High resolution 3-D LES simulations: a link between shallow and deep cumulus?

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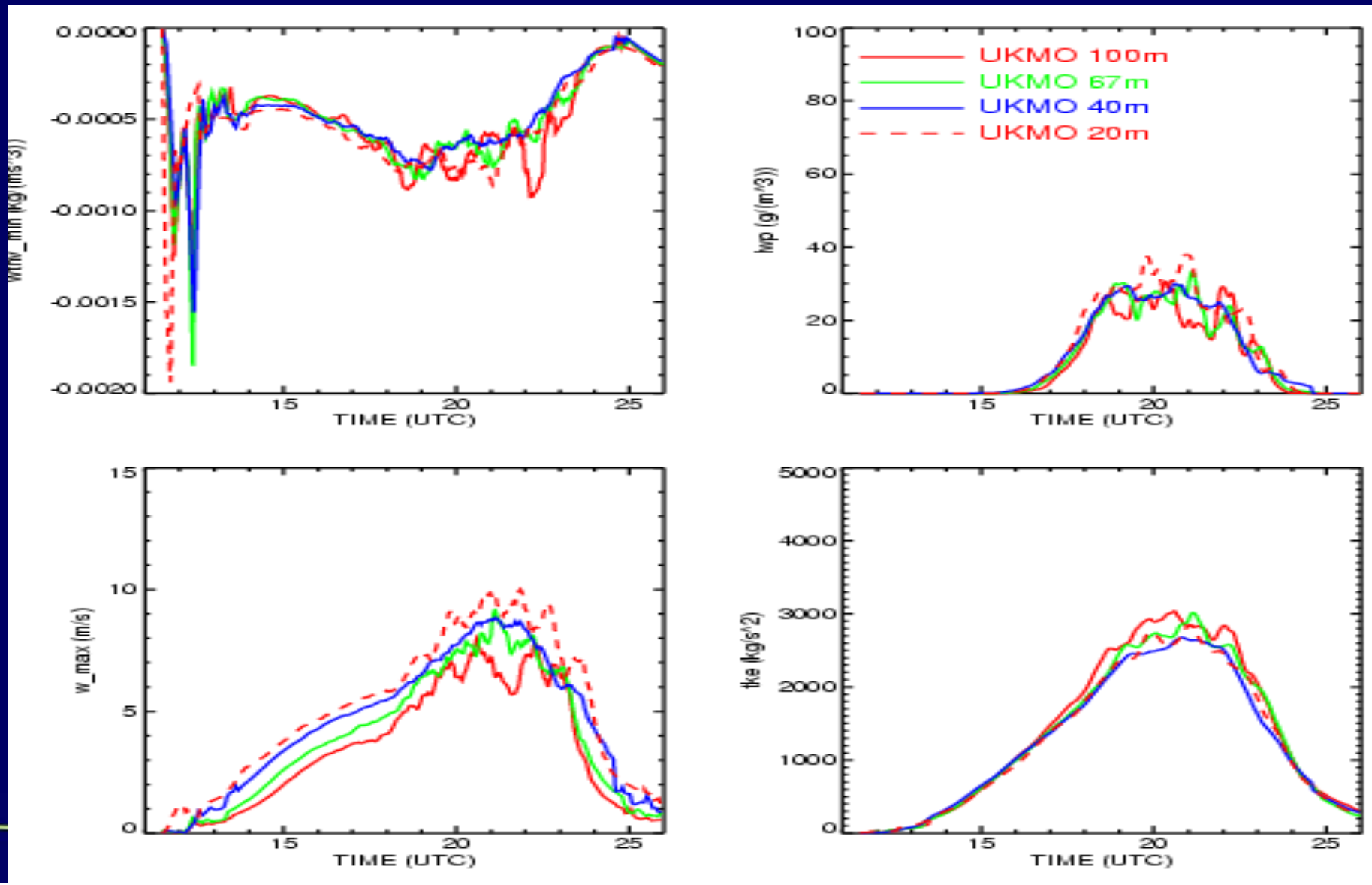
  - Better surface fluxes (closer to shallow case)
  - More moist I.C
  - Sensitivity studies
- Summary

Results from shallow case – high resolution tests



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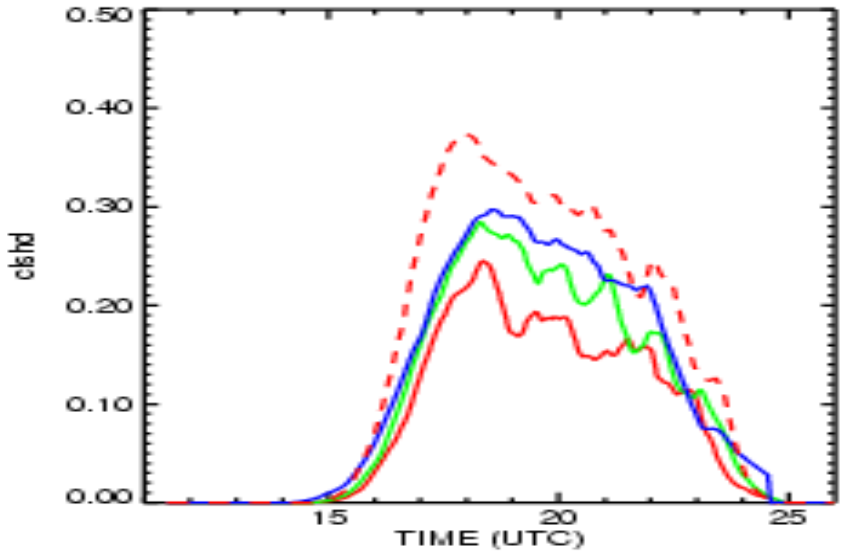
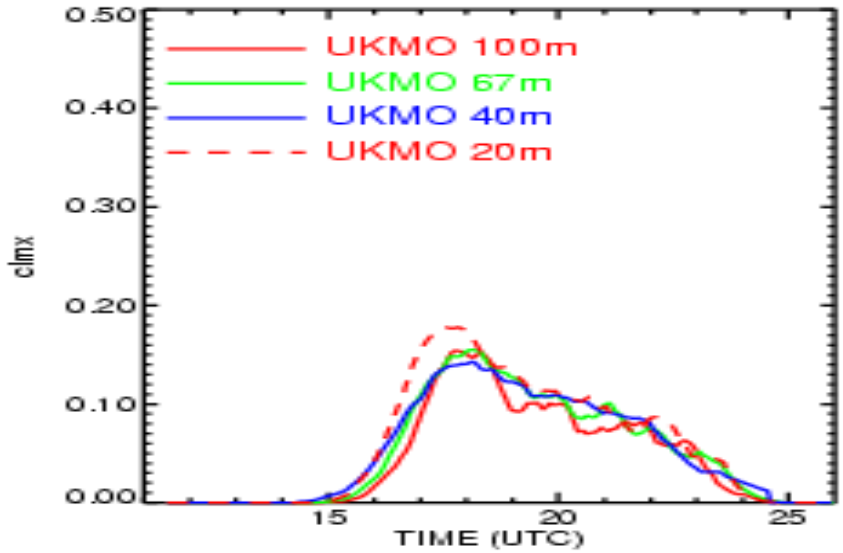
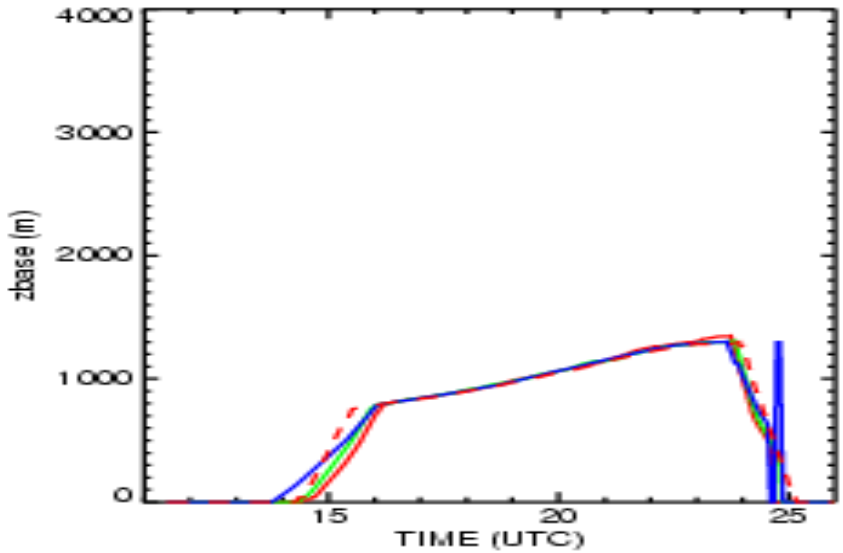
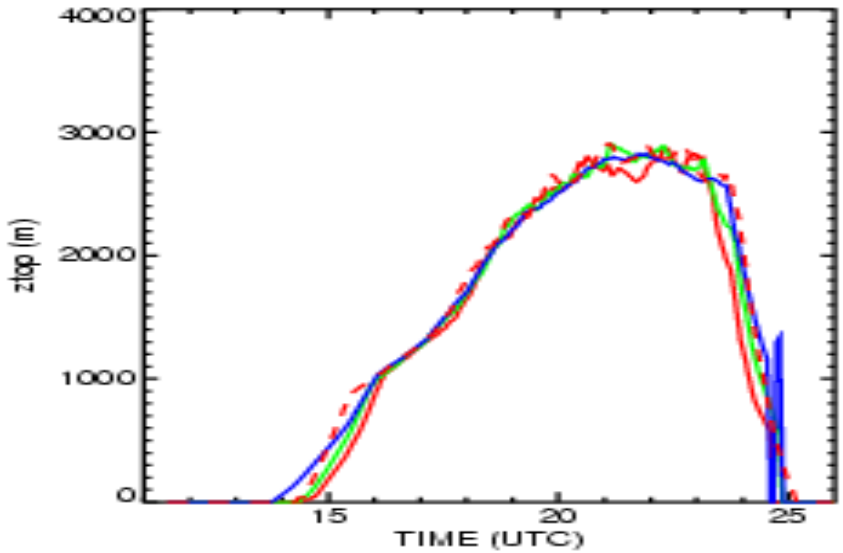
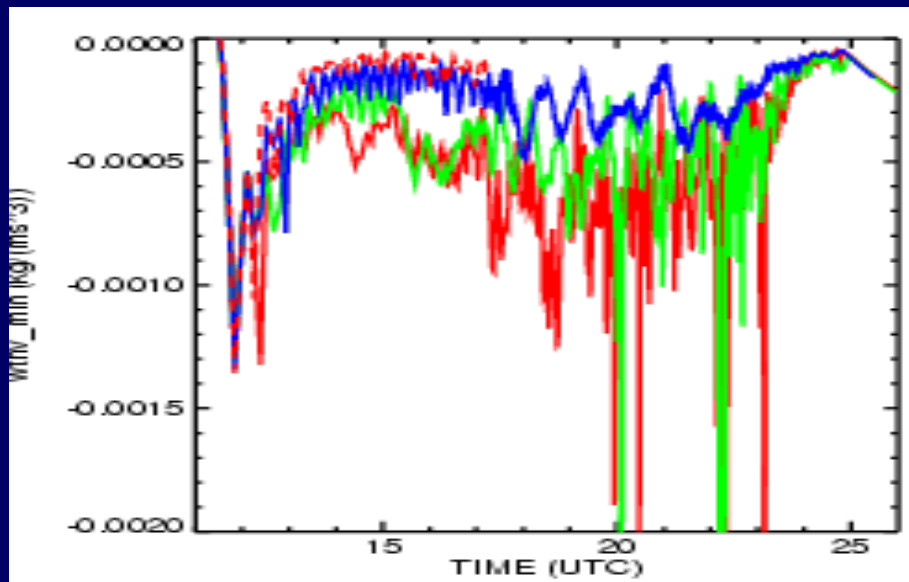


