# ECMWF OPERATIONAL FORECASTS IN THE SW AND NE MONSOON REGIONS

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## 1. INTRODUCTION

The SW and NE monsoonal circulations cover a substantial area of the earth's surface; the forcing of the SW monsoon in particular is known to be very large scale, extending across the complete latitudinal range of the tropical belt with a flow from the SH subtropics into the Indian subcontinent. Substantial temporal variations on a time scale of the order of a week or so are also observed in these circulations. Furthermore it seems reasonable to expect that temporal variations in such large scale low latitude circulations will have an impact on the midlatitude region of greatest interest to the Centre.

For the foregoing reasons it is appropriate to examine the performance of the Centre's model in the SW and NE monsoon regions.

The Centre has been producing operational analyses and forecasts for the complete globe since August 1979. Thus the periods June - September 1980 and November 1980 - January 1981 provide us with an opportunity of assessing performance by examination of a large selection of cases. The Centre is currently one of very few meteorological services producing operational analyses and forecasts for the regions in question. The evaluation has been largely qualitative and of course the methods of assimilation and forecasting are those in operation at the time. The Centre's data assimilation scheme has been described recently by Lorenc (1981); during June-September 1980 the operational scheme differed from that description in that the $p \rightarrow \sigma$ transformation used after the analysis to vertically interpolate data to the forecast model's $\sigma$ levels was not performed using analysis increments, but using the full fields of the analysis. The interpolation of increments technique was introduced into operations on 10 December 1980, during the NE monsoon season. Whilst the impact of the technique is significant, particularly in terms of preserving boundary layer structures, it is thought not to have a significant role in the generalized discussions of this paper. It is also worth noting that no humidity analyses were being used operationally during the period in question - the model's $\sigma$-level first guess humidity field being used instead. The latter approximates quite well to an analysed field, and again the results presented here are considered to be unaffected materially by the absence of a humidity analysis. The operational forecast model remained unchanged throughout the period, though a subsequent change to the topography field (implemented operationally on 1 April 1981) is known to effect the model's performance significantly in the SW monsoon region and this aspect is discussed later. The forecast model also currently lacks a diurnal cycle, a factor which may have some adverse impact on the quality of both forecast and data assimilation in the tropics.

The availability of observational data for the SW monsoon region is poor, and inadequate to provide very reliable operational analyses. This is confirmed by examination of analyses based on unusually comprehensive data bases such as those provided by FGGE/MONEX. The atlas of analyses produced by Krishnamurti et al (1979) shows that the identification of, for example, the Arabian Sea vortex which marked the onset of the SW monsoon in 1979 is closely dependent on the availability of the additional FGGE/MONEX data sources, particularly the low level balloon data and the satellite wind data over the Arabian Sea. Neither of these sources was available to the operational analyses of the SW monsoon in 1980. The operational data network consists of the sparse land based network over Africa (but with quite a good PILOT/TEMP network over Madagascar) with improving coverage over land as one proceeds north eastwards over Arabia, the Indian subcontinent and Asia. Over the Indian Ocean, the Arabian Sea and the Bay of Bengal there are occasional SHIP reports and surface synoptic reports but very few upper air ascents.

The temperature/thickness soundings of the polar orbitting satellites provide little useful information in these low latitude regions. Aircraft wind reports are received over the northern part of the region, and down towards Indonesia/Australia, but are not normally available over the Indian Ocean south of the equator. The decline of the southern hemisphere drifting buoy system in the post FGGE period has also presumably led to reduced quality of the southern hemisphere analyses and forecasts and hence presumably to a reduced ability to identify and predict the large scale forcing of the SW monsoon. Relatively speaking the observational network for the NE monsoon region is better, with good radiosonde coverage over China and parts of SE Asia. The continued availability of satellite winds (HIMAWARI) over the west Pacific is also thought to be useful for the purpose of analysing features of the NE monsoon.

## 2. THE SW MONSOON

### 2.1 The quality of the analyses and forecasts

Currently there is no detailed or systematic evaluation of the tropical analyses produced operationally, the priority being given to evaluation of midlatitude regions. Indeed no systematic evaluation of the quality of the tropical analyses has been made in this study either. What has been done has been to monitor the 12Z wind analyses each day at 850 and 200 mb, and the corresponding daily forecasts at the same levels. Rainfall forecasts have also been examined. Typical analyses at these two levels are shown in Fig. 1 for 12Z, 30.6.80. The forecast (also considered to be typical) at D+3 days at the same two levels is shown in Fig. 2 and the verification analyses for this forecast time in Fig. 3. Considerable differences between the verification analyses and the forecast are evident, the most reasonable interpretation being that the analysis is being constrained by the observational data to a fair extent (though as already discussed the analysis is presumably lacking in some areas); and that the forecast has considerable

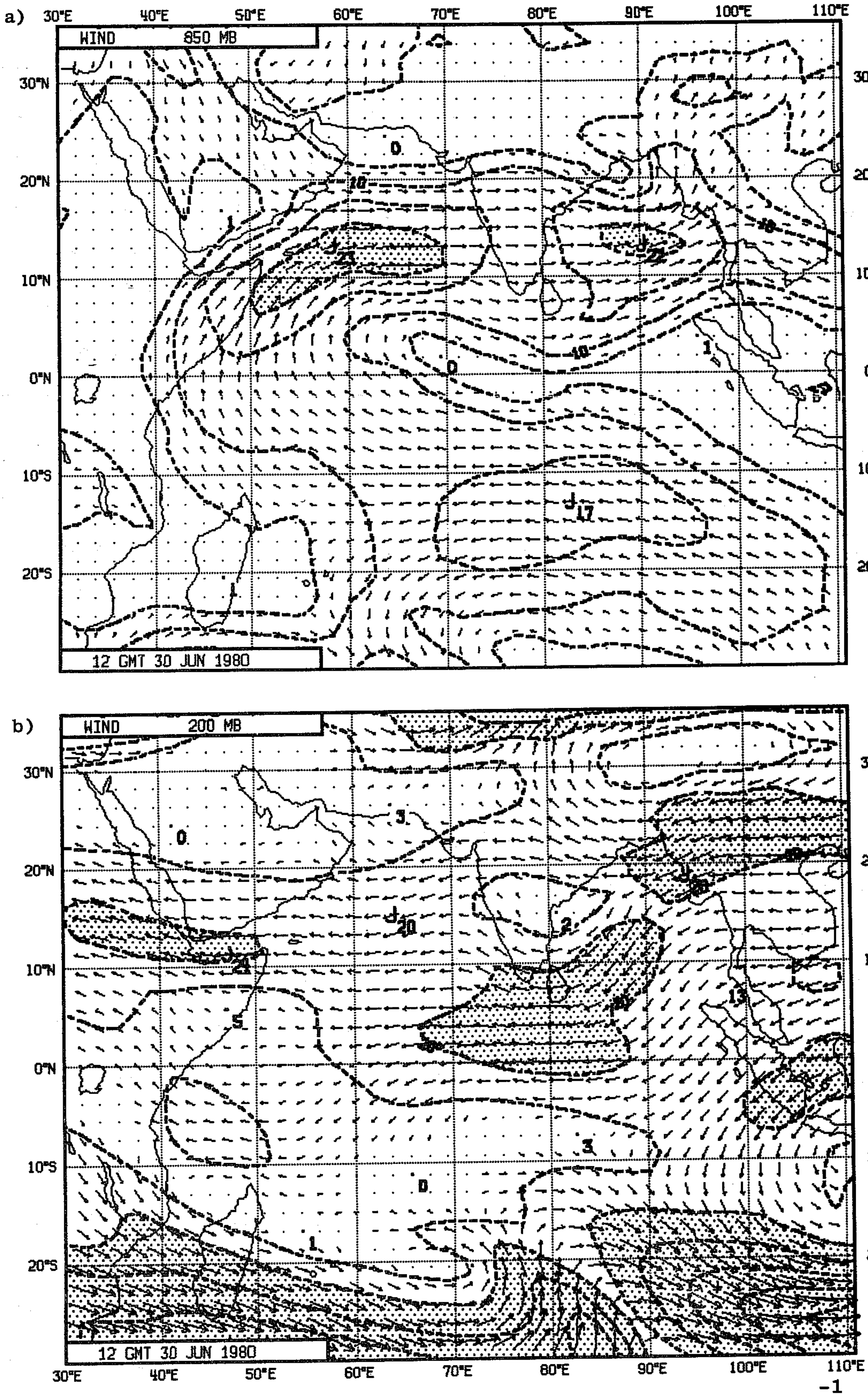

Fig. 1 Analysed wind field 12 GMT 30 June 1980. Units m $sec^{-1}$. Winds in excess of 20 m $sec^{-1}$ are shaded.

(a) 850 mb. Isotach interval 5 m $sec^{-1}$

(b) 200 mb. Isotach interval 10 m $sec^{-1}$.

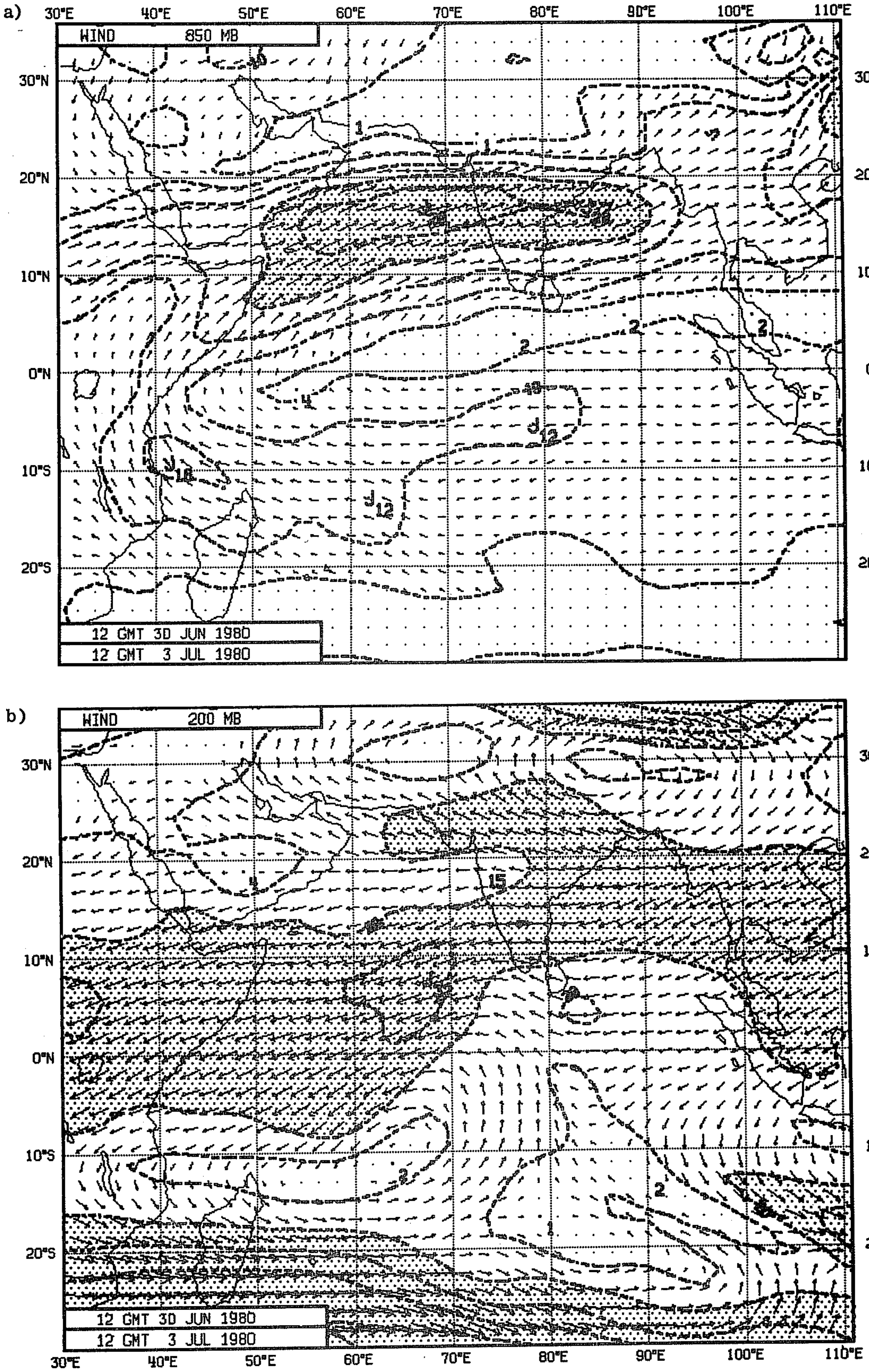

Fig. 2 D+3 forecast wind field, from 12 GMT 30 June 1980.
Units etc. as in Fig. 1.

