NWP Post-Processing at the Met Office

Bruce Wright, Manager Gridded Post-Processing

Canadian Meteorological Centre (CMC) – 16 June 2014

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How it used to be

Observations

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Interpret & Communicate

…Capabilities have evolved

improved observations – increased remote sensing

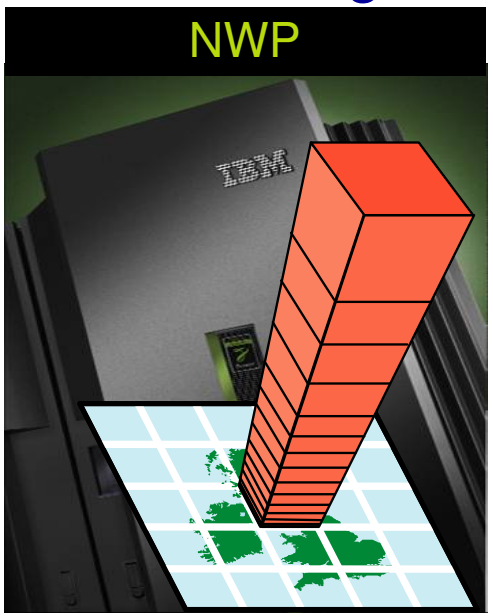
Numerical Weather Prediction

Observations

Interpret & Communicate

…Capabilities have evolved

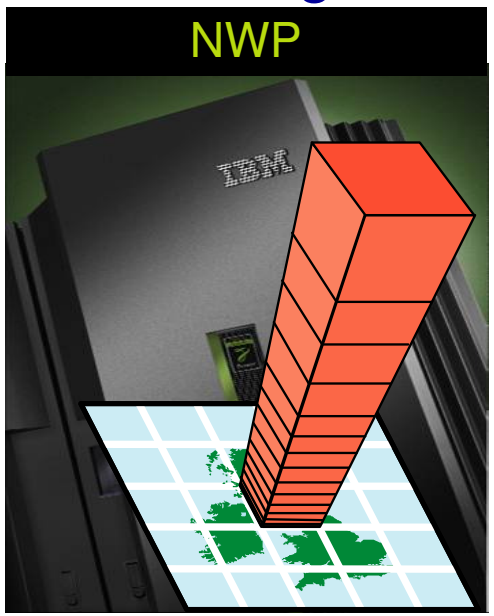
improved models – high resolution & ensembles



…Capabilities have evolved

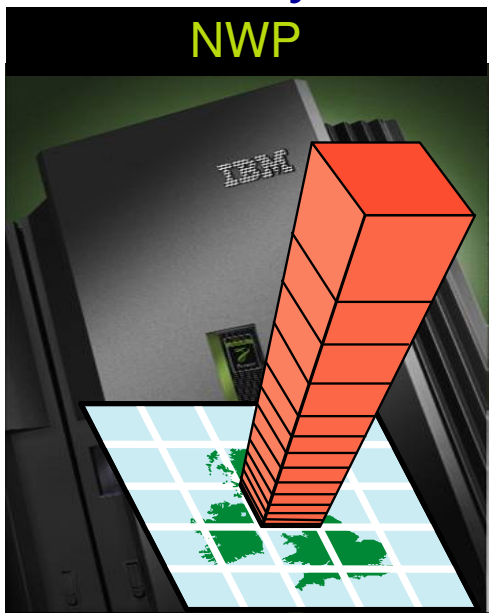
improved forecasting tools & greater automation

Met Office



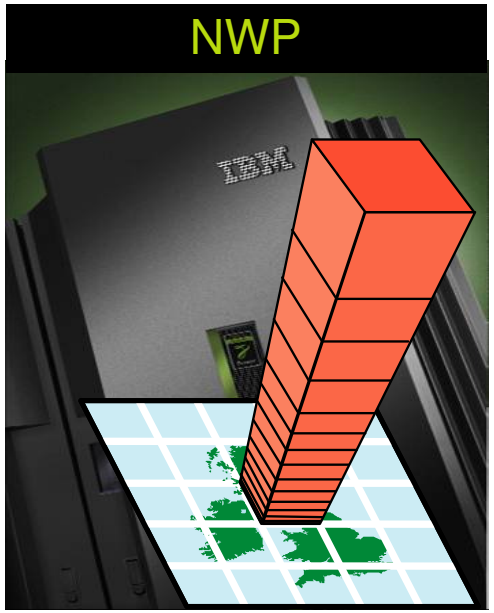
…More focus on impacts

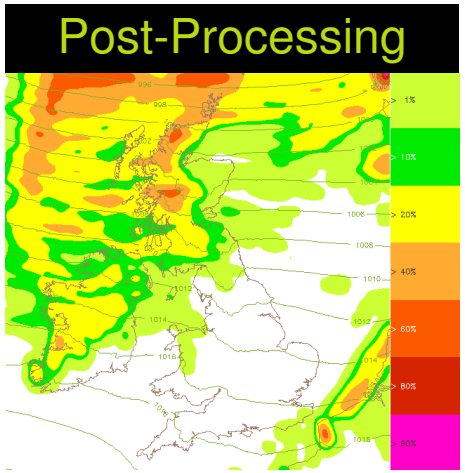
working more closely with customers



…Post-processing

adding value

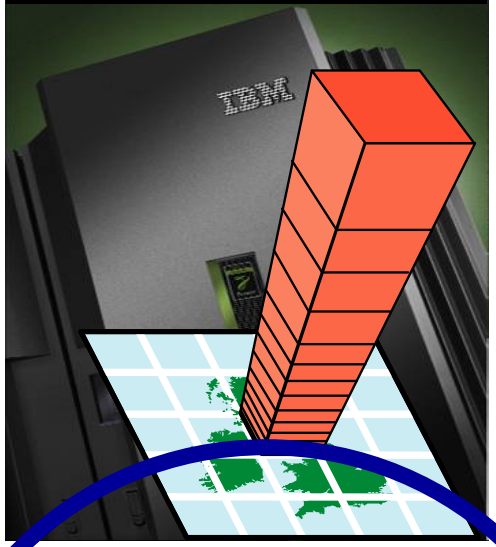




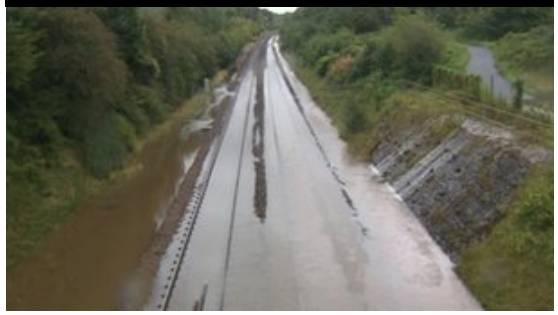
Today, we focus on…

Met Office

NWP

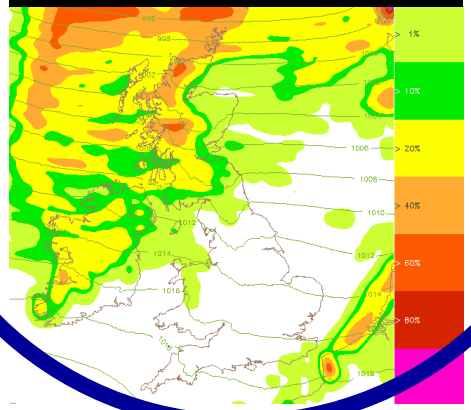


Manage Impact



Observations

Post-Processing



Interpret & Communicate

The NWP modelling capability

Comprehensive NWP suite

Global

- 25km 70 Levels
- 48 hour forecast twice/day
- 6 day forecast twice/day

NAE will be retired on 1 July

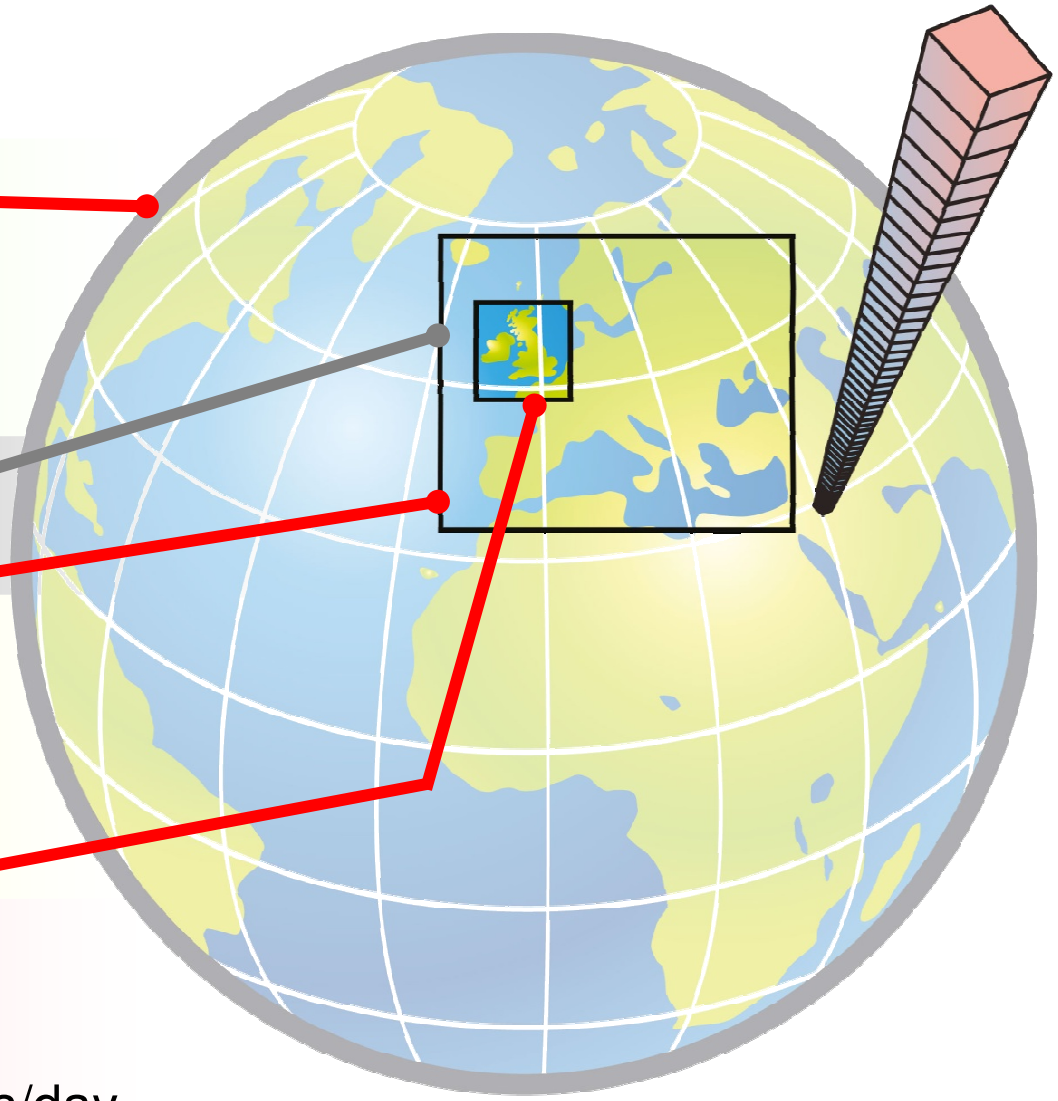
(our previous regional model)

Euro4

- 4.4km 70 Levels
- 60 hour forecast twice/day
- 5 day forecast twice/day

UKV

- 1.5km 70 Levels
- 36 hour forecast eight times/day



Comprehensive NWP suite

Continually improving

Global

17km 70 Levels
- 48 hour forecast twice/day
- 6 day forecast twice/day

NAE will be retired on 1 July
(our previous regional model)

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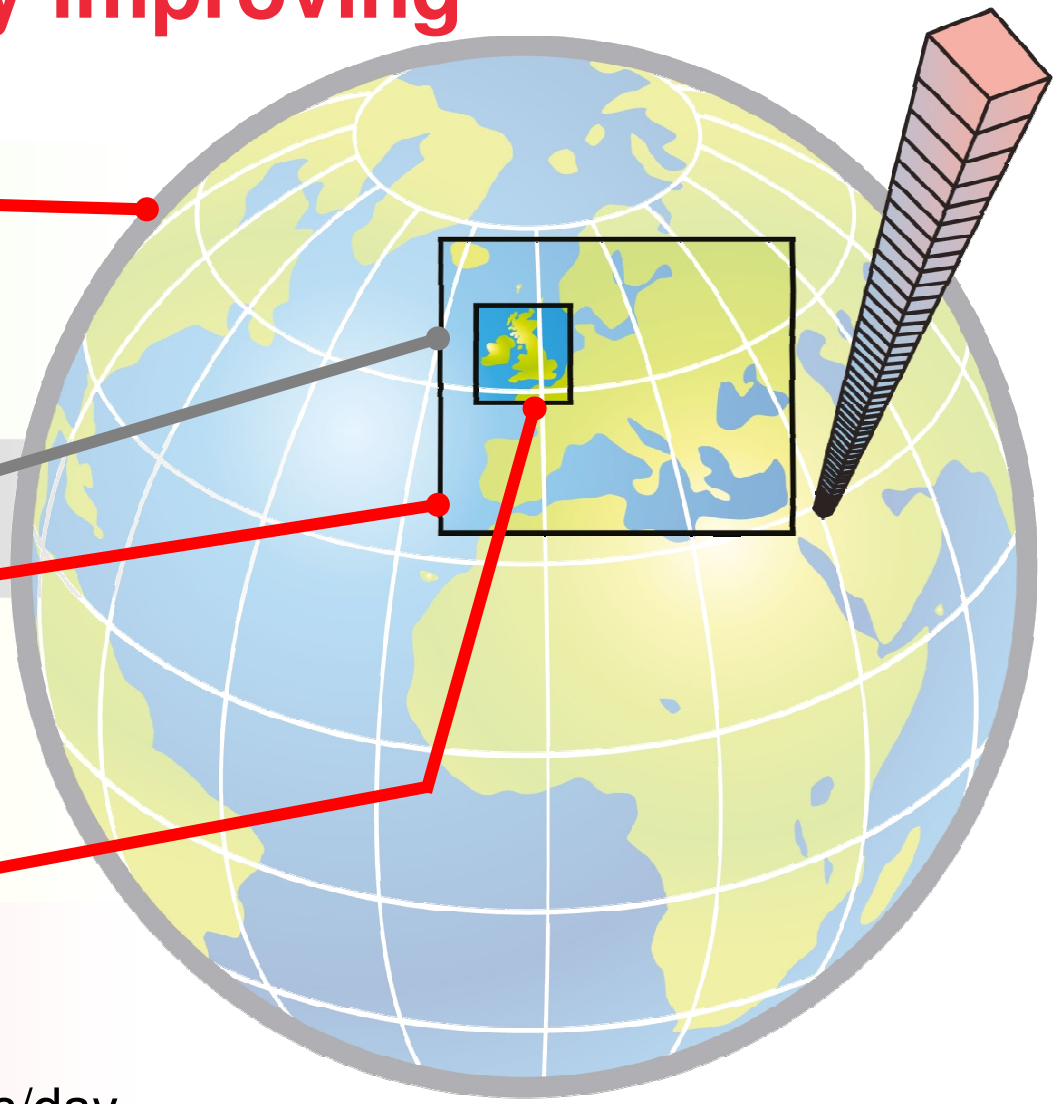
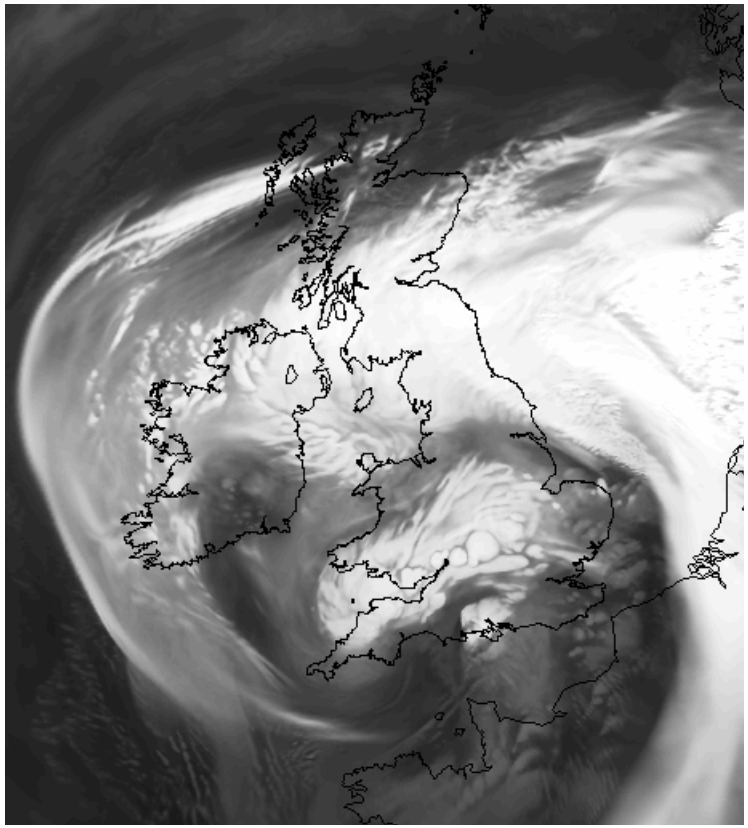
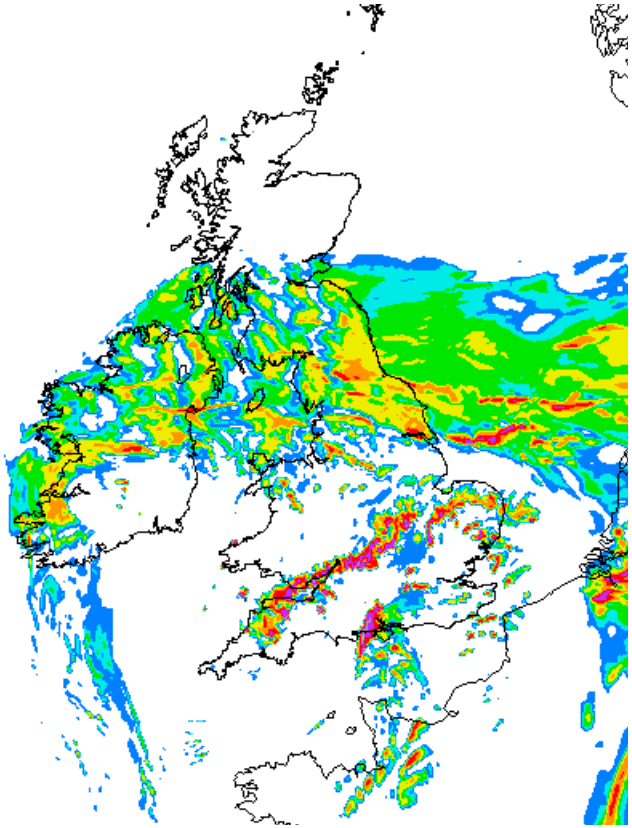


Very high resolution NWP

an unprecedented level of detail





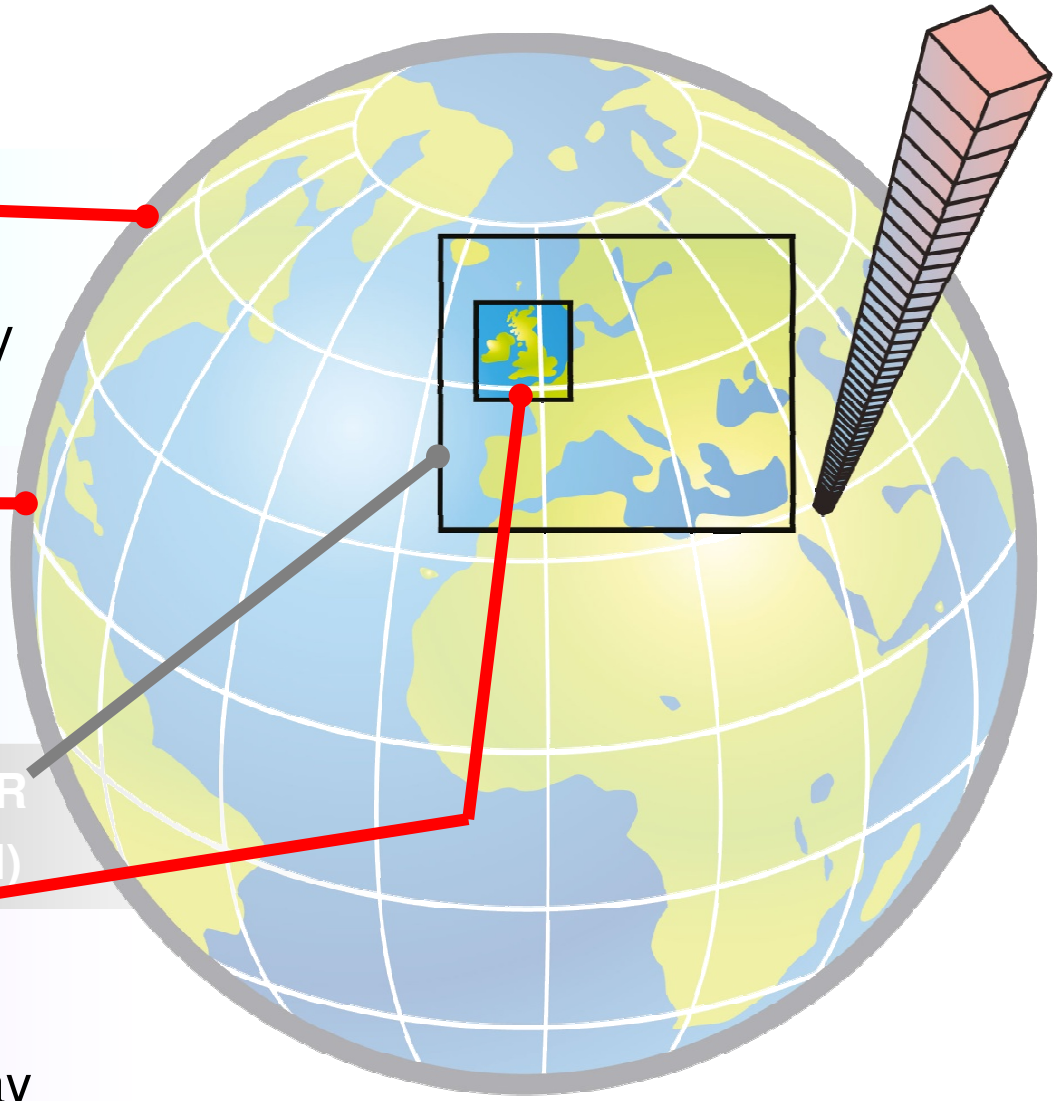
Ensemble modelling capability

MOGREPS-15
- 60km 70 Levels
- 15 day forecast 2 times/day
- 24 members

MOGREPS-G
- 33km 70 Levels
- 3 day forecast 4 times/day
- 12 members

We no longer run MOGREPS-R (our regional ensemble model)

