TROPICAL FORECASTS FROM THE UK OPERATIONAL GLOBAL MODEL

C. D. Hall
Meteorological Office
Bracknell, UK

Summary: The performance of the UK operational global model in tropical regions is assessed. Verification of T+72 forecasts is presented, and three case studies illustrate the accuracy of forecasts of various synoptic-scale disturbances.

1. INTRODUCTION

Since the first numerical models were developed in the 1950s and 1960s major advances have been made in numerical weather prediction in the extra-tropical regions of the northern hemisphere. Early models covered a limited domain and it is only during the last ten years or so that global models have been run operationally, making available regular forecasts for the tropics. Several centres run global models and the products from three of them, Washington, Bracknell and ECMWF, are routinely distributed in grid-point format on the Global Telecommunication System and are used widely for operational forecasting at many national centres. This paper considers the performance of the Bracknell model in the tropics; it has been in operational use since 1982, and has a grid of resolution 1.5 degrees latitude by 1.875 degrees longitude with 15 levels in the vertical. The forecast system is described in more detail in Bell and Dickinson (1987).

Although the value of numerical forecasts in the tropics has steadily improved in recent years, their accuracy remains poor compared with those for the extra-tropical northern hemisphere. An important reason for this is the inadequate coverage of observations in the tropics. There are far fewer reports from surface stations, aircraft and radiosondes; in addition the temperature soundings from polar-orbitting satellites, which provide good definition of the large-scale thermal structure in mid-latitudes, are of less value near the equator where the balance between the mass and wind fields is not so strong. The most important data in the tropics are the cloud-motion winds from geostationary satellites, however, their accuracy is limited and they do not provide complete coverage either in the horizontal or vertical dimension. Another important factor is the dominance of physical forcing. Tropical prediction is highly sensitive to the treatment of convection and radiative transfers, and although some of the inadequacies of their parametrizations have been overcome in recent years, many problems remain to be solved. Tiedtke et al. (1988) have demonstrated a marked reduction of the systematic errors in the ECMWF model since an earlier investigation by Heckley (1985), and attributed it to changes to the model and the data assimilation system.

In spite of recent advances, the systematic errors of numerical models remain much larger in the tropics than in mid-latitudes and in some regions approach the magnitude of the climatological variability at the longer forecast periods. However, performance with respect to transient disturbances on the synoptic scale is more encouraging. Reed et al. (1988)

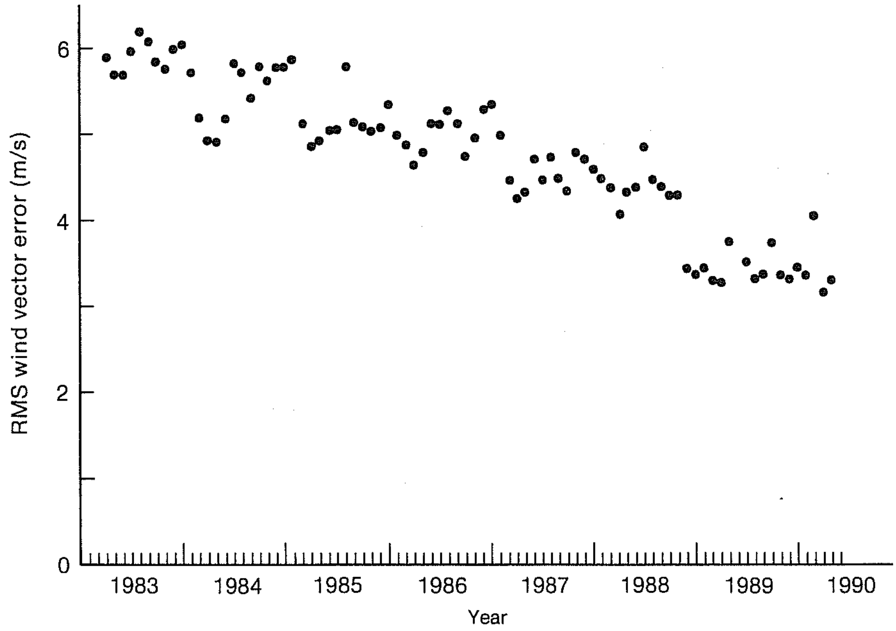

Figure 1. RMS vector error in ms^{-1} of T+24 forecasts of 850 hPa wind in the area 10N-10S. Verification against analyses over the period 1983-1990.

demonstrated that the ECMWF model showed considerable skill in forecasting easterly waves over North Africa and the tropical North Atlantic, and where the systems developed into tropical storms the model was able on occasions to capture the genesis process. Several studies have been made into the accuracy of numerical forecasts of tropical cyclone tracks and most show that useful levels of skill are obtained, particularly in the medium range. Hall (1987) evaluated the forecast errors of the UK global model for all systems in the northern hemisphere in 1986 and concluded that some of the most successful cases were for recurvature where forecasts based on persistence or climatology can lead to large errors.

In section 2 below absolute measures of error of tropical forecasts from the UK model are presented, while in the following section, 3 case studies demonstrate the skill in handling specific synoptic systems.

2. FORECAST ERRORS IN THE TROPICS

Forecast errors in the extra-tropical regions of the northern hemisphere have fallen steadily, so that by today values are approximately half what they were 20 years ago. Over the shorter period for which tropical forecasts have been available routinely, the corresponding decline in forecast error has almost been as large as Figure 1 shows. Here the RMS vector error of 850 hPa wind forecasts from the UK operational global model is plotted for the period 1983-1990. Verification is against analyses from the numerical data assimilation system. The starting point is the early 1980s, at a time when little attention had been paid to the tropics, and the model showed little or no skill there. Model resolution remained unchanged during the period, and the improved performance can probably be attributed to better versions of the data assimilation scheme and improvements to the parametrizations of the physical processes introduced over the years. The discontinuities around Decemeber 1986 and November 1988 correspond to changes made to the operational system in those months. The lower values which obtain today are no larger than elsewhere on the globe, but in the tropics where the day to day variability is low, they do not

