Boundary Layer and Convection issues with the 100m scale UM.

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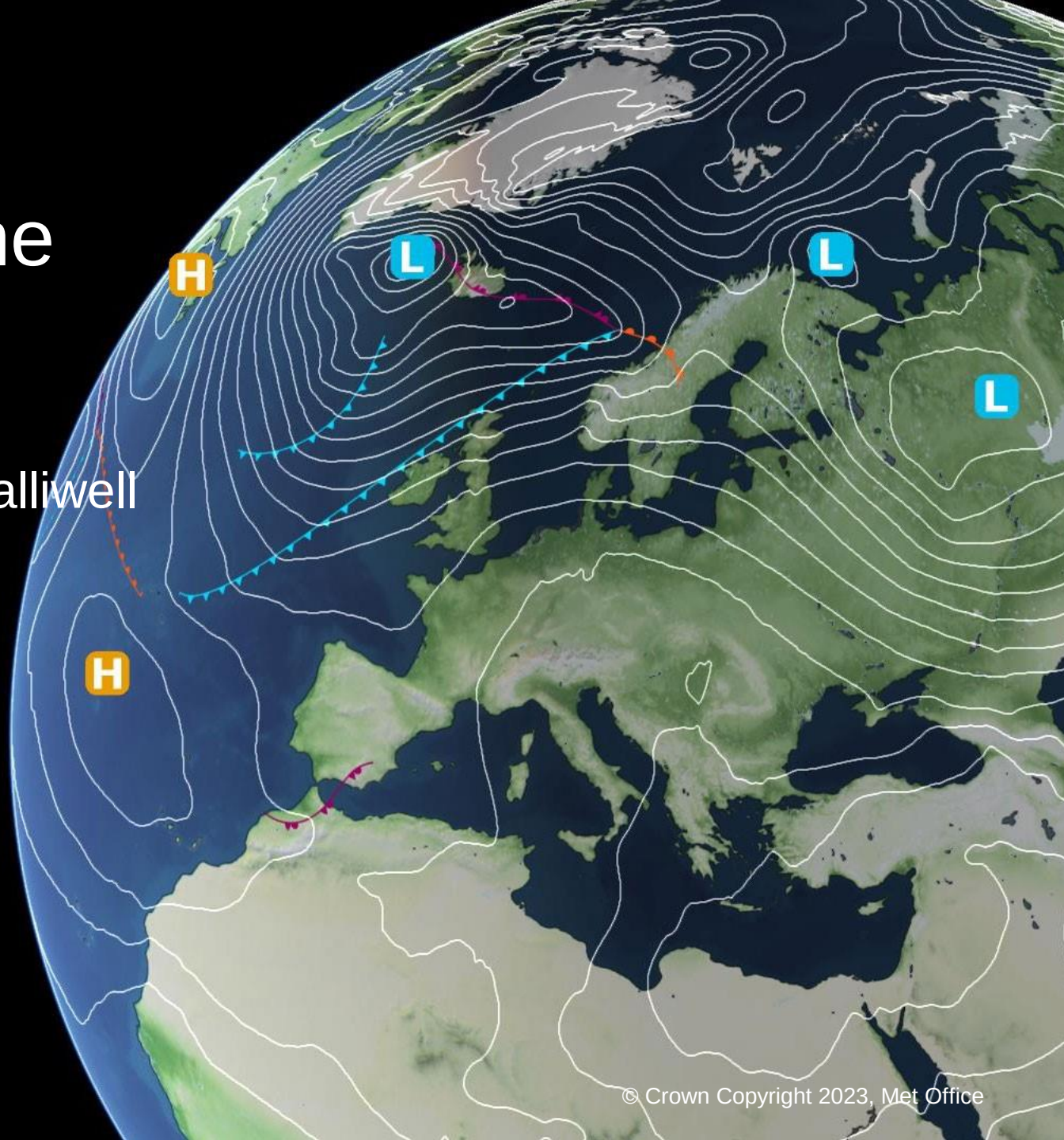


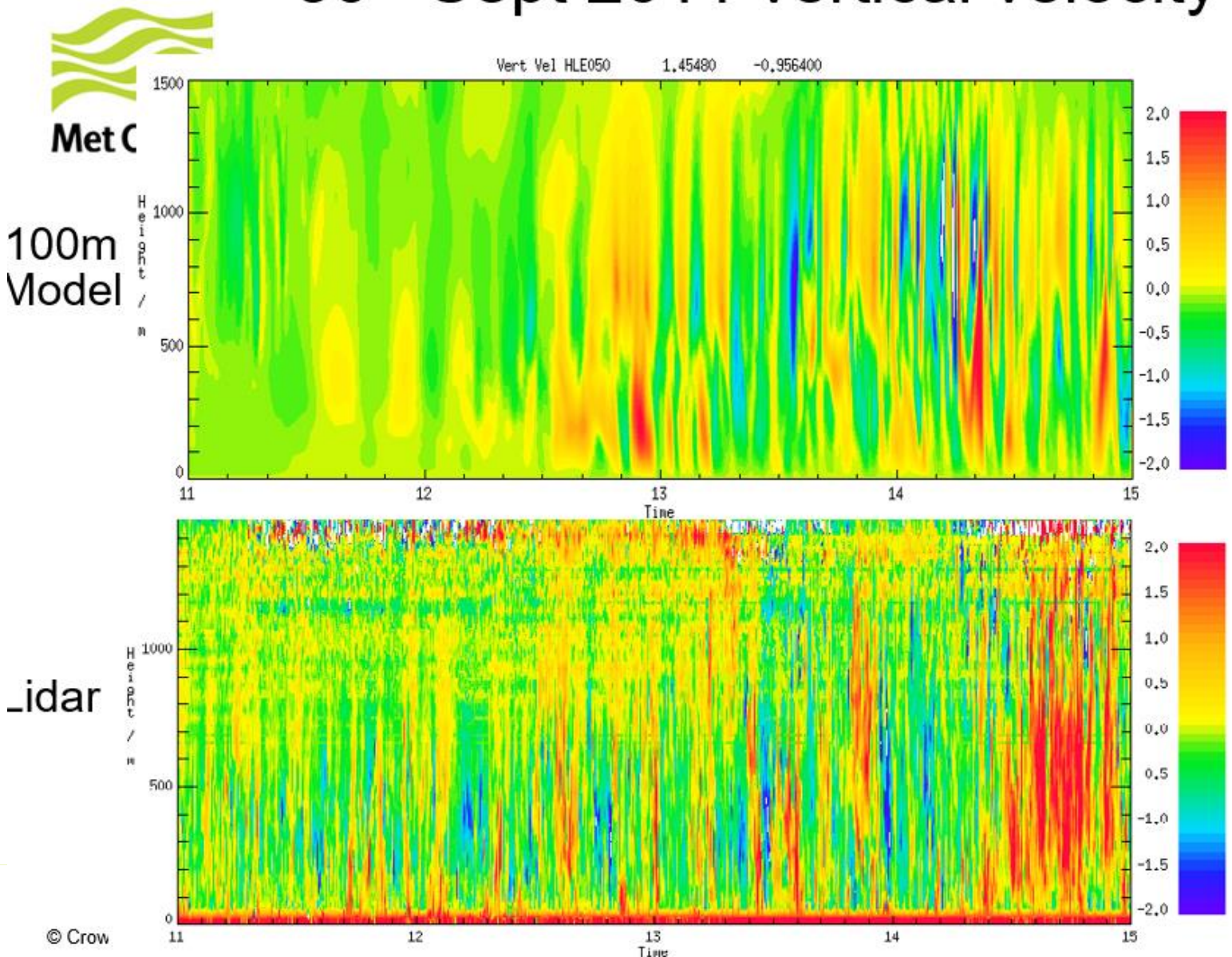
Hectometric Workshop, DWD, Feb 2024

Introduction

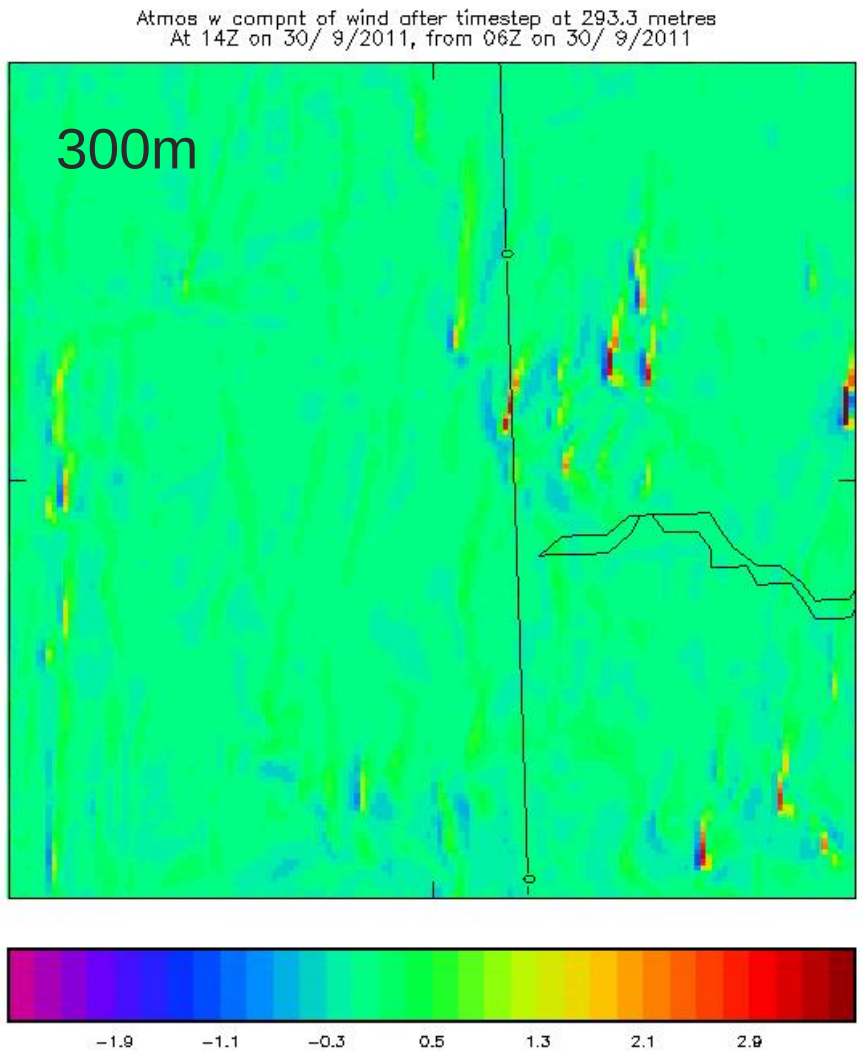
- In our work on 100m scale versions of the UM we have noticed a number of model problems/questions that often come up.
- This talk aims to document these, in most cases without comprehensive solutions.
- Would be good to know if other centres see similar issues and discuss possible answers….

