Met Office

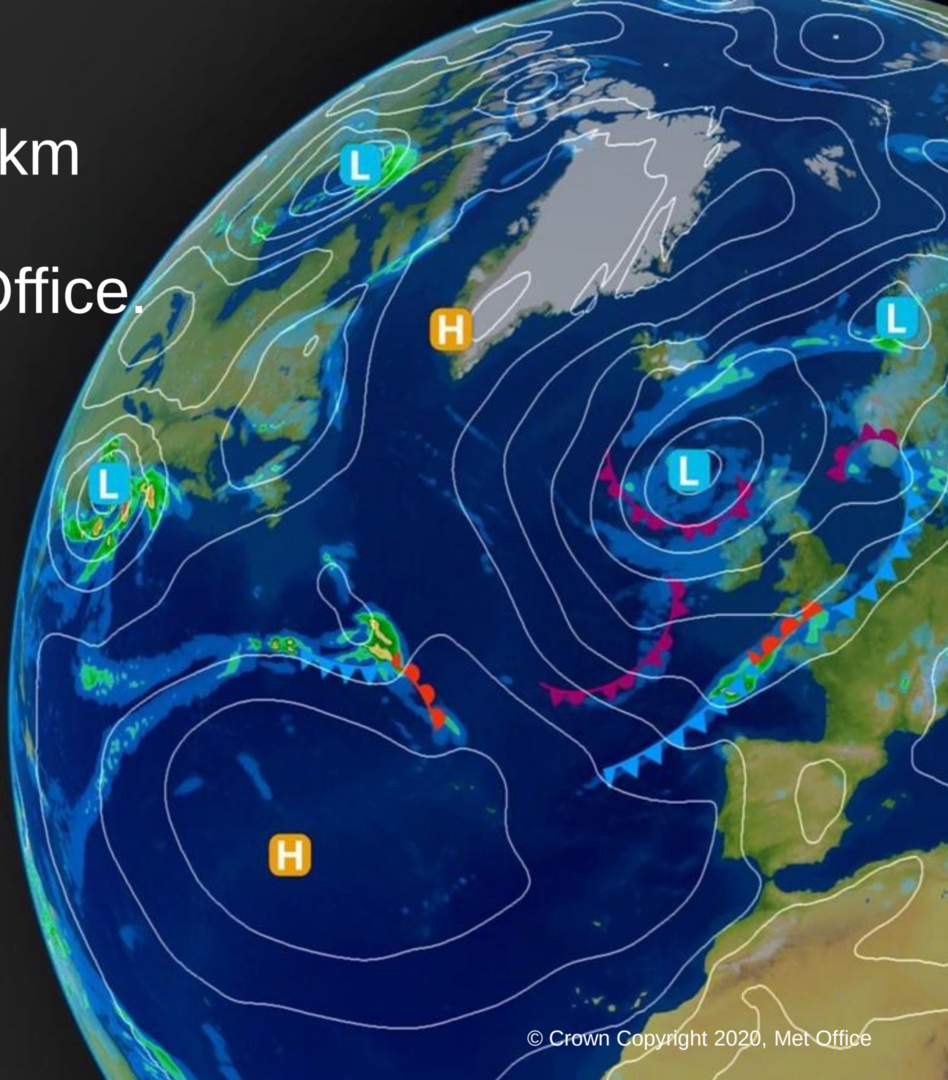
Progress with km scale and sub-km scale modelling for high impact weather and climate at the Met Office.

Humphrey Lean

Convective Scale Modelling Research
RMED, MetOffice@Reading

Contributions from many – in particular:

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



BoM Annual Research Workshop Oct 2020

Met Office

Introduction

- Convection permitting Models have given many benefits for prediction of hazards on weather and climate timescales.
- Here will focus on Convection and on urban hazards (heat, AQ).

Paris 10/7/2017

PARIS

Pollution au plomb : un centre de loisirs fermé

75

Le Parisien

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

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

Les ratés du marketing : la pièce Jimenez P. 14

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

+ JEUX BD

Paris 26/7/2019

Convection Permitting Model benefits

- “Step Change” in ability to forecast rainfall (Clark et al 2016)
- Look realistic to eye compared to 12km.
- Outperform 12km models for convection by subjective (forecaster) and objective (fuzzy) verification.
- Systematic benefits from not using convection scheme..
- UKV (1.5km model) is primary model for UK forecasting.
- Need to bear in mind predictability constraints.

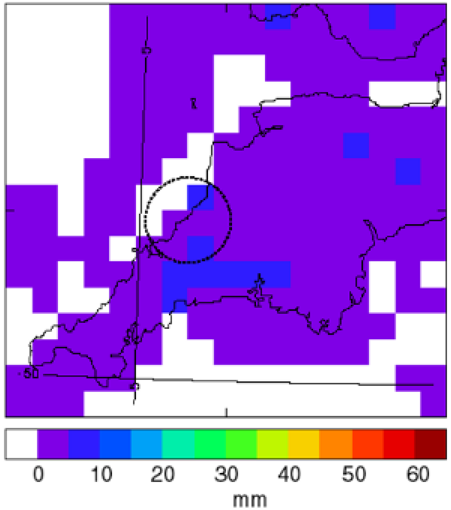
Timeline of operational UK versions of UM

- Hydrostatic “mesoscale model” 17km early 1990s
- Resolution improved to 12km and area increased 1998
- UK 4km model (Non Hydrostatic) in operational April 2005.
- “On demand” 1.5km model (9 domains) from Dec 2006
- UKV 1.5km model from Nov 2009 3hr DA cycle.
- Extended range UK 4km (global downscaler) from Dec 2010
- MOGREPS-UK Convective ensemble (2.2km) from June 2012
- Larger domain UKV (low res) and out to T+120 Nov 2016
- Hourly cycling UKV Sep 2017
- Convection permitting downscaling of climate model UKCP12, UKCP18).
- Hourly Cycling MOGREPS-UK 2019

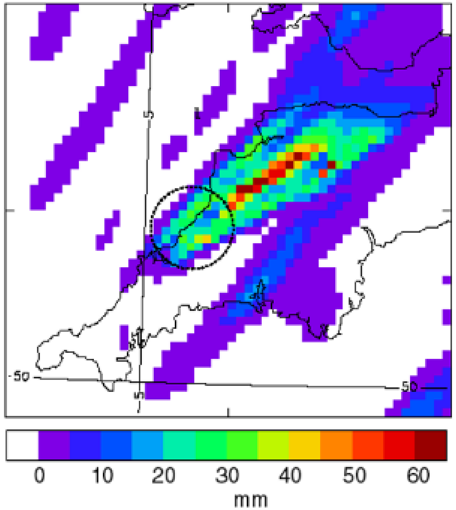
Boscastle Flood 16/08/2004

Met Office

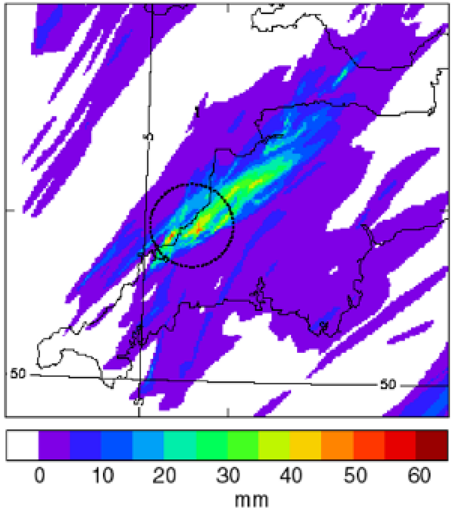
12-km forecast (PC003) from 00 UTC
Rainfall accumulations 12 to 18 UTC



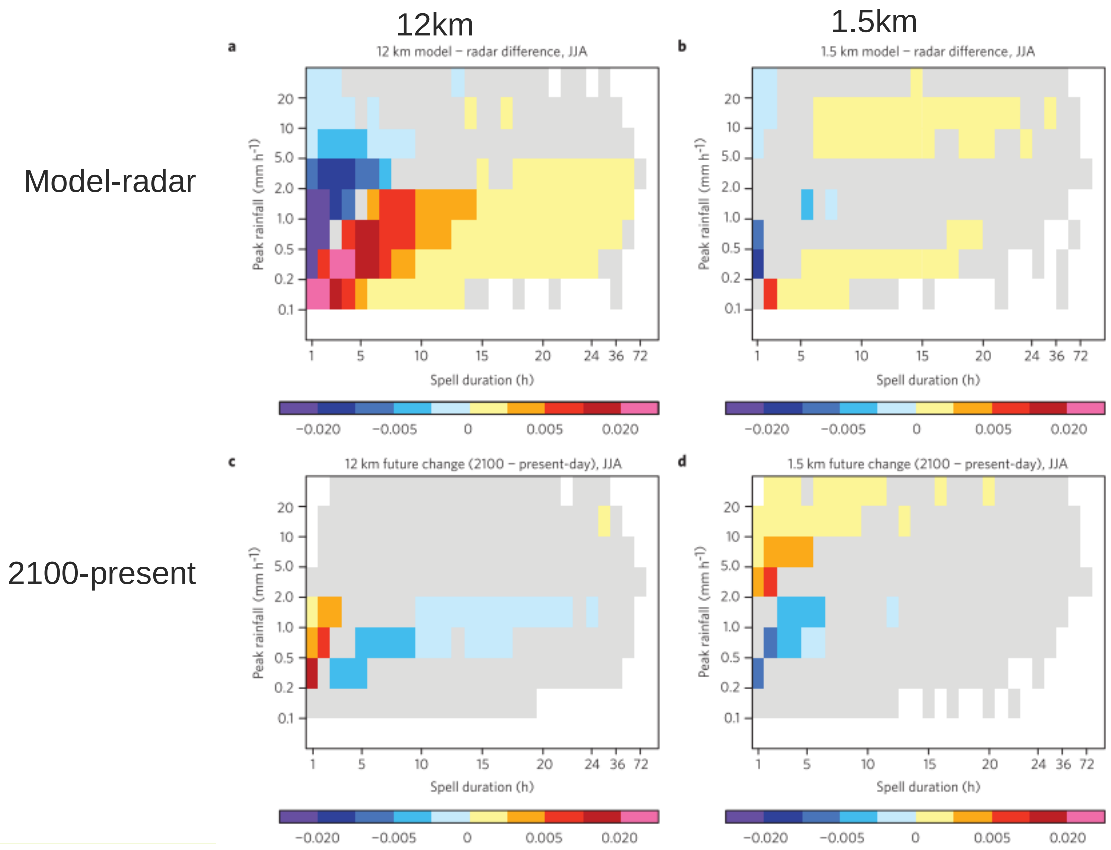
4-km forecast (PC003) from 00 UTC
Rainfall accumulations 12 to 18 UTC



1-km forecast (PC003) from 00 UTC
Rainfall accumulations 12 to 18 UTC



Convection Permitting climate modelling probes how extreme events change.