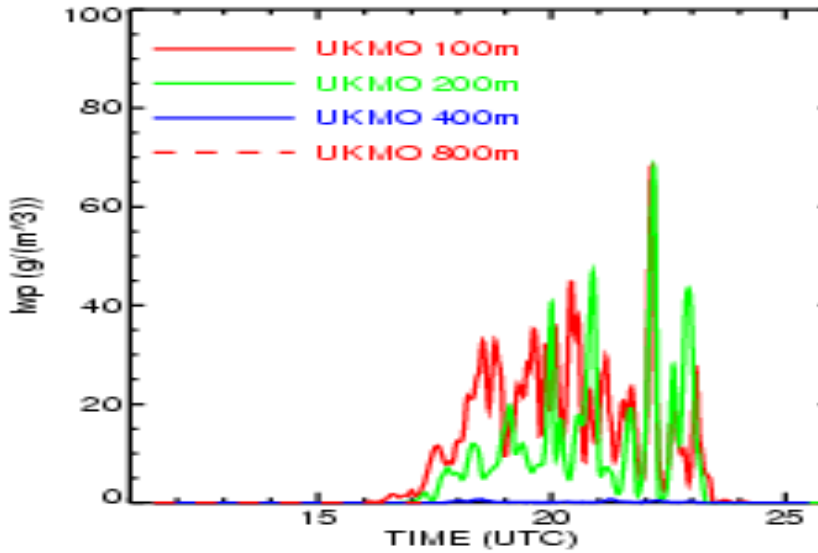


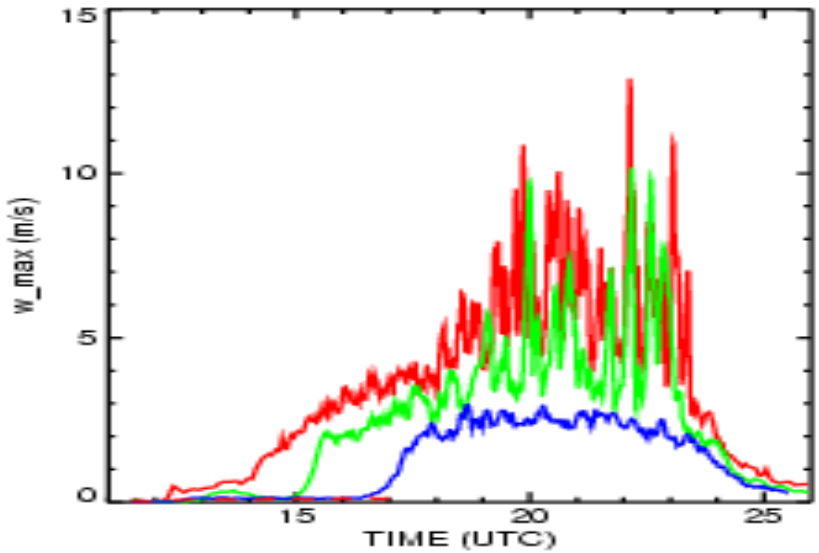


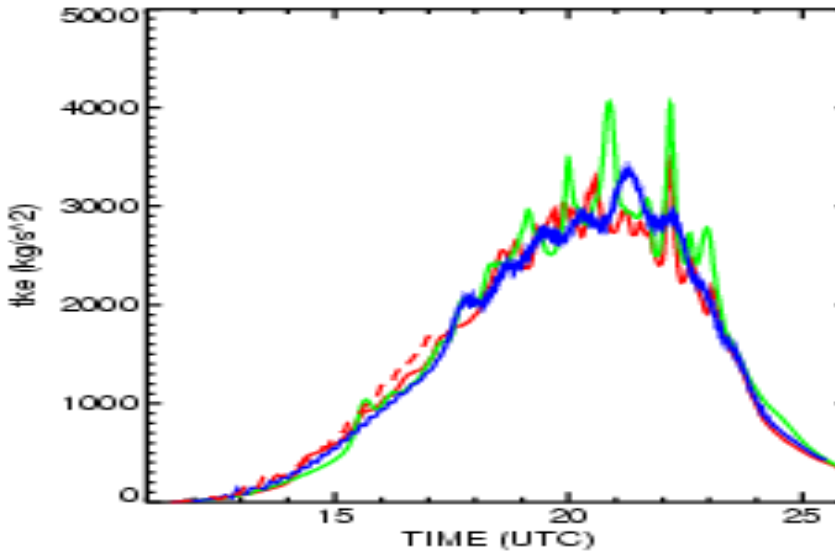


Results from shallow case – low resolution tests









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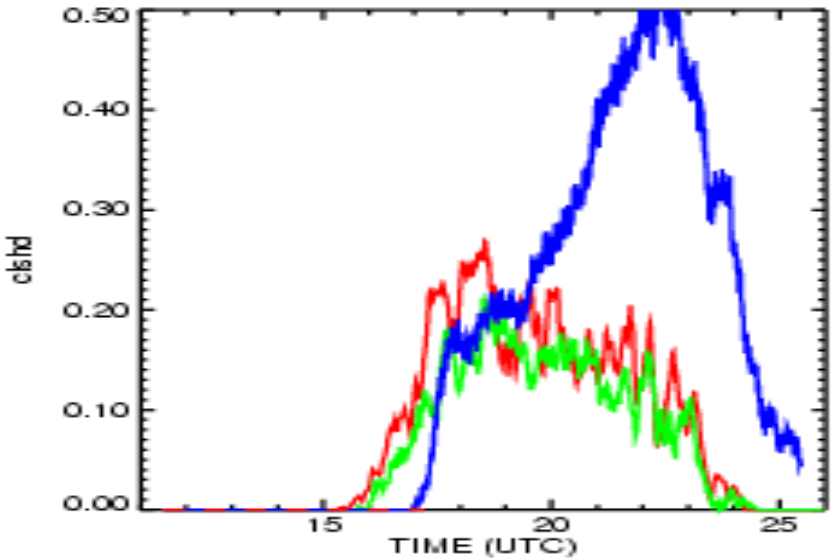
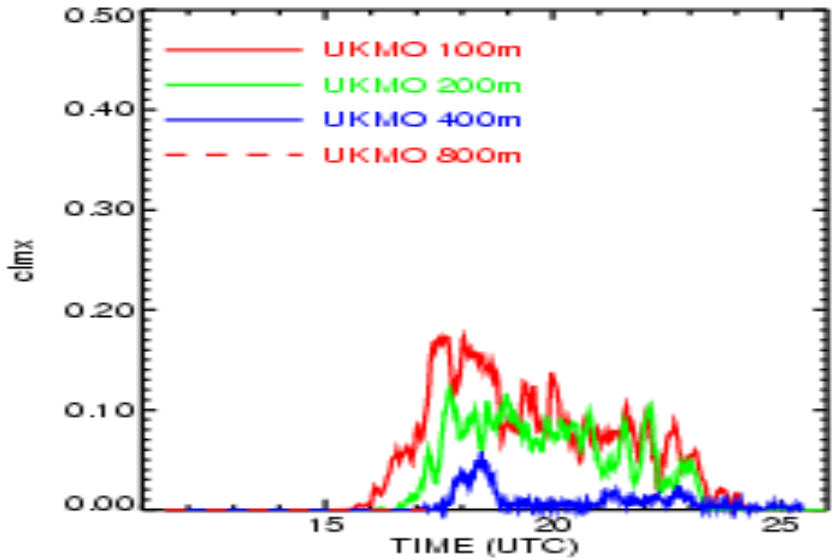
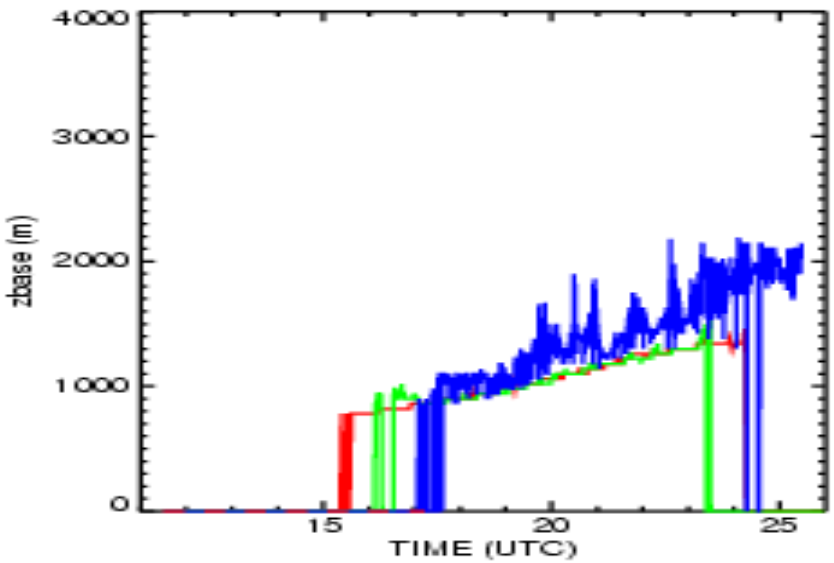
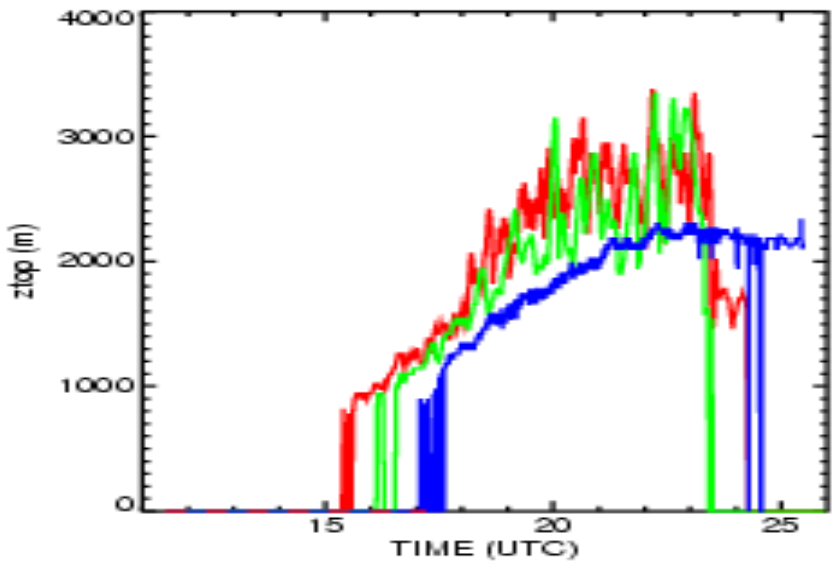








Shallow case summary

- Basic information
  - Cloud forms around **12pm** local time
  - Peak is between **1 and 4pm** local time
  - Cloud fractions peak around **20%**
  - Cloud top builds to **3 km** at **6pm**
  - Liquid water paths of **30 g m^{-2}**
- Resolution study
  - 100 m and less shows convergence
  - 200 m not too bad
  - 400m or 800 m is poor and blows up or forms no cloud
  - Other models gave similar results at default 100 m (not shown)
- Domain and 2D/3D differences
  - 2D not tested but had given strange results in BOMEX case
  - Domain was 6.4km x 6.4km

Some questions (I don't plan to answer many of them!)

- Can we begin to bridge the gap between the shallow and deep cases?
- Model related questions. What is the impact of:
  - higher resolution?
  - smaller domain size?
  - going from 2-D to 3-D?
  - more detailed microphysics?
- Simulation related questions. How important are:
  - the initial conditions?
  - the surface fluxes?
  - Large scale forcing and/or radiation?

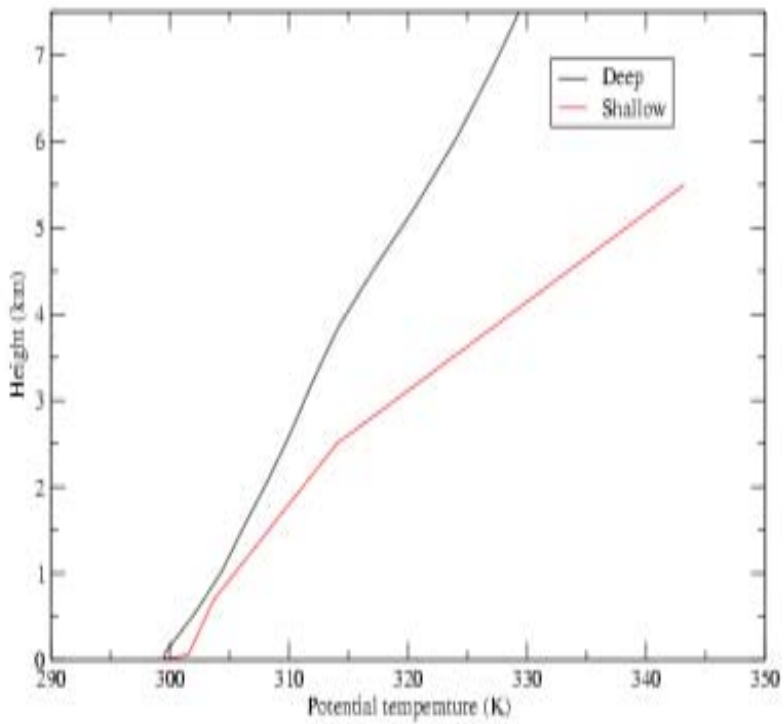
Points of interest

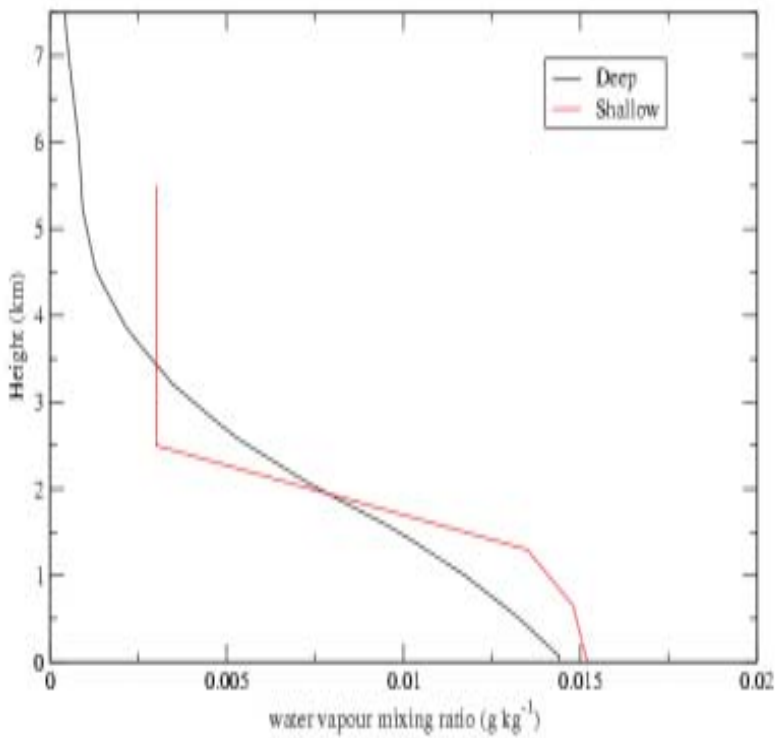
- At what point does the shallow cumulus deepen?
- How long does it stay shallow?
- How long does it take to rain after it goes deeper?
- How long does it take to reach upper troposphere?
- Do interesting things occur at freezing level?

Intermediate simulations

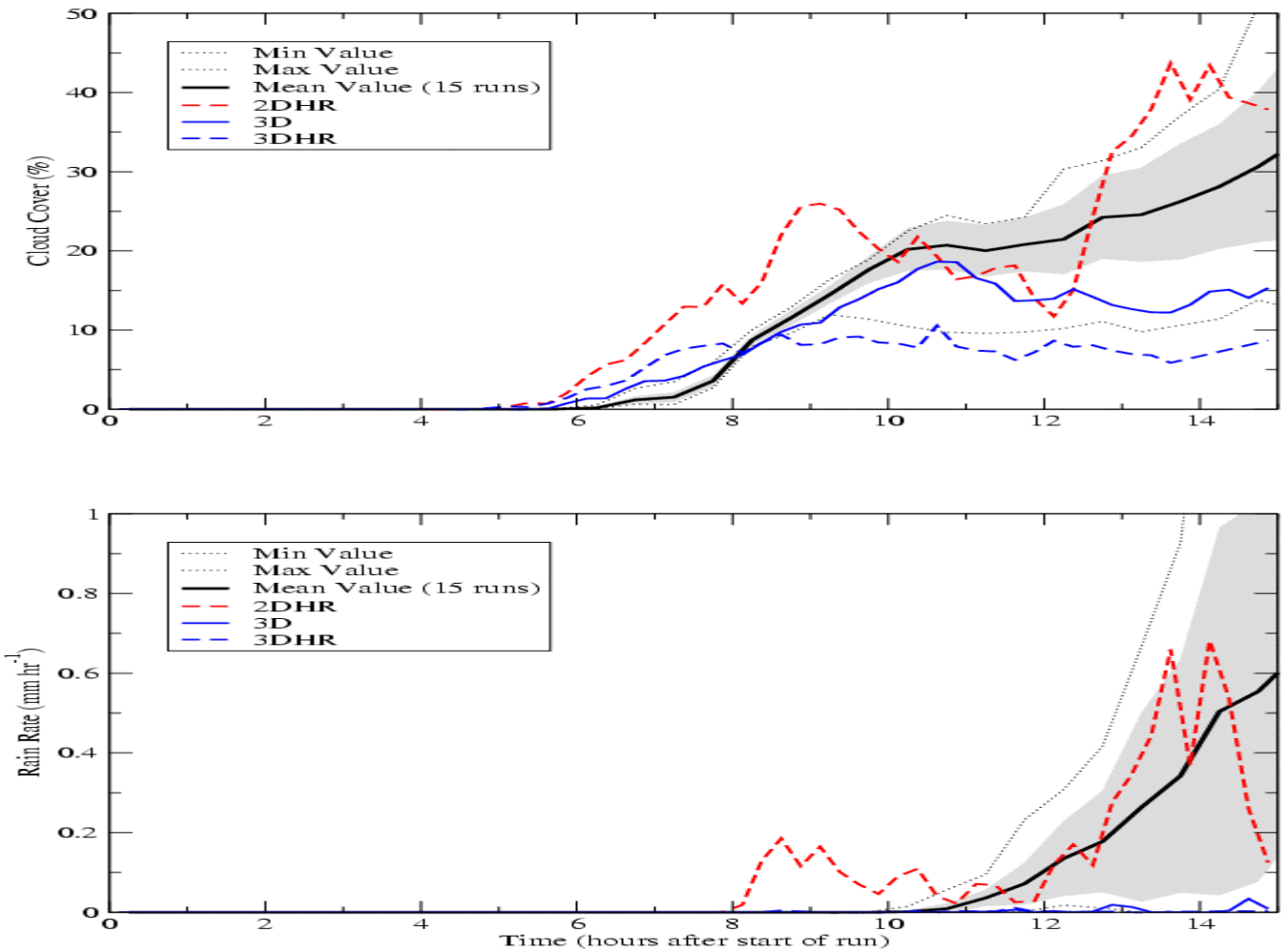
- Model
  - Met Office CRM/LEM (as used in shallow case)
  - 120 vertical levels (15 km domain)
  - 100m or higher vertical resolution
  - Forced with standard semi-idealised case
- Simulation
  - 2D
    - » 250 m ensemble from 15 runs (250 km domain)
    - » 100 m (160 km domain)
  - 3D (100x100 points)
    - » 100 m (10 km x 10 km)
    - » 250 m (25 km x 25 km)

