17D.9

Met Office Global Model tropical cyclone performance following a major model upgrade and new initialization technique

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1. TRIAL OF MODEL UPGRADE

A new dynamical core (named ENDGame) was implemented in the Met Office Global Model (MOGM) operationally in 2014 (Wood *et al*., 2014; Met Office, 2014). At the same time a number of changes to the model physics, an increase in horizontal resolution (approximate grid spacing at mid-latitudes reduced from 25 km to 17 km) and improved satellite data usage were also introduced. The complete package was known as Global Atmosphere 6 (GA6) (Walters *et al*., 2016).

Prior to the implementation of GA6 it was trialled for a period of several months. The impact of the model upgrade on tropical cyclone (TC) forecasts from the MOGM as seen in this trial can be found in Heming (2014). For TC track prediction the key result was that track errors were reduced by 8.6% as shown in Figure 1. Comparative results for the European Centre for Medium-Range Weather Forecasts (ECMWF) model during the trial period indicate that ECMWF errors were much lower than MOGM errors during the trial period, but GA6 reduced the gap by 28%.

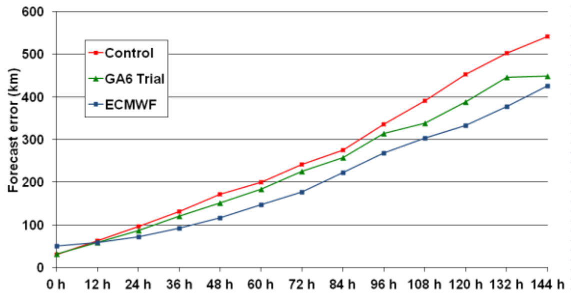

Figure 1. TC positional forecast errors during trial of new MOGM configuration GA6. Comparative ECMWF results for version of model operational during trial period.

Results for TC intensity prediction showed that with GA6 TCs were much stronger and absolute errors and biases in forecast intensities were reduced. The mean forecast central pressure was 11.1 hPa lower and 10m wind 13.4 knots higher. The mean absolute error in central pressure forecasts was reduced by 3.6 hPa and the mean absolute error in 10m wind forecasts reduced by 9.0 knots. In the trial, GA6 had only a small impact on the weak bias in the model's analysis of central pressure (reduced from 15.1 to 13.5 hPa), but by 144 h into the forecast the weak bias of 15.6 hPa was turned into a strong bias of 3.5 hPa. The impact of GA6 on the central pressure forecast bias is shown in Figure 2. Comparative results for the ECMWF model during the trial period indicate that under GA6 the MOGM has very similar characteristics for TC intensity as the ECMWF model.

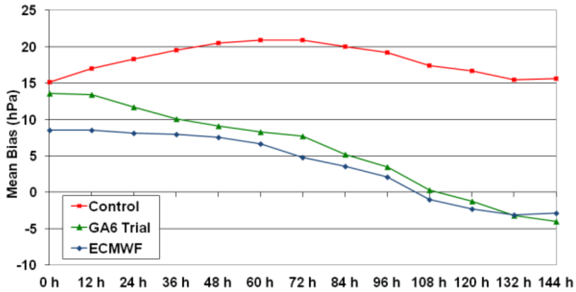

Figure 2. TC central pressure forecast bias during trial of new MOGM configuration GA6. Comparative ECMWF results for version of model operational during trial period.

GA6 was implemented in the MOGM on 15 July 2014. The MOGM performance since implementation will be discussed in more detail in Section 3.

2. TC INITIALIZATION USING CENTRAL PRESSURE ESTIMATES

2.1 Background to the new initialization technique

For many years the Met Office used a TC initialization technique which involved the insertion of bogus observations of wind speed and direction at the surface and three lower tropospheric levels. This technique proved extremely successful and reduced TC track forecast errors by 34% on average in trials (Heming *et al*., 1995). The technique was revised in 2007 (Heming, 2009), but in 2012 was found to be no longer beneficial to MOGM forecasts and thus was switched off (Heming, 2016).

