Does convection select moist environments?

Martin Köhler, Thijs Heus, Olaf Stiller

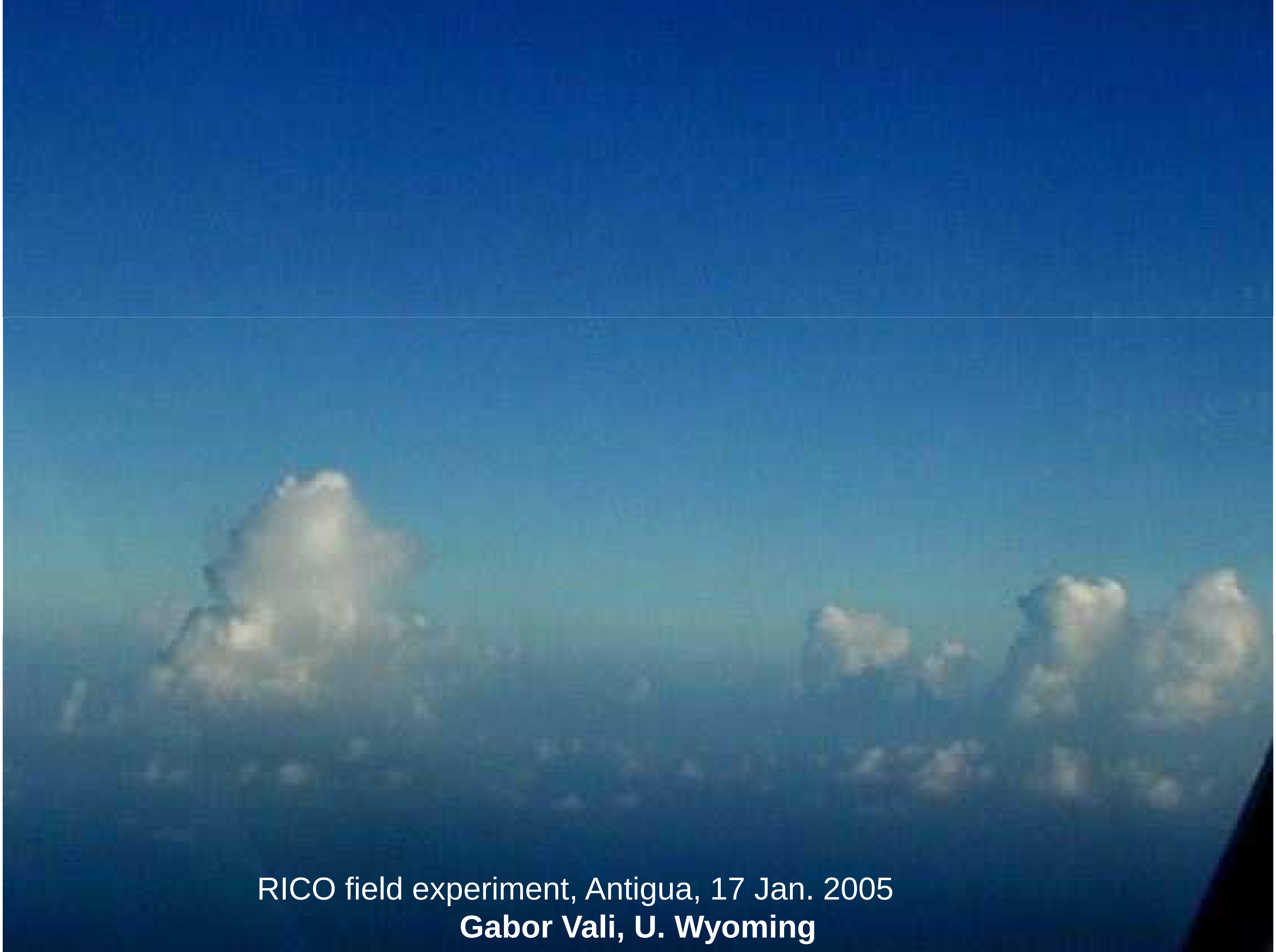
- idea
- cloud bubbles in an LES model
- shallow cumulus parameterization

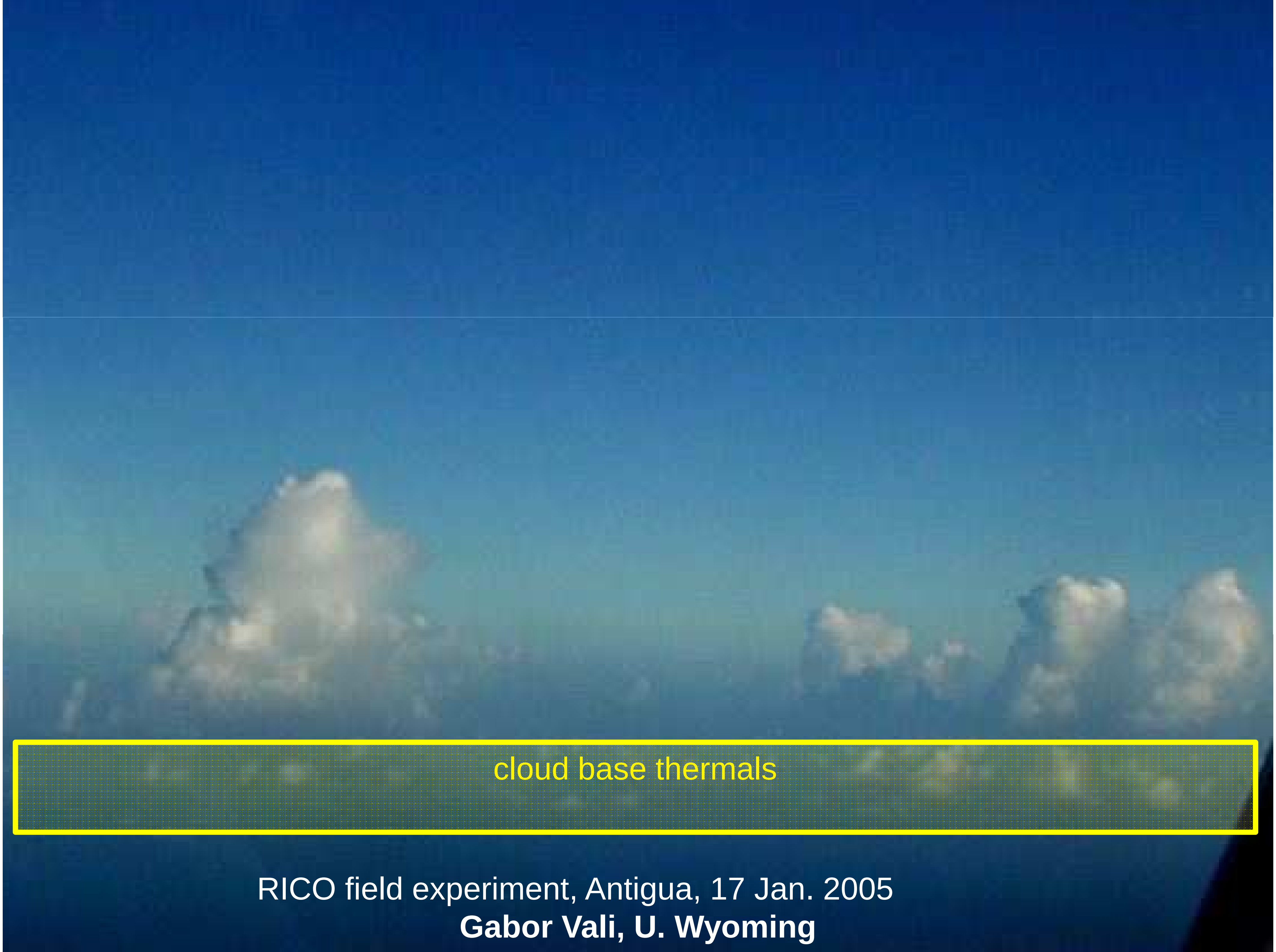
Does convection select moist environments?

Brian Mapes (~1995 cloud modeling meeting):

Postulates that convection selects favourable environment.

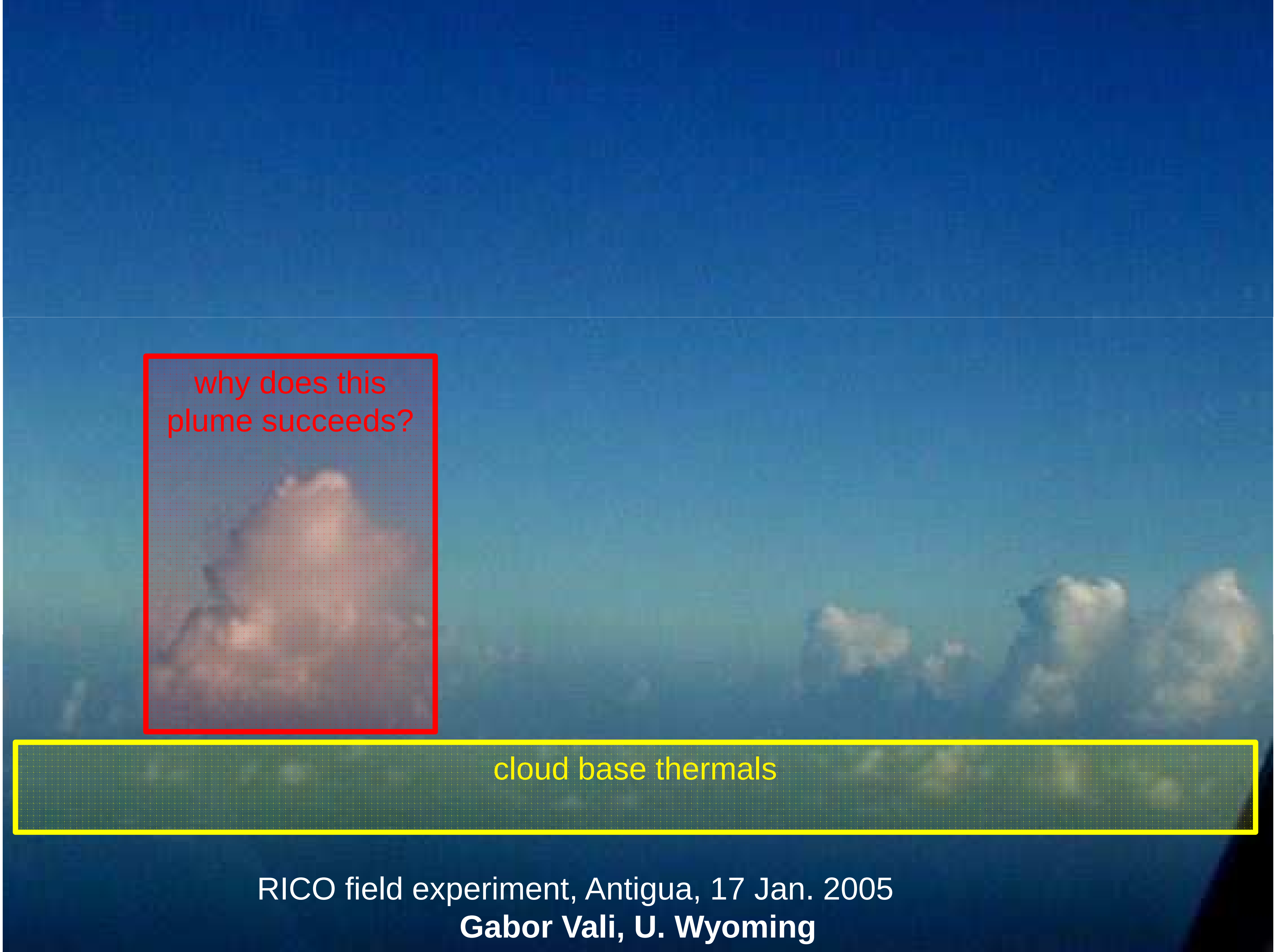
Storm filled horizon, Red Bluff, California. U.S.
Michele Sholaas, cloudappreciationsociety.org


RICO field experiment, Antigua, 17 Jan. 2005
Gabor Vali, U. Wyoming



RICO field experiment, Antigua, 17 Jan. 2005

Gabor Vali, U. Wyoming


why does this plume succeeds?
cloud base thermals
RICO field experiment, Antigua, 17 Jan. 2005
Gabor Vali, U. Wyoming

Redelsperger et al 2002: moisture recovery

q_v radiosonde TOGA COARE

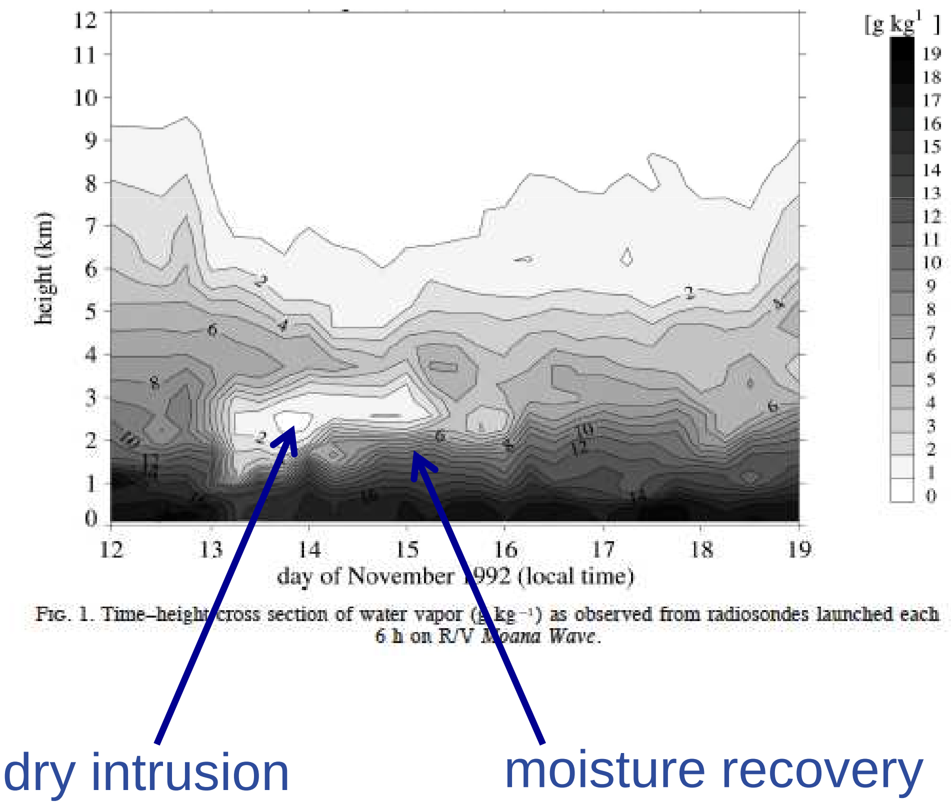


FIG. 1. Time–height cross section of water vapor (g kg^{-1}) as observed from radiosondes launched each 6 h on R/V *Moana Wave*.

"The moisture in the lower and middle troposphere recovered in large part from clouds repeatedly penetrating into the dry air mass."

Burnet, Brenguier 2010: SCMS shallow cumulus

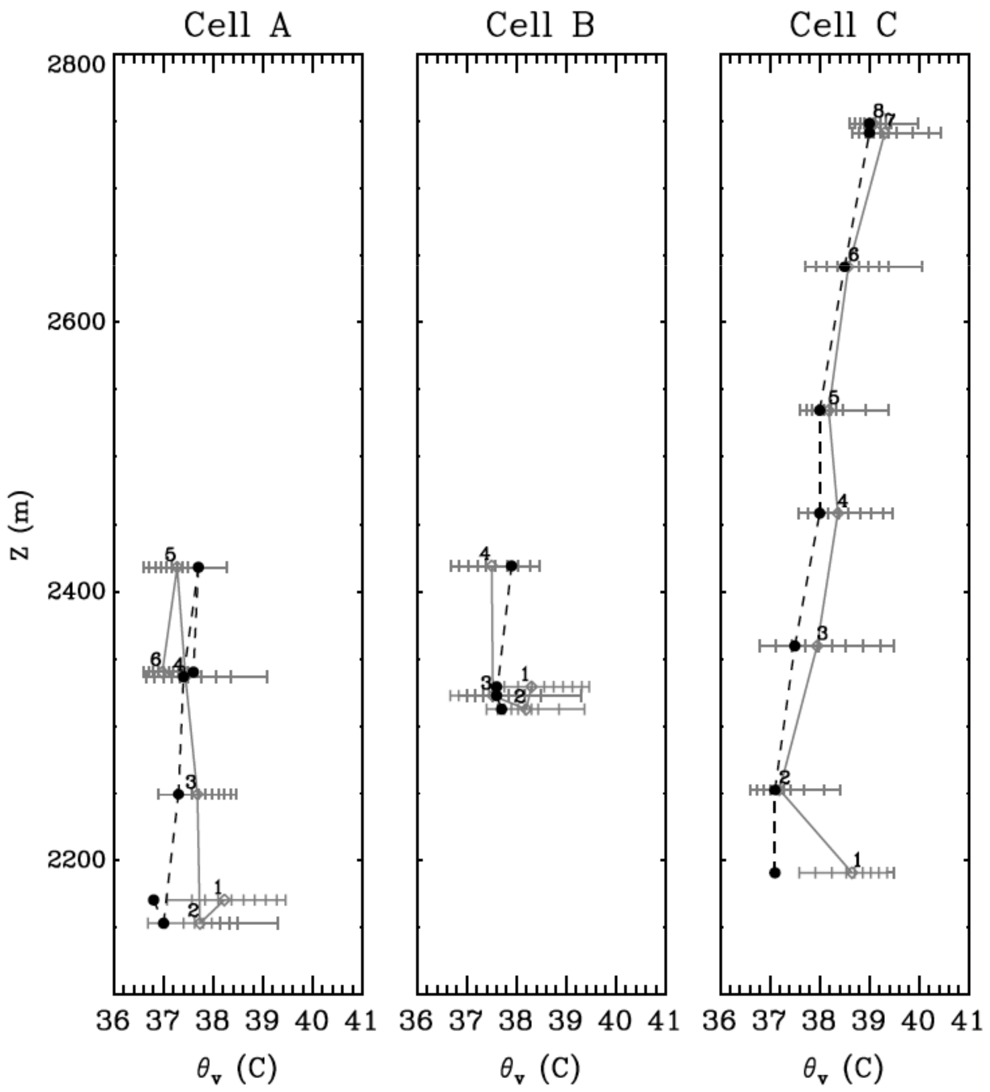
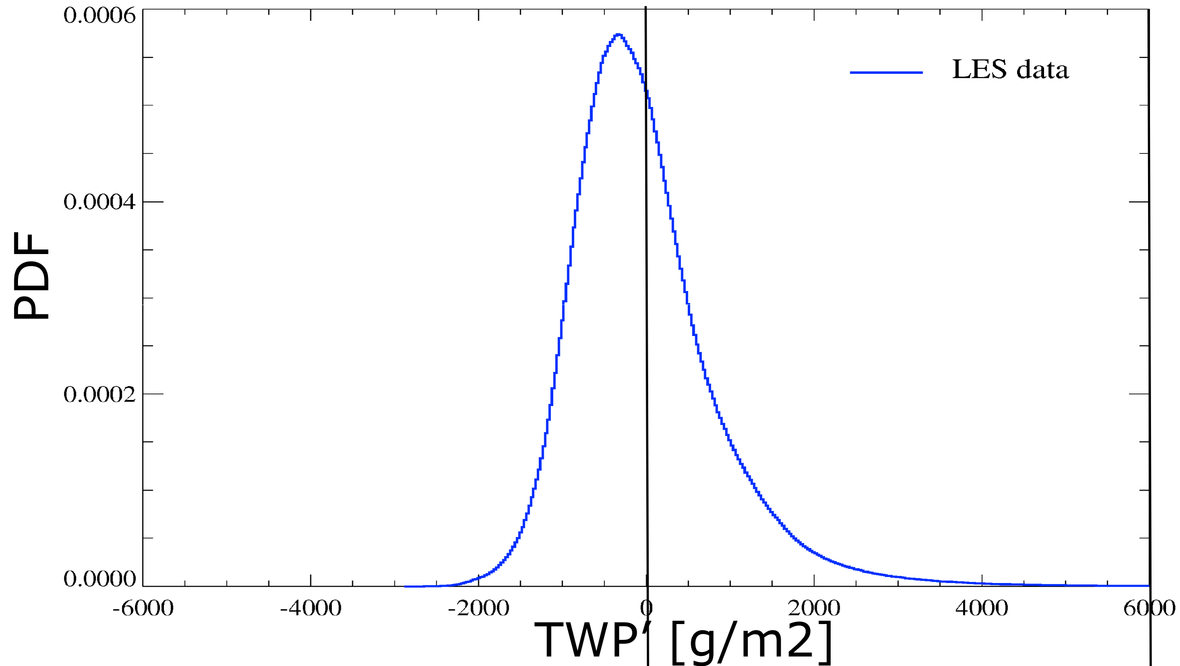
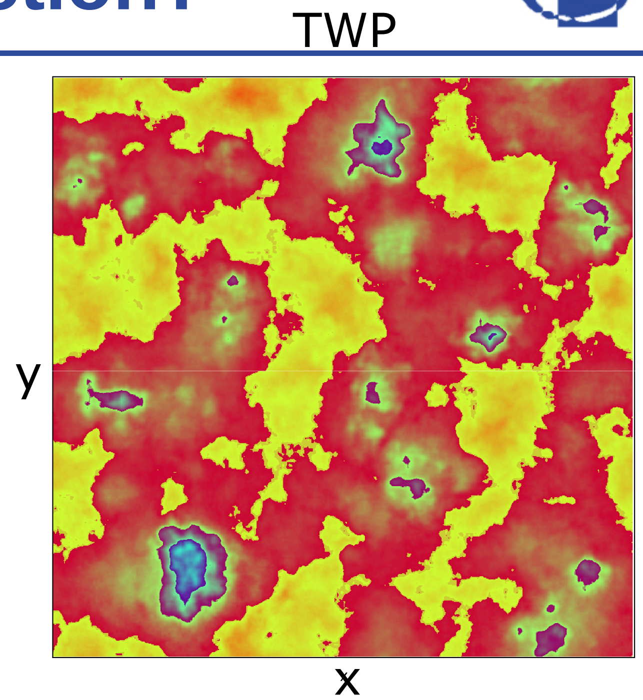


Figure 7. Vertical profiles of virtual potential temperature in the environment (black dots) and in cloud (grey) with mean (diamonds) and deciles of each cloud traverse statistics, for the three cloud cells (same dataset as in Figure 3(d)).

