Met Office

High Resolution Developments at the Met Office.

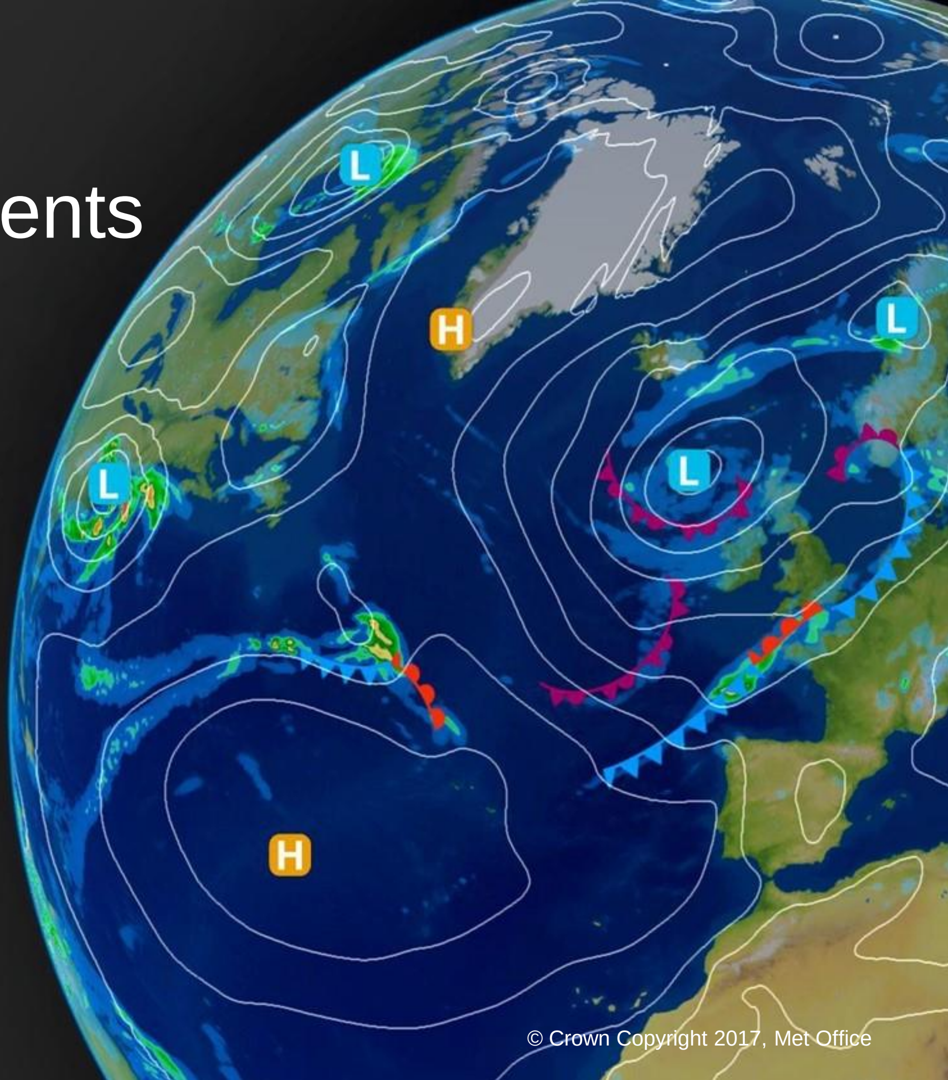
Humphrey Lean

Convective Scale Modelling Research
RMED, MetOffice@Reading

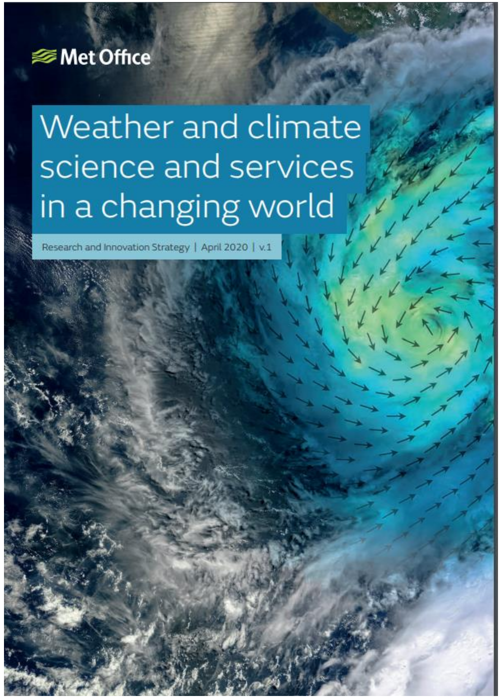
Contributions from many – in particular:

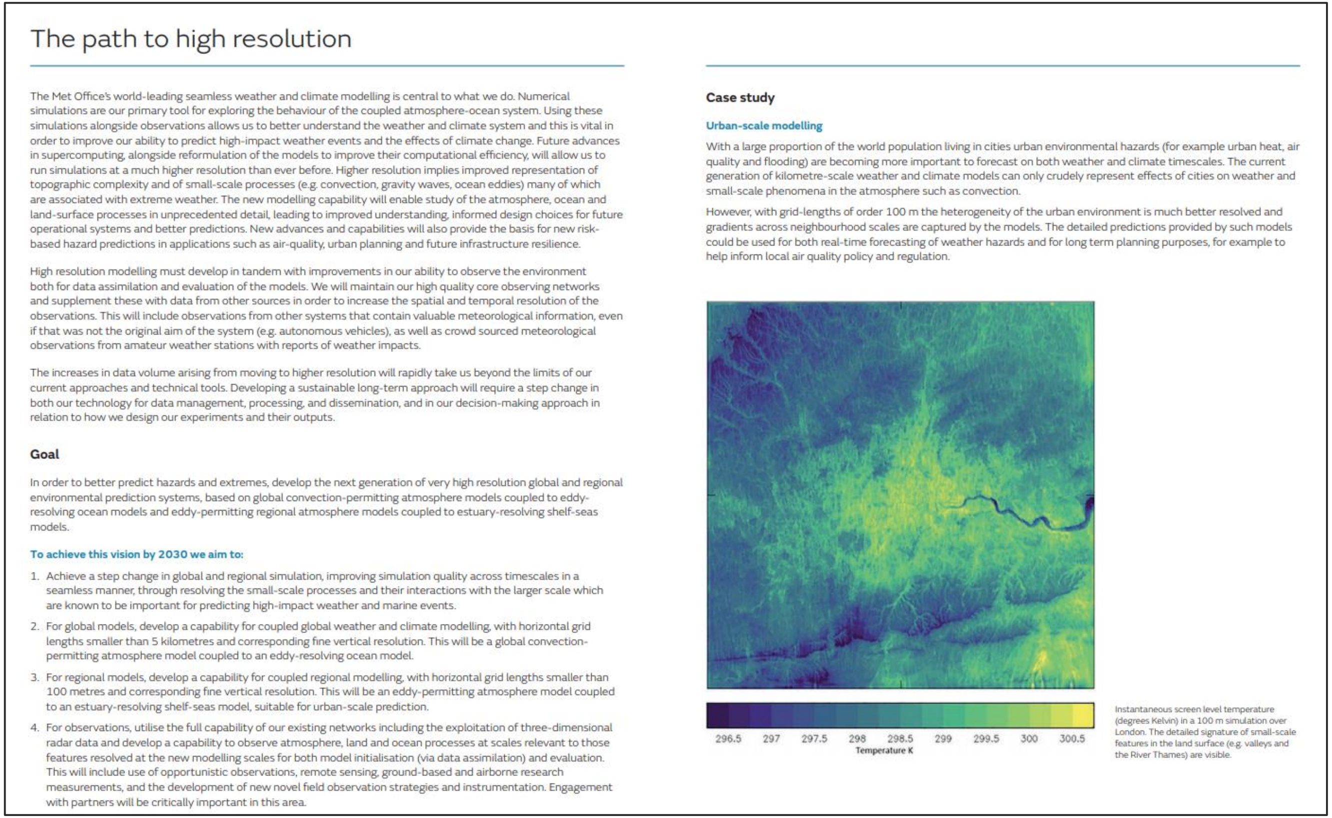
Kirsty Hanley, Carol Halliwell, Sylvia Bohnenstengel, Jon Shonk.

