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# ANALYSIS AND PREDICTION OF THE MONSOON FLOW DURING THE SUMMER MONEX

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## 1. INTRODUCTION

The Asiatic summer monsoon is one of the largest seasonal perturbations of the atmospheric general circulation. The seasonal reversal is primarily caused by differential heating of land and ocean which occurs due to asymmetric continentality and the seasonal march of the sun. The total monsoon flow consists of a large scale quasi-stationary circulation and superimposed on the large scale monsoon circulation are different space and time scales of monsoon disturbances which determine the geographical locations of precipitation and provide the latent heat of condensation necessary to maintain the monsoon circulation. The most important disturbances are the monsoon troughs and cyclonic disturbances referred to as monsoon depressions.

The transient component of the circulation is dominated by the formation, growth, movement and decay of synoptic scale disturbances known as monsoon depressions. These disturbances first appear as low pressure areas over the Bay of Bengal where they intensify to attain significant amplitudes and then move westward and west-northwestward over India. The formation of these depressions over the Bay of Bengal is attributed either due to the dynamical instabilities of the monsoon flow which is barotropically unstable at all the levels and baroclinically unstable at the upper levels (Shukla, 1977), or due to the amplification of the westward propagating predecessor disturbances located further east (Saha et al., 1981). Latent heat of condensation is the primary energy source, and the Conditional Instability of the Second Kind (CISK) is considered to be the primary mechanism for the amplification of the low pressure areas to attain the intensity of a depression or a deep depression. Monsoon disturbances produce large amounts of rainfall over India, and the cumulative heating associated with such disturbances is one of the important forcings for the maintenance of monsoon circulation.

The analysis and prediction of these disturbances was one of the central scientific objectives of the summer Monsoon Experiment (MONEX) conducted during July, 1979 as an extension of the second Special Observing Period (SOP) of the Global Weather Experiment (GWE), also referred to as the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE). Due to the paucity of the meteorological observations over the tropical oceans in general, and the Bay of Bengal in particular, it has not been possible, in the past, to conduct dynamical analysis and prediction experiments for the monsoon depressions. Special observations gathered during MONEX and FGGE provide a unique opportunity to examine the problems and limitations of deterministic prediction of monsoon disturbances.

A monsoon depression appeared over the Bay of Bengal during the field phase of the summer MONEX. A weak circulation near 500 mb was first detected over the northeastern Bay by an aircraft mission on July 3. Within two days the circulation over the Bay was well marked and by July 6, the cyclonic circulation had achieved the intensity of a monsoon depression. Two research aircraft (NOAA's P3 and NCAR's Electra) flew intensive missions on July 7 to determine the large scale and the synoptic scale structure of the monsoon depression. These observations provided, for the first time, a detailed three-dimensional structure of the temperature, wind and moisture fields of a monsoon depression and the prevailing large scale flow.

The purpose of this study is first to carry out a four-dimensional analysis of the global circulation for the period 1-7 July 1979 utilizing the Goddard Laboratory for Atmospheric Sciences (GLAS) forecast model using the data from the FGGE and MONEX platforms. Secondly, three day predictions are made from the initial conditions of 5 and 7 July 1979, and the predictive skill of the total observing system is evaluated. Comparison with the forecasts made from only the conventional data permits an assessment of the capabilities of the FGGE/MONEX observing system for analysis and prediction of the monsoon circulation.

## 2. ANALYSIS AND ASSIMILATION OF FGGE/MONEX DATA

In this section we describe the objective analysis and assimilation procedure used with the FGGE/MONEX data.

### The Model

The model utilized in this study is the global fourth order GLAS general circulation model described in detail in Kalnay-Rivas et al. (1977) and Kalnay-Rivas and Hoitsma (1979). The model is based on an energy conserving scheme with horizontal differences computed with fourth order accuracy. A 16th order Shapiro (1970) filter is applied periodically to remove unresolved scales. There are nine vertical layers equal in sigma with a uniform horizontal grid (4° in latitude by 5° in longitude). The parameterization of subgrid-scale processes is identical to that of the GLAS climate model (Shukla et al., 1982). Long and short wave radiation are included with a diurnal cycle which allows a convective cloud parameterization, conditional instability supersaturation clouds, a bulk formula parameterization of surface fluxes and a realistic orography.

