Dynamical Climatology

Forecasts and analyses of the onset of the Southwest monsoon

by

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This paper presents some results of forecast experiments for one of the cases selected by the Working Group on Numerical Experimentation for comparison of prediction models. The period is the 11th to 19th June 1979 during which time the onset of the Southwest monsoon occurred over India. The first experiments started from the European Centre for Medium Range Weather Forecasts' FGGE IIIB analysis for 12Z on 11th June (Lorenc, 1981), and used the highest resolution version of our 11-layer general circulation model (Saker, 1975). This is a global, primitive equation, gridpoint model having a horizontal resolution of 2° latitude by 3° longitude. It utilises sigma as its vertical coordinate and incorporates routines which parametrize important physical processes, such as turbulent exchanges in the boundary layer, large scale rain, dry and moist convection, and radiative effects.

A successful prediction of the onset must simulate the following developments in the 850 mb wind field. The ECMWF analysis for 11th shows the low level jet (maximum speed 14 m/s) confined to the western part of the Arabian Sea and the main branch of the monsoon flow still to the south of India (figure 1). By the 15th the jet has strengthened (20 m/s) and extended eastwards to the southern tip of India (Figure 2). A cyclonic vortex has also formed over the eastern Arabian Sea, on the northern flank of the jet. Four days later this vortex has intensified and, having moved first north then west, is centred near 18N, 60E (figure 3). The jet is stronger (29 m/s) and the monsoon flow has extended northwards to cover much of the Indian peninsula. It is clear that the main features to be predicted are the strengthening and eastward extension of the jet, the formation of the onset vortex, and the northward movement of the monsoon flow.

The first set of experiments using the general circulation model demonstrated that the predictions were very sensitive to some aspects of the model's formulation. By varying the radiation, diffusion and convection routines forecasts could be obtained which ranged from quite good to very bad. Figure 4 shows these two extremes, one forecast producing a substantial increase in wind speed, the other hardly any. Both these experiments had one thing in common with most of the others in the series; they did not develop an onset vortex. Only two out of nine forecasts did produce such a development, and then only as a weak feature. Nevertheless they indicated that two changes to the model were necessary for it to predict the vortex. Firstly, the interactive radiation scheme (Slingo, 1982) which uses forecast humidity fields in the calculation of radiative fluxes had to be used, rather than the climatological scheme which does not. Secondly, the treatment of evaporation of falling precipitation in the convection routine had to be modified. The evaporation of precipitation in the kth layer of the general circulation model is given by

$$C_{EV} M_{K-1} \left[q_s\left[T_k^e\right] - q_k^e\right] \left[10p^*\Delta\sigma/g\right]$$

where C_{EV} is an arbitrary constant, M_{K-1} the vertical mass flux into the layer, $q_s(T_k^e)$ the saturation specific humidity of the air in layer k, q_k the specific humidity in layer k and g the gravitational acceleration. The effects of modifying C_{EV} are discussed in Rowntree (1984) but it was found that in these experiments better predictions of the onset vortex were obtained when C_{EV} was set to 9 rather than 3 or 0. Figure 5 shows the 8-day forecast of the 850 mb wind field from the experiment which produced the strongest vortex; it has several other encouraging features. The jet has strengthened (maximum speed 24 m/s) and extended eastwards. However, this eastward extension occurred rather too slowly during the forecast, and although the vortex formed by day 4 (15th June) its intensification and northward movement were not correctly predicted.

There are some reasons for suspecting that this timing error might be caused by errors in the initial conditions. It is well known that the exclusion of diabatic effects in the initialization used at ECMWF led to the damping of vertical motion in the tropical analyses. A subjective comparison with observations showed that the analyses also tended to underestimate the strength of the low level jet. It was decided, therefore, to try to improve on these results by using initial conditions generated by a more recent version of the UKMO operational data-assimilation scheme. This uses optimum interpolation to analyse the observations and produce a set of corrections to a background field (Bell, 1983). These corrections are then assimilated directly into the prediction model. The model itself has 15 levels and a horizontal resolution of $1^1/_2$° latitude by $1^7/_8$° longitude (Foreman, 1983). It was hoped that this increased resolution would lead to better predictions than those obtained with the general circulation model. The two models have different representations of the boundary layer, but the same convection routine and the same climatological radiation scheme.

Using this scheme a series of analyses were produced for the period 9th to 19th June 1979: these will be called the UKMO FGGE analyses. They were used to start and verify several 8-day forecasts. The analysis of the 850 mb wind field for 11th June (Figure 6) shows some differences from the ECMWF product. The maximum winds are stronger, especially in the low level jet (peak speed 23 m/s) but also over the northern Arabian Sea and northern India, for example. The analysis isn't as smooth as ECMWF's, but it does seem to fit the observations better. Analyses for subsequent days show similar characteristics: on the 15th (figure 7) there is a jet of 30 m/s over the Arabian Sea with a stronger onset vortex; by the 19th (figure 8) there is a peak speed of 34 m/s, again with a stronger vortex.

Control forecasts were run using the 15-level model from initial conditions valid at 12Z on 11th June and also on successive days. The forecast from the 11th was in many respects better than the earlier predictions with the general circulation model. By day 4 the jet had correctly extended eastwards to the southern tip of India and by day 8 (figure 9) its maximum speed was 29 m/s. The most encouraging feature is the prediction of the northward progression of the monsoon westerlies up the west coast of India. In this respect this forecast compares favourably with most others for the same case which appear in the literature, for example in the report on the WGNE comparison experiments (Temperton et al, 1983), and also in more recent work reported by the meteorological department of Florida State University (Krishnamurti et al, 1983). However, a major problem with the integration is its failure to develop an onset vortex, and all the control integrations started from subsequent days exhibit the same reluctance to predict this development.

The 15-level model also has the same sensitivity as the general circulation model to the specification of C_{EV} in the convection routine. The control forecasts had C_{EV} set to 4, the value used operationally, but forecasts run with C_{EV}=9 were much improved because they all developed the onset vortex. The prediction starting from 11th June was not perfect in that the vortex was not generated until day 7 of the forecast, four days late. The 850 mb wind chart for day 8 of this integration (figure 10) shows the vortex further north than in the general circulation model prediction but not far enough west. None of the integrations started from subsequent days predicted this westward movement of the vortex either. In fact these later integrations showed a distinct tendency to move the vortex eastwards over India. The effect of increasing the value of C_{EV} is to increase the rainfall over the sea and reduce it over land. Charts of the difference between the experimental forecast with C_{EV}= 9 and the control show a substantial local increase in the rainfall close to the centre of the vortex. It seems likely therefore that increased latent heat release is an important forcing of the development of the vortex in the model.

Other workers have obtained improvements in the prediction of the movement of the onset vortex by using an envelope orography in their models (Krishnamurti et al, 1983), in which the height allocated to each gridbox is increased above its mean value by adding some proportion of the standard deviation of the terrain height within the gridbox, the intention being to represent better the barrier effects of mountain chains. A further series of prediction experiments was run using an envelope orography, in this case taking the mean height plus one standard deviation at each gridbox. The results were not encouraging; all integrations using the higher orography failed to predict the development of a vortex in the Arabian Sea, even when they had C_{EV} set equal to 9. Figure 11 shows an example, the 8-day forecast from 11th June. It is not yet clear why the envelope orography should have this effect, which has also been observed in our general circulation model.

The graph of the area mean wind speed over the Arabian Sea (figure 12) shows some interesting differences between the forecasts made from 11th June. The UK FGGE analyses show that this statistic increases by about 10 m/s during the eight days of the prediction period, and much of the increase occurs during the time when the onset vortex was developing. The control forecast only predicts an increase of 4-5 m/s but the integration with C_{EV} = 9 is better with an increase of 6-7 m/s. Notice also that this improvement occurs during the last three days when the model developed the vortex. The forecast which also includes the envelope orography has stronger winds throughout days 4 to 7 and from this graph it might be concluded that it was the best of the three predictions. This would be wrong, however, because it failed to form the onset vortex. Moreover, a graph of the root mean square vector wind errors for the entire tropical zone at 850 mb (figure 13) shows that the prediction with envelope orography has the largest errors during the first five days. The forecast with C_{EV}= 9 has the lowest errors during the first four days, although it is very similar to the control, and it is encouraging that the forecast errors are less than persistence throughout the period.

