Application and verification of ECMWF products 2015

Assembled by Dr Marion Mittermaier, Numerical Modelling, Weather Science, Met Office

1. Summary of major highlights

Though the weights are still small, ECMWF deterministic and ensemble forecasts are actively used in the site-specific “Best Data” blend which drives our automated forecast offering. The old “Decider” weather regime classification code is being retired, and replaced by a new clustering algorithm, which has been verified for a 4.5 year period. Both ECMWF and Met Office ensembles are processed. The use of ECMWF analyses for verification of the global model continues, providing important own-model independence in the assessment process. High-quality “competition” from the ECMWF model continues to provide a spur for our own R&D efforts which is beneficial and should not be underestimated.

2. Use and application of products

2.1 Post-processing of ECMWF model output

2.1.1 Statistical adaptation

Both deterministic and ensemble forecasts are post-processed for specific locations using a Kalman Filter (KF) approach before being blended with a range of other models at different lead times to produce what is called “Best Data”.

2.1.2 Physical adaptation

Operational Air Quality Forecasting

The Met Office provides the UK national Air Quality forecast. This is delivered using the AQUM configuration of the UM. AQUM is an on-line limited-area forecast configuration of the Met Office Unified Model which uses the UKCA (UK Chemistry and Aerosols) sub-model. AQUM has been developed to fulfil two purposes: (i) the operational delivery of daily air quality forecasts and (ii) to enable atmospheric modelling studies to address scientific and air quality policy-related questions. Model LBCs are a combination of chemistry and aerosol data from the MACC (and previously GEMS) global model and meteorological data from Met Office global weather forecast model. Use of MACC LBCs has enabled the Met Office to benefit from the considerable investment in data assimilation of composition at ECMWF and has also offered savings as the Met Office has not needed to develop or maintain a global Air Quality model. Verification of AQUM against observations and MACC forecasts is carried out as a routine part of the daily air quality forecast. This demonstrates clearly the added skill that AQUM offers over the UK and has also enabled the Met Office to feedback to ECMWF regarding MACC performance and thereby enhance the collaborative nature of this work.

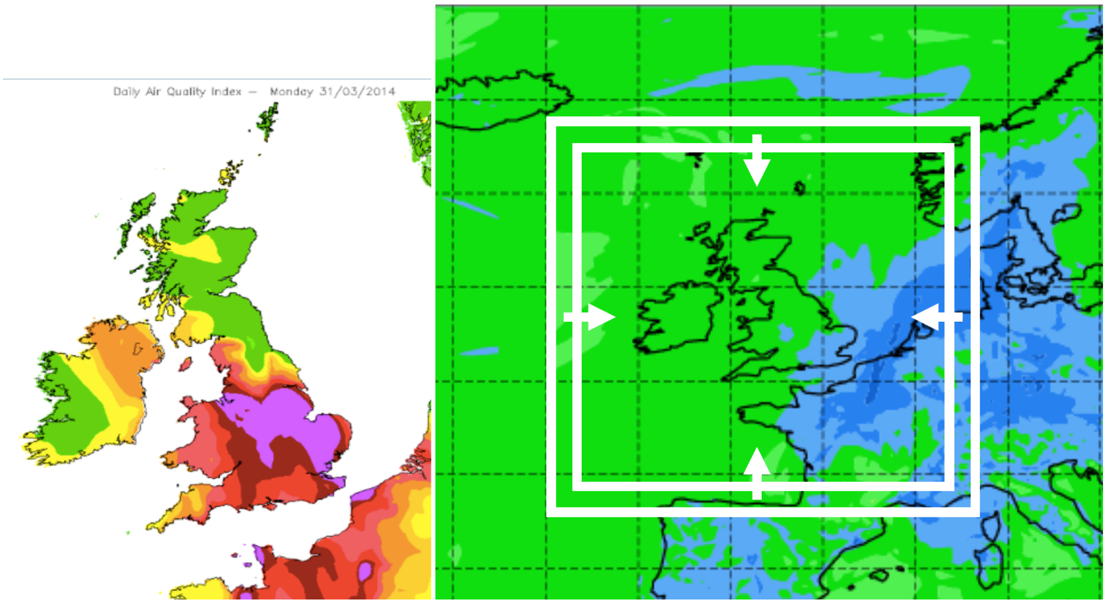


Fig. 1: UK Air Quality forecast (left) and diagram of domain extent (right) and application of LBC.

Operational Dispersion Hazard Forecasting

The Met Office provides a range of national and international emergency response dispersion forecast services. These are delivered using NAME, the Met Office Lagrangian dispersion model, which operationally is driven by NWP data from the UM. ECMWF NWP data is routinely used by researchers supporting hazard forecasting both as a compliment to UM based predictions and also for historic analysis (ERA data). Work is also currently (2015) underway to add ECMWF deterministic forecast data to the NAME operational system thereby enabling the forecaster's the ability to select the most suitable NWP data for an event and also explore some of the effects of NWP forecast variability. Future plans will extend this to include NWP ensemble data.

Biomass Burning Haze Forecasting

The Met Office and the Meteorological Service Singapore have been engaged in a collaborative project aimed at providing an operational biomass burning PM10 and PM2.5 air quality forecast for Singapore. Multiple approaches for both fire monitoring and emissions estimation are being investigated and used. A significant contribution to this work comes from the use of the GFAS fire and emission estimates provided under MACC and Copernicus from the ECMWF global composition analysis and forecast. These emissions, updated daily, have been used as source terms within the Met Office's NAME atmospheric dispersion model to provide 48 hour forecast (Figure 2) shows and example output.

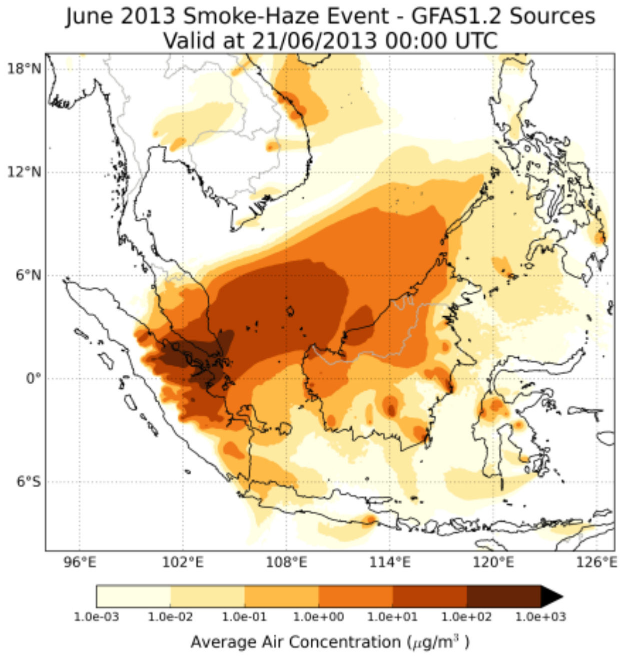


Fig 2: Output from NAME showing dispersion of particulate matter with sources taken from GFAS 1.2
Prediction results are verified in near real time using surface observations within Singapore. Analysis for 2013 and 2014 has lead to the development of a dynamic bias correction scheme that has been deployed within the forecast system and demonstrates improved forecast skill. Daily forecasts are routinely delivered forming part of local and regional advice. Further research and development is planned including the continued use of updated GFAS products.

2.1.3 Derived fields

Both 15- and 32-day forecasts are used from ECMWF in the Met Office weather regime clustering algorithms creating regime forecasts for 30 or 8 regimes. An example of an 8-regime forecast is shown in Fig. 3.

