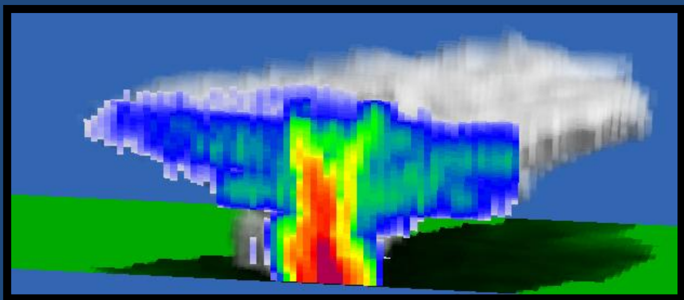
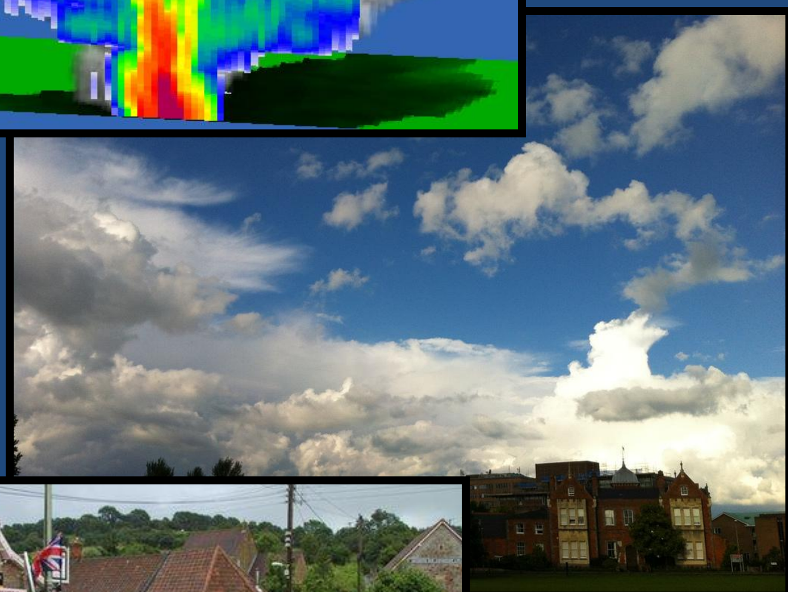
The Dynamical and Microphysical Evolution of Convective Storms

DYMECS

A statistical evaluation of convective storms in high-resolution Unified Model simulations





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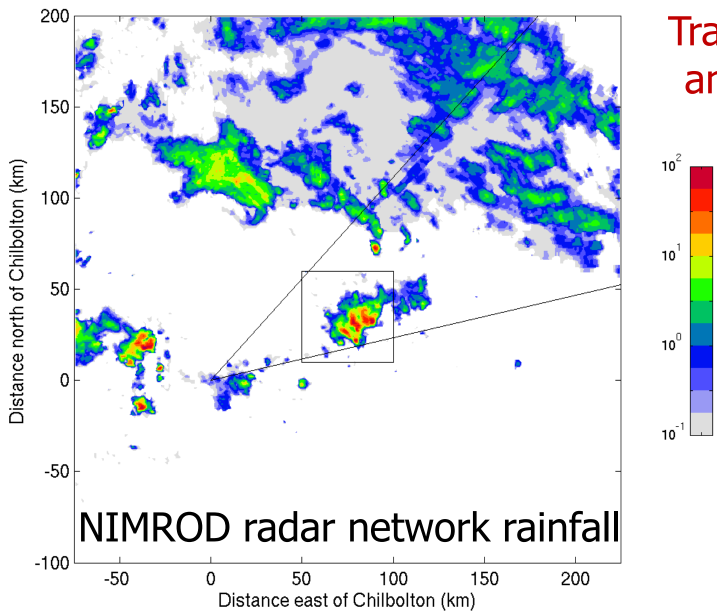
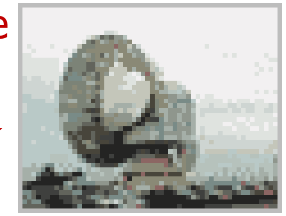
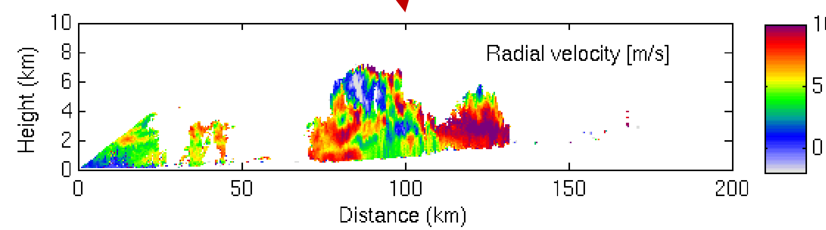
The DYMECS approach: beyond case studies



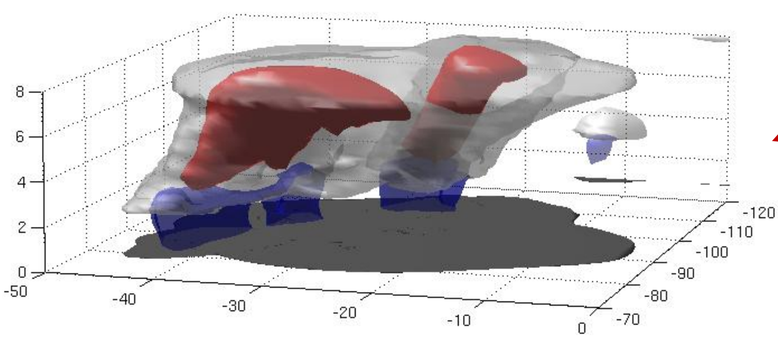
Track storms in real time and automatically scan Chilbolton radar

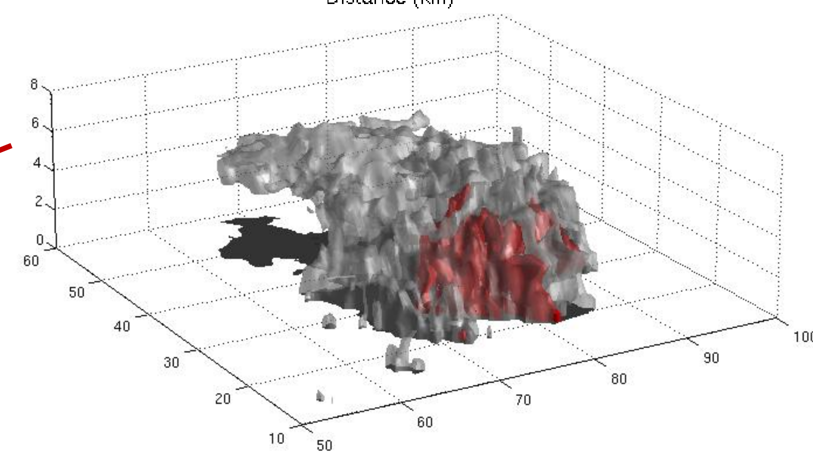


Derive properties of hundreds of storms on **~40 days**:
Vertical velocity
3D structure
Rain & hail
Ice water content
TKE & dissipation rate



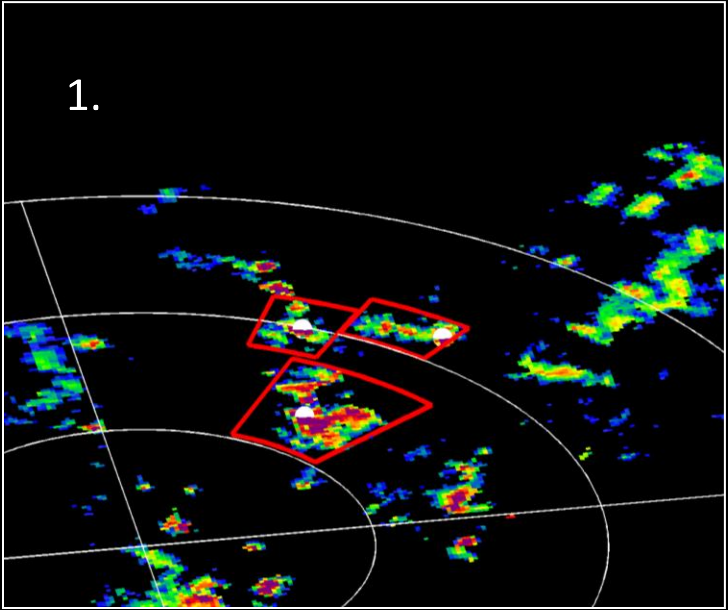
Evaluate these properties in model varying:
Resolution
Microphysics scheme
Sub-grid turbulence parametrization





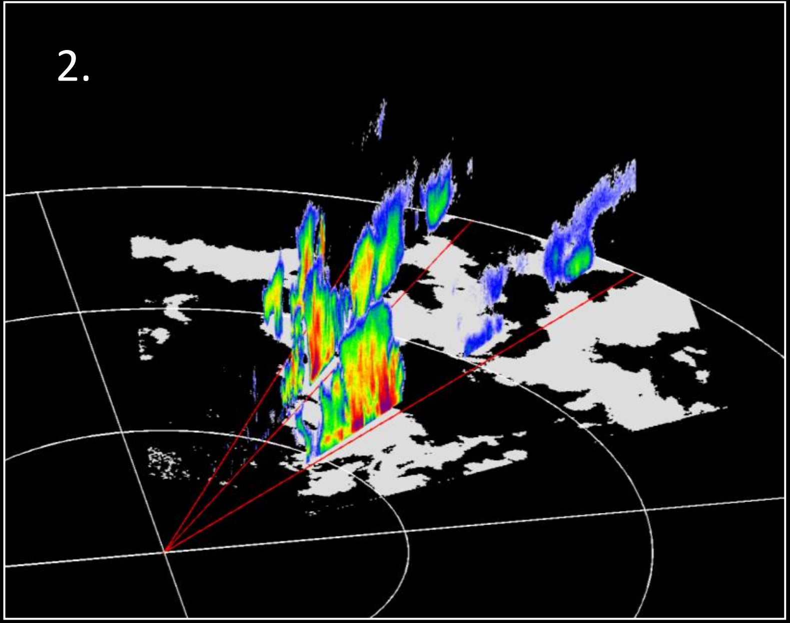
Automated scanning with CAMRa

1.

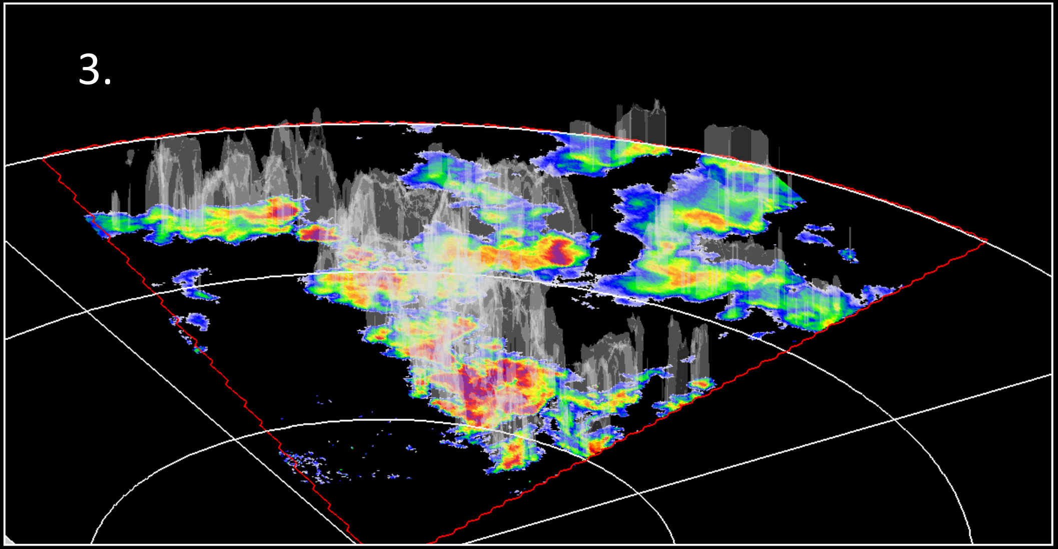


0. Storms were tracked in MetOffice rainfall radar data.
1. The scan scheduler prioritized storms by area and mean rainfall, with a preference for previously scanned storms and locations.
2. Sets of 4 RHIs were performed through locations of maximum rainfall.
3. A volume scan of 6-12 PPIs was performed through prioritized storms (either separately, or in a single volume if grouped closely in azimuth).

2.



