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Performance of the ECMWF model in forecasting the tracks of tropical cyclones in the South China Sea and parts of the western North Pacific

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1. Introduction

Since 1986 the Hong Kong Observatory (HKO) has been receiving the European Centre for Medium-Range Forecasts (ECMWF) model forecast products based on 12 UTC analysis via the WMO Global Telecommunication System (GTS). The data are available at 2.5° × 2.5° resolution at 24-hour intervals. In the first few years, low pressure centres on surface prognoses and cyclonic circulation centres on 1000 hPa and 850 hPa forecast charts were used to forecast the movement of tropical cyclones (TC). An example of these early attempts can be found in Chan & Lam (1989), which reported on predictions of the movement of a particularly difficult TC in 1986.

The Director of the HKO from 1965 to 1981, G. J. Bell, found that subjective forecasts issued by the operational warning centres were generally little better than forecasts obtained from a simple combination of persistence and climatology (Bell, 1962). Recognising that conventional synoptic/statistical type 24-hour forecasts were at the limit of their predictive power, Bell (1979) drew attention to the need to look to numerical models for improved forecasts for periods of 48 hours or more. In the early 1980s, however, arrangements for the dissemination of observations and the methods of objective TC analysis were inadequate to generate useful forecasts beyond 48 hours. Yet, a decade after Bell, Lam (1992) found that numerical models were still not able to outperform simple methods such as persistence in 24-hour TC position forecasts and had made little significant impact on the quality of forecasts of up to 48 hours and beyond.

In recent years, however, front-line forecasters have observed significant improvements in the forecasting of TCs by using the ECMWF model. This paper discusses the recent performance of the ECMWF model in TC track prediction in the South China Sea and parts of the western North Pacific.

2. Verification of tropical cyclone forecasts

2.1. Data and methodology

Tropical cyclones over the western North Pacific and the South China Sea are classified into four categories – tropical depressions (TDs), tropical storms (TSs), severe tropical storms (STTs) and typhoons (Ts) – according to the maximum sustained surface winds near their centres (Table 1).

The model forecast positions of TCs in the period 1991–8 were verified against the ‘best track’ analysed by the HKO within the Hong Kong area of responsibility for issuing TC warnings for shipping, 10–30 °N, 105–125 °E. The best-track positions of the TCs were determined after the event with the benefit of all available data and the wisdom of hindsight. This verification area was chosen to facilitate comparison with HKO subjective forecasts. The subjective forecasts during the period 1975–98 were also verified against the best-track
positions to highlight long-term trends and to compare them with the model performance during the latter part of the period. In this paper, the forecast error is defined as the great-circle distance between the forecast position and the best-track position of the TC.

The positions of the point of minimum mean sea level pressure (MSLP), as determined from ECMWF prognostic data, were treated as the TC centres. The point of minimum was determined by the fitting method of overlapping parabolic interpolation (Manning & Haagenson, 1992). In addition, the positions of the centre of maximum 850 hPa relative vorticity were also used to track the TCs in 1998, for comparison with the position errors associated with tracking using the minimum MSLP centres. In view of the vertical alignment of centres at different levels in mature TCs, predictions based on 850 hPa vorticity centres should not be too much different from those based on the MSLP centres. One advantage of using 850 hPa vorticity fields is that such centres are often easier to locate in weak systems with circulations that cannot be adequately represented in the MSLP field. Because of this, the 850 hPa vorticity field generally gave better continuity in the course of tropical cyclone evolution (Lam & Lai, 1994).

When using the 850 hPa relative vorticity field to track the TCs, a threshold of $50 \times 10^{-6} \text{ s}^{-1}$ was adopted to identify and track the TC positions on the prognostic charts. The forecasts were verified even if the TC had not formed at the model initial time; this indicated to some extent the model's ability to forecast TC genesis.

