Evaluation of cloud ice/snow size distributions and fallspeeds in CAM5 using observations

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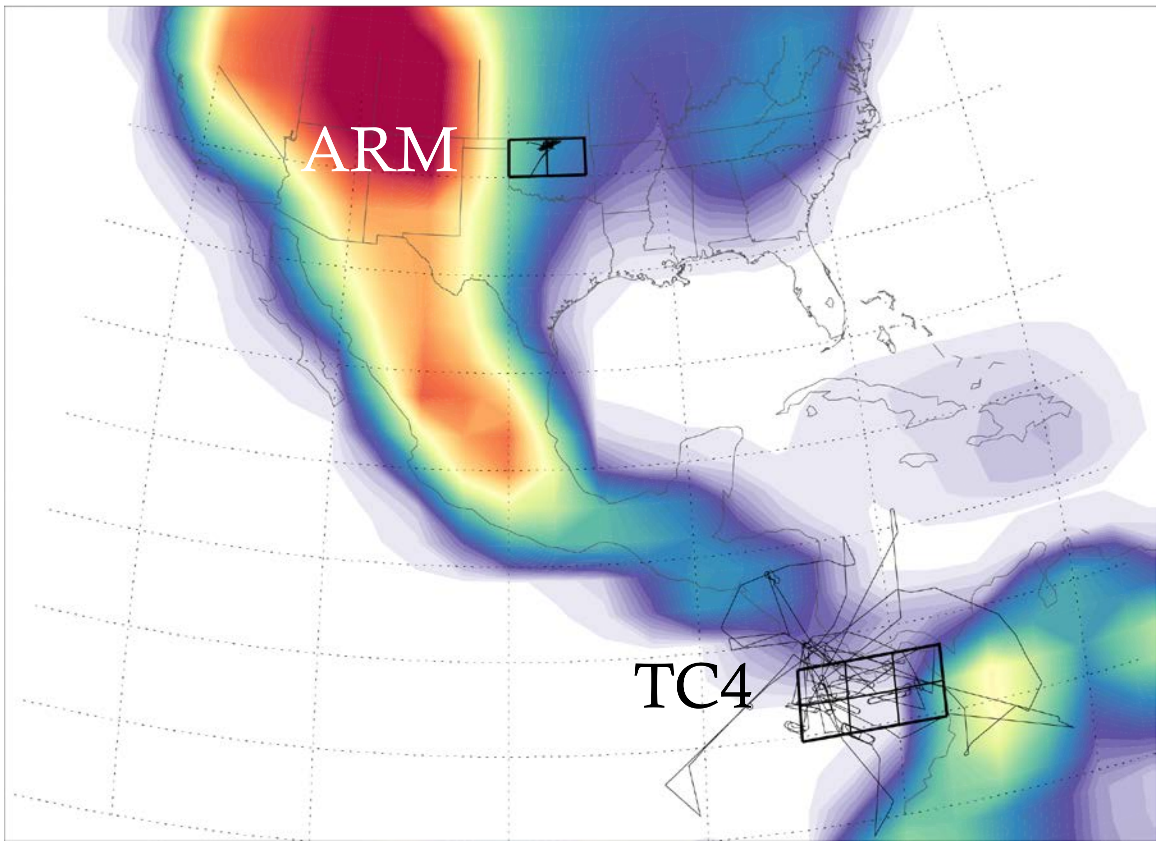
Introduction/motivation

- Ice microphysics in models is responsible radiative forcing.
- Important to represent microphysics in the most realistic/physical-based way.
- Some issues with the global model CAM (Community Atmosphere Model)
  - Different representation of snow and ice, partitioning into different species with specific characteristics (particle density, fallspeed).
  - Parameterizes autoconversion from ice to snow, assuming an arbitrary particle size.
  - Empirical relations, such as fallspeed parameters are used beyond appropriate size range
  - Inconsistent treatment of ice particle shape effects for different processes/parameters (e.g., effective radius, fallspeed)

With these limitations, how well does CAM perform in regards to microphysical parameters (size distribution, fall speed, concentration) compared to measurements?

How does changes in autoconversion settings change microphysical parameters?

Measurements



Stratiform case (in situ synoptically generated cirrus clouds)

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Spring Cloud IOP,
March 2000, Oklahoma

Convective case (convectively formed cirrus clouds)

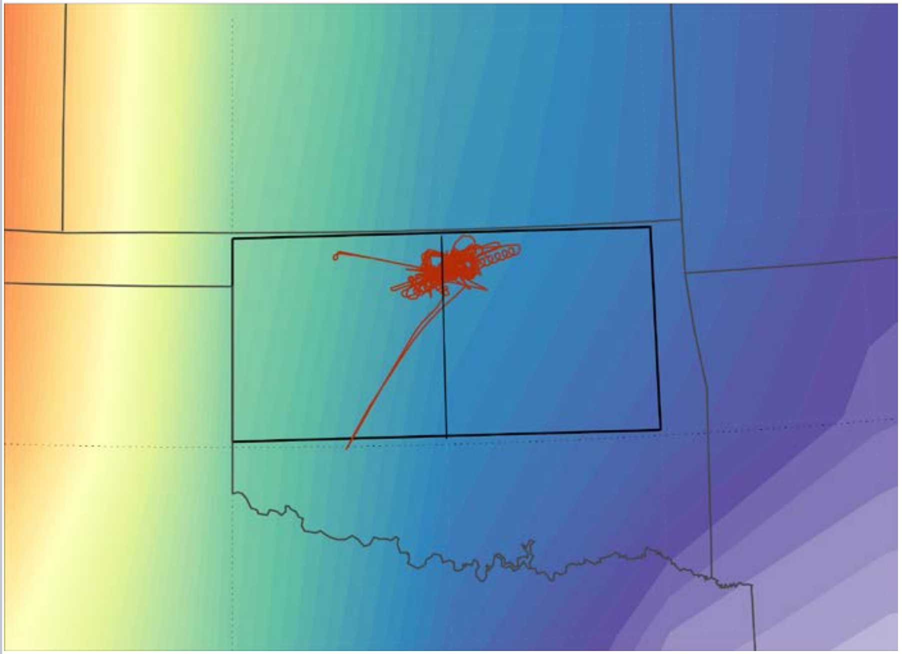
TC4

Tropical Composition, Cloud and Climate Coupling mission,
July 2007, Costa Rica

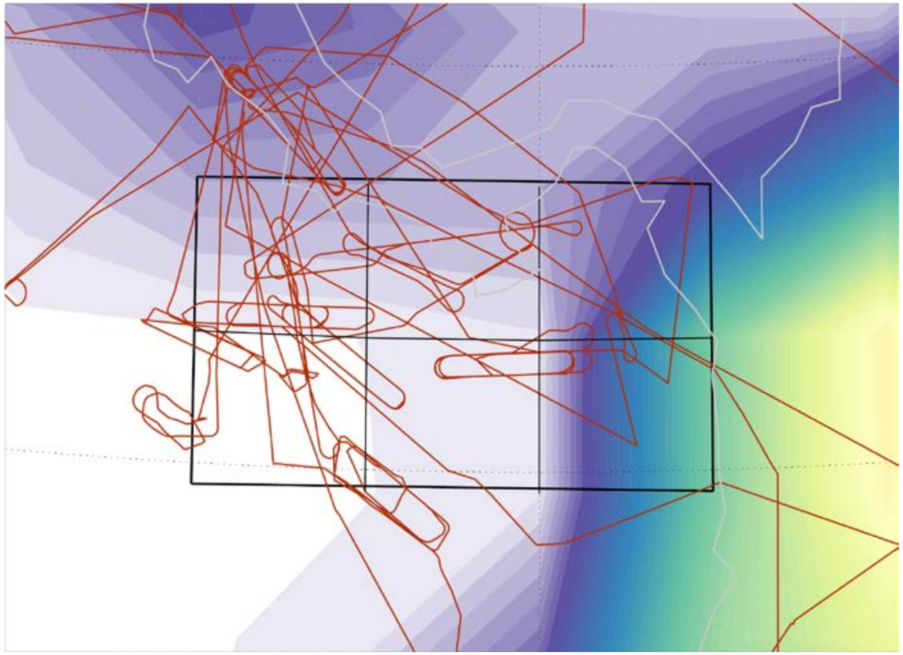
Heymsfield et al. (2013, JAS, in print)

