Sensitivity of climate simulation to changes in the mean effective size of ice particles using the CCCma GCM3

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- Introduction
- Parameterization of the mean effective size of ice particles
- CCCma climate simulation
- Finally summarize conclusions

The role of ice clouds

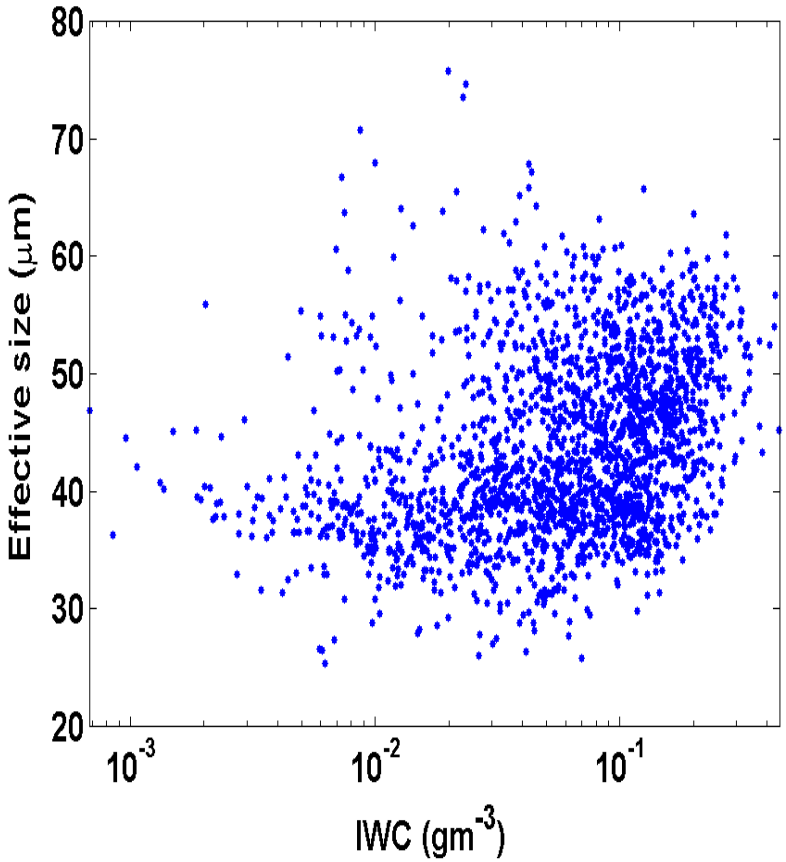
- Effect on climate (no well understood)
  - Due to poor parameterization of the optical properties of ice particles in models
- Climate models are not capable of simulating ice particles SD, thus parameters that are useful for deriving optical parameters such as D_{ge} and A_C should be parameterized, but how to parameterize this quantity and how it varies with geographic location is still a contentious issue
- Currently some of the challenging problems are
  - Measurement of small ice particles
  - Measuring or derivation of ice mass in general
- There are some parameterizations of ice particles SD in the mid and Tropical regions, but they suffer all from the same problems.
- In this study Boudala et al. (2002) D_{ge} parameterizations are tested using the CCCma GCM3

