



Verification of space weather forecasts at the UK Met Office

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Outline

- Met Office Space Weather Operations Centre (MOSWOC)
- Verification in near real-time
 - Flare forecasts
 - Geomagnetic storm forecasts
- Summary

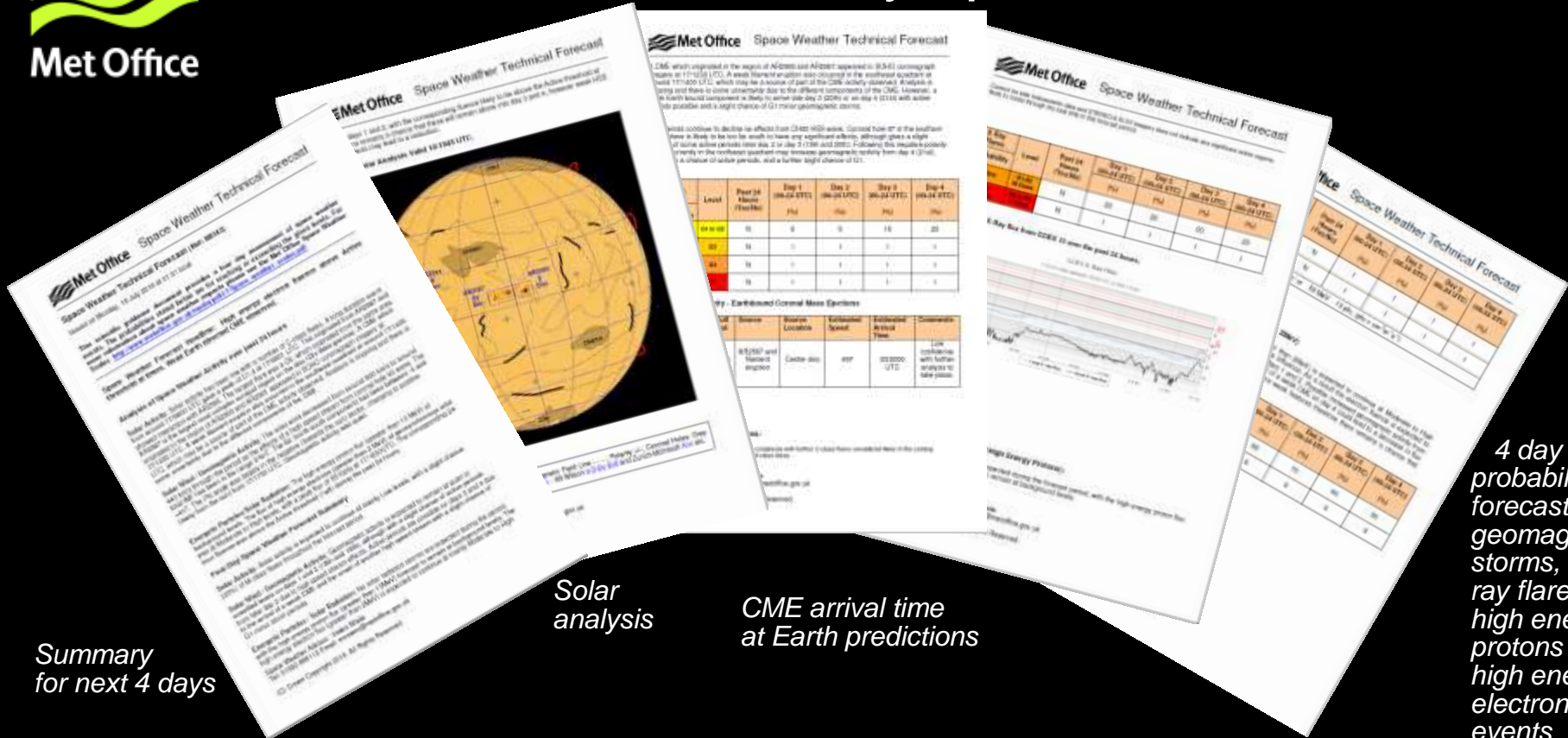
Met Office Space Weather Operations Centre (MOSWOC)



- 24/7 space weather monitoring since 2014
- Fully integrated in Met Office Operations Centre
- 2 space weather forecasters on duty (1 dedicated to space weather)
- Provides twice daily forecasts, & timely alerts & warnings
- 14 Forecasters, 6 Scientists, 4 Business, IT Developers
- National capability supporting: government, military & critical sectors (power, satellite operators, etc)

Public webpages: <https://www.metoffice.gov.uk/public/weather/space-weather/>

MOSWOC twice daily space weather forecast



The collage displays several pages from the MOSWOC (Met Office Space Weather Outlook) forecast. Key elements include:

- Summary for next 4 days:** A text-based overview of the forecast.
- Solar analysis:** A globe showing solar activity and magnetic field lines.
- CME arrival time at Earth predictions:** A table with columns for Level, Start Time (UTC), and arrival times for Days 1 through 4.
- 4 day probability forecasts for: geomagnetic storms, X-ray flares, high energy protons & high energy electron events:** A table showing probability percentages for these events over a 4-day period.
- High energy protons:** A line graph showing proton flux levels over time.