Initial conditions

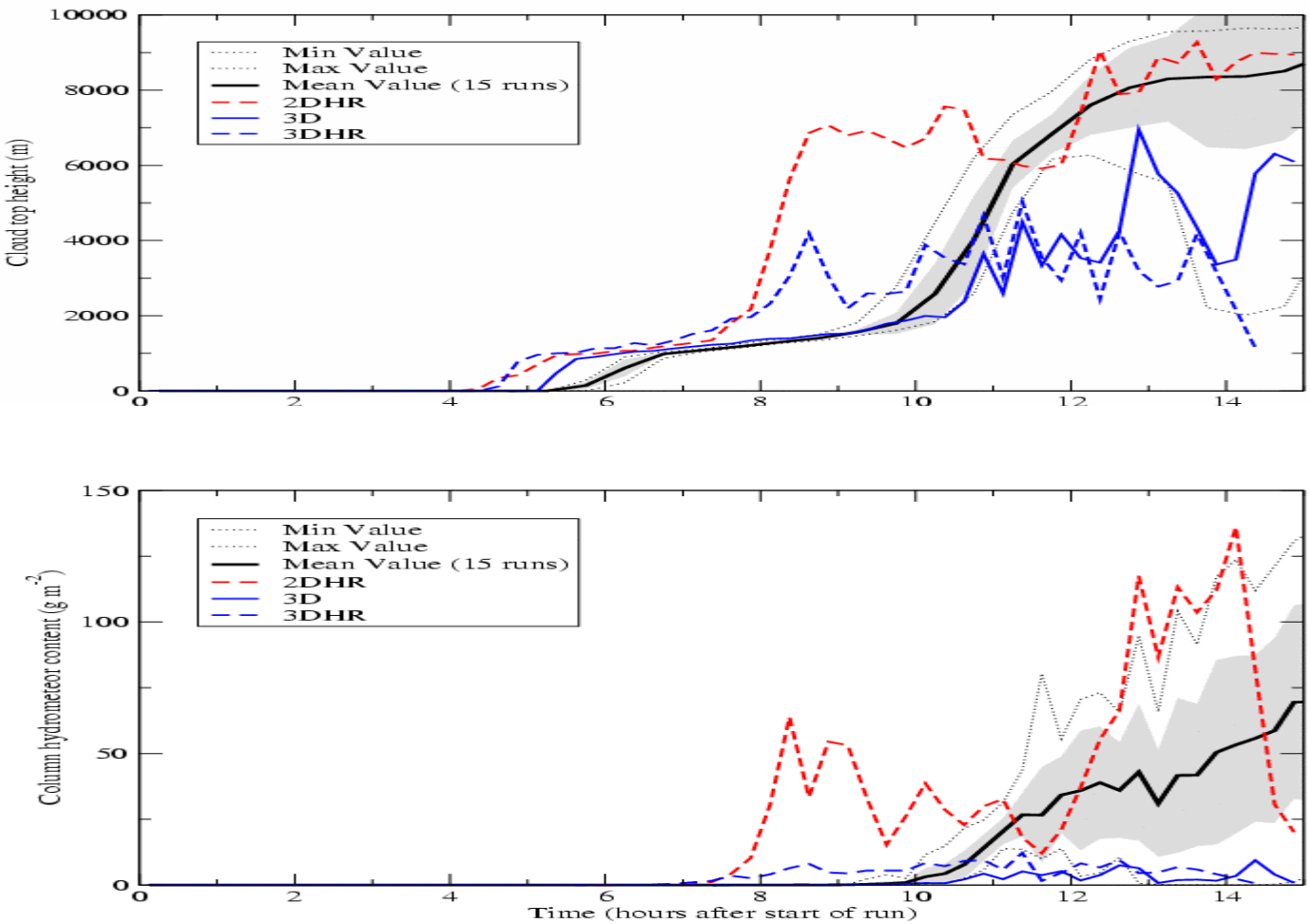




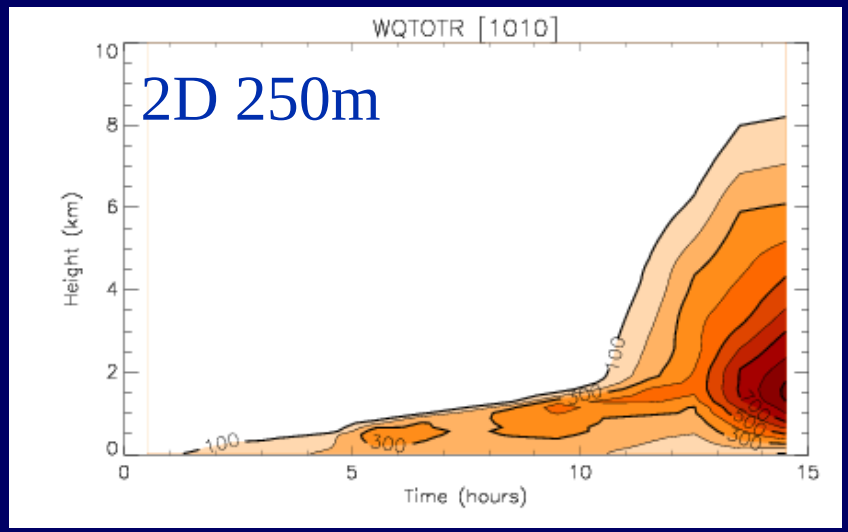
Cloud cover and rain rate

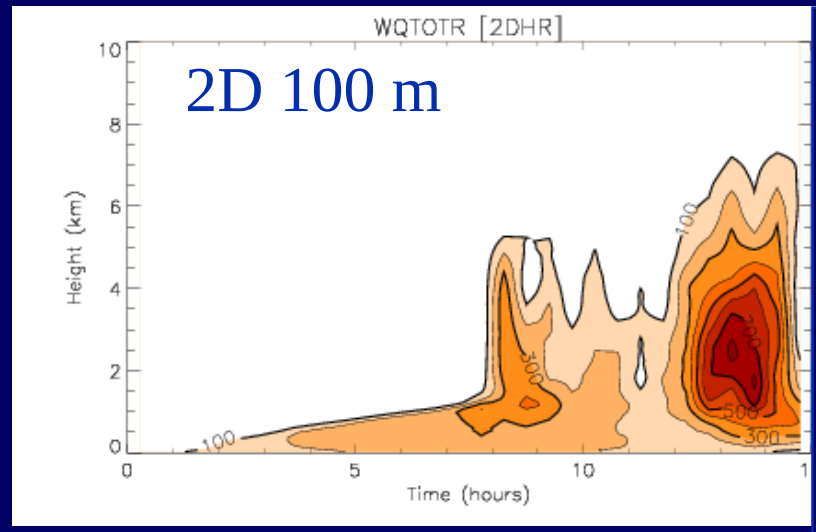


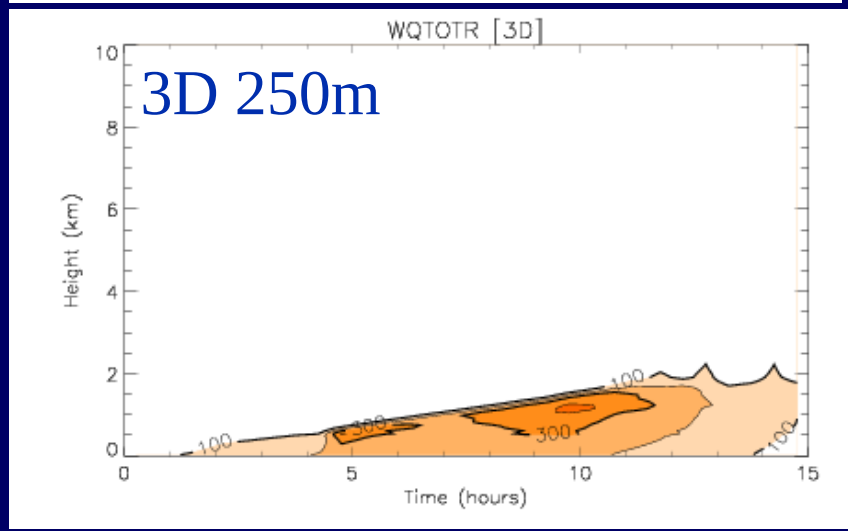
Cloud top height and column hydrometeor

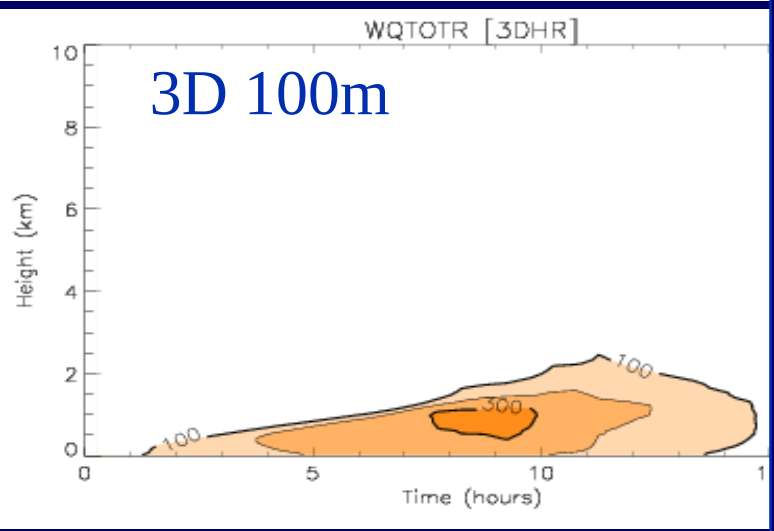


Water vapour transport (w'q')





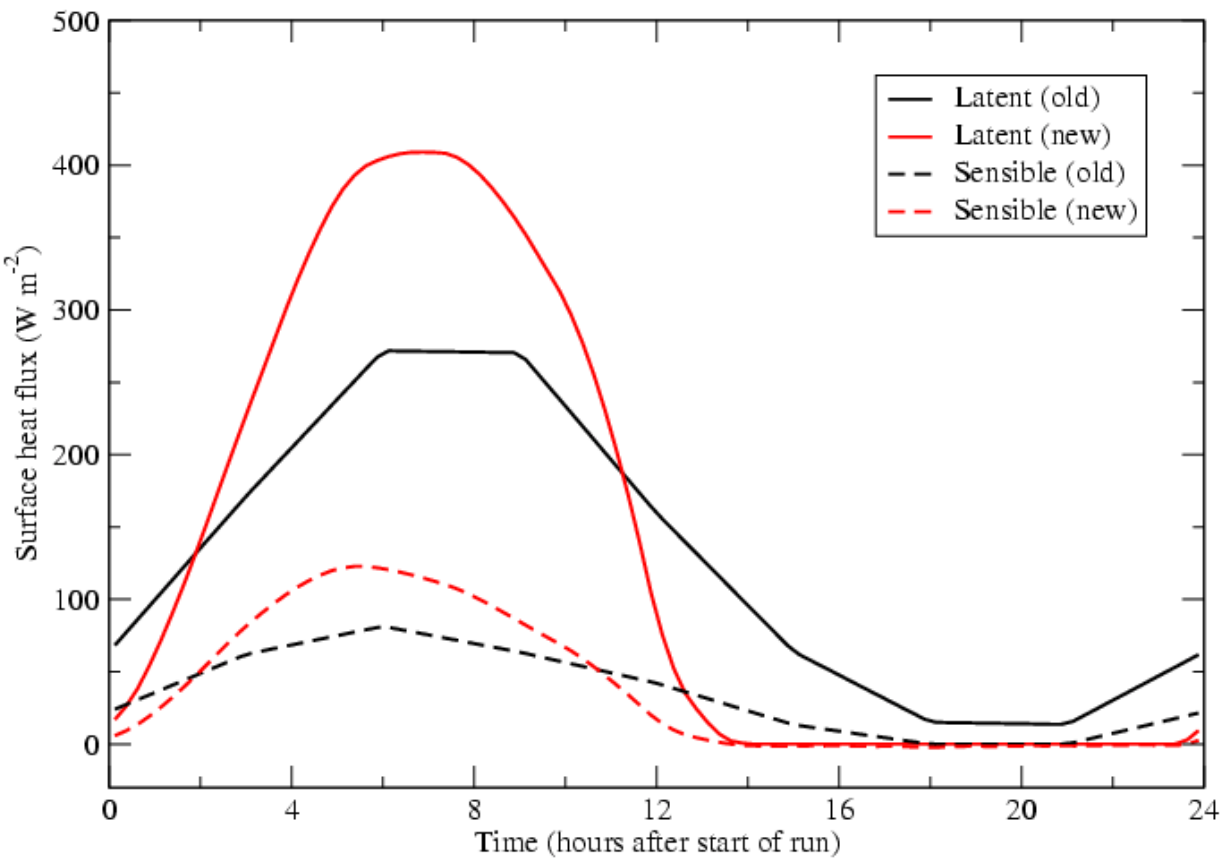




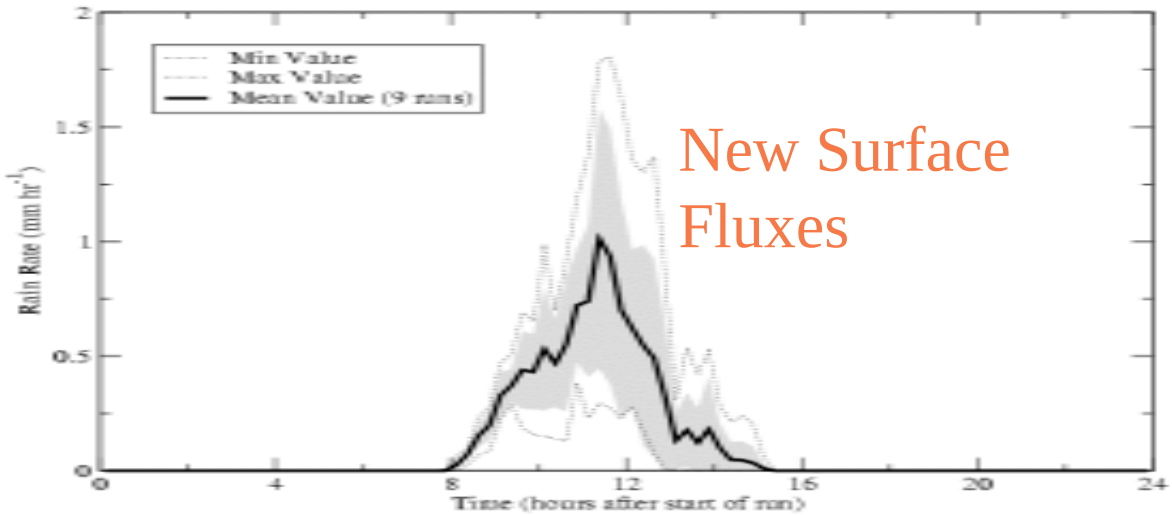
Too little cloud

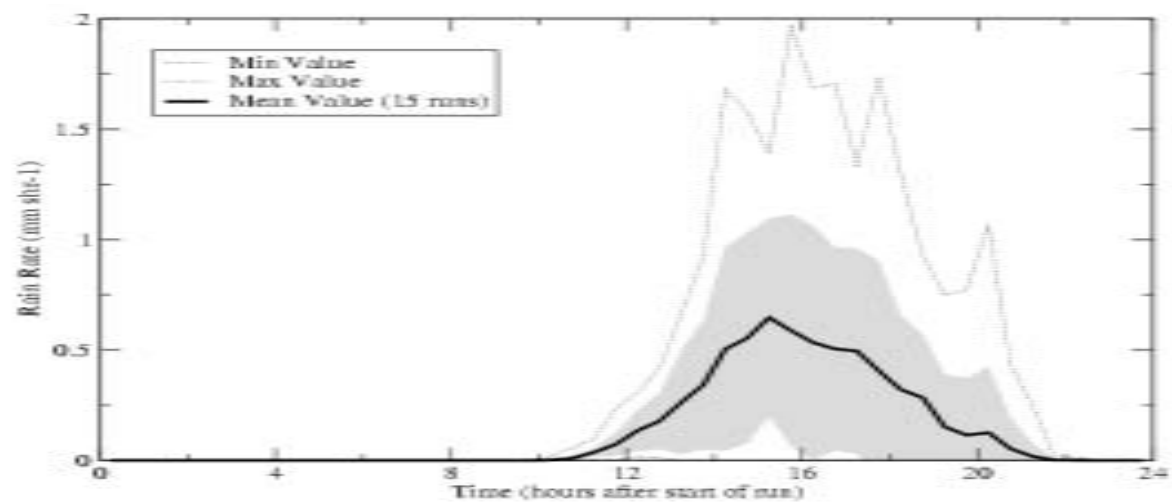
- 3D runs produce very little cloud water and no deep convection
  - Surface fluxes were very different to Shallow case and not very realistic due to variational analysis done by ARM

New surface fluxes (NSF)