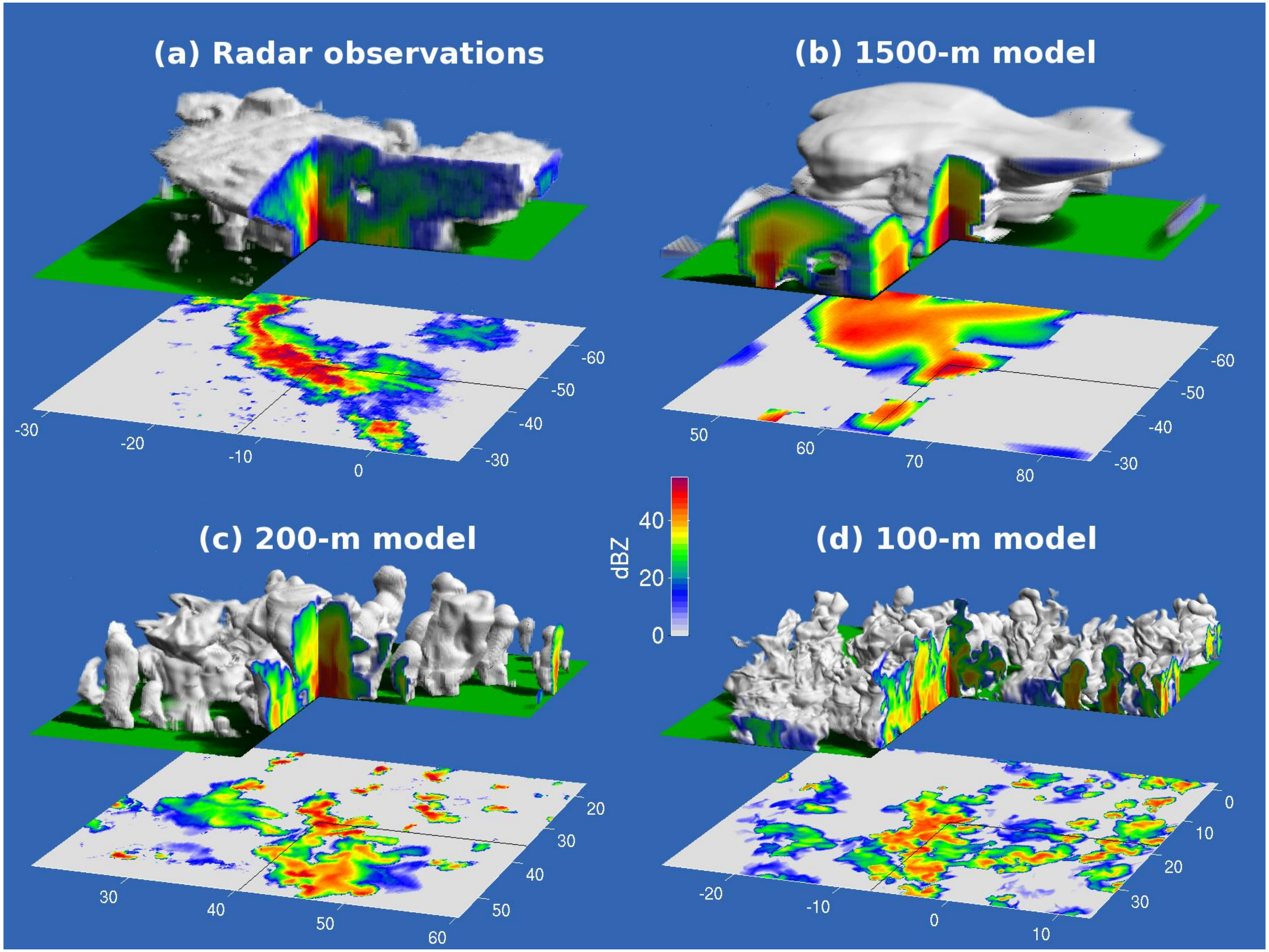
3.



3D visualisation of data

25 Aug 2012

Cutaway: reflectivity
Surface: rainrate
Shading: extent of cloud

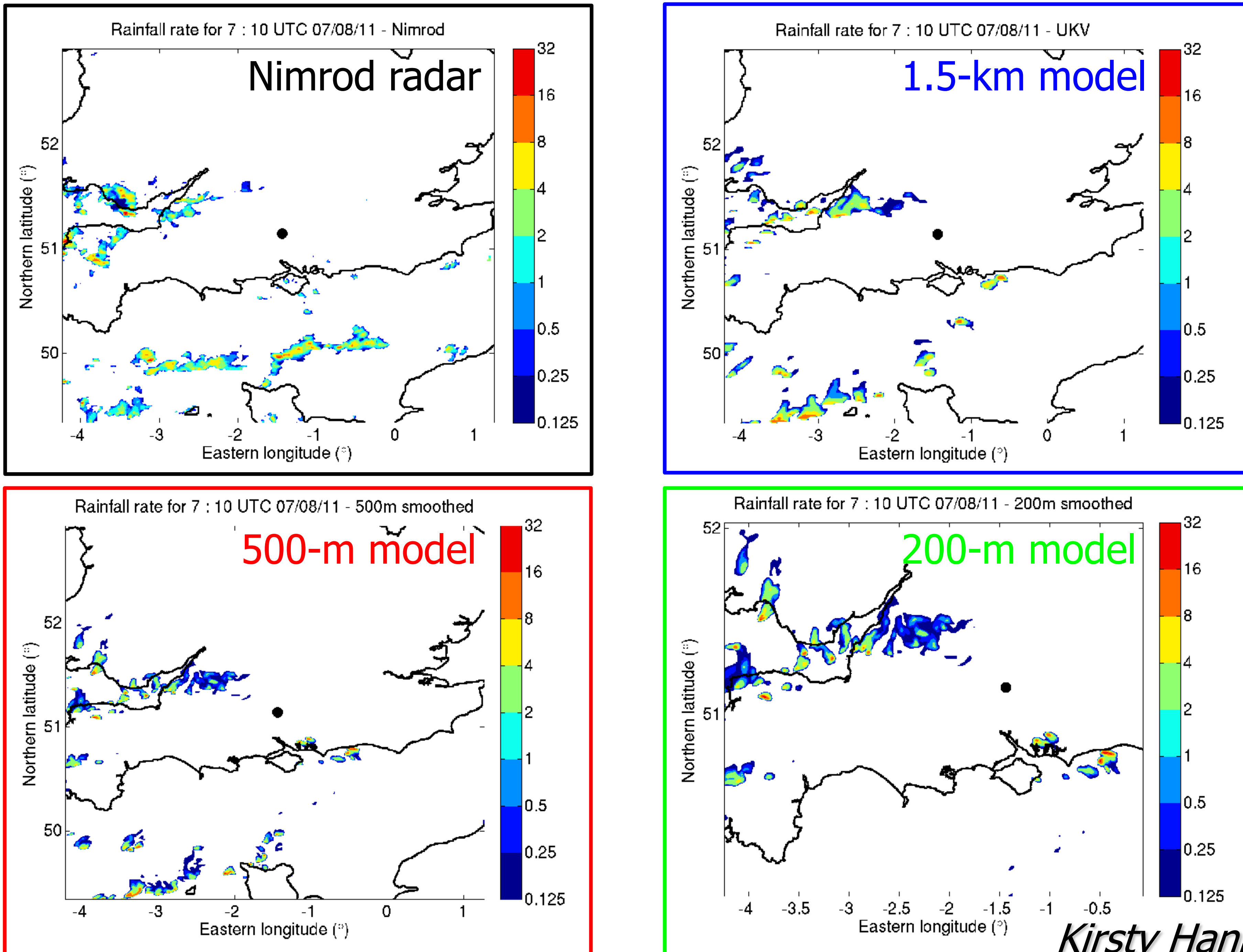


Robin Hogan

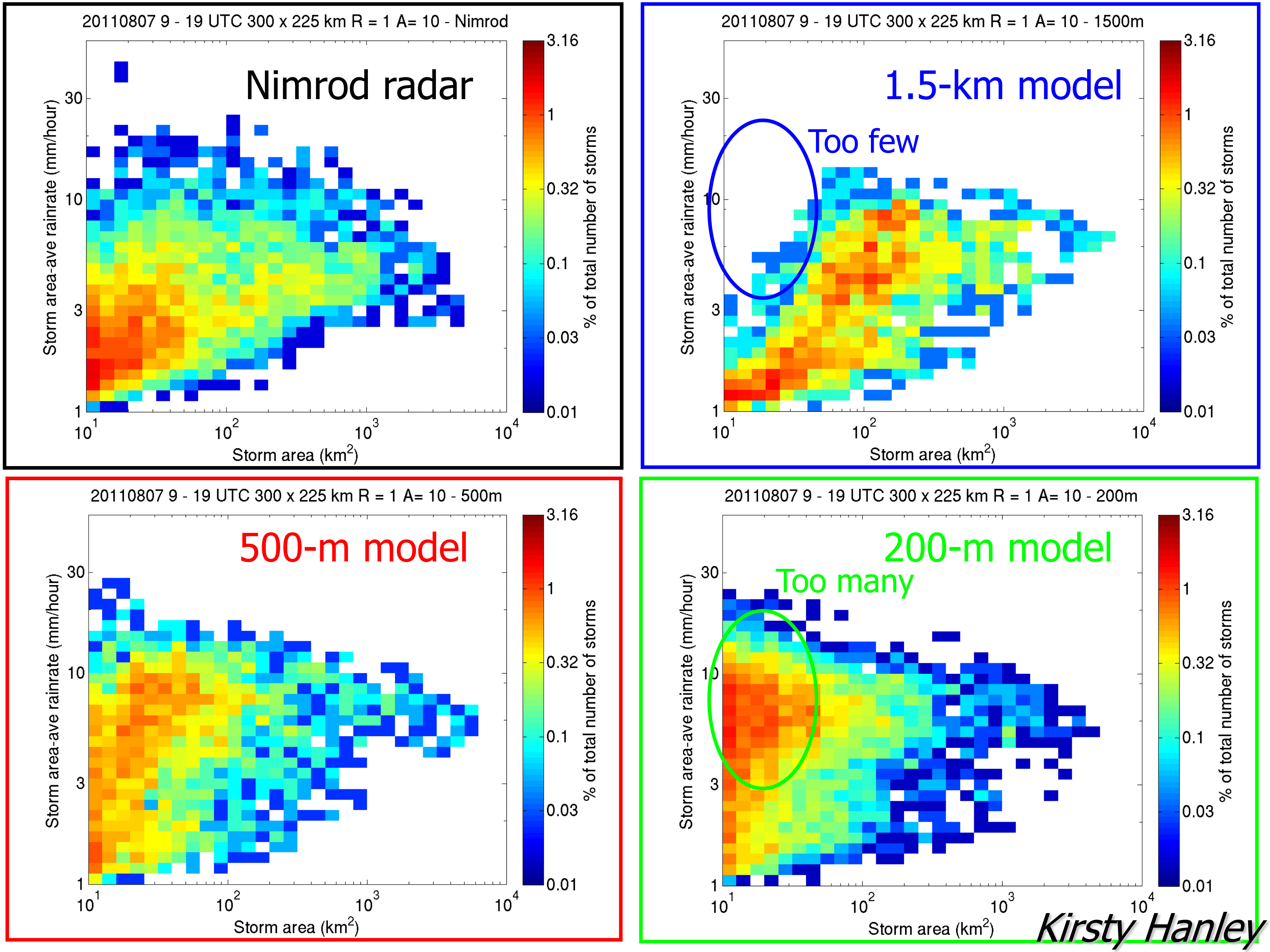
Evaluate convective storm characteristics in the Unified Model

Precipitation patterns and life cycles

Storm and updraught structure

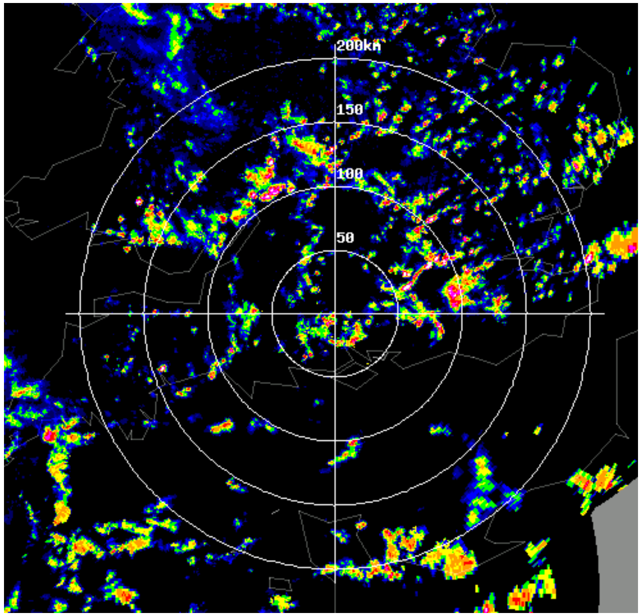


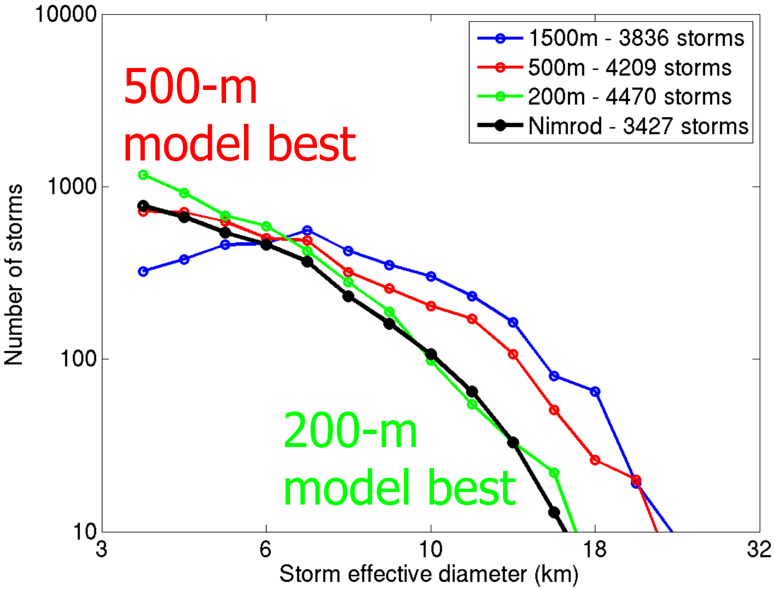
Kirsty Hanley



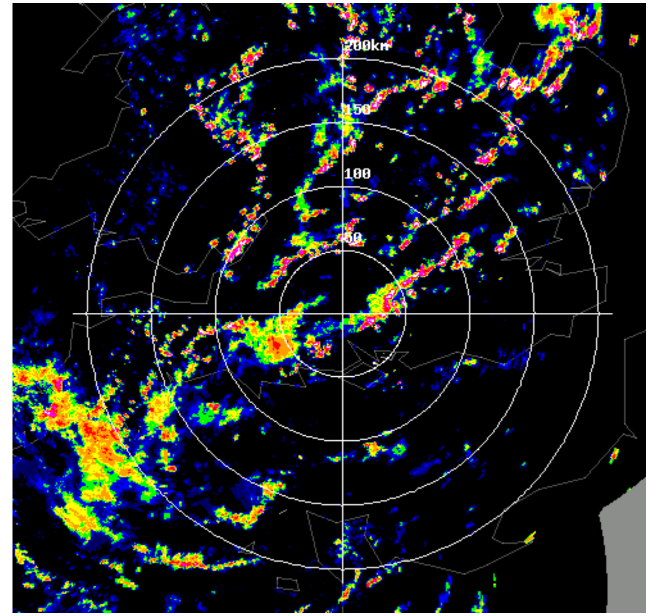
20110807 9 - 19 UTC 300 x 225 km R = 1 A= 10 - Nimrod
Nimrod radar
20110807 9 - 19 UTC 300 x 225 km R = 1 A= 10 - 1500m
1.5-km model
Too few
20110807 9 - 19 UTC 300 x 225 km R = 1 A= 10 - 500m
500-m model
20110807 9 - 19 UTC 300 x 225 km R = 1 A= 10 - 200m
200-m model
Too many
Storm area-ave rainrate (mm/hour)
Storm area (km2)
% of total number of storms
3.16
1
0.32
0.1
0.03
0.01
Kirsty Hanley

