The analyses with and without aircraft data by objective and subjective methods were compared by computing RMS error, average kinetic energy, maximum vorticity etc (Table 1).

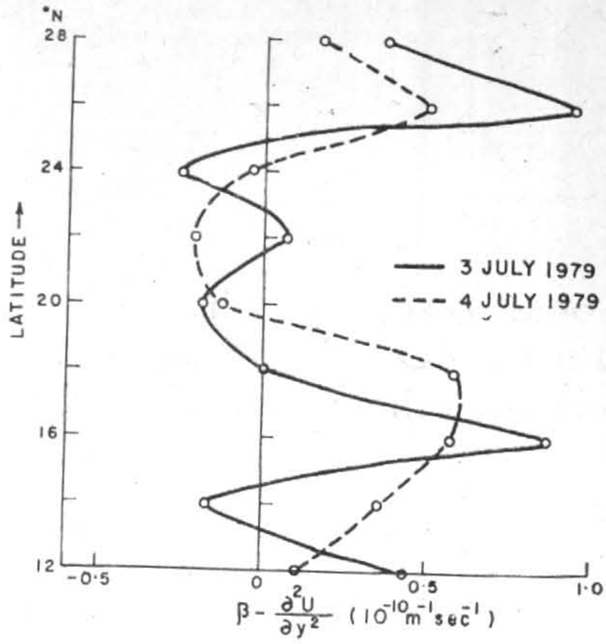

Fig. 1. Meridional section of the meridional gradient of the absolute vorticity

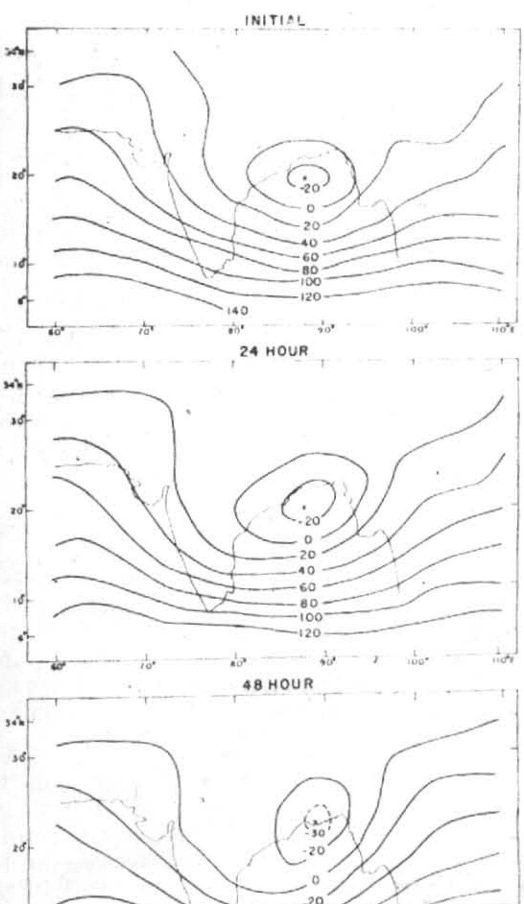

Fig. 2. Input analysis set I

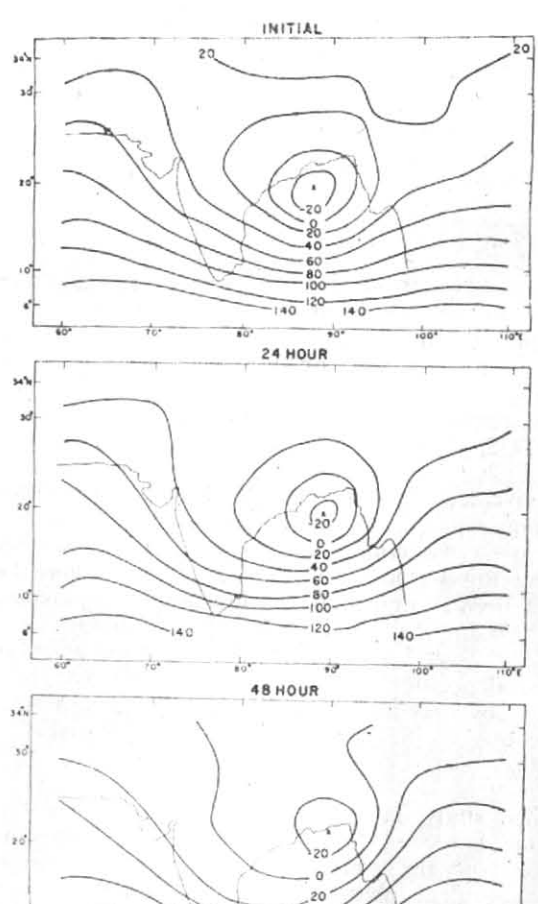

Fig. 3. Input analysis set 2

Figs. 2 & 3. Initial (12 GMT, 700 mb, 7 July 1979) and forecast (24 hour and 48 hour) stream function charts

TABLE 1

RMS error (m s^{-1}), average wind (m s^{-1}), kinetic energy (m^2 s^{-2}) and maximum vorticity (10^{-5} s^{-1}) in different types of analyses

No.	Quantity	5 July 79		6 July 79		7 July 79	
		Without dropsonde	With dropsonde	Without dropsonde	With dropsonde	Without dropsonde	With dropsonde
1 (a)	RMS error u-comp.	3.8	2.5	3.4	3.4	4.7	3.4
(b)	RMS error v-comp.	2.7	2.7	3.2	3.1	3.1	2.9
2 (a)	Average u-comp (sub)	7.1	7.1	4.9	5.0	4.9	4.8
(b)	Average u-comp (obj)	5.6	6.2	3.6	4.5	3.0	4.1
3 (a)	Average v-comp (sub)	−1.5	−1.7	−1.4	−1.3	−2.2	−2.0
(b)	Average v-comp (obj)	−1.9	−1.8	−2.4	−2.2	−1.9	−0.9
4 (a)	Kinetic energy (sub)	53.5	55.6	41.8	47.3	46.4	51.8
(b)	Kinetic energy (obj)	38.0	41.8	42.9	52.2	44.8	55.0
5 (a)	Maximum vorticity (sub)	4.7	8.9	6.5	9.0	8.2	10.0
(b)	Maximum vorticity (obj)	4.8	4.2	5.0	5.4	5.9	5.9

The RMS error for the domain from 70° to 100° E and from 8° to 30° N between objective and subjective methods in most of the cases are below 4 m/sec, suggesting a fair agreement between the two methods. Also the RMS errors are reduced when the additional aircraft data over the Bay of Bengal are utilised in both subjective and objective analyses. This implies that the additional data improves the analyses. The maximum value of relative vorticity in all cases increases with the intensification of the monsoon depression and attains maximum on 7 July when the system is most intense. The maximum values of the vorticity obtained in objective analyses are less than those in subjective analyses. This may be due to the smoothing of the wind field which is inherent in the objective analysis. A look at the wind field suggested that the systems were better defined in the cases of analyses which included additional data over the Bay of Bengal.

