Using Bin Microphysics Simulations to Evaluate the Potential for Irreversible Dehydration by Overshooting Convection

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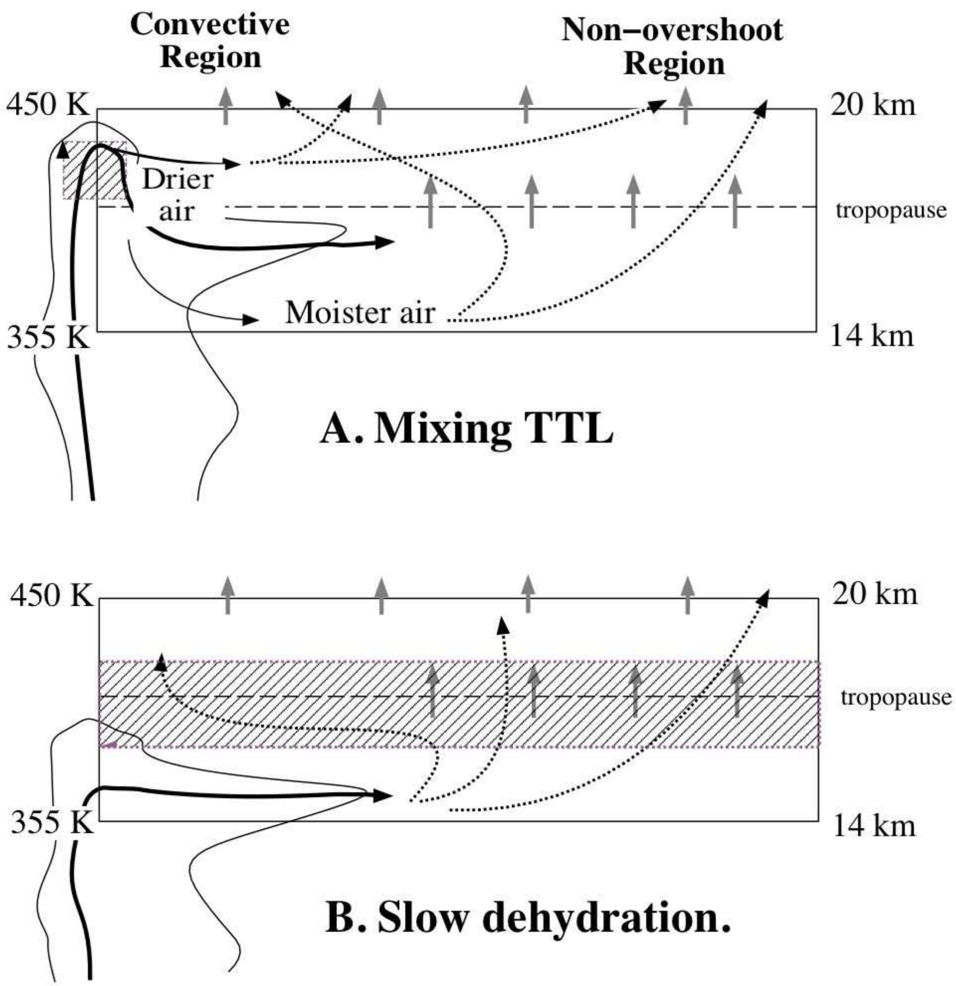

Irreversible dehydration requirements:

1. Removal of vapor in cold overshoot

2. Sedimentation of ice before detrainment and warming

Impact of convection on TTL thermal structure not addressed

from Sherwood and Dessler [2000]

Overshooting convection simulations with DHARMA

- Large-eddy simulation fluid dynamics code [*Stevens and Bretherton, 1997*]
  - Smagorinsky subgrid-scale model
  - third-order advection
  - 60 x 48 x 24 km domain, dx = dy = 500 m, dz = 275 m
- Size-resolved microphysics code [*Jensen et al., 1994; Ackerman et al., 1995*]
  - 24 size bins each for aerosols, droplets, ice, and graupel
    - aerosols 5 nm – 0.5 μm radius
    - droplets, ice, and graupel 1 μm – 1.2 cm radius
  - aerosol activation
  - homogeneous and heterogeneous ice nucleation
  - collision-induced and spontaneous breakup
  - gravitational sedimentation and collection
- Two-stream radiative transfer code [*Toon et al., 1989*]
  - 44 wavelength bands
  - Mie scattering and absorption (volume-equivalent spheres)