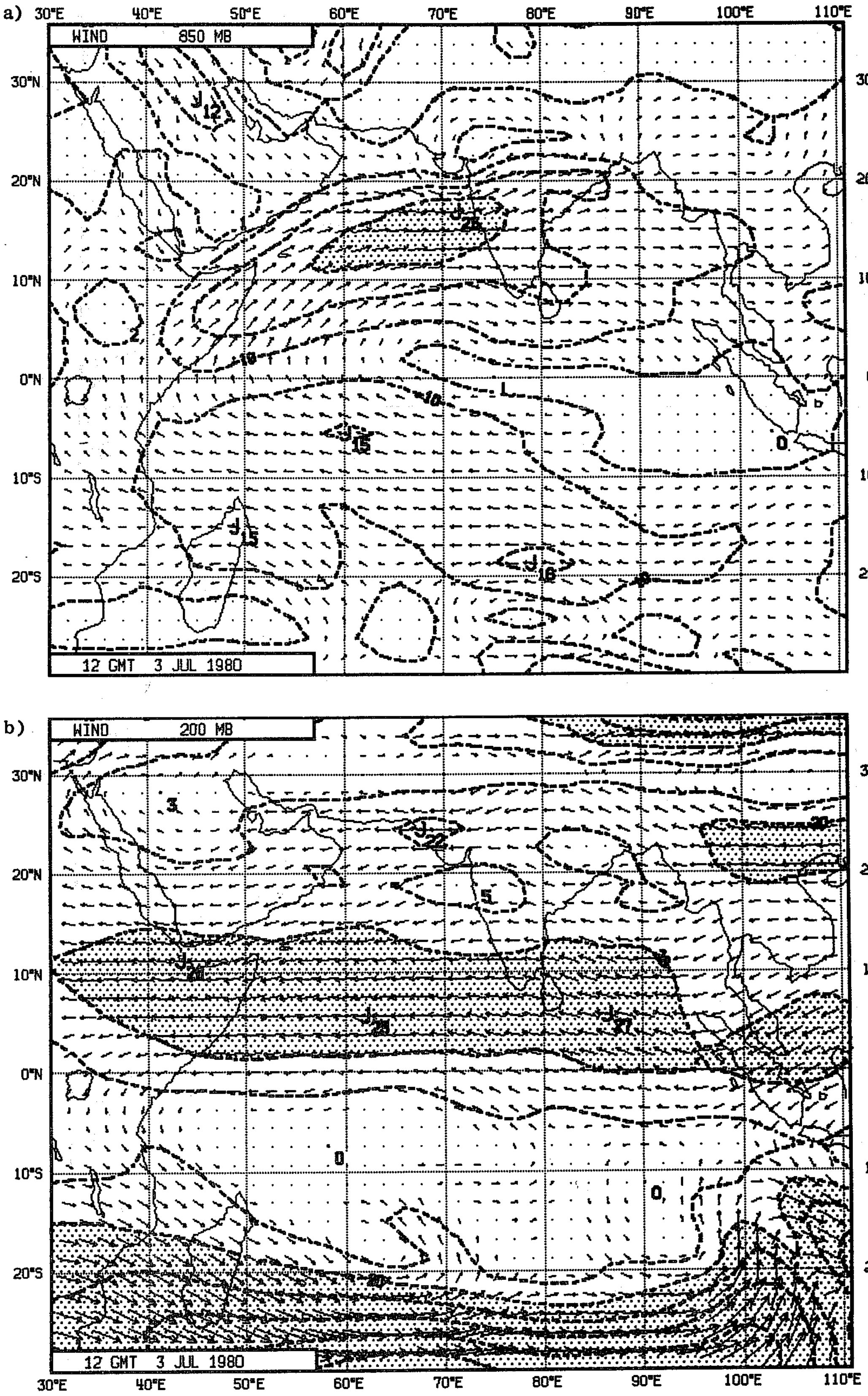

Fig. 3 Analysed wind field 12 GMT 3 July 1980. Units etc. as in Fig. 1.

errors after only a few days. There are several features of particular note in the initial 850 mb analysis.

There is a good representation of the low level Somali jet, with an orientation and wind strength that is in general agreement with other studies (e.g. Findlater, 1971). The flow shows a broad belt of quite strong winds (>10 $msec^{-1}$) at the southern region of inflow, south of the equator, with an acceleration of the flow as the air moves off the Horn of Africa and out over the Arabian Sea. The strong winds over the African mainland are restricted to the narrow area east of the East Africa highlands.

Over the Arabian Sea there is some inflow originating from the north, over Arabia, but most of the flow is originating in the SH. In particular there is little inflow from central Ethiopia (~10N 40E). Further east the low level flow recurves slightly equatorward over Sri Lanka with marked cyclonic curvature over the Bay of Bengal. (The lack of troughing downstream of the Ghats is somewhat atypical). The monsoon trough, with a NW/SE orientation, is evident in the northern Bay of Bengal. The winds over Burma are fairly light. All the foregoing features are reasonably realistic, lending confidence to what is a fairly typical 850 mb analysis.

Turning to the 200 mb wind analysis, this too looks synoptically reasonable, with a well established easterly jet (maximum ~25 $msec^{-1}$) over the Indian Ocean. In the extreme northern section of the chart, the mainstream of the westerly flow is evident, the centre of the gyre which marks the transition zone of the two wind regimes being located at 30°N, on the south side of the Tibetan Plateau.

The 3 day forecasts at 850 mb and 200 mb (Fig. 2) show considerable differences to the initial and verification fields, and contain errors common to the majority, if not all, of the operational forecasts. At 850 mb the low level jet over the Arabian Sea has been displaced northwards, with a more zonal orientation than is found in reality. Much of the inflow into the Arabian Sea is now originating from the west, the outflow from northern Ethiopia exceeding 15 msec$^{-1}$. This incorrect westerly flow can be traced westwards across the entire African continent. The cross equatorial flow has been reduced, associated with a weakening of the SE trades (a feature noted elsewhere in these proceedings (Hollingsworth and Cats)). Where the SE trades reach the east coast of Africa, the model's orography is only partly successful in deflecting the flow northwards. Compared to the real atmosphere, the flow continues too far inland.

In the eastern part of the chart, the mainstream of the monsoon flow continues to be too zonal and too far to the north. An area where the forecasts are persistently poor is SE China. Around 25N 110E (to the east of the Himalayan mountains) an excessively strong westerly flow is evident. Fig. 2(b) shows the 3 day forecast at 200 mb. The most noticeable change from the initial state is the considerable overall strengthening of the upper winds. Winds in excess of 20 msec$^{-1}$ now cover a very large part of the West Indian Ocean and Northern Bay, a change not well supported by the verifying analysis. An important conclusion to be made from a subjective examination of these changes is that the forecast particularly at 850 mb is not as good as persistence. This is true for all forecast periods, not just 3 days and beyond. It is also substantiated by objective verification scores for the Indian region (pers.comm., R. Nieminen). Fig. 4 shows the anomaly correlation of vector wind for the ensemble of operational forecasts for July 1980 for the Indian region, using the operational analyses as verification; it shows persistence to be substantially better than the forecast. The forecasts in the SW monsoon region appear to be poor compared to those in other tropical regions.

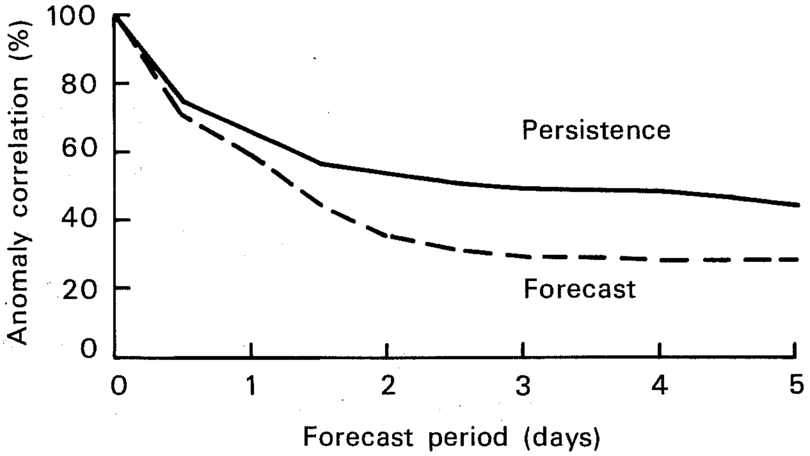

**Fig. 4** **Anomaly correlation of vector wind at 850 mb for the ensemble of July 1980 forecasts for the Indian region [33°N-6°N, 72°E-102°E].**

The deficiencies in the sample forecast discussed above are fairly typical of all the operational forecasts of the SW monsoon during 1980. Time averaged states of ensembles of forecasts show similar errors. Figs. 5 and 6 show the July 1980 mean stream function of the (initialized) analysis and of the 3 day forecast respectively. At 850 mb in the mean forecast there is a systematic reduction of the non divergent mass transfer across the equator and the overall monsoon circulation is changed towards a more zonal flow, with a much greater longitudinal extent than is indicated in the analysed fields. At 200 mb the 3 day forecast mean shows the systematic exaggeration of the easterly jet north of the equator. Much of the cross equatorial upper flow over the Indian Ocean (in both analysis and forecast) is contained in the divergent part of the flow and so is not seen in the diagrams.

It is evident that the forecasts over the SW monsoon region have marked systematic errors which develop quite quickly in the course of a 10-day forecast; the errors discussed above are much more systematic than the model's extratropical systematic errors in that they occur repeatedly in all the operational forecasts for the time of year in question.

Given that the model moves towards its own climatology (or at least departures from the true climatology) so quickly in the tropics it is of interest to compared the model's SW monsoon circulation with that of general circulation models. Gilchrist (1977) has examined the simulation of the Asian summer monsoon by various general circulation models. The models examined simulated the basic circulations with varying degrees of success. The two models most similar to the Centre's model, at least in terms of spatial resolution, are the Meteorological Office's GCM (Saker 1975) and the GFDL model (Hahn and Manabe 1975), both of which used 11 vertical levels. Details of the intensity of the monsoon in the latter simulation are not known to the author; it is notable that the Meteorological Office's 11 layer GCM and the Centre's model have striking similarities in their simulations.

