Focus on deep and shallow convection, and turbulence

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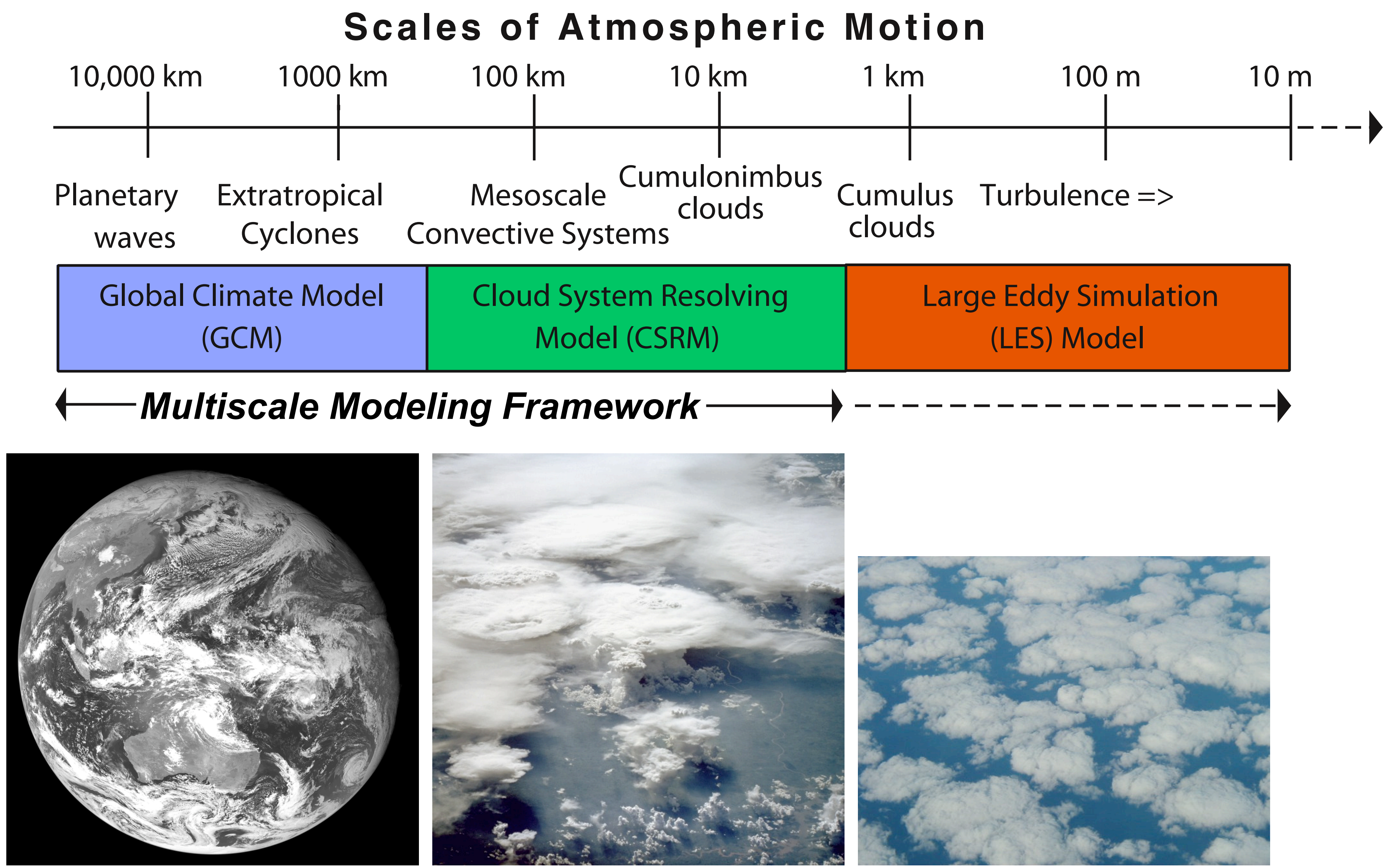
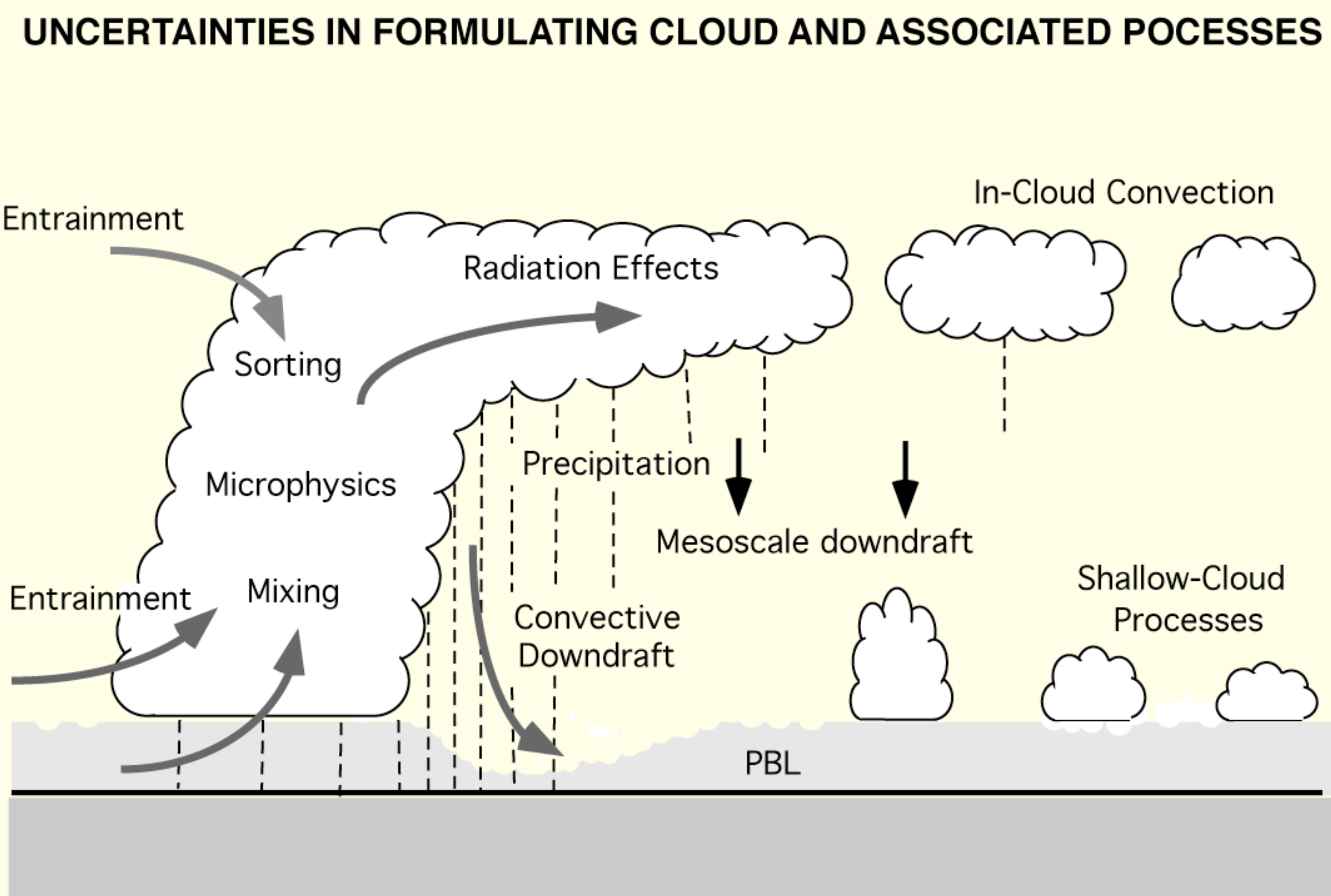


Scales of Atmospheric Motion
10,000 km
1000 km
100 km
10 km
1 km
100 m
10 m
Planetary waves
Extratropical Cyclones
Mesoscale Convective Systems
Cumulonimbus clouds
Cumulus clouds
Turbulence =>
Global Climate Model (GCM)
Cloud System Resolving Model (CSRM)
Large Eddy Simulation (LES) Model
Multiscale Modeling Framework



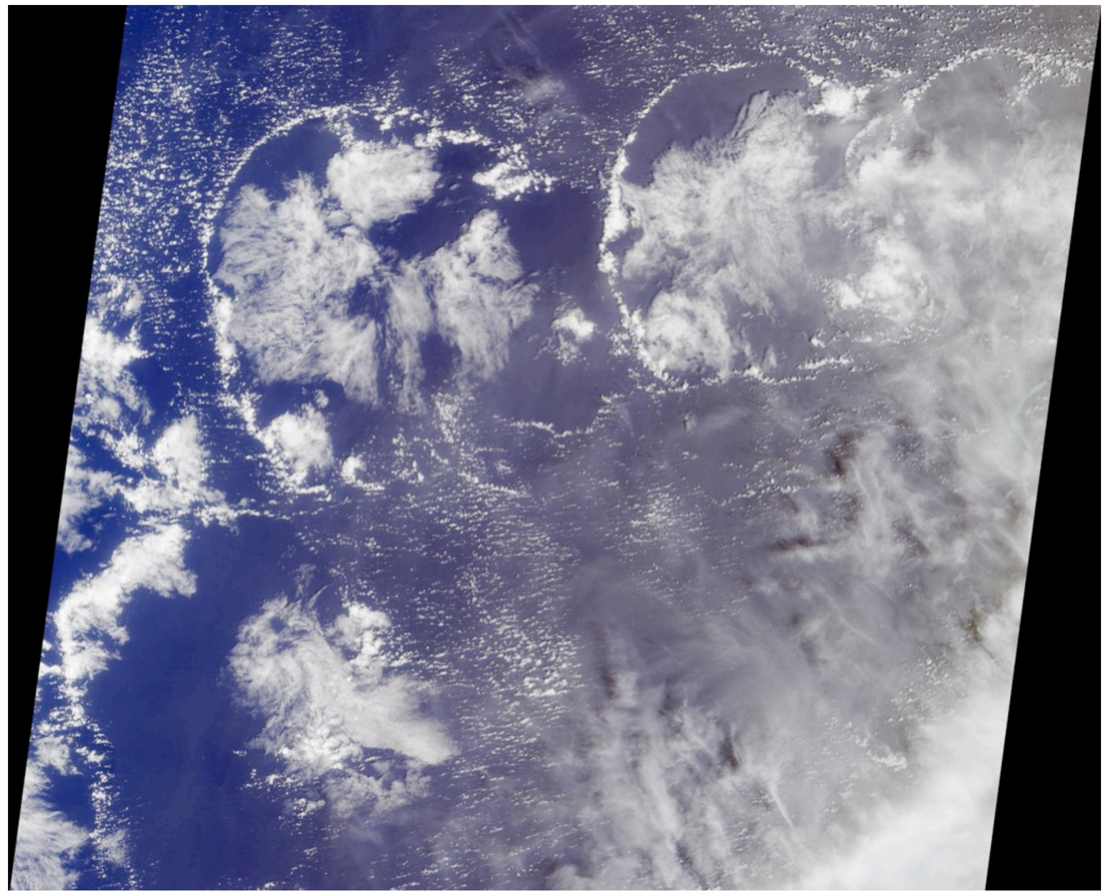
from Arakawa and Jung (2003)

Boundary layer clouds in deep-convection-resolving models (DCRMs)

- DCRMs are CRMs with horizontal grid sizes of 4 km or more.
- Used in MMF, GCRMs (global CRMs), and tropical cyclone models.
- In MMF and GCRMs, DCRMs are expected to represent all types of cloud systems.
- However, many cloud-scale circulations are not resolved by DCRMs.
- Representations of SGS circulations currently used in DCRMs can be improved.

