The Transition from Shallow to Deep Convection in the GIGALES

CMMAP Team Meeting Physical Processes Breakout
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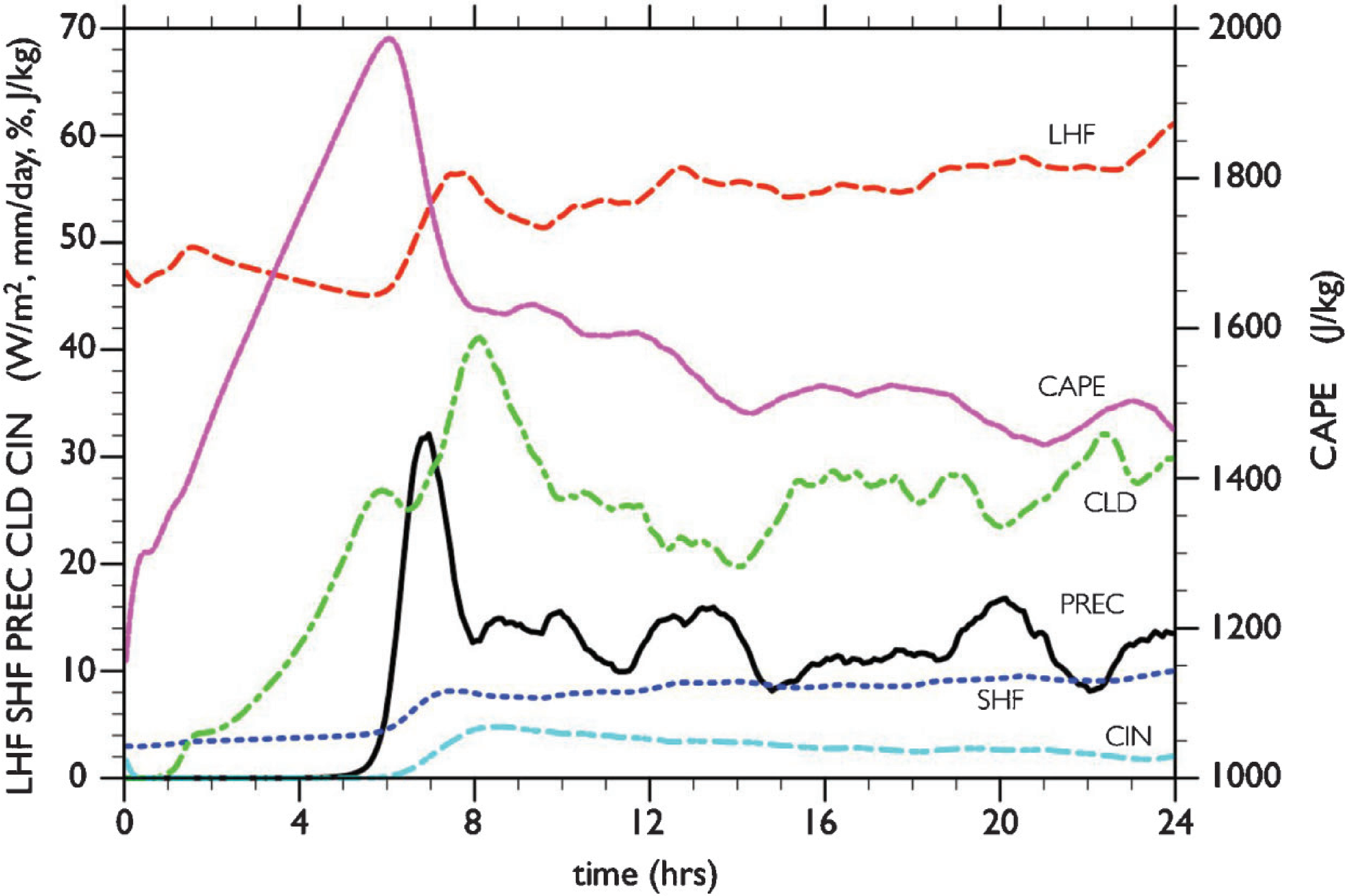
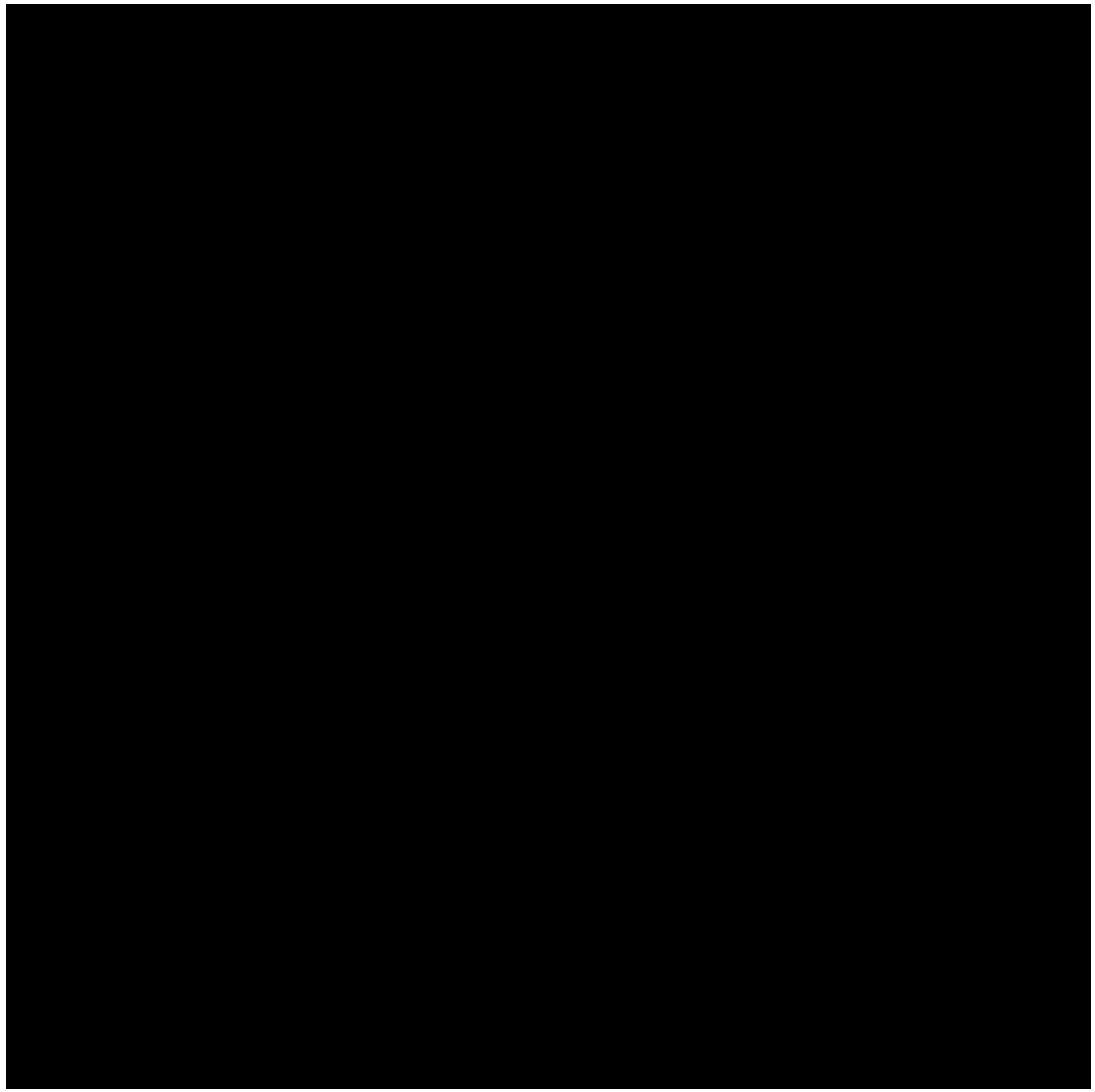
GIGA-LES

- Large Eddy Simulation using SAM
- GATE Idealized steady forcing
- 2048x2048x256 grid points (~1 billion)
- 100m horizontal, 50m to 100m vertical in troposphere

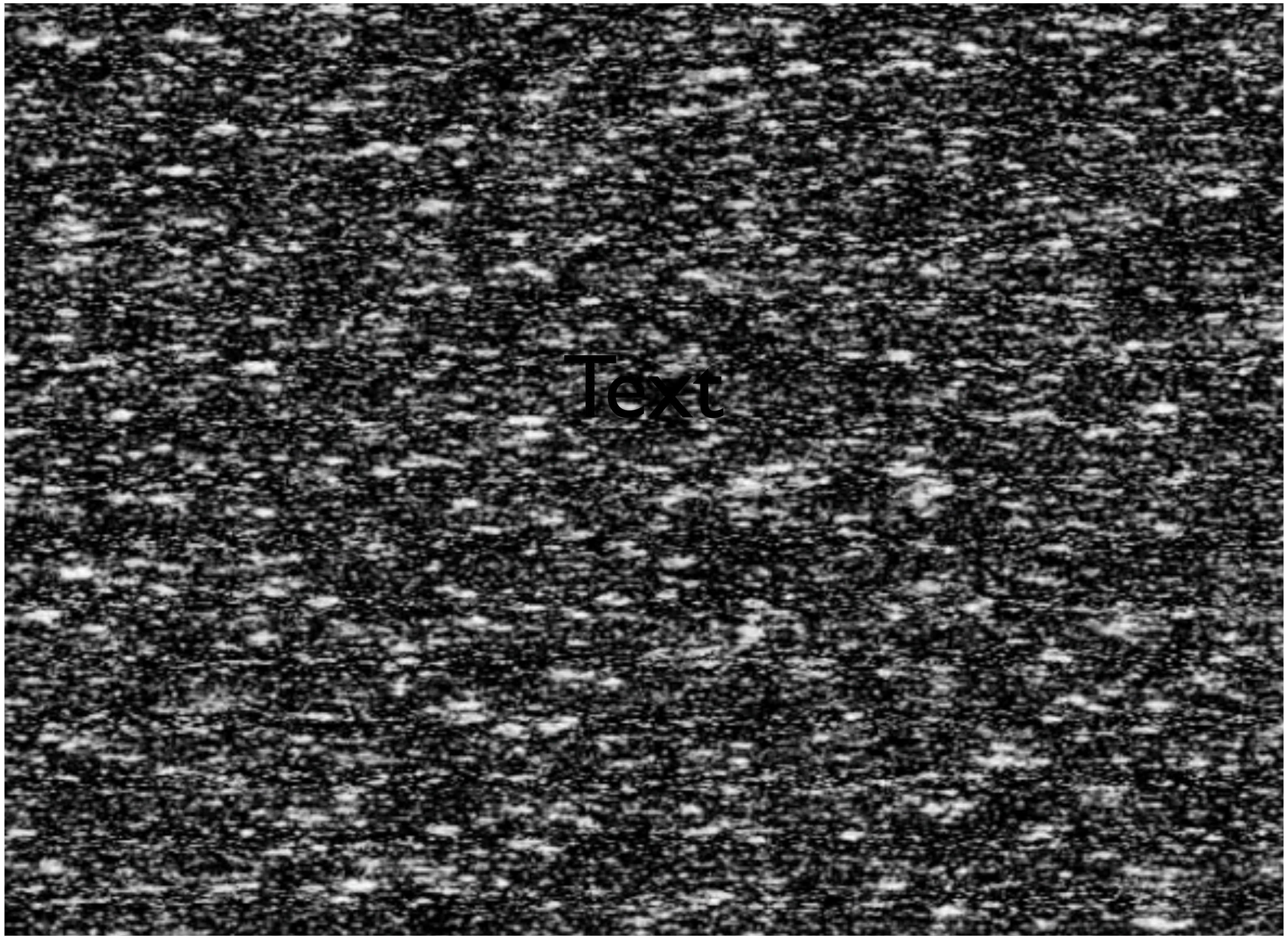


LHF SHF PREC CLD CIN (W/m², mm/day, %, J/kg)
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
time (hrs)
2000
1800
1600
1400
1200
1000
CAPE (J/kg)
LHF
CAPE
CLD
PREC
SHF
CIN

