



# Ensemble applications and integration with deterministic post-processing

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**Thanks to** Caroline Jones, Rob Neal, Piers Buchanan, Andrew Jones,  
James Canvin, Andrew Bennett, Stephen Moseley and Jo Robbins.



# MOGREPS

**Met Office Global and Regional Ensemble Prediction System**

24 members | Operational since Sept 2008 after 3-years of trials

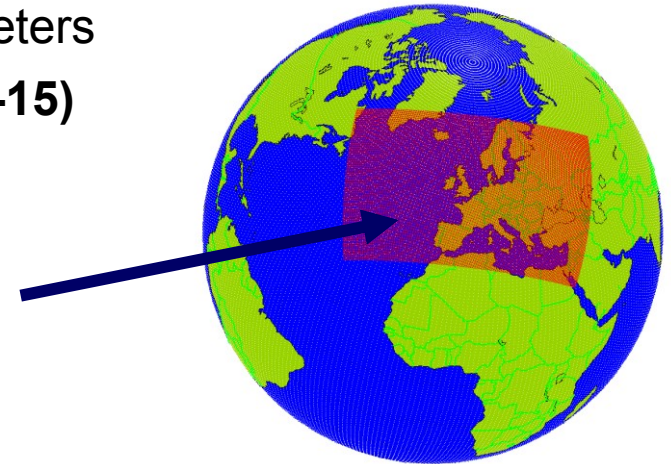
## Global Component (MOGREPS-G)

- 60km, 70 Levels
- T+72h
- Run at 00Z and 12Z
- ETKF for IC perturbations
- Stochastic physics (SKEB2) and random parameters
- Also run at ECMWF out to 15 days (**MOGREPS-15**)



## Regional Component (MOGREPS-R)

- Runs over the North Atlantic and Europe (NAE)
- 18km, 70 Levels
- T+54h
- Run at 06Z and 18Z with boundary conditions from MOGREPS-G

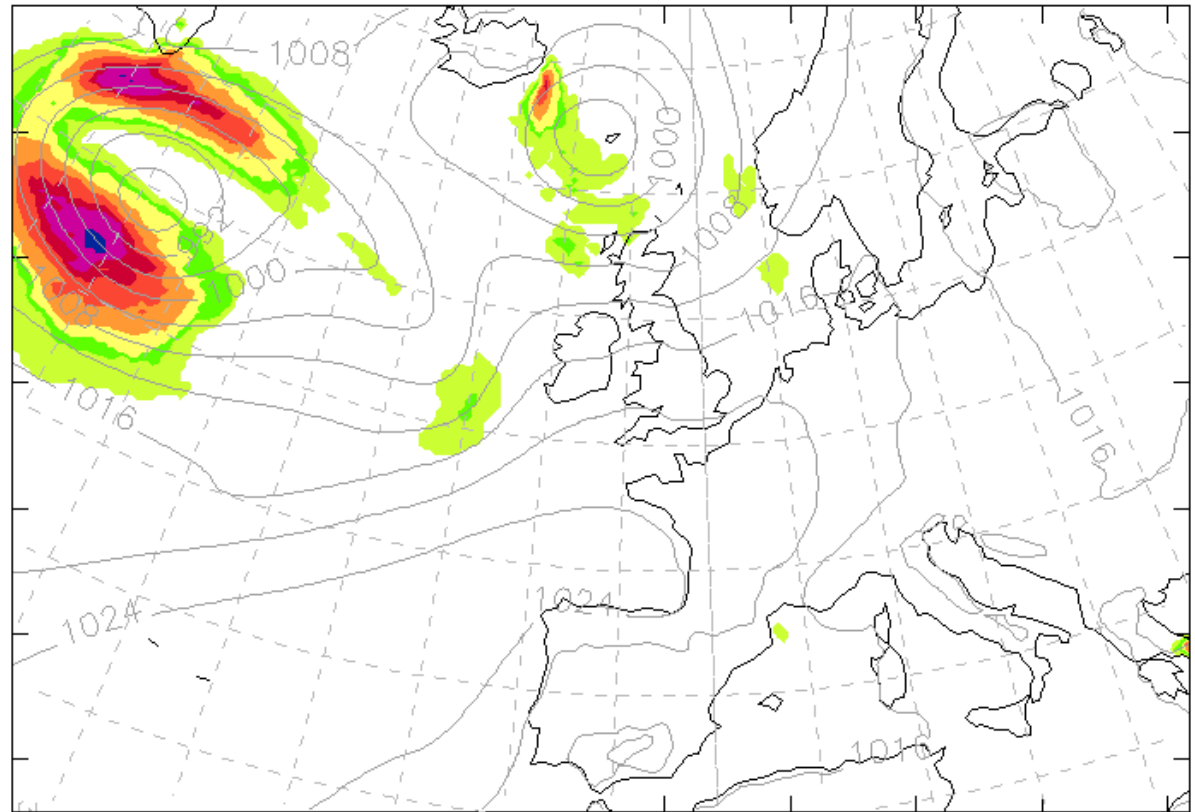




# Many web-based products e.g. Prob of Gusts > 40kt

MOGREPS (Regional) Probability map for GustSpeed > 40.0knots  
DT 06Z on Thu 15/07/2010 VT 12Z on Sat 17/07/2010 lead time 54h  
(Ensemble Mean PMSL plotted as faint background)

- Probabilities, ensemble mean and spread also stored as GRIB2 files for display on forecaster workstations alongside deterministic forecasts
- Ensemble members in GRIB2 for
  - Exchange
  - TIGGE-LAM
  - Product generation





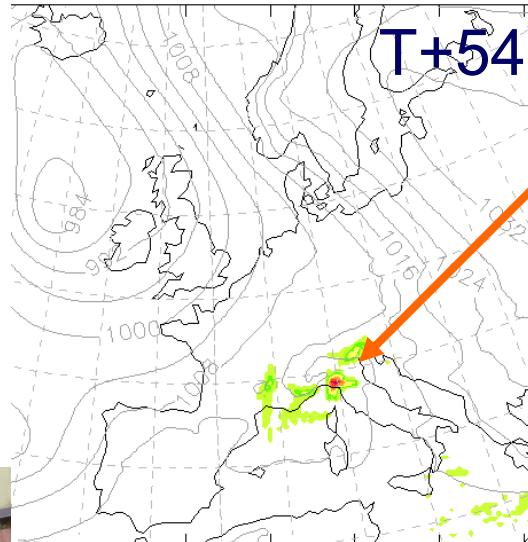
# Italy Floods

## 26 Oct 2011

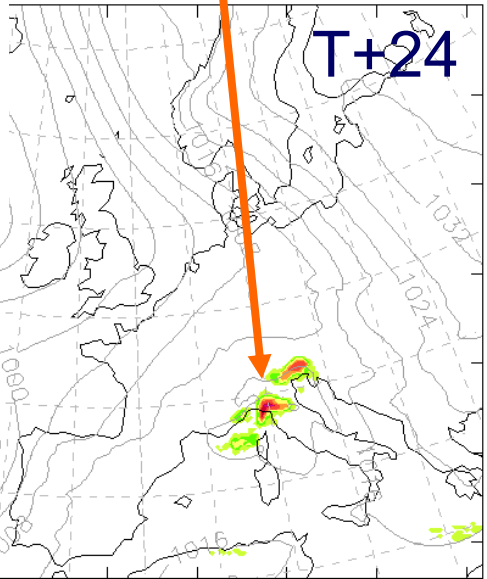
- MOGREPS-R probs of 24h precip > 100mm accurately pinpoint severe floods
- Prob > 80% at T+54



Probability map for 24HourPrecip > 100.0mm  
1 VT 00Z on Wed 26/10/2011 lead time 54h  
(an PMSL plotted as faint background)



Probability map for 24HourPrecip > 100.0mm  
06Z on Wed 26/10/2011 lead time 24h  
(L plotted as faint background)



No Members 0.01 0.1 0.2 0.4 0.6 0.8 0.9 0.99 All Members

### DEADLY DOWNPOUR

At least five people are dead, with several more reported missing, after flooding hits Italy





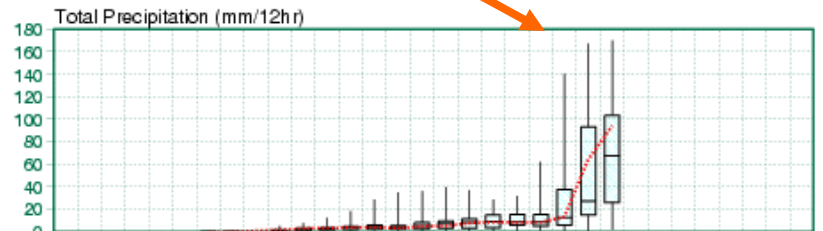
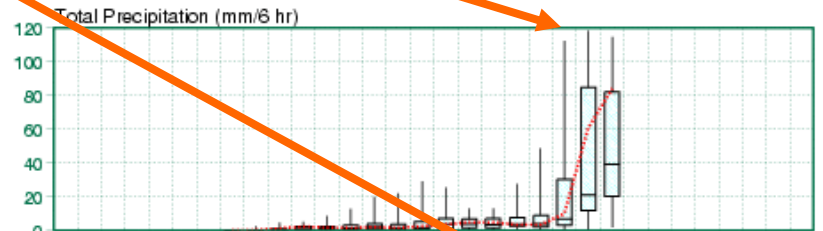
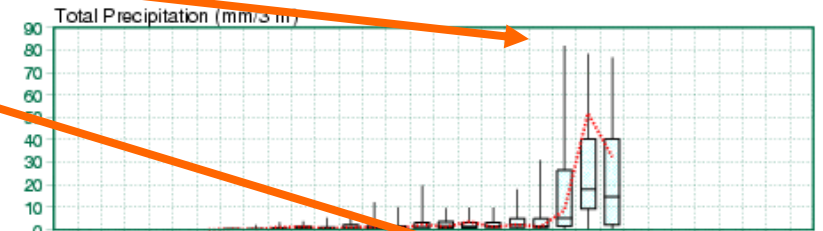
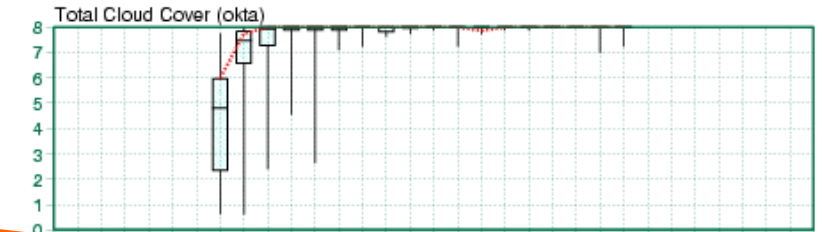
# Italy Floods 26 Oct 2011

## 2-day Forecast:

- 3h precip up to 80mm
- 6h precip up to 120mm
- 12h precip up to 160mm
  - Median over 60mm
- Observations over 400mm reported



MOGREPS European EPS Meteogram  
CIMONE MOUNTAIN (16134) 44.2° N 10.7° E  
RAW - EPS Forecasts : 23 October 2011 18 UTC



SUN 23 MON 24 TUE 25 WED 26 THU 27  
OCTOBER 2011  
Note: All times in UTC  
Met Office, Crown Copyright



# MOGREPS-W

First-guess Severe Weather Warnings for NSWWS

Estimating Impact – a Risk tool

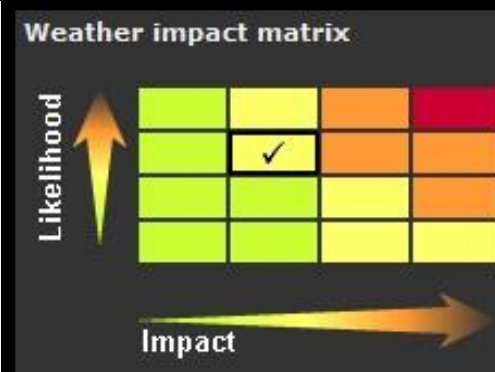


# The New National Severe Weather Warning Service (NSWWS)

- Alerts/warnings based on **likelihood** and **impact**
  - **Alerts** - issued more than 24 hours ahead
  - **Warnings** - issued up to 24 hours ahead
- Regionally varying impact thresholds
- Alerts/warnings presented by shape areas on a map rather than just by county area



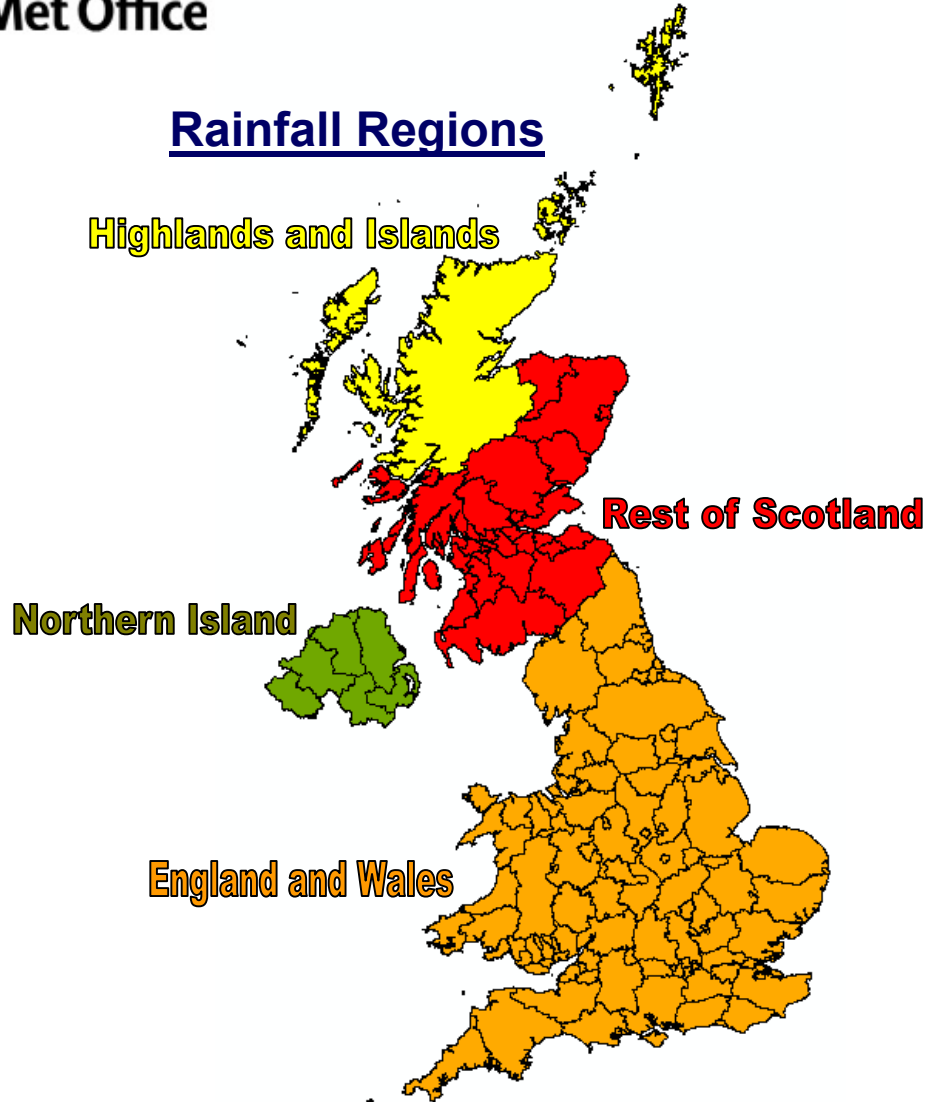
|   |                   |
|---|-------------------|
|   | No severe weather |
|  | Be aware          |
|  | Be prepared       |
|  | Take action       |



