Impact of cloud-base turbulence on CCN activation

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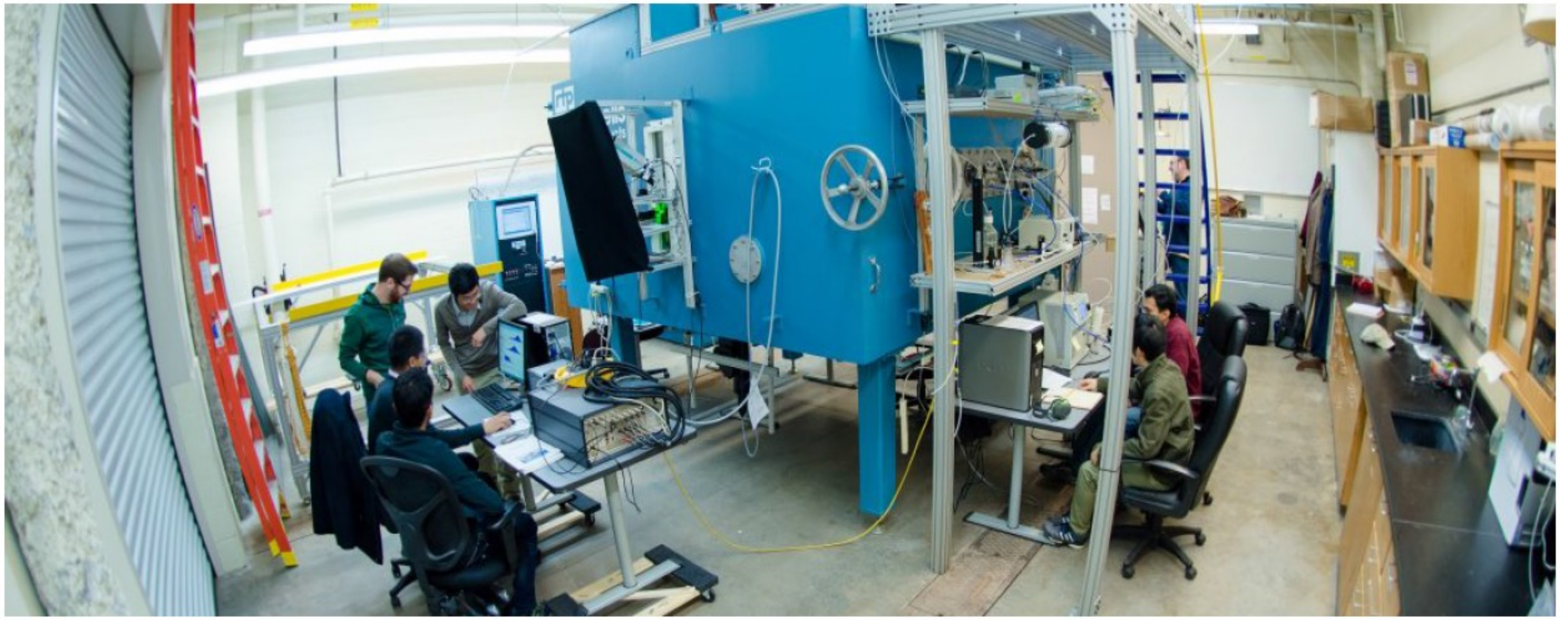
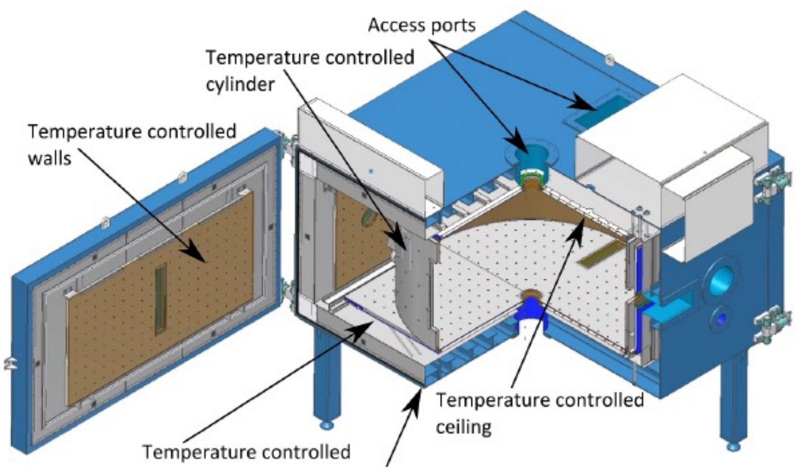
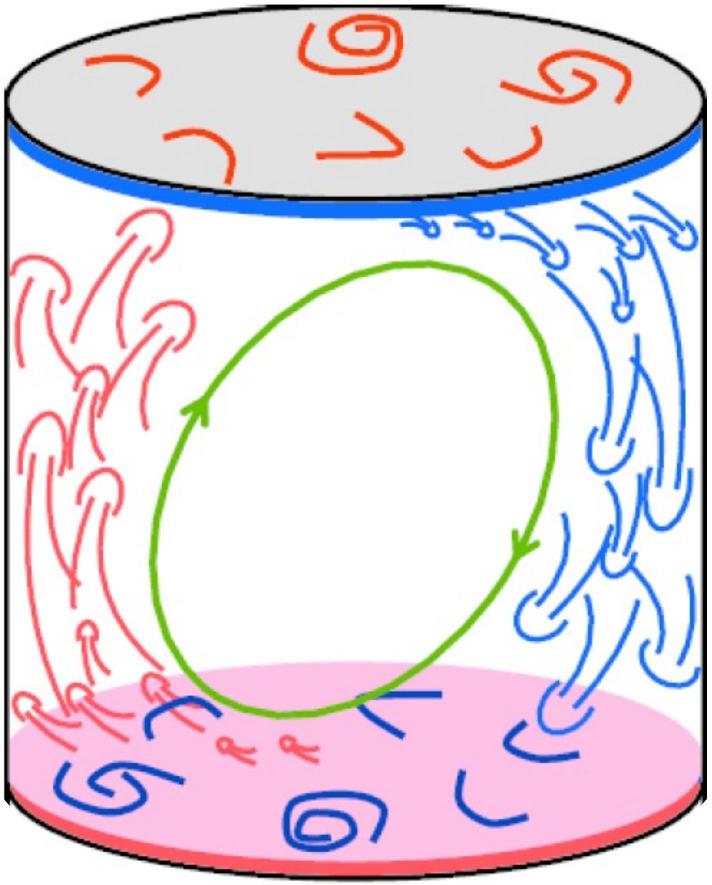




Pi Cloud Chamber
at the Michigan Technological University (Raymond Shaw et al.)

http://phy.sites.mtu.edu/cloudchamber/facility/

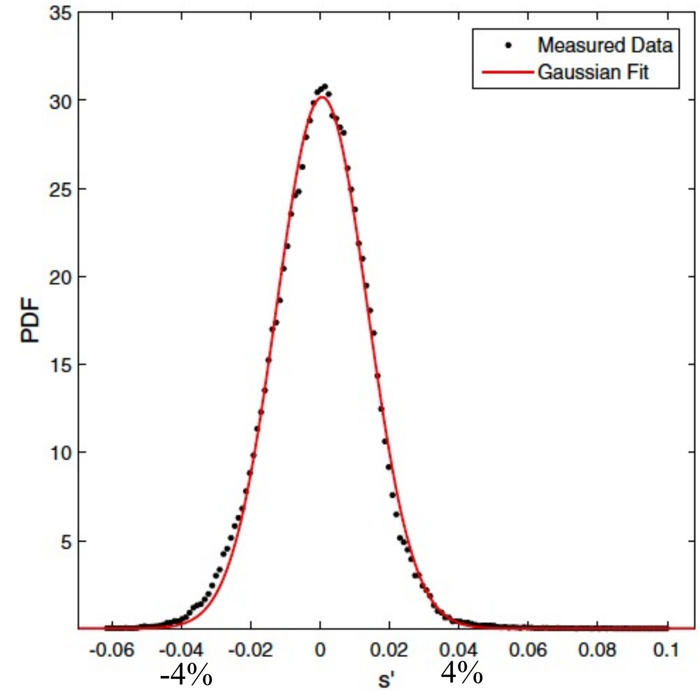


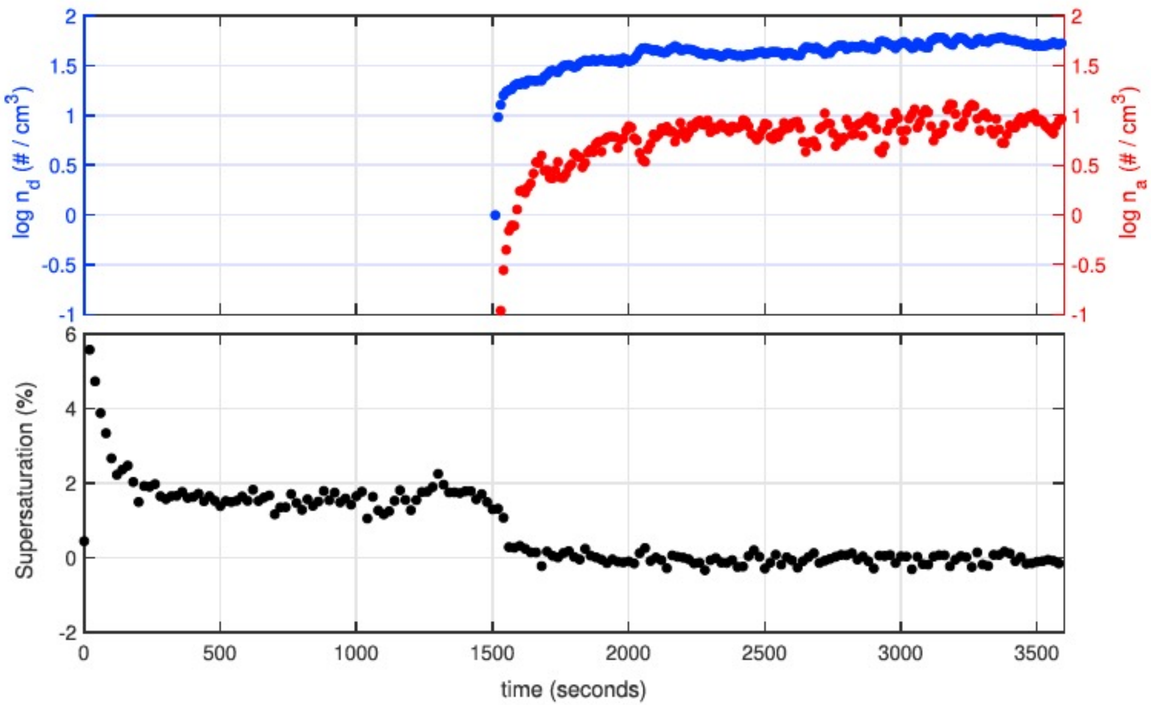
Rayleigh-Benard convection:
thermal plumes, large-scale circulation, and boundary layers…

https://www.google.com/search?q=Rayleigh-benard+convection&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjcgJ2b7Y_kAhVE7J4KHcBPBVgQ_AUIEigC&biw=1009&bih=625#imgrc=zOVbURp3ov4uPM:

Chandrakar et al. *PNAS* 2019

Observed supersaturations fluctuations before start of CCN injection





Simulated supersaturations and droplet/CCN concentrations before and after start of CCN injection to the cloud chamber

