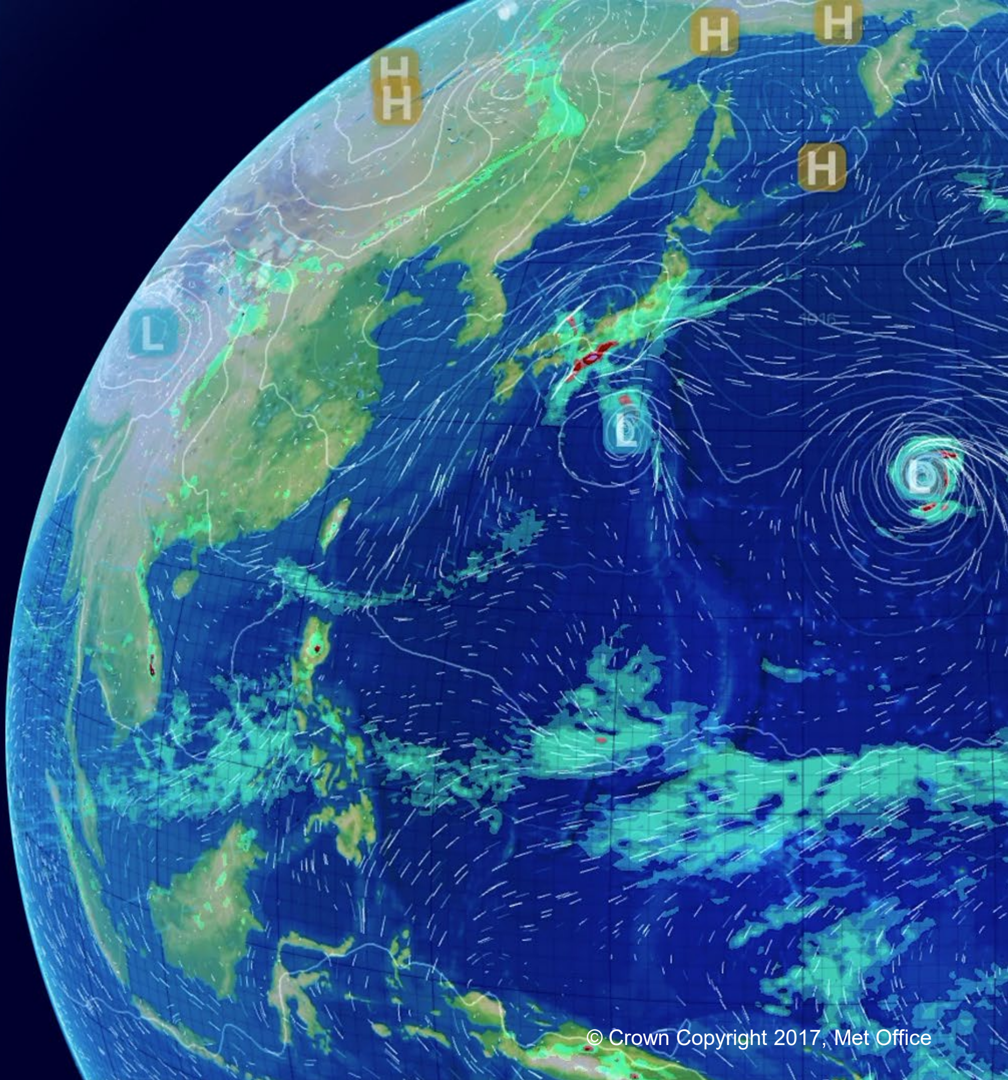
Met Office

Convection in 100m versions of the UM

Kirsty Hanley, Humphrey Lean
Urban-scale Modelling Group
MetOffice@Reading



Met Office

Urban-Scale Modelling

Vision Statement:
Deliver an enhanced Urban-scale modelling capability (an atmospheric model with grid lengths in the range 25-300m) for application across timescales to exploit next-generation supercomputing.

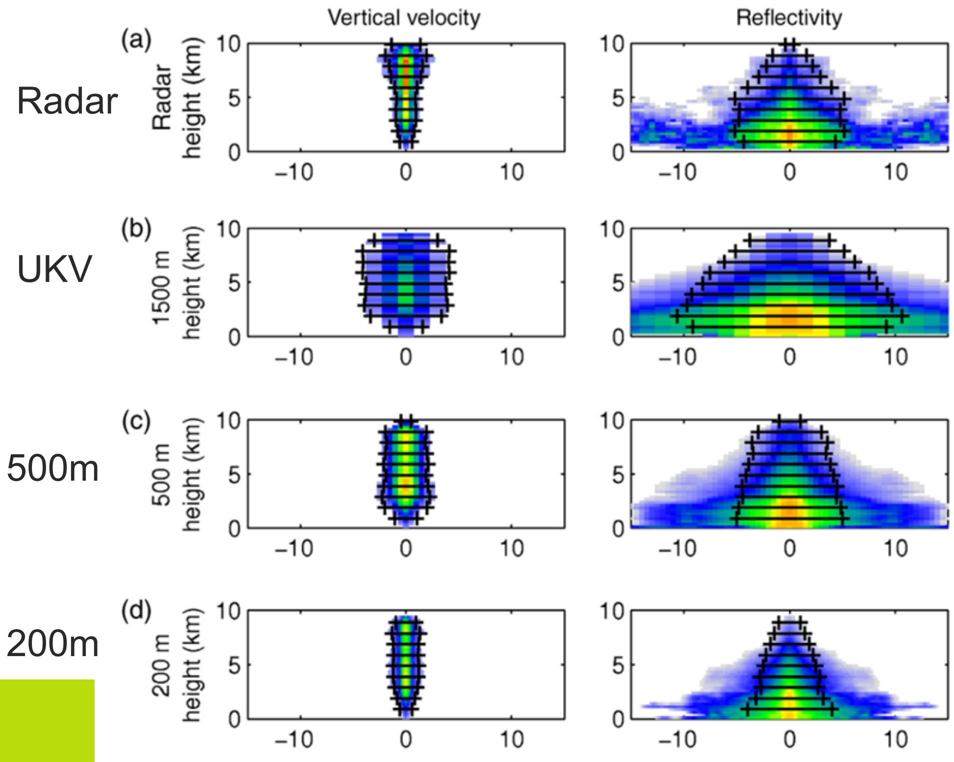
The high resolution of these models will enable improved representation of many important meteorological phenomena as well as better resolved urban areas. In conjunction with coupled sub-models this will enable, within predictability constraints, accurate forecasting of high impact hazards on neighbourhood scales. The use of large domains will allow the representation of important interactions between the mesoscale and urban scales.