The implementation of GA6 in 2014 (described in the section above) resulted in a significant reduction in TC track forecast errors and TC intensity forecast bias. However, it was notable that GA6 had very little impact on the model's weak bias in the analysis for TCs (see Figure 2). Thus attention was turned to how this weak bias could be reduced through the development of a new form of TC initialization. It was decided to trial usage of central pressure estimates from TC warning centres since they had the potential to reduce the model's weak bias whilst allowing the model to make its own balanced adjustments to the wind structure.

2.2 Formulation of the new TC initialization technique

TC warning centres around the globe (e.g. Japan Meteorological Agency, National Hurricane Center) produce estimates of the position and structure of all active TCs every three or six hours. These include estimates of maximum sustained wind and central

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pressure. Whilst in most cases these are estimates (i.e. not directly measured) based on a combination of techniques such as Dvorak (1975, 1984) and Knaff and Zehr (2007), they provide information which is potentially of value to numerical models. The previous TC initialization scheme used by the MOGM made use of the estimates of maximum sustained wind and radii of 34 knot, 50 knot and 64 knot winds provided by TC warning centres, but not the estimates of central pressure.

The new technique was designed to ingest estimates of the central pressures of all active TCs from a variety of TC warning centres around the globe. These are available at 6-hourly intervals and sometimes at 3-hourly intervals. It was considered that assimilating a single central pressure observation every six hours may have limited impact on the MOGM analysis or forecast. Hence the scheme was designed to produce hourly values of TC central pressure. These are based on a combination of interpolation and extrapolation of the estimates from TC warning centres. For example, the 1200 UTC run of the MOGM has an observational time window of 0900 UTC to 1459 UTC. If estimates of position and central pressure for an active TC are available at 0600 UTC and 1200 UTC these are used to derive estimates of central pressure at 0900 UTC, 1000 UTC and 1100 UTC by linear interpolation. The 1200 UTC value from the warning centre is used directly and values for 1300 UTC and 1400 UTC are derived by linear extrapolation. Hence, six values of TC central pressure and position are presented to the data assimilation during the 6 h time window and are used in the production of a model analysis, being treated in a similar way to other surface observations, including passing through quality control procedures. Met Office models currently use a hybrid 4D-Var data assimilation system (Clayton *et al*., 2013) to produce a model analysis.

2.3. Trial of the new TC initialization technique

A trial period from September to November 2013 was chosen. In total there were 23 TCs during this period across the northern hemisphere. Although the trial period was from 2013, the Control and Trial used the configuration of the MOGM operational from July 2014 which included the major model upgrade described above (GA6). The GA6 configuration of the model was used since it was vital to assess the new TC initialization technique against this baseline which was already in operations at the time the trials were conducted.

For TC track the results show that forecast errors were lower in the Trial at all lead times. When averaged over all forecasts from 6 h to 144 h at 6-hourly intervals, the Trial track forecast errors were 6.2% lower than the Control. The Trial track forecast skill scores were on average 2.7% higher than the Control. Track forecast errors for the Control and Trial are shown in Figure 3 and also include the values for the configuration of the model which was operational during the trial period. i.e. the version before the implementation of GA6 (known as GA3). This illustrates the combined impact of GA6 and the new TC initialization technique.

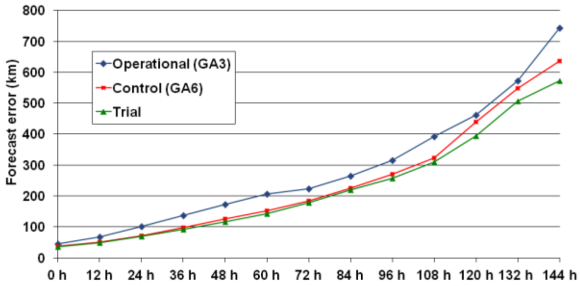

Figure 3. TC track forecast errors during trial of the new initialization technique.