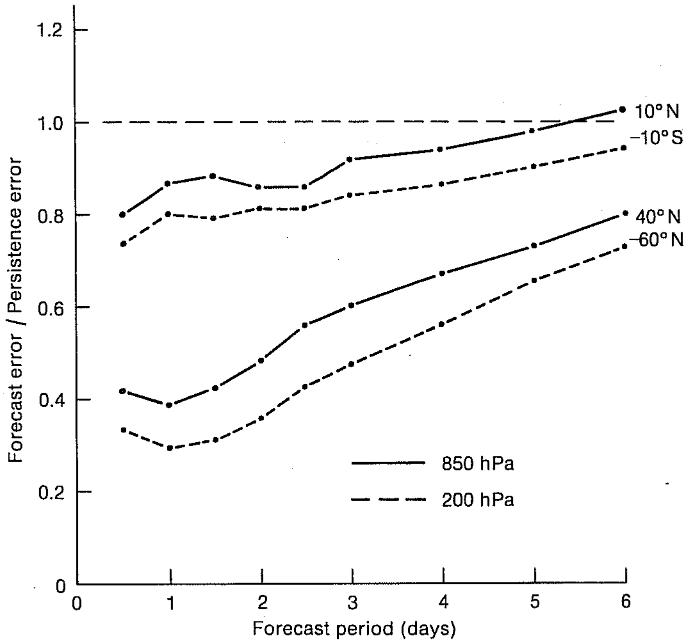

Figure 2. RMS vector error in ms^{-1} of wind forecasts normalised by the persistence error in 1989 at two levels, 850 hPa and 200 hPa, and two areas, 10N-10S and 40N-60N.

represent a particularly high level of skill. Normalisation of the forecast error by the RMS persistence error provides a more reliable measure of performance and values are shown in Figure 2 for 1989 at levels 850 hPa and 200 hPa. At almost all forecast times the ratio is less than 1.0, but values of about 0.8 in the tropical band (10N-10S) at short forecast times compare unfavourably with values around 0.4 in the northern latitude band (40N-60N). Values for the ECMWF model at T+24 are similar (Heckley, 1985).

Direct comparison between models may be made using the monthly verification scores produced by many centres according to a standardised scheme devised by WMO/CBS. Verification is against the analyses of each centre for various fixed areas. Figures for the tropical area (20N-20S) in 1989 are presented in Table 1 below for 4 centres running operational global models: Bracknell, ECMWF, Tokyo and Paris. Although there are differences in the models' performances at various levels and forecast periods, the overall standard of tropical prediction seems broadly similar.

	850 hPa		250 hPa	
	T+24	T+72	T+24	T+72
Bracknell	3.5	5.0	5.1	7.9
ECMWF	3.4	4.3	6.8	9.9
Tokyo	4.4	5.4	5.7	8.6
Paris	3.4	4.4	6.0	8.9

Table 1. RMS vector wind errors in ms^{-1} for 4 forecasting centres running operational global models. Verification against analyses of each centre in the area 20N-20S according to the WMO/CBS standardised scheme. Period 1989.

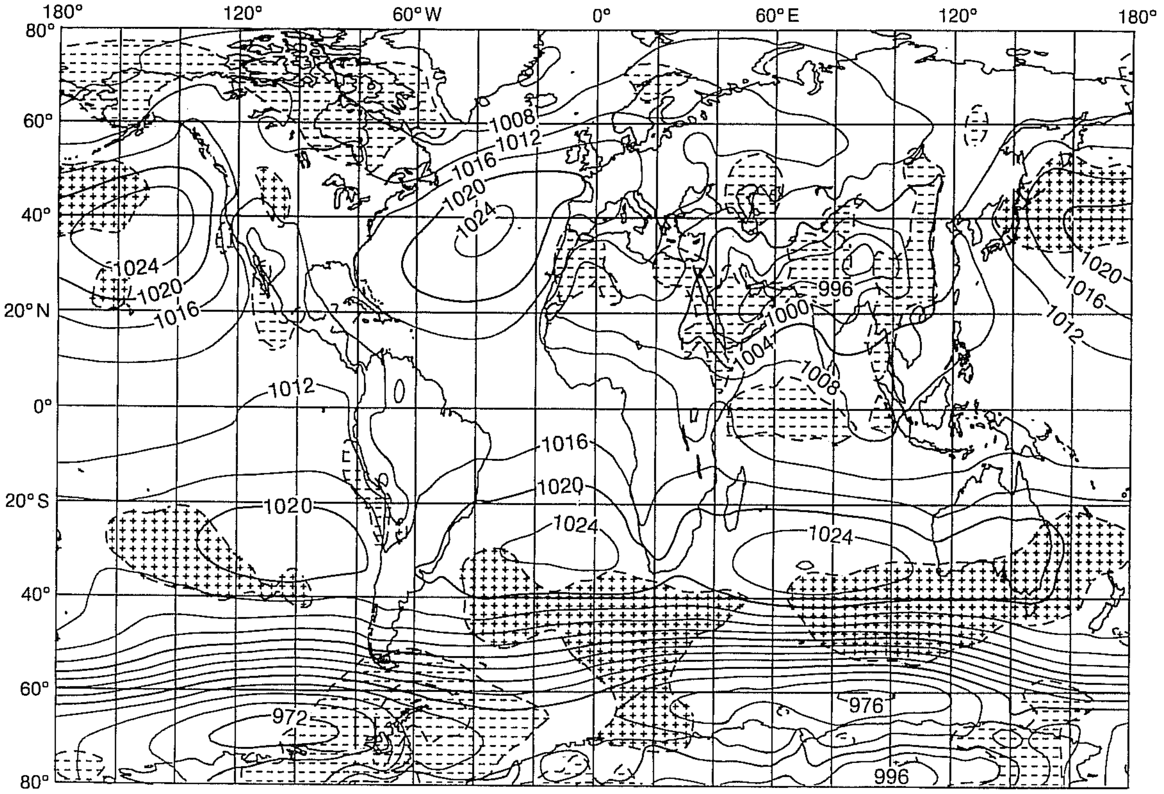

Figure 3. Mean forecast mean sea-level pressure at T+72 in hPa for the period June to August 1989. Mean errors greater than 2 hPa (+++) and less than -2 hPa (---) are indicated.