Cloud Water Path

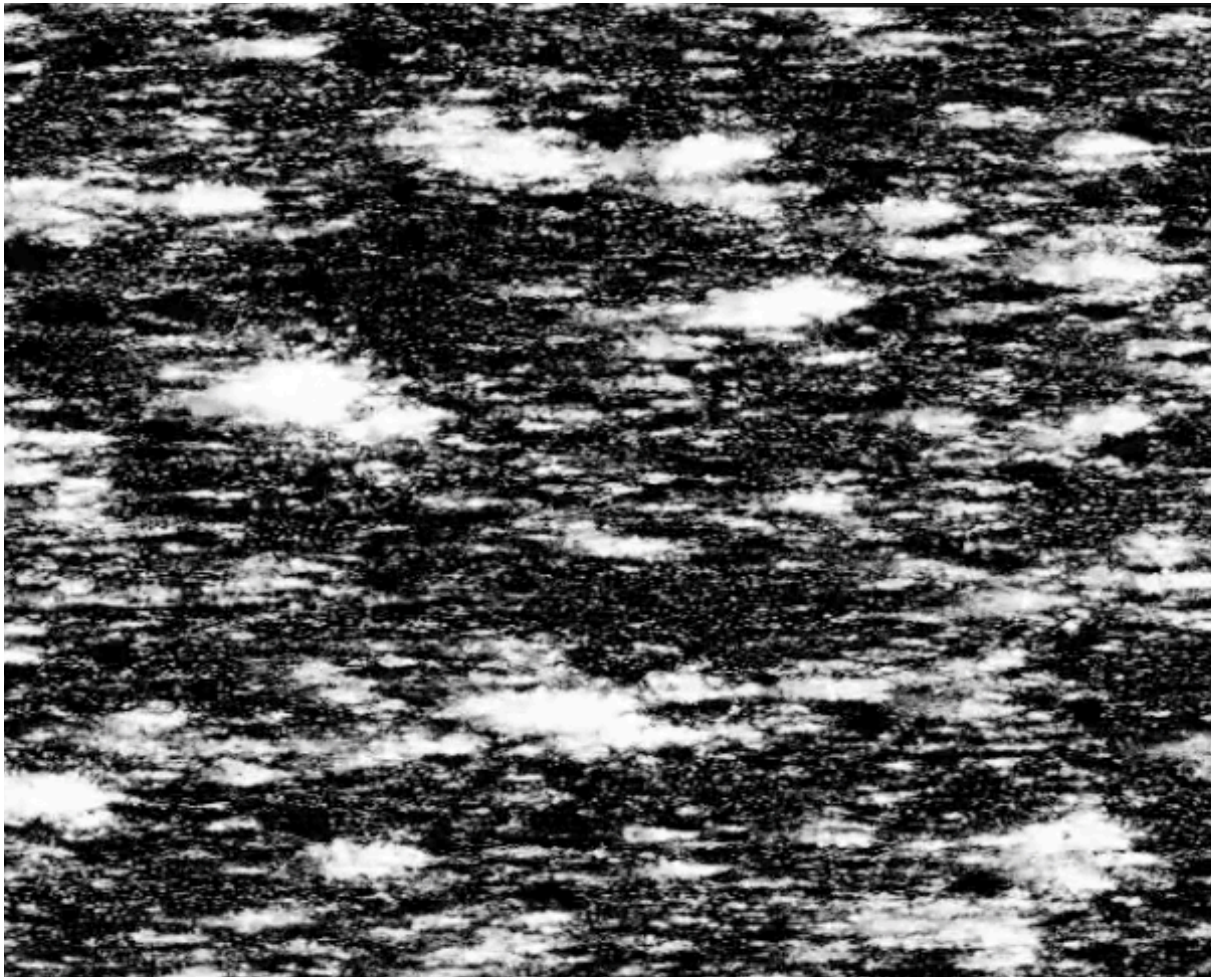


Shallow Convection



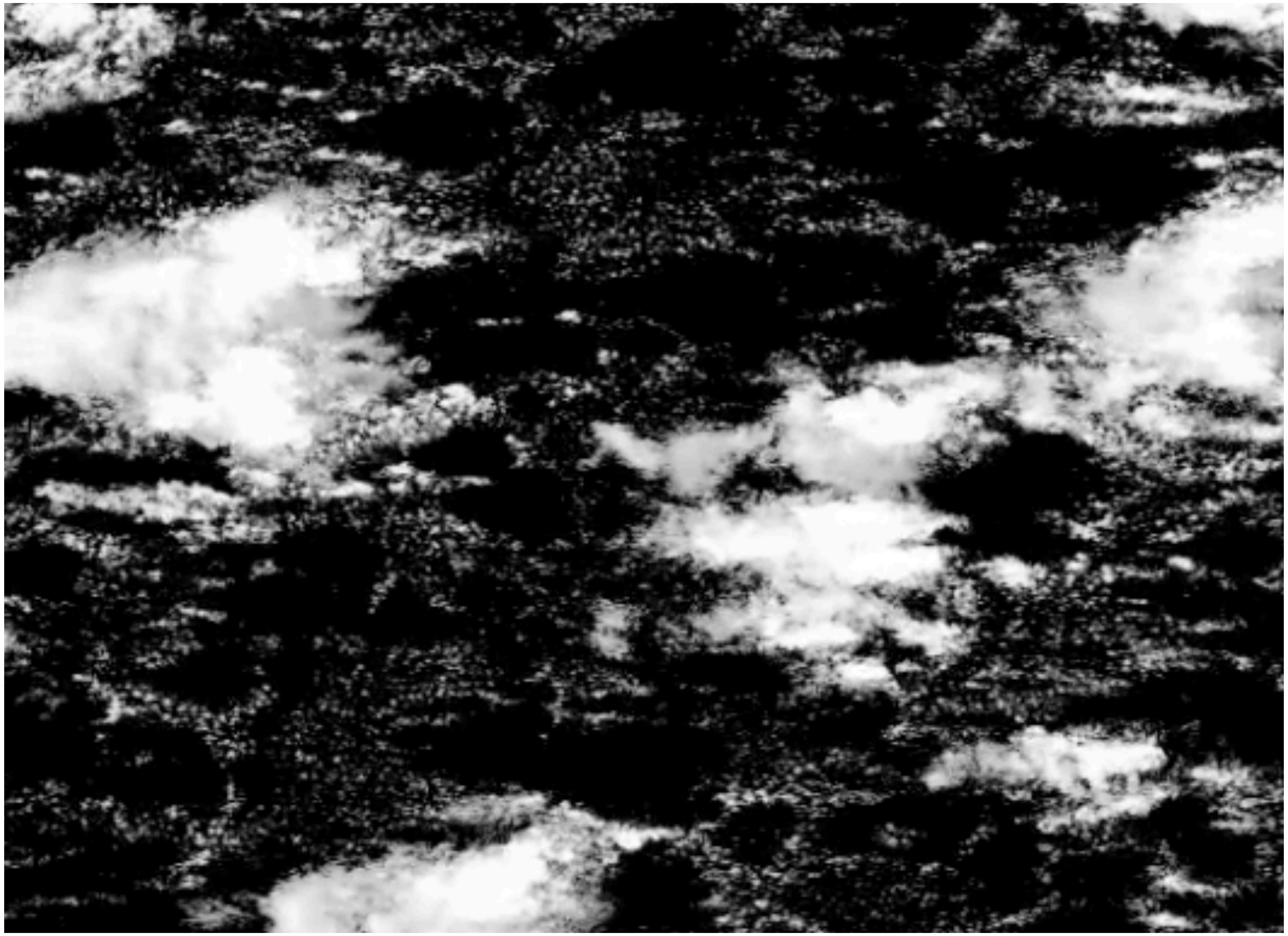
Cloud Water Path at t = 4 hours

Congestus



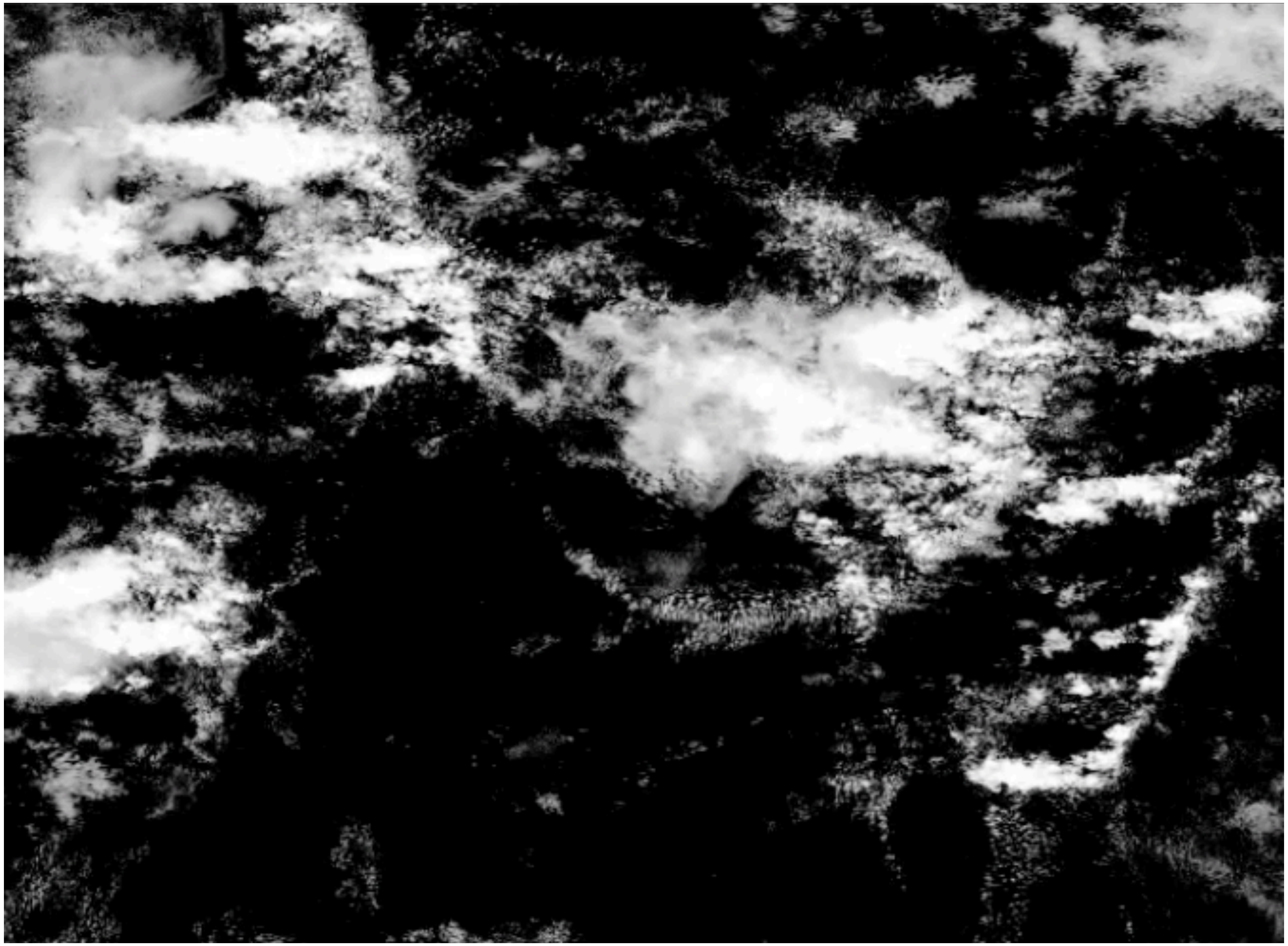
CWP at t = 5.75 hours

Transition



CWP at t = 7 hours

Deep Convection



CWP at t = 12 hours

Profiles of MSE

- An entraining plume is less dilute for a lower entrainment rate
- Lin and Arakawa 1997 Fig. 8

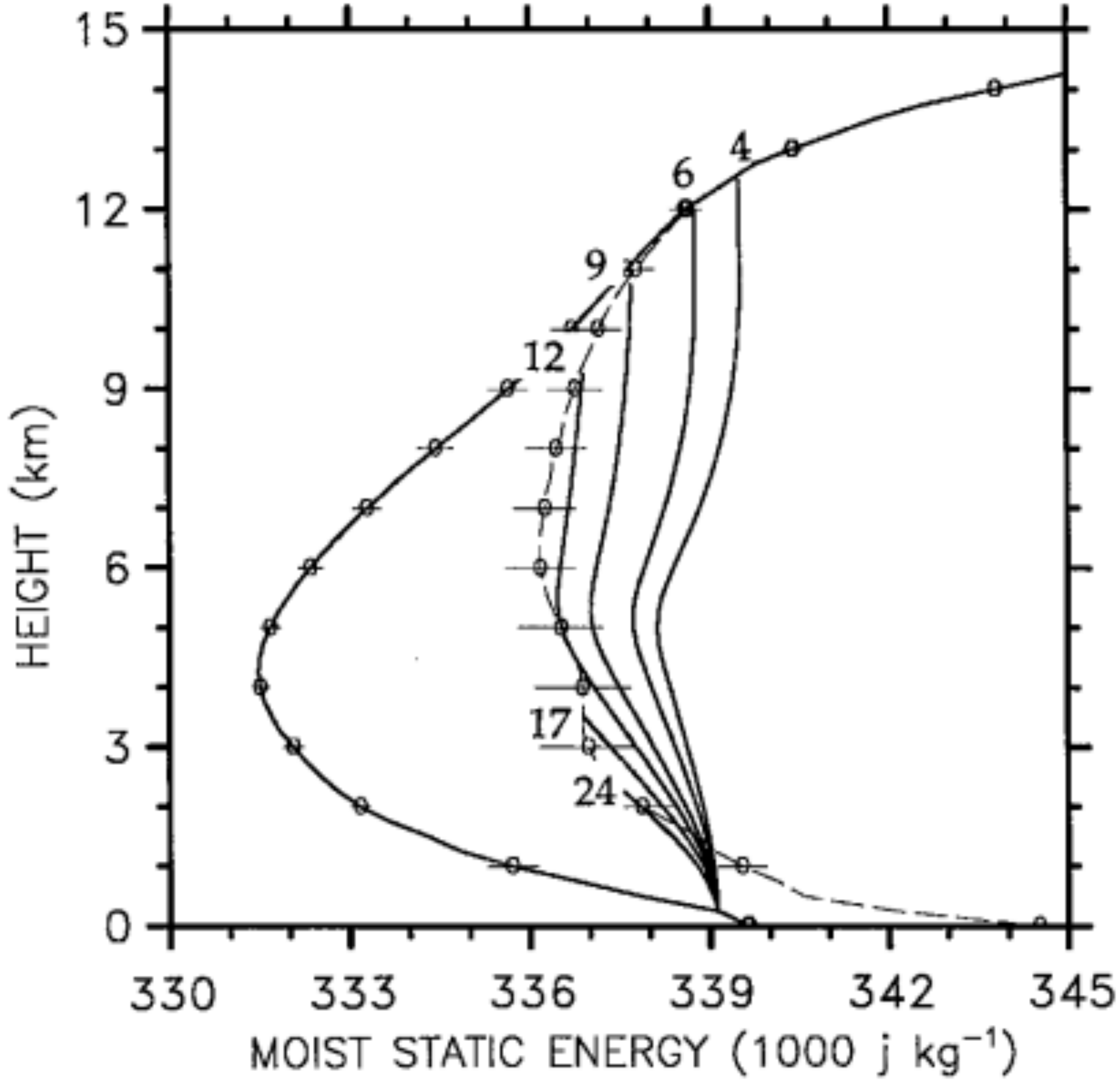


FIG. 8. The vertical profiles of in-cloud moist static energy for different cloud types predicted by the λ-version spectral cumulus ensemble model of the Arakawa–Schubert cumulus parameterization. The corresponding fractional rate of entrainment for each cloud type is indicated at the top of the profile (unit: % km^{-1}). The domain and

