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Challenges in Convection Permitting Modelling

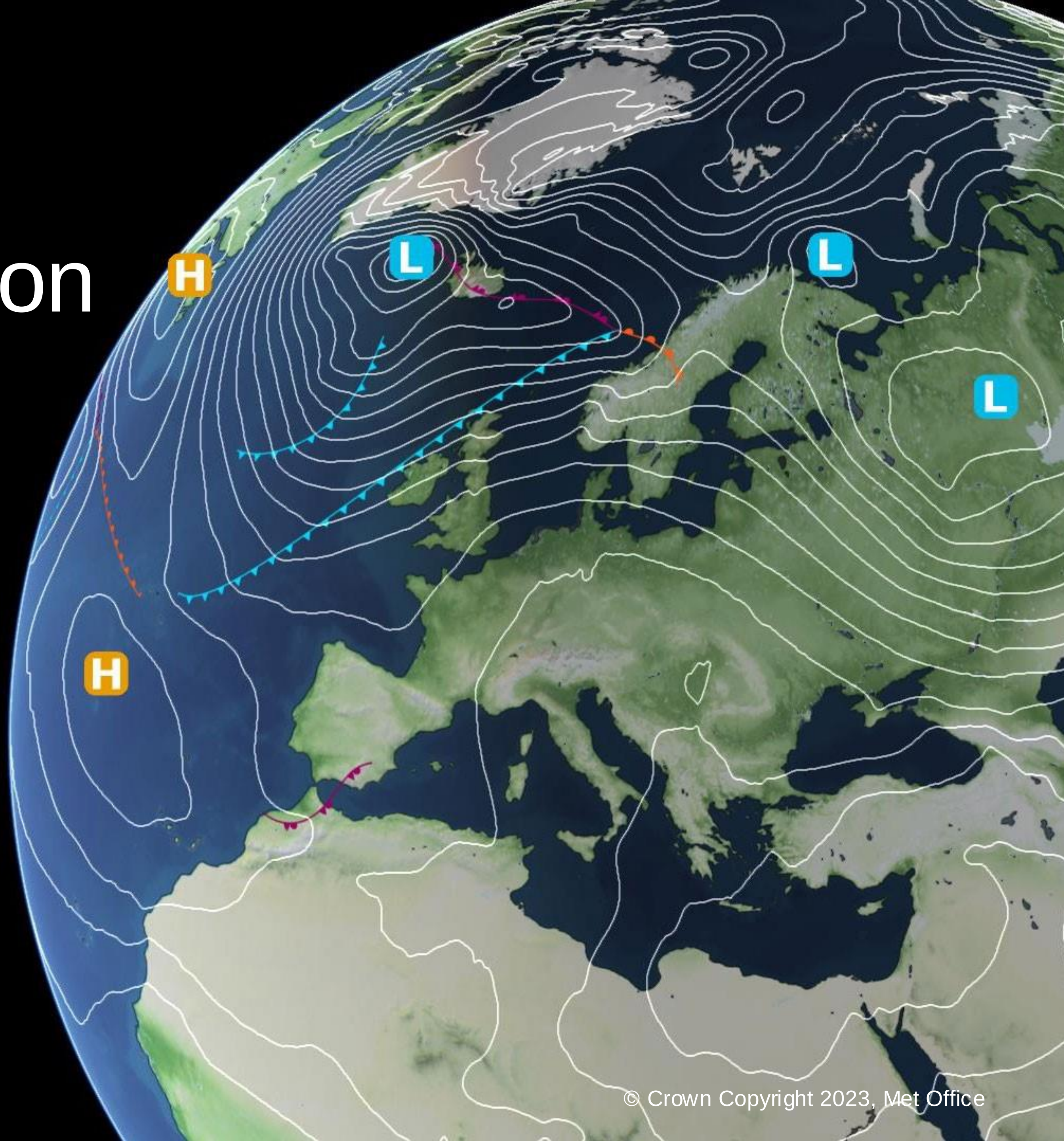
Humphrey Lean,

MetOffice@Reading

Reading UK.

Including work of many others.

Momentum Workshop, Melbourne, Sept 2024



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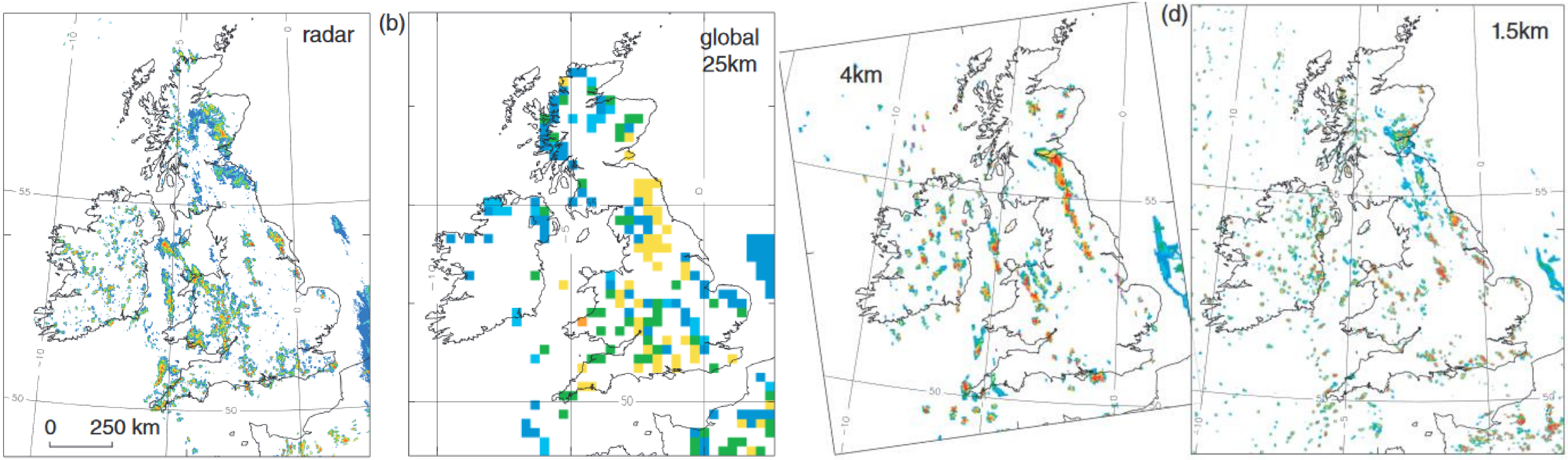
Km scale models



From Clark et al (2016) https://doi.org/10.1002/met.1538.

- Km scale models (introduced around 2010) produce a much more realistic representation of convection, and other weather, than the previous generation of order 10km models.
- Workhorse of forecasting for many Met services – also used for climate downscaling.
- Often used in ensemble mode.

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List of Biases in km scale models
From UM Partnership Convection Working Group (2019)

Cloud-scale biases
Too much heavy rain and too high peak rainfall rates.
Too strong and deep updrafts.
Not enough light rain.
Too many small cells, too few large if convection is well resolved.
Too few cells if under-resolved

Organisation biases
Cells too circular if under-resolved, too elongated if well resolved and orientation tends to be too much along wind.
Lack of propagation of squall lines.
Poor representation of elevated convection (e.g. lack of organisation).

Biases in response to large-scale / boundary layer / diurnal forcing
Timing of initiation of convection.
Other timing issues.
Land-sea contrast issues - in particular excessive convective rainfall over land and light rain over the ocean.

