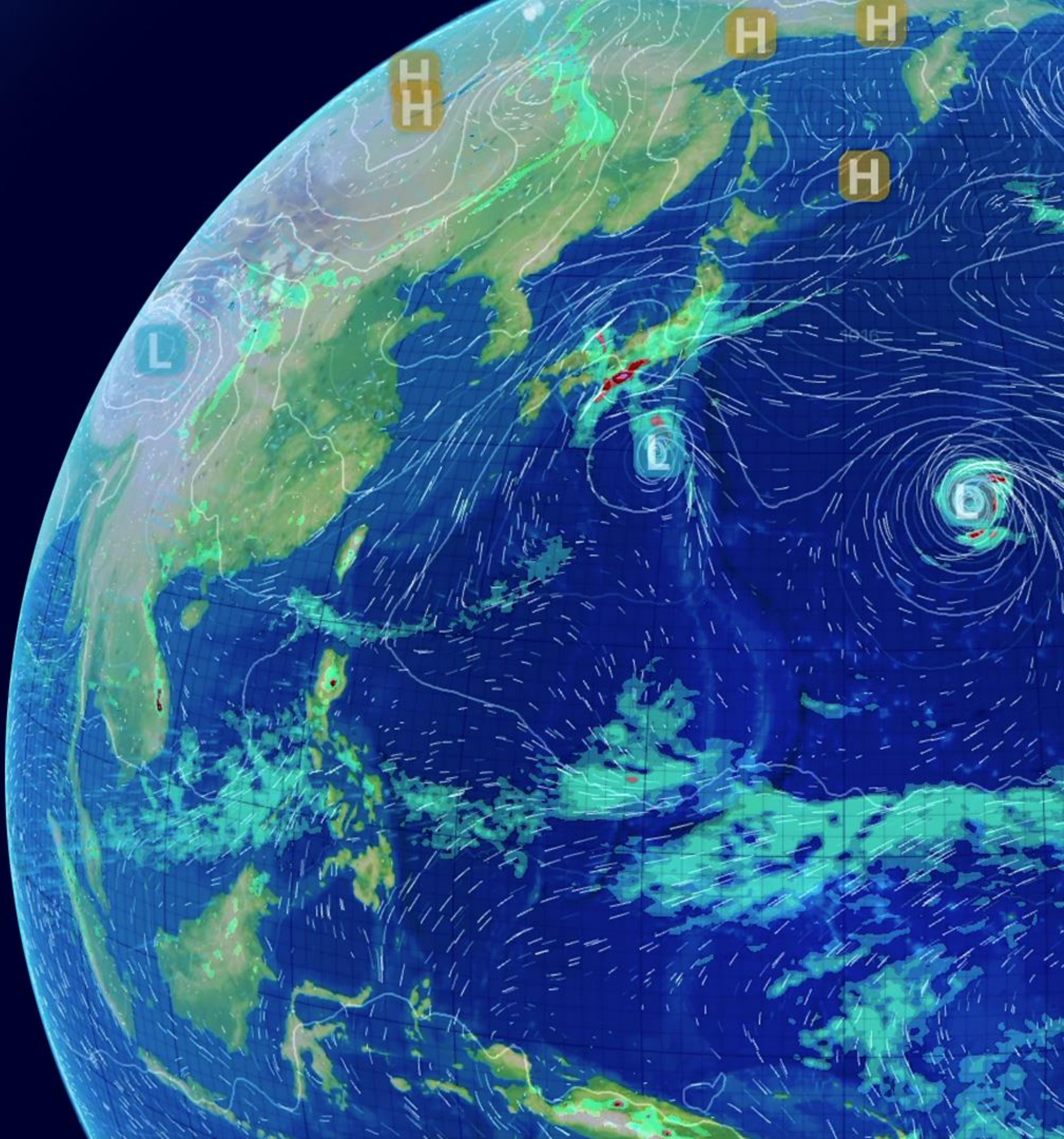
Met Office

IMPROVER: the new probabilistic post processing system at the Met Office.



Nigel Roberts
(previous Science Lead for IMPROVER)

Met Office

A new probabilistic post processing system called IMPROVER

IMPROVER

Provide the Met Office with a single source of blended, probabilistic forecast information for the UK and globe.

Why?

Modern world want here and now forecasts
To exploit frequently updated km-scale NWP models and ensembles
Current post processing needs updating

High resolution NWP needs different corrections
Probabilistic framework for km-scale ensembles and multiple models
A seamless forecast message from all forecasts
Potential data overload

IMPROVER timeline

2016

Project initiation

2019

Alpha release
Real-time running

2021

Now

Operationally Supported March 2021

2022

Fully Operational

Not the end though

Errors and higher resolution ?

1. **The forecasts are not representative of particular locations**

   E.g. the temperature on a hill is not captured in model grid square

2. **The forecasts are biased.**

   E.g. consistently too much/too little rain or too high/too low temperatures

3. **The weather of interest is in the wrong place (or wrong time or coverage) on the day**

   E.g. the shower is over Ostend not Bruges

Errors and higher resolution ?

1. **The forecasts are not r... ...ons**

   E.g. th... ...not captured in model grid square

Representativeness error greatly improved – grid square closer to point value – use grid

2. **The forecasts are bia...**

   E.g. co... ...rain or too high/too low temperatures

Biases become more complicated – statistical methods, machine learning

3. **The weather of interest is in ... ime or coverage) on the day**

   E.g. the ... Ostend not Bruges

Misplacement errors often largest – require ensemble and spatial / temporal methods