Figure 3 shows the mean forecast of mean sea-level pressure at T+72 over the globe, and the distribution of significant mean errors (greater than 2 hPa in magnitude). The period chosen is June to August 1989 and many of the characteristics displayed here are similar in other seasons. Positive errors in excess of 2 hPa are found over and to the poleward side of the subtropical highs and are largest in the winter hemisphere (the pattern is reversed in the period December 1989 to February 1990). In the equatorial trough pressure errors are mostly slightly negative and exceed -2 hPa around the Indian Ocean. The resulting excessive easterly gradient shows up in the low-level wind field (Figure 4) where easterly winds in the Pacific and Southern Indian Oceans increase by 2-3 ms^{-1} between the initial analyses and the 72-hour forecasts. The summer monsoon trough over India and South East Asia is too deep in the forecasts of mean sea-level pressure, which, combined with the positive errors in the subtropical high lying to the east, results in a southerly surface flow over the Chinese mainland that is considerably too strong. Such systematic errors have significant impact on the quality of forecasts of synoptic features in the region.

Apart from the excessive strength of the easterly flow noted above, T+72 forecasts of wind at 850 hPa do not show particularly large systematic departures from the initial analyses. The Indian monsoon maximum in the low-level wind over the horn of Africa and the Arabian Sea weakens by 1-2 ms^{-1} in the forecasts and its axis moves marginally to the north, but in general it is well represented at T+72. Systematic errors in the low-level wind field are found to be largest at the 850 hPa level in the Pacific and Indian Ocean basins, however, in the Atlantic, north and south of the equator, the excessive strength of the easterly flow occurs rather higher in the atmosphere at around 700 hPa.

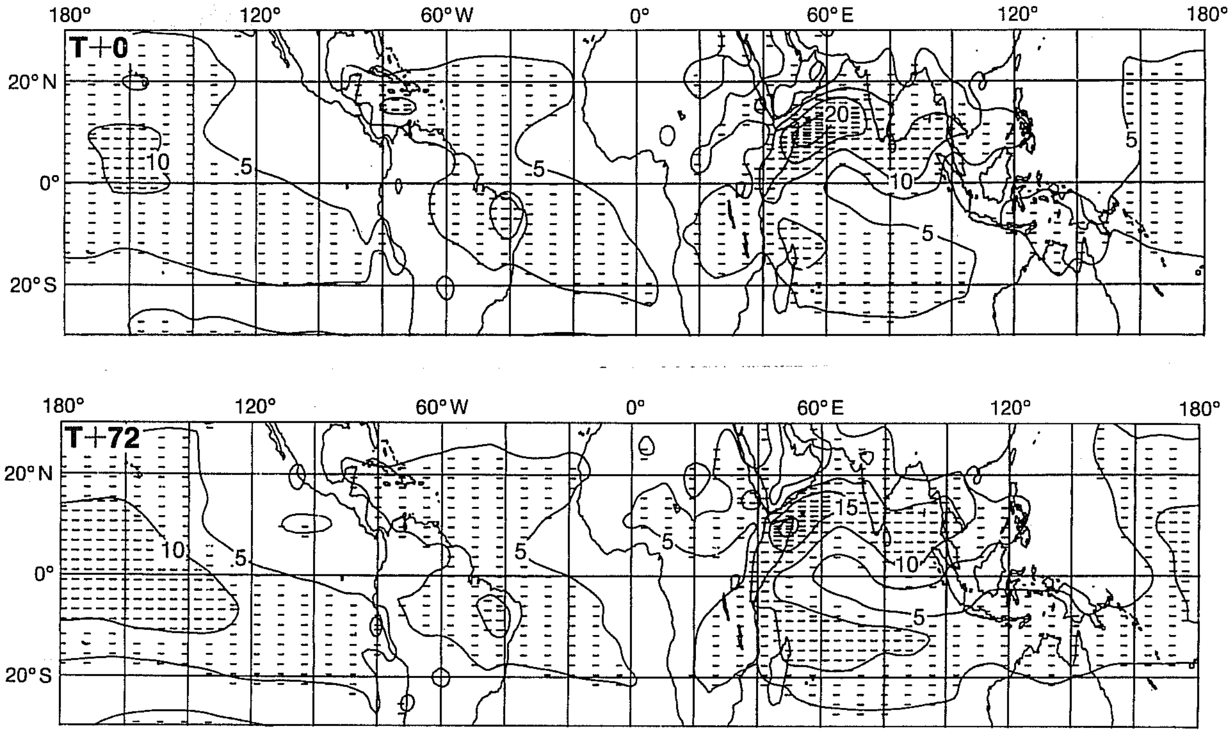

Figure 4. Mean wind speed in ms^{-1} at 850 hPa for the period June to August 1989. Top T+0; bottom T+72.

