TECHNICAL MEMORANDUM

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Preliminary results of an investigation into the quality of ECMWF forecasts in the tropics

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1. INTRODUCTION

The most striking differences between tropical and extratropical weather occur because of the dominance of quasi-steady circulations in the tropics. There is little day to day variation in wind or temperature. The most important ingredient of the tropical climate is rainfall. Seasons in the tropics as opposed to extratropical seasons are marked by wet or dry periods. Temperature has little or, in places, no seasonal variability. All human activity in the tropics is heavily dependent upon the supply of water. In the zonal mean minimum rainfall occurs over the equatorial trough zone which migrates with the seasons. Latitudes near to the equator receive two rainfall maxima per year while those further away receive only one. Within this latitudinal distribution of rainfall there exists a very large longitudinal variability, an area receiving hundreds of centimetres annual rainfall may lie only a few hundred km from a completely dry zone. Tropical precipitation is intermittent and can be very localised making its measurement very difficult.

For a forecasting model to be of use in the tropics it must at least be able to maintain the quasi-steady circulations and also forecast quantities of interest. With these ideas in mind it was decided to begin an examination of the quality of the ECMWF forecasts in the tropics. This report presents some of the preliminary findings of that study.

2. RAINFALL FORECASTS

One of the principal problems in forecasting rainfall in the tropics is that of verification. There is little data over the land areas and virtually no data over the oceans. Exceptions to this are South America, India and Indonesia. In order to smooth out some of the intrinsic variability of the rainfall it was decided to examine monthly means, and to smooth the data over a 3.75° grid (the model currently has a 1.875° grid). Shown in Fig. 1 are zonal means of the monthly mean rainfall for February, March and April, 1981.

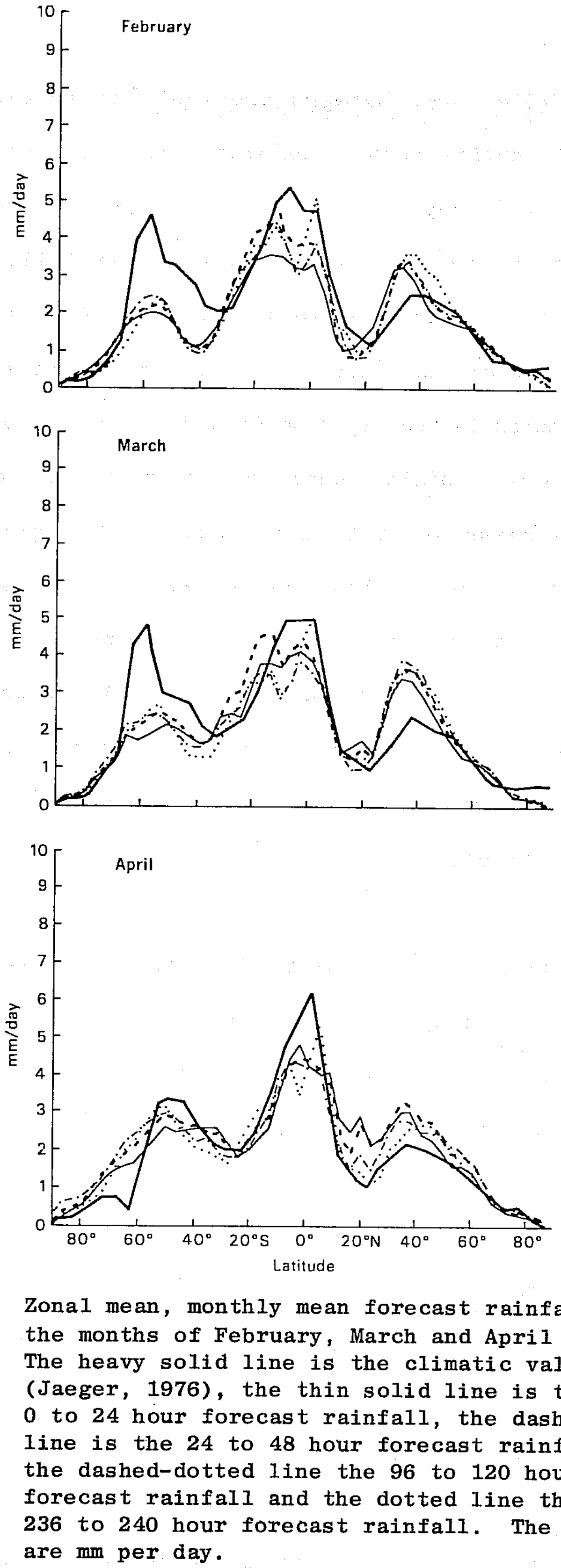

Fig. 1 Zonal mean, monthly mean forecast rainfall for the months of February, March and April 1981. The heavy solid line is the climatic value (Jaeger, 1976), the thin solid line is the 0 to 24 hour forecast rainfall, the dashed line is the 24 to 48 hour forecast rainfall, the dashed-dotted line the 96 to 120 hour forecast rainfall and the dotted line the 236 to 240 hour forecast rainfall. The units are mm per day.

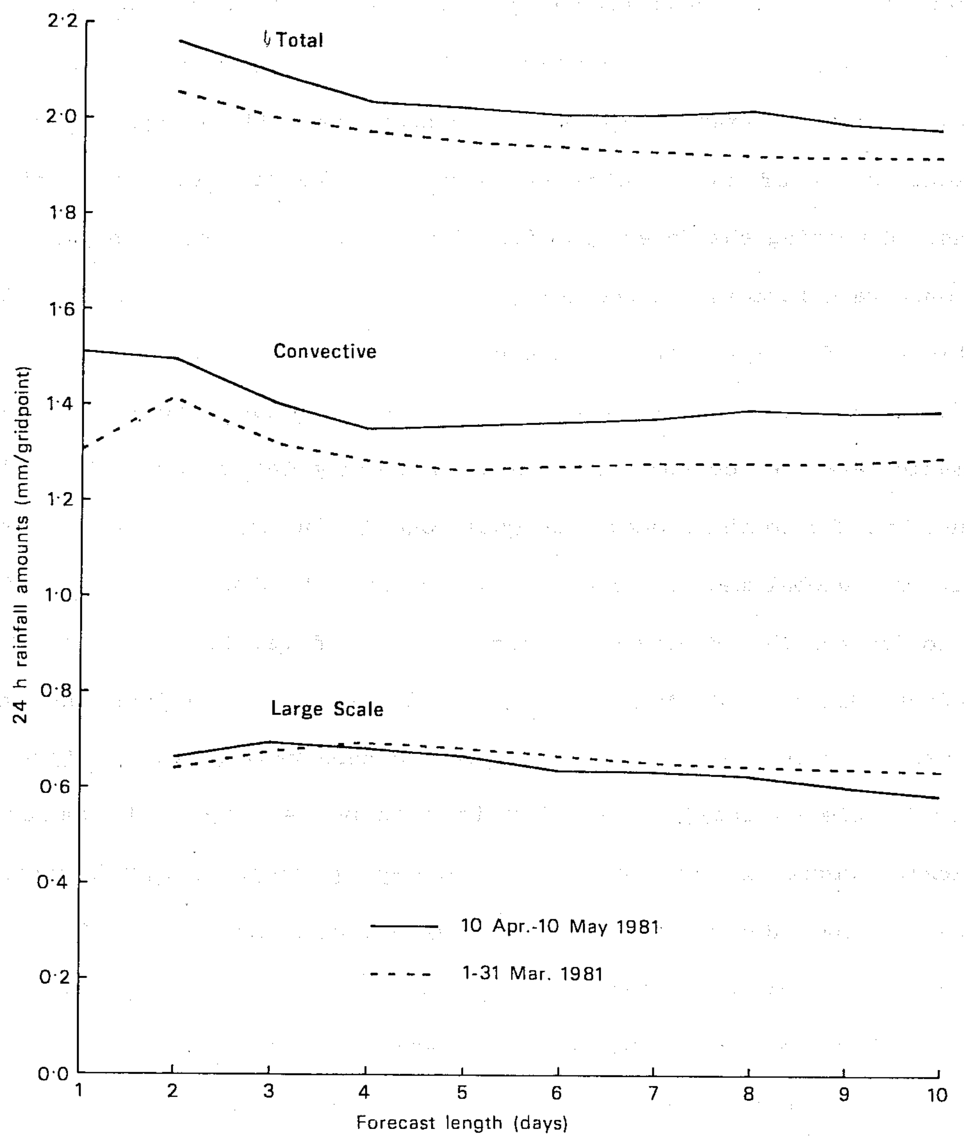

Fig. 2 Global mean 24 hour accumulated rainfall amounts as a function of forecast length. The dashed line refers to the monthly mean for March 1981 and the solid line refers to a mean from 10 April to 10 May 1981. The units are mm/grid point.

The units are mm/day. The thin solid line refers to the 24h forecast, the dashed line the 48h forecast, the dashed-dotted line the 120h forecast and the dotted line the 240h forecast. For comparison, the climatic values calculated by Jaeger, 1976, are indicated as a thick solid line. The seasonal march of the equatorial trough is clearly evident in the zonal means. Comparing the forecasts with climate the most obvious differences are too much rain forecast in the northern hemisphere extratropics and ~20% too little rain forecast near to the equator. The differences in the northern hemisphere extratropics occur largely over the oceanic areas, Jaeger's climatic data over oceanic regions is possibly inaccurate. The climatic values for the Southern Ocean are questionable due to the lack of any real data. The global mean rainfall for March, Fig. 2, shows an increase from day one to day two then decreases slightly to day five, then remaining almost steady to day ten. In April there is no increase between days one and two, instead there is a decrease to day five and then remains almost steady to day ten. Little systematic relation is seen between rainfall amounts and forecast length, in the zonal mean, except perhaps in April where there appears to be a decrease in forecast rainfall with time around 20° to 50°N. Apart from the seasonal shift, the February and March zonal means have a very similar character. The differences in April could be associated with the changes in the model orography introduced on April 1, 1981.

