The Met Office Urban-scale modelling programme

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Urban Scale Modelling Research
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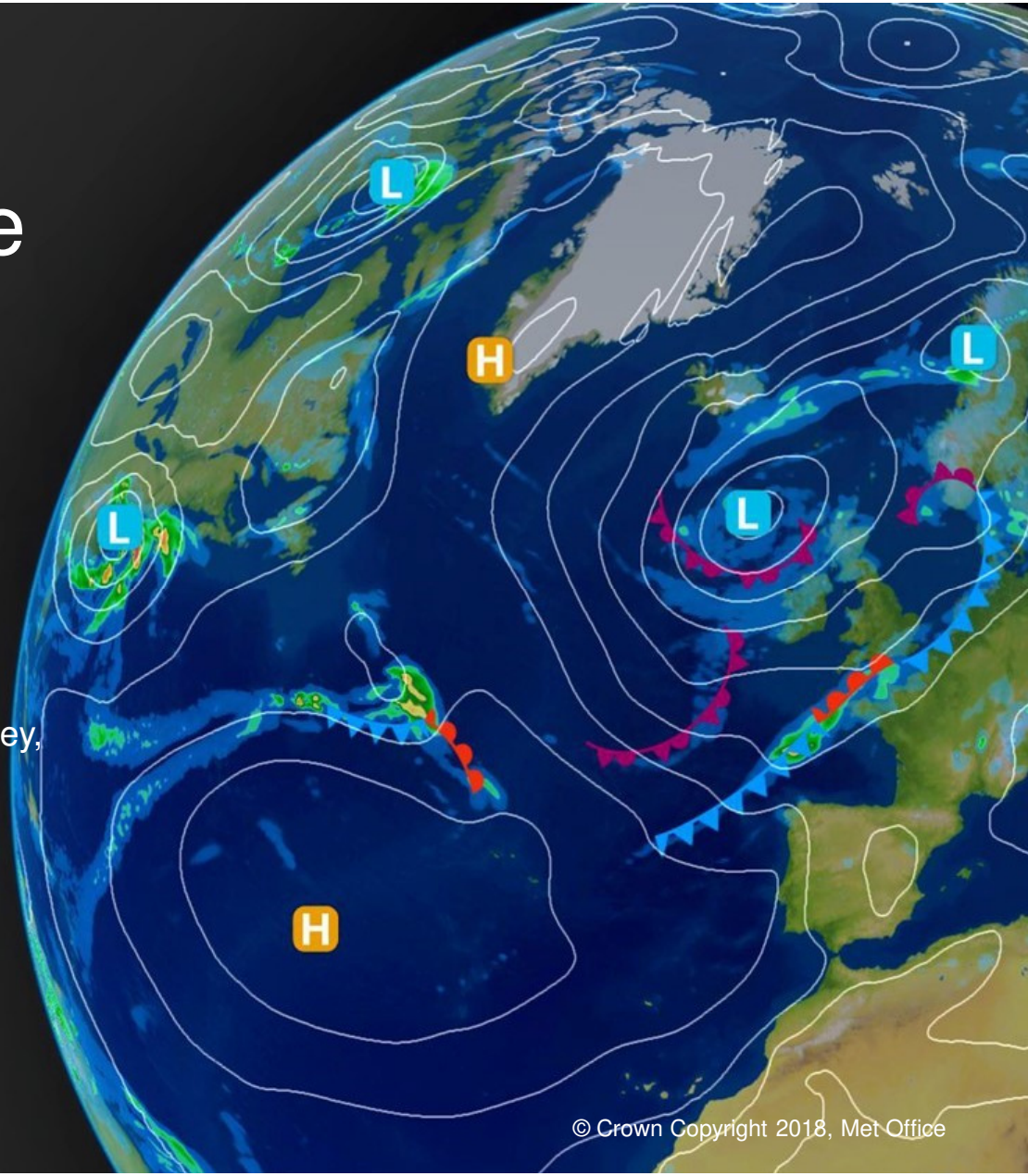
Contributions from many within Met Office particularly Kirsty Hanley, Carol Halliwell, Jon Shonk, Lewis Blunn.

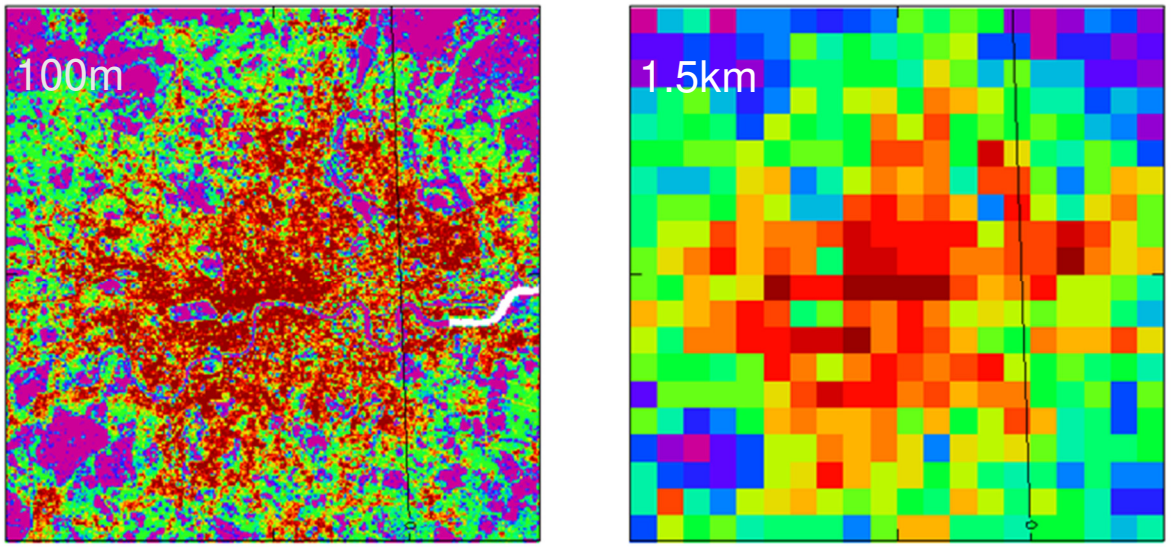


EWGLAM, Brussels, Sept 2022.

Urban Scale Modelling

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.



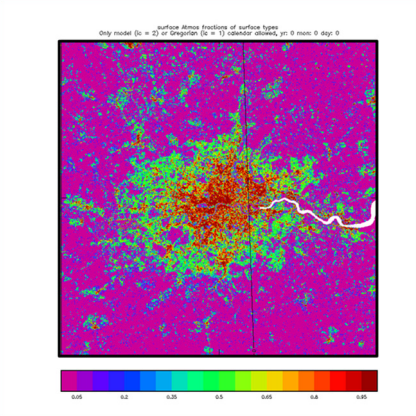
Comparison of London land use fraction for 100m (left) and 1.5km models.

Urban Scale Modelling

Terms for Urban-scale (25-300m gridlength)

100m term	Equivalent Km term	Notes
Urban-scale	Convective-scale	Describes likely most important property for applications.
City-scale	Convective-scale	Synonym for Urban-scale
100m-scale	Km-scale	NB effective resolution ~5-10Δx
Hectometric scale	Km-scale	European term for 100m-scale
Sub-km	(Sub-10km not used)	Also encompasses >300m – outside range of interest here.
Turbulence permitting	Convection permitting ("Convection allowing" in US).	Focus on important atmospheric process
~~**Turbulence resolving (Not used)**~~	~~Convection resolving~~	INCORRECT not to be used…

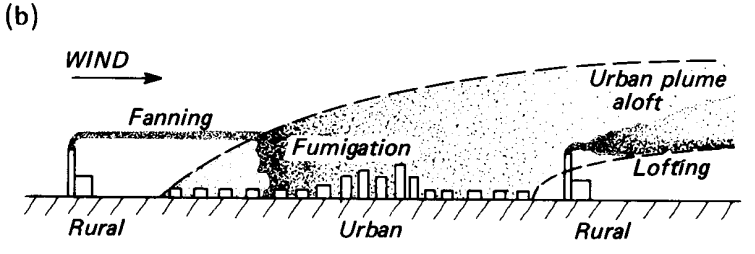
Urban Scale Modelling



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

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

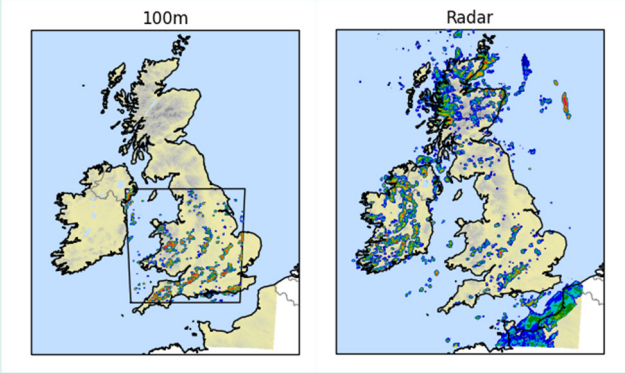
Potential benefits of high resolution



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

Motivation for urban NWP

- Large proportion of the population live in cities
- There are a number of meteorological hazards that we would like to forecast on weather and climate timescales.
- Several involve other coupled models (e.g. air quality requires chemistry model, flooding requires hydrology) but:
- Good representation of urban meteorology is fundamental

The path to high resolution

Urban-scale Modelling
Key Potential Benefit areas

Area	Stakeholders
Urban Temperatures	Hadley Centre Climate Programme (HCCP), Climate services, National Severe Weather Warning Service (NSWWS)
Urban Winds/turbulence	Civil Aviation Authority (CAA)
Convection (urban flooding)	CAA, NSWWS, defence, Climate services.
AQ/dispersion	Clean Air
Fog	CAA, NSWWS

Developing internal (Met Office) Science to Services Steering Group with internal stakeholders to work up use cases.