4. Barotropic instability

Several studies suggest that barotropic instability may be the initiation mechanism for the formation of a depression. In this case the criterion for the barotropic instability in the observed data prior to the formation of the depression is examined. As the system showed intensification on 5 July, data corresponding to 3 and 4 July were considered relevant for testing the barotropic instability criterion. Fig. 1 shows the latitudinal profile of meridional gradient of absolute vorticity of the basic current. The basic current in this case is defined as the average zonal wind for the longitudinal belt of 70°-100° E. A change of sign in the meridional gradient of absolute vorticity around 20° N is very clearly noticed in the observed data of 3 and 4 July (Fig. 1), satisfying the barotropic instability criterion. It is of interest to point out that the depression formed around 20 °N subsequently. To test whether a barotropic model would result in the amplification of the disturbance, wind data of 700 mb, 3 July 1979 were used as input to the model for a 48-hour forecast. The forecast result showed no amplification in the region of the depression. It is relevant to point out that this is only a necessary condition for the barotropically unstable wave to form and this instability mechanism alone has not been sufficient to amplify the wave in this particular situation. The rapid growth of monsoon disturbances is essentially linked with the subgrid scale heating accompanying organised convection. As the barotropic P.E. model has no way to incorporate the effect of cumulus heating, the non-development of the disturbance in the numerical experiment reported here is not surprising.

