**129 PROBABILISTIC GLOBAL CONVECTIVE HAZARD FORECASTS AND VERIFICATION**

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## 1. INTRODUCTION

The Met Office has a role in providing advice on the potential for hazardous global weather to the UK government, the Foreign Commonwealth Office (FCO) and to Non-Governmental Organisations (NGO's) overseas. The Met Office produces a range of forecasts for severe convection diagnostics using its in-house Convection Diagnosis Procedure (CDP) system (Hand, 2010). The system was initially set up to run using deterministic model data, however in 2012 the system was developed to run an extended trial using the model output from the Met Office Global and Regional Ensemble Prediction System in the global configuration (MOGREPS-G).

This study assesses the performance of several of the hazard diagnostics in the CDP at locations around the world. Objective verification investigates the skill and reliability of lightning forecasts over Europe. Lightning can be critical to the aviation industry. Therefore accurate lightning forecasts are an important component of aviation forecasting. This verification is specifically carried out for civil airports across Europe throughout the 2013 summer (June-August). Additionally subjective verification is used to assess the model performance for selected cases during the 2013 tornado season in the United States and for a severe hail case study in Australia. The purpose of this is to identify strengths and potential improvements to the diagnostics.

## 2. USING THE CDP IN MOGREPS-G

MOGREPS-G is the global configuration of the Met Office ensemble system. The model consists of 12 members at 33km horizontal resolution with 70 vertical levels. Running the CDP with the global ensemble generates 6 probabilistic severe weather diagnostics. These consist of hazard specific diagnostics forecasting the risk of lightning, hail and tornadoes and thresholds of surface-based CAPE (Convective Available Potential Energy), Lifted Index and precipitable water.

The CDP is run daily with the 0Z and 06Z runs of MOGREPS-G only, with forecast lead times of T+12, 18, 24, 30, 36, 42, 48 and 60. The diagnostics are produced as a probability of occurrence and plotted on a global map as in the sample case in Figure 1.