Scope and Terminology

Development of the capability for model configurations with gridlengths in the range 25-300m. We term these models as "Urban-scale". This is because being able to better resolve city areas is likely to be the most important practical property of these models which will define many future applications. This is analogous to the common practice of referring to km scale models as "Convective Scale models" where the ability to start to explicitly represent convection has been the key benefit. It is important to note that the use of the term "Urban-scale" does *not* exclude non-urban specific applications of these models, such as better representation of convection etc.

Convection in km-scale models

- The Met Office currently run both a 1.5km gridlength deterministic model (UKV) and a 2.2km gridlength ensemble (MOGREPS-UK) over the UK with convection handled explicitly.
- However, convection is often very under-resolved in the UK at these gridlengths:



- Profiles show that updrafts are too shallow and broad in the 1.5km UKV – this is mirrored in reflectivity.
- Improved with increased resolution (but becomes too narrow).

Aggregate of characteristics of convective cells over southern UK from 1200-1600 UTC 25/08/2012

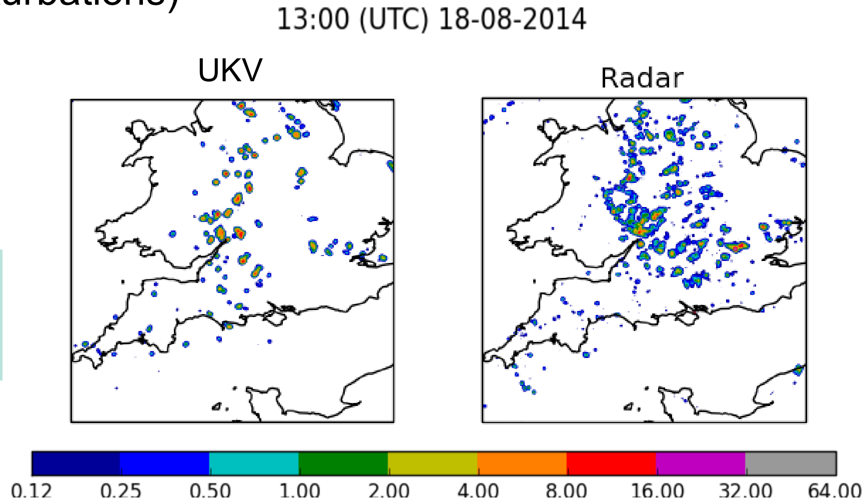
[Nicol et al (2015)]

Met Office

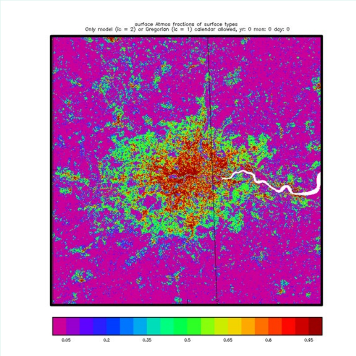
Convection in km-scale models

- As a result of being under-resolved, in kilometre-scale versions of the UM (such as the UKV) we tend to see:
  - A delay in the initiation of convection (which can be improved by modifying the model physics e.g. including stochastic BL perturbations)
  - Too few smaller, lighter showers
  - Too many heavy “blobby” cells
  - Often miss organisation

Example of surface rain rate from the operational UKV and the radar-derived surface rainfall composite.

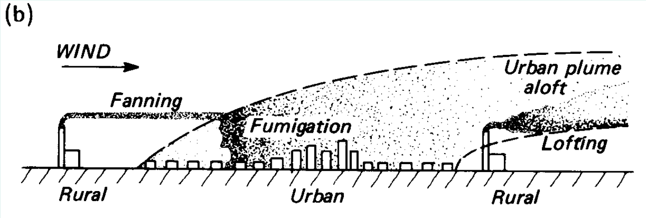


Potential benefits of urban-scale models



Better representation of underlying surface e.g. urban fraction, orography.