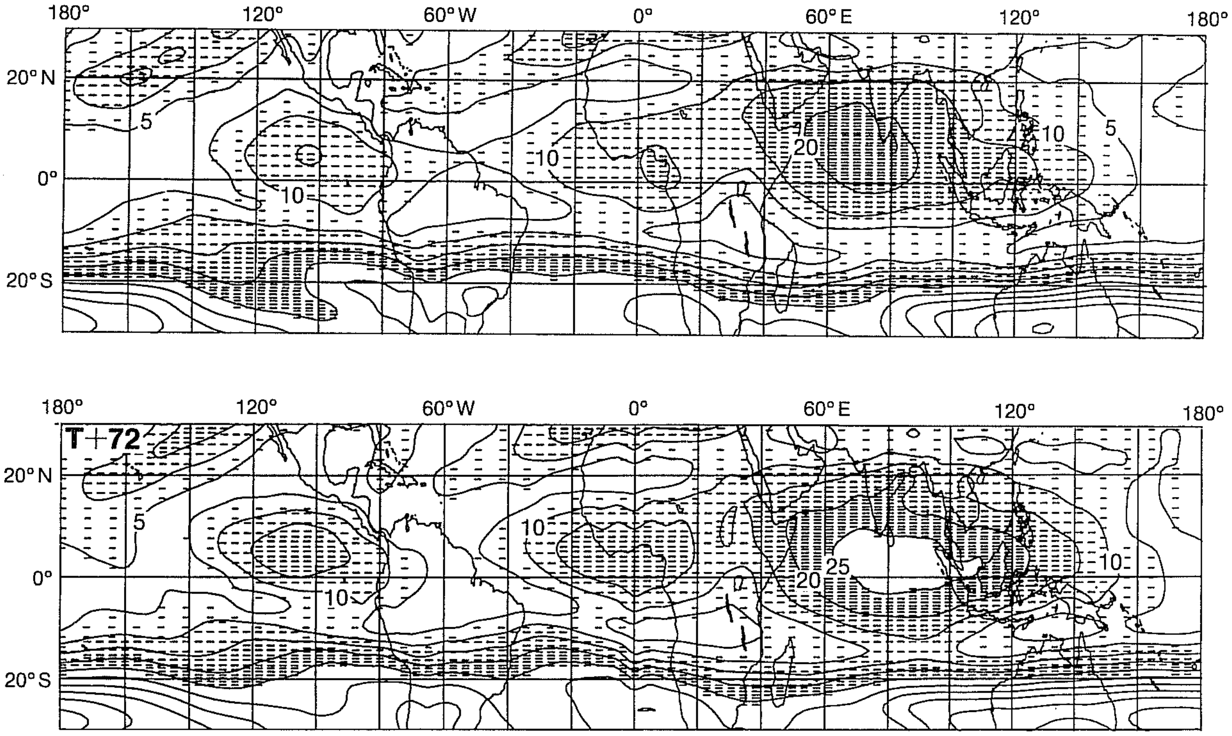

Figure 5. Mean wind speed in ms^{-1} at 200 hPa for the period June to August 1989. Top T+0; bottom T+72.

At 200 hPa the speed of the mean wind at T+0 and T+72 is shown in Figure 5 for the same 3-month period June to August 1989. An easterly bias is again apparent in the forecasts and extends from the Indian Ocean across Africa and the Atlantic to the East Pacific. By contrast, in the Central Pacific the incursion of westerly winds to the equator is a little stronger at T+72 than in the verifying analyses. Together with the easterly bias in the wind at 850 hPa, it seems that in this region the Walker circulation becomes stronger during the forecast.

In all these examples verification has been performed against analyses and the results should be placed in the context of the likely analysis errors. Data assimilation in the tropics is hampered by the lack of good observations, and where none are available numerical schemes have to rely on short-period forecasts. Analysis errors are therefore likely to be very dependent on errors in the forecast system. Tiedtke et al. (1988) compared an ensemble of analyses from two versions of the ECMWF model and found differences of up to 1C in the temperature fields and up to 6 ms^{-1} in the upper tropospheric winds. Hall (1988) compared the short-period forecasts used within the data assimilation system with radiosonde observations in the tropics, and found systematic errors of order 1-3 ms^{-1}. He suggested that systematic errors of similar magnitude were likely in the analyses in data sparse regions. In both cases the estimates of error were not much less than the differences between analyses and forecasts identified here.

3. EXAMPLES OF FORECASTS OF SYNOPTIC-SCALE DISTURBANCES

3.1 Case 1

The Australian Monsoon Experiment (AMEX) which took place in early 1987 made available a greatly increased number of observations over northern Australia during a period of active monsoon flow. These observations were used in a reanalysis performed at ECMWF using the 1987 version of their data assimilation system (Puri et al., 1990), and an example of the 850 hPa wind field on a date near the beginning of the experiment is shown in Figure 6 (from Heckley and Puri, 1988). The observations were not available in real time at Bracknell and the operational analysis, made using a smaller number of observations from the regular observing network, is shown for comparison in Figure 7. On this occasion the largest differences between the two analyses occur to the north of the equator and not in the region of enhanced observation cover. In particular the strength of the flow around typhoon Orchid lying to the west of the Philippines is in excess of 30 ms^{-1} in the UK analysis while it is about half that strength in the ECMWF analysis. This is probably a result of the operational use of bogus data in the UK model to specify the initial state of a tropical cyclone, absent in the ECMWF system. The second region of large differences is in the South China Sea to the east of Malaysia where again the UK wind strengths are greater. The area lies between the radiosonde reports available at the time and there is no other source of low-level data for independent verification.

To the south of the equator there are smaller differences between the analyses; weak westerly winds over Indonesia come up against the easterly flow extending across the northern tip of Australia. This particular date marks a critical period in the onset of the westerly monsoon over northern Australia; three days later on 14 January the westerly flow has strengthened and extended further east with its axis along latitude 10S (Figure 8). A crucial factor is the cross-equatorial northerly winds connecting this flow with the north-easterly monsoon established in the South China Sea. The T+72 forecast for the period spanning the development is shown in Figure 9