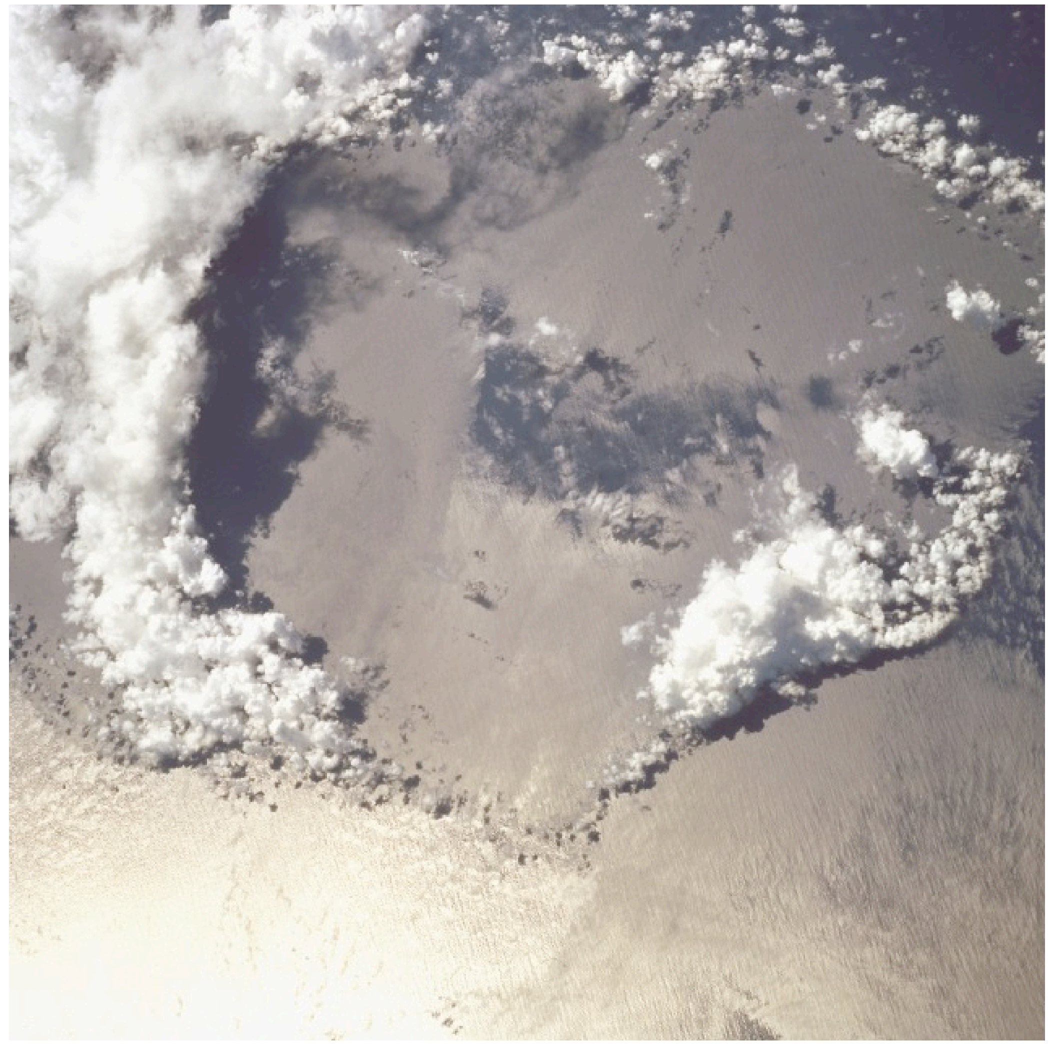
Boundary layers in deep precipitating convective cloud systems

- Tropical convective cloud systems may organize too readily in the FRCGC GCRM and in MMF GCMs.
- *Possible causes:*
  - Convectively-generated cold pools are too strong.
  - Boundary layer stabilization due to shallow convection is under-estimated.
- Poor horizontal resolution may contribute to both.



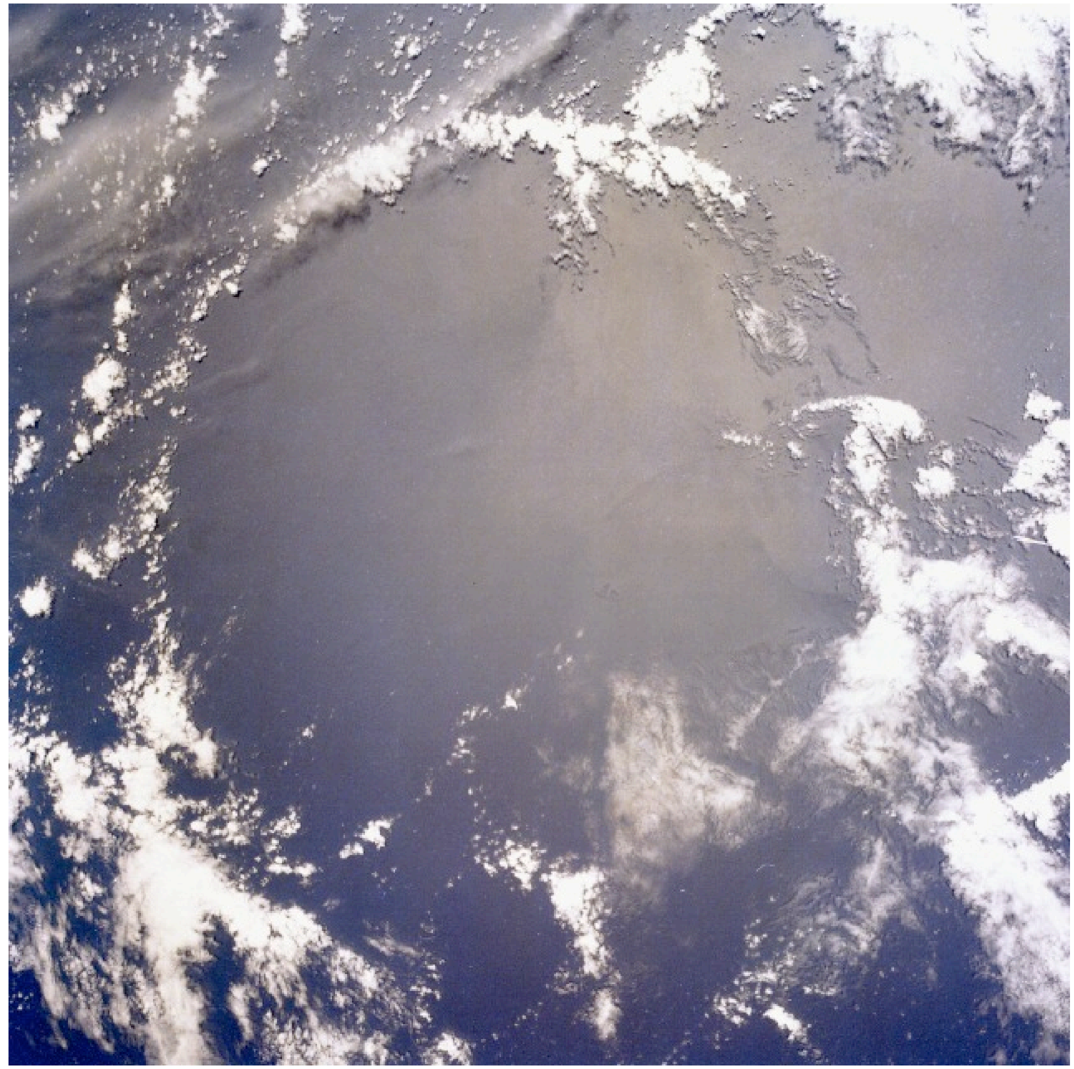
Shallow cumulus clouds and mesoscale organization

- Typical DCRMs grid sizes are too large to resolve shallow cumulus.
- A DCRM with a suitable SGS parameterization should be able to represent shallow cumulus and resolved mesoscale organization.
- LES can be used to provide a benchmark simulation.



Outline of this talk

- Introduction
  - Objectives of focus
  - Scope and relationship to old WGs
- Science issues
- Meeting the objectives



Introduction

- **Objectives of focus:**
  Improve the representation of SGS convection and turbulence in deep-convection-resolving models (DCRMs), for use in MMFs, GCRMs, and NWP.
- **Scope and relationship to old WGs:**
  - Extensions, evaluations, and applications of the prototype MMF(s)
  - Development and testing of improved parameterizations of microphysics and radiation for use in CSRMS, MMFs, and GCRMs
  - Development and testing of improved parameterizations of boundary layer clouds and turbulence for use in CSRMS, MMFs, and GCRMs
  - Accelerated improvement of conventional parameterizations
  - Optimal use of computational and data storage resources
  - Knowledge-transfer to climate modeling centers
  - Knowledge transfer to numerical weather prediction centers

Science Issues

Representation of the following cloud systems and boundary layer regimes in DCRMs:

- Deep precipitating convective
- Transition from shallow to deep convection
- Diurnal cycle of shallow convection over land
- Trade cumulus
- Marine stratocumulus
- Cold-air outbreaks over mid-latitude oceans
- Convective plumes from leads during winter
- Boundary layers over inhomogenous surfaces or terrain

Meeting the Objectives

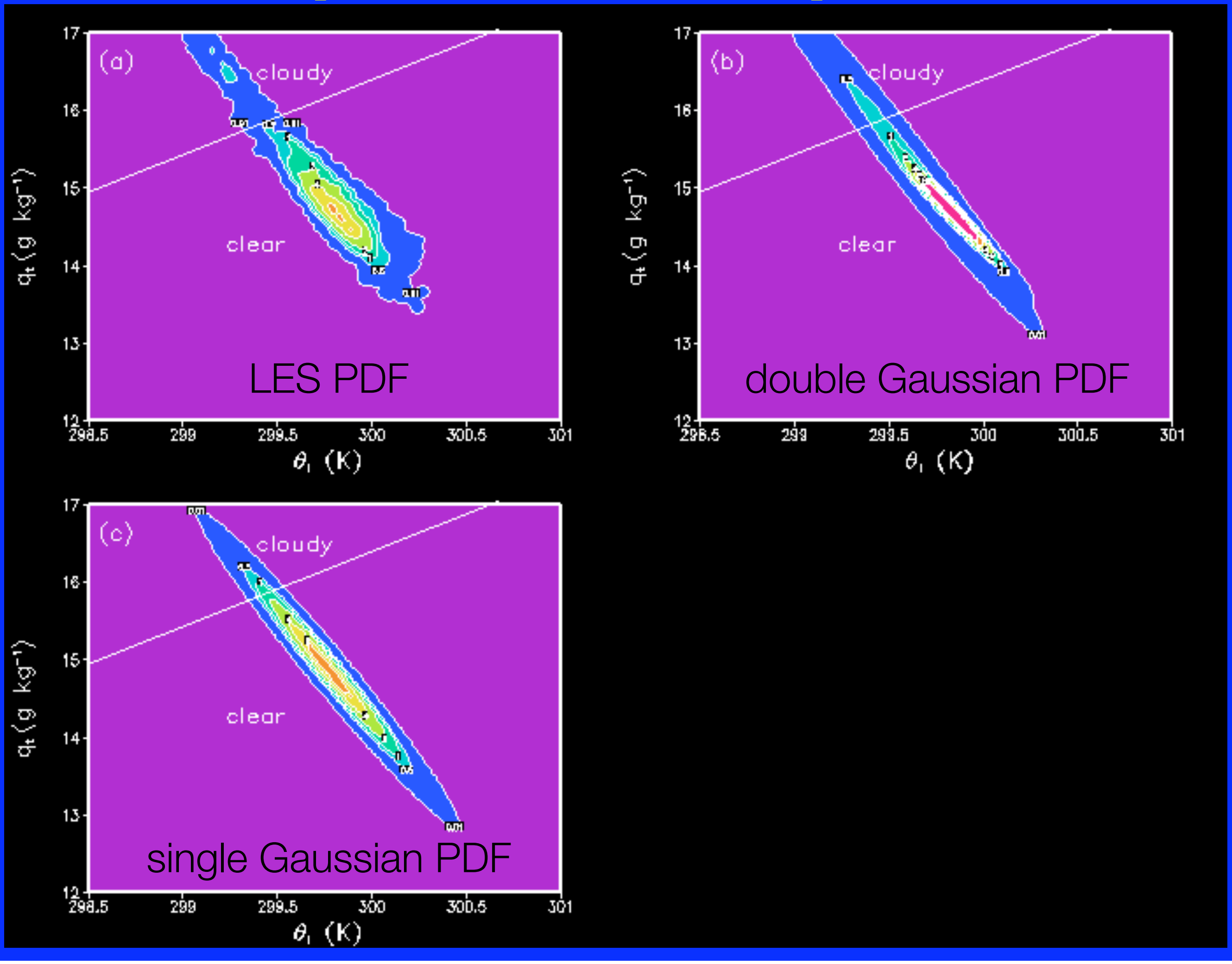
Develop and test improved representations of SGS convection and turbulence in DCRMs.