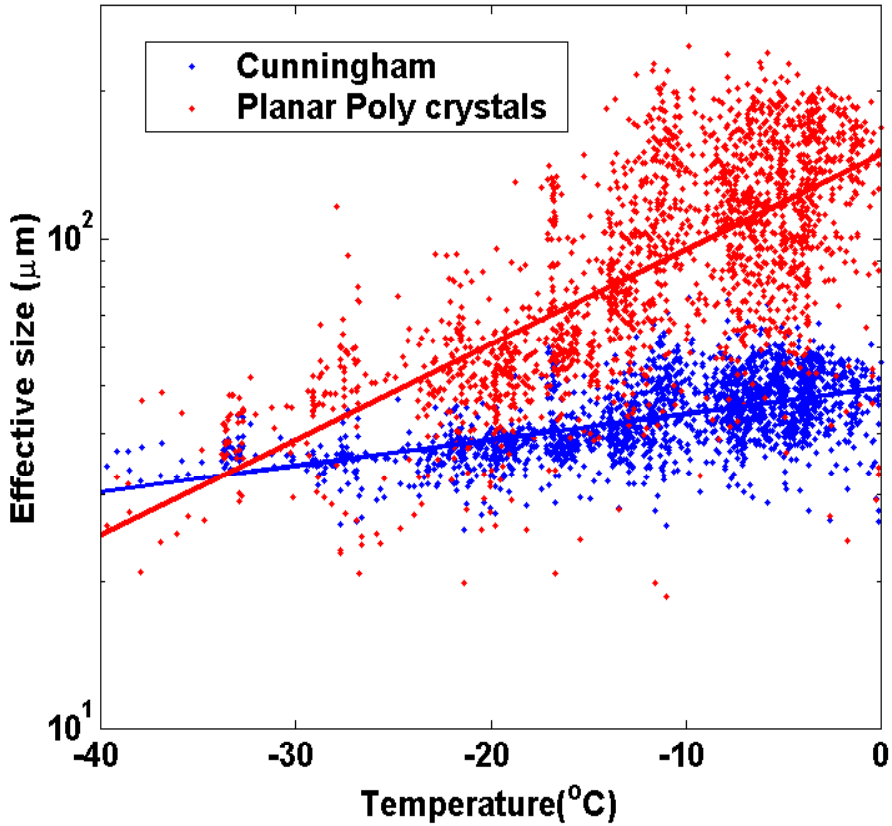
The definition of the mean effective size of ice particles

$D_{ge} \sim IWC/p_i A_c$ (Fu et al. (1996), others)

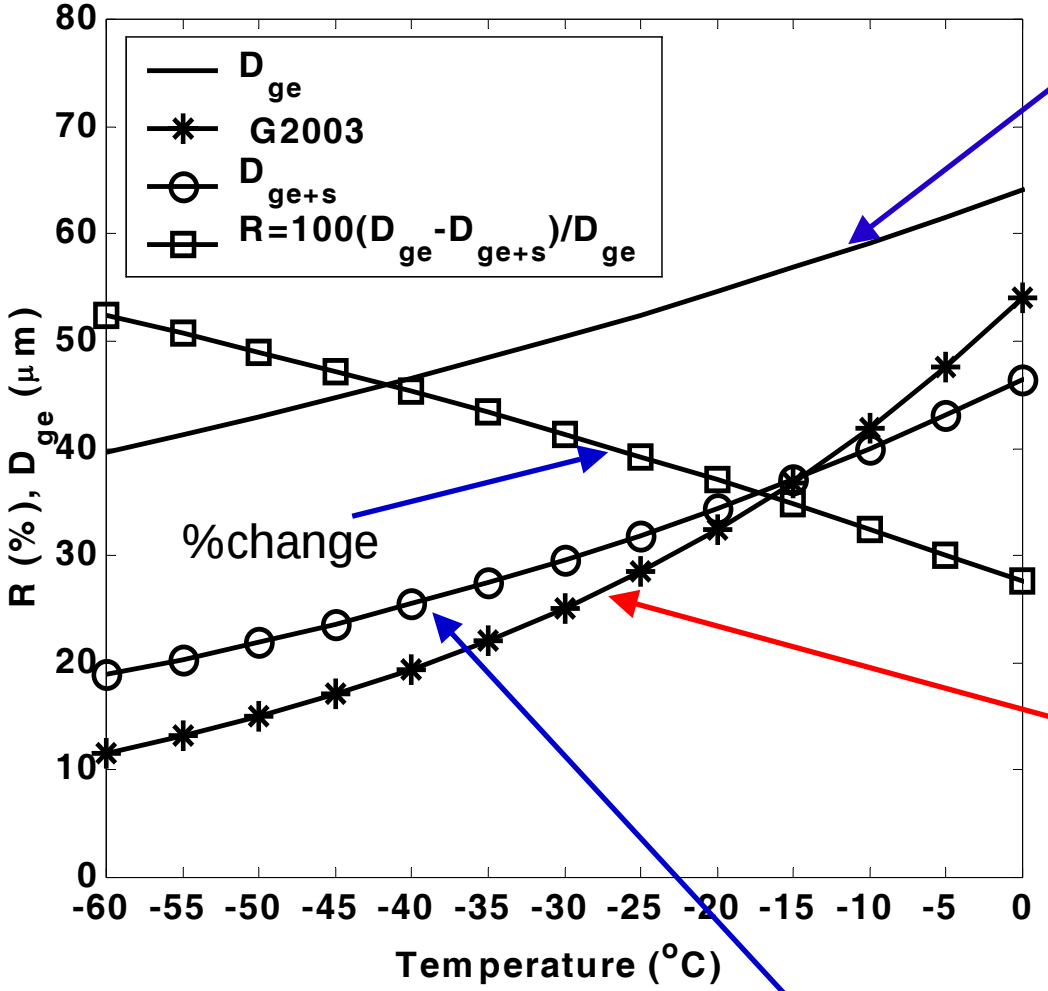
- A_c the mean cross-section area per unit volume of ice particles can be measured with optical probes at least for particles greater than 4 pix
- The measurement or estimation of IWC and the reliably to determine the density of ice particles are more difficult