5. Results of prediction experiment

5.1. *Prediction experiment with three sets of analyses*

The initial and forecast stream function fields are shown in Figs. 2, 3 and 4 corresponding to input analyses sets 1, 2 and 3 respectively of one day only, that of 7 July 1979. Table 2 presents the observed and forecast positions of the monsoon depression from 5 to 7 July 1979 in respect of all three sets of analyses. It may be seen from Table 2, that the model failed to predict the movement of cyclonic circulation in all cases of analyses and for all days. In forecast field the system showed either slight eastward or northeastward movement or remained stationary except for the case of 8 July (set 2) when a slight westward movement could be seen as compared to a very fast movement in the actual case.

Identity of the closed circulation is lost in the 48-hr forecast field based on the input of set 1 for 5 and 6 July and also of the set 3 for 5 July. However, the geometry of the system in the forecast field based on the input of set 2 for all the days are preserved. This improvement in the forecast field may be due to the inclusion of additional data in the input analyses by subjective method.

Failure of model prediction in the present case may perhaps be due to prevailing weak easterlies in northern sector of the cyclonic circulation. To assess the strength of easterlies in northern sector and westerlies in southern sector, the mean zonal wind at 700 mb in the cyclonic domain for two monsoon depression series, one from 4 to 6 August 1968 and other, the present series from 5 to 8 July 1979, were computed. The results are presented in Table 3. The movement of the former series of depressions was predicted with a fair degree of accuracy

TABLE 2

Forecast and observed positions of the centre of monsoon depression input 12 GMT, 700 mb, 5-7 July 1979

Date (July 1979)	Observed position (°N)	Observed position (°E)	24-hr forecast position (°N)	24-hr forecast position (°E)	48-hr forecast position (°N)	48-hr forecast position (°E)
Set 1 : Input analyses without aircraft data, subjective analysis						
5	22	90	22	92	Trough	
6	20	90	20.5	90.5	Trough	
7	20	88	20	88	23	89
Set 2 : Input analysis with aircraft data, a subjective analysis						
5	22	92	21	93	21	95
6	20	90	20	91	22	92
7	20	88	20	89	22	90
8	20	82.5	21	82	23	81.5
Set 3 : Input analyses with aircraft data, objective analysis						
5	20	92	20	94	Trough	
6	20	92	20	93	21	94
7	20	89	20	90	22	92

TABLE 4

As in Table 2 except input 12 GMT 700 mb, 6-8 July 1979 (modified analysis)

Date (July '79)	Observed position (°N)	Observed position (°E)	24-hr forecast position (°N)	24-hr forecast position (°E)	48-hr forecast position (°N)	48-hr forecast position (°E)
First modification—Easterly in northern sector strengthened artificially						
6	20	90	20	90	Trough	
7	19	88	20	88	22	90
8	20	82	21	82	22	80
Second modification—Easterly in northern sector strengthened and westerly in southern sector weakened artificially						
6	20	90	20	90	20	87
7	20	88	20	88	22	90
8	20	82	20	82	22	80

TABLE 6

As in Table 2 except input 00 GMT, 700 mb, 23-24 June 1979

Date (Jun 79)	Observed position (°N)	Observed position (°E)	24-hr forecast position (°N)	24-hr forecast position (°E)	48-hr forecast position (°N)	48-hr forecast position (°E)
23	20	88	22	88	22	88
24	20	87	20	88	22	90

TABLE 3

Distribution of mean zonal wind (m s^{-1}) at 700 mb across the monsoon depression in two synoptic series

Date	Lat. (°N) 12	14	16	18	20	22	24	26	28
Case 1									
5 Aug 68	10.4	9.3	9.2	8.3	3.7	-1.5	-6.1	-9.4	-2.7
5 Aug 68	11.4	12.3	11.6	9.8	4.4	1.6	-6.5	-10.3	-6.6
6 Aug 68	9.8	9.8	9.2	7.6	4.0	0.2	-5.0	-7.1	-7.0
Case 2									
5 Jul 79	12.5	12.7	12.1	10.2	5.5	2.0	0.7	0.3	0.9
6 Jul 79	11.9	11.9	9.2	7.1	1.6	-1.1	-2.6	-2.2	-0.9
7 Jul 79	12.2	12.4	10.7	6.0	-0.9	-3.3	-2.5	-1.0	-0.7
8 Jul 79	12.0	11.1	9.2	5.5	0.5	-1.7	-3.6	-2.7	-0.8

