Insights from convection-cloud chamber experiments: aerosol activation, cloud droplet growth, and mixed-phase clouds in a turbulent environment

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Thanks to the many members of the Pi Chamber team over the last ~7 years

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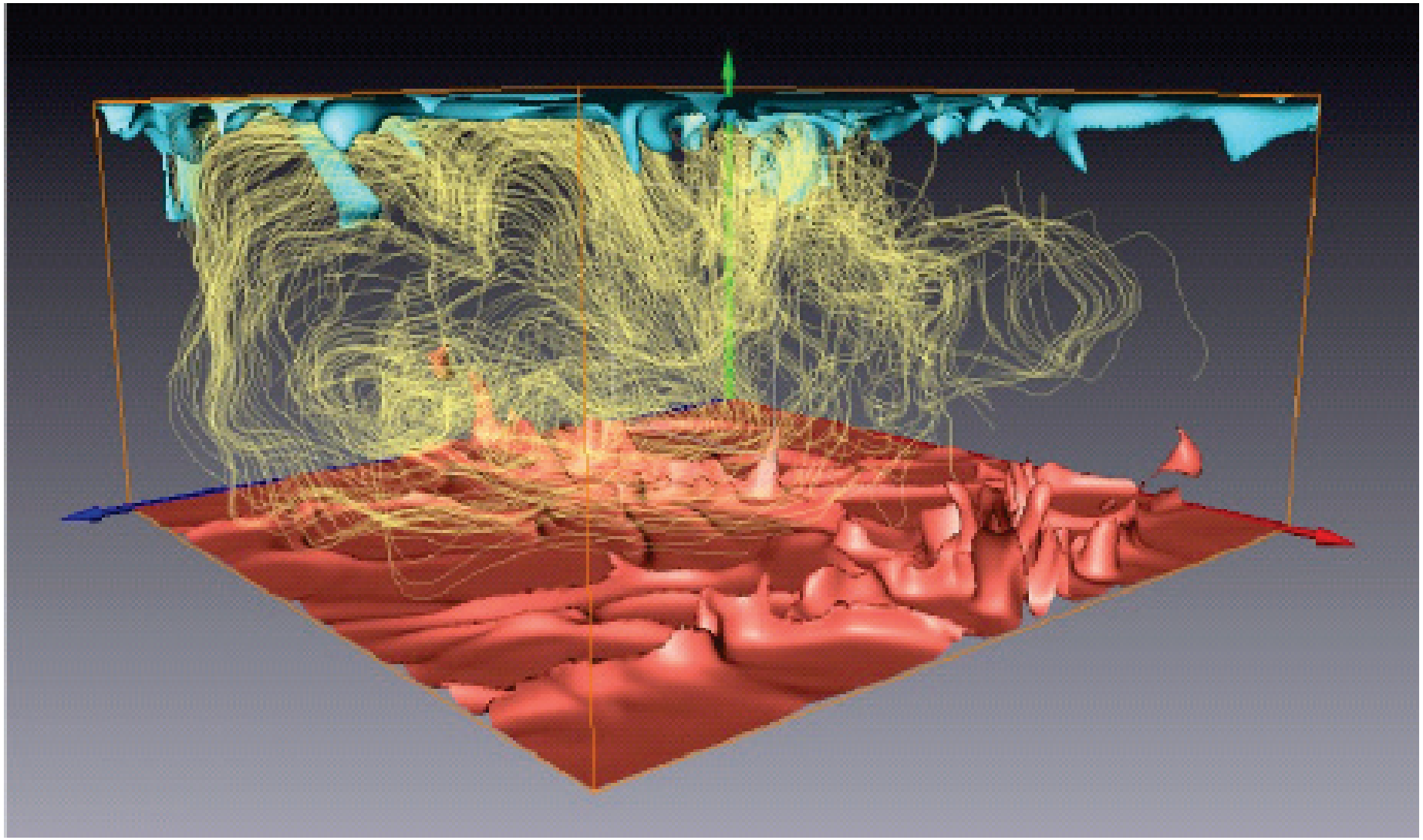
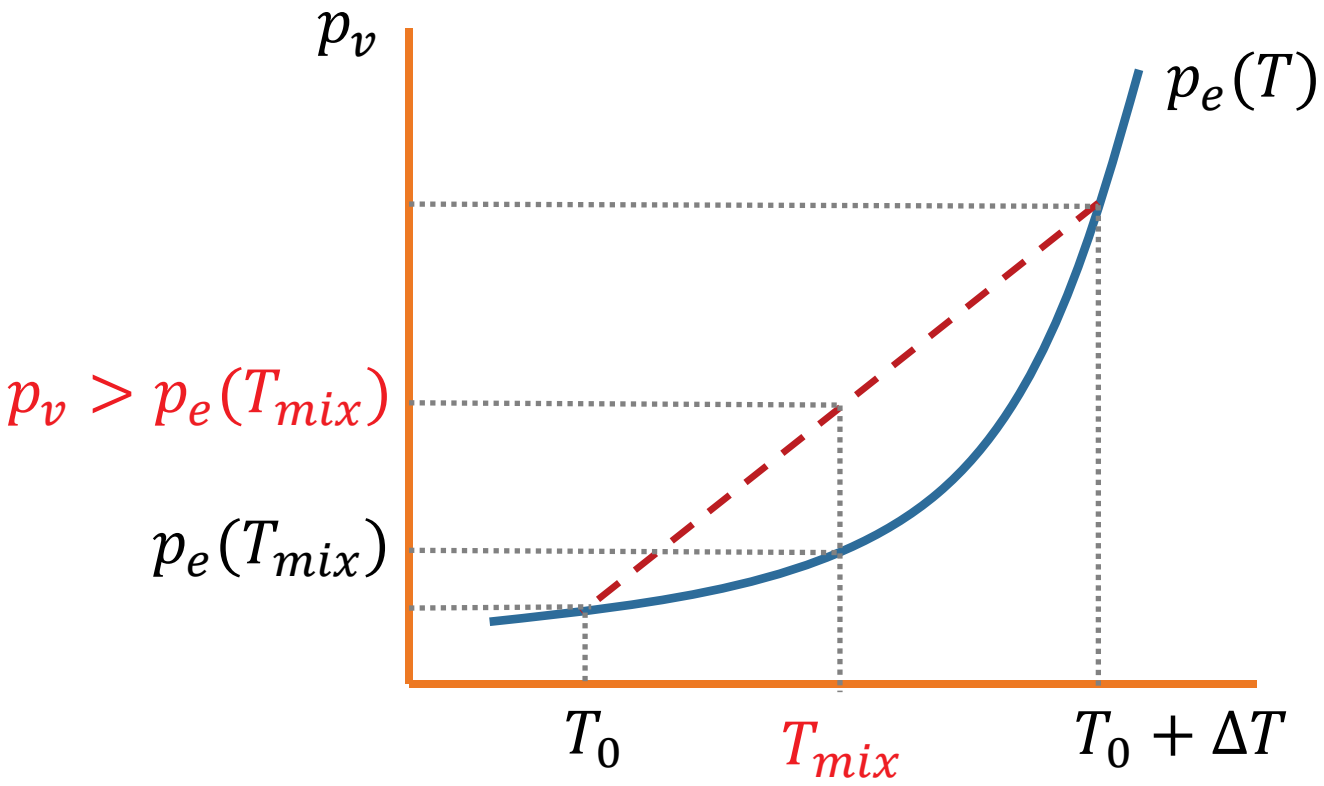
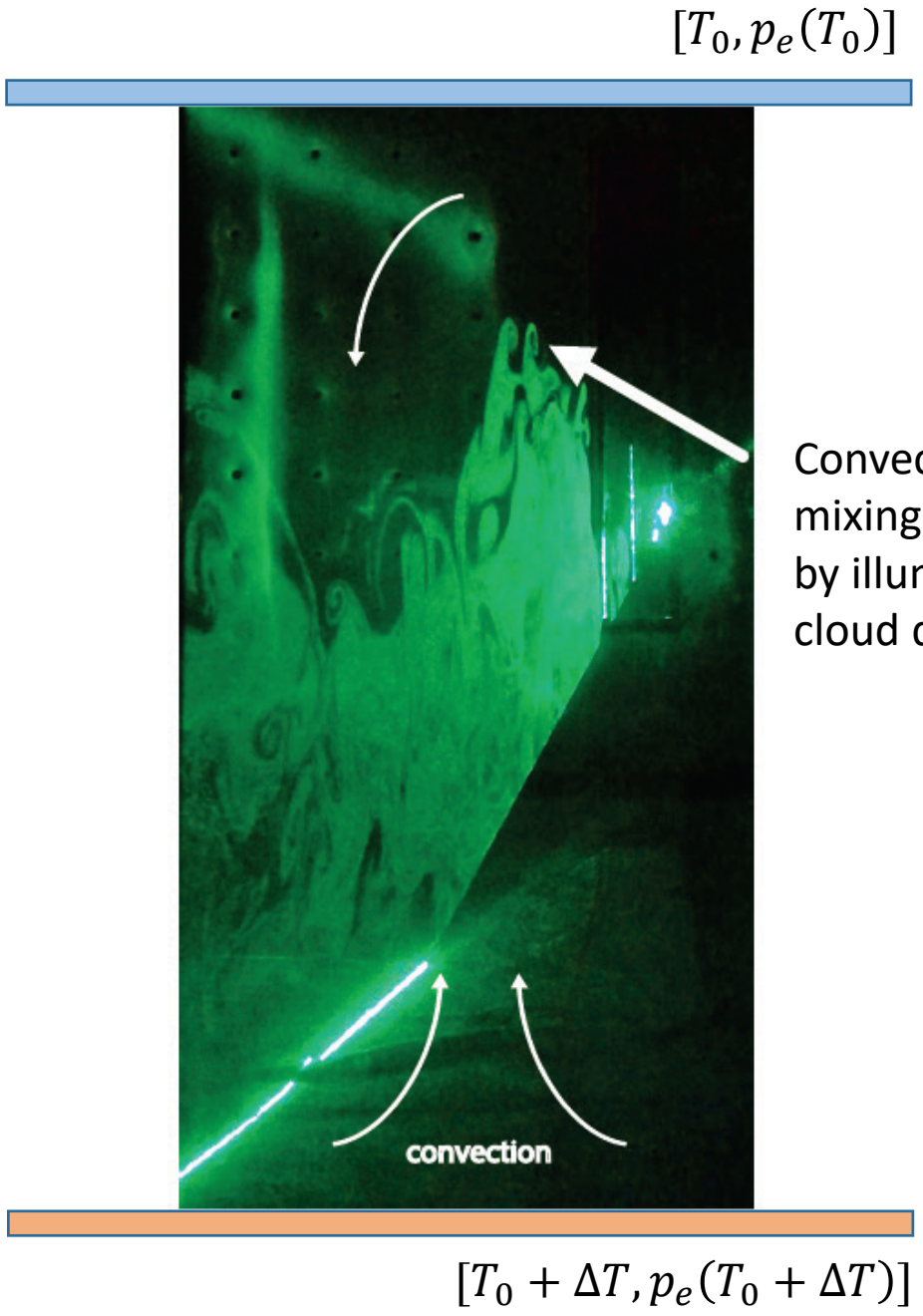


