Met Office

Experiences with Convection Permitting Versions of the UM at the Met Office

Humphrey Lean and contributions from many others

Met Office (MetOffice@Reading)

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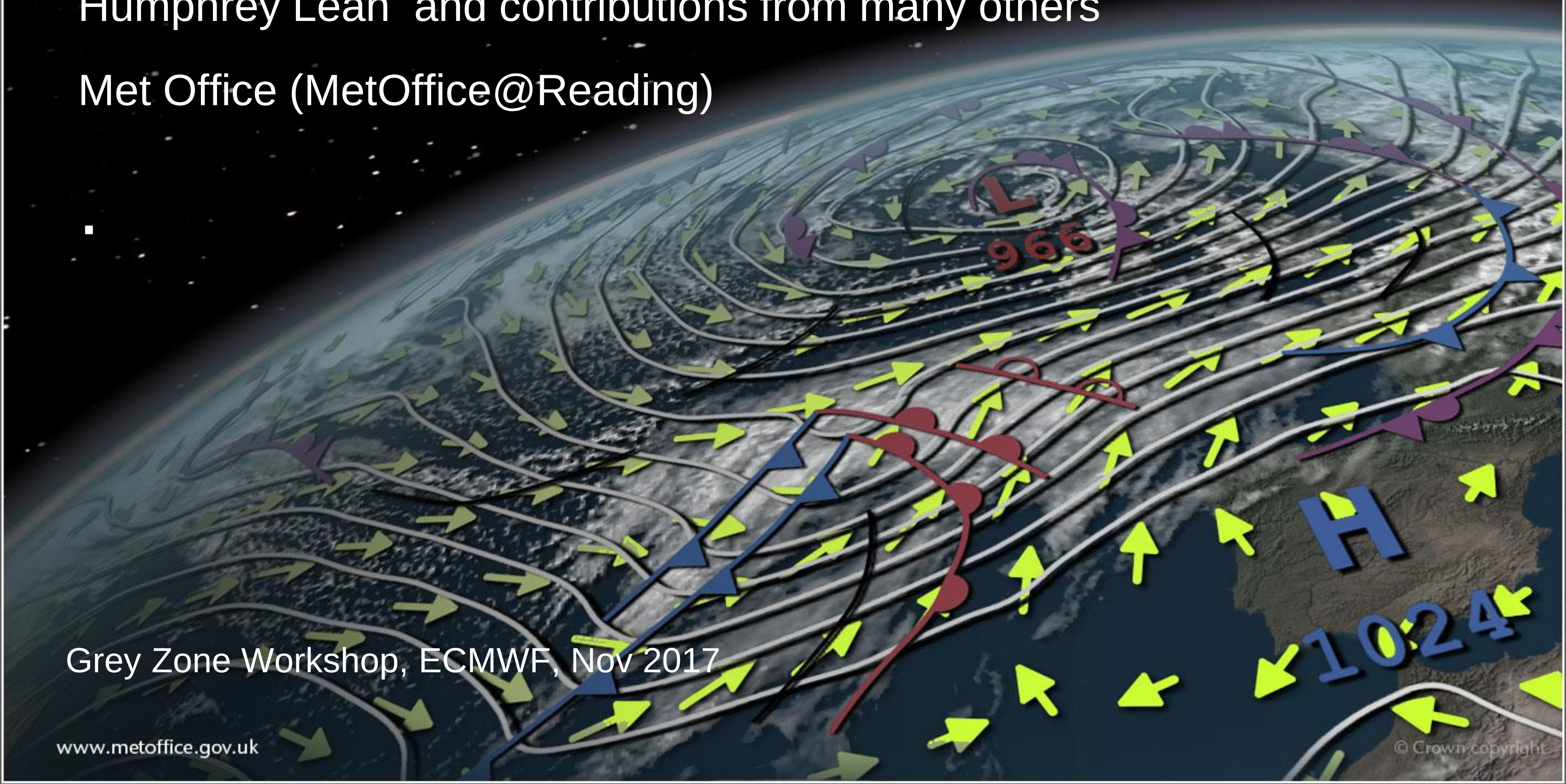

Grey Zone Workshop, ECMWF, Nov 2017

Timeline of operational UK versions of UM

- Hydrostatic “mesoscale model” 17km early 1990s
- Resolution improved to 12km and area increased 1998
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- “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
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- Larger domain UKV (low res) and out to T+120 Nov 2016
- Hourly cycling UKV Sep 2017
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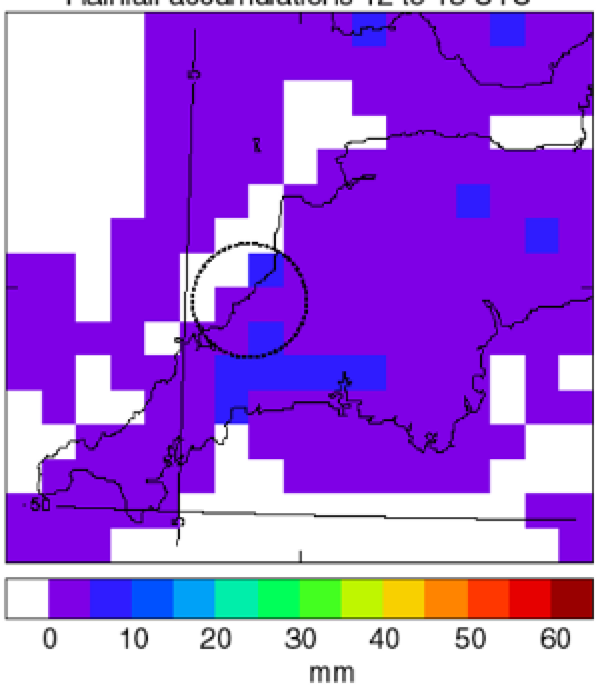
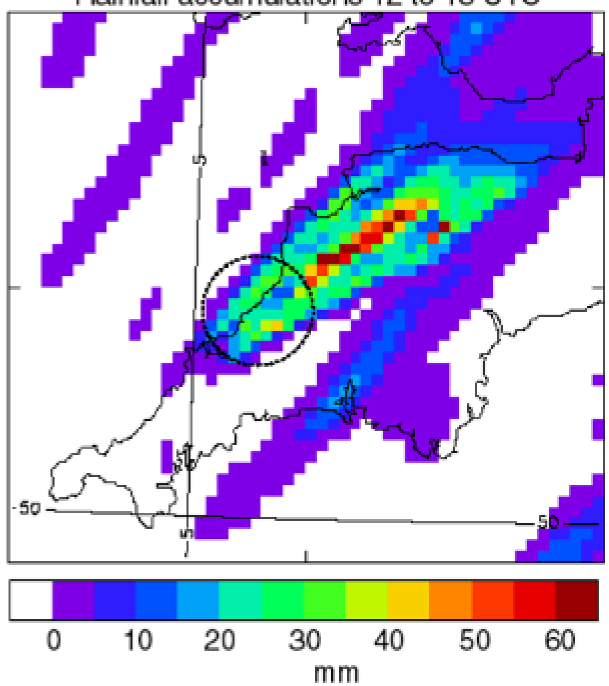
Boscastle Flood 16/08/2004

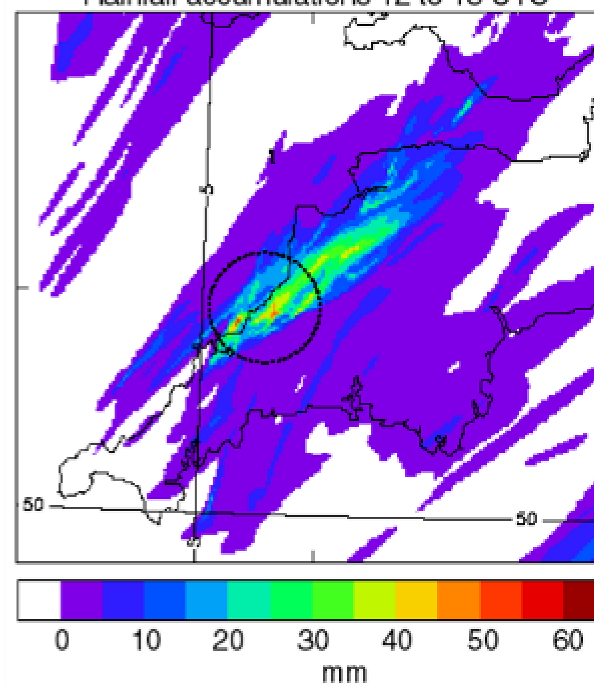
12-km forecast (PC003) from 00 UTC
Rainfall accumulations 12 to 18 UTC



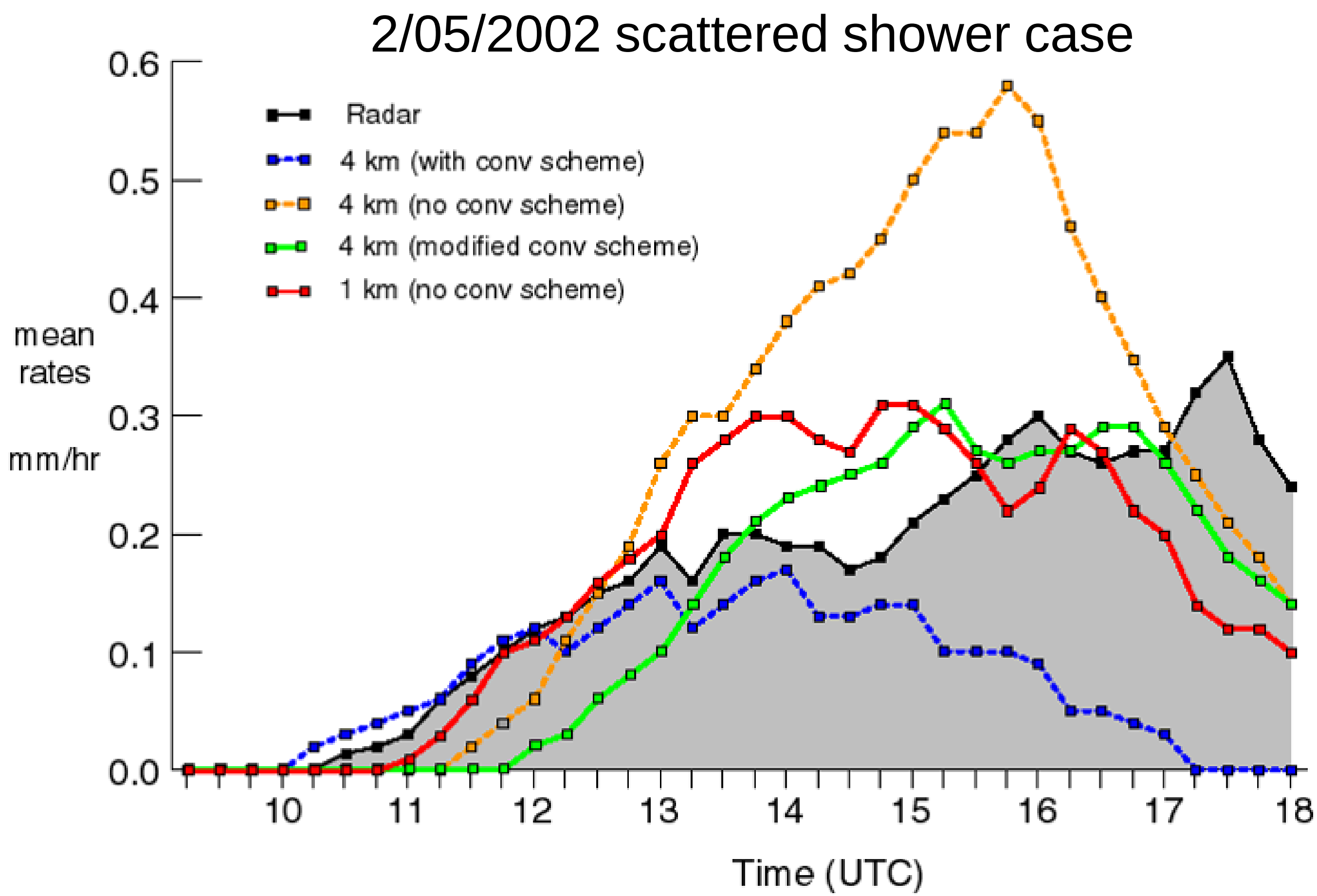
4-km forecast (PC003) from 00 UTC
Rainfall accumulations 12 to 18 UTC



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



Convection in 4km model



Used modified convection scheme (Nigel Roberts)
CAPE dependent CAPE closure timescale
First “grey zone” scheme - still in use in 4km models

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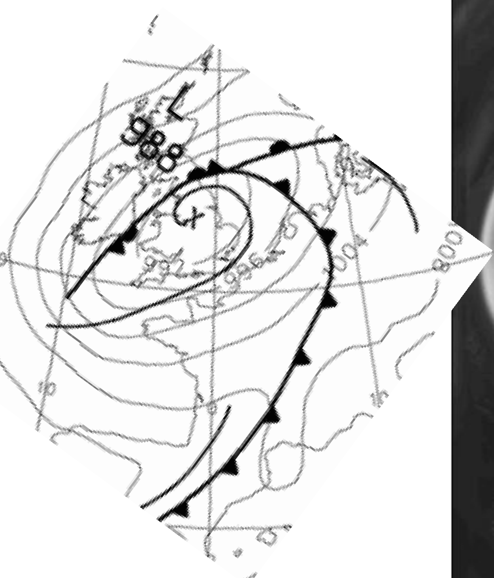
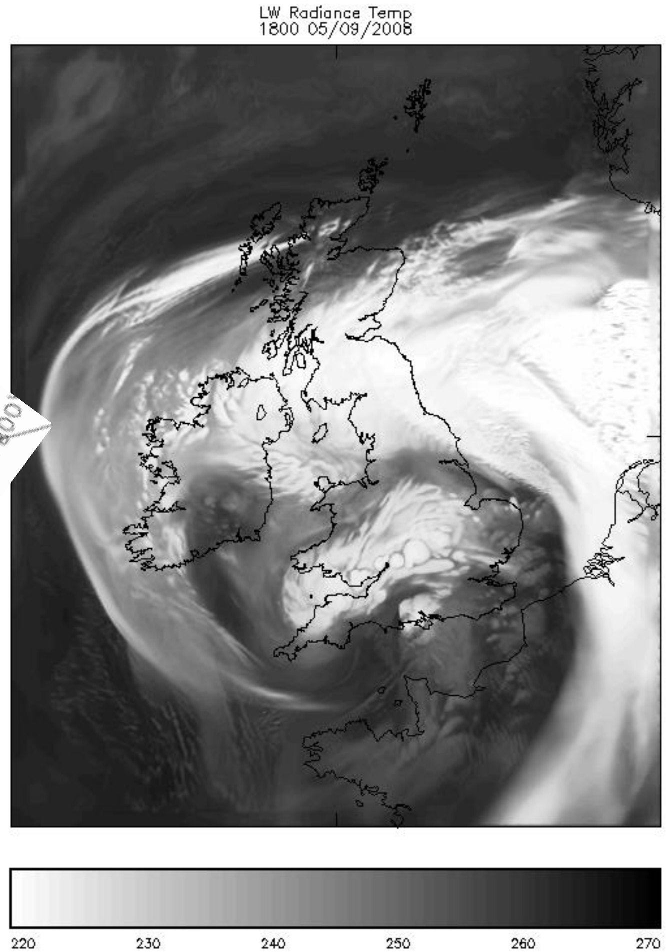
Convection permitting models benefits.

