Ice Nucleation In Mid-latitude Cirrus

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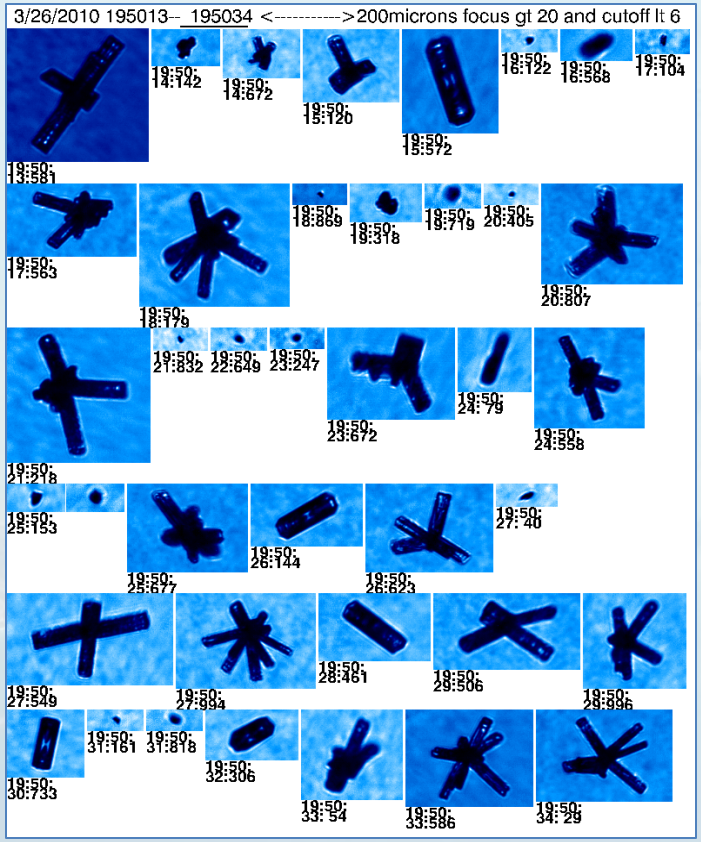
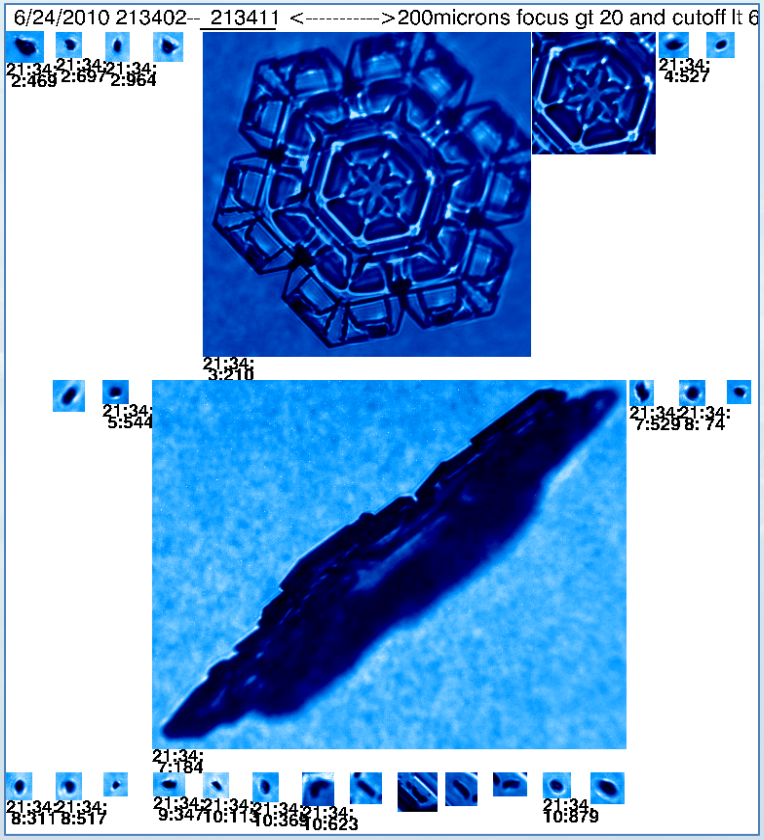




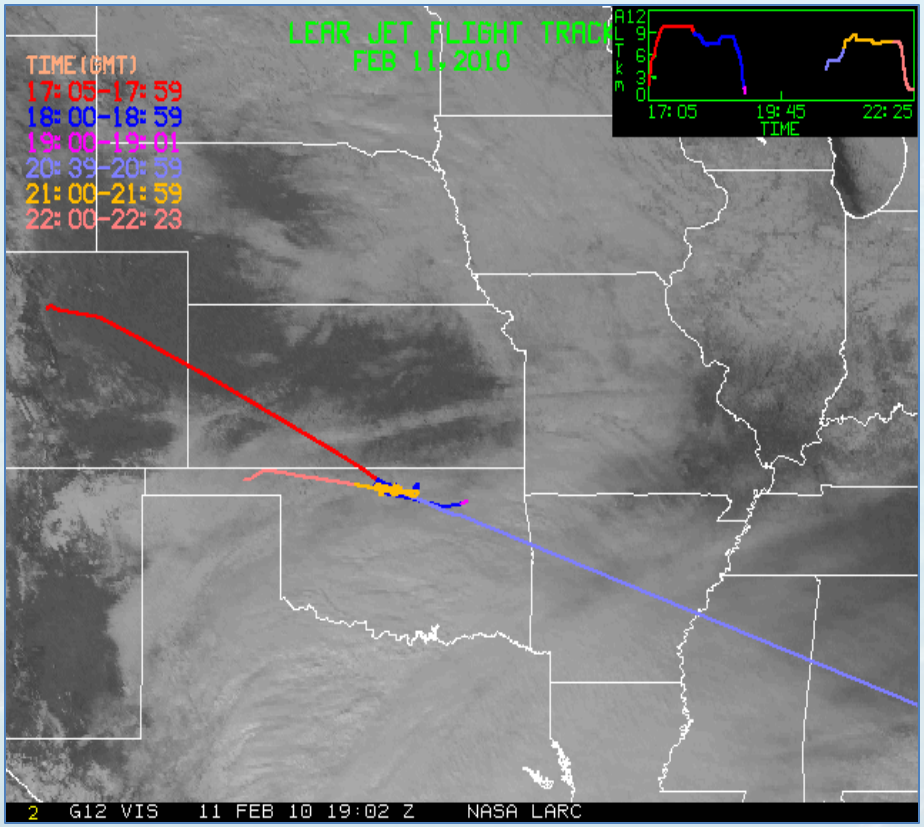
Case Study Selection

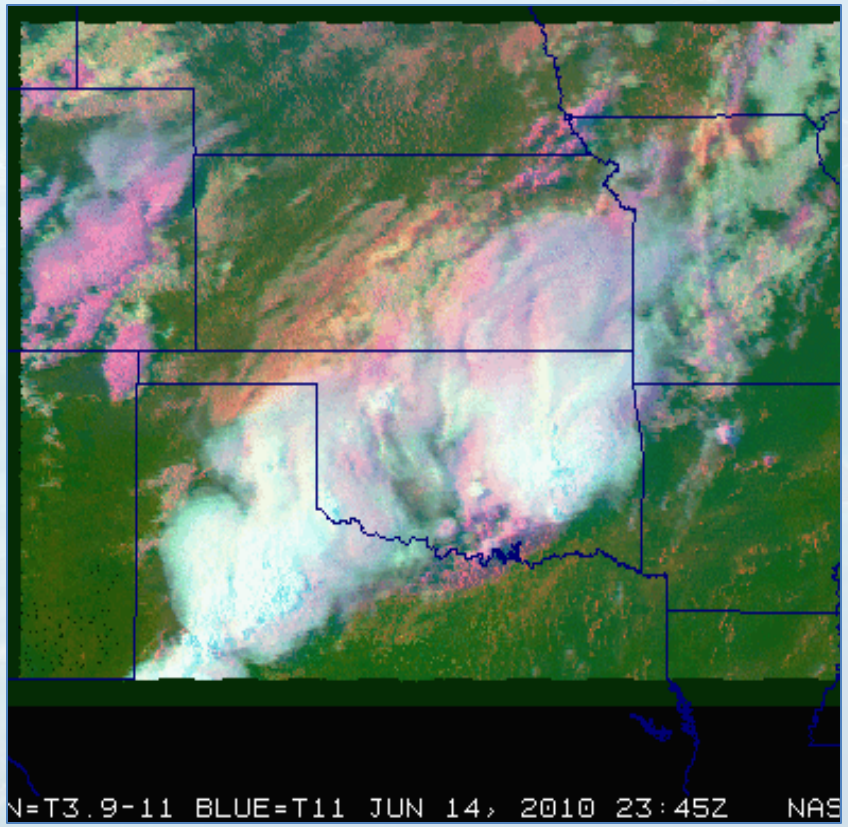
Sparticus Anvil Cirrus	Sparticus Synoptic Cirrus
April 22nd, 2010 (Flight A)	Jan 19th, 2010 (Flight A)
April 28th, 2010 (Flight A & B)	Jan 20th, 2010 (Flight A & B)
June 12th, 2010 (Flight A & B)	Jan 26th, 2010 (Flight A)
June 14th, 2010 (Flight A)	Jan 27th, 2010 (Flight A)
June 15th, 2010 (Flight A)	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)

Cloud segments are identified for each case by making sure that

- they contain no liquid water,
- they have good sampling statistics and utilize a good fraction of the data
- they are sampled under relatively steady microphysical conditions

Satellite Images Help Determine Cloud Type (Anvil/Synoptic Cirrus)





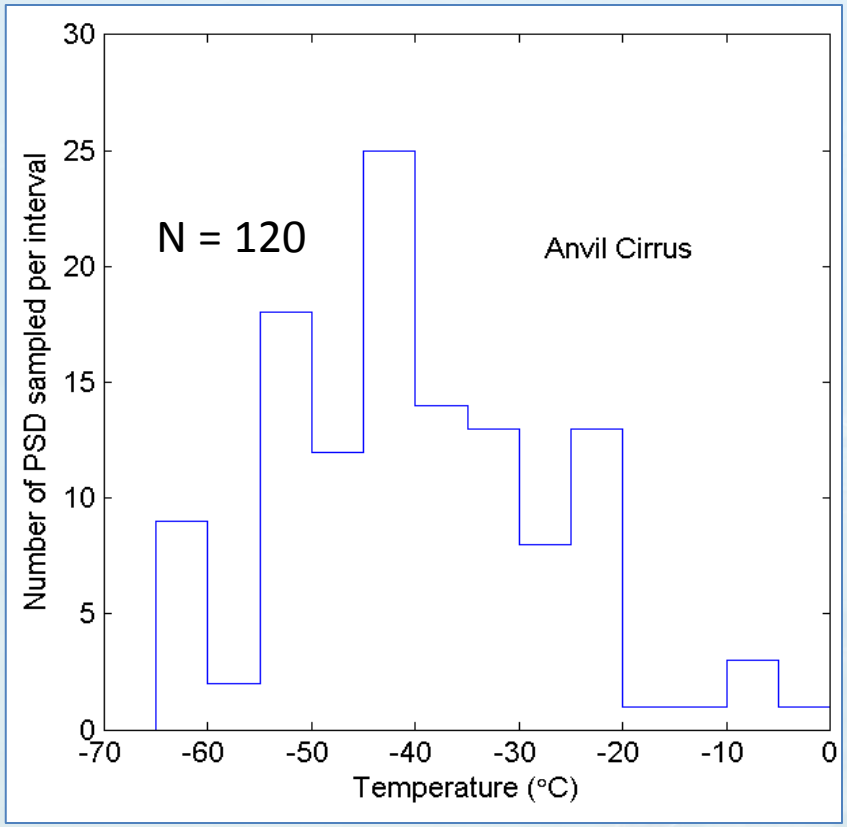
Source: P. Minnis (NASA Langley)

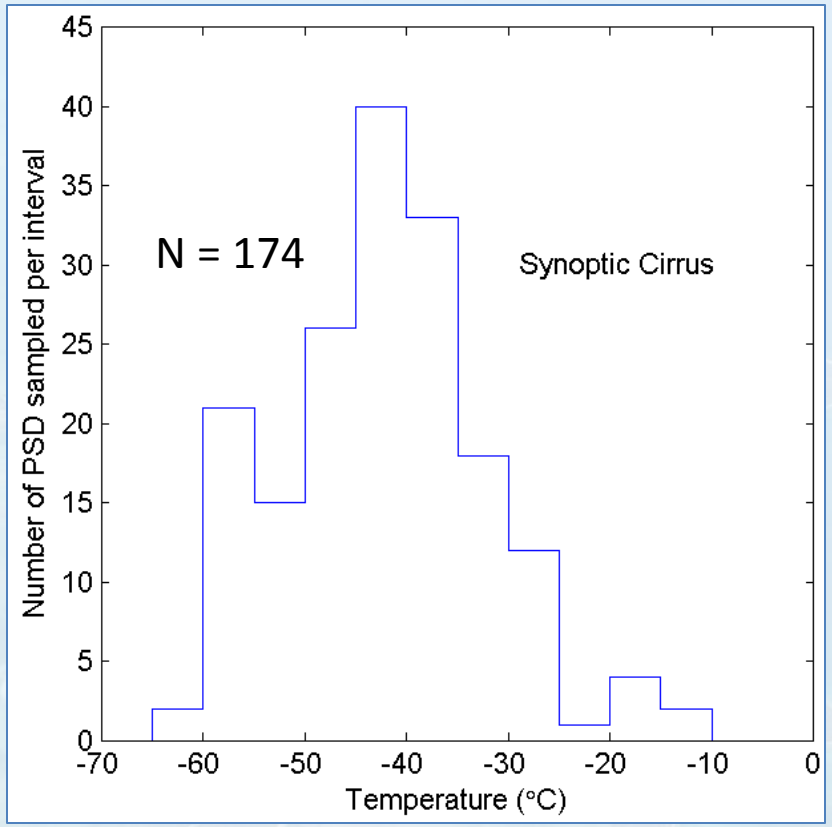
http://www-angler.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=ARM-SPARTICUS

Liquid Water Screening

- CPI images were inspected (T > -40 ^{o}C) to remove cloud segments that indicated the presence of liquid water.
- If 2D-S data indicated a concentration of more than 3/cc or the FSSP probe indicated a concentration of more than 10/cc, the cloud segment was considered to have liquid and hence removed from the data set.
- Cloud segments with RH(water) of over 90% were removed from the data set.

