(Towards) Large Eddy Simulation of Deep Convection

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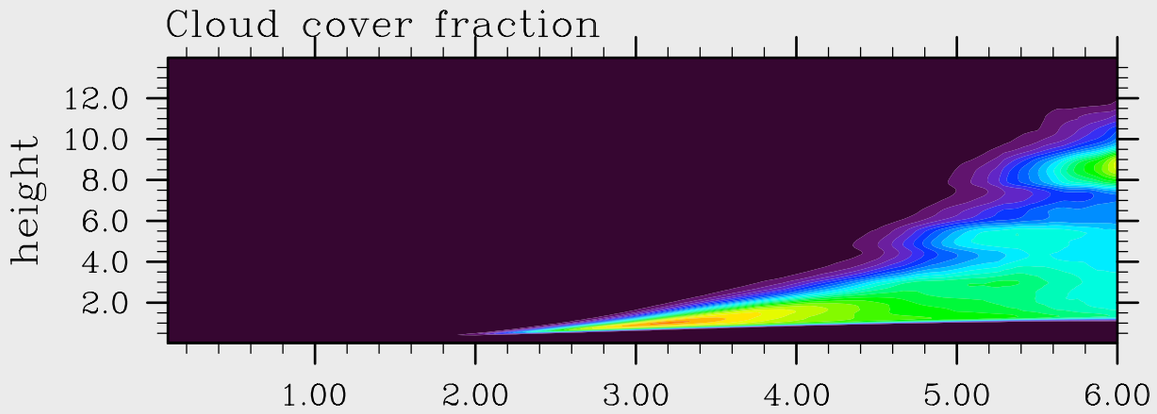
Motivation

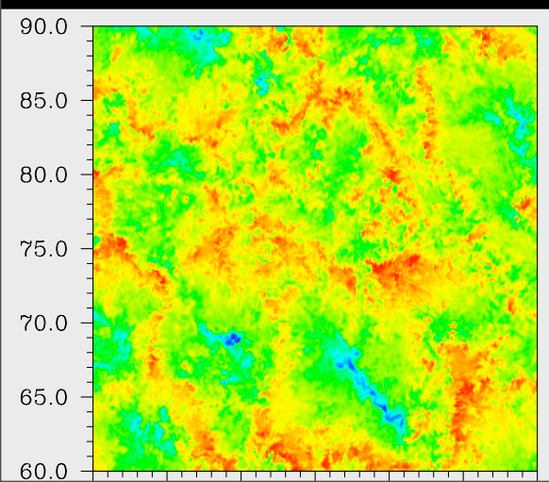
- Convection tends to organize itself on mesoscale;
- CRMs have resolved meso-scale structure rather well but usually at the expense of resolving small-scale features and clouds;
- What do we miss by under-representing shallow/congestus clouds in CRMs?
- How do deep and shallower clouds interact?
- There is a need for a benchmark high-resolution simulations of typical mesoscale cloud regimes (‘Numerical Field Experiments’).
- Such simulations may inspire new ideas for parameterization development efforts for GCMs and NWP.

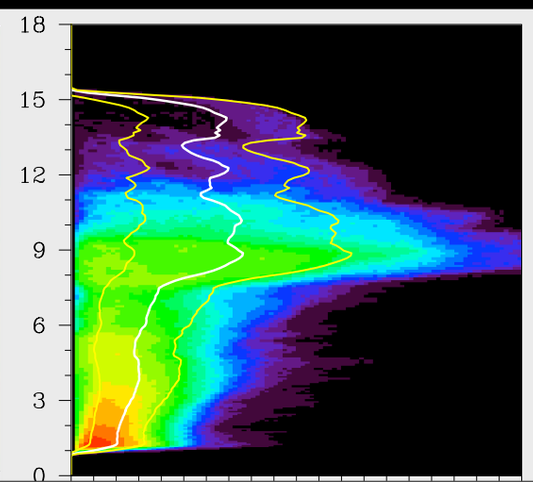
GCSS WG4 Case 4 :

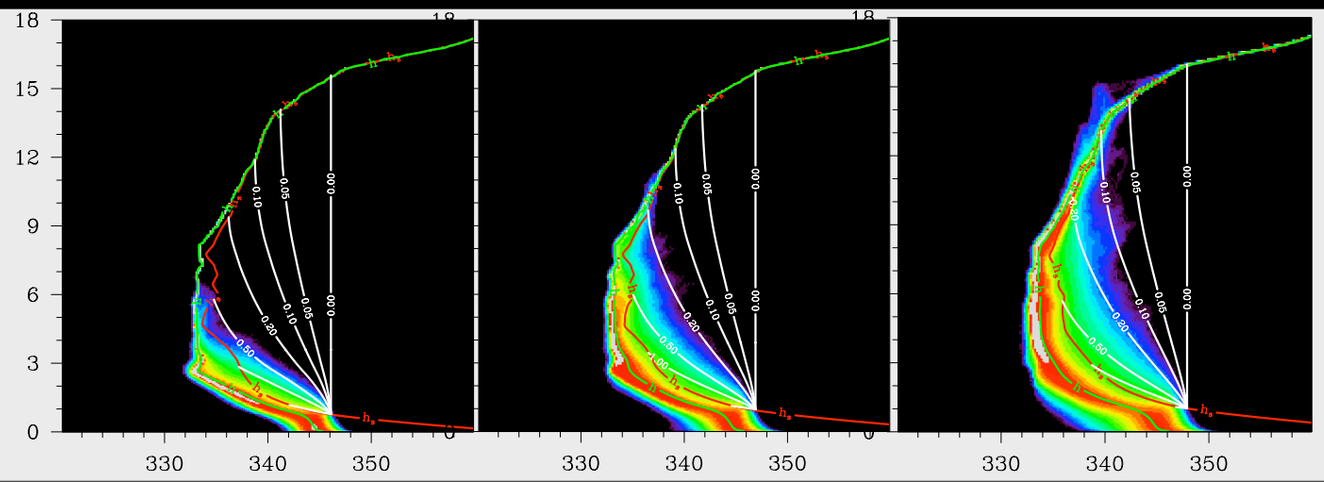
Daytime convective development over land based on TRMM-LBA (Amazonia) observations