Biases in response to driving model
Spin up effects when starting from low resolution start data
Spin up effects at edge of domain
Errors passed from larger scale driving models.

Many of these inter-related and reflect same issues with representation of convection.

Humphrey Lean, Beth Woodhams and whole group

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Large Scale Errors

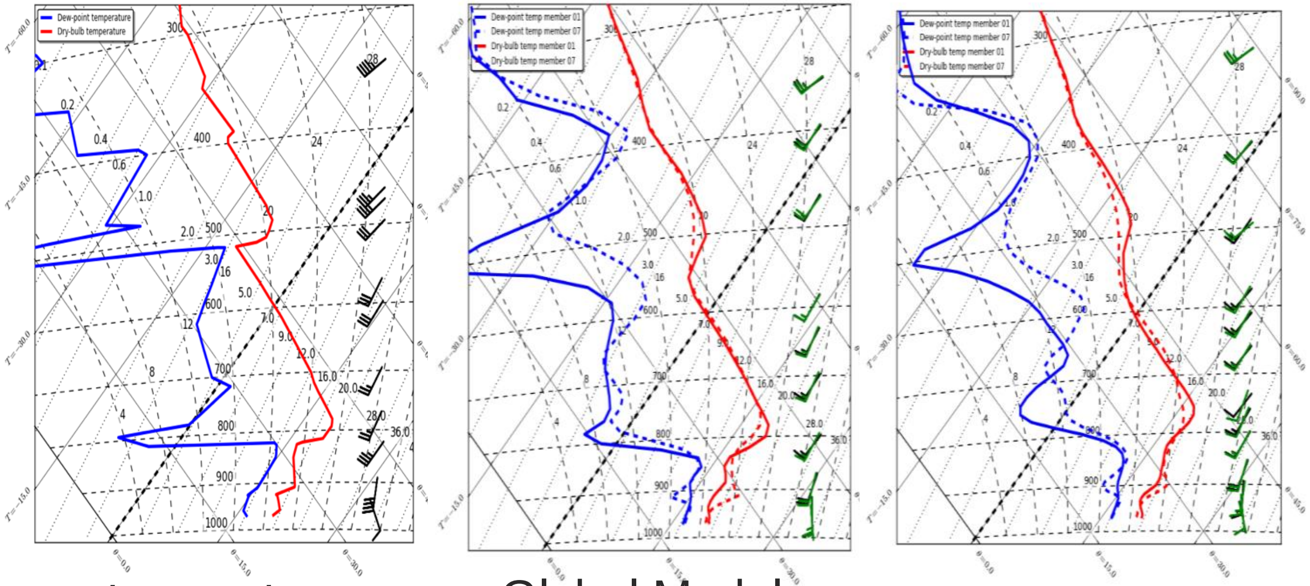
- Large scale errors. Very common problem is errors imported from the driving model (“Adding detail to something wrong”).

- Possibility of these errors to combine with small scale errors.

- Ensembles might be viewed as part of the solution to this *but* only work if model is unbiased.

Example of compensating errors: Hanley and Lean https://doi.org/10.1002/qj.4049. Ensemble study of convection initating on Great Plains. Most members initiated too early due to lack of CIN in profile and the one that did best compensated by being too dry and warm. Lack if CIN likely related to driving global model (convection scheme?).

Norman, OK, 12UTC 16/5/2017



Observations Global Model 2.2km

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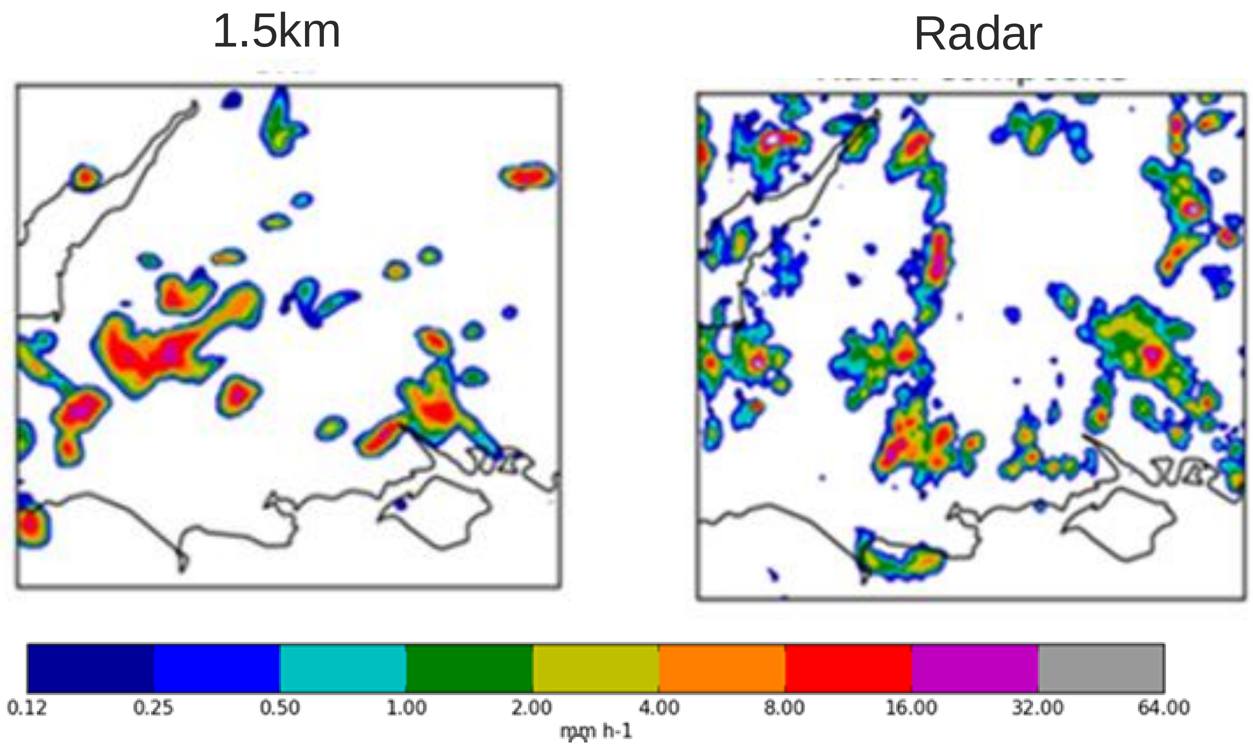
Km-scale representation of convection

Convection too “blobby” and structures likely to be aligned too along the wind.

Threshold (mm/hr)	Radar	UKV
0.125	7.81	16.04
0.25	6.32	13.21
0.5	5.58	11.71
1.0	4.42	9.93
2.0	3.28	7.95
4.0	2.57	5.96
16.0	2.13	3.37

Average cell diameter (km)
(averaged over 22 convective cases)



Convection often too small to be properly represented explicitly.