EWGLAM Oct 2020



Met Office Research and Innovation Strategy





The path to high resolution

The Met Office's world-leading seamless weather and climate modelling is central to what we do. Numerical simulations are our primary tool for exploring the behaviour of the coupled atmosphere-ocean system. Using these simulations alongside observations allows us to better understand the weather and climate system and this is vital in order to improve our ability to predict high-impact weather events and the effects of climate change. Future advances in supercomputing, alongside reformulation of the models to improve their computational efficiency, will allow us to run simulations at a much higher resolution than ever before. Higher resolution implies improved representation of topographic complexity and of small-scale processes (e.g. convection, gravity waves, ocean eddies) many of which are associated with extreme weather. The new modelling capability will enable study of the atmosphere, ocean and land-surface processes in unprecedented detail, leading to improved understanding, informed design choices for future operational systems and better predictions. New advances and capabilities will also provide the basis for new risk-based hazard predictions in applications such as air-quality, urban planning and future infrastructure resilience.

High resolution modelling must develop in tandem with improvements in our ability to observe the environment both for data assimilation and evaluation of the models. We will maintain our high quality core observing networks and supplement these with data from other sources in order to increase the spatial and temporal resolution of the observations. This will include observations from other systems that contain valuable meteorological information, even if that was not the original aim of the system (e.g. autonomous vehicles), as well as crowd sourced meteorological observations from amateur weather stations with reports of weather impacts.

The increases in data volume arising from moving to higher resolution will rapidly take us beyond the limits of our current approaches and technical tools. Developing a sustainable long-term approach will require a step change in both our technology for data management, processing, and dissemination, and in our decision-making approach in relation to how we design our experiments and their outputs.

Goal

In order to better predict hazards and extremes, develop the next generation of very high resolution global and regional environmental prediction systems, based on global convection-permitting atmosphere models coupled to eddy-resolving ocean models and eddy-permitting regional atmosphere models coupled to estuary-resolving shelf-seas models.

To achieve this vision by 2030 we aim to:

1. Achieve a step change in global and regional simulation, improving simulation quality across timescales in a seamless manner, through resolving the small-scale processes and their interactions with the larger scale which are known to be important for predicting high-impact weather and marine events.
2. For global models, develop a capability for coupled global weather and climate modelling, with horizontal grid lengths smaller than 5 kilometres and corresponding fine vertical resolution. This will be a global convection-permitting atmosphere model coupled to an eddy-resolving ocean model.
3. For regional models, develop a capability for coupled regional modelling, with horizontal grid lengths smaller than 100 metres and corresponding fine vertical resolution. This will be an eddy-permitting atmosphere model coupled to an estuary-resolving shelf-seas model, suitable for urban-scale prediction.
4. For observations, utilise the full capability of our existing networks including the exploitation of three-dimensional radar data and develop a capability to observe atmosphere, land and ocean processes at scales relevant to those features resolved at the new modelling scales for both model initialisation (via data assimilation) and evaluation. This will include use of opportunistic observations, remote sensing, ground-based and airborne research measurements, and the development of new novel field observation strategies and instrumentation. Engagement with partners will be critically important in this area.

Case study

Urban-scale modelling

With a large proportion of the world population living in cities urban environmental hazards (for example urban heat, air quality and flooding) are becoming more important to forecast on both weather and climate timescales. The current generation of kilometre-scale weather and climate models can only crudely represent effects of cities on weather and small-scale phenomena in the atmosphere such as convection.

However, with grid-lengths of order 100 m the heterogeneity of the urban environment is much better resolved and gradients across neighbourhood scales are captured by the models. The detailed predictions provided by such models could be used for both real-time forecasting of weather hazards and for long term planning purposes, for example to help inform local air quality policy and regulation.

296.5 297 297.5 298 298.5 299 299.5 300 300.5
Temperature K

Instantaneous screen level temperature (degrees Kelvin) in a 100 m simulation over London. The detailed signature of small-scale features in the land surface (e.g. valleys and the River Thames) are visible.

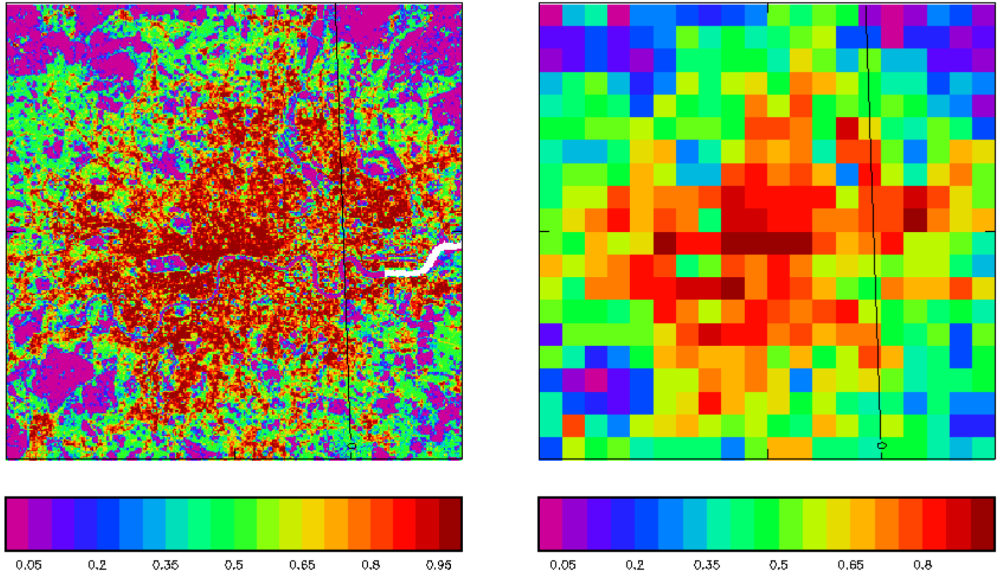
April 2020

Available at: https://www.metoffice.gov.uk/research/approach/research-and-innovation-strategy

100m/City Scale Modelling

- Assumed to be O(100m) model, in particular of a city area. Enables “neighbourhood scale” forecasts. *Currently highest res model 1.5km UKV.*

- Urban representation and high resolution don’t *necessarily* go together (currently have an urban scheme in UKV and in 2.2km UKCP18) but assume will need higher resolution to realise full benefits.

