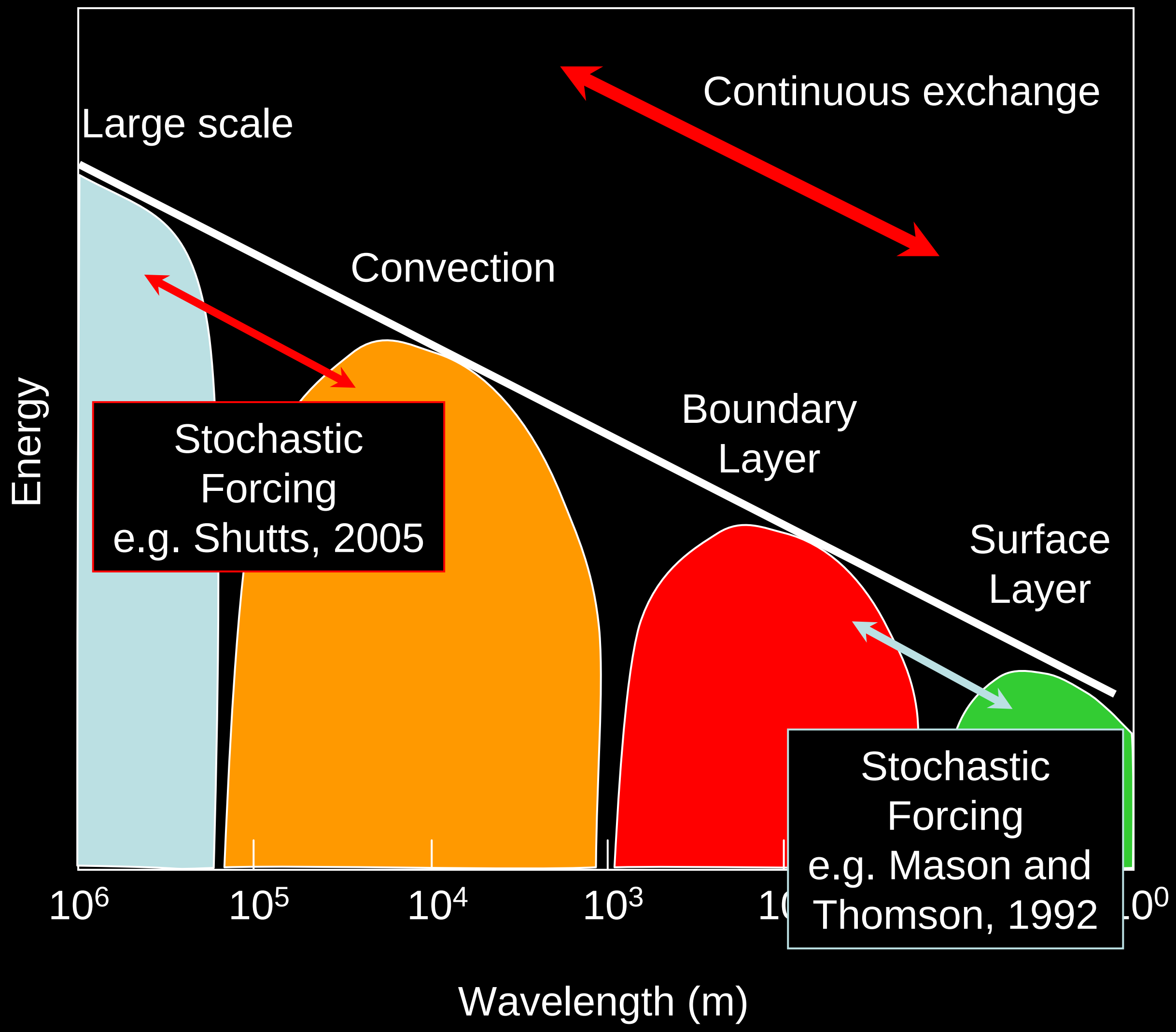
Experience of transition from shallow to deep convection in the Met Office Unified Model at convective scales.

Peter Clark, Joint Centre for Mesoscale Modelling, Reading

Outline

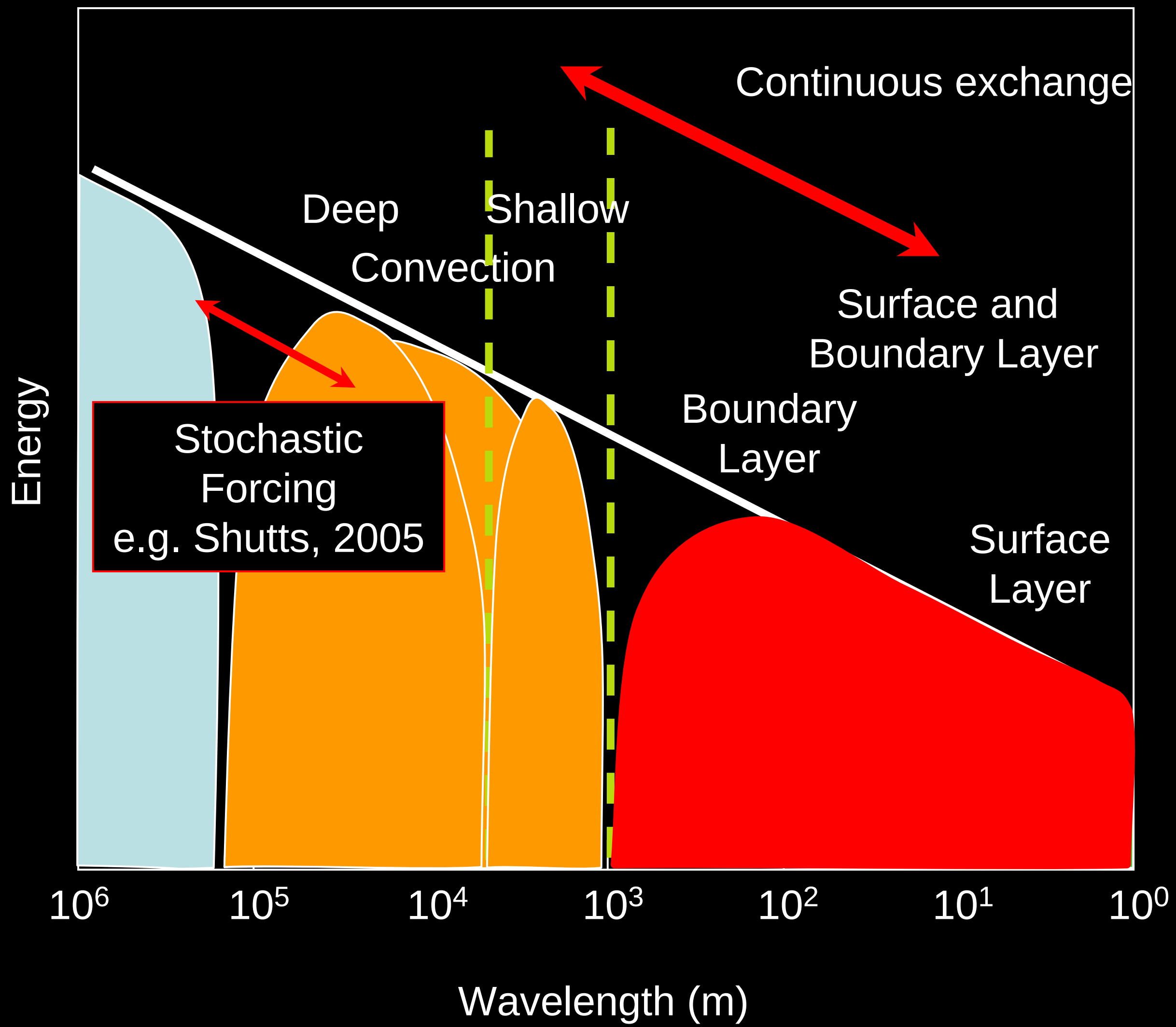
- Some revision – RANS/LES and grey zones.
- We have a really tough problem to solve, and our models shouldn't work.
  - I'm looking forward to seeing the solutions presented at this workshop!
- But they do (quite often)!
  - Why?

A simple view of models



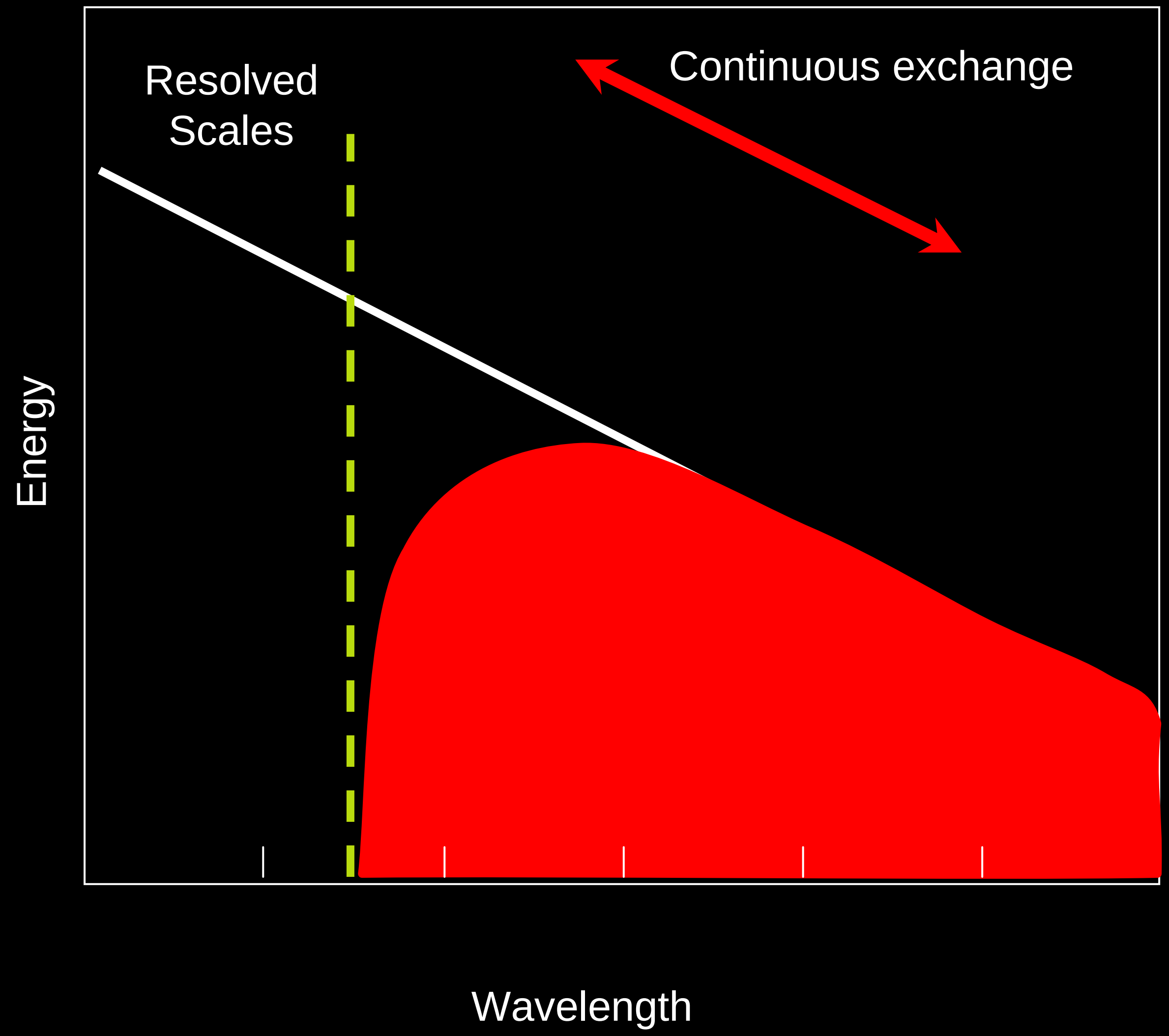
- Conceptual split by ‘well-defined’ phenomena.
- Artificial spectral gaps.
- Parametrization of whole phenomena based on Reynolds average concepts.
- Recent developments: gaps bridged by stochastic forcing.

A simple view of models



- The Parametrization determines the scales in the flow.
- Ideally, model resolution corresponds to these scales (sufficient but not overkill).

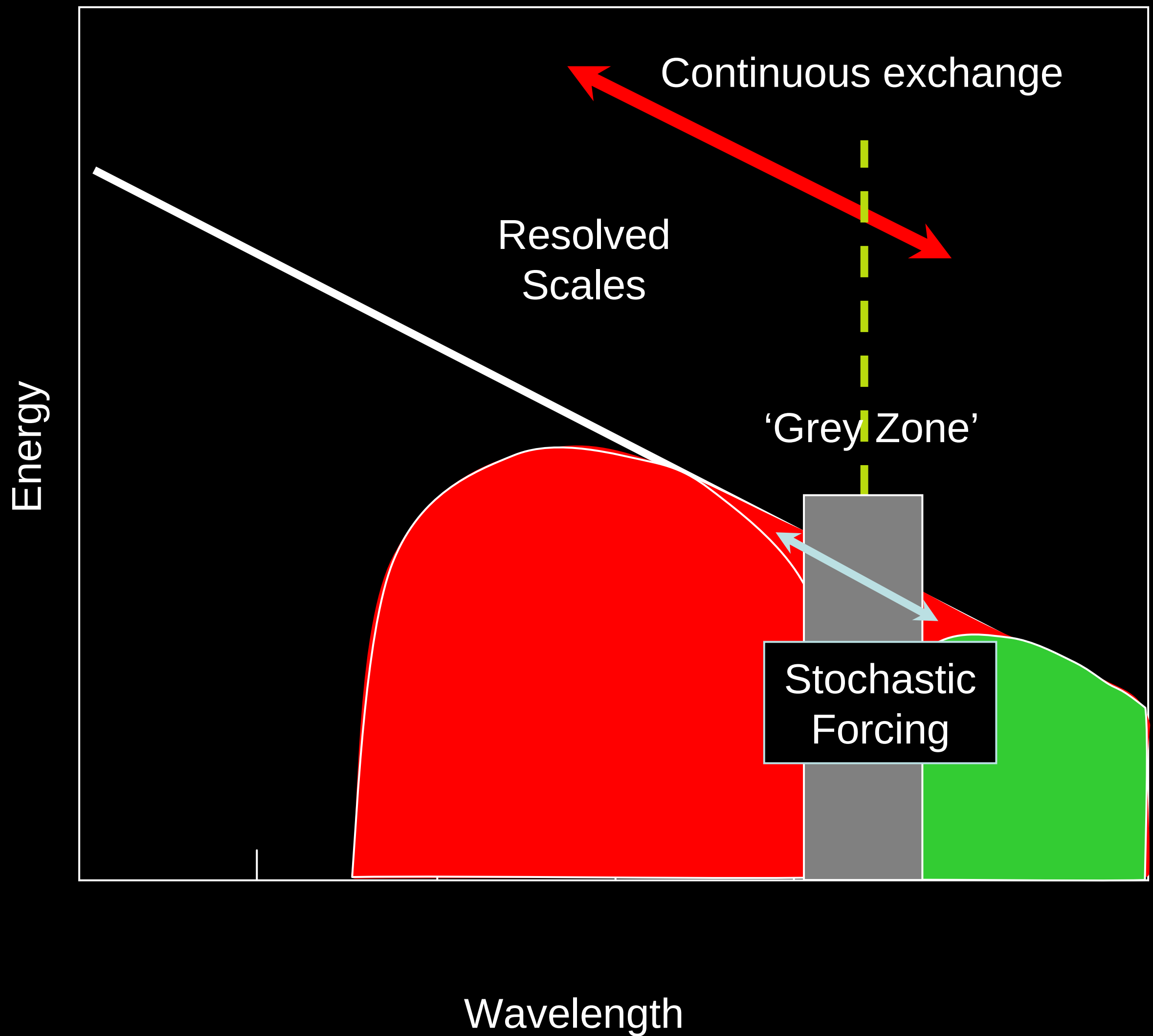
Boundary layer Reynolds Average



Parametrization 'does everything'

- 1D ensemble mean treatment.
- Missing energy at 'interface'?
- Stochastic interface?

Traditional LES



Parametrization 'overlaps'

• 3D treatment (explicit or implicit).

• Ensemble treatment + 'sampling error'.

or

• Stochastically forced low order coherent structures.

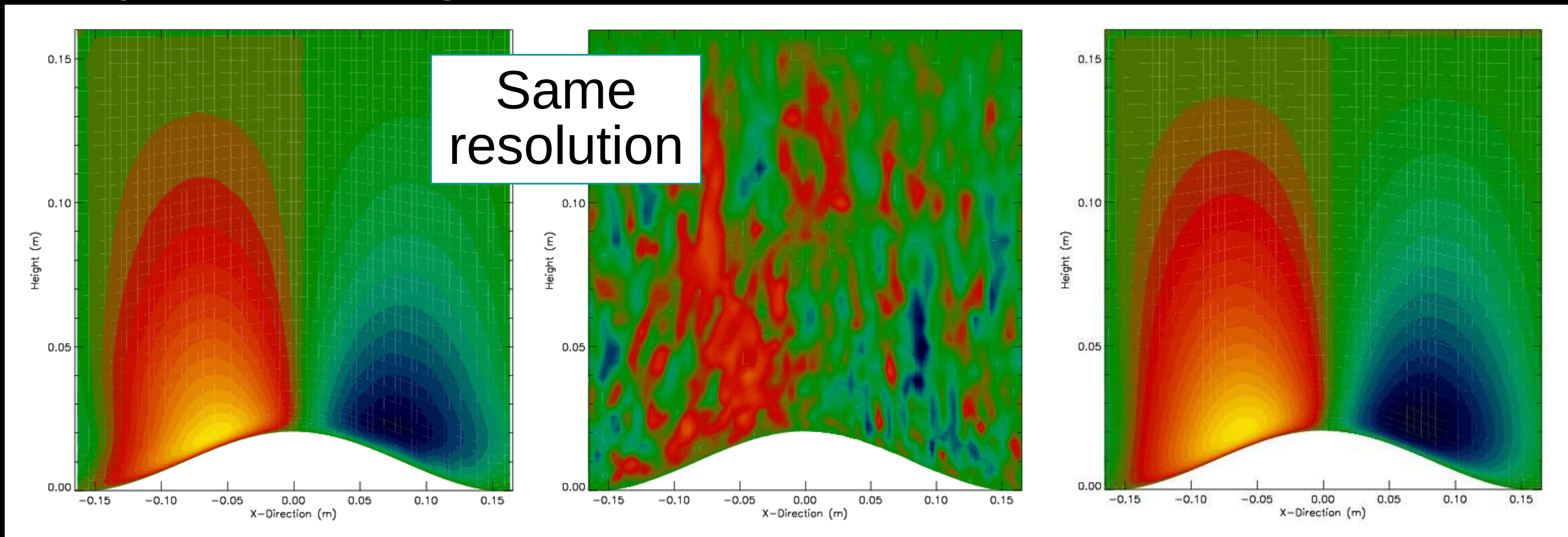
Reynolds averaging and LES

- There is no 'sub-grid' in RANS.
  - Spatial averaging can be additionally imposed leading to 'dispersive fluxes'.
- Equivalence of space/time average with RANS requires spectral gap in space/time.
- Traditional LES based on space average (filter), with filter length scale Lf<<L=Largest eddies (energy input length scale) BUT assumptions in sub-filter scheme based on local equilibrium/stationarity/smoothness of forcing that they amount to a 'sub-ensemble average'.

Closure model and LES vertical velocity fields

Blasius flow over hill – w field

Reynolds Averaged | LES SNAPSHOT | LES AVERAGE



Message:
The parametrization determines the flow, not the resolution!

Courtesy Andy Brown

Grey zones

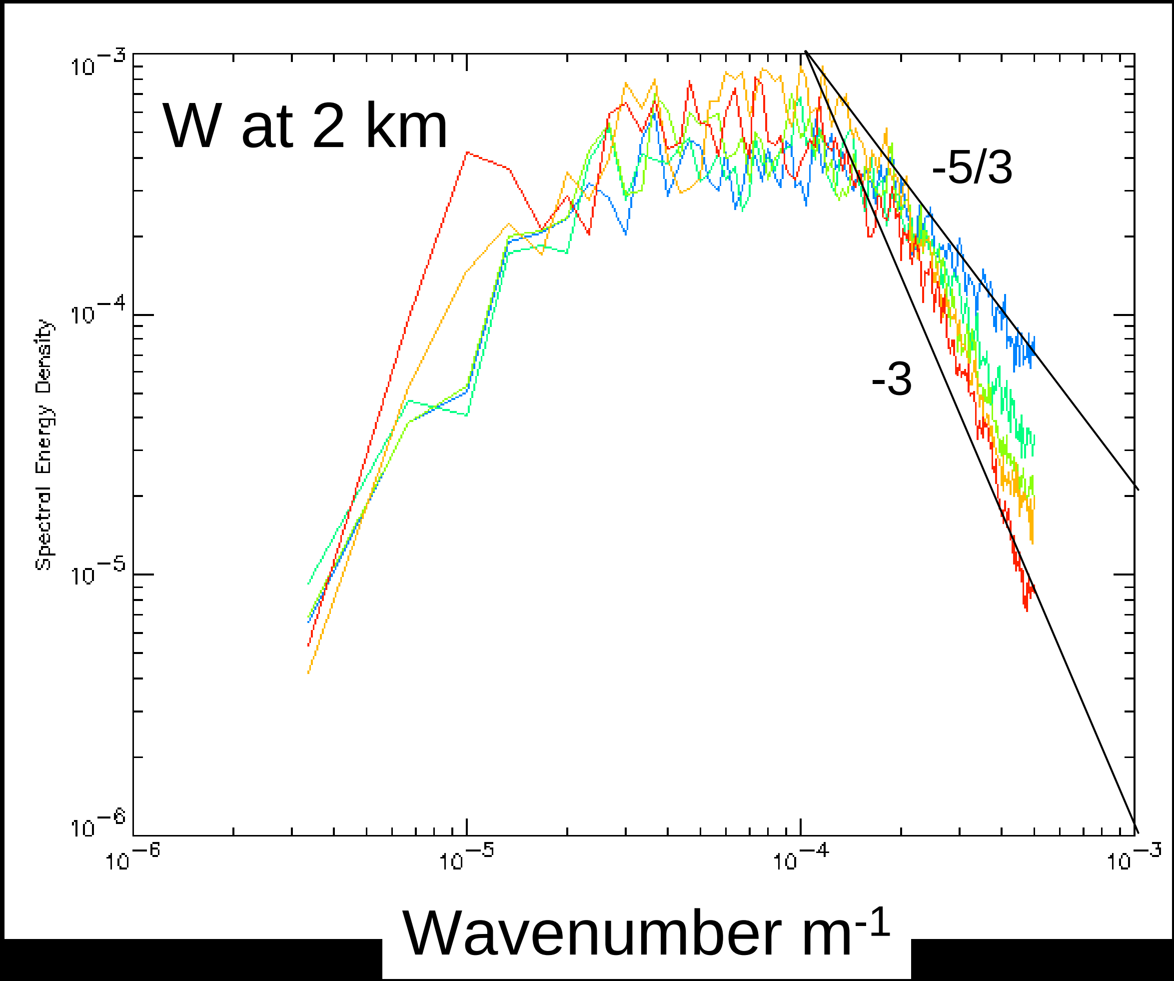
- Grey zones may have different origins:

1. Filtering intentionally within cascade from scales where energy injected.
    - LES in CBL (e.g. L~100 m).
    - Deep (Cb) convection with L< cloud spacing but >cloud size (e.g. L~5 km).
    - Shallow Cu with L< cloud spacing but >cloud size (e.g. L~1-2 km).
2. Apparently scale limited process,Lf>>L, with (weak) upscale transport due to neglected processes
    - Moist CBL (e.g. de Roode et al, 2004).
3. Sudden, rapid upscale transport due to triggering of strongly non-linear process.
    - RH>100% rectification produces sub-harmonics.

The boundary-layer/deep convection grey zone

- With horizontal resolution ~1-2 km, generally one of 3 possibilities:
  - Using a 1D turbulence scheme in BL or
  - Horizontal mixing from 3D scheme in BL << effective diffusion from dynamics.
  - Horizontal mixing from 3D scheme in BL > physically realistic.
- Effective dissipation at near-gridscale controls nature of solution – analogous to shifting viscosity such that Re and Rayleigh number relatively small.
  - Typically cell spacing/size/timing.

Velocity spectra in scattered convection: Limited Area Model



'No Diffusion'

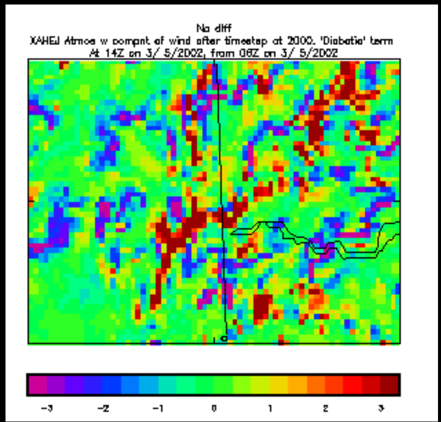
16dt ∇^4

8dt ∇^4

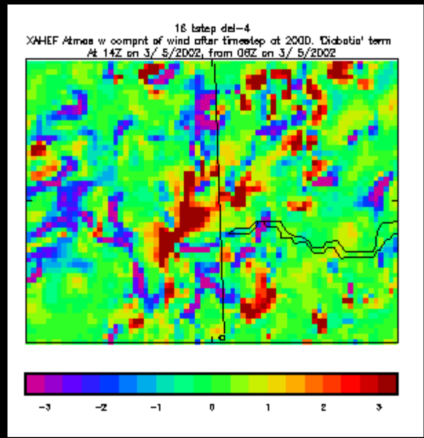
16dt ∇^2

8dt ∇^2

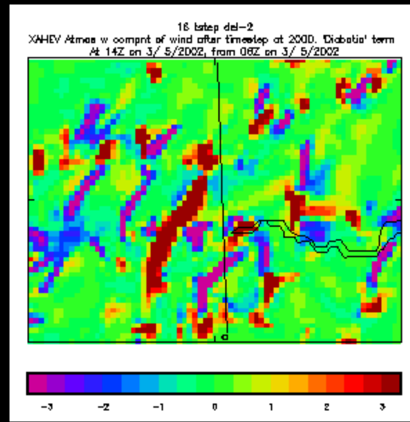
Impact of fixed horizontal diffusion



‘No Diffusion’

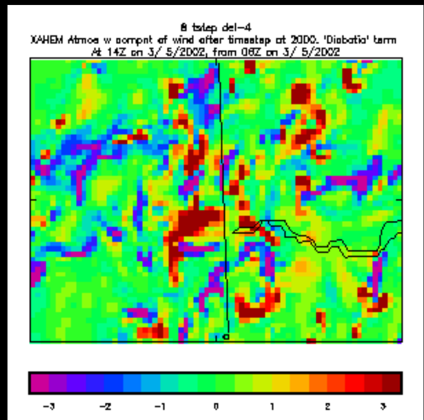


16dt ∇^4

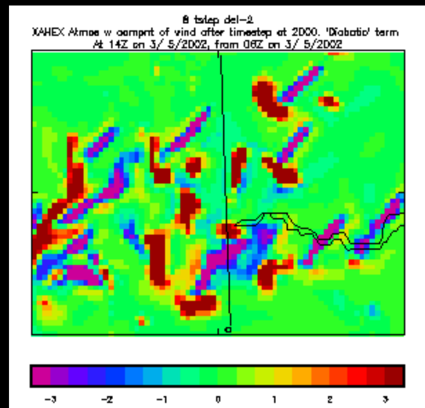


16dt ∇^2

Timescale=
E-folding time for
2dx waves



8dt ∇^4

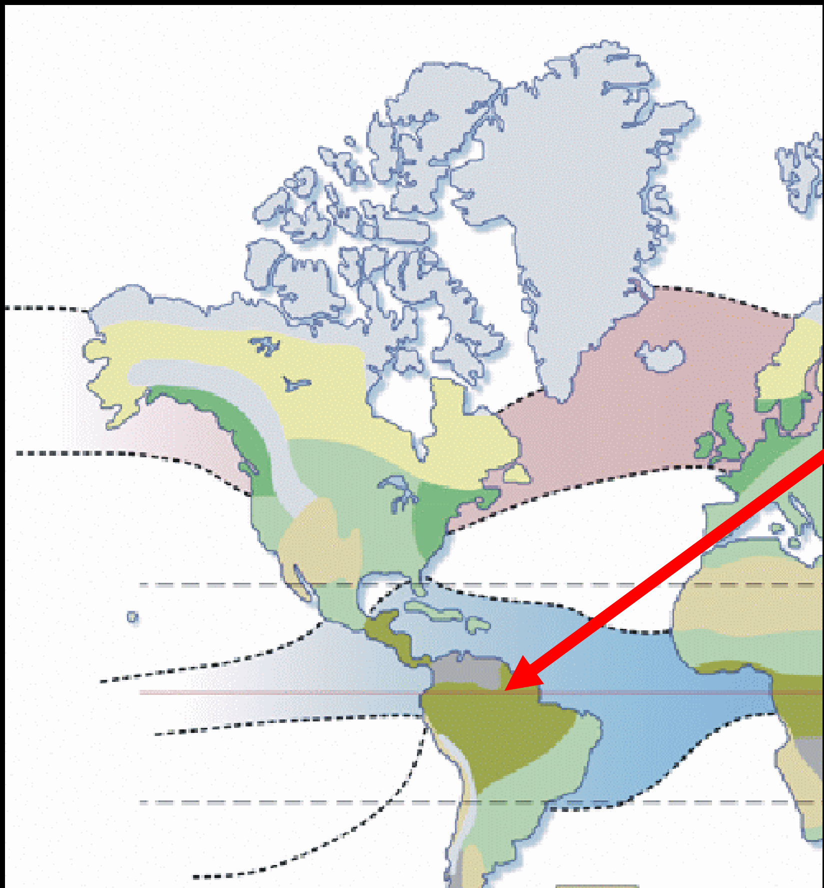


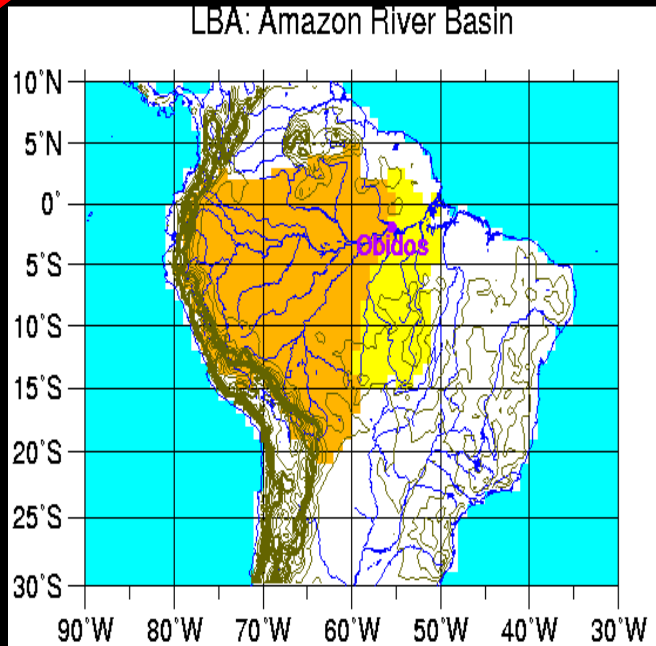
8dt ∇^2

W at 2 km

GCSS Case 4 (LBA)

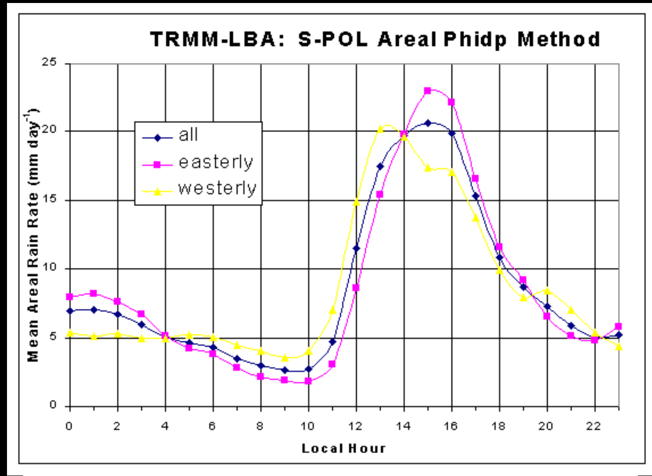
LBA The Large Scale Biosphere-Atmosphere Experiment in Amazônia



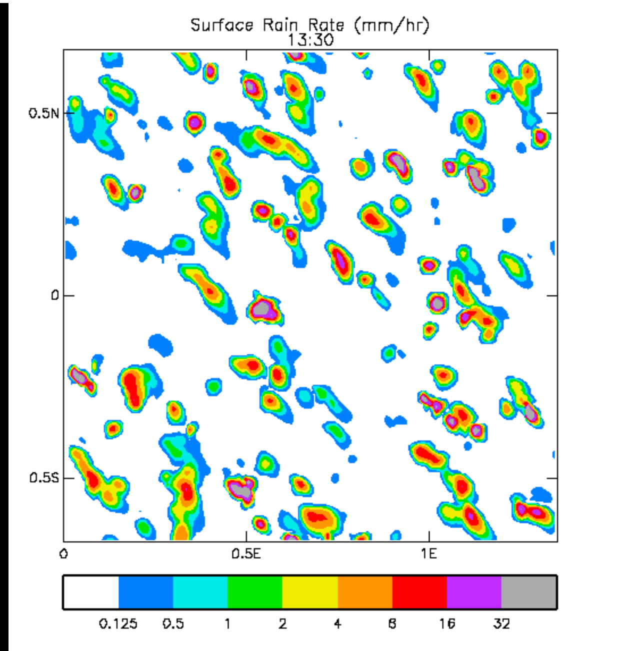


LBA Diurnal Cycle Case Study

- Data from TRMM LBA observational campaign (Rondonia, Brazil)
- Initialisation from representative single profile at sunrise (07:30 am local time). Diurnally varying surface fluxes. Bicyclic model domain.
- Intercomparison of CRMs (GCSS Deep Convection WG Case 4, *Grabowski et al. 2006*).
- Focus on development of convection in first 6 hours. Observed onset of precipitation is ~10:30 (3 hours after sunrise).



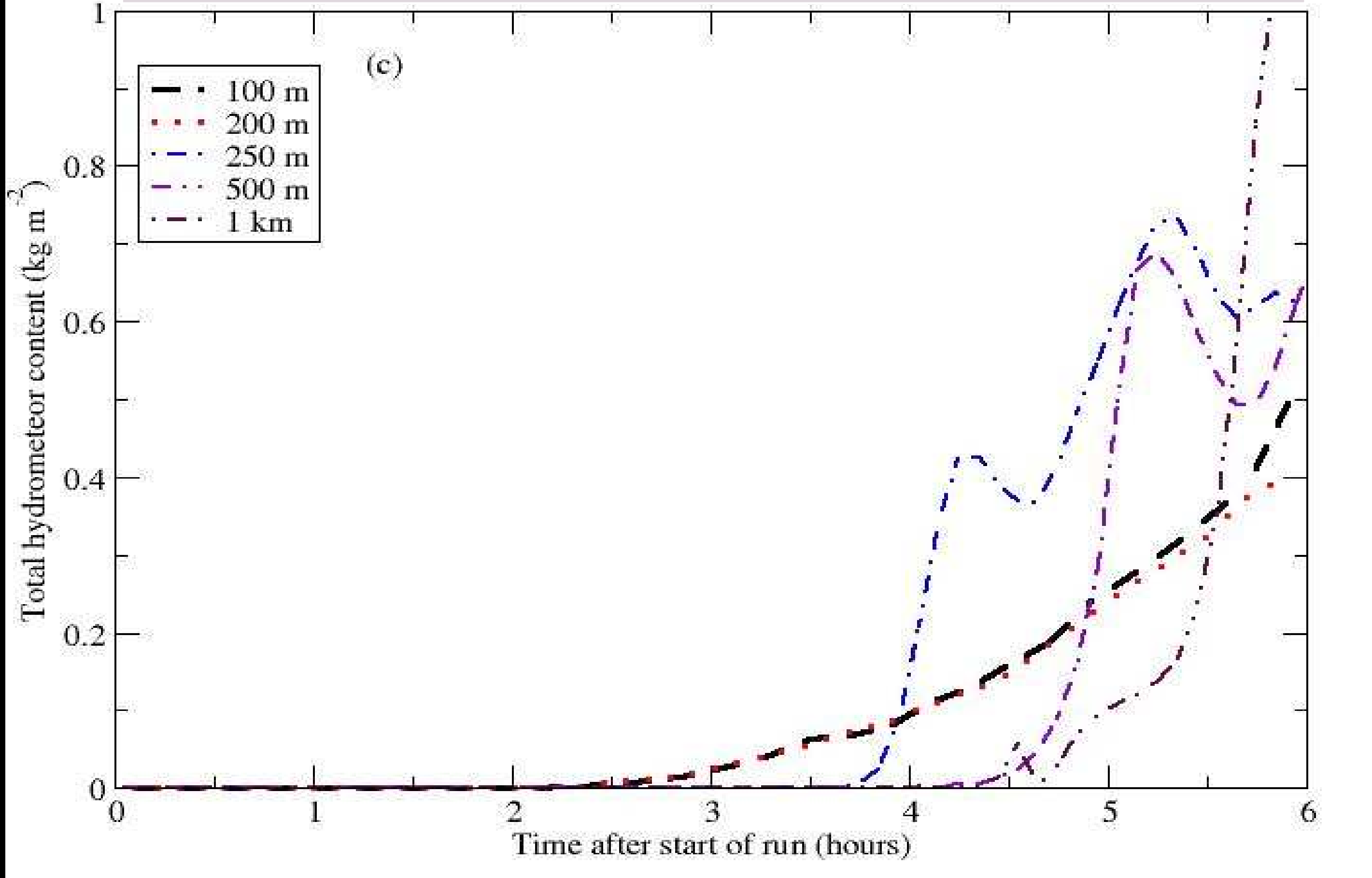
Average rainrates through the diurnal cycle from TRMM-LBA radar.



Plan view of model surface rain rate 6 hours after sunrise (1.30pm local time).

The LBA simulation – MetO CRM

total hydrometeor content from 3D runs



Met Office CRM

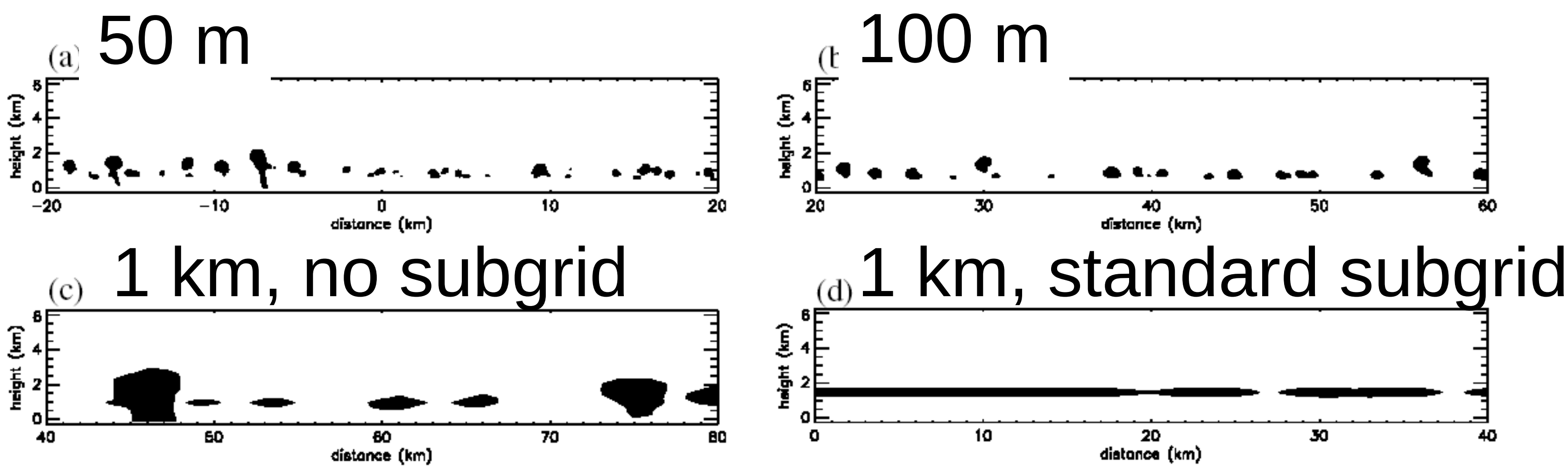


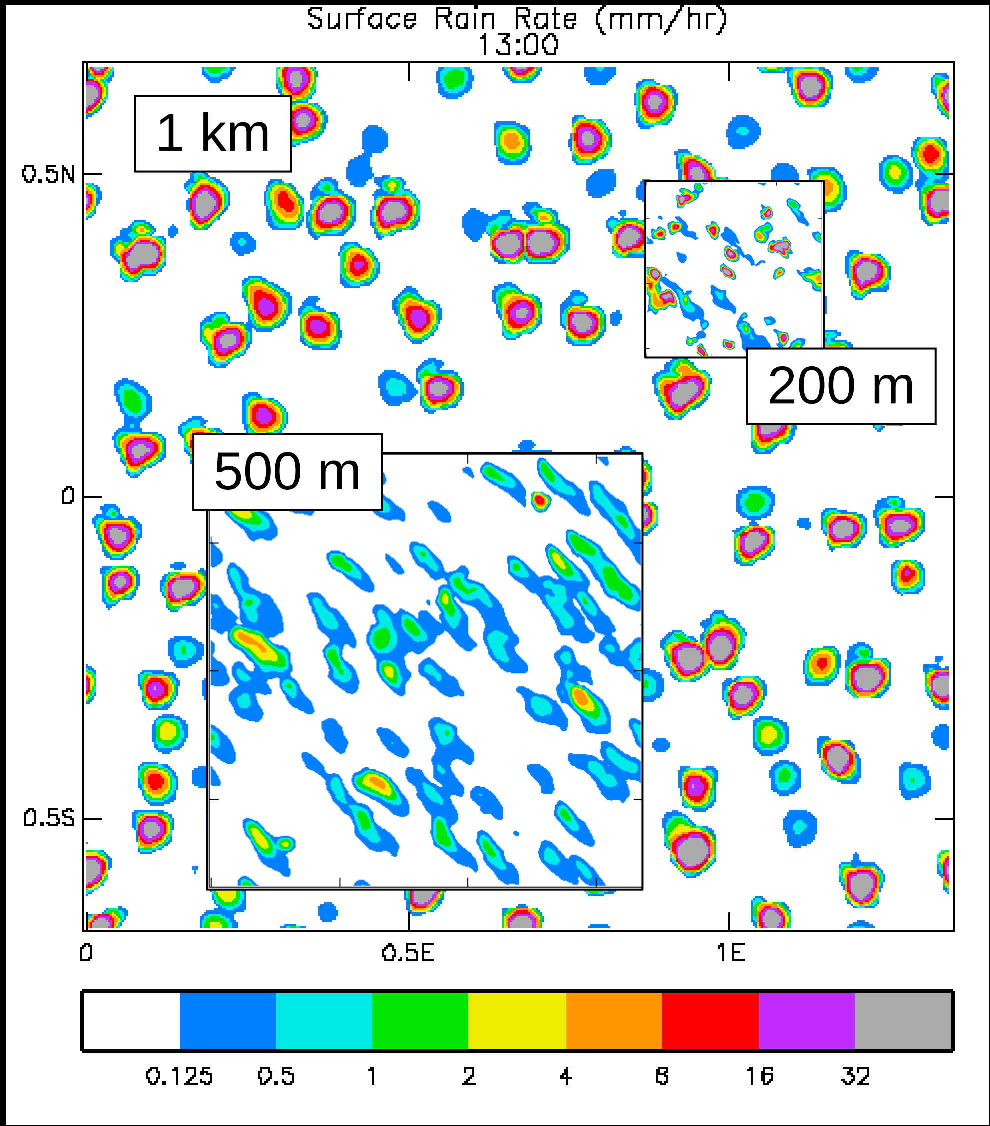
Figure 5. Shaded areas represent regions with a total hydrometeor mixing ratio greater than 0.05 g kg^{-1} at a time shortly after the first clouds have formed. Each run is focused on a 40 km region which is typical of the full domain. Results from 2D runs using a grid length of (a) 50 m, (b) 100 m, (c) 1 km and no subgrid mixing, and (d) 1 km and standard subgrid mixing.