Flight tracks and model grid boxes

ARM: CAM model results from March



TC4: CAM model results from July



Resolution: 1.9° x 2.5°

Snow and ice size distributions

Snow and ice size distributions are typically represented with gamma functions:

$$\phi(D) = N_0 D^{\mu} e^{-\lambda D}$$

λ: Shape parameter

N_0: Intercept

μ: Dispersion (in CAM, μ= 0 -> size distribution is exponential)

MOMENTS

$$M_k = \int_{D_{min}}^{\infty} N_0 D^k e^{-\lambda D}\, dD$$

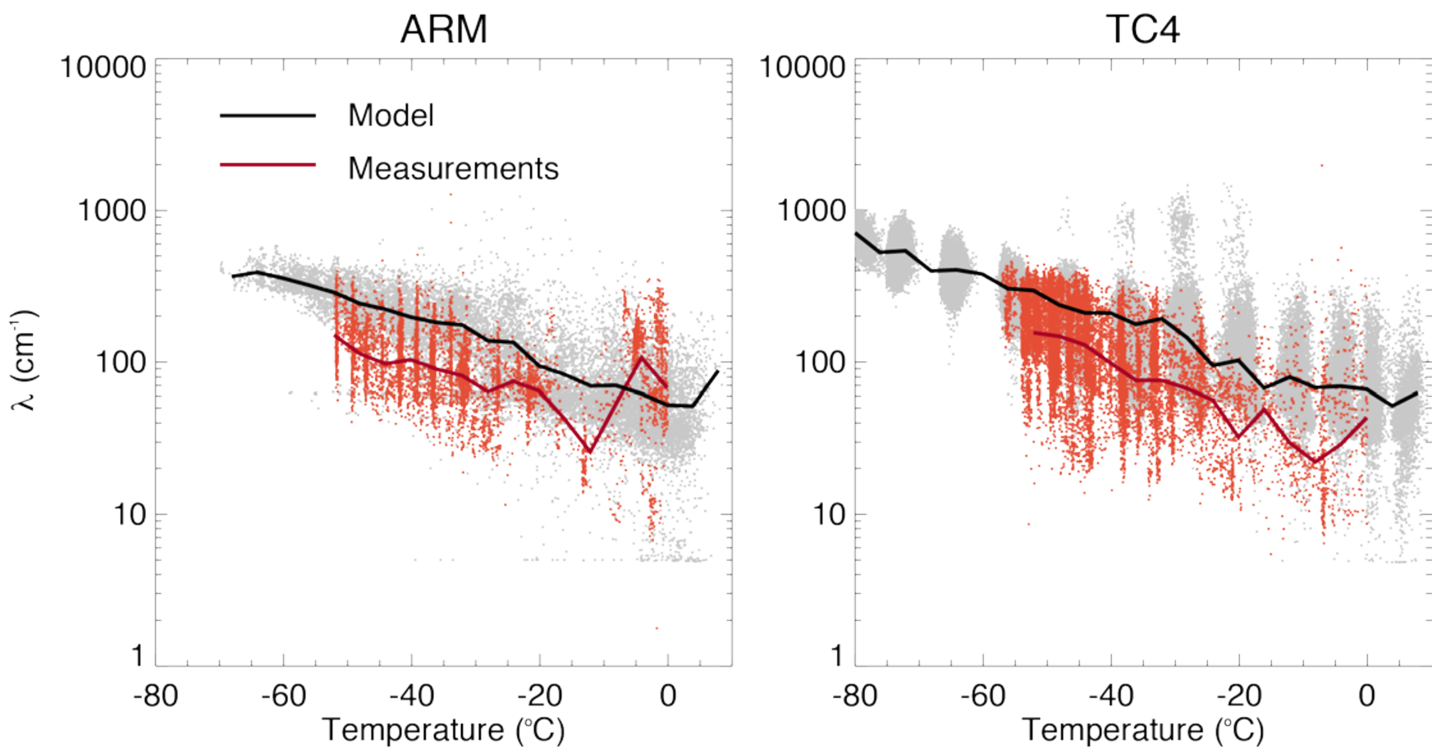
Here D_{min}=75 μm (cut of size for measurements)

Shape parameter (λ)

$$\lambda = \left(\pi\rho\frac{N}{q}\right)^{1/3}$$

N: number concentration
q: mixing ratio

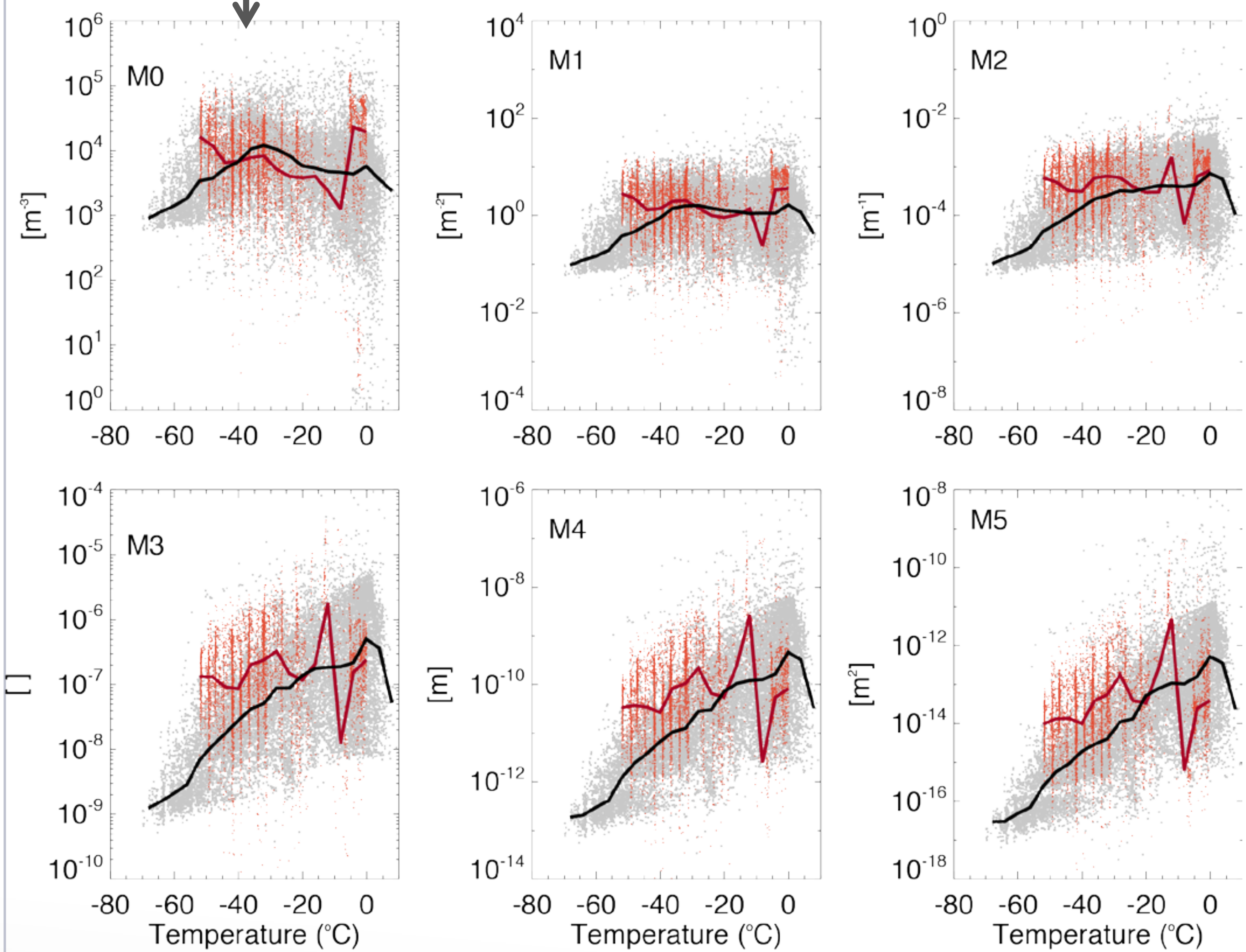
$$\phi(D) = N_0 D^{\mu} e^{-\lambda D}$$