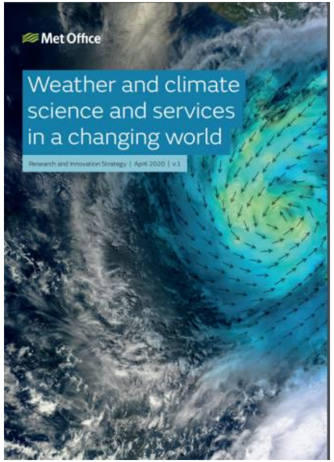


- Peak rainfall vs duration plots for JJA.
- Model against radar shows 1.5km model captures high intensity events.
- Climate change signal shows increase in high intensity, short duration rain in 1.5km model.

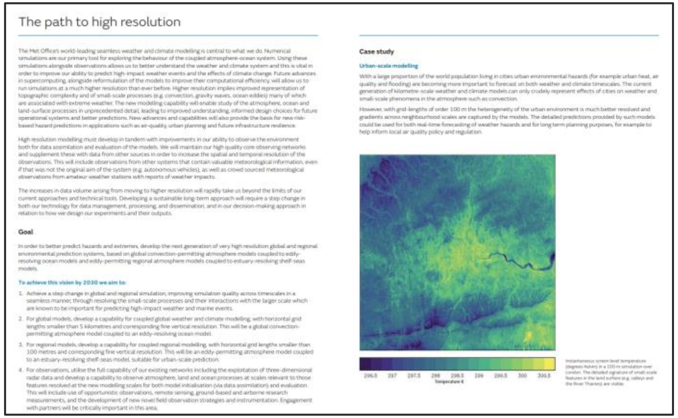
Kendon, E.J.,et al. https://doi.org/10.1038/nclimate2258

Met Office

Met Office Research and Innovation Strategy



April 2020

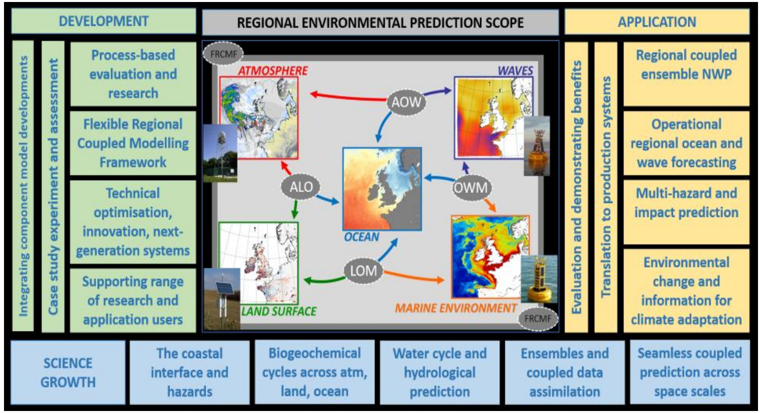

The path to high resolution

Case study

Urban-scale modelling

Goal

100m scale modelling



Regional Environmental Prediction

Also:

- K-SCALE – large km scale domains
- 5km coupled global modelling.

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

~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)

Met Office

The path to high resolution

100m Scale Modelling
Analysis of potential benefits

From High Res surface representation

From High Res Model

Orographic Rain

Cold pooling in valleys

Temperature distribution in cities

Fog

Convective BL

Turbulence/gusts

Urban/Orog Winds

Convection

Air Quality/Dispersion

Tornadoes

Sea Breezes

Improved feedback to larger scales

Convection

Norman OK, 9/05/2016

Met Office

Km Scale Model Issues for convection

- Despite all the benefits there are still significant problems with km scale convection permitting models.
- Convection often under-resolved in UK – for km scale models need scale aware convection scheme
- Often compensating errors.
- Errors imported from driving large scale models often key issue with convection permitting forecasts.

List of Biases (UM Partnership Convection Working Group)

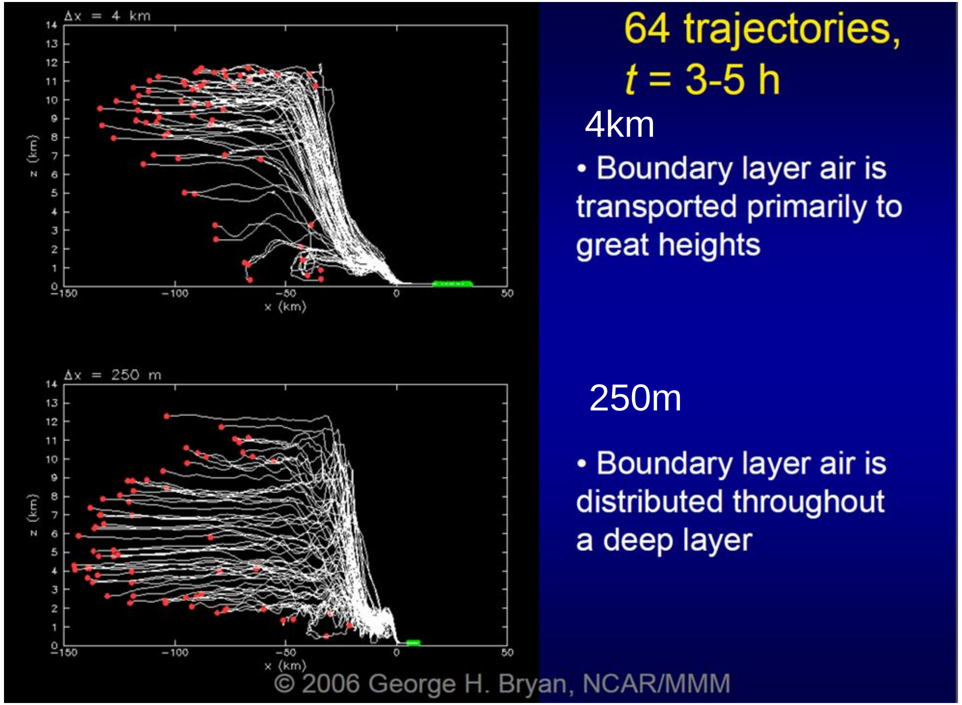
Cloud-scale biases
Too much heavy rain and too high peak rainfall rates.
Too strong and deep updrafts.
Not enough light rain.
Too many small cells, too few large if convection is well resolved.
Too few cells if under-resolved

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.

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 issues inter-related



George Bryan, NCAR (unpublished). Transport of tracer injected at base of updraft in an idealised squall line.

- Key to many of these issues is inability to resolve detrainment at edge of plume.
- In km scale models updraft tends to go straight up without mixing.
- Explains why km scale models often have lack of light rain and too intense, narrow cores.
- Key is to understand 3d structure of clouds, updrafts and turbulence.

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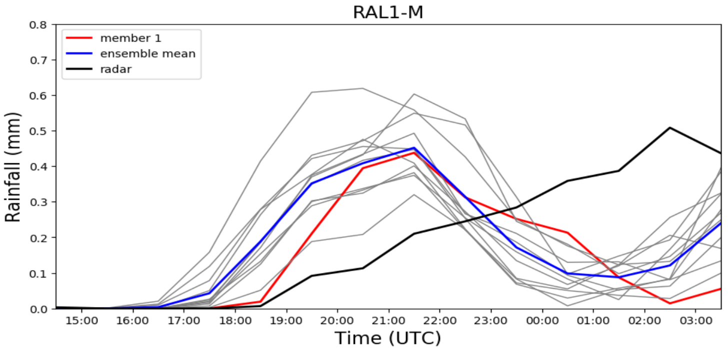
Convective Initiation

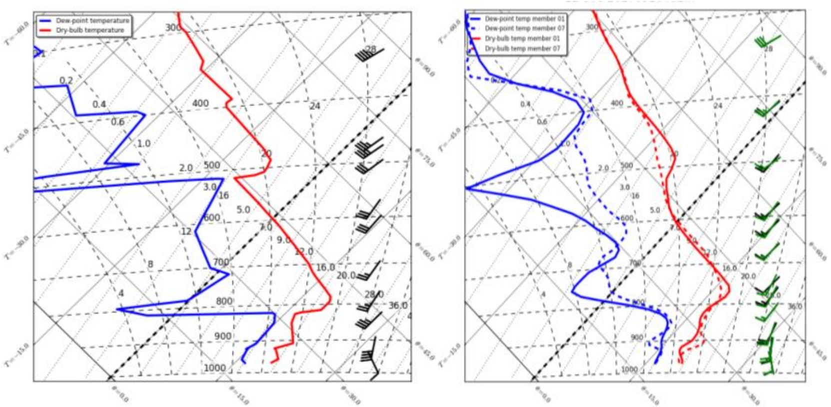
- Initiation time in model is a balance of:
  - Delay due to not being able to resolve small initial plumes (has to happen on the relatively coarse grid). *Modify by changing resolution/diffusion in model.*
  - Amount of CIN in profile. *May be wrong because of driving model or surface proceses in regional model.*
  - Effect of stochastic perturbations. *Added to either represent gridscale effects of unresolved parts of the spectrum or as an ad-hoc fix.*
- Lots of scope for compensating errors.
- Also issue about how convection grows once initiated (too fast – related to previous slide).

