Ice Fall Speed Parameterizations: Results from SPARTICUS

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Introduction

General Circulation Models (GCMs) are highly sensitive to the representation of clouds and their feedbacks. According to a study by Sanderson et al. (2008), the ice fall velocity (V_i) is the second most important factor affecting the global feedback parameter in GCMs.

However, V_i in climate models is highly uncertain due in part to its dependence on the ice particle size distribution (PSD), which has been plagued with measurement uncertainties from small ice particles produced by shattering. Data processing techniques used in conjunction with new probes in recent field campaigns have significantly reduced the artifact concentration of small ice particles .

The ice mass sedimentation rate (V_m) in mid-latitude cirrus is parameterized in terms of cloud temperature (T) and ice water content (IWC), and also by relating V_m to ice particle effective diameter (D_e). Although the correlations of V_m and D_e with T were higher than the correlations of V_m and D_e to IWC, it is demonstrated that V_m is better predicted by using both T and IWC.

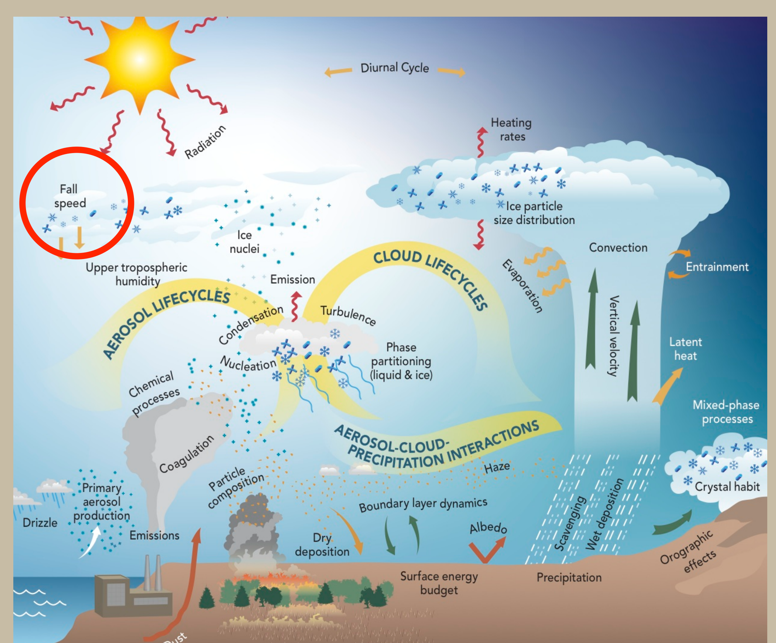


Fig. 1(a) Atmospheric Processes
(Source: http://asr.science.energy.gov)

Fig. 1(b) 2D-Stereo (or 2DS probe)
(Source: *Lawson et al, 2006: J. Atmos. And Oceanic Tech.)*

Figure 1(a) shows various atmospheric process that affect earth's climate and seasonal variability. We are addressing **fall** speed which affects cloud life time. Cloud life time is vital to the estimation of the earth's radiation budget and hence climate sensitivity.
Figure 1(b) shows the 2DS probe. Two diode laser beams cross at right angles and illuminate two linear 128-photodiode arrays that work independently as high-speed and high-resolution optical imaging probes. To accurately estimate ice mass sedimentation rates, accurate measurements of the PSD regarding ice particle number, projected area and mass are needed. The 2DS probe measures these 3 quantities from 10 to 1280 µm, using an ice particle projected area-mass relationship to estimate the size-resolved mass concentrations.

Theory

This study uses 2D-S data from SPARTICUS, a recent field campaign sampling mid-latitude cirrus. The treatment of D_e (effective diameter) is general for liquid, mixed phase and ice clouds and is expressed as:

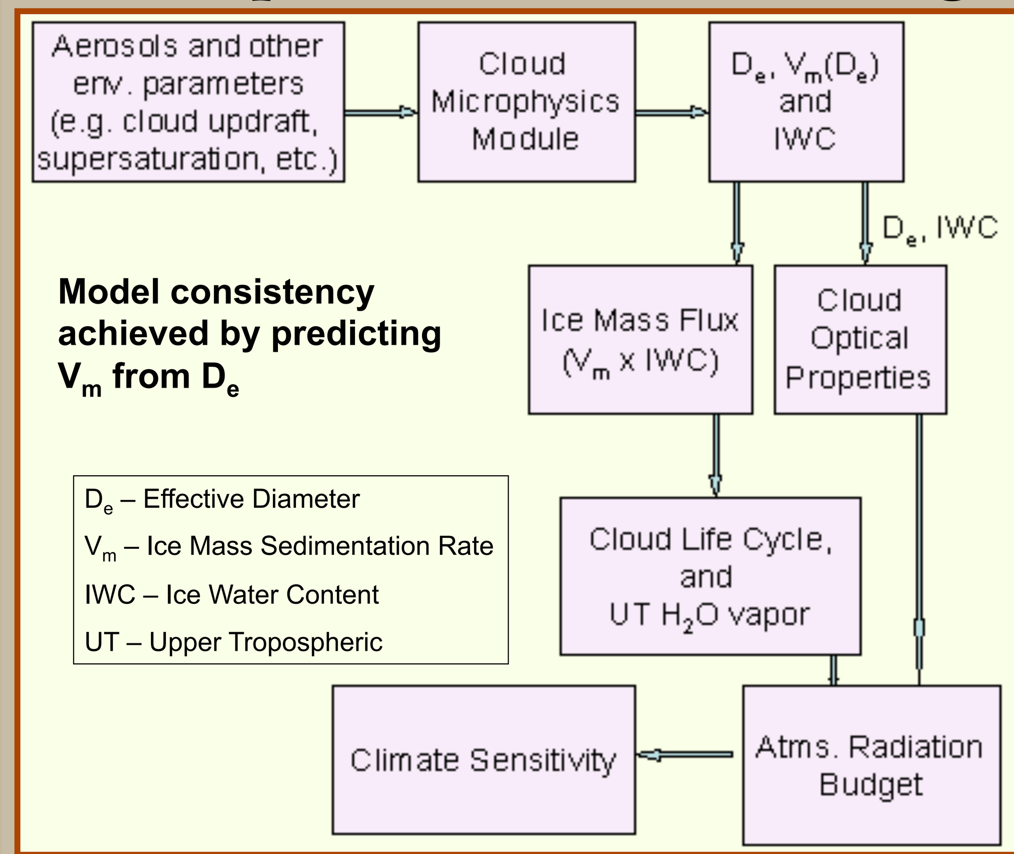
$$D_e = 3/2(IWC/\rho_i A_t)$$

V_i (ice particle fall speed) is calculated by using two different methods, namely the Mitchell-Heymsfield (2005) method (MH) and the Heymsfield-Westbrook (2010) method (HW). V_i is generally expressed as:

$$V_i = aD^{\beta}$$

In the above equations:
ρ_i = bulk density of ice (0.917gcm-3), A_t = total projected area of the PSD, $V_i(D)$ = ice particle fall velocity, D = ice particle maximum dimension, a and β constants are based on measurements of ice particle habits.