The path to high resolution

Urban-scale Modelling
Key activities.

- 300m London Model upgrade (PS49).
  - 300m variable resolution, small ensemble.
- Paris 2024 RDP - *focus on 100m scale forecasting*
  - Model Intercomparisons (Heat, convection).
  - Obs campaign 2022 (includes OBR lidar etc).
- WesCon *Wessex Convection Experiment 2023.*
  - *FAAM, OBR surface obs, Chilbolton, others..*
- Collaboration with city observational campaigns
  - *FUTURE, ASSURE, Urbisphere etc..*
- Focus on Urban Heat *climate services, NSWWS*
- Work towards 100m UK (or near UK) model for case study work.

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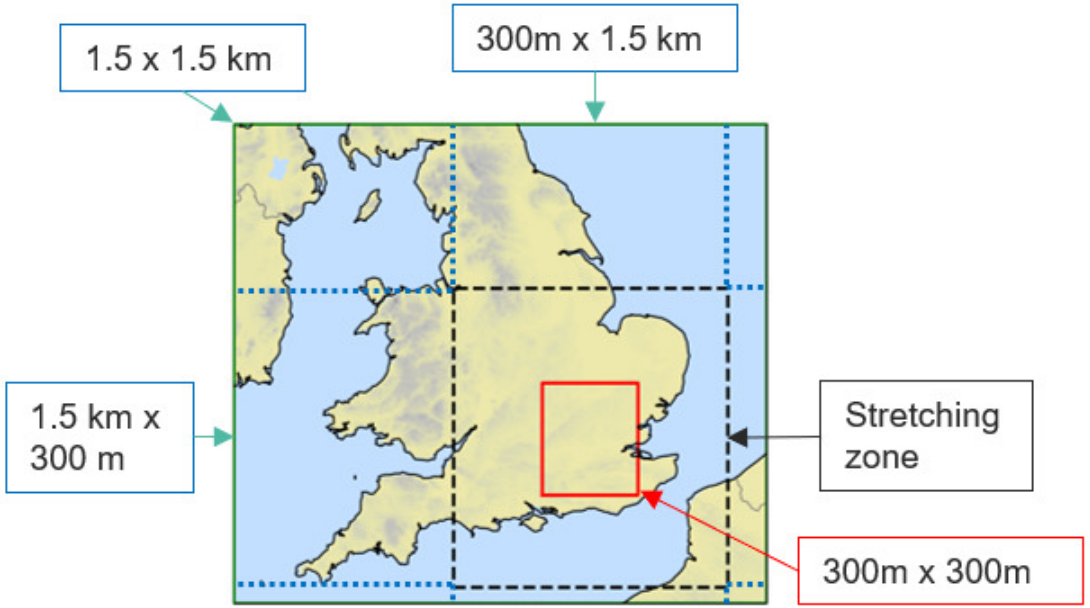
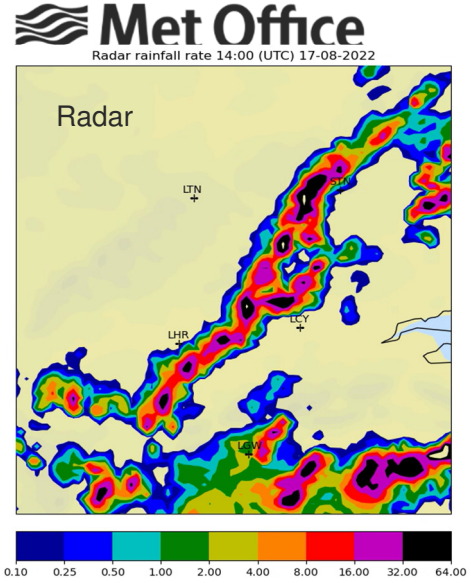
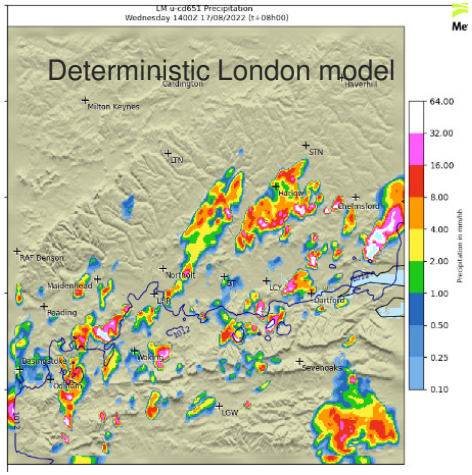
Upgraded 300m London Model (LMV)

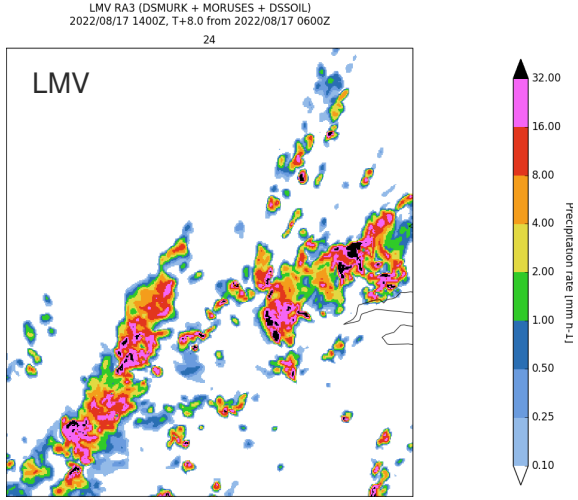


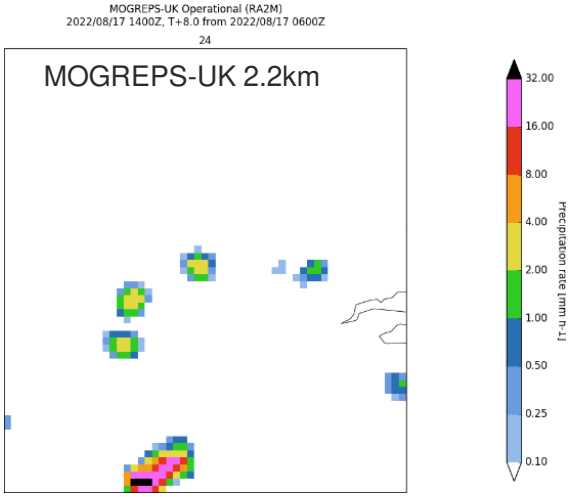
- Expand existing routine research London Model (LM) (red area) with a variable resolution domain (LMV) ensemble and make operational.
- Primary aim to improve representation of convection.
- Tests show existing LM gives little benefit for convection due to domain being too small.
- LMV domain almost as good as very large 300m domain
- Have routinely run this model every day for 23rd June – 12th Sept 2022

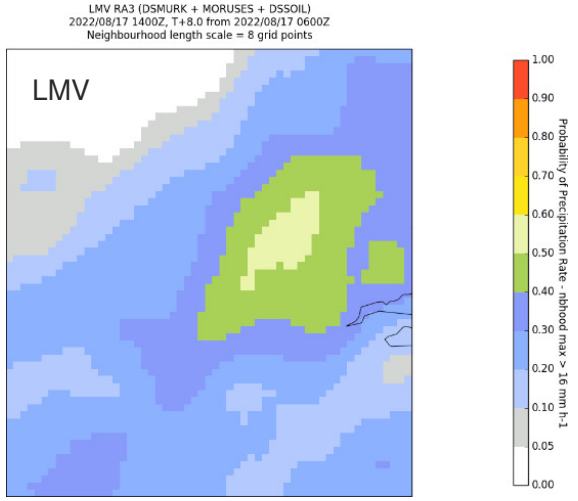
Preliminary results – 1400 UTC 17th August 2022

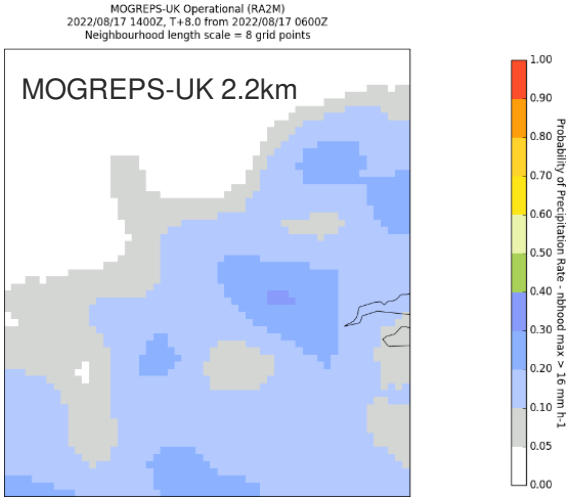












Some LMV members were able to capture the organisation of the band of intense ppn better than the equivalent MOGREPS-UK members.

