MS/CS “Green Book’ Report 2024

Section 1: Background

* 1.1 Country

UK

* 1.2 Authors

Dan Suri with particular thanks to Robert Neal for a major contribution to Section 3.3 and thanks, also, to all operational meteorologists at the Met Office who contributed insight and input, in particular Matthew Lehnert, Dan Harris and Chris Bulmer, and to Rosie Nation for additional insight.

* 1.3 Organisation

Met Office

* Section 2: Summary of major highlights

ECMWF output is widely used by the Met Office at many timescales, especially the week 2 period where the Met Office remains particularly dependant on ECMWF output. The heaviest users of ECMWF output include the Chief and Deputy Chief Operational Meteorologists, who make up the Expert Weather Hub team and provide forecast guidance across the organisation, primarily for the UK but also for many other areas around the world. Another regular user of ECMWF output are hydrometeorologists at the Flood Forecasting Centre. Meanwhile, a number of other operational positions are making increased used of ECMWF output. All operational users, of course, will use ECMWF output in tandem with the Met Office's own NWP suite and downstream post-processed outputs.

Increasingly multi-model forecast tools and decision aids are being developed to support the operational community. ECMWF output also forms part of 'BestData', a multi-model blend producing site-specific forecasts available, for example, on the Met Office public website.

Major highlights since 2022 have included further improvements to tools developed to help operational meteorologists visualize ensemble output, for example a multi-model blend being developed in the DECIDER synoptic regimes tool. Another highlight has included joining the boundary conditions programme with access to 06Z and 18Z ECWMF output being considered of value by the operational community. Meanwhile, the launch of the pre-delivery schedule in March 2024 was highly beneficial to the Met Office operational community, in particular the Expert Weather Hub who produce centralised guidance for the Met Office and issue public service warnings. Earlier receipt of ECMWF HRES allows this team to assess the range of new main synoptic hour deterministic model runs faster than before, which in turns facilitates issue of enhanced detail and better considered guidance in a more timely fashion. Finally, during the past couple of years a major internal strategic action - called Exploiting Ensembles - has been underway and aims to investigate how more optimal use of ensembles can be made as the Met Office seeks to transition increasingly to a more ensemble-led approach to forecasting whilst concurrently developing tools to improve operational use of ensembles.

Section 3: Forecast Products

To support Section 3 a user-survey of the Met Office’s operational community was conducted with response received from a wide breadth of the community including:

- The Expert Weather Hub.
- The Flood Forecasting Centre.
- The marine and aviation forecasting communities.

- The Mobile Met Unit who are military reservists who deploy to operational military theatres to support operations.
- An operational meteorologist who recently completed a secondment to the Antarctic Peninsula with the British Antarctic Survey.

3.1. Direct use of ECMWF forecast products

* a) Medium Range (e.g. for high impact weather forecasting)

ECMWF output is available to the Met Office forecasting community via three main sources - ECMWF's website (open charts and ecCharts), internal Met Office websites and the Visual Weather meteorological workstation which most operational meteorologists at the Met Office have access to. In Visual Weather, ECMWF output is visible via WMS layers and a subset of deterministic output is directly ingested. Direct ingestion of NWP into the workstations is a particularly useful method of visualization as it allows easy like-for-like comparison of different models and model runs and allows users to exploit some of Visual Weather's more advanced features and derive their own diagnostics and indices from model fields and otherwise not available, for example lifted index or fog points.

A number of internal web-based tools and diagnostics which use ECMWF output have been developed. For example, a tool classifying ensemble members by synoptic type to objectively assess signals and known internally as Decider has been available for some time and more information about recent developments with this tool follow in Section 3.3. Situations when it is of particular use includes identifying regime changes or the threat of severe weather (Neal et al. 2016), or in downstream forecast applications to identify the risk of coastal flooding, fluvial flooding or landslides.

Operational meteorologists at the Met office use ECMWF output alongside the Met Office's own model suite which includes hourly-cycling, convection-permitting deterministic and ensemble output (respectively UKV and MOGREPS-UK), the global model, which is run 4 times a day with a horizontal resolution of approximately 10 km and a time-lagged 18 member ensemble, MOGREPS-G.