MOGREPS-UK
- 2.2km 70 Levels
- 36 hour forecast 4 times/day
- 12 members



Ensemble modelling capability

Continually improving

MOGREPS-15

- 60km 70 Levels
- 15 day forecast 2 times/day
- 24 members

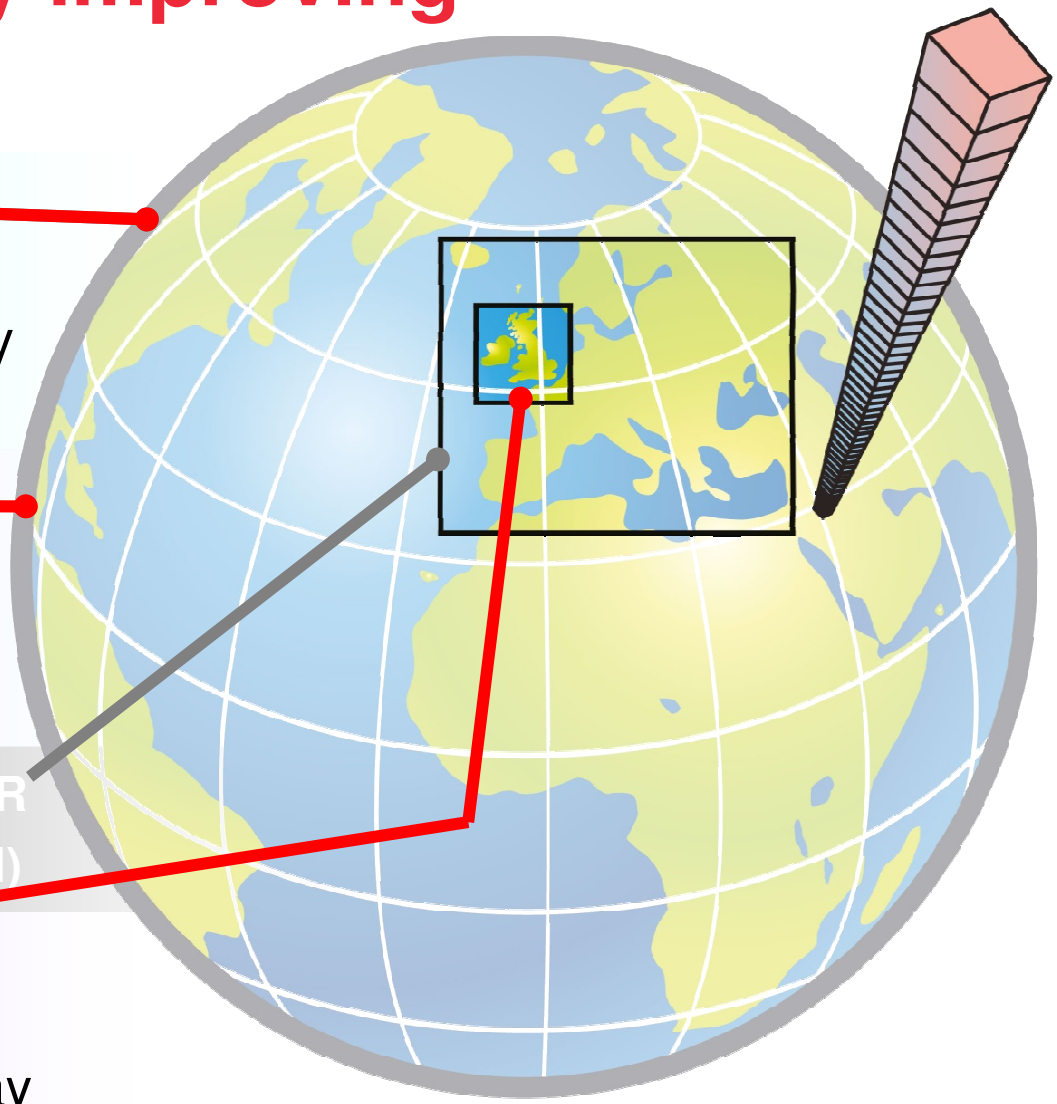
MOGREPS-G

- 33km 70 Levels
- 7 day forecast 4 times/day
- 12 members

We no longer run MOGREPS-R (our regional ensemble model)

MOGREPS-UK

- 2.2km 70 Levels
- 36 hour forecast 4 times/day
- 12 members



Ensemble modelling capability

Continually improving

MOGREPS-15

will be retired by March 2015

MOGREPS-G

– 33km 70 Levels
– 7 day forecast 4 times/day
– 12 members

We no longer run MOGREPS-R

(our regional ensemble model)

MOGREPS-UK

– 2.2km 70 Levels
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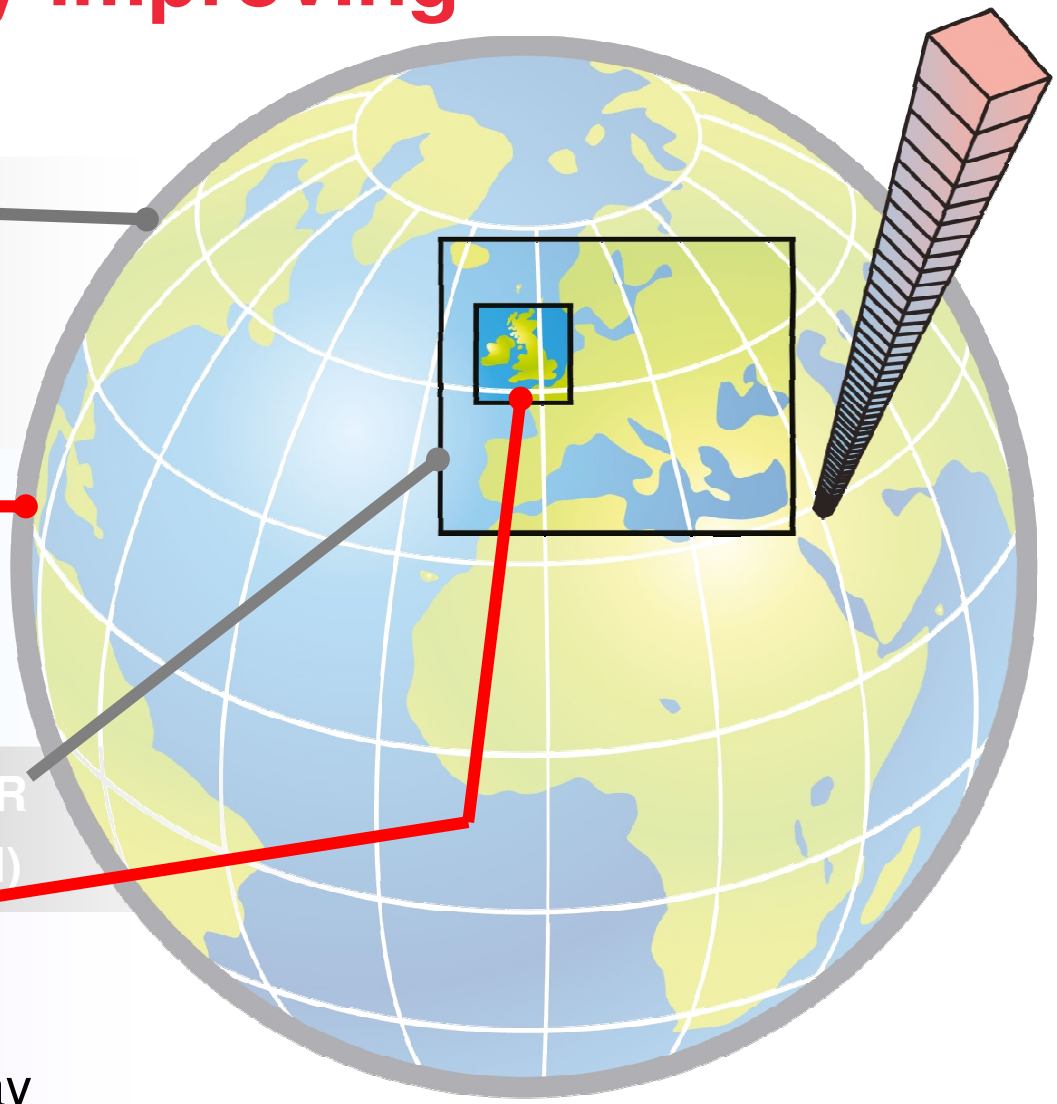
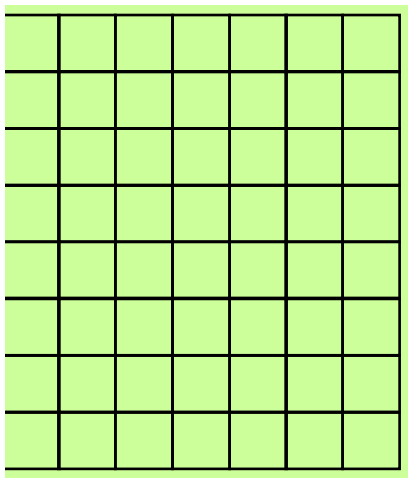


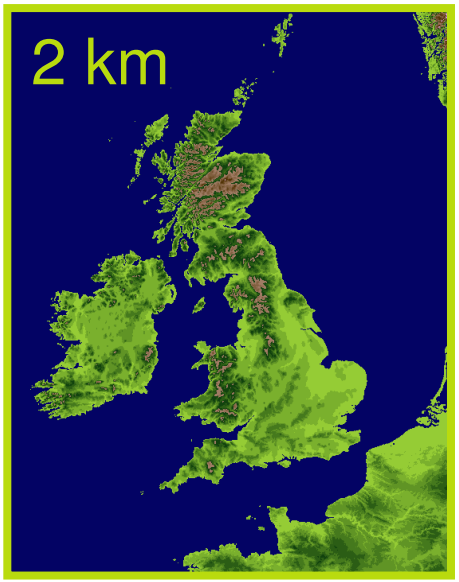
Gridded Post-Processing
& Downscaling

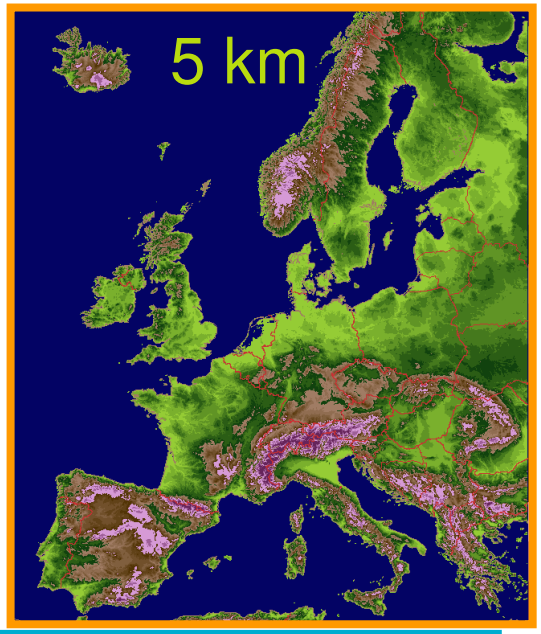
Downscaling

Standard grids

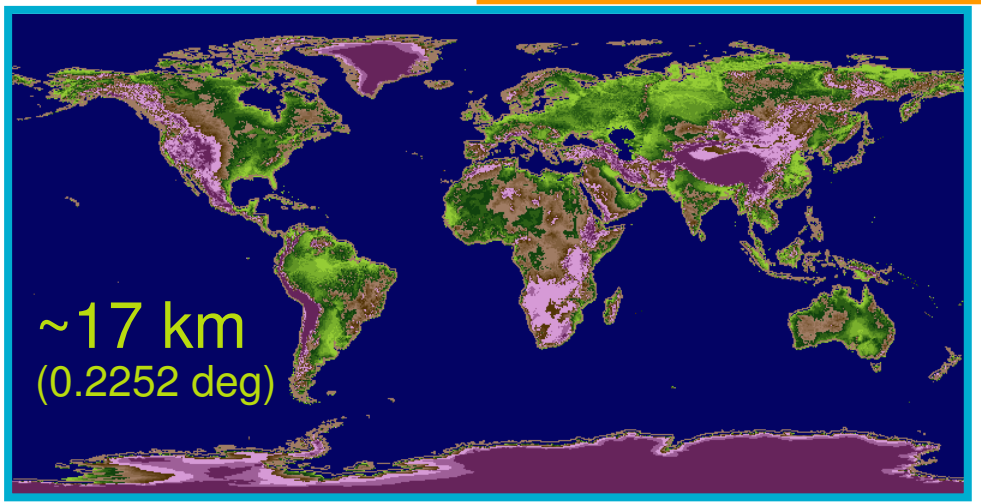


Regular Arakawa-A grids

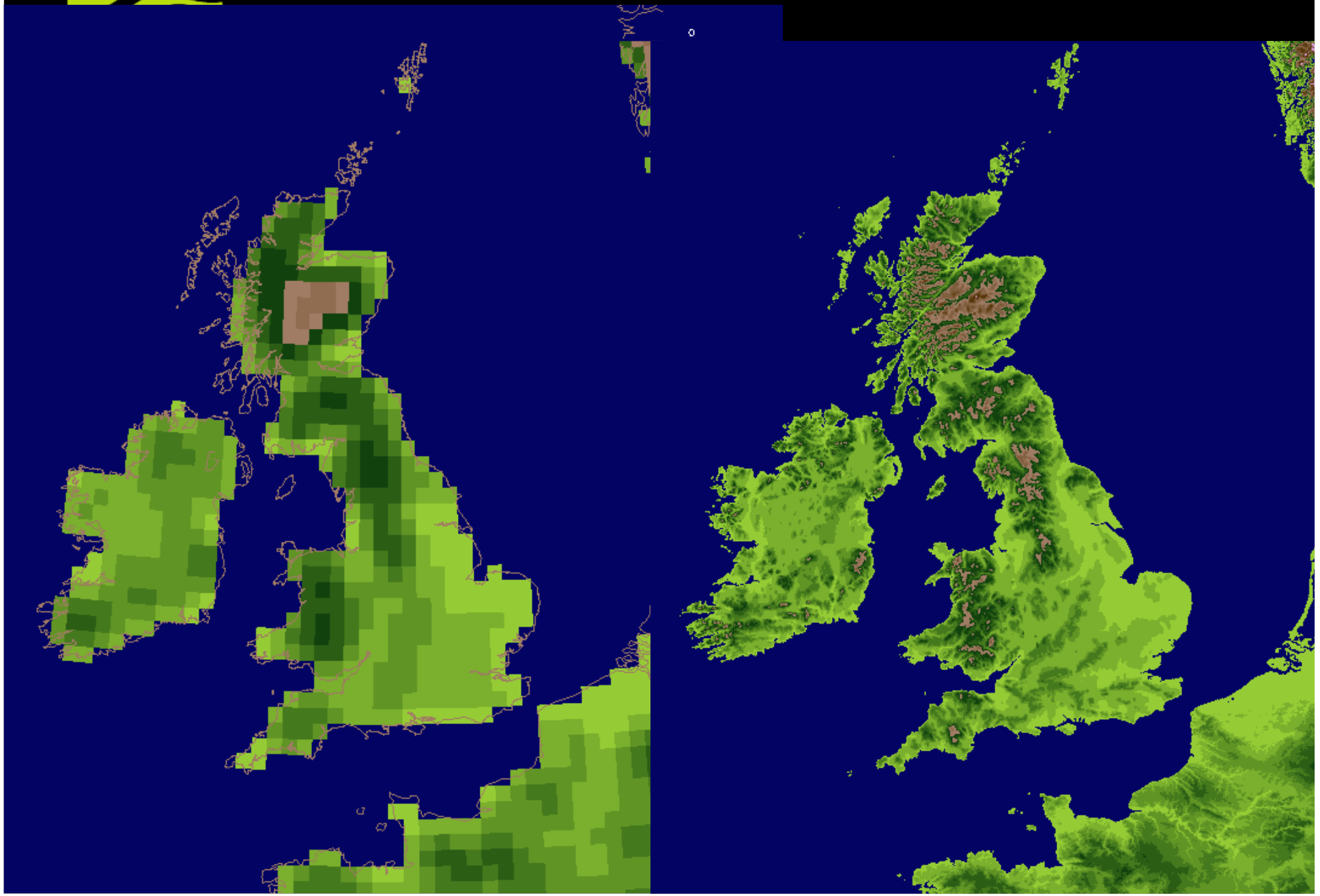




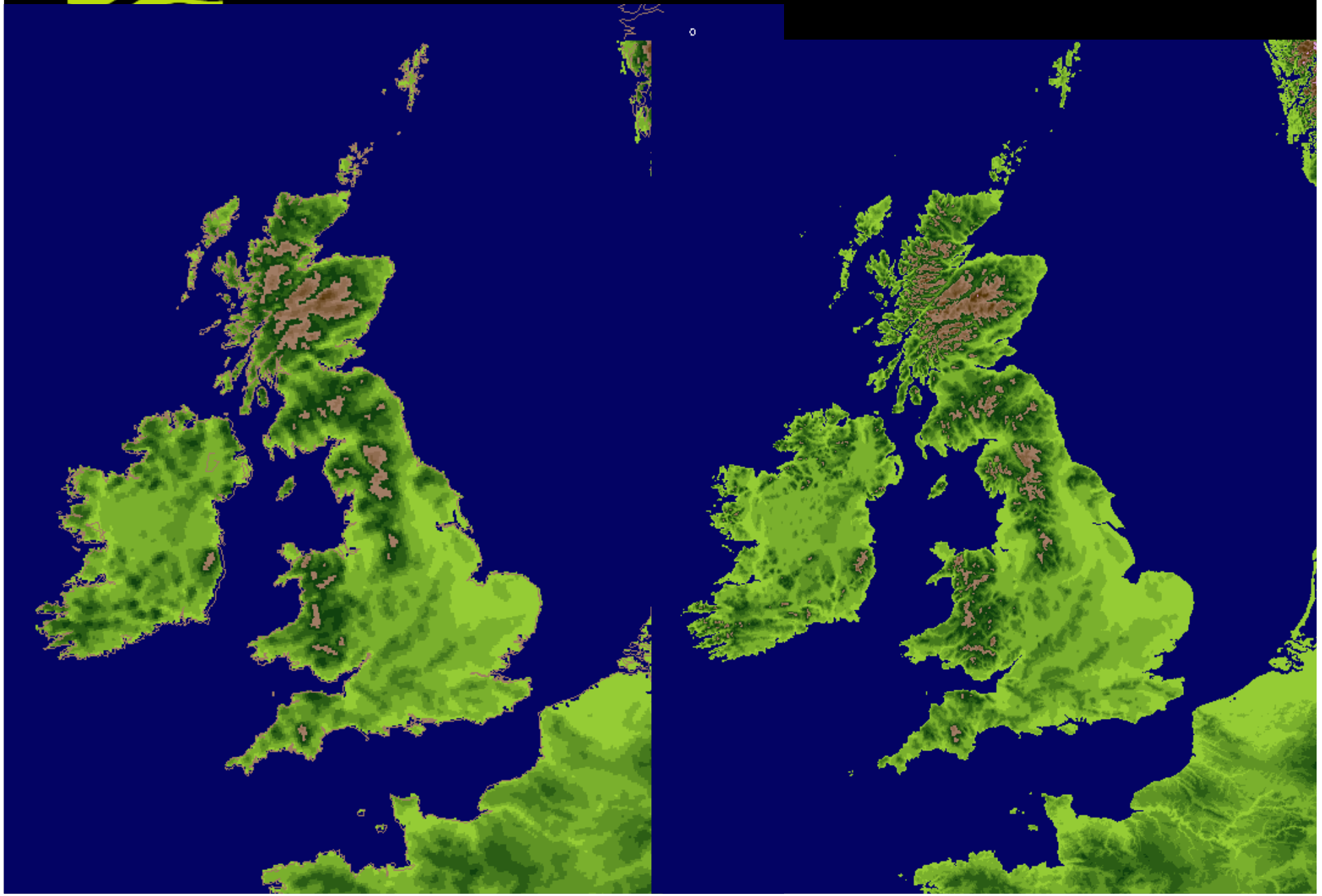
Standard Coordinate Reference Systems in common use