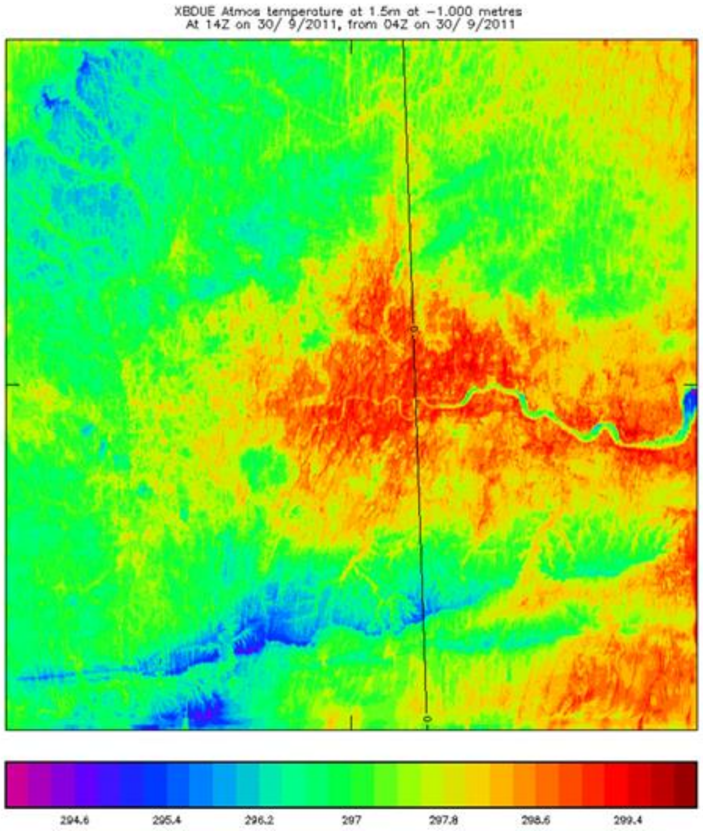


Comparison of London land use fraction for 100m (left) and 1.5km models. Smaller cities will be V poorly resolved at 1.5km.

Two Motivations for order 100m Models

1. Better representation of surface features, topography, land use etc.

- Example shows 100m model representation of 1.5m temperature over London.

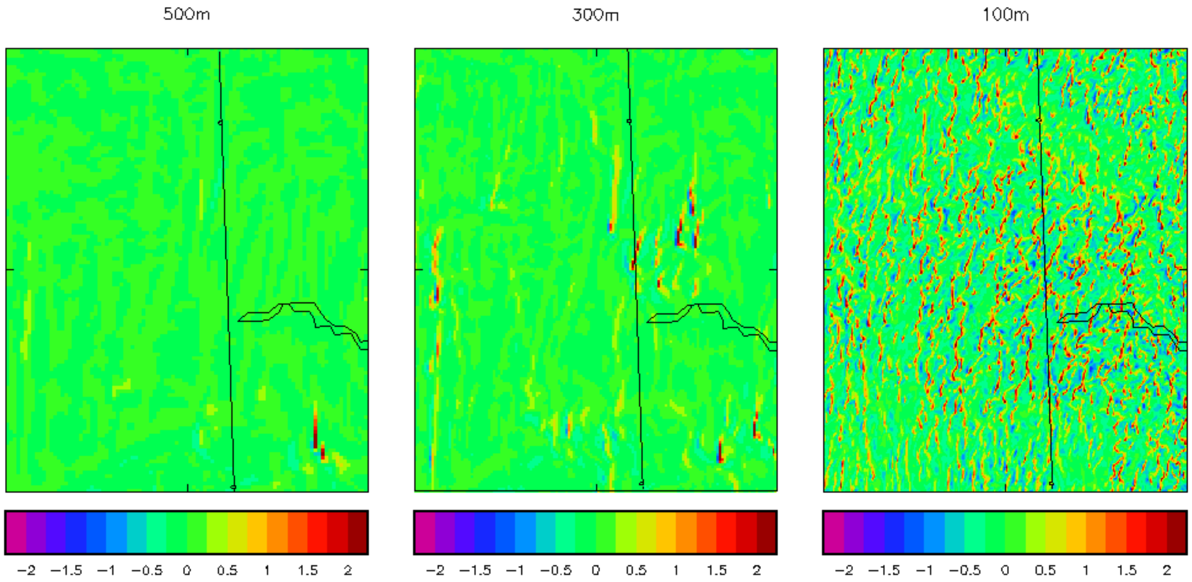


Lean et al QJRMS 2019

Two Motivations for order 100m Models

2. Better representation of meteorology - turbulence, convection etc.

- Example shows vertical velocity in a clear, convective BL. At 500m there is not much explicit overturning, at 300m there is gridscale structure but the overturning looks more realistic at 100m.



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.

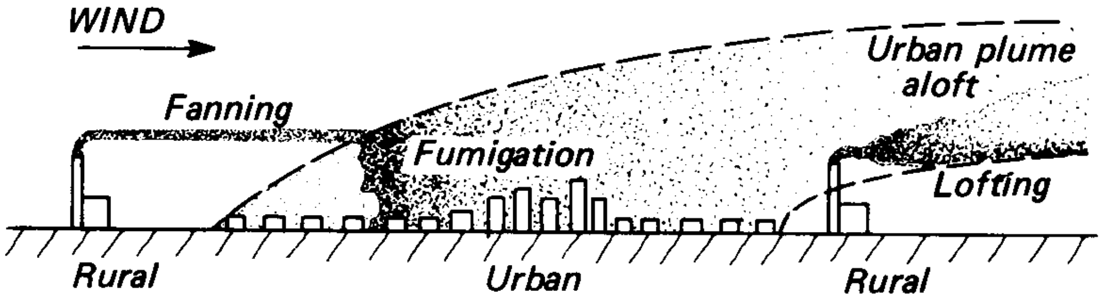
- Several involve other coupled models (e.g. air quality requires chemistry model, flooding requires hydrology) but:

- Good representation of urban meteorology is fundamental

Motivation

Need to capture neighbourhood scale effects

From Oke 1987



- Example: Good representation of boundary layer structure critical for air quality.

~100m UM Research Models at Met Office

•Cold pooling in valleys COLPEX (Clark, Vosper Carter, 2013)

•Convection DYMECS (Stein, Clark, Lean, Halliwell Hanley 2015)

• Fronts (Eagle, Harvey 2017)

•Tornadoes (Hanley 2016)

• StCu (Boutle 2014)

• Fog inc nesting in ensemble LANFEX (Boutle, 2018)

• London (Lean 2019)

And (lots of) others…….

In addition 300m routinely running model of London area for fog (Finnenkoetter, Boutle 2016)

(Dates shown are those of publications)

Issues to consider

- Affordability
- Spin up issues
- Predictability
- Urban surface representation
- Model issues (turbulence grey zone etc).