- **Proposed parameterizations**
  - *PDF/HOC:* Cheng & Xu, Lappen & Randall
  - *Two-scale MMF:* DCRM plus boundary-layer-eddy-resolving model (ERM)
- **Additional physics to be included**
  - Effects of *surface inhomogeniety* (elevation, land surface properties): both resolved by the DCRM and SGS
- **Proposed evaluation methods**
  - Analysis of and comparison to *benchmark simulations*
  - Comparison to *observational datasets*

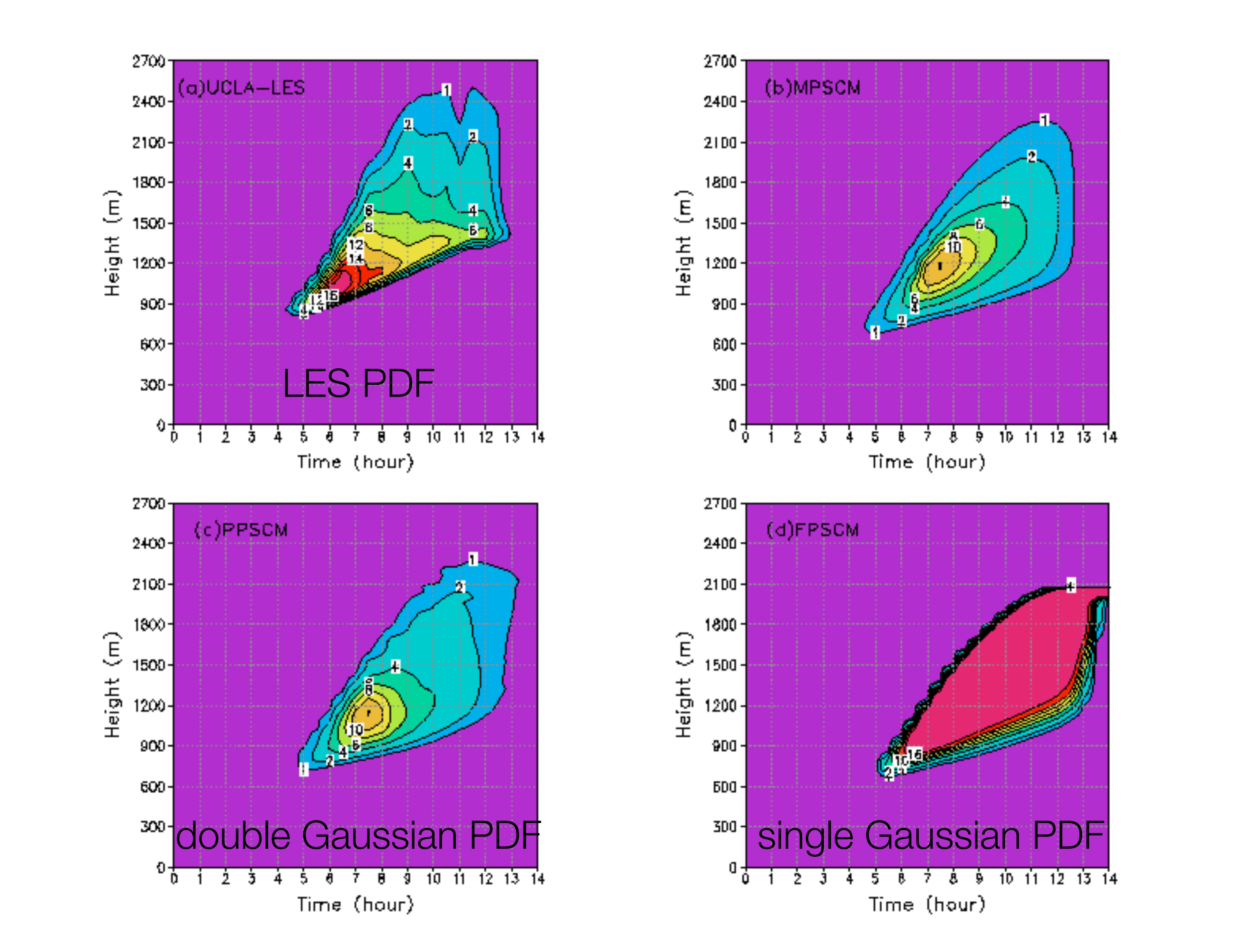
Boundary-layer Clouds in a Multi-scale Modeling Framework (MMF)

Anning Cheng, Kuan-Man Xu, Yali Luo,
Jiundar Chern, and Wei-Kuo Tao

Joint PDF of total water and liquid water potential temperature



Continental shallow cumuli (ARM)



Randall, D. A., Q. Shao, and C.-H. Moeng 1992: A Second-Order Bulk Boundary-Layer Model. *J. Atmos. Sci.*, 49, 1903-1923.

Lappen, C.-L, and D. A. Randall, 2001: Towards a unified parameterization of the boundary layer and moist convection. Part I. A new type of mass-flux model. *J. Atmos. Sci.*, 58, 2021-2036.

These papers show that:

- Mass flux methods can be married with higher-order closure.
- With this approach, the triple-moment terms of the second moment equations can either advect or diffuse, depending on the regime.

Proposed Evaluation Methods

- **Benchmark simulations**
  - Large-domain LES (e.g., 100 km x 100 km domain, 0.1 km grid size)
  - Compare to DCRM results using various SGS parameterizations.
  - Compare to SCM results.
  - Analyze results to gain insight into scale interactions, etc.

High-Resolution Simulation of Shallow-to-Deep Convection Transition over Land

(Khairoutdinov and Randall 2006)

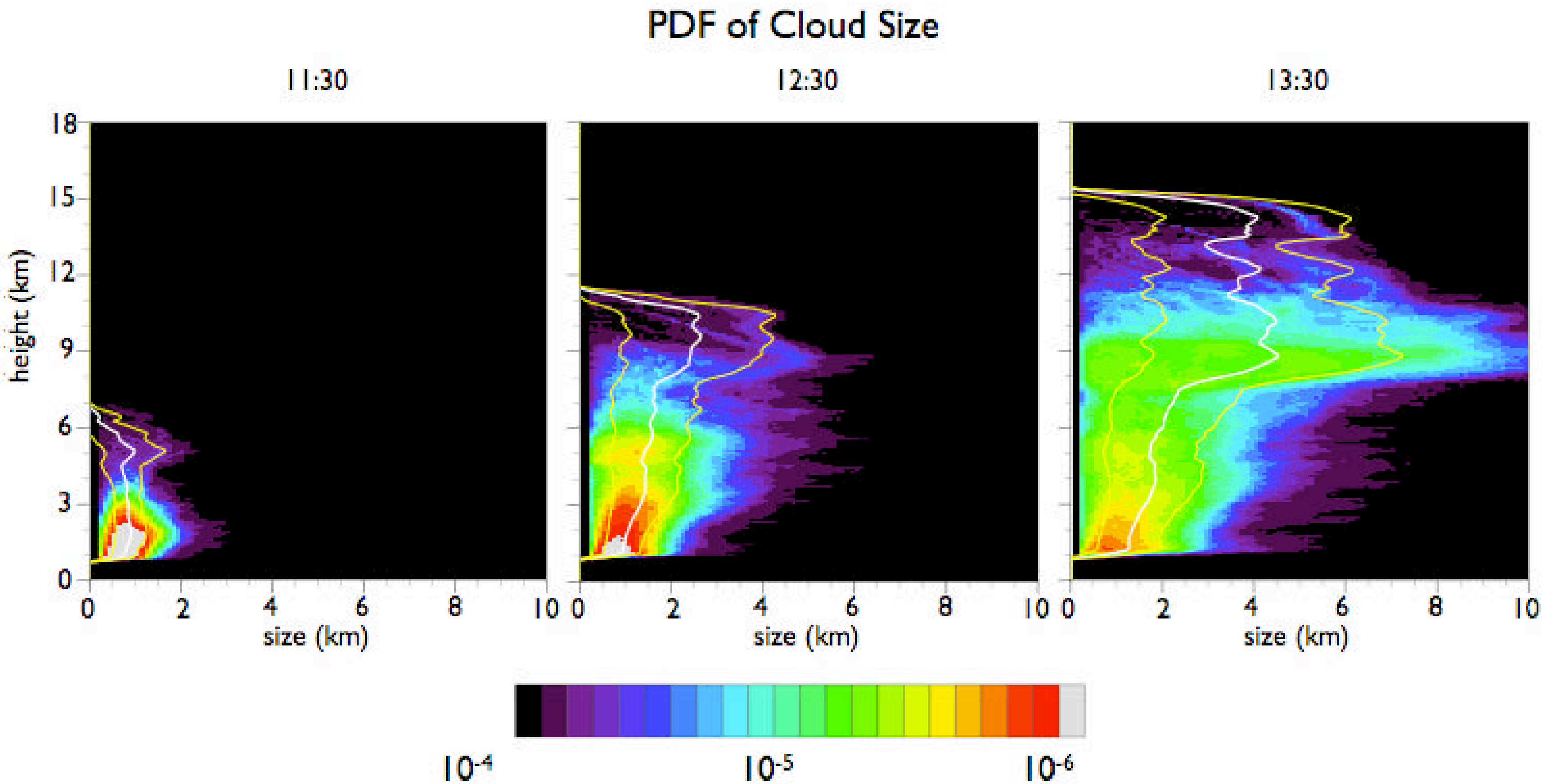


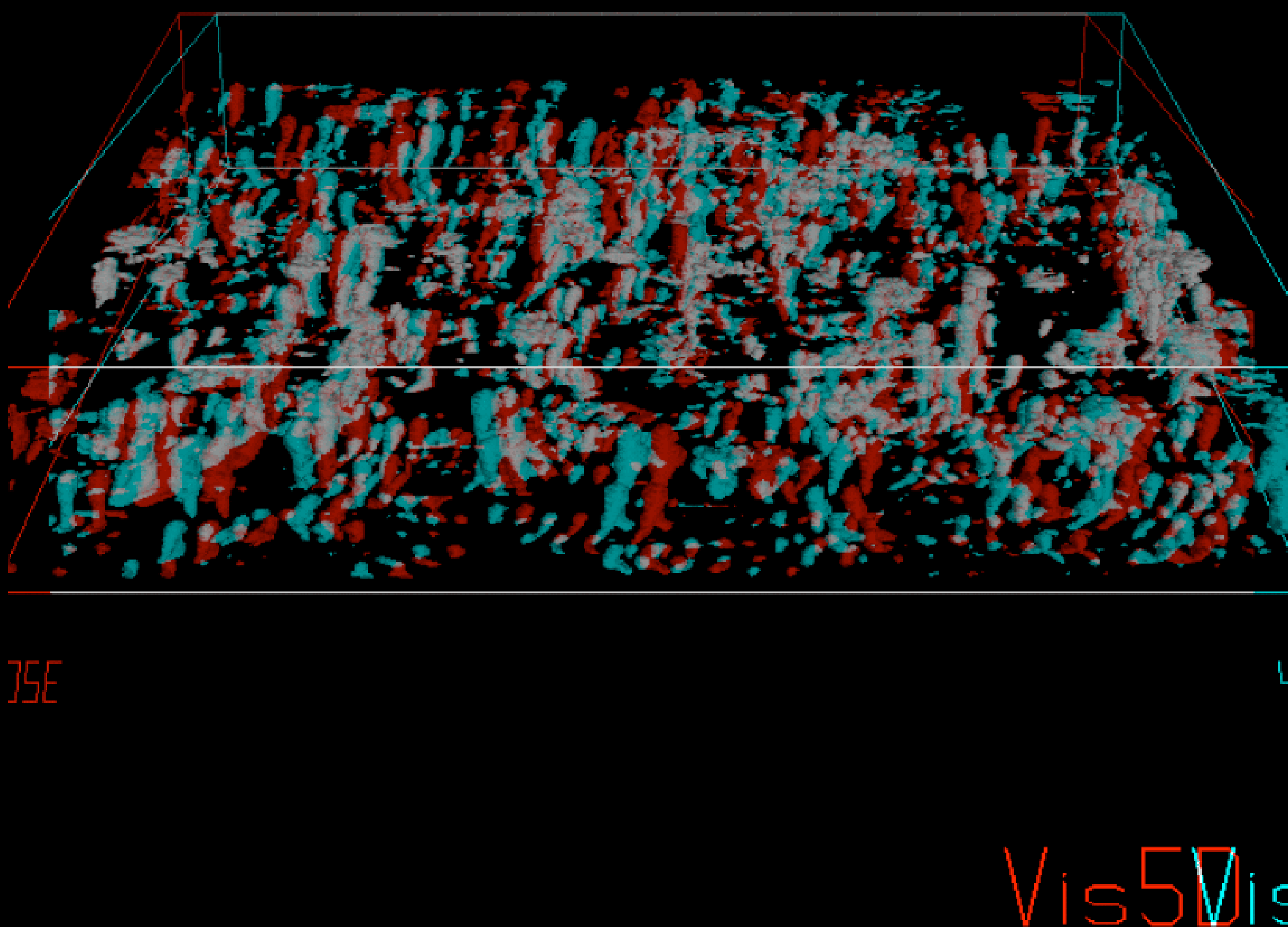
Figure 8. PDF of cloud size as a function of height shown for three different simulation times. Mean and standard deviations are shown by the white and yellow lines, respectively.