This FGGE case study has been useful because it has enabled us to run and verify our operational numerical weather prediction system using a much better observational database than that currently available. In particular the presence of large numbers of cloud-track winds (SATOBS) over the Indian Ocean gives us much more confidence in the wind analyses for this region. There is little doubt that the provision of such data in future would greatly improve the World Weather Watch database.

The operational data-assimilation system has performed reasonably well in this study, and some quite successful predictions of the onset of the southwest monsoon have been made. The work has suggested ways to improve our operational predictions in the tropics by making specific changes to the parametrization of convective and radiative processes. Increasing the value of C_{EV}, which controls the evaporation of falling convective precipitation, and including an interactive radiation scheme seem likely to prove beneficial. Running such a radiation scheme in the global version of our 15-level model has not yet been possible but this will be given a high priority in future research. It is also intended to undertake an objective verification of our analyses against FGGE observations and we would like to make comparisons with improved IIIB analyses from other centres. It would also be interesting to exchange these analyses for use as initial conditions in other numerical prediction models; that sort of exercise helps to isolate the effects of analysis errors from model errors. Such comparisons of analyses and forecasts have much to offer and should be encouraged for other tropical case studies during the FGGE year. Good examples might be the formation of a monsoon depression and perhaps some interesting episode of the winter monsoon.

Finally, I would like to acknowledge the assistance of my colleague Paul Harker in furthering this research and in producing charts and graphs for this talk.

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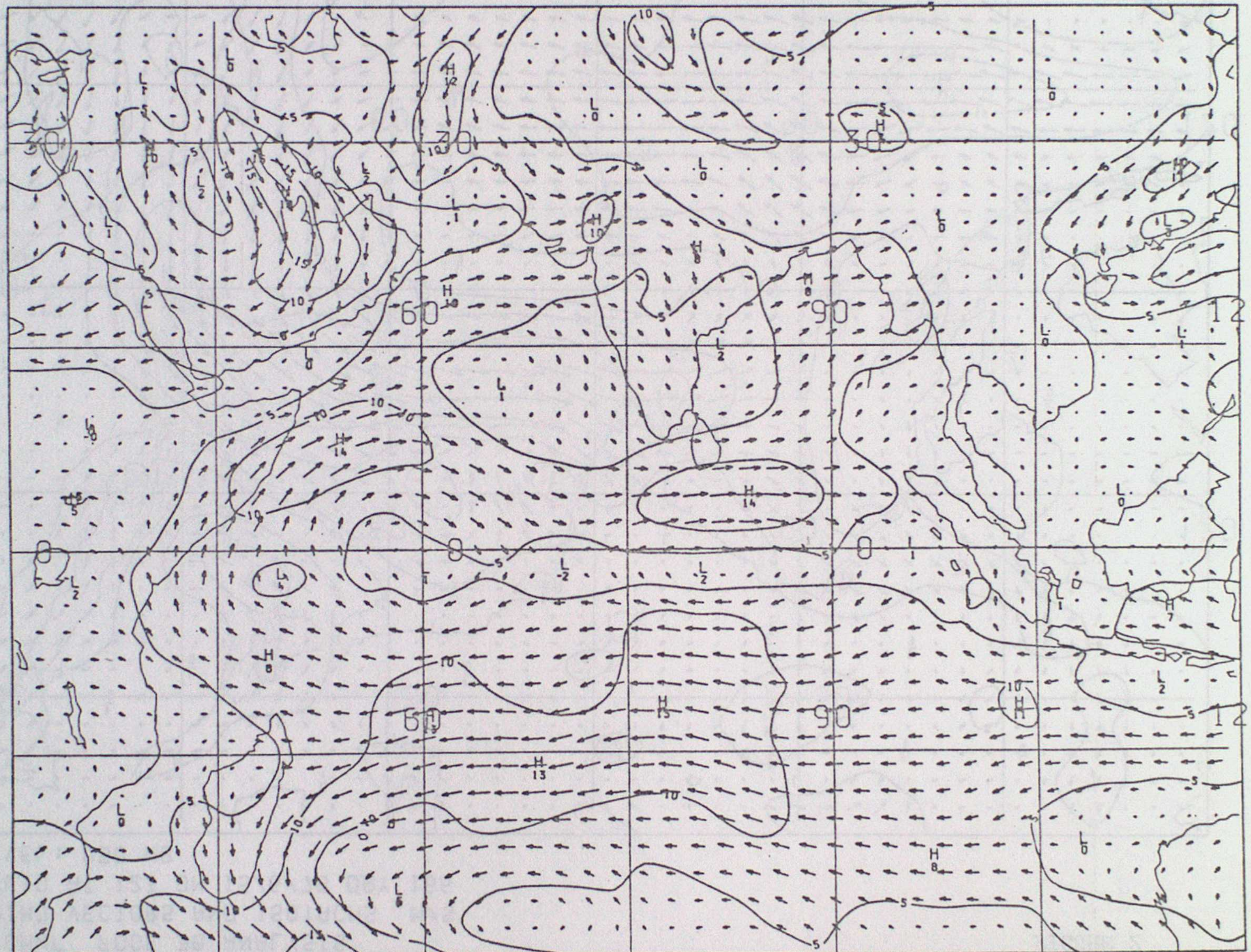
FIGURE 1

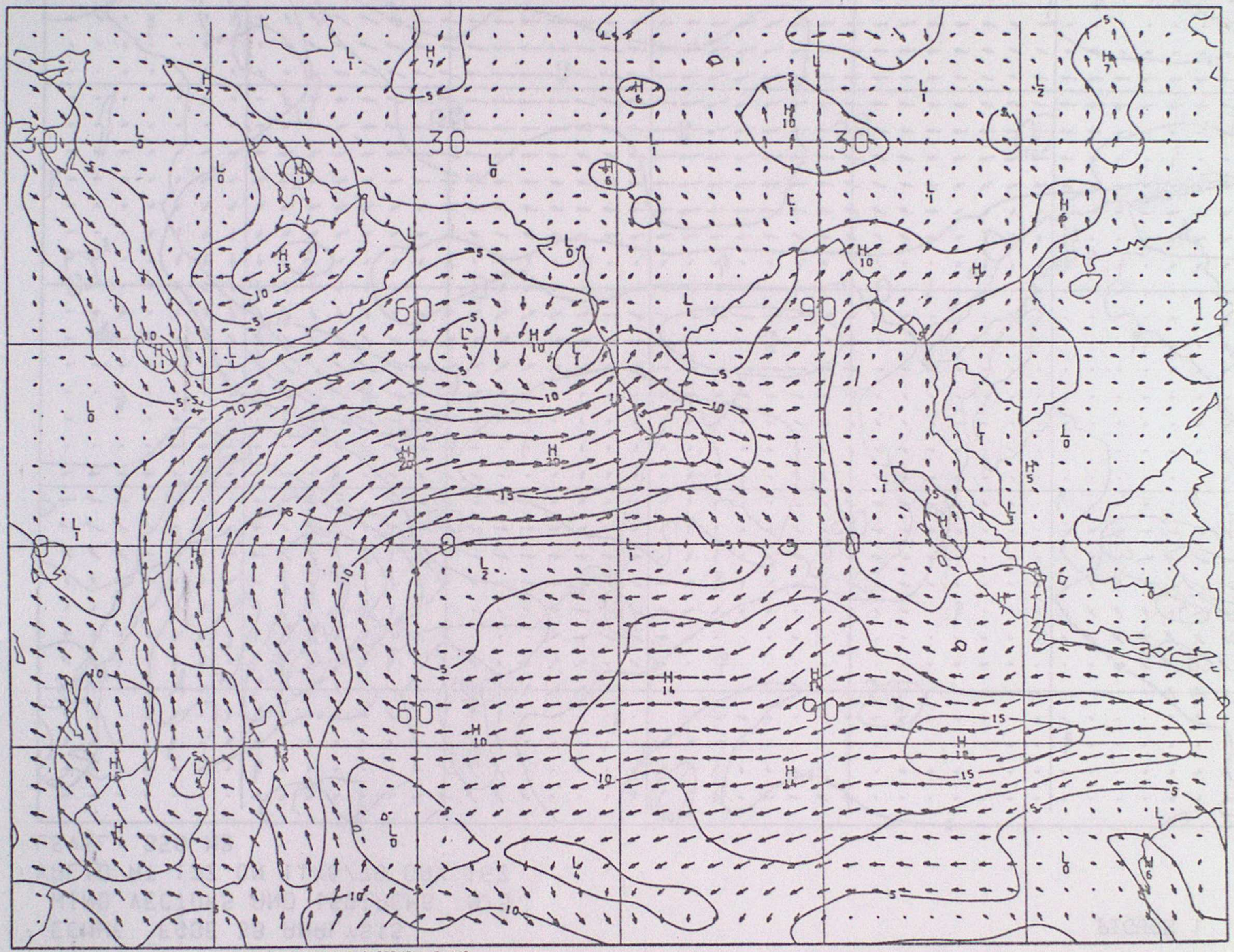
ECMWF FGGE 3B ANALYSIS
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 11/6/79 DAY 162
LEVEL: 850 MB