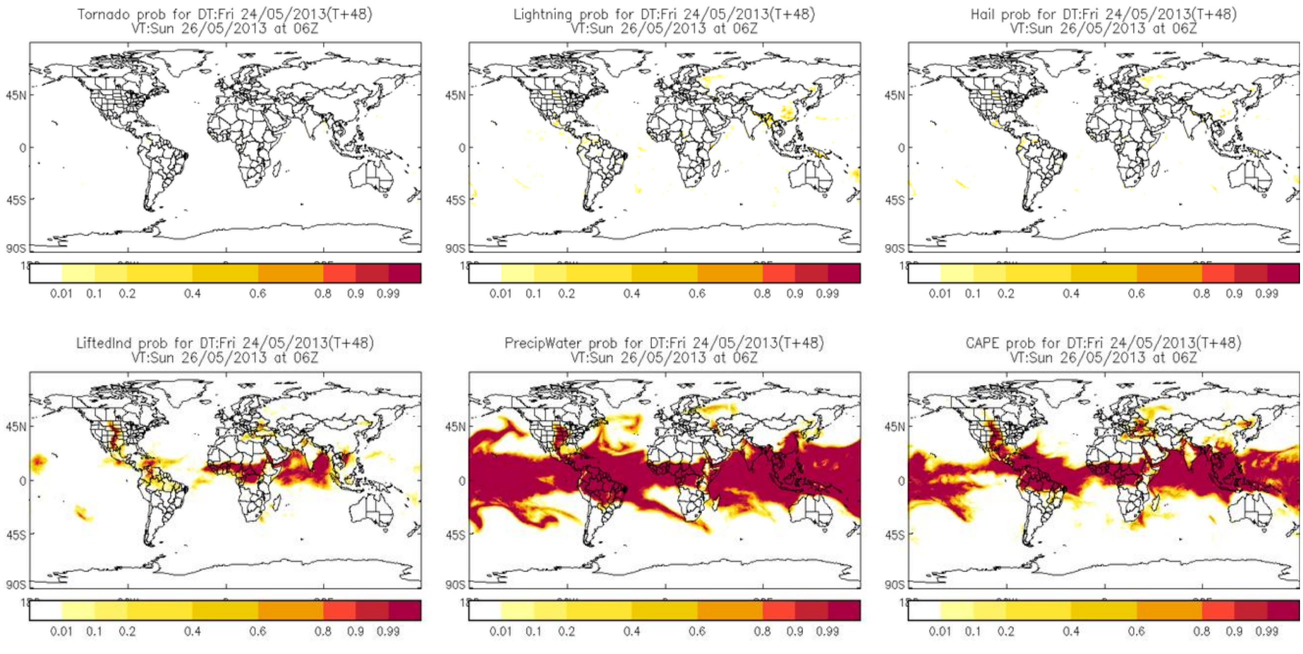


**Figure 1: MOGREPS-G convective forecasts for 26/05/2013 at 6Z.**

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All of the convective hazard diagnostics are run for each of the 12 ensemble members enabling a probability to be calculated based on how many members exceed a specific threshold. In future trials it is hoped to take advantage of lagging the last 2 runs to make a 24 member ensemble to generate probabilities from.

### 2.1 Lightning Diagnostic

The lightning diagnostic calculates the risk of lightning occurring using the Lightning Index (LI). The lightning index has 3 outcomes: 0, 1 or 10. A lightning index value of 0 indicates that lightning is unlikely and remains the default value unless there is at least 200J/kg of CAPE and the model is forecasting precipitation in that area. A lightning index value of 1 highlights a risk of lightning and typically corresponds to areas of high rainfall or the release of potential instability aloft in frontal zones. An index of 1 is set when either of the following environmental conditions are satisfied. Firstly when the wet-bulb potential temperature at -20°C is less than that at the freezing level and the model precipitation rate is greater than 10.0mm/hr. Secondly where the convective cloud top, base and depth exceed certain thresholds, CAPE is greater than 365J/kg and model precipitation rate is greater than 0.5mm/hr. Finally the most significant outcome is a lightning index of 10, this indicates a deep convectively unstable environment with lightning possible. This value is set when conditions for a value of LI1 are satisfied, CAPE in the thermo-electric layer (0°C to -20°C) is greater than 365J/kg and a relative humidity threshold is exceeded. When the lightning diagnostic is run with MOGREPS-G a probability of LI ≥ 10 and LI ≥ 1 is produced.

### 2.2 Hail Diagnostic

The hail diagnostic derives the probability of hail greater than 10mm in diameter. This is calculated using the technique of Miller (1953) and adapted as reported by Hand and Cappelluti (2010). Hail is only diagnosed if the model precipitation rate is greater than 0.5mm/hr and lifted index is greater than 0. This ensures that any forecasted hail is fixed to precipitating areas with deep convective instability. If these conditions are not satisfied the probability of hail is set to 0.

### 2.3 Tornado Diagnostic

The tornado diagnostic produces a probability of tornadic activity based on the probability of exceeding specified values of the Fuzzy Tornado Parameter (FTP). Firstly the FTP assesses for severe storm conditions by which the following conditions are satisfied. Rainfall rate > 0.5mm/hr and CAPE, Lifted Index and precipitable water exceed the minimum thresholds as in Table 1.

**Table 1: Thresholds used for the Fuzzy Tornado Parameter.**

| | |
|---|---|
| CAPE min | 500 $Jkg^{-1}$ |
| CAPE max | 3000 $Jkg^{-1}$ |
| Precipitable water min | 30mm |
| Precipitable water max | 40mm |
| Lifted index min | -3 |
| Lifted index max | -10 |

If these conditions are met the FTP is calculated using the following formula:

$$[(CAPE-CAPEmin)/(CAPEmax\ CAPEmin)] * [(PW-PWmin)/(PWmax-PWmin)] * [(LI-LImin)/(LImax-LImin)]$$

A second step is implemented in order to capture the threat of weaker tornadoes developing in less severe criteria. This step is necessary when the FTP < 1.0. The diagnostic calculates the Significant Tornado Parameter (STP) (Thomson et al, 2002), where a significant tornado would produce EF2 (Enhanced Fujita) or greater damage. The STP uses CAPE, 0-6km Bulk Wind Shear, 0-1km Storm-Relative Helicity, Lifting Condensation Level and CIN (Convective Inhibition) to indicate the presence of conditions capable of producing EF2-EF5 tornadoes. When the STP > 2.0 and various thresholds for rainfall rate, CAPE, Storm-Relative Helicity and several convective cloud conditions are met the FTP is adjusted to 1.0.