Petch, 2006, Q.J.R.M.S 132, 345-358

UM GCSS LBA Idealised diurnal cycle

Cloud scale determined by horizontal resolution.

Carol Halliwell and
Richard Forbes



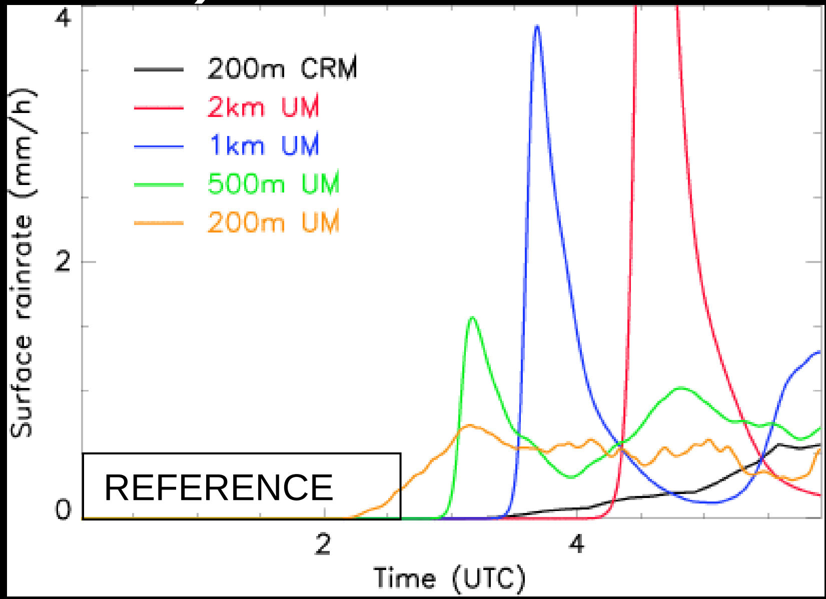
UM Simulations

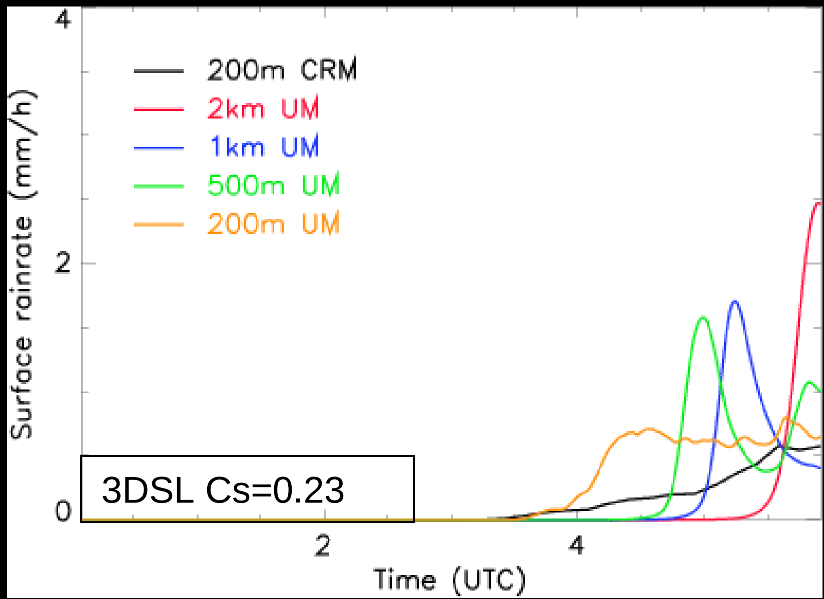
Met Office

- Reference:
  - 1D vertical non-local boundary layer scheme.
  - Constant horizontal diffusion.
- 3DSL
  - "3D" Smagorinsky-Lilly local turbulent mixing scheme with Cs=0.23.
  - Tested at 50 m in CBL and other cases, suggests 0.16 compares better with LEM.
- Series of sensitivity simulations with variations to mixing length (Cs) and combinations of the above.

Sensitivity to grid resolution (Surface rainrate)

- Increasing delay of first rain and overshoot with decreasing resolution
- “3D” Smagorinsky scheme reduces overshoot significantly and reduces variation of delay with res.
- 200m “3D” Smagorinsky scheme is close to 200m CRM (within uncertainty)
- 1km reference run has the first rain at the same time as the 200m UM and CRM

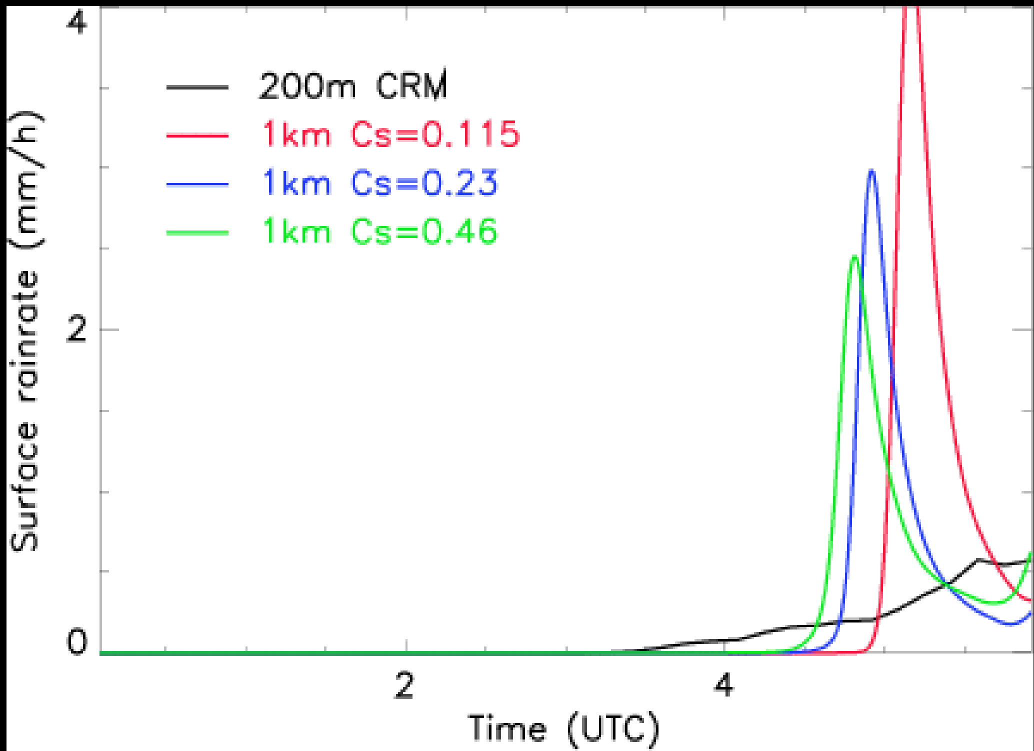




Impact of vertical mixing

Met Office

- Increased vertical mixing in the boundary layer leads to earlier convective initiation



All UM runs have constant horizontal diffusion K=1430

Impact of vertical mixing

Met Office

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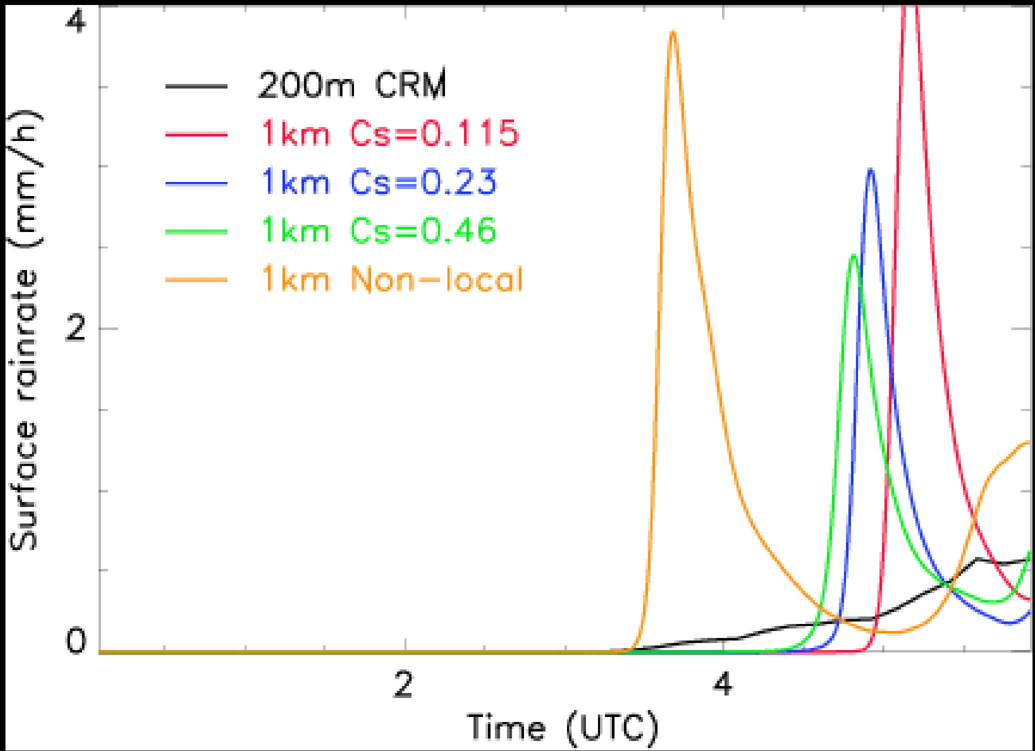
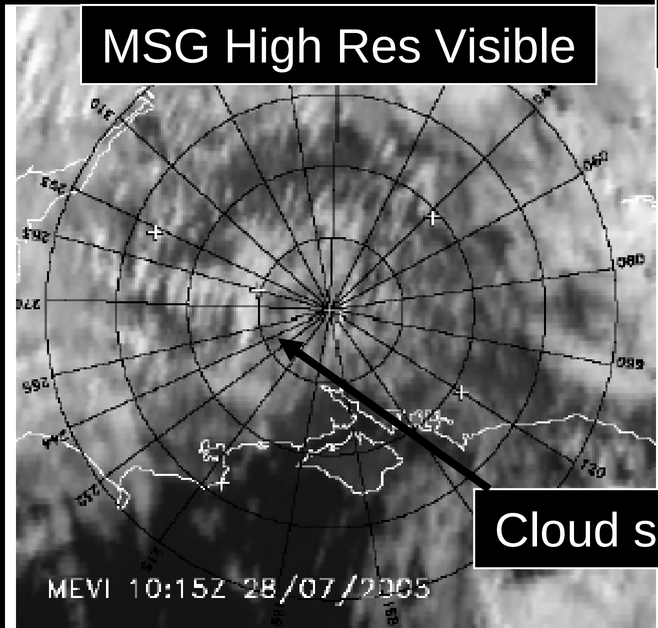
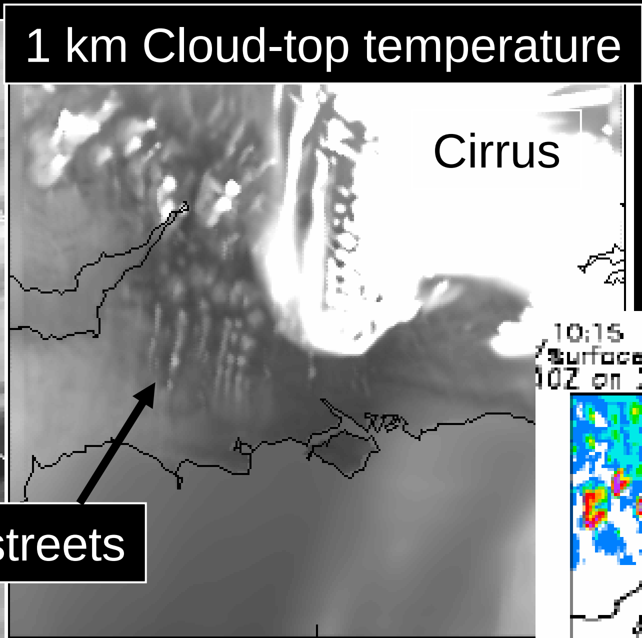
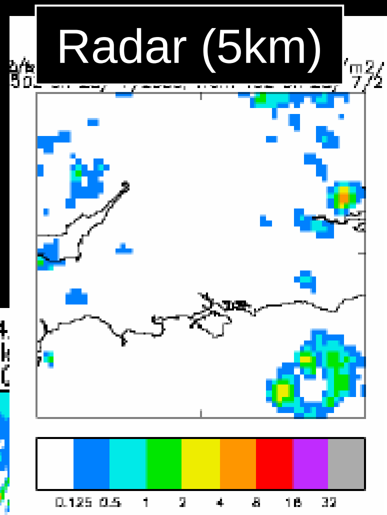


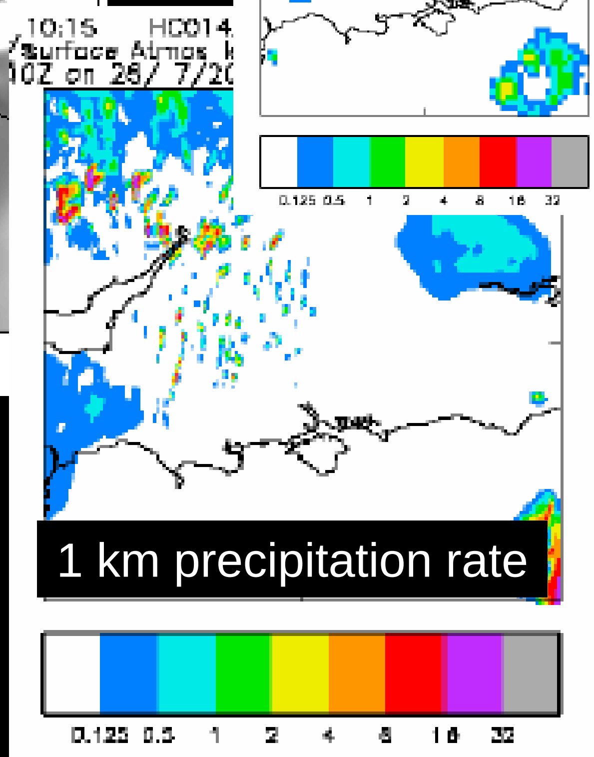
All UM runs have constant horizontal diffusion K=1430

Problems with initiation and shallow cumulus









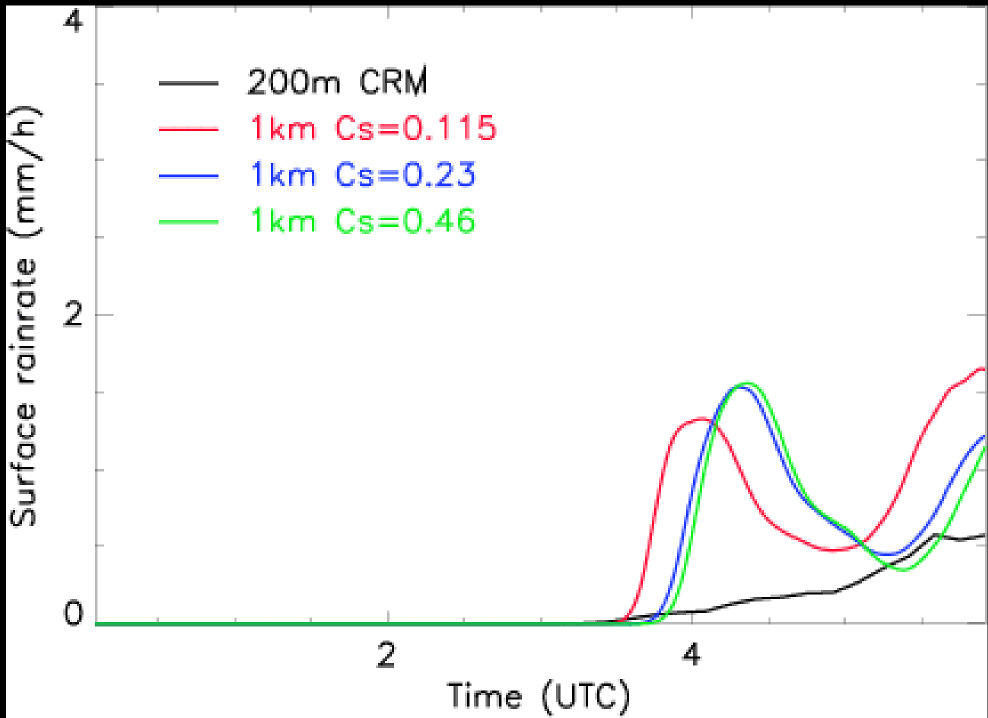
CSIP IOP 12 28/07/2005

With reference scheme we have a consistent problem of precipitation from explicit 'shallow' cumulus.

Impact of horizontal mixing

Met Office

- Increased horizontal mixing in the boundary layer leads to later convective initiation

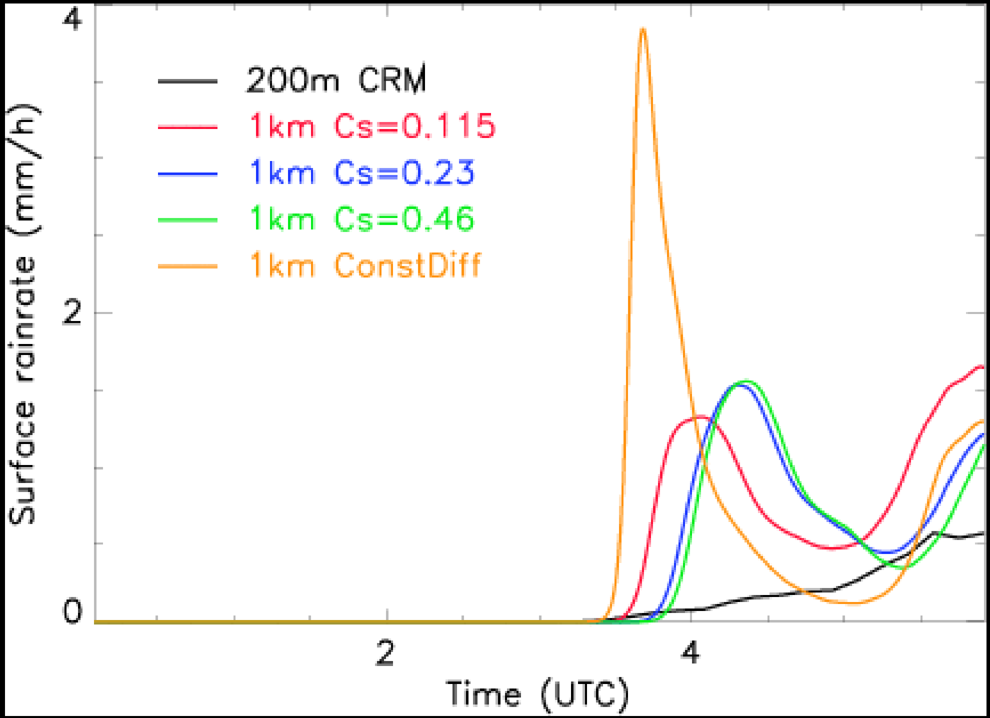


All UM runs have the non-local boundary layer scheme in the vertical

Impact of horizontal mixing

Met Office

- Increased horizontal mixing in the boundary layer leads to later convective initiation
- Smagorinsky horizontal improves transient



All UM runs have the non-local boundary layer scheme in the vertical.

<u>ConstDiff Coefficient:</u> K=1430.

<u>Max Diff for Cs runs:</u> K=2086.

Separate roles of horizontal and vertical mixing

Met Office

Vertical mixing in boundary layer promotes initiation

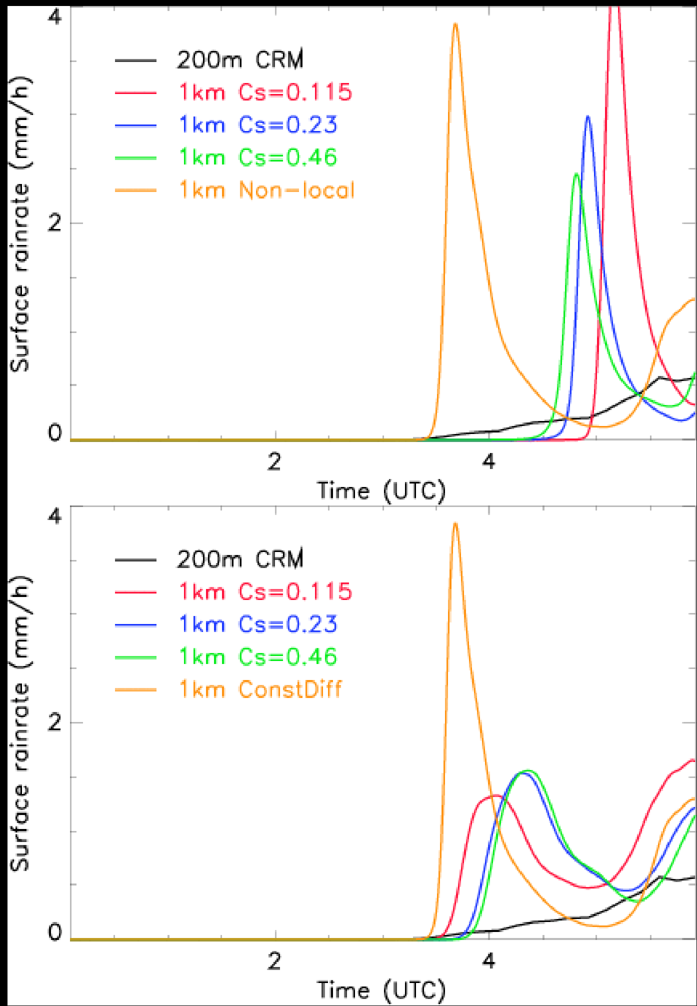
Horizontal mixing delays initiation but controls magnitude of deep clouds

Constant horizontal diffusion K=1430

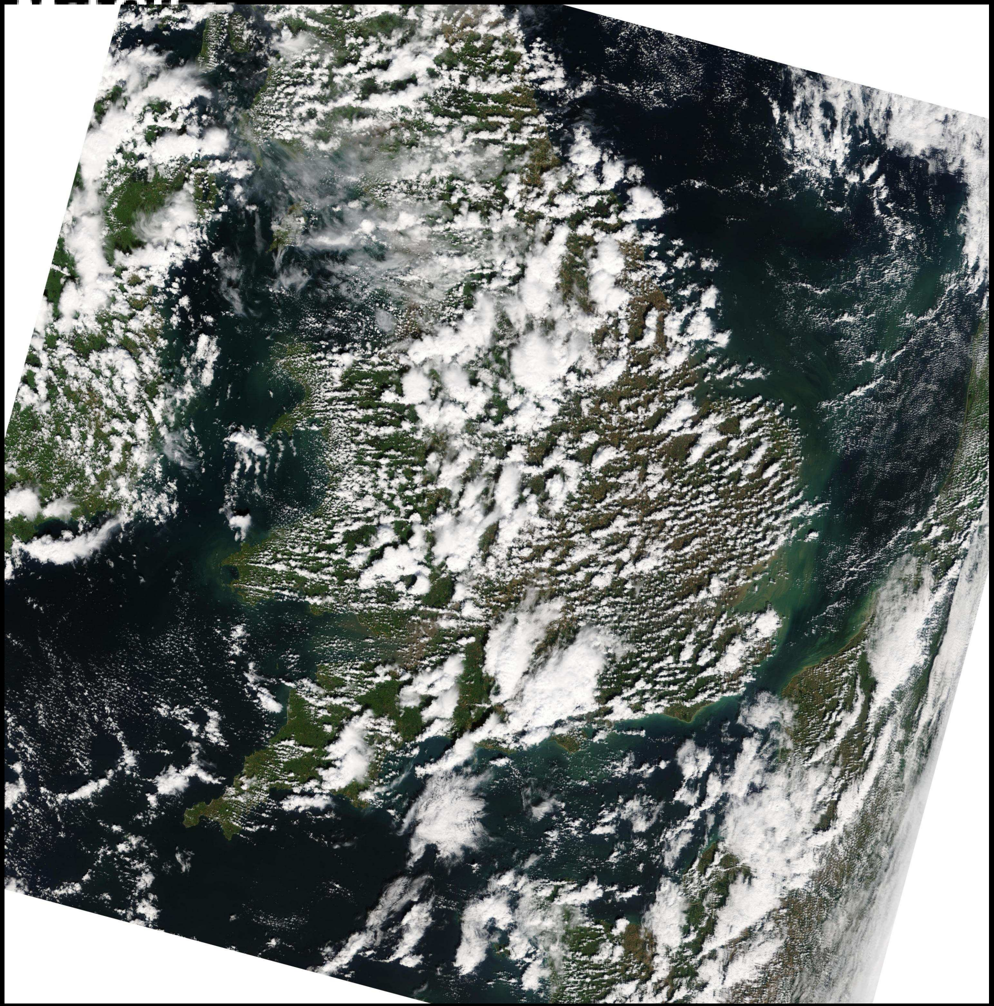
Non-local boundary layer scheme in the vertical.

ConstDiff Coefficient: K=1430.

Max Diff for Cs runs: K=2086.

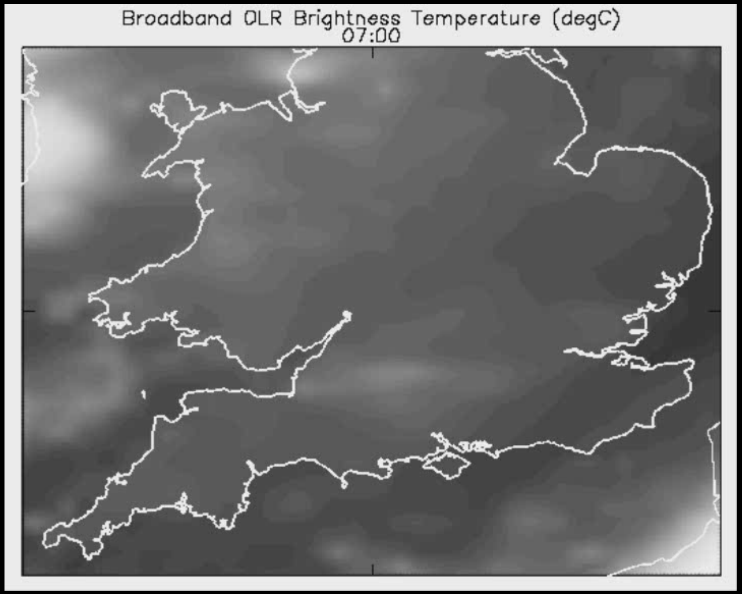


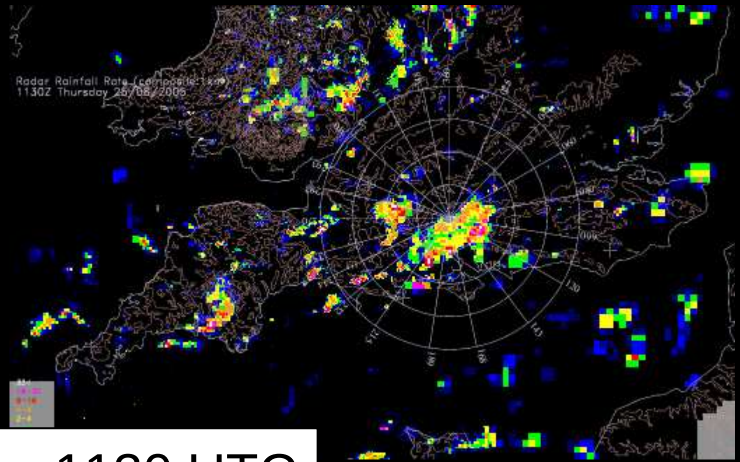
CSIP IOP 18 – 25/08/2006



Modis Terra 1125 UTC

Model forecast

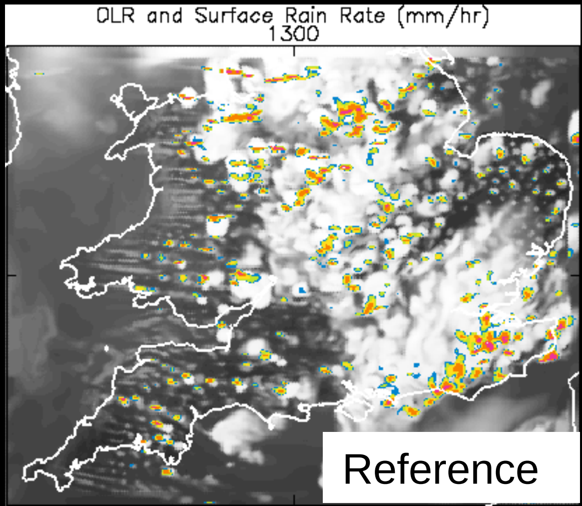


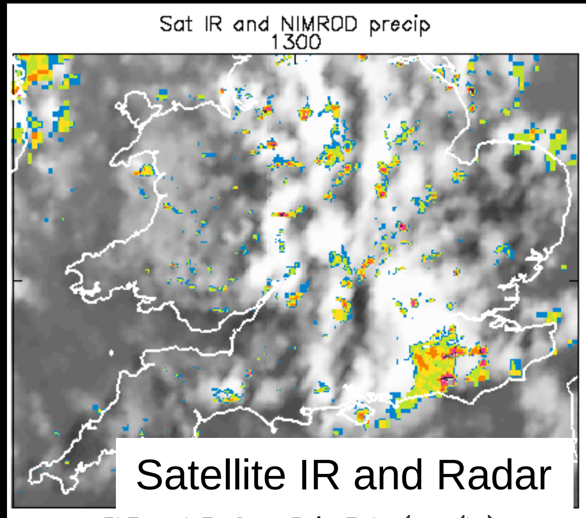


Radar 1130 UTC

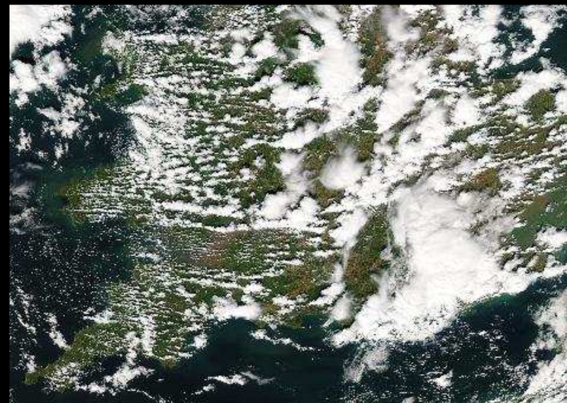
Met Office

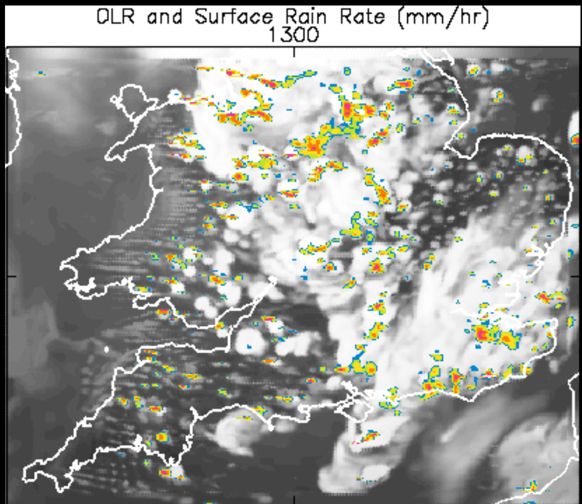
Impact of turbulence scheme on convective forecast (CSIP IOP18 - 25th Aug 2005)



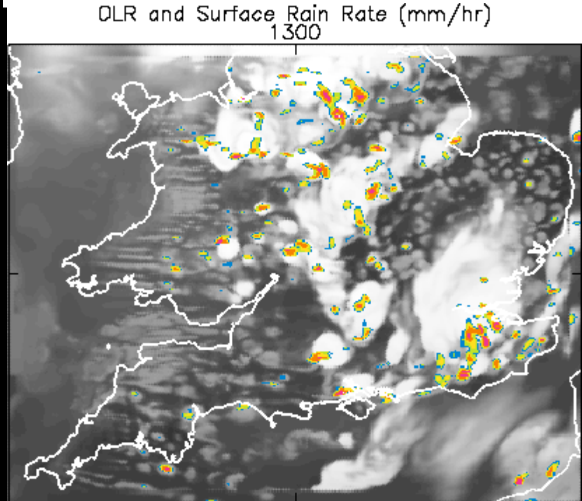


Satellite (Visible) MODIS

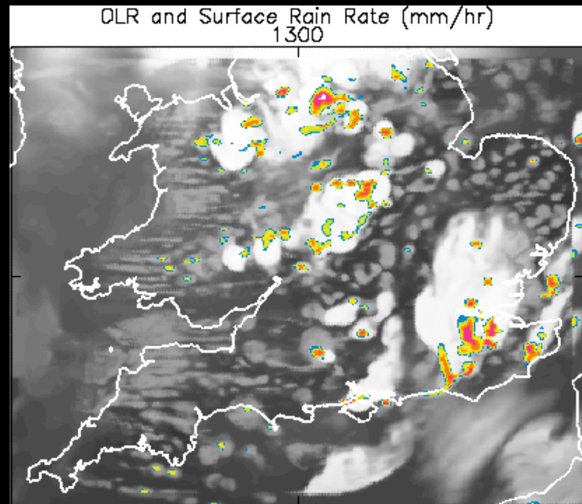




Horiz Cs=0.075

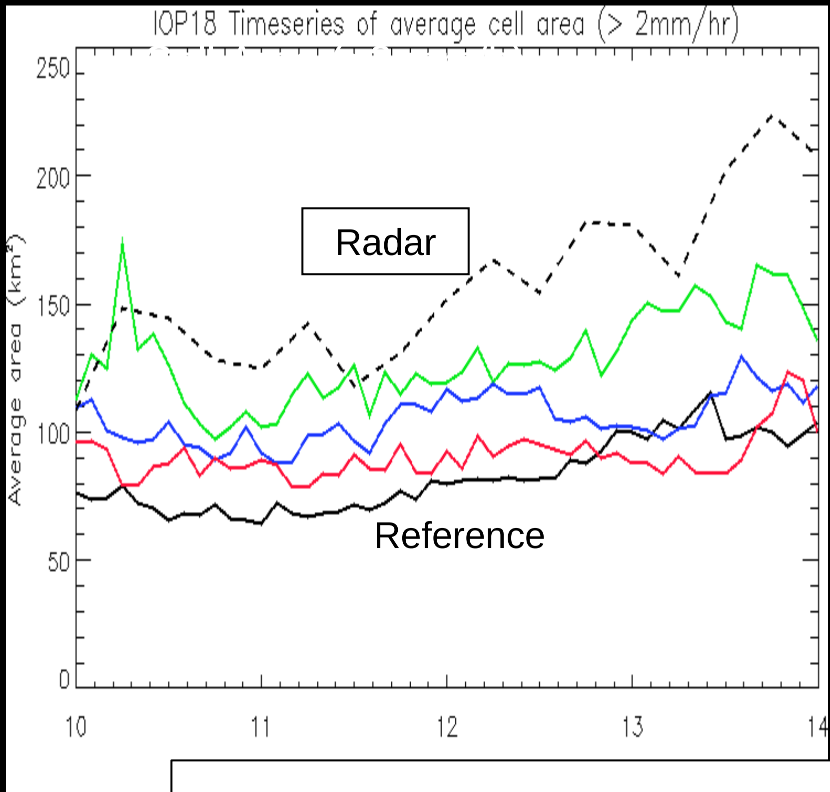


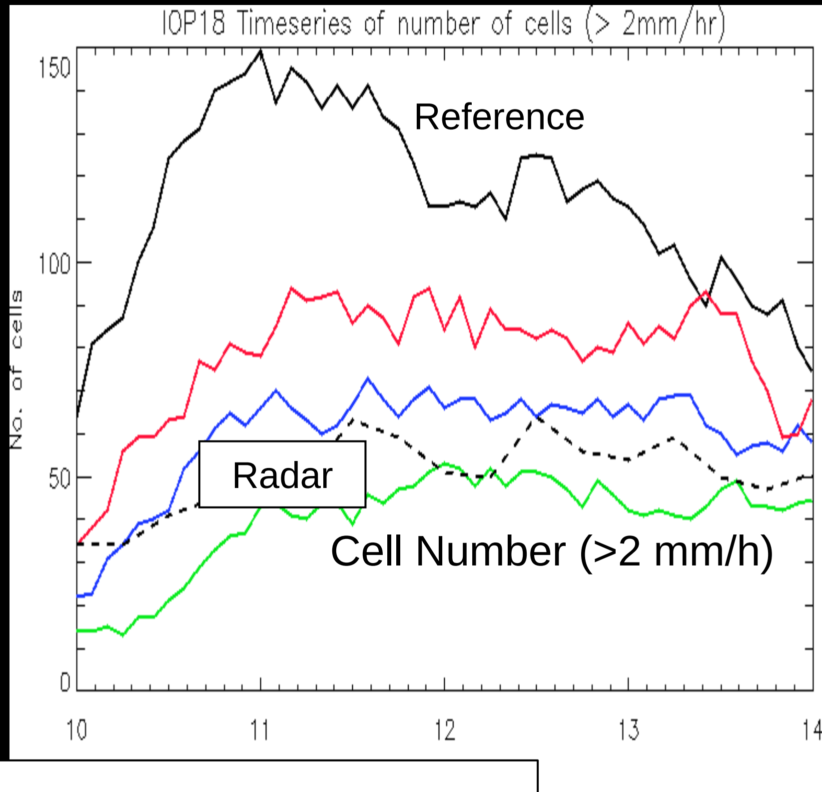
Horiz Cs=0.10



Horiz Cs=0.15

Convective cell statistics (CSIP IOP18)
Sensitivity to turbulence scheme





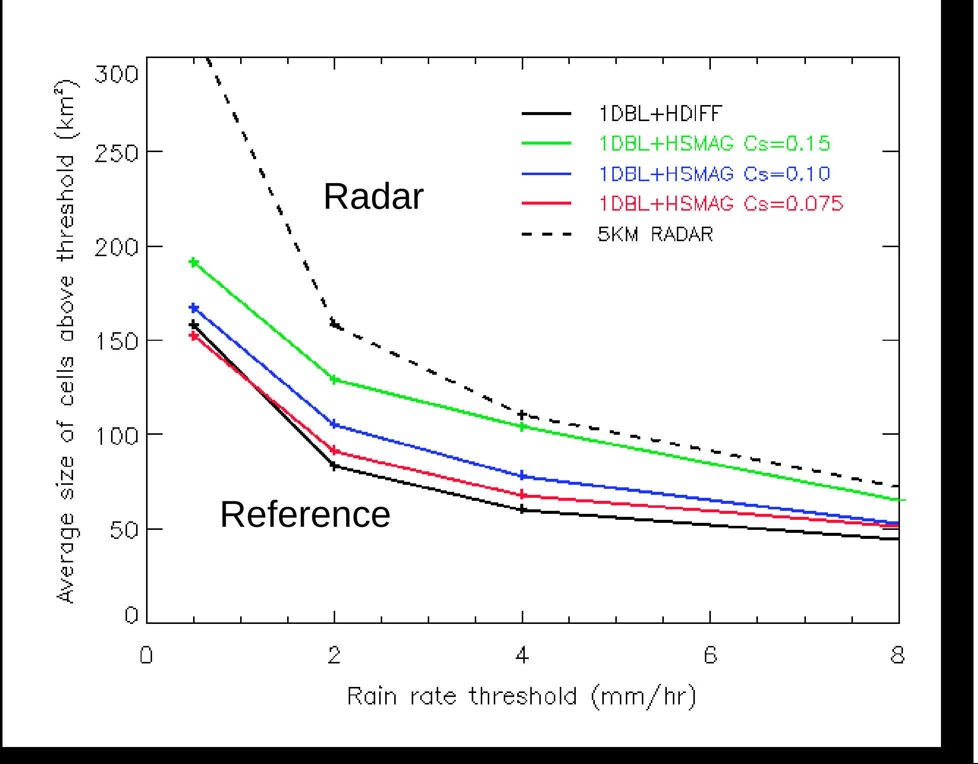
Operational value 0.15~0.2 but 'right' number may be case-dependant.

