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Precipitation Growth in Western Atlantic Cumulus Clouds

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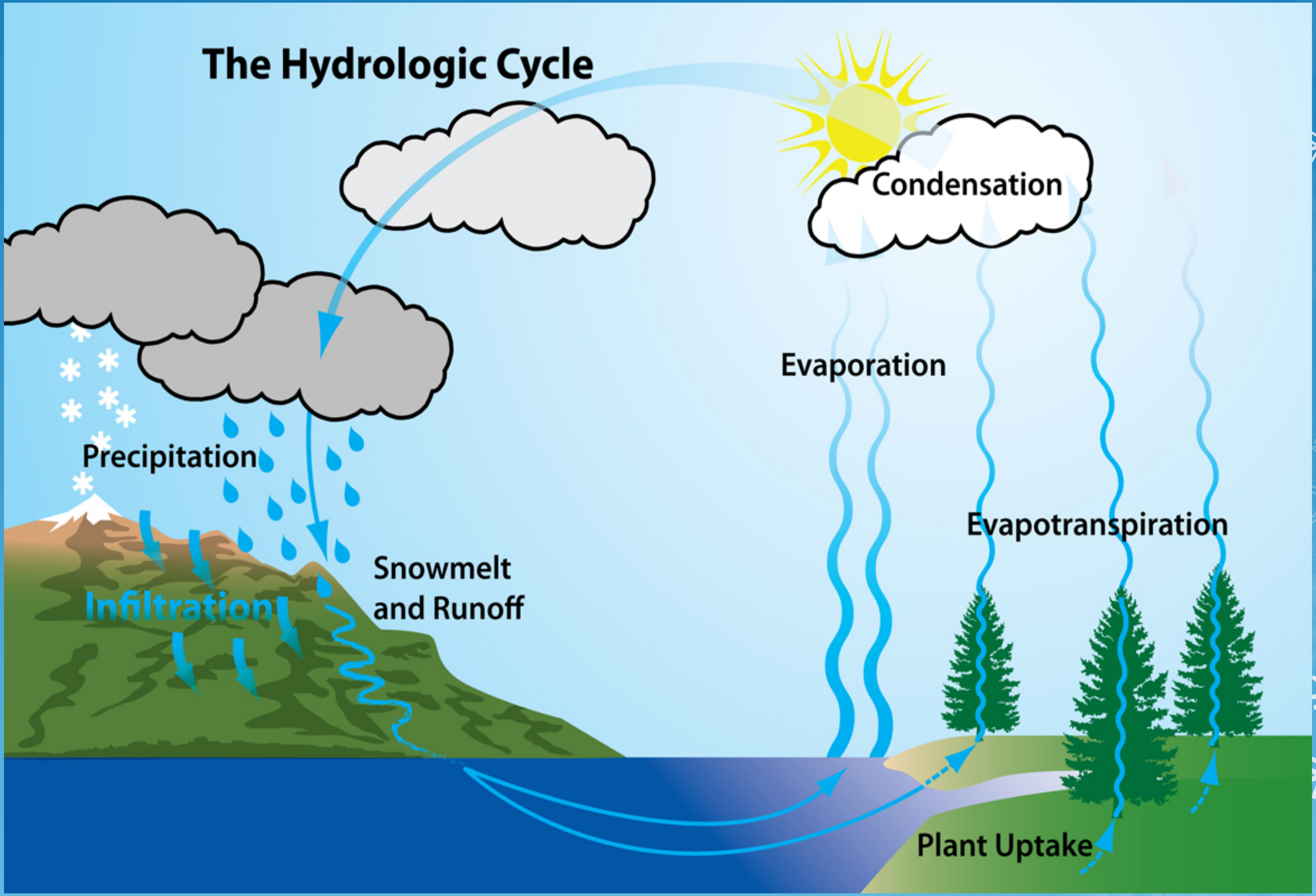
Outline

