Parameterizations of Ice Particle Size Distributions and Bulk Microphysical Properties for Cirrus and Stratiform Ice cloud Layers

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andy, for your talk in hawaii can you include some constructive but hard-hitting criticism of the deficiencies of ice microphysics in "bulk" microphysics schemes, such as the ones currently used in most cloud-resolving models?

Outline

- PSD Parameterization Issues
  - Examine data sets
- Develop an Approach
  - Again examine data
- Results
- Summary and Conclusions

Issues (1)

- Species, especially ice/snow distinction
- Ice Particle Densities
  - Snow, 0.1 g/m^3
  - Graupel, 0.3 to 0.4 g/m^3
  - Hail, 0.9 g/m^3
- Terminal Velocities
  - Pressure dependence, “spread”

Issue 2: PSD Parameterization

- Representation of snow PSDs
- how do we parameterization the PSDs using one moment schemes in operational forecast models
- strong sensitivity of diffusion growth to the PSD
- terminal velocity affects cloud bulk properties to a minor extent
- Representation of graupel/hail PSDs
- terminal velocity crucial (affects riming/LW depletion rates)
- particle density is also crucial
- Two moment schemes to represent the PSDs
- predict the total number concentration by species and ice mixing ratio. Are there other, better variables?

PSD Parameterization Issues

- Representation of Snow PSDs

-----Exponentials

$$N = N_o \, e^{-\lambda D}$$

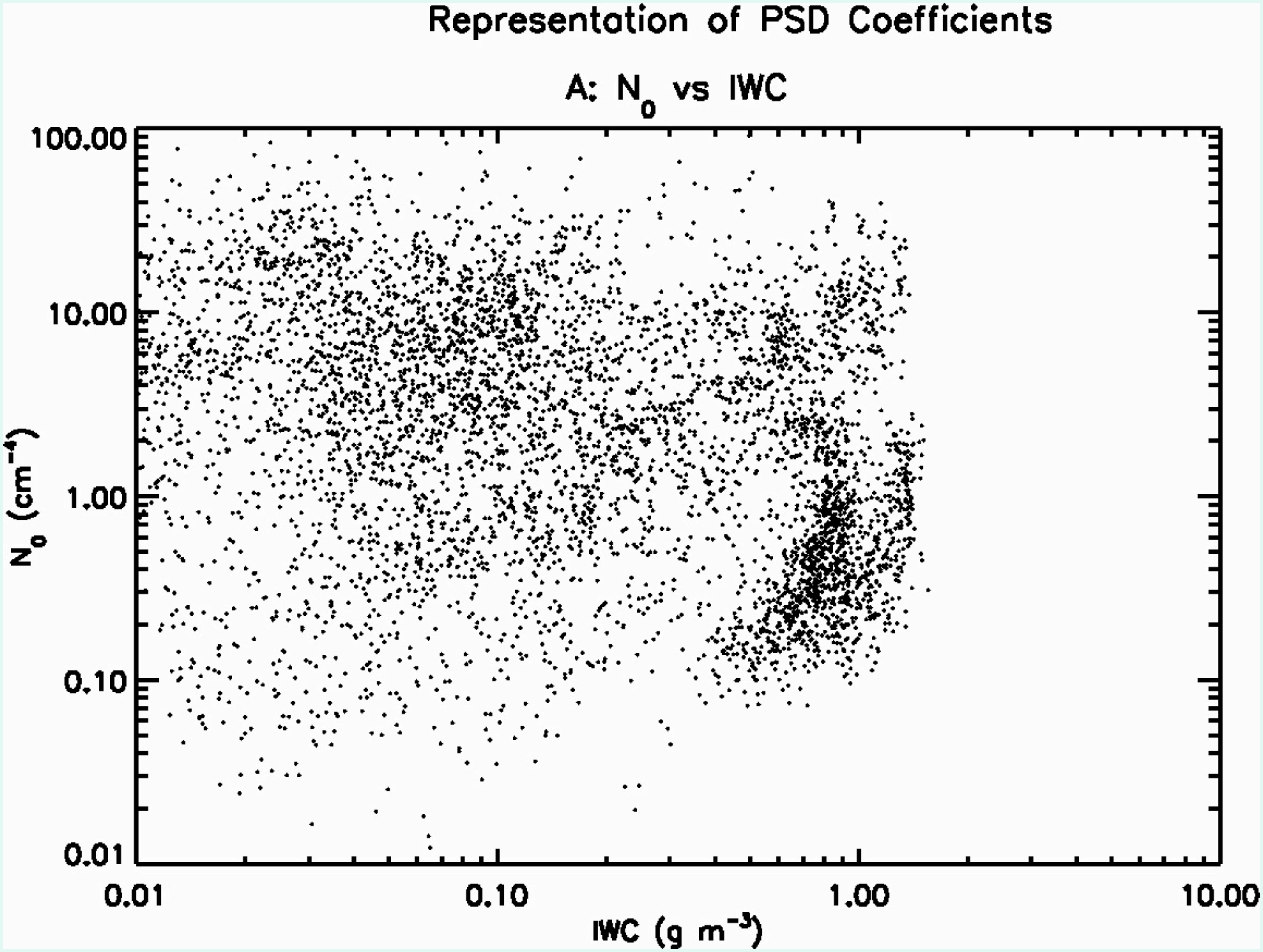
For Marshall Palmer,

$N_0 = 0.08$ (cgs), $\lambda = 41R^{-0.21}$

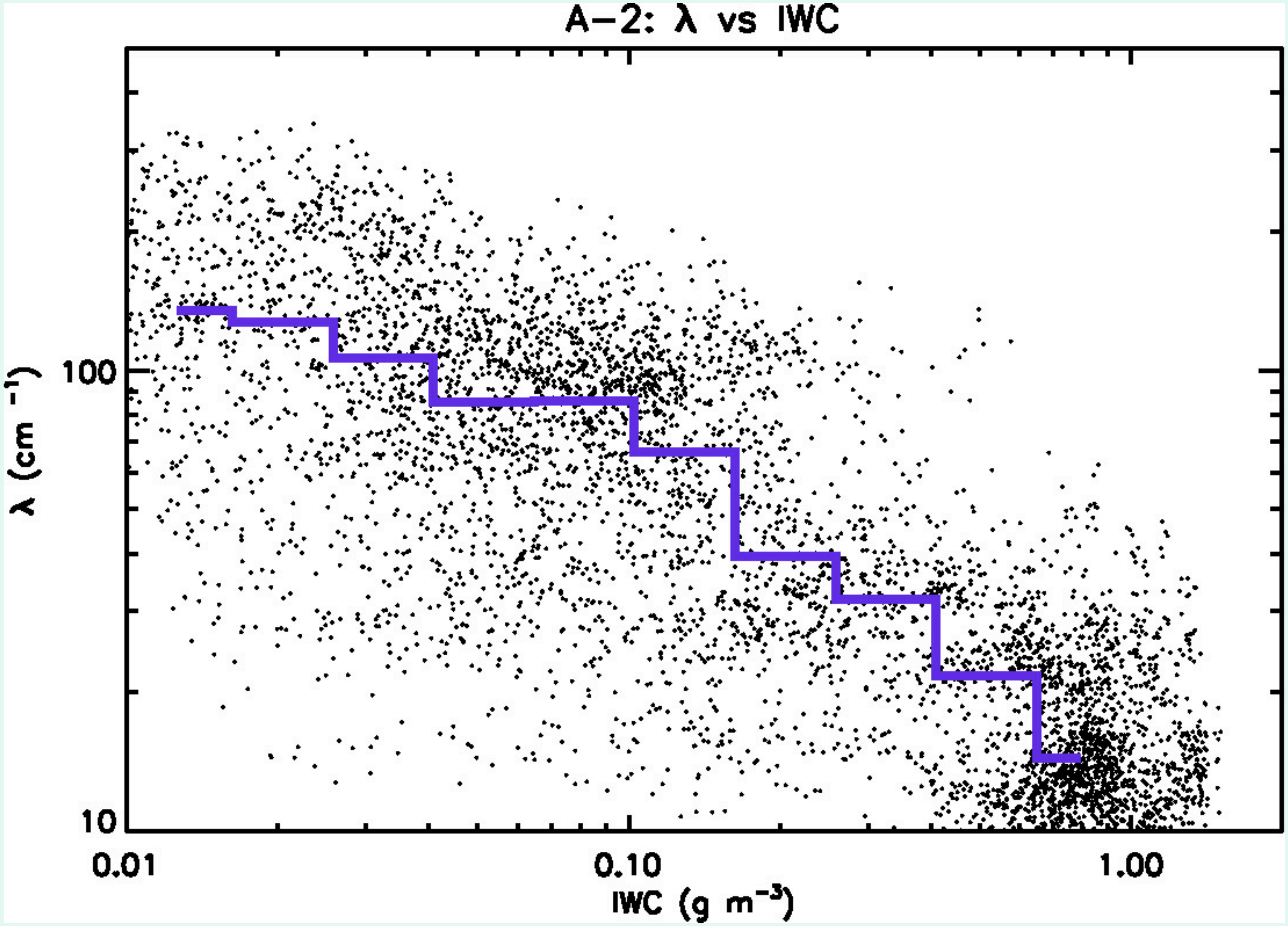
---For Ice PSDs, R~ V_t x IWC~100 IWC

Therefore, N_0 should be constant, $\lambda \propto IWC^{-p}$

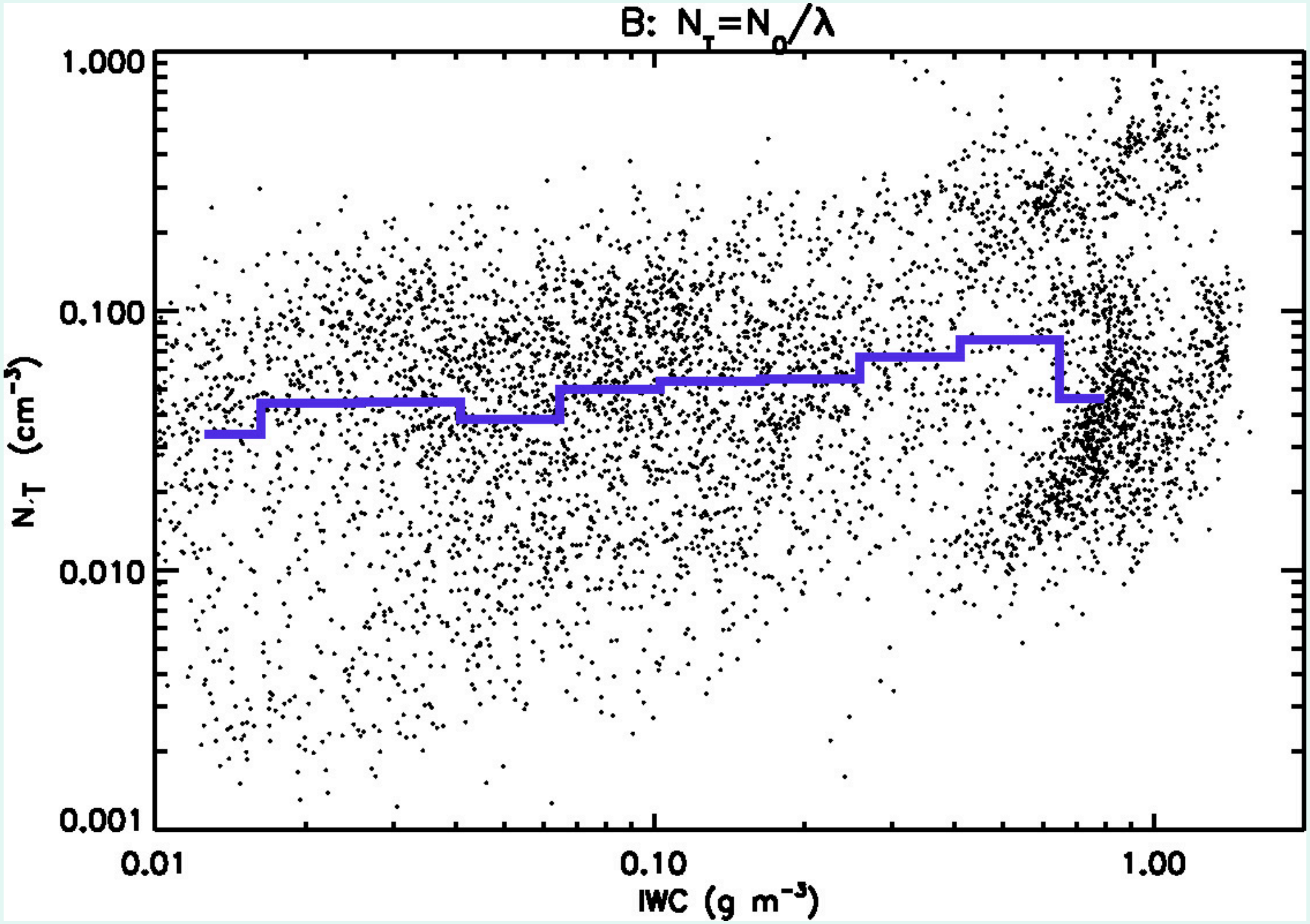
CRYSTAL DATA SET



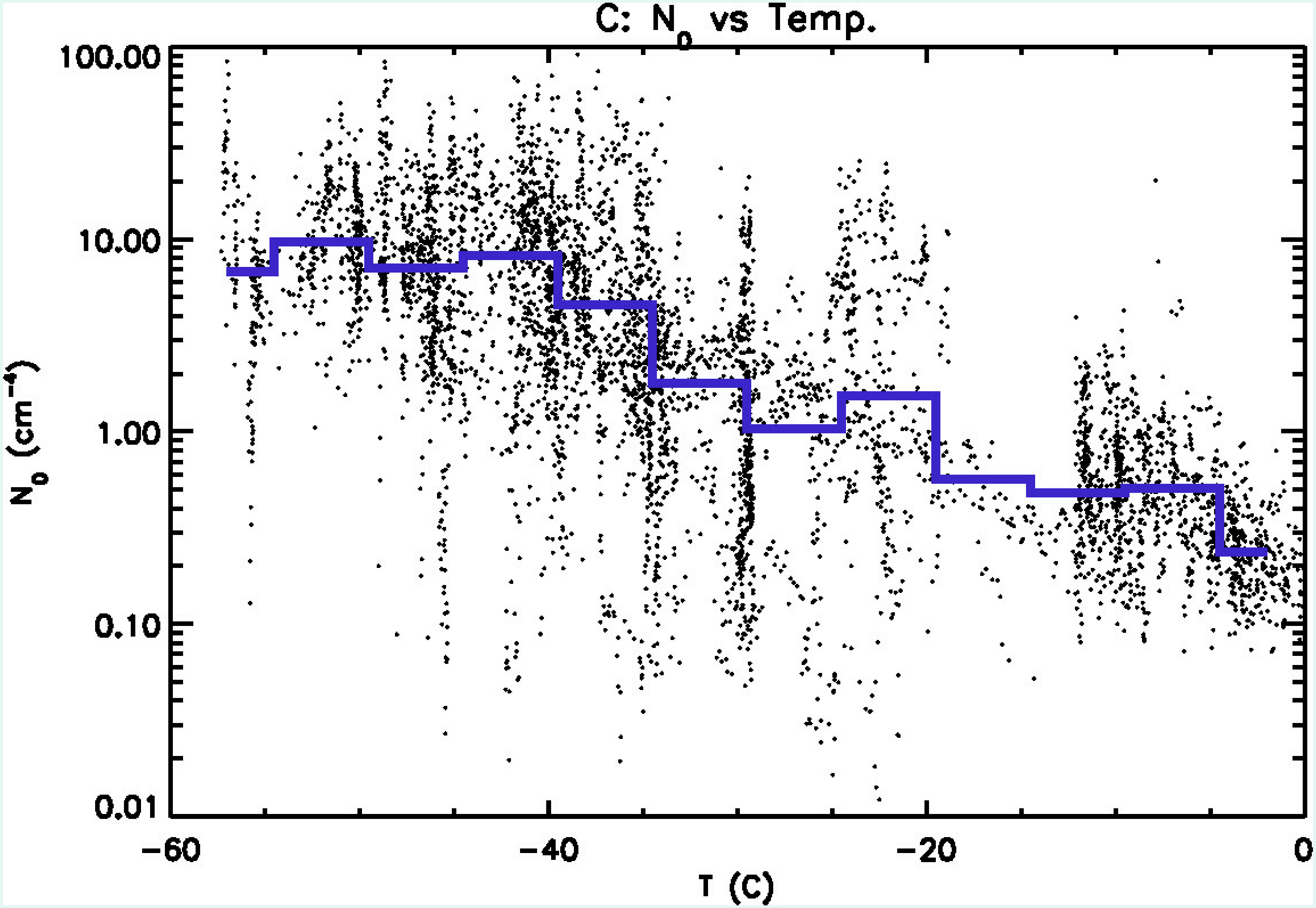
N_0 for ice PSDs is therefore not constant