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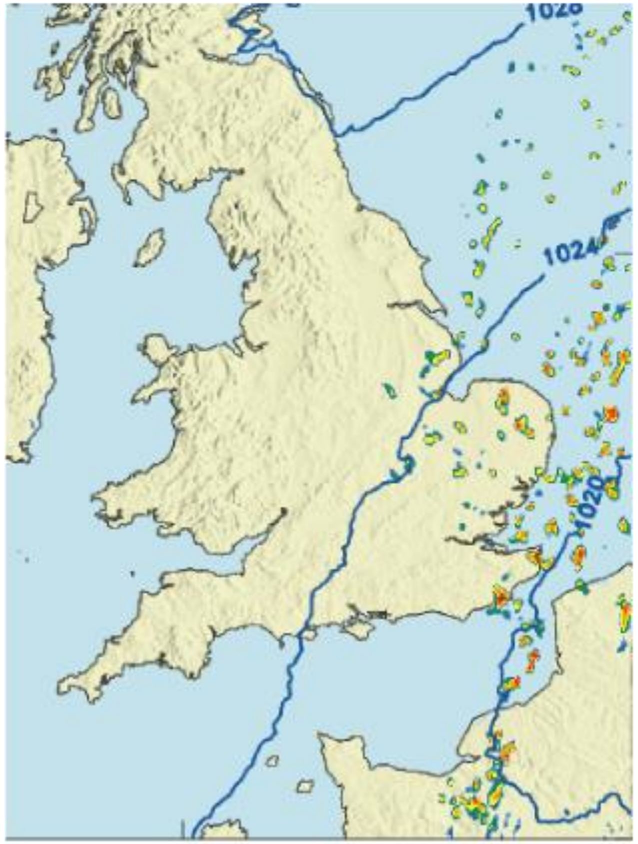
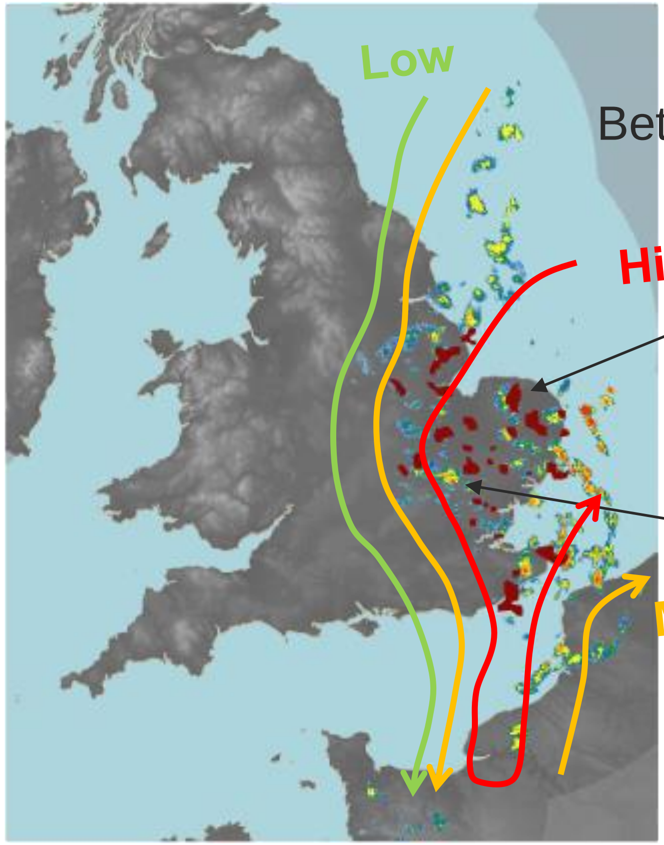
Need for post-processing high-resolution models

IMPROVER

UKV model forecast (1.5km)



Radar for the same time



Better to give a chance of rain

Forecast rain, not happening

Rain not forecast

Wrong twice!
Double penalty

Not good for a forecast for a particular place and time
- or verification scores – or automated outputs

IMPROVER

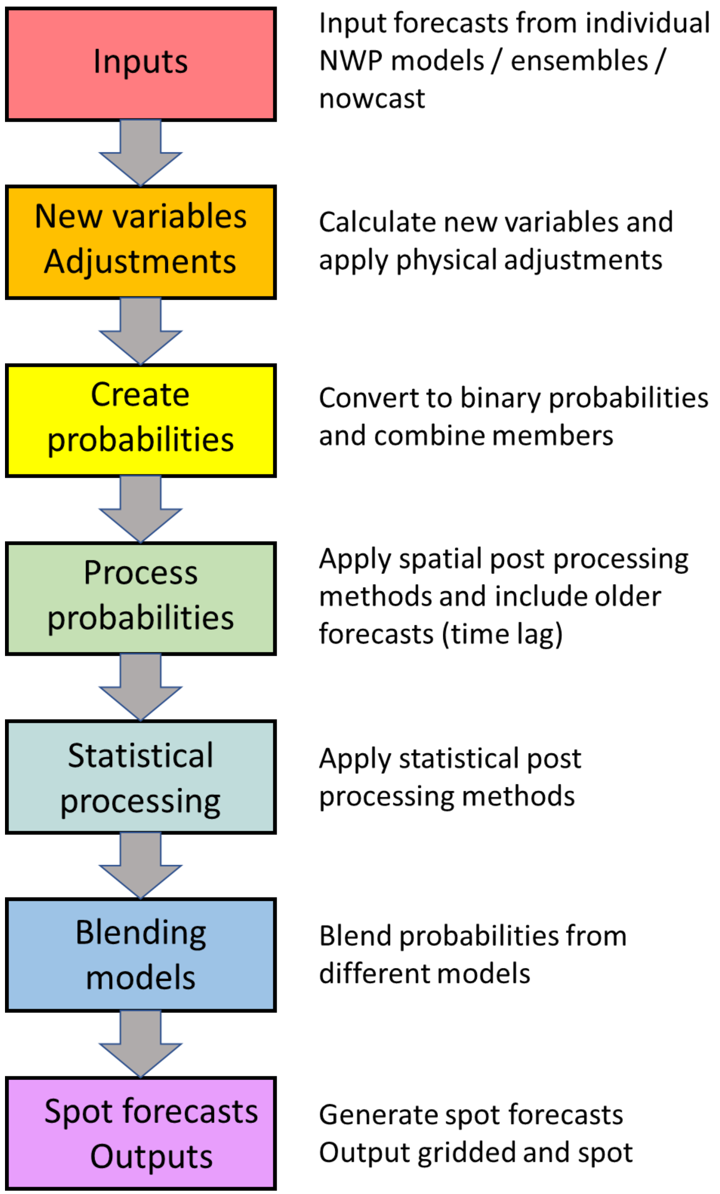
Initial user – Digital, Web pages, App (wider usefulness & interest).

7-day forecasts for now -> 14 days

Principles

- **Single modular processing chain for each gridded variable**
- **Operate on the whole grid**
- **Probabilistic at the core**
- **Spot forecasts from gridded probabilities at the end (consistency)**
- **Objective verification at every stage for real time and trials**
- **Seamless from nowcast to medium range (multiple models / ensembles)**
- **Updating seamless blend as new forecasts come in**

Roberts & Mittermaier 2016

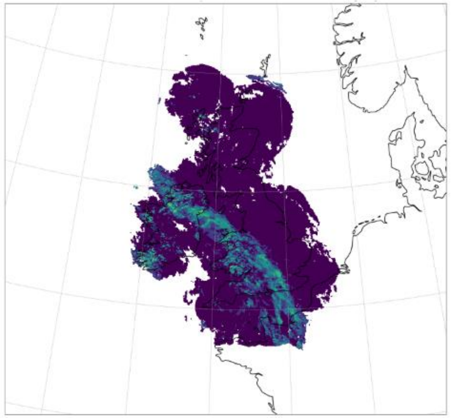


Met Office

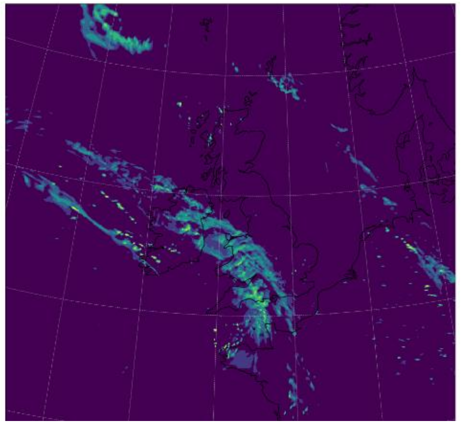
Inputs

Inputs	Input forecasts from individual NWP models / ensembles / nowcast
New variables Adjustments	Calculate new variables and apply physical adjustments
Create probabilities	Convert to binary probabilities and combine members
Process probabilities	Apply spatial post processing methods and include older forecasts (time lag)
Statistical processing	Apply statistical post processing methods
Blending models	Blend probabilities from different models
Spot forecasts Outputs	Generate spot forecasts Output gridded and spot