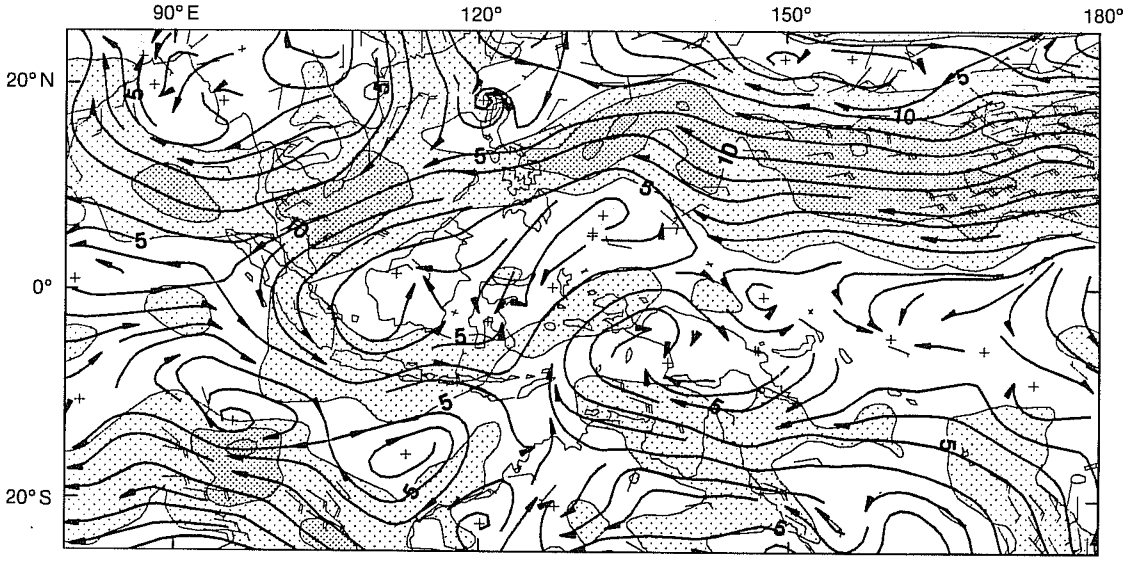

Figure 6. Analysed wind speed in ms^{-1} and streamlines at 850 hPa from the ECMWF data assimilation system using all AMEX data. Data time 1200 UTC 11 January 1987.

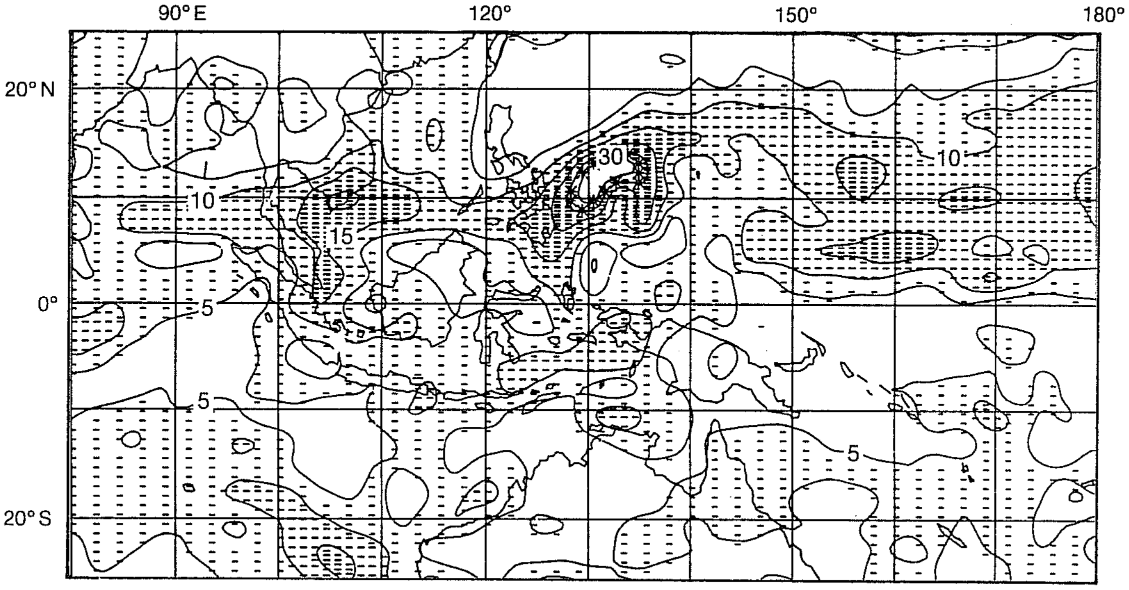

Figure 7. Analysed wind speed in ms^{-1} at 850 hPa from the operational UK global model. Data time 1200 UTC 11 January 1987.

and demonstrates rather limited forecast skill. Some eastward extension of the westerly flow is correctly predicted but its strength is too light and concentrated too close to the equator. The cross-equatorial component is almost absent and wind strengths north of the equator are too great. This example illustrates a general point that NWP in the tropics is often least successful where the principal dynamical processes driving the development themselves lie within the tropical region; in this case the interaction of the two monsoon systems via a cross-equatorial flow. In contrast where the dynamical forcing originates from outside the tropics, for example as occurs with a mid-latitude trough extension, numerical models can be quite skilful as the next case shows.

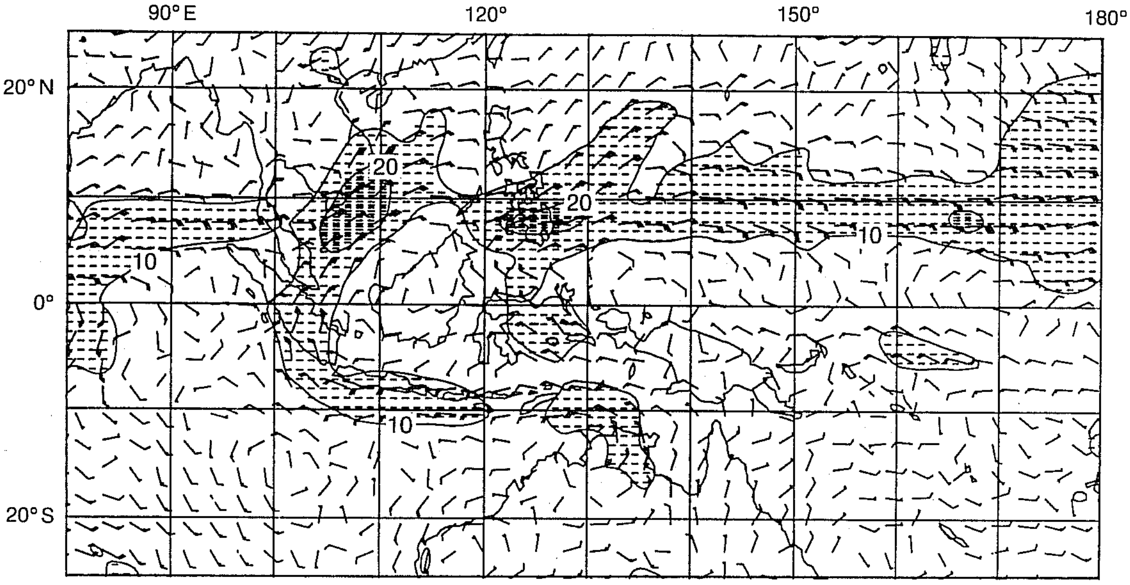

Figure 8. Analysed wind at 850 hPa from the operational UK global model (isotachs in ms^{-1} and wind vectors). Data time 1200 UTC 14 January 1987.