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

Kirsty Hanley

Met Office

Key problems which need to be addressed

- Cost
- Turbulence grey zone/representation of convection.
- Predictability/ensembles
- Observation sources
- Data assimilation
- Representation of urban surface inc sources of urban data.

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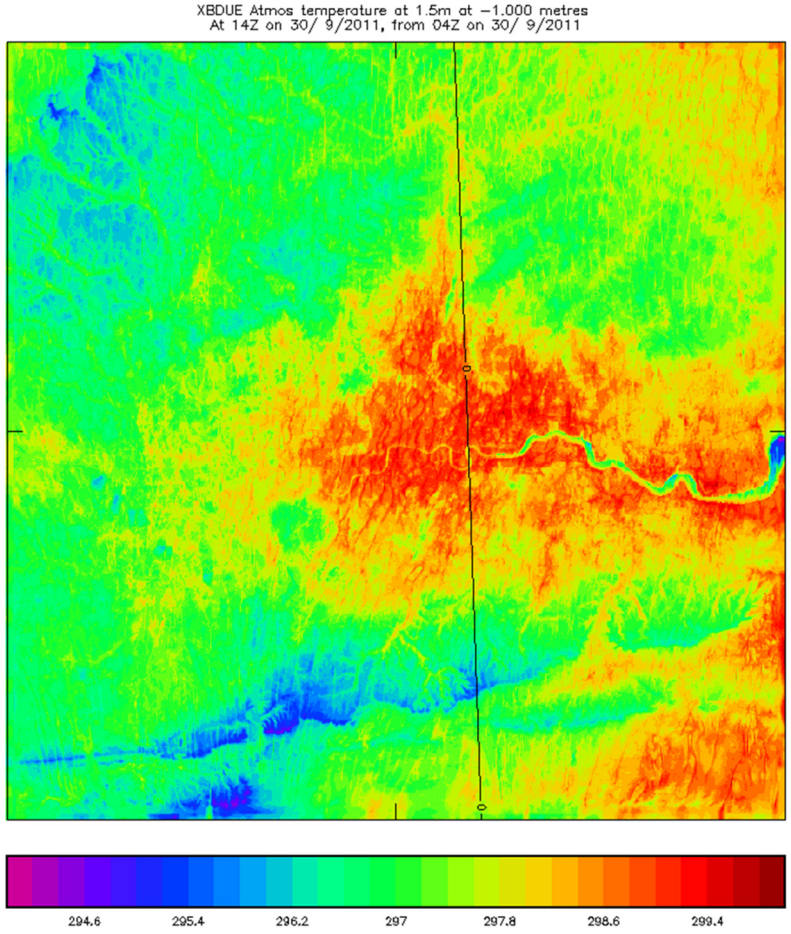
Cost of Urban-scale models.

- These models are *very* expensive!
- Emphasis of project is on developing capability and understanding resolution trade-offs for different applications.

Configuration	Tstep	levels	Npts factor	**Npt facs*tstep fac**
1.5km (UKV)	60s	70	1.0	**1.0**
300m LM	12s	70	25.0	**125**
100m	3s	140	450	**9000**
55m	1s	140	1487	**87,480**
25m	1s	140	7200	**432,000**

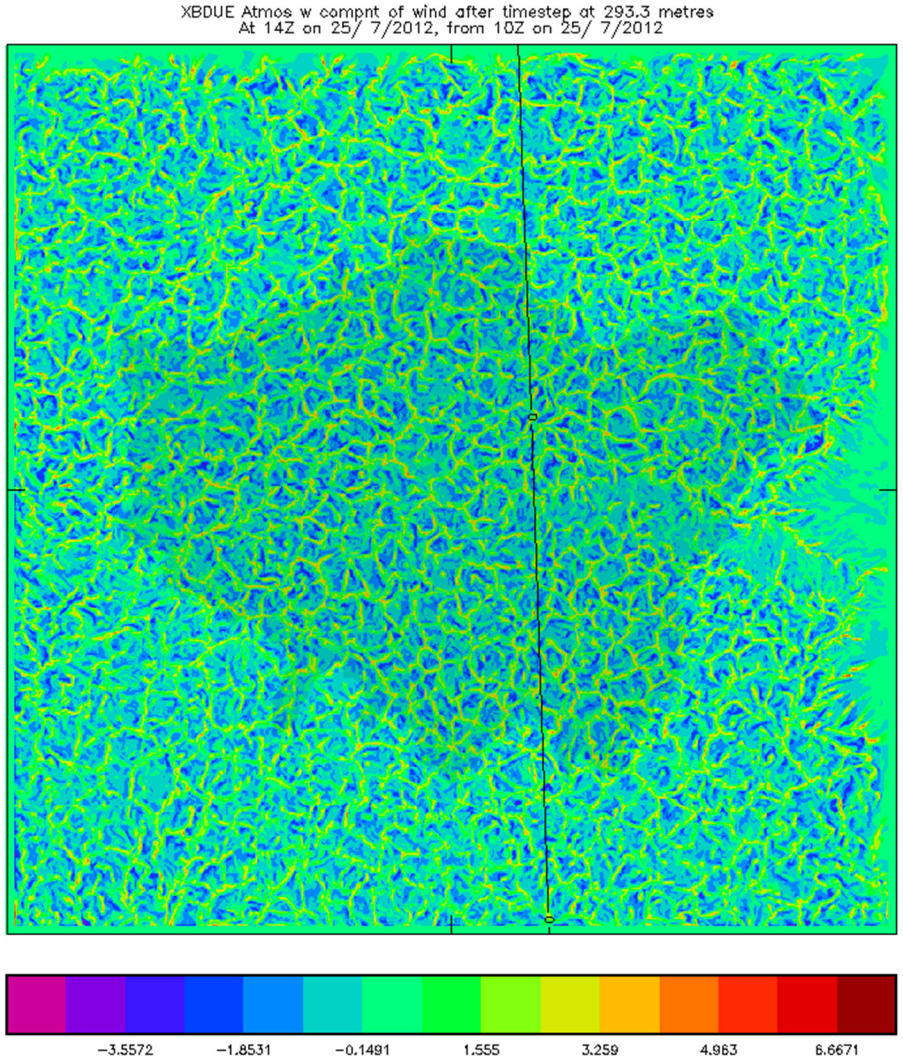
Approx. relative costs of models for same area and run length **based on current research configurations**.

When do we need Urban-scale models?



- Example of 1.5m temperature over London on a sunny day in 100m model.
- Much of this structure (river, large parks etc) is clearly coming from surface information.
- Might be able to do as well using downscaling/ML techniques driven by coarser model.
- Justification for running model would be in terms of meteorological structures e.g. sea breezes, downslope flows etc.