Regarding forecasting operations, over-arching, authoritative guidance is provided by the Expert Weather Hub with the Chief Operational Meteorologist having ultimate accountability for forecast output and responsibility for operational delivery of the National Severe Weather Warning Service (NSWWS) which is the Met Office's impact-based public and civil protection warning service. Output from the Expert Weather Hub includes guidance on global forecast matters across multiple timescales, with customers including Met Office meteorologists working outside of the UK, UK government departments, to whom support is provided during periods of severe weather globally, and cross-European projects such as ARISTOTLE. On-shift, the Expert Weather Hub assess a broad range of model data, comparing output to observational data and considering known systematic model biases. ECMWF output is considered in tandem with other outputs, primarily the Met Office's own model suite, with the medium range forecasting effort tending to feature more use of a broader range of ECMWF data than shorter period forecasting which, for details, tends to be more reliant on the Met Office's own higher resolution, convection-permitting output.

Other forecast teams, for example aviation, media and marine, then use this guidance to influence their own more customer-specific output, where necessary drawing on other outputs or data directly themselves for more niche outputs or forecast limits not covered by guidance. These forecast teams are spread across the UK with operational meteorologists working in a hybrid fashion or based at either UK military bases, Met Office operations centres in Exeter and Aberdeen or embedded with clients, for example at some UK airports and transport agencies. In addition, there are a number of operational teams at locations around the world such as the Falkland Islands, Gibraltar and Cyprus. The Flood Forecasting Centre, meanwhile, is a joint partnership with the Environment Agency set up in the wake of severe flooding over parts of the UK in 2007 and comprises of a team of dedicated hydrometeorologists providing advice on fluvial, pluvial and tidal flooding.

ECMWF output is well-respected and increasingly used by the operational community at the Met Office, more so since access to output became easier through the open data policy. Some of the more popular outputs from ECWMF include the cyclone database, EFI, point rainfall products and meteograms with model climate. This testifies to the need for ensemble-based outputs to be both visually clear in

providing good summary information and the usefulness of the model climate to provide contextualisation, especially for potentially severe weather.

Feedback praising ease of online access to charts via https://www.ecmwf.int/en/forecasts and the ability to click on a chart to make a meteogram appear was received. ecCharts, meanwhile, whilst considered an essential tool, remains perceived as being at times slow and unreliable (more so outside of Europe, although in admittedly very remote locations such as the Falklands and Antarctic Peninsula) with requests received asking if the service can revamped and sped up.

*** b) Extended Range (monthly)**

Feedback has been received that for the extended range the old website display is preferred because this allowed parameters on a chart to be changed more quickly whereas now users need to go back and forth, or open a set of charts.

The visualization interface where users can open anomaly charts (e.g. pressure or precipitation anomalies) and slice by base time, or timestep, has been found particularly useful. However, summary plots of weekly MSLP anomalies can result in signals for some high impact-low likelihood events being not easily identified and perhaps plots of other fields, such as anomalies of convective rainfall, snow, wind speed and lightning density, may help here.

Subjective experience notes that even with the extended running daily, output can still be jumpy at times, especially at longer lead times but it running daily is still welcomed.

*** c) Long Range (seasonal)**

An improvement put forward would be to run the seasonal system run more frequently, say weekly, to take better account of factors (e.g. MJO) which can influence the early stages of seasonal forecasts. At the Met Office, the main monthly/seasonal forecast is issued late in the month and by then the seasonal model run is quite old. Whilst not always an issue, this can raise some questions and a more frequent update cycle would be welcomed.

*** d) CAMS and Fire-related output (ecCharts mainly)**

GloFAS and EFas products are used by the Expert Weather Hub to support some decision-making. Use tends to be more as a broad guide to potential river flooding with some users commenting that they do not have enough information about the hydrology in most countries to be able to properly critically evaluate the output.

CAMS output is seen as particularly useful when there are wildfire interests and airmass questions (e.g. Saharan dust potential), and these outputs are considered reliable.

3.2. Cycle 48r1

*** a) Positive impacts of model cycle 48r1**

No specific positive feedback about positive impacts of model cycle 48r1 was received.