Figures 3 to 6 show the 24-hour monthly mean rainfall amounts for the 24-hour, 48-hour, 120-hour and 240-hour forecasts for March 1981. The principal features of the 24-hour forecast are an intense band of rain orientated NW to SE in the Central Pacific with over 16 mm/day, widespread rain of over 8 mm/day over Colombia and Brazil, heavy rain of over 16 mm/day over Central Africa, Sudan and Ethiopia, heavy rain of over 8 mm/day over southern China, and heavy rain in the Indian Ocean. At day two the pattern is very similar to day one. The areas of heavy rain noted in the 24-hour

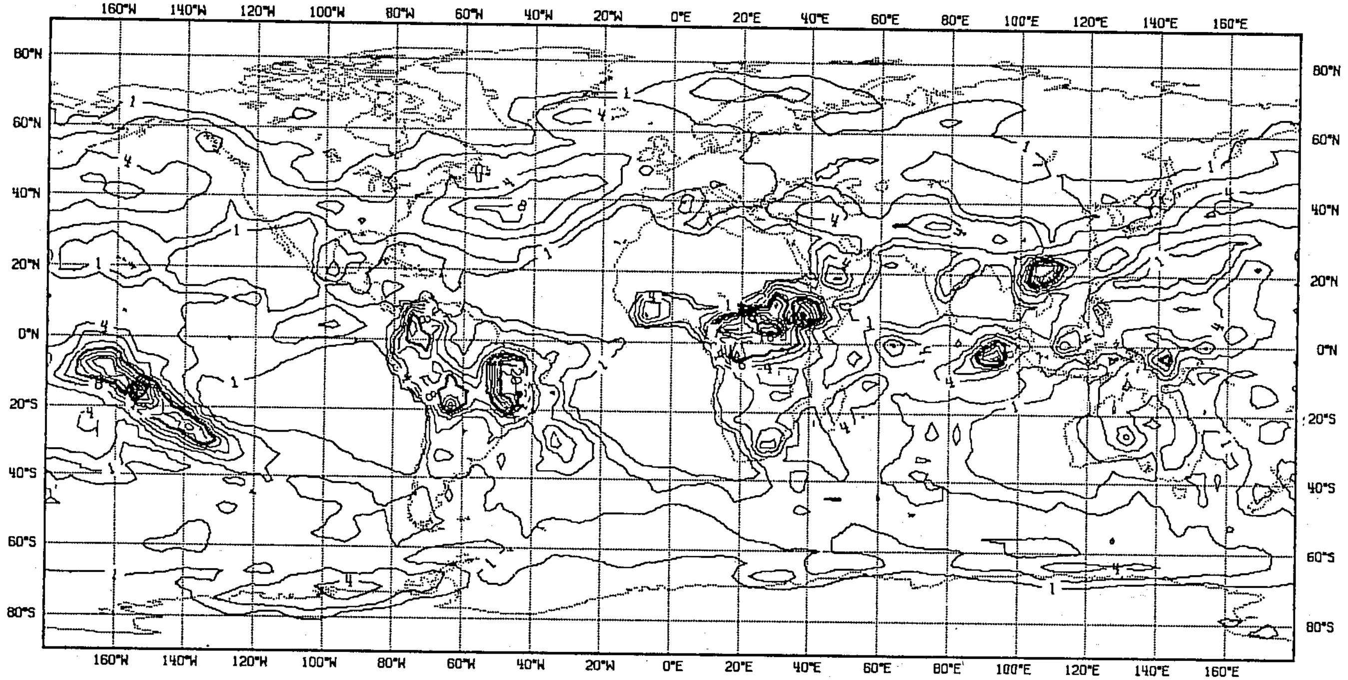

Fig. 3 Monthly mean 0 to 24 hour accumulated forecast rainfall for March 1981.
Units: mm