- Need a km-scale scale aware convection scheme (grey-zone of convection). Work in progress – see Sally Lavender talk.
- NB most other centres use shallow scheme at km scales

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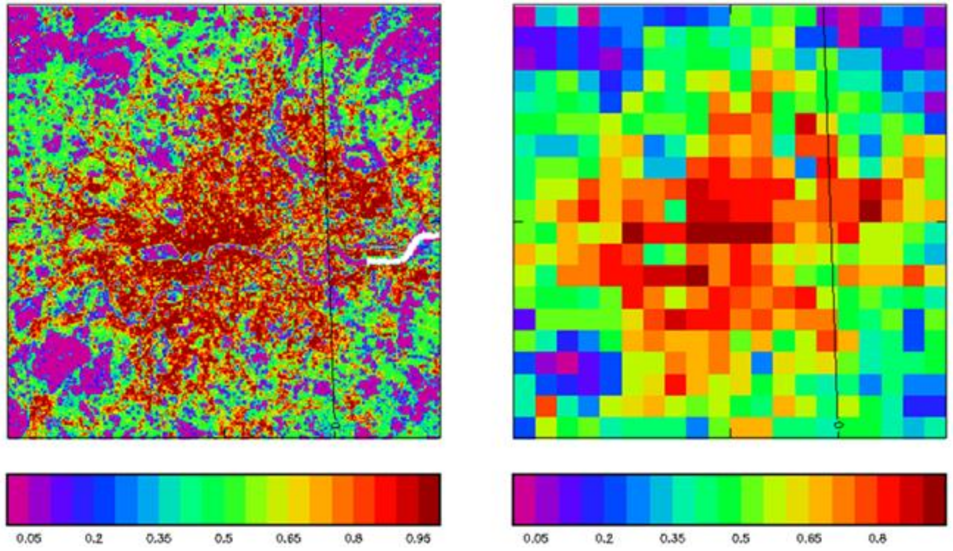
Urban Scale Modelling

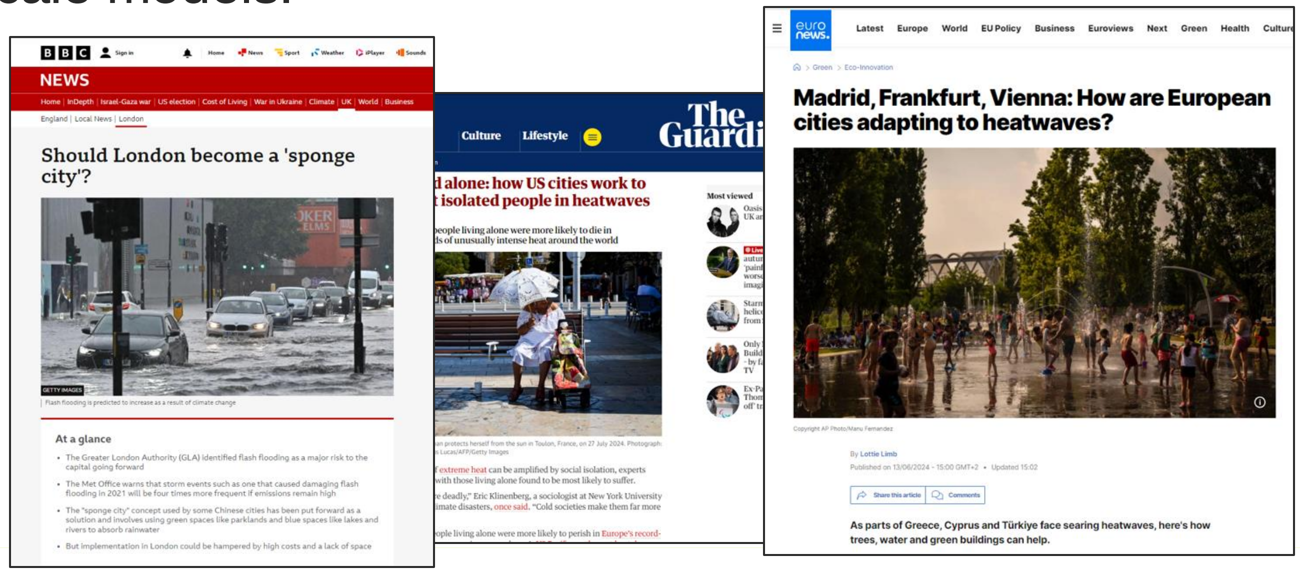
Vision Statement:
Deliver an enhanced Urban-scale modelling capability (an atmospheric model with grid lengths in the range 25-300m) for application across timescales to exploit next-generation supercomputing including sufficient understanding to specify practical systems.

- A key attraction is better resolution of urban areas. (Interest in urban heat/flooding on climate and weather timescales, WMO guidance to produce integrated urban services https://doi.org/10.1016/j.uclim.2020.100623).

- Expect higher resolution to give a better representation of convection. Also helpful to understand issues with convection in km scale models.



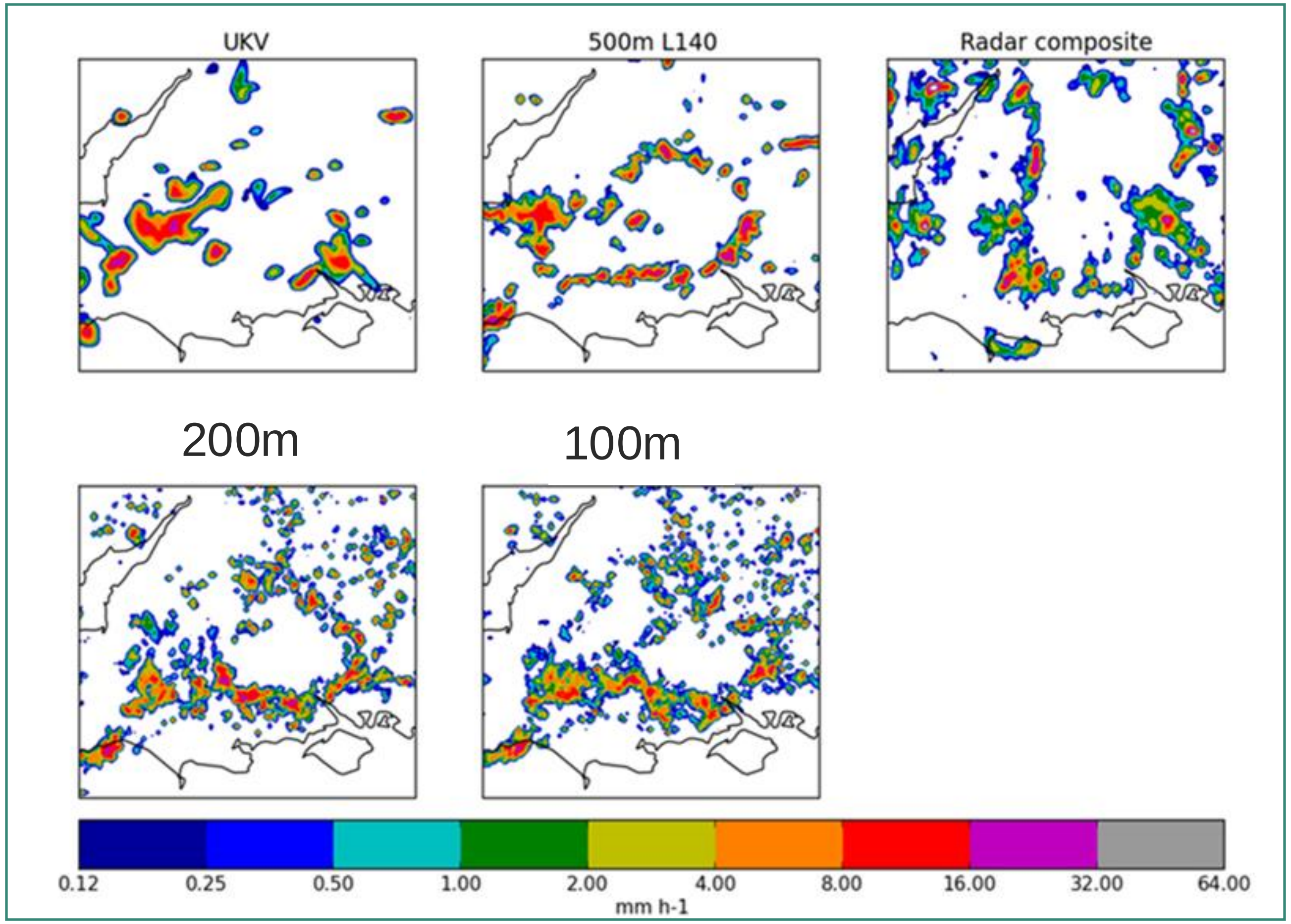
Comparison of London urban land use fraction for 100m (left) and 1.5km models.



