Tropical Cirrus Cloud Precipitation Processes

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Outline

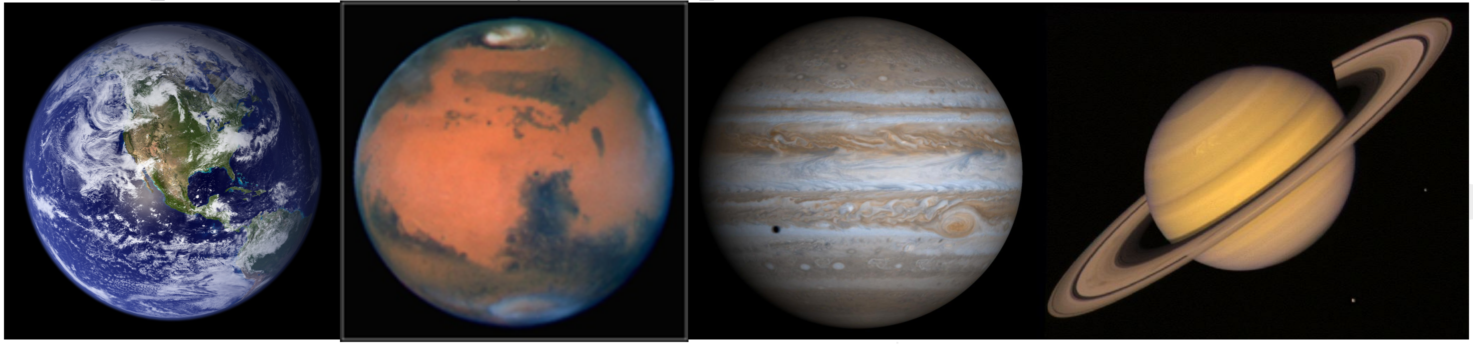
- Introduction
- Model Description
- Results and Discussion
- Conclusion