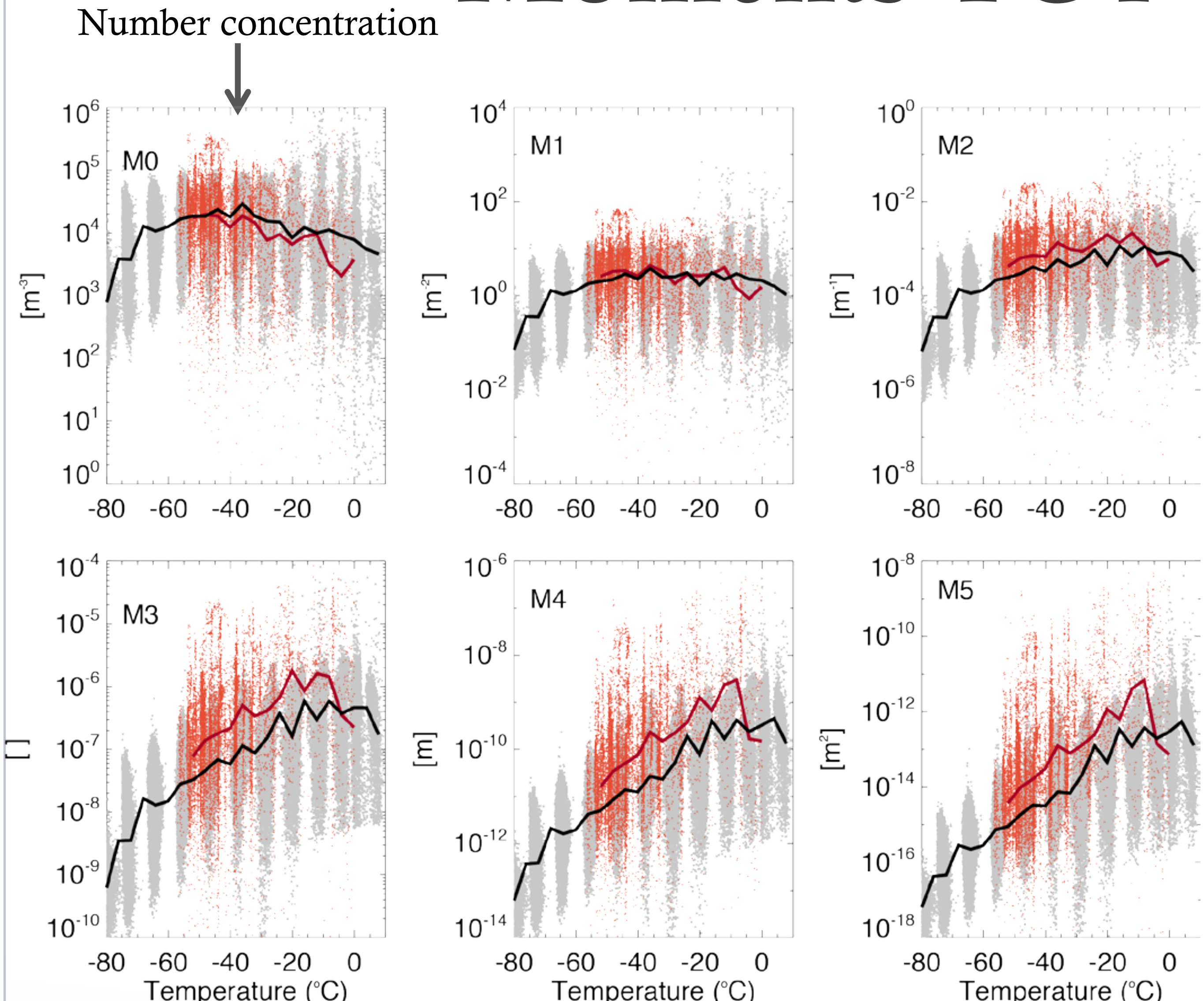
Moments ARM

Number concentration

Red: Measurements
Black: Model



Moments TC4



Red: Measurements
Black: Model

Fall speed parameters

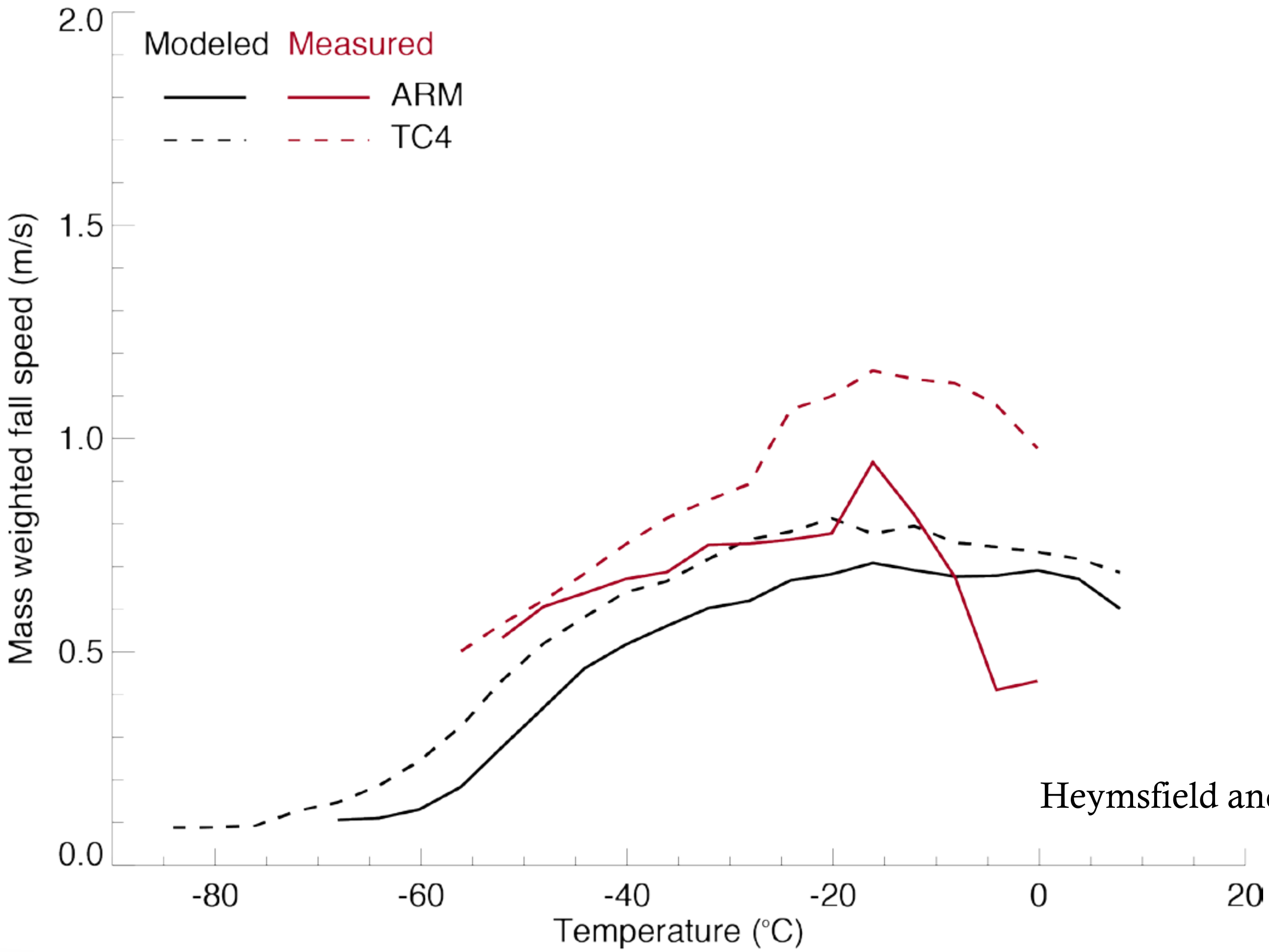
$$V_t = aD^b$$