### The Data

For this study we utilized FGGE data collected from 0000 GMT 1 July 1979 to 1200 GMT 7 July 1979 and special MONEX data (dropwindsondes and aircraft). To improve the quality of the objective analysis each piece of data collected over the Bay of Bengal was subjectively edited by comparing with hand analyses. A summary of the data deletions is contained in Table 1. As may be seen in Table 1, only two pieces of dropwindsonde data were deleted, and these were temperature data.

Table 1. Data deleted over Bay of Bengal (10N - 25N, 80E -100E). Multiple deletions of the same sounding or flight are counted only once. All operational and enhanced TIROS-N soundings were deleted after 18z 2 July. CTW denotes cloud-track winds.

| | | Rawin/Pibal | Sfc/Ship | Dropwindsonde | Aircraft | CTW |
|---|---|---|---|---|---|---|
| July 1 | 00Z | 3 | 1 | | 1 | |
| | 06Z | 1 | | | 3 | |
| | 12Z | 2 | | | | |
| | 18Z | 2 | 1 | | 1 | |
| July 2 | 00Z | 5 | 1 | | | |
| | 06Z | | 5 | | | |
| | 12Z | 4 | 2 | | | 1 |
| | 18Z | | | | 2 | |
| July 3 | 00Z | 1 | | | 2 | |
| | 06Z | 2 | | | 2 | 2 |
| | 12Z | 4 | | 2 | 1 | |
| | 18Z | 1 | 2 | | 6 | |
| July 4 | 00Z | 4 | 3 | | 1 | |
| | 06Z | 1 | | | | 2 |
| | 12Z | 2 | 1 | | 1 | 1 |
| | 18Z | 2 | | | 4 | |
| July 5 | 00Z | 2 | 2 | | 1 | |
| | 06Z | | 2 | | 1 | 7 |
| | 12Z | 5 | 2 | | | 3 |
| | 18Z | 1 | 2 | | 2 | |
| July 6 | 00Z | 4 | 4 | | 1 | |
| | 06Z | 1 | 2 | | 2 | |
| | 12Z | 3 | 2 | | | |
| | 18Z | 2 | 3 | | | |
| July 7 | 00Z | 3 | 2 | | | |
| | 06Z | 2 | 1 | | | 7 |
| | 12Z | 2 | 3 | | | |

Starting from the initial conditions (provided by the NMC global analysis) of 0000 GMT 1 July 1979, two assimilation experiments were conducted. One experiment utilized only the conventional surface and upper air data, and the other the same conventional data plus all of the available FGGE/MONEX data. We refer to these two assimilations as the CONTROL assimilation and the FGGE/MONEX assimilation. From the initial conditions valid at 1200 GMT for 5 and 7 July 1979, arrived at by assimilating the two different datasets, we have made numerical predictions with the GLAS fourth order model.

## Objective Analysis Procedure

In the GLAS objective analysis scheme (Baker et al., 1981) eastward and northward wind components, geopotential height and relative humidity are analyzed on mandatory pressure surfaces. The 6 h model forecast provides a first guess for these fields at 300 mb and at sea level, where pressure and temperature are also analyzed. The first guess for the other levels is obtained from the model first guess modified by a vertical interpolation between the two closest completed analyses. Vertical consistency is maintained through static stability constraints. The analysis at each level is performed with a successive correction method (Cressman, 1959) modified to account for differences in the data density and the statistical estimates of the error structure of the observations. The average distance d between data points is found in a circle with a radius of 800 km centered at each grid point. Three scans are performed with a radius of influence $R_i = c_i d$, where the coefficients $c_i$ (1.6, 1.4, 1.2) were chosen to minimize the analysis error (Stephens and Stitt, 1970). However, the radius of influence is not allowed to become smaller than 300 km. During this process, all data are checked for horizontal consistency. The completed analyses are smoothed and then interpolated to the model sigma levels.

The assimilation procedure provides for the intermittent analysis of batches of data grouped in a ± 3 h window about each synoptic time. In these experiments, the wind and height fields were analyzed independently with no explicitly coupling or balancing.