## 3. VERIFICATION

### 3.1 Lightning in Europe

Due to the importance of convective hazards to the aviation industry, the focus of this objective verification is the performance of the lightning diagnostic within a certain radius of civil airports across Europe. The 1116 civil airports used are displayed in Figure 2. The verification period covers June, July and August 2013. Forecasts valid at 18Z were used from the 0Z model run, therefore with a lead time of 18 hours. Throughout the summer months lightning across Europe is of greatest intensity due to the greater surface temperatures and instabilities in the atmosphere.

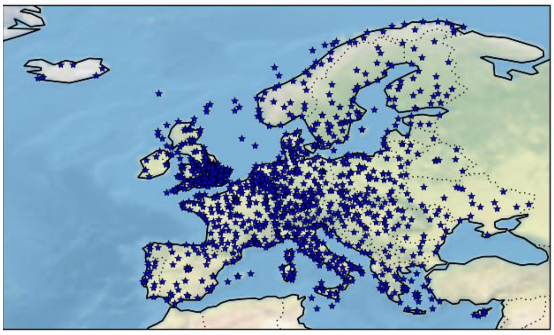

**Figure 2: Distribution of civil airports across Europe.**

The Met Office operates the Arrival Time Difference Network (ATDnet) system, an automatic lightning location network that senses lightning strokes over a geographical area. Lightning strokes are located by timing the arrival of the unique low frequency radio waves ('Sferics') produced by a singe stroke at the ATDnet outstations. The difference in the arrival times between two stations is then used to construct a hyperbola plot showing where the stroke could have occurred. This is repeated for all available stations. At least four stations must detect the stroke in order to minimise the detection of rogue strokes. The intersection point of the hyperbolae indicates the location of the lightning stroke, the system then registers the latitude, longitude and time of the stroke. For the purpose of this verification a stroke count was processed to give the number of strokes within a 50km radius of each airport over a 6 hour period. A lightning event is then classified by a stroke count of 2 or more at a given airport, this threshold allows for any potential spurious strokes that may have been registered by the system.

The CDP lightning diagnostic produces a probability of lightning index exceeding 10 and 1, both thresholds have been verified in order to assess the potential of any lightning event. For each airport a single probability has been derived from the model. In order to consider all forecasts within a 50km radius of the airport, the maximum value of five grid points surrounding the airport was derived. The grid points consist of the grid point in closest proximity to the airport and the 4 grid points directly to the north, south, east and west of central point (Figure 3). A hit is classified when a non- zero probability of lightning is forecast for the given threshold.