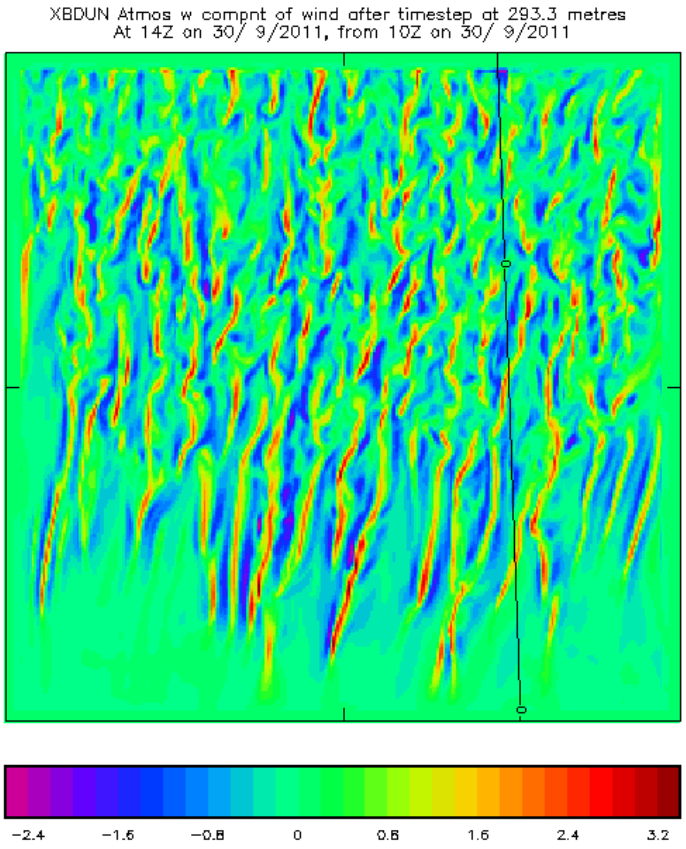
25th July 2012



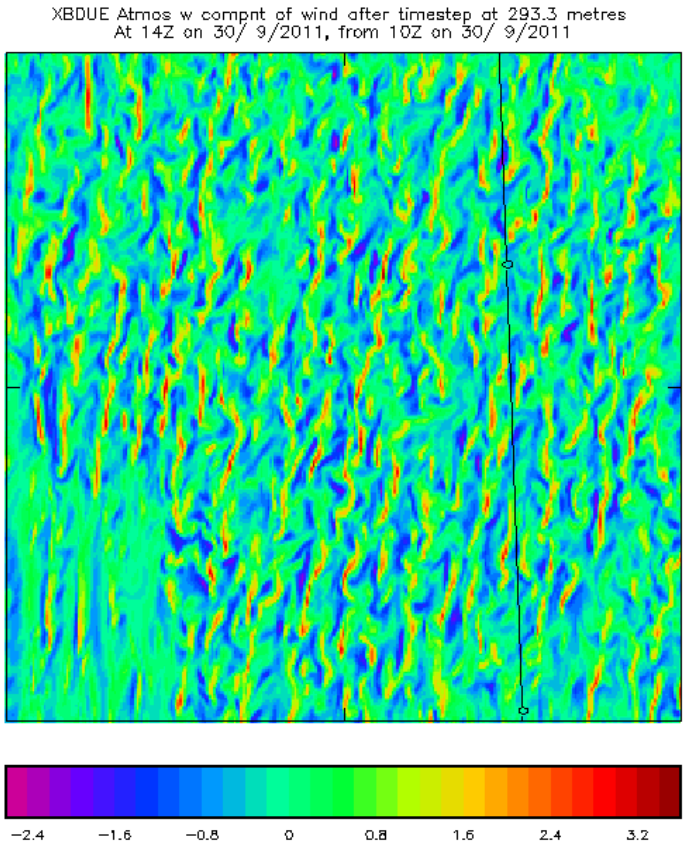
- Example of convective overturning over London in 100m model.
- Note sea breeze fronts at the end of animation.

Spin up effects important in these models.

- Spin up of turbulence for clear CBL case with southerly flow.
- Solution: large domains (expensive), inject noise or variable resolution.



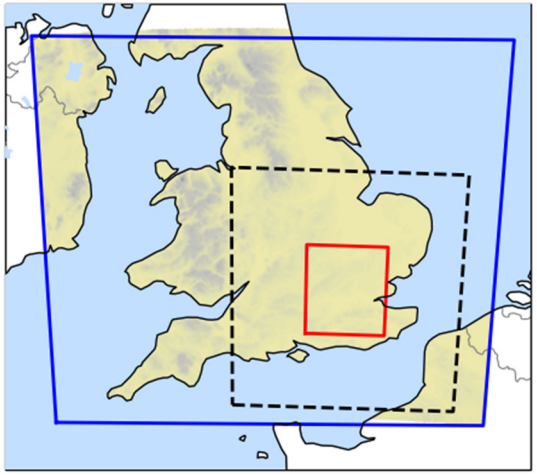
Small 30x30km 100m model



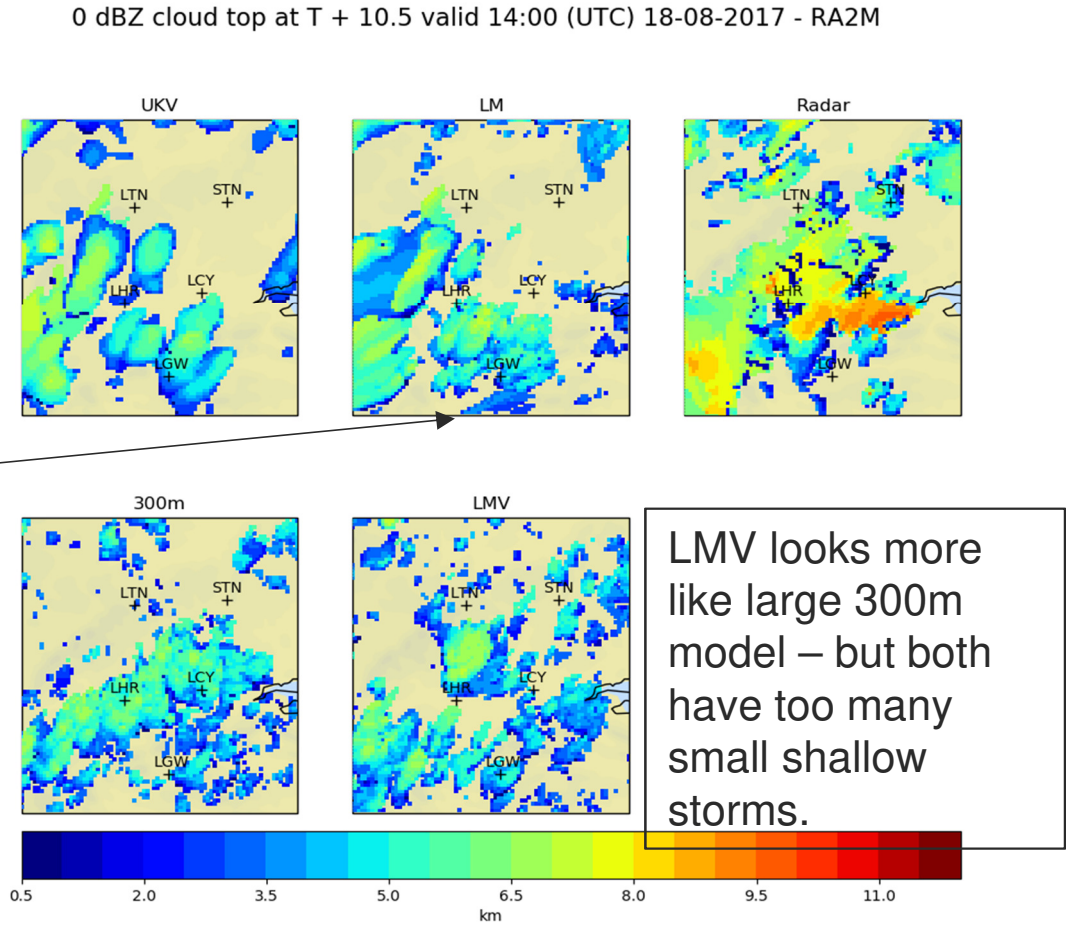
Subset of large 80x80km domain

Variable resolution 300m model (LMV)

1.5km grid length at edge to 300m grid length in inner region with a stretching region (-- line).
Outer region covers large 300m model domain – but with ¼ number of grid boxes.
Inner region LM domain.
Nested within UKV – no ancillaries yet!



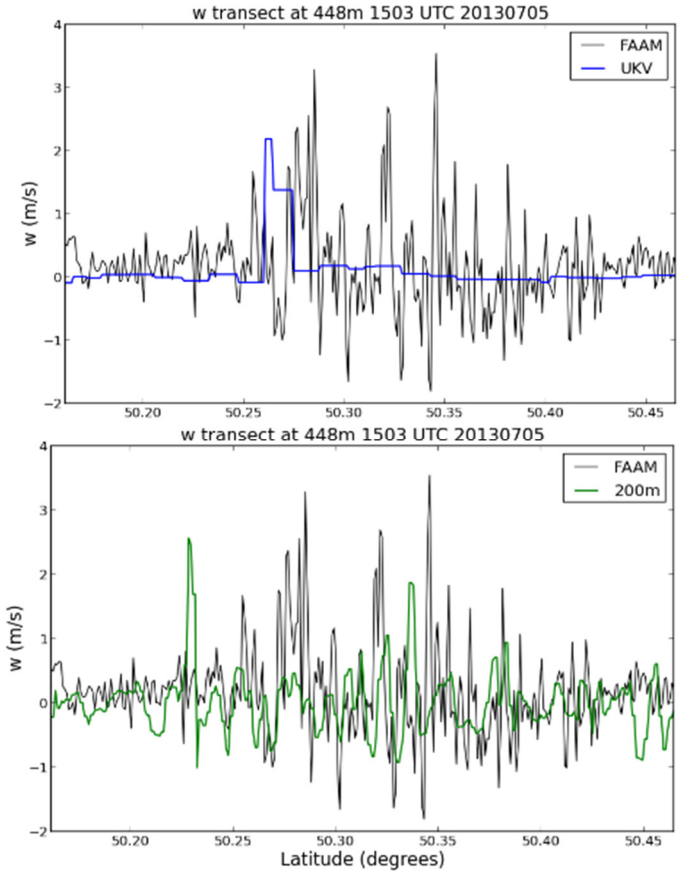
300m LM domain too small for features to spin-up – closely follows UKV with spin-up extending far into domain.