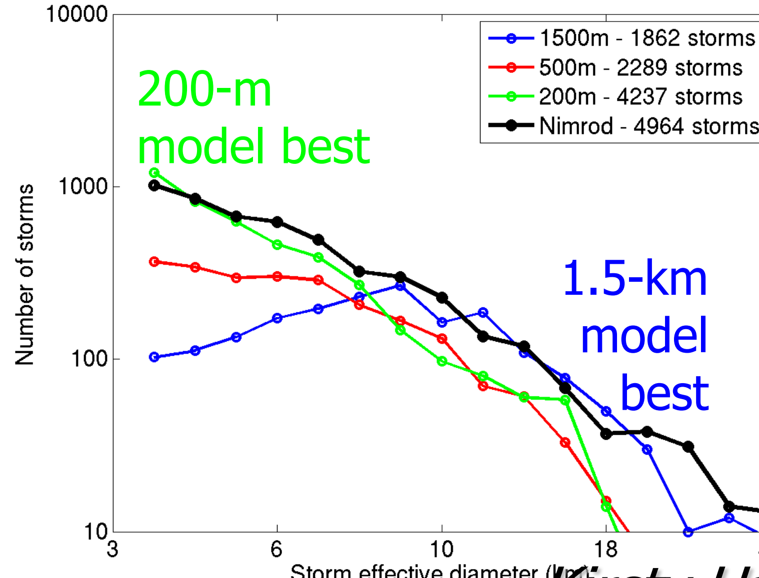
20 April 2012





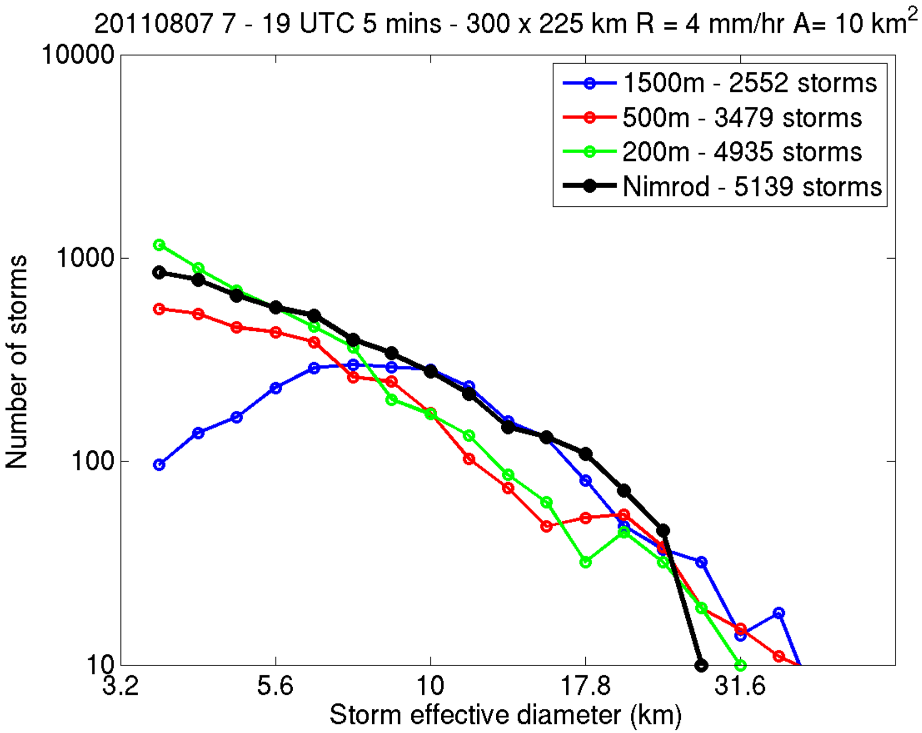
25 Aug 2012

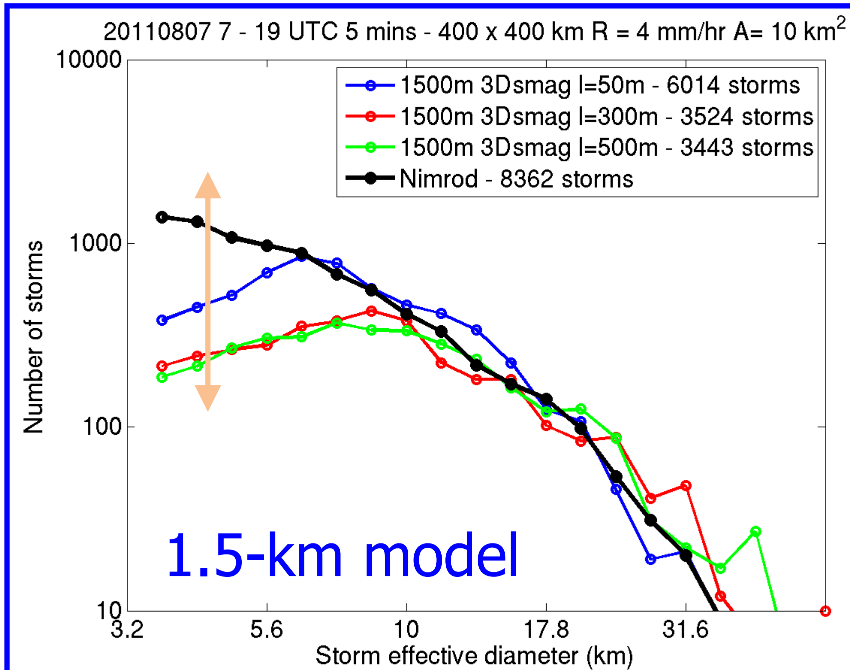


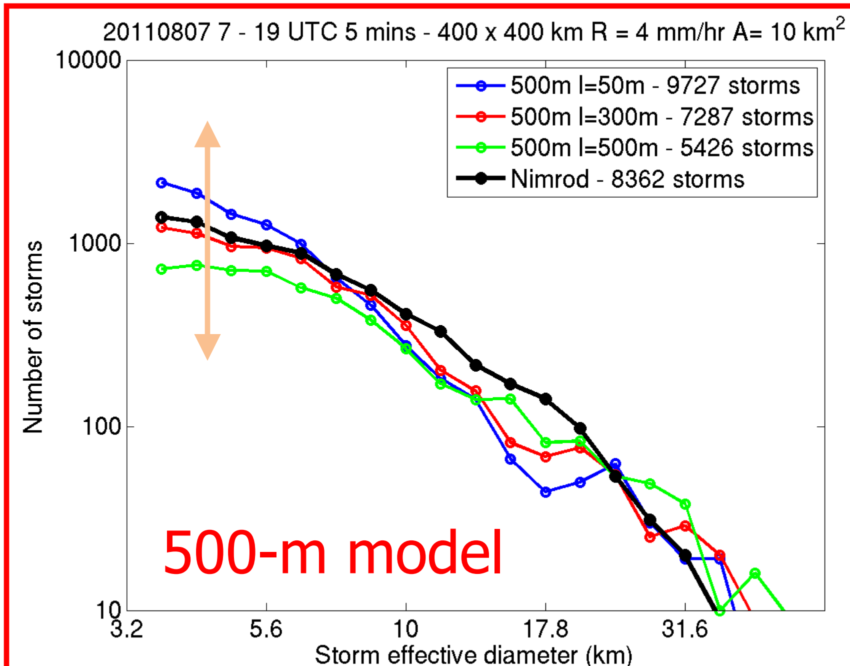


Kirsty Hanley

Storm size- Mixing length



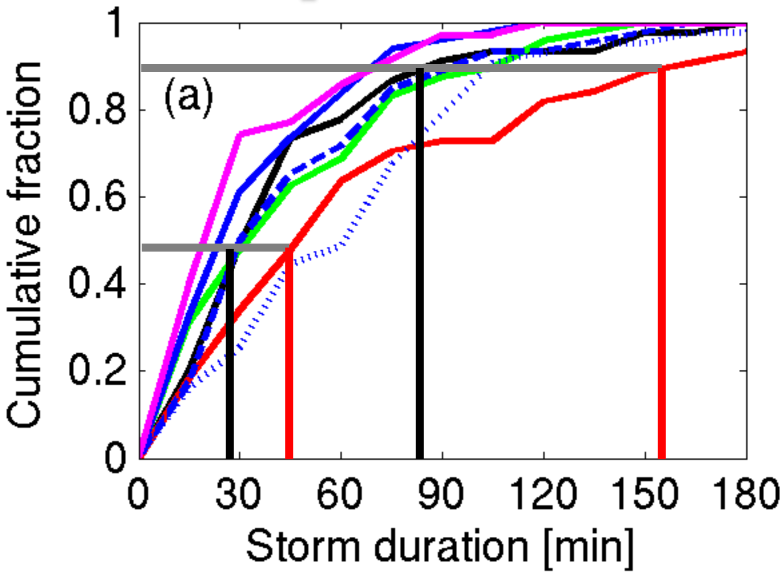




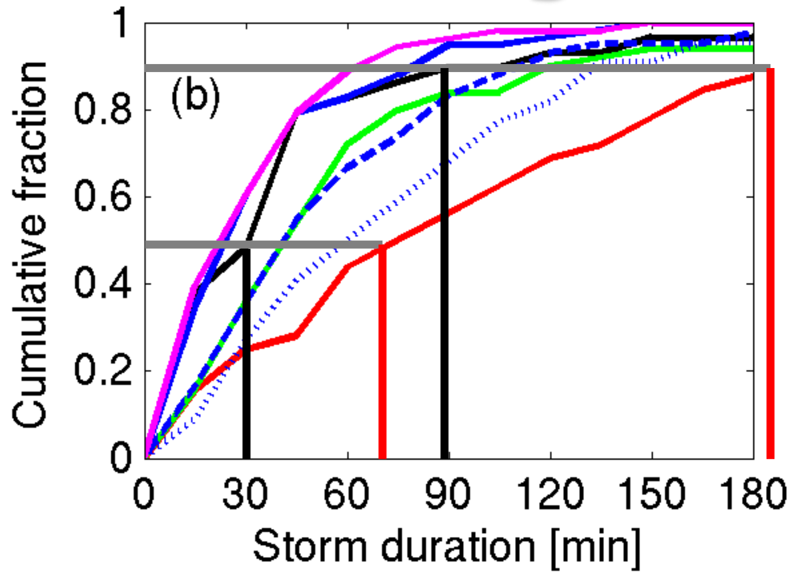
- Smagorinsky mixing length plays a key role in determining number of small storms

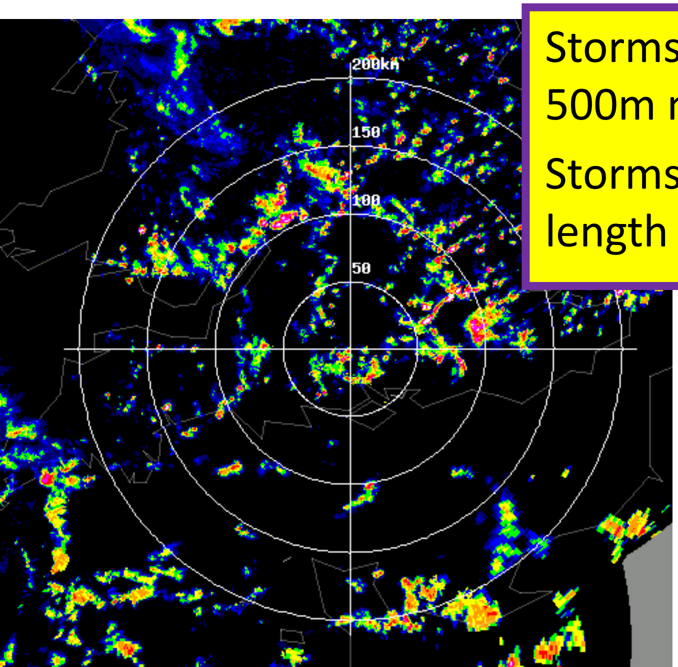
Kirsty Hanley

20 April 2012



25 Aug 2012

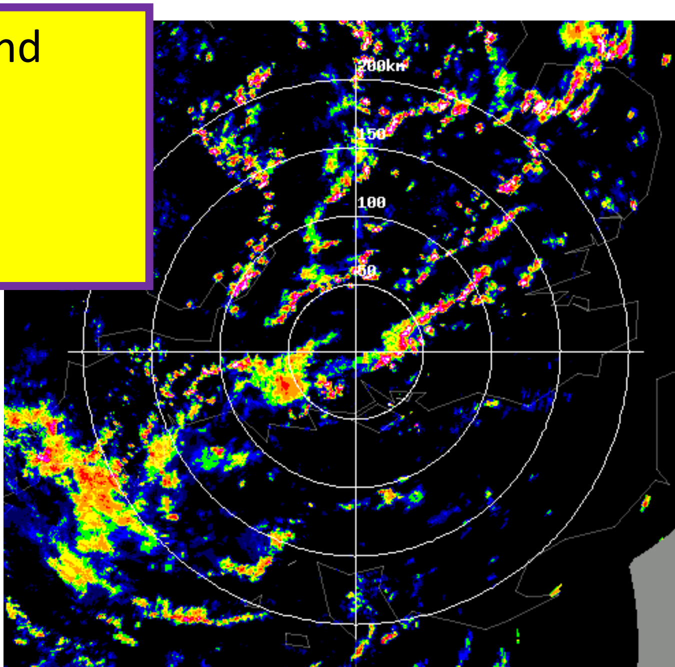




Storms last too long in the 1500m and 500m models.