Turbulent Rayleigh-Bénard Convection

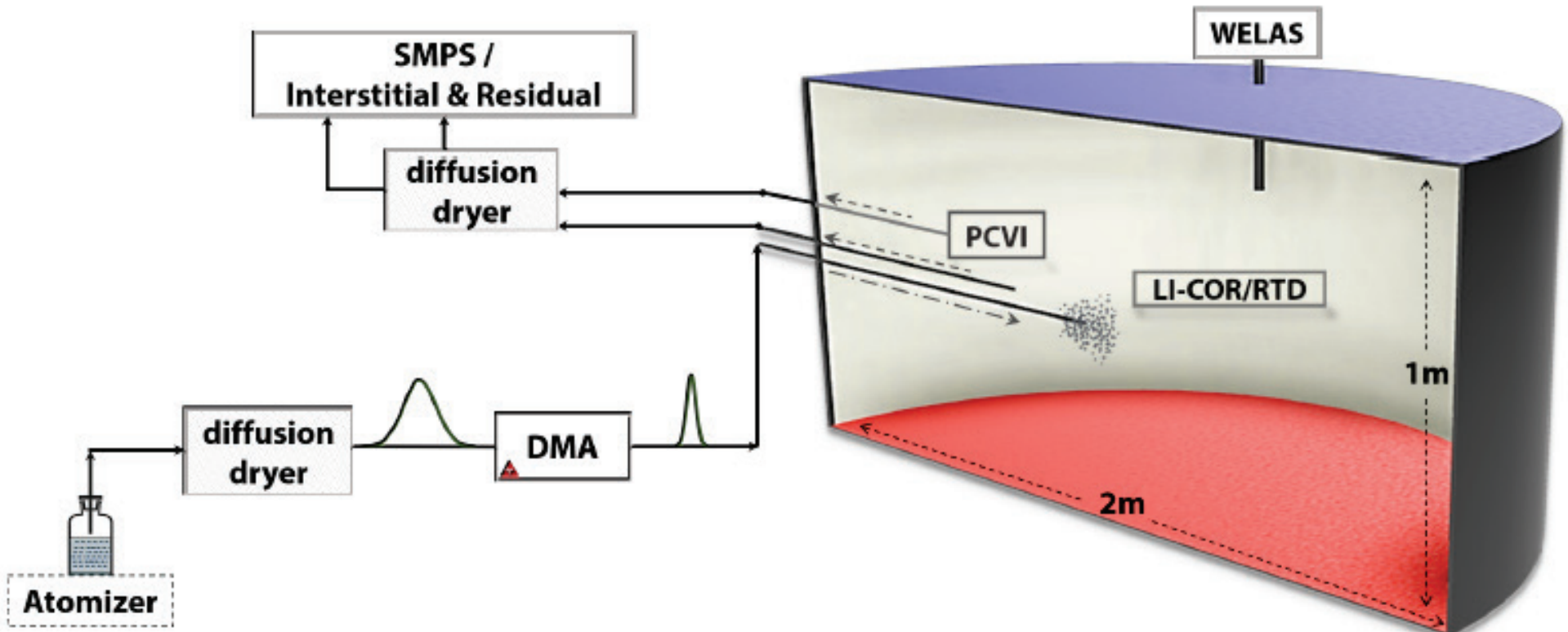
(Courtesy of J. Schumacher – TU Ilmenau)



