Parameterizations of HIWC/HAIC PSDs for modeling

G. McFarquhar[1], S. Zhu[1], J. Um[1], J.W. Strapp[2], A. Schwarzenboeck[3], A. V. Korolev[4], & D. Leroy[3]

[1]University of Illinois, Urbana, IL

[2]Met Analytics, Toronto, ON

[3]Université Blaise Pascal, Clermont, France

[4]Environment Canada, Downsview, ON

OUTLINE

1. Use of gamma functions in numerical models
2. Techniques to fit HIWC/HAIC size distributions as gamma functions
   - Volume of equally realizable solutions
3. Complications with multiple modes during HIWC/HAIC
4. Implications for model studies
5. Shapes of small particles & radiative impacts

Gamma Functions

- **Gamma functions used to characterize N(D)**

$$N(D) = N_0 \; D^{\mu} \exp(-\lambda D)$$

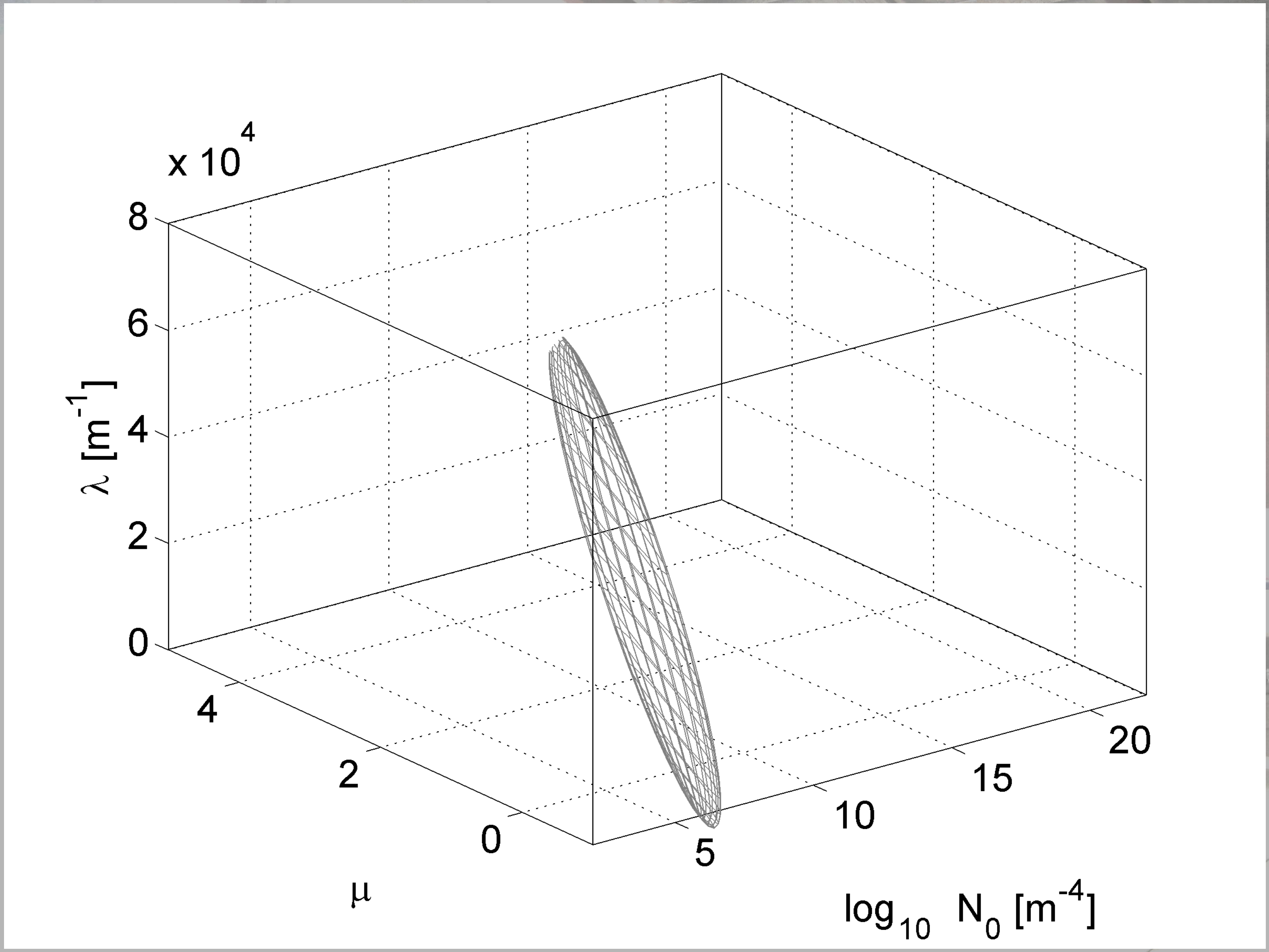
with N_0 intercept, λ slope and μ shape

- **N_0, μ, and λ determined from observed size distributions (SDs)**
- **Little attention placed on uncertainty in N_0, μ and λ**

Determining N_0, μ and λ

- N_0, μ, and λ calculated through Incomplete Gamma Fit (IGF) developed at UI that minimizes χ^2 difference between fit and observed moments (any 3 moments can be chosen)
  - Accounts for fact measured SDs do not cover complete range of particle sizes
  - Any (N_0,μ,λ) within $\Delta\chi^2$ of minimum χ^2 regarded as equally realizable solution
  - $\Delta\chi^2$ determined from statistical uncertainty on measured moments on which fit based
  - $\mu > -1$ and $\lambda > 0$ are forced

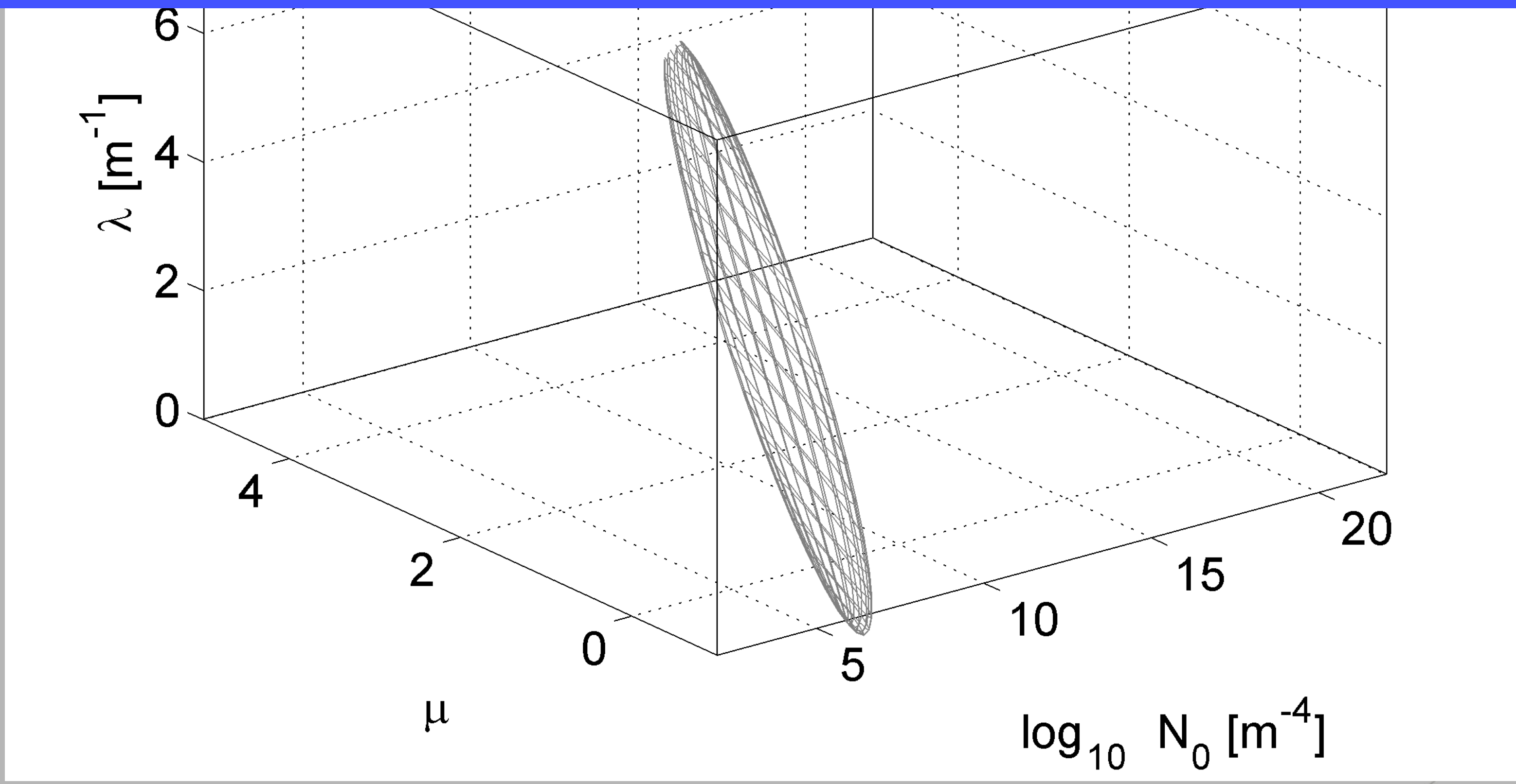
Volume of Equally Realizable Solutions



Volume of Equally Realizable Solutions

Broad range of $N_0/\mu/\lambda$ that fit SD well within allowed tolerance

→ Tolerance determined by uncertainty in measured SD



Apply to HIWC Project

- Phase I of High Ice Water Content (HIWC) conducted out of Darwin, Australia
- HIWC designed to investigate high IWCs in convective clouds over tropical oceans occurring in absence of radar echoes > 20 dBZ
  - Lots of small ice crystals; what causes them?
- Models will play critical role in hypothesis testing:
  - Are parameterizations based on data collected in conventional conditions appropriate for such model simulations?

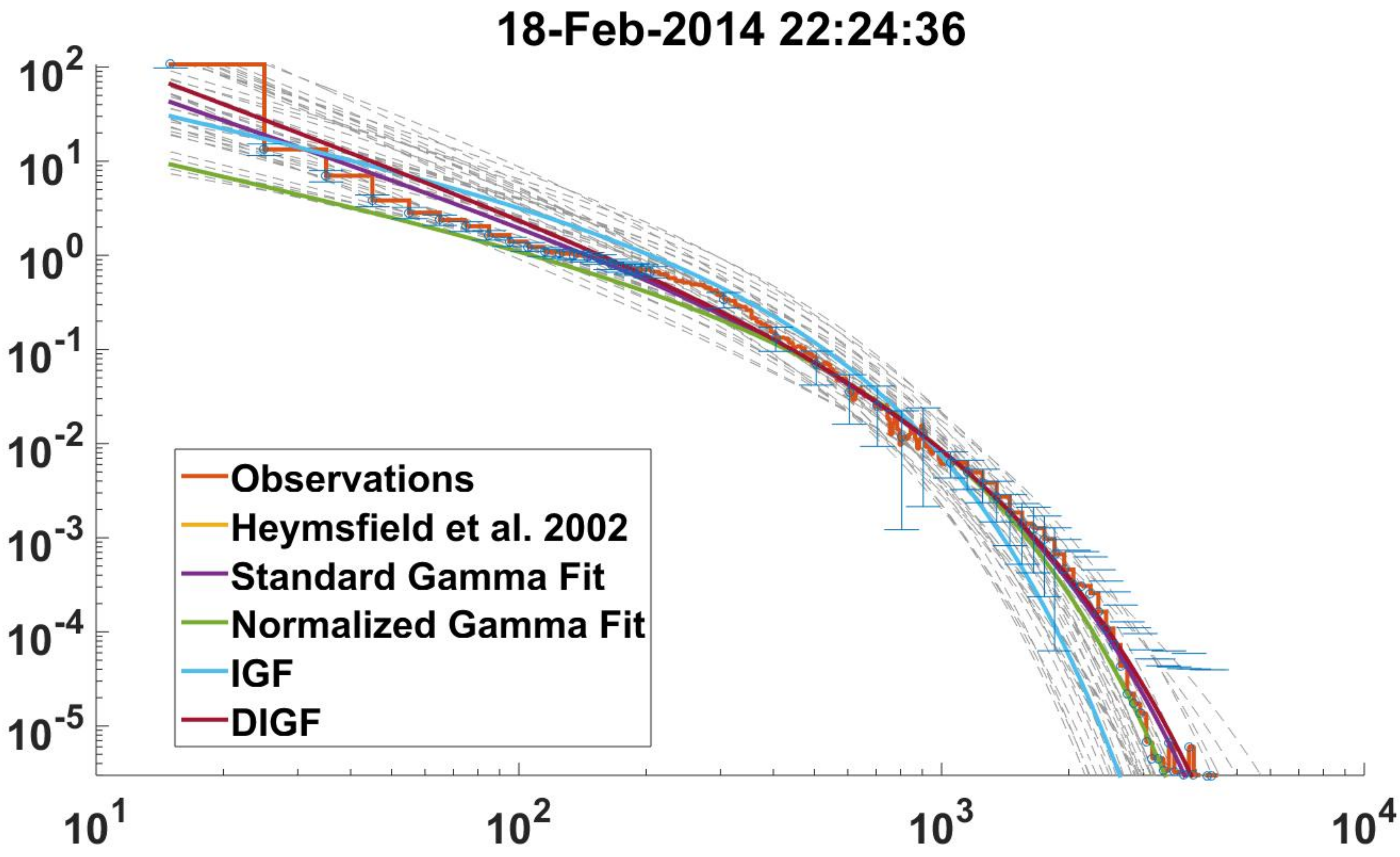
HIWC Data

- Size distributions measured by 2DS (25 μm < D < 1 mm) & PIP (D > 1 mm), bulk water content measured by Isokinetic Evaporator Probe (IKP) installed on French Falcon
- Examine a PSD from flight on 18 Feb 2014

HIWC Data

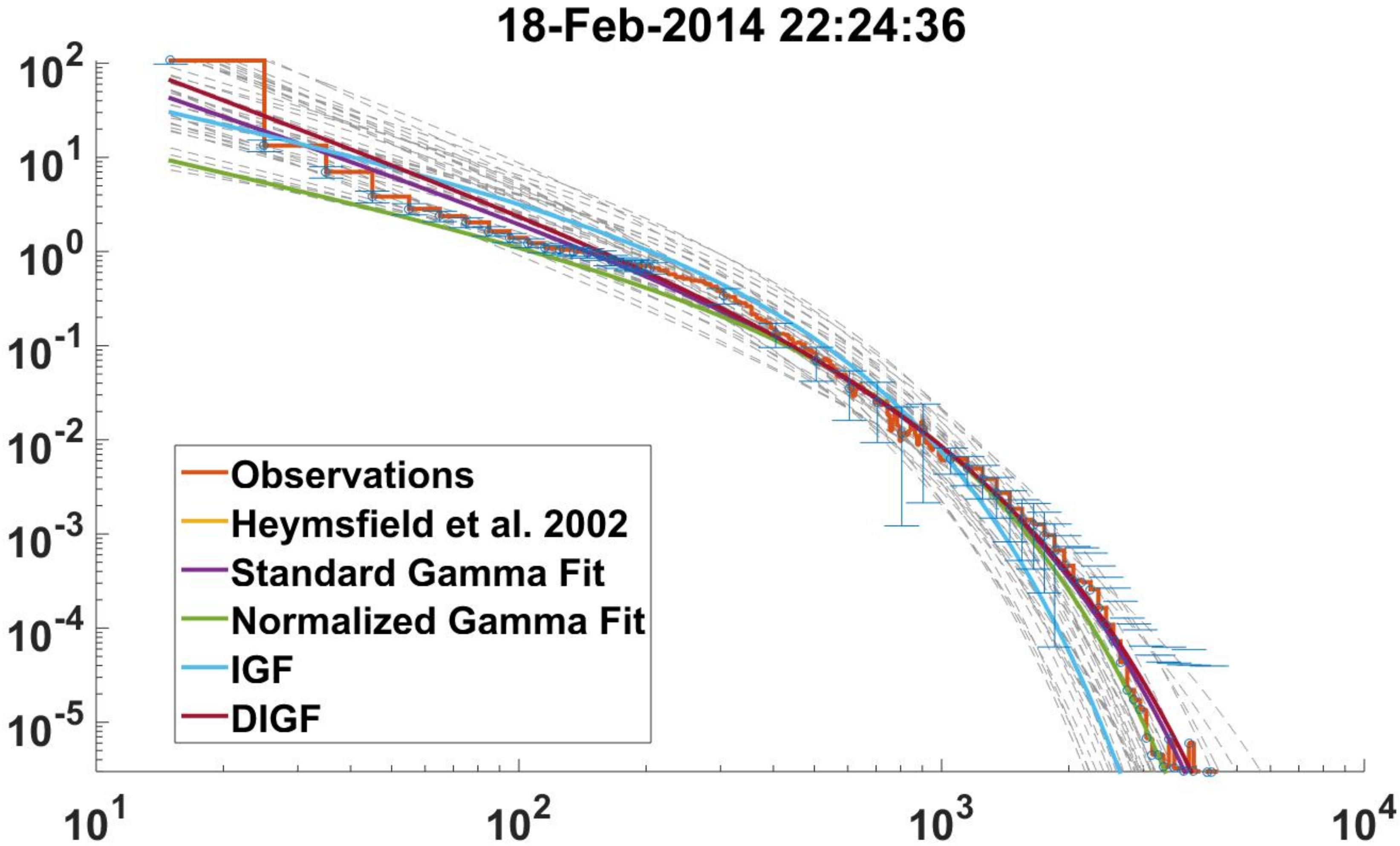
- Size distributions measured by 2DS (25 µm < D < 1 mm) & PIP (D > 1 mm), bulk water content measured by Isokinetic Evaporator Probe (IKP) installed on French Falcon
- Examine a PSD from flight on 18 Feb 2014

