Representation of model error in a convective-scale ensemble

Alison Rudd
Department of Meteorology, University of Reading

Laura Baker, Stefano Migliorini & Ross Bannister

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Motivation

Errors in forecasts originate from a number of sources;

- Initial conditions (IC)

- Boundary conditions (BC)

- Model formulation - model error due to parameterisation of unresolved processes (e.g. microphysics, turbulent boundary layer processes, convection)

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Motivation

Errors in forecasts originate from a number of sources;

- Initial conditions (IC)
  - **assume this is most important at synoptic scales**
- Boundary conditions (BC)

- Model formulation - model error due to parameterisation of unresolved processes (e.g. microphysics, turbulent boundary layer processes, convection)
  - **likely to be very important at convective-scale resolution**
    - **want to add representation of model error**

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Questions

At convective-scale:

- **How does model error affect the spread of the ensemble?**
- **How does model error affect the forecast skill?**

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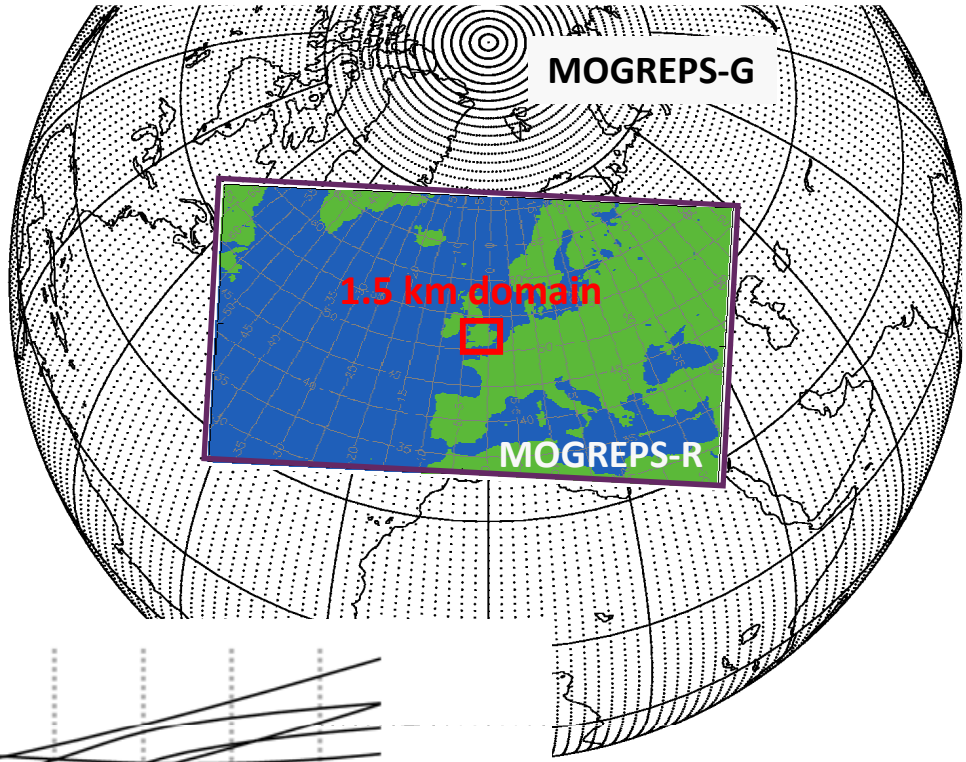
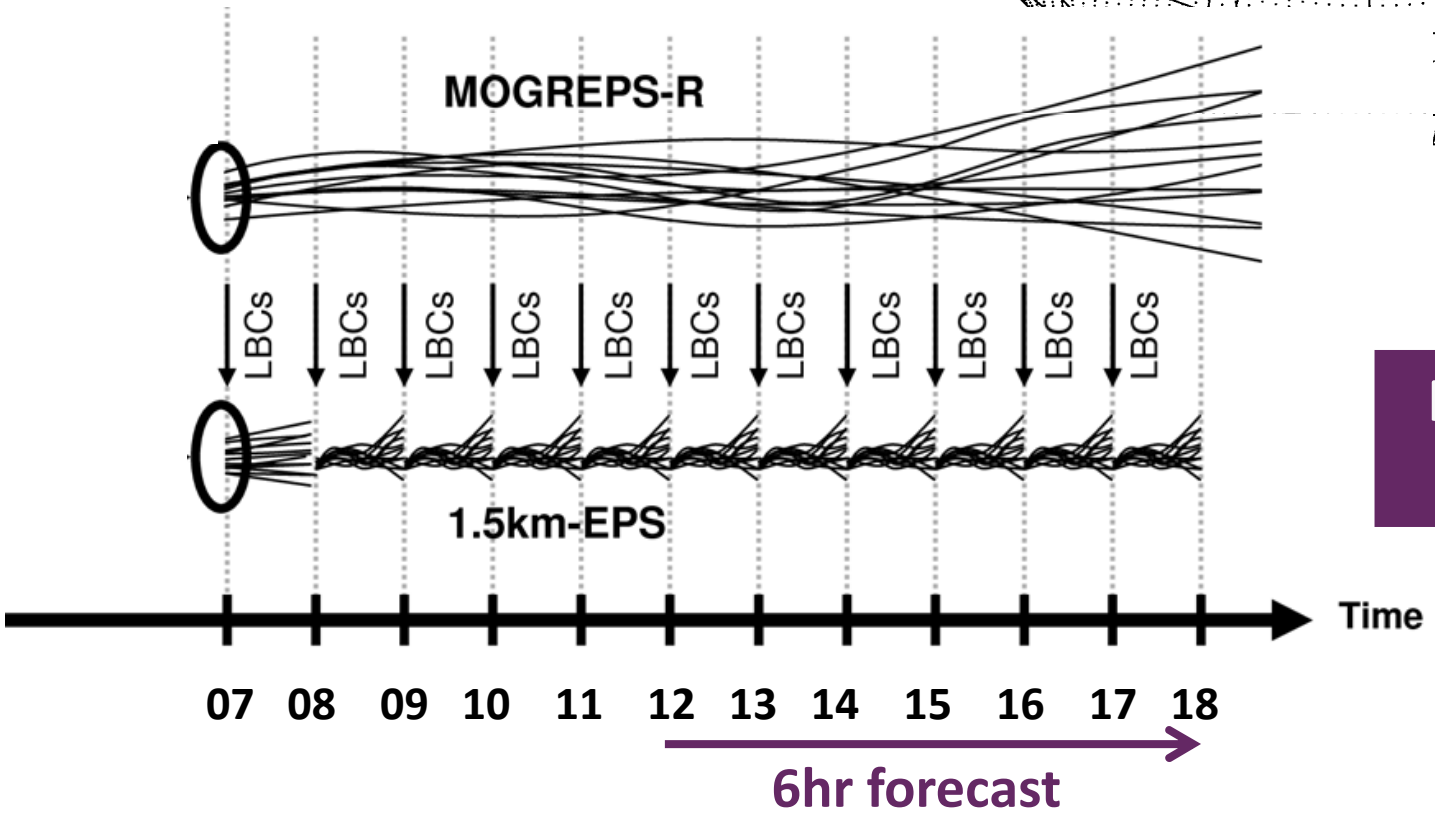
Outline

- Method
- Case study
- Ensemble evaluation
- Summary
- Ongoing work

1.5km-EPS: The setup

- ctl: 3D-Var analysis & 23 members
- LBCs from MOGREPS-R and UK 4km
- first cycle IC perts from MOGREPS-R
- IC perts - hourly cycling ETKF
- convection-permitting
- southern UK domain





RESEARCH EPS

Simulating model error

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- Use the **random parameters** (RP) scheme
- Used operationally in MOGREPS
  - not previously been used in the 1.5km-EPS
- Random parameters scheme treats parameters in various parameterisation schemes as stochastic variables
- Applies different random perturbations to the parameters for each ensemble member
- MOGREPS - parameters are fixed for 3 hours

RP scheme formulation

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- Based on first-order auto-regression model:

$$P_t = \mu + r\,(P_{t-1} - \mu) + \varepsilon$$

where P_t is the parameter value at time t

μ is the mean value of the parameter

$r = 0.95$ is the auto-correlation of P

ε is the stochastic shock term (random value in the range $\pm\,(P_{max} - P_{min})/3)$

- P_{max} and P_{min} are physically sensible max and min values of the parameters
- μ is the default parameter value
- P_t rounded up/down to P_{min}/P_{max} if new value goes outside the range

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RP parameters

- MOGREPS (2008)

  RP scheme applied to 2 parameters in each of the

  - Convection
  - Gravity-wave drag
  - Boundary layer (5 more added in 2010)
  - Large-scale precipitation

  schemes

RP scheme for convective-scale

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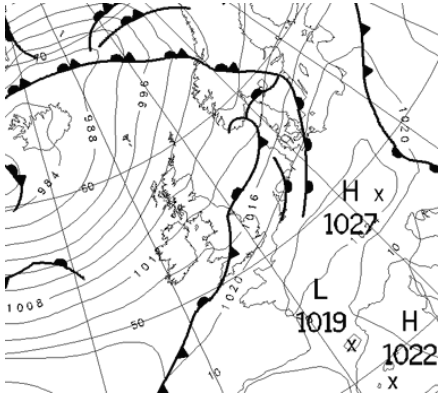
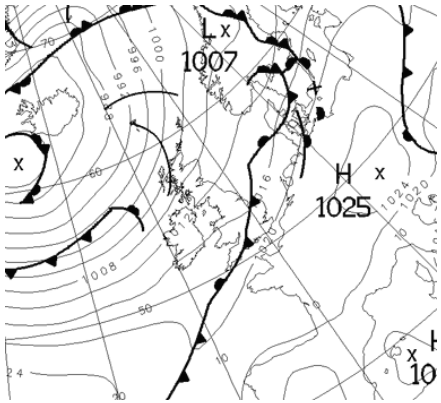
- At 1.5km resolution the convection and gravity-wave drag schemes are not active

- Modifications:
  - Added about 20 new parameters to the RP scheme
    - Identify extra parameters in the large-scale precipitation scheme to perturb
    - Sensitivity tests with the parameters set individually to the maximum and/or minimum values in suggested range
  - Revised update time: results here for 30-minute update (instead of 3 hours)

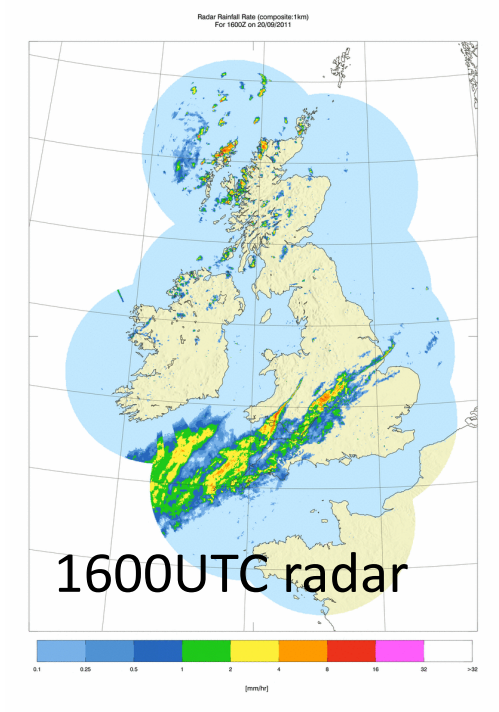
Case Study: 20th Sept 2011



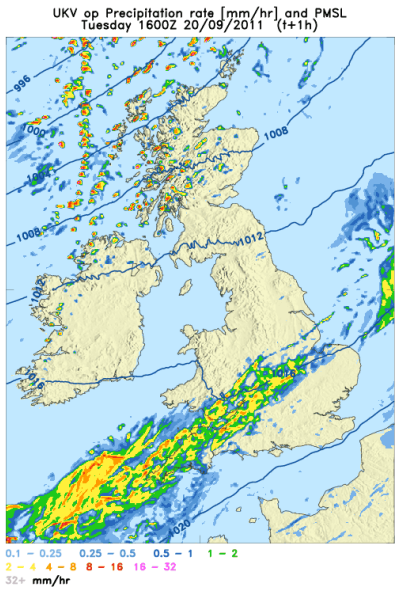
1200UTC analysis



1800UTC analysis

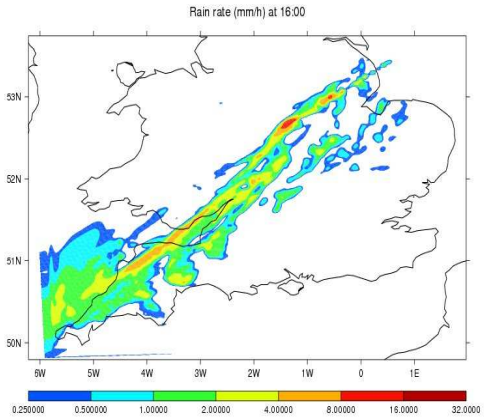


1600UTC radar



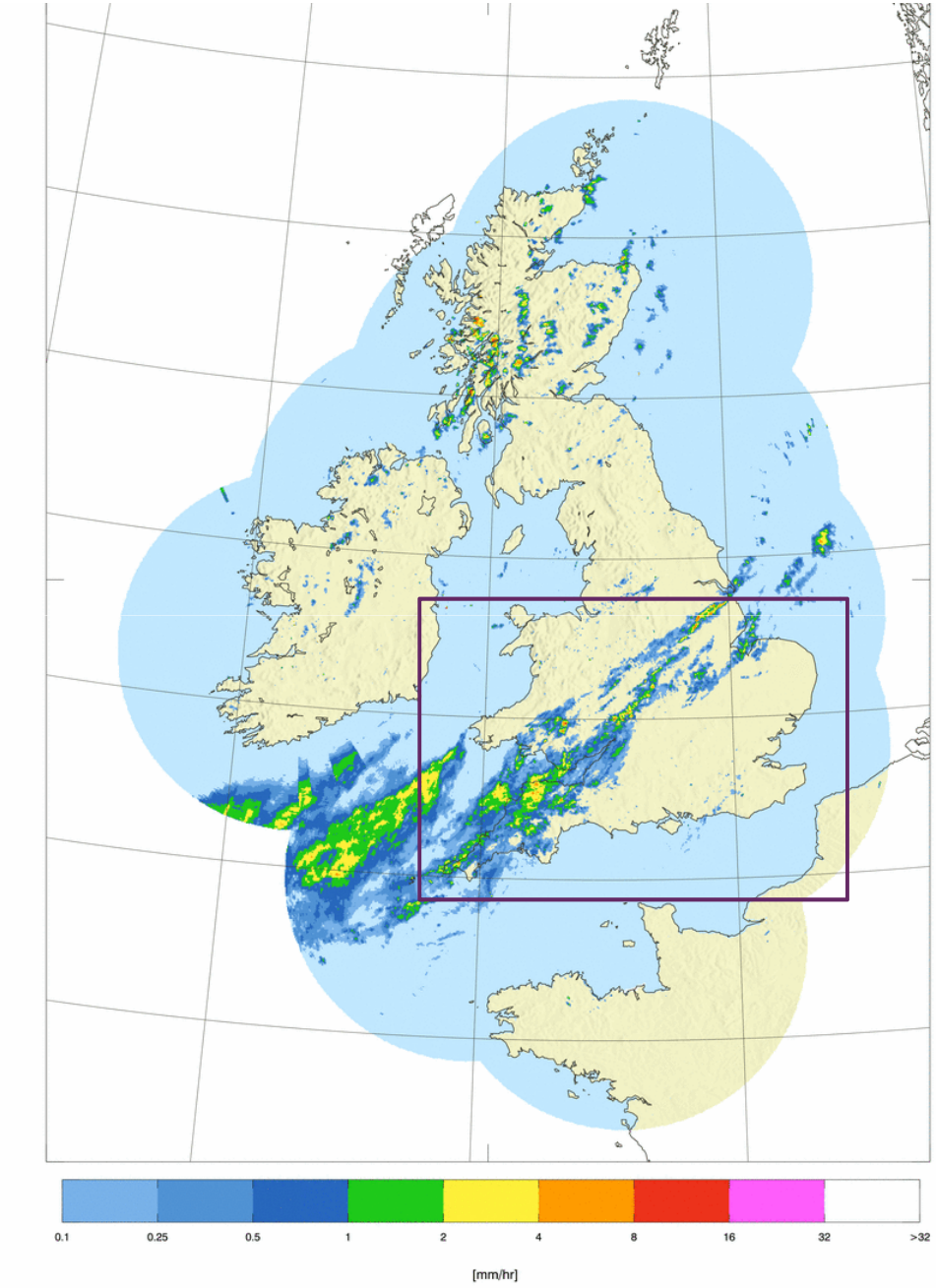
1600UTC UKV T+1h

- DIAMET IOP2
- Frontal wave structure
- Trailing cold front
- SW-NE flow across southern UK
- Interesting banded structure in radar not captured in operational 1.5km forecast or our control forecast



Control forecast, 1600UTC (T+4)

Radar rainfall rate (1km composite)



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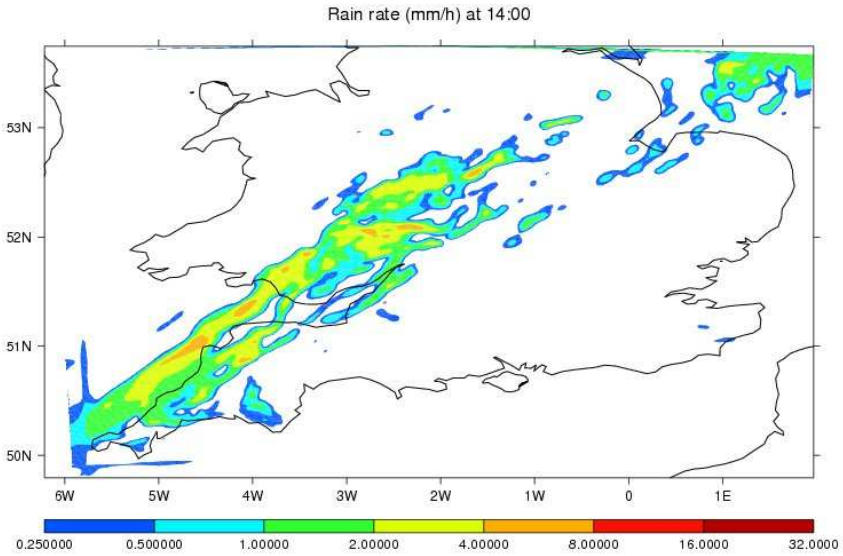
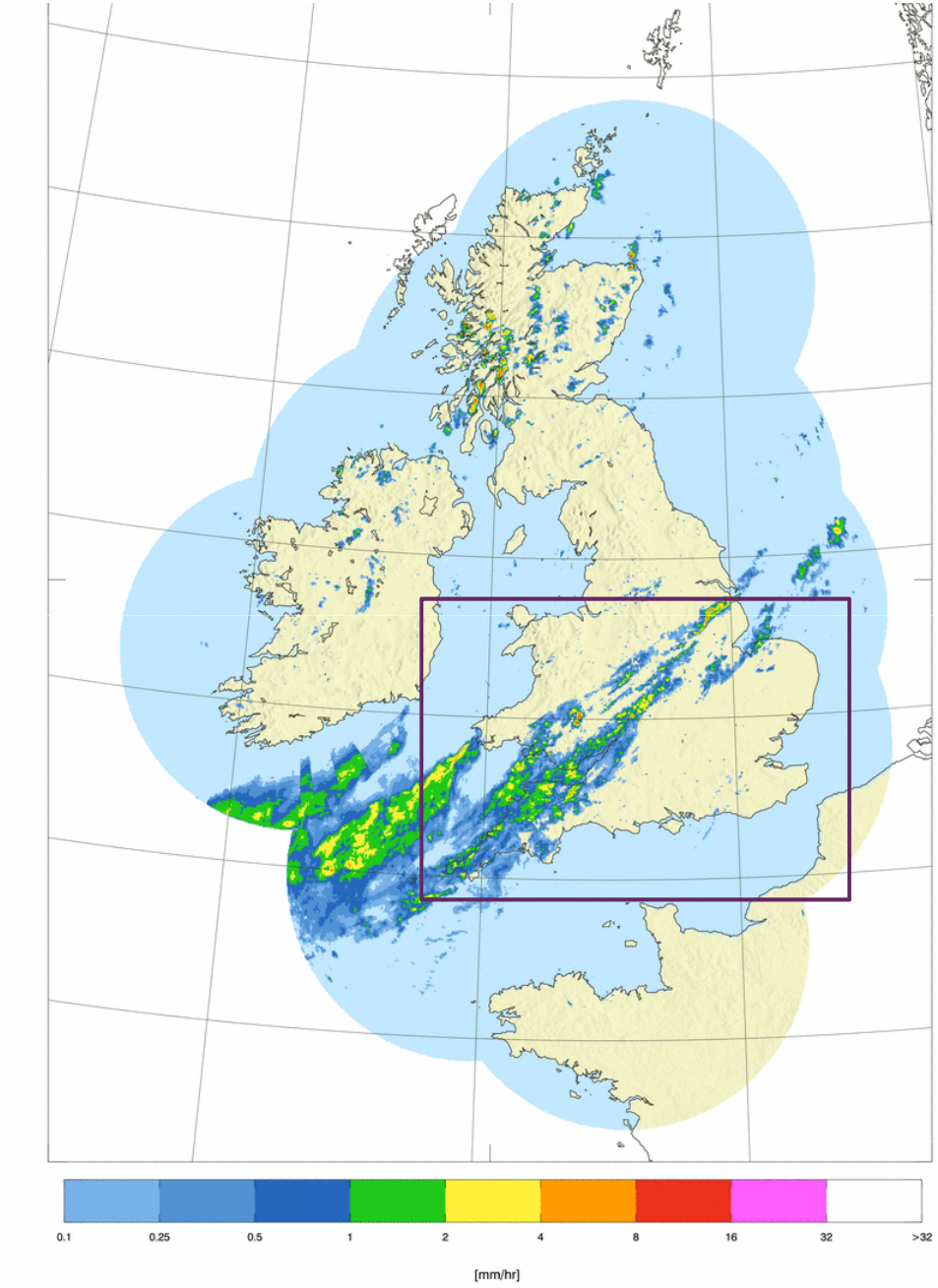
Control forecast rainfall rate