For TC intensity, the statistics indicate that the weak bias in the analysis was markedly reduced in the Trial with the central pressure bias of 11.5 hPa cut to 6.3 hPa. With increasing lead time the difference between the Control and Trial narrowed and beyond 108 h both had a bias very close to zero. Thus the introduction of assimilation of central pressure estimates has reduced the weak bias in the analysis and short lead time forecasts without resulting in an over-deepening at longer lead times when the Control already had a very small bias. Figure 4 shows these results together with the central pressure bias for the configuration of the model which was operational during the trial period (GA3). This shows that the combination of GA6 and the new TC initialization technique slashes the bias in forecast central pressure. Biases which ranged between approximately 17 hPa and 28 hPa before these two changes now ranged between approximately 0 and 10 hPa.

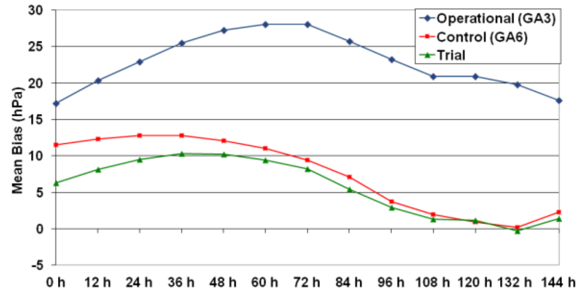

Figure 4. TC central pressure forecast bias during trial of the new initialization technique.

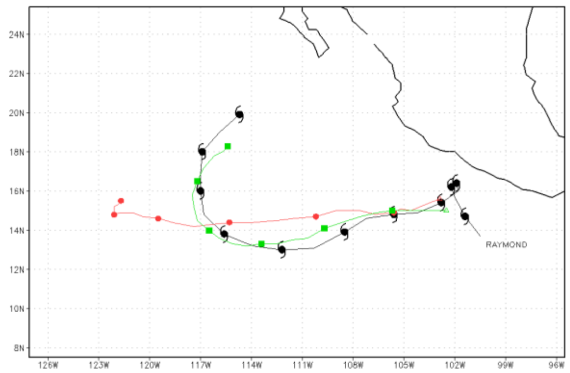

Figure 5. Control (red circles) and Trial (green squares) forecast tracks (24 h steps) for 1200 UTC 23 October 2013 plotted against best track observed positions for Hurricane Raymond. Corresponding analysis positions shown as triangles. Trial included the new initialization technique.

2.4. Case studies

Examination of some individual cases illustrates some of the characteristics of the new TC initialization technique.

The reduction in track forecast errors is exemplified in a forecast for Hurricane Raymond in the eastern North Pacific shown in Figure 5. The Control forecast had a fast westward movement for the hurricane whereas the Trial had a slower movement with a gradual curve towards the north. The latter matches the observed track far better and thus produced much lower track forecast errors.

The impact of the new TC initialization technique on TC intensity can be seen in central pressure predictions for typhoons Wutip and Wipha. During the period from 27 to 29 September 2013 Typhoon Wutip deepened from 1000 hPa to 965 hPa. The Control analysis did not keep pace with the rate of deepening and the subsequent forecasts were also unable to predict the intensity of the typhoon. However, assimilation of central pressure estimates resulted in the analysis being much closer to the observed intensity and even too deep in a couple of runs. The resulting forecasts had central pressures much closer to the observed values in most cases as seen in Figure 6.

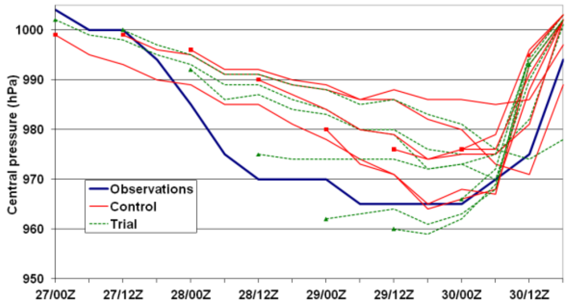

Figure 6. Control (solid red lines) and Trial (dashed green lines) central pressure forecasts plotted against best track observed data (solid blue line) for Typhoon Wutip (September 2013).
Trial included the new initialization technique.