Khairoutdinov and Randall, JAS 2006





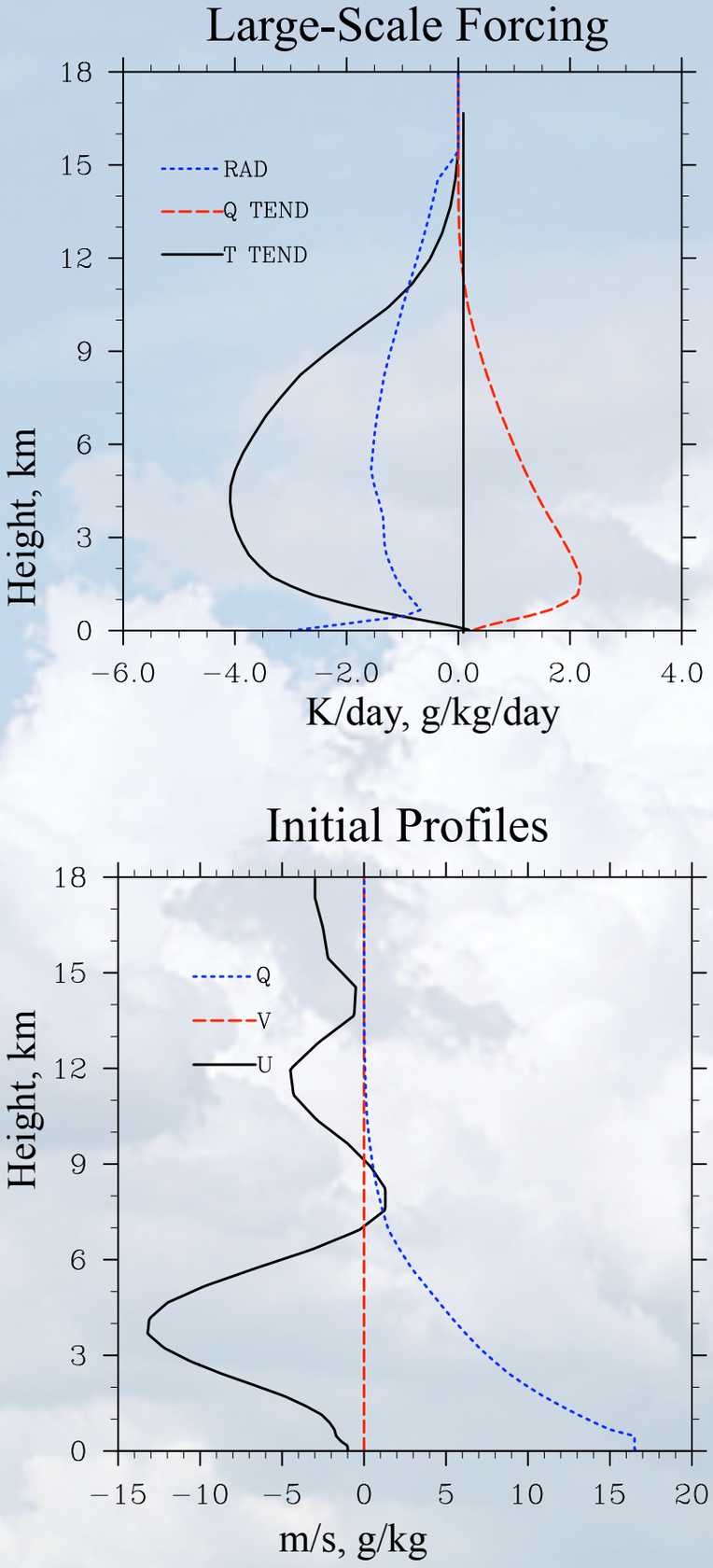


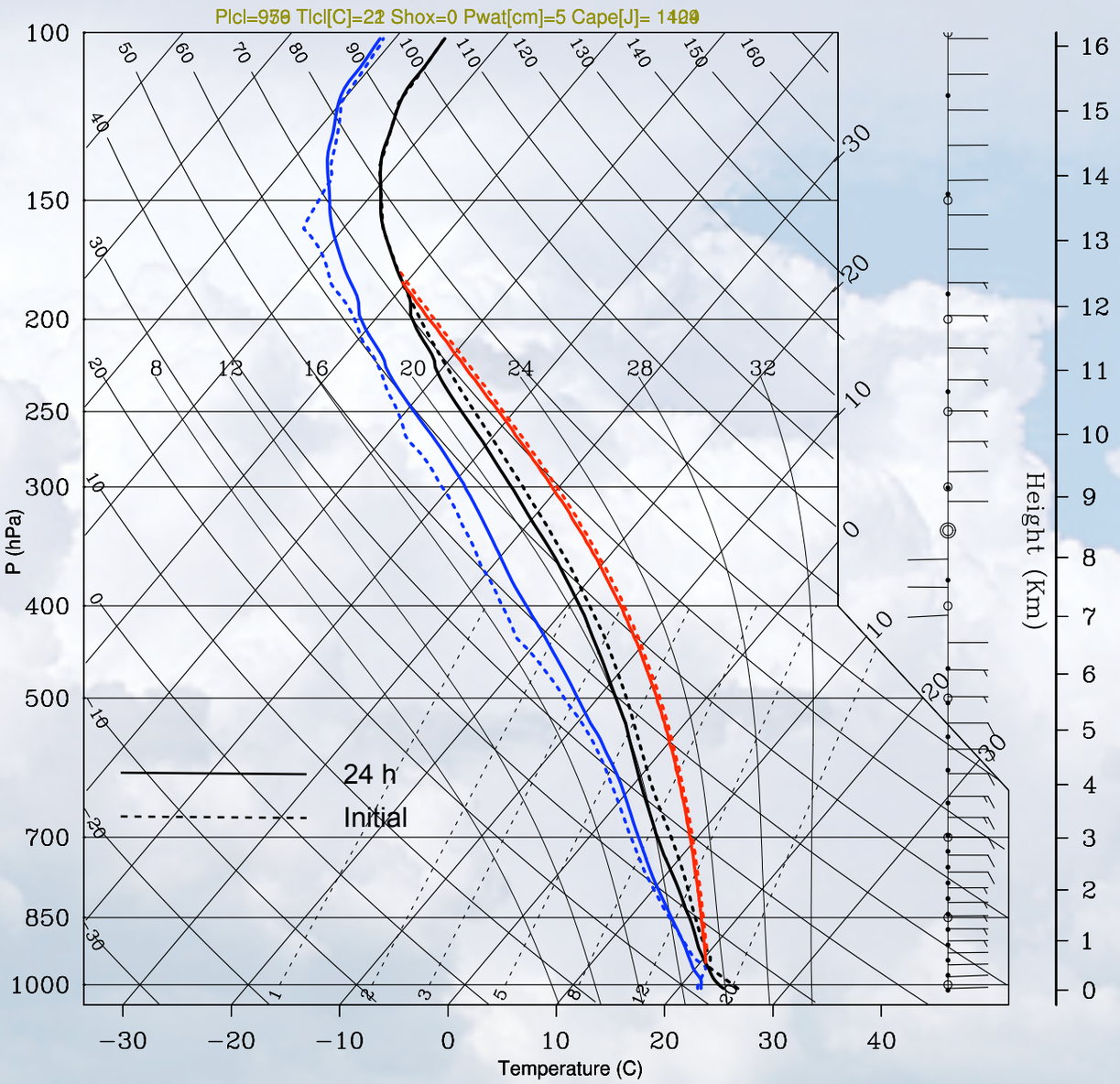
Case of organization of convection on mesoscale

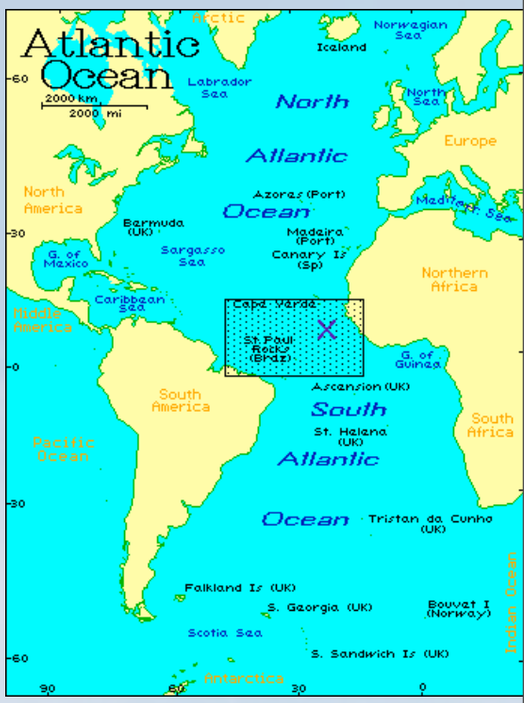
GATE Phase III Mean Conditions

30 August - 19 September, 1974

Xu et al (1992)