150 km x 150 km, 100 m grid size, 6 h

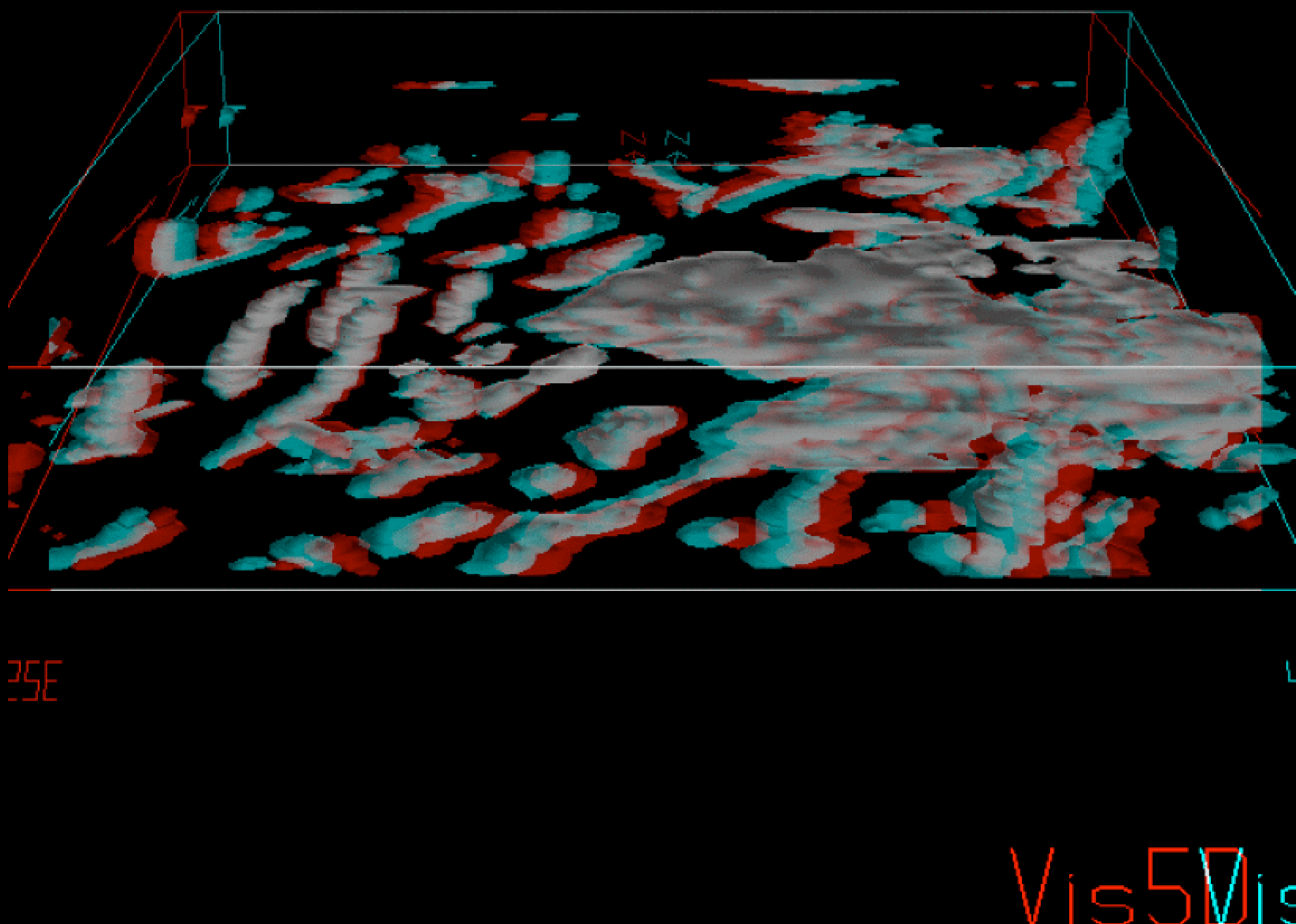
Grid-size dependence in a large domain LES

- **RICO trade wind cumulus case:** 19 Jan 2005
- **Control simulation:** 100 m horizontal grid size, 40 km x 40 km domain, 24 h simulation
- **Grid-size dependence simulations:** 500 m, 1000 m, 2000 m, 4000 m horizontal grid sizes, otherwise unchanged from control
- **Next:** stereo images of clouds at 12 h