1400 UTC

Radar rainfall rate (1km composite)



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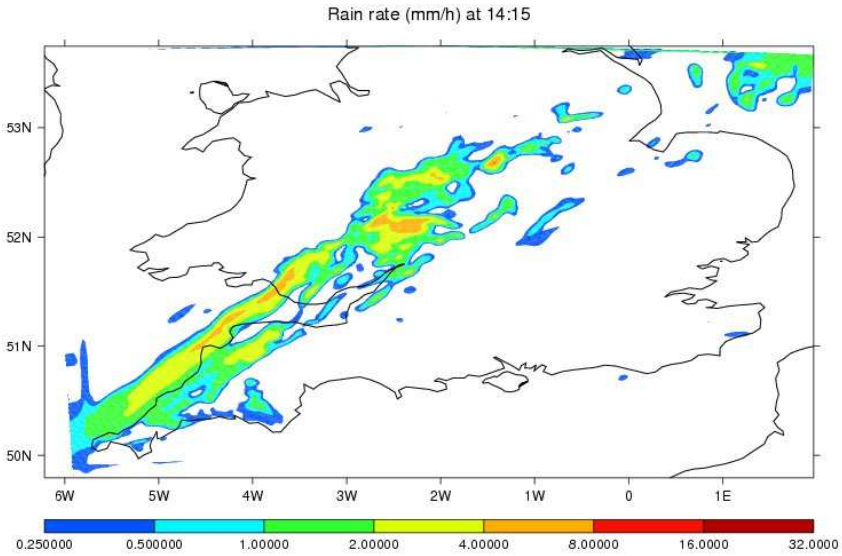
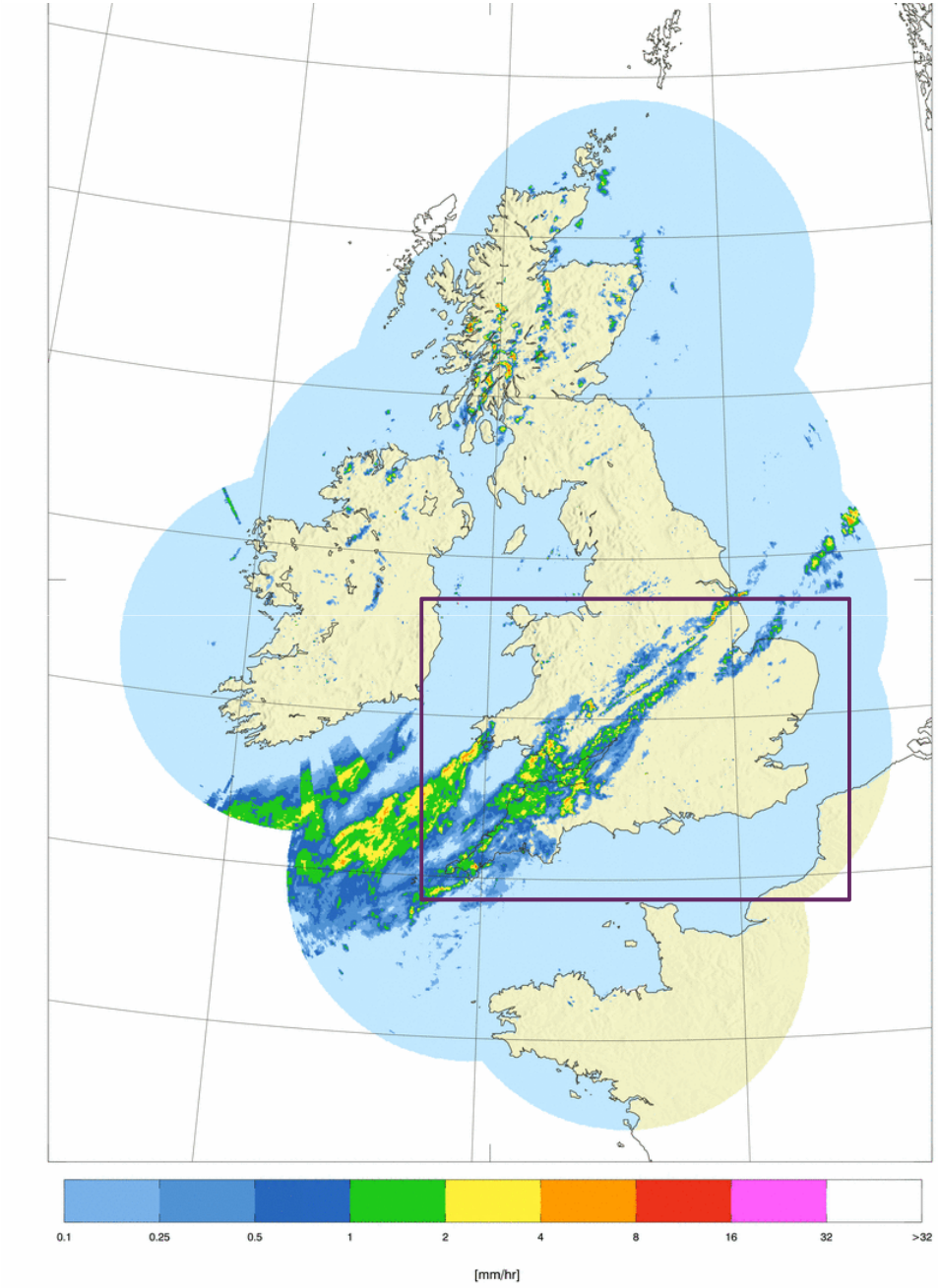
Control forecast rainfall rate



1415 UTC

Radar rainfall rate (1km composite)



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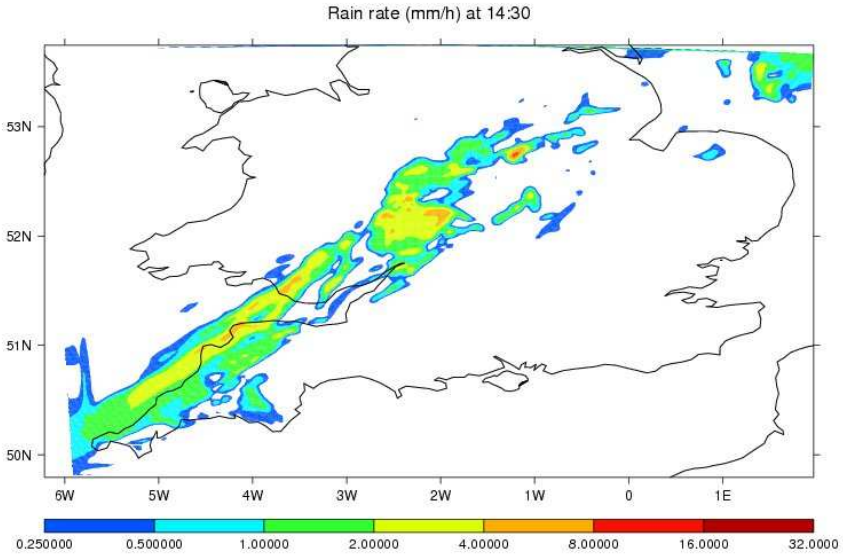
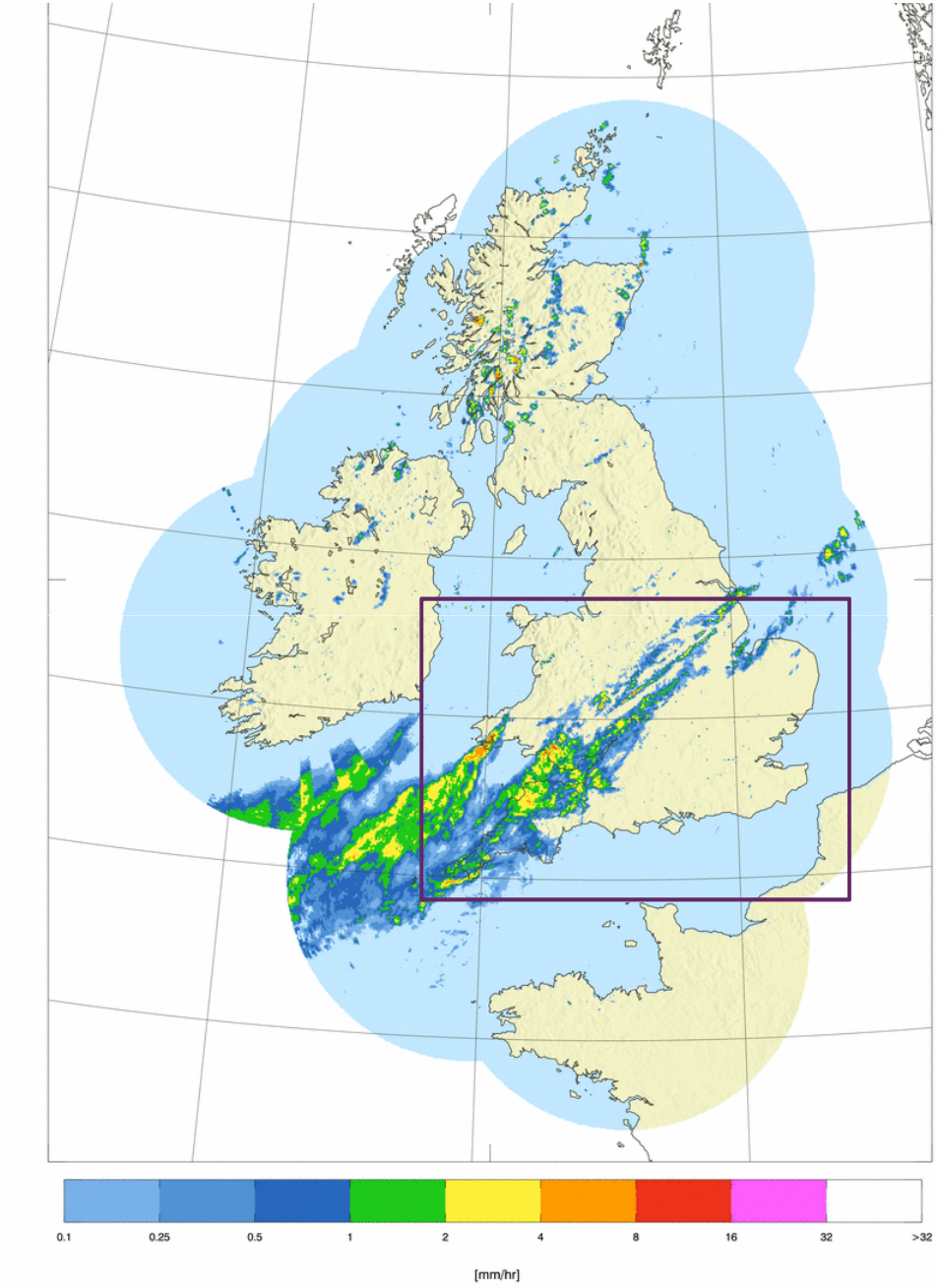
Control forecast rainfall rate



1430 UTC

Radar rainfall rate (1km composite)



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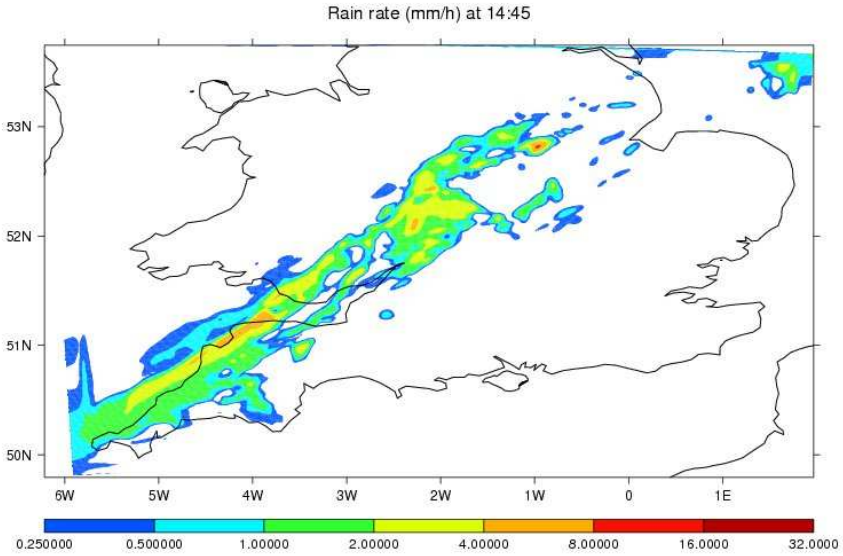
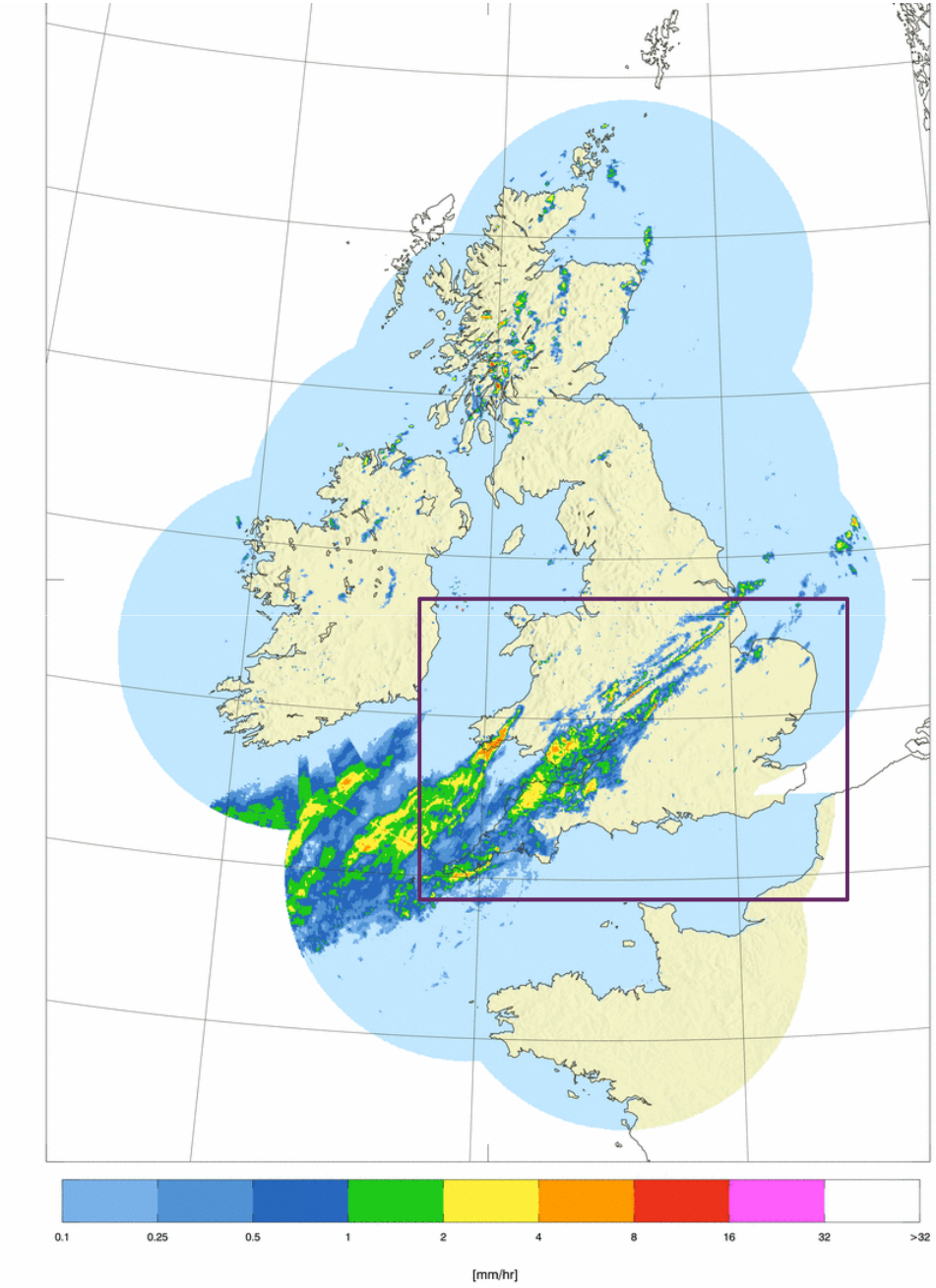
Control forecast rainfall rate



1445 UTC

Radar rainfall rate (1km composite)



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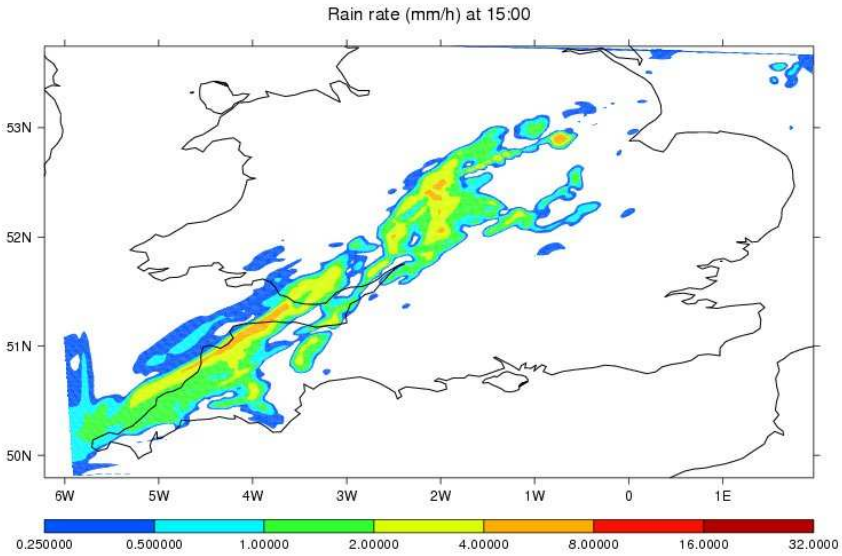
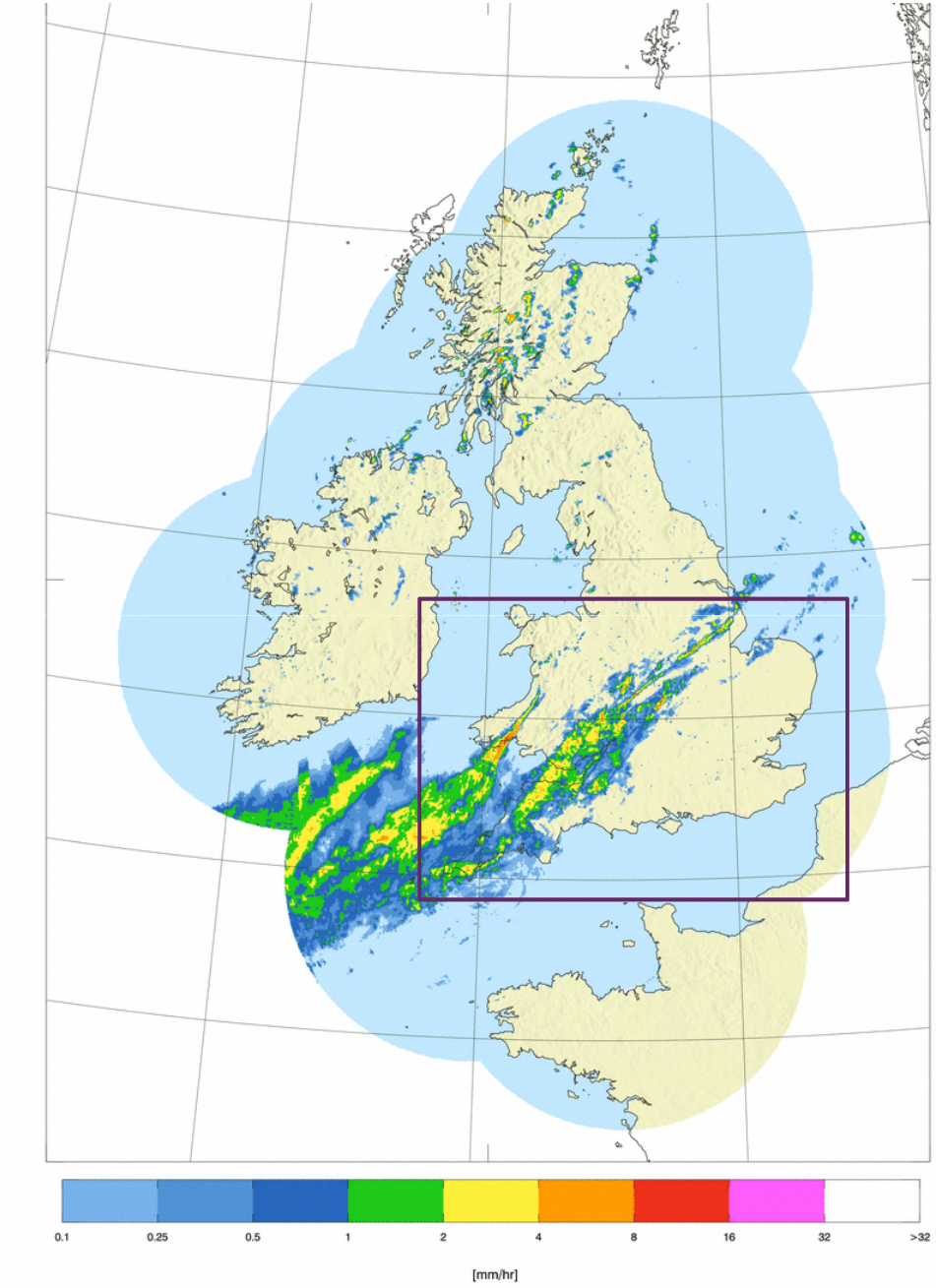
Control forecast rainfall rate



