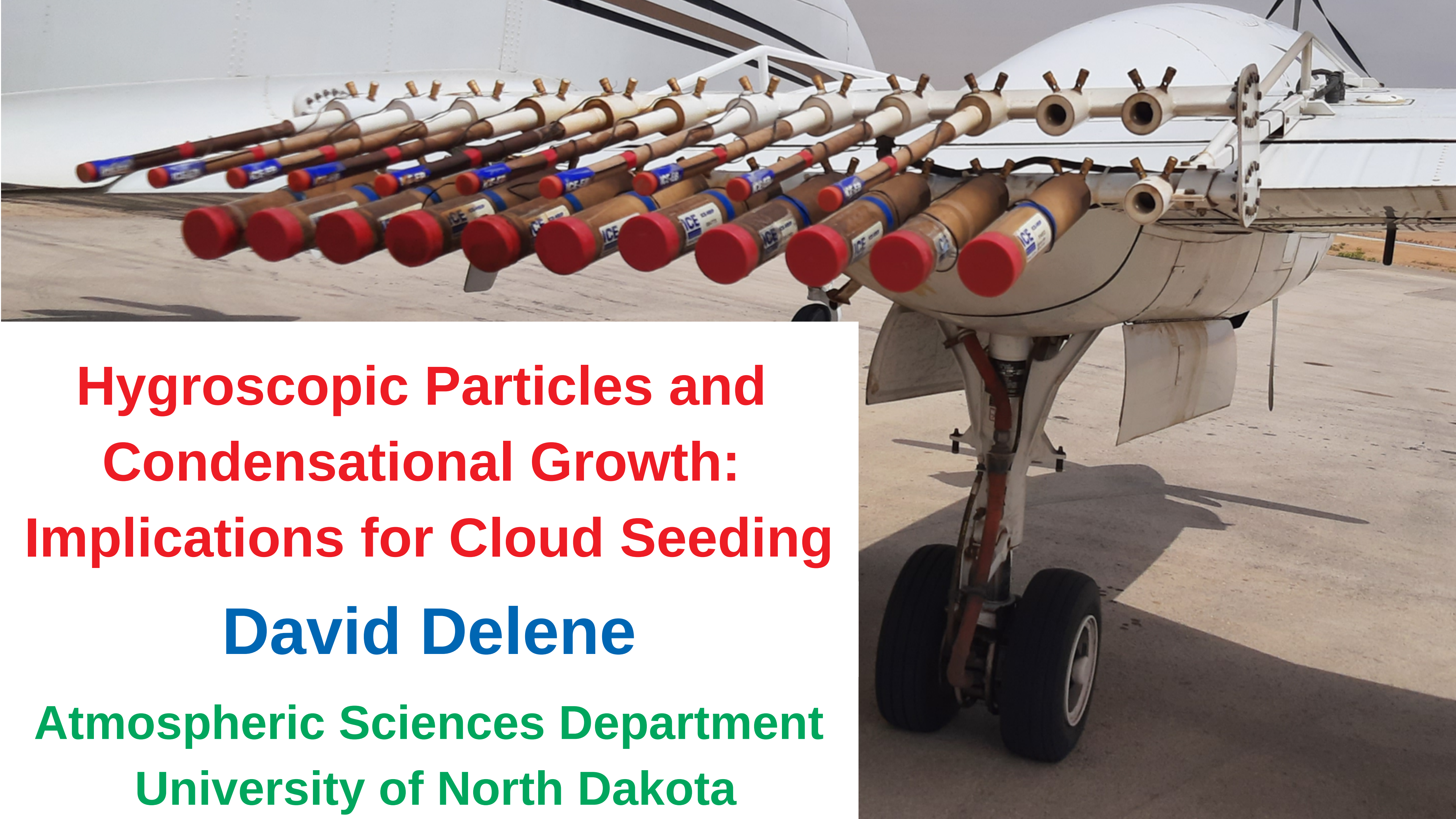

Hygroscopic Particles and Condensational Growth: Implications for Cloud Seeding

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