Thomas et al. *JAMES* 2019

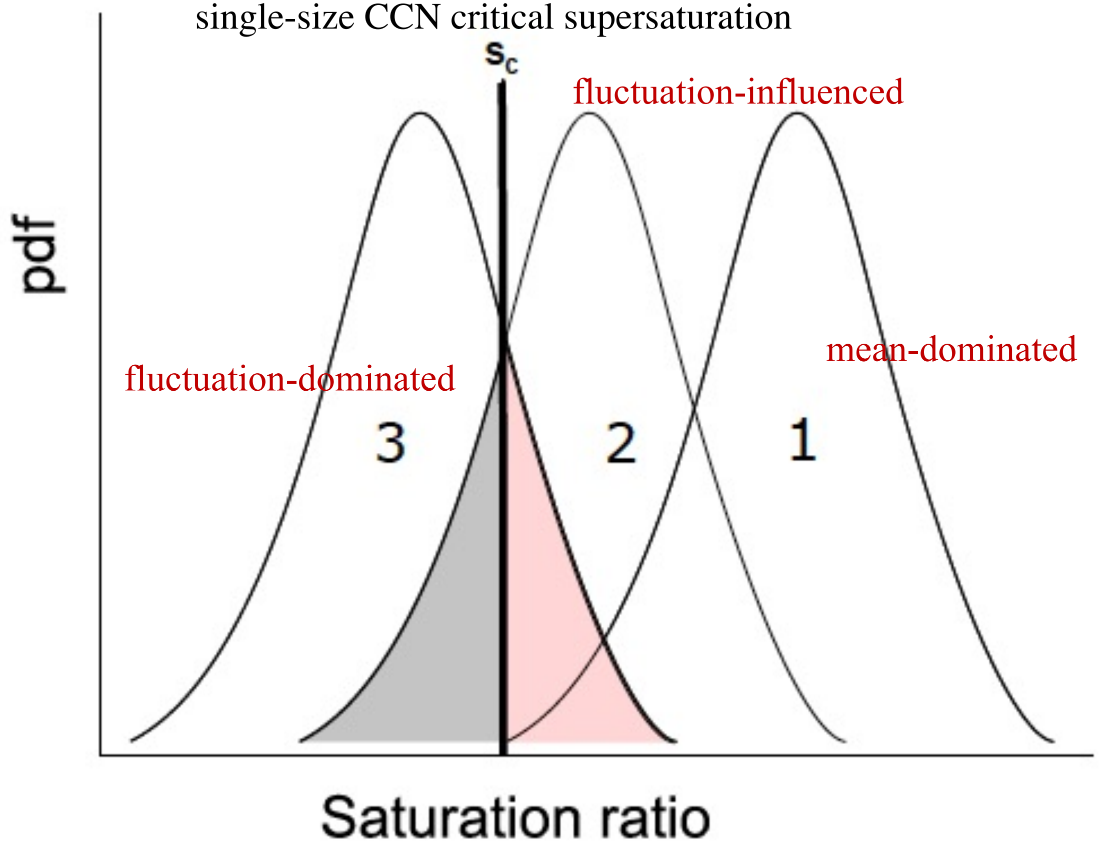


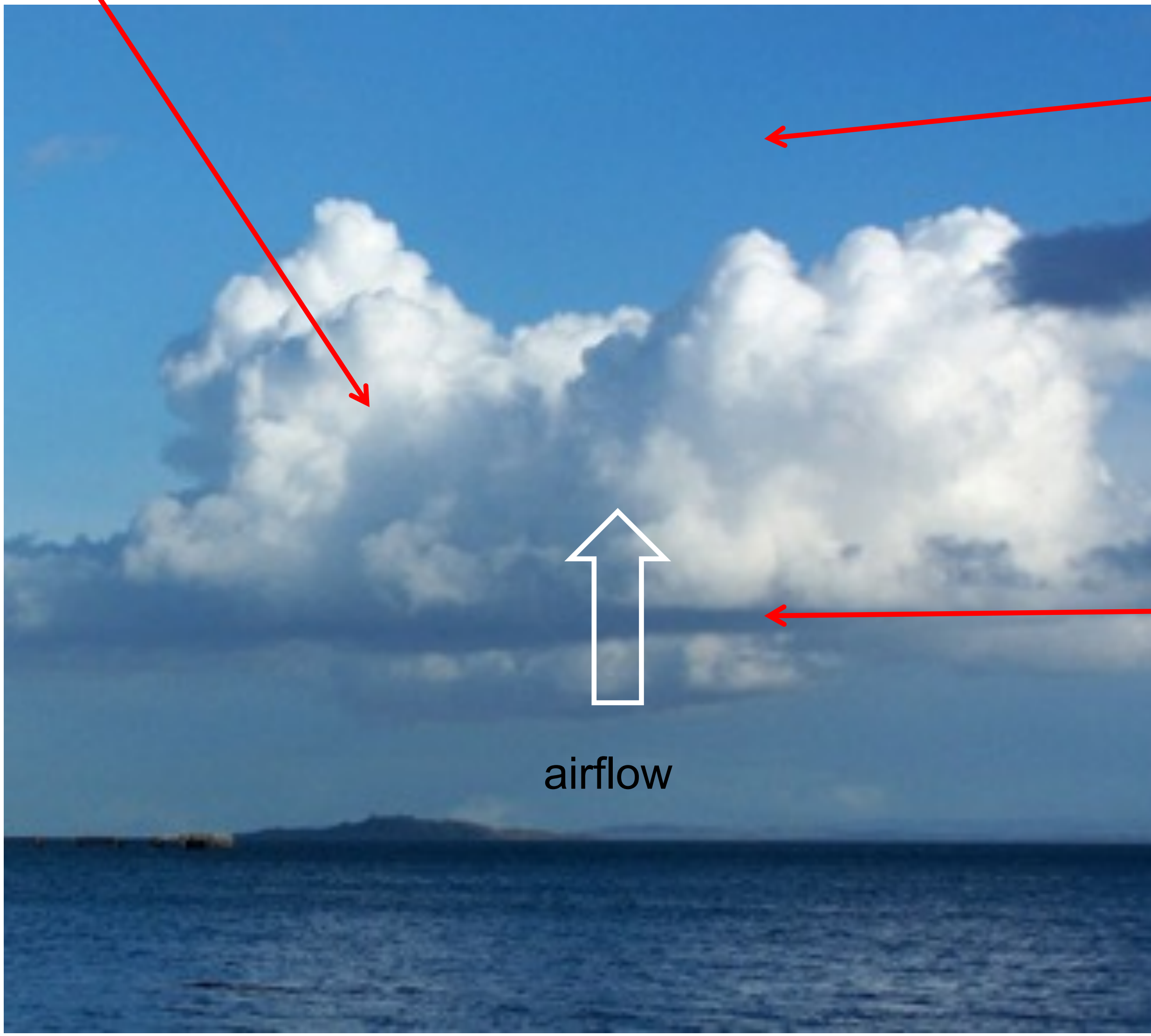
Fig. 1. Schematic representation of the saturation ratio distributions depicting three CCN activation regimes, as shown. S_c indicates the critical saturation ratio for a monodisperse aerosol. Regime 1 is mean-dominated activation, regime 2 is fluctuation-influenced activation, and regime 3 is fluctuation-dominated activation. The gray region indicates the subcritical zone of regime 2 and the light red color indicates the supercritical zone of regime 3.

Activation regimes in the turbulent cloud chamber with a single-size CCN

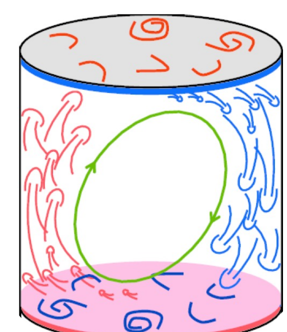
Prabhakaran et al. *PNAS* 2020

turbulent
cloud

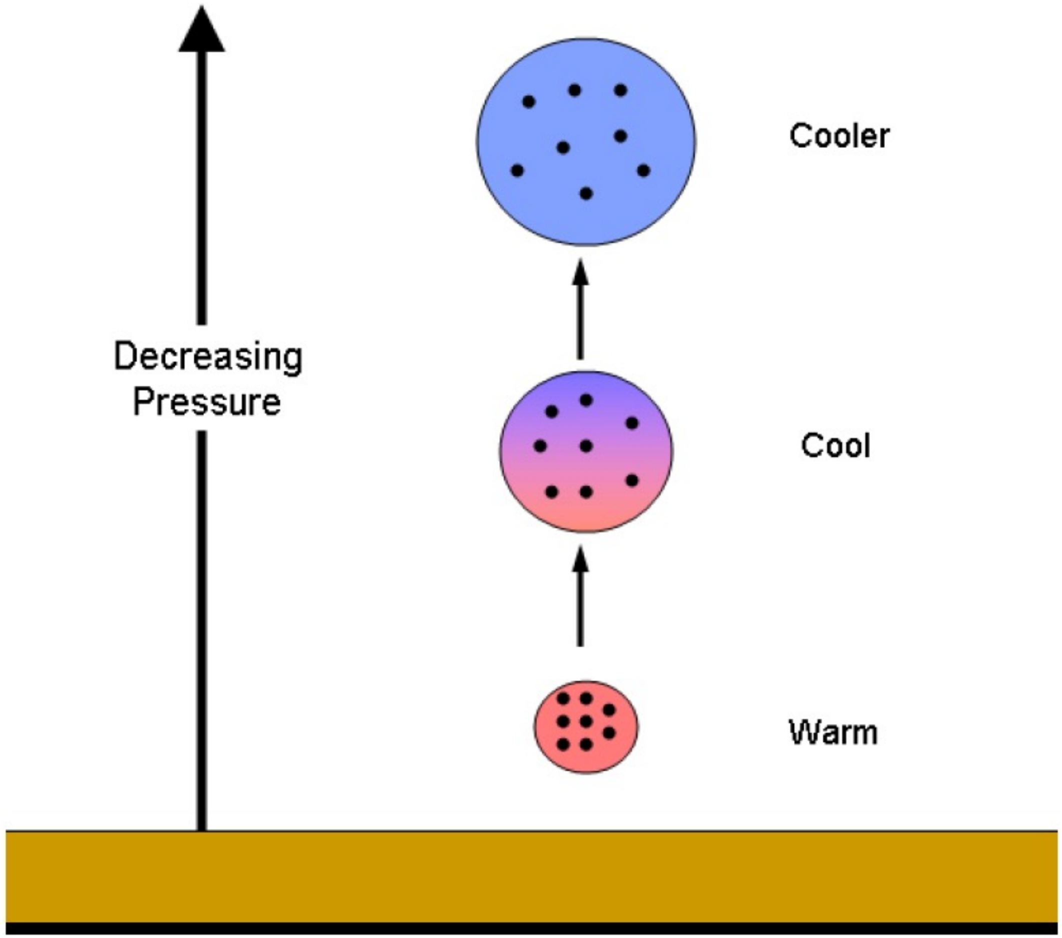
calm (low-
turbulence)
environment



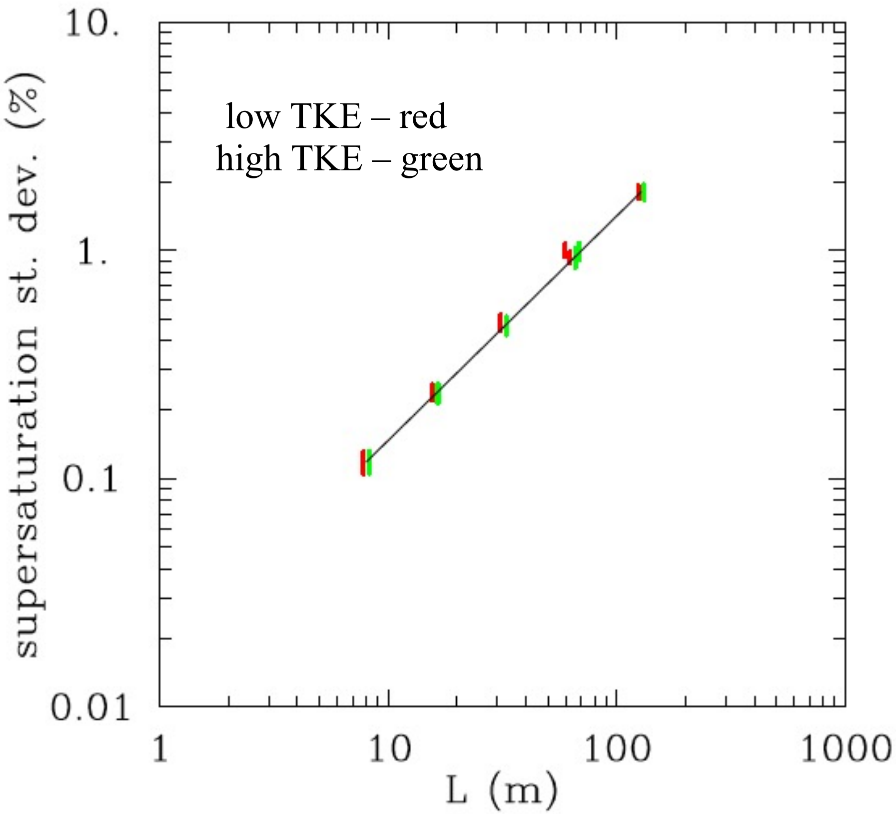
cloud base:
activation of cloud
droplets



Cloud formation: adiabatic expansion of an air volume rising in the stratified environment and reaching saturation:

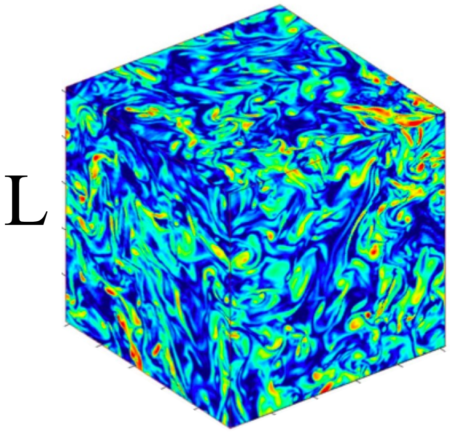


Turbulent supersaturation fluctuations without condensation: the impact of spatial scales



$$\partial T/\partial t + \mathrm{div}\,(\boldsymbol{u}\,T) = -\,g/c_p\,u_z$$

$$\partial q_v/\partial t + \mathrm{div}\,(\boldsymbol{u}\,q_v) = 0$$



$(\Delta T)_{max} \sim \mathrm{L}$

Supersaturation standard deviation as a function of the domain size L for low (red color) and high (green color) TKE dissipation rates. The symbols are shifted to the right (green) and left (rad) to avoid overlap. The symbol vertical extent shows the standard deviation of the temporal evolution. Results from simulations of 64^3 and 128^3 are shown for L=64 m. The solid line shows the fit for all simulation results.

The key point:

In turbulent simulations, often the key issue is about the Reynolds number Re. Re depends on the resolved range of scales, from the TKE input scale L to the TKE dissipation scale η.

$$\frac{L}{\eta} \sim Re^{3/4}$$

This is only marginally relevant to the problem considered here as the largest scales dominate the supersaturation fluctuations…

Broadening of Cloud Droplet Spectra through Eddy Hopping: Turbulent Entraining Parcel Simulations

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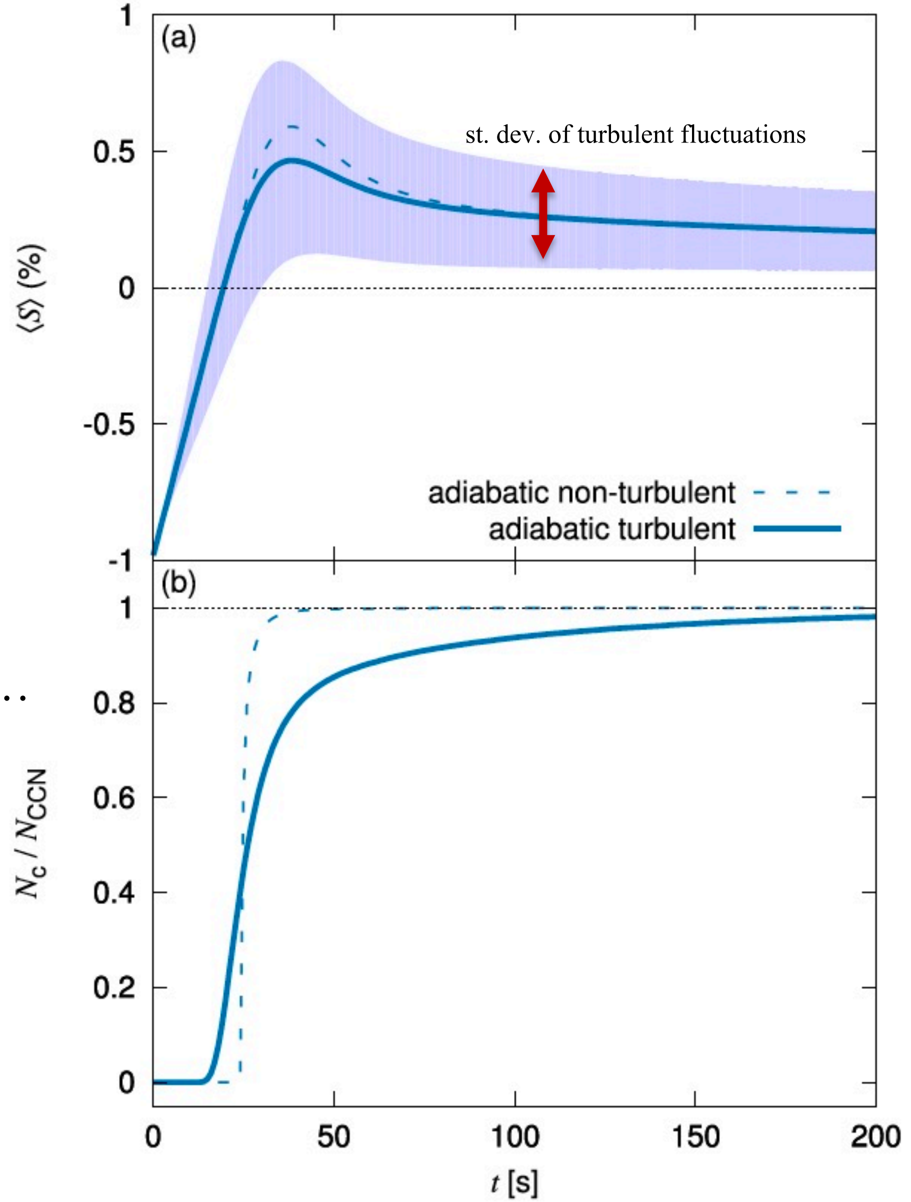
Comparing supersaturation evolution and its impact on CCN activation is a rising adiabatic parcel with and without turbulence applying a stochastic model for supersaturation fluctuations…