1500 UTC

Radar rainfall rate (1km composite)



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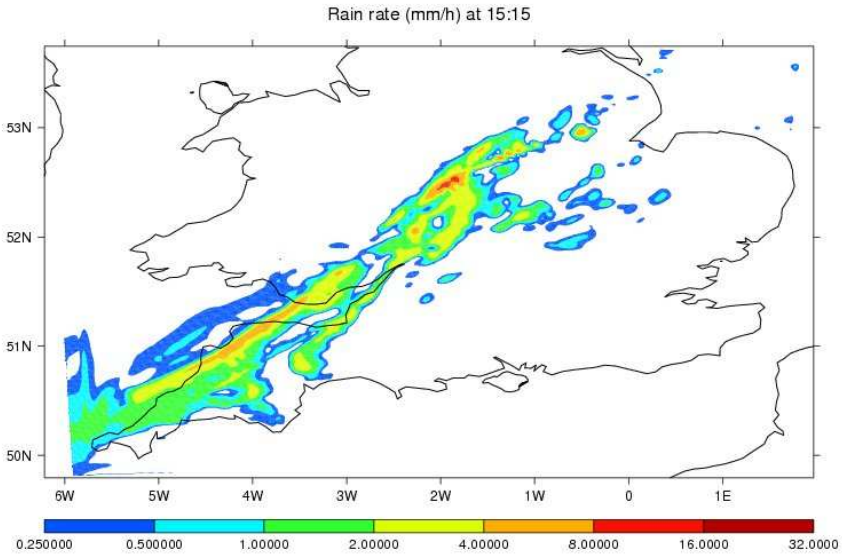
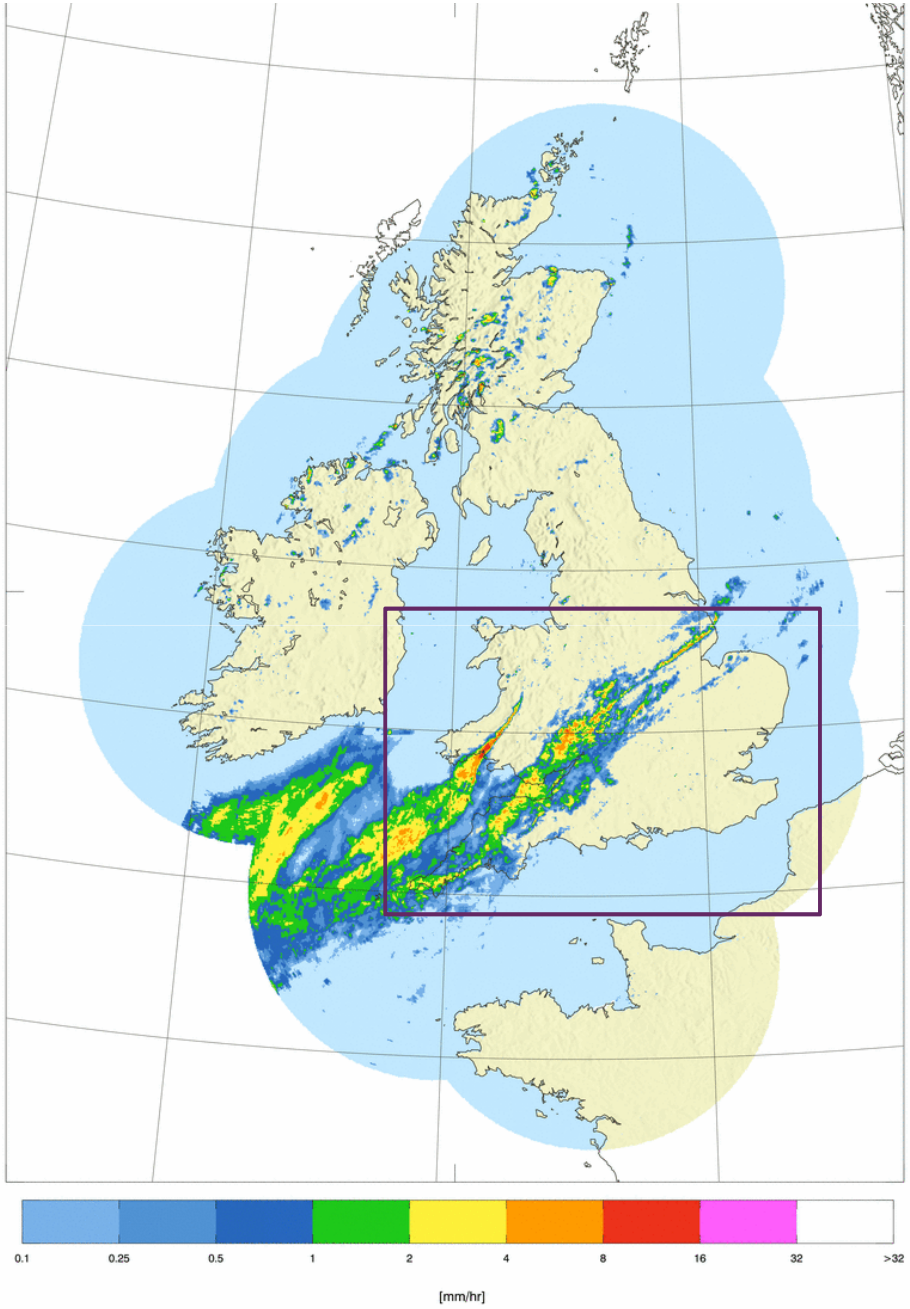
Control forecast rainfall rate



1515 UTC

Radar rainfall rate (1km composite)



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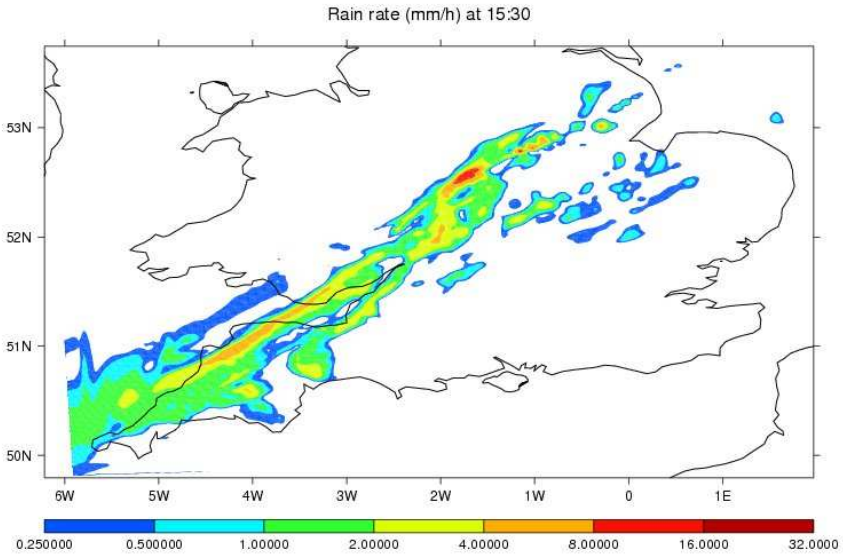
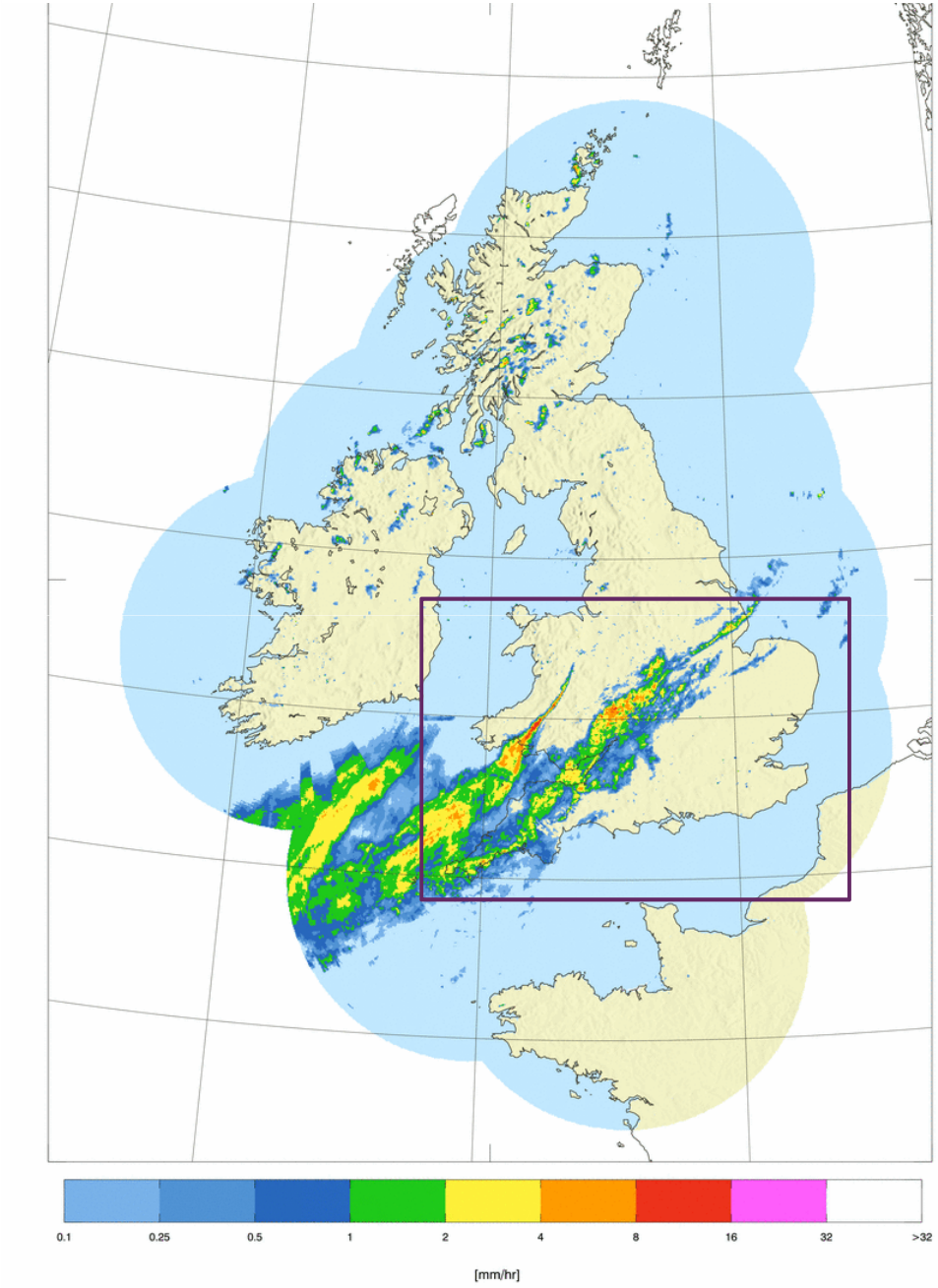
Control forecast rainfall rate



1530 UTC

Radar rainfall rate (1km composite)



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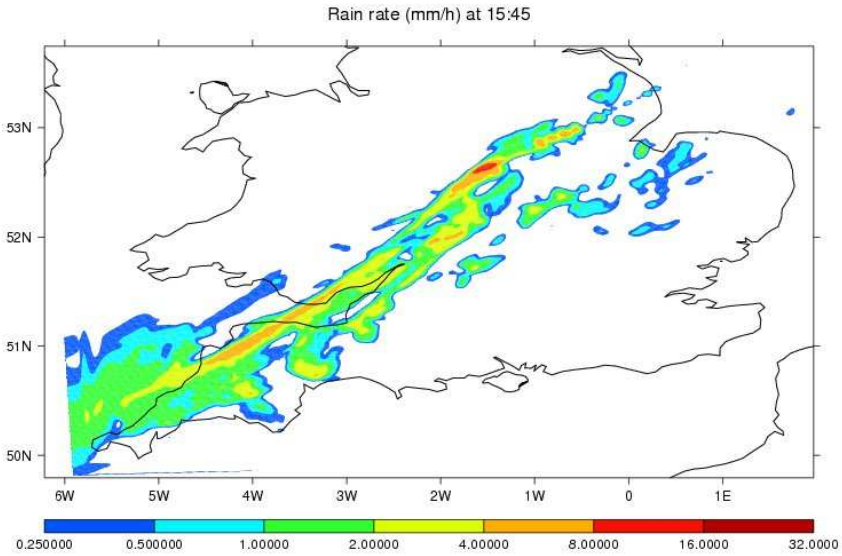
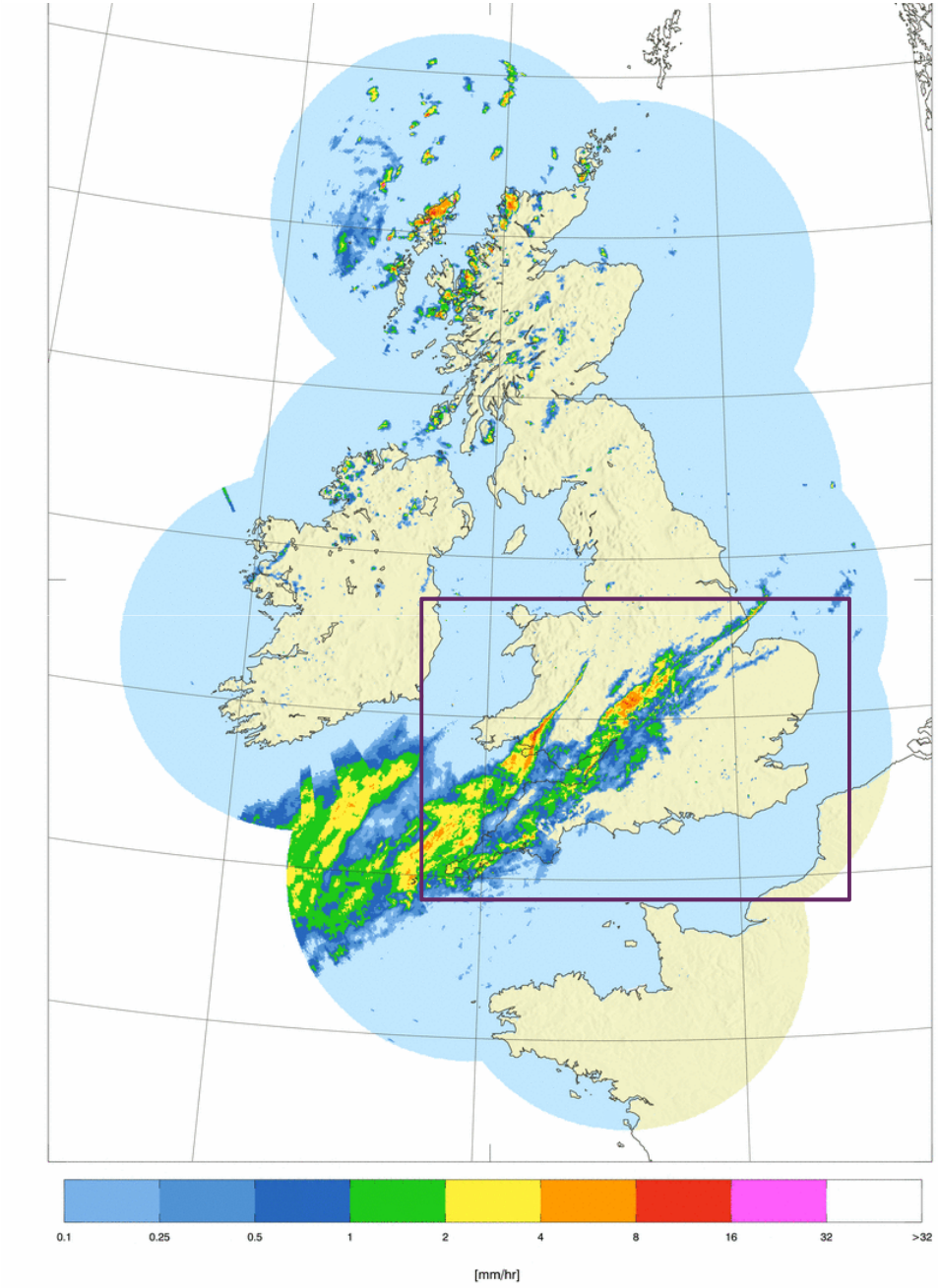
Control forecast rainfall rate



1545 UTC

Radar rainfall rate (1km composite)



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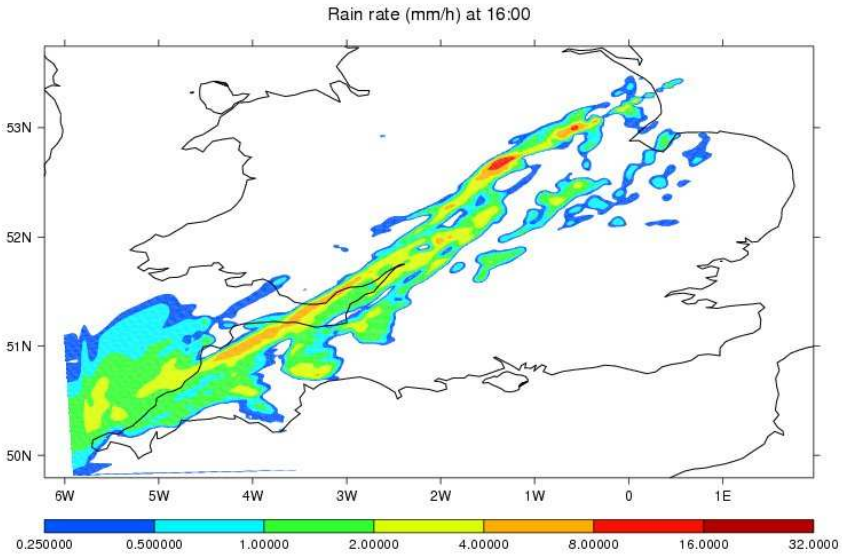
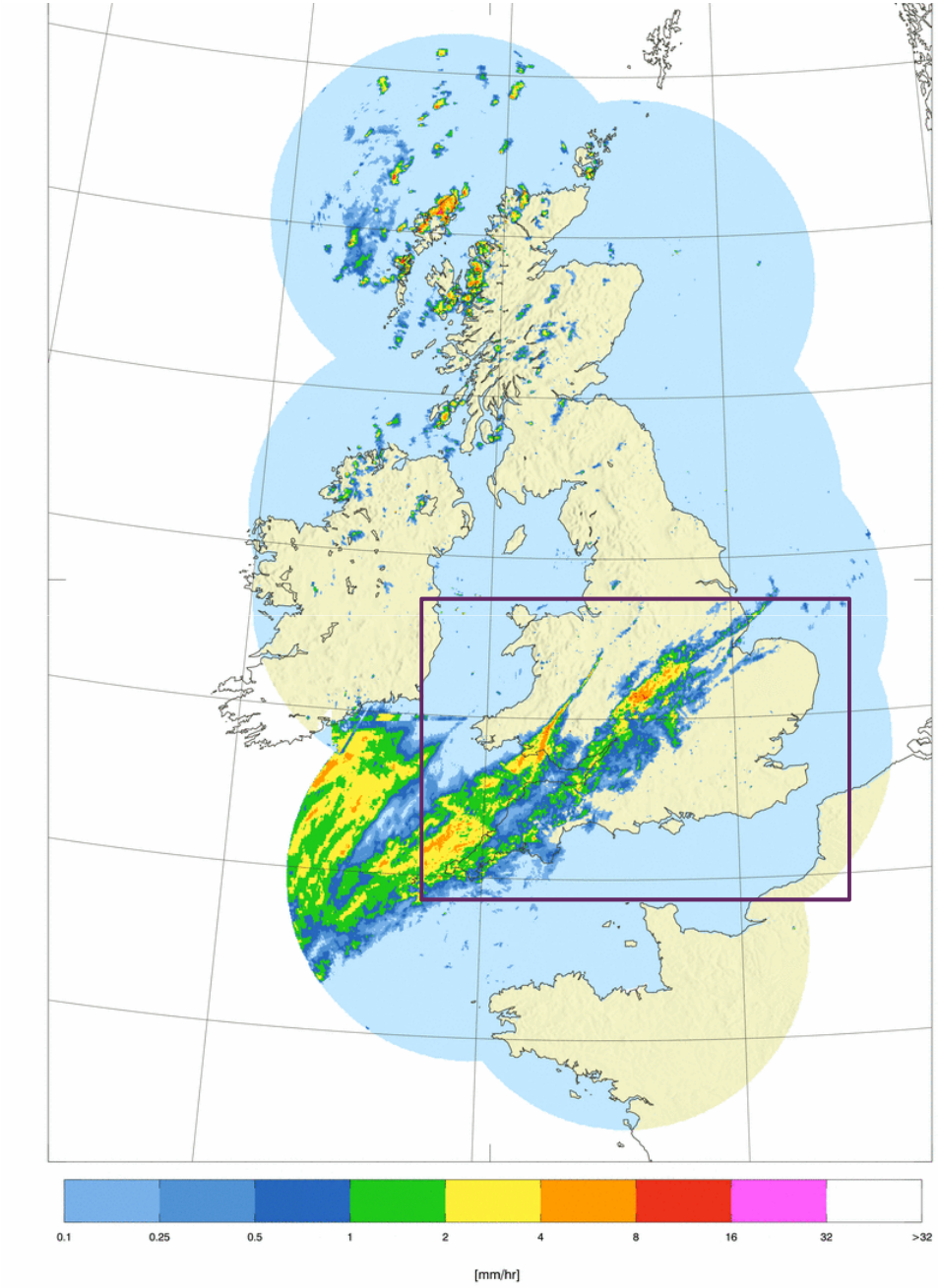
Control forecast rainfall rate