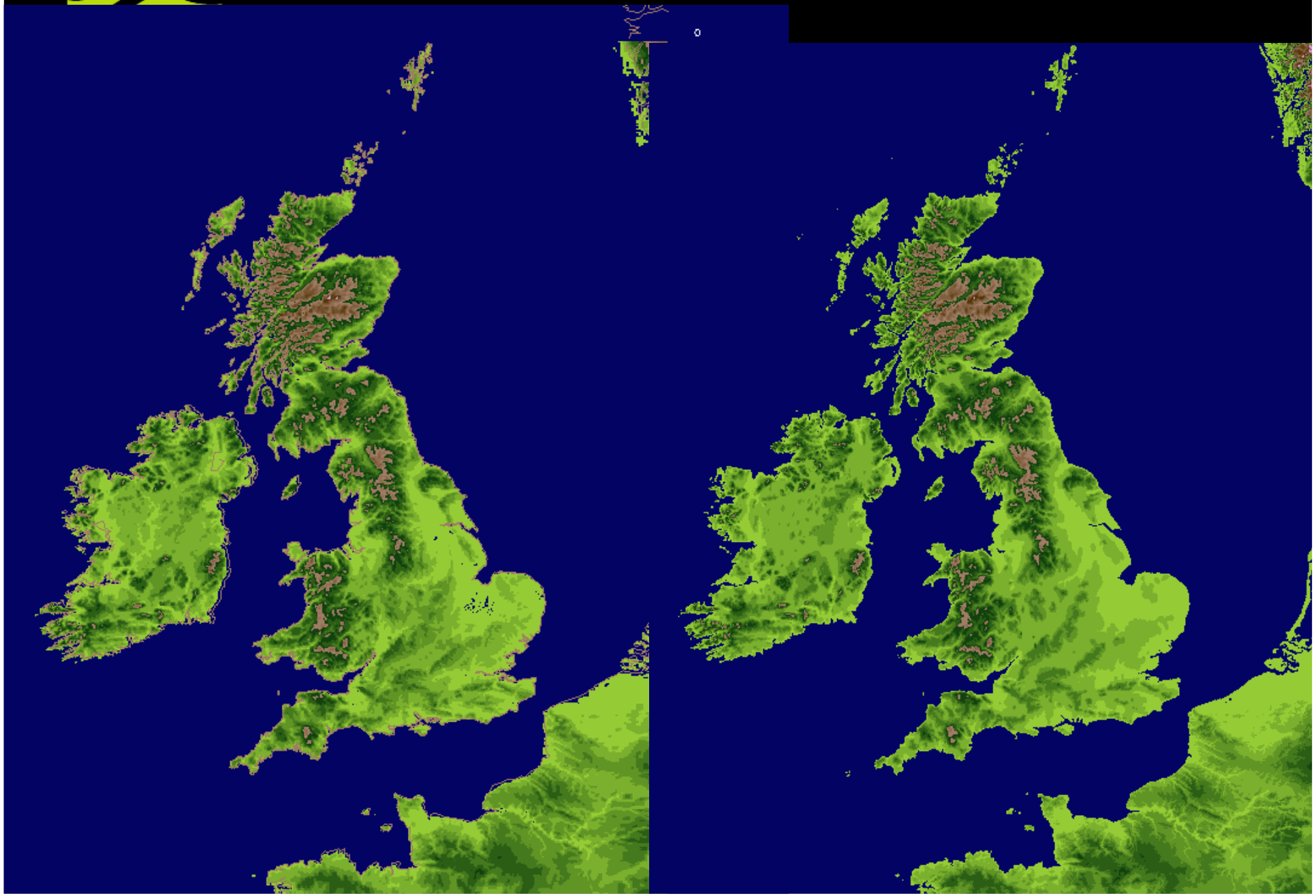
Global vs UKPP resolution



Euro4 vs UKPP resolution

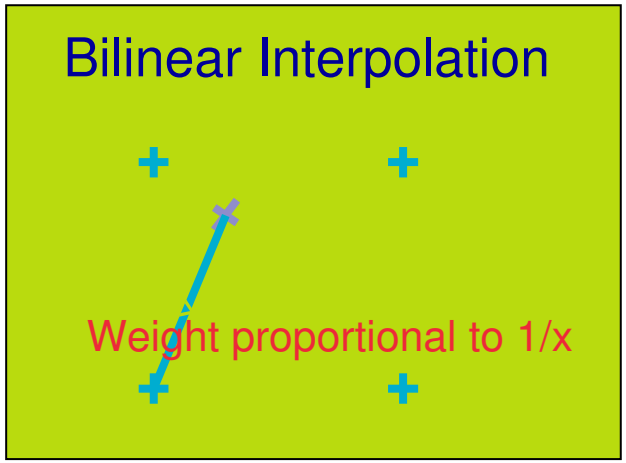


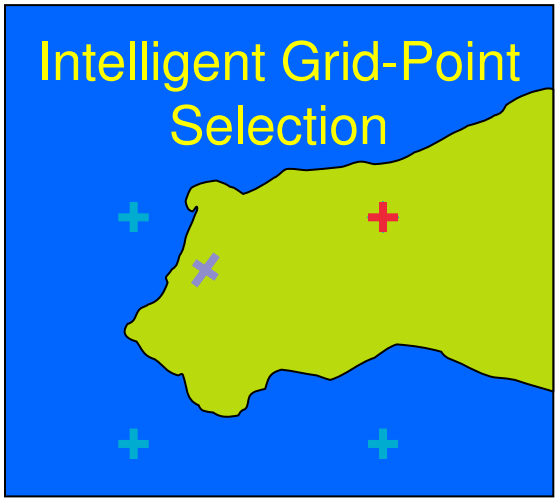
UKV vs UKPP resolution

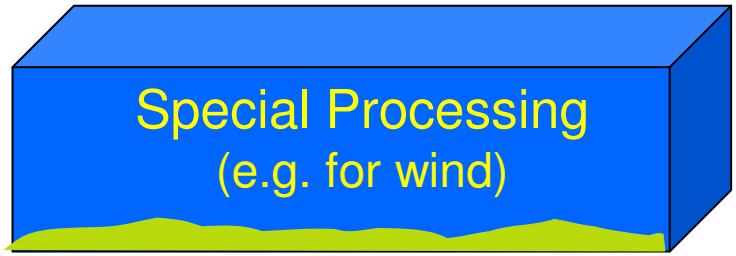


Downscaling

Multiple techniques

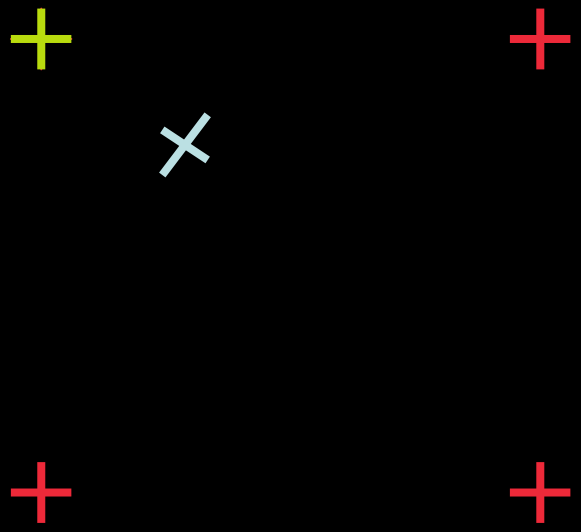






Downscaling techniques

Nearest point



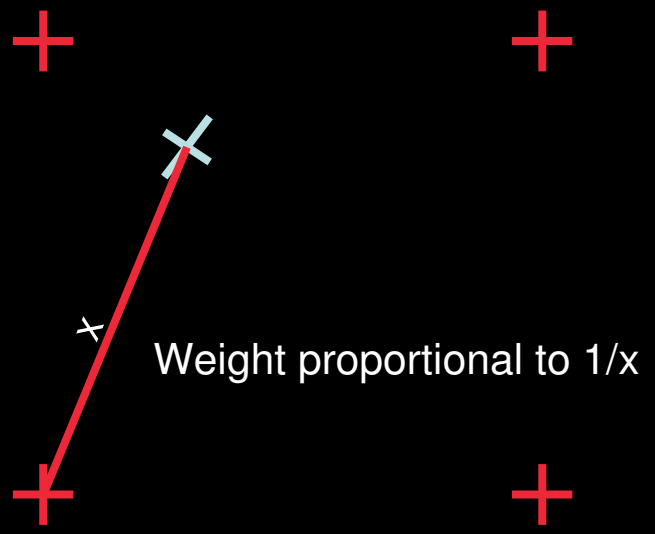
- Unadjusted value from the nearest available model grid-point
- Used for non-linear fields

Cloud
precipitation rate and accumulation
radiation fluxes
run-off for river-flow model
snow melt
soil evaporation

Downscaling techniques

Bilinear interpolation

- Spatially adjusted value from the four nearest available model grid-points
- Used for linear fields



Mean sea level pressure
Aerosol and water-content (for visibility)
Boundary-layer depth
Ultra-violet flux
Wet-bulb freezing level
Snow depth

Downscaling techniques

Trilinear interpolation

- 3D Spatially adjusted value from the four nearest available model grid-points at the nearest levels
- Used for linear 3D fields

3D Temperature 3D Relative Humidity

- With additional interpolation below lowest model level (using level 1-2 model lapse rate)

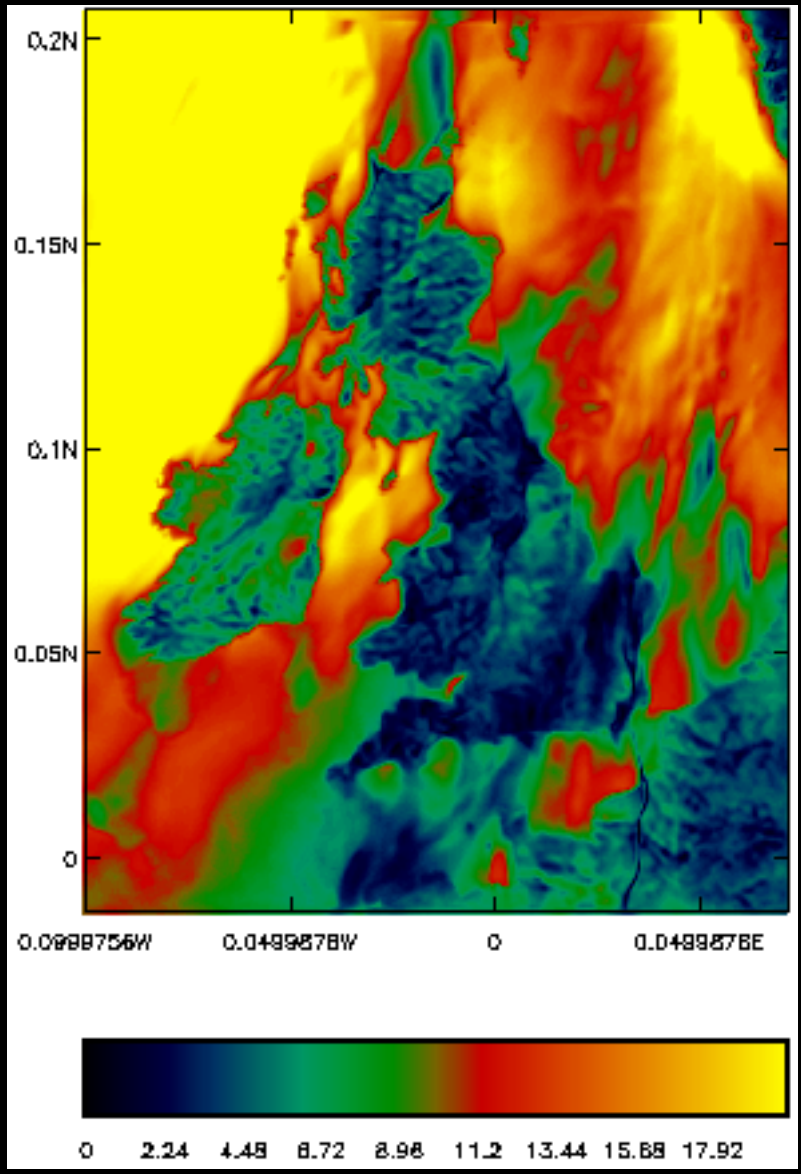
3D Pressure

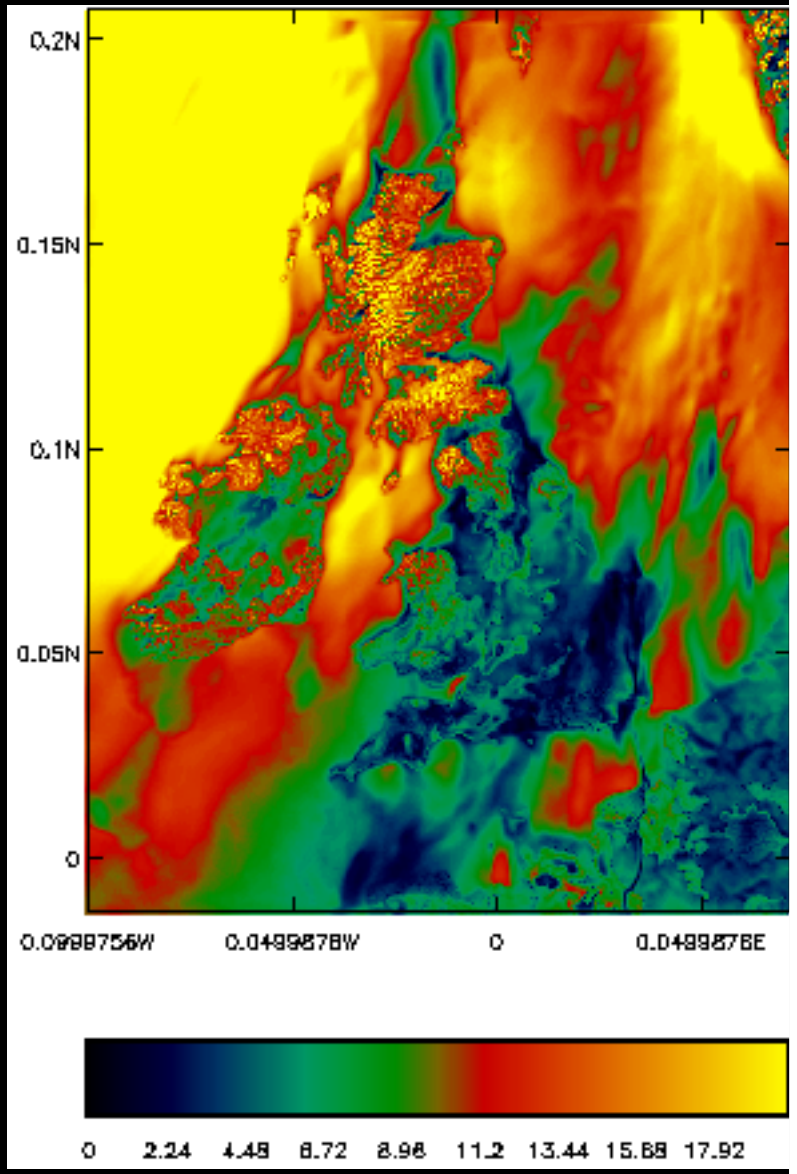
Downscaling techniques

Wind interpolation

- Trilinear interpolation in free-atmosphere
- Near-surface points re-calculated by selecting lowest free-atmosphere point and applying a more appropriate drag-coefficient
- This is not required for the highest resolution models (1.5km and 2.2km) where the model drag becomes insignificant

Downscaling – Wind example

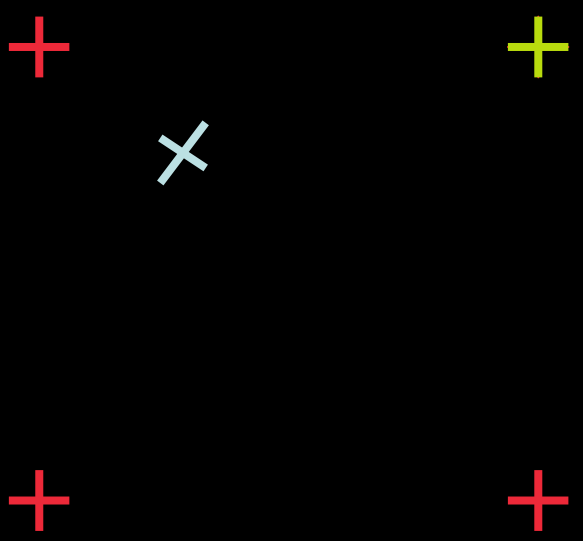




Downscaling techniques

Intelligent grid-point selection

- Uses model grid-point most closely matching target grid-point for land/sea status and orographic height.



Surface temperature
Other soil diagnostics

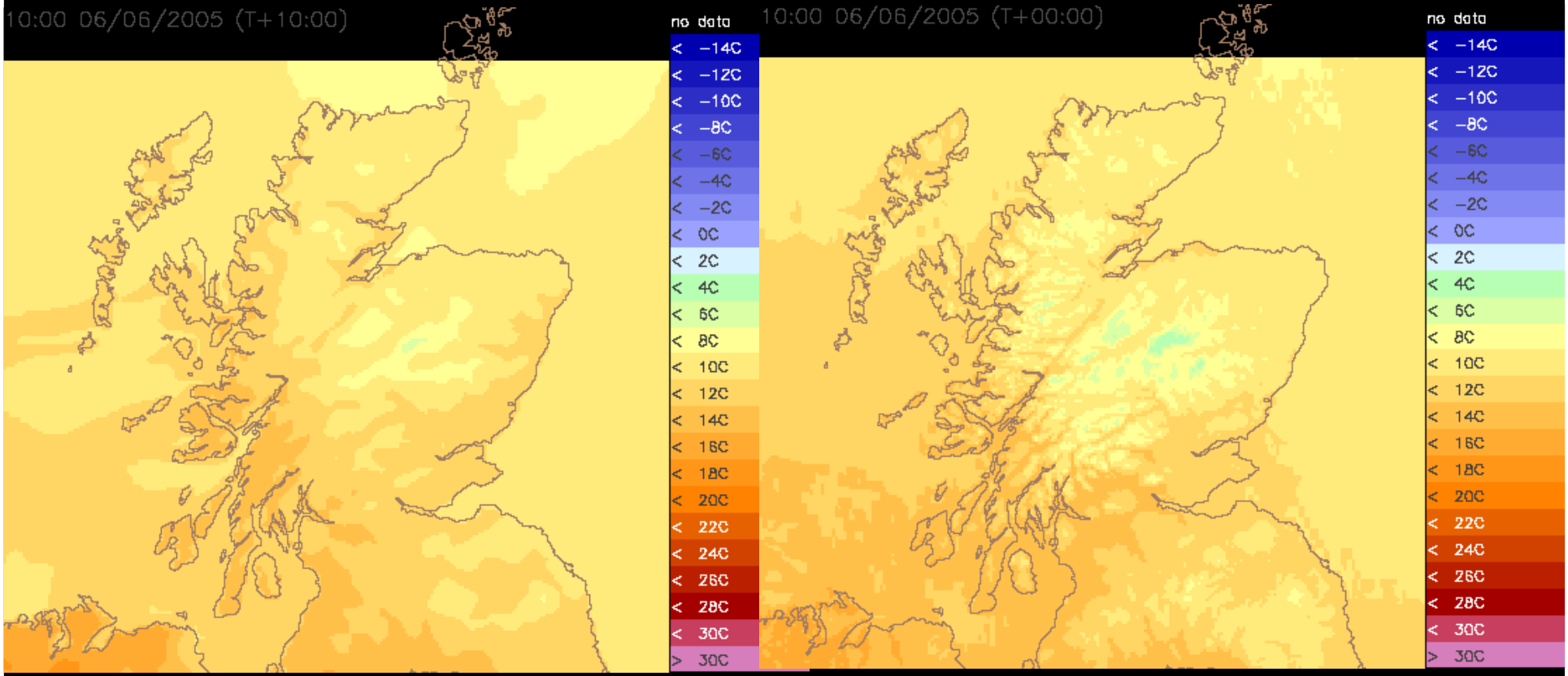
Downscaling techniques

Screen temperature

- Combination of techniques
- Between two model levels: Trilinear interpolation
- Below lowest model level (unresolved valley):
  - If Lapse rate <= 0: Apply lapse rate correction according to height difference
  - If Lapse rate >0 (inversion): Apply lapse rate correction according to height difference up to a maximum of 70m. (Prevents excessively cold valleys)

Downscaling
Temperature example

4km model data

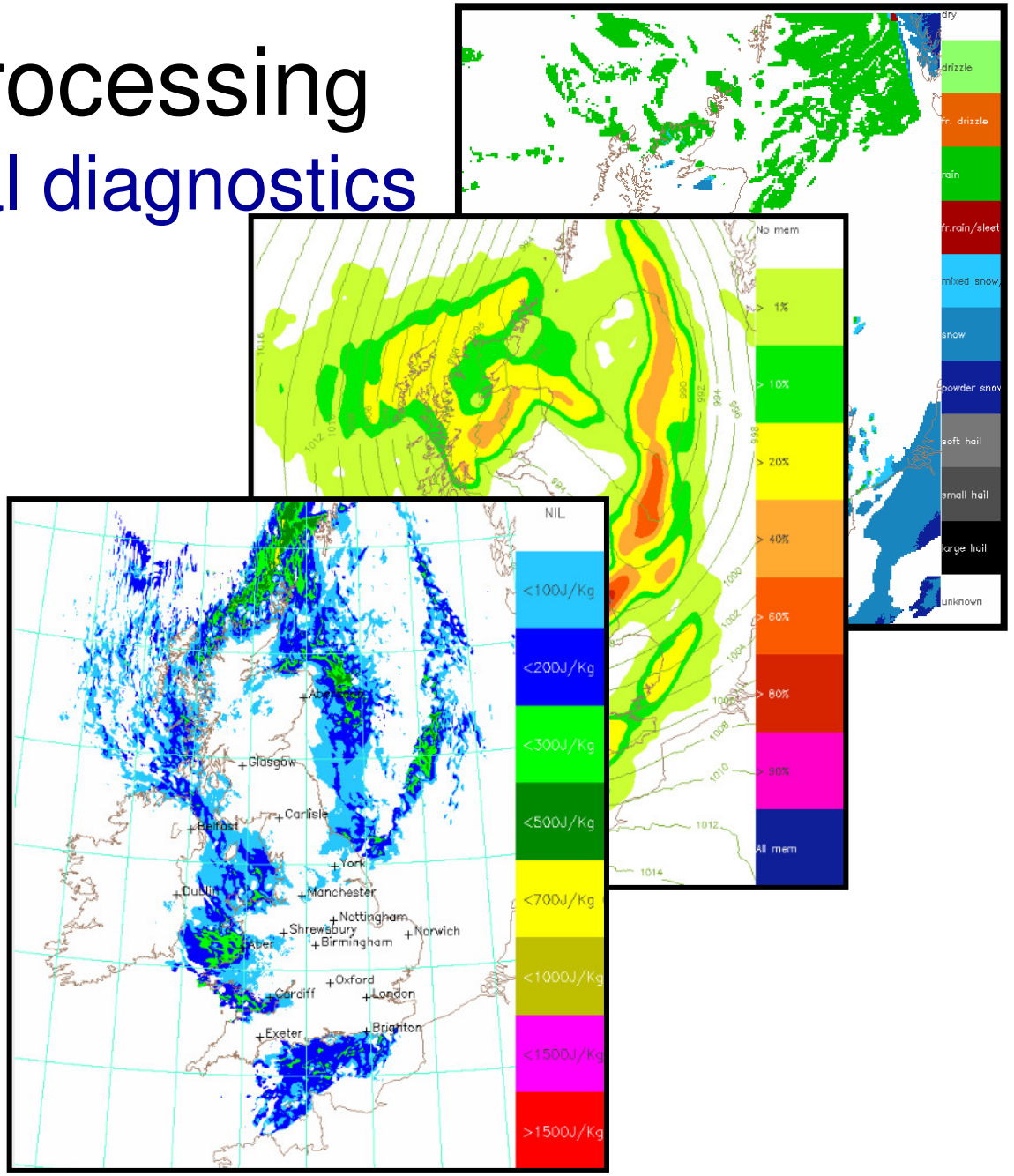


Before downscaling

After downscaling

Post-Processing
Additional diagnostics

- Precipitation type
- Rainfall probabilities
- Severe convective weather
- …



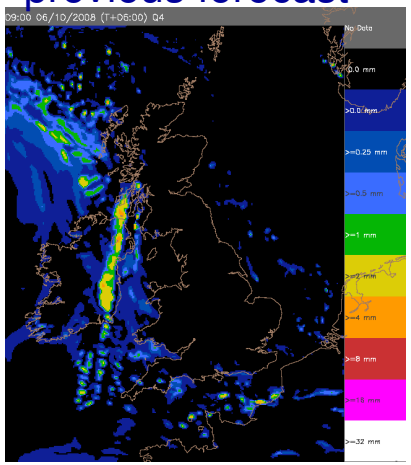
Nowcasting & STEPS

Nowcasting

Exploiting the latest information

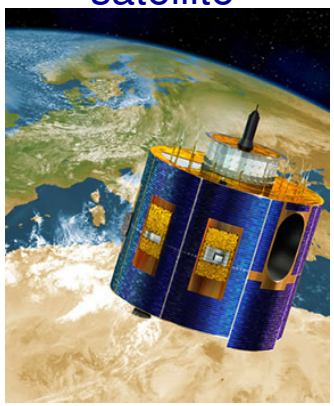
- Current forecast models do not have the update frequency to be reliable
- Use extrapolation techniques to 'fill the gap'