"The reasons why the third cloud reaches a higher altitude possibly includes pre-moistening of its environment."

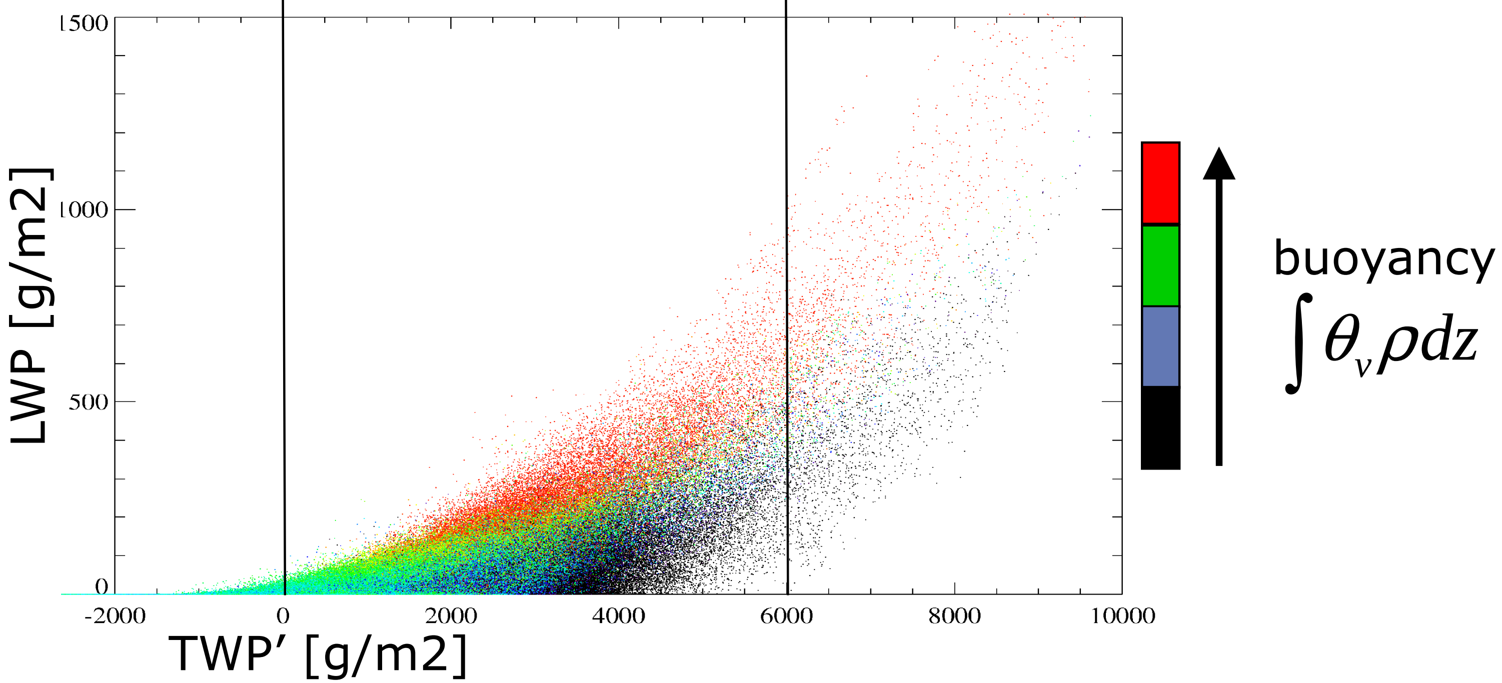
BOMEX LES   convective moist selection?





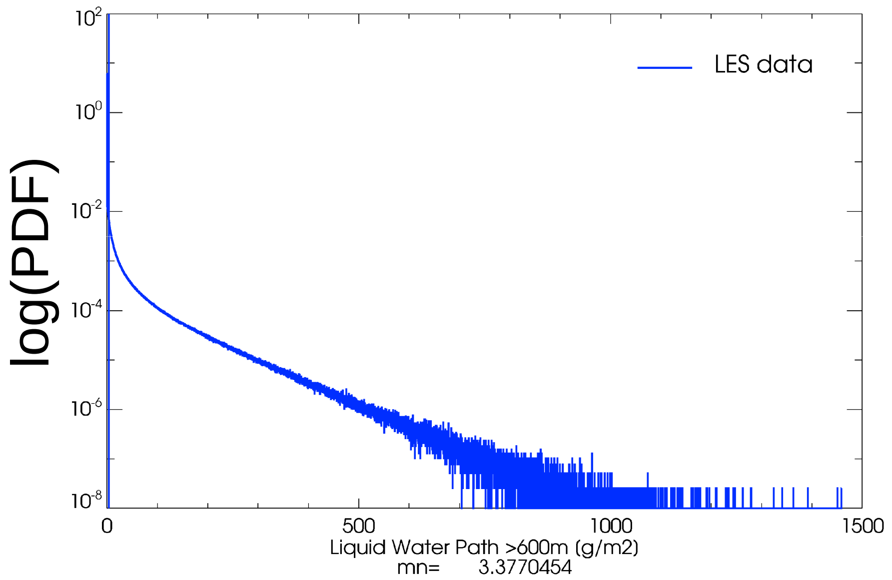
LES:

no shear
dx=*dy*=25m, *dt*=30s
duration: 20h
12.8km x 12.8km

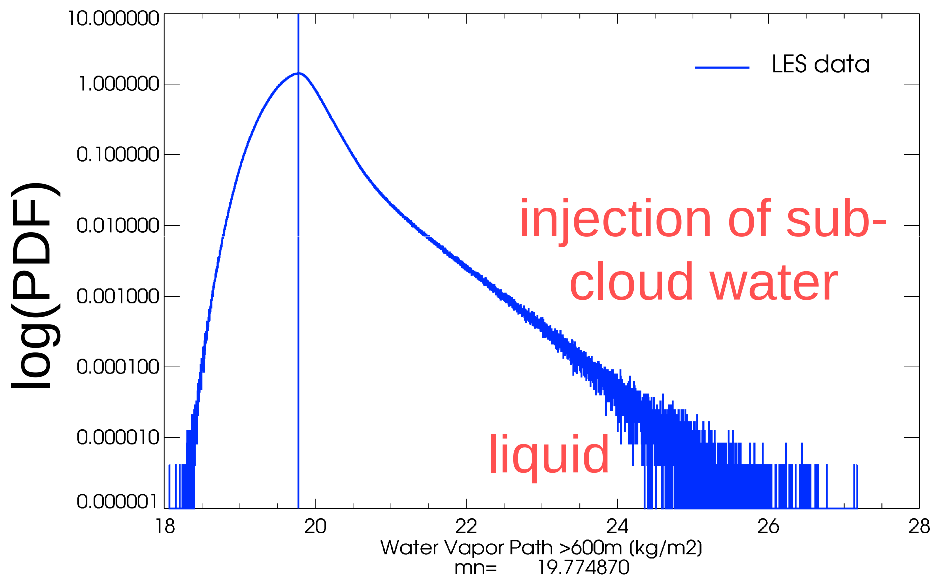


BOMEX LES: PDF above cloud base (600m)

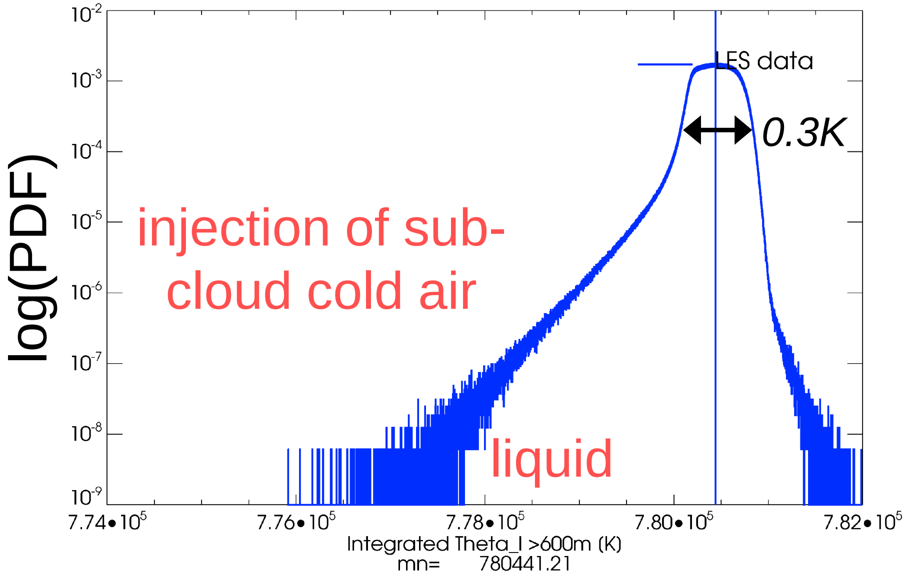
LWP above 600m



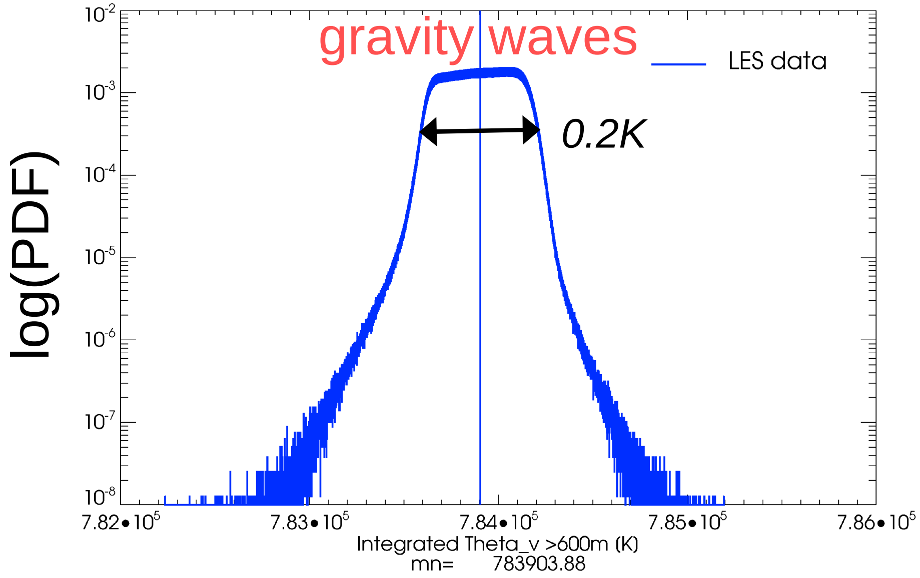
TWP above 600m



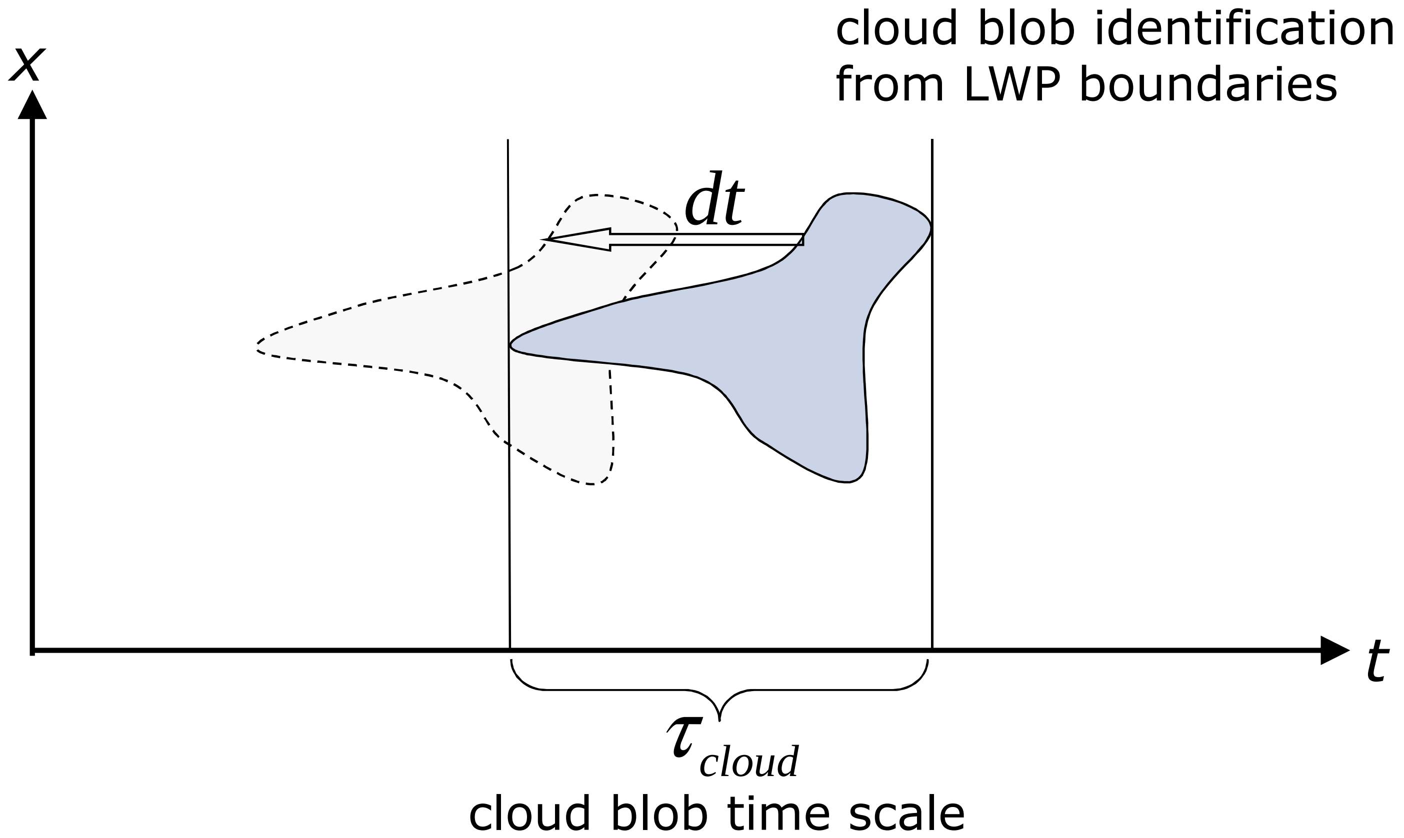
mean θ_l above 600m



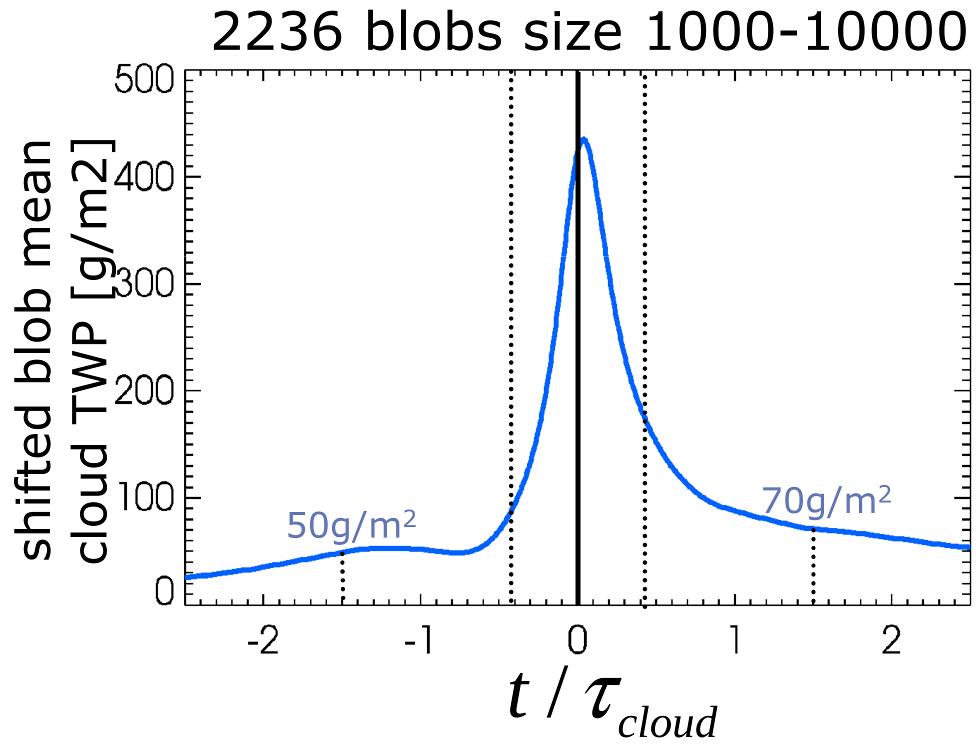
mean θ_v above 600m



BOMEX LES: cloud blobs



BOMEX LES: cloud blobs



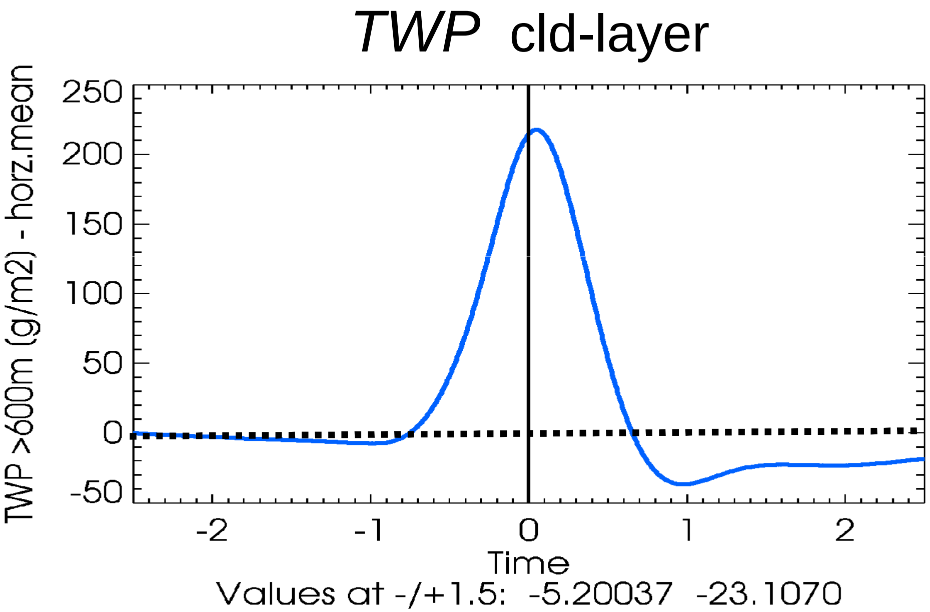
Time, lagged around blob center, normalized by blob time scale