1600 UTC

Radar rainfall rate (1km composite)



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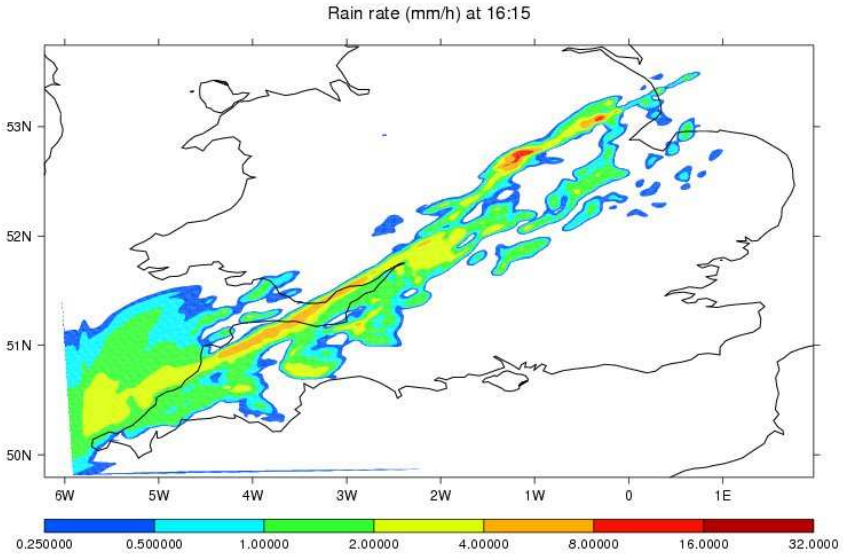
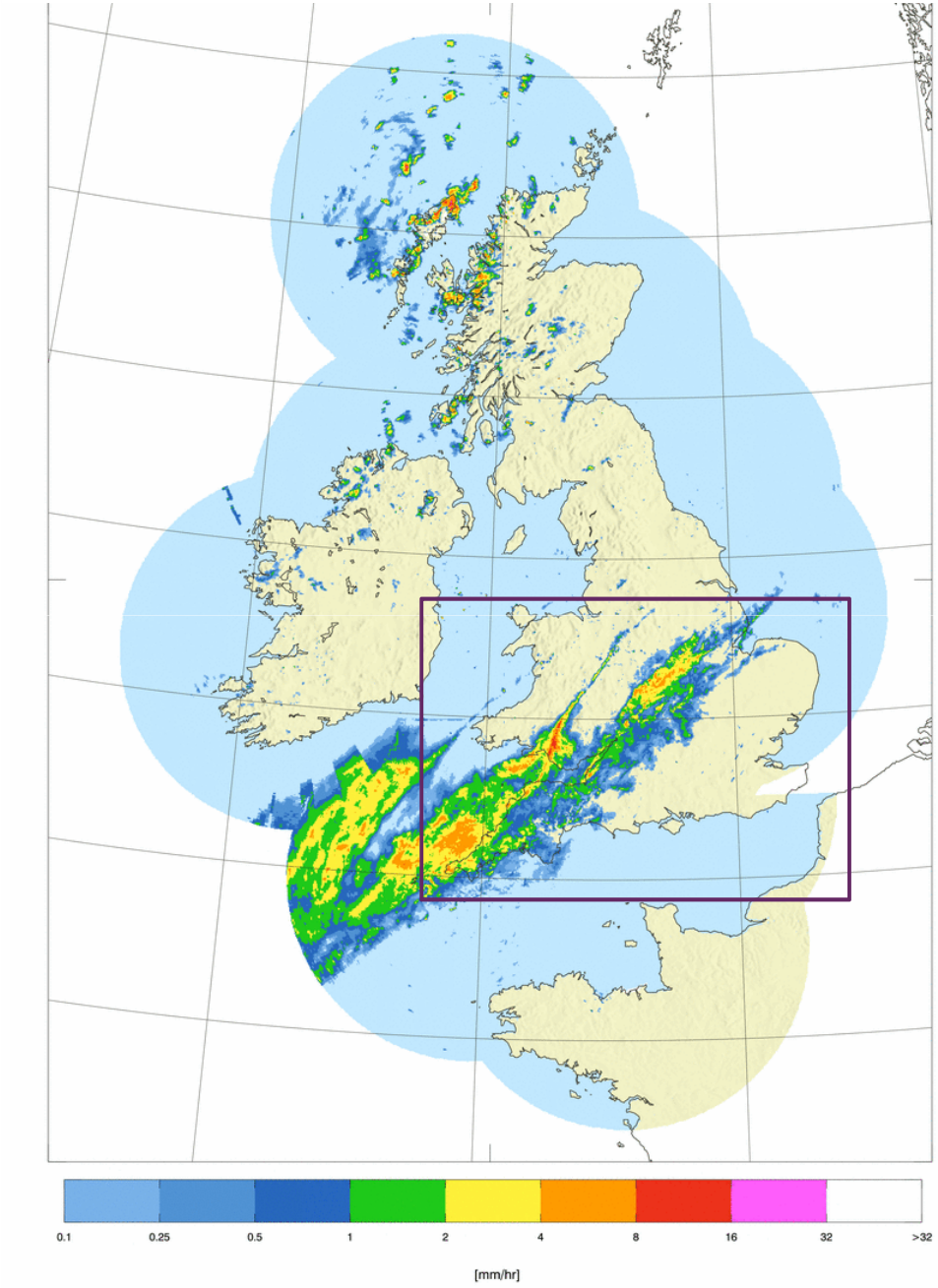
Control forecast rainfall rate



1615 UTC

Radar rainfall rate (1km composite)



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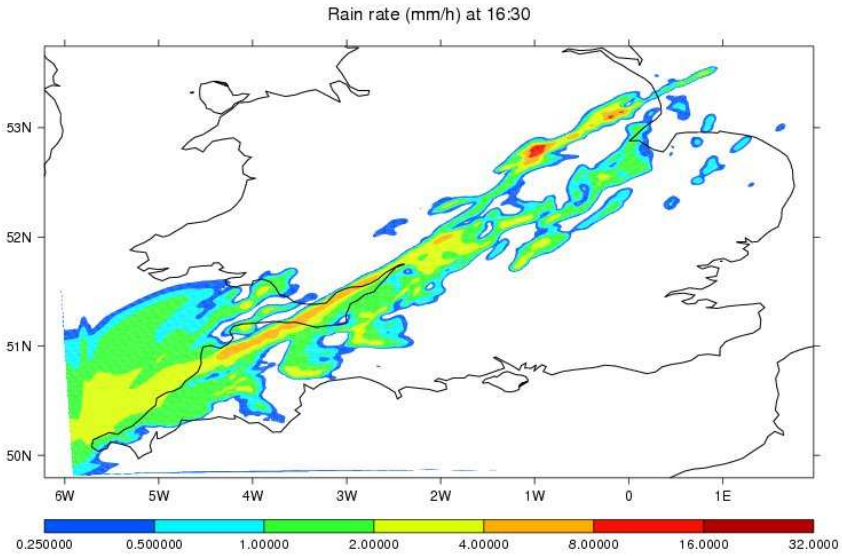
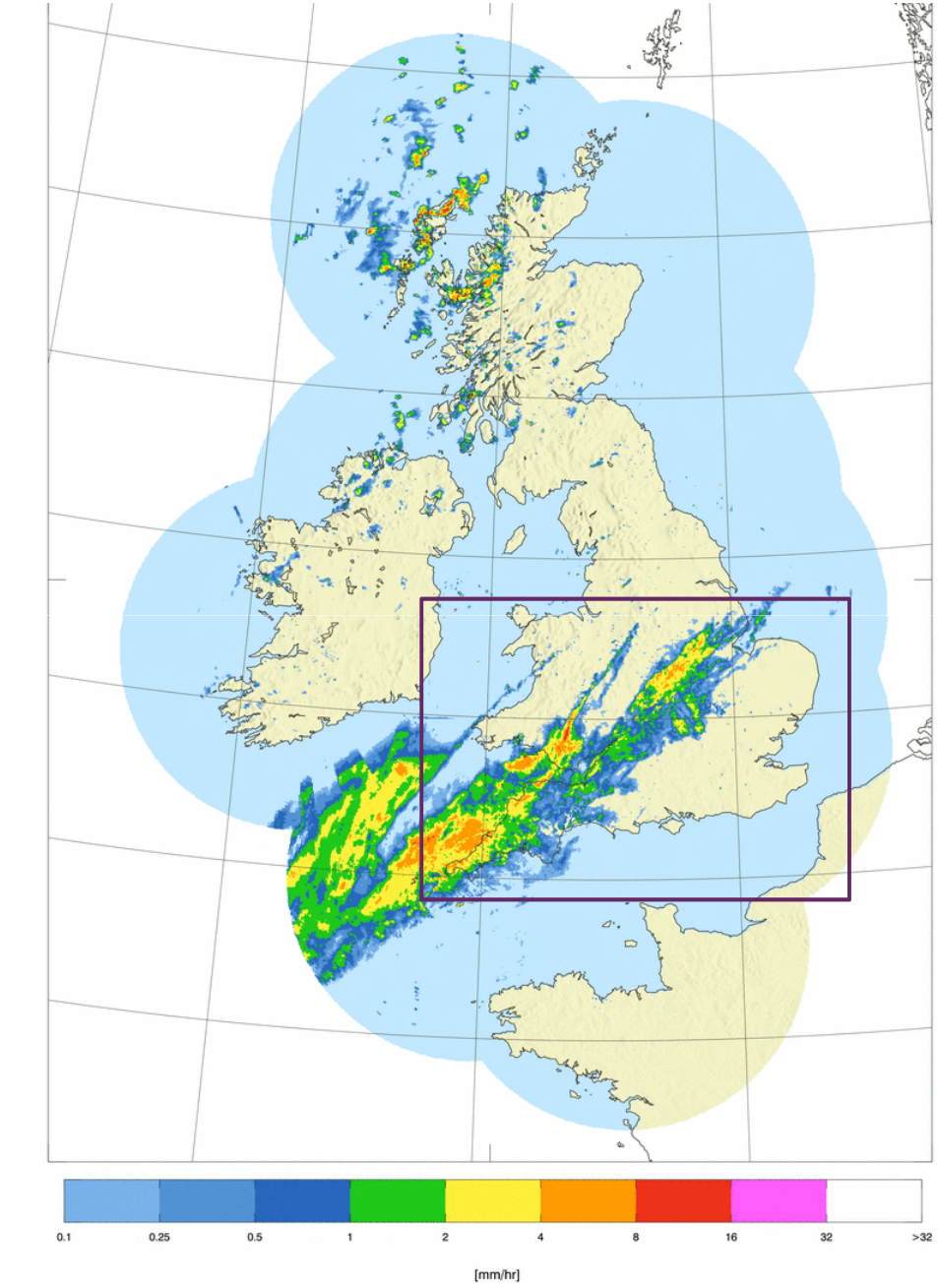
Control forecast rainfall rate



1630 UTC

Radar rainfall rate (1km composite)



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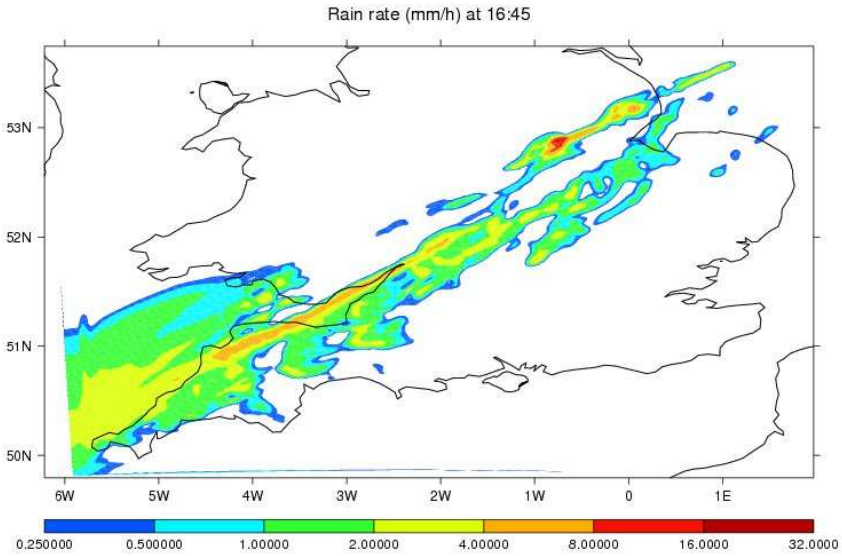
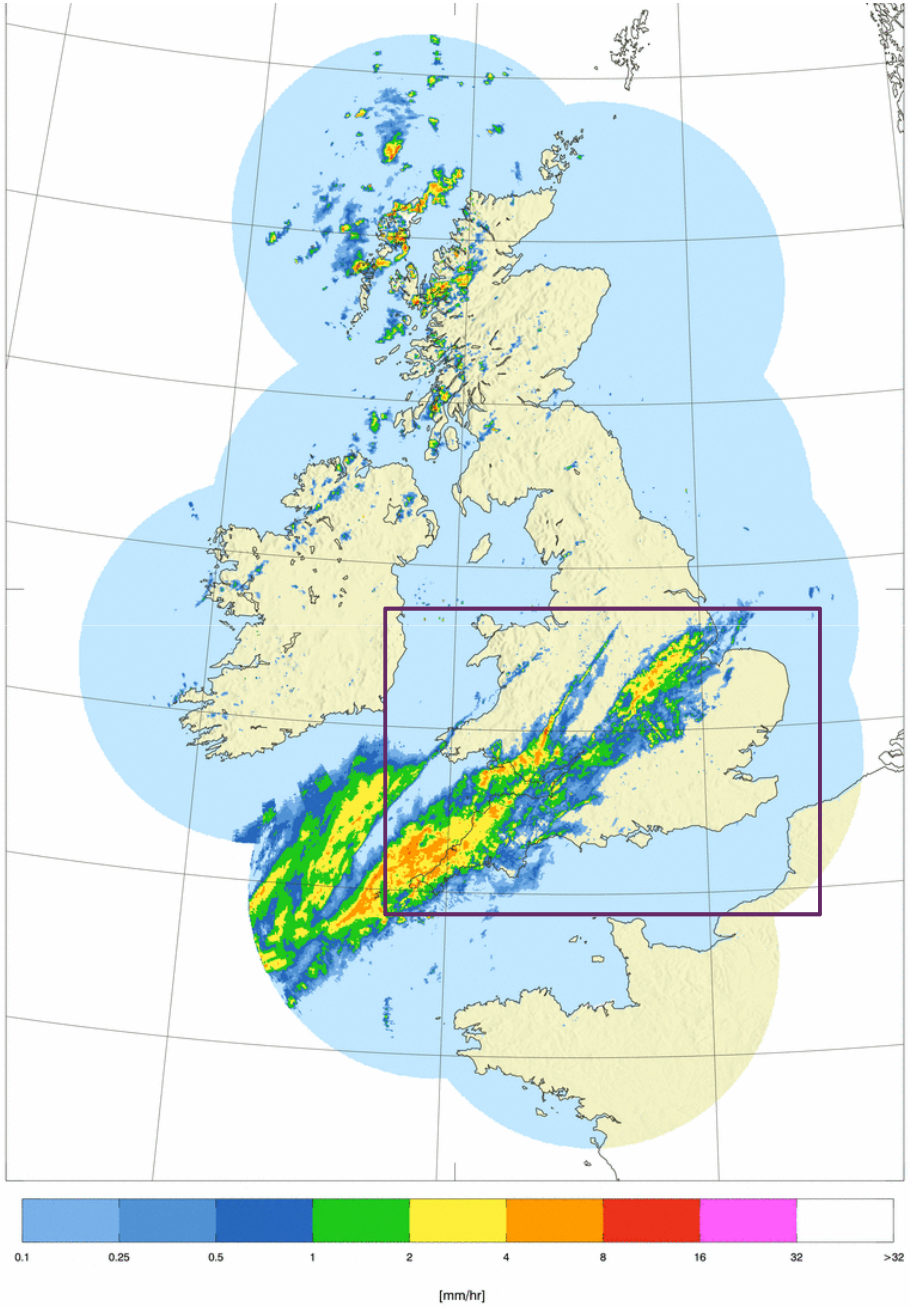
Control forecast rainfall rate



1645 UTC

Radar rainfall rate (1km composite)



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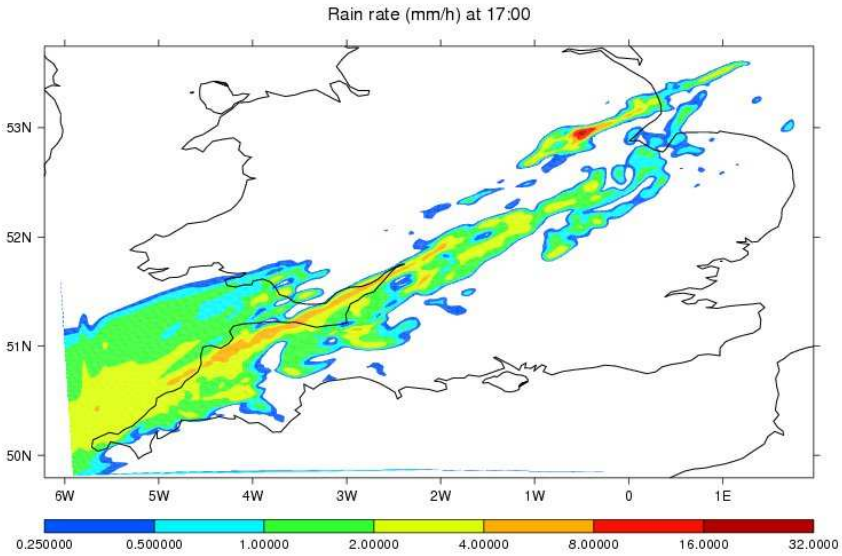
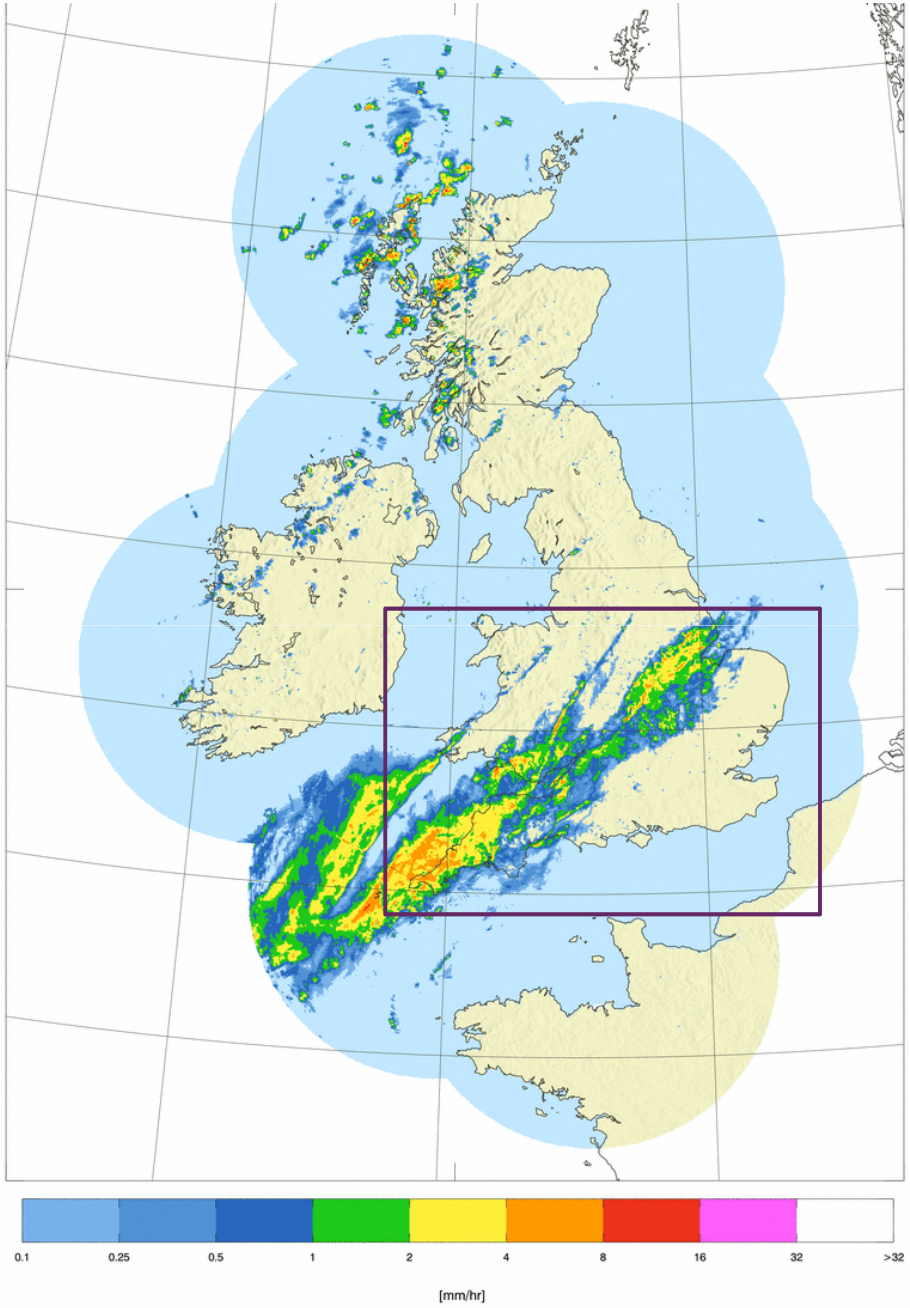
Control forecast rainfall rate