Volume of Equally Realizable Solutions

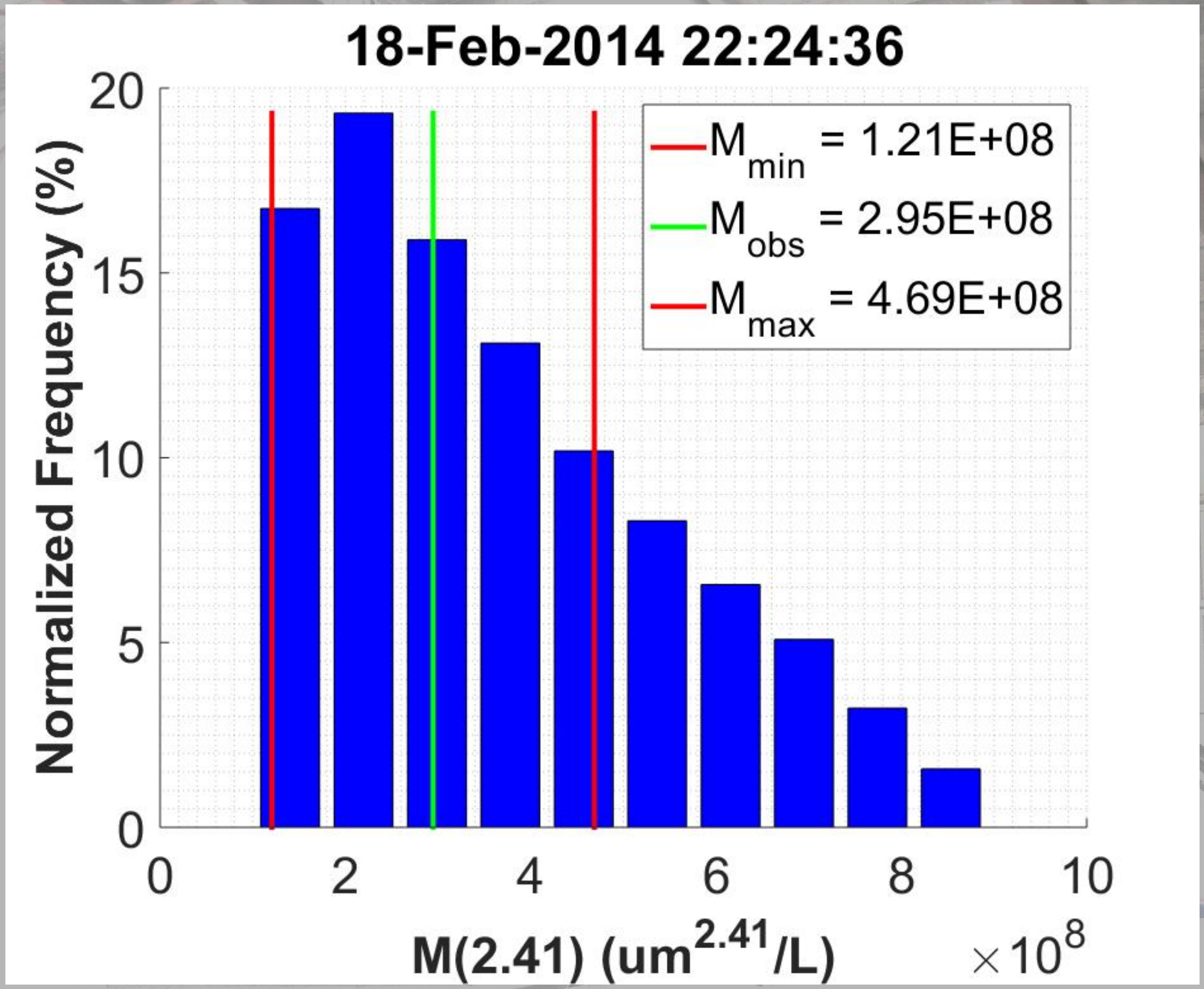


Look at single SD from HIWC, and apply IGF to generate volume of equally realizable N_0,λ,μ

Volume of Equally Realizable Solutions



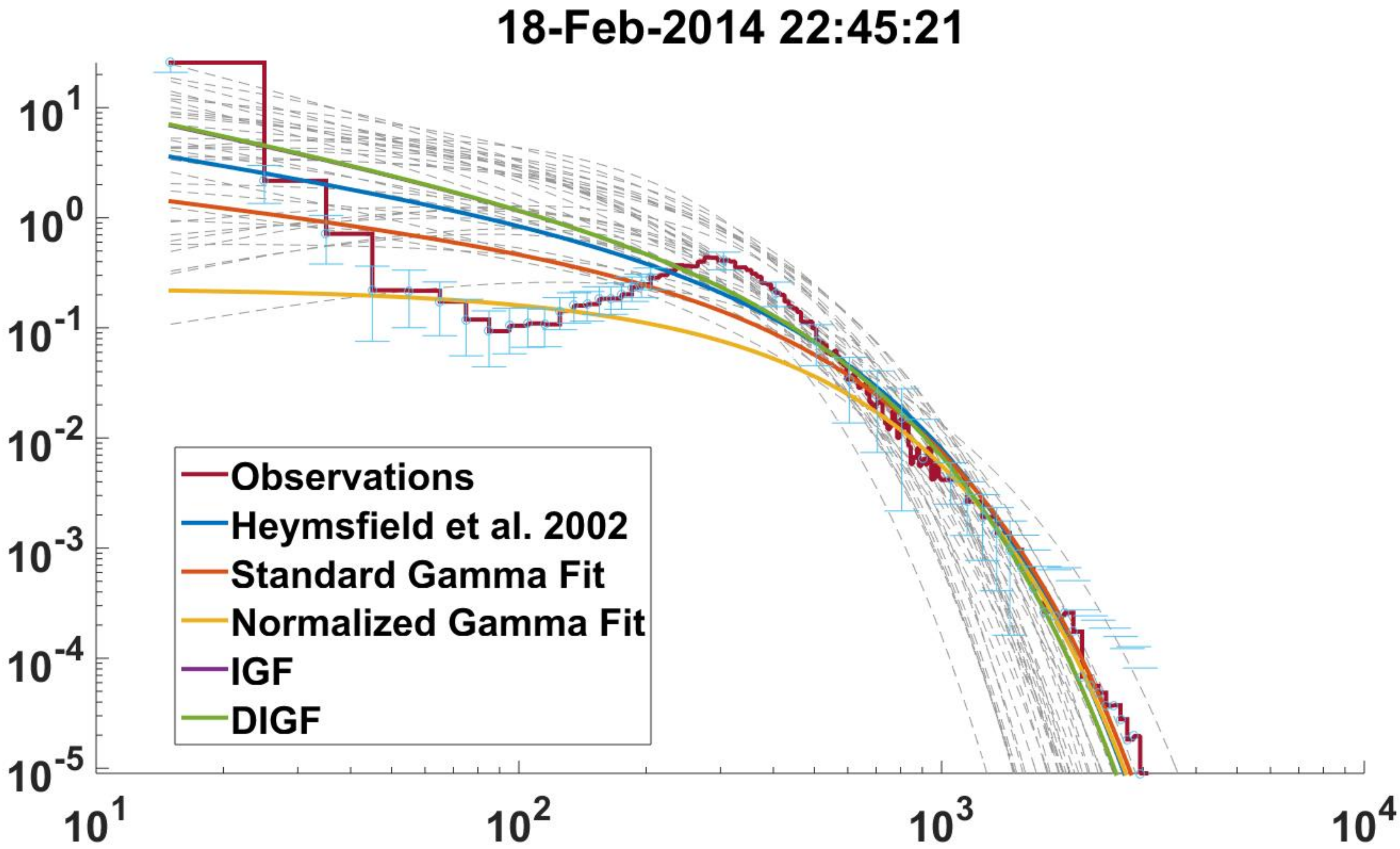
Randomly select $N_0/\mu/\lambda$ value from volume
- large spread especially for D < 150 μm



Distribution moments related to μphysics process rates

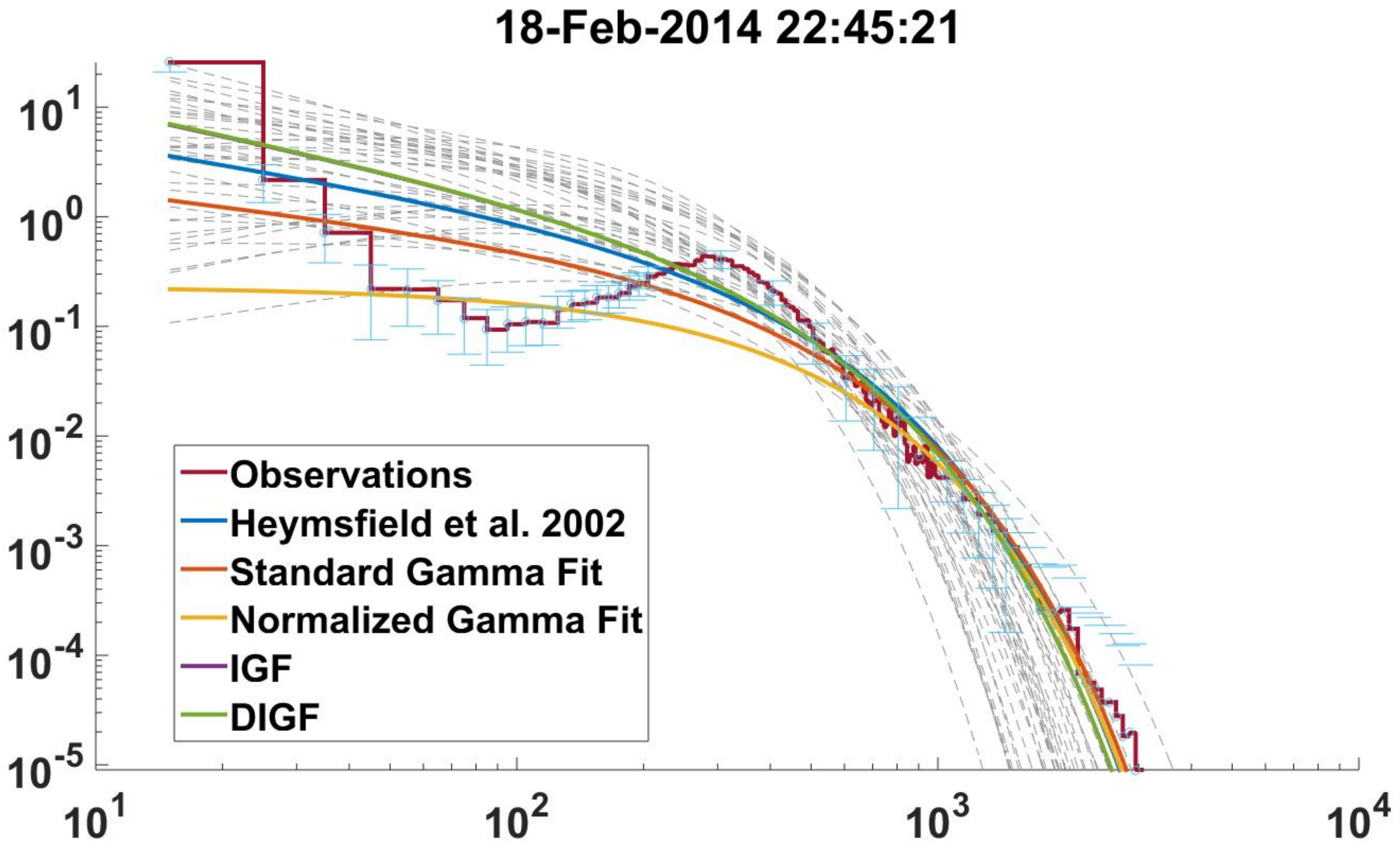
- calculate M(2.41) by randomly choosing values from N_0-μ−λ volume
- calculated moments match observed moments

HIWC SDs



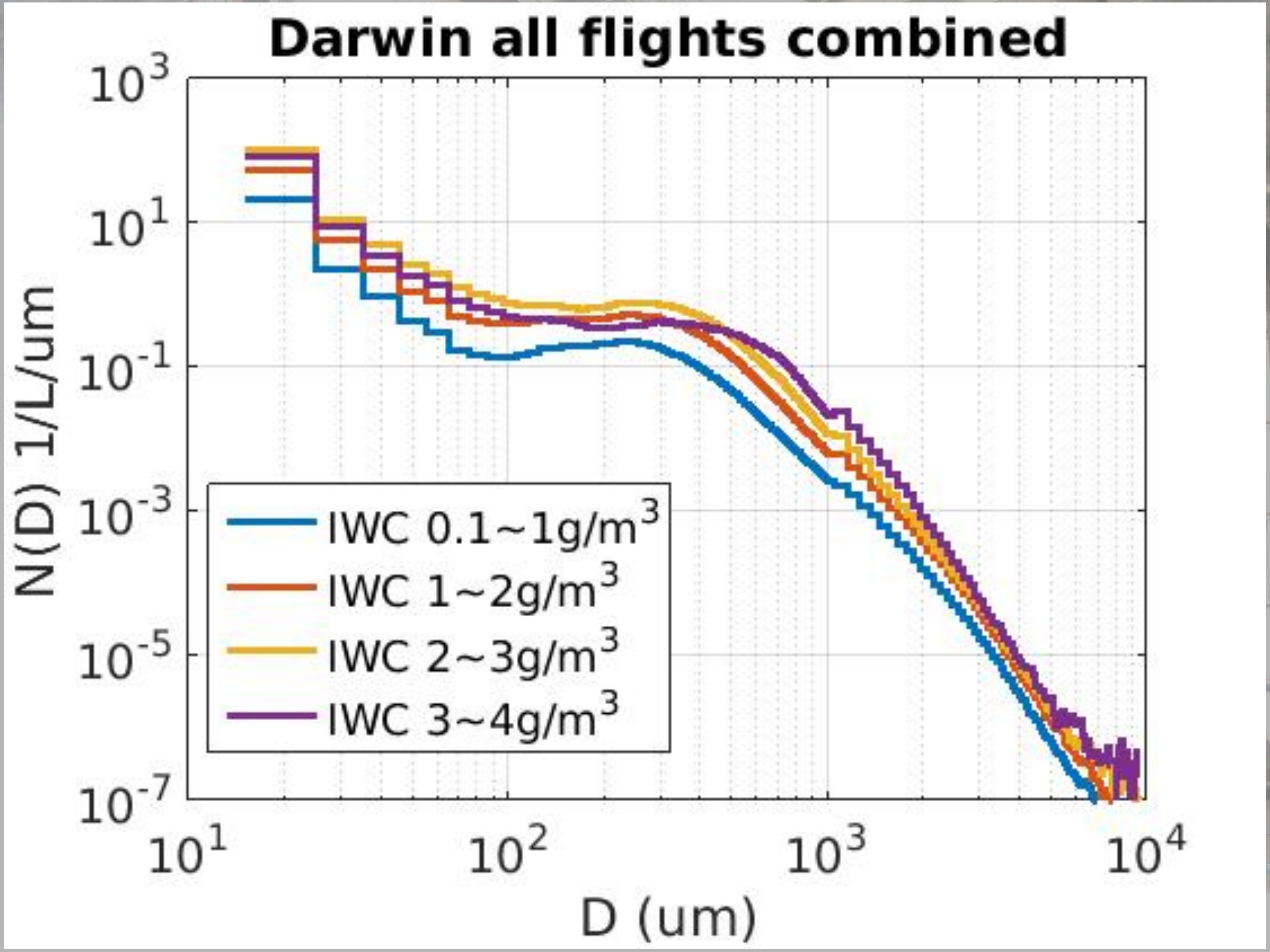
- But, many of the HIWC SDs have multiple modes!
-