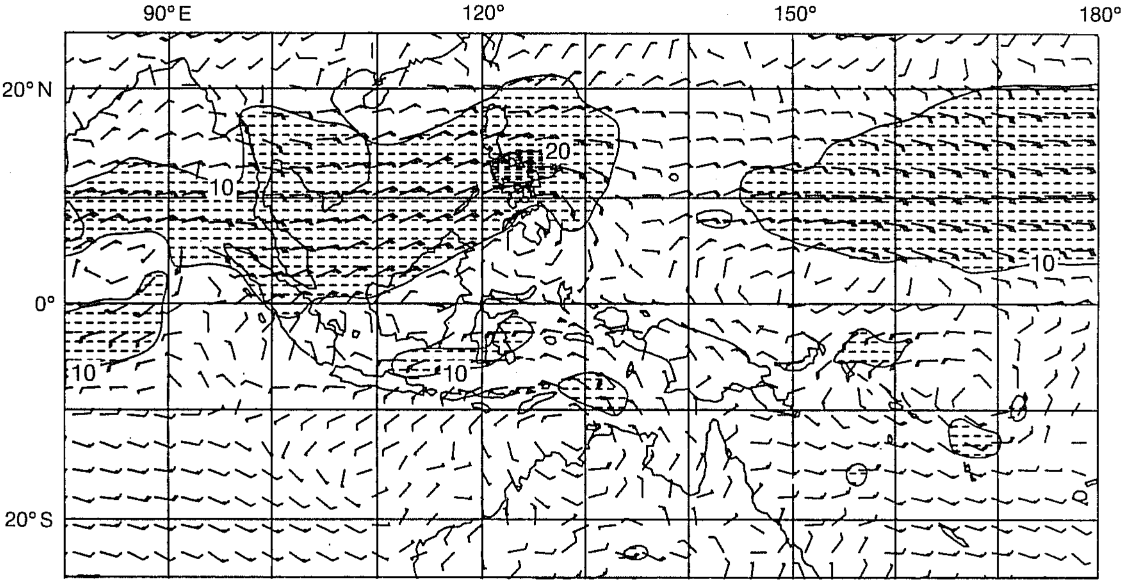

Figure 9. T+72 forecast wind at 850 hPa from the operational UK global model (isotachs in ms^{-1} and wind vectors). Valid 1200 UTC 14 January 1987.

3.2 Case 2

Figures 10a and 11a show analysed mean sea-level pressure and 10 m wind over southern Africa on 16 and 19 September 1988 respectively. On the 16th there are weak easterly winds over East Africa feeding from the tropical Indian Ocean. A low centre lying near 40S 30W deepens over the 3-day period while at the same time there is a substantial build of pressure behind it. On the 19th southerly winds have brought much cooler air up the Mozambique Channel and they spread to quite low latitudes. This development is often associated with cloudly damp conditions as the air rises over the high ground of East Africa. The corresponding fall in the temperatures at 850 hPa over this period (Figures 10b and 11b) is as much as 10C. T+72

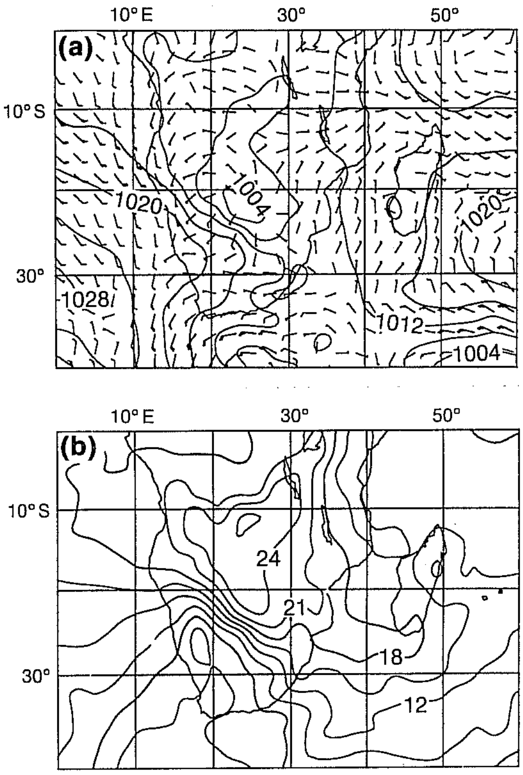

Figure 10. Analysis valid 0000 UTC 16 September 1987; a) mean sea-level pressure and 10 m winds (1 fleche = 5 ms^{-1}), b) 850 hPa temperature.