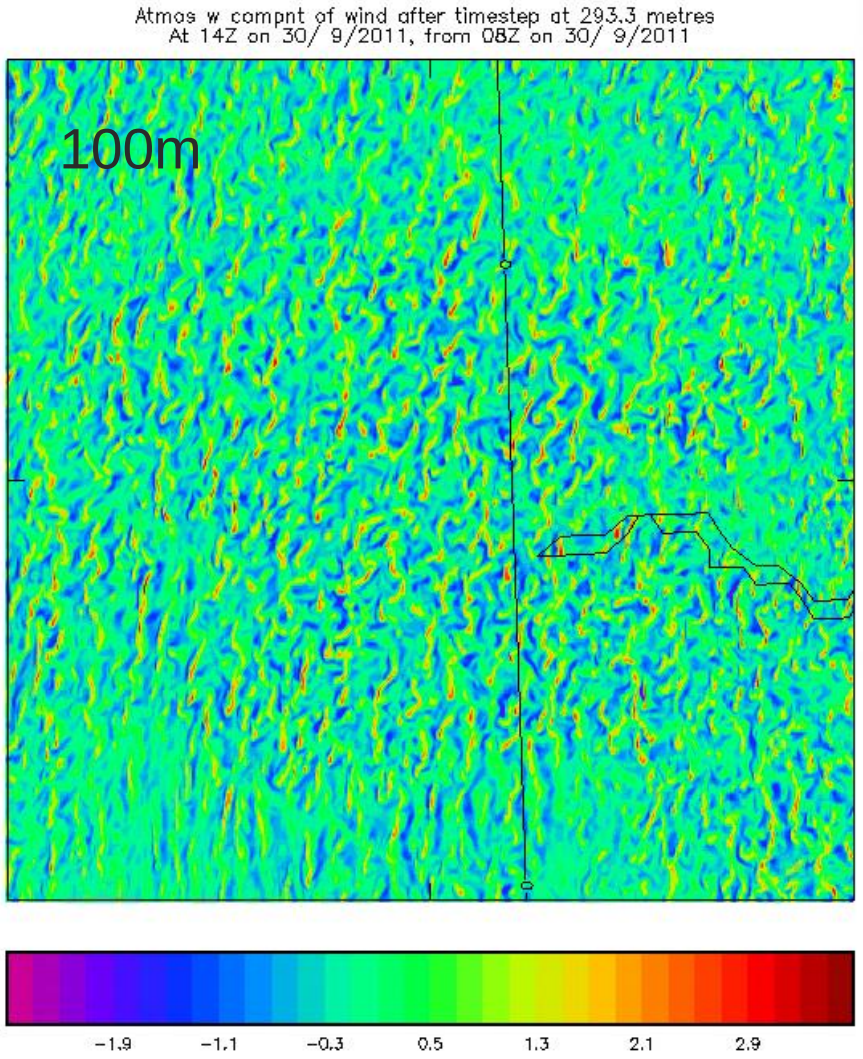
Convective Boundary Layer

30th Sept 2011 vertical velocity



300m-100m CBL Comparison



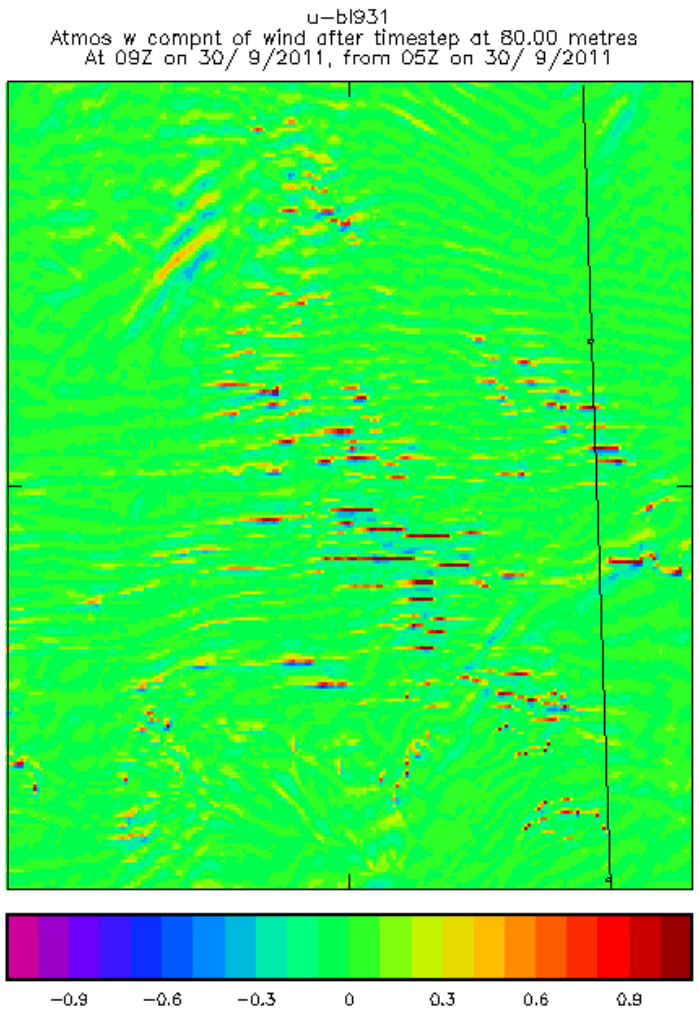


Overturning becomes on gridscale in 300m model

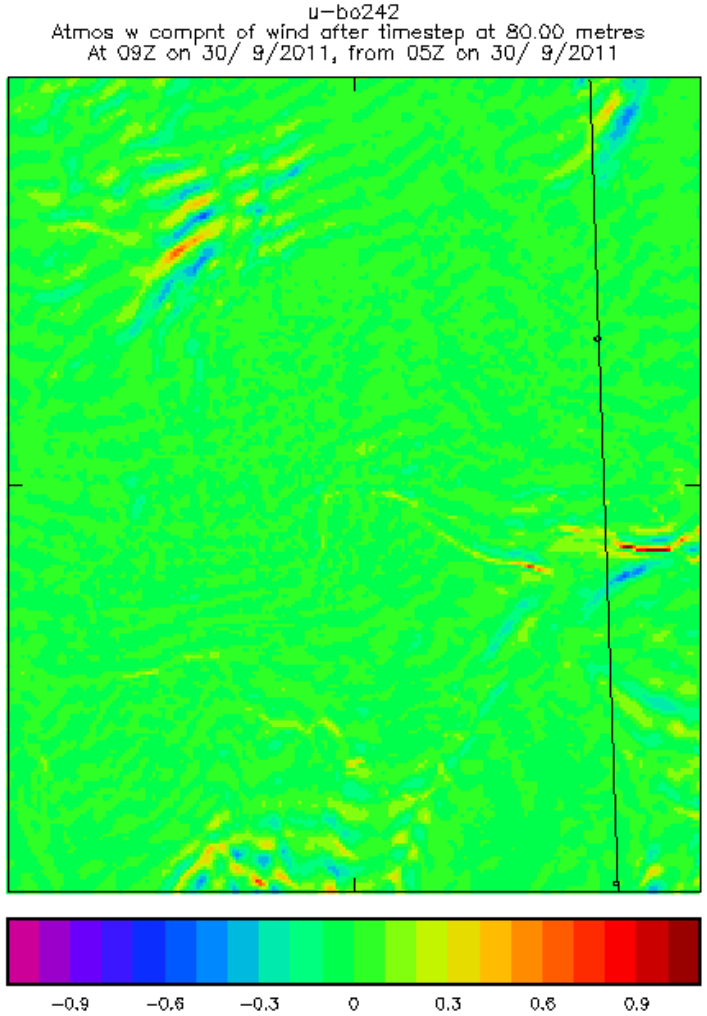
With typical CBL depths in UK

Need to correctly handle CBL grey zone

- Can’t escape turbulence grey zone even at 100m if BL is shallow enough!!!!
- Figures show vertical velocity field in 100m model in morning when BL depth is about 400m.
- 3d TE Scheme looks promising in that model not trying to do overturning explicitly when under-resolved.



Smagorinsky

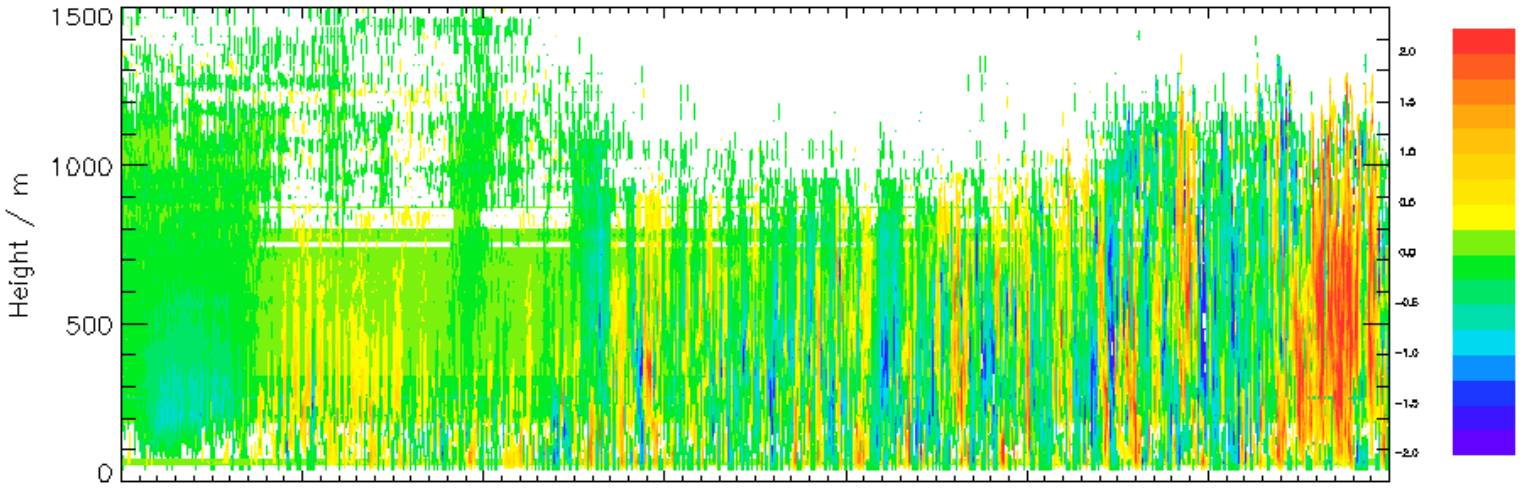


3d te (Mark 1)