Motivation for studying Cirrus Clouds

- Role on weather and climate processes

T. F. Stocker, Q. Dahe, and G.-K. Plattner, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers (IPCC, 2013)

- Atmospheric thermodynamic processes



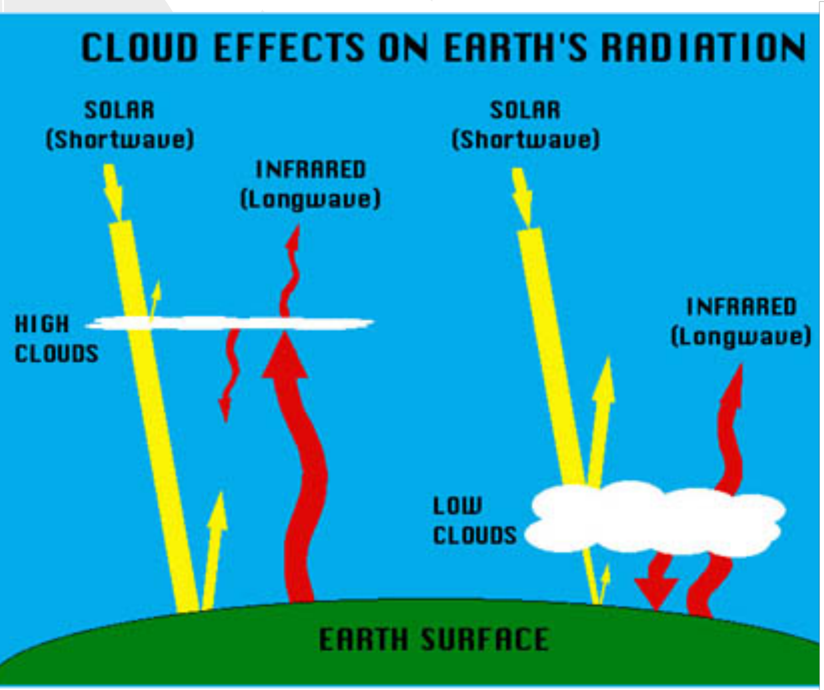
Cirrus Clouds

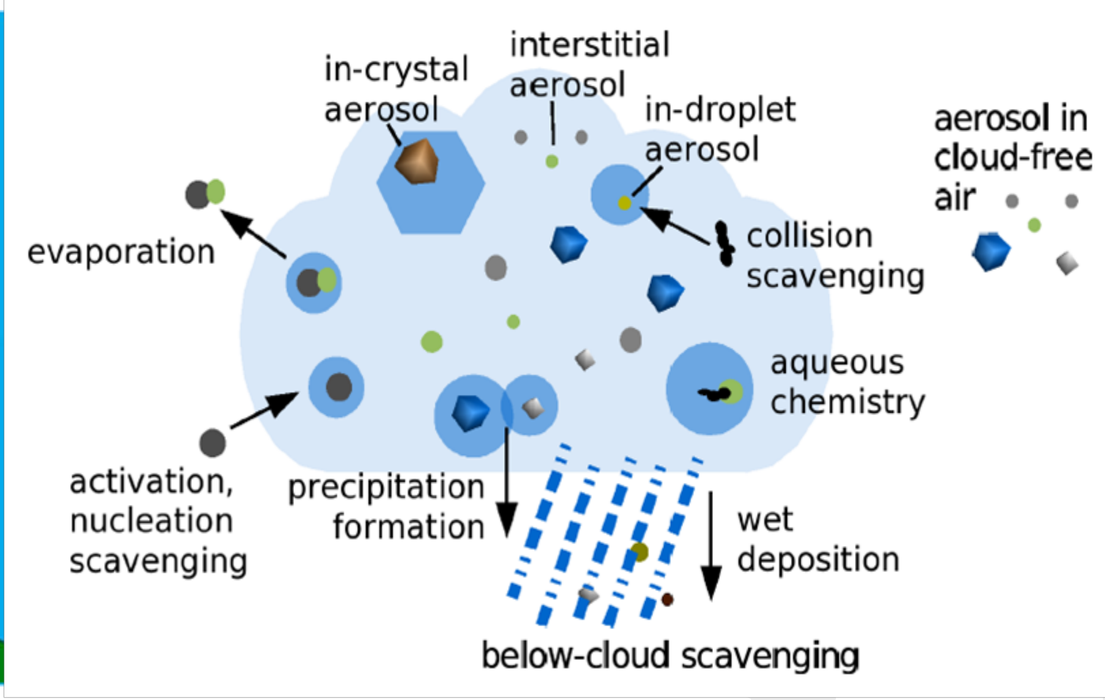
- upper troposphere/lowermost stratosphere
- optically thin consisting mostly of ice crystals
- Earth-Atmosphere system effects
  - light scatter → cooling → albedo effect
  - absorption/emission of IR→ warming → greenhouse effect