Model data is area-averaged to 5km radar grid

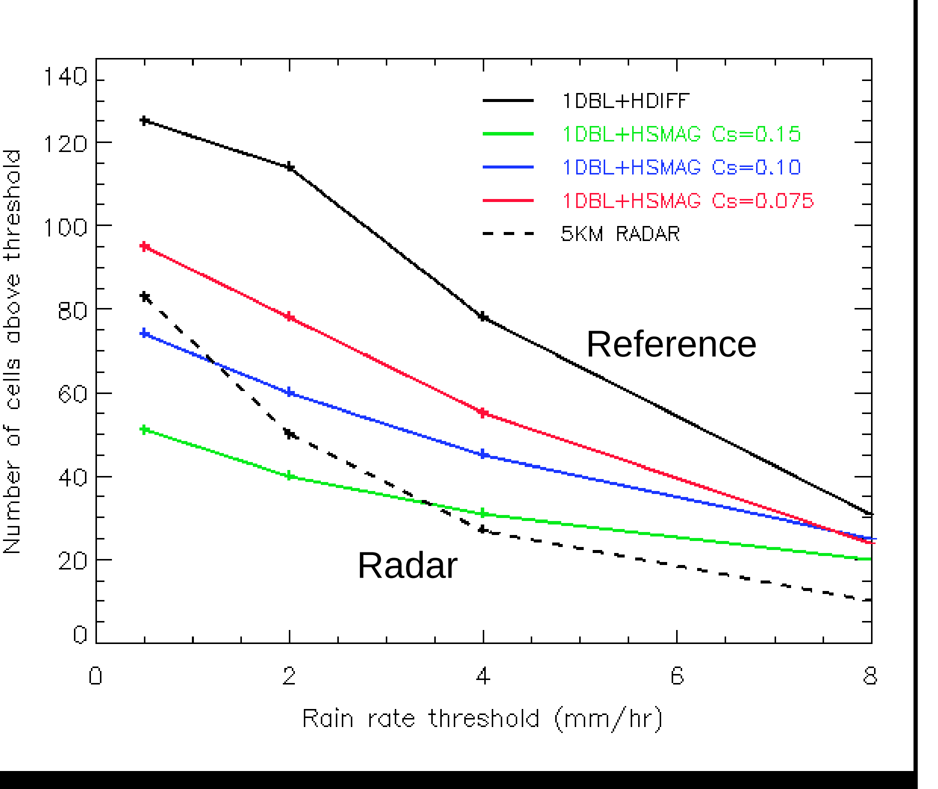
Convective cell statistics (CSIP IOP18)
Sensitivity to turbulence scheme

Met Office

Average convective cell size as a function of rainrate threshold

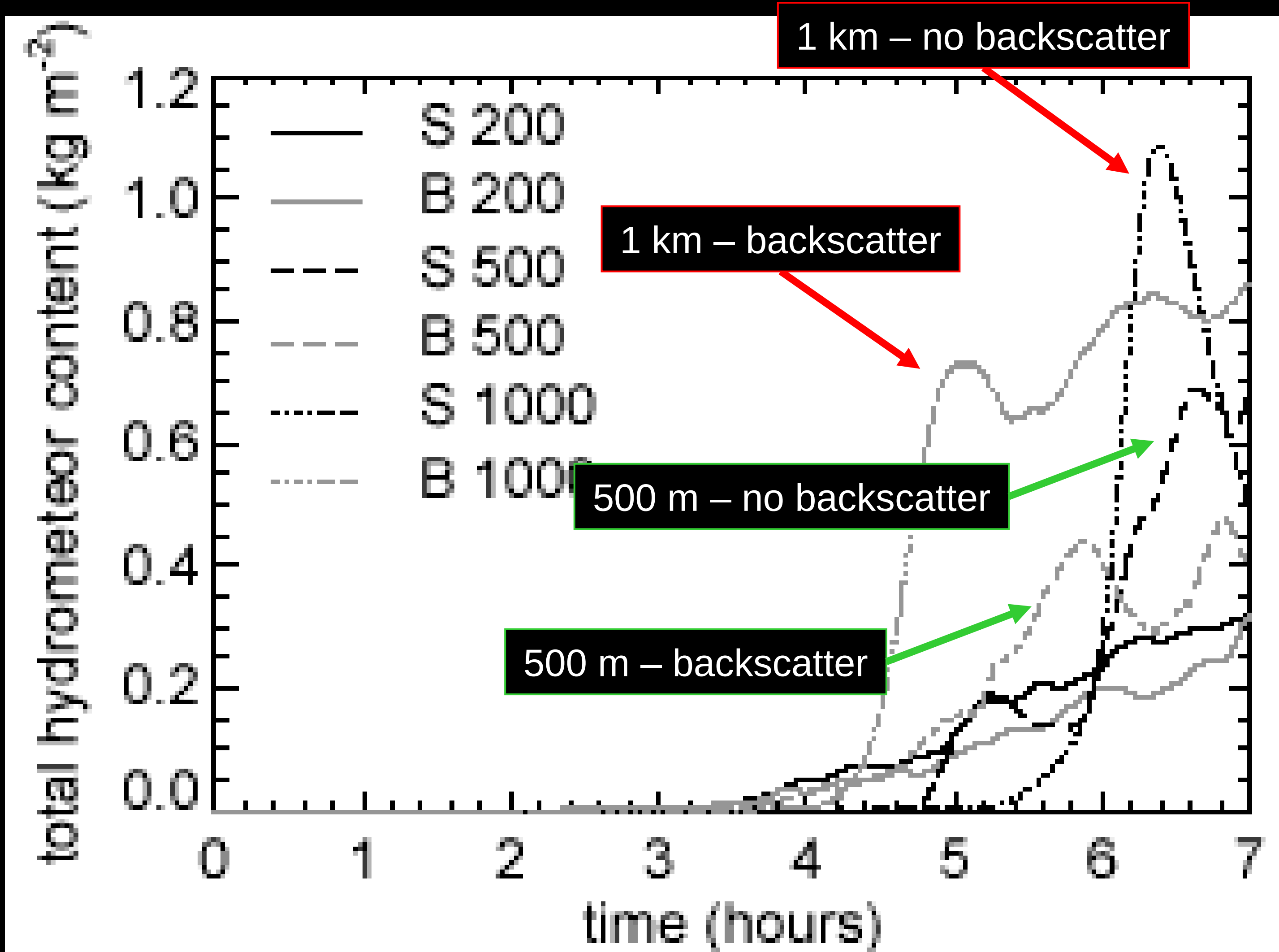


Average number of convective cells as a function of rainrate threshold



Model data are area-averaged to 5km radar grid

Stochastic Backscatter in LBA Diurnal Cycle



(Sonja Weinbrecht and Paul Mason, Reading)

Experiments with Temperature Perturbations

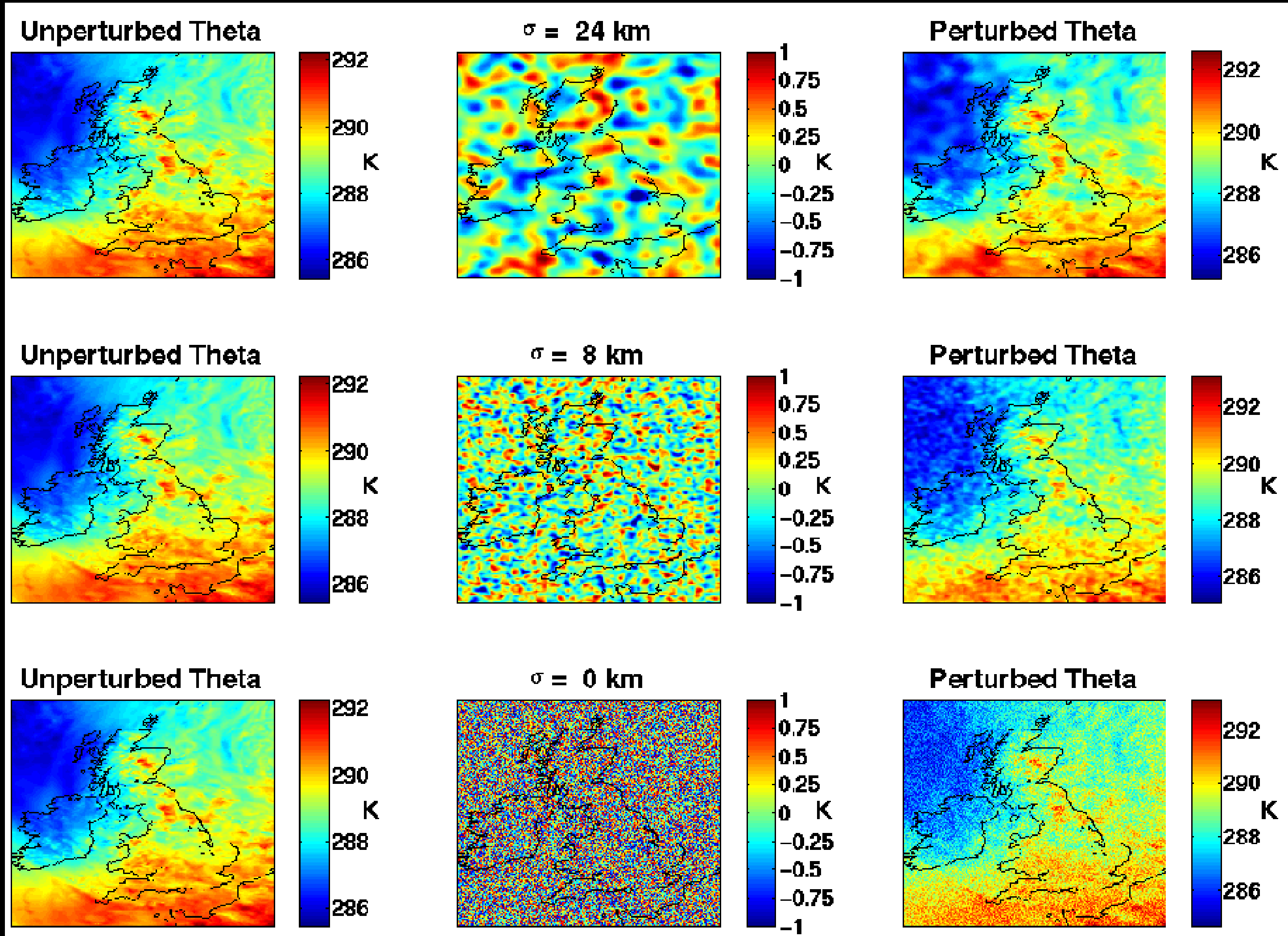
- CSIP IOP 18 widespread convection
- Using 4 km model (cost!)
- Simplistic approach: 2D Gaussian kernel applied to random numbers – chose scale and amplitude.
- Potential temperature
- Applied at fixed model level - not very sensitive if in CBL.
- at regular intervals (30 min) (experiments at longer).

- 3 amplitudes: 1, 0.1, and 0.01 K (cf theta*)
- 3 std: 24, 8, and 0 km

Giovanni Leoncini (Reading)

Perturbation Strategy

Perturbation Structure

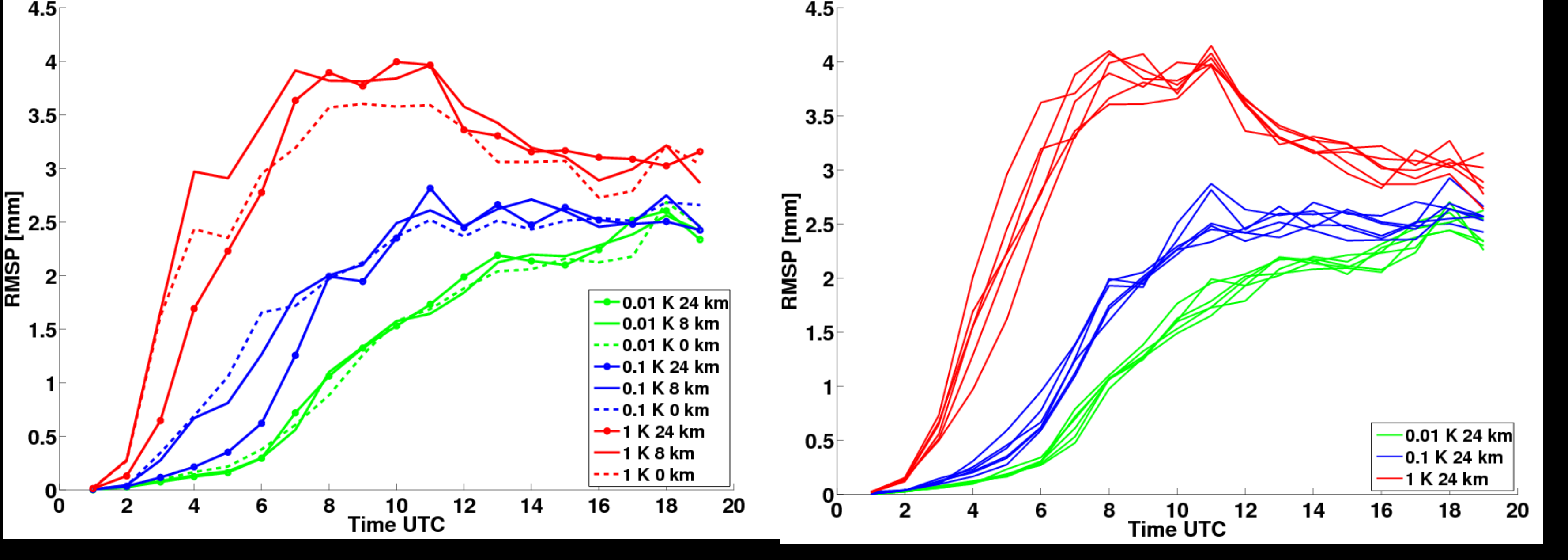


Giovanni Leoncini (Reading)

Results sequential perturbations

Ensemble spread seems insensitive to perturbation scale

RMSE Hourly Accumulated Precip

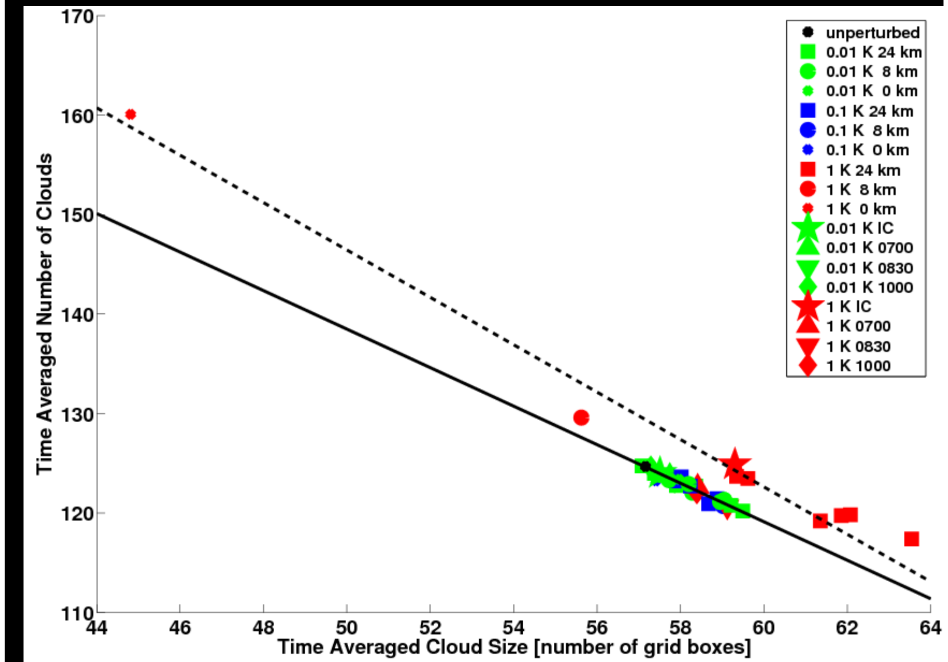


Giovanni Leoncini (Reading)

Impact on cloud stats

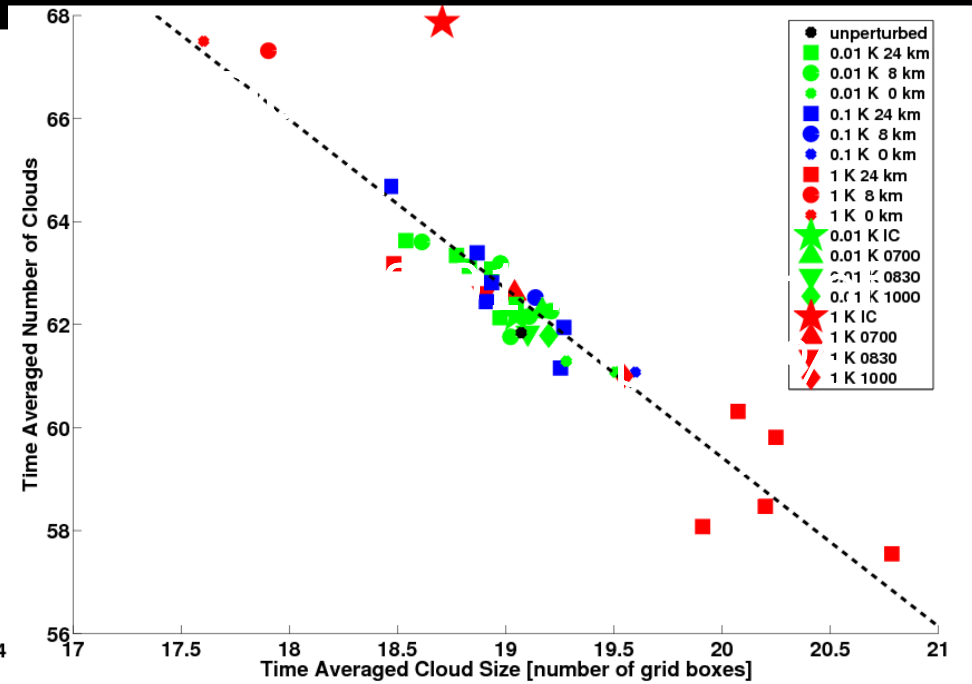
Non cirrus

TWC > 0.05 kgm^{-2}



Precipitating clouds

Rain rate > 1 mmh^{-1}



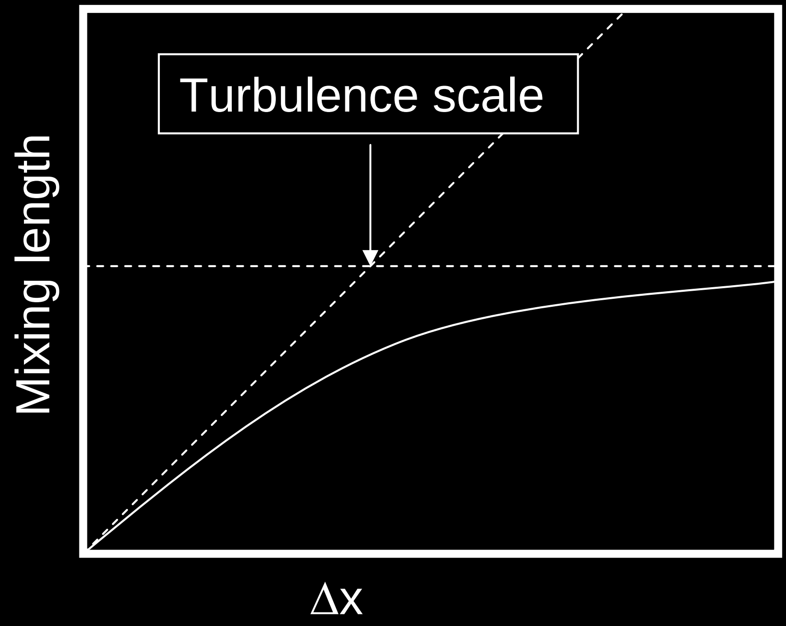
Giovanni Leoncini (Reading)

Conclusions/Future Work

- Sequential perturbation method is a useful for experiments – needs much more work to be considered ‘stochastic physics’.
- Amplitude of perturbations main driver, scale length secondary.
- 1 K experiments are qualitatively different
- 0.1 and 0.01 K similar values of RMSP.
- Sensitivity to the time of day.
- Relation to convective equilibrium.
- Improve representation of balance in perturbation (acoustic waves esp.).

Future plans - turbulence

- ‘Blended’ BL and (moist) 3D turbulence.
  - Mixed turbulence/large eddy behaviour in BL
  - Horizontal may always need tuning.
  - Smagorinsky outside (?)
  - Moist vertical mixing in cloud cores? Stability functions or convective cores?



- Stochastic backscatter.
  - Initially based on Weinbrecht/Mason
  - Extensions for shallow Cu?

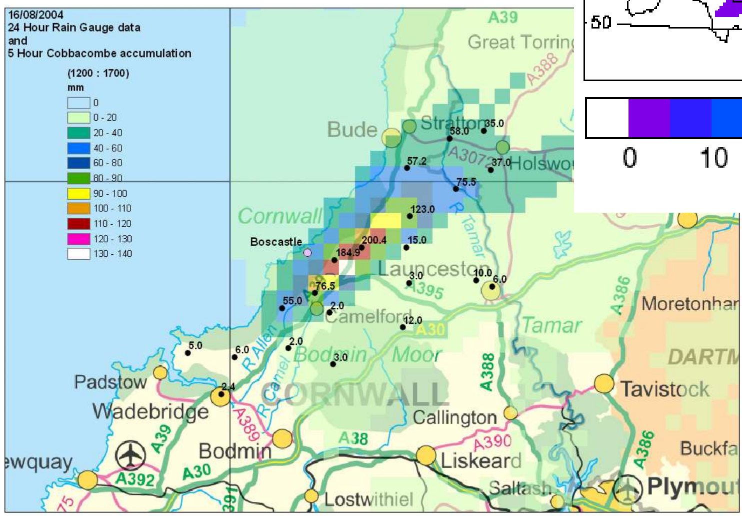
Part 2

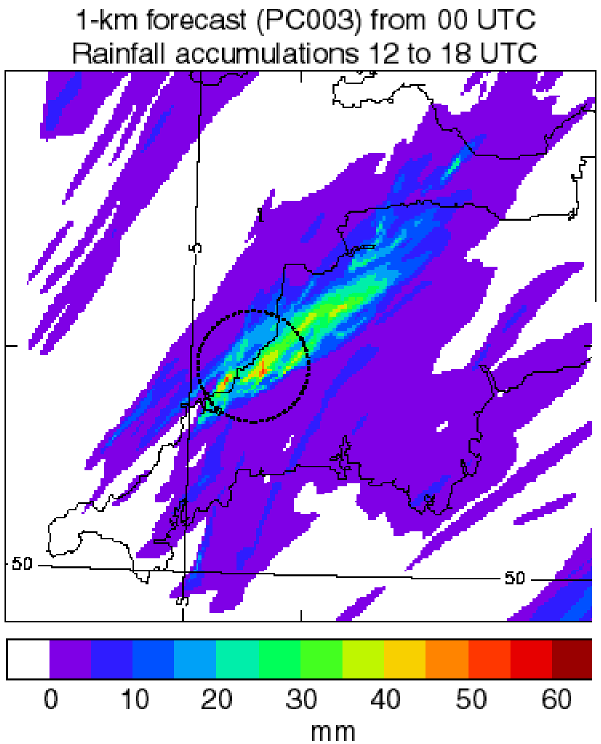
- We have lots of problems with the boundary-layer/convection ‘grey zone’ – controls triggering, cloud scales etc.
- ~1 km should be hopelessly inadequate.
- But we get very useful forecasts remarkably often.

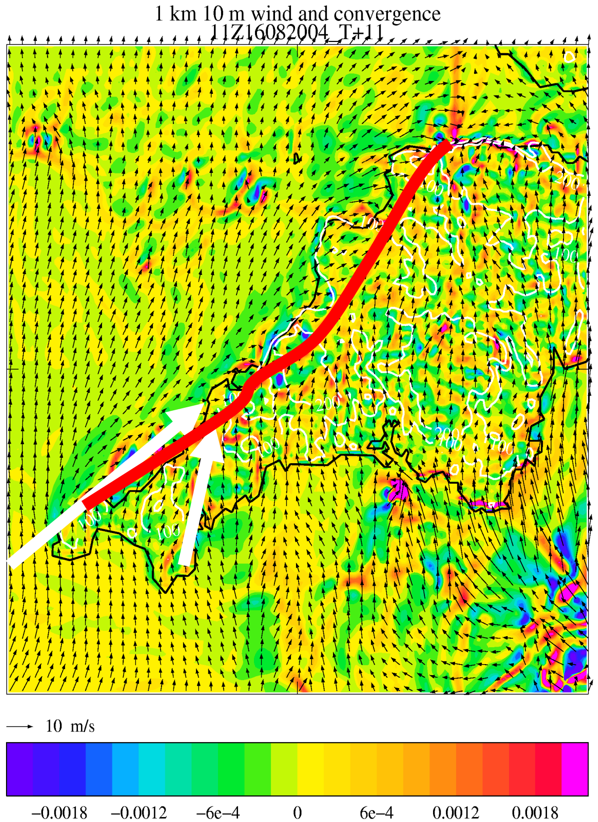
Why?

The Boscastle Flood

16th August 2004



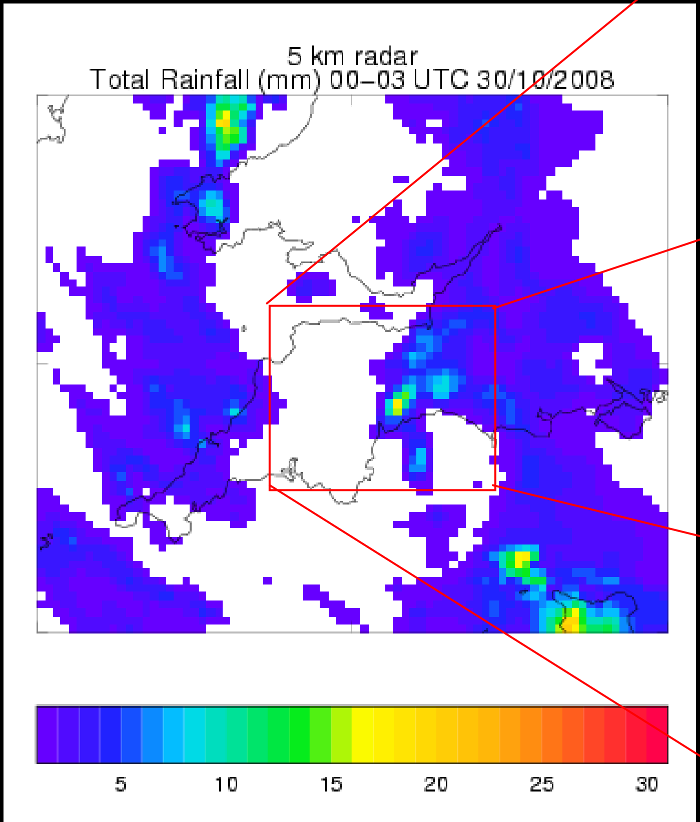


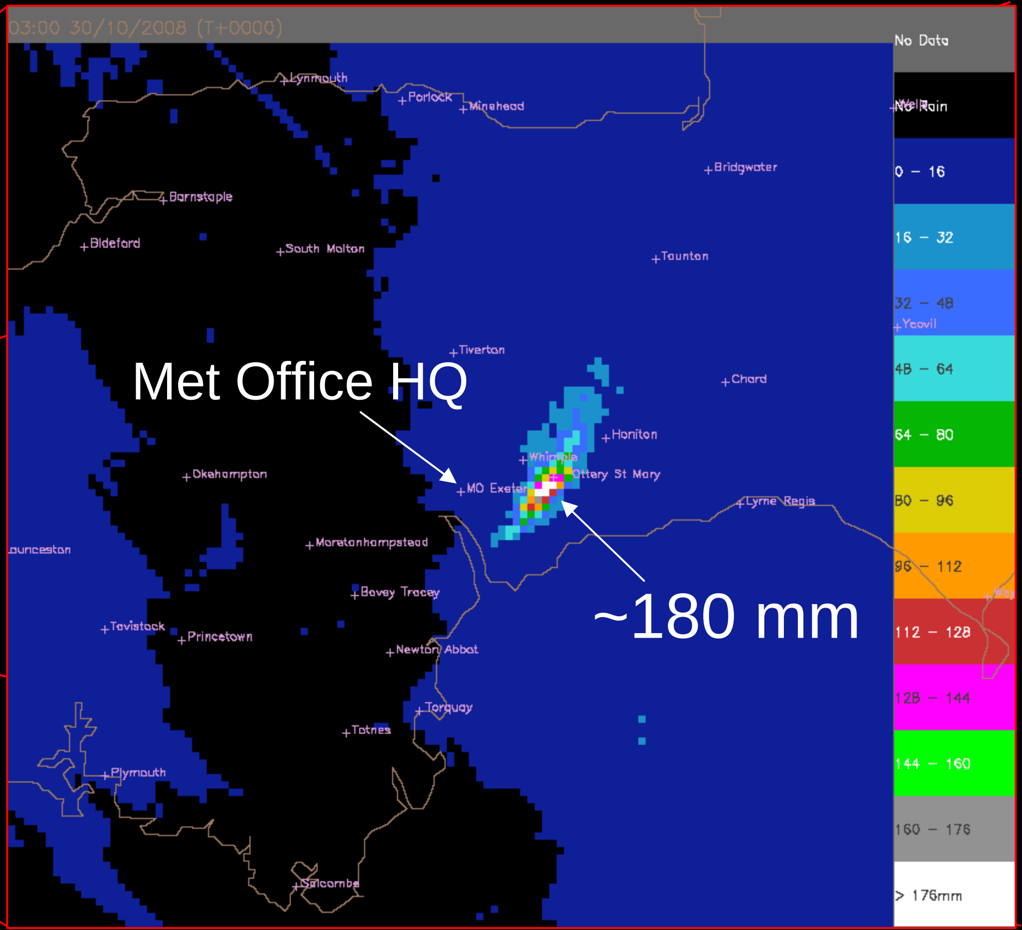


The Ottery St. Mary Hail Storm 30/10/2008

BBC, 30/10/2008

The Ottery St. Mary Hail Storm

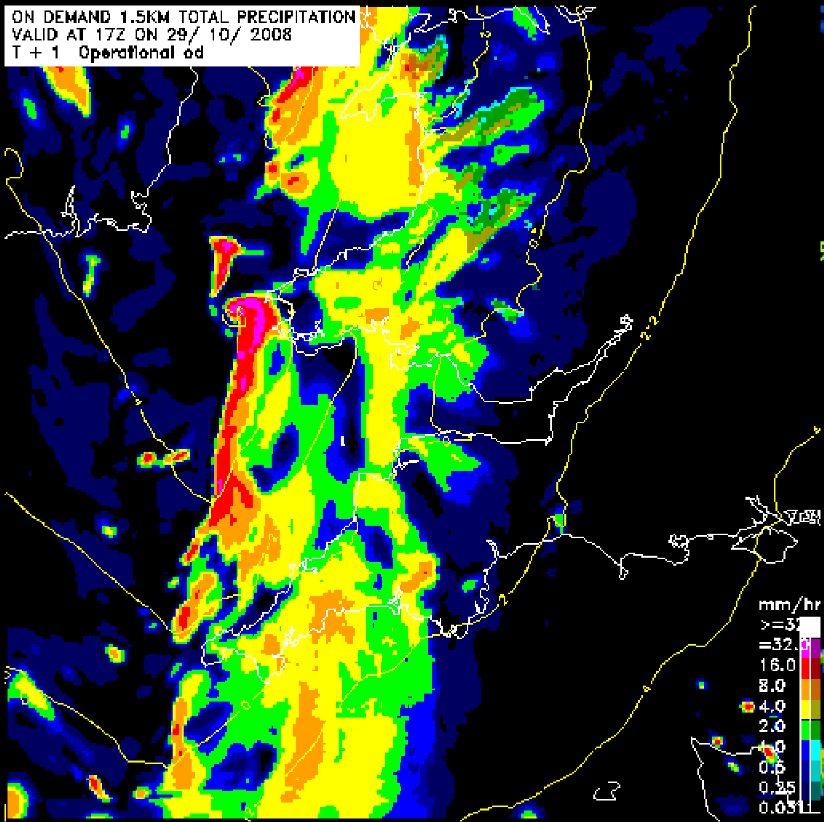




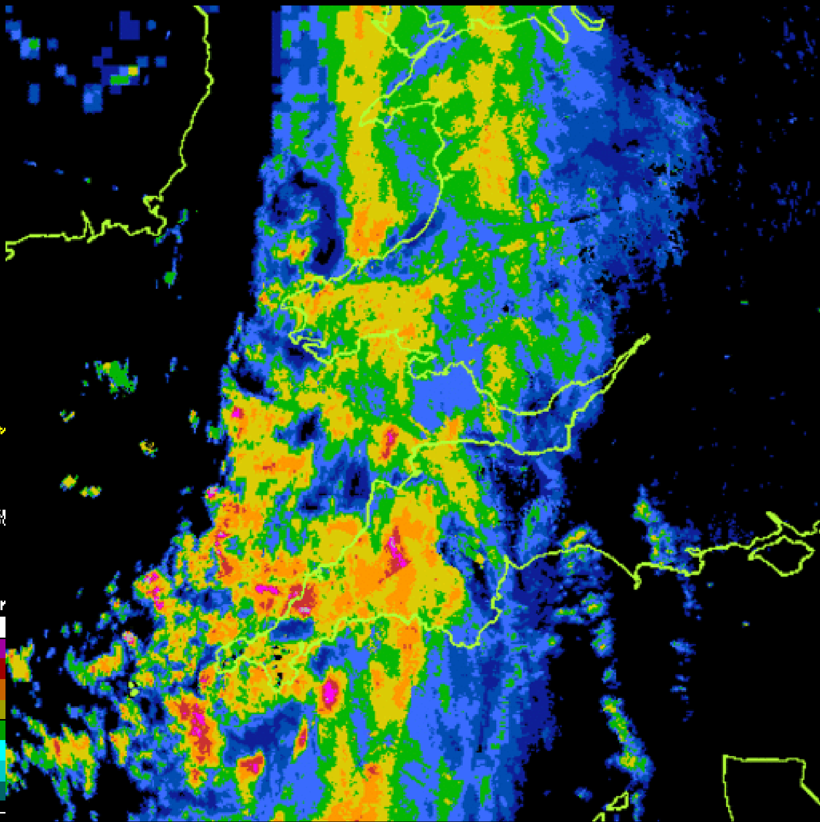
5 km radar composite
0000-0300 accumulation