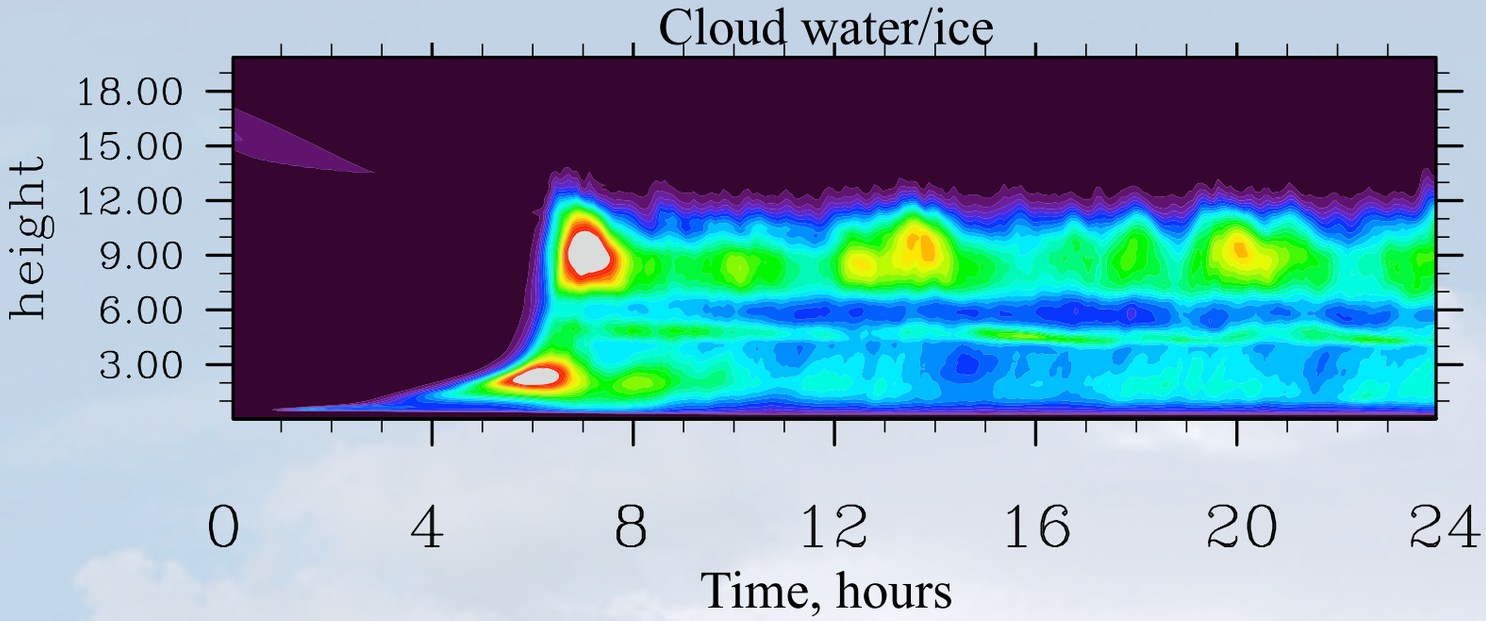


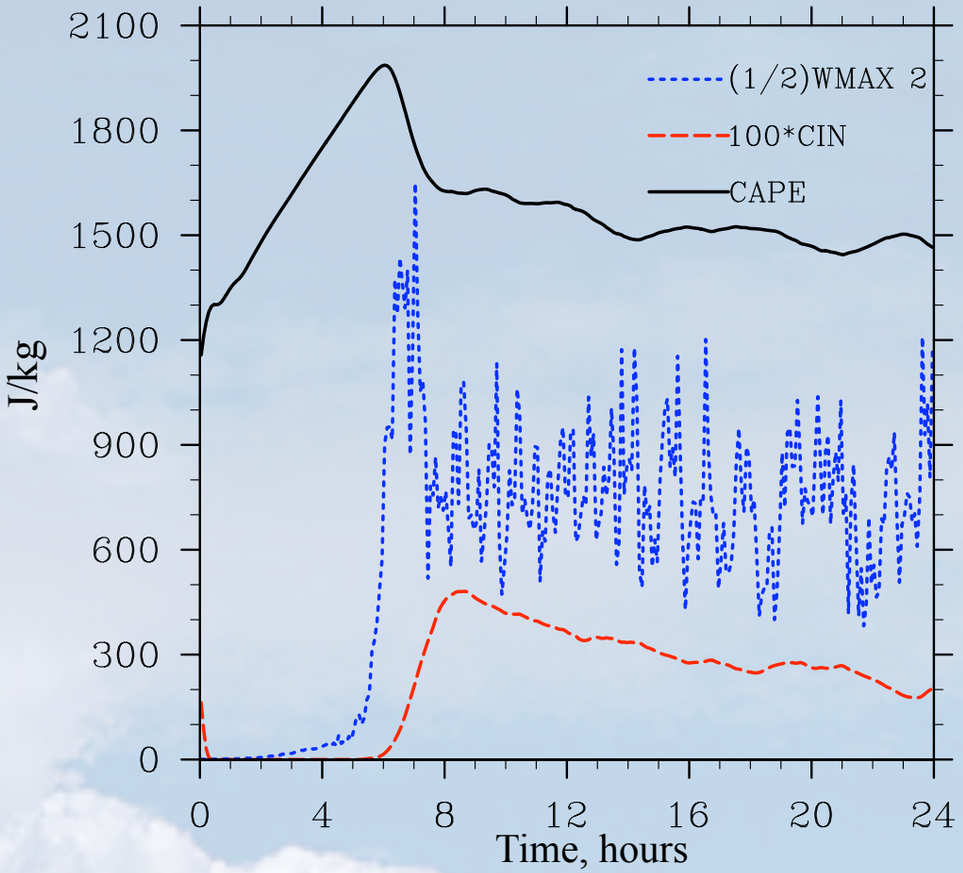
Run Set-up

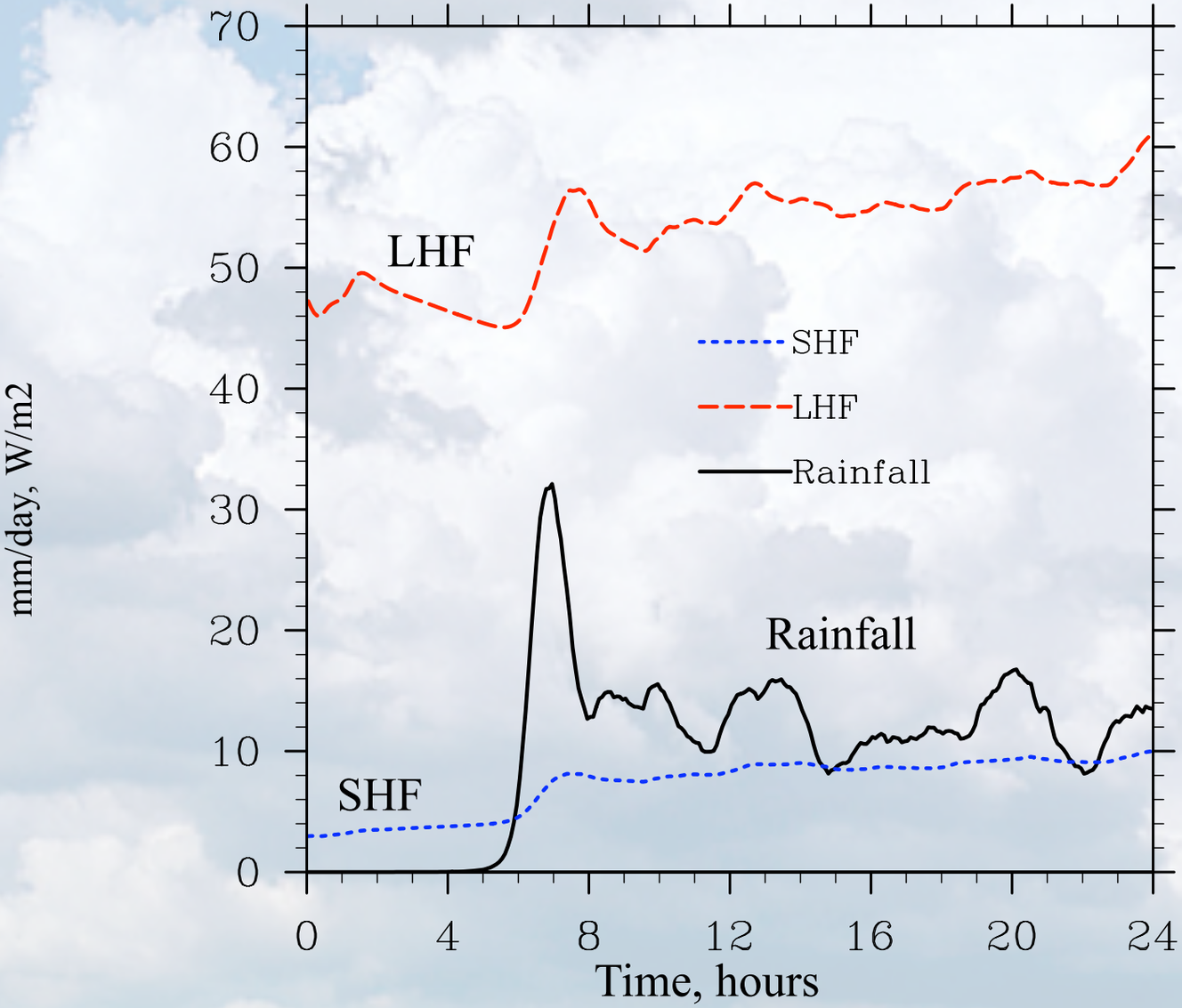
System for Atmospheric Modeling, SAM 6.7;