Measurements can provide estimates for a and b

Mass weighted fall speed

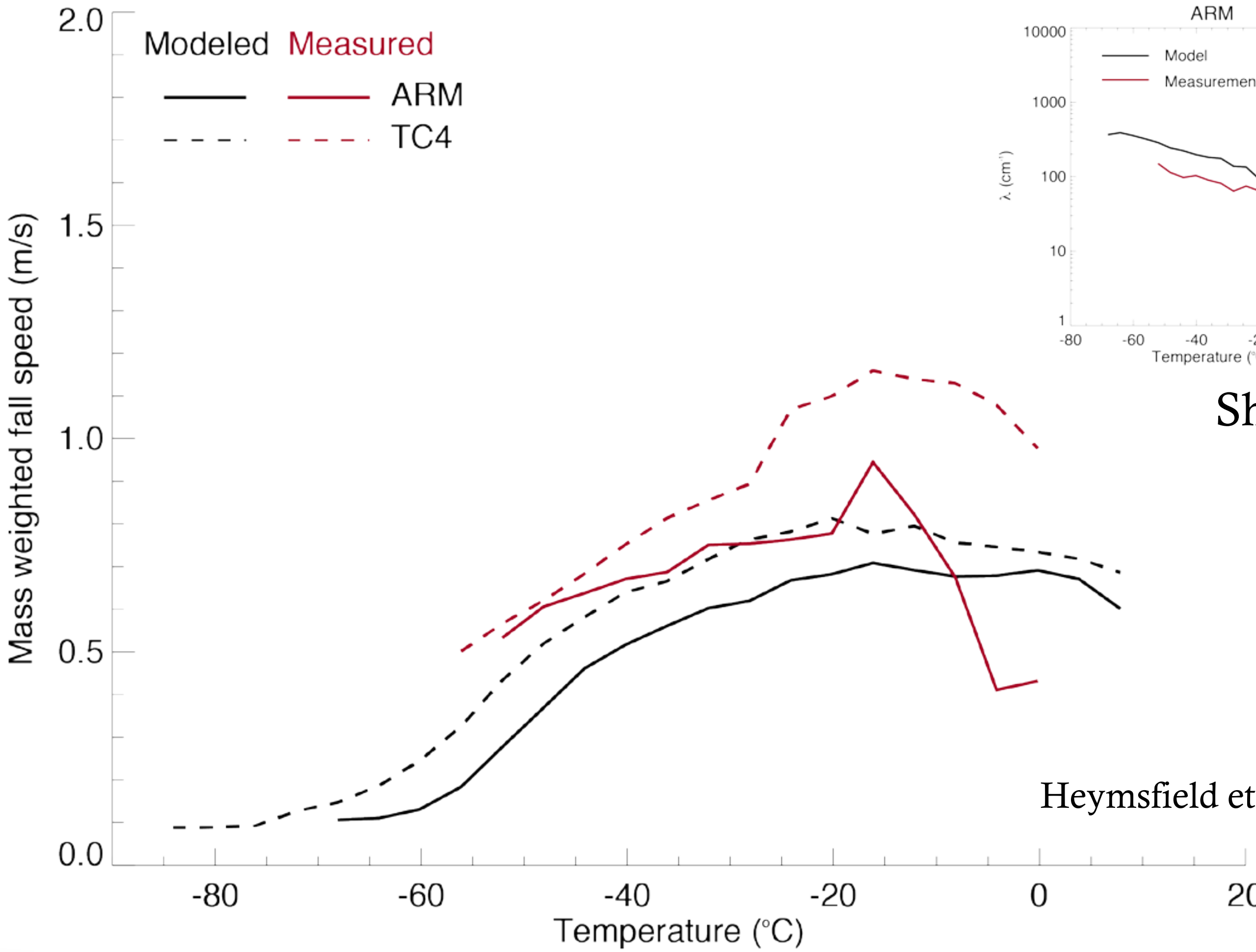
$$V_{t,m} = \frac{a\Gamma(b+4)}{6\lambda^b}$$

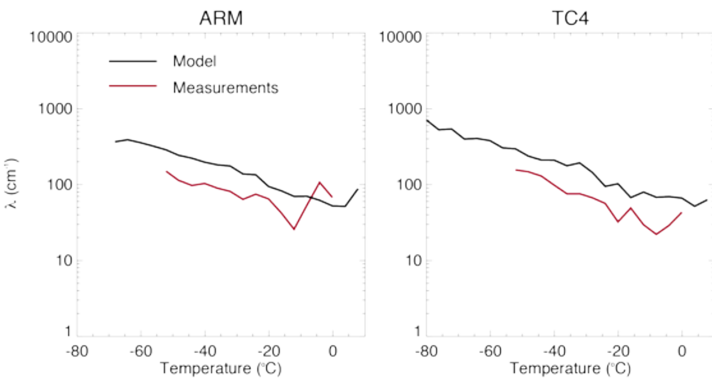
Mass weighted fall speed



Heymsfield and Westbrook (JAS 2010)