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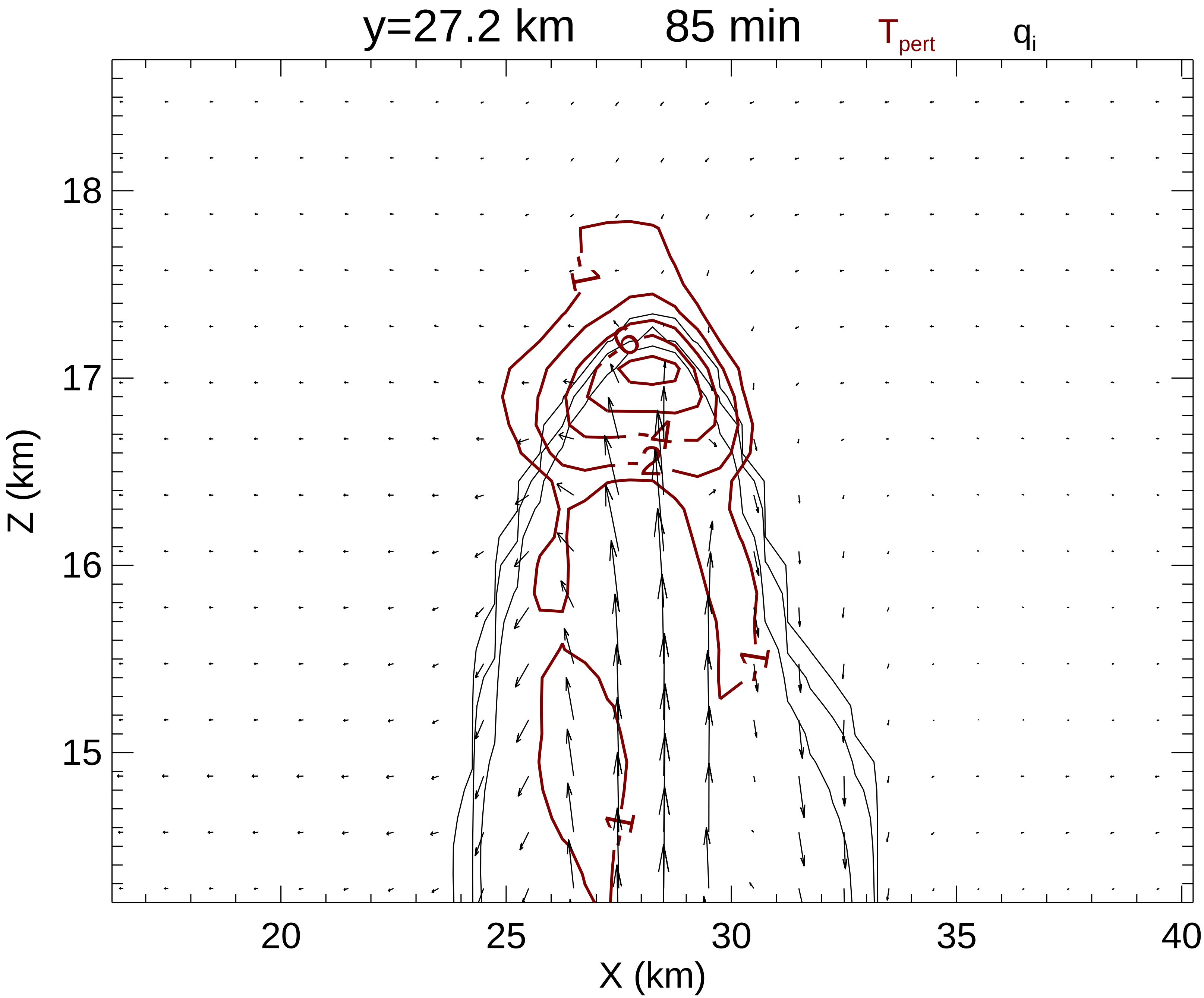
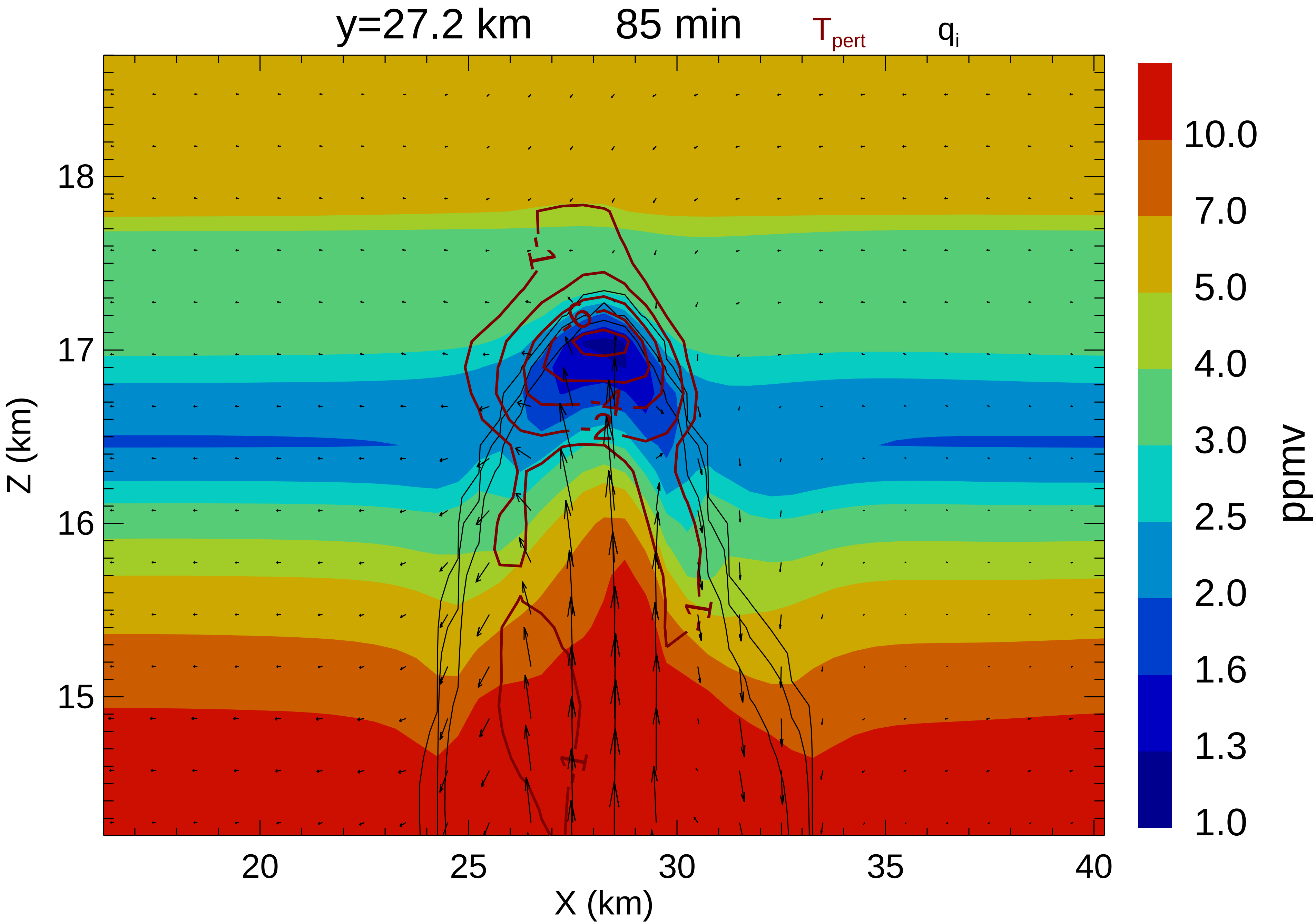
Overshooting case study

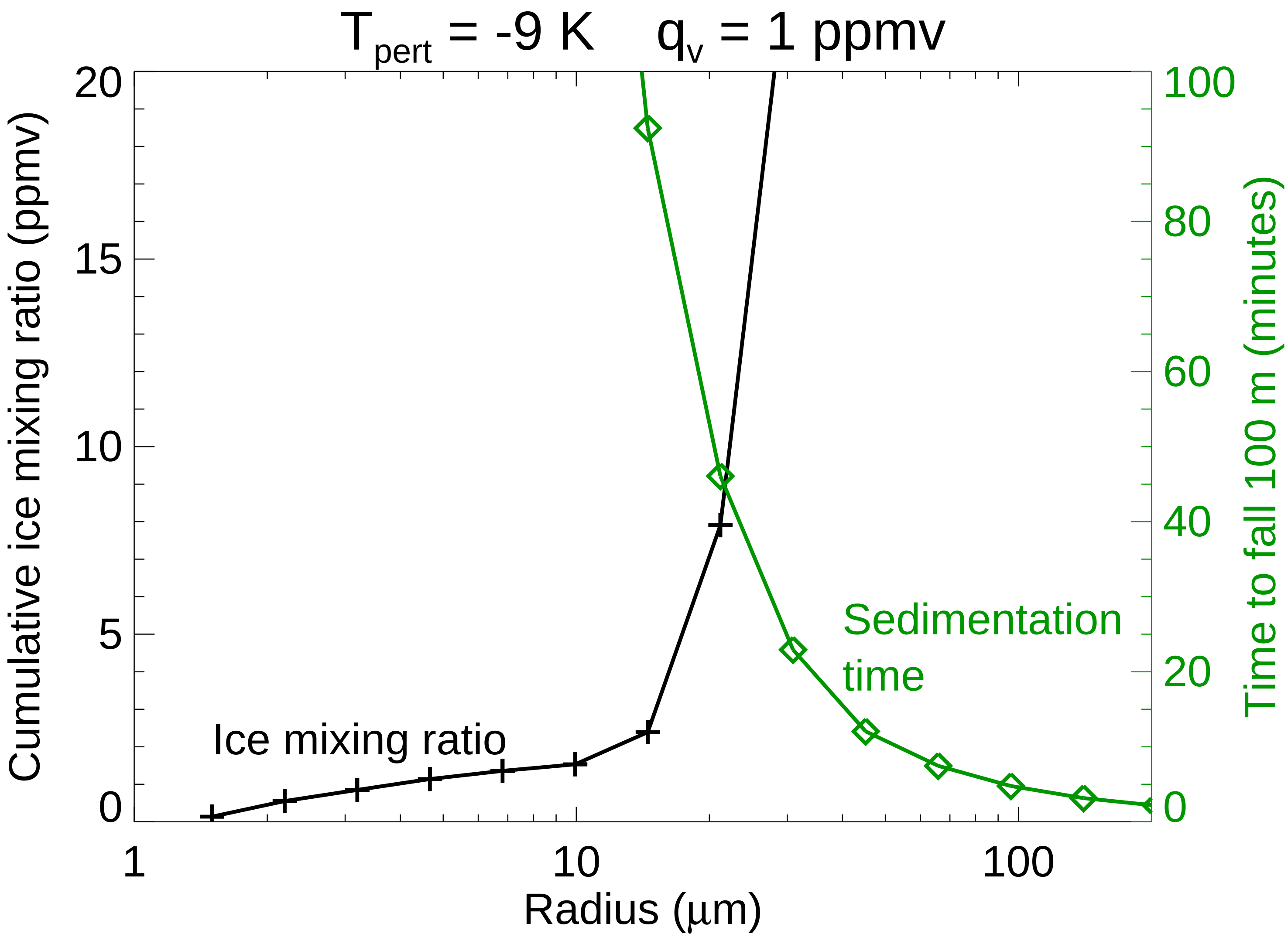
- Darwin, Australia sounding taken from DAWEX
- CAPE = 5.5 kJ kg^{-1}
- TTL relative humidity w.r.t ice = 90%
- N_{CN} = 100 cm^{-3} (clean)
- Convection triggered by localized surface heat fluxes
- Convective core updraft speeds as high as $\simeq$35 m s^{-1}
- core overshoots LNB (16.5 km) and reaches about 17.3 km