⇒net positive feedback

Cirrus Cloud Precipitation Processes

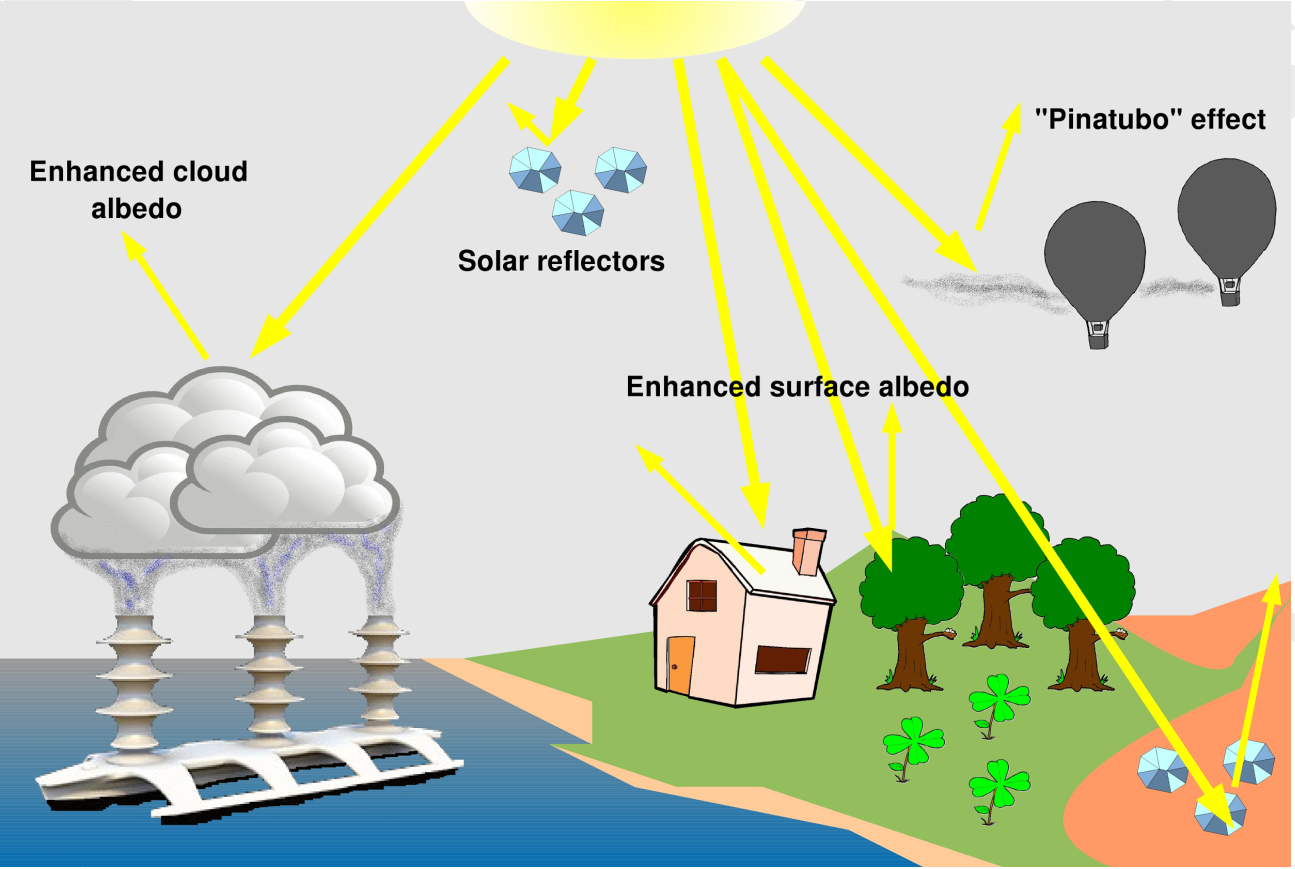
- feedback uncertainty due to complexity of microphysics





Credit: http://www.nasa.gov/images/content/57913main_Cloud_Effects.jpg
https://www.imk-aaf.kit.edu/img/image298.png

Importance of Modeling



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Model Description 1

Ice Droplet Diffusional Growth[1]:

$r(t) = [r_o^2 + (2(S-1)/(K+D))(t-t_o)]^{½}$

Where r_o is the initial radius

S is the supersaturation

<u>K is a value composed of $L_{iv}^2\rho_L/\kappa R_v T^2$</u>

Where L_{iv} is the latent heat of fusion

ρ_L is the density of water

κ is the atmospheric thermal conductivity

R_v is the gas constant for vapor

<u>D is a value composed of $\rho_L R_v T/e_s(T)D_v$</u>

Where D_v is the water vapor diffusivity

Driven by condensation of water onto initial droplet. As latent heat of condensation increases the temperature of the droplet, the growth speed decreases. The vapor pressure of the droplet needs to exceed the saturation vapor pressure of the droplet or growth will not occur. [1]

Assumptions:

-Quantity of condensable water in air in infinite and will continue to accumulate for all time.