HIWC SDs



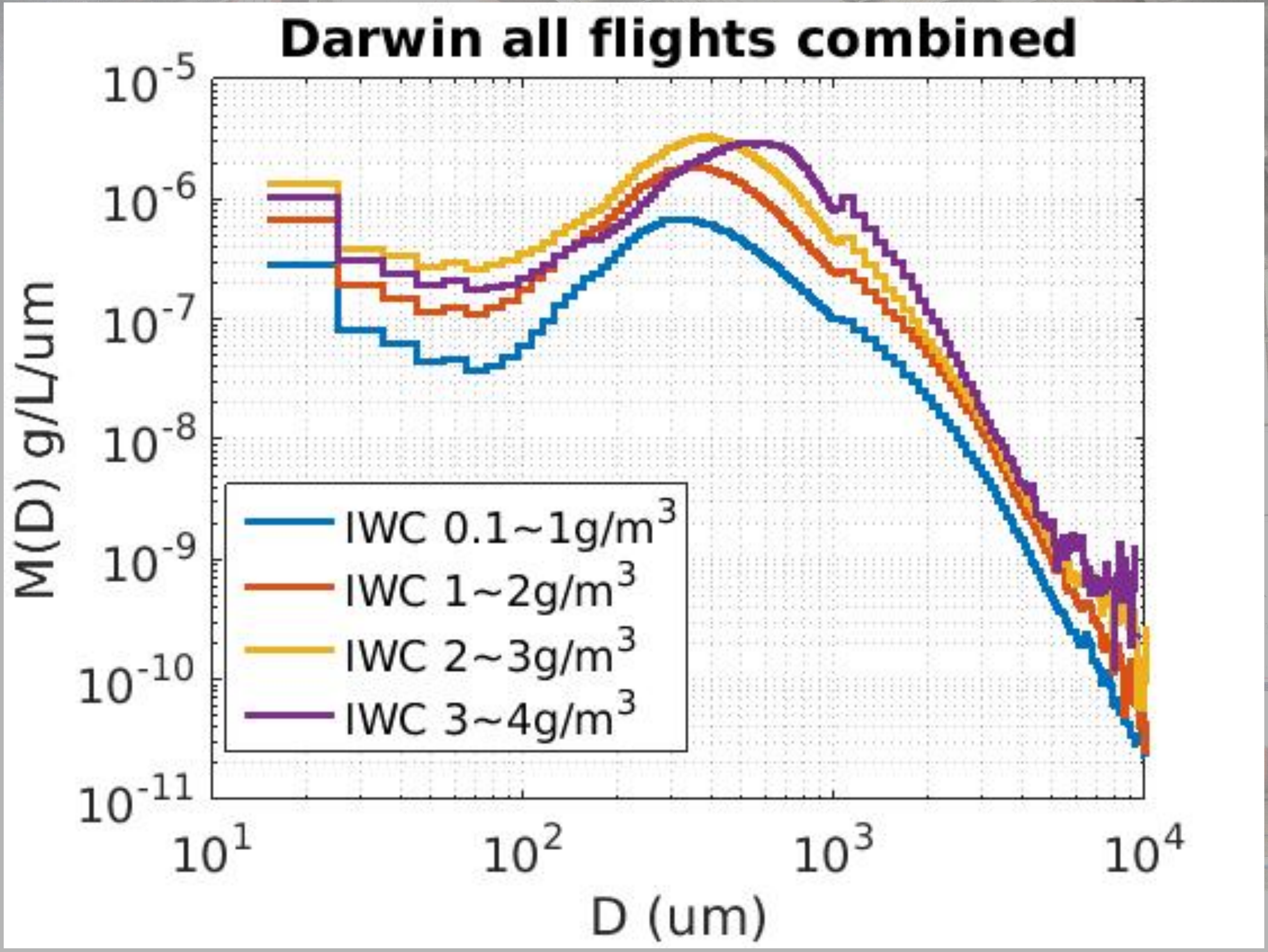
- But, many of the HIWC SDs have multiple modes!
- Gamma fit does not fit data well

HIWC SDs



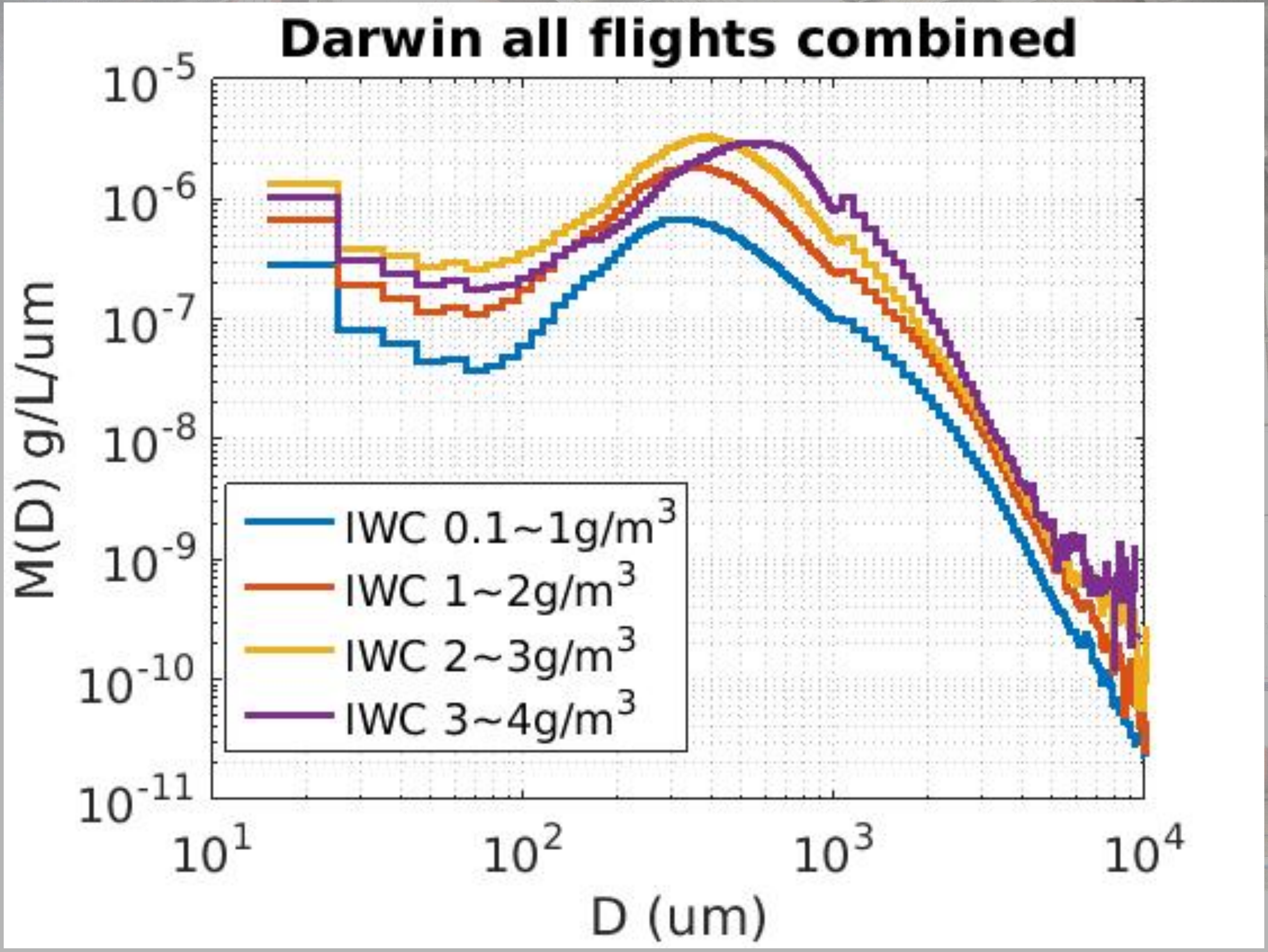
- SDs from HIWC have frequent multiple modes → application of IGF difficult

HIWC SDs



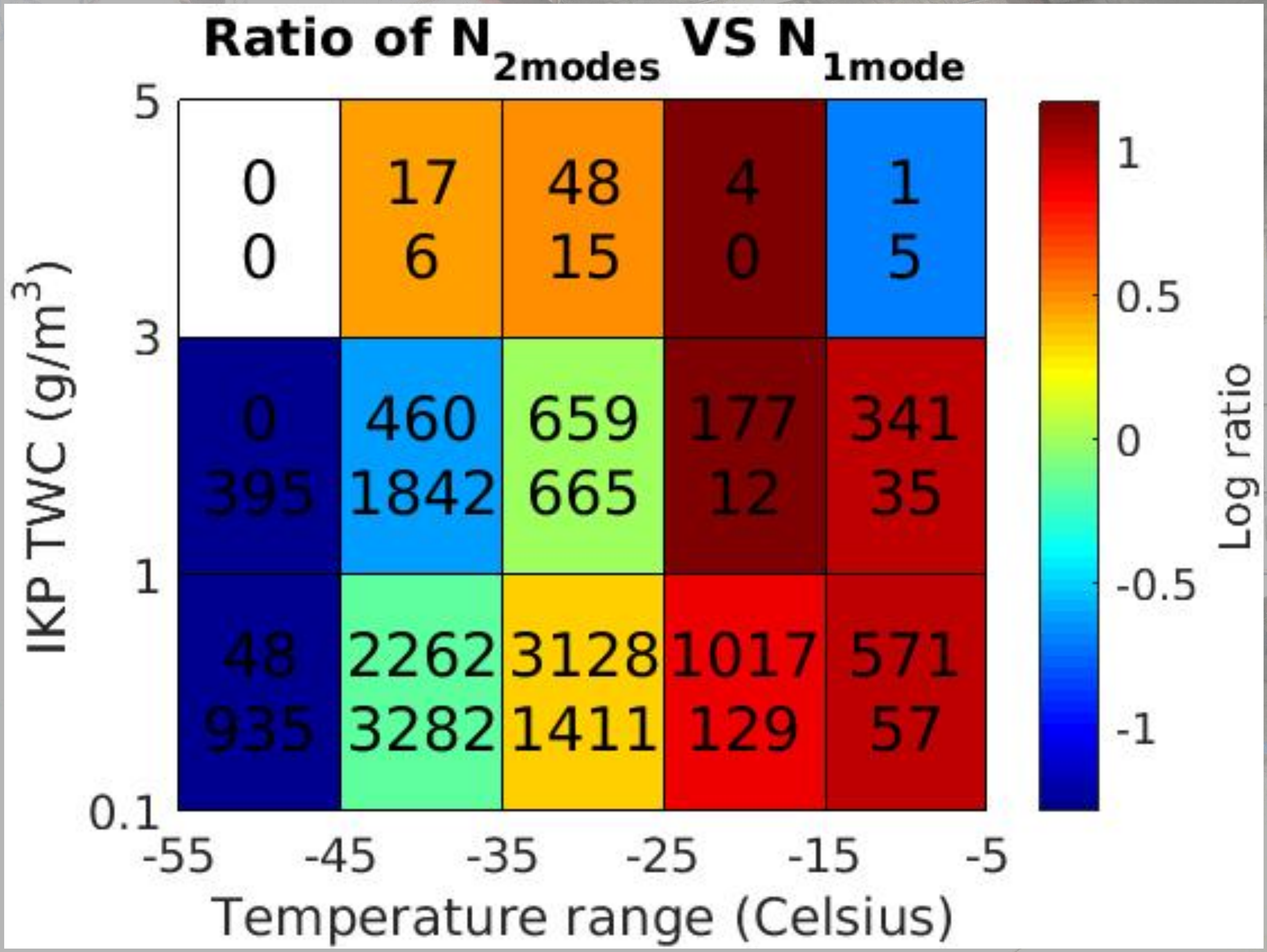
- Peaks in mass distributions are especially prominent

HIWC SDs

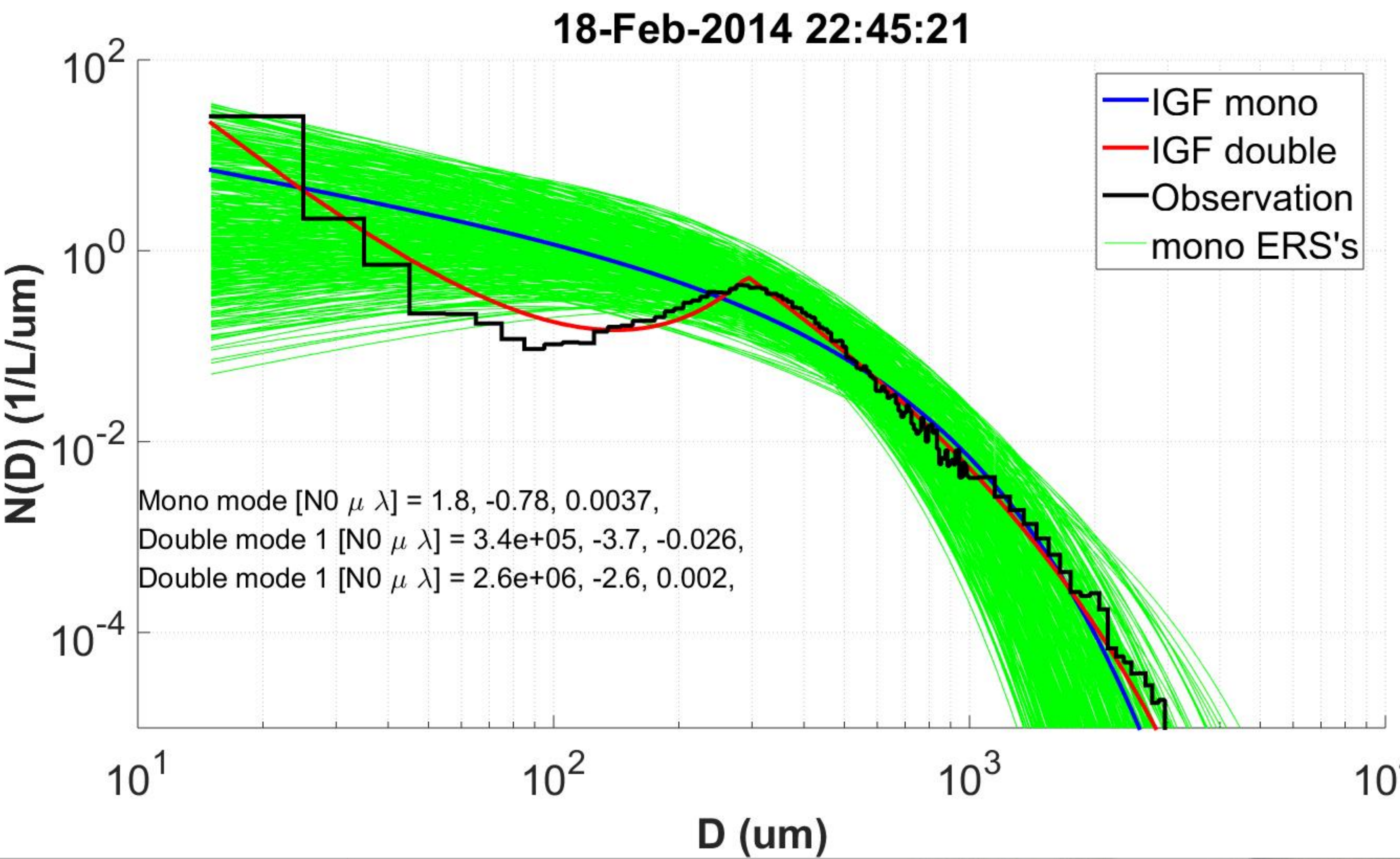


- Peaks in mass distributions are especially prominent→ apply IGF to modes separately