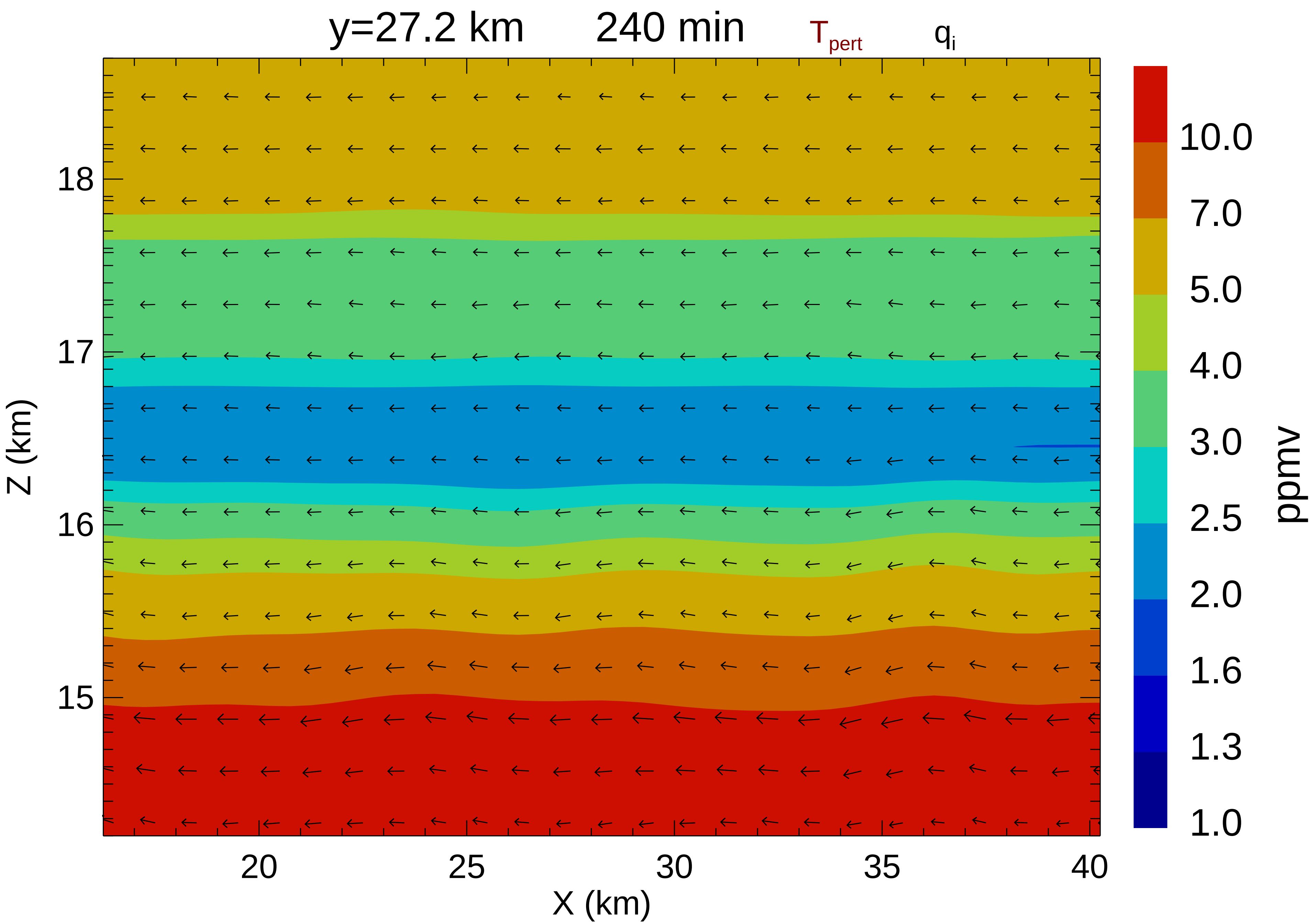
y=27.2 km
85 min
T pert
q i
Z (km)
X (km)
18
17
16
15
20
25
30
35
40
-1
-6
-4
-2
-1
-1



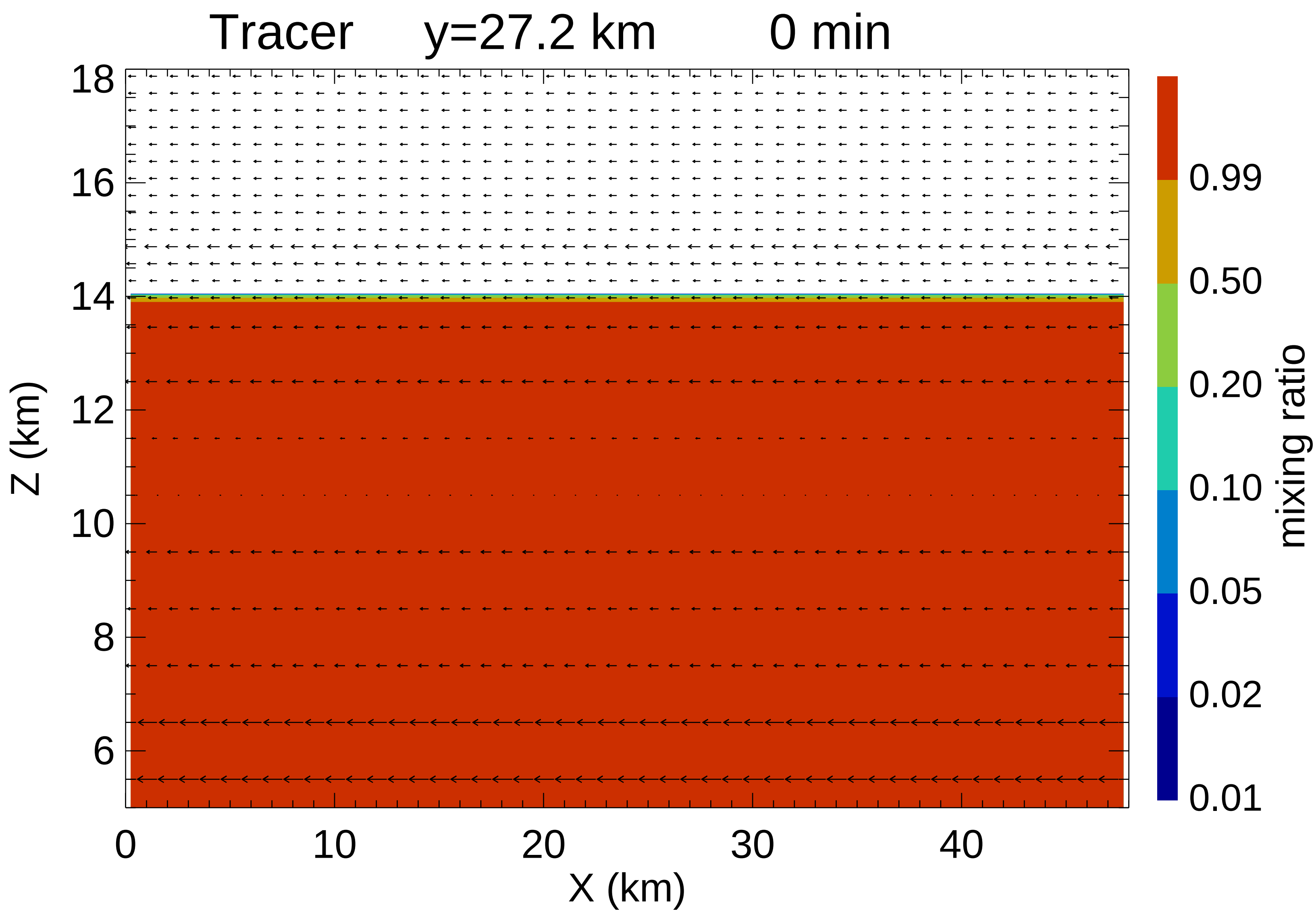
y=27.2 km
85 min
T_{pert}
q_i
18
17
16
15
Z (km)
20
25
30
35
40
X (km)
-1
-6
-4
-2
10.0
7.0
5.0
4.0
3.0
2.5
2.0
1.6
1.3
1.0
ppmv