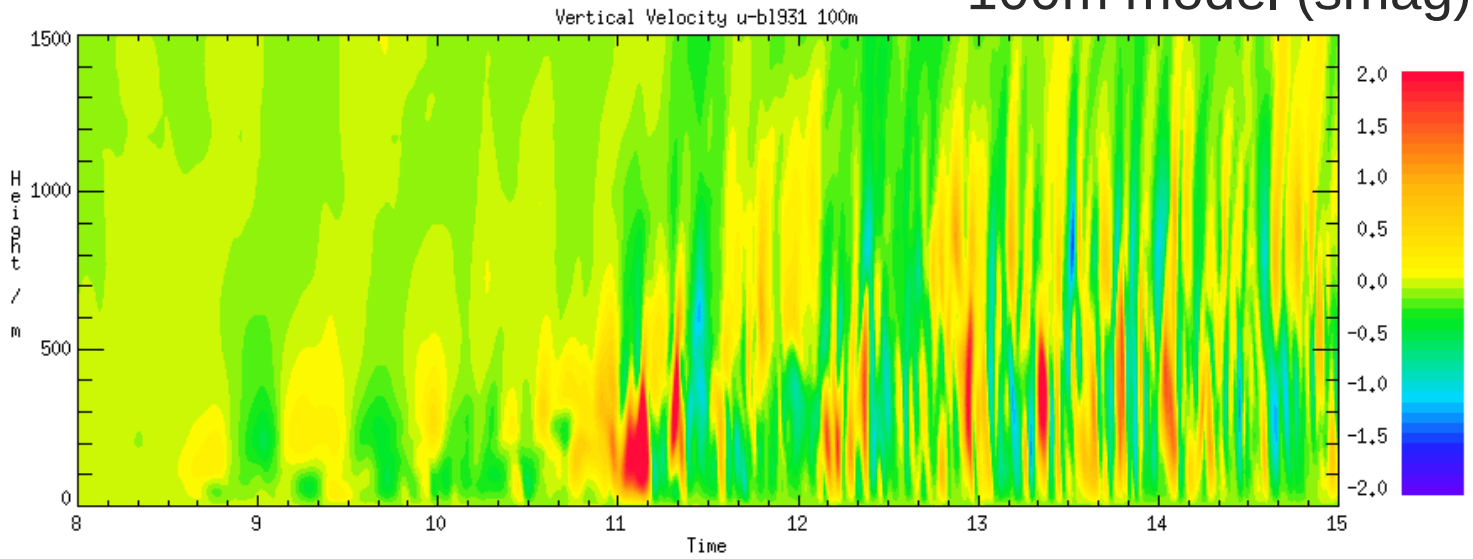
Morning growth of mixed layer

- Morning growth of mixed layer is important for applications (.e.g pollution).
- Evident by eye that not enough w at early times.

lidar



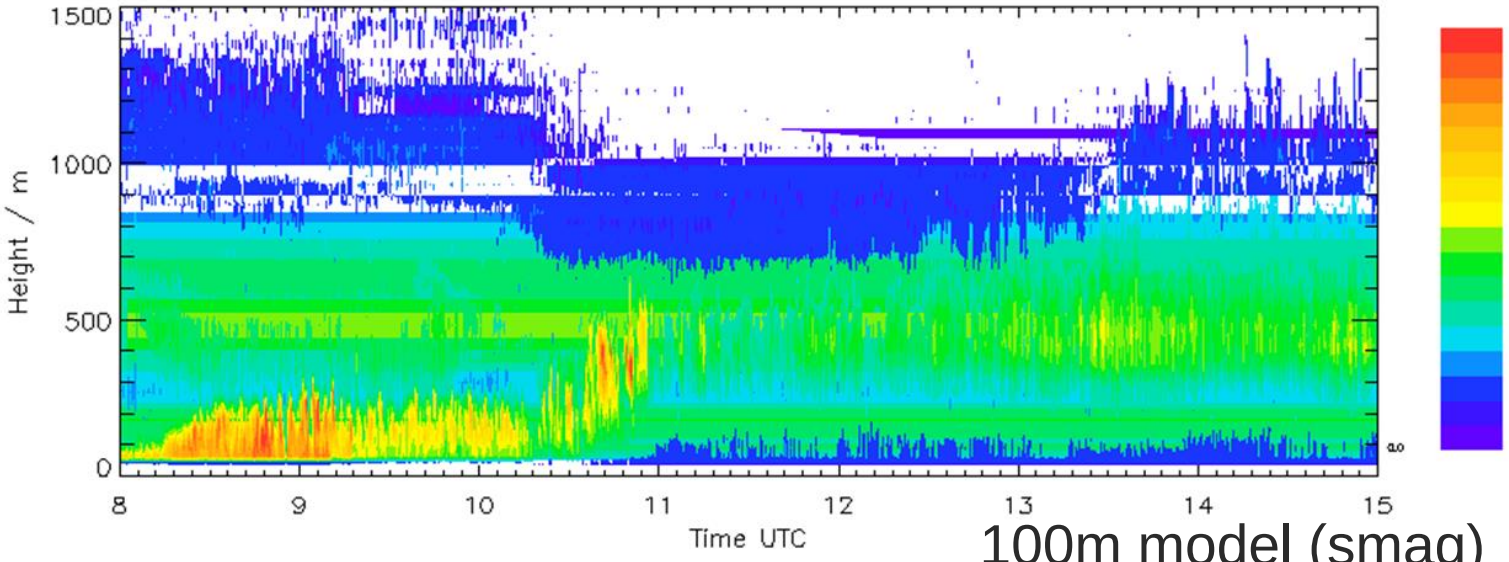
100m model (smag)



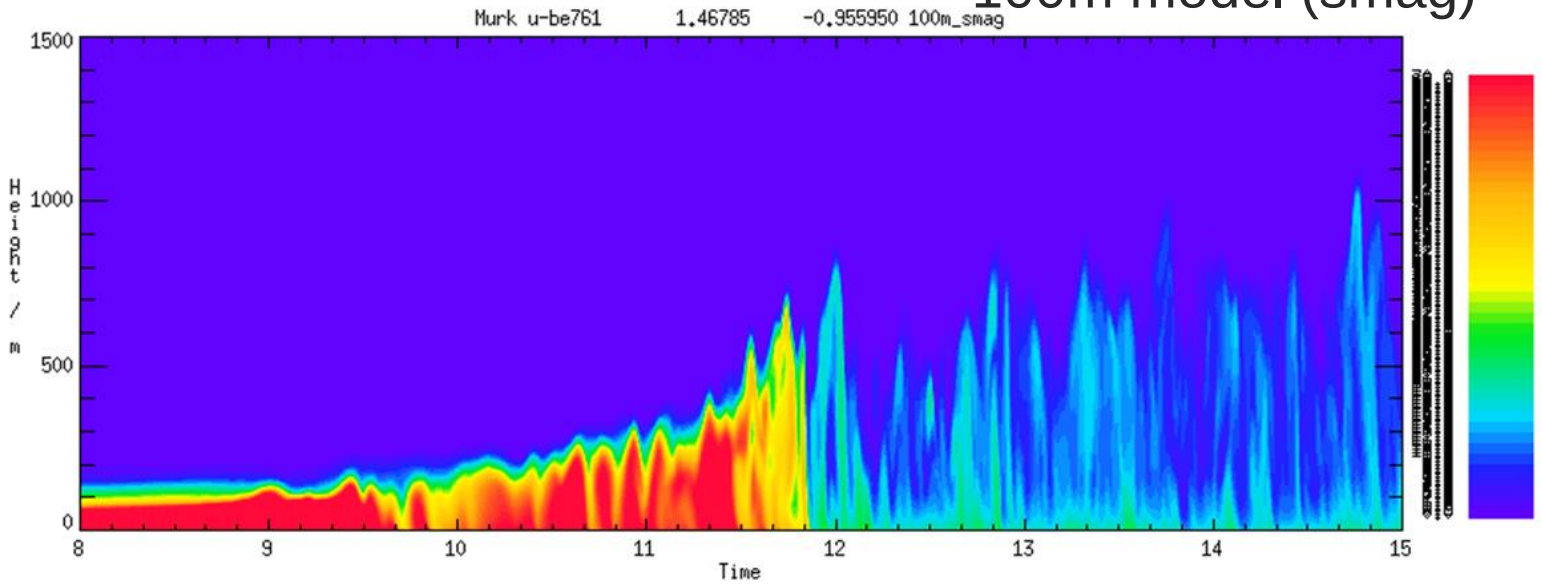
Lean, Clark and Barlow (2022). https://doi.org/10.1002/qj.4291.

