Understanding Ice Supersaturation and Particle Growth in Cirrus Clouds

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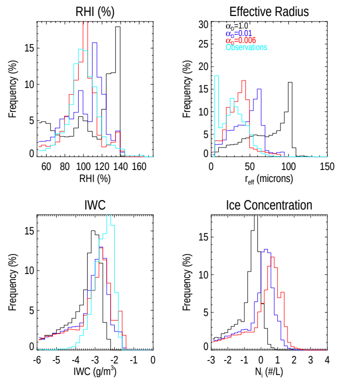
Introduction

Observations of large ice supersaturation in cirrus are explored using a 1D explicit-binned cirrus model. Particle growth rate (controlled through the deposition coefficient) and subgrid processes are examined as controlling factors in predicting observed relative humidity with respect to ice (RHI) and microphysical properties in cirrus clouds.

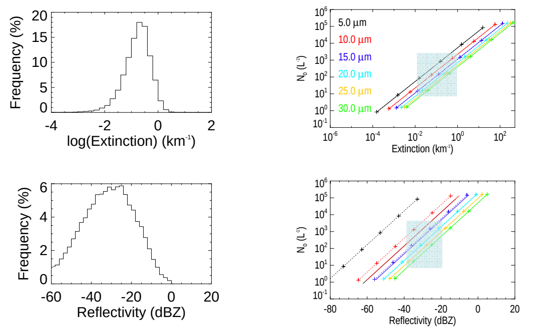
Fast vs. Slow Growth of Ice Crystals



- New laboratory measurements suggest that the deposition coef. (α_D) is ~0.006 for small ice crystals, indicating slower growth of crystals (Magee et al. 2006).
- Our model simulations indicate that the slow growth model gives consistent results in terms of RHI, r_{eff}, and IWC as compared with observations assuming conditions of large-scale ascent.
- RHI is drawn down in the slow growth run because more ice crystals nucleate, creating a larger total surface area available for water uptake. The result is smaller crystals with larger IWC.

What Number Concentrations are Reasonable?

Aircraft probes are believed to overestimate ice number concentrations. What does the remote sensing data predict?



Frequency Distribution of measured Raman Lidar Extinction and MMCR Reflectivity in Cirrus at SGP in 1999 and 2000.

Theoretical calculations of Extinction at 355 nm and 35 GHz Radar Reflectivity for gamma (dotted line) and bimodal (solid) size distributions for varying mode radii (colors).

Shaded region (right) indicates the range of ice crystal number concentrations (N_i) that explain the observed extinction and reflectivity values. The overlapping range of N_i for radar and lidar observations is between 10 and 1000 L^{-1}.

Summary

- RHI in cirrus is strongly influenced by the number of ice crystals that nucleate. Larger concentrations of smaller crystals draw down RHI closer to 100% due to more total surface area available for uptake of water vapor.
- Both slow growth of ice crystals and subgrid variability contribute to produce reasonable N_i, RHI, IWC, and r_{eff}.
- Subgrid water vapor variability varies with height (stronger near cloud top), which may act to dampen the effects of slow particle growth.
- Improved observations of the particle size distribution, RHI, and vertical velocity in cirrus will improve interpretation of simulations of ice cloud processes.

Details

- Case Details: Dec 7, 1999, Southern Great Plains
- Model: 1D model with explicit binned ice processes (Lin et al. 2005) modified to run in a single column model framework.
- Runs assume homogeneous nucleation, and initial thermodynamic profiles are from Raman lidar (water vapor) and radiosonde data. Vertical velocity is derived from ARM variational analysis data.
- IWC and r_{eff} are retrieved using the lidar-radar algorithm of Wang and Sassen (2002).

Effects of Sub-grid Variability and Water Vapor Uptake

Sub-grid variability is primarily caused by meso-scale cloud structures, which are not resolved in the 1D/SCM framework.

We estimate the sub-grid variability in water vapor (q) by calculating the uptake of water vapor using ARM remote sensing measurements combined with ARM variational analysis.

SG: Sub-Grid (relative to the SGP forcing) q forcing

$$q = \bar{q} + q'$$

q : local water vapor mixing ratio

$\bar{q}$: resolved by the SGP forcing data

q' : unresolveable by the SGP forcing data

$$SG = -\left(\bar{u}\frac{\partial q'}{\partial x} + u'\frac{\partial q}{\partial x} + \bar{v}\frac{\partial q'}{\partial y} + v'\frac{\partial q}{\partial y} + \omega'\frac{\partial q}{\partial p}\right)$$

$$\frac{\partial q}{\partial t} = \underbrace{-\bar{u}\frac{\partial \bar{q}}{\partial x} - \bar{v}\frac{\partial \bar{q}}{\partial y}}_{HQADV} \underbrace{-\bar{\omega}\frac{\partial q}{\partial p}}_{VQADV} + SG + \text{Evap/Sublimation}$$

Evap/Sublimation = -Uptake

Therefore, $SG = \text{Uptake} + \frac{\partial q}{\partial t} - \text{HQADV} - \text{VQADV}$

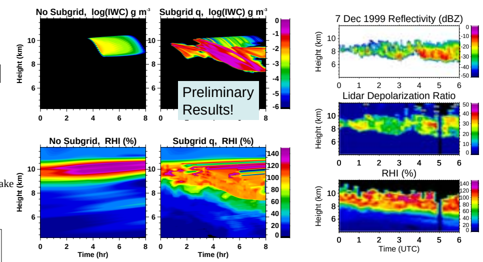
<u>How to obtain those terms on the RHS of the equation?</u>

Uptake: MMCR reflectivity, bext and RHI from Raman lidar, T from sondes

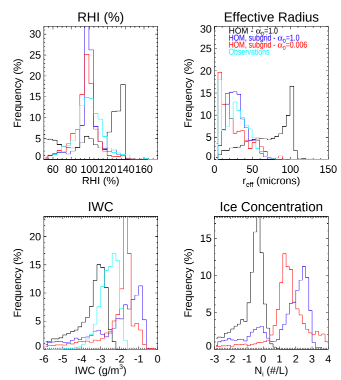
$\frac{\partial q}{\partial t}$: Raman lidar

HQADV: from the SGP forcing data

VQADV: $\frac{\partial q}{\partial p}$ from Raman lidar; $\bar{\omega}$ from the SGP forcing data



Including subgrid variability creates a more realistic simulation with improved cloud evolution.



Including subgrid variability does not "blow up" the effects of slow particle growth.

References

Lin et al., JGR, 2004JD005362, 2005

Magee et al., GRL, 2006GL026665, 2006

Wang and Sassen, JAM, 41, 2002.