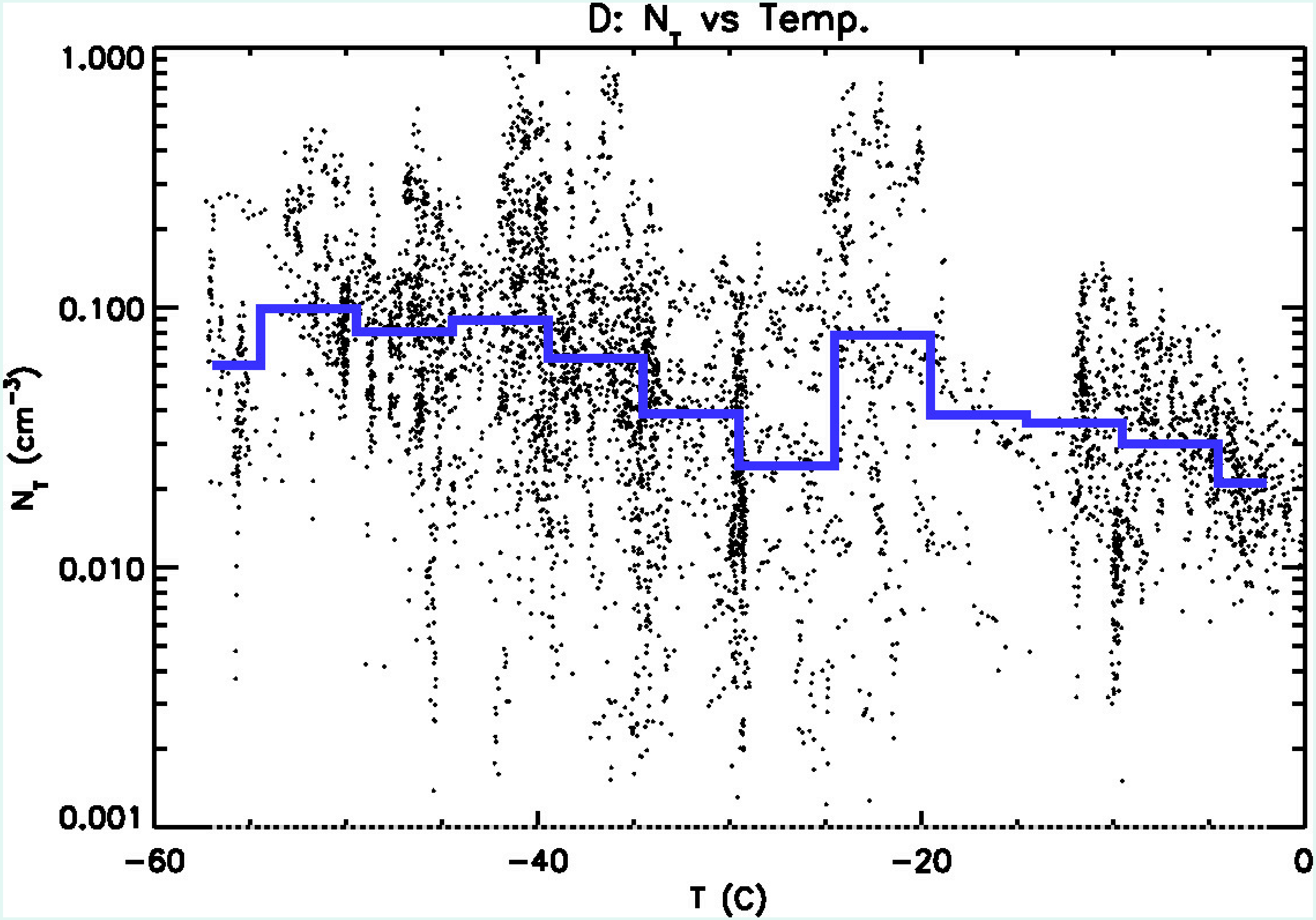
 is loosely related to IWC



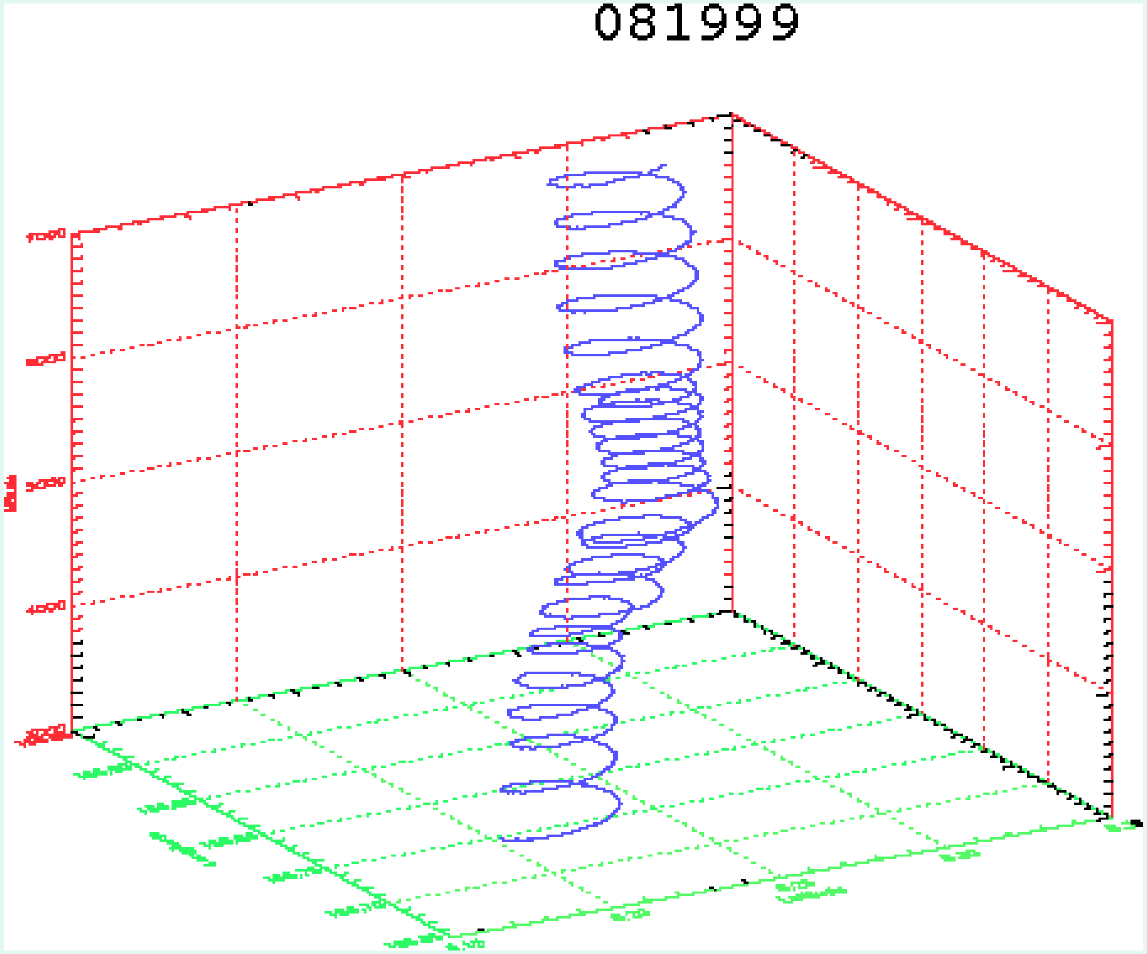
B: $N_T=N_0/\lambda$
1.000
0.100
0.010
0.001
N_T (cm^{-3})
0.01
0.10
1.00
IWC (g m^{-3})