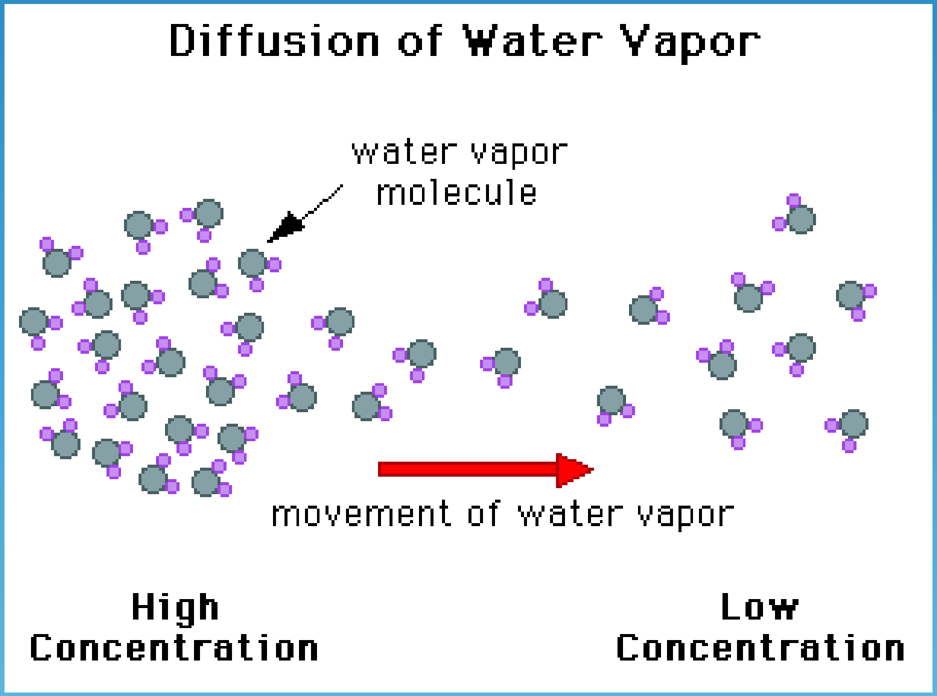
Introduction

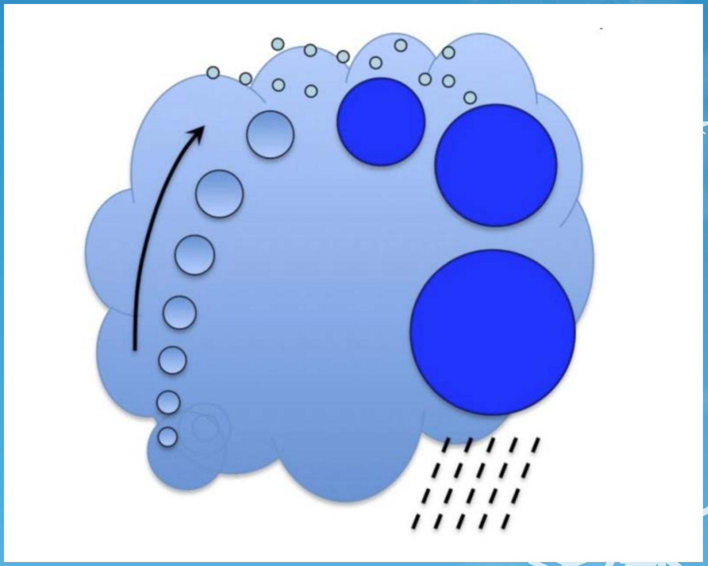


Picture from http://water.usgs.gov/edu/watercycle.html

Introduction

- Droplet Growth Processes
  - Diffusion

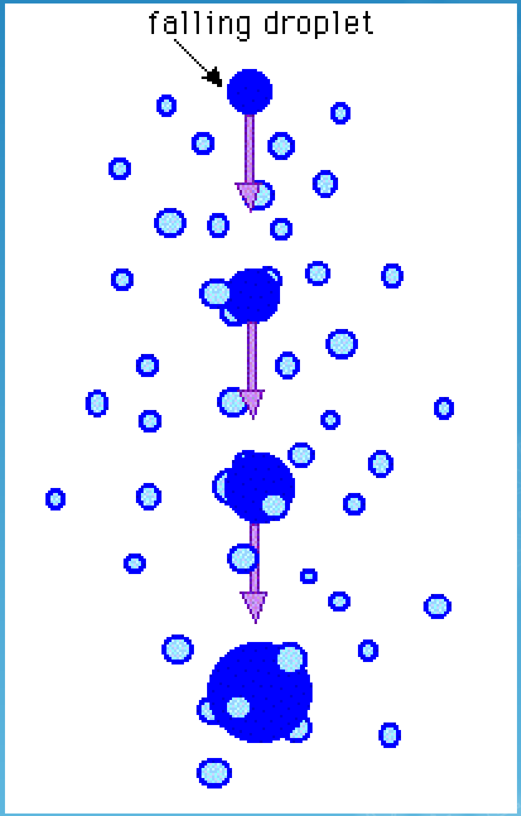




Pictures from http://www.shodor.org/os411/courses/411c/module07/unit03/droplet.html

Introduction

- Droplet Growth Processes
  - Aggregation:



Pictures from http://www.shodor.org/os411/courses/411c/module07/unit03/droplet.html

Cumulus Clouds

- Typical Altitude: 1-3 km
- Composition: Liquid Water

Cumulonimbus Clouds

- Typical Altitude: 1-13 km
- Composition
  - Liquid Water throughout the cloud
  - ice crystal at the top

Model Description and General Assumptions

- Growth rate model
- Assumption: Constant Property Cloud
  - Constant Temperature
  - Constant Supersaturation
- Theoretical Particle Growth
  - It is known that particularly small particles grow differently
  - Continued growth without fallout

Liquid Droplets

- Sources of data (Common Cumulus Clouds):
  - Supersaturation: 0.5 to 2%
  - Temperature: 2°C to -7°C

$$r\frac{dr}{dt} = \frac{S-1}{\rho_l\left(\frac{L_{lv}^2}{\kappa R_v T^2} + \frac{R_v T}{e_s D_v}\right)}$$

Equation: Curry and Webster 1999

Ice Spheres

- Sources of data (Cumulus-Type Clouds):
  - Supersaturation: 0.5 to 2%
  - Temperature: 0°C to -14°C

$$\frac{dm}{dt} = \frac{4\pi C(S_i - 1)}{\left(\frac{L_{iv}^2}{\kappa R_v T^2} + \frac{R_v T}{e_{si} D_v}\right)}$$

Equation: Curry and Webster 1999

Aggregate Snow

- Data:
  - Mixing Ratio: 0.046 – 0.092
  - Snowflake Density: 95 – 105 kg/m^3

$$\frac{dR}{dt} = \frac{\pi}{3}\int_0^R \left(\frac{R+r}{R}\right)^2 n(r) r^3 dr$$

$$w_l = \frac{\rho_l}{\rho_a}\int_0^\infty \frac{4\pi}{3} n(r) r^3 dr$$

$$n(r) = A r^2 e^{-Br}$$

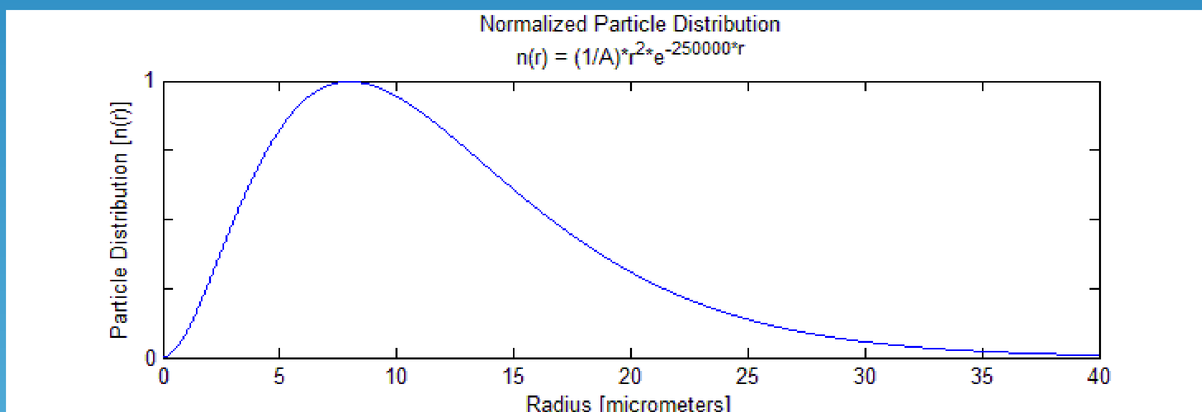
$$\frac{dR}{dt}\frac{4\rho_l}{\rho_a w_l} = \frac{\int_0^R \left(\frac{R+r}{R}\right)^2 e^{-Br}\frac{4\pi}{3} r^5 dr}{\int_0^\infty e^{-Br}\frac{4\pi}{3} r^5 dr} = Ratio \cong 1.991$$