Frequency of Multi-mode distributions

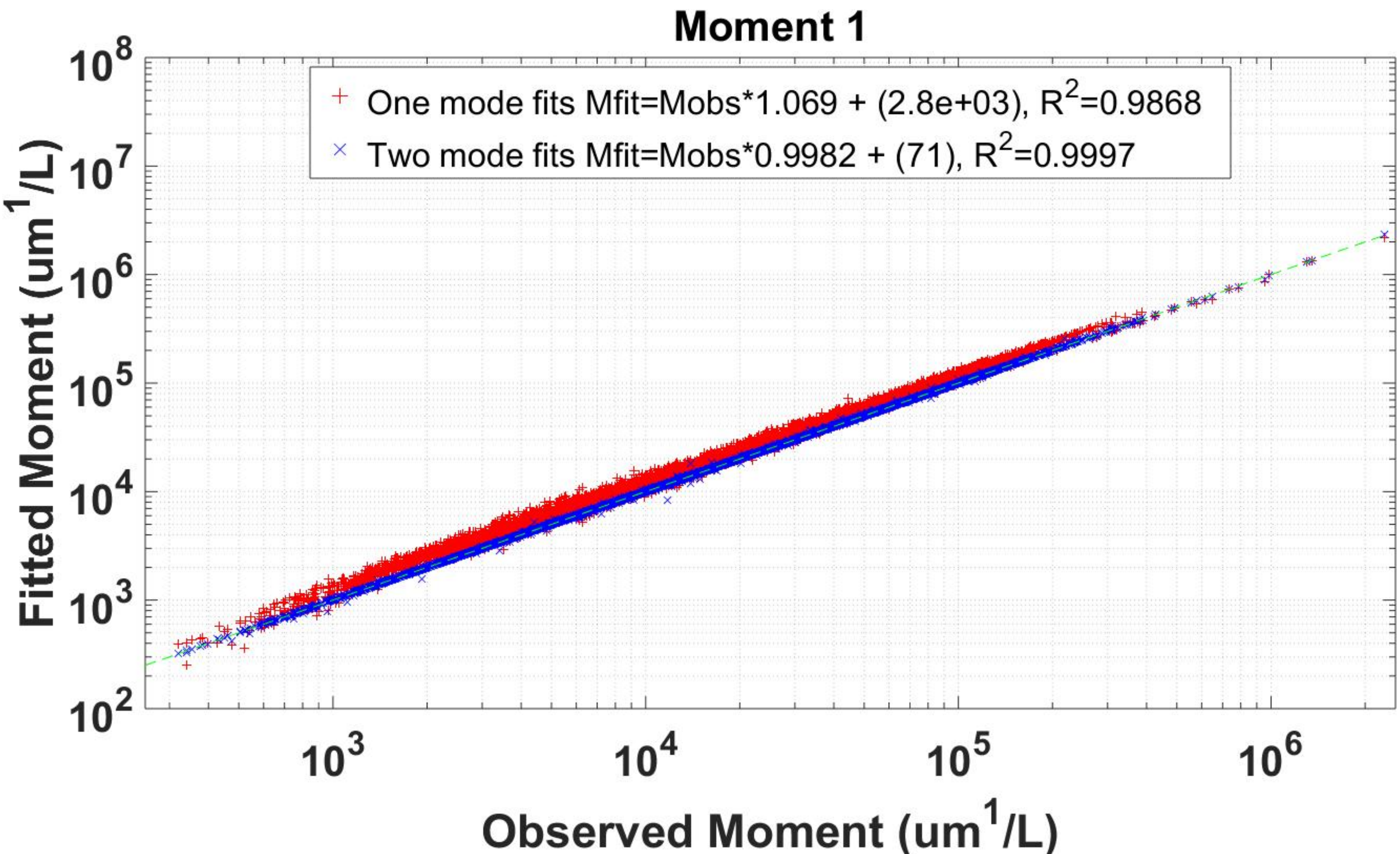


Fits to Multiple Modes



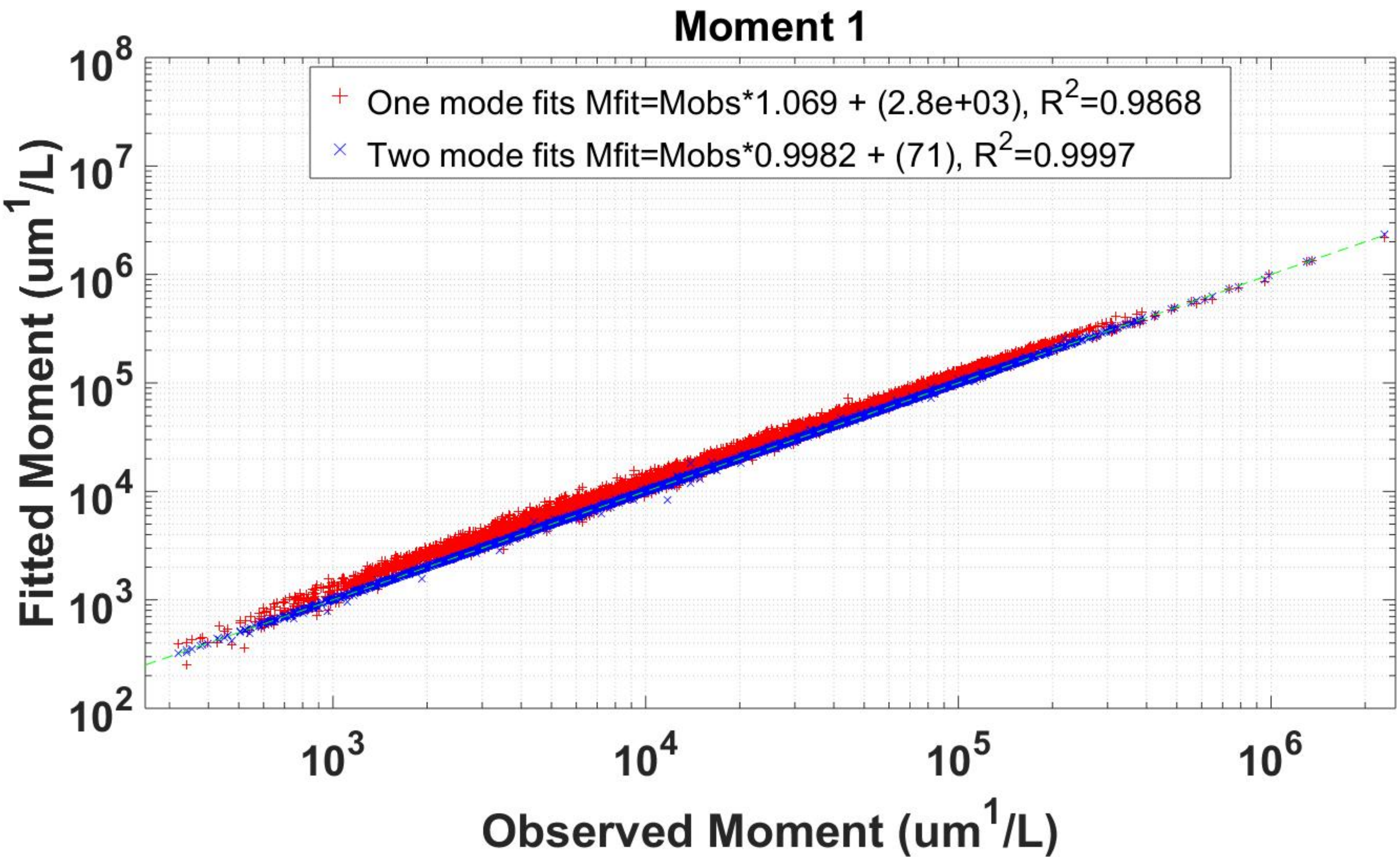
- 2-mode fit visually provides better match to observed SD

Fits to Multiple Modes



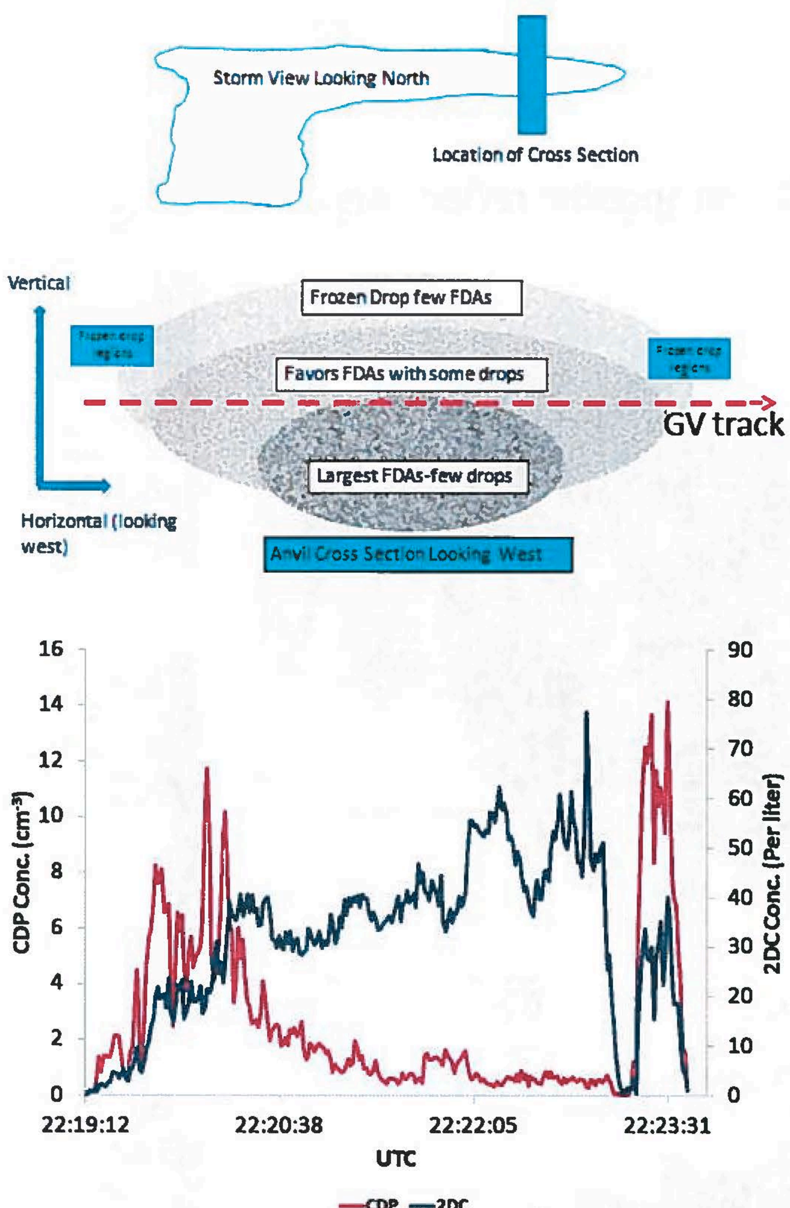
- 2-mode fit does better job than 1-mode fit representing some moments of PSD