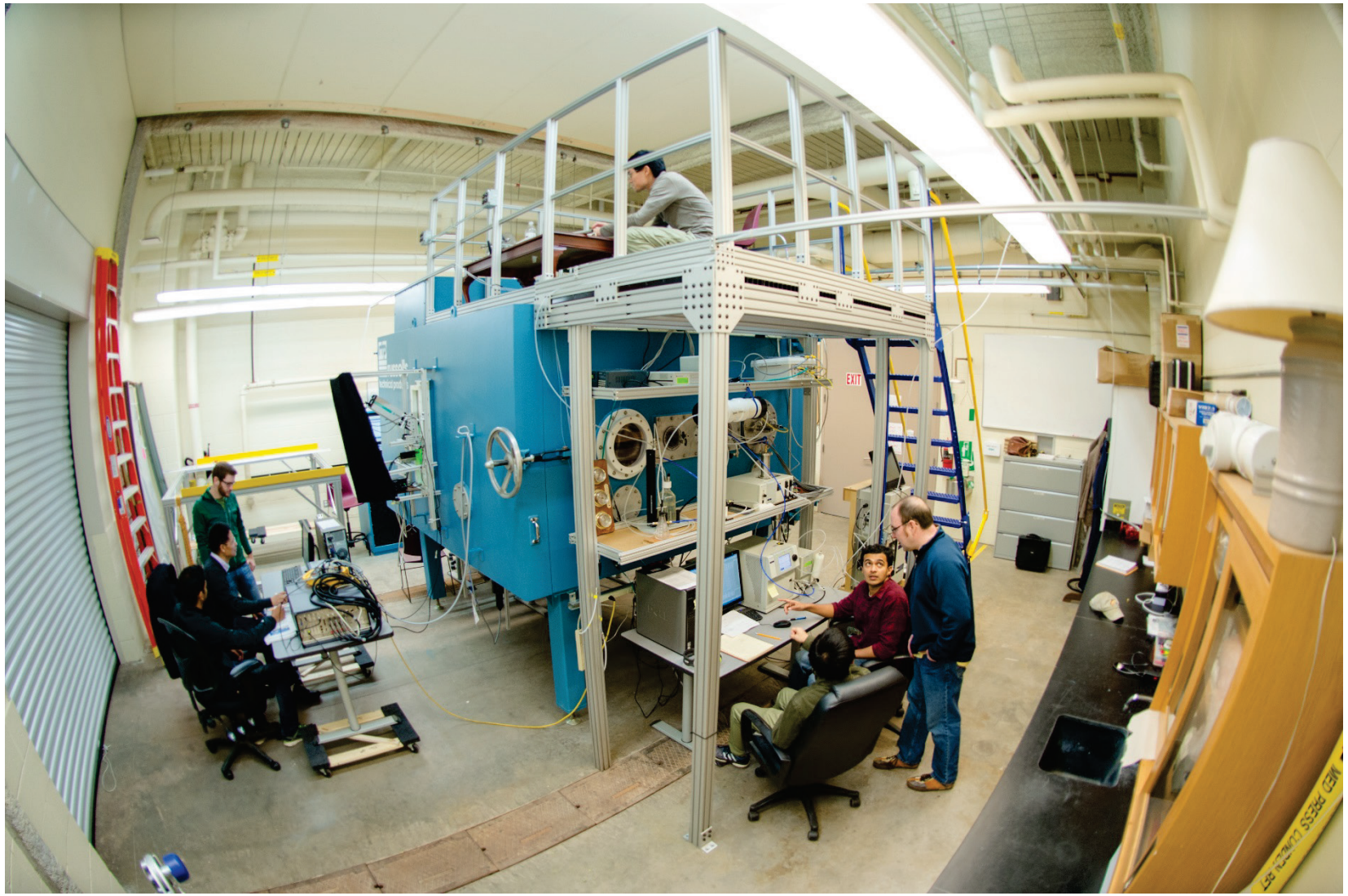
$$S = \frac{p_v}{p_e(T)}$$



Convection and mixing visualized by illuminated cloud droplets.



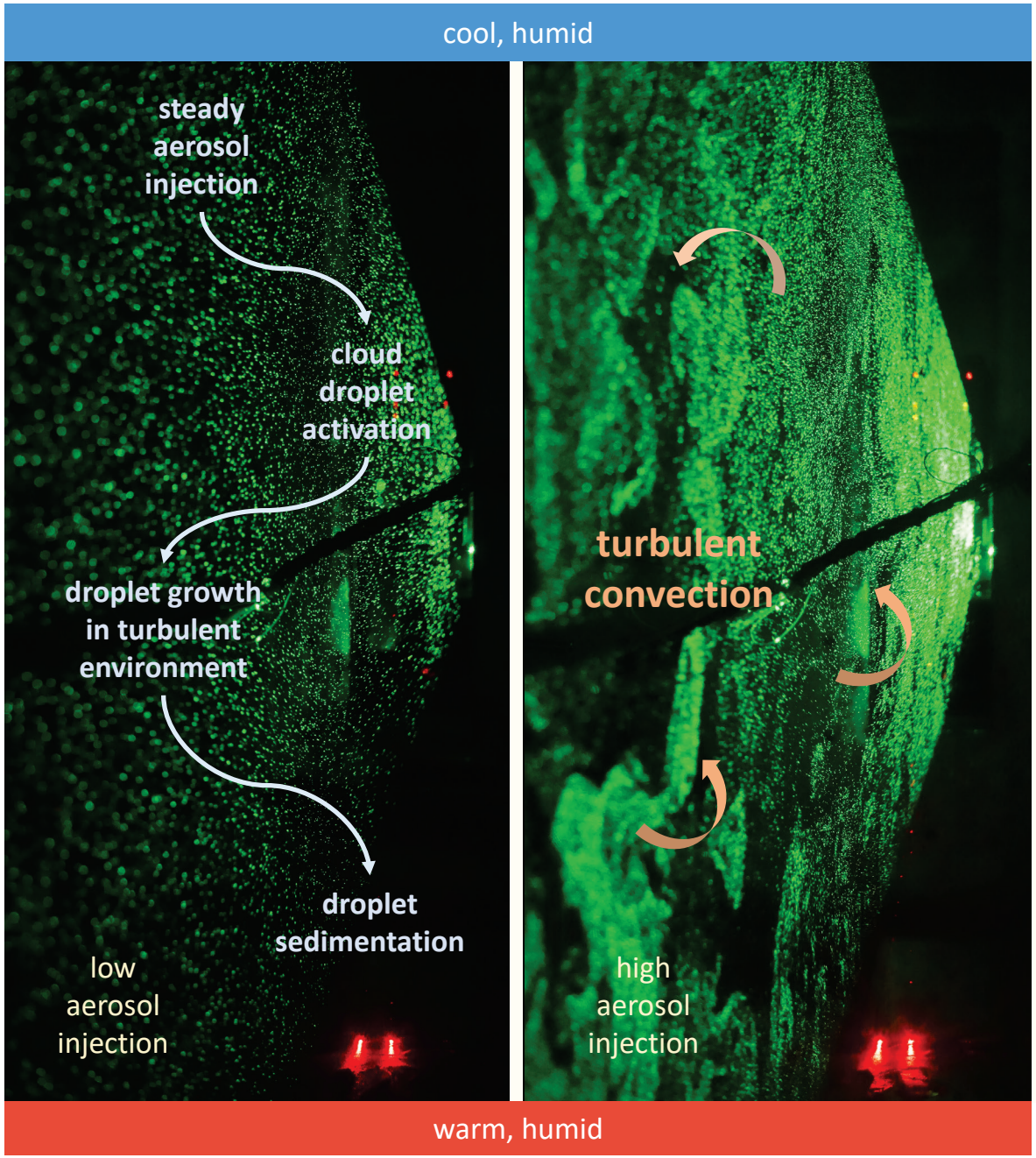
Shawon et al. JGR (2021)



Pi Chamber:

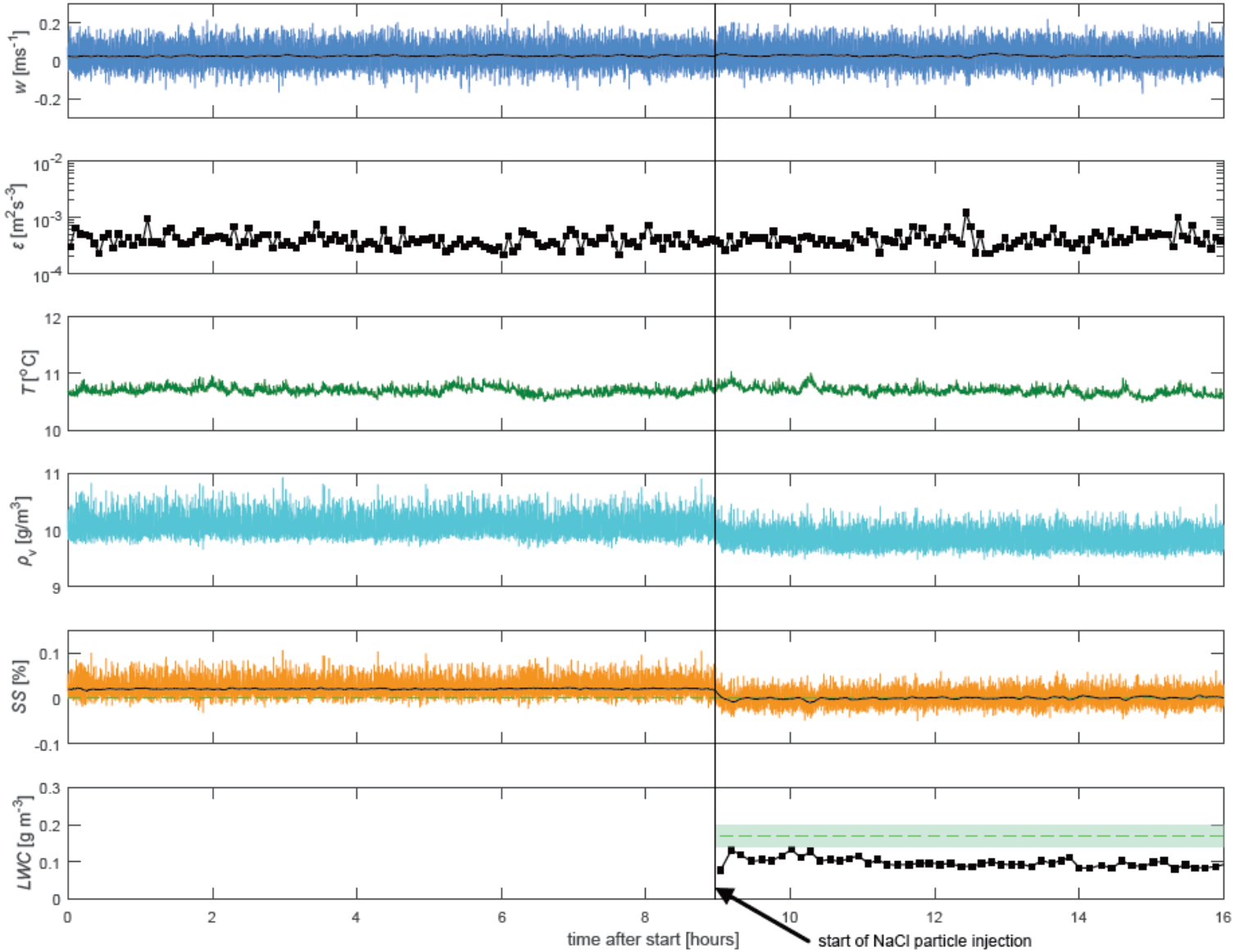
- $Ra \sim 10^8$
- $\Gamma = \frac{D}{H} = 2$
- Vol 3.14 m^3
- Aerosol input fully controlled
- Interstitial and residuals sampled
- Measurement of thermodynamics, turbulence and cloud microphysics

