Outline

● Introduction
● Model Description
● Results and Discussion
● Conclusion
Motivation for studying Cirrus Clouds

- Role on weather and climate processes
- 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
Importance of Modeling

Enhanced cloud albedo
Solar reflectors
Enhanced surface albedo
"Pinatubo" effect

Institute for Atmospheric & Climate Science
Eidgenössische Technische Hochschule (ETH) Swiss Federal Institute of Technology Zurich
Model Description 1

Ice Droplet Diffusional Growth\(^{[1]}\):

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

Where \( r_o \) is the initial radius
S is the supersaturation
K is a value composed of \( L_{iv}^2 \rho_L / \kappa R_v T^2 \)
Where \( L_{iv} \) is the latent heat of fusion
\( \rho_L \) is the density of water
\( \kappa \) is the atmospheric thermal conductivity
\( R_v \) is the gas constant for vapor
D is a value composed of \( \rho L R_v T/e(T)D_v \)
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)
Snowflake Aggregation Growth: 
\[ \frac{dR}{dt} = \left( \frac{\rho_a E}{4 \rho_l} \right) w_l u_T(R) \]

Where \( \rho_a \) is the pressure of air 
\( E \) is the collection efficiency (Assumed 1) 
\( \rho_l \) is the snowflake density 
\( w_l \) is the mixing ratio for ice particles in the air 
\( u_T \) is the terminal velocity of the falling particle

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.
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 (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

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 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

\[ \frac{dR}{dt} = \frac{\rho_a E}{4 \rho_i} \times w_i \times u_T(R) \]
Figure 4 - Growth time to reach 1 cm by aggregational growth with varying ice particle densities

- Cirrus Ice Particle Density = 0.0355 cm$^{-3}$
- 2X Initial Particle Density
- Particle Density = 1 cm$^{-3}$

127 years
63.5 years
4.75 years
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 Effect²

- 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 heterogeneous 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

<table>
<thead>
<tr>
<th>Current Cirrus Clouds</th>
<th>Future Possibilities</th>
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<tbody>
<tr>
<td>• Cirrus clouds have a net warming effect</td>
<td>• Aerosol seeding forms larger particles</td>
</tr>
<tr>
<td>• Removing cirrus clouds from atmosphere through precipitation or settling causes global cooling</td>
<td>• Particles have higher settling velocity</td>
</tr>
<tr>
<td>• Not feasible based on our model!</td>
<td>• Cirrus clouds dissipate more quickly</td>
</tr>
<tr>
<td>• Cirrus clouds take many years to precipitate for upper estimates of parameters</td>
<td>• Less warming from cirrus clouds</td>
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Acknowledgement

Course Professor: Lynn Russell

Thank you!
References