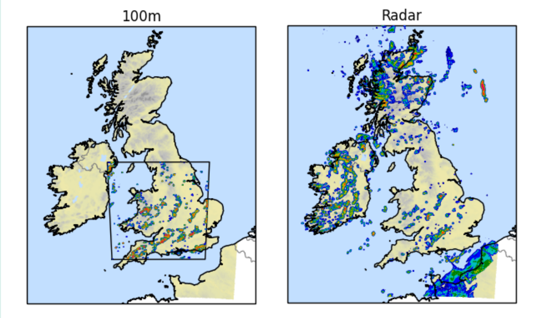
Benefits for orographic precipitation, cold-pooling in valleys, temperature distribution in cities.



Can capture urban/neighbourhood scale effects.

Potential for neighbourhood scale forecasts (within predictability constraints).

Good representation of boundary layer structure critical for AQ/Dispersion.

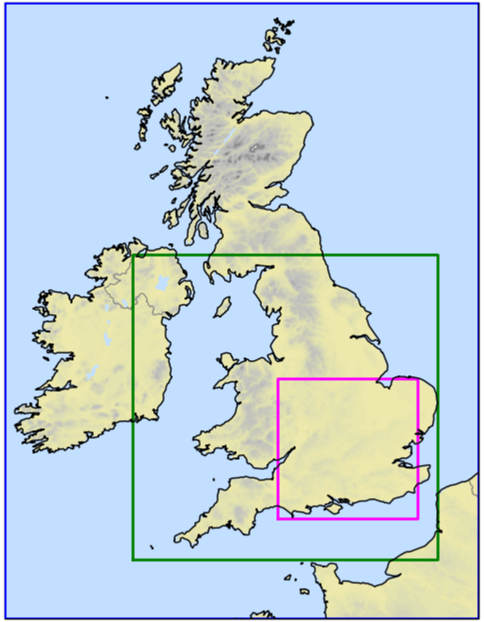


Model dynamics will better resolve some atmospheric processes such as convergence lines, entrainment, turbulence.

Benefits for convection, sea breezes, tornadoes

Met Office

Nested model setup



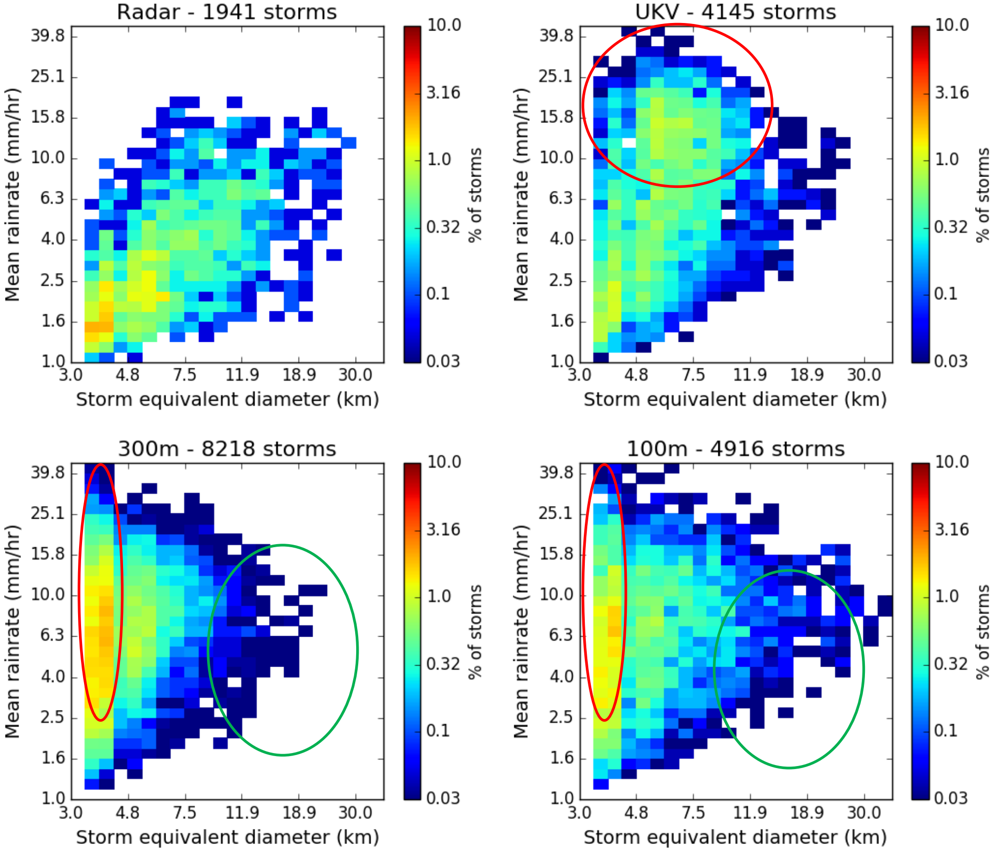
Model name	Grid length (km)	Size (grid points)	Levels	Timestep
UKV	1.5 → 4	950 x 1025	70	60s
300m	0.333	1800 x 1800	70	12s
100m	0.1	2750 x 2750	140	2s

Using the Regional Atmosphere and Land configuration version 2.0 (RAL2: Bush et al, 2022):