See Urban-scale modelling review: Lean, Theeuwes et al. 2024 just accepted in QJ

Sub-km scale "urban –scale" modelling

- Going to high resolution with current configurations improves some aspects of convection but not all.



	Issue	Possible causes/mitigation.
1	Produce too many showers	Sub-grid mixing/microphysics
2	Tendency for shallow convection to precipitate too easily	Sub-grid mixing/microphysics
3	Generally initiate convection too early	Sub-grid mixing/microphysics/large scale errors.
4.	Tendency for structures to be more aligned along wind than across	Sub-grid mixing/microphysics/large scale errors/stochastic perts
5	Spin up from the boundary can extend tens of kms into domain	Explore use of variable resolution.

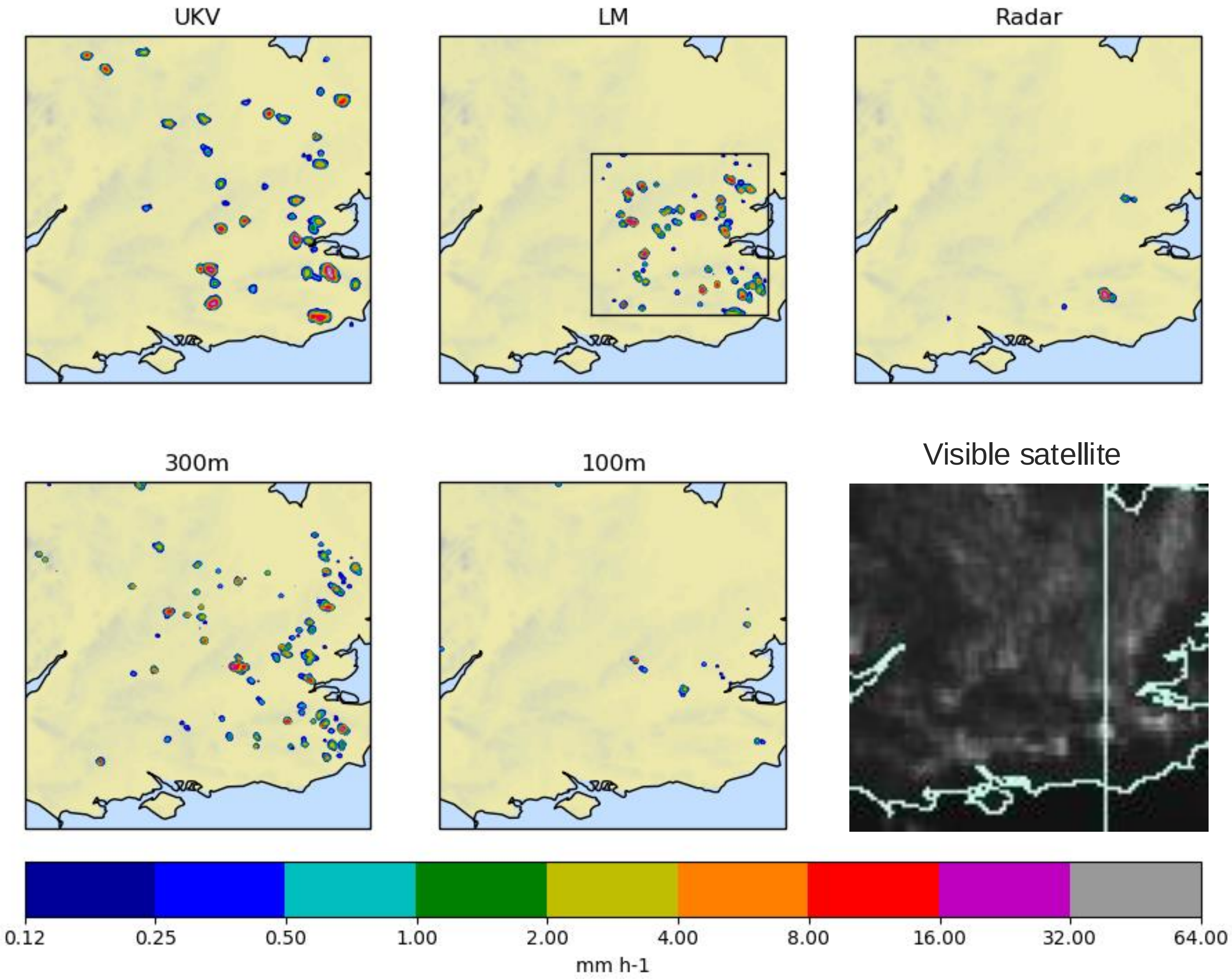
Table of issues with convection in 100m scale models

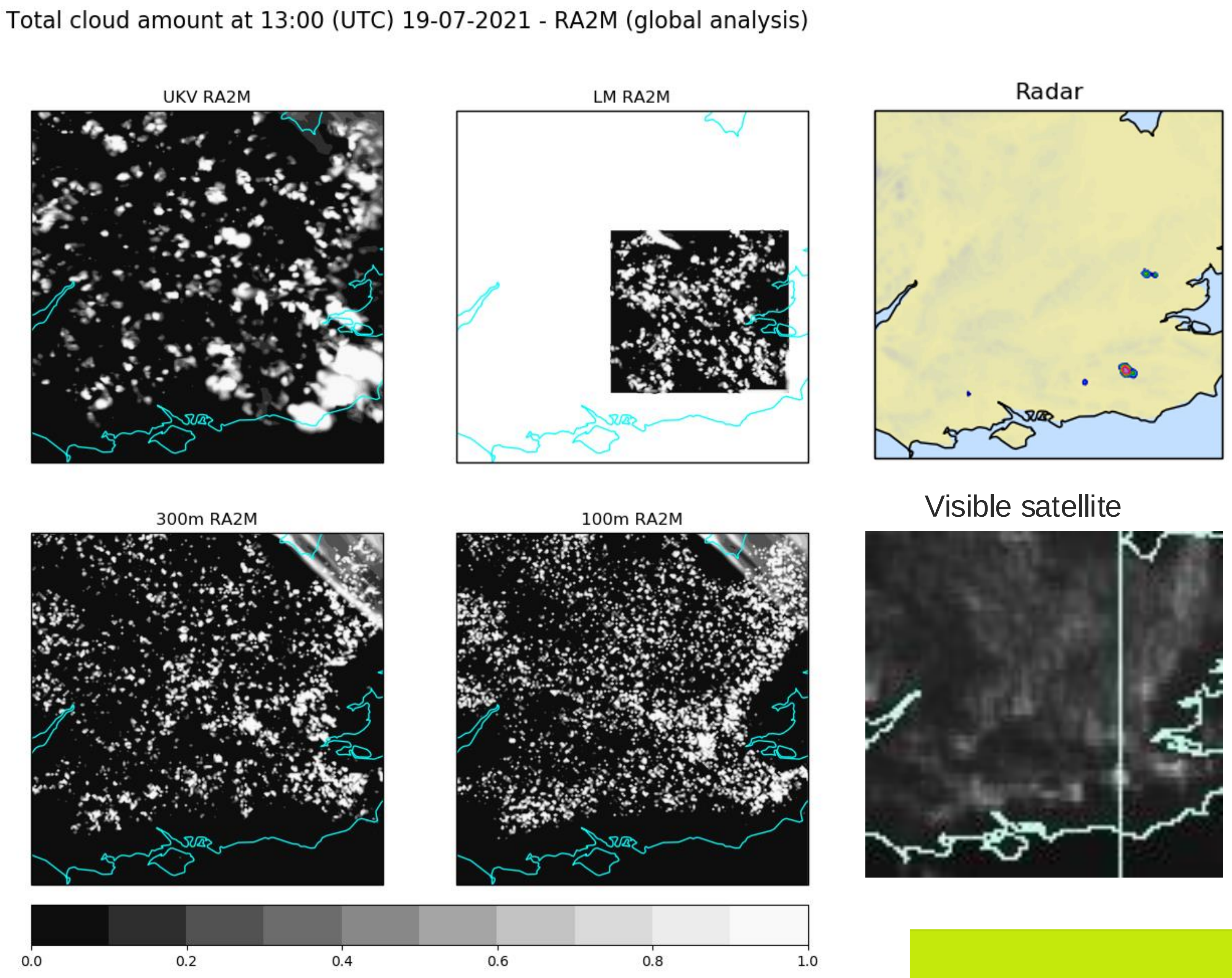
- Need to ensure that better resolved structures are realistic