Chang et al. BAMS (2016)

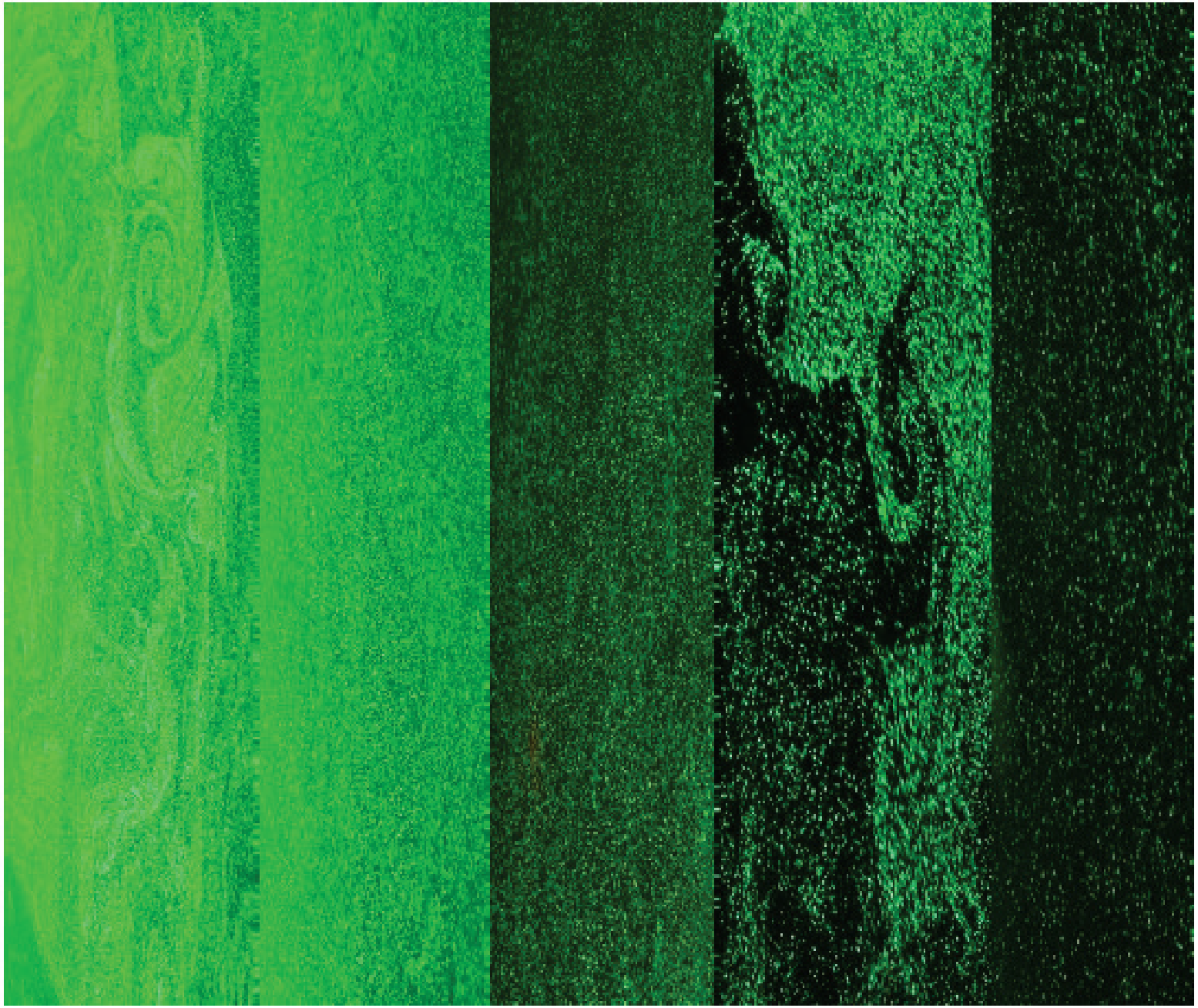


Chandrakar et al. PNAS (2016)

$T_0 = 10°C, \Delta T = 8K$

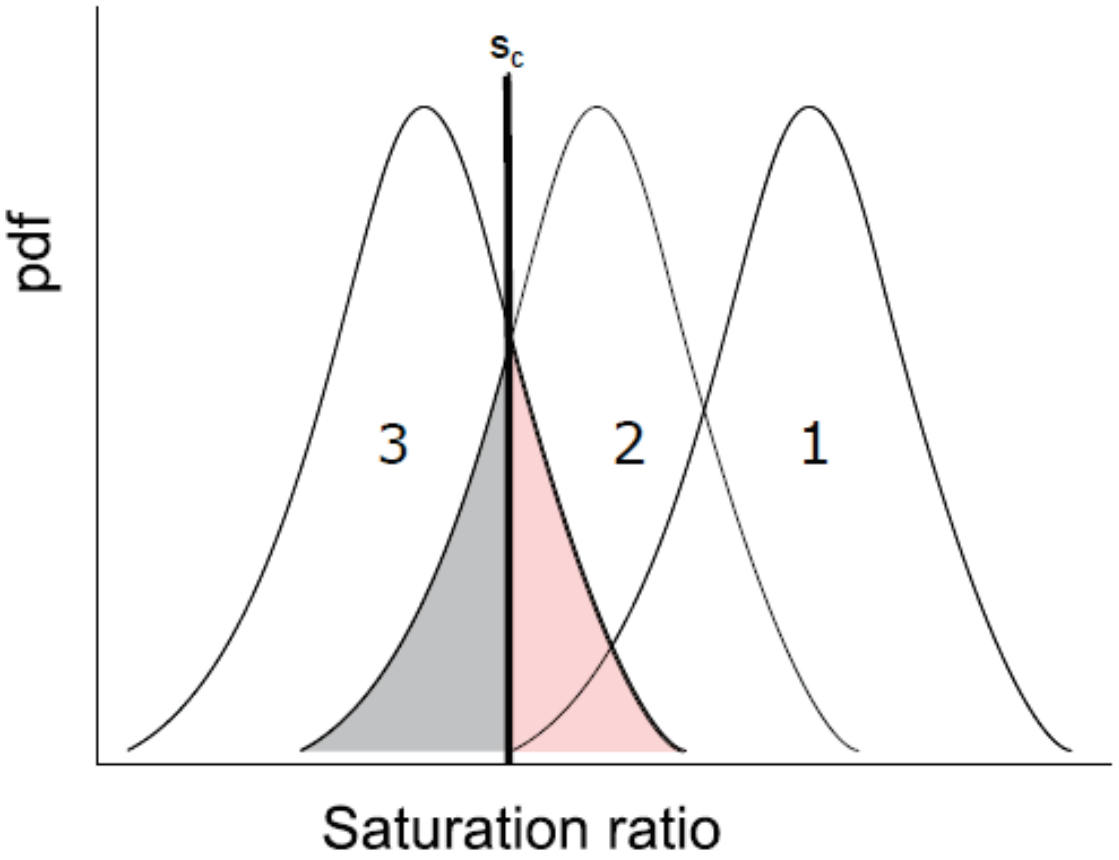


Niedermeier et al. Phys. Rev. Fluids (2018)