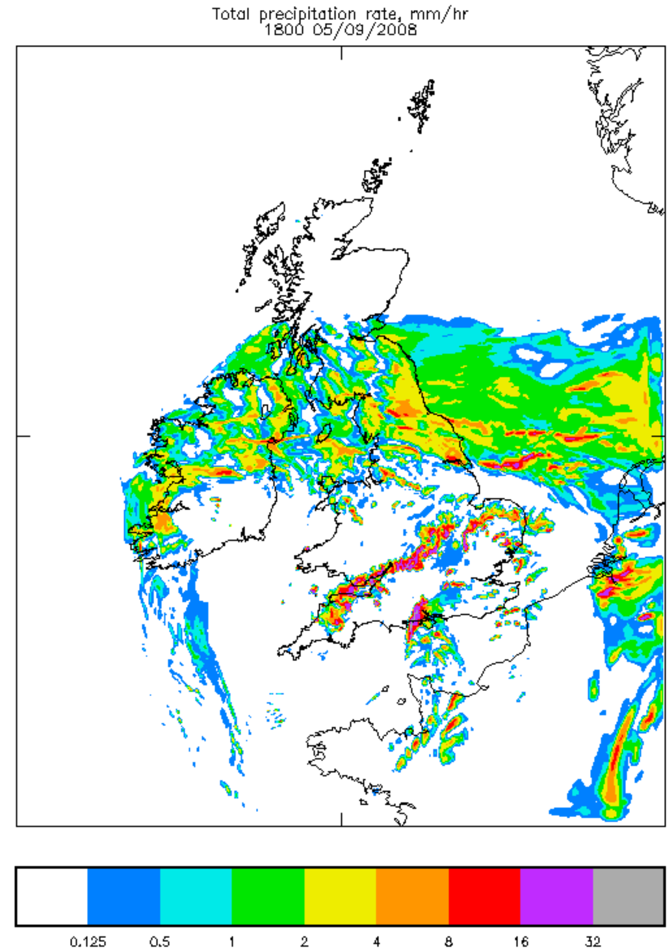
- “Step Change” in ability to forecast rainfall (Clark et al 2016)
- Look realistic to eye compared to 12km.
- Outperform 12km models for convection by subjective (forecaster) and objective (fuzzy) verification.
- Systematic benefits from not using convection scheme..
- Need to bear in mind predictability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

UKV Model

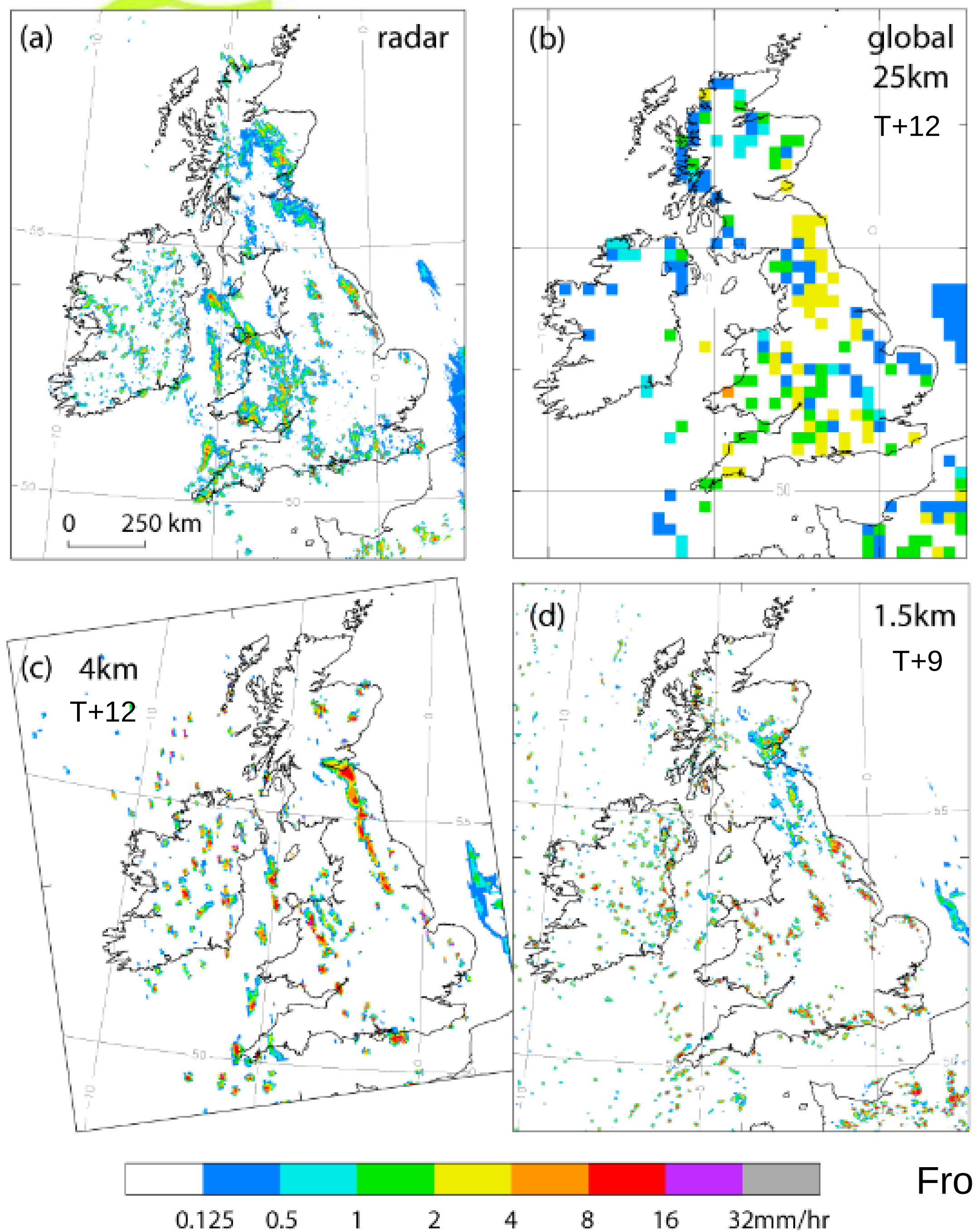
The ‘Morpeth Flood’, 06/09/2008







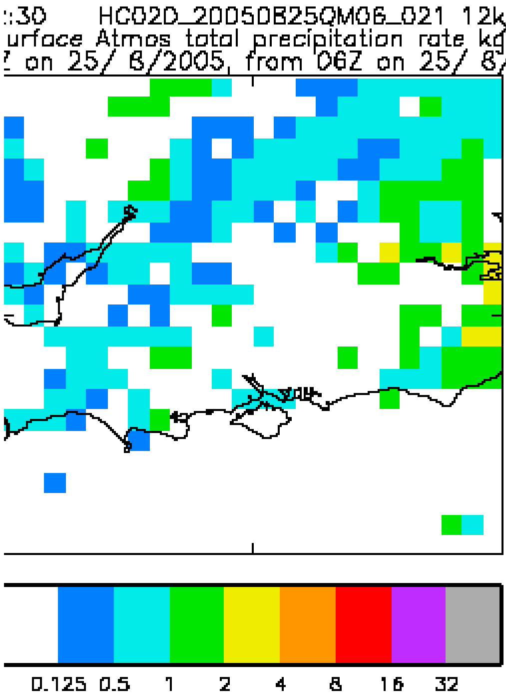
8th July 2014 showers case



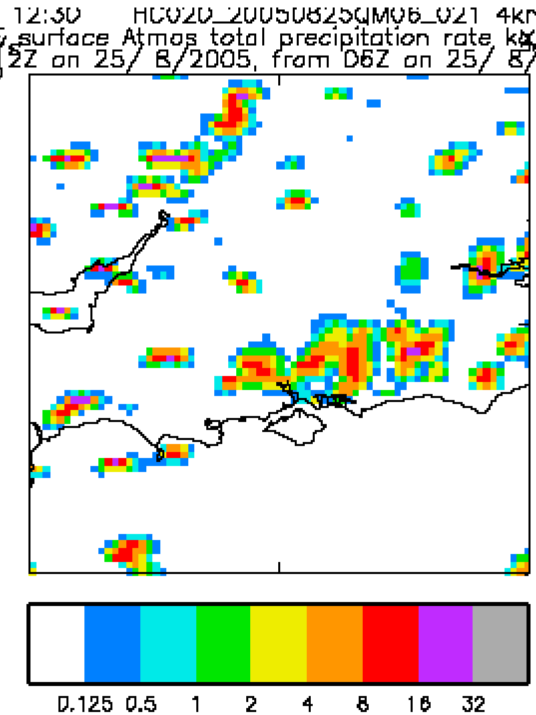
- Global intermittent in time and gives little indication of organisation of rain and areas of heavy rain.
- 4km Better at organised features but too much heavy rain and not enough light and features tend to be too large. If animated features would now advect.
- 1.5km Better scales in rainfall field (features smaller). Better balance between heavy and light rain compared to radar (but still overdoes heavy rain and underdoes light).