## 3. RESULTS

We have calculated the root mean square error for wind and geopotential height for all the standard levels in the troposphere for 3 day forecasts from the initial conditions of 1200 GMT of 5 and 7 July 1979. The upper and lower panels in Fig. 1 show the tropospheric root mean square error for vector wind and geopotential height, respectively. The letter C refers to the CONTROL initial conditions and F the FGGE/MONEX initial conditions. Digits 5 and 7 following C and F refer to the date of the initial conditions. For example, the curve labeled C7 refers to the forecast error out to 72 h (abcissa) from the CONTROL initial conditions on 1200 GMT 7 July 1979. The letter P refers to the persistence forecast error. It is found that the FGGE/MONEX forecast from the initial condition of 7 July is slightly better than that from the CONTROL initial conditions, but only slightly. There is no clear difference between the forecasts from 5 July. It should be recalled that there was very good data coverage on 7 July from the FGGE/MONEX platforms. The most noteworthy feature of both the upper and the lower panels is that the forecast error is as bad or even worse than the persistence error during the first 24 h. The geopotential height field seems to have almost no predictability even in the first 24 h.

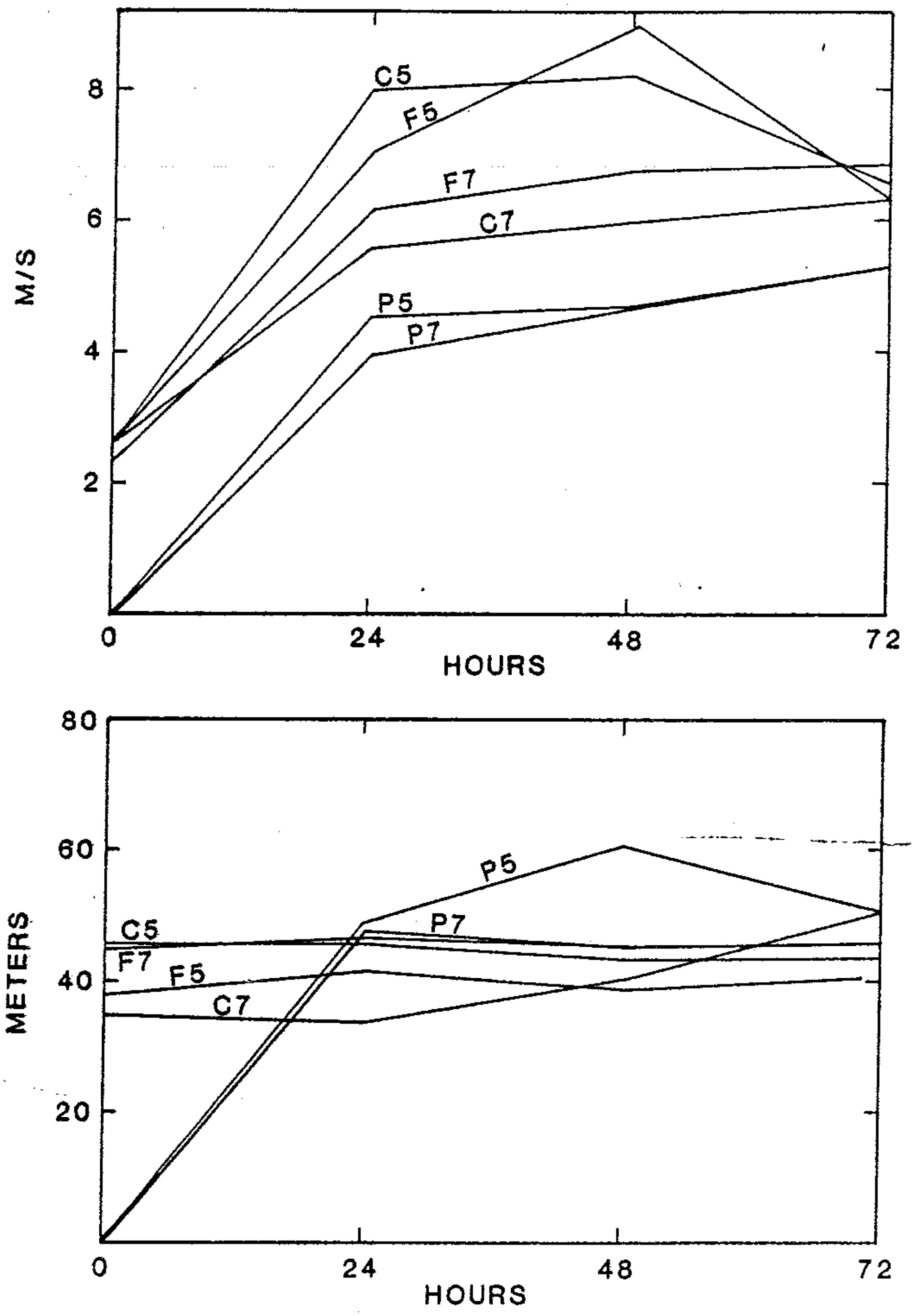


Figure 1. Rms vector wind (top) and geopotential height (bottom) error for 72 h forecasts initialized at 1200 GMT 5 and 7 July 1979. See text for explanation.

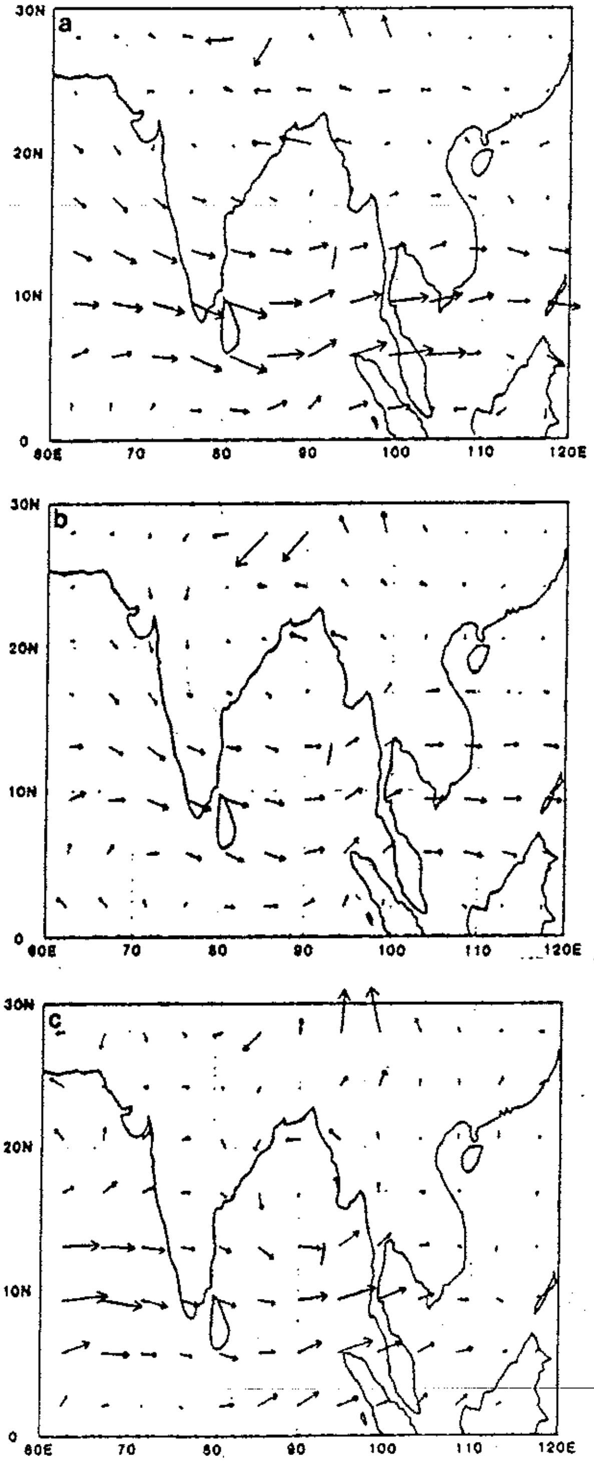


Figure 2. Wind field at 850 mb for the 1200 GMT 5 July case. a) 48 h FGGE/MONEX forecast. b) 48 h CONTROL forecast. c) FGGE/MONEX analysis at 1200 GMT 7 July 1979.