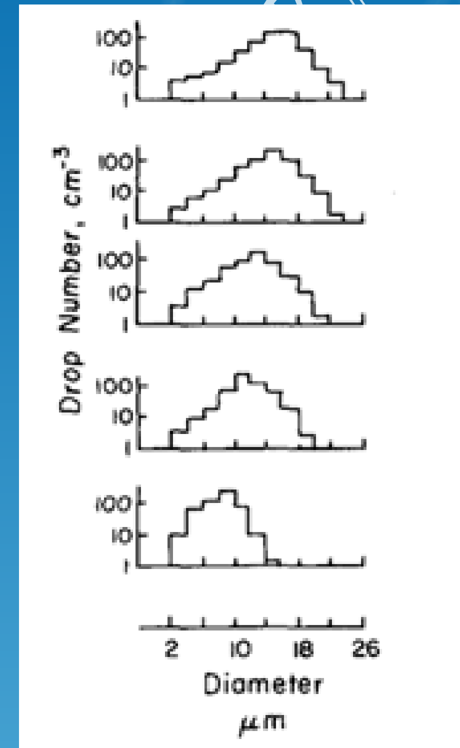
$$\Delta R = \frac{1.991 \rho_a w_l}{4\rho_l}\Delta t$$

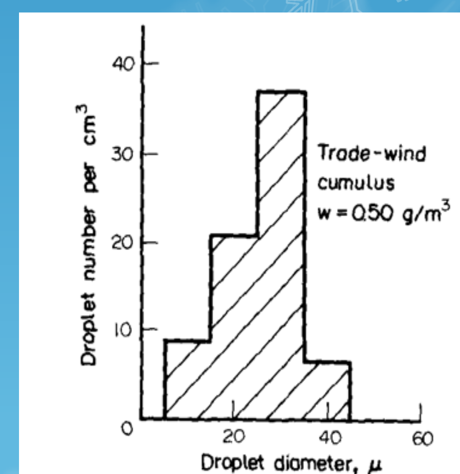
Equations: Curry and Webster 1999

Aggregate Snow

- Distribution Function
  - Schemenauer et al. 1980
  - Fletcher 1962



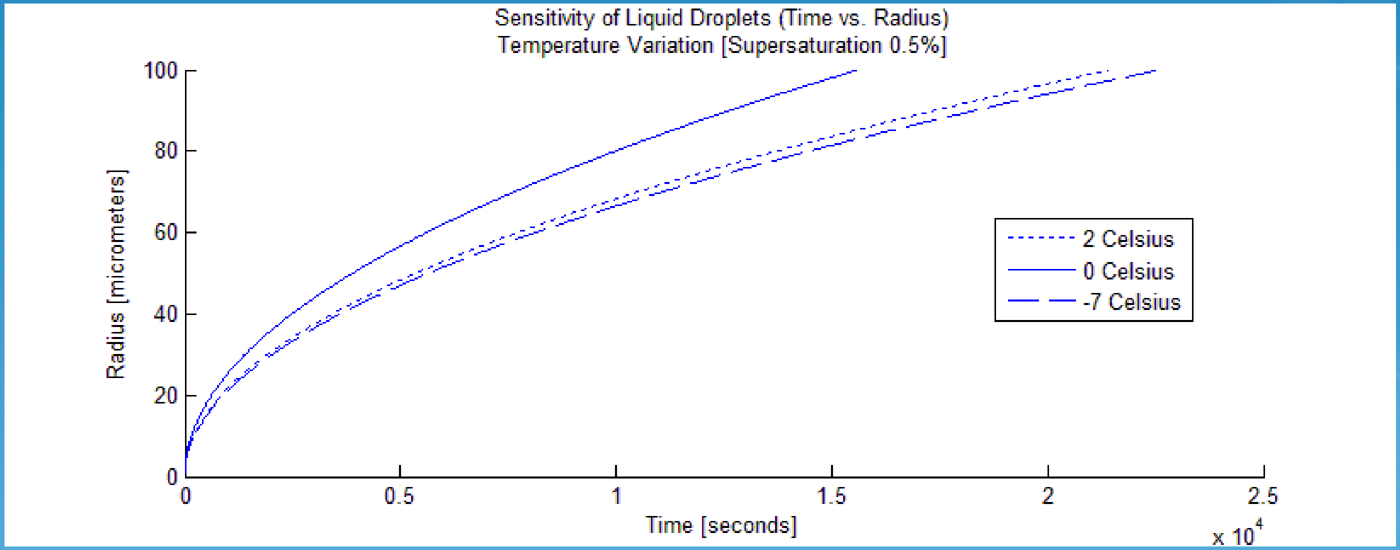




Schemenauer et al. 1980 and Fletcher 1962