→ REPRESENTS 20 M/S UNITS: M/S CONTOUR INTERVAL: 5 M/S

ECMWF FGGE 3B ANALYSIS
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 15/6/79 DAY 166
LEVEL: 850 MB

FIGURE 2



→ REPRESENTS 20 M/S UNITS: M/S CONTOUR INTERVAL: 5 M/S

ECMWF FGGE 3B ANALYSIS
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 19/6/79 DAY 170
LEVEL: 850 MB

FIGURE 3

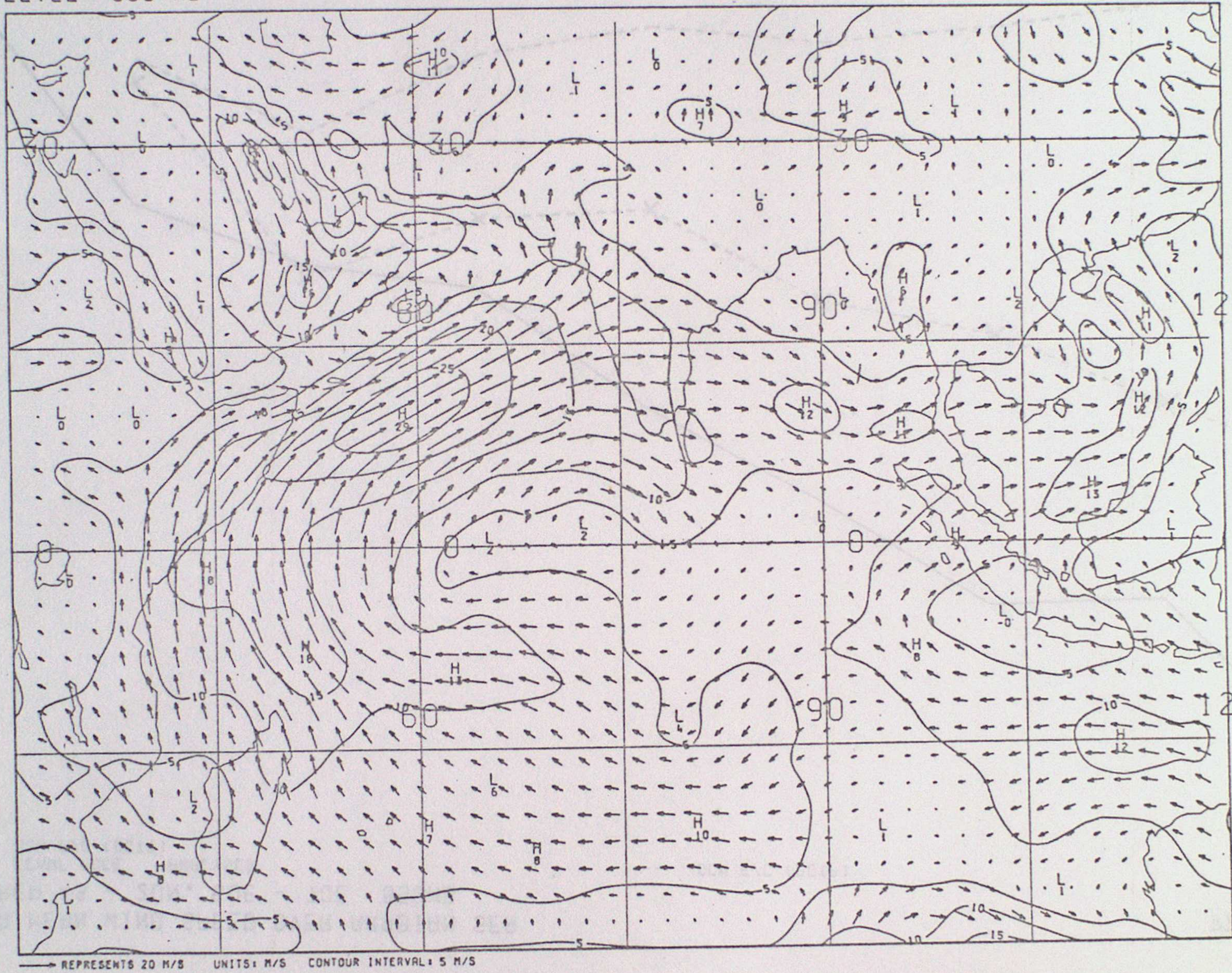


FIGURE 4

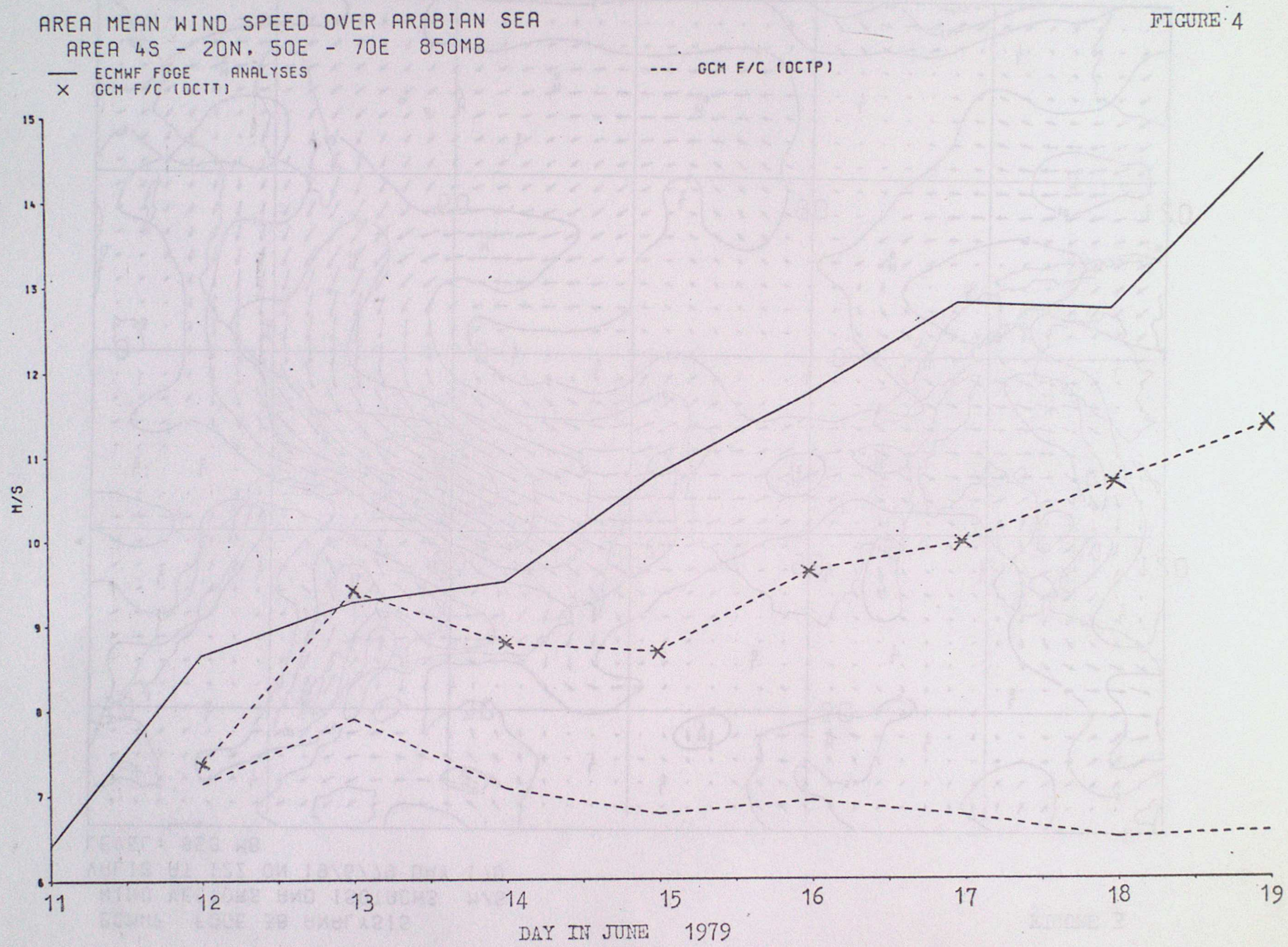
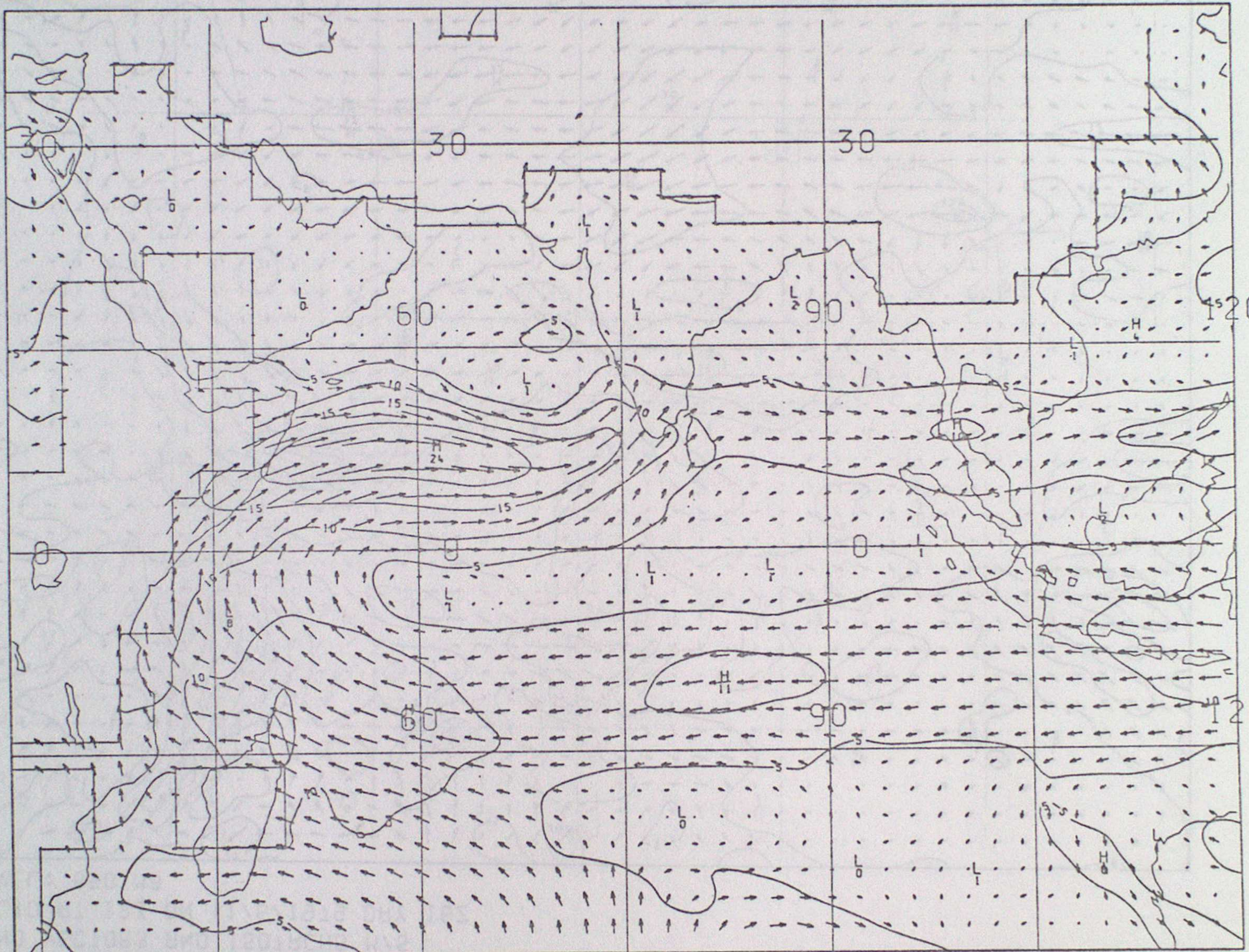

AREA MEAN WIND SPEED OVER ARABIAN SEA
AREA 4S - 20N, 50E - 70E 850MB
ECMWF FGGE ANALYSES
X GCM F/C (DCTT)
--- GCM F/C (DCTP)
M/S
6
7
8
9
10
11
12
13
14
15
11
12
13
14
15
16
17
18
19
DAY IN JUNE 1979

FIGURE 5

G C M FORECAST

WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON DAY 8 DATA TIME 12Z ON 11/6/79
LEVEL: 850 MB EXPERIMENT NO.: 1255



REPRESENTS 20 M/S UNITS: M/S CONTOUR INTERVAL: 5 M/S

FIGURE 6

UKMO FGGE ANALYSIS (WB05)
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 11/6/1979 DAY 162
LEVEL: 850 MB