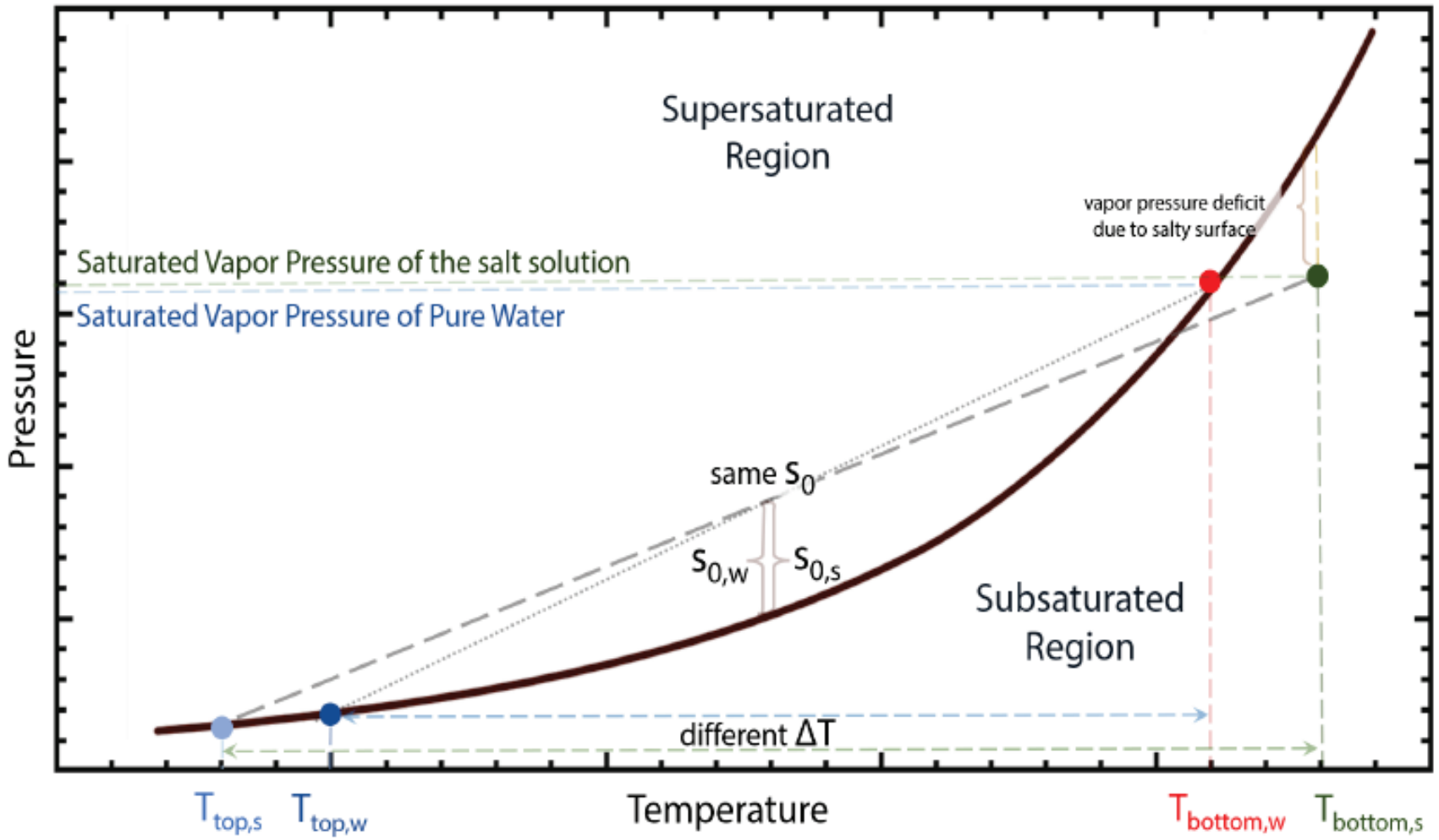
Snapshots of ‘steady-state’ clouds… decreasing aerosol injection rate to the right

Fluctuations and activation



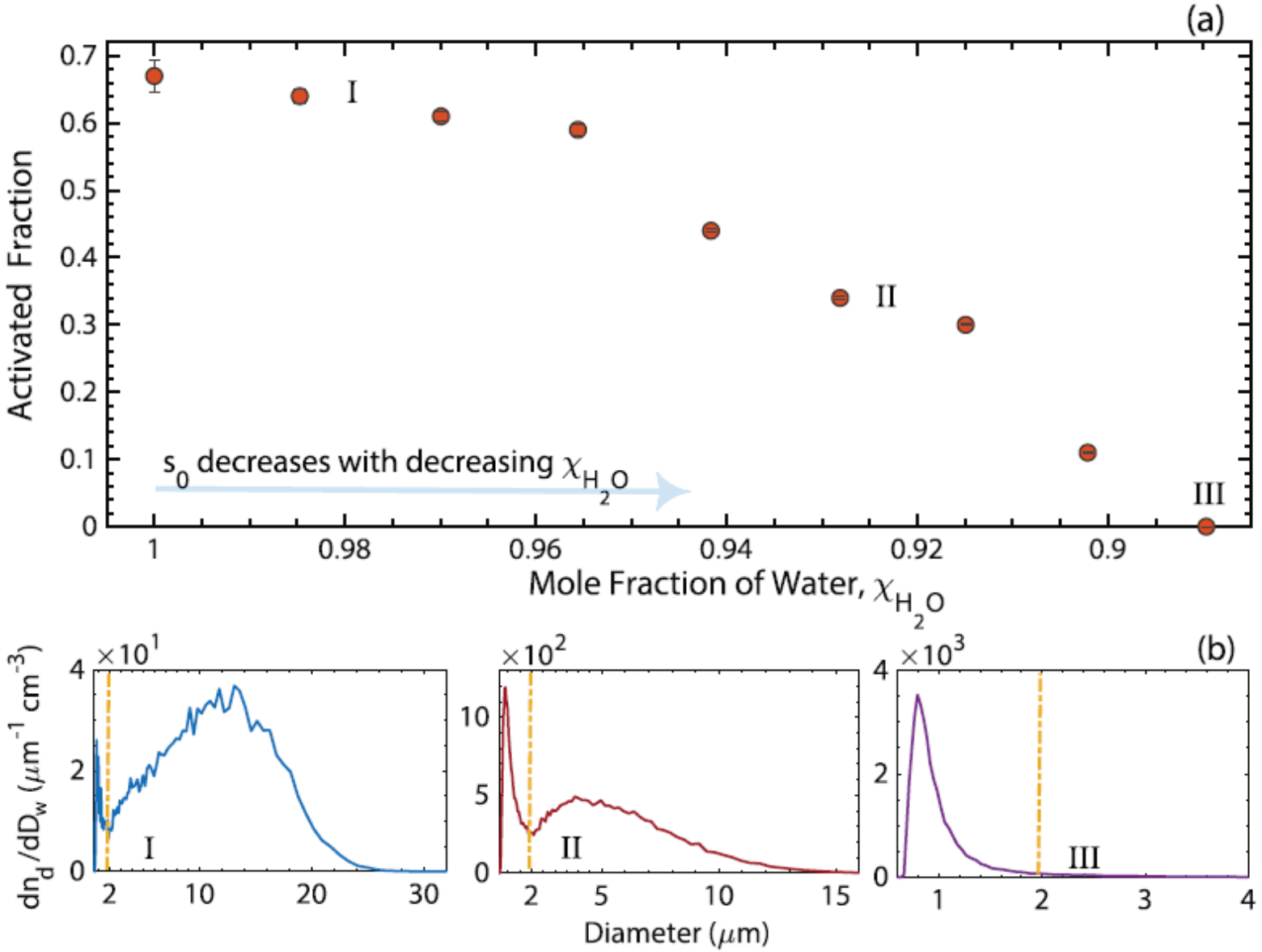
Prabhakaran et al. PNAS (2020)