	Tue 15 Jul	Wed 16 Jul	Thu 17 Jul	Fri 18 Jul	Sat 19 Jul	Sun 20 Jul	Mon 21 Jul	Tue 22 Jul	Wed 23 Jul	Thu 24 Jul	Fri 25 Jul	Sat 26 Jul	Sun 27 Jul	Mon 28 Jul	Tue 29 Jul	Regime description	Historic occurrence J/J/A
Regime 1								2	9	8	5	7	7	11	14	Blocked	17.0%
Regime 2														1	2	Cyclonic Wly	15.0%
Regime 3								1	1	2	3	6	7	7	11	Unbiased NWly	18.9%
Regime 4	51	45				14	18	7	3	4	4	4		3	5	Unbiased SWly	13.9%
Regime 5			51	51	50	31	23	20	19	20	19	20	16	9	7	Anticyclonic Sly	10.3%
Regime 6		6					3	8	7	7	10	9	15	12	8	Anticyclonic SWly	10.6%
Regime 7					1	6	6	3	4	4	6	2	1	1		Cyclonic SWly	9.0%
Regime 8							1	10	8	6	4	3	5	7	4	Anticyclonic Wly	5.2%
Total	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	---	---

Fig. 3 Example 8-regime forecast based on ECMWF 51-member ensemble.

2.2 Use of ECMWF products

2.2.1 Ensemble forecasting & 'Best Data'

The Met Office uses a number of in-house systems to visualize ECMWF data. The PREVIN (Predictability Visualisation) Ensemble Web Pages continues to receive ECMWF data via DART and provides output aimed at identifying first order signals from ensemble data (e.g. summary maps). However, the PREVIN system is coming towards the end of its working life and a number of new tools are being introduced to our operational meteorological community. For example, the EPS-W tool (Neal et al 2014) ingests ECMWF data to help generate firs guess impacts-based warnings. Another tool, known as Decider, uses a new synoptic-typing scheme (Neal et al 2015) developed in-house to help interpret ensemble output and highlight regime changes and the threat of high-impact meteorological scenarios. This tool features heavily in the production of medium and longer range guidance.

The Met Office uses ECMWF data blended with Met Office model data to produce what it calls 'Best Data' for around 15,000 sites, approx. half of these are in the UK. The data being used includes: precipitation amount, screen temperature, 10m wind-speed and direction, wind-gust, dew point temperature, surface temperature, snowfall, total cloud amount, MSLP, min/max temperature. Our suite of models focuses on the first week of the forecast and the UK area in particular. However, with the retirement of MOGREPS-15 we are moving to a position where ECMWF is the primary source for our week 2 forecasts, supplemented by other models where they add benefit.

2.2.2 Operational Meteorologists (general) & Guidance Unit

ECMWF products remain well-respected and are widely used along with output from other centres as a comparator against our own model output. The following ECMWF products are accessed via EC Charts:

ECMWF Global GRIB - Td, gph, height, Tmax, Tmin, WBPT, MSLP, P, RH, Specific Humidity, T, T 2m, Cloud cover, total precip, total snow, theta-w, CAPE/CIN, Vert Velocity, wind u, wind v (T+0 - T+240). Ensemble GRIB - Sig wave height, total precip, prob of precip, wind gust (T+0 - T+120). EC wave data both deterministic and ensemble is also used. The recent additions of new fields, in particular instantaneous rainfall rates, to EC Charts has been well-received by our operational meteorologist community.

EC EFI output is frequently used along with EFI EPS meteograms, model climatology and the basic EPS meteograms for a wide variety of locations globally. EFI has proven particularly useful to the Met Office Global Guidance Unit whose remit includes identification of severe weather for UK and partner organisation interests around the world. Deterministic data from the EC website for various global regions provides useful information beyond T+144. EC tropical cyclone pages and database, 'Dalmatian plots' and fronts animations are widely used for the guidance assessments.
EC Meteograms (both 10 and 15 day) containing max/min temperature, 10m wind speed and total precipitation (mm/6hr) continues to be used for a small number of Open Road customers.

The Guidance Unit look at a number of ECMWF products via the main website but also EC Charts (available to member states). There is also access to post-processed info via Met Office systems such as PREVIN, EPS-W and Decider. EC gridded data is also available and well-used on Visual Weather. All of these are visualised but some are included in guidance. The actual data does not drive any products directly in the Guidance Unit.

2.2.3 Flood Forecasting/extreme weather

The EC Charts application is used extensively in the Flood Forecasting Centre (FFC) in the Met Office where ECMWF data in visual weather used as comparison against Met Office UM data. Precipitation and wind fields are of particular interest. The FFC also use EFAS products.

The ECMWF EFI output is also used and accessed both from the ECMWF website and EC Charts. ECMWF ensemble precipitation forecasts, wave data (deterministic and ensemble are used. ECMWF ensemble postage stamp forecasts are viewed from PREVIN pages and longer range anomaly maps. EPS meteograms are used when required alongside the EFI output to provide additional confirmation of severe weather.

2.2.4 Climate applications

The Met Office Climate Applications team are using products from the following ECMWF systems: VarEPS/monthly system, the seasonal system and EUROSIP. From these monthly rainfall and temperature products for East, West and southern Africa are made available to African collaborators. ECMWF and EUROSIP visualised seasonal forecast products are also used to help generate consensus seasonal outlooks at Regional Climate Outlook Forums in East, West and southern Africa. The main products used are probabilistic rainfall products and ENSO plumes. Digital forecast and hindcast data from the ECMWF system is also used in capacity training and forecast generation.

2.2.5 Monthly and seasonal forecasting: Public Weather Service (PWS)

ECMWF data is used to generate products (e.g. the monthly outlook) for the UK and other regions globally with predictions made weekly. Parameters used include Temp mean, Temp max, Temp min, precipitation, windspeed (10m), PMSL and Z500.

The EC Var EPS/monthly system is utilised for monthly forecasts for Africa (International Aid Programme)
The 3 month outlook (primarily for contingency planners) uses data for the UK. For other regions, including Africa etc., products (related to tropical storm activity over the next 6 months) are created using multi-model combinations. The EC seasonal pages are also used to compare with other Met Office outputs.

2.2.6 Future requests for new and enhancement of existing products and data

Met Office users of EC data and services have the listed the following items which they believe would add value to the data and products they currently receive from the Centre:

- Severe weather products to help provide forecast guidance for longer lead times (3-5 days and beyond)
- Improving access to higher resolution EC Charts Website data
- Being able to incorporate high resolution deterministic model (perhaps as a weighted member) into **regime change** diagnostics, especially 6-15 day lead times.
- Additional thresholds/parameters to support weather regime products
- EC Charts - Omega equation components and further diagnostics to aid forecasting of severe convective events, eg hail and lightning diagnostics.
- Ingesting more EC Fields on SWIFT/VISUAL weather
- Training for operational meteorologists on how EC products can be used to assist their work
- Extending the windstorm concept to cover rainstorms and snowstorms
- Postage stamps type displays for other parts of the world

3. Verification of products

3.1 Objective verification

3.1.1 Direct ECMWF model output (both HRES and ENS)

Nothing to report.

3.1.2 ECMWF model output compared to other NWP models

Model developers routinely use the ECMWF model analyses to compare with our own analyses and also verify our own forecasts for our experiments assimilating satellite data. It has proven valuable as an independent source of information. Recent VarBC experiments for testing satellite changes are a good example of this. There is also work planned to generate simulated imagery from the ECMWF analyses to compare with real satellite imagery.