Profiles of MSE

- After Kuang and Bretherton 2006

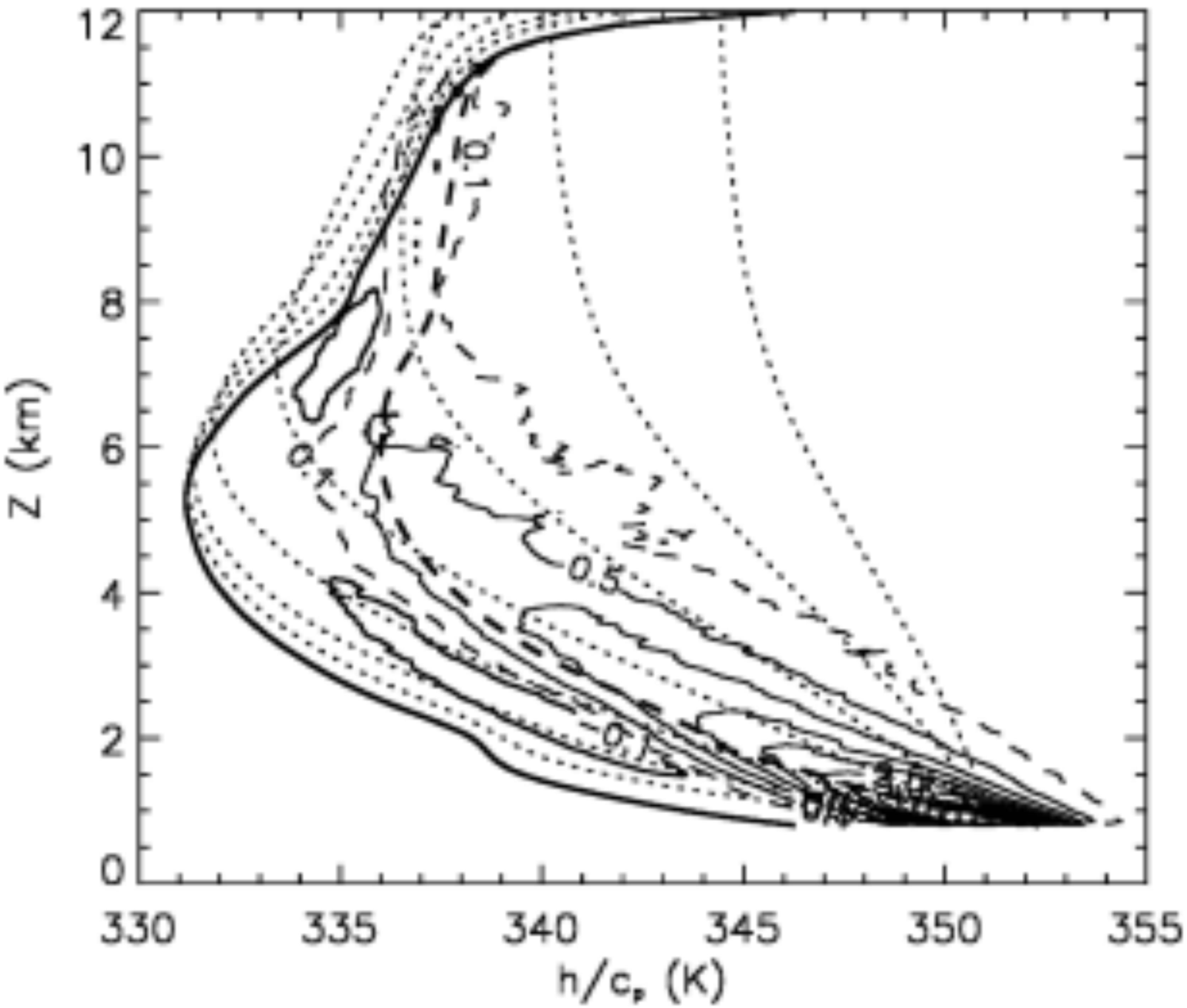
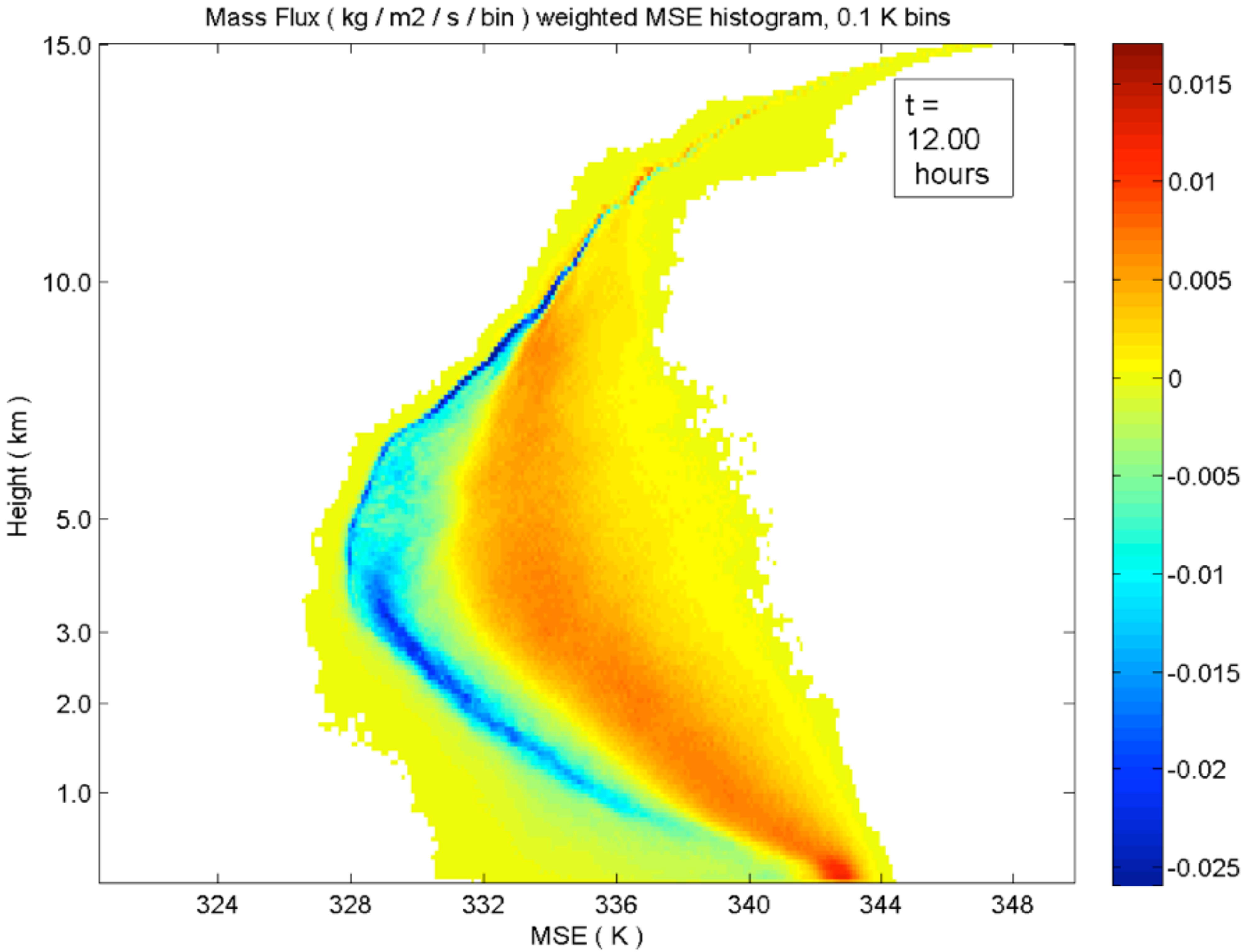


FIG. 11. Same as Fig. 9, except for the deep cumulus regime and for a bin size of 0.5 K in h/c_p.