1 km radar composite
0000-0300 accumulation

The Ottery St. Mary Hail Storm
Forecast rainfall rates

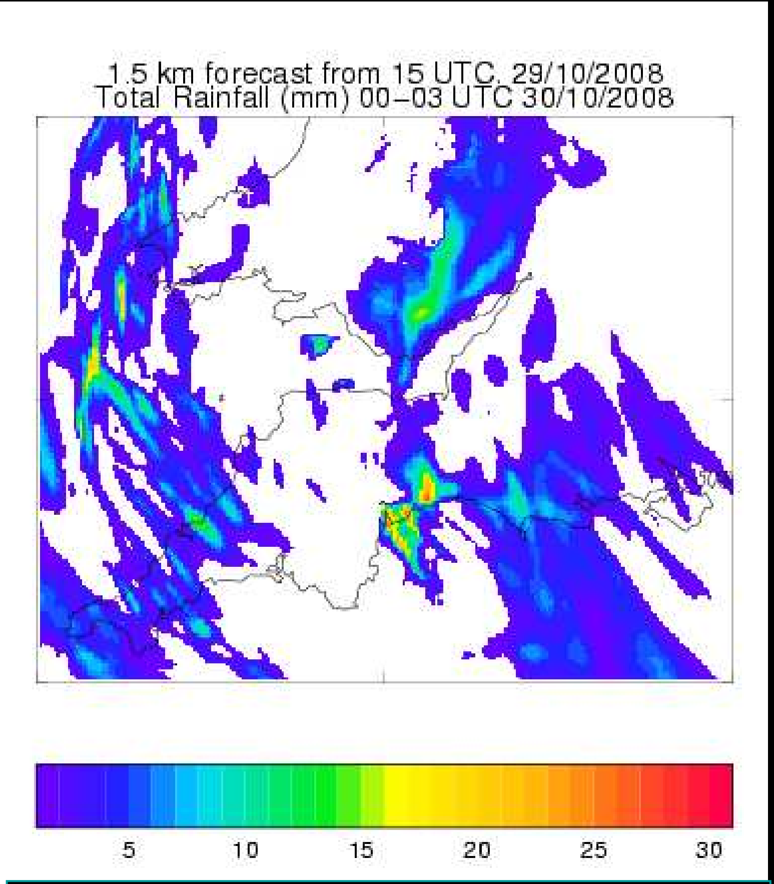


1.5 km model
from 15 UTC, 29/10/2008

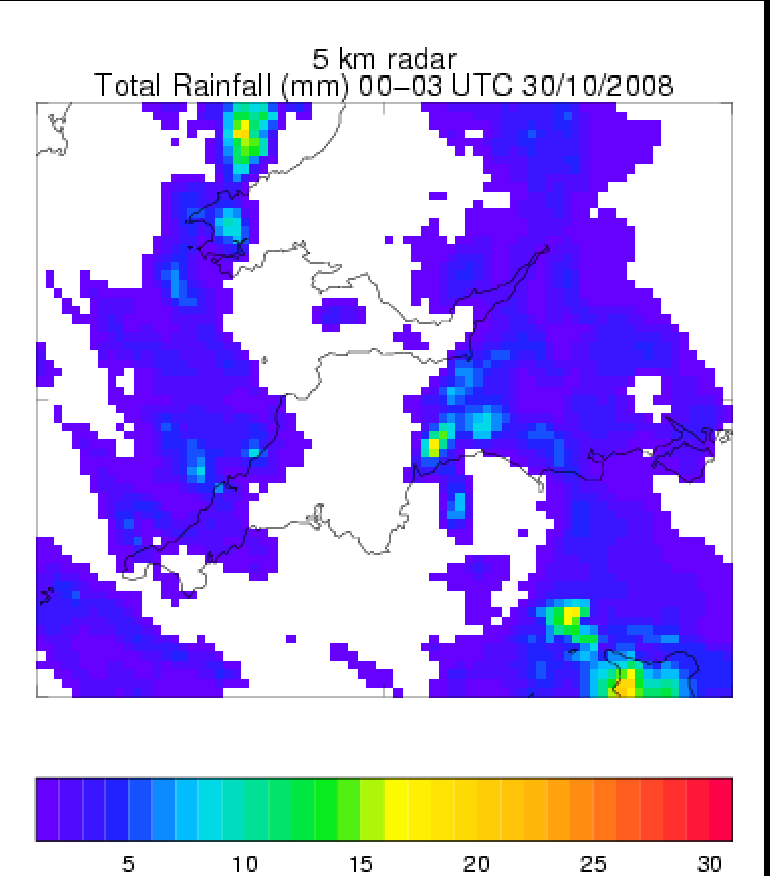


Radar Composite

The Ottery St. Mary Hail Storm
Forecast rainfall total



1.5 km model
from 15 UTC, 29/10/2008



Radar Composite

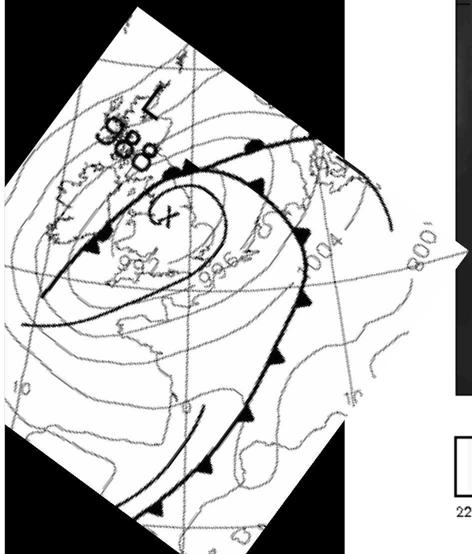
The 'Morpeth Flood', 06/09/2008

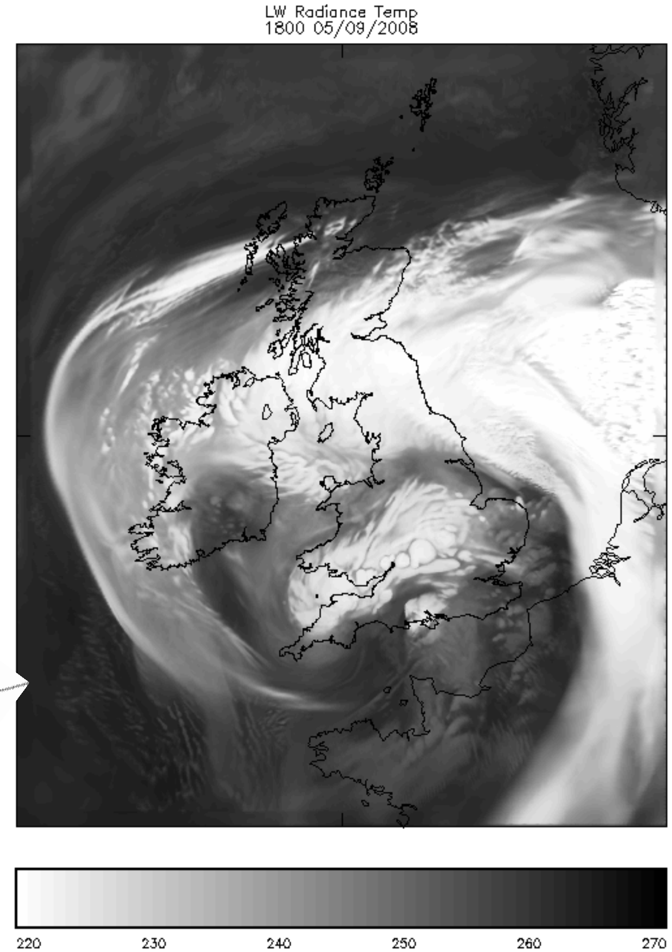
BBC, 06/09/2008

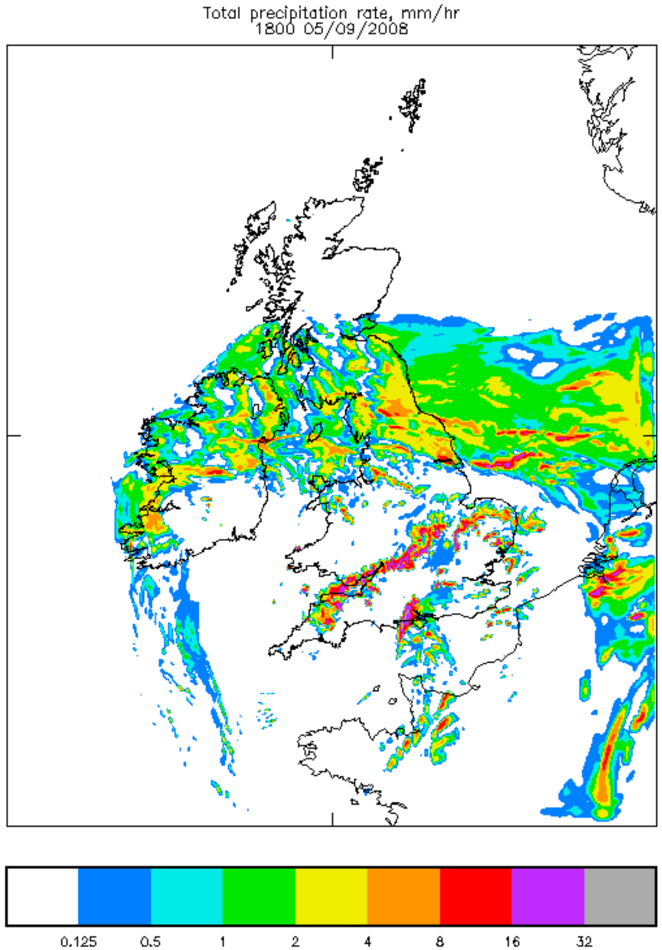
Independent, 7/09/2008

The ‘Morpeth Flood’, 06/09/2008

1.5 km L70
Prototype UKV
From
15 UTC 05/09
12 km

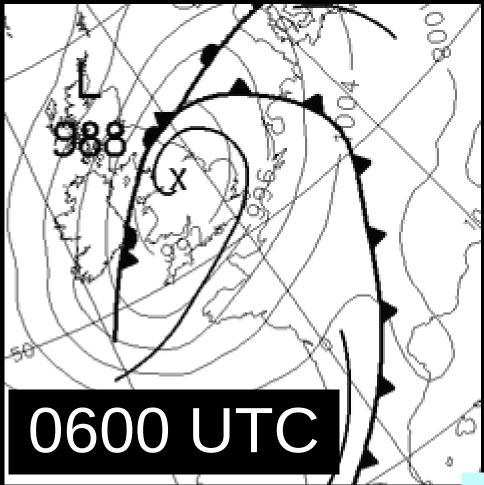




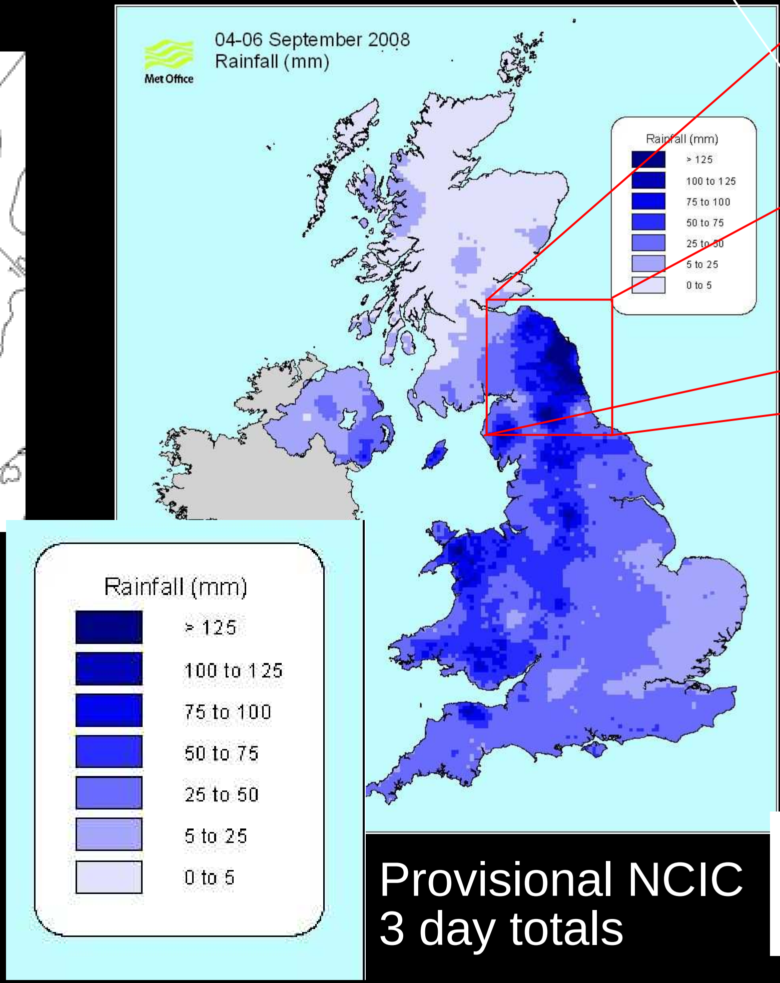


0600 UTC

The ‘Morpeth Flood’, 06/09/2008 Prototype 1.5 km forecast

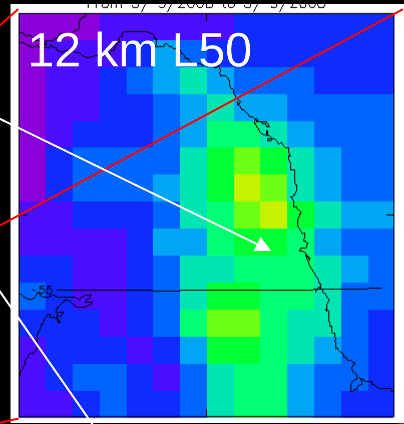


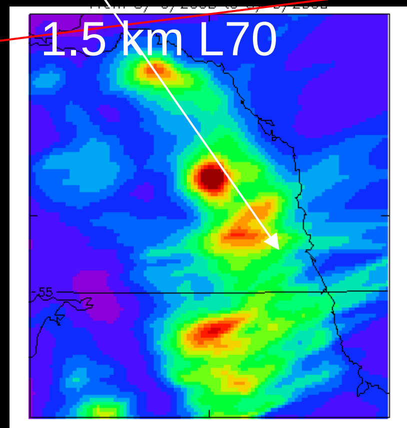
‘Morpeth flood’
06/09/2008

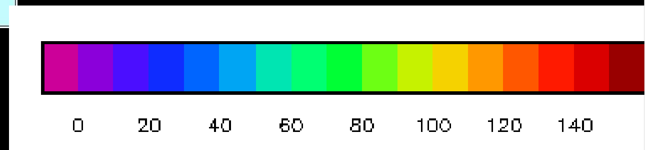


Provisional NCIC 3 day totals

Morpeth



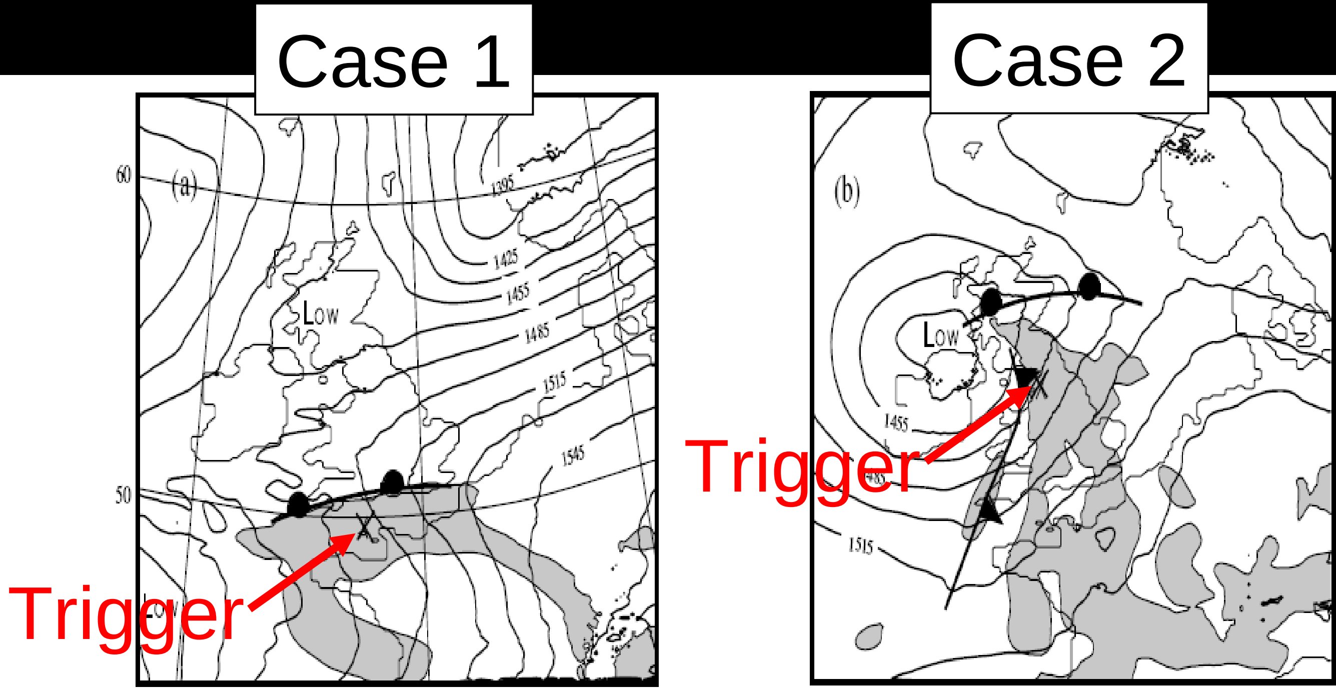




Equilibrium and Predictability

- Convection can only (obviously) occur where inhibition zero (or very close if we allow ‘overshoot’).
- Convective Inhibition (CIN) is often eroded over a period of time (i.e. widespread stability -> instability).
- If eroded over a large area (cf cloud spacing), small spatial fluctuations control triggering. Likely to be unpredictable. Many clouds, slow evolution, likely to achieve equilibrium with forcing.
- If eroded preferentially a over small area, convection is likely to be as predictable as the area of erosion. Few clouds. Non-equilibrium behaviour.

Low CIN vs high CIN Cases studies

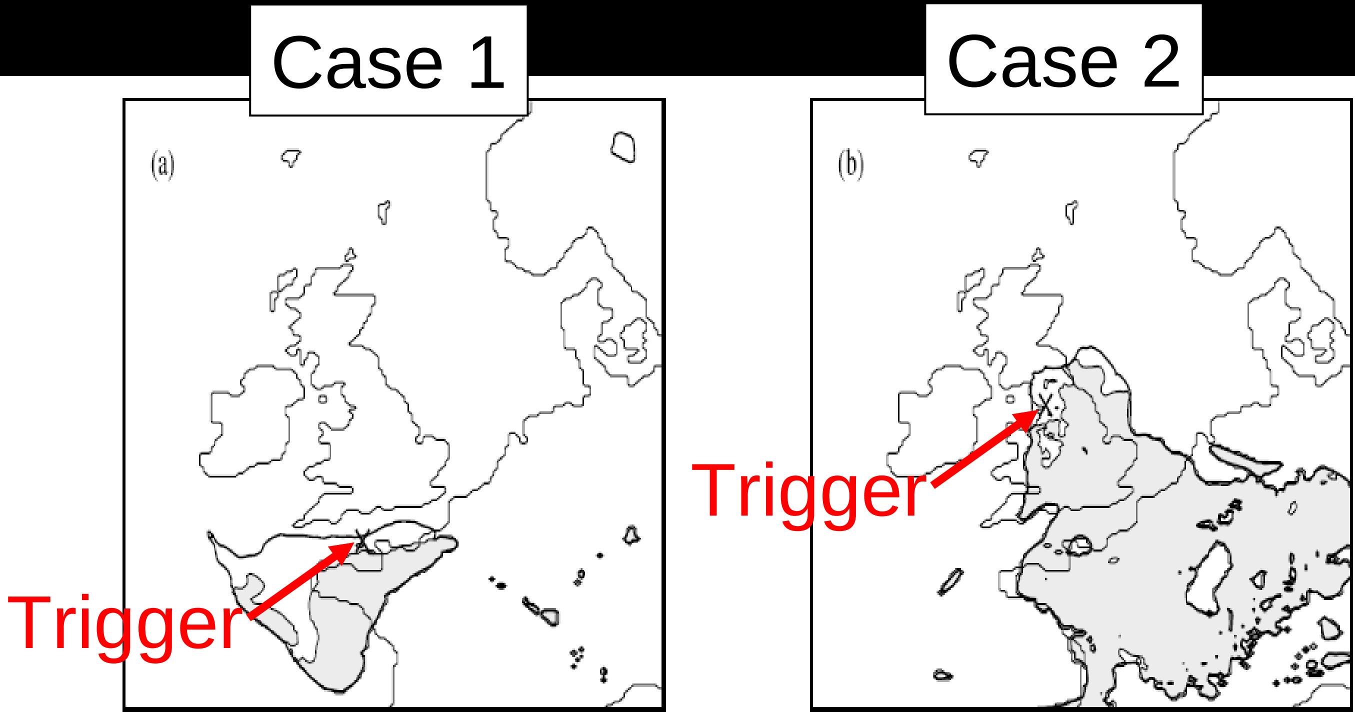


850 hPa height, θw>289K shaded.

Chosen on basis of consistency of forecasts.

Done, Craig, Gray, Clark and Gray

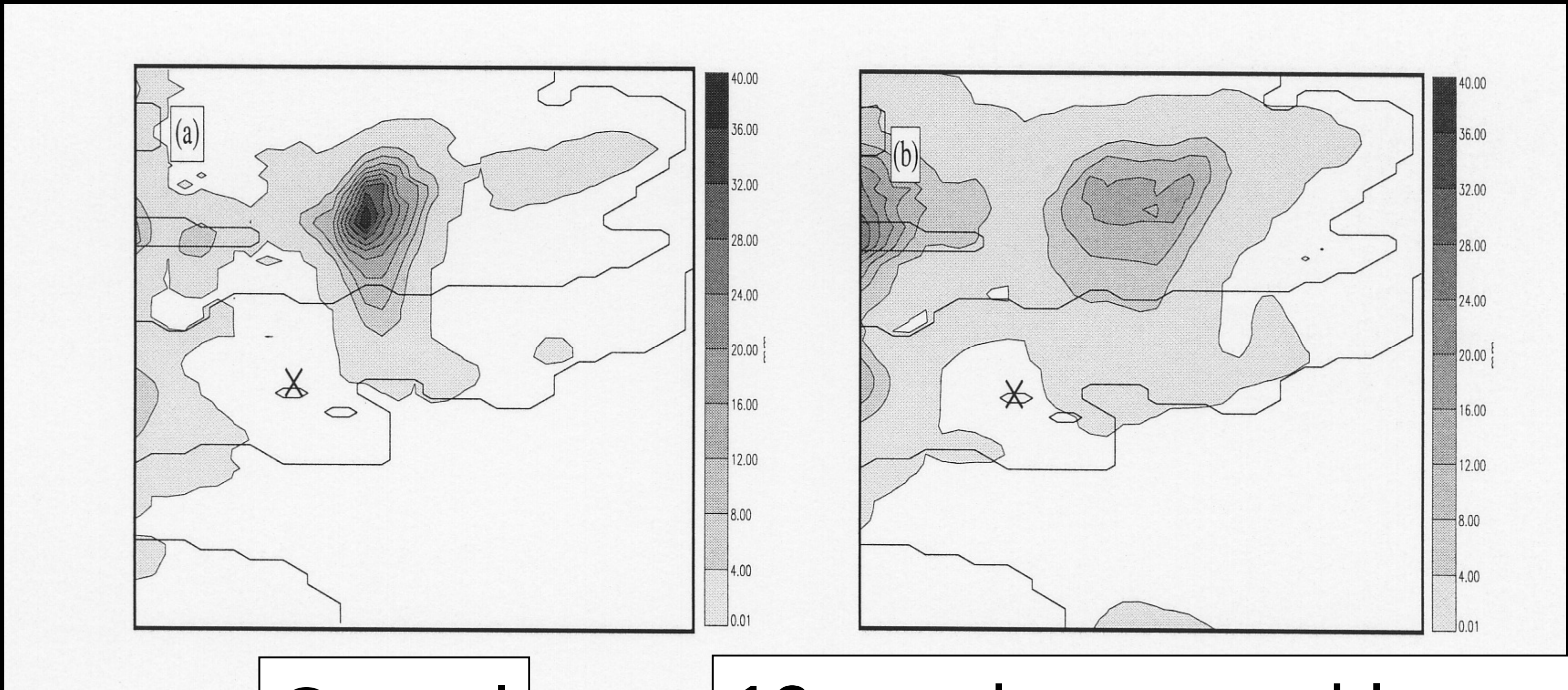
Low CIN vs high CIN Cases studies



CAPE (Contour, 300 J/kg Case 1, 500 J/kg Case 2)
CIN (Shaded) >10J/kg

Done, Craig, Gray, Clark and Gray

Case 1 – explicit ensemble results

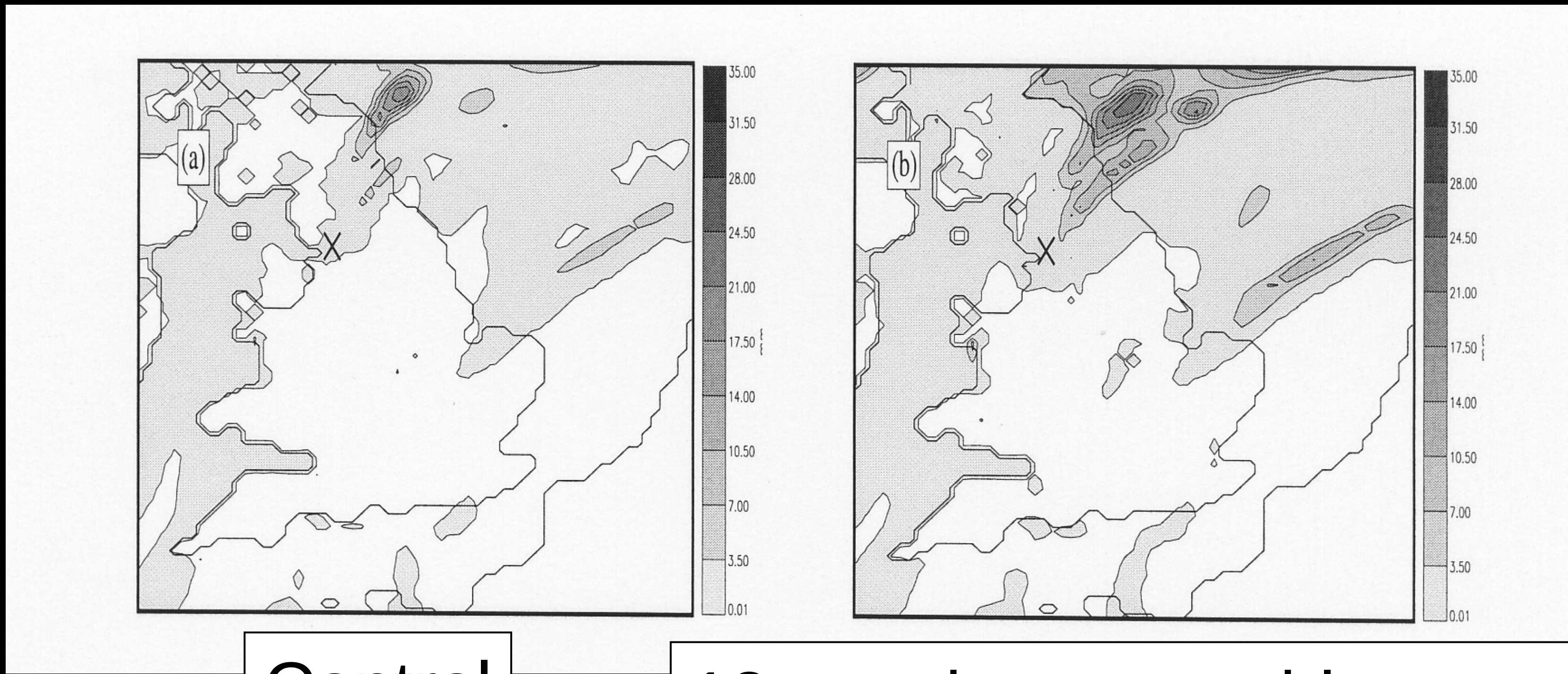


Control

12 member ensemble mean

Accumulated precipitation, explicit 12 km solution

Case 2 – explicit ensemble results



Control

12 member ensemble mean

Accumulated precipitation, explicit 12 km solution

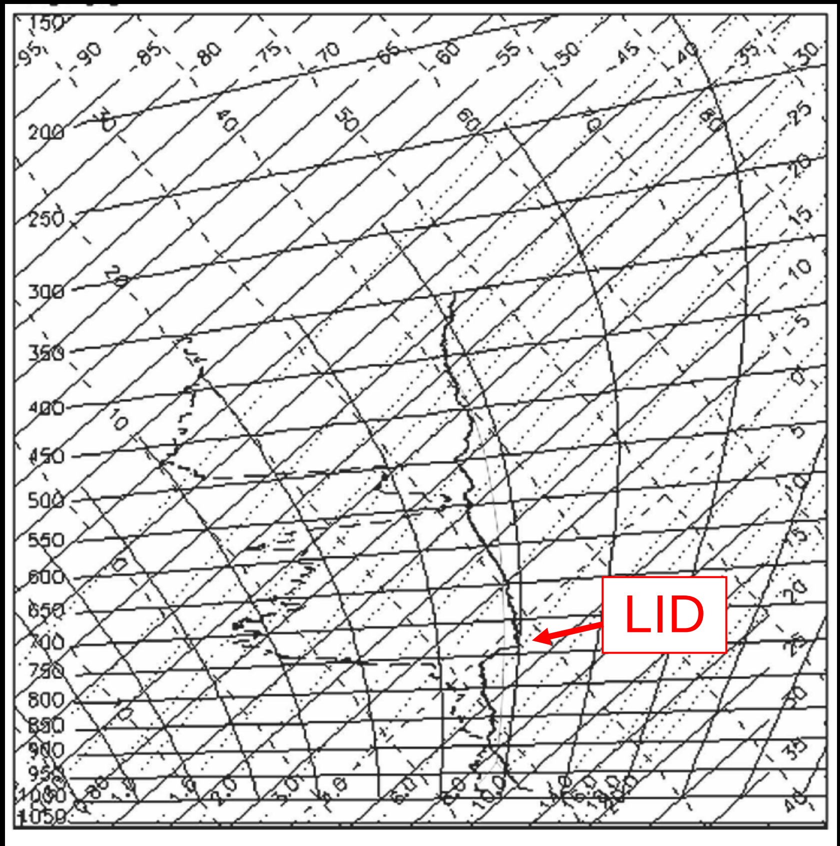
Comments

- CASE 1 - Large area of low CIN, convection able to respond to forcing.
  - Explicit ensemble produces large spread.
  - Ensemble mean resembles parametrized solution (even though explicit very under-resolved).
- CASE 2 – Small area of low CIN, CAPE able to build up.
  - Explicit ensemble produces very small spread – very predictable.
  - Parametrized solution very poor – completely wrong place.
  - Predictability arises because low CIN region from land/sea contrast.

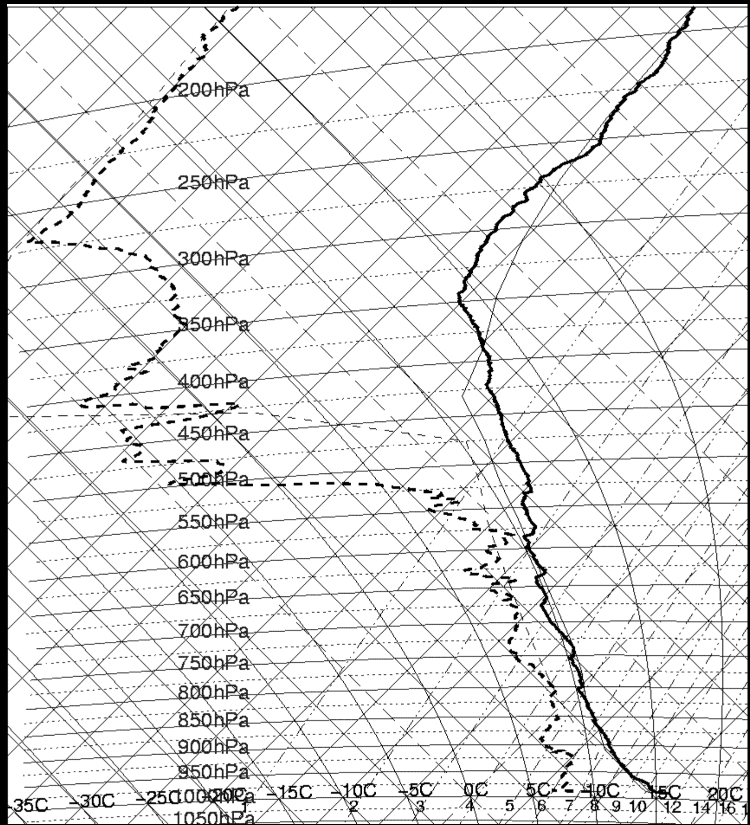
Two contrasting CSIP cases

CSIP was neatly bracketed by two ‘extreme’ cases:
IOP 1 – high CIN, one very predictable shower
IOP 18 – low CIN, ‘chaotic’ development.

CSIP IOP 1 1100 15/06/2005

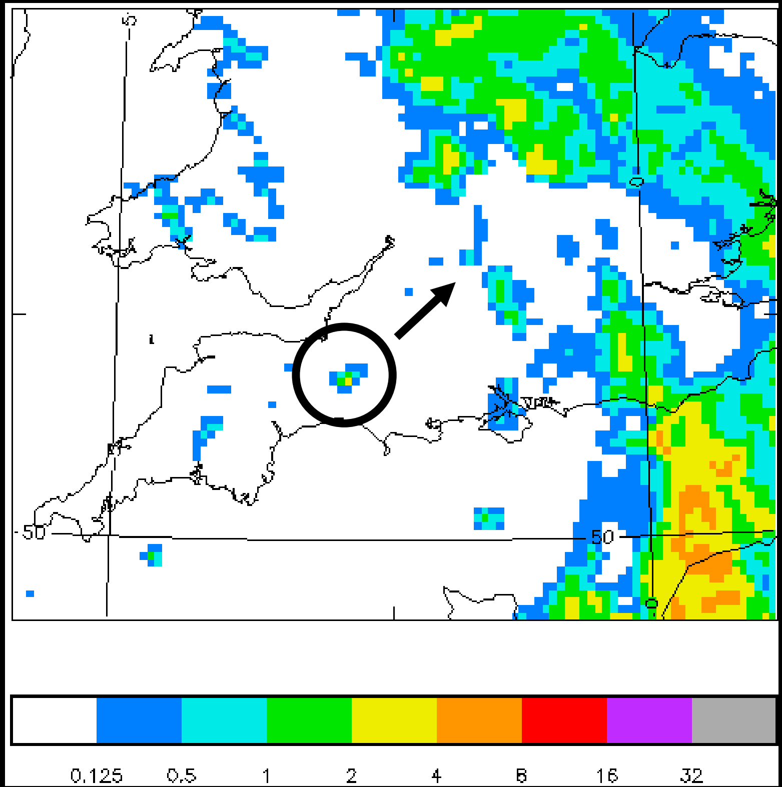


CSIP IOP 18 1000 25/08/2005

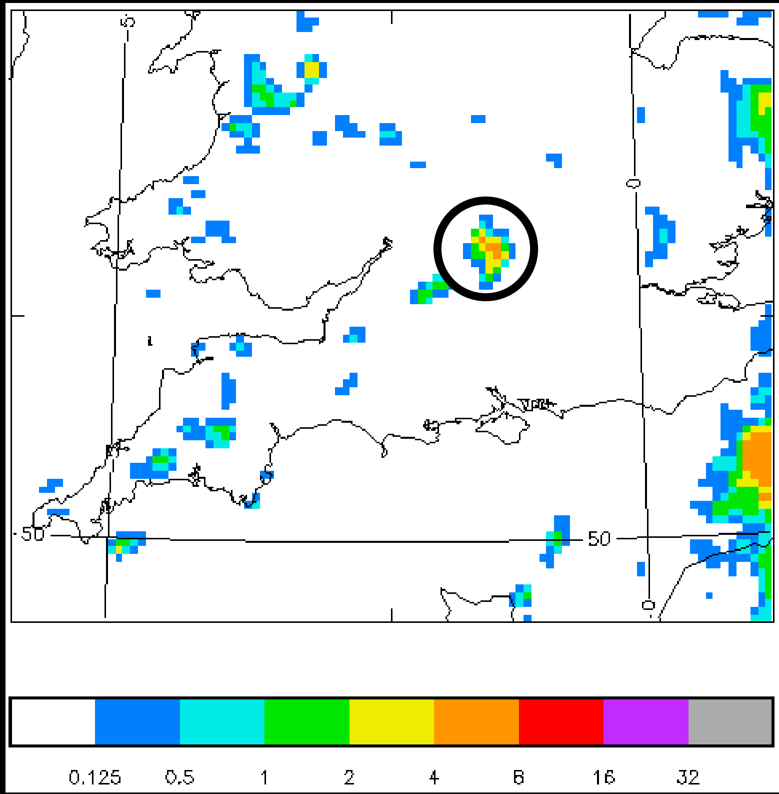


CSIP IOP 1 – Isolated triggering

09:30 UTC

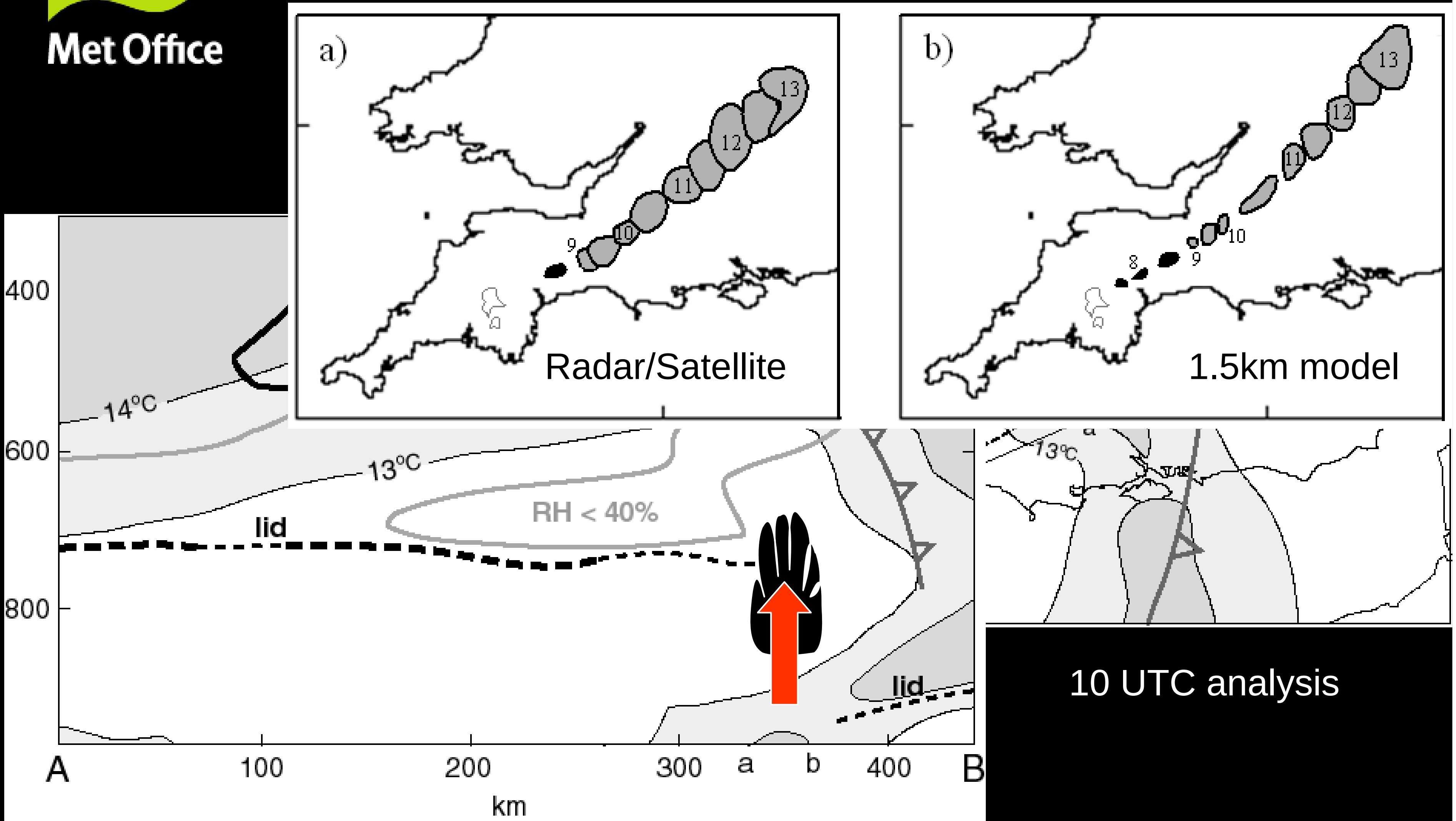


12:00 UTC



CSIP IOP 1 15th June 2005

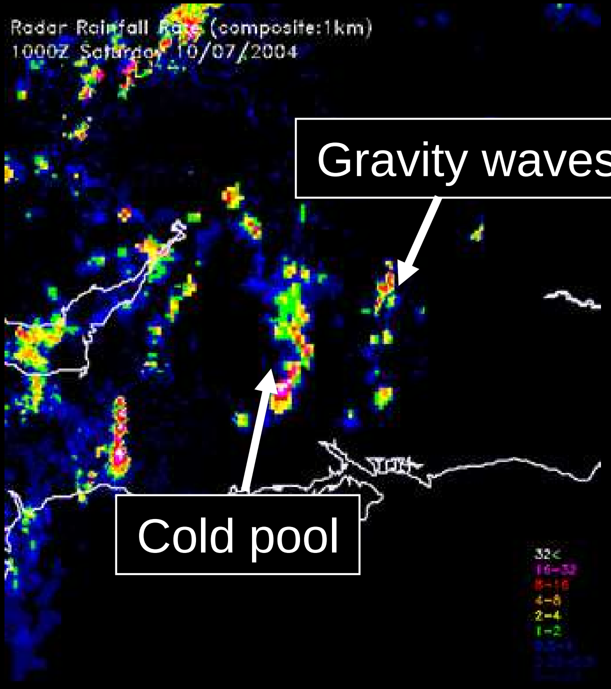
CSIP IOP 1 analysis

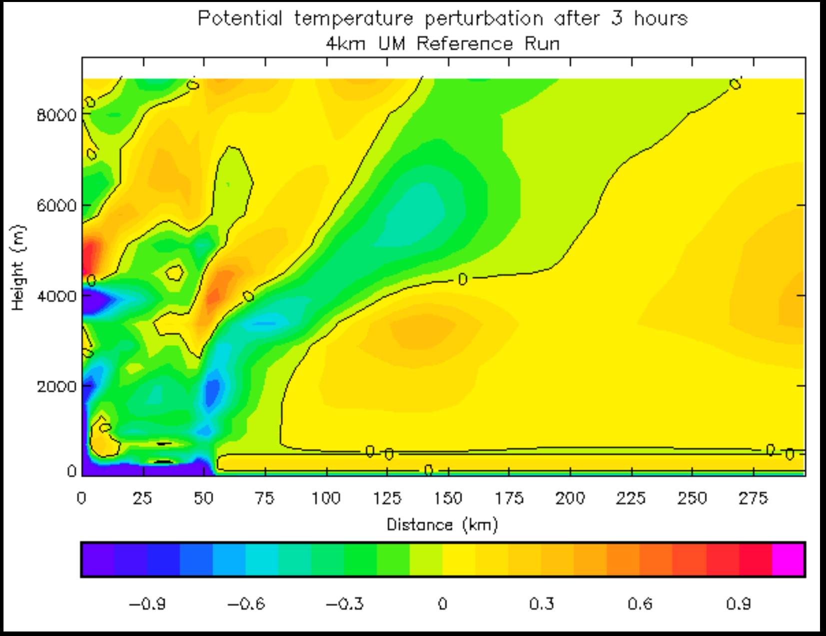


10 UTC analysis

Morcrette *et al*, 2007

Modulation of CIN by gravity waves – CSIP Pilot 10th July 2004





Idealised UM – gravity wave response from warm bubble (4 km resolution)

The UM produces very good primary initiation (coast convergence) and reasonably good secondary initiation (cold pool) but does NOT produce regular downstream initiation from gravity waves. Idealised studies show GW response similar to CRM.

Some comments on convection /turbulence parametrization

- The model does not 'know' about reality – if we impose a spectral gap or a filter, we are solving a different problem.
  - We should not be surprised to get the 'wrong' answer when applying a scheme 'correct' at 100 m to a 1 km model (e.g. Bryan *et al*, MWR 2003).
- The issue is 'is our model still useful'?
- Classic 'airmass' convection has low CIN over wide area – close to assumptions of convection schemes. Most difficult problem for explicit convection.
- Extreme events (over UK, at least), usually involve building up CAPE and releasing locally. Very difficult for parametrization, explicit solution is useful despite limitations.
- Given asymmetry of grid, vertical fluxes are likely to dominate horizontal – however, horizontal dissipation has a major role in the soluton.

Thank you for listening.
Any questions?