TABLE 5

Distribution of mean zonal wind (ms^{-1}, at 700 mb across the monsoon depression, 6-8 July 1979 (modified analysis)

Date (Jul 79)	Lat (°N) 12	14	16	18	20	22	24	26	28
First modification—Easterlies in northern sector strengthened									
6	11.9	11.9	9.2	7.1	1.6	-1.8	-4.2	-4.9	-3.1
7	12.2	12.4	10.7	5.8	-1.7	-4.2	-3.6	-1.3	-0.7
8	12.0	11.1	8.7	5.5	0.6	-2.2	-4.0	-4.8	-2.0
Second modification—Easterlies in northern sector strengthened and westerlies in southern sector weakened									
6	11.9	10.8	8.3	6.0	1.3	-2.5	-4.6	-4.6	-3.2
7	12.2	11.4	9.9	5.6	-1.8	-4.6	-3.5	-2.0	-1.0
8	12.0	8.9	7.5	3.9	0.6	-3.2	-4.2	-4.5	-2.0

TABLE 7

As in Table 5 except for 23-24 June 1979

Date (Jun 79)	Lat (°N) 12	14	16	18	20	22	24	26	28
23	14.6	11.7	9.4	7.7	3.1	-1.6	-3.1	-1.9	-1.2
24	15.6	12.1	9.6	6.1	-0.1	-3.5	-3.4	-5.1	-4.4

TABLE 8

As in Table 2 except input 00 GMT, 24 June 1979 and 12 GMT, 700 mb, 7 July 1979 (effects of terrain included)

Date	Observed position (°N)	Observed position (°E)	24-hr forecast position (°N)	24-hr forecast position (°E)	48-hr forecast position (°N)	48-hr forecast position (°E)
24 Jun 79	20	87	20	88	22	86
7 July 79	20	88	20	88	22	88

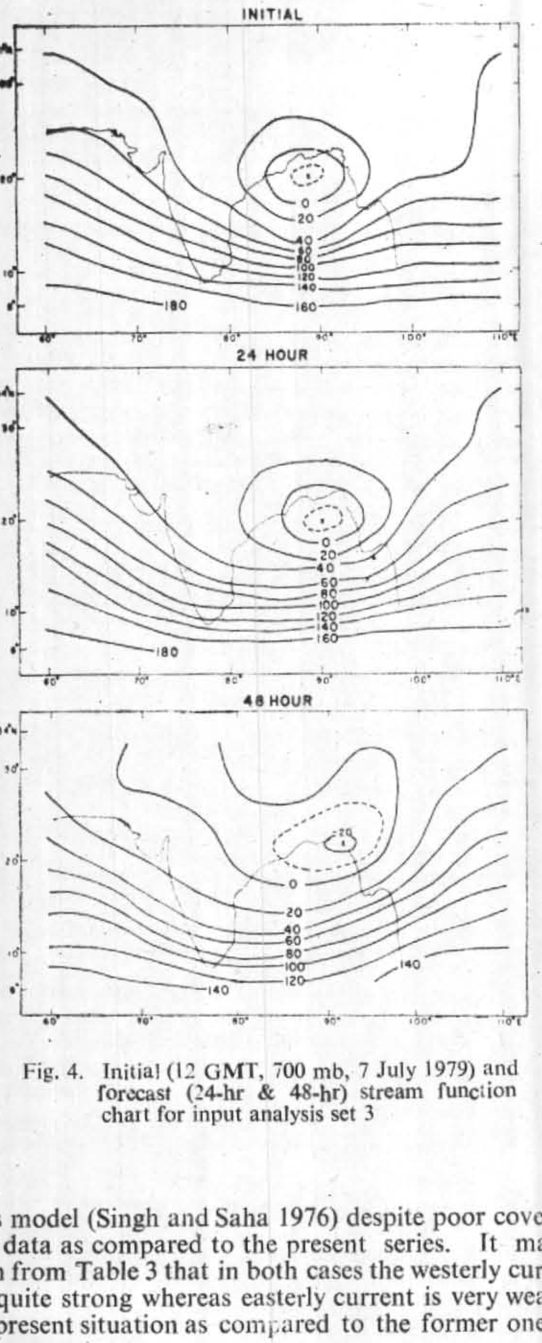

Fig. 4. Initial (12 GMT, 700 mb, 7 July 1979) and forecast (24-hr & 48-hr) stream function chart for input analysis set 3

