MOSAC

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SESSION 2

PAPER No 9.3

Title: Recent Severe Weather Events and Performance of the NWP System

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Introduction
August and September 2004 saw a large number of severe weather events both in the UK and other parts of the world. Several hurricanes made landfall in the USA and Caribbean causing many fatalities and widespread damage to property. Several Atlantic hurricanes underwent extra-tropical transition and contributed to what was already a very unsettled spell across the UK. Other large scale and mesoscale rain events during August brought flooding to many areas of the UK. Elsewhere, severe flooding was produced by several days of heavy rain in Central China. This paper will examine the performance of the Met Office NWP system in forecasting some of these events.

Tropical Cyclones
After a quiet start (no tropical cyclones in June or July) August saw near record tropical cyclone (TC) activity in the Atlantic with 8 tropical storms, 4 becoming hurricanes and 3 major hurricanes (Category 3-4-5). September had more named storm days and major hurricane days than any September since 1950 (Gray and Klotzbach, 2004a and b). Of the 12 tropical storms which occurred in August and September 2004, 7 made landfall over the USA; 3 as tropical storms, 4 as hurricanes of which 3 were major hurricanes. Mean track forecast errors and skill scores for all 12 of these Atlantic tropical cyclones are shown in Table 1.

<table>
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<td>44</td>
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Table 1. Track forecast errors (km) and skill scores (%) for Atlantic TCs A to L, 2004 and mean figures for 2003 Atlantic season

These figures show that for all 12 TCs the track forecast errors and skill scores are similar to those from the 2003 season except at T+96 when this year’s errors were lower by 16%. A few individual cases are examined below.

1. Hurricane Charley
Mean track forecast errors were above average for Hurricane Charley, which proved to be unpredictable at certain stages. Global model forecasts were excellent at the 84-hour and 24-hour lead times, but were poor at times in between. The interaction with Tropical Storm Bonnie may have been responsible for the model’s unpredictable behaviour. The Met Office global model 00Z tracks can be found at Figure 1. The TC ensemble tracks produced by ECMWF should provide useful information on predictability, but in this case they were not of great value. Figure 2 shows tracks from the 12Z 11 August run where all ensemble tracks were to the left of the deterministic track which itself was well left of the actual track of the TC. Previous evaluation of ECMWF TC ensembles found that the spread was not great enough, but there were often outlier tracks (Heming et. al., 2004). Changes made by ECMWF on 28 September 2004 were aimed to address some of the known problems with the TC ensemble prediction system (ECMWF, 2004).

2. Hurricane Ivan
Whilst there was a right-of-track bias in models (Met Office and others), the last few forecasts prior to landfall over the USA were excellent (Figure 3). The landfall location was predicted accurately in all but one forecast up to 96 hours ahead and all track forecast errors were less than 70km up to 72 hours ahead.

A trial high resolution (17km) simulation of Hurricane Ivan gave a much better representation of its strength at landfall. The 24-hour global model prediction had a central pressure of 990mb and peak 10m wind of 43 knots. The 17km model had 962mb and 70 knots. The observed values at landfall were 943mb and 105 knots. The 17km model also had a good representation of the hurricane’s eye in the 10m wind field (see Figures 4 and 5). Rainfall predictions in the 17km model were also much better when compared with TRMM (not shown).
3. **Hurricane Jeanne**

Jeanne caused its greatest devastation as a tropical storm just a couple of days after formation. Met Office global model forecasts predicted that the centre of the storm would skirt north of Hispaniola, whereas it actually passed over the island causing devastating floods and large loss of life. It has been observed in the past that the global model handles mature and strong TCs much better than developing weaker tropical storms such as in this case. Table 1 includes track forecast errors for Atlantic TCs A-L, but just for cases where the TC was a hurricane at verifying time. This shows that track forecast errors were far lower than when the weaker cases are included. Later forecasts for Hurricane Jeanne were generally good. In particular, the slow loop and westward turn was predicted well at the time that the USA GFS model was predicting rapid acceleration to the north-east (not shown).

**Extra-tropical Transition**

During a typical Atlantic hurricane season a few hurricanes will undergo extra-tropical transition as they recurve and head north and east towards Western Europe. This season has seen a high proportion of events which have either undergone complete extra-tropical transition or whose remnants have enhanced the development of mid-latitude lows which have formed off the North American coast. Of the 12 Atlantic TCs in August and September, 10 of them impacted mid-latitude developments in some way. A few of these cases are examined here.