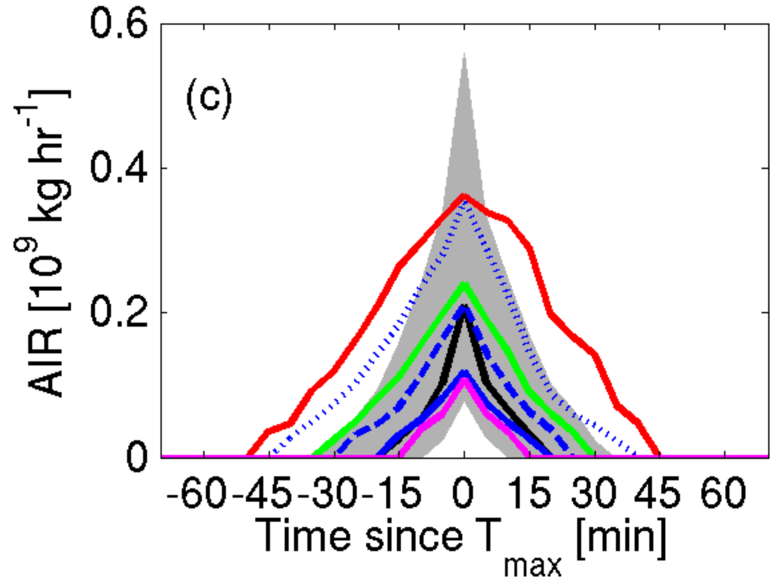
Storms also last longer when mixing length is increased.

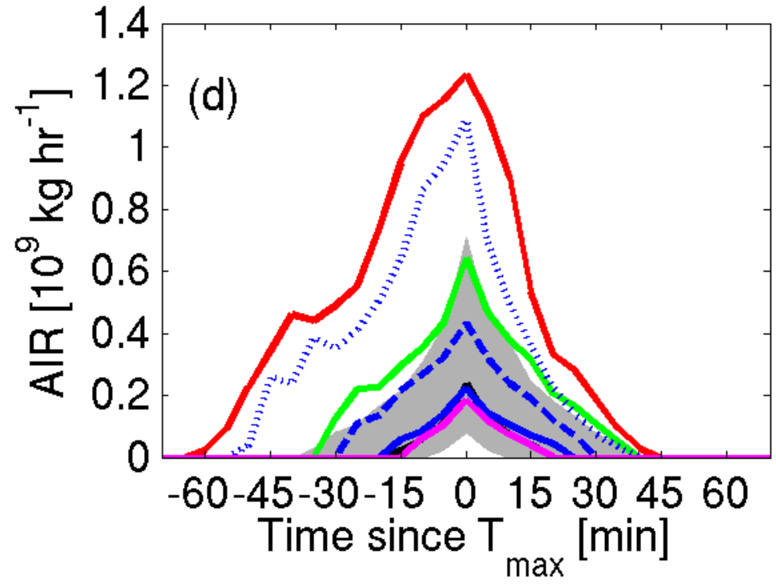
200m model, 40m mixing length
100m model
200m model, 100m mixing length
200m model, 300m mixing length

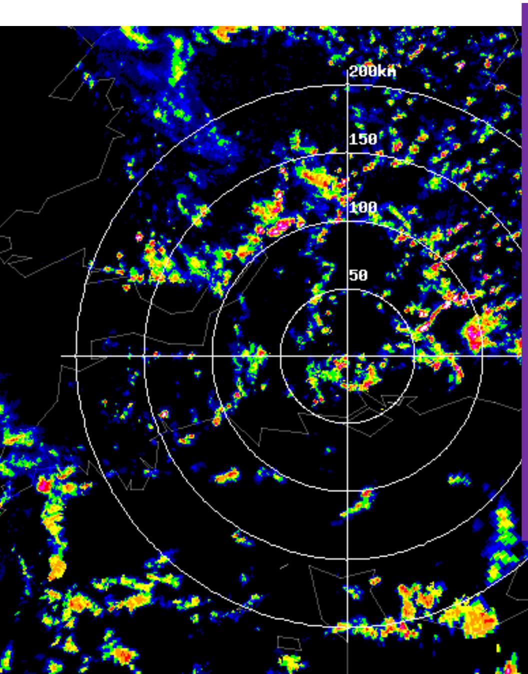


20 April 2012

25 Aug 2012



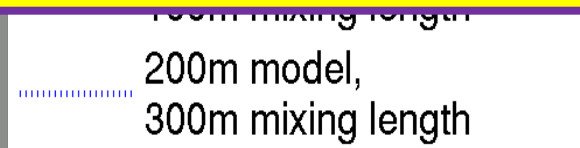


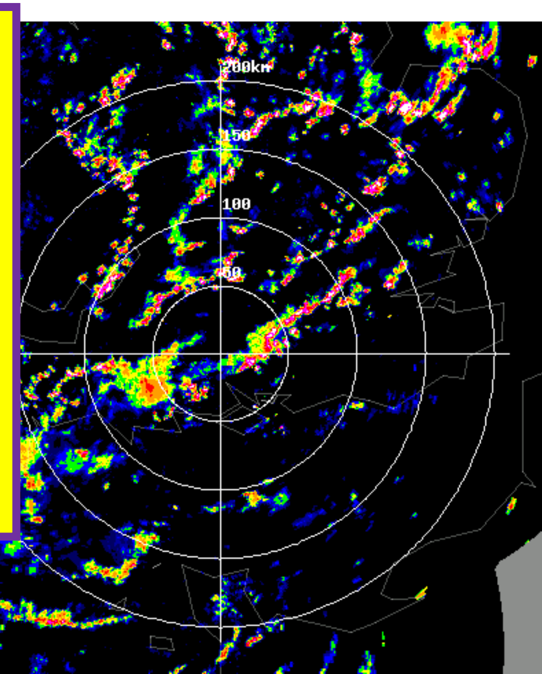


For the median life cycle (weighted by storm duration):

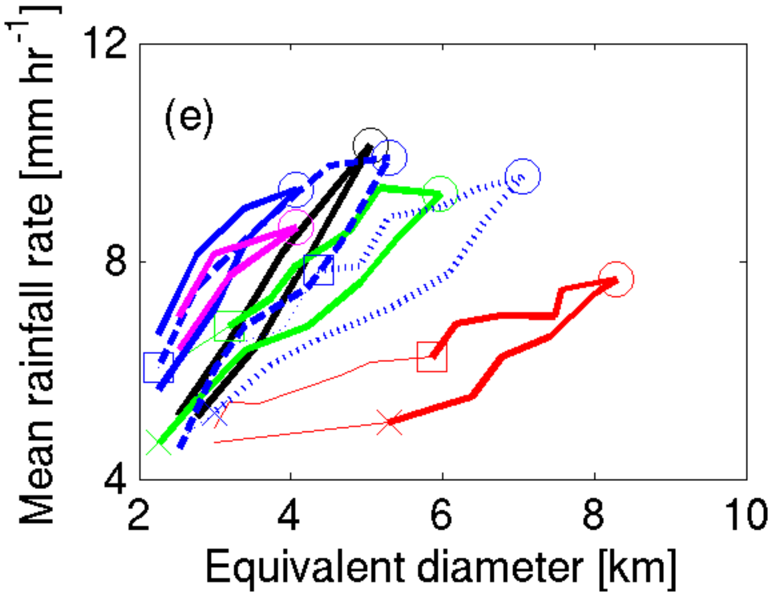
Area-integrated rainfall is reduced as grid length is reduced, with 200m and 100m models performing best.

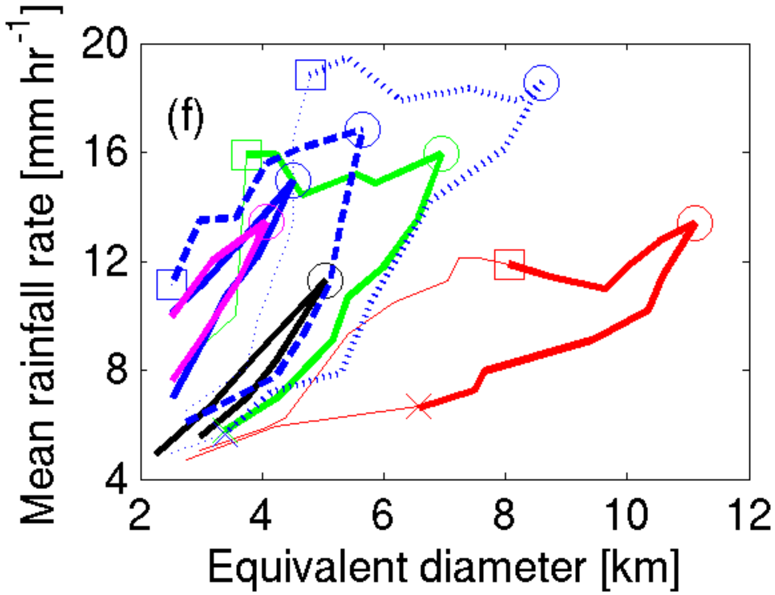
Area-integrated rainfall is increased with increasing mixing length, with 40m (default for 200m model) best.

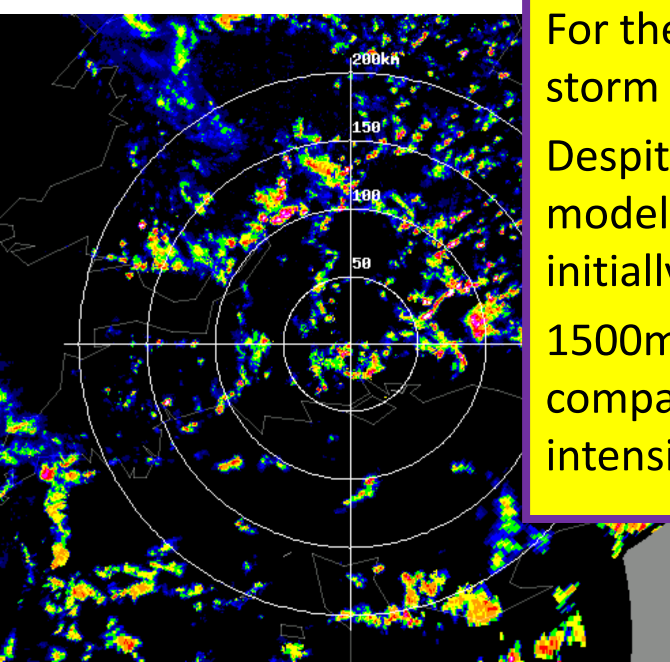




20 April 2012   25 Aug 2012





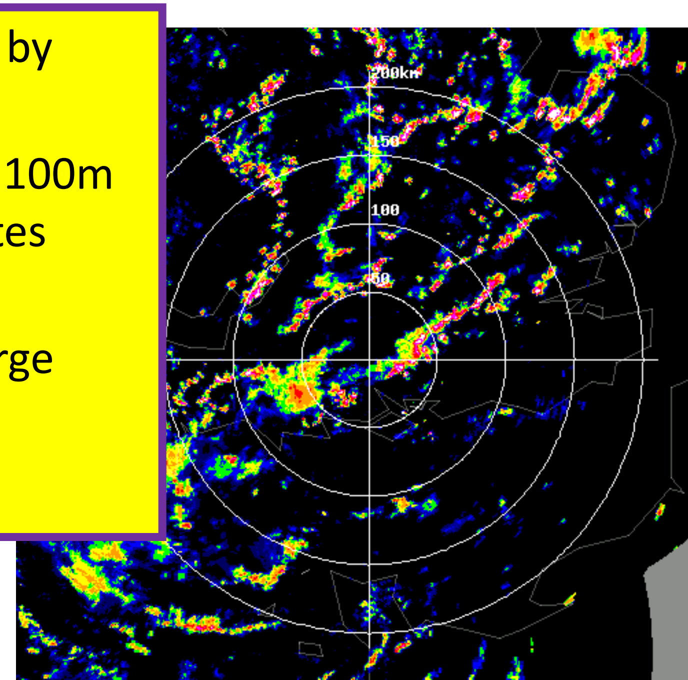


For the median life cycle (weighted by storm duration):