The dependence of the mean effective sizes of ice particles on IWC, temperature, and particle shape





The temperature dependence of Dge parameterization



Without small ice particle
Boudala et al.(2002)

Garrett et al. (2003)

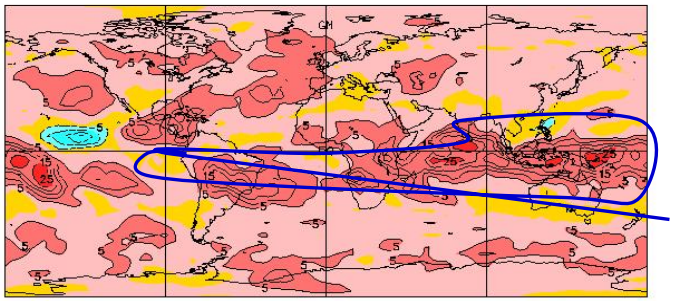
With small ice particles
Boudala et al.(2002)

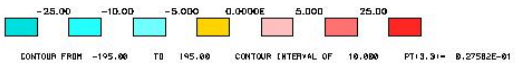
GCM 5 year interactive simulation

- $D_{ge+s}(T)$ and D_{ge}
- $D_{ge+s}(T,IWC)$
- Optical properties are parameterized as a function of IWC and T
- Cloud water contents are diagnosed based on adiabatic condensation assumption
- Cloud cover is diagnosed based on RH

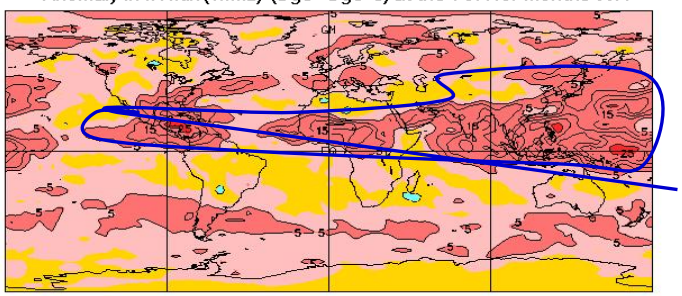
The OLR anomaly is correlated well with Satellite observation of high clouds (Wylie and Menzel,1999, *J. Climate*)