As a measure of tropical cyclone forecast skill, forecast errors are usually compared with those obtained by the simple climatology-persistence (CLIPER) method (Bell, 1962; Neumann, 1972). The skill score is defined as $(\text{CLIPER error} - \text{forecast error}) / \text{CLIPER error}$ expressed as a percentage. A positive skill score means that the model is more skilful than CLIPER. A comparison of the forecast skill of the ECMWF model and that of the subjective forecasts in the 1990s is presented in section 2.4.

More detailed analysis of the 1998 dataset was carried out with the verification area expanded to cover the western North Pacific (i.e. 0–45 °N, 100–180 °E). The tracks of the TCs in 1998 are shown in Figure 1. A total of 20 TCs occurred, of which 19 TCs were included in the verification dataset. TS Nichole was not verified because its maximum 850 hPa vorticity never reached the threshold during its relatively short life-span.

### Table 1. Classification of tropical cyclones over the western North Pacific and the South China Sea.

<table>
<thead>
<tr>
<th>Class</th>
<th>Maximum sustained surface winds near TC centres (knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TropicalDepressions</td>
<td>22 – 33</td>
</tr>
<tr>
<td>Tropical Storms</td>
<td>34 – 47</td>
</tr>
<tr>
<td>Severe Tropical Storms</td>
<td>48 – 63</td>
</tr>
<tr>
<td>Typhoons</td>
<td>Greater than 63</td>
</tr>
</tbody>
</table>

2.2. Subjective forecasts by HKO: the 1980s and 1990s compared

Figure 2(a) shows the trend of annual mean errors of model forecasts compared with those of the HKO operational subjective forecasts up to 48 hours ahead over the area 10–30 °N, 105–125 °E. Looking at the results since the 1980s, the weighted mean of 24-hour and 48-hour forecast errors for subjective forecasts in the 1980s (1980–9) were 196 km and 419 km respectively while they were 183 km and 378 km in the 1990s (1990–8). There are indications of better subjective forecasts during the 1990s than in previous years.
Similar results were found in an earlier study by Lam (1992) based on 1961–90 data.

The relatively large error in the 48-hour subjective forecasts for 1998 can be accounted for by the activity of two TCs, Vicki and Zeb. In the early stages of Vicki, there was another vortex to its west over the South China Sea, and the divergent scenarios forecast by different global models from the Japan Meteorological Agency (JMA) and ECMWF puzzled forecasters. In the case of Zeb, its acceleration after recurving over the western North Pacific was difficult to predict.

Figure 2(b) shows the skill score of operational subjective forecasts by the HKO and of predictions by the ECMWF model in forecasting TC positions in the region 10–30 °N, 105–125 °E. Prior to 1990, the CLIPER method often outperformed the operational subjective 48-hour forecasts. At that time, HKO forecasters mainly used statistical/synoptic methods in TC forecasting. But since 1986, ECMWF model products have been used in operational forecasting, and additional global model products from the UK Met. Office (UKMO) and JMA have also been acquired since 1994 and 1997 respectively. The CLIPER method is now performing less well against these new model techniques.

2.3. Model forecasts: the early 1990s and late 1990s compared

In contrast to the situation regarding subjective forecasts, the model forecast position errors for all forecast...
ranges have decreased, particularly since 1996 (Figure 2(a)). In the early 1990s (1991–3), the model mean forecast errors for 24-hour, 48-hour and 72-hour positions were 215 km, 340 km and 453 km respectively, compared with 155 km, 244 km and 292 km for those in the late 1990s (1996–8). In particular, they were reduced to 136 km, 203 km and 237 km respectively in 1998.

Figure 2(a) indicates that the improvement in ECMWF model forecasts of TC positions was most noticeable in the most recent years (1996–8).

Table 2. Forecast position errors (mean error and standard deviation) for TCs in the area 10–30 °N, 105–125 °E for the years 1991–8. ME: mean error; SD: standard deviation; N: number of cases.