Some comments on convection /turbulence parametrization

- The model does not ‘know’ about reality – if we impose a spectral gap or a filter, we are solving a different problem.
  - We should not be surprised to get the ‘wrong’ answer when applying a scheme ‘correct’ at 100 m to a 1 km model (e.g. Bryan *et al*, MWR 2003).
- The issue is ‘is our model still useful’?
- True 1D
  - Rest of model must ensure energy in smallest resolved scales close to zero to match assumptions in parametrization.
  - Is our band-limited parametrization missing an important feature of the process? (e.g. de Roode et al, JAS 2004 on size of LES domain).
- 3D schemes in ‘overlap’ regime
  - Explicitly 3D
  - Prognostic variables (e.g. Gerard & Geleyn, 2005).
  - Coupling to local dynamics (e.g. w-dependent triggering, as Kain-Fritsch) – depends on development of unstable w and hence horizontal (and vertical) mixing.
  - Do we understand how we control scales in parametrization? (e.g. Mason & Brown, JAS 1999)
- Classic ‘airmass’ convection has low CIN over wide area – close to assumptions of convection schemes. Most difficult problem for explicit convection.
- Extreme events (over UK, at least), usually involve building up CAPE and releasing locally. Very difficult for parametrization, explicit

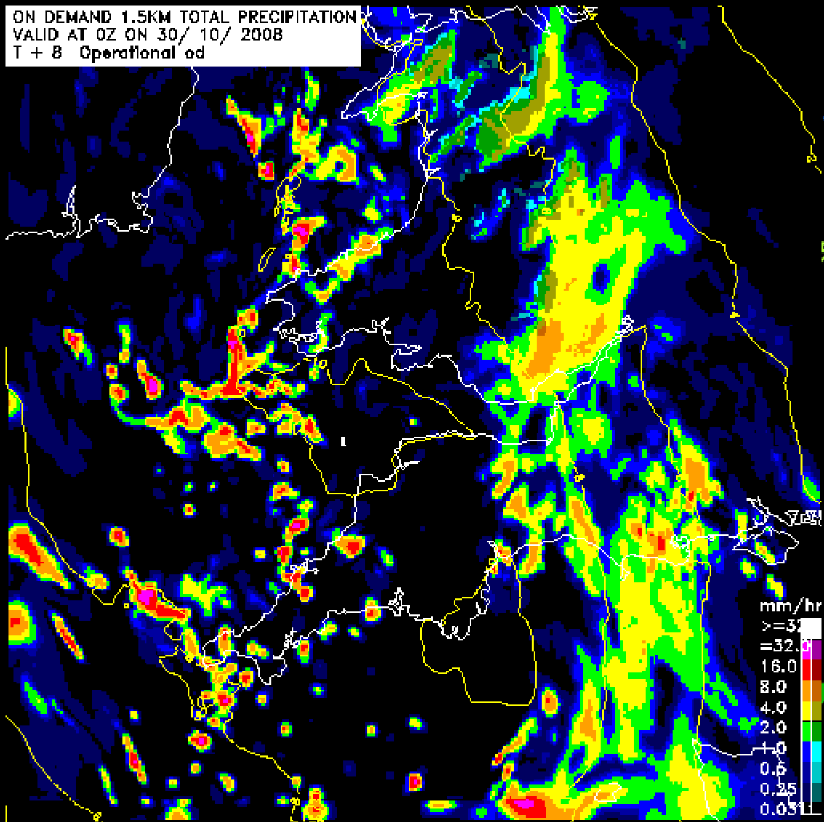
Challenge: the 'grey-zone' for BL/Cu

- Jump from ~10 km to ~1 km to avoid 'grey-zone' for parametrization of deep convection.
  - Grey-zone = too coarse to treat explicitly, too fine to fully parametrize.
  - We accept explicit convection at ~1 km. Something will be wrong!
  - Arguably, we should still be parametrizing convective cores (e.g. Gerard & Geleyn, 2005)
- In practice, we know 1 km is inadequate for explicit convection (e.g. Bryan et al, MWR 2003).
  - How much do we care?
  - Performance depends on 'turbulence' scheme.
- 'Shallow' Cu has it's own 'grey zone'.
  - Not every Cu grows up to be a Cb!
  - 'Smooth', parametrized fields must spontaneously break symmetry. (e.g. de Roode et al, JAS 2004 on size of LES domain for one mechanism).
  - Stochastic physics?

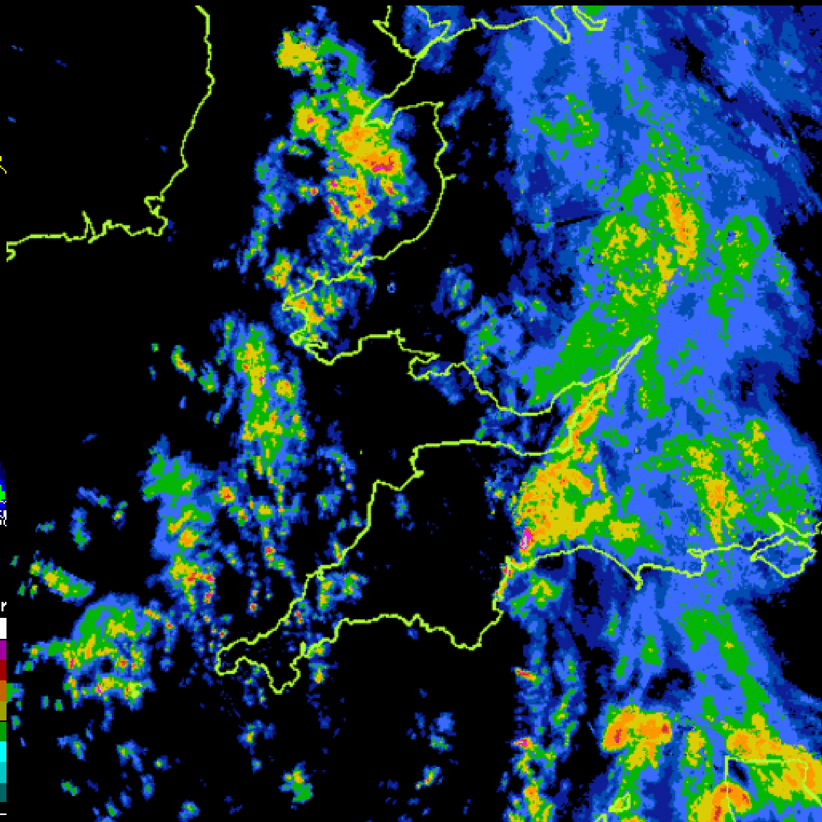
Some Conclusions

Why variable resolution?

The Ottery St. Mary Hail Storm
Forecast rainfall rates

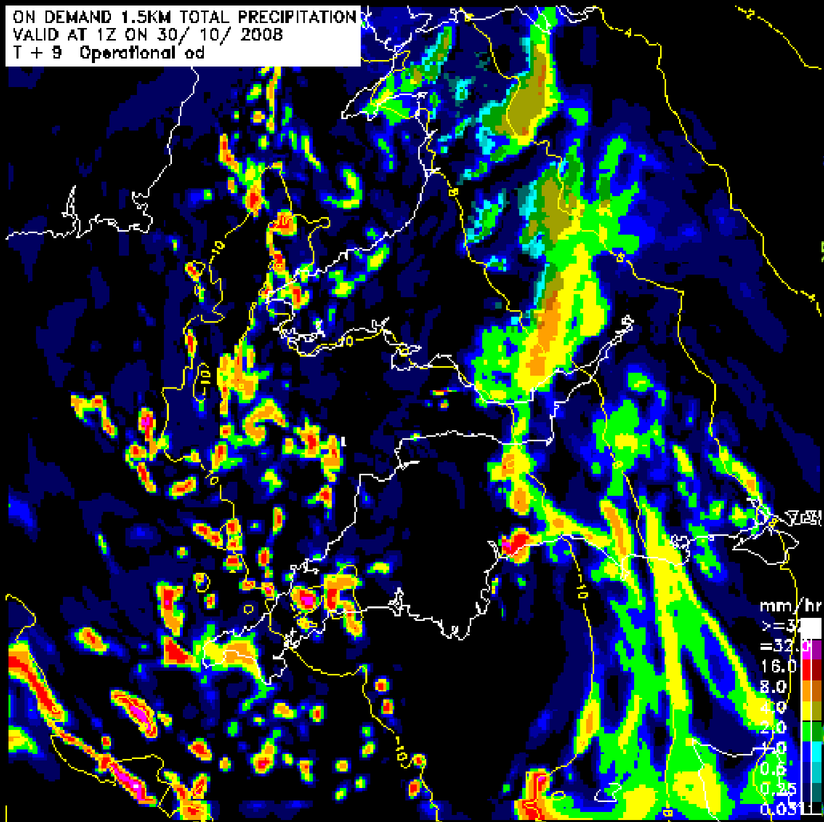


1.5 km model
from 15 UTC, 29/10/2008

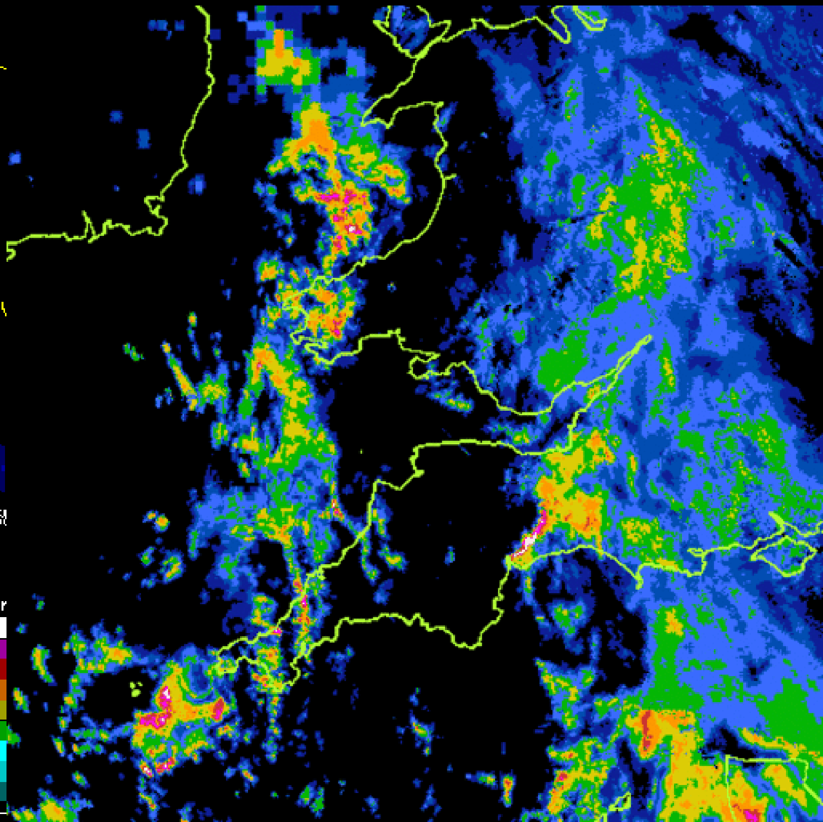


Radar Composite
00:00 30/10/2008

The Ottery St. Mary Hail Storm Forecast rainfall rates

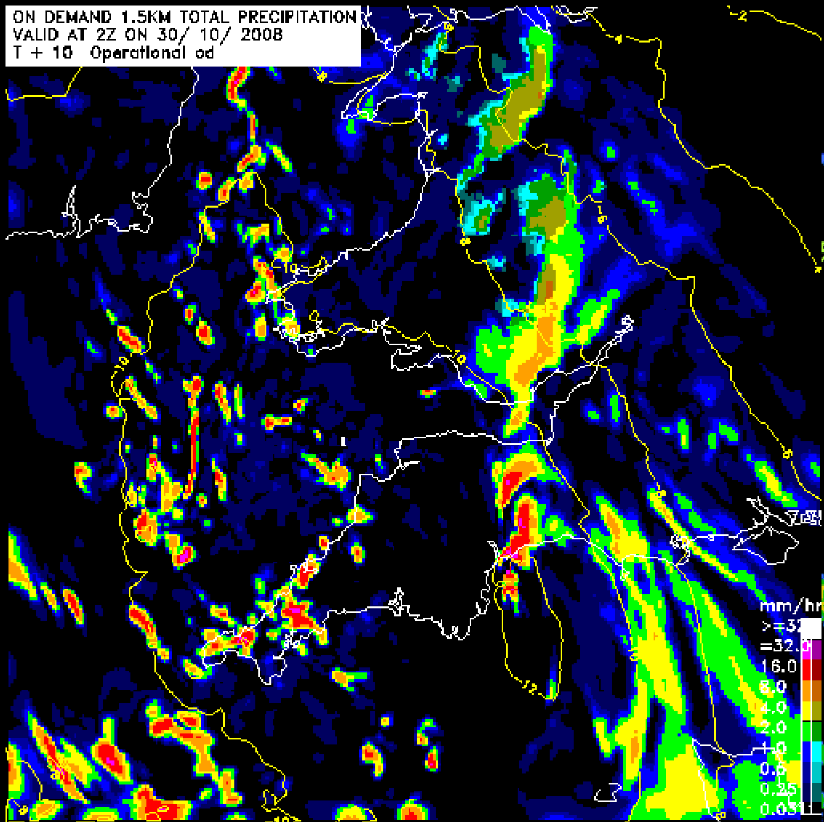


1.5 km model
from 15 UTC, 29/10/2008

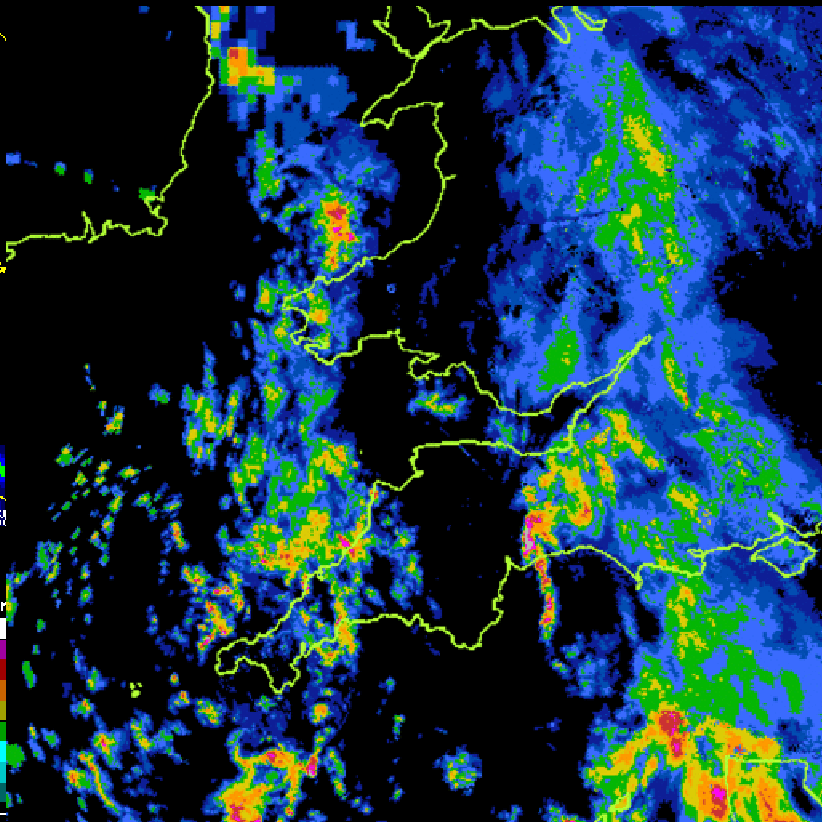


Radar Composite
01:00 30/10/2008

The Ottery St. Mary Hail Storm
Forecast rainfall rates

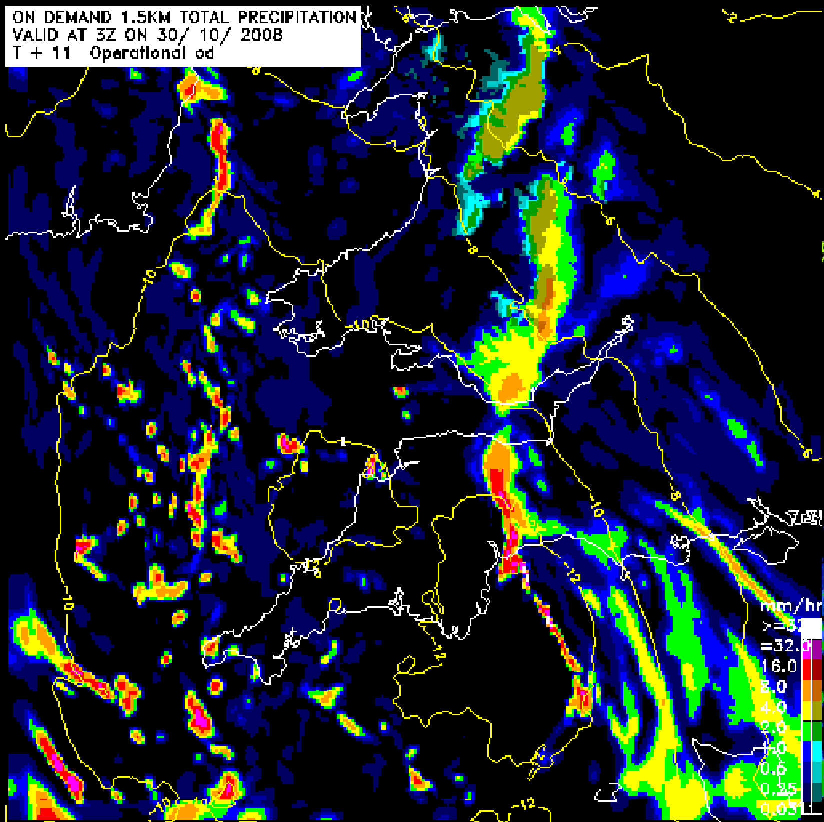


1.5 km model
from 15 UTC, 29/10/2008

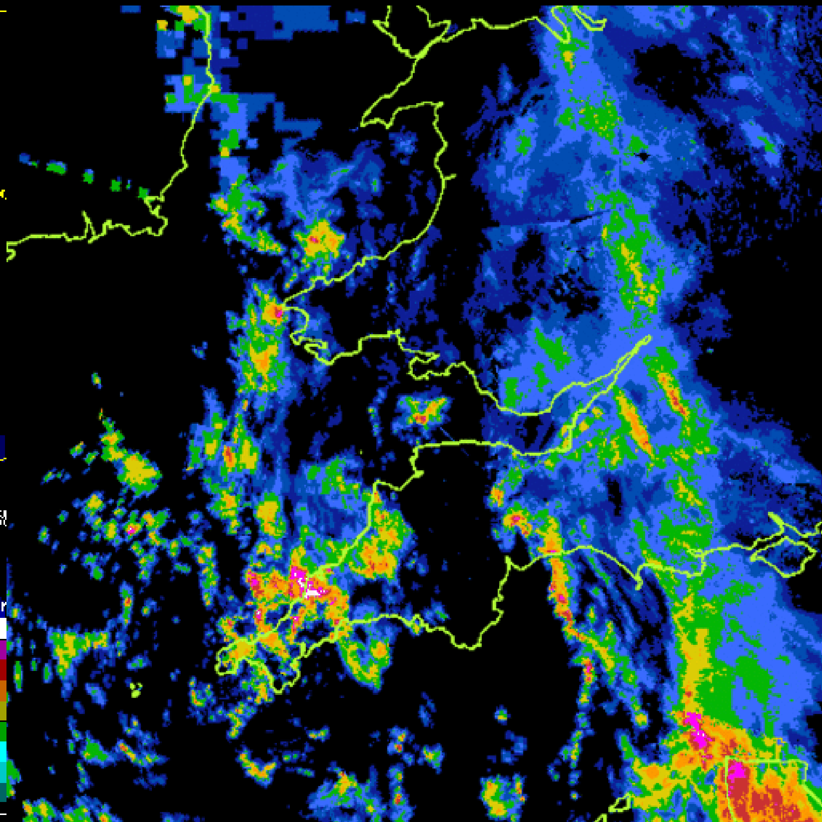


Radar Composite
02:00 30/10/2008

The Ottery St. Mary Hail Storm
Forecast rainfall rates



1.5 km model
from 15 UTC, 29/10/2008



Radar Composite

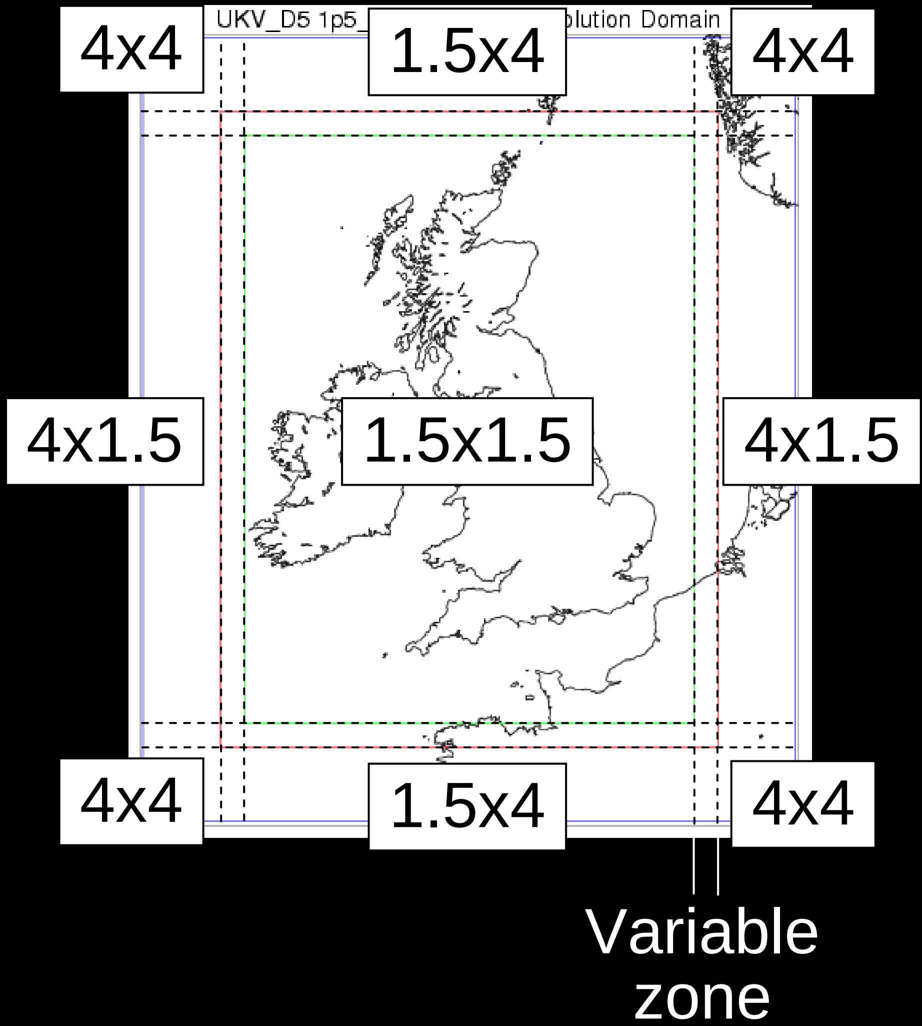
03:00 30/10/2008

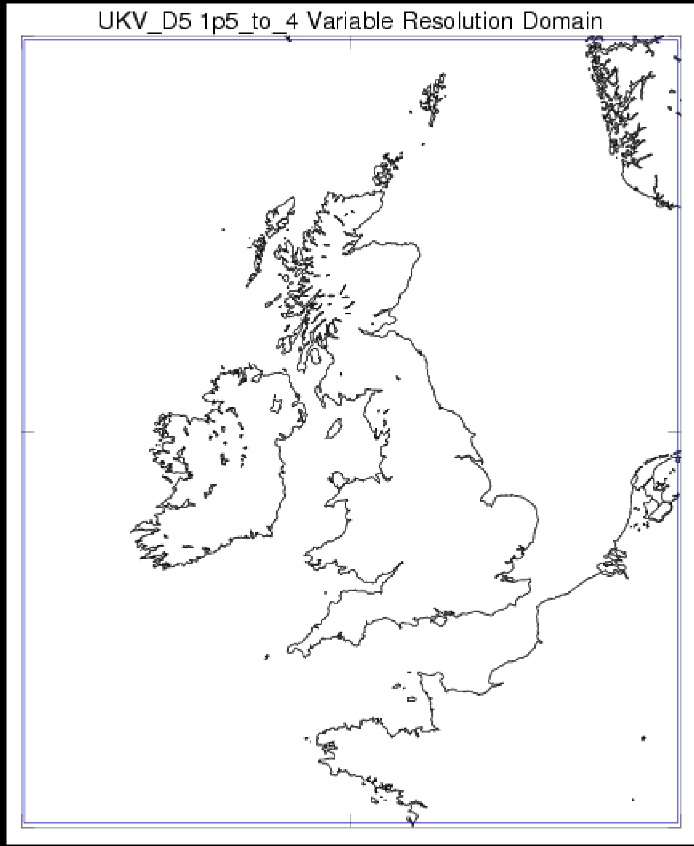
Why variable resolution?

- 1.5 km nested in 12 km NAE : 1:8 nesting ratio. Can give problems (e.g. strong cold fronts).
- One-way nesting – need to store huge amounts of lateral boundary data – realistically half-hour updating.
- ‘Spin up’ from ‘smooth’ parametrized convection to individual clouds takes time/space.
- 12-4-1.5 possible but complex, and no business need for 4 km model (and issues with convection).
- ‘Variable-resolution’ – 4-1.5 solves some of these problems, pushing boundaries further away from UK.

The UKV model

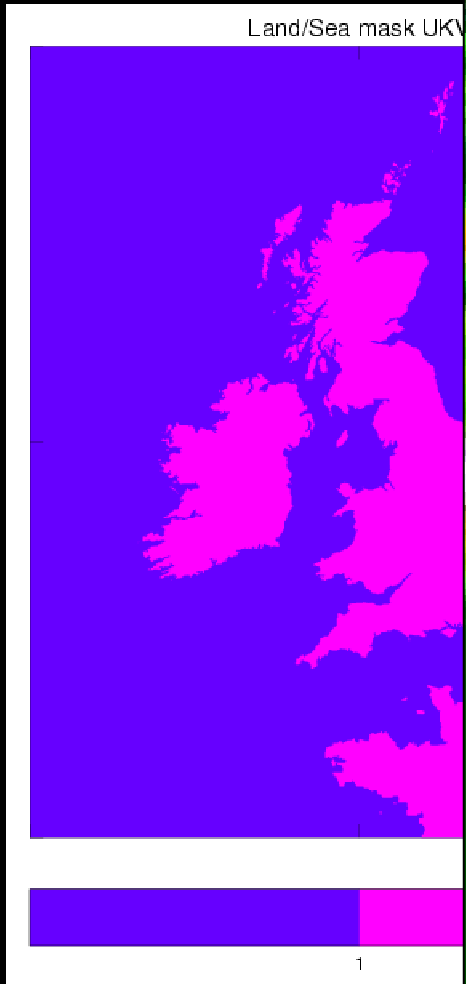
UKV Domain



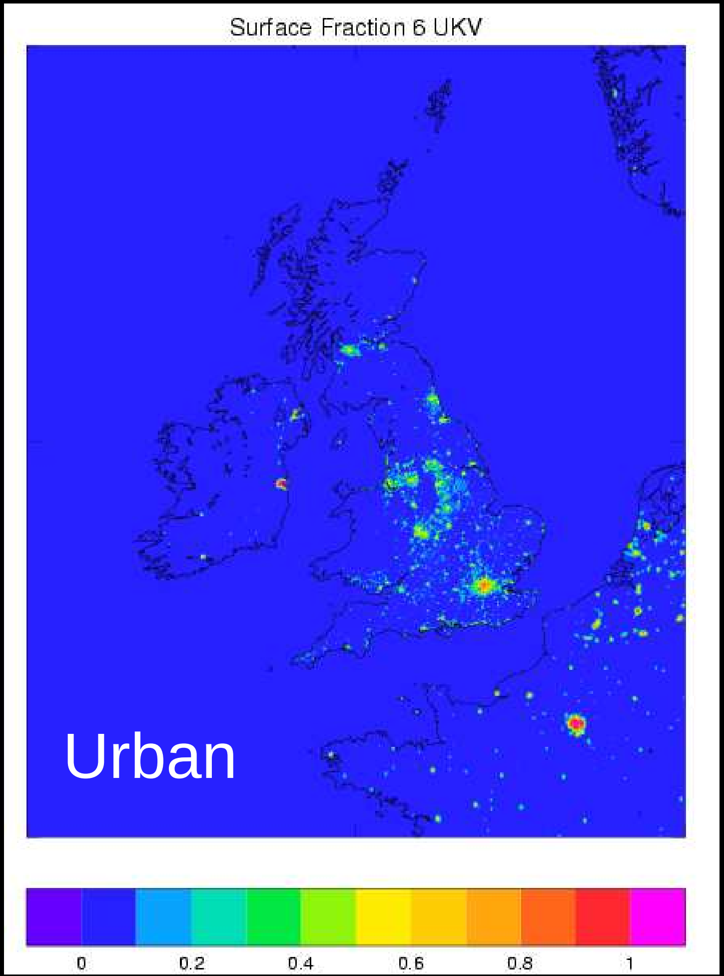


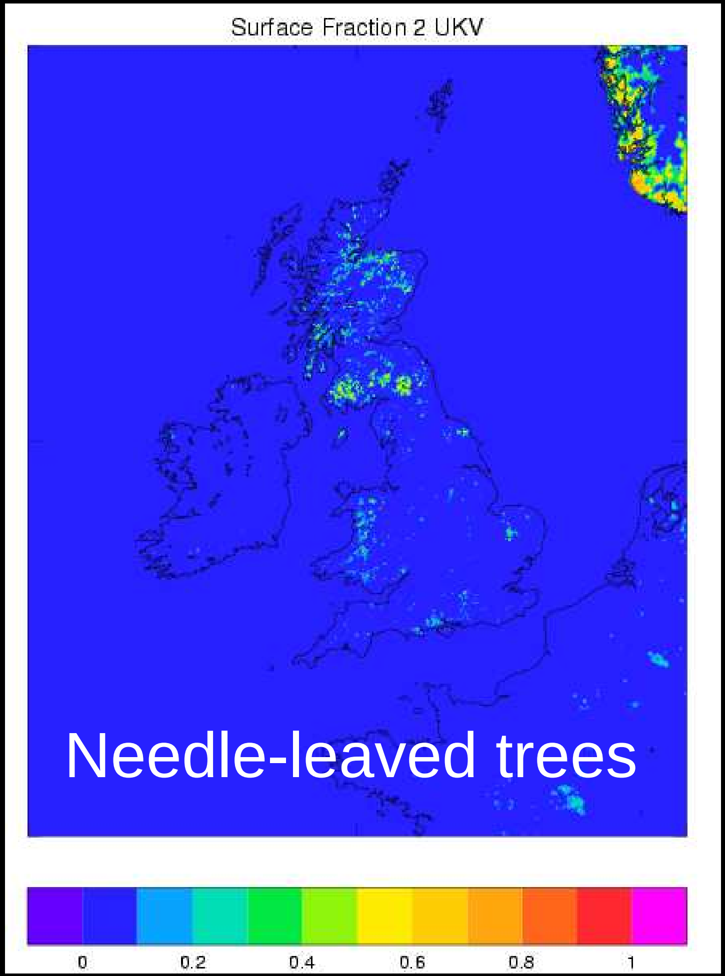
744(622) x 928(810) points

UKV Land/sea mask and orography



UKV Land-use - Examples

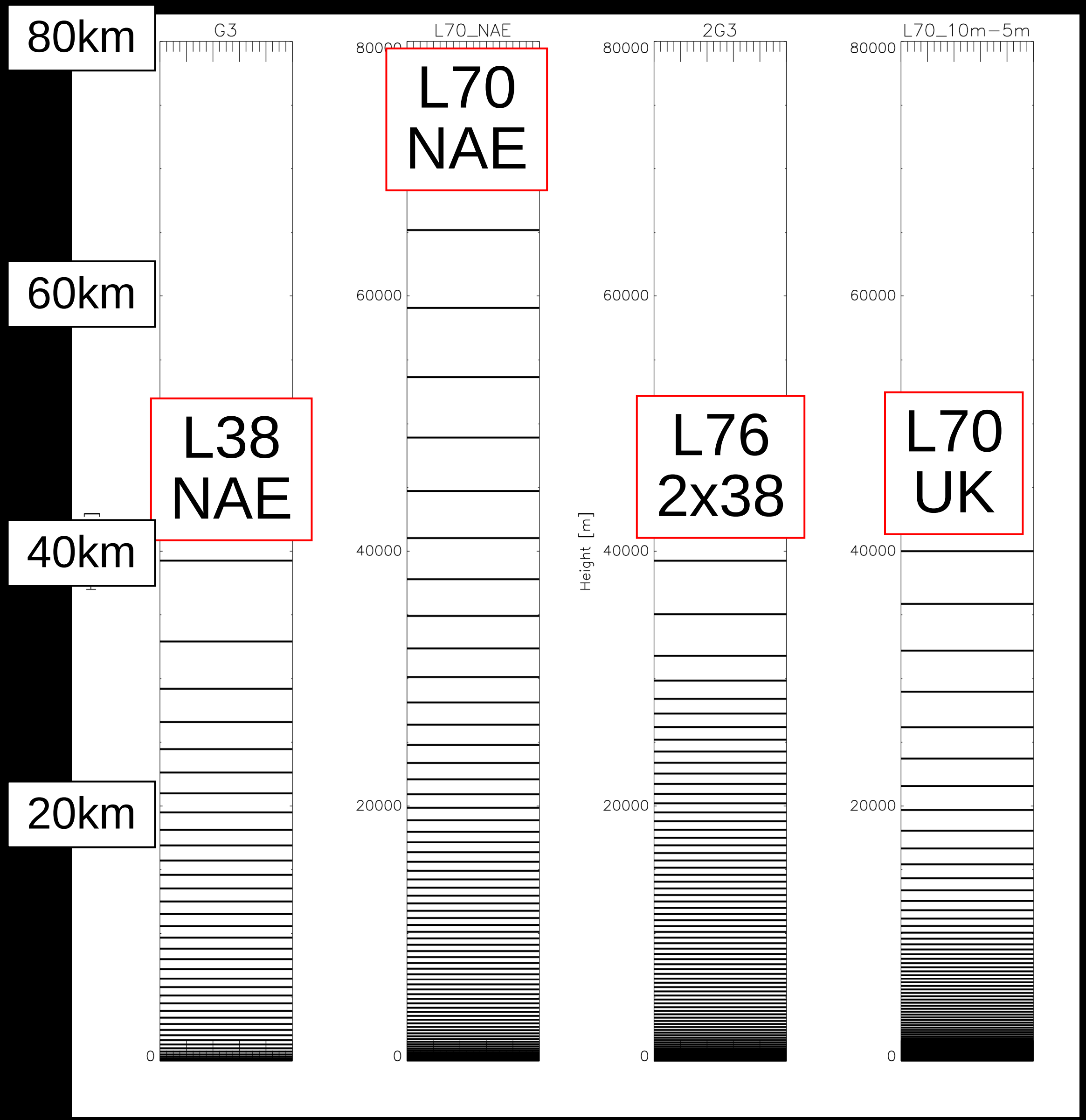




Vertical resolution

70 Level NAE/Global: emphasis on whole atmosphere, higher top.

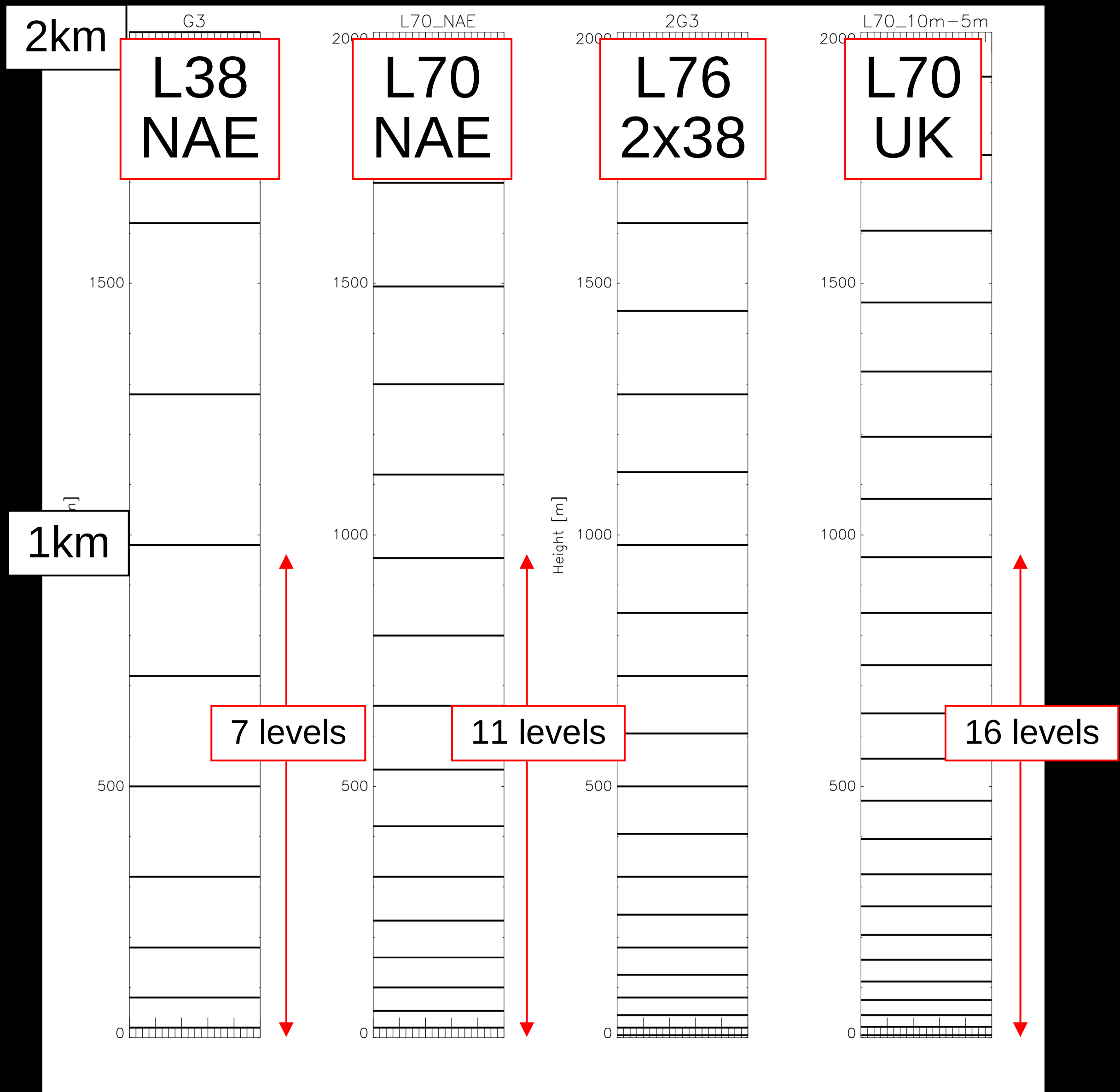
70 Level UK 4/1.5 Emphasis on BL and lower troposphere.



Vertical resolution near surface

70 Level NAE/Global: emphasis on whole atmosphere, higher top.

70 Level UK 4/1.5 Emphasis on BL and lower troposphere.



UKV data assimilation and operational cycle.

- UKV is seen as a replacement for UK 4. Main forecasts at 03, 09, 15, 21 Z.
- Initial implementation will use 3DVAR DA + Latent Heat Nudging (surface rainfall rate) + MOPS assimilation as UK4.
- BUT
- We have tested in smaller domains, and hope to use hourly rather than 3 hourly DA cycle and 15 minute radar, hourly MOPS cf hourly/3 hourly in UK4.
- Doppler winds and reflectivity in pipeline.
- 4DVAR also in pipeline – initially in ‘nowcasting’ testbed.

What are we confident of?

- Convective inhibition has a major role in controlling the location and nature of deep convective clouds.
- Where CIN is high, and convection surface-forced, mesoscale convergence lines which have substantial length-scales (cf clouds) and timescales often play a major role.
- The convergence lines are generated by many surface features:
  - Surface changes – roughness and heating
  - Orography – lifting and heating
  - Cloud shadows
- Even where CIN is low, these features can have a major role in pre-conditioning boundary layer for first generation cells but internal variability soon dominates.

What are the remaining research questions?

- Many lids can be traced to tropopause folds or upper tropospheric air near them but:
  - What limits our ability to model these?
  - Multiple layers seem very common. What mechanism?
  - What is the role of BL history, diurnal cycle and K-H instability?
- Links between CIN, equilibrium and predictability need further work.
- Convectively-generated gravity waves can also play a role in modulating CIN, but precisely how and when this operates is poorly understood (by at least one person!).
- Mid-level convection can be extremely important and is very poorly understood.
  - Presumably gravity waves are very important.
  - Role of other modes of instability, e.g. CSI.

Questions and answers

Implications for sub-grid turbulence parametrization

- Results are a subtle balance of horizontal mixing (delays initiation) and vertical mixing (promotes initiation).
- For ~1km grid resolution, the results suggest:
  - The non-local scheme is appropriate for vertical mixing in the boundary layer.
  - There is a need for increased mixing of convective updraughts in the free-troposphere to reduce the overshoot. A shear/stability dependent approach is more physical than constant coefficient diffusion.
- For 200m grid resolution, the results suggest:
  - The shear/stability dependent approach of the Smagorinsky-Lilly scheme is more appropriate than the non-local scheme.
  - The model is close to convergence (from earlier comparison with 100m resolution simulations).