previous forecast



3 hourly

satellite

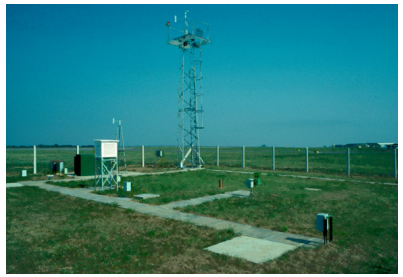


every 15 mins

radar

every 5 mins

surface observations



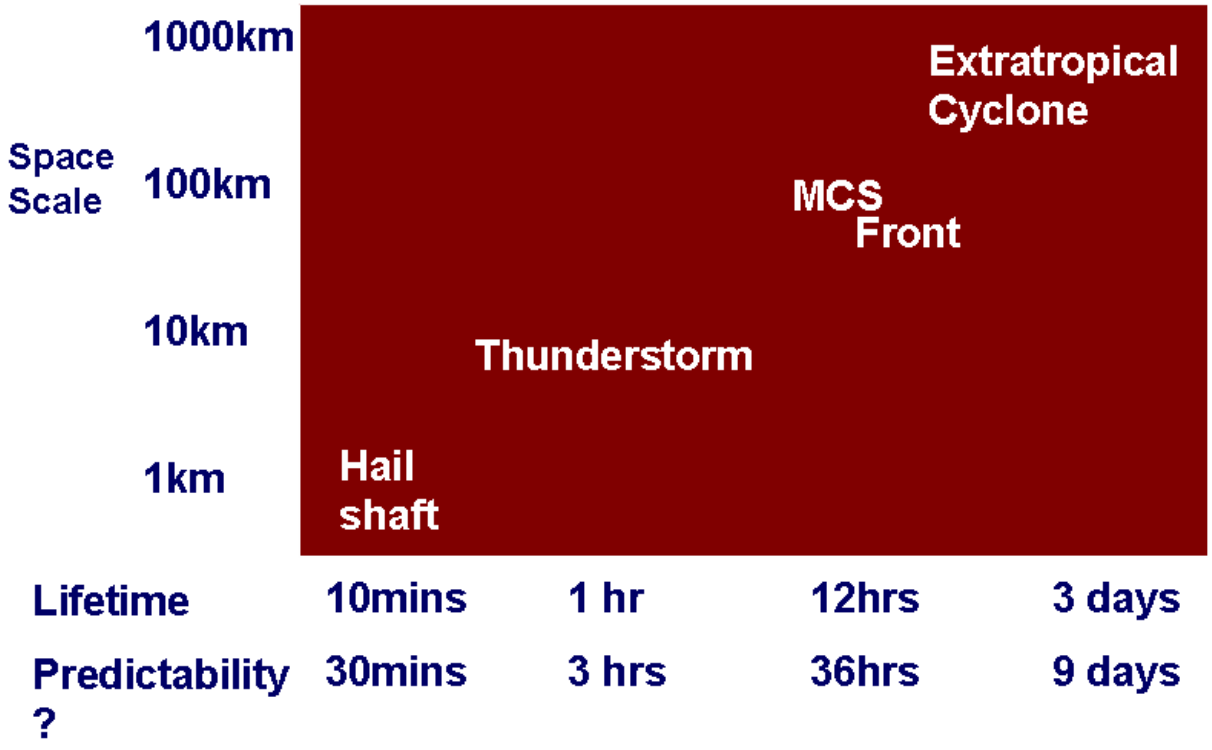
every 10 mins

lightning location

every 5 mins

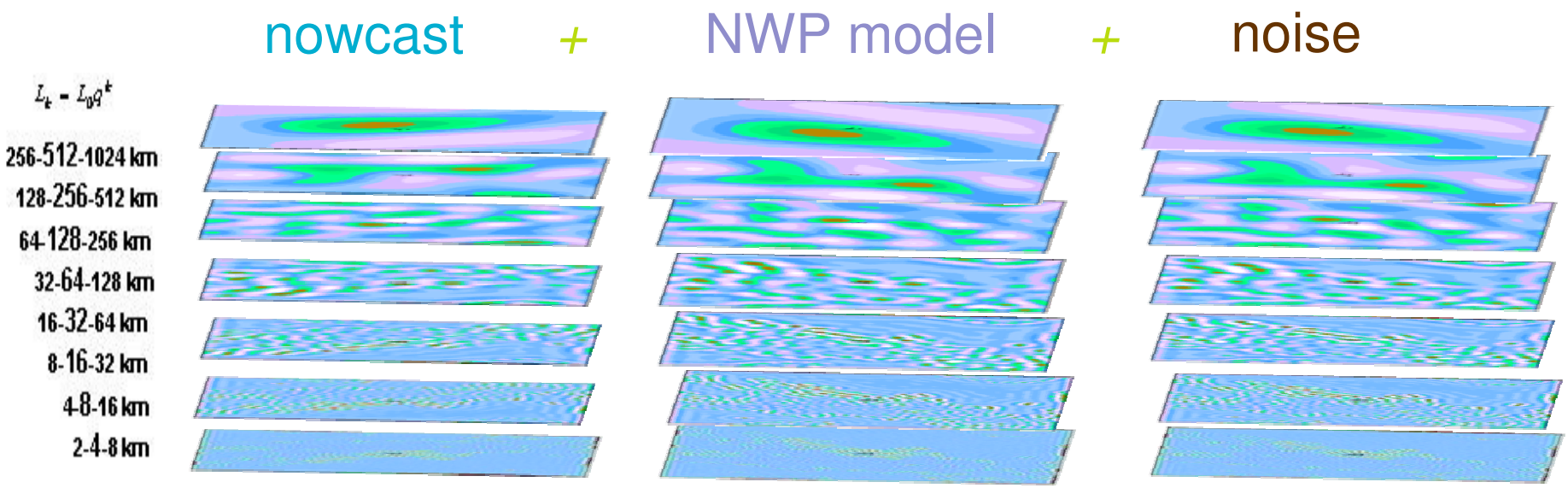
Precipitation Characteristics

- Non-Gaussian distribution
- Nugget at zero – discontinous
- Spatial and temporal scaling properties



STEPS
Modelling framework

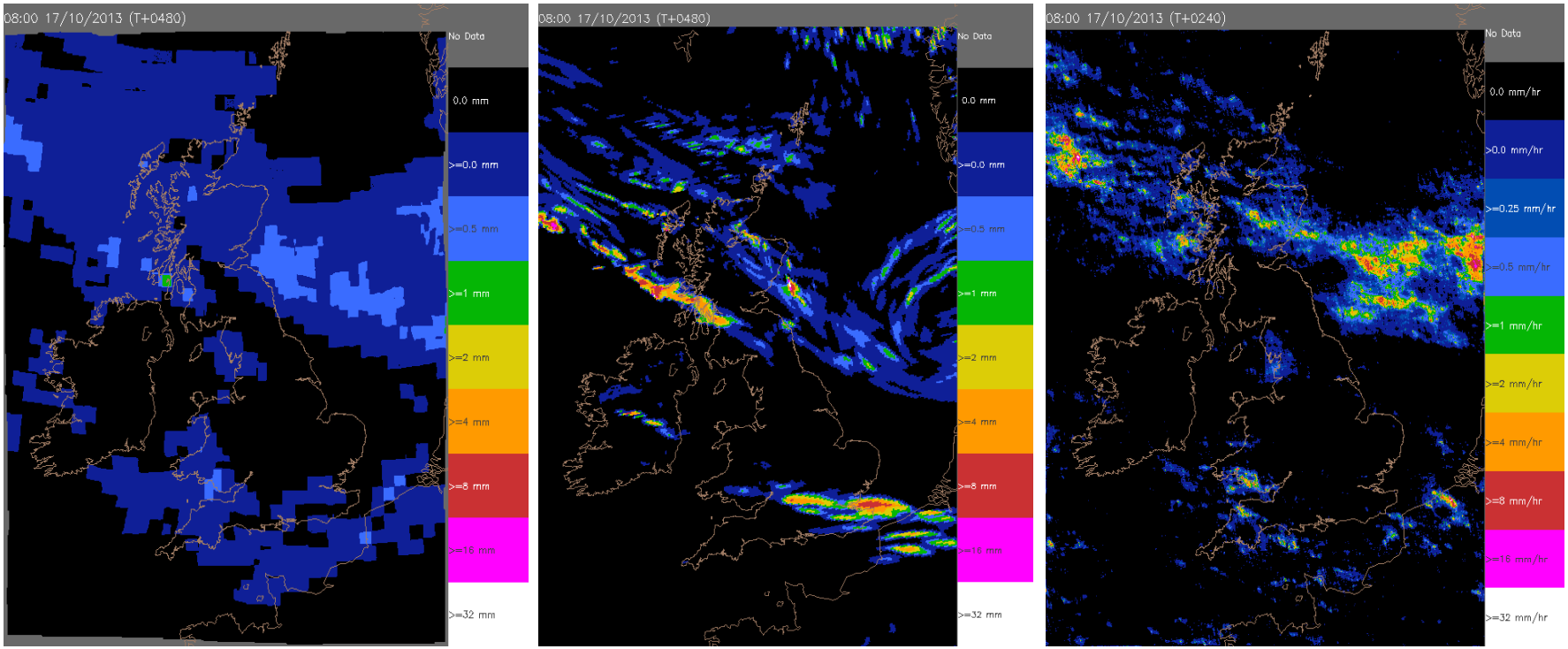
- Scale-decomposition framework
- Seamless combination of nowcast & NWP forecasts
- Noise used to generate ensembles & downscale NWP
- Self-calibrating



STEPS
Noise

- What is noise?
  - Random numbers which look like radar or model forecast precipitation
- Why do we need noise?
  - Represent uncertainty in the evolution of forecast precipitation fields
  - Downscale model precipitation forecasts
  - Produce multiple scenarios

Experimental MOGREP-G downscaling using non-parametric noise generator



MOGREPS-G forecast 1 hr rain accum 08Z 17/10/2013	Euro4km forecast 1 hr rain accum 08Z 17/10/2013	Downscaled MOGREPS-G 1h rain accum using Euro4 non-parametric noise

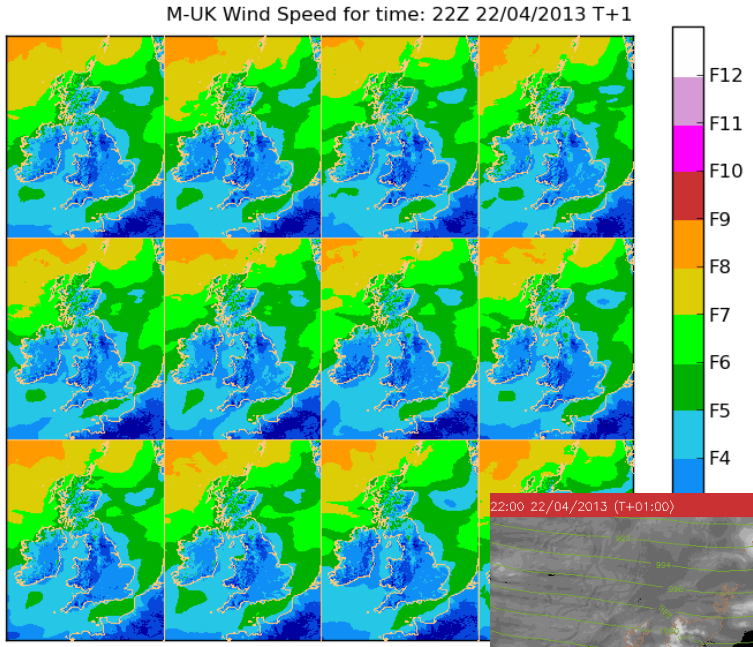
Other Nowcast Products

- Precipitation
  - Accumulations
  - Probability of snow
- Visibility
  - Analyses & forecasts of screen visibility
  - Fog probabilities
  - Screen temperature & dewpoint, as products of visibility scheme

Ensemble probabilities
& Neighbourhoods

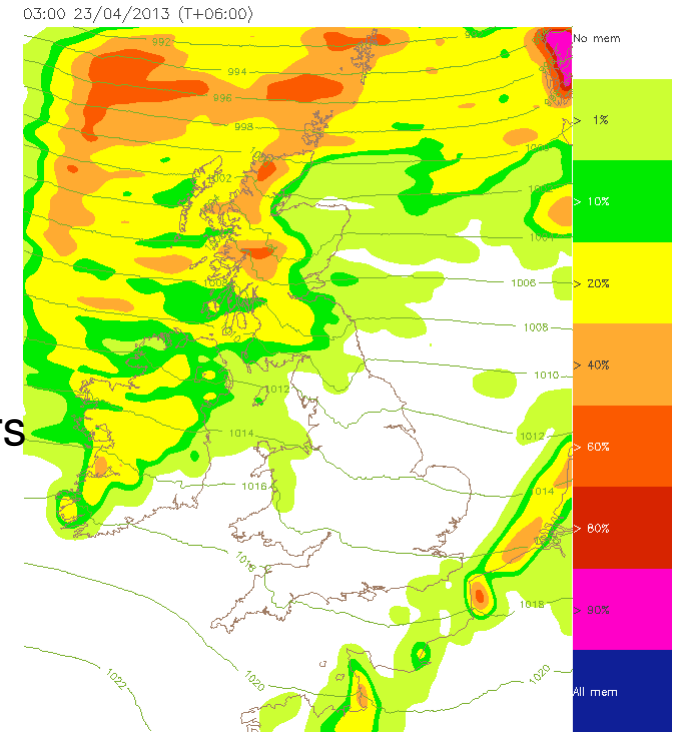
Ensembles

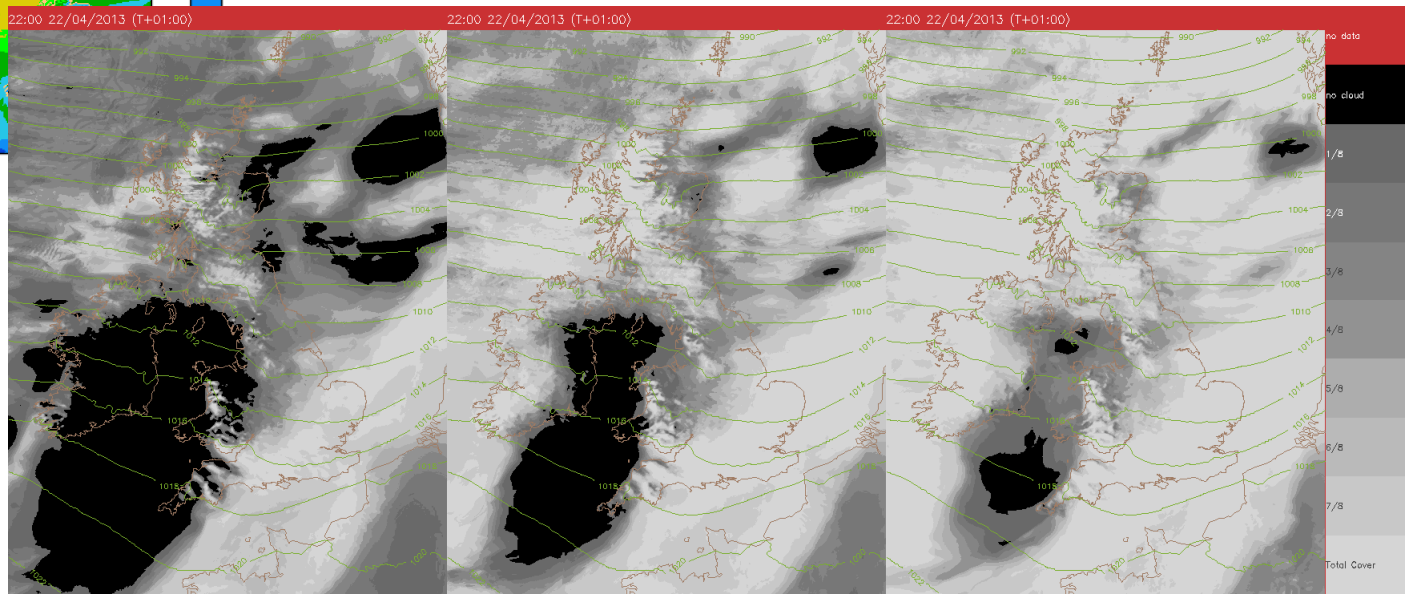
increasing use



MOGREPS-UK

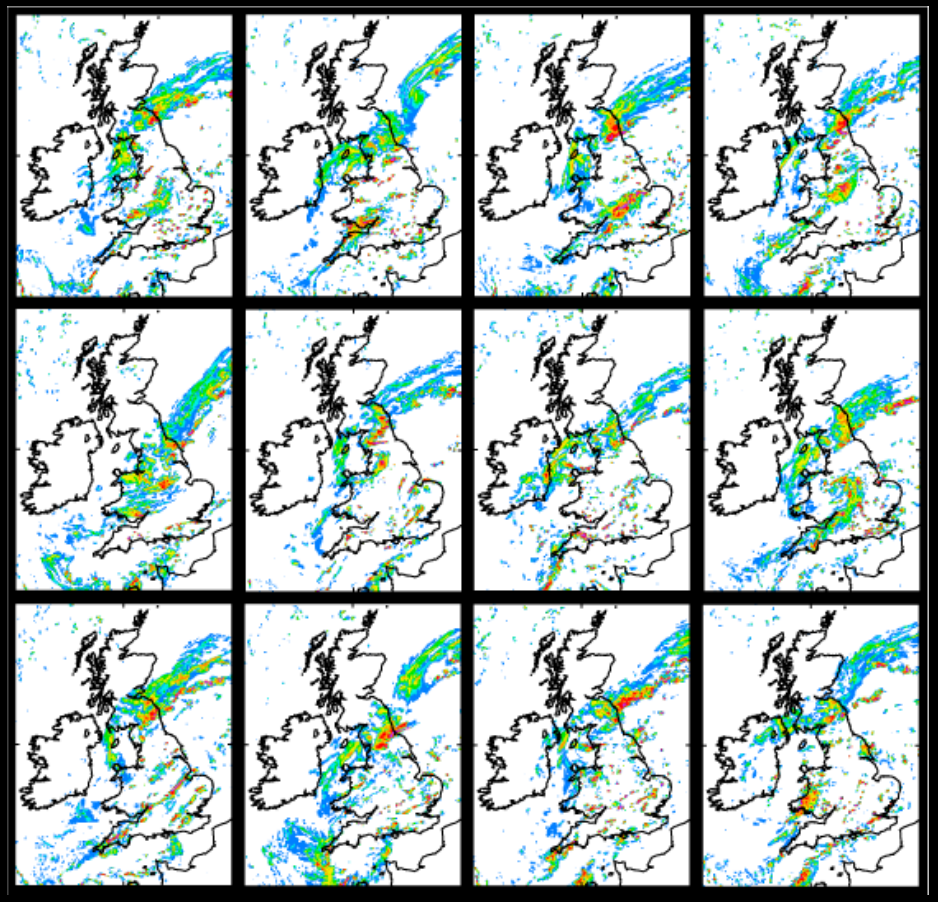
- Ensemble members
- Percentile ranges
- Probabilities (with Neighbourhood processing)



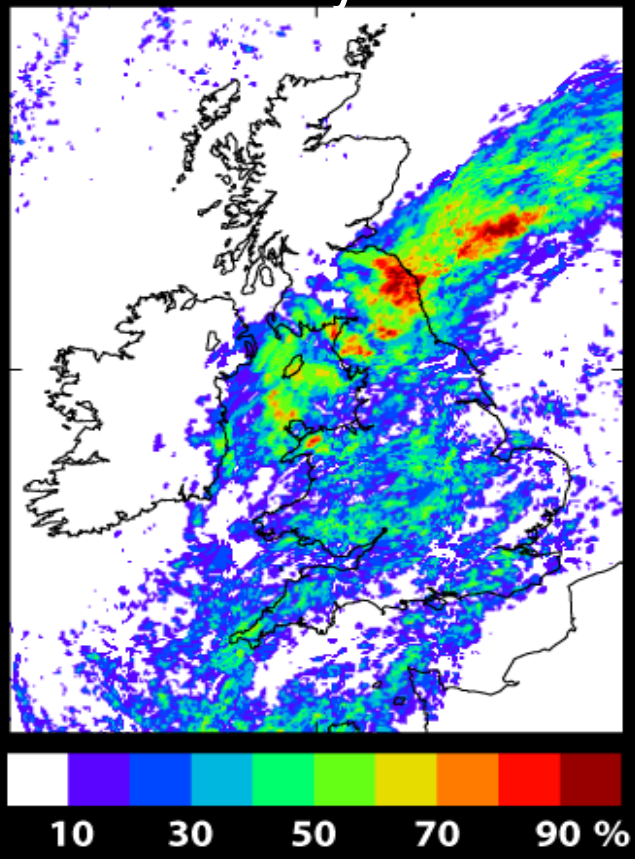


Improving presentation of convective ensemble probabilities

MOGREPS-UK (12 members)

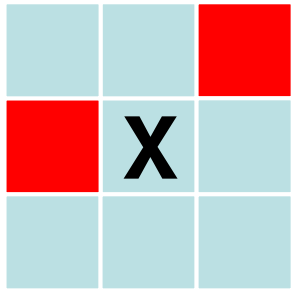


Probability of rain



Undersampling leaves “holes” of zero-probability … where showers could still occur

Neighbourhood processing – a way of getting more ensemble members



3x3 neighbourhood

What happens at a particular model grid square is equally likely to occur at nearby grid squares

