Effects of Cloud Vertical Inhomogeneity on Ice Cloud Property Retrievals using Solar and IR methods

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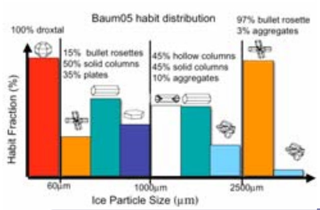
Introduction

Reality: Although most ice clouds have at least some degree of vertical inhomogeneity, they are usually assumed to be homogenous in the bi-spectral and the split-window methods which are two most widely used ice cloud property retrieval algorithms.

Questions: To what extent does the retrieval based on the homogenous cloud model represent the nature of real ice clouds? How is the retrieval dependent on the vertical inhomogeneity of ice clouds? Can inhomogeneity lead to significant discrepancy between the two method and why?

Ice particle model



The ice particle model used in this study is developed by [*Baum et al.*2005]. In this model, ice particles are categorized into six habits. The variation of ice particle habit with the maximum dimension is accounted for by the following size-dependent habit distribution

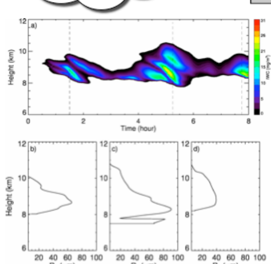
Retrieval Results

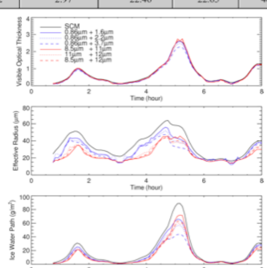
Case A: Small ones on top

Case B: Large ones on top

Case A				
$\tau_c = 3.0$; cloud top $r_e(0) = 15\mu m$, cloud base $r_e(\tau_c) = 45\mu m$; IWP=54 (g/m^2)				
λ (μm)	τ_c^*	r_e^* retrieval (μm)	r_e^* estimate (μm)	IWP retrieval (g/m^2)
0.86 + 1.6	2.87	25.81	26.56	44.44
0.86 + 2.2	2.85	25.40	25.47	43.43
0.86 + 3.7	2.66	20.73	22.10	33.04
11 + 12	3.16	24.39	24.10	46.24
8.5 + 11	3.06	23.61	22.10	43.34
8.5 + 12	3.06	24.00	22.65	44.06
Case B				
$\tau_c = 3.0$; cloud top $r_e(0) = 45\mu m$, cloud base $r_e(\tau_c) = 15\mu m$; IWP= 54 (g/m^2)				
λ (μm)	τ_c^*	r_e^* retrieval (μm)	r_e^* estimate (μm)	IWP retrieval (g/m^2)
0.86 + 1.6	3.07	30.64	31.60	56.43
0.86 + 2.2	3.08	30.96	31.28	57.21
0.86 + 3.7	3.28	34.78	33.81	70.53
11 + 12	3.15	24.57	24.10	46.43
8.5 + 11	2.99	20.26	22.10	36.34
8.5 + 12	2.97	22.46	22.65	40.02

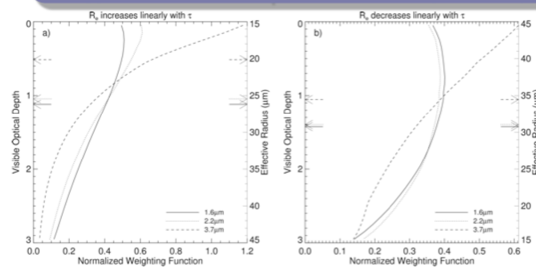
Single-Column ice cloud model





Single-column model is courtesy of J. Comstock

Effects on the Bi-spectral solar reflective method



Weighting function

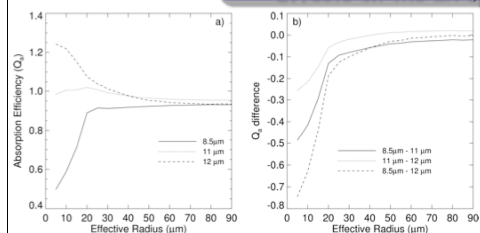
Platnick [*Platnick*, 2000] proposed that: if the bi-spectral method is used to retrieve the effective radius (R_e) of an inhomogeneous cloud (i.e., R_e varies with height) and the retrieval is based on the homogenous cloud model, the retrieved R_e can be related to the profile of R_e of the inhomogeneous cloud through a weighted integral

$$r_e^*(\lambda) = \int_0^{\tau_c} r_e(\tau) w(\lambda, \tau) d\tau$$

The weighting function, ***w*** is defined based on the "maximum penetration of reflected photons"

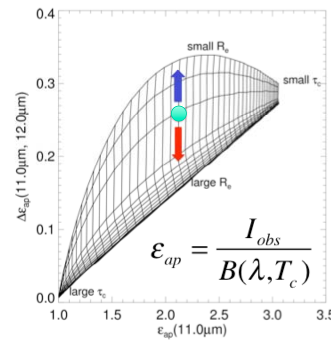
$$w_m(\lambda, \tau, \tau_c) = \frac{1}{R(\lambda, \tau_c)} \frac{dR(\lambda, \tau)}{d\tau}$$

Effects on the IR split window method



The IR split window method relies on the difference of ice particle absorption at different IR wavelengths for R_e retrieval:

- The absorption efficiency (Q_a) is an index of ice particle absorption.
- $Q_a(8.5\mu m) < Q_a(11\mu m) < Q_a(12\mu m)$
- The difference is larger when ice particles are small and decreases quickly with R_e. When ice particles become large enough, the difference is very small.



In the light of the success of the weighting function in the Bi-spectral solar reflective method, we derive a set of weighting function for the IR split-window method. The weighting function reveals that **1)** Cloud and surface contributions are both important in determining the ε_{ap} and therefore both important for optical thickness retrieval. **2)** There is a cancellation mechanism working so that the contribution from cloud emission to $\Delta\varepsilon_{ap}$ is almost negligible