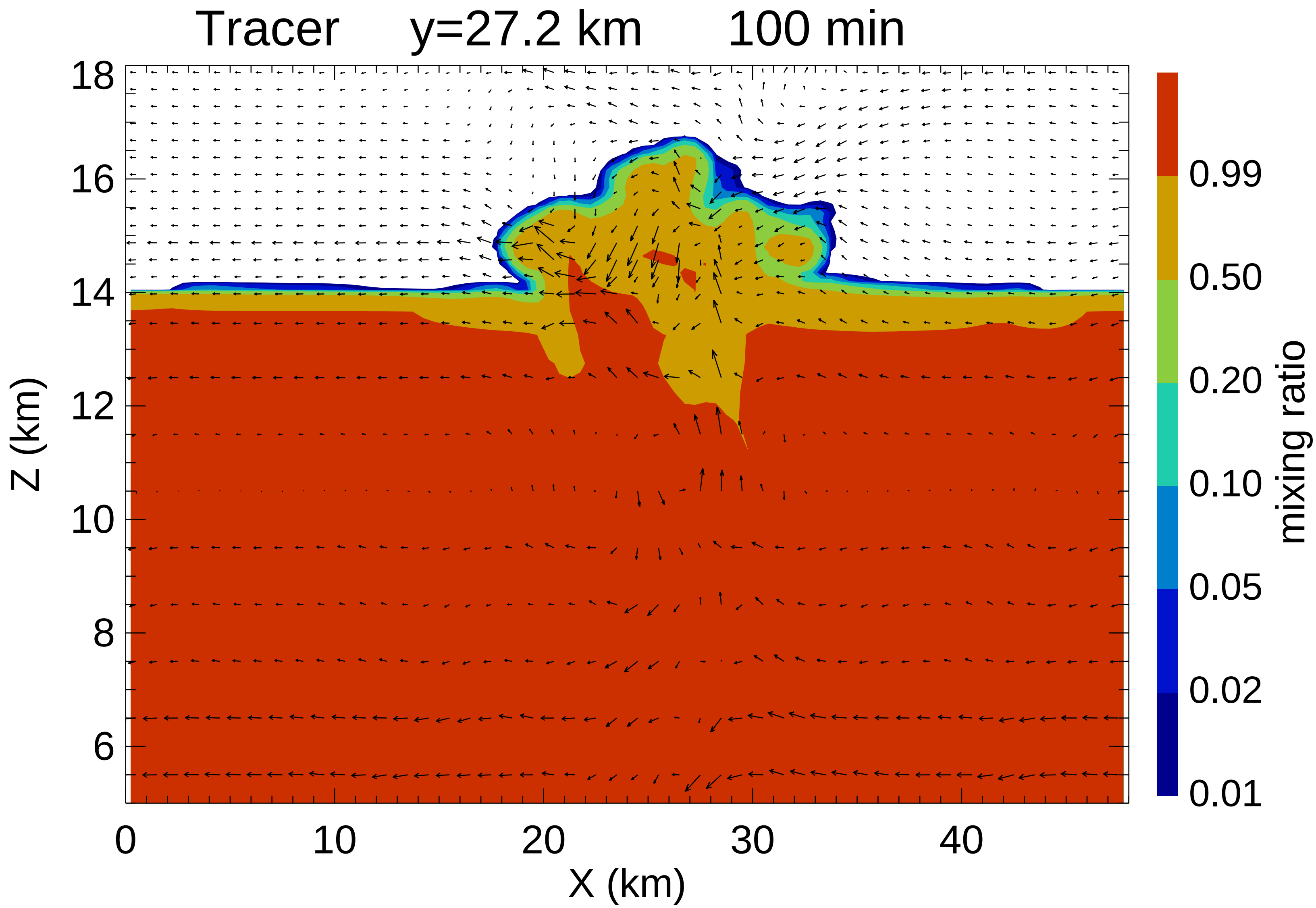


T_pert = -9 K q_v = 1 ppmv
Cumulative ice mixing ratio (ppmv)
Time to fall 100 m (minutes)
Radius (μm)
Ice mixing ratio
Sedimentation time
0
5
10
15
20
0
20
40
60
80
100
1
10
100

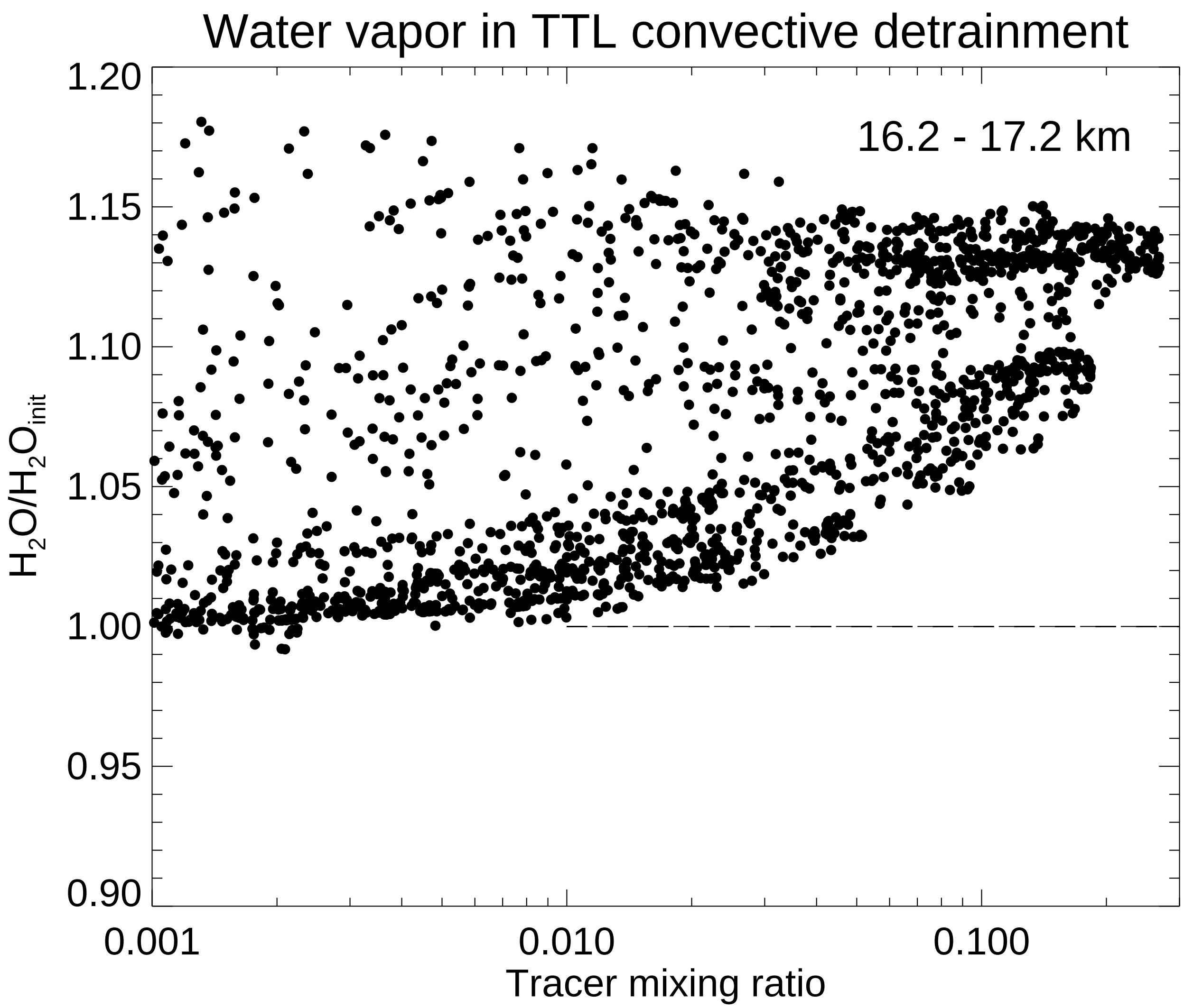


y=27.2 km
240 min
T pert
q i
18
17
16
15
Z (km)
20
25
30
35
40
X (km)
10.0
7.0
5.0
4.0
3.0
2.5
2.0
1.6
1.3
1.0
ppmv