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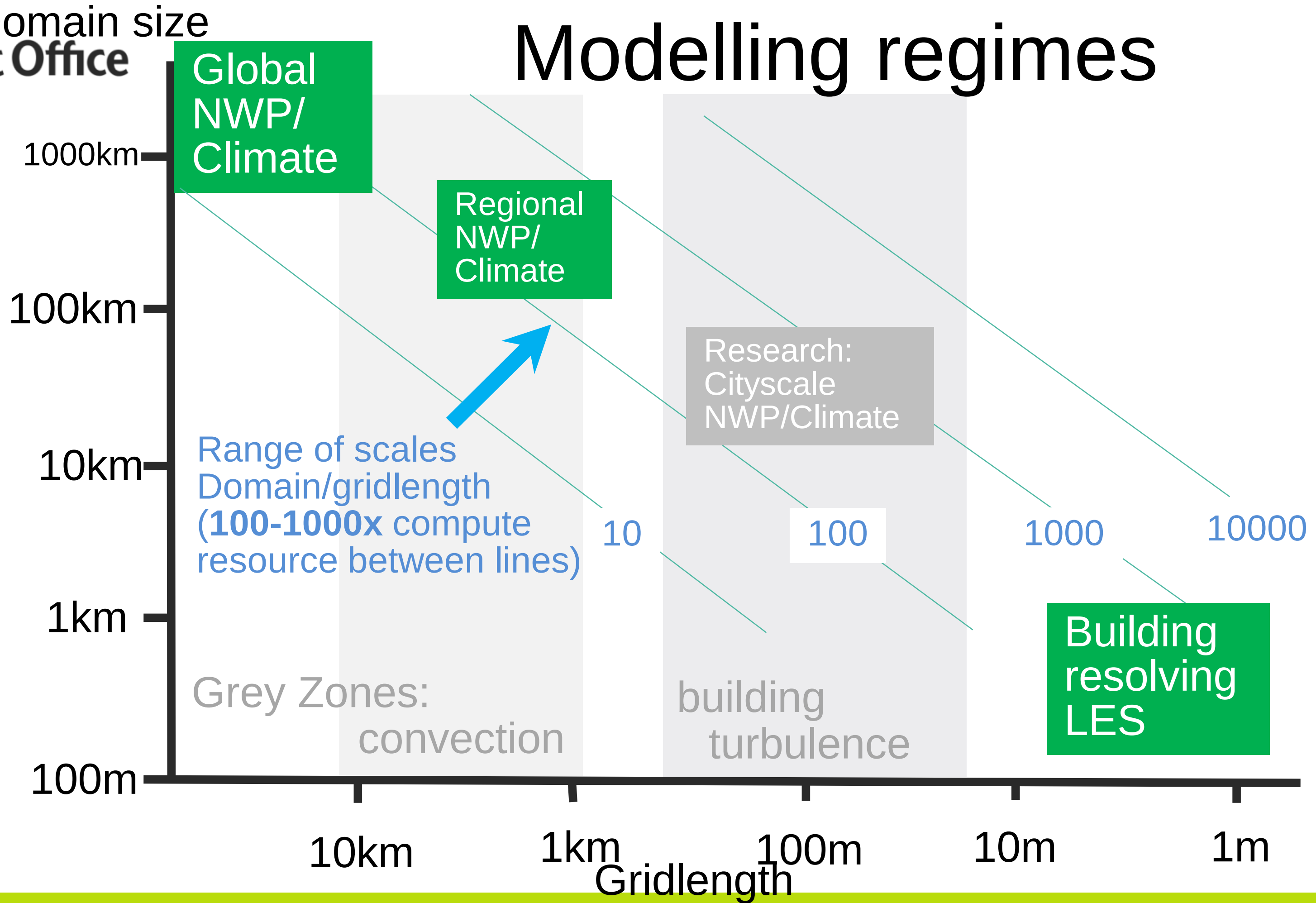
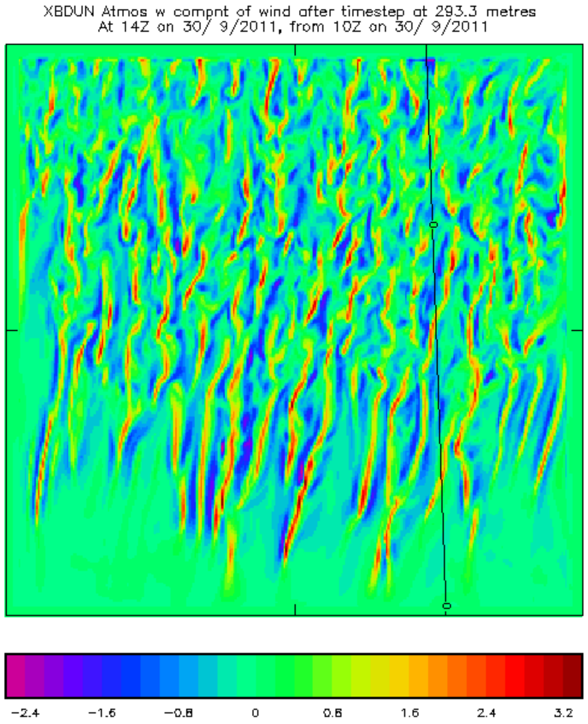
Modelling regimes

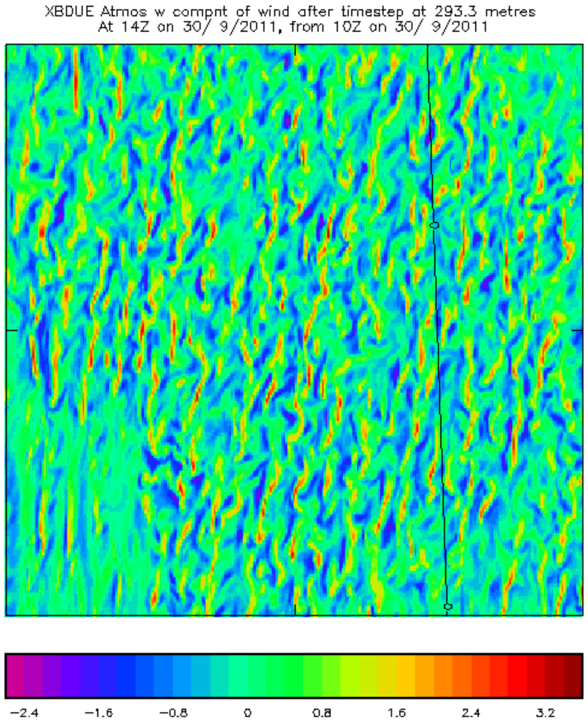


Spin up effects important in these models.

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



Small 30x30km 100m model

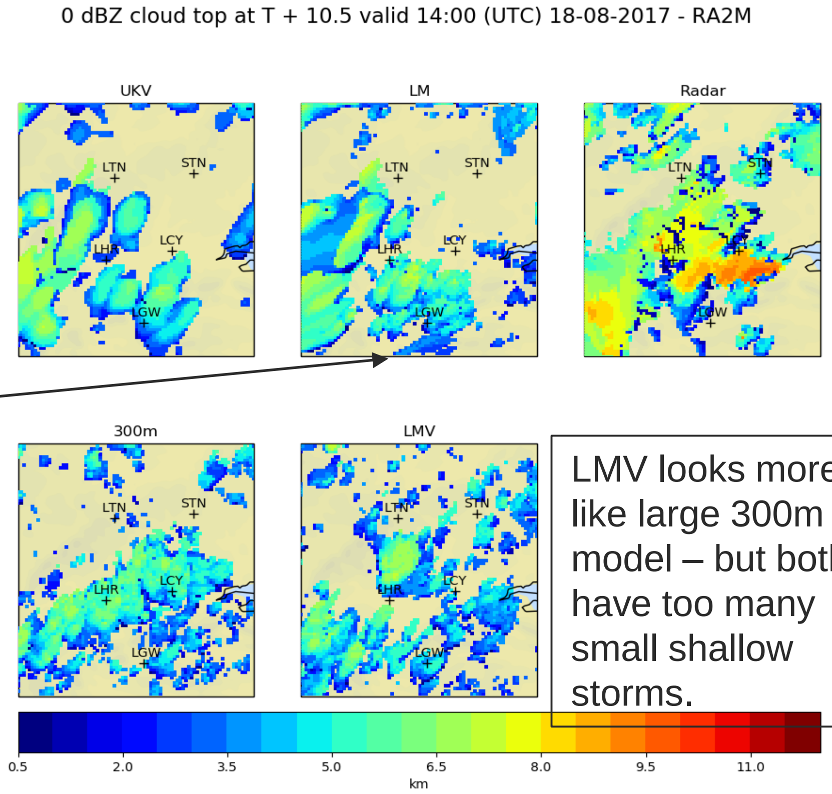


Subset of large 80x80km domain

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.

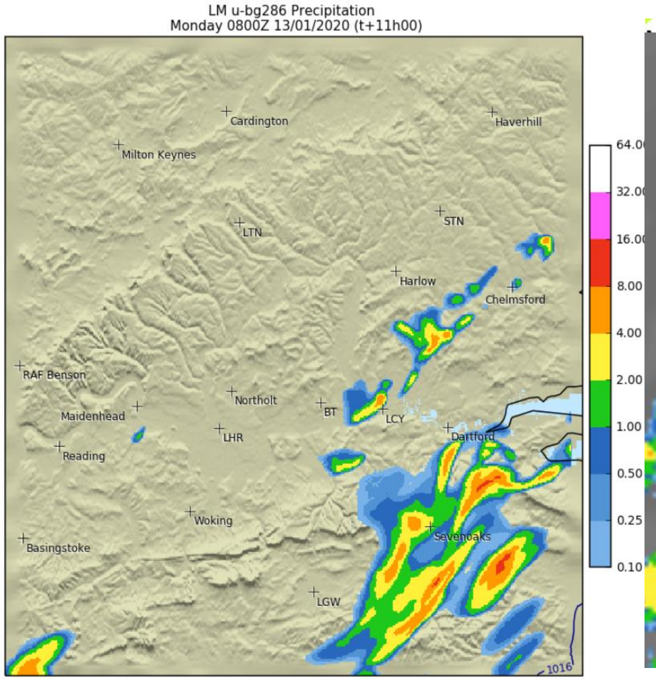


LMV looks more like large 300m model – but both have too many small shallow storms.