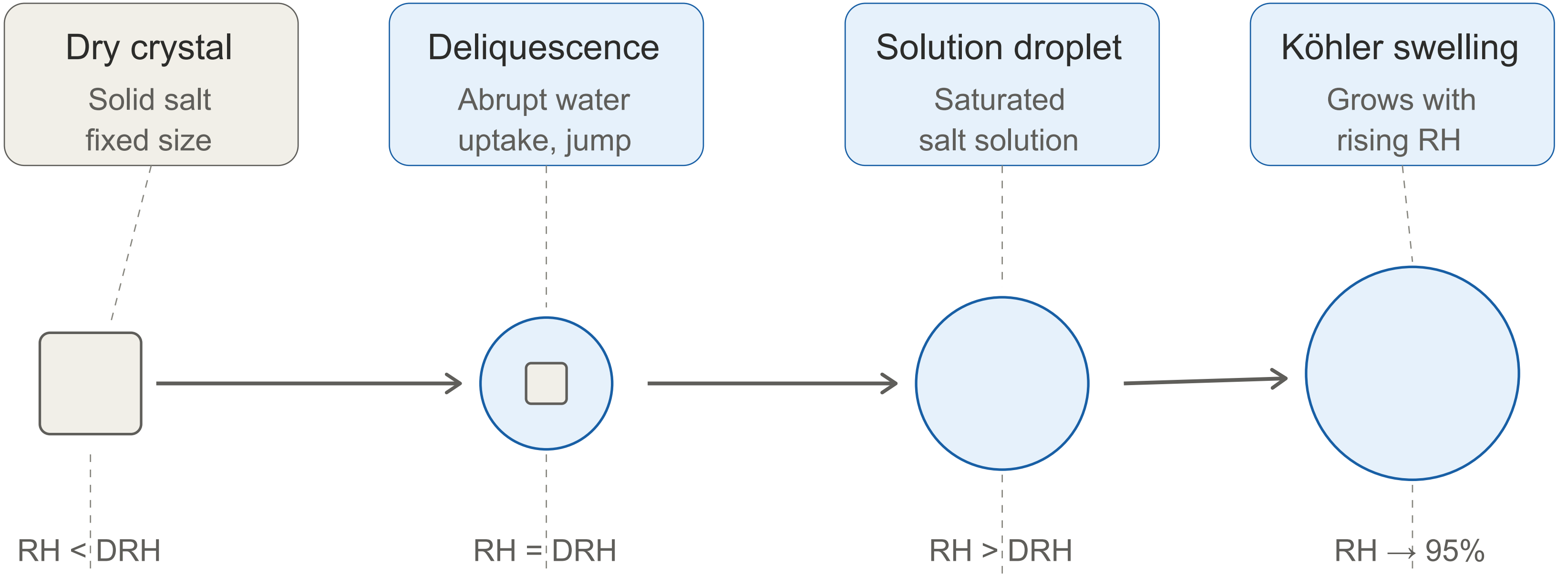
Objective: Particle Growth from Crystal to Droplet

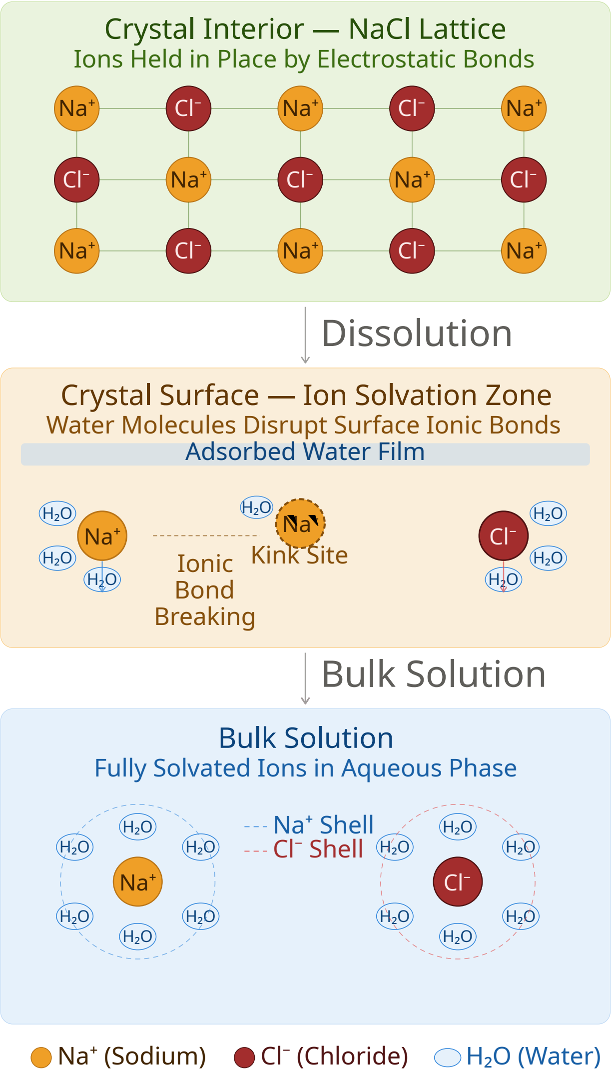
Understanding particles size changes with time.