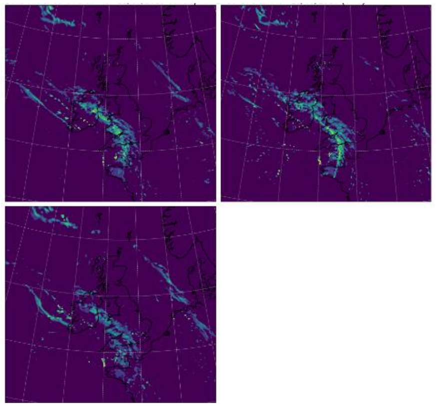
IMPROVER



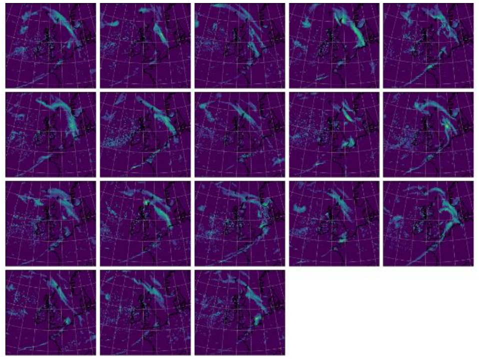
Radar extrapolation Nowcast
Out to 6 hours, every 15 minutes
Run in IMPROVER MONOW/UKV suite
- Caroline Sandford, Stephen Moseley



UKV 1.5km
Out to 12 hours, every hour



MOGREPS-UK 2.2km
Out to 5 days, 3 forecasts every hour



MOGREPS-G ~20km
Out to 7 days, 18 forecasts every 6 hours

New variables, adjustments

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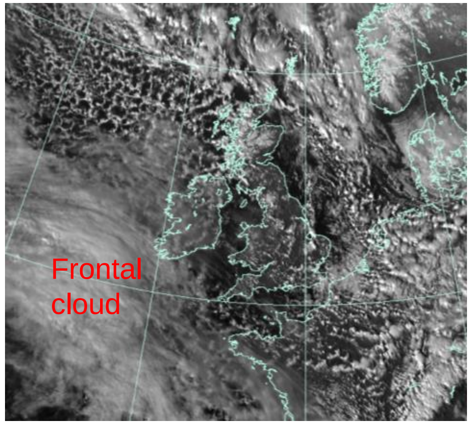
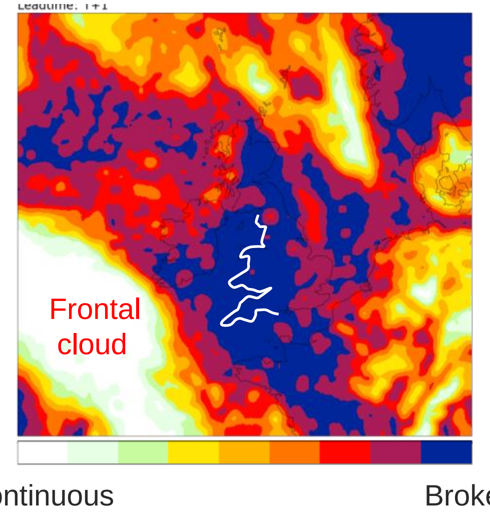
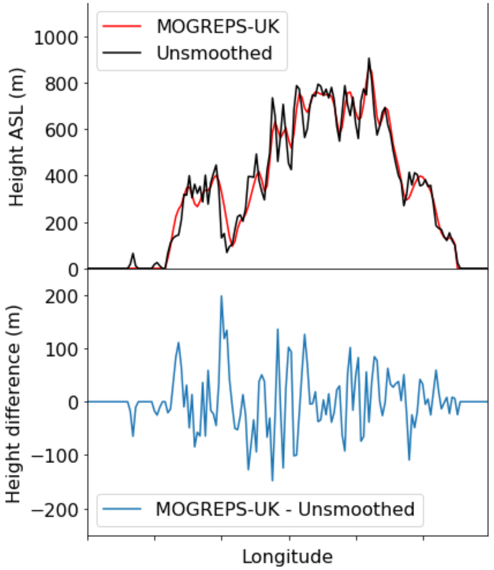
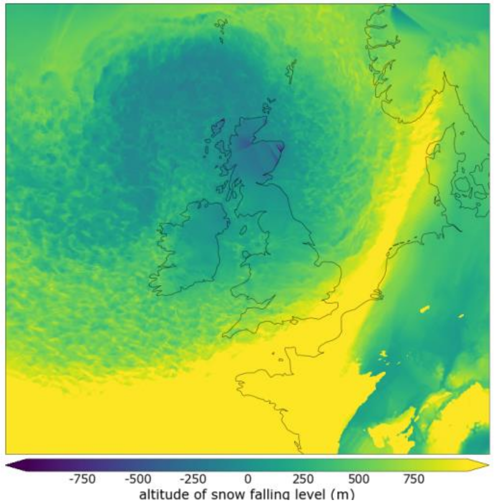




Cloud texture
- used to determine whether showers
- Ben Ayliffe, Kat Hurst

Altitude adjustment –
then temperature adjustment
(from Sheridan et al 2010)
Ben Ayliffe





Snow melting level
- used for precipitation type probabilities
Stephen Moseley

Methods applied to each forecast

Create probabilities

Inputs	Input forecasts from individual NWP models / ensembles / nowcast
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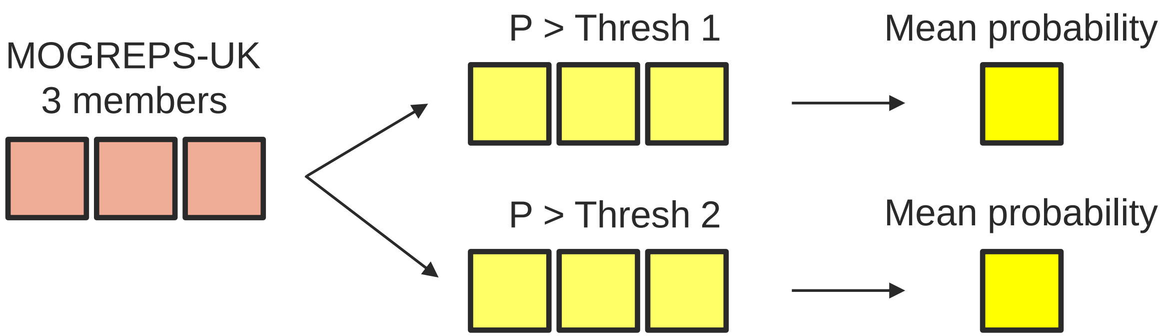