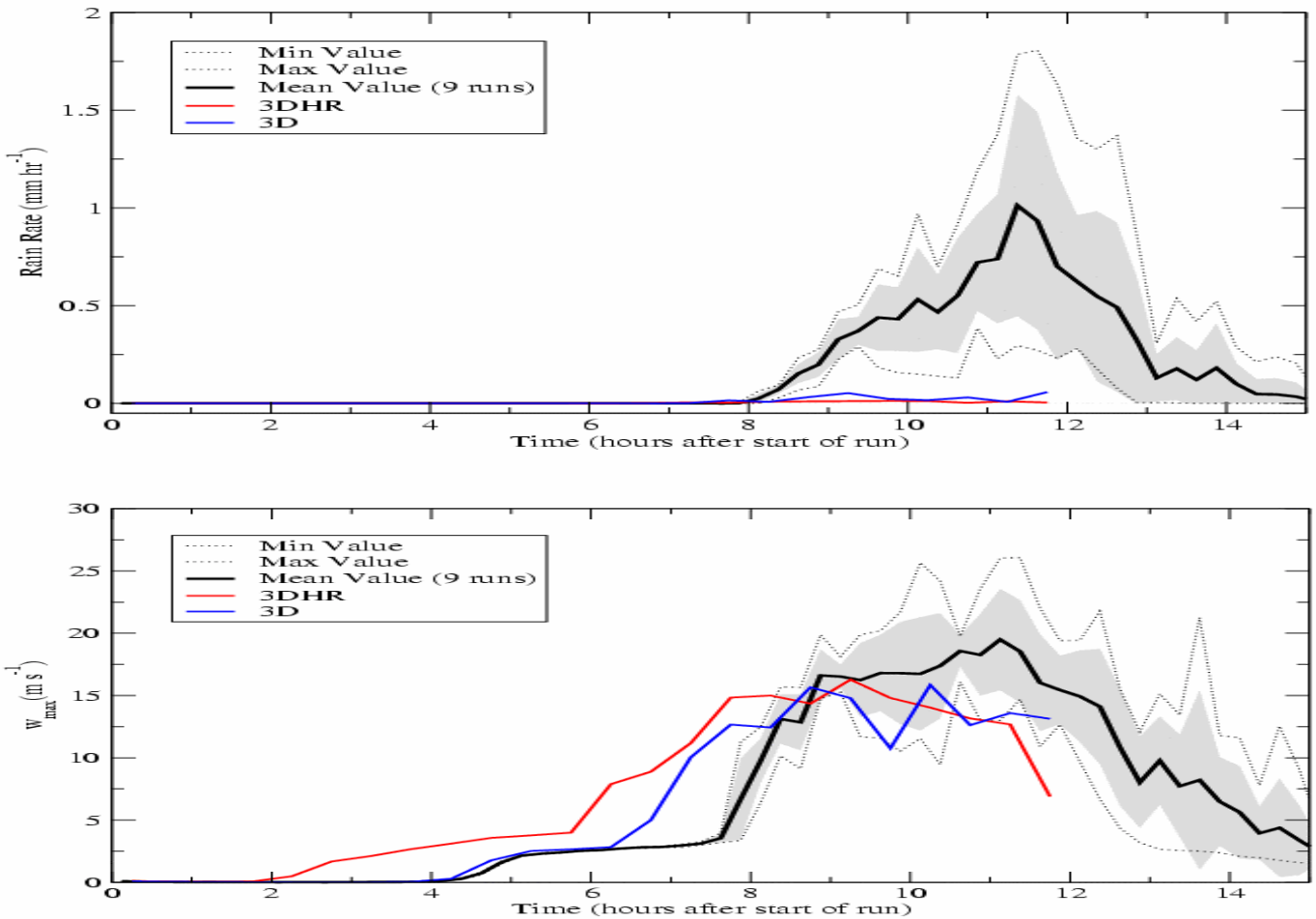


Impact of NSF on basic 2D runs: rain rate

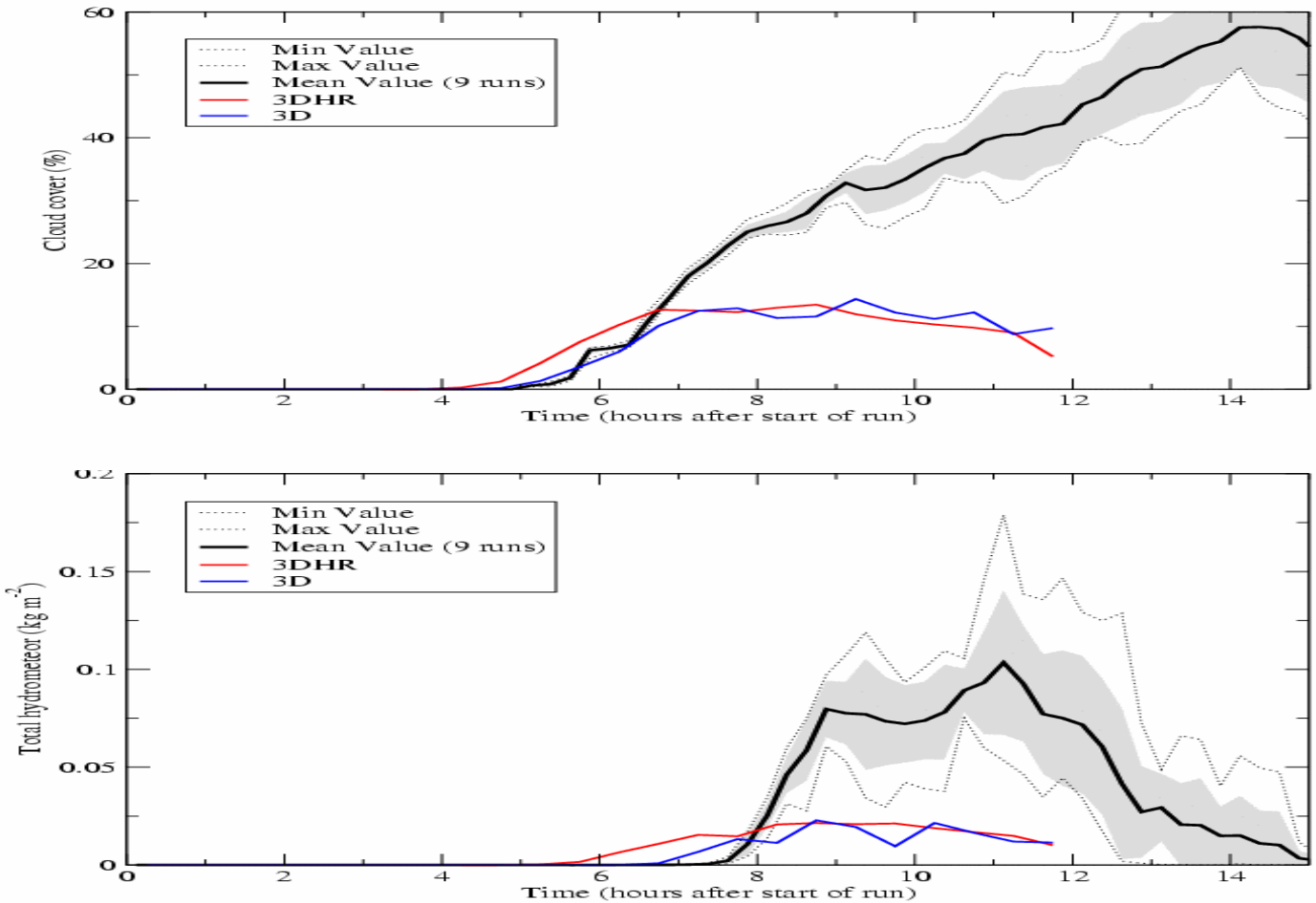




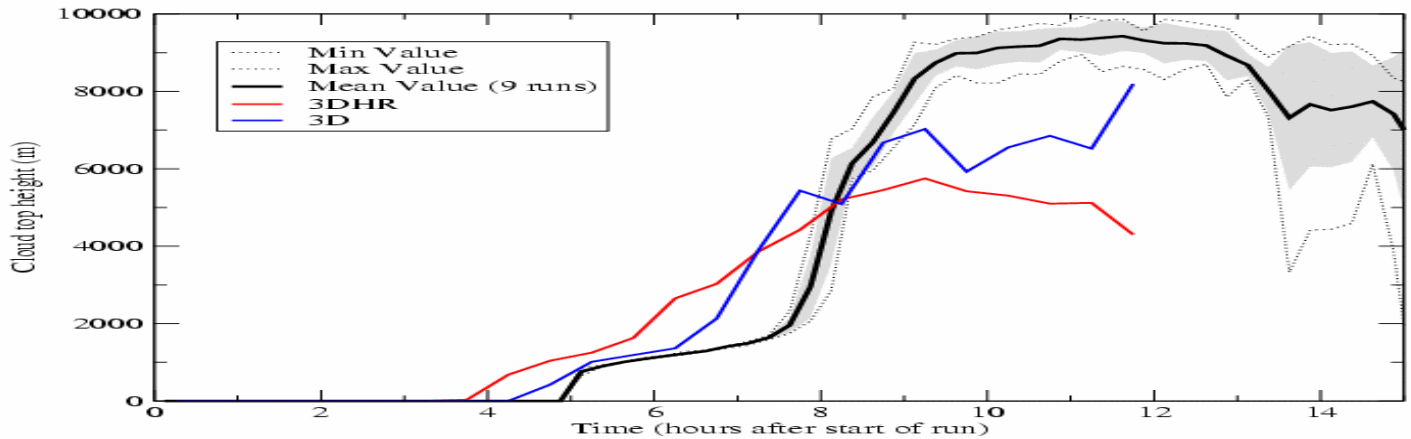
Rain rate and w_{max} (NSF)

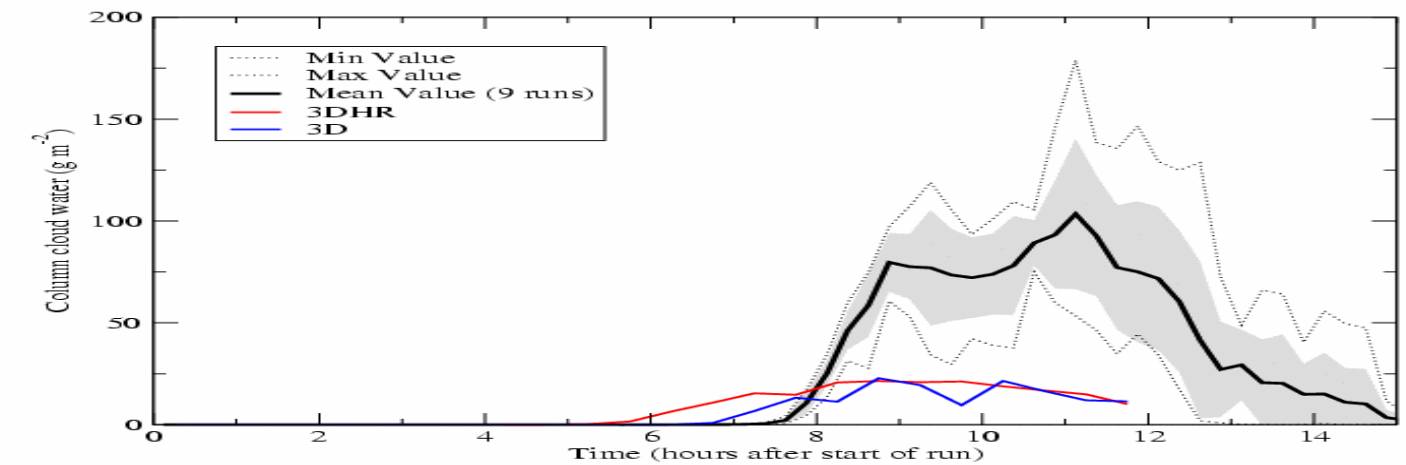


Cloud fraction and total hydrometeor (NSF)

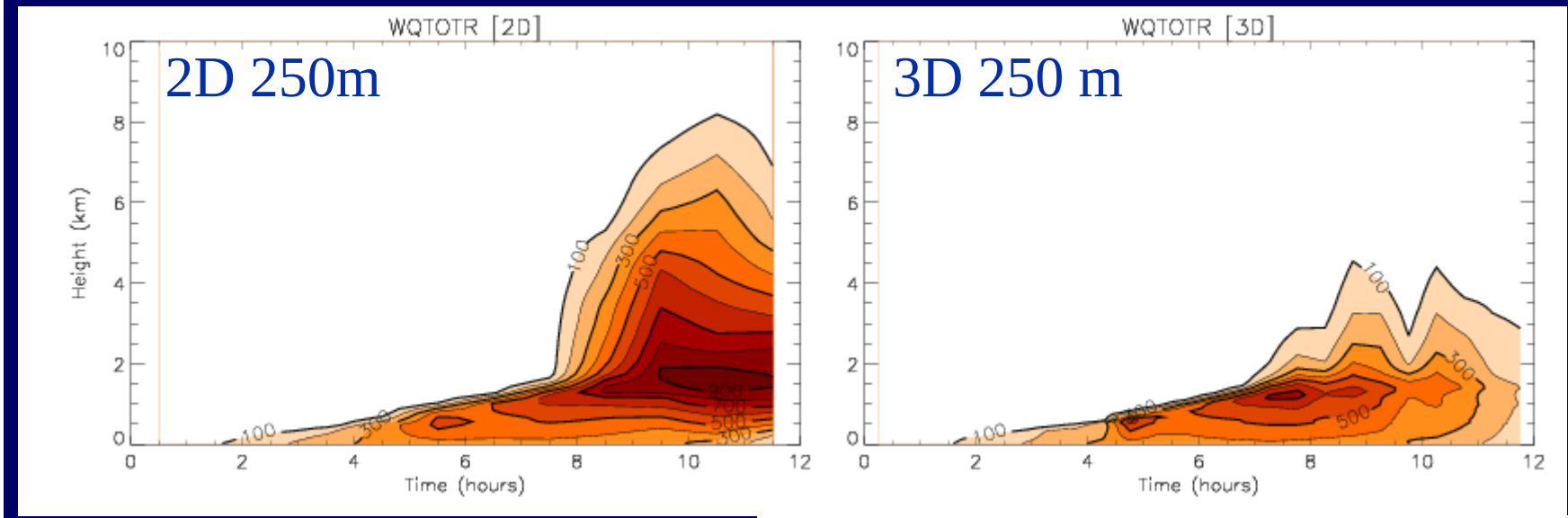


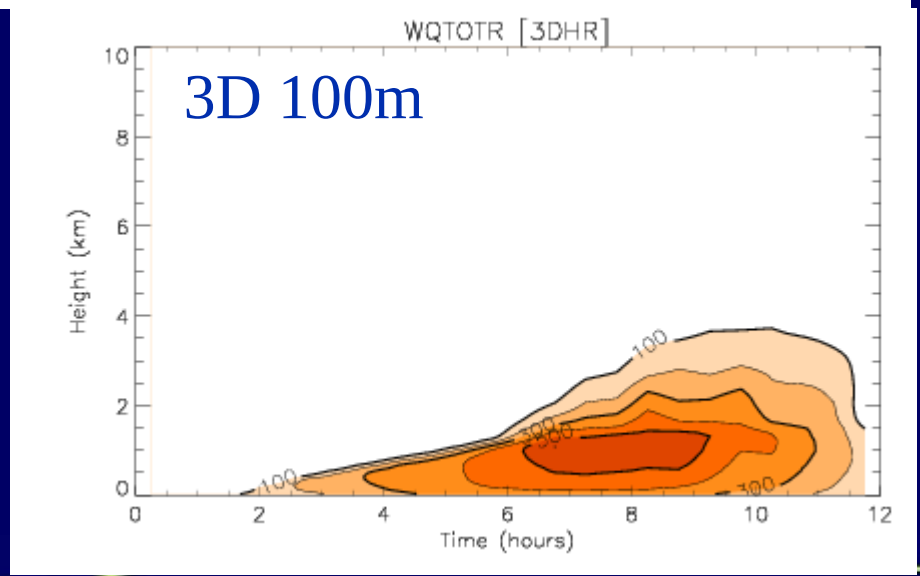
Cloud top height and liquid water (NSF)