- Need a grey zone turbulence scheme

Rainrate at T + 13.0 valid 13:00 (UTC) 19-07-2021 - RA2M (Global analysis)

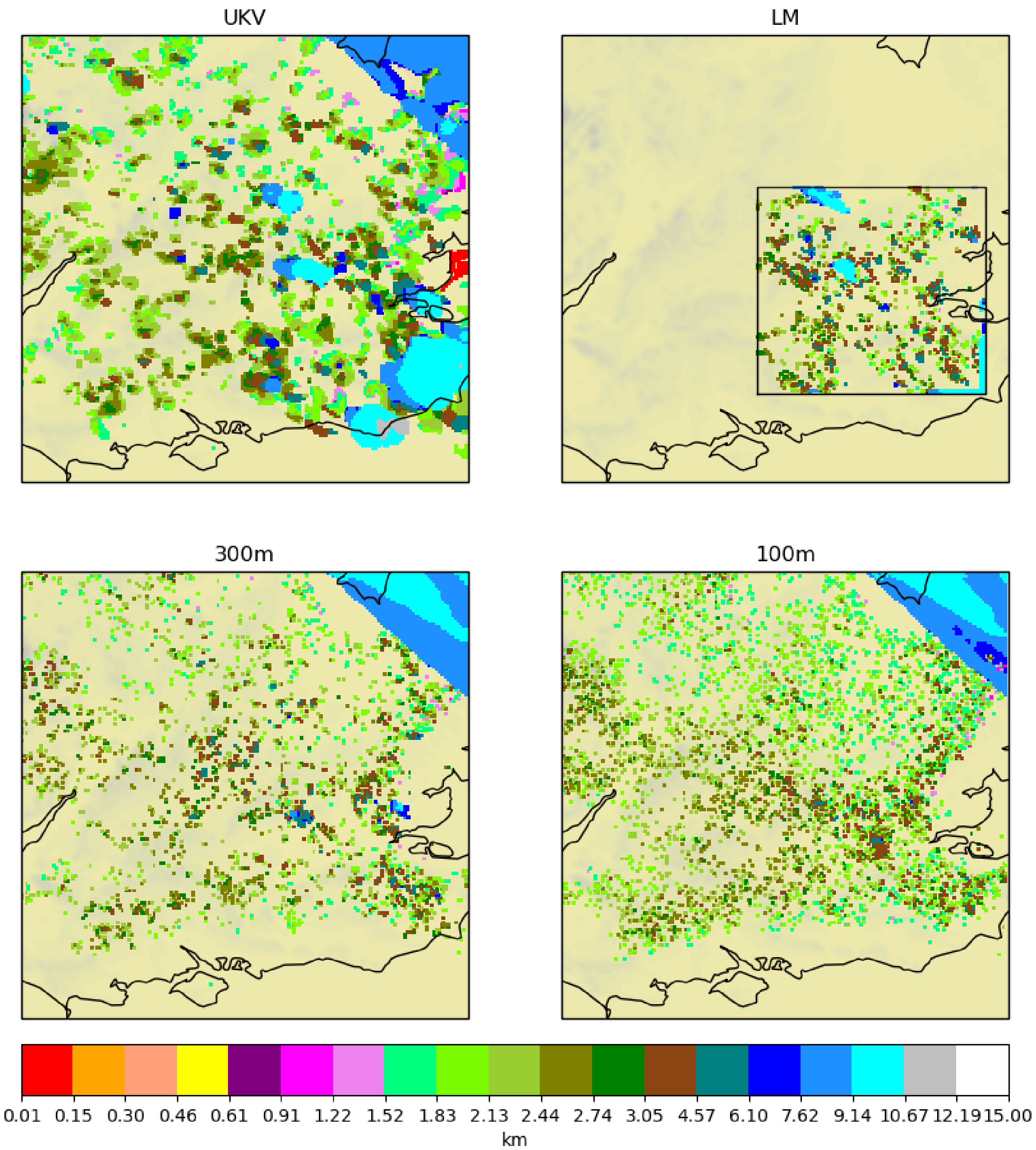
UK Heatwave situation

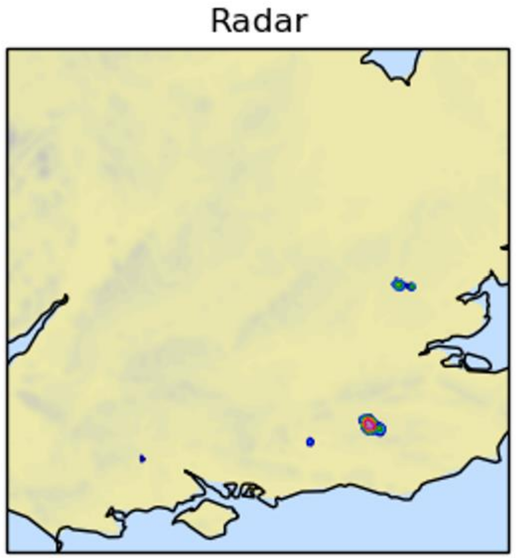


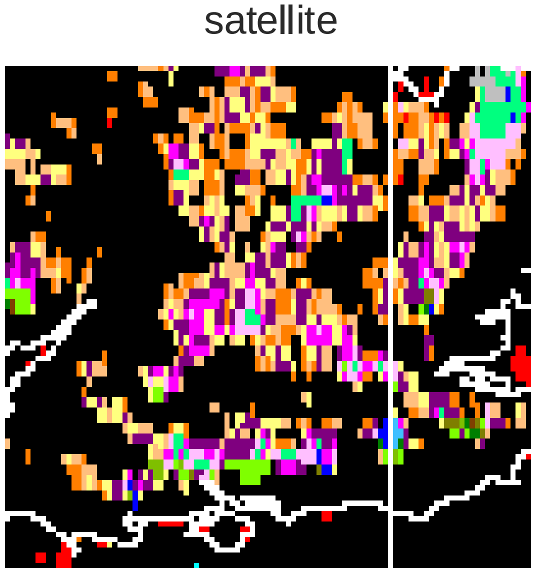


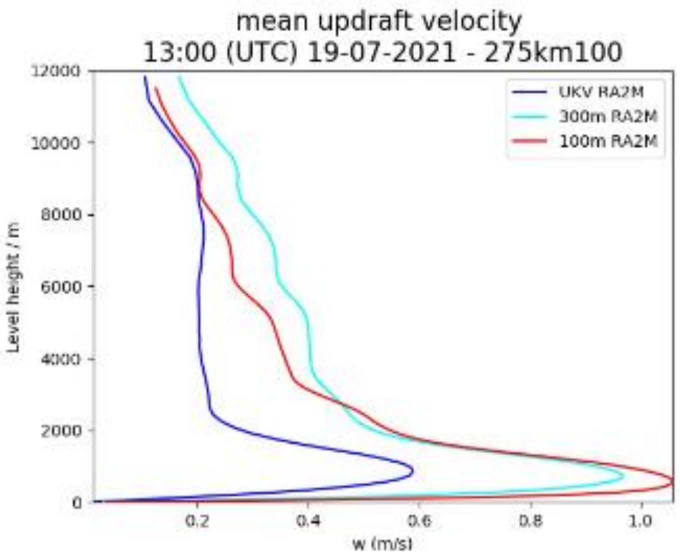
- Clouds continue to get smaller as gridlength reduced.
- Not clear if this is a fundamental issue.
- Corollory is that size of small clouds in 1.5km models is determined by the gridlength.

Total cloud top height at 13:00 (UTC) 19-07-2021 - RA2M









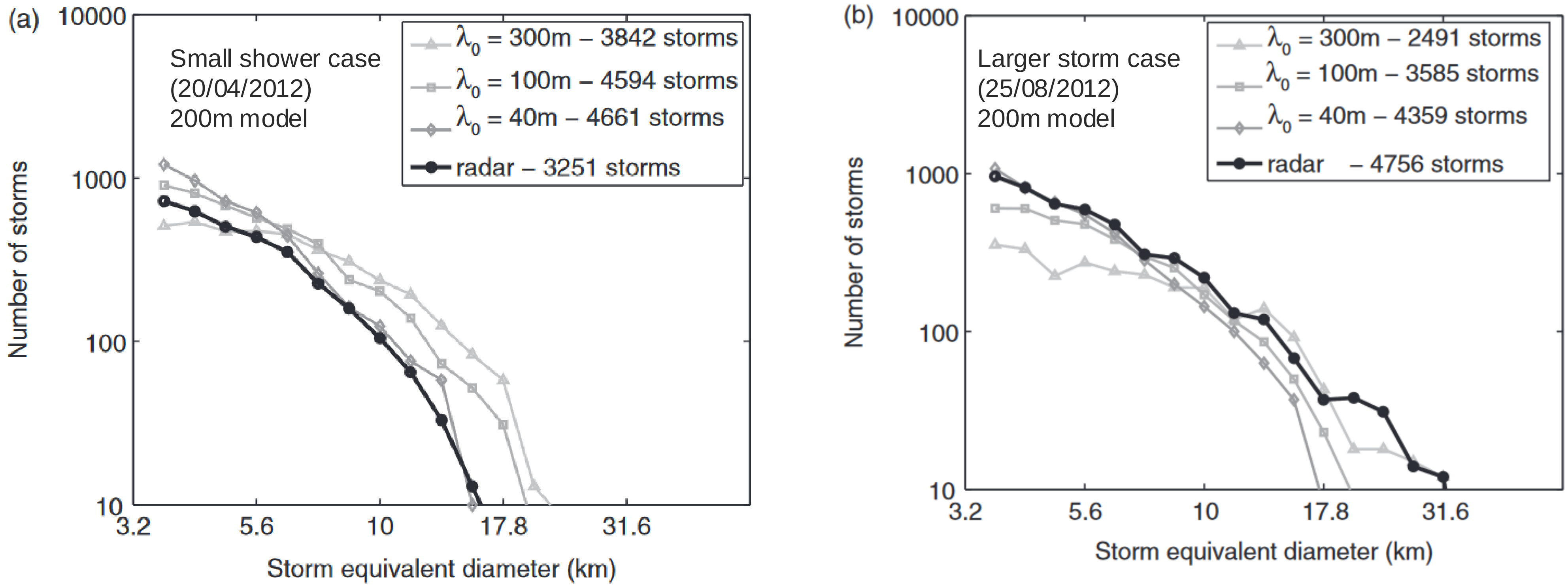
Precipitating storms usually exceed 3km.

Modelled storms often exceed 3km – 100m model (with less precip) has fewer storms exceeding 3km

Observed storms generally below 3km

Need vertical velocity observations as in WesCon

Evidence that storm morphology controlled by turbulence scheme



- Hanley et al (paper from DYMECS project) showed that the storm morphology is sensitive to mixing length using Smagorinsky scheme. Increasing mixing length reduces number of small showers and increases numbers of big ones.

- No mixing length gives satisfactory numbers of large and small storms in all situations.

Hanley et al 2015 https://doi.org/10.1002/qj.2356