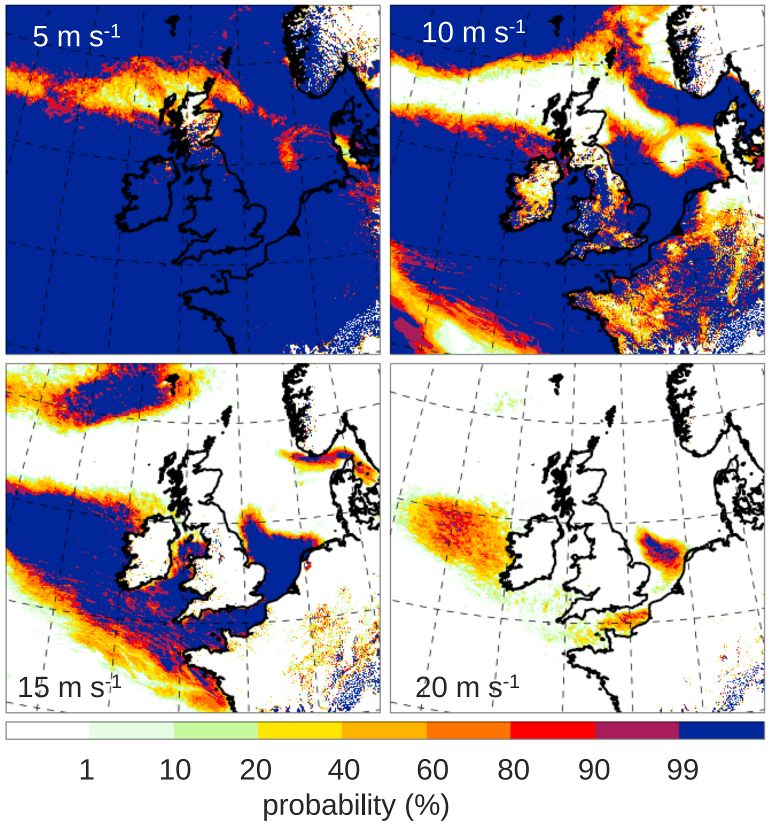

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Process probabilities

Inputs	Input forecasts from individual NWP models / ensembles / nowcast
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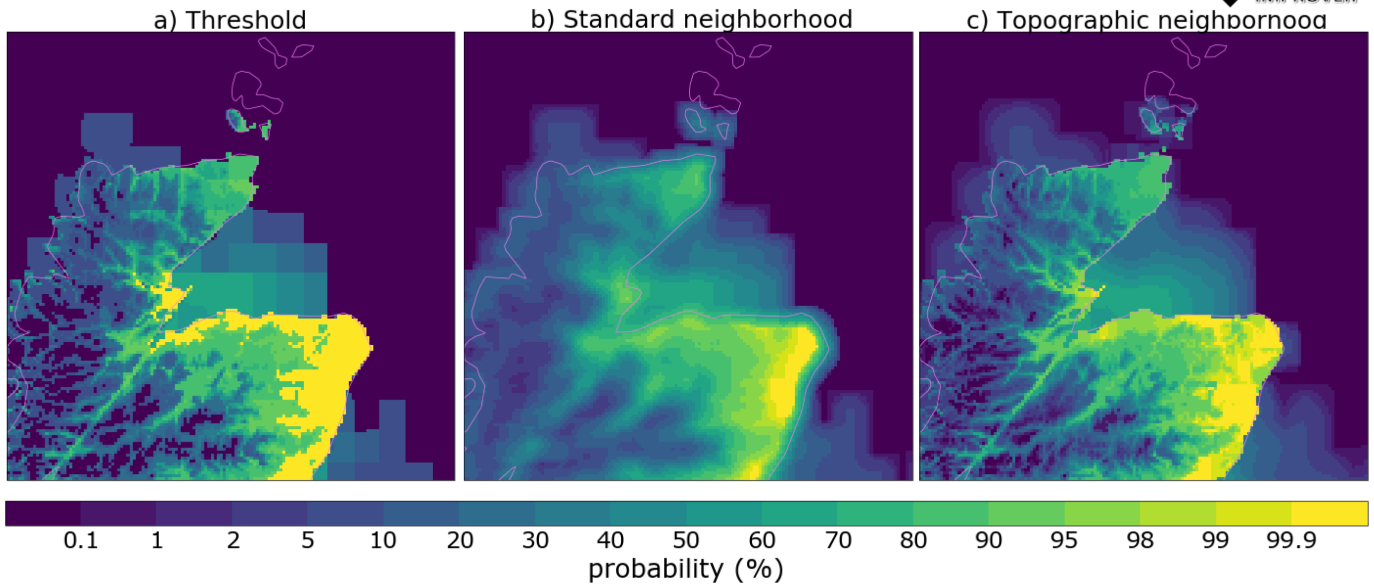
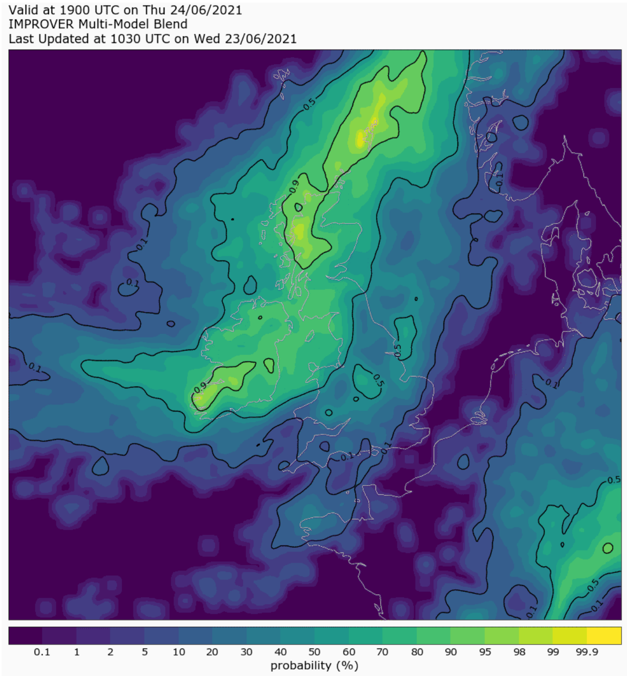


Fiona Rust



Time-lagging (cycle blending):

3 members MOGREPS-UK per hour becomes
18 members after including the latest 6 forecasts