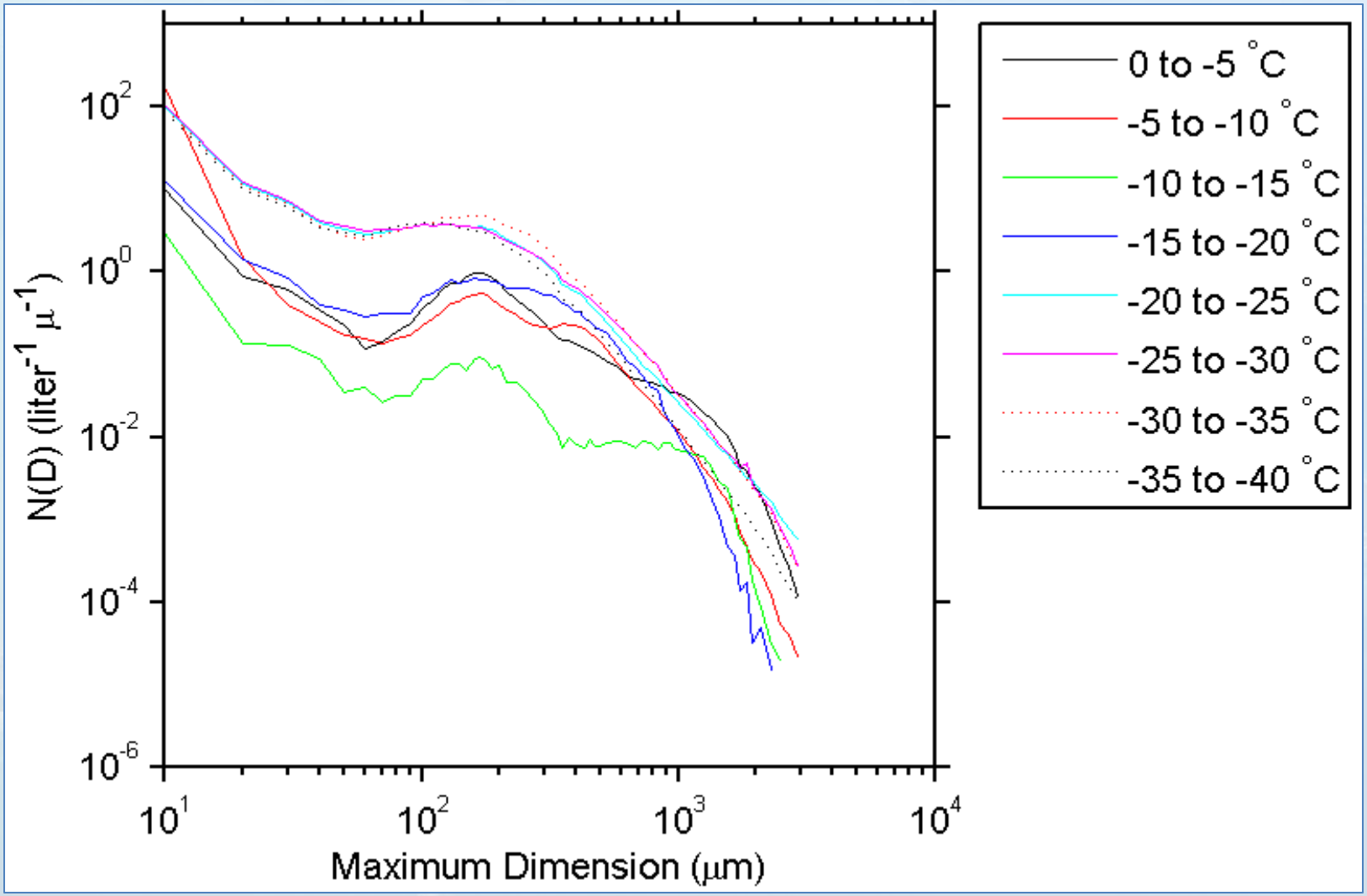
Sampling Statistics



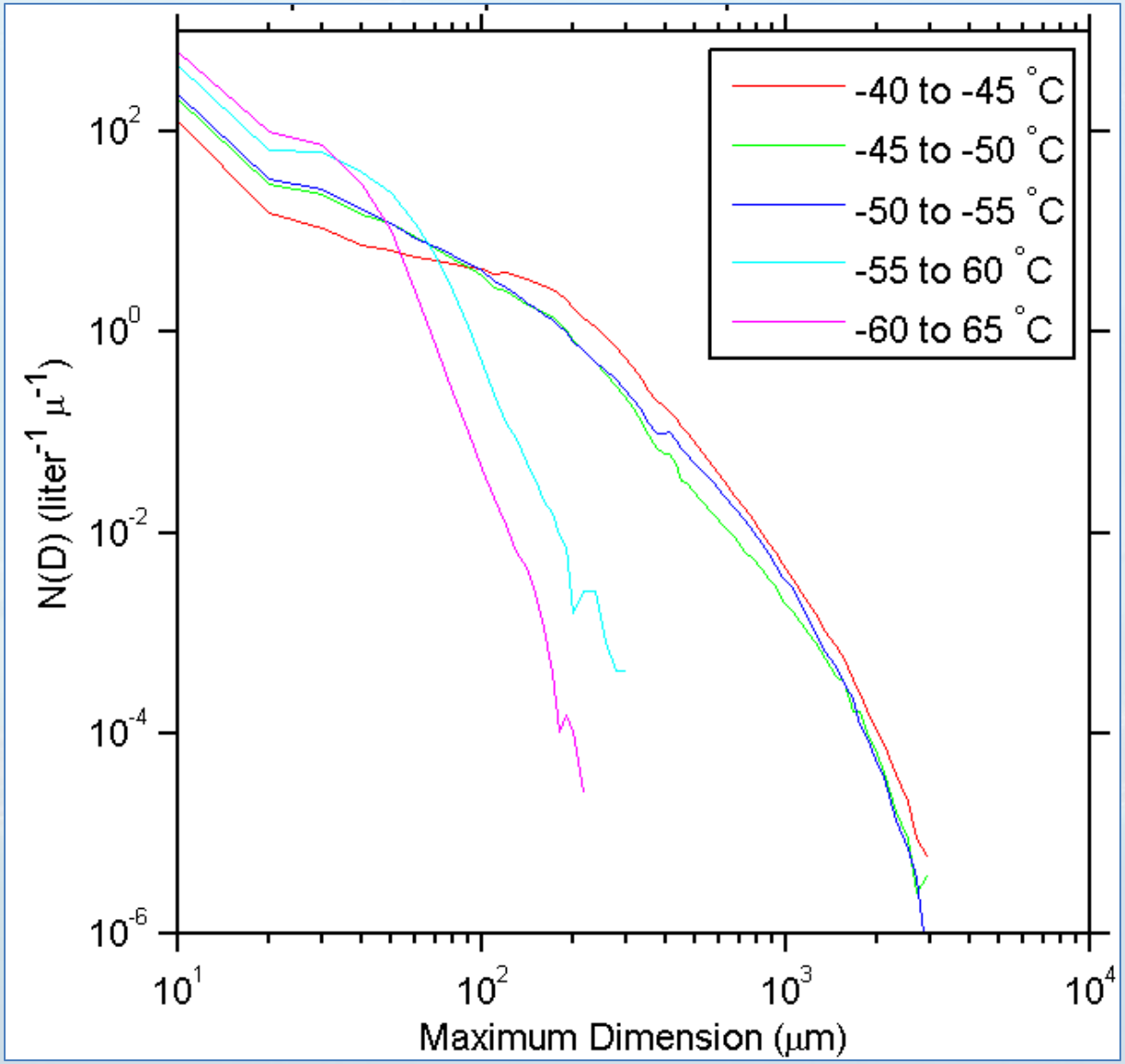


The SPARTICUS PSD used here are from 1-2 minute periods of flight time where the cirrus microphysical properties (median mass dimension and extinction coefficient) were not changing rapidly over time. A total of 294 SPARTICUS PSD were processed comprising of 120 anvil cirrus cloud segments and 174 synoptic cirrus cloud segments from 14 different days and 22 different flights.

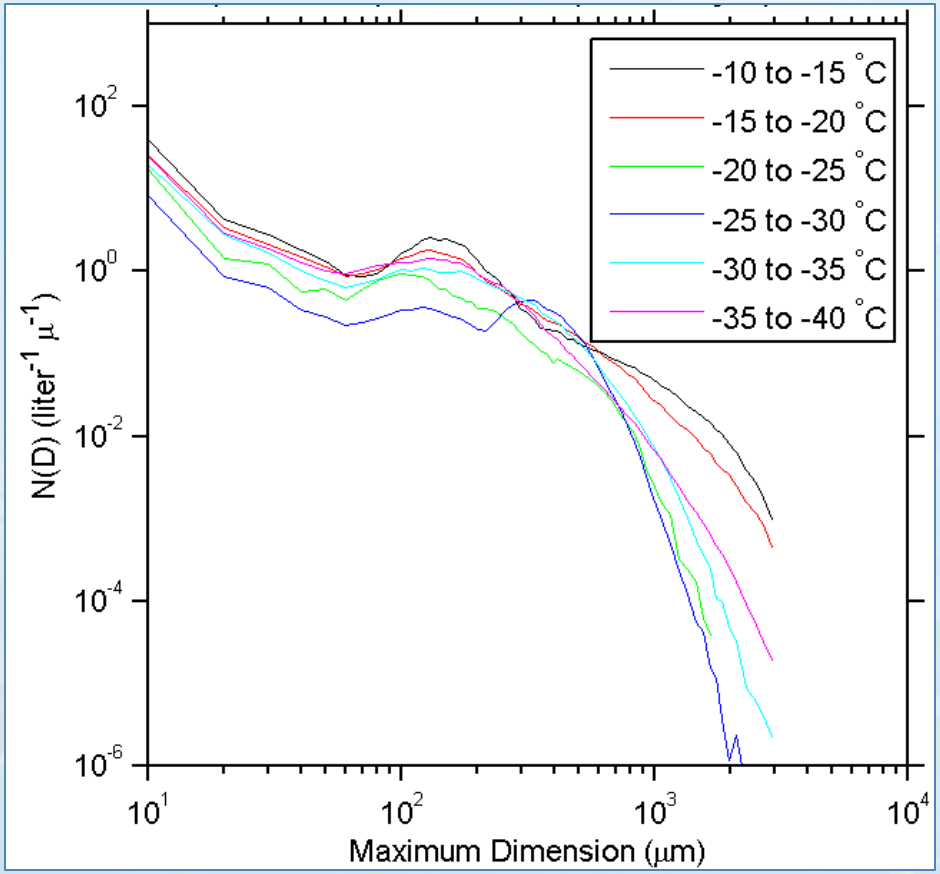
Anvil Cirrus (T > -40 °C)

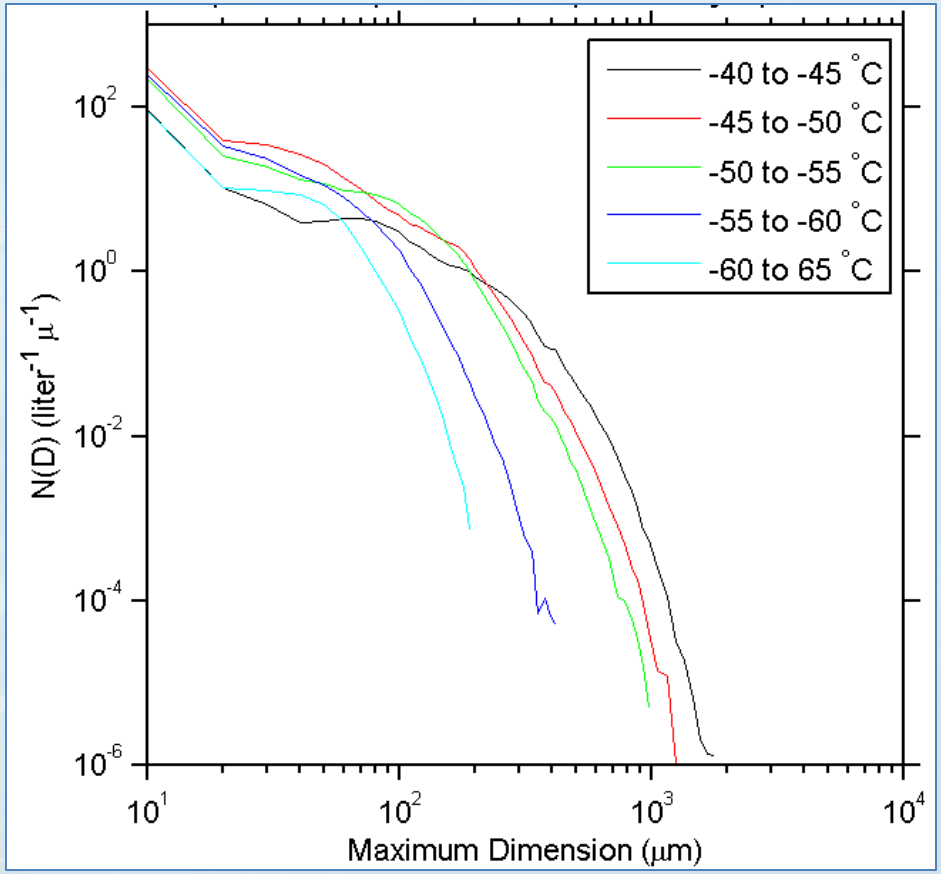


Anvil Cirrus (T < -40 °C)