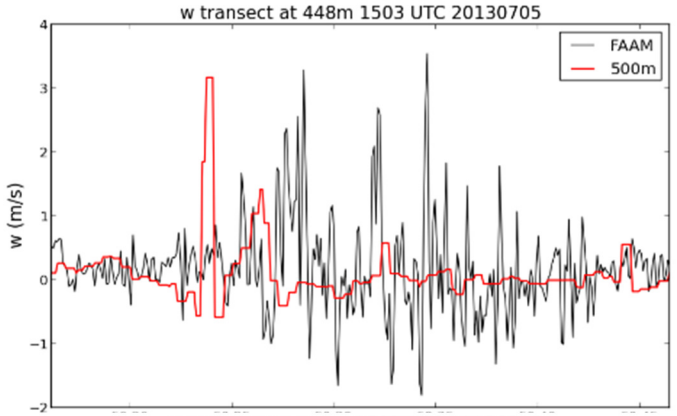


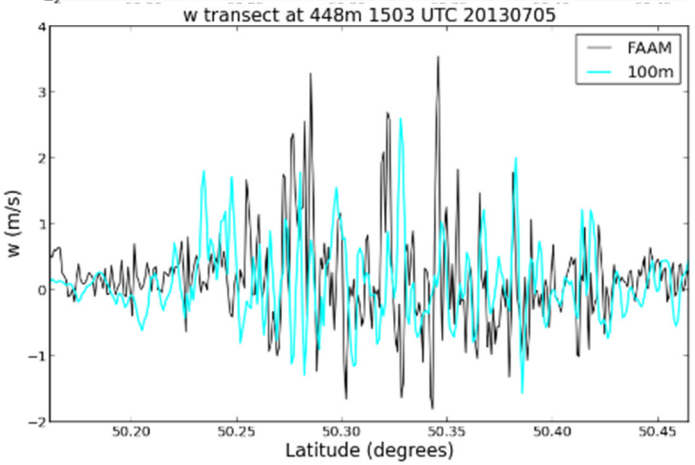
LMV looks more like large 300m model – but both have too many small shallow storms.

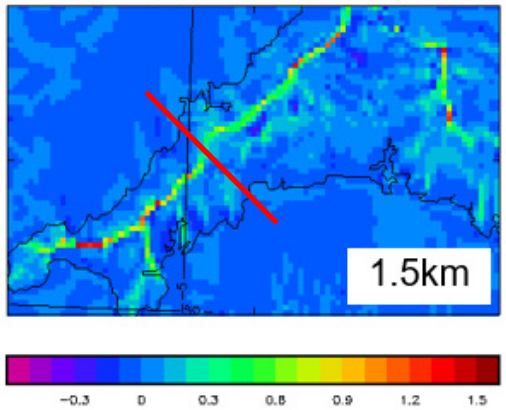
Representation of convection/turbulence.

COPE IOP2 5/07/2013 w comparison with aircraft flight level vertical velocity.









Transect across Cornwall peninsula and peninsula convergence line

200m, 100m start to resolve turbulence.

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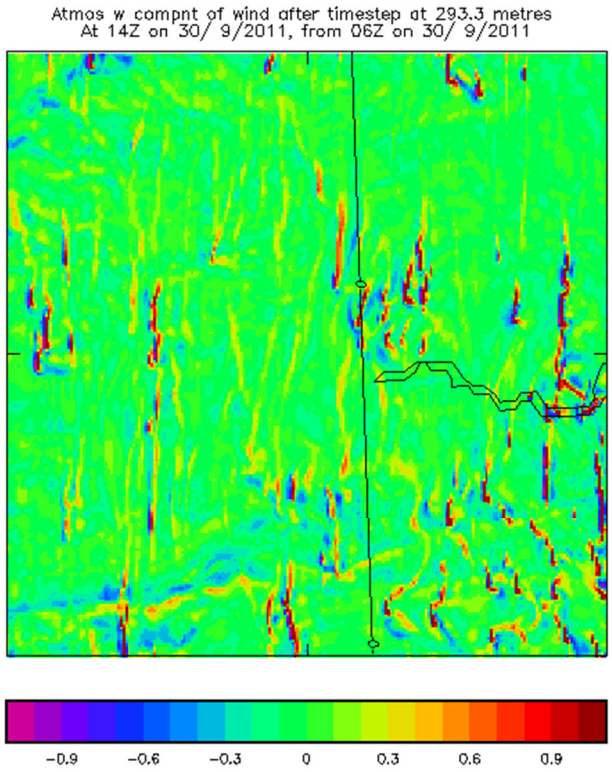
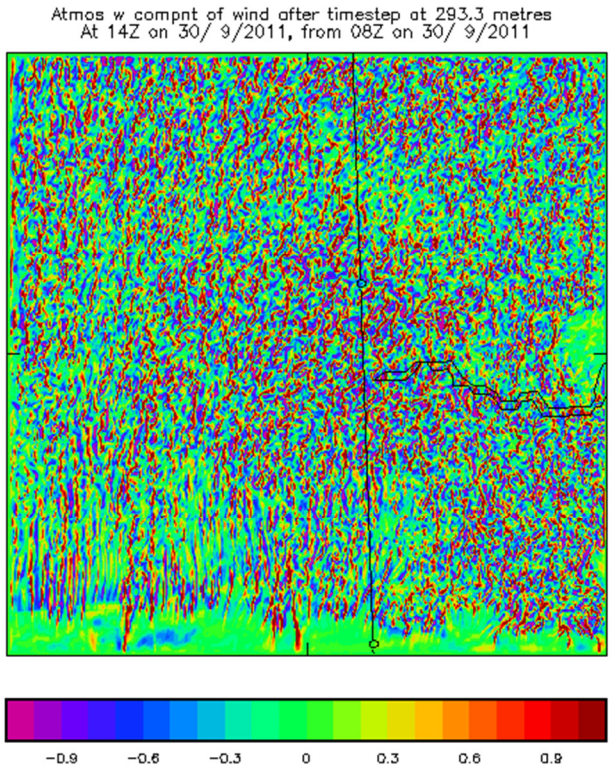
Convective Boundary Layer

300m



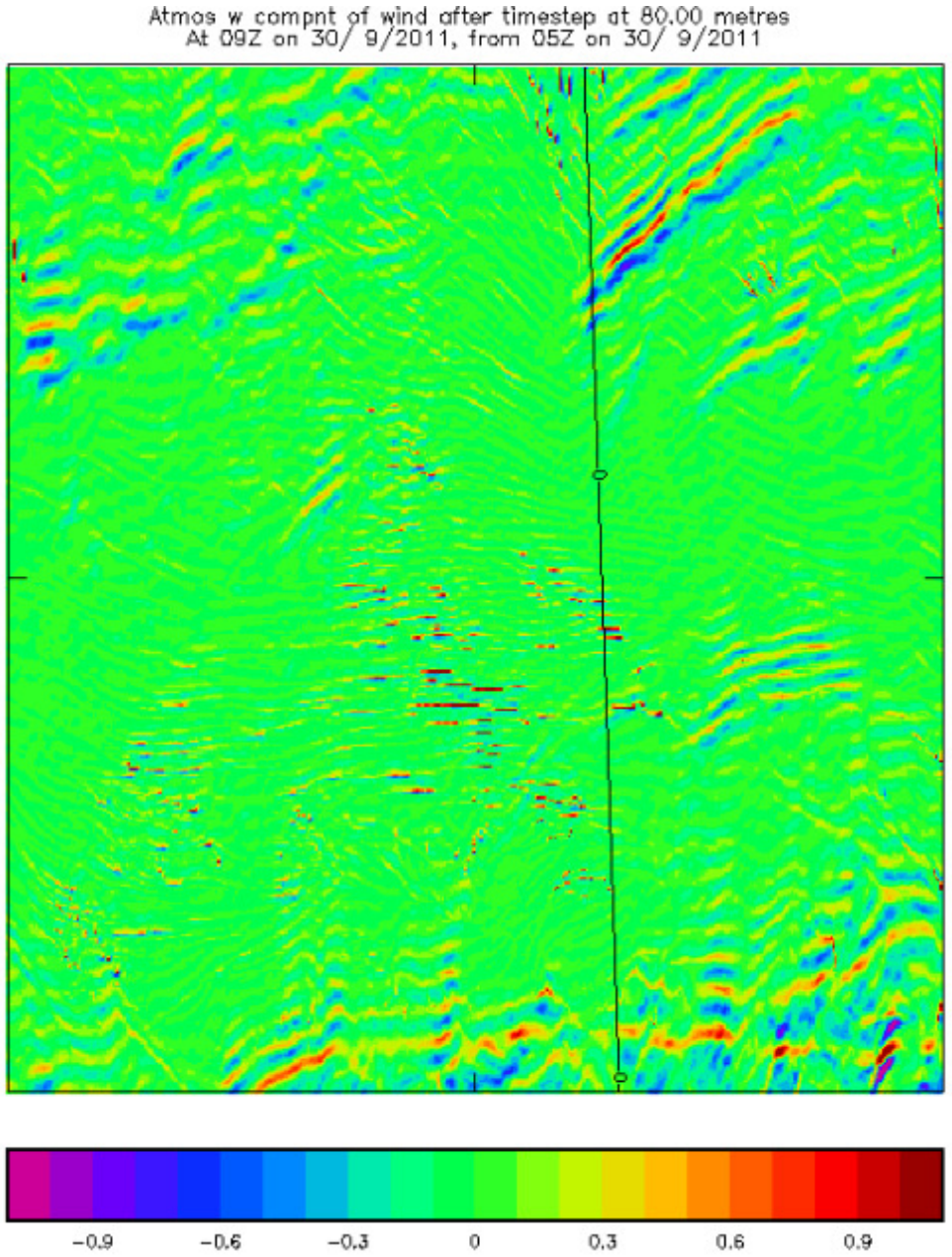
100m



~1km deep BL 300m model struggling to resolve. Grid scale structure – grey zone artifacts.