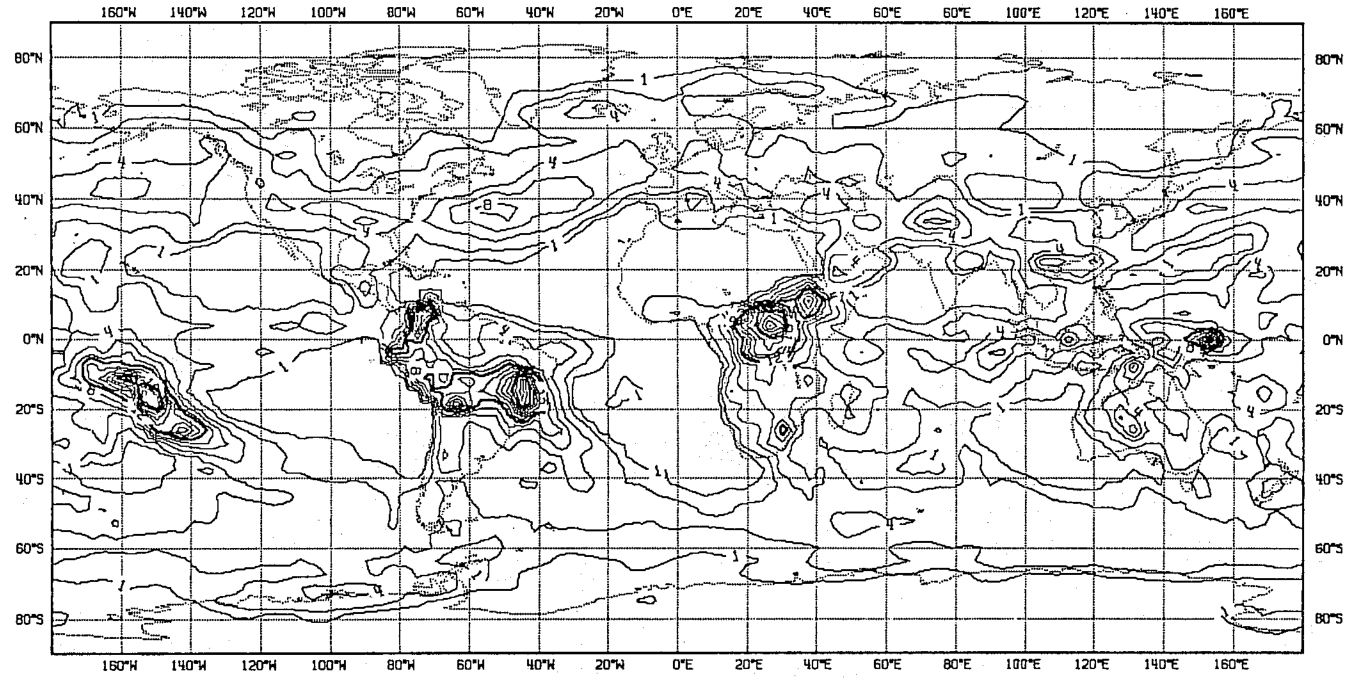

Fig. 4 As Fig. 3 for 24 to 48 hours

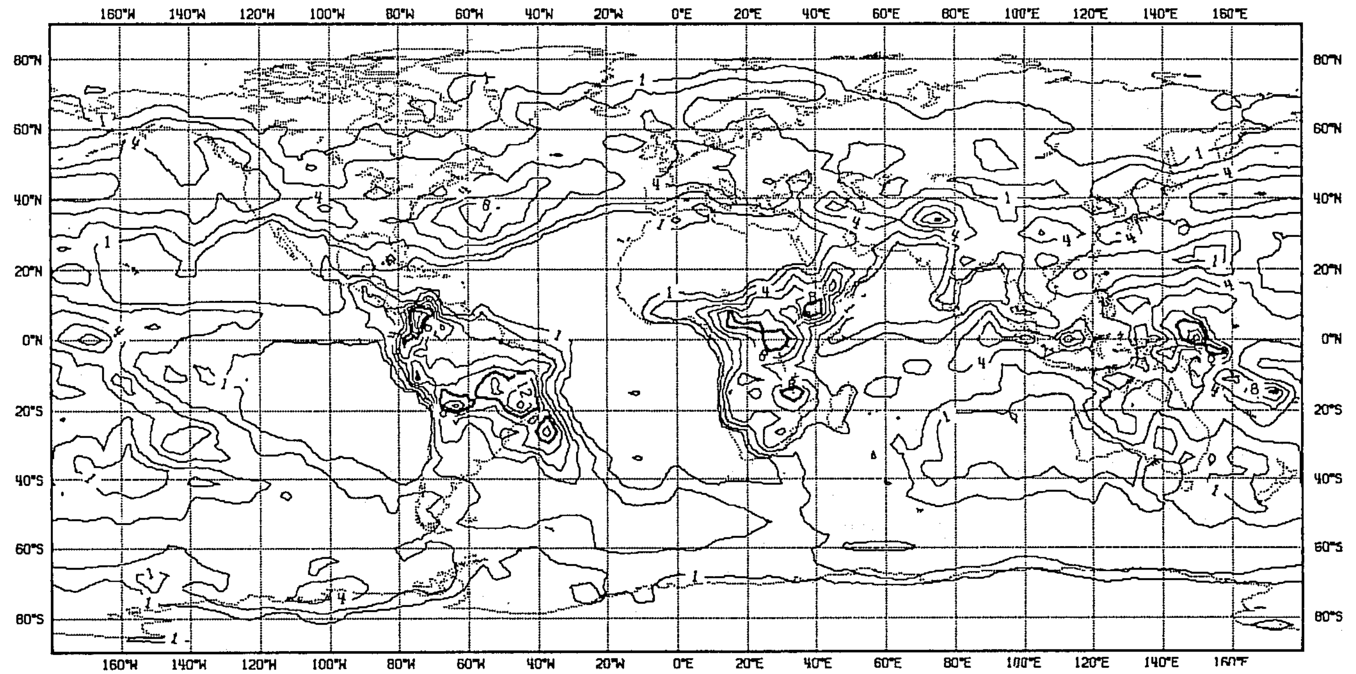

Fig. 5   As Fig. 3 for 96 to 120 hours

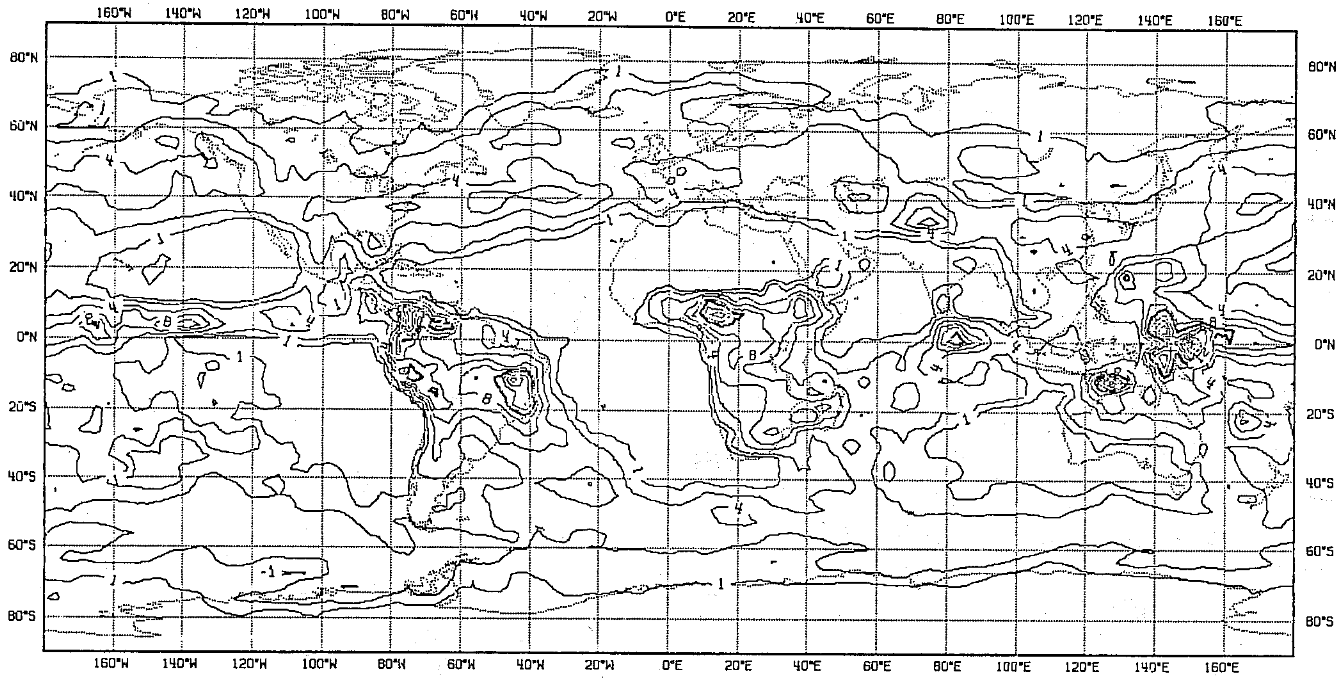

Fig. 6 As Fig. 3 for 216 to 240 hours

forecast have, in general, intensified and become more widespread, an exception to this is the rainfall over southern China which has weakened. By day five the geographical distribution is beginning to change and the rainfall maxima over the Pacific, South America and Central Africa are weaker. The band of rain in the Pacific has decreased to 6 mm/day, the rainfall over South America is similar to the one day forecast. There has been a slight intensification of the rainfall over Tibet. The pattern continues to change and by day ten there is no longer any sign of the intense NW to SE band of rain in the Pacific. Over the oceans the rainfall at this time occurs along the ITCZ with the heaviest rain over the Indonesian region. Over land the heaviest rainfall occurs over Venezuela, Colombia, Peru, Central Brazil, Central Africa, Madagascar and Tibet.

As already mentioned, verification of rainfall in the tropics presents something of a problem, as a rough guide we can compare the monthly means with climate. Fig. 7 shows the climatic rainfall for March reproduced from Jaeger's data. Compared with Figs. 3 to 6 it is clear that the forecast rainfall bears more and more resemblance to the climatological distribution as forecast length increases. The resemblance between the ten-day forecast (Fig. 6) and climatology, ignoring the Southern Ocean, is quite striking. The most obvious difference is the band of rain extending from Central Africa to Brazil which is missing in the forecasts, and the under prediction of rainfall in the Indonesian, western Pacific region.

Fig. 8 shows the monthly mean outgoing longwave radiation (Wm^{-2}) derived from NOAA Satellite data for March 1981. Areas with less than 250 Wm^{-2} are shaded, these "cloudy" areas correspond closely with the areas of maximum forecast rainfall in the one or two day forecasts. Note the NW to SE orientated band of cold clouds in the Pacific coincident with the forecast rainfall. Also worth noting is the absence of cold clouds in the band from Central Africa to Brazil across the equatorial Atlantic, which lends support

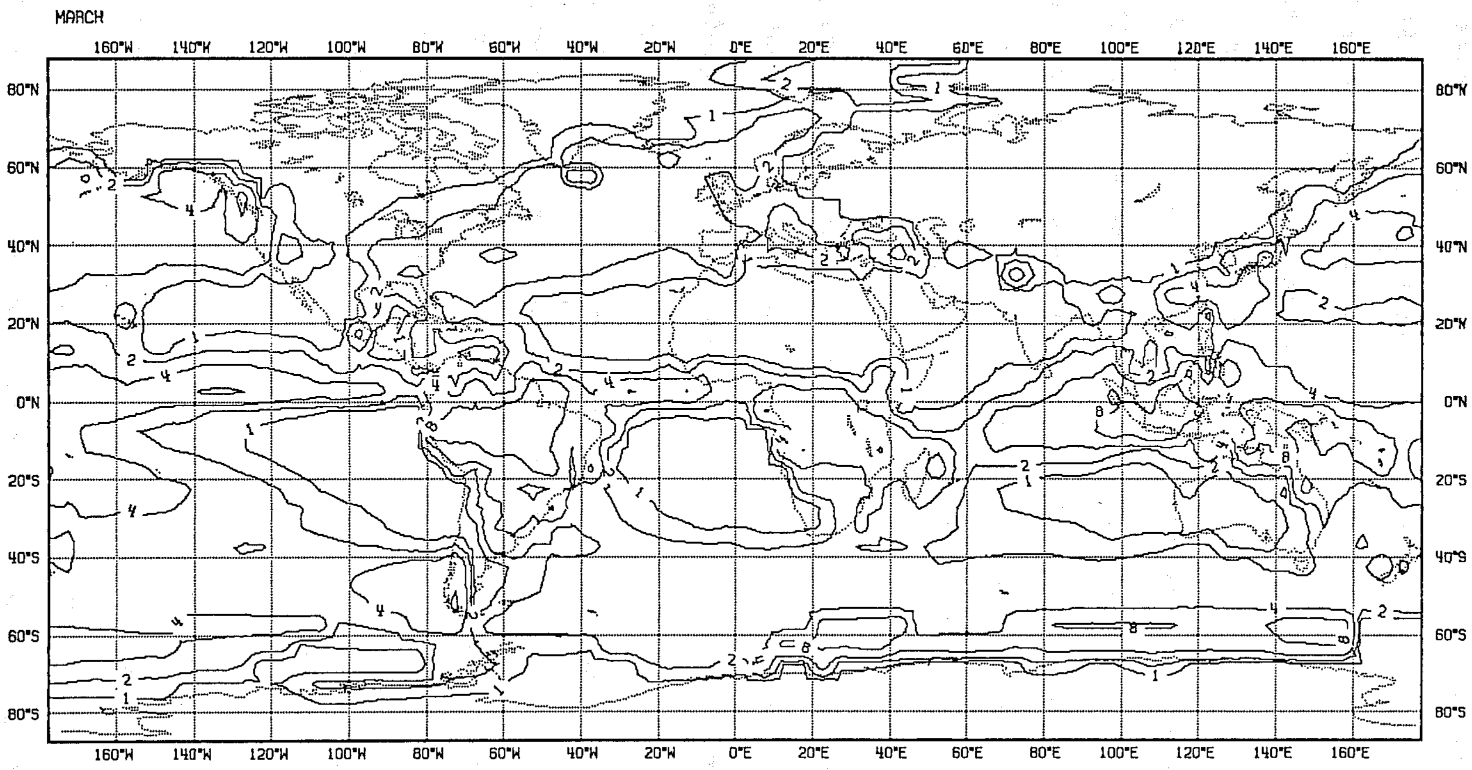

Fig. 7 Climatic distribution of rainfall for March 1981. Taken from Jaeger, 1976. The units are mm.