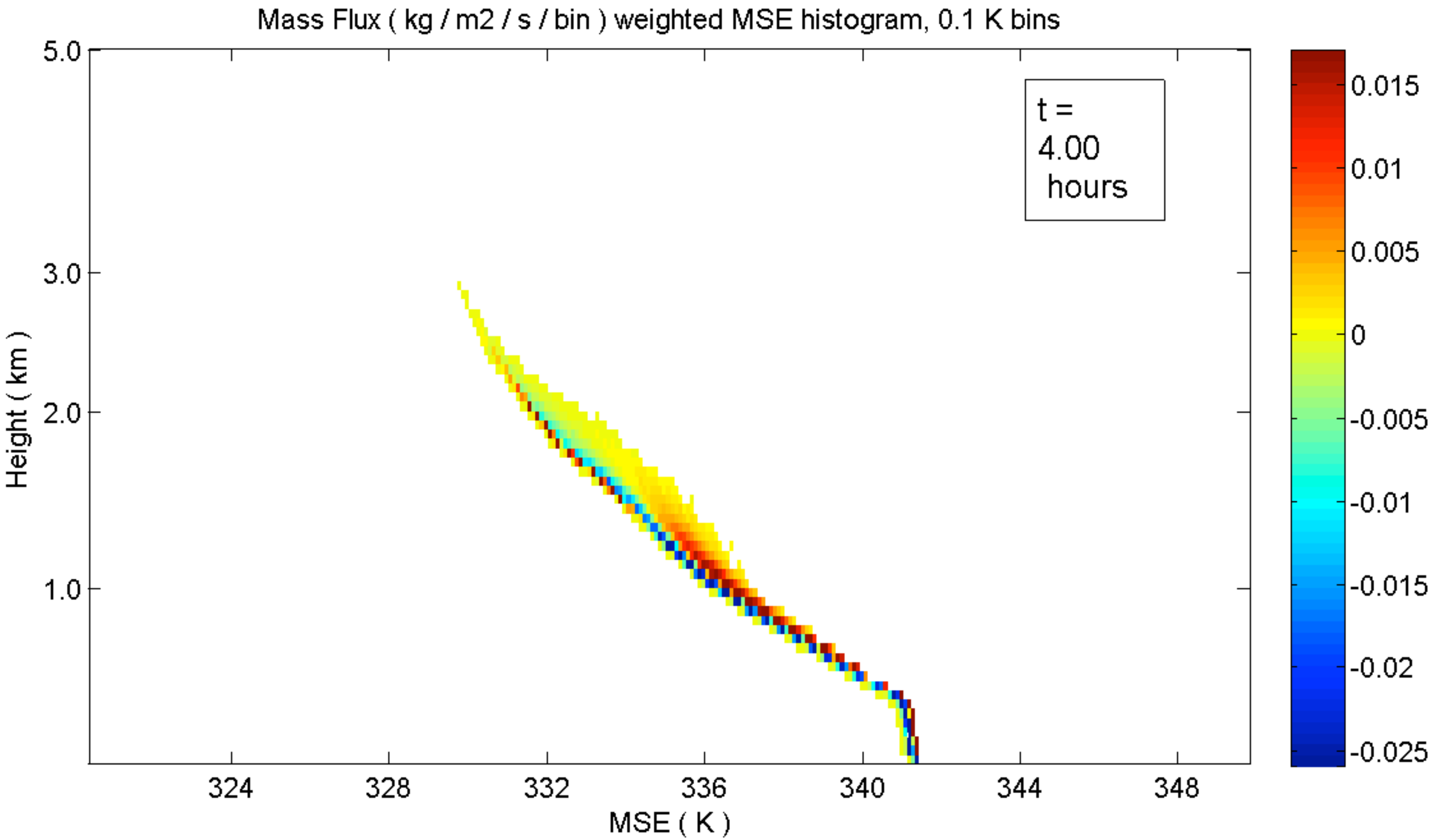
Deep Convection at 12 hrs



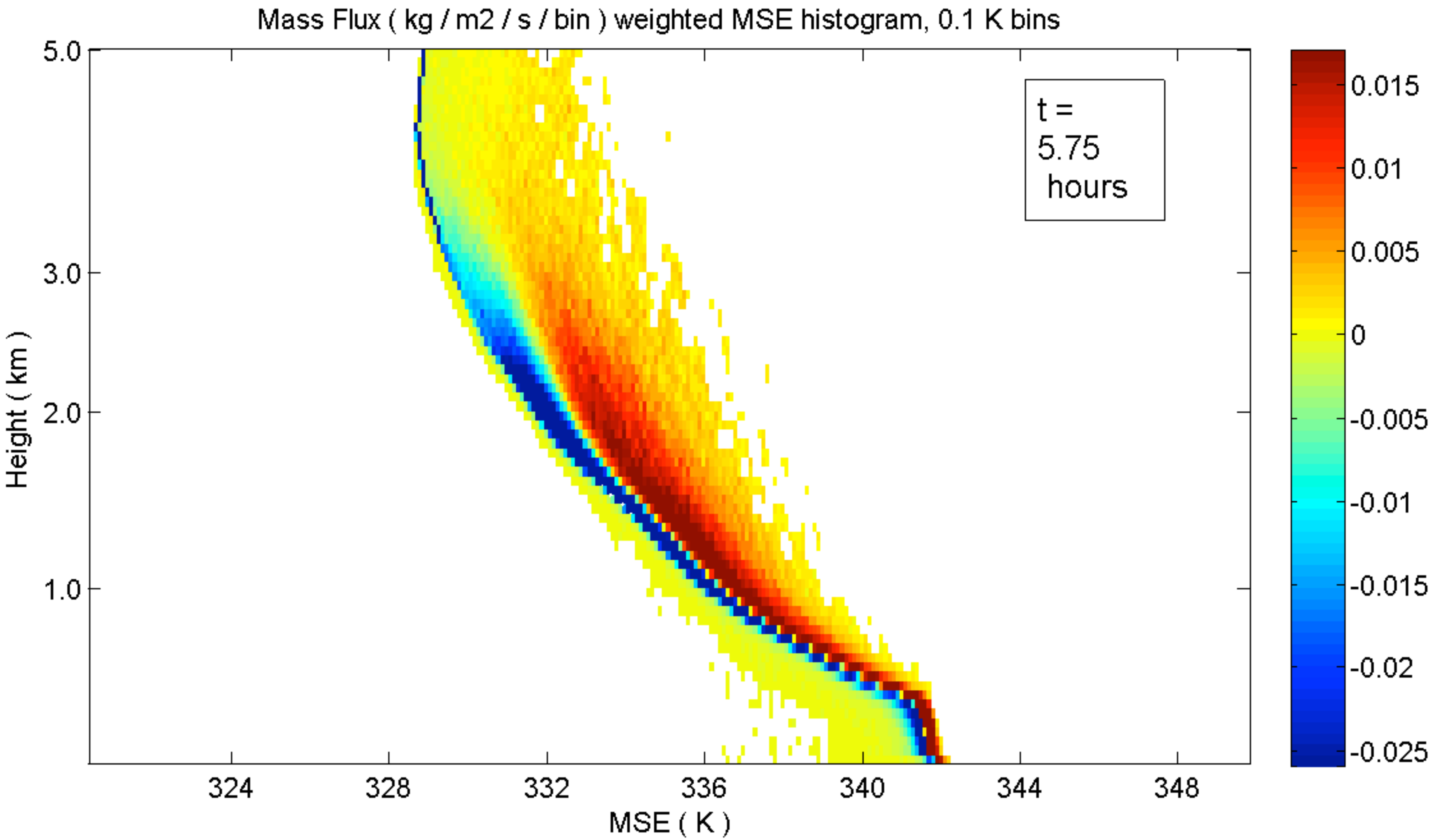
The transition over time

- Focusing on the lowest 5 km

Shallow Convection

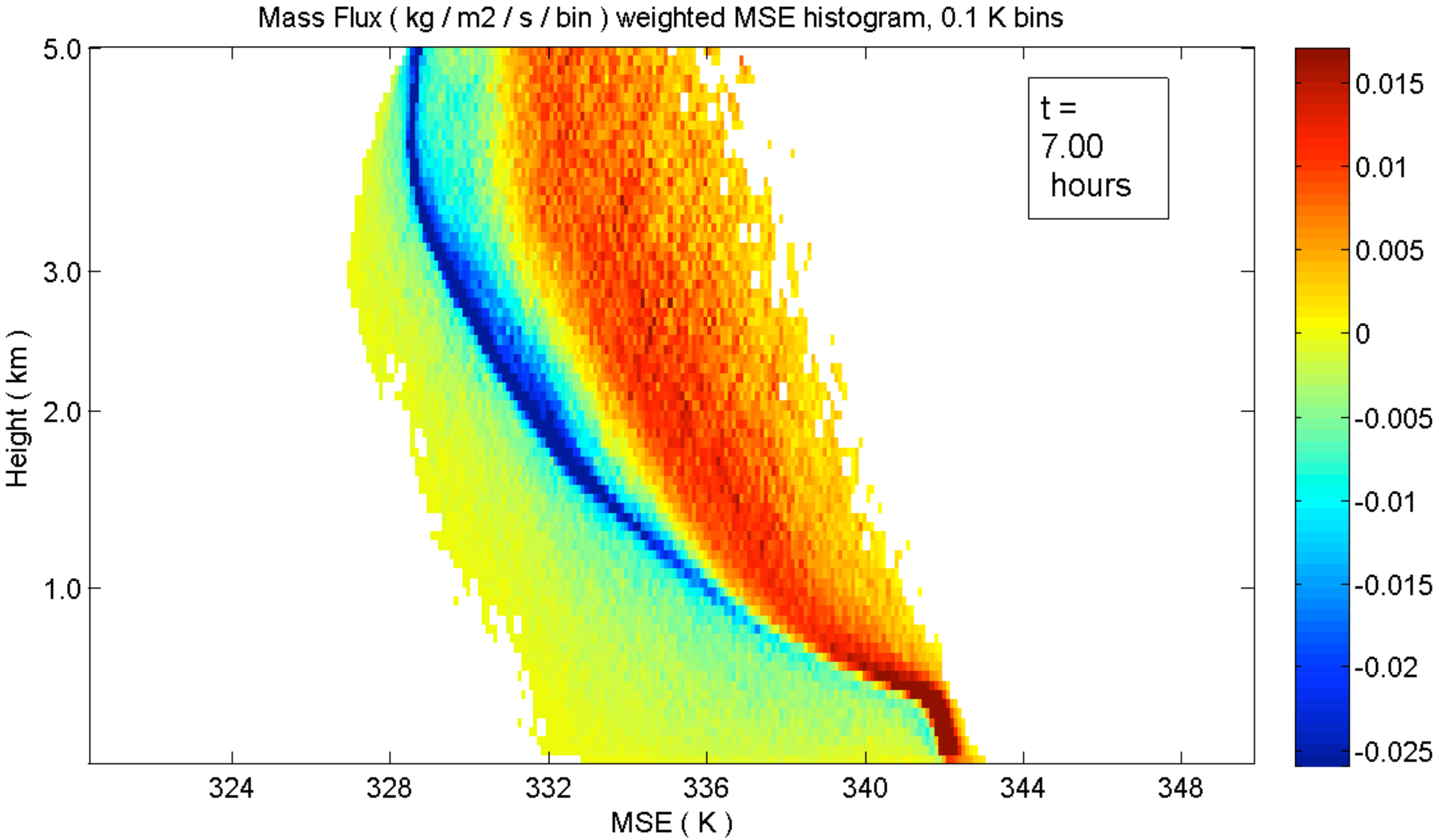


Congestus

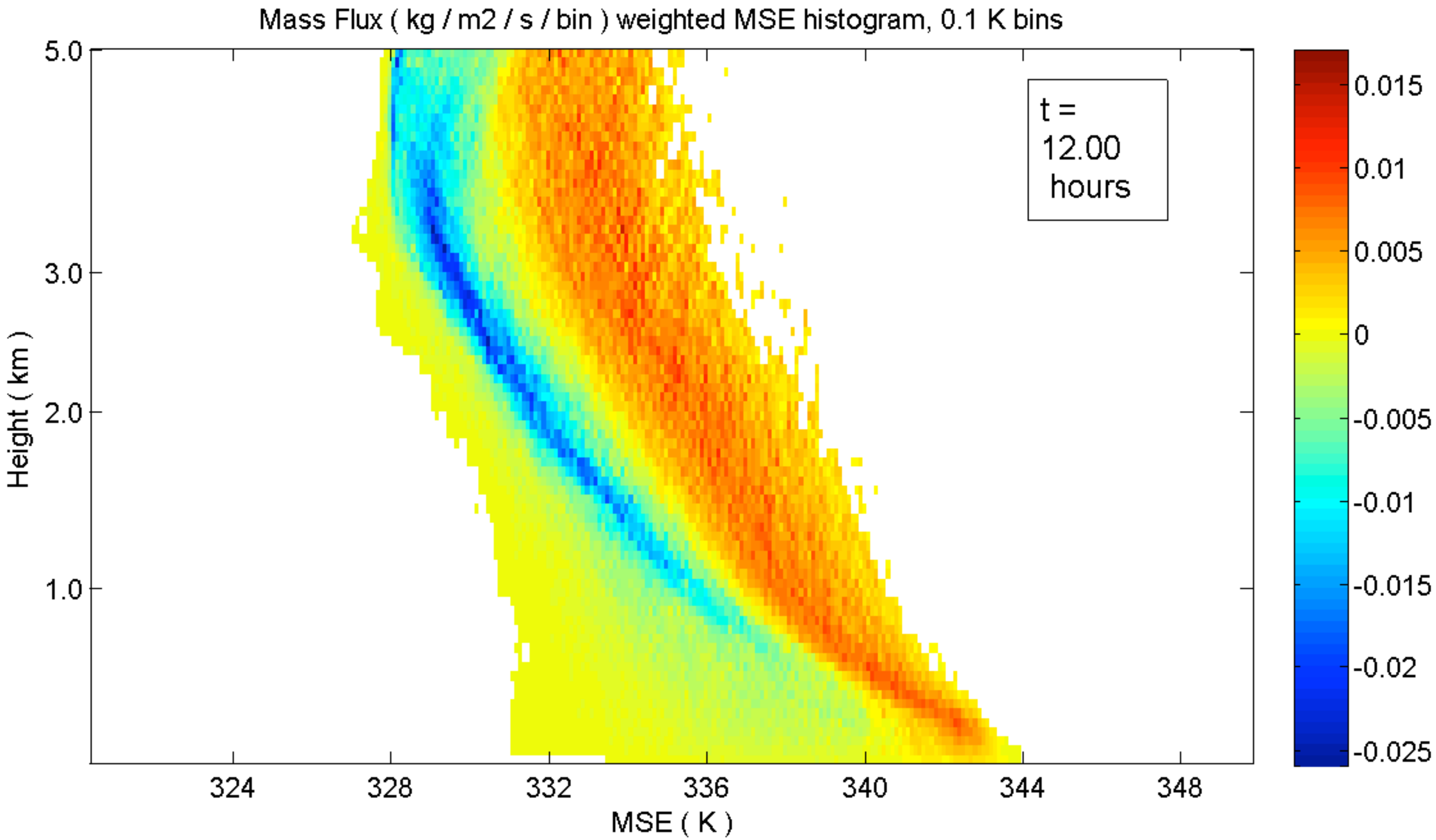


Mass Flux (kg / m2 / s / bin) weighted MSE histogram, 0.1 K bins
5.0
3.0
2.0
1.0
Height (km)
324
328
332
336
340
344
348
MSE (K)
t =
5.75
hours
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025

Vigorous Transition

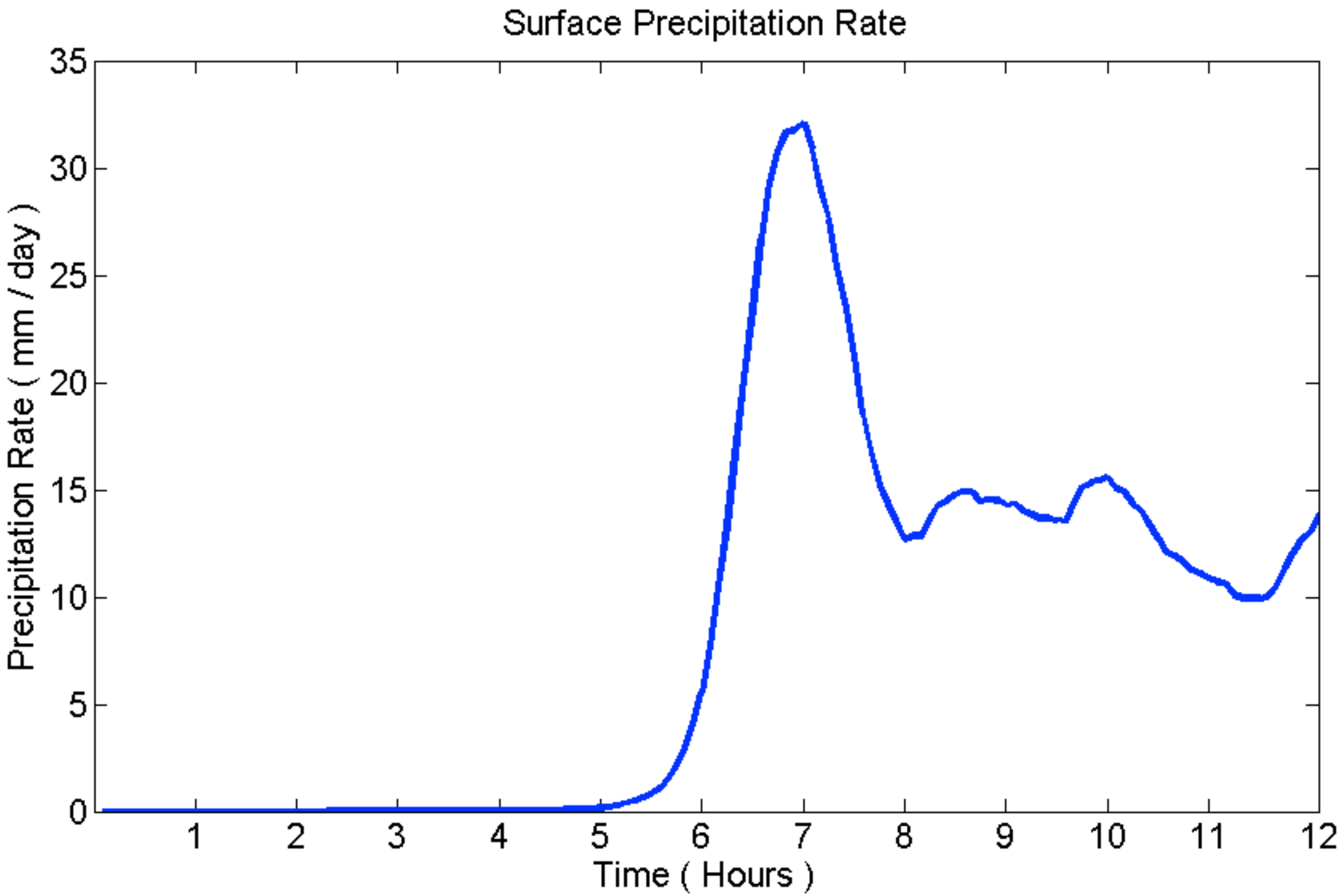


Deep Convection



Precipitation Rate Profiles

- High precipitation rate is sometimes the definition of "deep convection" (Fletcher and Bretherton 2010)
- Show peak rates occur at 7 hours into the simulation
- The depth through which the precipitation is falling increases over time
- And the rate increases dramatically, suddenly


Surface Precipitation Rate
Precipitation Rate (mm / day)
Time (Hours)
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12

Question concerning transition

- Does simulation show shallow Cu's precipitation needed to evaporate and form cold pools before vigorous deep convection can occur?