From Clark et al 2016

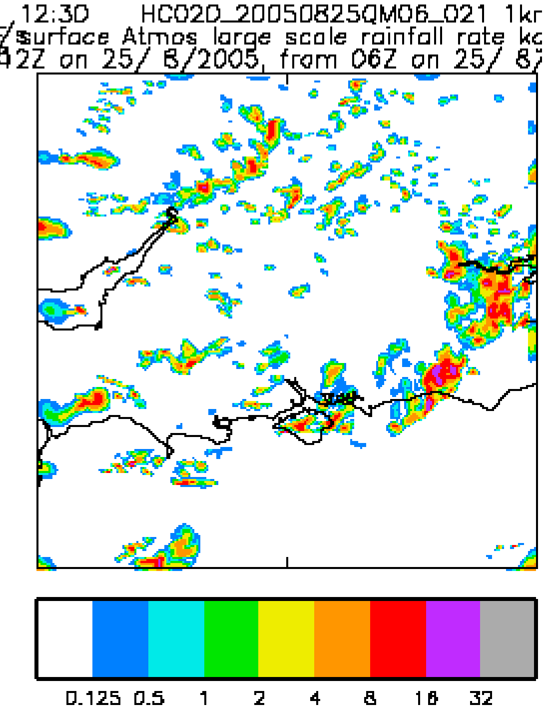
12:30 UTC 25/08/2005



12km



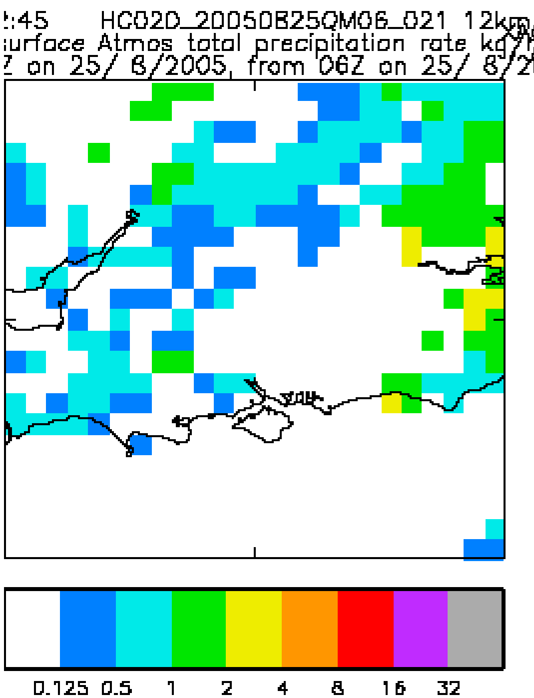
4km



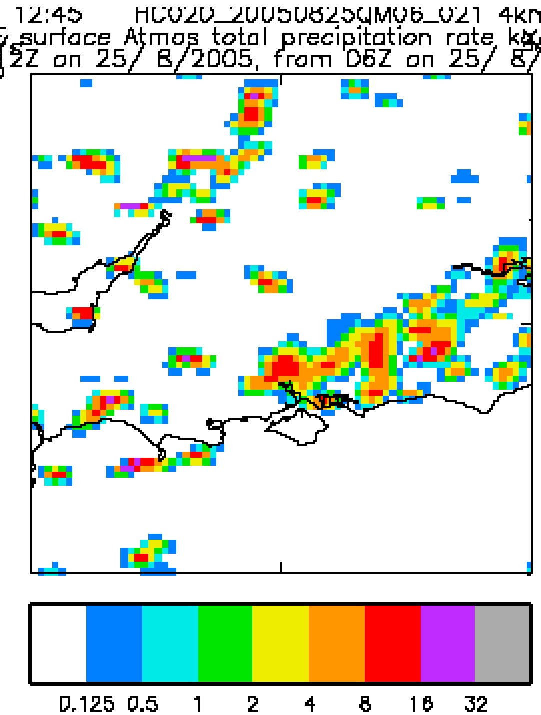
1km

12:45 UTC 25/08/2005

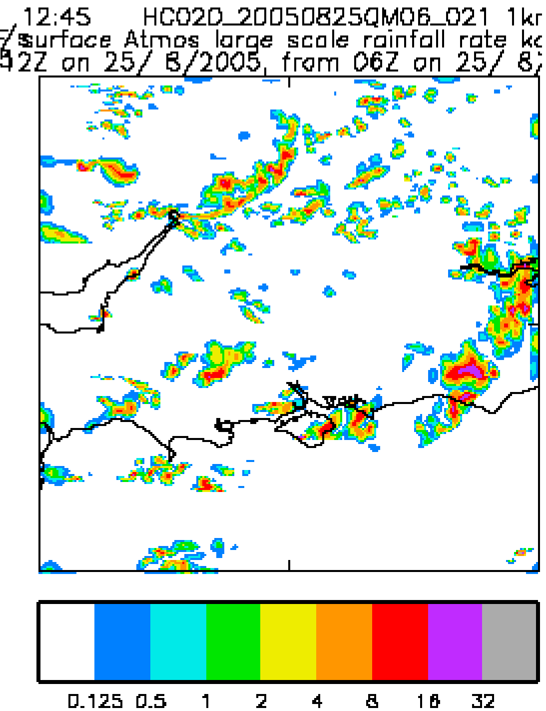
Met Office



12km



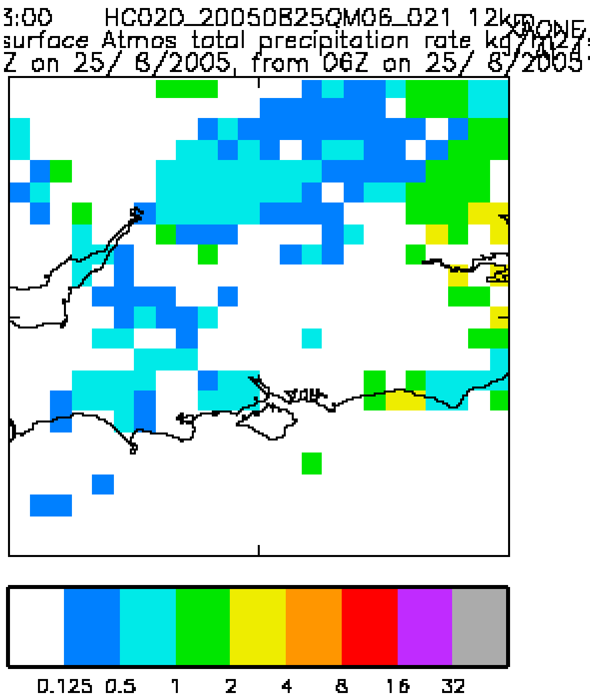
4km



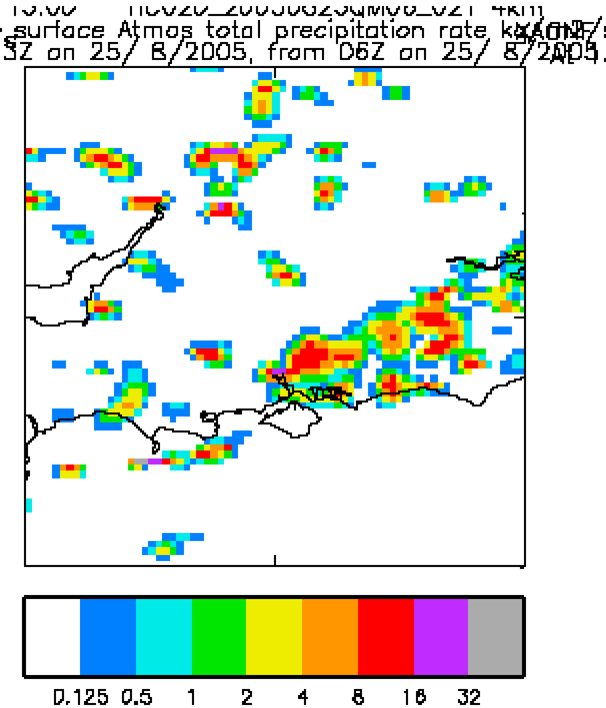
1km

13:00 UTC 25/08/2005

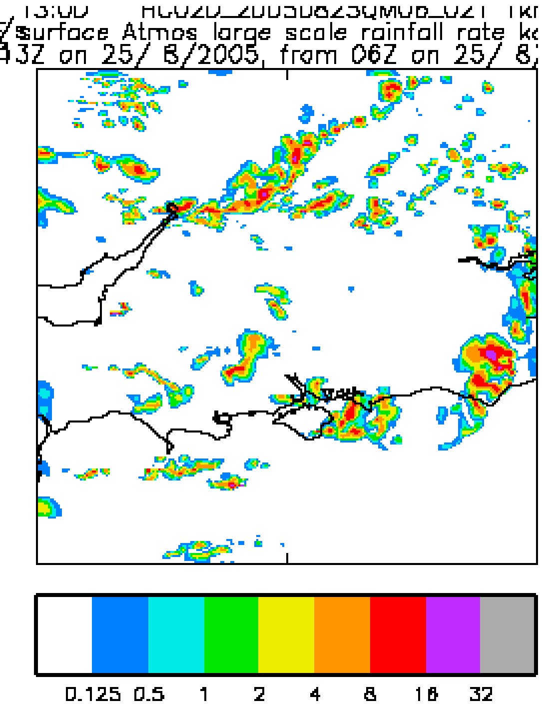
Met Office



12km

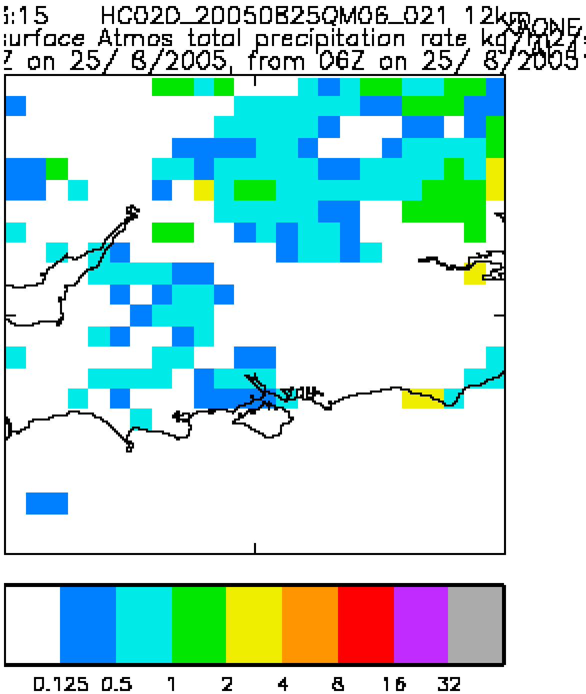


4km

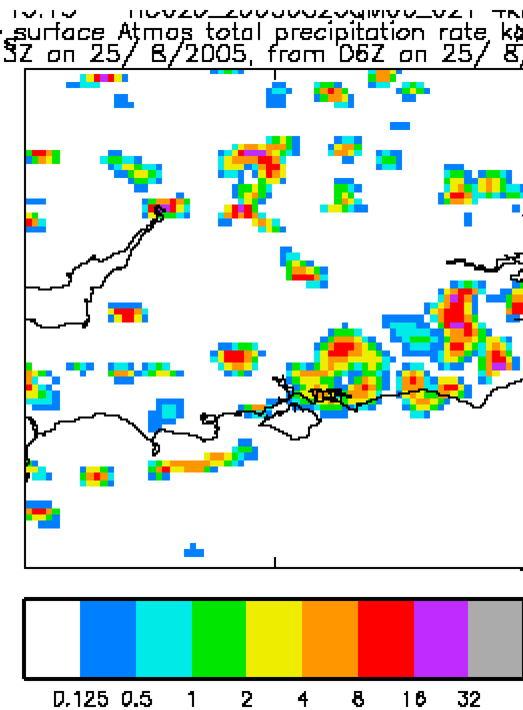


1km

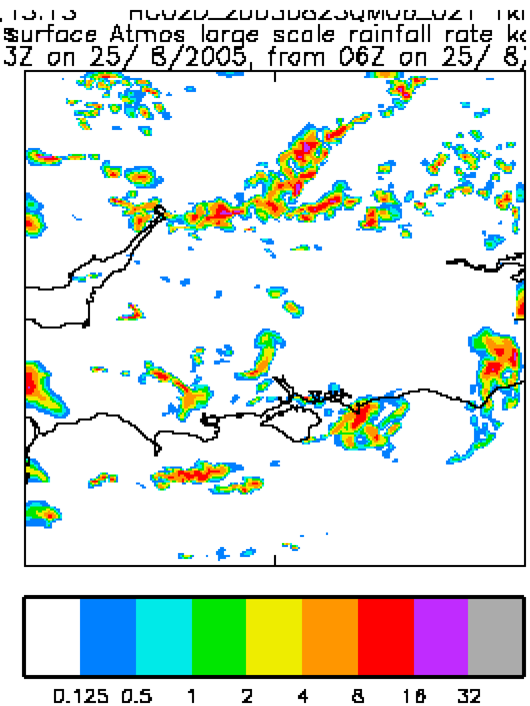
13:15 UTC 25/08/2005



12km

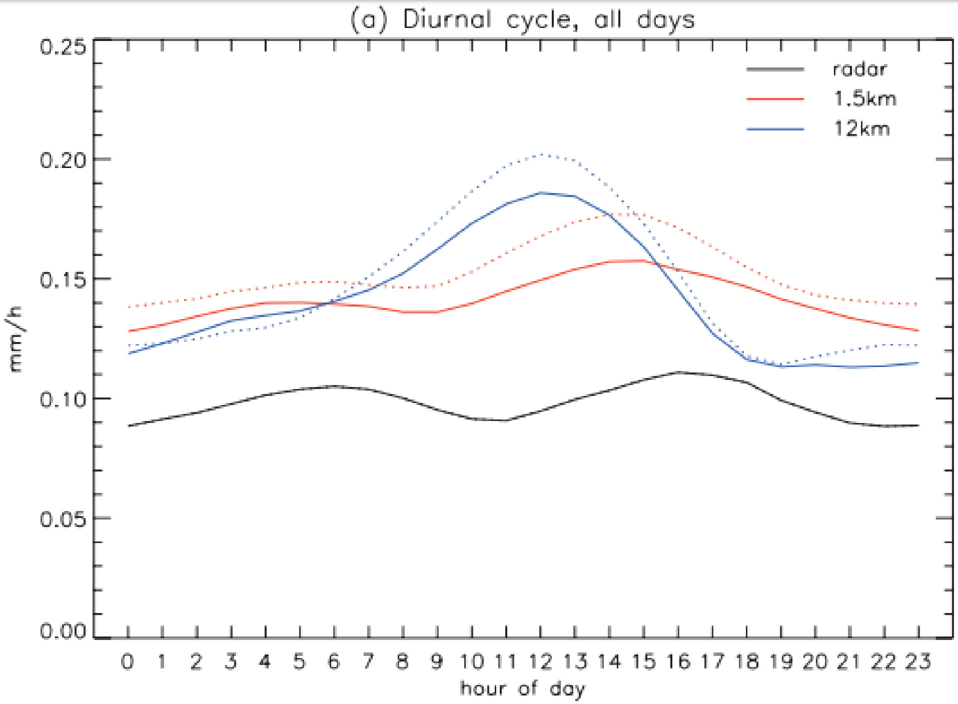


4km

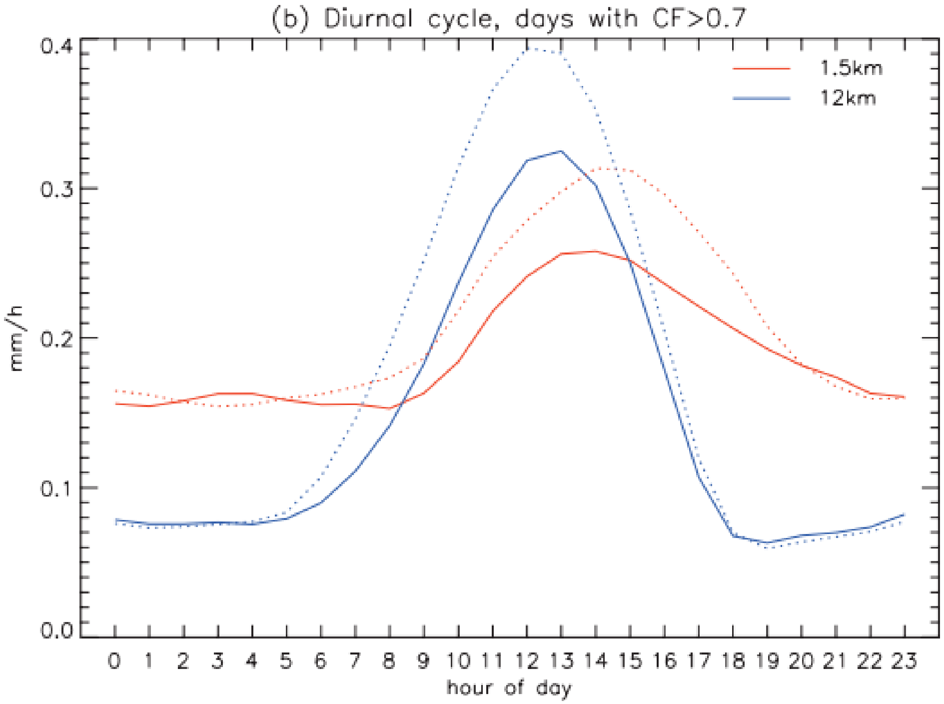


1km

Diurnal cycle of convection



Hourly mean rainfall averaged over S England.