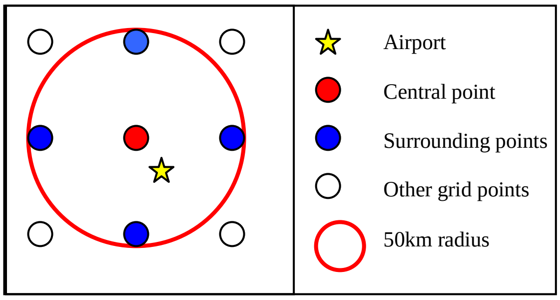


**Figure 3: Grid points used to produce a single forecast value for a 50km radius around each airport.**

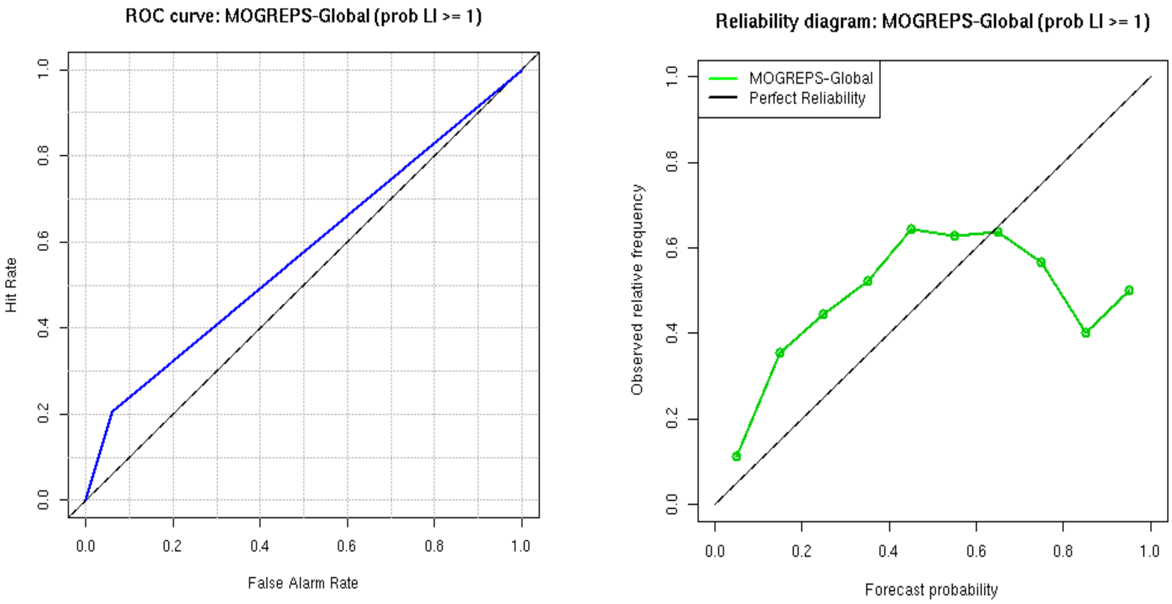


**Figure 4: ROC curve for the probability of LI ≥ 1 (left). Reliability diagram for the probability of LI ≥ 1 (right).**

The verification of the lightning diagnostic is displayed using the Receiver Operating Characteristic (ROC) curve and the reliability diagram. The ROC curve assesses the ability of the forecast to discriminate between a lightning event and a non lightning event. A forecast with perfect skill would produce a curve that travels from bottom left to top left to top right. The reliability diagram displays how well the predicted probabilities of an event correspond to their observed frequencies. Further information on verification statistics is explained in Forecast Verification by Jolliffe and Stephenson.

The probability of LI exceeding 1 indicates the probability of the potential lightning events. This threshold captures more hits because the broader conditions allow weaker and smaller storms to be forecasted. However this does have a consequential effect on the false alarm rate causing it to increase. Figure 4 shows the verification results for this threshold. Due to the rare nature of lightning the points on the ROC curve are focused closer to the origin. Also, due to the small number of ensemble members, the lowest probability is limited, and the number of points along the ROC curve is reduced. The ROC curve displays skill in the forecast, despite the small ROC area the forecast shows good skill given its resolution, global capability and the rarity of lightning. The reliability diagram shows very good forecast reliability. The curve lies very close to the perfect reliability line despite showing slight over-forecasting at low probabilities and slight under-forecasting at high probabilities.

The probability of LI exceeding 10 produces similar verification results. As discussed with LI exceeding 1, this threshold produces slightly less hits however a lot fewer false alarms as the confidence of lightning is higher. The reliability diagram shows much more scattered results however this is most likely due to the small sample exceeding this threshold particularly with higher probabilities.

### 3.2 Hail in Australia

On the 16th November 2013 the hail diagnostic indicated the probability of hail greater than 10mm in diameter in South-East Queensland. At a lead time of T+30, a 30-50% chance of 10mm hail was forecast for 6Z (4pm local time) focused along the coast between the Sunshine Coast and Newcastle (Figure 5).