Statistical processing

Inputs	Input forecasts from individual NWP models / ensembles / nowcast
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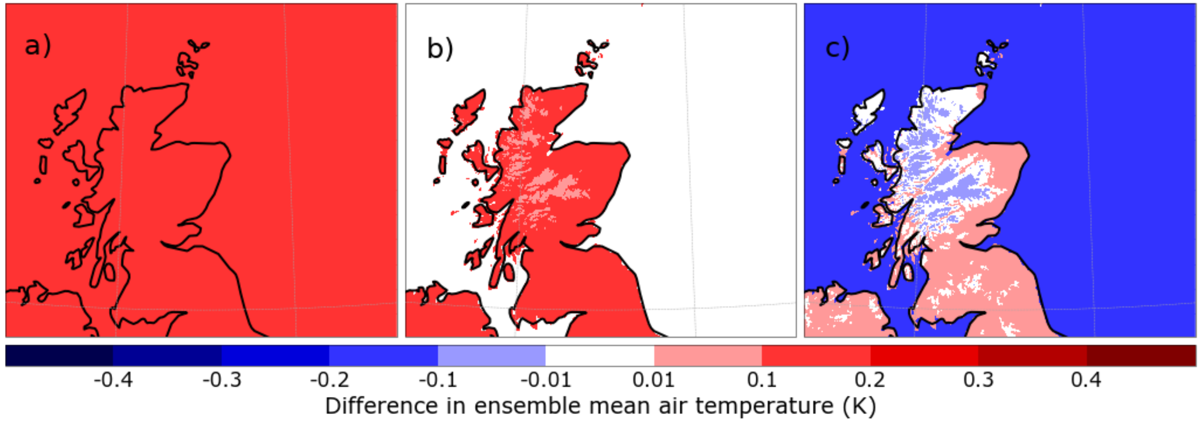
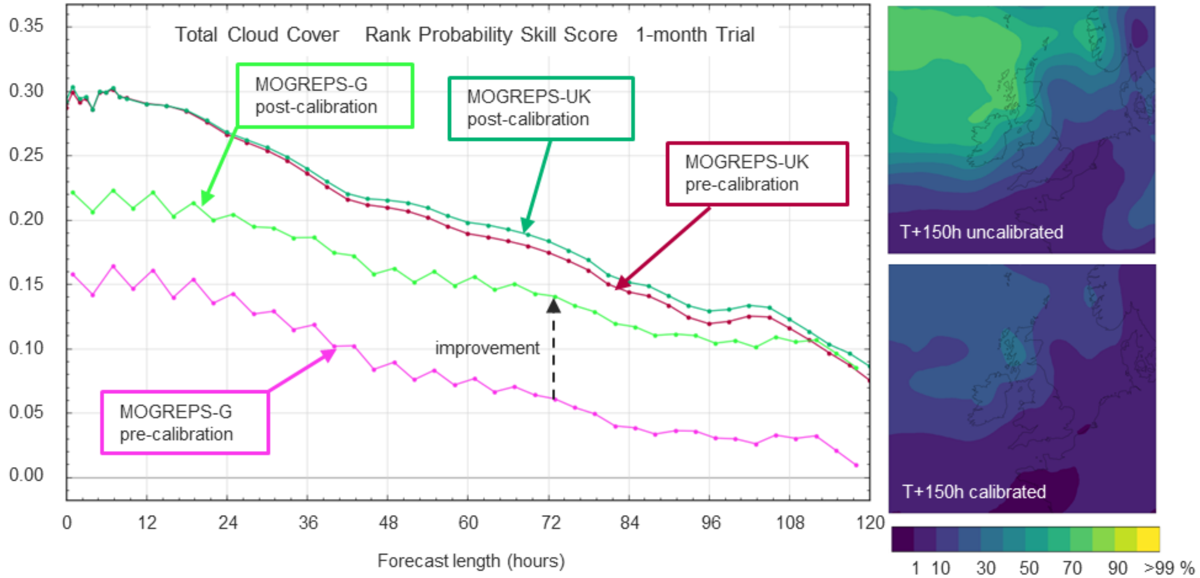
EMOS - temperature, wind - based on Gneiting et al 2005, Gavin Evans



Reliability Calibration - precipitation and cloud - Fiona Rust, Gavin Evans



Based on Flowerdew et al 2014 *Tellus 72, 1-19*

Met Office

Blending models

Step	Description
Inputs	Input forecasts from individual NWP models / ensembles / nowcast
New variables Adjustments	Calculate new variables and apply physical adjustments
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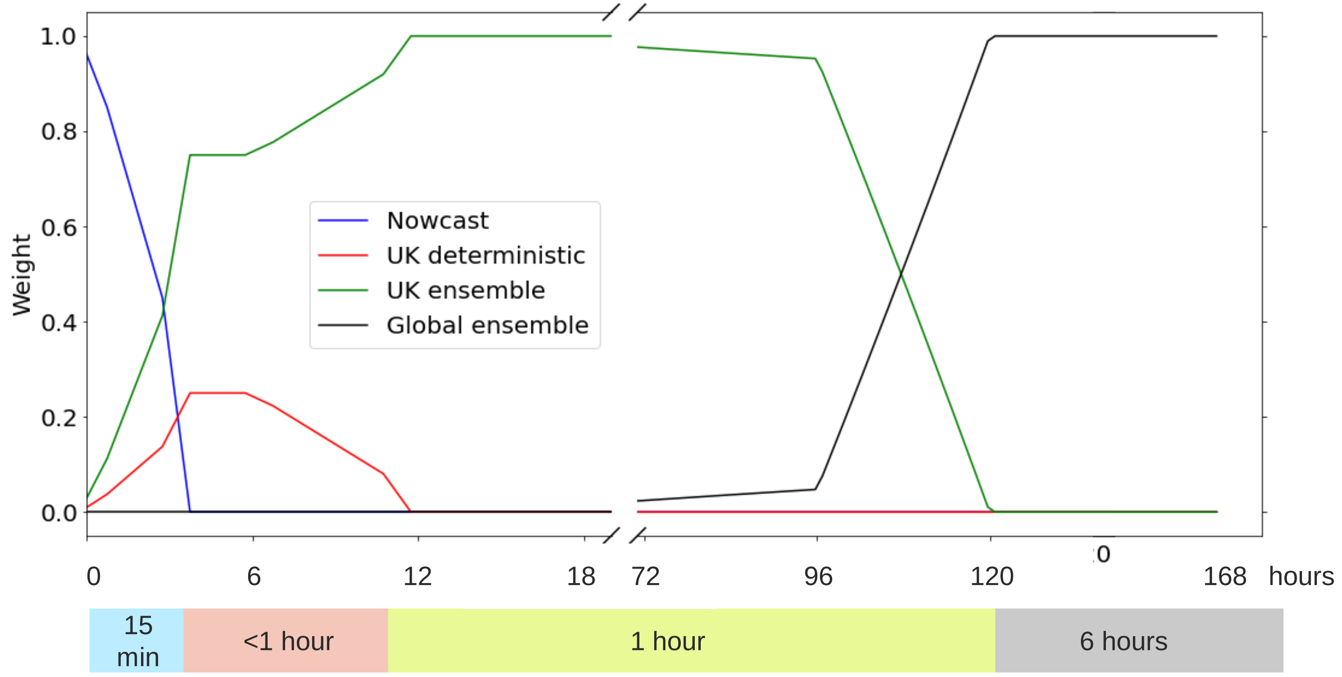
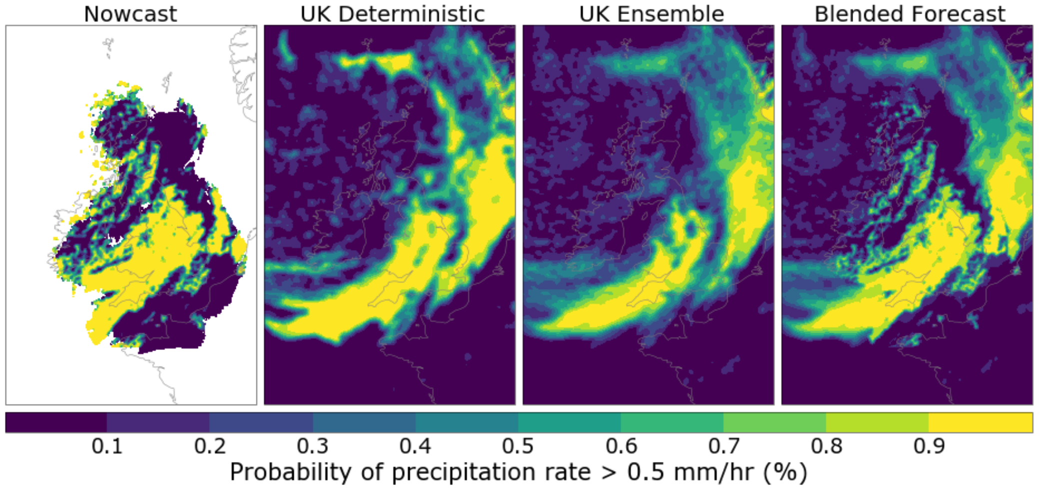