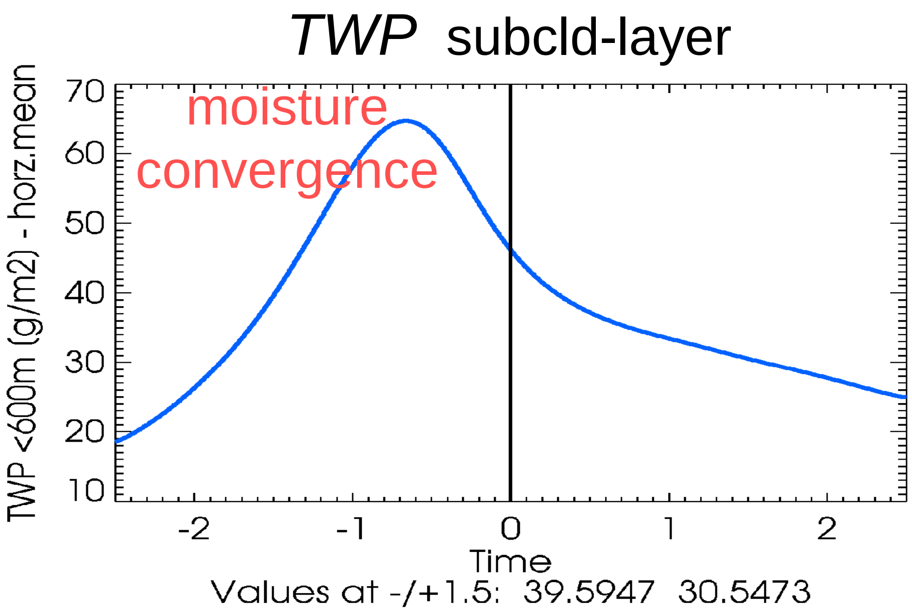
blobs size 1000: (250m)² · 300s

$$\sigma_{WVP} = 890 \mathrm{g/m^2}$$

BOMEX LES: water (size 100-320)

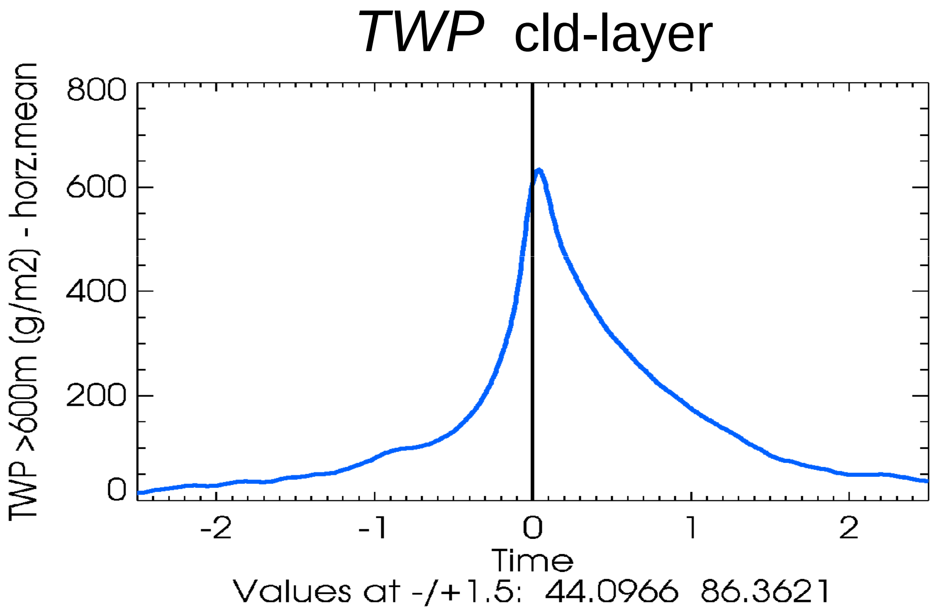
n=7383

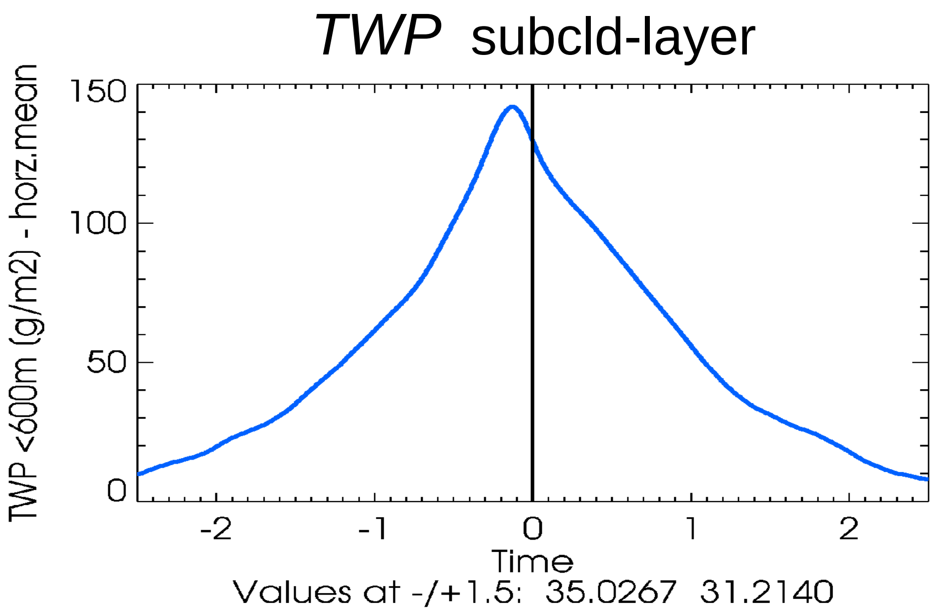




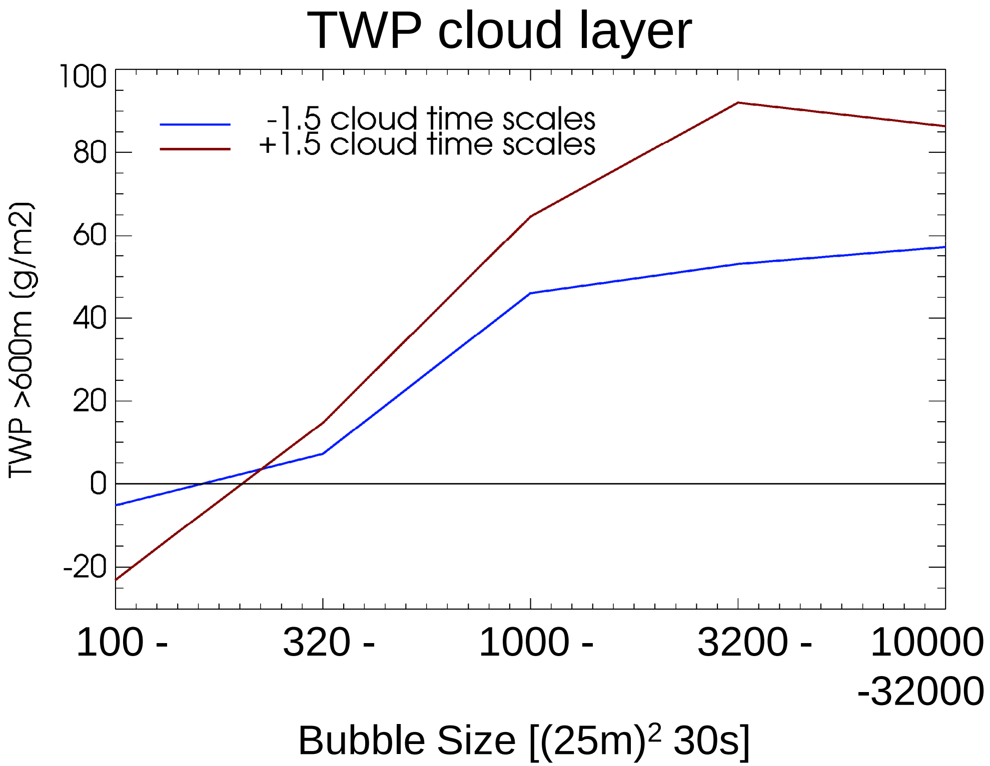
BOMEX LES: water (size 10000-32000)

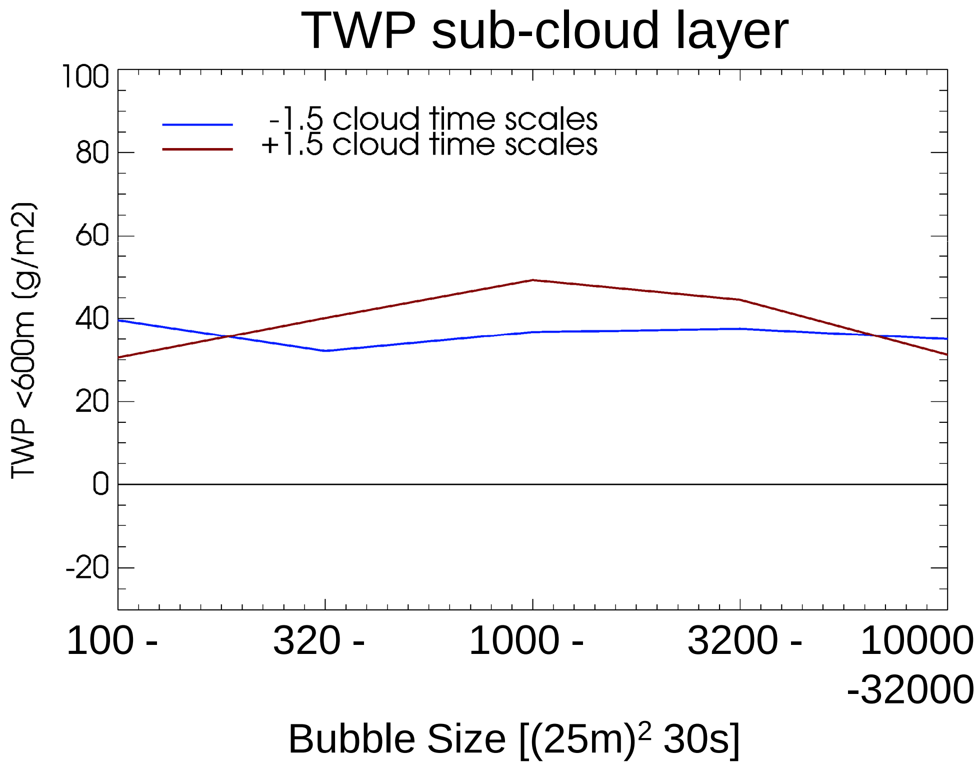
n=92





BOMEX LES: size





- all clouds live in top half moist environment (TWP>600m)
- smallest clouds consume TWP (>600m)
- big clouds add TWP (>600m)
- sub-cloud layer plays no role in cloud size selection

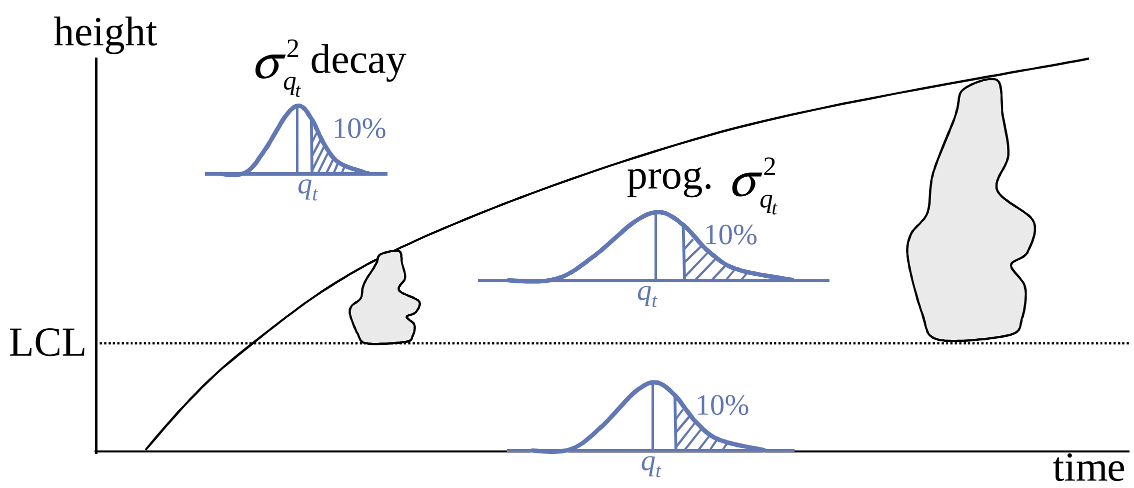
DUALM convective pre-conditioning

- ➔ prognostic total water variance equation

$$\frac{\partial \sigma_{q_t}^2}{\partial t} = -2\overline{w'q'}\frac{\partial \overline{q_t}}{\partial z} - \frac{\partial \overline{w'q_t'q_t'}}{\partial z} - \frac{\sigma_{q_t}^2}{\tau}$$

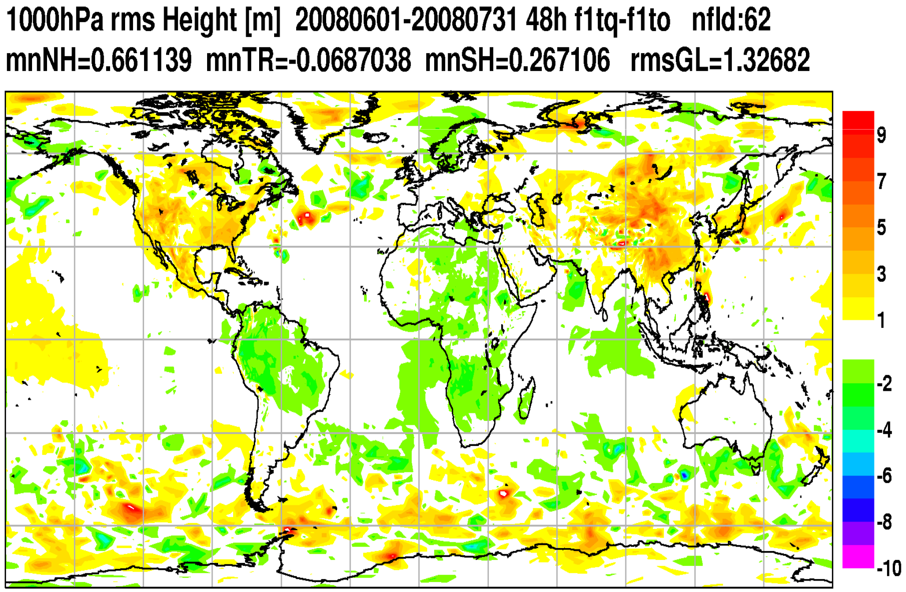
- ➔ most moist environment favours shallow convection

$$\frac{\partial q_{t,up}}{\partial z} = -\varepsilon(q_{up} - \overset{\text{moist}}{q}_{env})$$

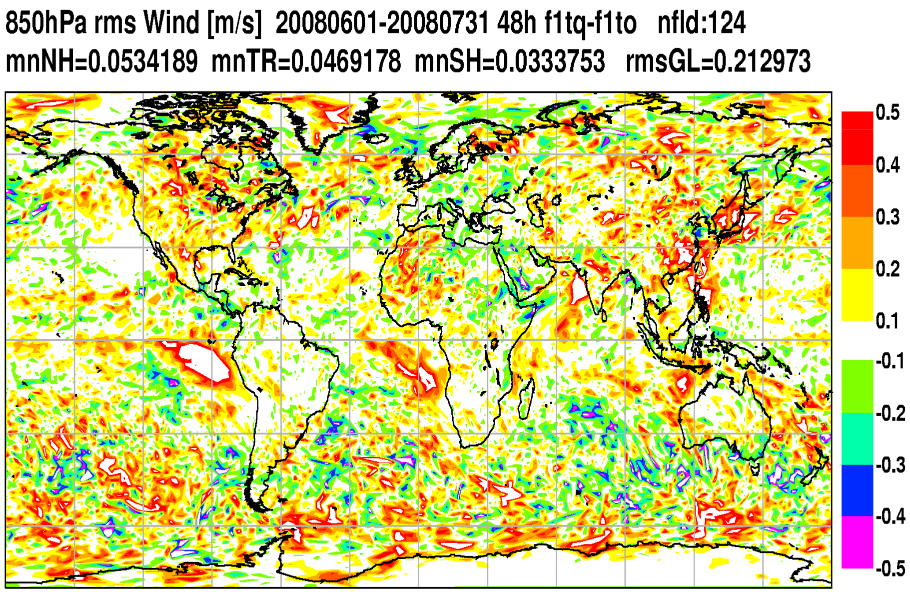


DUALM errors without premoistening

Z1000



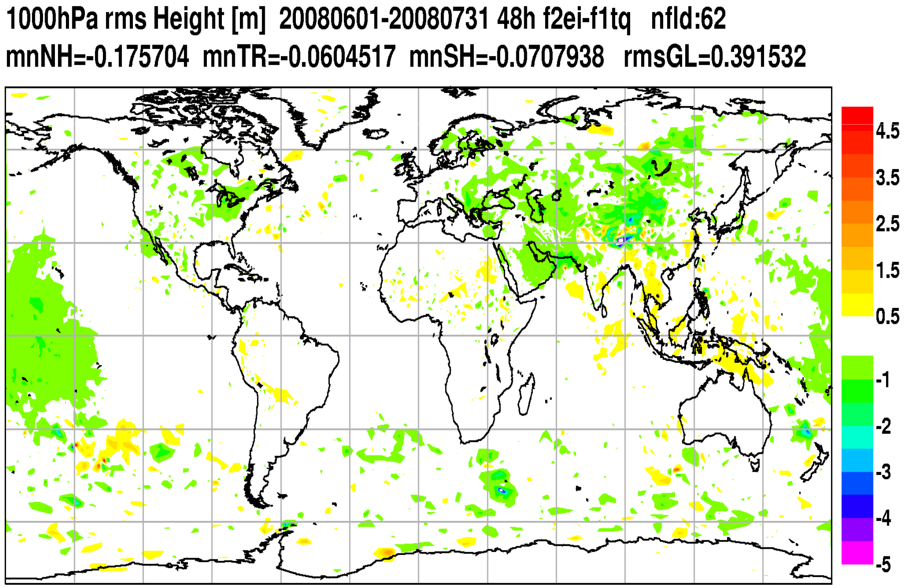
U850



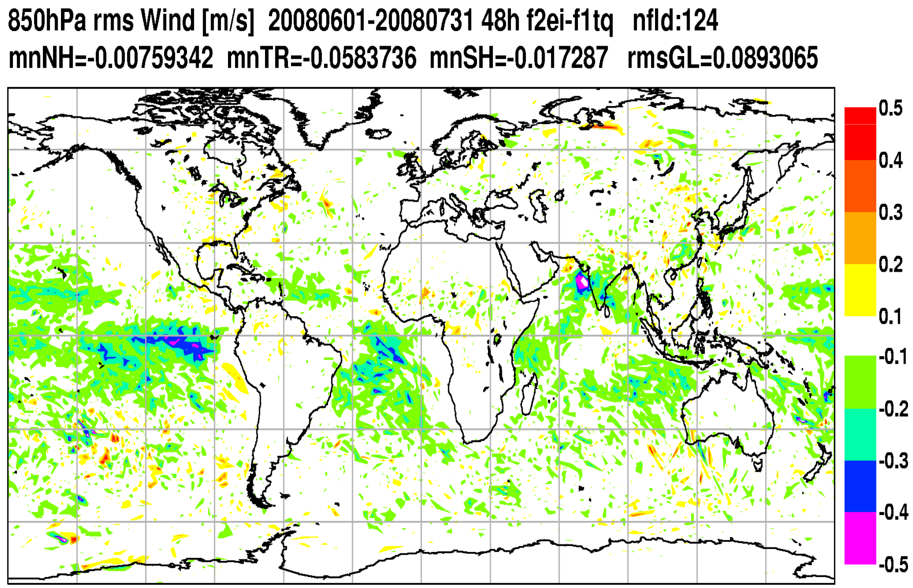
Tests in ECMWF model with DUALM shallow convection.

DUALM: impact of convective preconditioning

Z1000



U850



Tests in ECMWF model with DUALM shallow convection.