1. **Hurricane Alex**

At long lead times (96 hours and greater) the mistiming of the entry of Hurricane Alex into the mid-latitude jet resulted in some large errors in the forecast evolution of the extra-tropical system near the UK. Figure 6 shows the analysis for 12Z 8 August 2004 where ex-Hurricane Alex is a mature cut-off low to the west of the UK. Figure 7 shows the 120-hour forecast verifying at this time and depicts ex-Hurricane Alex as a shallow wave to the west of Biscay. However, forecasts at lead times shorter than 96 hours were very good. Figure 8 shows the 84-hour forecast which is good in terms of both position and depth of the low.

2. **Tropical Storm Bonnie**

On 16 August 2004 ex-Tropical Storm Bonnie had formed into an elongated area of low pressure on the cold side of the jet near Greenland (see Figure 9). Forecasts for this situation at lead times of 72 hours and greater were erratic due to complex interactions between ex-Tropical Storm Bonnie, ex-Hurricane Charley and the mid-latitude jet. Figure 10 shows a 96-hour forecast with a deeper ex-Tropical Storm Bonnie and more buckled jet with associated downstream differences near to the UK and over Scandinavia. However, at lead times shorter than 72 hours the large scale developments were well predicted (see Figure 11). These forecasts were for the day of the Boscastle floods (see later). Three days later ex-Tropical Storm Bonnie directly affected the UK and the global model predicted the large scale pattern for this time very well up to 120 hours ahead (charts not shown).

3. **Hurricane Danielle**

Hurricane Danielle threatened to undergo extra-tropical transition and affect the UK and this was indicated by a 120-hour forecast verifying on 22 August. However, this did not occur and Danielle drifted in the sub-tropics for a while before dissipation (see Figures 12 and 13). Whilst the 120-hour forecast was poor, forecasts at lead times of 96 hours and shorter correctly predicted that Danielle would not undergo extra-tropical transition. See the 48-hour forecast at Figure 14.

**Chinese Floods**

Severe Flooding was experienced in the central Chinese province of Chongqing on 3-9 September 2004 (Guardian, 2004). A peak total of 327.3mm of rain was recorded over 3 days. An evaluation was made of the global model’s precipitation forecasts leading up to the event. Nine successive forecasts (starting 12Z 1 September) of 72-hour rainfall accumulations from the model yielded peak values of 240-320mm over this area. Figure 15 shows the 72-hour accumulation from the 12Z 3 September forecast. These results indicate that the global model gave a useful prediction of the heavy rainfall which occurred.
Larger Scale UK Events
A number of the rain events which occurred during August were associated with large scale developments and were reasonably well handled by the current 12km resolution mesoscale model.

1. Central Scotland Rainfall
Figures 16 and 17 show the radar rainfall for 12Z 10 August and 12-hour forecast from the mesoscale model verifying at this time. The spread and intensity of the rainfall across central and southern Scotland and Northern Ireland were well forecast at this time. Earlier forecasts (not shown) had shown a timing error in the rainfall forecasts.

2. South Wales Rainfall
Figures 18 and 19 show the rainfall radar for 00Z 12 August and 12-hour forecast from the mesoscale model verifying at this time. The event is fairly well captured at this time, although the heaviest rain over South Wales was too far east in the forecast. Earlier forecasts (not shown) had the rain band in the correct place, but did not show the intensities which actually occurred.

3. North-West England Rainfall
Figures 20 and 21 show the rainfall radar for 16Z 12 August and 15-hour forecast from the mesoscale model verifying near this time. Whilst the large scale rain event was captured (with some error over North-East England), the model did not capture the small scale convective events occurring across the Midlands and North-West England at the time. The model’s convective precipitation was generally light and too widespread.

Convective Scale UK Events
Some of the severe weather events which occurred across the UK in August were of a convective scale, such that the current 12km resolution mesoscale model was able to provide little or no useful guidance.

1. West London and High Wycombe Rainfall
On 3 August an area of heavy thunderstorms broke out between West London and the Severn Estuary. Exceptionally heavy rain was experienced in parts of West London and at High Wycombe (42.4mm in 38 minutes). Figures 22 to 25 show the predicted 6-hour accumulations from the 12km mesoscale model and experimental 4km and 1km versions of the model, along with the Nimrod accumulations. These indicate the inability of the 12km model, with parametrized convection, to represent the local extremes in precipitation captured better by the explicit convection in the 4km and 1km models.

2. Boscastle Floods
On 16 August a period of exceptionally heavy rain (152.2mm in 4.5 hours) occurred in North Cornwall which led to the severe floods in Boscastle. Figures 26 to 29 show the predicted accumulations between 12Z and 18Z from a rerun 00Z forecast from the 12km mesoscale model and experimental 4km and 1km versions of the model, along with the radar accumulations. This again indicates the inability of the 12km model to represent the convective scale orographically enhanced rainfall which occurred. The 4km model gave higher accumulations than the 1km model, but spread these high values too far to the north-east. The 1km model peak accumulations were accurately located. The 4km model was able to represent the low level convergence which occurred along the north coast of Cornwall whereas the 12km model could only represent the broad scale south-westerly flow which was present in the area on that day (not shown).