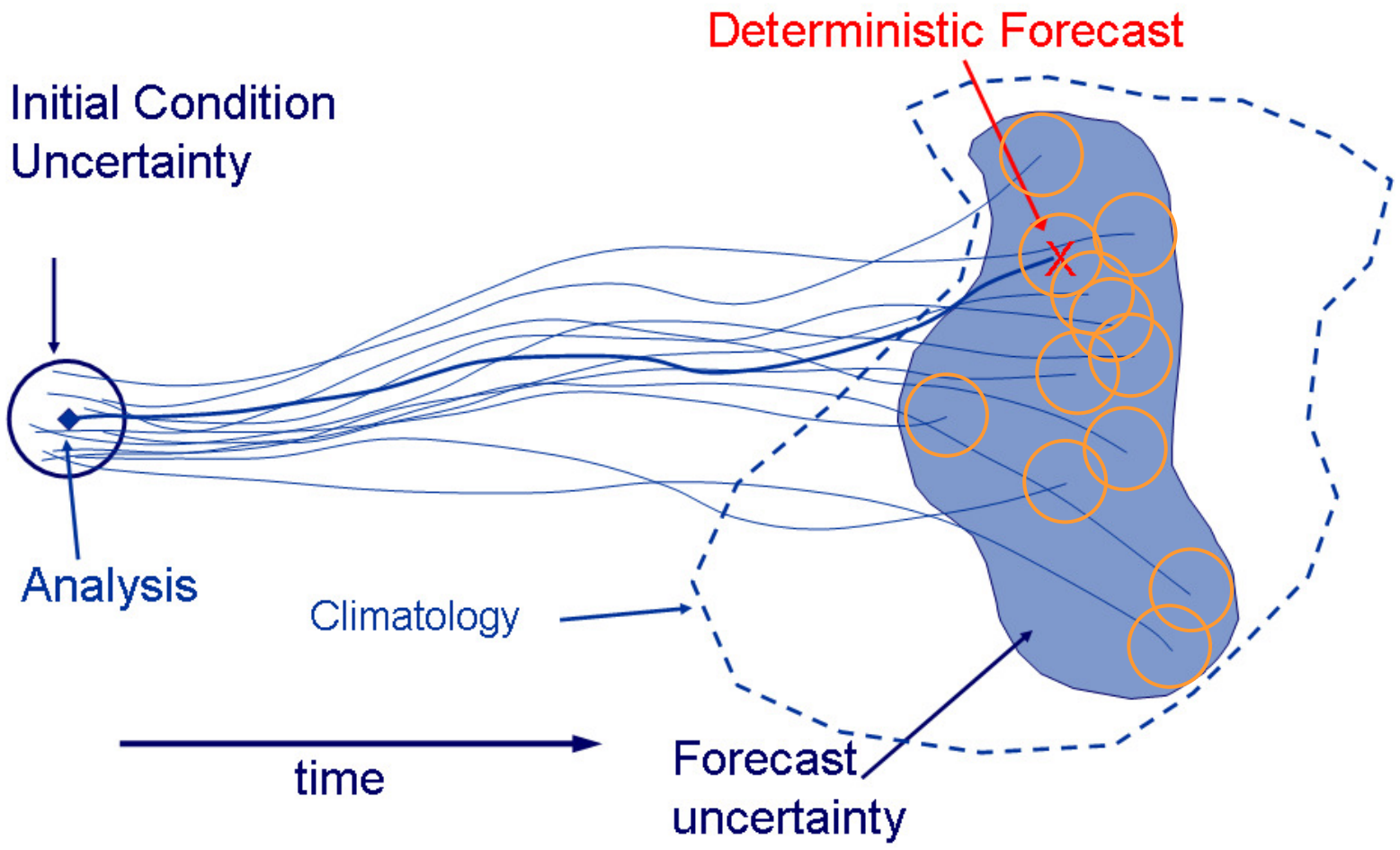
Probability at **X** = 2/9 = 22%

A deterministic forecast becomes a 9-member ensemble

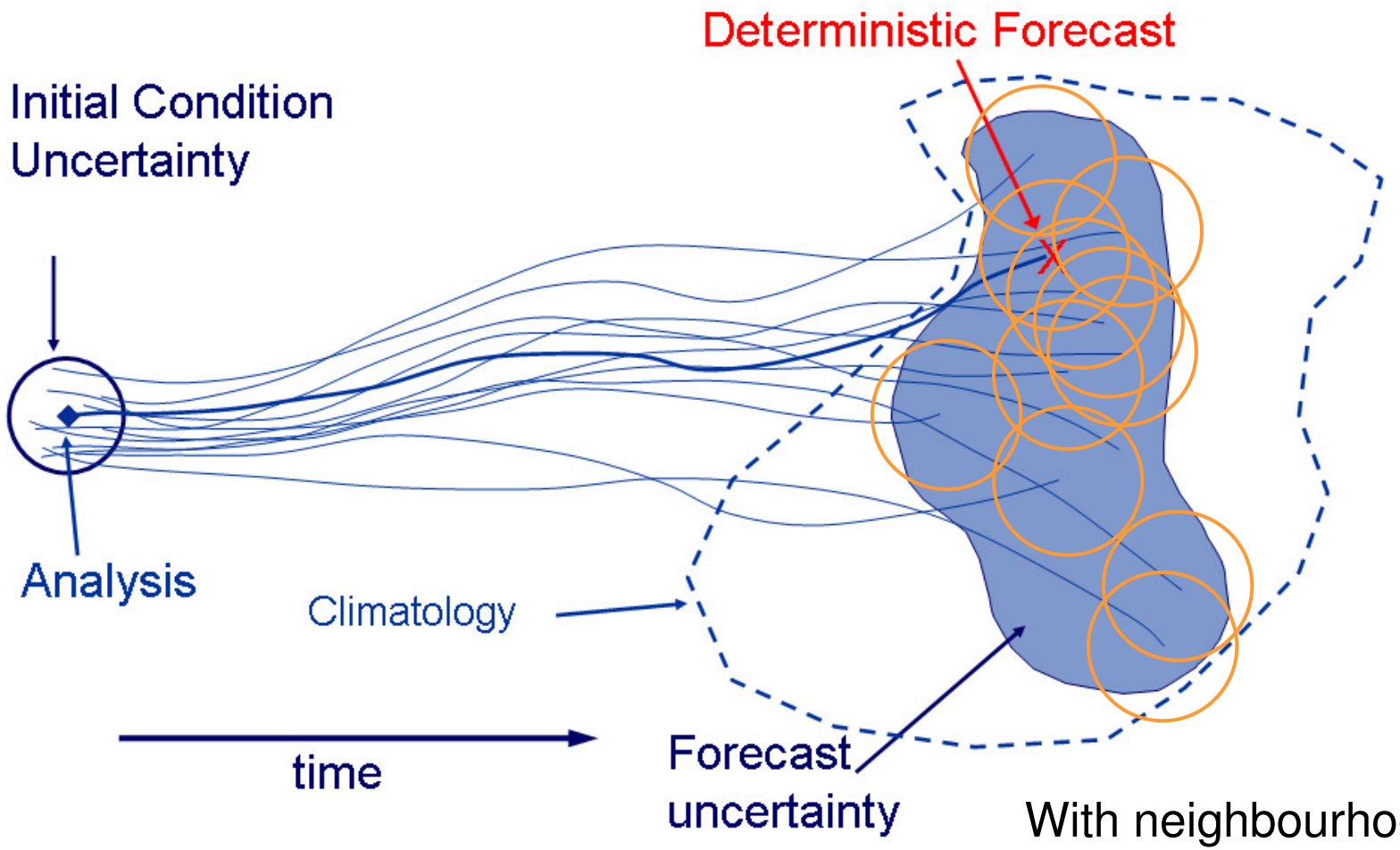
A 9x9 neighbourhood and 12-member ensemble = 972 members

Not independent members – but justifiable for unpredictable scales

Ensemble NWP forecast
with a neighbourhood

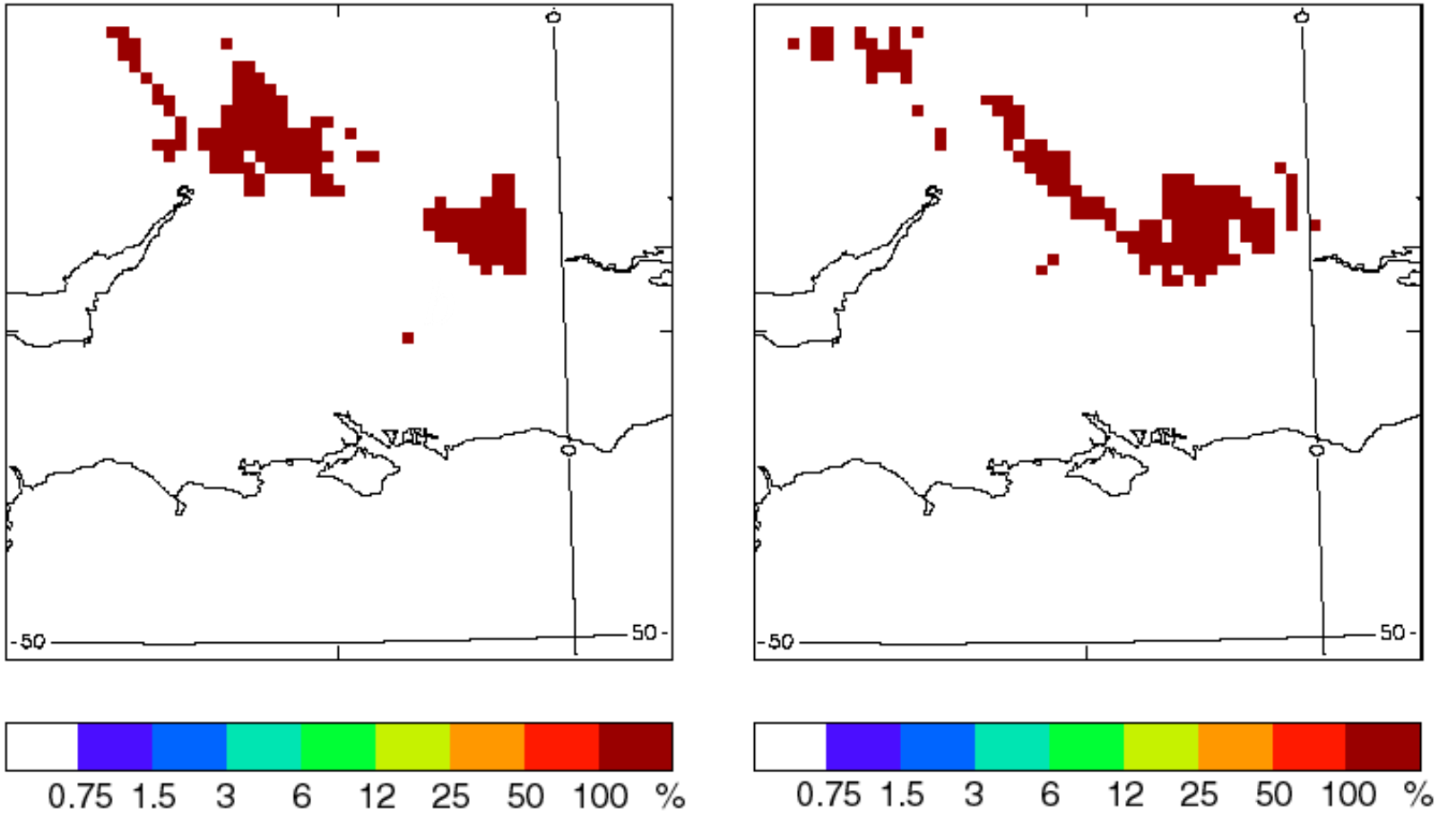


Ensemble NWP forecast
with a bigger neighbourhood!

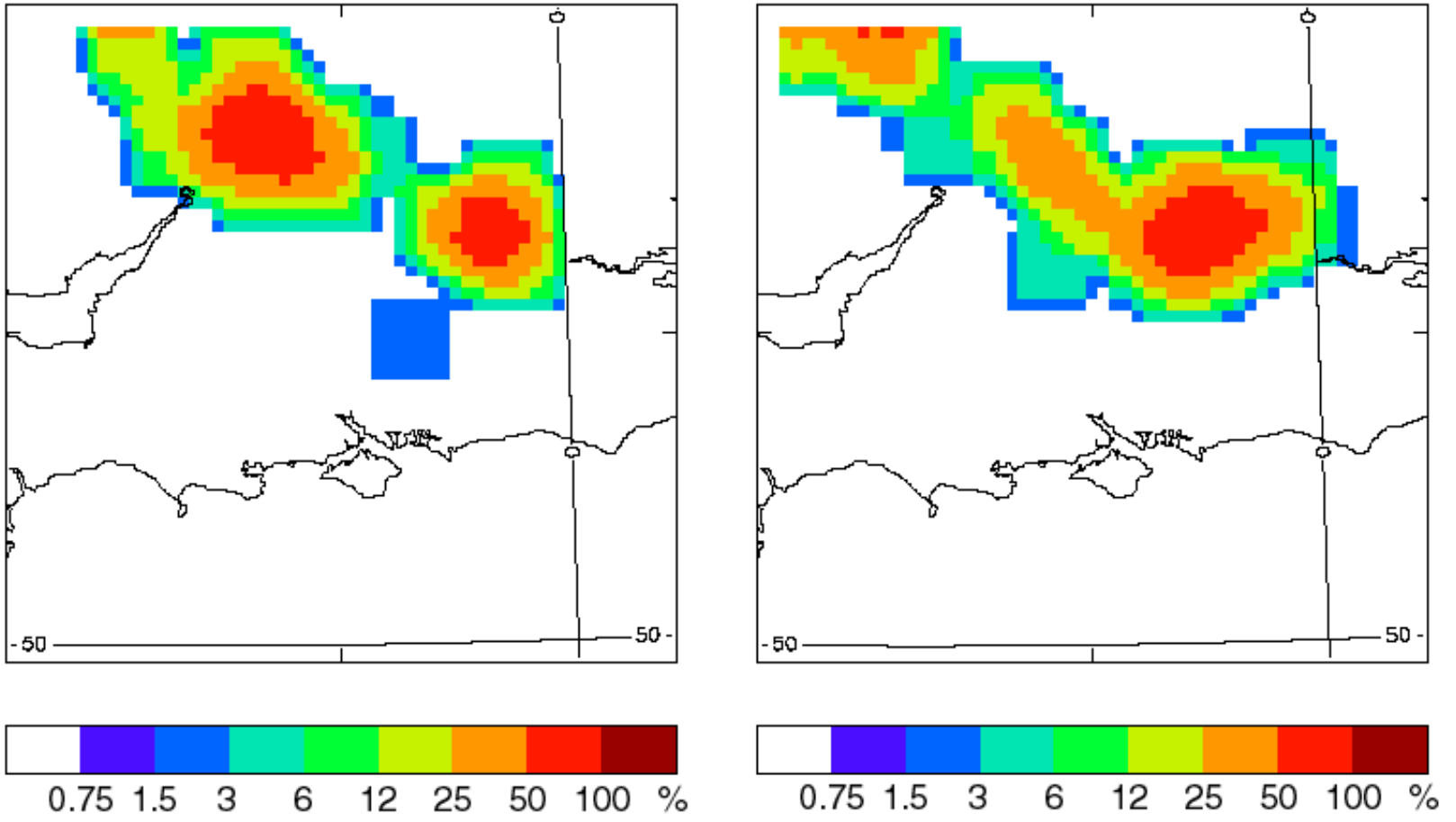


With neighbourhoods size matters !