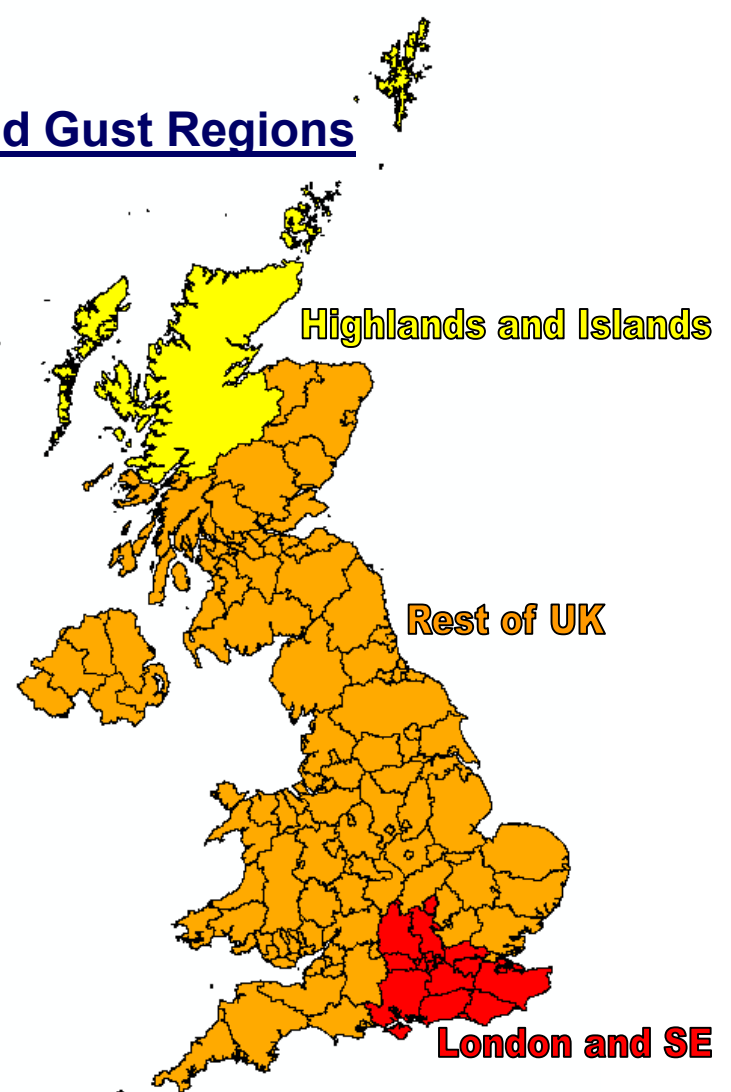


# Regional Impact Thresholds

## Rainfall Regions



## Wind Gust Regions

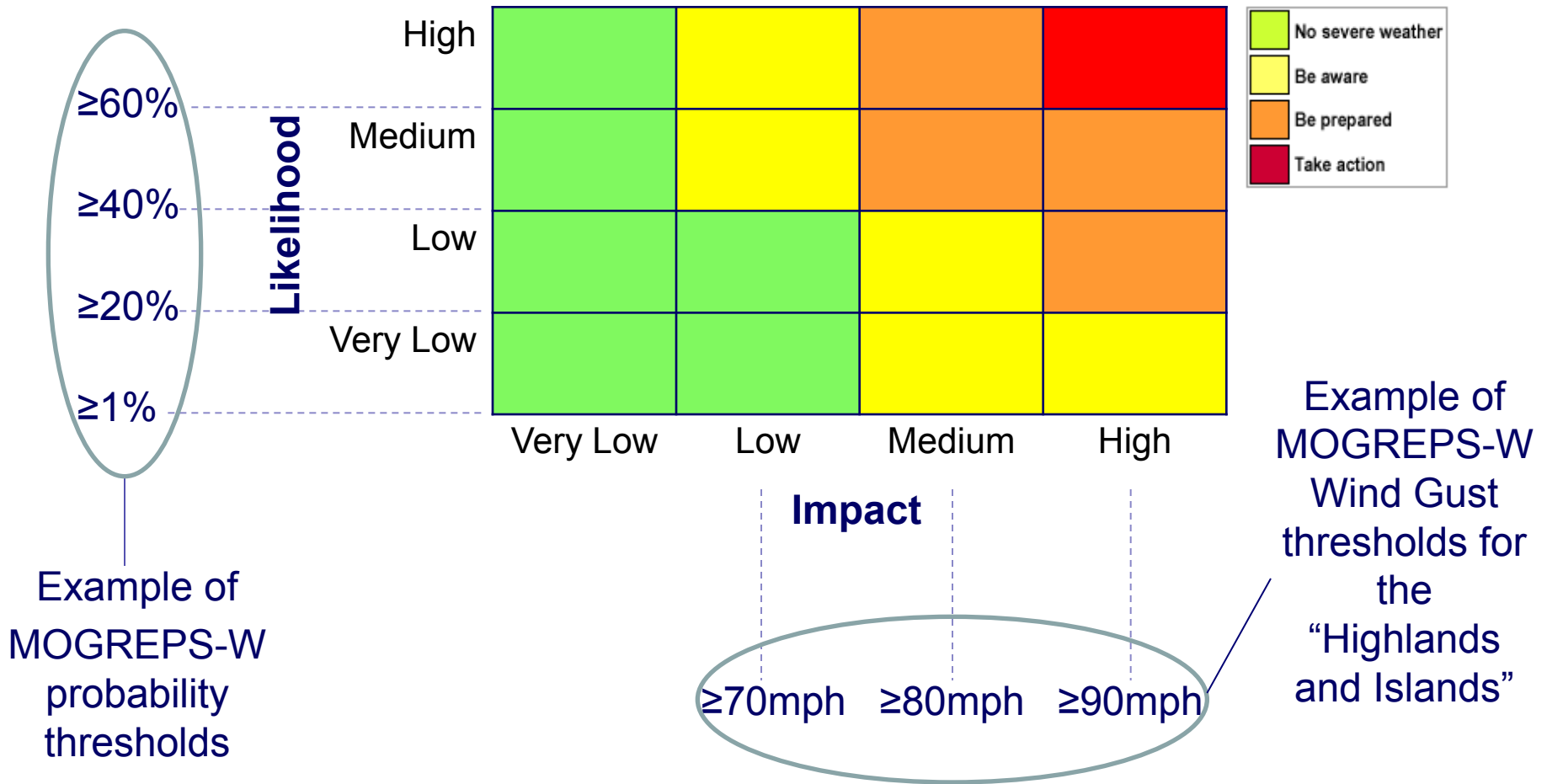






# Impact-based MOGREPS-W

## Weather Impact Matrix





# MOGREPS-W Example

## Ex-hurricane Katia, 12<sup>th</sup> Sep 2011

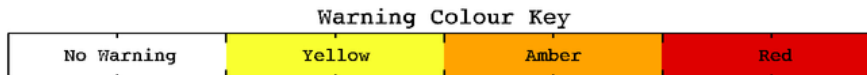
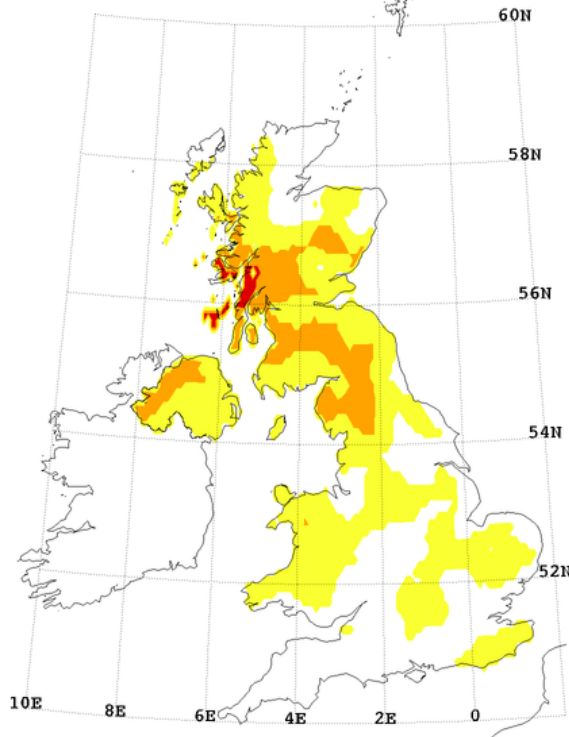


MOGREPS-R Overall Warning Colour for Wind Gusts  
 DT 06Z on Sun 11/09/2011  
 Valid over all 54 hours of run

|      |          |          |     |        |
|------|----------|----------|-----|--------|
|      | High     |          |     |        |
| ≥60% | Medium   |          |     |        |
| ≥40% | Low      |          |     |        |
| ≥20% | Very Low |          |     |        |
| ≥1%  |          |          |     |        |
|      |          | Very Low | Low | Medium |
|      |          |          |     | High   |
|      |          |          |     |        |

MOGREPS-W first guess wind gust warning. Note small area of Red (but not enough to justify *widespread*)

Good agreement with warning issued by forecaster on Sunday morning (right)



© Crown Copyright 2011. Source: Met Office



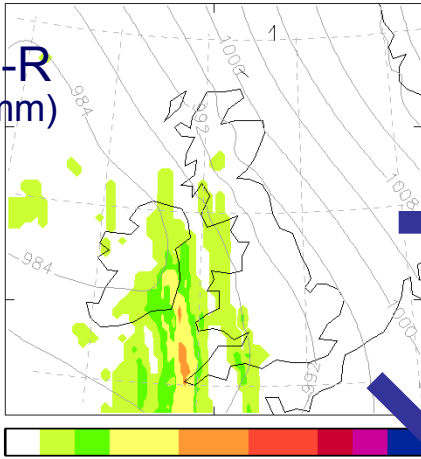
# MOGREPS-W Example

## Heavy Rain on 24<sup>th</sup> October 2011

|            |      |          |          |     |        |      |
|------------|------|----------|----------|-----|--------|------|
| Likelihood | ≥60% | High     | Very Low | Low | Medium | High |
|            | ≥40% | Medium   | Very Low | Low | Medium | High |
|            | ≥20% | Low      | Very Low | Low | Medium | High |
|            | ≥1%  | Very Low | Very Low | Low | Medium | High |
|            |      |          | Impact   |     |        |      |

MOGREPS (Regional) Probability map for 24HourPrecipUK > 50.0mm  
 DT 06Z on Sun 23/10/2011 VT 00Z on Tue 25/10/2011 lead time 42h  
 (Ensemble Mean PMSL plotted as faint background)

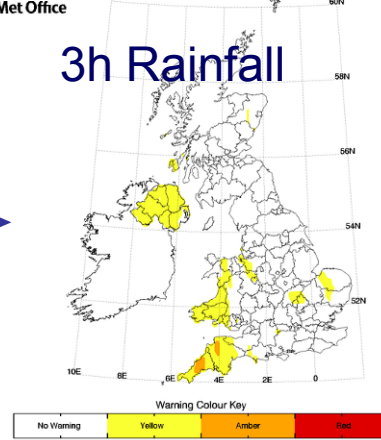
MOGREPS-R  
 p(24h-ppn>50mm)  
 T+42



No Members All Members

MOGREPS-W Overall Warning Colour for 3Hr Precipitation  
 DT 06Z on Mon 24/10/2011  
 Valid over all 54 hours of run

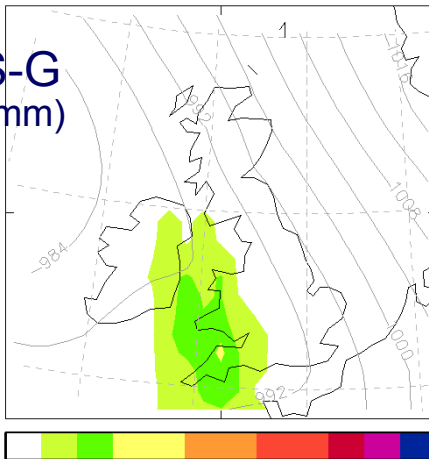
3h Rainfall



DIGITAL MAP DATA © COLLINS BATHOLOMEW LTD (2011) © Crown Copyright 2011. Source: Met Office

MOGREPS (Global) Probability map for 24HourPrecipUK > 50.0mm  
 DT 00Z on Sun 23/10/2011 VT 00Z on Tue 25/10/2011 lead time 48h  
 (Ensemble Mean PMSL plotted as faint background)