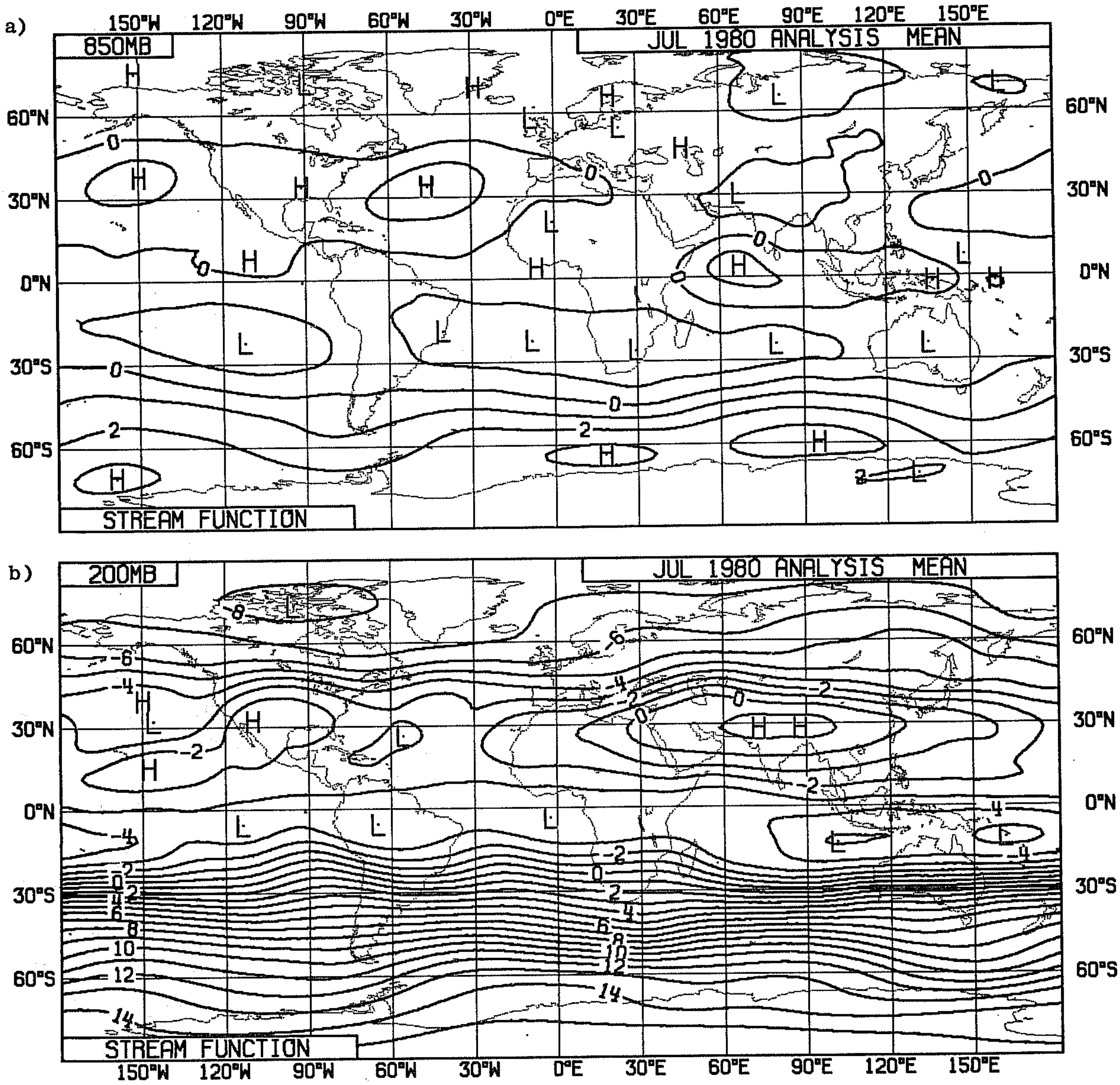

Fig. 5 Stream function of the ensemble of July 1980 analyses for (a) 850 mb (b) 200 mb. Units $10^7$ $m^2$ $s^{-1}$.

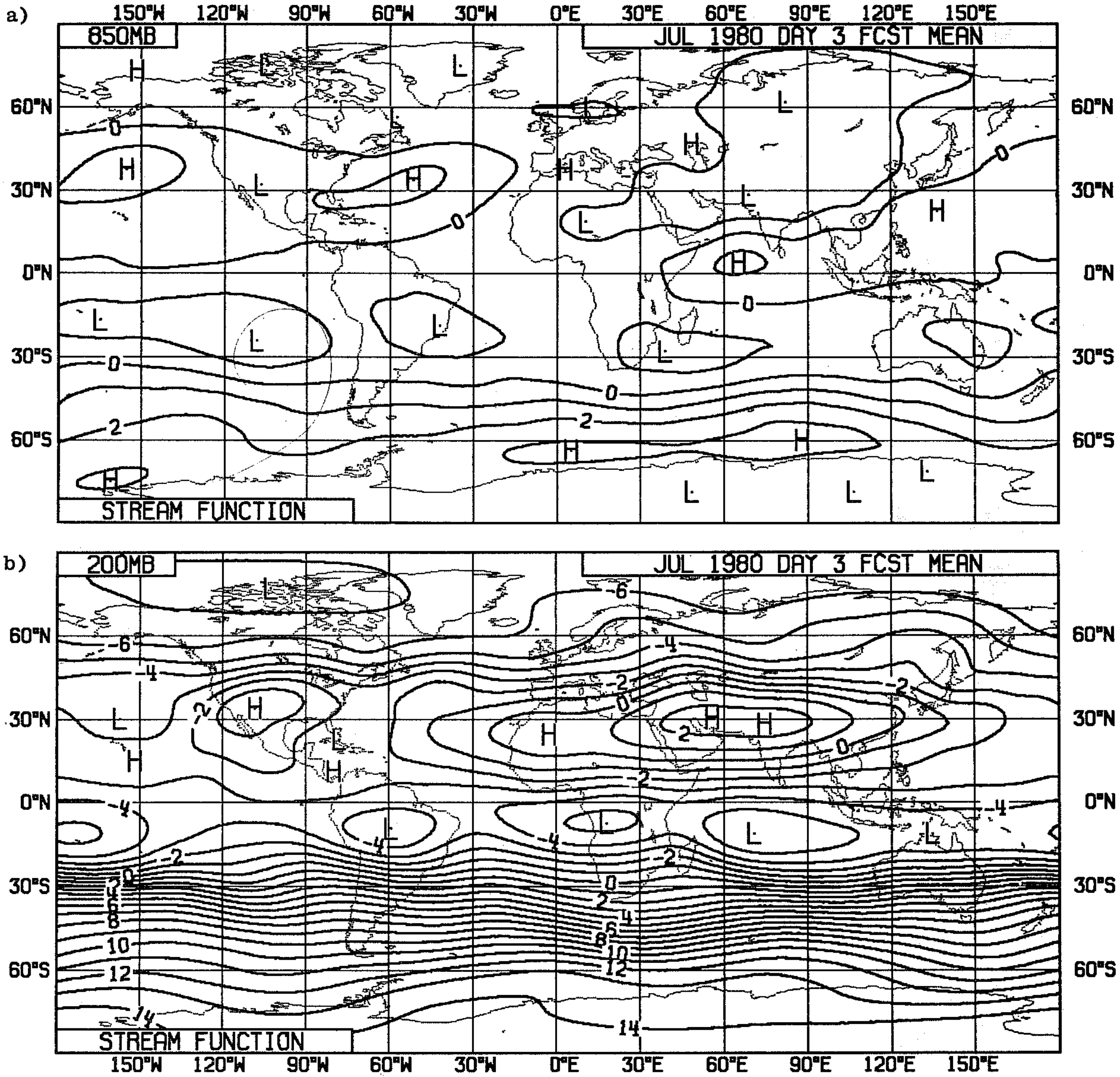

Fig. 6  Stream function of the ensemble of July 1980  D+3 forecasts for (a) 850 mb (b) 200 mb.  Units as in Fig. 5.

Of particular note are the excessively strong winds over south-east Asia at 850 mb and the excessively strong easterlies at the upper level. The sensitivity to convective parameterization of the Met. Office's 11 layer GCM simulation of the SW monsoon has also been noted (Shaw, 1980).

The rainfall produced in the operational forecasts reflects the deficiencies noted in the atmospheric flow. Fig. 7 shows the 24 hour convective rainfall total up to D+3 in the forecast already discussed. By far the greater part of the model's tropical rainfall is convective and as such tends to be discontinuous in its spatial and temporal distribution. Consequently not all the features of the rainfall field shown are typical, but some are. Perhaps the most general point of note is that the main area of rainfall near India is arranged in an almost zonal belt near 20°N, with no sign of the rainfall belt that occurs in reality down the length of the Western Ghats. Earlier periods in the forecast shows more meridional orientation of the rainfall belt over the east Arabian Sea but as the monsoon flow is shifted northwards and becomes more zonal, so this change is evident in the rainfall. To the west, over the Horn of Africa and the west Arabian Sea, the lack of forecast rainfall accords well with observation. However erroneous and quite heavy rainfall is predicted over Arabia and Northern Ethiopia; some of this deficiency is related to the specification of initial soil water content and is discussed later.

### 2.2 Sensitivity to topography

Orography plays an important role in the SW monsoon circulation. Of particular note are the Himalayas, the East Africa mountains, the hills of Burma and NE India, the Western Ghats of India, and the Zagros Mountains of Iran (GARP Publication Series No.18,1976). Fig. 8 shows the orography used in the operational model during 1980. It is seen to be unduly smooth. The East Africa highlands have a maximum height less than 1800 m; the Western

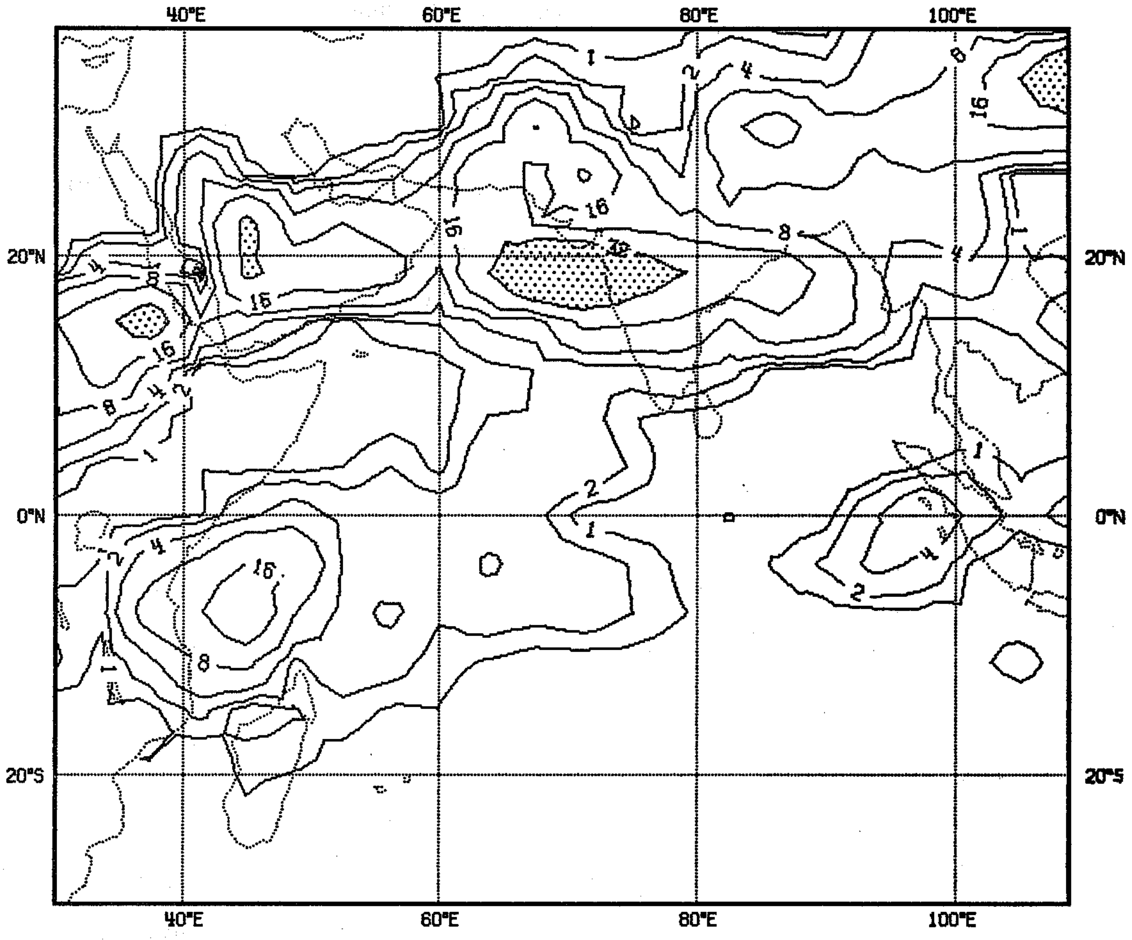

Fig. 7 Forecast rainfall in the 24 hrs up to D+3, started from analysis at 12 GMT 30 June 1980. Units: mm. Areas of rainfall in excess of 32 mm shaded (some spatial averaging has been applied to improve legibility).

