MOGREPS Ensemble Systems

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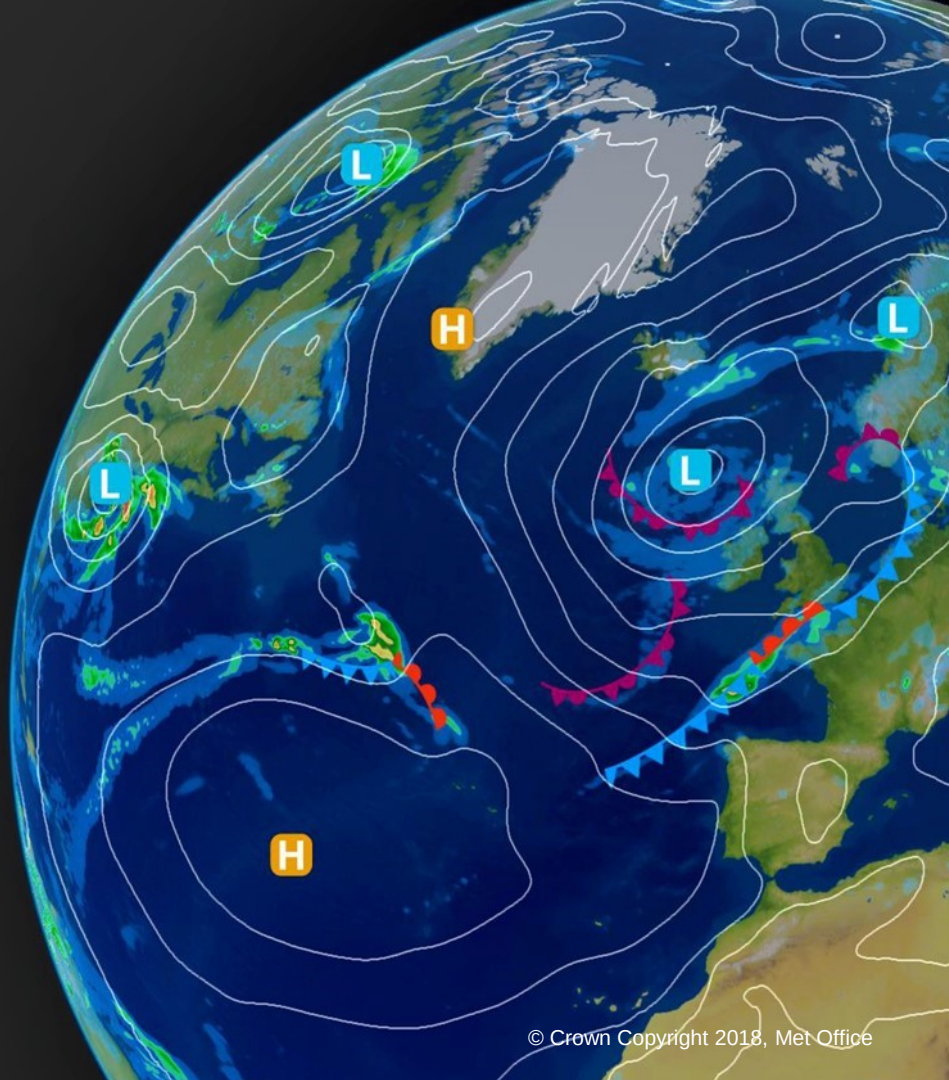


Outline

An integrated ensemble-based NWP system

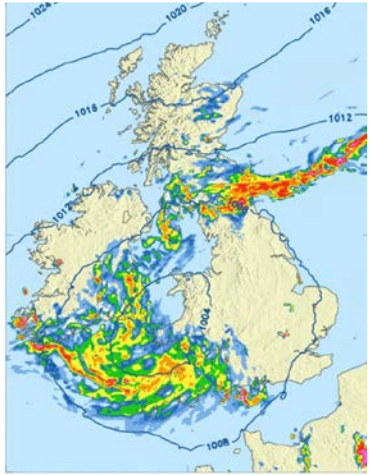
- MOGREPS-G Global Ensemble
  - A few user application tools
- MOGREPS-UK Convective Scale Ensemble
- IMPROVER blended probabilistic post-processing
  - More info on posters

Deterministic models, global and UK, remain an important part of our NWP, but are heavily integrated with MOGREPS through hybrid 4D-Var, and are blended in IMPROVER.

Two model Strategy: Global and UK

Strategy defined ~10 years ago, almost complete

N x Global predictions at ~20km with lead times of days to weeks: **Synoptic drivers**



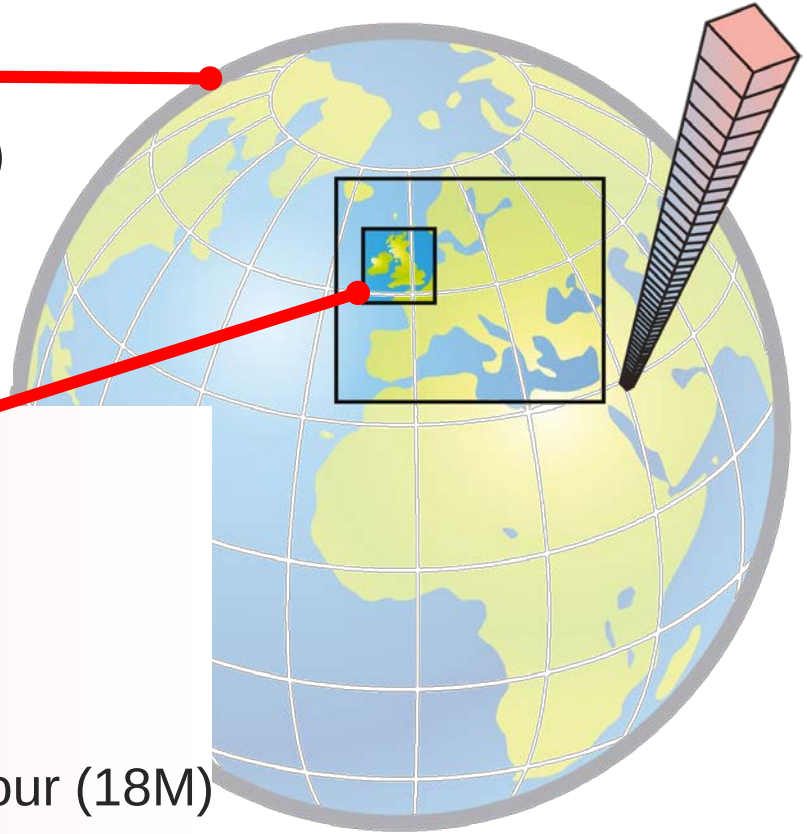
<N x Regional predictions at ~1km: **Local meteorology**

PDF of local hazard: **Impacts**

NWP Configurations: 2019

Global NWP:

- 10/20km deterministic/MOGREPS-G (36M)
- 70 vertical levels (80km top)
- Hybrid 4D Variational Data Assimilation
- Forecasts to T+48 or T+192hr every 6 hrs



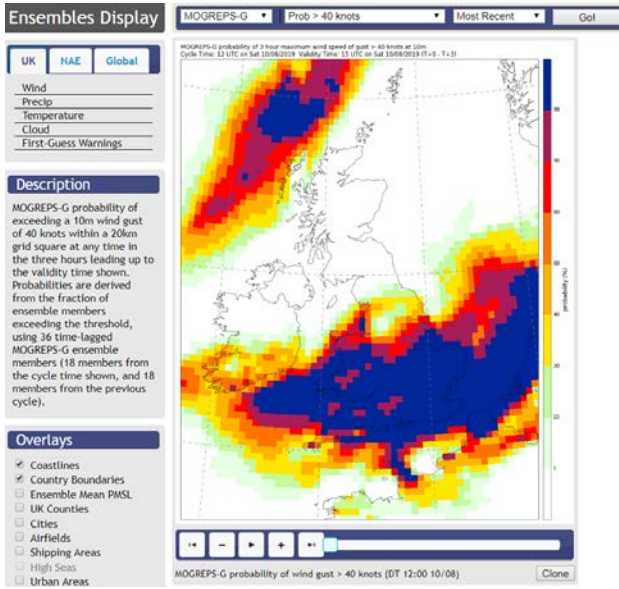
UK NWP:

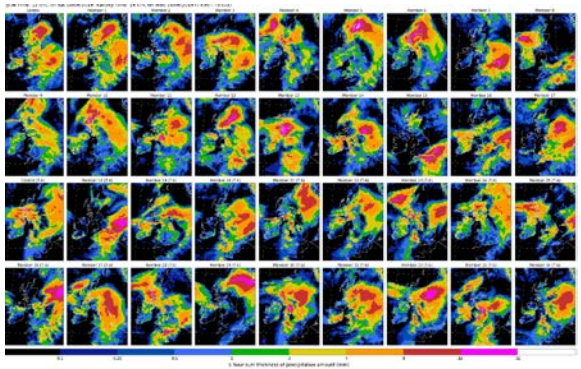
- 1.5/2.2km deterministic/MOGREPS-UK
- 70 vertical levels (40km top)
- Hourly 4DVar Analysis and 12h forecast
- Forecasts to T+54h every 3hr
- MOGREPS-UK to T+120 updated every hour (18M)

MOGREPS = Met Office Global & Regional Ensemble Prediction System

Brief description MOGREPS-G

- 36-member time-lagged Global ensemble with UM at ~20km grid resolution
  - 18 members run every 6 hours with last two cycles combined to provide 36 member forecasts
  - Forecasts to 7 days
- Initial perturbations by ETKF with localisation
- Stochastic physics by SKEB and SPPT (details to follow)
- Wide-ranging post-processing applications…