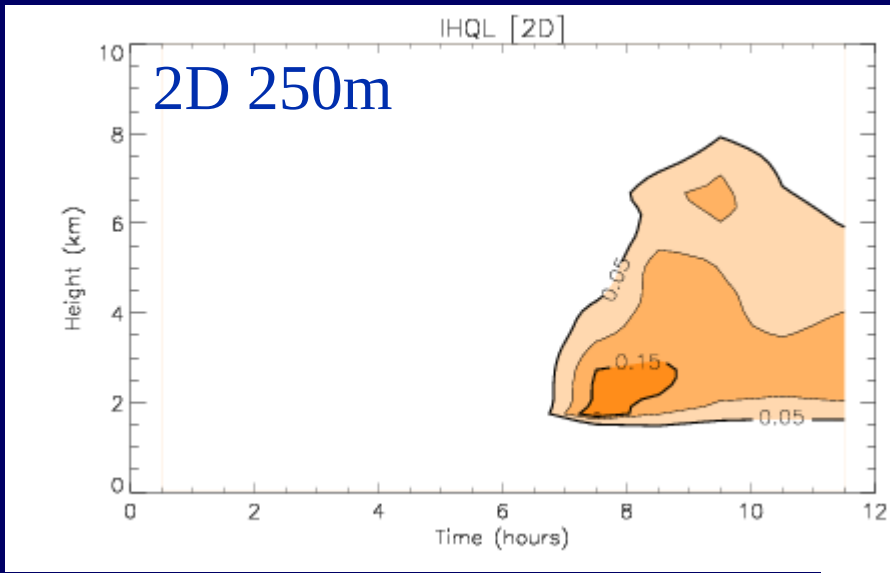


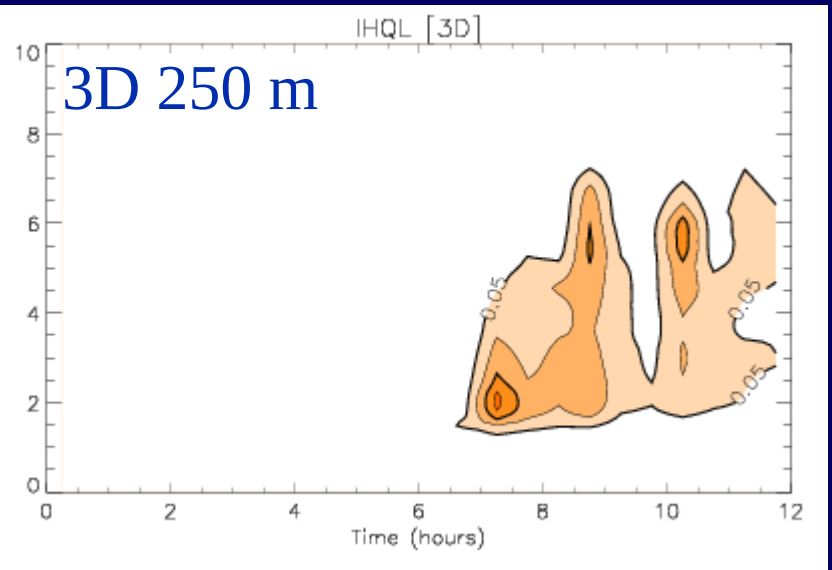
Water vapour transport (NSF)

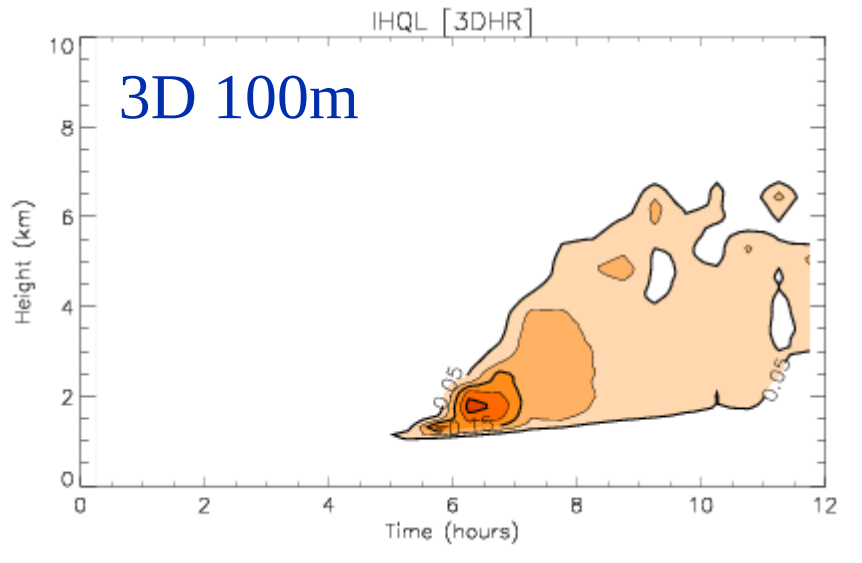




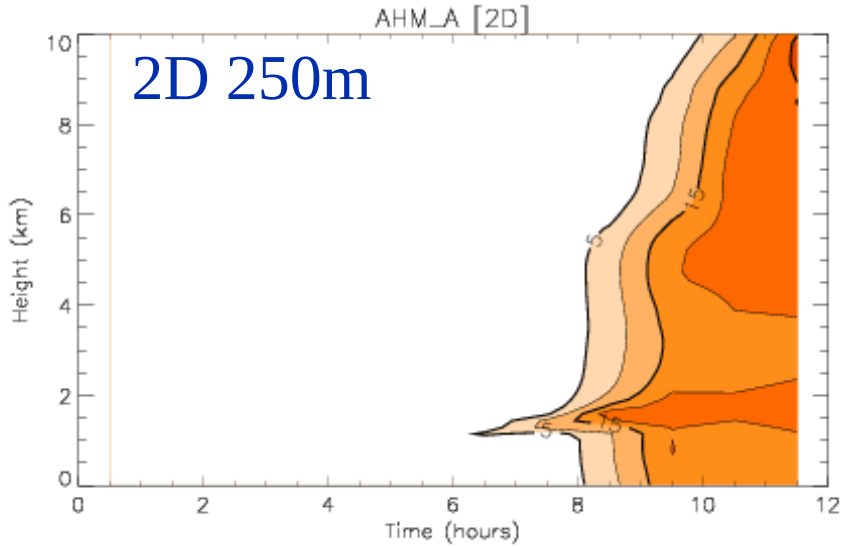
In-cloud liquid water (NSF)

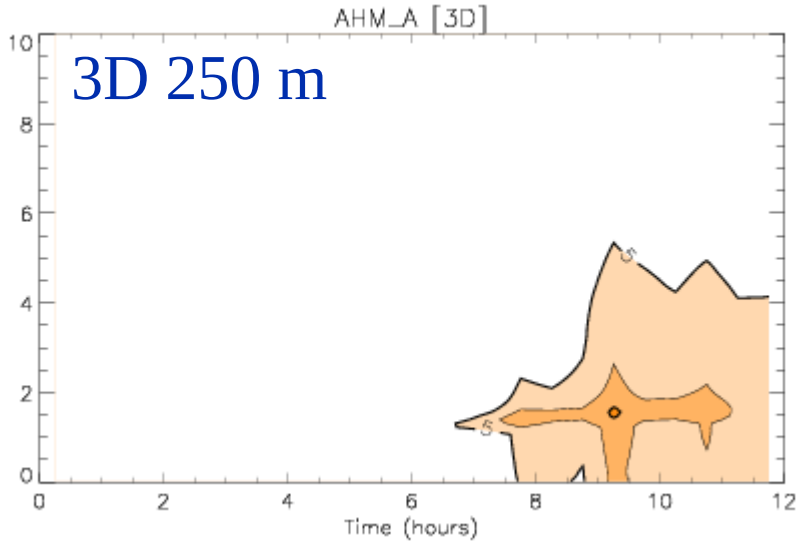


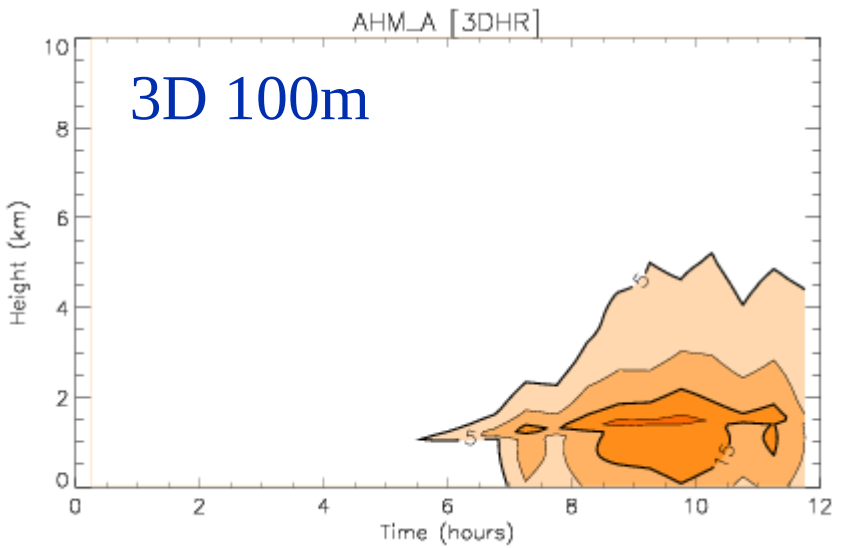




Cloud fraction (NSF)



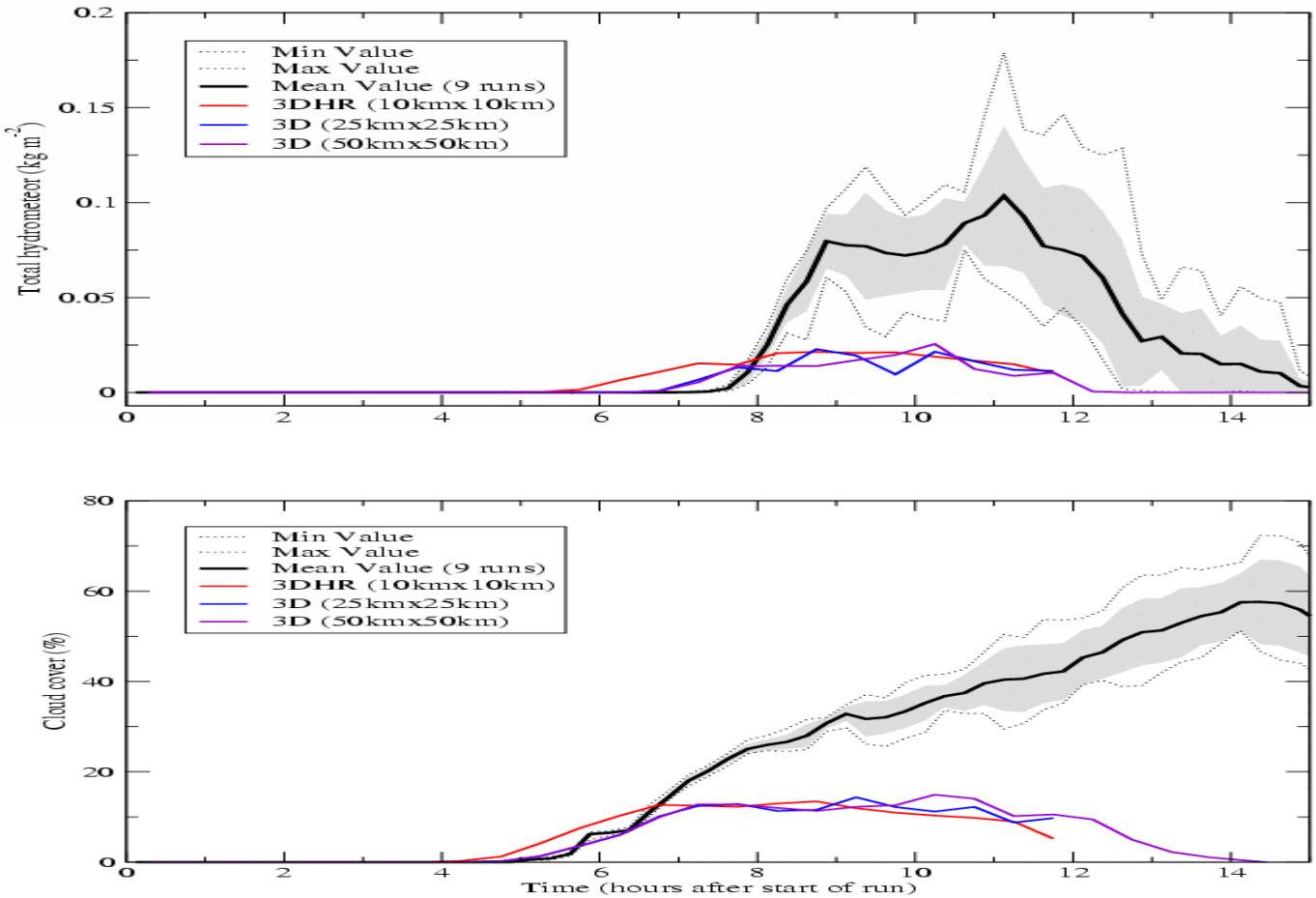




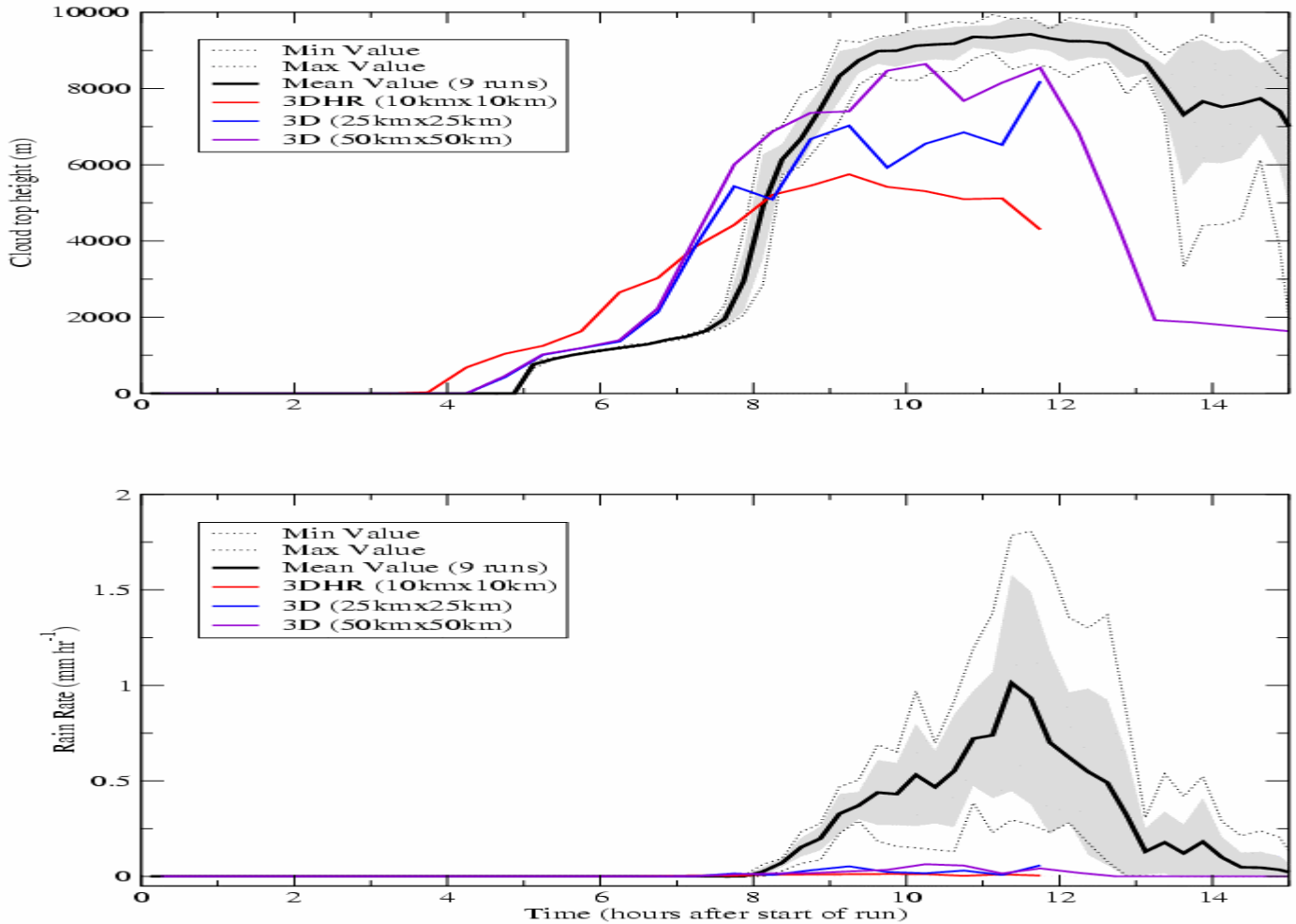
Summary so far

- 3D runs of CRM are very similar to shallow case
  - timing of initial cloud and peak; cloud fractions; LWP
- High resolution (100m) runs do develop convection (shallow and deep) earlier than the 250 m runs but results are similar otherwise
- Bigger differences between the 2D and 3D runs
  - Similar in cloud water contents but much less cloud area above 4km
  - Are differences due to small domain?