Question concerning transition

- Or does simulation show shallow Cu's moistening of upper levels

- Followed by strong over shooting deep convective heavy precipitation, then cold pools and stabilized deep convection

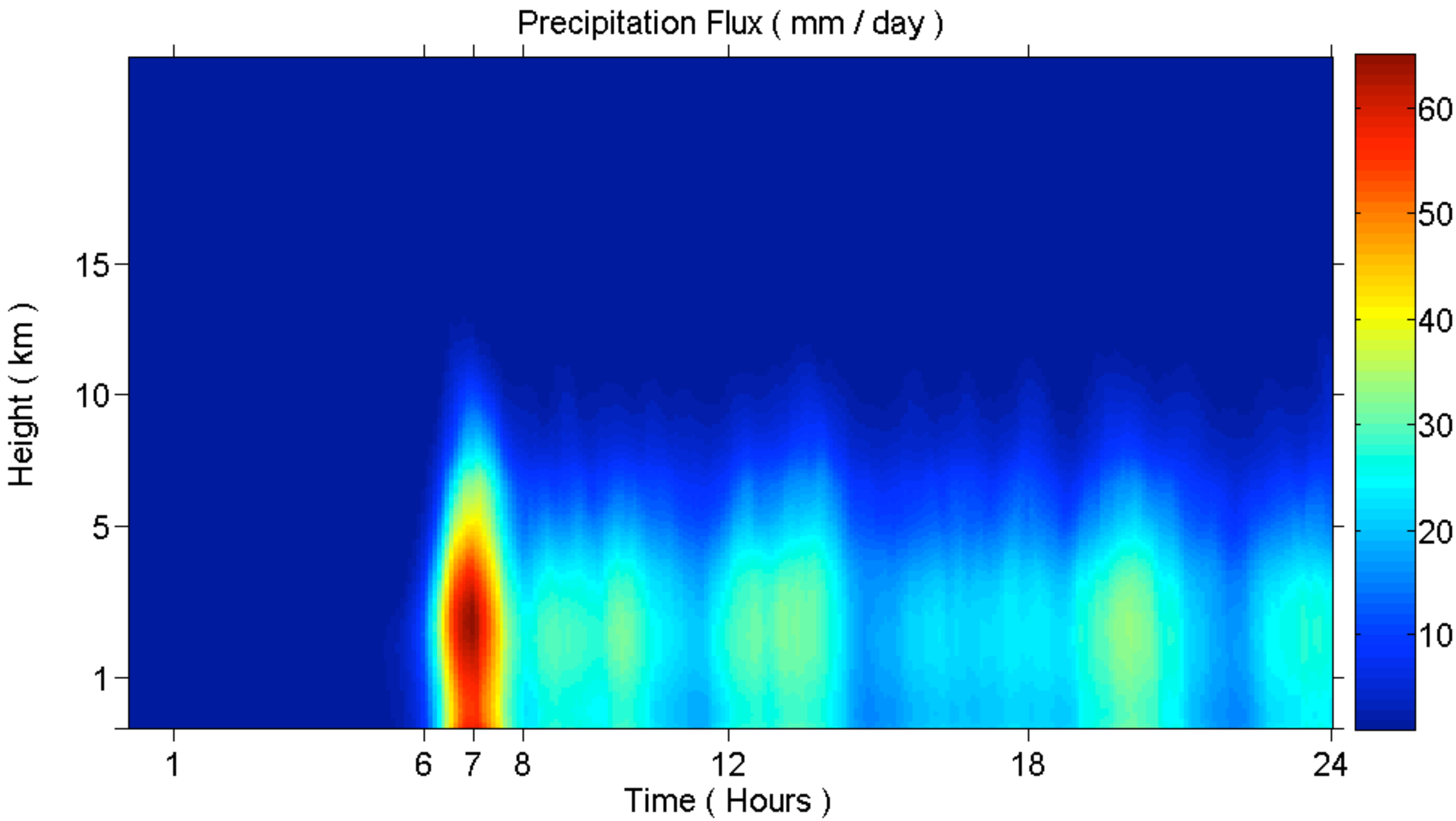
- Or something else?

Precipitation Flux

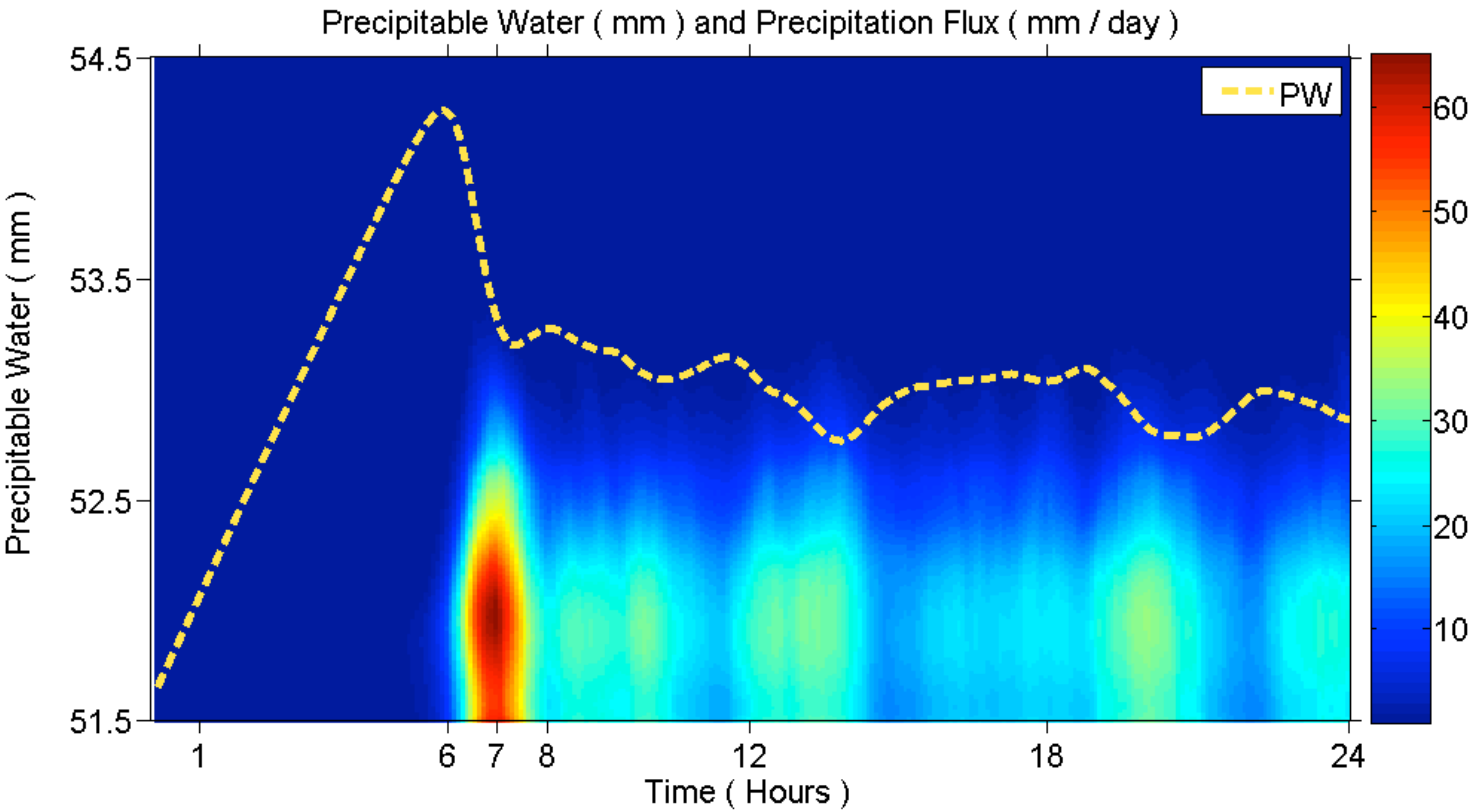
- Time-Height diagram of precipitation rate at each level (mm/day)

- Recall Maximum Surface Precipitation Rate at 7 hours

Precipitation Flux



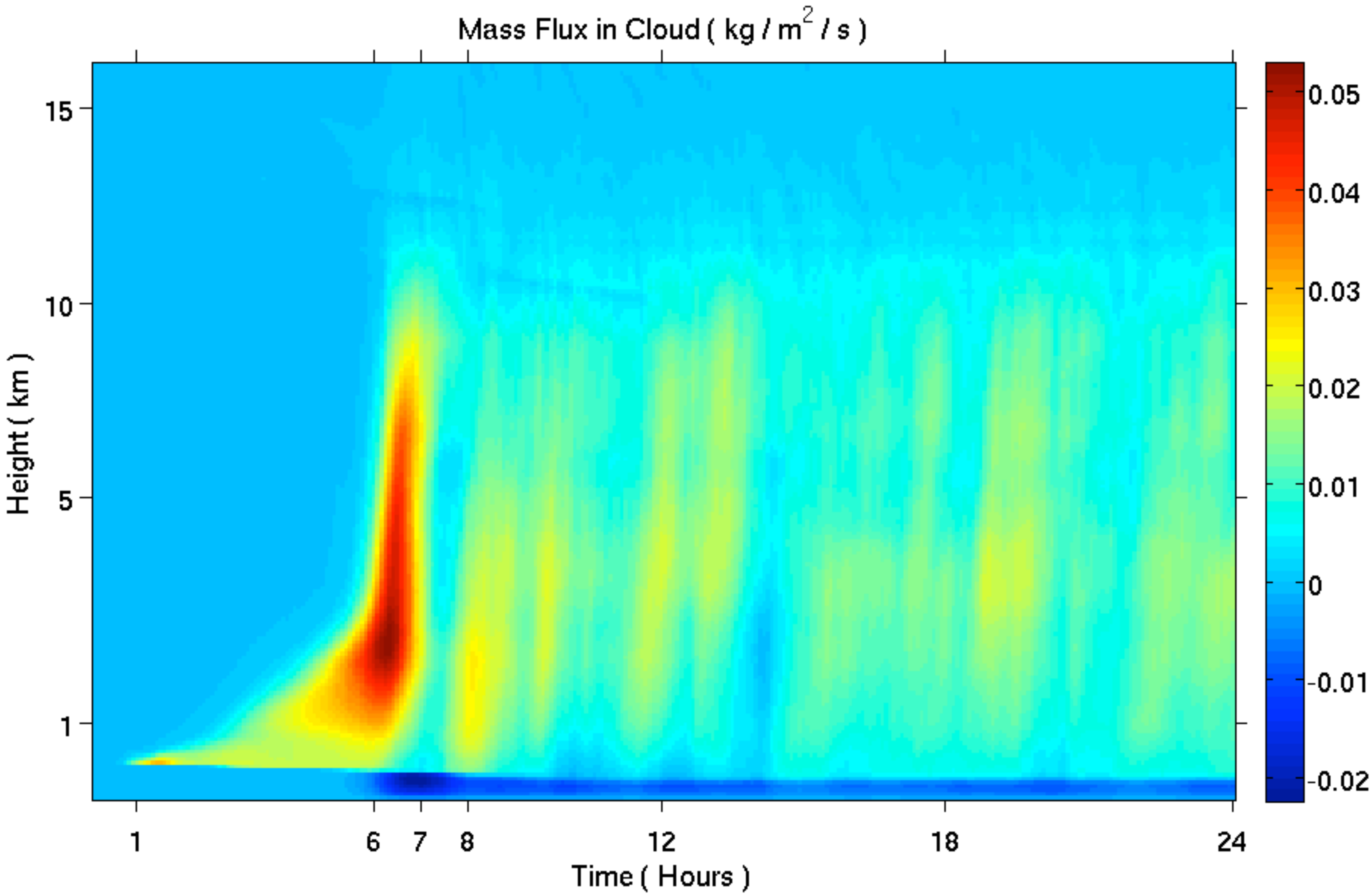
Precipitable Water



Precipitation Flux

- Is the early PW trend due to large scale prescribed tendency?

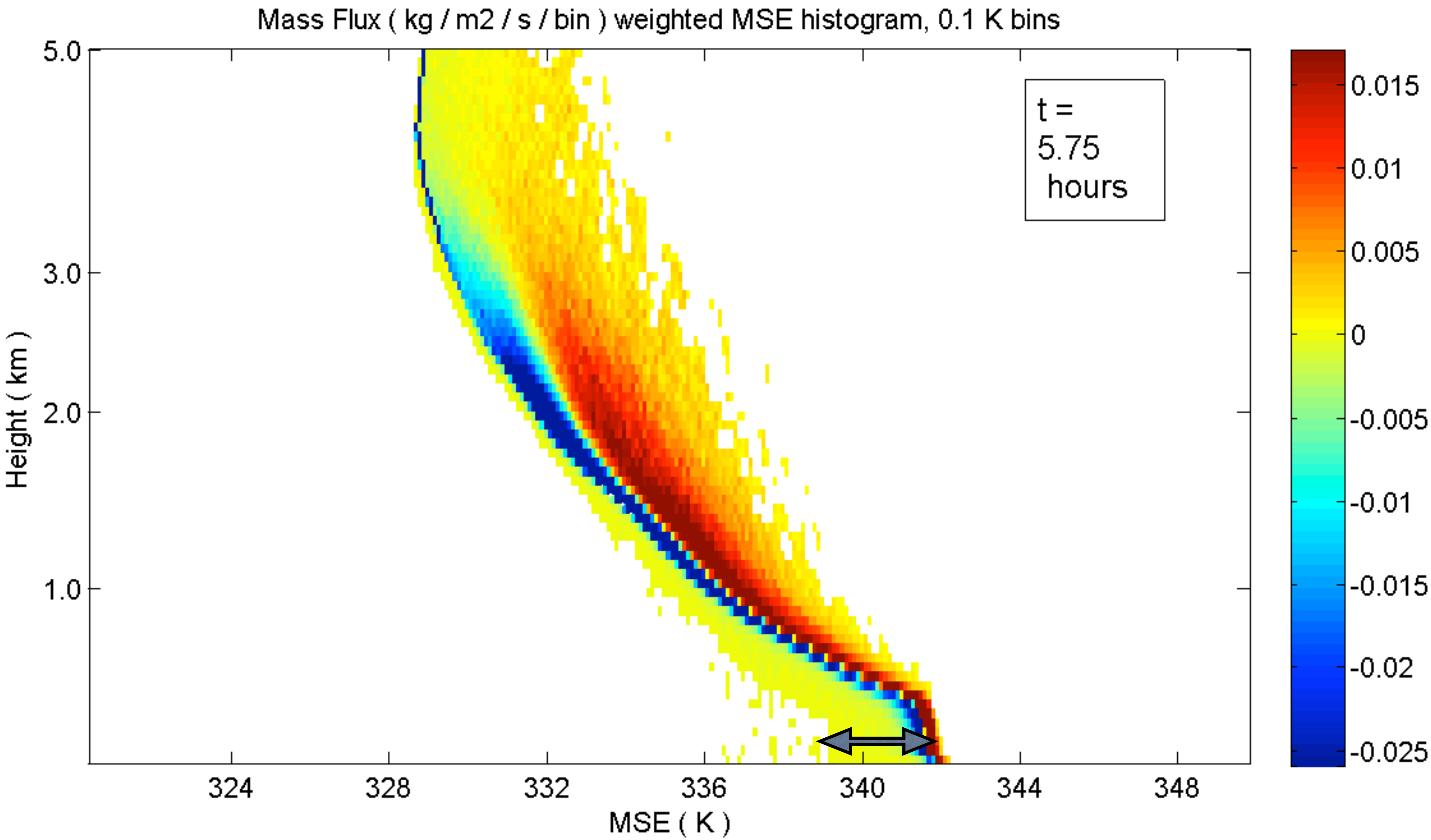
Mass Flux in Cloudy Cells: Note Negative Flux at 7 Hrs