-Droplets are spherical (big assumption)

Model Description 2

Snowflake Aggregation Growth[1]:

$dR/dt = (\rho_a E/4\rho_I)*w_I u_T(R)$

Where ρ_a is the pressure of air

E is the collection efficiency (Assumed 1)

ρ_I is the snowflake density

w_I is the mixing ratio for ice particles in the air

u_T is the terminal velocity of the falling particle

Snowflakes grow by contacting other ice particles. Efficiency of snowflake growth by aggregation is less understood than water droplet growth by aggregation. This is due to aerodynamic reasons (non spherical snowflakes) and geometric structures of snowflakes.[1]

Assumptions:
-Spherical snowflakes
-Collection efficiency is unity

Flight Study of Tropical Cirrus Cloud

- I. V. Gensch *et al.* (2008), Supersaturations, microphysics and nitric acid partitioning in a cold cirrus cloud observed during CR-AVE 2006: an observation–modelling intercomparison study. *Environ. Res. Lett.* **3** 035003
- Flights for eastern pacific tropical cirrus
- In situ measurements of upper tropospheric cirrus cloud properties
- Airplanes can disturb clouds

Measured Cirrus Cloud Parameters

Flight Study Measurements:

Pressure = 100 mb

Temperature = 186 K (-87˚C)

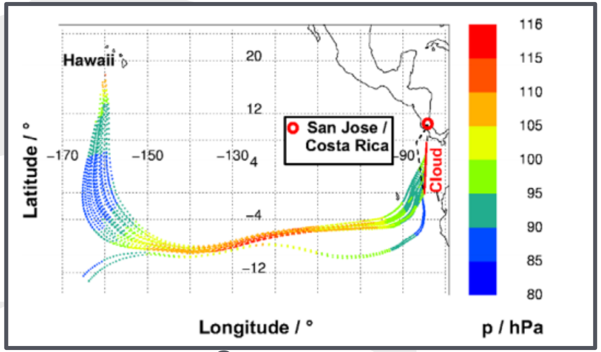
Ice crystal number density = .001-.07 cm^{-3}

Ice mixing ratio = .00155 g/kg

Terminal velocity = .003 m/s

Supersaturation = 250%

Average Particle Size (20um)



**It can be noted that the values for ice particle fall rate, mixing ratio, and number density are *very* low vs. other cloud types. This drastically impacted the results of our calculations