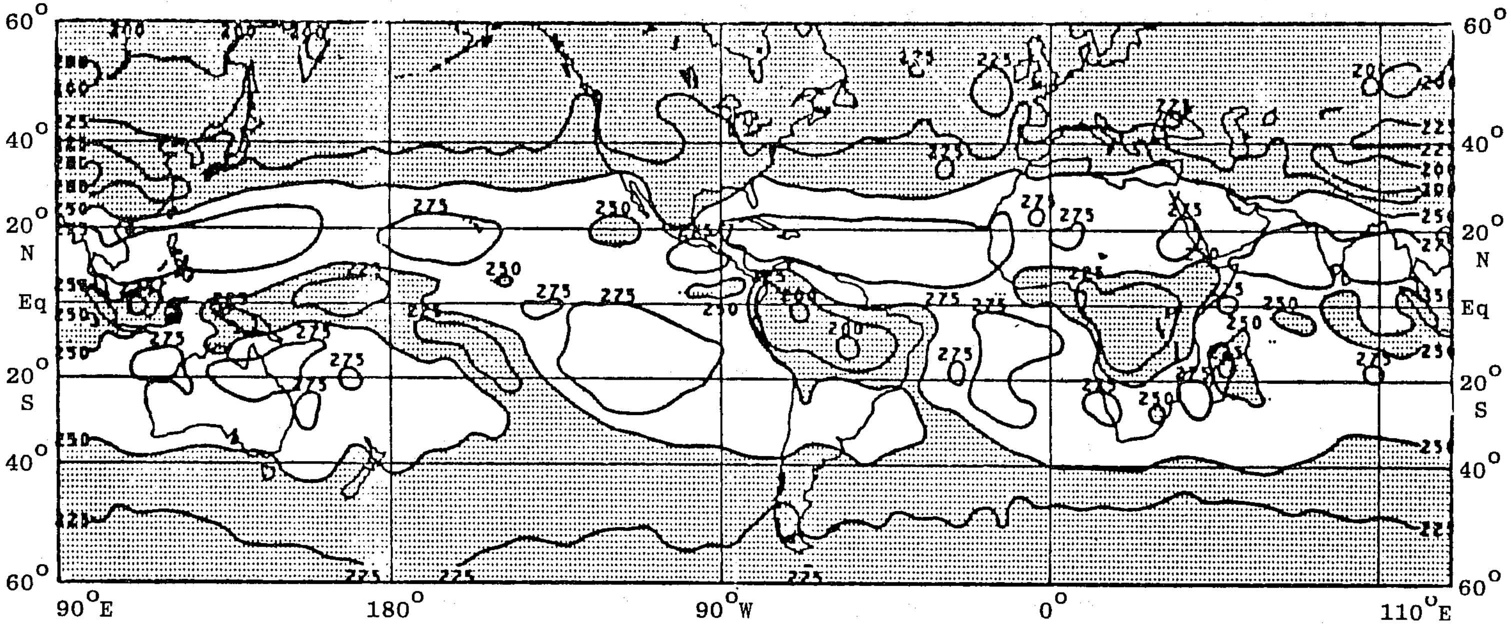

Fig. 8 The monthly mean outgoing longwave radiation for March 1981. Supplied by NOAA. The units are WM^{-2}.

to the lack of forecast rainfall compared to climatology in this region.

We have seen that in the monthly mean the forecast rainfall in the tropics is (at least qualitatively) quite well predicted for the first one or two days of the forecast and thereafter tends towards the climatological distribution. In order to obtain a more quantitative measure of the quality of the forecast rainfall, the rainfall reports for South America for March 1981 were averaged to obtain the monthly mean shown in Fig. 9. The large numbers refer to the forecast rainfall in tenths of mm/day and the small numbers refer to the observed rainfall in tenths of mm/day. The areas with observed rainfall greater than 8 mm/day have been outlined with a dashed line. The areas do not coincide exactly but there is a broad agreement. The most obvious differences appear in Colombia where there is an underprediction of rainfall on the western side of the Andes and an overprediction on the eastern side. There is also an overprediction of rainfall over the Bolivian Plateau. Over most of Brazil the differences do not have a consistent sign and the rainfall (given the localised nature of tropical rainfall) is well predicted.

3. VELOCITY POTENTIAL FIELDS

Shown in Fig. 10 are the velocity potential fields at 1000 mb for the initialized and uninitialized monthly mean analyses for March 1981. Over most of the tropics the velocity potential field has been slightly weakened by the initialization. The most noticeable difference occurs over the western Pacific, Indonesian region where there has been a weakening of the divergent circulation. Fig. 11 shows the same fields at the 850 mb level. At this level the main differences again occur in the western Pacific, Indonesian region, other differences, such as a slackening of gradients over Colombia, can also be seen but are quite small.

As the initialization procedure is only effective on the first five vertical

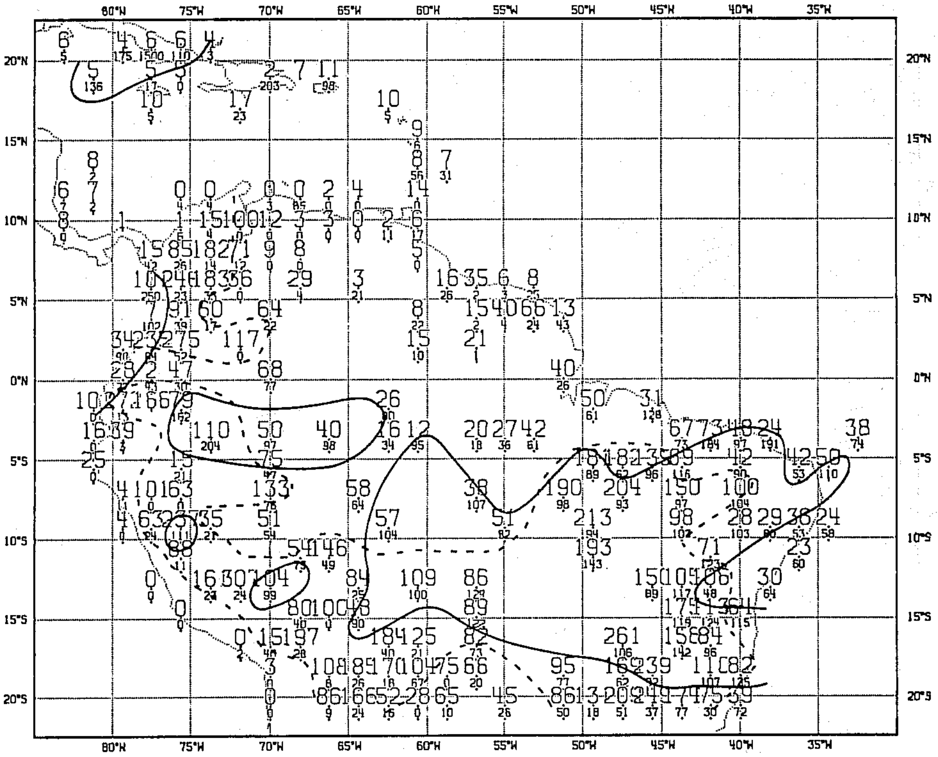

Fig. 9 Monthly average forecast and observed precipitation for March 1981. The large numbers refer to the forecast precipitation and the small numbers to the observed. The 8 mm/day contour is drawn as a solid line for the forecast and as a dashed line for the observations. The units are tenths of mm/day.

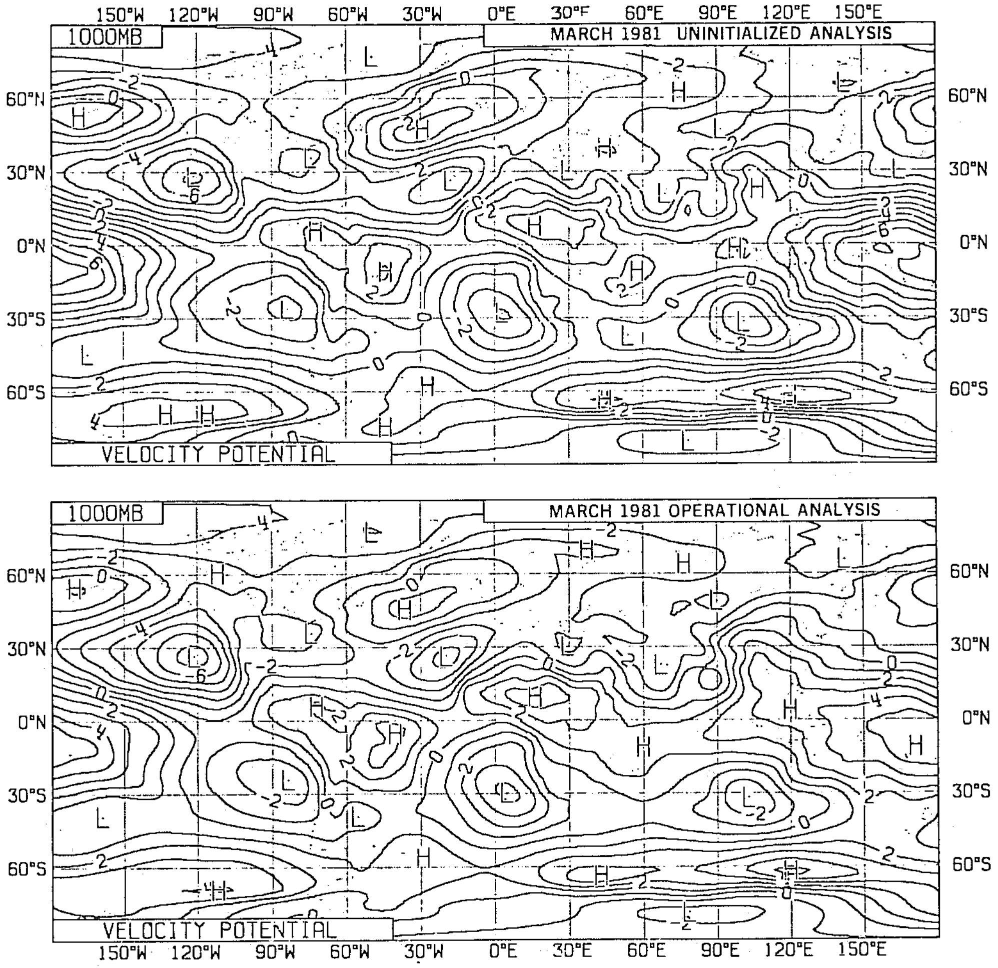

Fig. 10 Monthly mean velocity potential fields for March 1981 at 1000 mb

Top: The uninitialized analysis.