Parcel size: L=50 m



Impact of cloud base turbulence on CCN activation: Single size CCN

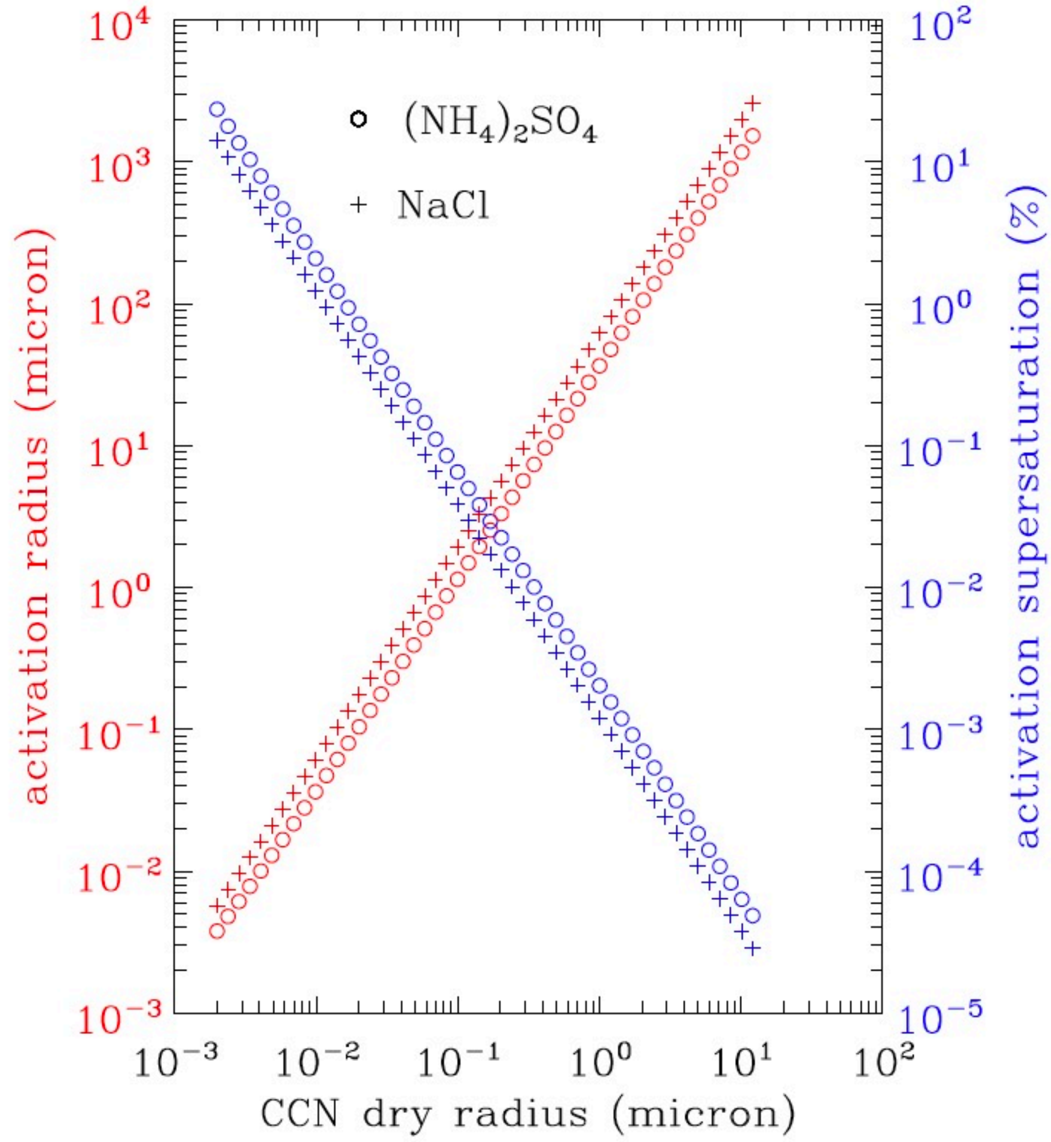
Wojciech W. Grabowski[1], Lois Thomas[2,3], and Bipin Kumar[3]

[1]Mesoscale and Microscale Meteorology Laboratory, National Center for Atmospheric Research*, Boulder, CO 80307, USA

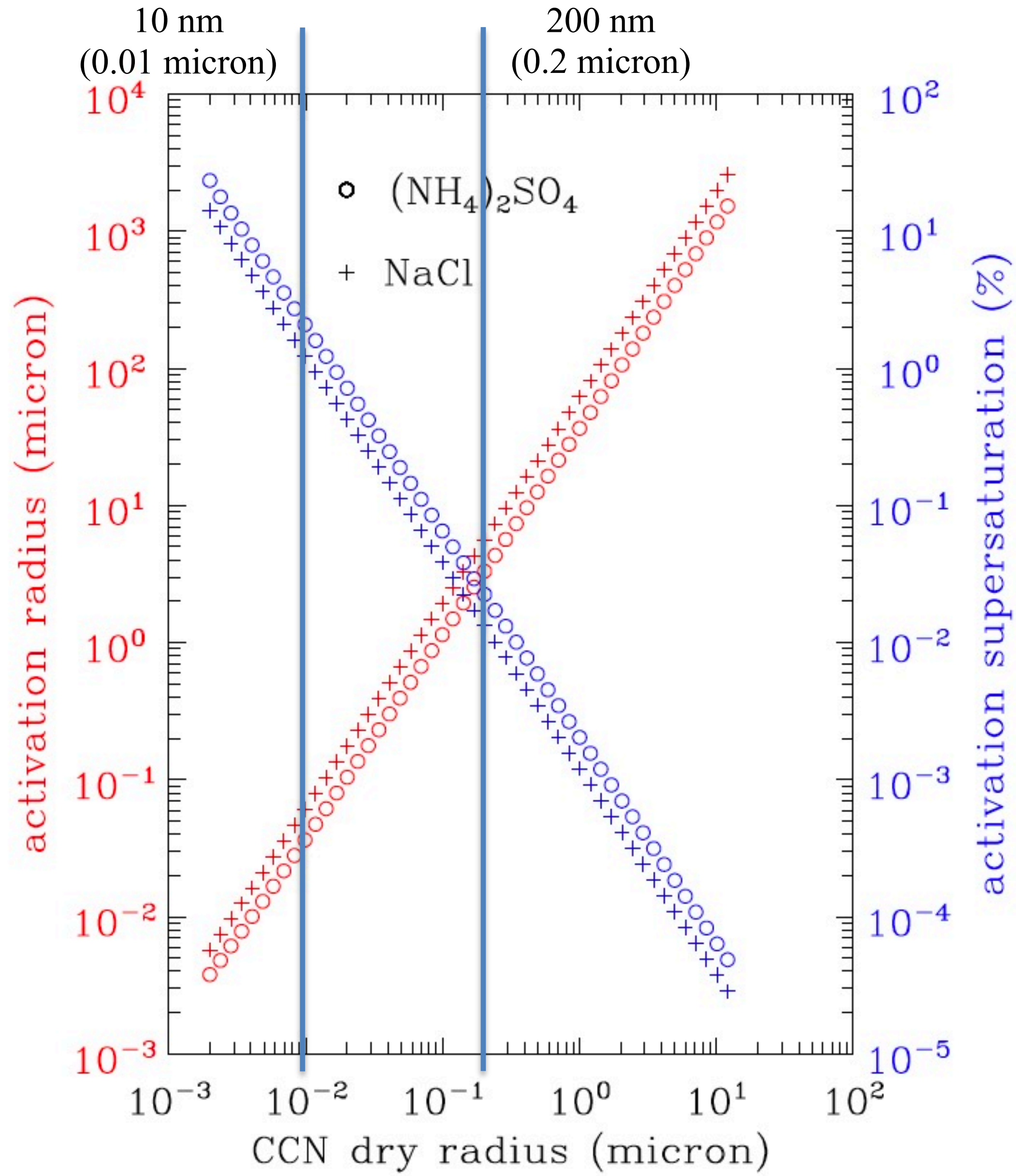
[2]HPCS, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune 411008, India

[3]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune 411007, India

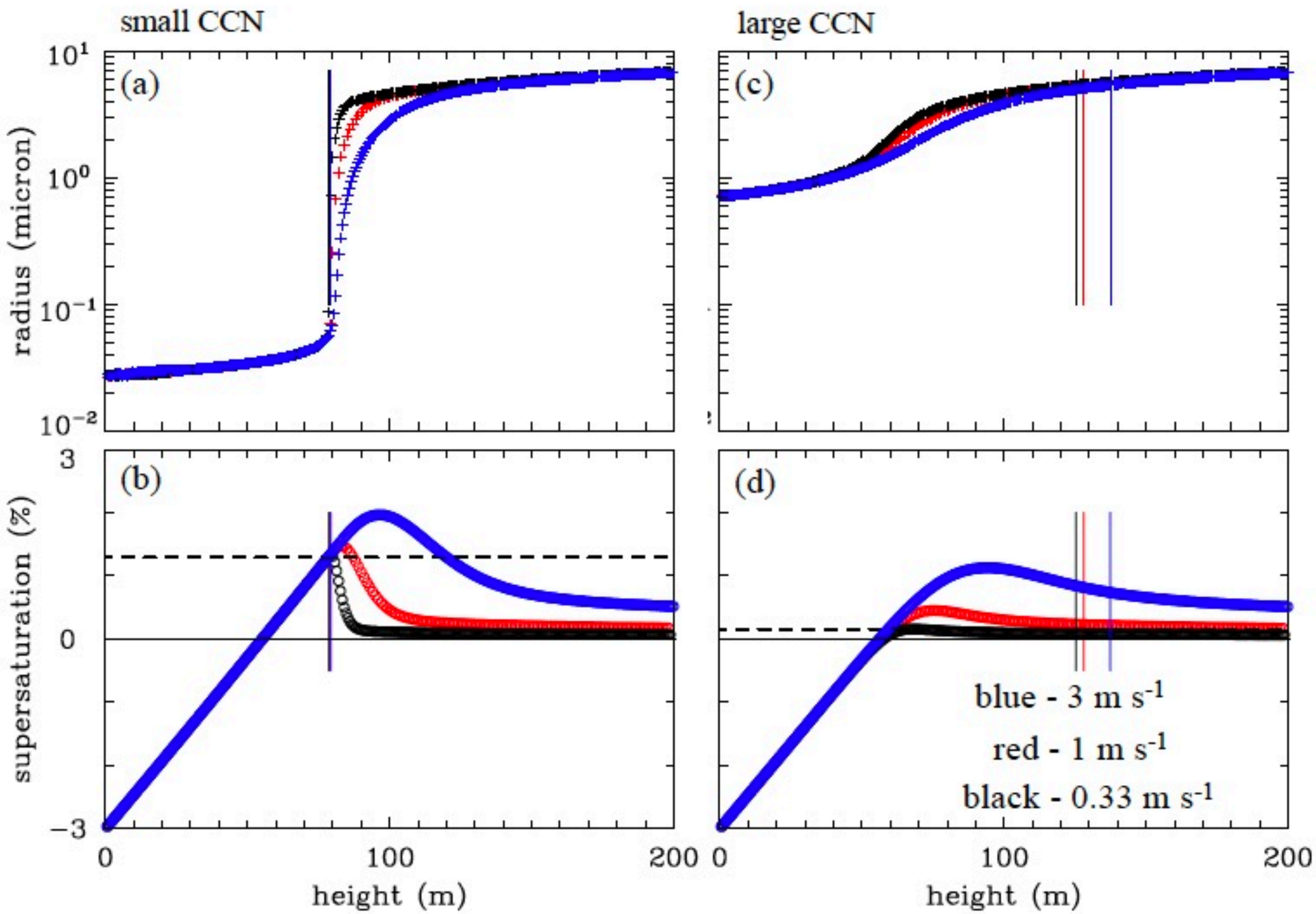
J. Atmos. Sci., in review


10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
activation radius (micron)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
activation supersaturation (%)
$(NH_4)_2SO_4$
NaCl
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
CCN dry radius (micron)

Two NaCl sizes selected in concentration of 200 per cc (i.e., separate simulations for the two sizes)



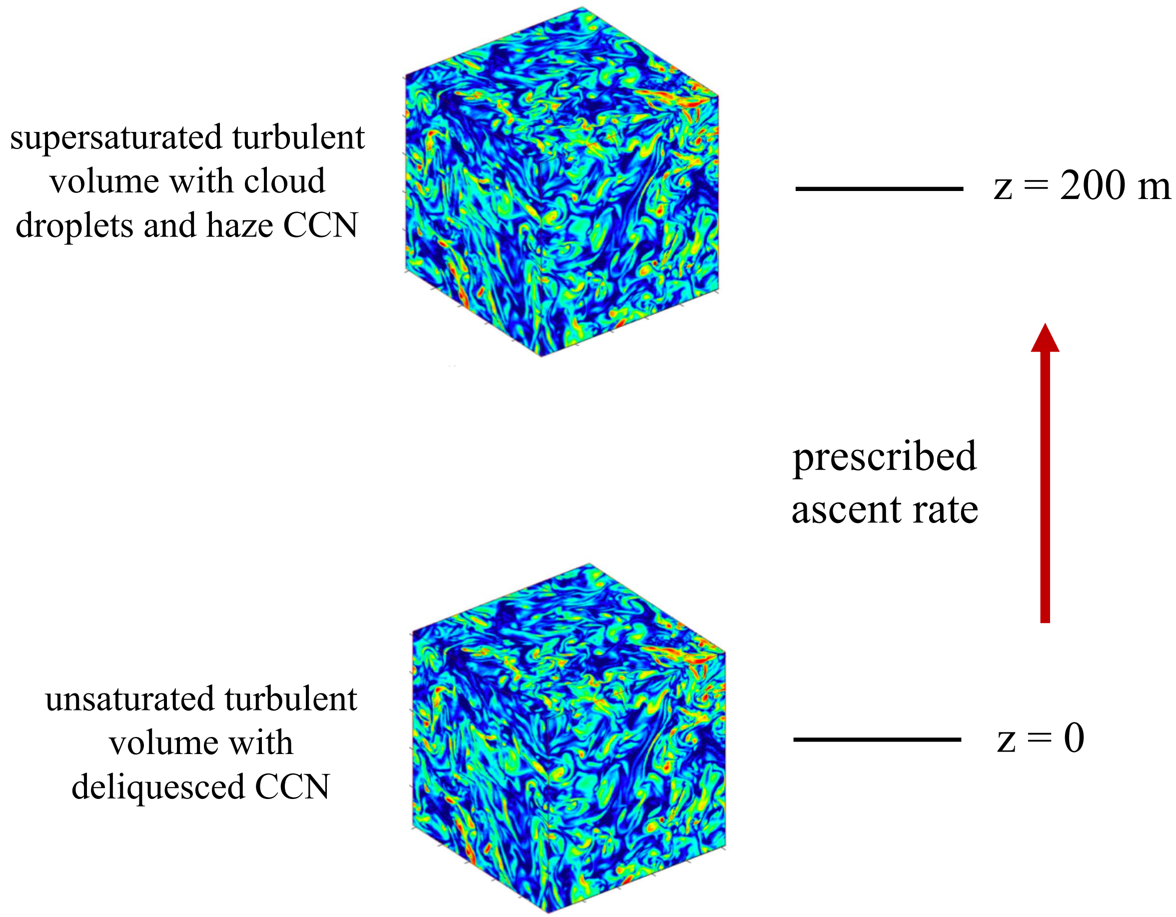
Traditional approach: adiabatic parcel crossing the cloud base with 0.33, 1, 3 ms^{-1}
(initially RH = 97%, p = 900 hPa, T = 283 K)