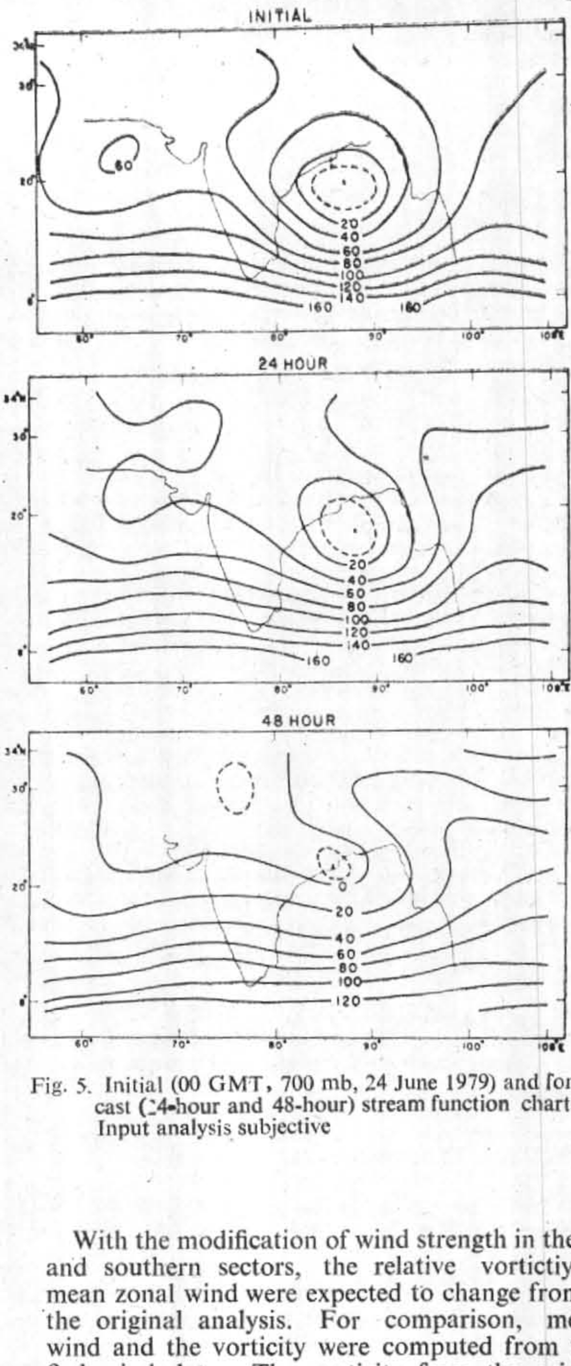

Fig. 5. Initial (00 GMT, 700 mb, 24 June 1979) and forecast (24-hour and 48-hour) stream function charts: Input analysis subjective

by this model (Singh and Saha 1976) despite poor coverage of data as compared to the present series. It may be seen from Table 3 that in both cases the westerly current is quite strong whereas easterly current is very weak in the present situation as compared to the former one.

5.2 *Prediction experiments with modified analysis of set* 2

To investigate the impact of easterlies on the forecast movement more critically, the actual speed of easterlies in the northern sector of the cyclonic domain (22° to 30°N and 84° to 100°E) was subjectively increased and the modified wind data were used as input to the model. In another experiment the easterlies in the northern sector were strengthened and westerlies in the southern sector (14° to 18°N and 80° to 100°E) were weakened, and the new set of wind data thus obtained were also used as input to the model. The forecast results using these modified inputs are presented in Table 4. It may be seen from Table 4 that no significant improvement in the forecast movement could be achieved with the modified inputs.