Mass weighted fall speed

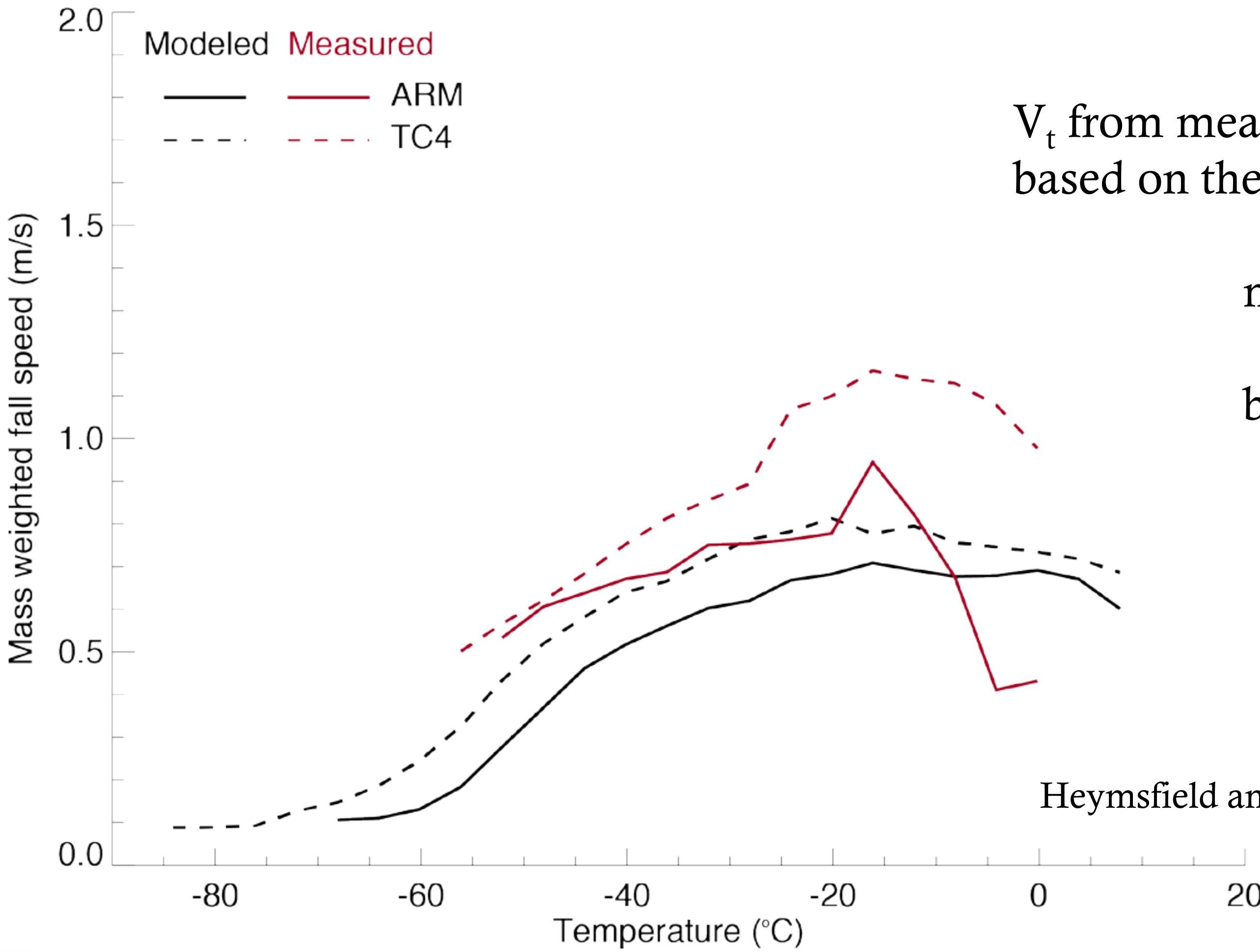




Shape parameter

Heymsfield et al. (2013, JAS, in print)

Mass weighted fall speed



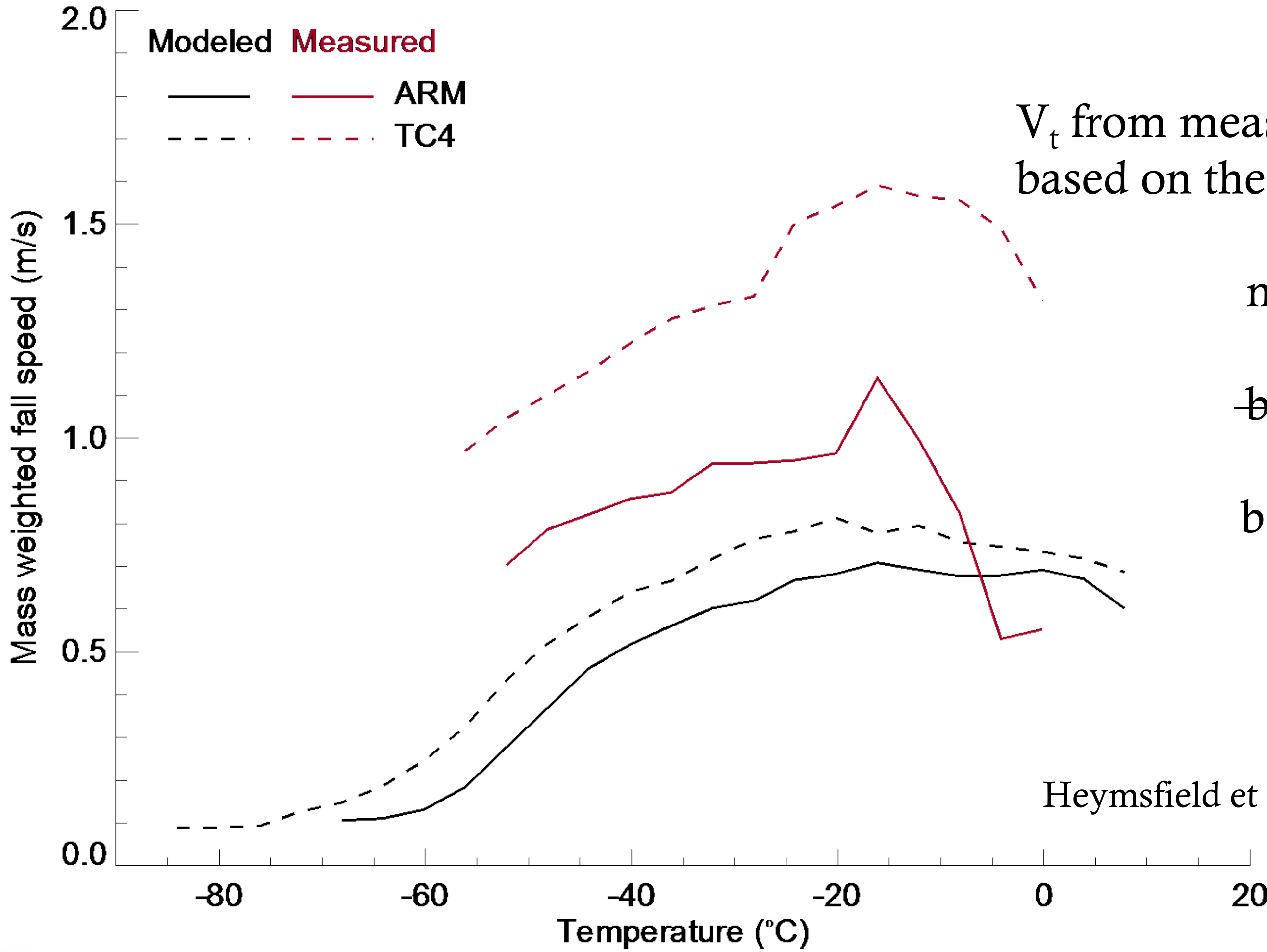
V_t from measurements determined based on the relationship

$$m = aD^b$$

$$b = 2.1$$

Heymsfield and Westbrook (JAS 2010)

Mass weighted fall speed



V_t from measurements determined based on the relationship

$m = aD^b$

~~b = 2.1~~

b = 2.05

Heymsfield et al. (JAS, 2004)