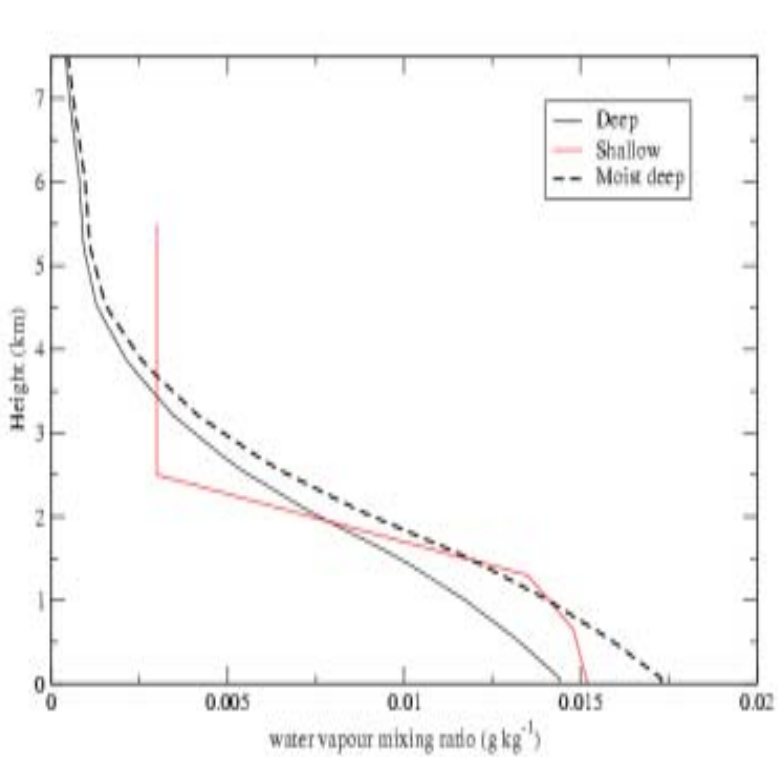
Total hydrometeor and cloud cover

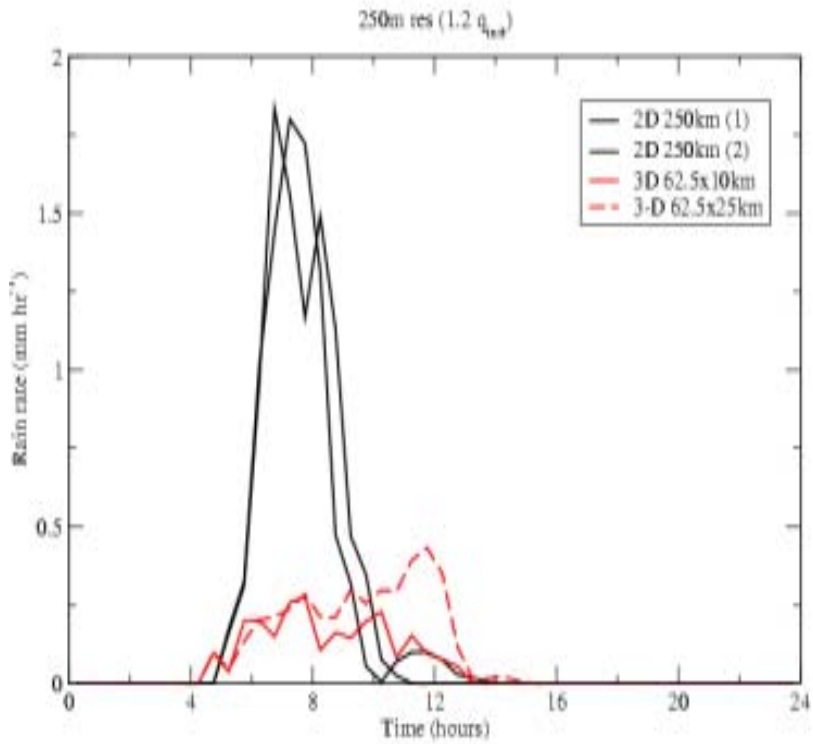


Cloud top height and rain rate

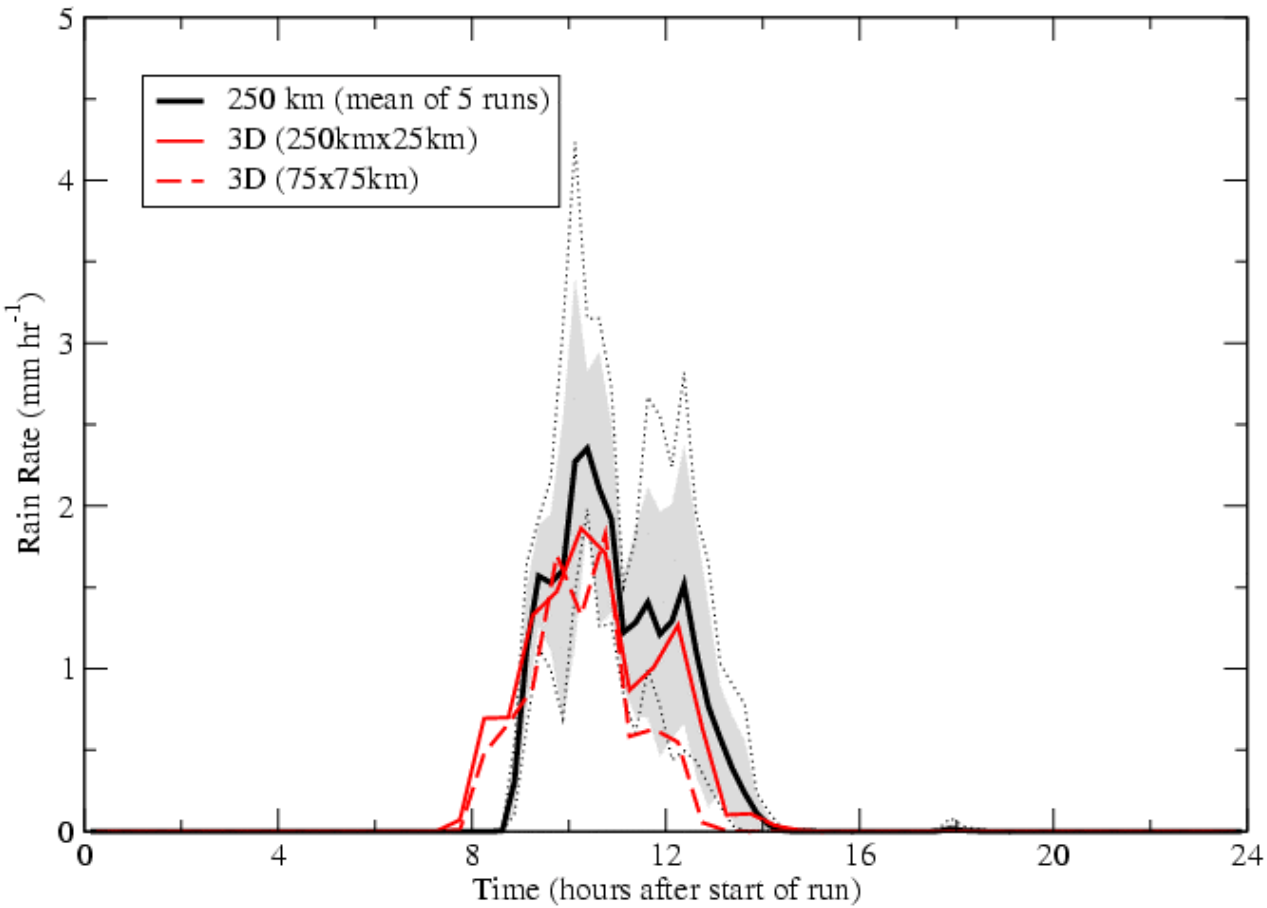


Increased moisture and rectangular domain





Increased moisture, bigger domain but lower resolution (1km)



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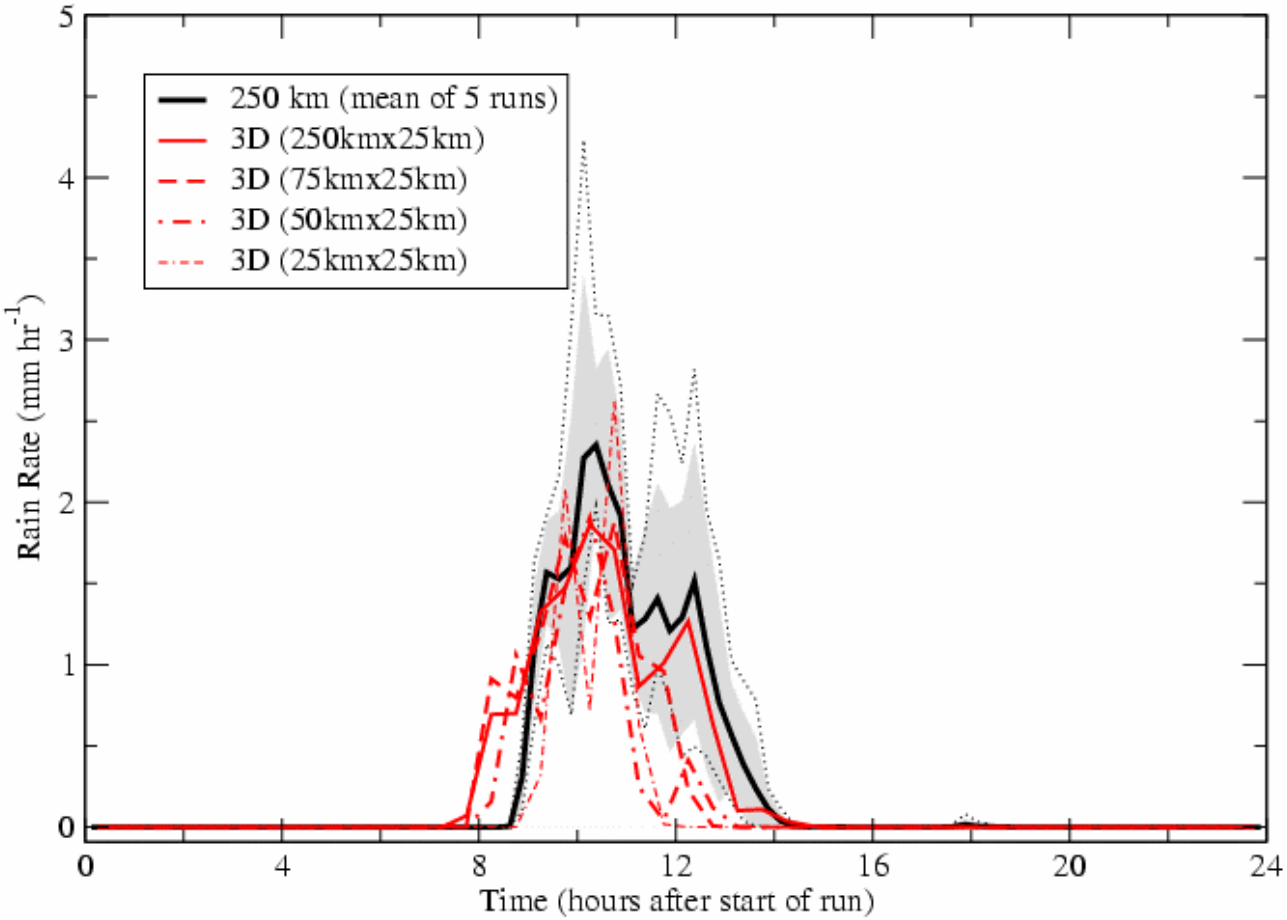
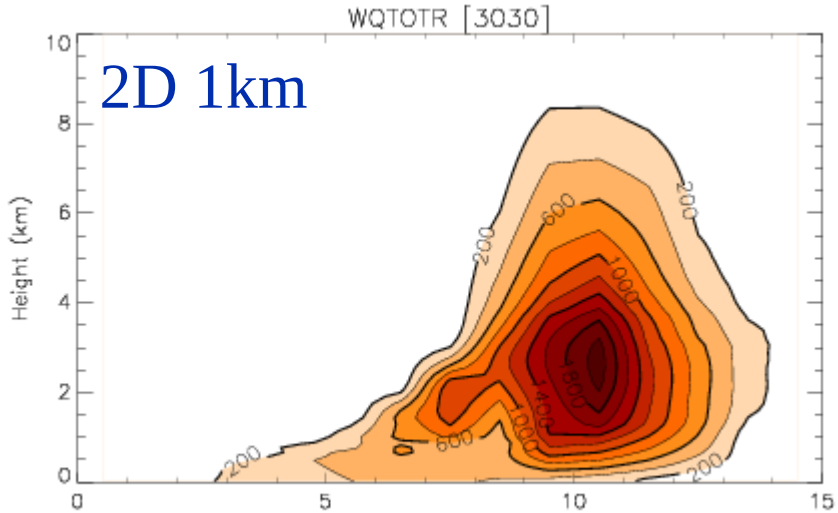
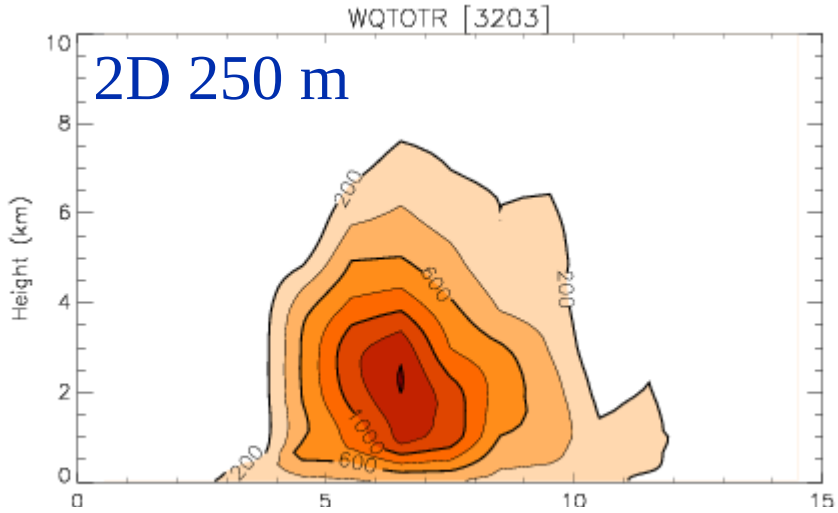
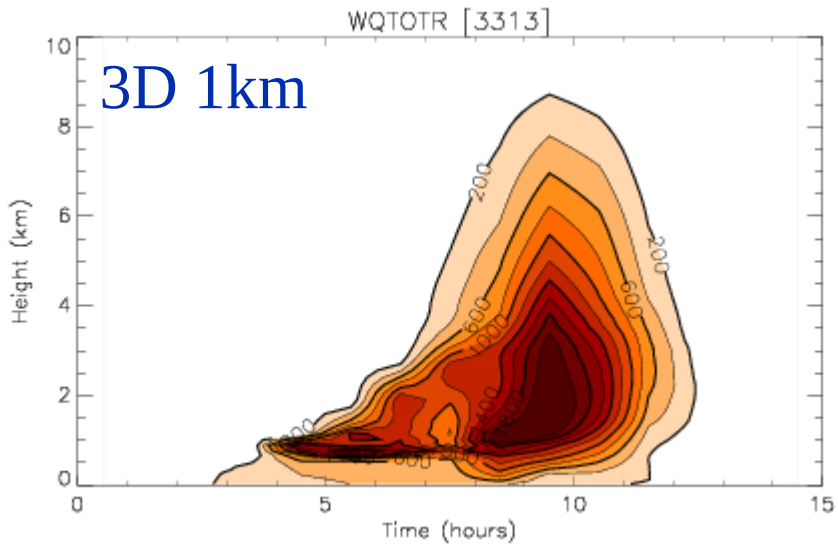
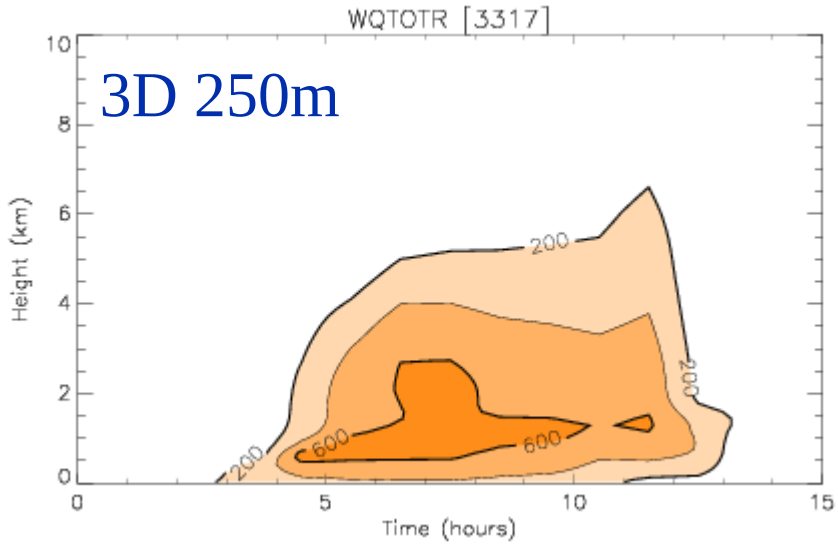


