1. Abstract

The Met Office Space Weather Operations Centre (MOSWOC) monitors space weather 24/7; twice daily forecasts and warnings are produced by a dedicated space weather forecaster. Verification is important for forecasters, customers, modellers and stakeholders because it helps to improve the quality, skill and accuracy of the service. Verification results for four day multi-category probabilistic forecasts of geomagnetic storms are presented below, calculated using an automatic, near real-time verification system [2]. To understand how well these forecasts perform they are compared against a reference climatology of geomagnetic activity using the Ranked Probability Skill Score (RPSS).

2. Forecasting geomagnetic storms

To prepare a four day probabilistic geomagnetic storm forecast, a MOSWOC forecaster will consider the following:

- Auto-regressive, Integrated Moving-Average (ARIMA) and neural network model forecast data provided out to 3 days by the British Geological Survey (BGS);
- Any Earth-directed transients (CMEs) and Enlil output to estimate arrival time at Earth and solar wind speed;
- A 27-day persistence model [1] to understand if any structures (e.g. HSS & OR) may rotate back onto the visible solar disk;
- Current observations (BGS magnetometer data and in-situ L1 solar wind measurements);
- Planetary K index (Kp) proxies (produced by both BGS & SWPC) and K_UK (local estimate produced by BGS using 3 UK magnetometers). Met Office forecasters combine this information with their own judgement, to issue a four day forecast (Table 1) for the probability of exceeding each geomagnetic storm level out to four days ahead.

3. Real-time verification results

- Geomagnetic storm forecasts are verified using the Area Forecast Verification System [2] which was originally developed to verify terrestrial weather products such as the shipping forecast.

- Figure 1 shows a box-plot-line-graph which is produced to illustrate how the forecast categories compare with estimated (SWPC) Kp values in near real time. Definitive Kp values (GFZ Helmholtz Centre in Potsdam) cannot be used because they have a one month latency.

- Figure 2 shows probability density functions for each day of the forecast; these plots display the probability of occurrence of each geomagnetic storm category, with the maximum observed Kp shown in red.

- The Ranked Probability Score (RPS) is calculated to measure how well the forecast predicted the observed category. In this case G2 was observed on day 1 when G1/2 was predicted with 60% probability and the resulting RPS was 0.025; whereas, on day 2 the RPS is lower indicating a more accurate forecast in this particular case.

- The Ranked Probability Skill Score (RPSS) is calculated to benchmark the RPS against a reference; the reference used is a rolling two year climatology of definitive (GFZ) Kp.

- Figure 3 shows rolling 12 month forecast performance to the end of October 2016. Black horizontal lines indicate the number of verified forecasts, vertical coloured lines are 90% confidence intervals with the median value displayed horizontally. All median values are >0.5 indicating greater skill than the benchmark climatology.

4. Conclusions

- Verification of MOSOC geomagnetic storm forecasts reveal:
  - that skill is greatest on day 1;
  - evidence (at the 90% level) to suggest that the skill on day 1 exceeds the skill associated with the climatology;
  - Borderline evidence (at the 90% level) to suggest that the skill on days 2-4 also exceeds that associated with the climatology;
  - Real time verification webpages are made available to MOSWOC forecasters for examination, prior to issuing subsequent forecasts.

Table 1: Example geomagnetic storm forecast issued by MOSWOC, 14th Oct 2016.

<table>
<thead>
<tr>
<th>Probability</th>
<th>Level</th>
<th>Day 1 (00-24 UTC) (%)</th>
<th>Day 2 (00-24 UTC) (%)</th>
<th>Day 3 (00-24 UTC) (%)</th>
<th>Day 4 (00-24 UTC) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor or Moderate</td>
<td>G1 to G2</td>
<td>60</td>
<td>25</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Strong</td>
<td>G3</td>
<td>10</td>
<td>5</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Severe</td>
<td>G4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Extreme</td>
<td>G5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</table>

References

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