Example of compensating errors

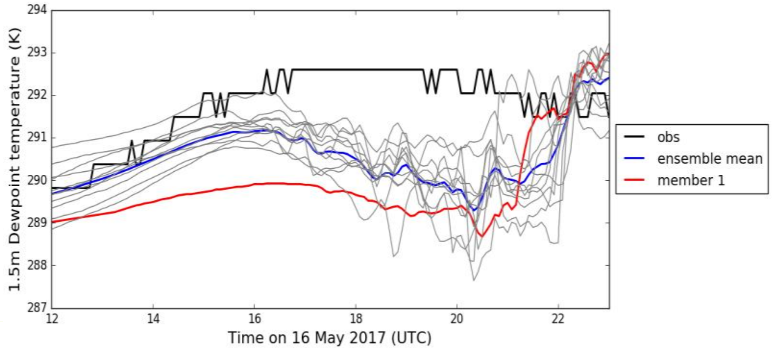
- Ensemble study of 16th May 2016 case on US Great Plains (HWT).



Domain avg rainrate vs time (black obs red member1)



Profiles. Left obs right model (solid member 1, dotted member7)



1.5m dewpoint vs time (black obs red member1)

- Member 1 which initiates at best time (later) has more CIN due to being unrealistically warm and dry.
- Low CIN also case in driving model.

Hanley and Lean in review QJRMS

Will higher resolution help with convection?

- In principle it should do (given issue of being under-resolved in UK).
- However, NOT true that it can be assumed that things are necessarily automatically better at higher resolution
  - Need different parameterisations for newly partially resolved processes (scale aware).
  - Compensating errors in coarser models cause issues when resolution increased.

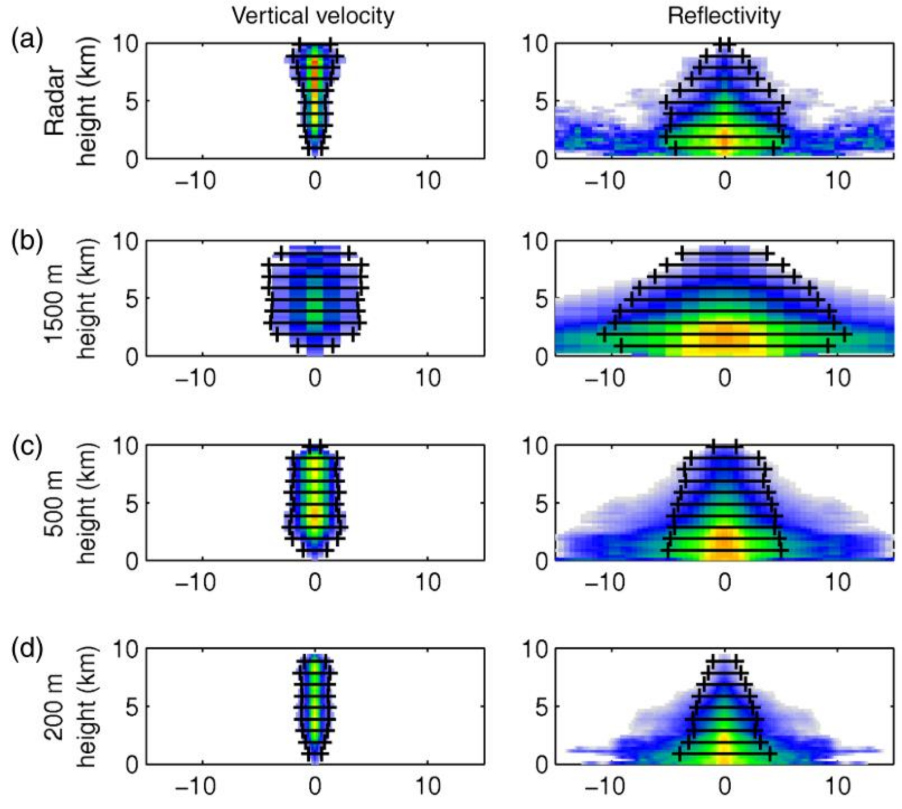
Sub-km model convection issues

	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	Spin up from the boundary can extend tens of kms into domain	Explore use of variable resolution.

Kirsty Hanley (RMED pages).

3d observational analysis

- Vertical velocity and reflectivity profiles from Chilbolton radar.



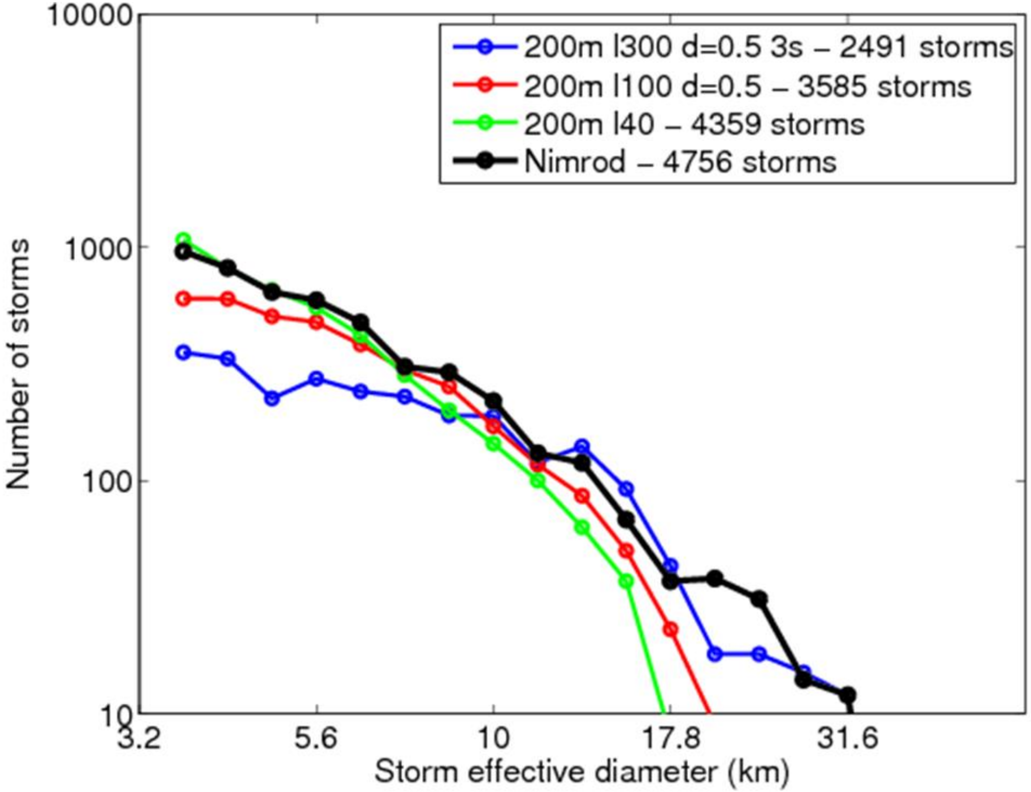
25th Aug 2012

- Profiles show that updrafts too shallow and broad in 1.5km model and mirrored in reflectivity.

- Improved with increased resolution (but becomes too narrow).

Nicol et al https://doi.org/10.1002/qj.2602

Behaviour sensitive to mixing formulation



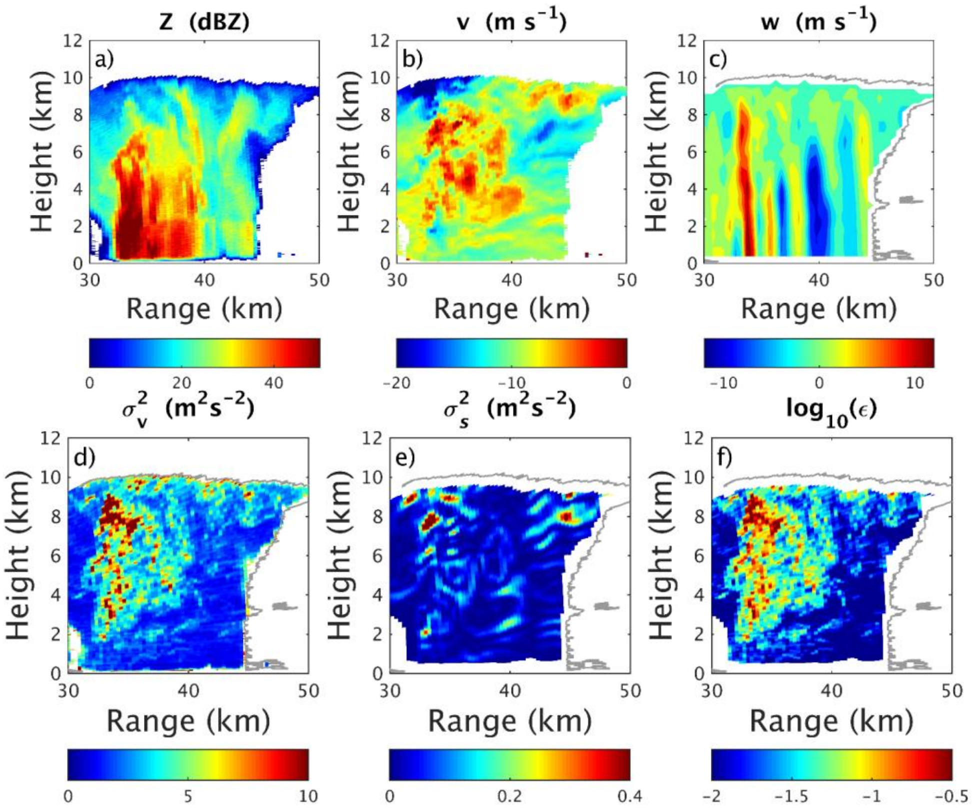
Cell statistics as measured by surface rainrate with 4mm/hr threshold.