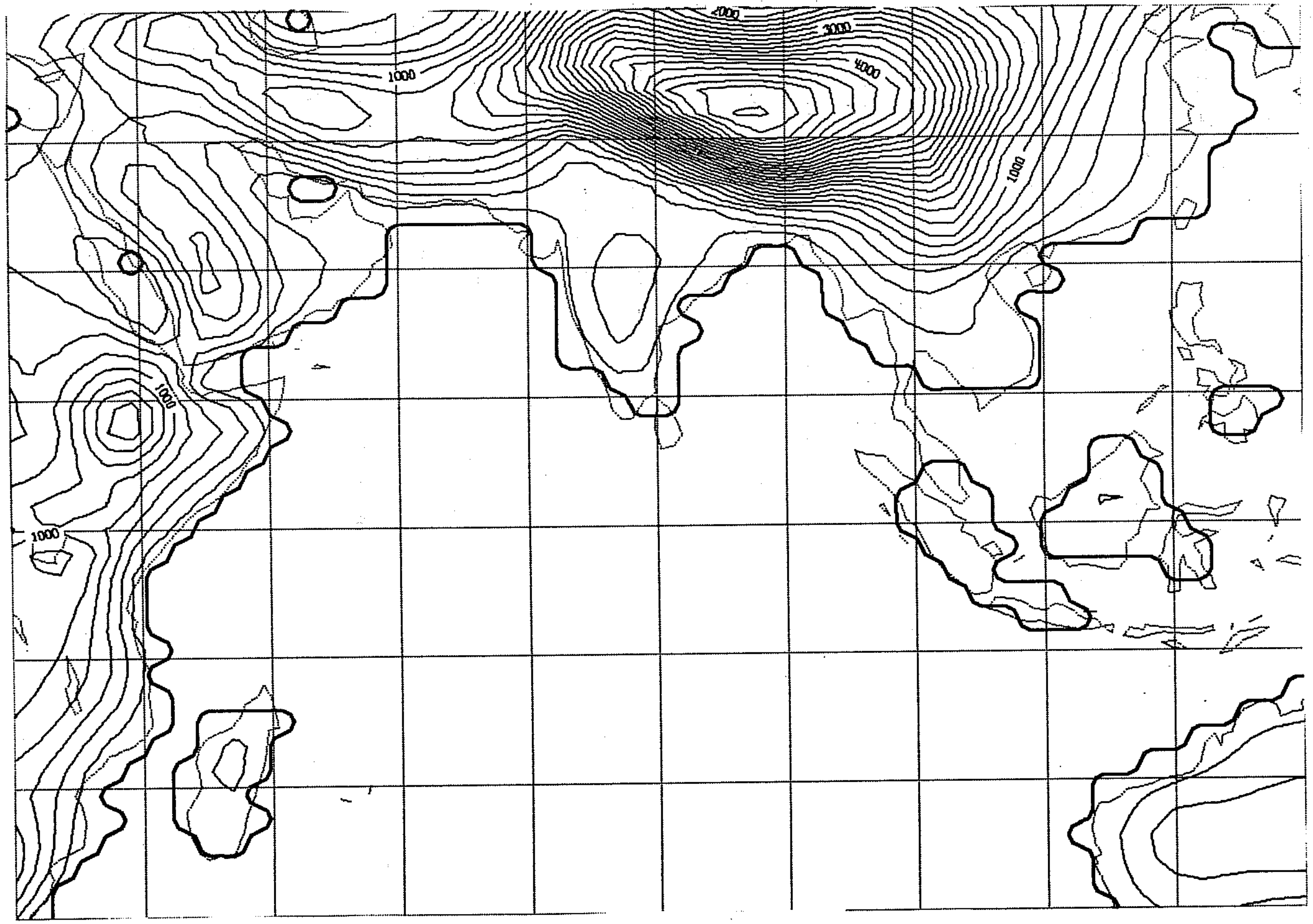

Fig. 8 Orography used in operational model during 1980. Units: metres. Contour interval 200 m. The model's land/sea boundaries are depicted by the thick black line.

Ghats, which should be evident down the west side of the Indian peninsula, are not discernible as a separate range and the Himalayas, instead of being a large plateau with a very strong gradient on its south side is represented as a much smoother obstacle to the flow. The figure also shows the land/sea boundary of the model and the true representation of the coastline. The Red Sea, Horn of Africa, the Persian Gulf and the Indian peninsula itself are all poorly approximated, so that the surface exchange processes of the model will be at best imprecise in these regions. The importance of the East Africa mountains as a western barrier to the low level flow has been demonstrated by Krishnamurti et al (1976). Using a simplified model they produced a reasonable representation of the Somali jet, given (a) a prescribed large scale forcing (i.e.SE trades) as an eastern boundary inflow condition (b) a coriolis force to provide the eastward turning of the air as it moves northwards away from the equator (c) the presence of the East African mountains to act as a western barrier to the low level flow. In the absence of the latter the flow is not deflected northward as it impinges on the African coast, but continues its north westerly progression over Africa. Noting this effect, and the deficiencies in the operational model's orography discussed above, it is to be expected that an improved representation of orography should yield a better representation of the Somali jet. Improved representations of the topography and coastlines in the Centre's N48 model have recently been produced and evaluated by Tibaldi and Geleyn (1981).

A sequence of data assimilations to 12Z 5.6.80 was performed, followed by a 10-day forecast, using the orography and land/sea boundary shown in Fig. 9. (This topography is very similar, but not identical, to the version introduced into operations on 1 April 1981). Comparison of Figs. 9 and 8 shows that all the deficiencies discussed above have been reduced. In particular the longitudinal orographic gradient in equatorial East Africa has been increased by a factor of 2 and the mountains to the north (around 10N 40E) have been increased in parts by over 600 metres. The forecast using

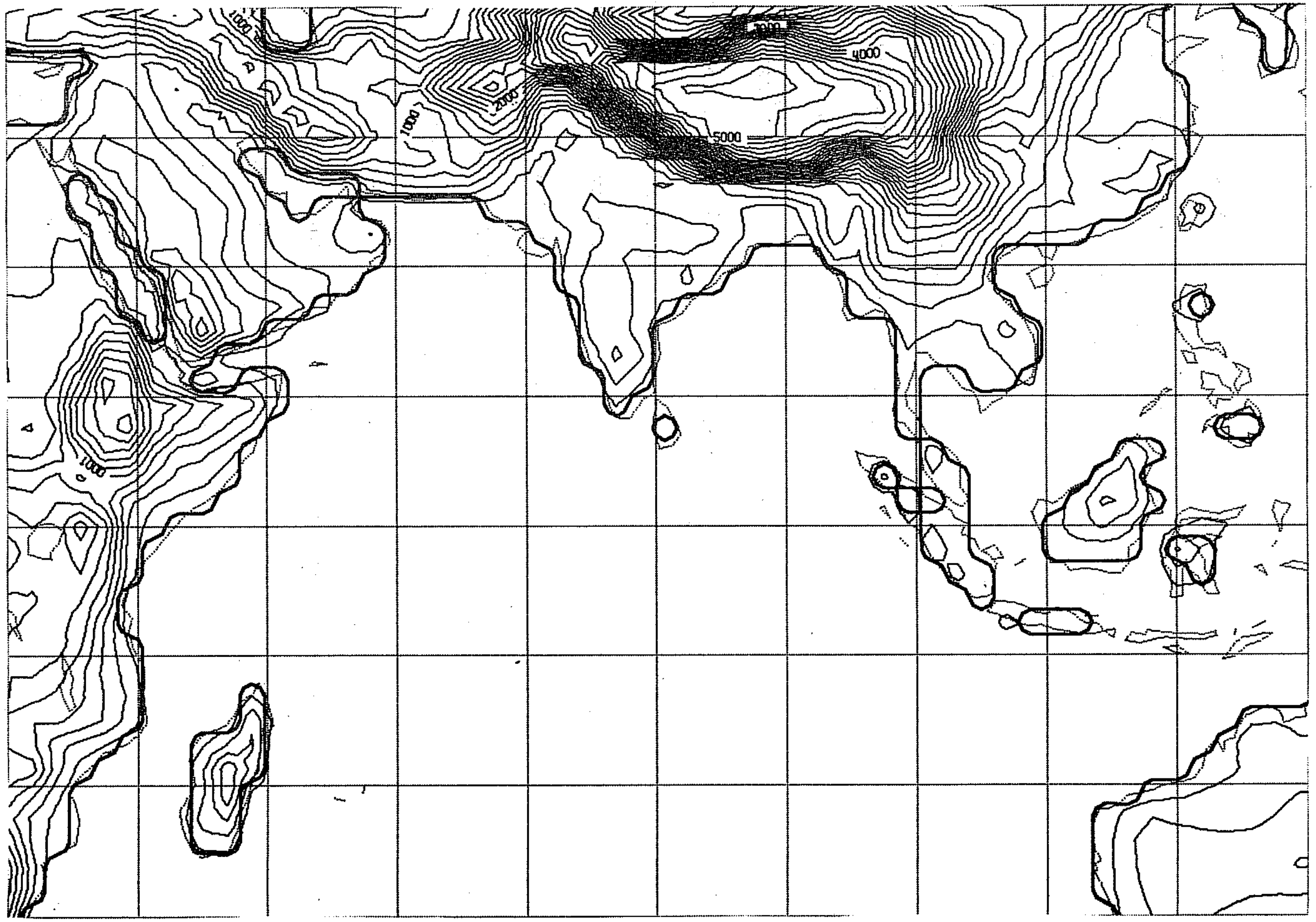

Fig. 9 Revised orography, used in test forecast. Units etc. as in Fig. 8.

this revised orography does indeed show an improvement; Figs. 10 and 11 show the D+2 forecasts at 850 mb using the old and new topography representations respectively.

The large scale flow in the southern hemisphere is not greatly different in the two forecasts at 48 hours. There are however considerable differences over Africa and the Arabian Sea. The 'old topography' forecast has the flow from the southern hemisphere penetrating further inland, resulting in a southerly flow north of Lake Victoria. Further north this flow links up with the erroneous WSW flow from Central Africa which travels round the northern flank of the (poorly represented) Ethiopian Highlands, giving a maximum wind not over the Horn of Africa or Arabian Sea but over Aden. The 'new topography' forecast preserves the identity of the East African circulation more faithfully, the mainstream of the flow being constrained to the east of the orographic barrier. The flow off the Horn of Africa is both stronger and better positioned as a result. The forecast with the new topography also shows marked differences to the other forecast where the flow approaches the Indian peninsula, and further east, the coast of Burma. The excessively strong circulations in the new topography forecast in both regions are associated with vigorous convective activity and are possibly a consequence of changes in surface conditions associated with changes in the land/sea boundary (rather than orography) made in this particular experiment. They are thought not to be typical of forecasts using the new topography.

### 2.3 Sensitivity to initial soil water content (SWC)

Currently in the Centre's operational forecasts the SWC of the initial state of each forecast is a monthly climatology field. During the 10-day forecast the SWC is fully interactive with the model. The climatological specification during operations in the first part of 1980 was derived from the time mean states of an independent general circulation model integration,

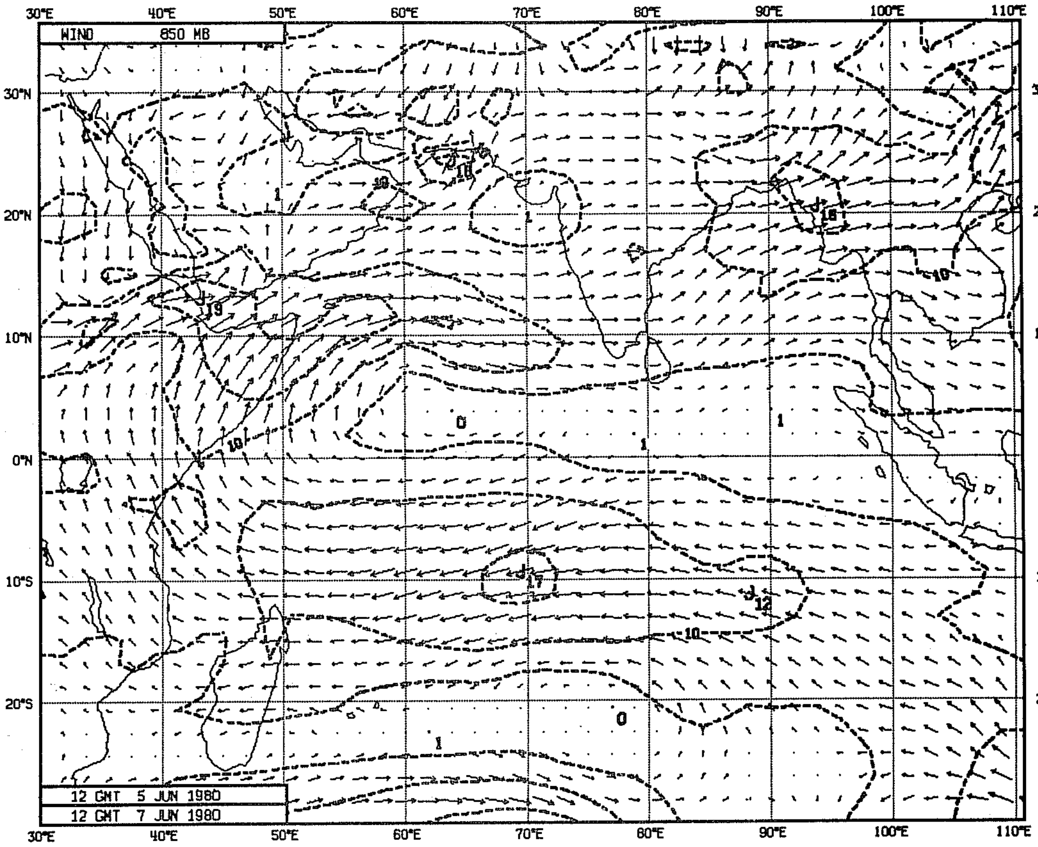

Fig. 10 D+2 forecast wind field, at 850 mb, from 12 GMT 5 June 1980 using operational topography. Units as in Fig. 1.