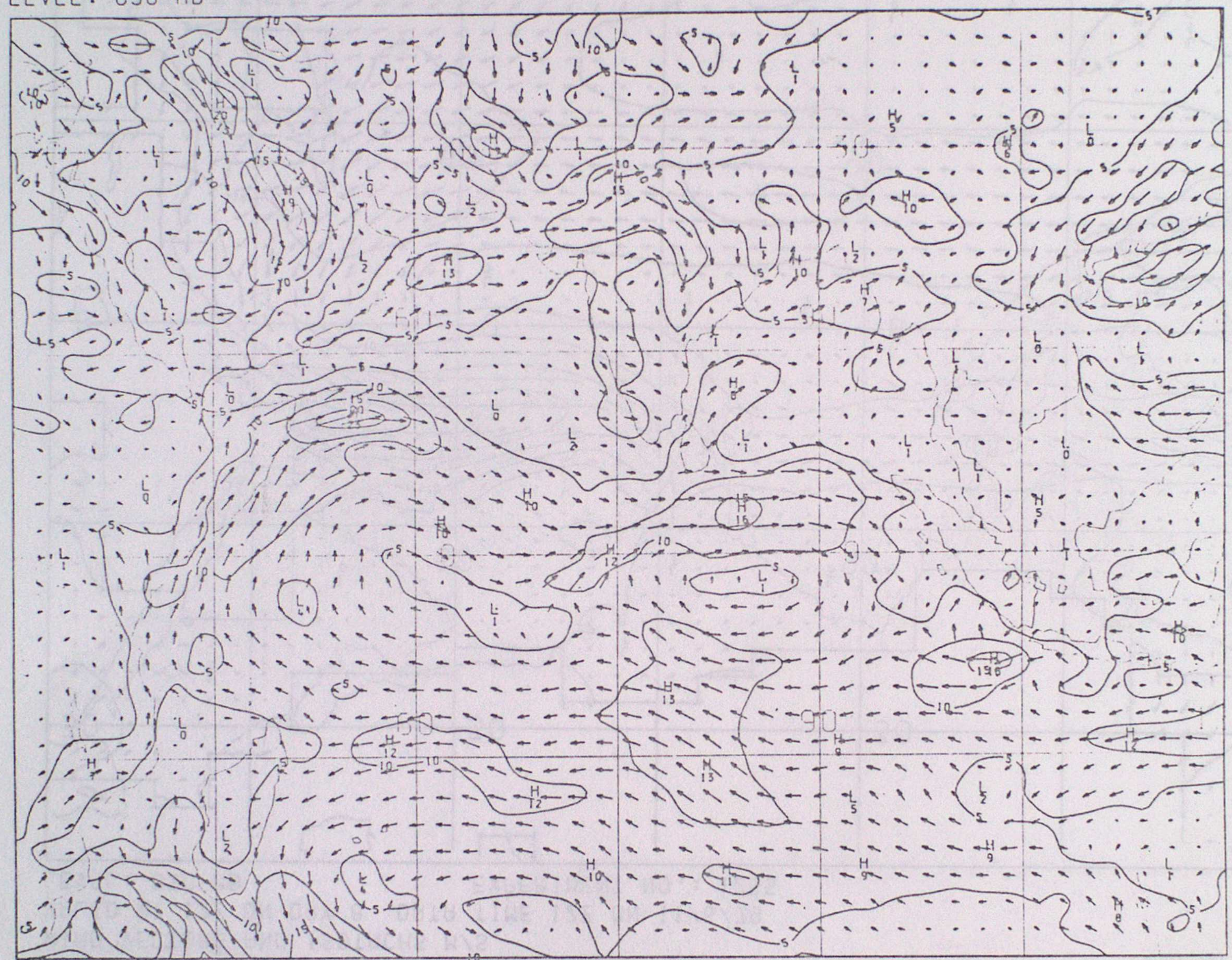
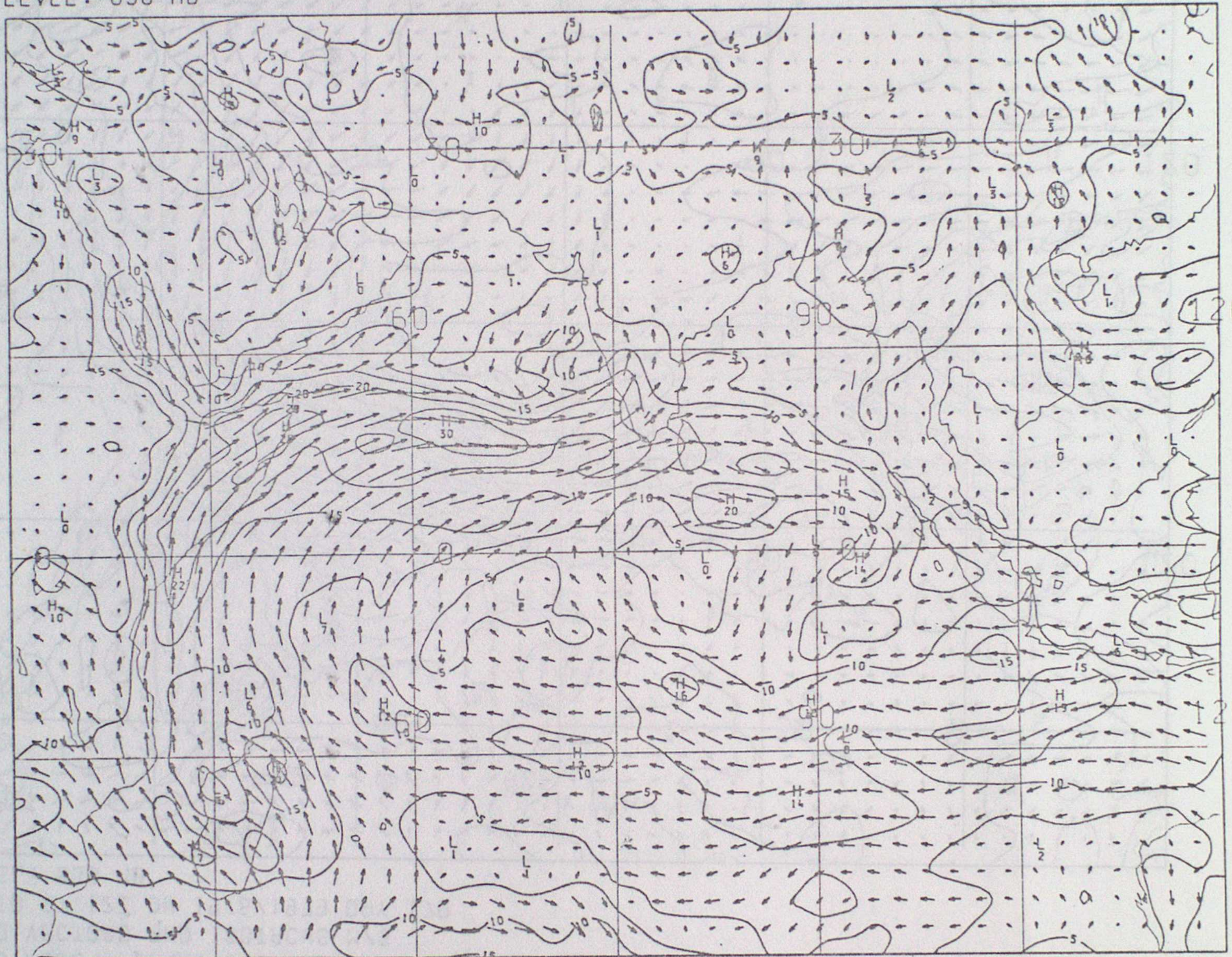