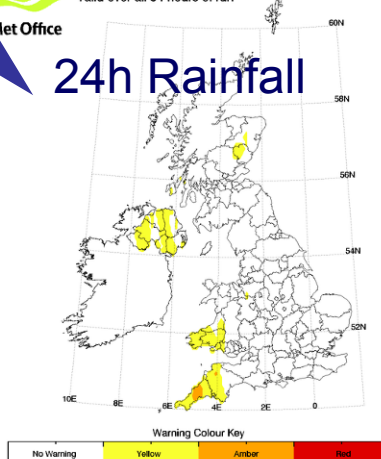
MOGREPS-G  
 p(24h-ppn>50mm)  
 T+48



No Members All Members

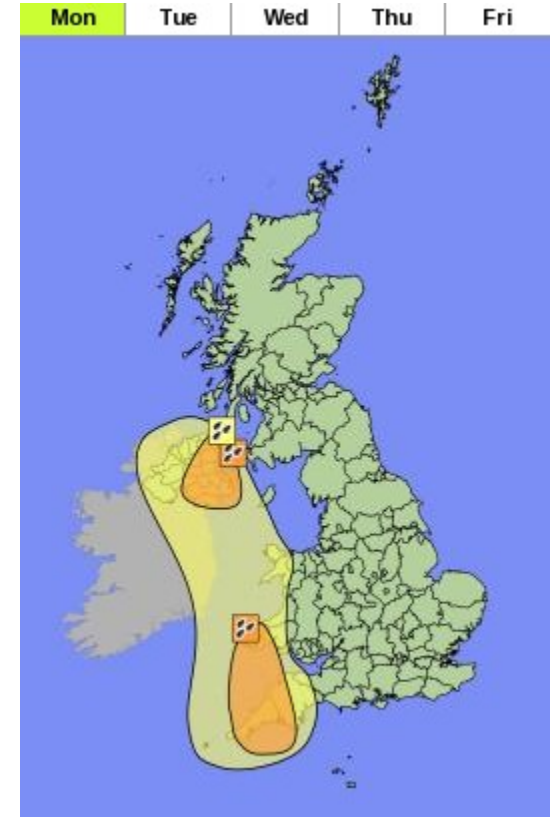
MOGREPS-W Overall Warning Colour for 24Hr Precipitation  
 DT 06Z on Mon 24/10/2011  
 Valid over all 54 hours of run

24h Rainfall



DIGITAL MAP DATA © COLLINS BATHOLOMEW LTD (2011) © Crown Copyright 2011. Source: Met Office

Good agreement  
 with warning  
 issued by  
 forecaster (below)



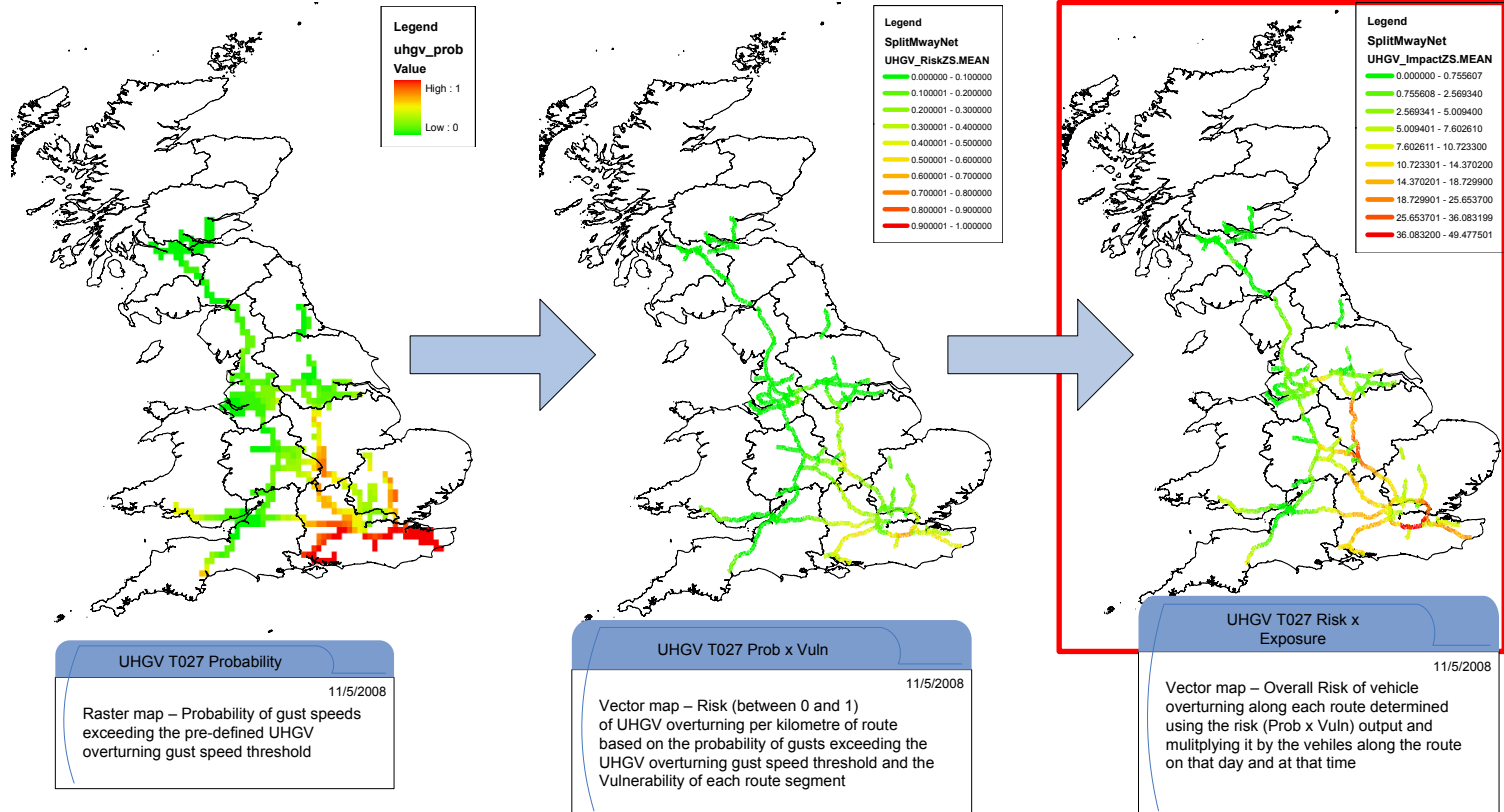
# Converting Hazard to Risk

## Example for road vehicle overturning due to strong winds

Probability, Vulnerability & Exposure = Risk of Vehicles Overturning

Wednesday, November 05, 2008

### OVERALL RISK MAP





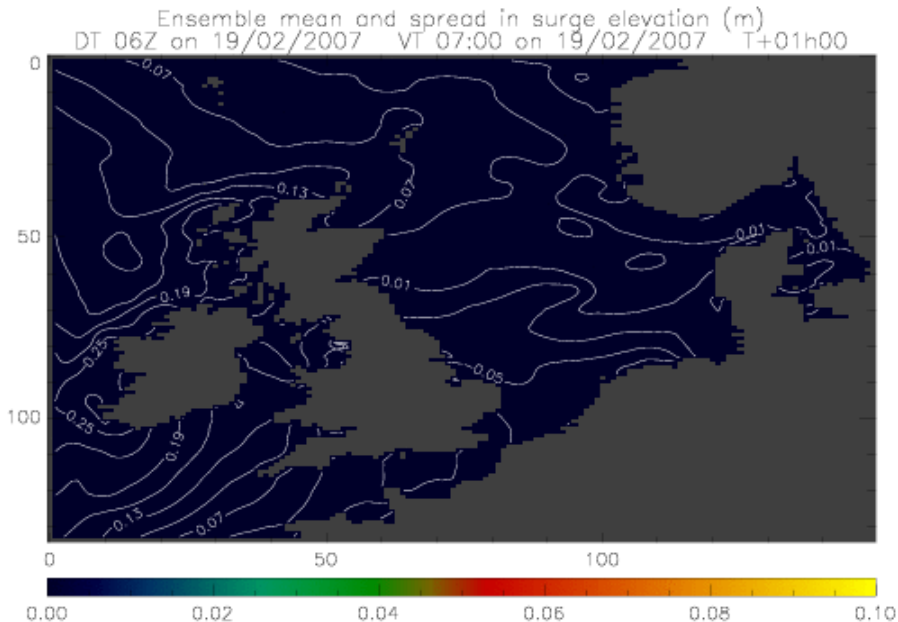
# Storm surge ensemble

Coupling a surge model to MOGREPS –  
In support of coastal flood forecasting by the  
Environment Agency

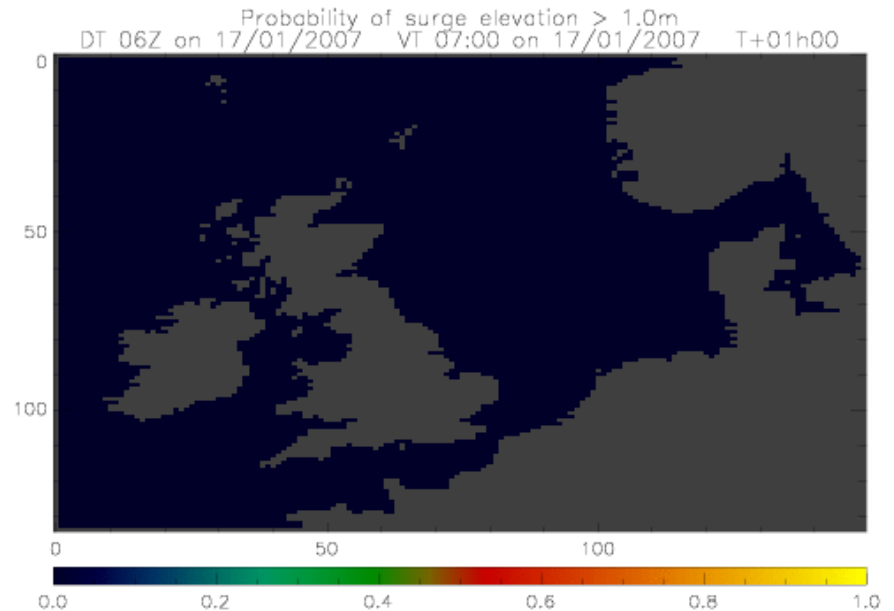


# Storm surge Ensemble – recently extended to 7 days

- Storm surge model coupled to MOGREPS-R and MOGREPS-15



- Mean and spread of surge elevation

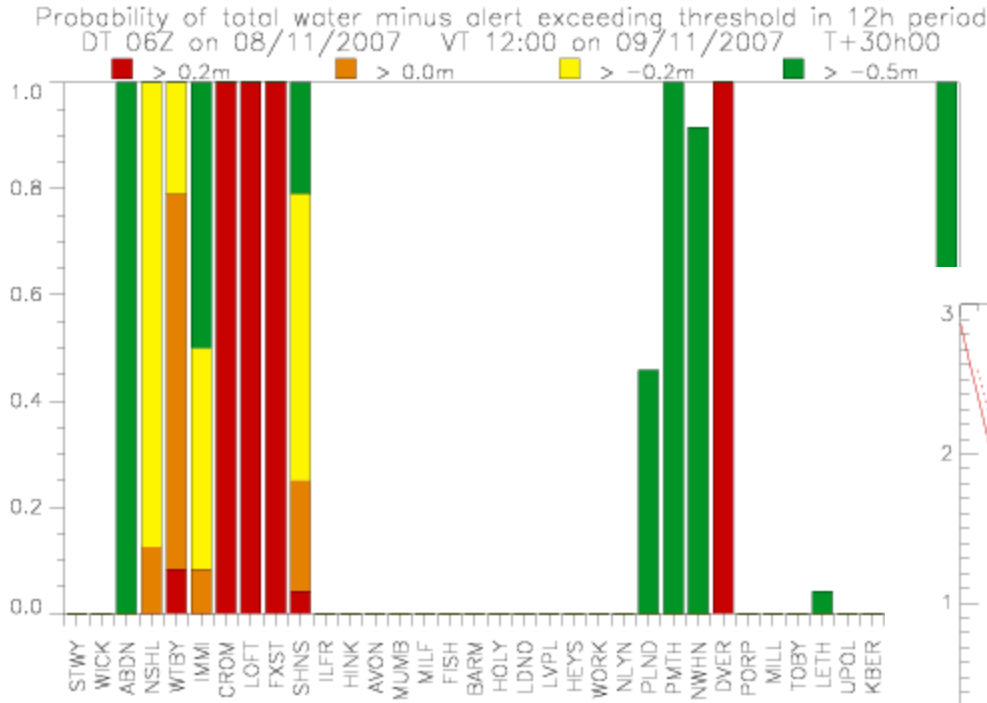


- Probability of surge elevation >1.0m



# Storm surge ensemble for EA

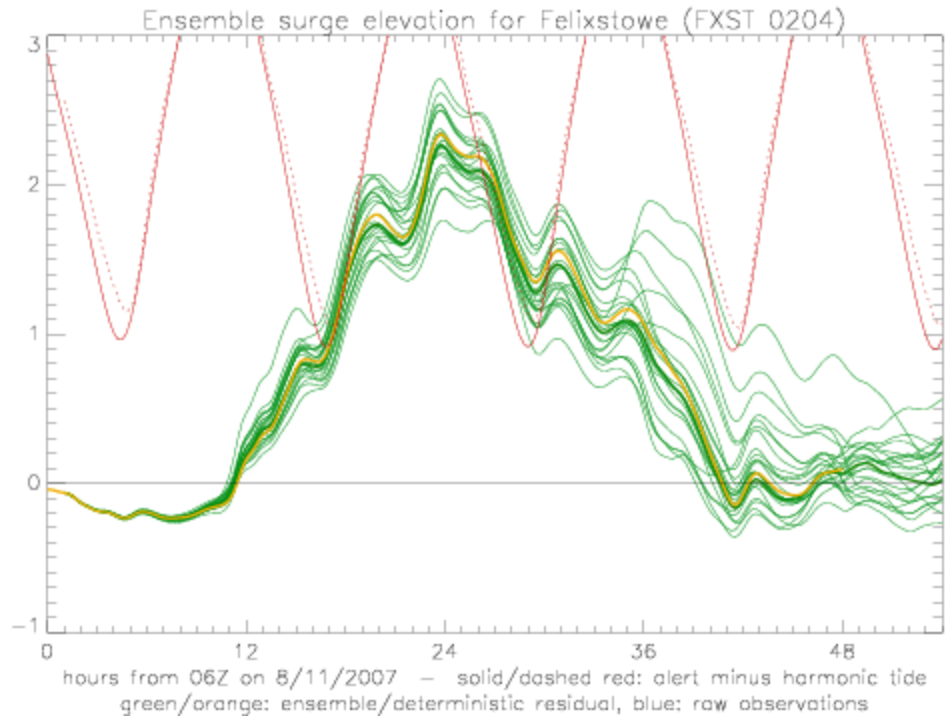
## Risk assessed relative to 3 impact thresholds