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Effect of mixing length on small showers problem

- Intuitively would like to increase mixing length to mix out and enlarge spurious small showers.
- This (sometimes) correctly reduces number of showers but delays initiation may cause remaining showers to be too large, deep and blobby (rather like comparison of 300m and 2.2km).
- It may also inhibit organisation later in the day (capturing of which leads to most of the benefits we see from 300m).
- Is a cleverer turbulence scheme the answer?
- Or representing the smallest showers around initiation by a convection scheme?

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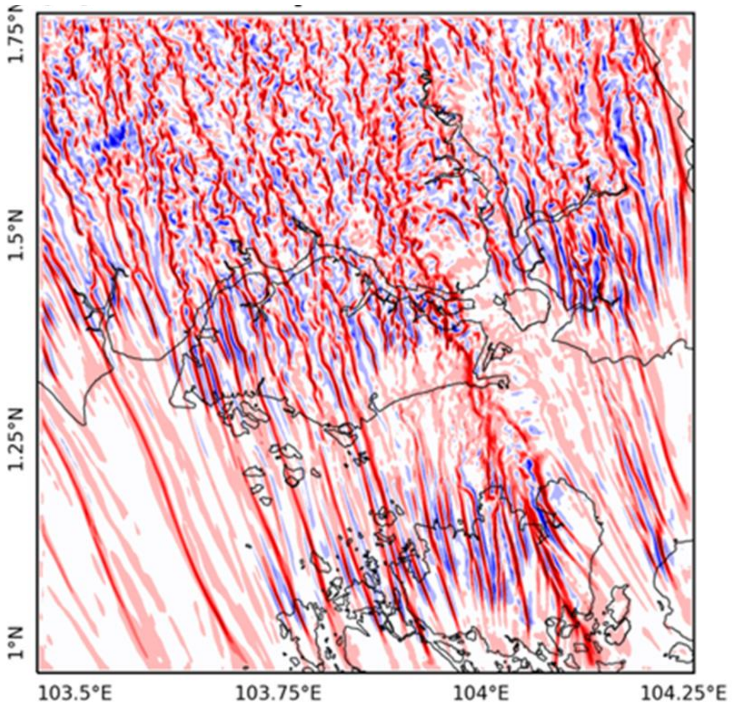
Boundary Layer considerations. Km scale and sub-km

- Boundary Layer is important in initiation of (non-elevated) convection.
- Representation of cold pools and sea breezes important.
- How do convective boundary layers feed into deep convection? Relationship between scales in BL and clouds forming above. Important for parameterisations and sub-km models.
- Urban-scale models which can start to resolve overturning seem very keen (too keen?) to produce boundary layer along-wind rolls. Maybe related to tendency of km and sub-km scale models to have deep convection too oriented along the wind.