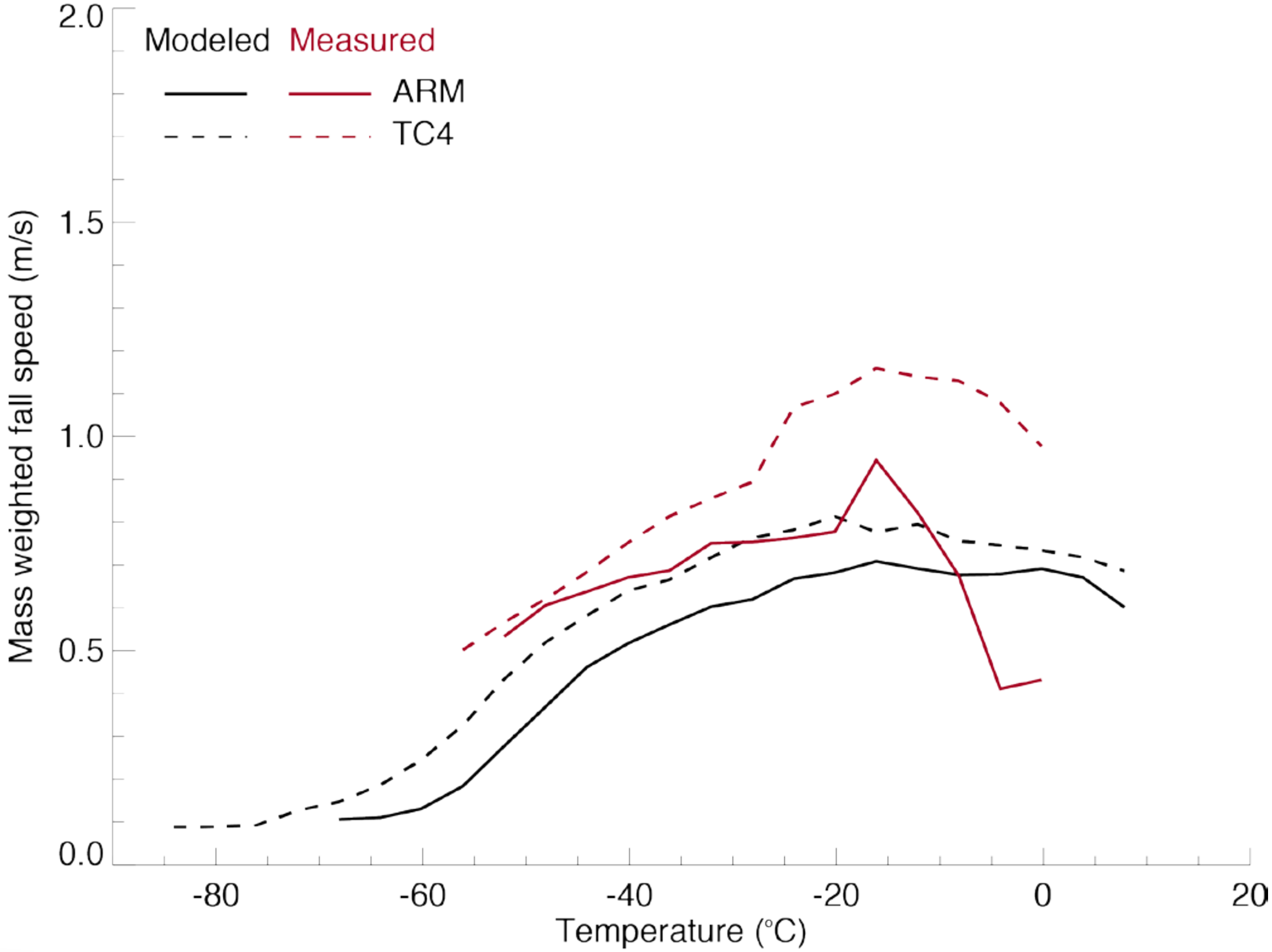
Autoconversion of ice to snow

Ice mass and number concentration for particles larger than a **<u>specified</u>** threshold size (D_{CS}) is converted to snow over an assumed timescale.

This threshold size is a major tuning nob in models.

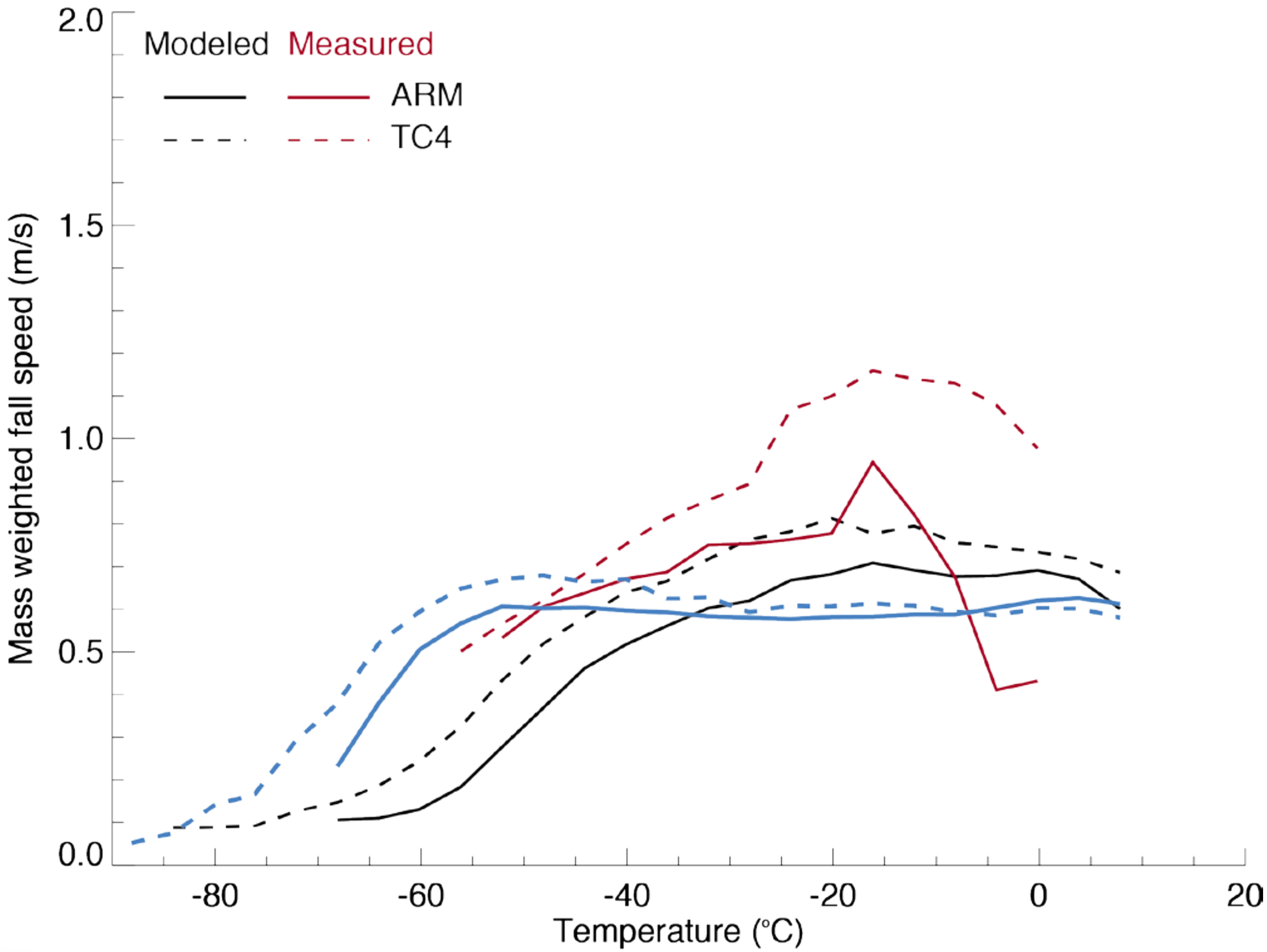
How does changes to D_{CS} affect fall velocity and ice water content?