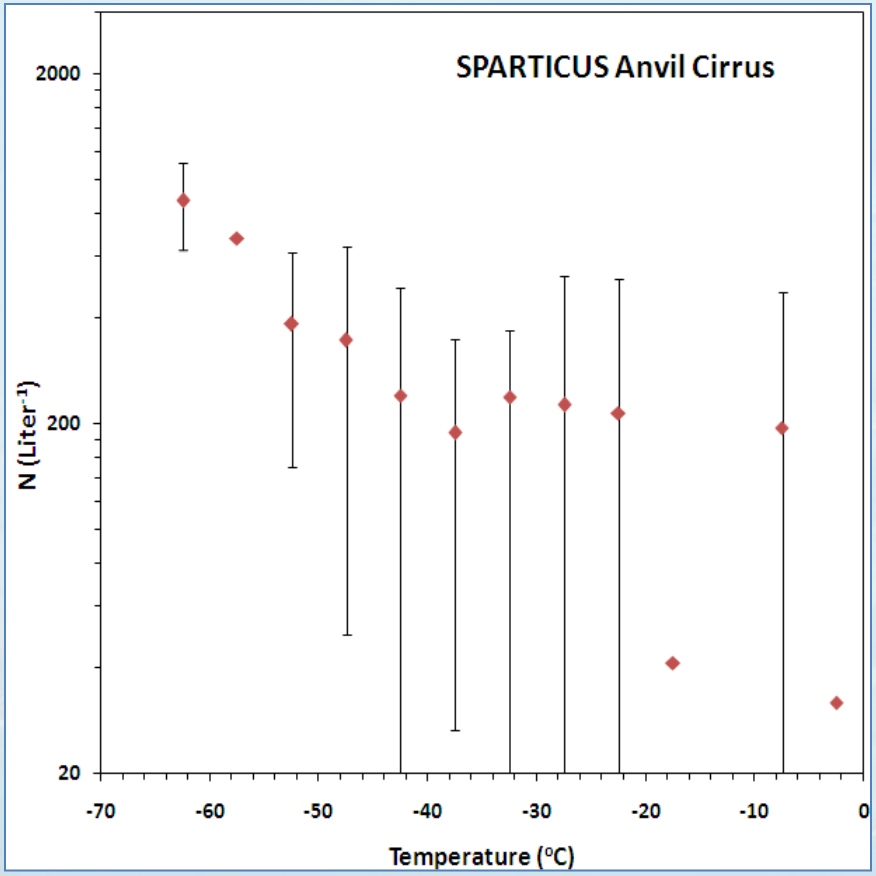
Synoptic Cirrus

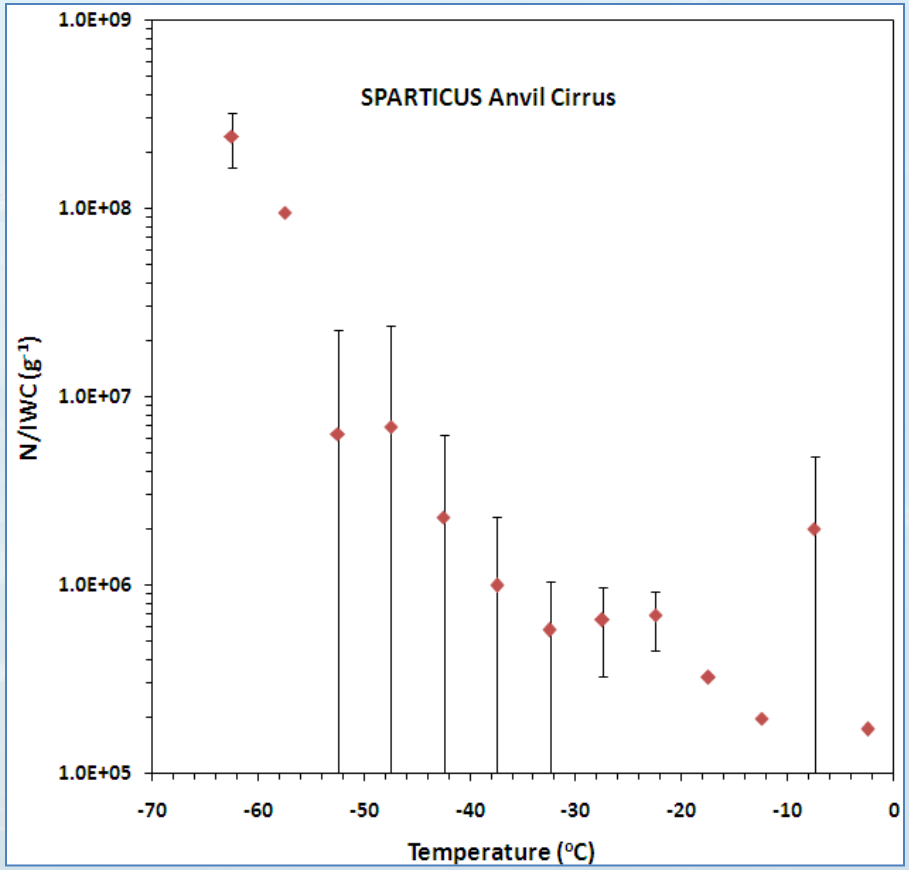




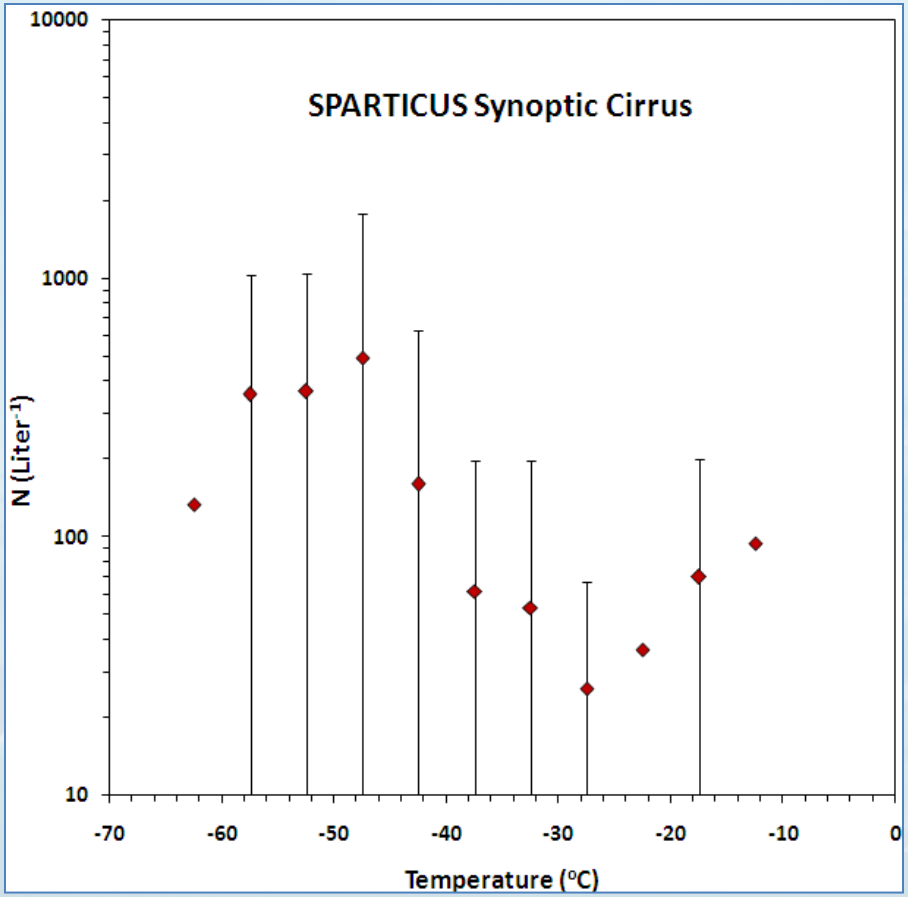
- **Nucleation Rate (J)** – defined as the rate of generation of ice germs per unit volume (related to mass) of condensate per unit time
- **N/IWC** - This ratio denotes a time integration of J in a cloud parcel, from ice nucleation onset to sampling time (ignoring processes such as aggregation and ice fallout)
- **N/IWC** can serve as an indicator for homogeneous nucleation in cirrus clouds. Since J for homogeneous freezing is known to be higher than J for heterogeneous processes, N/IWC should also be higher for temperatures less than -40°C if homogeneous freezing is dominating ice production.

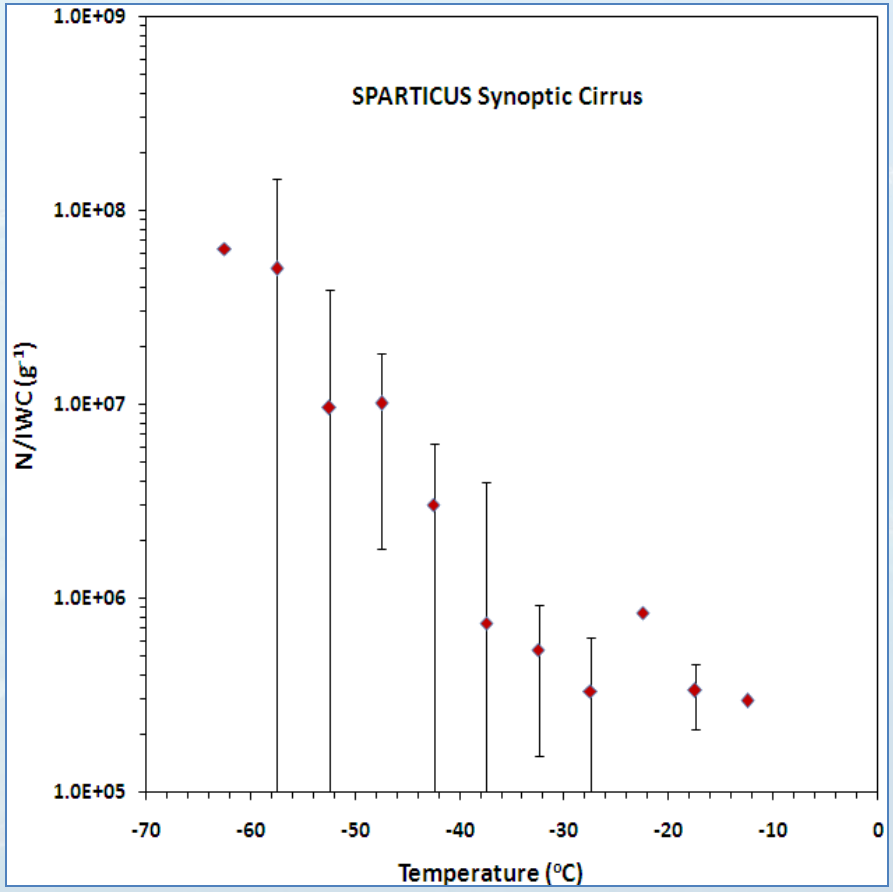
Temperature Dependence of Ice Particle Number concentration (N) and N/IWC – Anvil Cirrus



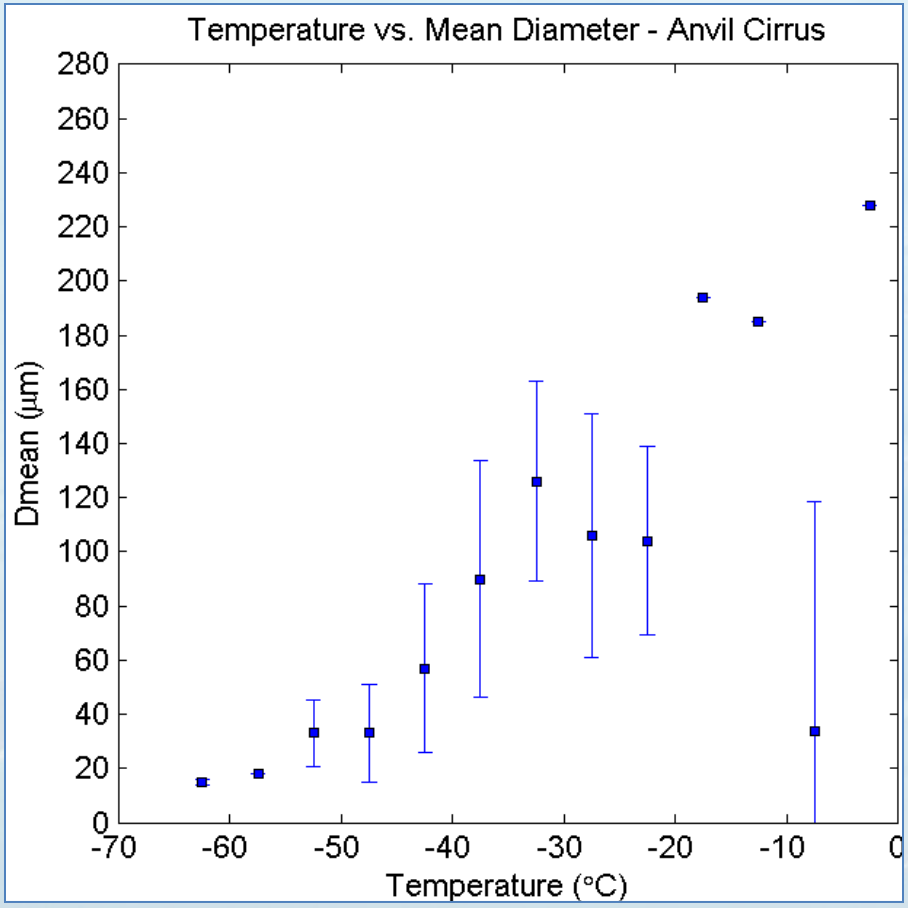


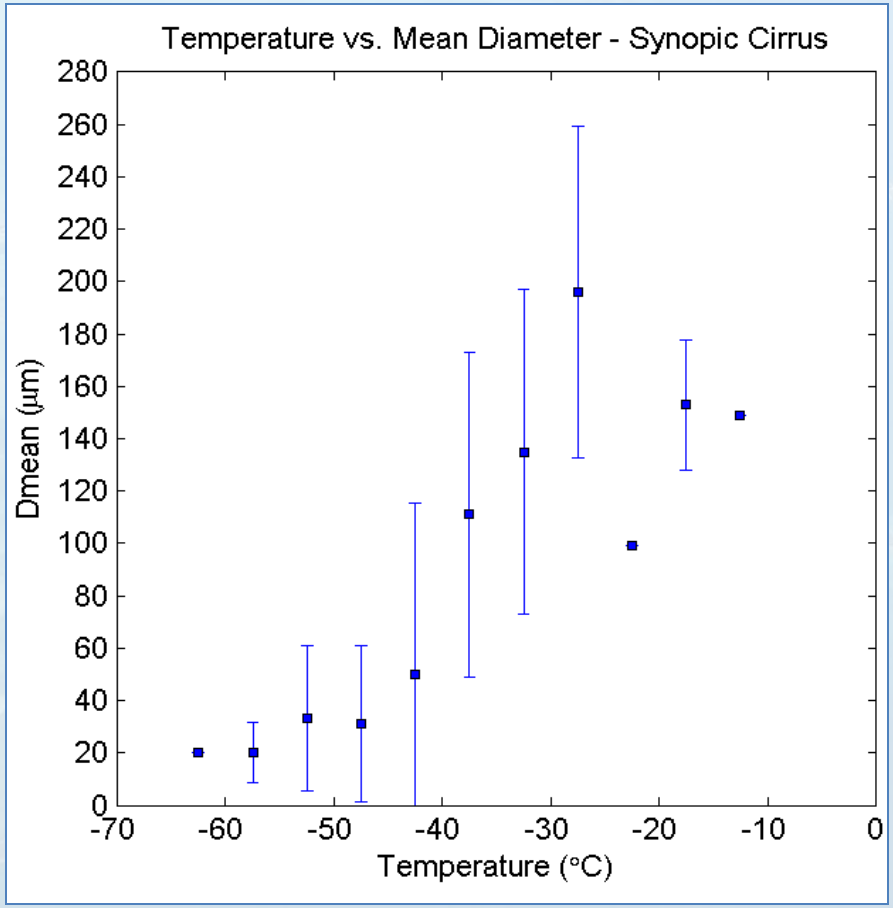
Temperature Dependence of N and N/IWC – Synoptic Cirrus

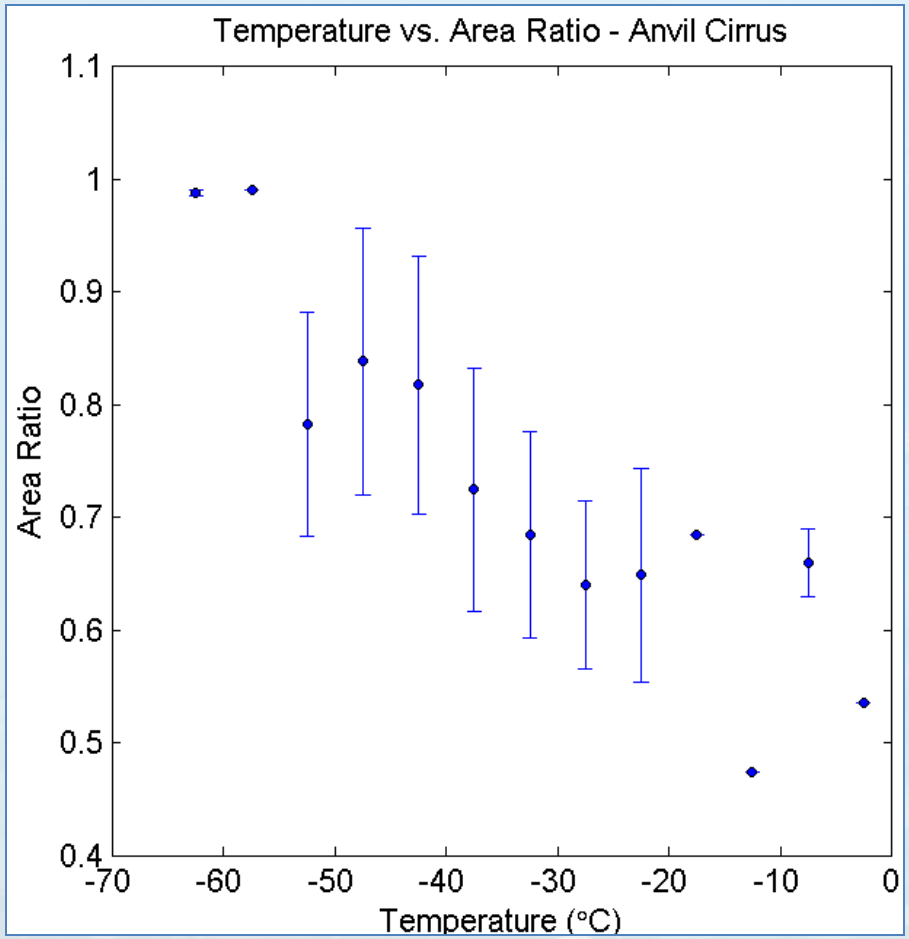


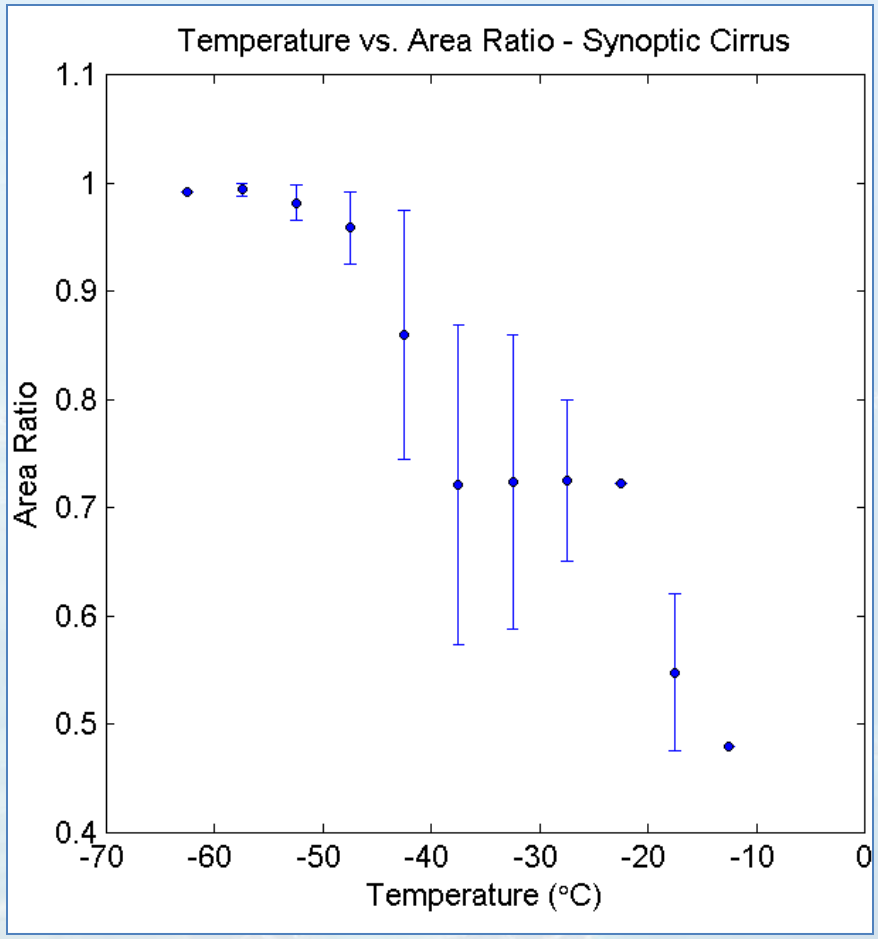


Temperature dependence of the PSD Mean Size (D_{mean})