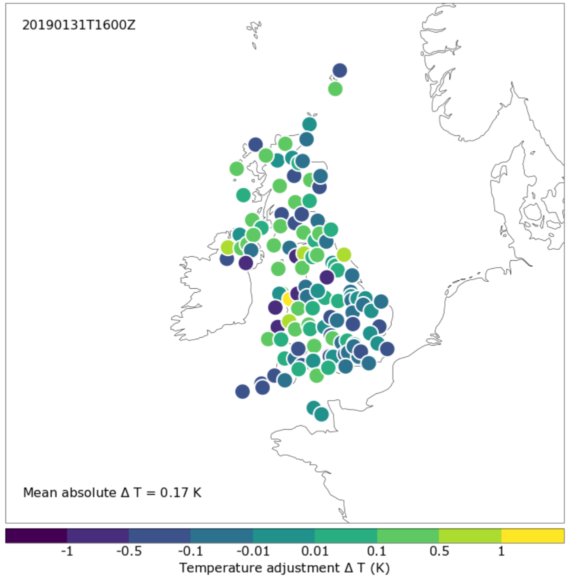


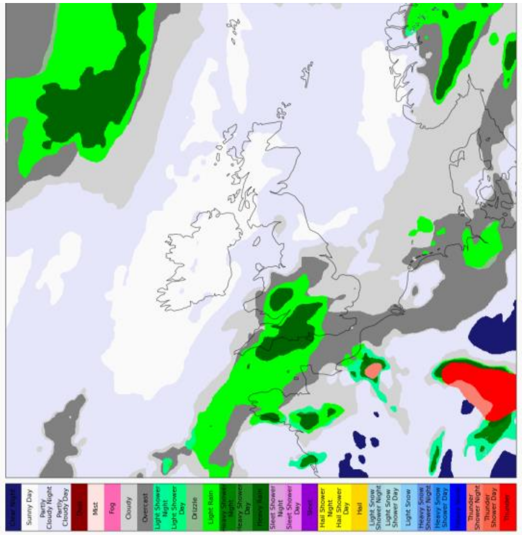
Spot forecasts, gridded and spot outputs

Met Office

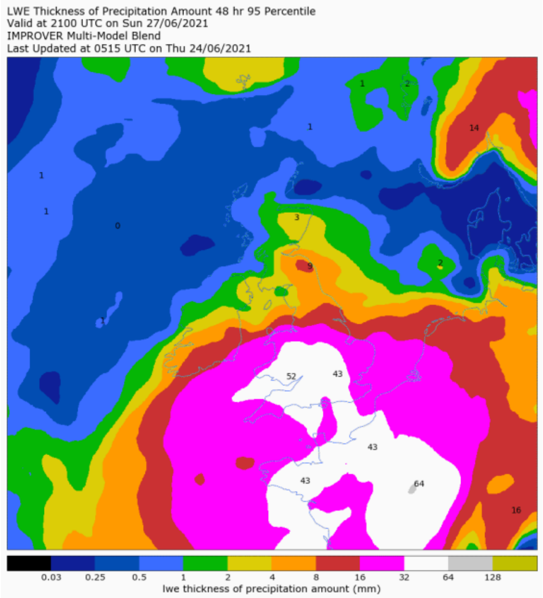
IMPROVER

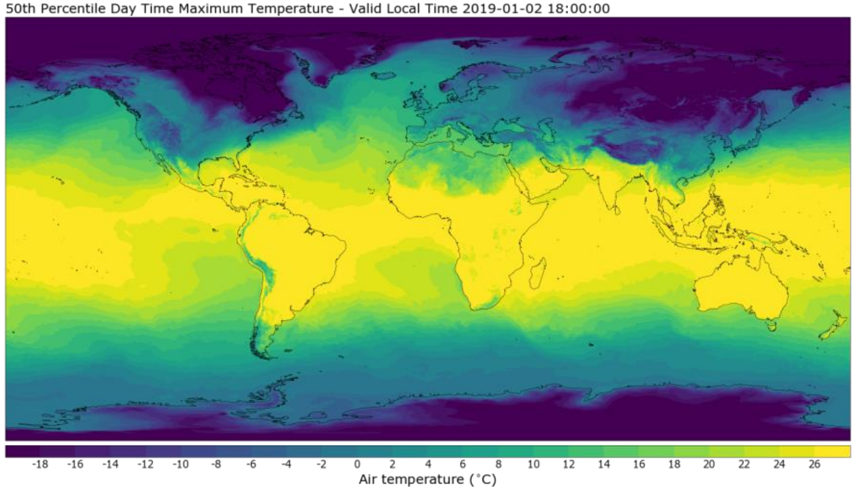
- **Inputs** — Input forecasts from individual NWP models / ensembles / nowcast
- **New variables Adjustments** — Calculate new variables and apply physical adjustments
- **Create probabilities** — Convert to binary probabilities and combine members
- **Process probabilities** — Apply spatial post processing methods and include older forecasts (time lag)
- **Statistical processing** — Apply statistical post processing methods
- **Blending models** — Blend probabilities from different models
- **Spot forecasts Outputs** — Generate spot forecasts Output gridded and spot





fog rain hail thunder
clear cloud sleet snow



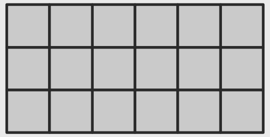


Met Office

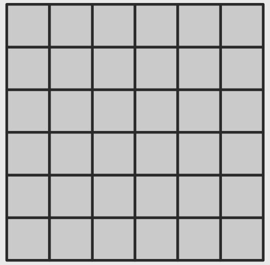
Nowcast

UKV

MOGREPS-UK



MOGREPS-G



NWP models (level 1)

IMPROVER

Converts individual forecasts into probabilities and percentiles

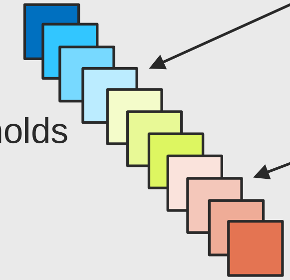
Improves skill

Blends forecasts together to give seamless probabilities and percentiles. Ordering

Updating blend as new forecasts come in

Blended probabilities

Thresholds



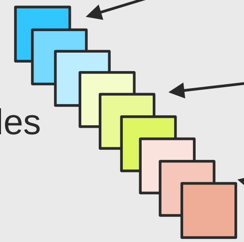
Probability of being warmer than 0C (e.g. 90%)

Probability of being warmer than 20C (e.g. 5%)

Gridded and spot (UK and globe)

Blended percentiles

Percentiles



Possible low temperature 5th percentile. (e.g. -3C)

In the middle (median) temperature (e.g. 11C)

Possible high temperature 95th percentile. (e.g. 22C)

Service Hub (level 3)

Met Office

Nowcast

UKV

MOGREPS-UK

MOGREPS-G

NWP models (level 1)

