Representing the Ice Fall Speed in Climate Models: Results from TC4, SPARTICUS and ISDAC

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Motivation

• Global Climate 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 climate sensitivity in GCMs.
Satellite Images Help Determine Cloud Type (Anvil/Synoptic Cirrus)

Source: P. Minnis (NASA Langley)

http://www-angler.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=ARM-SPARTICUS
General Approach

• The size resolved 2D-S measurements of number, projected area and mass concentration appear reasonable.
  - Ice artifacts from shattering greatly reduced
  - Good agreement between 2D-S and CVI IWC during TC4

• 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:
  \[
  D_e = \frac{3}{2}(\text{IWC}/\rho_i A_t)
  \]

• \( V_i \) (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).

• Applying the above methods to the 2DS measurements, \( D_e \) and \( V_m \) (the PSD mass weighted fall-speed) were expressed as:
  \[
  V_m = \sum V_i(D) m(D) N(D) \Delta D / \sum m(D) N(D) \Delta D
  \]
  \[
  D_e = \frac{3}{2} \sum m(D) N(D) \Delta D / (\rho_i \sum A(D) N(D) \Delta D)
  \]
A: Time series of the 2D-S and CVI IWC for a TC4 case study. CVI response time lagged 6 seconds behind 2D-S measurements, producing a slight offset.  
B: 2D-S IWCs compared with CVI IWCs for 12,000 1-Hz measurements (averaged over 10-s) in TC4 anvils cirrus.
Comparison Between MH(2005) and HW(2010) schemes

\[ V_{HW} = 0.9364 \, V_{MH} + 0.3 \]
\[ r^2 = 0.9956, \, N = 59 \]

\[ V_{HW} = 0.8033 \, V_{MH} + 7.5 \]
\[ r^2 = 0.9316, \, N = 162 \]
SPARTICUS Synoptic Cirrus PSDs from 2DS

Temperature Dependence of Sparticus Synoptic Cirrus

N(D) (liter$^{-1}$m$^{-1}$)

Temperature Ranges:
- -10 to -15 °C
- -15 to -20 °C
- -20 to -25 °C
- -25 to -30 °C
- -30 to -35 °C

Maximum Dimension (µm)

Temperature Ranges:
- -35 to -40 °C
- -40 to -45 °C
- -45 to -50 °C
- -50 to -55 °C
- -55 to -60 °C

Maximum Dimension (µm)
SPARTICUS SYNOPtic CIRRUS: $V_m$ vs. $T$ and $V_m$ vs. IWC

**SPARTICUS Synoptic Cirrus**

\[ vH = 116.617 + 1.734T \]
\[ R^2 = 0.7846 \]

**SPARTICUS Synoptic Cirrus**

\[ V_{HW} = 0.902 + 30.667 \log(IWC) \]
\[ R^2 = 0.619 \]
SPARTICUS $V_m$ and $D_e$ Related To IWC & T

**Predicted $V_m$ (HW) vs. Observed $V_m$**

- **Equation**: $V_m = 105.595 + 1.55 T + 0.05 \text{IWC}$
- **$R^2$**: 0.831

**Predicted $D_e$ vs. Observed $D_e$**

- **Equation**: $D_e = 160.27 + 1.8 T + 0.04 \text{IWC}$
- **$R^2$**: 0.769
TC4 $V_m$ Related To IWC & T

Predicted $V_m$ vs. Observed $V_m$

- Aged cirrus
- In situ cirrus
- Anvil cirrus
- Linear-regression
- Reference

$R^2 = 0.75$

$V_m = 102 + 1.27 \, T + 0.0152 \, IWC$

Units: IWC - mg m$^{-3}$, $T$ - °C
SPARTICUS Fall Speed Related To $D_e$ Using:

$$V_{HW} = 0.004D_{eff}^2 + 0.191D_{eff} - 5.640$$
$$R^2 = 0.992$$

$$V_{MH} = 0.006D_{eff}^2 - 0.161D_{eff} + 5.034$$
$$R^2 = 0.993$$
TC4 and ISDAC Fall-speed Related to $D_e$

Heymsfield 2003, TRMM data

TC4 Anvil Cirrus
TC4 Aged Anvil Cirrus
In Situ Cirrus

$T = -20^\circ C$
$p = 500$ mb

$V_m = 0.8052 \times D_e - 25.4$
$r^2 = 0.9647, N = 59$

$V_m = 0.7260 \times D_e - 21.2$
$r^2 = 0.911, N = 162$
Model consistency achieved by predicting $V_m$ from $D_e$