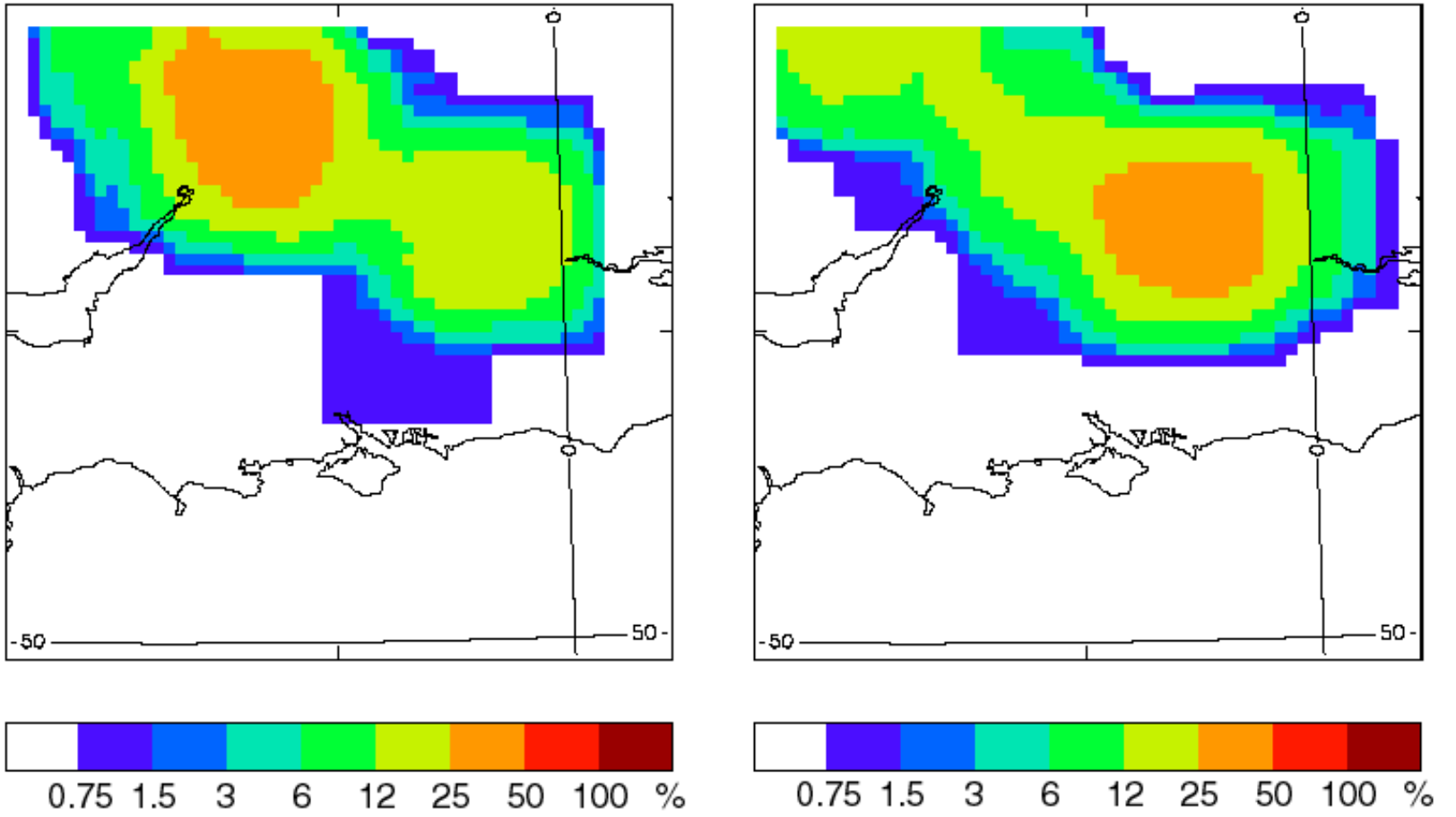
Effect of neighbourhood processing



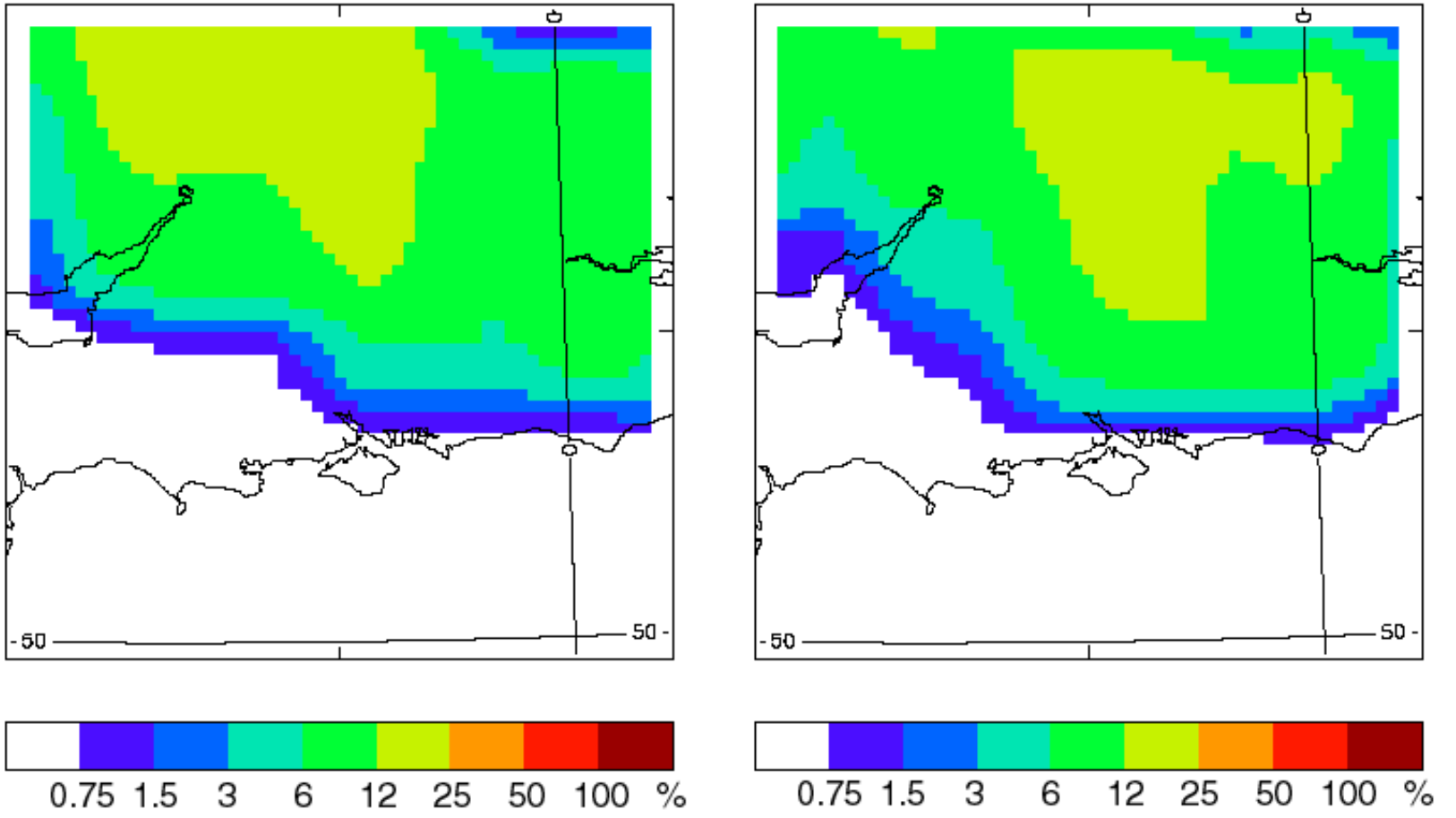
Effect of neighbourhood processing



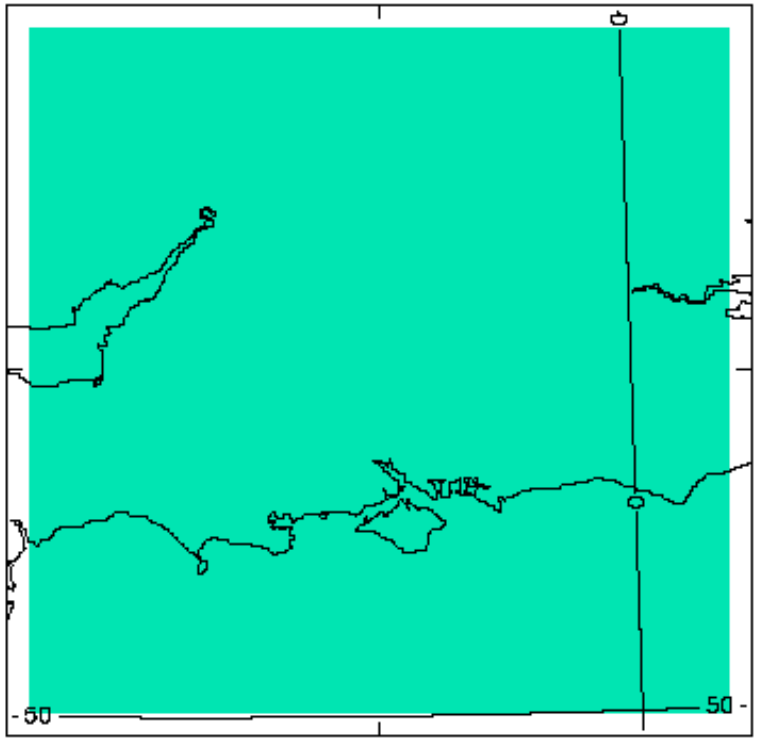
Effect of neighbourhood processing

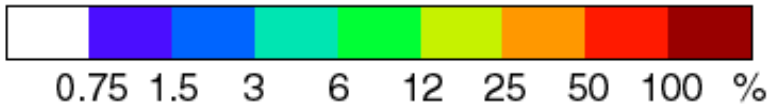


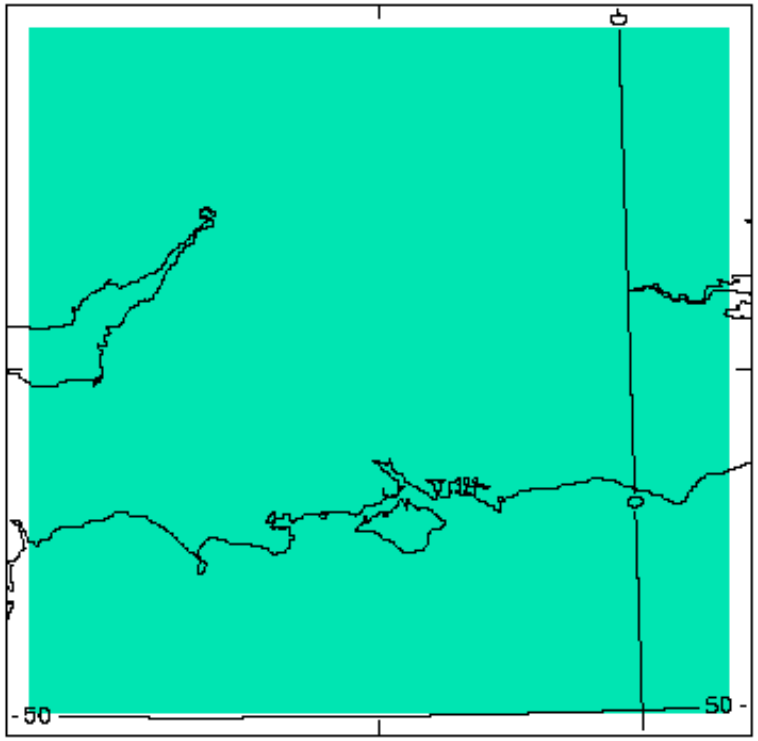
Effect of neighbourhood processing

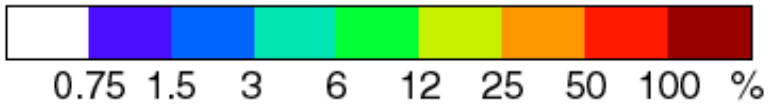


Effect of neighbourhood processing









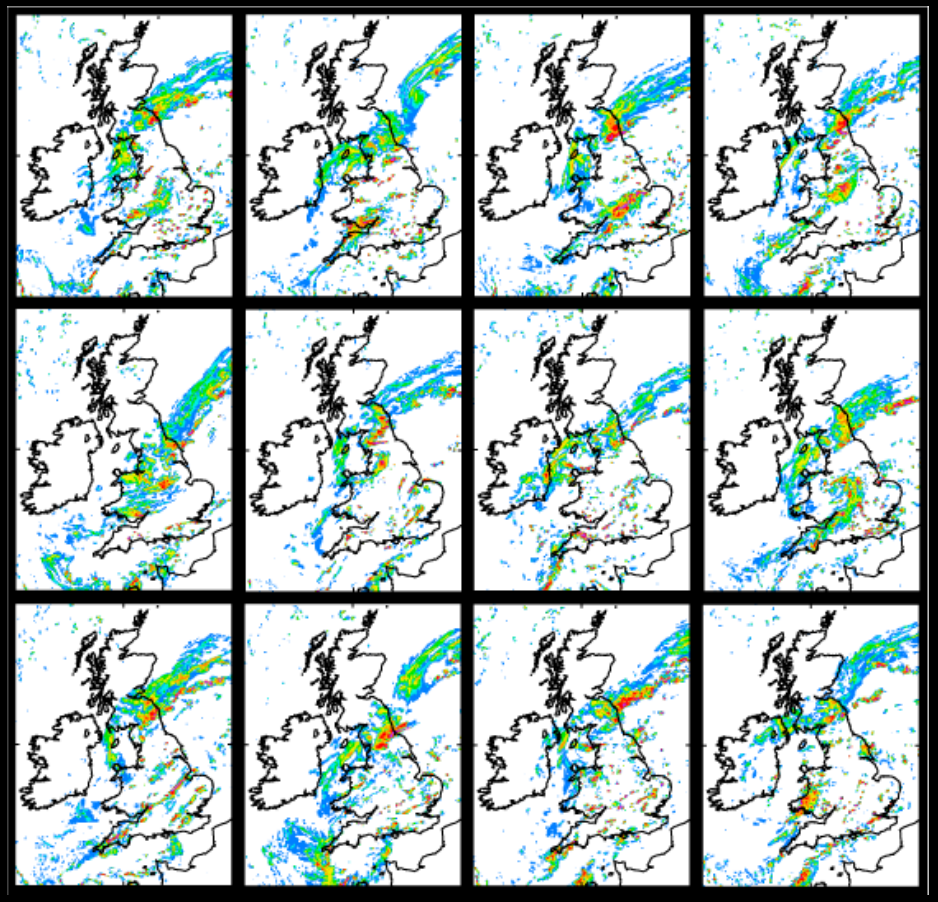
MOGREPS-UK
Neighbourhood processing

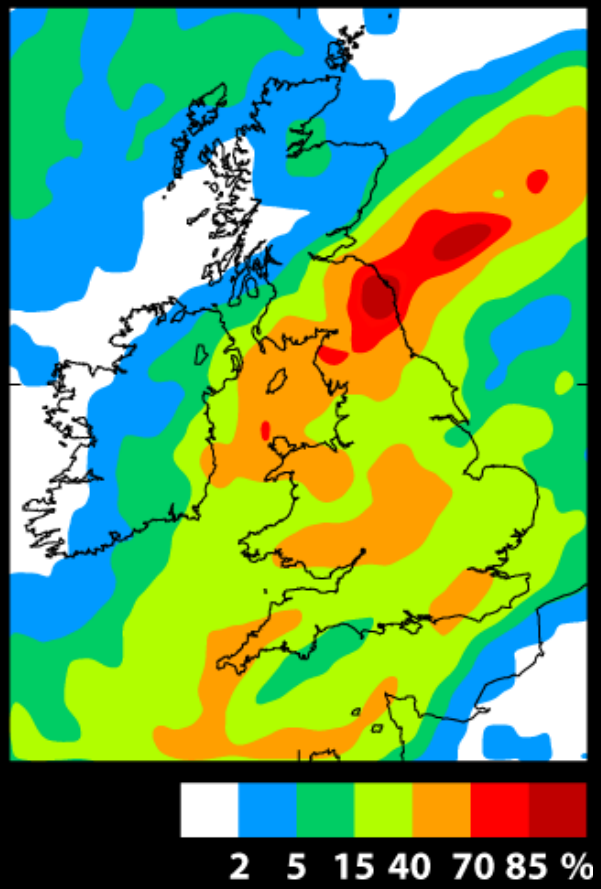
1. Fuzzy thresholds
   - A rainfall rate of 3.9mm/hr does not mean there is no chance of exceeding 4.0mm/hr.
2. Time windowing
   - Takes account of temporal errors. For example, due to the initiation and decay of rain at the wrong times.
3. Apply neighbourhood to each member
   - Generate a probability for the centre grid point by calculating how many grid points in the neighbourhood exceed the (fuzzy) threshold.
4. Calculate ensemble mean neighbourhood
5. Apply recursive filter to smooth out probability field
   - Makes probabilities look more Gaussian
   - Makes square neighbourhoods become more “circular”

With Neighbourhood processing: MOGREPS-UK (12 members)

Met Office

Creation of probability of rain product





Zero-probability “holes” filled in
& No spurious detail

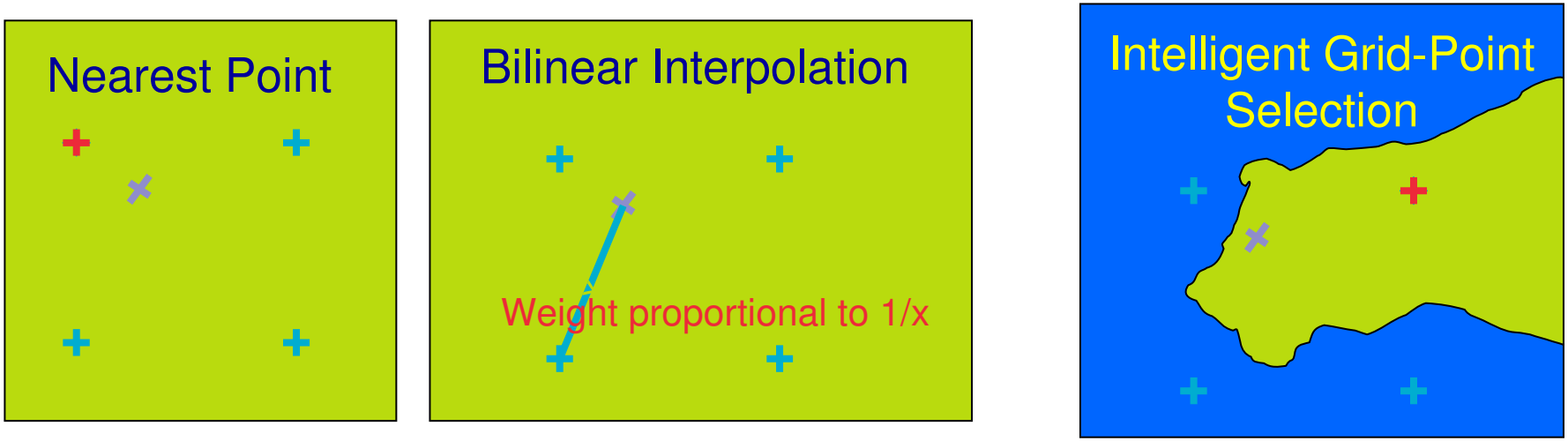
Site-specific post-processing

Site-specific post-processing

- 6500 UK sites:
  - Population centres
  - Sporting venues
  - Tourist attractions
  - Customers' sites
- ~6500 world-wide sites

Site-specific post-processing

Interpolation to site



(Either post-processed or raw model forecasts)

Kalman Filter to improve at observation sites

BestData
Concept

- Generic site-specific forecast data
- Makes ‘best’ use of our operational models
- Updated regularly (hourly)
- Includes deterministic and ensemble model data
  - A single ‘best’ value and, where appropriate, a set of percentiles

BestData
Combining data

- Between longest forecast horizon (T+360) and T+0 there are
  - 30 MOGREPS-15 runs
  - 30 EC-ensemble runs
  - 20 ECMWF-deterministic runs
  - 14 Global runs
  - 19 Euro4 runs
  - 10 MOGREPS-G runs
  - 12 UKV runs
  - 6 MOGREPS-UK runs
  - 6 nowcasts
- For any given forecast horizon, want to make good use of available models
  - But, don't want to keep all of these on-line in order to create a multi-model ensemble, so …

BestData

Building ‘the Blend’

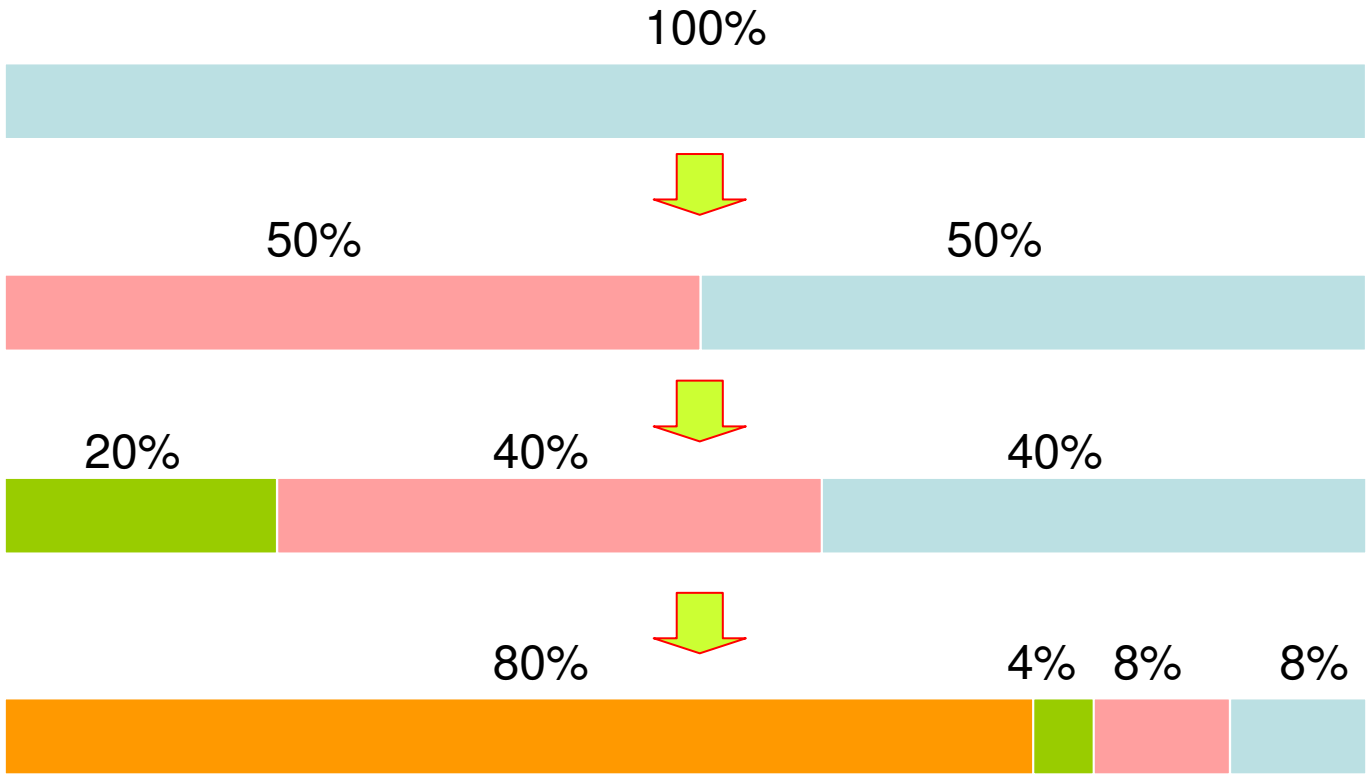
Start with a single model

Add a model with the same weighting

Add another model with a lower weighting

And another with a much higher weighting

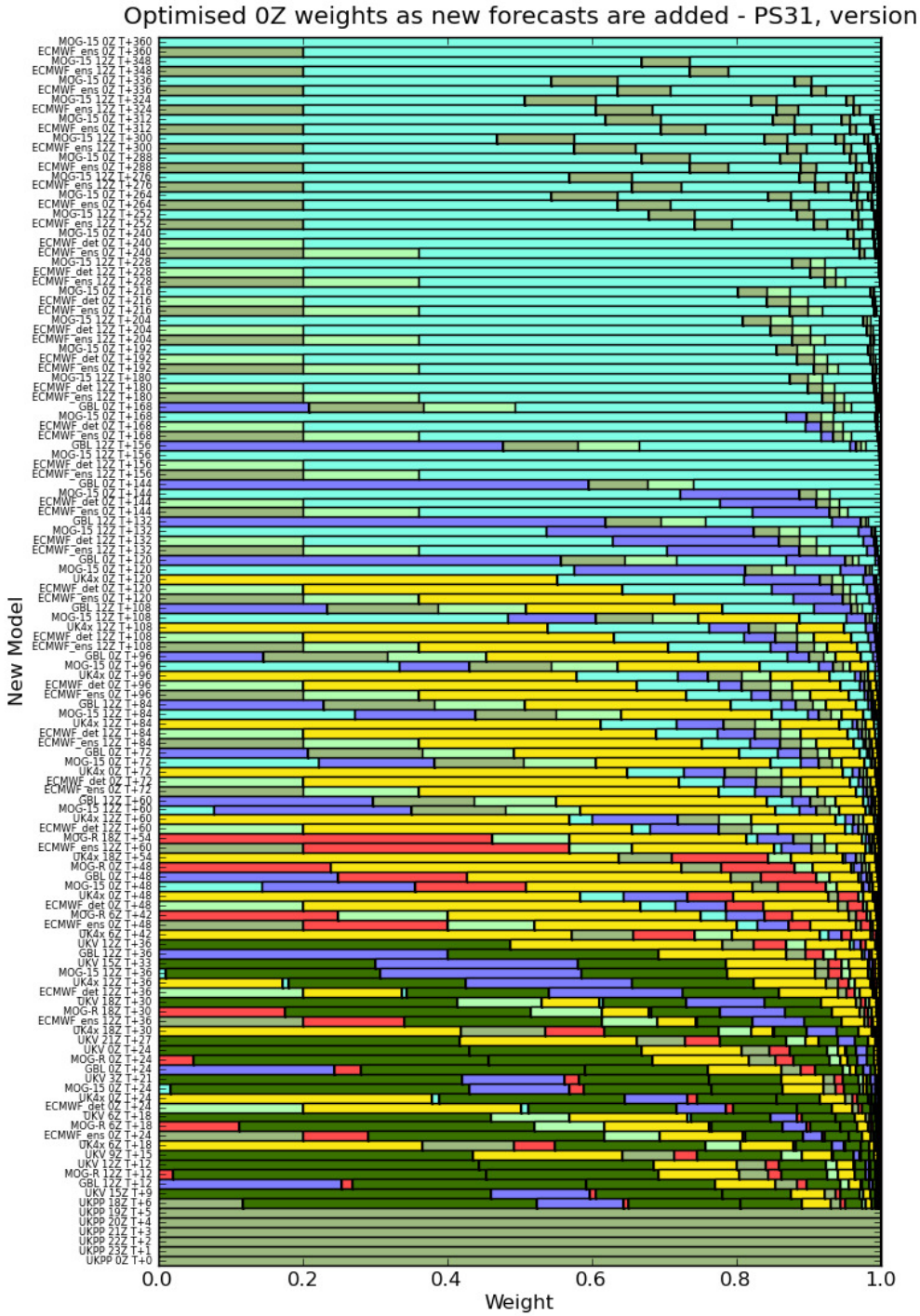
etc



- Weights for each model and lead-time optimised to reduce overall error
- Percentiles derived from ensembles are blended in the same way

BestData

What the Blending weights look like as new forecasts are added



Towards ‘Best Gridded Data’

Best Gridded Data

Covers a number of aspects

Standardisation

(technology-focus)

Greater exploitation of ensembles

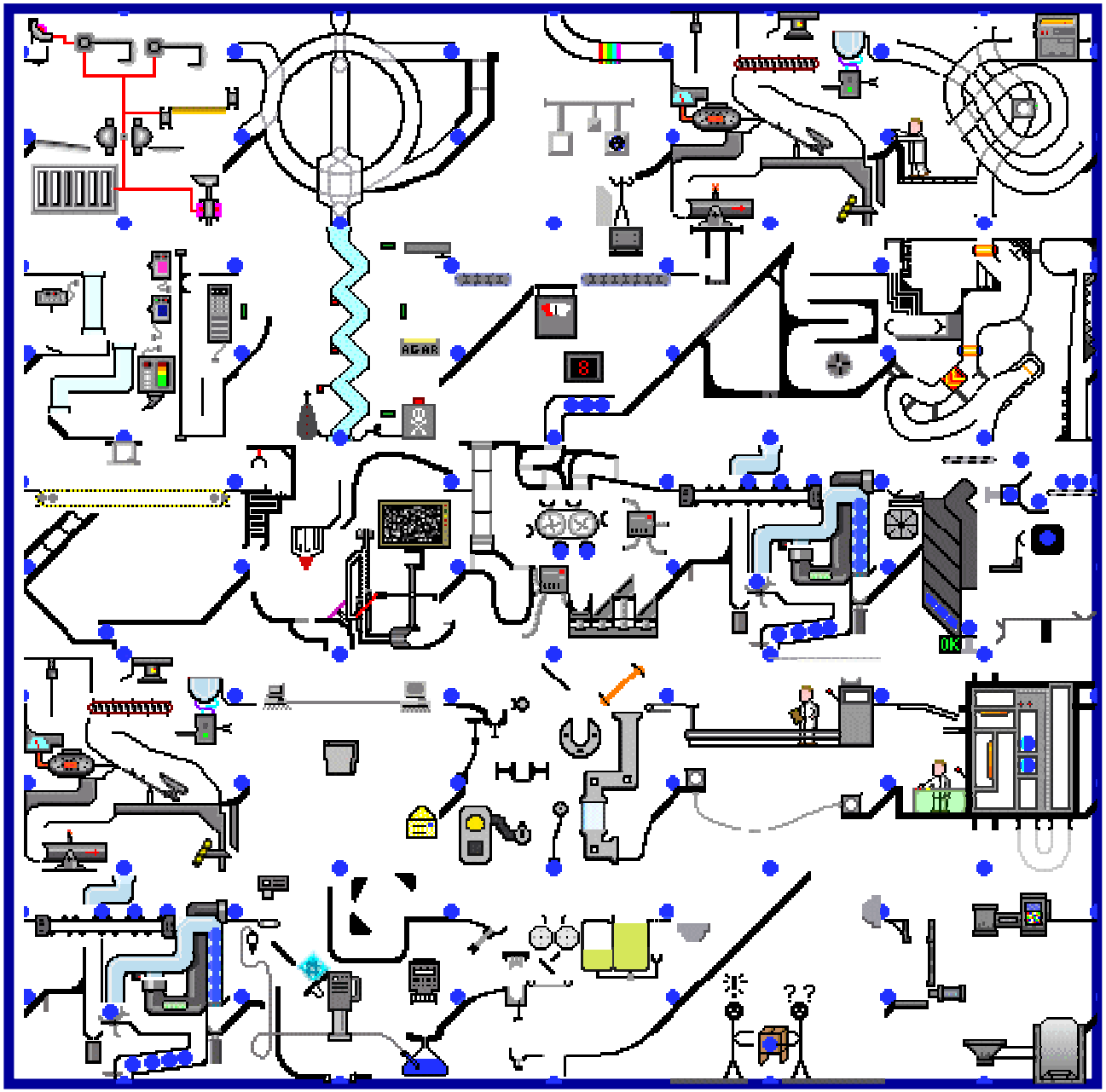
(science-focus)

Gridded version of ‘BestData’

(science-focus)

Why standardisation?

Because currently post-processing looks rather like …



Standard forecast information
model-independence

NWP model-specific forecast information	Standard Forecast Information	User-specific forecast information

Break the direct link between:

- NWP model
- Customer products & services

Provide a controlled bridge between producer and customer, to ensure:

- A change to one does not effect other
  (i.e. no costs incurred away from the change)
- Customers receive data in the right form

Standard diagnostics

Standard, rationalised list of diagnostics across all gridded data products

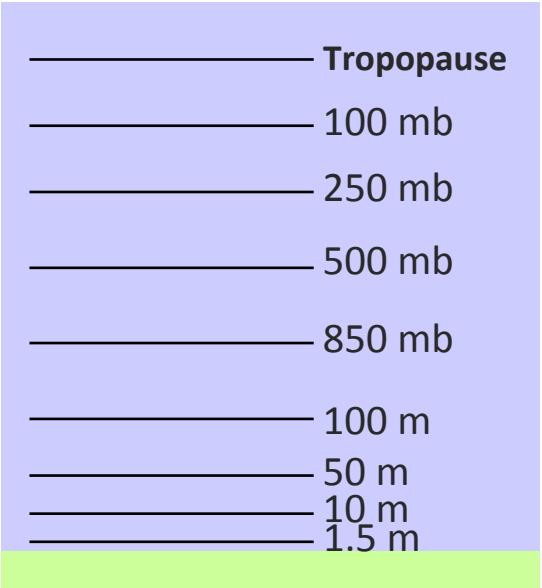
air_pressure wind_speed relative_humidity air_temperature cloud_

e.g. provide relative humidity rather than specific humidity or humidity mixing ratio

Standard levels

Same sets of levels across all products

Do not expose data on model levels



Special levels, if required

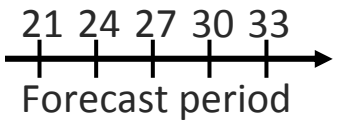
Pressure for higher levels

Height above orography within boundary layer

Standard time frequencies

All standard diagnostics out to 5 days ahead

Smaller core set of standard diagnostics out to 15 days ahead



Standard time intervals

Standard Processing

standard
triggering

standard
software

single
process

standard
delivery

standard
languages

modular
process

standard
packaging

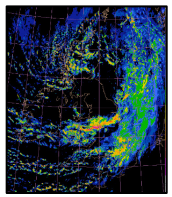
standard
libraries

standard
formats

Comprehensive metadata

document and catalogue the data

Data **Items**



- fully described
- single standard diagnostics
- standard grid & level (or set of levels)
- standard set of times