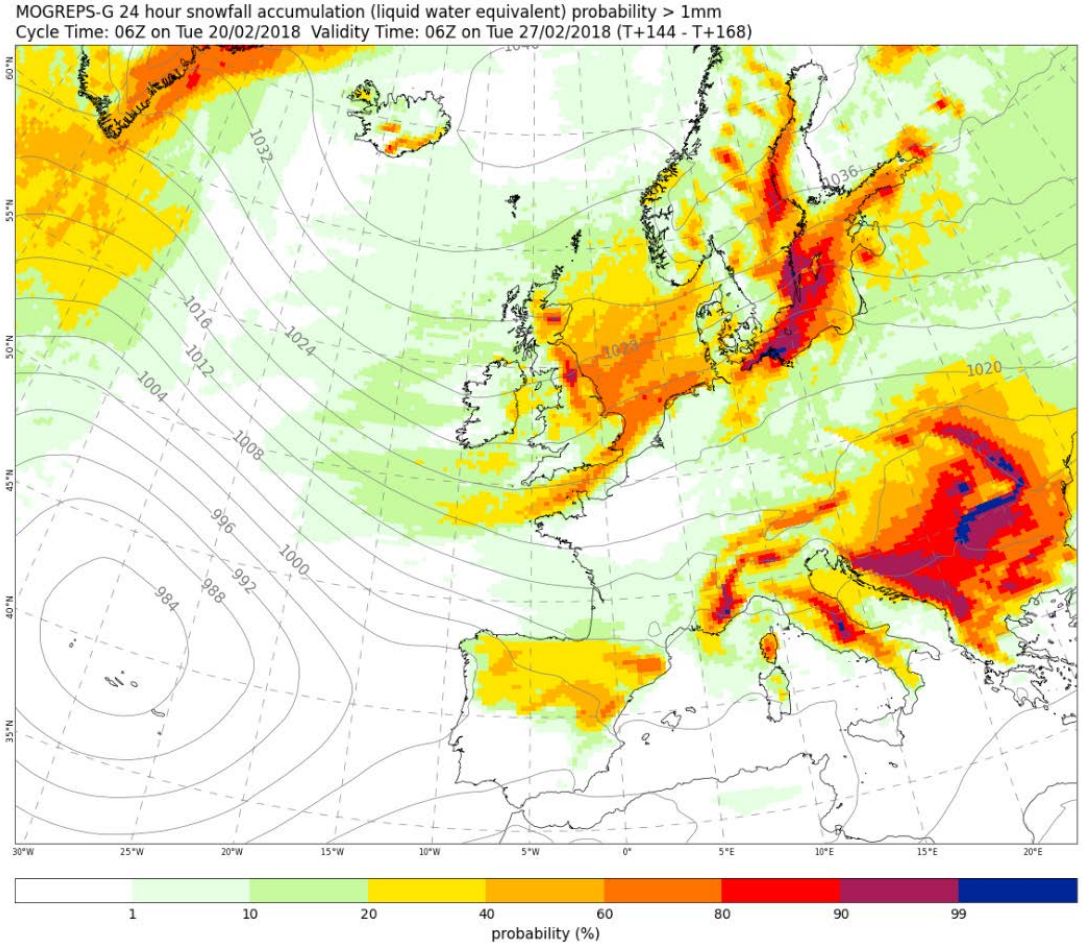


Met Office

Major Snow event, Mar 2018

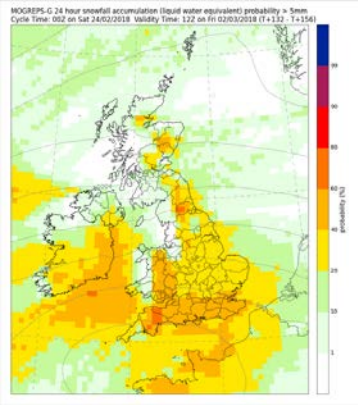
Probability 24 hour snowfall > 1cm

High probabilities showing up over the North Sea and eastern side of the country at a **6 to 7 day lead time**, signalling the first snow of this cold spell.

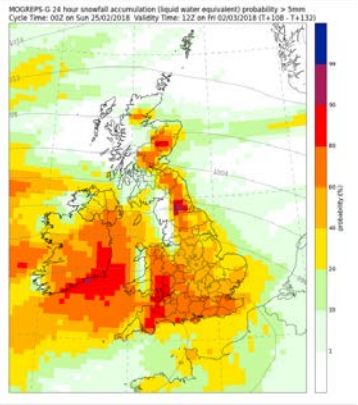


MOGREPS-G probability forecast evolution

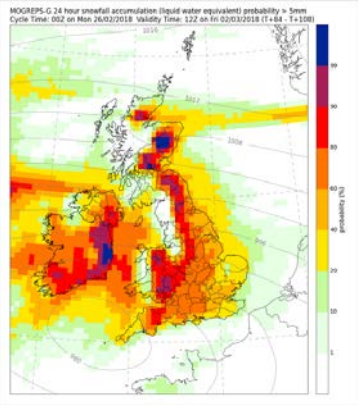
Probability 24 hour snowfall > 5 cm, valid 12:00 Thu 1st Mar to 12:00 Fri 2nd March 2018



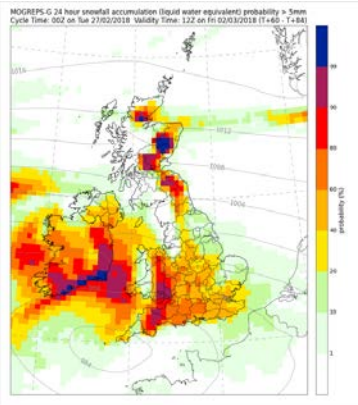
6 day forecast



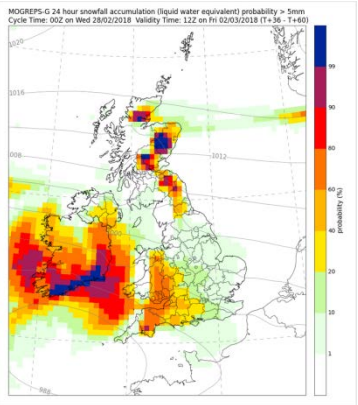
5 day forecast



4 day forecast



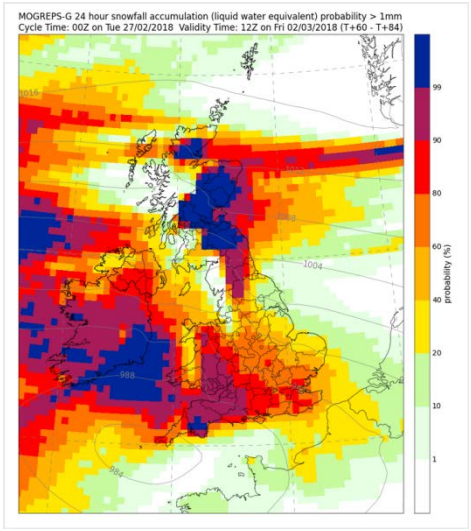
3 day forecast



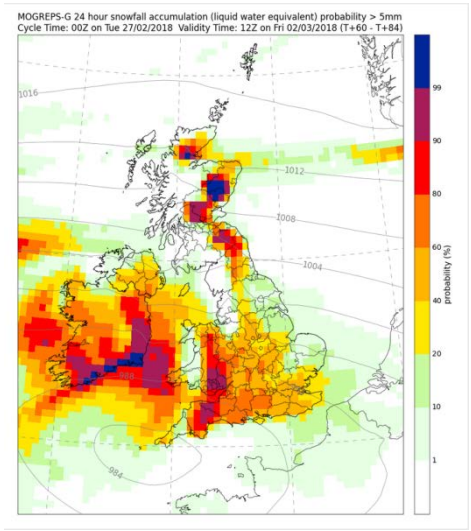
2 day forecast

MOGREPS-G probability forecasts for different snow amounts (SW snow event)

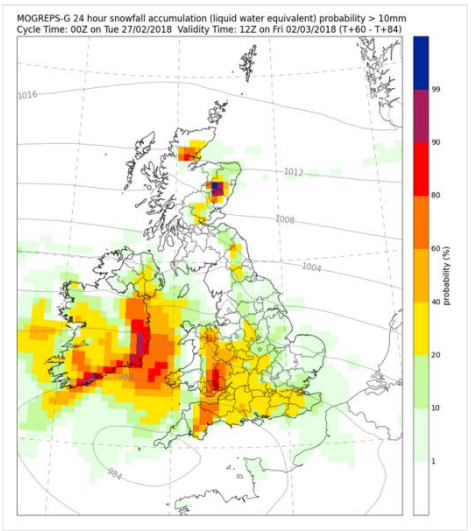
Valid 12:00 Thu 1st Mar to 12:00 Fri 2nd March 2018 – 3 day lead time



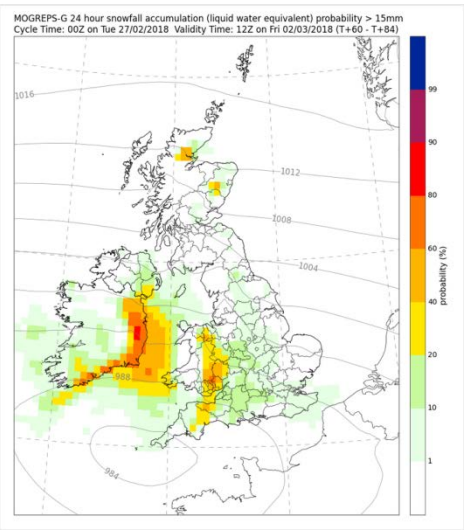
Probability > 1 cm



Probability > 5 cm



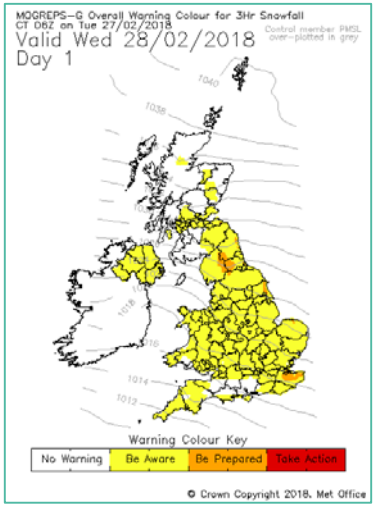
Probability > 10 cm

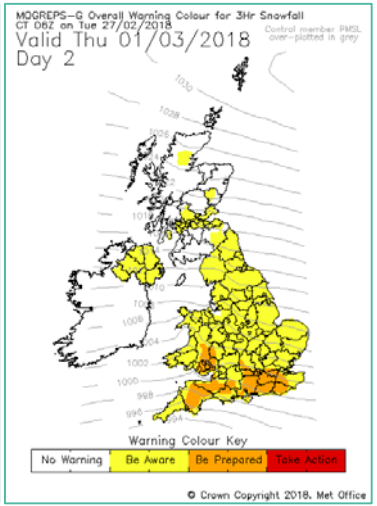


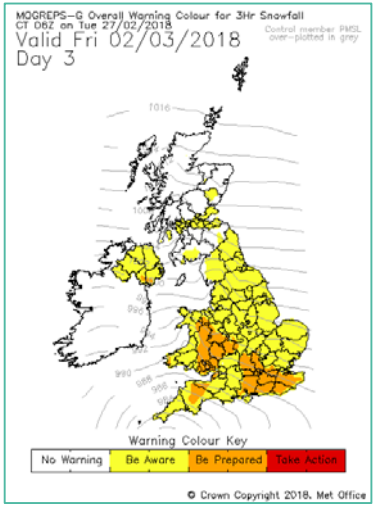
Probability > 15 cm

Viewing probabilities for several snowfall thresholds helps pinpoint the areas most at risk

MOGREPS-G first guess warnings for snow

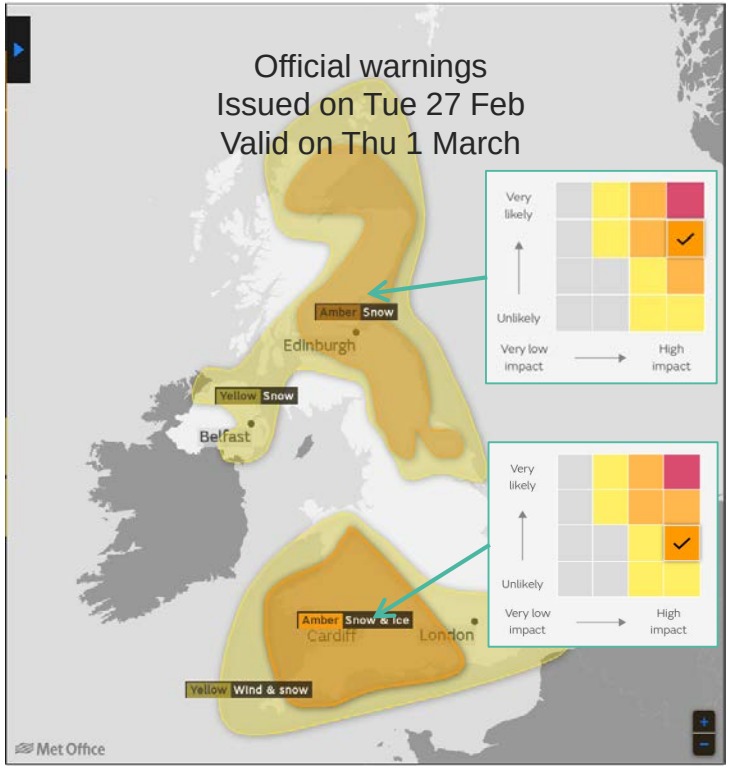






MOGREPS-G **first-guess** warnings
Issued on Tue 27 Feb and valid on
Wed 28th Feb (left), Thu 1st March (middle) and Fri 2nd March (right)

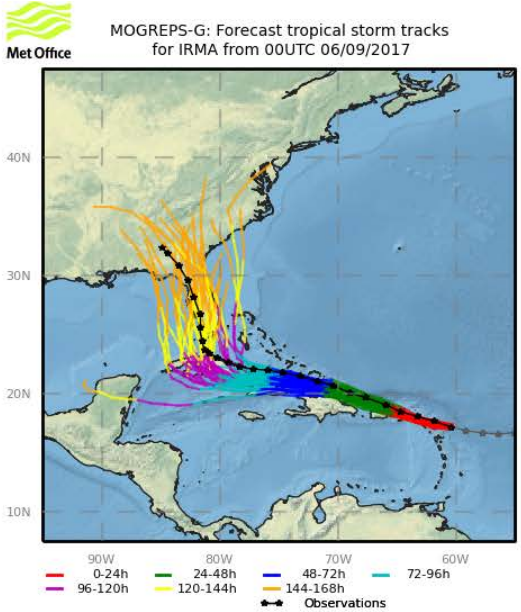
MOGREPS-G is not resolving the heaviest snow showers in the NE, but is capturing the frontal snowfall in the south much better. The UKV (1.5 km) and MOGREPS-UK (2.2 km) are able to help with the showers.