Forecasting 'strategy'

Met Office

40/25/16 km Global Model + 90/60/? km ensemble
Longer Range

12/12/Retired km NAE + 24/16/Retired km ensemble
Regional Picture

Now/2009/2011+

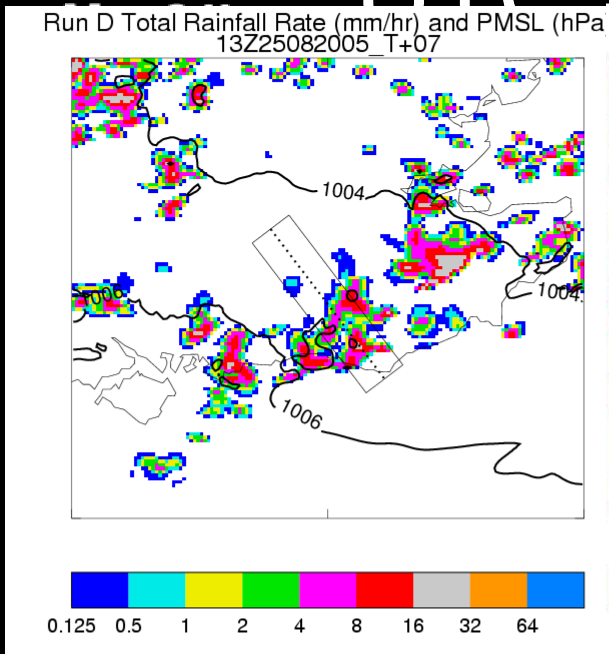
New emphasis

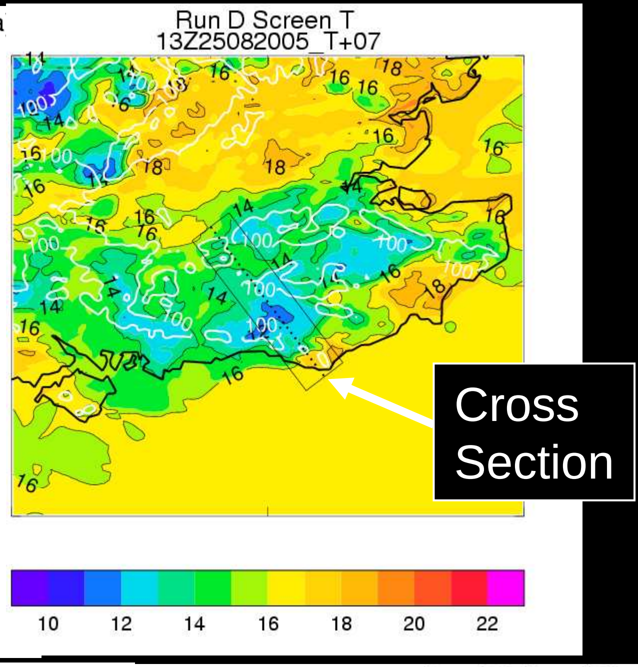
4/1.5/1.5 km UK Model + small ensemble+nowcast
Convective storms, improved orography, surface

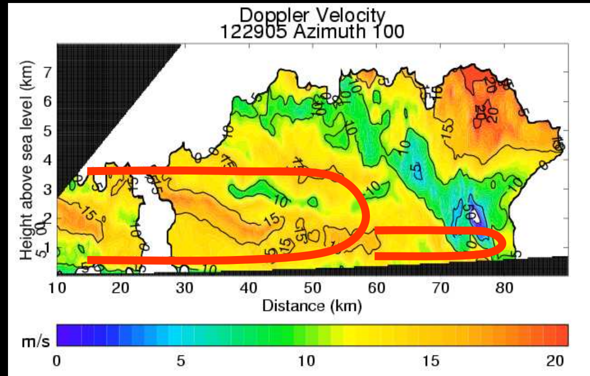
UKPP post-processing
2/2/1? km product hourly updated

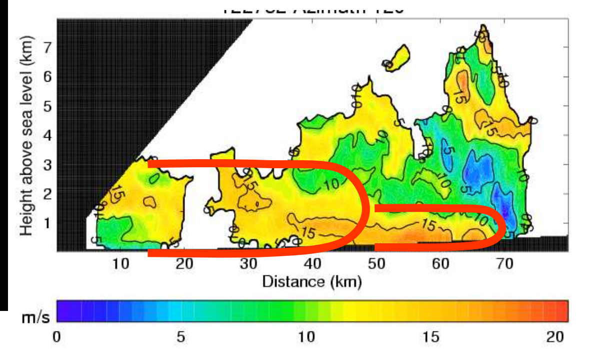
Forecaster
Experience, local knowledge, recent data

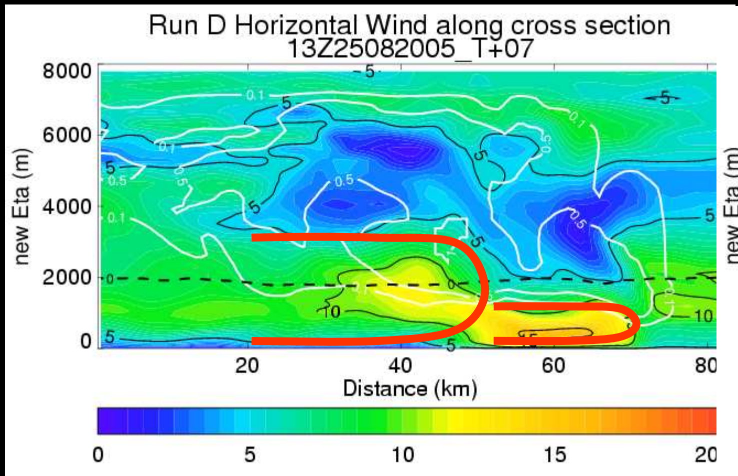
1.5 km L76 UM Forecast 13 UTC

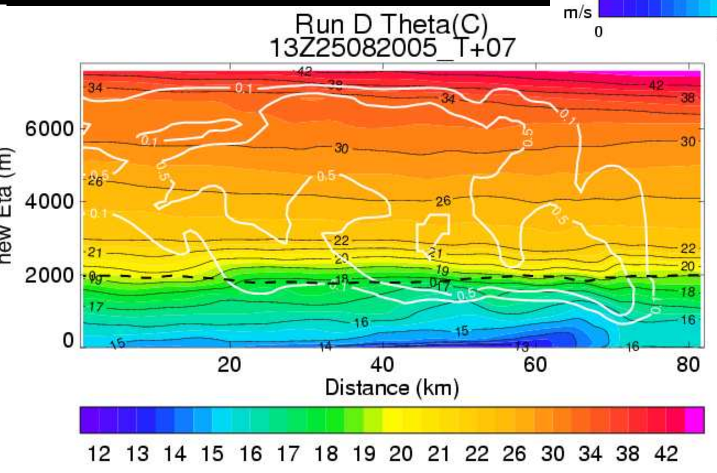


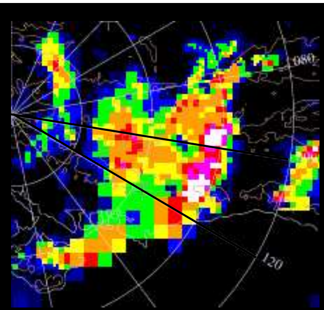




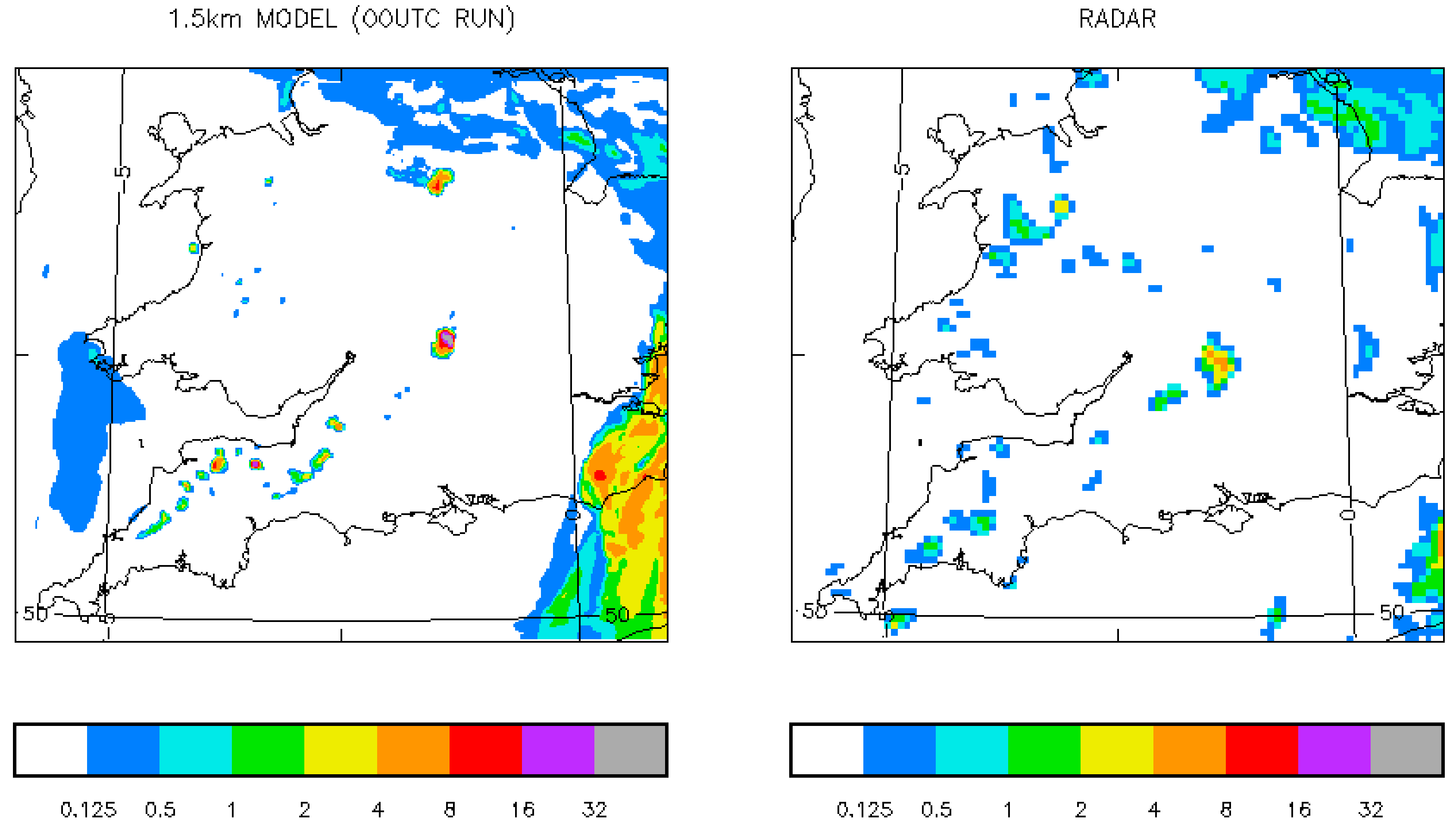






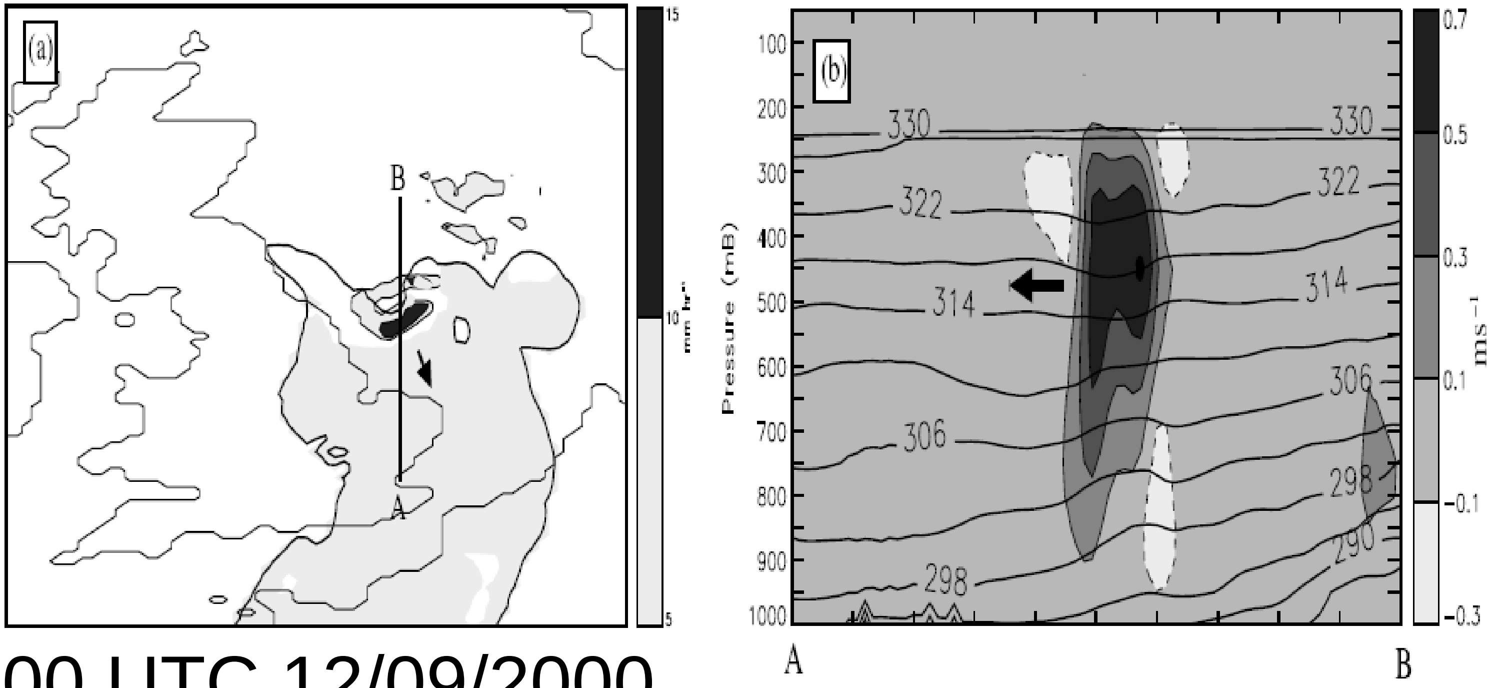


CSIP IOP 1 – 1.5 km UM Forecast



12 UTC

Case 2 - enforced convective equilibrium



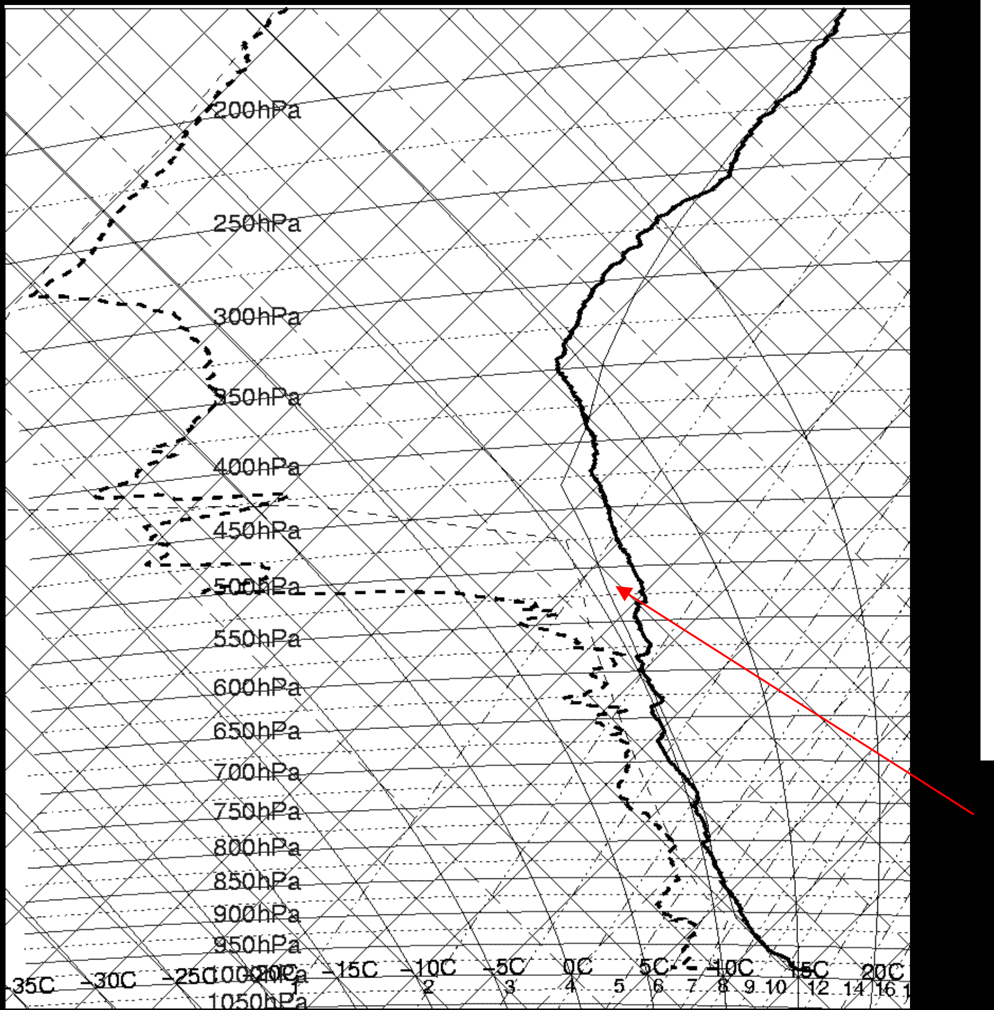
00 UTC 12/09/2000

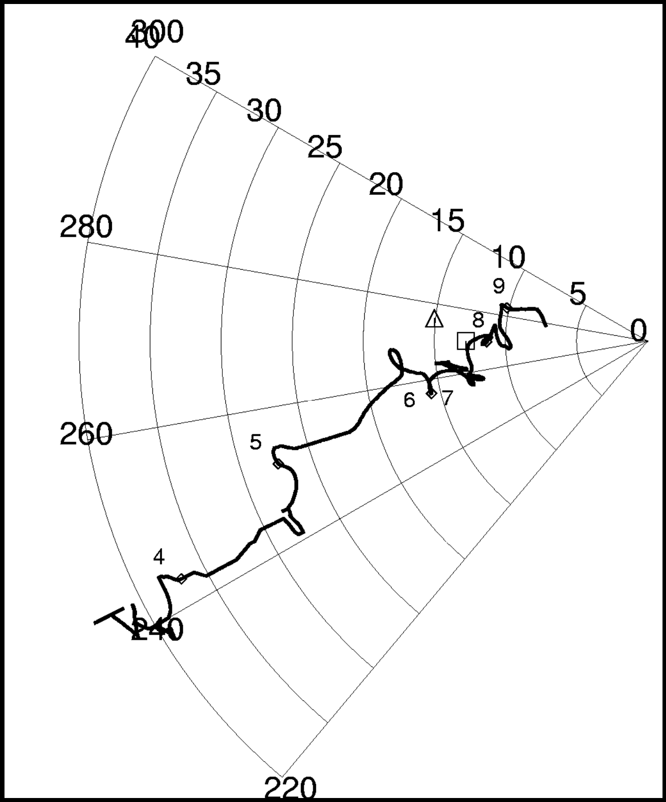
A couple of examples.

The role of CIN

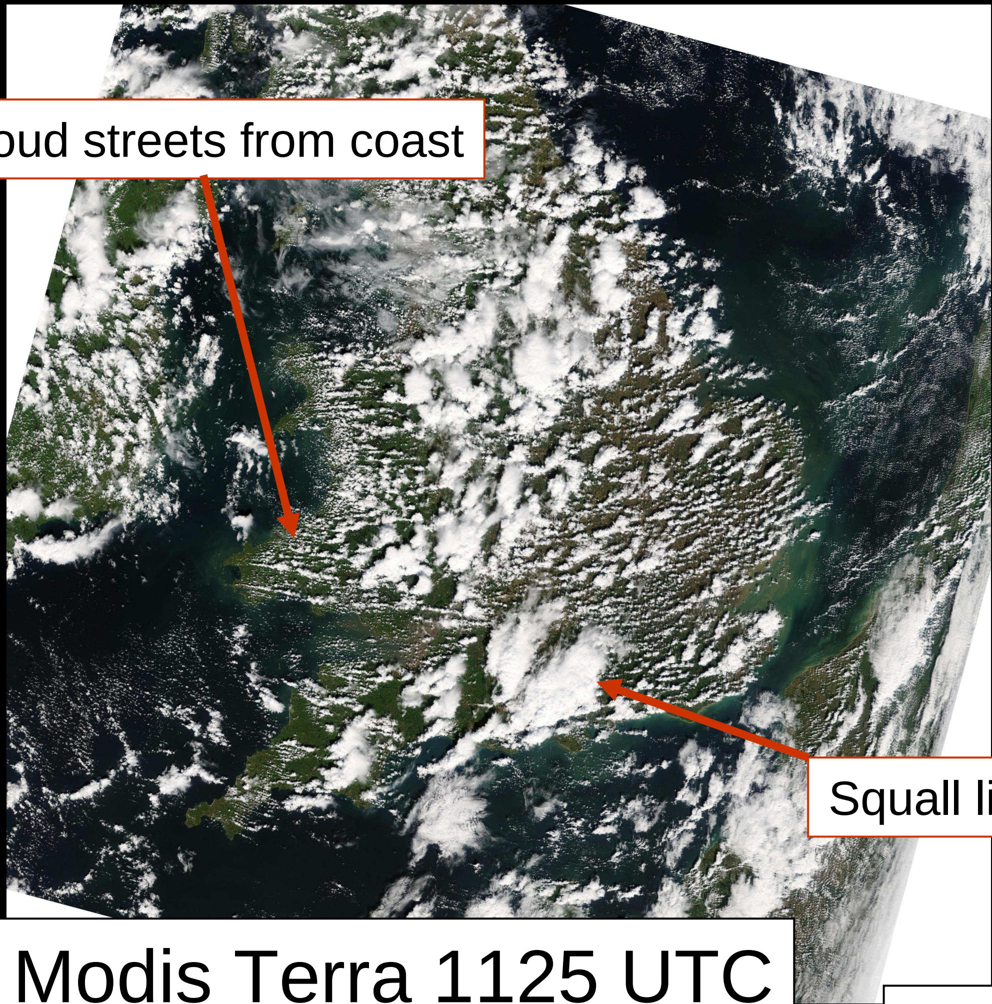
- Locally, zero CIN required for convection. If CIN everywhere, clearly not in equilibrium, but easy to parametrize!
- So-called trigger function is therefore a statement about variability of CIN. Only parametrizable if assumed either random, or diagnostic function of inputs (e.g. sub-grid orography). A problem if CIN organised on small scale, e.g. by mesoscale flow over orography, convergence lines etc..
- Balanced boundary layer flow scale NH_{bl}/f~100 km, so expect non-local impacts of surface.

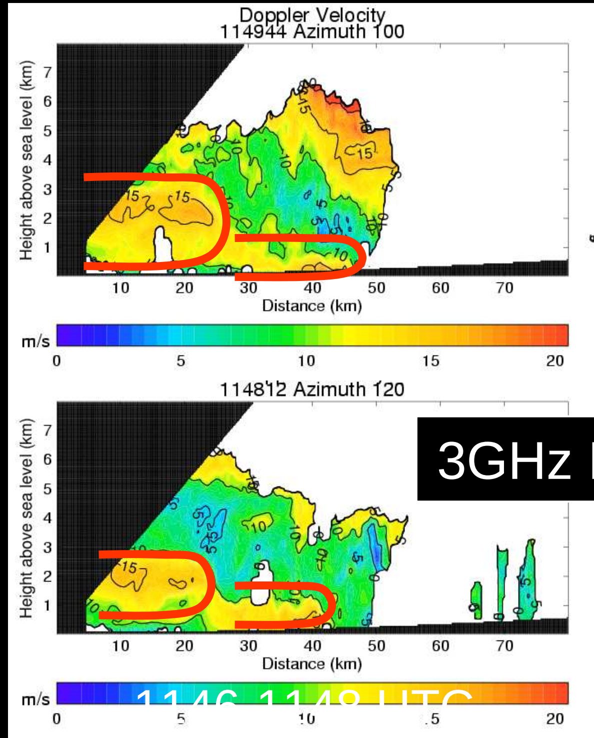
CSIP IOP 18 25/08/2005

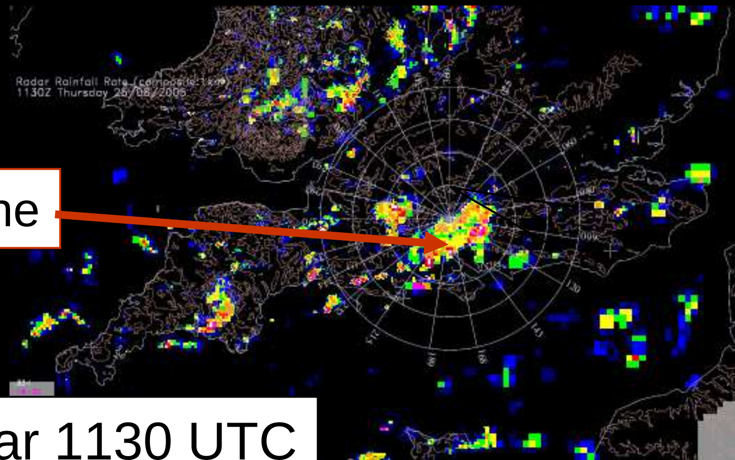




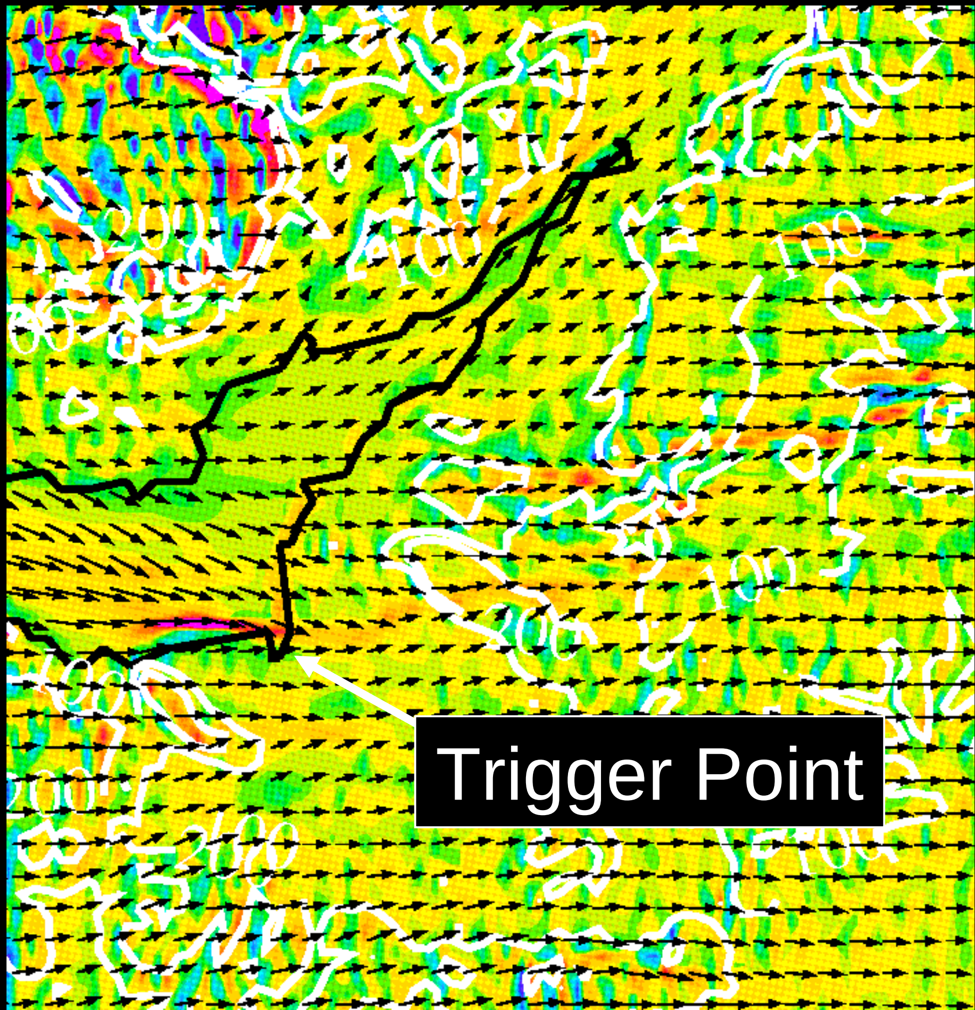
CSIP IOP 18 – 25/08/2006



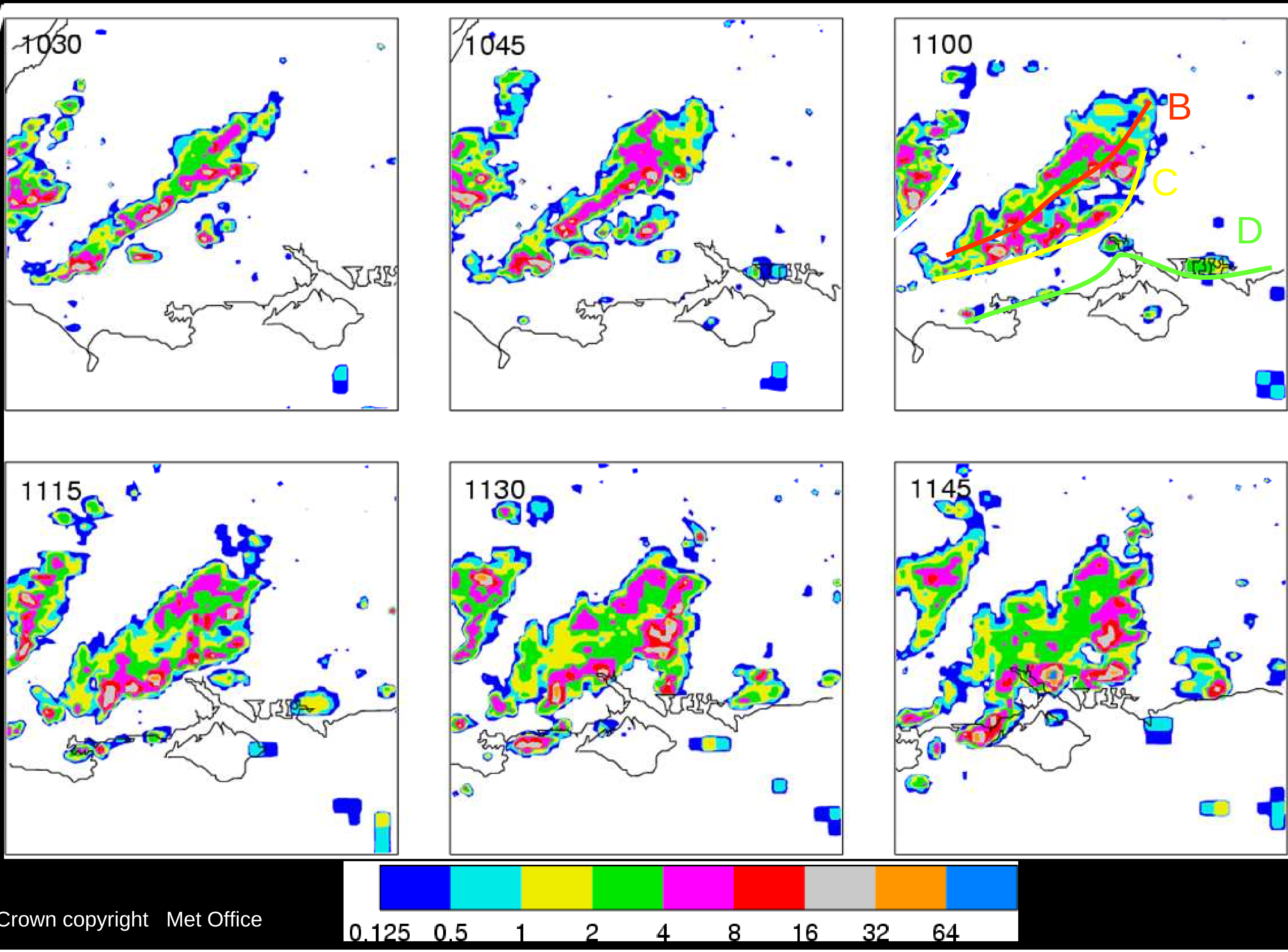




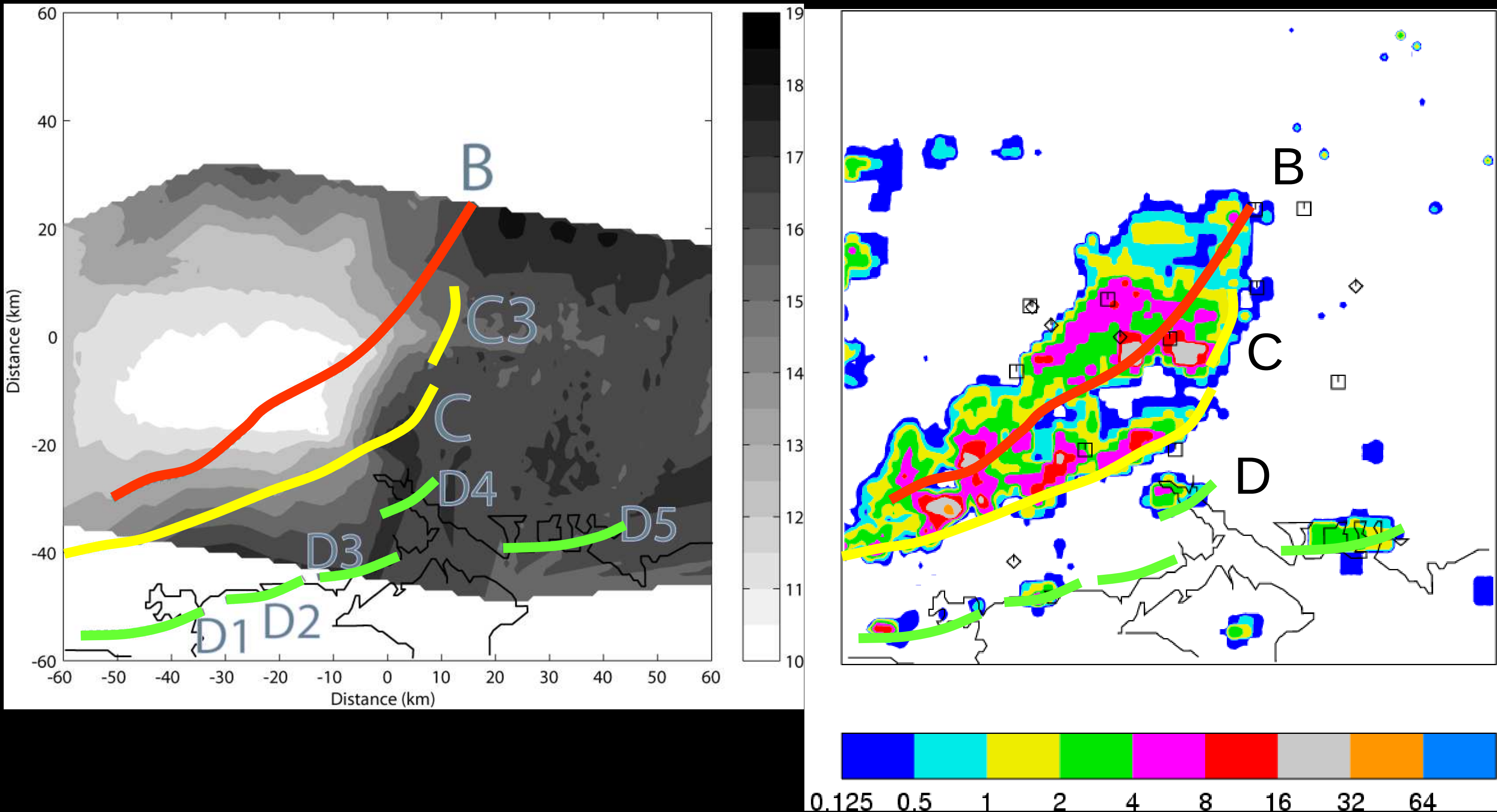
CSIP IOP 18 – 25th August 2005 – 08 UTC



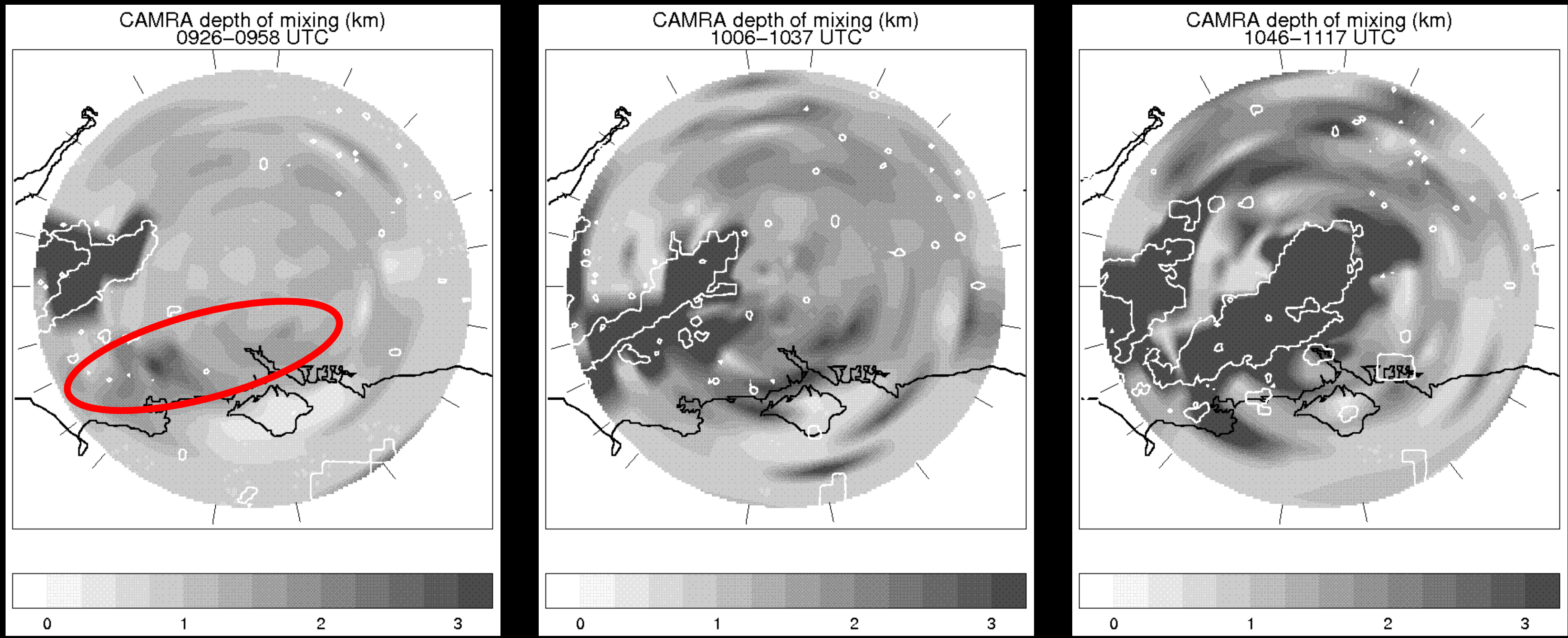
Transition Phase



Cold pool at 1100 UTC



Development of Areas of Deeper Convection

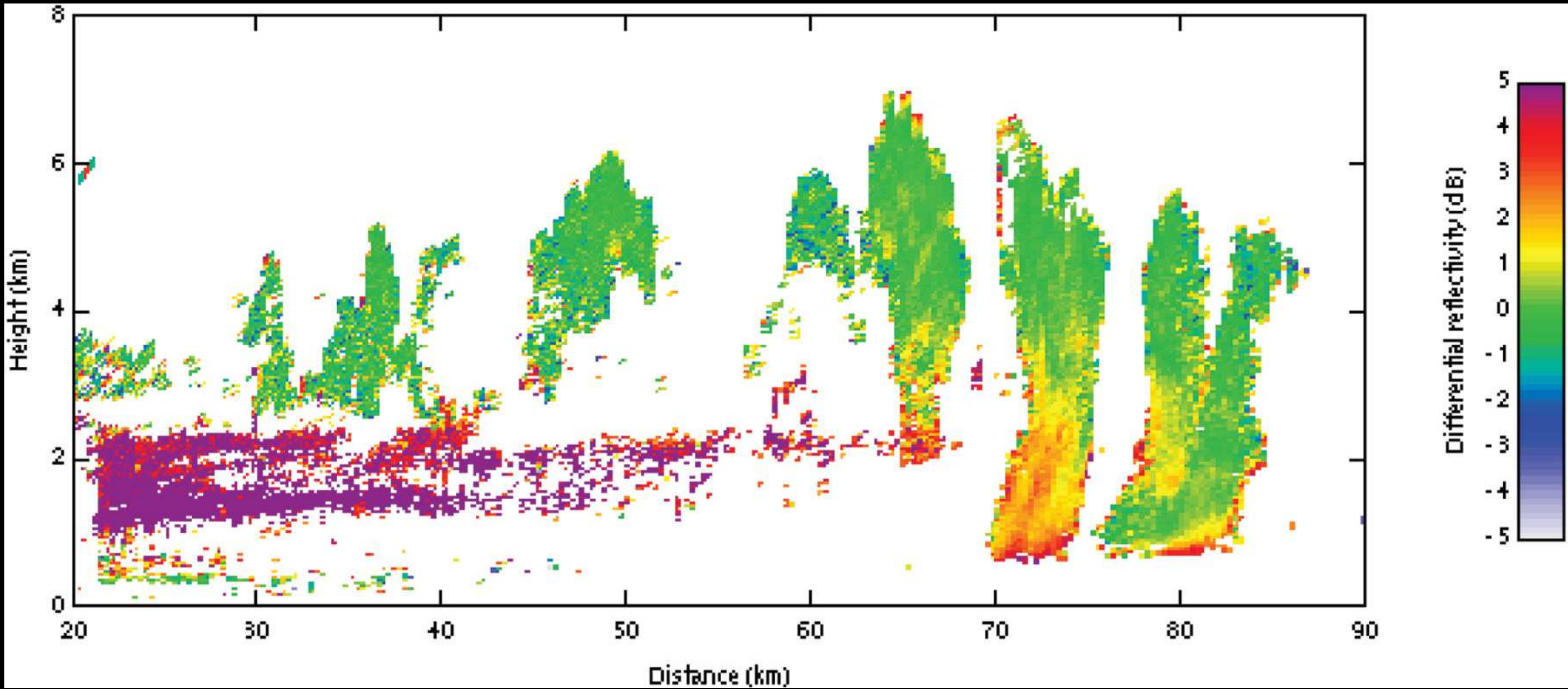


CSIP IOP 18 Comments

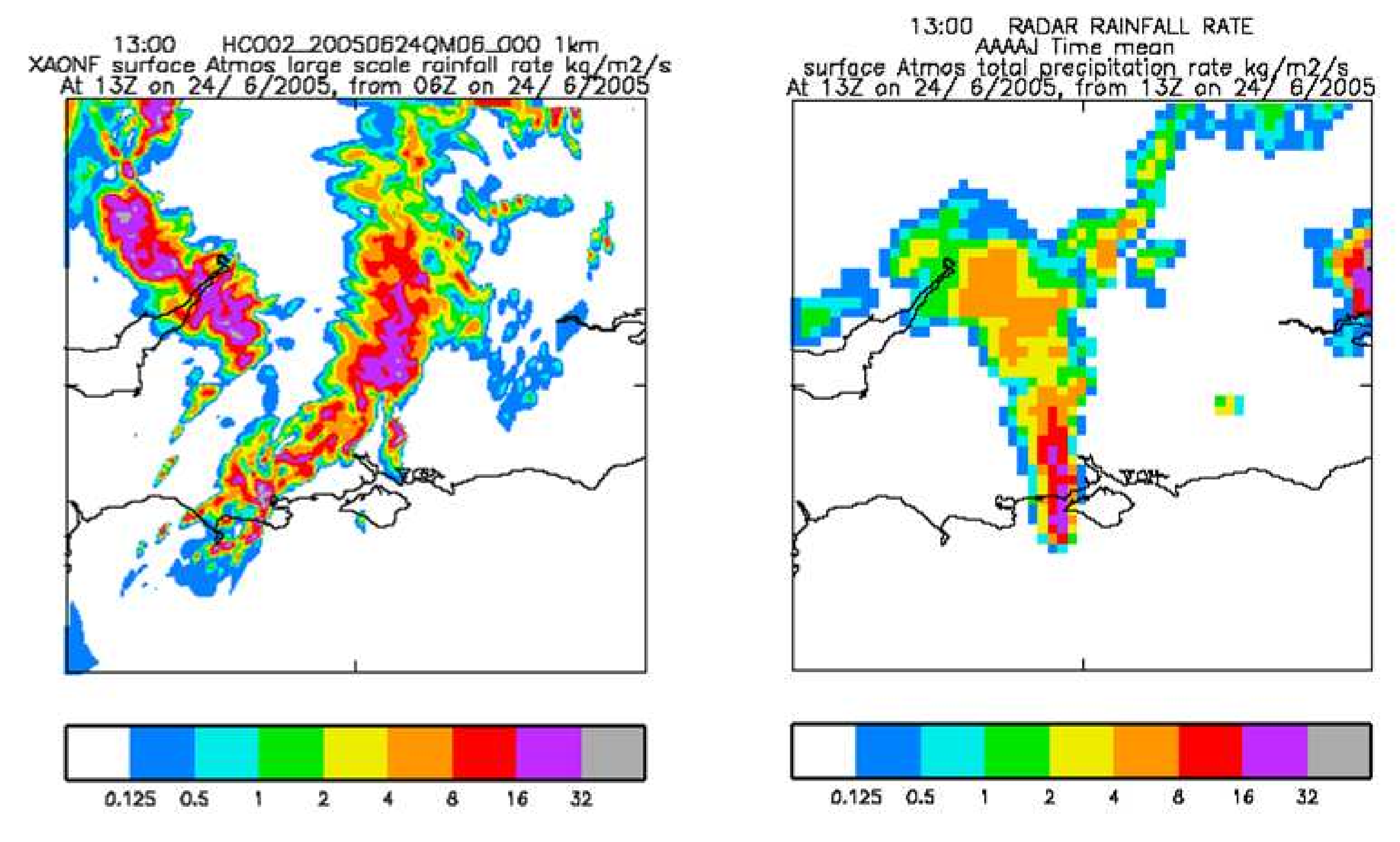
- Low level of eventual predictability but:
  - Initial cells formed on coastal convergence.
  - Subsequent development dominated by organised cold pools ~100 km across.
  - Coastal convergence visible as deeper boundary-layer convection at least an hour before triggering of deep convection.