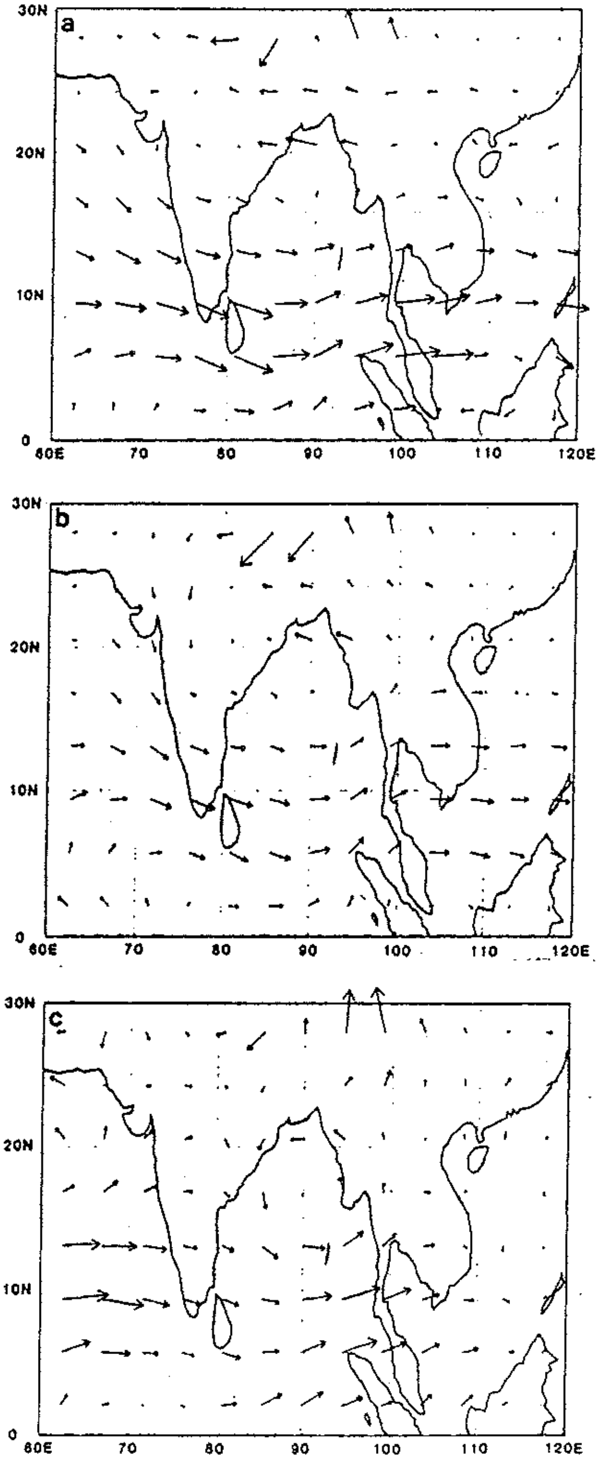
From an analysis of the mean forecast error of 14 forecasts during winter 1979, Kalnay et al. (1981) have shown that the large forecast root mean square error within the first three days is mainly due to systematic errors, and that the forecast error associated with the transients is not too large out to three days. We, therefore, present actual maps of the wind field forecasts and subjectively examine the skill of the CONTROL and FGGE/MONEX forecasts.

Figs. 2a and 2b show the 48 h 850 mb wind field forecast from the FGGE/MONEX and CONTROL initial conditions at 1200 GMT 5 July 1979. Fig. 2c shows the FGGE/MONEX analysis valid at 1200 GMT 7 July 1979. Over the south Bay of Bengal the 850 mb winds have strengthened on 7 July due to the appearance of a monsoon depression in the northern Bay. This is seen from the FGGE/MONEX analysis, and is also verified from subjectively analyzed charts. The FGGE/MONEX forecast, which clearly shows the wind strengthening in the south Bay with a better definition of the vortex in the north Bay, is definitely superior to the CONTROL forecast.

Figs. 3a, 3b and 3c are the same as Figs. 2a, 2b and 2c for the initial conditions at 1200 GMT 7 July 1979. Fig. 3c, which is the NMC analysis valid at 1200 GMT 9 July 1979, is shown only for completeness because our analysis cycle did not extend beyond 7 July. A comparison of Figs. 3a, 3b and 3c with hand analyzed synoptic maps and satellite cloud winds shows that the NMC analysis is rather unrealistic over northeast India and southwest of Srilanka. In both the CONTROL and FGGE/MONEX forecasts, the monsoon trough is maintained over India. However, in the CONTROL forecast, the trough is depicted too far south. The center of the depression is not correct in either of the forecasts. In the FGGE/MONEX forecast it is too far west. Based on synoptic evaluation of both forecasts, it is difficult to establish the superiority of one compared to the other; however, based on the root mean square vector wind error, the CONTROL forecast is superior to the FGGE/MONEX forecast.