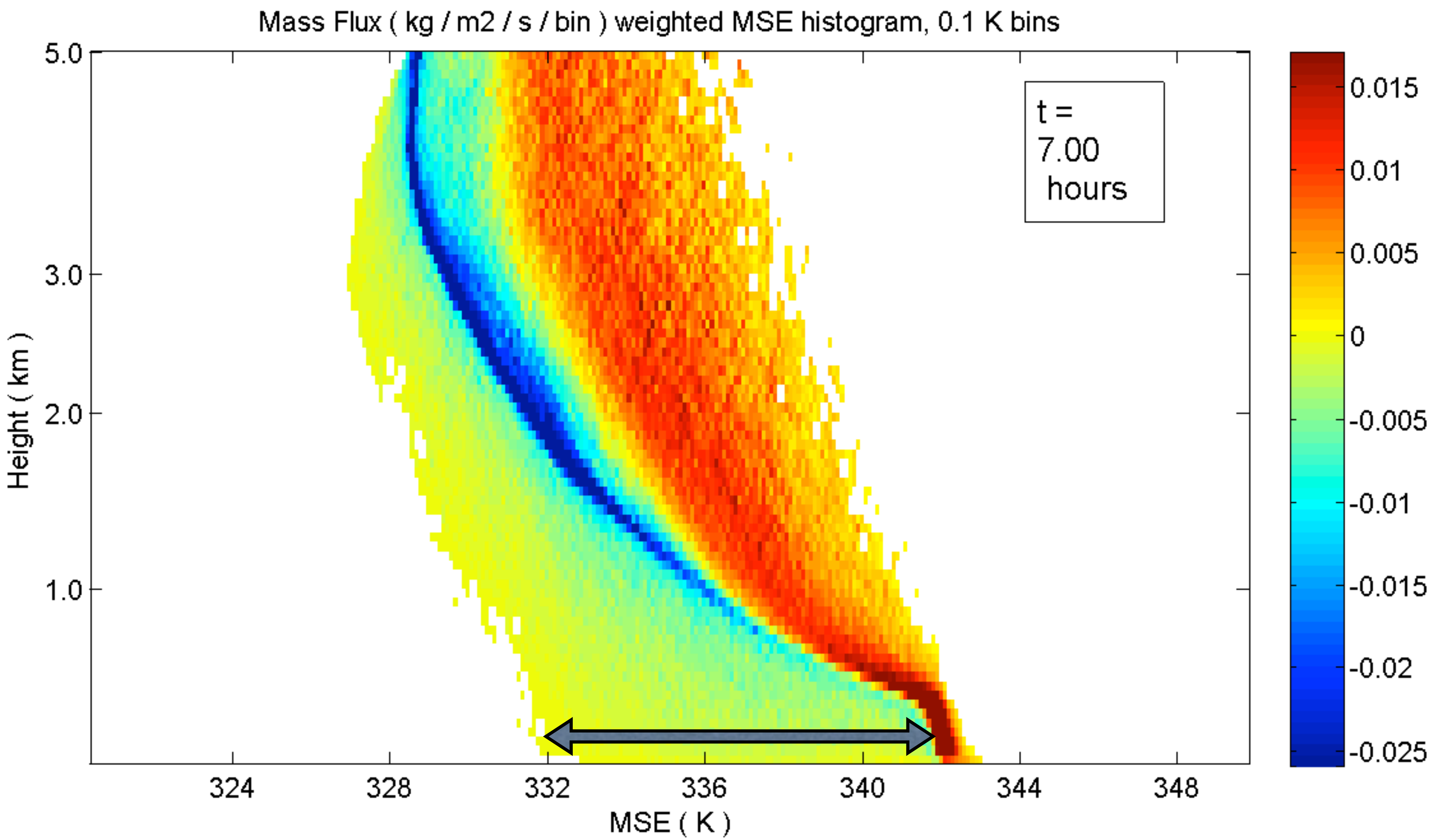
Cold Pools Timing

- The low level mass flux between 6-8 hours shows the formation of the cold pools
- Another way is to look at the variance of the MSE in the downdrafts