3.1.3 Post-processed products

As part of the NWP SAF activities ECMWF generate a diverse atmospheric profile dataset from the model fields. This diverse profile dataset is widely used in Satellite Applications for radiative transfer simulations of different atmospheric conditions which help improve our exploitation of the satellite data.

As mentioned 2.1.1 ECMWF forecasts are used in the blend for site-specific output known as “Best Data”. Figures 4 to 7 show a range of aggregated monthly metrics for minimum and maximum temperatures, 10 m wind speed and direction for the 6-36h forecast range. All the values shown are for post-processed model output using a KF. The results show resolution dependence with the soon-to-be retired MOGREPS-15 at 90 km resolution having the worst results. Best Data has the lowest rmse and MAE though not always the best mean error (bias) or the lowest proportion of gross errors.

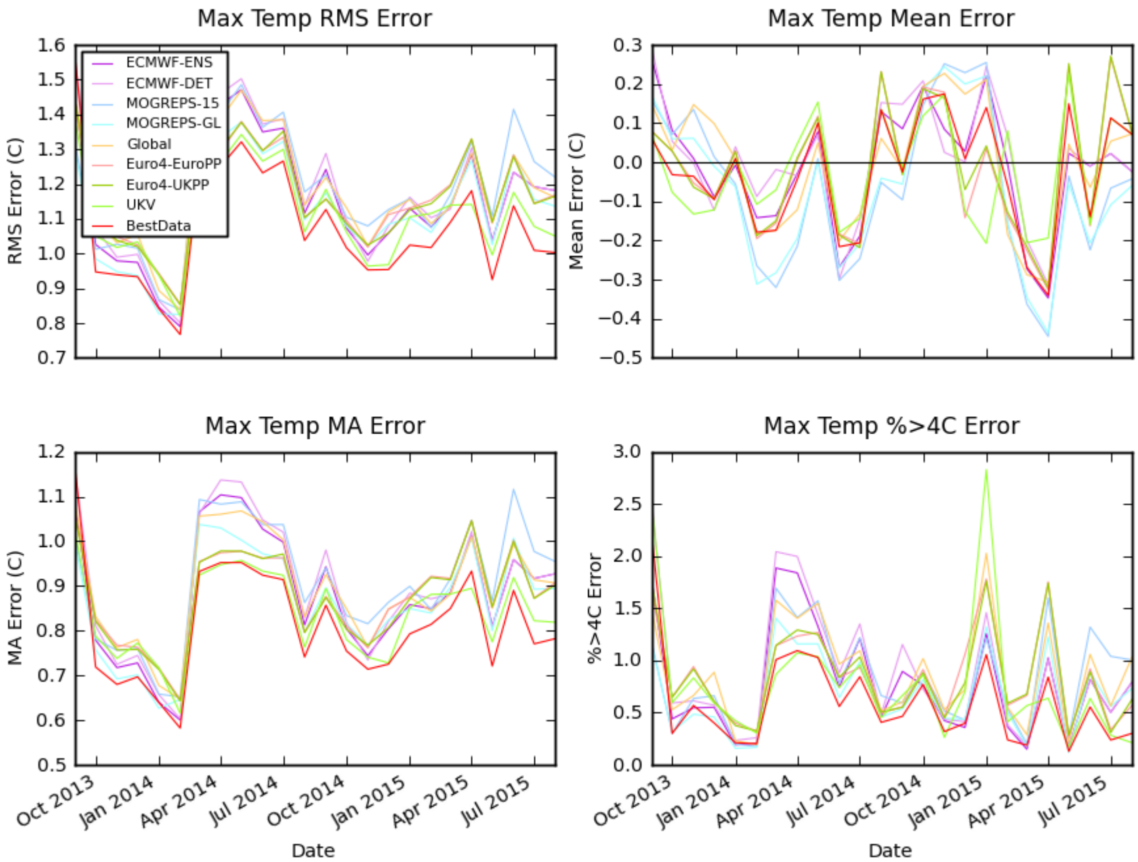


Fig. 4 Time series of maximum temperature rmse, mean (bias) and MAE as well as the proportion of forecasts with errors greater a certain margin.

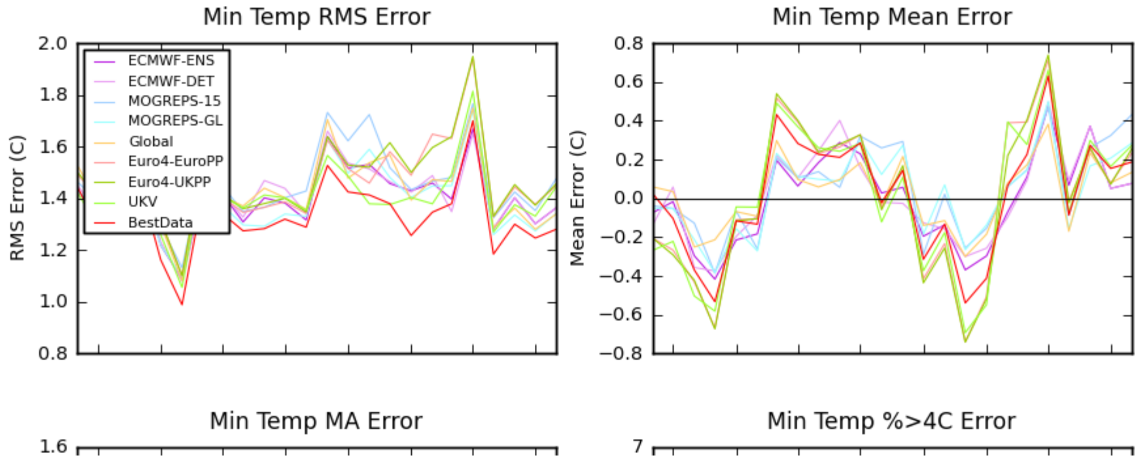


Fig. 5 Same as Figure 2 but for minimum temperature.