IMPROVER

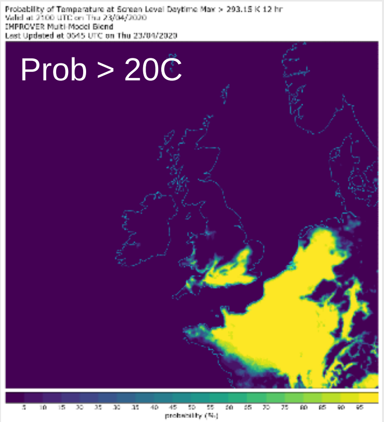
Converts individual forecasts into probabilities and percentiles

Improves skill

Blends forecasts together to give seamless probabilities and percentiles. Ordering

Updating blend as new forecasts come in

Blended



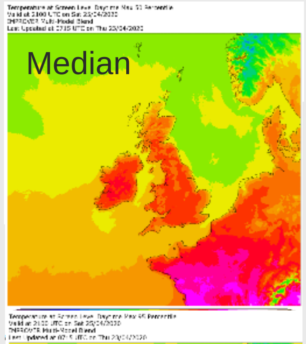
5% 50% 95%

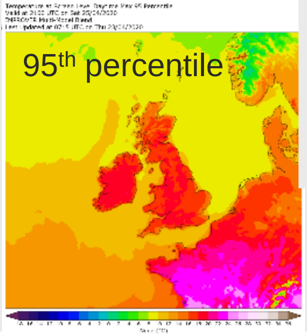
Probability of being warmer than 0C (e.g. 90%)

Probability of being warmer than 20C (e.g. 5%)

Gridded and spot (UK and globe)

Blended





Possible low temperature 5th percentile. (e.g. -3C)

In the middle (median) temperature (e.g. 11C)

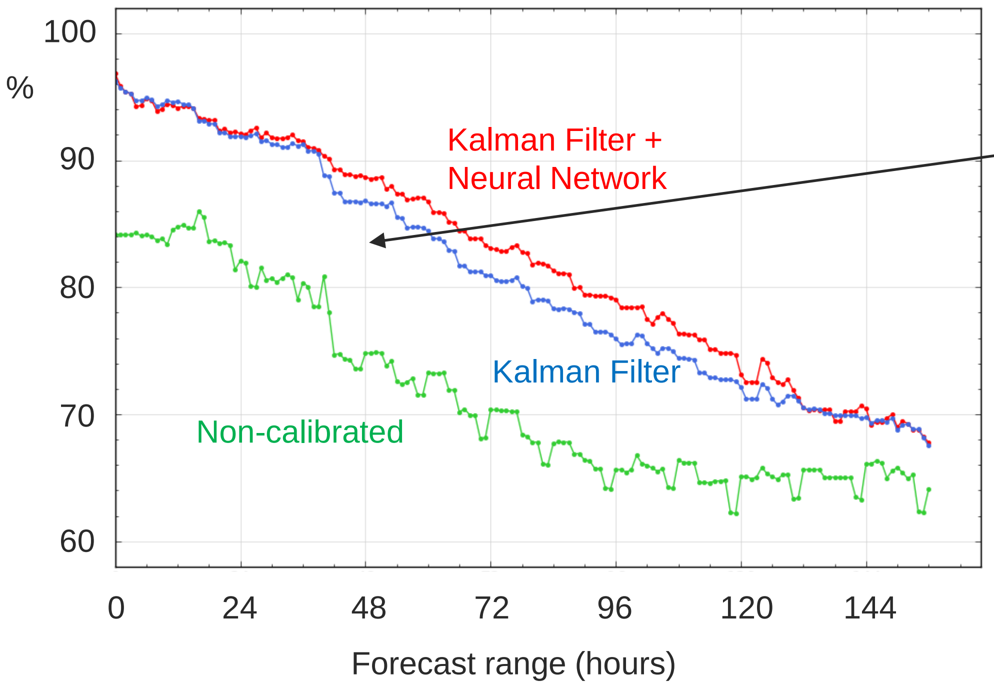
Possible high temperature 95th percentile. (e.g. 22C)

Service Hub

Machine learning at sites for temperature

Current (not IMPROVER) system – calibrate temperature for observed sites using a Kalman Filter and Neural Network (Simon Jackson)

% of maximum temperature forecasts within 2^{o}C – July 2021



Courtesy of Ben Ayliffe & Gavin Evans

BUT - calibration (KF+ML) at sites gives benefit at only a tiny fraction of locations

IMPROVER is meant to improve forecasts for <u>all</u> locations (where people are)

Can IMPROVER beat previous uncalibrated? Measure of improvement for nearly everyone. Yes.

Can IMPROVER match calibrated sites using its own site calibration / ML? Current project.

Can the site calibration / ML also be applied to the grid? To be seen.

"Not everything that counts can be counted, and not everything that can be counted counts"
Probably William Bruce Cameron (not Albert Einstein)

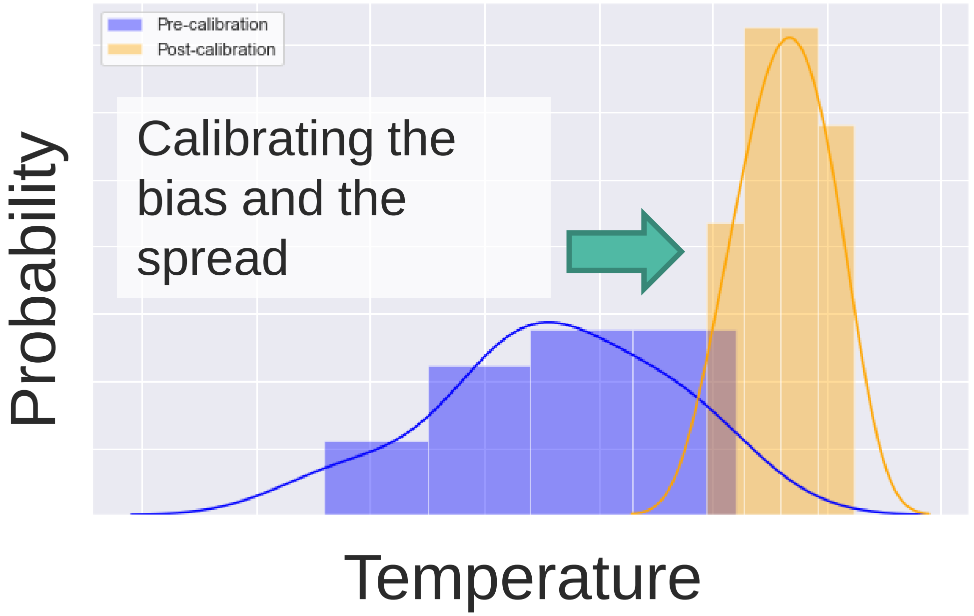
Met Office

Site calibration

Comparing two approaches for calibrating temperature forecasts at sites.

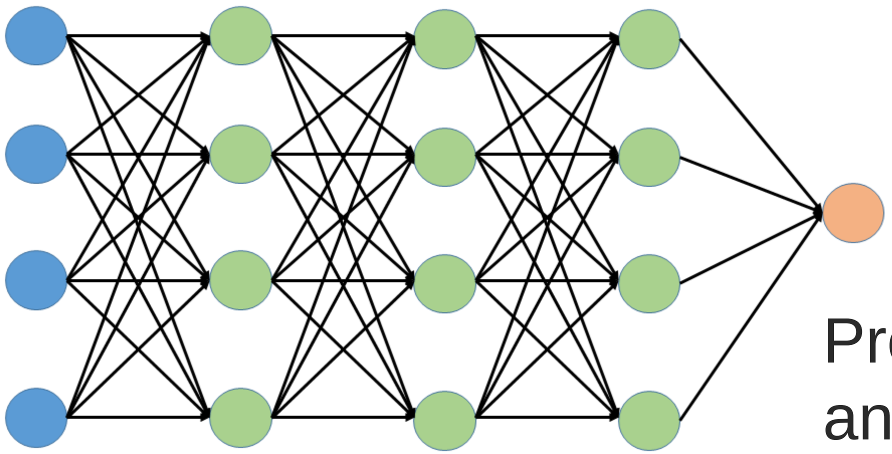
Ensemble Model Output Statistics

- Calibrates full ensemble distribution.