- Blended PBL-3D Smagorinsky turbulence scheme
- Single moment microphysics

Initialised from 03Z UKV analysis
All data regridded to the 1.5km grid

Storm characteristics

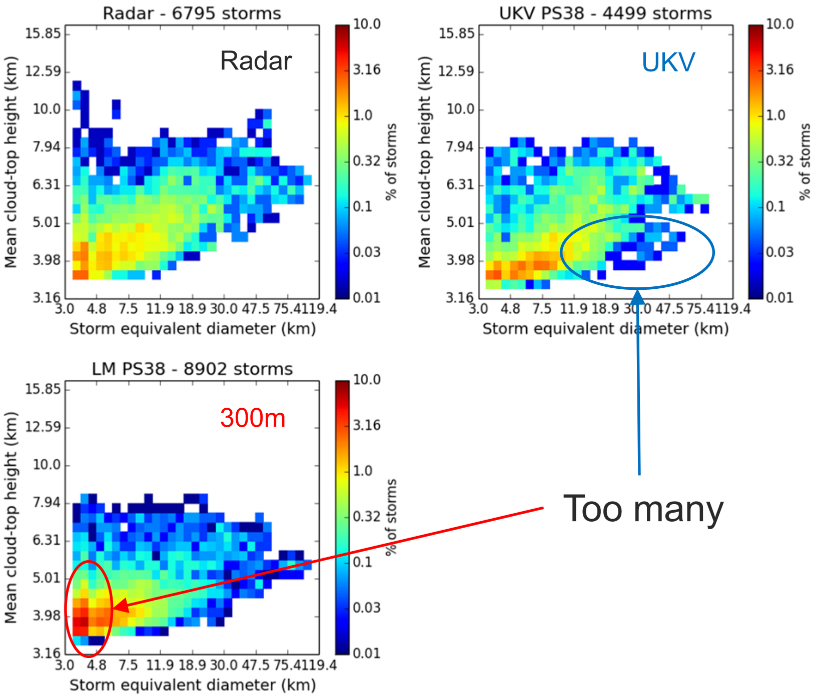


2D histograms of storm mean rainrate against storm diameter. Storms identified using a rainrate threshold of 1 mm/hr and minimum area of 4 UKV grid boxes.

- Sub-km models have too many small storms with too high rainrates – this is worse at 300m than 100m.
- Sub-km models have too few larger storms with moderate rainrates.

Met Office

Storm depth – composite of 8 cases

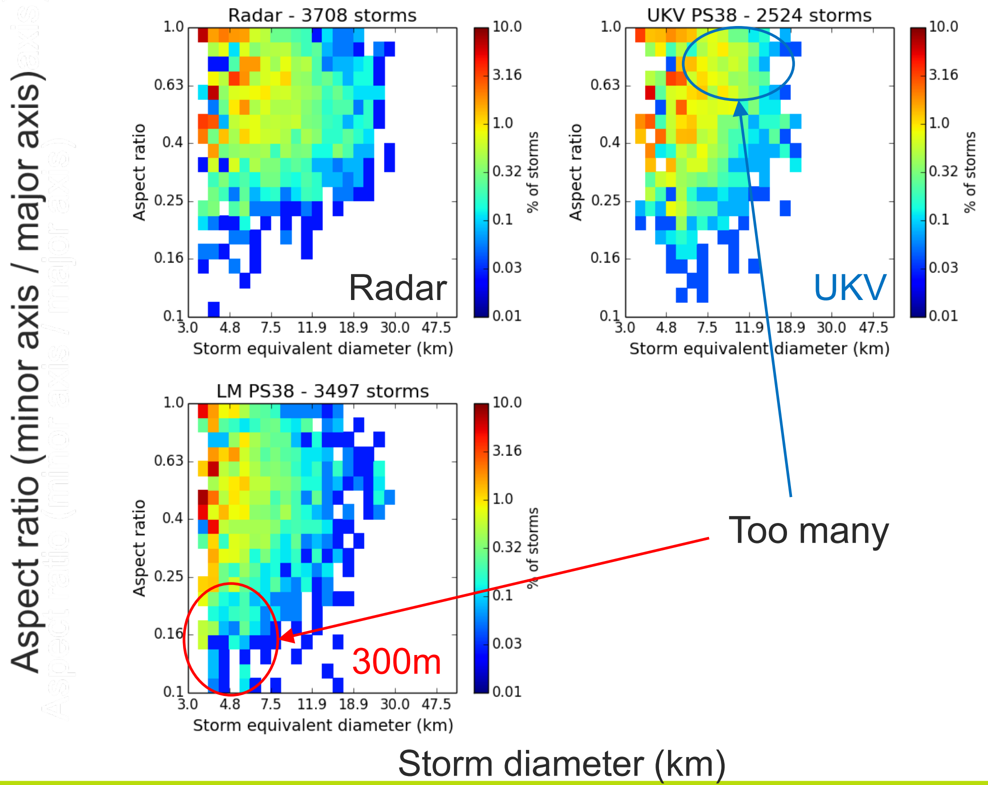


2D histograms of 0 dBZ echo-top height against storm diameter.
Storms identified using a height threshold of 3.5km and minimum area of 4 UKV grid boxes.

- Both UKV and 300m model miss deepest storms
- The UKV has too many large diameter shallow storms.
- The 300m model has too many small diameter shallow storms.