Final thoughts

- ➔ conclusions from LES analysis
  - ➔ bigger clouds rise into more moist troposphere
  - ➔ bigger clouds add moisture in previous cloud layers („pre-moistening“)

- ➔ application to convection parameterisation
  - ➔ entrainment of moist patch
  - ➔ land deep convective diurnal cycle delayed by period of shallow convection pre-moistening mid-levels
  - ➔ convection parameterization based on PDFs will turn off at high resolution because variance goes to 0

Extra Slides

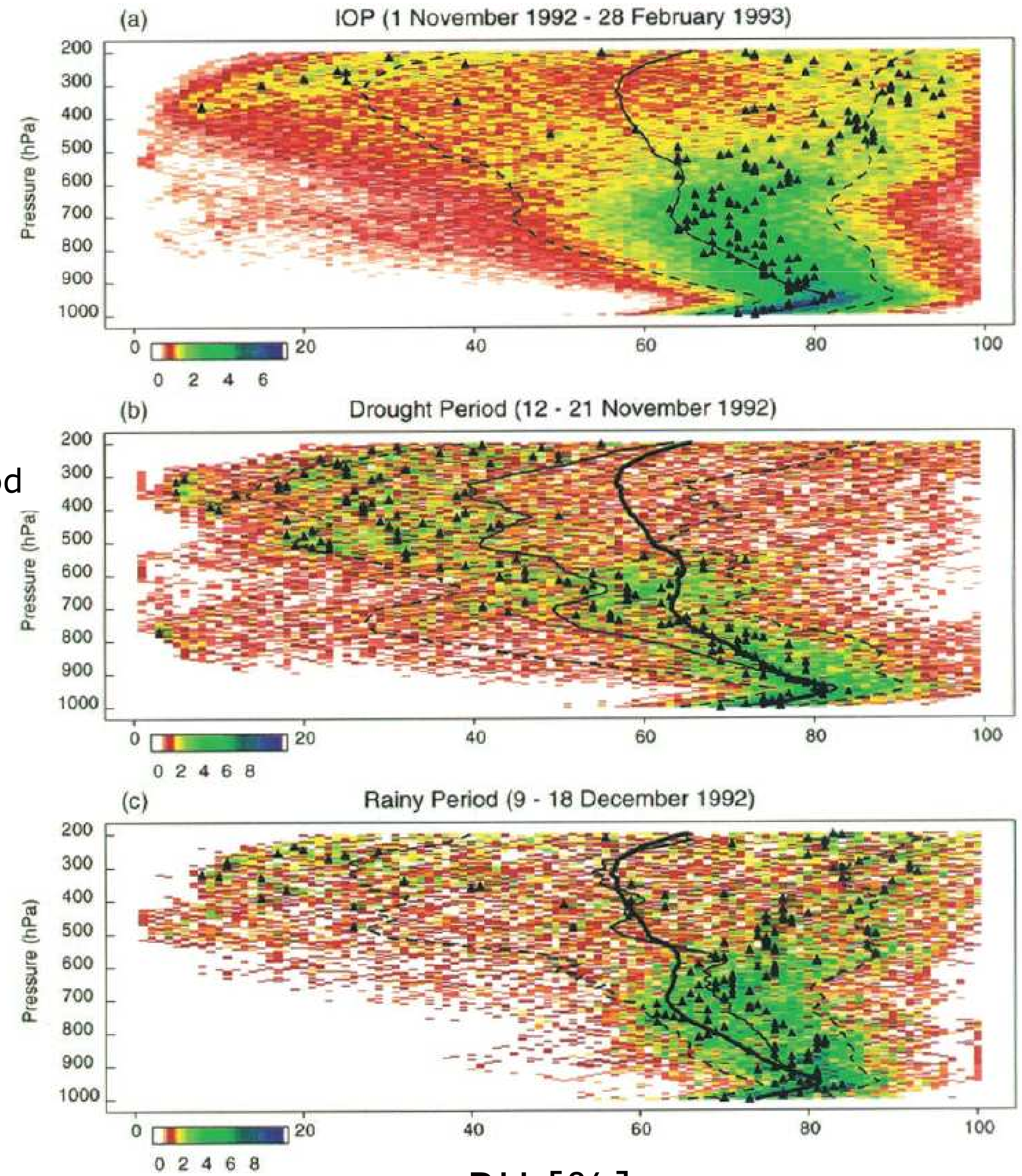

RICO field experiment
Gabor Vali

Brown, Zhang 1997: *RH during TOGA/COARE*

All Nov-Feb 1992/3

Drought Period

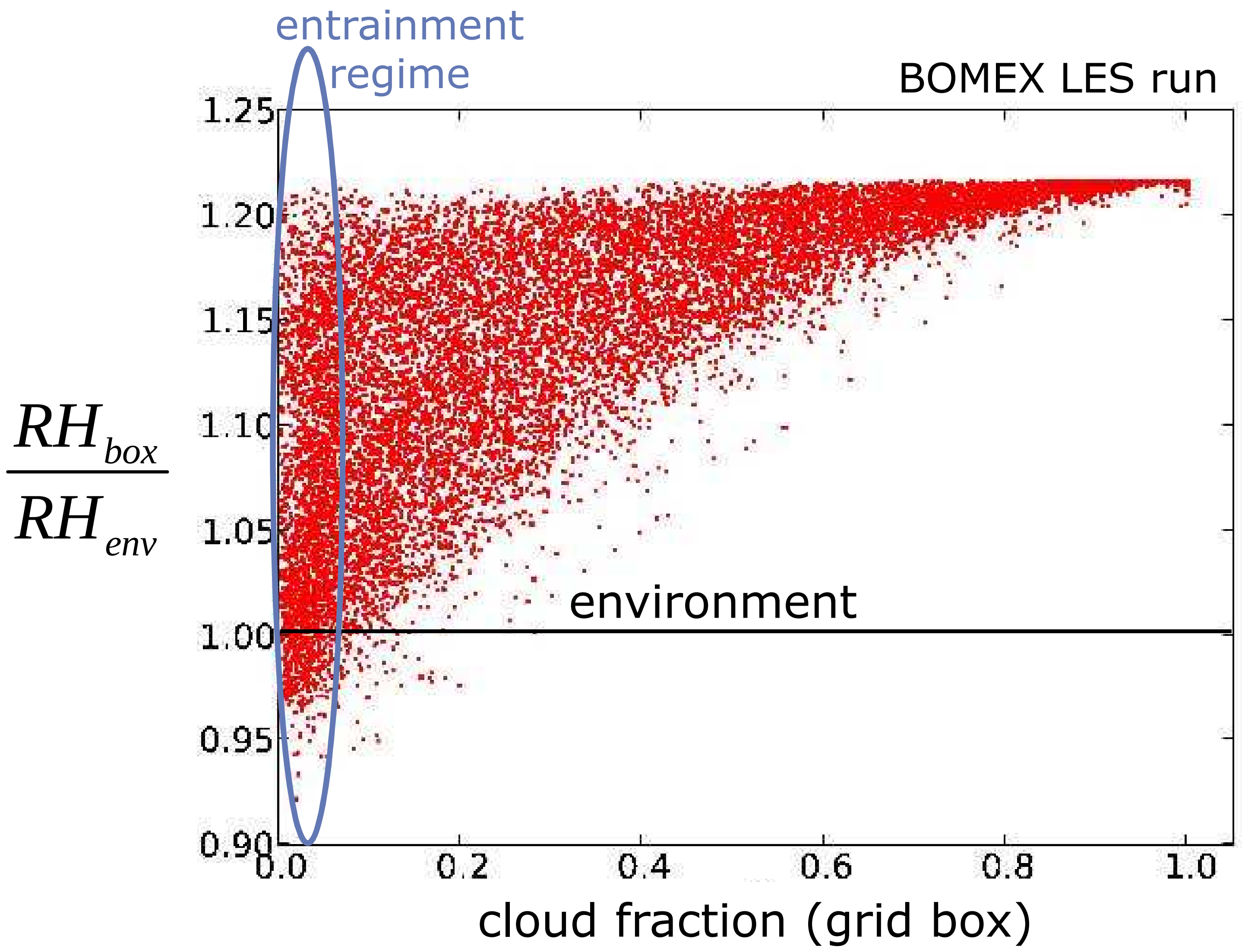
Rainy Period



RH [%]

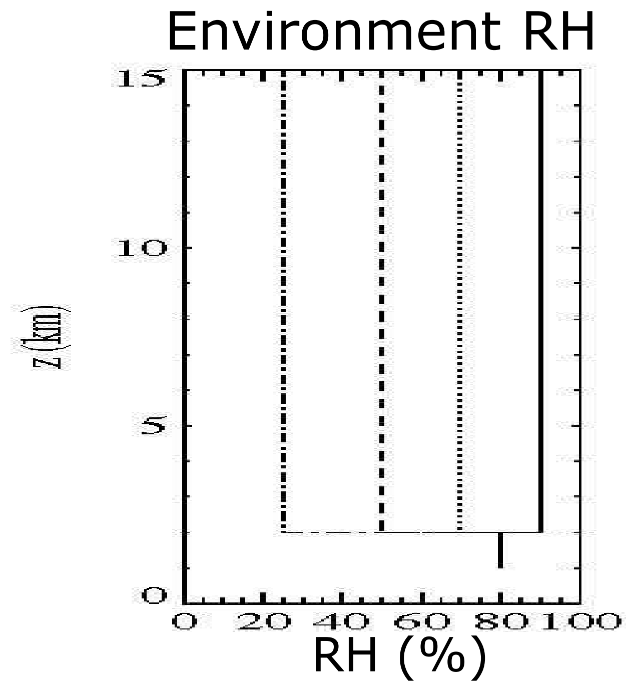
Moist low levels (~800hPa) favour deep convection

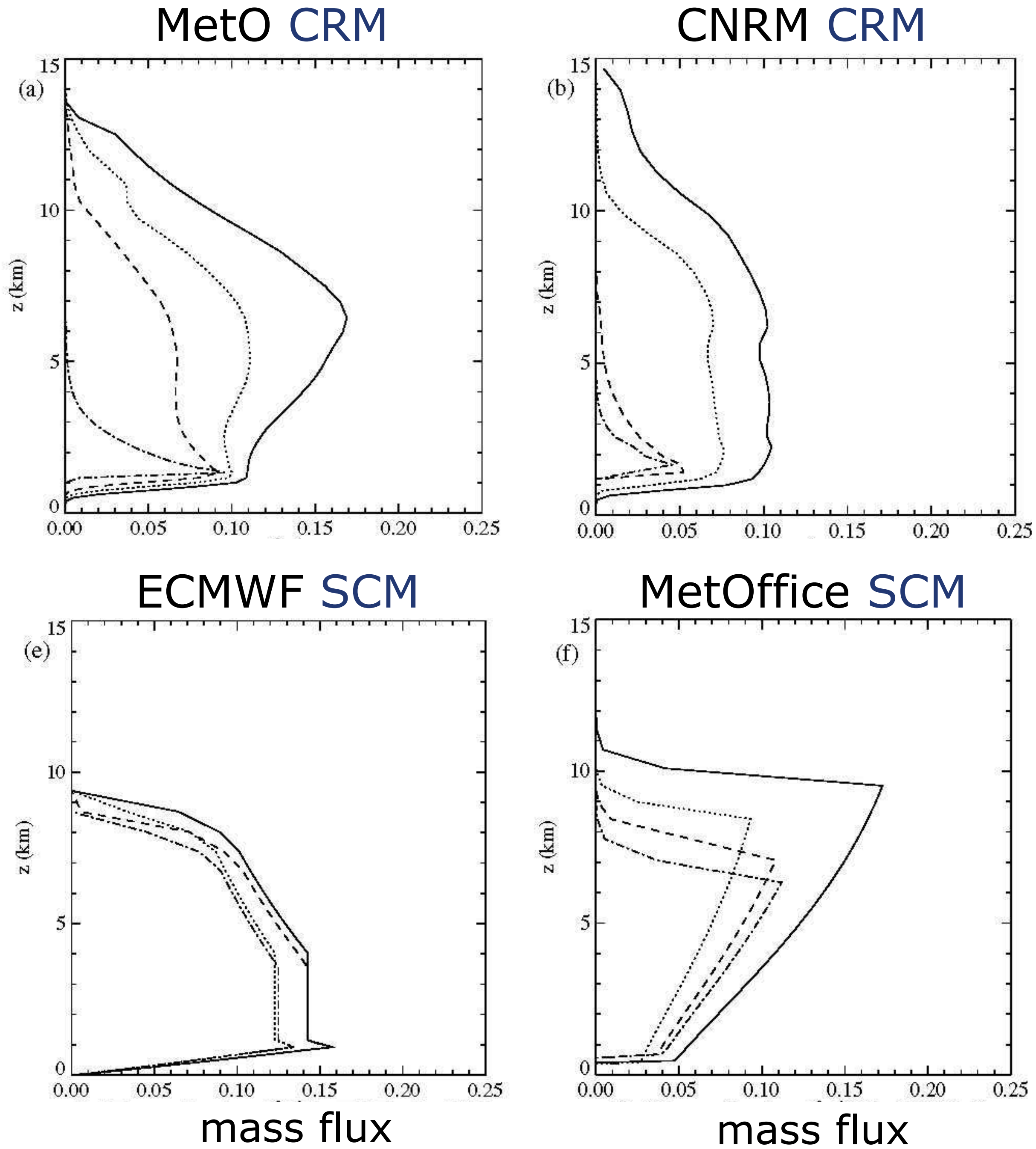
Jarecka, Grabowski, Pawlowska, 2009



Entrained air is pre-moistened.

Derbyshire et al 2004: *RH dictates cloud top*

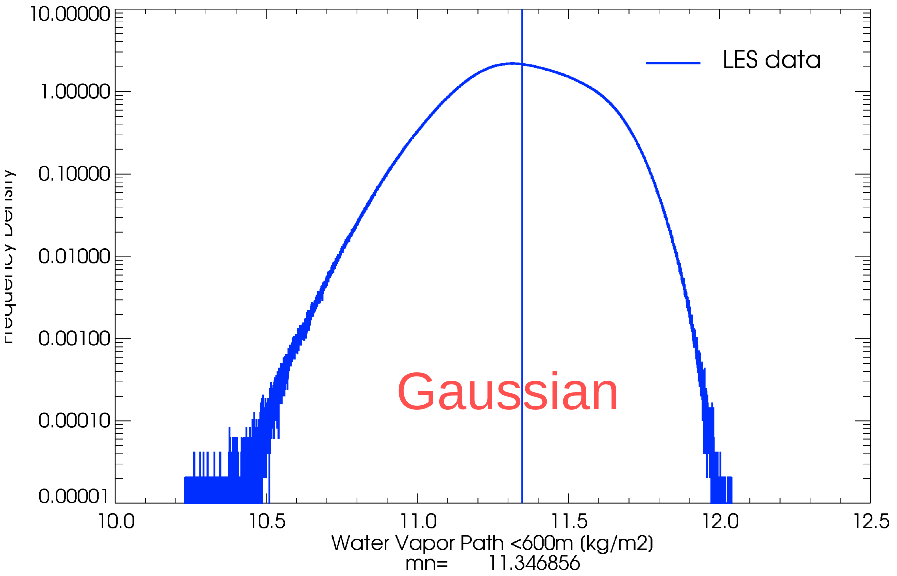




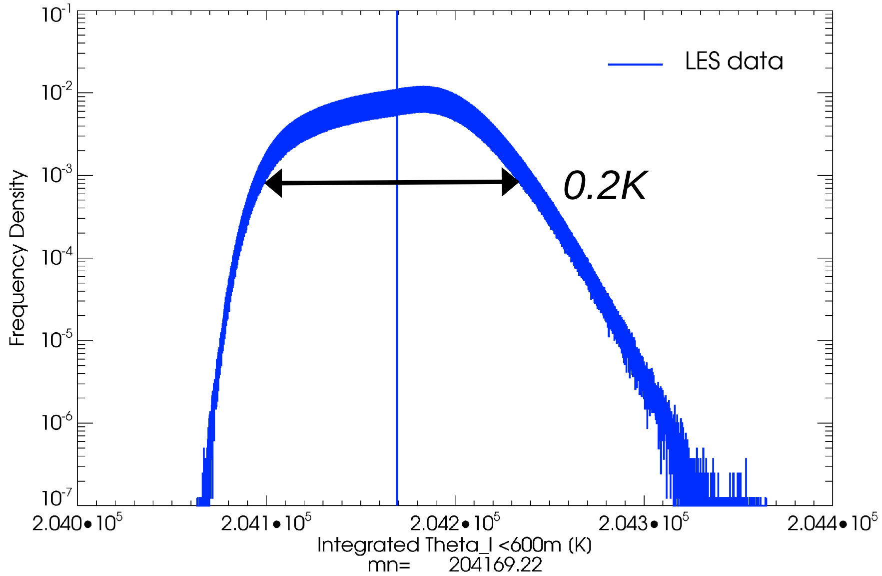
- small ε to get high cloud top
- large ε to get large RH sensitivity

LES results

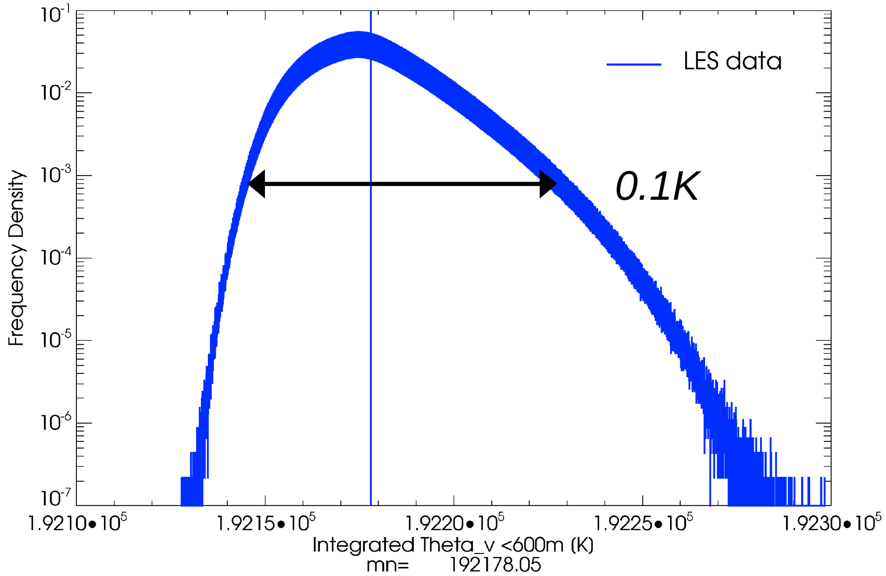
TWP below 600m



mean θ_l below 600m



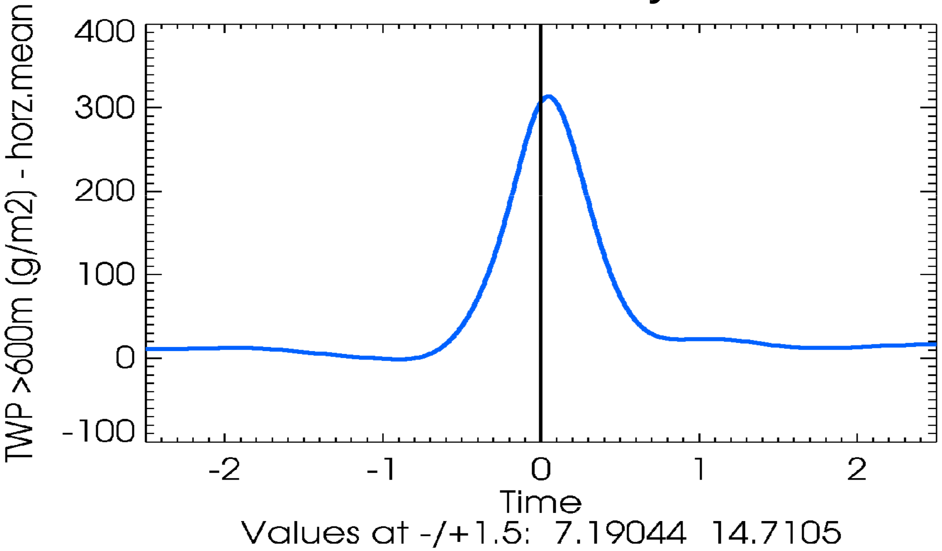
mean θ_v below 600m



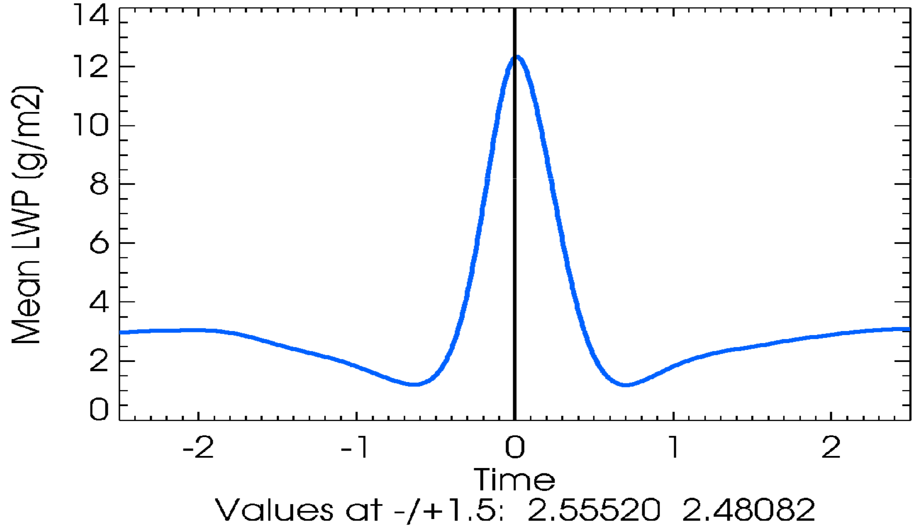
LES results: water (size 320-1000)