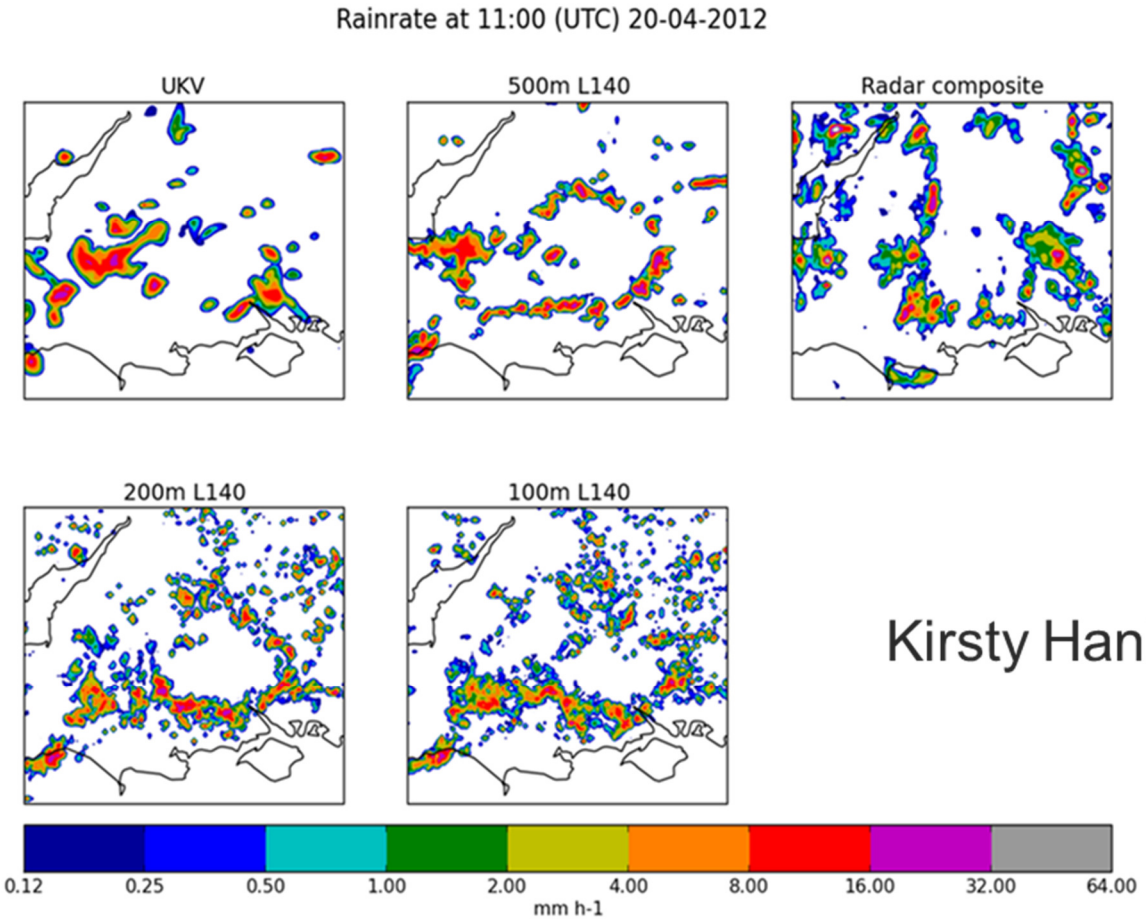
Need to correctly handle turbulence grey zone

- It has been noticed previously that 300m runs suffer from gridscale w structure in CBL situations.
- Due to depth of mixed layer being similar to effective resolution of model.
- Same is true in growing BL in 100m model if look early while mixed layer is shallow.
- Answer should be that gridscale motions are parameterised (scale aware scheme).



Cumulus Convection

- A-priori would hope convection would improve with increasing resolution.
- Experiments show this is the case in some ways (e.g. light rain heavy rain balance) but not in others (e.g. extra small cells).
- Expect this is due to compensating errors in low res models (which config is based on) and also due to inadequate (scale aware) parameterisations.



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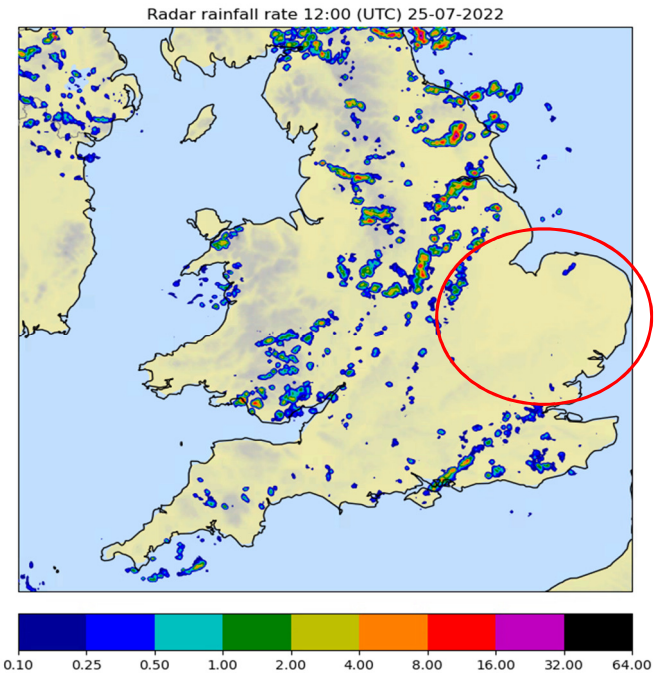
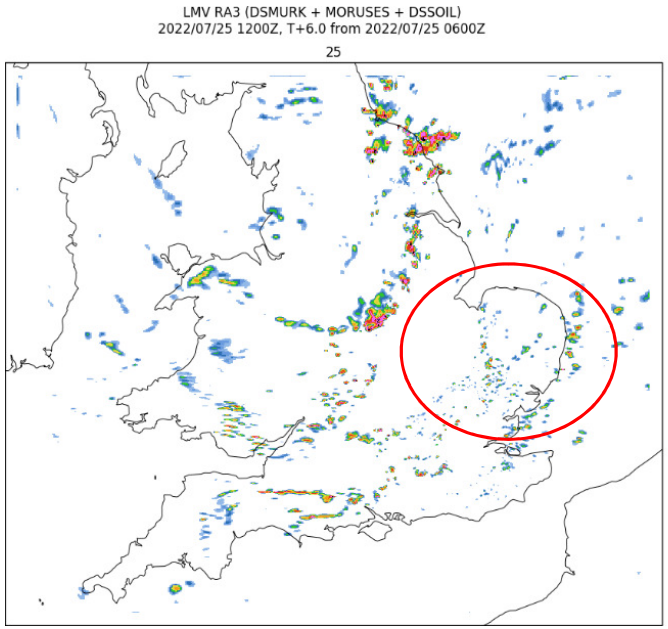
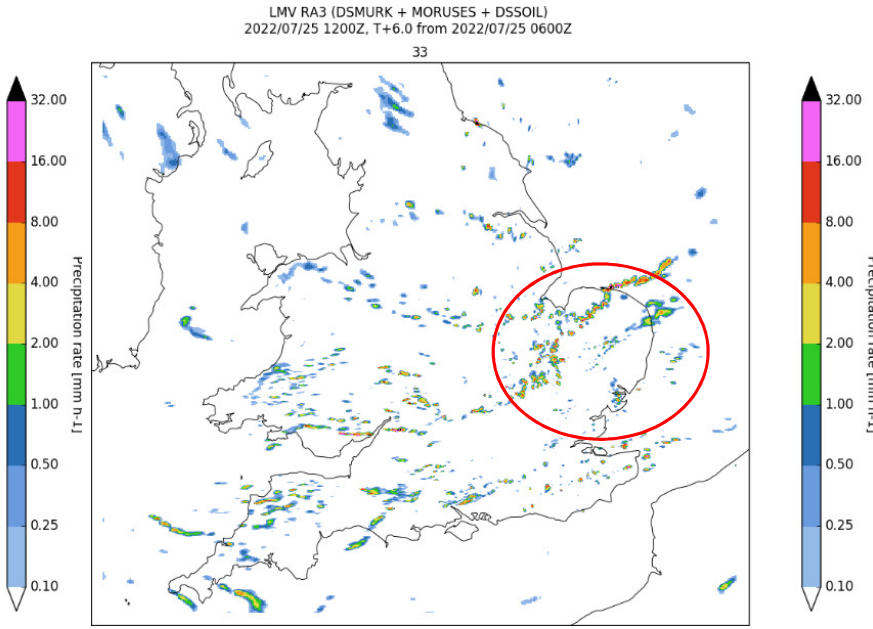
The path to high resolution