Met Office

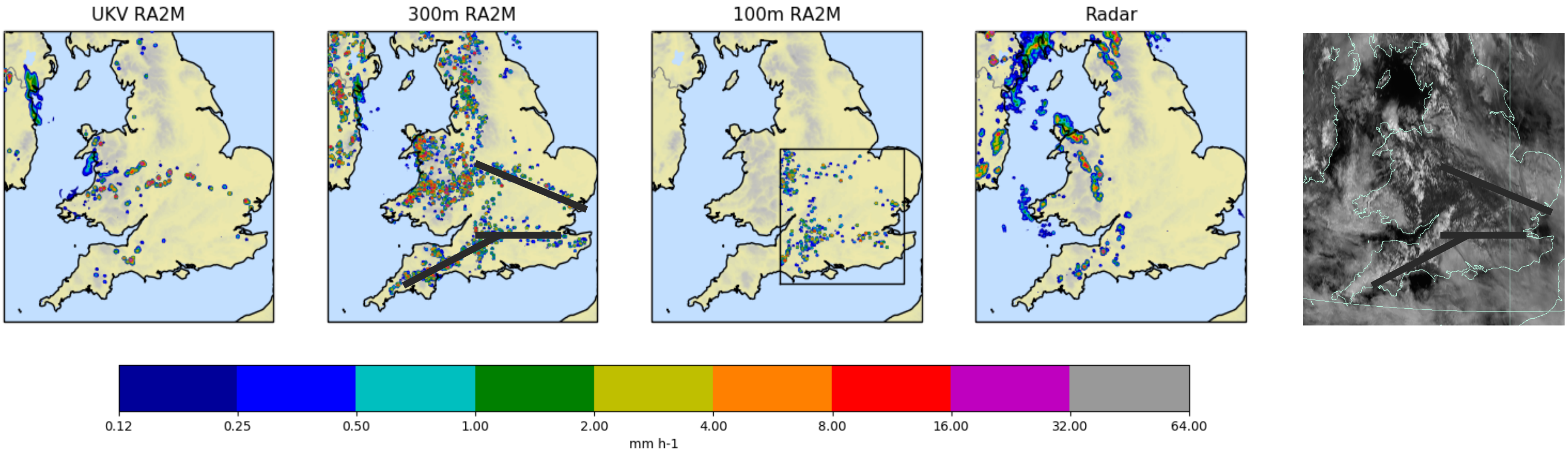
Storm shape – composite of 6 cases



Fit ellipses to surface rainfall features – identified using a 4 mm/hr rainrate threshold and minimum area of 4 UKV grid boxes.

- UKV has too many medium-sized circular storms.
- 300m model has too many small elongated storms.

Representation of small showers



- Location of convergence lines agrees well but no rain in reality.
- Need to understand reason for spurious rain:
  - Some evidence shallow clouds are going too deep, possibly due to too strong updrafts and missing entrainment
  - Microphysics issues?
  - Something else?

Met Office

Representation of Convection at 100m

- Some aspects improved such as organisation
- However, tend to see too many small storms which precipitate too easily
- Storms tend to be too linear – often aligned along the wind direction
- Does not automatically improve at higher resolution due to:

1. Compensating errors in km scale models including those imported from the larger scale driving model. *Requires detailed analysis of errors – 3d observations of cloud, updrafts, turbulence. The Wessex Summertime Convection (WesCon) field campaign in 2023 will provide observations to validate model against.*

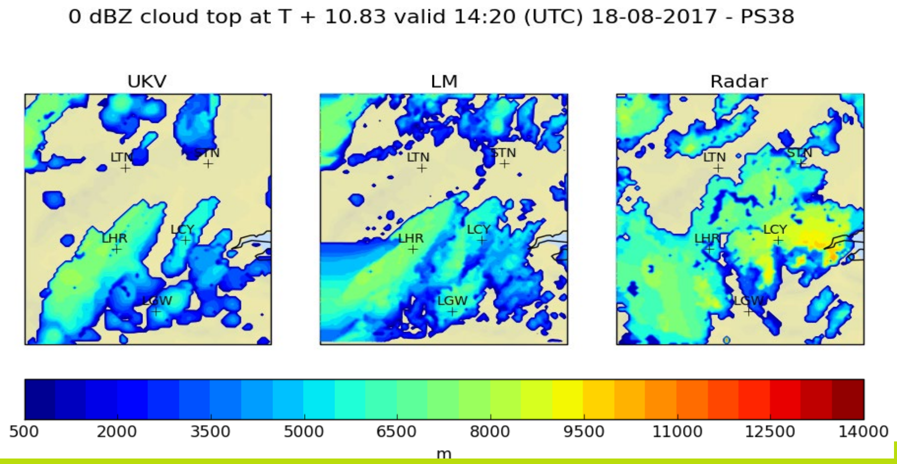
2. Need appropriate and scale aware parameterisations. *E.g. Convection, turbulence, microphysics. Scale aware convection may not be directly relevant at 100m but affects characteristics of driving model.*

3. Domain size. Spin-up from the boundaries can extend 10s of km into the domain. Need a sufficiently large domain for convection to spin up. *Variable resolution might be a solution.*

Met Office

The 300m London Model

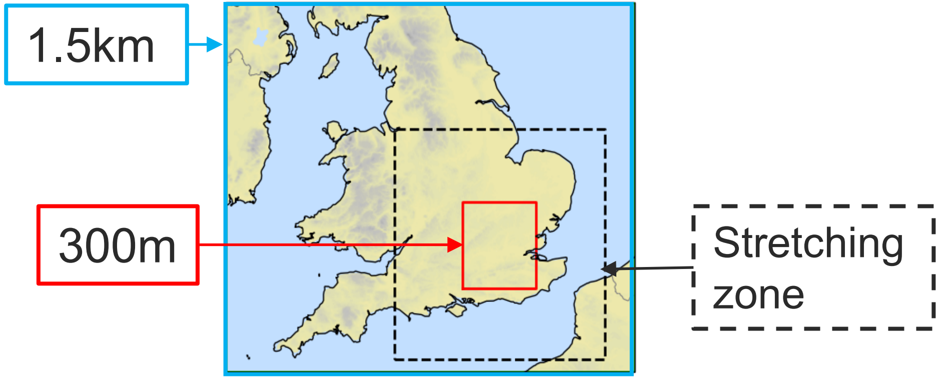
- Mirrors UKV configuration (timestep = 12 s).
- Primarily used for fog forecasting, where it has been shown to have improved performance compared to the UKV (Boutle et al. 2016, QJ).
- Is convection also better represented?