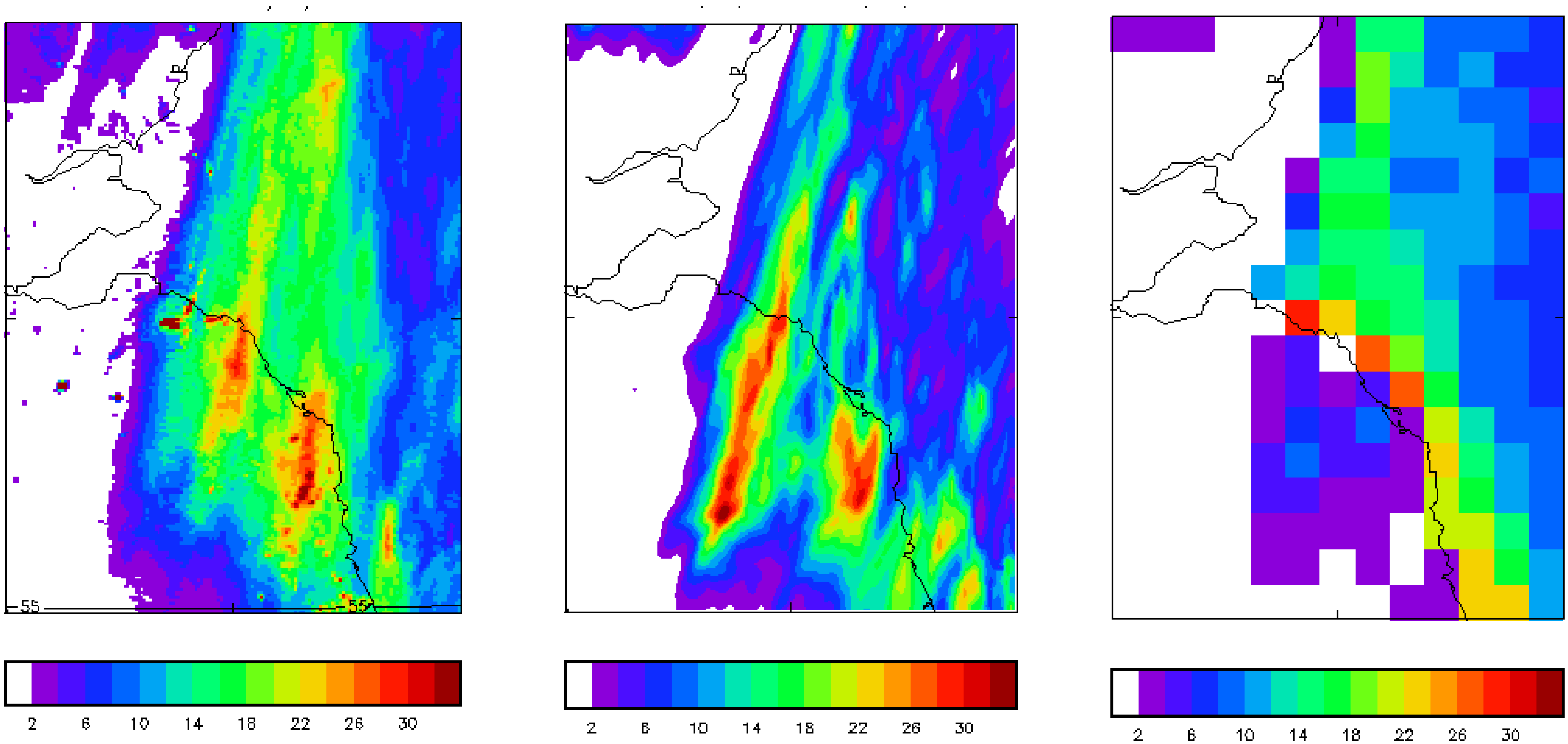


Days with high convective fraction.

Kendon et al 2011

Snow Showers penetrating inland

24 hour precip accumulation (mm) 25th Nov 2010



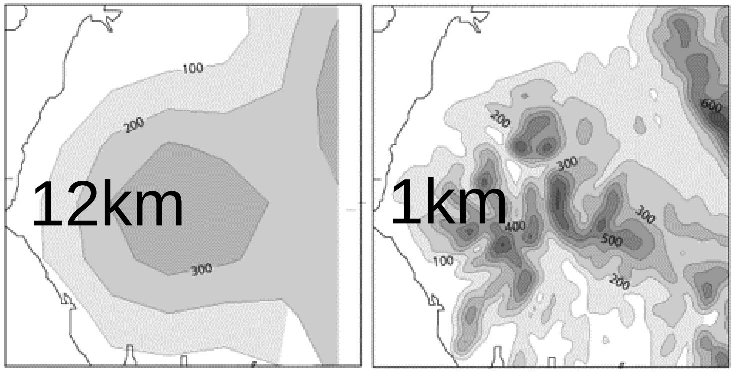
1km radar   UKV (1.5km)   NAE (12km)

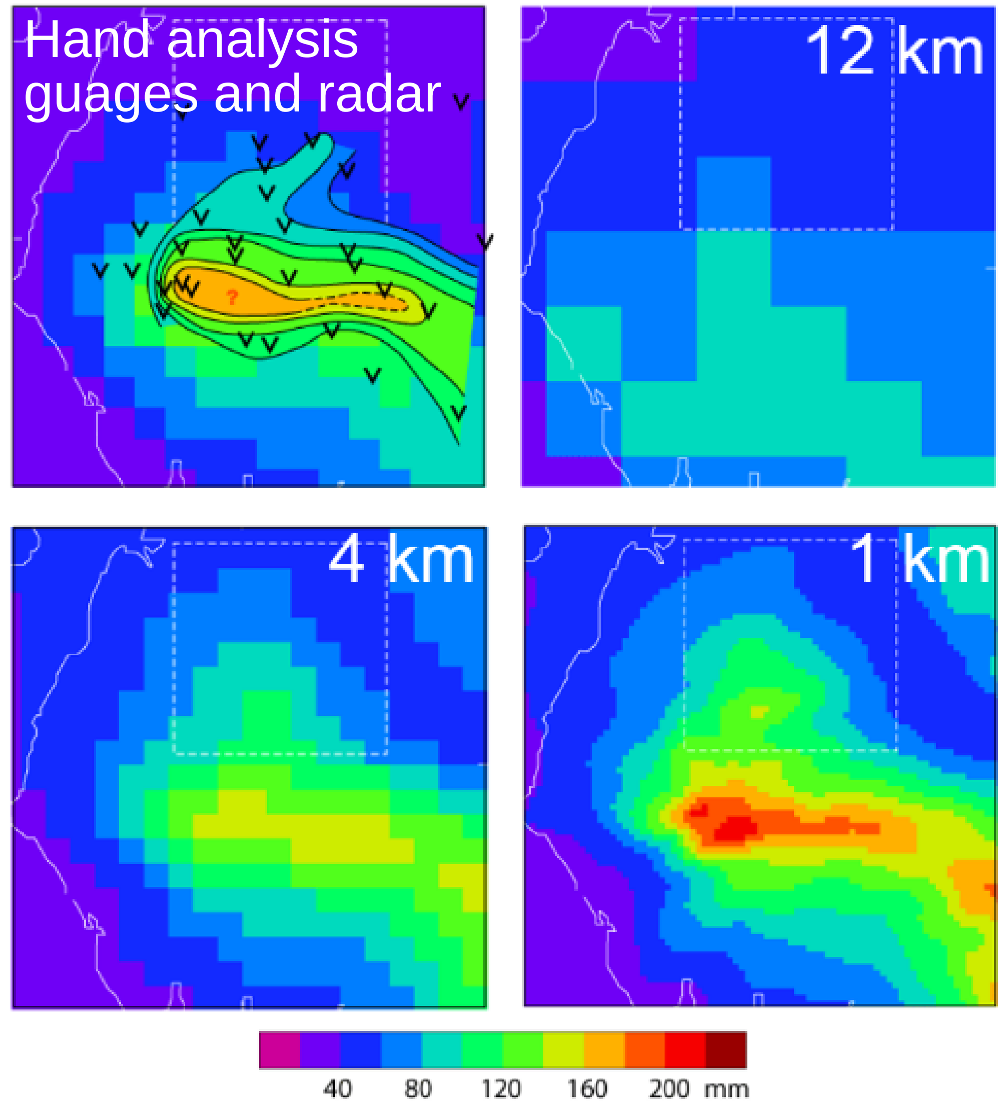
Operational models

Benefits of higher resolution orography

Carlisle flood – observed and forecast accumulations

Roberts et al (2008) Met Apps



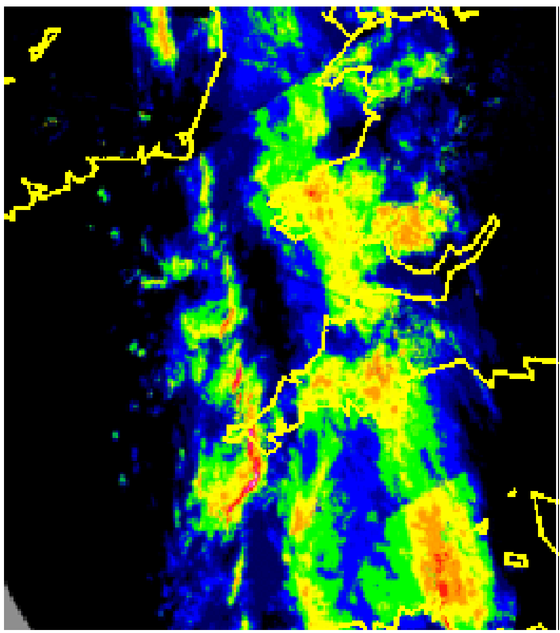


- Orographic rainfall improved due to better orography.
- Similarly benefits for fog

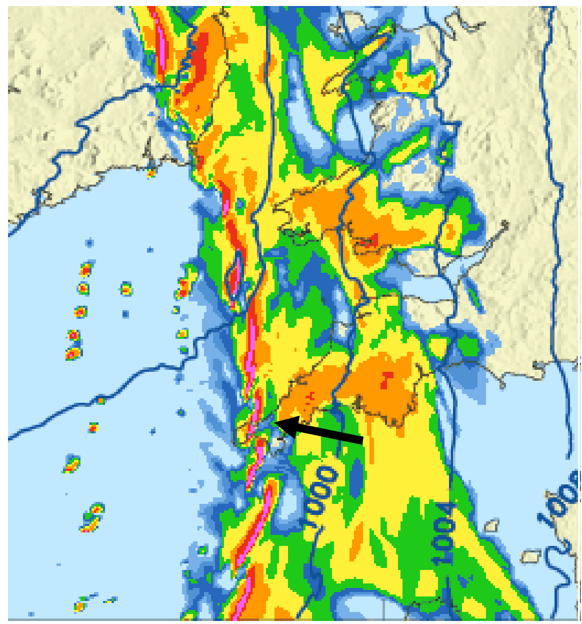
Small Scale Predictability

Bodmin Moor Flood 3 UTC 17th Nov 2010

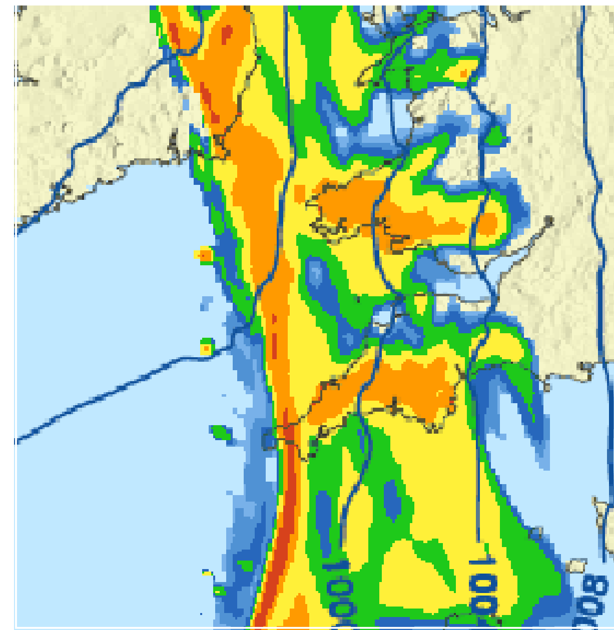
Radar



UKV



UK4



Frontal structure better in UKV (line segments) but UK4 gave better (larger) accumulations over Bodmin Moor – line segments in wrong place.

- Need to avoid presenting data from models or verifying on unpredictable scales → Ensemble/probability/neighbourhood approaches.

Convection Permitting models issues.

- Despite all these benefits there are still significant problems with convection permitting models
- NOT true that it can be assumed that things are necessarily automatically better at higher resolution – need different parameterisations for newly partially resolved processes.
- Errors imported from driving large scale models often more significant when looking at smaller scale forecasts.

List of biases
(UM Partnership Convection WG)

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 (noted particularly in Singapore).

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.

Classification of biases

Many of the items on the above list are inter-related.

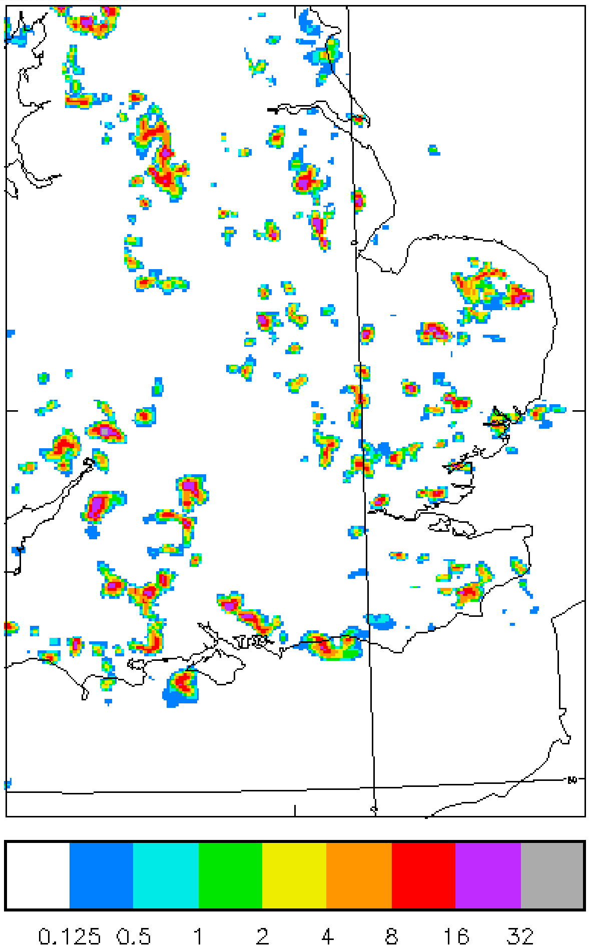
There are several fundamental issues with the model which probably lead to most of these:

- Poorly resolved/not parameterised shallow/early stages convection.
- Poorly resolved/incorrectly parameterised turbulence.
- Dynamics issues (conservation)
- Other parameterisations e.g. microphysics
- Spin up issues (artificially smooth fields from boundaries or at start)
- Errors imported from larger scale driving model.