Anomaly in IR flux (W/m2) (Dge -Dge+s) at the TOA for months DJF

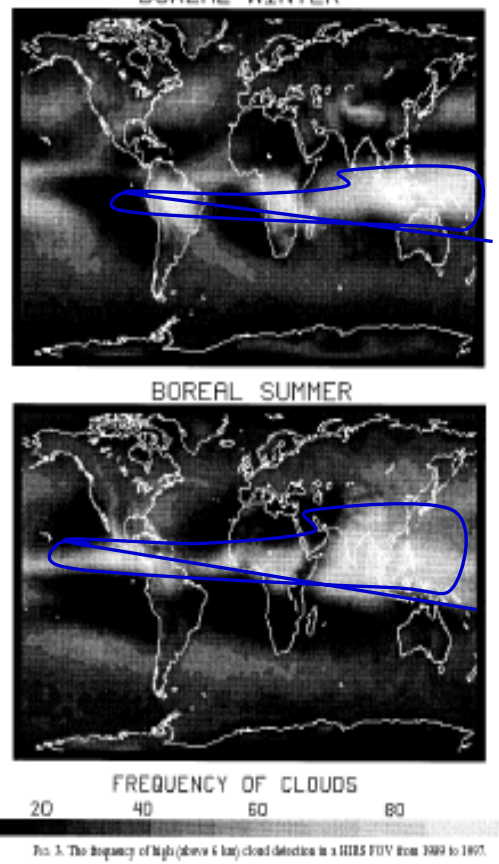




Anomaly in IR flux (W/m2) (Dge - Dge+s) at the TOA for months JJA

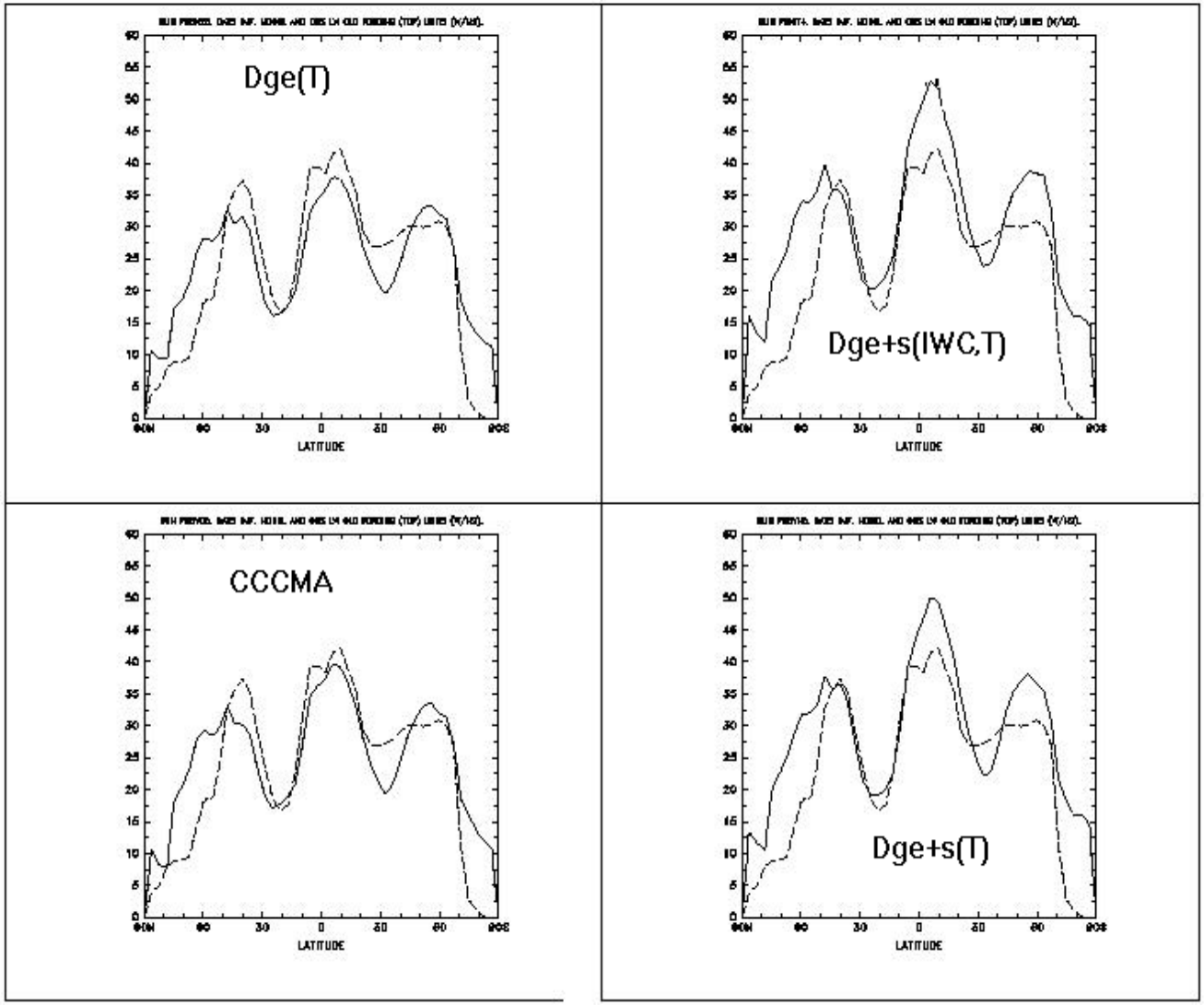


Frequency of high clouds



Zonally averaged long wave cloud forcing at the TOA: Model and satellite in Winter

5 DJFs, long wave cloud forcing



$D_{ge}(T)$ = without small particles

$D_{ge+s}(T)$ = with small particles

$D_{ge+s}(IWC,T)$ = with small particles

The dash line is ERBE satellite observation