Summary for next 4 days

Solar analysis

CME arrival time at Earth predictions

4 day probability forecasts for: geomagnetic storms, X-ray flares, high energy protons & high energy electron events



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MOSWOC flare forecast

Example MOSWOC 4-day probabilistic flare forecast

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	N	20	20	15	10
Very Active	R3 to R5 X Class	N	2	2	1	1

Flare category

Flare occurred in past 24h?

Probability that flare will occur for each of the next 4 days. Not exceedance, i.e. probability is of M-class occurring, not M-class or above.

- Geomagnetic storm forecasts: exceedance, 4 categories

Adapting terrestrial near real-time verification systems

MOSWOC probabilistic forecast

System 1

Used for shipping forecast

System 2

Used for gale warnings

Treat as **multi**-category

Use Area Forecast Verification System (AFVS) to assess highest category predicted in that 24h:

Assess human forecast skill by comparing against observations, & calculating:
Ranked Probability Score (RPS)

As a performance benchmark, calculate RPS for a 'short-term climatology' (flares: based on previous 120 days of obs)

Assess forecast performance by comparing RPS_{MOSWOC} to RPS_{ref} :
Ranked Probability Skill Score (RPSS)

Treat each category/level **separately**

Use Warnings Verification System (WVS):

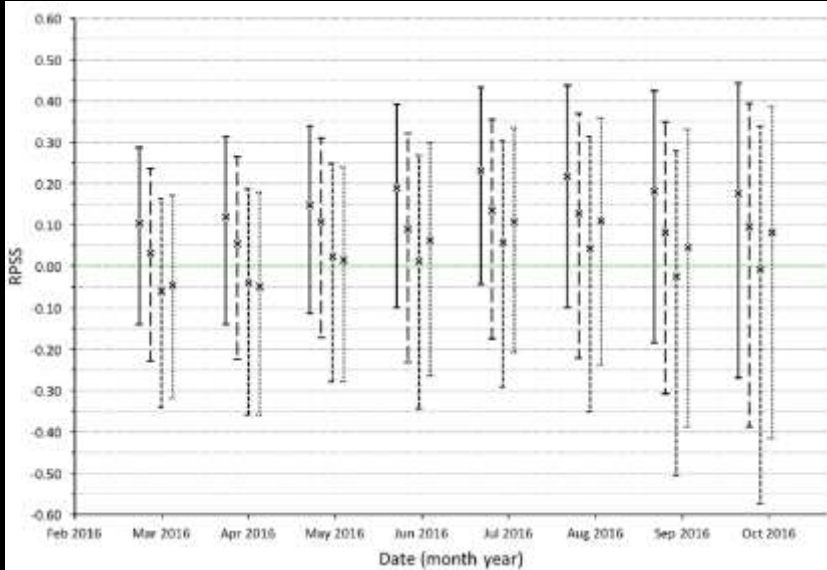
Assess forecast **resolution**:
Relative Operating Characteristic (ROC) plots

Assess forecast **reliability**:
Reliability diagrams



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Flare forecast verification results: Ranked Probability Skill Score (RPSS)



Rolling monthly performance of MOSWOC flare forecasts compared to reference forecast (frequency of occurrence over preceding 120 days)

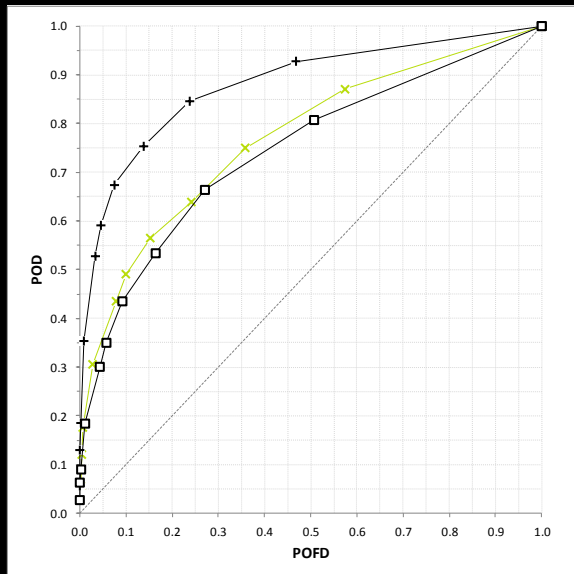
(RPSS: relative improvement of probability forecast over reference forecast in predicting category which observation fell into)