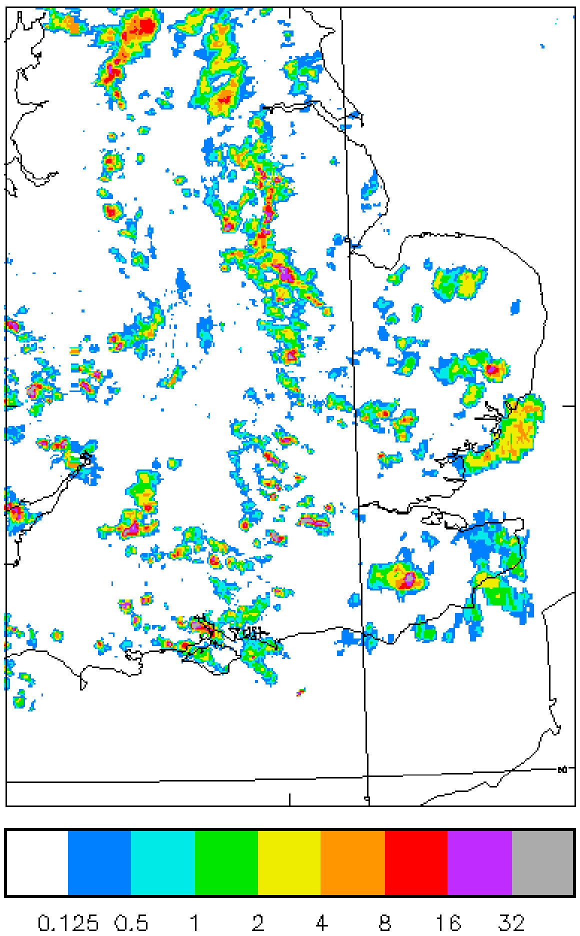
In some cases several of these seem relevant and not clear which is most the main issue.

Too much heavy rain, not enough light

1.5km model



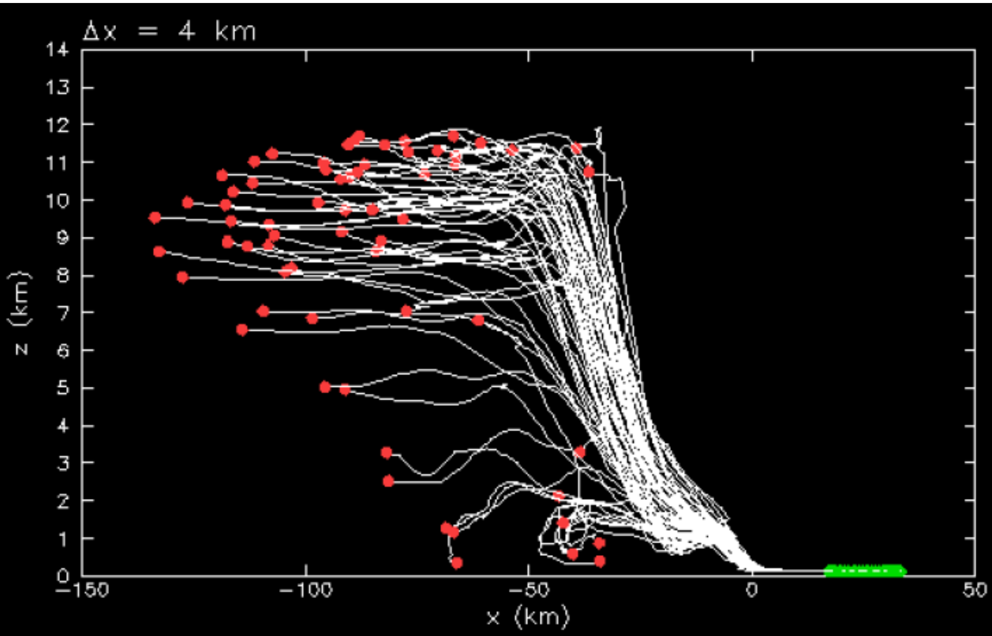
Radar



15 UTC 12th April 2012

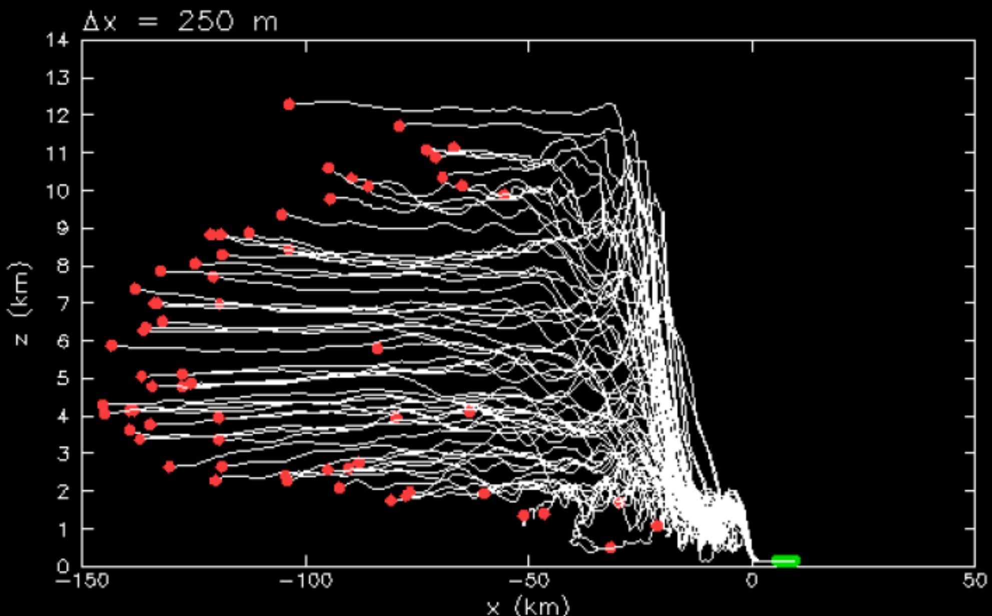
•Typically seen in UKV model.

64 trajectories, *t* = 3-5 h



4km

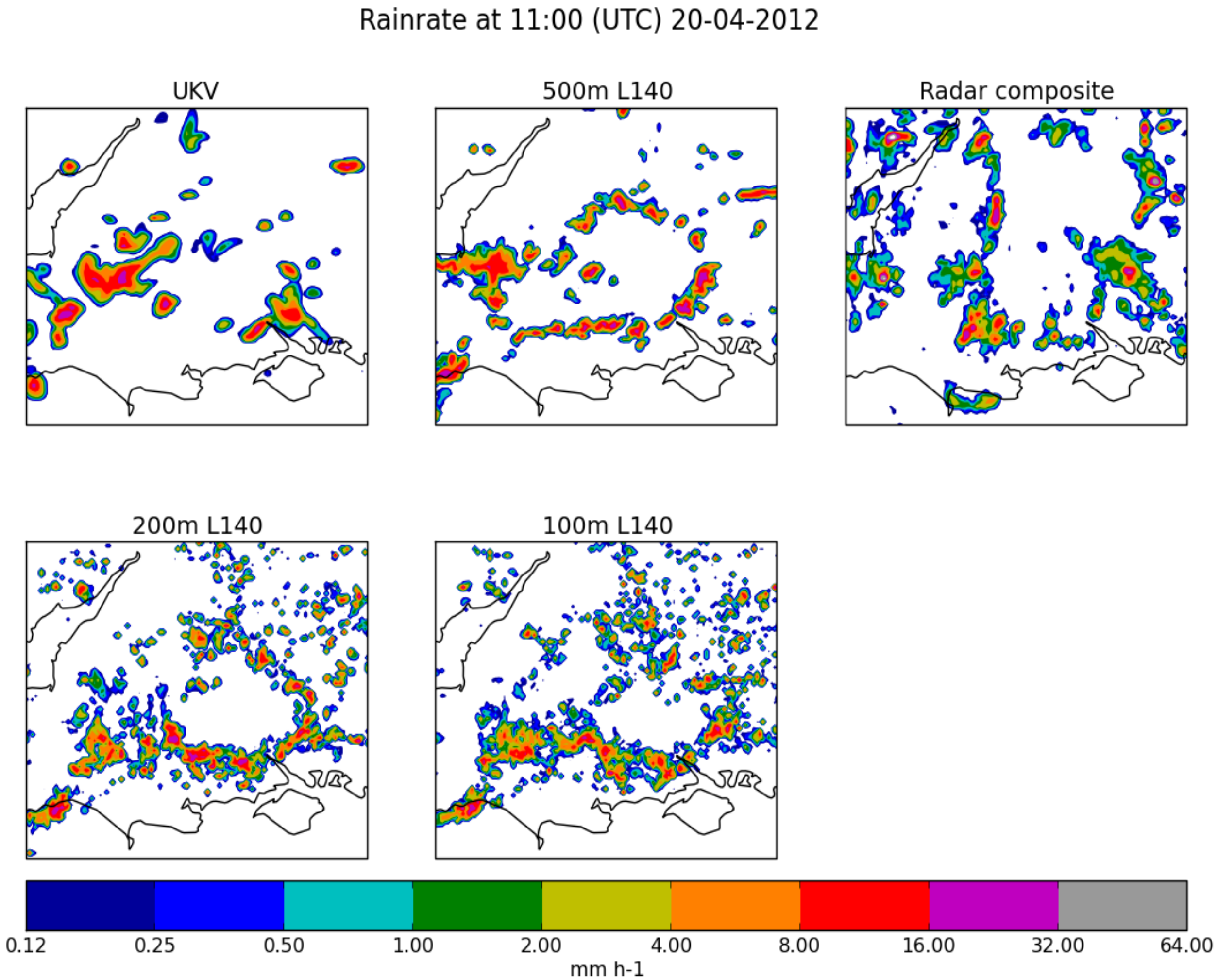
- Boundary layer air is transported primarily to great heights



250m

- Boundary layer air is distributed throughout a deep layer

Increased resolution in UK



- Heavy/light ratio appears to improve with increased resolution.

Kirsty Hanley DYMECS

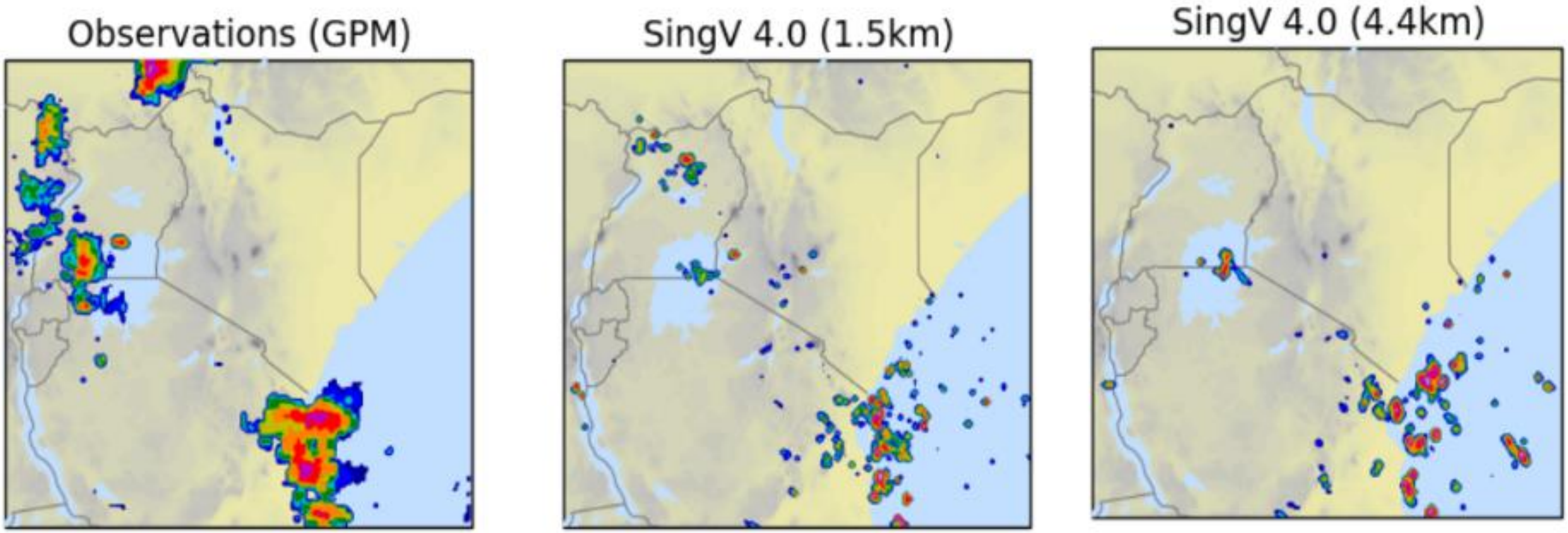
Too much heavy rain, not enough light

- Very commonly seen in km scale models.

- Can be seen as aspect of not resolving detrainment from plume.

- Also can be adjusted with microphysics (KMA experiments with drop size distribution). Conservation affects heavy rainrates.

Too many small cells when well resolved.