FIGURE 7

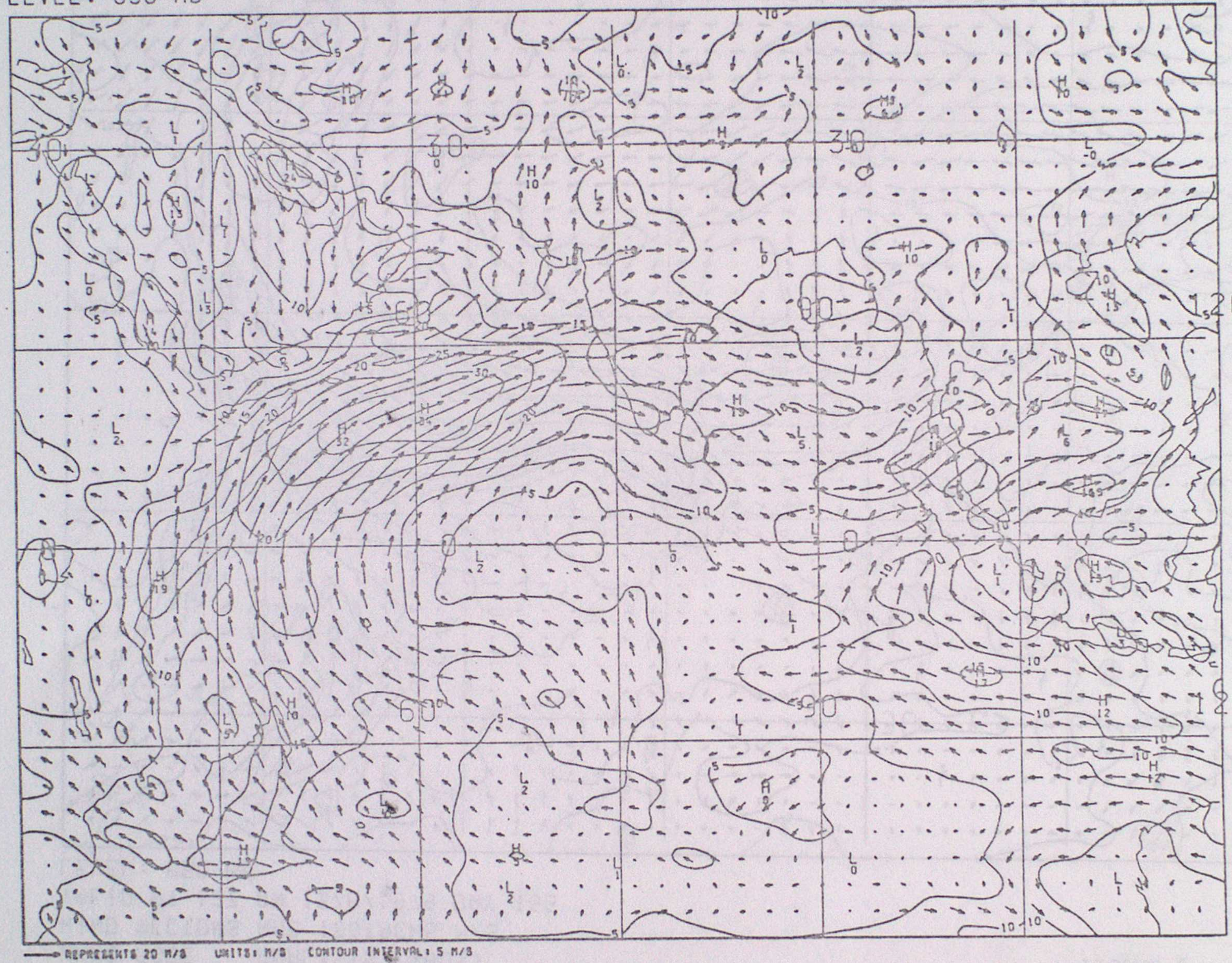
UKMO FGGE ANALYSIS (WB05)
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 15/6/1979 DAY 166
LEVEL: 850 MB



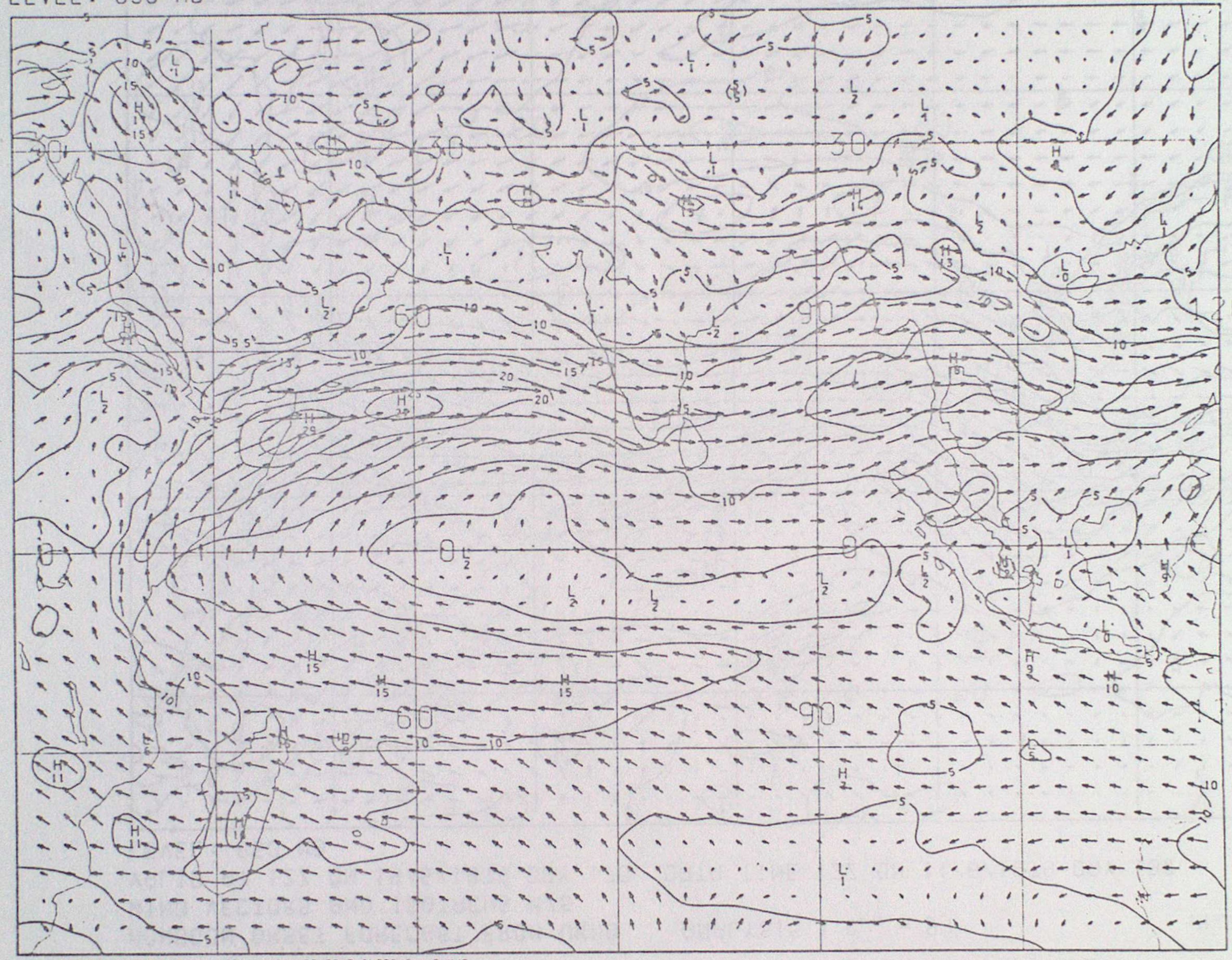
→ REPRESENTS 20 M/S UNITS: M/S CONTOUR INTERVAL: 5 M/S

FIGURE 8

UKMO FGGE ANALYSIS (WB05)
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 19/6/1979 DAY 170
LEVEL: 850 MB



MONSOON ONSET FORECAST FROM UKMO ANALYSIS FIGURE 9
WIND VECTORS AND ISOTACHS M/S
VALID AT 12Z ON 19/6/1979 DAY 170 DATA TIME 12Z ON 11/6/1979 DAY 162
LEVEL: 850 MB