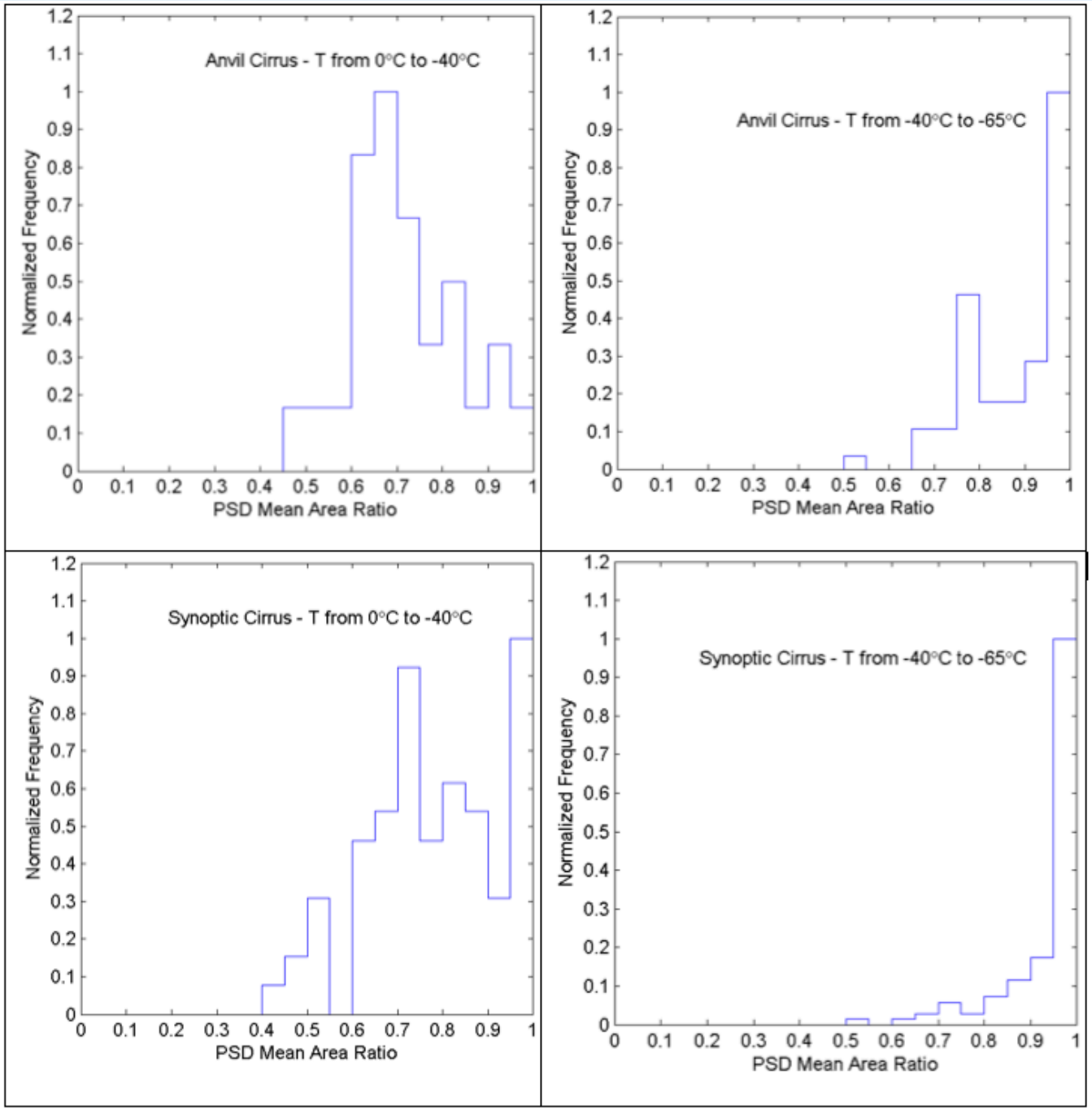




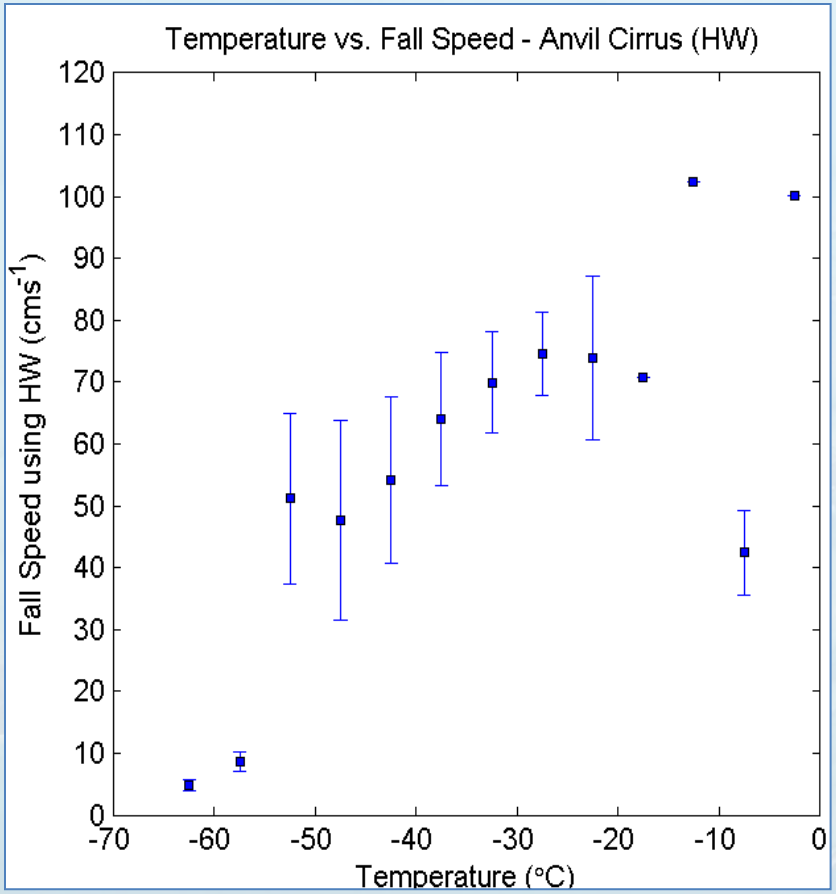


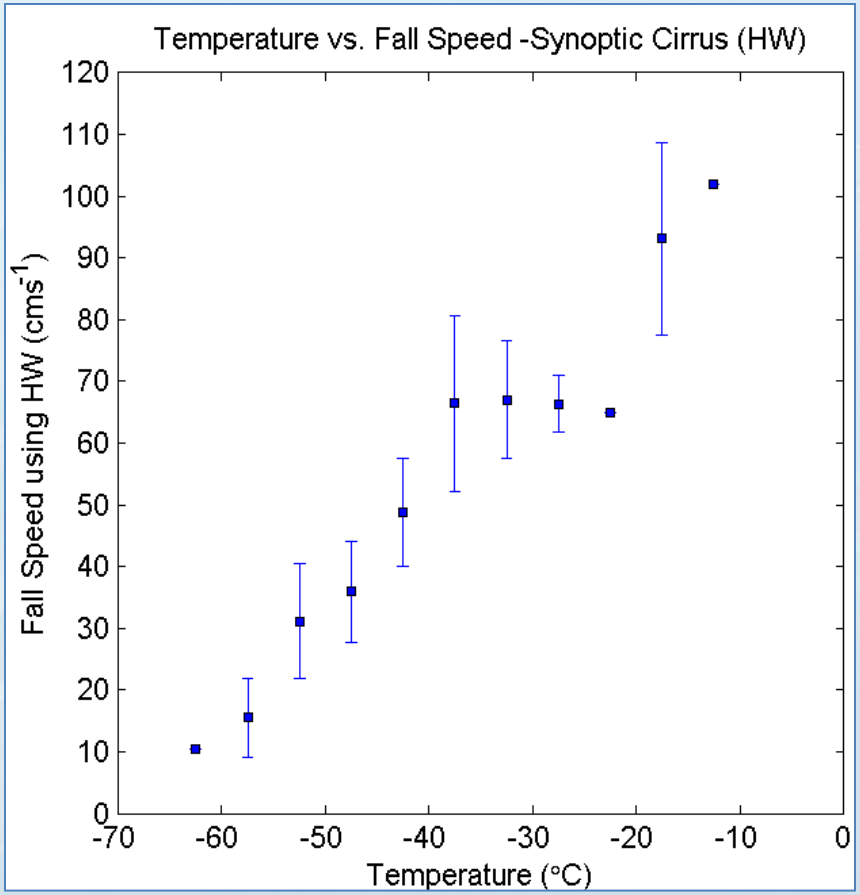


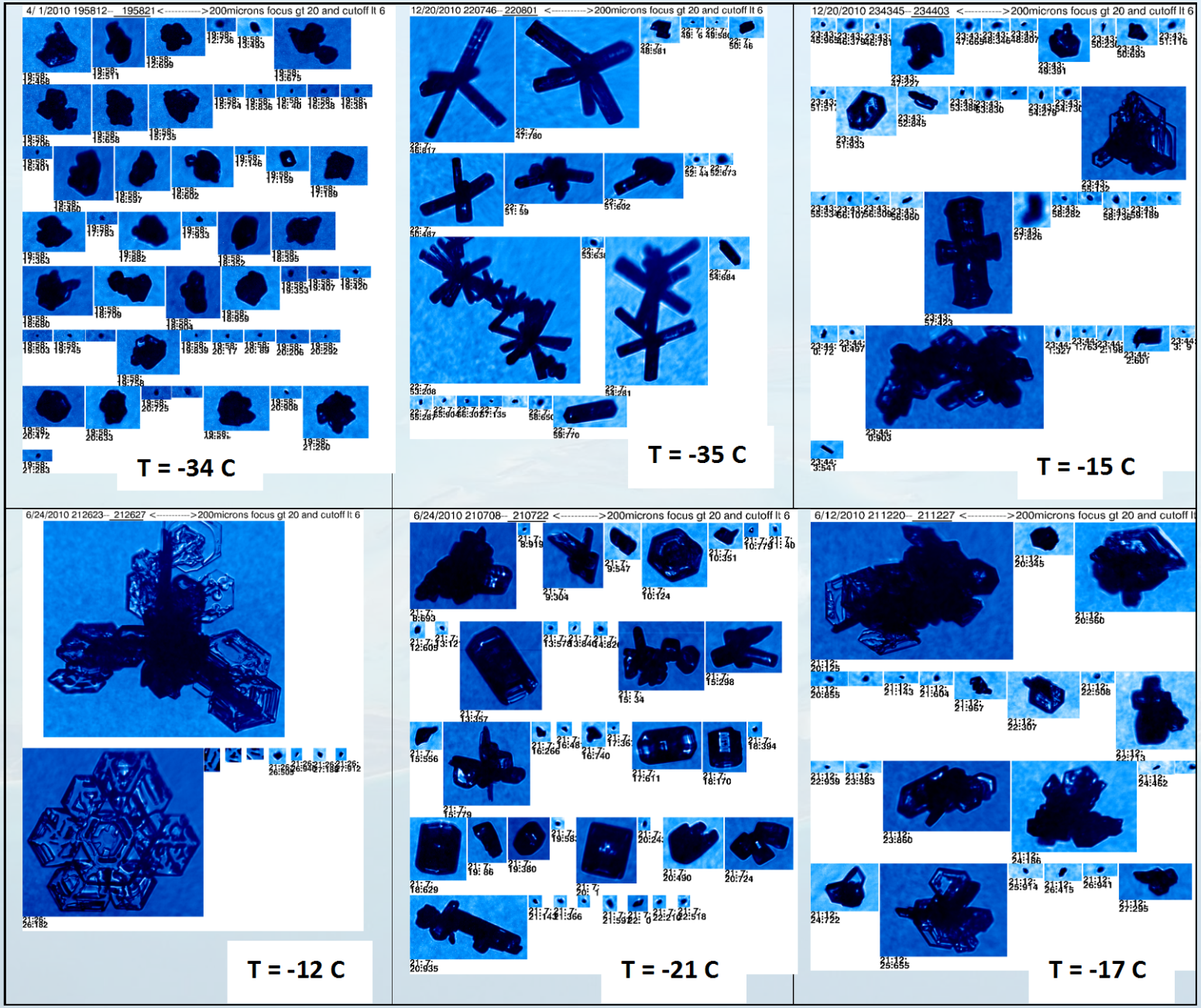
Temperature dependence of the area ratio calculated from the mean PSD. Vertical bars are standard deviations. Points without such bars have less than 3 PSD samples


Anvil Cirrus - T from 0°C to -40°C
Normalized Frequency
PSD Mean Area Ratio
Anvil Cirrus - T from -40°C to -65°C
Normalized Frequency
PSD Mean Area Ratio
Synoptic Cirrus - T from 0°C to -40°C
Normalized Frequency
PSD Mean Area Ratio
Synoptic Cirrus - T from -40°C to -65°C
Normalized Frequency
PSD Mean Area Ratio

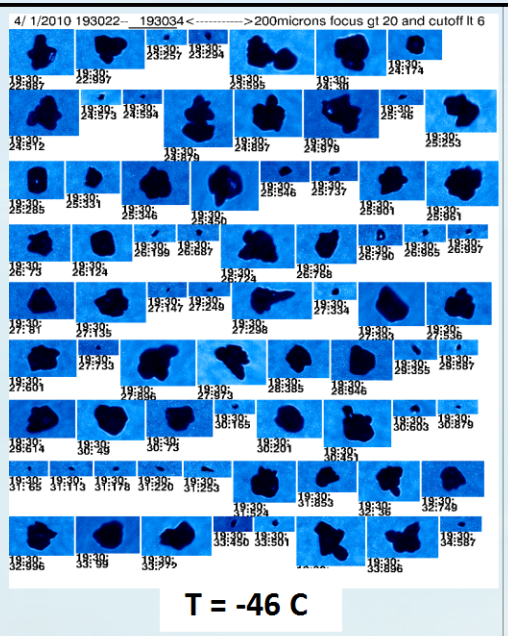
Temperature dependence of Mass Weighted Fall Speed (V_m)