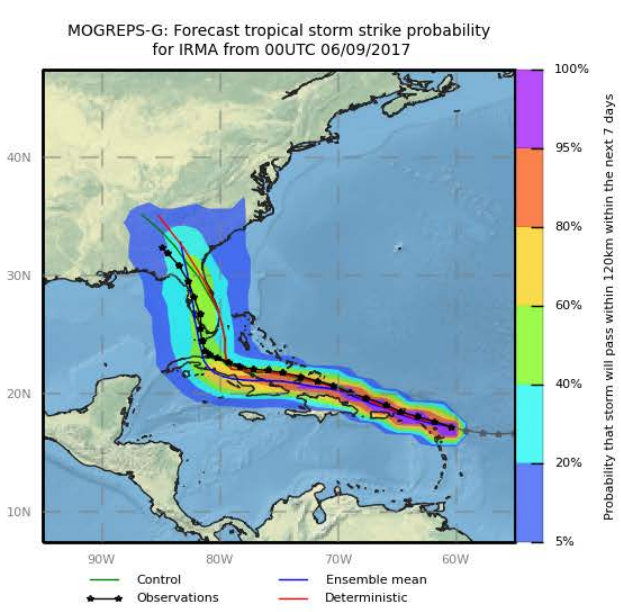


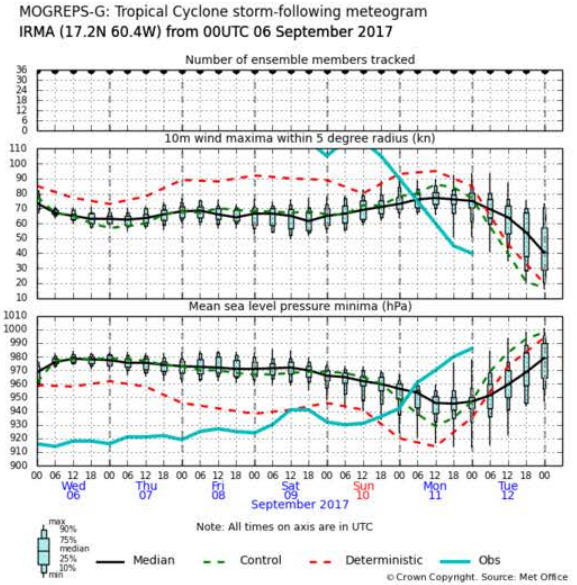
Hurricane Irma 6th 00z run

Plots c/o Helen Titley

Tropical cyclone tracking and storm-following meteograms





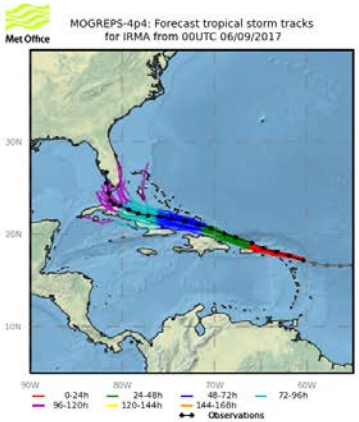


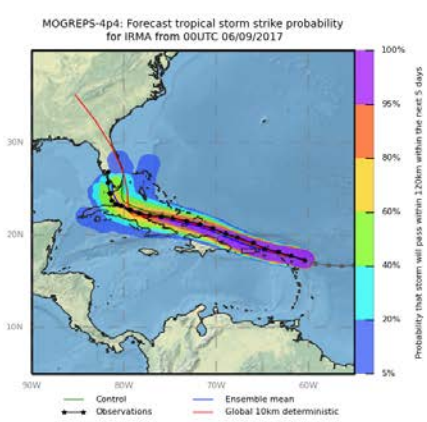
Capability to downscale 4.4km nested TC ensemble

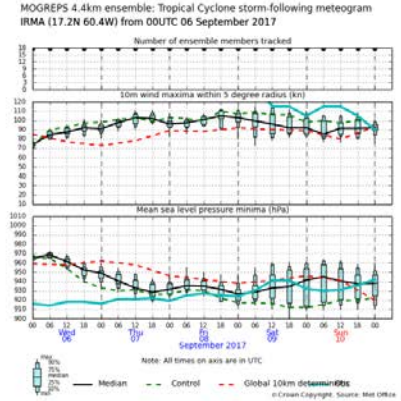
Hurricane Irma 6th 00z run

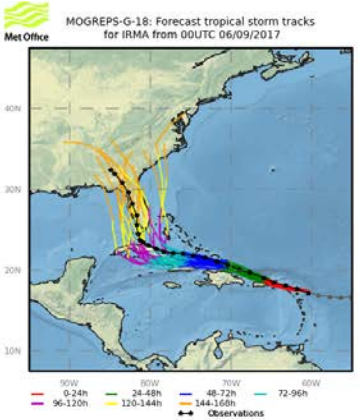
Plots c/o Helen Titley

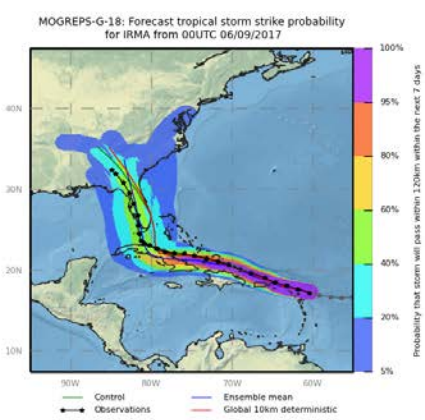
- Top = 5 day forecast for 4.4 km
- Bottom = 7 day MOGREPS-G forecast (18 not 36 members)
- 5v7 day forecast complicates direct comparison of plots.
- Actual track is overlaid in black
- Tracks broadly similar
- Propagation speed better in 4.4 km ensemble (compare location of purple lines)
- PMSL intensities in 4.4 km ensemble encompass observed value after T+48.
- “Usual” peak 10 m wind underestimation

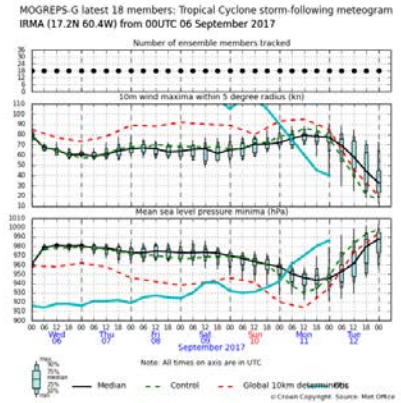






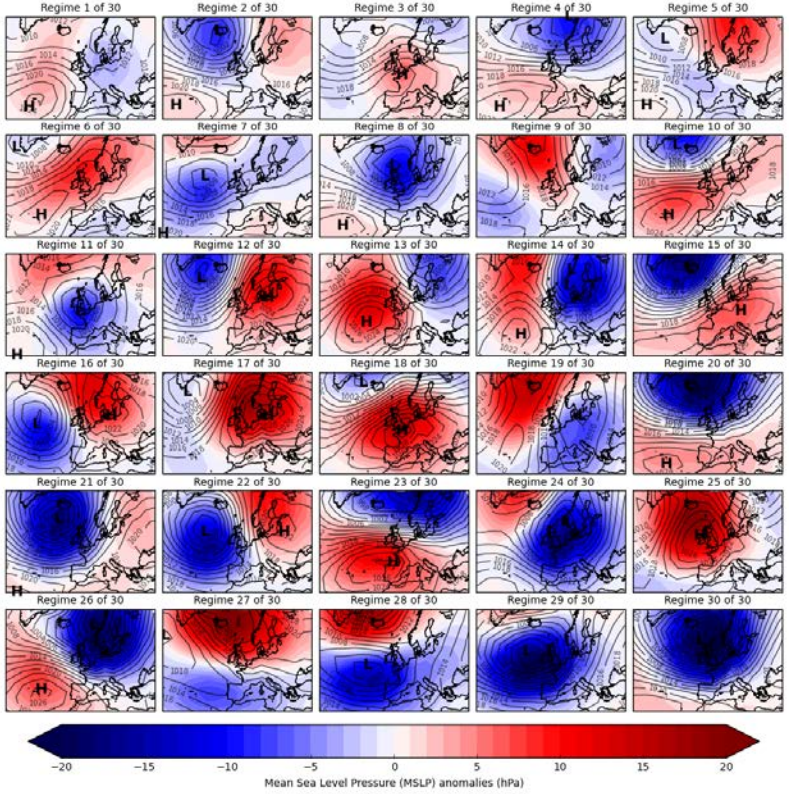






Regime Analysis and the Decider tool

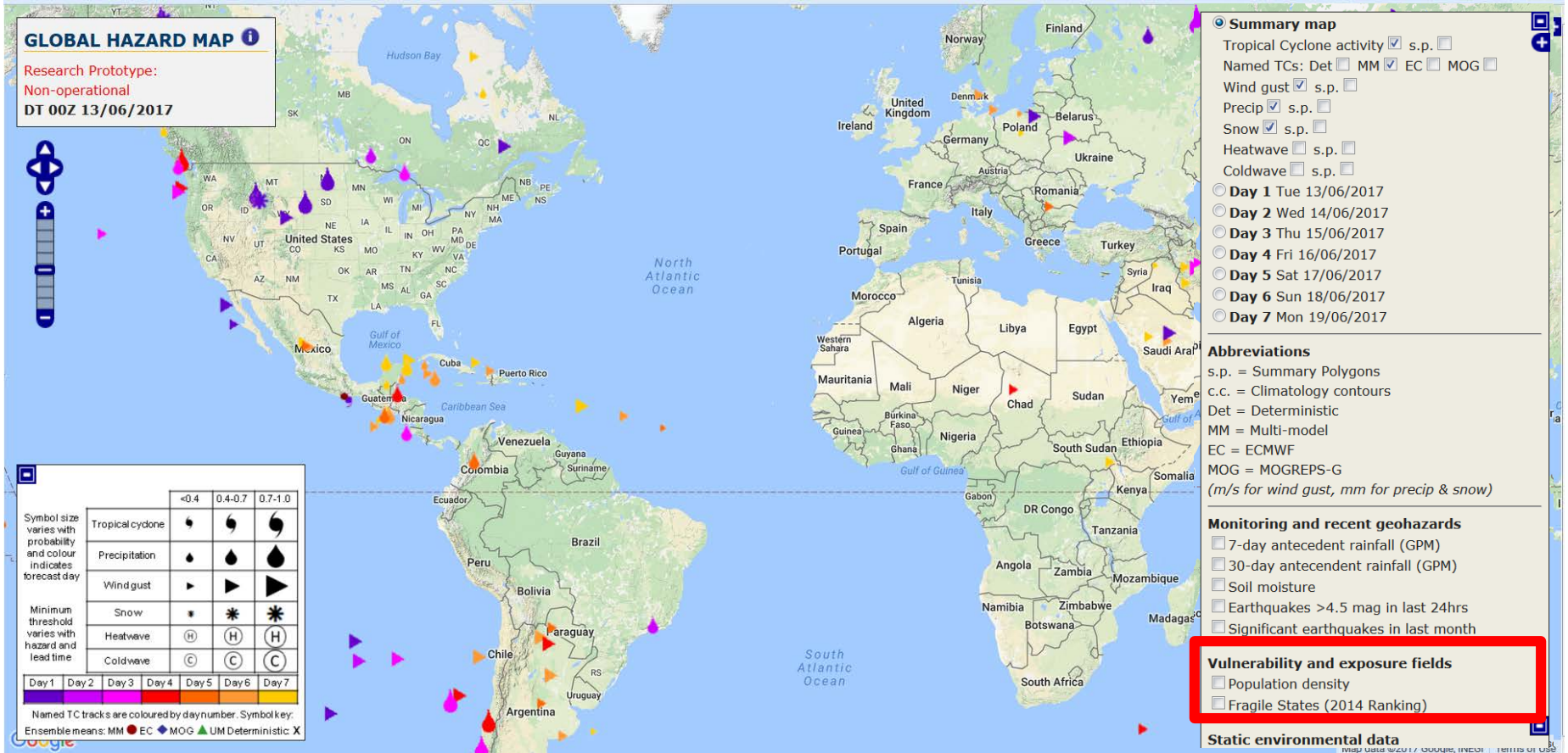
Seamless ensemble clustering:
Monthly with Glosea; Medium-Range using MOGREPS-G and ECMWF ENS