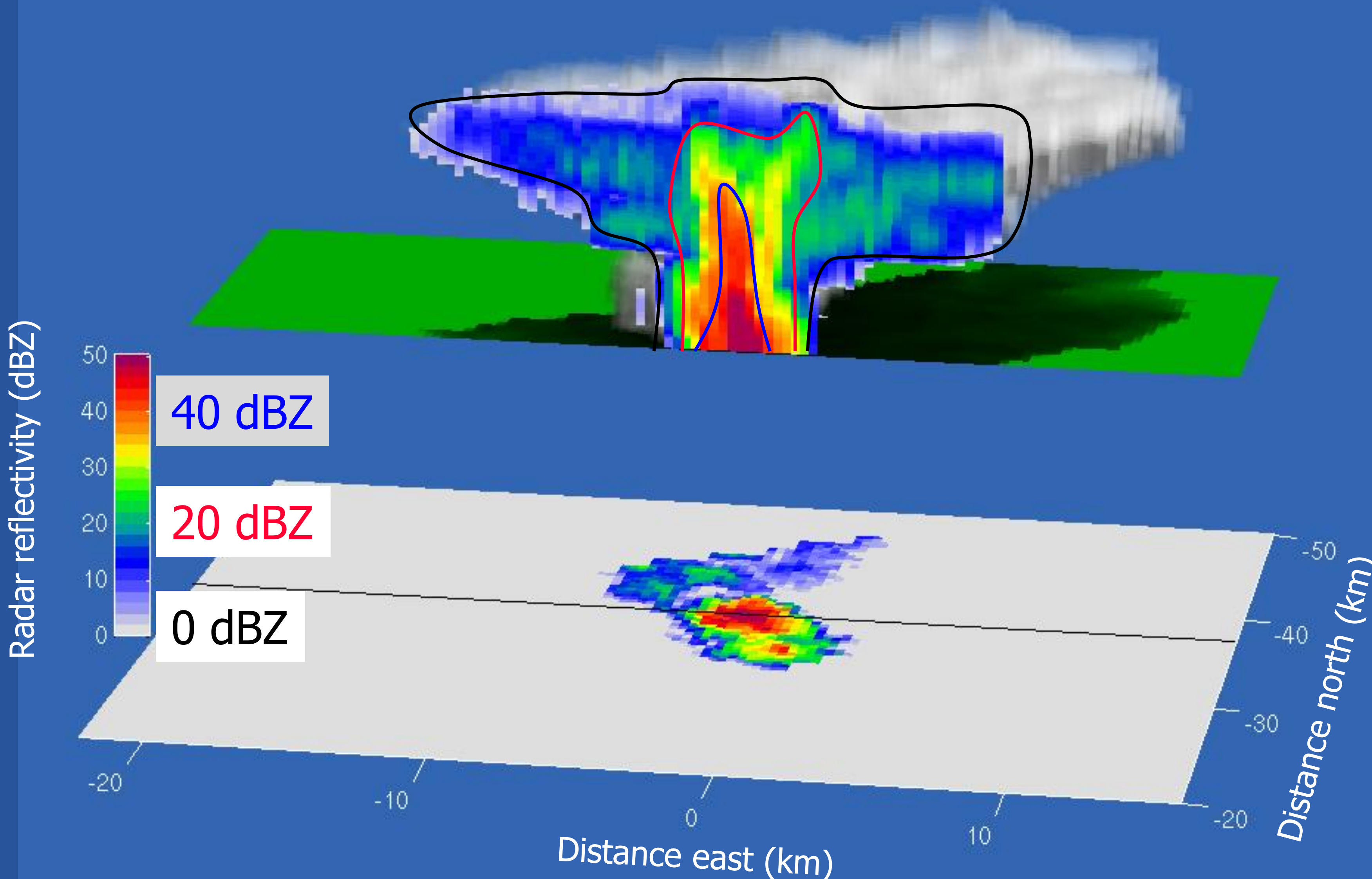
Despite good AIR cycles, 200m and 100m models have too high mean rain rates initially, also at small areas.

1500m has storms that grow too large compared to observations, though intensity is ok.

200m model,
300m mixing length



Storm structure from radar



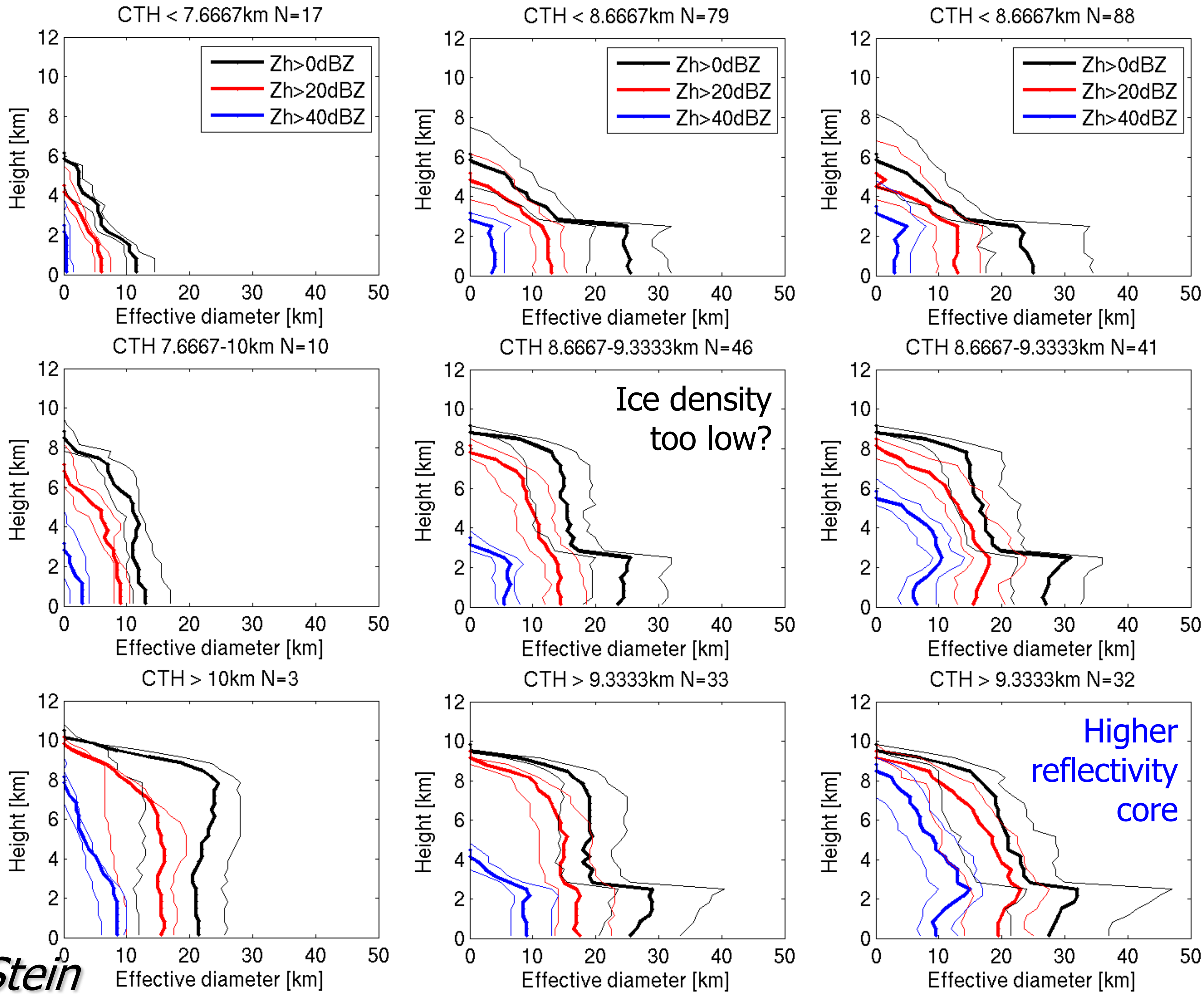
Vertical profile

Observations | **1.5-km model** | **1.5-km + graupel**

First 60% of storms by cloud-top height

Next 30%

Top 10%



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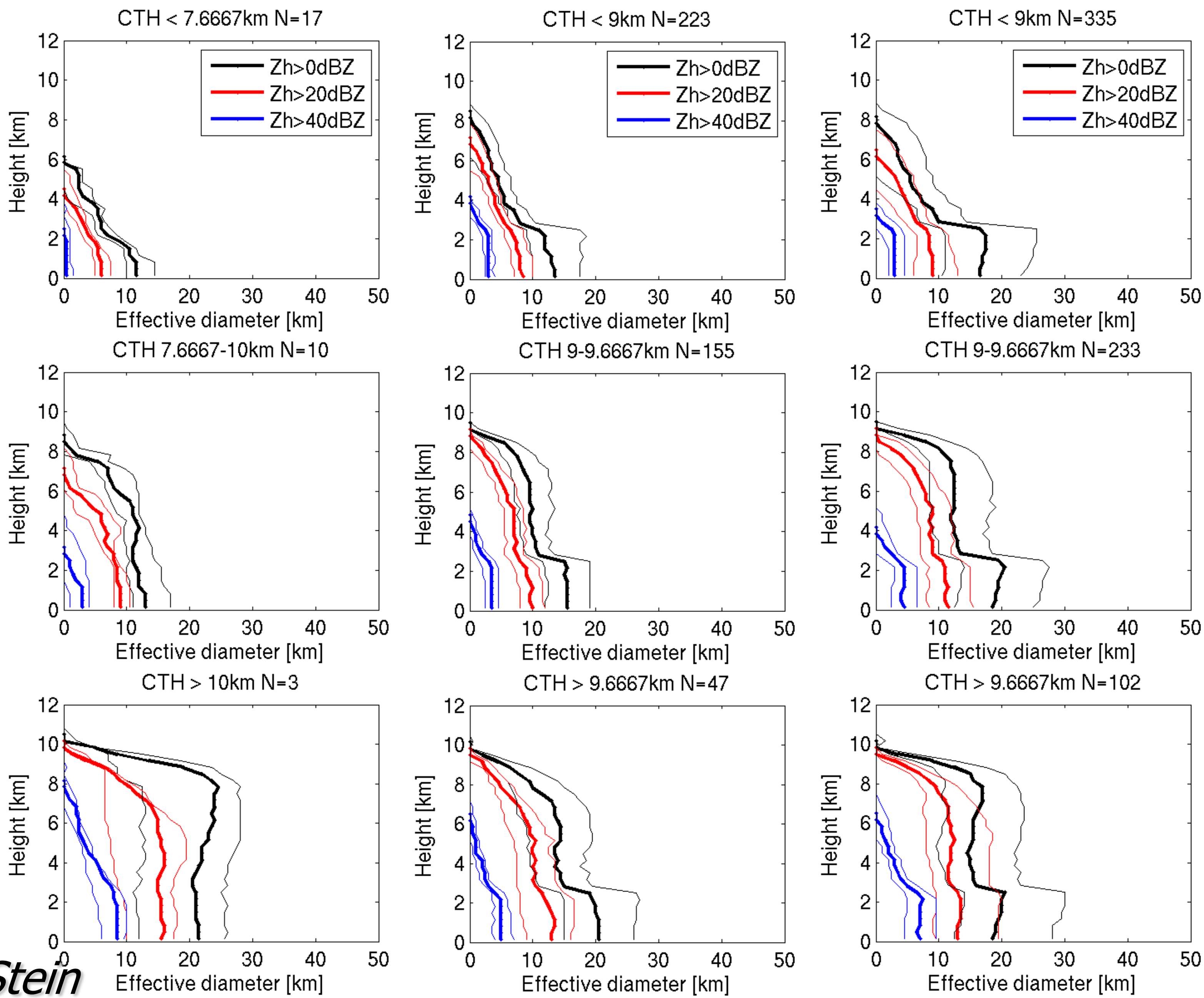
Vertical profile

