Experimental Investigation of Cloud Formation and Growth in Turbulent Moist Convection: Turbulence Induced Droplet Activation and Growth

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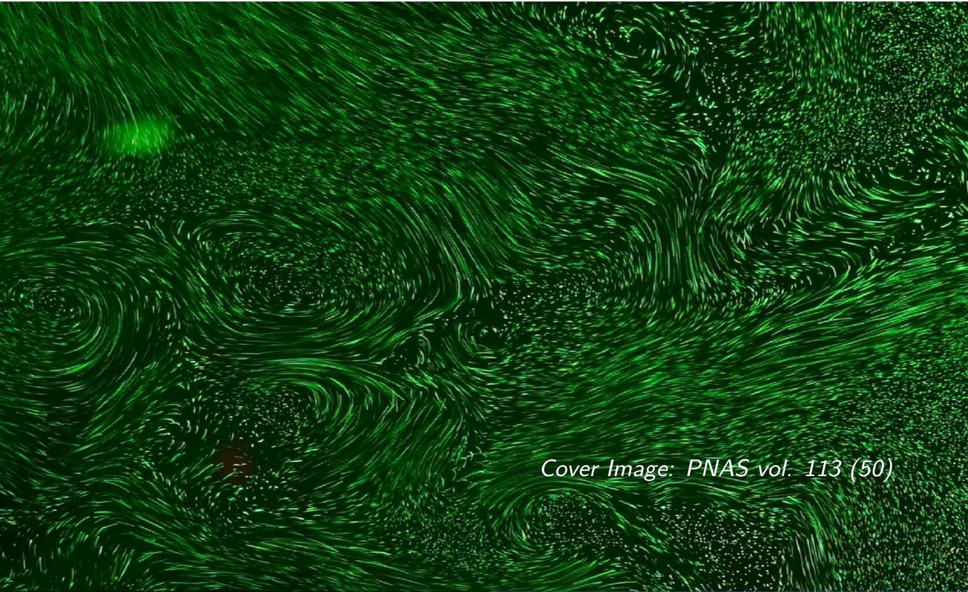
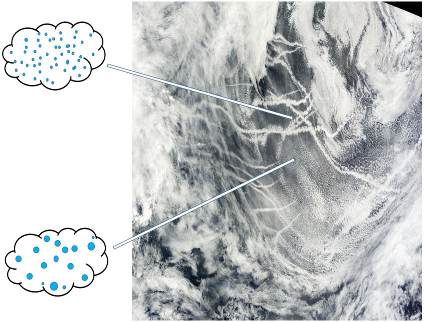
Acknowledgment : National Science Foundation


Cover Image: PNAS vol. 113 (50)

Clouds: An Important Element of Earth System

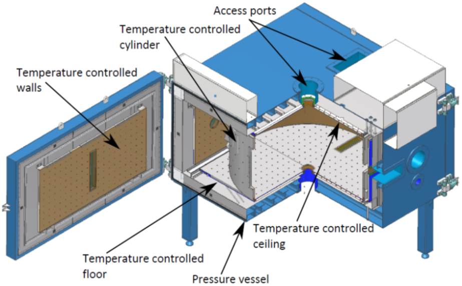
- Impact of pollution in clouds and climate change
- Role of turbulence in cloud microphysics



Source: NASA Earth Observatory

Aerosol concentration and turbulent environment ⇒ Cloud Microphysics **?**

Π-Chamber



$$Ra \sim 10^8 - 10^9,\ \frac{D}{H} = 2\ (2m \times 1m)$$

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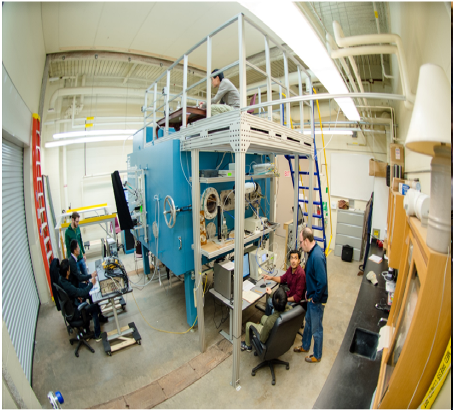
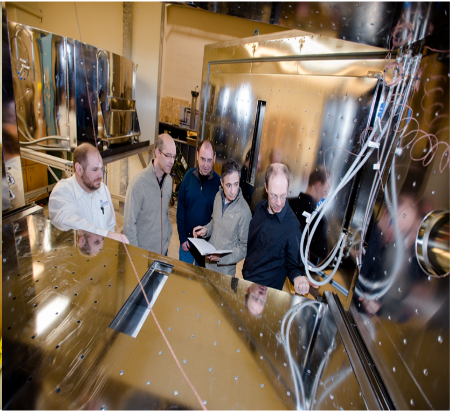
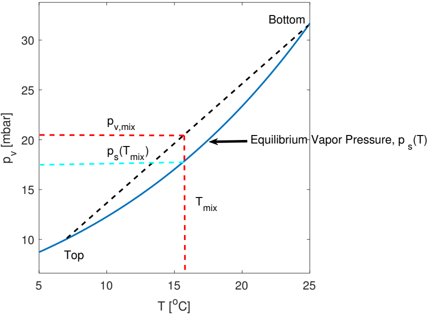