n=4164

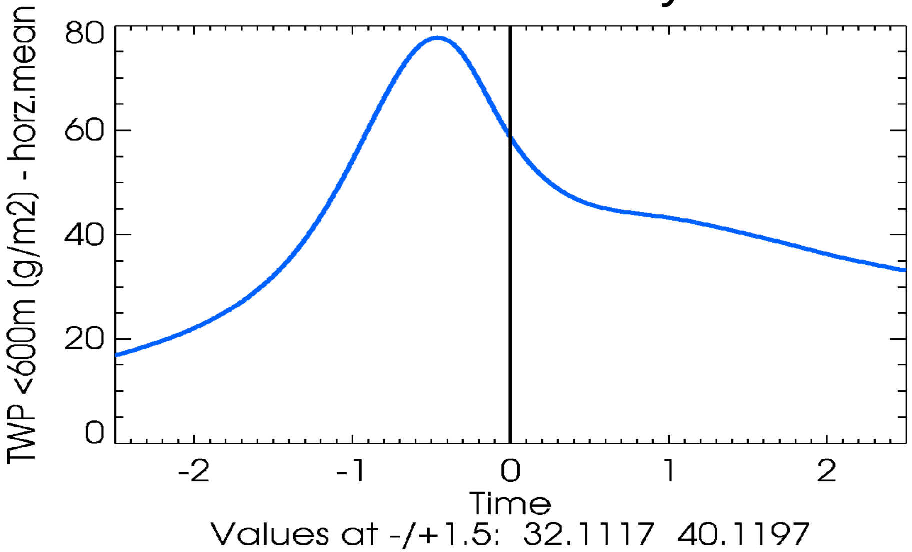
TWP cld-layer



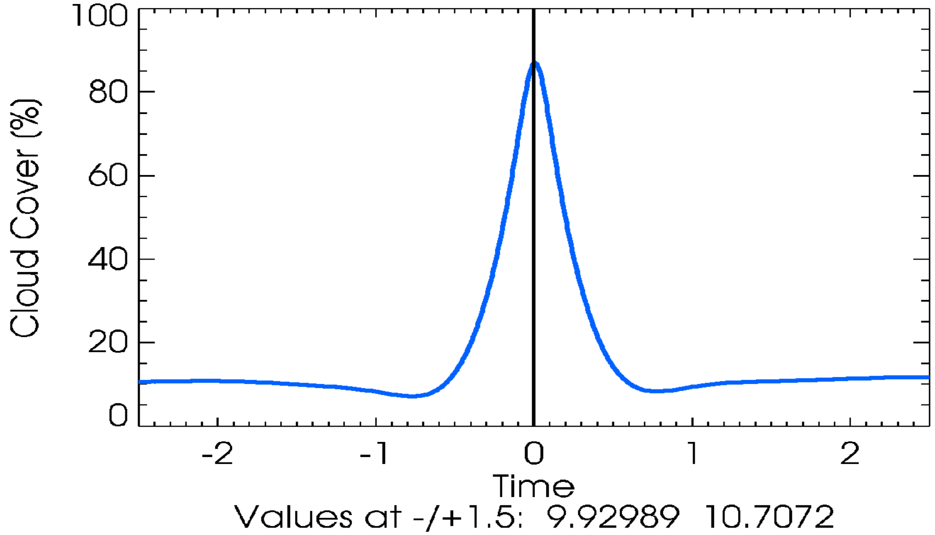
LWP



TWP subcld-layer

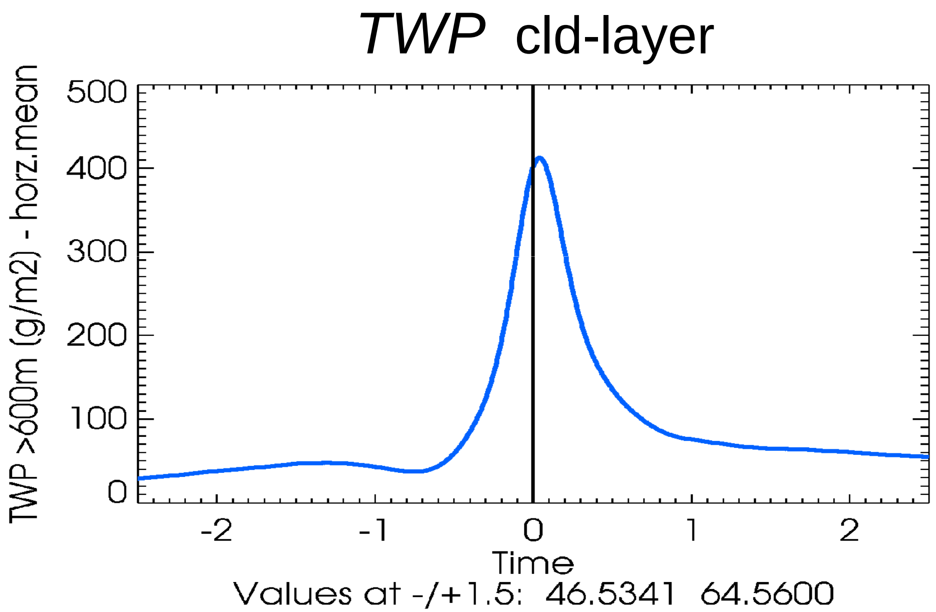


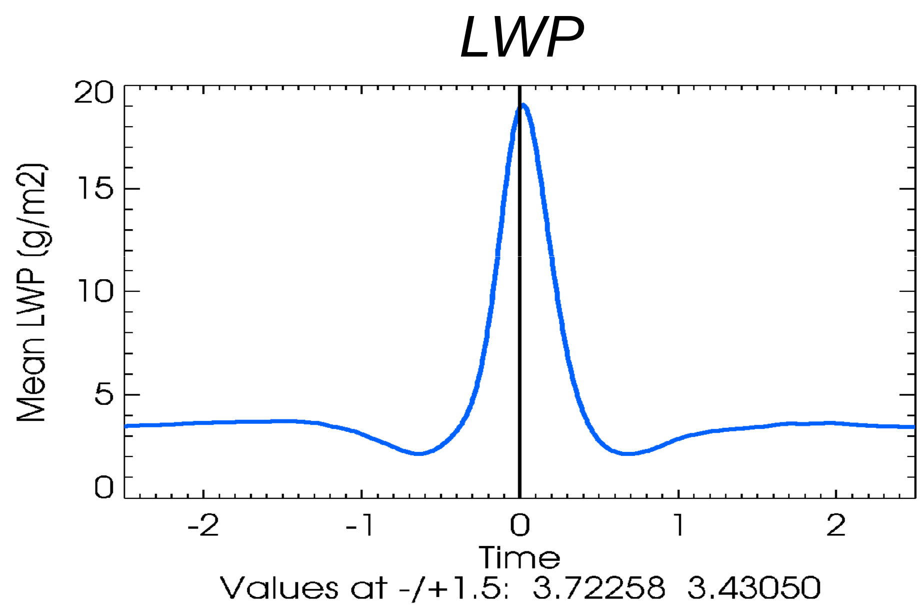
cloud cover

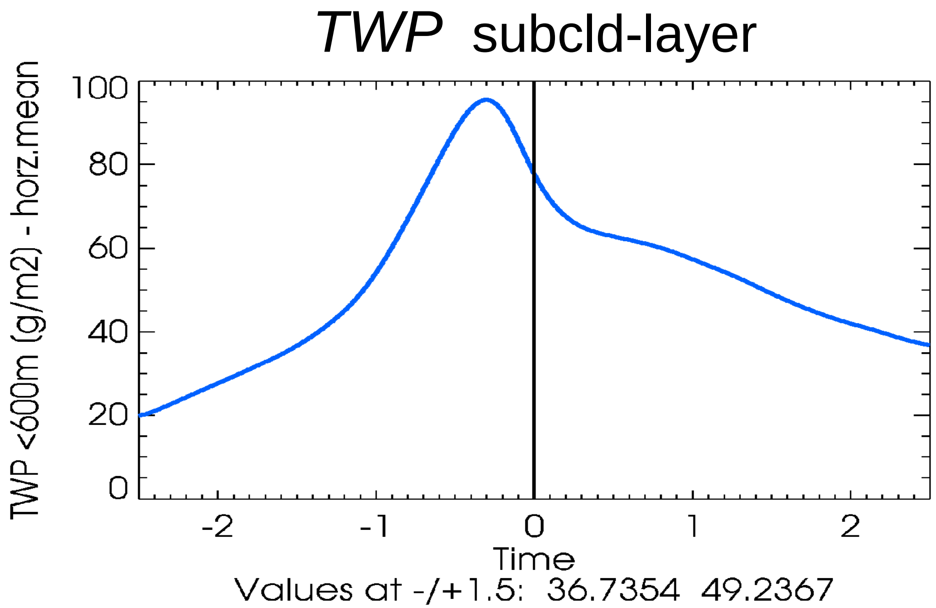


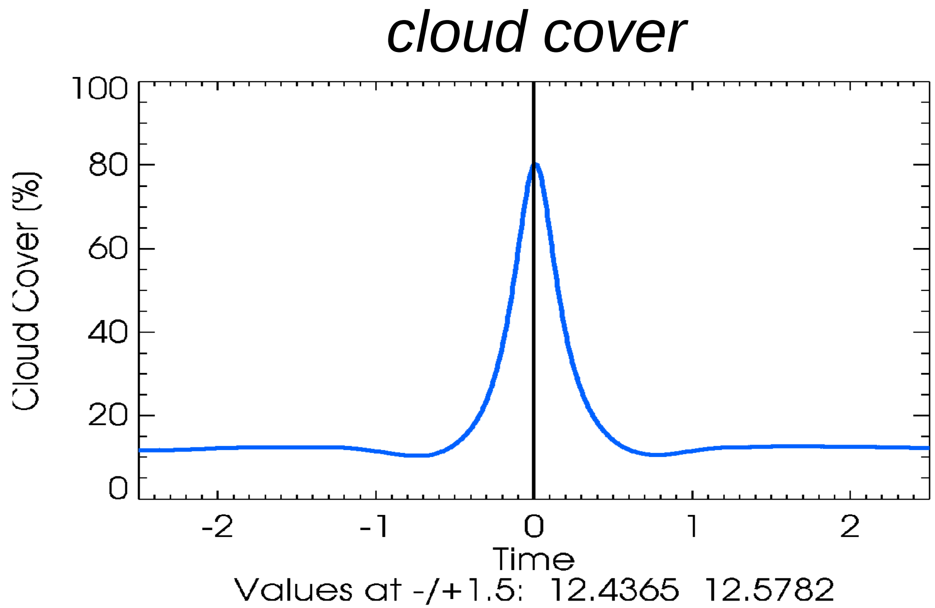
LES results: water (size 1000-3200)

n=1690





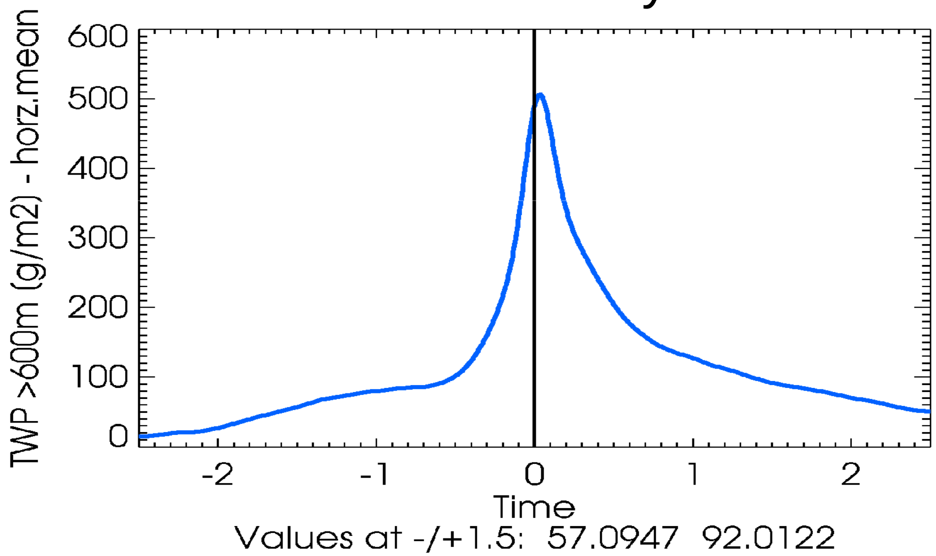




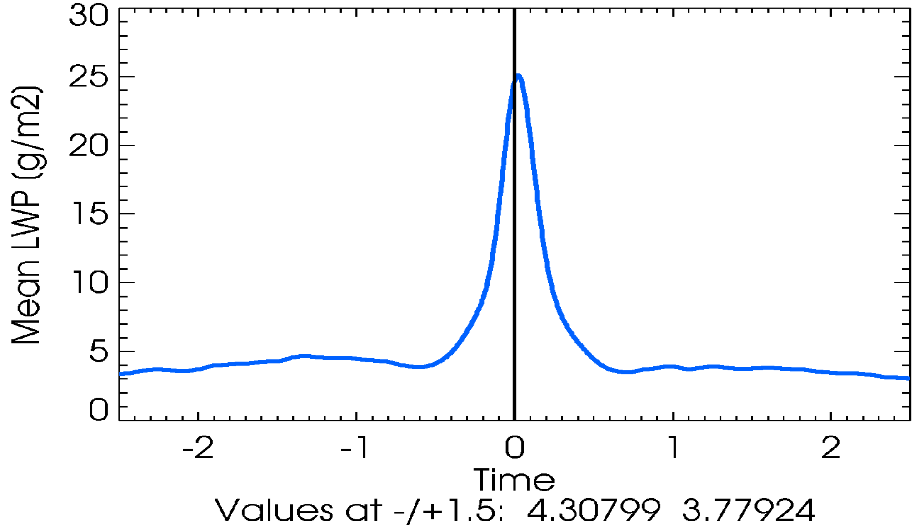
LES results: water (size 3200-10000)