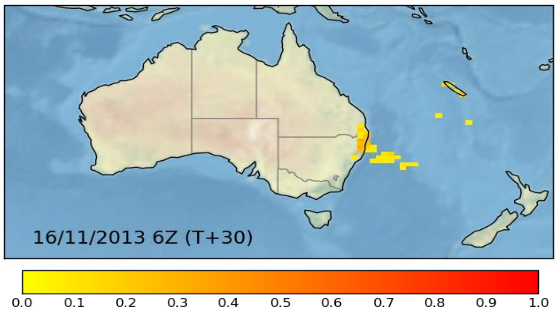


**Figure 5: MOGREPS-G probability of hail > 10mm in diameter on 16/11/2013 at 6Z.**

The Bureau of Meteorology in Australia recorded various reports of large hail across South-East Queensland. Reports of 3-5cm and 6-8cm (approximately 'tennis ball-sized') diameter hail were recorded across the South-Eastern corner of the state. The storm impacted the local population with many smashed roofs, windows and cars. Observations of accumulated precipitation data made up of rain gauge measurements and radar data in Figure 6 shows the intensity and location of the storm. There is agreement between the MOGREPS-G CDP forecast and the observations highlighting the strength in the hail diagnostic with a lead time of over a day.

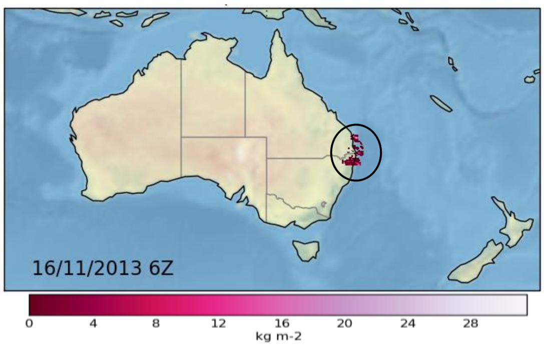


**Figure 6: Accumulated precipitation at 6Z on 16/11/2013 (Seed, 2007).**

### 3.3 Tornadoes in USA

On the 31st May 2013 36 tornadoes were reported, mainly throughout Oklahoma and Missouri (NOAA SPC). Using a threshold of FTP > 0.5, the tornado diagnostic displayed up to a 60% chance of tornadic activity across several states in the Central Plains (Figure 7). At a lead time of T+60 this tornado diagnostic provided an early warning of the general area at risk that day. Using a higher threshold (FTP > 1.0) the risk area was greatly reduced, focused around the centre of the tornado reports along the Kansas/Missouri border. As discussed with the lightning diagnostic using a lower threshold produces a wider forecast area; however, this does create many more false alarms which would need to be assessed differently in the tornado diagnostic.

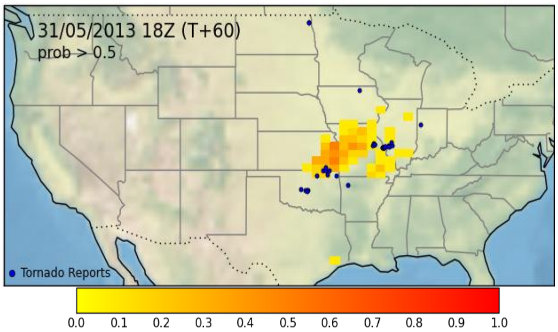


**Figure 7: MOGREPS-G probability of Fuzzy Tornado Parameter > 0.5 on 31/5/2013 at 18Z.**

## 4. CONCLUSIONS AND FUTURE WORK

The forecasts show skill and reliability given the resolution and global capability. They are global forecasts intended to give early warnings of potential hazardous weather.

The lightning diagnostic shows slight under forecasting and recalibration could improve results. Further verification research into the diagnostic will be carried out.

The MOGREPS-G CDP output for the USA was monitored by Met Office forecasters during the NOAA Hazardous Weather Testbed 2013 Spring Forecast Experiment. Particular focus was given to the tornado diagnostic to produce case studies as discussed in this report. The model output will also be monitored during the 2014 Spring Forecast Experiment.

Future work will include more objective verification of the lightning diagnostic and potential additions to the tornado diagnostic to create a probability of supercells. Different hail thresholds could also be trialled which could have the potential to discriminate between hail forecasts of different severities.

## 5. REFERENCES

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