For Typhoon Wipha (Figure 7) the Control analysis was unable to represent the intensity of the TC and by 1200 UTC 13 October 2013 had a central pressure of 969 hPa compared to an observed value of 930 hPa. In contrast the Trial analysis central pressure was 935 hPa. Consequently Trial forecasts of central pressure were much better in most cases. However, this case illustrates a known characteristic of the MOGM in that it tends to continue deepening TCs beyond the point at which they reach their peak intensity in reality as they move towards the subtropics. This resulted in an over-deepening in some forecasts, particularly for the Trial. There were also a couple of Trial analyses which had large negative central pressure biases (i.e. low centres too deep). This can happen as a result of assimilating central pressure observations which have observation minus background values larger (in absolute terms) than the difference between observed and background *central* pressure due to a positional error in the location of the TC in the background field.

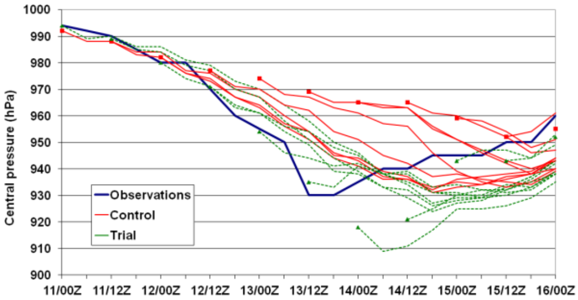

Figure 7. Control (solid red lines) and Trial (dashed green lines) central pressure forecasts plotted against best track observed data (solid blue line) for Typhoon Wipha (October 2013).
Trial included the new initialization technique.

Typhoon Haiyan devastated parts of central Philippines and was likely the most intense TC recorded at landfall (Lander, 2014). It occurred in November 2013 which fell during the latter part of the trial period. Control and Trial forecasts of the track of Typhoon Haiyan were both very good with 72 h to 96 h forecasts of landfall having an error around 100 km. Typhoon Haiyan went through rapid intensification with the central pressure dropping 60 hPa in 24 hours and 87 hPa in 48 hours. The MOGM was unable to simulate these extreme rates of deepening, even over a period of six hours – the length of forecast used as the 'background' for the next model cycle. Thus the observation minus background values for the central pressure observations created by the new initialization technique were very large. These observations are subject to the same quality control procedures as other conventional observations. On this basis, once rapid intensification of Typhoon Haiyan was underway (around 0600 UTC 5 December 2013) all central pressure observations were flagged due to large observation minus background values and were not assimilated into the model. The consequence of this is that the MOGM predictions of the central pressure from about 12-24 h after this point were no better in the Trial than the Control as seen in Figure 8.

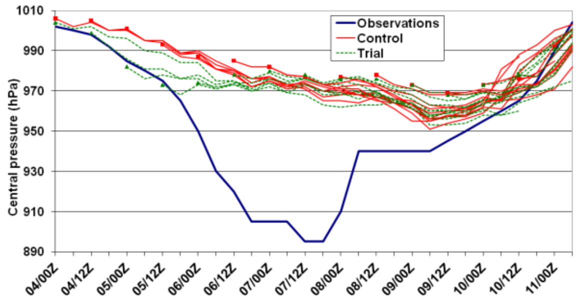

Figure 8. Control (solid red lines) and Trial (dashed green lines) central pressure forecasts plotted against best track observed data (solid blue line) for Typhoon Haiyan (November 2013).
Trial included the new initialization technique.

2.5. Conclusion from trial of the new TC initialization technique

The new TC initialization technique was developed primarily with the aim of reducing the weak bias in model forecast intensities at short lead times. Evidence from the trial indicates that this was achieved without causing a significant over-deepening at longer lead times. The technique was not developed with the primary aim to reduce TC track forecast errors. However, the trial track forecast errors were reduced by 6.2%.