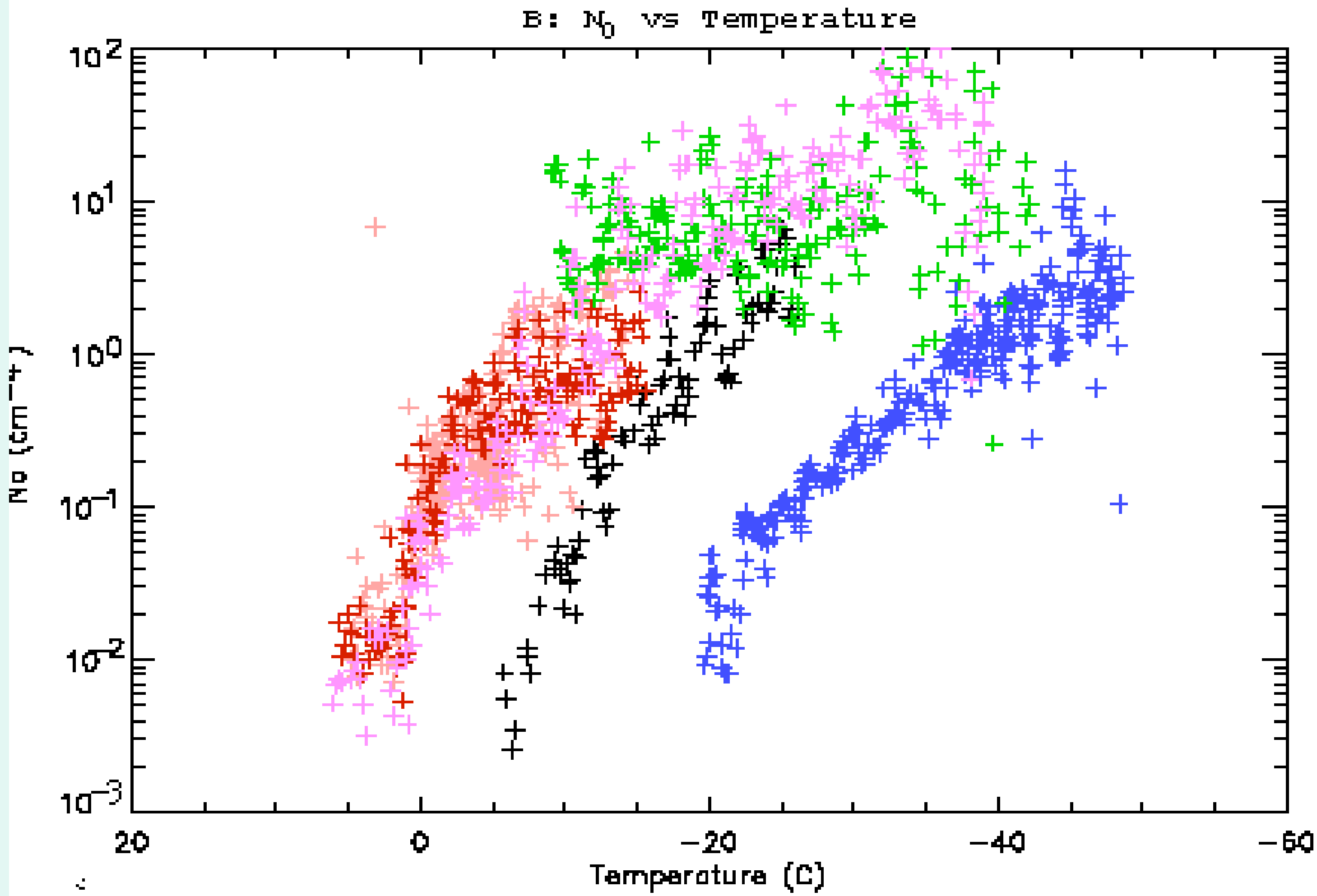


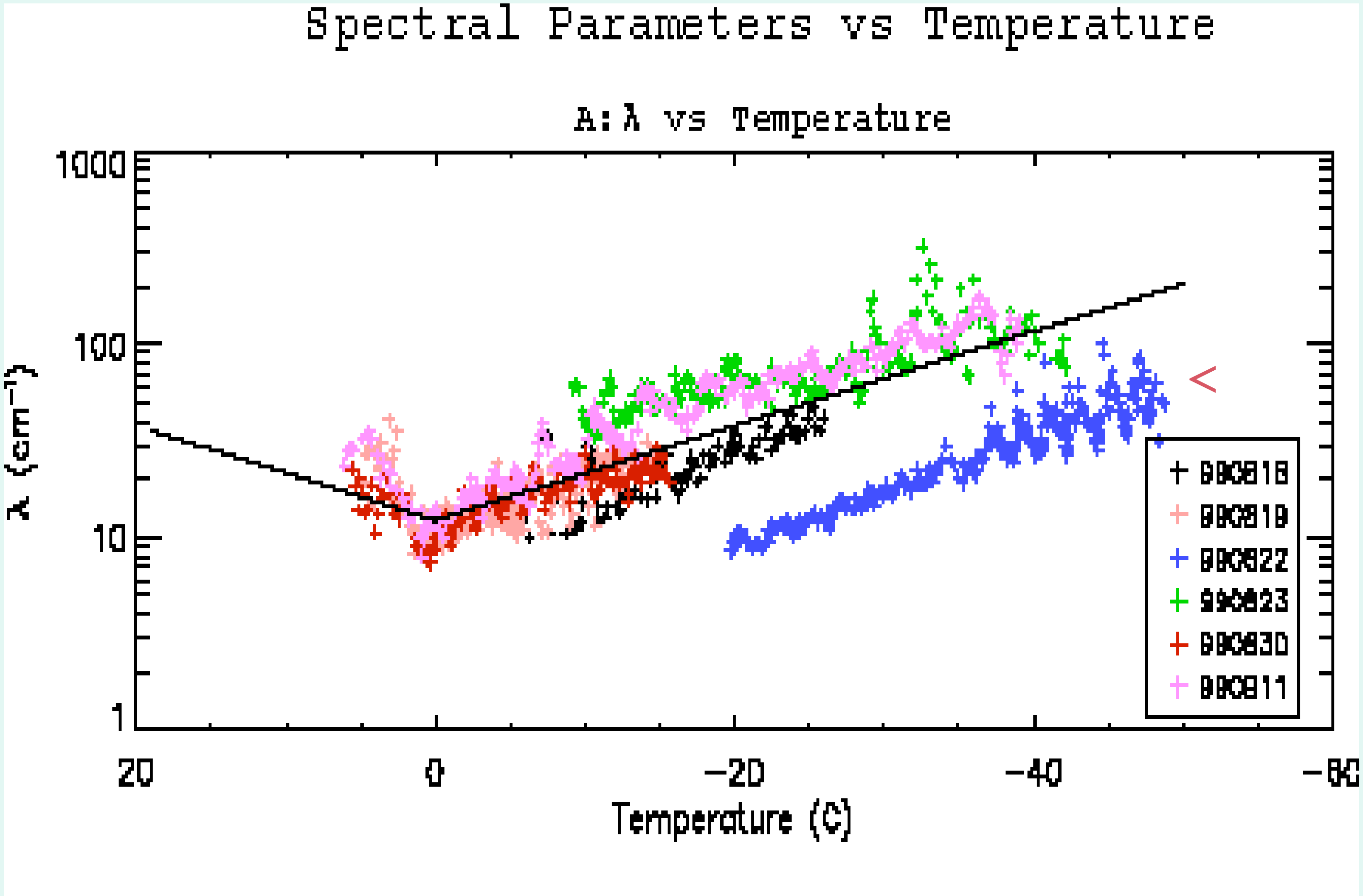
N_o is reasonably well correlated with temperature


D: N_T vs Temp.
1.000
0.100
0.010
0.001
N_T (cm^{-3})
−60
−40
−20
0
T (C)