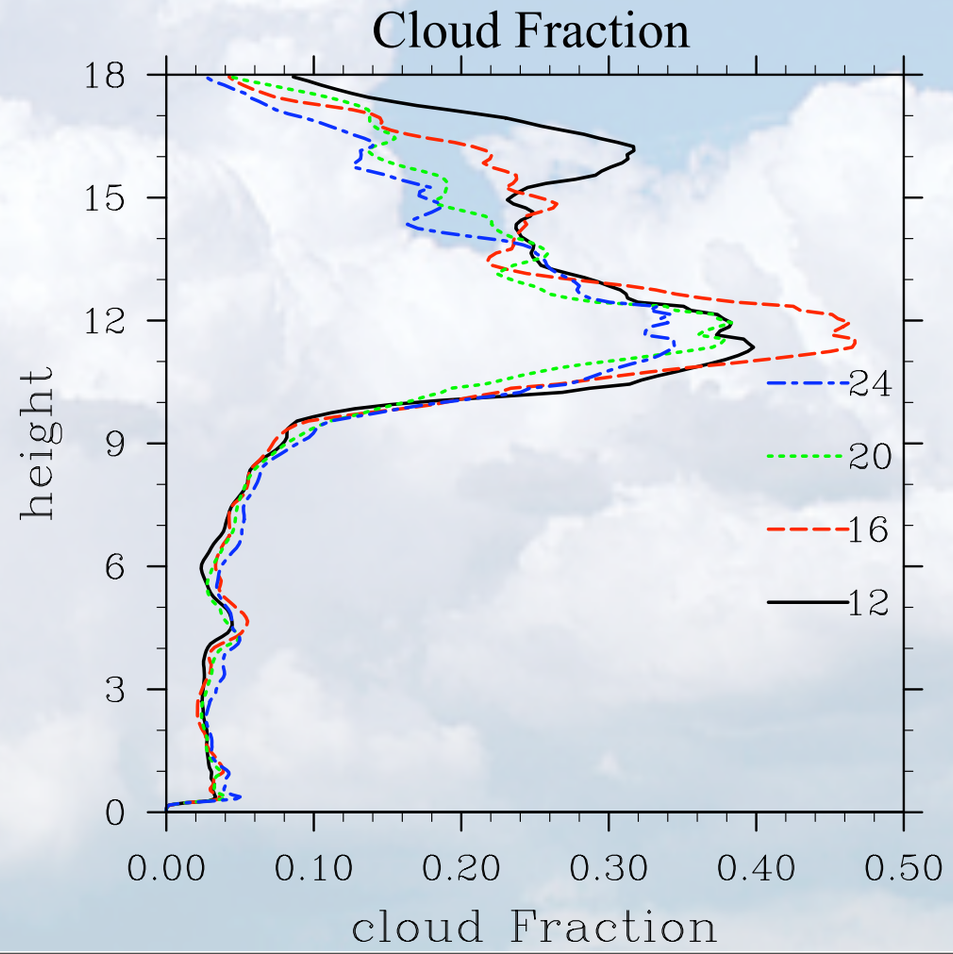
- Grid: 2048 x 2048 x 256, or 205 x 205 x 27 km3;
- Horizontal res. 100m; periodical lateral boundaries;
- Vert. res. 50m below 1km,50-100m @1-5km; 100m @5-18km; 100-300m above;
- Time step 2 sec;
- Initialization: Random small temperature noise at the lowest grid levels;
- Forcing applied continuously horizontally uniform; surface fluxes computed; horizontal mean wind nudged to obs on 2 hour timescale;
- Durarion of run: 24 hours
- 2048 processors; IBM BlueGene BG/L @BNL;

Time evolution





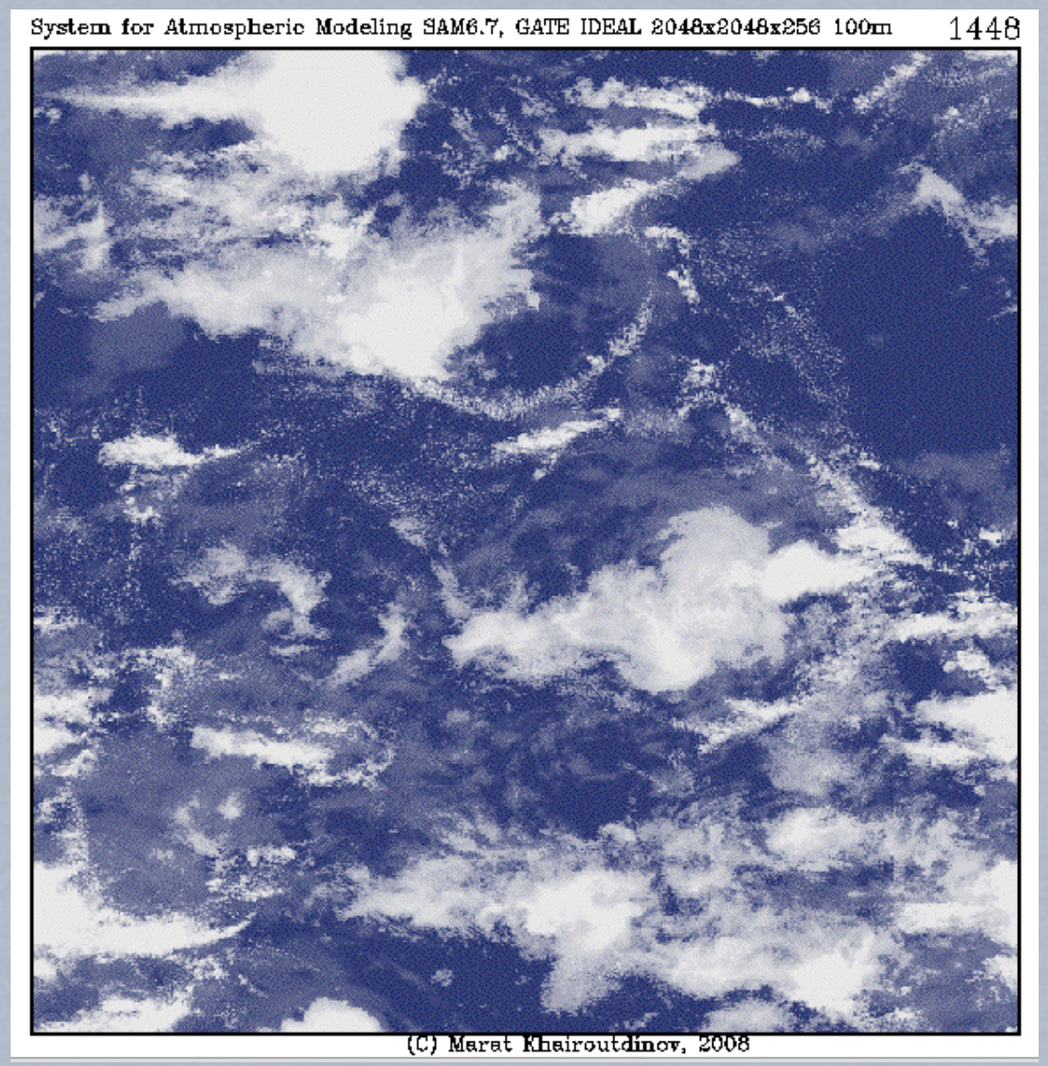




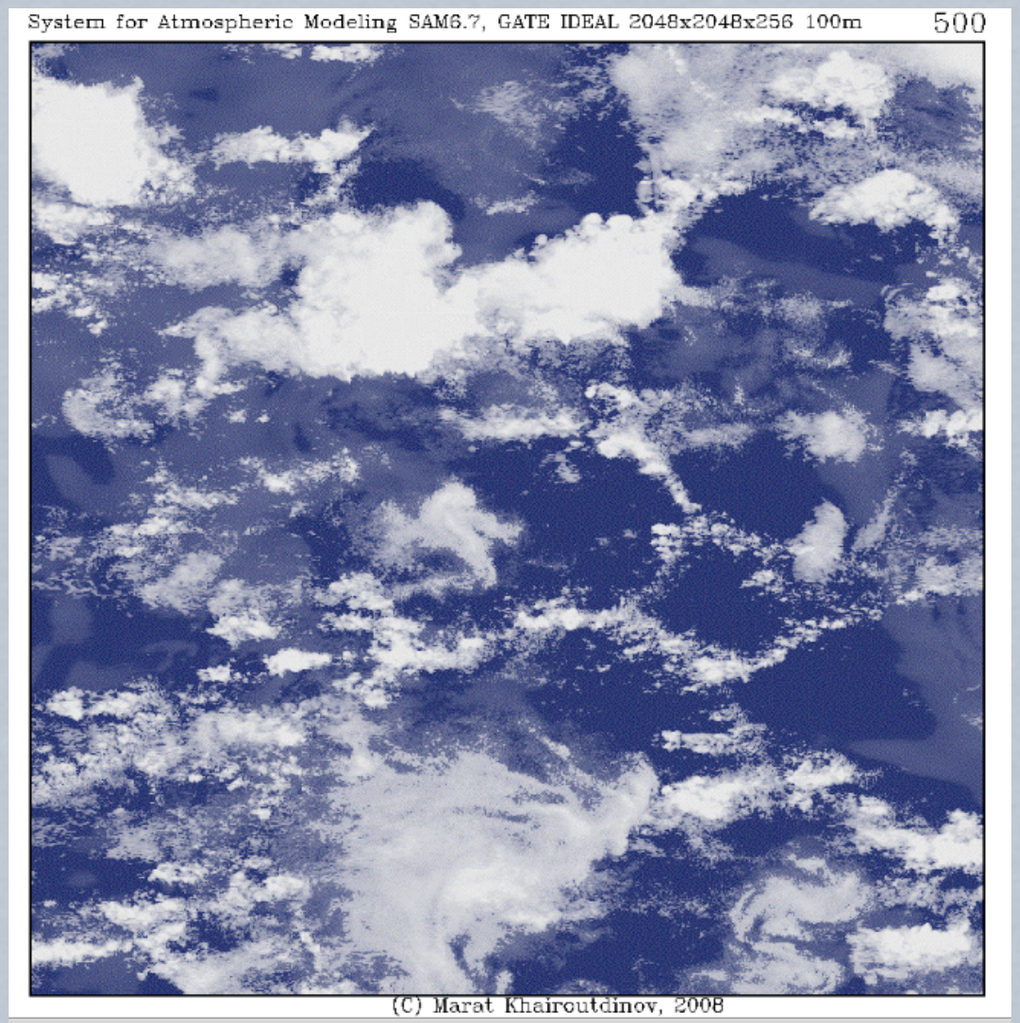
Animation of mock-up ‘visible-light albedo’
205x205 km2 (Full domain)
24 hours, 1 min time resolution