Total water vapour transport

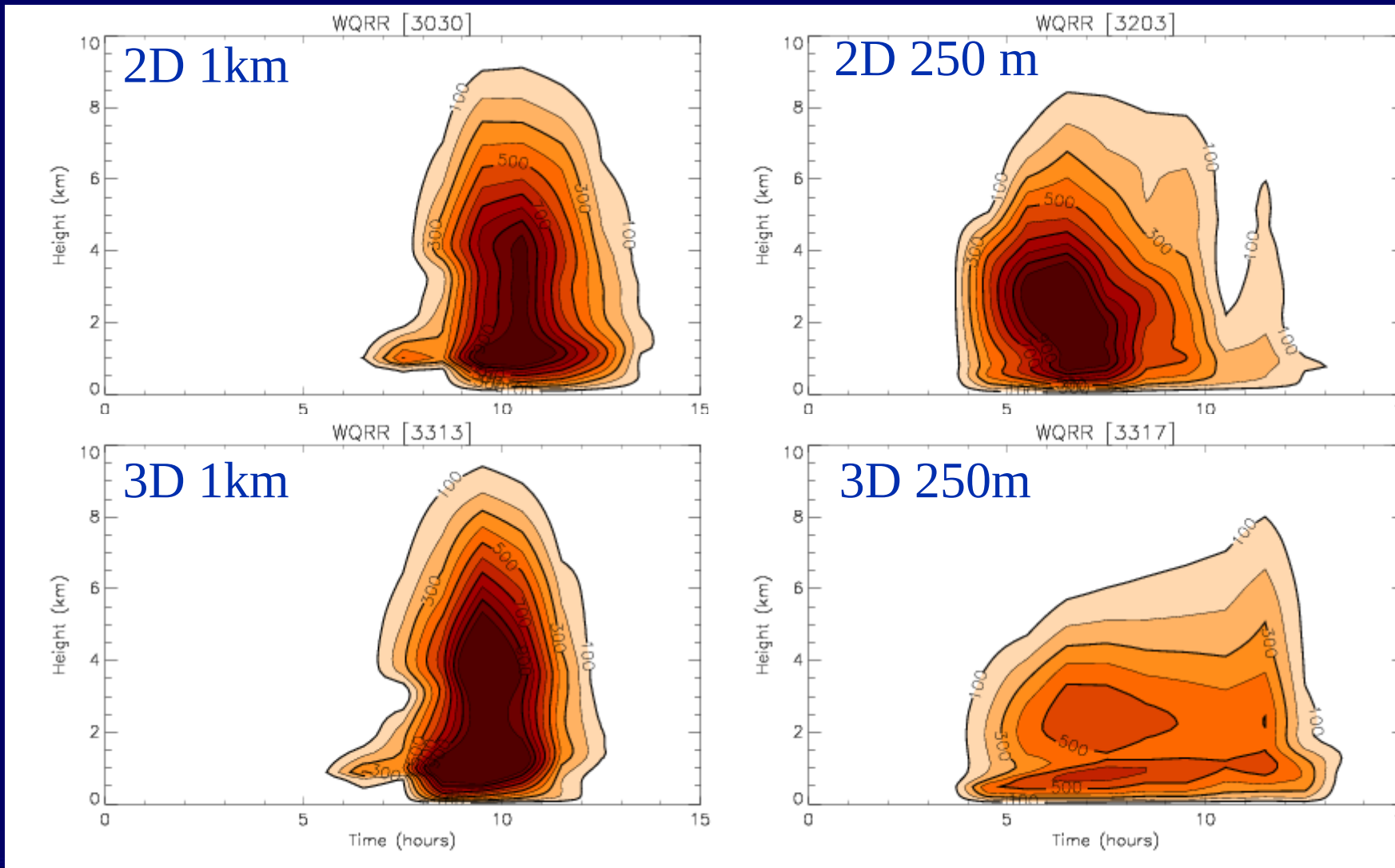






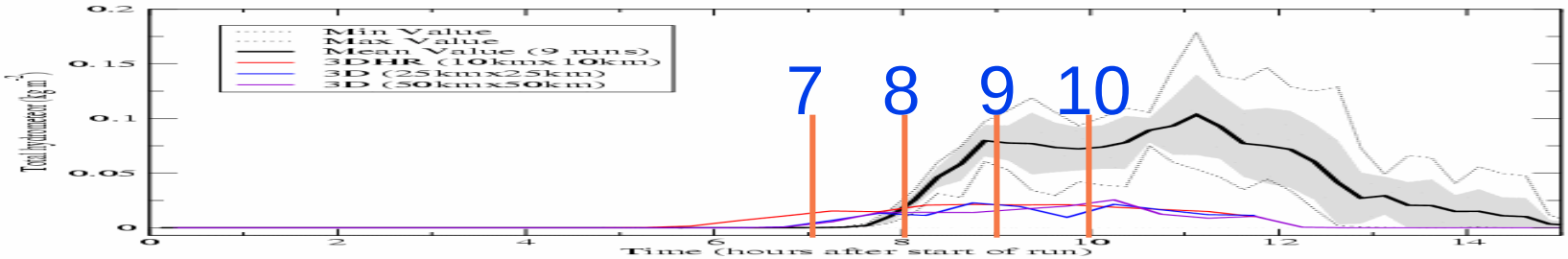


Resolved water vapour transport

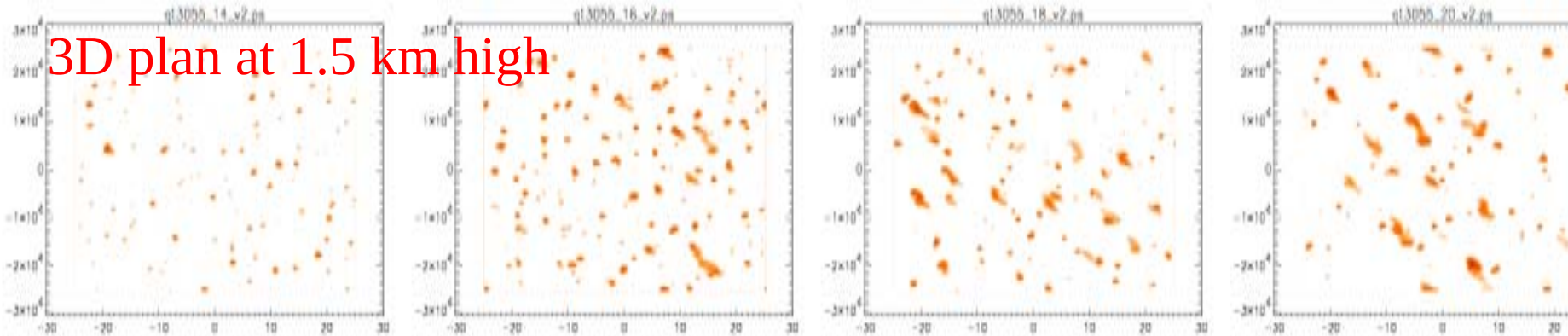


2D, 3D and resolution

- 3D produces less deep cloud and rain than 2D at 250m and 100m resolution
  - no very large domain 3-D runs but went up to over 60km in a rectangle and 50km in a square
  - little sensitivity to domain size between 25 and 50 km
- 3D and 2D produce similar amounts of cloud and rain at 1km resolution
  - even with smaller domains (i.e. ones used at high res.)
  - much of the transport of water vapour is by sub grid processes right up to the time of significant precipitation



3D plan at 1.5 km high



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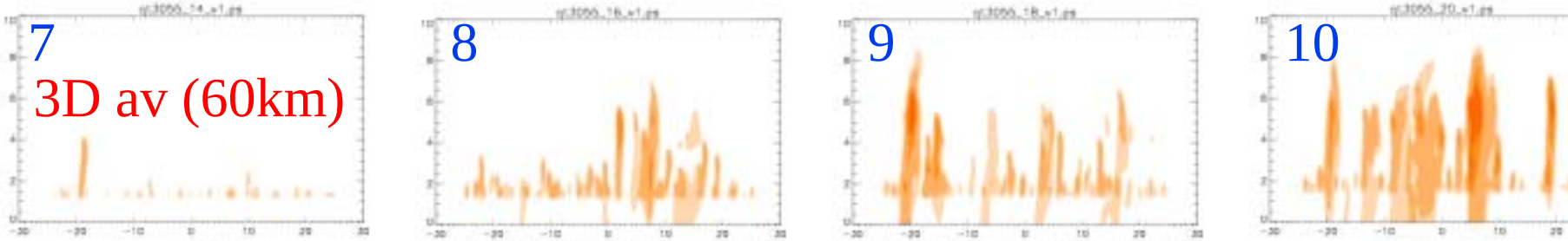
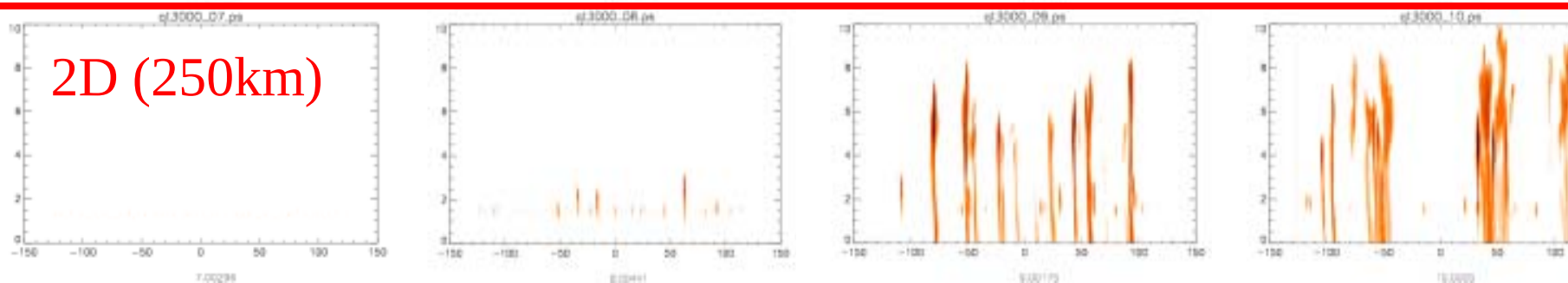
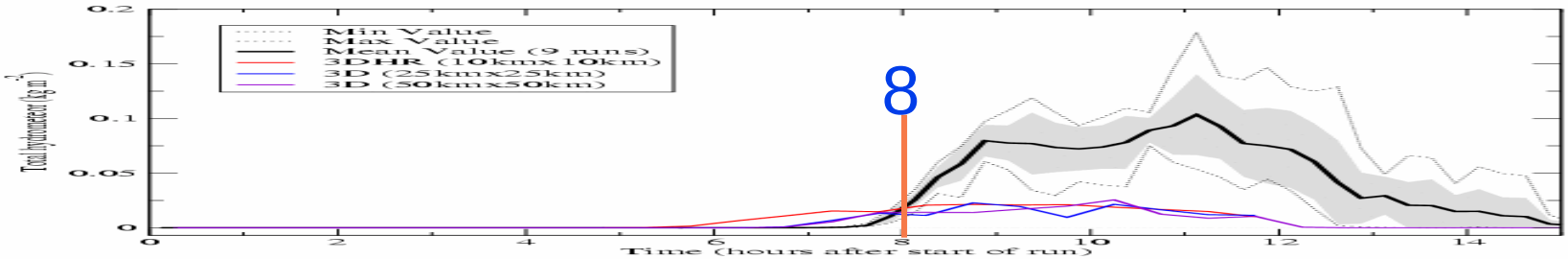
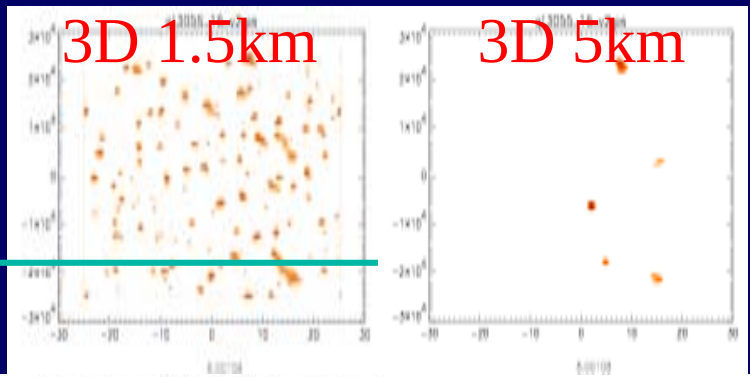
3D av (60km)

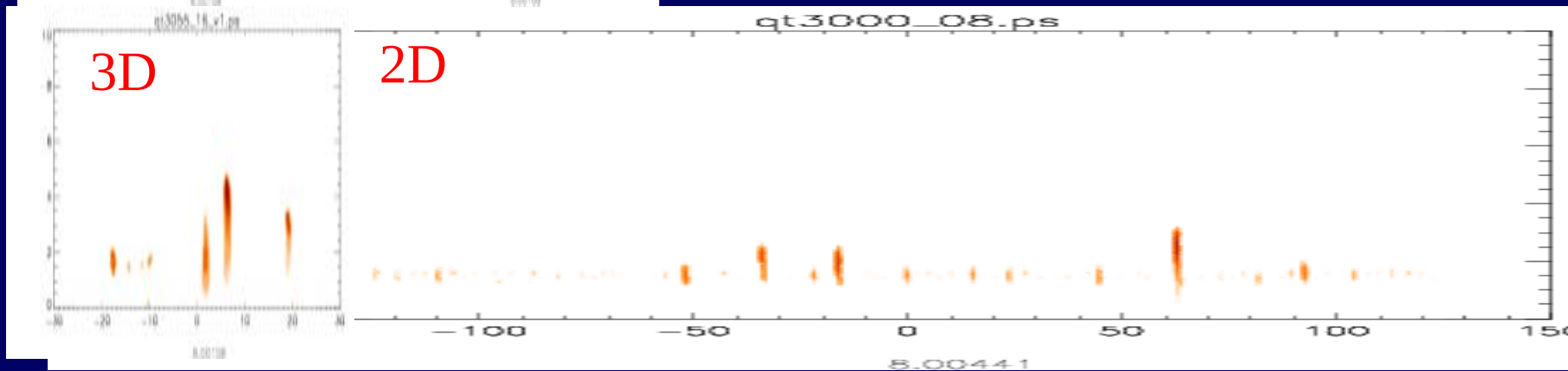


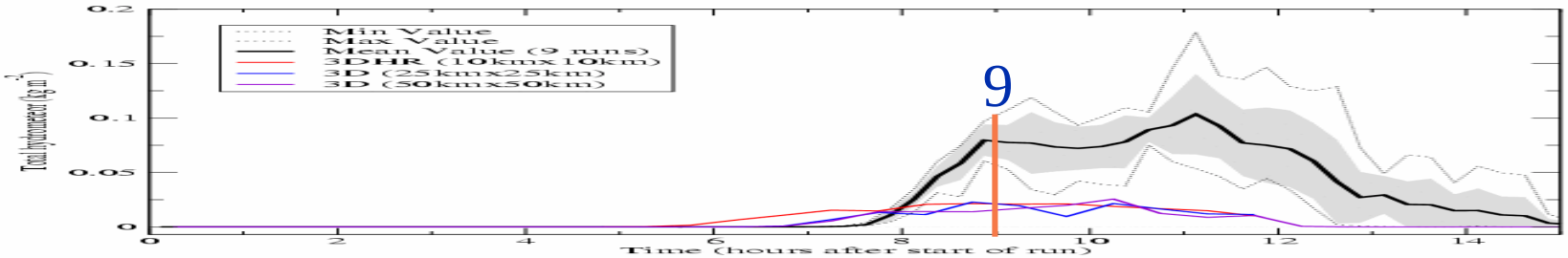
2D (250km)