The issue of central pressure observations being flagged by quality control when TCs rapidly intensify was seen in the case of Typhoon Haiyan and several other cases in the trial. Whilst this is not ideal, it is considered that in a case such as Typhoon Haiyan when the lowest central pressure value was close to 900 hPa and the pressure gradient near the centre of the TC was near 42 hPa over the distance of one model grid spacing (17 km) (Morgerman, 2014), it may not be appropriate to assimilate central pressure values in the current configuration of the MOGM. This is a matter which will be the subject of further investigation and experimentation.

The evidence from the trial presented above was considered in late 2014. Given the positive results overall the decision was taken to implement the new initialization technique in the MOGM on 3 February 2015.

3. OPERATIONAL IMPACT OF GA6 AND THE NEW TC INITIALIZATION TECHNIQUE

GA6 was implemented in the MOGM on 15 July 2014. Thus most of the 2014 northern hemisphere TC season occurred after the implementation date. The new initialization technique was implemented on 3 February 2015 meaning the whole of the 2015 northern hemisphere TC season occurred after implementation date. Hence, a time series of northern hemisphere TC forecast errors from the MOGM gives a good perspective on the impact of these two changes after they became operational.

The mean TC track forecast error for northern hemisphere TCs in 2014 was almost 25% lower than the mean for the previous five seasons (2009-13) and in 2015 was a further 3.2% below the 2014 figure. Even when examining the 5-year running mean of TC track forecast errors, which normally smooths out large interannual variability, there was still a sharp drop in the errors in 2014-15 as seen in Figure 9.

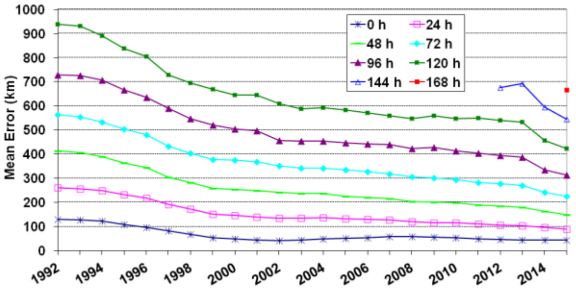

Figure 9. 5-year running mean of MOGM northern hemisphere TC track forecast errors.

Figure 10 shows the northern hemisphere TC central pressure bias for the years 2011 to 2015. In 2014, although analyses were still too weak, the central pressure bias dropped steadily with forecast lead time to a value close to zero by 168 h. In 2015 the bias in the analysis was more than halved compared to previous years and the bias in the forecast was also markedly reduced. At longer lead times (beyond 96 h), the bias was very close to zero.

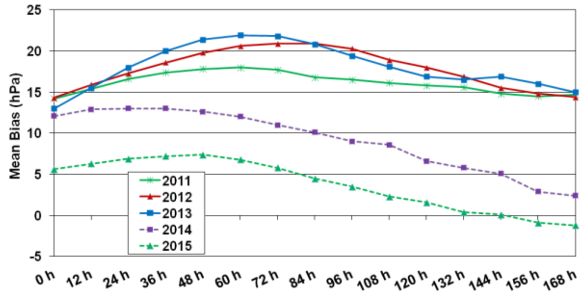

Figure 10. Mean TC central pressure bias in the northern hemisphere for the MOGM.

These operational results support the results seen in the separate trials of both GA6 and the new TC initialization technique and indicate that these two changes have had a significant positive impact on MOGM forecasts of both TC track and intensity.

4. SUMMARY

In 2014 a major model upgrade to model dynamics, physics, horizontal resolution and satellite data usage (GA6) was implemented. In 2015 this was followed by implementation of a new form of TC initialization involving assimilation of central pressure estimates. Results presented in this paper show that both of these changes resulted in significant reduction in TC forecast errors (for track, intensity or both) in forecasts from the MOGM.

Issues which require further research include how the new initialization technique handles rapidly intensifying TCs and the MOGM's propensity on occasions to continue deepening TCs beyond their actual point of peak intensity. This will be undertaken against a backdrop of wider model development which in coming years will include changes to the convective parametrization, further increases in horizontal and vertical resolution and coupling to the ocean, all of which are likely to impact upon TC forecast performance.

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