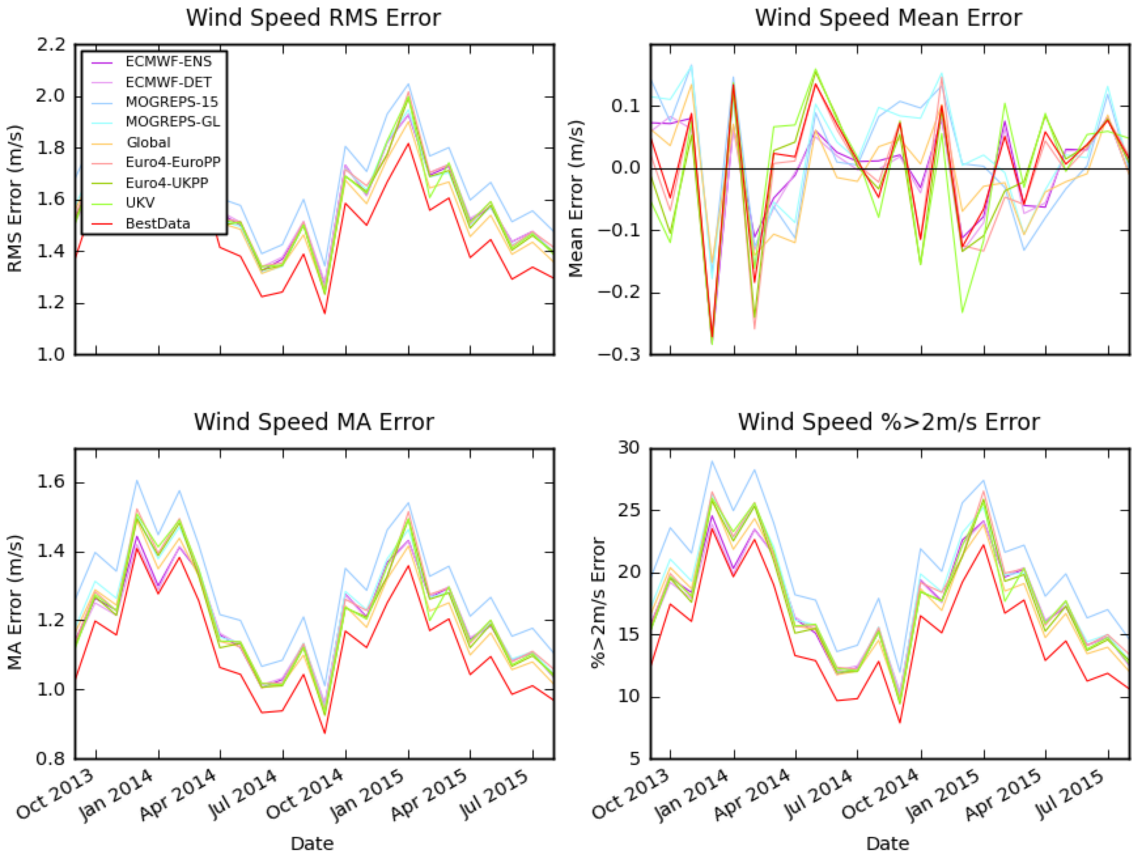


Fig.6 Same as Figure 2 but for wind speed.

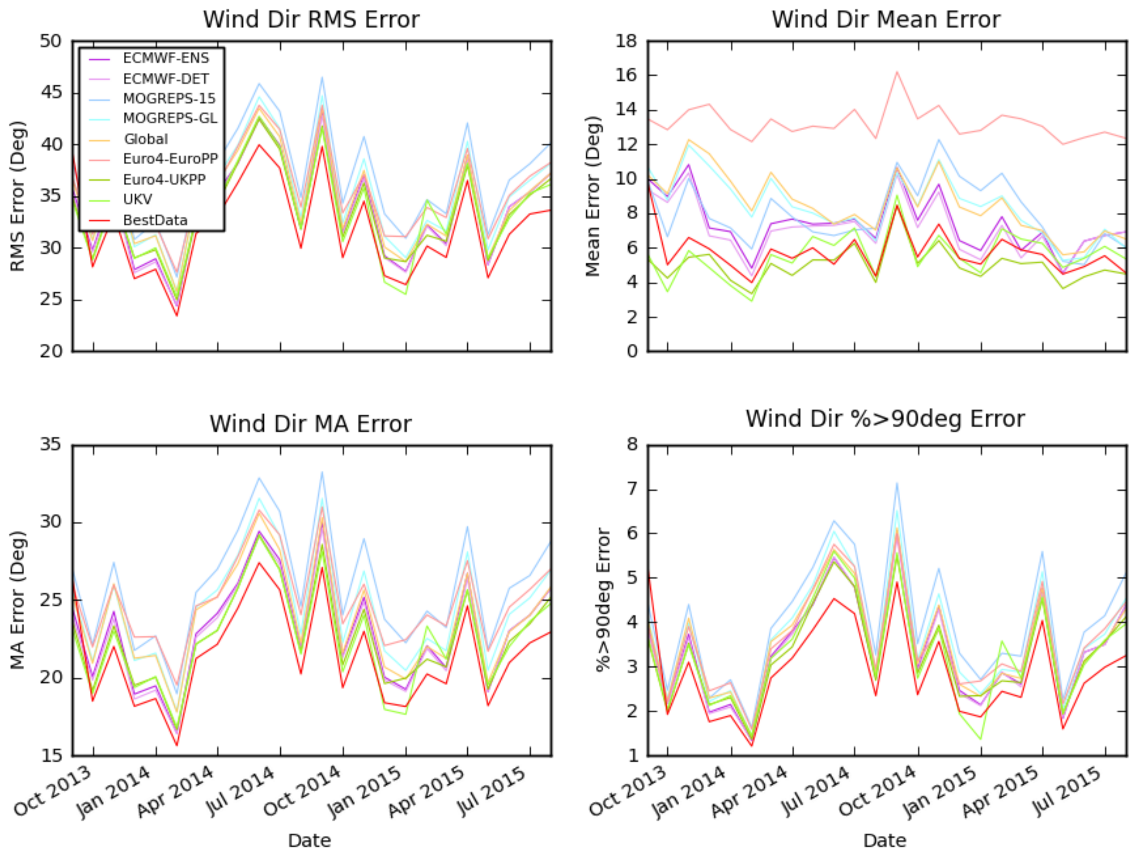


Fig.7 Same as Figure 2 but for wind direction.

3.1.4 End products delivered to users

Weather regime forecasts are provided to a number of customers/users. An initial verification study covered the period January 2010 to June 2014. As explained in 2.1.3 forecasts for both 30 and 8 regimes are produced. Figure 8 shows the frequency of forecasting specific regimes in the evaluation period by regime type. The box plots show the ensemble spread. Crosses indicate the classification of the global model (GM) and the solid line is referenced to a secondary y-axis which shows the sample size per regime per lead time. It can be seen that some regimes tend to be under- (below the horizontal line) and over-forecast (above) with lead time. Note that a straight line does not mean that the forecasts are correct at longer lead times, just that they occur with the same frequency. The GM demonstrates similar trends at short lead times.