Typical Citation Spiral Descent

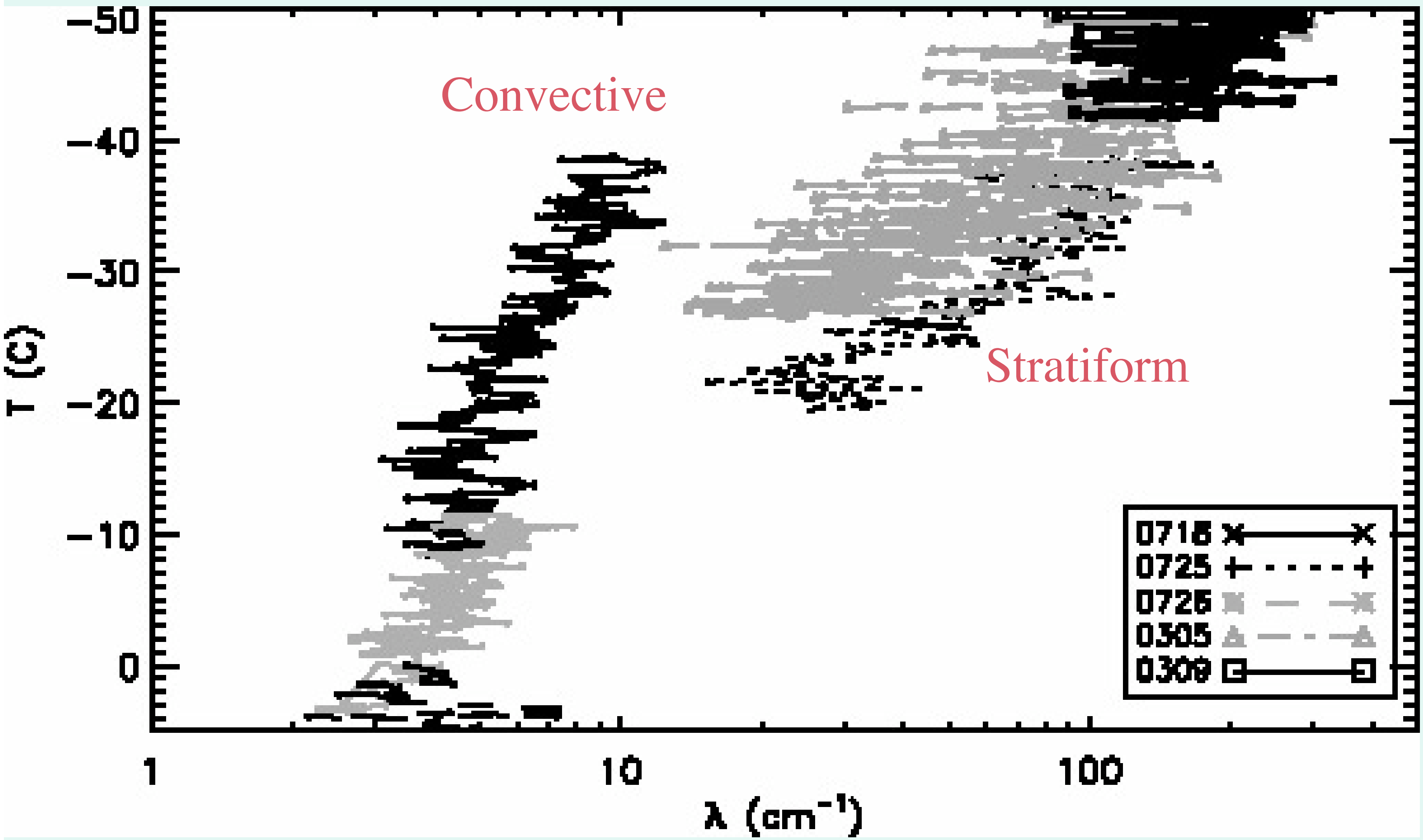


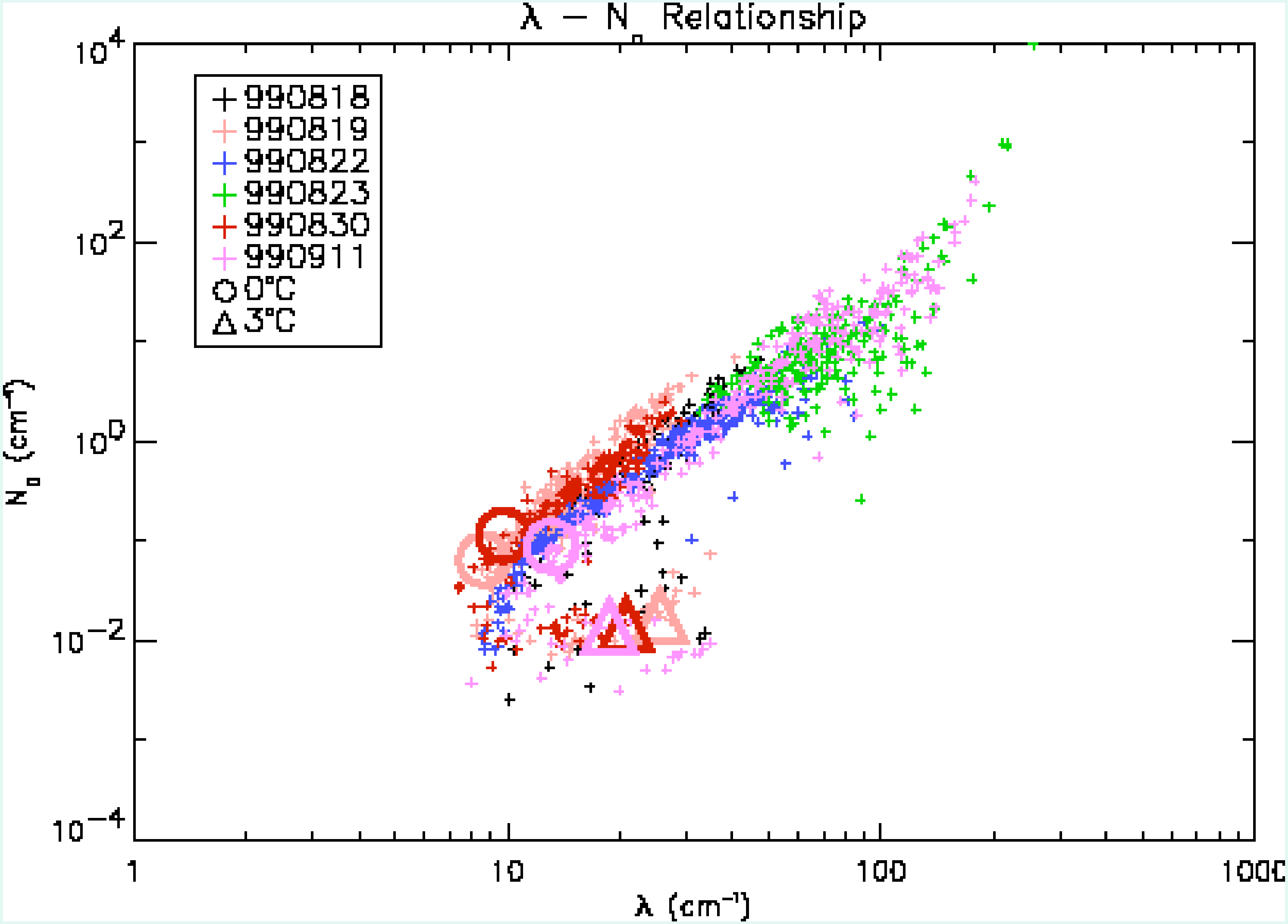

B: N0 vs Temperature
No (Cm^-4)
10^2
10^1
10^0
10^-1
10^-2
10^-3
20
0
-20
-40
-60
Temperature (C)