→ REPRESENTS 20 M/S UNITS: M/S CONTOUR INTERVAL: 5 M/S

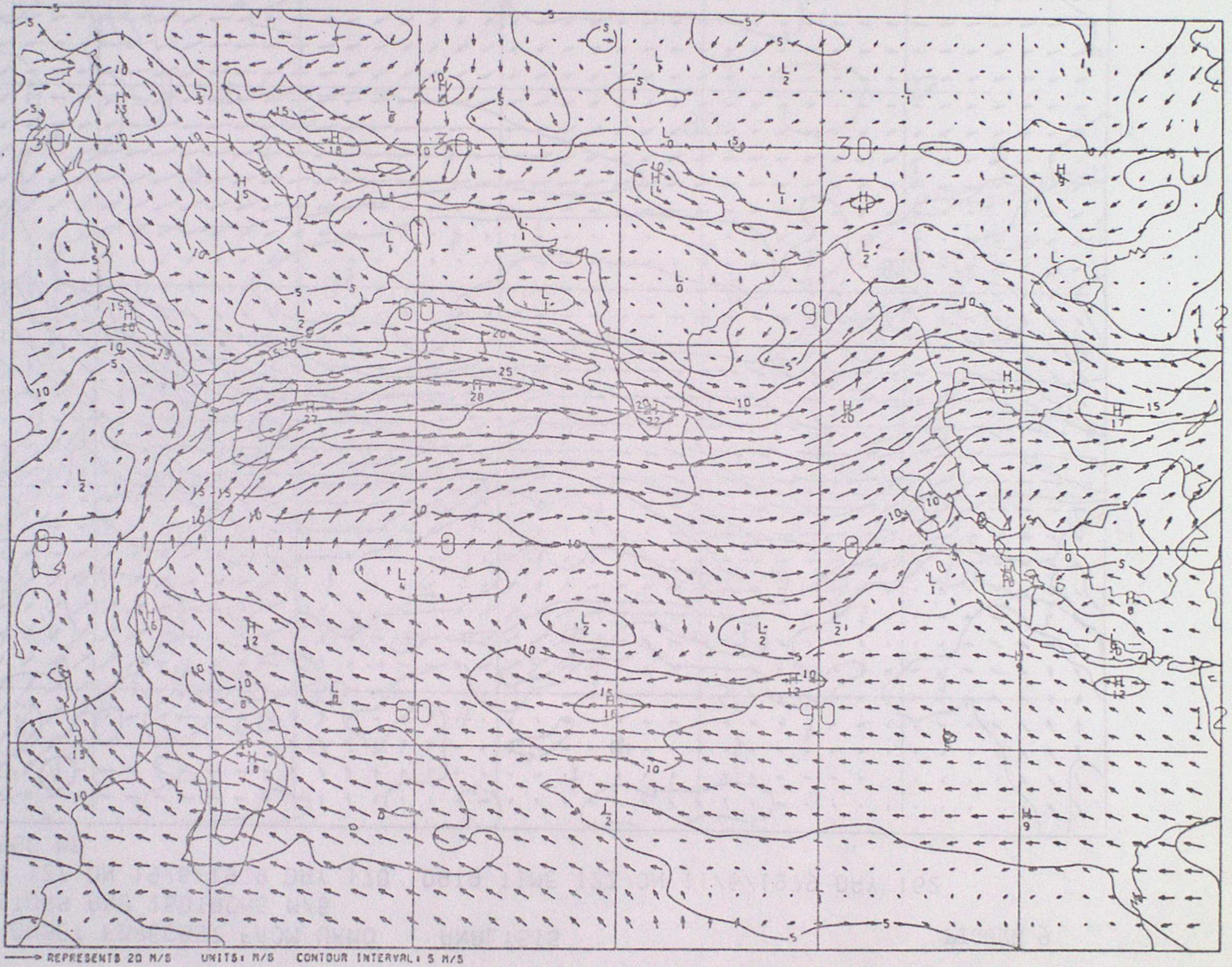
MONSOON ONSET FORECAST FROM UKMO ANALYSIS ($C_{EV} = 9$)

FIGURE 10

WIND VECTORS AND ISOTACHS M/S

VALID AT 12Z ON 19/6/1979 DAY 170 DATA TIME 12Z ON 11/6/1979 DAY 162

LEVEL: 850 MB



→ REPRESENTS 20 M/S UNITS: M/S CONTOUR INTERVAL: 5 M/S

ENVELOPE OROGRAPHY F/C FROM UKMO ANALYSIS ($C_{EV} = 9$)

WIND VECTORS AND ISOTACHS M/S

VALID AT 12Z ON 19/6/1979 DAY 170 DATA TIME 12Z ON 11/6/1979 DAY 162

LEVEL: 850 MB

FIGURE 11

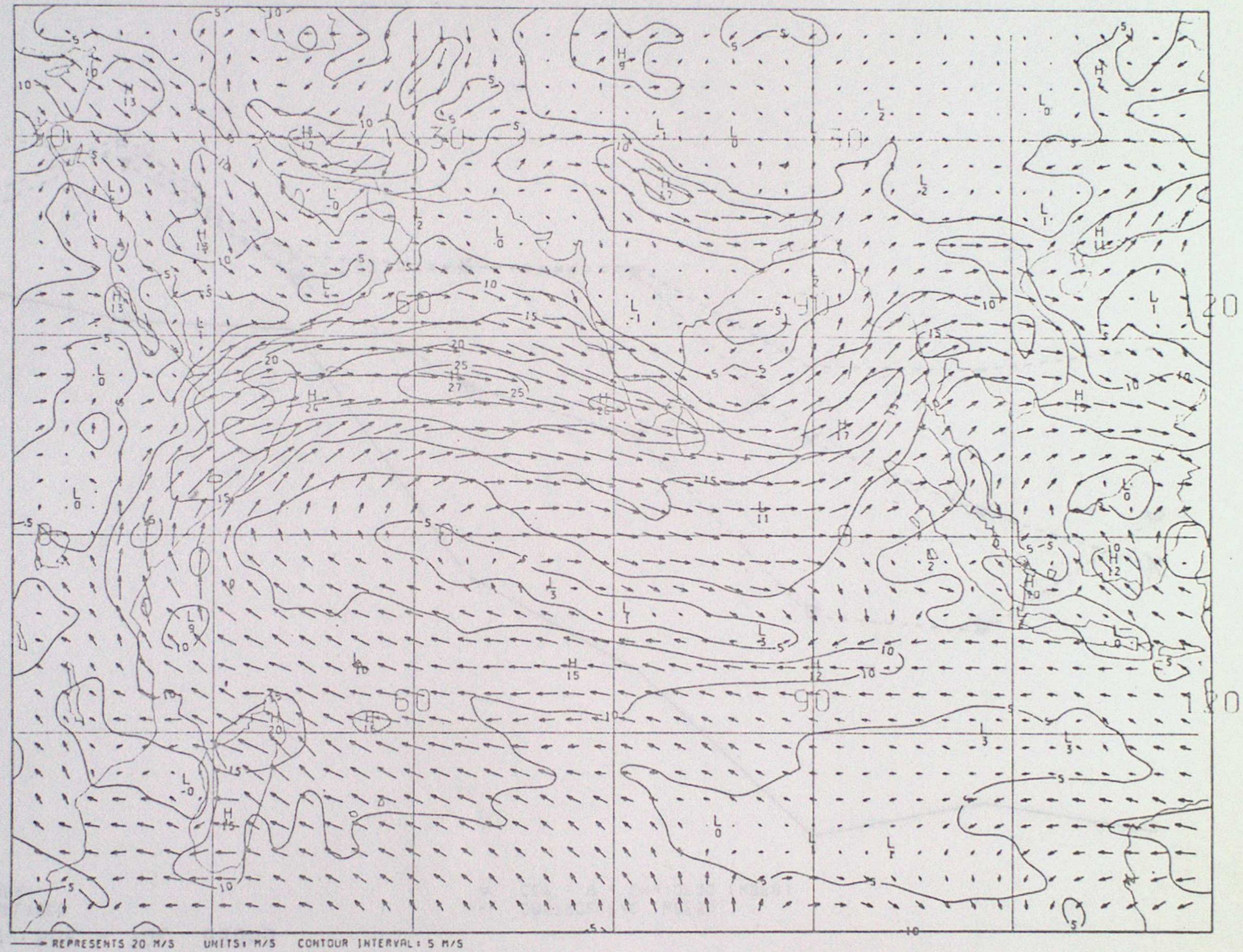
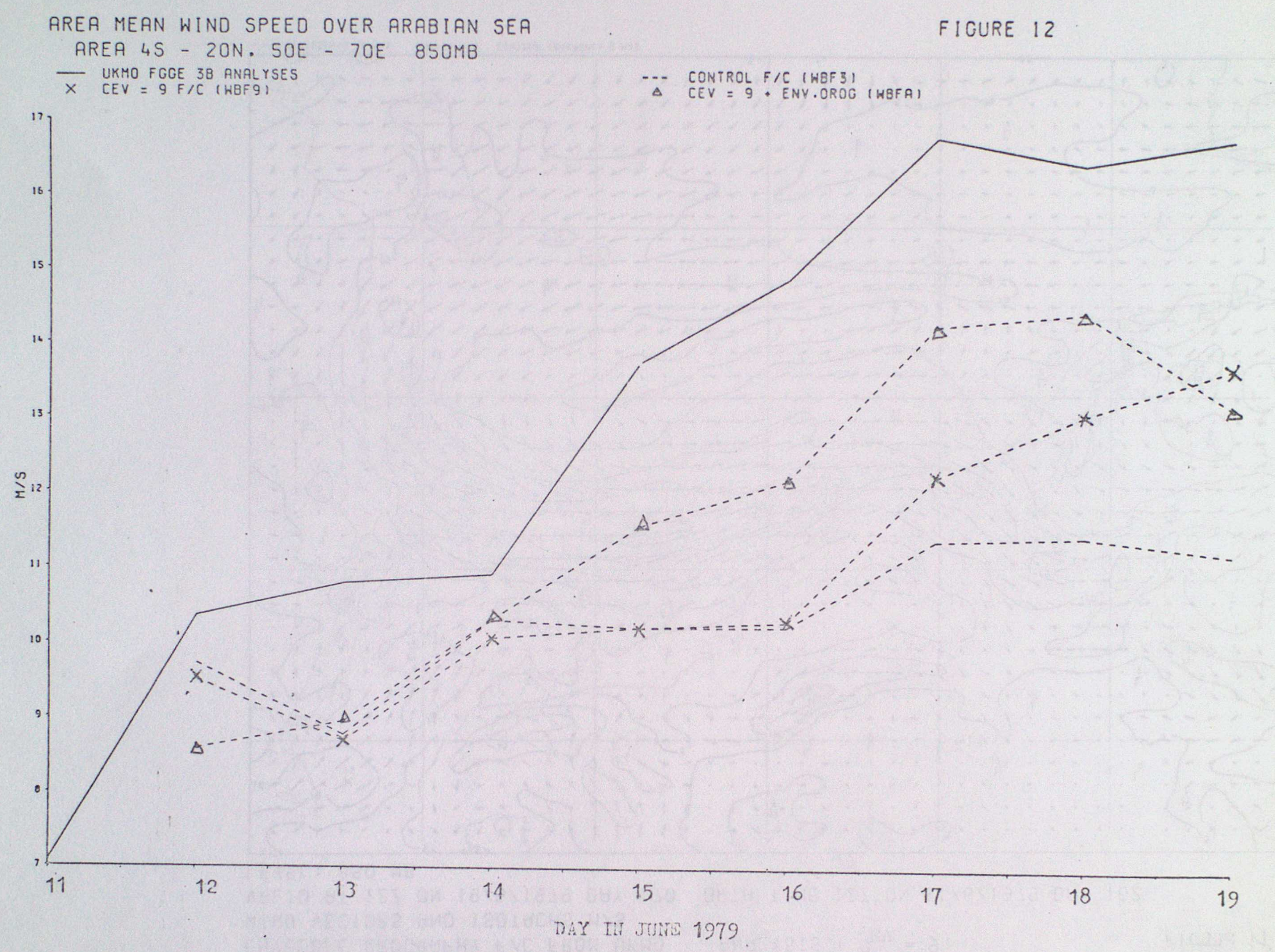