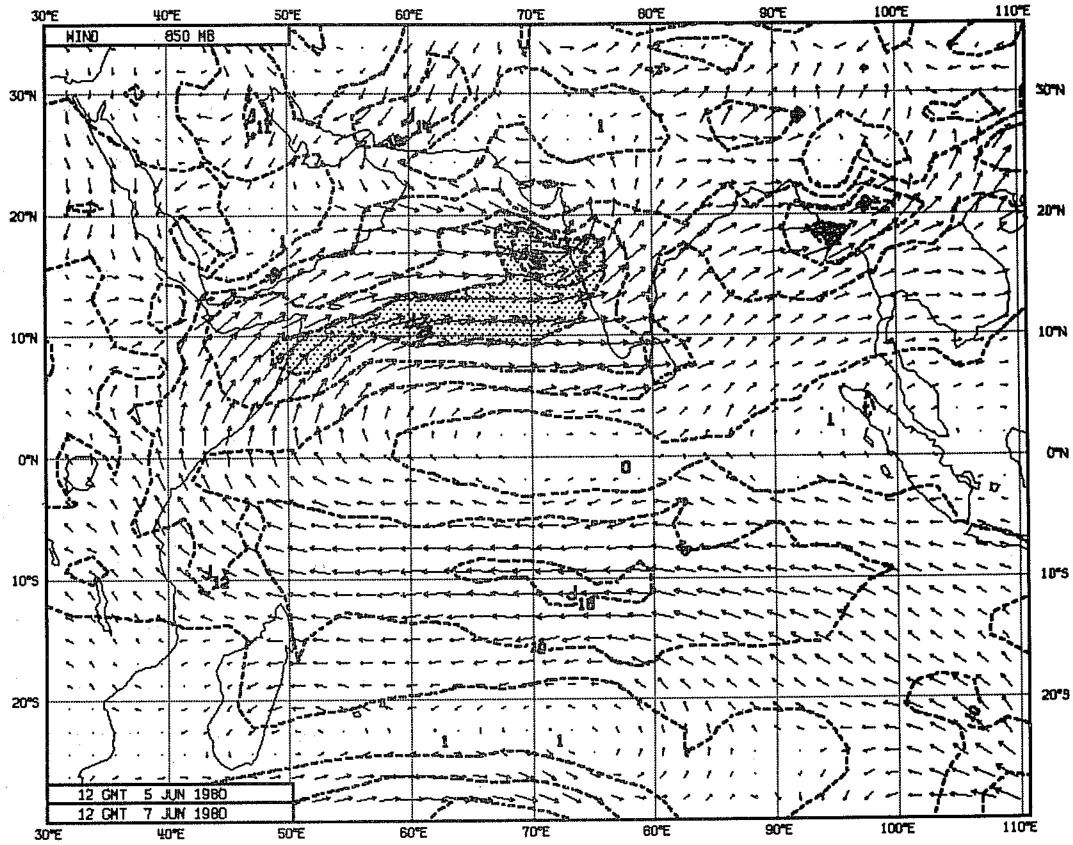

Fig. 11 As Fig. 10, but with revised topography.

with a spatial interpolation to the grid of the Centre's model. The resulting fields, while giving broadly correct discrimination of major deserts and tropical rainforests, are not satisfactory when examined in detail. A case in point is the SWC over Arabia. Fig. 12 shows the SWC for June used operationally in 1980, and derived as described above. The high SWC over Southern Arabia is incorrect; its most obvious (and adverse) impact on the operational forecasts was to produce intense convective activity over the region, producing incorrect and extremely high rainfall rates and temperature errors which were evident even at 50 mb. To eliminate this obvious error a new set of monthly SWC climatologies was derived, based not on the results of a model integration, but on climatological rainfall data and simple empirical relationships for evaporation. The new SWC climatology for June is shown in Fig. 13. This new field is seen to be more reasonable in terms of its spatial continuity, and in its representation of the dry areas of the Sahara, Arabia and the Horn of Africa.

An experiment based on this new climatology has been made; 5 cycles of assimilation (incorporating the new climatology each 6 hours) ending at 12Z 18 June 1980, followed by a 10 day forecast, were performed and the results compared with a forecast using the old climatology. In both forecasts the SWC was initially set at its appropriate climatology, thereafter it interacts with the forecast. As expected the localised problems over Arabia were greatly reduced; the change in the initial SWC also had an impact on some of the more regional aspects of the circulation. Fig. 14 and 15 show the 850 mb wind forecasts at D+8 for the old SWC and new SWC climatologies respectively. South of the equator the two forecasts are similar, but over the Arabian Sea there are considerable differences. The new SWC climatology leads to the low level jet being displaced towards the equator, the strong winds being in a narrower band and of reduced intensity. All of these three changes are improvements. In the 'old SWC' forecast the broadness and strength of the flow over the Arabian Sea stems partly from the incorrect inflow from the

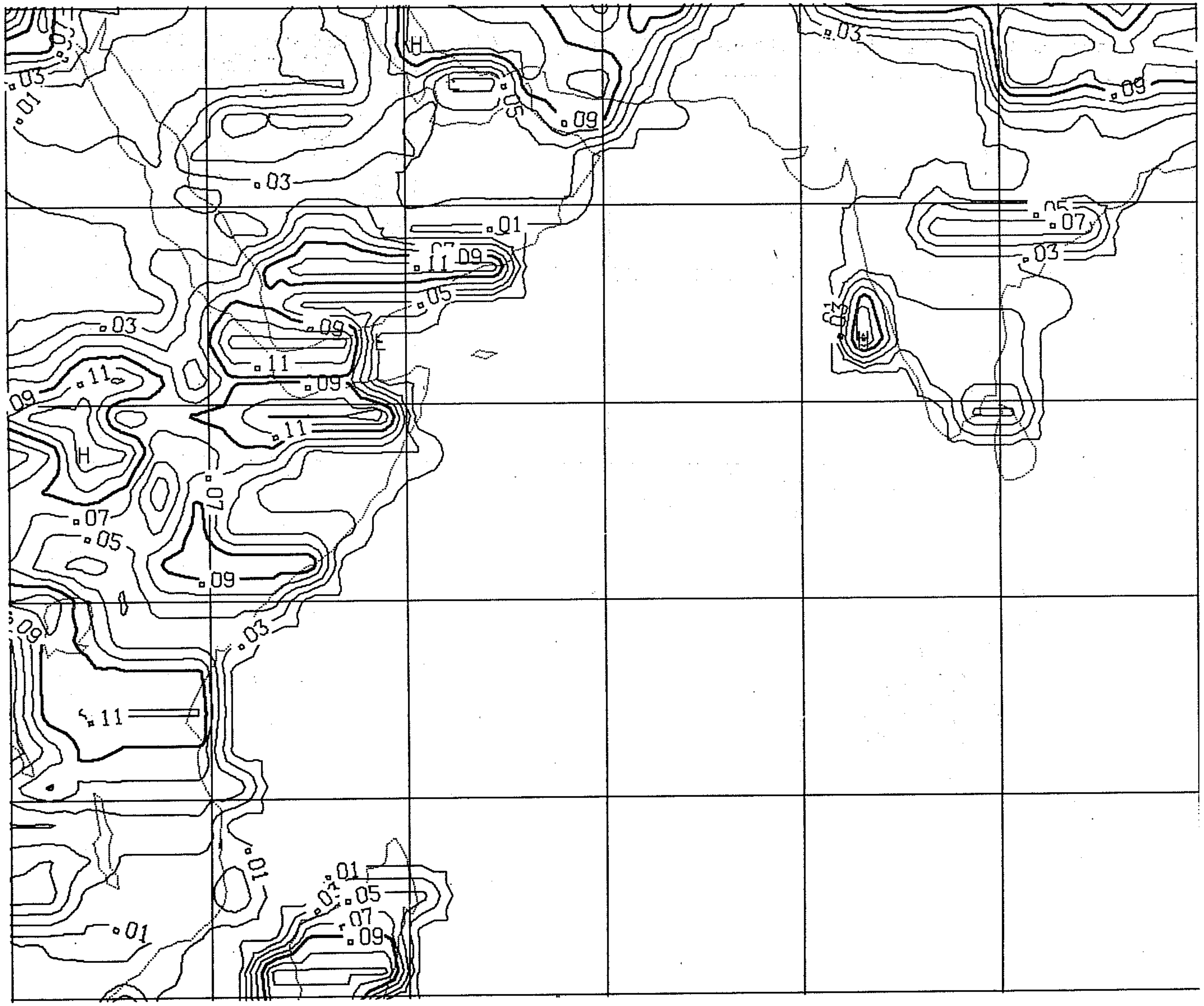

Fig. 12 SWC climatology used in operations during June 1980. Units: metres of water. Contour interval 0.02 m.

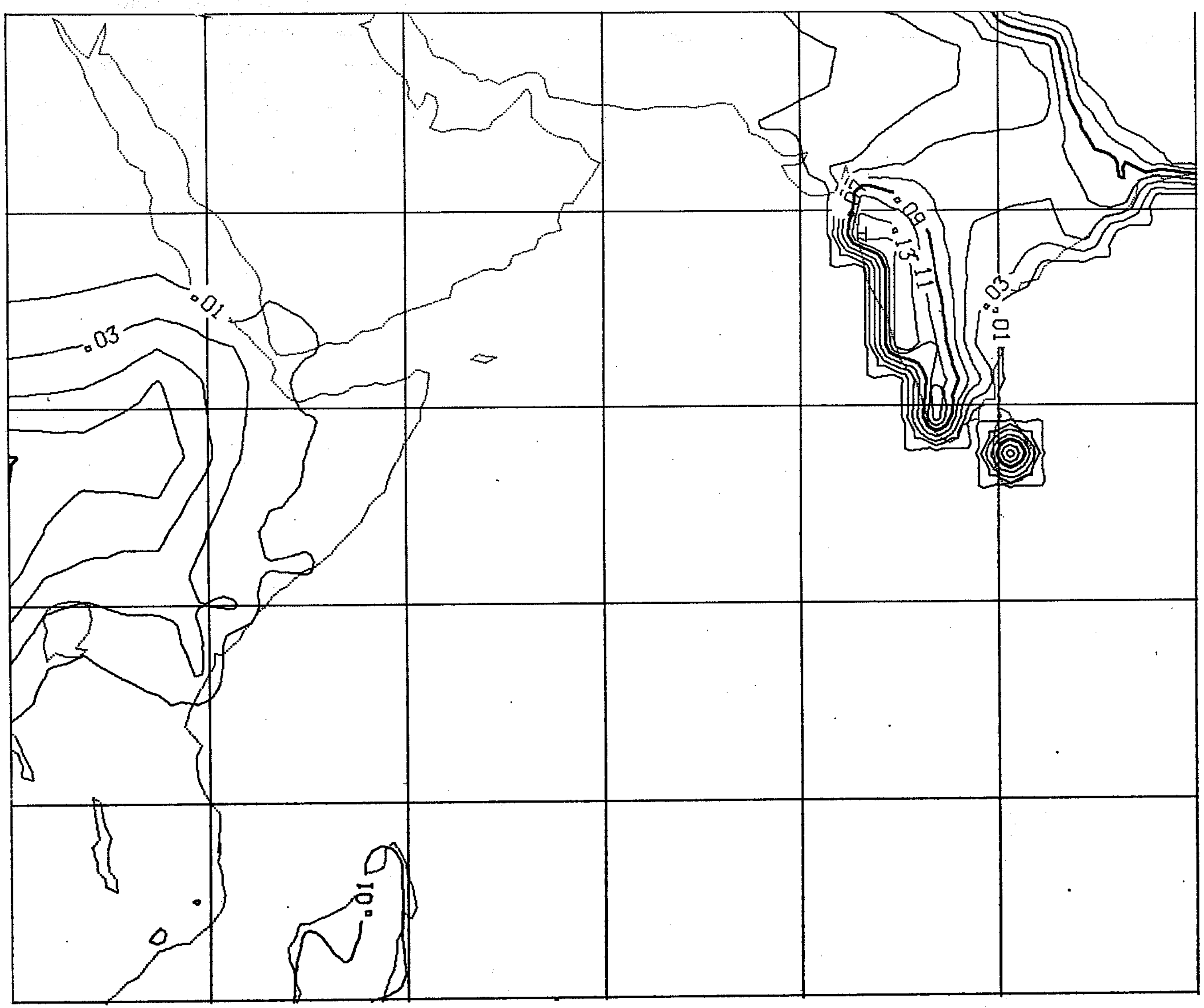

Fig. 13  Revised SWC climatology, used in test forecast. Units etc. as in Fig. 12.