*** b) Negative impacts of model cycle 48r1**

No specific negative feedback about positive impacts of model cycle 48r1 was received.

c) Systematic changes in forecast output since model cycle 48r1 was implemented

Nothing specific reported.

That neither specific positive or negative feedback nor systematic changes have been received may reflect working practices more critically appraising Met Office models, which are the primary outputs for

many operational meteorologists, especially UKV. It may also be the case that weather types/systems most impacted by 48r1 have not affected the UK and thus not drawn attention. Either way, in spite of an absence of feedback, it is accepted that 48r1 is likely to have been beneficial.

3.3: Derived Fields

Below follows a description of a new seamless blended multi-model weather pattern forecast which makes the new 101-member ECMWF ensemble.

Decider is the Met Office product name given to a probabilistic weather pattern forecasting tool for the medium- to extended-range periods (Neal et al., 2016). This tool clusters ensemble members according to their common weather pattern assignments, using a set of 30 predefined (static) weather pattern definitions. This tool has long been available using output from several separate models (MOGREPS-G, GEFS, ECMWF medium-range, ECMWF extended-range and GloSea6), however a new seamless blended multi-model version was implemented in July 2022. Objective verification over a 6-year period shows that the multi-model version is at least as skilful as the best performing individual model (ECMWF). Not only are forecasts more skilful on average, but they provide a single best forecast helping to speed up the decision-making process for operational meteorologist – work which is described in more detail in Neal et al. (2024).

The multi-model was further enhanced following ECMWF's IFS Cycle 48r1 in June 2023, with the addition of the daily running 101-member ensemble. This change saw ECMWF getting a larger weighting within the blend from Week 2 onwards to reflect the larger ensemble size. In addition, the new extended-range ensemble was added to the blend from Day 1 (albeit with small weights) to take advantage of these members using separate perturbations to the 51-member medium-range ensemble. Although no objective verification of its inclusion in the blend is available yet, forecaster feedback suggests that weather pattern probabilities in week 2 and beyond are providing a better signal with less run-to-run jumpiness (as a result of the daily running) and a smoother transition in weather pattern probabilities as the forecast lead time increases (e.g. Figure 1).