The Key Equations

Condensation Growth

$$r(t) = \sqrt{r_0^2 + \frac{2(S-1)t}{K+D}}$$

Aggregation Growth

$$\frac{dR}{dt} = \frac{\rho_a E}{4\rho_i} \times w_i \times u_T(R)$$

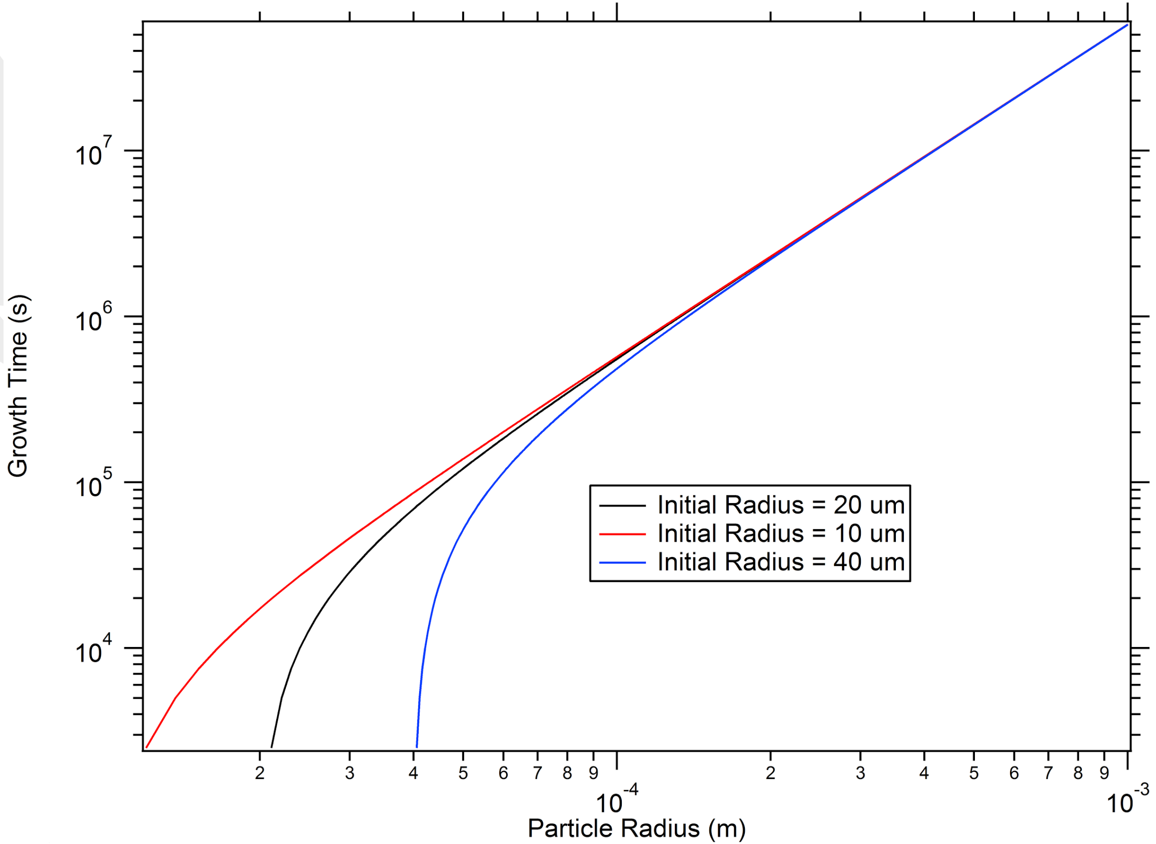


Figure 1:Time required to reach 1000um by diffusional growth with varying initial size.

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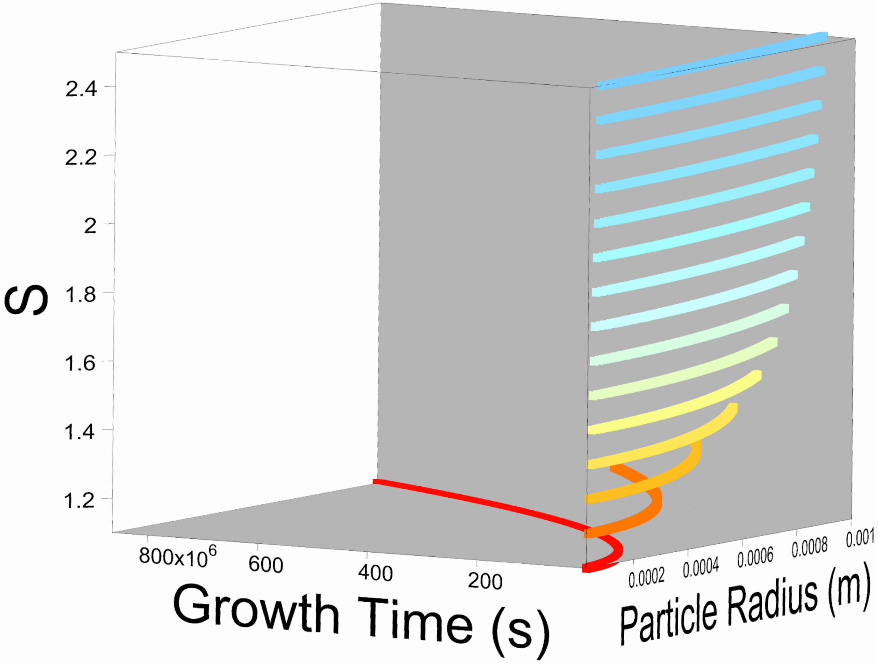

Figure (2) - Time required to reach 1000 um by diffusional growth while varying supersaturation (S) level. *Note decreasing growth rate with respect to time. This is caused by latent heating of droplet by condensation.