Bottom: The initialized analysis. The units are $10^{-6} m^2 s^{-1}$.

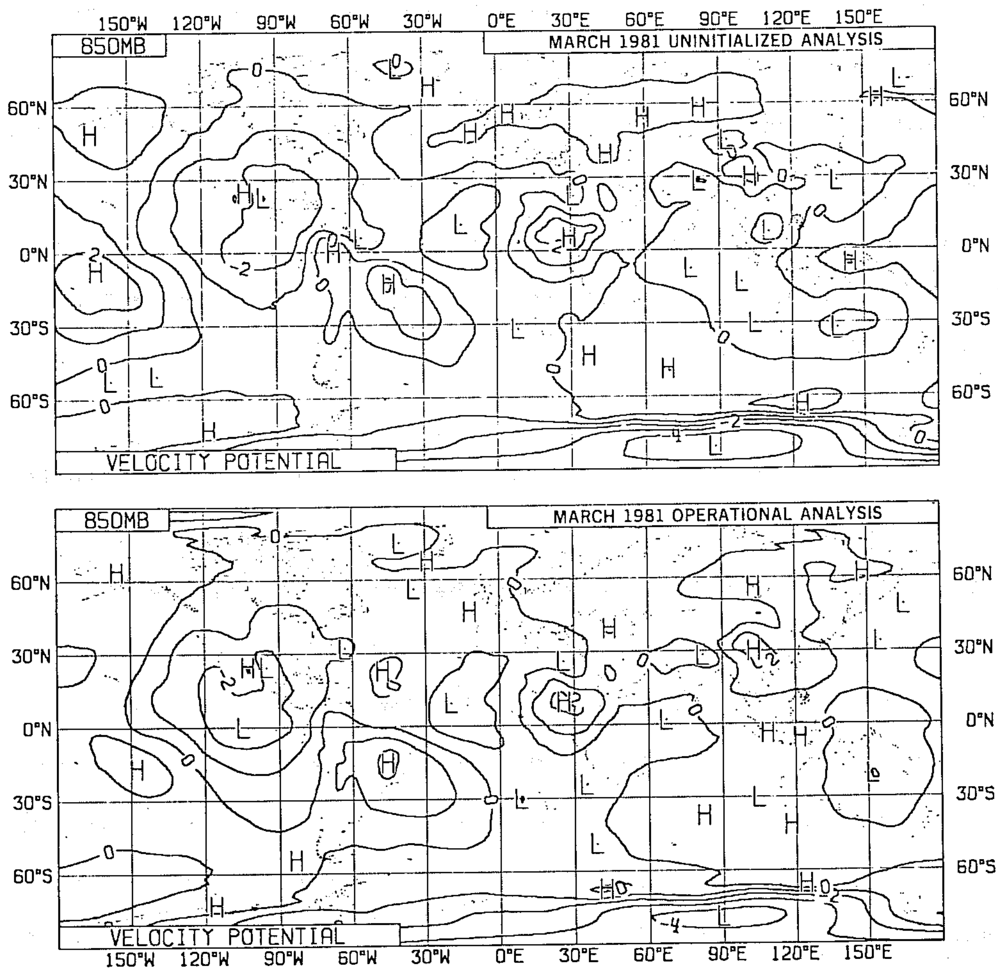

Fig. 11 As Fig. 10 for 850 mb.

modes features with a small vertical scale in the lower troposphere should be unaffected. The velocity potential at 1000 and 850 mb is largely a product of Ekman pumping in the PBL and therefore, due to the small vertical extent of the PBL, will be largely unchanged by the initialization. The larger (vertical) scale convectively driven features will be removed by the initialization as the initialization procedure does not include physical (as opposed to dynamic) processes. Thus the changes in the velocity potential field in the western Pacific, Indonesian region are most likely due to failure of the initialization procedure to retain the observed large-scale convective circulations.

Figure 12 shows the velocity potential fields at 1000 mb and 850 mb for the 24-hour forecast. At 1000 mb the divergent circulation has increased slightly in intensity and over most of the tropics is very similar to the uninitialized analyses. The divergent circulation in the western Pacific, Indonesian region removed by the initialisation, has returned with almost its original magnitude although the centre is slightly too far eastward. The gradients over South America have returned to about the level of the uninitialized analyses. The largest change has occurred over Africa where the velocity potential has a value twice that of either analyses. At 850 mb the divergent circulation is generally more intense than in either analyses, especially over Africa where the velocity potential has a magnitude some three times that of the analyses. By day 5 at 1000 mb (Fig. 13) the velocity potential over Africa has weakened by ~20%; the largest velocity potential at day one in the Pacific has weakened and intensified to the west, consistent with the reduction of rainfall in this region between days one and five. At 850 mb the principal changes between days one and five are a reduction of the velocity potential of ~35% over Africa and a shift ~60° westward of the high velocity potential originally in the central Pacific. At day ten (Fig. 14) the velocity potential field at 1000 mb has all the gross features of the analyses and is nearer to the analyses in intensity than at day 1 or day 5.

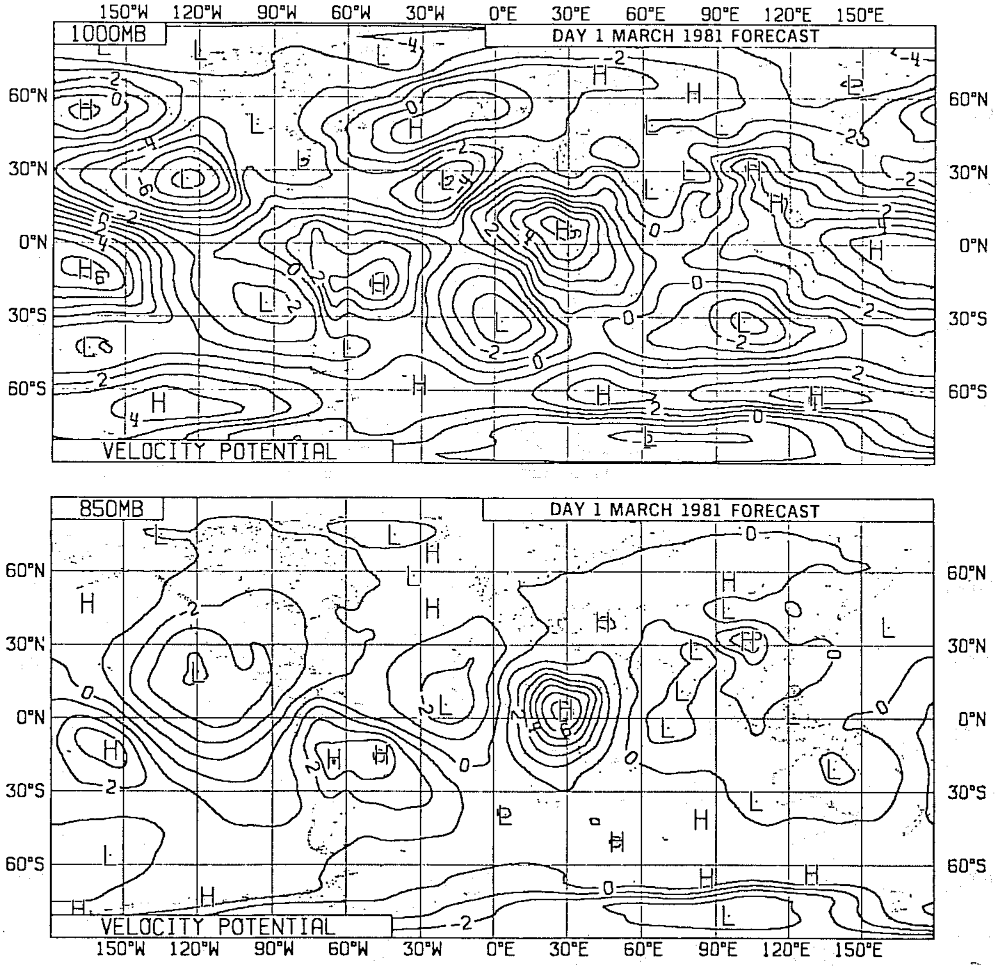

Fig. 12 Monthly mean velocity potential fields for the 24 forecast for March 1981

Top: 1000 mb

Bottom: 850 mb. The units are $10^{-6} m^{2} s^{-1}$.