- Plot updated daily on Met Office system to monitor rolling skill of forecasts compared to reference
- X-axis: Feb '16 – Oct '16, Y-axis: RPSS
- Crosses: mean RPSS/month for days 1-4
- Vertical lines: 90% bootstrapped with replacement confidence intervals (CIs)
- Point averages suggest day 1 forecasts are more accurate than days 2-4 (*day 1 is based on model*)
- Point averages for days 1 & 2 lie above no-skill line, & most of days 3 & 4, suggesting forecasts perform better than reference
- But CIs cross no-skill line so no statistically significant evidence that forecasts outperform reference in predicting max daily flare class (*flares are difficult to forecast!*)



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Geomagnetic storm forecast verification results: ROC plot



*ROC-plot for day-1, G1, geomag storm forecast.
Apr '15 – Oct '16.*

Green line: standard verification system (no flexing)

(□): the flexed including low-misses

(+) flexed excluding low-misses

POFD=probability of false detection. POD=probability of detection.

www.metoffice.gov.uk

Relative Operating Characteristic (ROC) plot:

- Measures forecast discrimination – ability of forecast to discriminate between categories. Plotted with Reliability diagram.
- X-axis: false alarm rate
- Y-axis: hit rate
- Diagonal: no-skill
- Gives info on hit rates & false alarm rates expected from using different probability thresholds to trigger advisory action
- Flexing: e.g. if G3 was predicted but G2 occurred then system gets some reward
- Points are all above the grey diagonal no-skill line, thus indicating that geomag storm forecast has skill at discriminating events of G1 or above (better than chance)

Summary of verification results

- Terrestrial verification systems have been adapted for flare & geomag storm forecasts:
 - Updated daily
 - Provide understanding of forecast performance & skill (RPSS, ROC, Reliability plots)
 - Benchmark climatology forecast used: based on observations from previous few months, e.g. for flares, the previous 120 day frequency of occurrence
- Rolling 12-month analysis using RPSS indicates:
 - day 1 geomagnetic storm activity forecasts typically perform better than a climatology benchmark
 - no consistent evidence for flare forecasts (flares are more difficult to predict)
- ROC & Reliability plots suggest: forecasts were skilful at identifying M-class flares & geomag storms, although both were over-forecast

Summary of verification results continued

- It's early days for operational space weather verification – not enough X-class flare occurrences since service began to allow verification
- Common meteorological verification techniques can be easily adapted for space weather
- Near real-time verification is particularly useful in the operational environment



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MOSWOC forecast verification papers

Space Weather

AN AGU JOURNAL [Explore this journal >](#)

Research Article

Flare forecasting at the Met Office Space Weather Operations Centre

S. A. Murray , S. Bingham, M. Sharpe, D. R. Jackson

First published: 18 April 2017 [Full publication history](#)

DOI: 10.1002/2016SW001579 [View/save citation](#)

Key Points:

- Flare forecasts produced daily at the Met Office Space Weather Operational Centre
- Forecasts since 2014 verified using numerical weather prediction methods
- Clear benefit to human 'influence' on issued flare forecasts
- Forecast skill shown to decrease for longer forecast lead times
- Real time verification has been implemented for forecaster use

Space Weather

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Research Article

Verification of Space Weather Forecasts issued by the Met Office Space Weather Operations Centre

M. A. Sharpe , S. A. Murray

Accepted manuscript online: 9 October 2017 [Full publication history](#)

DOI: 10.1002/2017SW001683 [View/save citation](#)

Key Points:

- An operational real time verification system has been developed for geomagnetic storm and solar flare forecasts.
- Ranked (probability) skill score, ROC plots, and reliability diagram analyses are shown for a period between April 2015 and October 2016.
- Both geomagnetic storms and flare were generally over-forecast.
- The skillful rolling prediction periods of 180 and 120 days were identified for geomagnetic and flare forecasts, respectively.

Work in progress with NASA CCMC & flare forecast centres/modellers:

Applying the Met Office verification systems to provide verification of the CCMC Flare Scoreboard





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Thank you