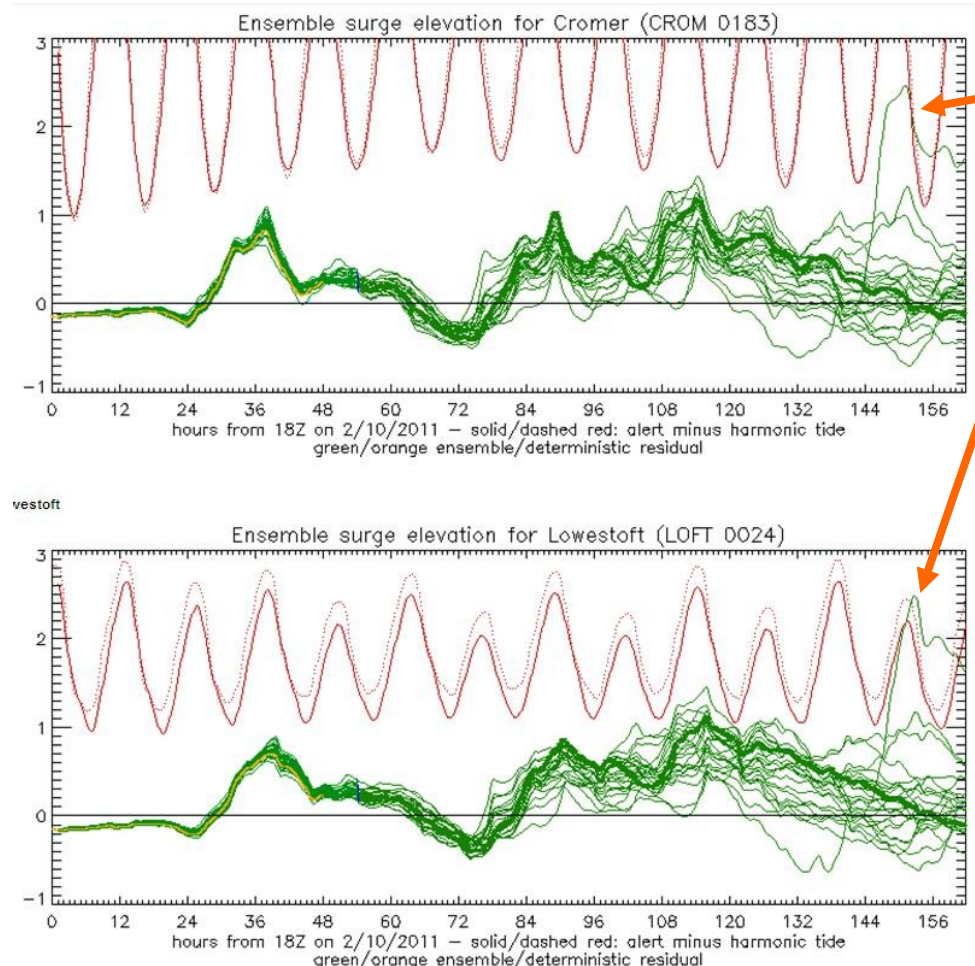
↑  
 12h ending  
 1200 (T+30)

Probability of water level  
 exceeding impact levels

### Felixstowe



# Surge ensemble 7-day forecast from 18Z on 2<sup>nd</sup> Oct 2011



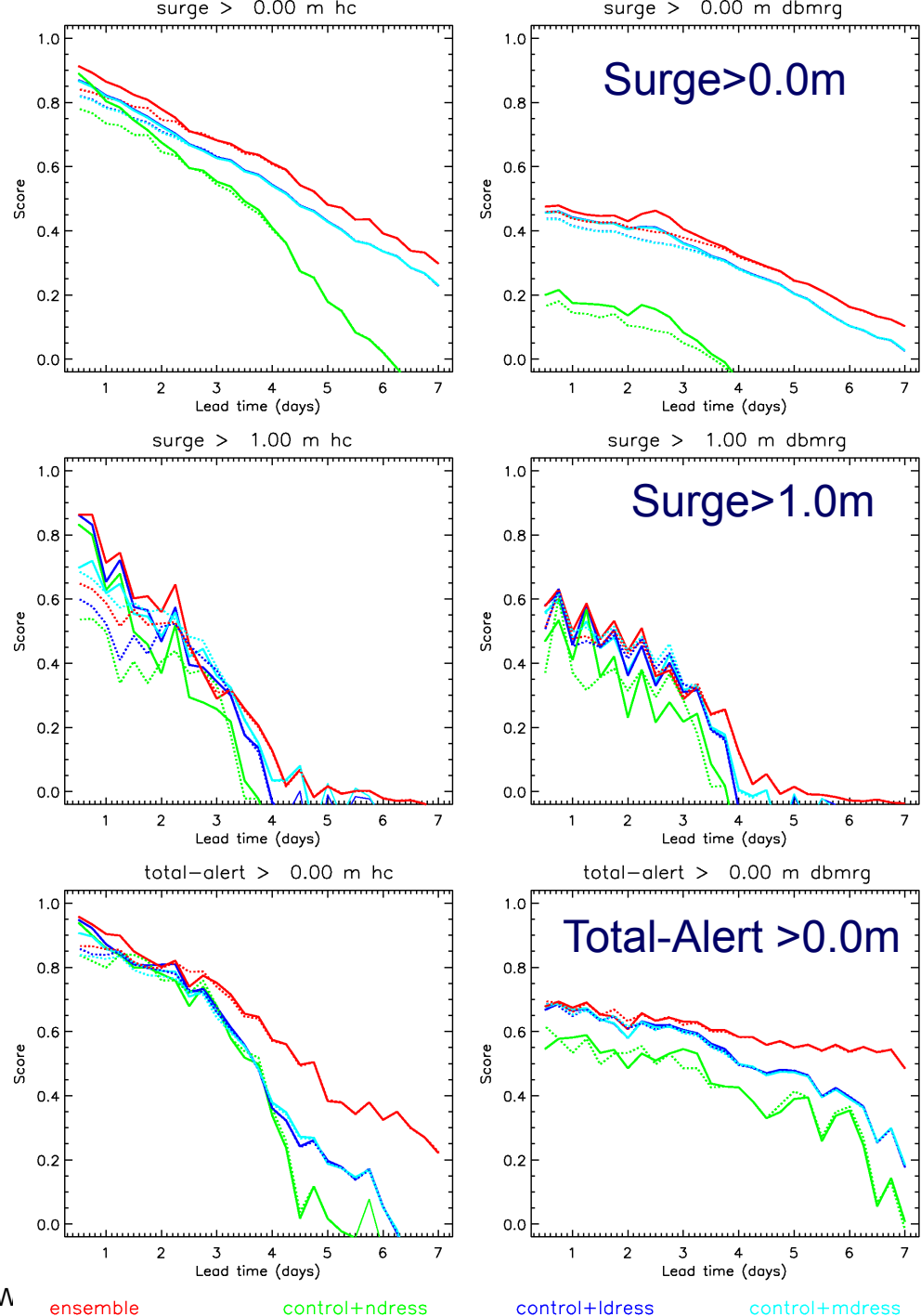
- One member of the ensemble predicts an extreme surge 7 days ahead
- Classic case of low probability of high impact
- In the event nothing happened – as was most likely –
- but EA was able to take early preparedness actions at little cost





# Brier Skill Score

- Summarises overall skill of probabilistic forecast
- Based on 'rms error' of probability, where truth is 0 or 1 in each case
- Ensemble beats dressed deterministic
- Greatest benefit at long lead times





Met Office

# Uncertainty in Dispersion Modeling

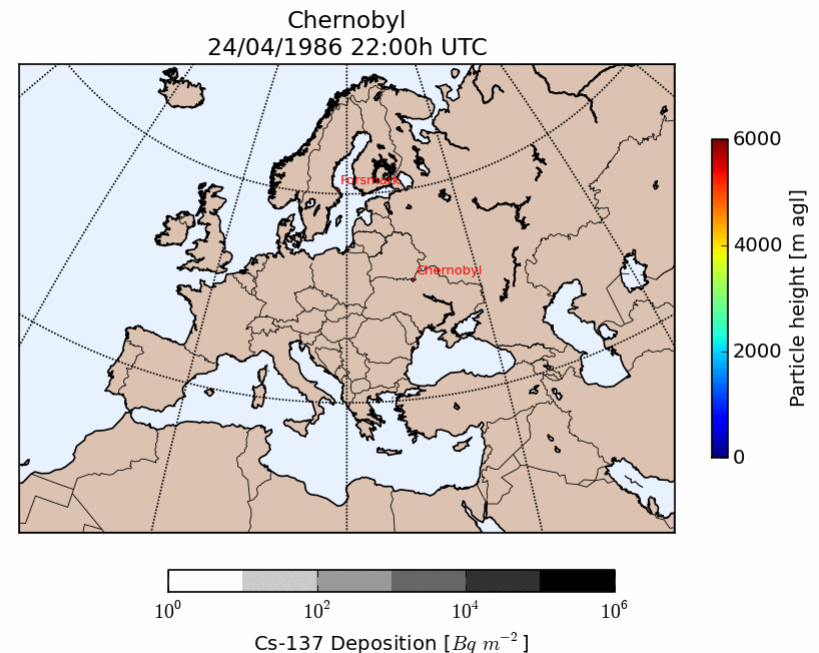
Volcanic Ash, Chemical and  
Nuclear Accidents



# NAME

## Numerical Atmospheric-dispersion Modelling Environment

- Development started following the Chernobyl accident
- Initial purpose to give emergency response dispersion predictions for nuclear incidents
- NAME has been and continues to be under constant development
  - Starting in 1999 code completely rewritten
  - Science updates occur continuously
- Used by 12 organizations
- Lagrangian stochastic model
- Model particles are released and followed to predict plume
- Very wide range of physics, functionality and application



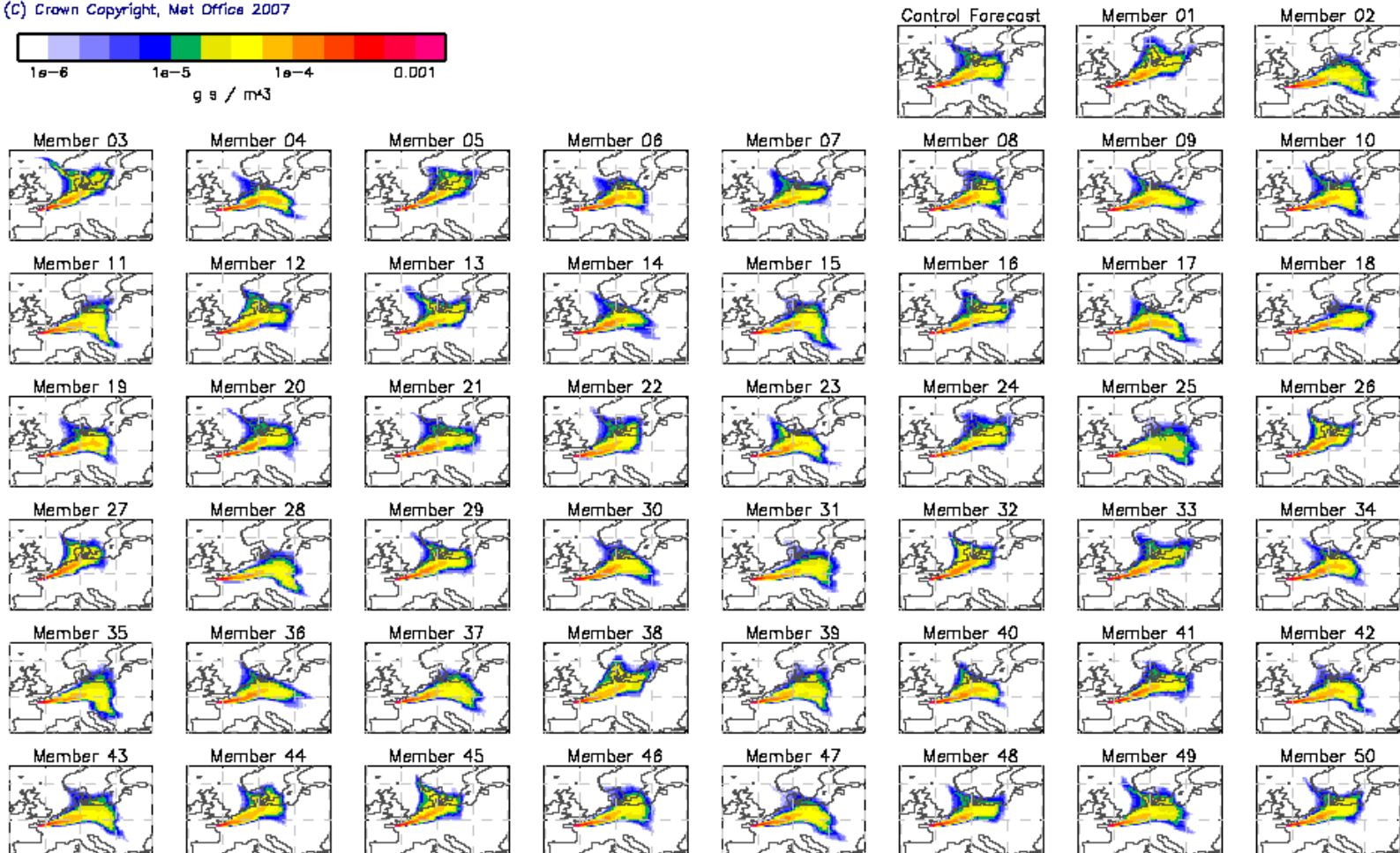
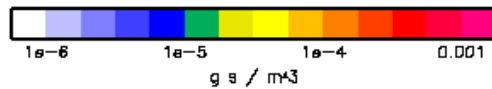


# EPS-based dispersion modelling

NAME III / ECMWF EPS: PMCH Dosage at 0 m (g s / m<sup>3</sup>)  
All Members  
T+75h