FIGURE 12



AREA MEAN WIND SPEED OVER ARABIAN SEA
AREA 4S - 20N. 50E - 70E 850MB
UKMO FGGE 3B ANALYSES
CEV = 9 F/C (WBF9)
CONTROL F/C (WBF3)
CEV = 9 + ENV.OROG (WBFA)
M/S
7
8
9
10
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12
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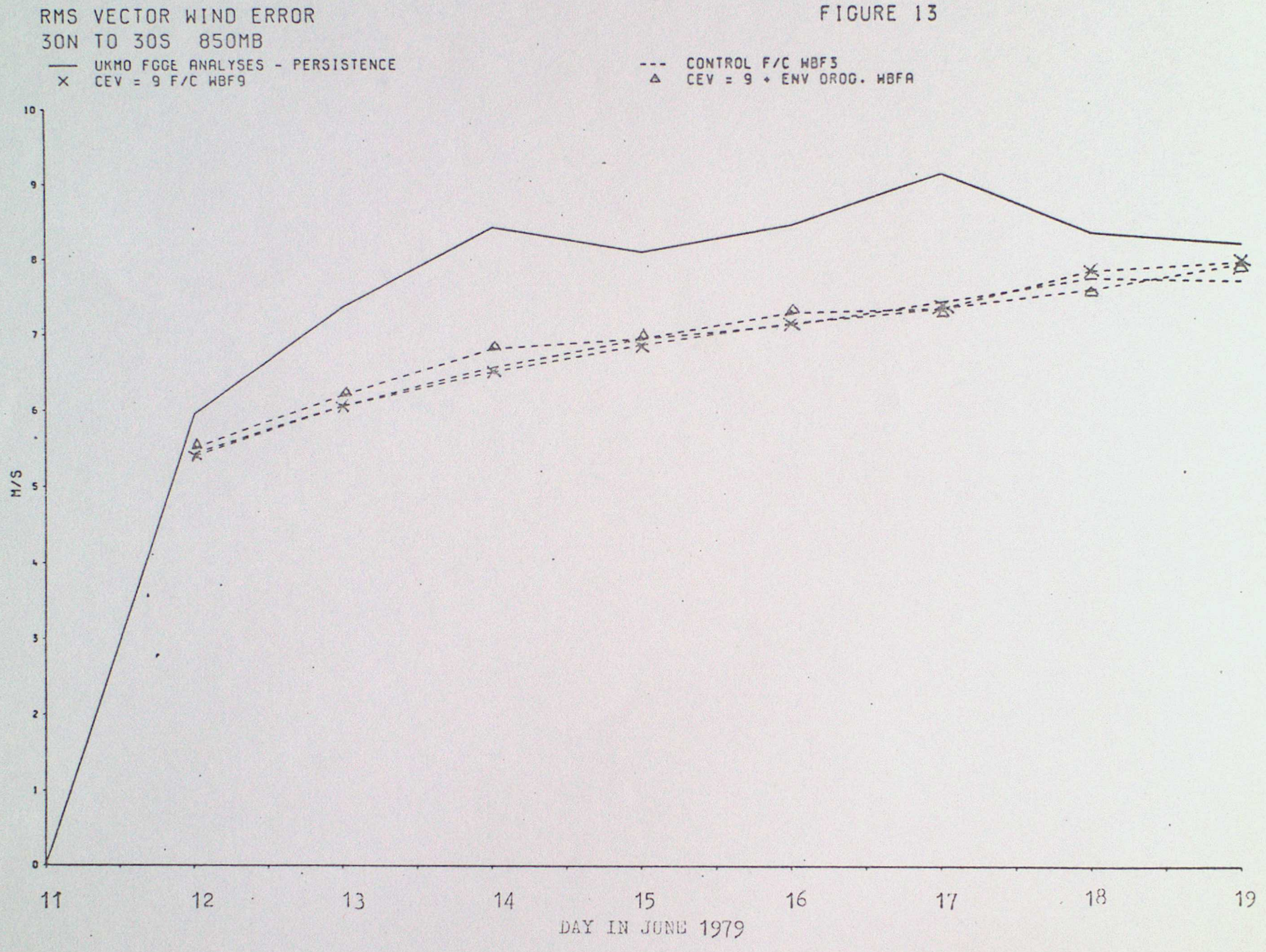
16
17
11
12
13
14
15
16
17
18
19
DAY IN JUNE 1979

FIGURE 13


RMS VECTOR WIND ERROR
30N TO 30S 850MB
— UKMO FGGE ANALYSES - PERSISTENCE
× CEV = 9 F/C WBF9
--- CONTROL F/C WBF3
△ CEV = 9 + ENV OROG. WBFA
M/S
0
1
2
3
4
5
6
7
8
9
10
11
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13
14
15
16
17
18
19
DAY IN JUNE 1979