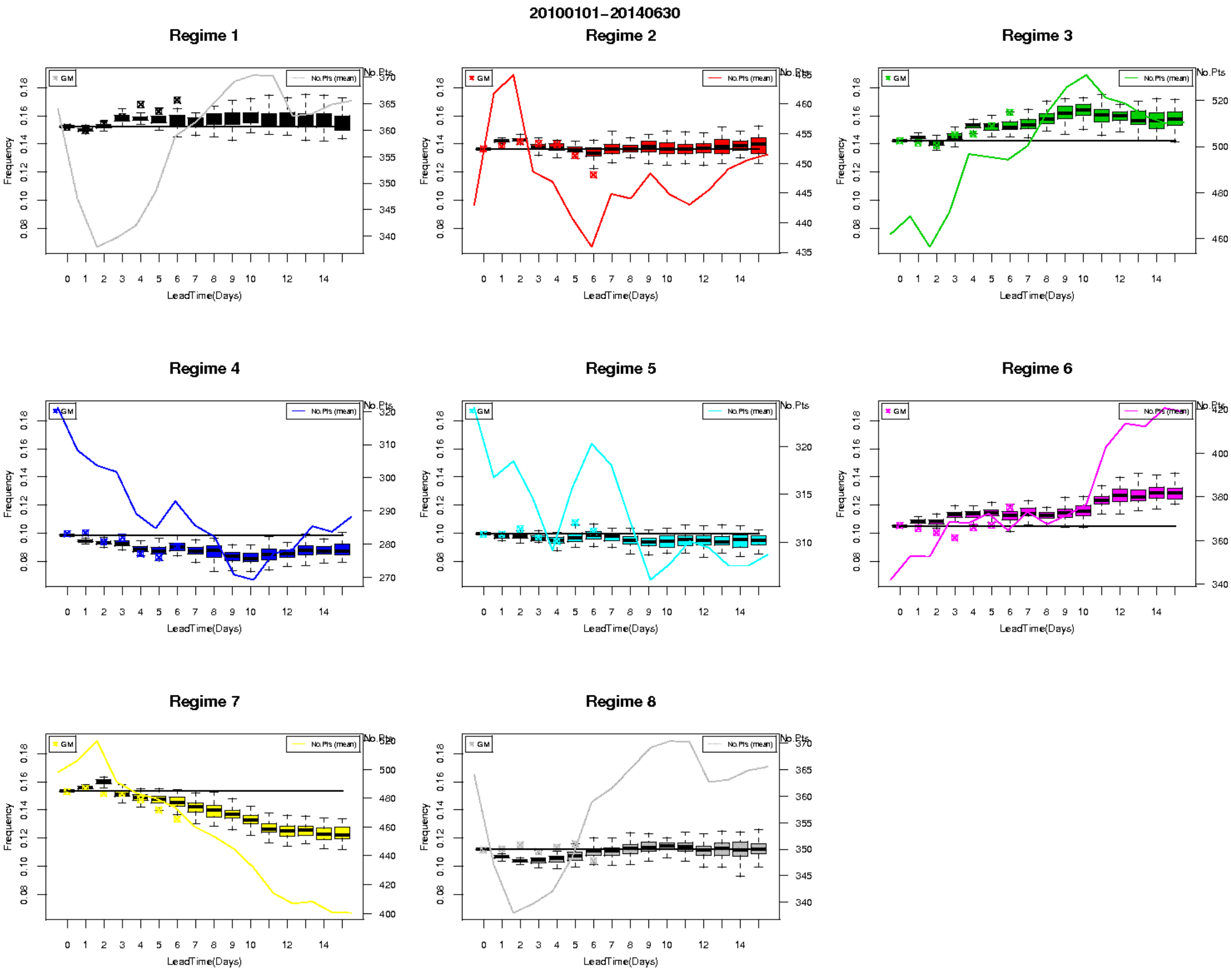


Fig. 8 Frequency of forecasting particular weather regimes as a function of lead time based on the 15-day forecasts.

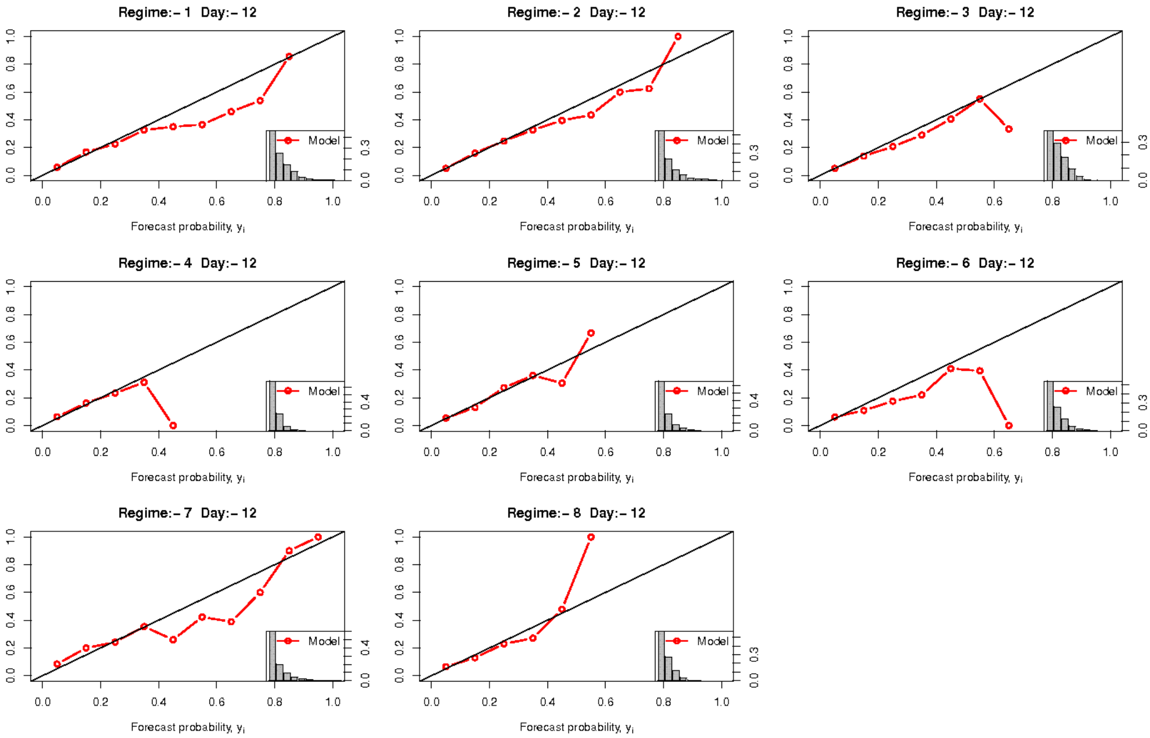


Fig. 9 Reliability plots for ECMWF forecasts per regime at day 12.

Considering the reliability of the 8-regime forecasts in Figure 9 it can be seen that some regimes are reliable though lacking in larger probabilities. This is because the ensemble spread is higher at longer lead times, leading to lower probabilities.

A multi-event contingency table was populated by considering each ensemble member regime classification separately for each lead time. This is summarised for day 10 in Table 1. From this it can be seen that the largest entries are on the diagonal. It is also interesting to compare the marginal totals to consider the overall bias in forecasting particular regimes.

Considering the regime forecasts probabilistically Figure 10 shows the Brier Score for each regime by creating contingency tables for each regime. Getting the regime correct is a hit, and forecasting any other regime is a miss. A single score for the system can also be computed by averaging the scores for each of the 8 regimes (grey line in the middle). The Brier baseline is calculated from the sample climatology (2010-2014), but the uncertainty term will be different for each regime, so that regime scores are not directly comparable, though forecasts from different models of the same regime are (as they will share the same uncertainty term). The Brier Score increases (becomes worse) with lead time. Converting each regime to a Brier Skill Score (which makes them comparable) we see that regime 2 is generally the best scoring regime. All regimes seem reliable with lead time. There is a spread in resolution which tails off with increasing lead time, i.e. less ability to resolve the correct regime. This is due to the increasing range of regimes being forecast as the lead time increases.

This work was presented at the WWRP Open Science Conference in Montreal in August 2014.

Table 1 Contingency table for day 10 ECMWF ensemble members for the period January 2010-June 2014.

		Forecast regime – Day 10								
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***Total***
Observed Regime	***1***	*7937*	*1235*	*4349*	*972*	*2848*	*3046*	*2667*	*2446*	*25500*
	2	*936*	*7699*	*3320*	*2512*	*851*	*2095*	*2657*	*2877*	*22947*

	3	4296	3004	6999	1099	1043	2007	2528	2688	23664
	4	1337	2738	1612	2846	2153	1746	2478	1716	16626
	5	3168	983	1524	1688	3631	1771	2570	1291	16626
	6	2324	1732	2668	1278	1558	4583	696	2807	17646
	7	4257	2636	3638	2065	2667	1247	7859	1233	25602
	8	2445	2843	3229	1355	1127	2802	729	3983	18513
	Total	26700	22870	27339	13815	15878	19297	22184	19041	