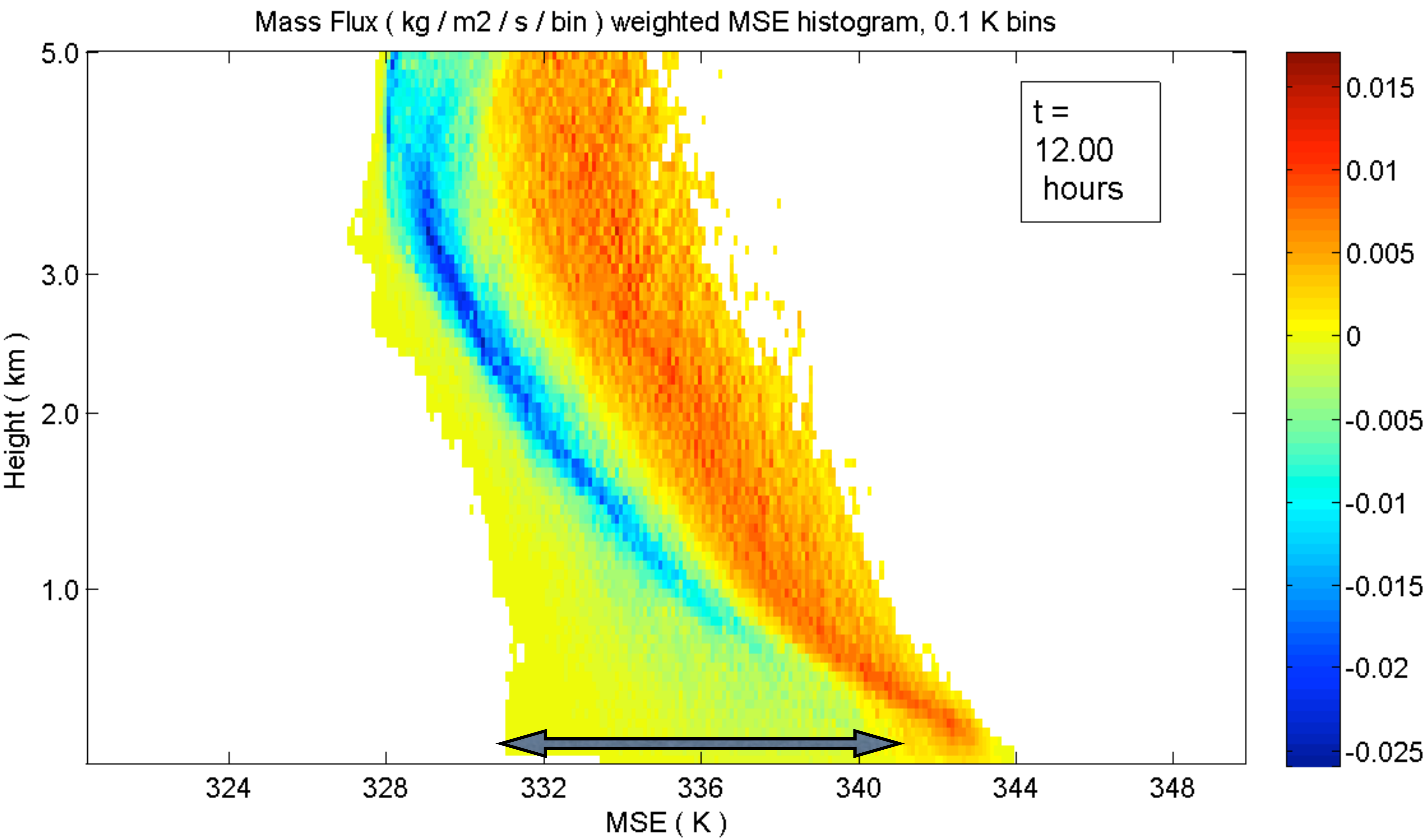
SFC Rain Rate = 2 mm/day



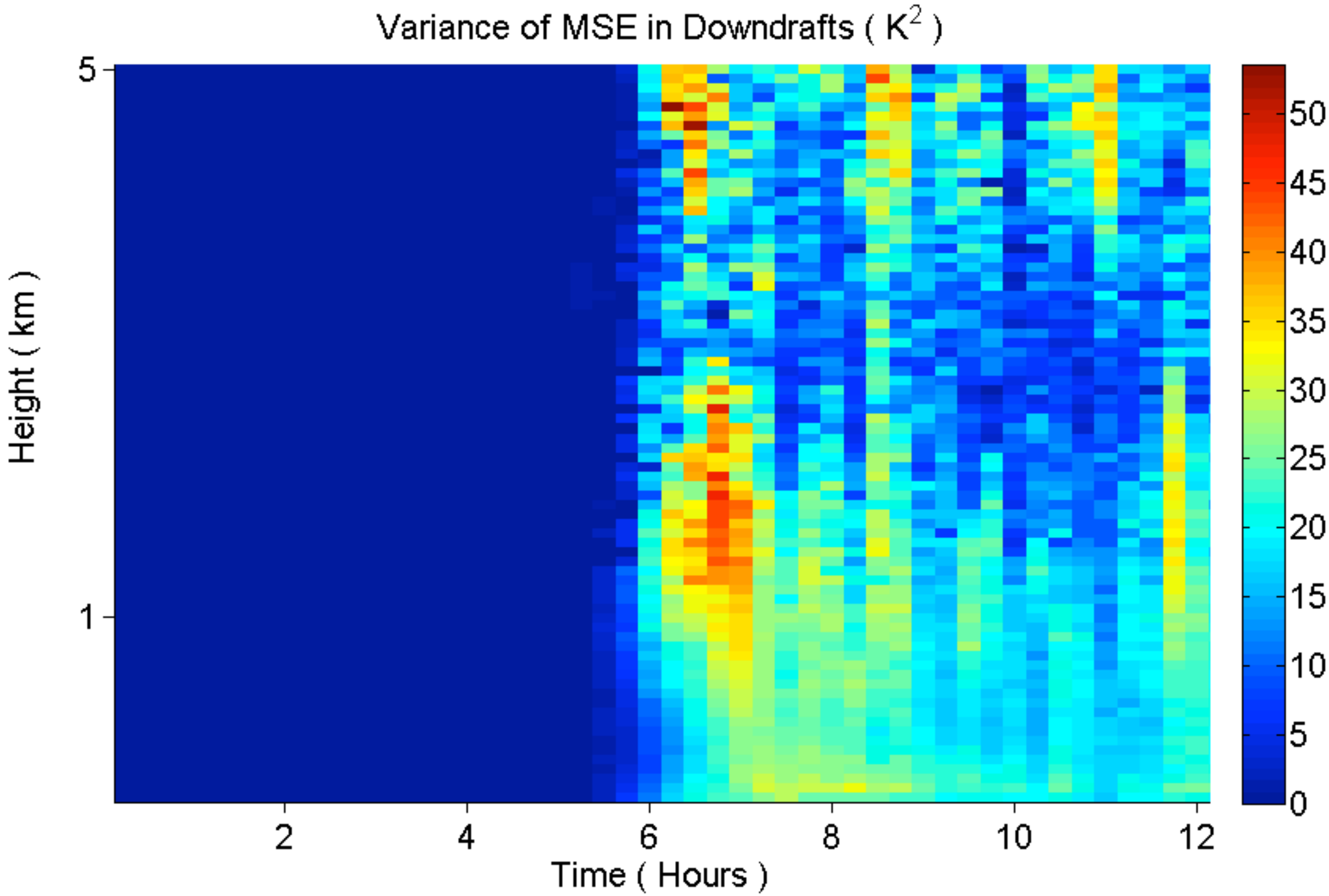
Sfc Rain Rate = 31 mm/day



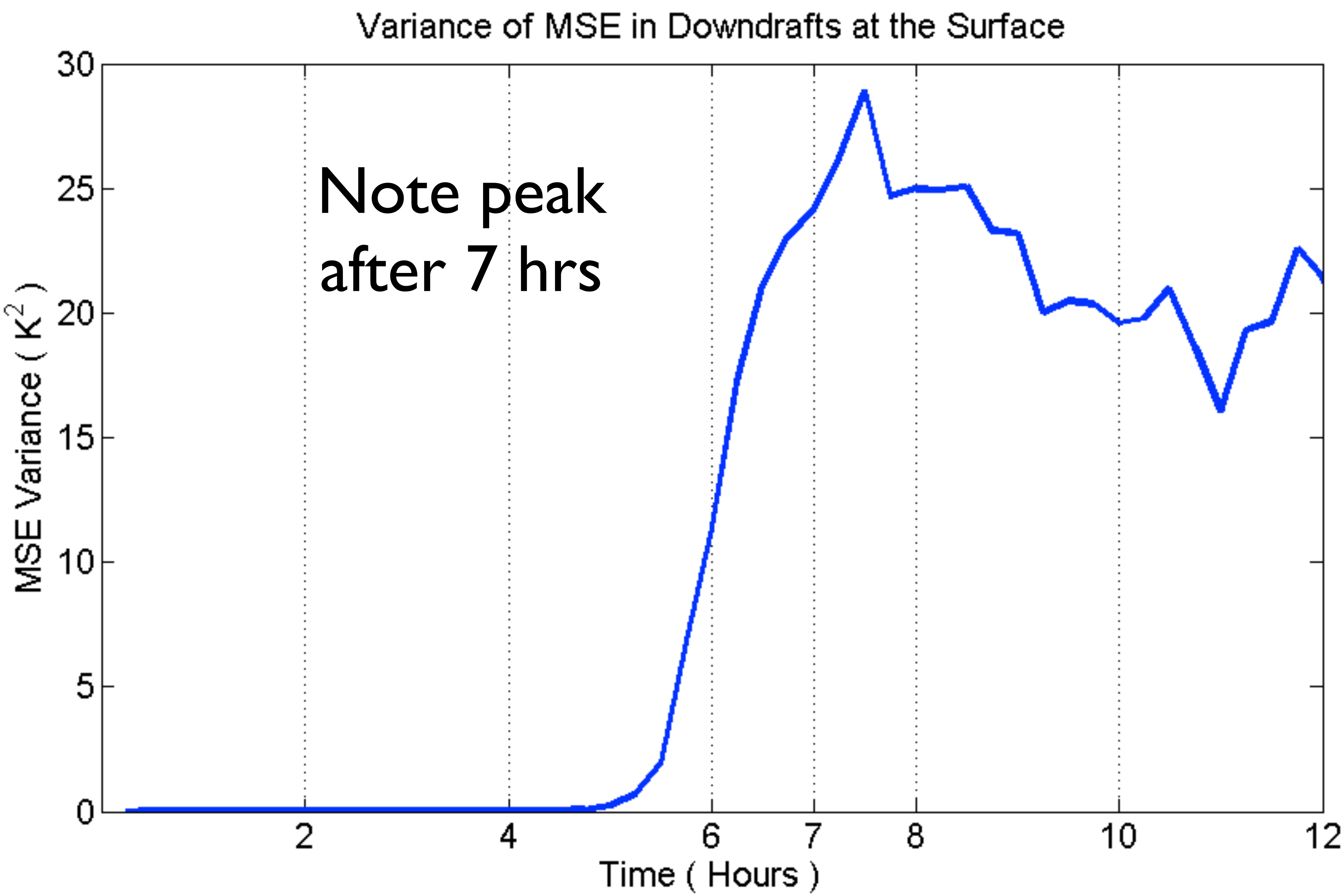
Sfc Rain Rate = 14 mm/day



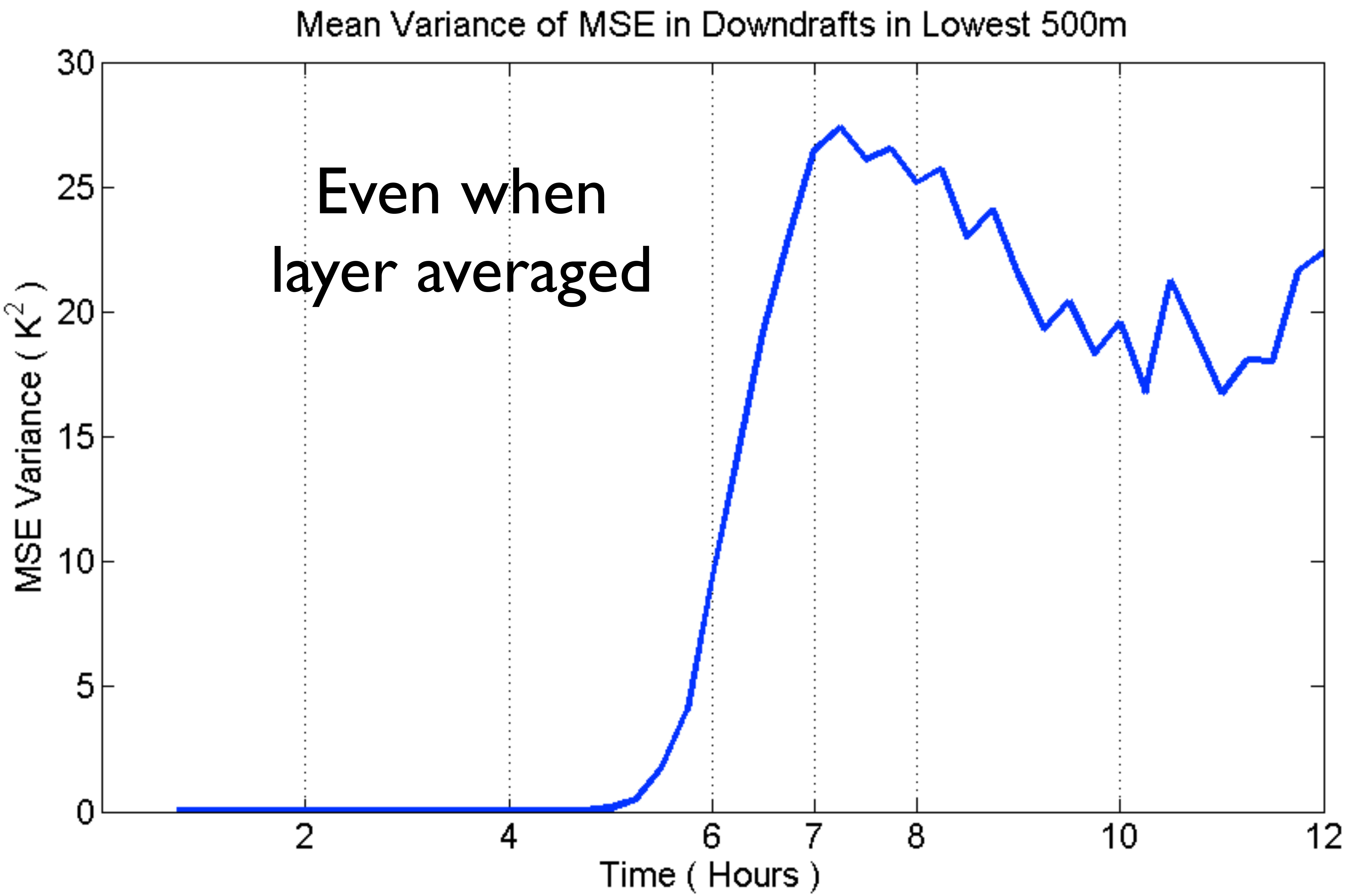
MSE Variance below 5 km



Downdraft MSE Variance at SFC



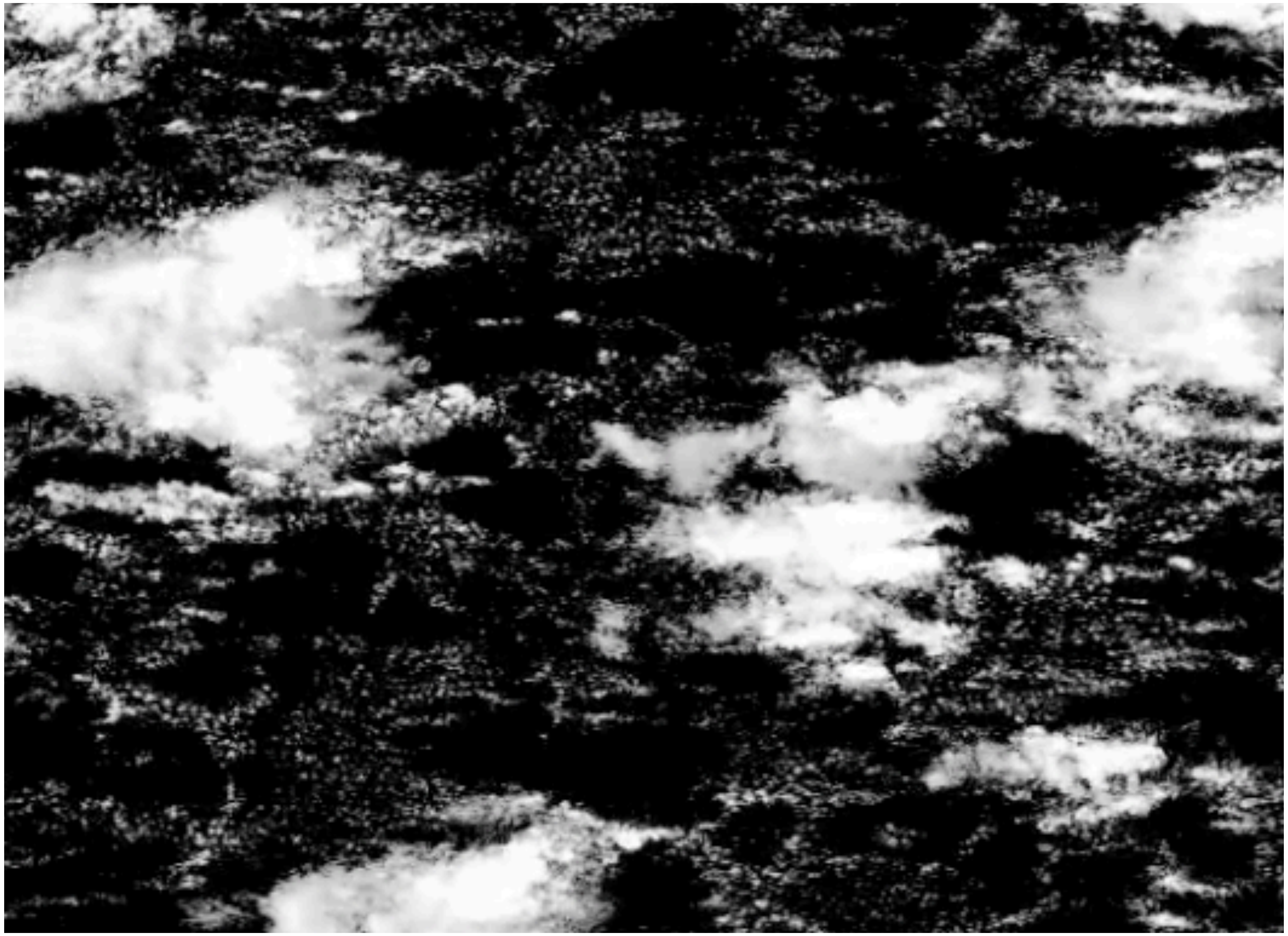
Mean MSE Variance Below 500m



Transition

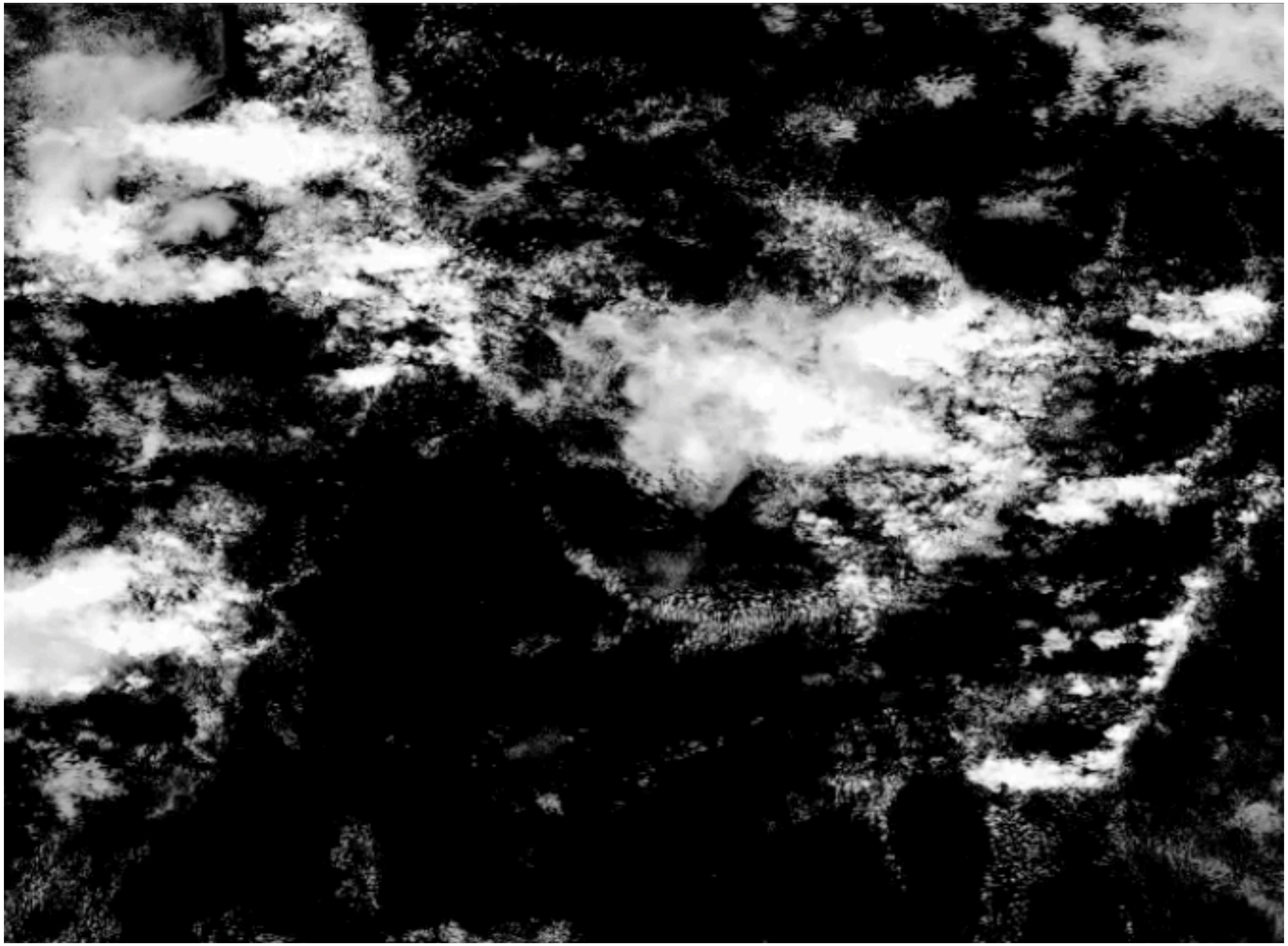
- What happens to the shallow Cu after deep convection forms?
- CWP shows their disappearance