Kirsty Hanley

Radar retrieval of turbulence in convective clouds

Follow on from DYMECS (joint project looking at statistics of convective clouds).

University of Reading

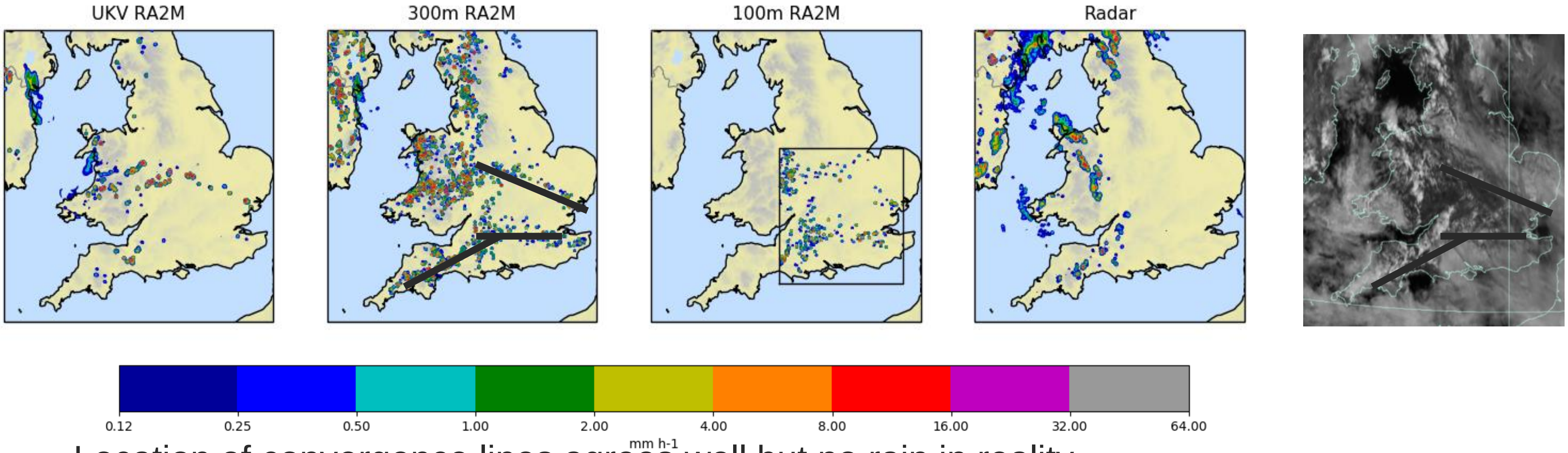


- Example retrieval from "deep cloud" case day
- Statistics determined over many clouds
- Vertical velocity retrievals (Nicol et al., 2015)

Feist, M. M et al (2019). QJRMS, 145(719), 727–744. https://doi.org/10.1002/qj.3462

Matt Feist

1200 UTC 1 June 2018

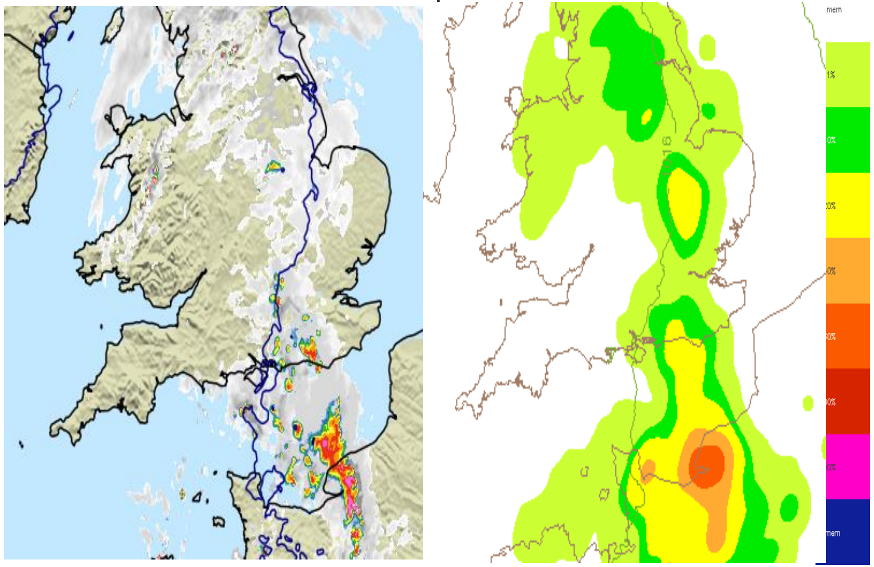


- Location of convergence lines agrees well but no rain in reality.
- Need to understand reason for spurious rain:
  - Too strong vertical velocity?
  - Microphysics issues?
  - Etc?

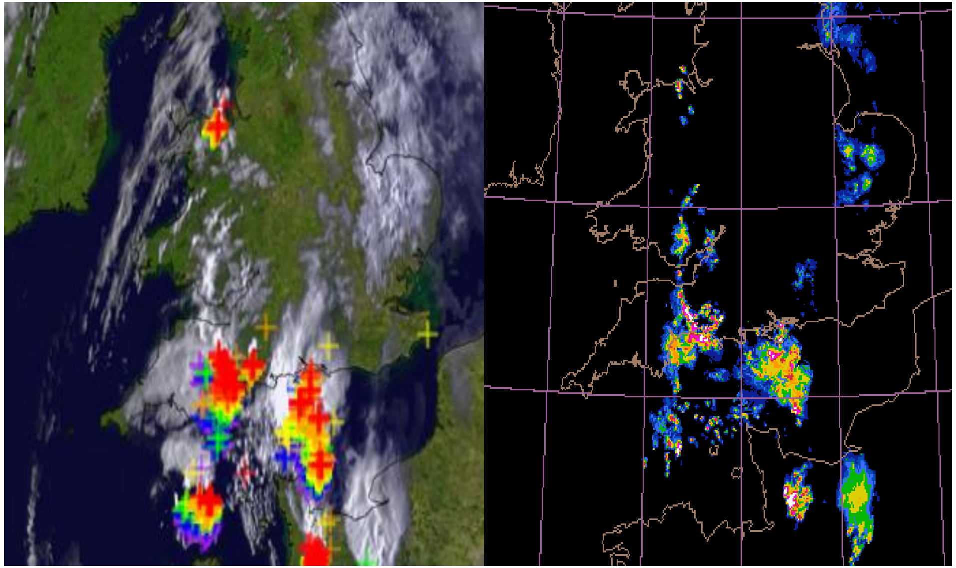
MOGREPS-UK Ensemble Spread is a concern for operations

Example: case of a thundery breakdown poorly captured by our models

UKV (left), and MOGREPS UK (right) available by midday Sat valid 7pm Sat.



Cloud and lightning (left) and rainfall (right) at 7pm Saturday



N.B May be a short range rather than convective scale problem….

Steve Willington

Towards hourly cycling:

Cold start

ICs from MOGREPS-G

6-hourly, 12 members

T+36

Bowler et al., 2008
Operational in MOGREPS-R, 2012
Operational in MOGREPS-G, 2013

Re-centring onto UKV analysis + perturbations from MOGREPS-G

Stochastic physics

6-hourly, T+54

Tennant, 2015
McCabe et al., 2016
Hagelin et al., 2017
Operational in 2016

Re-centring onto UKV 4DVAR + perturbations from MOGREPS-G

Stochastic physics

Hourly + time-lagging

18 members, T+120

Operational in March 2019
Porson et al. 2020

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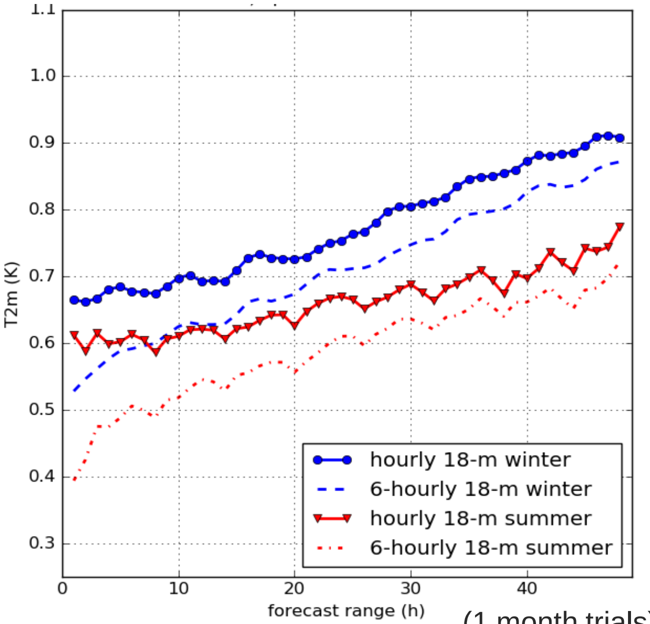
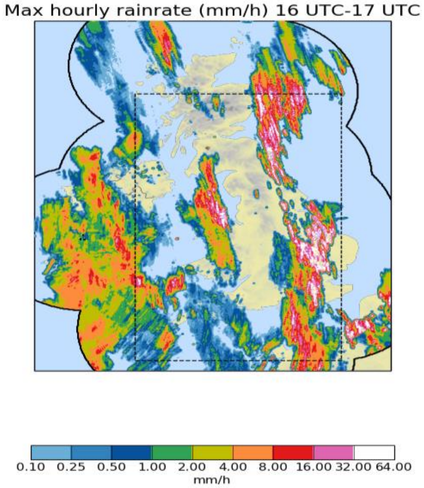
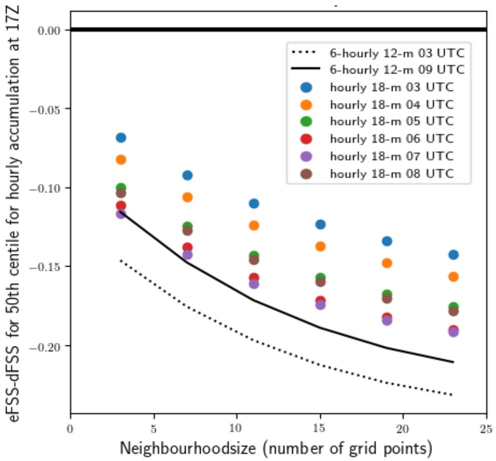
Ensemble spread (Aurore Porson and Anne McCabe)