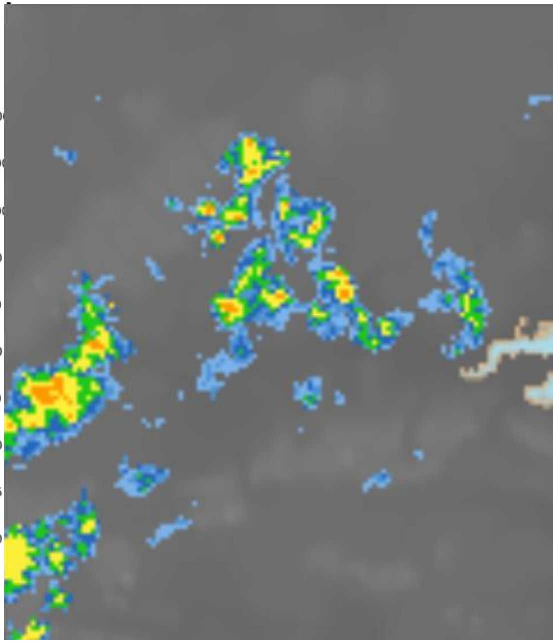
Predictability

- As we move to forecasting on smaller scales unpredictable scales become larger compared to the areas you are interested in forecasting.
- Example shows 10 hour forecast of showers in the London model which are well forecast but in wrong locations.
- 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.

0800 UTC 13th Jan 2020



300m London Model

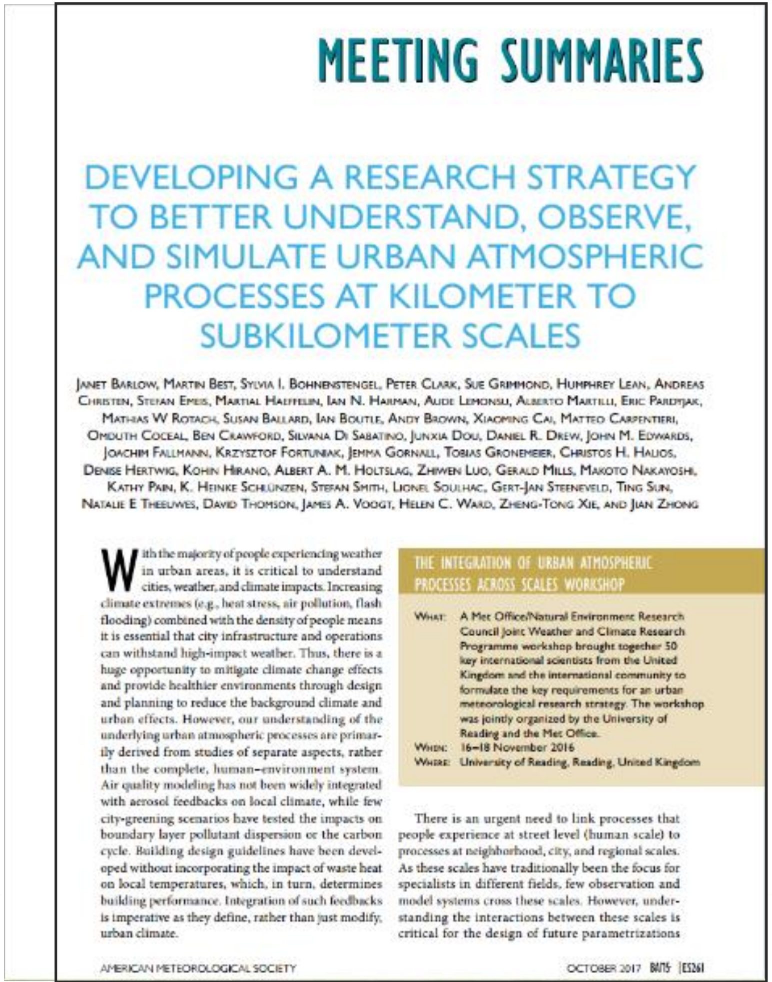


Radar

Representation of urban surfaces

- International workshop, Reading Nov 2016 to discuss issues and strategy.

- Headline conclusion was that main issues are heterogeneity on many scales (no scale separation) and anthropogenic sources.



MEETING SUMMARIES

DEVELOPING A RESEARCH STRATEGY TO BETTER UNDERSTAND, OBSERVE, AND SIMULATE URBAN ATMOSPHERIC PROCESSES AT KILOMETER TO SUBKILOMETER SCALES

Janet Barlow, Martin Best, Sylvia I. Bohnenstengel, Peter Clark, Sue Grimmond, Humphrey Lean, Andreas Christen, Stefan Emeis, Martial Haeffelin, Ian N. Harman, Aude Lemonsu, Alberto Martilli, Eric Pardyjak, Mathias W Rotach, Susan Ballard, Ian Boutle, Andy Brown, Xiaoming Cai, Matteo Carpentieri, Omduth Coceal, Ben Crawford, Silvana Di Sabatino, Junxia Dou, Daniel R. Drew, John M. Edwards, Joachim Fallmann, Krzysztof Fortuniak, Jemma Gornall, Tobias Gronemeier, Christos H. Halios, Denise Hertwig, Kohin Hirano, Albert A. M. Holtslag, Zhiwen Luo, Gerald Mills, Makoto Nakayoshi, Kathy Pain, K. Heinke Schlünzen, Stefan Smith, Lionel Soulhac, Gert-Jan Steeneveld, Ting Sun, Natalie E Theeuwes, David Thomson, James A. Voogt, Helen C. Ward, Zheng-Tong Xie, and Jian Zhong

With the majority of people experiencing weather in urban areas, it is critical to understand cities, weather, and climate impacts. Increasing climate extremes (e.g., heat stress, air pollution, flash flooding) combined with the density of people means it is essential that city infrastructure and operations can withstand high-impact weather. Thus, there is a huge opportunity to mitigate climate change effects and provide healthier environments through design and planning to reduce the background climate and urban effects. However, our understanding of the underlying urban atmospheric processes are primarily derived from studies of separate aspects, rather than the complete, human–environment system. Air quality modeling has not been widely integrated with aerosol feedbacks on local climate, while few city-greening scenarios have tested the impacts on boundary layer pollutant dispersion or the carbon cycle. Building design guidelines have been developed without incorporating the impact of waste heat on local temperatures, which, in turn, determines building performance. Integration of such feedbacks is imperative as they define, rather than just modify, urban climate.

THE INTEGRATION OF URBAN ATMOSPHERIC PROCESSES ACROSS SCALES WORKSHOP

What: A Met Office/Natural Environment Research Council Joint Weather and Climate Research Programme workshop brought together 50 key international scientists from the United Kingdom and the international community to formulate the key requirements for an urban meteorological research strategy. The workshop was jointly organized by the University of Reading and the Met Office.
When: 16–18 November 2016
Where: University of Reading, Reading, United Kingdom

There is an urgent need to link processes that people experience at street level (human scale) to processes at neighborhood, city, and regional scales. As these scales have traditionally been the focus for specialists in different fields, few observation and model systems cross these scales. However, understanding the interactions between these scales is critical for the design of future parametrizations

Barlow, J., et al (2017). BAMS, 98(10), 261-264.
https://doi.org/10.1175/BAMS-D-17-0106.1

Urban surface modelling strategy.