n=544

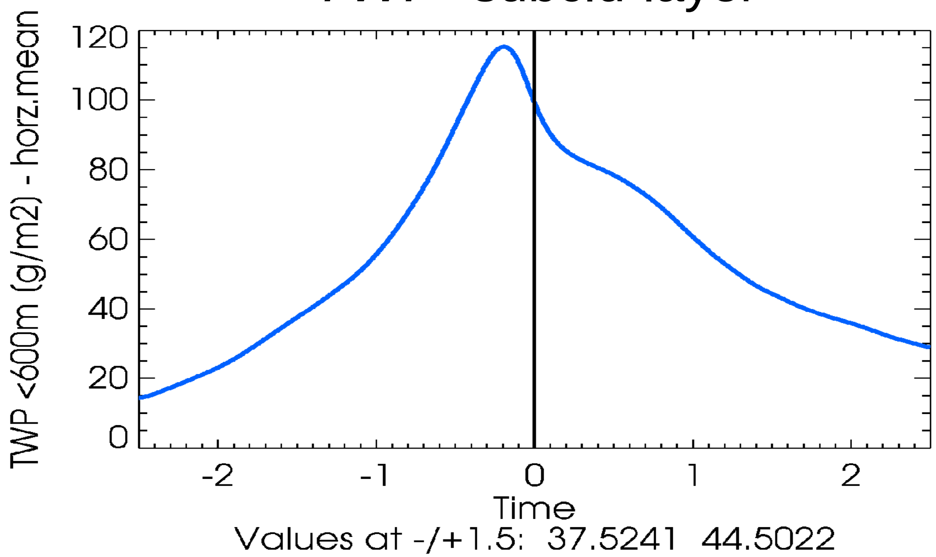
TWP cld-layer



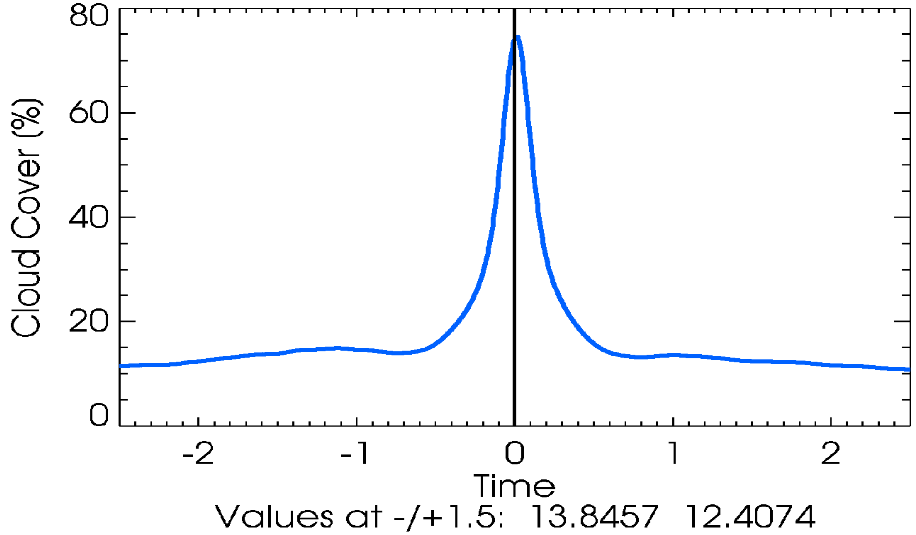
LWP



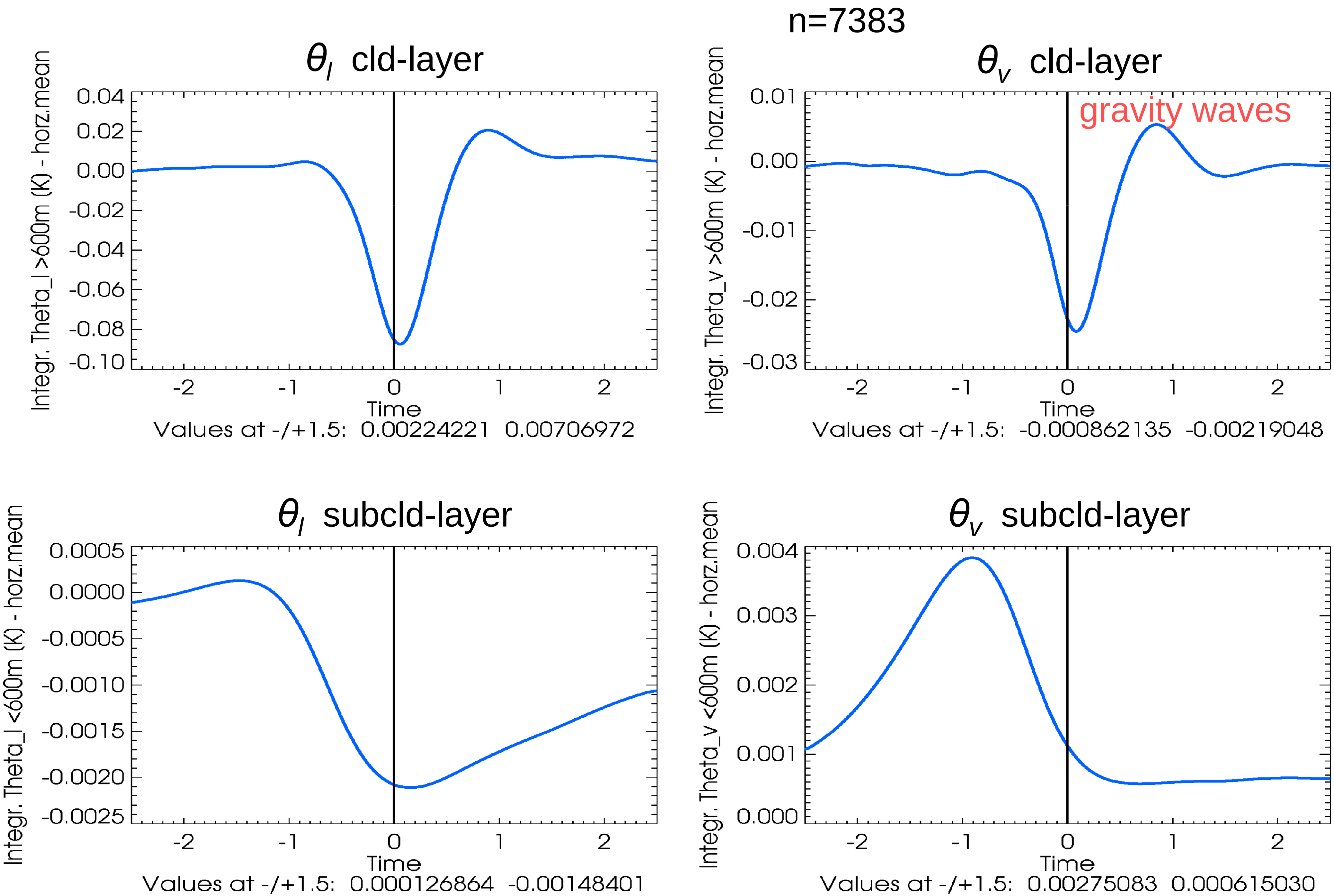
TWP subcld-layer



cloud cover

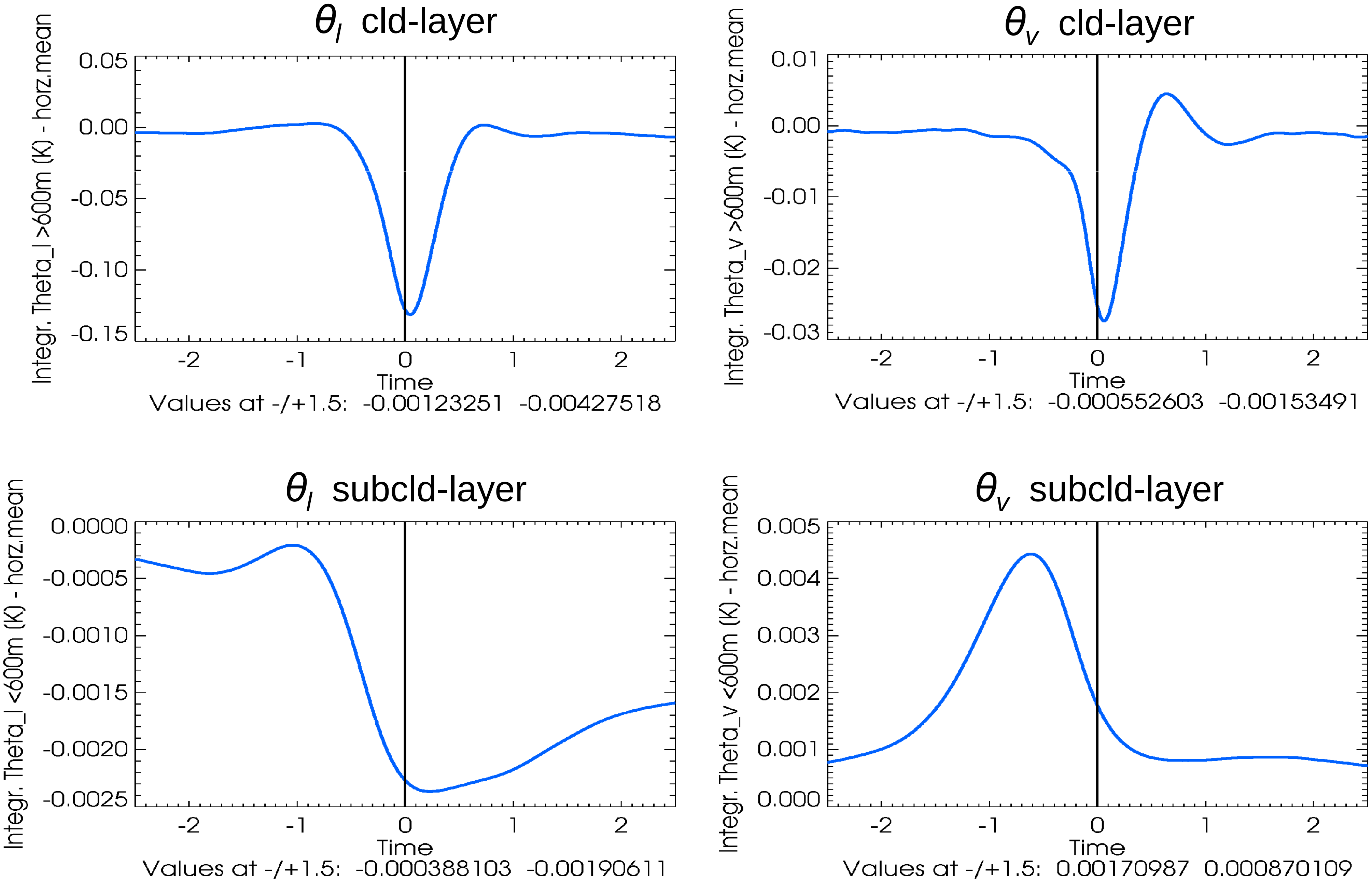


LES results: temperature (size 100-320)

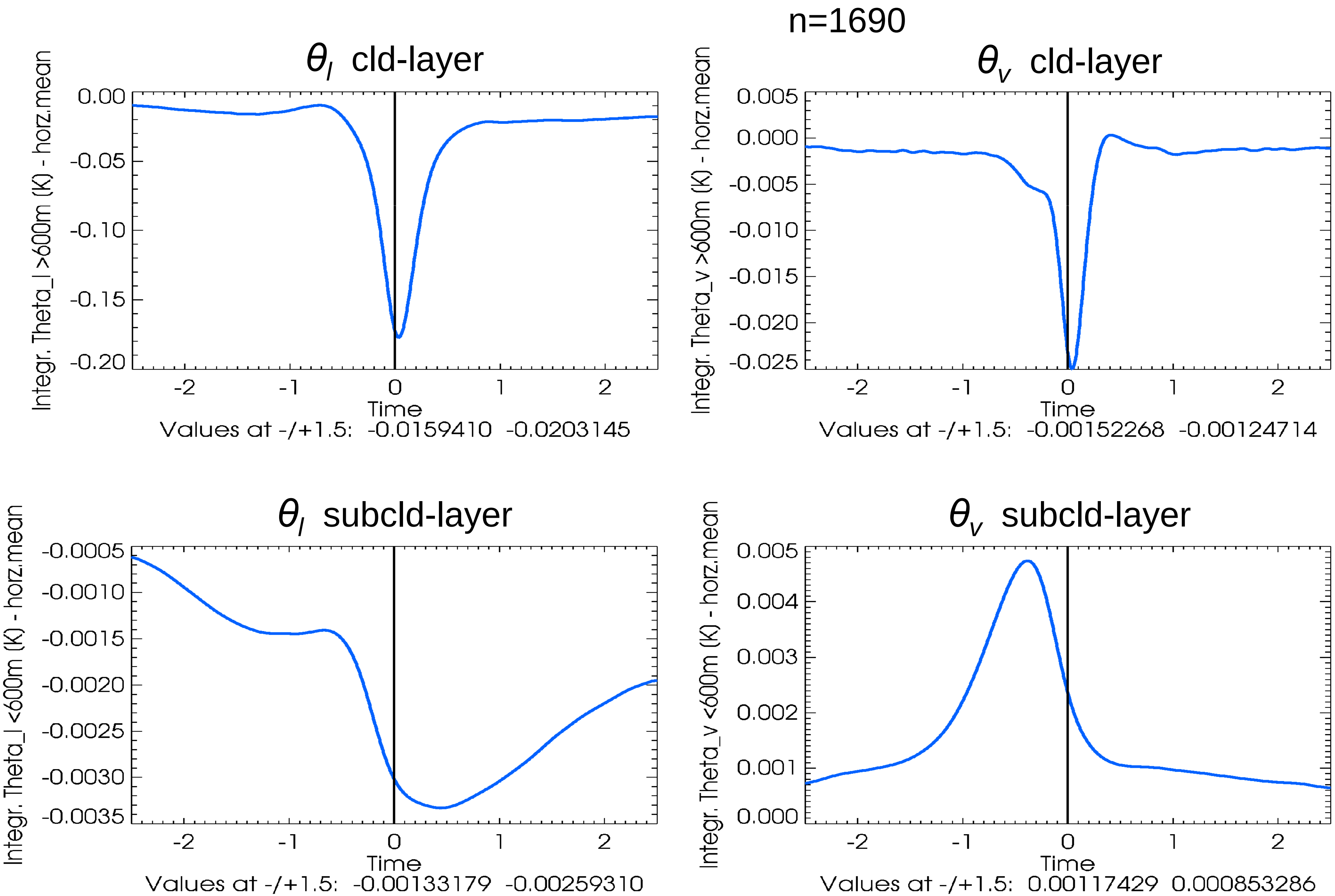


LES results: temperature (size 320-1000)

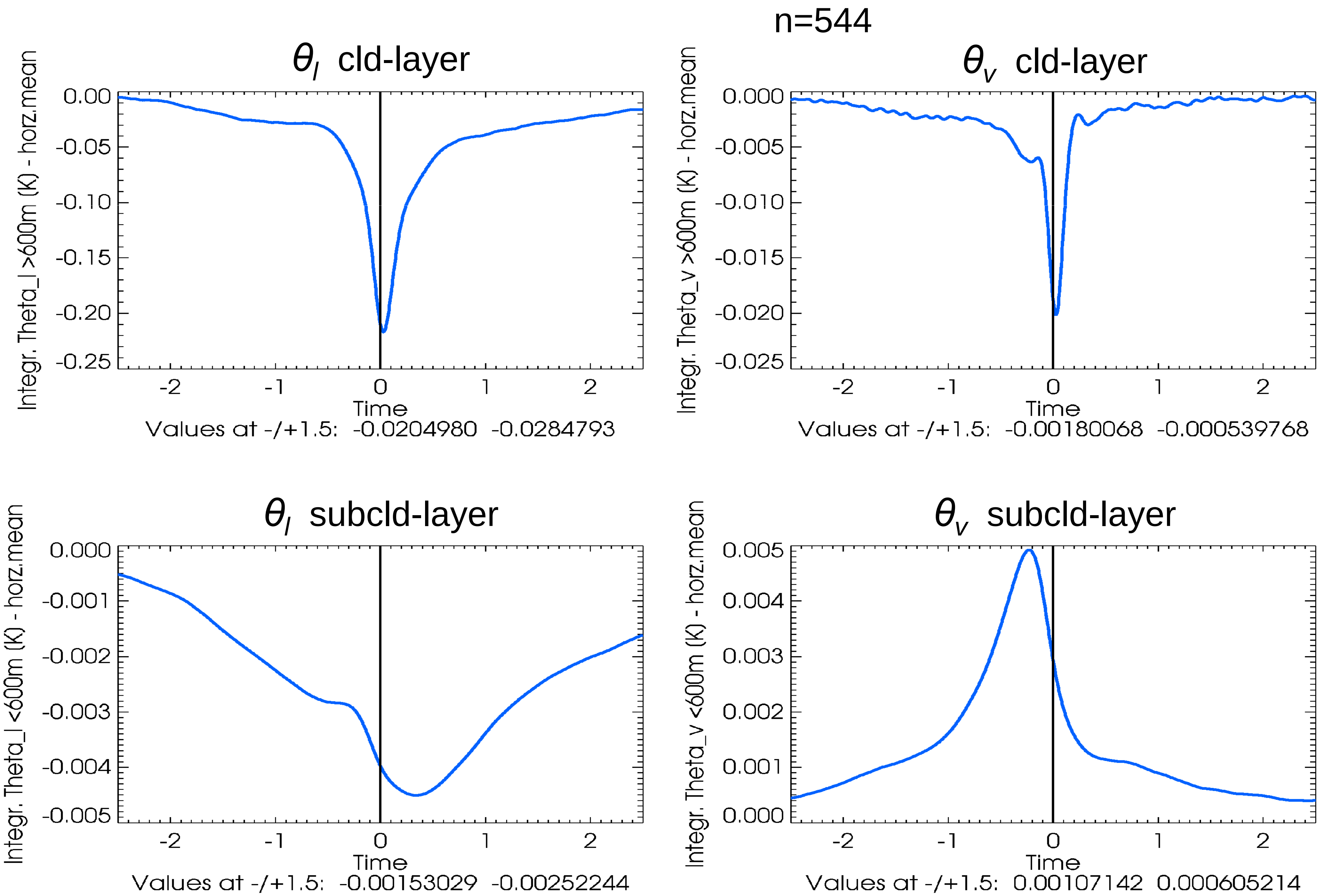
n=4164



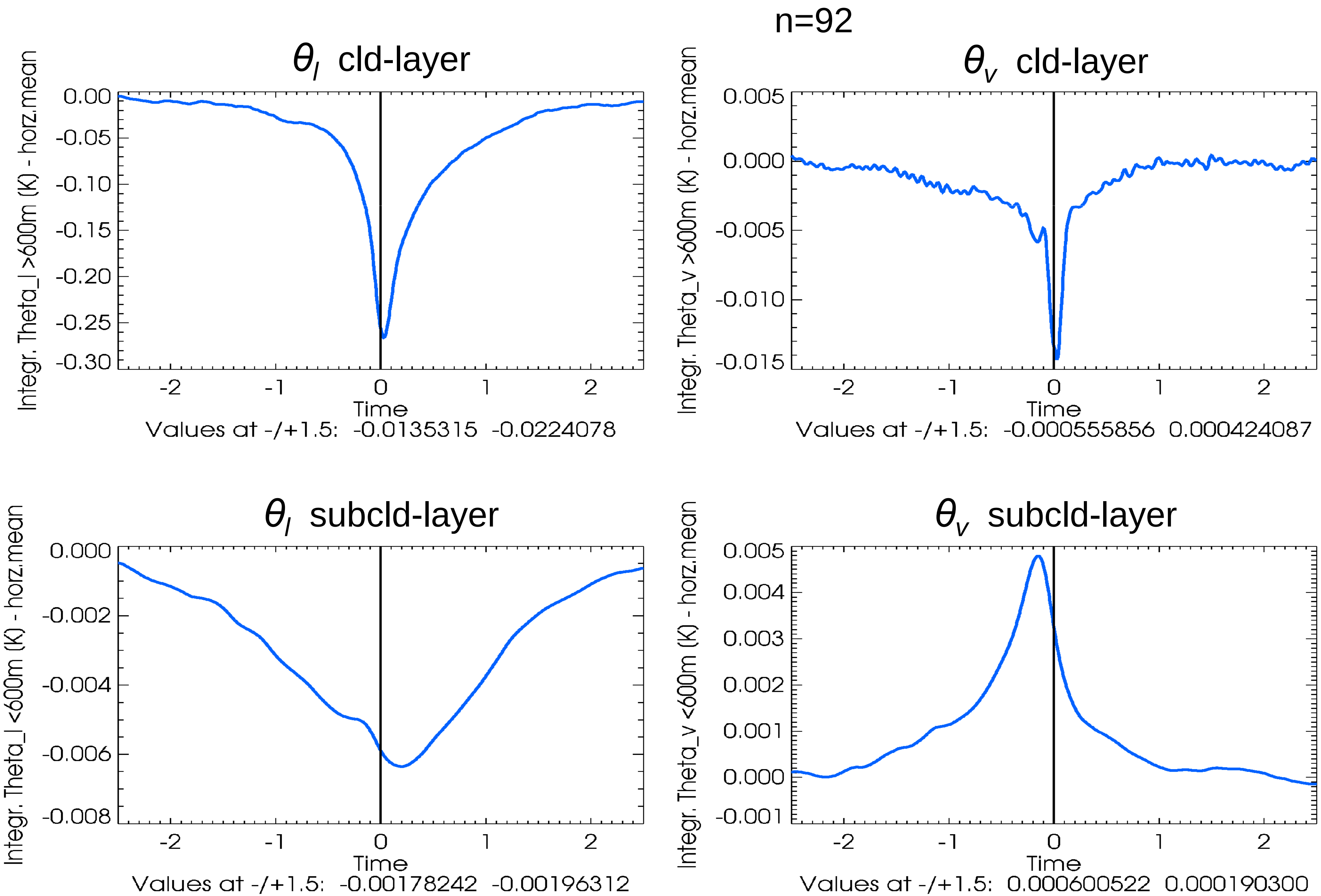
LES results: temperature (size 1000-3200)



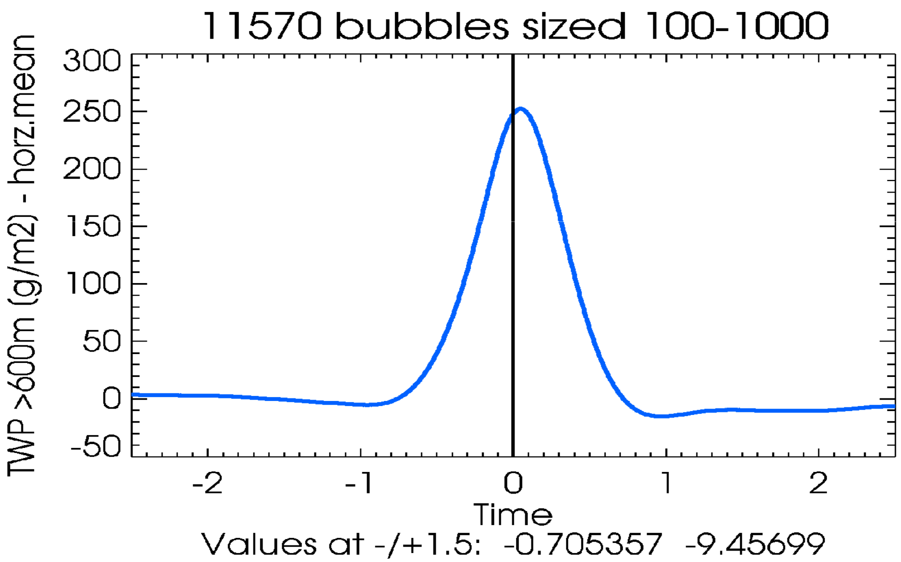
LES results: temperature (size 3200-10000)

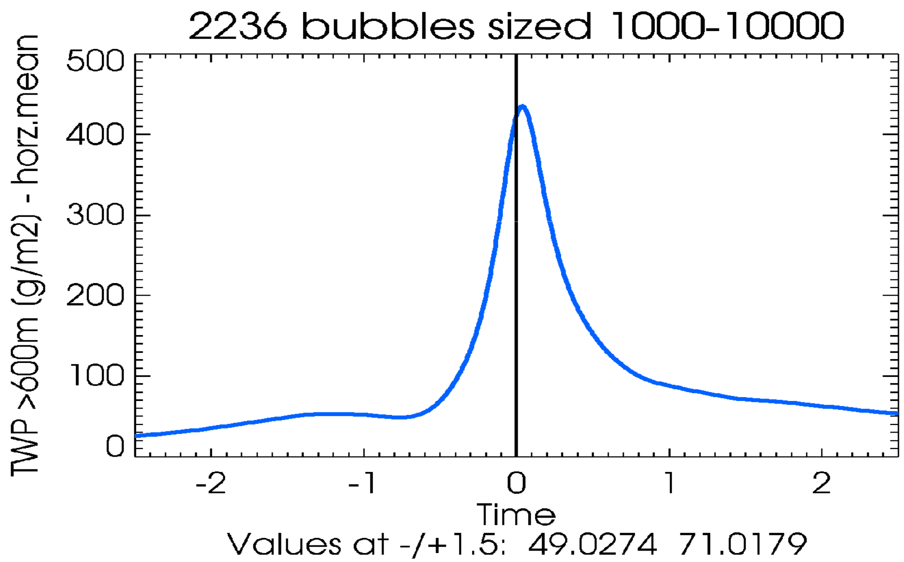


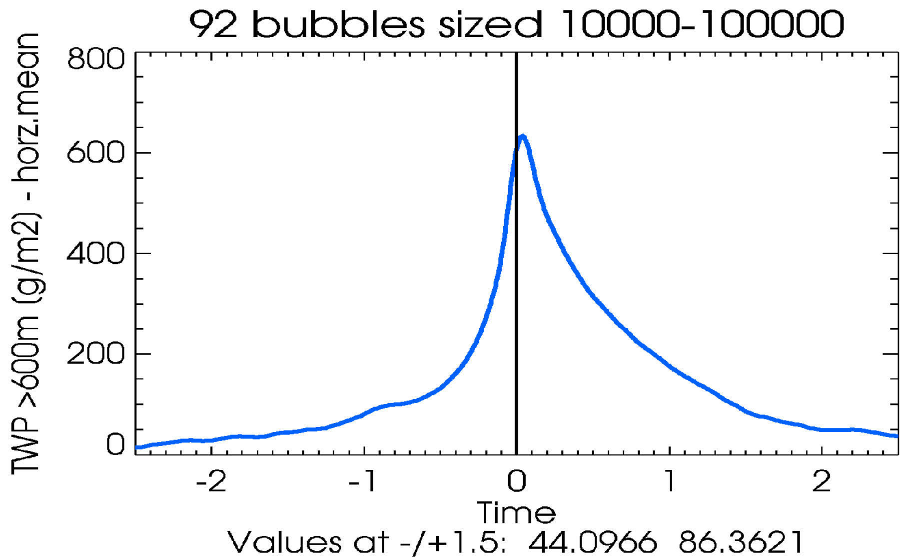
LES results: temperature (size 10000-32000)