1700 UTC

Radar rainfall rate (1km composite)



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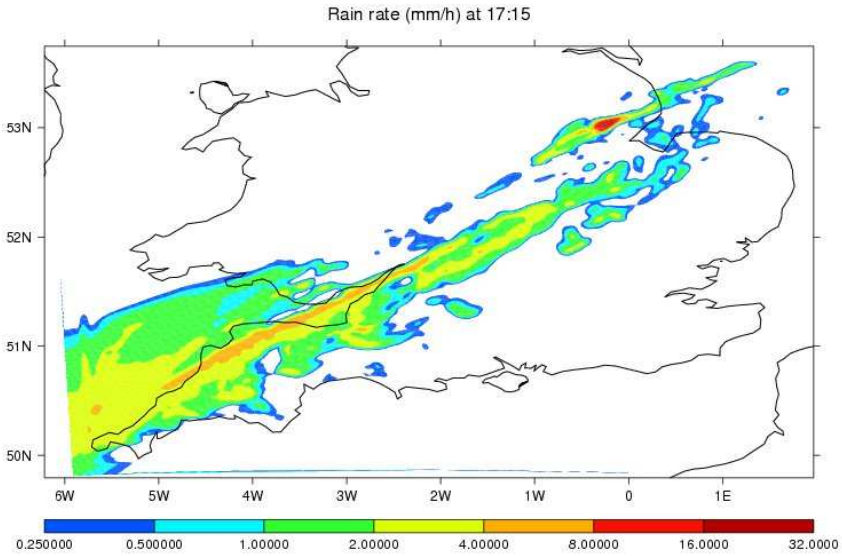
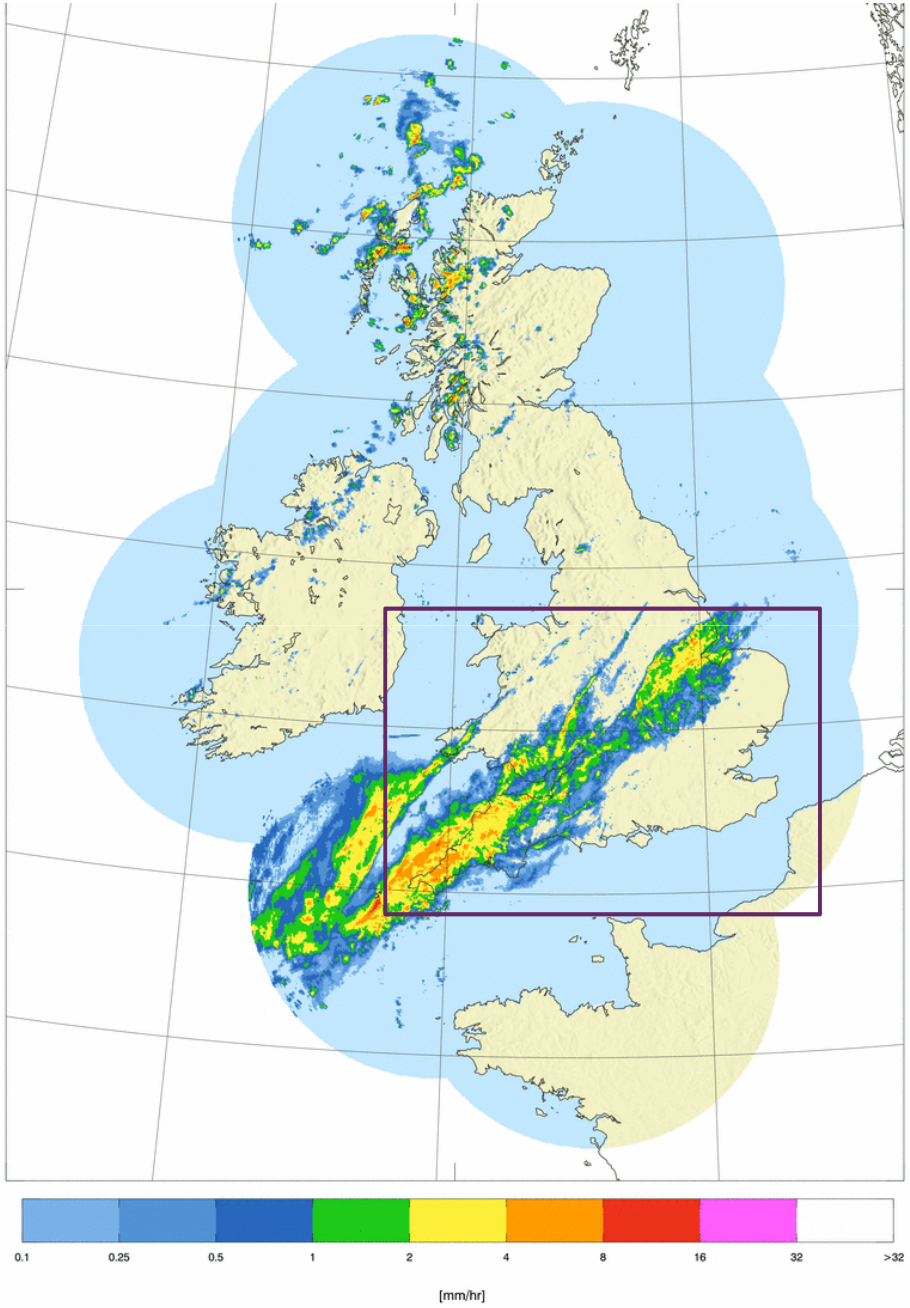
Control forecast rainfall rate



1715 UTC

Radar rainfall rate (1km composite)



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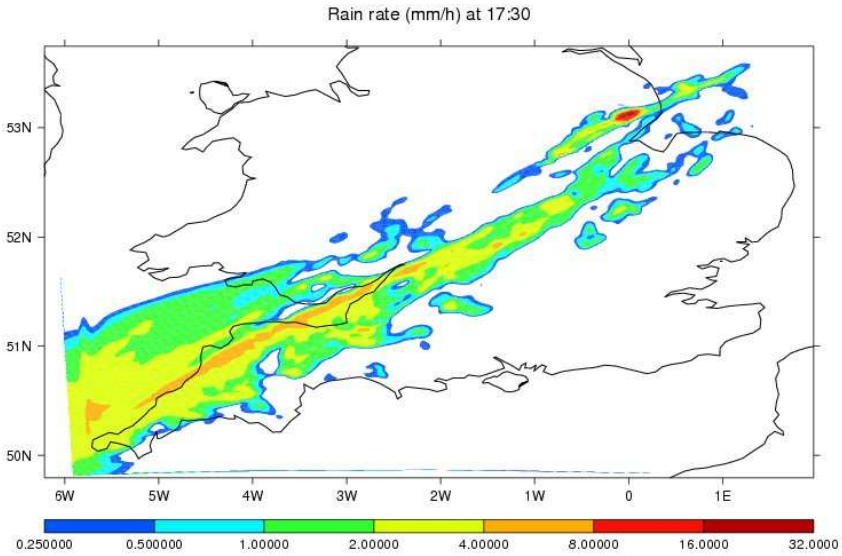
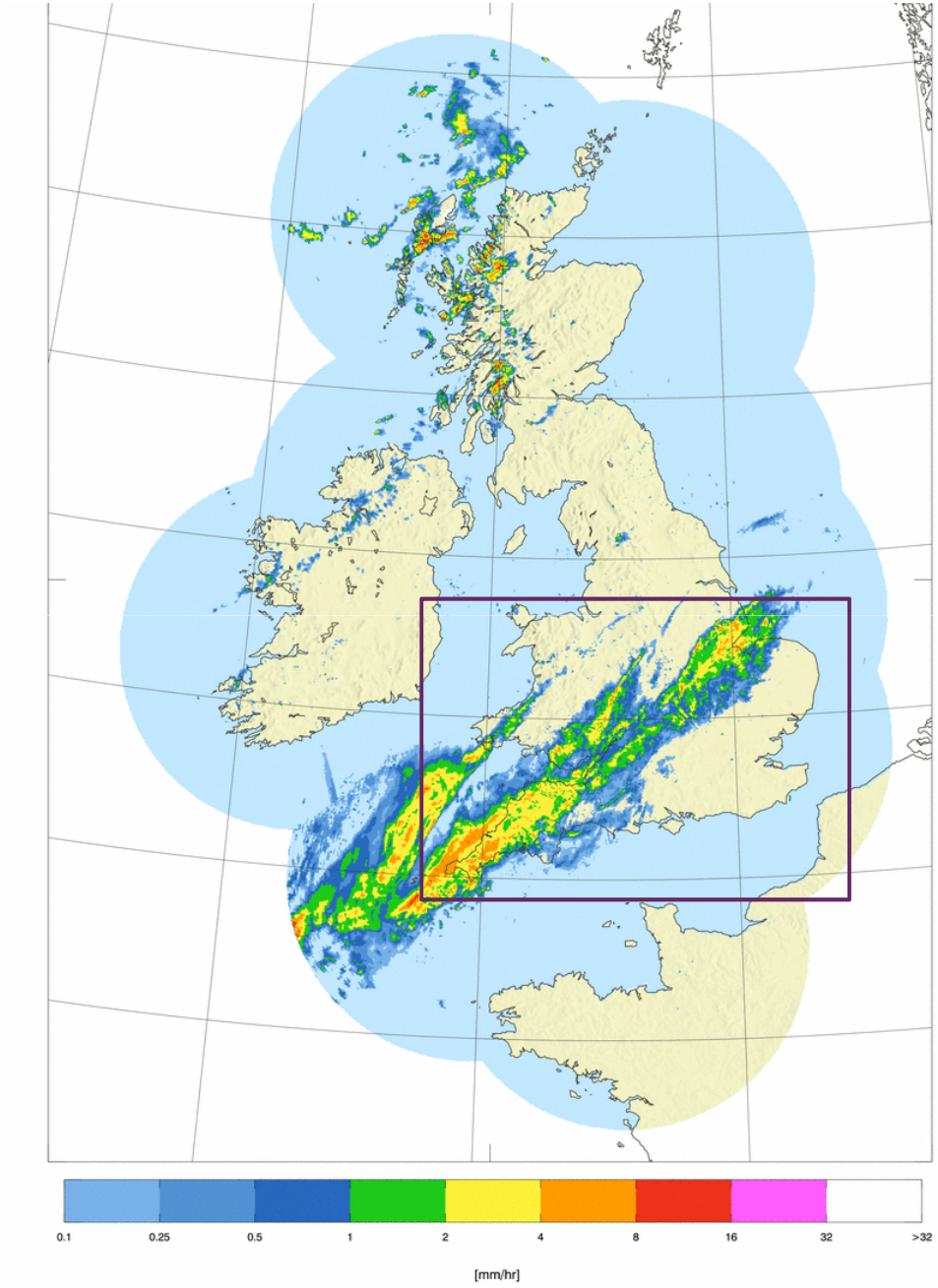
Control forecast rainfall rate



1730 UTC

Radar rainfall rate (1km composite)



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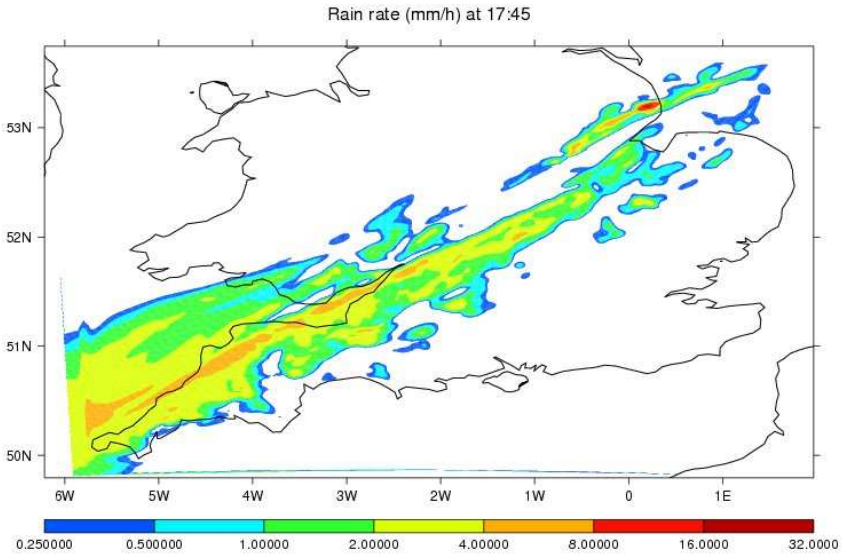
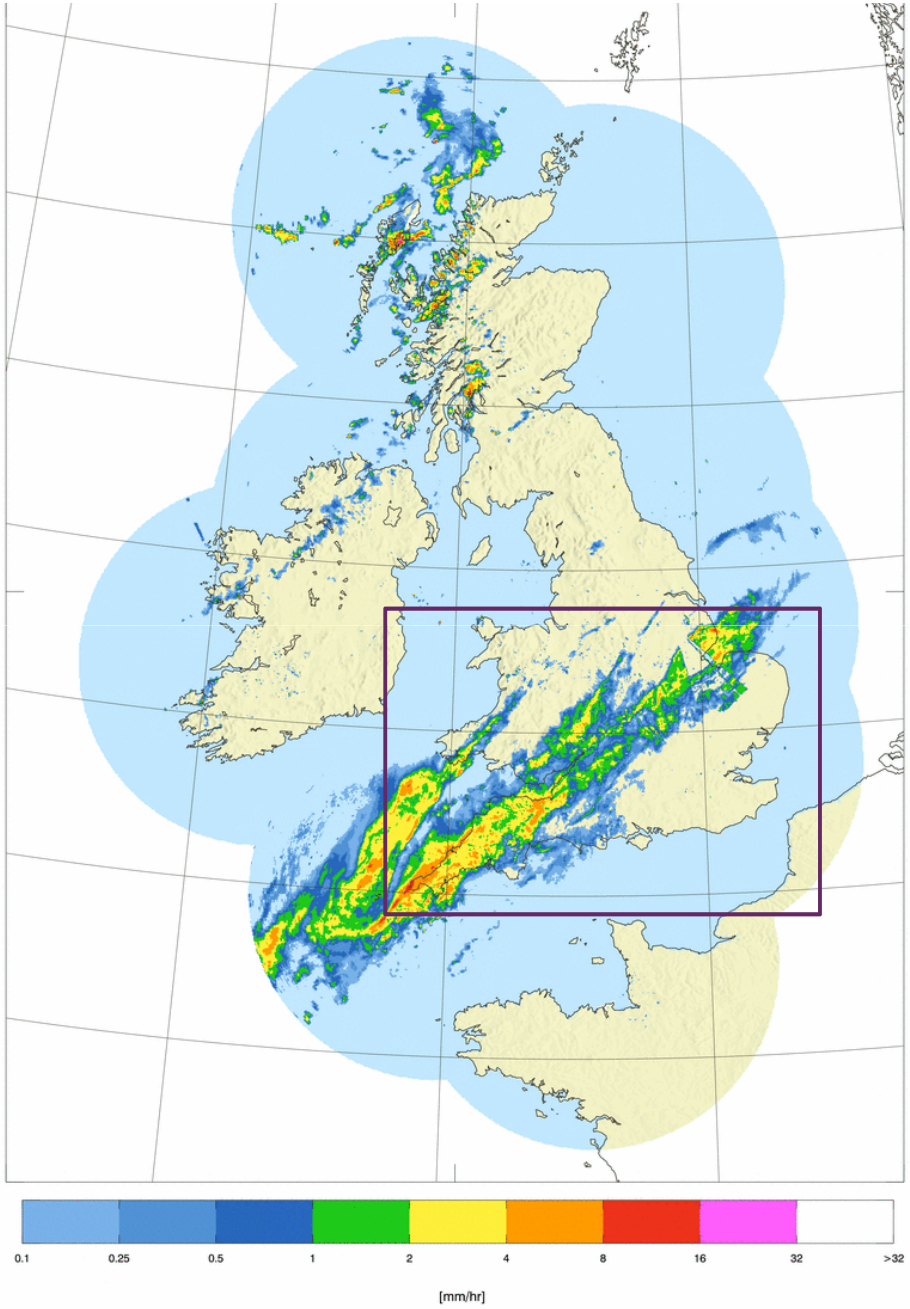
Control forecast rainfall rate



1745 UTC

Radar rainfall rate (1km composite)



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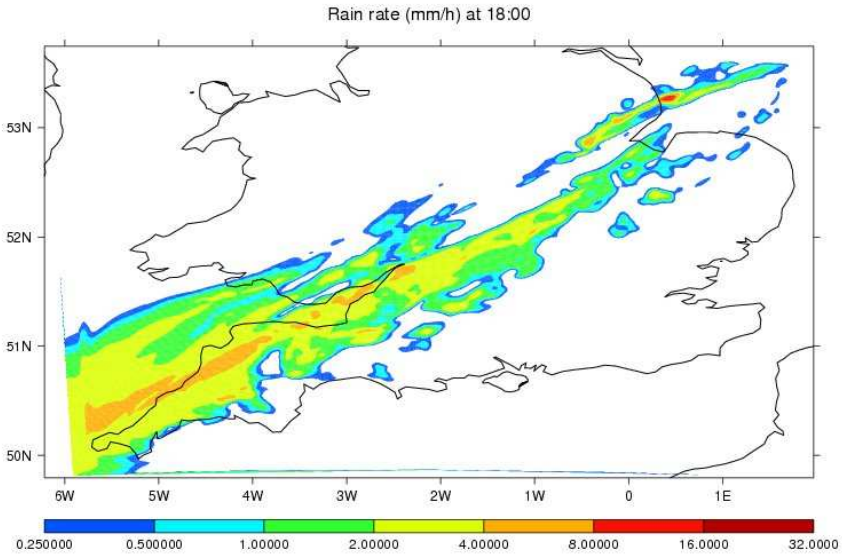
Control forecast rainfall rate



1800 UTC

Do any of the ensemble members capture the banding in the rain?

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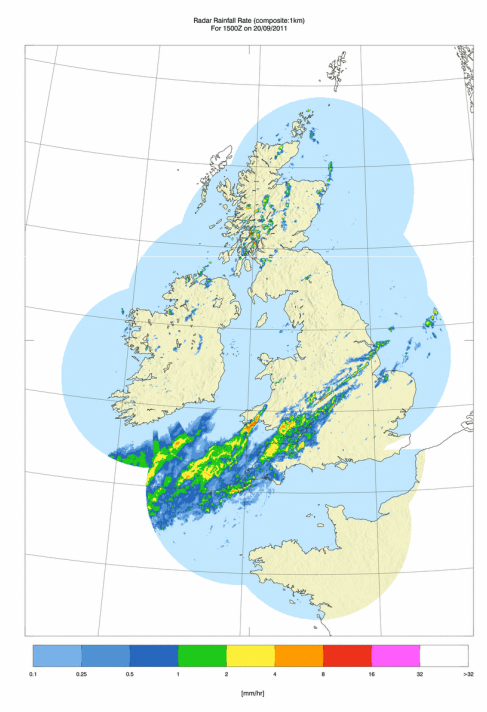
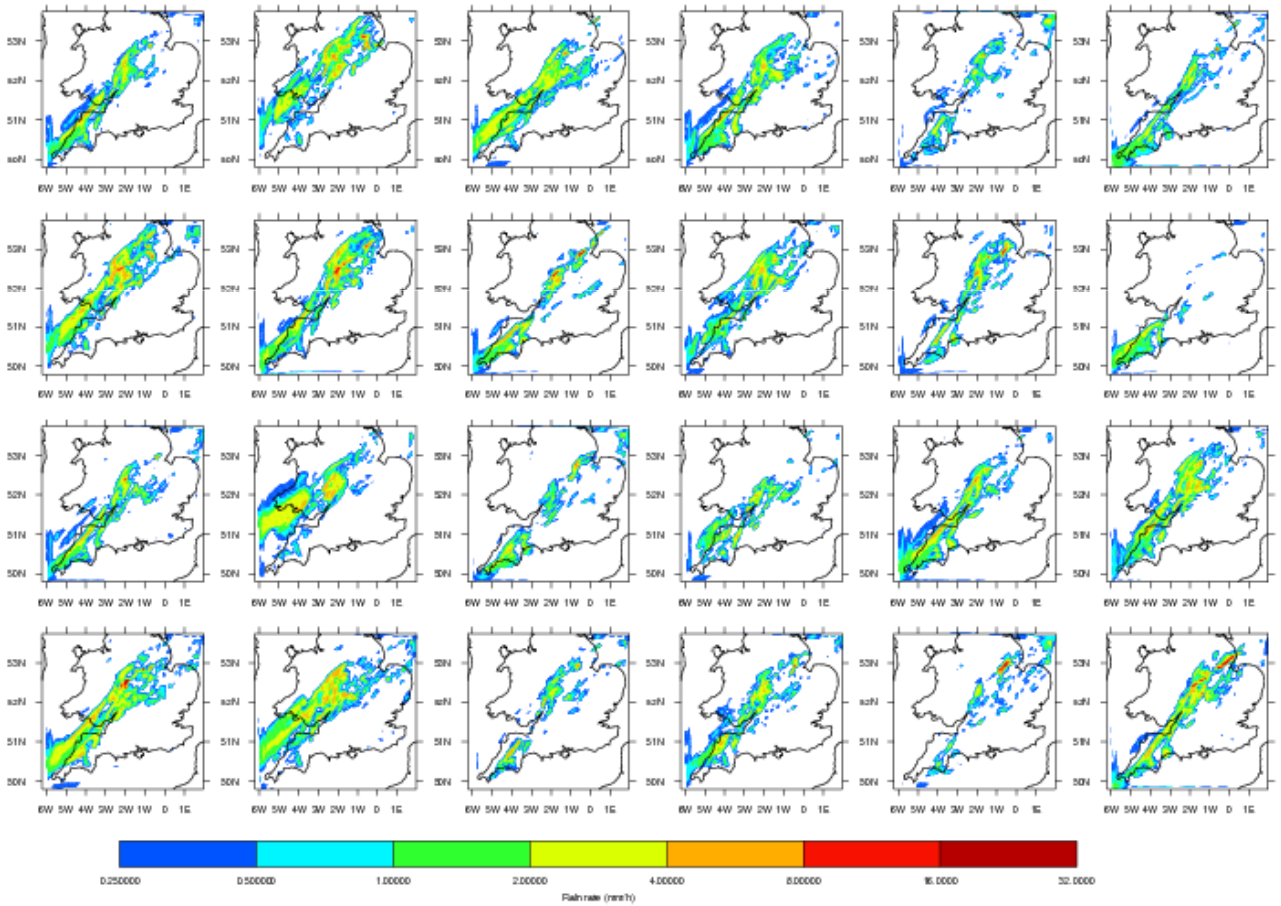
"stamp plot"

Ensemble: RP scheme off - without model error





1500 UTC

Do any of the ensemble members capture the banding in the rain?