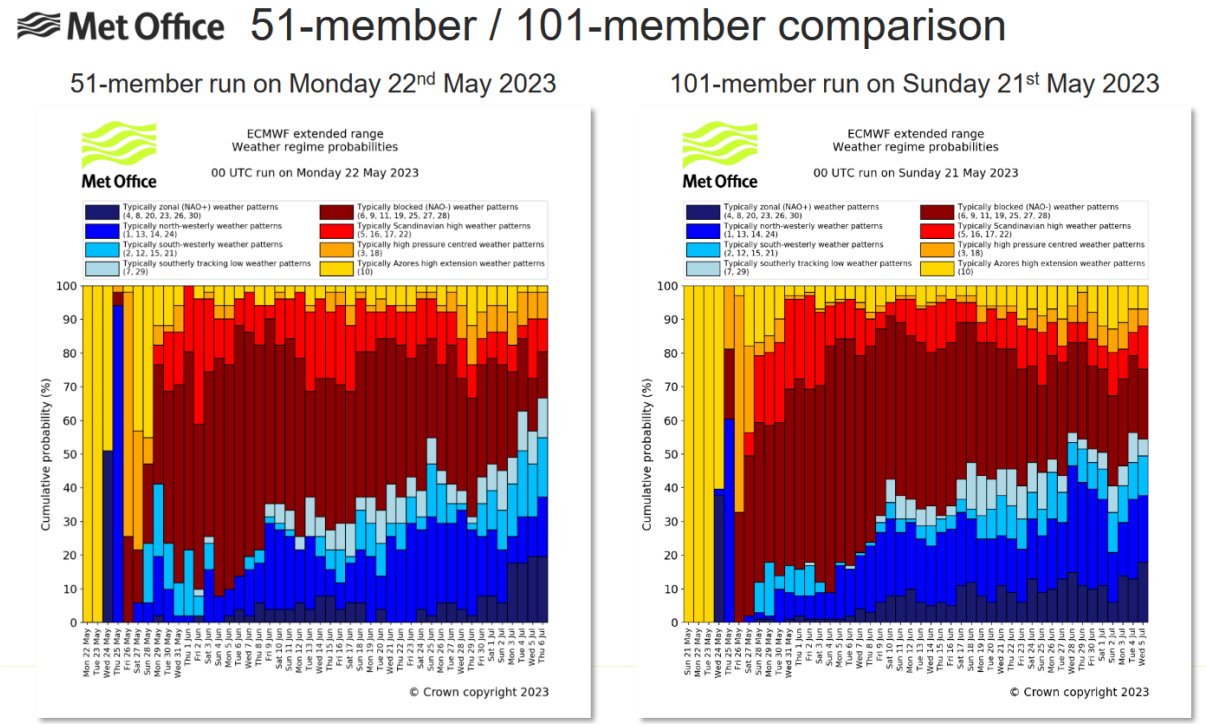


Figure 1. A comparison of weather pattern probabilities using the 51-member ensemble (left) and 101-member ensemble (right). As shown at UEF 2023.

ECMWF model data is blended with Met Office NWP to produce what is known in-house as 'BestData', a database of site-specific forecasts for thousands of sites used for many applications including, for example, forecasts on the Met Office's public web site. Here, ECMWF data is incorporated from day 2

onwards and becomes the primary source of data for forecasts for week 2. A new probabilistic post-processing system for use with ensemble output has been developed at the Met Office. Named IMPROVER (Roberts et al 2023), this system currently runs purely with Met Office NWP at the moment but is expected to be further developed to incorporate ECMWF output for week 2 in 2025.

3.4: Artificial Intelligence (AI) / Machine Learning (ML) techniques

At the time of writing the Met Office do not use Artificial Intelligence (AI) and/or Machine Learning (ML) techniques in your service, in conjunction with standard ECMWF model outputs. However, at the Met Office a good deal of consideration is being given regarding where to exploit AI and ML.

3.5: Dynamical Adaptation

ECWMF data is generally not used for modelling purposes. Instead for things like provision of initial/boundary conditions for limited area model runs the Met Office draw on their own modelling suite. However, C-IFS is used for boundary conditions for chemical species in the Met Office air quality model, AQUM.

3.6: Data-driven (AI) models

In the last year or so ECMWF has made available, on ecCharts and OpenCharts, selected fields from AI models (e.g. Pangu Weather, AIFS).

*** a) ECMWF's real-time AI model initiative**

This initiative has been welcomed, albeit with caution in terms of not overselling what outputs currently offer.

*** b) Use of AI forecasts for operational purposes**

The Expert Weather Hub have made occasional use of these AI forecasts, comparing the broader scale patterns on offer with other outputs for example. No solid conclusions on their use have been established, which may, in part, be due to limitations in visualization and fields on offer via the current static format of charts. However, there is a subjective view that they offer some useful guidance as to the general regime in the medium range. Concurrently, the view also exists that resolution and data availability means these outputs have not been used for hazard identification and concerns have been expressed regarding what these outputs offer in terms of skill 'in the tails of the distribution'. Verification of extreme/hazardous events alongside some of the more traditional verification metrics, which can appear blander to operational eyes, would be welcome.

Section 4: Verification

ECMWF does extensive verification of its products in the free atmosphere. However, our verification of surface parameters is more limited and can be constrained to only using synoptic observations. More detailed verification of these surface weather parameters by National Services is always valuable to us. We are most interested in results for the last 1 or 2 years. Also, any verification evidence you have of performance changes since the introduction of cycle 48r1 would be very valuable.

4.1 Raw model output from ECMWF, and other operational models/ensembles

In sub-sections a and b below please describe your verification activities and show and discuss related scores, in the two lead-time categories. This should include, where possible, comparisons between ECMWF and your own models/ensembles, and other models/ensembles.
Ideally focus on surface weather parameters in your own territory. Inclusion of conditional verification results is also strongly encouraged - e.g. stratification by a weather type - as these can provide very useful insights into model weaker points.

a) Short Range and Medium Range

Nothing to add beyond stating that the ECMWF analysis is used by the Met Office verification team as 'truth' to verify the Met Office's global model.

b) Extended Range (Monthly) and Long Range (Seasonal)

Nothing to add.