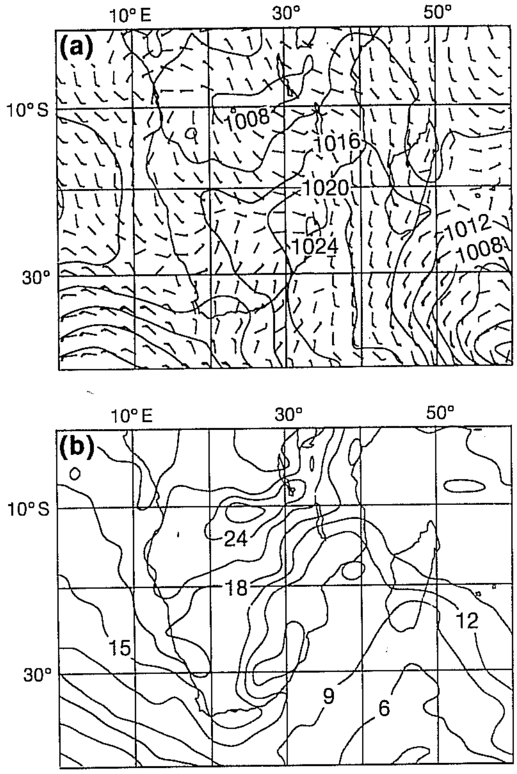

Figure 11. Analysis valid 0000 UTC 19 September 1987, otherwise as Figure 10.

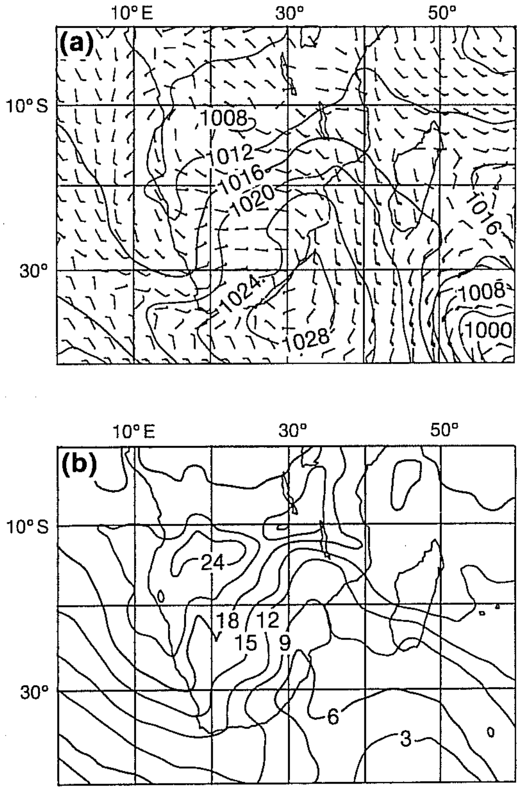

Figure 12. T+72 forecast valid 0000 UTC 19 September 1987, otherwise as Figure 10.

forecasts valid on the 19th are shown in Figures 12a and 12b and have some errors in detail in the mid-latitude systems; the high is too intense and the southerly winds a little too strong, but the general evolution is correct. Models often show this level of skill at high latitudes, even in the southern hemisphere where satellite temperature soundings are the only plentiful source of data. The interaction with the tropics is similarly well forecast; there is an equatorward extension of the southerly winds and the 850 hPa temperatures give a good representation of the surge of cold air. There are other regions where operational models regularly show skill in predicting the interaction of mid-latitude upper troughs with the tropical flow. Cold surges over South East Asia are one such instance, and the considerable skill achieved is no doubt due to the good cover of observations upstream over the Asian continent.

3.3 Case 3

A synoptic system of major interest in tropical regions is the tropical cyclone. Their circulations vary greatly in size from 100 km or less to 1000-2000 km across. The resolution of current global models is quite insufficient to represent the smallest systems while the factor limiting accurate analysis of the largest is the availability of good-quality observations. Satellite imagery usually provides an accurate estimate of the position of the centre of the circulation, and a rather less accurate estimate for the radius of strong winds. Both values are, nevertheless, usually better than can be obtained from the normal range of observations available to numerical data assimilation, and it is common practice to specify the initial vortex structure by bogus data or other means. In

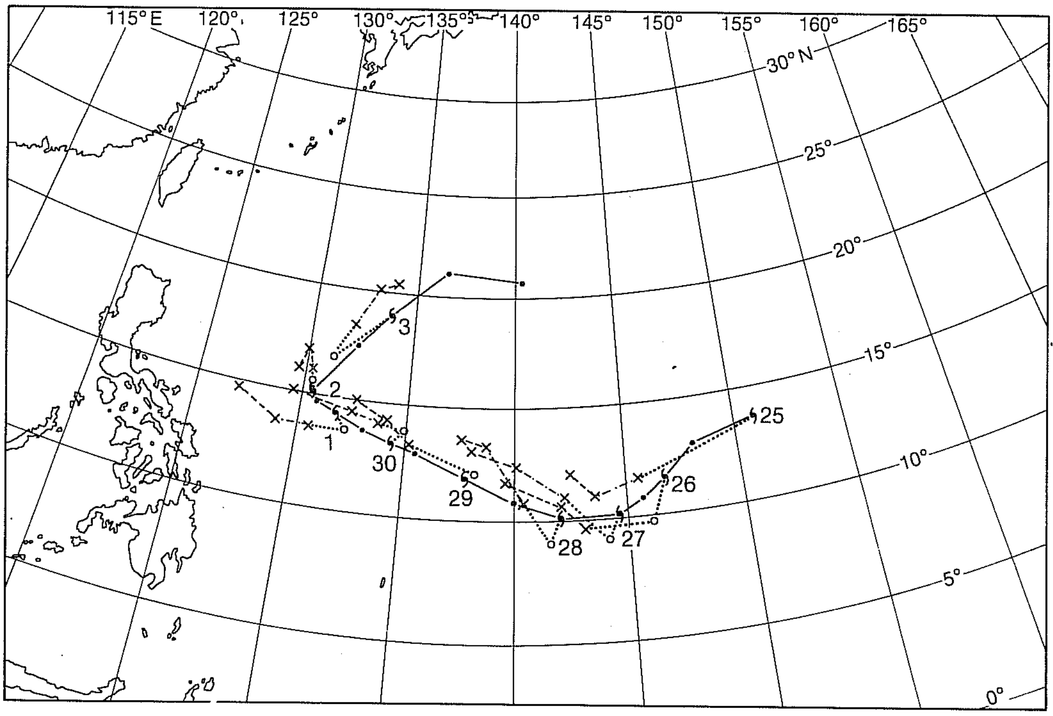

Figure 13. Observed and forecast tracks of typhoon Irma 25 November to 4 December 1989. The observed track is marked by a solid line and the symbol 🌀 indicates the typhoon position at 0000 UTC. The open circles mark the positions in the initial analyses valid at 0000 UTC, and the crosses mark the forecast positions at 24-hour intervals; the movement in 0-24 hours is shown by x.....x, 24-48 hours by x-.-.-x, and 48-72 hours by x-----x.