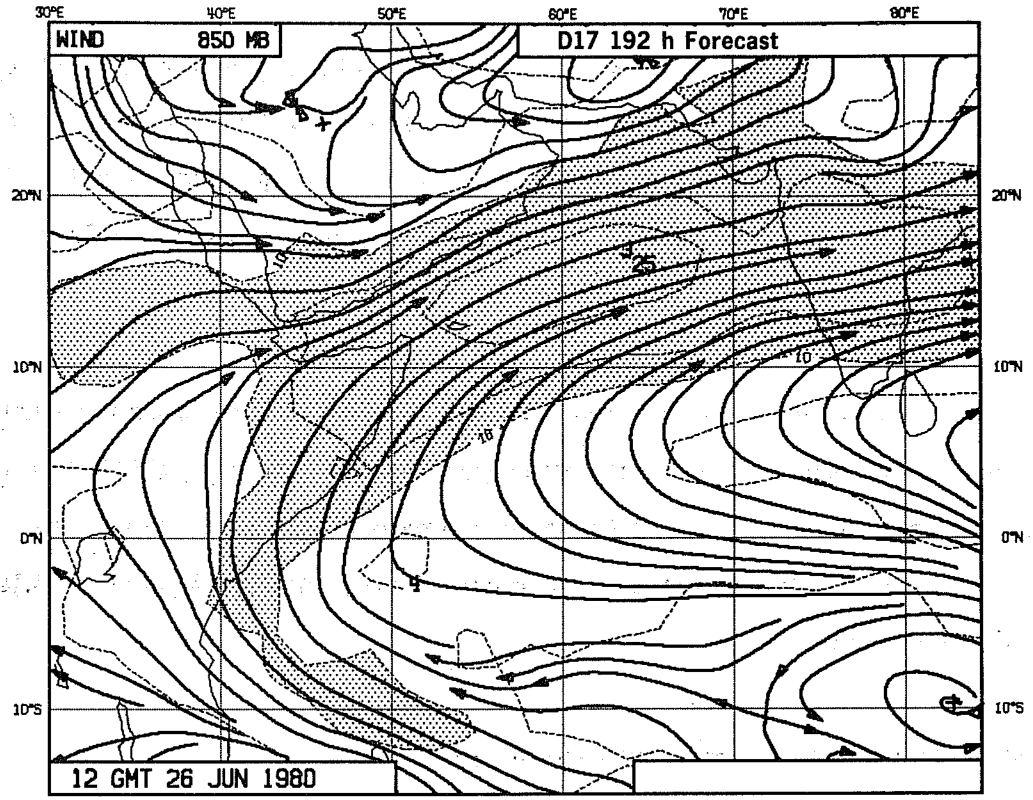

Fig. 14 D+8 forecast wind field, at 850 mb, from 12 GMT 18 June using operational SWC climatology. Units as in Fig. 1. Winds in excess of 10 m $sec^{-1}$ are shaded.

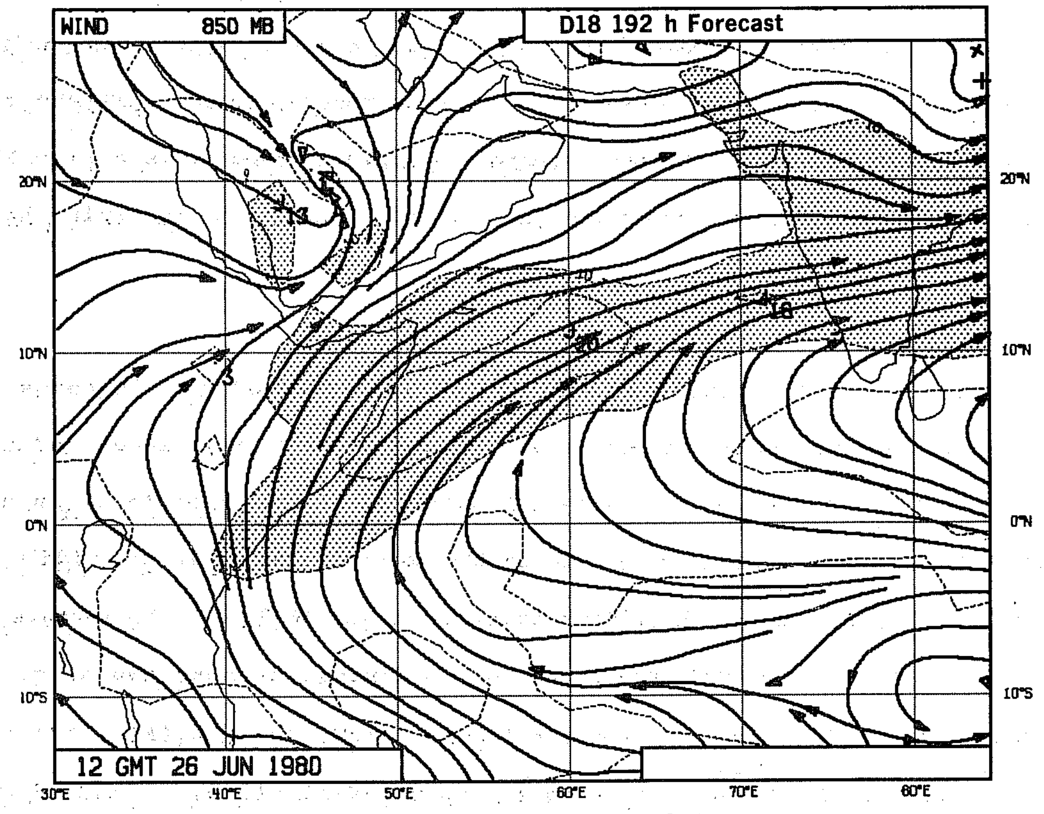

Fig. 15 As Fig. 14, but with revised SWC climatology.

Sudan ( ~ 10N 30E) which the new climatology field has moderated but not eliminated. In this particular experiment at least, the response in the forecast to the changed SWC climatology takes several days to establish itself, whereas the impact of the topography changes discussed earlier are evident from the early stages of the forecast.

The newly derived SWC climatologies were not introduced into operations until 19 August 1980, rather late in the SW monsoon season; the availability of the revised climatologies for the 1981 monsoon provides some encouragement, and there is the prospect of further refinement of these climatologies yielding further improvements.

### 2.4 Transient disturbances in the SW monsoon

During the SW monsoon most of the rainfall over NE India falls during the active periods of the monsoon trough, often in association with Bay of Bengal depressions. These features typically develop over the northern part of the Bay ( 20N 90E), having a scale ~ 500 km in their formative stage. As surface pressure features the central pressures are only moderately low ( 990-995 mb) and they do not develop hurricane intensity. Typical movement is a slow WNW movement from the Bay over northern India, though examples of recurving have been noted.

Although not the most extreme form of tropical disturbance in terms of circulation, the rainfall associated with such systems is very large and the ability to predict such features is of importance. A good example of such a disturbance during 1980 occurred late in the monsoon season, in the middle of September. Fig. 16 shows the 850 mb analysis at 12Z 16.9.80. The feature is already evident over the NW area of the Bay. During the next two days the depression gradually moved NW over the land; at 12Z, 18.9.80 (Fig. 17) the low is centred at 23N 83E. Daily totals of rainfall of 20, 22 and 26 cms

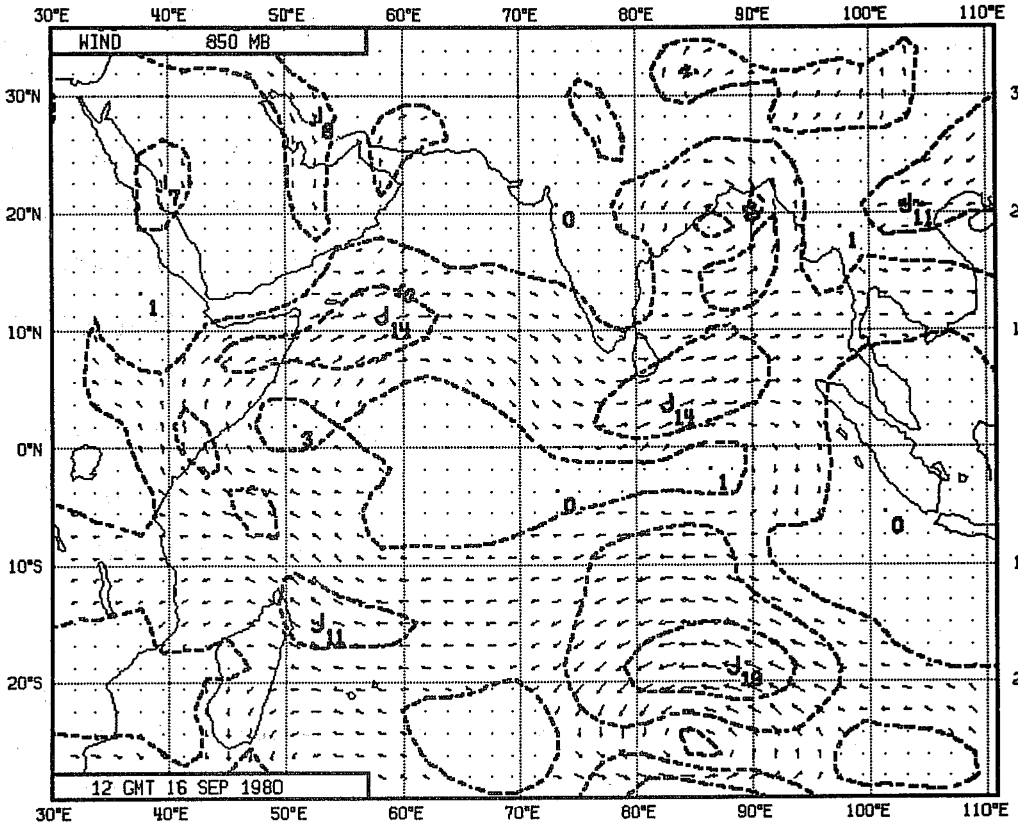

Fig. 16 Analysed wind field, at 850 mb, for 12 GMT 16 September 1980. Units etc. as in Fig. 1.

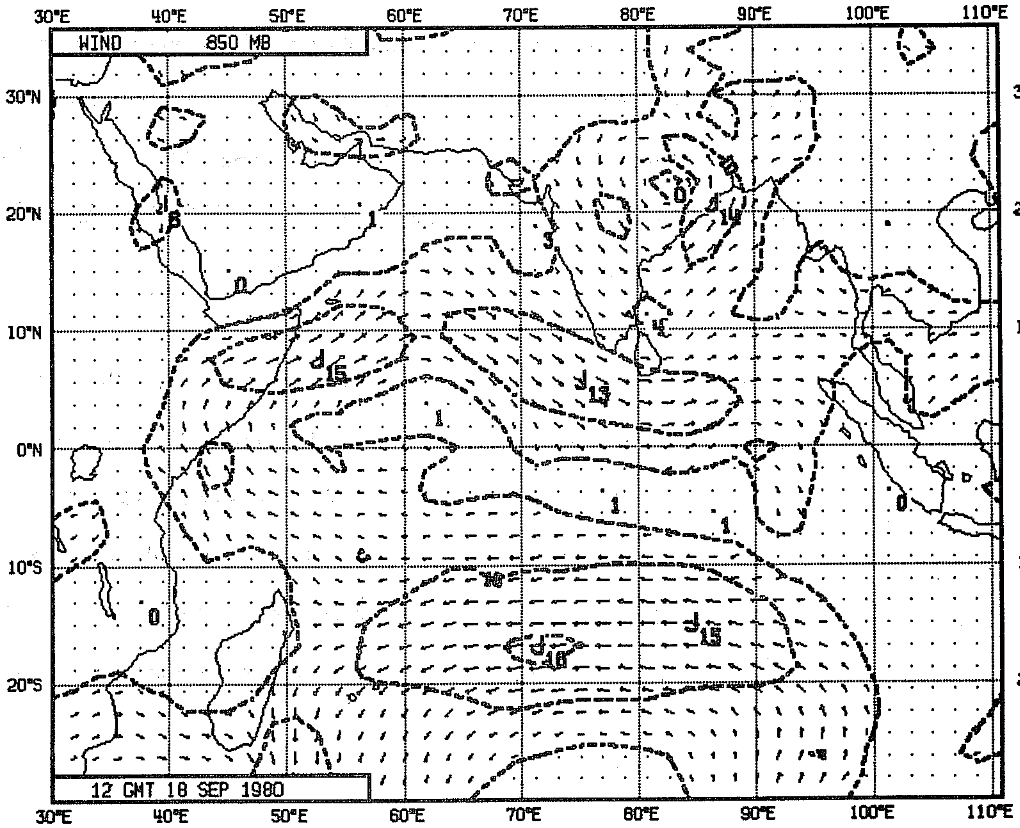

Fig. 17 Analysed wind field, at 850 mb, for 12 GMT 18 September 1980. Units as in Fig. 1.

were reported at three separate stations; around this time there was severe flooding of large areas. The data coverage over India is sufficient to identify the feature at this later time with confidence and so provide a good verification for a forecast from 12Z 16.9.80. Such a D+2 forecast is shown in Fig. 18. The predicted movement of the feature is very good; even the asymmetry of the circulation, with the strongest winds on the east side of the low, is correct. Elsewhere the forecast shows some of the same weaknesses discussed earlier - a failure to maintain a sufficiently strong cross equatorial flow east of Africa, with much of the inflow over the Arabian Sea originating in the northern, rather than the southern, hemisphere.