< Interesting

CRYSTAL, ARM DATA SETS



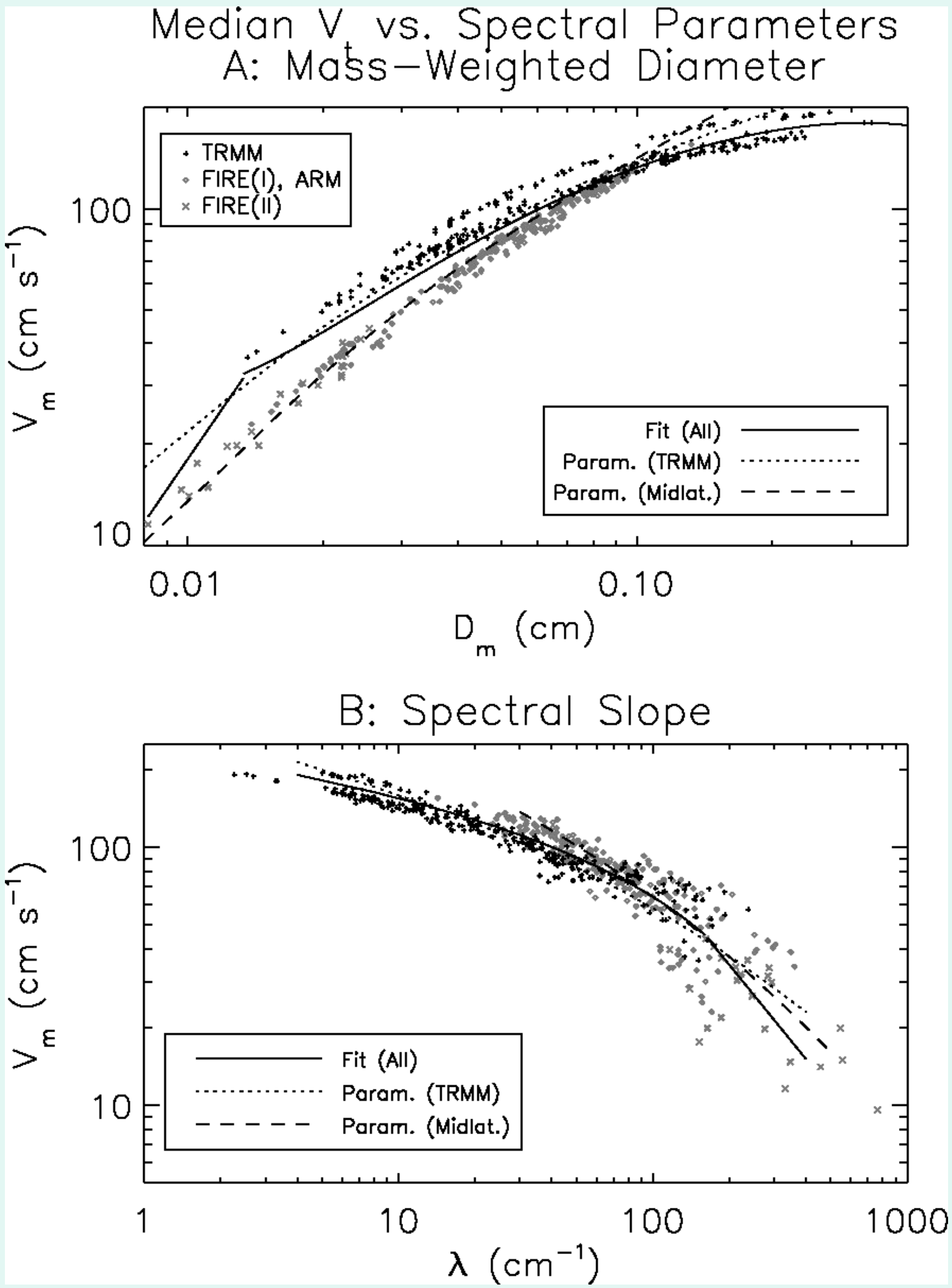


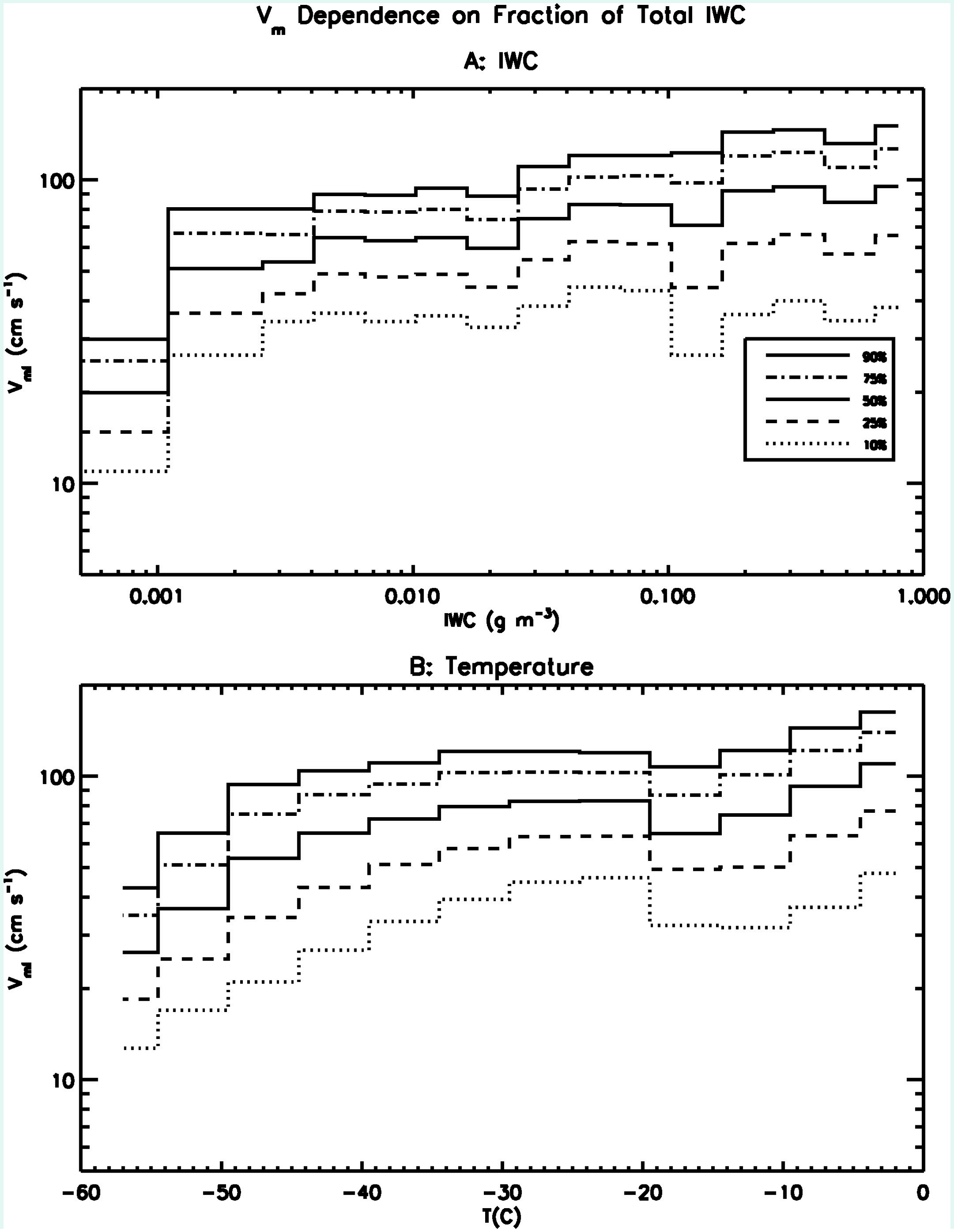
λ – N0 Relationship
990818
990819
990822
990823
990830
990911
0°C
3°C
N0 (cm⁻⁴)
λ (cm⁻¹)
10^4
10^2
10^0
10^-2
10^-4
1
10
100
1000

