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# The Impact on Tropical Cyclone Predictions of a Major Upgrade to the Met Office Global Model

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## 1. BACKGROUND TO MODEL UPGRADE

The last major upgrade to the dynamical core of the Met Office Unified Model (MetUM) was in 2002. 'New Dynamics' as it was known included a package of changes to both the dynamical core and model physics and had a major positive impact on tropical cyclone (TC) predictions. Track forecast errors in the Met Office Global Model (MOGM), which is one configuration of the MetUM, were reduced by over 5% and a weakening bias was also significantly reduced (Heming & Greed, 2002).

Since that time there have been numerous model changes which have had some impact on TC predictions from the MOGM including introduction of new data sources, 4D-Var data assimilation, model physics upgrades and changes in both horizontal and vertical resolution (e.g. Heming, 2010). However, there have been no major changes to the dynamical core until a system known as ENDGame (Wood et. al., 2013), which is due for implementation in all configurations of the MetUM starting in 2014.

For the MOGM, the implementation of ENDGame is packaged with a number of other model and observational changes. Those likely to have the largest impact on TC prediction include an increased entrainment rate in deep convection and an increase in the forecast model horizontal resolution from approximately 25 km to 17 km at mid-latitudes. Co-incident with this, the resolution of the data assimilation scheme is also increased from approximately 60 km to 40 km.

## 2. RESULTS OF TRIALS OF THE MODEL CHANGE

The package of changes to the MOGM were put under trial for two periods from June to September 2012 and November to December 2012. All results below relate to a combination of these two trial periods. There were 36 TCs during the combined trial periods including 330 analyses, 170 72-hour forecasts and 55 144-hour forecasts.

In addition to a Control run which had the same model configuration and resolution as used operationally, there were two trial configurations. Both included the same package of model dynamics and physics changes, but one had the same horizontal resolution as the Control (approximately 25 km) and the other had the higher horizontal resolution of approximately 17 km. These trials will be referred to as Trial25 and Trial17 respectively. It is the Trial17 configuration which is due for implementation in 2014.

### *2.1 Track Forecasts*

Figure 1 shows the track forecast errors for all TCs during the trial periods. The Trials were clearly better than the Control at all lead times with an overall reduction in track forecast error of 7.3% for Trial25 and 8.6% for Trial17. Thus, the model changes provided most of the improvement, but the increase in resolution also made a small further reduction to errors. Skill scores against climatology and persistence (CLIPER) calculated for lead times up to 72 hours were also improved – by 3.8% for Trial25 and 4.5% for Trial17 in the MOGM.

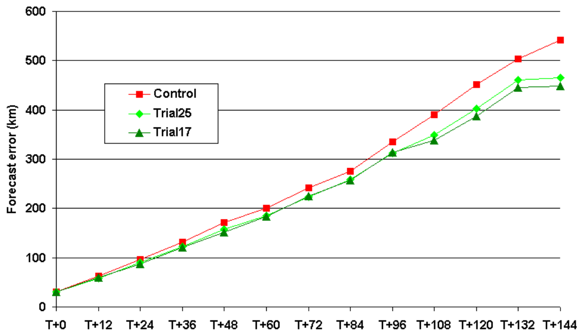


**Figure 1**. TC track forecast errors (km) for the Control and Trials

### *2.2 Intensity Forecasts*

Figures 2 and 3 show the mean values of central pressure and 10m wind during the trial periods. These show that the TC intensity in the analysis (T+0) was very similar for the Control and the Trials. However, there was a marked intensification of TCs in the Trials during the forecast compared to the Control which showed only a small intensification at longer lead times. Furthermore, model resolution had a much greater impact on intensity than it did on track as seen by the difference between the Trial25 and Trial17 results.

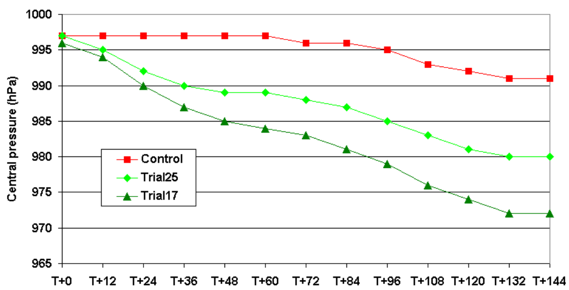


**Figure 2**. Mean TC central pressure (hPa) for Control and Trials

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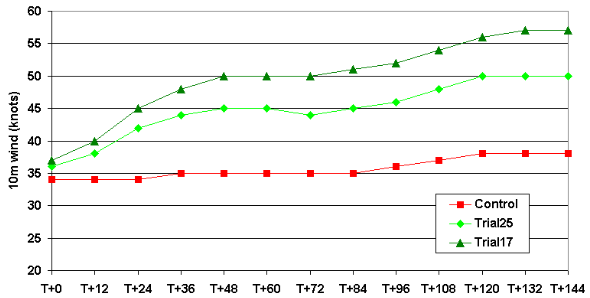