	Wed 2 Dec	Thu 3 Dec	Fri 4 Dec	Sat 5 Dec	Sun 6 Dec	Mon 7 Dec	Tue 8 Dec	Wed 9 Dec	Thu 10 Dec	Fri 11 Dec	Sat 12 Dec	Sun 13 Dec	Mon 14 Dec	Tue 15 Dec	Wed 16 Dec	Regime Descriptions (UK)	Historic Occurrence N/D/J
Regime 1											2			2		Unbiased NWly	2.0%
Regime 2											4	4	2			Cyclonic W-SWly, returning Pm airmass	2.8%
Regime 3								2	2		4		4			Anticyclonic SWly, ridge over N France	2.3%
Regime 4									2	2		6		2	4	Unbiased Wly	2.7%
Regime 5																Unbiased S-SEly, high over Scandinavia	2.7%
Regime 6																Anticyclonic, Azores high ext.	2.8%
Regime 7												2	6	4	4	Cyclonic SWly, low WNW of Ireland	2.2%
Regime 8										2	4	6	4	2	2	Cyclonic W-NWly, low near Shetland	3.1%
Regime 9										2	4	4		2	2	Anticyclonic N-NEly, high near Iceland	2.6%
Regime 10													2		2	Anticyclonic W-SWly, slight Azores ridge	3.4%
Regime 11													4	2		Cyclonic, low centred over southern UK	2.4%
Regime 12								2	4		2	2		2	2	Anticyclonic Sly, high over Poland	4.2%
Regime 13							2		6	16	10	6	8	2	2	Anticyclonic NWly, high SW of Ireland	4.4%
Regime 14											**10**	**12**	**12**	8	6	Cyclonic N-NWly, low near S Sweden	4.0%
Regime 15	100	51	84		2	18		6	12	4	6	6	8	4	8	Unbiased SWly, very windy NW Britain	4.6%
Regime 16												2	2	2	2	Anticyclonic S-SEly, high E of Denmark	2.7%
Regime 17								4	6	2	4		2			Anticyclonic E-SEly high over Denmark	4.3%
Regime 18						6	18	**55**	**39**	**25**	12	10		6	4	Anticyclonic SWly, high over N France	4.7%
Regime 19														**4**	4	Cyclonic Nly, low E of Denmark	4.0%
Regime 20			10	**100**	**76**	31			2	2		6	8	8	4	Cyclonic Wly, intense low near Iceland	4.1%
Regime 21										2	4	2	6	14	12	Cyclonic SWly, deep low S of Iceland	3.8%
Regime 22												2			2	Cyclonic Sly, low W of Ireland	3.2%
Regime 23		**49**	6		18	**41**	**80**	25	**27**	**31**	20	12	6	2	4	Unbiased Wly, windy in N	4.1%
Regime 24												2	12	14	14	Cyclonic Nly, low in N Sea	3.2%
Regime 25								6		6	6	6	2		**4**	Anticyclonic Nly, high centre Irish Sea	3.6%
Regime 26					2	4				6	8	8	2	6	14	Cyclonic NWly, low near Norway, windy	3.4%
Regime 27																Anticyclonic Ely, high in Norwegian Sea	3.7%
Regime 28													2			Cyclonic SEly, low SW of UK	2.8%
Regime 29												2	2	4	2	Cyclonic S-SWly, deep low W of Ireland	2.9%
Regime 30					2						2	2	8	12	4	Cyclonic W-SWly, deep low SE of Iceland	3.0%
Total Members	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	---	---

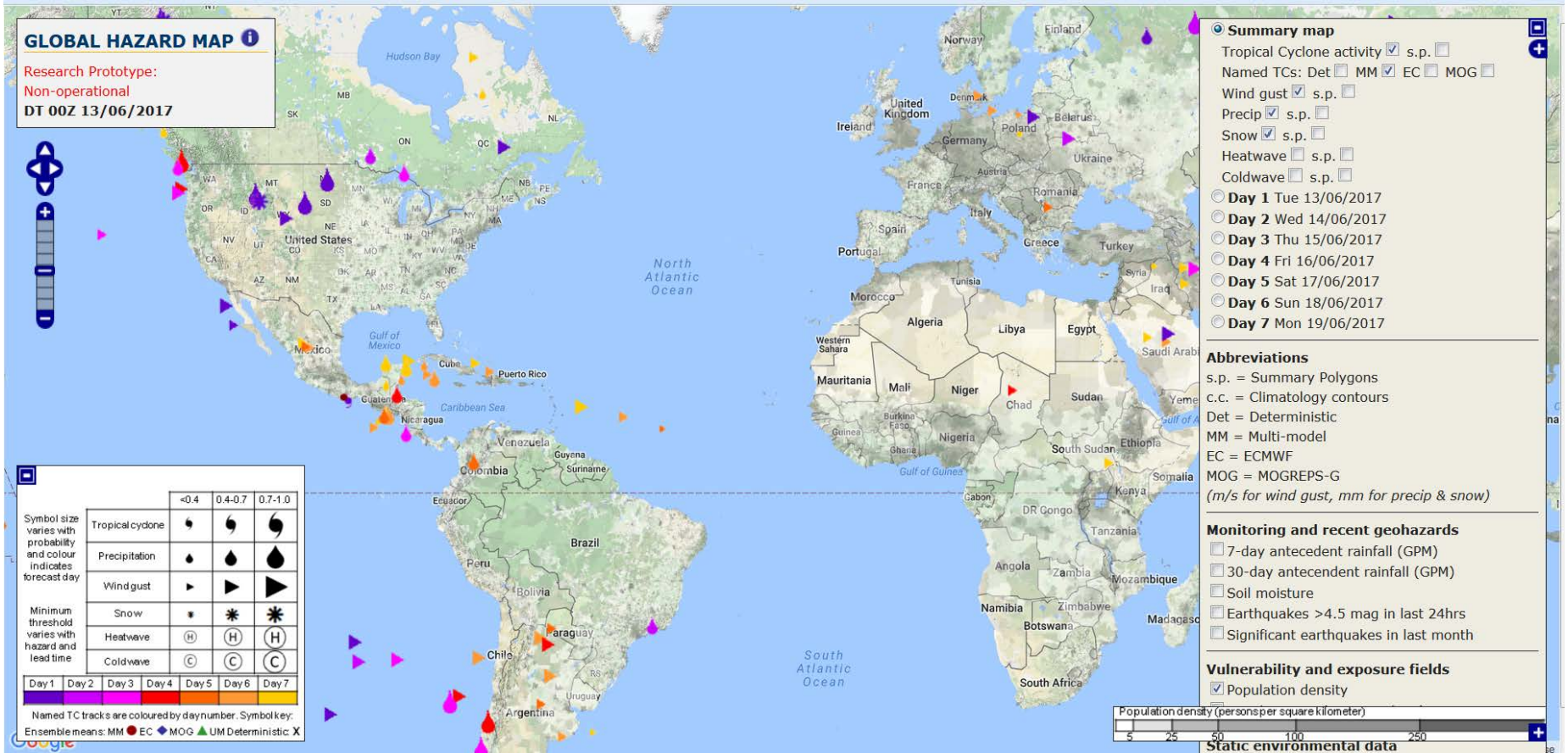
Global Hazard Map

Ensemble forecasts of extreme hazard probabilities …



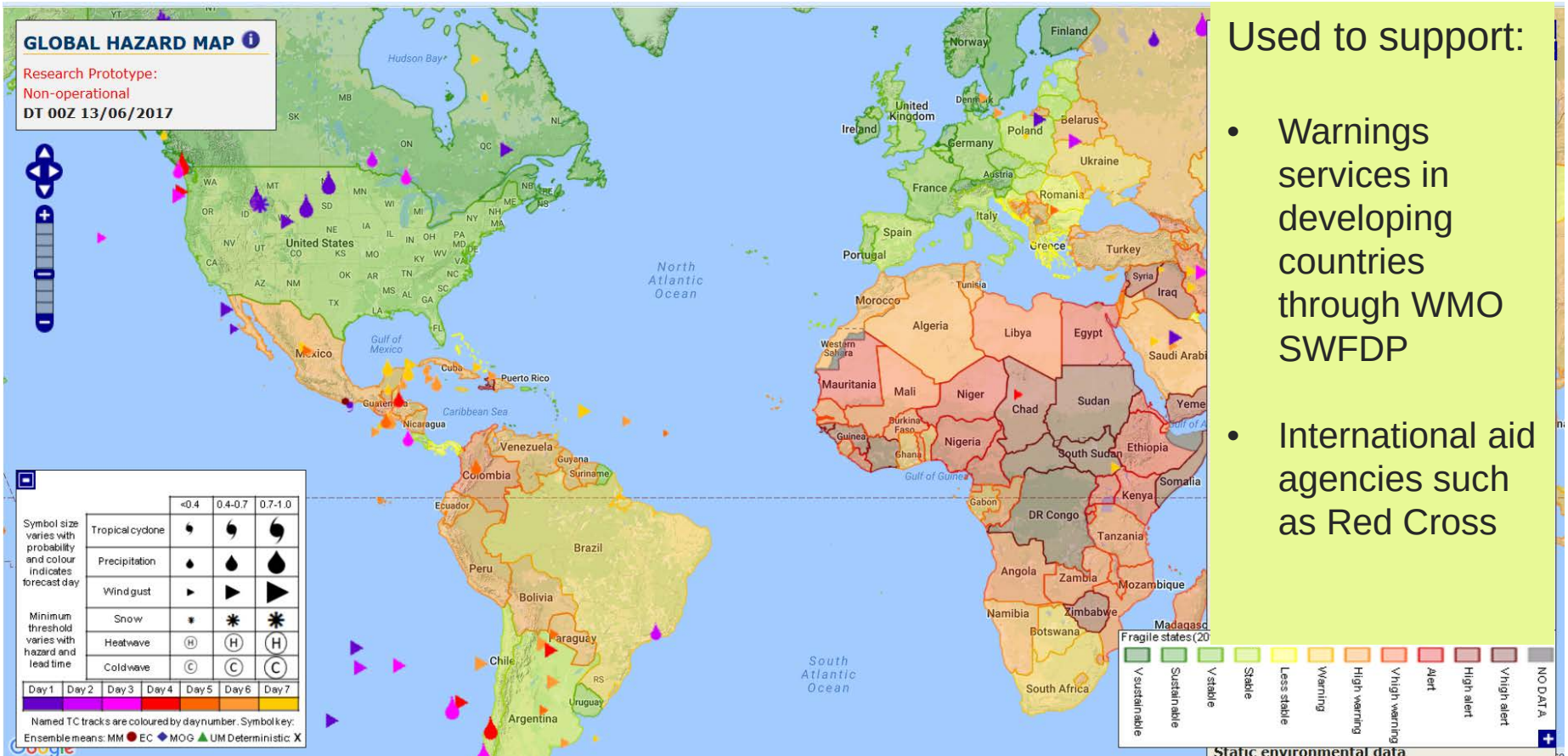
Global Hazard Map

Ensemble hazard probabilities overlaid against global scale vulnerability datasets – population density