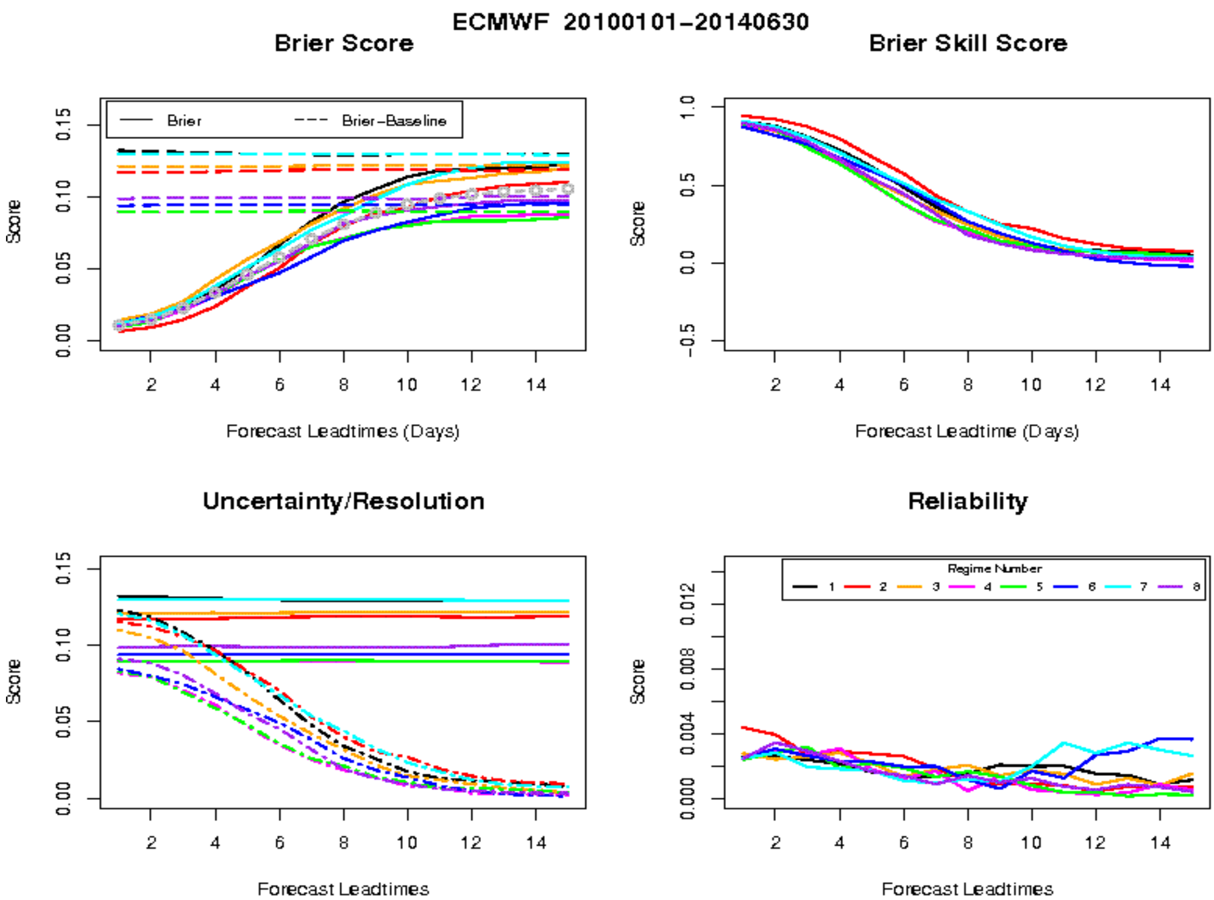


Fig. 10 Components of the Brier Score and Brier Skill Score.

3.2 Subjective verification

3.2.1 Subjective scores (including evaluation of confidence indices when available)

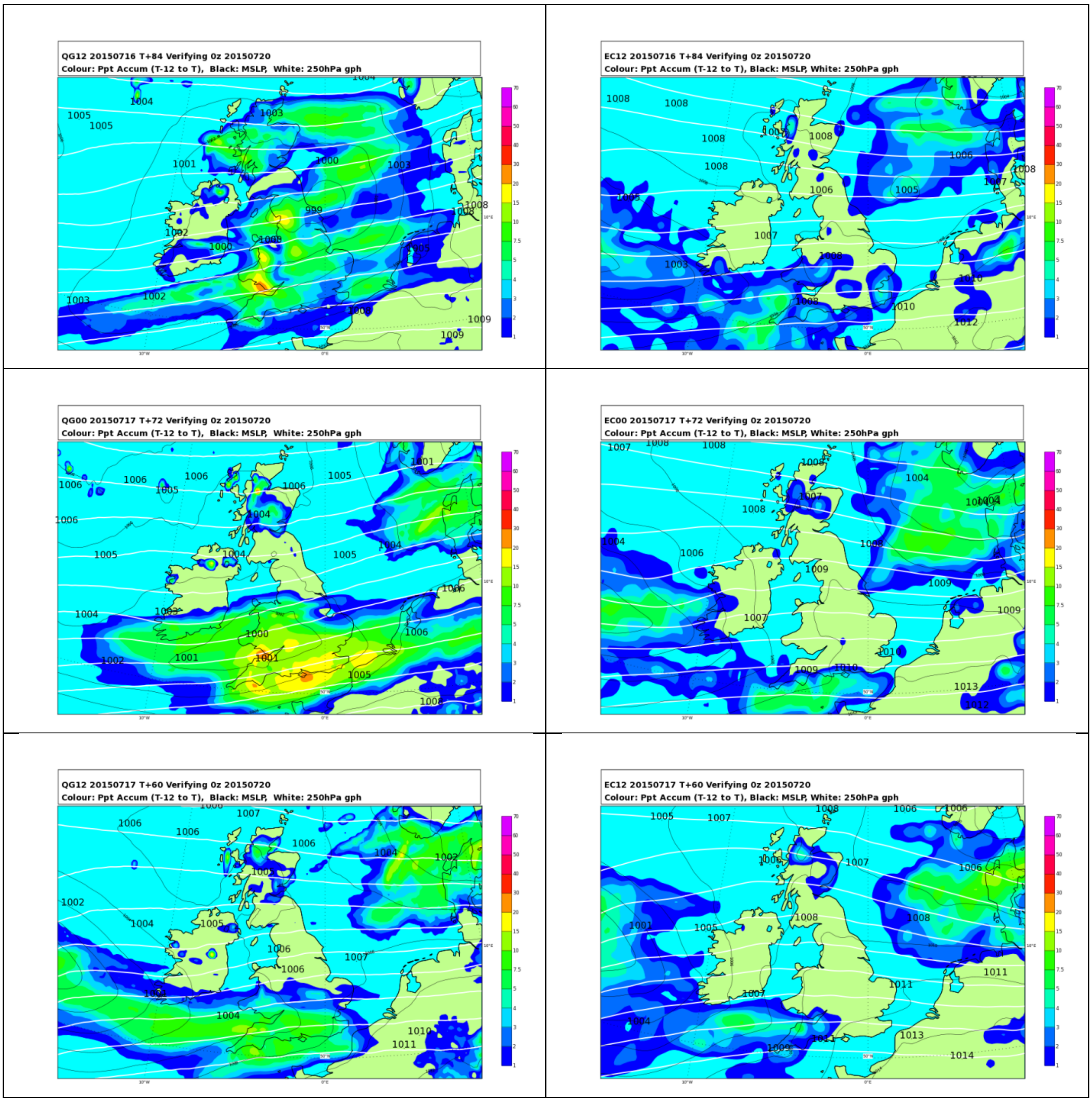
Nothing to report.

3.2.2 Case studies

Rapid Assessment Reports are intended as a concise and rapid assessment of a Global Model forecast error which is significantly larger than that normally observed. They are normally produced soon after the event.

The intention is that they provide: (a) a description of the degree and nature of the error; (b) a basis from which it may be judged whether further investigation is necessary; and (c) guidance on Global Model and MOGREPS-G performance.