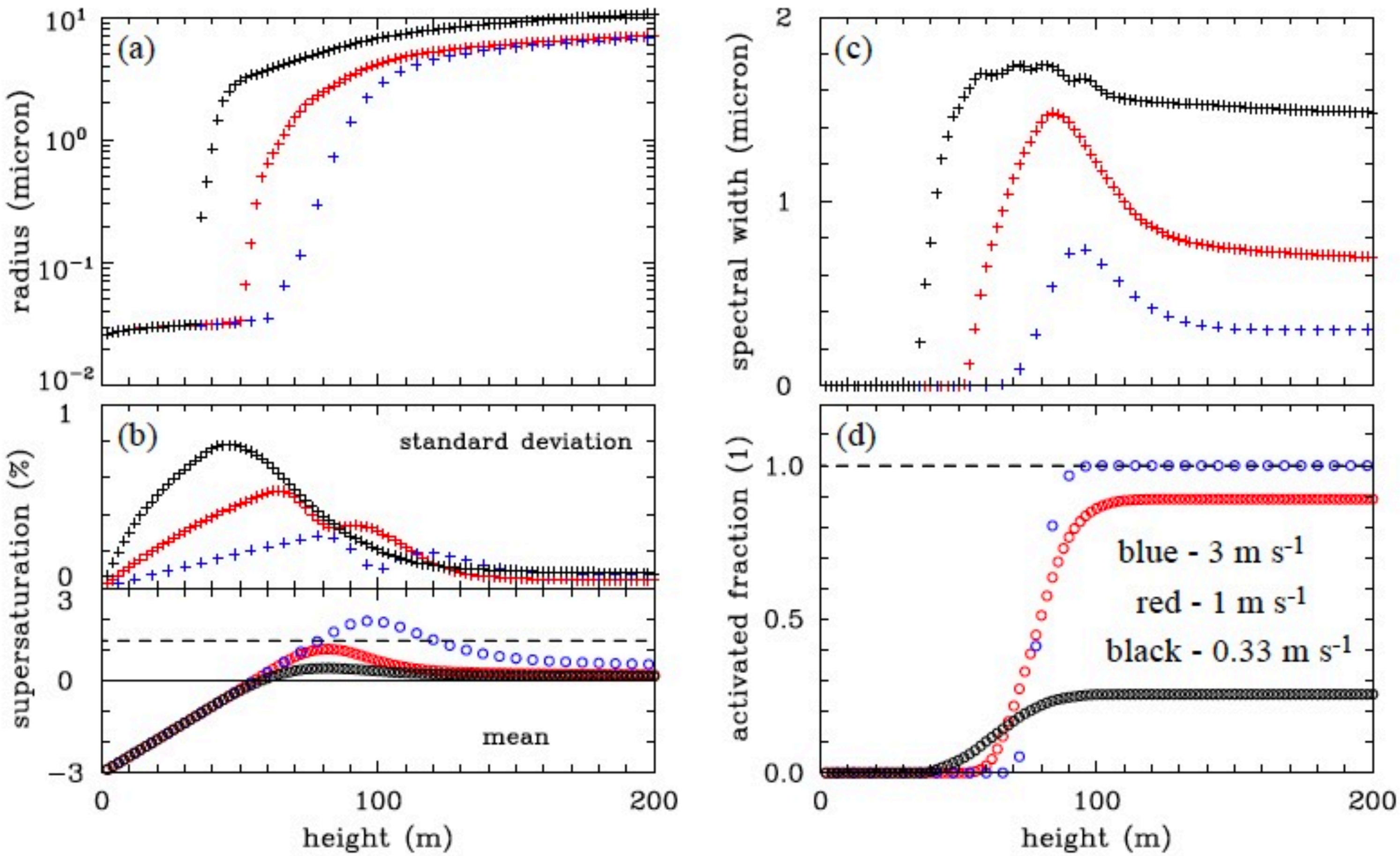
- Supersaturations needs to reach activation supersaturation
- All CCN activated with zero spectral width (all droplets have the same size)

turbulent adiabatic parcel crossing the cloud base with 0.33, 1, 3 ms^{-1}
(initially RH = 97%, p = 900 hPa, T = 282 K)

64^3 m^3
1 m grid length

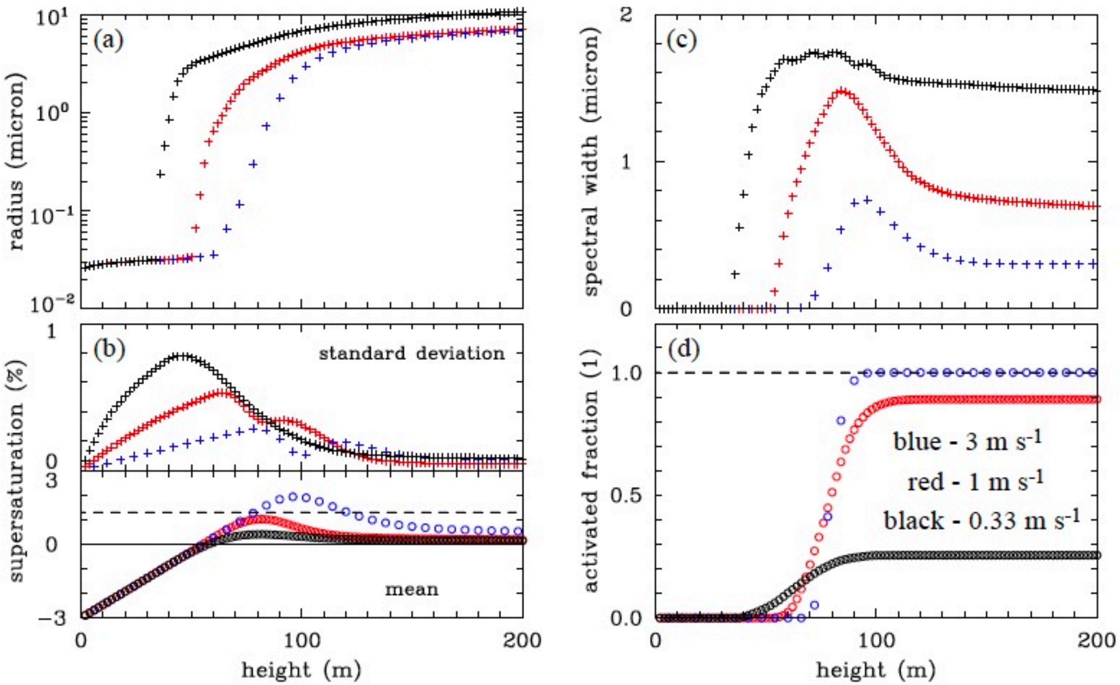


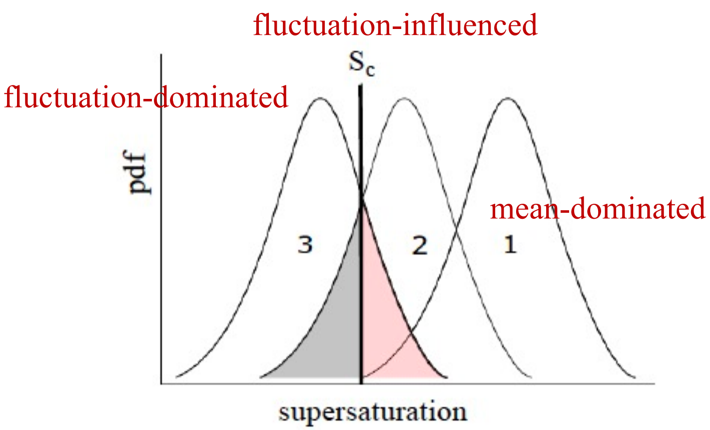
Small CCN: 10 nm (0.01 micron)



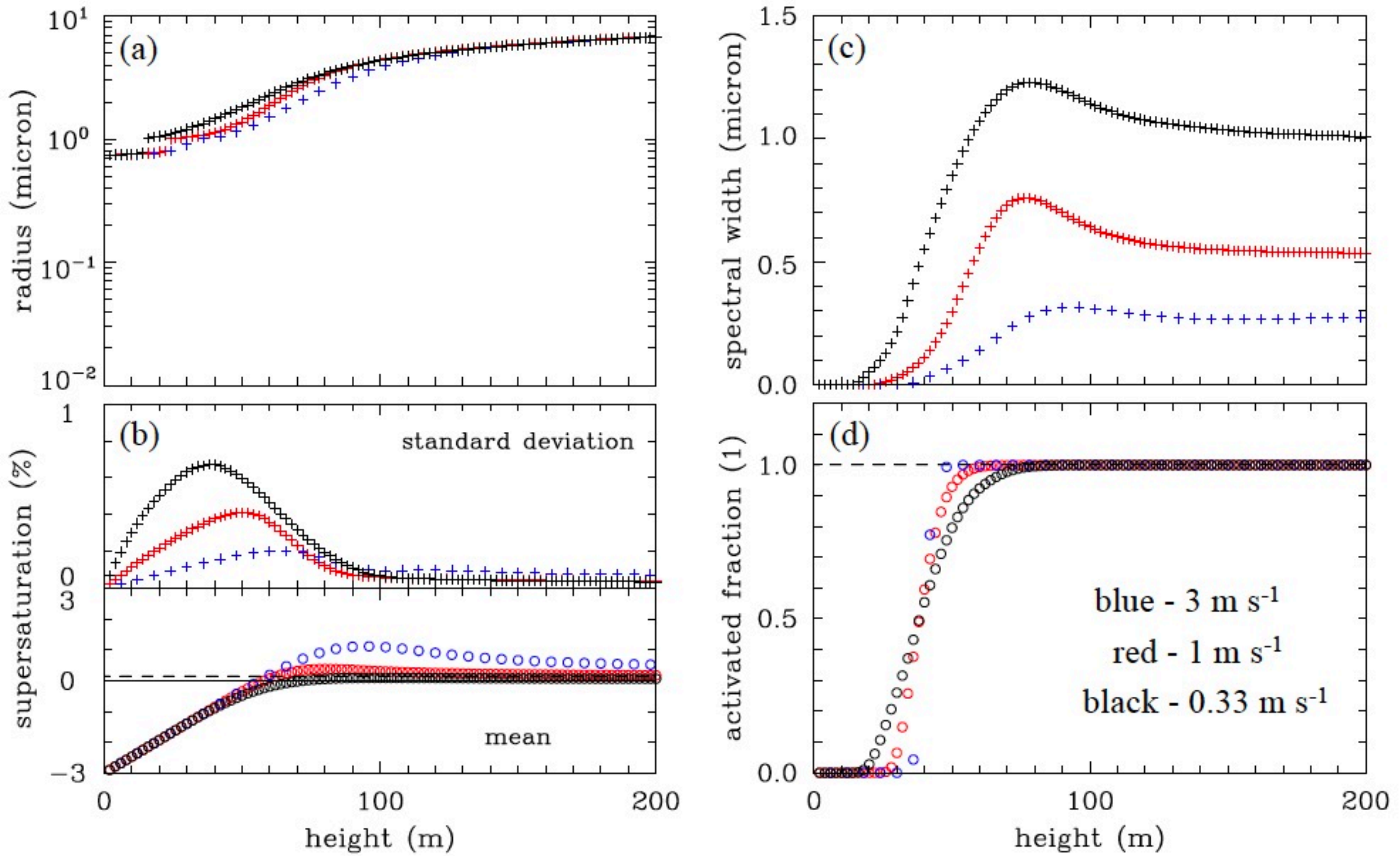
- Mean S does not have to reach activation supersaturation
- Not all CCN activated for 0.33 and 1 m/s: only about 25% for 0.33 m/s case!
- Significant spectral width just after activation

Small CCN: 10 nm (0.01 micron)



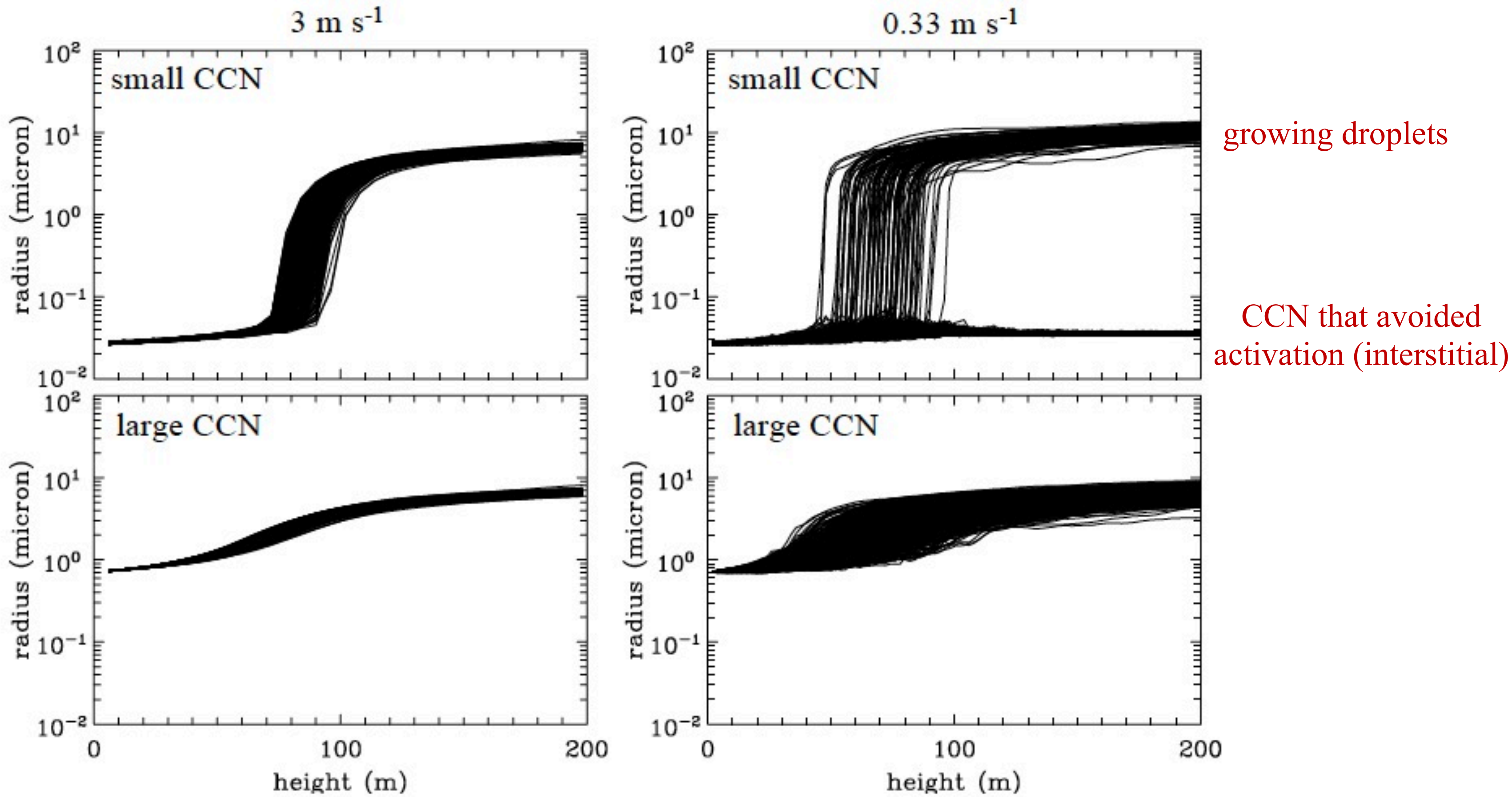


Large CCN: 200 nm (0.2 micron)



- Mean S does not have to reach activation supersaturation
- All CCN activated for the three updtafts.
- Significant spectral width just after activation

Radius evolutions of a small fraction of droplets:



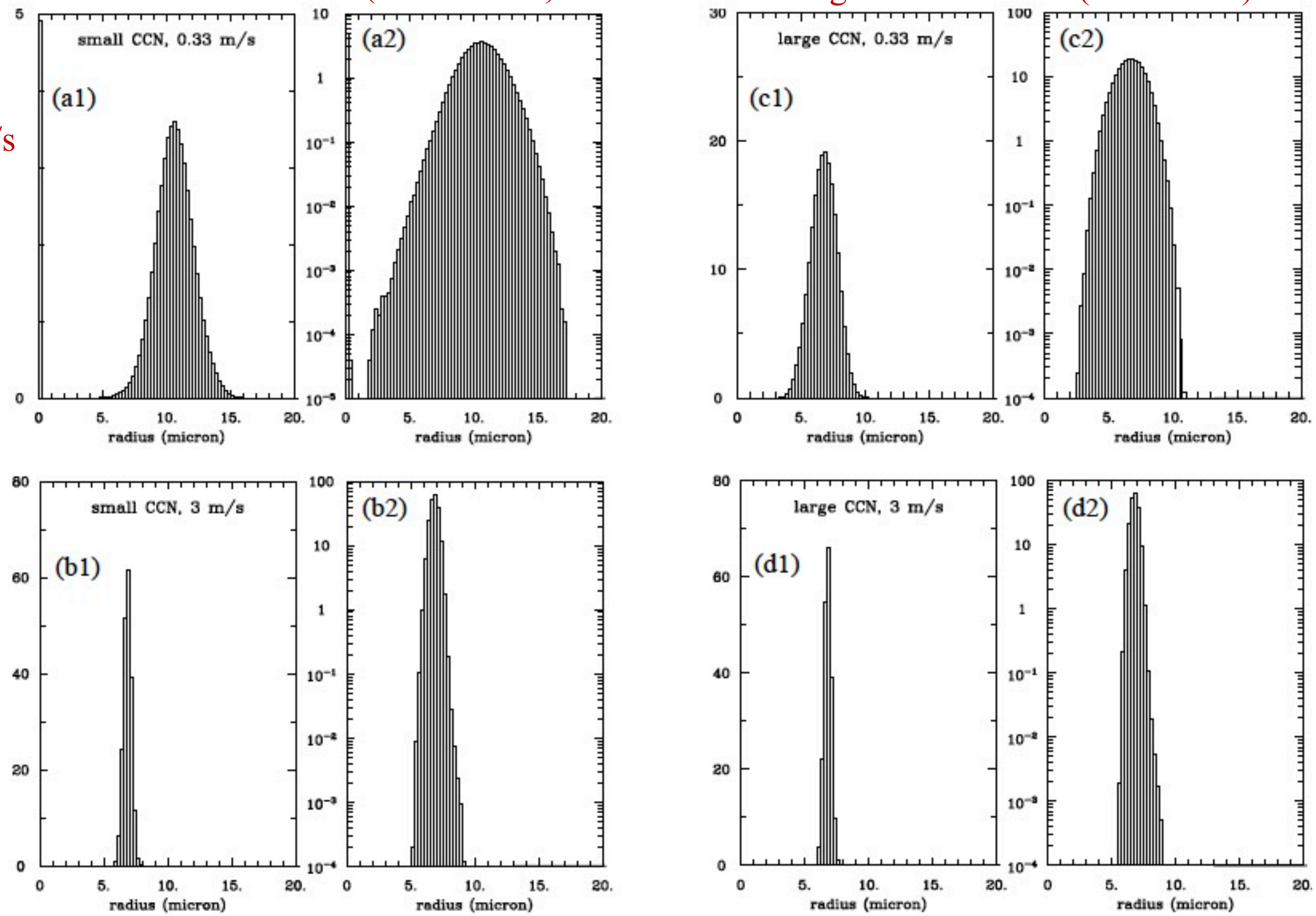
Finite spectral width comes from CCN activated at various times…

Droplet spectra at 200m height (linear and log vertical scale):

Small CCN: 10 nm (0.01 micron) — Large CCN: 200 nm (0.2 micron)

0.33 m/s

3 m/s



Impact of turbulence on CCN activation: CCN distribution

Wojciech W. Grabowski[1], Lois Thomas[2,3], and Bipin Kumar[3]

[1]Mesoscale and Microscale Meteorology Laboratory, National Center for Atmospheric Research, Boulder, CO 80307, USA

[2]HPCS, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune 411008, India

[3]Department of Atmospheric and Space Sciences, Savitribai Phule Pune University, Pune 411007, India

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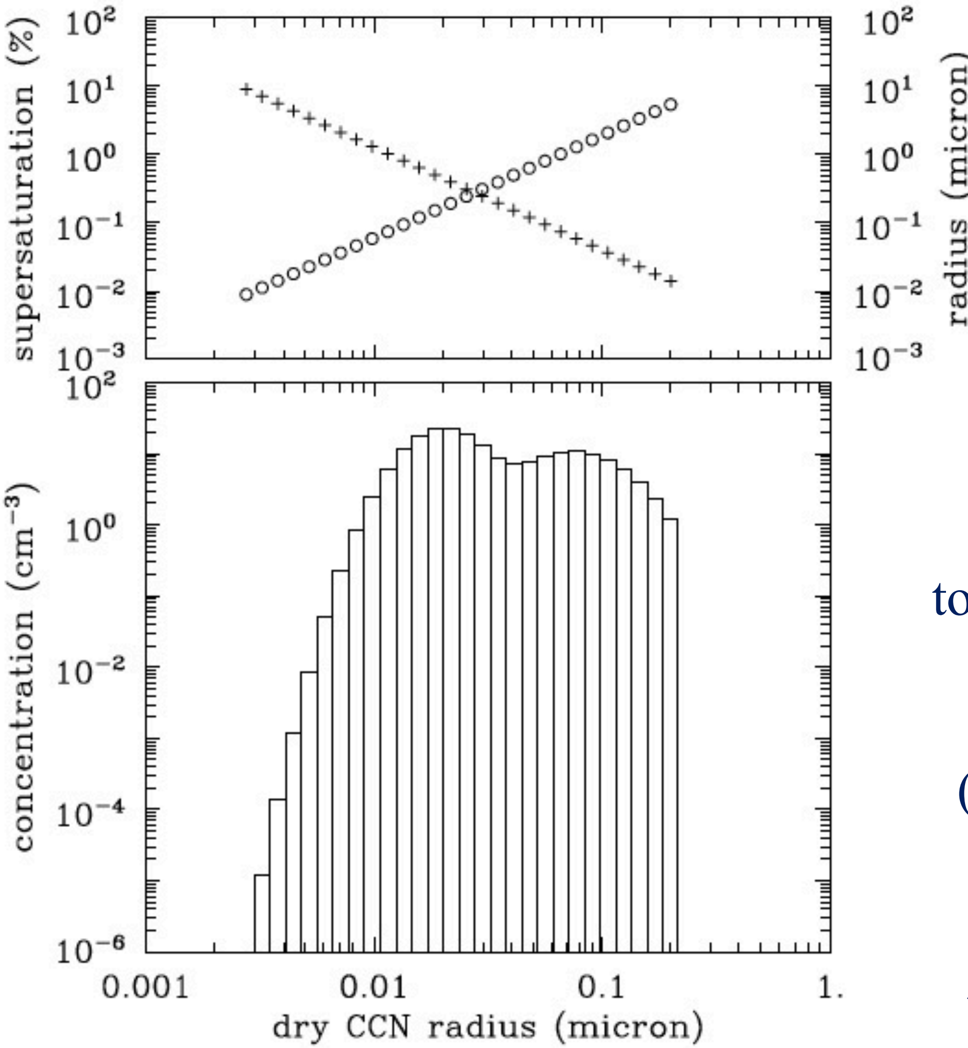
manuscript in progress…



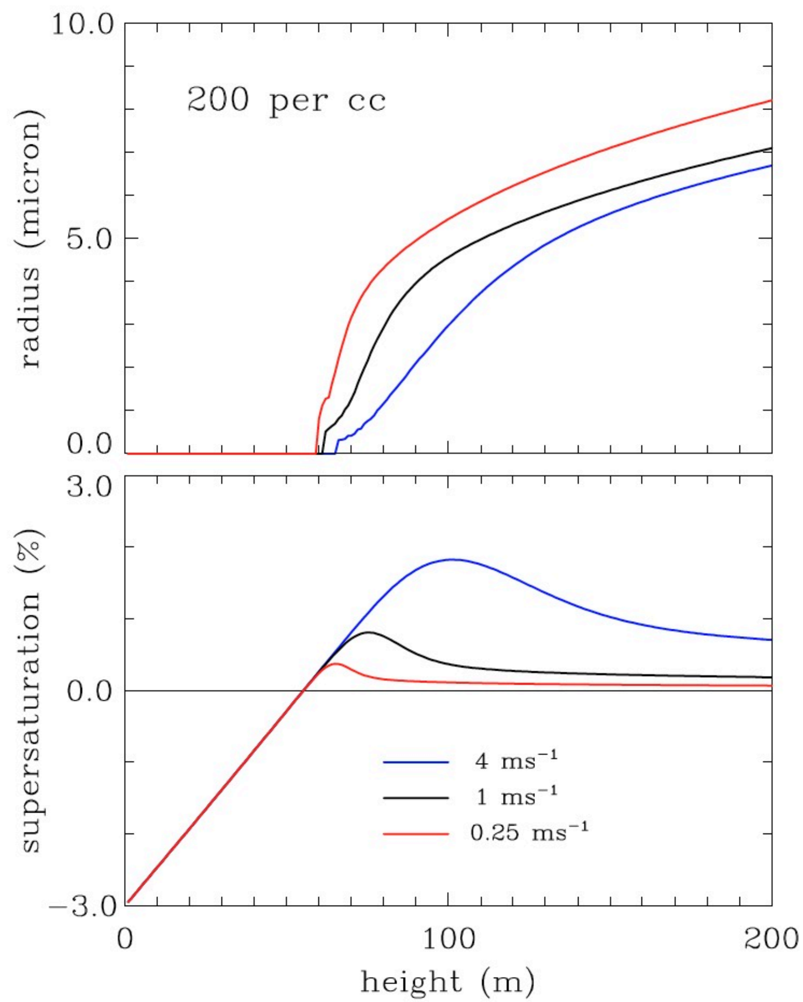
critical supersaturation and activation radius

size distribution

total concentration: 200 per cc

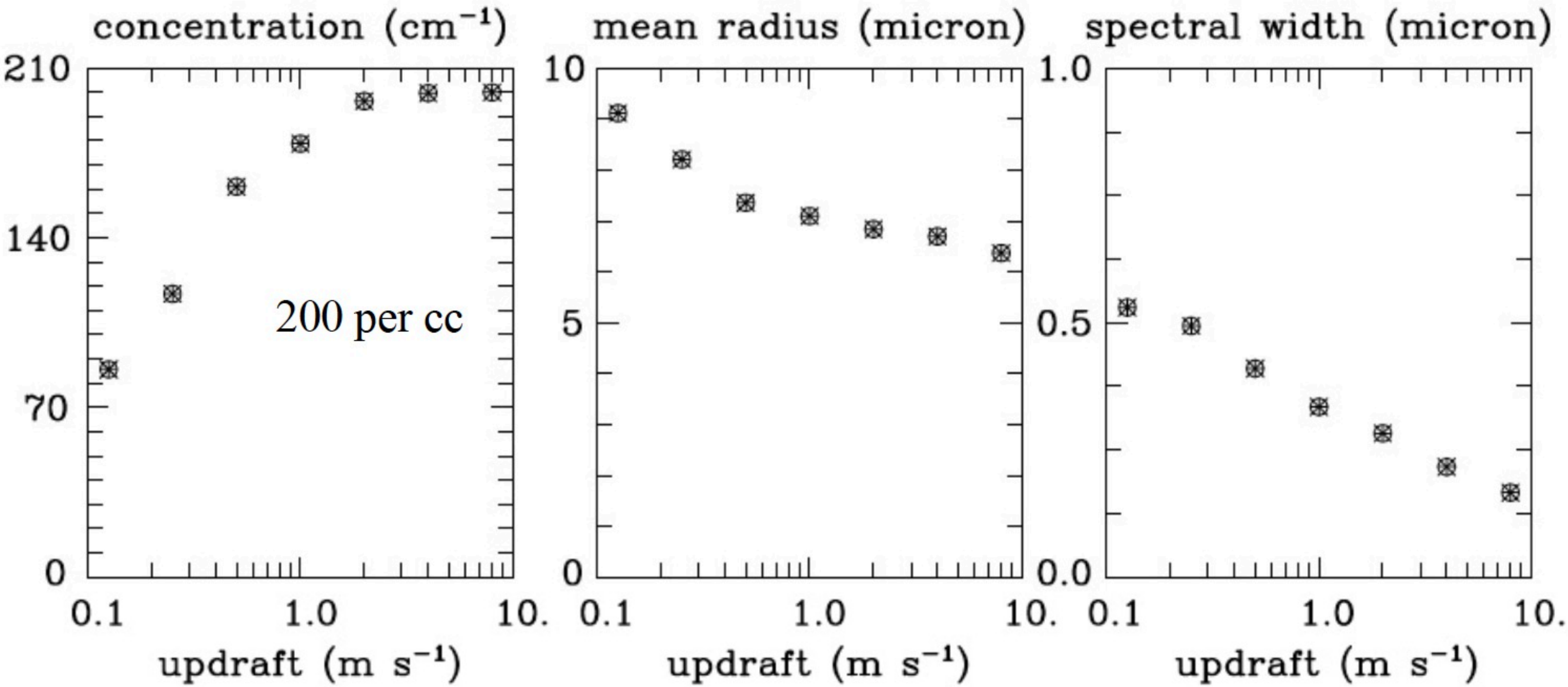
(also simulations with the same distribution but 2000 per cc, not presented here)

Traditional approach: adiabatic parcel crossing the cloud base with 0.25, 1, 4 ms^{-1}
(initially RH = 97%, p = 900 hPa, T = 283 K)