Things to notice:

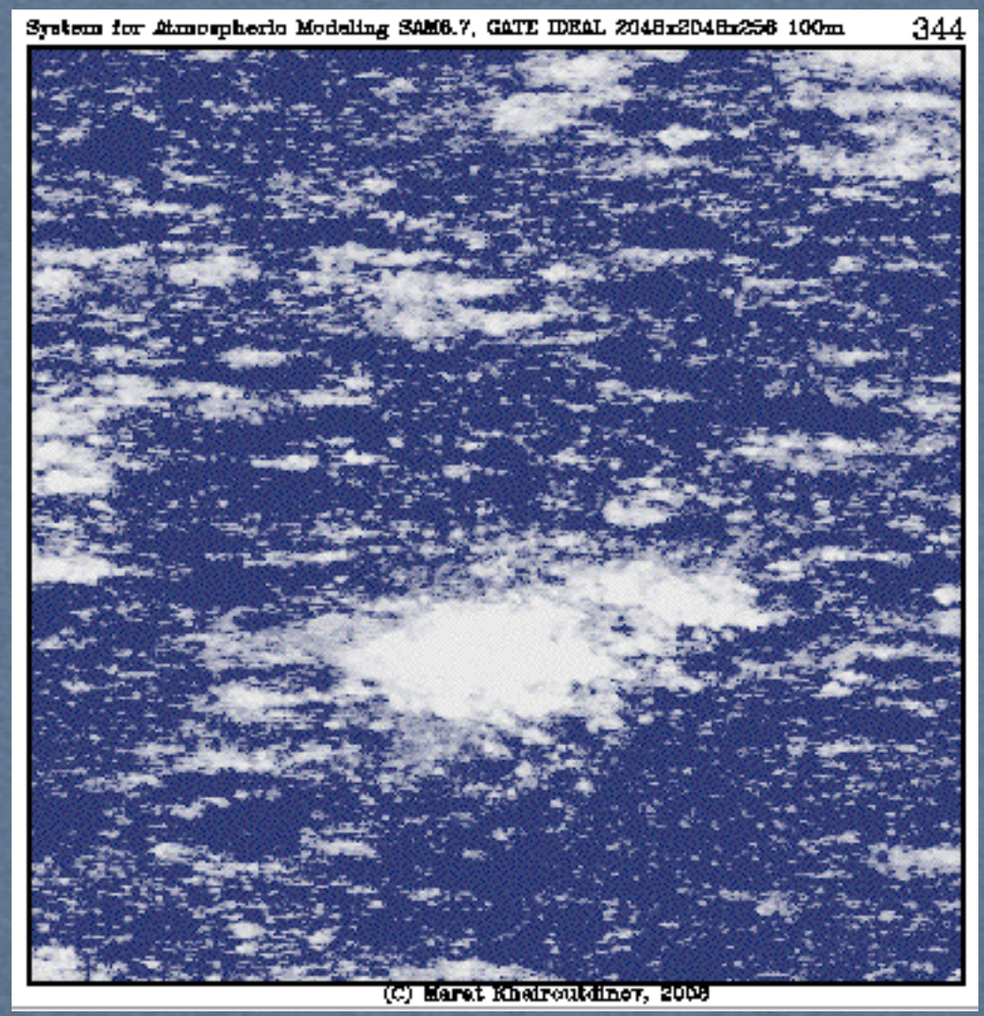
- Explosive deepening of shallow clouds during simulation spin-up;
- Spreading cold pools with new convection forming over cold pool edges;
- Gravity ways visualized by thin cirrus deposition/evaporation;



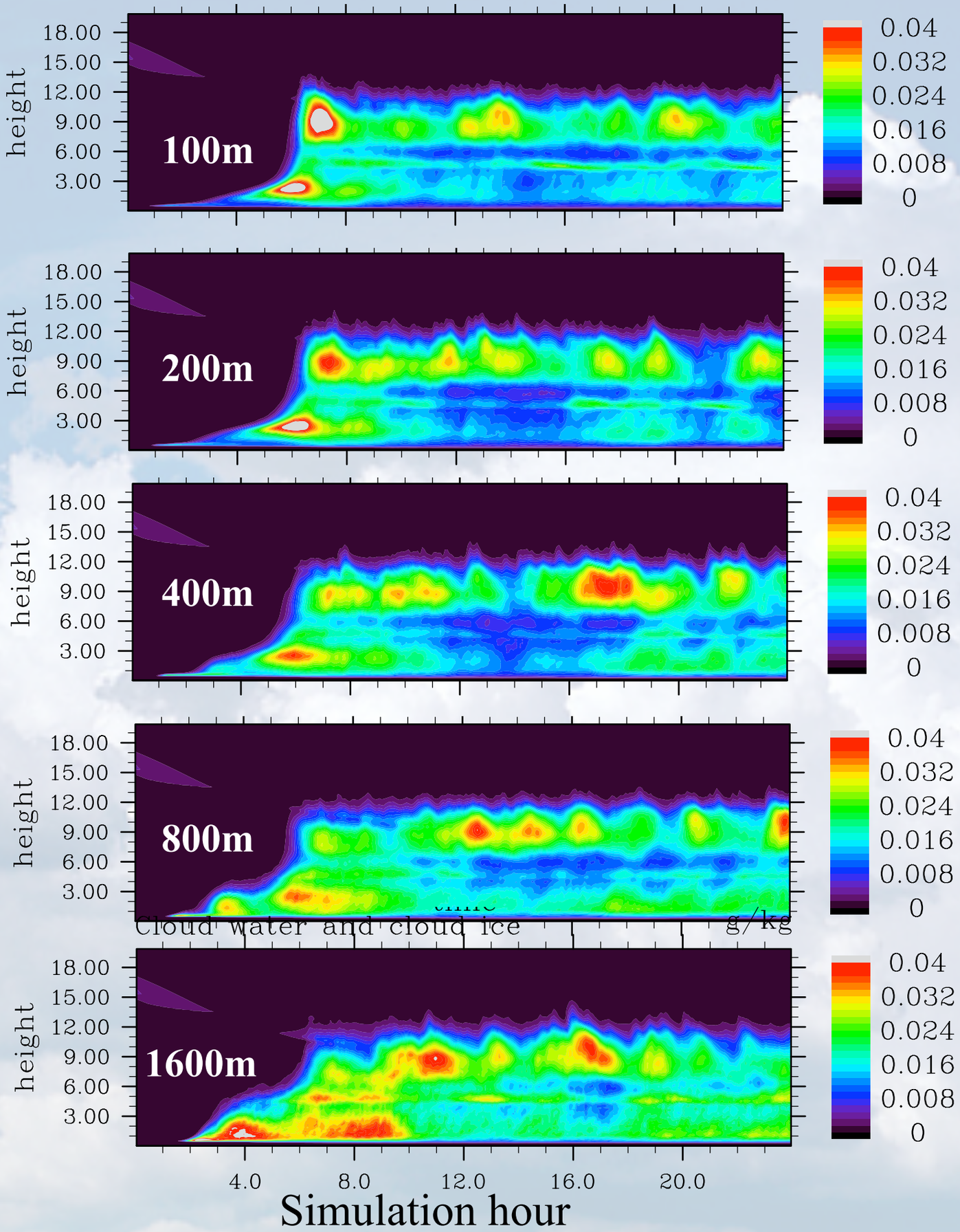
Animation of mock-up ‘visible-light albedo’
100x100 km2 (Zoom-in into quarter of the full domain)
15 hours, 1 min time resolution
Things to notice:
Spreading cold pools with new convection forming over cold pool edges;
Formation of new deep clouds as the result of painstaking process of congestus clouds (‘smoking plumes’) merging together;