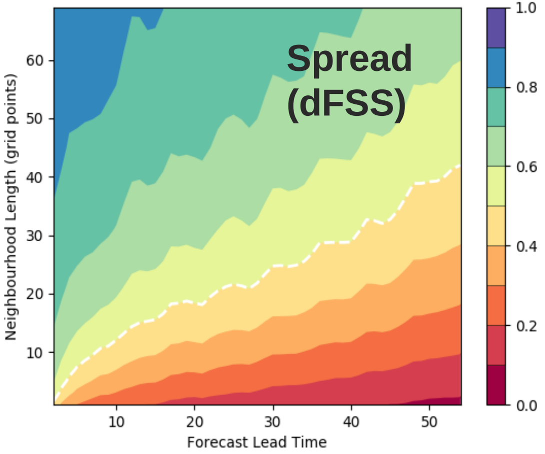
Standard deviation (members to ensemble mean)/
Standard deviation (ensemble mean – obs)

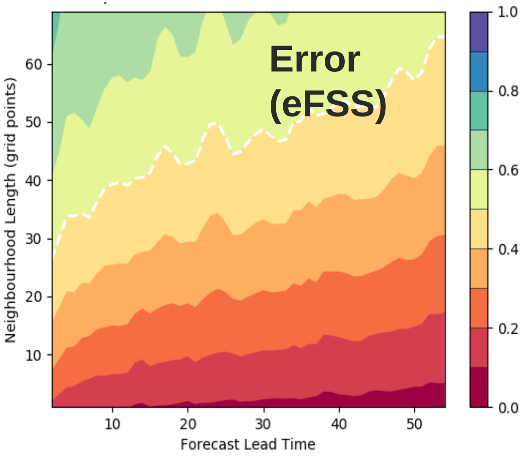


(1 month trials)









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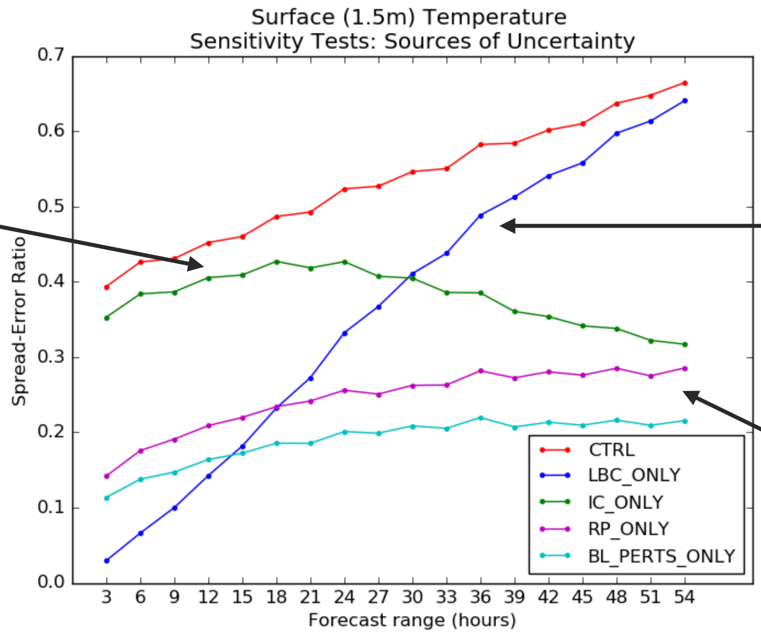
Initial results from sensitivity tests

Initial conditions are most important in the early part of the forecast – they begin to lose significance after 12 hours but dominate over LBC's until T+30.



The impact of the LBC's shows a steady increase throughout the forecast

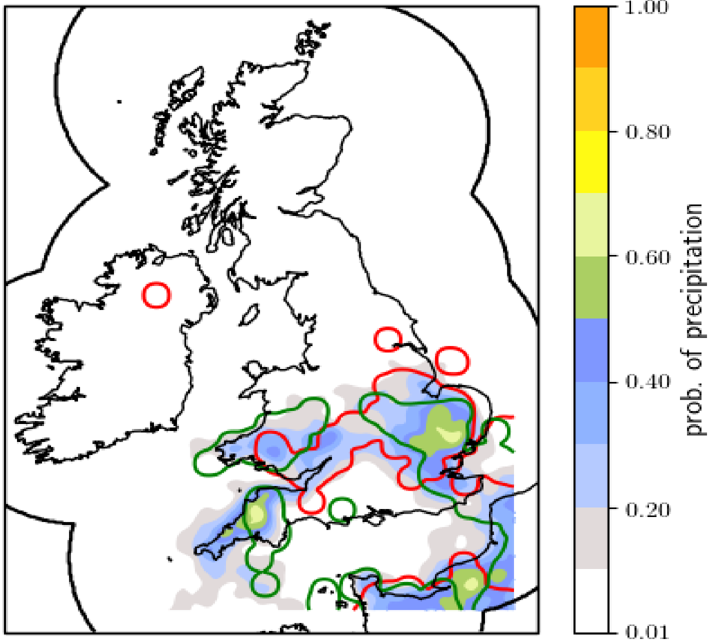
Stochastic physics generates 30 – 40% of the full ensemble spread

16th August 2020

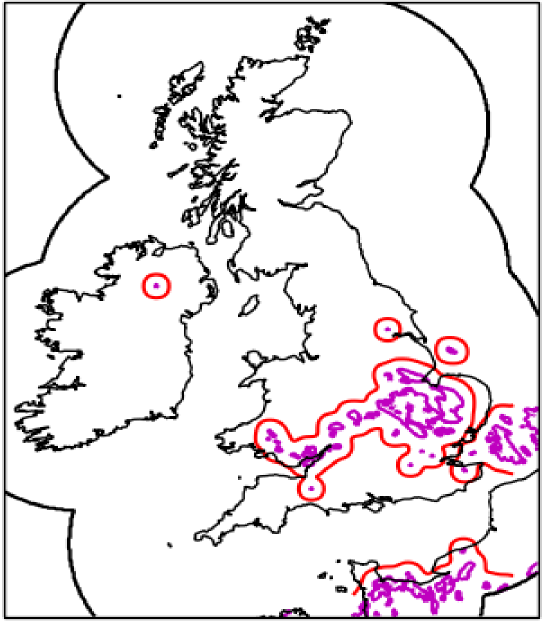
UKV   radar

The ensemble helps to capture the areas with severe convection developing over the Midlands.

20200816 at 17 UTC from 20200816 at 00 UTC
Prob 3-hourly Rain Accum 12.0mm



20200816 at 17 UTC
Radar Prob 3-hourly Rain Accum 12.0mm



Aurore Porson

Urban Hazards

Pollution in London from Primrose Hill

Motivation for urban NWP

- Large proportion of the population live in cities

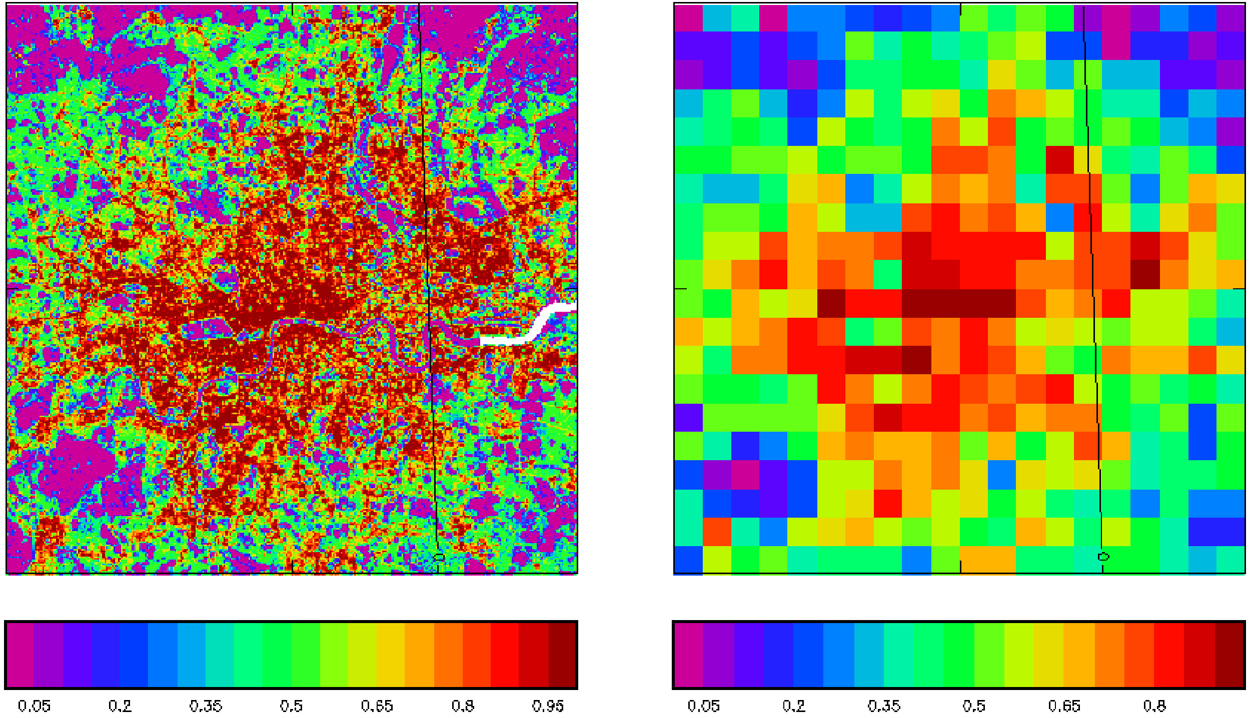
- There are a number of meteorological hazards that we would like to forecast on weather and climate timescales.