## 4. DISCUSSION

The question which we originally proposed to investigate, i.e., What is the impact of the FGGE/MONEX data set?, seems to be of secondary importance compared to a more fundamental question: What is the limit of predictability of the tropical atmosphere? Based on idealized predictability studies, it was suggested (Shukla, 1981) that the limit of deterministic prediction for the tropics will be considerably shorter than that for the middle latitudes. We are quite surprised to see that the limit, for the cases considered here, is so small. We have shown that there is some skill in predicting the evolution and propagation of transient disturbances for 2-3 days, which suggests, as shown by Kalnay et al. (1981), that there was rather rapid degradation of the mean field. The so called 'climate drift' problem in the tropics seems to be a more serious problem than in the mid-latitudes. If moist convection is the main reason for such a rapid degradation of the quasi-stationary planetary scale tropical flow, a prescribed diabatic heating field might be more appropriate (see Shukla, 1981).



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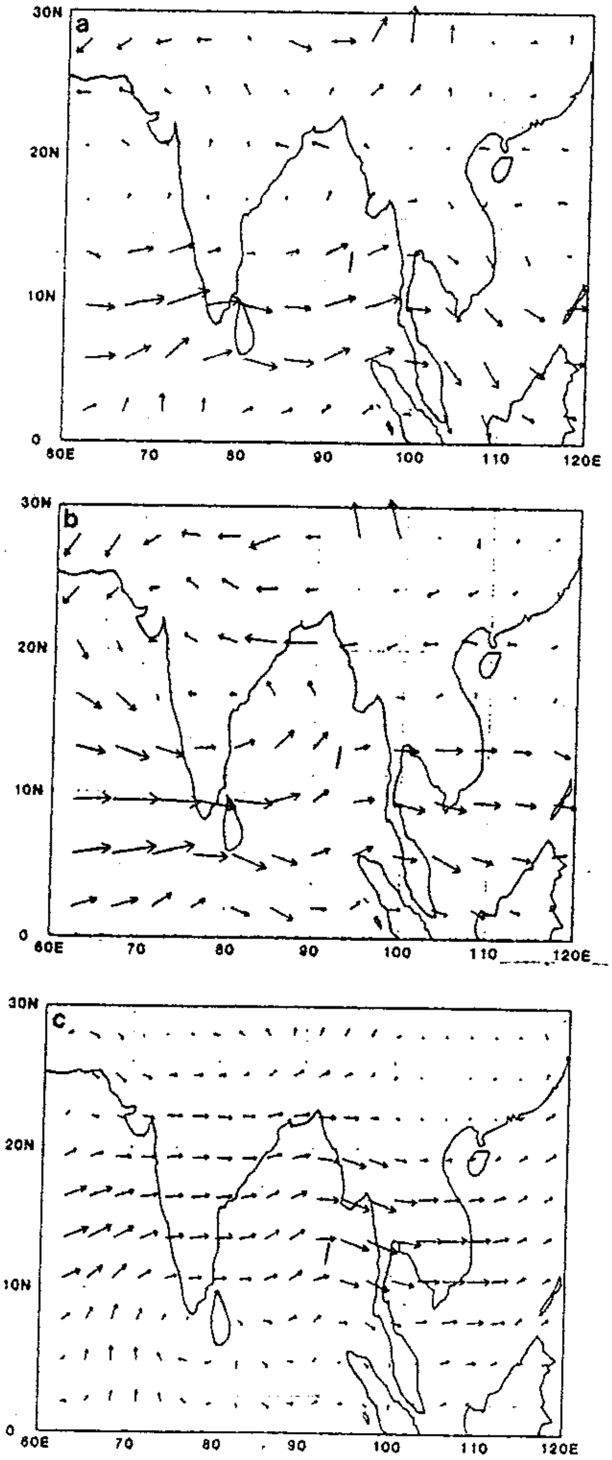

Figure 3. Wind field at 850 mb for the 1200 GMT 7 July case. a) 48 h FGGE/MONEX forecast. b) 48 h CONTROL forecast. c) NMC analysis at 1200 GMT 9 July 1979.

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