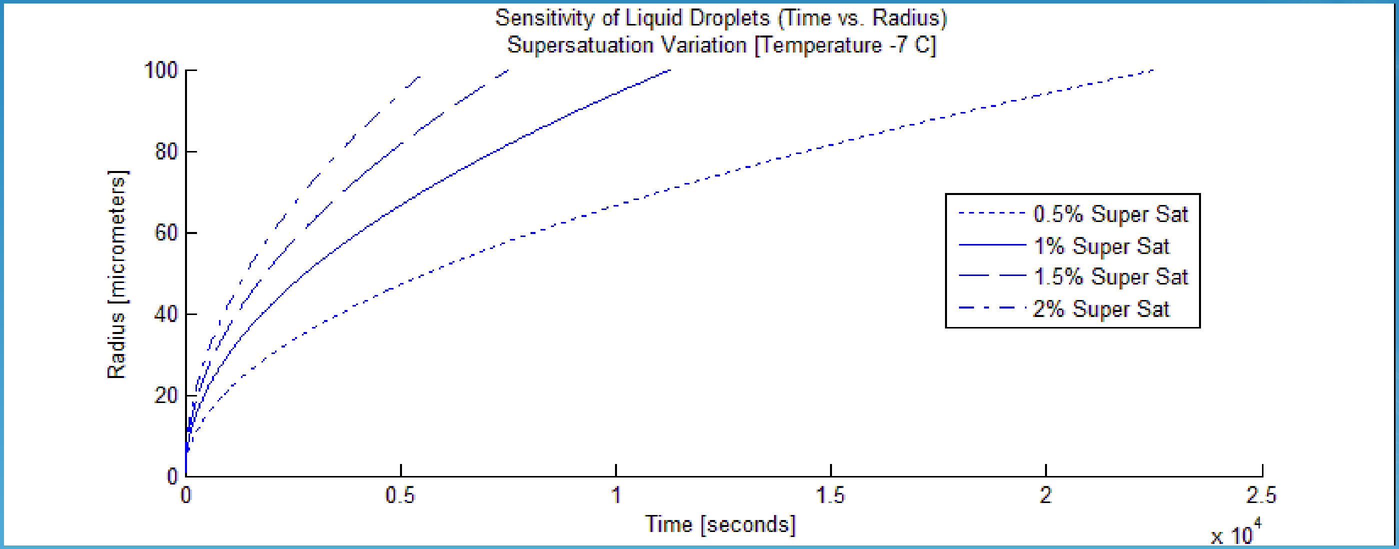
Liquid Droplets - diffusion

- Diffusional growth of liquid droplets is fastest at 0°C
- Faster at 2°C than at -7°C



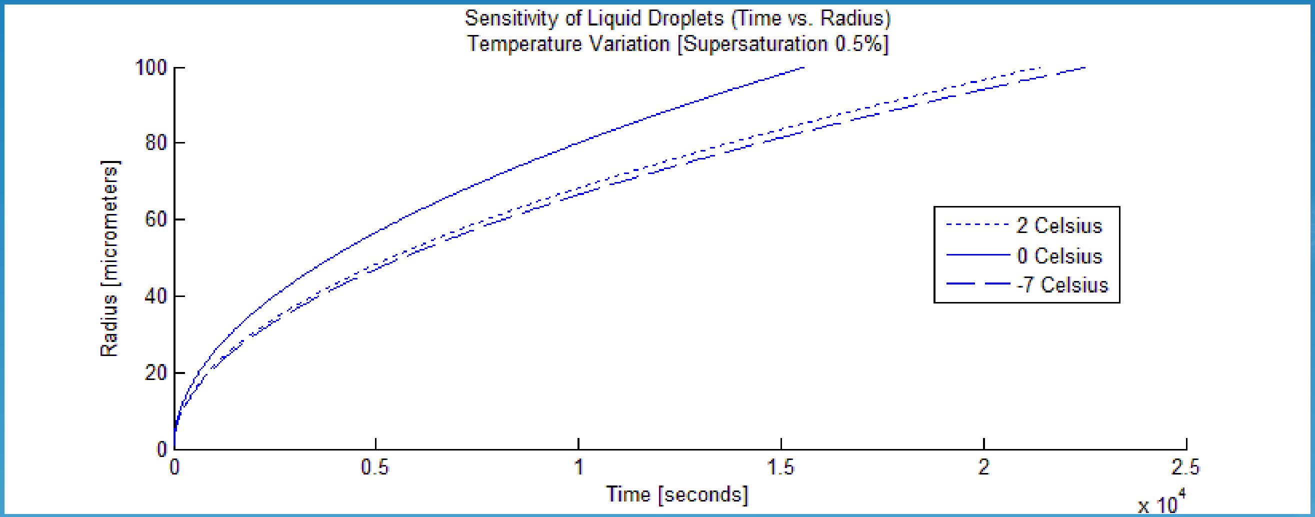
Liquid Droplets - diffusion

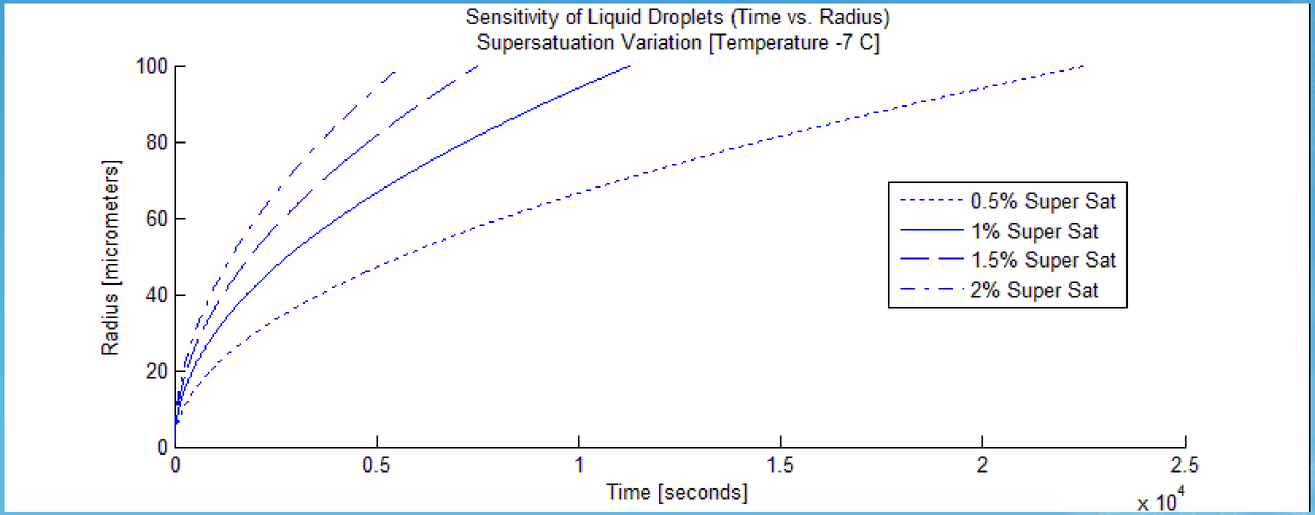
- Higher levels of supersaturaton yielded faster growth rates