Fluctuations and activation



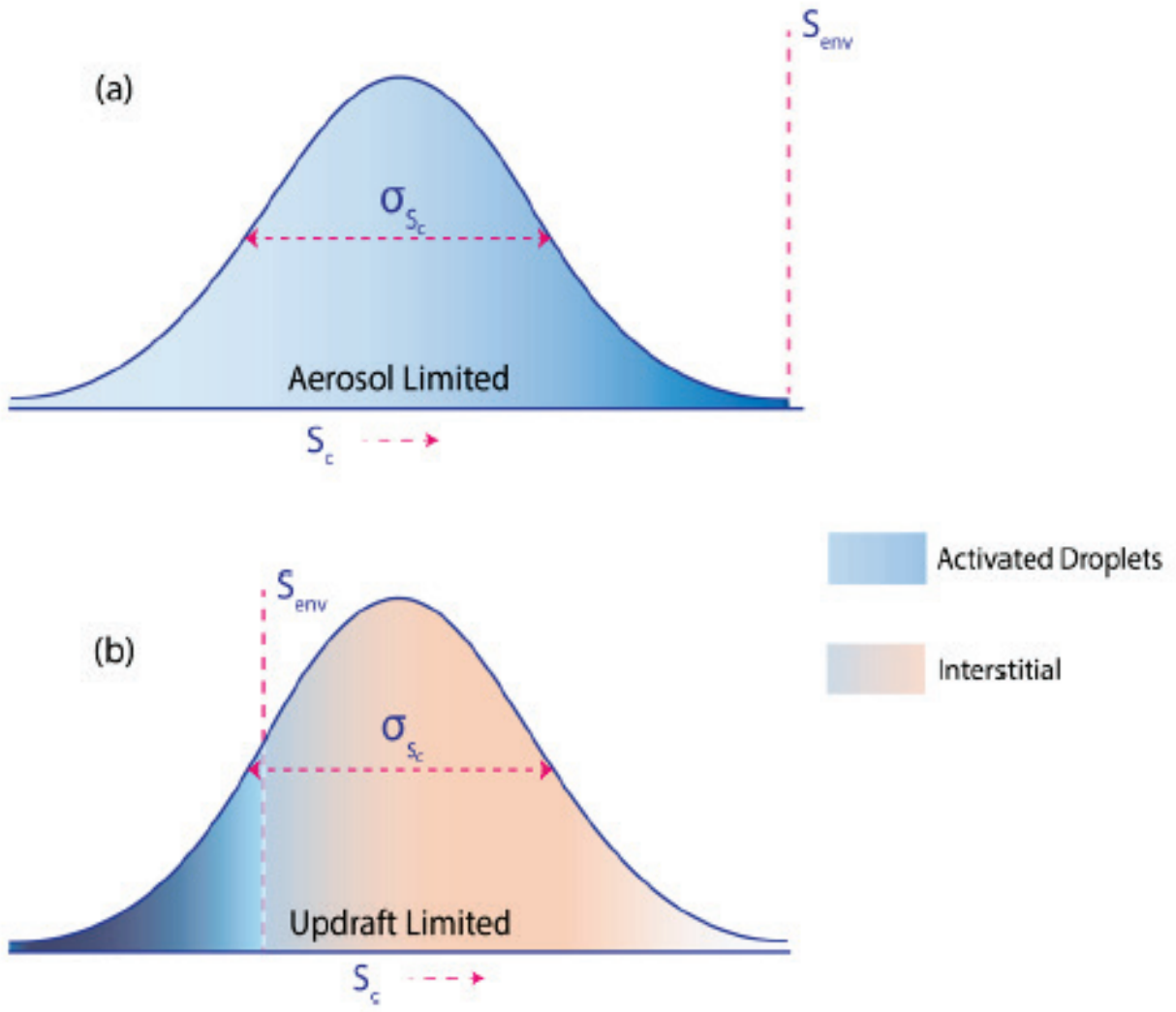
Shawon et al. JGR (2021)

Fluctuations and activation



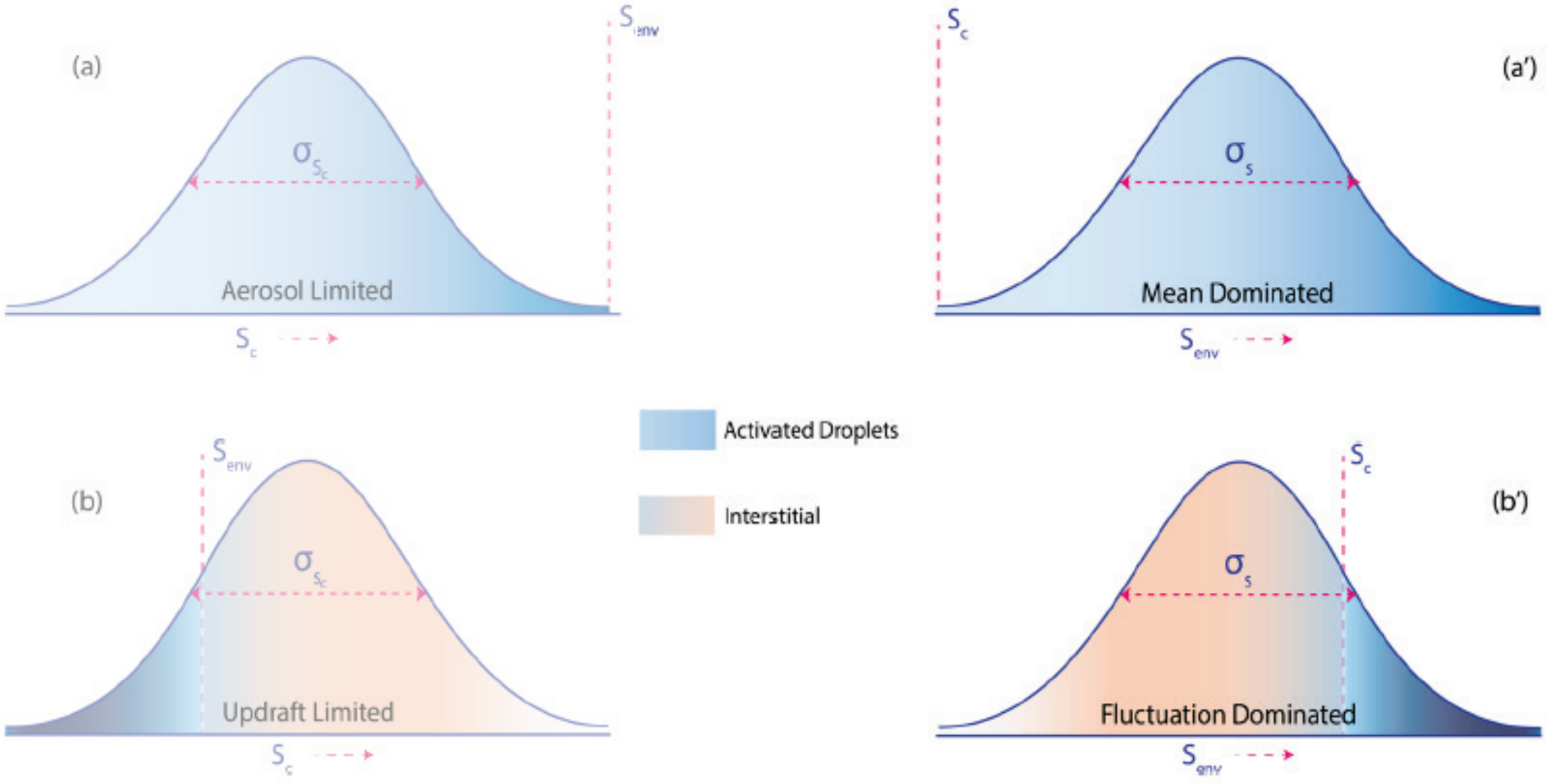
Shawon et al. JGR (2021)