Fits to Multiple Modes

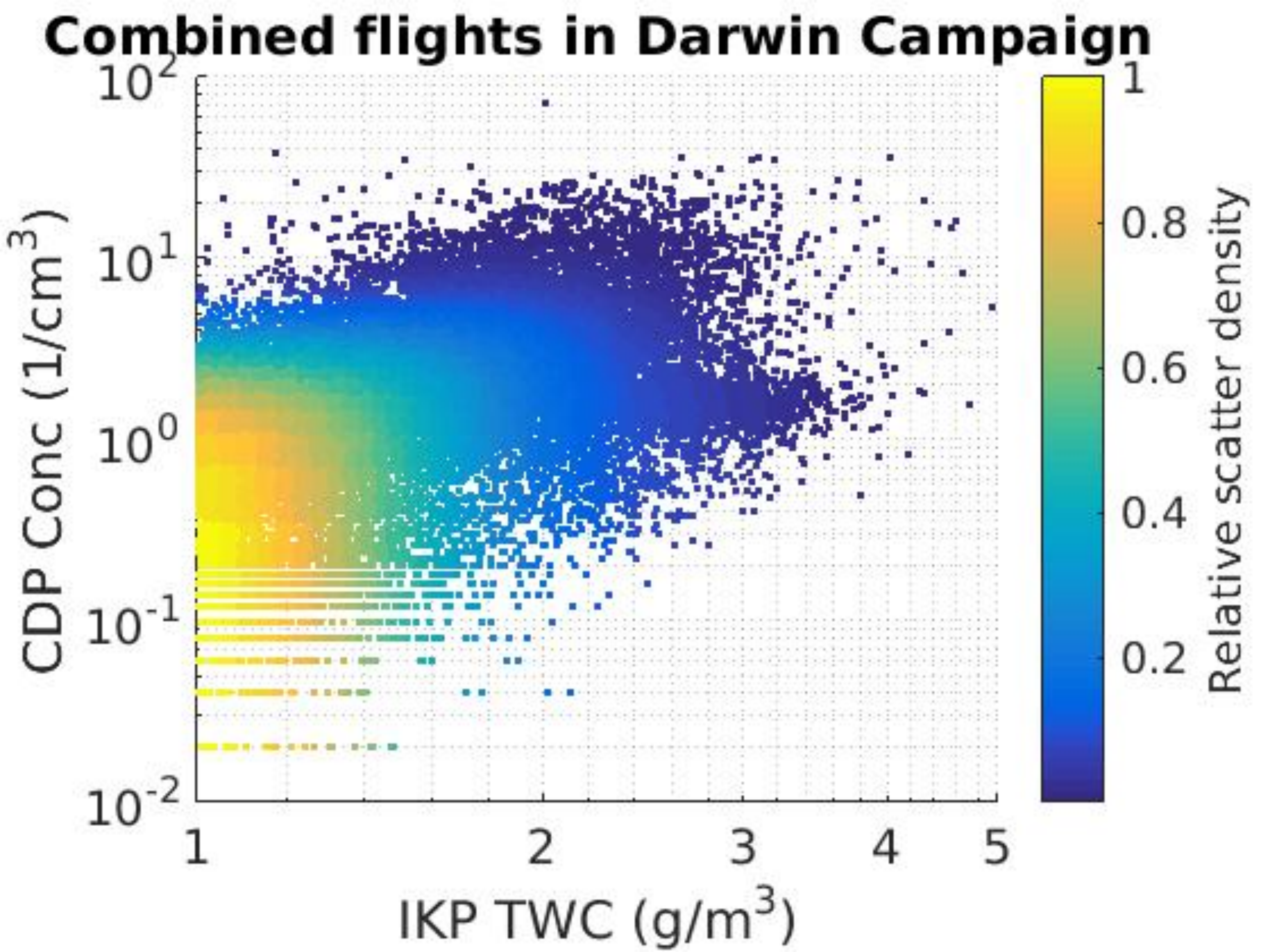


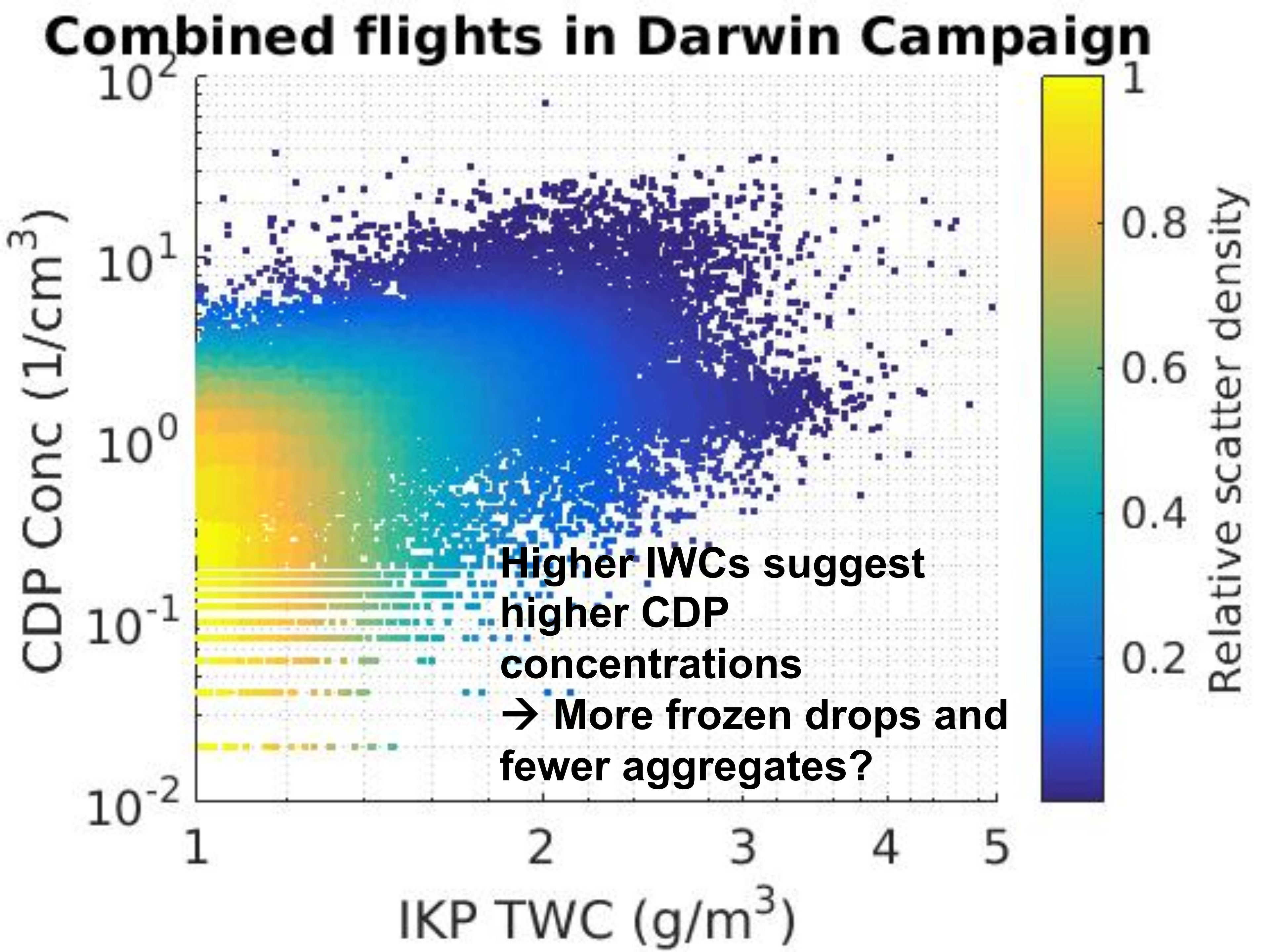
- 2-mode fit does better job than 1-mode fit representing some moments of PSD

Radiative Impact of Small Particles

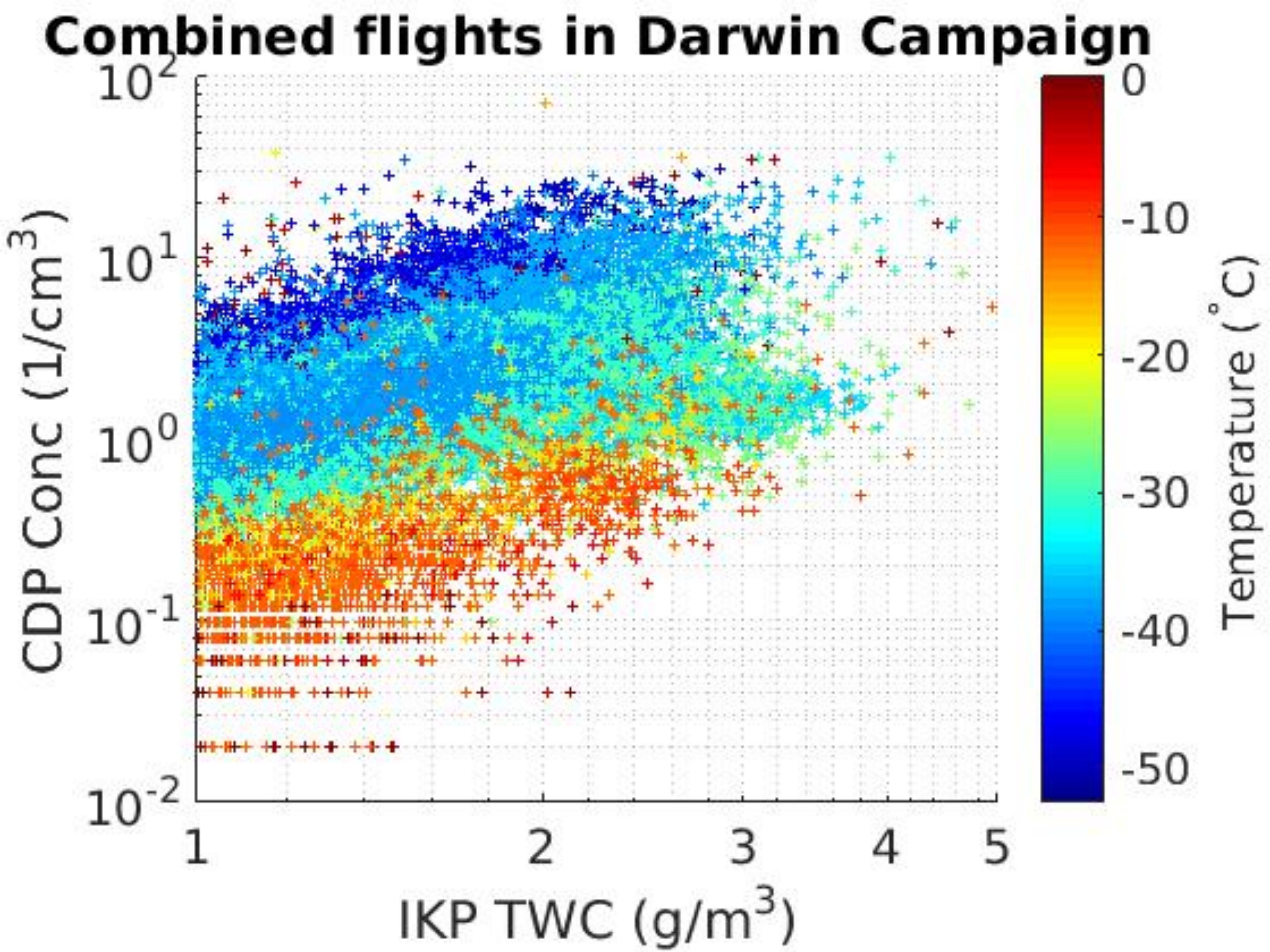


- DC3 observations (Stith et al. 2015) show aggregates of frozen drops in anvil surrounded by frozen drops
  - What does HIWC data show?
  - What are radiative impacts of different shapes?

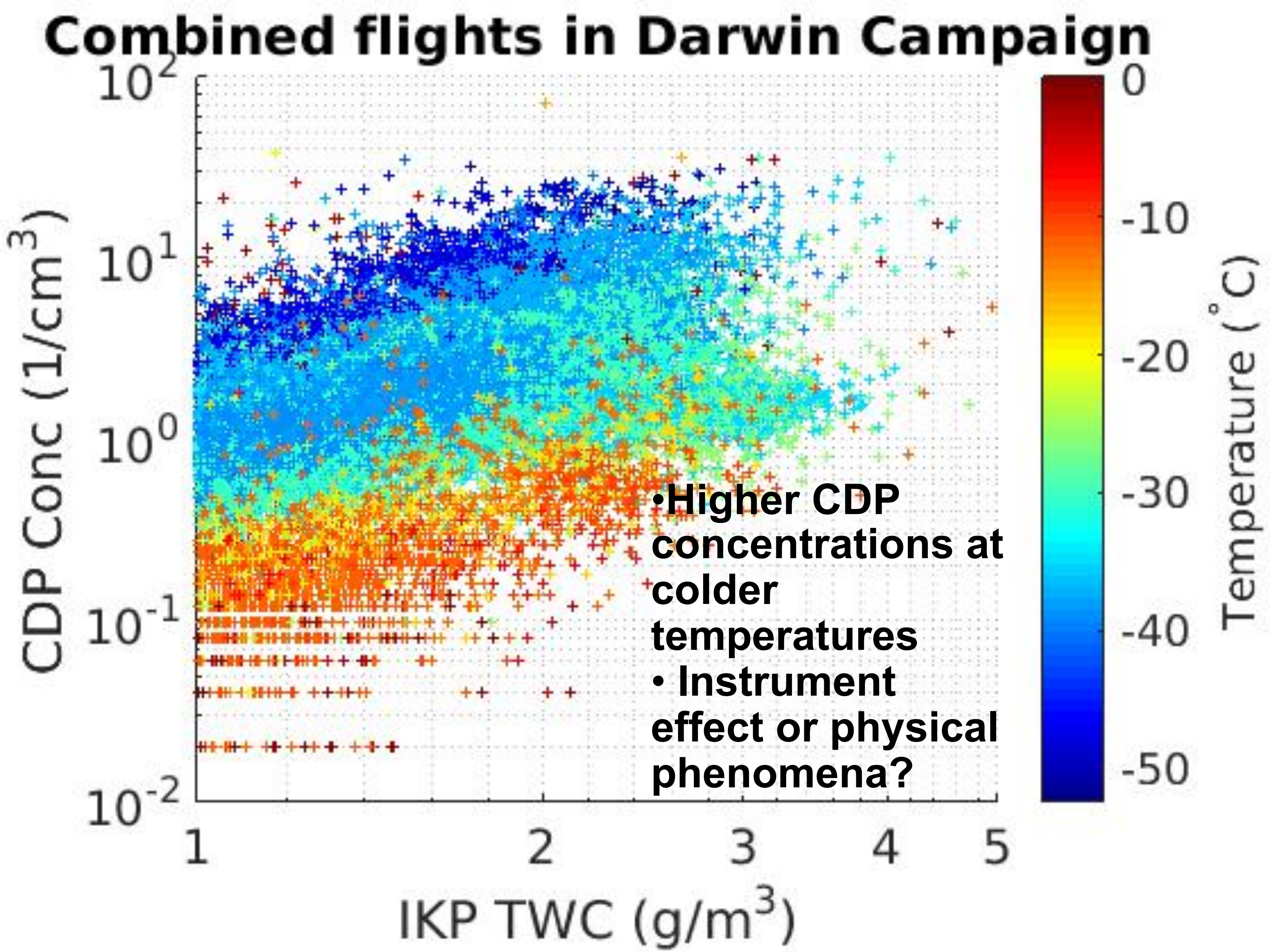

Combined flights in Darwin Campaign
CDP Conc (1/cm^3)
IKP TWC (g/m^3)
Relative scatter density
10^2
10^1
10^0
10^{-1}
10^{-2}
1
2
3
4
5
1
0.8
0.6
0.4
0.2



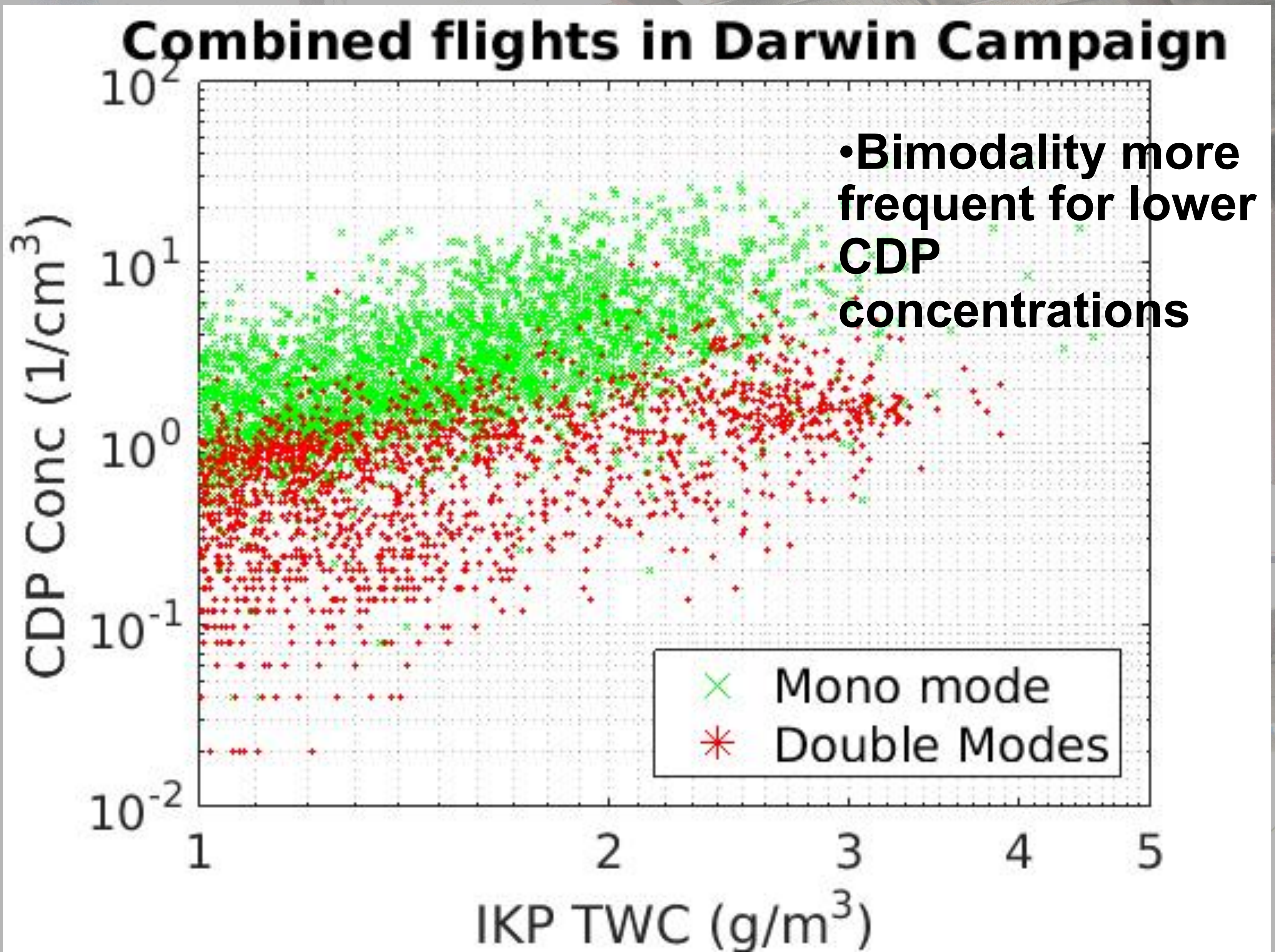
Combined flights in Darwin Campaign
CDP Conc (1/cm^3)
10^2
10^1
10^0
10^{-1}
10^{-2}
1
2
3
4
5
IKP TWC (g/m^3)
1
0.8
0.6
0.4
0.2
Relative scatter density
Higher IWCs suggest higher CDP concentrations
→ More frozen drops and fewer aggregates?