Less well characterised issues

CSIP IOP 3 Mid-level convection

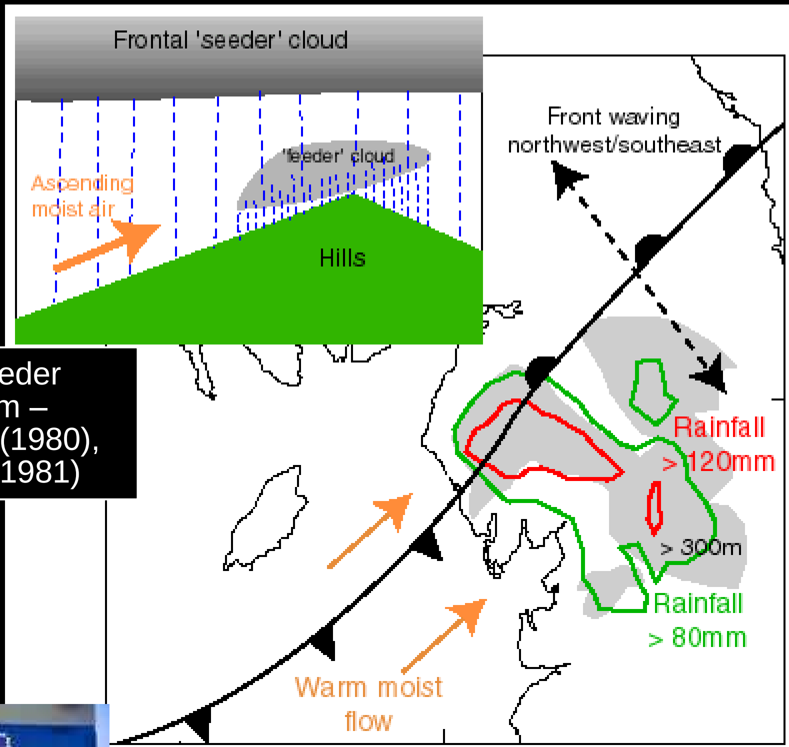


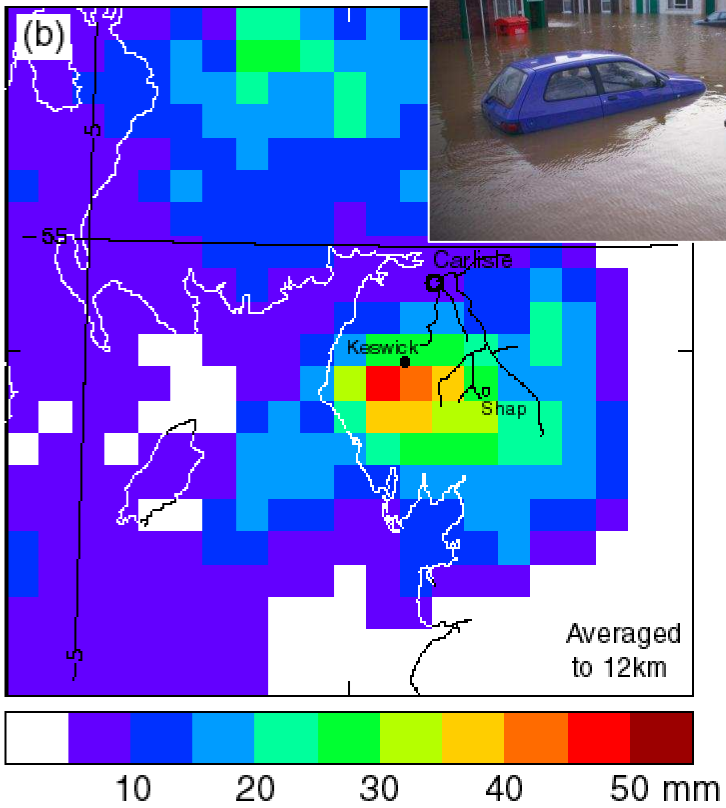
CSIP IOP3 - Mid level convection



High resolution NWP and hydrological forecasting

Seeder-feeder mechanism – Browning (1980), Hill *et al* (1981)



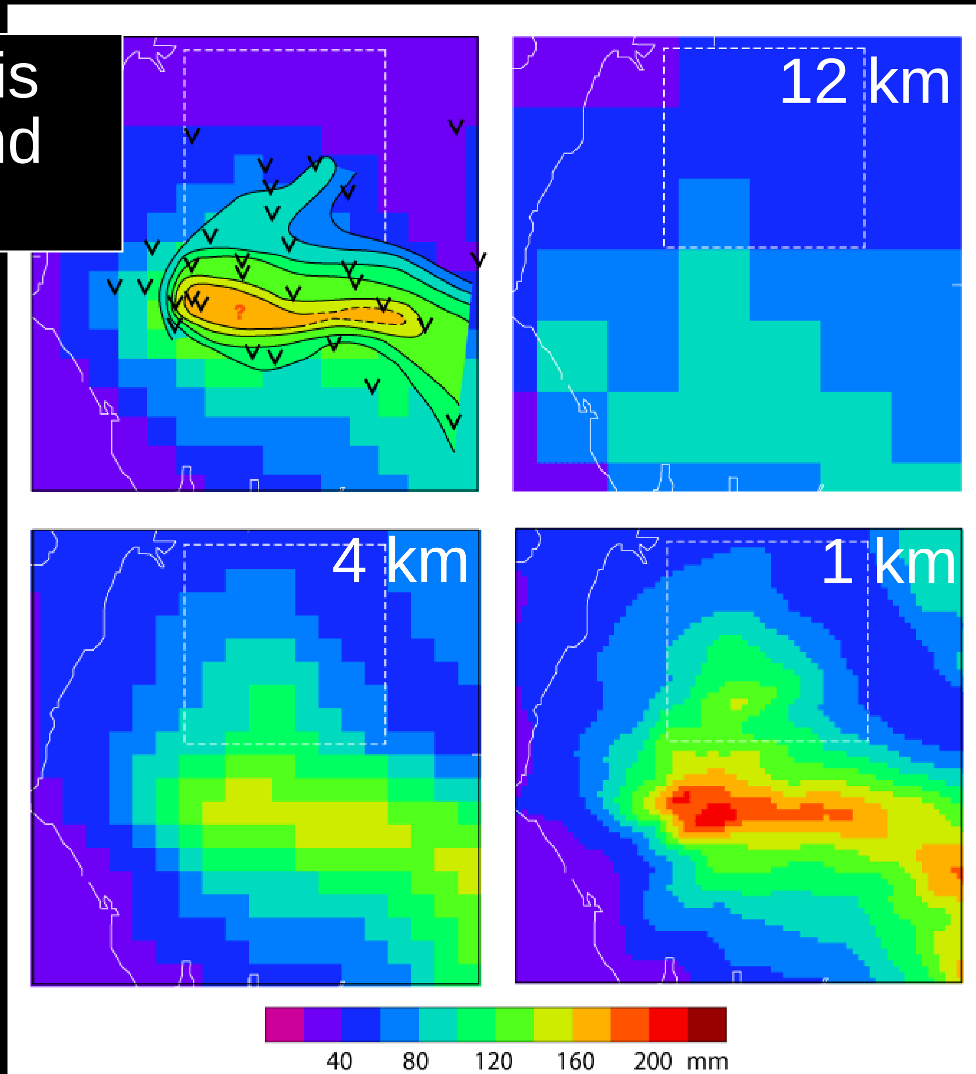


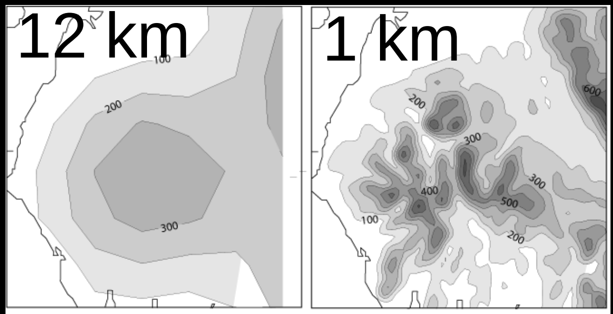
Carlisle Flood 7-8th January 2005

'Radar' Accumulation
18 UTC 7th – 00 UTC 8th

Carlisle Flood - Observed and Forecast Accumulations

Met Office

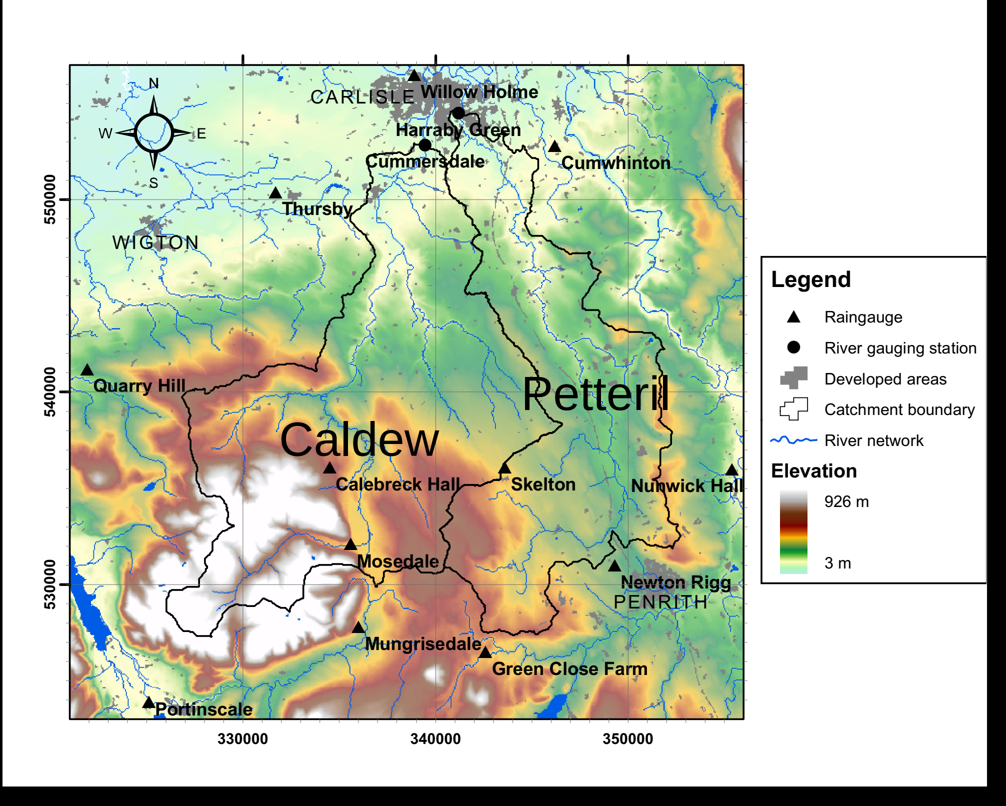




Model Orography

1 km forecast closer to Shap rain gauge measurement than radar!

Coupling to hydrological models



River Catchments

Experiments driving PDM lumped rainfall/runoff Model using NWP forecasts compared with gauges and NIMROD for two catchments

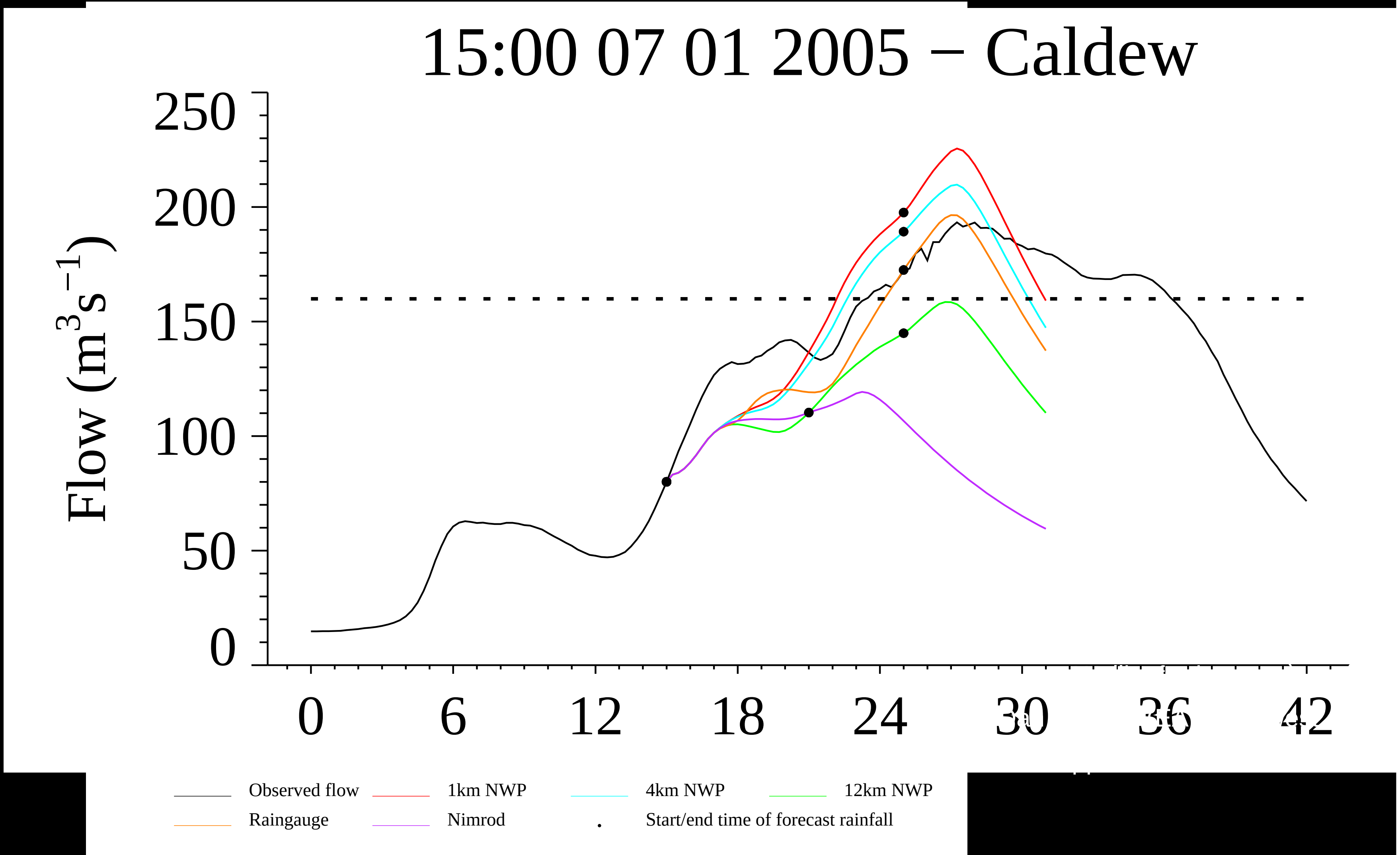
Nigel Roberts, Richard Forbes (MetO)

Steve Cole & Bob Moore (CEH) Wallingford

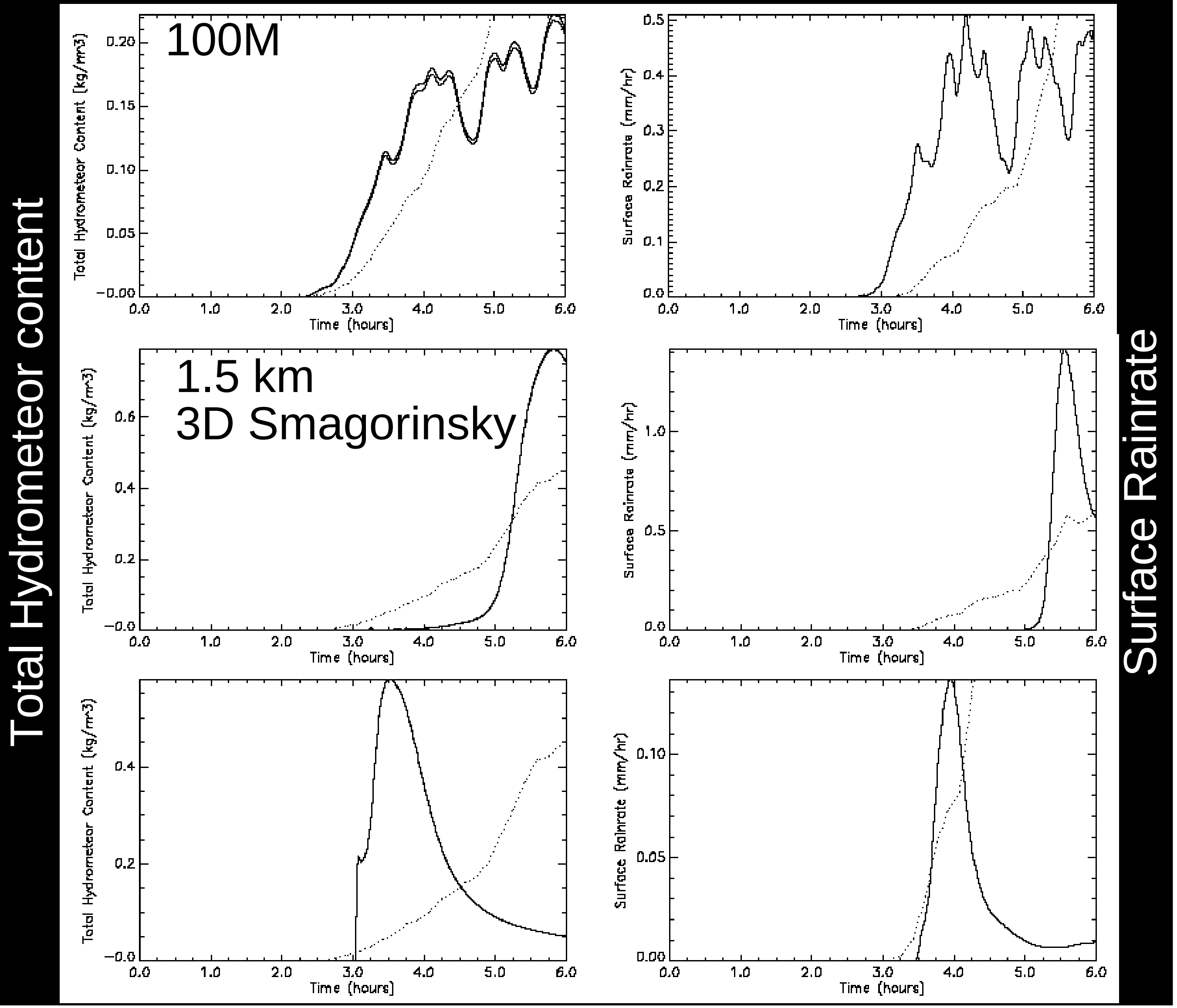
Dan Boswell (EA) Northwest

Met. Apps., In Press

Coupling to hydrological models



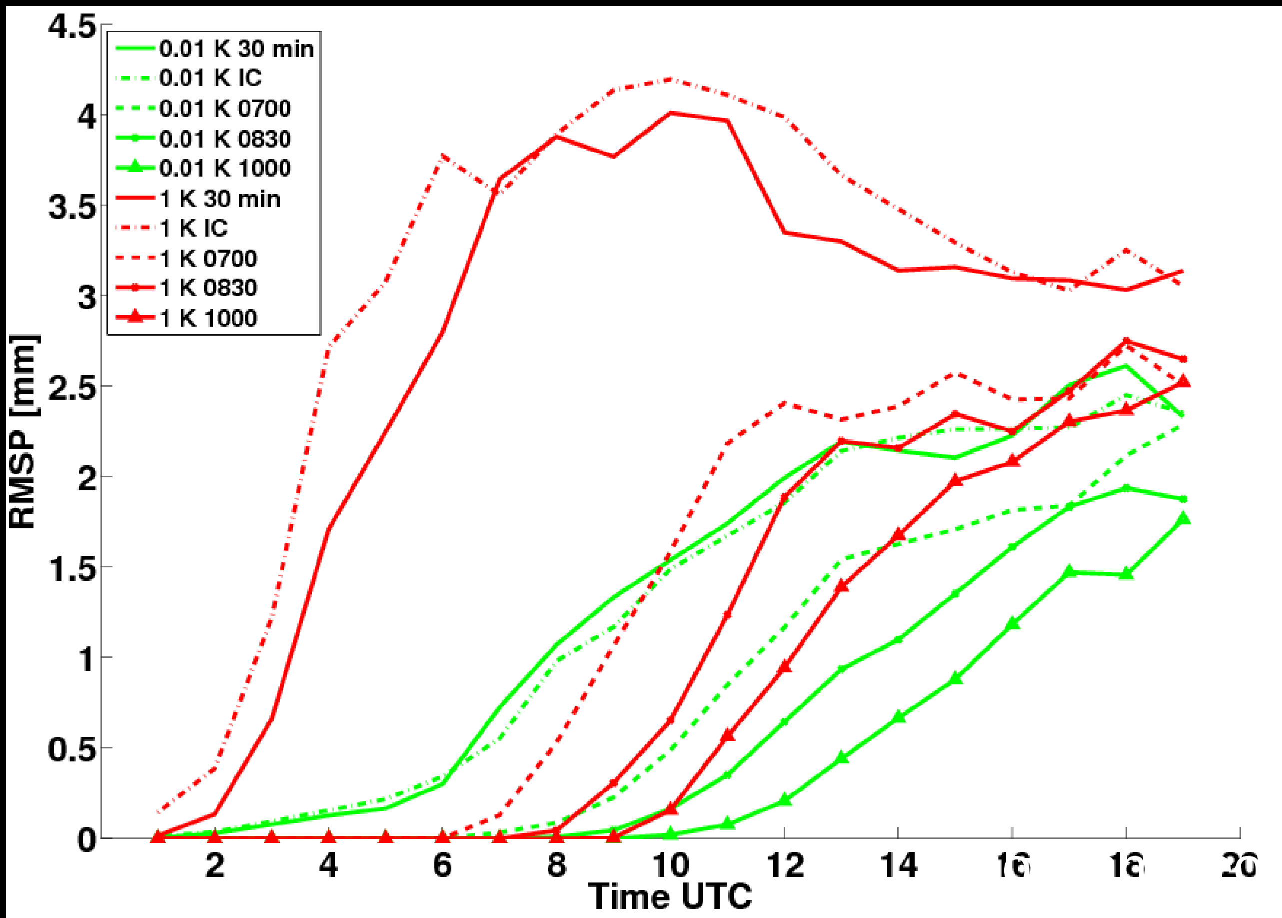
MetUM LBA experiments



Results

Direct Effects

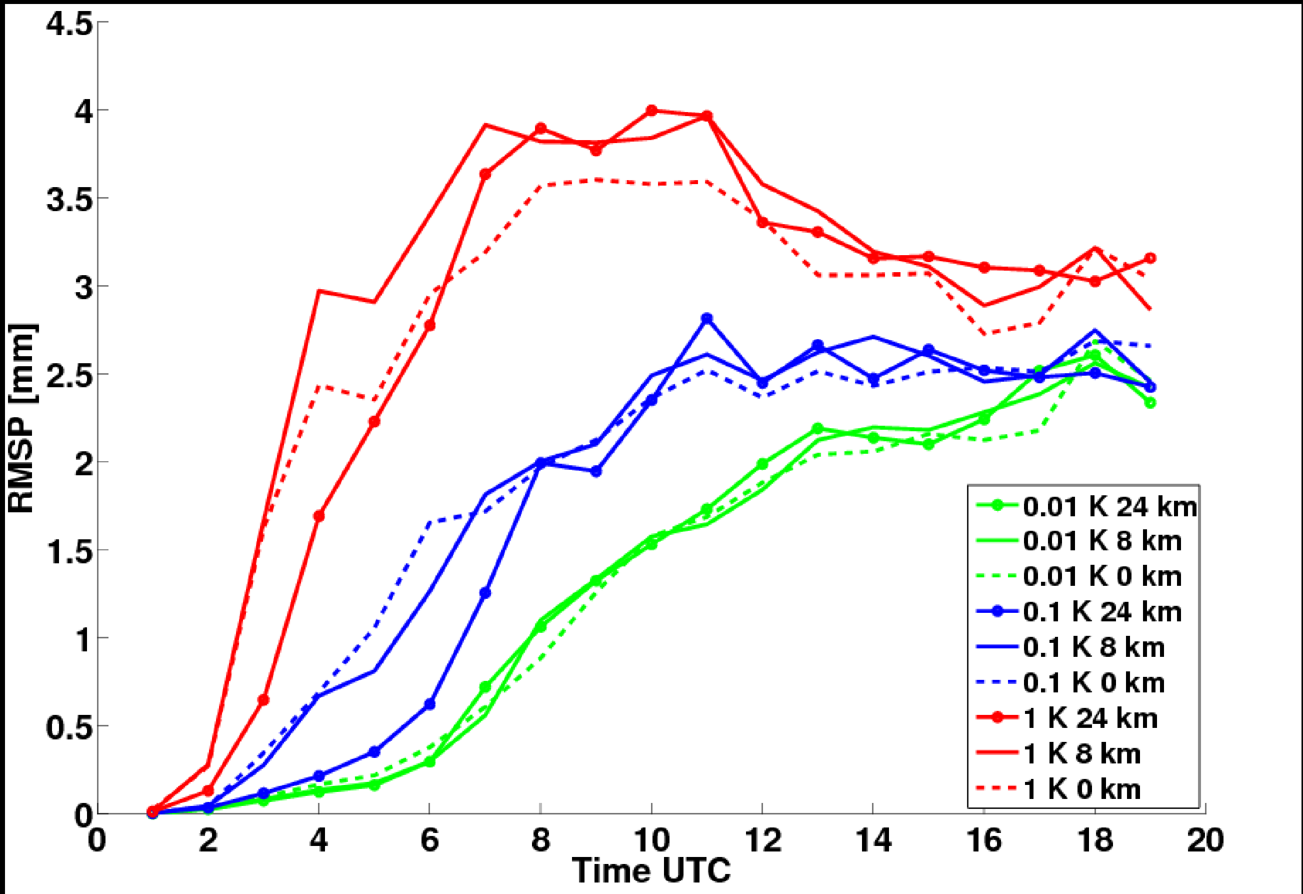
RMSE Hourly Accumulated Precip



cini (Reading)

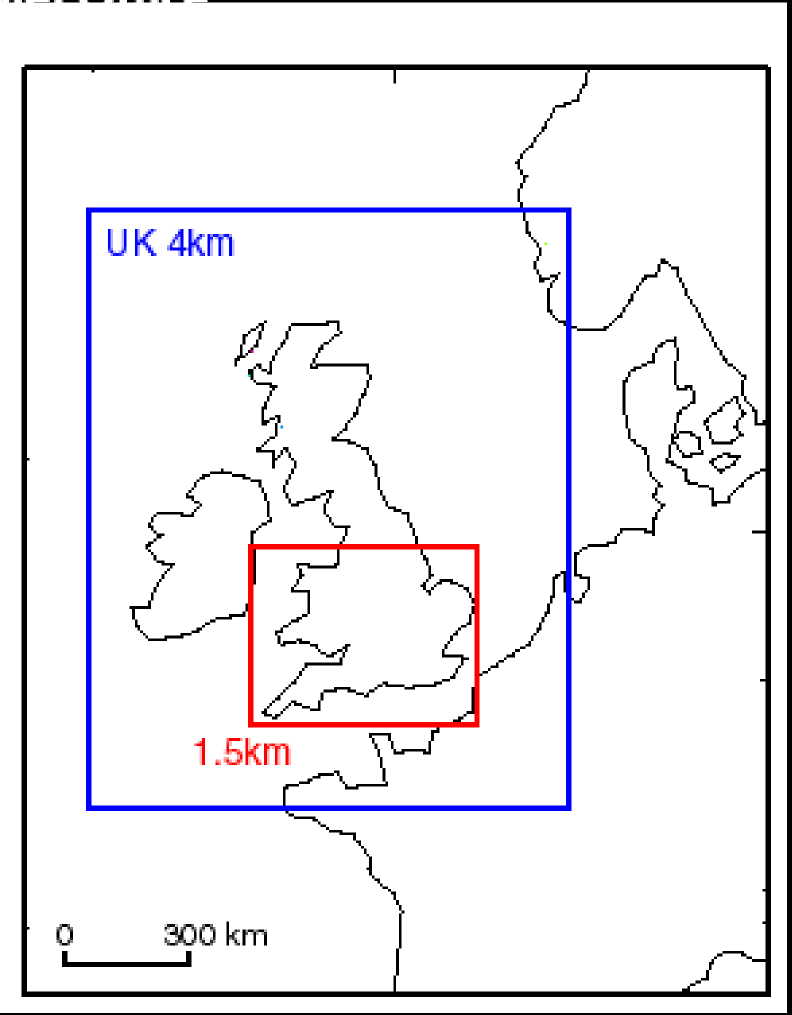
Results sequential perturbations

RMSE Hourly Accumulated Precip

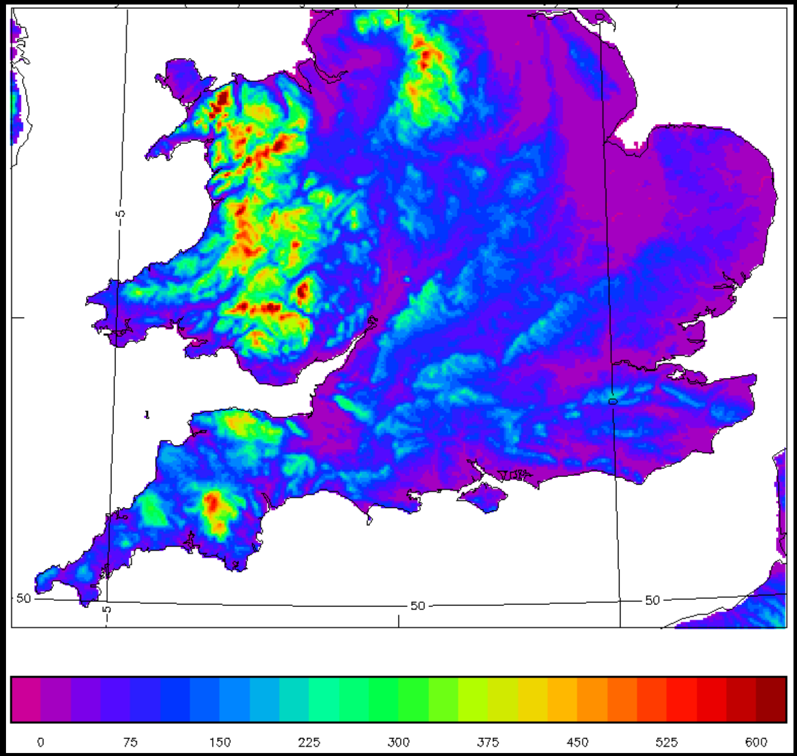


Giovanni Leoncini (Reading)

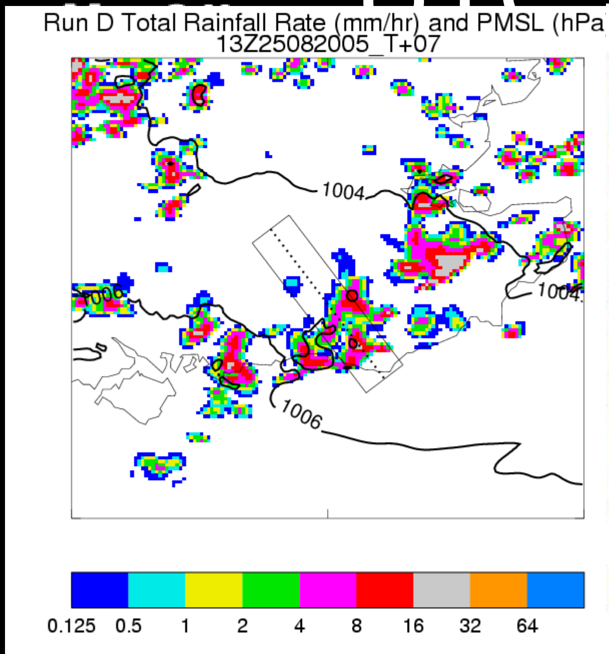
Unified Model 1.5km Domain

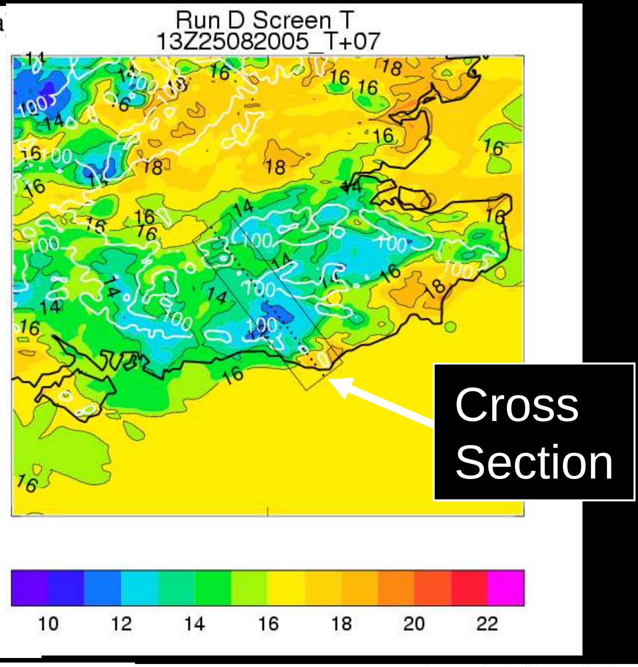


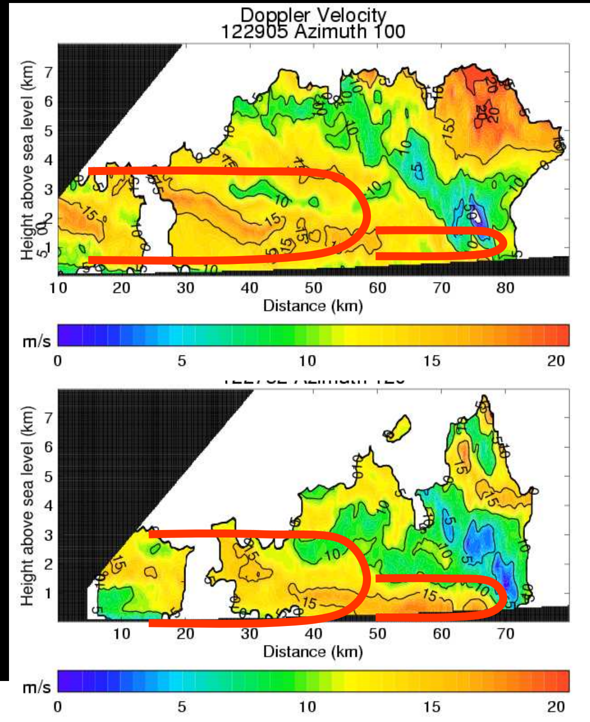
- 360x288 gridpoints
- 76 Vertical Levels
- Nested in UK 4km model
- Initial and LBC operational 06 UTC 12 km 'UK Mesoscale'
- No additional DA

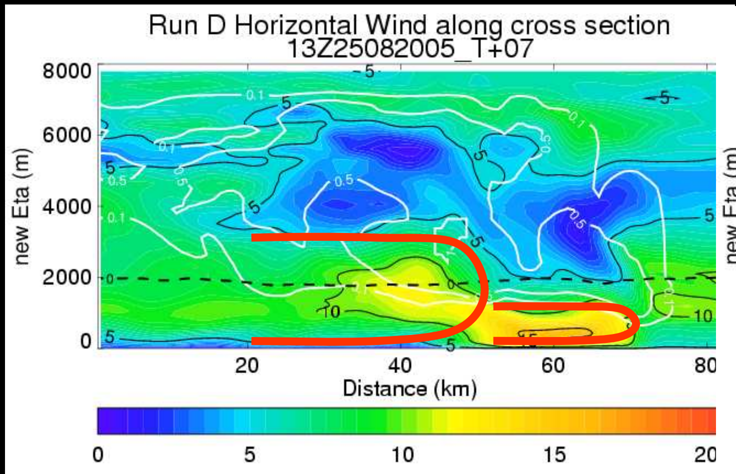


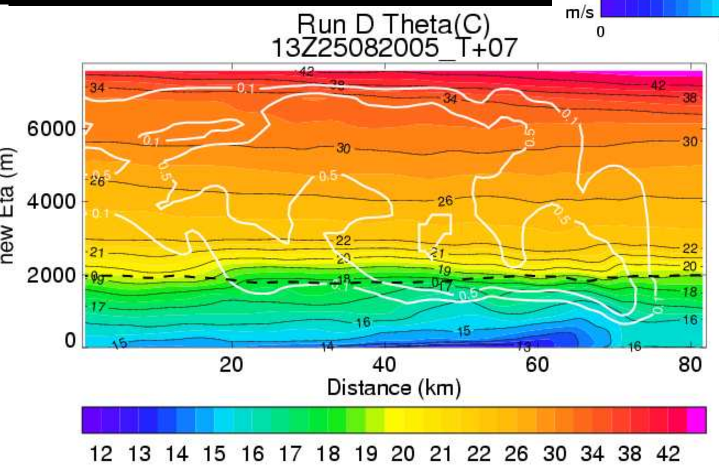
1.5 km L76 UM Forecast 13 UTC

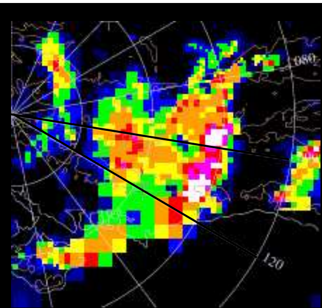




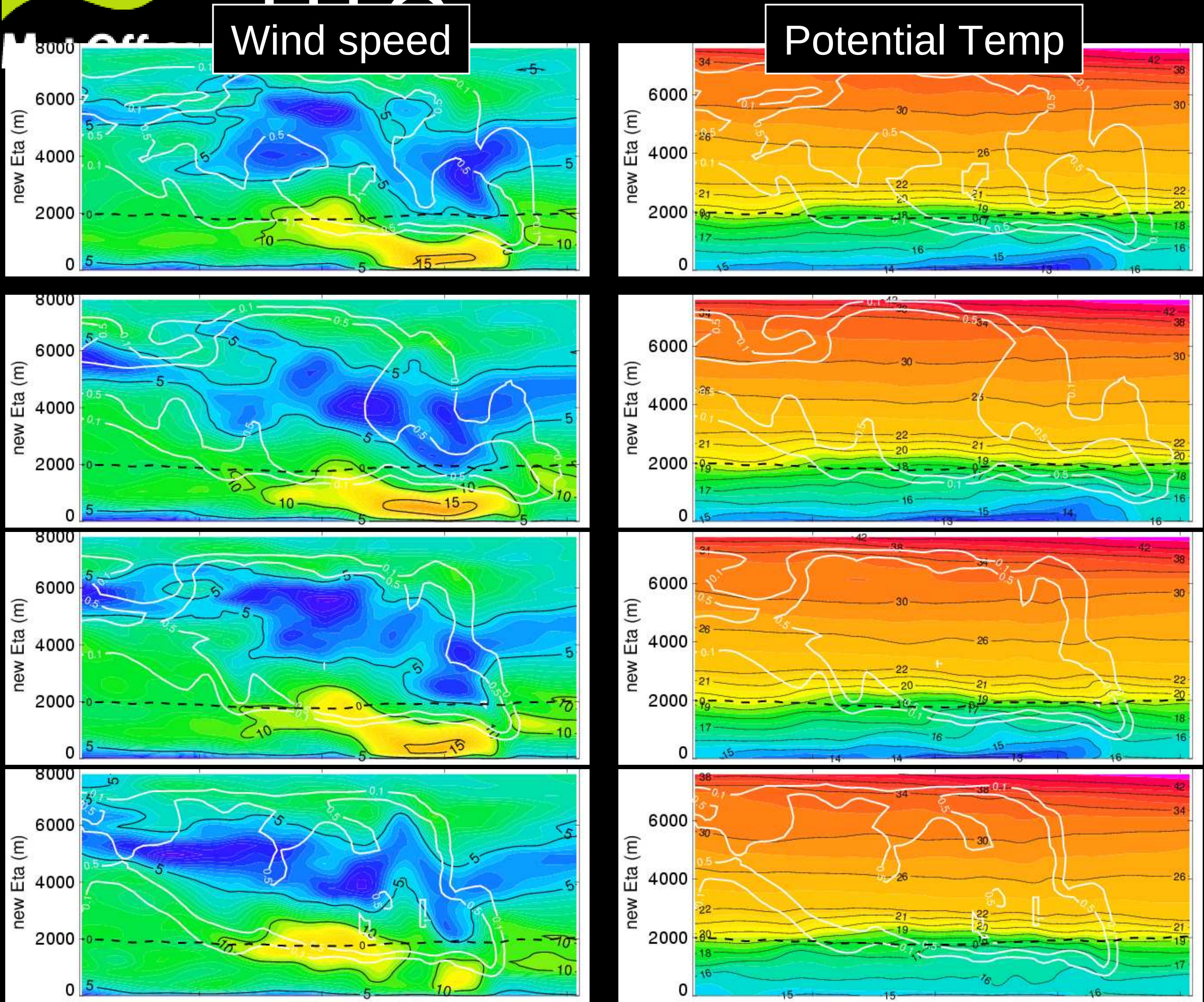








Microphysics sensitivity 11 UTC



Control

Heterogeneous Nucleation only at T<-40C

White contours= Cloud fraction

With graupel

No rain evaporation

Turbulence at 1 km

- Current forecasting capability of UM at 1 km horizontal resolution uses 'standard' non-local 1D BL plus fixed (del-4) horizontal diffusion.
  - Works well but not perfectly.
  - Anticipate need for 3D scheme, but highly asymmetric grid.
  - Starting point is Smagorinsky-Lilly approach: horizontal and vertical diffusion function of Richardson no., shear and a mixing length that scales with grid length.
- Tested robustness of the UM dynamics and implementation of scheme by comparing genuine large-eddy simulation with the Met office Large-eddy model (which has been thoroughly tested at this limit).
  - Dry CBL
  - Cu-capped BL (BOMEX equilibrium trade cumulus case)
- Tested appropriate choice of scheme at ~1 km using idealised diurnal cycle and real cases.