1. Developments to Surface Energy Balance scheme (MORUSES)

Establish as default oper scheme worldwide, higher resolutions, main land-use, urban vegetation, roughness formulation, soil tiling, displacement heights.

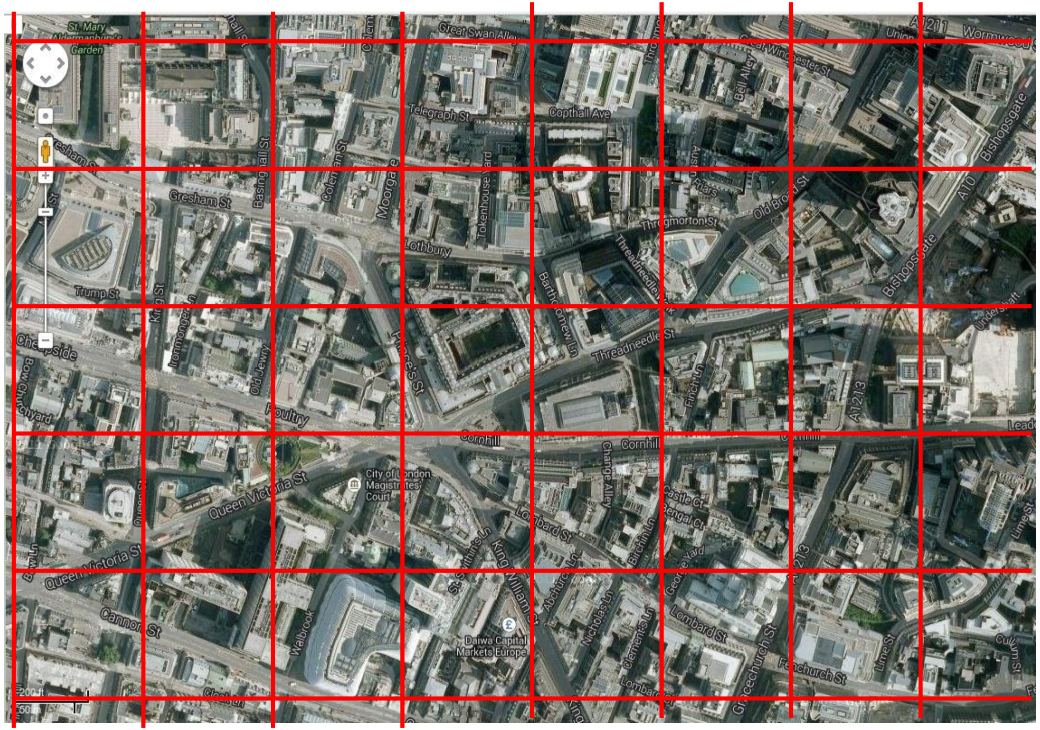
2. Anthropogenic Fluxes

More realistic anthropogenic datasets, temporal and spatial variation.

3. Distributed Urban Canopy Schemes.
Needed (as opposed to extrapolating downwards) due to horizontal inhomogeneity.
Challenging scientifically and technically.

Much of this work in collaboration with academia (esp Reading)

Specific issue for O(100m) models:



100m grid superimposed on city of London

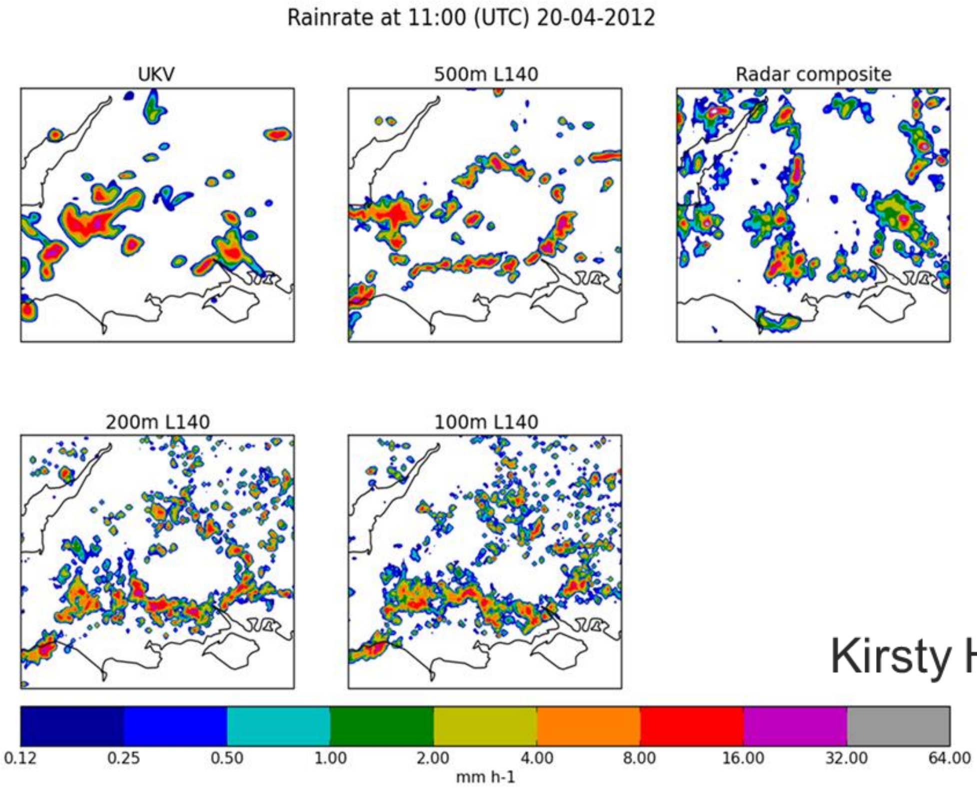
- building “grey zone” – *neither resolved or many per gridbox*.

O(100m) Model Issues.

- Issue with model being tuned to work for particular gridlengths often including compensating errors.
- Example is 1.5km UKV which has smaller diffusion than might otherwise have and larger stochastic perturbations to compensate for convection being very under-resolved.
- Need thorough understanding of model issues.
- Move towards scale-aware parameterisations (e.g. convection, turbulence) to correctly handle grey zones.

O(100m) Model Issues.

Running at high res with UKV configuration tends to give too many small convective cells. Corollory is cell size in UKV completely dominated by gridlength.



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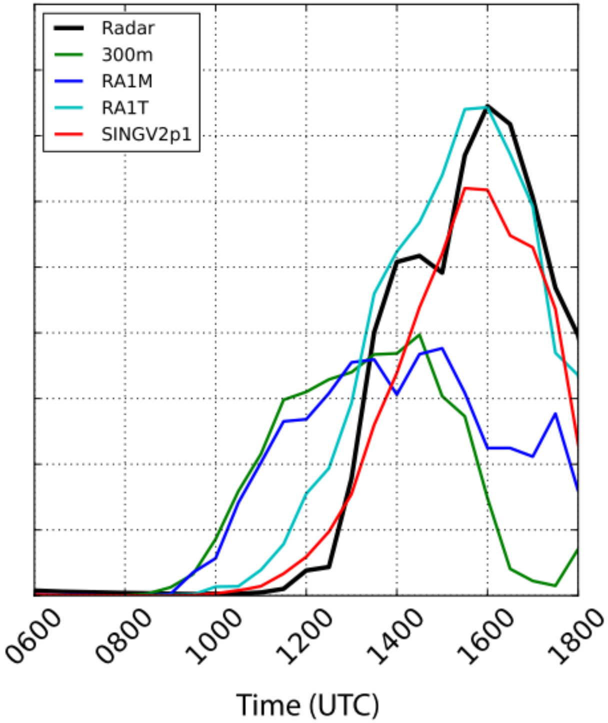
O(100m) Model Issues.