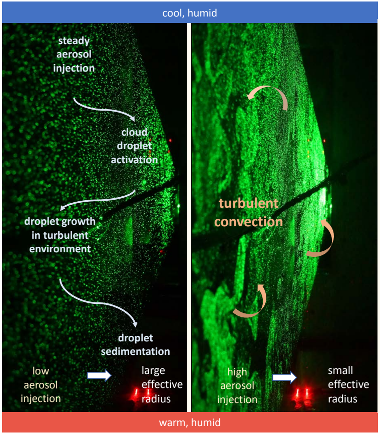


Turbulent Mixing Cloud Formation in the Π-Chamber

$$s = \frac{p_v - p_s}{p_s}$$

$$p_s(T) \sim p_0 \exp\left(-\frac{\ell}{kT}\right)$$





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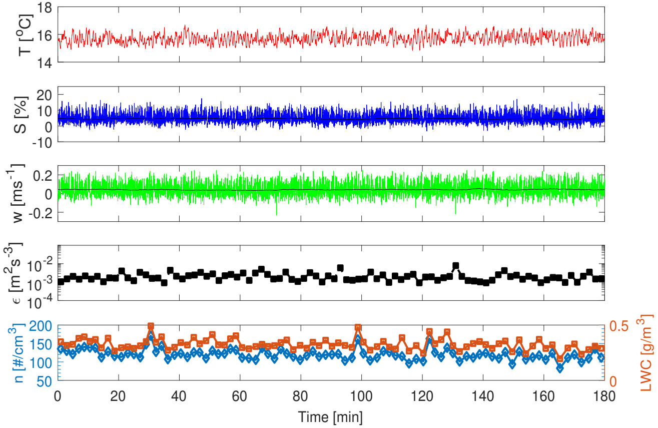
Steady-State Cloud Properties



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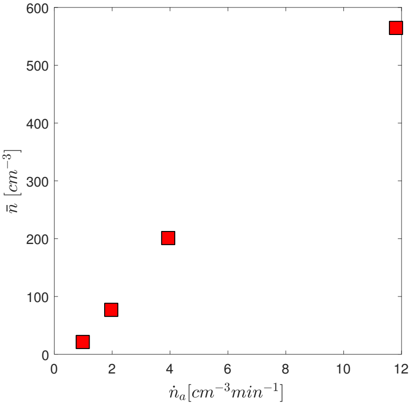
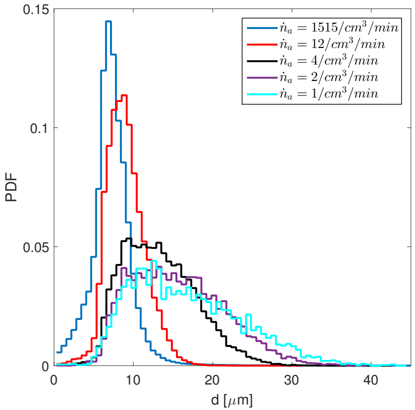
Droplet Size Distribution at Steady-State





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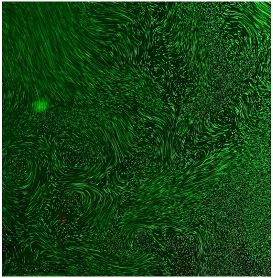
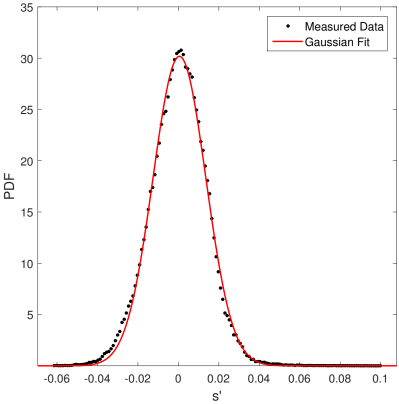
Supersaturation Fluctuation





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Fluctuations in s $\Rightarrow$ droplet size distribution **?**