Global Hazard Map

Ensemble hazard probabilities overlaid against global scale vulnerability datasets - fragile states



Used to support:

- Warnings services in developing countries through WMO SWFDP
- International aid agencies such as Red Cross

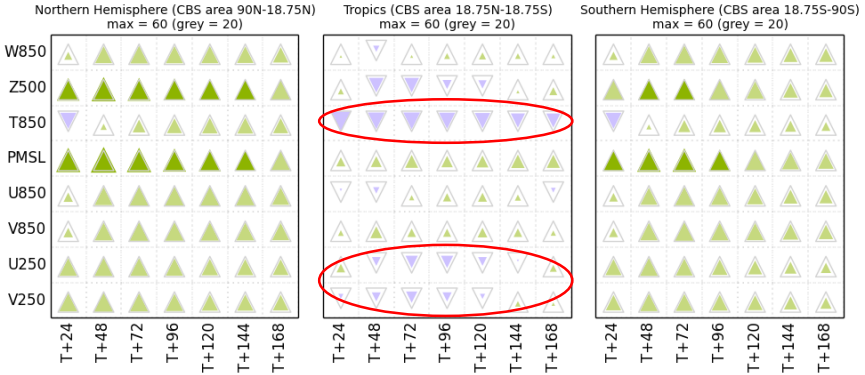
Ensemble comparison with other centres

Data source: Japan Meteorological Agency – JMA – website http://epsv.kishou.go.jp/EPSv

Scorecards vs individual centres

CRPS scorecard MOGREPS-G vs JMA Oct 2018. Up-green (down-purple) triangles show better (worse) performance in MOGREPS-G.

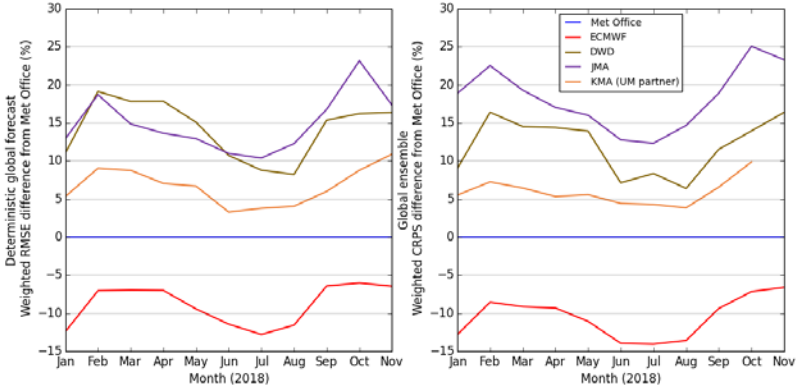
- Weaker tropical 250hPa winds improved in PS41, but 850hPa temperature bias degraded



Index time-series vs all centres

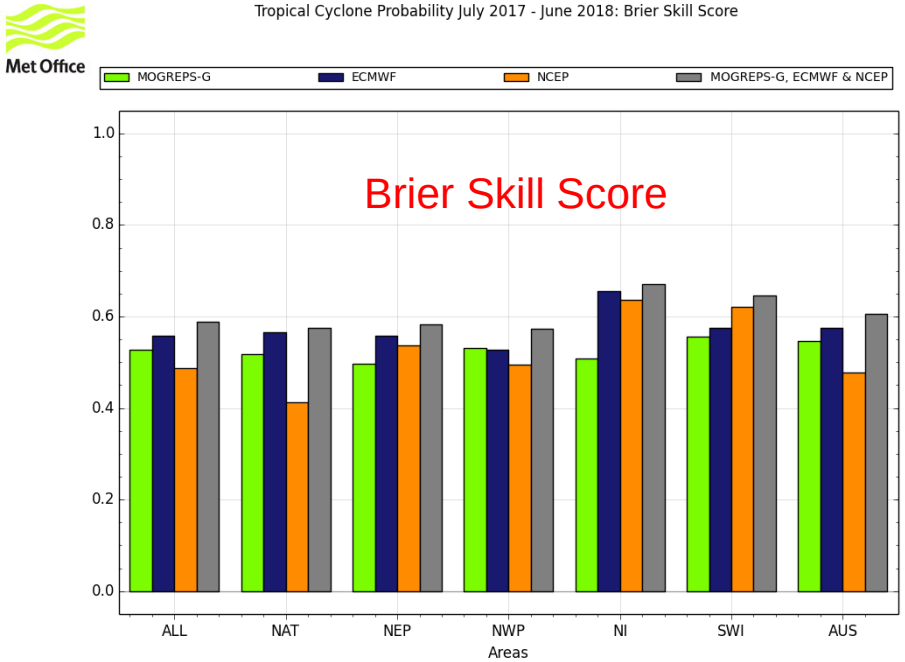
High-res deterministic RMSE Index (left) and ensemble CRPS Index (right) time-series with Met Office as zero (blue) line.

- Ensemble performance close to deterministic, but also highlights specific features linked to the ensemble



Tropical Cyclone 7-day strike probability forecasts

88 named storms in Jul 2017 – Jun 2018

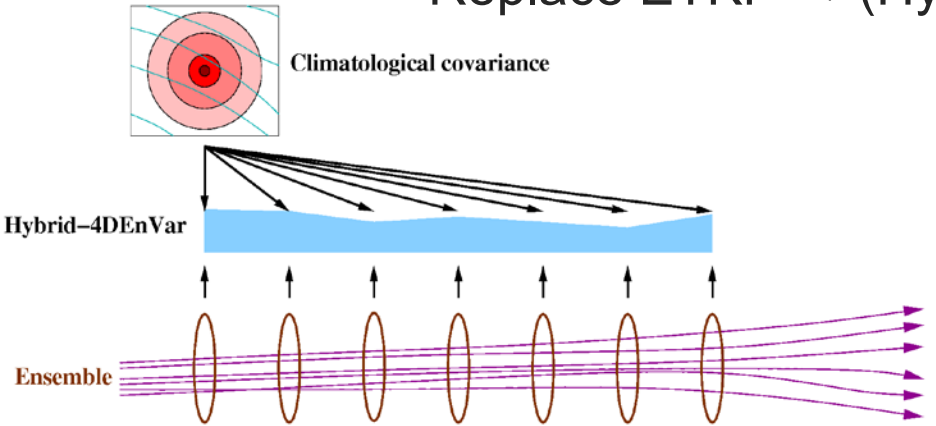


Rebecca Bowyer (nee Stretton)

- No single ensemble system is best in all areas for strike probability
- MOGREPS-G in 2nd place overall
- Multi-model system always best for this metric

PS43 Ensemble upgrade (Sep 2019)

Replace ETKF → (Hybrid-)En-4DEnVar

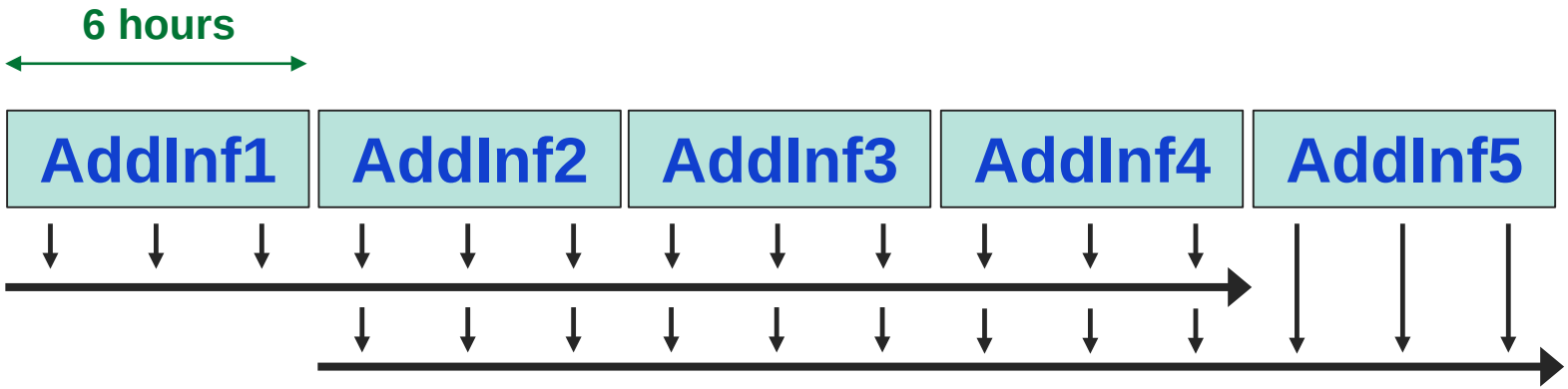


- 4DEnVar does not need a linear PF model (simplifies code maintenance) because it uses ensemble information throughout assimilation window
- Still uses climatological background error covariances (hybrid scheme)
- The 4DEnVar executable can also do an ensemble of analyses: **En-4DEnVar**:
  - (For each member, create increments relative to its own background trajectory)
- Routines available to deal with inflation, perturbed observations, etc.

Stochastic Physics and Model Error schemes

Scheme	Complexity/Cost	Maintenance	Effectiveness
SKEB (Stochastic Kinetic Energy Backscatter)	• Theory not fully robust • Widely used, but in decline • Moderate cost	Well established in UM, no significant cost	++
SPT (or SPPT) (Stochastic Perturbation of Tendencies) ***(Impl. PS41 in 2018)***	• Widely used • Simple and flexible • Moderate cost	Part of GA7 (as with SKEB), stable performance	++
Additive Inflation (using DA Incr archive) ***(Impl. PS43 in 2019)***	• New idea, less tested • Code lacks documentation • Large offline IO & storage	Needs regular updating of operational Analysis Increment archive	+++
Perturbed parameters ***(Retired in PS41 2018)***	• Very simple • Minimal cost • Can be expanded to 2D	Needs to keep track with physics developments. Magnitude and correlation of perturbations complex.	+

Additive inflation



Create a year-long archive of data assimilation increments, then at each time-step during the model forecast add:

1. a randomly selected historical analysis increment (with 50% scaling) per six-hour period, retaining the selection for the same validity time in subsequent forecast cycles
2. a three-month mean increment, as a bias correction (with no scaling)

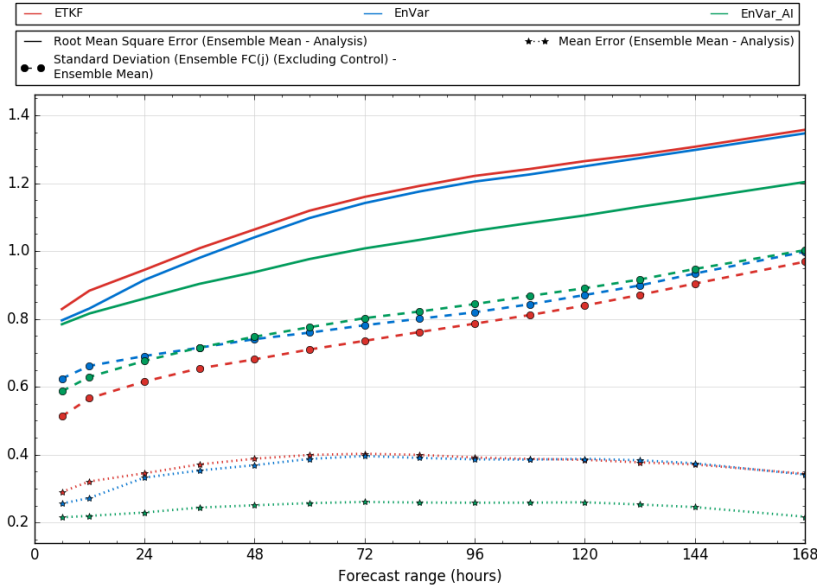
   Note: the random selection and mean are both from the same three-month period, corresponding to the day/month of the forecast to account for seasonal dependencies