- Some aspects improved (initiation time) but small domain size doesn't allow features to spin-up, tends to follow UKV.
- Spin-up from the boundaries can extend ~50km.
  - ➢ Need a larger domain
- Additionally, the unpredictable scales are large compared to the domain size and therefore storms can appear missed altogether.
  - ➢ Need an ensemble.

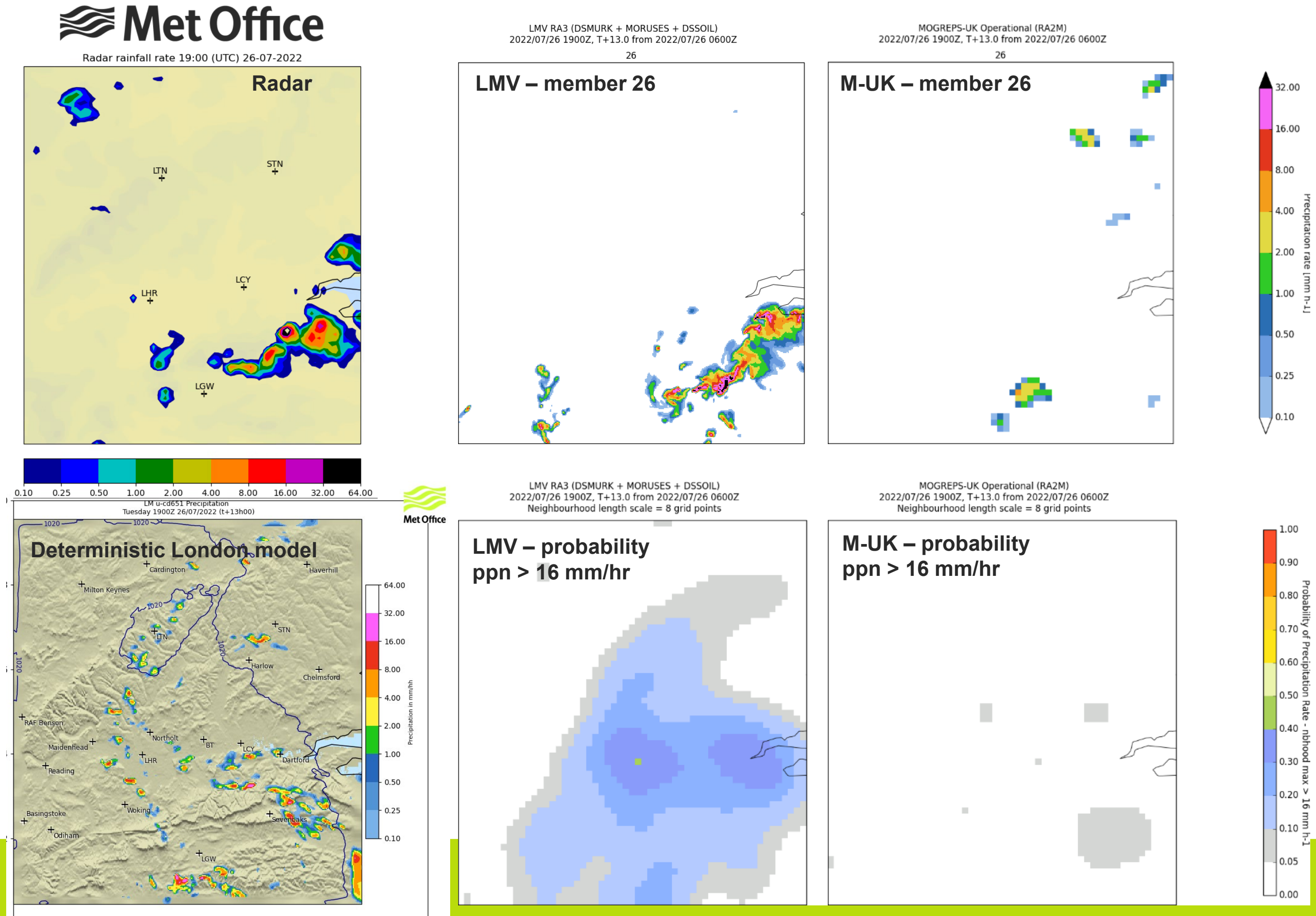
Variable resolution London Model (LMV)

- Sub-km models are very expensive to run (more grid points, smaller timestep).
- Using variable resolution can mitigate this by allowing the boundaries of the model to be further away from areas of interest (e.g., London Heathrow) at cheaper computational cost.
- Set up a variable resolution London model ensemble (18 members):



Model	Gridlength (km)	Grid points	Cost relative to LM
LM	0.333	380x420	1x
LMV	0.333 -> 1.5	910x872	5x
600km 300m	0.333	1800x1800	20x

- Run LMV ensemble once per day during July-September 2022 with ICs and LBCs provided by the operational 2.2km gridlength MOGREPS-UK ensemble.