The Key Equations

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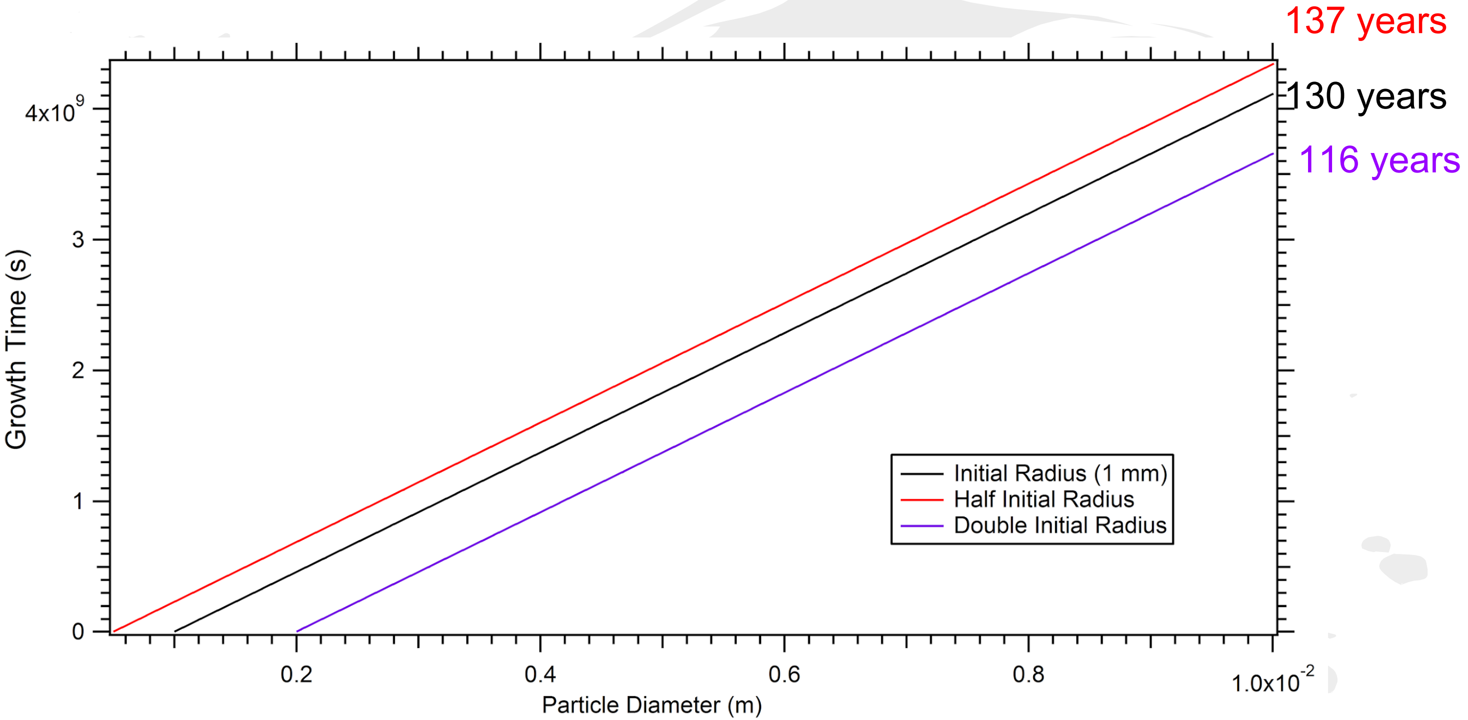
$$r(t) = \sqrt{r_0^2 + \frac{2(S-1)t}{K+D}}$$

Aggregation Growth

$$\frac{dR}{dt} = \frac{\rho_a E}{4\rho_i} \times w_i \times u_T(R)$$

Figure 3 - Time required to reach 1 cm by aggregation growth while varying starting size (1 mm initial)