Combined flights in Darwin Campaign
CDP Conc (1/cm^3)
10^2
10^1
10^0
10^{-1}
10^{-2}
1
2
3
4
5
IKP TWC (g/m^3)
0
-10
-20
-30
-40
-50
Temperature (°C)


Combined flights in Darwin Campaign
CDP Conc (1/cm³)
10²
10¹
10⁰
10⁻¹
10⁻²
1
2
3
4
5
IKP TWC (g/m³)
0
-10
-20
-30
-40
-50
Temperature (°C)
•Higher CDP concentrations at colder temperatures
• Instrument effect or physical phenomena?

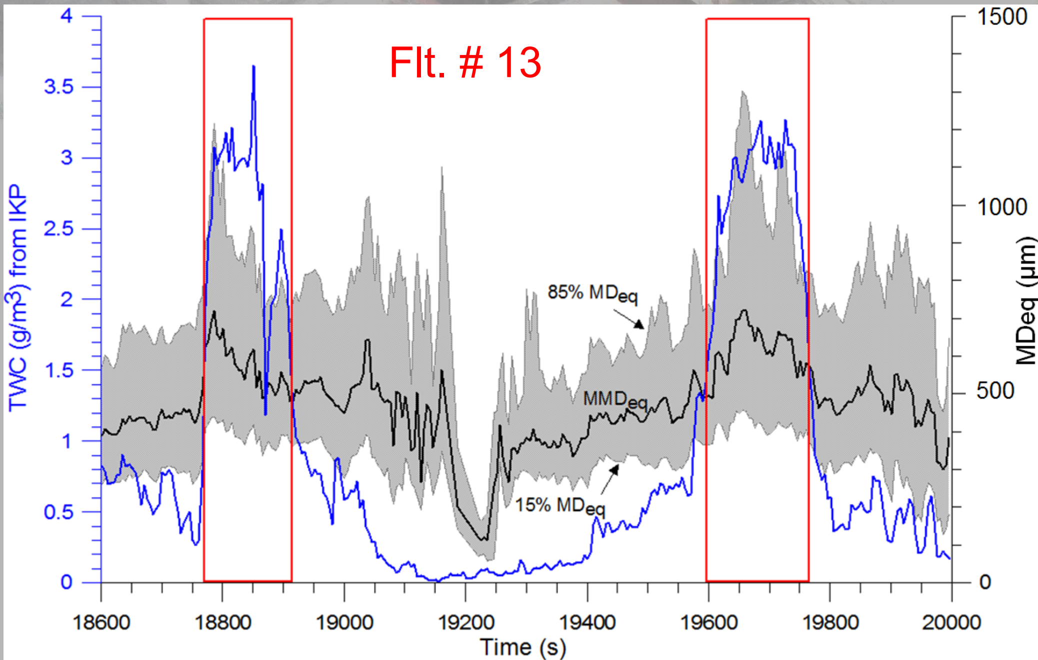
Relation to Larger Crystal PSDs



- Bimodality more frequent for lower CDP concentrations

Summary

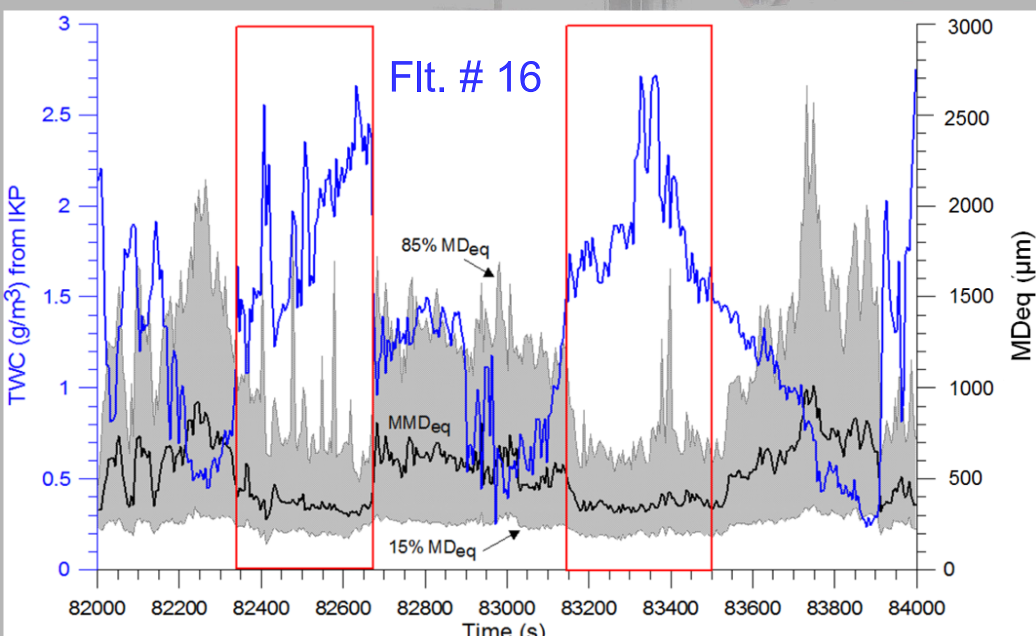
- Developed technique for representing *N(D)* as gamma function as volume of equally realizable solutions in N_0, λ and μ phase space
- Modified to account for multi-modal HIWC SDs → don't need to separate snow & graupel
- Can be applied in Monte Carlo parameterization to see how uncertainties cascade up to model predicted parameters
- Looking at small particles and their radiative impact (comparison with DC3 data)
-

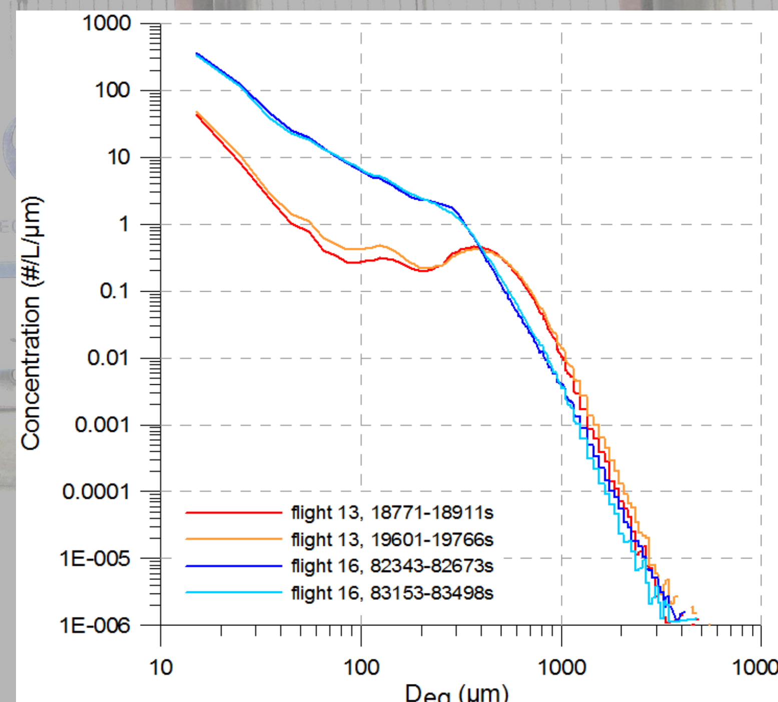


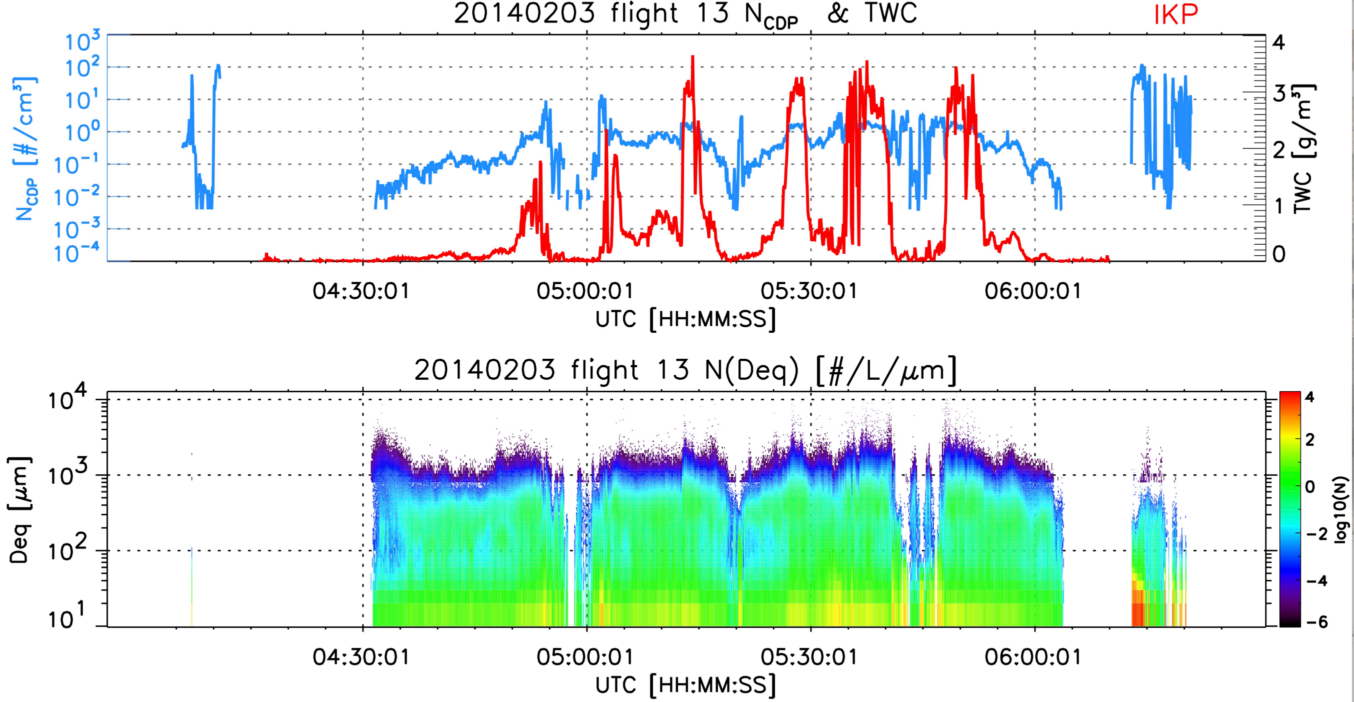
- **Leroy et al. (2015, part 2)**

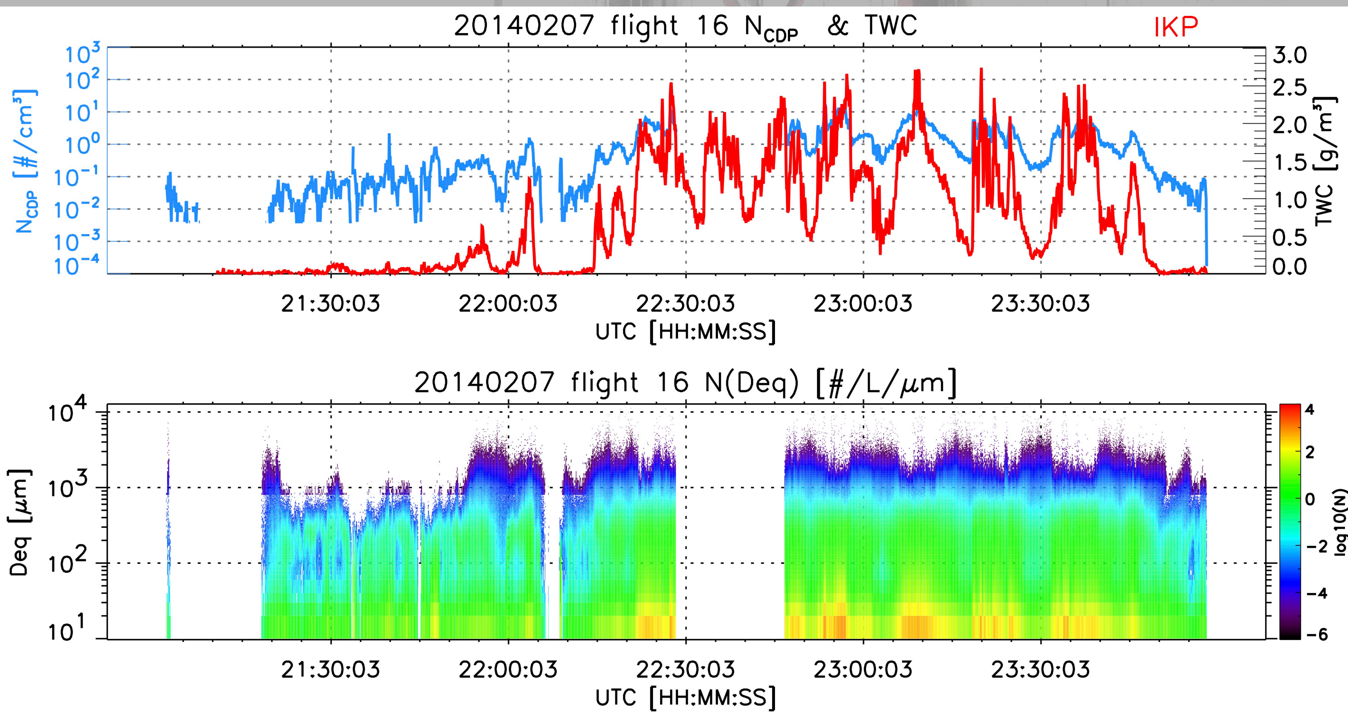
increasing MMD with HIWC for flt. #13
- **higher contribution of larger particles**

decreasing MMD with HIWC for flt. #16
- **higher contribution of smaller particles**