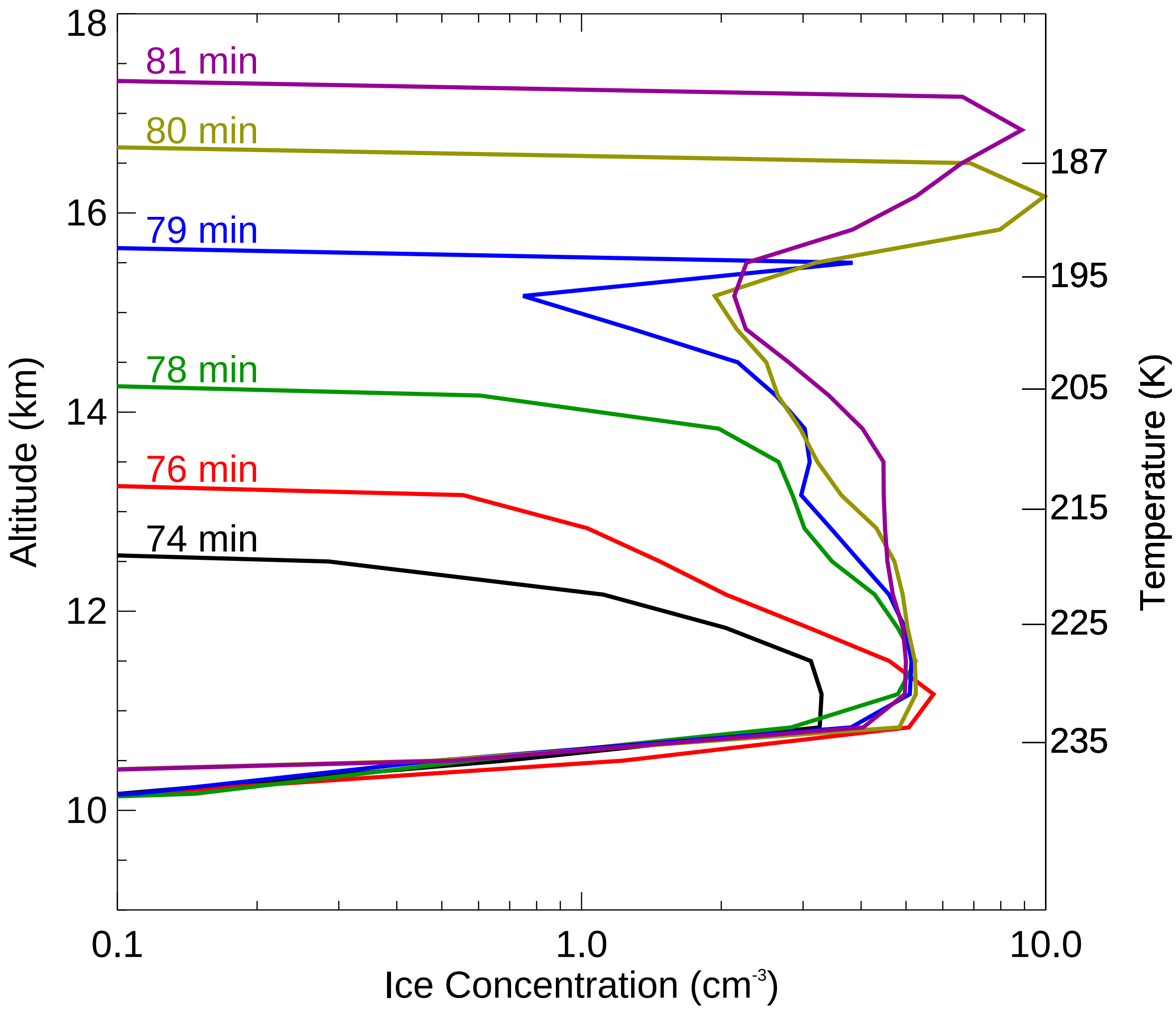

Tracer y=27.2 km 0 min
Z (km)
18
16
14
12
10
8
6
0
10
20
30
40
X (km)
0.99
0.50
0.20
0.10
0.05
0.02
0.01
mixing ratio



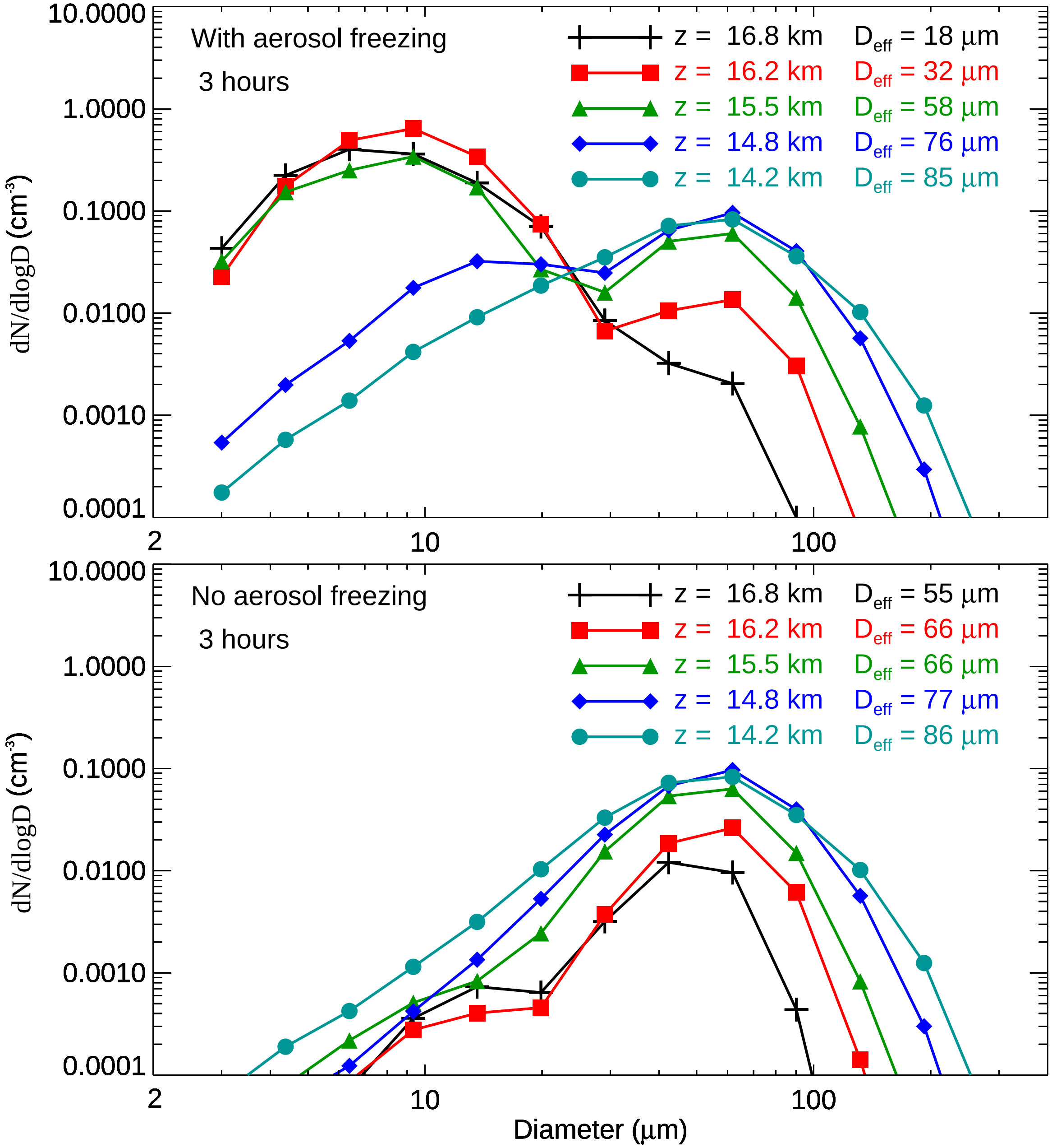
Tracer y=27.2 km 100 min
Z (km)
18
16
14
12
10
8
6
0
10
20
30
40
X (km)
0.99
0.50
0.20
0.10
0.05
0.02
0.01
mixing ratio