- **The forcing is more significant in the Tropics with small particles**
- **For extra-tropical, including small ice particles appear to improve certain regions compared to observations**
- **The effect of IWC seems to be insignificant**

Why is that the OLR anomaly at the TOA is more sensitive in the Tropics?

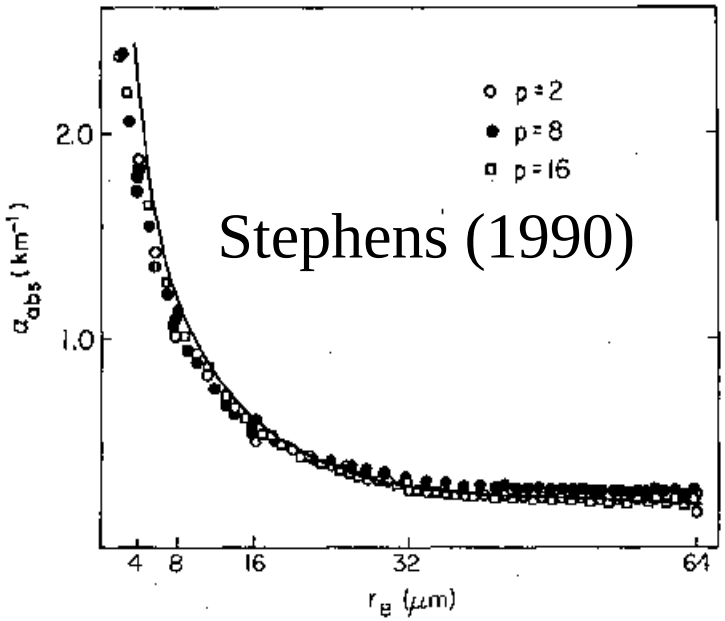
- The effect of change in clouds?
  - It is possible, but moisture and temperature anomalies are not significant
- One possible explanation could be the change in the D_{ge} parameterizations with temperature