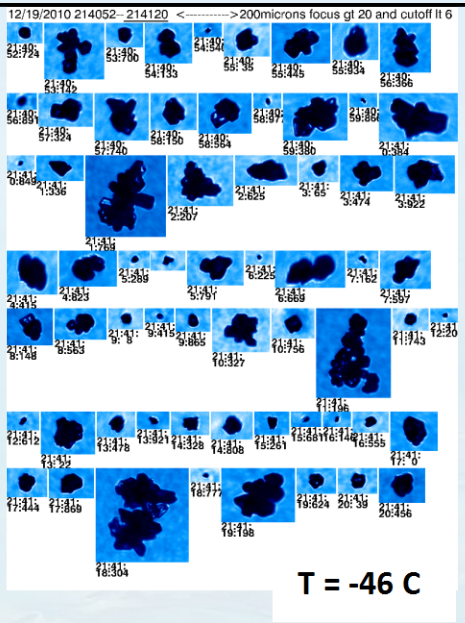


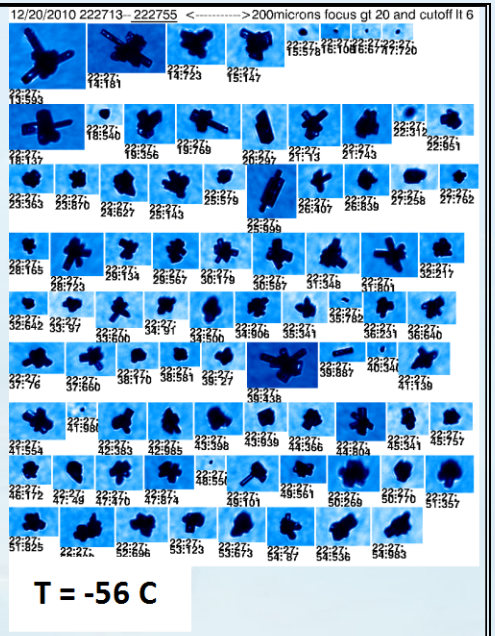


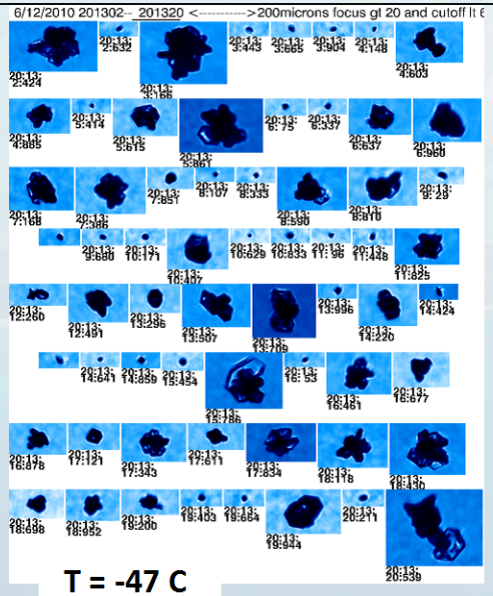


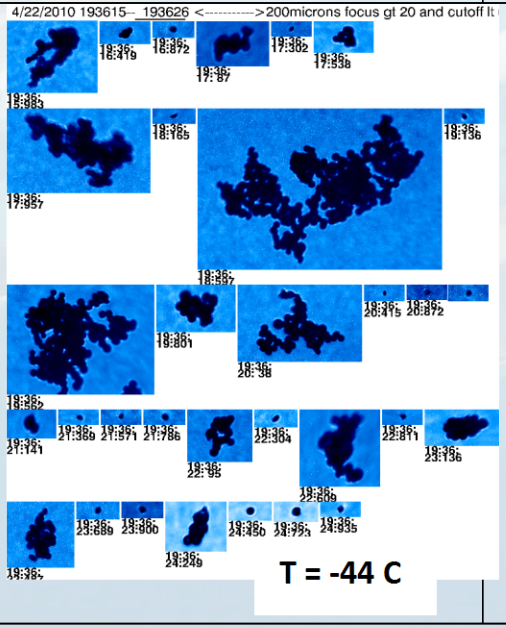
SYNOPTIC ANVIL

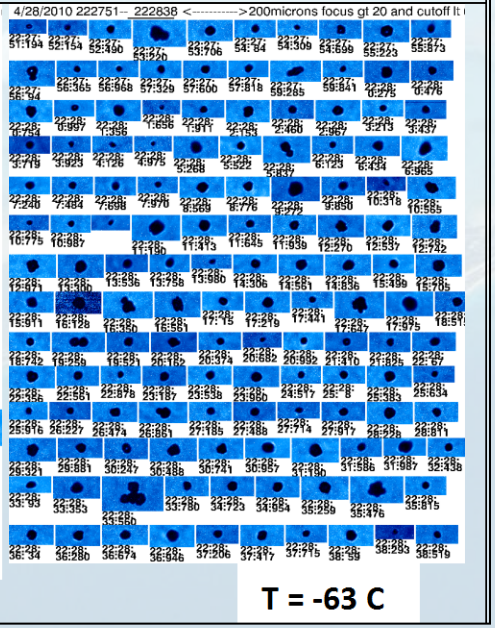










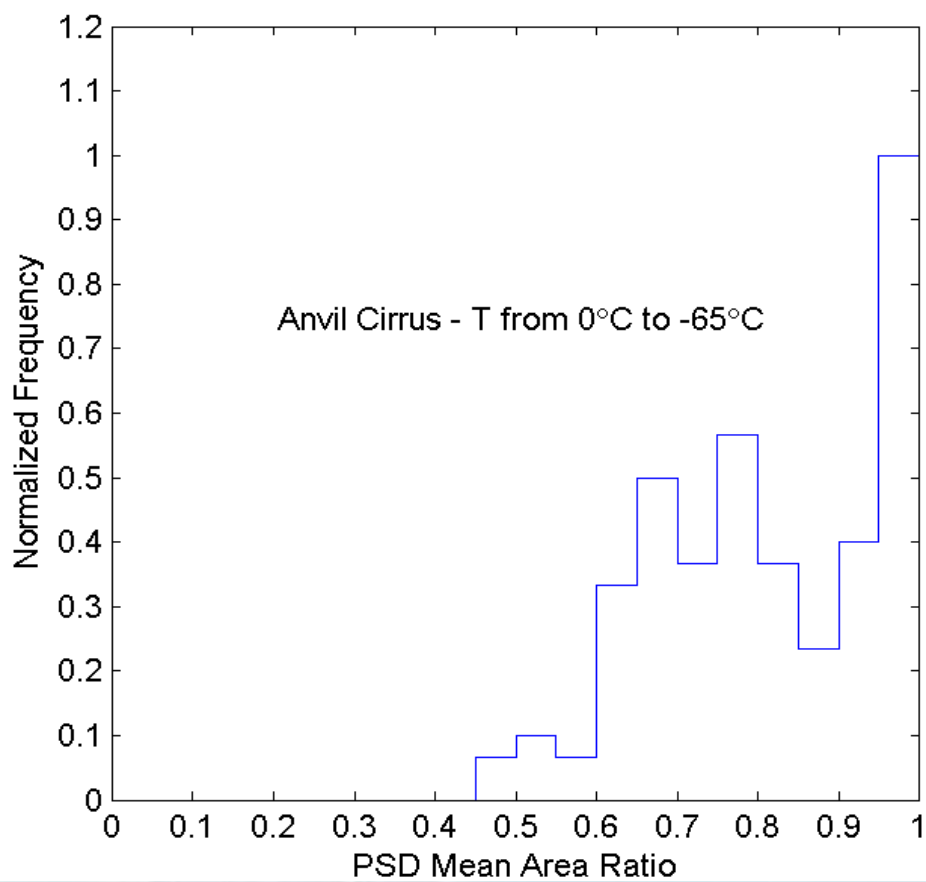


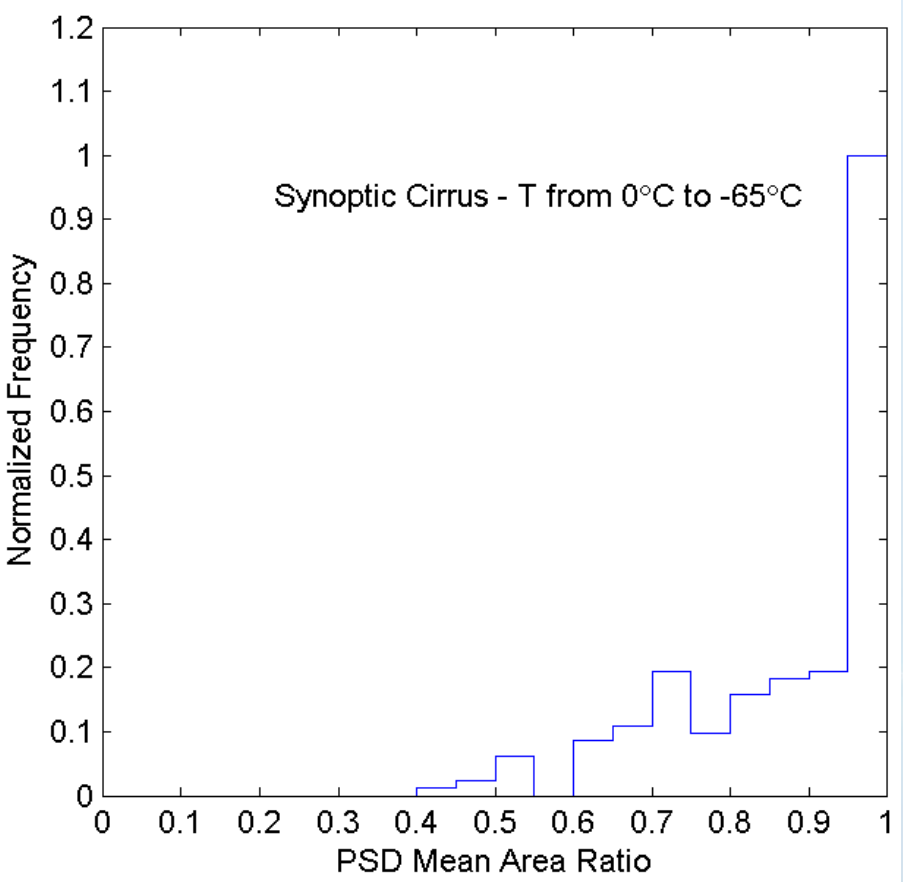
SYNOPTIC ANVIL

THANK YOU!

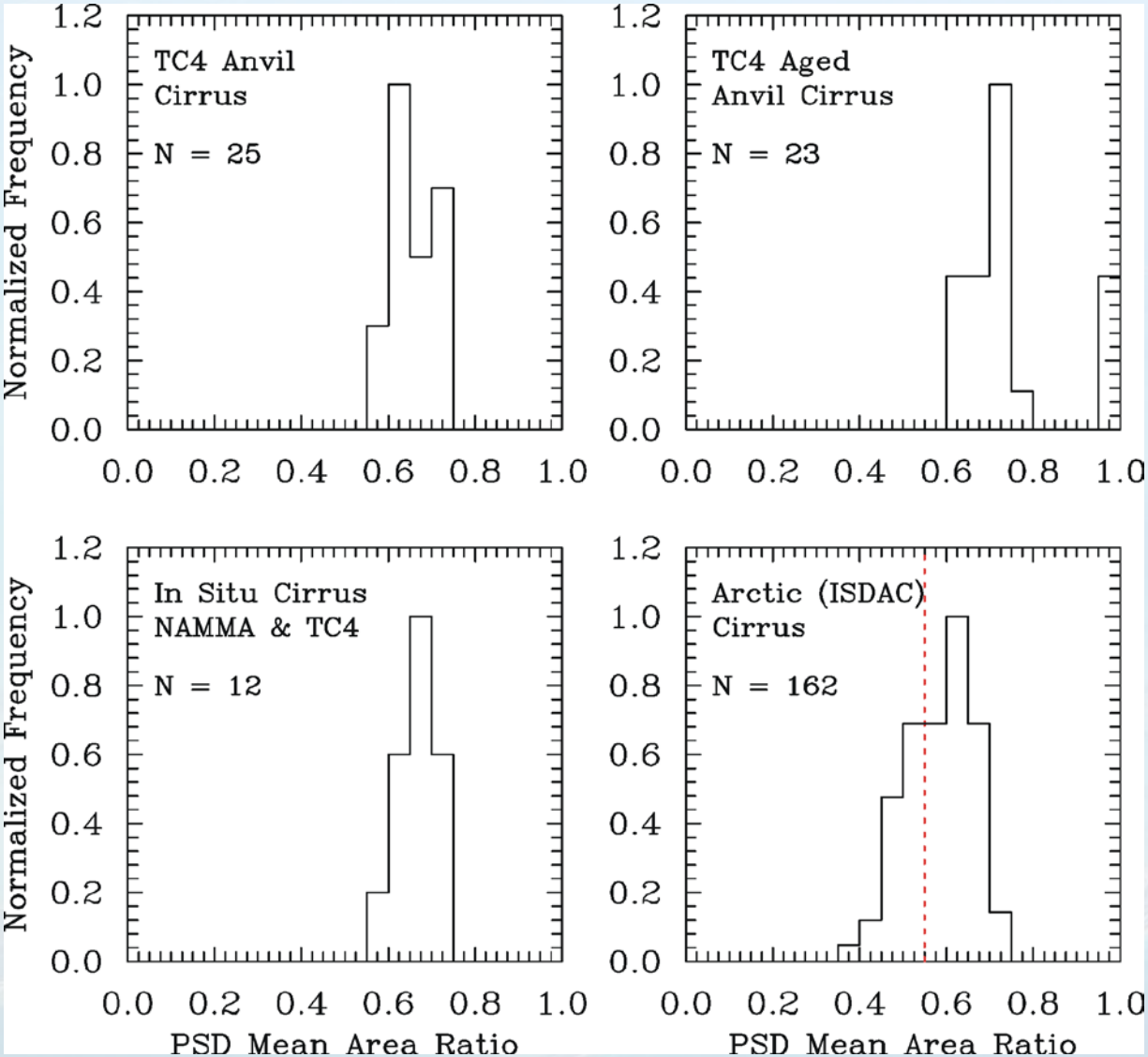
EXTRA SLIDES

Ice Particle Area Ratios (AR)