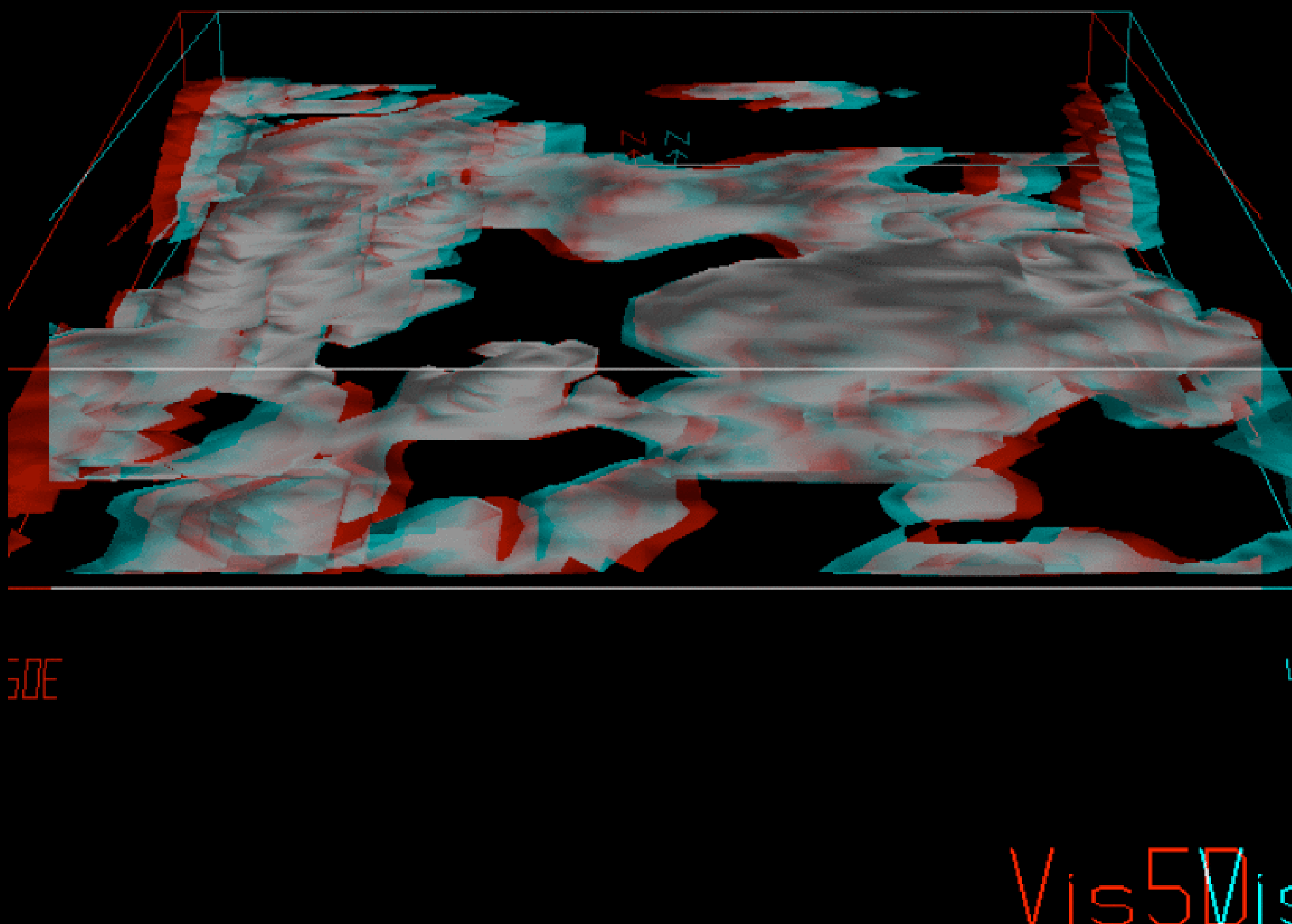
100 m



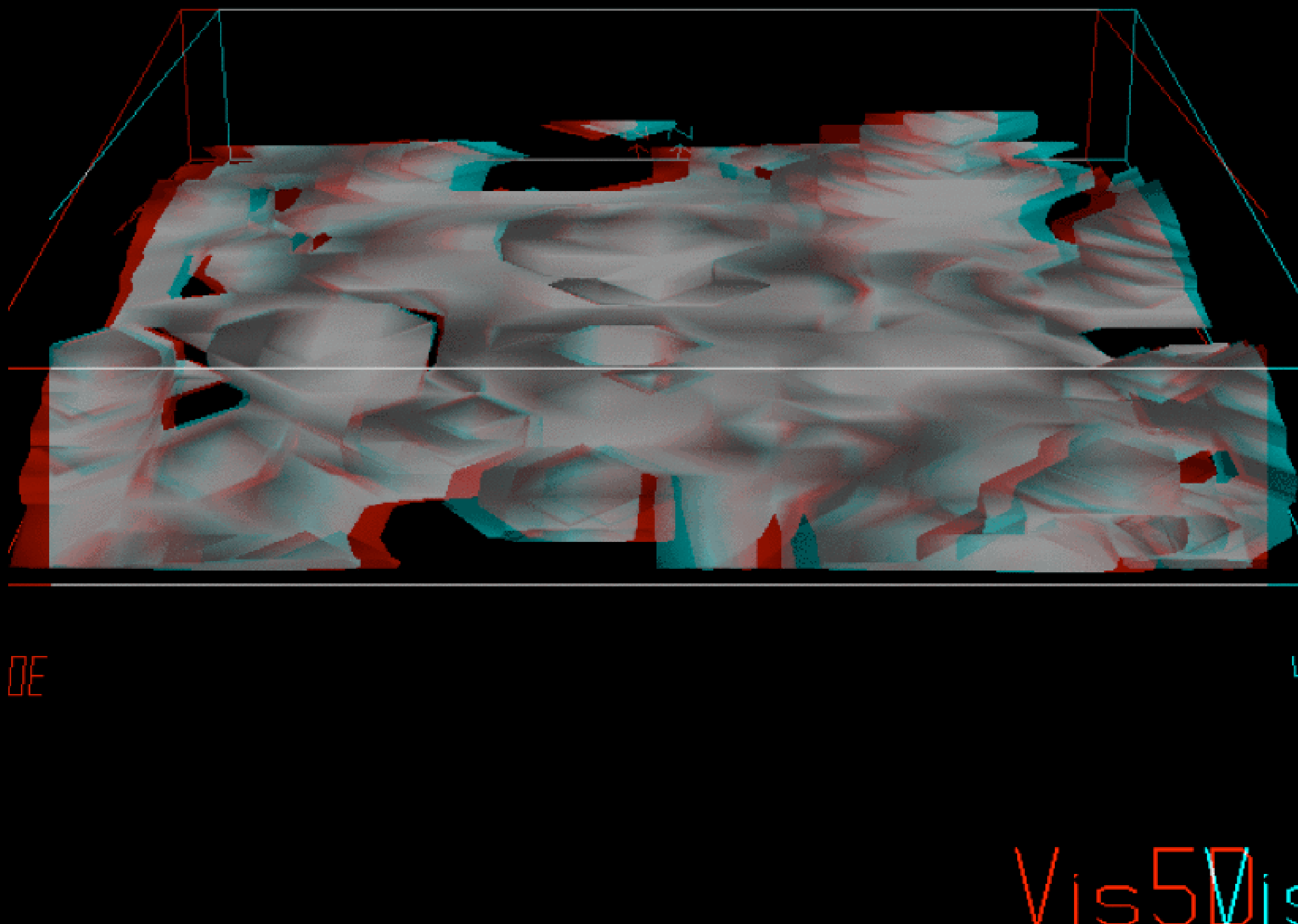
500 m



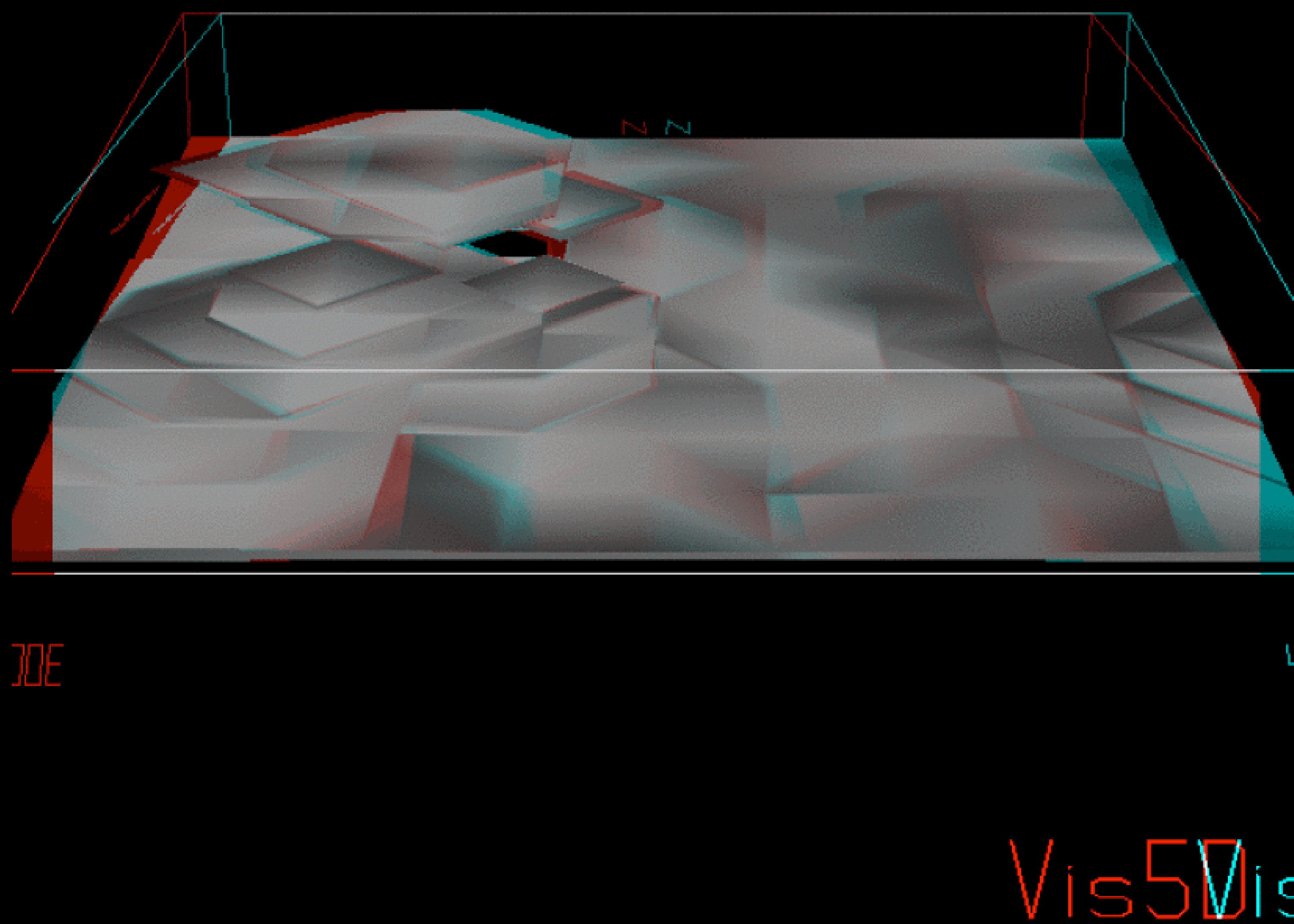
1000 m



2000 m

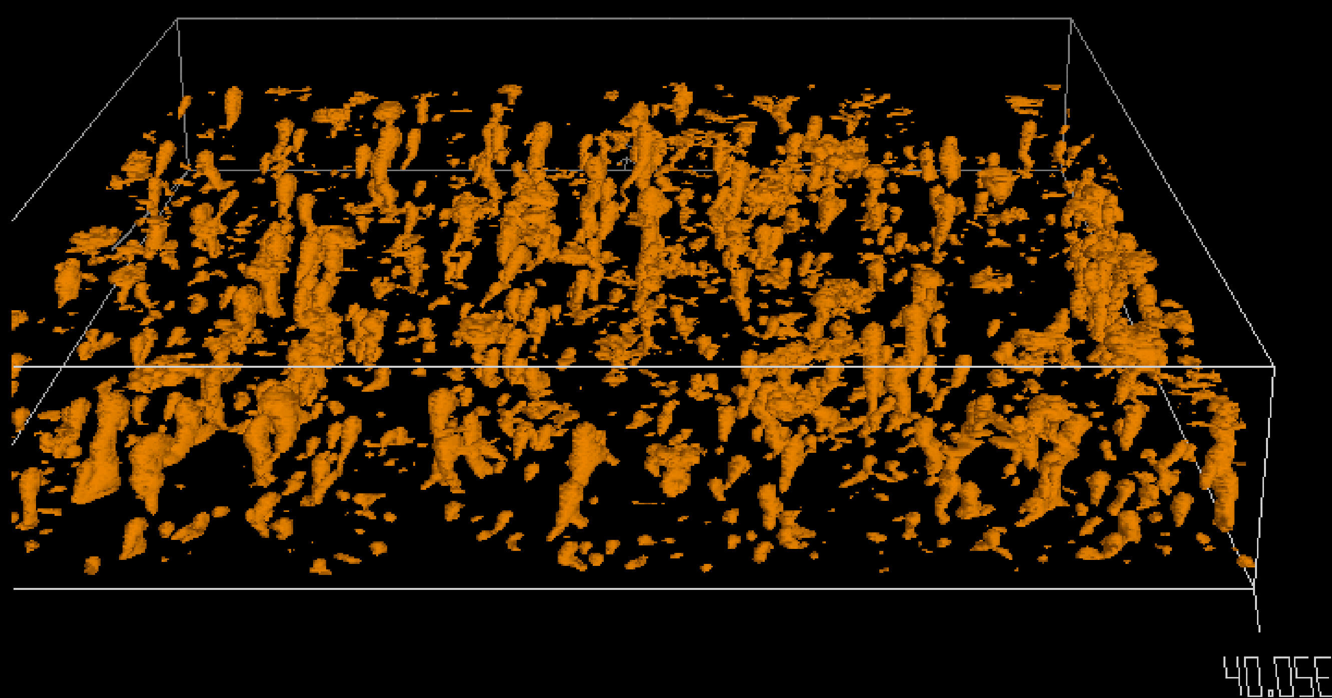


4000 m



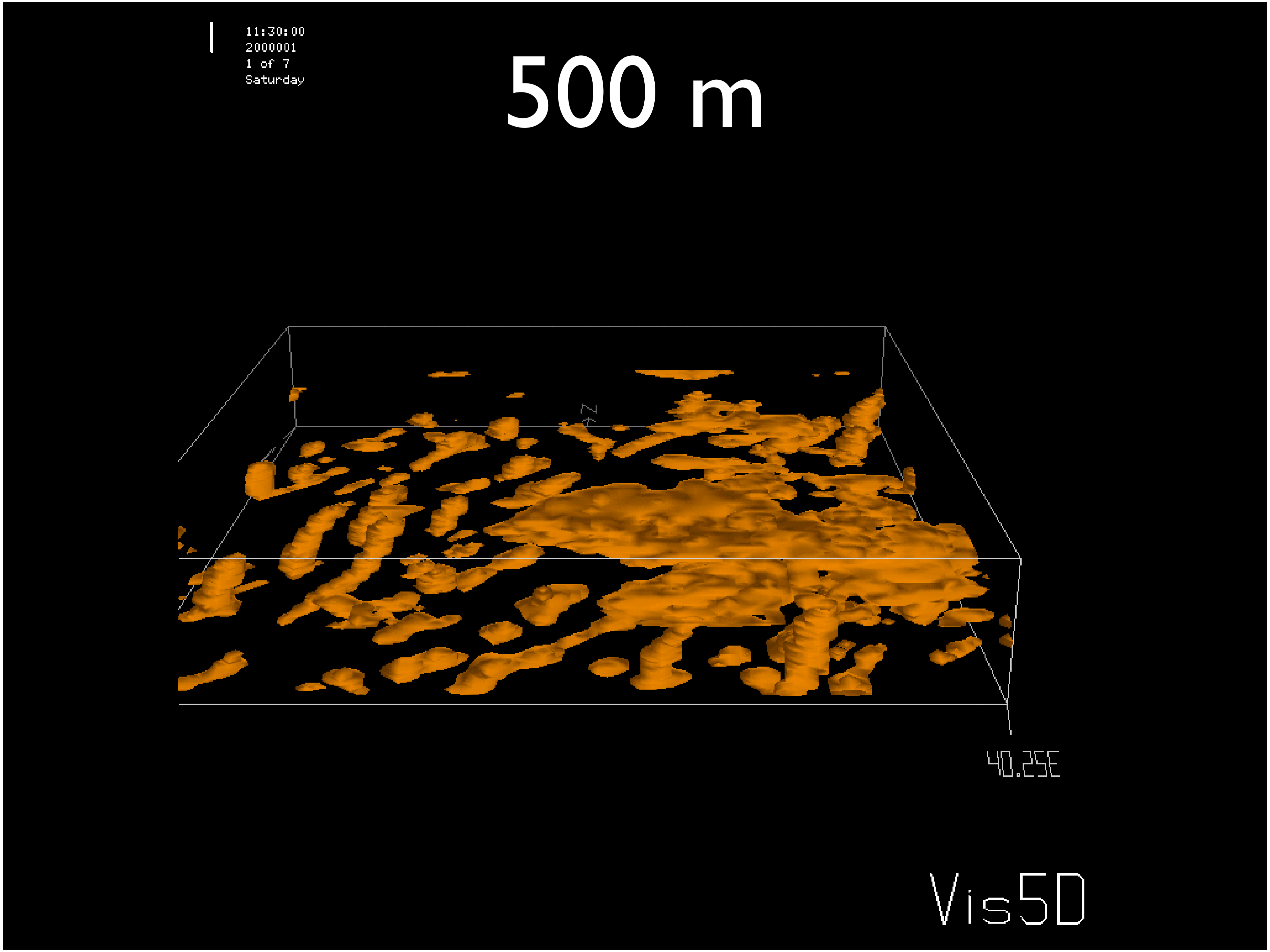
11:30:00
2000001
1 of 7
Saturday

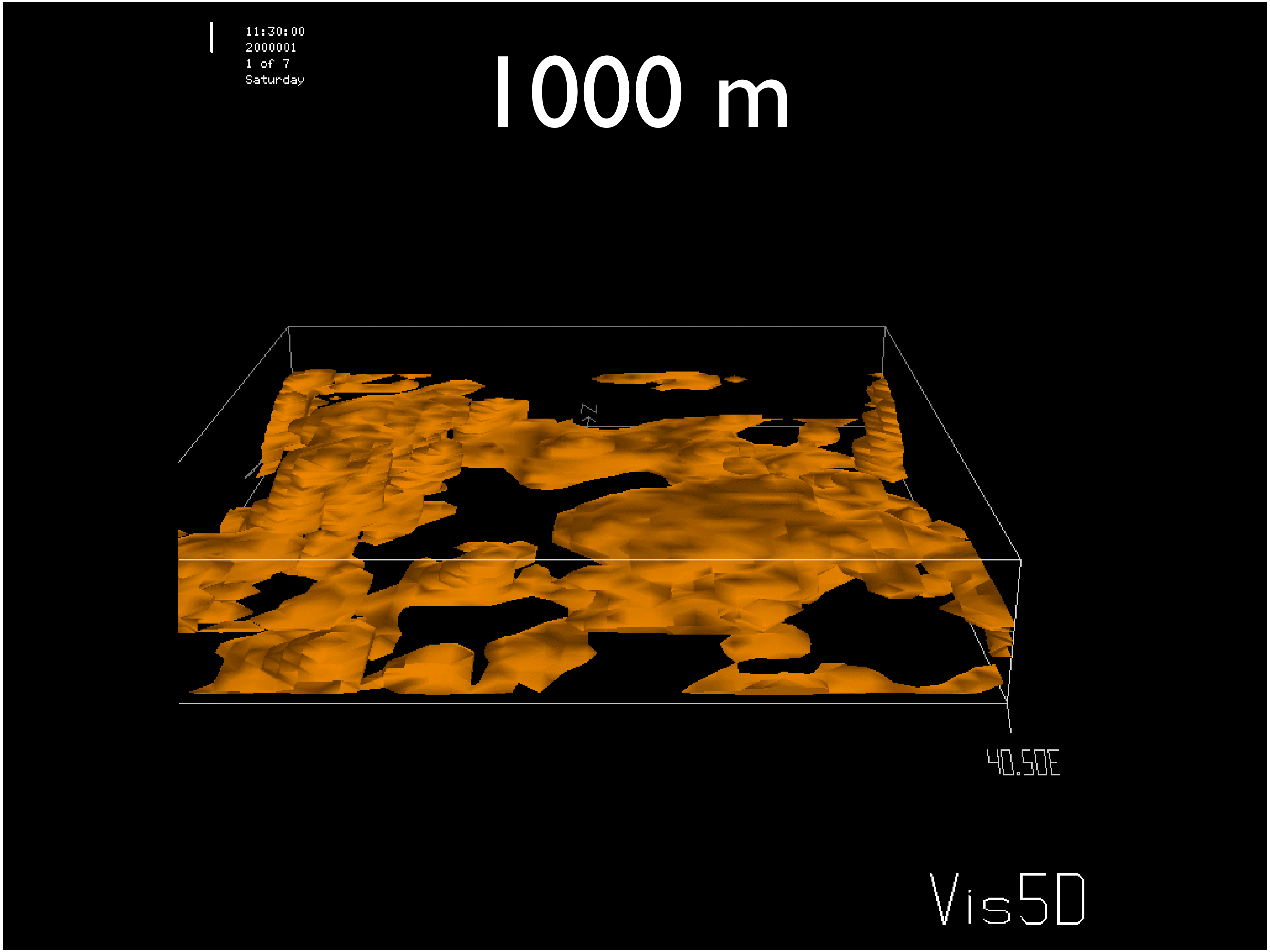