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

- Good representation of urban meteorology is fundamental

Motivation for 100m city models

- Current km scale models only just resolve larger cities and will represent very little detail within them

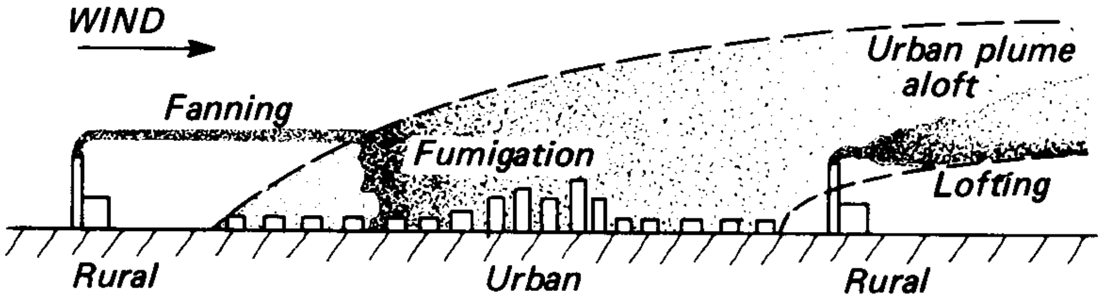


Comparison of London urban land use fraction for 100m (left) and 1.5km models. Smaller cities will be V poorly resolved at 1.5km.

Motivation

Need to capture neighbourhood scale effects

From Oke 1987

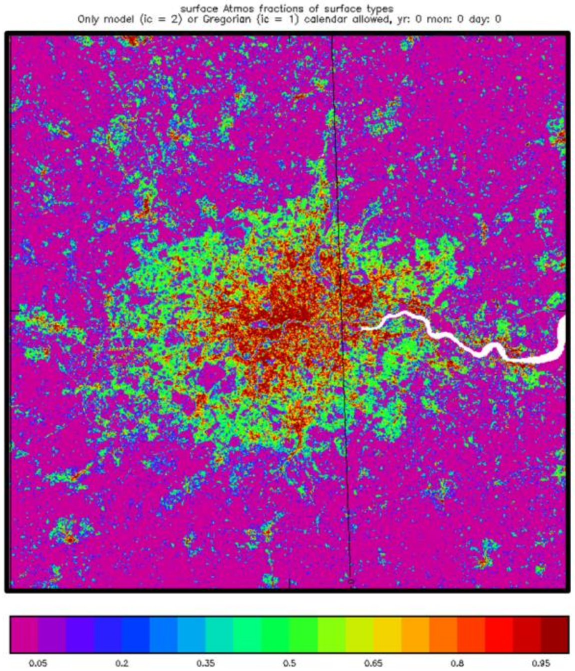


- Example: Good representation of boundary layer structure critical for air quality, urban temperature etc.

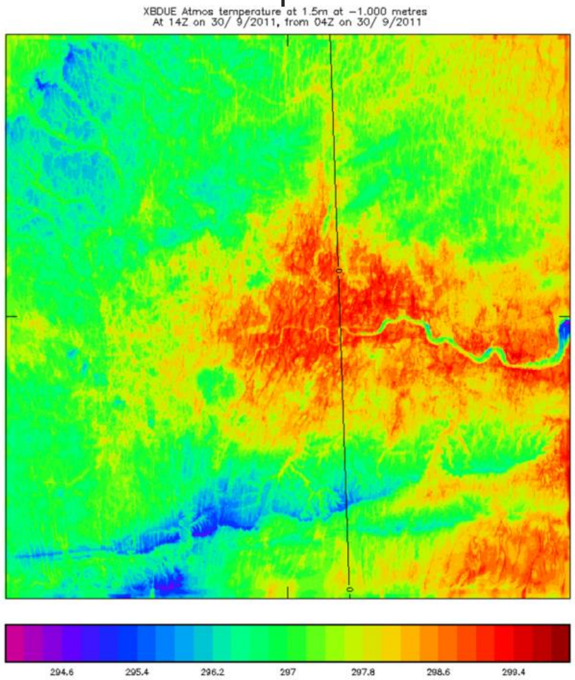
100m Model

14 UTC

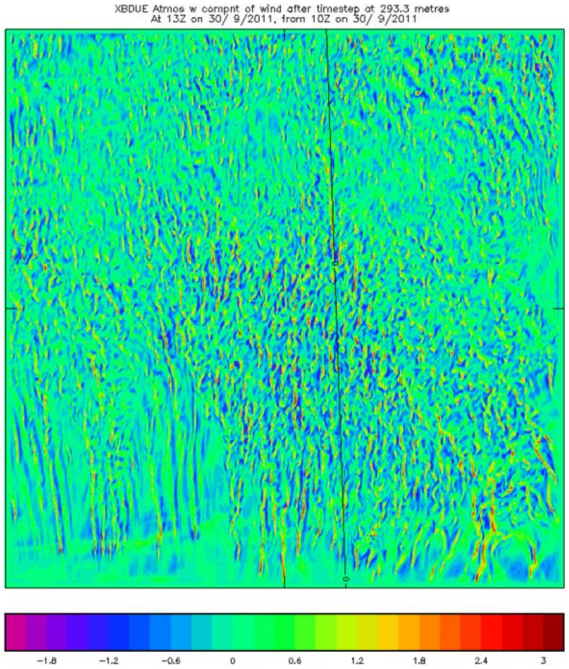
Urban Fraction



1.5m temperature



w at 293m

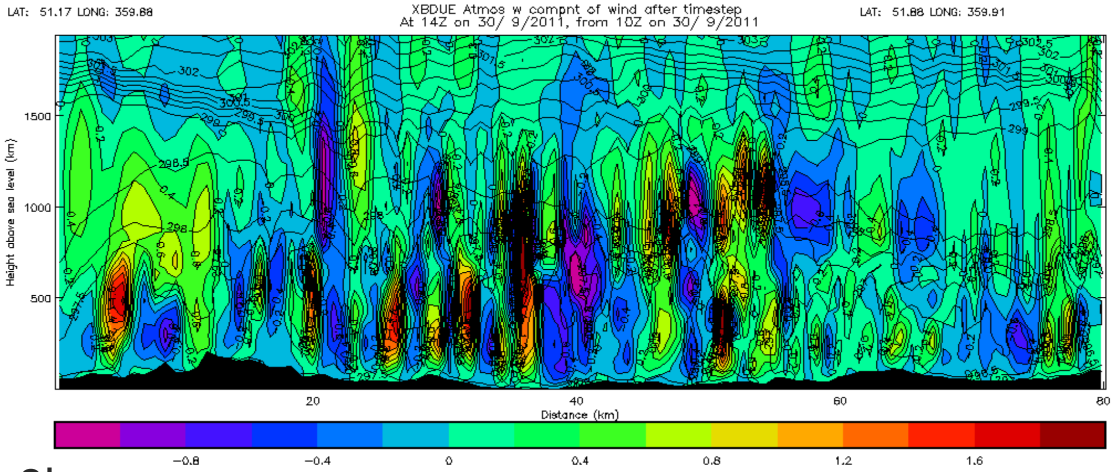


- Initial look shows that model 1.5m temperature follows surface characteristics. Could be useful (Rhonda et al 2017 carried out a 100m analysis of Amsterdam).
- Convective overturning which can be seen to be more pronounced over the city.

Met Office

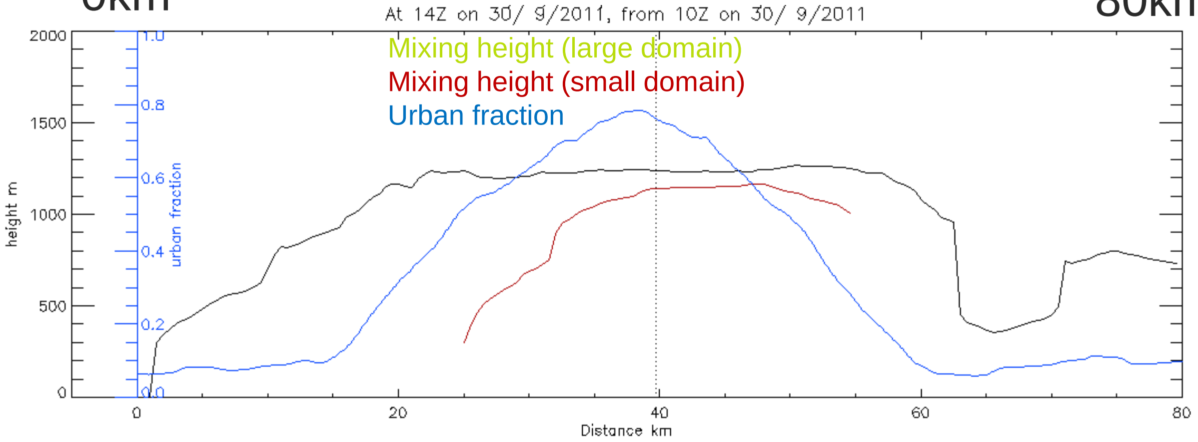
South-North transect through BT tower location

- Spatial variation across urban area looks sensible. Max mixing height appears to be capped by larger scale more stable region.
- Spin up region clearly visible in smaller domain (~10km).