The forecast only captured well the movement of the depression once it had been resolved in the analysis; forecasts from initial states proceeding 16.9.80 were less successful. The reason for this may lie in some deficiency in the initial states (including specification of surface conditions) or in the forecast model, or indeed in the more general question of predictability. The ability of the model to predict the movement of these depressions is similar to that noted for another model having similar spatial resolution (Shaw, 1977). More detailed study of the representation of these transient disturbances, in both analyses and forecasts, is desirable.

Another transient phase of the SW monsoon which is of crucial importance is of course the actual onset; however any predictive skill that the model may have in this regard is difficult to detect because of the large systematic errors found in all the forecasts and discussed earlier. Detailed studies of the monsoon onset for the FGGE year, when the onset was well identified observationally and quite dramatic in its intensity, are planned at the Centre.

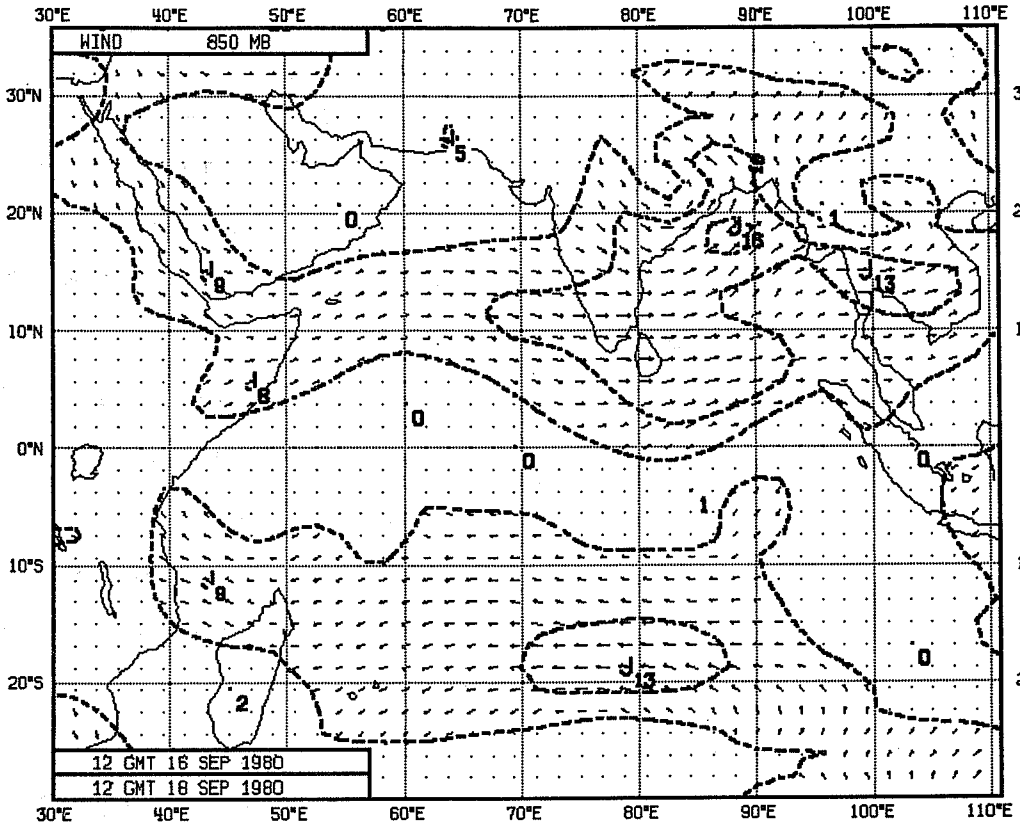

Fig. 18 D+2 forecast wind field, at 850 mb, from 12 GMT 16 September 1980. Units as in Fig. 1.

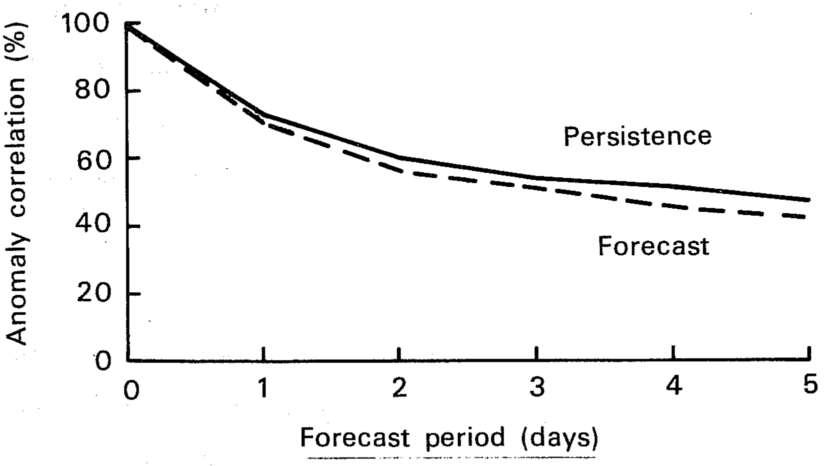

Fig. 19 Anomaly correlation of vector wind at 850 mb for the ensemble of January 1981 forecasts for the Indonesian region [18°N-12°S, 102°E-132°E].

## 3. THE NE MONSOON

The significance of the NE monsoon as a major feature of the global circulation has been shown by Krishnamurti et al (1973). The Indonesian region during December and January is the centre of a very intense upper tropospheric outflow region which not only feeds the east/west and Walker circulations but is also the major component of the zonally averaged Hadley circulation. The extent to which this large scale divergent flow is represented in the Centre's assimilations and forecasts is discussed by Hollingsworth and Cats (Workshop Paper). Associated with this upper tropospheric outflow there is marked convective activity with monthly rainfall totals averaging between 25 and 50 cms The subtropical jet is at its most intense in this region and at this time of year.

Some transient features are also of note, particularly the northerly outbursts of cold air from the Asian continent which are a common feature of the low level flow. The west Pacific region is the area where a great many tropical cyclones develop, though their incidence during January and February is not very common. Several mountain ranges are thought to influence the NE monsoon flow, but in a more localised way than is found with the SW monsoon (GARP Publication Series No.18,1976). With the current resolution of global models it is difficult to resolve these features adequately and the delineation of land/sea boundaries for the west Pacific region is very approximate (see for example, Fig. 9).

The operational analyses produced during Dec '80/Jan'81 are based on a relatively good data network, at least near the surface. The land based network over SE Asia is better than some other parts of the tropics and the continued availability of the cloud drift winds from the HIMAWARI satellite is very useful. The forecasts produced from these analyses do not have such obvious systematic errors as were found in the SW monsoon. The December monthly mean forecast streamfunction at D+3 at 850 mb and at D+5 at 150 mb are shown in the Workshop Paper of Hollingsworth and Cats (their Fig. 18 and 21 respectively).

While both show serious deficiencies elsewhere in the tropics, in the Indonesian region the 850 mb forecasts are free of serious bias and as the authors note, the systematic errors at 150 mb only become evident after several days of the forecast. By D+5 the model is exaggerating the upper level equatorial easterly flow. Objective verification scores for the month of January 1981 for the 850 mb wind are shown in Fig. 19. As with the SW monsoon region, the forecast is seen to be not as good as persistence, though the scores are much more equal than those obtained for the SW monsoon region. These objective scores confirm the subjective impression gained from examination of individual forecasts. However there are some synoptic sequences which the model predicts with some success. One of the first examples of a cold monsoon burst found in the 1980/81 season occurred at the end of November 1980. The effect on the lower tropospheric winds is evident in Figs. 20 and 21 which show the 850 mb winds at the beginning and end of the period. On the 2 December, a vortex has been established at 27N 115E with the strong flow on its northern side carrying cold air out from the continent to produce a strong north westerly flow over the ocean, some of which links into the NNE'ly flow over the south China Sea. (The circulation shown in Fig. 21 is less than the circulation analysed, because of a failure to depict winds <5 msec$^{-1}$.In the analysis, the formation of the vortex is clear).A general but rather modest increase in the 850 mb circulation is seen. The D+3 forecast verifying at 12Z 2.12.80 is shown in Fig. 22. The development of the anticyclonic vortex is quite well predicted, at 30 N 112E, with the strong flow round its northern and eastern sides. This flow developes as a strong NEly over the ocean, carrying air all the way down to the equator and even into the southern hemisphere. The monsoon burst has been exaggerated; while the development at 30°N is successful the linkage

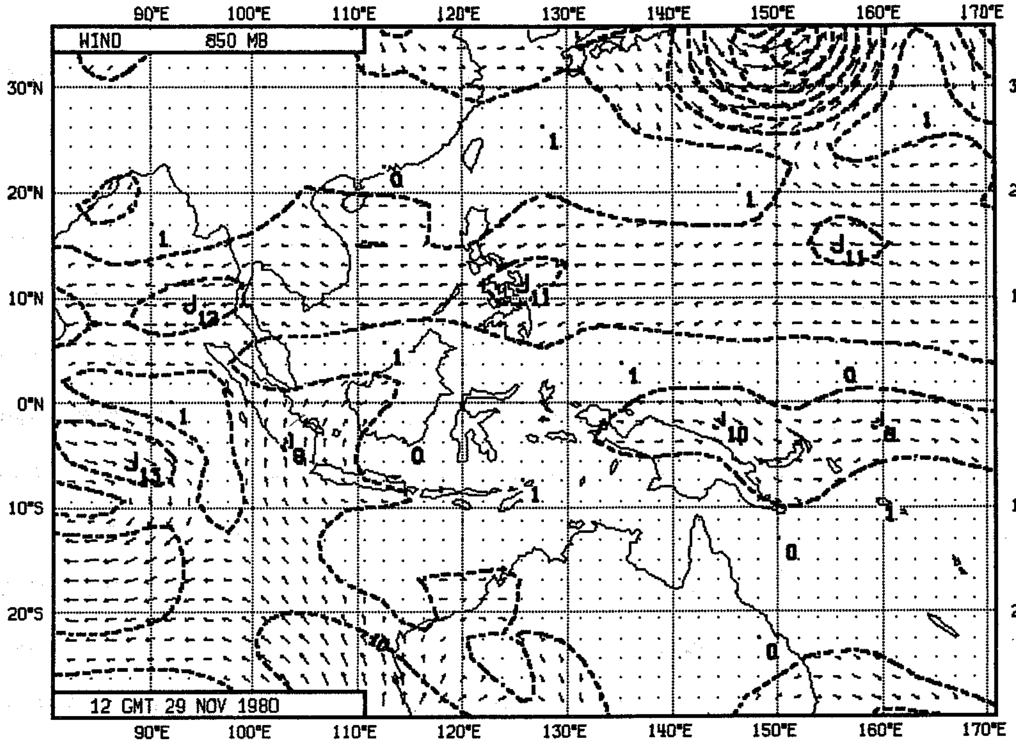

Fig. 20 Analysed wind field, at 850 mb, for 12 GMT 29 November 1980. Units as in Fig. 1.