Optical effect of small ice particles

$$\beta = \mathrm{IWC}(a_0 + a_1/D_{ge} + a_2/D_{ge}^2), \quad (3.1)$$

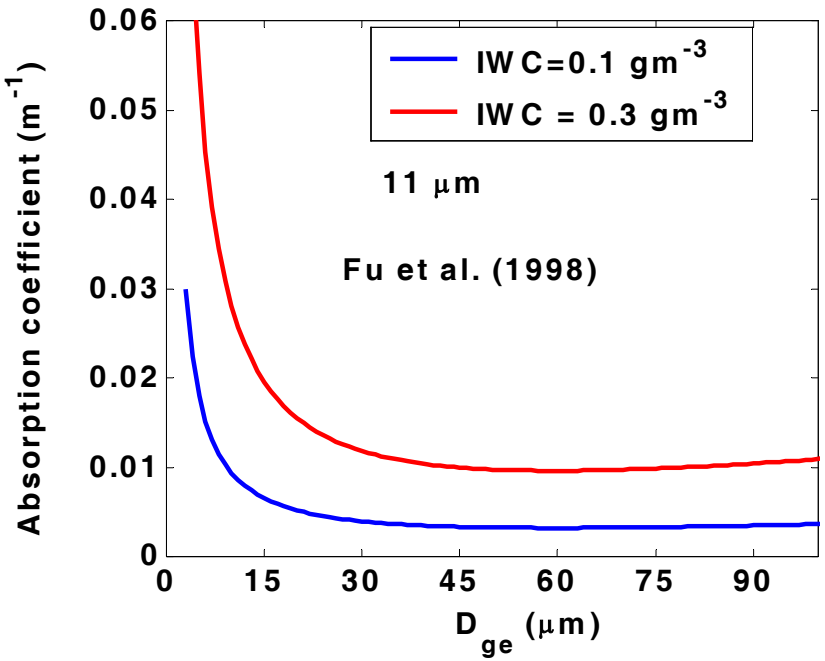
$$\beta_a = \frac{\mathrm{IWC}}{D_{ge}}(b_0 + b_1 D_{ge} + b_2 D_{ge}^2 + b_3 D_{ge}^3), \quad (3.2)$$

$$g = c_0 + c_1 D_{ge} + c_2 D_{ge}^2 + c_3 D_{ge}^3, \quad (3.3)$$



Stephens (1990)

FIG. 3. The relationship between 11 μm volume absorption coefficient and the effective radius as derived from Mie theory using the size distribution given by (17) in the text for the three values of p indicated and for fixed value of $w = 0.01$ g m^{-3}.



The change in global cloud forcing due to small ice particles

The net cloud forcing W/m^2

	with	without	change
Summer	-19	-21.4	2.4
Winter	-20.48	-22.18	1.7

These values are comparable to the current radiative forcing of climate due to an increase in CO2, and all other well mixed green house gases since t pre industrial time which are estimated to be about 1.46 and 2.43 W/m2 respectively (Ramaswamy et al. 2001).

Summary of GCM simulation

- **The application of D_{ge} in the current GCMs is uncertain**

Sensitivity to addition of small particles

- **IR radiation**
  - Less energy flux at the top of the atmosphere (more absorption)
  - More pronounced in the tropics
- **Solar radiation**
  - Increased cloud forcing (more reflection)
- **The net effect is spatially variable, but globally induces warming**
- **Model Comparisons of $D_{ge}(T)$, $D_{ge}(T,IWC)$**
  - CCCMA and $D_{ge}(T)$ gave similar results.
  - No significant difference between D_{ge+s} (T) and $D_{ge+s}(T,IWC)$.
- **With observation**
  - Hard to compare since CCCMA D_{ge} is tuned, but generally including small particles seems to improve the model results particularly in the Northern hemisphere mid-latitude, but not in the tropics and the tropics is better captured by $D_{ge}(T)$ simulation . This suggests that D_{ge}s in the tropics are larger. But, the recent result by Garrett shows that is not the case. This could be that the CCCma GCM has been tuned with unrealistically large D_{ge} to mach the observations.


Thank You Very Much
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Similar trends in shortwave cloud forcing

5 DJFs, Short wave cloud forcing