Problems with early initiation worse at high resolution.

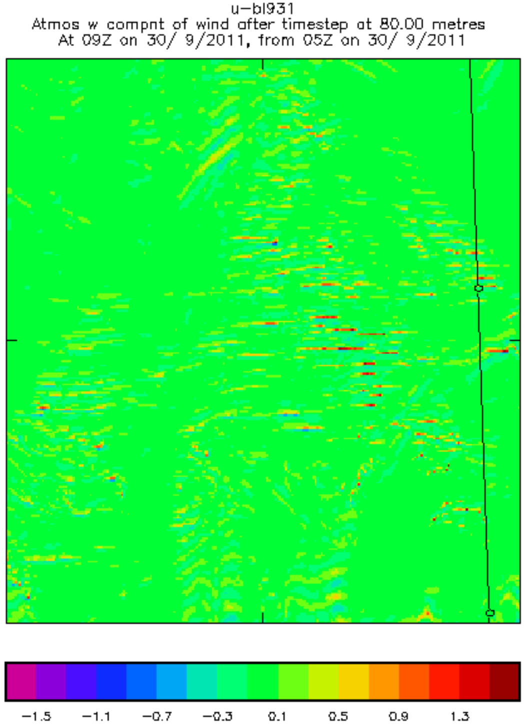


Keat, W. J et al (2019). Convective initiation and storm life-cycles in convection-permitting simulations of the Met Office Unified Model over South Africa. QJRMS, (October 2018). https://doi.org/10.1002/qj.3487

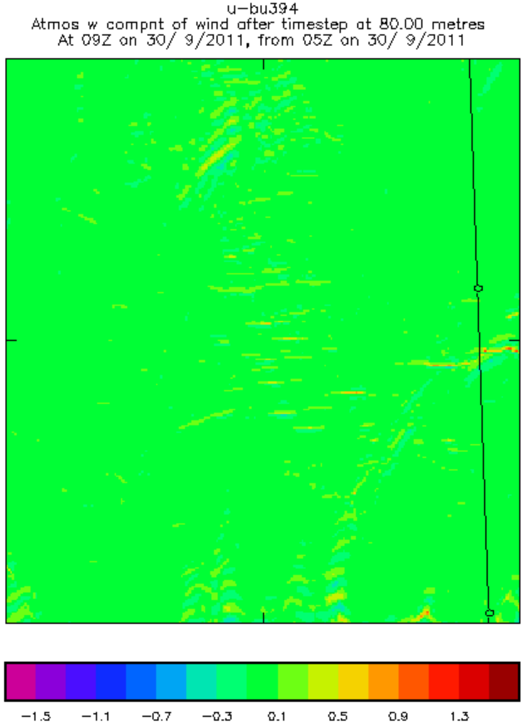
Initiation often too early in 100m scale models due to unphysically large stochastic perturbations applied in RAL-M configurations to compensate for being under-resolved.

Need to correctly handle CBL 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 in the day while mixed layer is shallow.
- Answer should be that gridscale motions are parameterised (scale aware scheme).
- Compare Smagorinsky with 3d tke scheme. 3d tke removes gridscale plumes.



100m Smagorinsky



100m Blended BL

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Future Work

- Currently developing strategy for 100m scale modelling.
- Developments of scale aware parameterisations: e.g. turbulence. Also urban surface.
- Optimisation of models to ameliorate CPU requirements.
- Specific issues around representation of convection.
- Coupling to other models.
- Ensembles.
- Involvement in potential UK convection campaign and Paris 2024 RDP.

Research Demonstration Project on the Paris 2024 Olympic Games

Aim: To advance research on the theme of the "future Meteorological Forecasting systems at 100m (or finer) resolution for urban areas".

Such systems would prefigure the numerical weather prediction at the horizon 2030.

Science Questions:

1. Nowcasting & Numerical Weather Prediction in cities at about 100m of resolution
2. High resolution thunderstorm nowcasting (probabilistic and deterministic) in the urban environment, Urban heat islands and cool areas, air quality, in cities
3. Nowcasting and forecast in coastal cities (for the Marseilles site)
4. Big data, non-conventional data, and their uses
5. How to deliver tailored weather, climate, environmental information at infra-urban resolution?

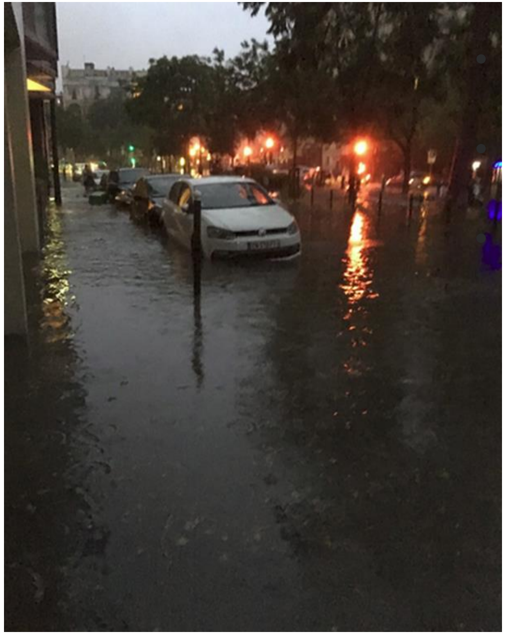
PARiS 2024

Valéry Masson (Meteo France)
9 National Meteorological Institutes participating.

WMO CNRM METEO FRANCE

Paris RDP Model Inter-comparison

Looking at two cases initially



Thunderstorm case

9-10 Jul 2017

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PARIS

Pollution au plomb : un centre de loisirs fermé

75

N° 23295 — VENDREDI 26 JUILLET 2019 — 2,70 €

Le Parisien.fr

CANICULE

RECORD BATTU À PARIS

42,6 °C

La deuxième grosse vague de chaleur de l'été a explosé les records de températures dans le nord de la France.

PAGES 2 À 4 ET CAHIER CENTRAL

Vos magazines

TV

WEEK-END

TOUS ÉVALUÉS

Argent P.7
Payer moins de frais bancaires à l'étranger

Faits divers P.10
L'ombre de Fourniret sur l'affaire Estelle Mouzin

Tour de France P.16 À 19
Quel suspense !

AU FIL DE L'ÉTÉ

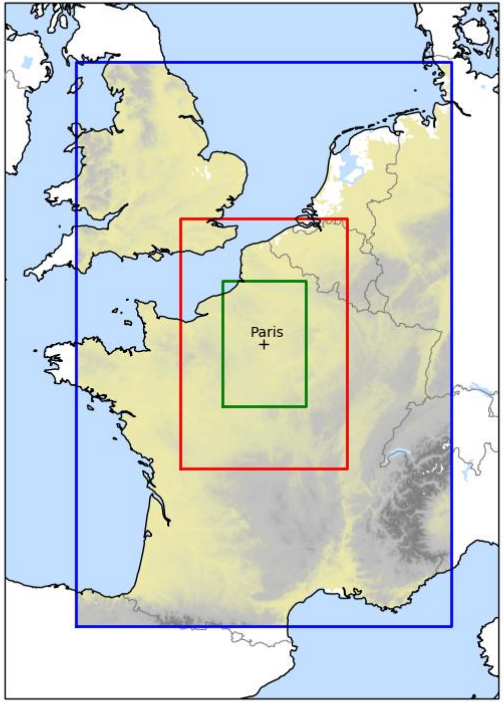
+ JEUX BD

Les ratés du marketing : la pièce Jimenez P.14

Le jour où... Thierry Ardisson a quitté la télé P.29

- Heat Wave case
- 22-26 Jul 2019
- UM being run by BoM (Vinod Kumar).