Subgrid turbulence scheme in MetUM

Smagorinsky-Lilly subgrid-turbulence scheme
with Richardson number (Ri) based stability factor

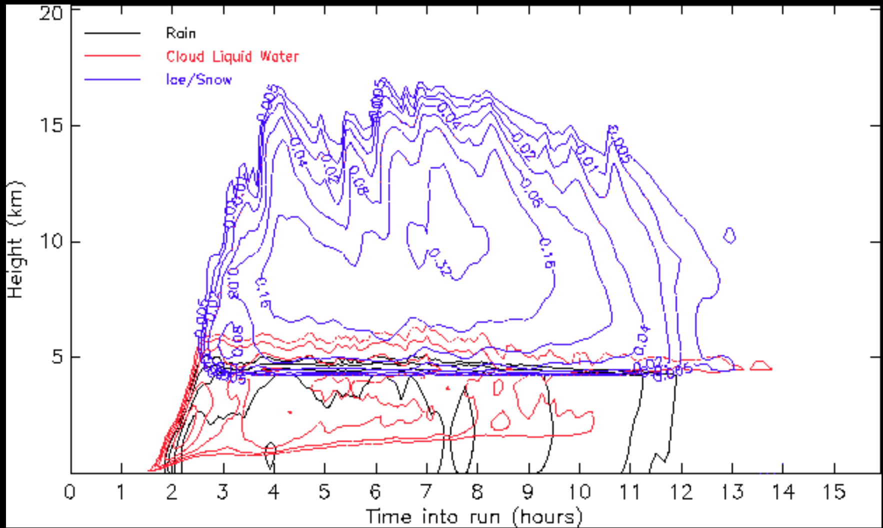
$$\nu = \lambda^2 S f_m(Ri) \qquad \nu_h = \lambda^2 S f_h(Ri)$$

Mixing length scale $$\frac{1}{\lambda^2} = \frac{1}{\lambda_0^2} + \frac{1}{\left[k(z+z_0)\right]^2}$$ where $$\lambda_0 = C_s \Delta x$$

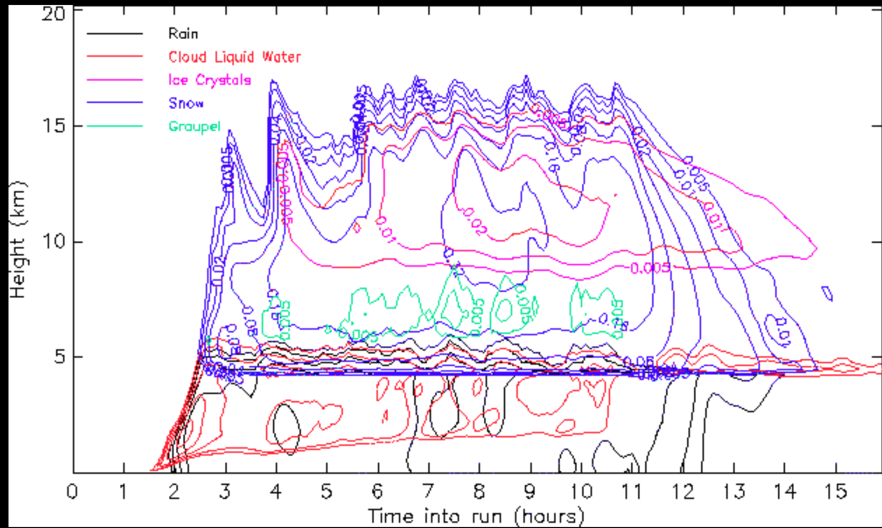
Wind shear $$S = \|S_{ij}\| / \sqrt{2} = \left(\frac{1}{2}\sum_{i,j,1,3} S_{ij}^2\right)^{1/2}$$ where $$S_{ij} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}$$

Stability function (unstable) $$f_m = (1-16Ri)^{1/2}$$ and $$f_h = \frac{1}{0.7}(1-40Ri)^{1/2}$$

GCSS TRMM-LBA Diurnal Cycle



UM Reference



UM with enhanced microphysics

Comparison with CRM – possibly excessive glaciation

Met Office CRM

Total hydrometeor content

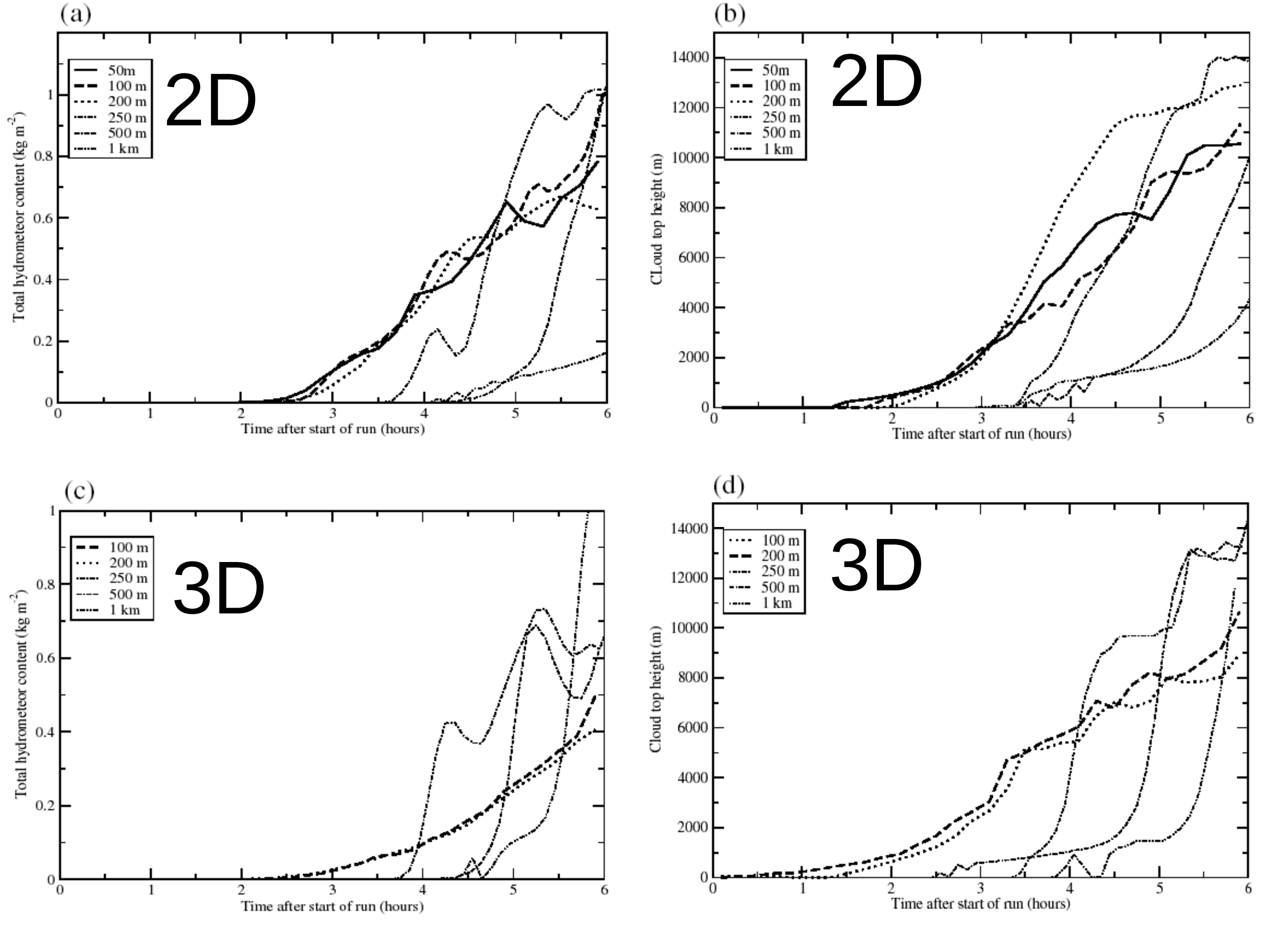
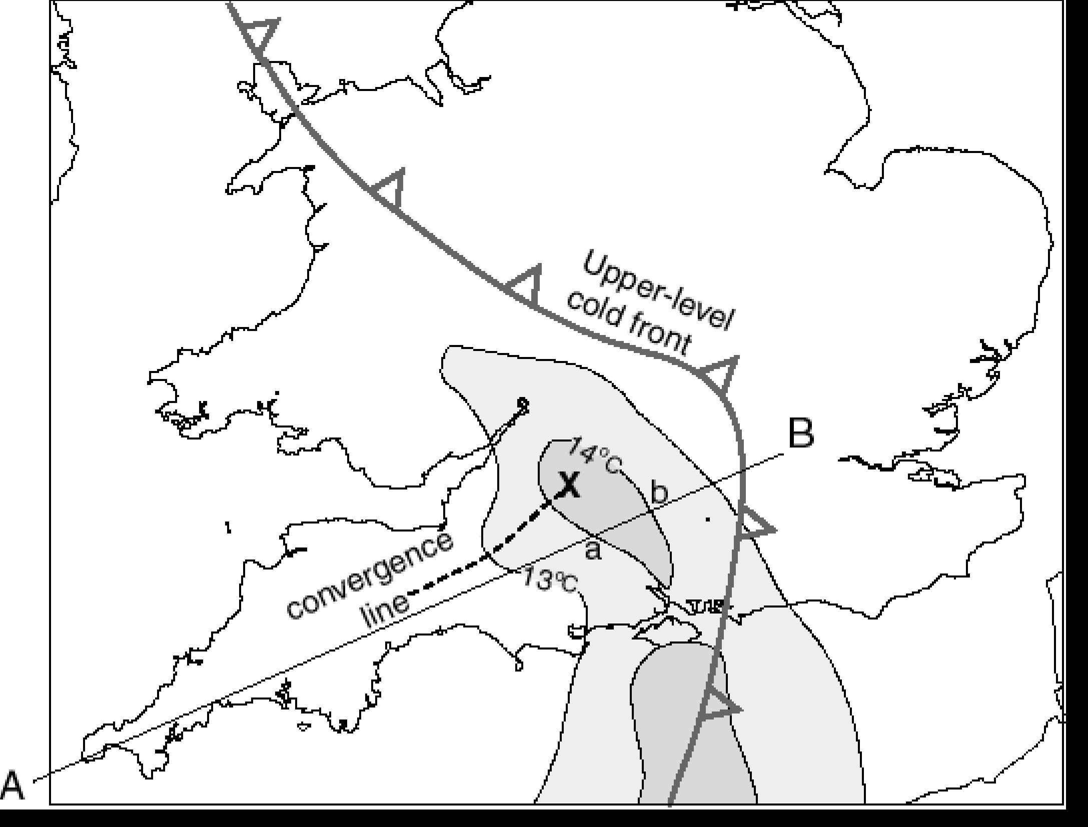


Figure 3. Time series for a range of horizontal grid lengths with standard subgrid mixing. (a) Total hydrometeor content from 2D runs, (b) maximum cloud-top height from 2D runs, (c) total hydrometeor content from 3D runs, and (d) maximum cloud-top height from 3D runs. Note that no 50 m grid-length runs were carried out in 3D.

Cloud top height

Petch, 2006, Q.J.R.M.S 132, 345-358

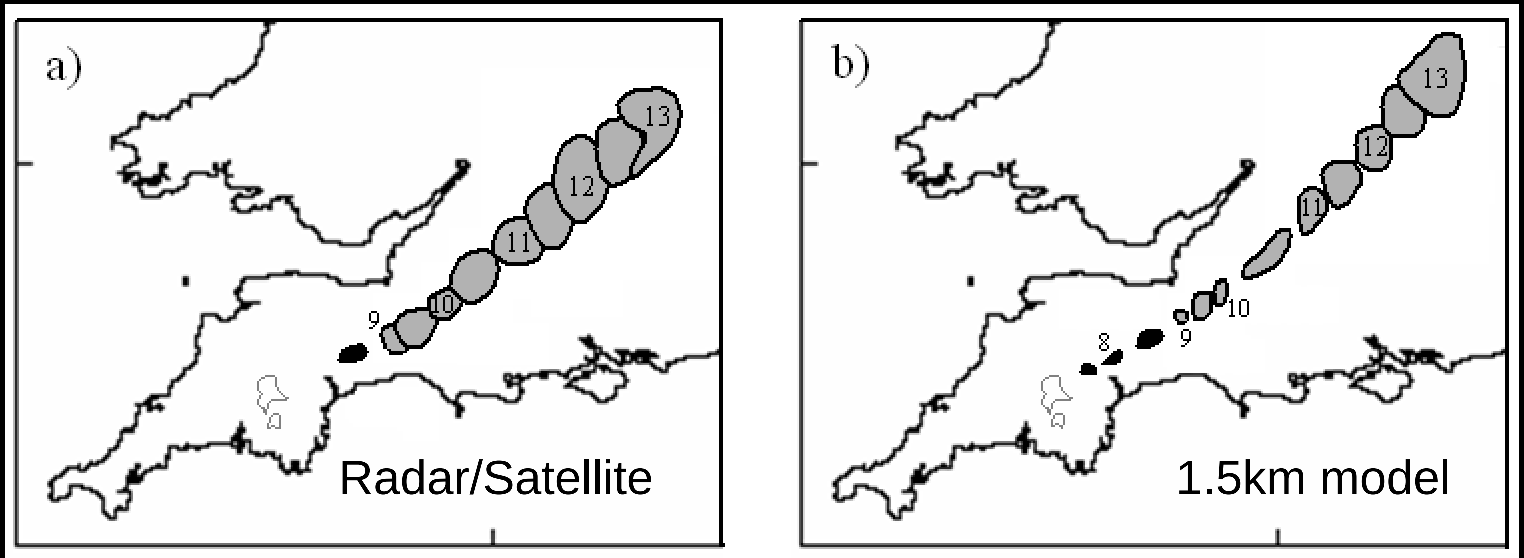
CSIP IOP 1 analysis



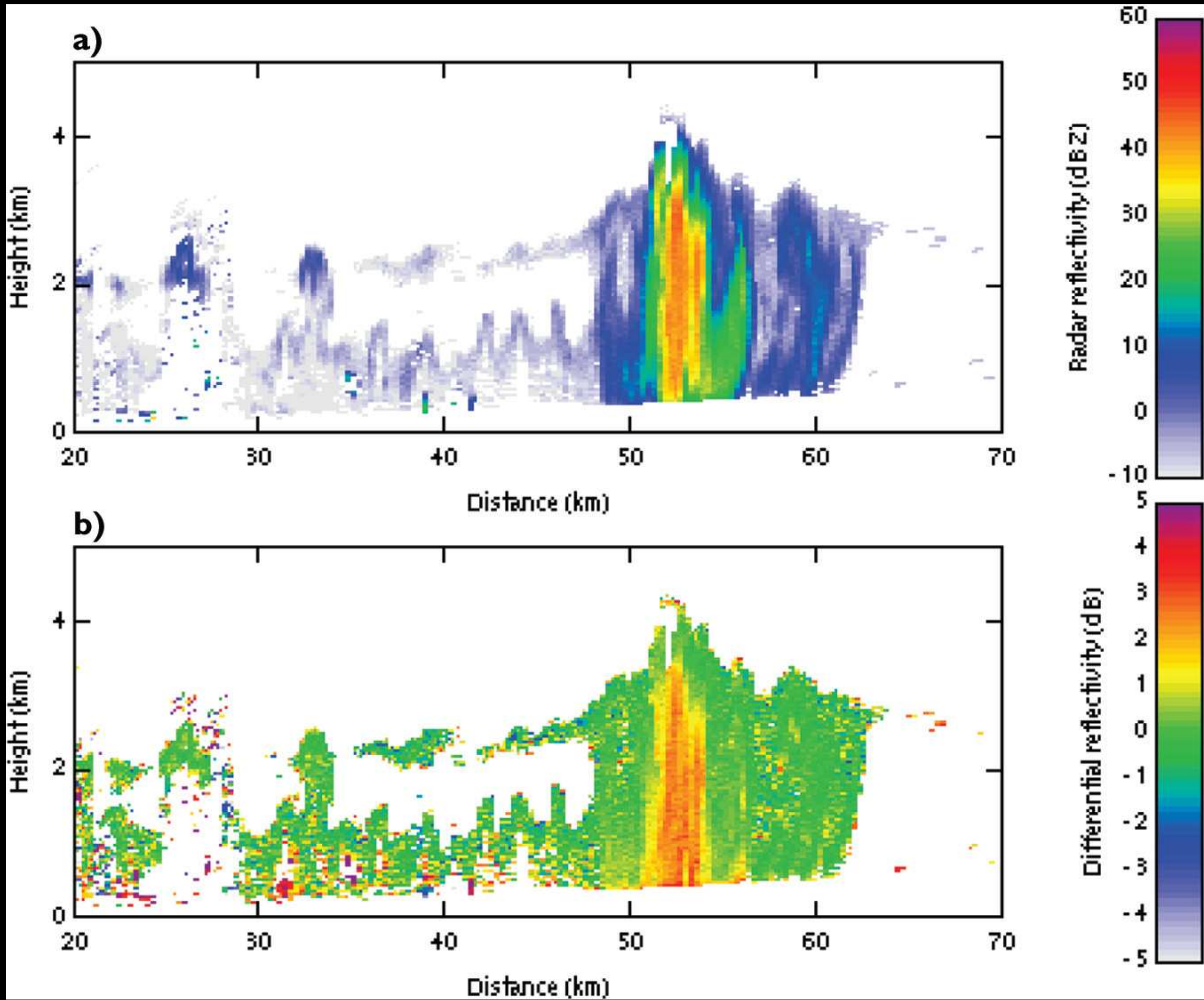
10 UTC analysis

Morcrette *et al*, 2007

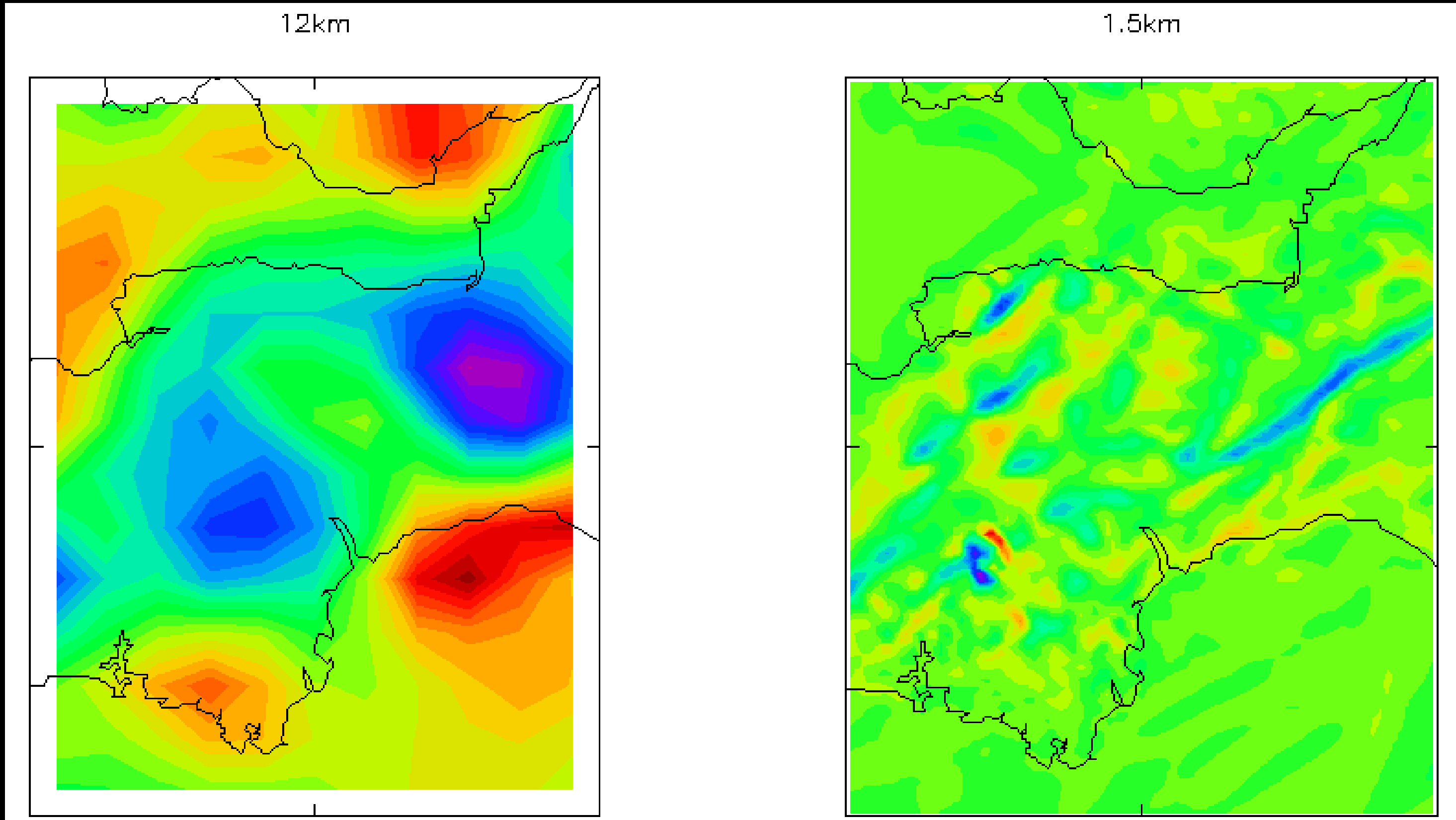
Comparison of radar with 00 UTC model run



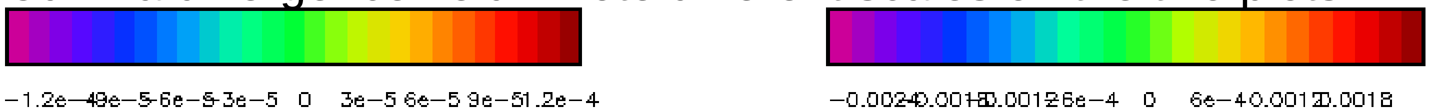
CSIP IOP 1 - Chilbolton 3 GHz Radar



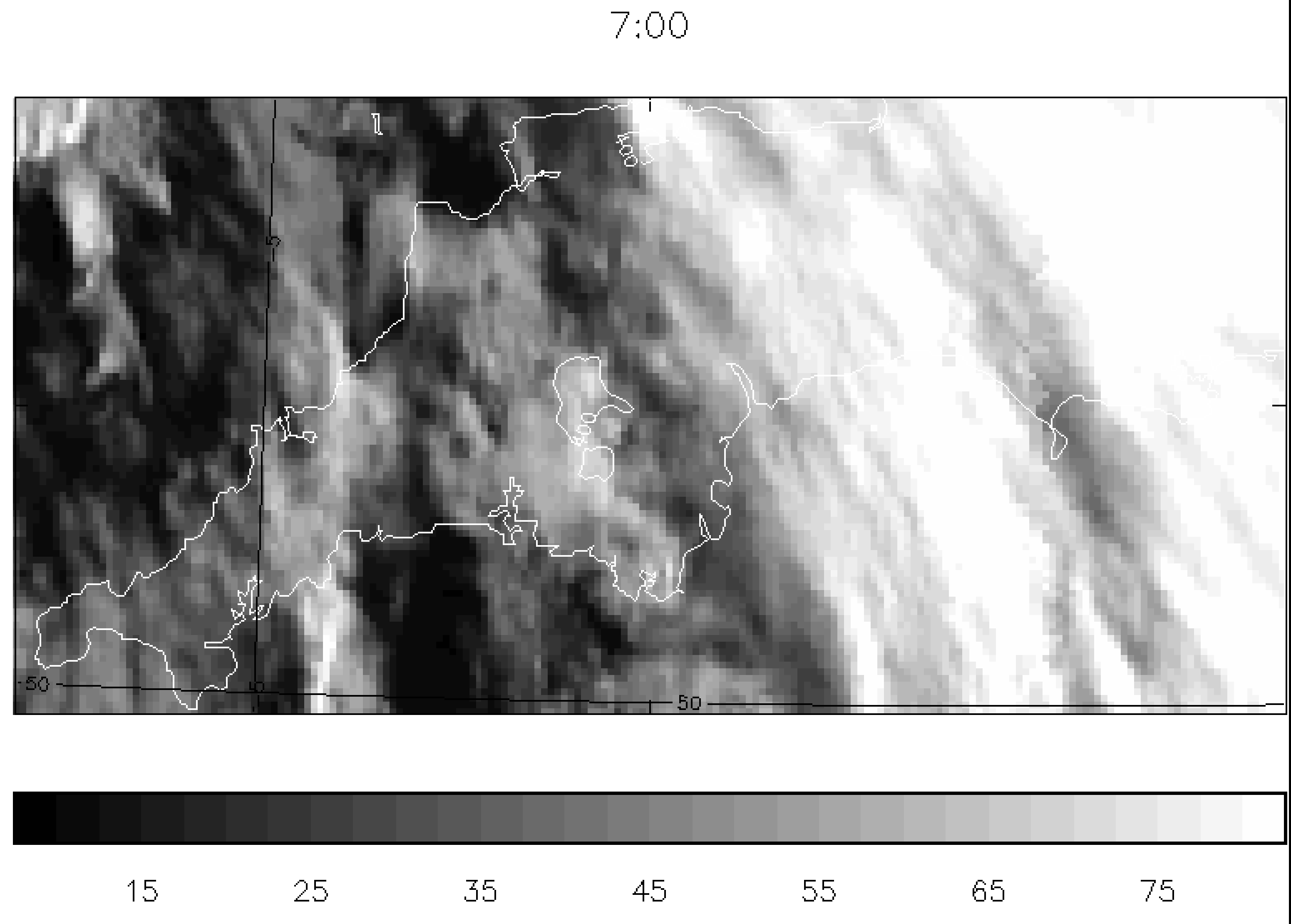
Comparison of model convergence lines 09 UTC



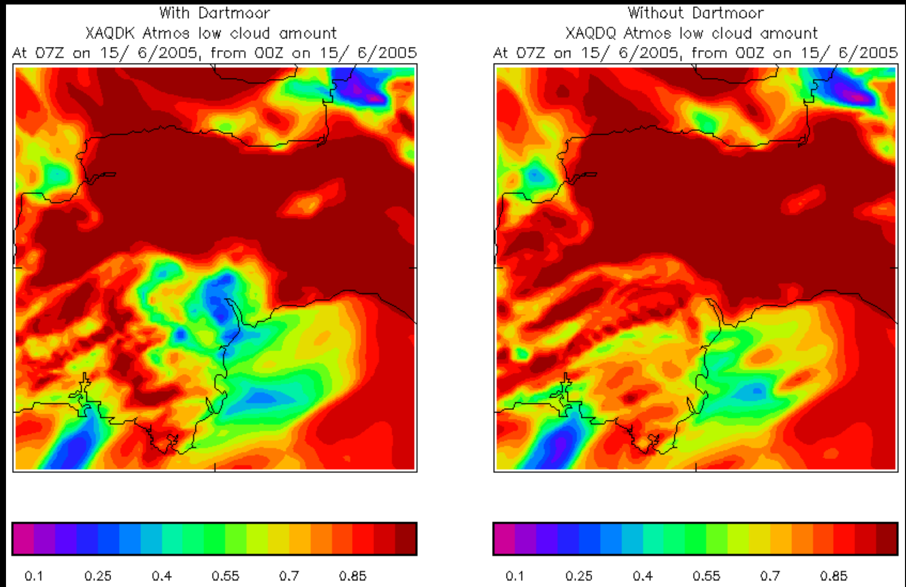
950 hPa divergence field - Note different scales on the two plots!!

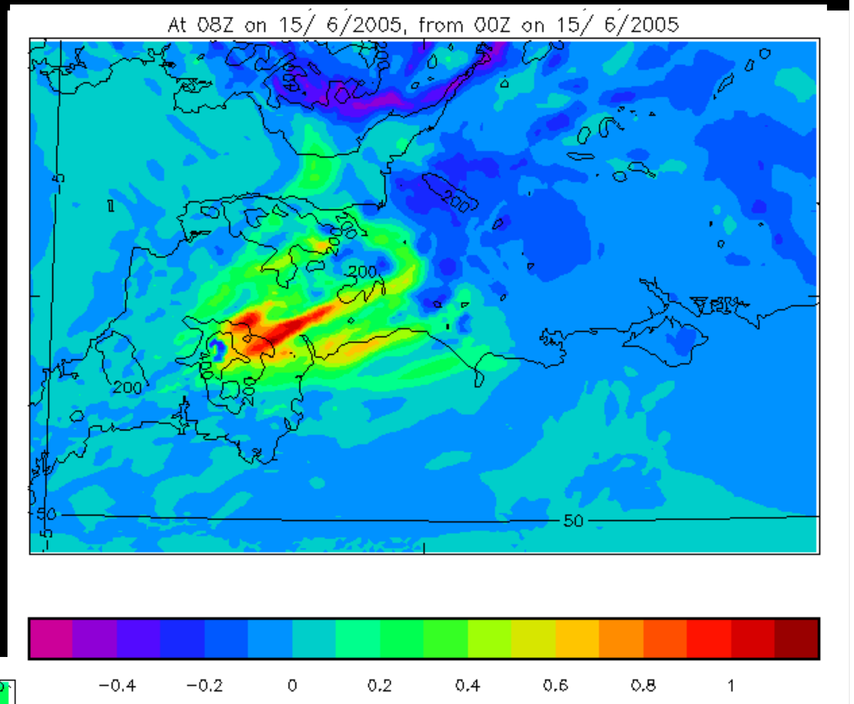


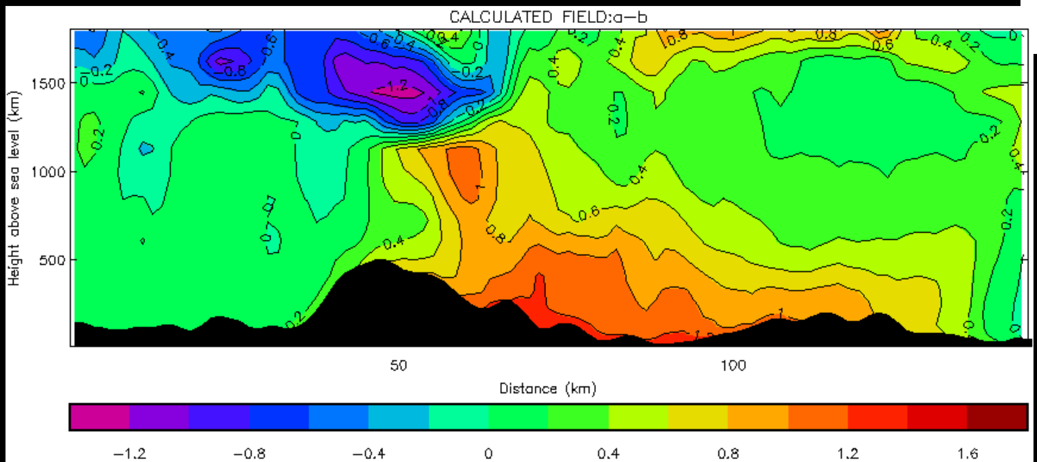
Downstream hole in cloud (Vis image)



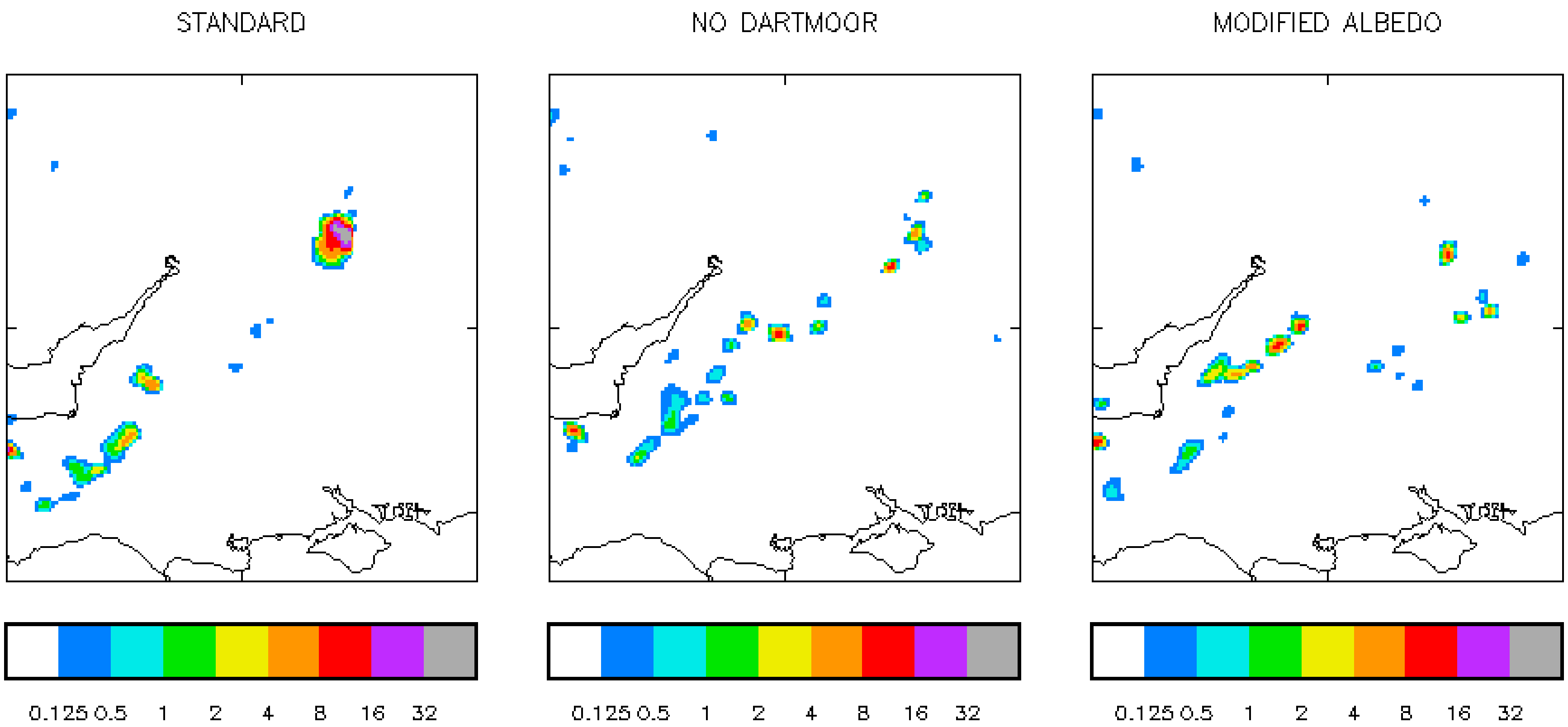
Downstream hole in cloud (1.5km model)







Effect on Shower at 12 UTC



IOP 1 Conclusions

- Good forecast of IOP1 event from 1.5km model due to correct interaction of mesoscale features (convergence line, lid, effects downstream of Dartmoor). High level of predictability.

- Reasonably accurate forecast requires:
    - Upper level forcing.
    - Low level warm/moist tongue.
    - Realistic 'lid'
    - Convergence line to lift and destabilise lid
    - Cloud hole and enhanced surface heating due to Froude number of flow over Dartmoor around 1.

Convective cell stats (CSIP IOP18) Sensitivity to turbulence scheme

- Reference run has too many, too small convective cells compared to the observations, particularly at low rain rates.
- Simulations with horizontal turbulence scheme have cell sizes closer to observed, particularly as the horizontal mixing is increased (higher Cs).
- Simulations with the horizontal turbulence scheme have cell numbers closer to observed, particularly at lower rain rates (<4 mm/hr) but still have too many cells with higher rain rates (> 4mm/hr).
  - (Note, the 8mm/hr threshold is dominated by the main organised squall line in the radar and is not representative.)
- The model still does not have enough stratiform rain around convective cores.

Summary

- 3D sub-grid turbulent mixing parametrization introduced into the UM (based on Smagorinsky-Lilly). UM works as LES (50 m).
- At ~ 1 km use hybrid approach combining the 1D non-local boundary layer scheme with aspects of the 3D scheme.
- Tested in idealised and real case studies and can have a very significant impact on convective initiation and evolution.
- Reduces over-prediction of small convective cells at 1.5km. Reduces excessive rain rates in larger storms.