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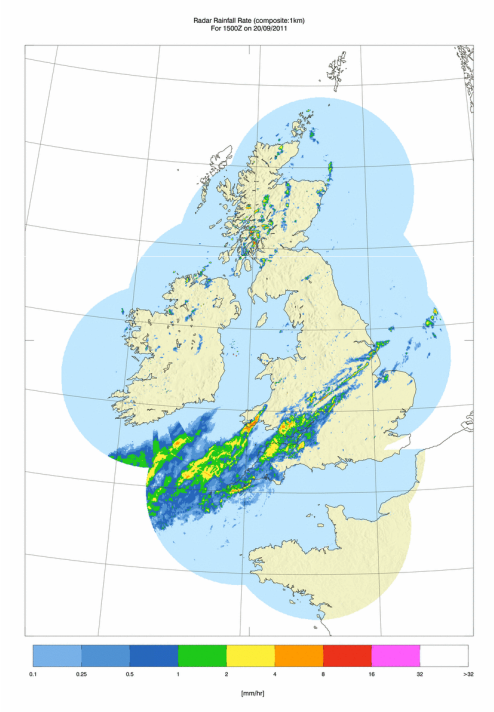
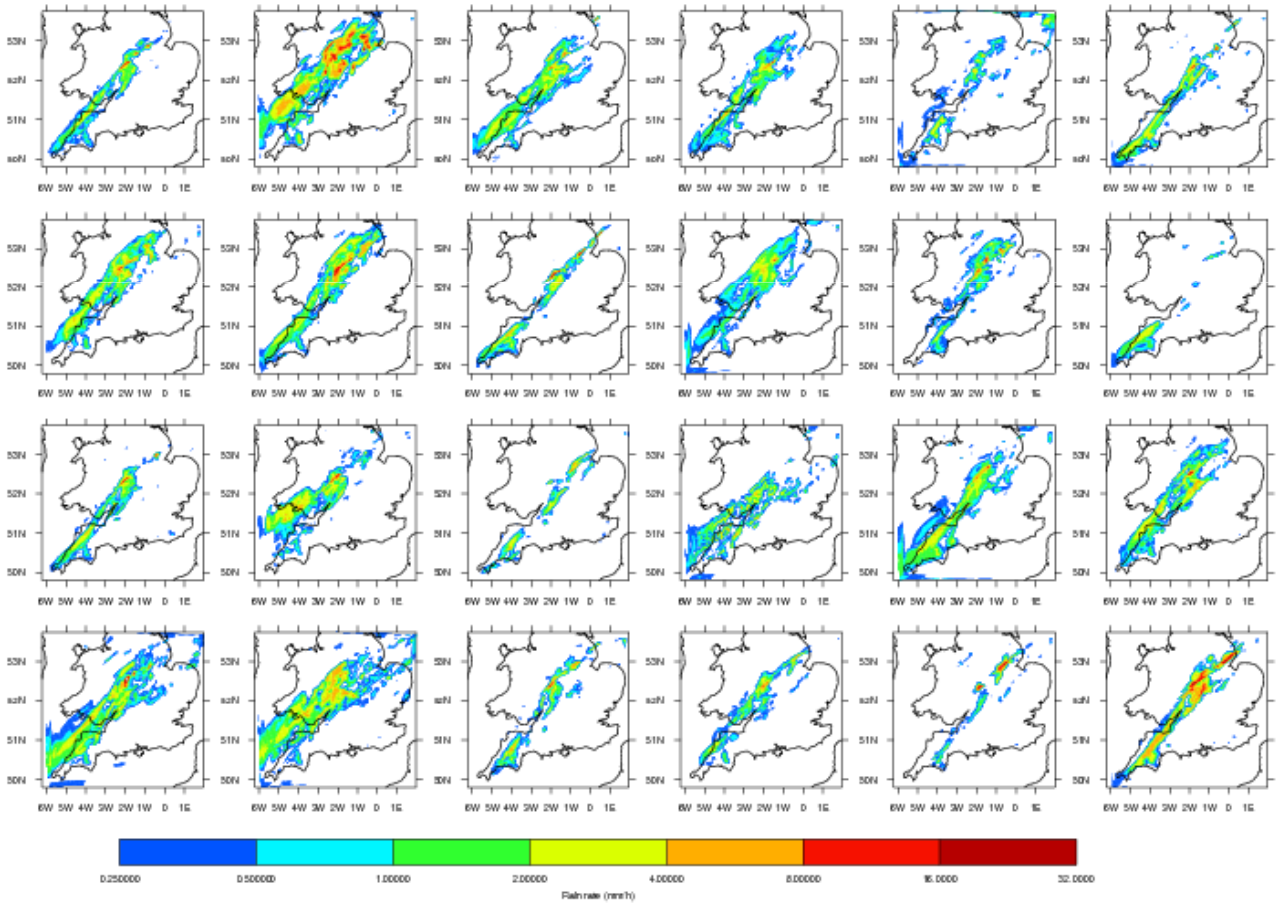
"stamp plot"

Ensemble: RP scheme on - with model error





1500 UTC

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Evaluating ensemble spread

- Ensemble spread calculated at each time as

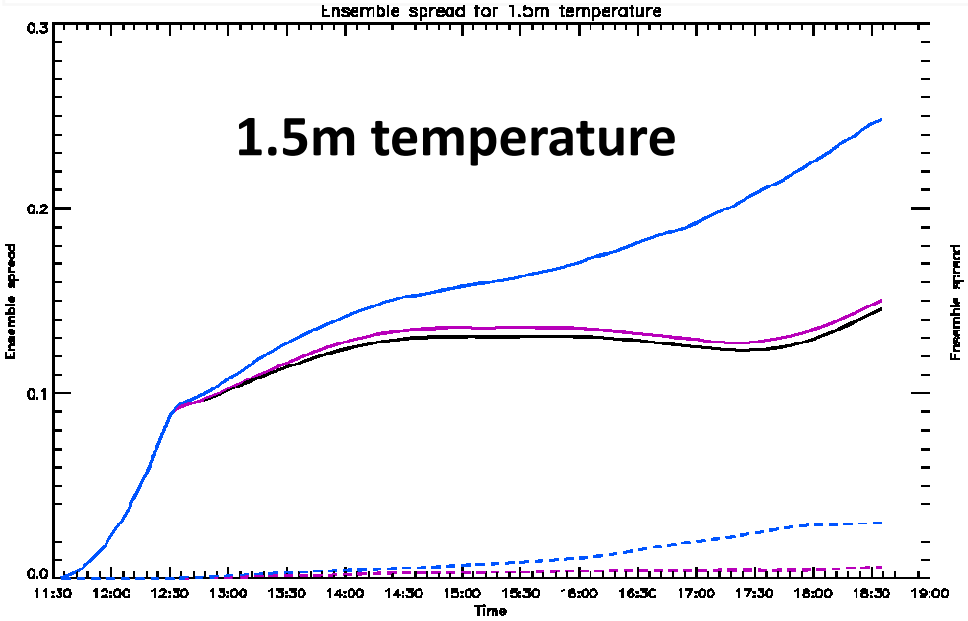
$$\frac{1}{nx \times ny} \sum_{ij} \sigma_{ij}^2$$

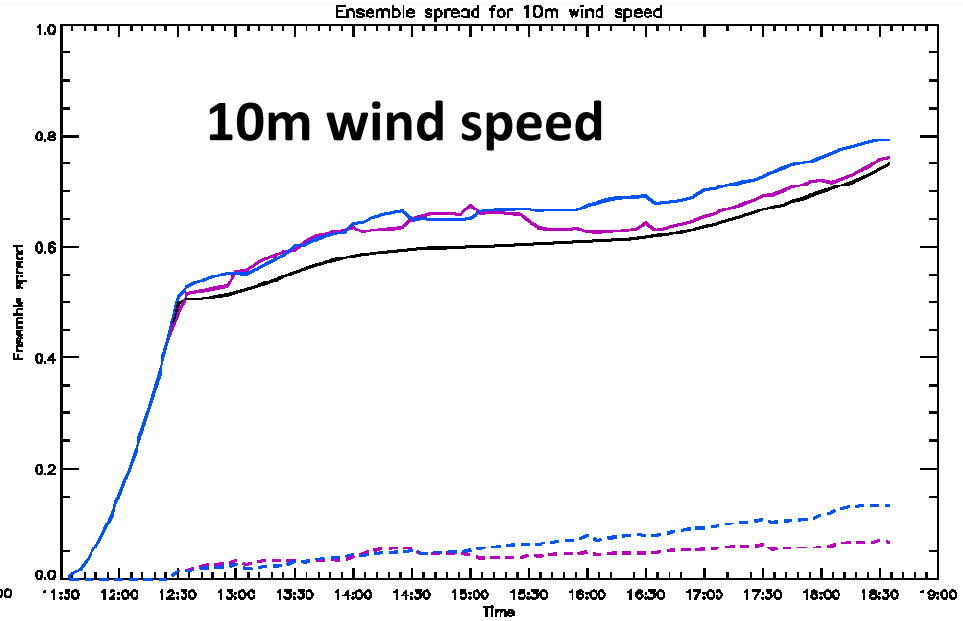
where $$\sigma_{ij}^2 = \frac{1}{m} \sum_{k=1}^{m} (p_{ijk} - < p >_{ij})^2$$

p_{ijk} is the *k*th ensemble member at point (*i,j*)

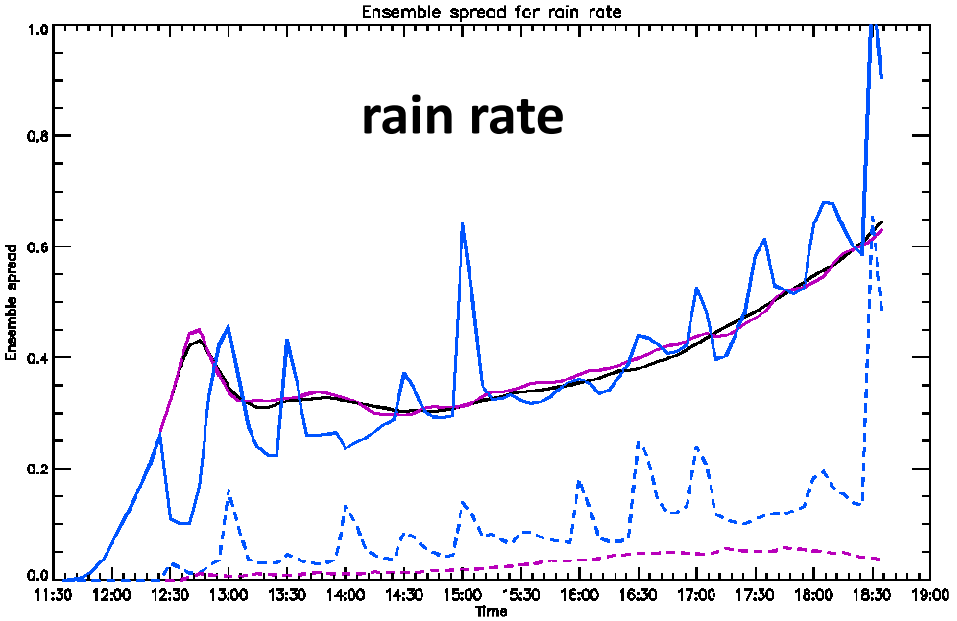
and $< p >_{ij}$ is the ensemble mean at that point.

Does model error affect the ensemble spread?





Similar plot as temperature for
1.5m relative humidity

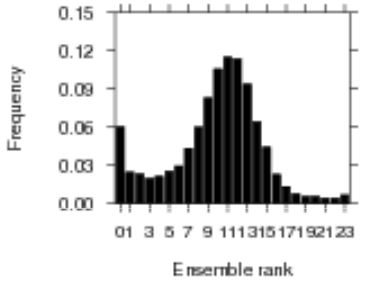


_____ modified RP scheme
_____ original RP scheme
_____ no RP scheme (IC perts only)
--- & --- model error only

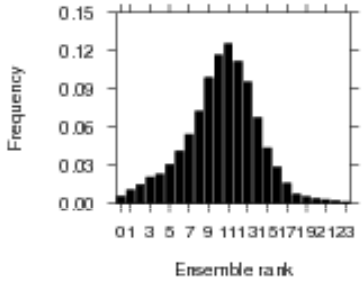
Does model error affect the ensemble spread?

Hourly rainfall accumulation

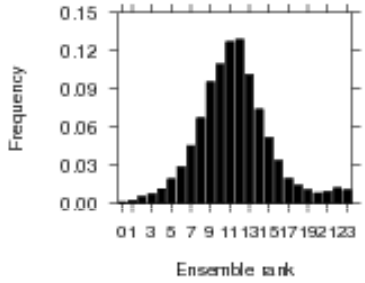
13UTC (T+1)



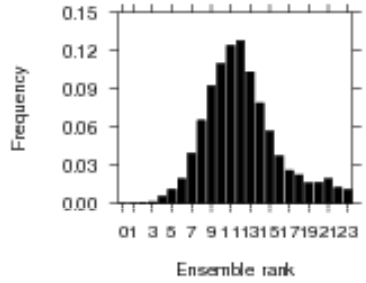
T+2

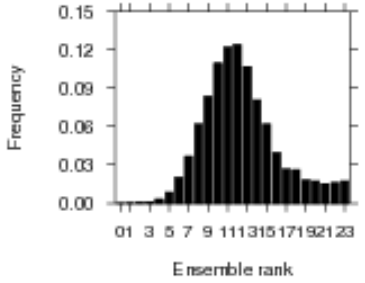


T+3

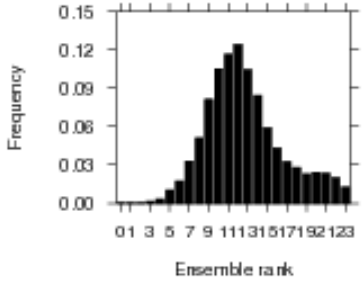


T+4





T+5



T+6

without model error

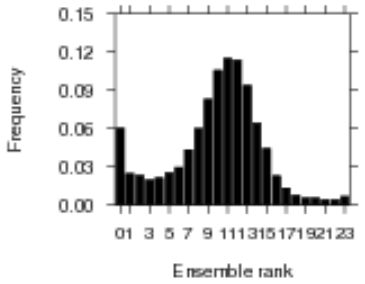
RP scheme turned off

over-dispersive, obs fall in middle ranks

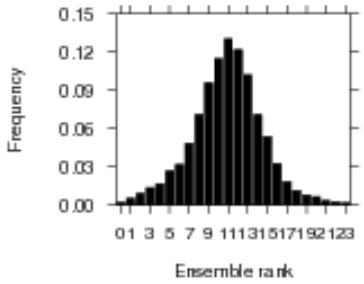
Does model error affect the ensemble spread?

Hourly rainfall accumulation

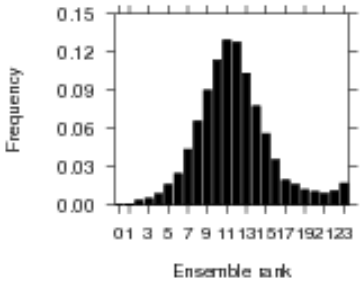
13UTC (T+1)



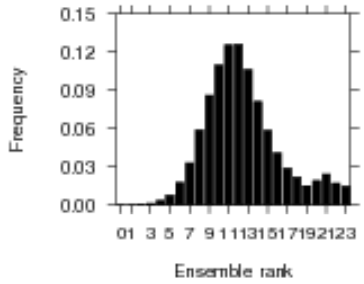
T+2

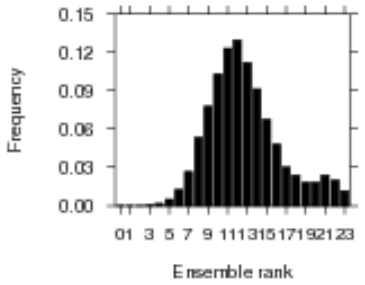


T+3



T+4





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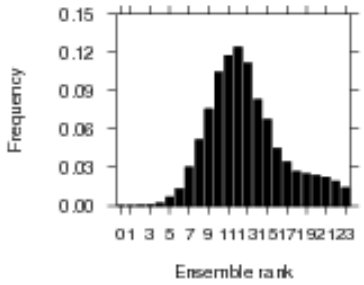


T+6

with model error

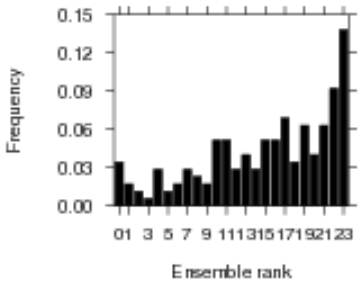
modified RP scheme

over-dispersive, obs fall in middle ranks

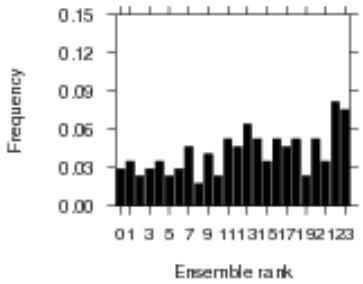
Does model error affect the ensemble spread?

Surface temperature

13UTC (T+1)



T+2



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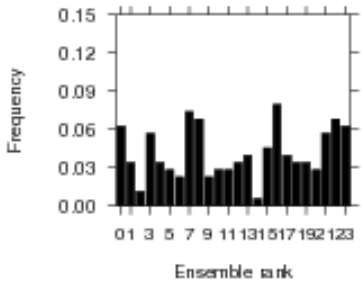

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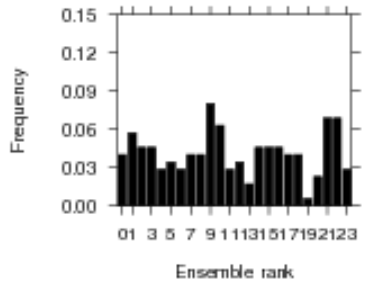

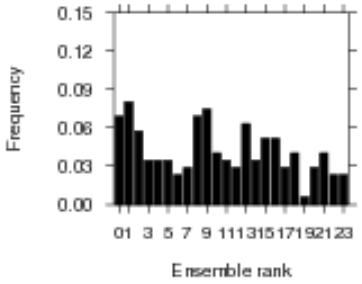

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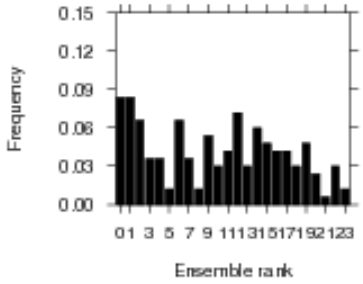


T+6

without model error

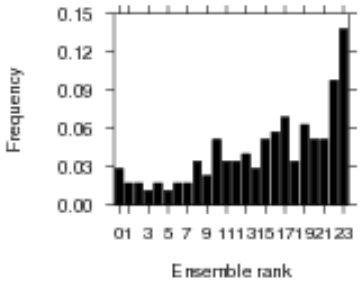
RP scheme turned off

initial negative bias, reduces, small positive bias at later times

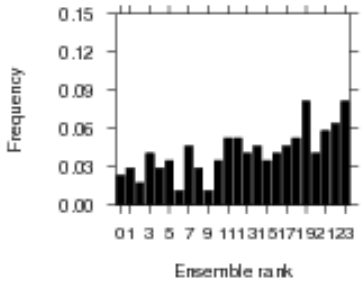
Does model error affect the ensemble spread?