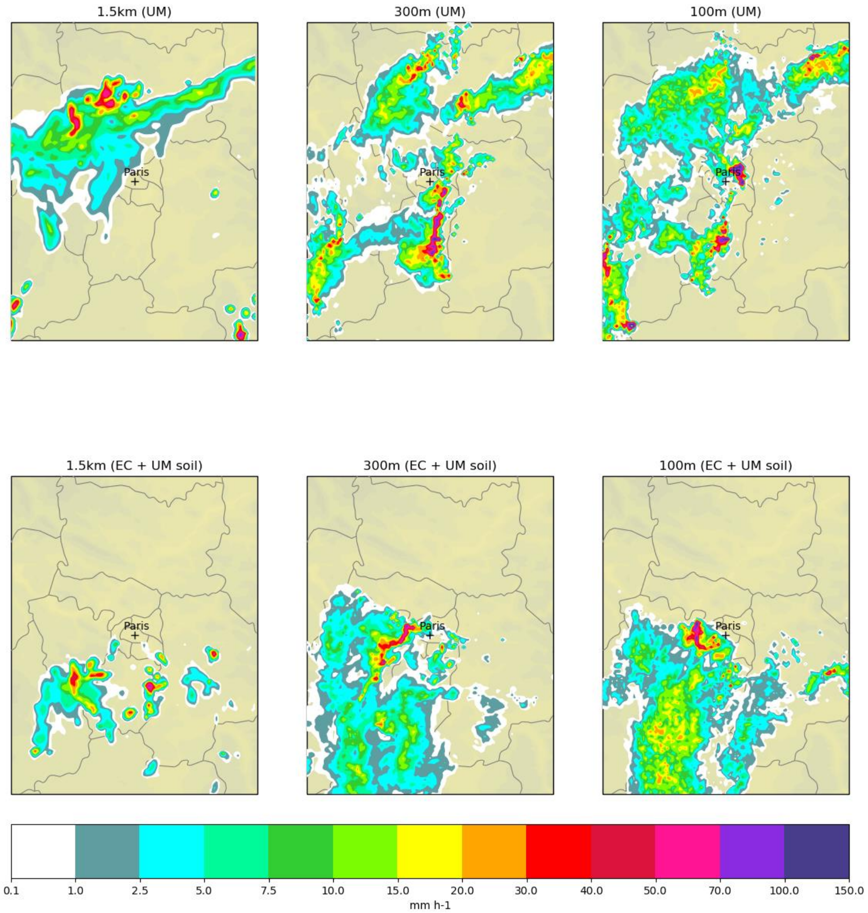
Model setup

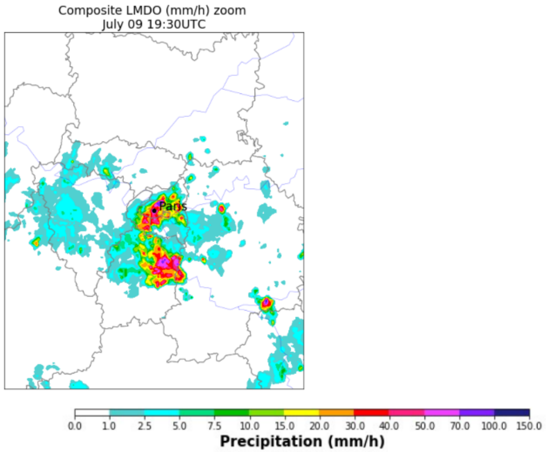


- Progress: set-up 1.5km, 300m and 100m domains over Paris and run the 9 July 2017 thunderstorm case using
  1. UM Global model
  2. ECMWF analysis + UM soil moisture to drive 1.5km model
- Initialise at 1200 UTC on 8 July 2017 run to T+48

Model	Points	Levels	Timestep	Configuration
1.5km	600x900	70	60s	RA2M
300m	1200x1800	70	12s	RA2M
100m	2000x3000	140	3s	RA2M

Rainrate at T + 31.5 valid 19:30 (UTC) 09-07-2017
RA2M





Source: Météo-France

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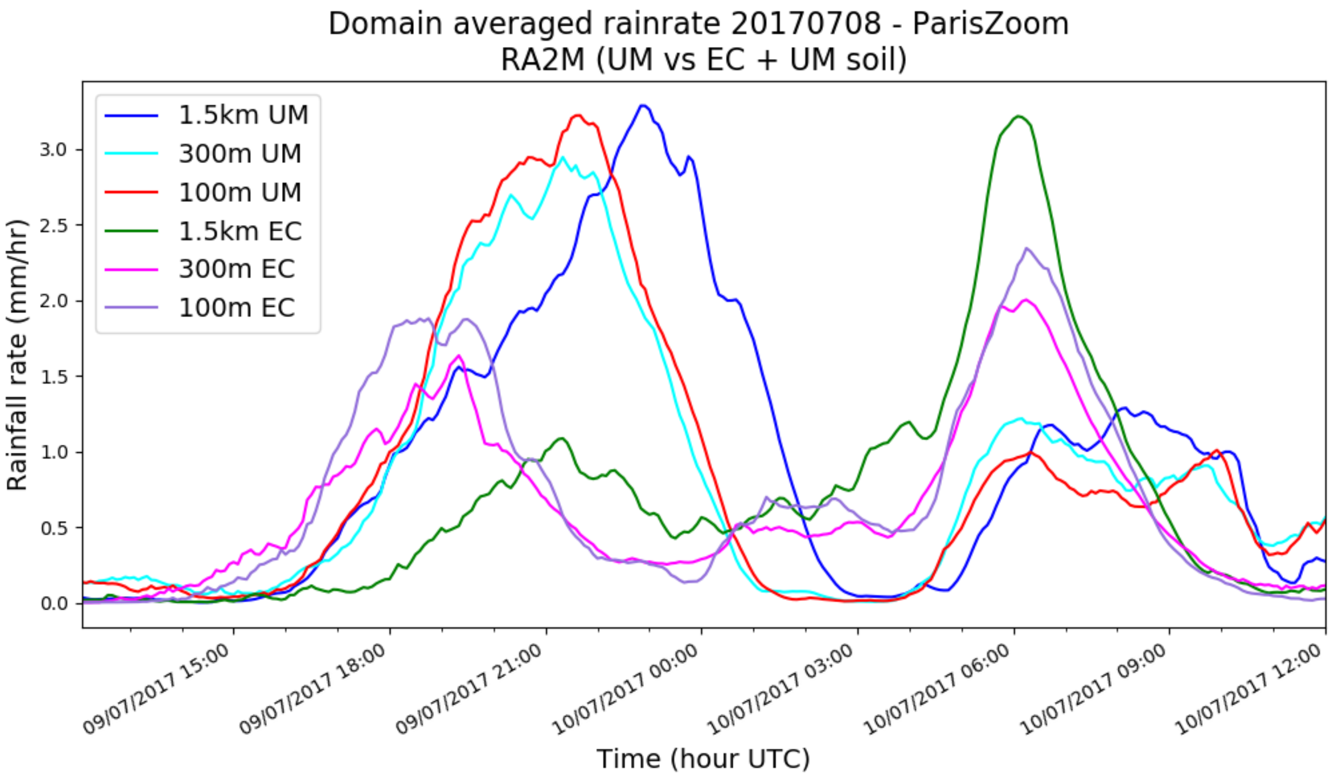

Kirsty Hanley

Conclusions

Met Office

- O(100m), “City Scale” Modelling is an aspiration and is the subject of current work and detailed plans are being developed going forward.

- O(100m) models have been run in various research contexts within the Met Office. However there is still work to do to develop optimal model configurations.

- There are numerous scientific and practical challenges in developing these models.

- WMO Paris RDP focussed on 100m scale modelling will be an important