Liquid Droplets - diffusion

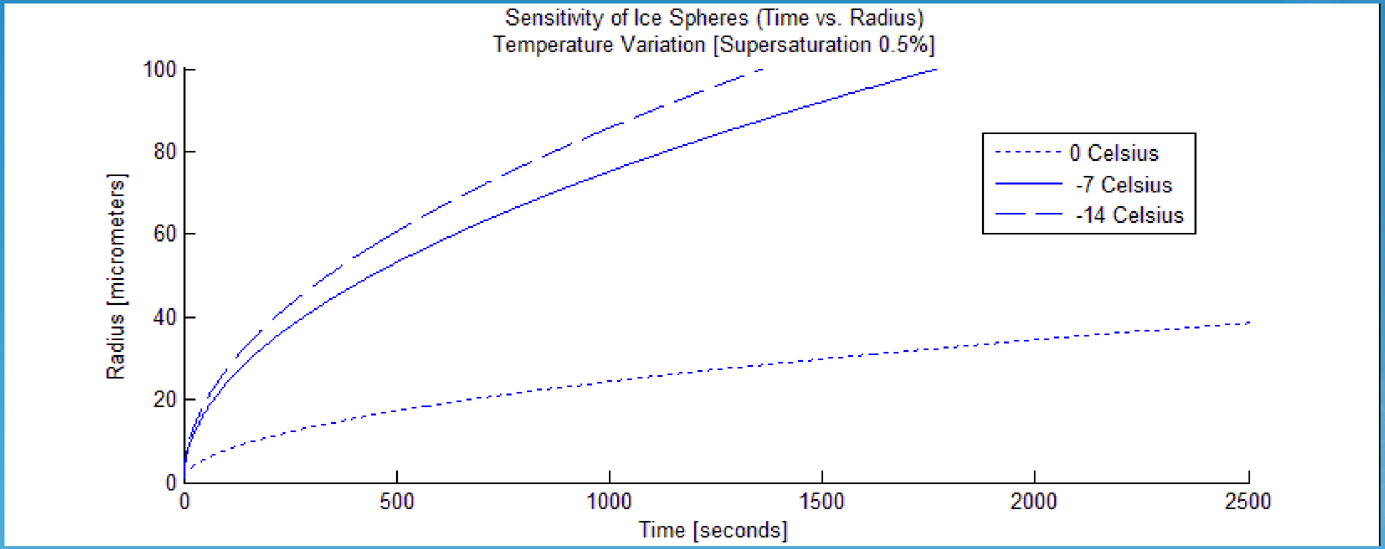
- Growth of liquid droplets in cumulus type clouds is more sensitive to supersaturation than to temperature