En-4dEnVar (early low-resolution results) Improves spread, bias and error

Period: 1 Sep – 15 Oct 2018; Truth = ECMWF Analyses

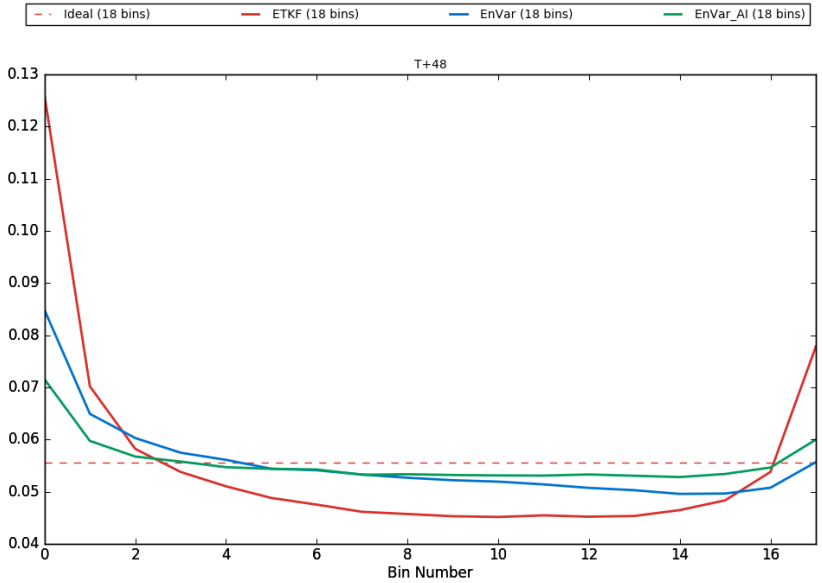
RMSE, spread, bias – T850 (tropics)

- *AI improves bias and RMSE*



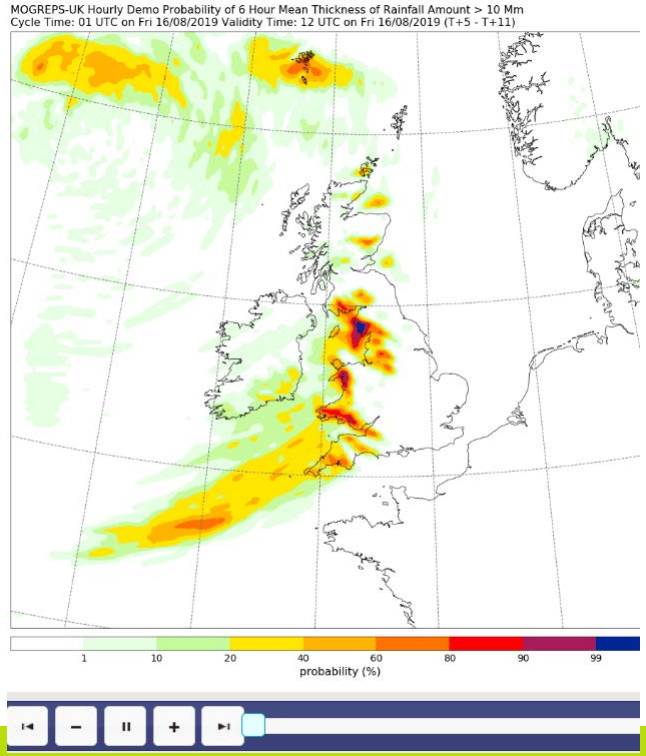
Rank histogram (T+48h) – T500 (NH)

- *En-4DEnVar improves under-dispersion and AI improves bias*

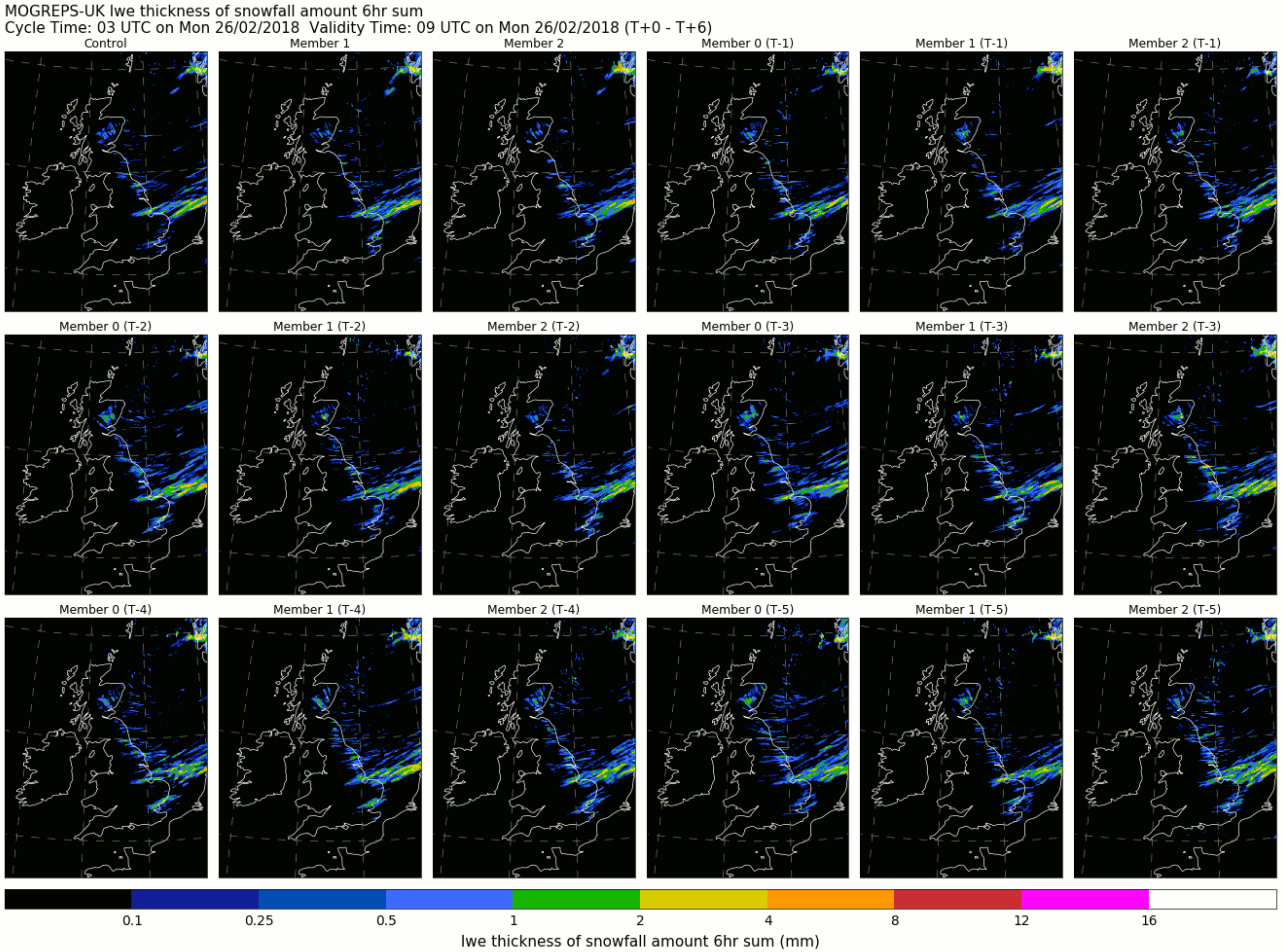


Brief description MOGREPS-UK

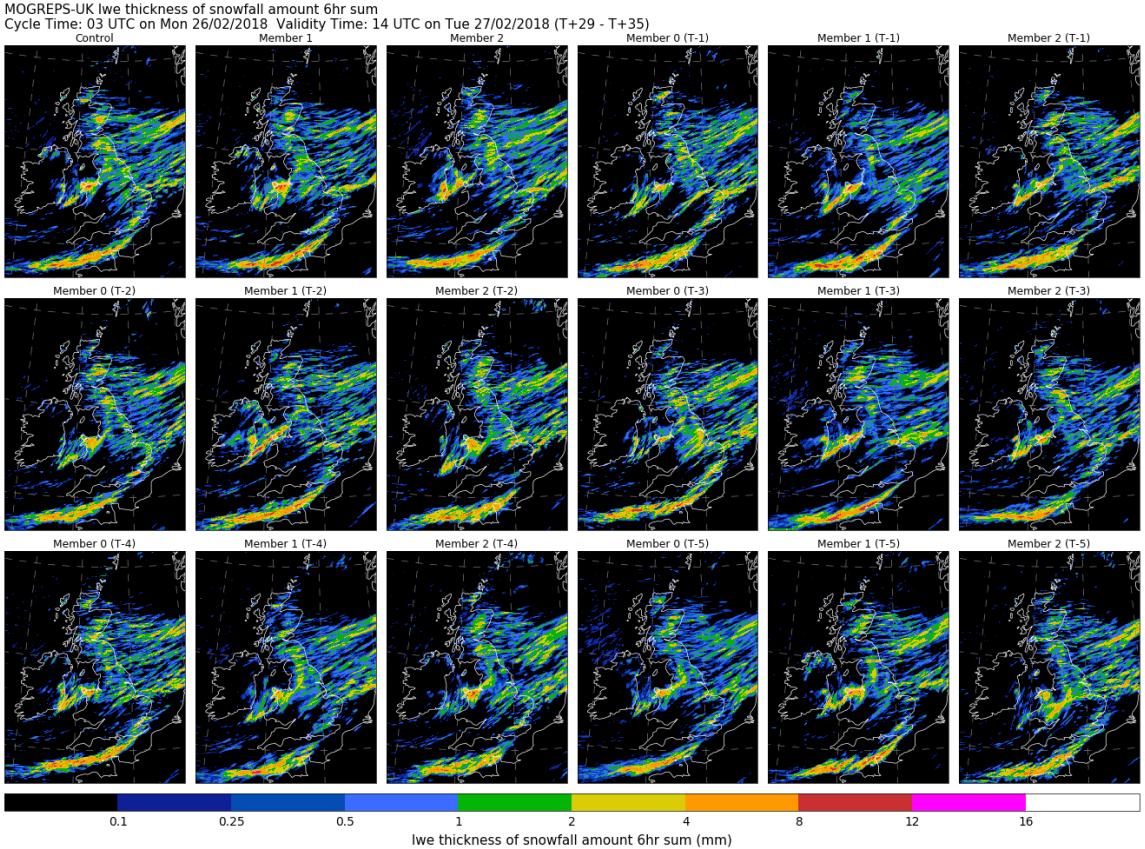
- 18-member time-lagged UK ensemble with UM at ~2.2km grid resolution
  - 3 members run every hour with last 6 cycles combined to provide 18 member forecasts
- Forecasts to **5 days**
- Downscaled global perturbations from corresponding MOGREPS-G members added to latest hourly 4D-Var UK analysis
- Stochastic physics by SKEB and SPPT