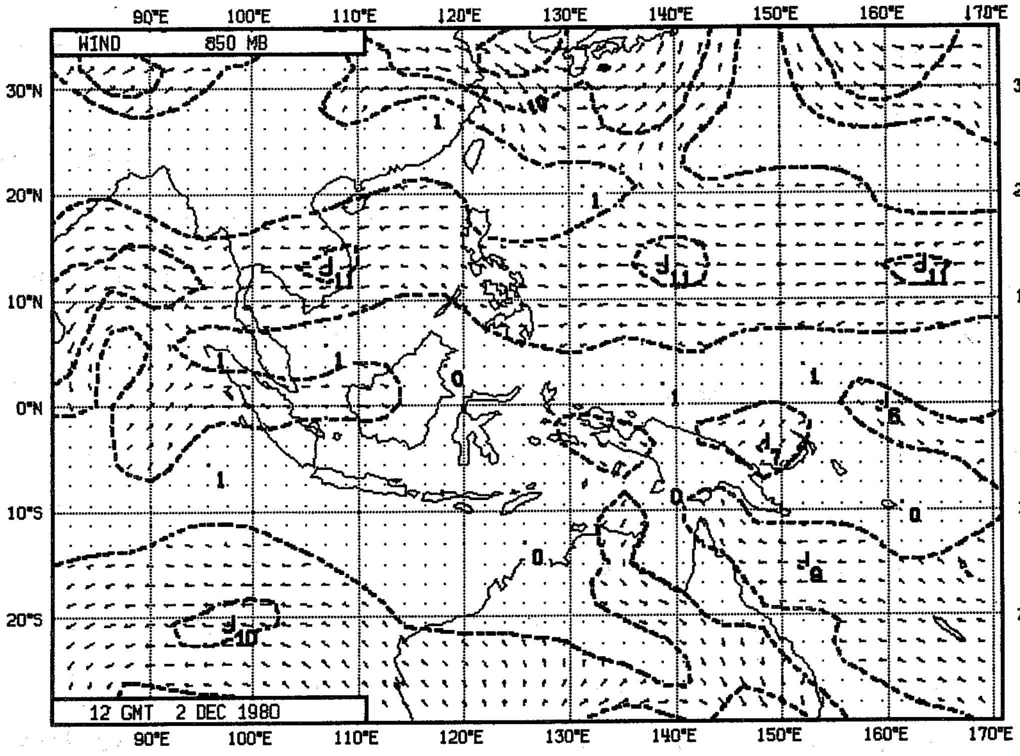

Fig. 21 As Fig. 20, for 12 GMT 2 December 1980.

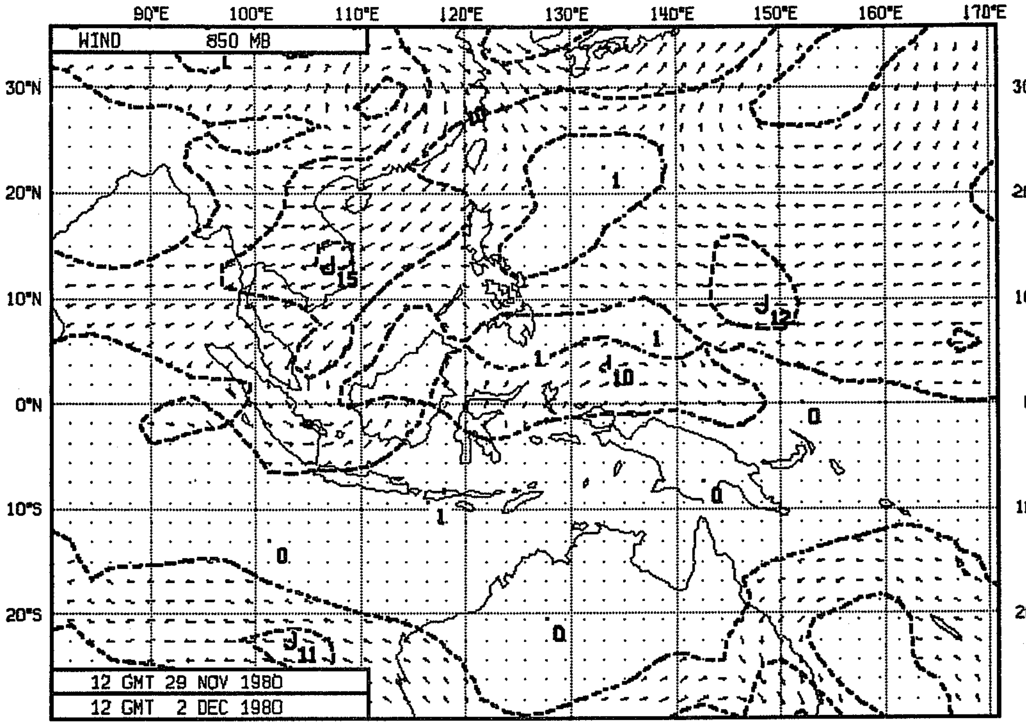

Fig. 22 D+3 forecast wind field, at 850 mb, from 12 GMT 29 November 1980. Units as in Fig. 1.

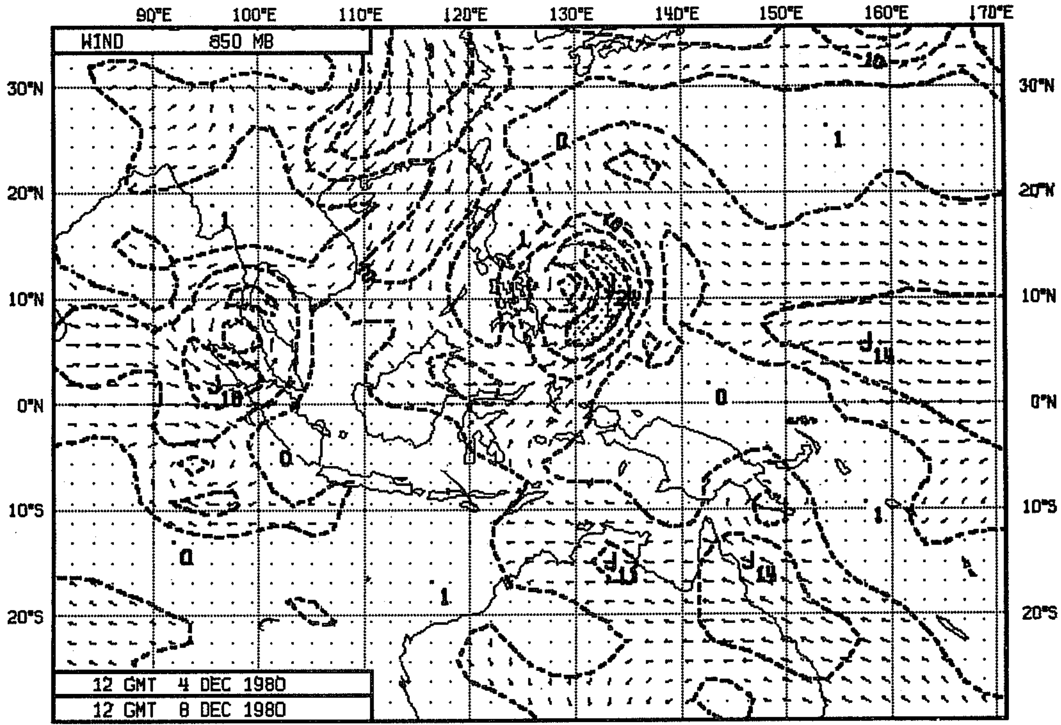

Fig. 23 D+4 forecast wind field, at 850 mb, from 12 GMT 4 December 1980. Units as in Fig. 1.

through to the equatorial zone is excessive. The same deficiency in the model's forecasts is found in other examples of NE monsoon bursts.

Another example of transient developments in the forecast model, and one which probably makes a considerable contribution to the poor objective scores, is the generation of intense 'grid point' storms. As already noted, during December and January tropical cyclones occur rather infrequently in the NE monsoon region. However in the prediction model intense cyclonic circulations are commonplace. Fig. 23 shows a D+4 forecast at 850 mb from 12Z 4 Dec 1980. The forecast is not atypical in terms of its development of these vortices. Two quite major cyclones are evident at 10N 130E and at 6N 97E. Less vigorous vortices are evident elsewhere, including the southern hemisphere. None of these developments are confirmed in the verifying analysis (not shown). Although commonplace, the vortices are not persistent in their location from one forecast to another; they are obviously sensitive to the details of the initial atmospheric state. Their occurrence is discussed more fully by Bengtsson, Bottger and Kanamitsu (1981). The rainfall predictions in the NE monsoon are frequently dominated by these vortices. Fig. 24 shows the 24 hr rainfall forecast up to D+4, to be related to Fig. 23. Given that the development of the vortices themselves are not correct, further discussion of such a rainfall chart serves little purpose.

## 4. CONCLUDING REMARKS

The model's predictions in the SW and NE monsoon areas are seen to have several weaknesses. However these assessments have been made on operational sequences with some known deficiencies. Some of these deficiencies will be removed before the forthcoming monsoon seasons. Other, more general, improvements are planned in both the data assimilation and forecast model. We can be confident that the quality of our operational predictions of the SW and NE monsoons will improve.

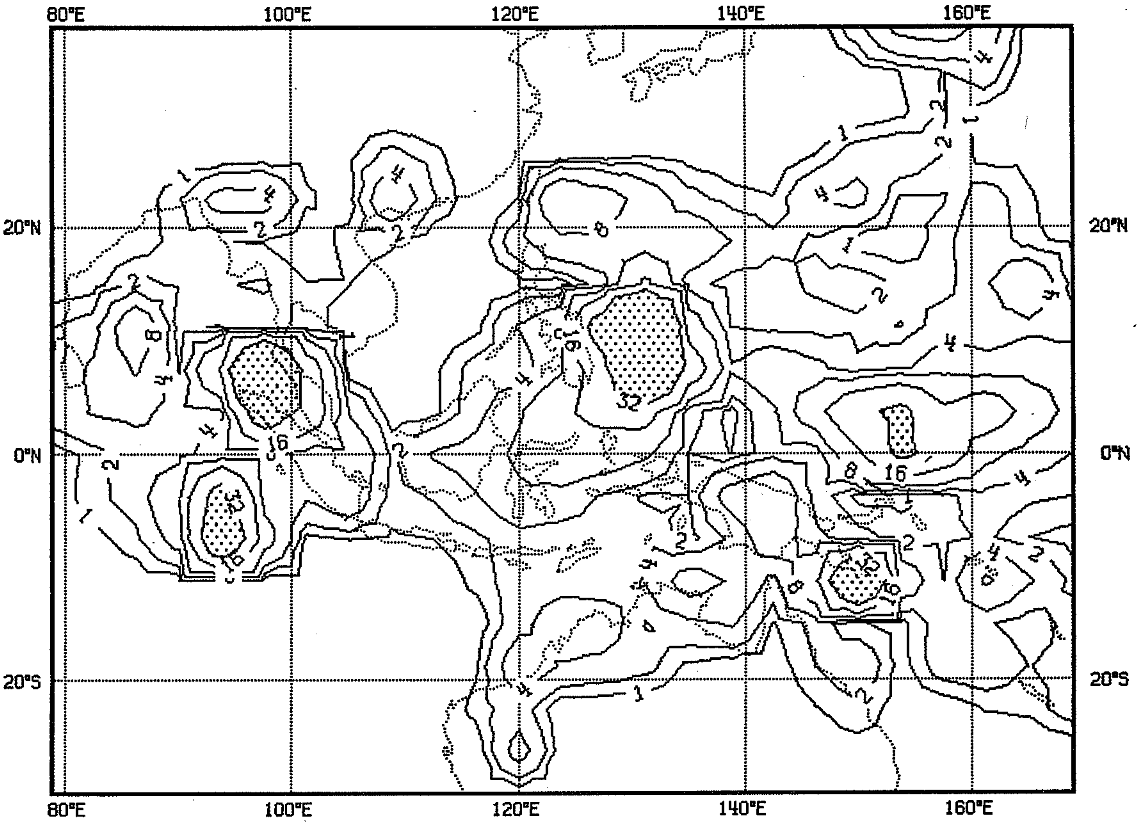

Fig. 24 Forecast rainfall in the 24 hrs up to D+4, started from analysis at 12 GMT 4 December 1980. Units: mm. Areas of rainfall in excess of 32 mm shaded. (Some spatial averaging has been applied to improve legibility).

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