**Figure 3**. Mean TC 10m wind speed (knots) for Control and Trials

In order to understand the nature of this apparent 'spin up' of TCs in the Trial forecasts, Figures 4 and 5 show the mean error of central pressure and 10m winds when compared with estimated values from TC warning centres (e.g. National Hurricane Center (NHC), Japan Meteorological Agency, Joint Typhoon Warning Center). These indicate that TCs were too weak in the analysis for both the Control and the Trials, but the errors reduced during the forecast in the Trials. The central pressure error actually became negative at long lead times for Trial17 indicating predicted values were lower than observed values on average. However, this result is heavily influenced by one case discussed in section 3.3 below.

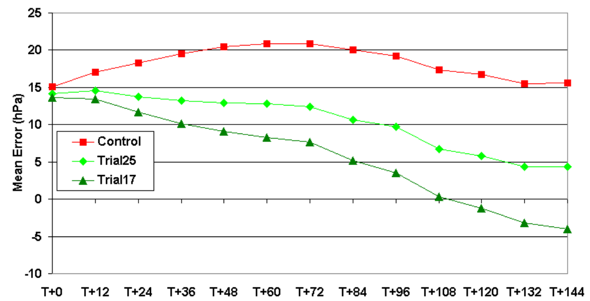


**Figure 4**. Forecast mean central pressure error against observations (hPa) for Control and Trials

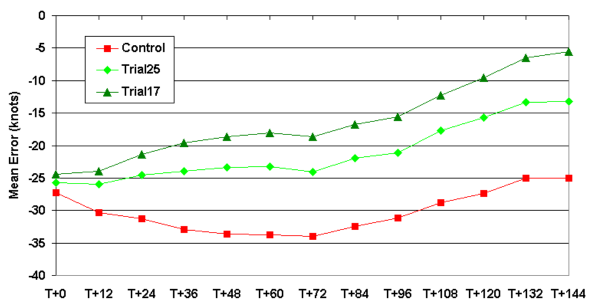


**Figure 5**. Forecast mean near surface wind speed error (knots) against observations for Control and Trials

When averaged over all forecast lead times TCs were 7.1 hPa and 8.9 knots stronger in Trial25 and 11.1 hPa and 13.4 knots stronger in Trial17 than the Control. Overall, mean absolute errors in intensity forecasts were reduced by 3.0 hPa and 6.7 knots in Trial25 and 3.6 hPa and 9.0 knots in Trial17.

These results show that the model changes have little impact on intensity of TCs in the analysis – they are still far too weak. However, the Trials do improve the intensity of TCs in the forecast. This manifests itself as an apparent 'spin-up' of TCs in the forecast as the intensity moves closer to reality.

### *2.3 Comparison with ECMWF*

In the last decade the European Centre for Medium-range weather Forecasts (ECMWF) TC track forecast errors have been consistently lower than those from the MOGM (Heming, 2012). Furthermore, the forecast intensity of TCs in the ECMWF model is higher and closer to reality than the MOGM. ECMWF TC forecasts have also consistently shown the lowest errors in intercomparisons of all major numerical models (Muroi, 2012). Thus it is useful to compare the impact of the proposed changes to the MOGM with the ECMWF model performance.

For the trial periods being considered here the ECMWF forecasts were compared with both the Control and Trial17 results. For track predictions it was found that Control errors were on average 29.6% larger than ECMWF, but this deficit was cut to 18.9% in Trial17. For intensity, the differences between the models were reduced by an even greater margin. For example, Control TCs were on average 13.7 hPa and 13.0 knots weaker than ECMWF, but Trial17 forecasts of central pressure were only 2.4 hPa weaker and 10m winds were actually 0.3 knots stronger than ECMWF on average.

In a comparison of mean absolute forecast errors against observations for TC intensity, Control errors were 4.6 hPa and 9.1 knots larger than ECMWF. However, Trial17 errors were only 1.1 hPa and 0.2 knots larger than ECMWF.