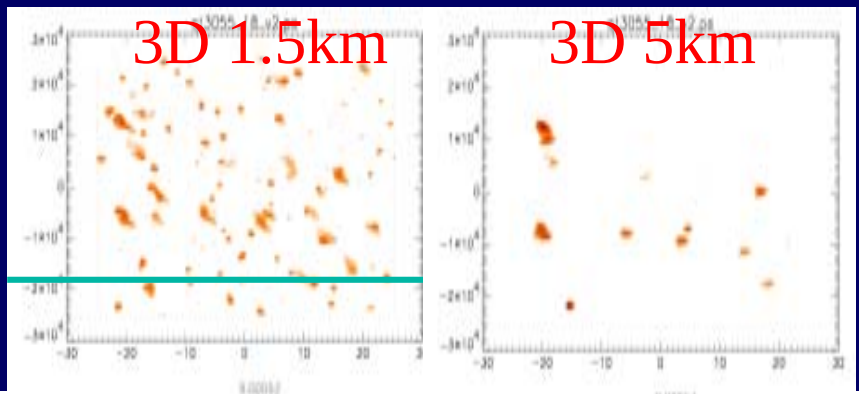


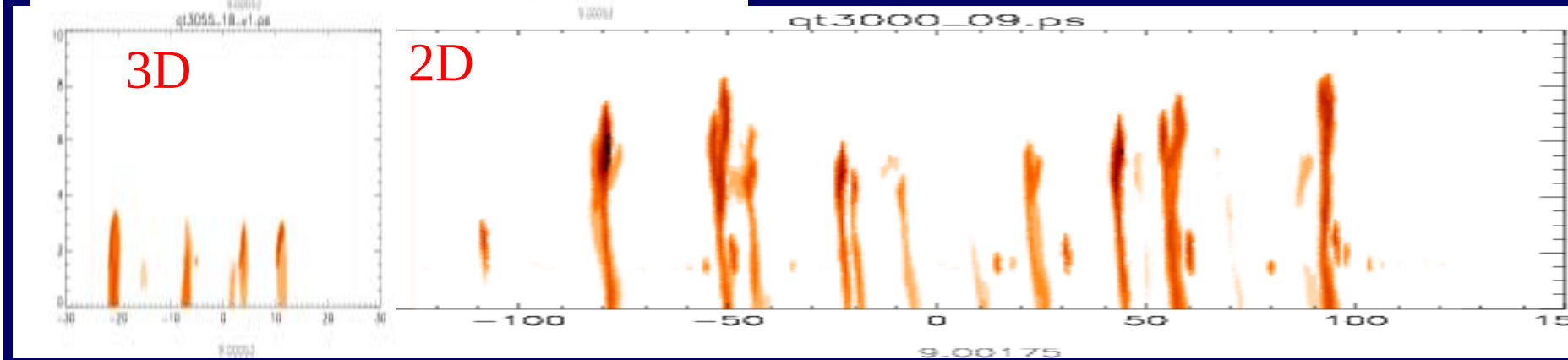

Min Value
Max Value
Mean Value (9 runs)
3DHR (10kmx10km)
3D (25kmx25km)
3D (50kmx50km)
8
Time (hours after start of run)

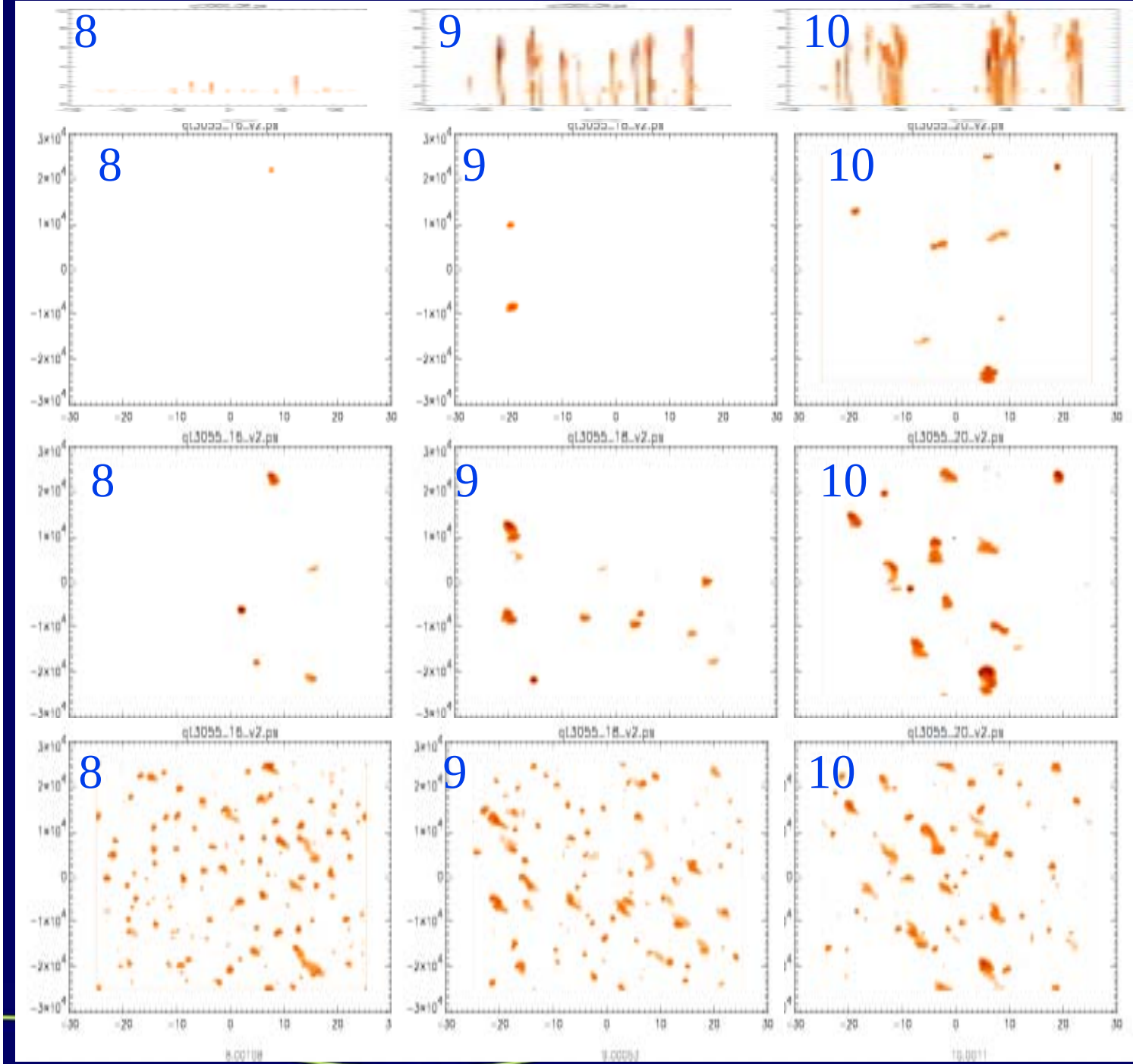

3D 1.5km
3D 5km

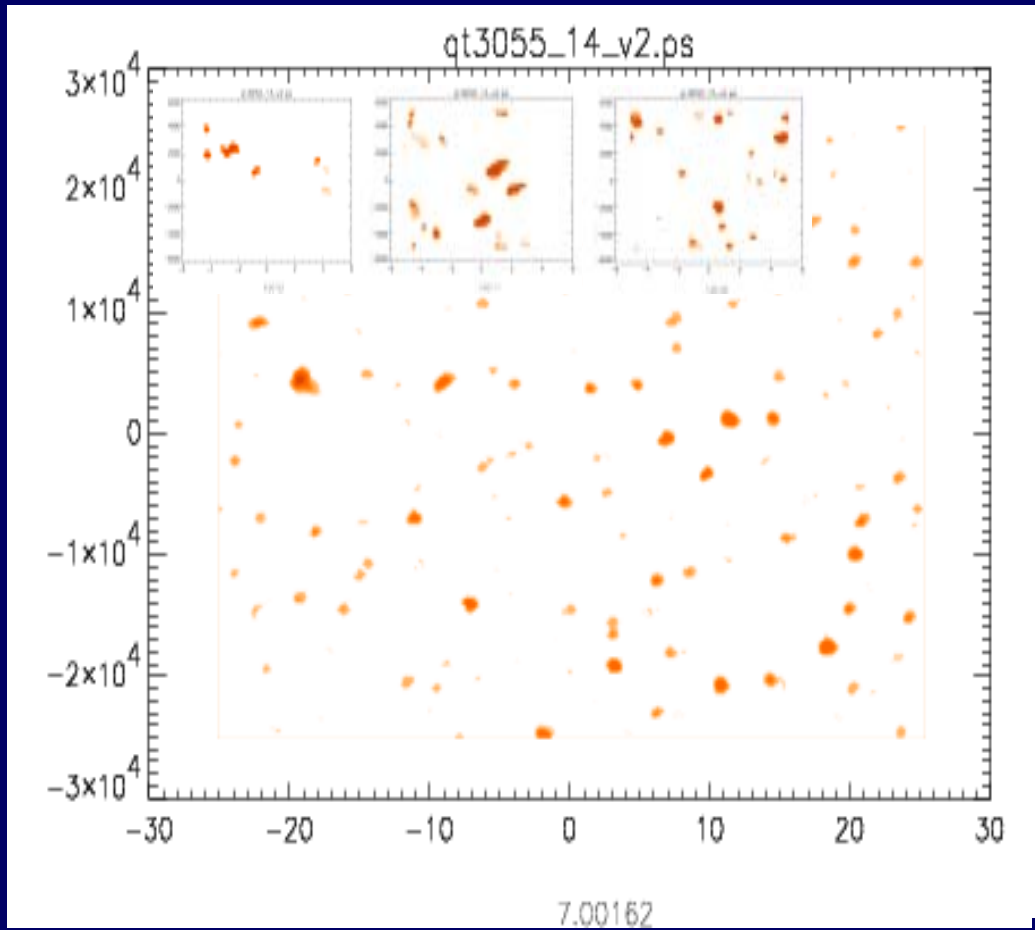

3D
2D
qt3000_08.ps
−100
−50
0
50
100
S.00441

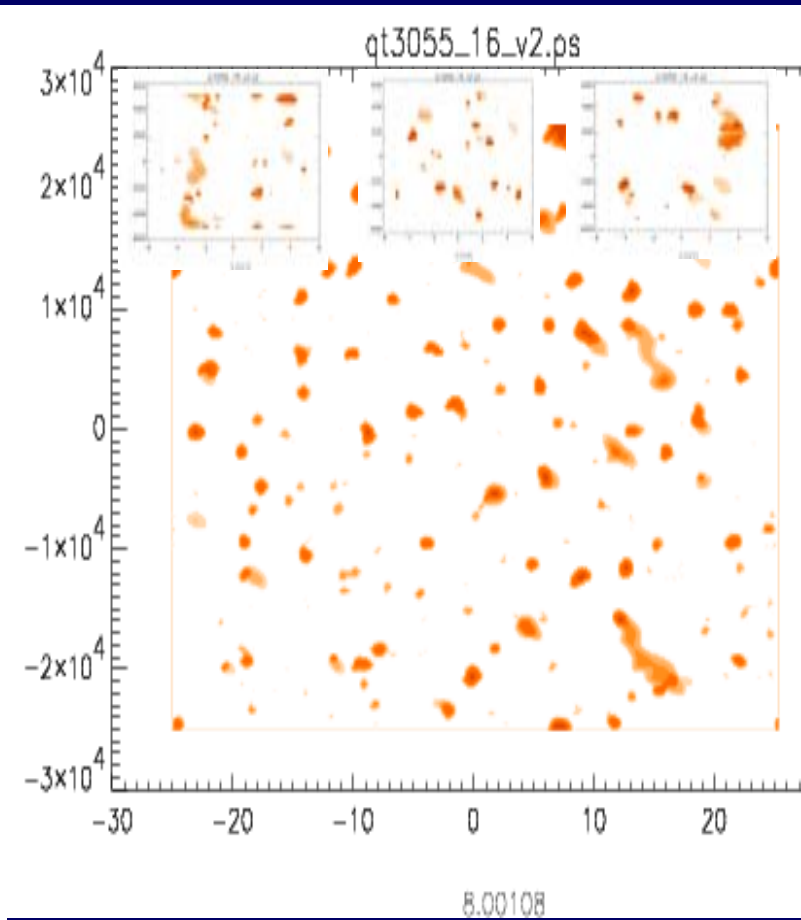

Min Value
Max Value
Mean Value (9 runs)
3DHR (10kmx10km)
3D (25kmx25km)
3D (50kmx50km)
9
Time (hours after start of run)


3D 1.5km
3D 5km

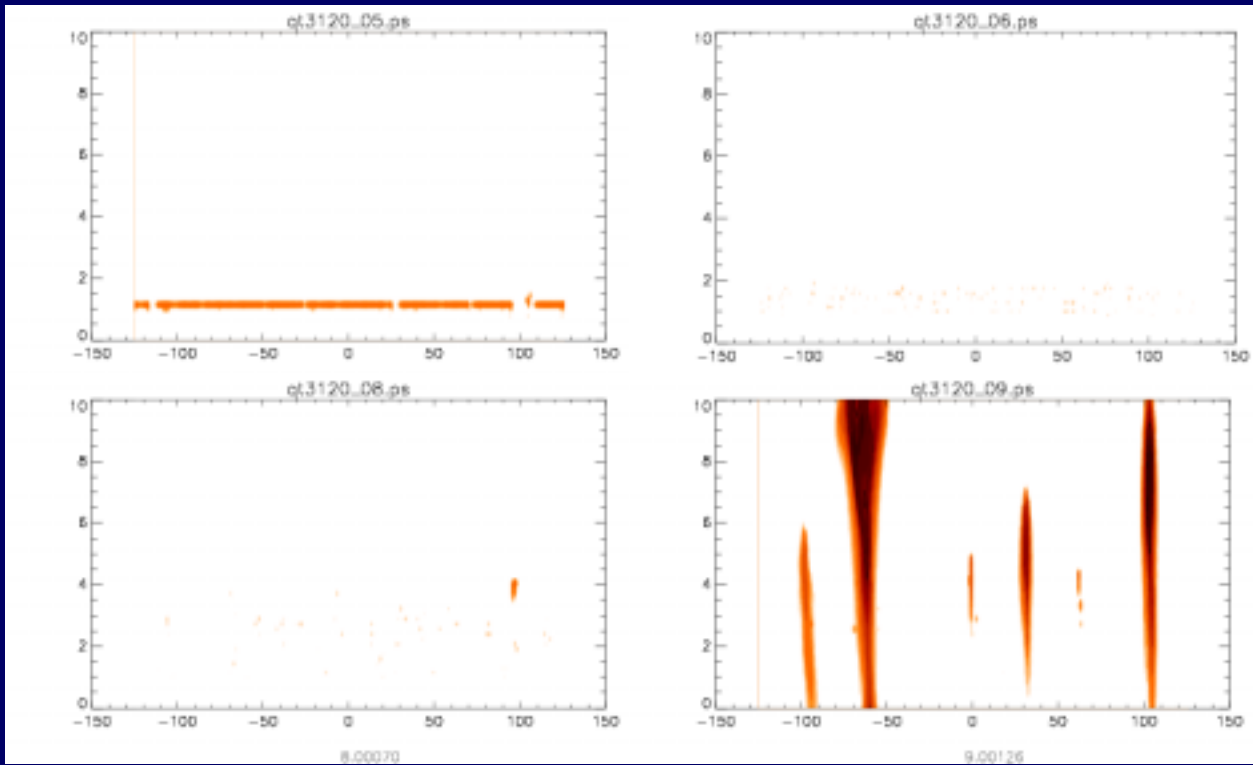

3D
2D
qt3000_09.ps
9.00175


8
9
10
2D
8
9
10
7km
8
9
10
5km
8
9
10
1.5km





100m v 250m cloud sizes



Poor representation of the formation of clouds in 1km simulations

Cloud properties summary

- 1km runs do not have realistic clouds during shallow or deepening phase
- 2D and 3D have similar size clouds and cloud spacing
- Typical cloud spacing during significant rain is of the order 40km and this increases with time
- 250 m and 100m runs have similar sized clouds

Final summary!

- Experimental issues:
  - We can do runs using similar I.C. and surface fluxes which begin like the shallow case and deepen
  - Large scale forcing and radiation is not too important
- Model issues:
  - 2D and 3D differ at high res but so no large 3D runs
  - At 1 km resolution 2D and 3D are the same even at small domain sizes
  - 3D or higher resolution (e.g. 100m) produce clouds earlier but this is a small effect
  - We can produce quite realistic cloud with 250m or better