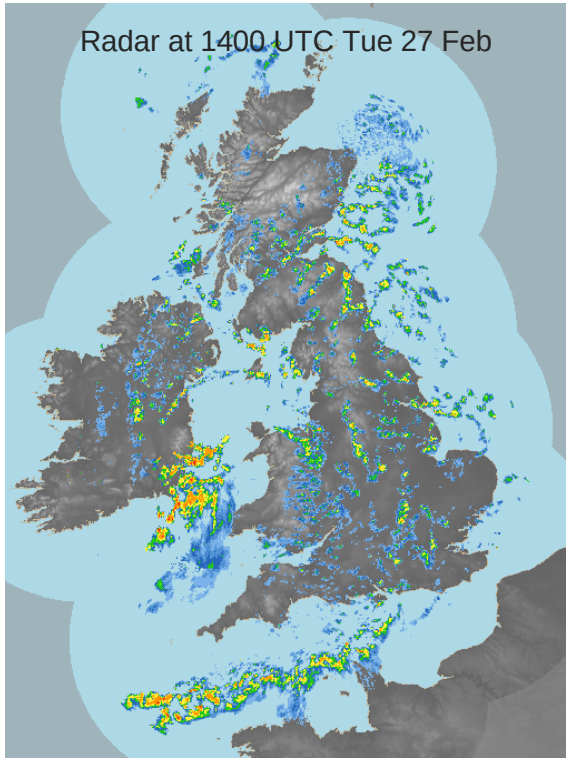


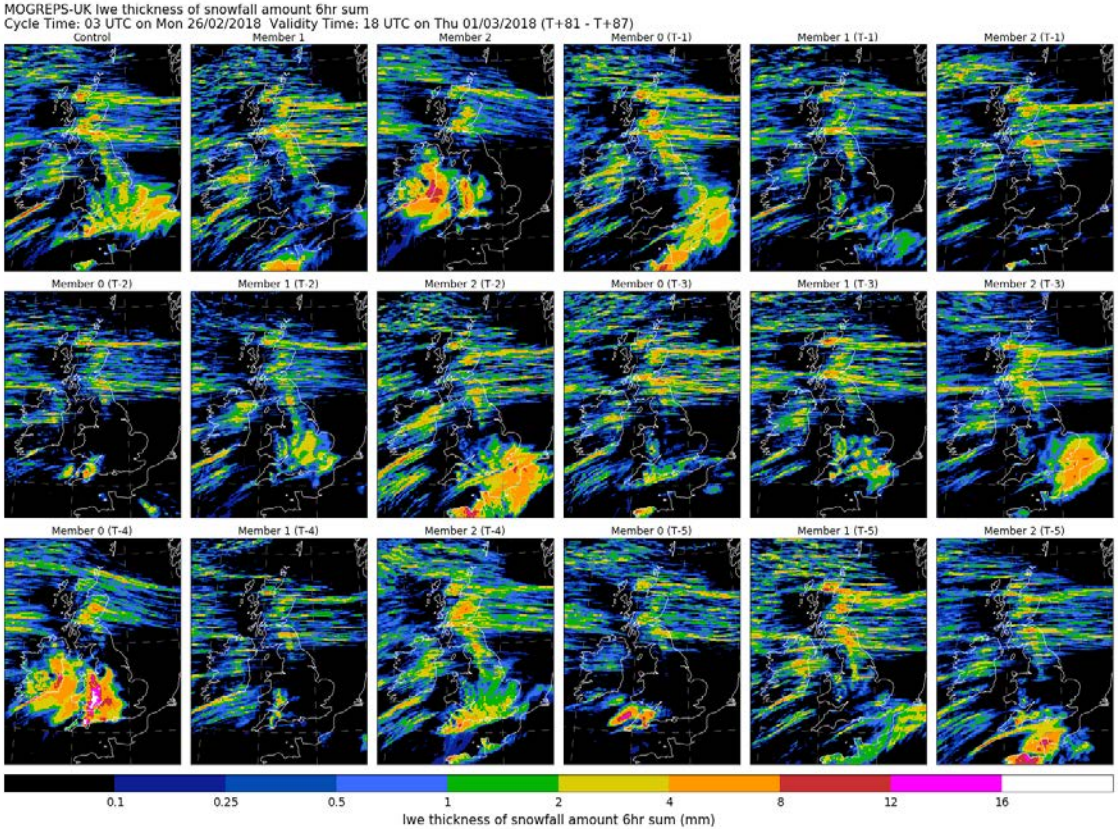
MOGREPS-UK snowfall postage stamps animation



T+29 to 35, Valid 1400 UTC on Tue 27th Feb







T+81 to 87
Valid Thu 1st March

Large spread in frontal snowfall positioning in the south and south west.

Lots of snow shower activity in the NE.

The Big Data Challenge: huge volumes and rapid updates

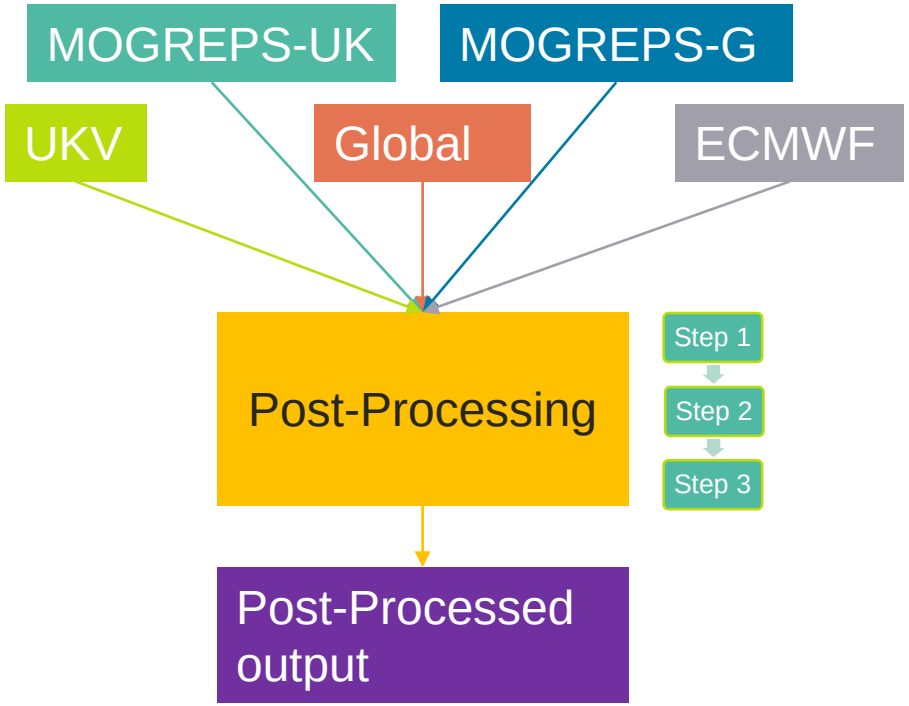
Forecast systems throwing out vast quantities of data for forecasters and users to assimilate:

- Global models: 690 Gbytes per day
- UK models: 3200 Gbytes per day
- **TOTAL: 3.9 Tbytes per day**

Forecasts updated every hour or more – *Drinking from a Firehose* of data!

Blended Probabilistic Post-Processing

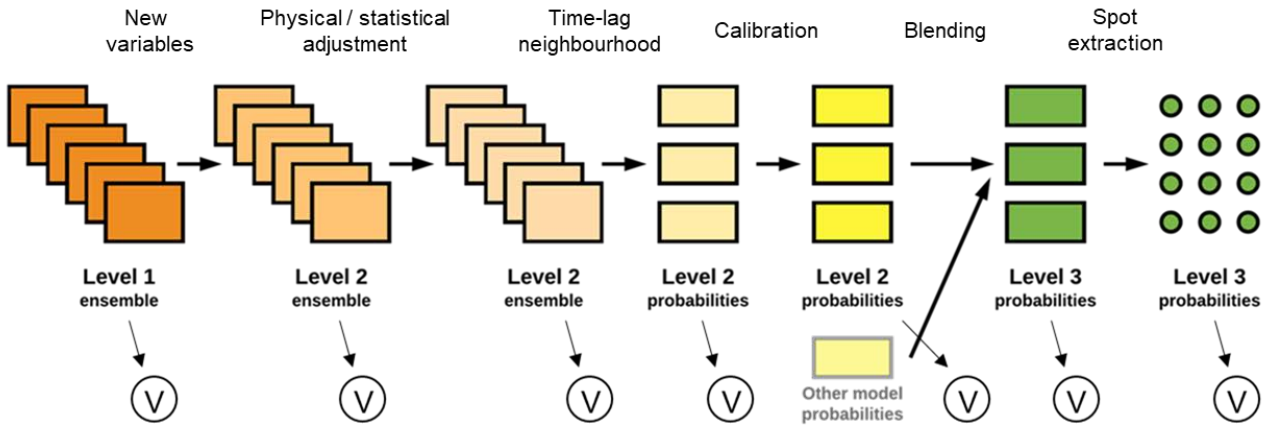
- Multiple forecasts from different models
  - Difficult for a user or operational meteorologist to keep track
- Single automated best-estimate forecast, blending the most appropriate model forecasts for any place and forecast time