- Relative Humidity (RH) < 95 %
  - Deliquescence (DRH – Deliquescence Relative Humidity)
- Relative Humidity (RH) > 95 %
  - κ-Köhler Theory (Petters & Kreidenweis 2007)



Theory: Particle Deliquescence (Phase Transition)

- Process by which a solid aerosol particle absorbs water vapor from the surrounding air and spontaneously dissolves into a liquid droplet.
- There is an abrupt, first-order phase transition where the surface water layers become sufficient to solvate ions at the crystal surface, breaking ionic bonds.
- Once dissolution begins, it is self-reinforcing as the now-dilute solution has a lower water vapor pressure than the saturated solution, drawing in more water vapor and driving further dissolution.



Theory: Droplet Activation (Critical Point Dynamics)

- Order Parameter Jump
  - Before activation, the system is pure vapor; after, it contains coexisting liquid droplets. The liquid volume fraction undergoes a discontinuous transition, defining a macroscopic order parameter.
- Critical Radius
  - The Kelvin equation defines a threshold nucleus size: droplets below this radius evaporate (unfavorable surface tension), above it grow spontaneously (favorable bulk condensation). This sharp stability boundary is phase-transition-like.
- Spinodal-like Behavior
  - As supersaturation increases, the critical radius shrinks. When it matches the size of available CCN particles, the system crosses an effective spinodal — the limit of metastability — and nucleation becomes explosive.