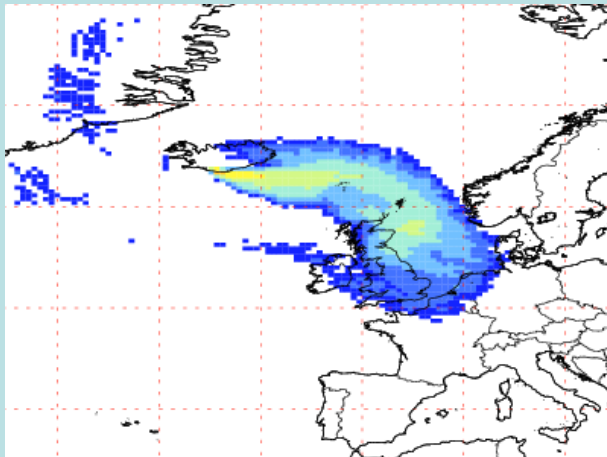
DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994

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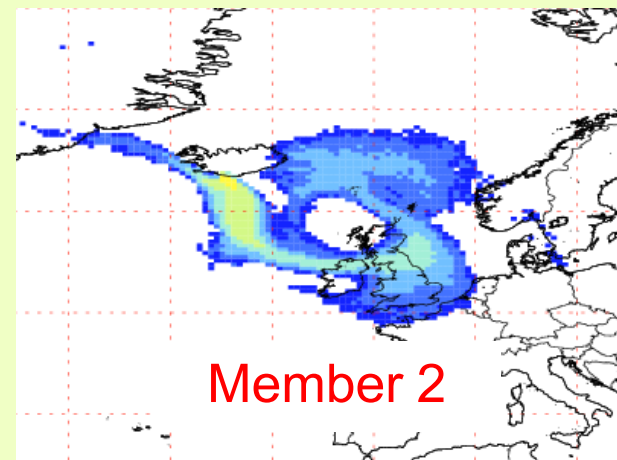
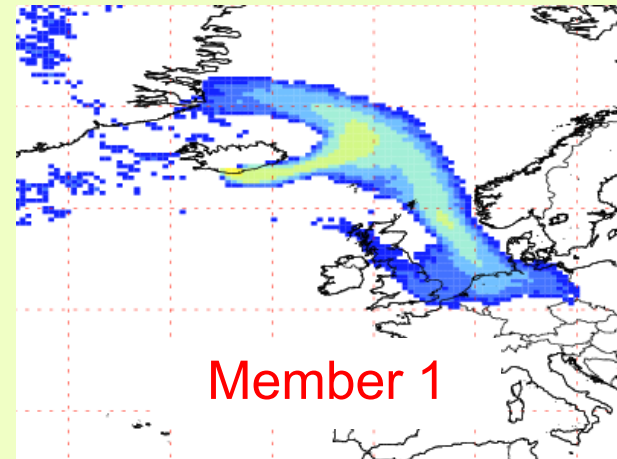
# NAME volcanic ash predictions using ECMWF EPS forecasts

## Control forecast

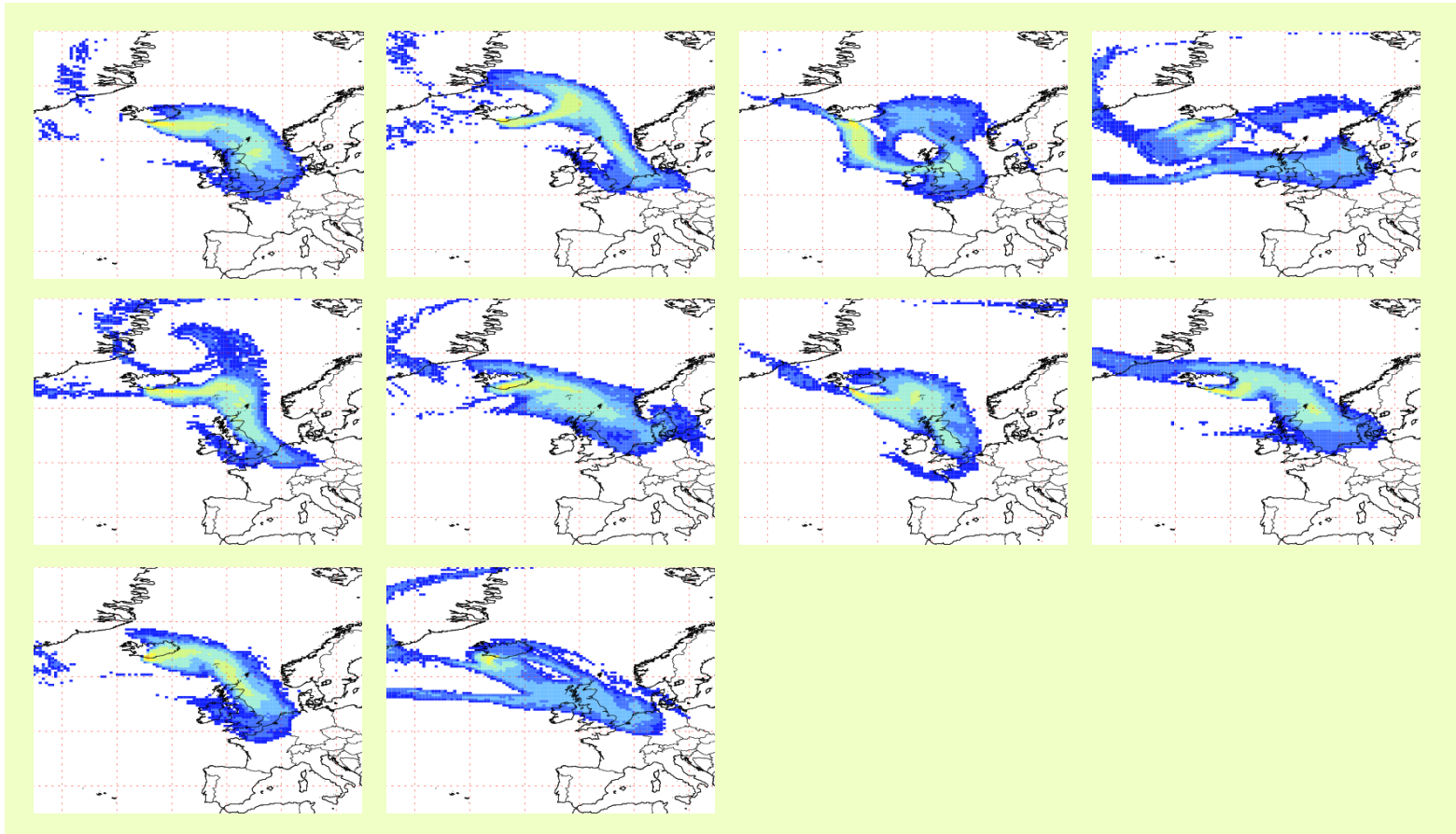


4 day forecast of FL000-FL200 ash concentration valid at 12UTC on 17/05/2010

## Perturbed forecasts



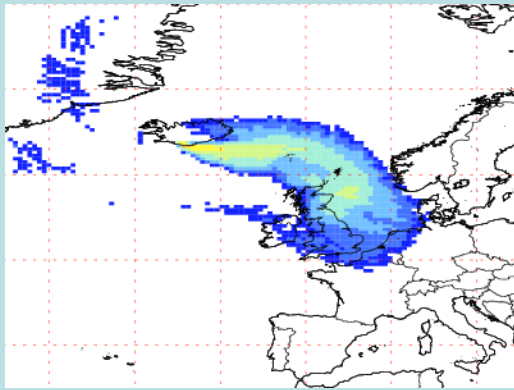
# NAME volcanic ash predictions using ECMWF EPS forecasts



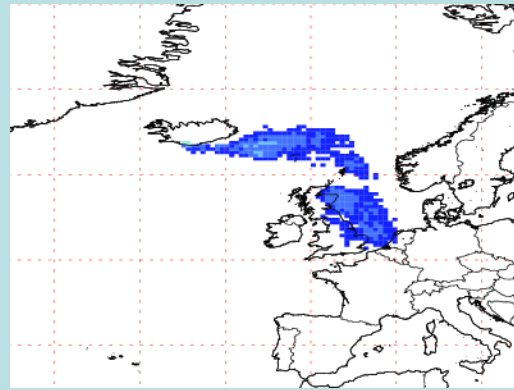
10 members of an ensemble forecast of FL000-FL200  
ash concentration valid at 12UTC on 17/05/2010

# Ensemble mean, median (and other percentiles ...)

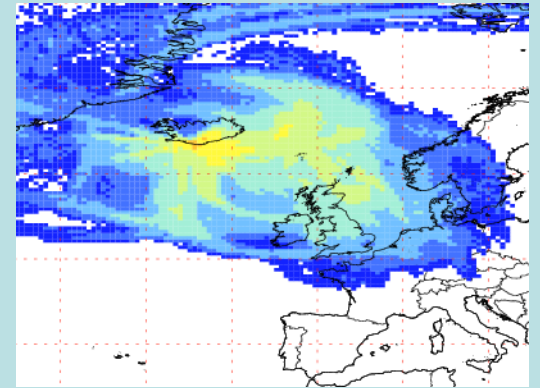
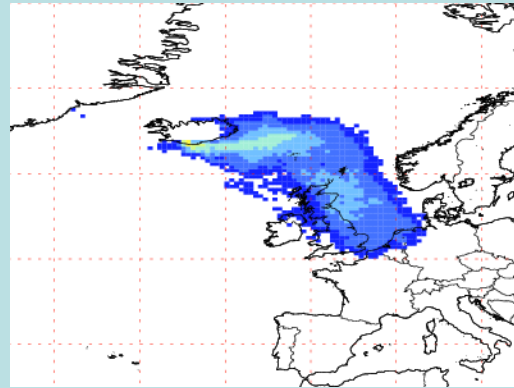
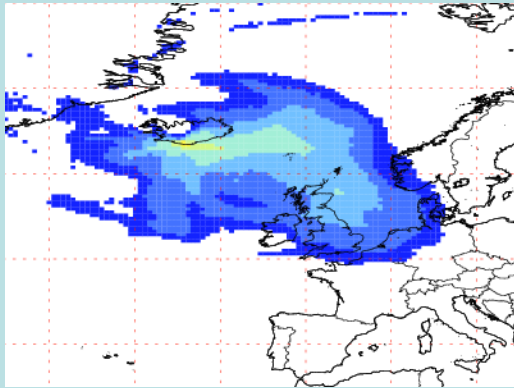
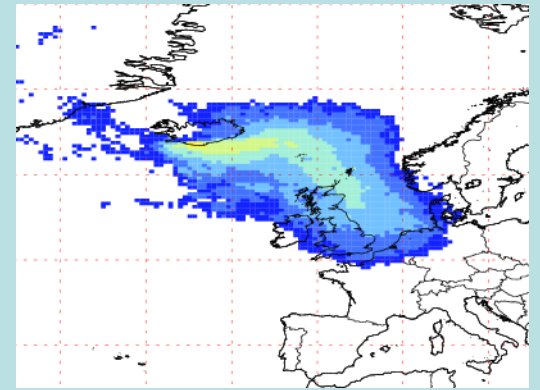
Control



25<sup>th</sup> perc



75<sup>th</sup> perc



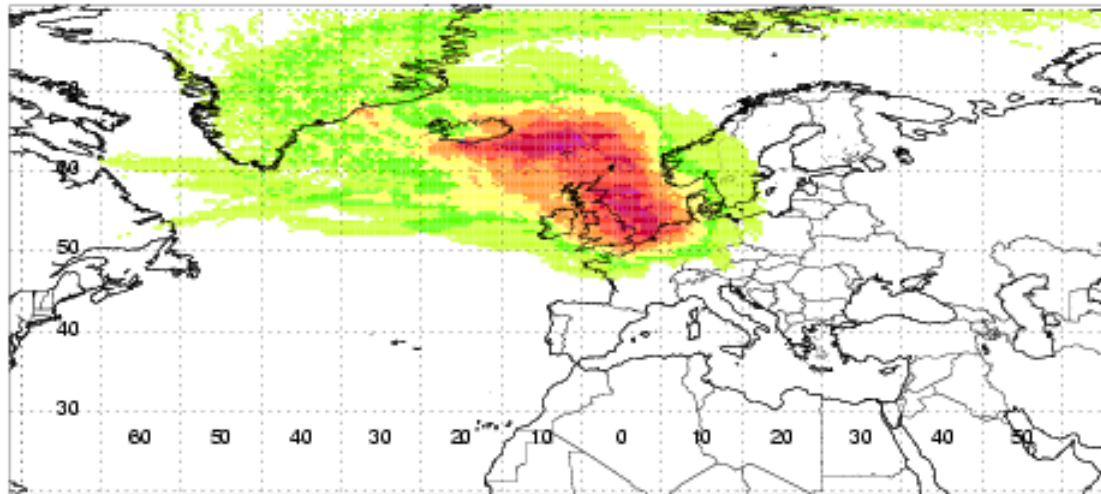
Ens Mean

50<sup>th</sup> perc

100<sup>th</sup> perc

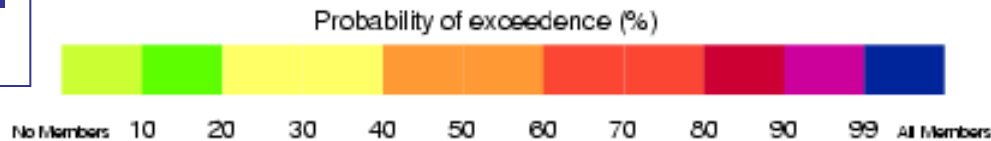


# NAME volcanic ash predictions using ECMWF EPS forecasts



prob(conc > VA threshold) in FL000-200 at T+72

N.B. meteorological uncertainty only!