Water vapor in TTL convective detrainment
16.2 - 17.2 km
1.20
1.15
1.10
1.05
1.00
0.95
0.90
H_2O/H_2O_{init}
0.001
0.010
0.100
Tracer mixing ratio

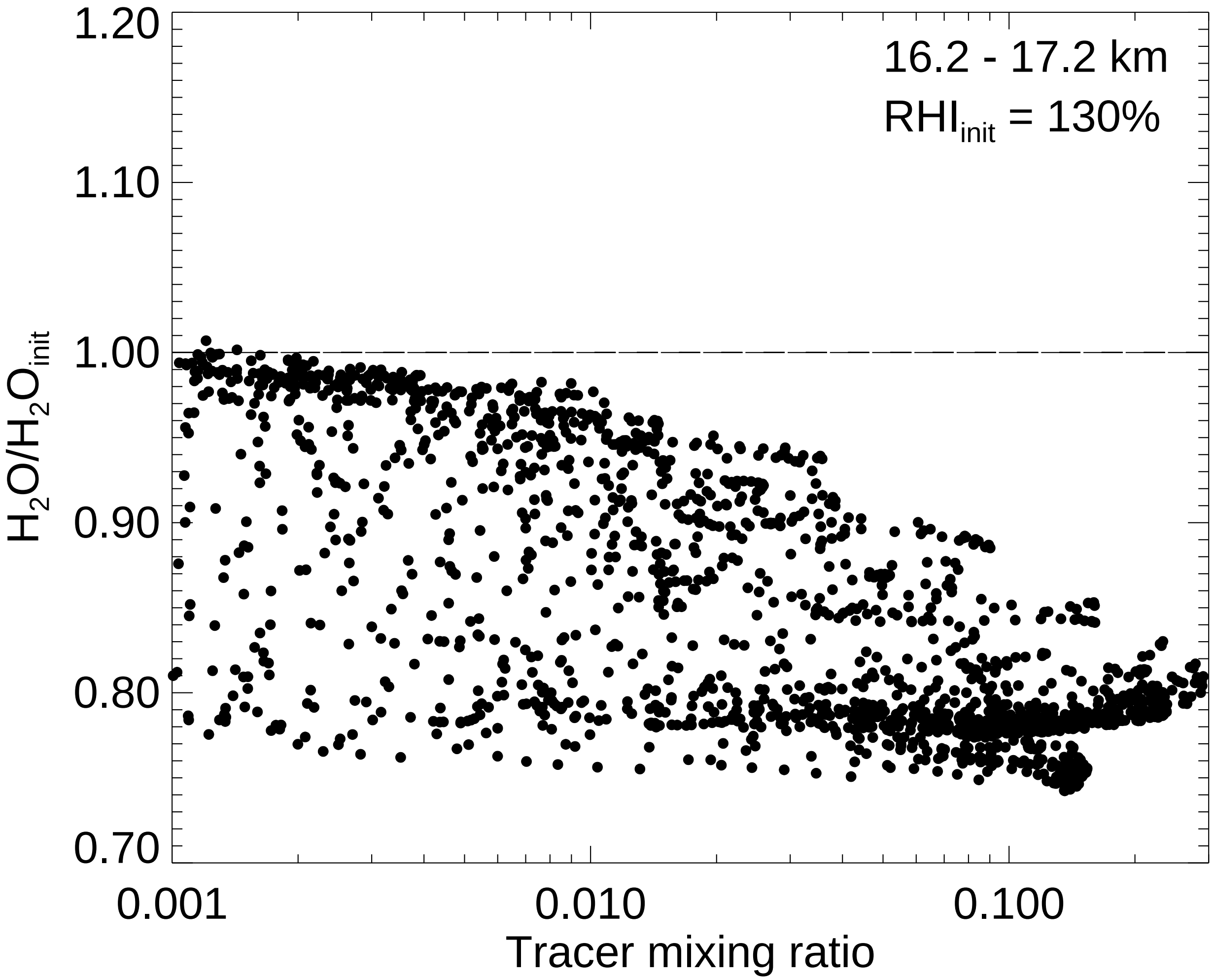


81 min
80 min
79 min
78 min
76 min
74 min
18
16
14
12
10
Altitude (km)
187
195
205
215
225
235
Temperature (K)
0.1
1.0
10.0
Ice Concentration (cm-3)



With aerosol freezing
3 hours
z = 16.8 km D_eff = 18 µm
z = 16.2 km D_eff = 32 µm
z = 15.5 km D_eff = 58 µm
z = 14.8 km D_eff = 76 µm
z = 14.2 km D_eff = 85 µm
No aerosol freezing
3 hours
z = 16.8 km D_eff = 55 µm
z = 16.2 km D_eff = 66 µm
z = 15.5 km D_eff = 66 µm
z = 14.8 km D_eff = 77 µm
z = 14.2 km D_eff = 86 µm
dN/dlogD (cm-3)
10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
2
10
100
Diameter (µm)