Fragmentation of large cells

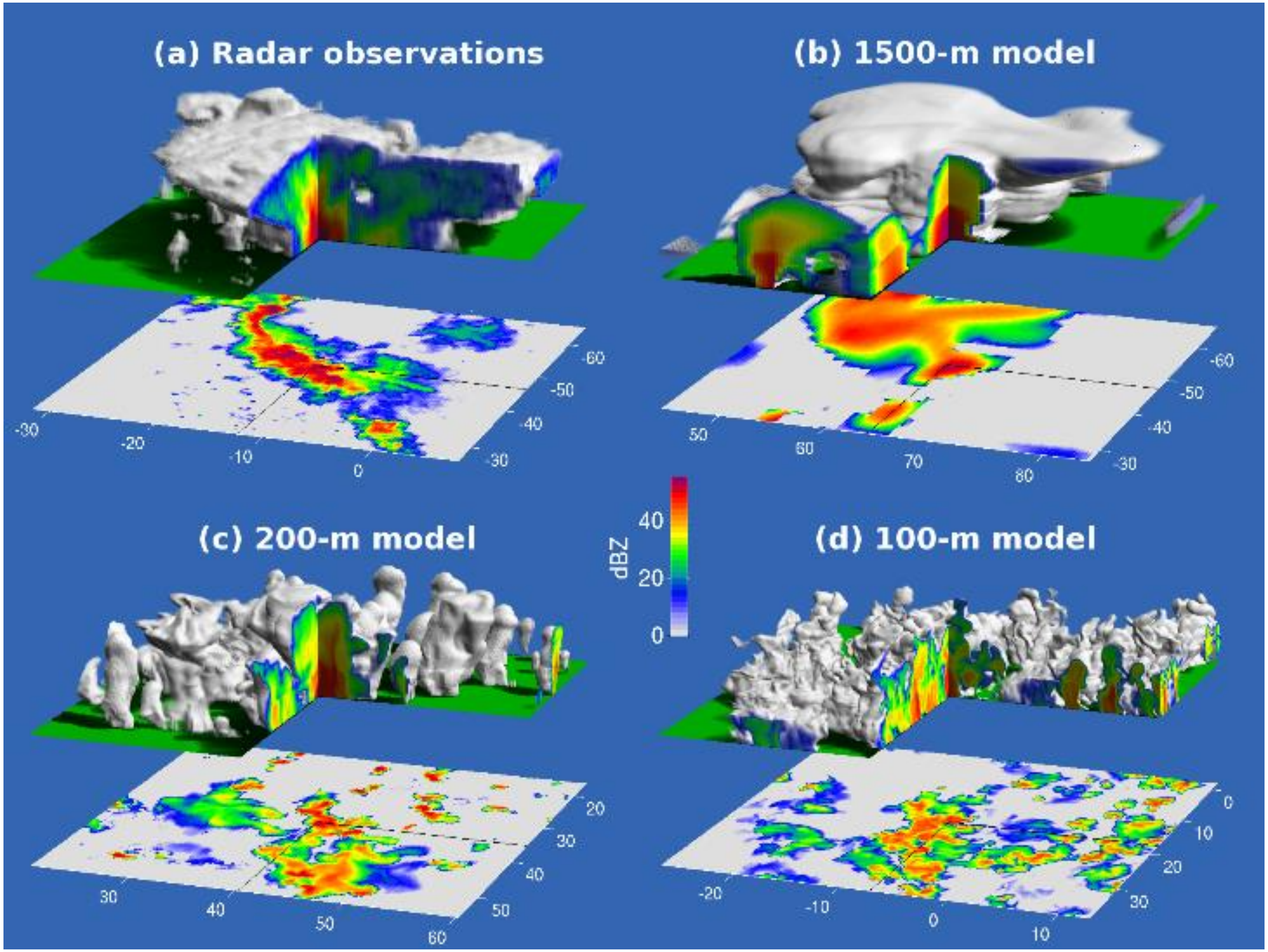
One manifestation of “Blobbiness”

Kirsty Hanley

3D visualisation of data

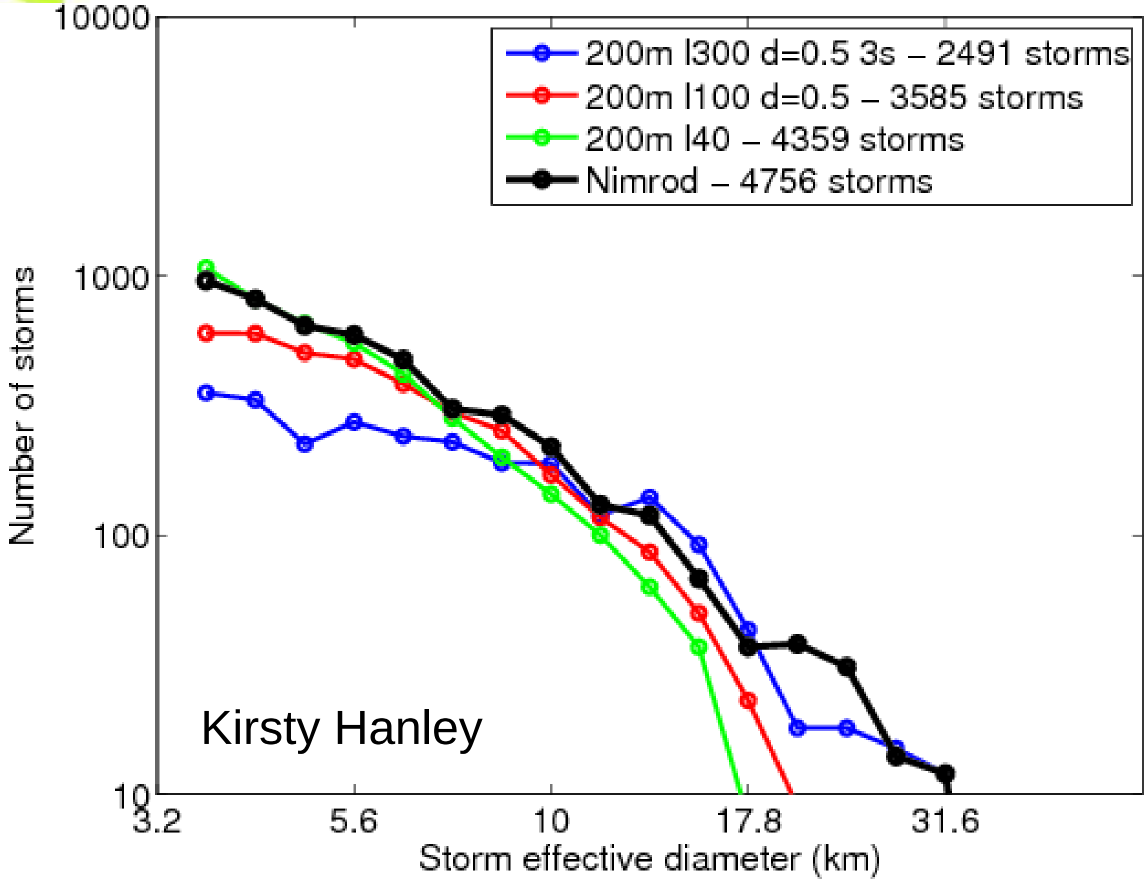
25 Aug 2012

Cutaway: reflectivity
Surface: rainrate
Shading: extent of cloud



Robin Hogan DYMECS Project

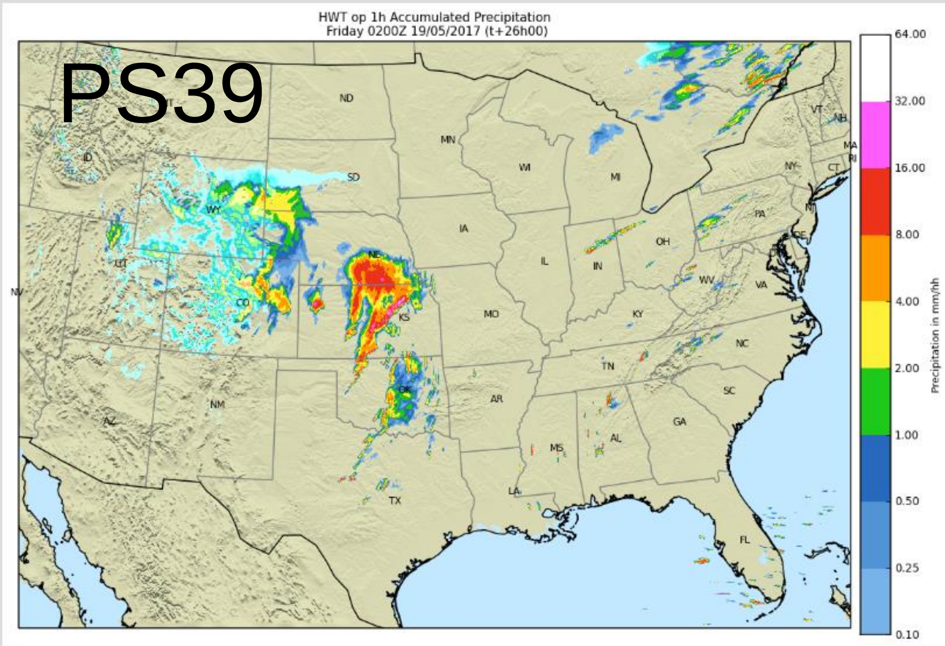
Cell statistics sensitive to mixing formulation

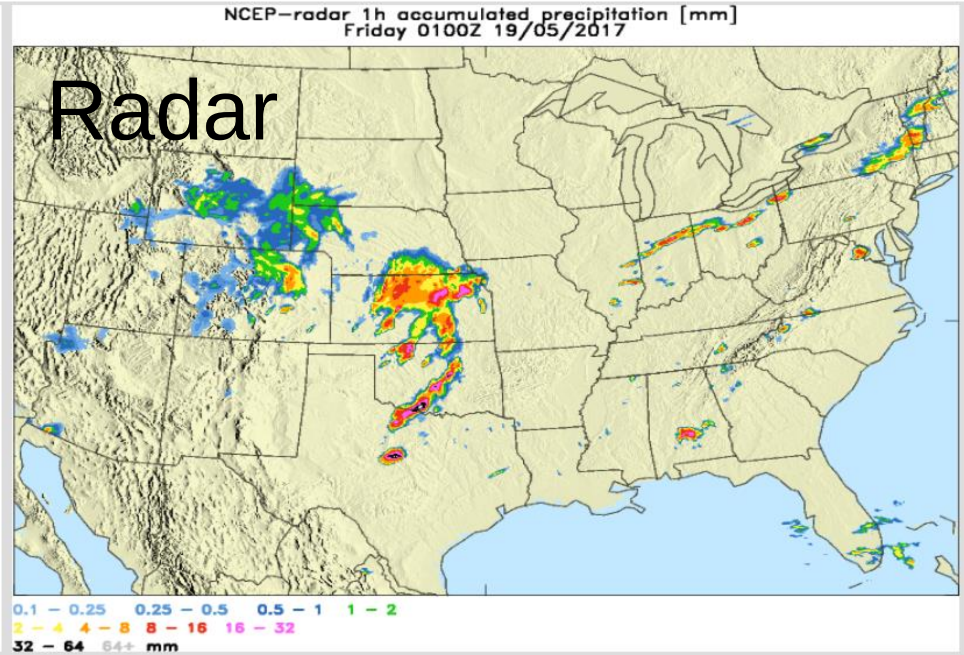


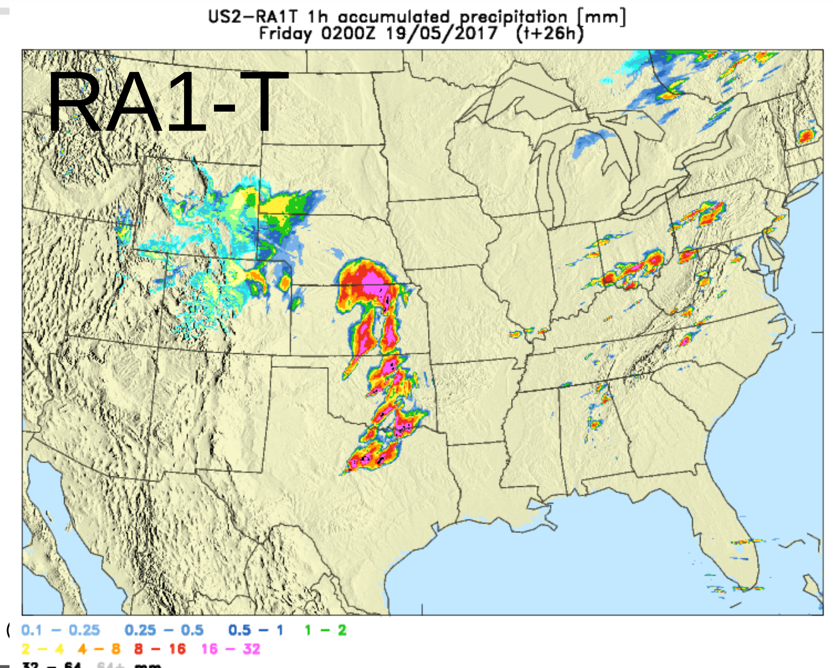
Cell statistics as measured by surface rainrate with 4mm/hr threshold.

- Implication is that there is not enough mixing (either subgrid or explicit) for larger cells with Smagorinsky formulation.
- Lock et al (Blobbiness Working Group) have found that, for RCE case, 200m UM consistent with equivalent Large Eddy Model.

PS39 – RA1-T difference for HWT.







1 hour accumulations 02UTC 19/05/2017 T+26

Upscaling of small storms in OK/TX very Different. Main difference PC2.

Too many small cells when well resolved.

- Often seen across many scales.

- Appears to be related to turbulence formulation.

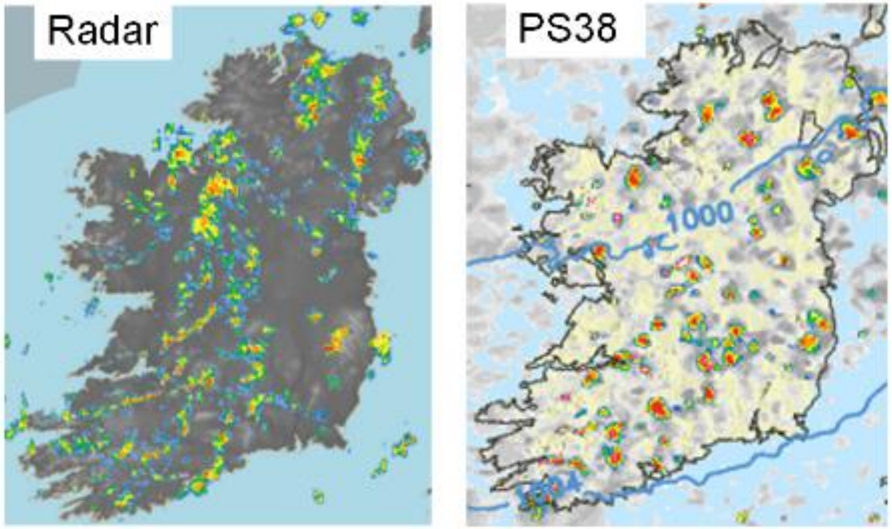
- Also sensitive to microphysics and cloud scheme

- Know that PC2 changes the blobbiness/upscaling of storms (SingV 4.1/RA1-T) example HWT.