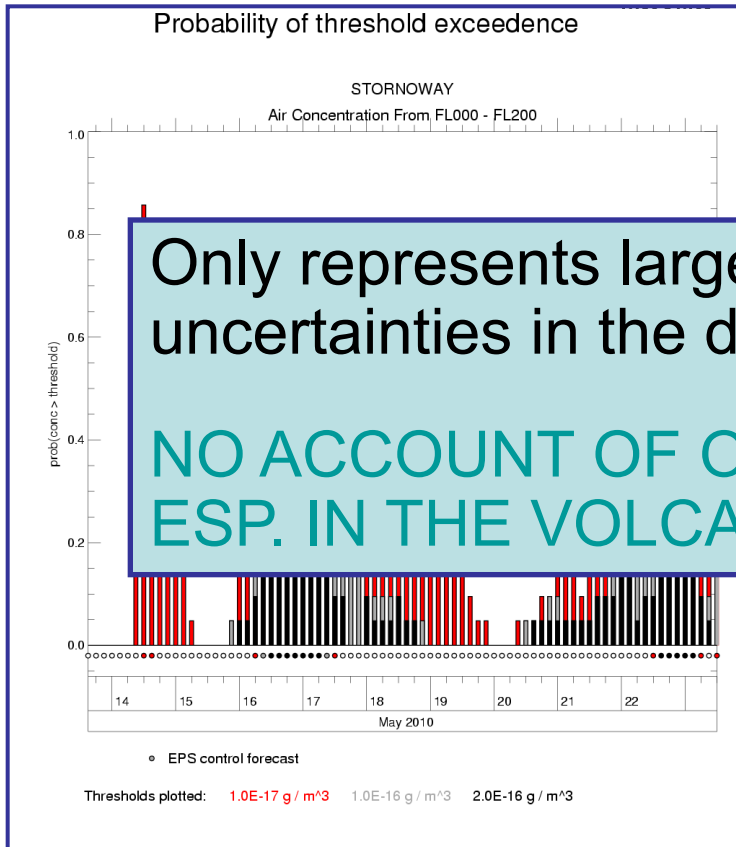
# Site-specific products

Risk category for threshold exceedence

Probability concentration exceeds red

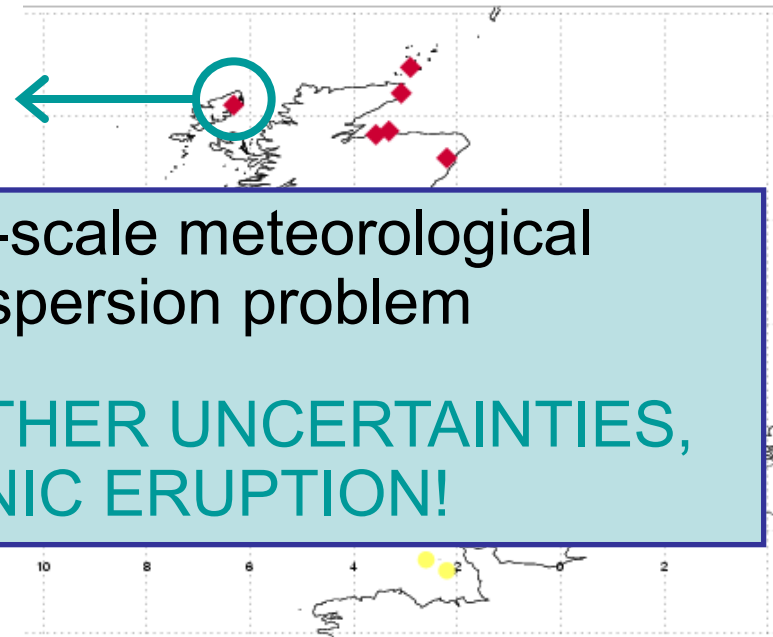
Air Concentration From FL000 - FL200

17/05/2010 12:00:00



Only represents large-scale meteorological uncertainties in the dispersion problem

NO ACCOUNT OF OTHER UNCERTAINTIES, ESP. IN THE VOLCANIC ERUPTION!



- Likelihood categories:
- Very Low
  - Low (0-30%)
  - Medium (30-60%)
  - ◆ High (60-90%)
  - ▲ Very High (> 90%)



# Dispersion Summary

Use of EPS is a powerful tool to understand the *atmospheric forecast uncertainty* in long-range dispersion

Full probabilistic prediction also requires:

- Source-term uncertainty
- Model uncertainty

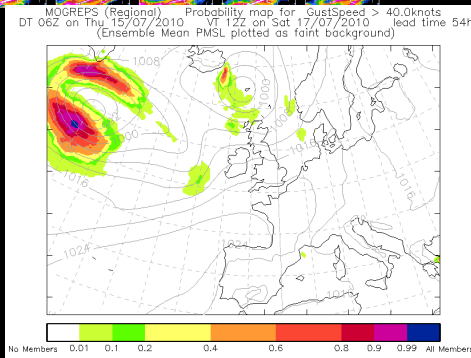
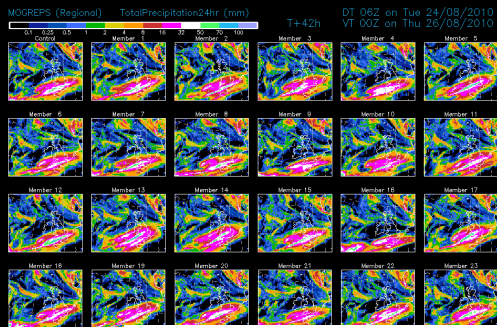
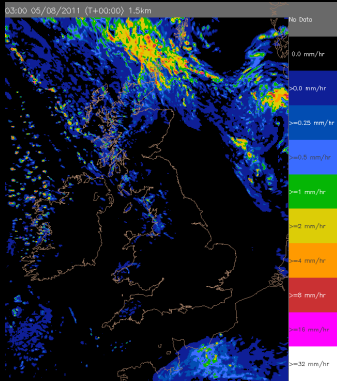
Current research is aiming towards a complete probabilistic prediction



# Integrating Post-Processing of Ensemble and Deterministic NWP



# Parallel systems



- Deterministic production systems
  - First-guess for charts and guidance
  - Site-specific forecasts for web and products
- *Supplementary* ensemble information
  - ECMWF EPS and MOGREPS
  - Lower resolution
  - Probabilistic risk information for forecasters
  - First-guess early warnings
  - A few customer-specific applications
- NWP Science strategy is ensembles for everything
  - How do we integrate applications?



# Site-specific forecasts



# “Best Data” provides a single source of forecast data for all products

- SSPA - Site-specific forecasts
  - 5000 UK sites
  - 10000 sites worldwide
  - Kalman filter bias corrections (where obs available)
    - Reduces effect of resolution differences
  - Cascade of models by lead-time
    - **Single Value**
      - UKV/UK4
      - NAE
      - MOGREPS Mean
    - **Multi Value (Percentiles)**
      - MOGREPS-UK
      - MOGREPS-R
      - MOGREPS-15

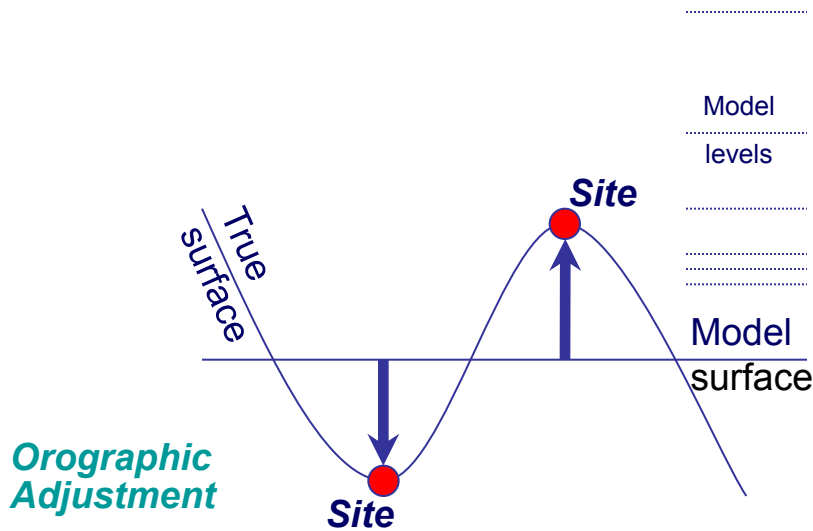
Ensemble starting to be used for “deterministic” Best Data

Ensemble spread adjusted to assure consistency

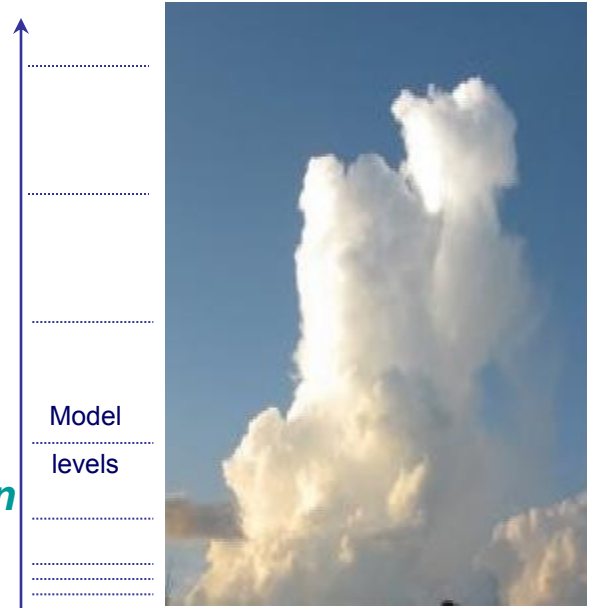


# SSPS Overview

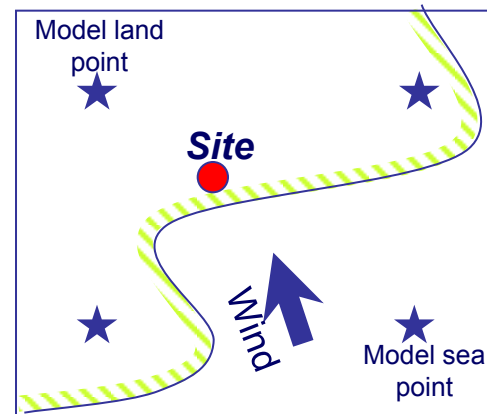
## Site-specific extraction from the grid



**Convection  
Diagnosis  
Procedure**



- Same method is used for deterministic & ensembles: Global and regional MOGREPS and ECMWF



**Coastal  
Adjustment**



# Best Data Blending

Continuous updating of best deterministic

To start – 15 days out

- $\text{BestData}(T+360) = \text{MOGREPS-15}(T+360) \text{ Mean}$

12 hours later

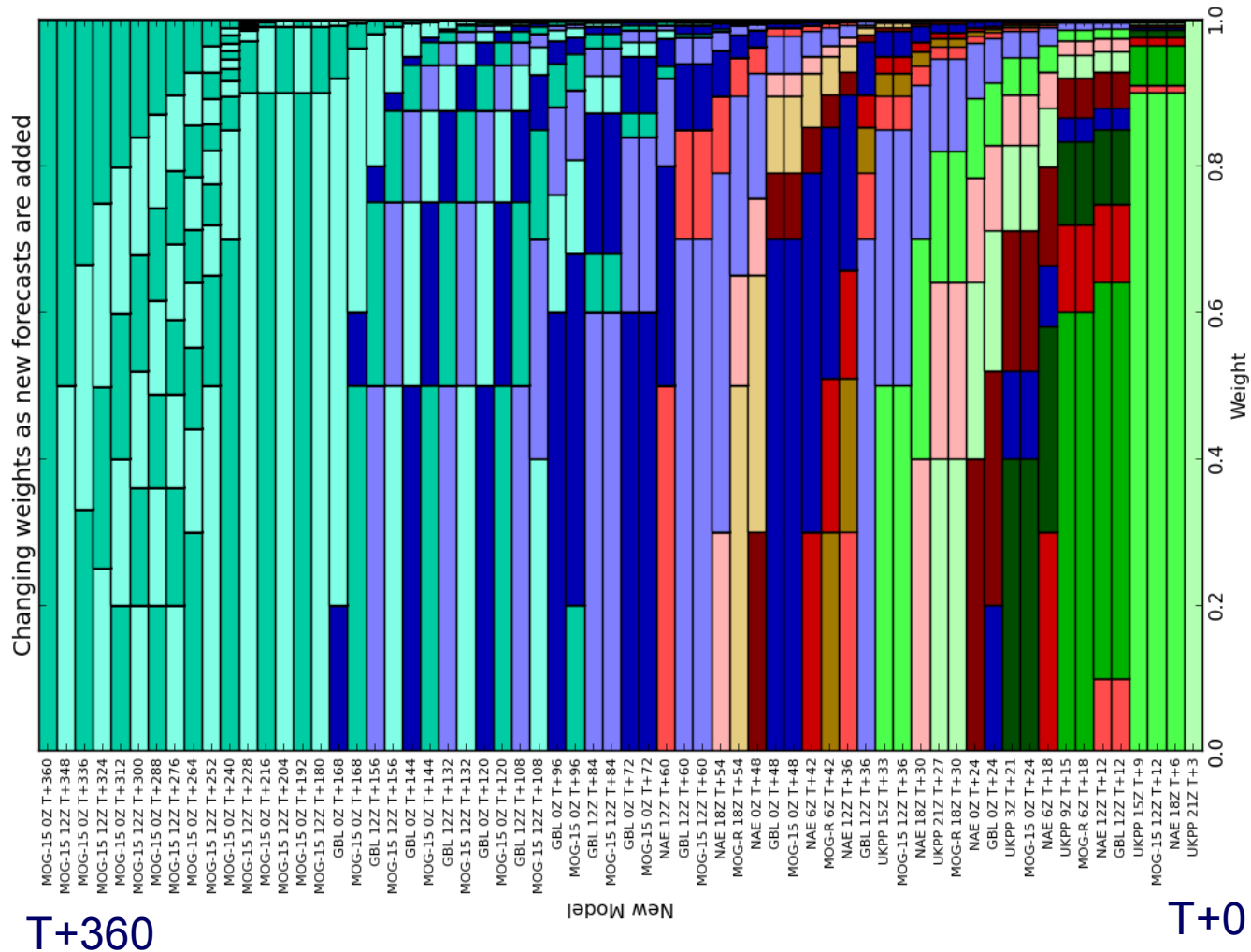
- $\text{BestData}(T+348) = 0.5 * \text{MOGREPS-15}(T+348) \text{ Mean} + 0.5 * \text{BestData}(T+360)$

Current BestData =  $a * \text{latest forecast} + (1-a) * \text{previous BestData}$

- 'a' varies with lead time and model combination
- At shorter range blend in:
  - MOGREPS-R
  - Higher resolution deterministic models including UKV
  - Nowcasts
- Coming soon – ECMWF data included in blend!