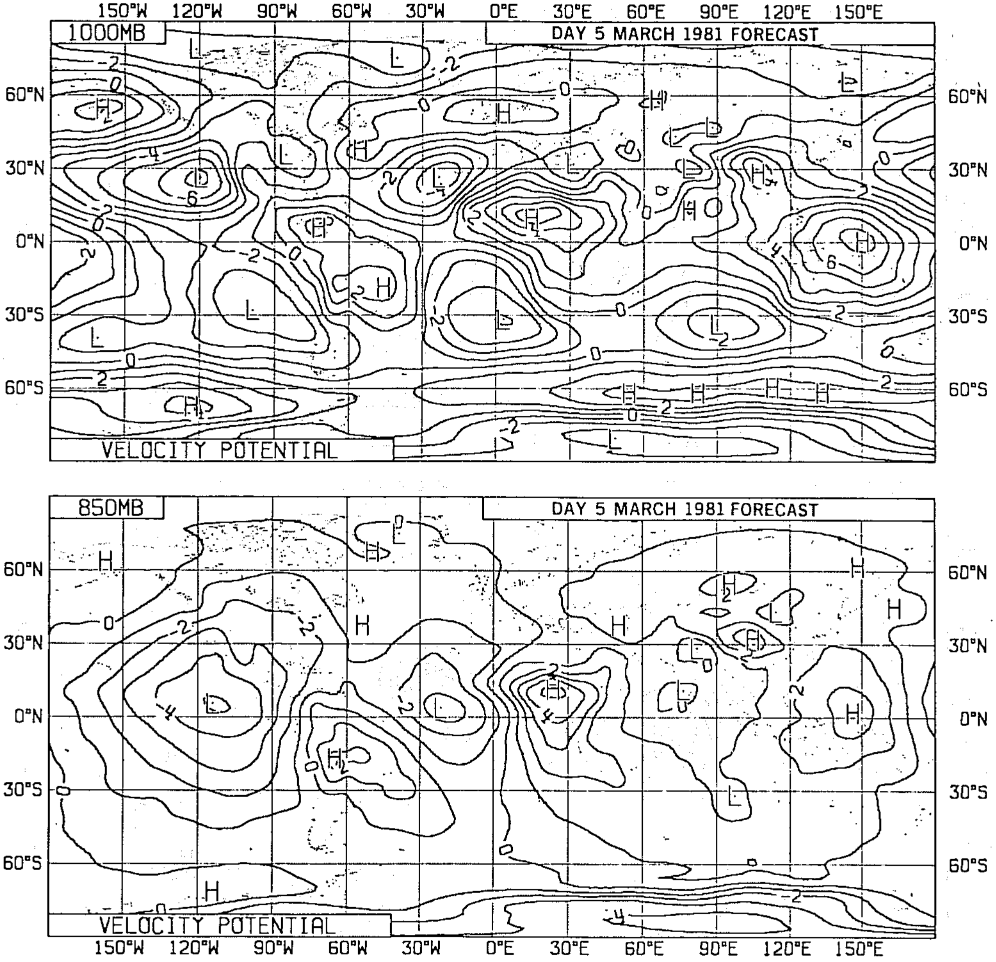

Fig. 13 As Fig. 12 for the 120 hour forecast

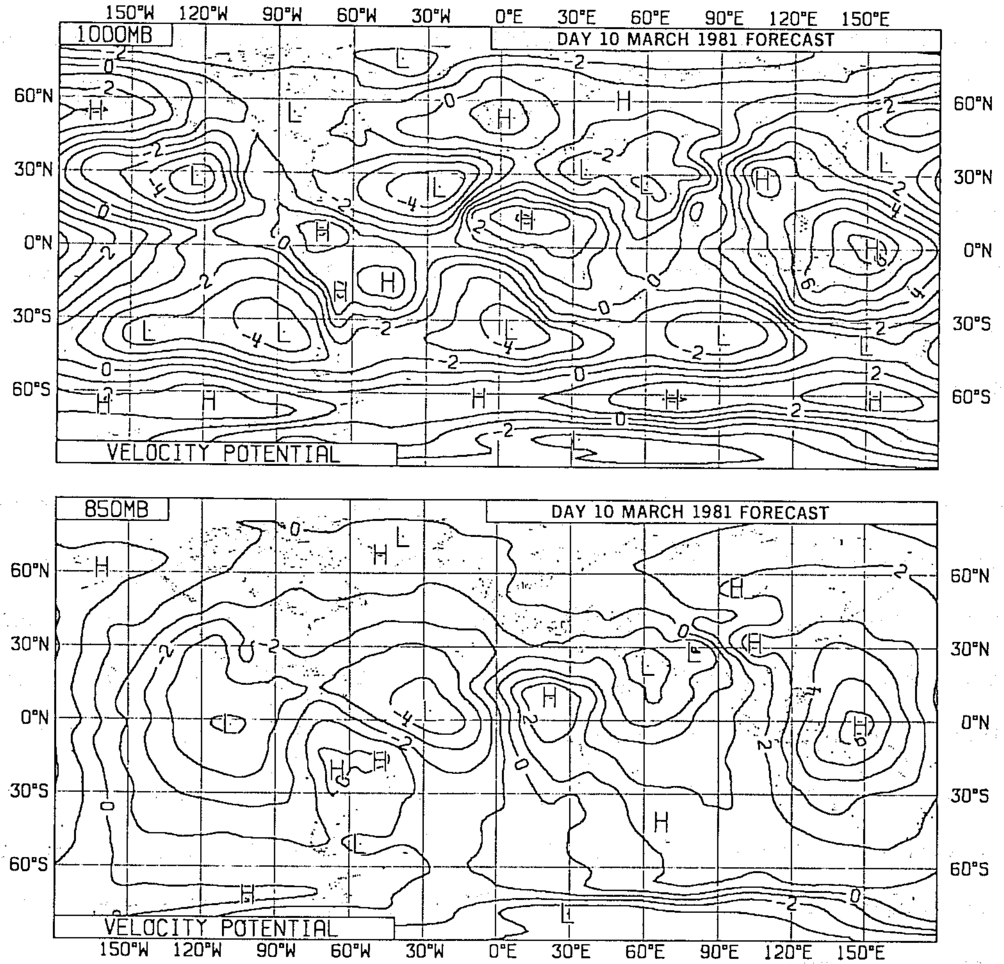

Fig. 14 As Fig. 12 for the 240 hour forecast

This is also true at 850 mb except over the western Pacific, Indonesian region.

The differences over the western Pacific Indonesian region are related to an intense NW-SE storm not captured by the earlier forecasts. The most serious error in the velocity potential field at these levels is the very rapid intensification of this field over Africa during the first 24 hours of the forecast, which slowly decays reaching reasonable values by day 10. The gross features of the field are retained well throughout the ten days of the forecast.

Before leaving the discussion of the velocity potential fields it is worth noting (comparing Figs. 3 and 12) the strong correlation between the velocity potential field and the rainfall. Because of this strong correlation and the relative ease that the velocity potential can be analysed compared to the analysis of rainfall, there exists a possibility of rainfall verification through verification of the velocity potential fields. Although there are uncertainties in the initial velocity potential field this may be a practical method of obtaining a quantitative measure of the quality of the rainfall forecasts over oceanic areas.

4. THE ATLANTIC TRADES

This discussion will only deal with the Atlantic trades, it should be noted that similar problems occur in the Pacific. Fig. 15 shows the operational analysis for the wind field at 1000 mb and 850 mb, once again, this is a monthly mean for March 1981. There is little discernable difference between the initialized and uninitialized analyses so only the initialized analysis is shown. The 24, 48, 120 and 240 hour forecasts are shown in Figs. 15 to 19. At 1000 mb the trade winds along the north west and south west coasts of Africa are well maintained throughout the forecast. Nearer the equator, the