Steps Involved in Predicting Climate Sensitivity

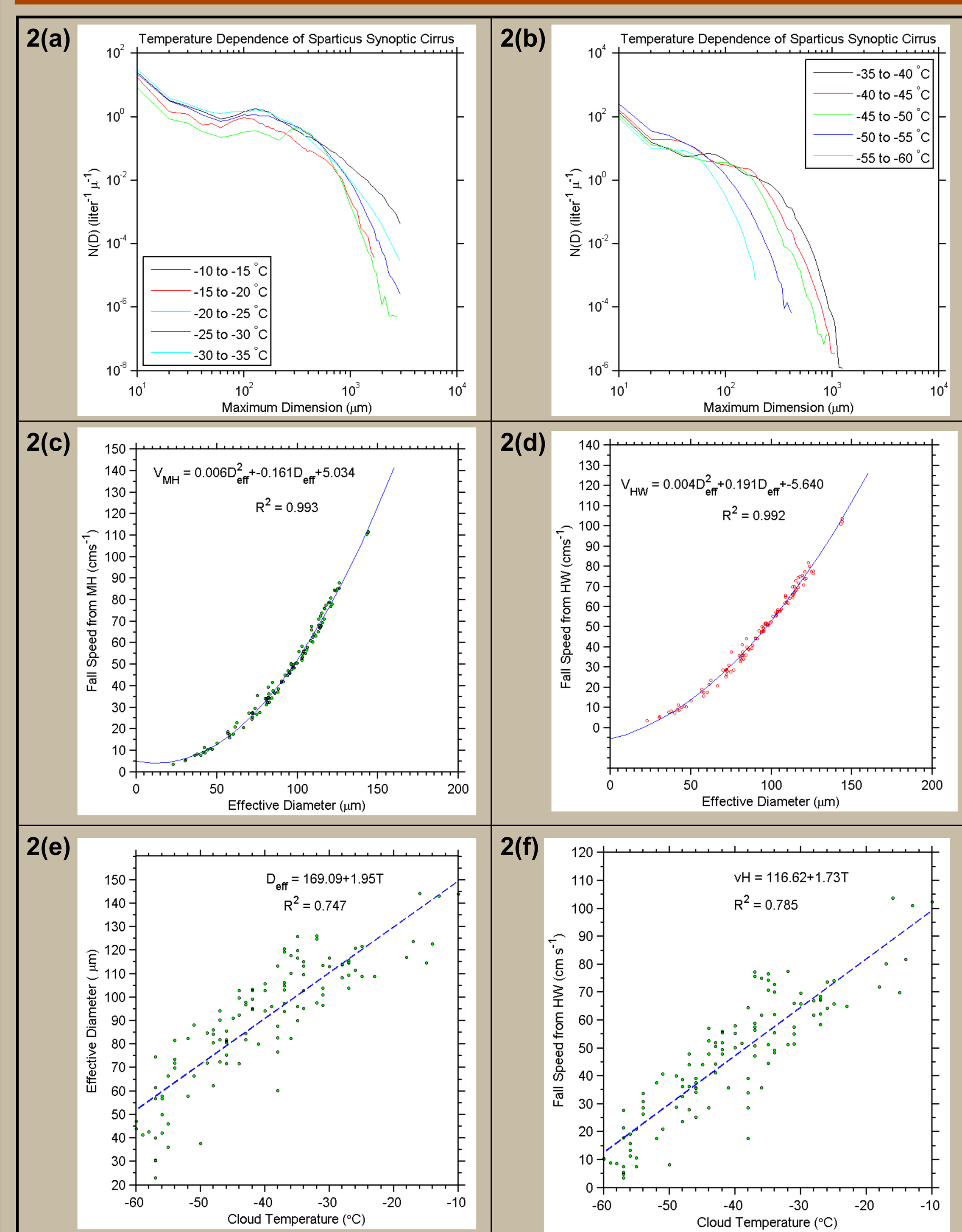


The adjacent block diagram shows processes that can affect climate sensitivity. Since V_m is a critical feedback parameter in climate models, it is important that V_m be realistically coupled with the cloud microphysics module and the cloud optical properties. This is accomplished by expressing V_m in terms of D_e, provided that D_e is predicted by the microphysics module and then passed on to the radiation component of the model. Note that a mere diagnostic treatment of V_m may render it insensitive to microphysics and microphysics-radiation interactions, neutralizing much of the cirrus climate feedback.

Selected Case Studies

Sparticus Anvil Cirrus	Sparticus Synoptic Cirrus
April 22nd, 2010 (Flight A)	Jan 19th, 2010 (Flight A)
April 28th, 2010 (Flight A & B)	Jan 20th, 2010 (Flight A & B)
June 12th, 2010 (Flight A & B)	Jan 26th, 2010 (Flight A)
June 14th, 2010 (Flight A)	Jan 27th, 2010 (Flight A)
June 15th, 2010 (Flight A)	Feb 11th, 2010 (Flight A & B)
June 24th, 2010 (Flight A & B)	March 23rd, 2010 (Flight A, B & C)
	March 26th, 2010 (Flight A)
	April 1st, 2010 (Flight A & B)

14 case studies were selected with six Anvil cirrus and eight cases representing Synoptic cirrus. Cloud segments were identified for each case by making sure that they contained no liquid water, had good sampling statistics, utilized a good fraction of the data, & were sampled under steady microphysical conditions



Results

2(a) and 2(b) show the dependence of ice PSD on temperature (T). A closer look at the figures shows the PSDs exhibit little T-dependence when T > -35C, but when T < -35C, the PSDs get narrower with colder temperatures.

In 2(c) and 2(d) V_m derived by using MH and HW methods is related to D_e and fitted by polynomial curves. V_m and D_e are related mathematically since V_m depends on the ice particle mass to area ratio while D_e depends on the ratio IWC/A_t. This results in a strong correlation between V_m and D_e.

In 2(e) and 2(f), D_e and V_m are related to temperature. D_e and V_m were also related to IWC. The correlation was higher for relations of D_e and V_m with T compared to IWC, as shown above in the right column. These results can be used to test and validate D_e and V_m predictions from various model microphysics modules.