Thus Trial17 cut the advantage that ECMWF had over the MOGM for predictions of TC track and in particular predictions of TC intensity.

## 3. CASE STUDIES

Several of the TCs which occurred during the trial periods show some interesting aspects of the impact of the model changes and are discussed below.

### *3.1 Typhoon Bopha*

Typhoon Bopha was a compact, but intense TC which tracked at low latitude in the western North Pacific making landfall over the southern Philippine island of Mindanao. At landfall the 1-minute average sustained wind speed was estimated at 140 knots and central pressure 930 hPa.

The Trial17 track of Bopha was far superior to the Control, persistently tracking Bopha across Mindanao, whereas the Control tended to turn Bopha north too soon making landfall over the central Philippines or not at all. Mean track forecast errors for Trial17 were 52% lower than the Control. The mean 144-hour track error for Trial17 was 233 km compared to a value of 650 km for the Control. Figure 6 is an example of the superior Trial17 track from one particular forecast.

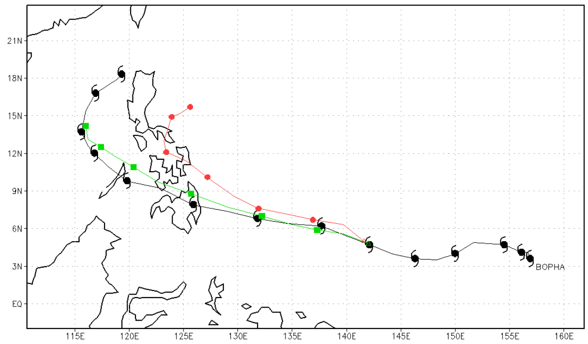


**Figure 6**. Typhoon Bopha forecast tracks from data time (DT) 0000 UTC 01 December 2012
Black: Observed, Red: Control, Green: Trial17. All symbols 24-hourly.

Figures 7 and 8 show the forecasts of central pressure and 10m wind speed for the Control and Trial17. These indicate that the Control prediction of intensity was very poor with no forecast predicting a central pressure below 995 hPa nor winds above 40 knots. Trial17, despite only slightly stronger analyses, did forecast a more intense TC with a central pressure as low as 969 hPa and winds over 70 knots. However, these values were still well short of the peak values which Bopha achieved when at its strongest. Figure 9 shows a 120-hour forecast for Typhoon Bopha and illustrates a large difference in central pressure (30 hPa) between the Control and Trial17 as well as a better position for Trial17.

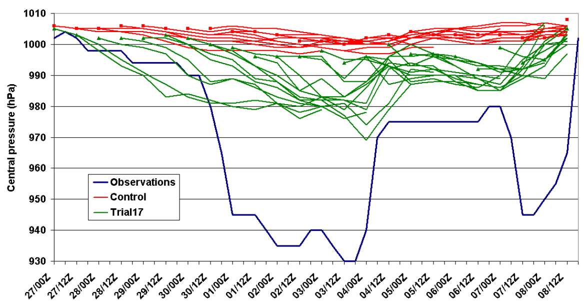


**Figure 7**. Time series of forecast central pressure for Typhoon Bopha for the Control and Trial17 November-December 2012

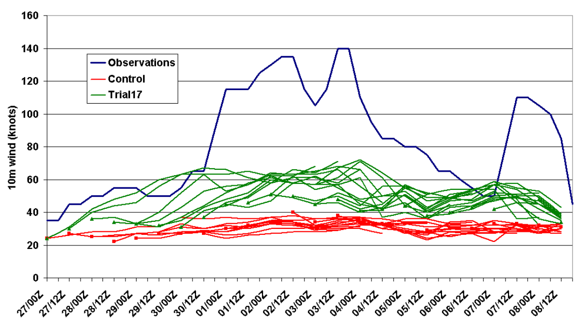


**Figure 8**. Time series of forecast 10m wind speed for Typhoon Bopha for the Control and Trial17 November-December 2012