Future Plans
The introduction of 4D-Var to the global model in October 2004 has already improved the capability of the NWP system in the time since the extreme weather events discussed above. Verification of the pre-operational trial showed improvements particularly in the storm track regions and in cases with largest errors (NWP Gazette, October 2004). TC track errors were also reduced by 4D-Var in the trial by an average 3.6%.

Improvements in the forecast of future extreme weather events by the current NWP system will be dependent on further development of data assimilation, model dynamics and resolution, which is covered in
Papers 9.1, 9.2 and 9.4. In addition, the Met Office’s involvement in THORPEX will include the development of multi-model ensembles, targeted observations, global and regional model ensembles and relocatable regional models. These will be used in the development of decision-making tools to mitigate the impact of natural disasters. This is discussed further in Paper 9.5.

Finally, the experimental results presented in this paper for small-scale convective events have prompted the advancement of plans to introduce an operational 4km resolution model as soon as supercomputer resources allow in 2005.

Summary
1. The recent spate of Atlantic hurricanes was generally well forecast by the global model with track forecast errors near to the recent average. The global model handled mature, strong TCs better than weak TCs. Experimental 17km resolution simulations of Hurricane Ivan gave a much improved forecast of its strength and rainfall at landfall.

2. Extra-tropical transition of Atlantic hurricanes introduces greater uncertainty into mid-latitude forecast developments at days 3-4 and beyond. Ex-hurricanes can amplify pre-existing errors in the mid-latitude flow and errors in the track of ex-hurricanes can be amplified by acceleration into the mid-latitude flow. At lead times shorter than 72 hours, the global model did a good job in handling extra-tropical transition in the majority of cases.

3. The global model gave a good indication of the large scale rainfall event resulting in floods over Central China.

4. The operational (12km resolution) mesoscale model was able to give useful guidance during some the larger scale heavy rain events which occurred in August across the UK.

5. The operational (12km resolution) mesoscale model tends to produce convection which is too widespread and was unable to predict small scale convective events such as that which led to the Boscastle floods. Experimental 4km and 1km resolution models did a much better job at predicting these small scale events, although evaluation during normal conditions as well as extreme events is required to assess the false alarm rate from these configurations of the model.

6. The introduction of 4D-Var, data assimilation and dynamics development in the NWP system, participation in THORPEX and the operational implementation of a 4km resolution model will all impact the capability to predict extreme weather events in the future.

Acknowledgements
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References
ECMWF, 2004. Data assimilation and forecast model changes (Cy28r3).


Figures

Figure 1: Hurricane Charley observed and global model forecast positions from 00Z runs

Figure 2: Hurricane Charley ECMWF ensemble tracks and deterministic forecast, 12Z 11 August 2004
Figure 3: Hurricane Ivan observed and global model forecast positions from 12Z runs

Figures 4 and 5: Hurricane Ivan global model (left) and 17km model (right) 24-hour forecast 10m winds
Figure 6: 12Z 8 August 2004 analysis

Figure 7: 120-hour forecast verifying at 12Z 8 August 2004

Figure 8: 84-hour forecast verifying at 12Z 8 August 2004
Figure 9: 00Z 16 August 2004 analysis

Figure 10: 96-hour forecast verifying at 00Z 16 August 2004

Figure 11: 60-hour forecast verifying at 00Z 16 August 2004
Figure 12: 00Z 22 August 2004 analysis

Figure 13: 120-hour forecast verifying at 00Z 22 August 2004

Figure 14: 48-hour forecast verifying at 00Z 22 August 2004
Figure 15: 12Z 3 September 2004 global model 0-72-hour rainfall accumulation

Figures 16 and 17: 12Z 10 August 2004 rainfall radar (left) and 12-hour mesoscale model forecast (right)

Figures 18 and 19: 00Z 12 August 2004 rainfall radar (left) and 12-hour mesoscale model forecast (right)
Figures 20 and 21: 16Z 12 August 2004 rainfall radar (left) and 15-hour mesoscale model forecast (right)

Figures 22 to 24: 09Z 3 August 2004 12-18Z forecast rainfall accumulations:
12 km model (left), 4km model (centre), 1km model (right)

Figures 25: 12-18Z 3 August 2004 Nimrod rainfall accumulations
Figures 26 to 28: 00Z 16 August 2004 12-18Z forecast rainfall accumulations:
12 km model (left), 4km model (centre), 1km model (right)

Figures 29: 12-18Z 3 August 2004 Radar rainfall accumulations