Convective injection will dehydrate an initially supersaturated TTL



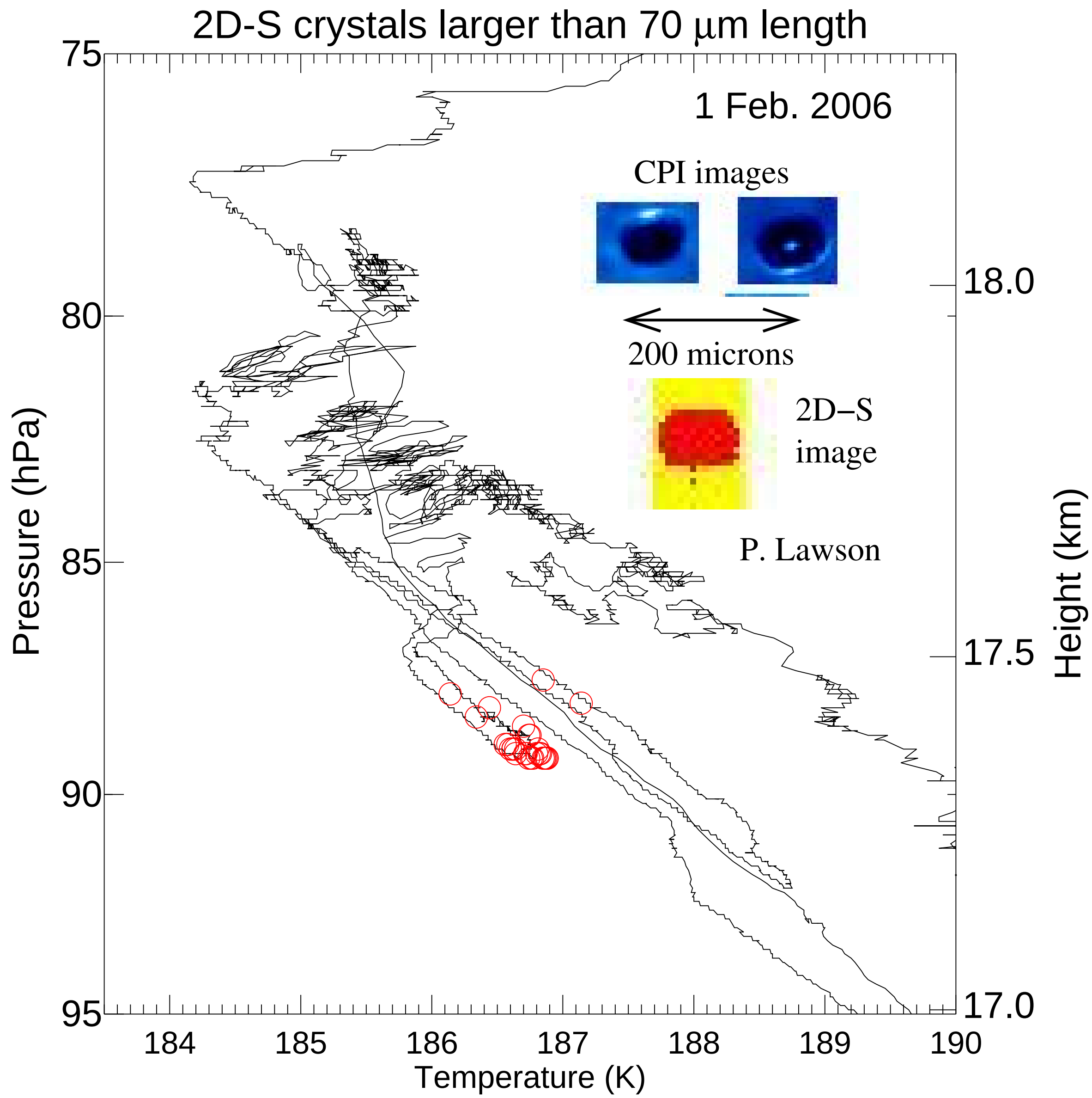
Summary

We find no evidence for irreversible dehydration caused by overshooting convection.

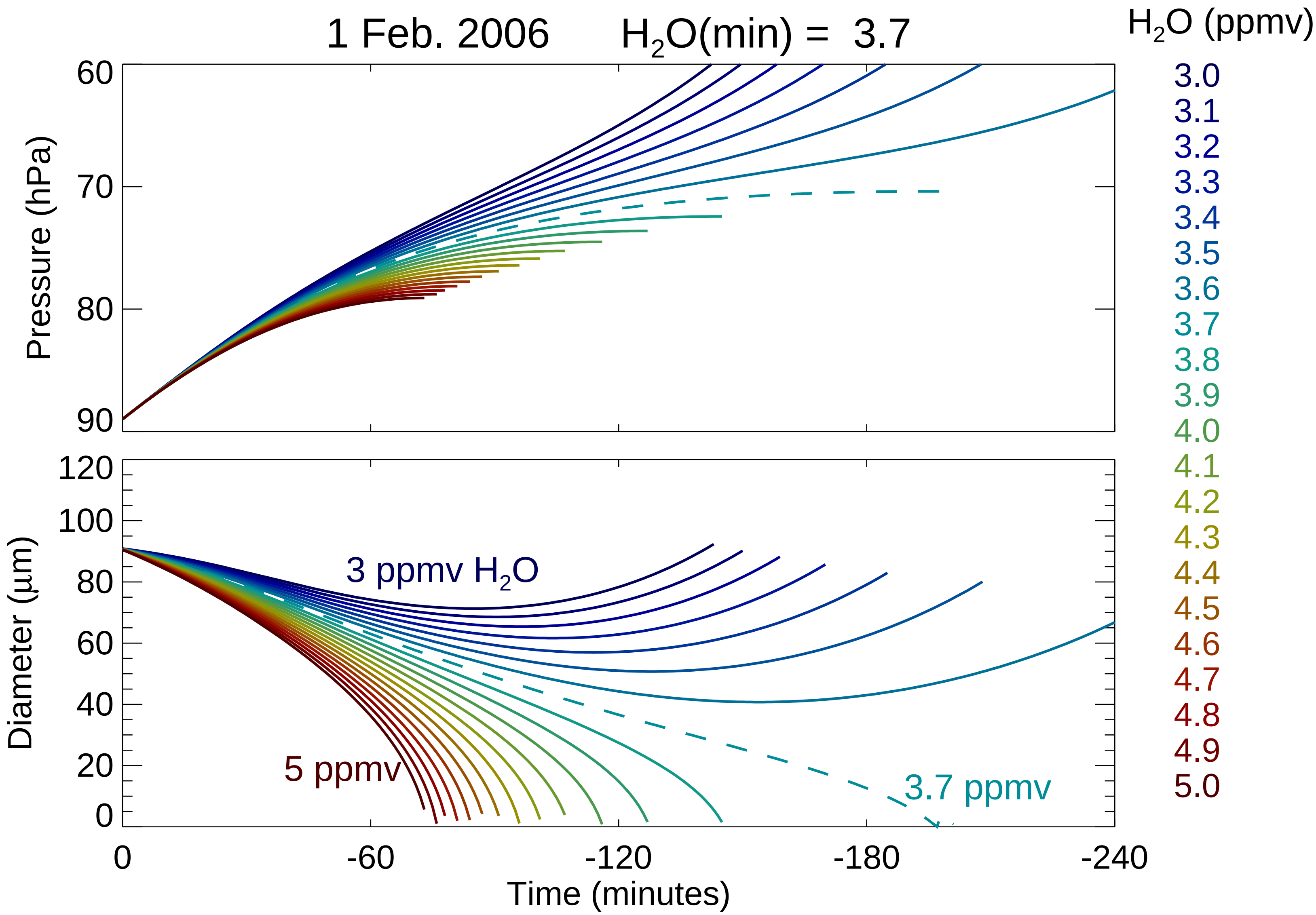
But, convection penetrating into the TTL is still very important:

- Convection affects the TTL thermal structure.
- Convectively-driven gravity waves are important.
- Convection is the primary source of air (and water) to the TTL.
- Convection can hydrate or dehydrate the TTL, depending on the ambient relative humidity.
- The net effect of convection depends on the climatology of TTL RHi in regions with deep convection.