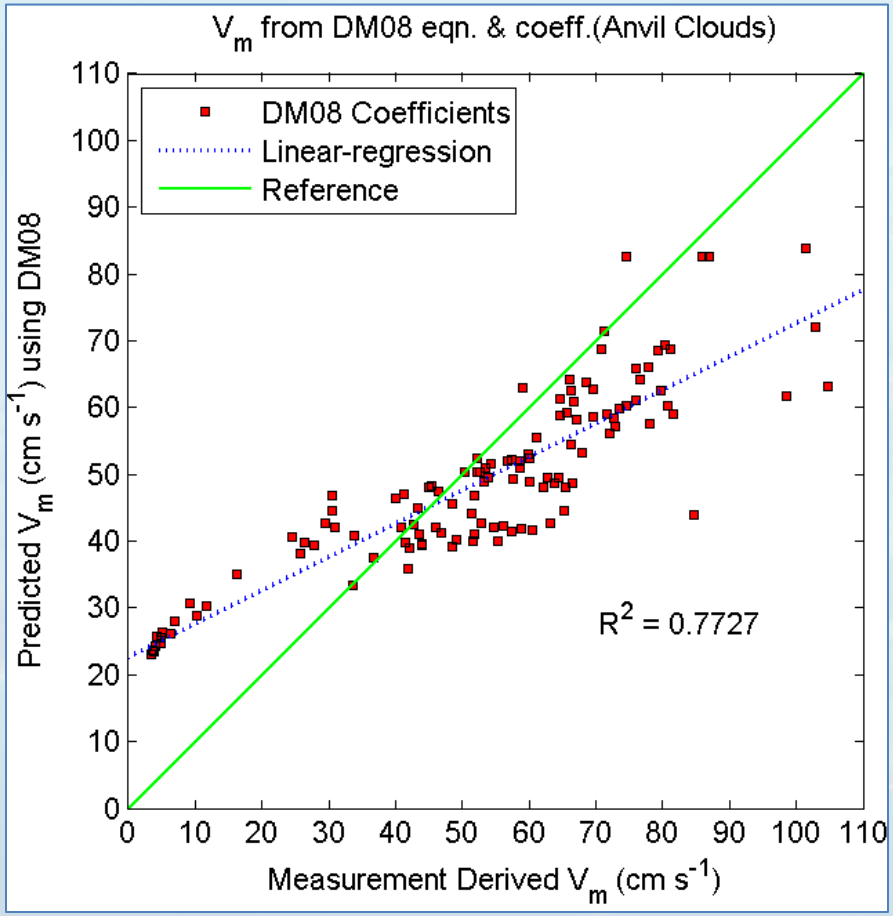


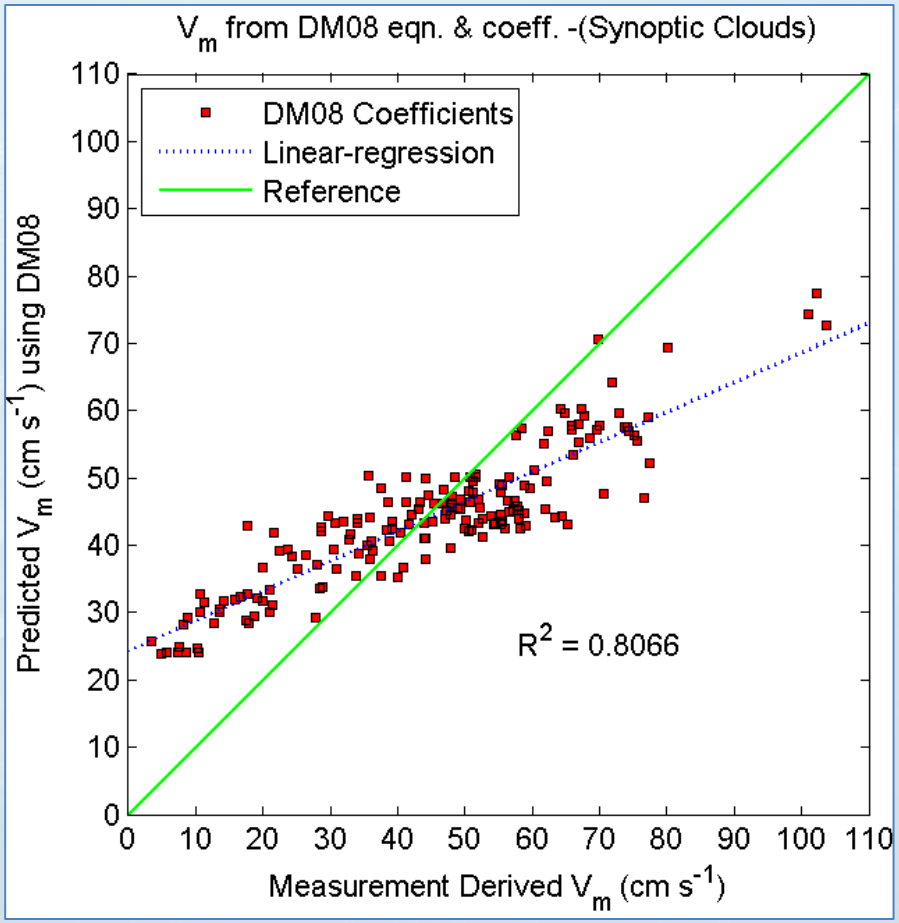
$$AR_{PSD} = \frac{\sum_{D=60\mu m}^{D=D_{max}} A(D)}{\sum_{D=60\mu m}^{D=D_{max}} A_s(D)}$$



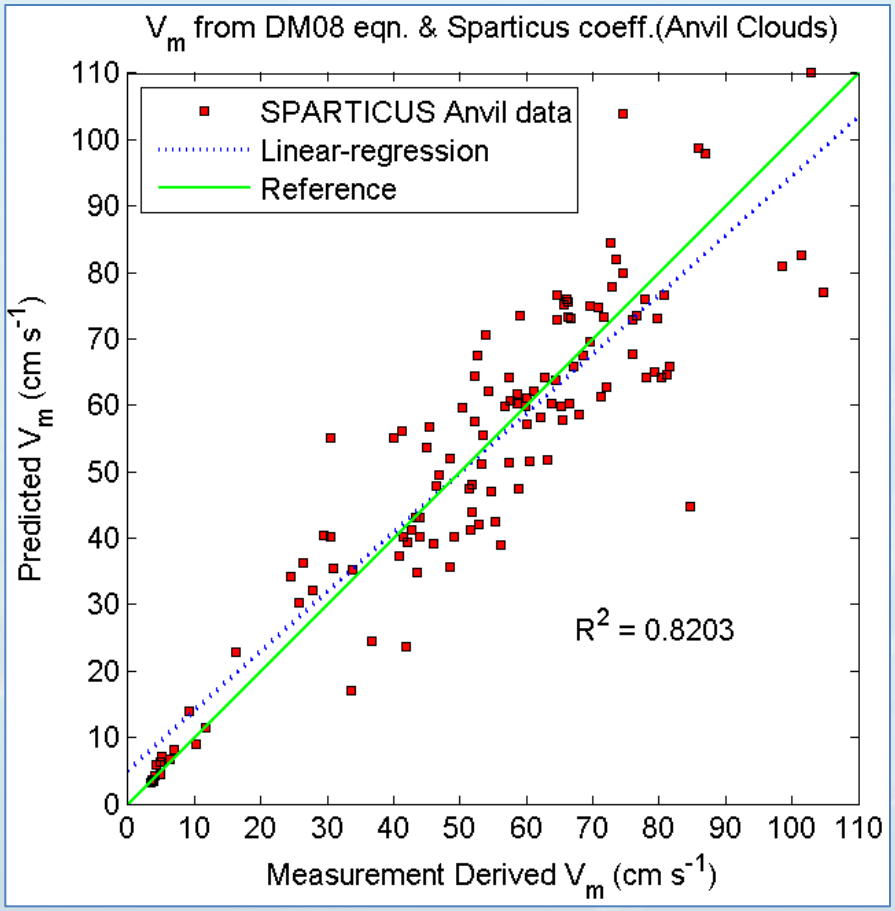
Normalized frequency distribution functions of PSD Area Ratios for four types of cirrus. (Adapted from Mitchell et al. 2011-JGR).

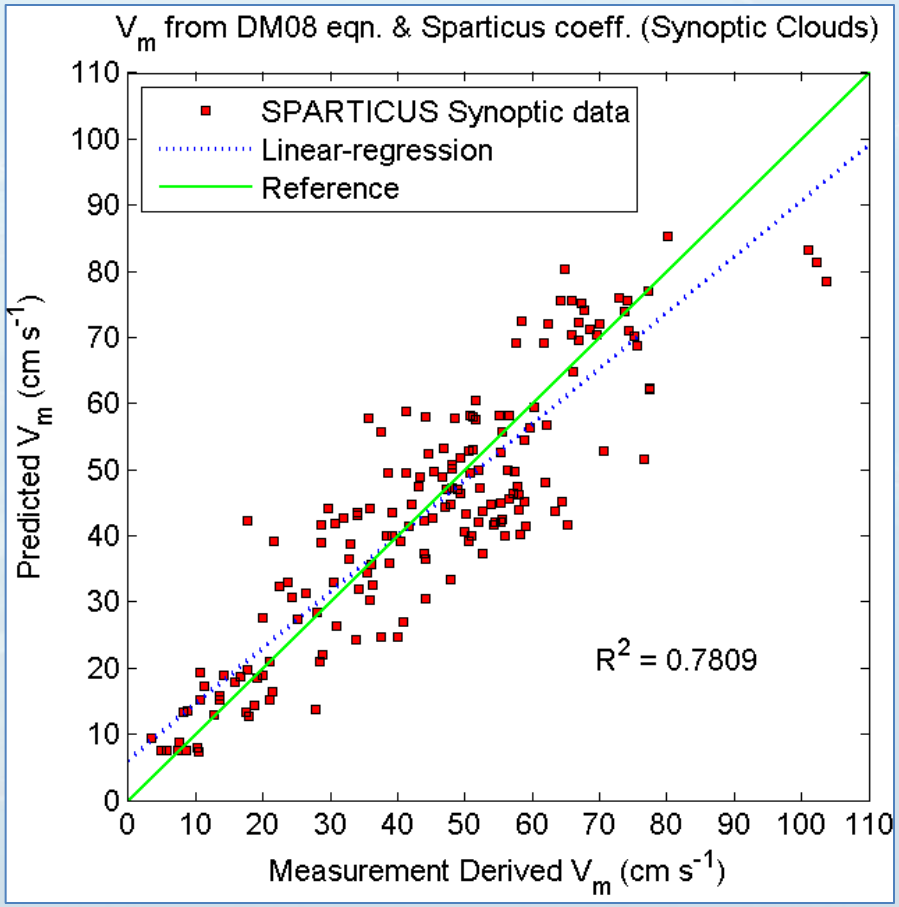
Predicting V_m in terms of T and IWC using the formulation of DM08 for Sparticus anvil and synoptic cirrus (coefficients derived for SGP cirrus by DM08)



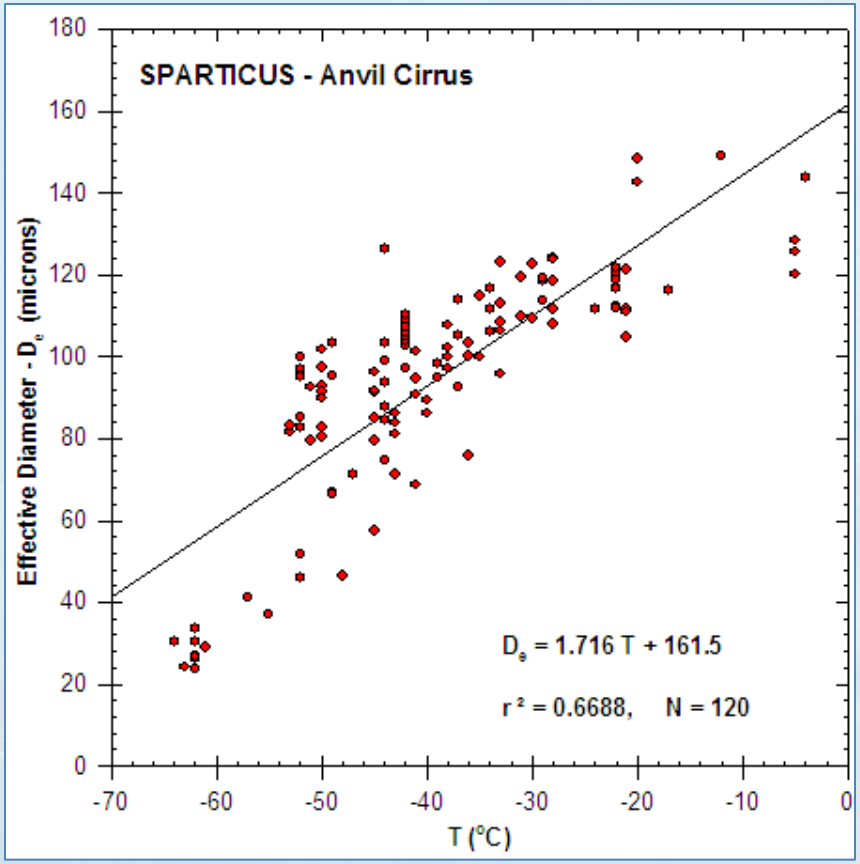


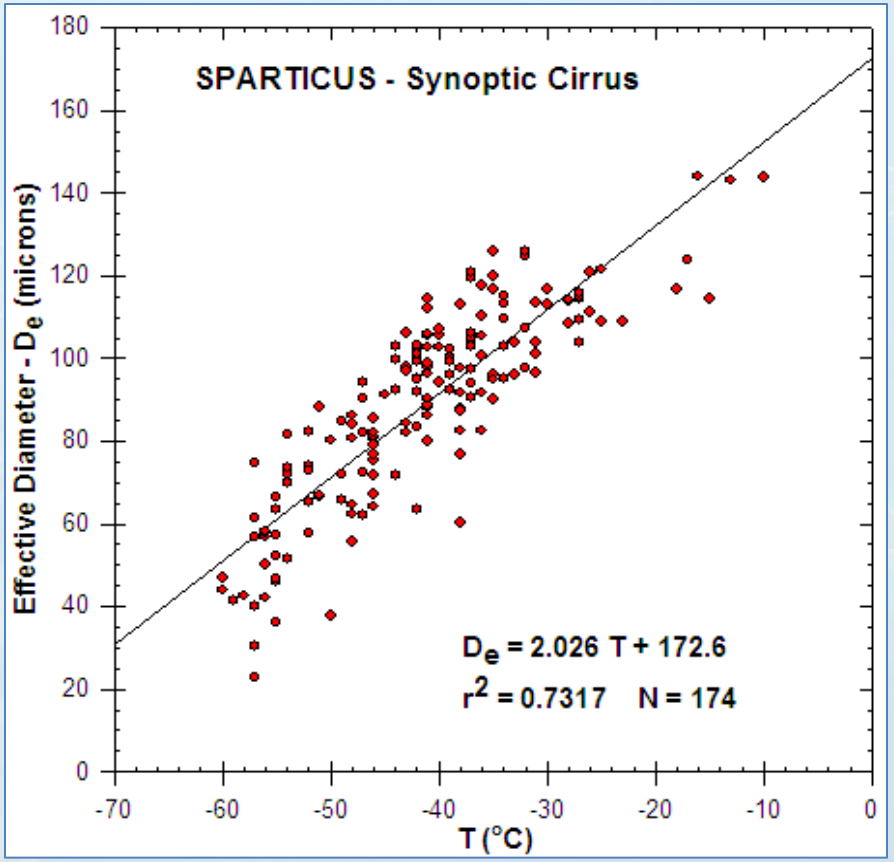
Predicting V_m in terms of T and IWC using the formulation of DM08 for Sparticus anvil and synoptic cirrus (coefficients derived from Sparticus)