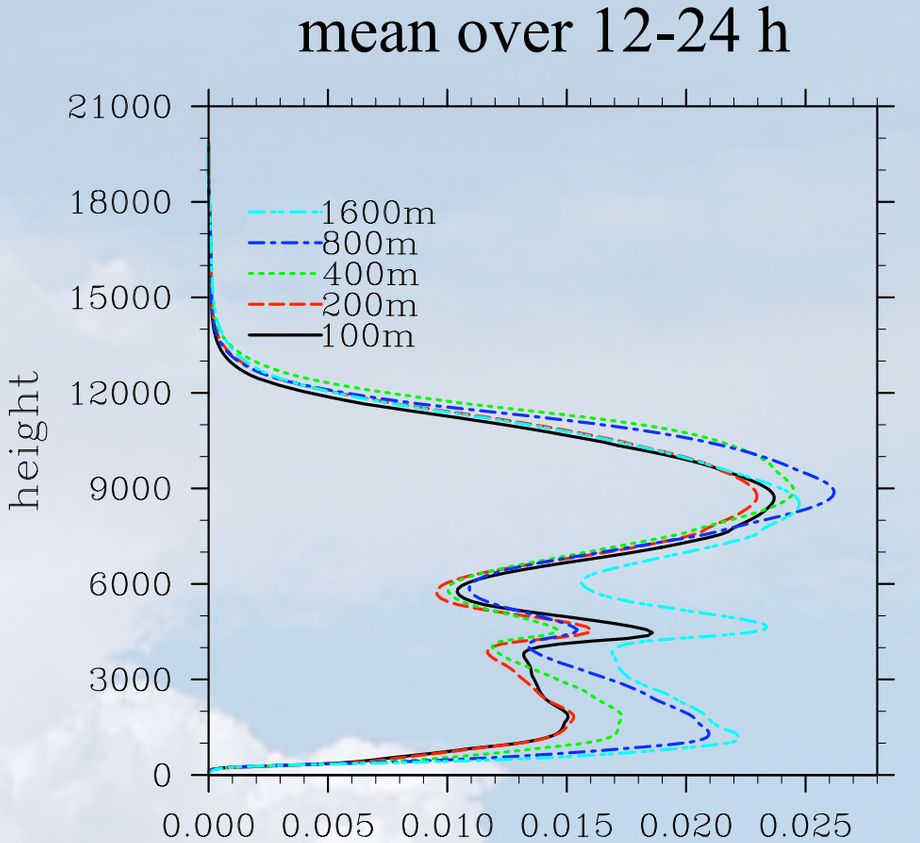


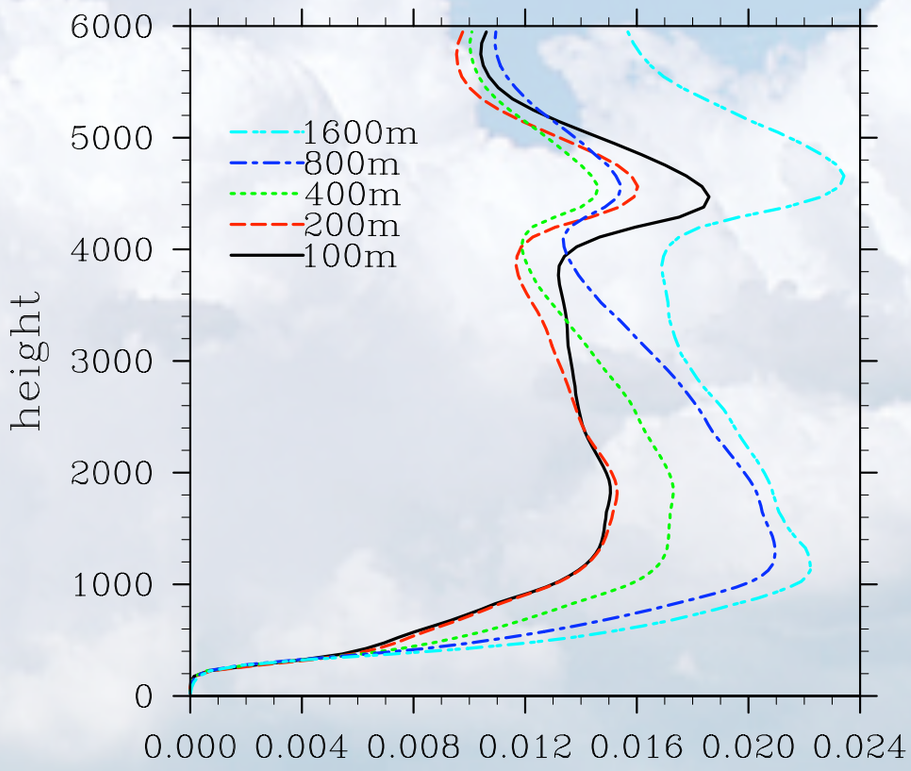
Animation of mock-up ‘visible-light albedo’
50x50 km2 (Zoom-in into 1/16th of the full domain)
3 1/3 hours, 1 min time resolution
Things to notice:
Rapid growth of congestus merging into clusters;
Growing clusters tend to suppress individual cells around them;
Explosive development of congestus clusters into deep clouds;