Fluctuations and activation



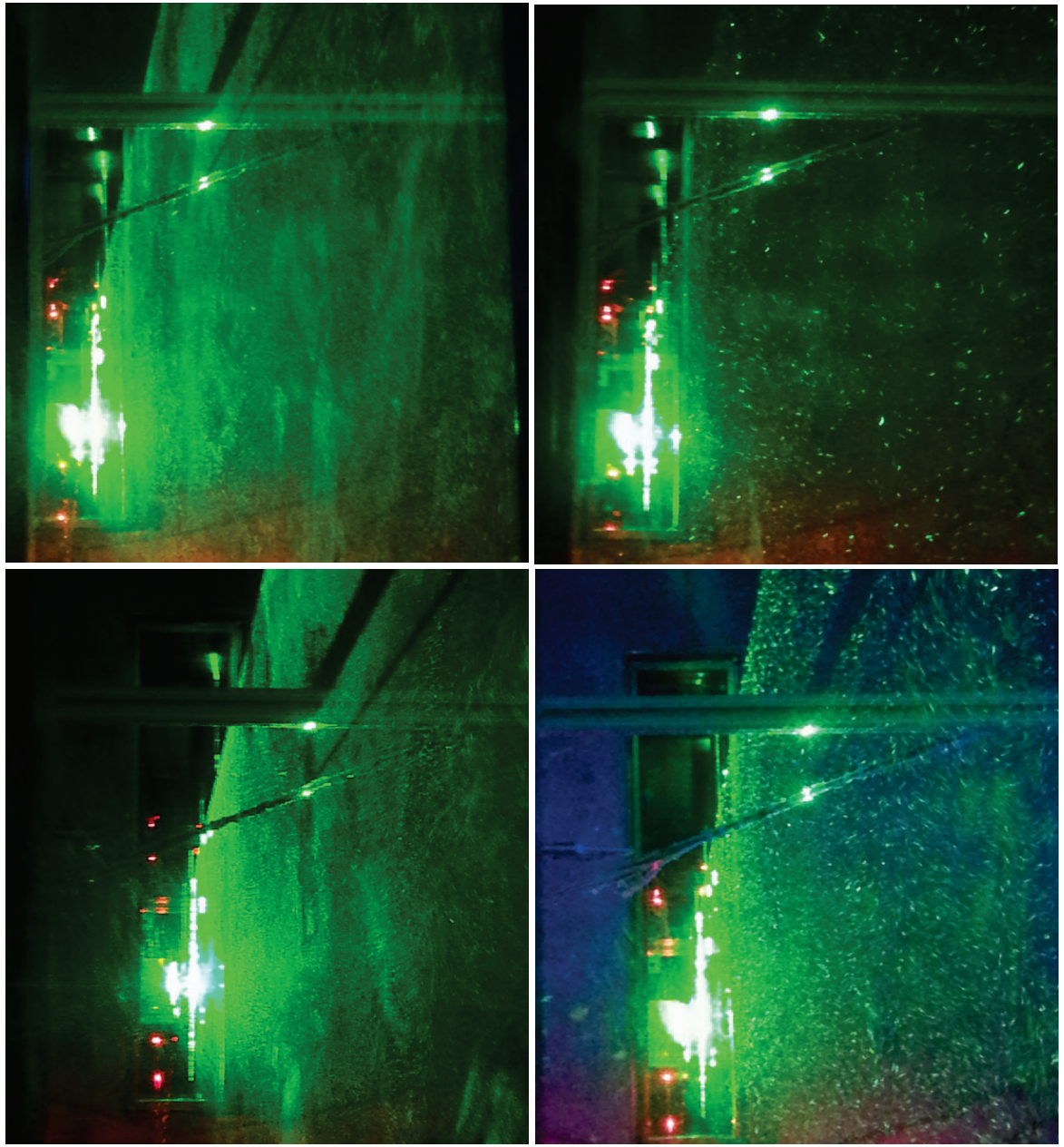
Shawon et al. JGR (2021)

Fluctuations and activation



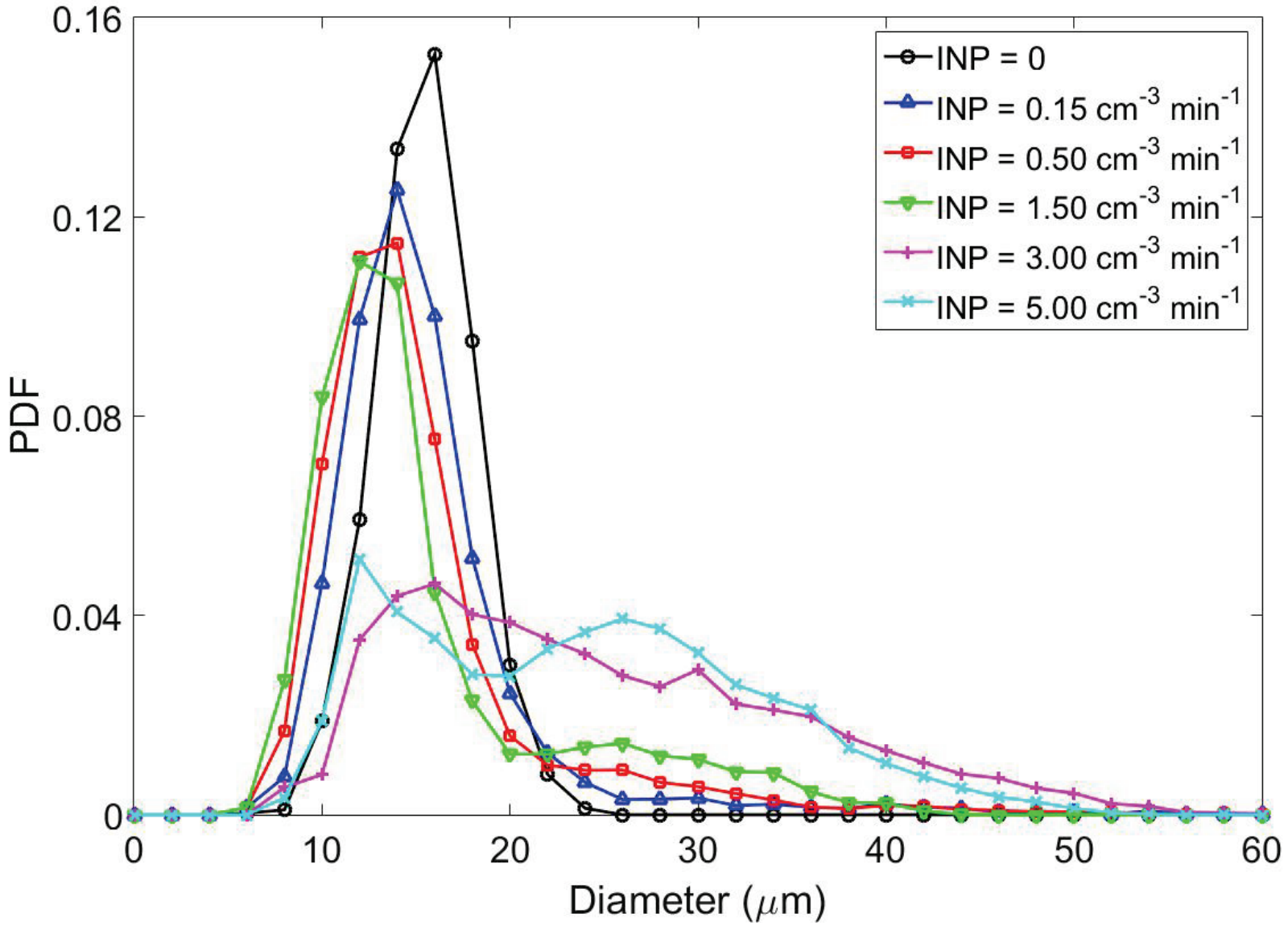
Shawon et al. JGR (2021)

Steady-state mixed-phase clouds



Desai et al. GRL (2019)