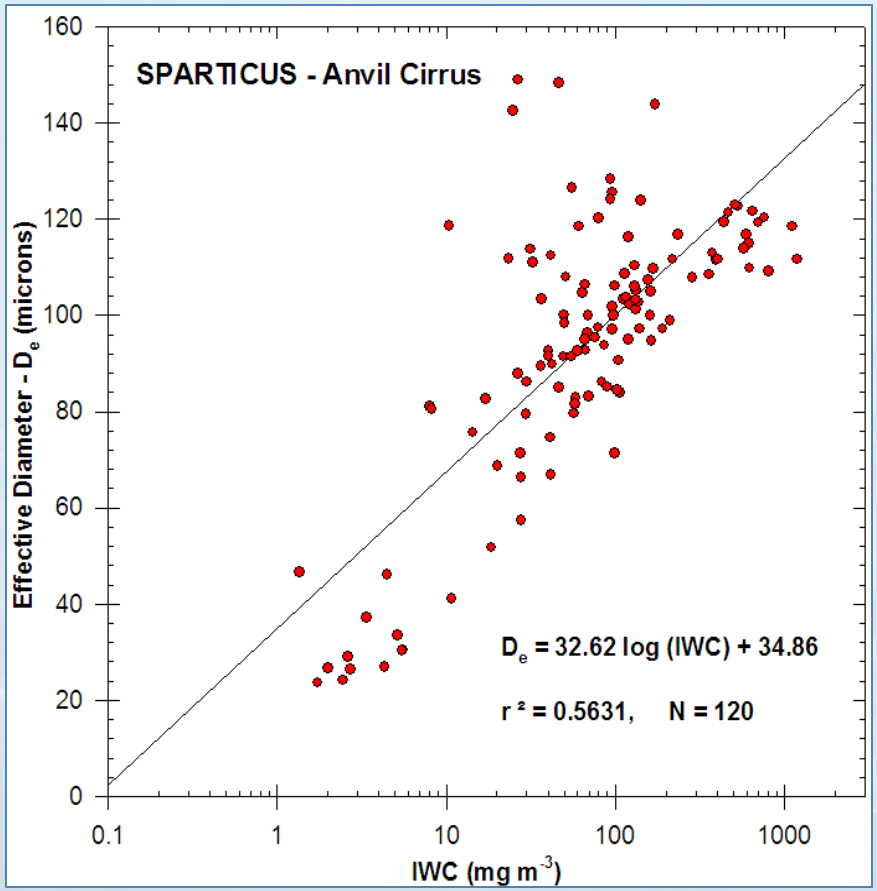


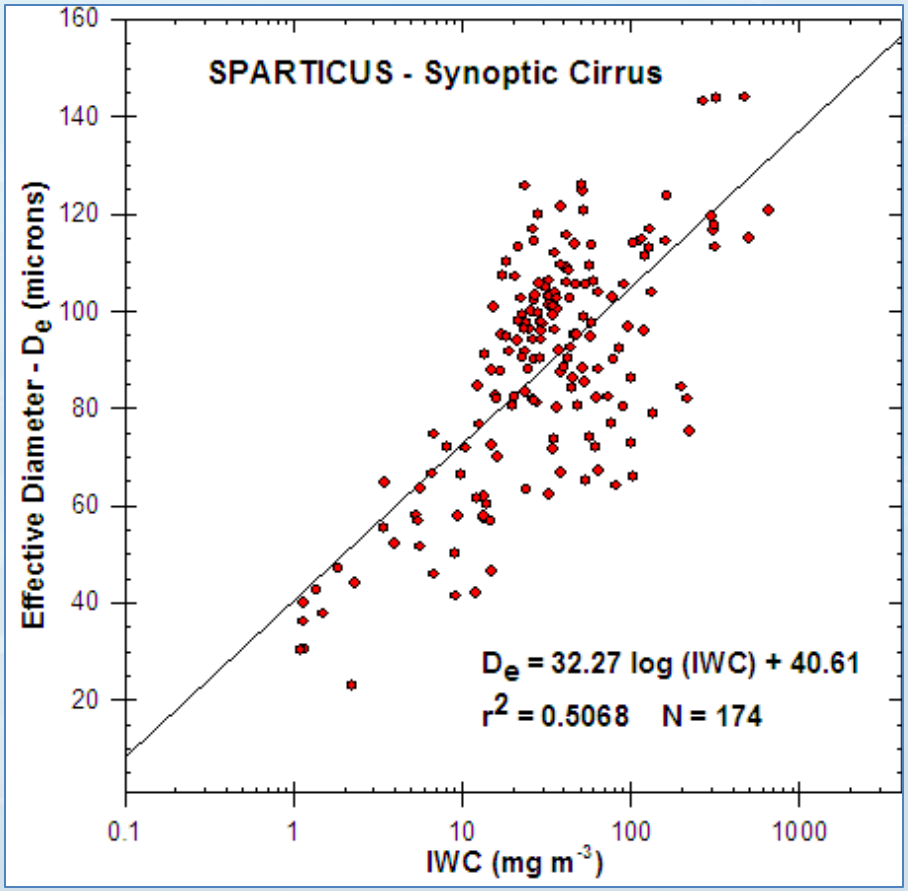
Temperature dependence of D_e for anvil and synoptic cirrus



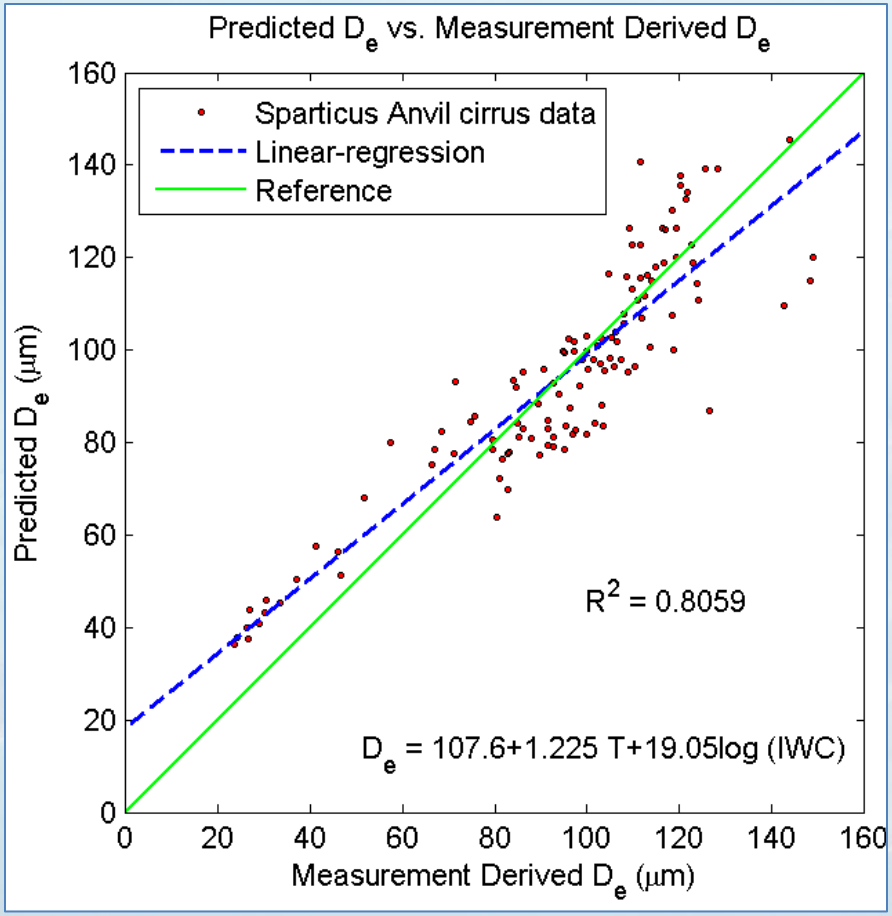


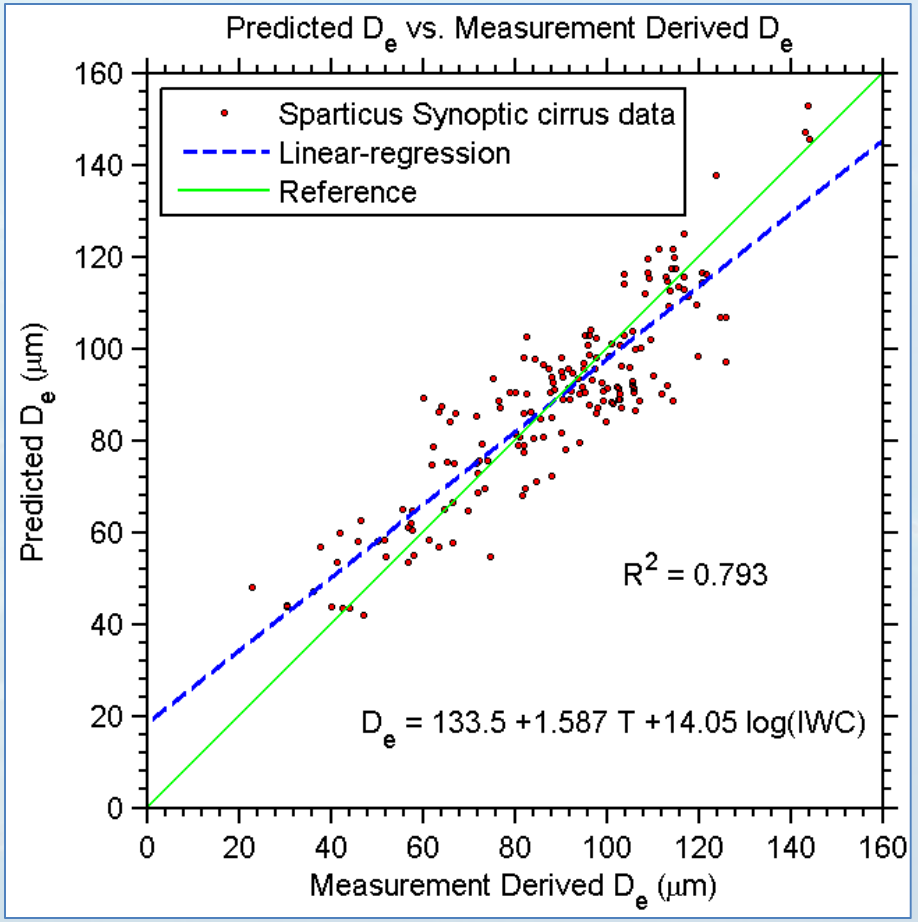
Dependence of D_e on ice water content (IWC) for anvil and synoptic cirrus



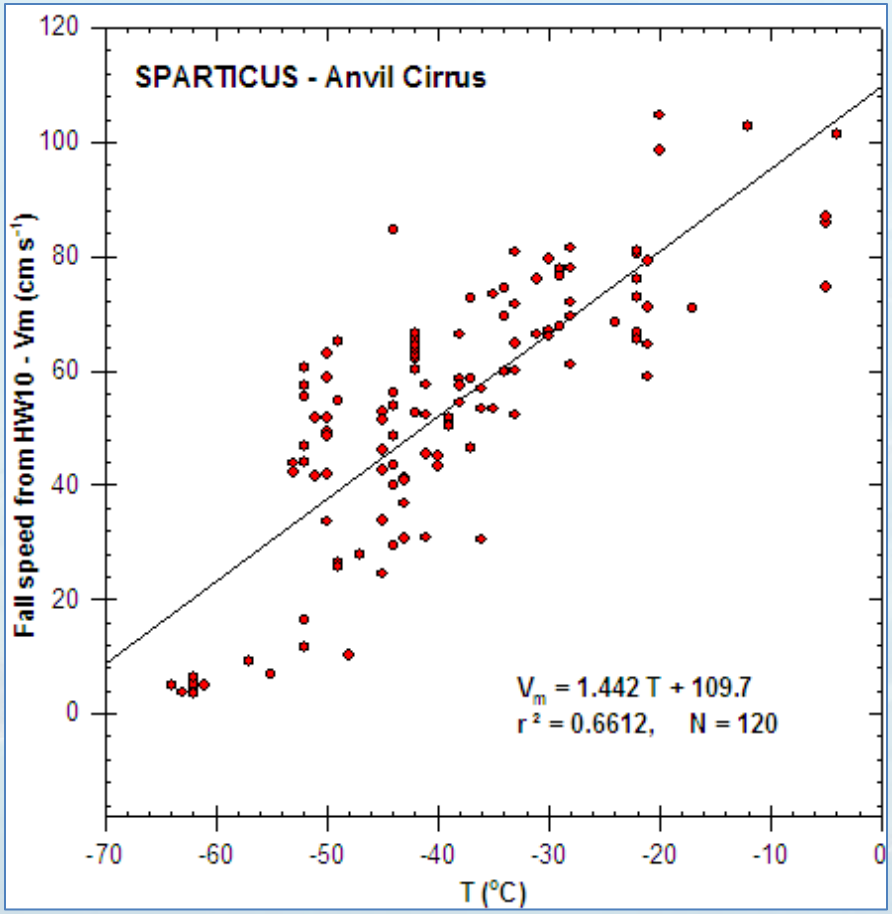


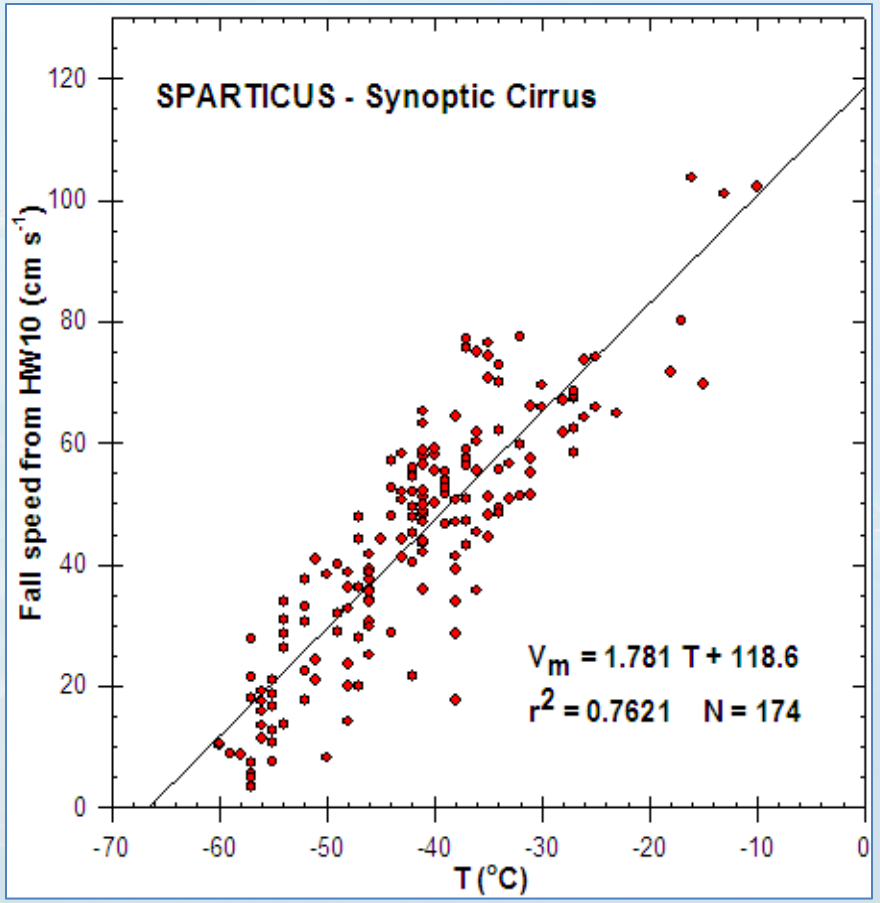
Multiple variable regression predicting D_e in terms of temperature and IWC