The Key Equations

Condensation Growth

$$r(t) = \sqrt{r_0^2 + \frac{2(S-1)t}{K+D}}$$

Aggregation Growth

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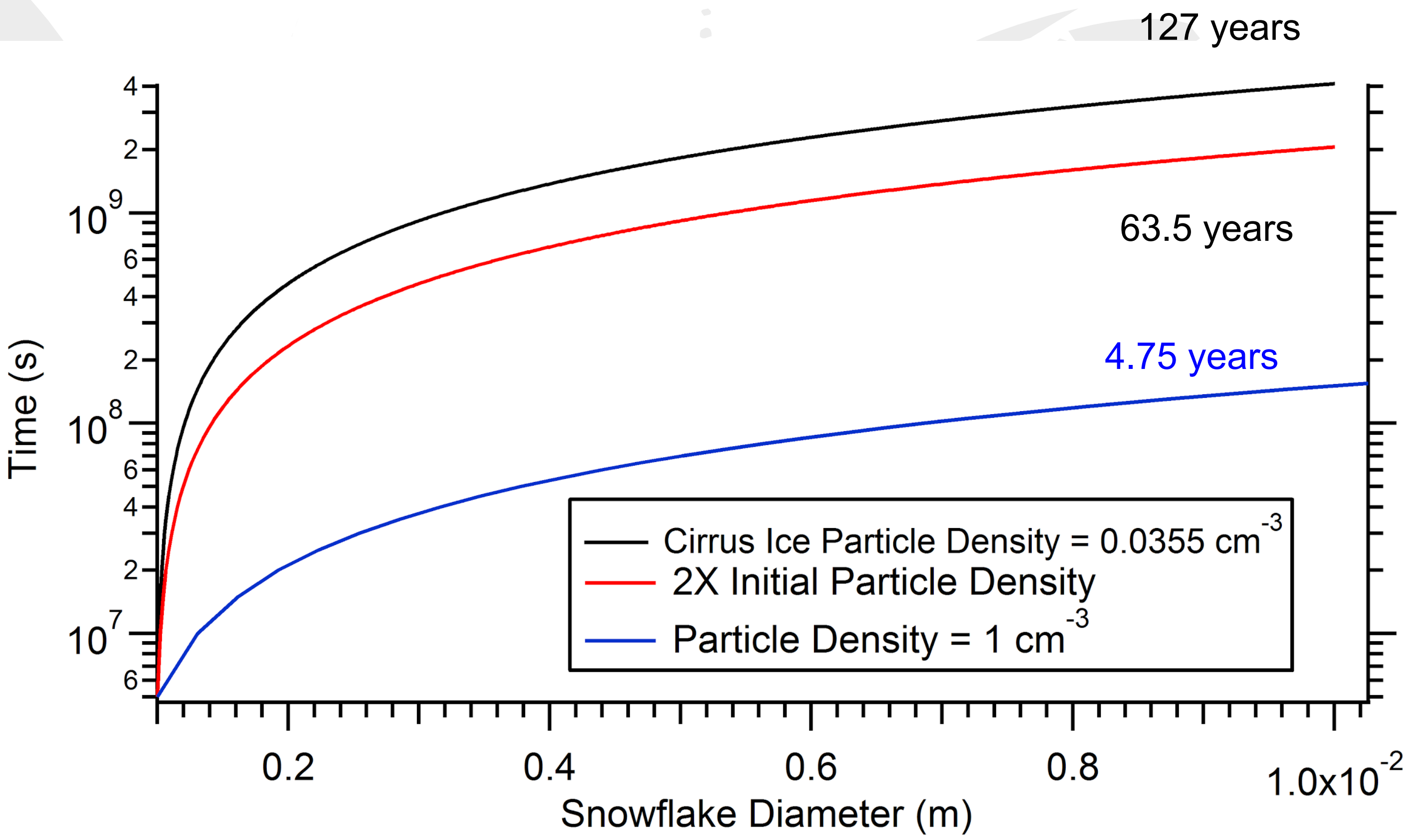
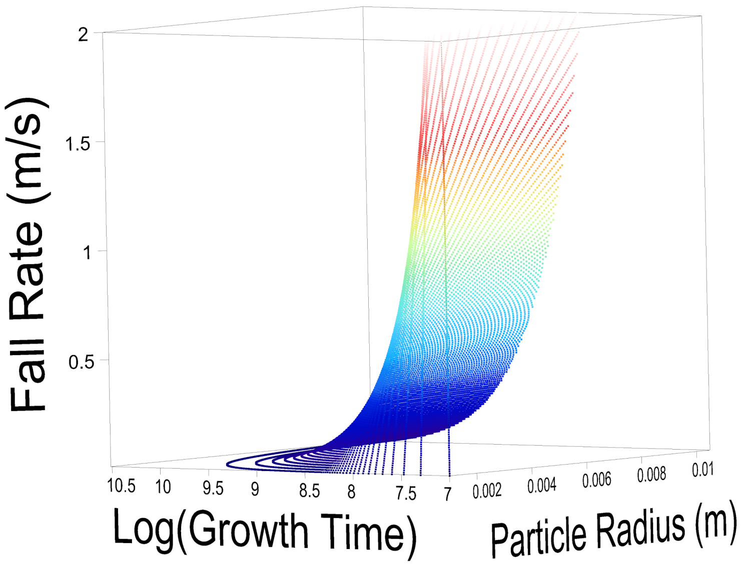
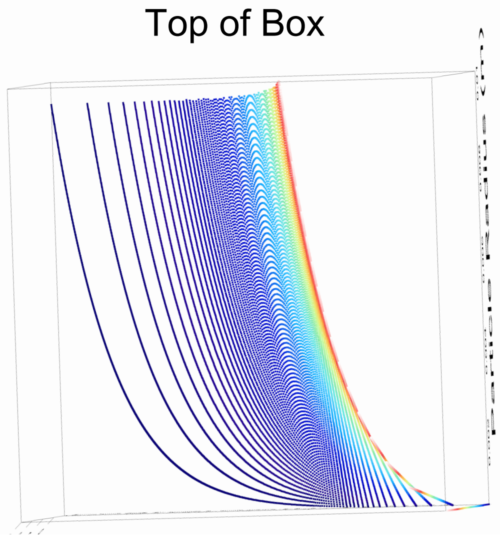