Stochastic Condensation Growth

$$ds(t) = \left[\underbrace{\frac{s_{eq} - s}{\tau_t}}_{\text{mixing to } s_{eq}} - \underbrace{\frac{s}{\tau_c}}_{\text{droplet growth}} \right] dt + \underbrace{\left(\frac{2\sigma_{s_0}^2 dt}{\tau_t} \right)^{1/2} \eta(t)}_{\text{fluctuation}}$$

Condensation Growth:

$$\frac{dr^2}{dt} = 2\xi s, \qquad \frac{d\sigma_{r^2}^2}{dt} = 4\xi \overline{s' r^{2'}}$$

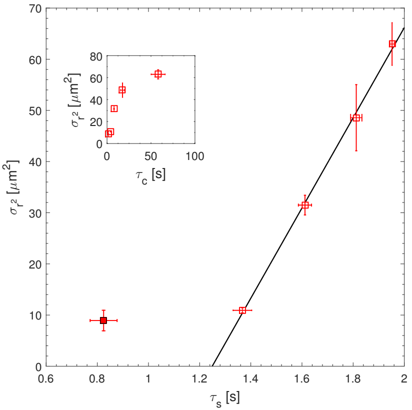
Turbulent Induced Broadening

$$\sigma_{r^2} \propto \overline{s' r^{2'}} \rightarrow \frac{\sigma_{s_0} \tau_s}{\tau_t} t^{1/2}$$

τ_s : $\frac{1}{\tau_s} = \frac{1}{\tau_t} + \frac{1}{\tau_c}$

τ_t : Turbulent correlation time (fixed)

τ_c : Phase relaxation time, $\propto \frac{1}{\bar{n}\,\bar{r}}$ (controlled by aerosol injection)



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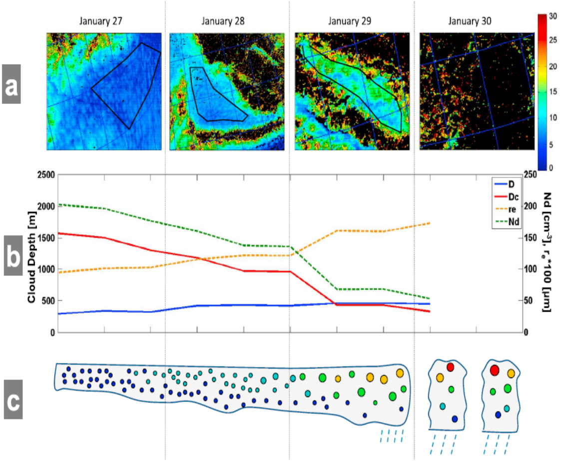
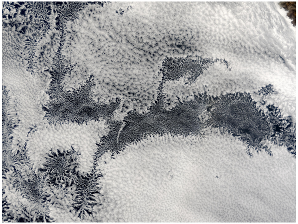
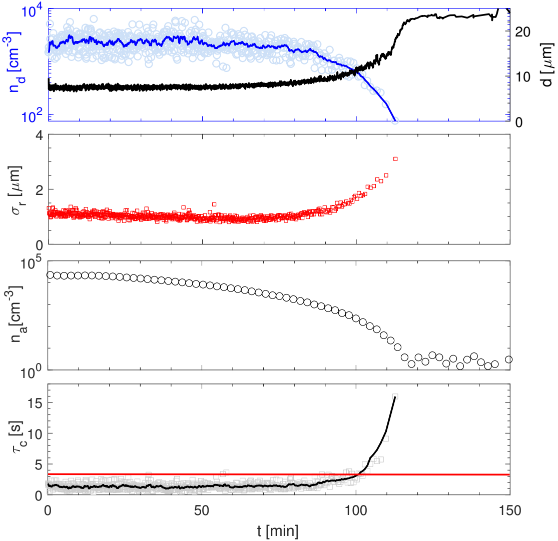




NASA Visible Earth

Goren and Rosenfeld JGR 2015

Cloud Cleansing: Radiative Properties and Precipitation



Chandrakar et al. GRL 2017

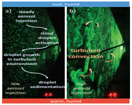
Summary

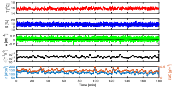
- Cloud form via isobaric mixing in a turbulent moist Rayleigh-Bénard convection.

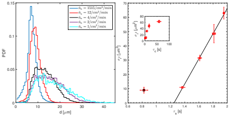
- Steady-state turbulent, cloud microphysics, and thermodynamics properties achieved.

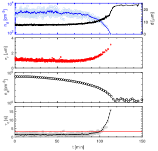
- Droplet size distributions become broad with a decrease in the aerosol input rate, and $\sigma_{r^2} \propto \overline{s' r^{2'}} \rightarrow \frac{\sigma_{s_0}\tau_s}{\tau_t} t^{1/2}$.

- Cloud cleansing through supersaturation fluctuations: a positive feedback









Thank You