<table>
<thead>
<tr>
<th>Forecast hour</th>
<th>ECMWF model forecast</th>
<th>HKO subjective forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME (km) SD (km) N</td>
<td>ME (km) SD (km) N</td>
</tr>
<tr>
<td>24</td>
<td>187 42 216</td>
<td>183 17 952</td>
</tr>
<tr>
<td>48</td>
<td>299 82 161</td>
<td>372 61 614</td>
</tr>
<tr>
<td>72</td>
<td>364 99 96</td>
<td>–</td>
</tr>
</tbody>
</table>

2.4. Model versus subjective forecasts: the 1990s

The mean position errors and the standard deviations of the model and subjective forecasts between 1991 and 1998 are given in Table 2. The model’s performance at 24 hours was comparable with that of the subjective forecasts, but the 72-hour model forecast error was about the same as the 48-hour subjective forecast error during the period. The HKO carried out experimental 72-hour subjective forecasts in 1976 and the mean error was 563 km; the accuracy of the model forecasts for 72 hours was much better than this in the 1990s.

As can be seen from Figure 2(b), the ECMWF model forecasts have been more accurate than CLIPER for all forecast ranges since 1994, with a significant increase in model skill against CLIPER (particularly for the T+72 hour forecasts) since 1996. Combining the forecast skill results of the subjective forecasts and the model forecasts, it would seem that the subjective forecasts have benefited from the much improved model forecasts over the years. That 48-hour subjective forecasts have not improved as rapidly as the model forecasts is an issue to be addressed by the HKO meteorological service.

2.5. Comparison within a wider verification area using the 1998 dataset

In operational forecasting, TCs that form over the western North Pacific are also monitored by the HKO forecasters as they may enter the South China Sea and affect Hong Kong. In view of this, it is also of interest to examine the model’s performance for TCs over this region. Table 3 summarises the model mean position errors within the area 0–45 °N, 100–180 °E, covering the South China Sea and the western North Pacific, compared with those in the much smaller sea area 10–30 °N, 105–125 °E, for 1998.

With the inclusion of the western North Pacific in the verification area, the model forecast errors were larger than those over the South China Sea only. The larger differences for the longer forecast ranges (around 25 % for 48-hour forecasts and 40 % for 72-hour forecasts) arose because recurving TCs over the western North Pacific tended to accelerate after recurving, bringing about large errors.

From the 1998 dataset, the maximum model-analysed position error was around 200 km, an error that had been as large as 400 km in the early 1990s (Lam, 1992). Initial positions of TCs have also been more accurately depicted in model analysis in recent years. This may be one of the reasons contributing to the overall improvement in model forecasting of TC tracks.

The 850 hPa vorticity field was also used to track TCs in 1998 in addition to the MSLP field. Table 3 indicates that there is not much difference in the errors of the TC position forecasts between the two verification areas.

Table 3. ECMWF model forecast position errors for TCs in 1998 over 10–30 °N, 105–125 °E and 0–45 °N, 100–180 °E. Cases with maximum 850 hPa relative vorticity ≥ 50×10⁻⁶ s⁻¹ are included in the comparison study.

<table>
<thead>
<tr>
<th>Forecast hour</th>
<th>10–30 °N, 105–125 °E</th>
<th>0–45 °N, 100–180 °E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MSLP ME (km) SD (km) N</td>
<td>850 hPa vorticity ME (km) SD (km) N</td>
</tr>
<tr>
<td>0</td>
<td>102 59 35</td>
<td>87 52 35</td>
</tr>
<tr>
<td>24</td>
<td>136 80 35</td>
<td>131 67 35</td>
</tr>
<tr>
<td>48</td>
<td>203 124 32</td>
<td>207 124 32</td>
</tr>
<tr>
<td>72</td>
<td>237 136 29</td>
<td>246 126 29</td>
</tr>
<tr>
<td>0</td>
<td>100 61 77</td>
<td>88 57 78</td>
</tr>
<tr>
<td>24</td>
<td>153 96 77</td>
<td>145 95 77</td>
</tr>
<tr>
<td>48</td>
<td>255 180 69</td>
<td>250 181 70</td>
</tr>
<tr>
<td>72</td>
<td>333 249 58</td>
<td>335 246 59</td>
</tr>
</tbody>
</table>
2.6. Case illustration of Typhoon Babs in 1998