100 m

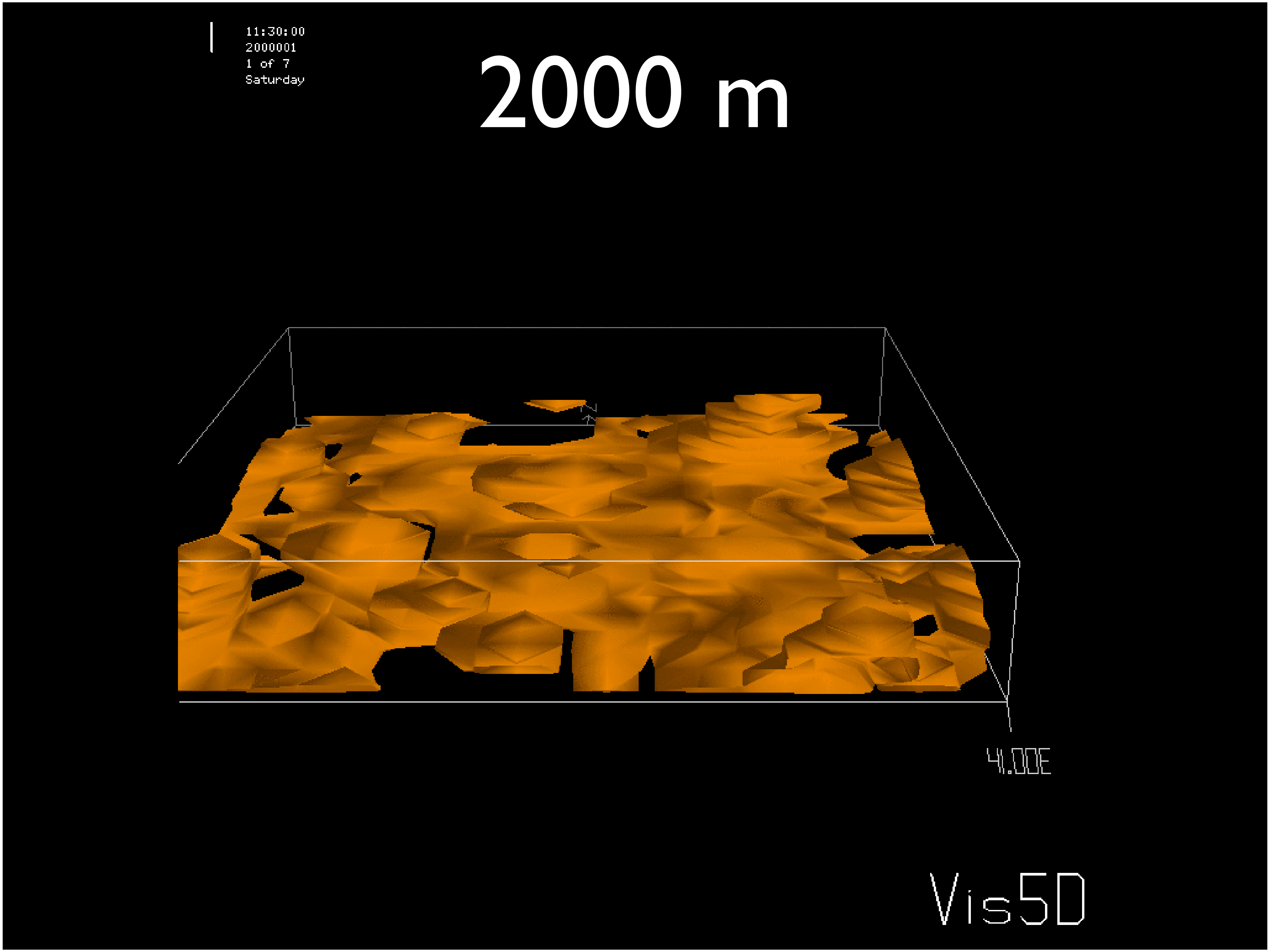


Vis5D

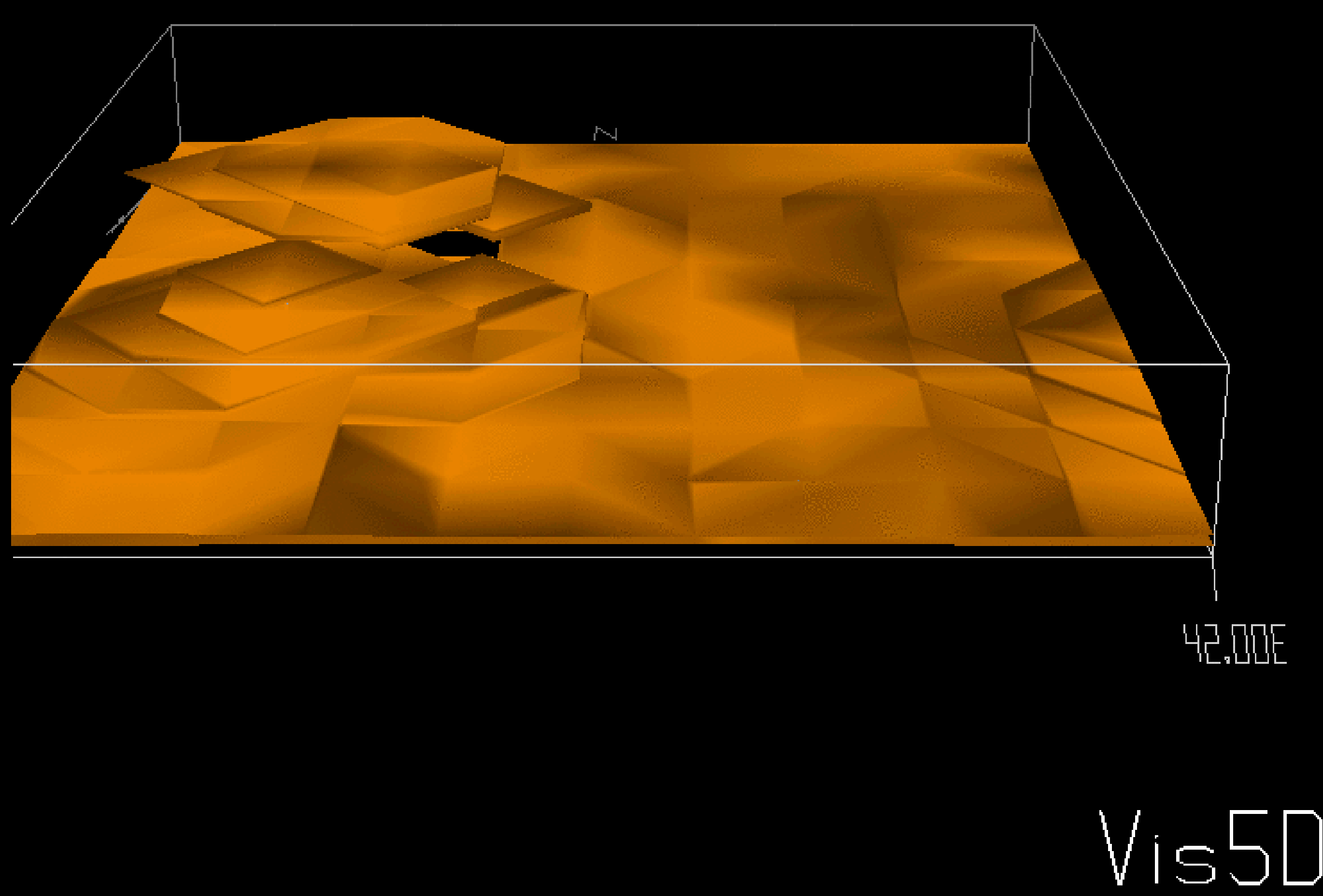
500 m



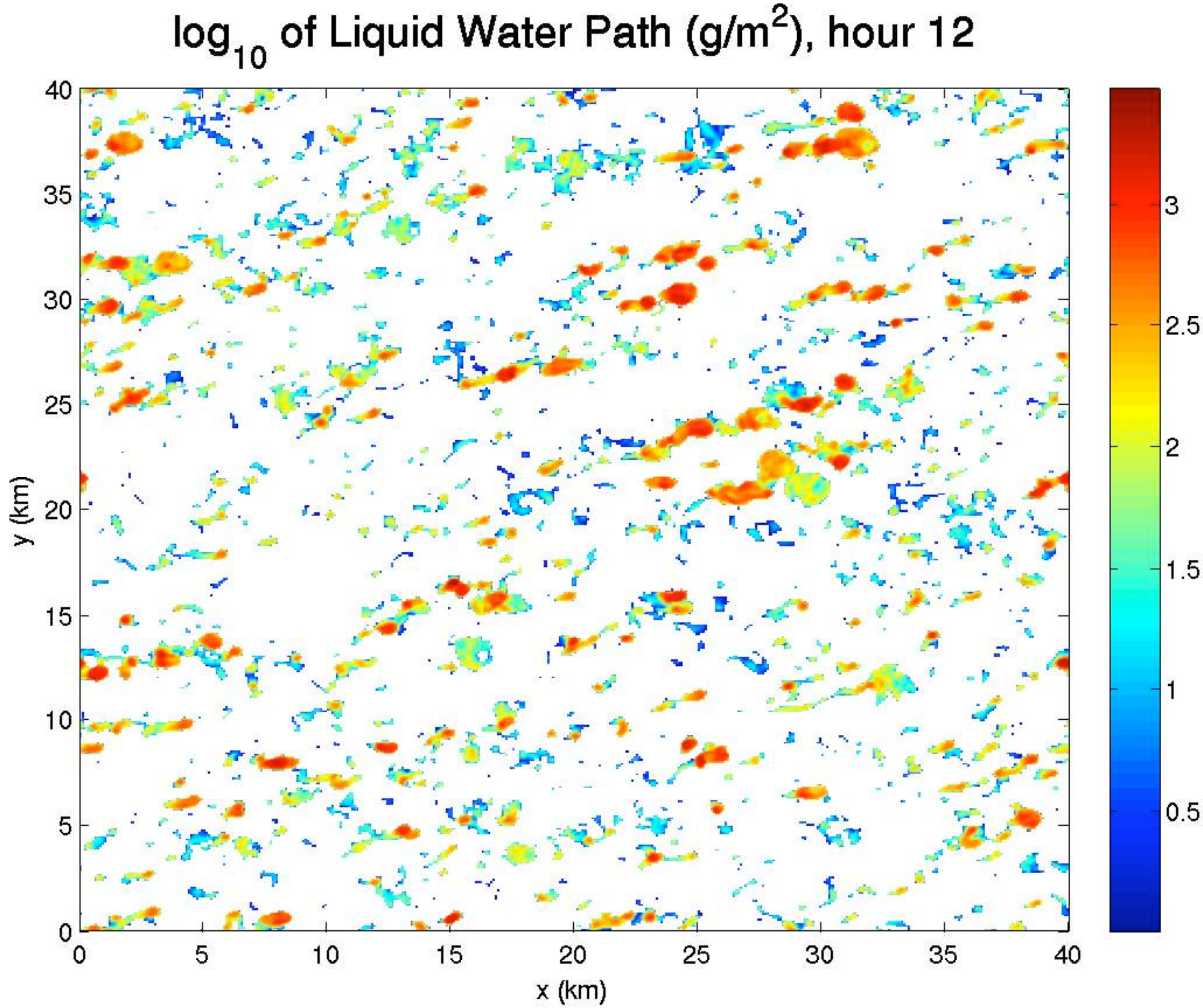

11:30:00
2000001
1 of 7
Saturday
1000 m
40.50E
Vis5D


11:30:00
2000001
1 of 7
Saturday
2000 m
41.00E
Vis5D

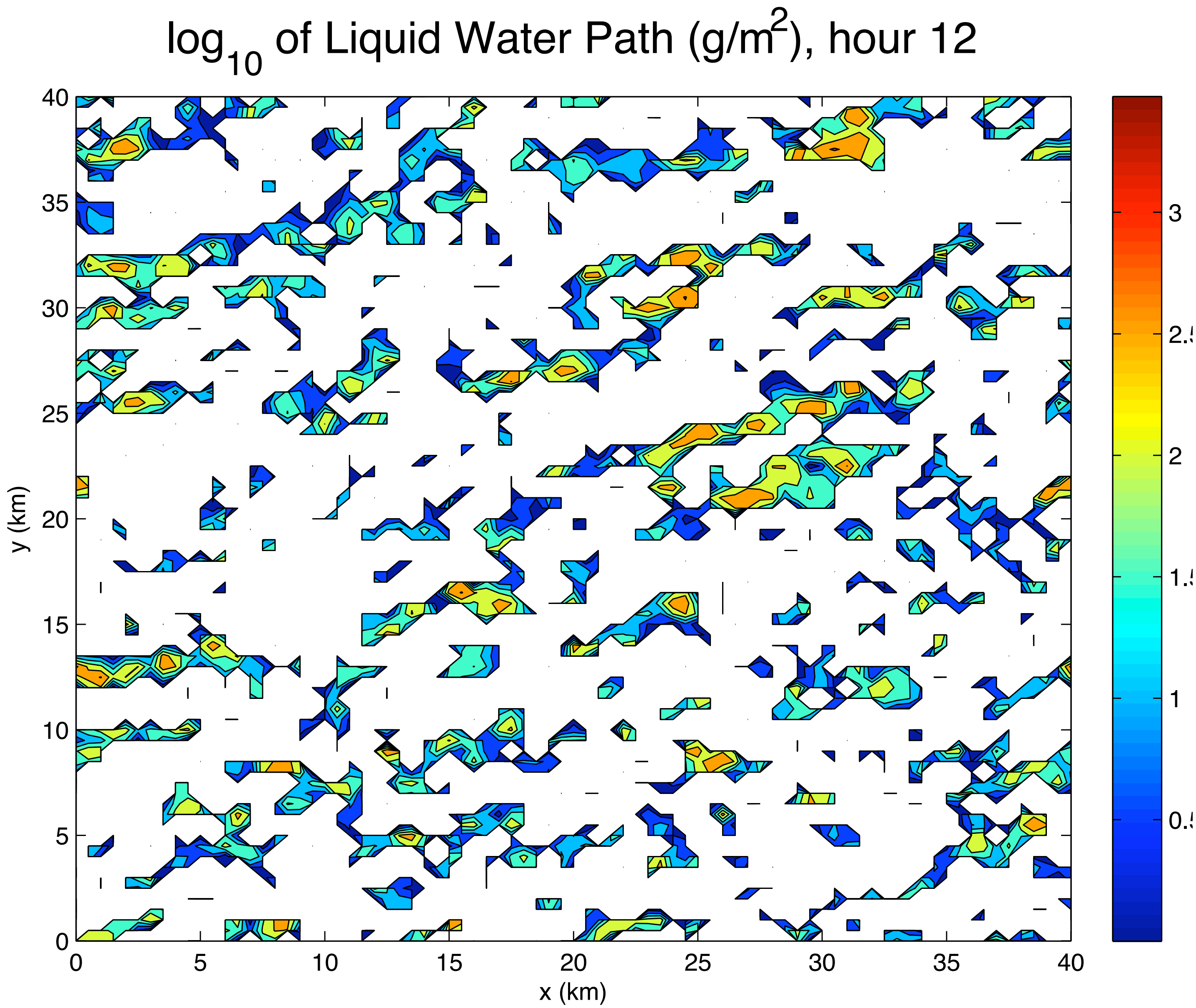
4000 m