Figure 4 - Growth time to reach 1 cm by aggregational growth with varying ice particle densities





Figures 5 and 5.5 - Growth time to reach 1cm from 1mm initial particle size while varying fall rate.

What Did We Learn?

- Ice droplets and snowflakes take a VERY LONG time to grow in cirrus clouds
- This is mainly due to the small ice crystal number concentration in cirrus clouds
- Even for upper estimates of parameters droplets and flakes will take years to grow to precipitable sizes

No Precipitation!

- Ice crystals take many years to grow from 1 µm to 1 mm
- Snowflakes take many years to grow from 1 mm to 1 cm
- Lifetimes of cirrus clouds are much shorter
- So why do we care?

Twomey Effect

- Aerosols facilitate heterogeneous nucleation
- Increased aerosol concentration causes more droplets to form
- More droplets causes warming in cirrus clouds

Negative Twomey Effect[2]

- In highly supersaturated cirrus clouds, homogeneous nucleation occurs
- Increasing CCN concentration would lead to more heterogeneous nucleation
- Hypothesized that heterogeneous nucleation could form larger particles
- Larger particles will fall out of clouds reducing number concentration and albedo

How to Geoengineer Cirrus Clouds

- CCNs can be ejected into clouds by aircraft
- Increased <u>heterogeneous</u> nucleation leads to larger particles
- Larger particles have higher settling velocities and fallout rate
- This reduces the albedo and cover of cirrus clouds in the atmosphere

Geoengineering Implications

Current Cirrus Clouds

- Cirrus clouds have a net warming effect
- Removing cirrus clouds from atmosphere through precipitation or settling causes global cooling
- Not feasible based on our model!
- Cirrus clouds take many years to precipitate for upper estimates of parameters

Future Possibilities

- Aerosol seeding forms larger particles
- Particles have higher settling velocity
- Cirrus clouds dissipate more quickly
- Less warming from cirrus clouds

Acknowledgement

Course Professor: Lynn Russell

Thank you!

References

[1] Curry, J., & Webster, P. (1999). Thermodynamics of atmospheres and oceans. San Diego: Academic Press.

[2] Mitchell, D., & Finnegan, W. (2009). Modification of cirrus clouds to reduce global warming. *Environmental Research Letters*, *4*, 045102-045102. Retrieved December 10, 2014.