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Tropical cyclone ensemble forecasting at the Met Office: Upgrades to the MOGREPS model and TC products, and an evaluation of the benefit of multi-model ensembles

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1. UPGRADES TO THE MOGREPS ENSEMBLE

The Met Office Global and Regional Ensemble Prediction System (MOGREPS; Bowler et al, 2008) has undergone a number of changes in the last couple of years. The 15-day version of the global ensemble, known as MOGREPS-15, which had previously been used in the Met Office tropical cyclone products, was retired in March 2016. This had run to T+360 with 12-hourly output, twice a day (00/12UTC), with 24 members, at a resolution of approximately 60km. To replace this model, MOGREPS-G, the higher resolution global ensemble, was extended to run to T+174 with 6-hourly output, four times a day (00/06/12/18UTC). MOGREPS-G runs at N400 resolution, or approximately 33km, and uses an Ensemble Transform Kalman Filter (ETKF) for its initial condition perturbations, with stochastic physics to increase the spread (Tennant et al, 2011). MOGREPS-G consists of 12 members each run, with products based on a lagged pair of ensemble runs (24 members).

In 2014 there was a major upgrade to the Met Office Global Models including a new dynamical core known as ENDGame (Met Office, 2014). In 2015 this was followed by implementation of a new form of TC initialization involving assimilation of central pressure estimates. These changes resulted in significant reduction in TC forecast errors (for track, intensity or both) in forecasts from the Met Office Global Model (Heming, 2016a).

2. MOGREPS-G TROPICAL CYCLONE PRODUCTS

The MOGREPS-G forecasts are processed through the Met Office Tropical Cyclone Tracking system (MOTCTracker; Heming, 2016b). This uses a bi-variate approach to identify and track TCs in the model fields using the 850mb relative vorticity and mean sea level pressure fields, and identifies both named storms and those forecast to form during the forecast.

For each named storm, a three panel image is produced, as shown in Figure 1 for Typhoon Koppu. The top panel shows the forecast tropical storm tracks out to seven days from each MOGREPS-G member, coloured according to lead time in 24-hour sections. In the centre is a strike probability forecast, showing the MOGREPS-G forecast probability that the storm will pass within 120km within the next seven days. The unperturbed control forecast is overlain in green, the mean of the ensemble tracks in blue, and the higher resolution Met Office Unified Model deterministic model track in red. Previous observed positions are shown in black. The bottom panel displays a storm-following meteogram, summarising the forecasts of storm intensity.

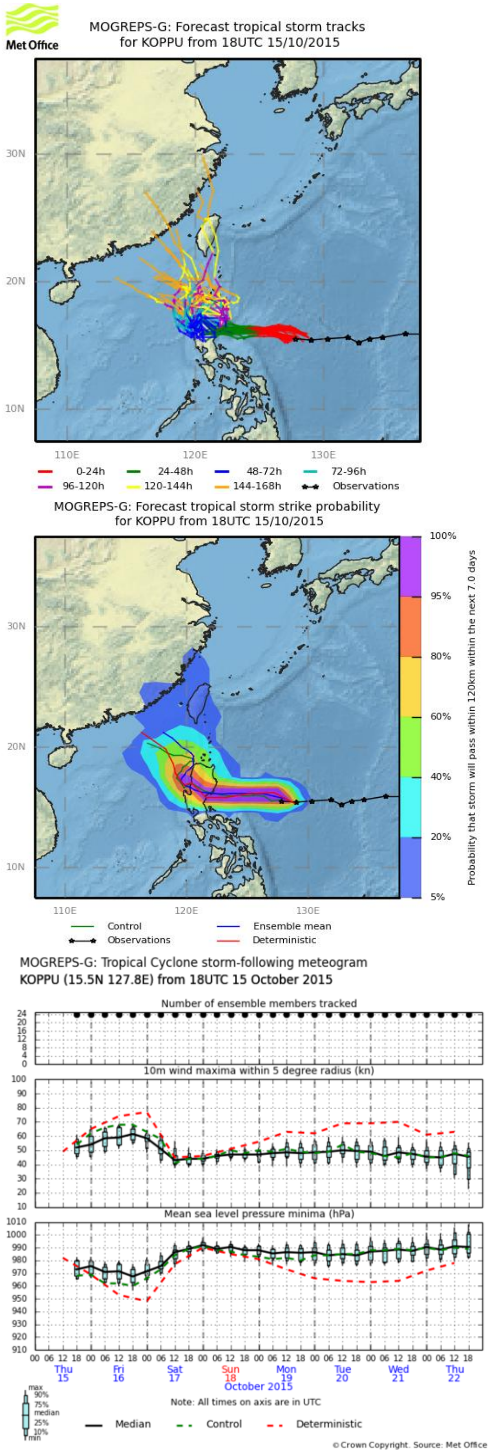

Figure 1. MOGREPS-G forecast for Typhoon Koppu from 18UTC 15th October 2015. Typhoon Koppu, known in the Philippines as Typhoon Lando, struck the Philippine Island of Luzon, resulting in at least 58 deaths.