With the modification of wind strength in the northern and southern sectors, the relative vortictiy and the mean zonal wind were expected to change from those of the original analysis. For comparison, mean zonal wind and the vorticity were computed from the modified wind data. The vorticity from the original data was also computed as well. The mean zonal wind are presented in Table 5. It is evident from Table 5 that the mean easterlies based on modified analysis are stronger than the original mean easterlies (Table 3) but these easterlies are still considerably weaker than the mean westerlies prevailing in the southern sector. Further, the vorticity patterns (not presented) remain more or less similar to those of the original except that the gradient of cyclonic vorticity is decreased in northwest and westnorthwest sectors of the cyclonic circulation. Since horizontal advection is considered to be one of the contributory factors for the movement of the system, the strengthening of easterlies and weakening of westerlies in the domain of the disturbance were expected to improve the tendency of westward advection. However, the results showed no improvement in the forecast movement. Thus, it may be inferred that increased tendency for the westward movement of cyclonic circulation gained by strengthening easterlies and weakening westerlies has perhaps been compensated by the decrease in the vorticity gradient.

5.3. *Prediction experiment with a monsoon depression, 23-24 June* 1979

As the above case did not yield a good movement forecast, another case of monsoon depression from 23 to 24 June 1979 during Monex-79 was considered. Wind data of 00 GMT of 700 mb was used as input to the model. The forecast results are presented in Table 6. As evident from Table 6, the model failed to predict the proper movement for these synoptic situations also. The mean zonal wind in these cases (Table 7) also show weak easterlies as compared to the westerlies. It may be pointed out that the mean westerlies in these two cases were the strongest out of all cases (Tables 3, 5 and 7) considered in this study.

Results of the barotropic prediction presented in this study lead us to infer that prediction with this model may be successful as far as movement of monsoon depression is concerned only when easterlies are quite strong and comparable in magnitude to those of westerlies. This requires further investigation.

5.4. *Prediction with the inclusion of terrain*

In another experiment the effects of terrain was investigated. For this purpose the smoothed terrain height to a maximum of 1.5 km was included in the model and 48-hour forecast fields were obtained for 24 June and 7 July 1979. The results are presented in Table 8. The initial and forecast stream-function fields are presented in Fig. 5. Although the inclusion of terrain in the model has not improved the forecast movement significantly, Table 8 clearly shows that eastward movement is checked and even there is westward movement in the case of 48-hour forecast for the case of 24 June.

6. Conclusion

The results of the present study point out the following aspects :

(*i*) Prior to the amplification of the vortex barotropic instability criterion was satisfied in the observed data of 3 and 4 July 1979. However, in the numerical integration experiment, the disturbance did not intensify suggesting that the barotropic instability was not the only mechanism for the intensification for the case under consideration.

(*ii*) Additional data improved the objective and subjective analyses in so far as the depiction of the depression circulation is concerned.

(*iii*) Improved coverage of data around the cyclonic circulation has distinct advantage in retaining the geometry of the system in the forecast field.

(*iv*) Merely good coverage of data has not been found to be efficient for the proper prediction with the P.E. barotropic model as far as movement of the system is concerned.

(*v*) Unsatisfactory forecast movement resulting from this study is perhaps due to the structure of this depression which had much weaker easterly flow to the north of the centre in comparison to the strong westerlies to the south. This is supported by the case of another depression (23-24 June 1979) during the Monex period.

(*vi*) Inclusion of terrain in the model has not significantly improved the forecast except for checking the tendency of eastward movement.

Barotropic model is considered as a good tool for prediction of movement of advecting systems. The results from this study, however, suggest that good forecasts are not achieved in some cases even when good coverage of data is available. Lack of expected impact of the additional data in this study may be due to two possible factors. Firstly, the disturbance investigated had a structure in which the easterly flow to the north of the centre was considerably weaker than the westerly flow to its south resulting in little movement of the disturbance in the forecasts whereas the observed movement was westward. Secondly, It is possible that the positive impact of additional data on the performance of a model may also be dependent upon the nature of model. The P.E. barotropic model being a simple one may not show significant response to additional data. Further work is required to establish the feasibility of this model for forecasting monsoon depressions.

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