Observations | **200-m model** | **500-m model**

First 60% of storms by cloud-top height

Next 30%

Top 10%



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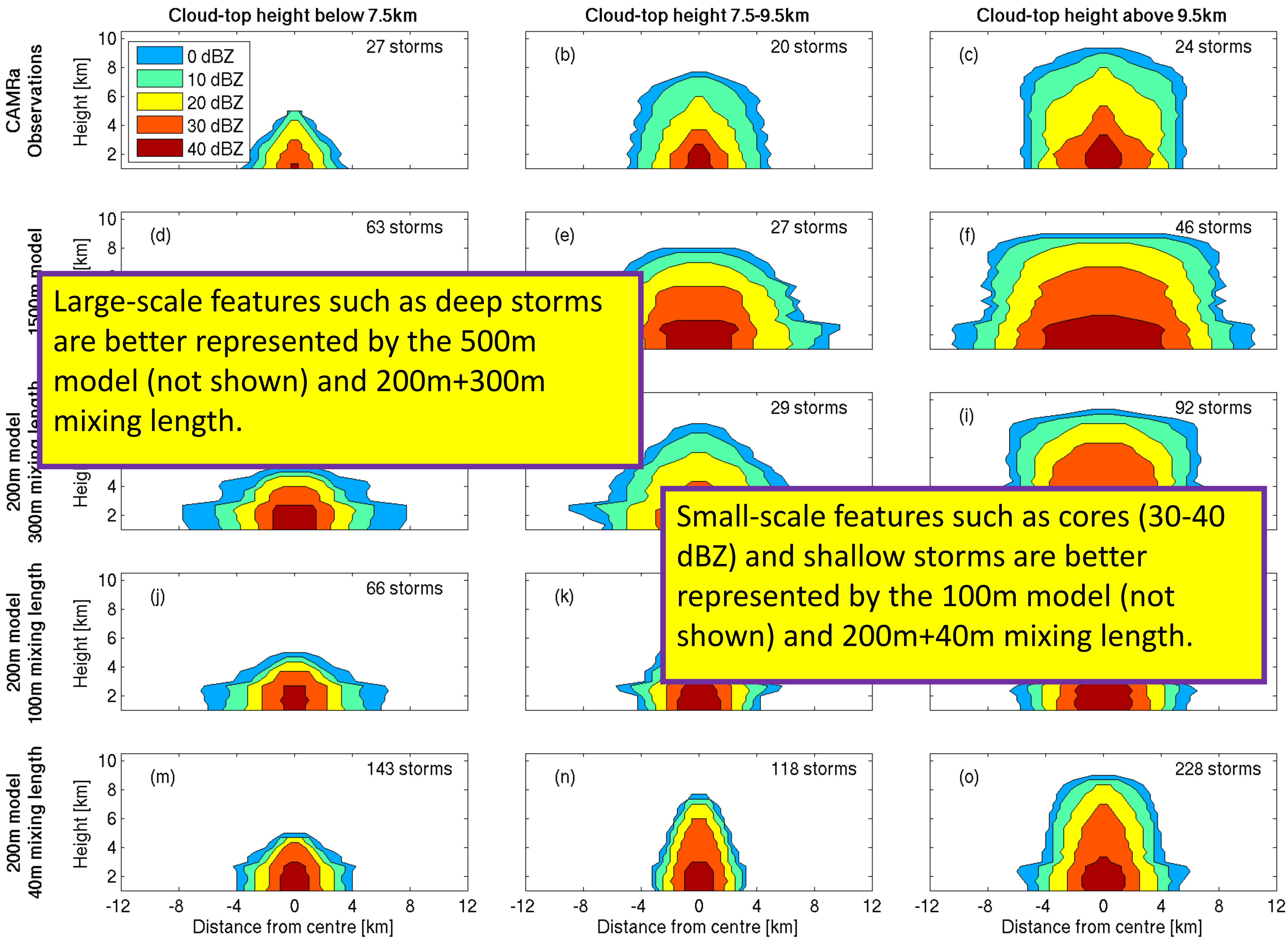
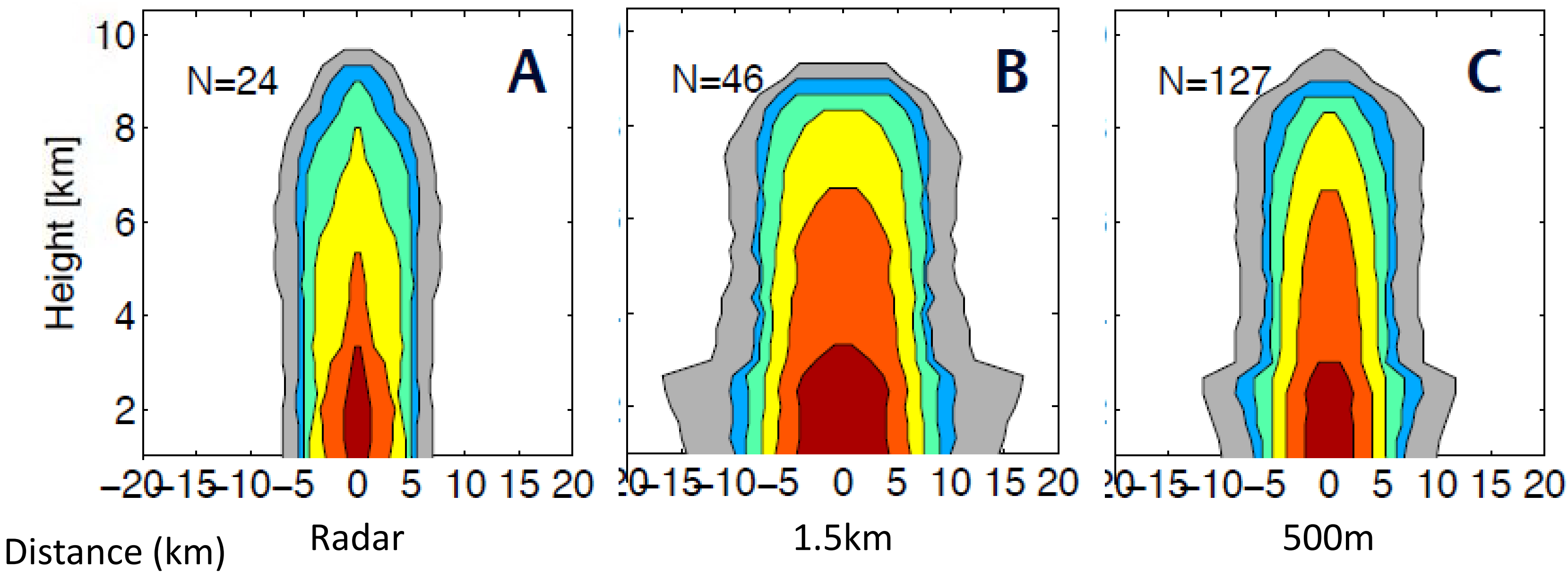


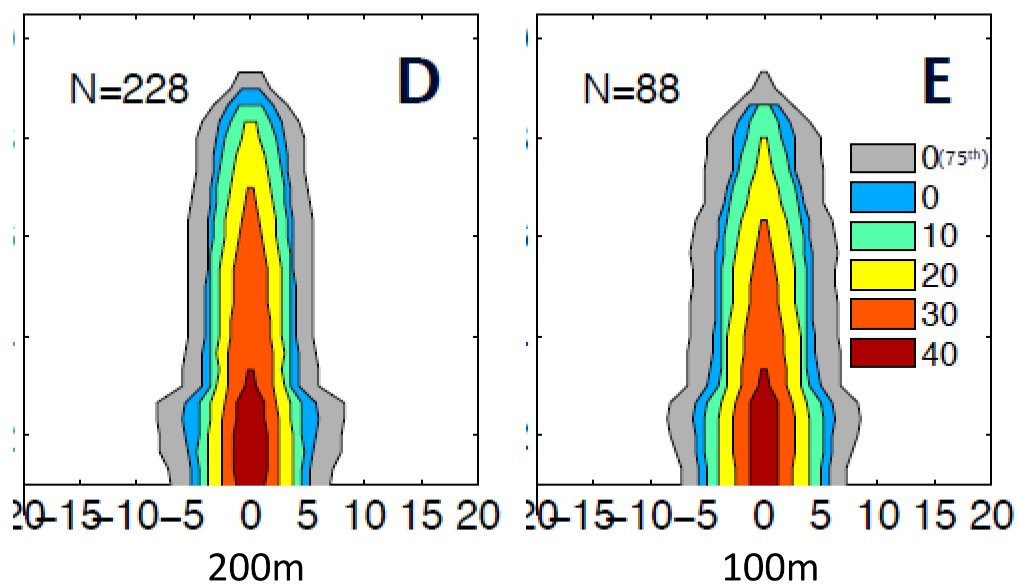
Large-scale features such as deep storms are better represented by the 500m model (not shown) and 200m+300m mixing length.

Small-scale features such as cores (30-40 dBZ) and shallow storms are better represented by the 100m model (not shown) and 200m+40m mixing length.

Cloud widths for different reflectivity thresholds.



Median width of deep storms
25th Aug 2012

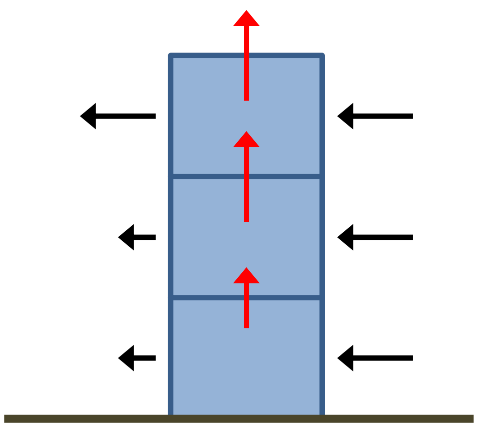


Thorwald Stein

Evaluation of Convective Updraughts

Estimation of vertical velocities from continuity

- Key uncertainty in models is convective updraught *intensity* and *spatial scale*
- Can we estimate updrafts from Doppler wind sufficiently well to characterize the distribution of intensity and spatial scale?



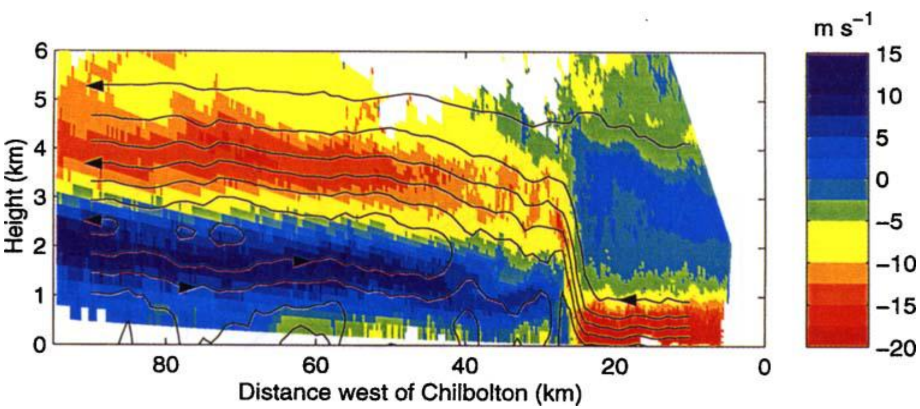
Vertical cross-sections (RHIs) are typically made at low elevations (e.g. < 10°)

Radial velocities provide accurate estimate of the horizontal winds

Assume vertical winds are zero at the surface

Working upwards, changes in horizontal winds at a given level increment the vertical wind up to that point

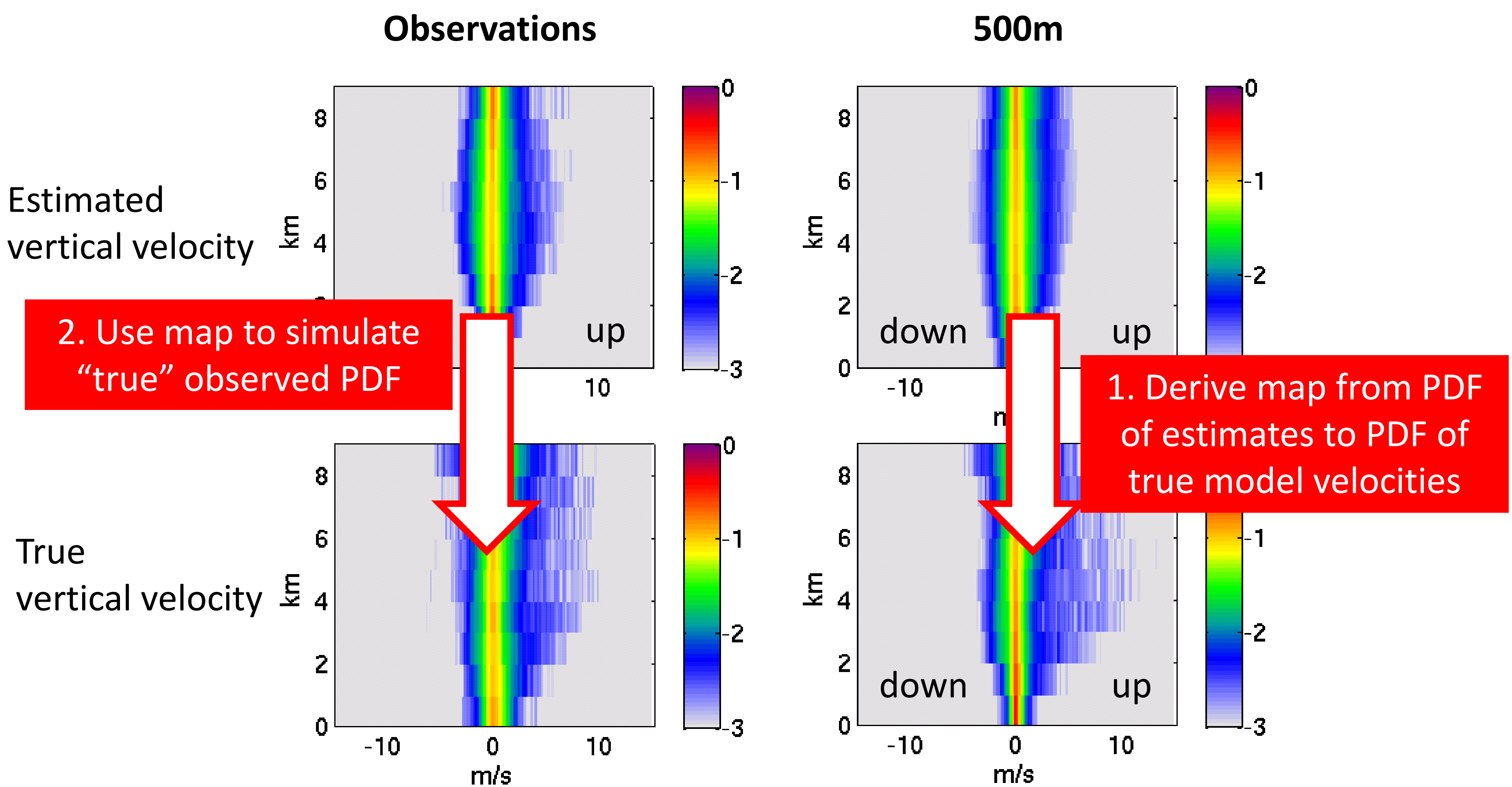
Must account for density change with height



Chapman & Browning (1998)