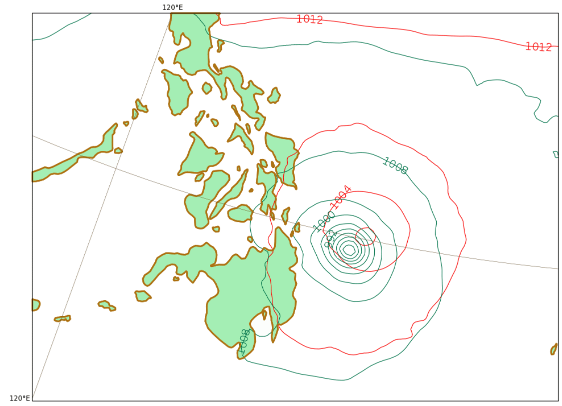

**Figure 9**. Typhoon Bopha 120-hour forecast from DT 0000 UTC 29 November 2012
Red: Control, Green: Trial17

### *3.2 Typhoon Bolaven*

Typhoon Bolaven was a large TC in the western North Pacific which reached a peak intensity of 910 hPa and 125 knots east of Taiwan before gradually weakening as it moved to higher latitudes, making landfall over the North Korea/China border region. Figure 10 shows the track of the TC and its observed central pressure at certain stages in its life. Mean track forecast errors for Trial17 were 35% lower than the Control, mostly as a result of reducing a leftwards bias in forecast tracks.

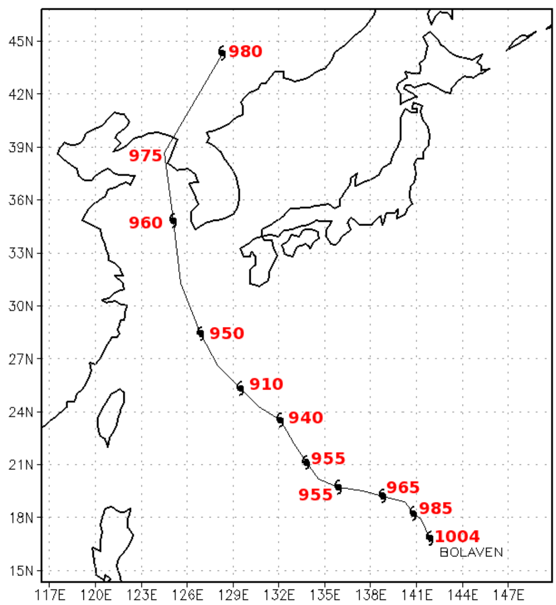


**Figure 10**. Typhoon Bolaven observed track and central pressure values (hPa). Symbols are 24 hours apart starting at 0000 UTC 20 August 2012

The time series of forecast predictions of central pressure in Figure 11 firstly shows that Trial17 analyses were still only slightly stronger than the Control, as was seen in the Typhoon Bopha case. However, Trial17 gave a much better prediction of intensity with many forecasts of central pressure lower than 950 hPa and a lowest value of 922 hPa. Although Trial17 forecast values of intensity were closer to observed values, the forecast peak in intensity occurred just prior to landfall near latitude 40°N and not several days earlier near 25°N as actually occurred. Thus for many forecasts, Trial17 actually overdeepened the typhoon at higher latitudes. The Control exhibited the same error in timing and location of peak intensity, but due to its much slower rate of intensification did not feature overdeepening in the majority of forecasts. Following on from the earlier comparison with ECMWF, it is worth noting that the ECMWF model also had the same problem. Peak intensity was predicted to occur just prior to landfall up to two days late and with central pressure values as low as 904 hPa.

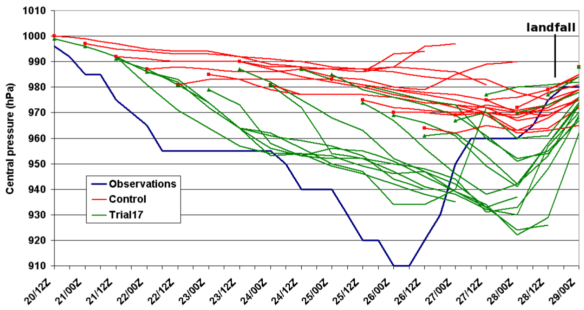


**Figure 11**. Time series of forecast central pressure for Typhoon Bolaven for the Control and Trial17 August 2012

### *3.3 Hurricane Leslie*

Hurricane Leslie formed from an easterly wave in the Atlantic and turned north prior to reaching the Lesser Antilles. It stalled for several days just south of Bermuda before accelerating northwards and making landfall over Newfoundland as shown in Figure 12.