# Complex sets of weights by lead-time





# Ensemble Best-Data Stored as Percentiles

| %        | Min  | 5%   | 10%  | 20%  | 25%  | 30%  | 40%  | 50%  | 60%  | 70% | 75% | 80% | 90% | 95% | Max |
|----------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|
| <b>T</b> | -3.1 | -2.9 | -2.8 | -2.3 | -1.8 | -1.7 | -1.6 | -0.7 | -0.4 | 0.0 | 0.1 | 0.9 | 1.5 | 2.5 | 4.6 |

- Allows interpolation of probability for any threshold
- Independent of ensemble size or combination of data sources
- Using blend of multiple sources including hi-res deterministic models ensures consistency of:
  - Most probable
  - Uncertainty measures



# Best Data Temperatures

Met Office : Invent - Weather: Map view - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.metoffice.gov.uk/public/pws/invent/weathermap/

Most Visited Support Metnet home page Google Ensemble Applications MOGREPS display web yourself People Search Capita Business Travel OPCHANGE

MOGREPS display web Met Office : Invent - Weather: ... Precipitation Rate and MSLP<... Probability map of Wind speed ...

Skip navigation • Mobile • Help • Site map

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Forecast Temperature 1300 Sat 6 Aug

Layers

- Rainfall
- Cloud Vis
- Cloud IR
- Pressure
- Temp. Map
- Weather
- Wind
- Temperature
- UV
- Feels Like Temp.
- Leisure areas
- Regional Forecasts
- Pollen Forecast

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Locations

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# Detail for London

Met Office: Invent - Weather: Text view - Location: London - Mozilla Firefox

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http://www.metoffice.gov.uk/public/pws/invent/weathertext/index.html?352409

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### 5 Day Forecast : London

Click on a day for more information

| Day             | Weather Icon  | Date            |
|-----------------|---------------|-----------------|
| Fri 05 Aug 2011 | Cloud         | Fri 05 Aug 2011 |
| Sat 06 Aug 2011 | Cloud         | Sat 06 Aug 2011 |
| Sun 07 Aug 2011 | Sun with rain | Sun 07 Aug 2011 |
| Mon 08 Aug 2011 | Sun with rain | Mon 08 Aug 2011 |
| Tue 09 Aug 2011 | Cloud         | Tue 09 Aug 2011 |

### Severe Weather Warnings

### Text Forecast : South East England

### Hourly Observations : London Olympic Park North (Nearest observation site to London)

### Development Product - Temperature Range Forecast : London

Maximum Temperature Range

| Day             | Max   | Min  |
|-----------------|---|------|
| Fri 05 Aug 2011 | 25°C (High), 24°C (Most Likely), 23°C (Low) | 17°C |
| Sat 06 Aug 2011 | 22°C (High), 21°C (Most Likely)             | 17°C |
| Sun 07 Aug 2011 | 21°C (High), 20°C (Most Likely)             | 17°C |
| Mon 08 Aug 2011 | 21°C (High), 20°C (Most Likely)             | 18°C |
| Tue 09 Aug 2011 | 21°C (High), 20°C (Most Likely)             | 17°C |

Product Description

Following public consultation this is a new way for the Met Office to present forecast information. Temperatures will fall within the indicated range roughly 9 times out of 10 with the most likely temperature shown in green. There may be variations between this product and the 5 day forecast. We will continue to develop and improve this product.

Legend:

- High Range (Black)
- Most Likely (Green)
- Low Range (Black)



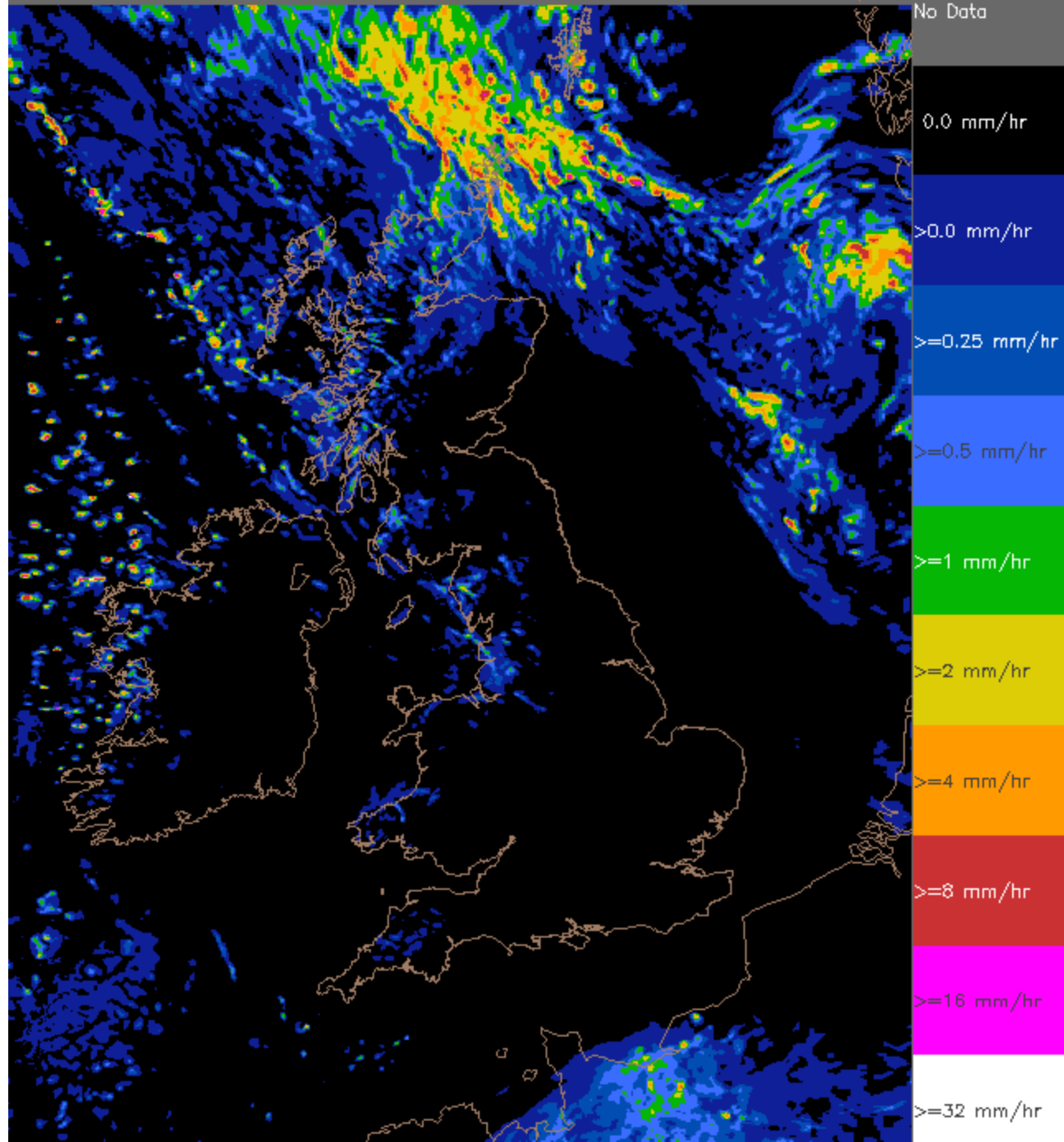
# Integrating Gridded Data UK Post-Processing (UKPP)



Met Office

## UKPP

- UKPP processes NWP outputs on a common 2km grid
- Orographic downscaling is applied to lower-resolution models
- Now applying downscaling to MOGREPS-R
  - Post-processing of MOGREPS-UK will be done on UKPP grid