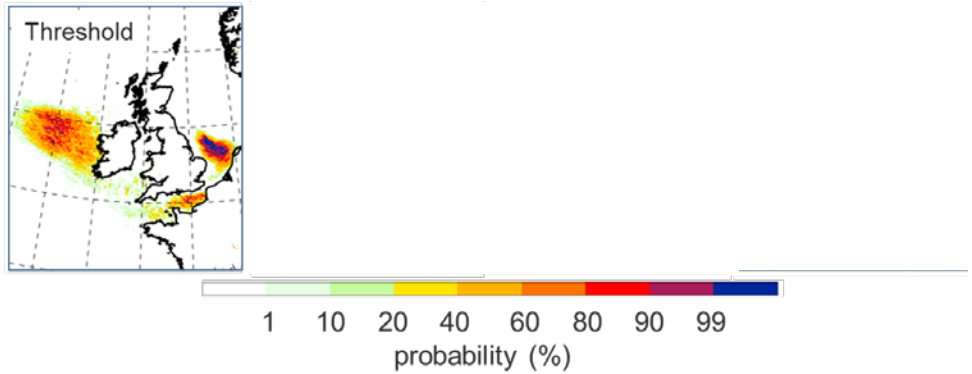


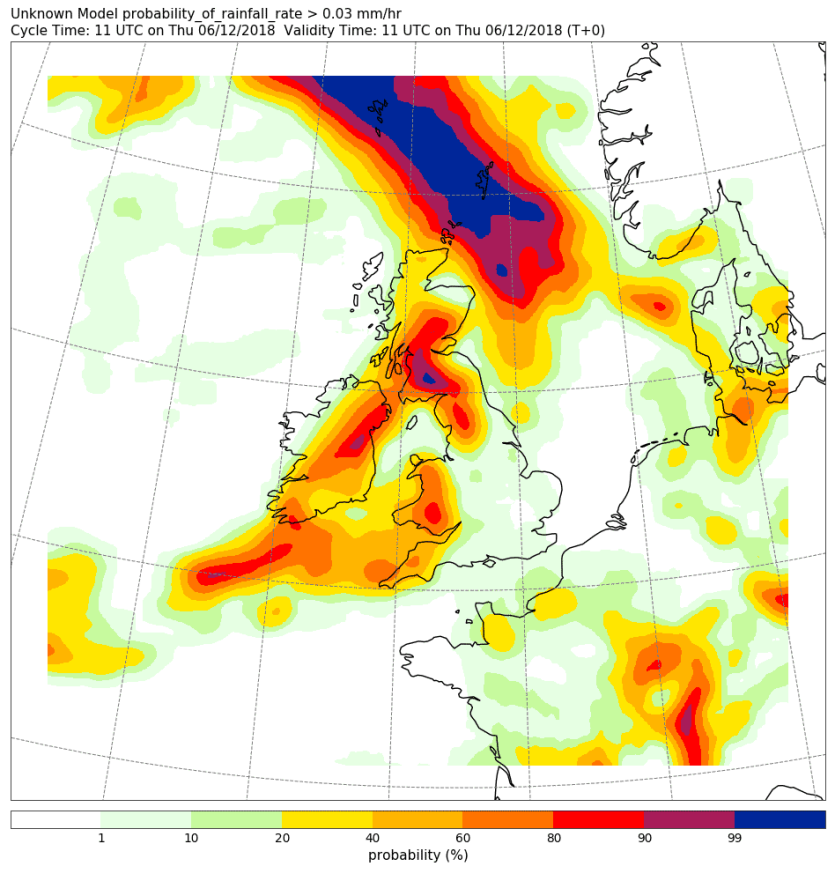
IMPROVER

IMPROVER chains

temperature, rain, snow, cloud, visibility, wind …



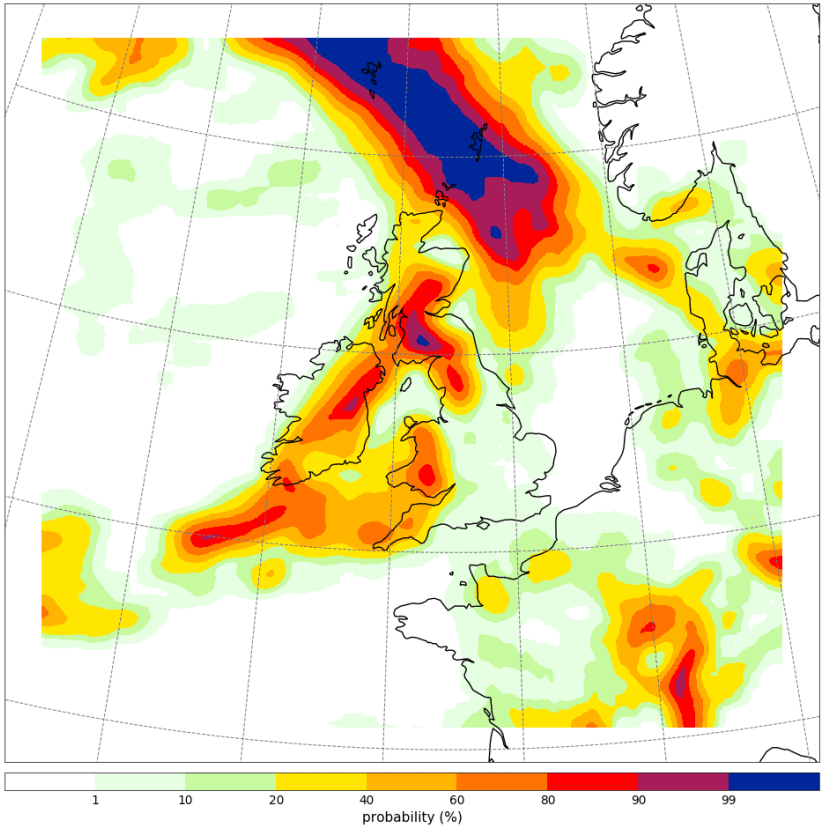




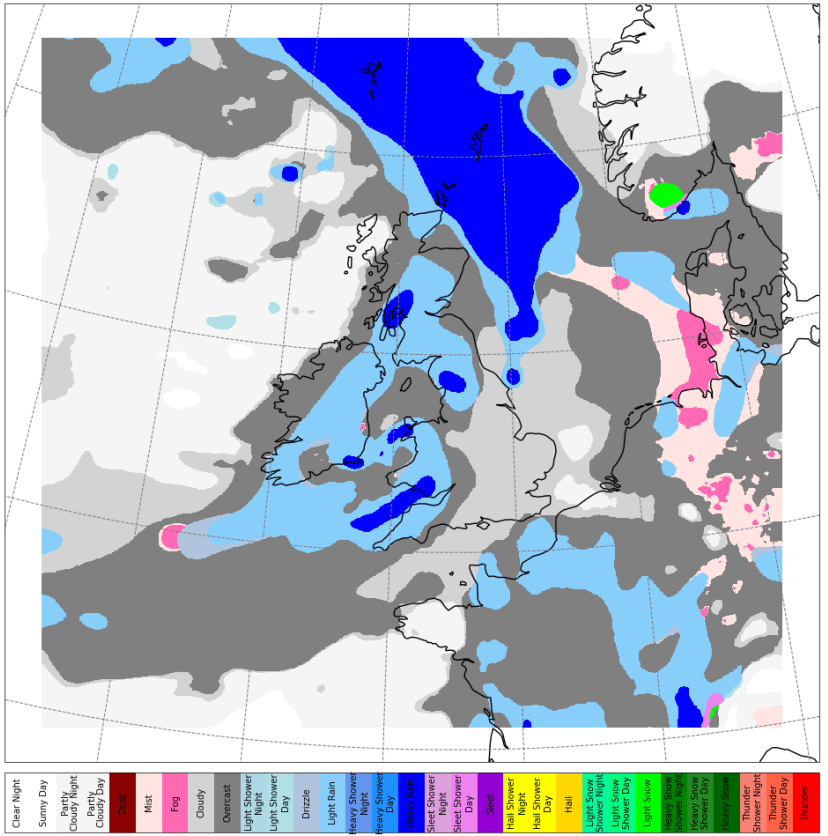
- Blended probability of rainfall
  - Showing prob (rain rate) > 0.03mm/hr
- Similar processing chains for snow, cloud, visibility, winds, temperatures, etc
- Combine to determine appropriate weather symbol…

Met Office

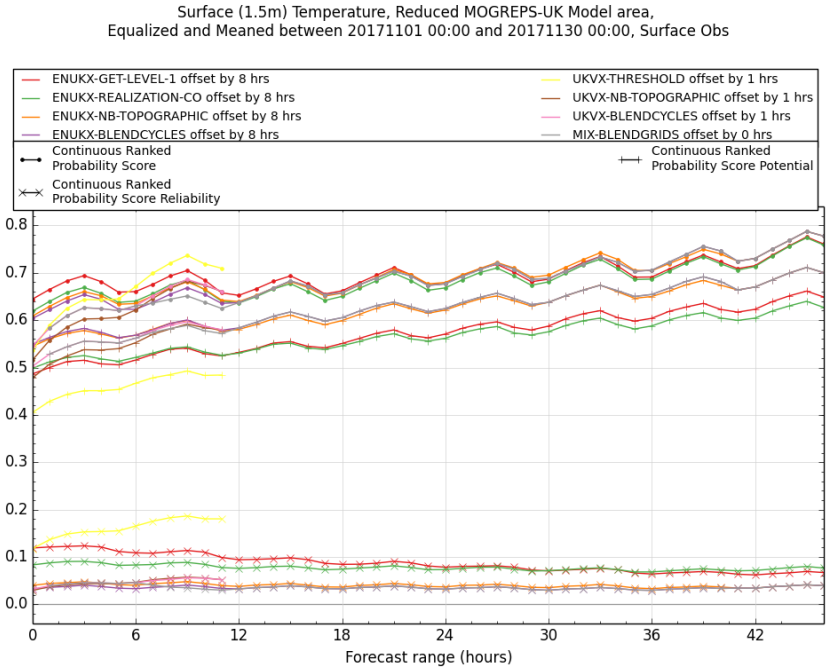
Unknown Model probability_of_rainfall_rate > 0.03 mm/hr
Cycle Time: 11 UTC on Thu 06/12/2018 Validity Time: 11 UTC on Thu 06/12/2018 (T+0)



Unknown Model weather_code
Cycle Time: 11 UTC on Thu 06/12/2018 Validity Time: 11 UTC on Thu 06/12/2018 (T+0)



Example of verification at each step: Temperature: CRPS



- CRPS (•) measures quality of full PDF. Lower is better
- Nbhood reduces reliability penalty (x) at the expense of 'potential' (+)
- Nbhood more net benefit to UKV (no prior spread)

The challenge to exploit ensemble prediction

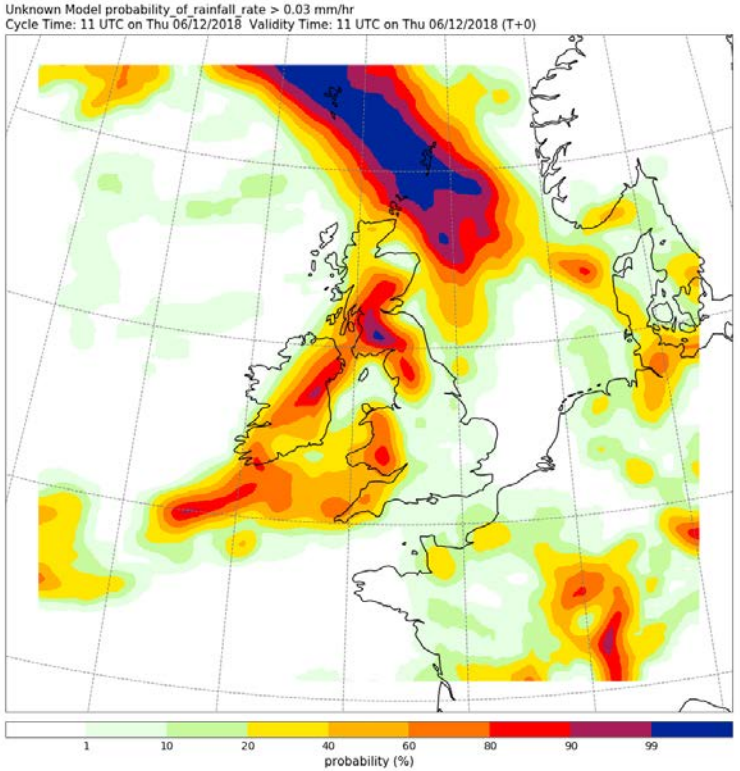
ECMWF and NCEP ensembles introduced in 1992; MOGREPS in 2005

Scientific case for ensembles overwhelming, but exploitation in services challenging:

- *…the public don't understand probabilities…*
- *…uncertainty is too difficult to communicate…*
- *…just tell me what will happen…I just need to make a decision…*

Risk Management Tool

Risk = Probability X Impact



Example: Probability of Precipitation from new IMPROVER blend of models (UKV and MOGREPS-UK) – see Roberts, MOSAC 2019.

Exploiting ensembles is a common challenge

My old friend and fellow ensemble campaigner Steve Tracton said to me about this workshop:

"*Can you believe after all these years the w/shop announcement starts with* **The workshop's central theme is to support NWS in its transition from single-value deterministic to ensemble-based probabilistic forecasting and to convey uncertainty to users…***"?*

I'd like to say we had made more progress, but here is a quote from the Met Office's emerging Science Strategy:

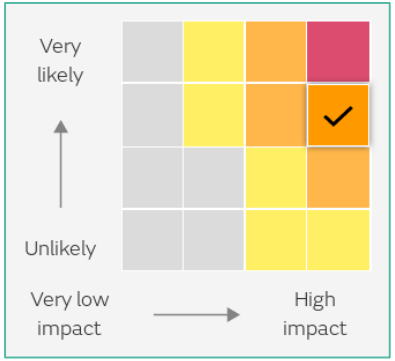
Theme: Producing and Exploiting Ensembles

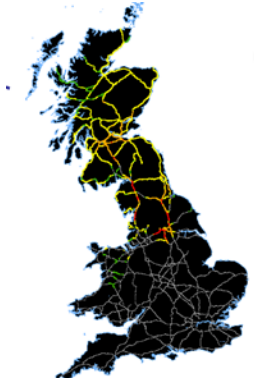
Goal 1: Transform operational prediction to be based on ensembles…

We *have* made progress – on both sides of the Atlantic – but we can do much better

Questions?

Examples of ensemble-based tools in support of risk-based decision-making





Risk Management Tool
Risk = Probability X Impact