100 m

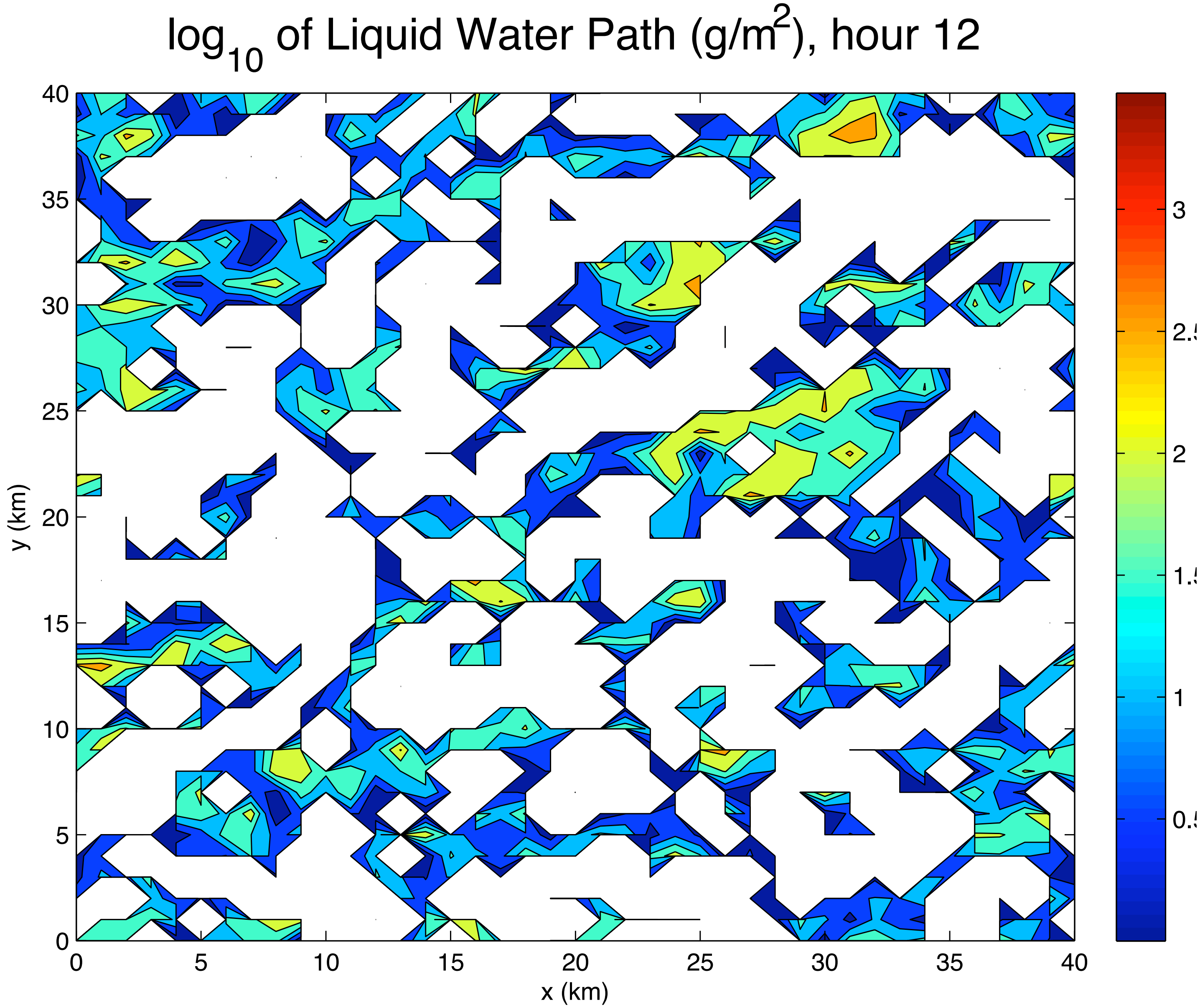

log$_{10}$ of Liquid Water Path (g/m^2), hour 12
y (km)
x (km)
0
5
10
15
20
25
30
35
40
0.5
1
1.5
2
2.5
3

Avg'd to 500 m

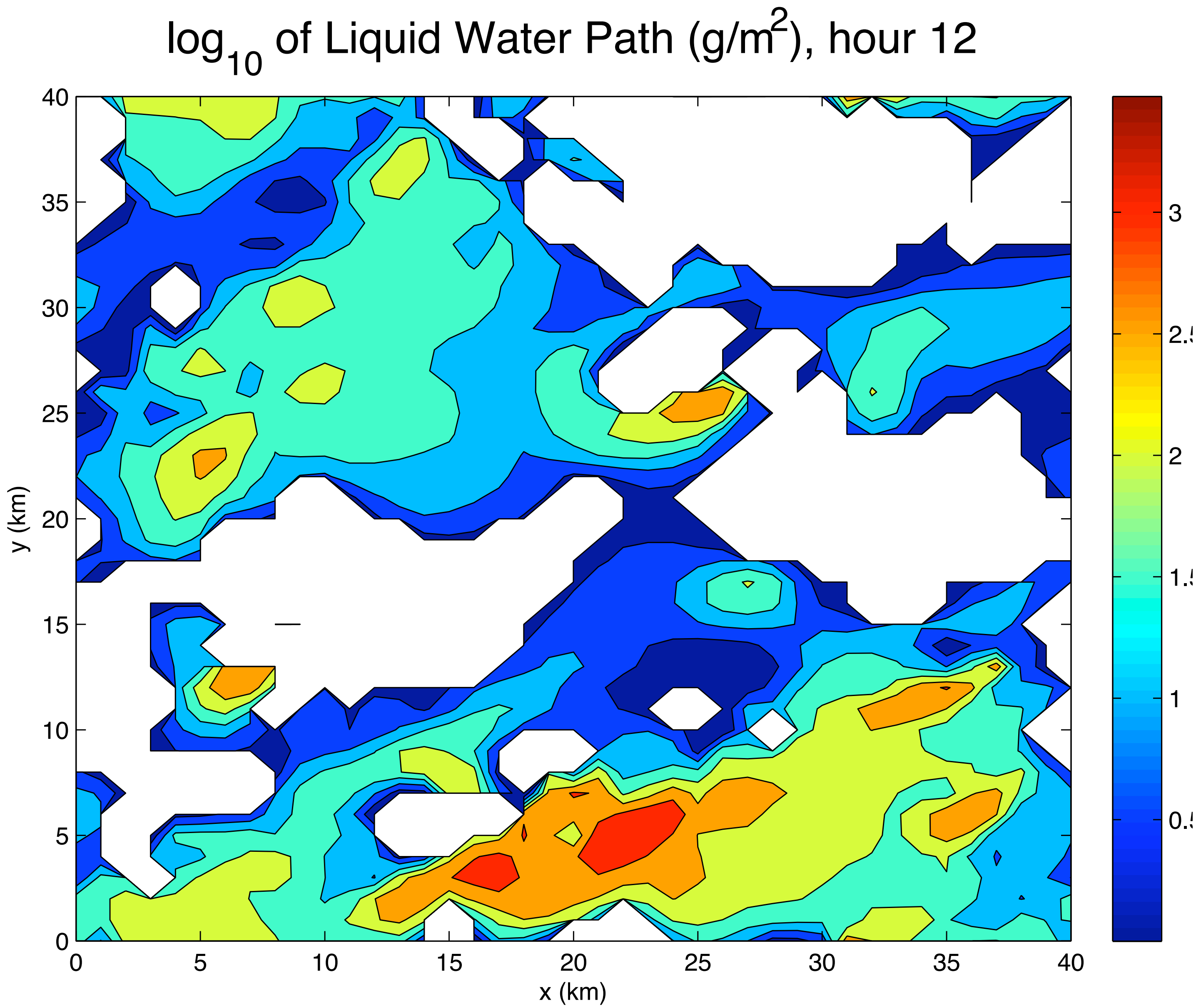


log10 of Liquid Water Path (g/m2), hour 12
y (km)
x (km)
0
5
10
15
20
25
30
35
40
0.5
1
1.5
2
2.5
3