4.2 Post-processed products and/or tailored products delivered to users

Nothing to add.

4.3 Subjective verification

A number of pieces of feedback were received here:

- Convection appears too strongly coupled to gravity waves.
- Convection/showers seem to develop too readily, and are too intense, even in air masses which do not support it.
- In the medium range, HRES possibly has a bit more variability between each run which can make it harder to produce a consistent story, at least when considering outputs with other solutions ahead of receipt of ensemble output.
- Boundary layer forecasts remain a little questionable at times; there still seems to be a slight clear bias to low cloud and a foggy bias resulting on calm, clear nights during the winter which have not always materialised.
- Lightning diagnostics are useful and seem to perform fairly well across a number climate environments and scenarios. However, it has been noted that they can struggle in the cold season maritime setups where there is an ongoing question of whether there are other factors at play (e.g. microphysical in very strong post-frontal airstreams) that contribute to charge generation.
- Peak wave heights and orographic rainfall totals can be underdone, though it is recognised that model resolution, and more so in the case of the latter, model topography will play a role here.
- Lying snow and snow depths being overdone (especially for sleet/wet snow) can be a problem.

A more generic comment was also put forward posing the question as to how well aware users are of systematic biases/errors now that ECMWF data is more widely available, especially with non-trained users. There have been occasions this winter when media attention has been drawn to ECMWF snow depths yet Met Office expectation was that these depths would be overdone, thus making Met Office messaging of the forecast harder.

4.4 Case Studies

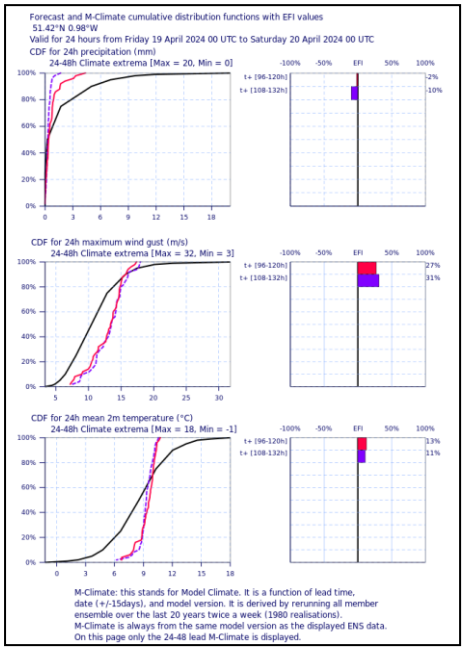
Nothing to add.

Section 5: Output Requests

a) Product request 1: *Extending EFI/CDF point product beyond day 5*

The EFI output has been one of the more useful products, as well as the EFI/CDF point product which allows users to look at the lead time variation of EFI and the CDF for temperature, wind and

precipitation. What would be a useful development is whether this could be extended to longer lead times as this only starts plotting at day 5. This would allow emerging signals towards the beginning of the period at which the Met Office can issue public service (NSWWS) warnings (day 7) to be picked out. The example below is the day 5 EFI/CDF for Reading and there are only two model runs plotted which means that trends may not become meaningful/confident to users until day 2 or 3.



b) Product request 2: ***Adding vertical profiles to open data charts***

Adding vertical profiles to open data charts in the same manner that users can access meteograms would be a welcome additional capability.

Section 6: References

Neal, R. et al (2016) A flexible approach to defining weather patterns and their application in weather forecasting over Europe. Meteorological Applications, 23, 389-400, https://doi.org/10.1002/met.1563

Neal, R. et al (2024). A seamless blended multi-model ensemble approach to probabilistic medium-range weather pattern forecasts over the UK. Meteorological Applications, 31(1), e2179. https://doi.org/10.1002/met.2179

Roberts, N. et al (2023). IMPROVER: the new probabilistic postprocessing system at the Met Office. Bulletin of the American Meteorological Society, 104(3), E680–E697, https://doi.org/10.1175/BAMS-D-21-0273.1

Section 7: Additional comments and Feedback

Nothing further to add.