Surface temperature

13UTC (T+1)



T+2



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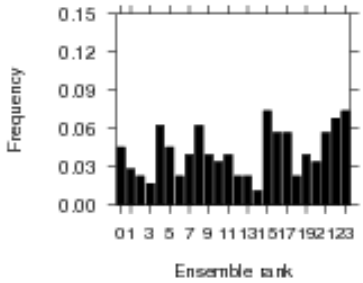

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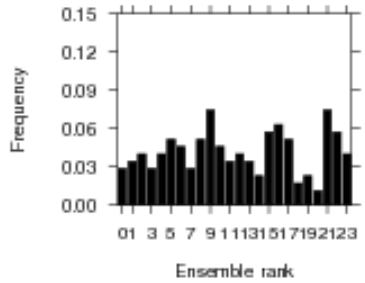
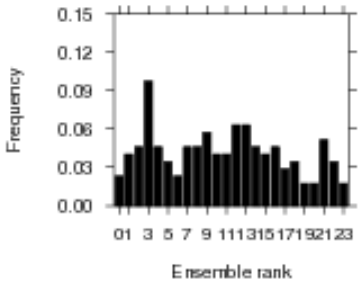
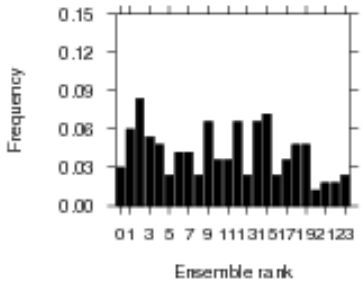




T+5



T+6

with model error

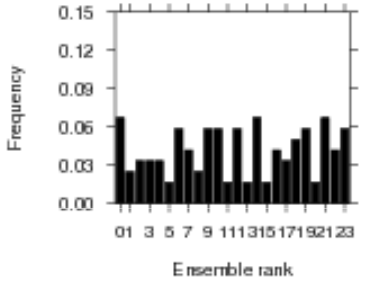
modified RP scheme

initial negative bias, reduces

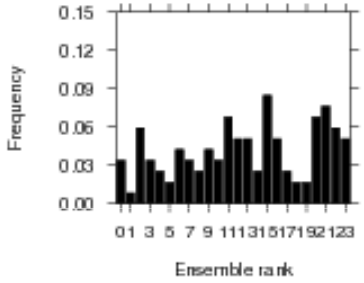
Does model error affect the ensemble spread?

Surface u - wind component

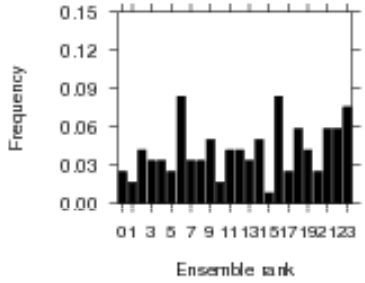
13UTC (T+1)



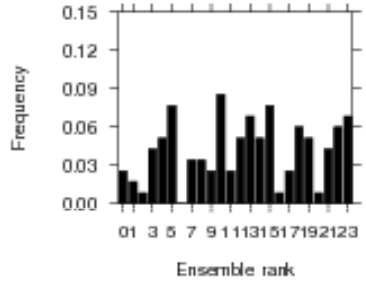
T+2

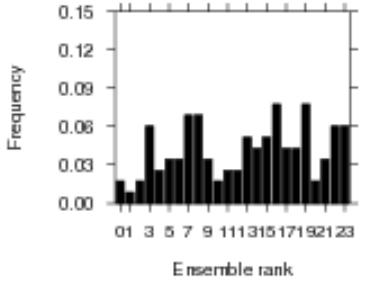


T+3



T+4





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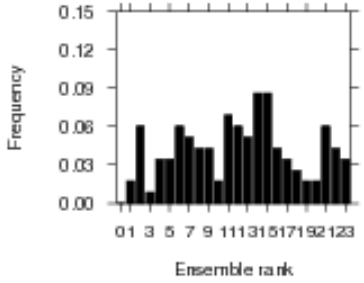


T+6

without model error

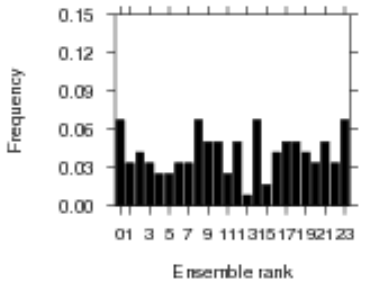
RP scheme turned off

Relatively flat, slightly over-dispersive at later time

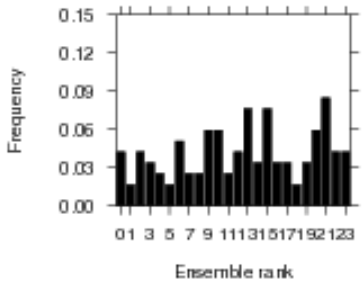
Does model error affect the ensemble spread?

Surface u - wind component

13UTC (T+1)



T+2



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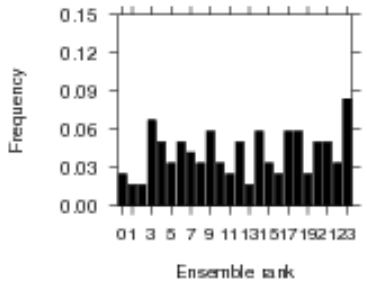

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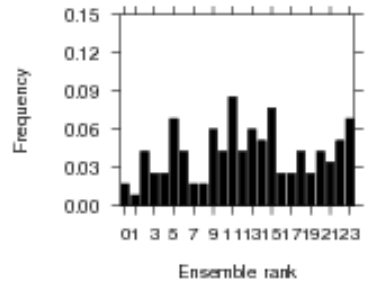
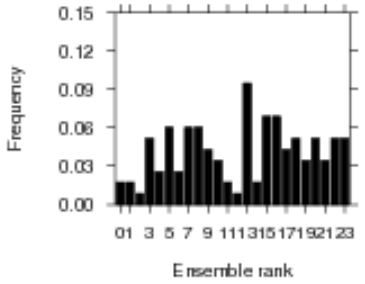
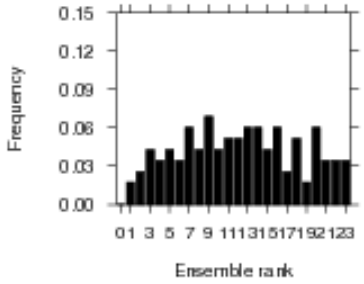




T+5



T+6

with model error

modified RP scheme

Relatively flat, slightly over-dispersive at later time

How does model error affect the forecast skill?

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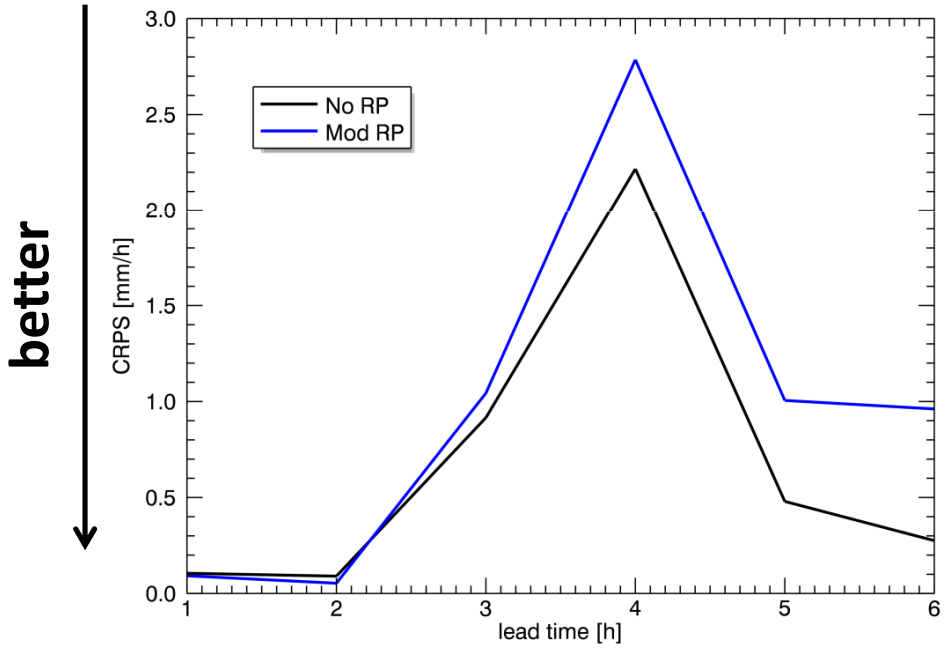
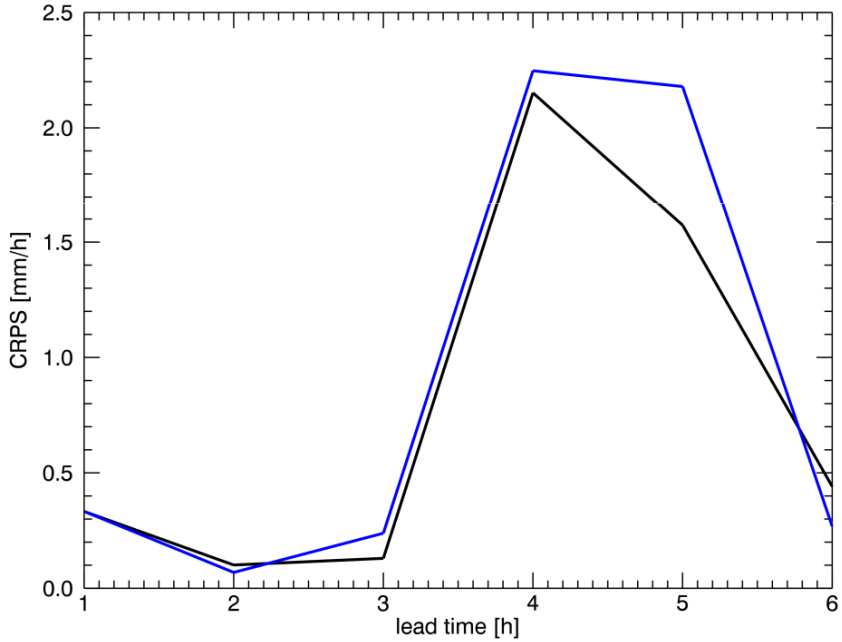
rain rate



hourly rainfall accumulation

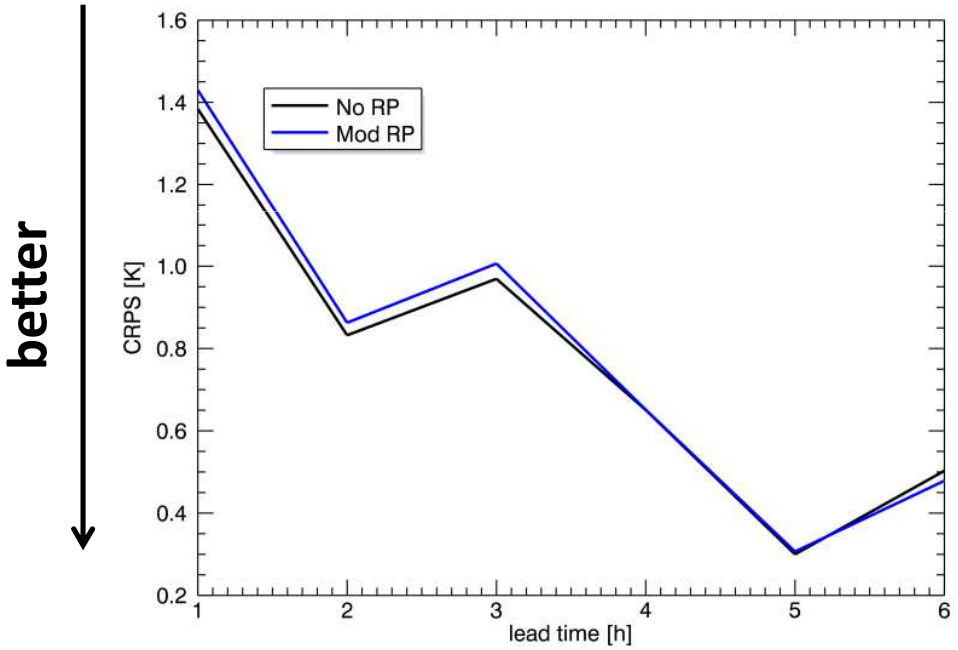


- Continuous Ranked Probability Score (CRPS)

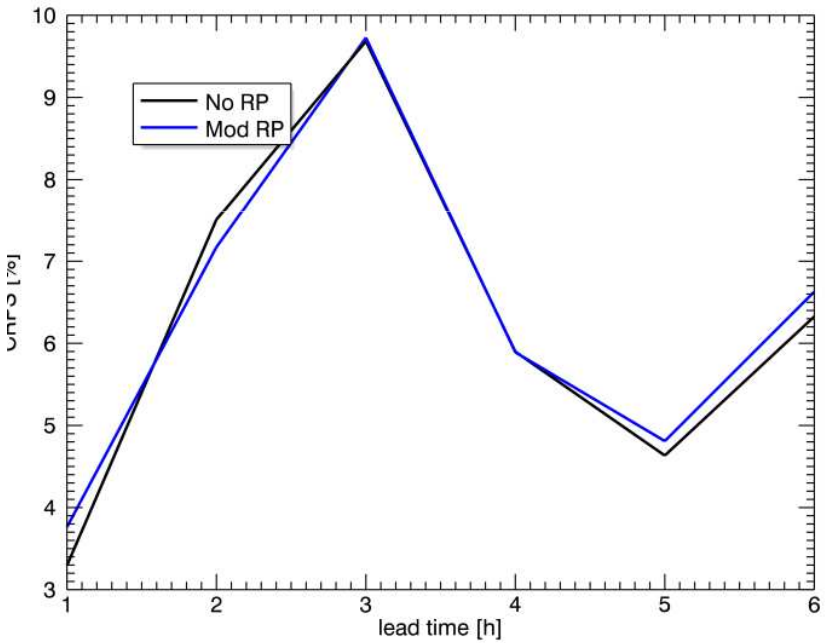
How does model error affect the forecast skill?

University of Reading

surface temperature



relative humidity



- Continuous Ranked Probability Score (CRPS)

How does model error affect the forecast skill?

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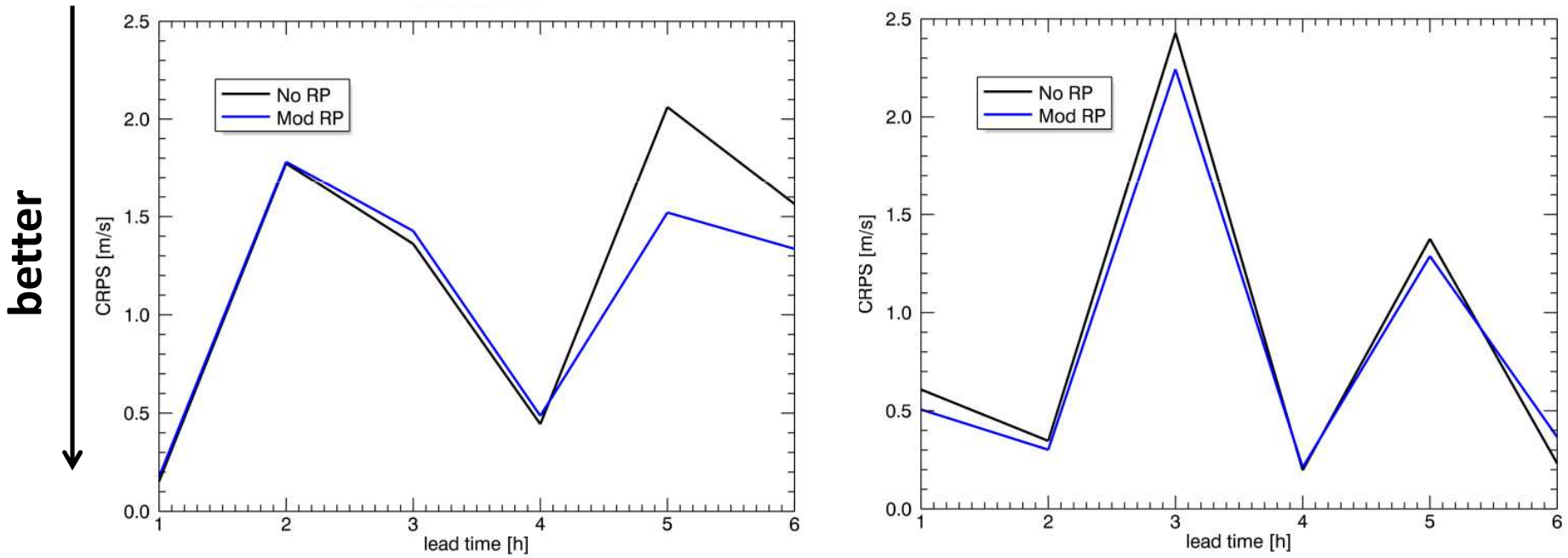
u-wind component

v-wind component



- Continuous Ranked Probability Score (CRPS)

Summary

University of Reading

- Does the convective scale ensemble capture the triple banded structure of the rainfall?
  - Not explicitly but there is variability in the exact location of the rainfall
- How does model error affect the spread of the ensemble?
  - **Temperature and relative humidity** – extra parameters appear to increase the spread compared to the original RP scheme
  - **Wind speed** – extra parameters appear to increase the spread a little compared to the original RP scheme
  - **Rainfall rate** - modified RP scheme has undesirable effect of making the spread in rainfall jump about
- How does model error affect the forecast skill?
  - Small affect on forecast skill

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Ongoing work

- Consider another case
- Evaluate forecast error covariance characteristics
  - for 23, 46 and 92 member ensemble (no model error)
- Compare the ensemble forecast error statistics with observation-derived forecast error statistics
  - Hollingsworth-Lönnberg method
- Balance diagnostics at convective-scale

Summary

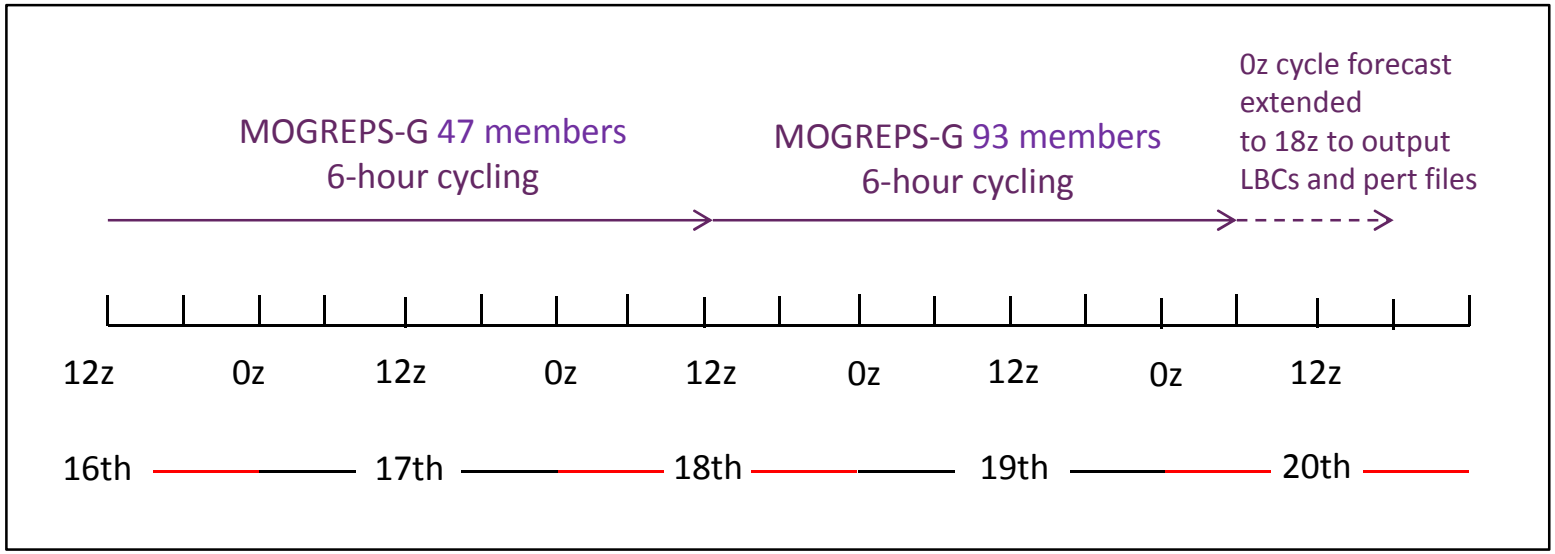
- Does the convective scale ensemble capture the triple banded structure of the rainfall?
  - Not explicitly but there is variability in the exact location of the rainfall
- How does model error affect the spread of the ensemble?
  - **Temperature and relative humidity** – extra parameters appear to increase the spread compared to the original RP scheme
  - **Wind speed** – extra parameters appear to increase the spread a little compared to the original RP scheme
  - **Rainfall rate** - modified RP scheme has undesirable effect of making the spread in rainfall jump about
- How does model error affect the forecast skill?
  - Small affect on forecast skill