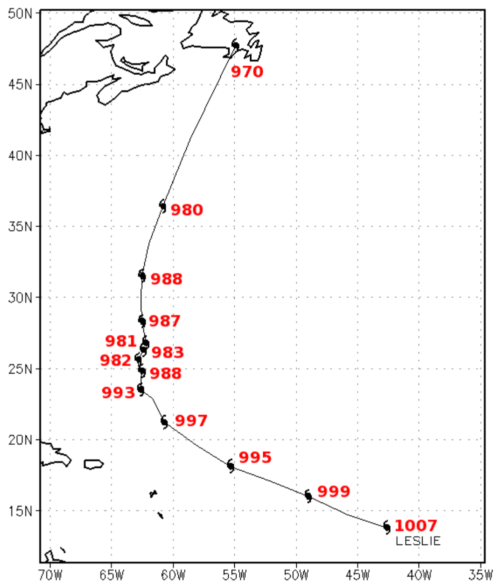


**Figure 12**. Hurricane Leslie observed track and central pressure values (hPa). Symbols are 24 hours apart starting at 1200 UTC 30 August 2012

Trial17 predicted the slow movement of Hurricane Leslie when south of Bermuda better than the Control. Overall, mean track forecast errors were 25% lower in Trial17 compared to the Control. However, Trial17 significantly overdeepened the hurricane as shown in Figure 13. In reality Leslie only underwent modest strengthening to a central pressure of 981 hPa during its main 'tropical' phase. Trial17 predicted a central pressure as low as 928 hPa. Even the Control overdeepened Leslie in several runs and it is likely that in this instance the quasi-stationary motion for a period of several days was a major contributory factor. In reality this slow movement caused upwelling of cooler water and thus inhibited strengthening. Observational data quoted in NHC advisories suggested that the sea surface temperature (SST) under the centre of the hurricane was reduced by up to 5°C by upwelling. The MOGM is an atmosphere only model which uses fixed SSTs. Thus the model could not simulate upwelling of cooler water and its impact on the atmospheric circulation. Since the Trial17 configuration is much more energetic in its treatment of TCs than the Control the overdeepening was much more noticeable. As for the Typhoon Bolaven case, the ECMWF model also significantly overdeepened Hurricane Leslie and at its most intense predicted a central pressure of 913 hPa.

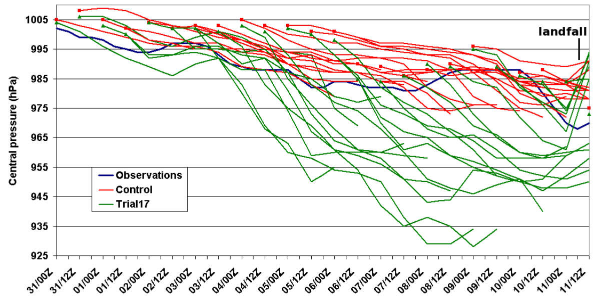


**Figure 13**. Time series of forecast central pressure for Hurricane Leslie for the Control and Trial17 August-September 2012

The overdeepening of Hurricane Leslie was exceptional and the majority of TCs in the trial periods were still too weak even in the Trial17 forecasts. However, the overdeepening of Leslie was so large that it did have a noticeable impact on some of the overall scores shown previously. For example, without the Leslie case the Trial17 forecast mean error against observations shown in Figure 4 does not dip below zero at longer lead times.

## 4. FUTURE WORK

Despite the new model configuration producing much better forecasts of TC intensity there was only a modest improvement to the analysed intensity of TCs. This suggests that there may be an underlying data assimilation issue which needs to be addressed. In addition to investigating this wider issue, there are plans to evaluate the benefit to model predictions of assimilating central pressure estimates from TC warning centres.

The stronger TCs seen in the new model configuration has highlighted a pre-existing problem in prediction of the timing of peak intensity for TCs which do not make landfall at low latitudes, but go on to weaken over the ocean as they progress polewards. This is an issue which requires further investigation.

There is ongoing work at the Met Office into development of a fully coupled atmosphere-ocean numerical weather prediction model. The case of Hurricane Leslie highlights a possible consequence of using an atmosphere only model with fixed SSTs for TC prediction. This case will be used in trials of the coupled model to evaluate the benefit of including ocean feedbacks.

**5. SUMMARY**

A major upgrade to the MOGM that is planned for implementation in 2014 is set to produce the single biggest impact of any model change on TC predictions in 20 years. Based on results in trials, track forecast errors are likely to be significantly reduced. TCs will also be more intense, particularly at longer forecast lead times. Overdeepening of TCs in the forecast is now possible in certain circumstances, but overall TCs are still expected to be too weak. However, the weak bias in TC forecasts is considerably reduced by the package of changes. The advantage ECMWF has held over MOGM in recent years for TC prediction is also considerably reduced, particularly for intensity. Thus overall, the package of changes is seen as a significant step forwards in improving the accuracy of predictions of TCs from the MOGM.

**6. REFERENCES**

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