Parameterization Development

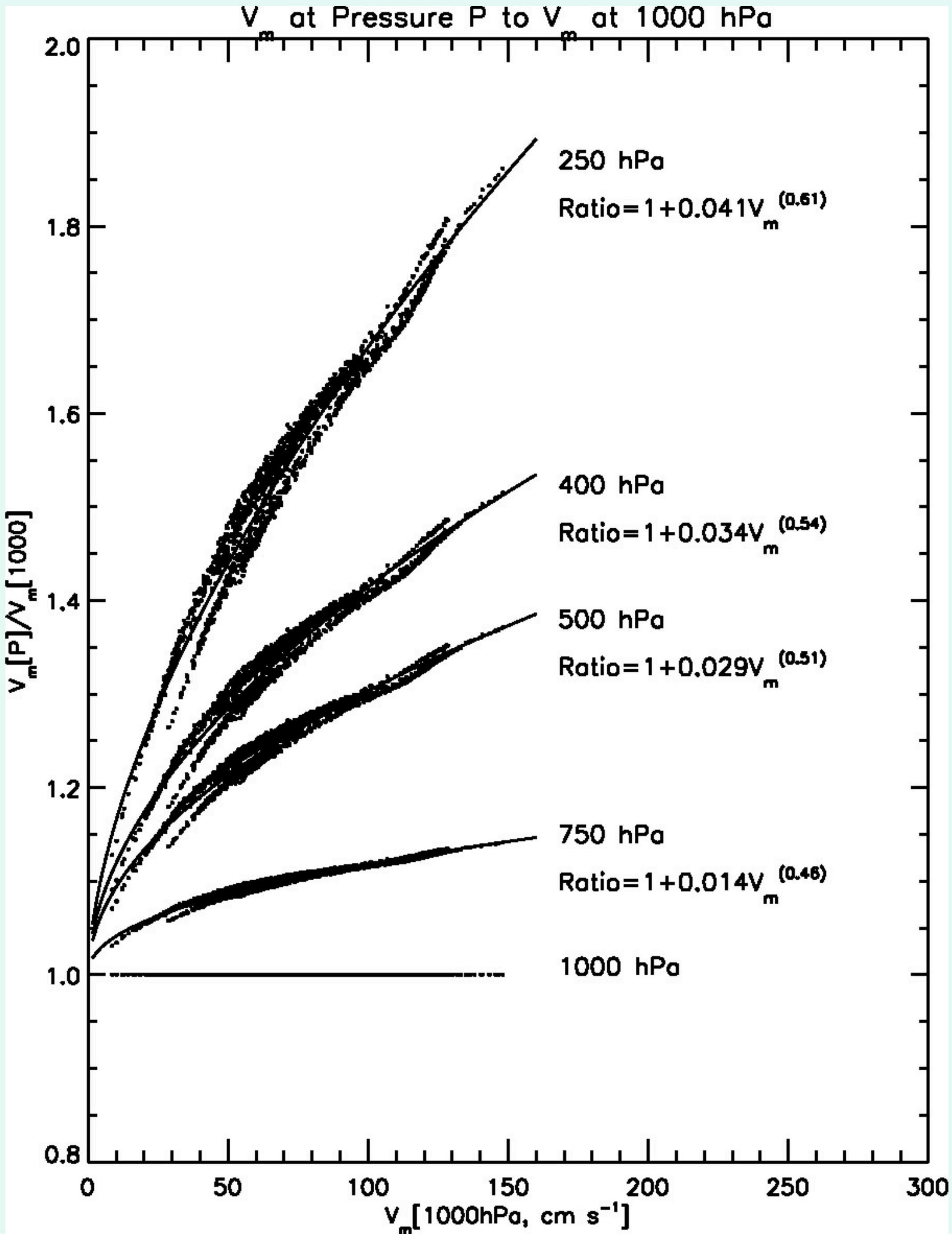
- N = $N_0 e^{-\square D}$
- $\square$ = $12.2x10^{-0.0245T}$ (after Ryan) stratiform
  - separate for close to convection
- IWC = $(\square/6)\ N_o \square\square\square(D)D^3e^{-\square D}dD=f(\square/\square)$
- R = $(\square/6)\ N_o \square\square\square(D)V_t(D)\ D^3e^{-\square D}dD$
- V_t (D) from Mitchell (1996), Heymsfield et al. (2001)

IWC $[\frac{g}{m^3}]$	$\frac{5.3 \text{ x } 10^3 N_{0\Gamma}\Gamma(3.4+\mu)}{\lambda_\Gamma^{(3.4+\mu)}}$
Z $[\frac{mm^6}{m^3}]$	$\frac{1.02 N_{0\Gamma} \text{ x } 10^8 \Gamma(5.7+\mu)}{\lambda_\Gamma^{(5.7+\mu)}}$
D_{mm} [cm]	$\frac{3.035 + \mu}{\lambda_\Gamma}$
dBZ_e[1]	$10 \log_{10} Z - 7.2$
$\mathbf{V}_m$ $[\frac{cm}{s}]$	$\frac{303\Gamma(3.9+\mu)\lambda_\Gamma^{-0.57}}{\Gamma(3.4+\mu)}$
V_Z $[\frac{cm}{s}]$	$\frac{244\Gamma(6.3+\mu)\lambda_\Gamma^{-0.57}}{\Gamma(5.7+\mu)}$
R $[\frac{mm}{hr}]$	$\frac{5.78 \text{ x } 10^4 N_{0\Gamma}\Gamma(3.9+\mu)}{\lambda_\Gamma^{(3.9+\mu)}}$
A_c $[\frac{cm^2}{m^3}]$	$\frac{5.3\text{x}10^3 N_{0\Gamma}\Gamma(2.9+\mu)}{\lambda_\Gamma^{(2.9+\mu)}}$
ϵ $[km^{-1}]$	$0.2A_c$
r_e $[\mu m]$	$\frac{107\Gamma(3.4+\mu)}{\Gamma(2.9+\mu)\lambda_\Gamma^{0.46}}$


Median V_t vs. Spectral Parameters
A: Mass−Weighted Diameter
TRMM
FIRE(I), ARM
FIRE(II)
Fit (All)
Param. (TRMM)
Param. (Midlat.)
V_m (cm s^-1)
100
10
0.01
0.10
D_m (cm)
B: Spectral Slope
Fit (All)
Param. (TRMM)
Param. (Midlat.)
V_m (cm s^-1)
100
10
1
10
100
1000
λ (cm^-1)



V_m Dependence on Fraction of Total IWC
A: IWC
V_{ml} (cm s^{-1})
100
10
0.001
0.010
0.100
1.000
IWC (g m^{-3})
90%
75%
50%
25%
10%
B: Temperature
V_{ml} (cm s^{-1})
100
10
-60
-50
-40
-30
-20
-10
0
T(C)



V_m at Pressure P to V_m at 1000 hPa
250 hPa
Ratio=1+0.041$V_m^{(0.61)}$
400 hPa
Ratio=1+0.034$V_m^{(0.54)}$
500 hPa
Ratio=1+0.029$V_m^{(0.51)}$
750 hPa
Ratio=1+0.014$V_m^{(0.46)}$
1000 hPa
V_m[P]/V_m[1000]
V_m[1000hPa, cm s^{-1}]
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
50
100
150
200
250
300

Summary and Conclusions

- Issues related to parameterizations of ice particle size distributions were examined
- Representations of PSDs properties in terms of temperature seem promising, especially if convective situations are separated from stratiform regions
- The slope of the PSDs, □, offer the most promise for parameterization
- Once □ is known, IWC yields the intercept parameter (two moment schemes), or a □ versus N_0 relationship(one moment) can be used to specify IWC.
- Given □ and N_0, many microphysical, radiative, and radar-related parameters can be derived.
- Eliminate ice/snow species distinction, consider spread of fall velocities and pressure dependence reliably.