Results (continued)

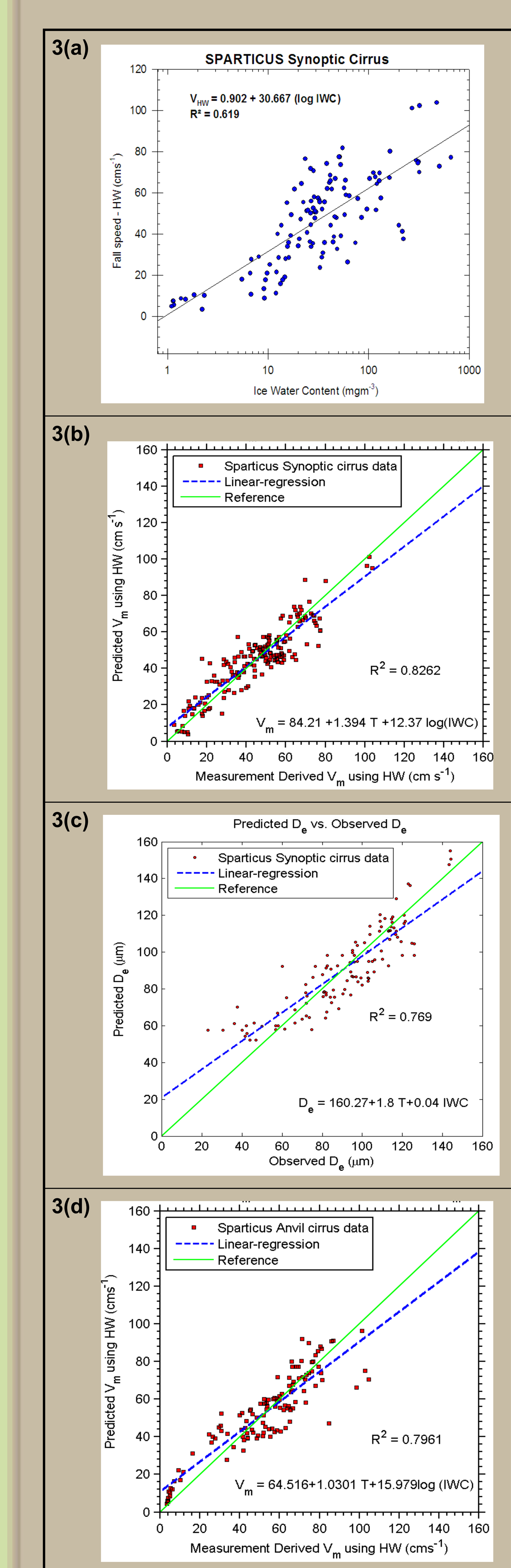


Figure 3(a) relates V_m to the cloud ice water content for synoptic cirrus sampled during SPARTICUS. While r^2 is not as large as with the V_m-T relationship, it still explains 62% of the variance, suggesting a multiple regression using both T and IWC may be more powerful in diagnosing V_m.

This multiple regression is shown in Figure 3(b), where V_m is predicted through T and IWC. Figure 3(c) shows a similar multiple regression for predicting D_e by relating it to both T and IWC. Using both T and IWC results in a significant improvement in diagnosing V_m, while the improvement in predicting D_e is relatively small.

Figure 3(d) shows the multiple regression relating V_m to T and IWC for anvil cirrus sampled during SPARTICUS. Similar to the synoptic cirrus case, it is observed that V_m is better predicted by using both T and IWC.

Discussion

Climate modeling can be improved through the development of physically based parameterizations that are coupled with various model components, such as the cloud microphysics, radiation and dynamics. This is achieved by relating V_m to D_e. In two-moment ice microphysical schemes that predict both the ice mixing ratio and number concentration, De is often predicted based on the IWC and PSD projected area, which require assumptions about the PSD and ice particle shape. Thus, predicting V_m from D_e provides self-consistency between V_m, D_e and assumptions about the PSD and ice particle shape.

Climate modeling can also be improved by relating predicted variables such as V_m to measured quantities such as T and IWC. The fairly robust relationship between V_m and (T, IWC) may provide a more rigorous test for climate models to reproduce. Models reproducing this relationship are more likely to have model physics that are consistent with that of the real world. However, if climate models predict V_m in terms of T and IWC only, it may mask some of the coupling between the cloud microphysical and optical properties since V_m is also dependent on the PSD projected area.

Summary

The results produced from this study indicate that improved measurements using the 2DS probe have resulted in better estimates of D_e and V_m. Simple representation of the mean behavior of D_e and V_m in a climate model may produce misleading results since V_m is a powerful climate feedback parameter.

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