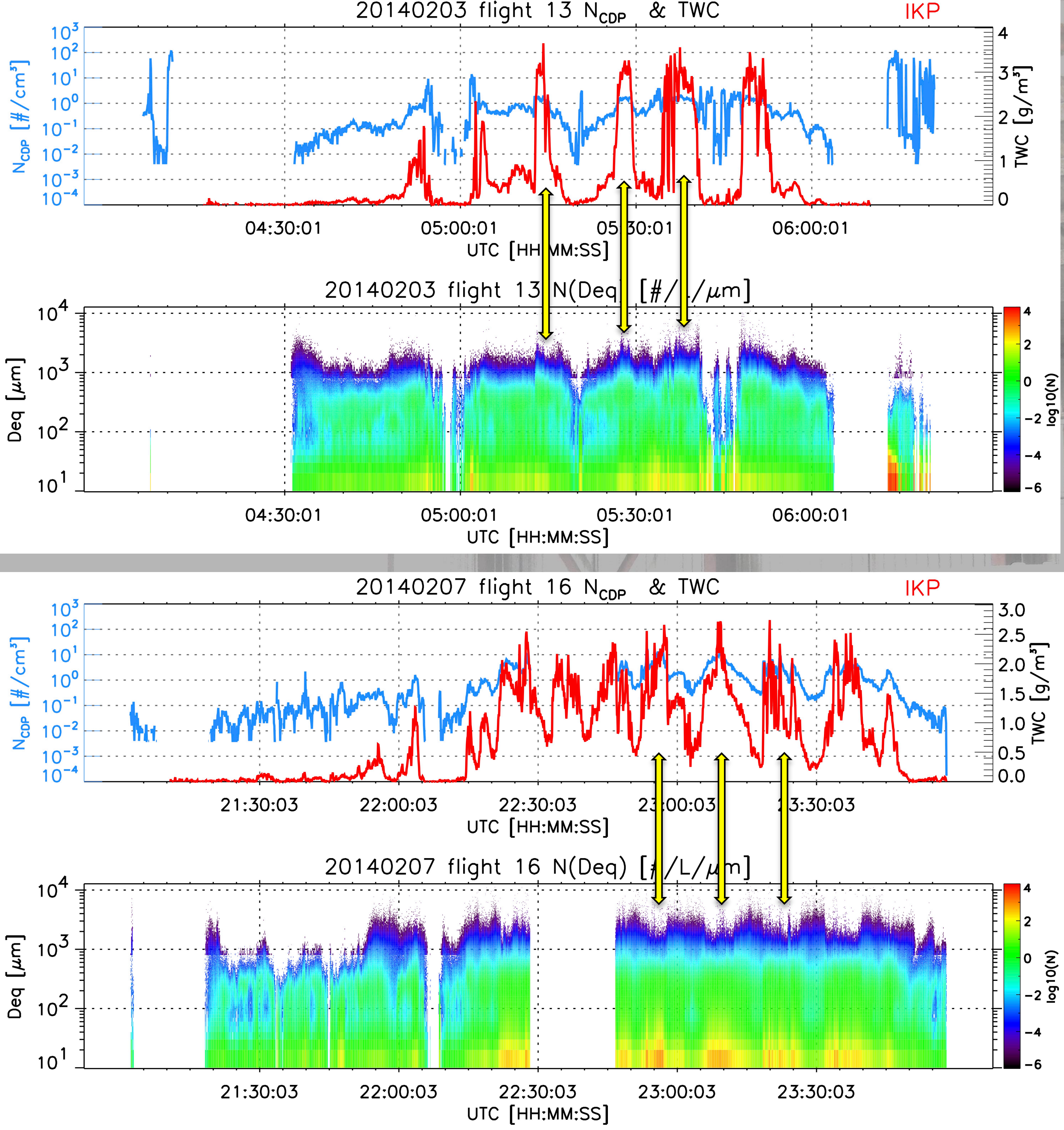





20140203 flight 13 N_CDP & TWC
IKP
N_CDP [#/cm³]
TWC [g/m³]
UTC [HH:MM:SS]
04:30:01
05:00:01
05:30:01
06:00:01
20140203 flight 13 N(Deq) [#/L/μm]
Deq [μm]
log10(N)
UTC [HH:MM:SS]


20140207 flight 16 N_CDP & TWC
IKP
N_CDP [#/cm³]
TWC [g/m³]
UTC [HH:MM:SS]
21:30:03
22:00:03
22:30:03
23:00:03
23:30:03
20140207 flight 16 N(Deq) [#/L/μm]
Deq [μm]
log10(N)
UTC [HH:MM:SS]