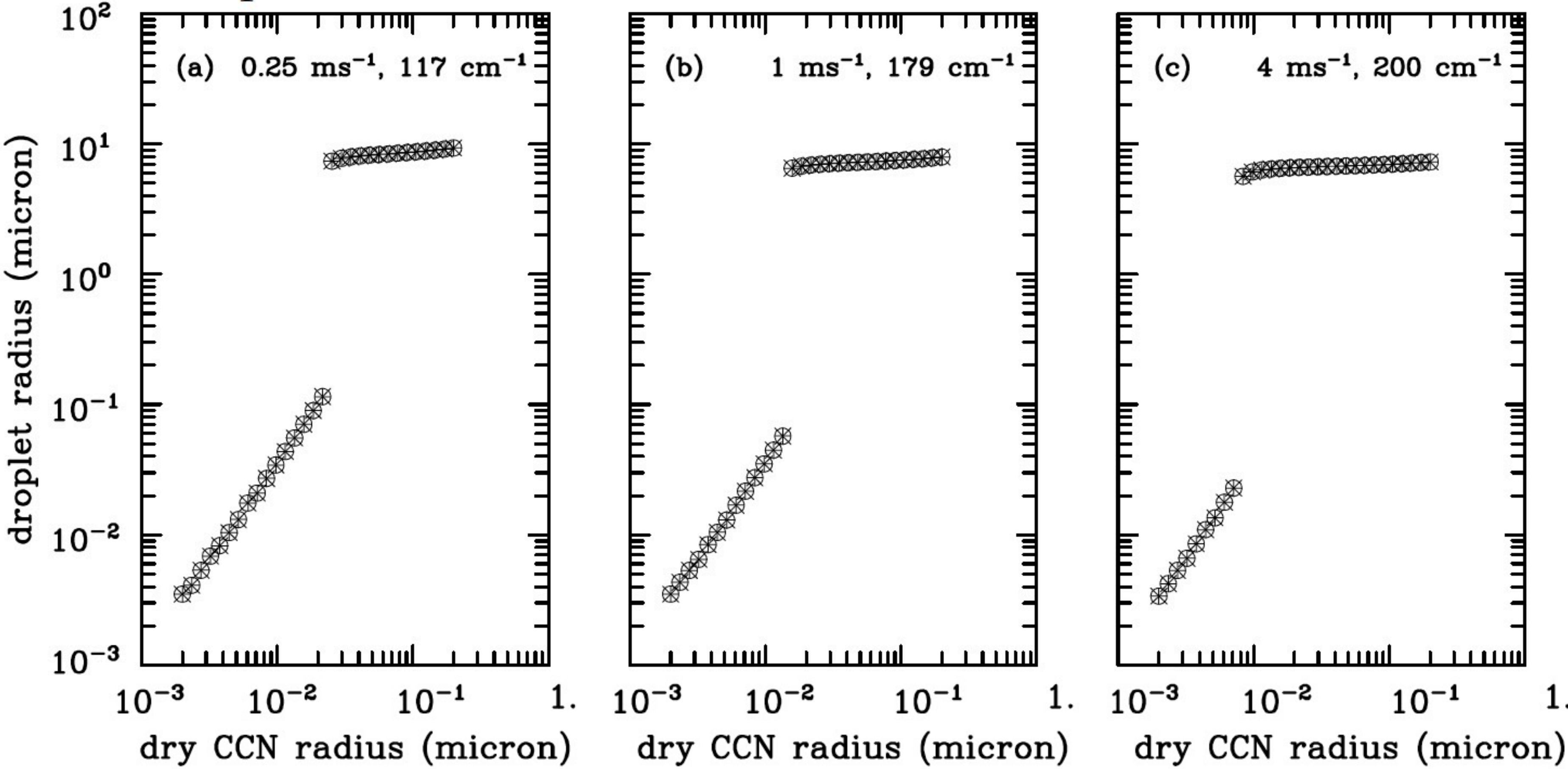
- Supersaturations needs to reach activation supersaturation for each class.
- Stronger updrafts lead to activation of smaller CCN, thus larger total concentrations, and smaller mean radii.

results at 200 m



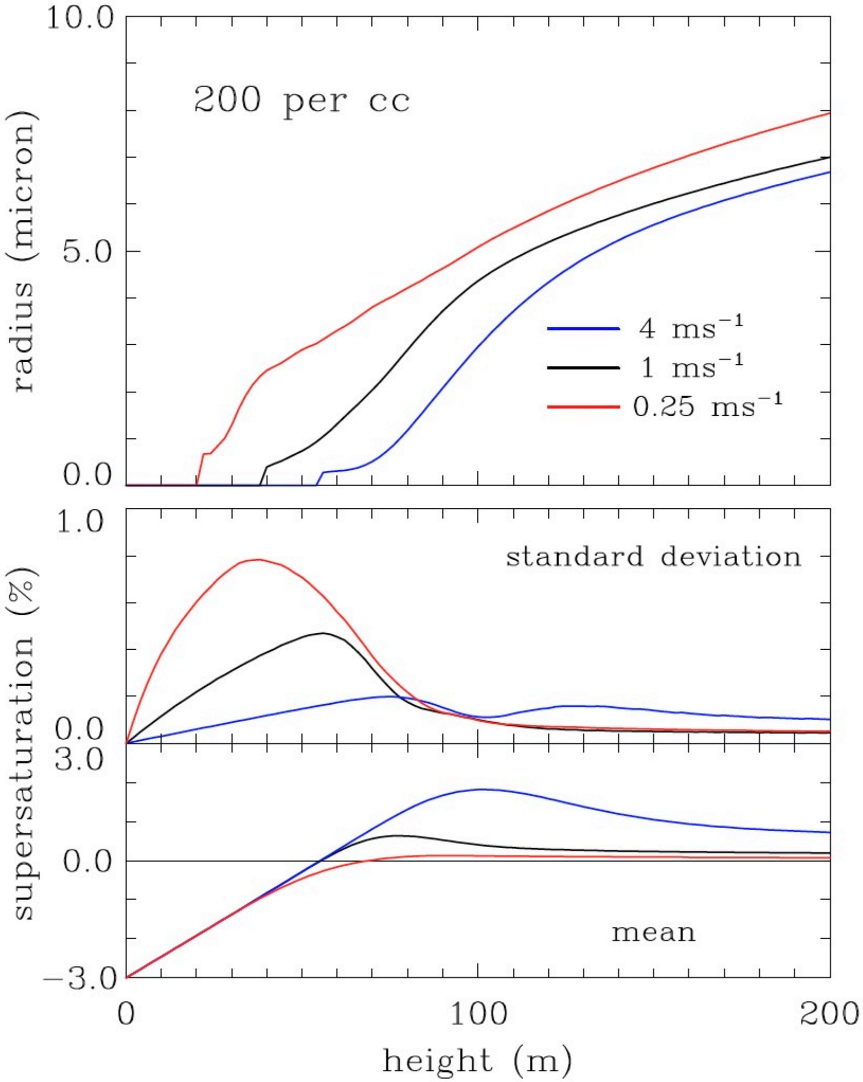
- Stronger updrafts lead to activation of smaller CCN.
- This leads to larger total concentrations, and smaller mean radii.
- Spectral width is few tenth of 1 micron, larger for smaller updrafts.