Song Chen, CCRS, Singapore

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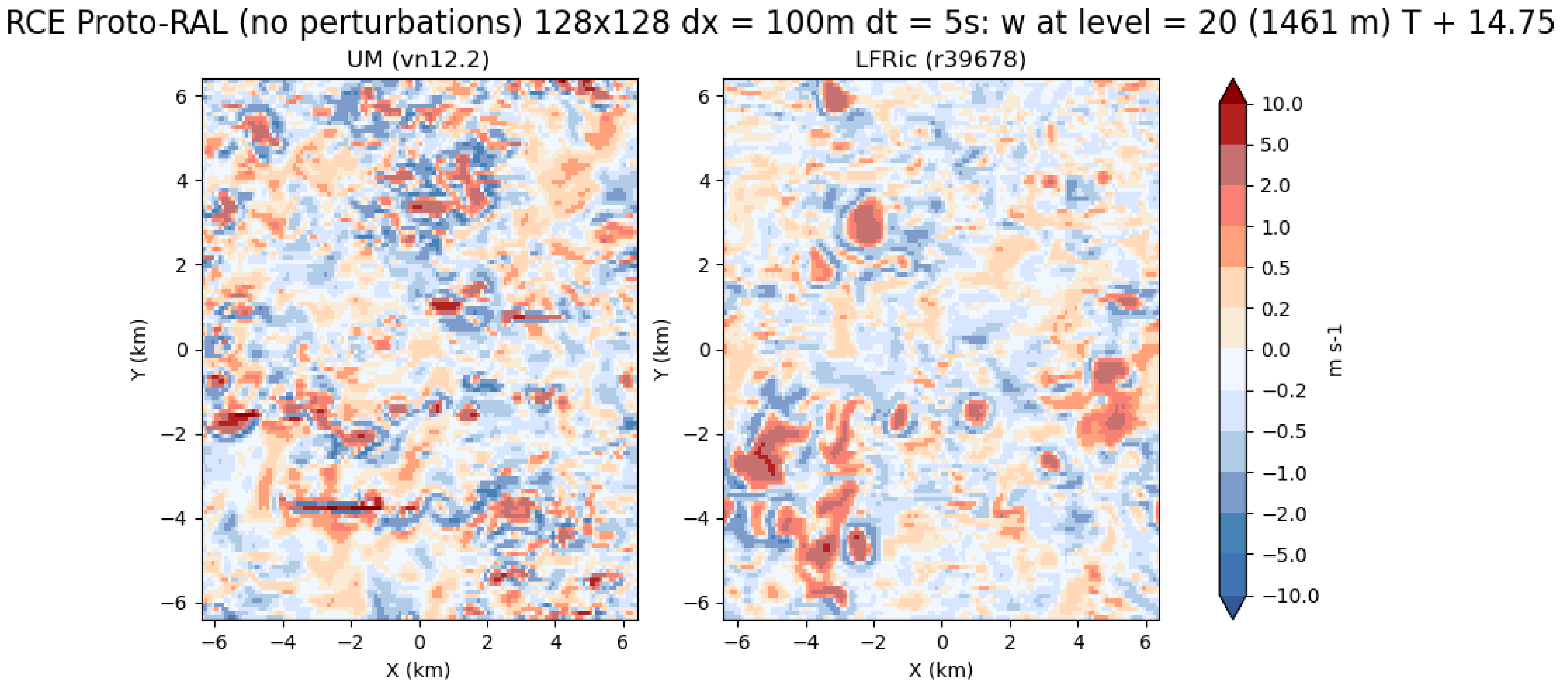
Early Lfric RCE (idealised) test



The UM develops along-wind streaky features – also seen in vertical velocity

(Will need to be repeated with new transport scheme)