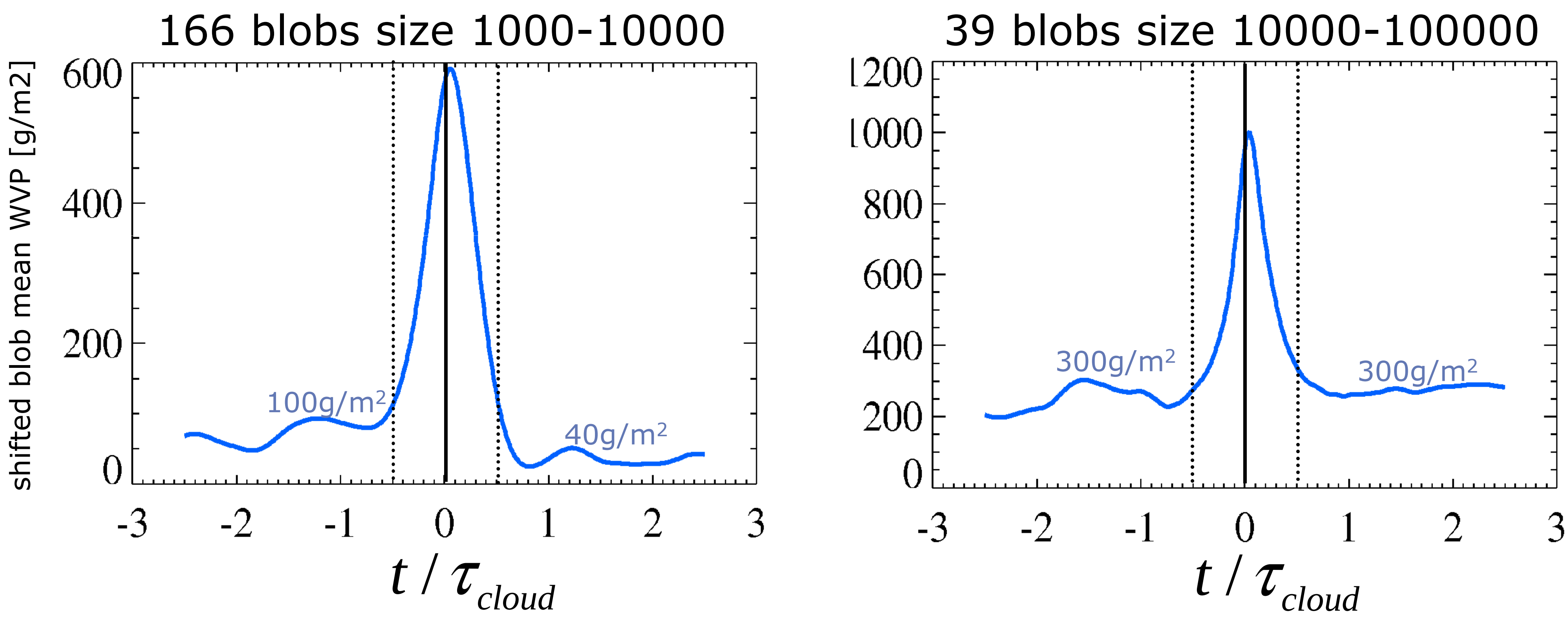
LES results


11570 bubbles sized 100-1000
TWP >600m (g/m2) - horz.mean
300
250
200
150
100
50
0
-50
-2
-1
0
1
2
Time
Values at -/+1.5: -0.705357 -9.45699


2236 bubbles sized 1000-10000
TWP >600m (g/m2) - horz.mean
500
400
300
200
100
0
-2
-1
0
1
2
Time
Values at -/+1.5: 49.0274 71.0179


92 bubbles sized 10000-100000
TWP >600m (g/m2) - horz.mean
800
600
400
200
0
-2
-1
0
1
2
Time
Values at -/+1.5: 44.0966 86.3621

BOMEX LES cloud blobs (old first run)

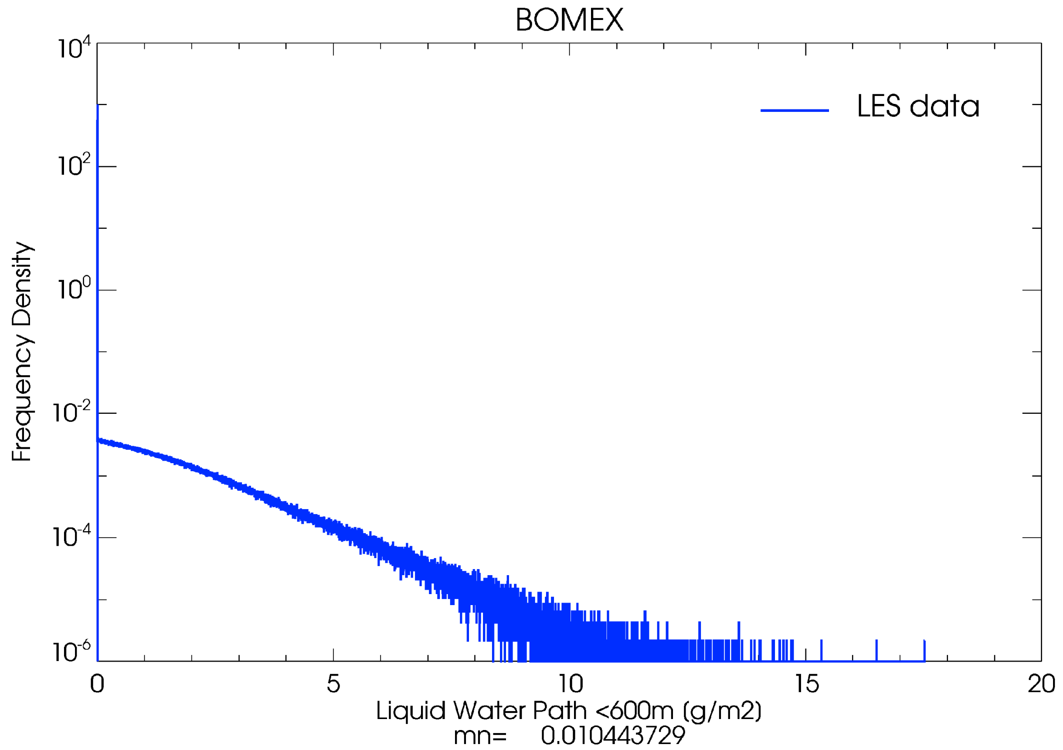


Time, lagged around blob center, normalized by blob time scale

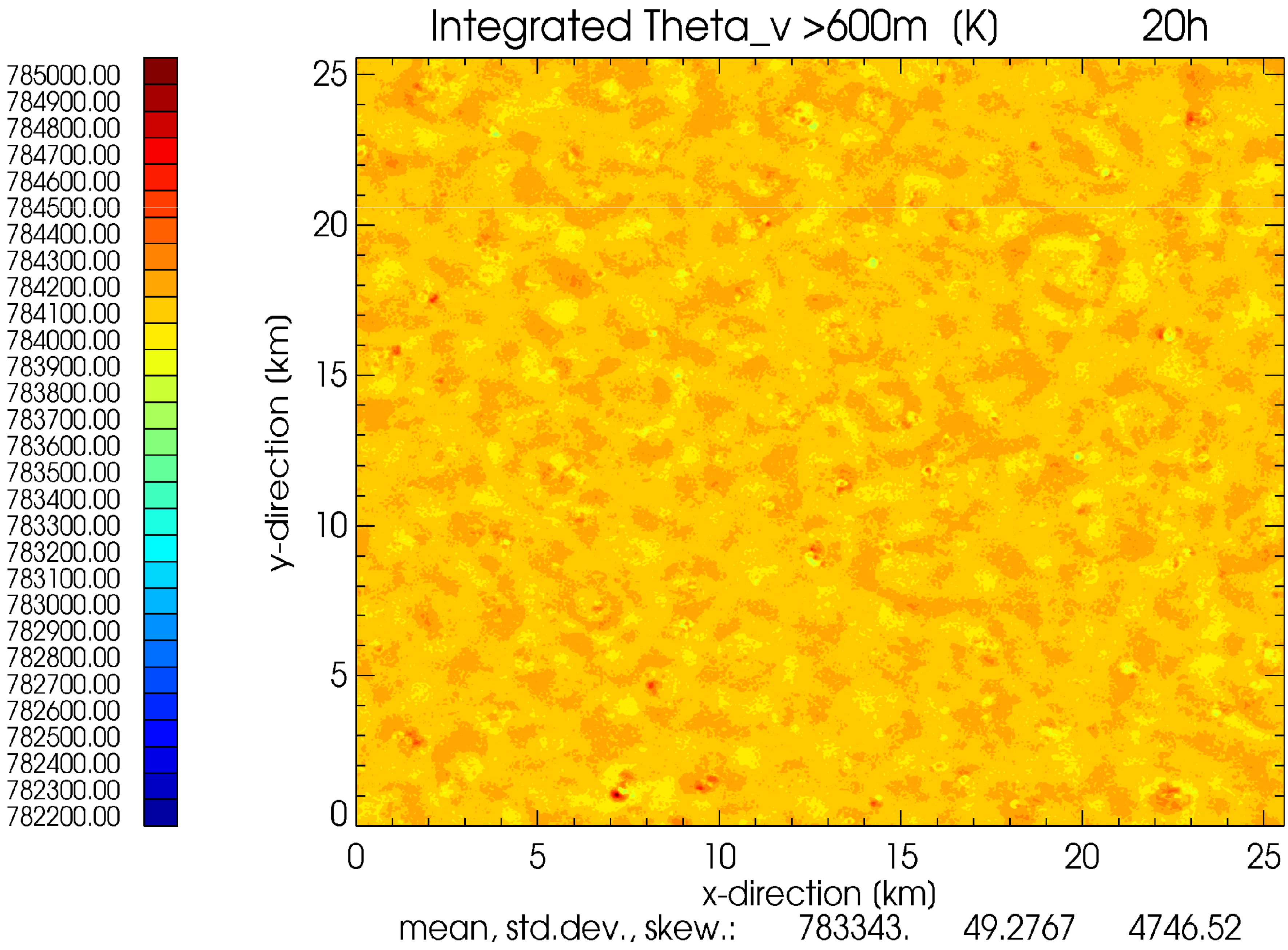
blobs size 1000: $(250m)^2 \cdot 300s$
blobs size 1000000: $(2500m)^2 \cdot 3000s$

$$\sigma_{WVP} = 890 g/m^2$$

LES results

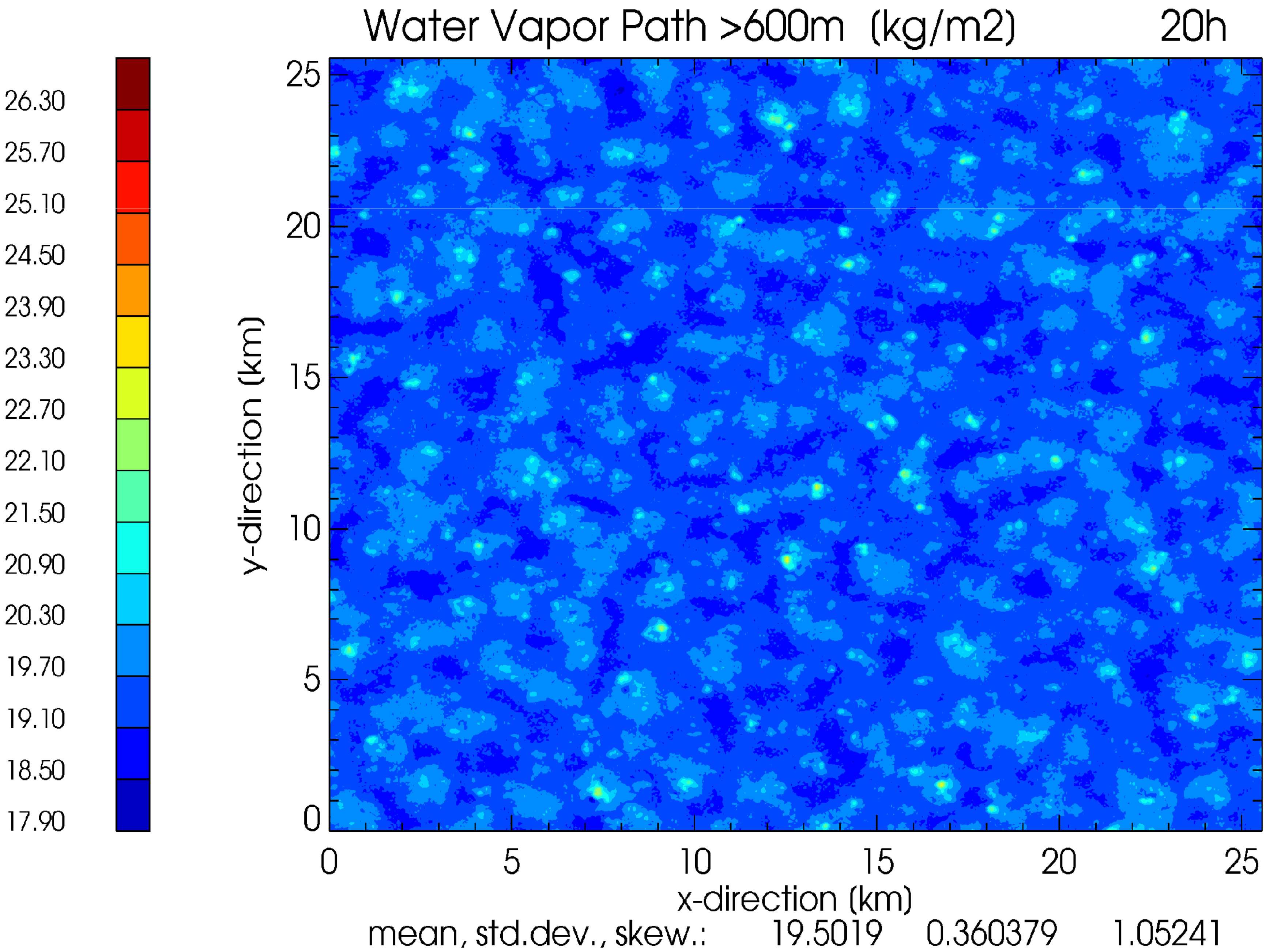

BOMEX
LES data
Frequency Density
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
0
5
10
15
20
Liquid Water Path <600m (g/m2)
mn= 0.010443729

LES results



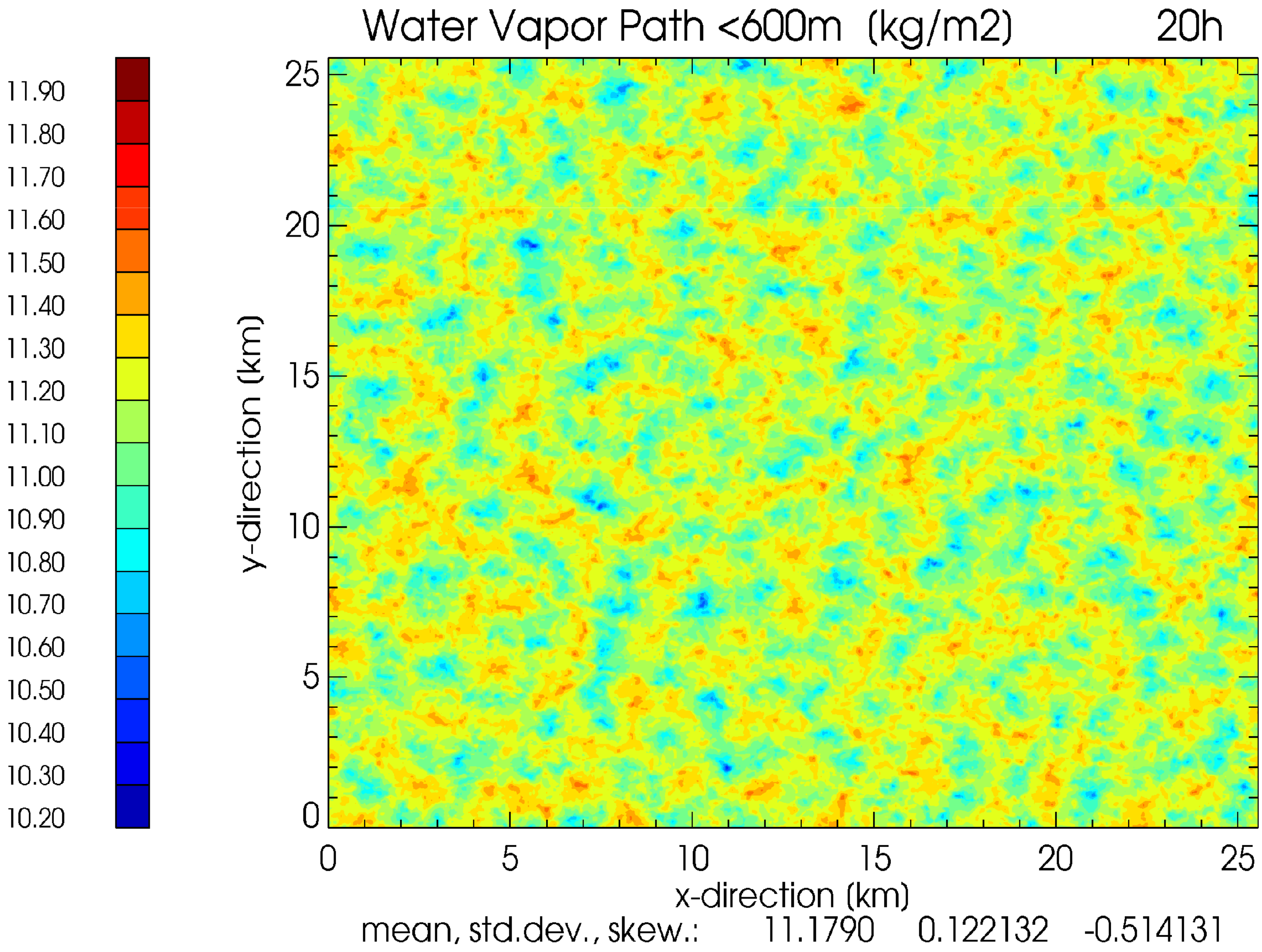
Integrated Theta_v >600m (K) 20h
785000.00
784900.00
784800.00
784700.00
784600.00
784500.00
784400.00
784300.00
784200.00
784100.00
784000.00
783900.00
783800.00
783700.00
783600.00
783500.00
783400.00
783300.00
783200.00
783100.00
783000.00
782900.00
782800.00
782700.00
782600.00
782500.00
782400.00
782300.00
782200.00
y-direction (km)
x-direction (km)
0
5
10
15
20
25
mean, std.dev., skew.: 783343. 49.2767 4746.52