A recent RAR was produced for 17 July 2015. The GM forecast produced a very wet day across the south of the UK for a sequence of successive runs from t+84h; in reality a very pleasant summer's day occurred across the UK with clear skies and little or no rain. Skill scores show the GM was considerably worse than both the ECMWF and GFS deterministic models (See Figs. 11 and 12), though these models also showed spikes. The MOGREPS-G ensemble from the same data time successfully indicates a large spread for the timing and intensity of the rain but nevertheless suggests probabilities of around only ~25% for a dry scenario. Error tracking techniques were used to trace the origins of the forecast error back to a broad area of low pressure to the south of Nova Scotia at the analysis time. Here the GM is observed to erroneously deepen the forward flank of the low and erroneously fill the rearward flank - this advances a small depression too rapidly into the North Atlantic which later interacts with a larger pre-existing North Atlantic depression and results in the observed GM error. Sequences of analysis increments and of mean changes in MSLP over 12 hours are used to show that the GM displays a systematic behaviour for these errors over the runs immediately preceding the forecast bust. A treatment of T+24 500hPa gph errors using Hovmoller diagrams was used to show that the original errors are consistent with observed GM biases within the North Atlantic.



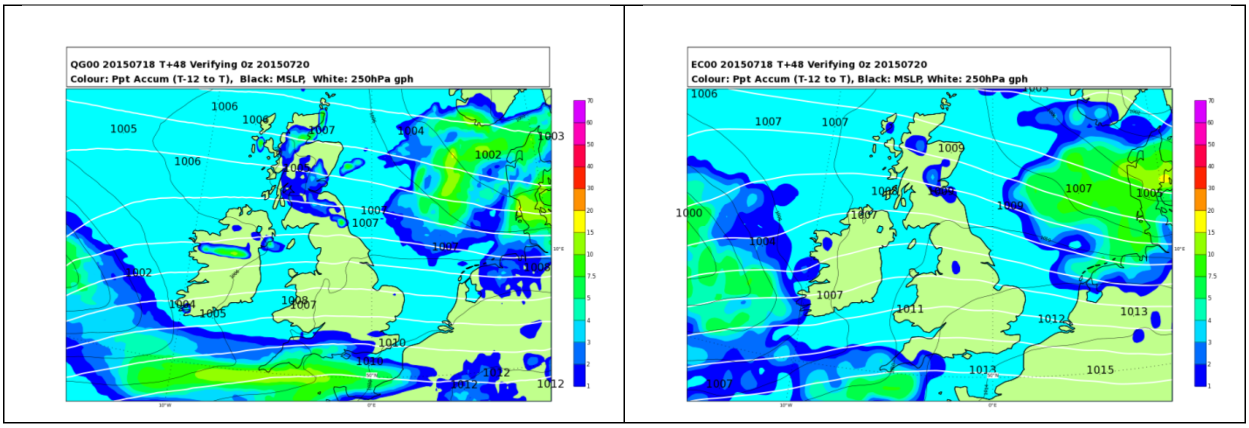


Fig. 11 12 hour precipitation accumulations for the GM (left) and ECMWF (right) deterministic models for 12UTC 19th July–00UTC 20th July.

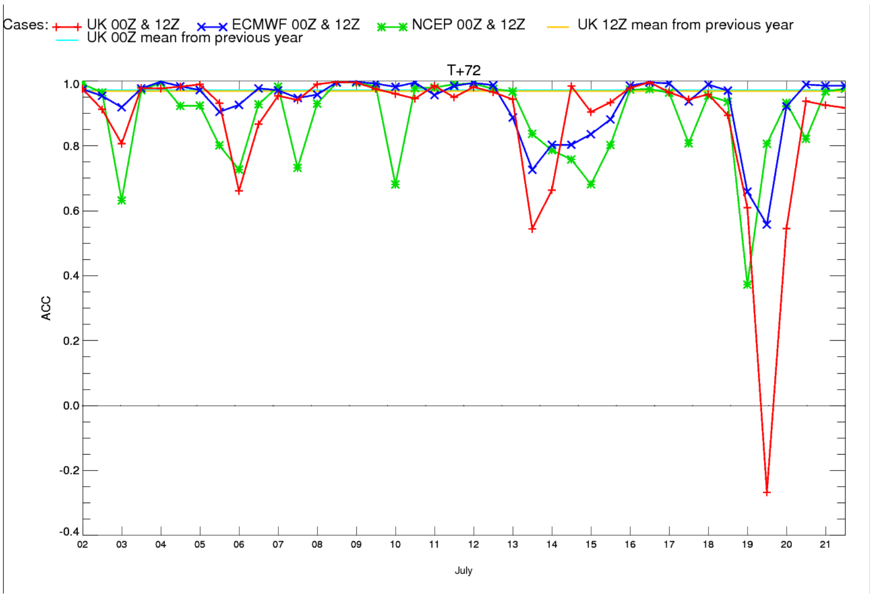
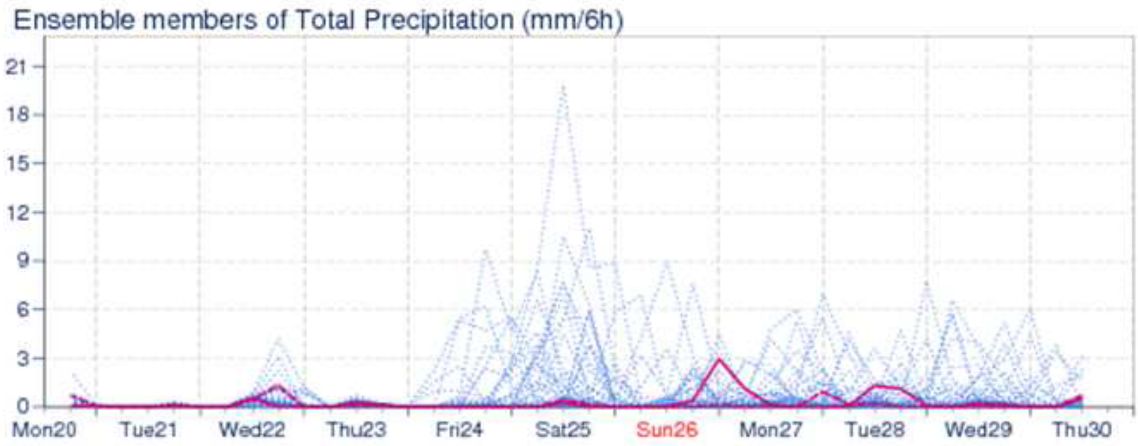


Fig. 12 MSLP ACC at T+72 for the UK area.

Another interesting case occurred a week later, focussing on 24/25 July 2015. The situation involved a split upstream flow across the Atlantic and the evolution was dependent on phasing between a warm air disturbance in the southern stream and an advancing upper trough in the northern stream. Guidance Unit meteorologists noted that there were significant differences in the track and development of a low pressure centre between:

a) GM and ECMWF deterministic models - the key aspect being that the GM had a consistent signal for development, bringing wet and windy weather across southern UK and parts of NW Europe on 24/25 July. ECMWF deterministic also had a consistent signal but this was non-development (i.e. no phasing in) which resulted in a shallow low running into Biscay and no significant weather over the UK.
b) ECMWF control run and ensemble members – a consistent signal in successive runs for the control member (and the deterministic run) to favour no development whereas a number of ensemble members were suggesting the alternative scenario.

Medium range guidance (from the Met Office Operations Centre) referred to these differences and Fig 13 highlights the issue below.



20/12Z

ECMWF ensemble plume for 6hr ppn totals at Reading. Note that whilst the control and high resolution forecasts (denoted by the red lines) indicate very little rain on Friday/Saturday, a number of ensemble members indicate some high totals (with one showing 21mm in 6 hours on Saturday). Over the past 24 hours the signal for more rainfall than the control and high resolution models has been increasing.