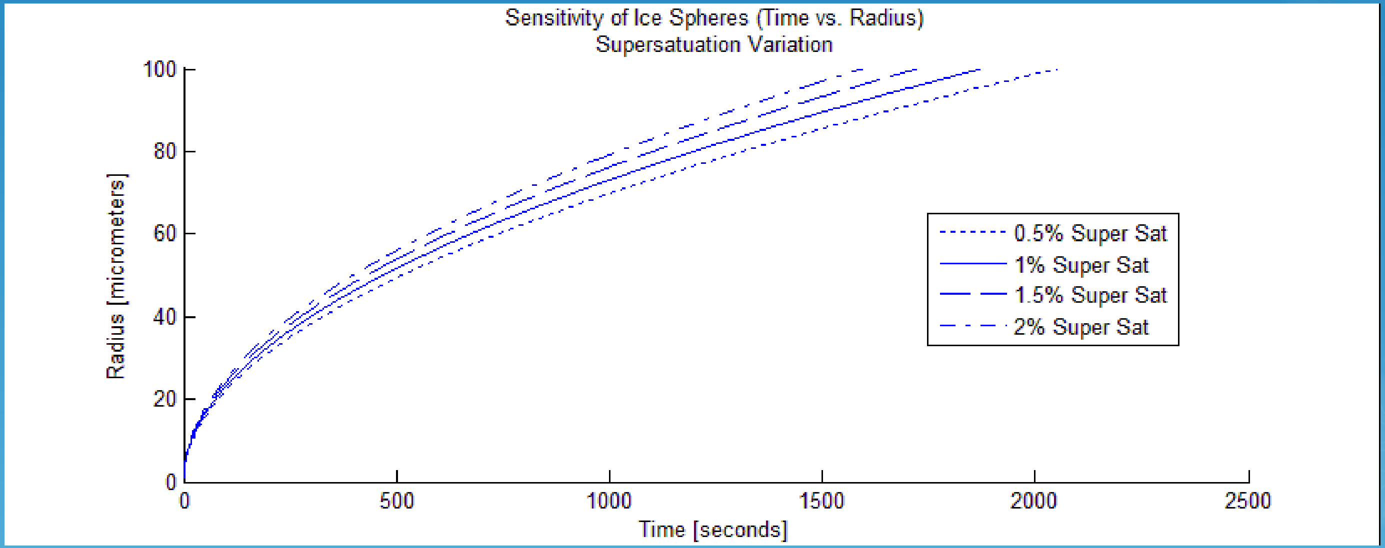
Ice Spheres - diffusion

- Lower temperatures yielded faster growth rates



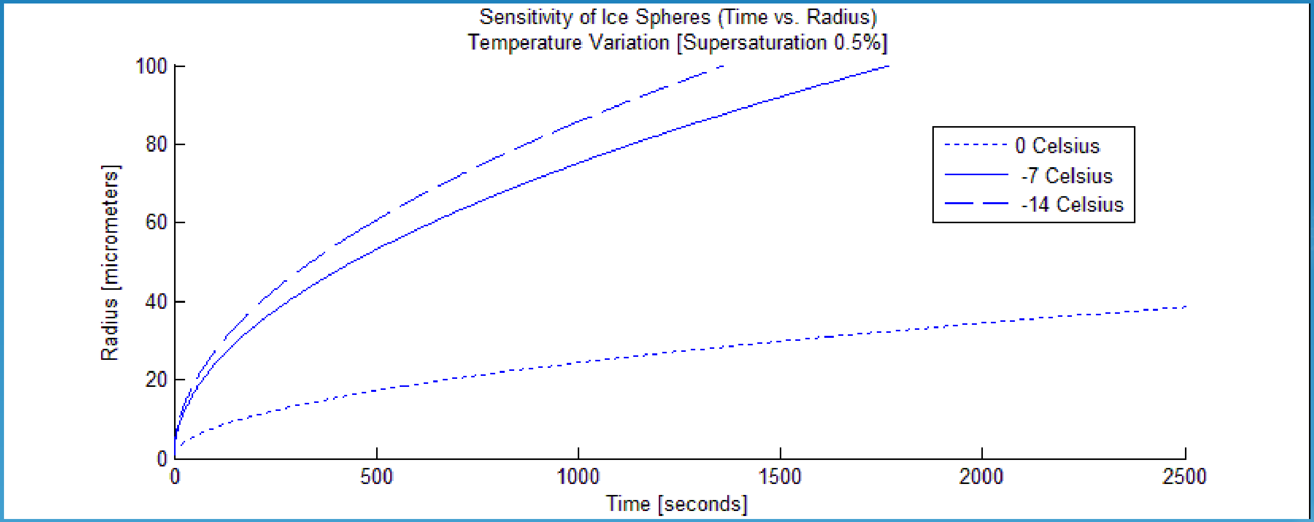
Ice Spheres - diffusion

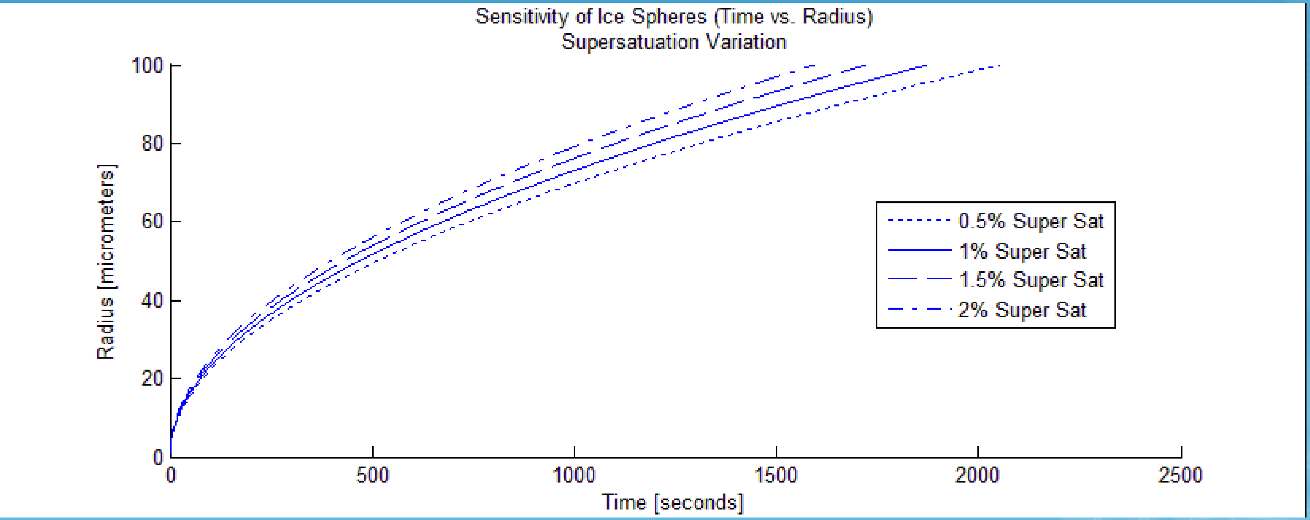
- Higher levels of supersaturaton yielded faster growth rates



Ice Spheres - diffusion

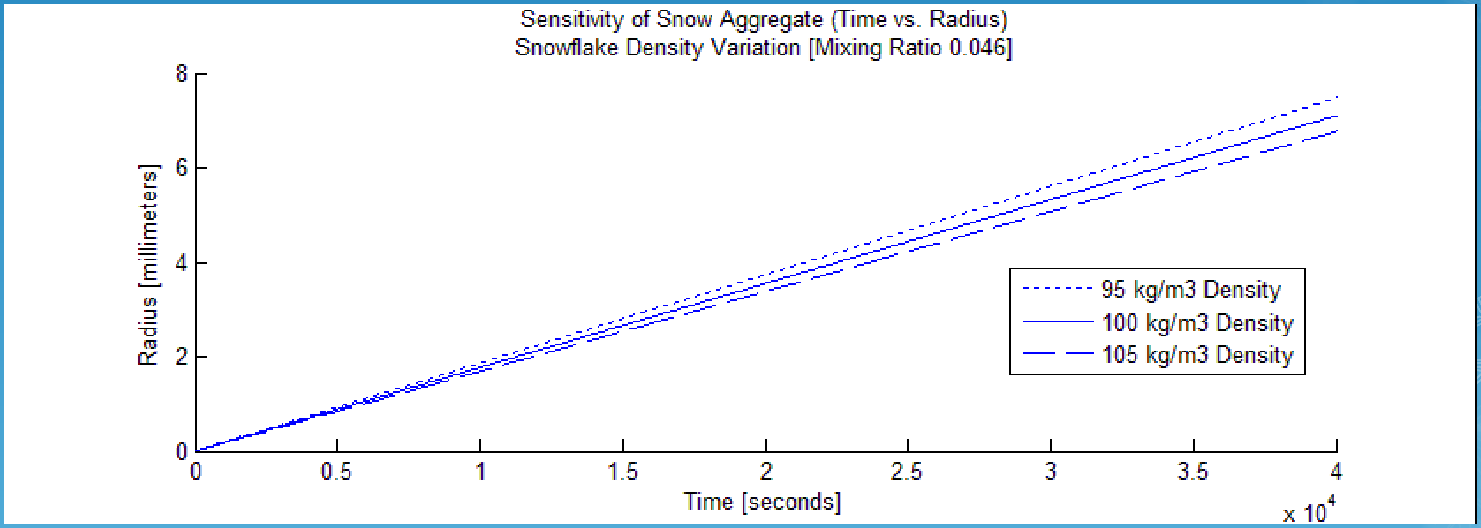
- Unlike liquid water droplets, growth of ice spheres is more sensitive to temperature than supersaturation