Murk (model) and lidar backscatter

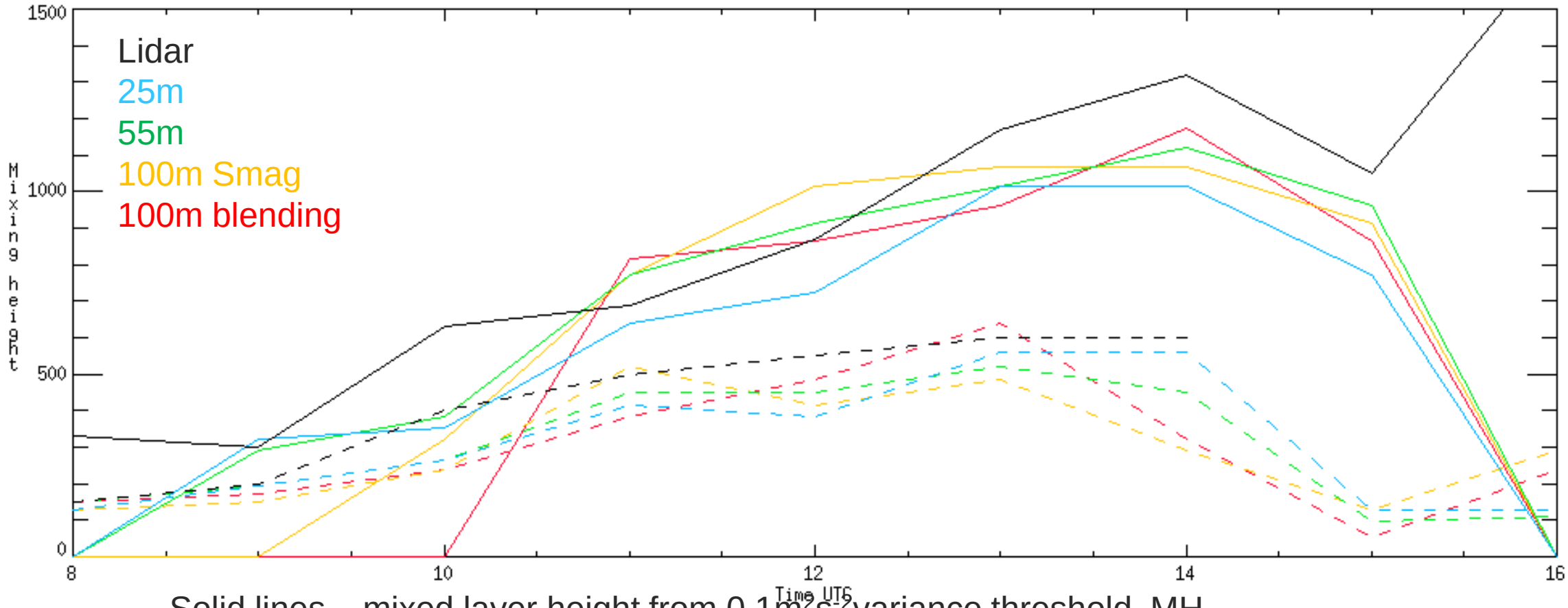
lidar



100m model (smag)



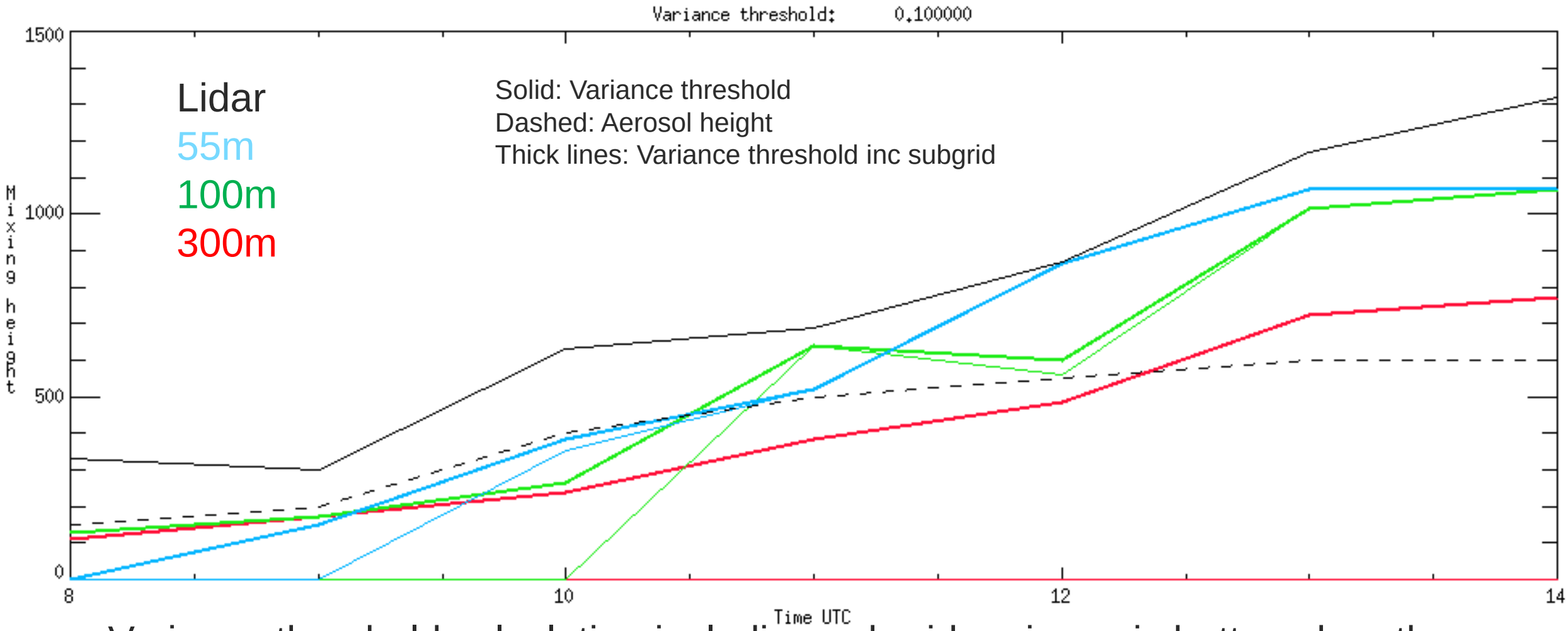
Morning growth of mixed layer



Solid lines – mixed layer height from 0.1m^{2}s^{-2}variance threshold, MH
Dashed – height murk aerosol gets to. MLH

Measures are different because turbulence measure includes wave motion (Lean et al, https://doi.org/10.1002/qj.4291).

Include sub-grid w variance in height calculation

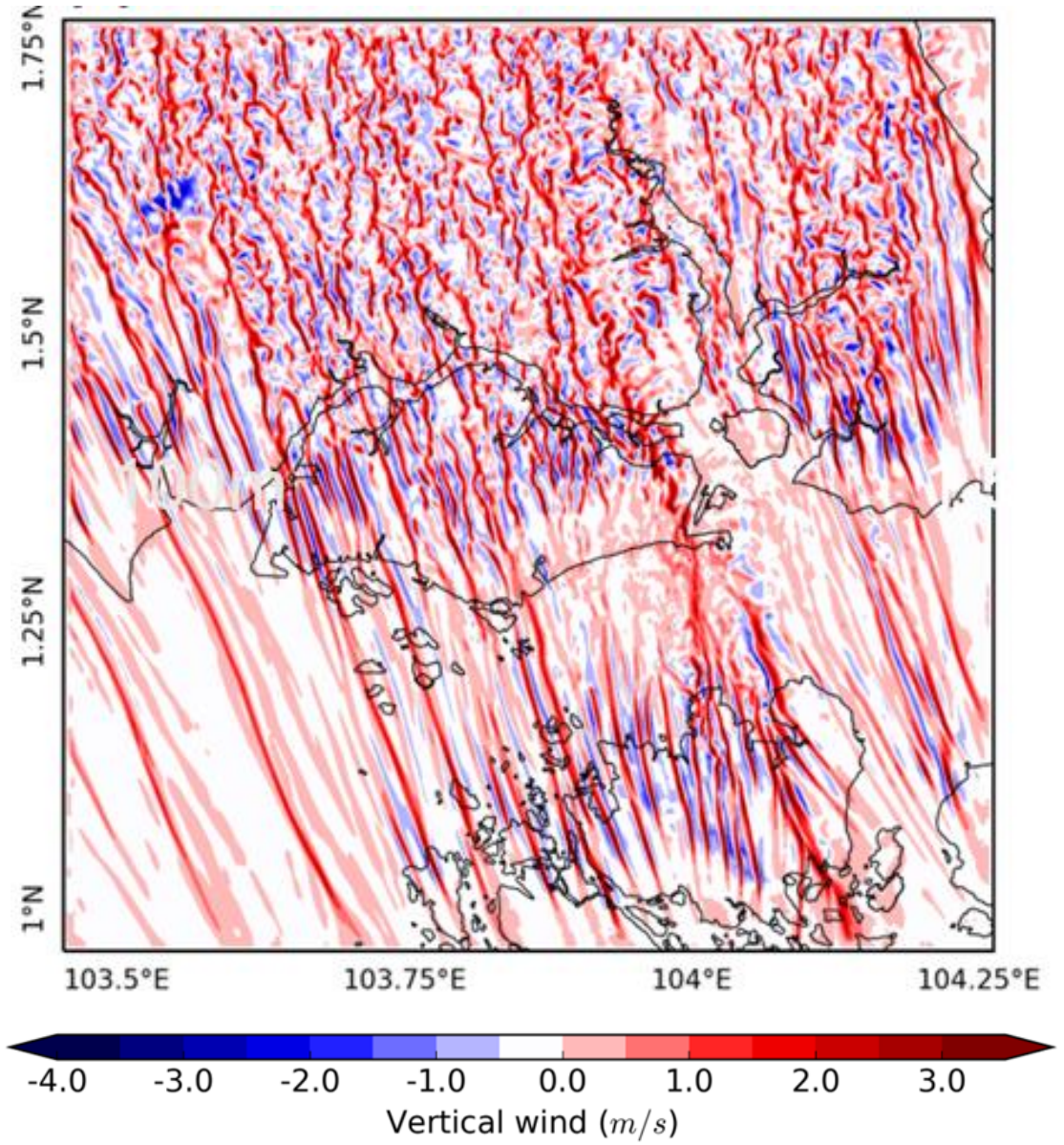


- Variance threshold calculation including subgrid variance is better when there is no or under-resolved explicit w (i.e. in 300m or early in other models).
- *Doesn't include wave region.*

Morning growth of CBL

- Can’t escape turbulence grey zone!
- Need parameterisation to hand over nicely to explicit overturning. Current blended BL scheme may be too weighted towards explicit (usual quandry!)
- Evidence that growth of CBL reasonably handled in a parameterised sense. 300m looks OK. However lack of explicit overturning means you lose some potentially physically important things (such as difference between BL depth measures).