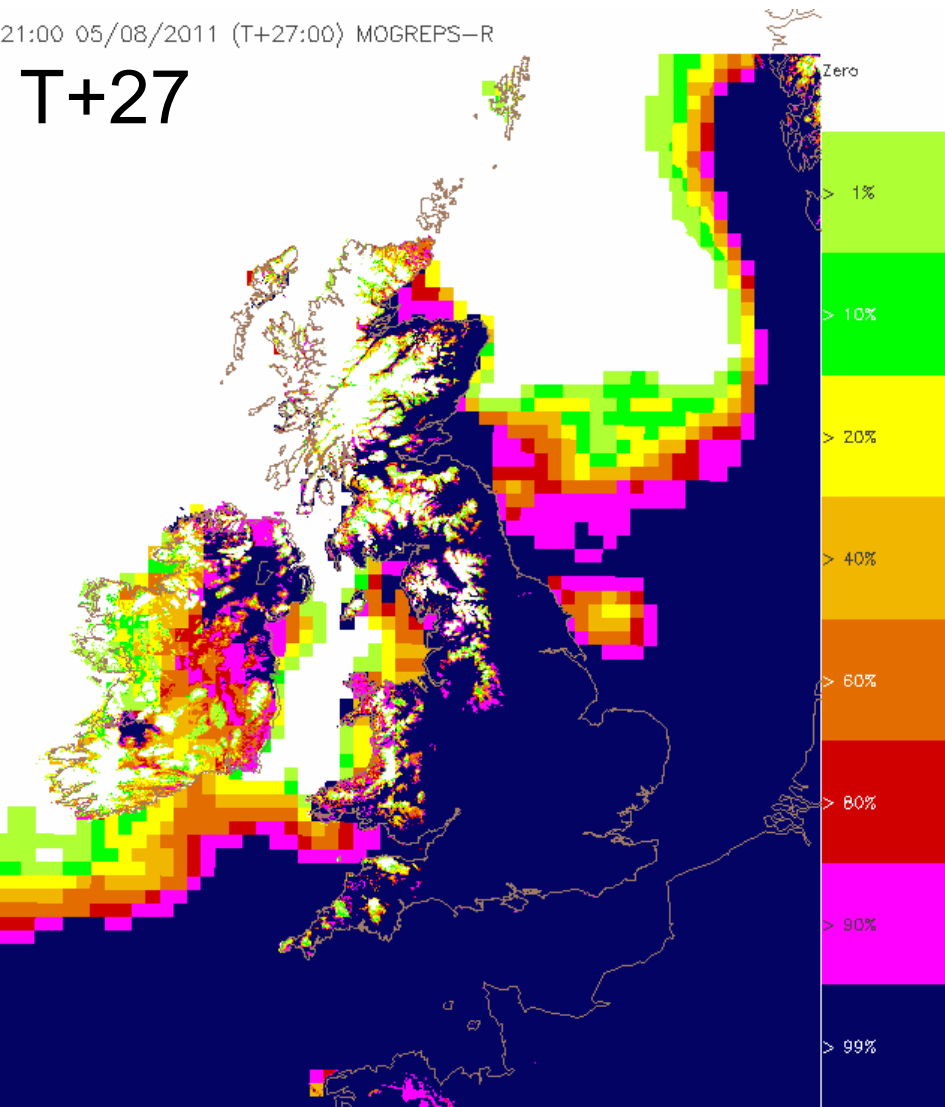




# MOGREPS Downscaled 2m Temperature Prob( $T_{max} > 15C$ ) Temperatures adjusted to high-res orography

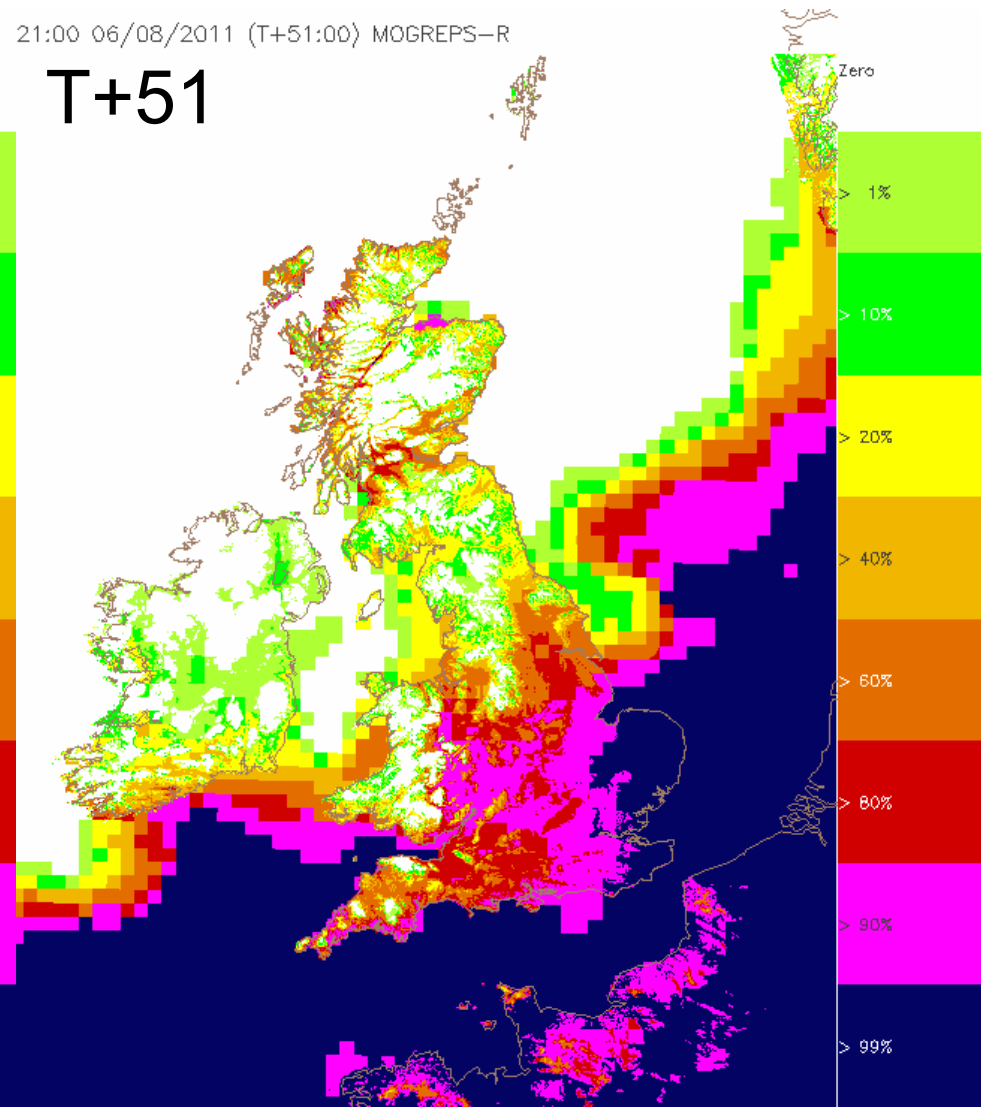
21:00 05/08/2011 (T+27:00) MOGREPS-R

T+27



21:00 06/08/2011 (T+51:00) MOGREPS-R

T+51

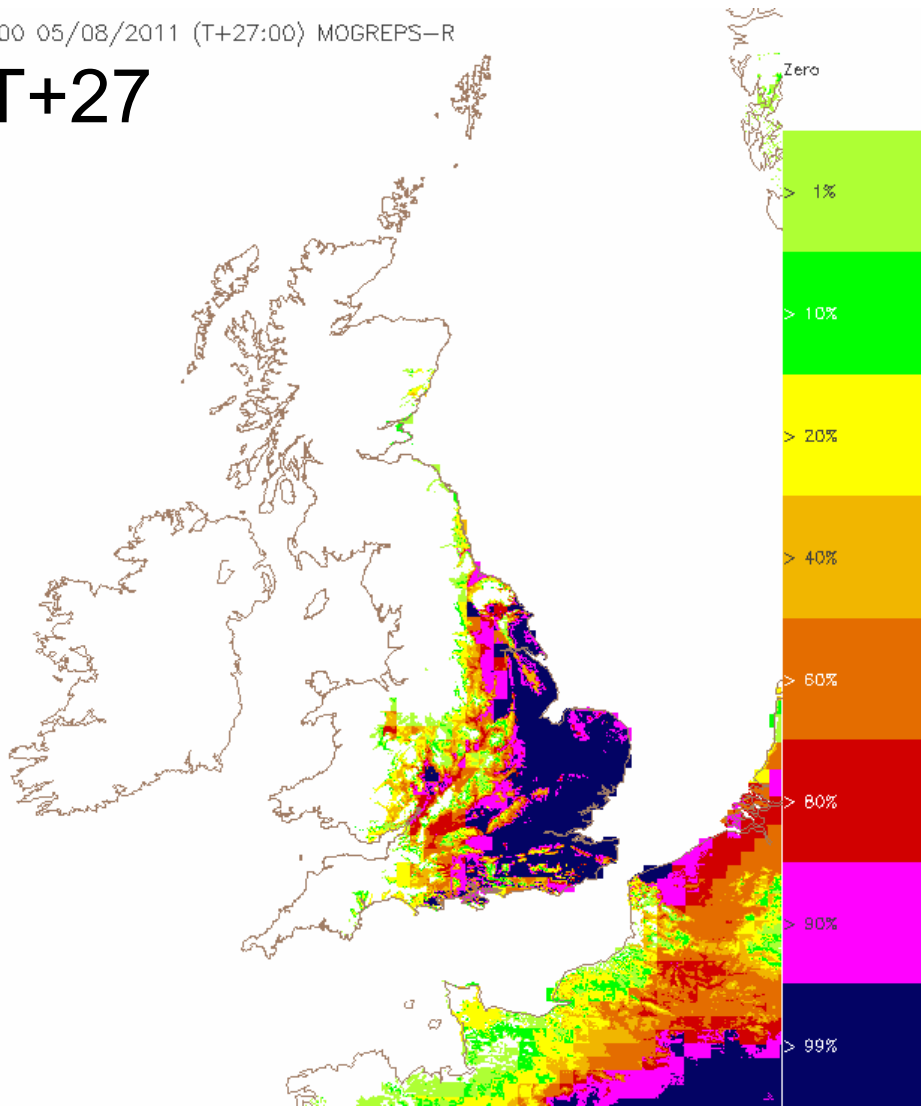




# MOGREPS Downscaled 2m Temperature Prob( $T_{max} > 20^{\circ}\text{C}$ ) Temperatures adjusted to high-res orography

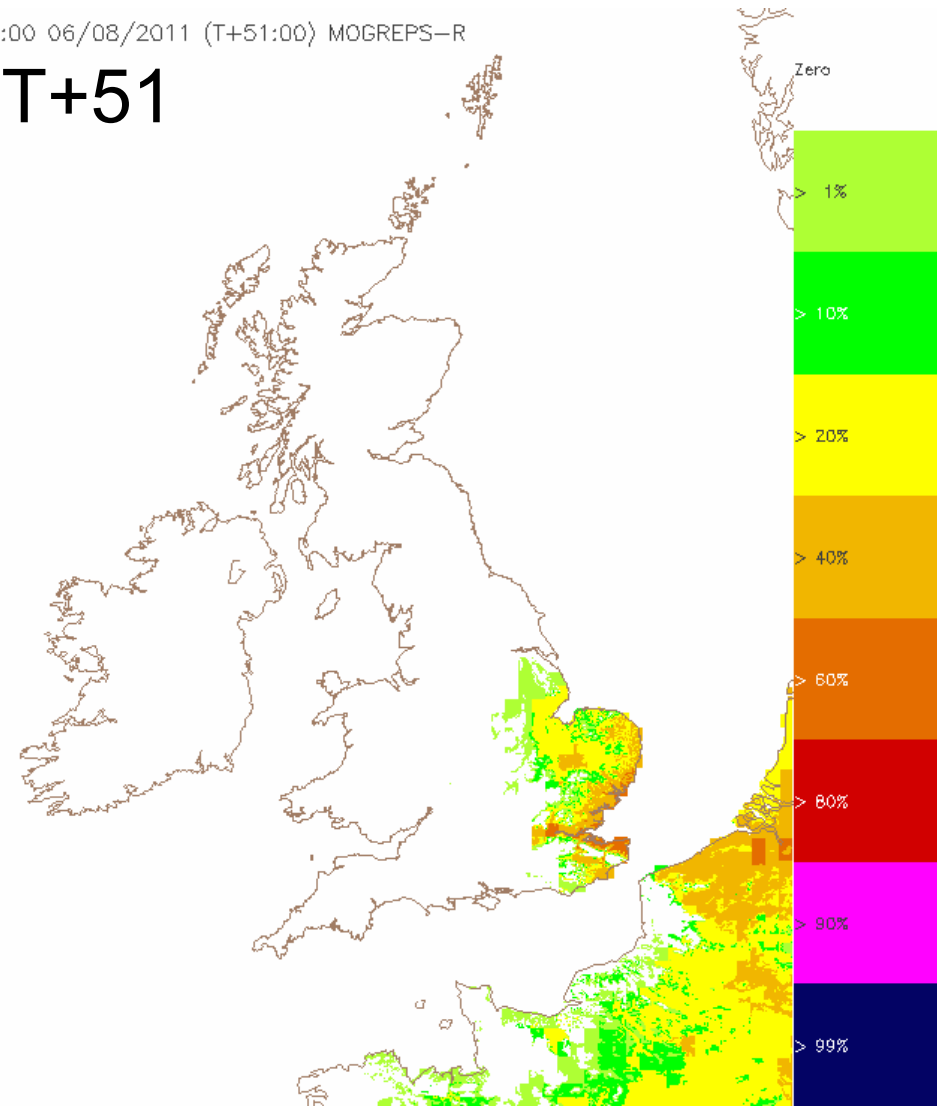
21:00 05/08/2011 (T+27:00) MOGREPS-R

## T+27



1:00 06/08/2011 (T+51:00) MOGREPS-R

## T+51

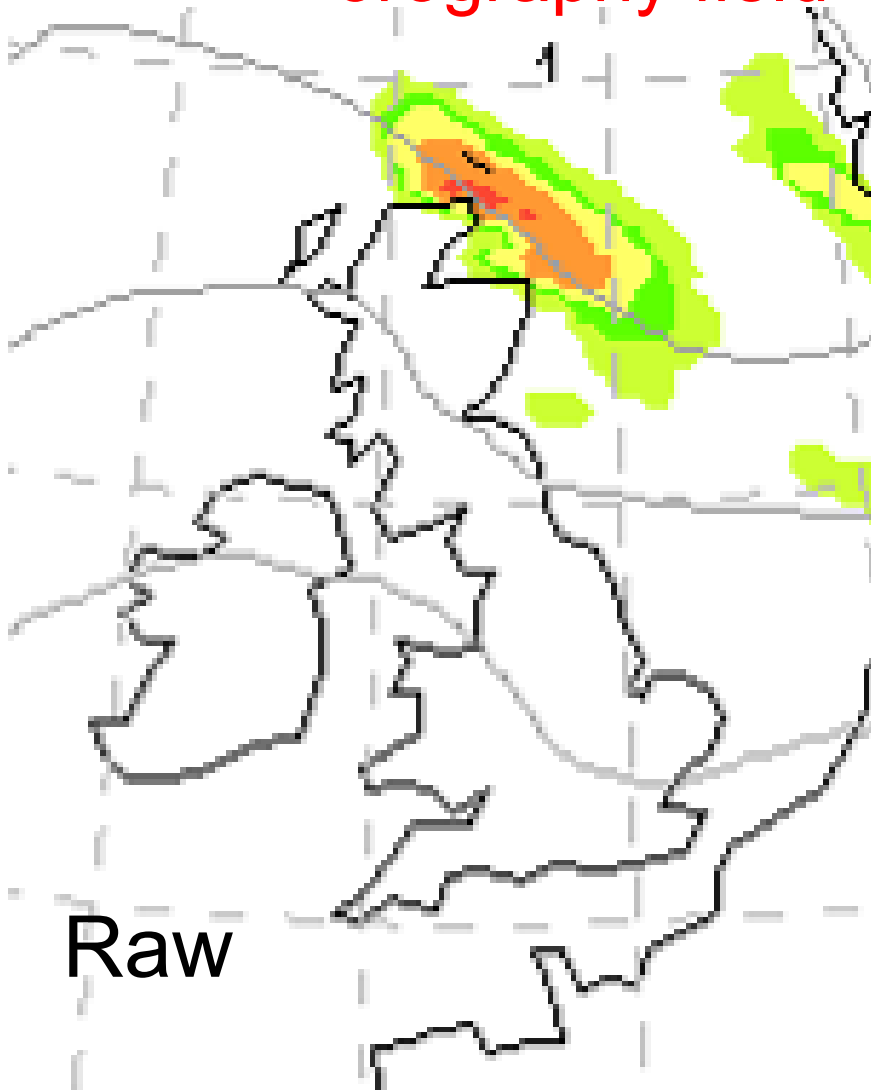




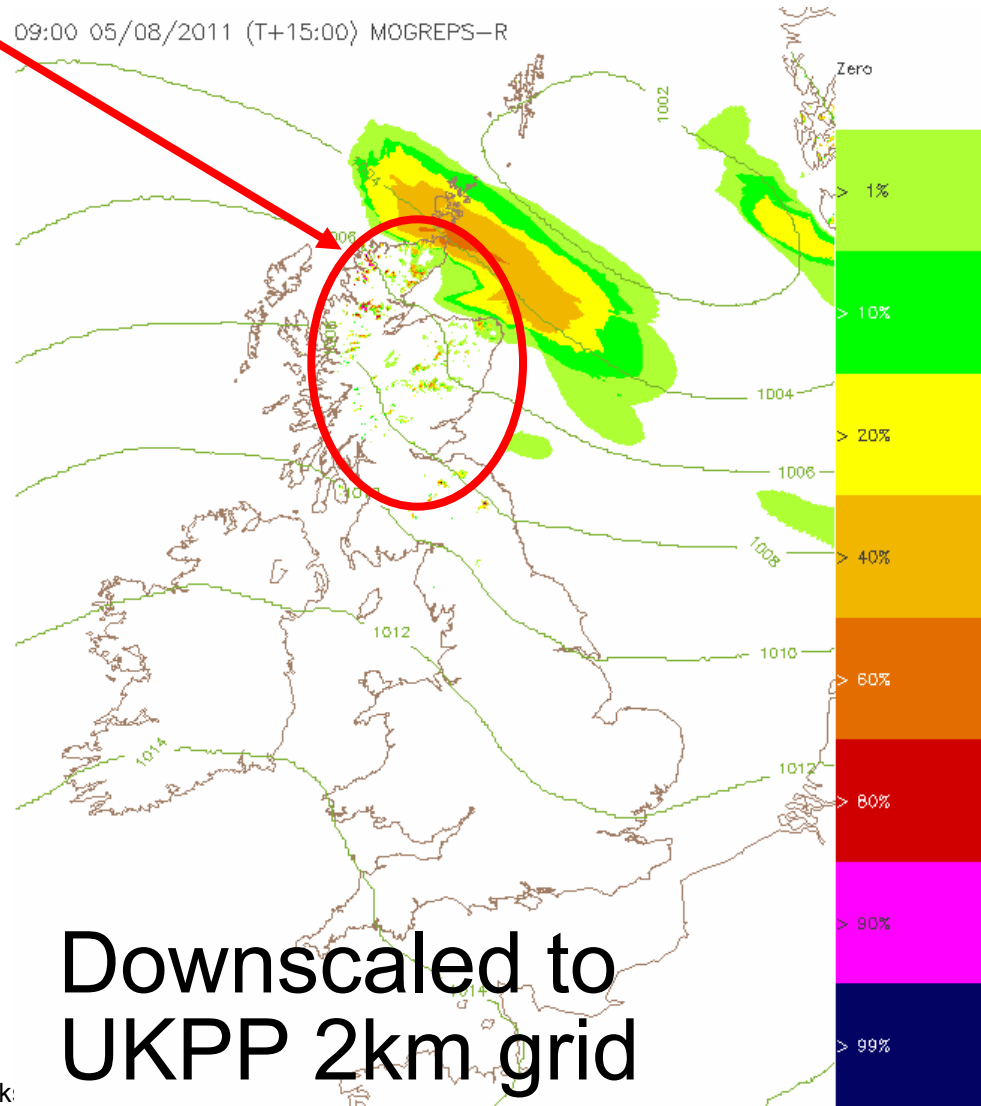


# MOGREPS $p(\text{WS} > 22\text{kt})$

Benefit of downscaling using hi-res orography field



Raw



Downscaled to UKPP 2km grid

# Summary

- Historically we have had:

“Operational”  
Deterministic  
Models



“Supplementary”  
EPS

- Finally we are getting integration:

- Common post-processing
- Compatible formats
- Blended Best Data

Blended  
Probabilistic  
NWP

- MOGREPS-UK will be integrated from Day 1



# Conclusions

- Ensemble forecasts are still widely considered to be a *nice to have* supplement to the deterministic forecast
- Integrated post-processing provides a consistent picture of the *complete* forecast
- Coupling of ensembles to a variety of impact models provides effective *risk* assessment