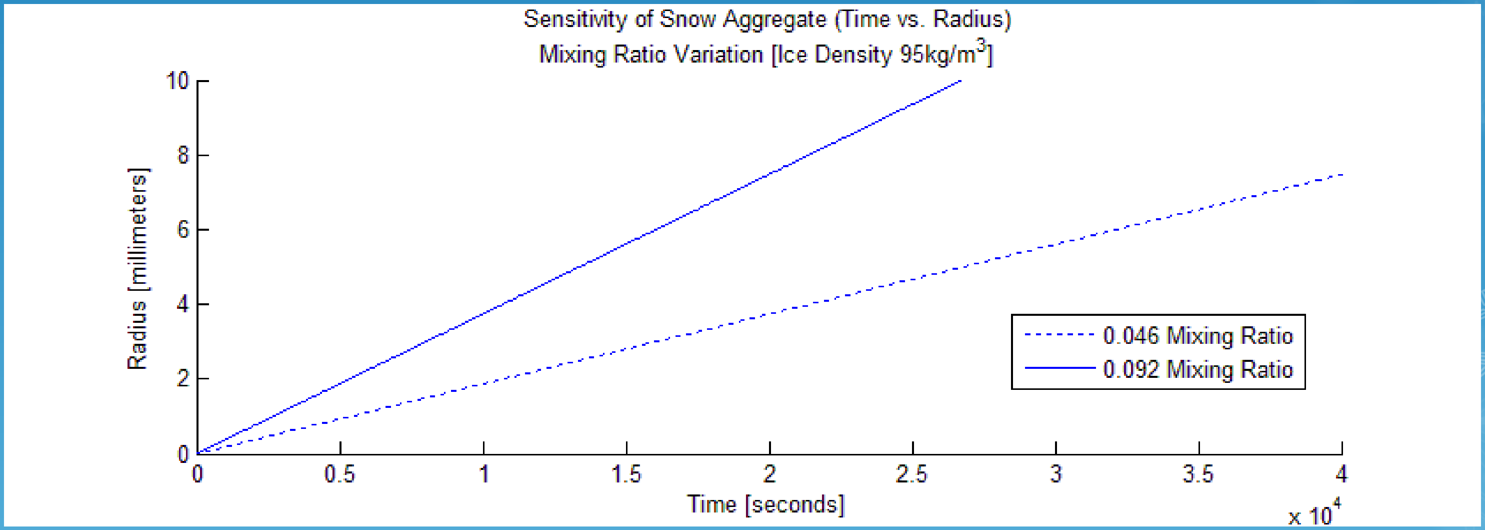
Snowflakes - aggregation

- Greater snowflake density -> slower growth rate (in terms of radius)



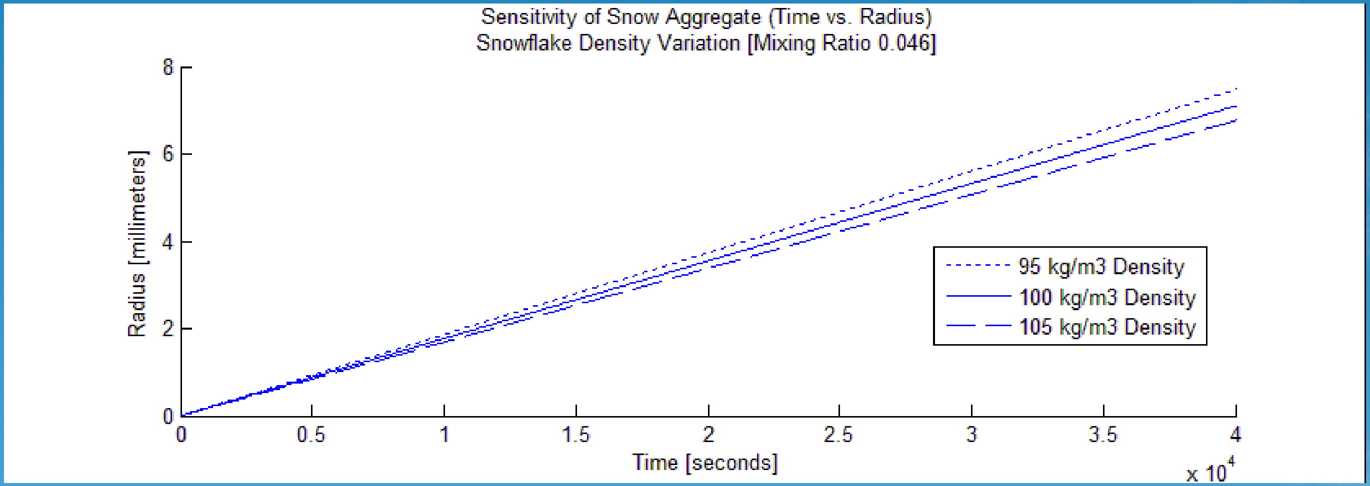
Snowflakes - aggregation

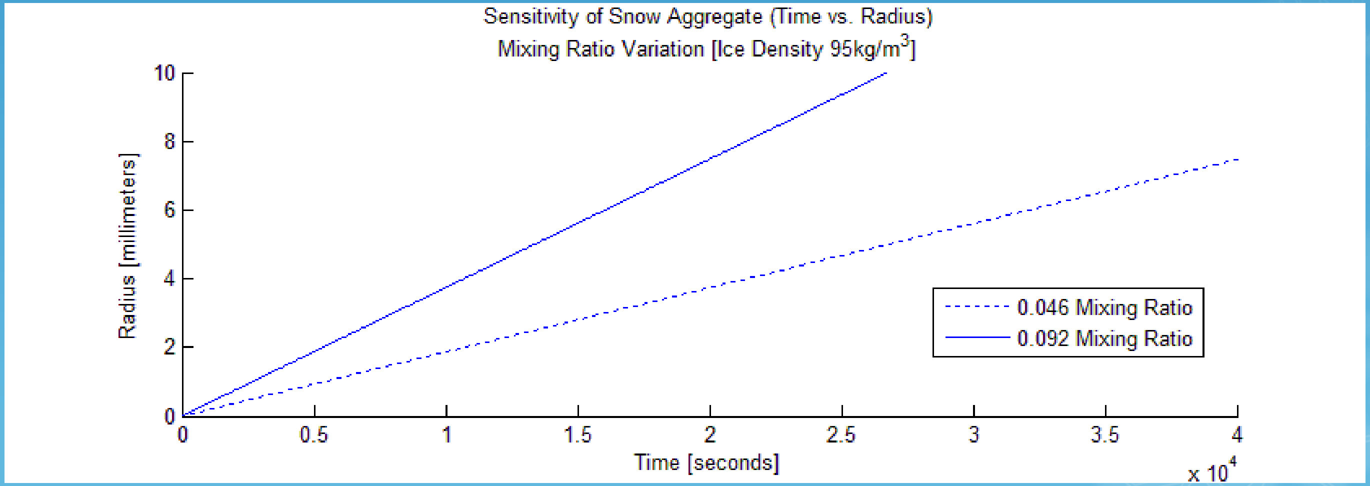
- Larger mixing ratio -> faster growth rate



Snowflakes - aggregation

- Snowflake growth by aggregation is more sensitive to mixing ratio than to snowflake density