200 per cc

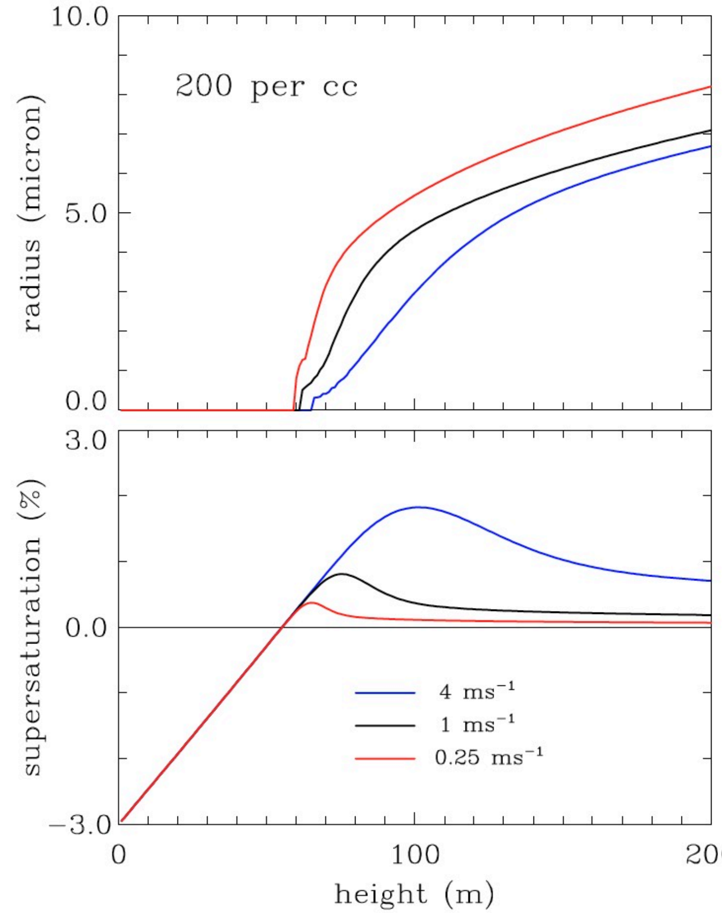


-Sharp separation between activated and un-activated (haze) CCN at 200 m height

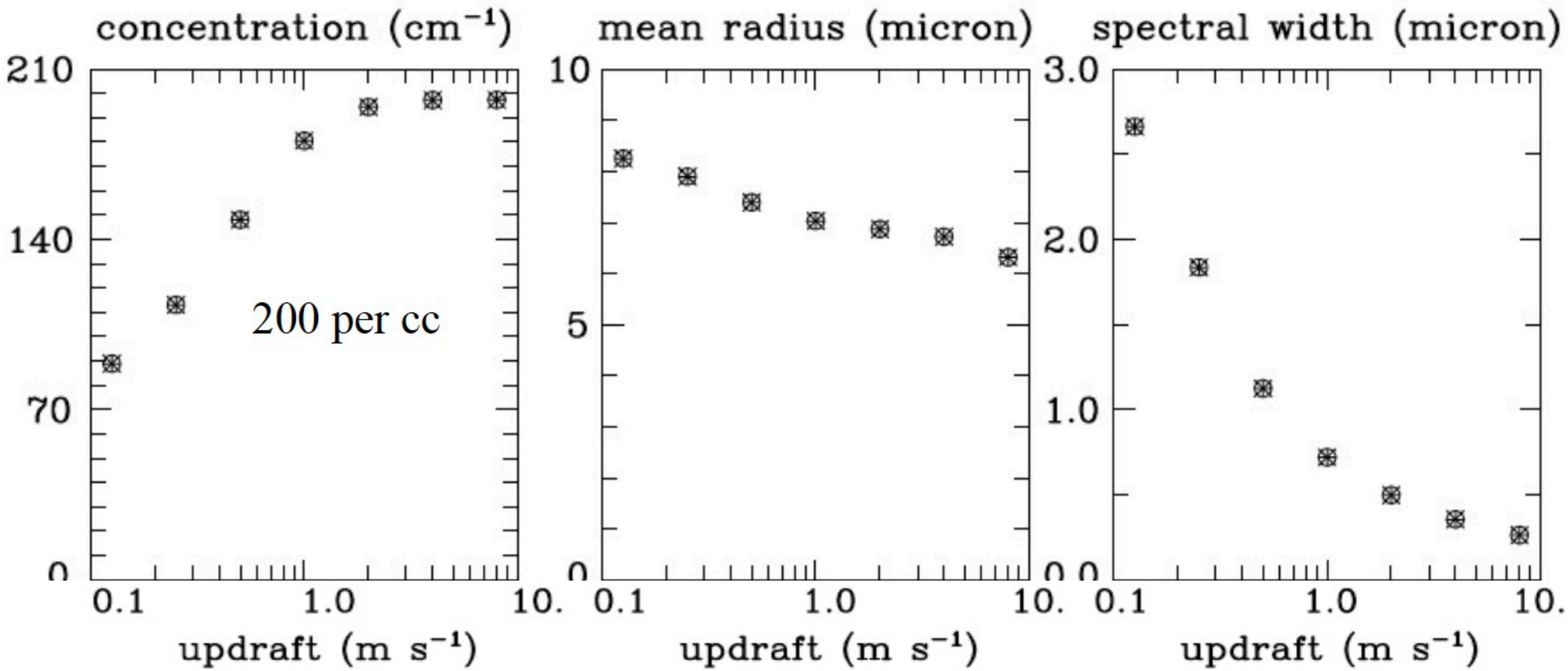
Turbulent parcel



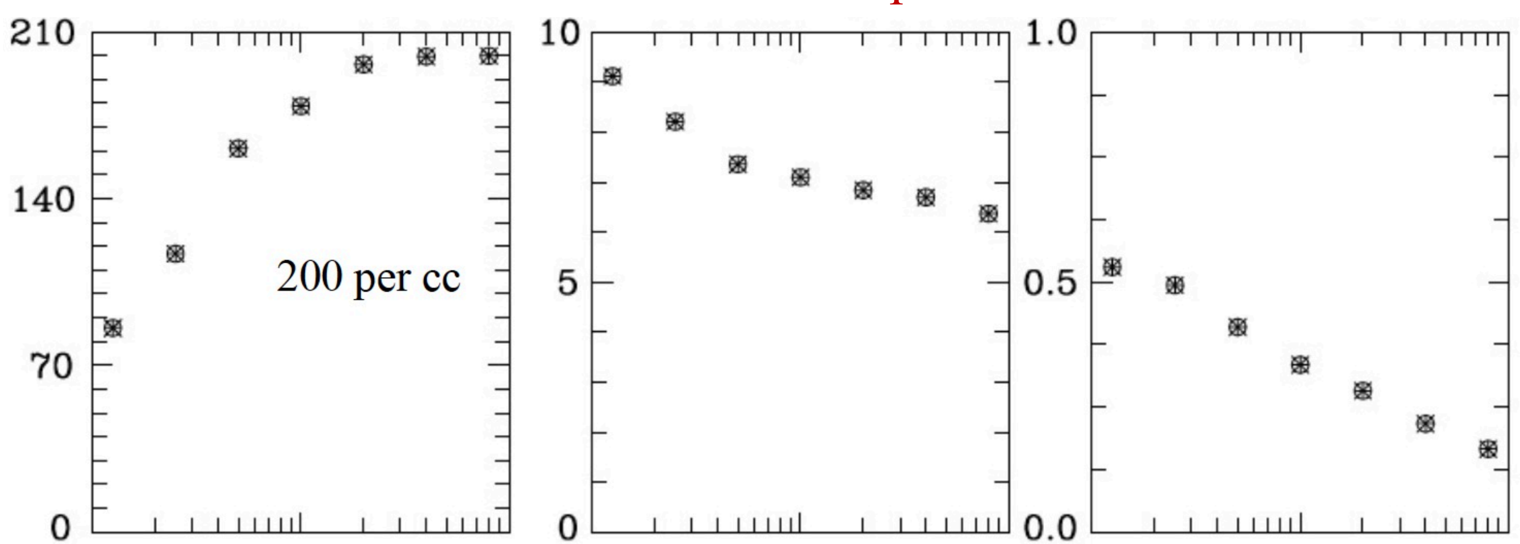
Non-turbulent parcel

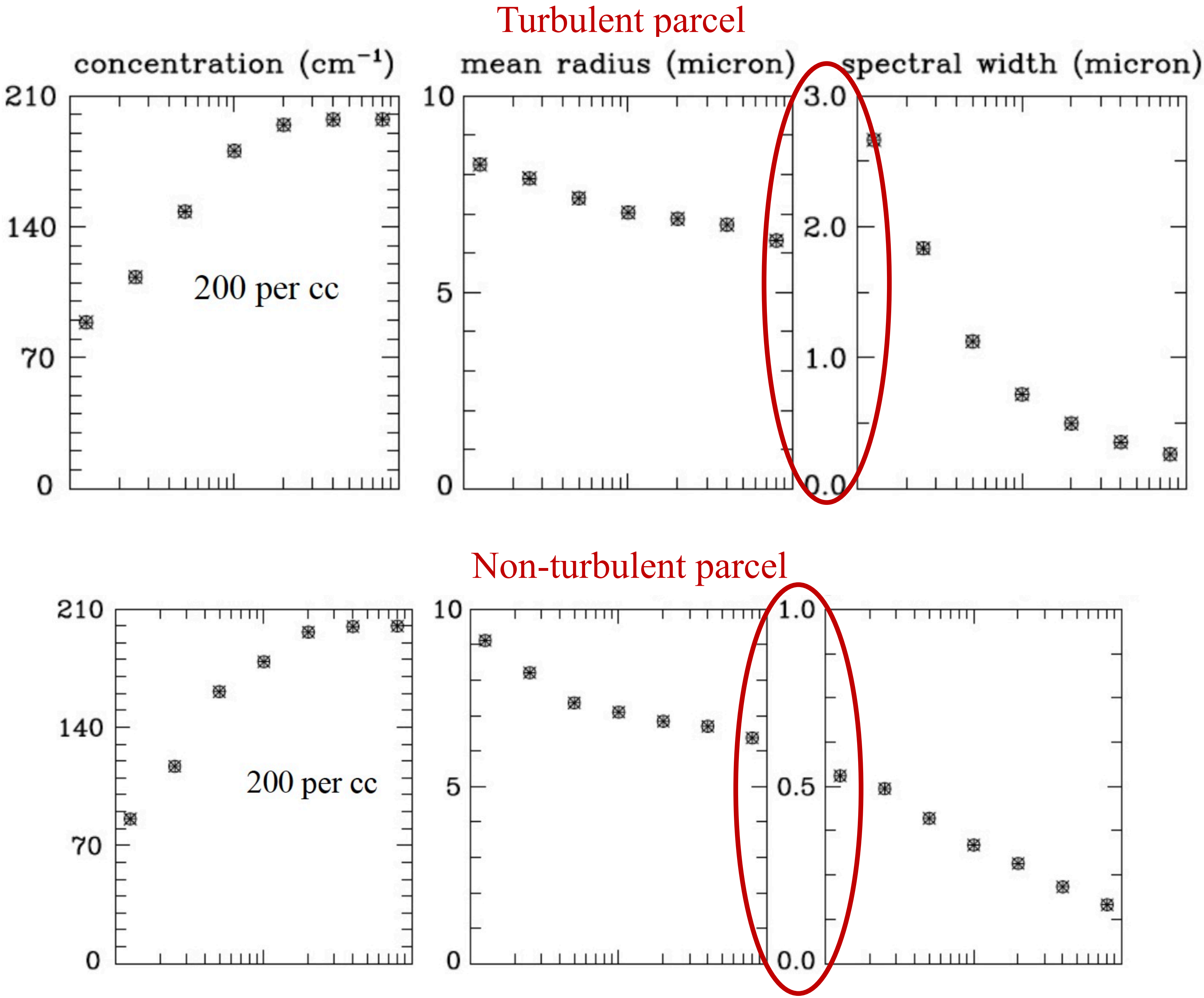


Turbulent parcel

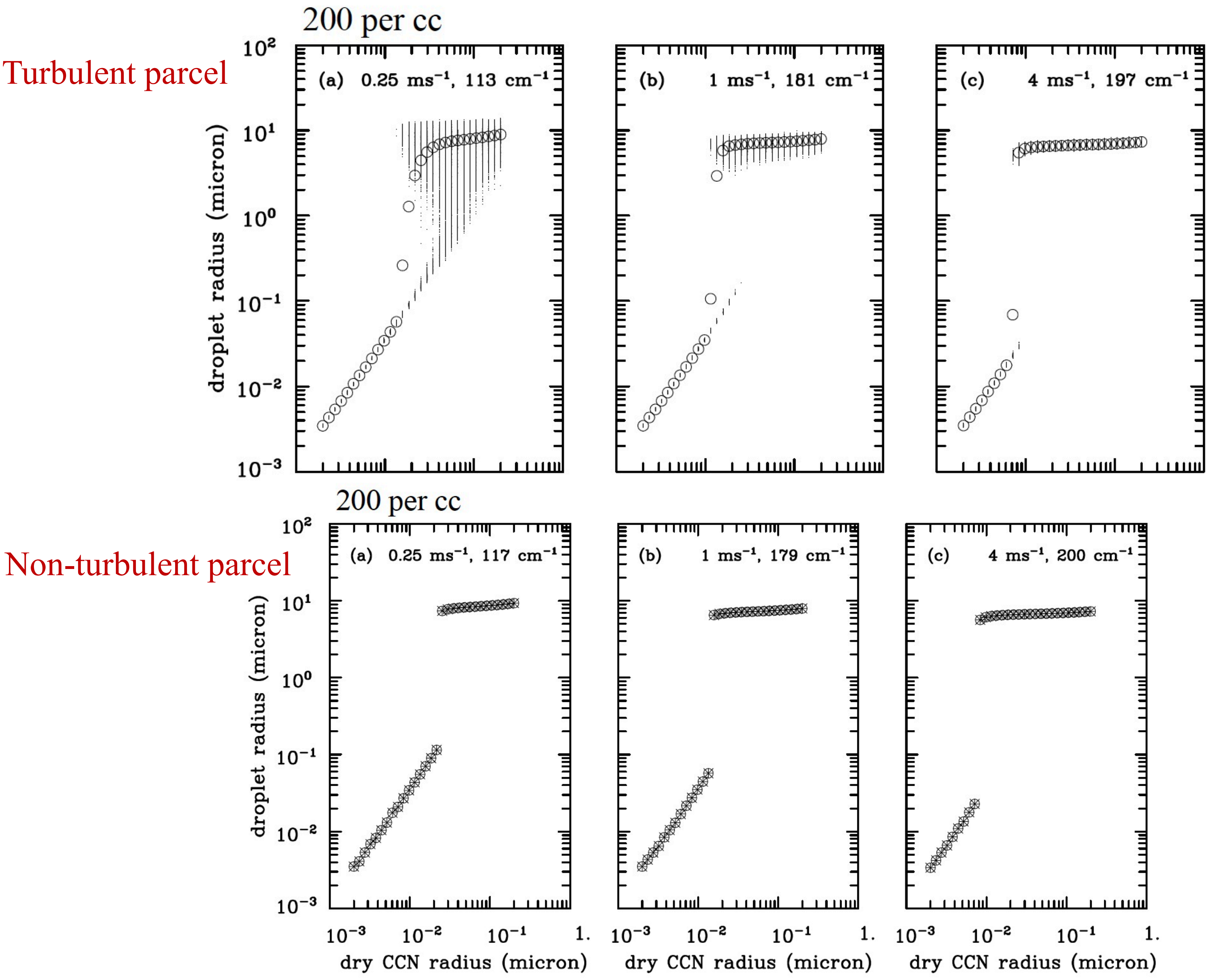


Non-turbulent parcel





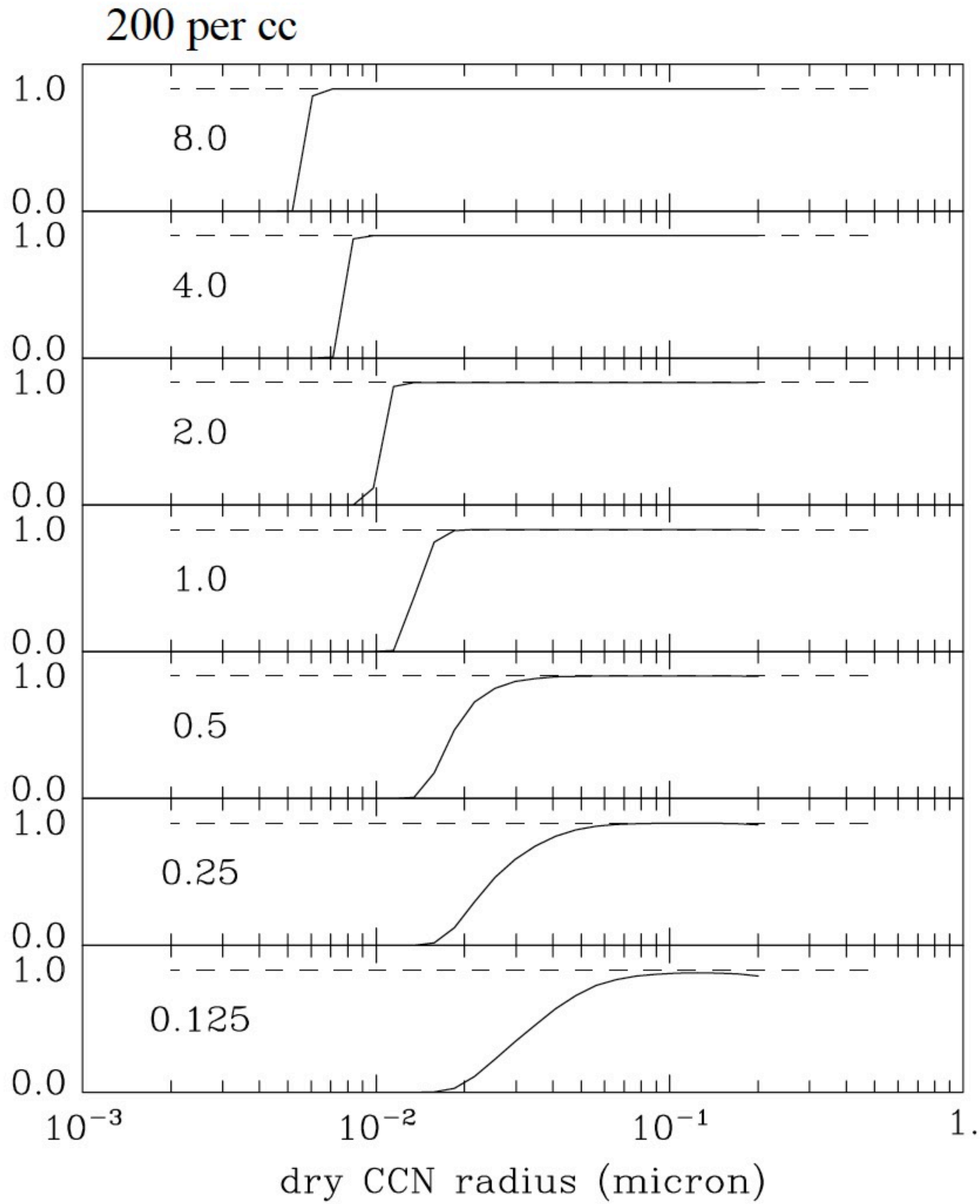
Turbulent parcel
concentration (cm⁻¹)
mean radius (micron)
spectral width (micron)
210
140
70
0
200 per cc
10
5
0
3.0
2.0
1.0
0.0
Non-turbulent parcel
210
140
70
0
200 per cc
10
5
0
1.0
0.5
0.0

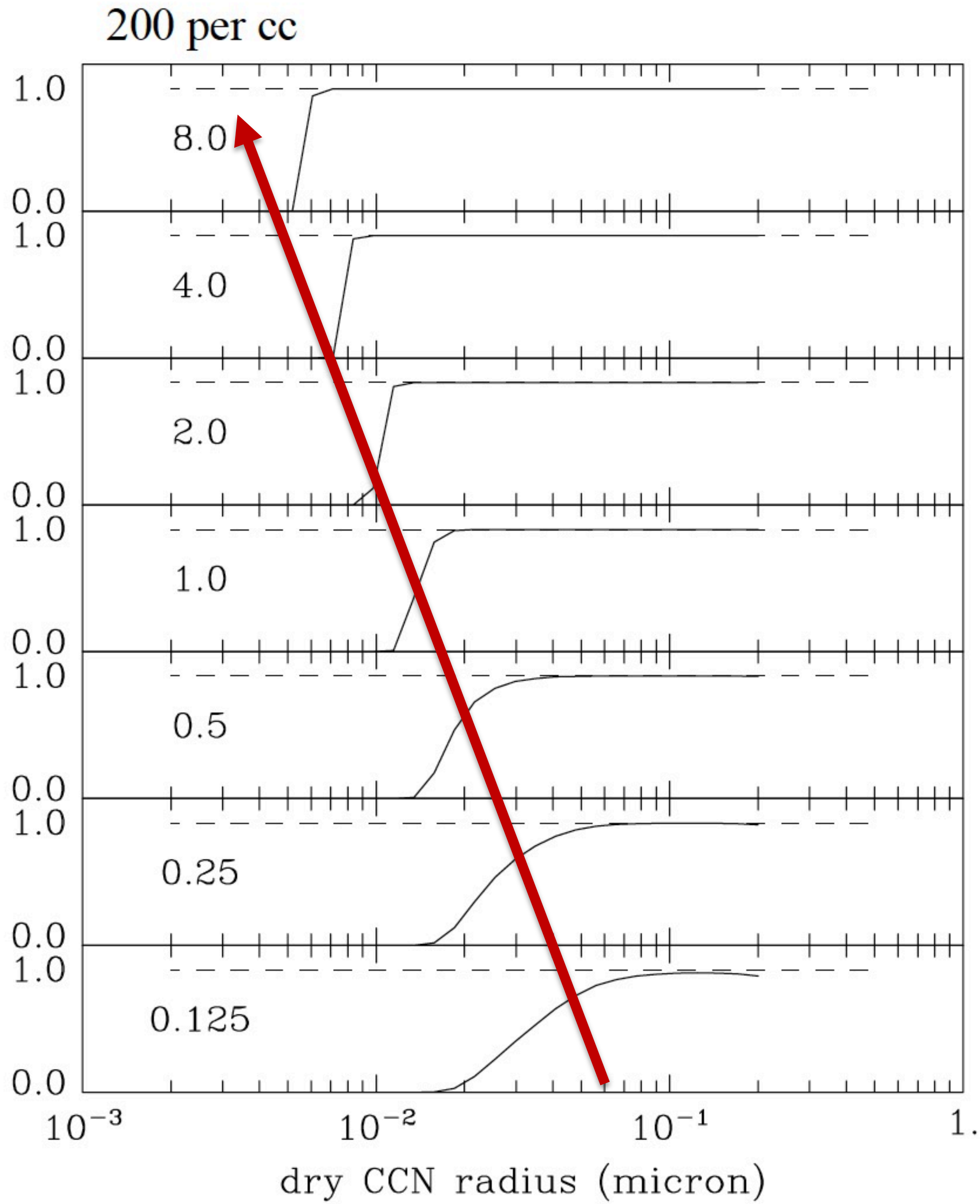


200 per cc
Turbulent parcel
(a) 0.25 ms⁻¹, 113 cm⁻¹
(b) 1 ms⁻¹, 181 cm⁻¹
(c) 4 ms⁻¹, 197 cm⁻¹
droplet radius (micron)
200 per cc
Non-turbulent parcel
(a) 0.25 ms⁻¹, 117 cm⁻¹
(b) 1 ms⁻¹, 179 cm⁻¹
(c) 4 ms⁻¹, 200 cm⁻¹
droplet radius (micron)
dry CCN radius (micron)
dry CCN radius (micron)
dry CCN radius (micron)