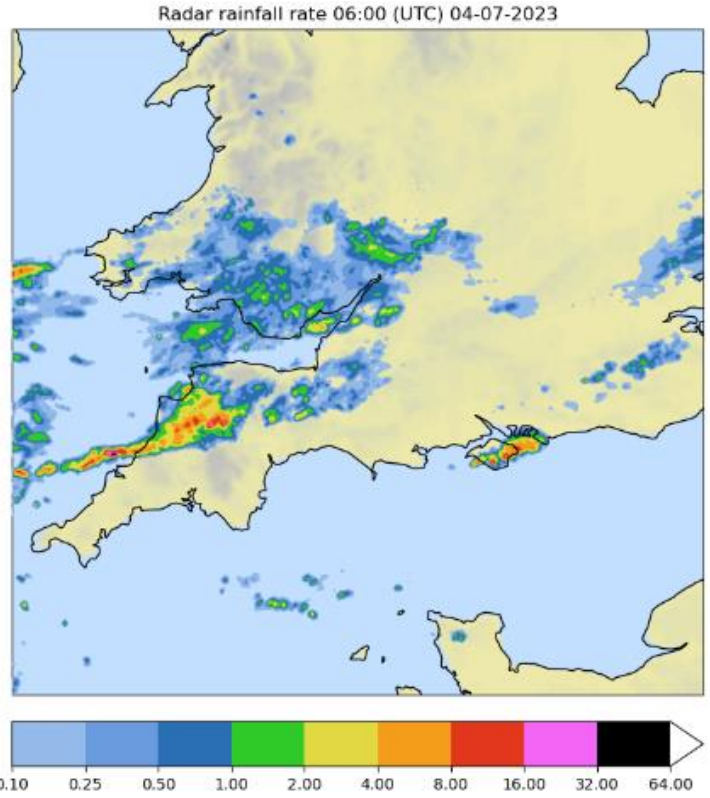
Streakiness in Boundary Layer

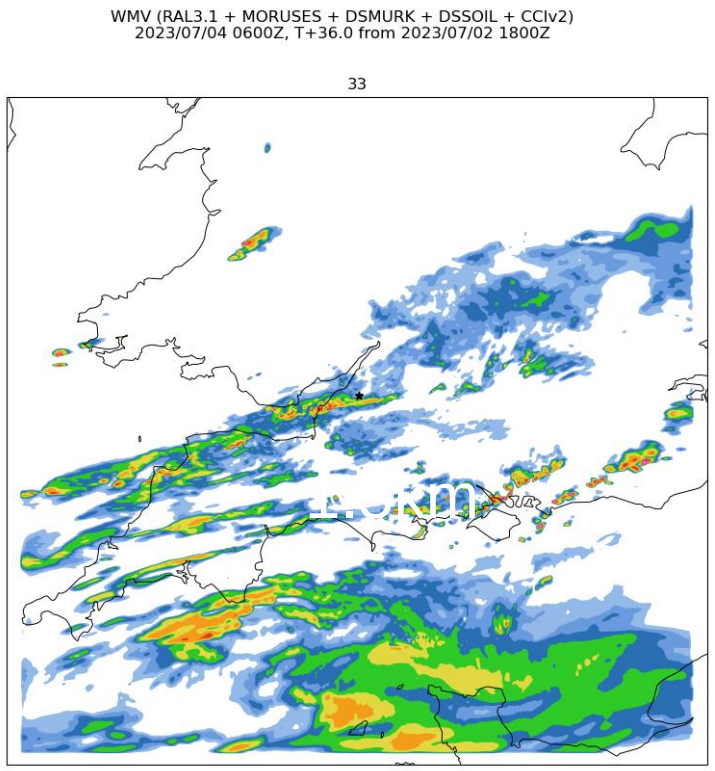


Song Chen, CCRS, Singapore

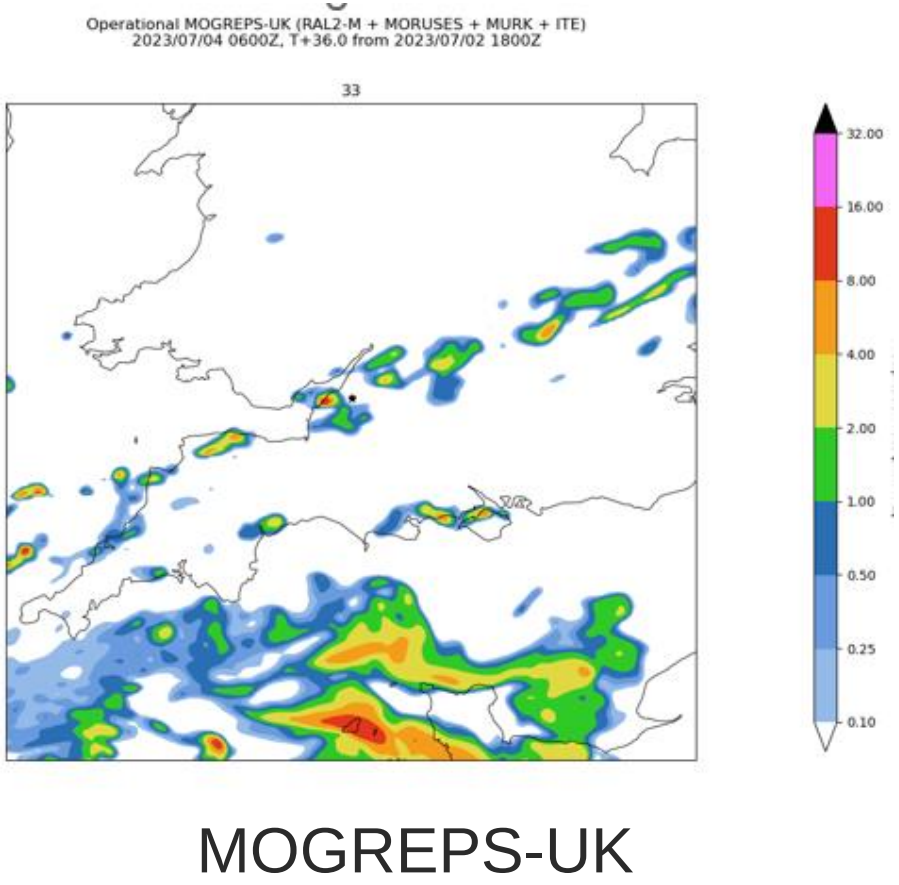
- 100m models often very streaky in BL.
- Streaky BL associated with a boundary either physical (e.g. coastline) or unphysical (boundary of model).
- Tends to form rolls due to shallow (growing) BL more likely to be shear dominated.
- Could be linked to along wind structures in deep convection.

Similar streakiness seen in convection in 100m and even km scale models





WMV

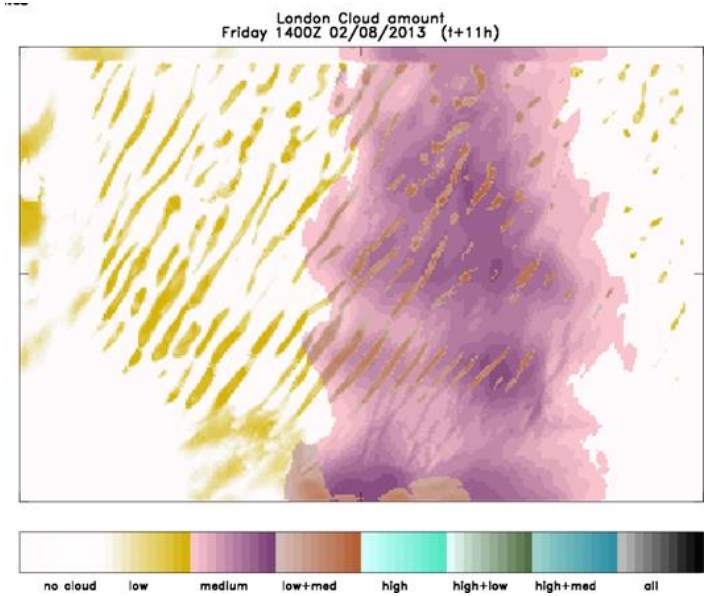


MOGREPS-UK

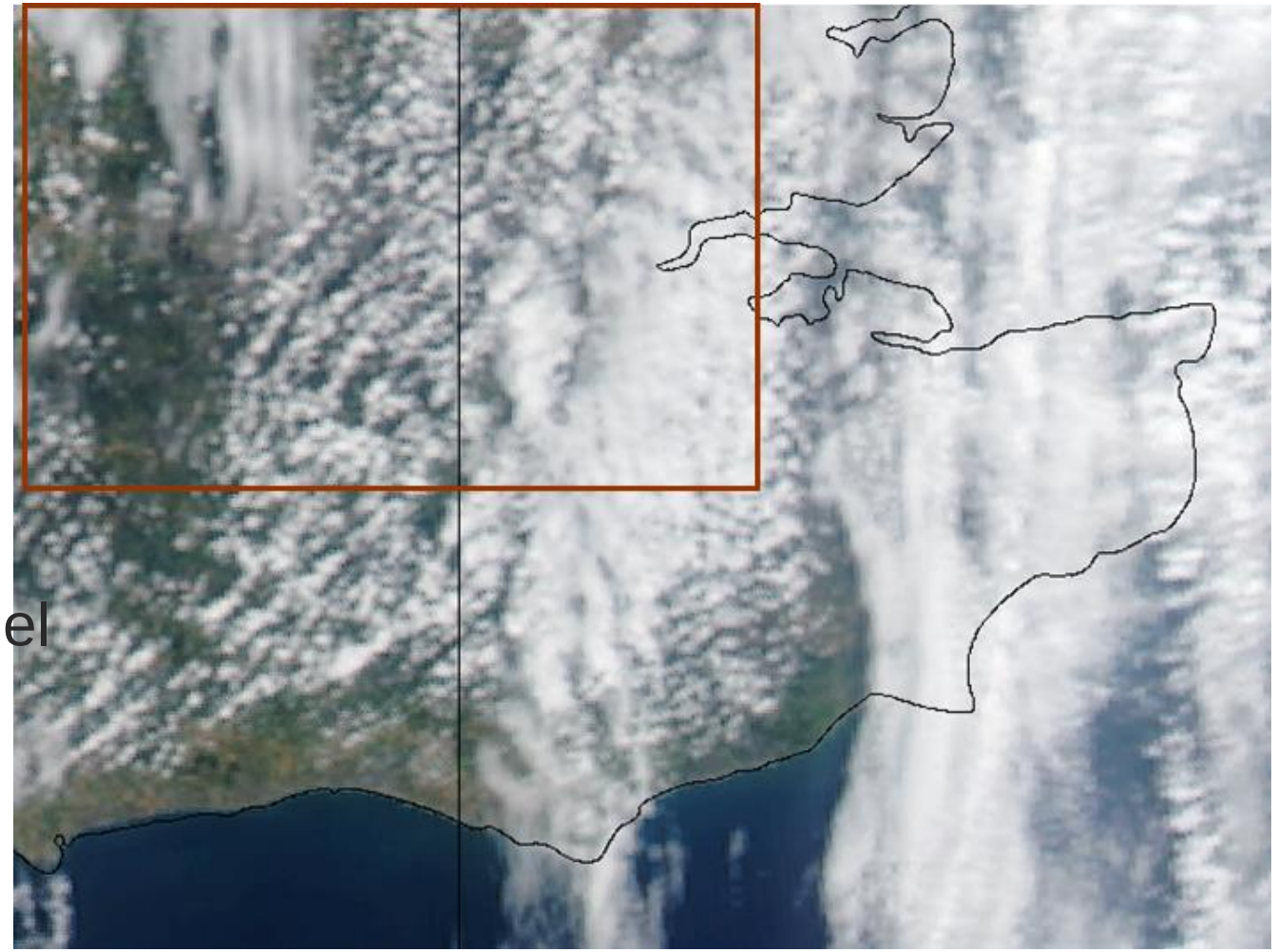
Cells tend to be too fragmented – circular in km scale models but are too elongated in 100m scale ones.