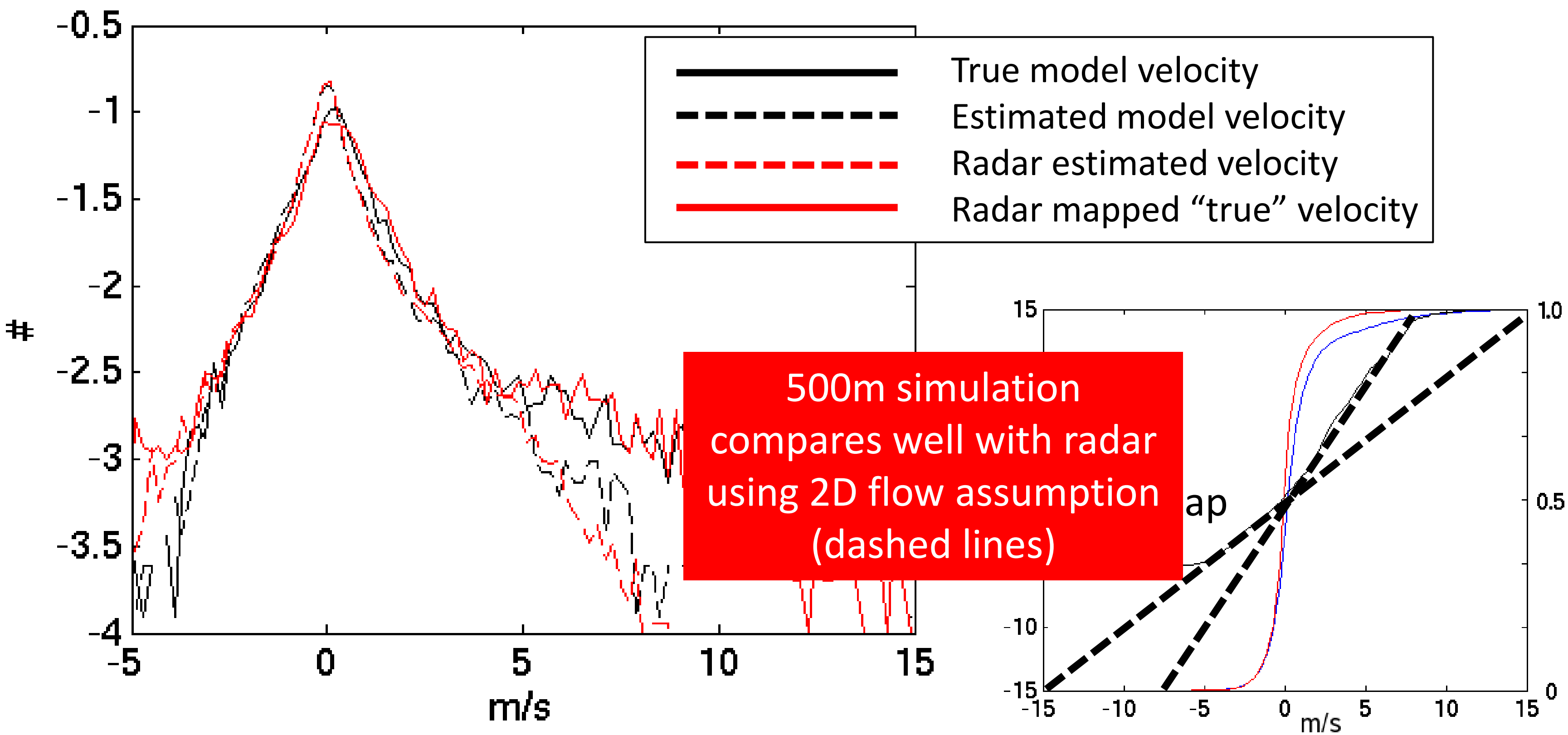
- In quasi-2D features (e.g. squall lines) can assume continuity to estimate vertical velocity

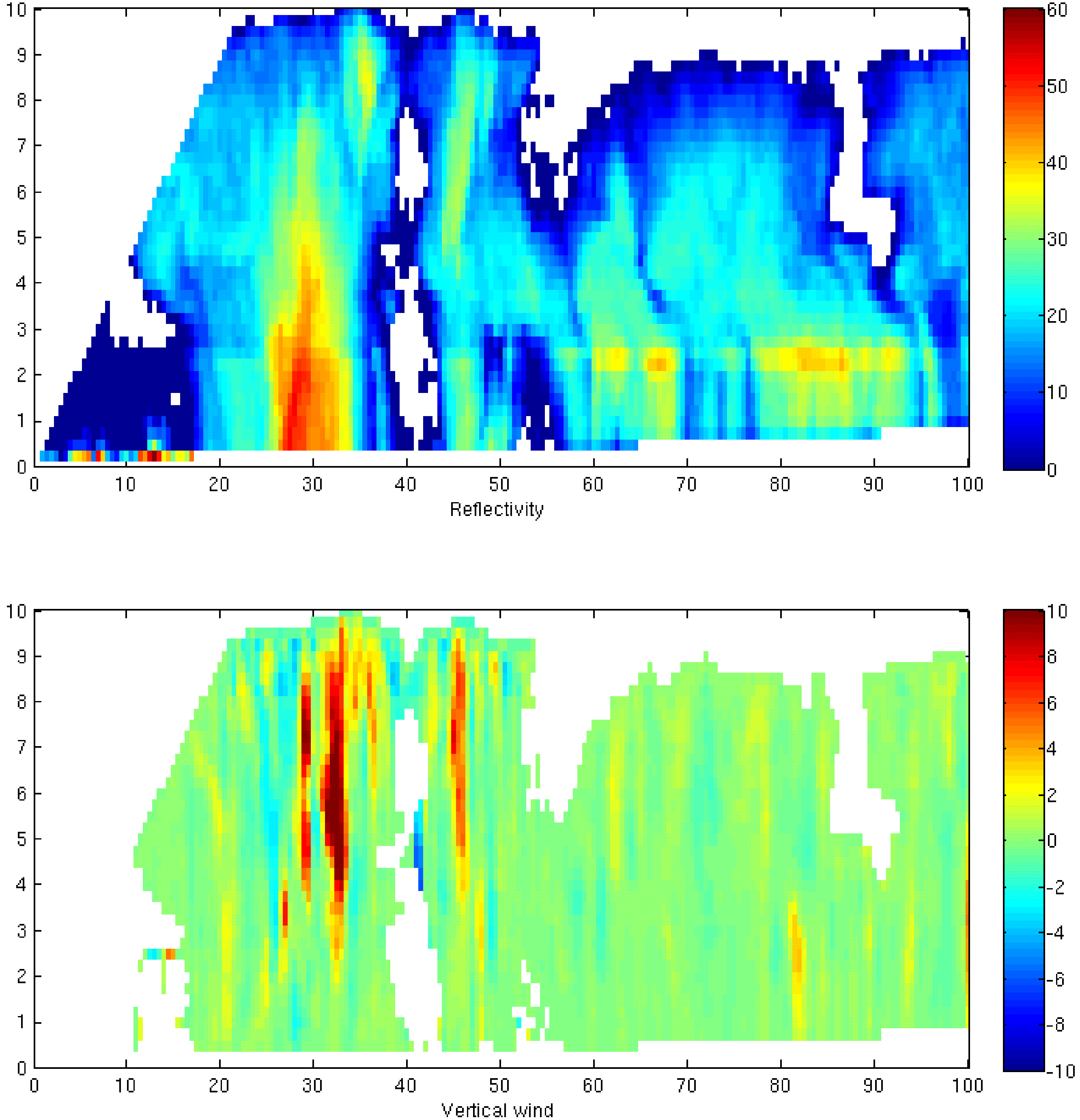
Vertical velocity distributions with height



Radar data with dBZ>0 within 90 km of the radar

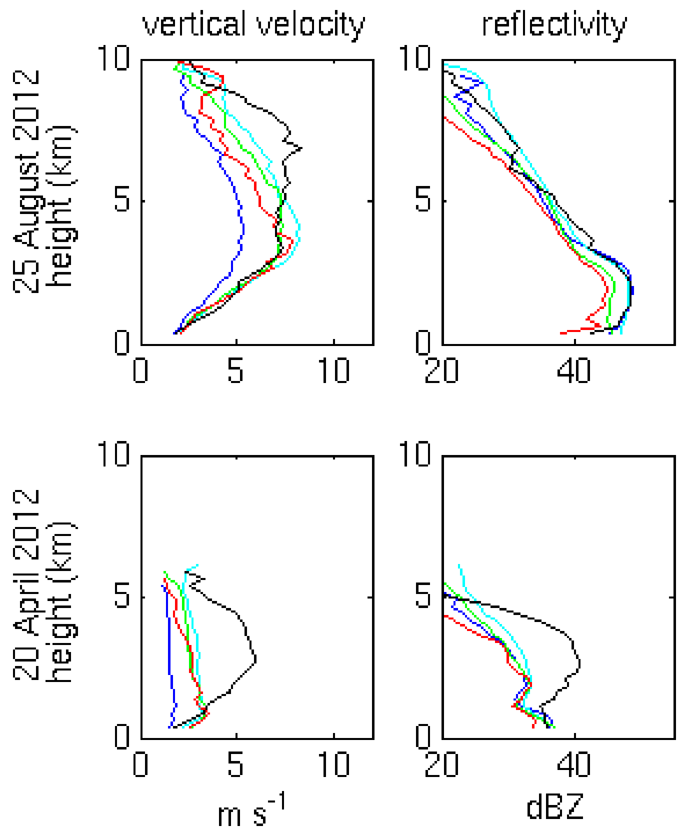
Vertical velocity distribution between 7-8 km





10
9
8
7
6
5
4
3
2
1
0
0 10 20 30 40 50 60 70 80 90 100
Reflectivity
60
50
40
30
20
10
0
10
9
8
7
6
5
4
3
2
1
0
0 10 20 30 40 50 60 70 80 90 100
Vertical wind
10
8
6
4
2
0
-2
-4
-6
-8
-10

Maximum vertical velocity and reflectivity associated with each rain cell as a function of height



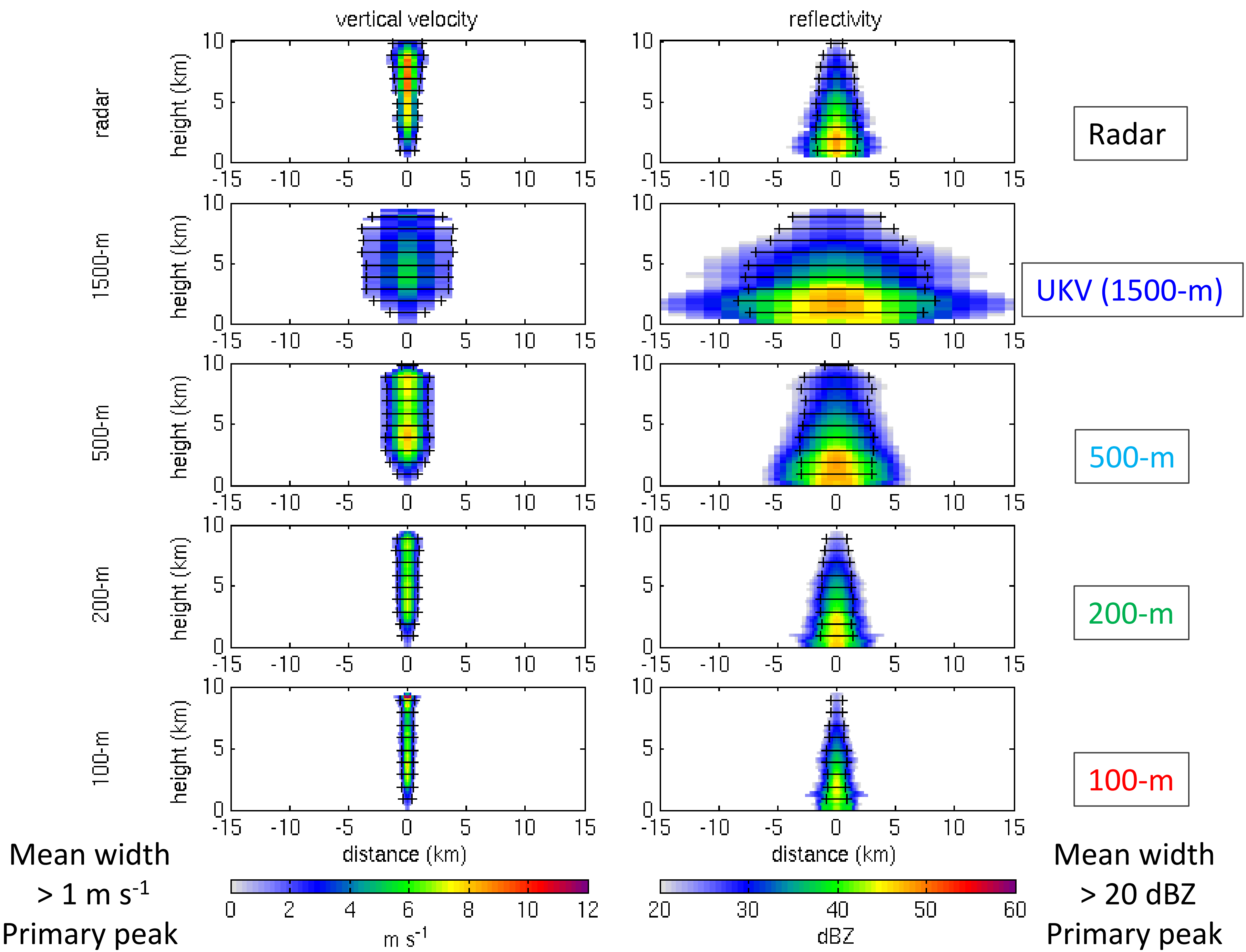
Rain cells defined by surface rainfall rates > 4 mm/hr over 10 km^2

Only the top 50% of cells based on cell-integrated rainfall rate have been analysed for each set of simulations (so the sampling of the population of cells is similar to the cells sampled by the radar)