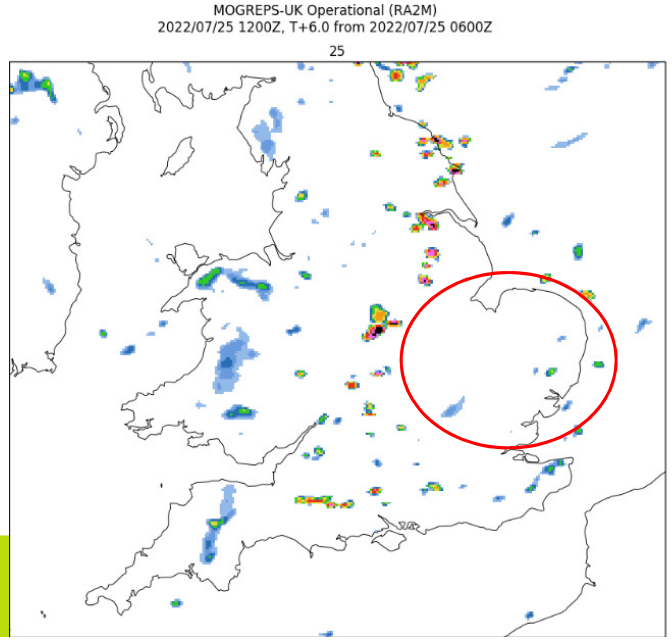
Urban-scale Modelling
100m scale convection issues.

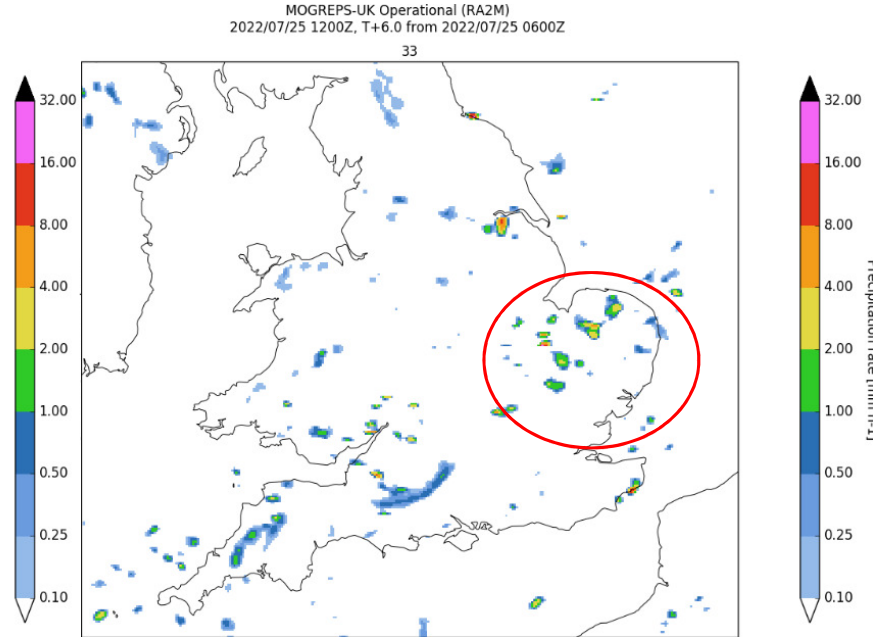
Rank	Performance Improvement needed	Actions
1.	Produce too many small showers	Understand influence of sub-grid mixing and microphysics on this behaviour including comparisons with 3D bespoke observations.
2.	Tendency for shallow storms to precipitate too easily	As 1.
3.	Generally initiate convection too early	Understand errors in pre-convective environment and resolution dependence of initiation.
4.	Spin-up of convection and turbulence from the boundaries can extend tens of kilometres into the domain	Explore use of variable resolution
5.	Tendency of convective cells to be unrealistically aligned along the wind rather than across wind.	Often caused by along wind rolls being too strong - need to understand reasons for this.











- The LMV (top) produces too many small precipitating showers.
- The equivalent M-UK members (bottom) do too but to a lesser extent.
- Doesn't appear to damage forecast later on because clouds are correct (to be confirmed)?

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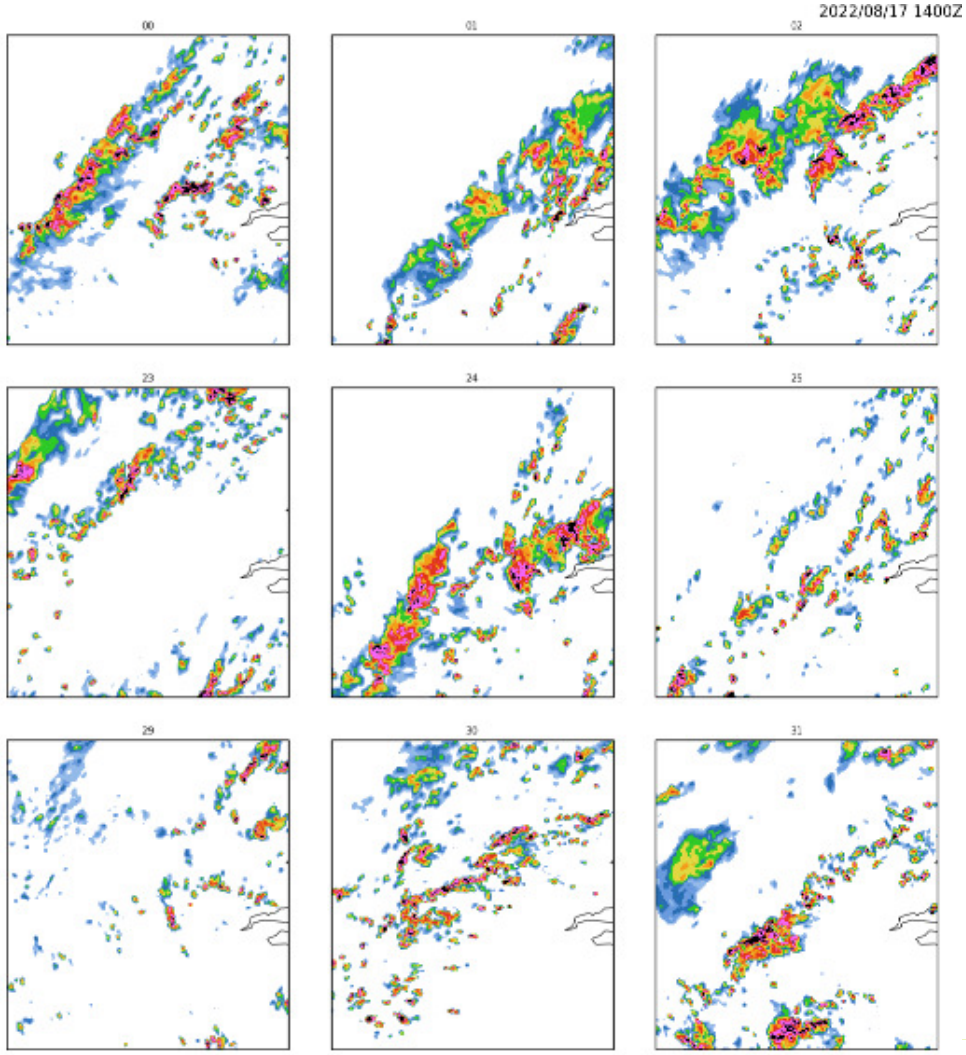
Predictability