Kirsty Hanley, Heather Guy did a subjective analysis.

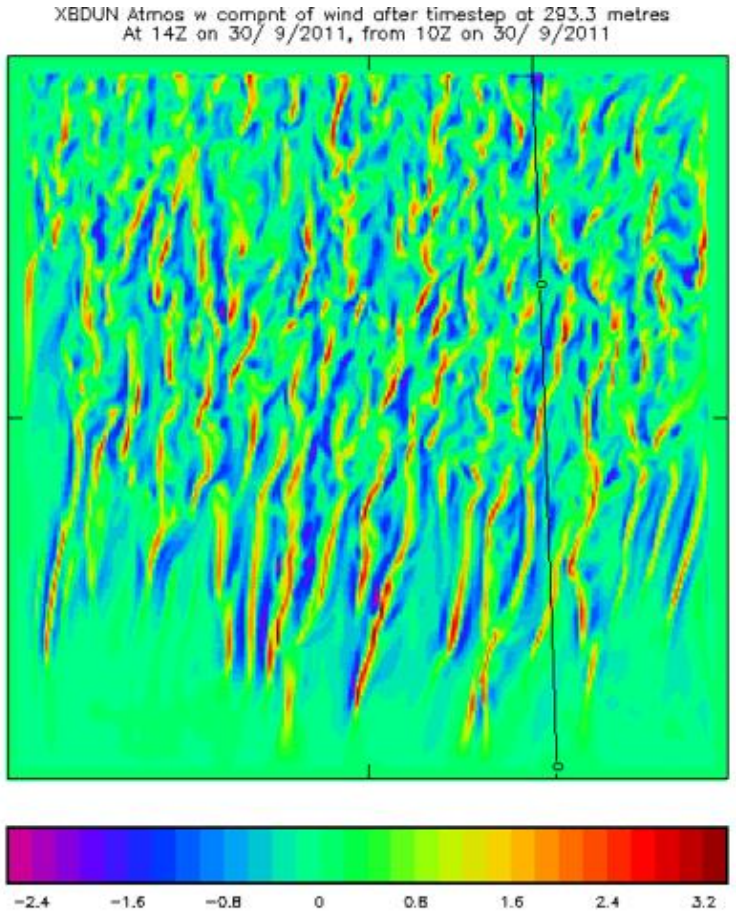
Boundary Layer rolls are a real phenomenon



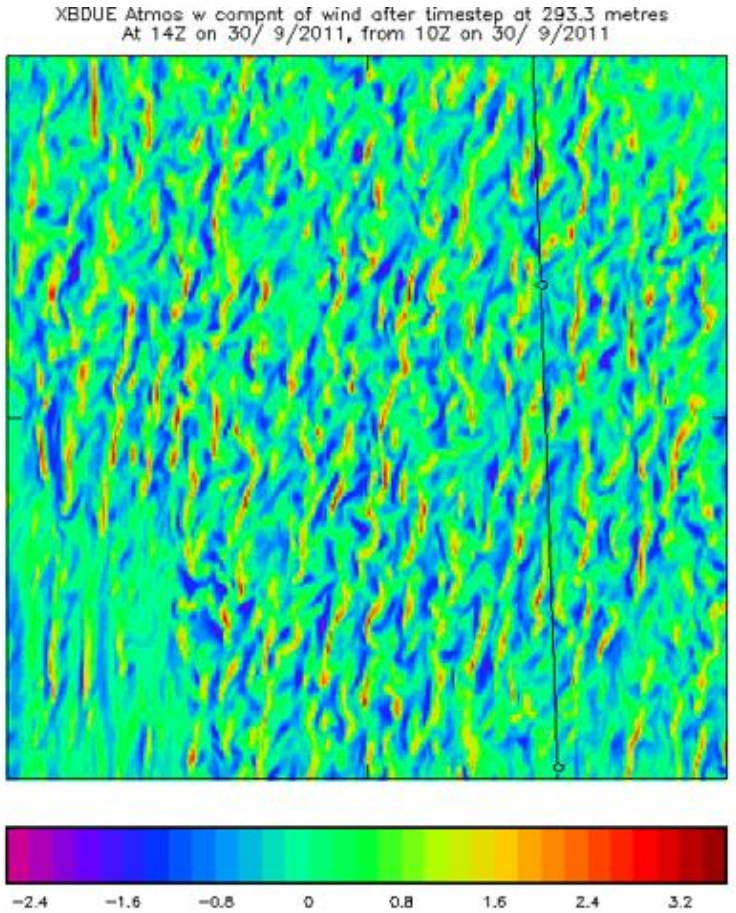
Cloud in 300m London Model



100m model over London



Small domain



Subset of std domain

- If there is significant wind see rolls near inflow boundary breaking up into along wind elongated segments downstream.
- Would like to know how realistic this is – clearly spin up at boundary not realistic but can see similar at coastlines/other boundaries which might be more so?
- Are line segments along wind once spun up realistic?

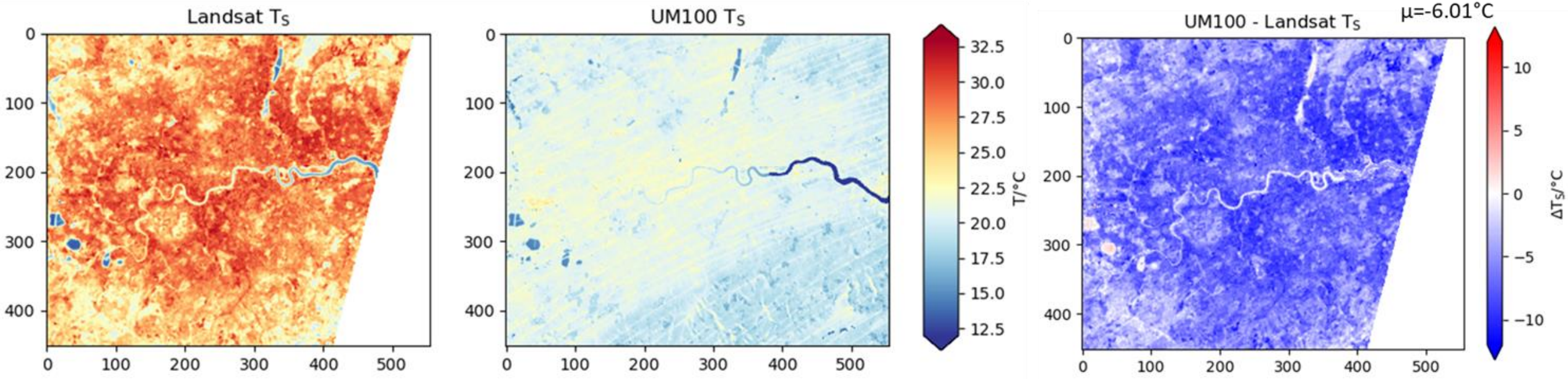
Met Office

Mitigations to spurious generation of rolls by boundaries:

- Large domains (expensive!)
- Variable resolution (cheaper version of above)
- More frequent boundary updating.
- Adding noise to boundaries.

Rolls may have unrealistic effects in model.

- Rolls in model affect near surface temperature which are not seen in observations:



Images from UM100 project. Hall et. al. QJRMS

- Assumption is that shouldn't see rolls perturbing surface temp (eddies get smaller as surface is approached).
- May be important distinction between surface and 1.5m temperature.

- Spectral analysis at different levels shows that scales in 100m (and even 50m models) are too long close to the surface.