Transition



CWP at t = 7 hours

Deep Convection

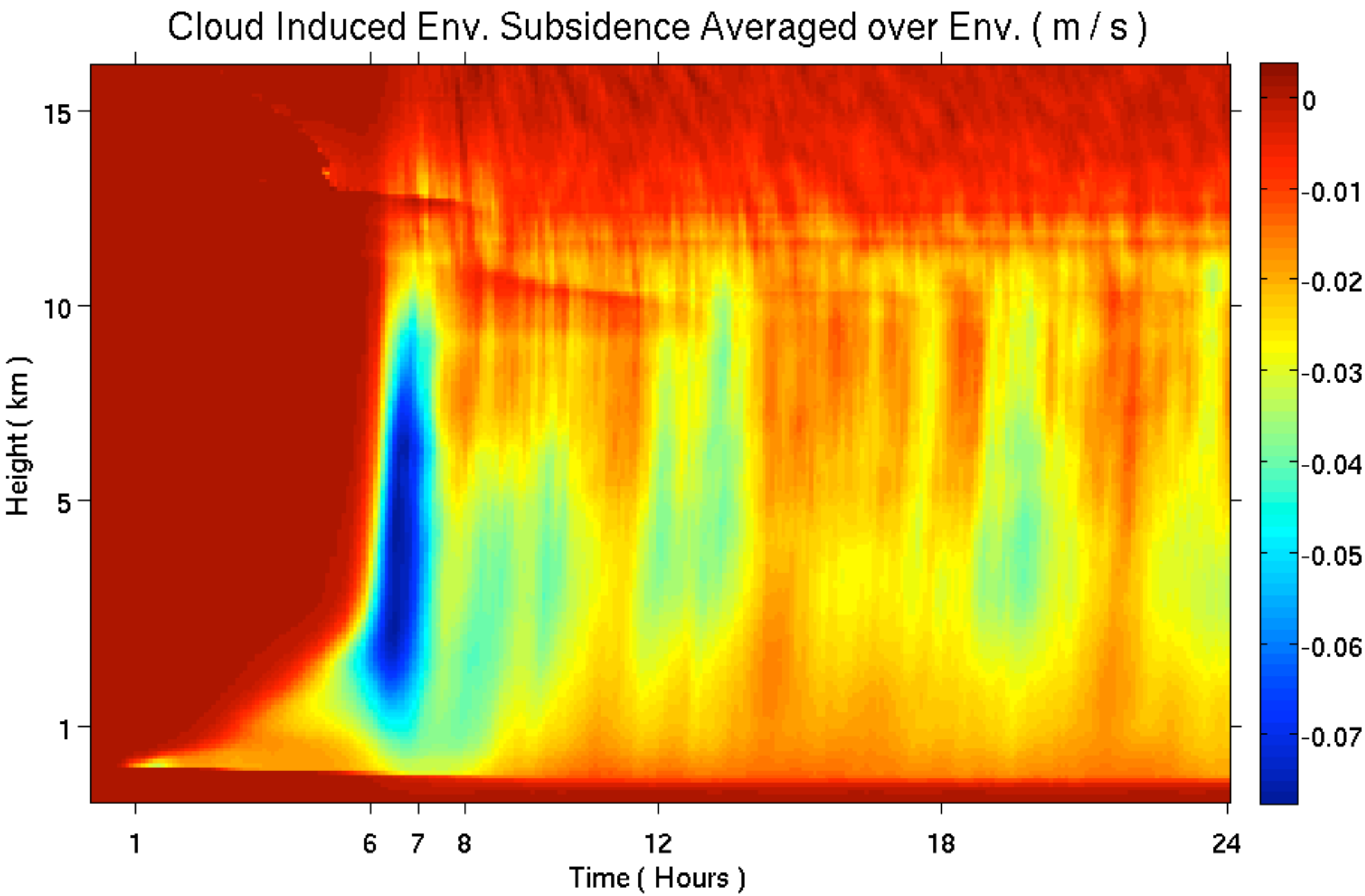


CWP at t = 12 hours

Transition

- Since mass flux and vertical velocity is necessarily zero averaged over the domain at any level
- Vigorous cumulus updrafts induce environmental subsidence
- Shallow convection is supressed

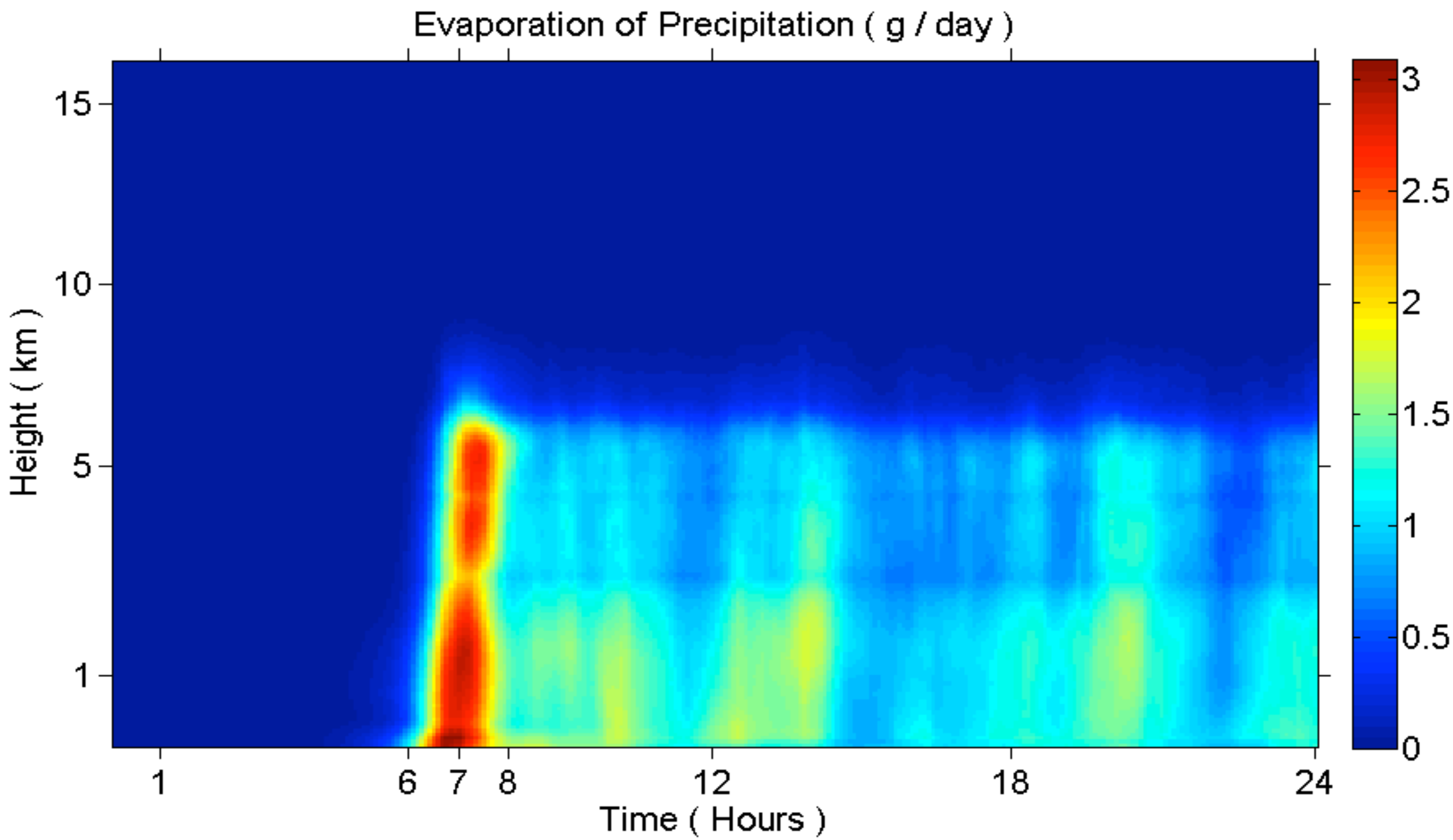
Cu Induced Subsidence



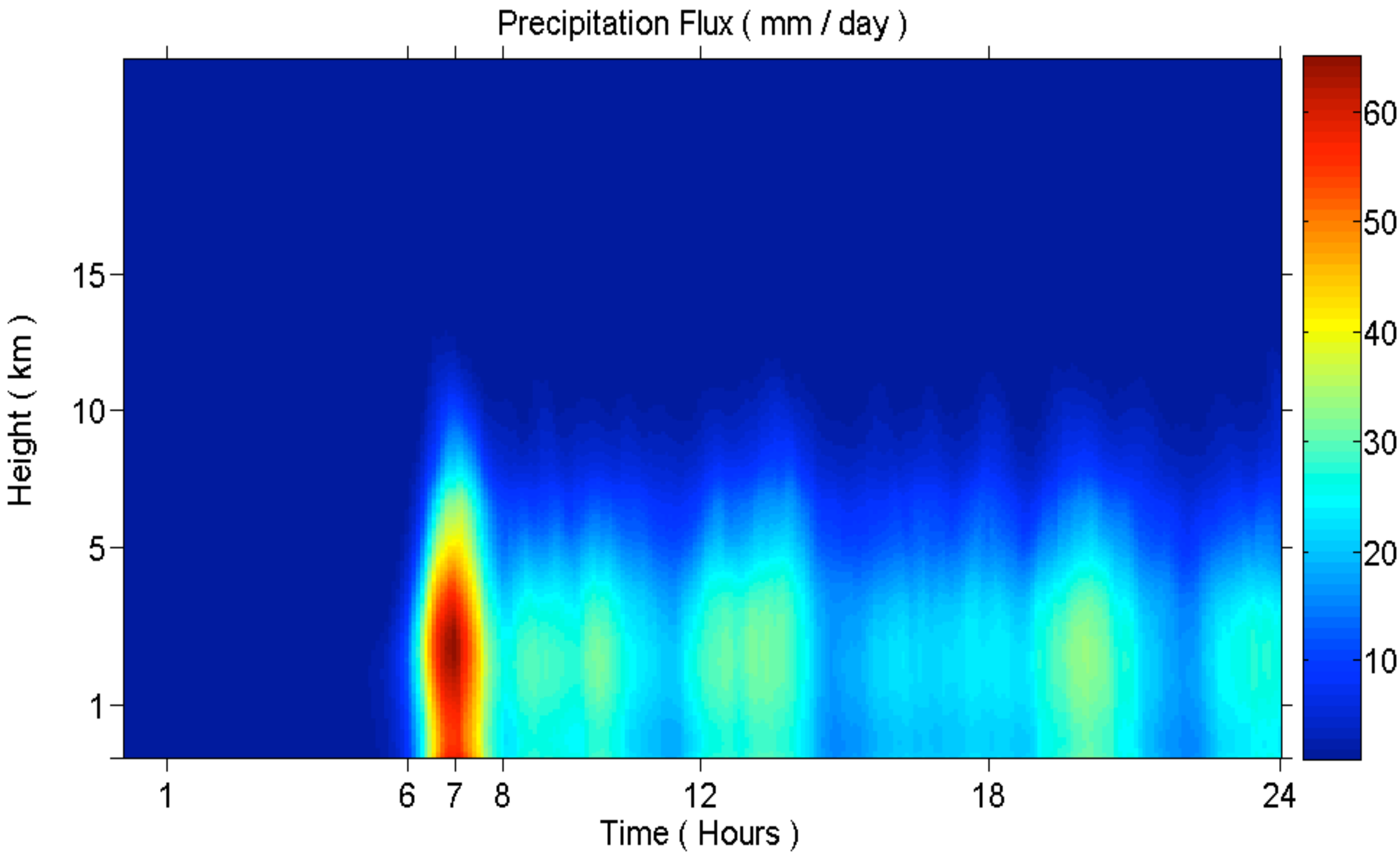
Cold Pools Timing

- The evaporation of precipitation is linked to cold pool formation (Khairoutdinov et al. 2009 Fig. 7)

Evaporation



Precipitation Flux



Summary:
Cold Pools

- High precipitation rate is sometimes the definition of "deep convection" (Fletcher and Bretherton 2010)

- Highest precipitation rates precede cold pool formation

- In GIGA-LES, vigorous deep convection precedes cold pool formation

Summary:
Vigorous Deep Convection

- Occurs after moistening of mid-layers
- Has highest precipitation rates
- Begins to inhibit shallow Cu by the deep Cu induced subsidence
- Precedes steady state cold pool regime
- The transition from shallow to deep convection is complete in GIGA-LES

References

- Fletcher, J. K. and Bretherton, C. S.: Evaluating boundary layer-based mass flux closures using cloud-resolving model simulations of deep convection, J. Atmos. Sci., 67, 2212–2225, 2010.
- Khairoutdinov, M. F., S. K. Krueger, C.-H. Moeng, P. A. Bogenschutz and D. A. Randall, (2009): Large-eddy simulation of maritime deep tropical convection. *J. Adv. Model. Earth Syst.*, *1*, Art. #15, 13 pp., doi:10.3894/JAMES.2009.1.15
- Kuang, Z., and C. Bretherton, 2006: A mass-flux scheme view of a high-resolution simulation of a transition from shallow to deep cumulus convection. J. Atmos. Sci., 63, 1895–1909.
- Lin, C.-C., and A. Arakawa, 1997: The macroscopic entrainment processes of simulated cumulus ensemble. Part II: Testing the entraining-plume model. J. Atmos. Sci., 54, 1044–1053.