whatever way the initial vortex is specified, it is not possible for global models, even those with the highest resolution, to represent any of the inner-core structure. Such extreme values and strong wind shears encountered near the eye are sub-grid scale. The value of global models in tropical cyclone prediction, lies not in the short range where the required accuracy in the track prediction is very high, but on the medium range (perhaps 2 to 5 days) where the interaction with the large-scale flow is important and often difficult to predict without a numerical model.

The track of some tropical cyclones is on occasions very irregular, as was the case for typhoon Irma which developed in the North West Pacific in November 1989. The track (Figure 13) was first equatorward, then a more normal westward direction followed by a sudden recurvature and dissipation between 2 and 4 December. The speed of movement was also highly irregular with two spells on 27 November and 1 December when it became slow moving. This was a particularly intense storm, with estimated maximum winds of 140 knots at one stage, and large enough to be well resolved by a global model. An example of a T+72 forecast and verifying analysis of mean sea-level pressure and 10 m wind is shown in Figures 14 and 15. The forecast tracks from successive 0000 UTC analyses are shown alongside the observed track in Figure 13. The initial slowing down and westward movement is fairly well forecast, but not the temporary faster movement on the 28th and 29th. The second slow-moving phase is also well forecast but not the sharp veering northeastward on the 2nd; indeed the forecasts from the 1st onwards completely fail to predict the final evolution. This typhoon followed a particularly erratic track, and though the numerical forecasts clearly demonstrate some skill, the level of accuracy is inferior to that typically expected of low-pressure systems of similar size in the extra-tropical northern hemisphere. Recurvature is not always poorly forecast and where it occurs at slightly higher latitudes ahead of a mid-latitude upper trough, forecasts can be particularly successful (eg Hall 1987).

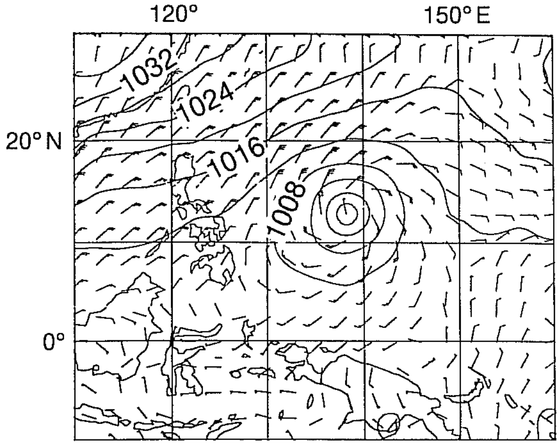

Figure 14. T+72 forecast valid 0000 UTC 30 November 1989. Mean sea-level pressure and 10 m wind (1 fleche =5 ms^{-1}).

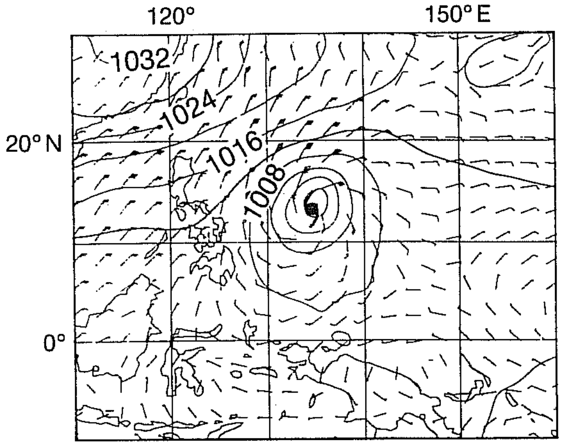

Figure 15. Analysis valid 0000 UTC 30 November 1989, otherwise as Figure 14.

4. CONCLUSIONS

Forecasts from global numerical models show skill in tropical regions, but the performance does not match that now expected in the extra-tropical northern hemisphere. Forecast errors are less than persistence errors at all forecast times, but not by nearly as much as in the latitude band 40N-60N. Systematic errors of the UK global model in the tropics, like the ECMWF model, are larger than in mid-latitudes; there is a general tendency for excessively strong easterly flow at low levels and in the upper troposphere. Because the data assimilation system is strongly dependent on the numerical model, systematic errors also exist in the analyses, which leads to uncertainties in all assessments of model performance.

The model generally shows more skill in forecasting synoptic-scale transient disturbances than the objective verification scores might lead to expect. Greatest skill is often shown where the dynamic forcing originates in the extra tropics. Because numerical forecasts usually handle mid-latitude systems accurately, where they interact with the tropical flow this skill may be transferred to tropical regions. An important example of such interaction is a cold surge associated with a meridional extension of an upper trough. These are important occurrences in synoptic forecasting and they are often well predicted by numerical models.

Although the structure of the inner-core region of a tropical cyclone with its extreme values of wind and wind shear is purely sub-grid scale, the large-scale circulation of many systems falls within the resolution of operational global models in use today. The track of cyclones in the medium range (2-5 days) is largely determined by the large-scale structure, both of the vortex and of the flow in which it is embedded. For this reason many global models, including the UK model, show useful skill in forecasting cyclone positions beyond T+48.

The performance of numerical forecasting systems in the tropics has advanced greatly since the first routine operational forecasts were produced not much more than 10 years ago. Although there is scope for further improvements in the models, in particular the parametrizations of the physical processes, a major limiting factor is the quality of the initial conditions. Analyses are unlikely to reach the standards expected in the extra-tropical regions of the northern hemisphere until there is a vastly improved coverage of observations.

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