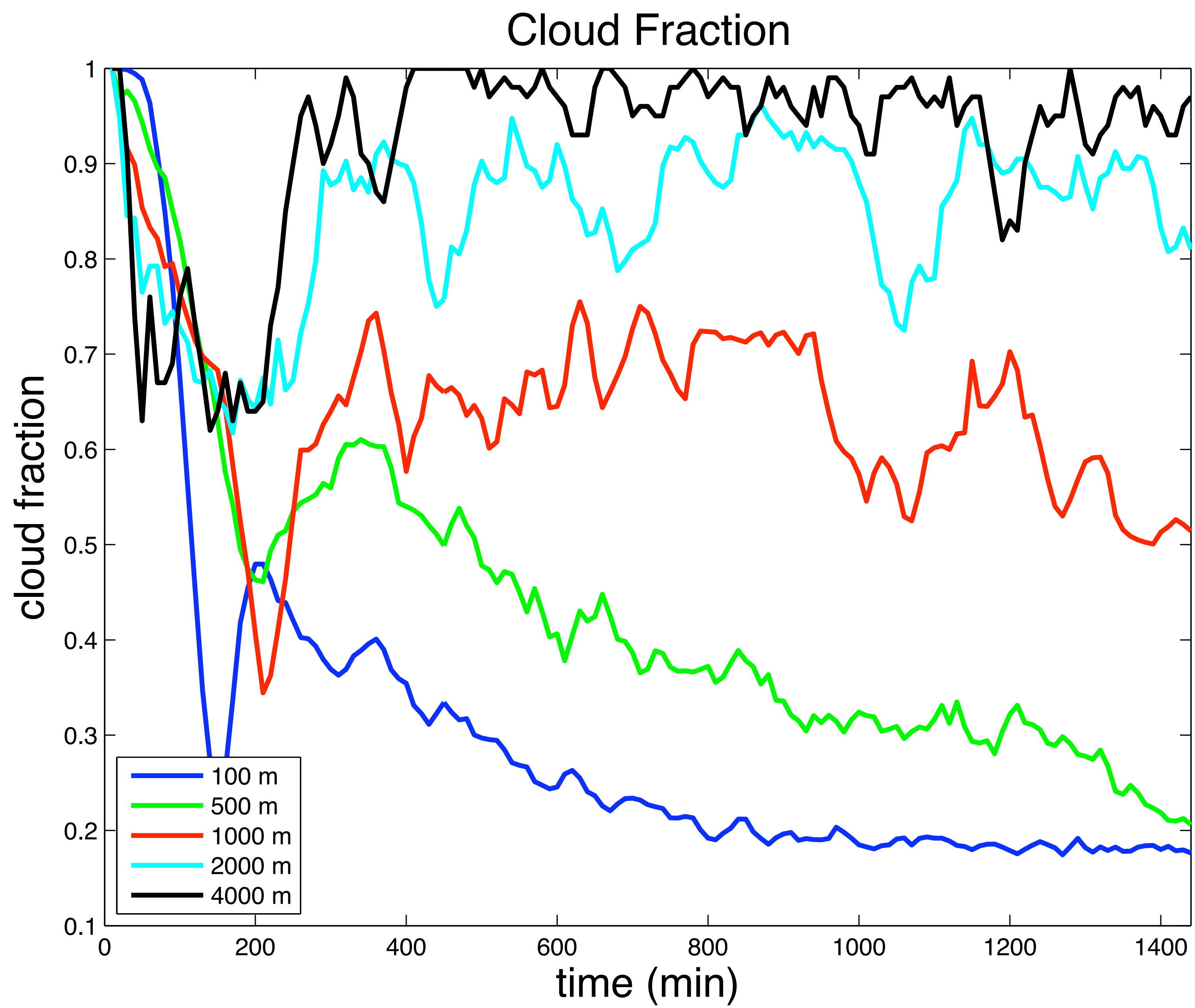
Avg'd to 1000 m



1000 m

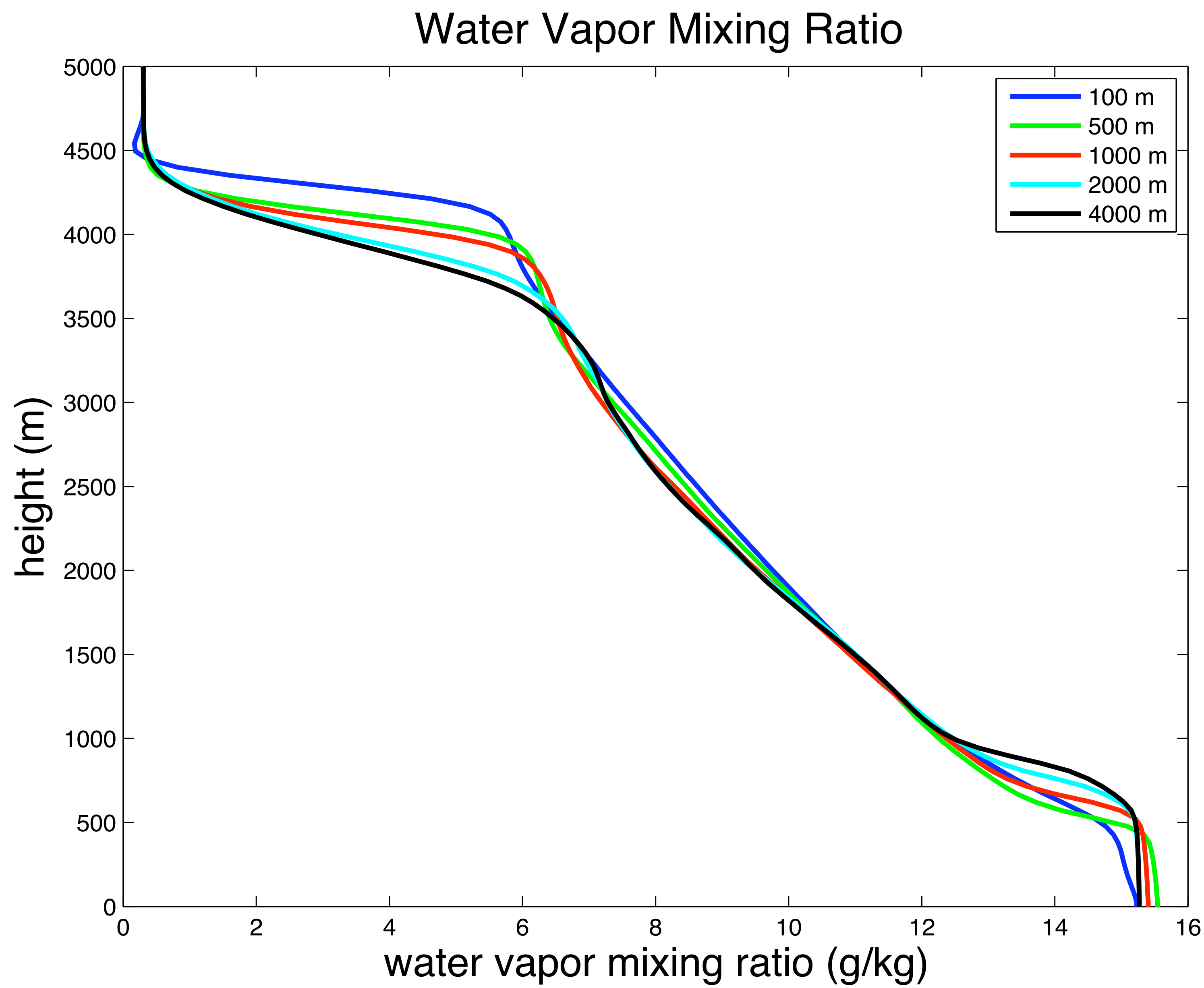


log10 of Liquid Water Path (g/m2), hour 12
y (km)
x (km)
0
5
10
15
20
25
30
35
40
3
2
1

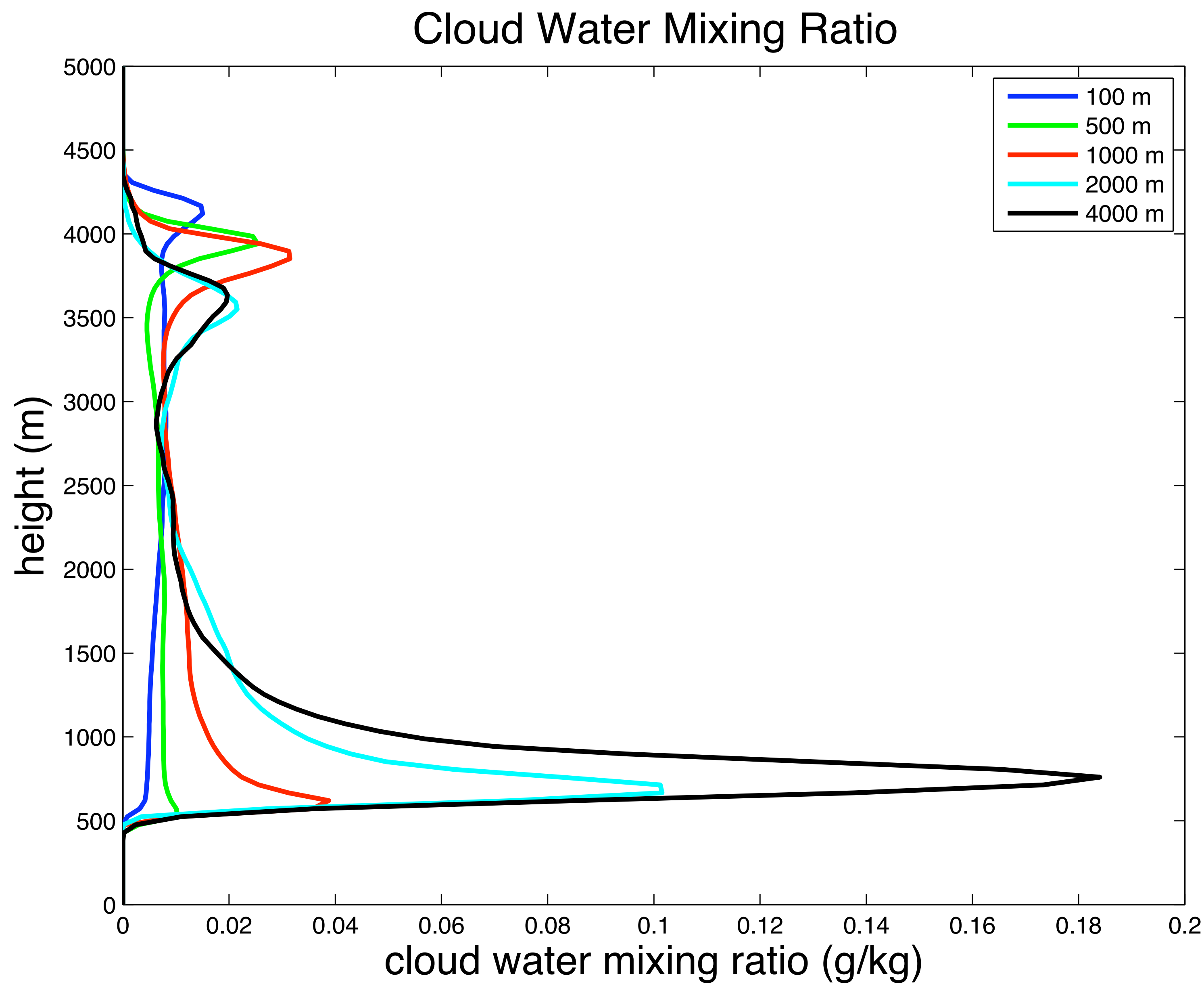


Cloud Fraction
cloud fraction
time (min)
100 m
500 m
1000 m
2000 m
4000 m
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
200
400
600
800
1000
1200
1400

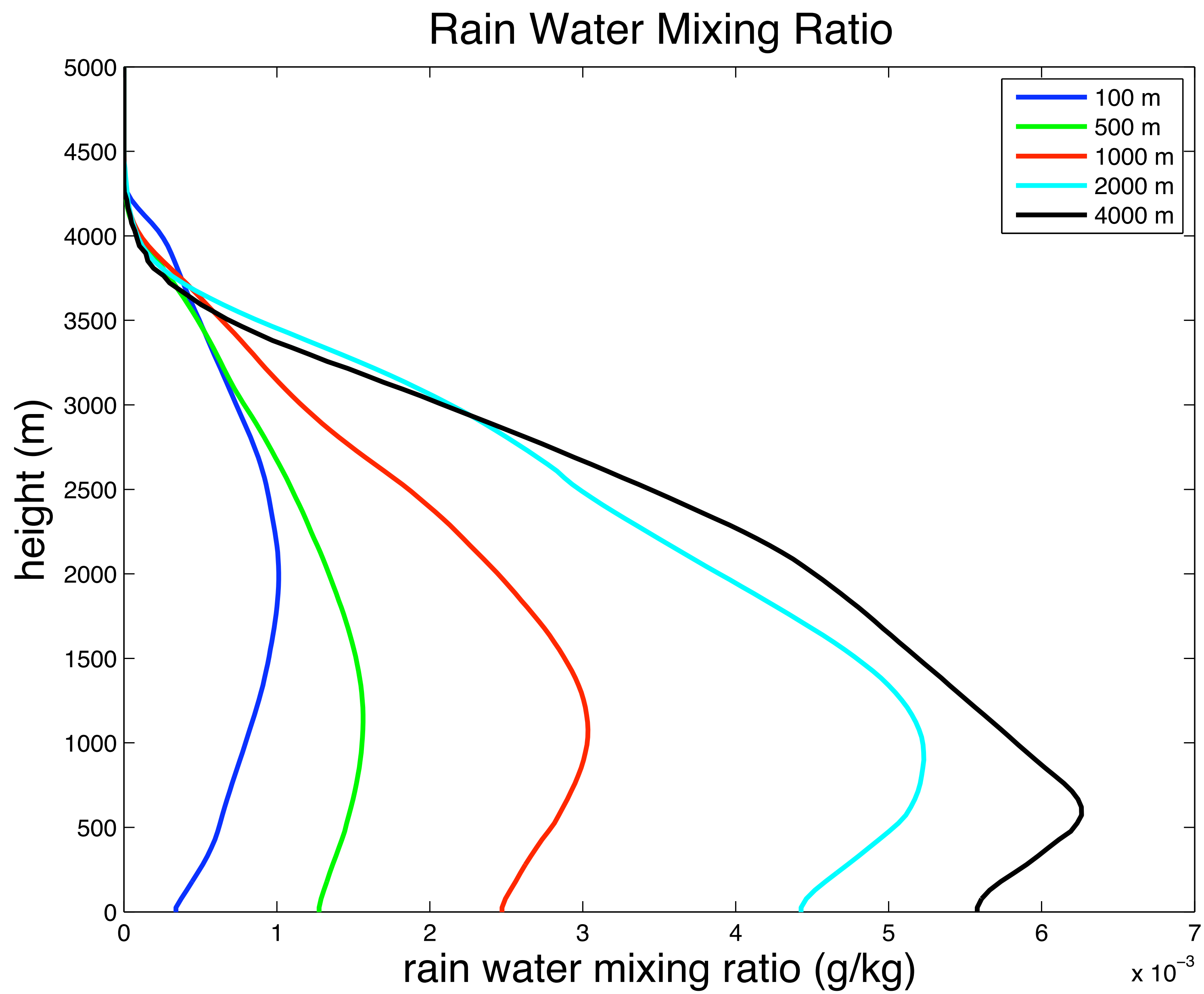
last 6 hrs	100 m	500 m	1000 m	2000 m	4000 m
cloud fraction	0.18	0.28	0.58	0.87	0.94
LWP (g/m^2)	23.9	26.7	46.0	69.1	96.7
precip rates (mm/hr)	0.003	0.022	0.050	0.038	0.070



Water Vapor Mixing Ratio
100 m
500 m
1000 m
2000 m
4000 m
height (m)
water vapor mixing ratio (g/kg)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
2
4
6
8
10
12
14
16



Cloud Water Mixing Ratio
100 m
500 m
1000 m
2000 m
4000 m
height (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
cloud water mixing ratio (g/kg)



Rain Water Mixing Ratio
height (m)
rain water mixing ratio (g/kg)
x 10^-3
100 m
500 m
1000 m
2000 m
4000 m
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
1
2
3
4
5
6
7

Proposed Evaluation Methods

- **Observational datasets**
  - High-resolution cloud properties from satellites: MODIS, ISCCP, etc
  - Vertical structure of clouds: CloudSat, ARM MMCR, TRMM
  - High-resolution hourly precipitation from rain gage and unbiased radar
  - Surface mesonet observations of T, RH, p, u, v
  - Aircraft-based measurements during field experiments