OPERATIONAL ANALYSIS

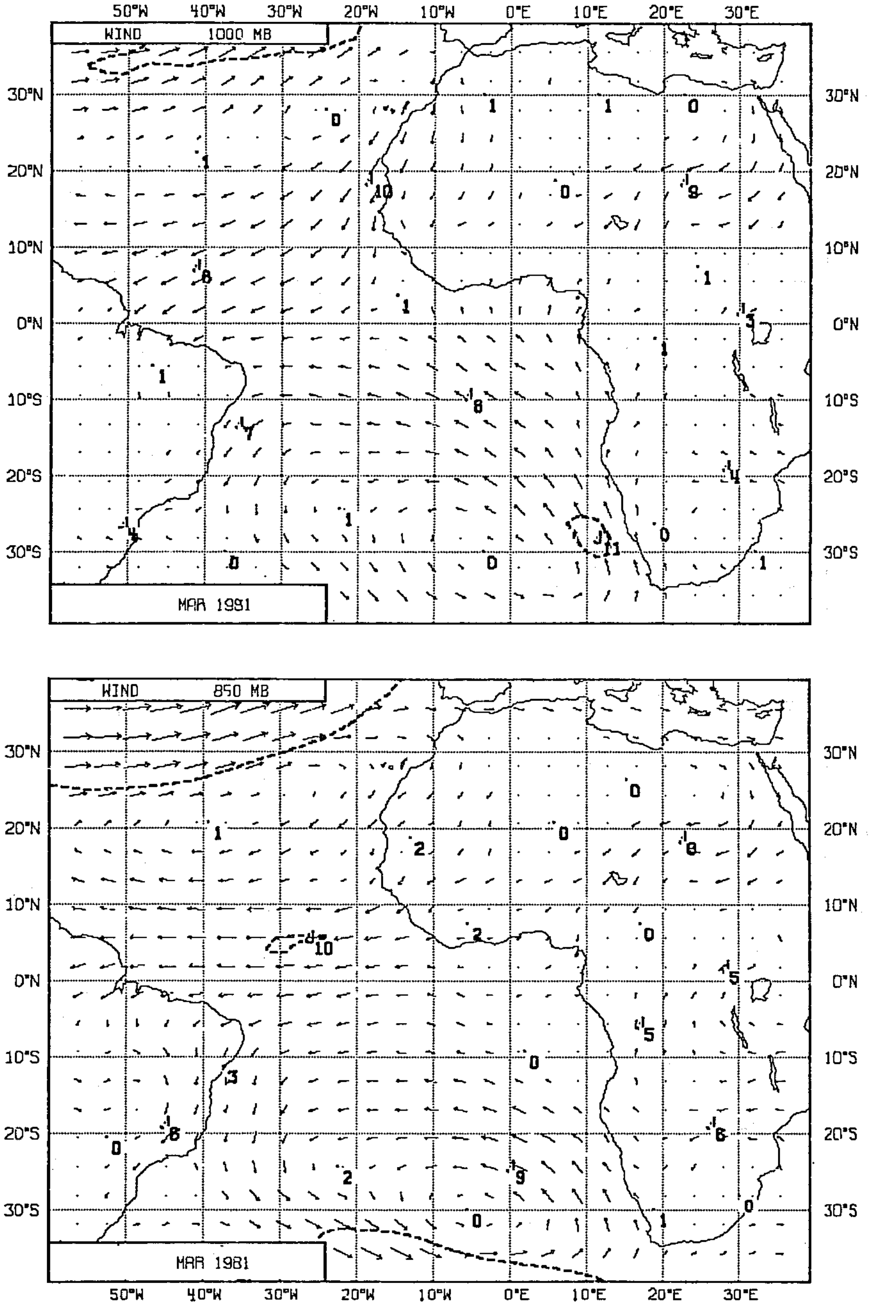

Fig. 15 The wind vectors over the Atlantic region corresponding to the operational analysis for the monthly mean for March 1981. Local maxima are indicated by numbers and the units are ms^{-1}.

Top: 1000 mb Bottom: 850 mb

OPERATIONAL FORECAST

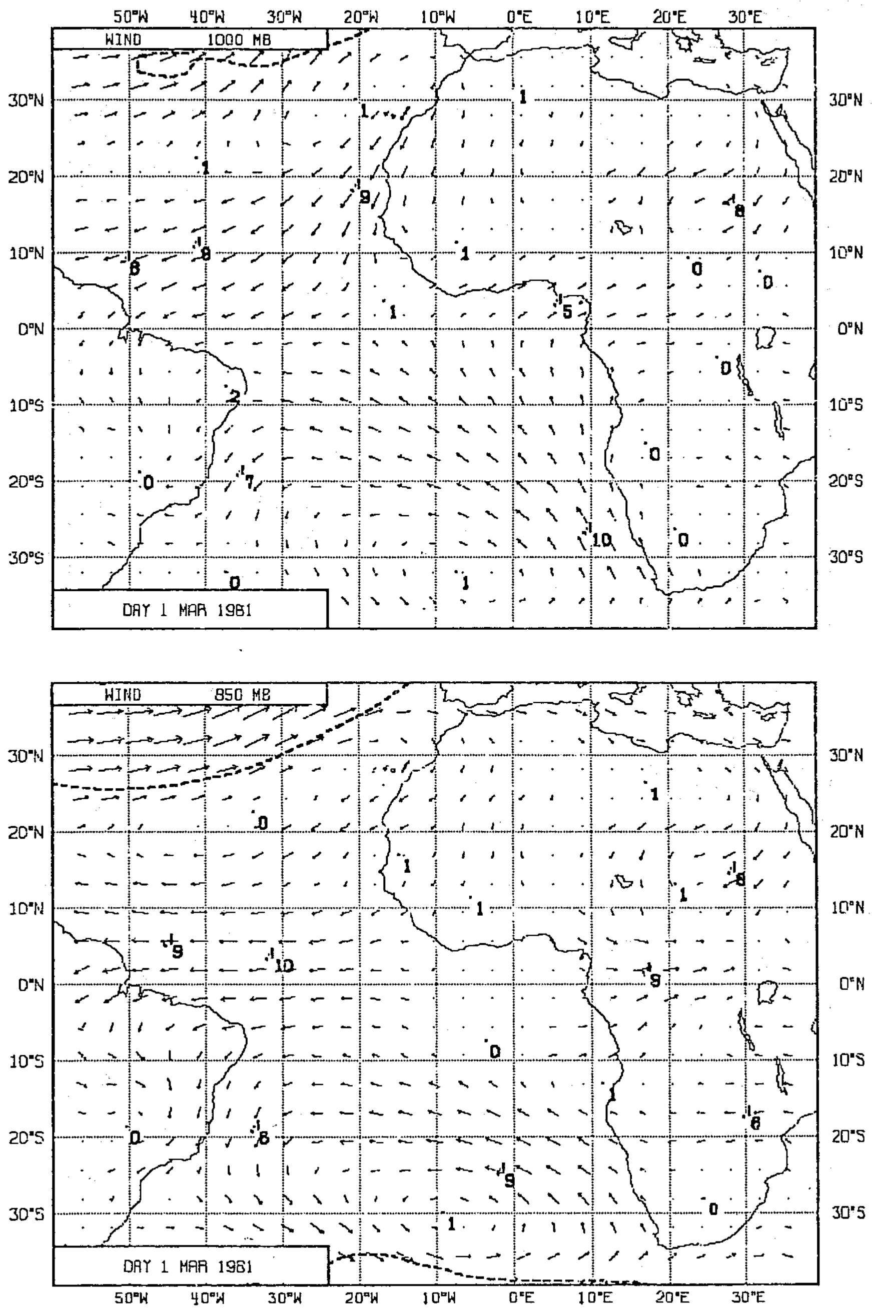

Fig. 16 As Fig. 15 for the 24 hour forecast.

OPERATIONAL FORECAST

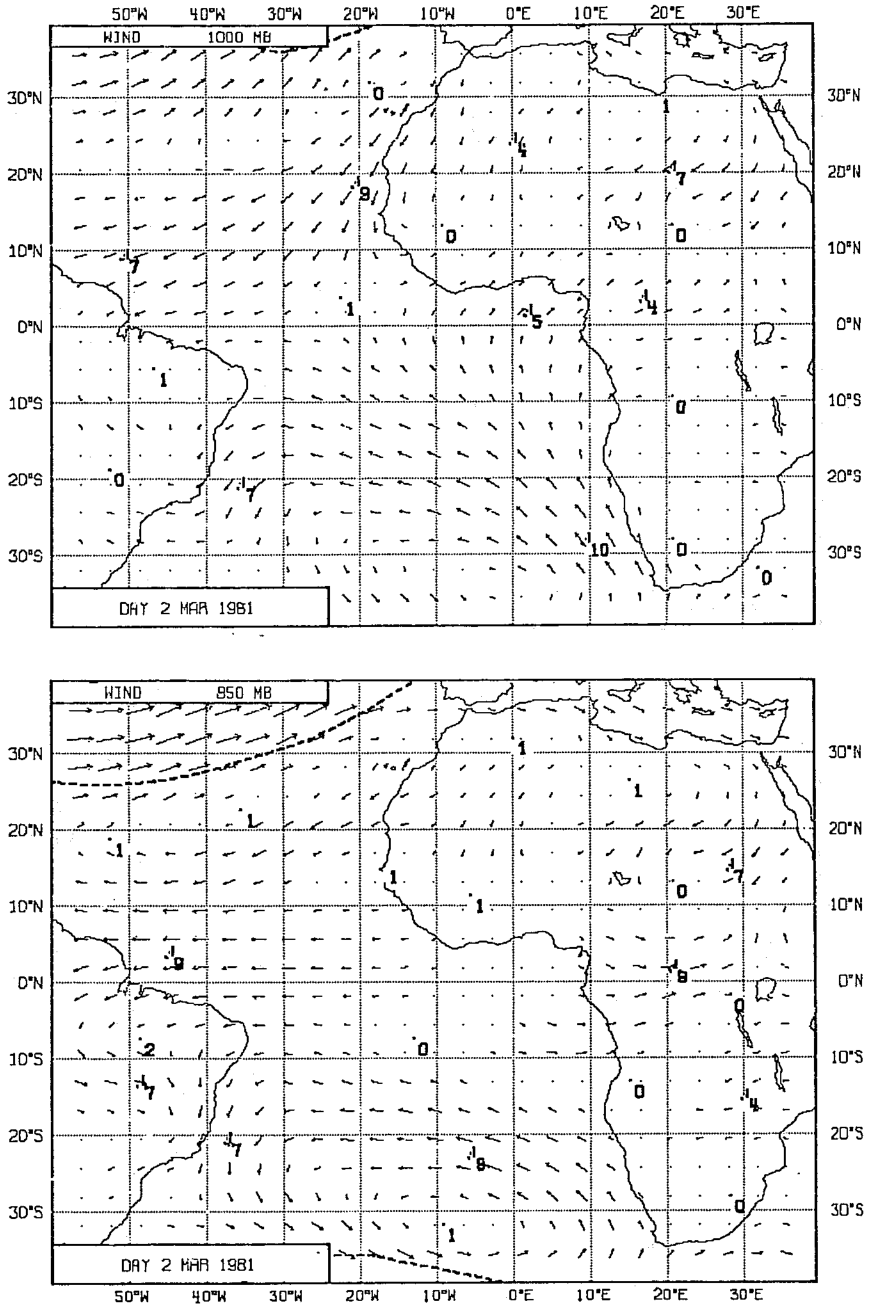

Fig. 17 As Fig. 15 for the 48 hour forecast.