26 July 2022 1900Z (T+13)

Intense storm over London with ppn rates > 16 mm/hr.

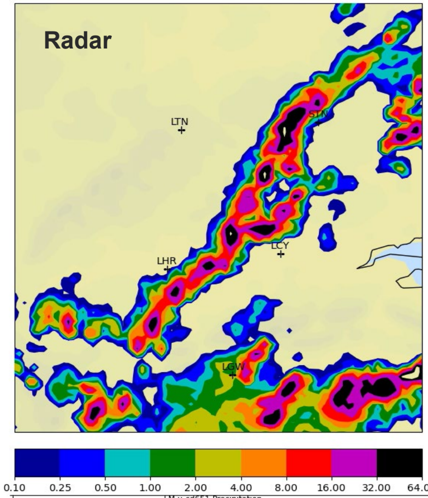
Some LMV members were able to capture the structure and location of this storm better than the equivalent MOGREPS-UK members.

This led to greater probabilities of ppn > 16 mm/hr in the LMV ensemble.

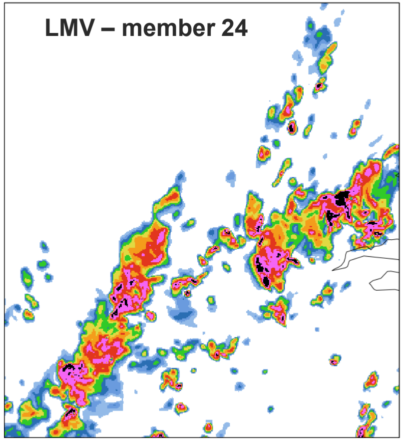
Probabilities are calculated using a neighbourhood length scale of 17.5 km.

Met Office

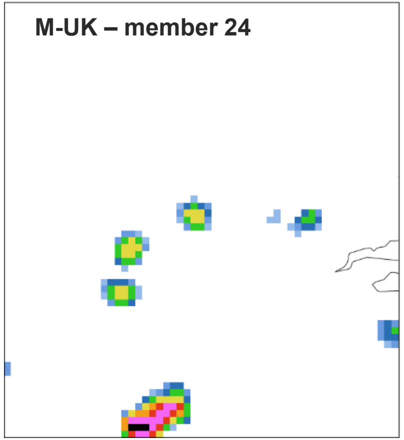
Radar rainfall rate 14:00 (UTC) 17-08-2022

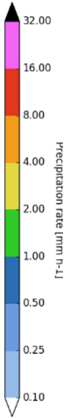


LMV RA3 (DSMURK + MORUSES + DSSOIL)
2022/08/17 1400Z, T+8.0 from 2022/08/17 0600Z
24



MOGREPS-UK Operational (RA2M)
2022/08/17 1400Z, T+8.0 from 2022/08/17 0600Z
24



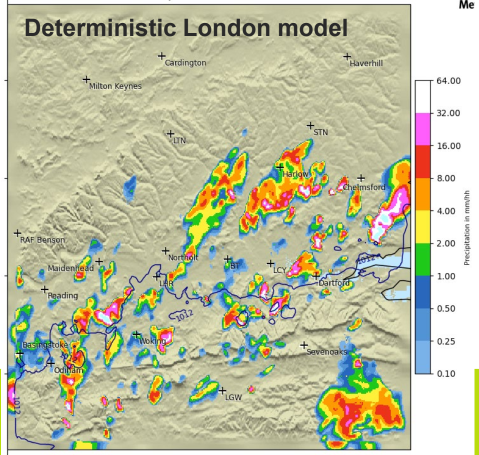


17 August 2022 1400Z (T+8)

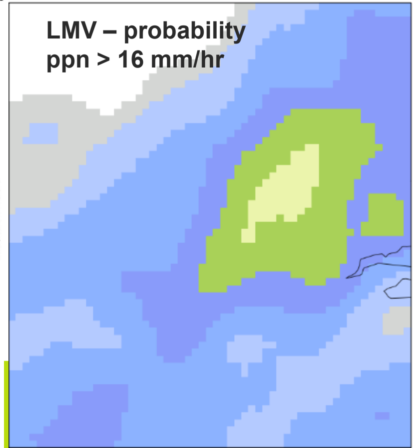
Intense band of ppn across London

Some LMV members were able to capture the organisation of the band of intense ppn better than the equivalent MOGREPS-UK members.

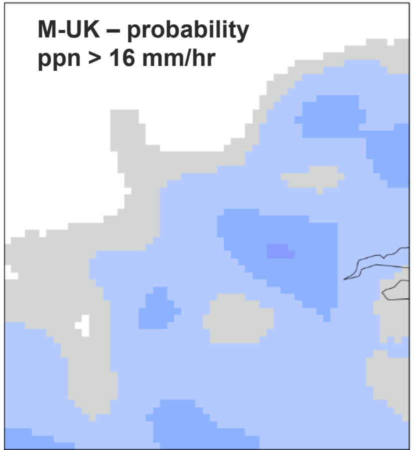
LM u-cd651 Precipitation
Wednesday 1400Z 17/08/2022 (t+08h00)

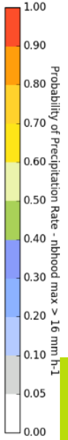


LMV RA3 (DSMURK + MORUSES + DSSOIL)
2022/08/17 1400Z, T+8.0 from 2022/08/17 0600Z
Neighbourhood length scale = 8 grid points



MOGREPS-UK Operational (RA2M)
2022/08/17 1400Z, T+8.0 from 2022/08/17 0600Z
Neighbourhood length scale = 8 grid points





This led to greater probabilities of ppn > 16 mm/hr in the LMV ensemble.