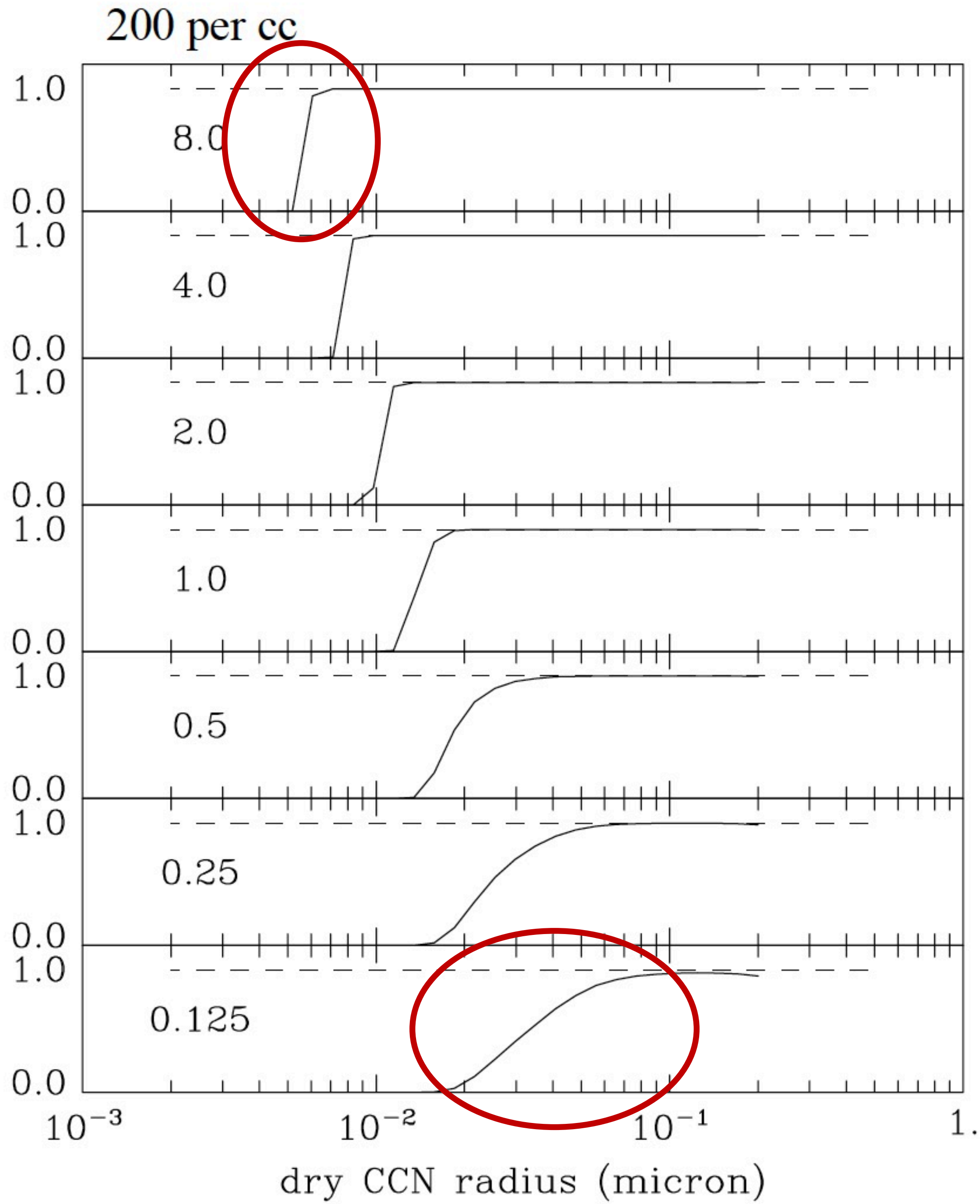
Turbulent parcel

Activated fraction
per bin
for different
updrafts





200 per cc
1.0
0.0
8.0
4.0
2.0
1.0
0.5
0.25
0.125
10^{-3}
10^{-2}
10^{-1}
1.
dry CCN radius (micron)

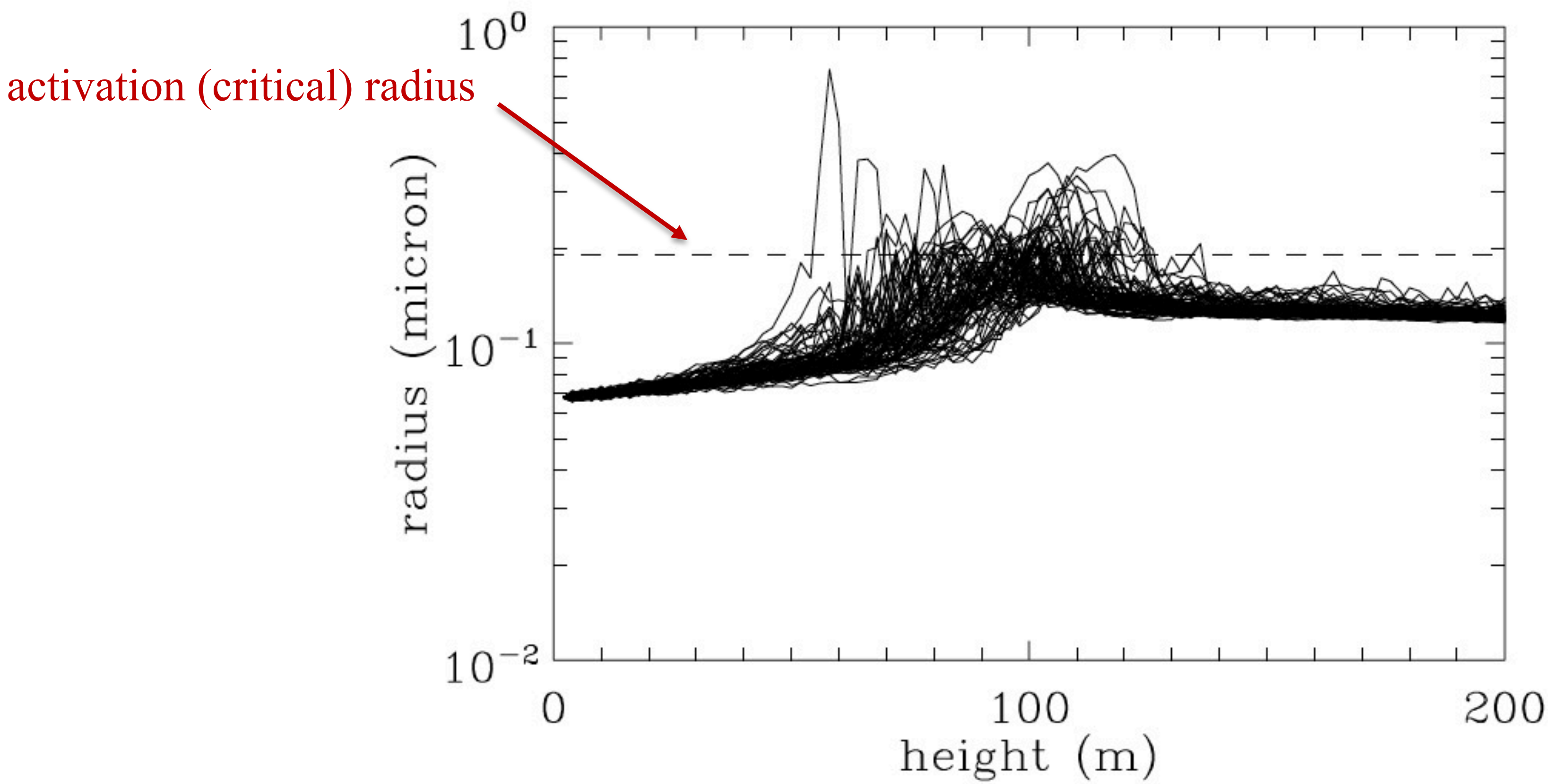


200 per cc
1.0
0.0
8.0
4.0
2.0
1.0
0.5
0.25
0.125
10^{-3}
10^{-2}
10^{-1}
1.
dry CCN radius (micron)

Example for 1 m/s updraft: bin #16, 0.022 micron dry radius, close to maximum concentration among all bins

Over 99% activated, only about 1% not activated.
From those eventually not activated, about half activated and then deactivated, some multiple times…

Below: evolutions of a radius of those eventually not activated



Summary:

Turbulence can have a significant impact on CCN activation.

In contrast to the adiabatic parcel, some CCN can activate early and some can avoid activation entirely when small-scale turbulence is present.

Details of the impact depend on specific details of the presented simulations (domain size, TKE, initial conditions, CCN, etc.) and call for more research in this area through very-high-resolution modeling.

A Numerical Experiment on Stochastic Condensation Theory

TERRY L. CLARK AND W. D. HALL

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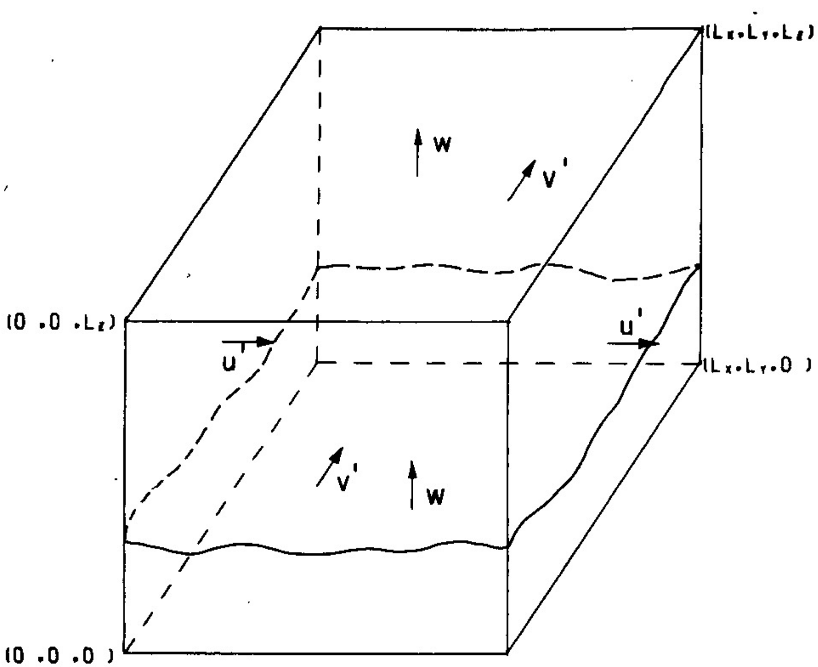

FIG. 1. Domain of integration. $L_x = L_y = L_z = 200$ m. Subcloud region typically extends from $z = 0$–50 m. Dry subcloud air is forced through the domain with a mean vertical velocity $\bar{w}$. Perturbation velocities u', v' and w' with zero horizontal averages are dynamically imposed on the flow.

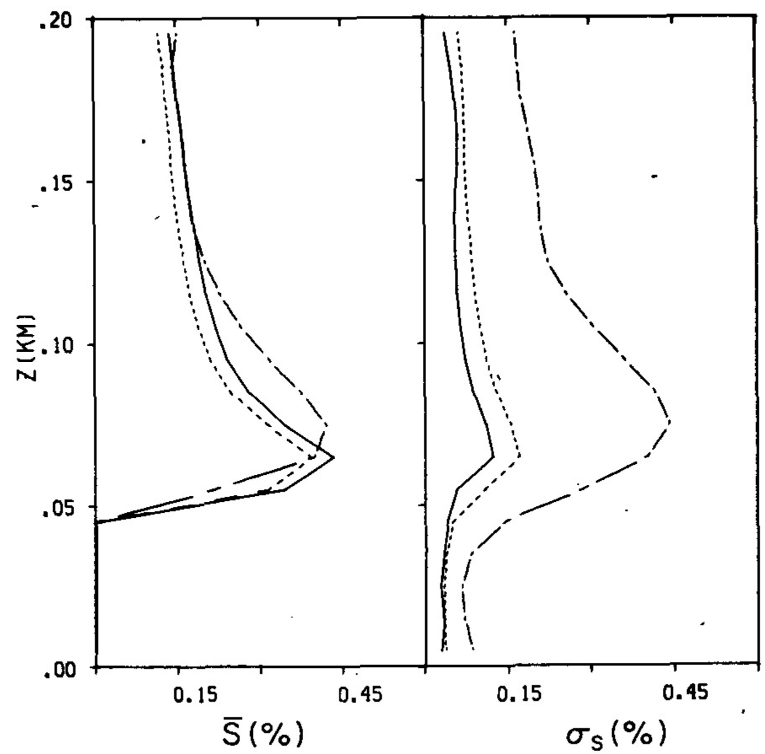

FIG. 3. Supersaturation profiles in units of percent for Runs 1, 2 and 3. Solid line: Run 1, CCl = 2000 cm^{-3}, $\bar{w} = 2.0$ m s^{-1}; short dashes: Run 2, CCl = 600 cm^{-3}, $\bar{w} = 1.0$ m s^{-1}; long and short dashes: Run 3, CCl = 100 cm^{-3}, $\bar{w} = 0.5$ m s^{-1}.

Q. J. R. Meteorol. Soc. (2005), **131**, pp. 195–220 doi: 10.1256/qj.03.199

Broadening of droplet size distributions from entrainment and mixing in a cumulus cloud

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(Received 24 October 2003; revised 16 August 2004)

NOVEMBER 2020 GRABOWSKI 3951

Comparison of Eulerian Bin and Lagrangian Particle-Based Microphysics in Simulations of Nonprecipitating Cumulus

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(Manuscript received 2 April 2020, in final form 28 August 2020)

SEPTEMBER 2021 CHANDRAKAR ET AL. 29

Impact of Entrainment Mixing and Turbulent Fluctuations on Droplet Size Distributions in a Cumulus Cloud: An Investigation Using Lagrangian Microphysics with a Subgrid-Scale Model

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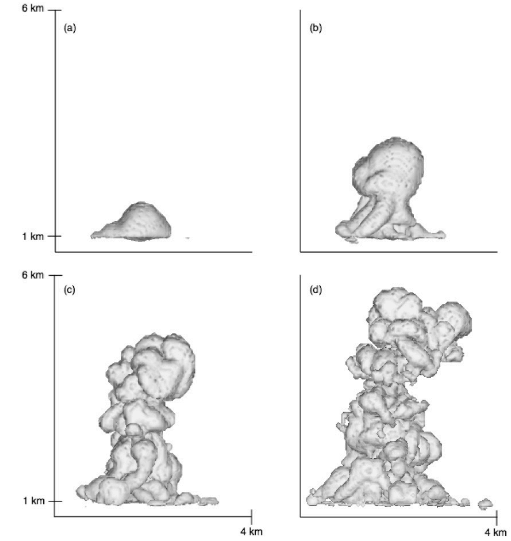
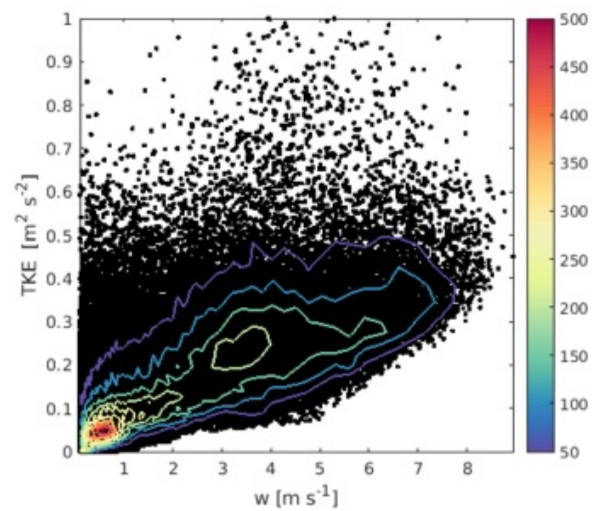
[a] *National Center for Atmospheric Research, Boulder, Colorado*





International Cloud Modeling Workshop congestus case:
a few m grid length simulations with resolved turbulence are needed …

Summary:

Turbulence can have a significant impact on CCN activation.

In contrast to the adiabatic parcel, some CCN can activate early and some can avoid activation entirely when small-scale turbulence is present.

Details of the impact depend on specific details of the presented simulations (domain size, TKE, initial conditions, CCN, etc.) and call for more research in this area through very-high-resolution modeling.

Significant point: Situation considered here is different than in the Pi chamber. A facility similar to Pi chamber, but with a decreasing pressure mimicking air rising through the cloud base would be needed…