Flight 13
Flight 16



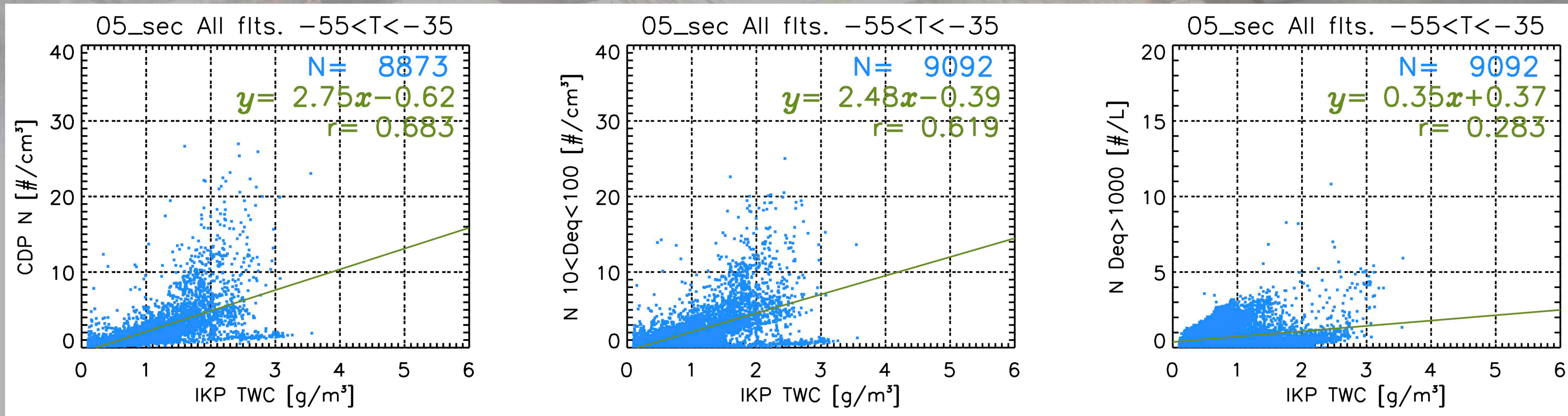
Flight 13

Presence of larger particle with HIWC

Increase/decrease rate of CDP N with TWC diff. for flights

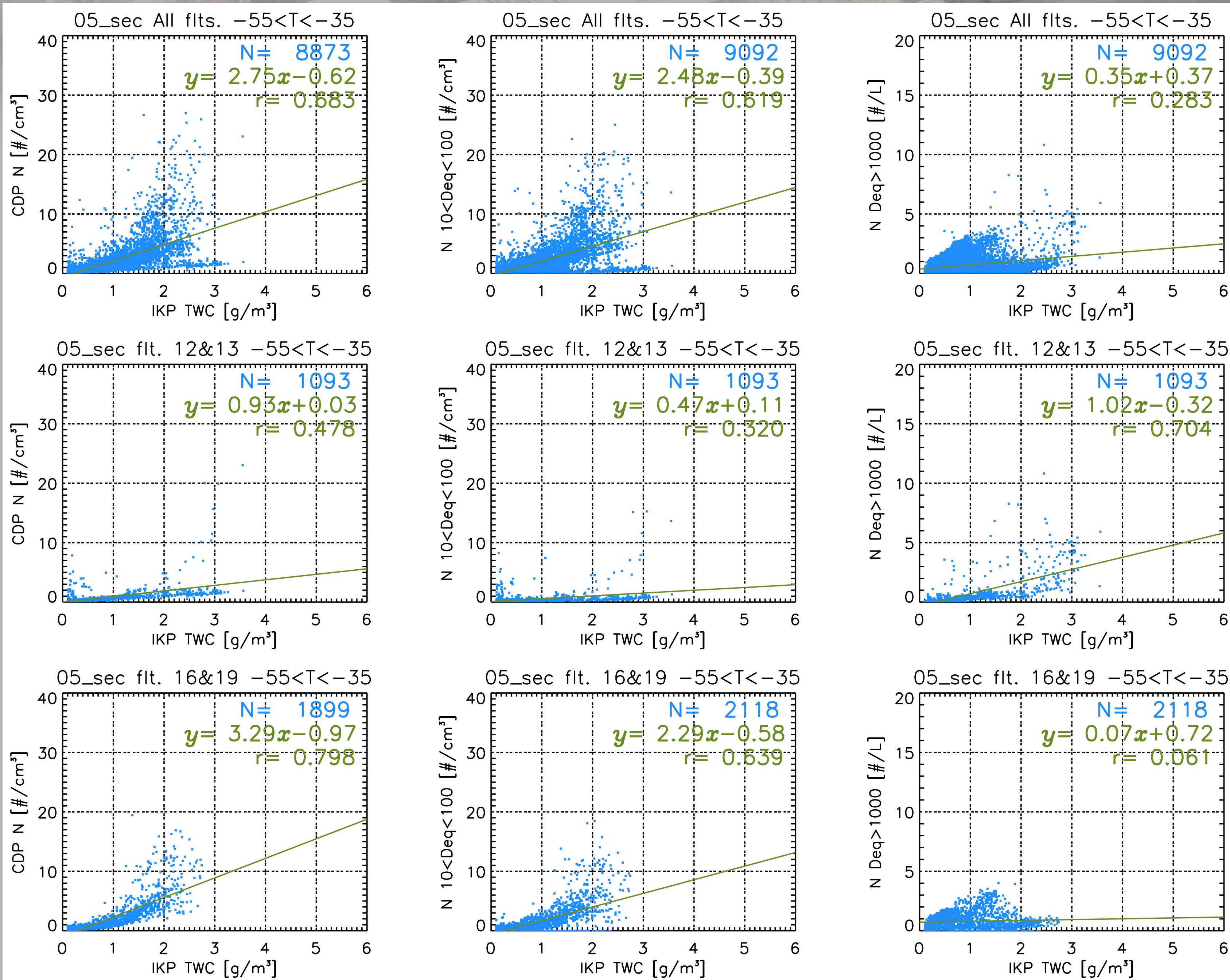
Flight 16

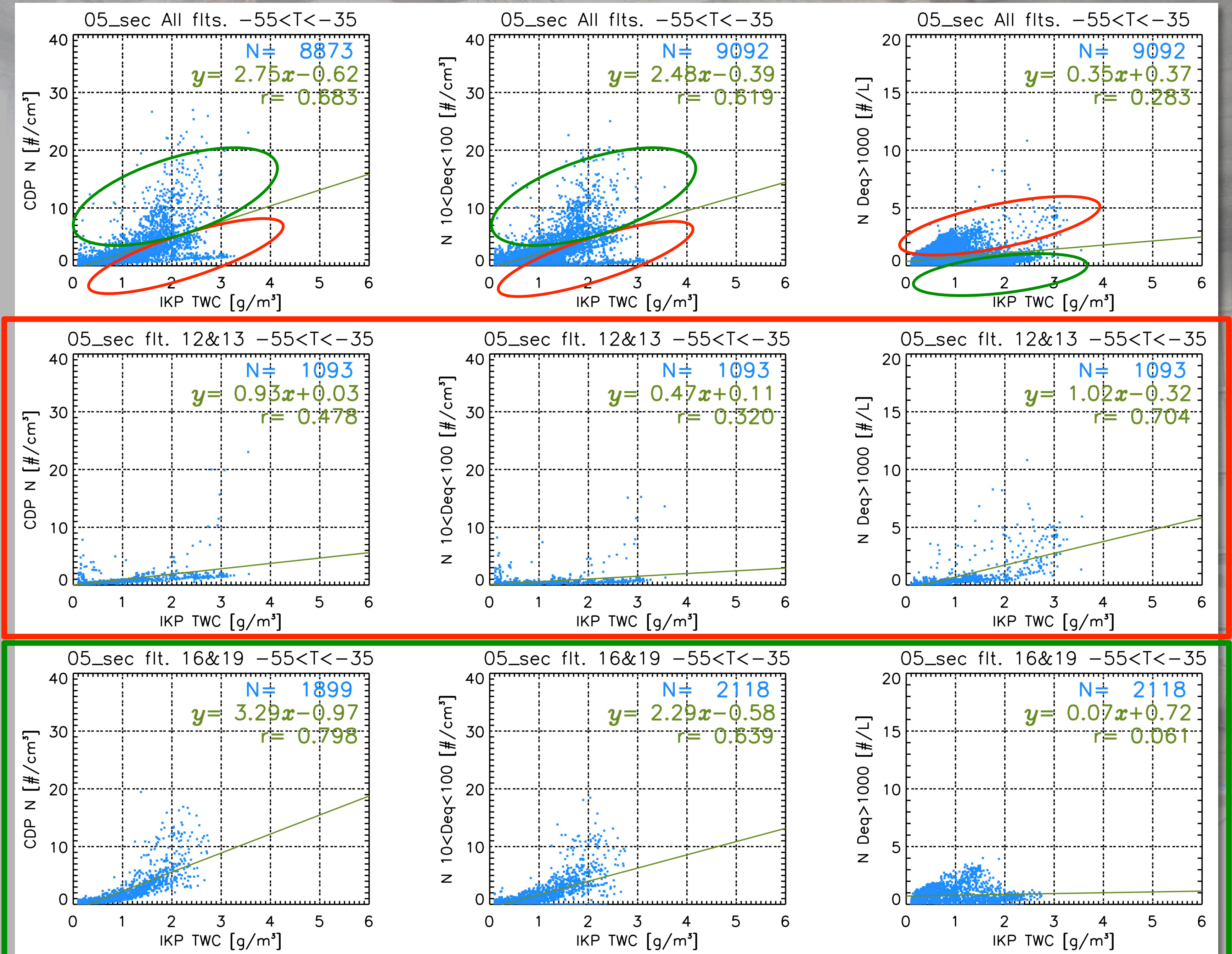
Absence of larger particle with HIWC

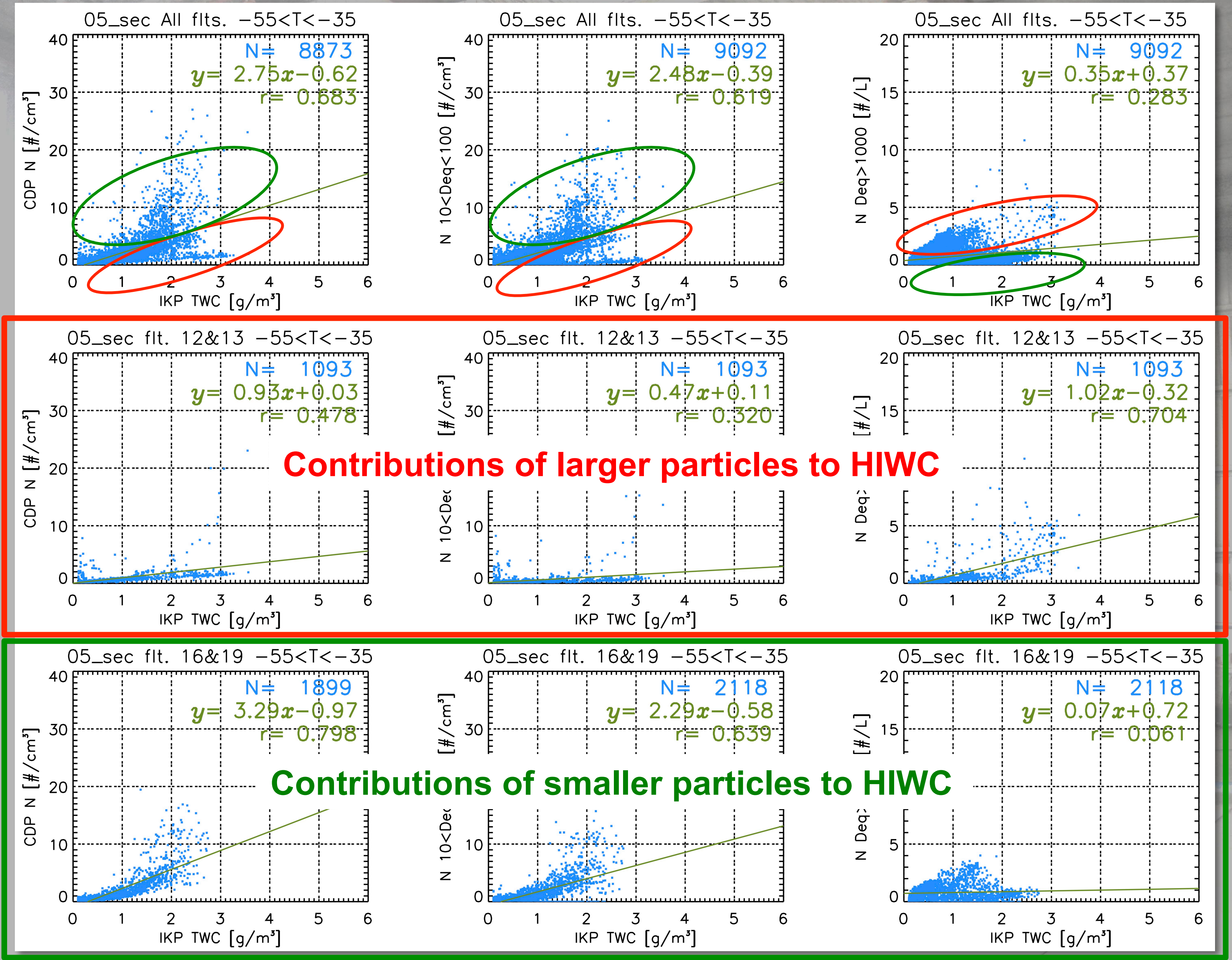


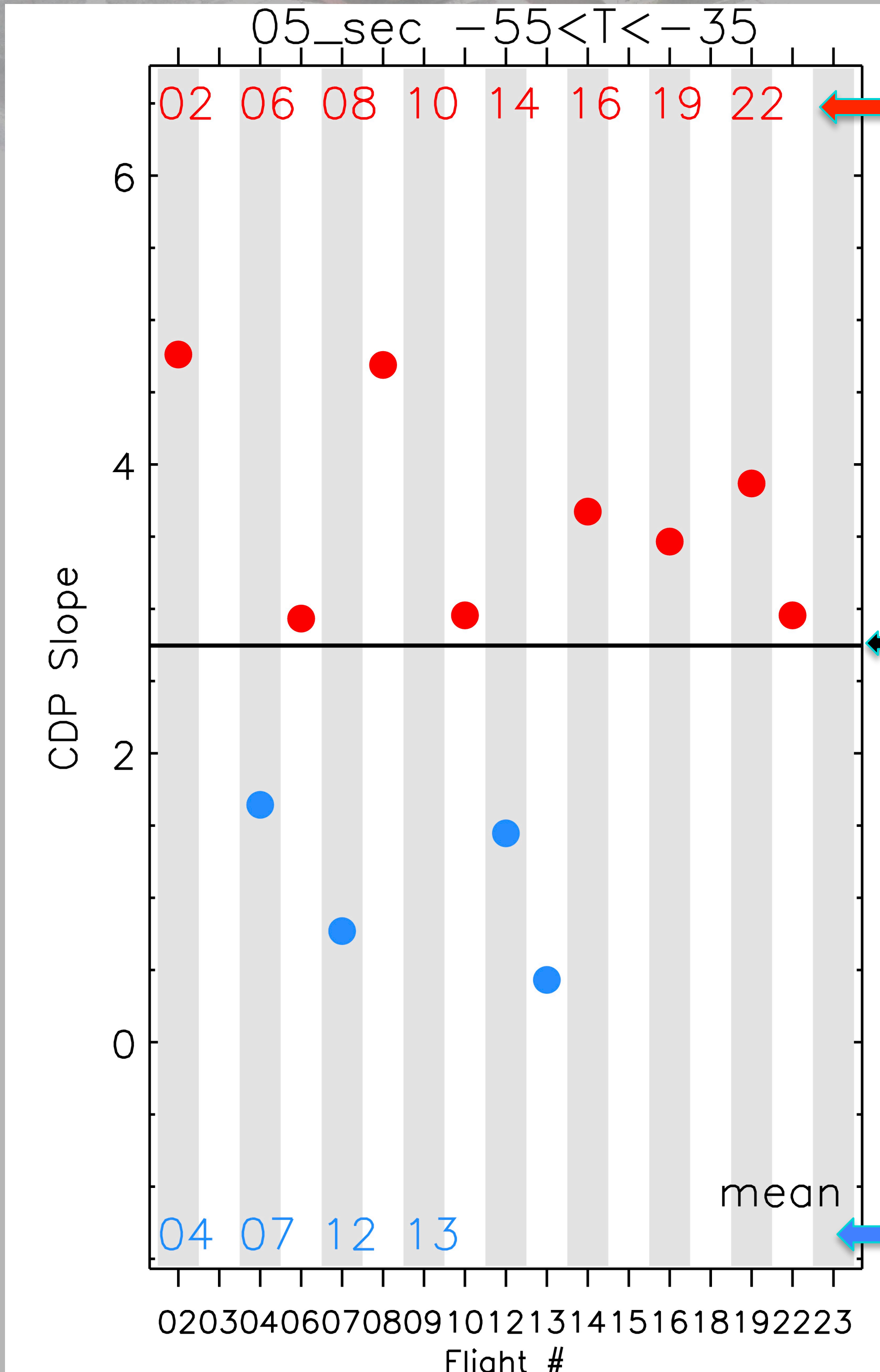
N CDP **N 10 < Deq < 100 μm** **N 1000 μm < Deq**

- IKP TWP > 0.1 g/m³, -55 < T < -35 °C
- Relative contribution of # particles in diff. size range to HIWC
- Classify each flight into two groups
  - i. higher contributions of smaller particles to HIWC
  - ii. higher contributions of larger particles to HIWC


05_sec All flts. −55<T<−35
N= 8873
y= 2.75x−0.62
r= 0.683
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec All flts. −55<T<−35
N= 9092
y= 2.48x−0.39
r= 0.619
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec All flts. −55<T<−35
N= 9092
y= 0.35x+0.37
r= 0.283
N Deq>1000 [#/L]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 0.93x+0.03
r= 0.478
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 0.47x+0.11
r= 0.320
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 1.02x−0.32
r= 0.704
N Deq>1000 [#/L]
IKP TWC [g/m³]
05_sec flt. 16&19 −55<T<−35
N= 1899
y= 3.29x−0.97
r= 0.798
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec flt. 16&19 −55<T<−35
N= 2118
y= 2.29x−0.58
r= 0.639
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec flt. 16&19 −55<T<−35
N= 2118
y= 0.07x+0.72
r= 0.061
N Deq>1000 [#/L]
IKP TWC [g/m³]


05_sec All flts. −55<T<−35
N= 8873
y= 2.75x−0.62
r= 0.683
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec All flts. −55<T<−35
N= 9092
y= 2.48x−0.39
r= 0.619
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec All flts. −55<T<−35
N= 9092
y= 0.35x+0.37
r= 0.283
N Deq>1000 [#/L]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 0.93x+0.03
r= 0.478
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 0.47x+0.11
r= 0.320
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 1.02x−0.32
r= 0.704
N Deq>1000 [#/L]
IKP TWC [g/m³]
05_sec flt. 16&19 −55<T<−35
N= 1899
y= 3.29x−0.97
r= 0.798
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec flt. 16&19 −55<T<−35
N= 2118
y= 2.29x−0.58
r= 0.639
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec flt. 16&19 −55<T<−35
N= 2118
y= 0.07x+0.72
r= 0.061
N Deq>1000 [#/L]
IKP TWC [g/m³]


05_sec All flts. −55<T<−35
N= 8873
y= 2.75x−0.62
r= 0.683
CDP N [#/cm³]
IKP TWC [g/m³]
05_sec All flts. −55<T<−35
N= 9092
y= 2.48x−0.39
r= 0.619
N 10<Deq<100 [#/cm³]
IKP TWC [g/m³]
05_sec All flts. −55<T<−35
N= 9092
y= 0.35x+0.37
r= 0.283
N Deq>1000 [#/L]
IKP TWC [g/m³]
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 0.93x+0.03
r= 0.478
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 0.47x+0.11
r= 0.320
05_sec flt. 12&13 −55<T<−35
N= 1093
y= 1.02x−0.32
r= 0.704
Contributions of larger particles to HIWC
05_sec flt. 16&19 −55<T<−35
N= 1899
y= 3.29x−0.97
r= 0.798
05_sec flt. 16&19 −55<T<−35
N= 2118
y= 2.29x−0.58
r= 0.639
05_sec flt. 16&19 −55<T<−35
N= 2118
y= 0.07x+0.72
r= 0.061
Contributions of smaller particles to HIWC



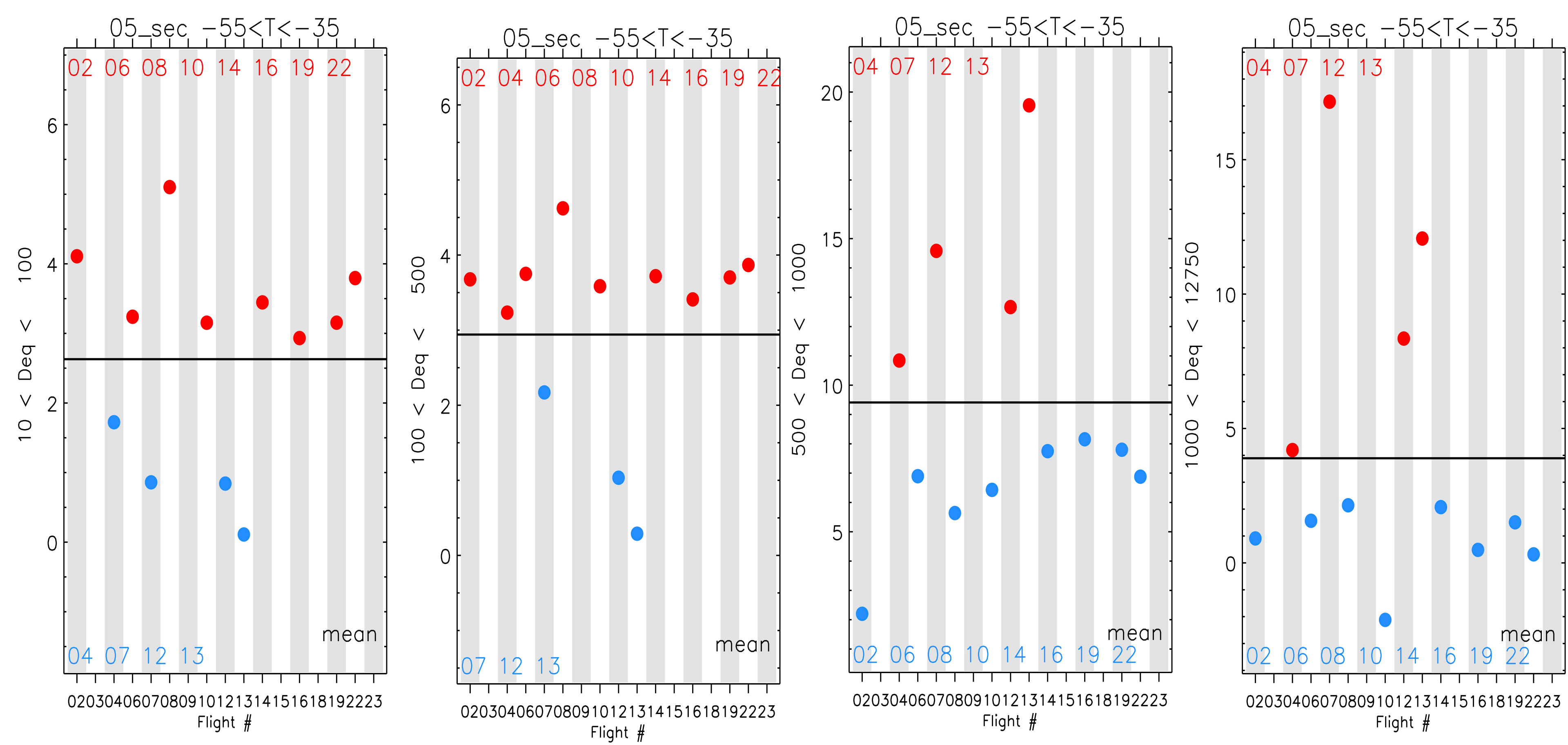
Flight #, slope of best fit line larger than mean

Contributions of particle to TWC increase with TWC

Slope of best fit line for all flights

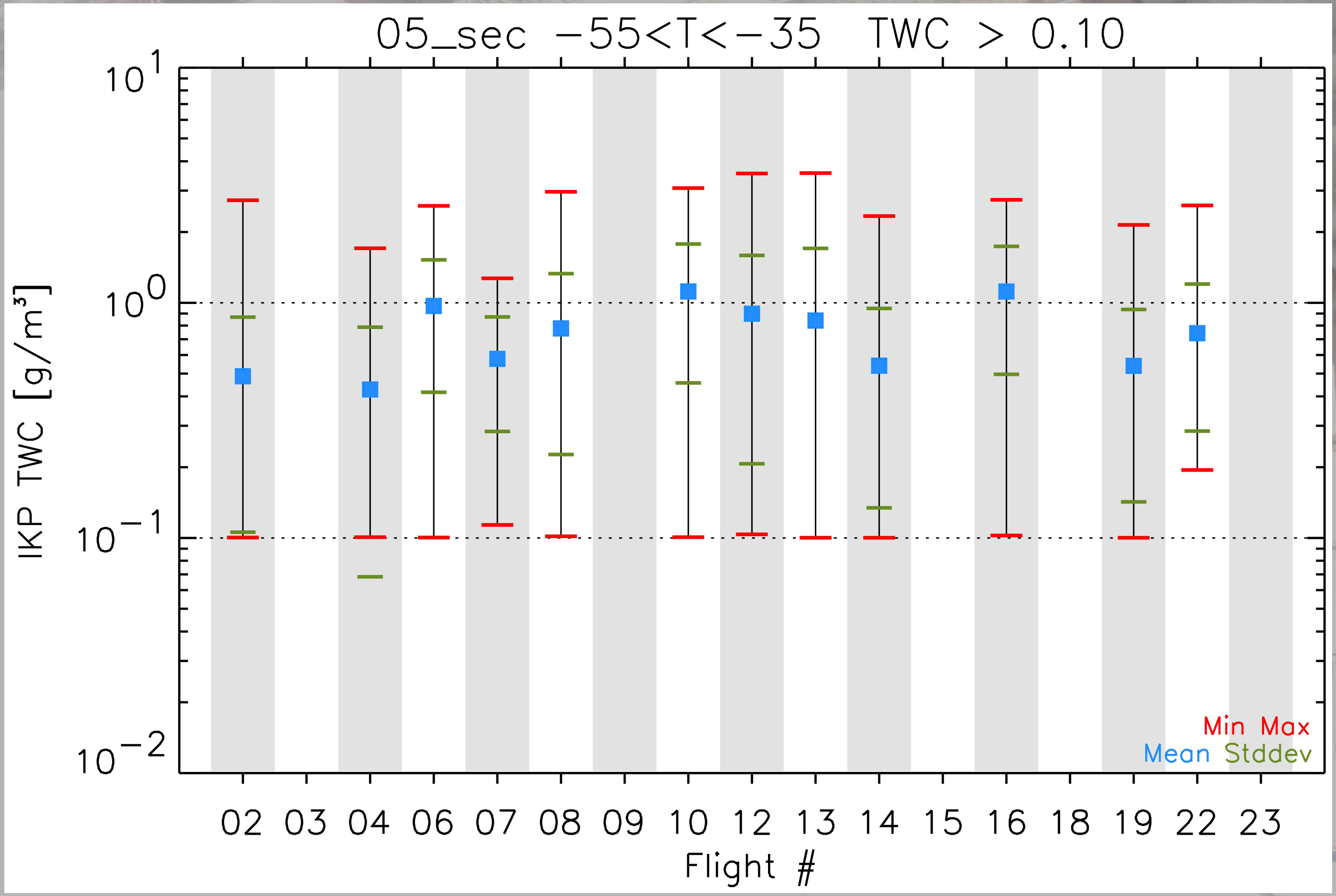
Flight #, slope of best fit line smaller than mean

Contributions of particle to TWC decrease with TWC



10 < Deq < 100 µm **100 < Deq < 500 µm** **500 < Deq < 1000 µm** **1000 < Deq**

- **Trend change @~ 500 µm**
- **Group 1 (4, 7, 12, 13) distinct from group 2 (2, 6, 8, 10, 14, 16, 19, 22)**
- **Group1: Contrib. # large particle (Deq>500) to TWC increase with TWC**
- **Group2: Contrib. # small particle (Deq<500) to TWC increase with TWC**
- **Related to multiple mode of PSDs, MMD**



- Group 1 (4, 7, 12, 13) distinct from group 2 (2, 6, 8, 10, 14, 16, 19, 22)
- Relatively lower TWC sampled for flight 4 & 7
- Flight 12 & 13 distinct from other flights
- Diff. formation mechanism? Diff Freezing? Aerosols?
- Further analysis...