Fall speed



D_{CS} = 250 μm

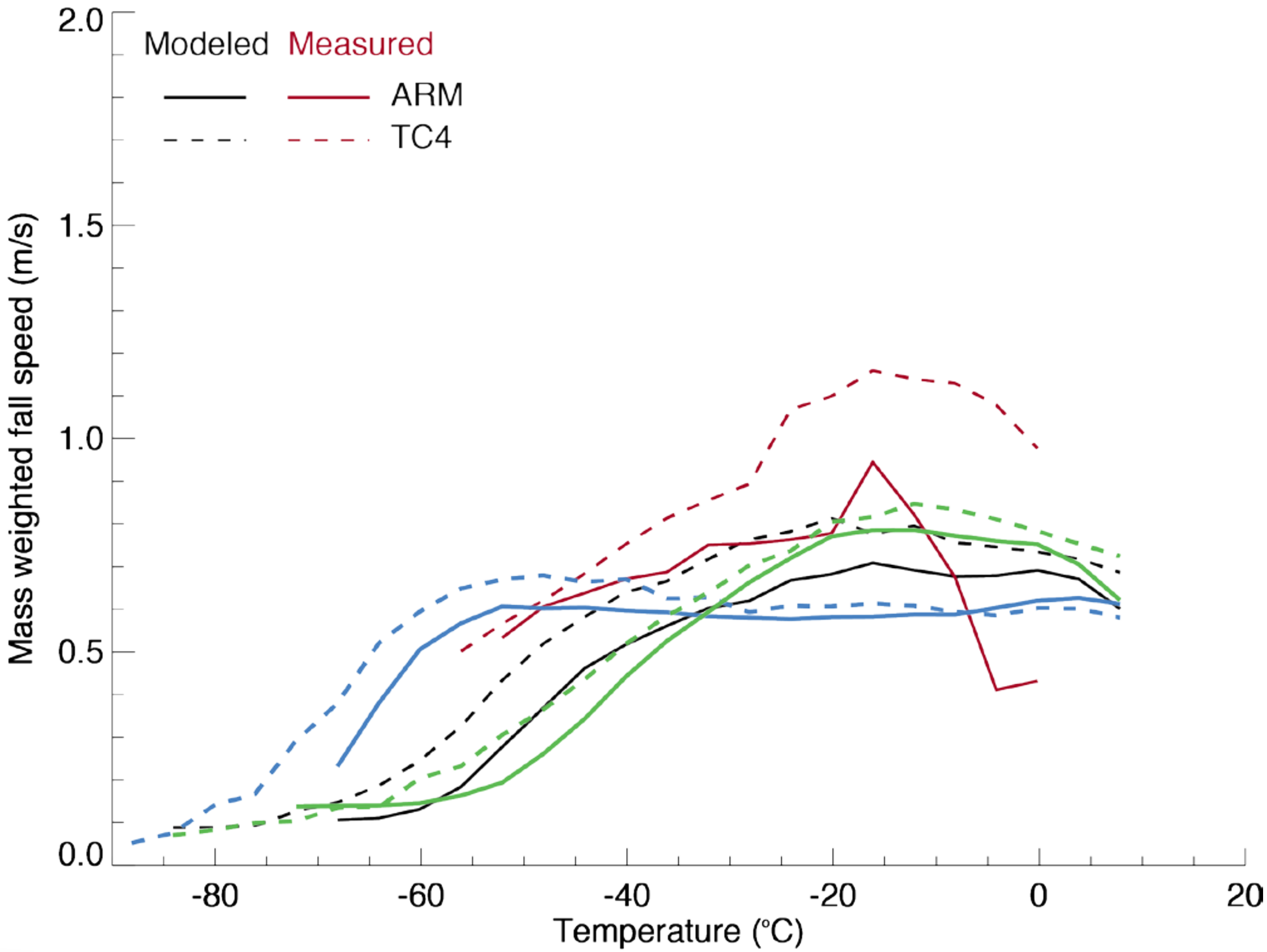
Fall speed



D_{CS} = 250 μm

D_{CS} = 100 μm

Fall speed



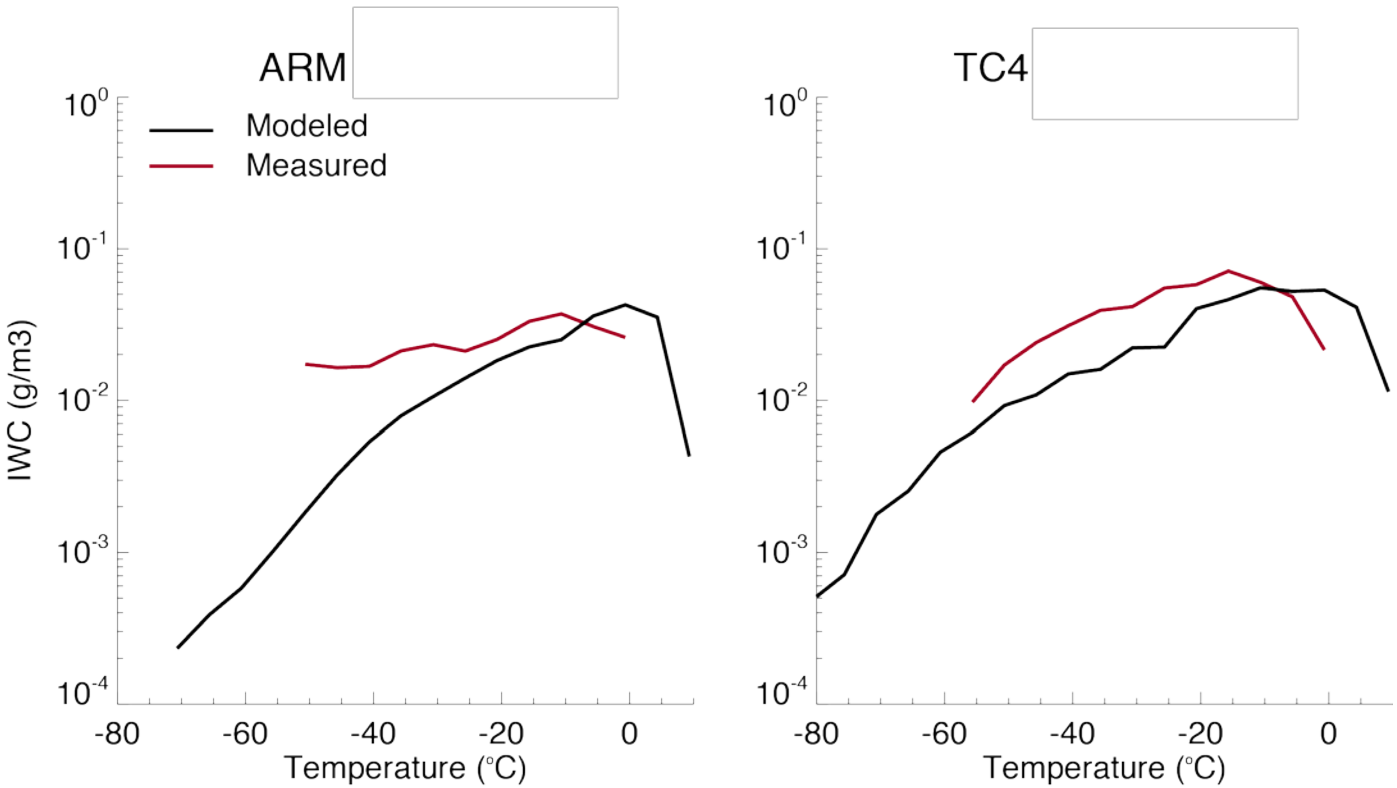
D_{CS} = 250 µm

D_{CS} = 100 µm

D_{CS} = 400 µm

IWC

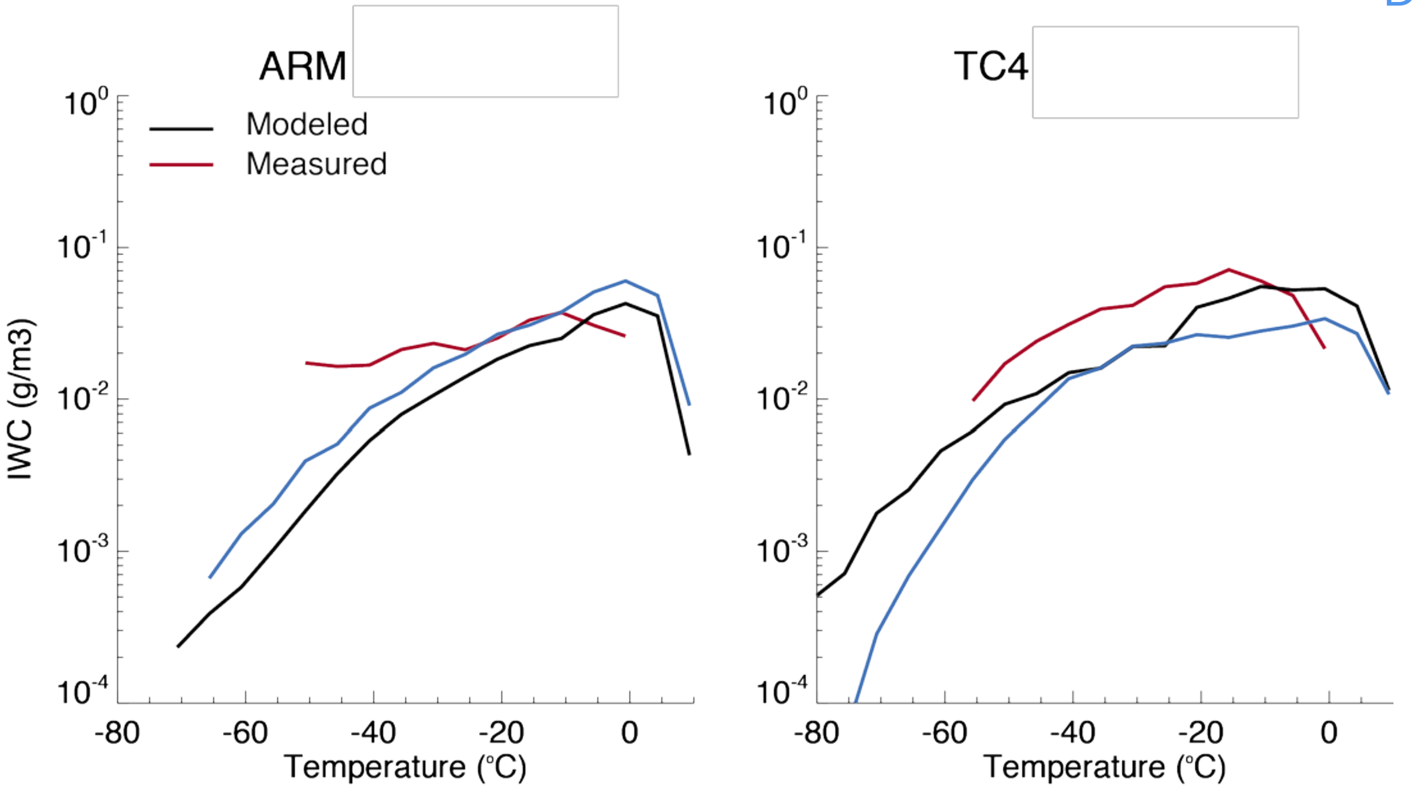
D_{CS} = 250 µm



IWC

D_{CS} = 250 μm

D_{CS} = 100 μm

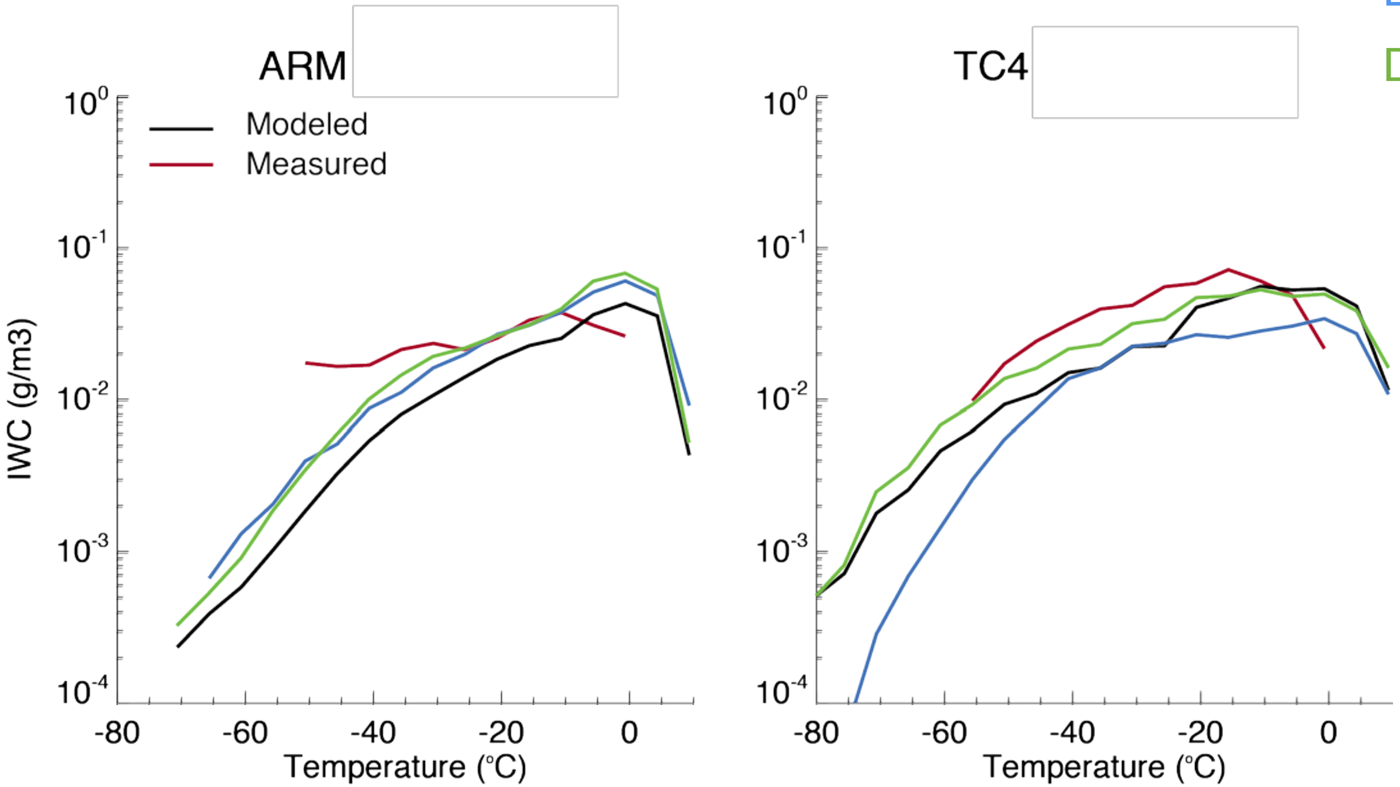


IWC

D_{CS} = 250 μm

D_{CS} = 100 μm

D_{CS} = 400 μm



- The choice of D_{CS} value clearly has an effect on fall velocities and ice water content. The effect is nonlinear, specially on IWC.
- **Propose to use new approaches predicting bulk particle properties instead of using separate ice species (such as in Morrison and Grabowski, 2008).**
    - Improved prediction of transition from pristine ice to snow and consistency of processes and parameters.

Conclusion

- Size distribution parameters from model (shape parameter, and moments) compare well with measurements. Mainly within one order of magnitude

- Model results and measurements have the same trends (as a function of temperature).

- The choice of threshold limit for transition from ice to snow (D_{CS}) has a large impact on fall velocity and IWC.

- Propose to improve how ice is transitioned into snow.

- Improve consistency of processes and parameters (fall velocity and effective radius calculations).