Methodology: Use Claude AI

3 Independent Parcels (κ-Köhler with Deliquescence

– 100 nm NaCl (κ=1.28),

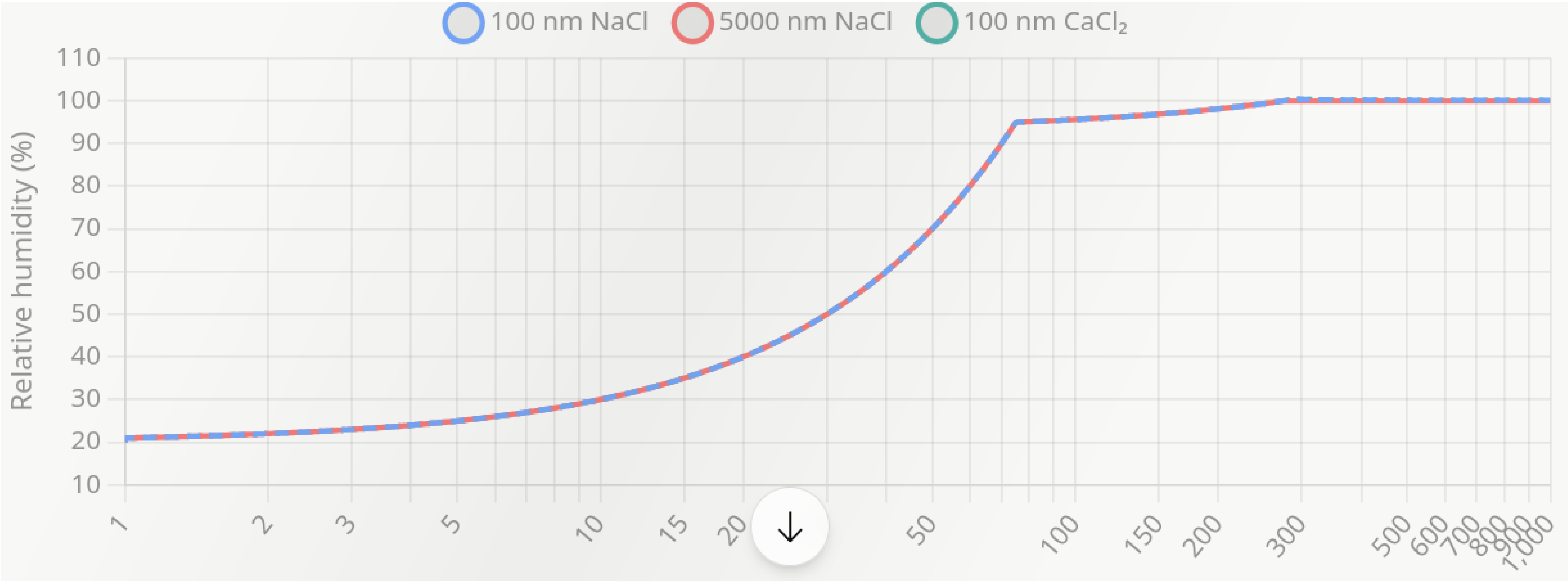
– 5000 nm NaCl

– 100 nm $CaCl_2$ (κ=1.12).

Forced ramp 20→95% at 1%/s, then prognostic.

- Updraft after 95% (m/s) – 0.5
- RH ramp rate (%/s) - 1.0
- 100 nm NaCl (per cc) 100
- 5000 nm NaCl (per L) – 10
- 100 nm $CaCl_2$ (per cc) - 100