Sensitivity of Cloud Water/Ice to horizontal grid spacing



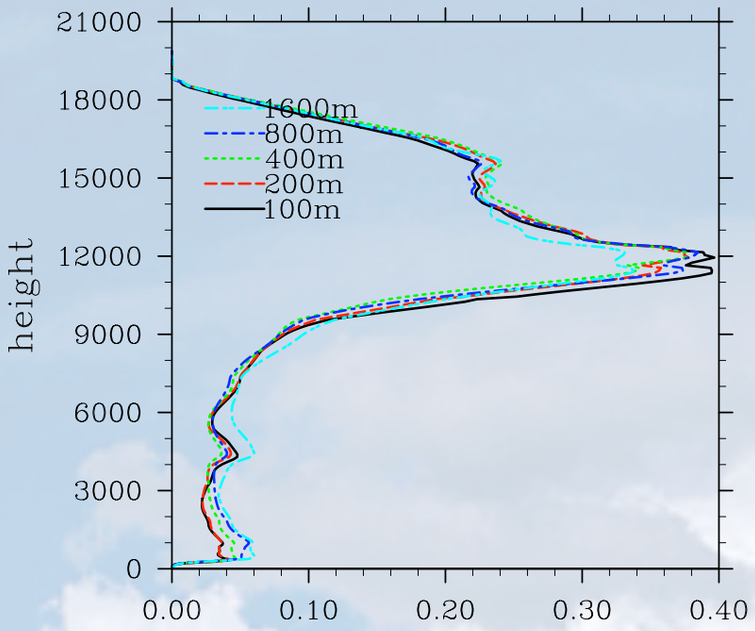




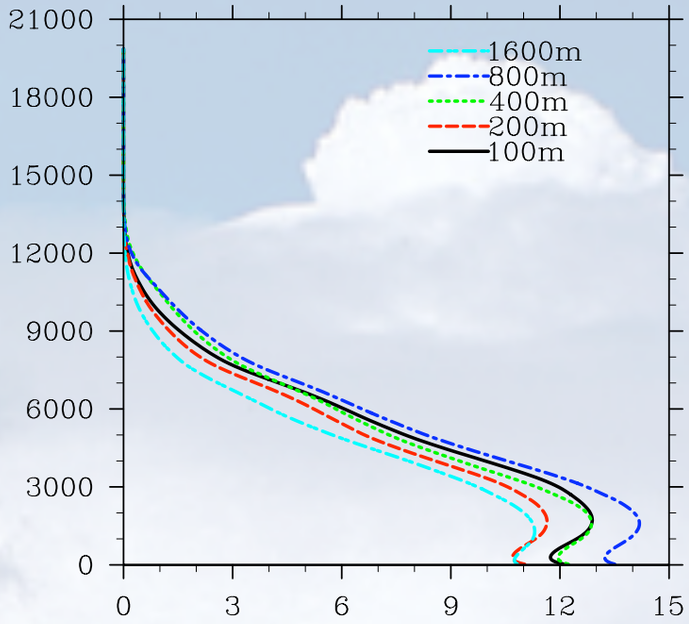
Sensitivity to horizontal grid spacing

mean over 12-24 h

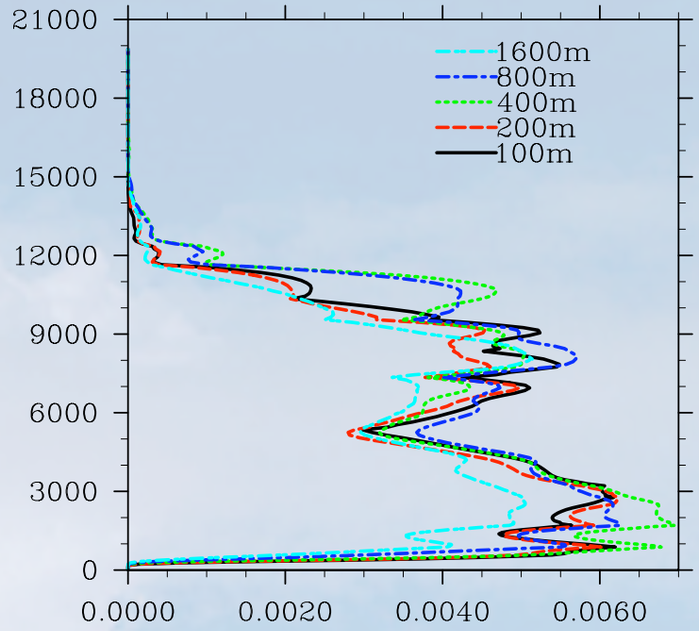
Cloud fraction



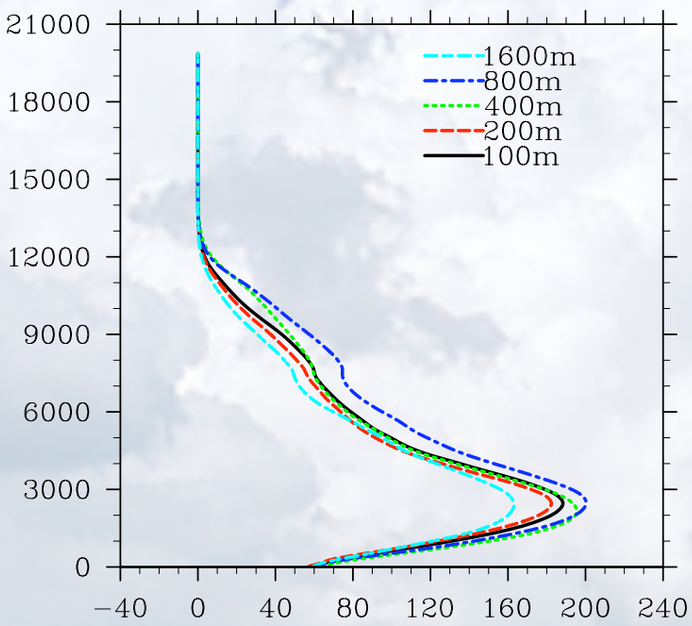
Precipitation flux, mm/day



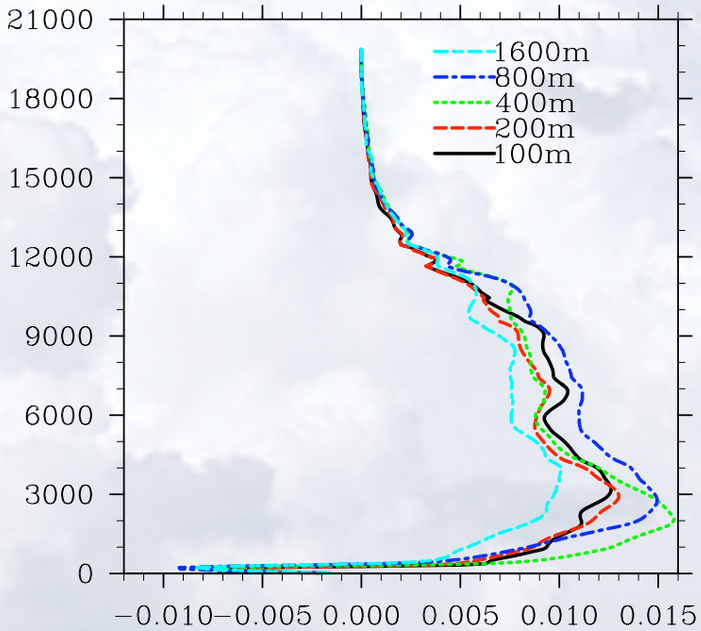
Cloudy updraft core fraction



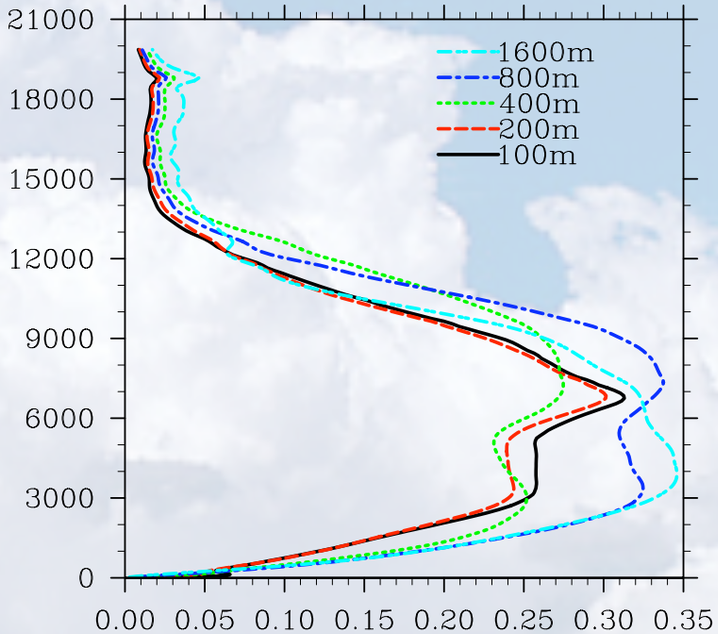
None-precipitating water flux, W/m2



cloud mass-flux, kg/m2/s

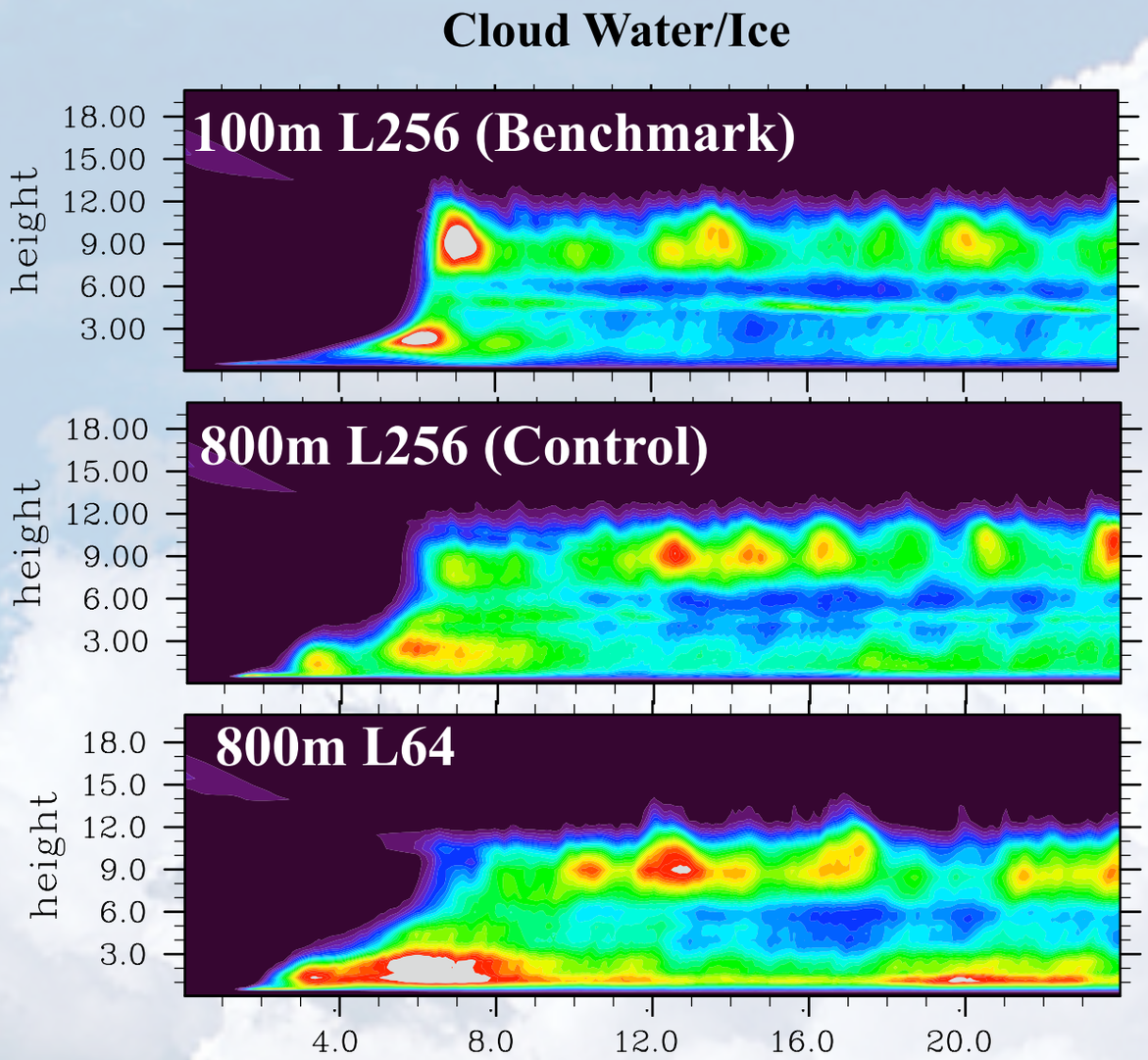


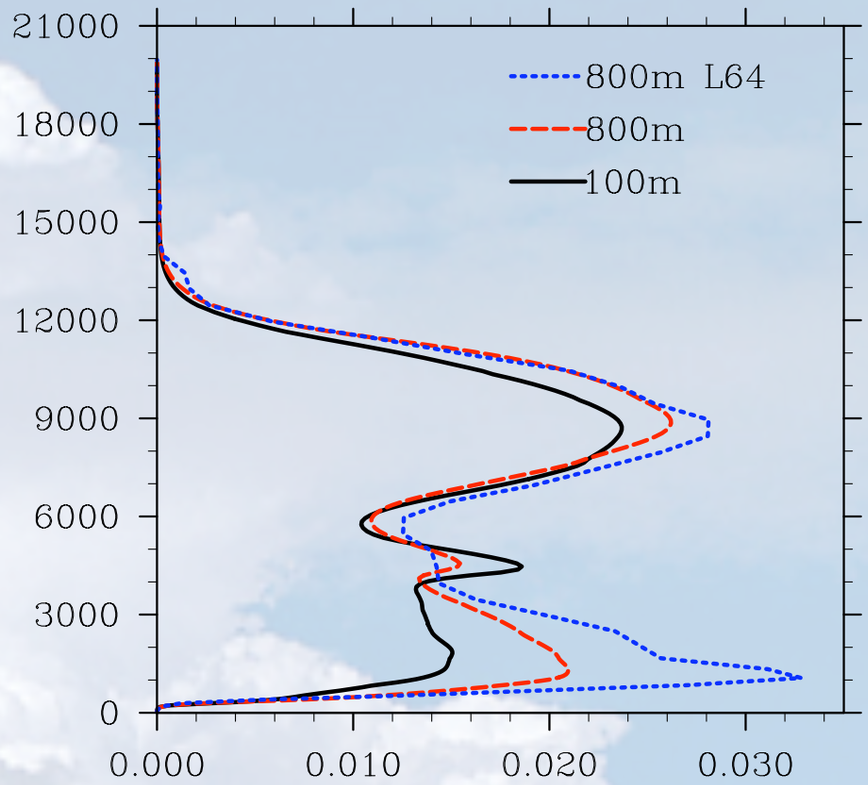
vertical velocity variance, m2/s2



- 200m results seem to converge to 100m results;
- Shallow cloud fraction and water content tend to increase with increasing spacing;
- Overall, rather weak sensitivity to horizontal grid spacing below 400m.

Sensitivity to vertical grid spacing

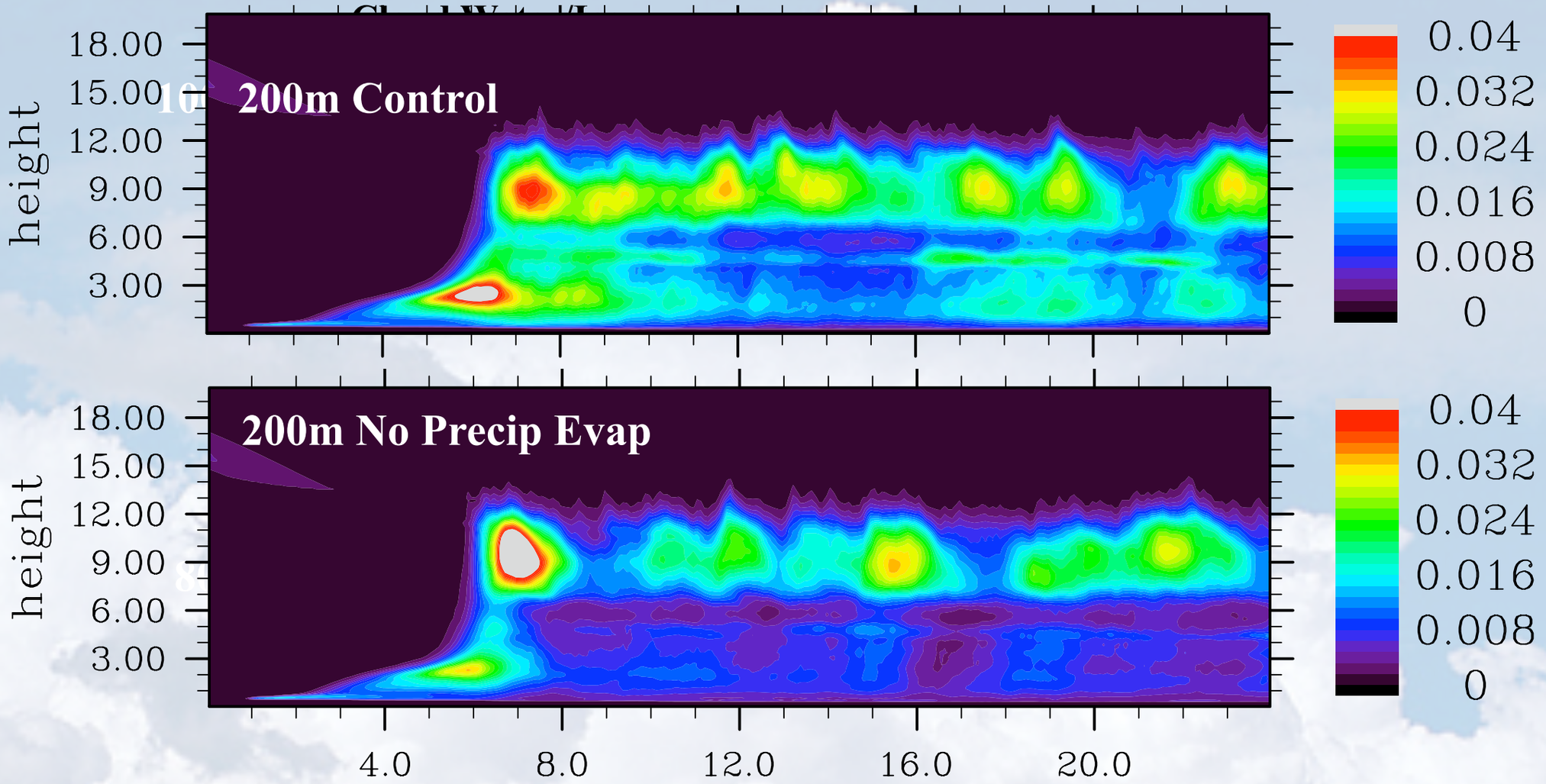




- The freezing-level cloud maximum is sensitive to vertical resolution;
- Shallow cloud fraction increases when degrading vertical resolution.

Sensitivity to evaporation of precipitation (sensitivity to cold pools)

Sensitivity to precipitation evaporation (cold pools)



- **Cold pools seem to promote shallow and mid-level convection**

Main Challenge: Tsunami of Data

- Total output size: 5.5 Tb per simulated day;
- For efficiency, each of 2048 MPI tasks produced its own output;
- Result: 1.8 million files per simulated day;
- Petascale computing is almost here. Good luck ...

Conclusions

- Simulated deep clouds appear to be initiated not by large-size individual bubbles/thermals but by merging/clustering of smaller clouds;
- The clustering can be random (as during the initial spin-up of the model) or heavily favored in the regions of moisture convergence over the cold pool boundaries;
- Cold pools from deep convection seem to promote high levels of mid-level (congestus) convection;
- The statistics appear to be quite sensitive to the vertical grid resolution but not as much to the horizontal resolution within reasonable range;