Neural Network

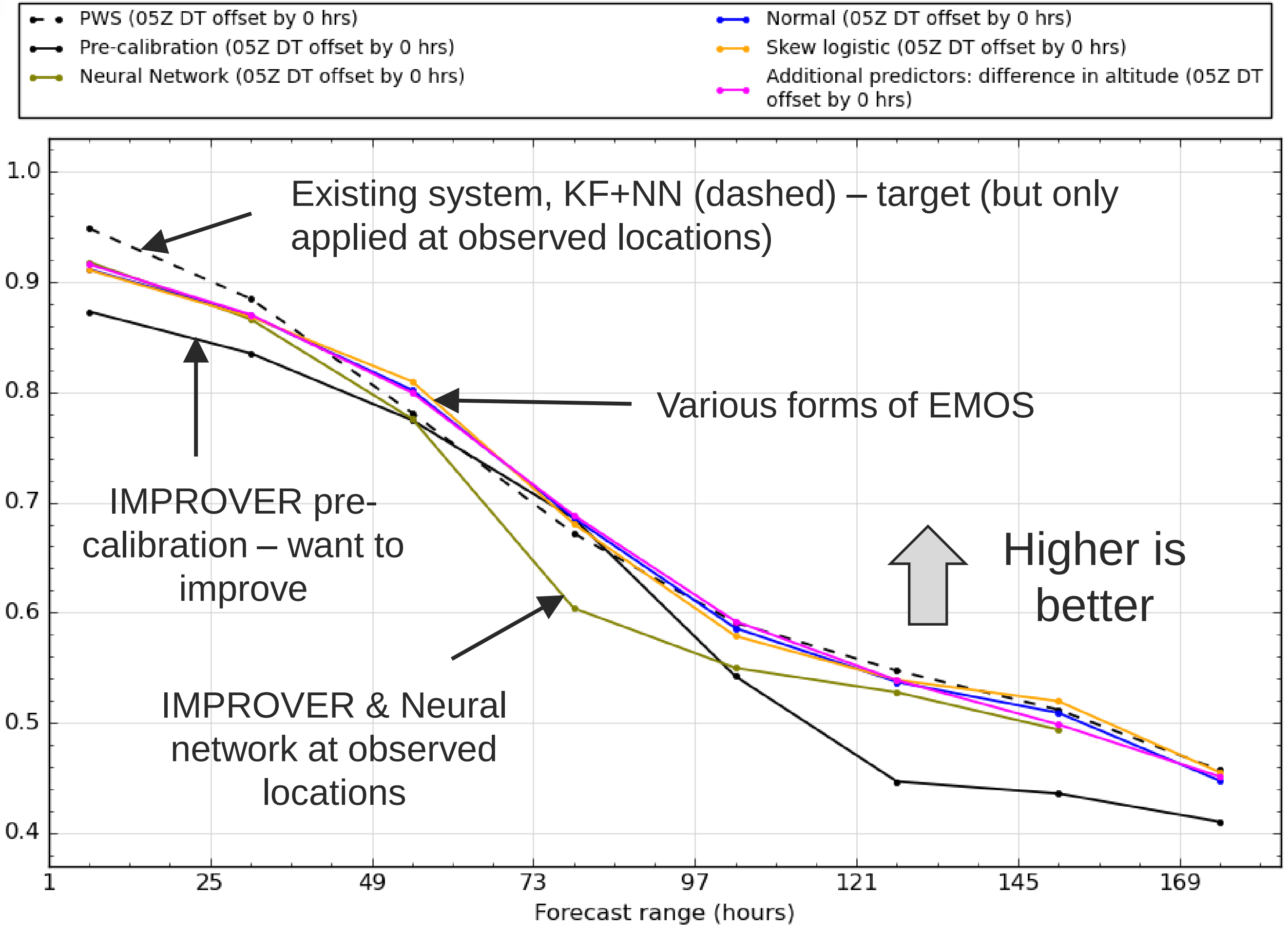
- In this study, focused on optimising the deterministic forecast.



Produces an optimal value

Site calibration

Example plot for daytime max in April 2020
Percentage within +/- 2 degrees



Multi-layer perceptron trained to estimate the error in the temperature forecast, with meteorological and geographical predictors/features) (simple by NN standards)

Rolling 30-day training (long dataset not available)

Use the Neural Net from the previous cycle as a starting point (i.e. a warm start) and a small number of iterations (epochs). Gradually evolves through the seasons.

Predictors: temperature, windspeed, difference in height between grid and spot location, distance to coast (by wind direction), lead-time

EMOS currently better than Neural Net

Potentially apply to grid with appropriate localisation / predictors

Met Office

Machine learning?

IMPROVER

Step	Description	Machine learning opportunities
Inputs	Input forecasts from individual NWP models / ensembles / nowcast	
New variables Adjustments	Calculate new variables and apply physical adjustments	Phenomena classification Multi-variate relationships Emulation (new members) Calibration (non-probabilistic) Geographical relationships -> localisation Scenarios / clusters Downscaling
Create probabilities	Convert to binary probabilities and combine members	
Process probabilities	Apply spatial post processing methods and include older forecasts (time lag)	Emulation Optimise scaling (neighbourhoods)
Statistical processing	Apply statistical post processing methods	Ensemble calibration
Blending models	Blend probabilities from different models	Blending weights
Spot forecasts Outputs	Generate spot forecasts Output gridded and spot	Calibration Text, weather “symbols” Multi-variate relationships -> scenarios (clustering)

Future?

Introduce 14-day global ensemble forecasts ECMWF / MOGREPS-G

Extend for high-impact thresholds (time windows & vicinity neighbourhoods)

More with calibration / ML

Common processing. Common Data Platform.

IMPROVER team

Ben Fitzpatrick, **Fiona Rust**, **Ben Ayliffe**, Laurence Beard, Tomek Trzeciak, Paul Abernethy, **Stephen Moseley**, **Gavin Evans**, Katie Howard, **Caroline Sandford**, Neil Crosswaite, Tom Gale, Chris Sampson, Katharine Hurst, Bruce Wright, Simon Jackson, Leigh Holly, Ken Mylne, Michael Sharpe, Simon Backhouse, Teresa Hughes, Daniel Mentiplay, Zhiliang Fan, Belinda Trotter

Mark Baker, Anna Booton, Clare Bysouth, Rob Coulson, Ric Crocker, Caroline Jones, Jonathan Flowerdew, Roger Harbord, Aaron Hopkinson, Sean Coultas, Dan Brierley, Marion Mittermaier, Nigel Roberts, Tim Pillinger, Mark Worsfold, Victoria Smart