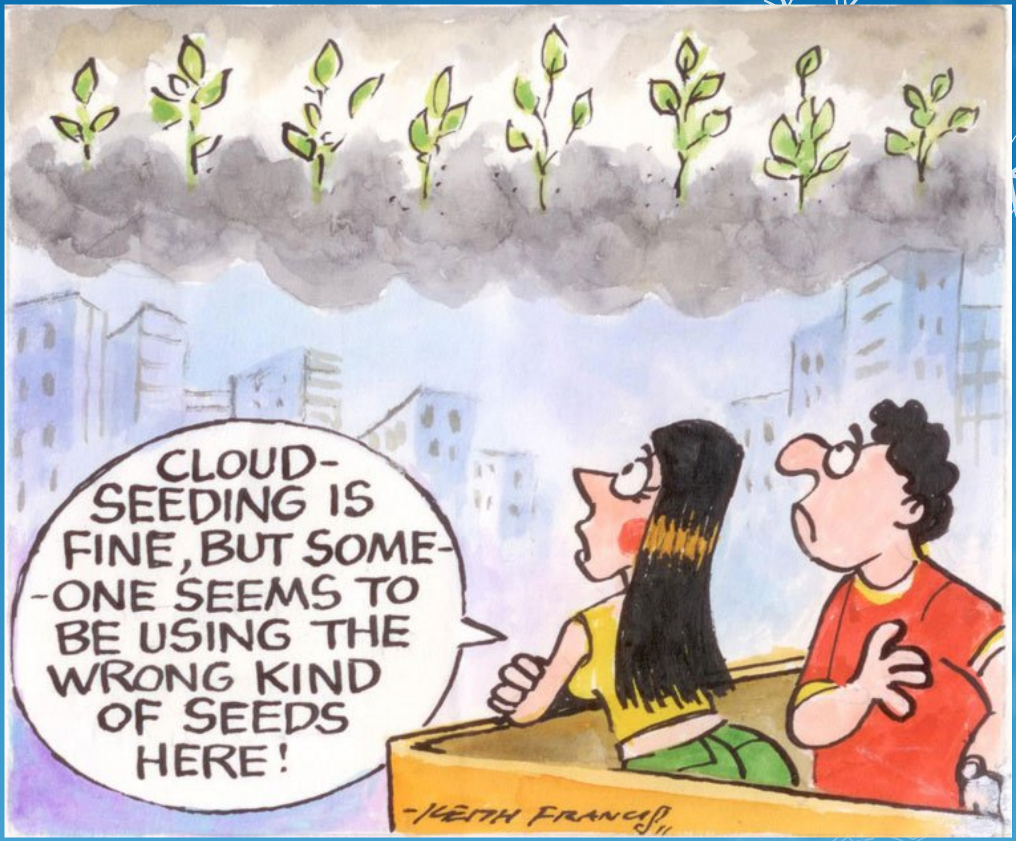


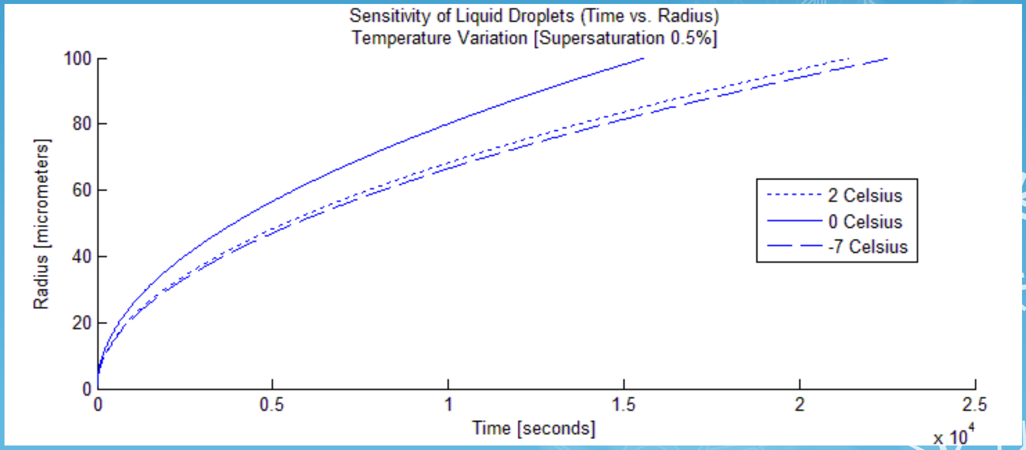


Physical Insight and Application

Wrong seeds? How?

- Too large of seeds will quickly fall out of the sky, bringing minimal water with them
- Too small of seeds won't result in rain where you want it
- Want nucleation-to-precipitation time <30 min
- CA seeding rain in…AZ?!?!





References

- Abel, S. J., R. J. Cotton, P. A. Barrett, and A. K. Vance. 2014. “A Comparison of Ice Water Content Measurement Techniques on the FAAM BAe-146 Aircraft.” *Atmospheric Measurement Techniques Discussions* 7 (May): 4815–57. doi:10.5194/amtd-7-4815-2014.
- Curry, Judith A., and Peter J. Webster. 1999. *Thermodynamics of Atmospheres and Oceans, Volume 65*. 1 edition. San Diego: Academic Press.
- Matrosov, Sergey Y., Carroll Campbell, David Kingsmill, and Ellen Sukovich. 2009. “Assessing Snowfall Rates from X-Band Radar Reflectivity Measurements.” *Journal of Atmospheric and Oceanic Technology* 26 (11): 2324–39. doi:10.1175/2009JTECHA1238.1.
- Obasi, G. O. P. 1987. *International Cloud Atlas, Vol. 2*. Geneva: Amer Meteorological Society.
- Pruppacher, H. R. 1997. *Microphysics of Clouds and Precipitation*. Springer Science & Business Media.
- Song, Xiaoliang, Guang J. Zhang, and J.-L. F. Li. 2012. “Evaluation of Microphysics Parameterization for Convective Clouds in the NCAR Community Atmosphere Model CAM5.” *Journal of Climate* 25 (24): 8568–90. doi:10.1175/JCLI-D-11-00563.1.
- Fletcher, N.H. (1962). The Physics of Rainclouds. Cambridge; Cambridge University Press, 386 pp.
- Schemenauer, R.S., and G.A. Isaac, 1980: Observations of cold and warm rain processes and their implications for cloud seeding in Canada. 3rd WMO Sci. Conf. Weather Modification, Clermont-Ferrand, 77-84.

Questions?