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The top section of the meteogram shows how many members have tracked the storm at each forecast time. The centre and lower section in the meteogram show the forecast 10m wind maxima within a 5 degree radius and mean sea level pressure minima respectively. The ensemble forecast distribution at each forecast range is represented by a box-and whiskers plot showing the median (solid line), the 25th and 75th percentiles (wide vertical box), 10th and 90th percentiles (narrower boxes) and the minimum and maximum values (vertical lines). The control forecast intensity is overlain in green, and the deterministic forecast intensity is overlain in red.

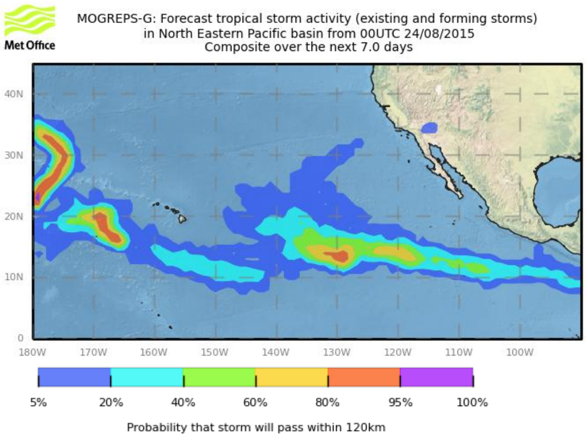

Figure 2. A MOGREPS-G tropical storm activity forecast for the North Eastern Pacific basin from the 00UTC run on 24th August 2015, composited over the full 7-day forecast.

Figure 2 shows an example of the tropical cyclone activity products that are produced from each MOGREPS-G run. Tropical cyclone activity is defined as the probability that any storm (whether it is an existing named storm, or one in the pre-genesis phase that is forecast to form during the forecast), will pass within 120km. The plots are produced for rolling 24-hour validity periods during the forecast and displayed as an animation, with a composite forecast also produced to show the overall probability of an area being affected by a tropical storm in the seven days of the forecast. This maximises the forecast signal as it will highlight the risk in situations where many members are predicting a storm to develop and track through a particular area, but at slightly different times. In Figure 2, two existing (Loke and Kilo) and two future (Ignacio and Jimena) hurricanes can be seen in the composite forecast, four of the record-tying 16 hurricanes in the 2015 Eastern and Central North Pacific hurricane season.

The MOGREPS-G TC products are available in real time to Met Office global forecasters and are disseminated alongside the track data to several international partners to contribute to their tropical cyclone forecasting.

3. VERIFICATION OF STRIKE PROBABILITIES

In 2015 the verification of ensemble forecasts of tropical cyclones has become embedded as part of the Met Office verification system. Verification has initially focussed on the strike probability forecasts for named storms (the centre plot in Figure 1), as defined as the probability that the storm will pass within 120km in the next 7 days. The results here compare the forecasts for all named storms in 2015 from the MOGREPS-G and MOGREPS-15 ensembles, before comparing MOGREPS-G against other international global ensemble forecasts and evaluating the benefit of multi-model forecasts.

3.1 MOGREPS-G vs MOGREPS-15 forecasts

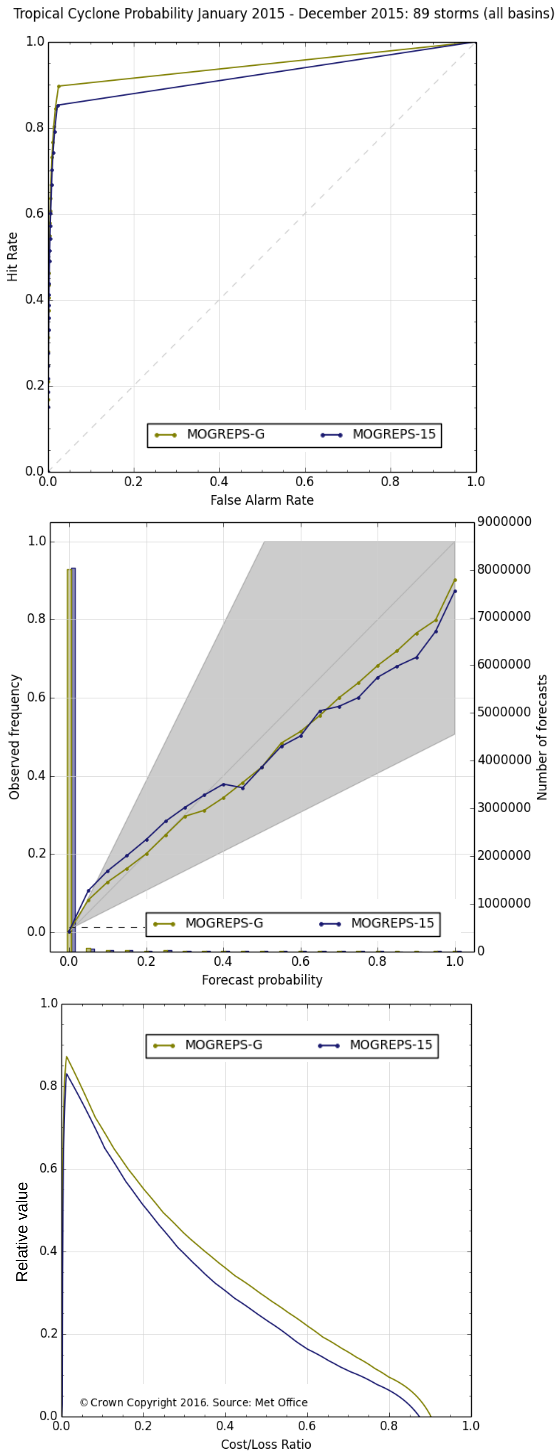

Figure 3. Verification plots comparing MOGREPS-G and MOGREPS-15 named storm strike probability forecasts from January to December 2015.