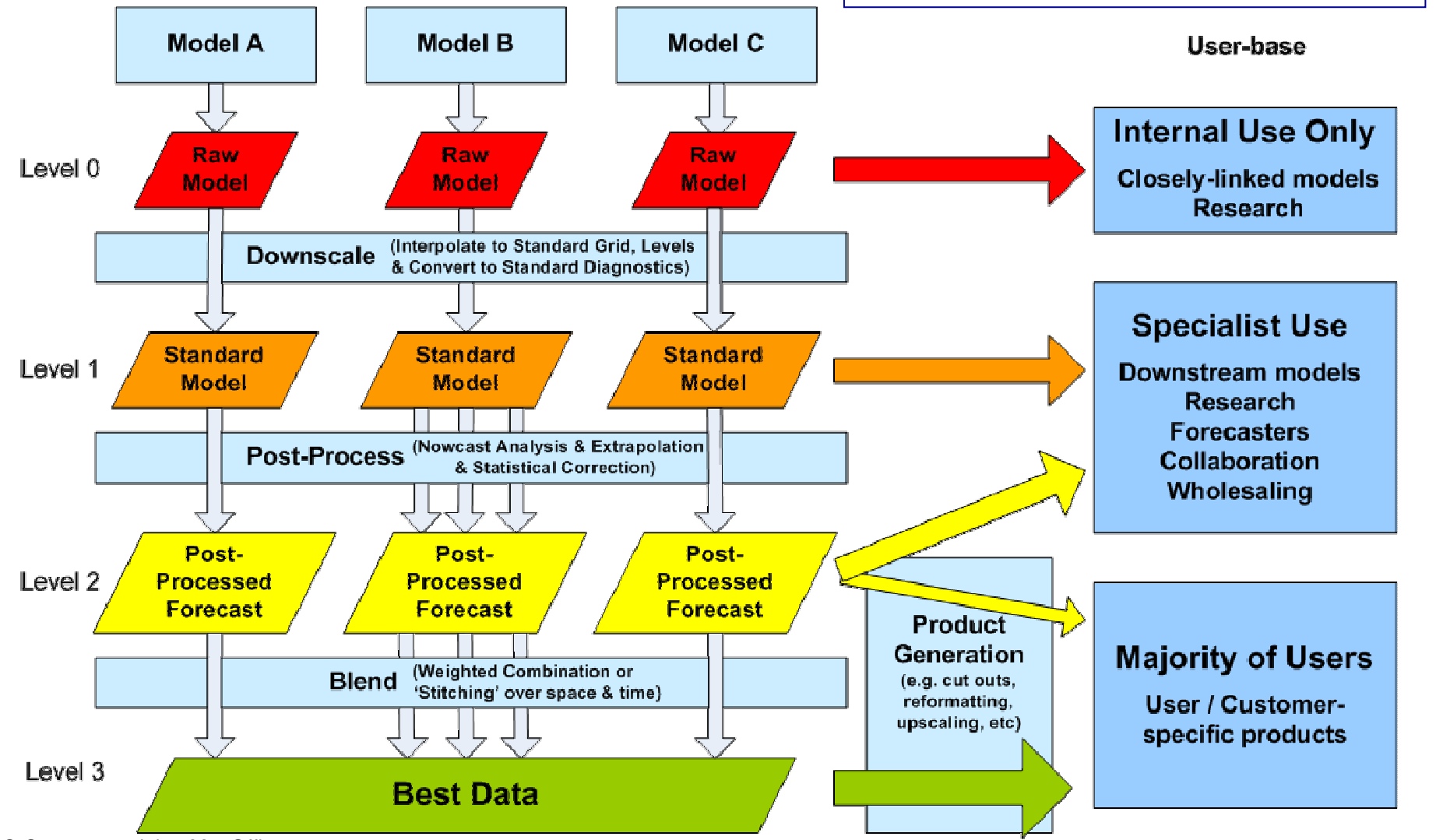
Data **Catalogue**

- covers all data

Processing framework

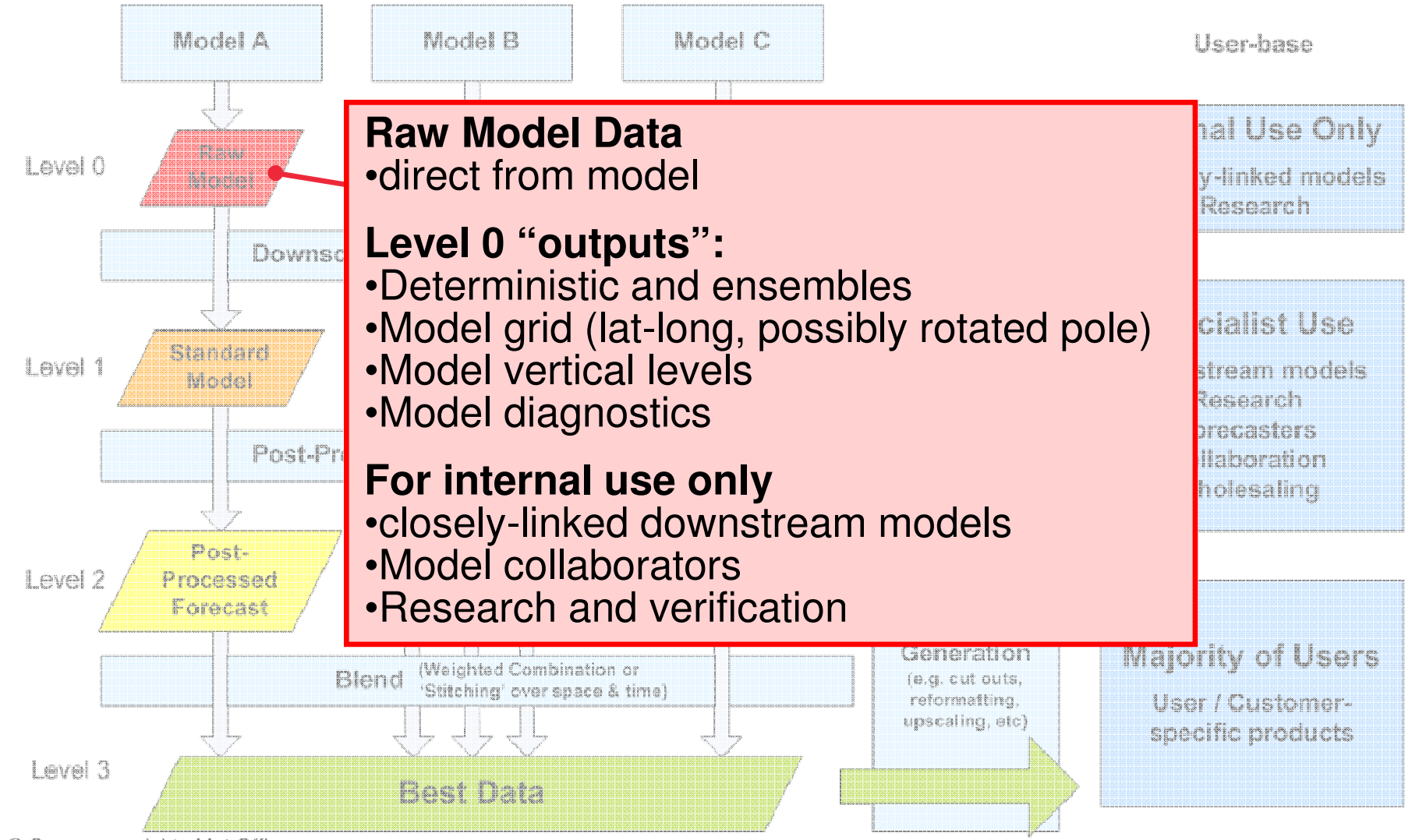
data processing levels

Use to define level of processing applied & appropriate usage



Processing framework

level 0: raw model



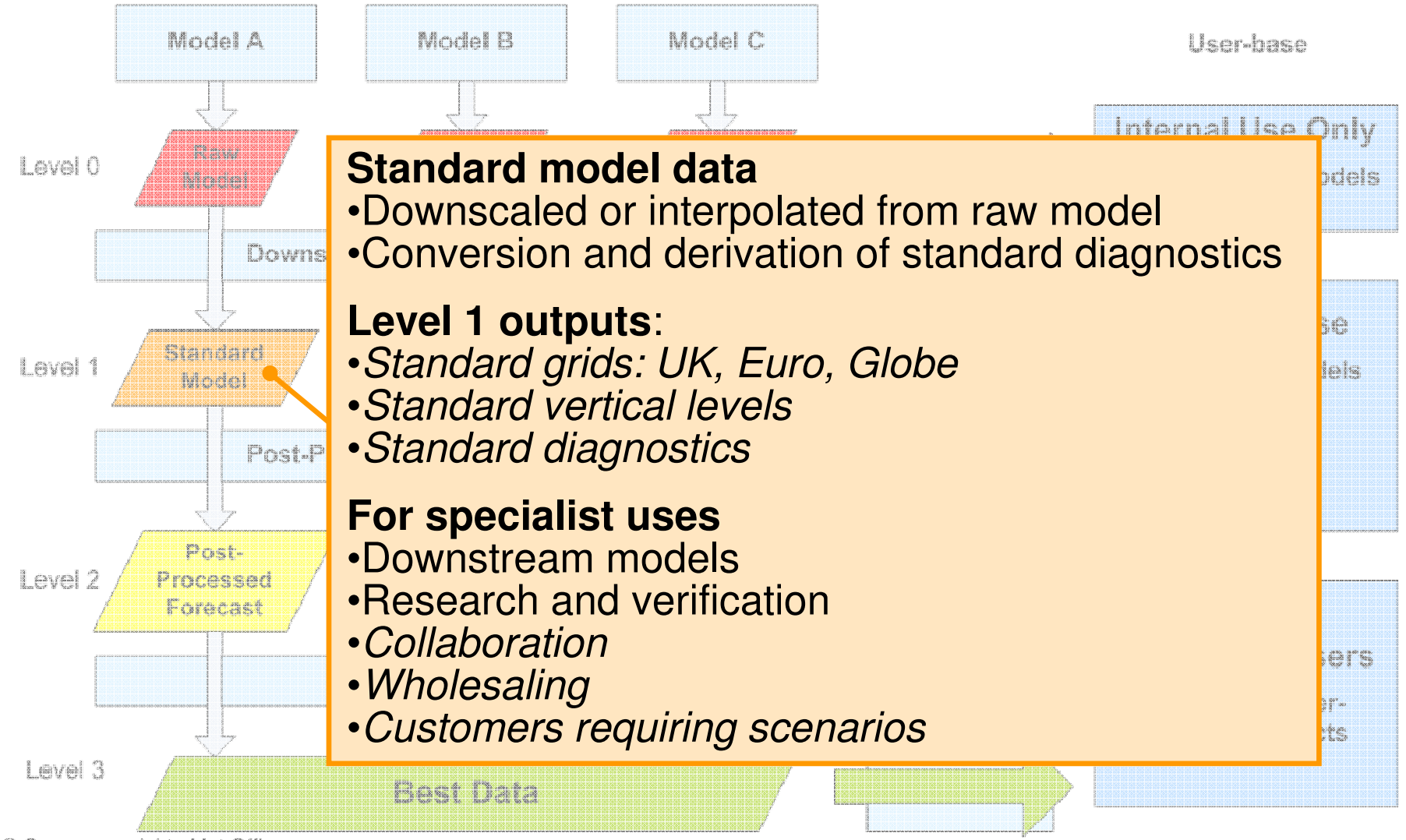
Raw Model Data
- direct from model

Level 0 "outputs":
- Deterministic and ensembles
- Model grid (lat-long, possibly rotated pole)
- Model vertical levels
- Model diagnostics

For internal use only
- closely-linked downstream models
- Model collaborators
- Research and verification

Processing framework

level 1: model in standard form



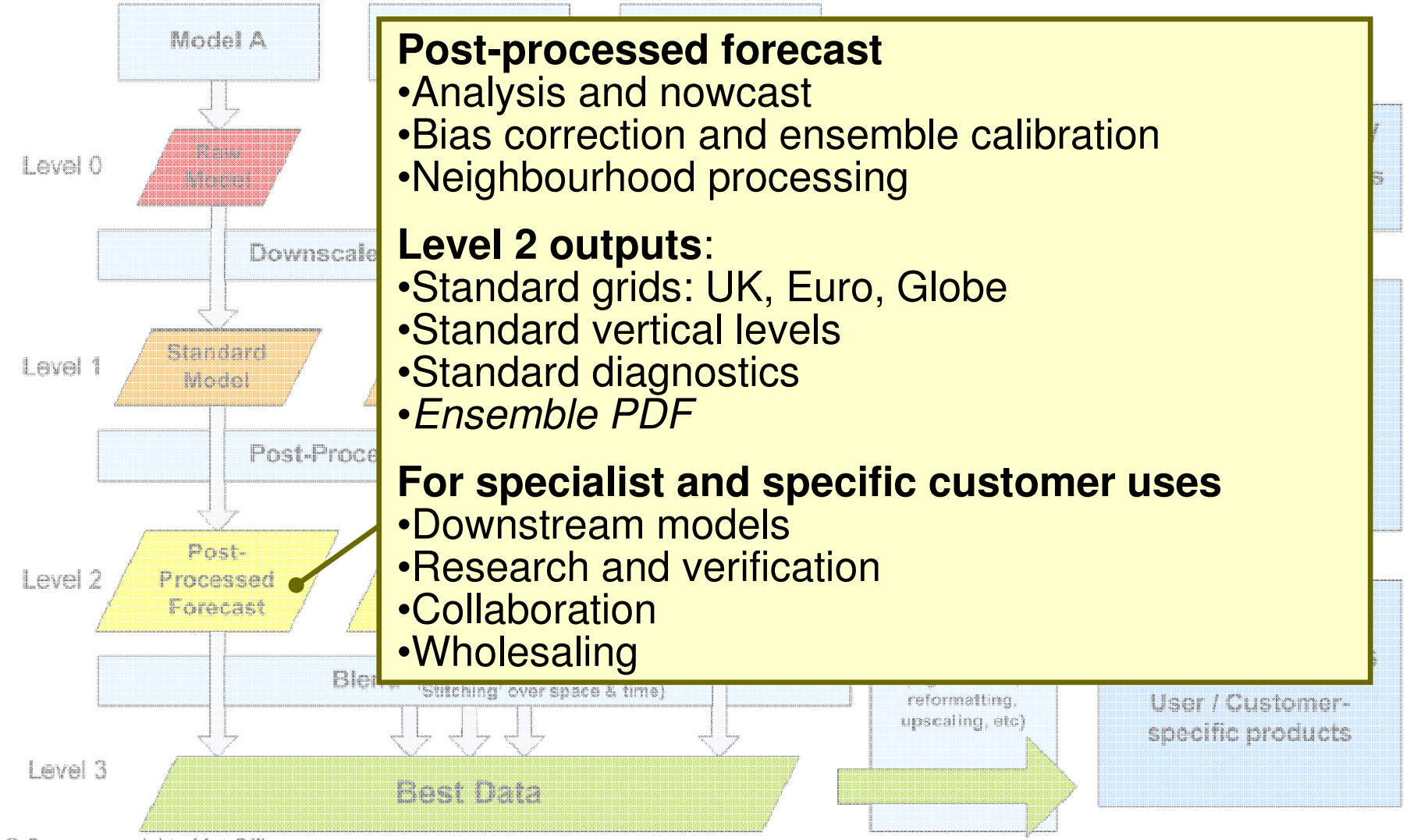
Standard model data
- Downscaled or interpolated from raw model
- Conversion and derivation of standard diagnostics

Level 1 outputs:
- *Standard grids: UK, Euro, Globe*
- *Standard vertical levels*
- *Standard diagnostics*

For specialist uses
- Downstream models
- Research and verification
- *Collaboration*
- *Wholesaling*
- *Customers requiring scenarios*

Processing framework

level 2: post-processed



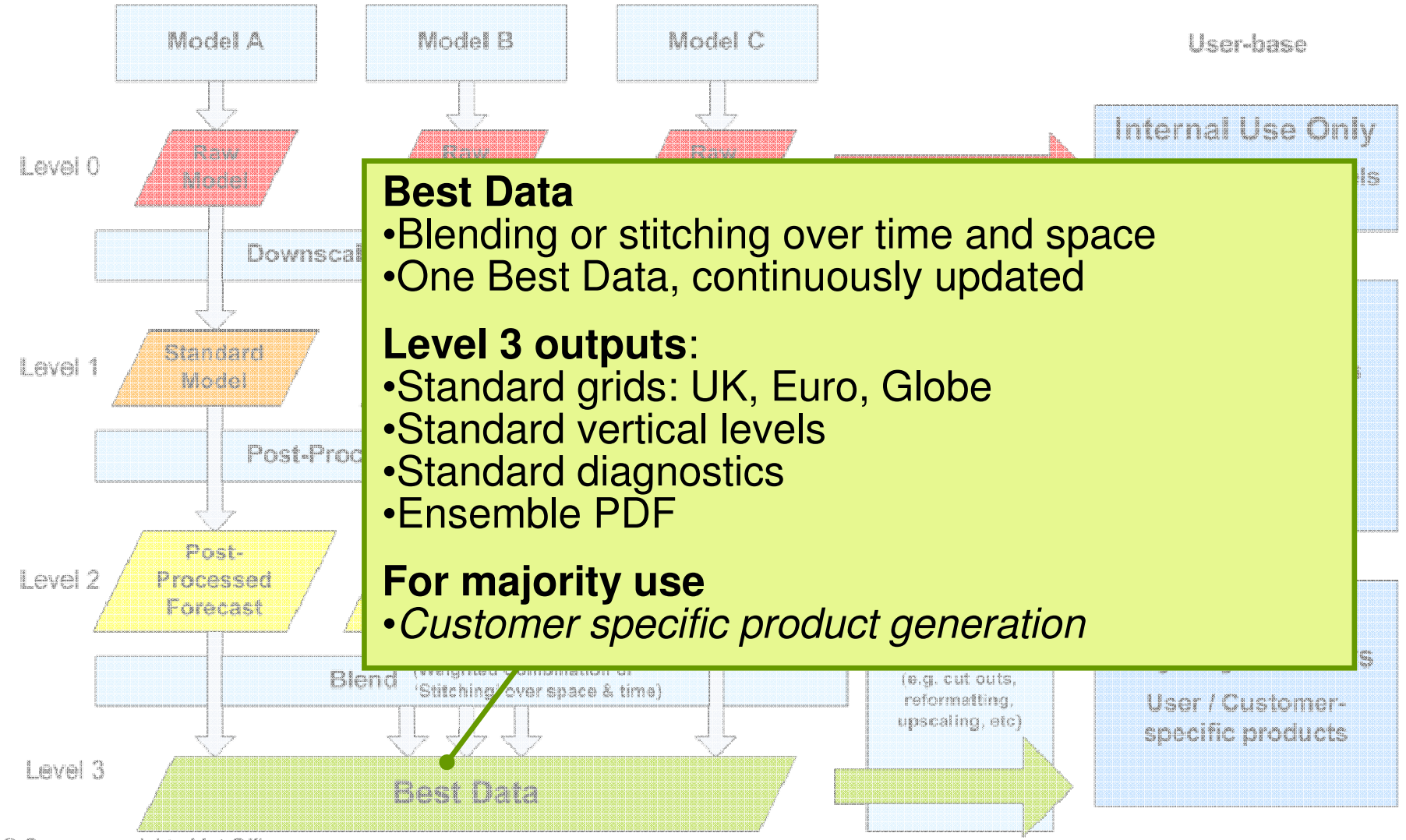
Post-processed forecast
- Analysis and nowcast
- Bias correction and ensemble calibration
- Neighbourhood processing

Level 2 outputs:
- Standard grids: UK, Euro, Globe
- Standard vertical levels
- Standard diagnostics
- *Ensemble PDF*

For specialist and specific customer uses
- Downstream models
- Research and verification
- Collaboration
- Wholesaling

Processing framework

level 3: ‘best data’



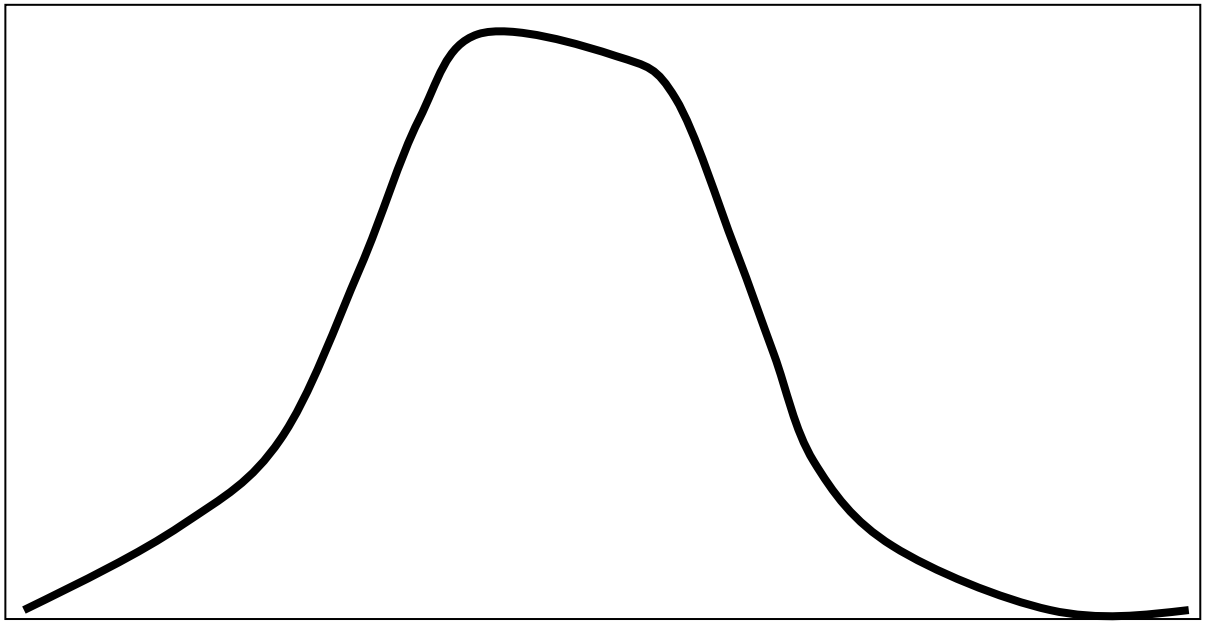
Best Data
- Blending or stitching over time and space
- One Best Data, continuously updated

Level 3 outputs:
- Standard grids: UK, Euro, Globe
- Standard vertical levels
- Standard diagnostics
- Ensemble PDF

For majority use
- *Customer specific product generation*

Greater use of ensembles

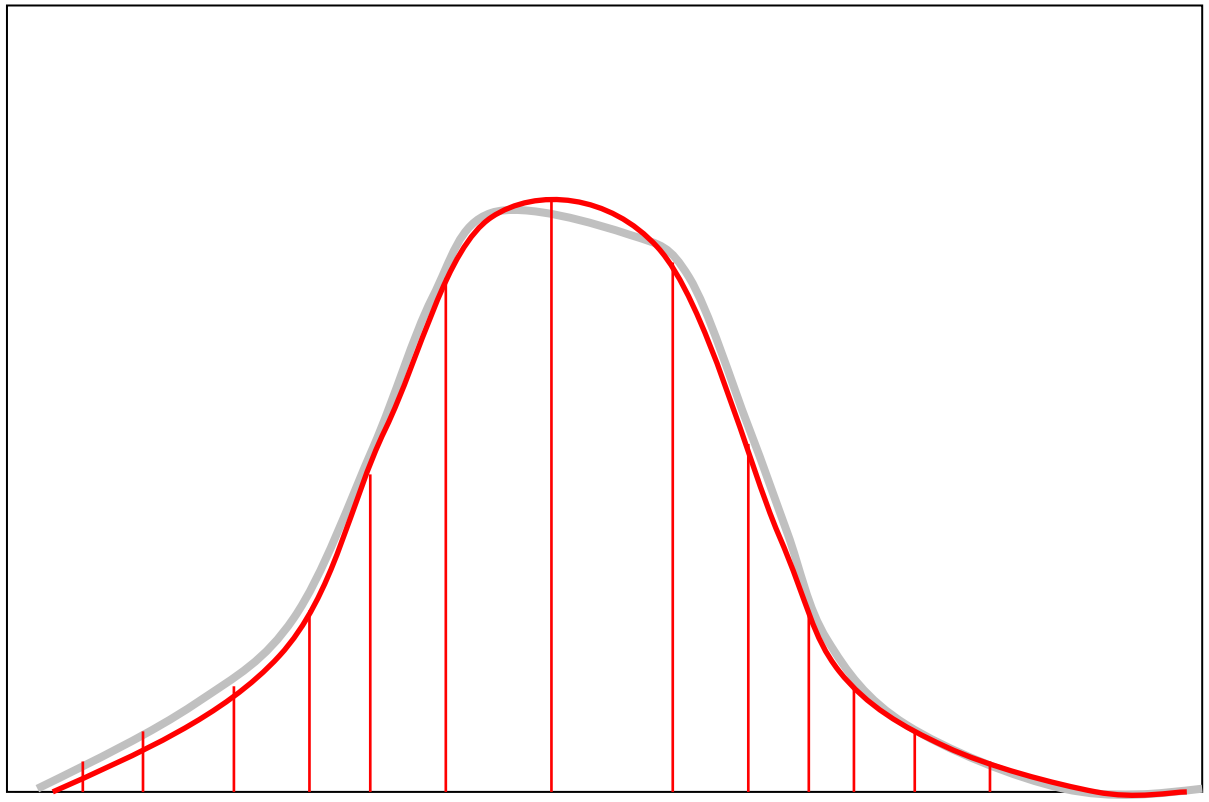
- Ensembles are…
  - Not just supplementary
  - Essential for quantifying forecast uncertainty
- Paradigm shift to use of uncertainty
  - Central to Best Gridded Data
  - Describe using Probability Density Function