Lack of small cells when poorly resolved (common in UKV)

Met Office

- Many of the small cells too small to be correctly resolved , (worse if you think about updrafts).
- Also relevant to initiation.
- Would like to use convection scheme but problems with conventional scheme.
- Subject of current work and NERC/MO "ParaCon" project.
- See talk by Mike Whittall later in workshop.



14UTC 27th Aug 2015, T+10

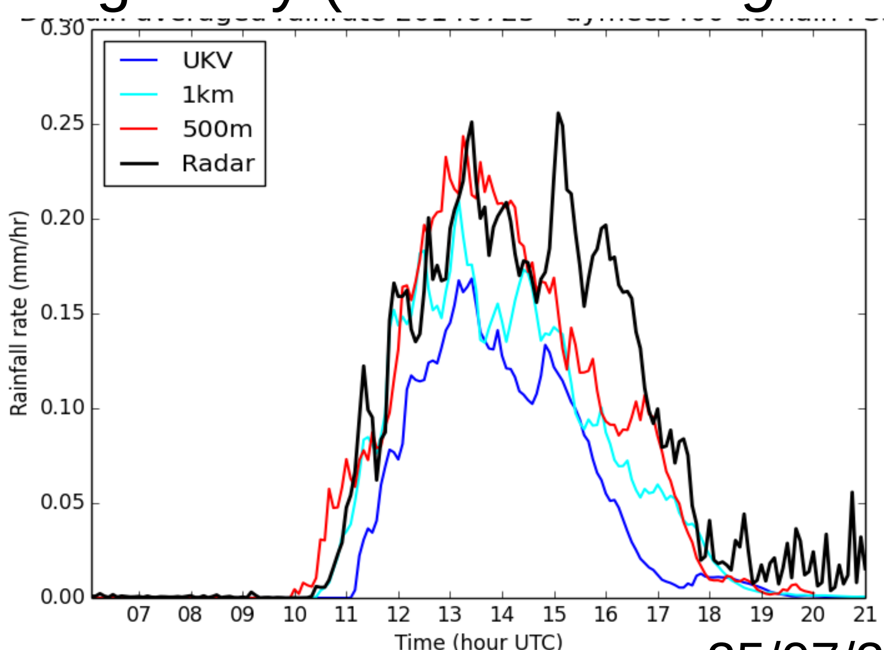
Threshold (mm/hr)	Radar	1.5km UKV
0.125	7.81	16.04
0.25	6.32	13.21
0.5	5.58	11.71
1.0	4.42	9.93
2.0	3.28	7.95
4.0	2.57	5.96
16.0	2.13	3.37

Average diameter of cells in UKV (Emilie Carter)

Another interesting example is convective initiation:

• A-priori expect convection to initiate late in convection permitting models because initial plumes too small to represent given (current) lack of subgrid representation (case for convection scheme).

•In UK this is seen to be the case with increased resolution/less mixing reducing delay (*or even making too early*).



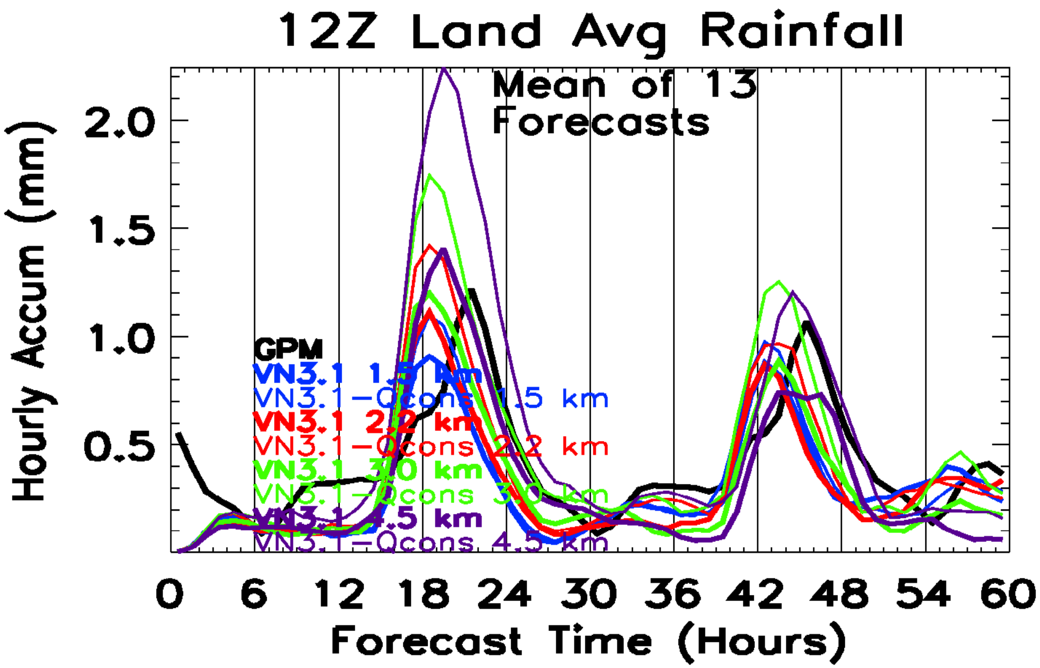
Kirsty Hanley

25/07/2014

Convective Initiation

- In tropics (e.g. Singapore) convection often initiates too early in models (changes with resolution/mixing the same direction).

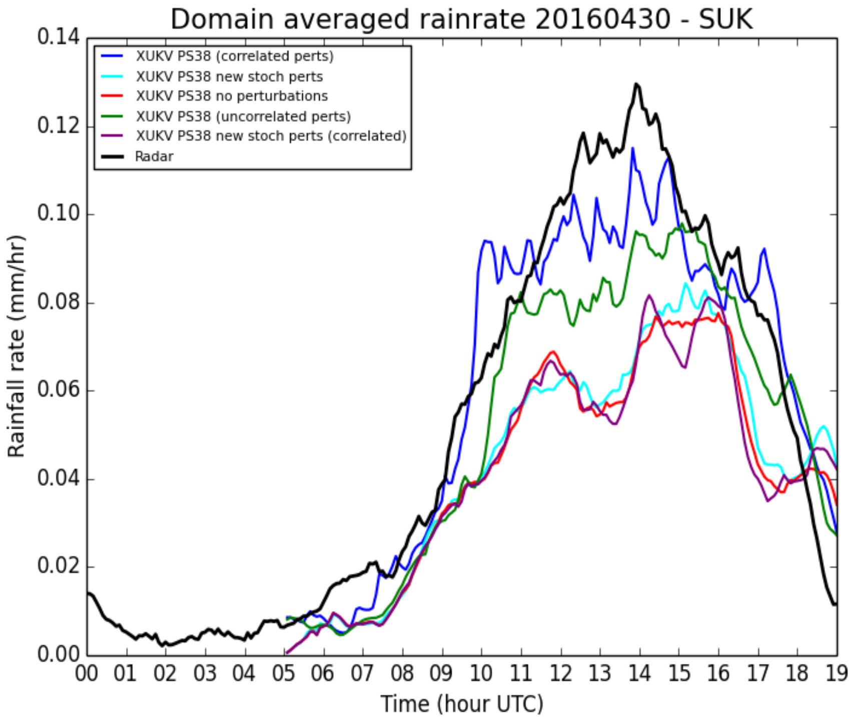
- Not known definitively why this is. Theory that CIN may be too small.



Stu Webster

Stochastic Schemes

- Also can influence initiation with stochastic schemes.
- Should compensate for unrealistic smoothness of fields due to finite resolution.



30/04/2016

Carol Halliwell

Convective Initiation:

- Again a number of ways in which we can change the time of initiation in the models: Resolution, mixing, stochastic perturbations, scale aware convection scheme...

- May also be trying to compensate for other errors in model: incorrect low level moisture, wrong amount of CIN etc.

Avoiding Compensating Errors....

• With these examples we have a number of things we can do in the model to change things.

•Danger of introducing compensating errors if choose wrong ones. Which would become evident in different situations or affect on other parameters.

• Answer to this is to fully understand what is causing issue.

• Will have to be compromises due to finite resolution of model.

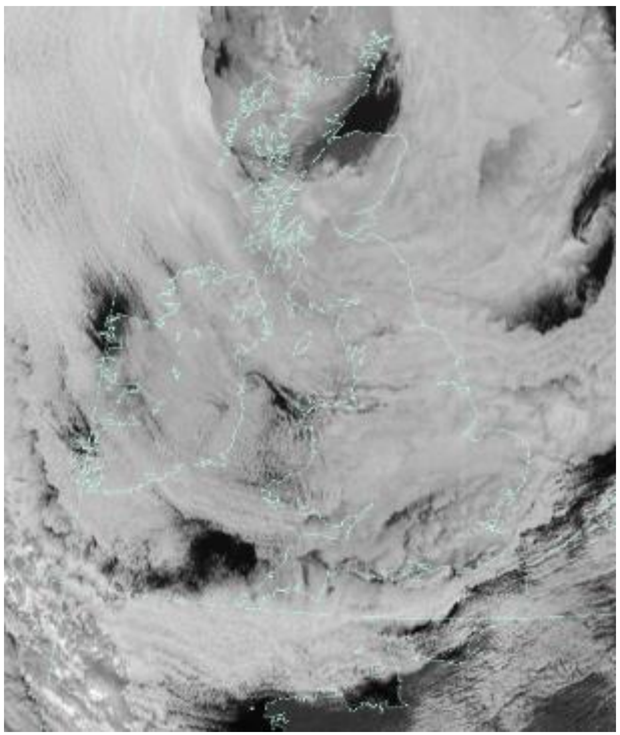
• Process studies on individual cases constrained by observations.

• Require detailed observations to help unpick things.

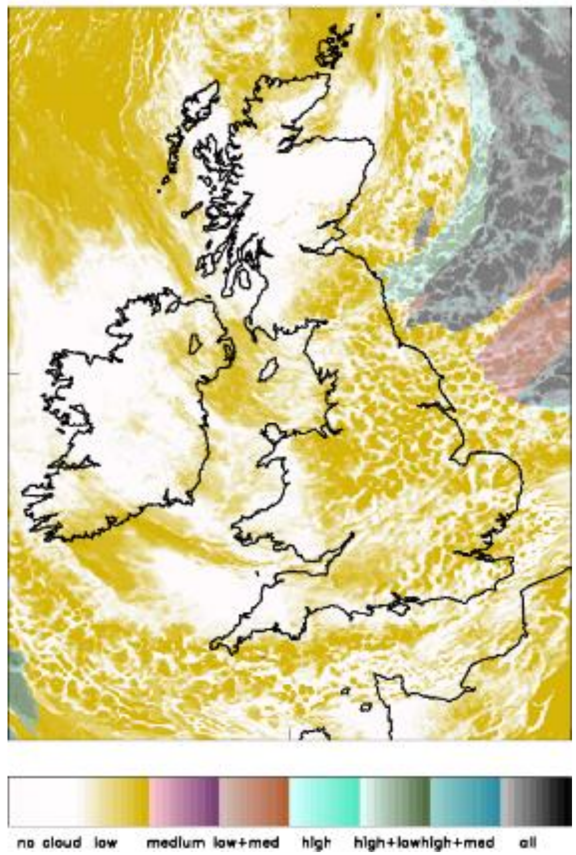
• In turbulence case can make observations of vertical velocities and turbulence with radar.

Effect of mixing change on cloud

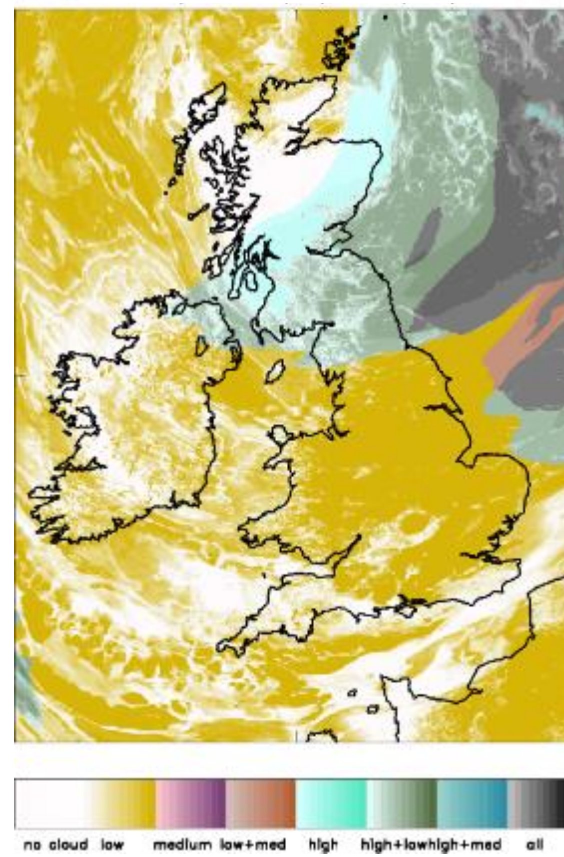
Amount of mixing influences amount of cloud. In this example if too little mixing cloud spuriously breaks up.