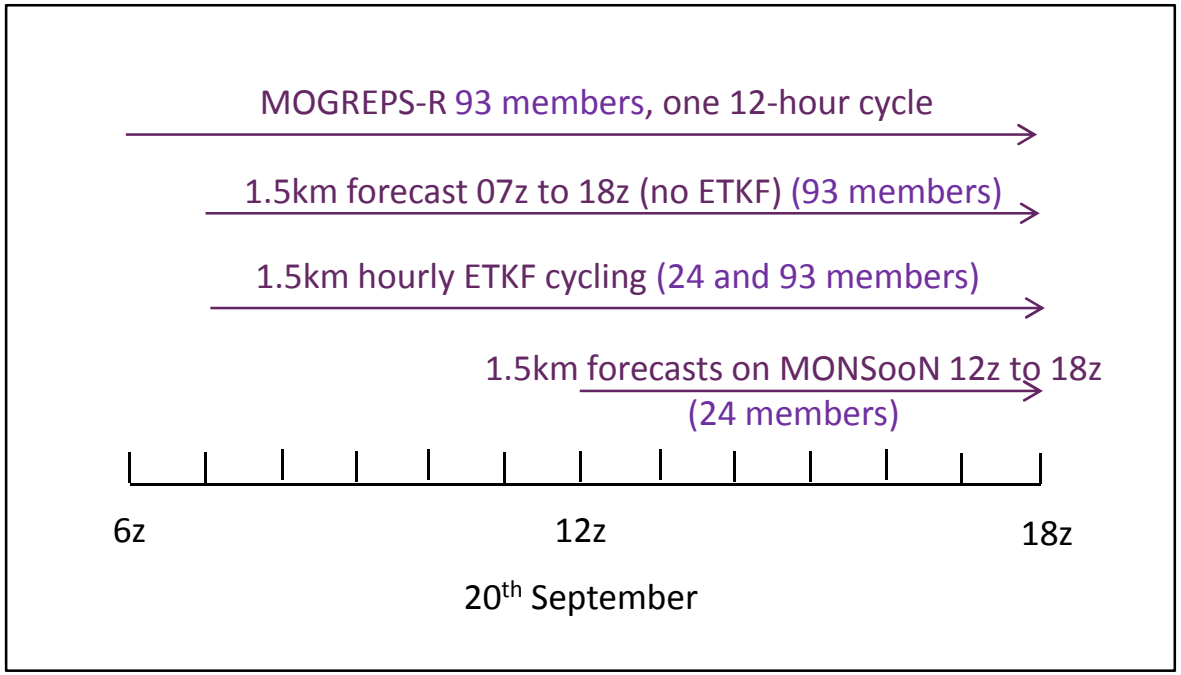
a.c.rudd@reading.ac.uk

University of Reading

Extra slides

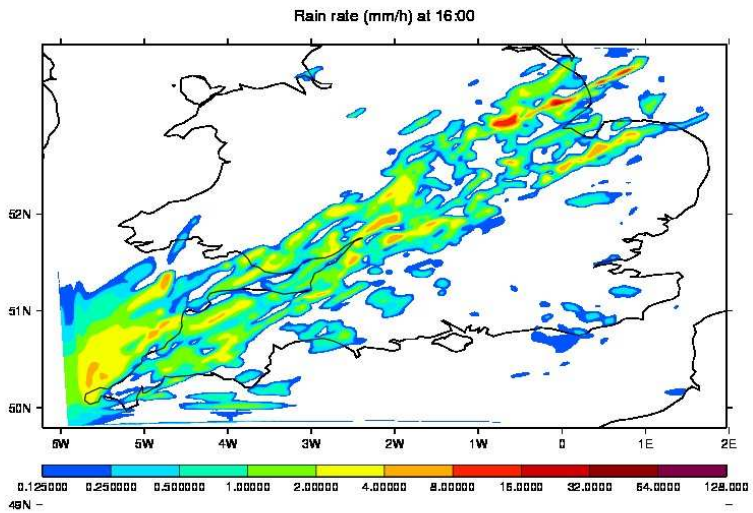
Summary of model runs for 93-member ensemble



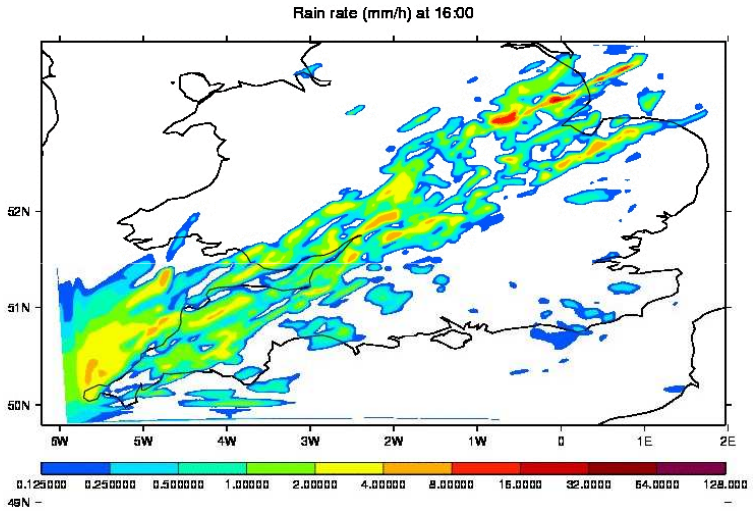


Large ensemble

Control and ensemble sequence



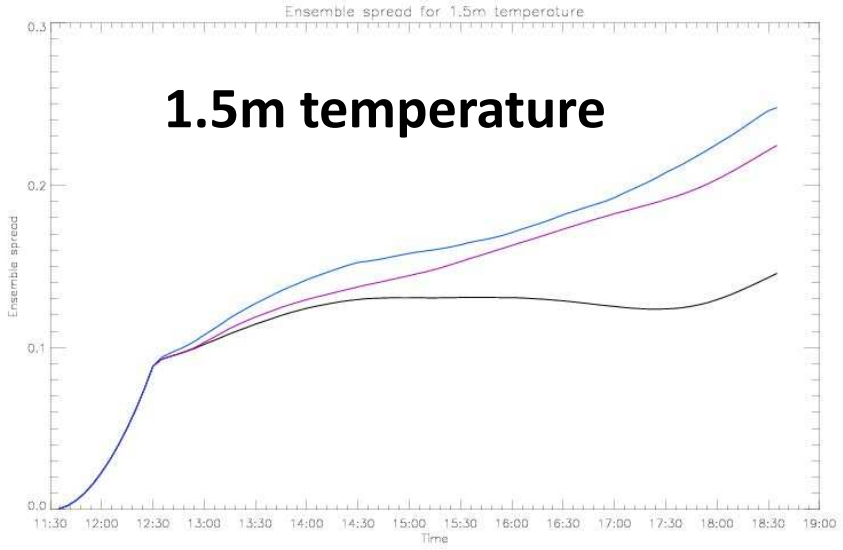
Control forecast 16:00 UTC

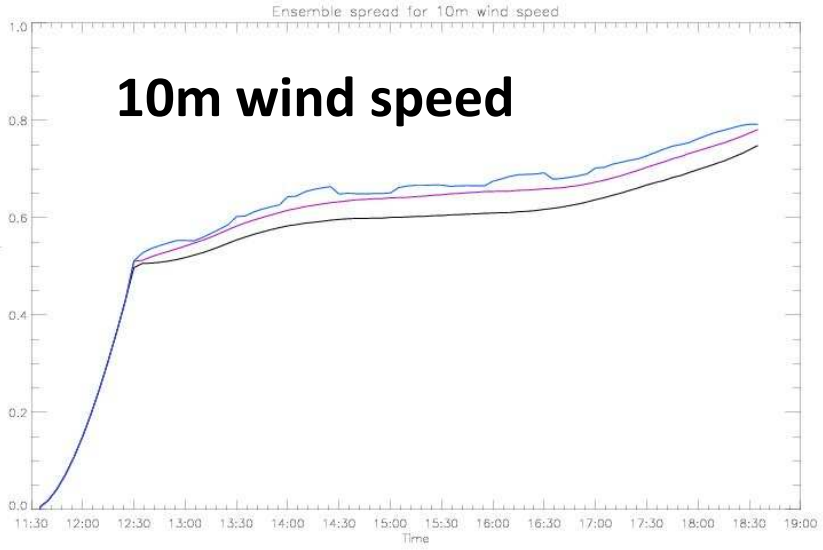


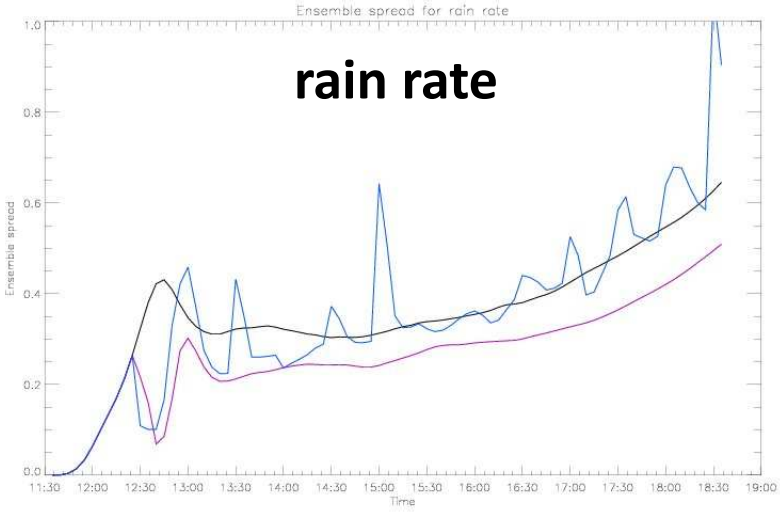
92 member animation

back

How does model error affect the spread?



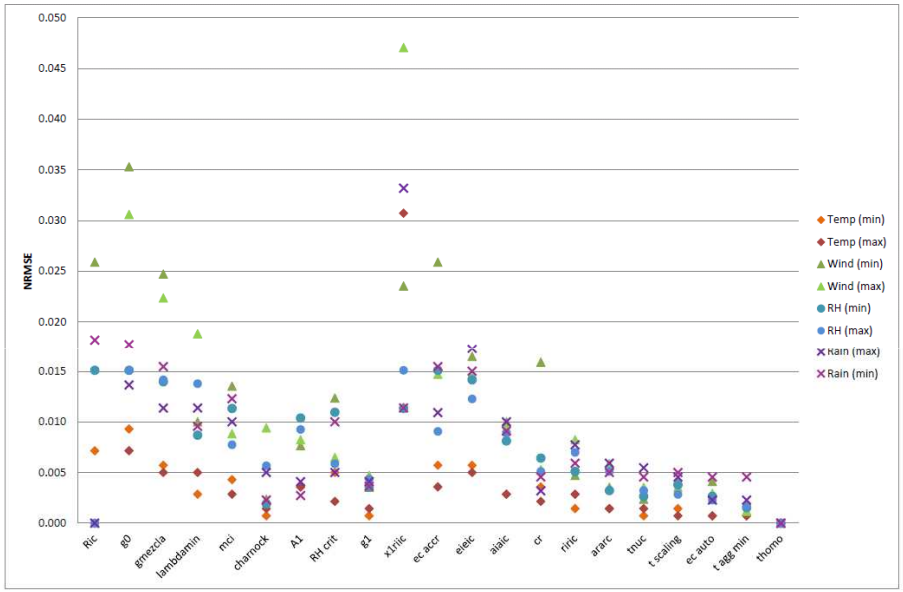




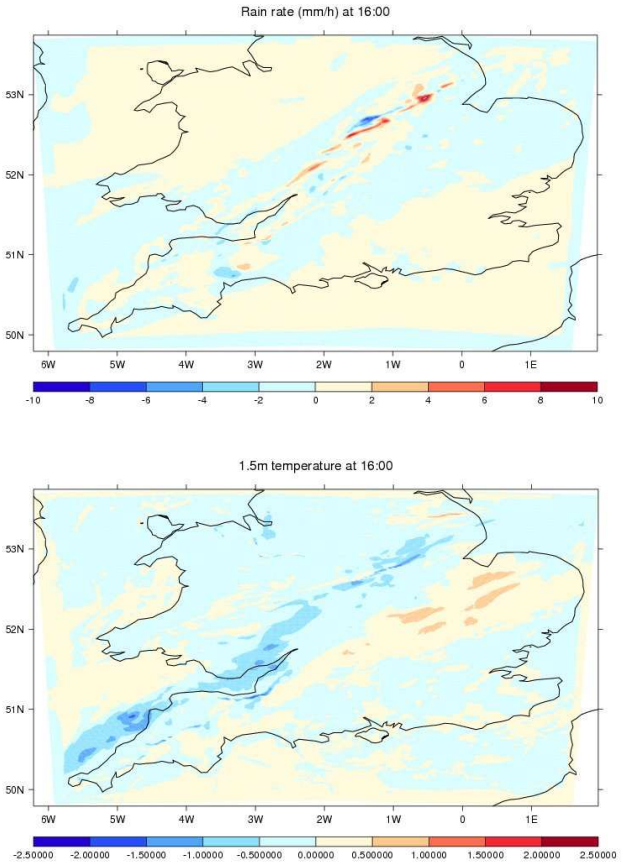
_____ modified RP (30 min update)
_____ modified RP (fixed parameters)
_____ no RP scheme (IC perts only)

back

How sensitive is the forecast to key model parameters?

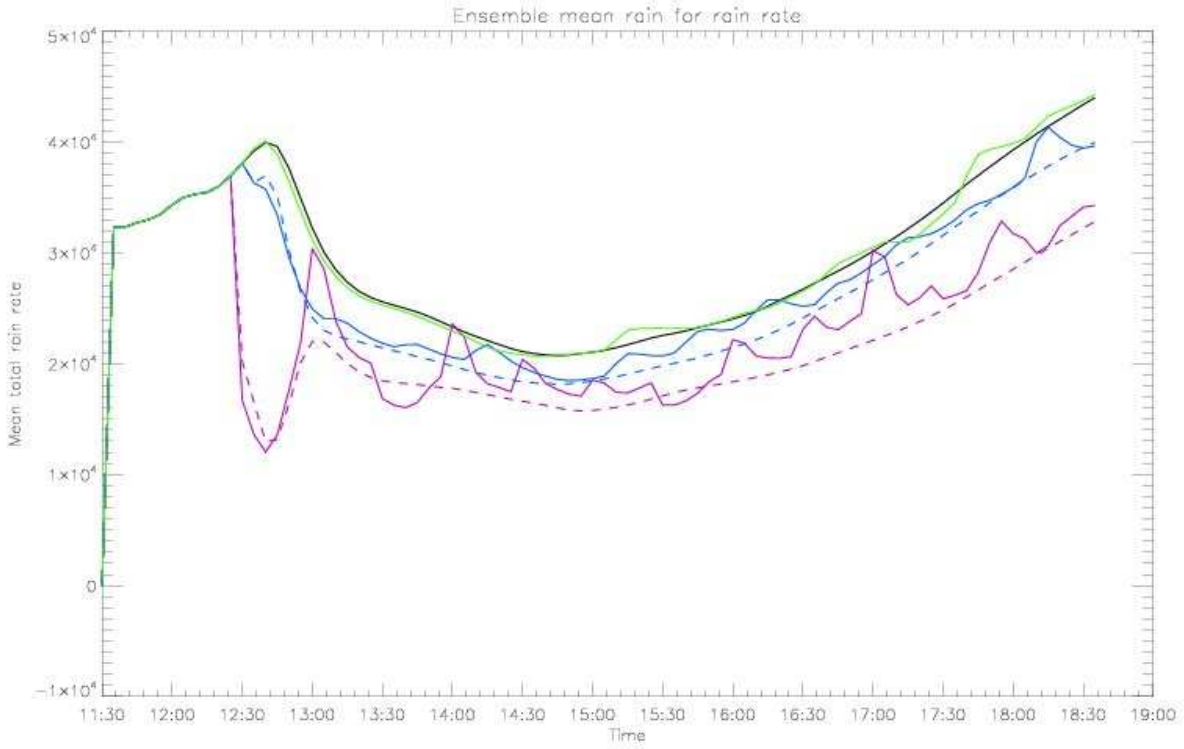


Normalised maximum RMSE for the perturbed forecast compared with the control



Difference between perturbed and control forecast for particle size distribution parameter, at 1600UTC

Total rain rate



-------- modified RP scheme (without PSD parameters) – 30 minute update
-------- modified RP scheme (with PSD parameters) – 30 minute update
-- -- -- modified RP scheme (without PSD parameters) – fixed
-- -- -- modified RP scheme (with PSD parameters) – fixed
-------- original RP scheme (30 minute update)
-------- no RP scheme (IC perturbations only)

- Calculated total rain rate over the domain at each time for each ensemble member, and computed the ensemble mean
- All our modified versions of the RP scheme reduce the total rain rate compared with the no-RP ensemble
- The original RP scheme has very little impact
- Including the PSD parameter reduces the total rain rate the most
- The 30-minute calls to the RP scheme seem to pull the rain rate up to meet the black line (see pink lines) – these peaks in total rain rate correspond to the peaks in ensemble spread seen in earlier plots

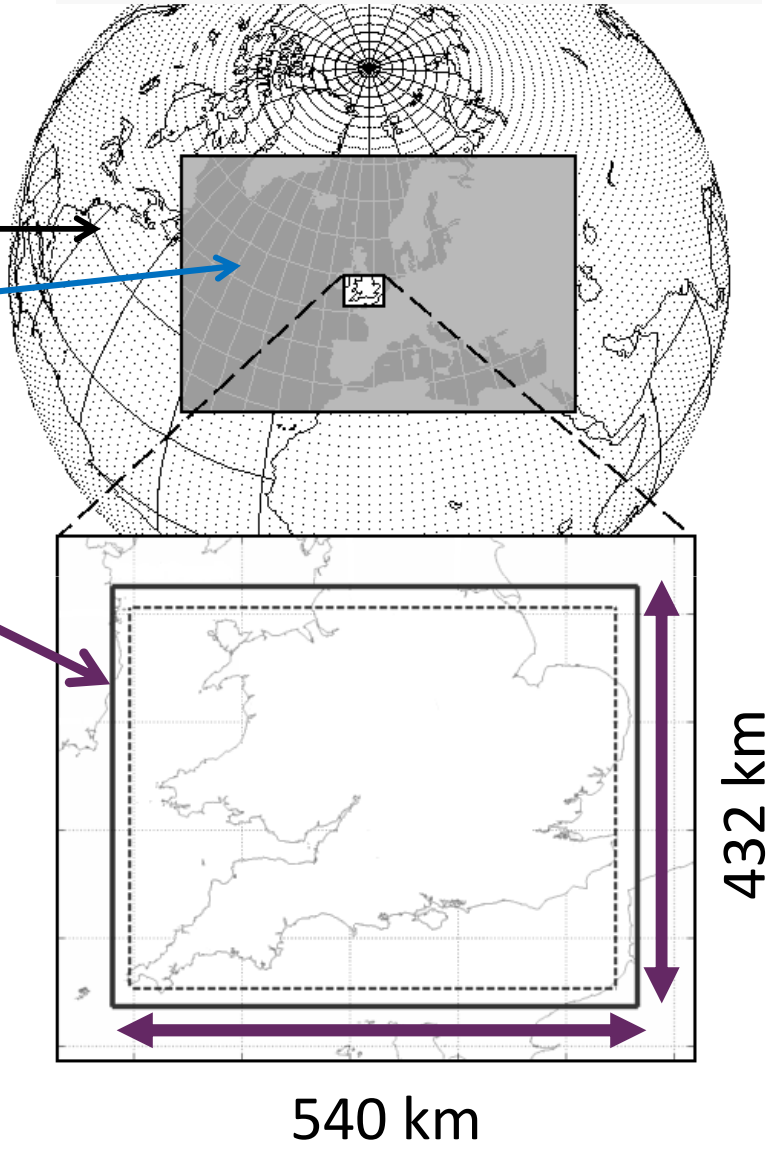
Generating a convective scale forecast ensemble

- MOGREPS-G (60 km) – operational
- MOGREPS-R (18 km) – operational
- **ETKF-1.5 km - research**

  southern UK domain

  - Control and 23 ensemble members with perturbed initial conditions
  - Hourly cycling
  - Convection-permitting
  - LBCs and IC perturbations from MOGREPS-R
  - Grid-point based NWP model
  - 70 vertical levels

MOGREPS: Met Office Global and Regional Ensemble Prediction System



Parameters in our modified RP scheme

Scheme	Parameter	Description	min	default	max
BL	Ri_c	critical Richardson number	0.25	1.0	1.0
BL	g_0	flux profile parameter	5	10	20
BL	g_{mezcla}	neutral mixing length	0.05	0.15	0.5
BL	λ_{min}	minimum mixing length	20	40	100
BL	Charnock	Charnock parameter	0.010	0.011	0.026
BL	A_1	entrainment parameter	0.1	0.23	0.4
BL	g_1	cloud-top diffusion parameter	0.5	0.85	1.5
MP	RH_{crit}	critical relative humidity	0.875	0.9	0.910
MP	m_{ci}	ice-fall speed	0.6	1.0	1.4
MP	$x1r$	particle size distribution for rain	$2x10^6$	$8x10^6$	$2x10^9$
MP	$x1i$	particle size distribution for ice aggregates	$1x10^6$	$2x10^6$	$1x10^7$
MP	$x1ic$	particle size distribution for ice crystals	$1x10^7$	$4x10^7$	$1x10^8$
MP	ec_{accr}	accretion efficiency	0.4	1.0	0.7
MP	ei	Best-Reynolds aggregates	0.1036	0.2072	0.4144
MP	eic	Best-Reynolds crystals	0.1036	0.2072	0.4144
MP	ai	ice aggregate mass diameter	0.0222	0.0444	0.0888
MP	aic	ice crystal mass diameter	0.2935	0.587	1.174
MP	cr	rain fall speed	250	386.8	500
MP	ri	area diameter relationship (aggregates)	0.1	0.131	0.2
MP	ric	area diameter relationship (crystals)	0.1	0.131	0.2
MP	ar	ice aggregate axial ratio	0.5	1.0	2.0
MP	arc	ice crystal axial ratio	0.5	1.0	2.0
MP	t_{nuc}	maximum ice nucleation temperature	−20	−10	−5
MP	$t_{scaling}$	scaling quantity for amount of ice in aggregate form	0.01	0.0384	1.0
MP	ec_{auto}	autoconversion efficiency (converting cloud to rain)	0.4	0.55	0.7
MP	t_{aggmin}	minimum temperature for aggregates	−50	−45	−40

- Parameters above the black line are in the existing scheme; those below are new
- We vary some parameters together where appropriate (eg. ei and eic; x1r, x1i and x1ic) – i.e. we use the same random seed for ei and eic so that they vary together rather than independently
- We have found that the particle size distribution parameters (x1r, etc.) have a larger effect than any others – possibly too large