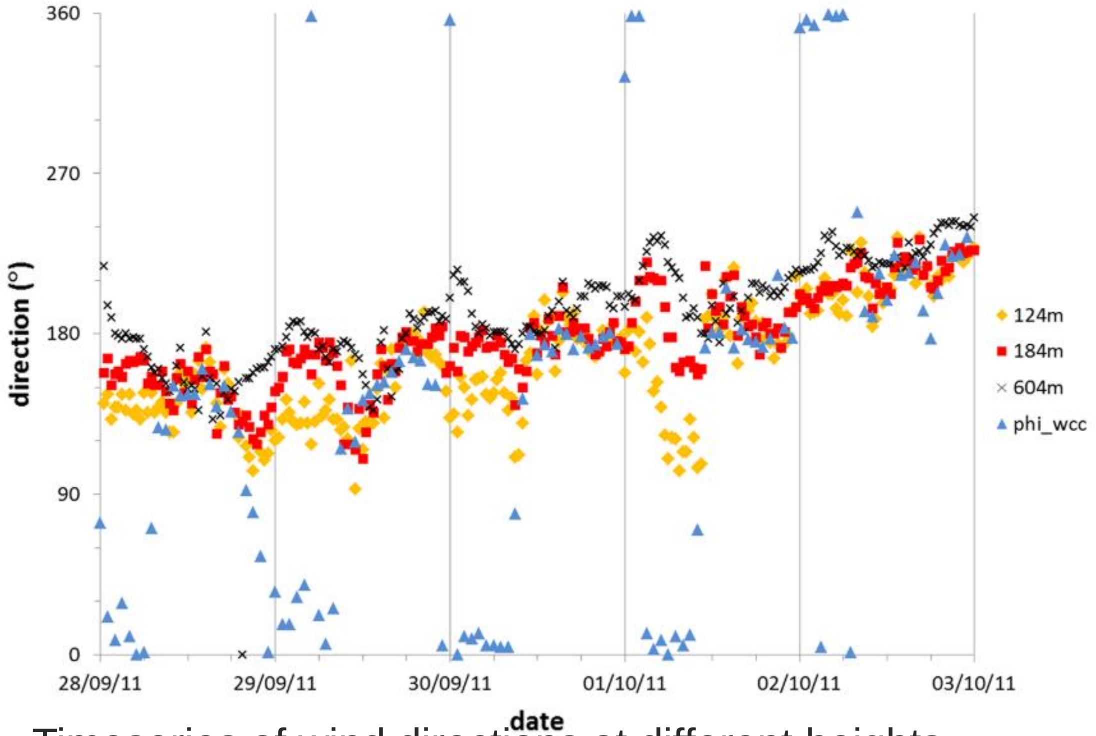
0km

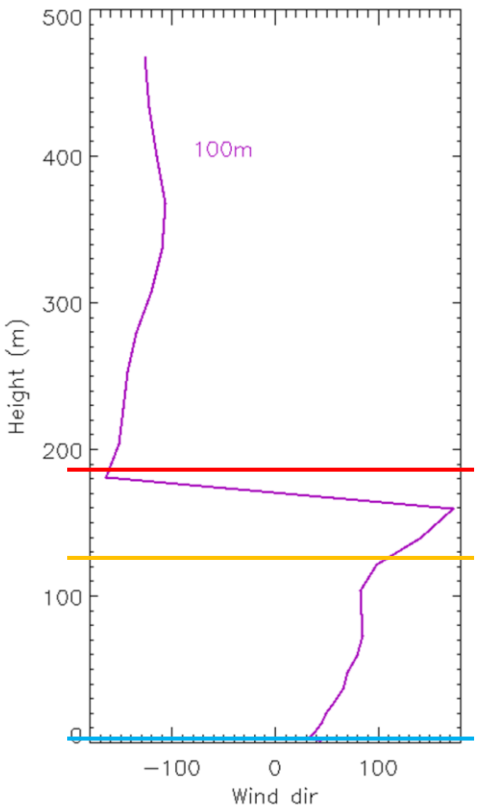
80km



Drainage flows.

100m model
05UTC 01/10/11

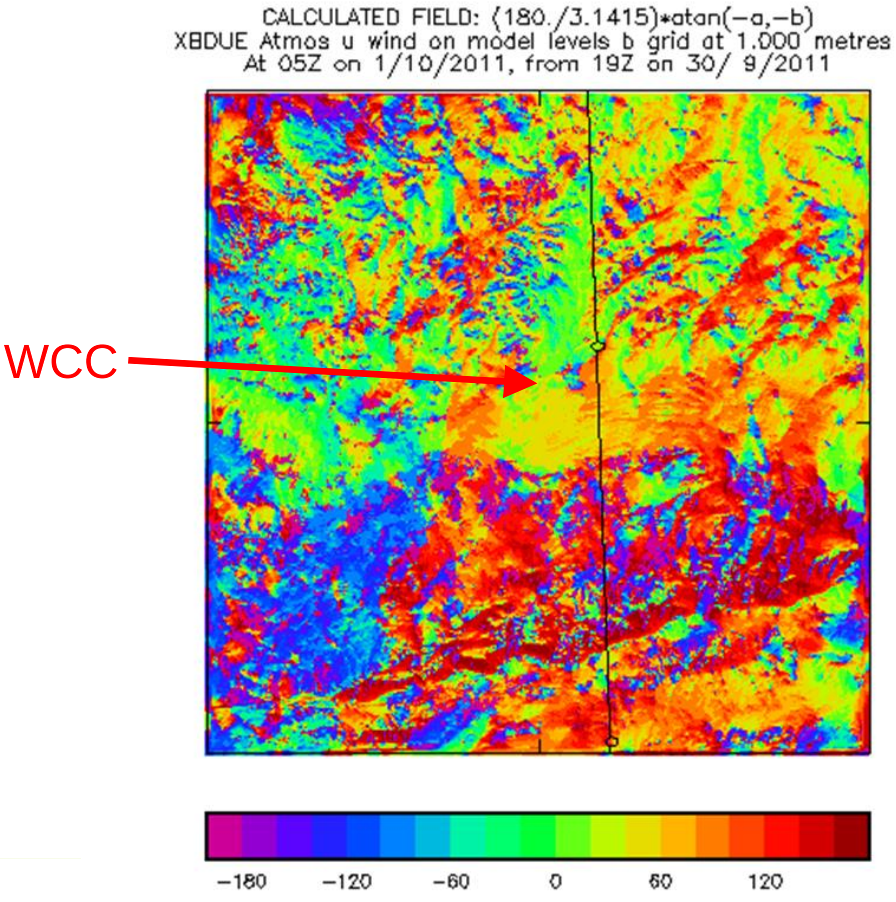


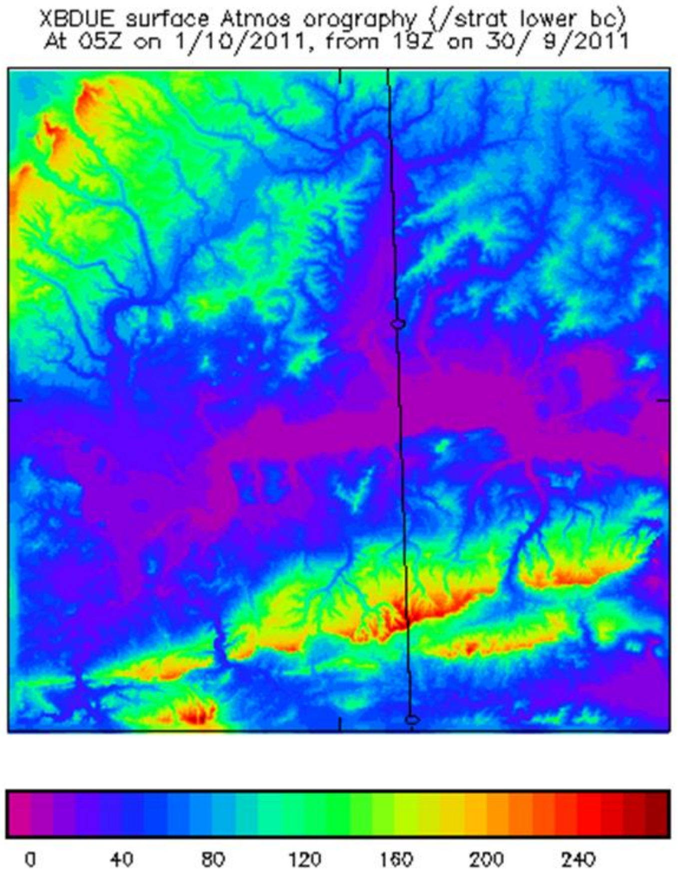


Timeseries of wind directions at different heights shows reversal at low levels at night.
From Barlow et al 2015.

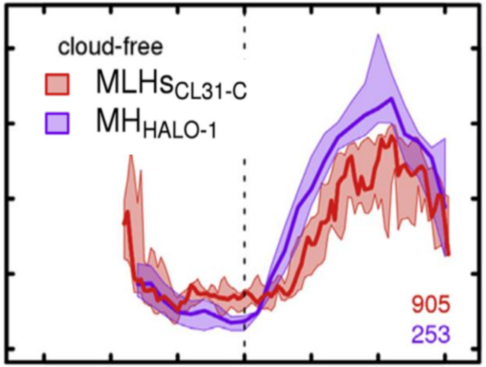
100m model captures this well.

Drainage flows.