The verification plots in Figure 3 highlight the increased skill, reliability and value from strike probability forecasts in MOGREPS-G compared to MOGREPS-15. The Relative Operating Characteristic (ROC) plot (top) assesses the skill of the forecast. The points along the curve are the hit rates and false alarm rates for each probability bin, so perfect skill would produce a curve from bottom left to top left to top right. The reliability plot (middle) displays how well the predicted probabilities correspond to their observed frequencies. Perfect reliability would be a diagonal line from (0,0) to (1,1). The Economic Value plot (bottom) indicates the relative improvement in economic value between the sample climatology and a perfect forecast for all cost loss ratios.

MOGREPS-G has a greater ROC area showing that for each probability bin it has a greater hit rate and smaller false alarm rate. The reliability plot shows good reliability for both models with MOGREPS-G showing less under forecasting at lower probabilities and less over forecasting at higher probabilities than MOGREPS-15. The MOGREPS-G economic value curve completely encompasses that of MOGREPS15.

3.2 Multi-model ensemble forecasts

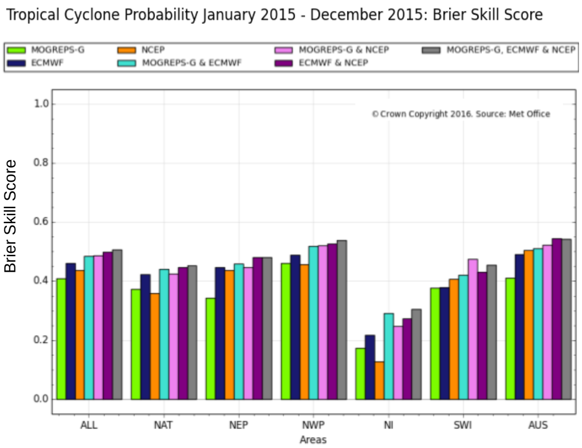

Figure 4. Brier Skill Score (with CLIPER as baseline) for MOGREPS-G, ECMWF ENS, NCEP GEFS and various multi-model combinations for named storm strike probability forecasts in each basin in 2015.

In addition to the MOGREPS-G ensemble forecasts, ECMWF ENS and NCEP GEFS forecasts are processed through MOTCTracker in order to provide the fairest verification comparison of the resulting tracks and strike probabilities. Named storm strike probability forecasts are produced using each individual ensemble, and also for each combination of multi-model ensemble. The Brier Skill Score results for named storms in 2015 (for all storms and broken down by basin) are shown in Figure 4. The Brier Skill score assesses the relative skill of the probabilistic forecast over that of climatology, in terms of predicting whether or not an event (in this case the passing of the storm within 120km) occurred. In this verification CLIPER (CLImatology and PERsistence) forecasts are used as the baseline in the calculation of the Brier Skill Score. 0 indicates no skill when compared to the reference forecast, while 1 would be a perfect score.

Out of the individual ensembles, ECMWF ENS has the greater skill, followed by NCEP GEFS and MOGREPS-G. In the northern hemisphere basins the ECMWF ENS consistently shows the greatest skill, while the relative skill of NCEP GEFS and MOGREPS-G changes depending on basin (for example MOGREPS-G outperforms NCEP GEFS in the North Atlantic (NAT) basin). In the southern hemisphere basins (SWI and AUS) NCEP GEFS is shown to be the individual ensemble with the greatest skill. Taking all basins together, all four of the multi-model ensemble combinations have greater skill than any of the individual ensembles. The 3-model multi-model ensemble forecasts have the highest skill.

4. SUMMARY AND FUTURE PLANS

The upgrade of the Met Office's tropical cyclone ensemble forecast products to use the higher resolution MOGREPS-G forecasts instead of MOGREPS-15 forecasts has resulted in additional skill and value in the strike probability product. ECMWF ENS is shown in the verification to be the most skilful of the three included global ensembles, with MOGREPS-G now comparable with NCEP GEFS in terms of forecast skill and value. All multi-model combinations are shown to add value to the individual ensemble strike probability forecasts.

The strike probability forecasts for named storms are now being routinely verified twice a year in January and July. In the coming year the tropical cyclone ensemble verification will be extended to verify the tropical cyclone activity and intensity products. Additional product development will focus on creating multi-model products in real-time and investigating additional products such as probability of intensity change and probability of landfall.

5. REFERENCES

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