LES results



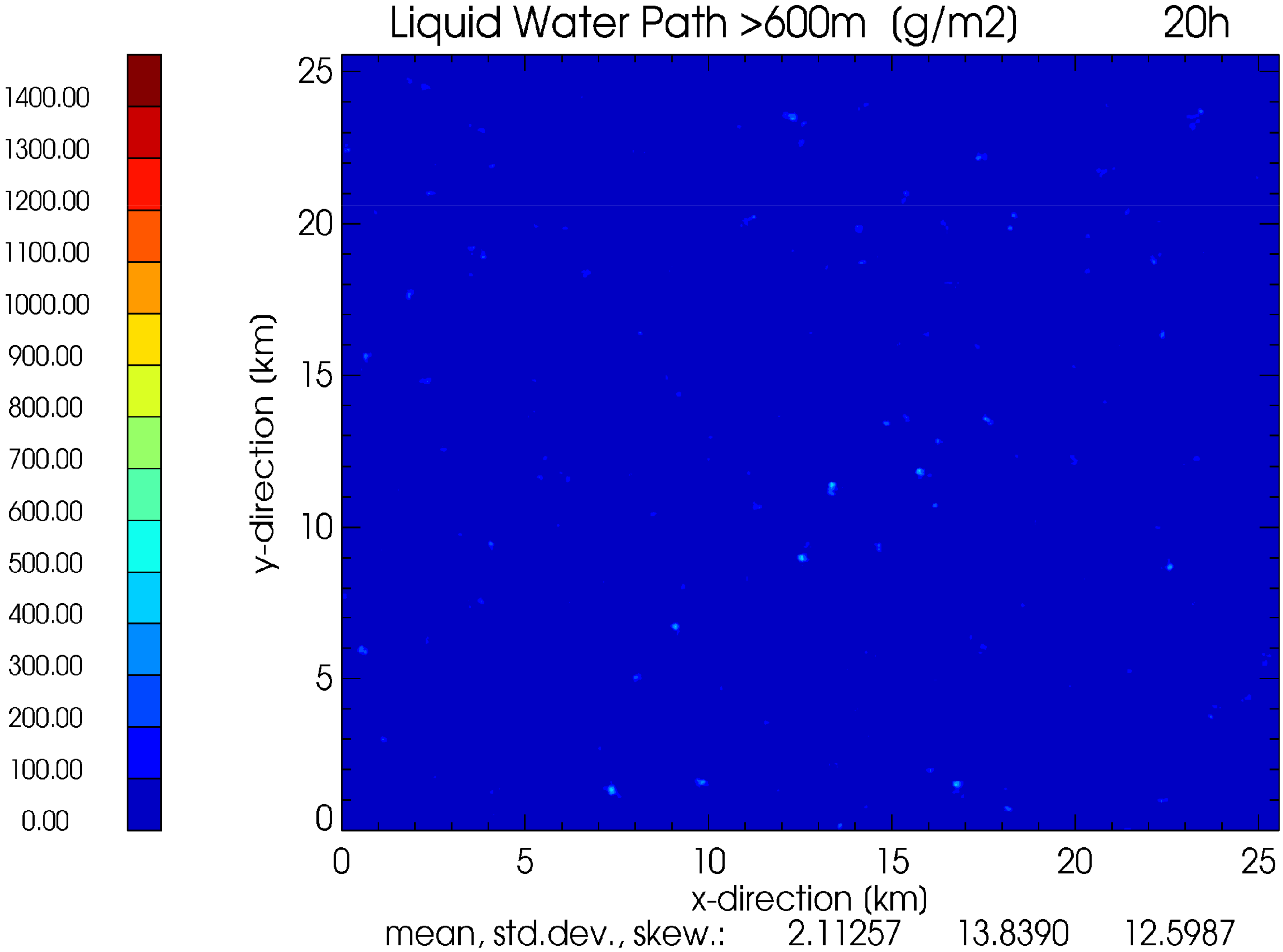
Water Vapor Path >600m (kg/m2) 20h
26.30
25.70
25.10
24.50
23.90
23.30
22.70
22.10
21.50
20.90
20.30
19.70
19.10
18.50
17.90
y-direction (km)
0
5
10
15
20
25
x-direction (km)
mean, std.dev., skew.: 19.5019 0.360379 1.05241

LES results



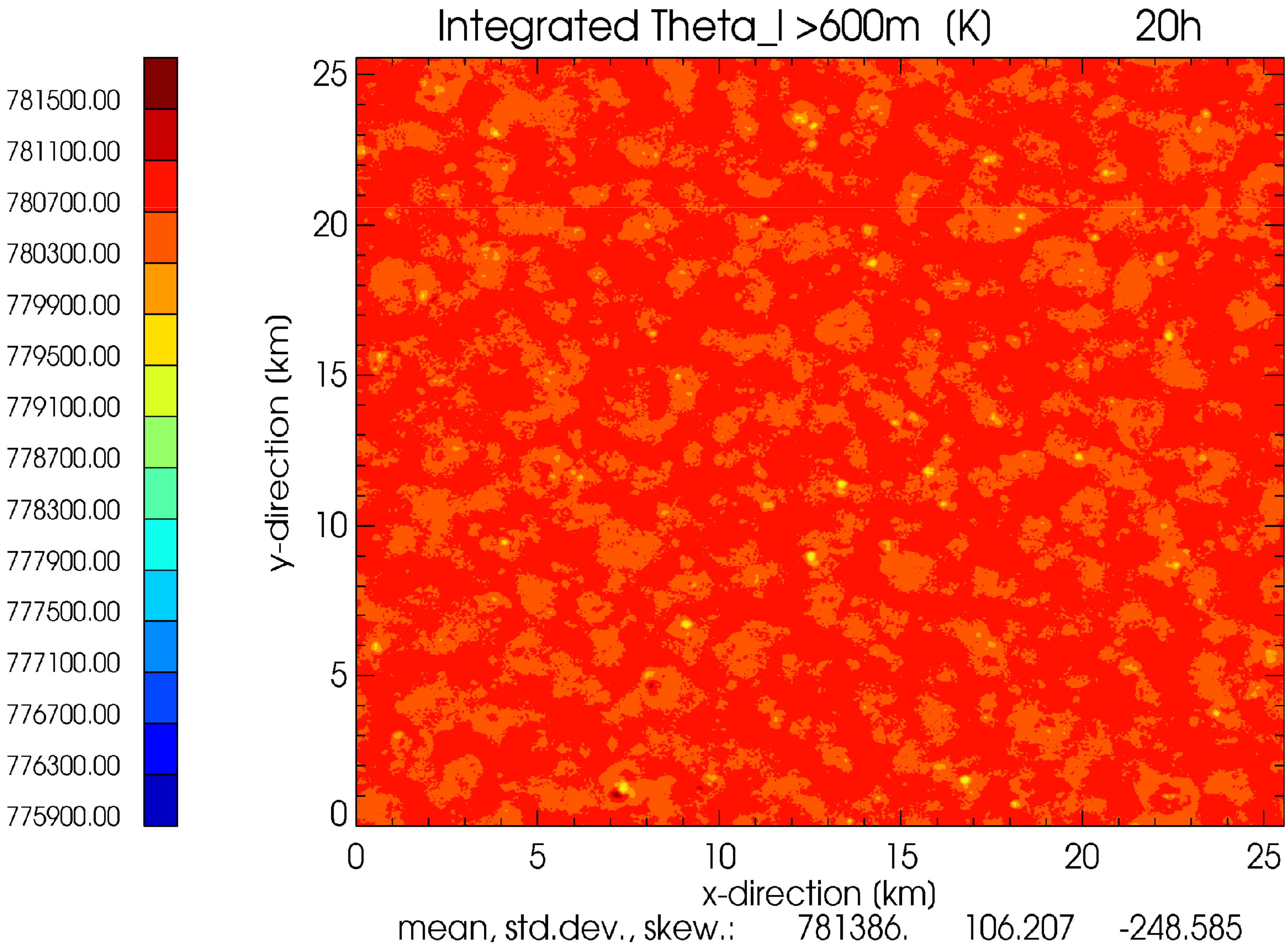
Water Vapor Path <600m (kg/m2)
20h
11.90
11.80
11.70
11.60
11.50
11.40
11.30
11.20
11.10
11.00
10.90
10.80
10.70
10.60
10.50
10.40
10.30
10.20
y-direction (km)
0
5
10
15
20
25
x-direction (km)
mean, std.dev., skew.: 11.1790 0.122132 -0.514131

LES results



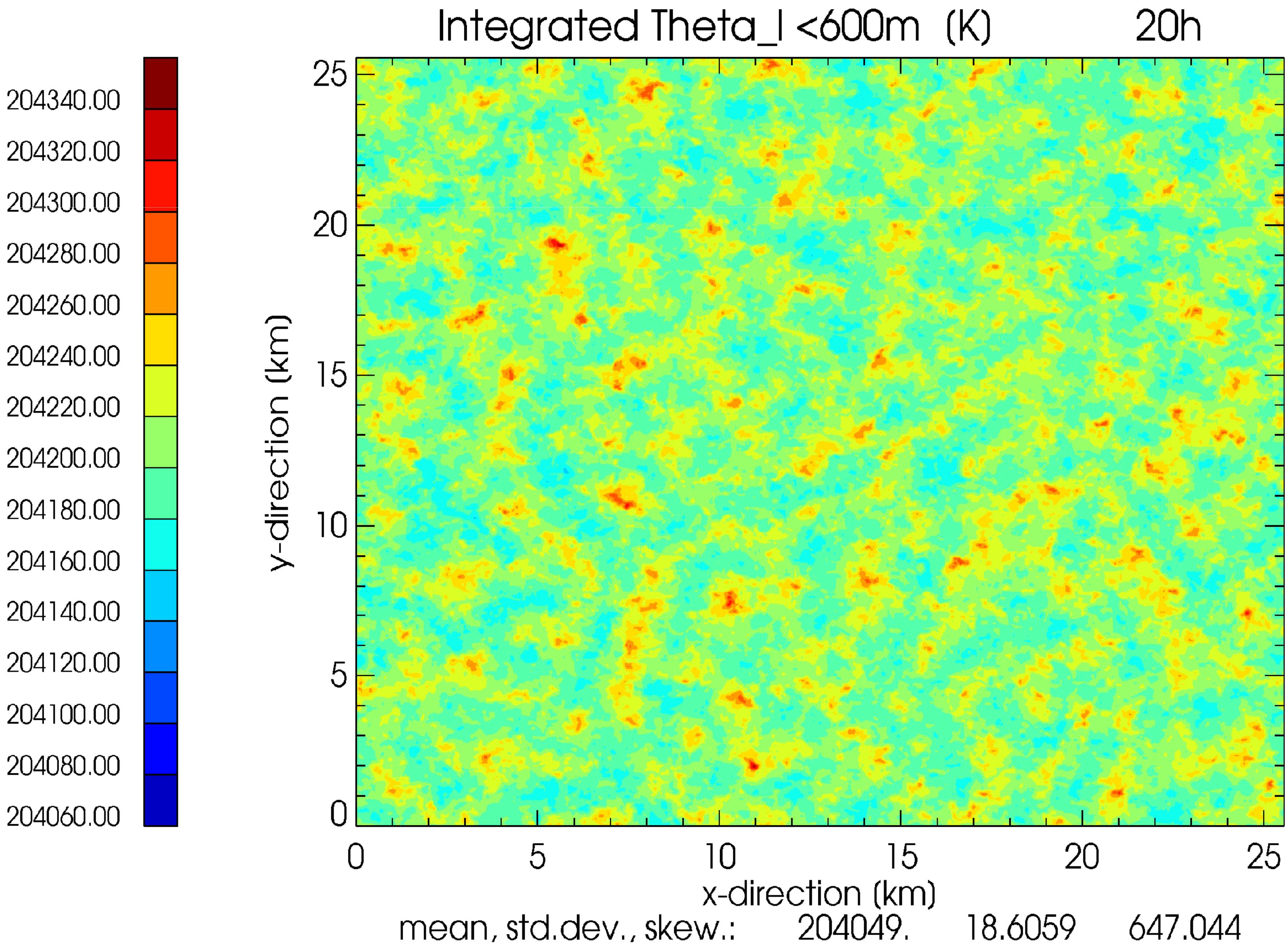
Liquid Water Path >600m (g/m2) 20h
1400.00
1300.00
1200.00
1100.00
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
y-direction (km)
x-direction (km)
0 5 10 15 20 25
mean, std.dev., skew.: 2.11257 13.8390 12.5987

LES results



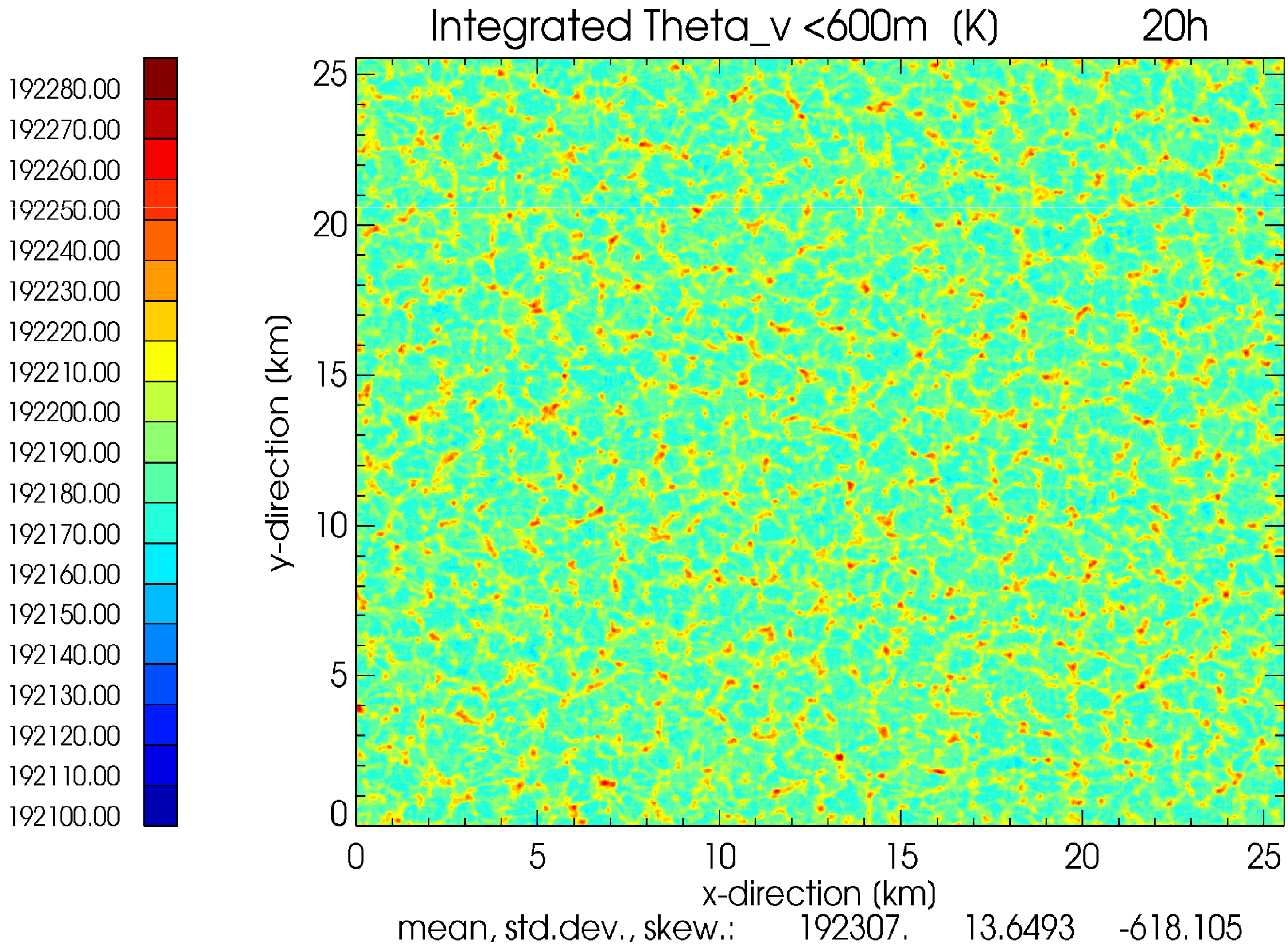
Integrated Theta_l >600m (K) 20h
781500.00
781100.00
780700.00
780300.00
779900.00
779500.00
779100.00
778700.00
778300.00
777900.00
777500.00
777100.00
776700.00
776300.00
775900.00
y-direction (km)
0
5
10
15
20
25
x-direction (km)
mean, std.dev., skew.: 781386. 106.207 -248.585

LES results

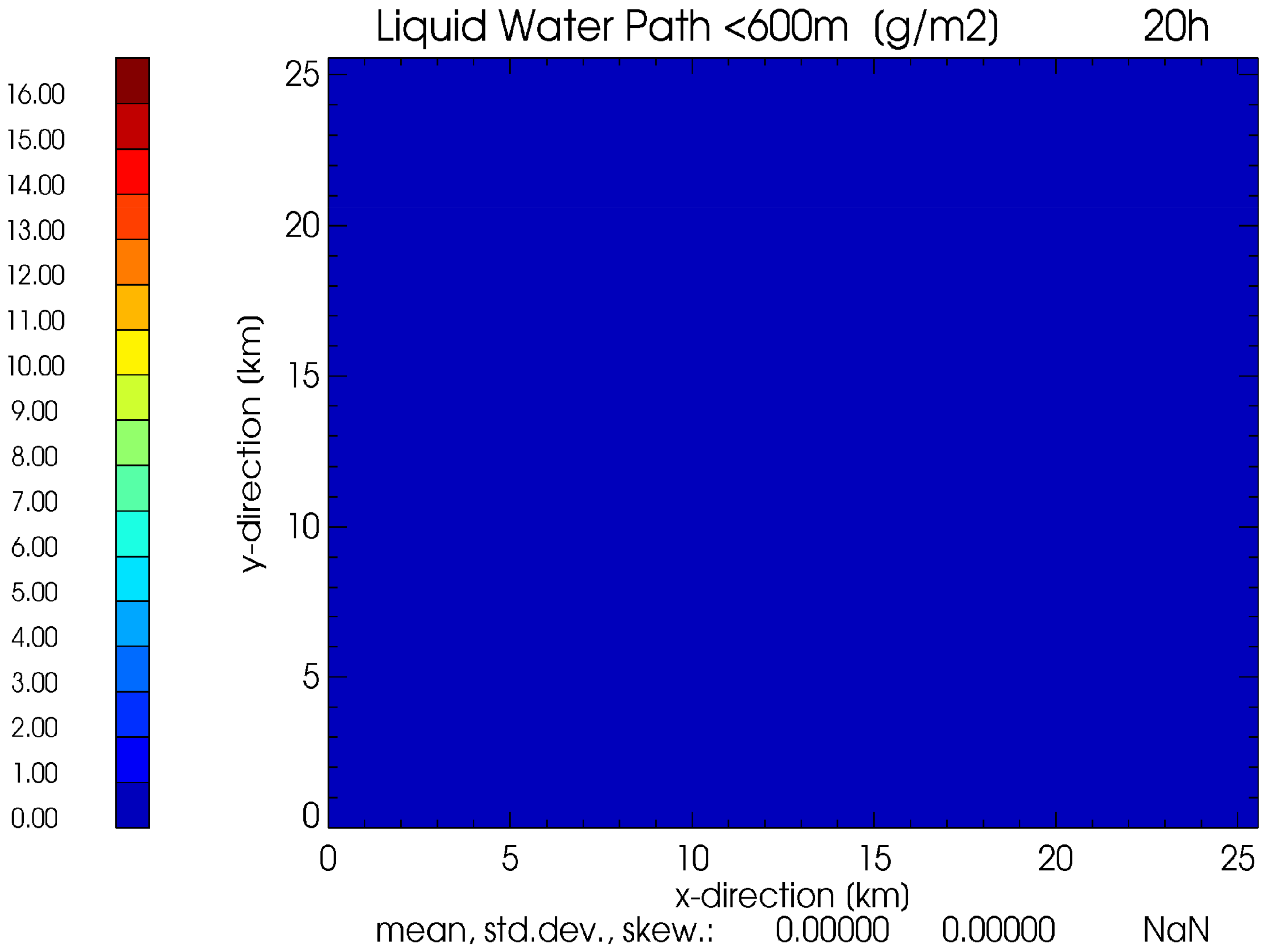


Integrated Theta_l <600m (K) 20h
204340.00
204320.00
204300.00
204280.00
204260.00
204240.00
204220.00
204200.00
204180.00
204160.00
204140.00
204120.00
204100.00
204080.00
204060.00
y-direction (km)
0
5
10
15
20
25
x-direction (km)
mean, std.dev., skew.: 204049. 18.6059 647.044

LES results


Integrated Theta_v <600m (K) 20h
192280.00
192270.00
192260.00
192250.00
192240.00
192230.00
192220.00
192210.00
192200.00
192190.00
192180.00
192170.00
192160.00
192150.00
192140.00
192130.00
192120.00
192110.00
192100.00
y-direction (km)
0
5
10
15
20
25
x-direction (km)
mean, std.dev., skew.: 192307. 13.6493 -618.105

LES results


Liquid Water Path <600m (g/m2) 20h
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
y-direction (km)
25
20
15
10
5
0
x-direction (km)
mean, std.dev., skew.: 0.00000 0.00000 NaN