From Lean et al 2019

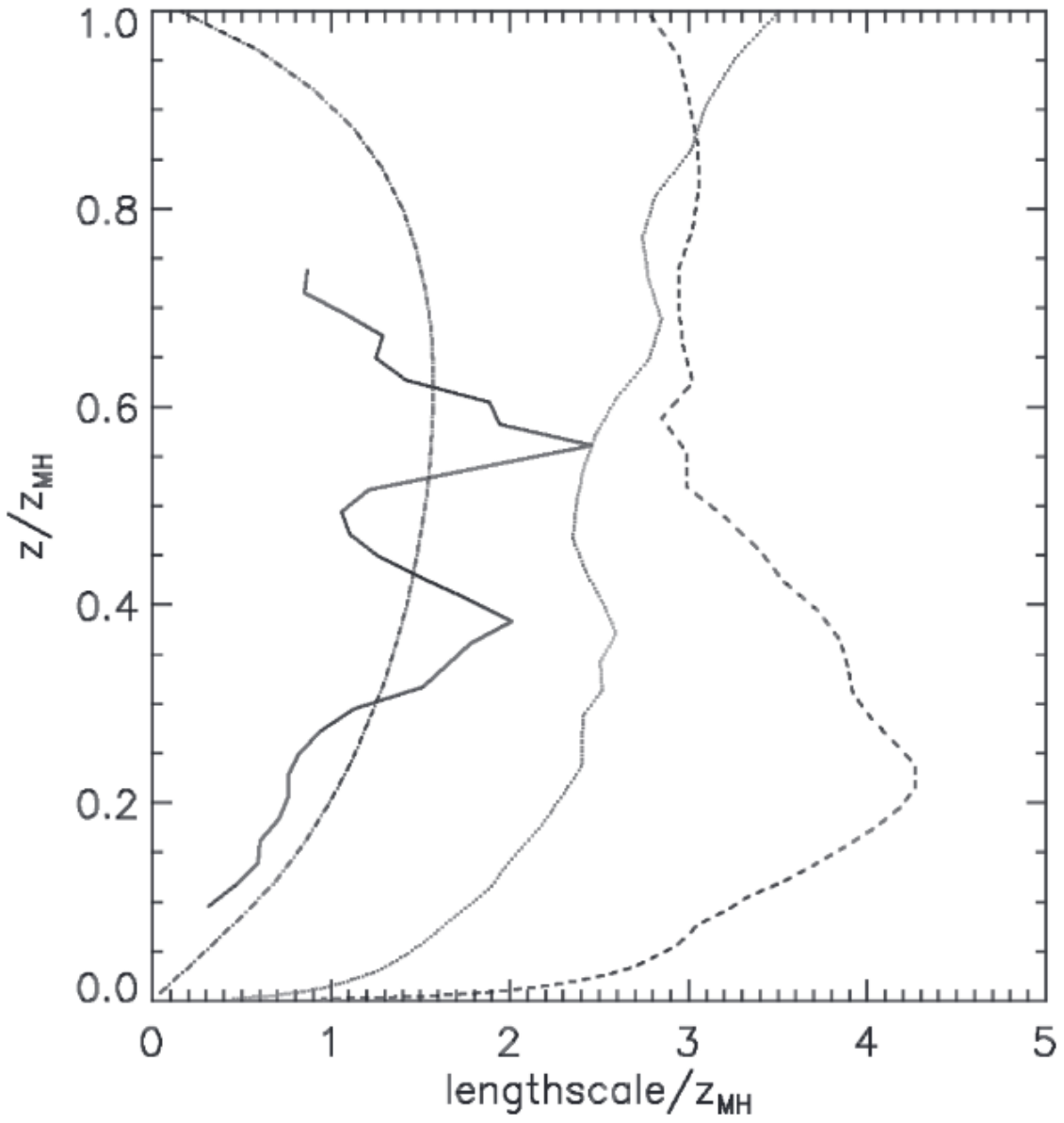
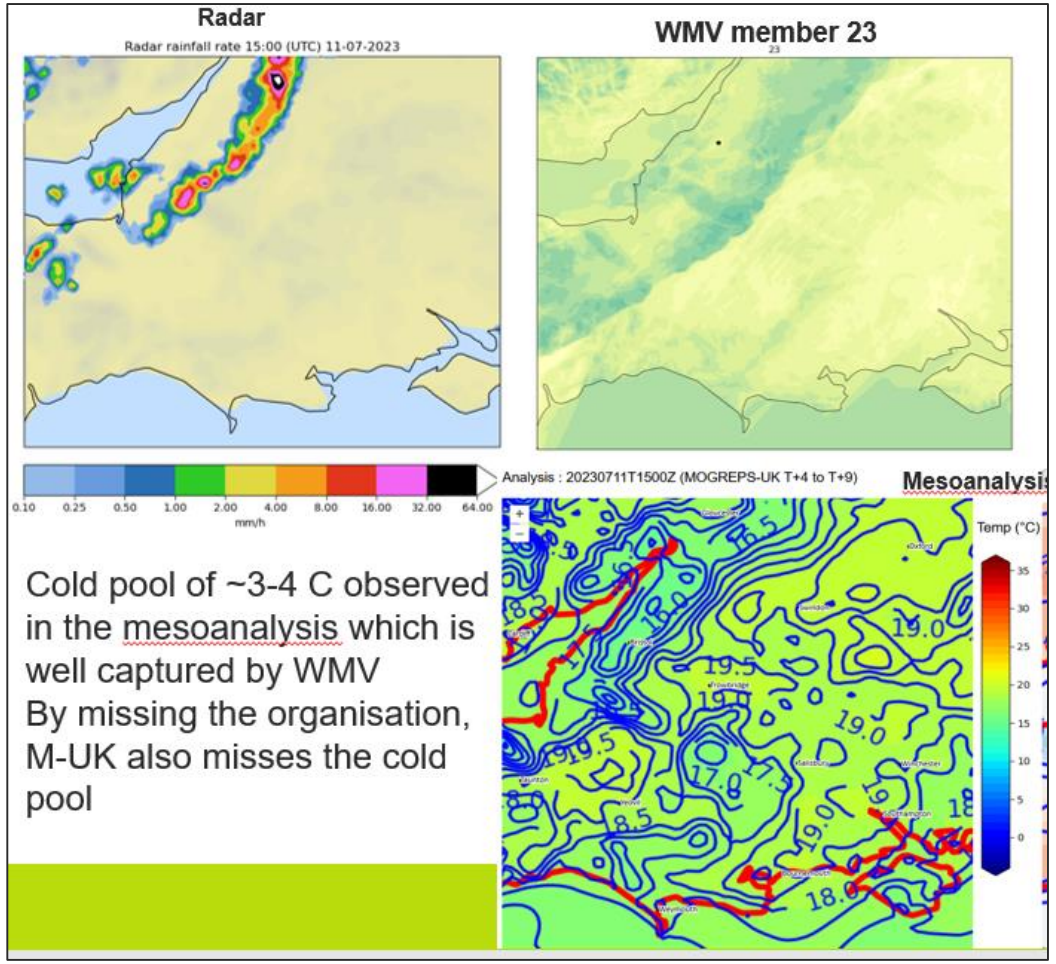


FIGURE 9 Turbulence length-scale as a function of height, both normalised by mixing height. Solid line is lidar data, dotted line from U50, dashed line from U100 and dash-dot line from Caughey and Palmer (1979)

Questions (Streakiness)

- Is BL is too keen to form rolls (even once boundary effects taken into account)?
- What is effect effect of BL structures on convection above BL?
- Are cold pools represented well and what is their effect on convection?
- Do BL rolls spuriously effect parameters near surface?
- Does improving BL (e.g. lack of gridscale structures) improve or hinder convection initaition.?

Need obs model comparisons for these questions.



Cold pools seen in one case with WMV
Kirsty Hanley

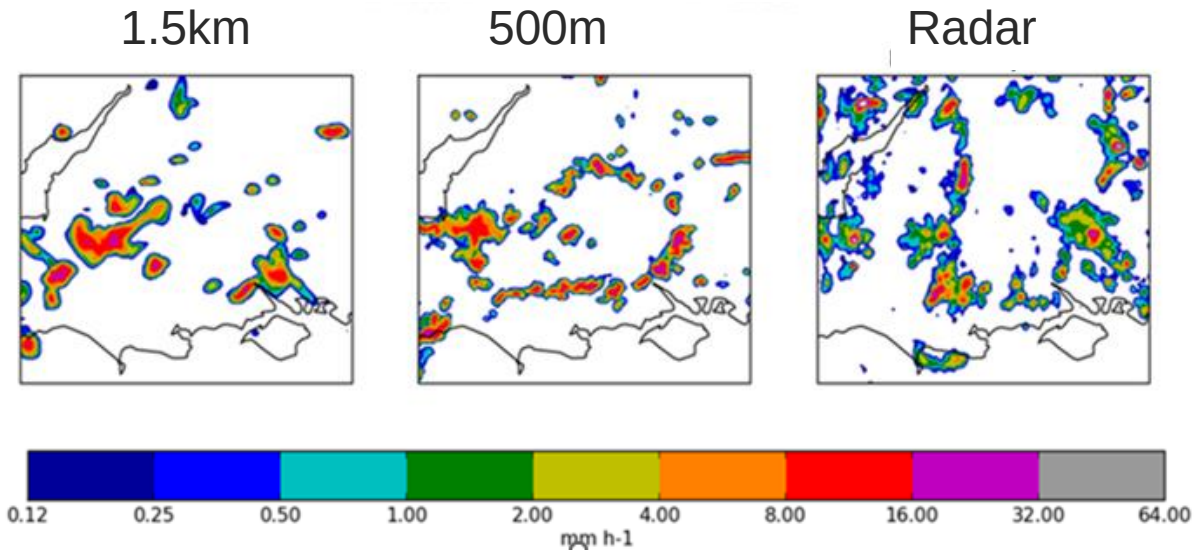
Met Office

Km-scale modelling

Problems with convection in km scale models/ensembles

- → Need to improve the representation of:
  - → Spatial structure of rainfall (too elongated or too circular!)
  - → Heavy rain too intense
  - → Not enough light rain
  - → Location of convection
  - → Cells unrealistically aligned with flow
  - → Elevated convection

As identified by UM Partnership Convection WG



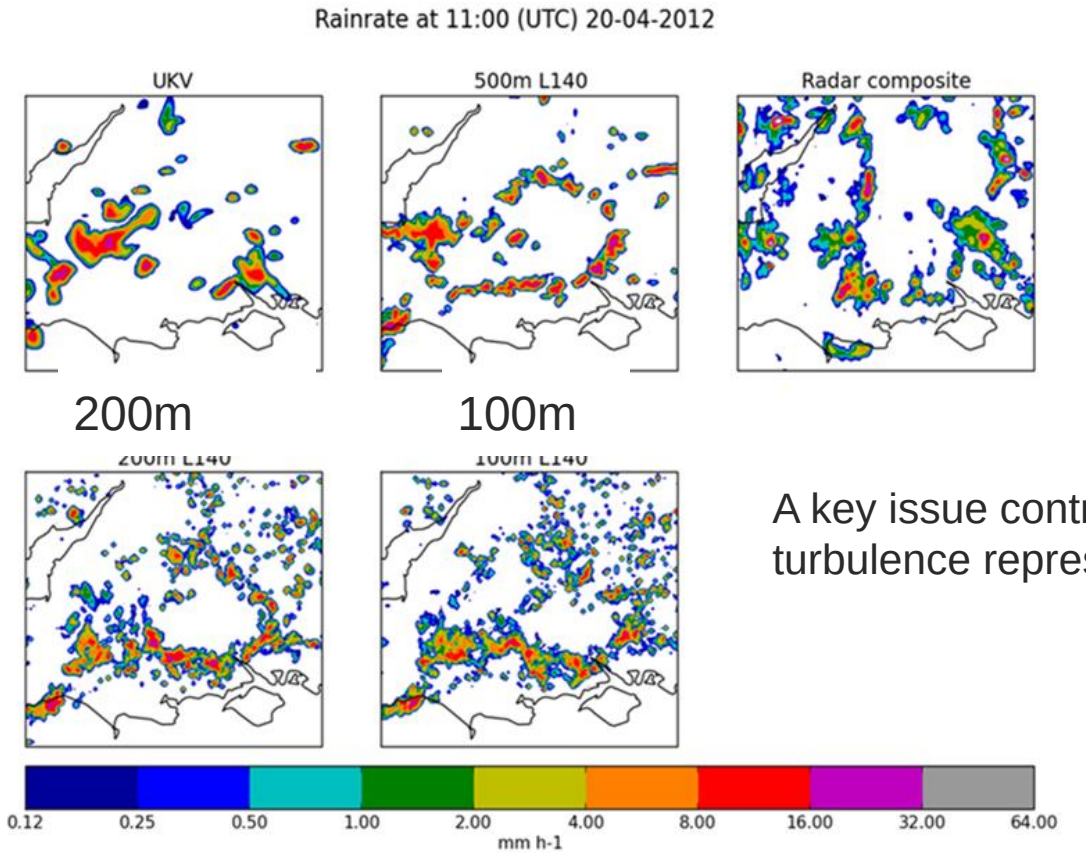
Root cause: Convection often too small to be properly represented explicitly.