OPERATIONAL FORECAST

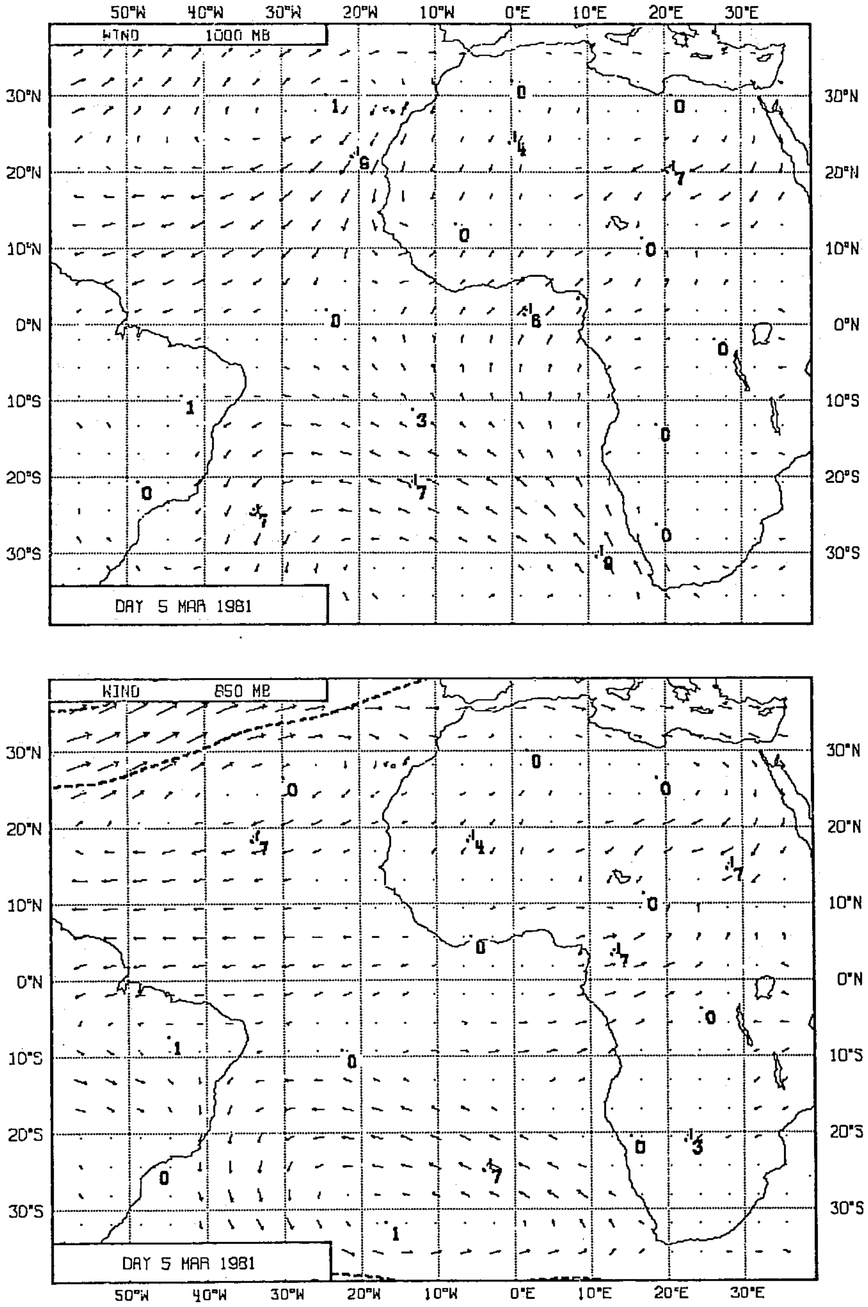

Fig. 18 As Fig. 15 for the 120 hour forecast.

OPERATIONAL FORECAST

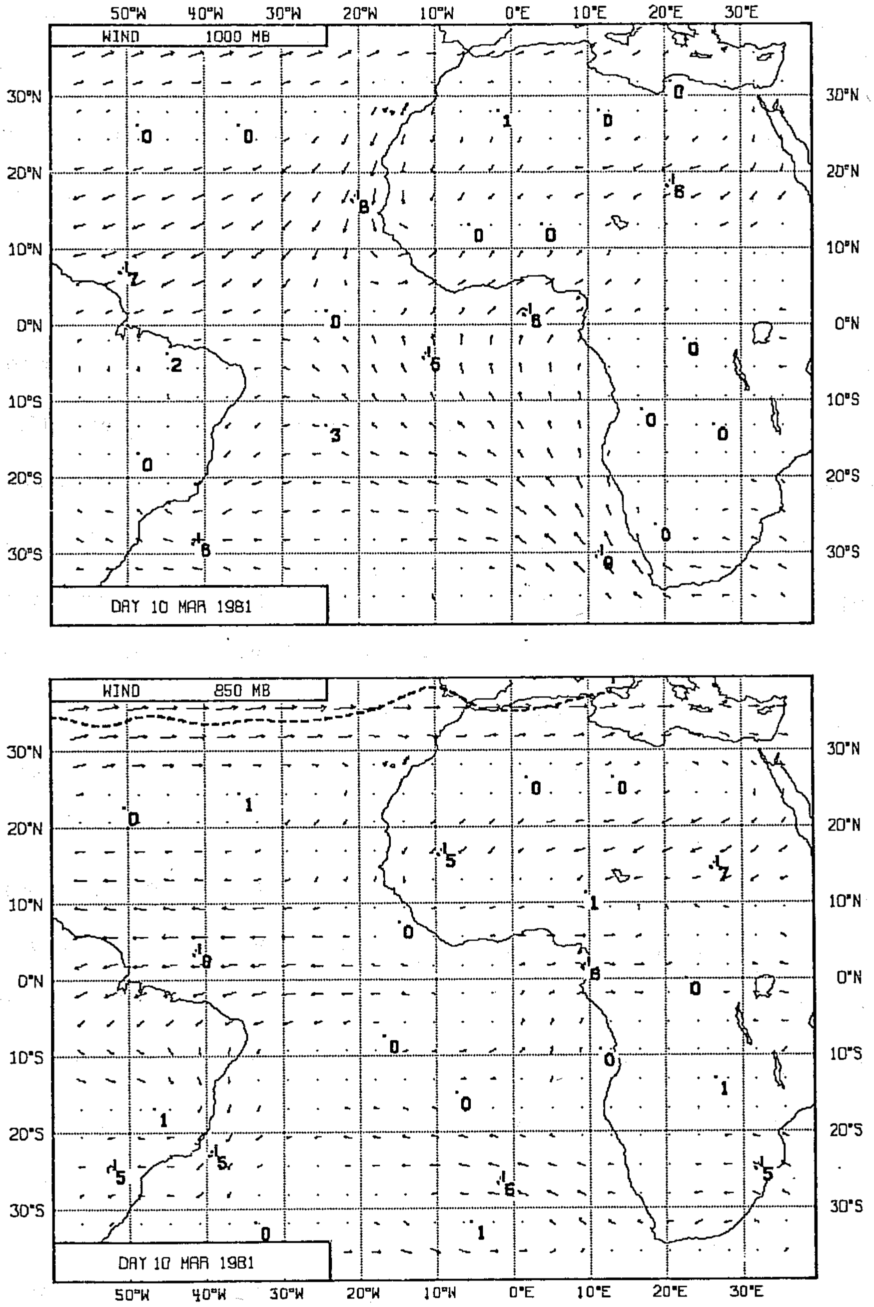

Fig. 19 As Fig. 15 for the 240 hour forecast.

air moving north-westwards in the analysis is forecast to move north-eastwards. A turning of the wind towards the African continent is evident in the forecast, which is presumably related to the over-intense forecast convergence over Africa. Another feature of the forecast at 1000 mb is a steady weakening throughout the forecast of the anti-cyclonic circulation in the North Atlantic and in the South Atlantic. This circulation has almost entirely disappeared by day 10.

At 850 mb the errors are larger and more obvious. At day 1 the forecast predicts westerly winds of 8 ms^{-1} over Central Africa where the analysis shows no wind at all. The errors over this region do not intensify with time as they do at 1000 mb, in fact they decrease slowly, at day ten the wind in this region has reduced to 4 ms^{-1}. As noted in Section 3 the error in the velocity potential field also decreased steadily between days one and ten in this region. The growing error at 850 mb is a weakening of the anti-cyclonic circulation in the North Atlantic and in the South Atlantic, as at 1000 mb.

In brief, there appear to be two kinds of error associated with the tropical wind field in this region. The first, which has a very large immediate effect at 850 mb, and a smaller but amplifying effect at 1000 mb, seems to be associated with the over intense divergent circulation over Africa. The divergent wind is directly opposed to the trade wind circulation off West Africa. This becomes less of a problem as the velocity potential field weakens but has a lasting effect on the low level flow field. The second kind of error which is initially very small but dominates towards the end of the forecast, is the weakening of the anti-cyclonic circulations in the north and south Atlantic. The cause of this error is not at all obvious and requires attention.

5. SUMMARY

In the monthly mean for March 1981 the rainfall locations are seen to be well forecast at day 1 and thereafter tend towards the climatological distribution. The intensities at day 1 are seen to be reasonably well forecast, at least over South America, although there is a clear under estimation of rainfall on the western side of the Andes and an overprediction on the eastern side. These differences are presumably related to problems with the vertical diffusion of moisture over orography. Elsewhere there is a clear underprediction of rainfall compared to climate over the Indonesian, western Pacific region. The velocity potential field at low levels with the important exception of Africa, is well forecast out to day ten. There are serious errors in the tropical wind field apparent at day one that appear to be associated with the errors in the low level velocity potential field over Africa. The trade winds off the coast of Africa are reasonably well maintained but the anticyclonic circulations in the North and South Atlantic are steadily weakened throughout the forecast.

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