Relative Humidity (RH) Time Series

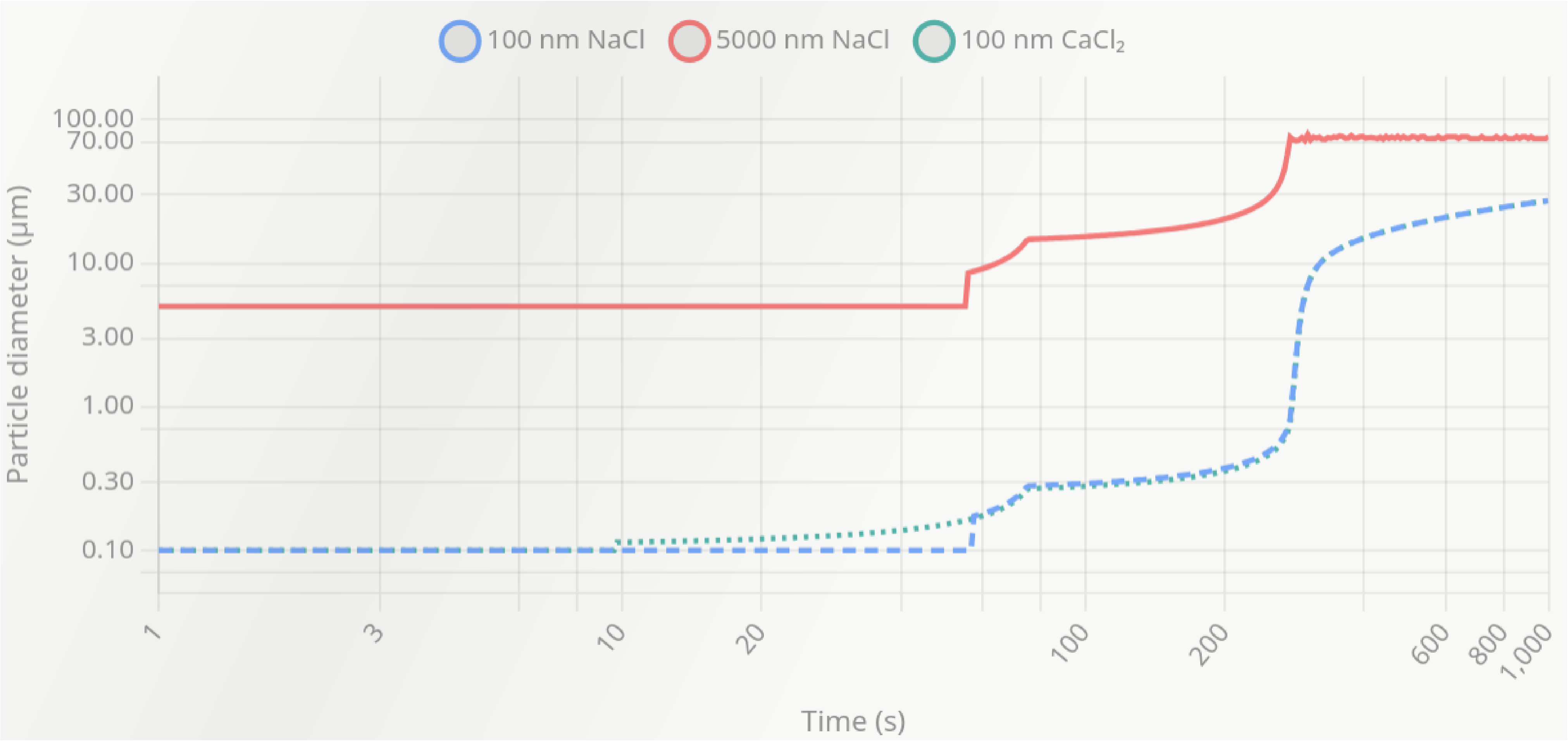


$CaCl_2$ Deliquescence RH - ~30 %

NaCl Deliquescence RH - ~75 %

Particle Diameter Time Series

Flat Dry Crystal → Deliquescence Jump → Growth



Discussion and Conclusions

- Paritlce deliquescence (dry→wet transition) and activation (κ-Köhler theory) are separate phase-transition property.
  - In deliquescence, humidity causes the crystal lattice to dissolve.
  - Droplet activation and growth of droplets are governed by the κ equilibrium.
  - $CaCl_2$ lower deliuescence, but NaCl has higher hygroscopicity parameter κ, <u>better cloud droplet actiavtion</u>.
- For the same size paritcles, $CaCl_2$ deliuescence at lower RH; however, the growth of droplets is nearly the same.
- <u>The paritcle size is what really makes a difference.</u>

Thank You - Team Effort

People in top imaged from left to right: David Delene, Shawn Wagner (Research Scientist), Christian Nairy (Ph.D.), Jenna Post (Undergrad), Jacob Halmos (Undergrad), Bryce Rickbeil (Undergrad), and Conrad Slad (Undergrad). People in left image from bottom/left to top/right: David Delene, Liz Cardoza (undergrad), Summer Coleman (Grad), Ashley Vos (Undergrad), Paramvir Singh (Undergrad), Benjamin Guida (Undergrad), and Tree (Kevin) Norby (Graduate).

κ-Köhler (Petters & Kreidenweis 2007)

$$S(D) = [(D^3 - D_d^3)/(D^3 - D_d^3(1-\kappa))]\cdot \exp(4\sigma M_w/(RT\rho_w D))$$

- A single hygroscopicity parameter κ replaces the van't Hoff / molar-mass bookkeeping.
  - κ(NaCl)=1.28
  - κ($CaCl_2$)=1.12
- Both highly hygroscopic, NaCl slightly more so per unit dry volume.
  - NaCl has higher hygroscopicity parameter κ → Beter Activation
  - $CaCl_2$ lower deliuescence RH → Easier dissolve of crystal lattice structure

Simulation Details

- Updraft after 95 % RH of 0.5 m/s (~100 ft/min)
- Below 95 % RH, 1.0 % increase per second.
- 100 nm NaCl and 100 nm $CaCl_2$ has 100 #/cm^3
- 5000 nm NaCL has 10 #/cm^3

- For 1500 s simulation (Parcel starts at 20 °C and 1000 mb):

Particle	100 nm NaCl	5000 nm NaCl	100 nm $CaCl_2$
Final Size	32.6 μm	37.9 μm	36.6 μm
Max SS	0.106 %	0.000%	0.113 %
DRH (298 K)	75.65 %	75.3 %	~30 %