- Need a km-scale convection scheme (grey-zone of convection)

Sub-km scale “urban –scale” modelling

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

Rank	Performance Improvement needed
1.	Produce too many small showers
2.	Tendency for shallow storms to precipitate too easily
3.	Generally initiate convection too early
4.	Spin-up of convection and turbulence from the boundaries can extend tens of kilometres into the domain
5.	Tendency of convective cells to be unrealistically aligned along the wind rather than across wind.



A key issue controlling convection is the turbulence representation

- Partially resolved turbulence also important for boundary layer representation (e.g. urban).

- Need improved turbulence representations in grey zone

Urban-scale Modelling
100m scale convection issues.

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Small showers problem

- Working hypothesis vertical velocities too strong/clouds too deep.
- May be related to turbulence scheme/microphysics

- Root cause probably small showers under-resolved. May need scale aware shallow convection scheme?

Urban-scale Modelling
100m scale convection issues.

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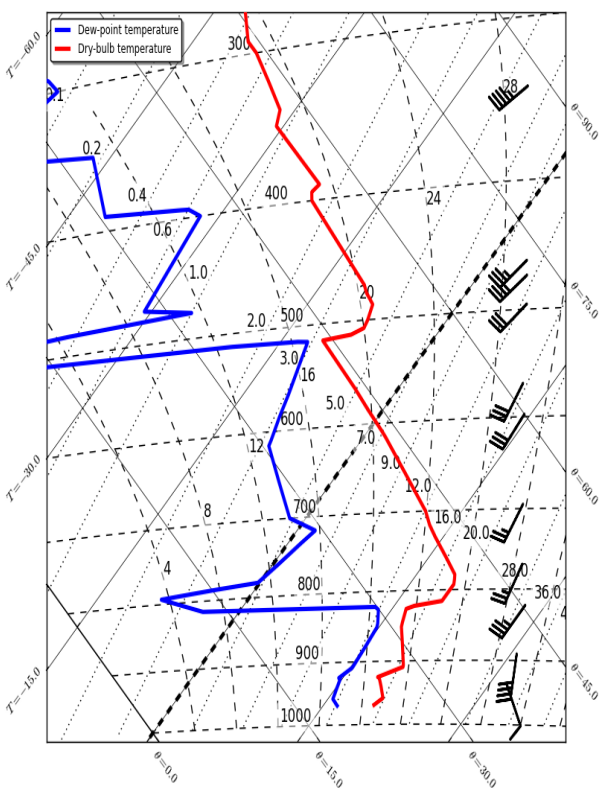
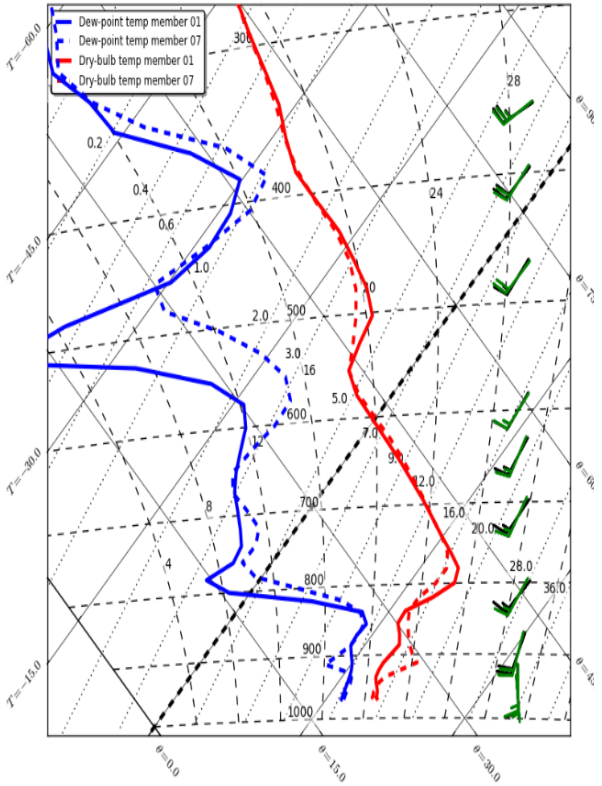
Initiation timing issue

- Also need to understand errors in pre-convective environment (inherited from larger scale models).

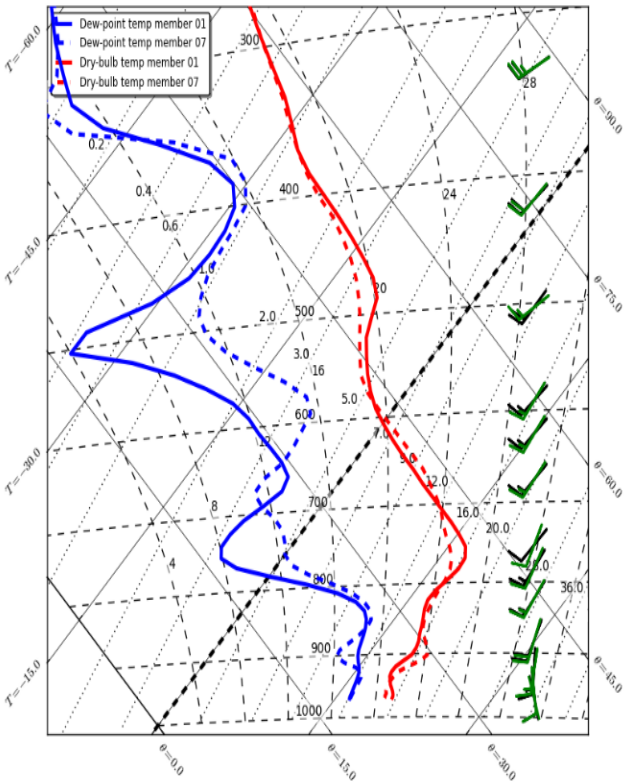
Norman, OK, 12UTC 16/5/2017



Observations



Global Model



2.2km

Hanley and Lean. https://doi.org/10.1002/qj.4049.

Urban-scale Modelling
100m scale convection issues.

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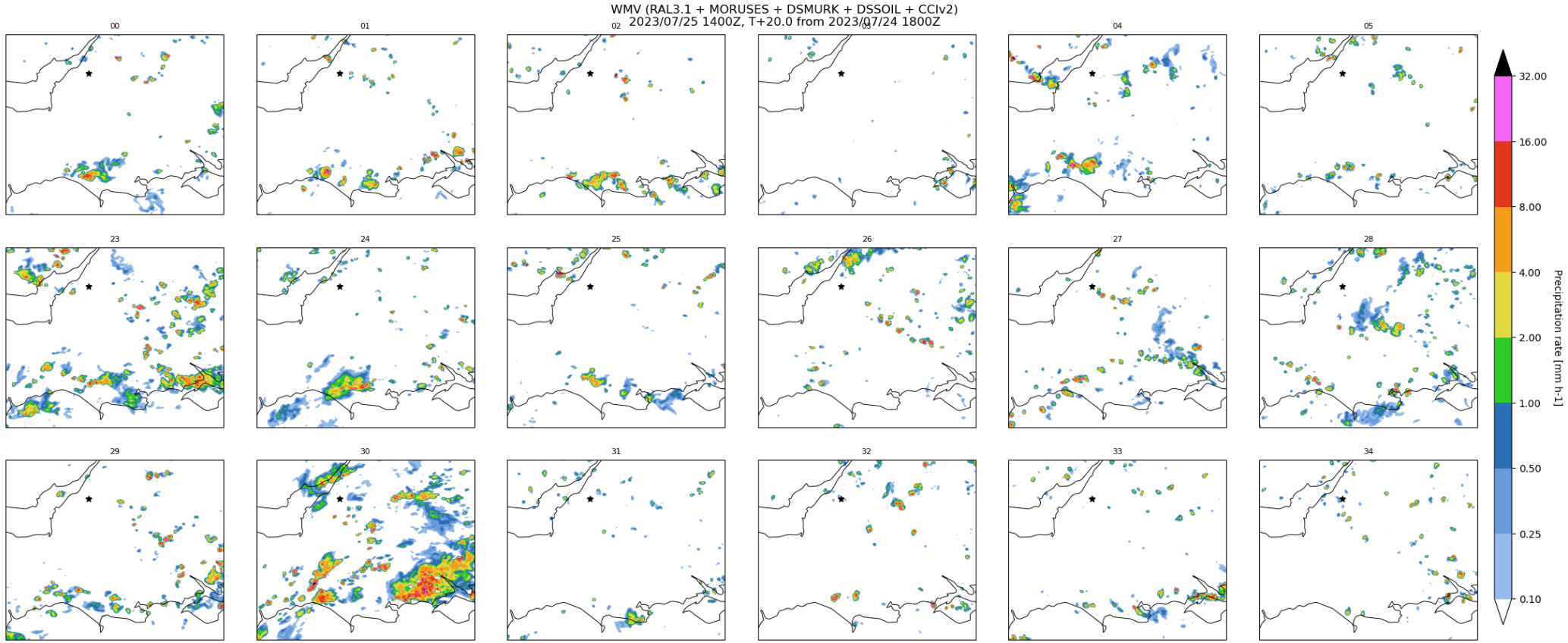
Organisation issue.

- Also true in km scale models but less obvious.
- Related to streakiness problem above.

Ensemble questions



WMV Postage stamps

We believe ensembles are essential for 300m convection forecasts because scales of predictability long compared to the scales we are trying to forecast on.

Research Questions relating to Urban-scale ensembles

- Why does ensemble appear underspread (comparison of spread vs error).
- Best ways to perturb high res ensembles?
- Best ways to postprocess
- Can we cluster on high resolution features.
- Can we save on cost by clustering on driving ensemble and running a few members.

Conclusions

- Many important science questions remain for development of Urban-scale models.

- We expect to work jointly with Met Office/NERC ParaChute project on these questions (see Alison Stirling talk).