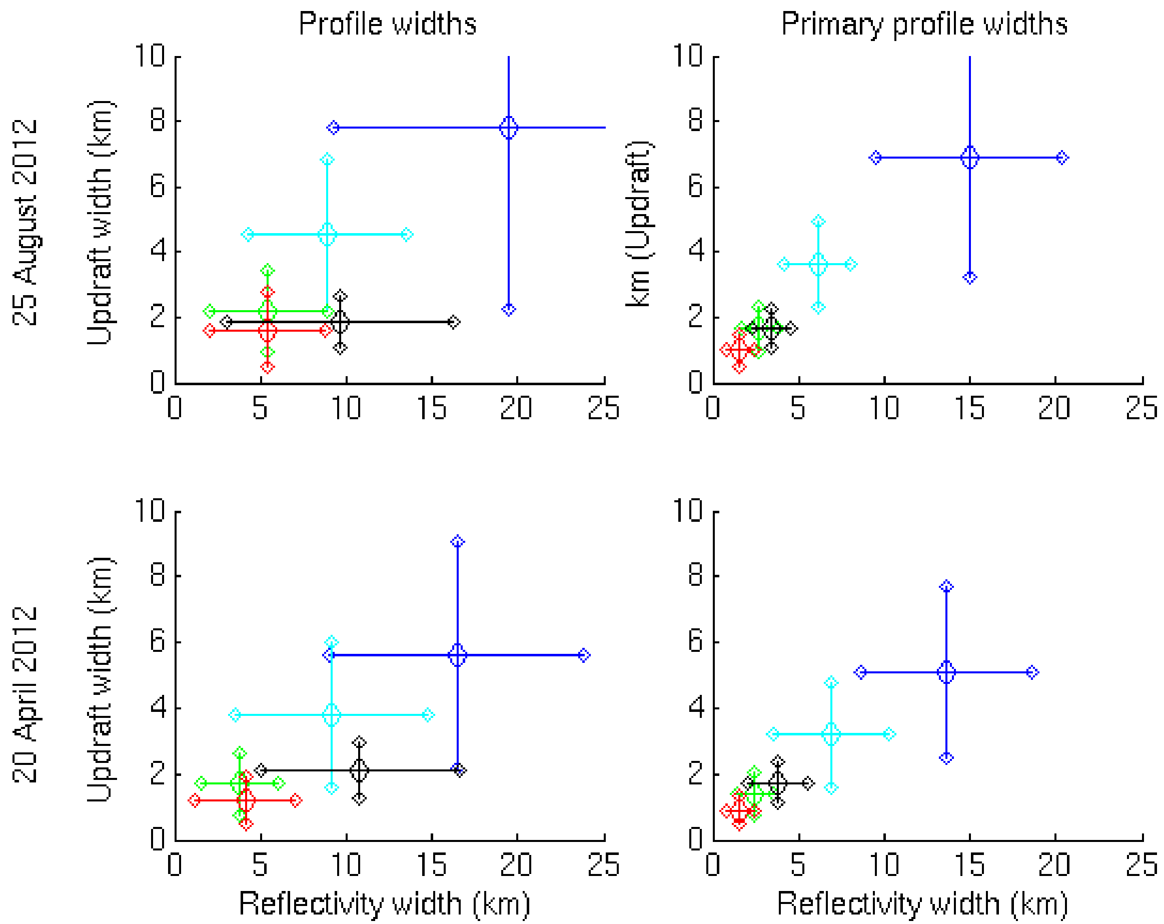
Two cases considered:
Deep convection (25th August 2012)
Moderate convection (20th April 2012)

Model grid length

UKV (1500-m) | 500-m | 200-m | 100-m | Radar


vertical velocity
reflectivity
radar
1500-m
500-m
200-m
100-m
height (km)
distance (km)
Radar
UKV (1500-m)
500-m
200-m
100-m
m s-1
dBZ
Mean width
> 1 m s-1
Primary peak
Mean width
> 20 dBZ
Primary peak

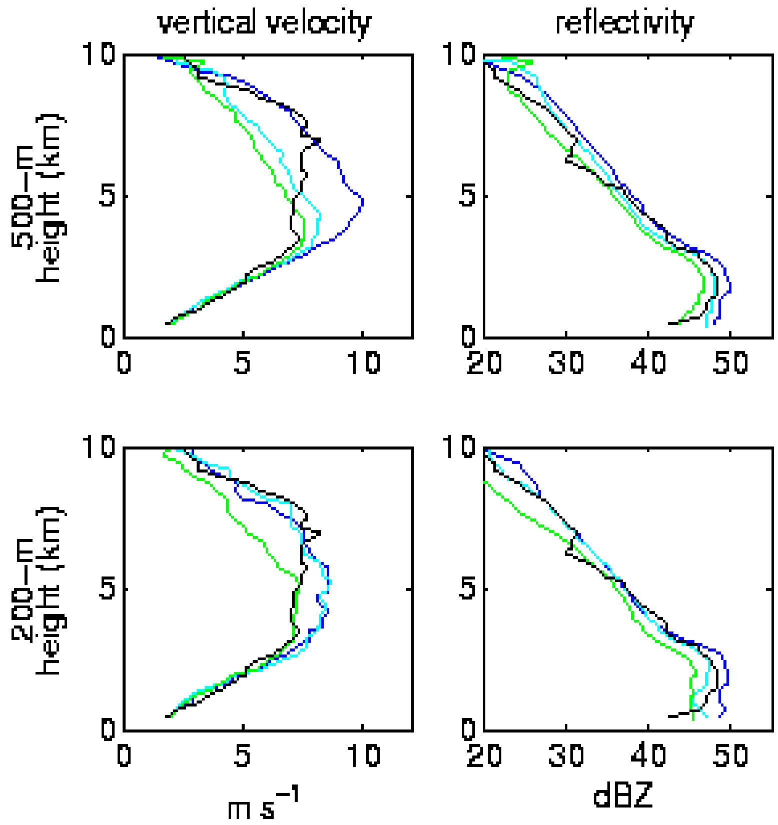
Updraught width vs. reflectivity width



Height= 3km

Radar
UKV (1500-m)
500-m
200-m
100-m

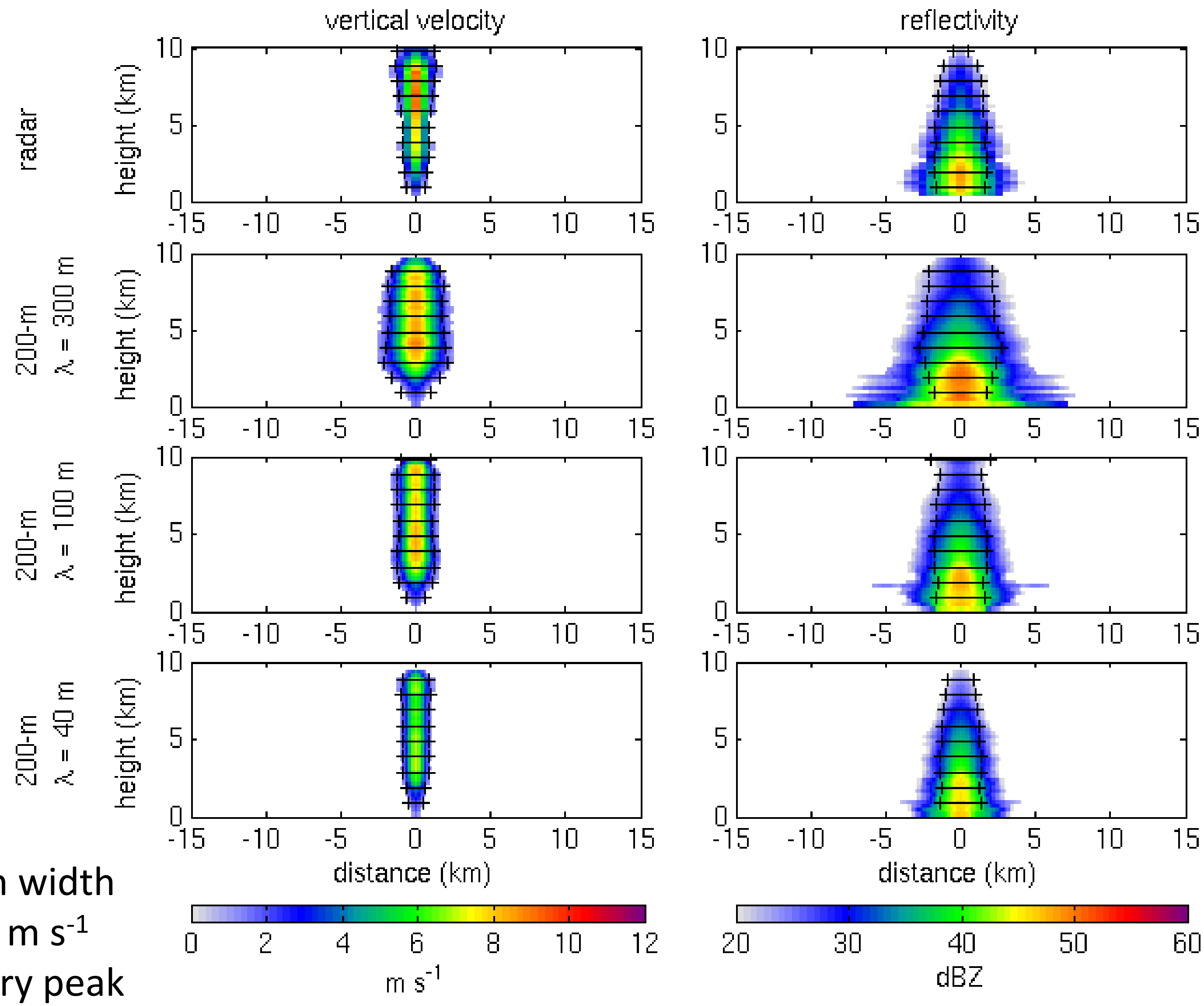
Influence of mixing length in the sub-grid turbulent mixing scheme



Scheme serves to diffuse humidity, temperature and wind fields due to unresolved turbulence

Default configuration:
Mixing length (λ) = 20% of the horizontal grid length

Mixing length: λ=300m λ=100m λ=40m

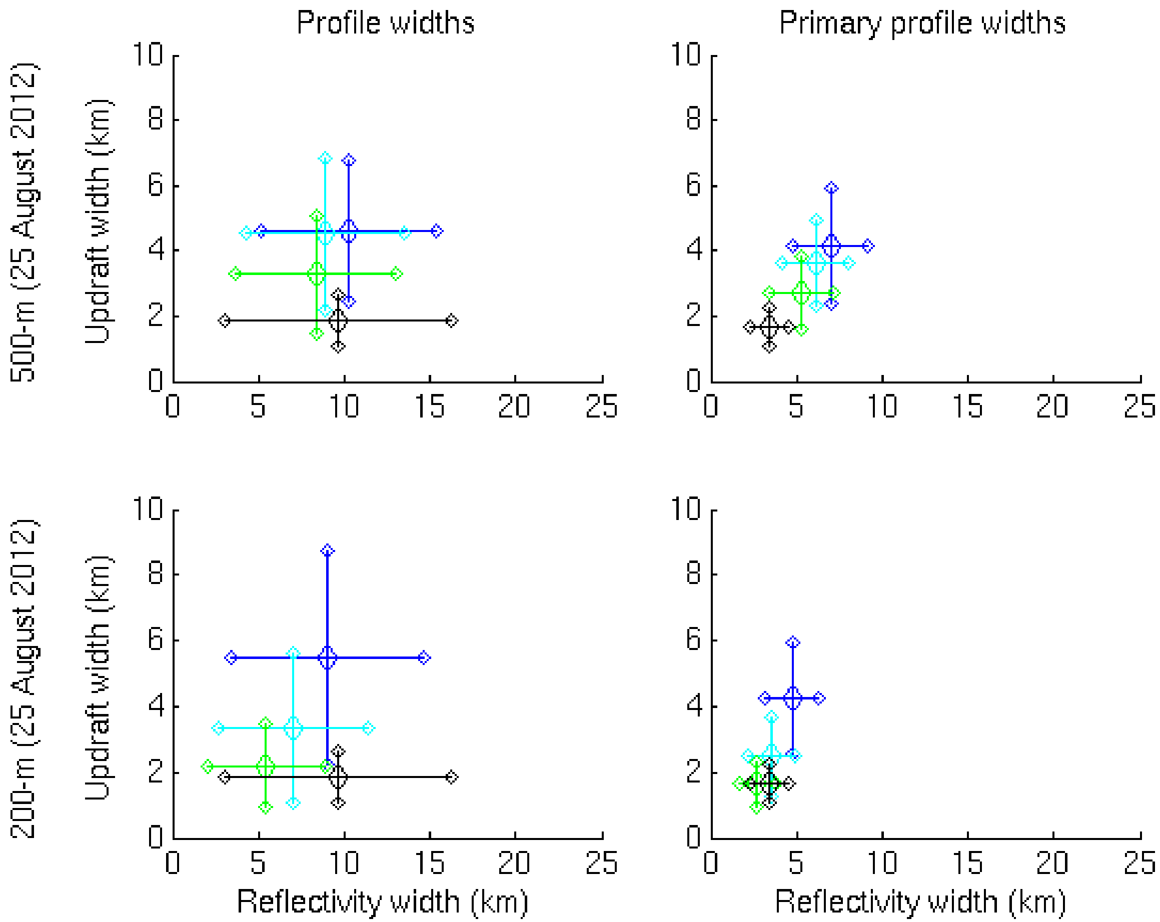


Mean width > 1 m s^{-1} Primary peak

Mean width > 20 dBZ Primary peak

Updraught width vs. reflectivity width

Height= 3km



500-m UM

25th August 2012

200-m UM

25th August 2012

Mixing length: λ=300m λ=100m λ=40m

Conclusions

- UKV under-resolves many small showers in UK while high-res models (~100m) improve some aspects but also have some problems.
- Models below 500m tend to produce too narrow showers (measured by surface rain or cloud) in cases where showers are large (for small showers 200m or 100m fits well). Cloud widths roughly the same in 200m and 100m.
- Updraught widths good in 200m model but too narrow at 100m.
- This implies that there may be an issue about how the model fills in cloud between updraft cores.
- Representation very sensitive to mixing. Also sensitivity to microphysics (fall speed).

- What can be done to understand lack of convergence and too narrow updrafts/clouds in 100m/200m models?
- Suspect problem is turbulence “grey zone”. Would better resolution of turbulence solve these problems at higher resolution? Try higher vertical/horizontal resolution and see if updraughts/clouds get wider (or stop collapsing). Work with LES community.
- Can we improve models with more appropriate subgrid mixing schemes?
- Effect of microphysics?

DYMECS

No satisfactory performance across all diagnostics

1500m model

Too long-lasting
Too much rain over lifetime
Too large rainfall area
Too large shallow structures
Too broad cores
Too broad deep structures
Weak and broad updrafts

100m model

Good duration
Good area-integrated rainfall
Too intense in early stages
Good structure for shallow
Good structure for cores
Too narrow deep structures
Good updraft strength and width

Results depend strongly on turbulent mixing length