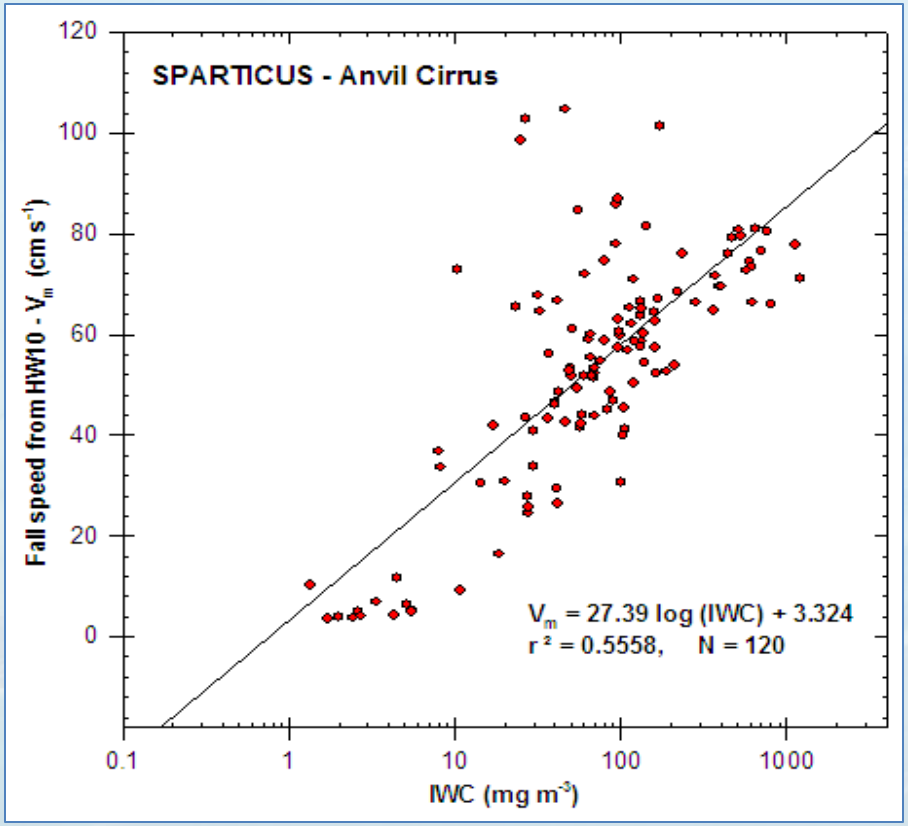


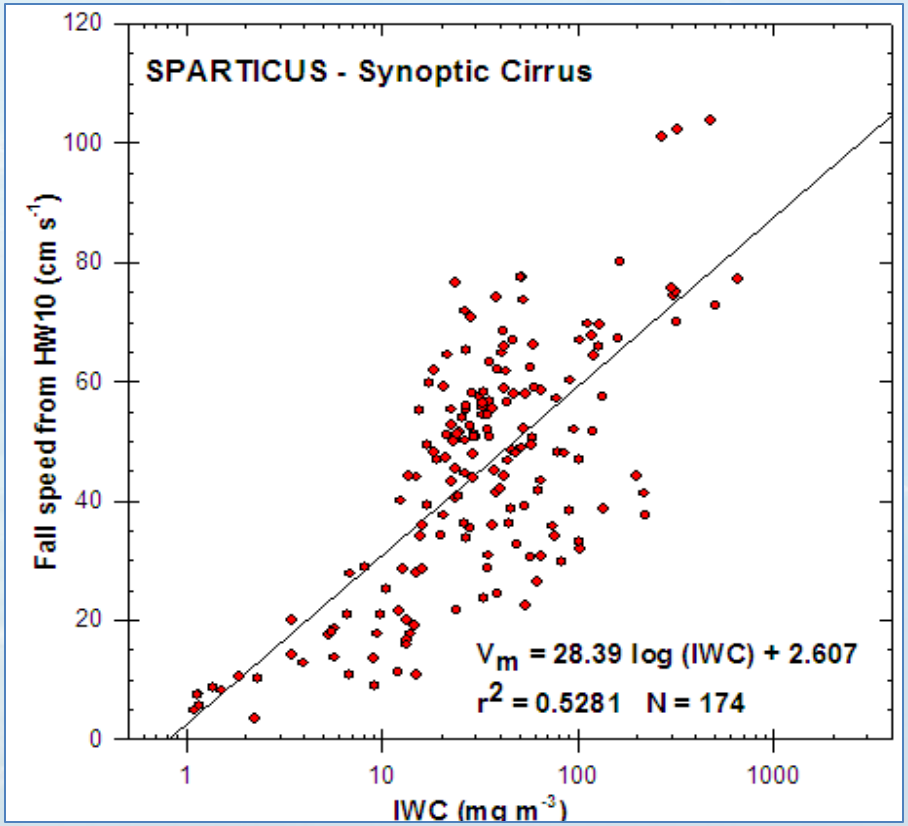
Temperature dependence of V_m for anvil and synoptic cirrus



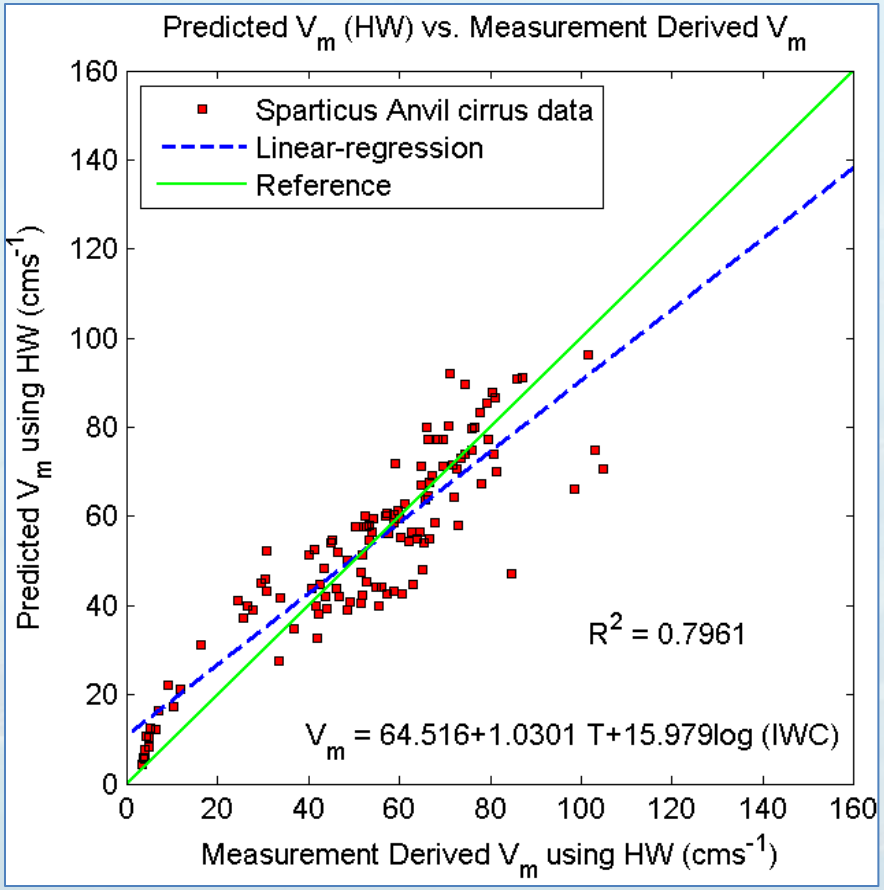


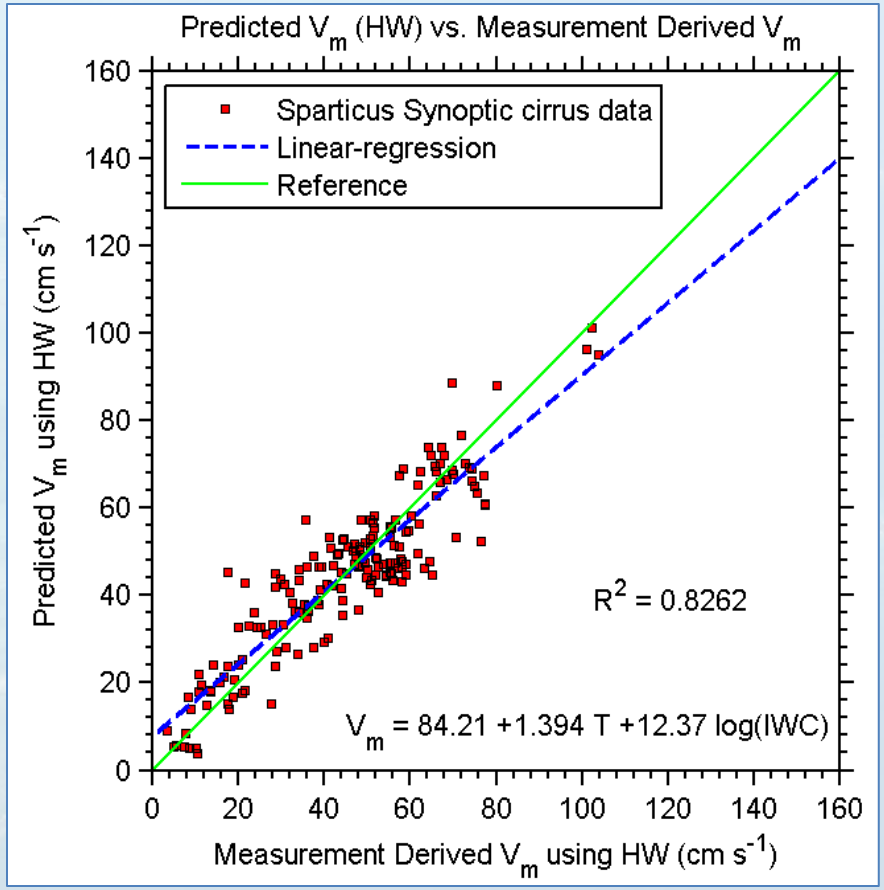
Dependence of V_m on ice water content (IWC) for anvil and synoptic cirrus

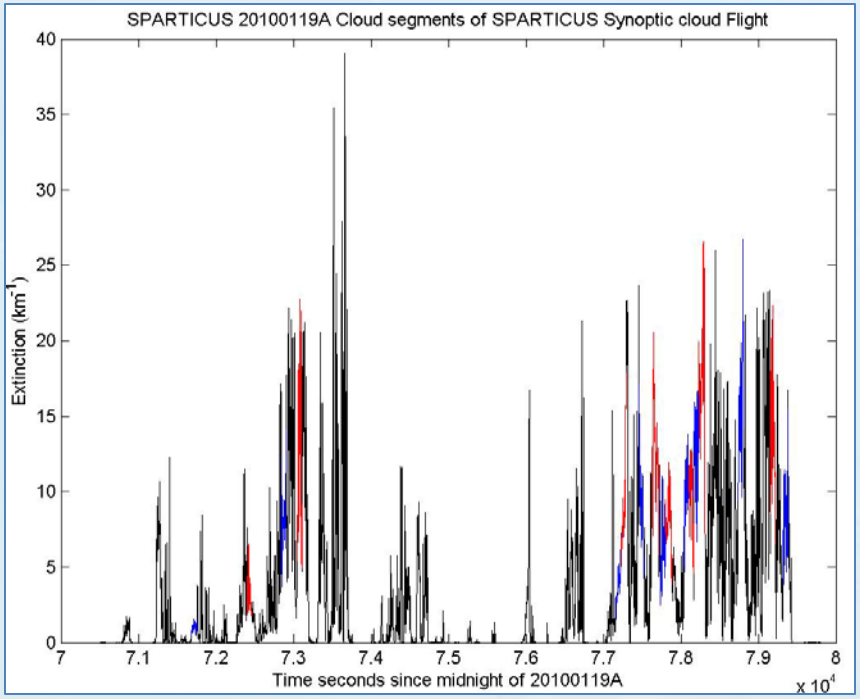


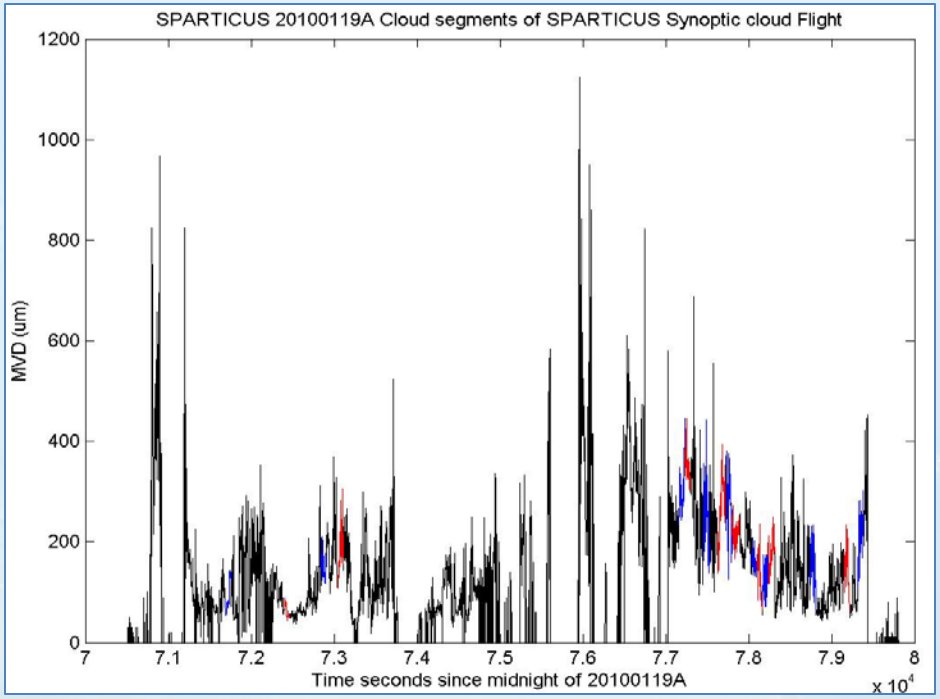


Multiple variable regression predicting V_m in terms of temperature and IWC







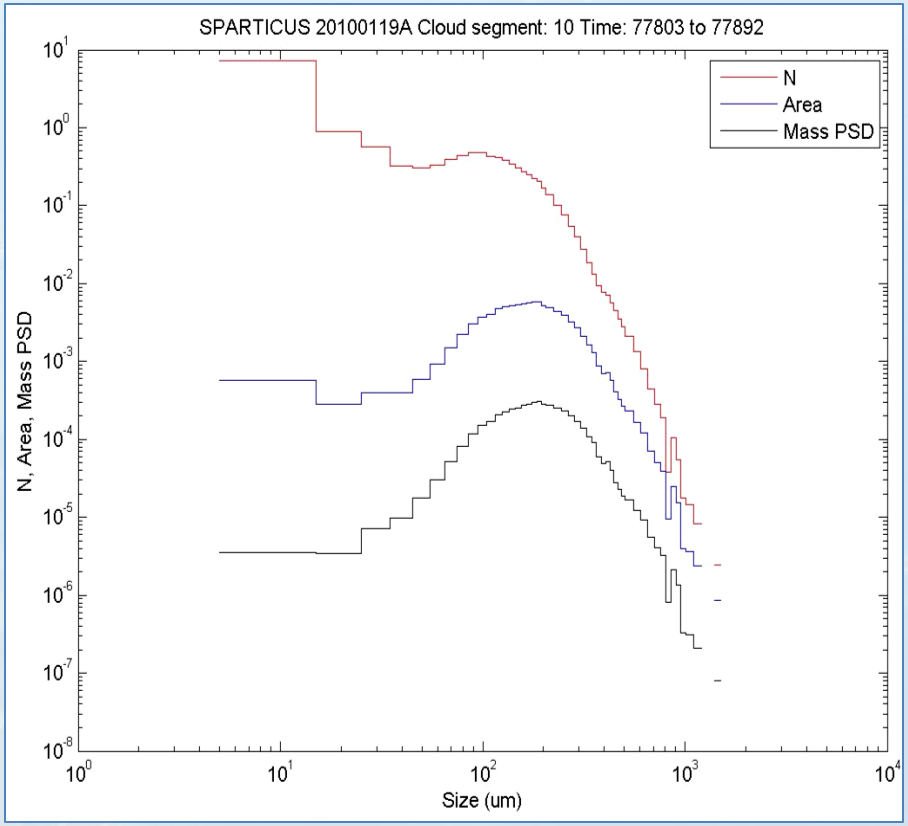


Selection of SPARTICUS cloud segments based on Extinction and MVD from the 2D-S probe

Motivation

- Model climates are sensitive to slight variations in cirrus coverage and ice microphysics that cannot be accurately determined without proper knowledge of ice nucleation mechanisms in cirrus.
- Despite the availability of a large body of literature dealing with heterogeneous and homogeneous freezing nucleation in cirrus clouds, there is no clear verdict on what process dominates at temperatures below -38°C .
- Aerosol indirect effect (AIE) represents the greatest uncertainty in radiative forcing among the components of the climate system. AIE is most pronounced when homogeneous nucleation dominates.

2 Dimensional-Stereo (2D-S) Probe



The 2D-S probe has an open path design that reduces shattering. It has a size resolution of 10 microns resulting in better estimates of ice particle area.