UKV control



Blended BL package



A Lock

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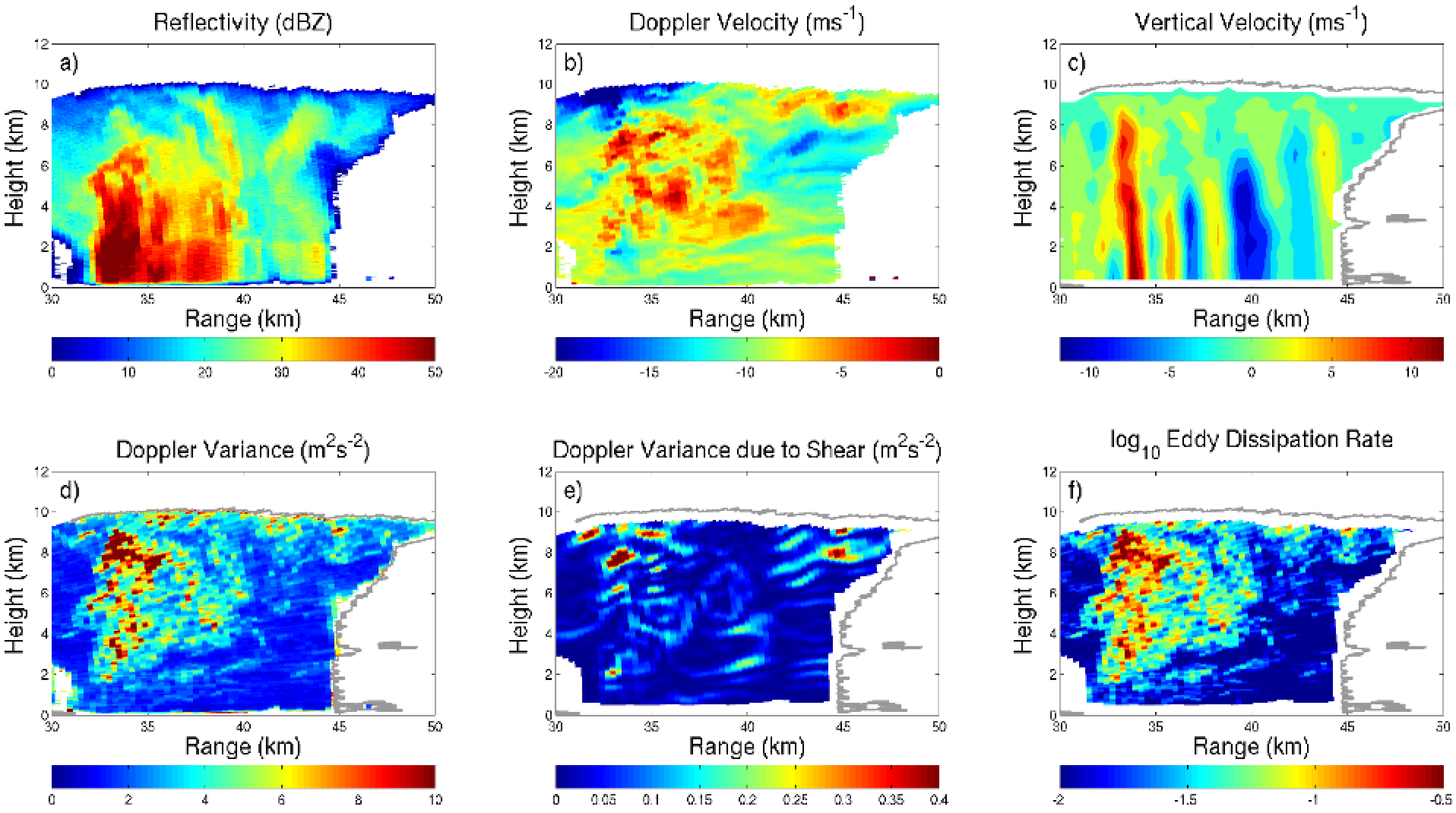
Turbulence in Convective Clouds

Example retrieval from 25th Aug 2012



Matt Feist.

Larger Scales

•Larger scale structures of convection may be determined by driving (global) model although upscaled effects from smaller scale convection also important.

• Study in from summer 2011 cases showed that leading cause of poor forecasts for important events in UKV was large scale forcing of model (consistent with initially running MOGREPS-UK as downscaling ensemble).

•UM generally considered to do well in HWT (subjective/objective verification scores better than NSSL WRF) despite biases in cell stats etc. Suspect this is because global model is good.

•Suspect larger scale less accurate/important in tropics where synoptic forcing less important. Upscaling of convection therefore likely to be more important.

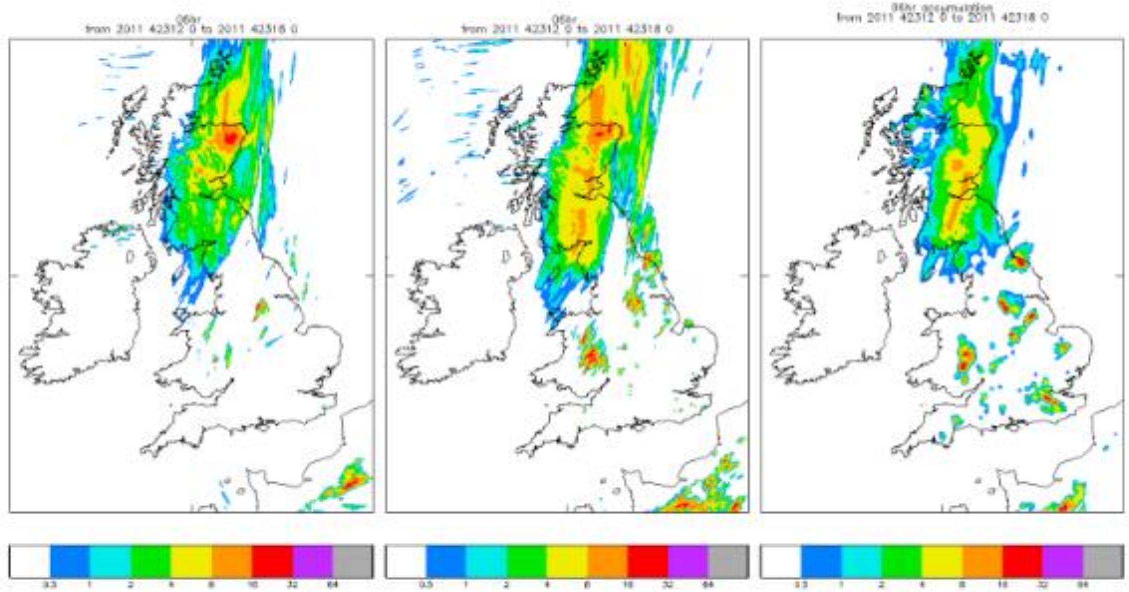
• These issues very relevant to question of how to run ensembles.

UKV problems often imported from larger scales

Met Office

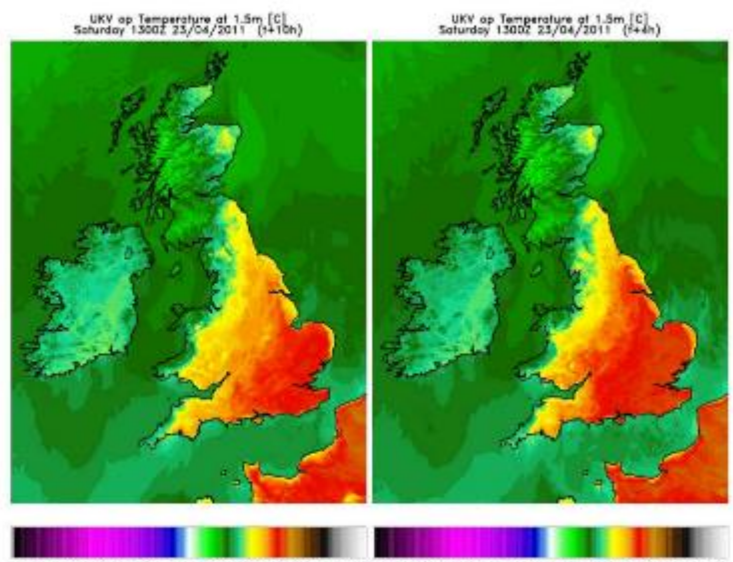
03UTC UKV 09UTC UKV Radar

12-18UTC Accumulations



(c)

Warmer temps ahead of front in 09UTC run due to different frontal structure.



23rd April 2011 Floods in Sheffield

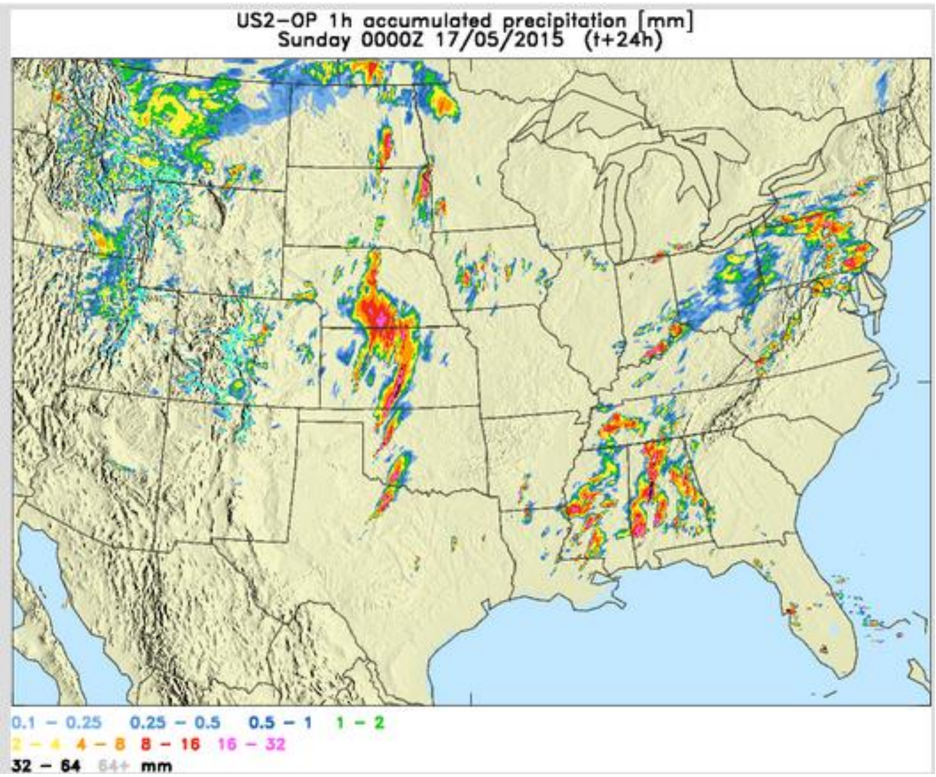
Met Office

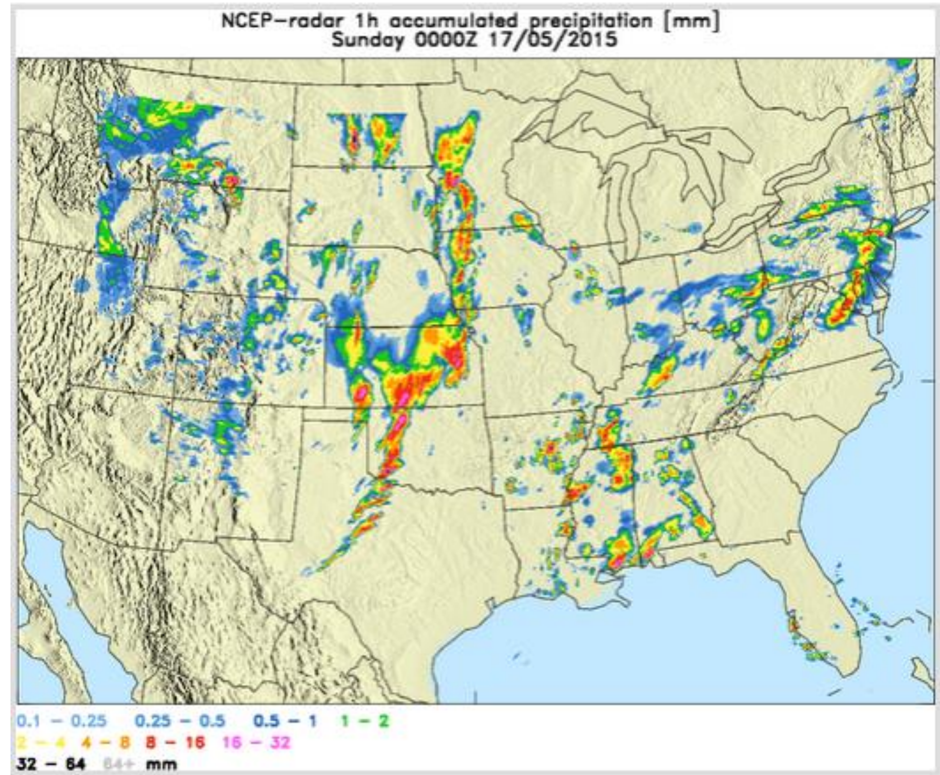
Example of US forecast.

2km UM

Radar

00 UTC 17th May 2015





- Despite biases in representation of convection good forecast.

Mark Weeks

Larger Scales

- Larger scale structures of convection may be determined by driving (global) model although upscaled effects from smaller scale convection also important.

- Study in from summer 2011 cases showed that leading cause of poor forecasts for important events in UKV was large scale forcing of model (consistent with initially running MOGREPS-UK as downscaling ensemble).

- UM generally considered to do well in HWT (subjective/objective verification scores better than NSSL WRF) despite biases in cell stats etc. Suspect this is because global model is good.

- Suspect larger scale less accurate/important in tropics where synoptic forcing less important. Upscaling of convection therefore likely to be more important.

- These issues very relevant to question of how to run ensembles.

- Predictability/balance of large and small scale errors an important area for research.

Conclusions and future developments

- Convection permitting models have provided a step change in ability to forecast convection (among others).

- Need to bear in mind lack of predictability on small scales when using or verifying these models.

- There are a number of biases in representation of convection in these models which are sometimes complex to address because of different possible causes.

- Interaction of large and small scales is an important aspect. This will be different in different situations/parts of world.

Future Directions

• Continue to improve representation of convection in km scale models by developing relevant parameterisations informed by observational work.

•Much work on convection and turbulence parameterisations.

• Moving on to O(100m) models (turbulence permitting regime). Much research at O(100m) – including by UM Partners. Initially over small areas e.g. city scale models. Formulating strategy for urban modelling.

Questions?