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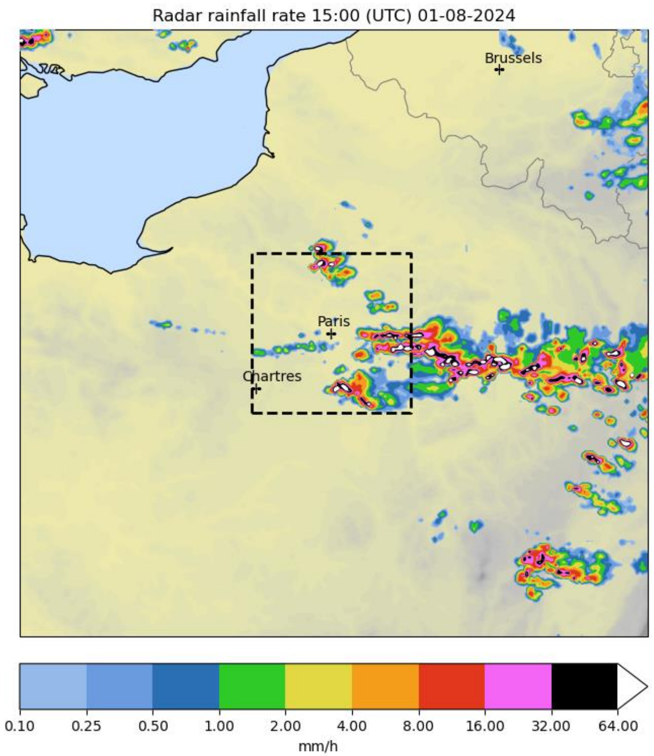
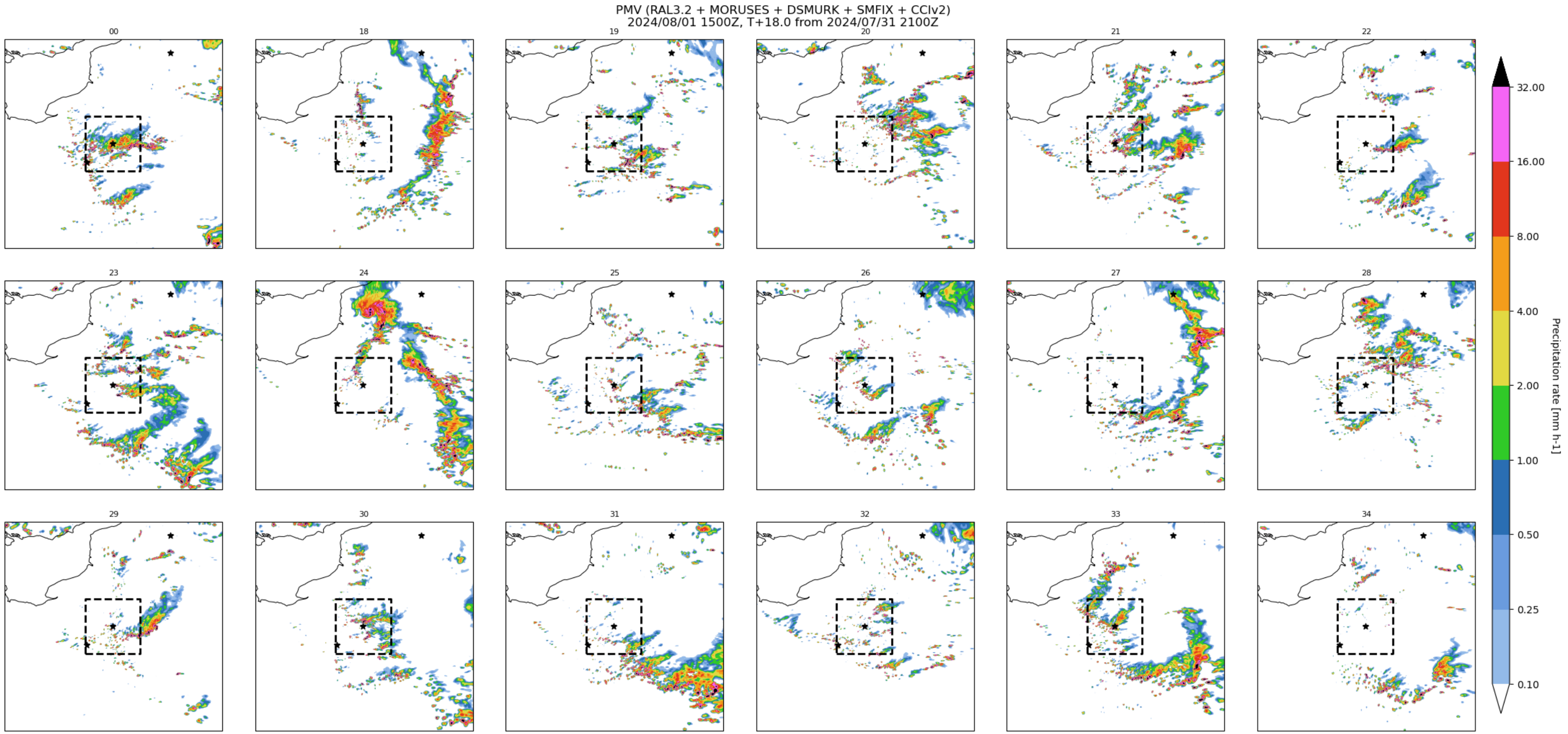
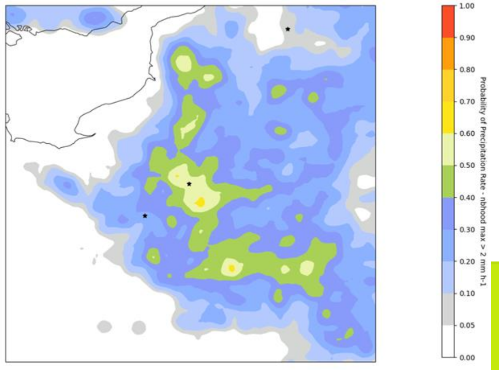
Ensemble/predictability questions.

Radar







probability ppn > 2 mm/hr

- Definite clusters of members. One with band of rain to E of Paris, second with large areas heavy rain NS oriented.
- Probability map mashes these two together.
- Need object/storm mode based clustering.

Kirsty Hanley

ParaChute Programme

Parametrizing **C**onvective [turbulence] at **H**ectometric [and km] scales, and **U**nderstanding the **T**urbulent **E**nvironment

Partnership and Opportunities Programme: £11m over four years, joint funding from NERC and Met Office (Feb 2023-2027). Includes Met Office staff and academic staff from Reading, Leeds, Exeter, Manchester and CEH.

Met Office: `Path to High Resolution’
UKRI strategic theme: ‘Building a secure and resilient world.’

Aim: To improve the understanding and representation of turbulent processes in km to sub-km scale models. Includes development of scale aware turbulence and convection schemes.

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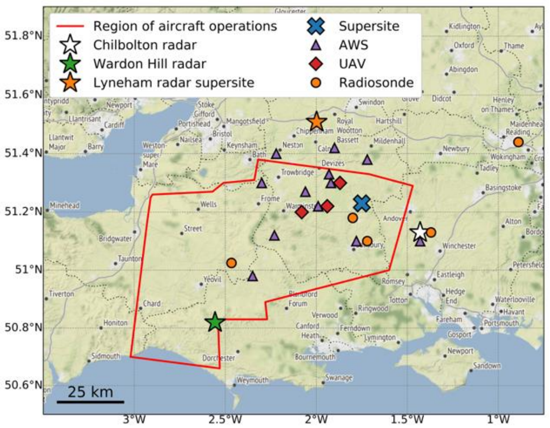
WesCon WOEST. 5th June - 25th August 2023

Met Office
University of Leeds
Imperial College London
Menapia
National Centre for Atmospheric Science – Natural Environment Research Council
University of Exeter
Jade Hochschule – Wilhelmshaven Oldenburg Elsfleth
FAAM Airborne Laboratory
University of Reading
Manchester 1824 – The University of Manchester
AMOF



Aircraft

- FAAM - 12 flights, >70 hours
- DIMONA - 16 Flights, >45 hours

Radars

- CAMRa, Kepler, NXPol1 & 2,
- Chilbolton, Lyneham, Wardon Hill
- 25+ Days scanning

Radiosonde

- Larkhill, Chilbolton, Ash Farm, Spire View, Reading.
- Extras: Camborne, Herstmonceux, Aberporth
- >350 in total.

WxUAS

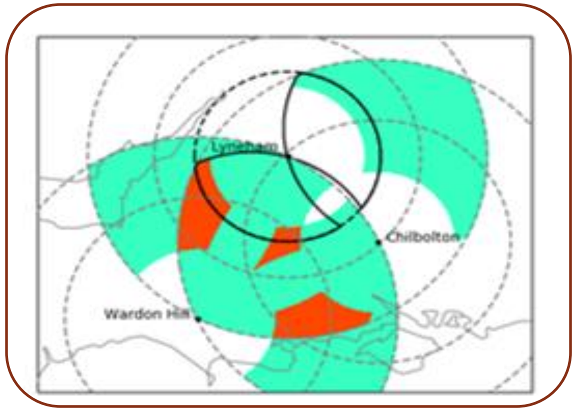
- Breach Hill, Heytesbury, Chilbolton, Wherwell Forest.
- ~120 flight hours.
- ~700 flights.
- First 2 km BVLOS.

Supersites

- Netheravon, Lyneham, Chilbolton
- Lidars,
- wind profilers,
- microwave radiometers,
- stereo cameras
- Masts

AWS sites

- 12 stations 24/7 operation



Doppler Radar network
Lyneham, Chilbolton, Wardon Hill

Long term observations and 30 Intensive Observation Periods #WesCon2023 link to more detailed talk (Youtube)

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Conclusions

- Km scale models are widely in use for weather and climate applications but still have issues.
- The biggest issues are the interaction of large-scale errors with km scale models and the smaller scale representation of the convection itself.
- The most likely route to improving the representation of convection in km scale models is through a scale aware convection scheme.
- Urban-scale models are being developed in their own right but also help to shed light on these issues. For example, it turns out that the size of storms in km scale models is often determined by the gridlength (because they get smaller at higher resolutions).
- For Urban-scale models in this case the turbulence scheme is the most important aspect.
- Use of ensembles at km and Urban-scale models is still a challenge that needs more research.