Large Crystals and Ice Supersaturations Observed in TTL Cirrus during CRAVE



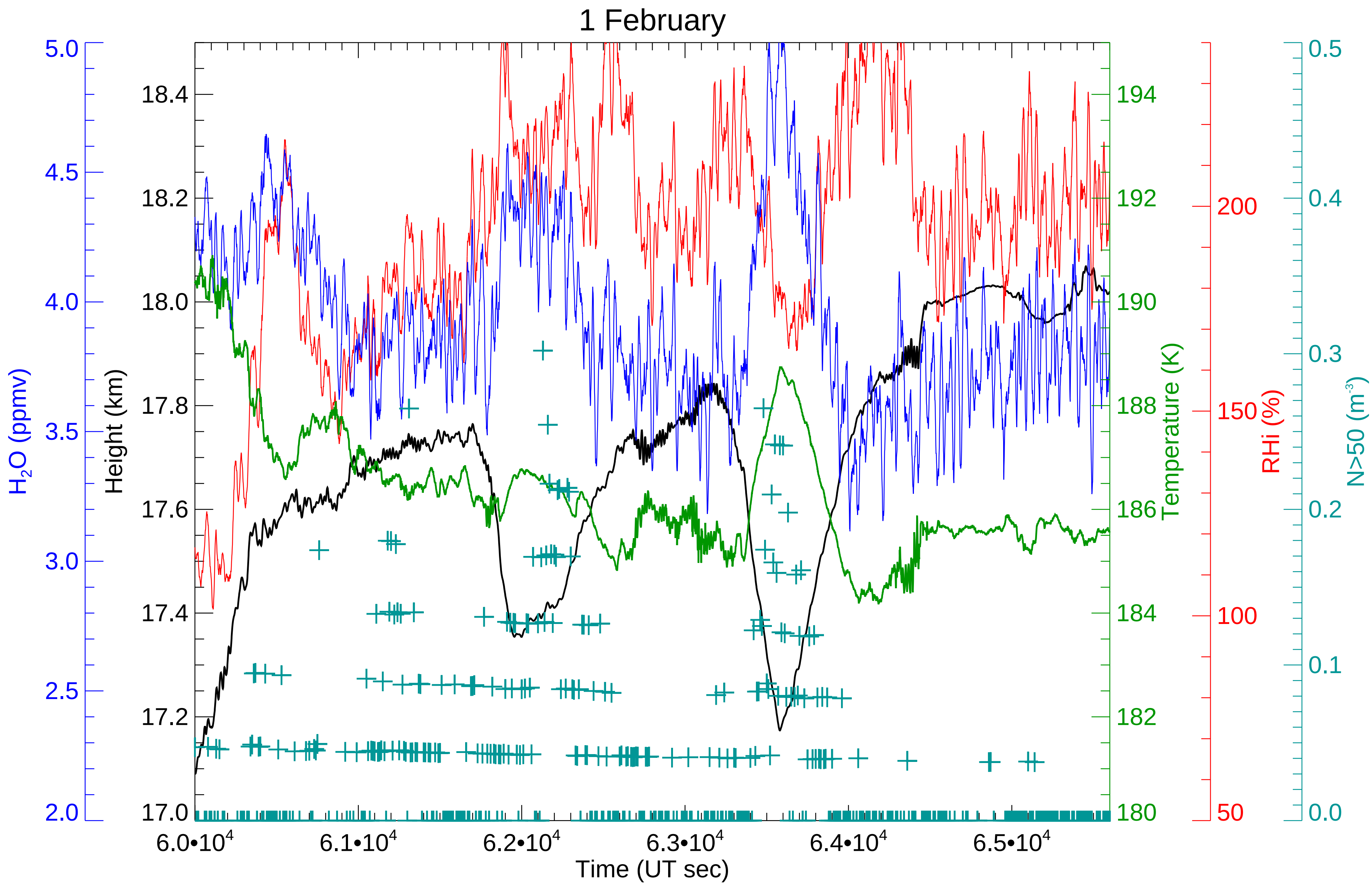
Reverse-time growth-sedimentation calculations

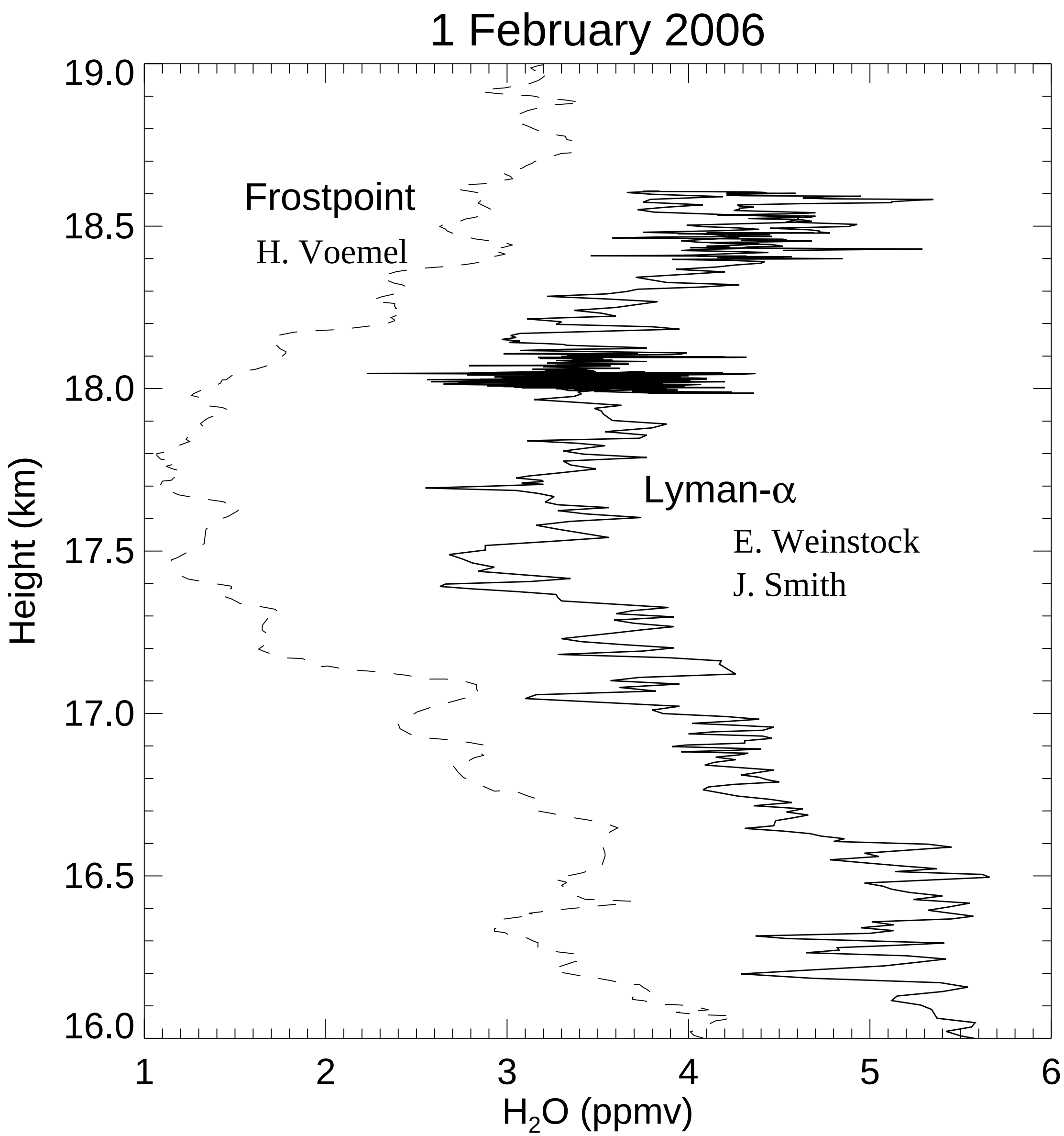


Factors controlling crystal growth

Issue	Assumption	Impact crystal growth
Upstream T-prof	Small stratospheric lapse rate	Deeper supersaturated layer
Deposition coefficient	Unity	Fastest possible growth
Nucleation threshold	RHi = 100%	Deepest possible supersaturated layer
Crystal temperature	$T_{ice} = T_{amb}$	Fastest growth
Ice phase (cubic/hexagonal)	Hexagonal	Fastest growth

- Wave-driven temperature and vertical wind perturbations help, but not much
- 3.5–4 ppmv H_2O still required for growth of large crystals


1 February
H2O (ppmv)
Height (km)
Temperature (K)
RHi (%)
N>50 (m-3)
Time (UT sec)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
18.4
18.2
18.0
17.8
17.6
17.4
17.2
17.0
194
192
190
188
186
184
182
180
200
150
100
50
0.5
0.4
0.3
0.2
0.1
0.0
6.0•10^4
6.1•10^4
6.2•10^4
6.3•10^4
6.4•10^4
6.5•10^4



1 February 2006
19.0
18.5
18.0
17.5
17.0
16.5
16.0
Height (km)
1
2
3
4
5
6
H2O (ppmv)
Frostpoint
H. Voemel
Lyman-α
E. Weinstock
J. Smith

Implications

- Large supersaturations ($RHi \simeq$ 200%) in TTL cirrus are real
- Higher than expected supersaturation thresholds for ice nucleation
- TTL in situ cirrus are not dehydrating RHi = 100% by any means
- Calibration of satellite H_2O measurements