Fig 13 ECMWF ensemble output and comments from Medium Range Guidance issued on 21 July 2015.

The ‘development’ scenario was favoured by the Guidance Unit and NSWWS warnings for rain and wind were subsequently issued prior to the event. The outcome was 20-40mm of rain across southern England whilst strong winds affected the Low Countries and northern Germany as the low deepened further (see Fig 14).

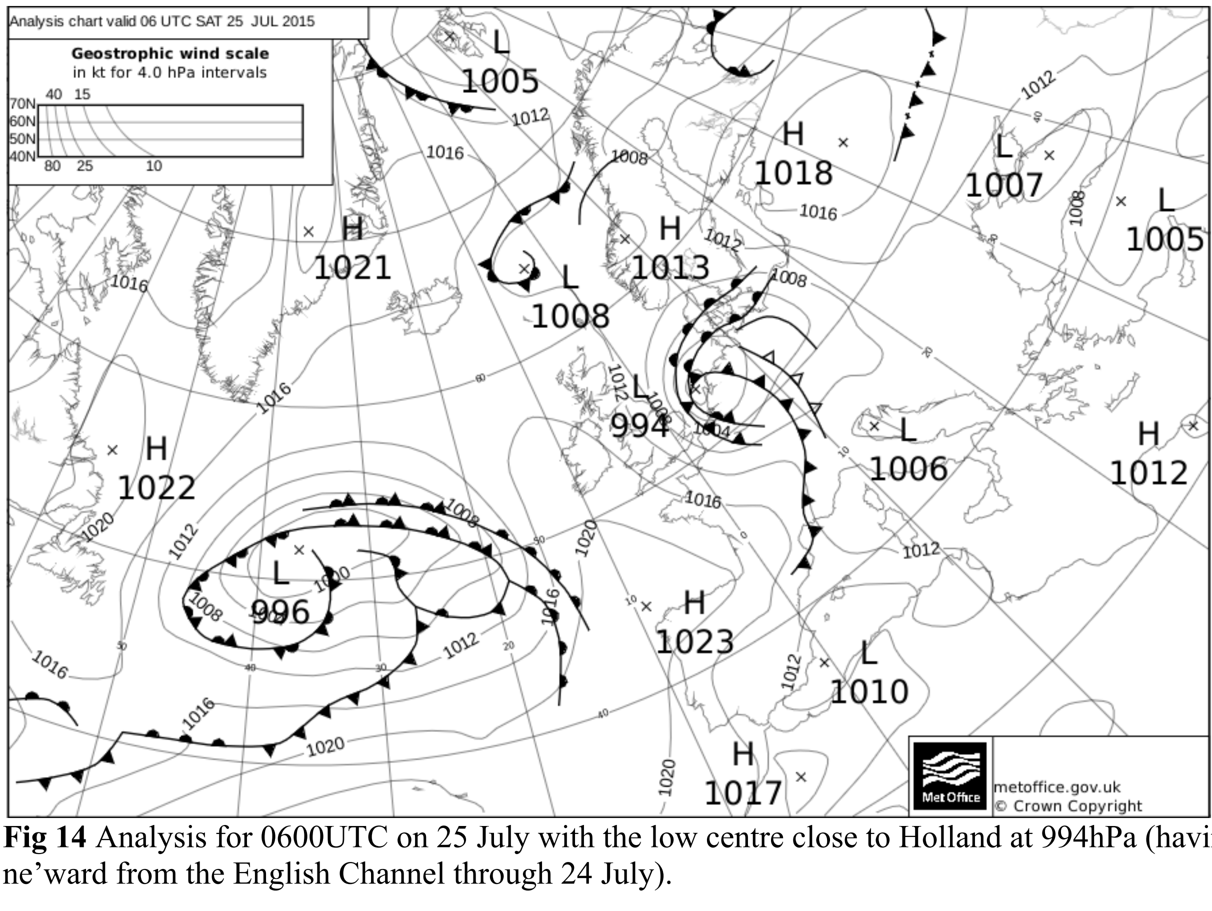


Fig 14 Analysis for 0600UTC on 25 July with the low centre close to Holland at 994hPa (having tracked ne’ward from the English Channel through 24 July).

This case was raised with ECMWF as a potential forecast bust and worthy of further investigation. Tim Hewson has performed a post-event analysis which confirms the bimodal nature of the forecast evolution (see Fig 15).

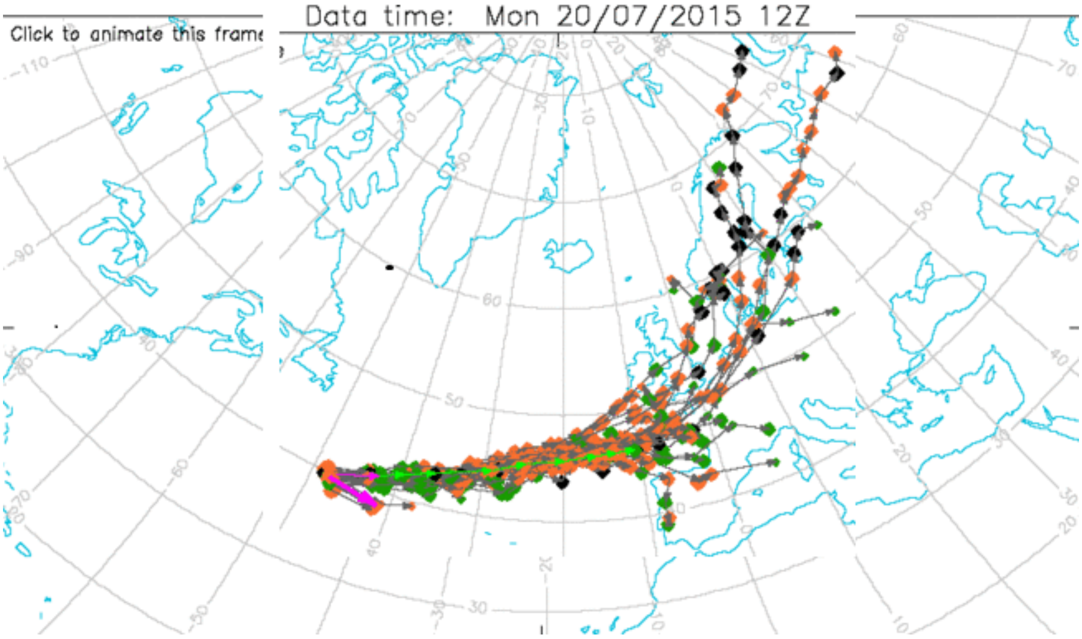


Fig 15 Tracks from ECMWF ensemble members (from 20/12Z run). The deterministic run (shown by the green arrows) indicates a weak low on a more southerly track which decays over north Biscay.

4. References to relevant publications

Neal, R. A., Boyle, P., Grahame, N. Mylne, K. and Sharpe, M. 2014; Ensemble based first guess support towards a risk-based severe weather warning service, Met Apps, 21, 562-577

Neal, R. A., Fereday, D., Comer, R. and Crocker, R. 2015: A flexible approach to defining weather regimes and their application in weather forecasting over Europe. Met Apps (in press)

Savage, N. H., P. Agnew, L. S. Davis, C. Ordonez, R. Thorpe. C. E. Johnson and M. Dalvi. Air quality modelling using the Met Office Unified Model (AQUM OS24-26): model description and initial evaluation. *Geosci. Model Dev*. **6**, 353–372 (2013).