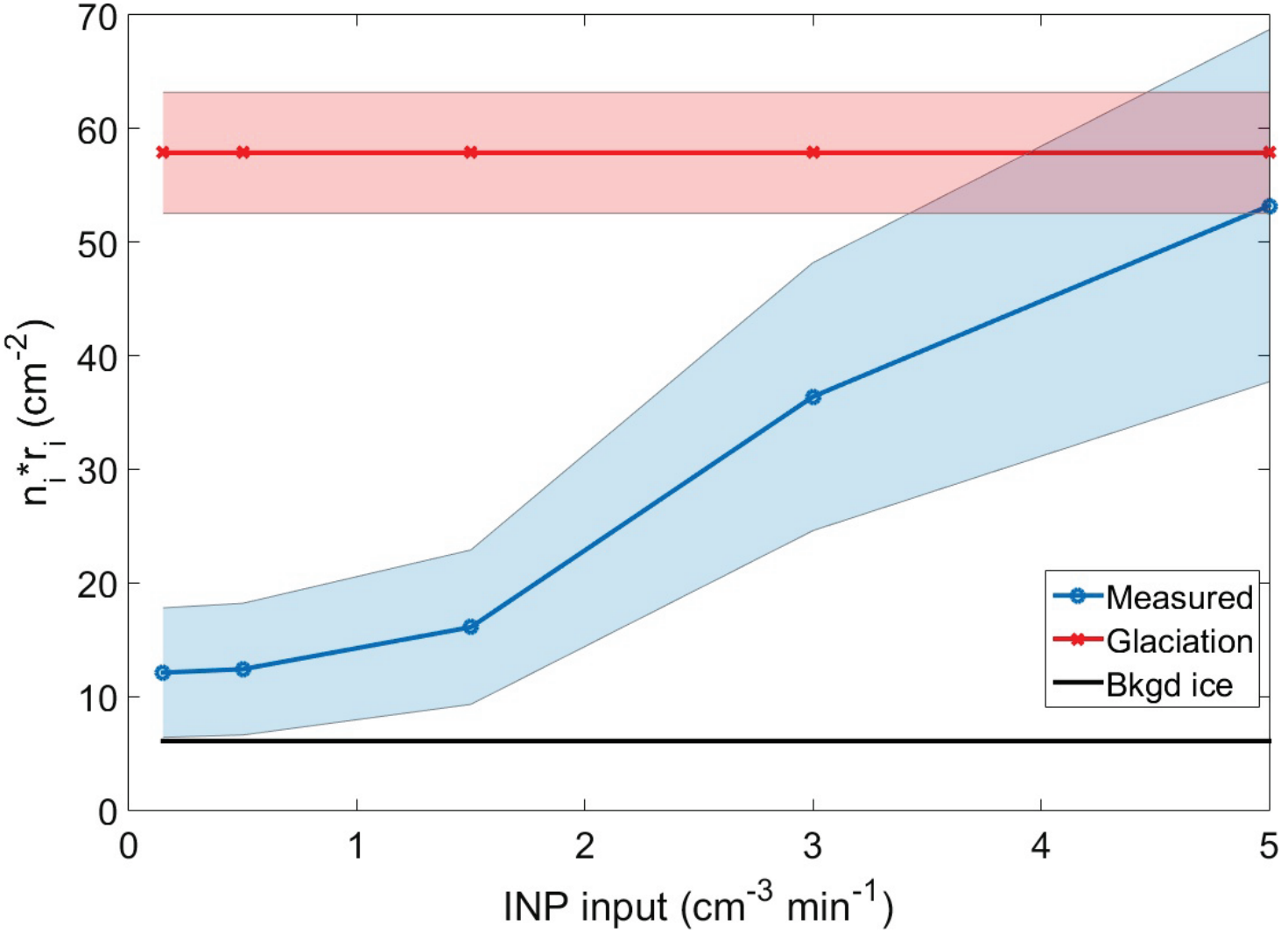
Steady-state mixed-phase clouds



Desai et al. GRL (2019)

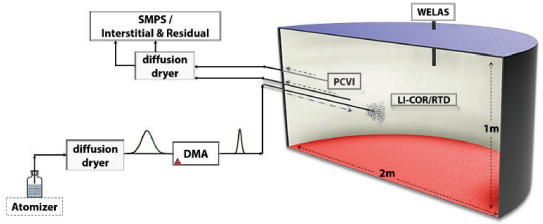
Steady-state mixed-phase clouds

$$n_i \bar{r}_i \leq \frac{1}{4\pi D_v \tau_t} \frac{s_{l,0}}{s_l^\star}. \quad (1)$$

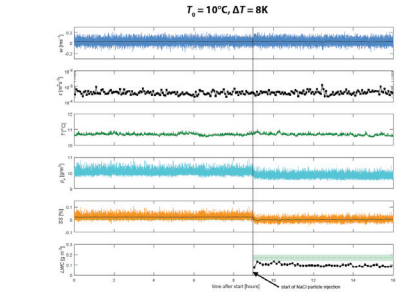


Desai et al. GRL (2019)

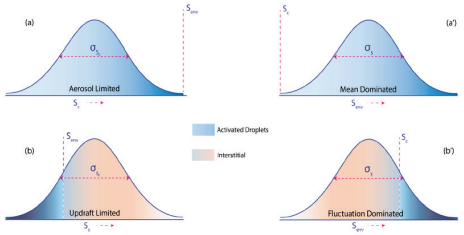
Summary…



Pi convection-cloud chamber: Moist Rayleigh-Bénard convection to generate supersaturated, turbulent mixed-layer



Steady-state microphysical conditions are achieved by balancing aerosol injection with droplet growth and sedimentation



Turbulent fluctuations in supersaturation can influence both activation and growth of cloud droplets

Mixed-phase clouds exist in steady state, with glaciated state depending on ice integral radius

References

Description of the chamber, mixing clouds

Chang et al., BAMS, 2016

Anderson et al., AMT, 2021

Aerosol → cloud properties

Chandrakar et al., PNAS, 2016

Desai et al., JAS, 2018

Chandrakar et al., JAS, 2018

Chandrakar et al., GRL 2018

Desai et al., GRL, 2019

Chandrakar et al., QJRMS, 2020

Cloud → aerosol properties

Chandrakar et al., GRL, 2017

Bhandari et al., Sci. Rep., 2019

Prabhakaran et al., PNAS, 2020

Shawon et al., JGR, 2021

Turbulence, radiative transfer, etc

Niedermeier et al., Phys. Rev. Fluids, 2018

Packard et al., J. Appl. Remote Sensing, 2018

Packard et al, JQSRT, 2019

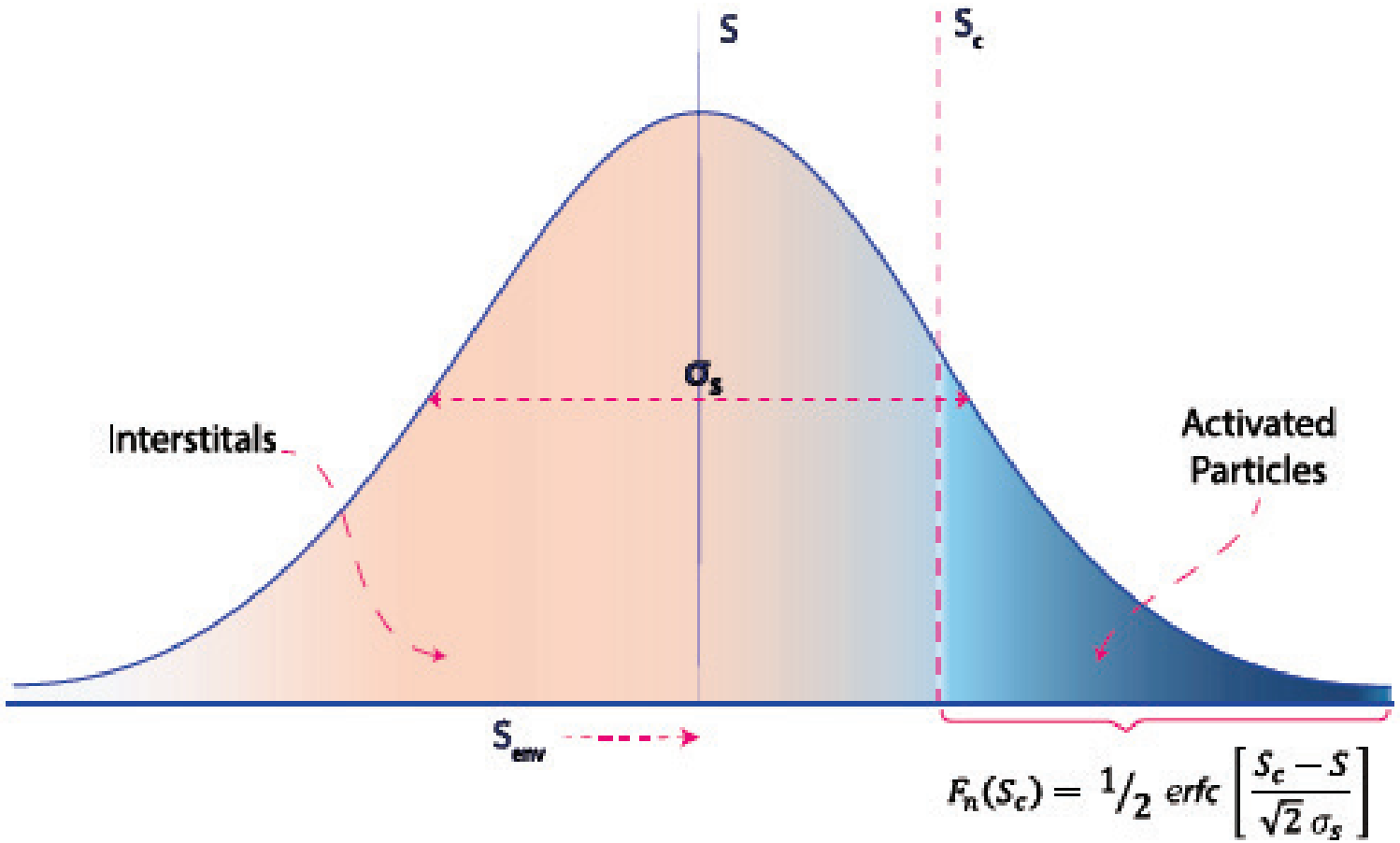
Thomas et al., JAMES, 2019

Packard et al., Atmosphere, 2020

Prabhakaran et al., GRL, 2020

Chandrakar et al., JFM, 2020

Thomas et al., JAS, 2021



Shawon et al. JGR (2021)