Probabilities are calculated using a neighbourhood length scale of 17.5 km.

Next steps

- Further analysis of LMV compared to MOGREPS-UK using the error and dispersion Fractions Skill Score (eFSS/dFSS: *Dey et al., 2014*) to assess skill and spread.
- Paris 2024 Research Demonstration Project:
  - ➢ Urban-scale model intercomparison (convection, heat) – do other models see similar biases at O(100m)?
  - ➢ Field campaign 2022
- WesCon 2023:
  - ➢ FAAM aircraft, Chilbolton Radar, Surface obs
  - ➢ 300m ensemble, possibly 100m sub-ensemble

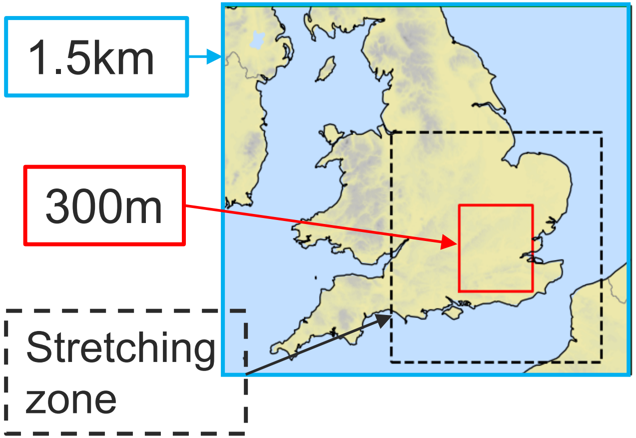
For more information please contact

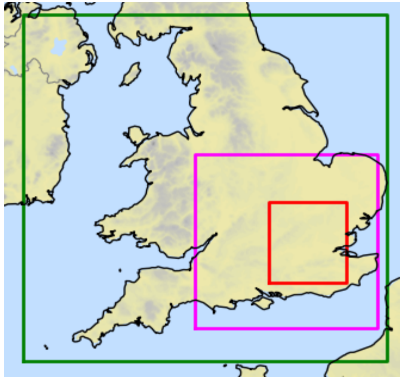
www.metoffice.gov.uk

Kirsty.Hanley@metoffice.gov.uk

Variable resolution London Model (LMV)

- Sub-km models are very expensive to run (more grid points, smaller timestep).
- Using variable resolution would allow the boundaries of the London model to be further away from areas of interest (i.e., London Heathrow) at cheaper computational cost.
- Compare a variable resolution 300m model to three fixed resolution 300m models:

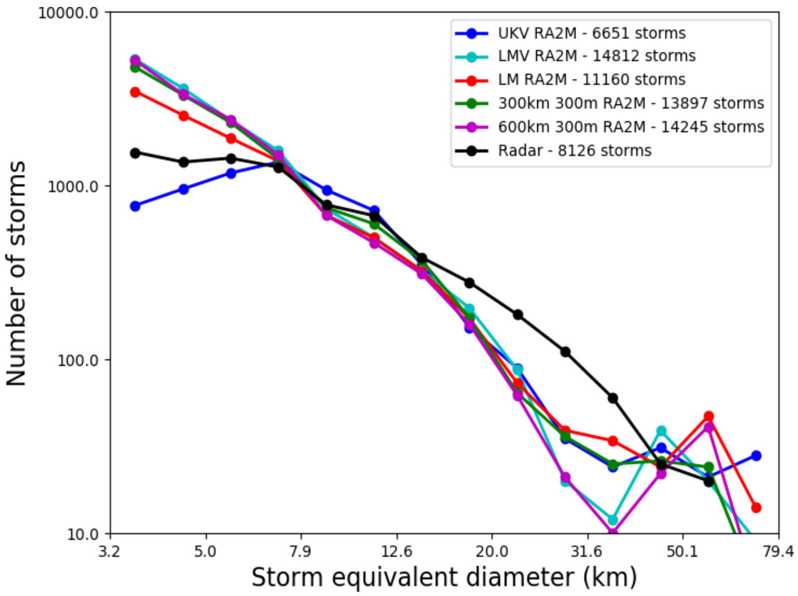




Model	Gridlength (km)	Grid points	Cost relative to LM
LMV	0.333 -> 1.5	910x872	5x
LM	0.333	380x420	1x
300km 300m	0.333	900x900	5x
600km 300m	0.333	1800x1800	20x

- Run for 6 cases of summertime convection - all 4 models are initialised using the 03Z UKV analysis and are run using RA2M with 70 levels and a 12 s timestep.

Storm size statistics – composite of 6 cases



- Data has been regridded to 1.5 km and is every 5 minutes from 09-19 UTC, with **distributions calculated over the LM model domain.**
- Storms are identified using a rainrate threshold of 1 mm/hr and minimum area of 4 1.5km grid boxes.
- The distribution of storm sizes in the LMV is very similar to the distribution of storm sizes in the 600km 300m model, suggesting that by the time storms reach the inner 300m grid length part of the LMV domain they are well spun-up.