An ensemble PDF

Good description

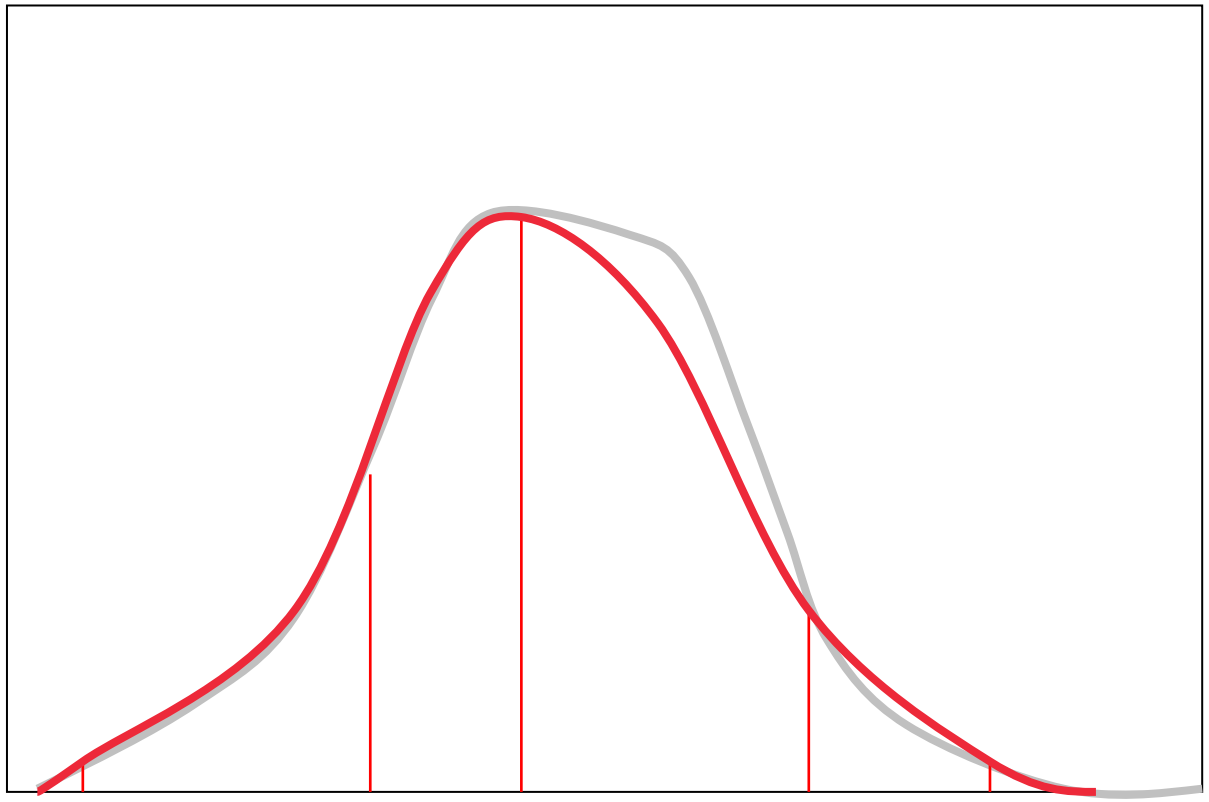
- 13 percentiles: 5%, 10% 20% 25%, 30%, 40%, 50%, 60%, 70%, 75%, 80%, 90%, 95%
- Lower and upper bounds
- Mean
- Mode
- Standard deviation



An ensemble PDF

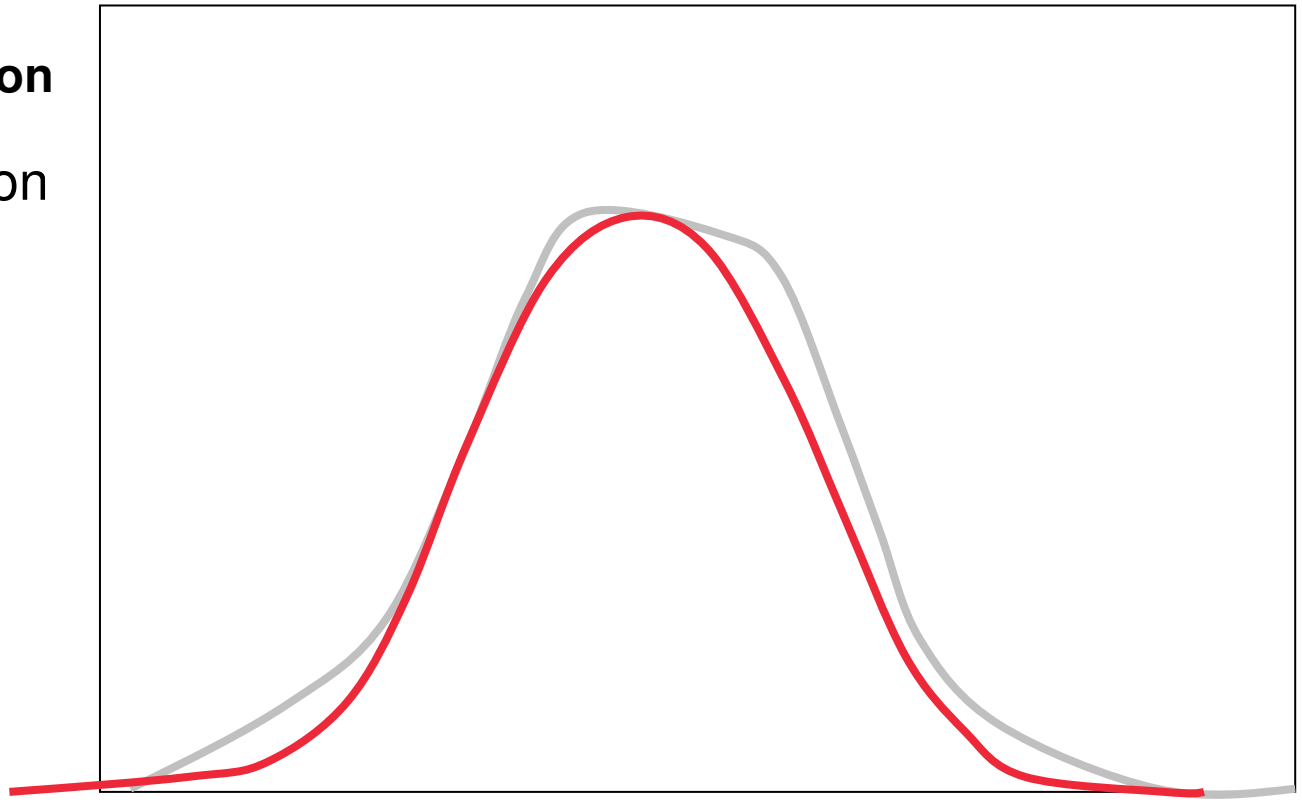
Reasonable description

- 5 percentiles: 5%, 25%, 50%, 75%, 95%
- Mean
- Standard deviation



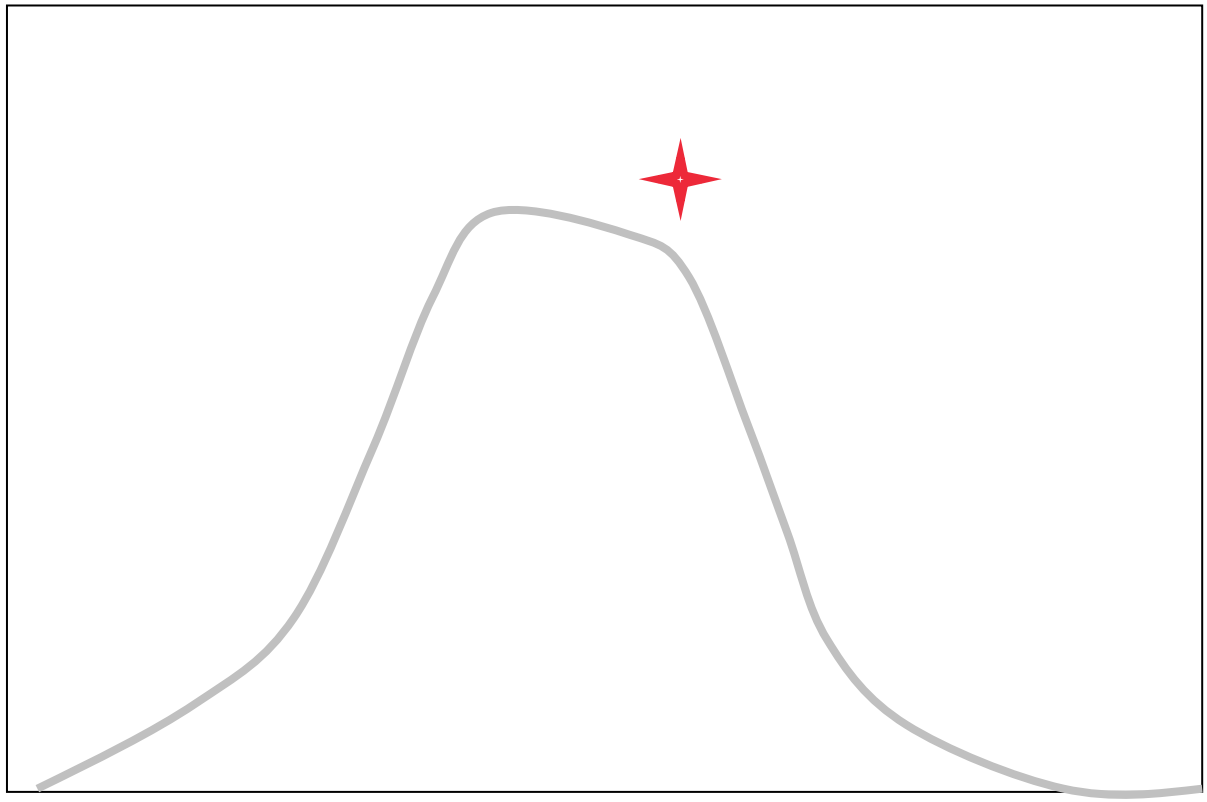
An ensemble PDF

Minimum description
- Mean
- Standard deviation



An ensemble PDF

Single description
- Mean



- No estimate of the uncertainty
- Can represent a deterministic forecast

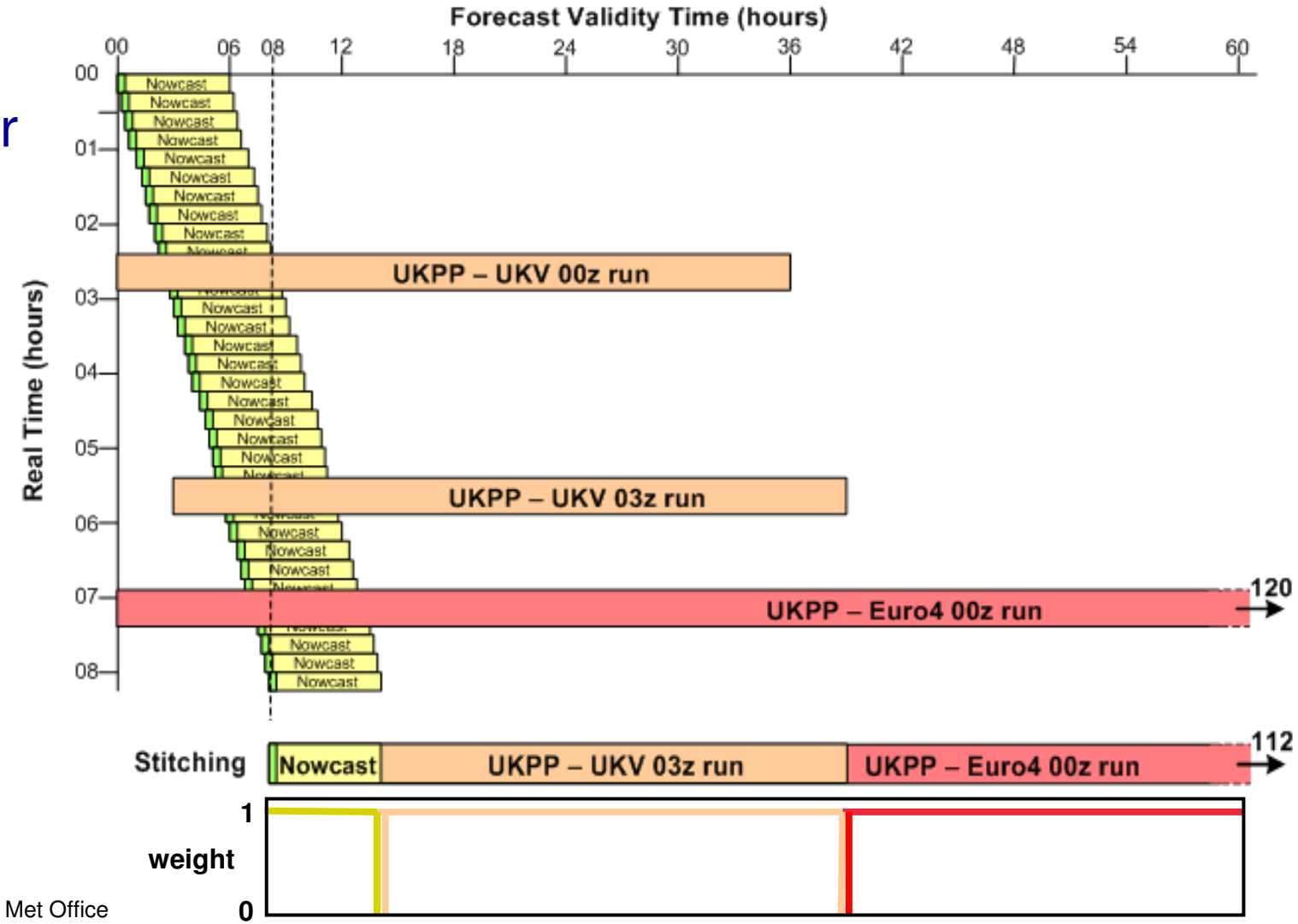
Extending BestData to Grids

- No single forecast is the best everywhere and “everywhen”©
- Combine many forecasts to get best single forecast (on average)
- Could use ‘Stitching’ or ‘Blending’
- Need to be careful with covariant diagnostics!

Best Gridded Data

More issues due to spatial consistency

'Stitching or blending?

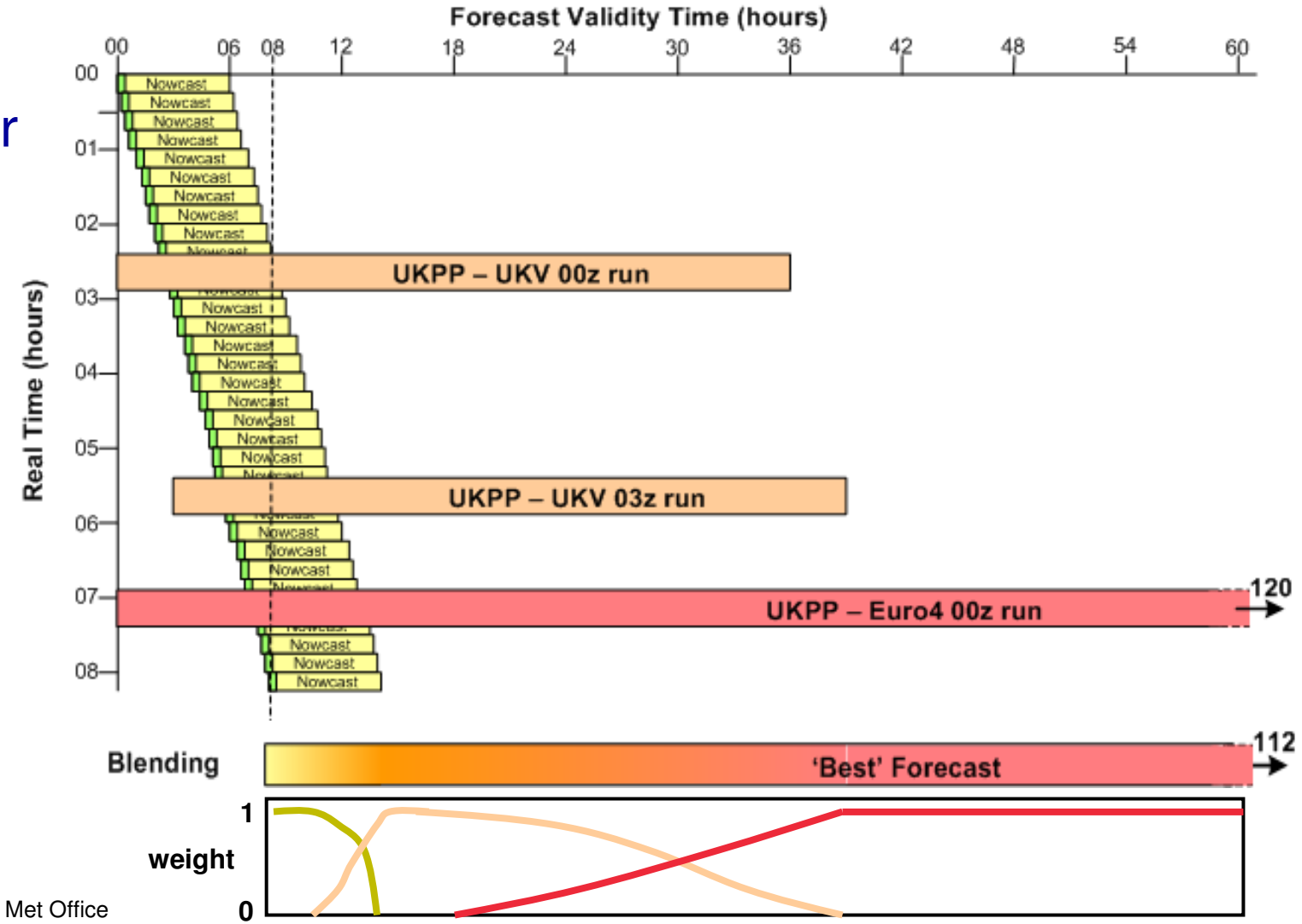


Best Gridded Data

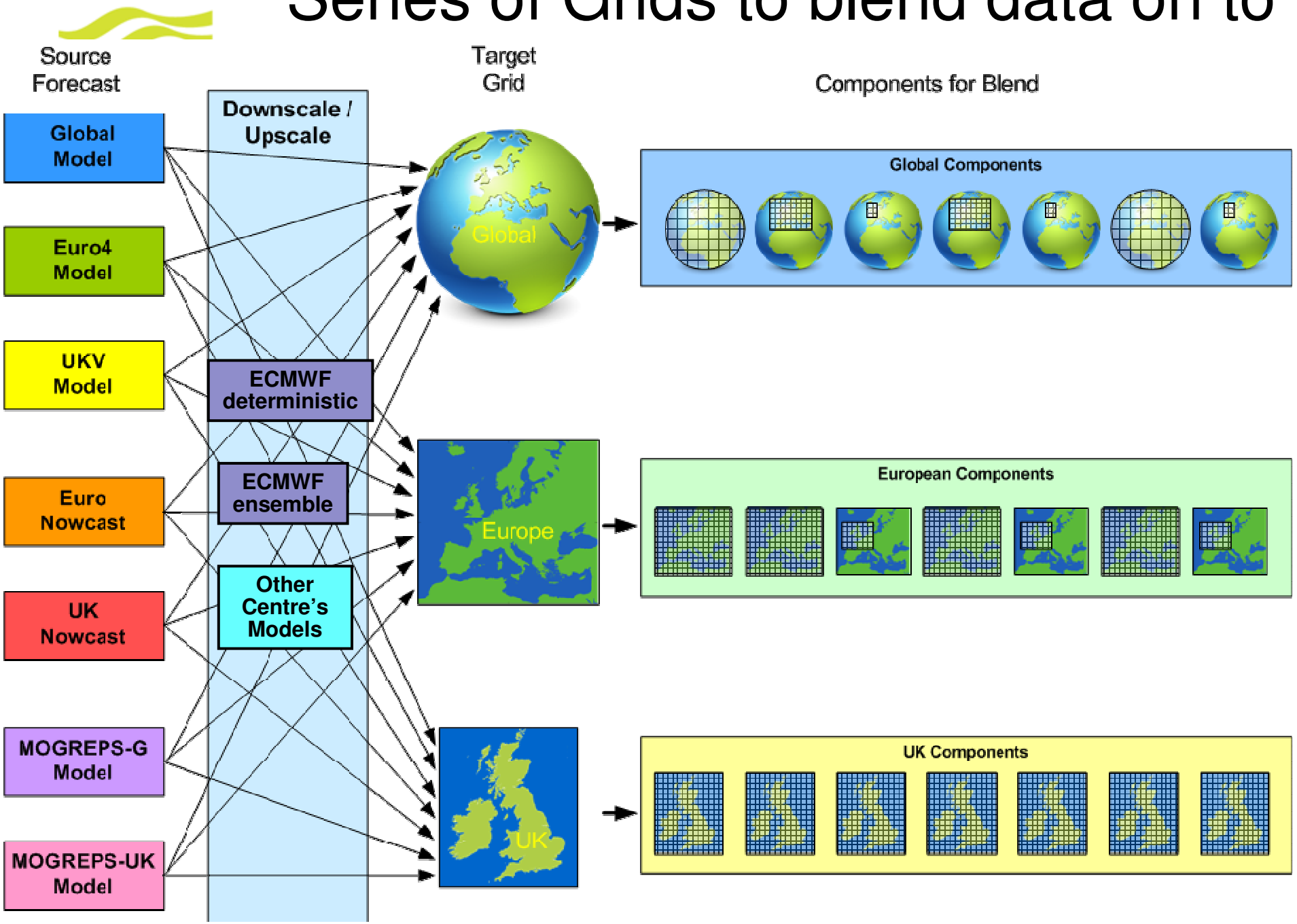
More issues due to spatial consistency

‘Stitching or blending?

Also in Space!



Series of Grids to blend data on to



Summary

Summary

- Have a comprehensive post-processing suite
  - Gridded downscaling & nowcasts (inc. STEPS)
  - Site-specific, with Kalman Filtering & BestData
  - Some exploitation of ensembles
- Moving to make Ensembles the key forecast tool, rather than the deterministic forecasts
  - Improved calibration & statistical correction
  - Neighbourhood processing
- Development of ‘Best Gridded Data’:
  - Standard processing
  - Gridded version of ‘BestData’

Questions?

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