In the context of operational tropical cyclone forecasting, warning the public and the marine community about tropical cyclones has always been the ultimate goal. An operational warning centre will need data on a whole range of factors, including initial TC detection, determination of position and intensity, forecasting movement, intensification and the point of landfall, as well as the timing and magnitude of the weather impact. The case of Typhoon Babs illustrates these issues of concern, and shows how model forecasts helped the warning services (HKO).

Figure 3 shows Typhoon Babs’ observed and successive ECMWF forecast tracks. The life history of Babs was the second longest in the western North Pacific TCs during 1998, and it posed a potential threat to Hong Kong after crossing Luzon and moving towards the south China coast. Babs slowed down and recurved within a distance of 300 km to the south-east of Hong Kong at around 12 UTC 25 October. The ECMWF model forecasts provided useful guidance in forecasting the recurvature of Babs to the east of Hong Kong, starting from the model run with the initial time of 12 UTC 24 October. This was an important piece of information as the impact of a TC on Hong Kong depends on whether the TC will make landfall to the east or west of Hong Kong and, of course, on the distance of closest approach and the strength of the TC. Hong Kong is less susceptible to the damaging effects of TCs if they make landfall to the east of Hong Kong, owing to the sheltering effect of the urban areas by mountains. In the case of Babs, the mean forecast errors for the ECMWF model were 93 km, 165 km, 248 km and 350 km for T+0, T+24, T+48 and T+72 hour forecasts respectively; these figures were based on centres deduced from the 850 hPa vorticity field with a threshold maximum vorticity value of $50 \times 10^{-6}$ s$^{-1}$ using around ten data points for each forecast hour during the period 17–27 October.

3. Overall assessment

The recent performance of the ECMWF model in forecasting tropical cyclones in the South China Sea and parts of the western North Pacific has been reviewed using the 2.5° resolution data which is available on the GTS for the period 1991–8. Since 1994, model forecasts of TC positions have been more accurate than those made from the simple climatology-persistence method over 24-hour to 72-hour forecast ranges. Improvements in model TC track forecasting have been most noticeable since 1996. However, subjective forecasts for the area 10–30 °N, 105–125 °E have not shown as much improvement during the past two decades or so, with mean errors staying in the region of 180 km and 380 km for 24-hour and 48-hour forecasts respectively. On the model side, the mean errors for 24-hour, 48-hour and 72-hour forecasts were reduced to 136 km, 203 km and 237 km respectively during 1998. However, over the larger verification area of 0–45 °N, 100–180 °E, the 48-hour and 72-hour forecast errors were larger by around 25 % and 40 % respectively and their standard deviations were much larger.

Improvements in TC forecasting by numerical modelling over recent years have also been reported elsewhere, for example for the UKMO (Heming, 2000) and JMA (JMA, 1998). It is pleasing to note that numerical modelling has become a reliable means of improving TC position forecasting. The verification results presented here should encourage operational forecasters to make better use of model outputs. Accurate forecasting of tropical cyclone motion helps reduce the impact of cyclone damage through improved meteorological warning services. This is a most fitting achievement to mark the end of the International Decade for Natural Disaster Reduction (IDNDR). Two decades after Bell’s (1979) wise words, numerical weather prediction has at long last come of age and is having a significant positive impact on the forecasting of tropical cyclones.

Acknowledgements

The author would like to thank Mr C.Y. Lam for his constructive comments. Preparation of the tropical cyclone data set by C. K. Chow, C. H. Au and his colleagues is much appreciated.
References