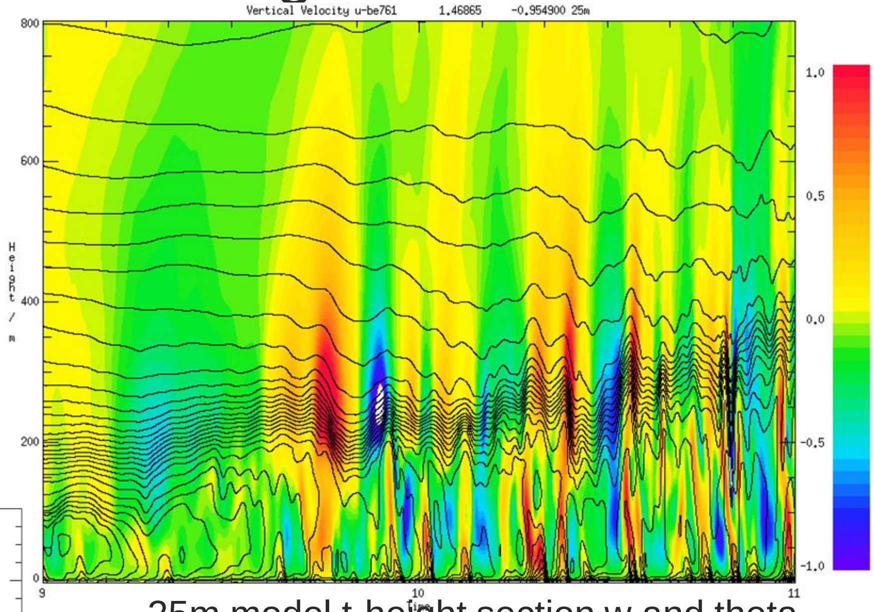




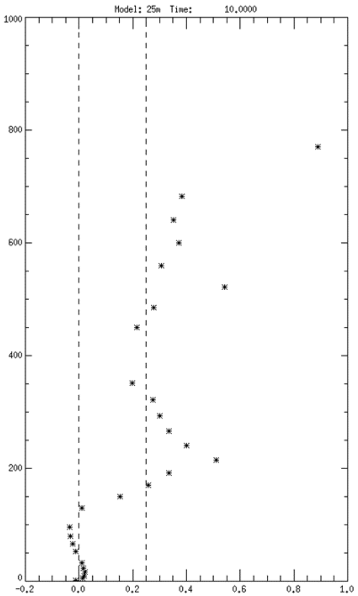
Understanding role of waves above BL



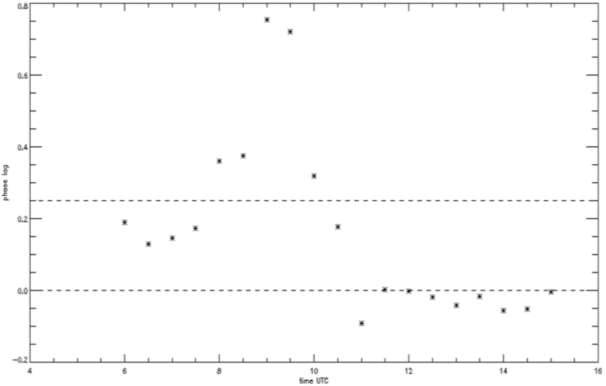
Kotthaus et al (2018).



25m model t-height section w and theta.



Phase v ht in 25m model



Phase v time in BT tower obs.

- Not all vertical motions transport pollutants. Need to be aware of waves above BL

Lean, Barlow, Clark in preparation.

Issues to consider

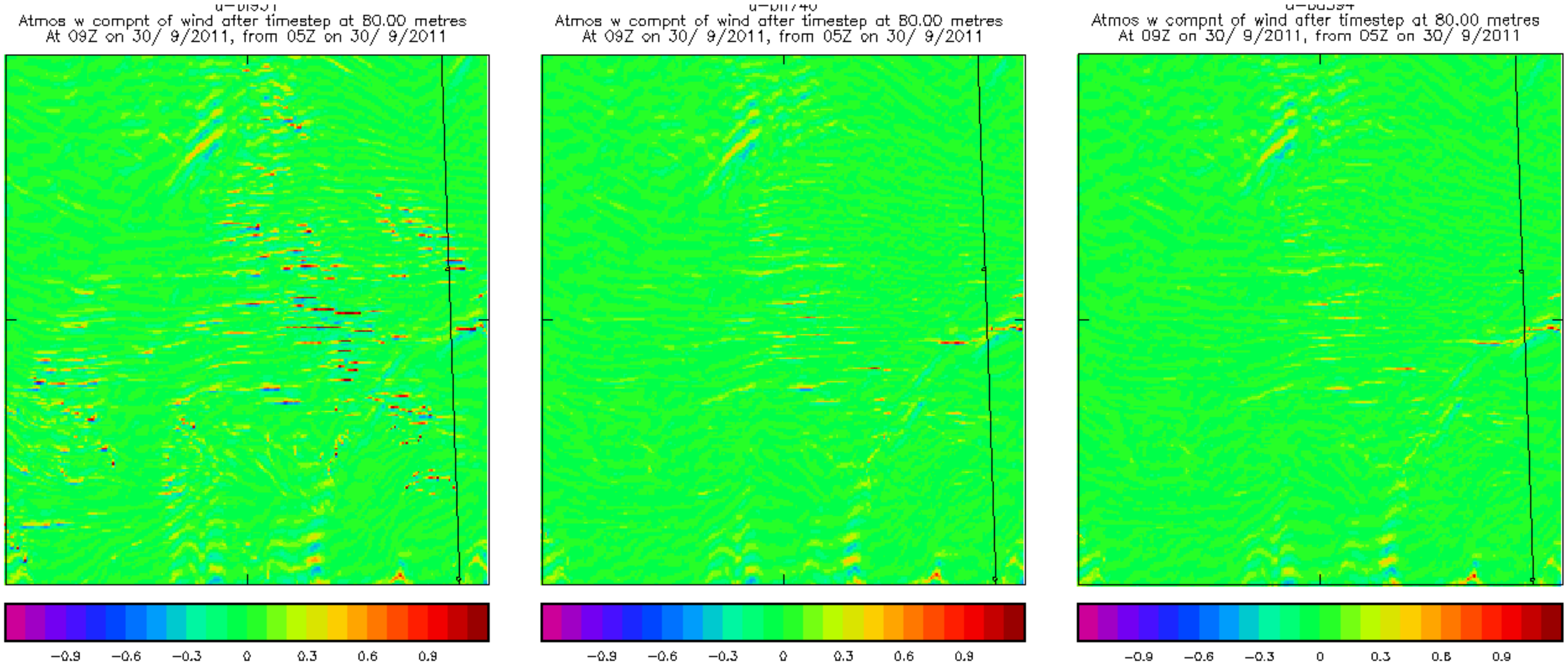
- Affordability
- Spin up issues
- Predictability
- Model issues (turbulence grey zone etc).
- Urban surface representation

Issues with 100m scale models

- Grey zones – in particular turbulence grey zone. Need scale aware parameterisations. Also need TKE scheme for horizontal variability.

Smag blending std modified blending

100m model
w at 80m
09 UTC
30/9/11



Issues with 100m scale models

- Urban Surface
  - 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.

- Urban surface strategy
  - Surface energy balance scheme
  - Anthropogenic fluxes
  - Vertically distributed canopy.


MEETING SUMMARIES

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

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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

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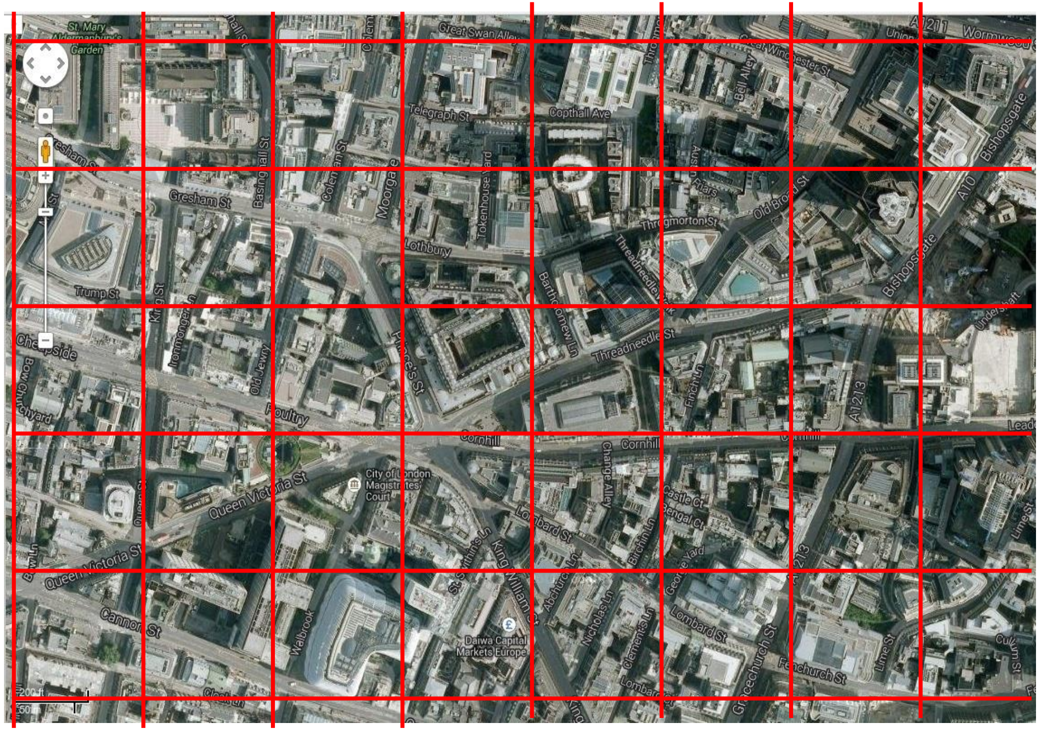
Specific issue for O(100m) models:



100m grid superimposed on city of London

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

100m scale modelling: 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.

Areas of work:

1. Intercomparison of 100m scale NWP models (already started).
2. Nowcasting
3. Air Quality
4. Observations (intensive campaign in 2022).

Aim to run real time systems for Paris 2024 but also to carry out research between now and then.

PARIS 2024

Organiser: Valéry Masson (Meteo France)

9 national meteorological institutes participating

WMO CNRM METEO FRANCE

Met Office

Thank you for listening

Questions