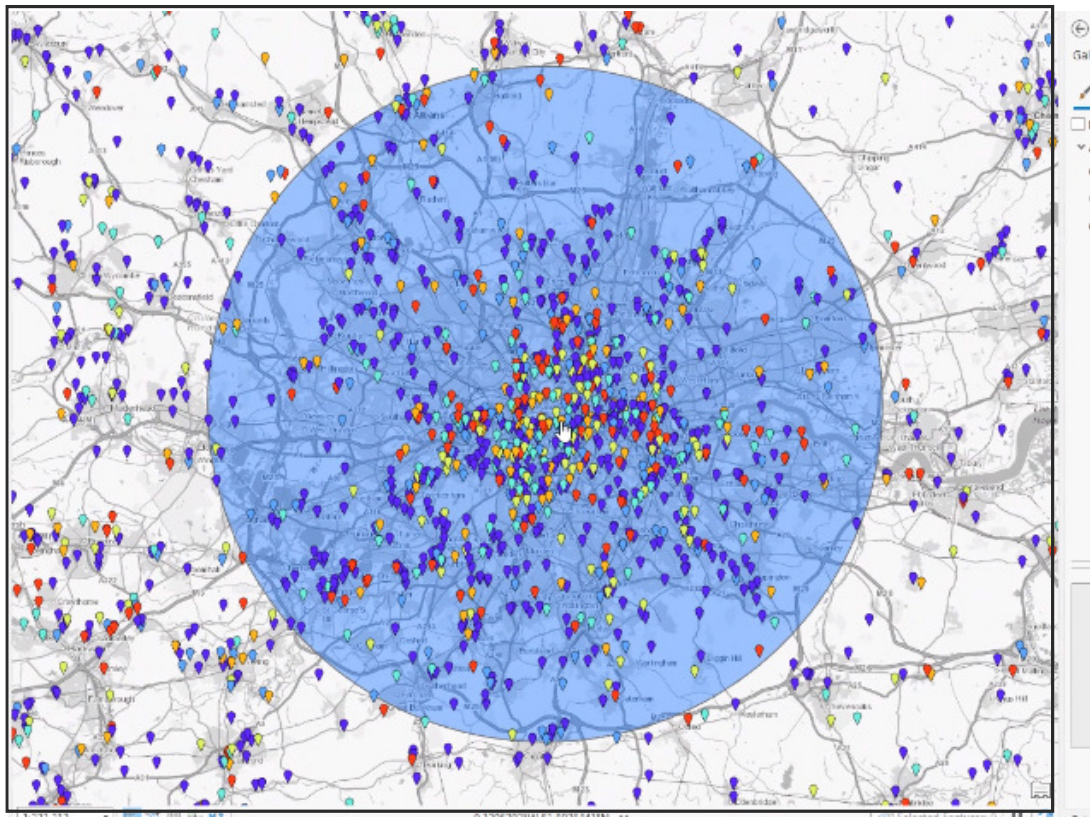
- As we move to forecasting on smaller scales unpredictable scales become larger compared to the areas you are interested in forecasting.
- Example shows LMV forecast illustrating apparent large spread when looking on small scales.
- *Depending on what model is required for (i.e. for anything other than locally forced effects) high res modelling will need to be in an ensemble context.*
- Need to understand optimal way to set up 100m scale ensembles.



Postage stamps for half LMV members 1400z 17/08/2022

Observations

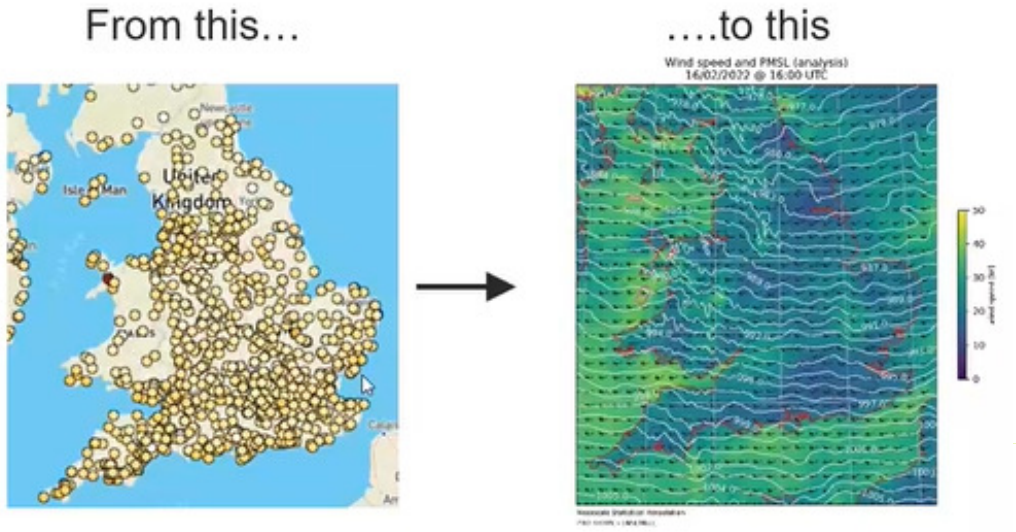
- Obs R&D in Met Office working on strategy for Urban-scale observations.
- Includes obs for model development, verification and data assimilation.
- Lot of interest in cloud sourced observations (WOW, netamo, Davis etc).
- Many issues to think about regarding representivity, errors and more practical issues such as ownership, metadata, timeliness.



Netamo stations for London area for 2020.
Blue points for full 12 months.
These points have T and RH. Half have rain and quarter wind data of all points in UK (may be different in urban areas).

Data Assimilation

- An obvious possible use for Urban-scale models is nowcasting. For this will need DA at these scales. Examples of uses: Correcting short range forecasting of thunderstorms. Reducing biases is short range urban temperature forecasts.
- Very little work on this so far. Some issues in common with km scale DA.
- Step in right direction: Ed Pavelin (Met Office nowcasting group) developing OI technique to fit WOW observations to gridded analysis.

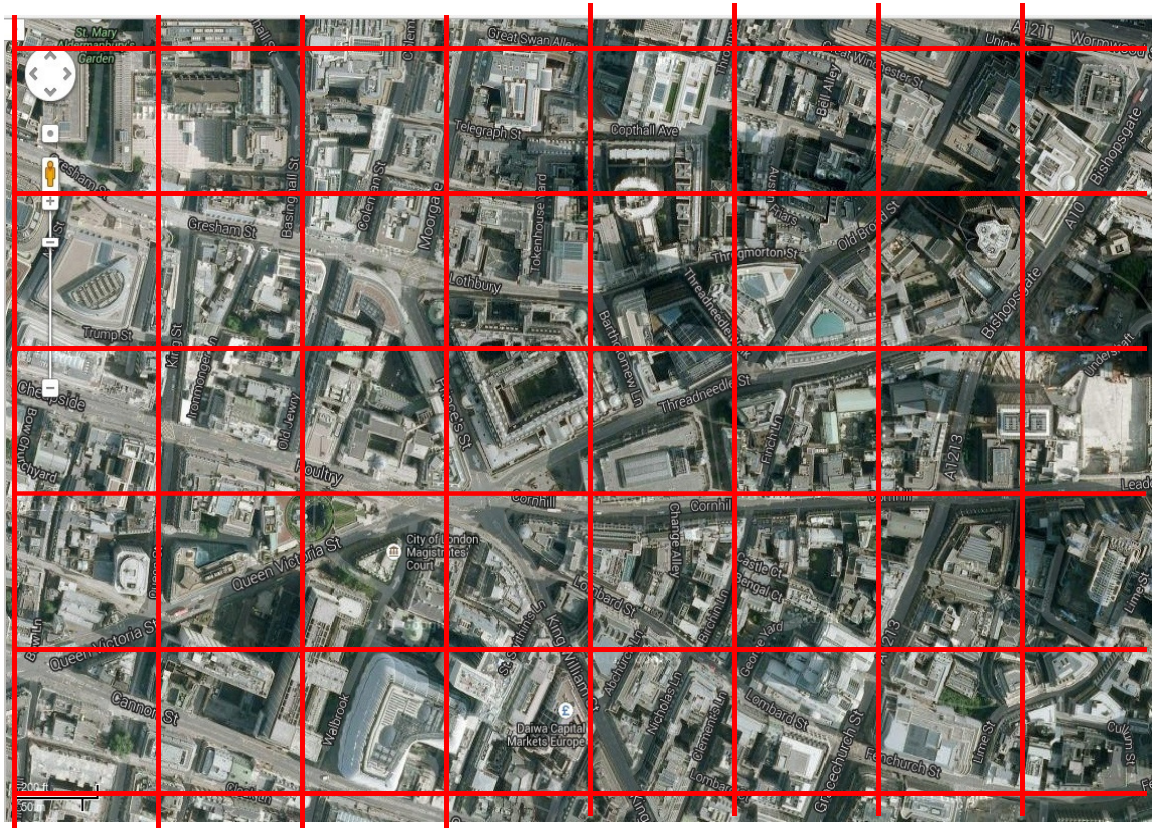


Urban Surface Model Development Priorities

- improving representation of anthropogenic fluxes;
- implementing a vertically distributed canopy;
- enhancing land cover and morphology data;
- including vegetation and water in the urban canopy;
- making changes specific to high resolution running.

Questions about Urban Applications

- 100m model clearly isn't resolving buildings. Rely on parameterising building effects.
- Key question is what can be done for urban applications with these models and what will still require CFD modelling of buildings/streets. *NB work (e.g. NIWA) to couple CFD models to UM.*
- Advantage of 100m models is ability to take into account larger scale features.



100m grid superimposed on city of London

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Challenges in 100m-scale NWP

- Costs!
- Stability and dynamics
- Representation of turbulence and convection
- Observations to use for verification
- Data assimilation
- Predictablity at these scales
- Representation of the (urban) surface
- Detailed land-use classification
- Spin-up at the boundaries

Planned: Peer-reviewed position paper to review progress in 100m-scale modelling (**not** exclusively urban) and scope out R&D work needed.

- 2-3 Experts on each of above topics
- Invite-only workshop in Dec 2022 @ KNMI, the Netherlands

Lead authors/organisers: ***Humphrey Lean (UKMO), Natalie Theeuwes (KNMI)***

A number of key participants already confirmed.

Conclusions

- Met Office has a project to develop the capability for “Urban-scale” 100m models.

- Although these models are promising in research there are a number of challenges to enabling their use for practical applications.

- For urban applications development is required to improve the representation of the urban surface along with research to understand the utility of these models for practical applications.

- Have presented a recent attempt to evaluate Urban-scale models representation of the spatial structure of the urban boundary layer.

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Questions?