Microphysical Properties of Tropical Tropopause Layer Cirrus: Insights from ATTREX

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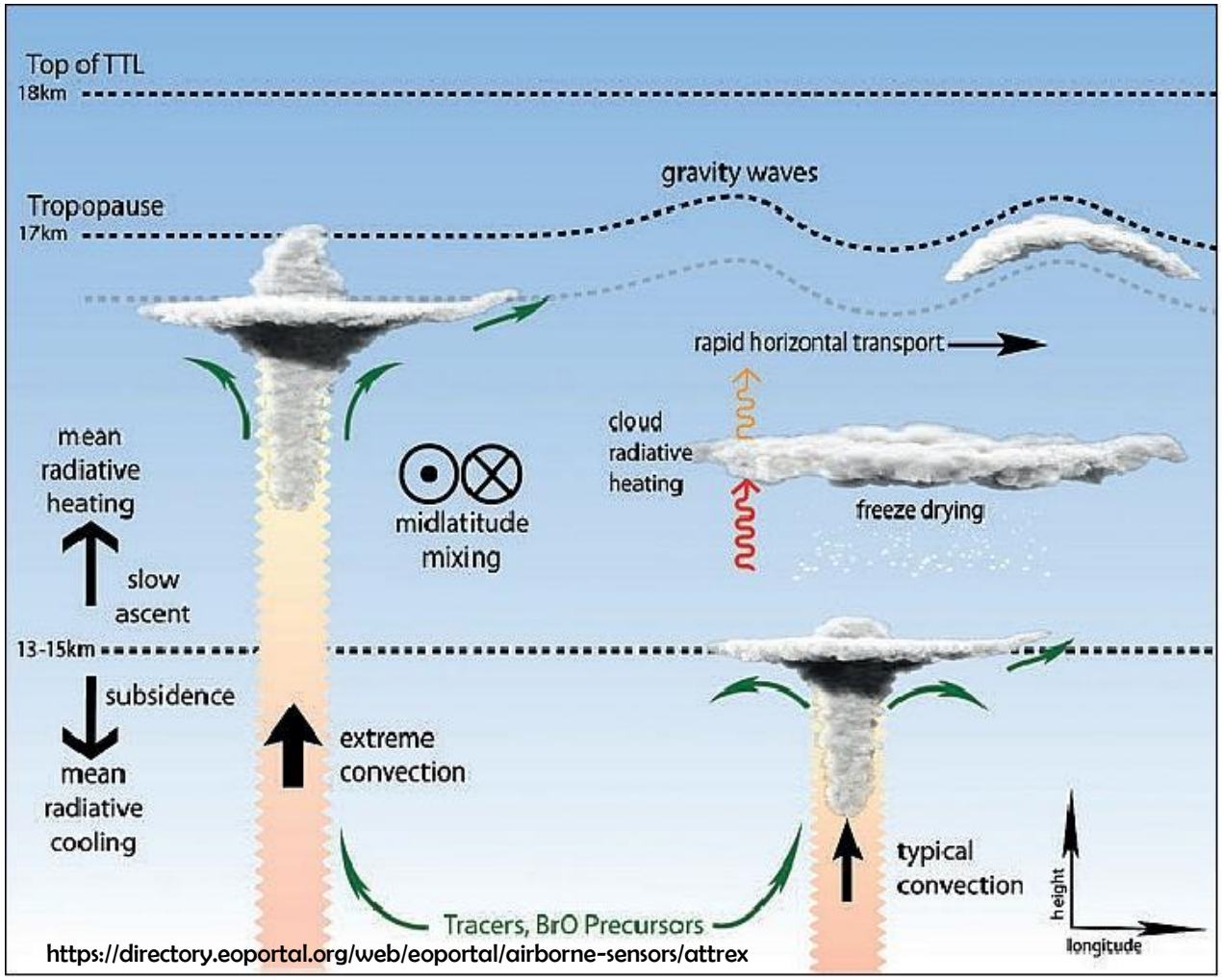
Motivation: Role of clouds in the Upper Troposphere/Lower Stratosphere

- How do clouds affect the humidity and chemical composition of air entering the stratosphere?
- Dehydration?
- Radiative Transfer?
- Relationship between RHice, temperature, convective influence, etc. and particle size, concentration, mass, and shape?

ATTREX yielded good suite of in situ measurements for investigating microphysical properties of TTL cirrus



ATTREX-3 flights, 2014

RF06, 11-12 March

RF02, 16-17 February

RF03, 4-5 March

RF04, 6-7 March

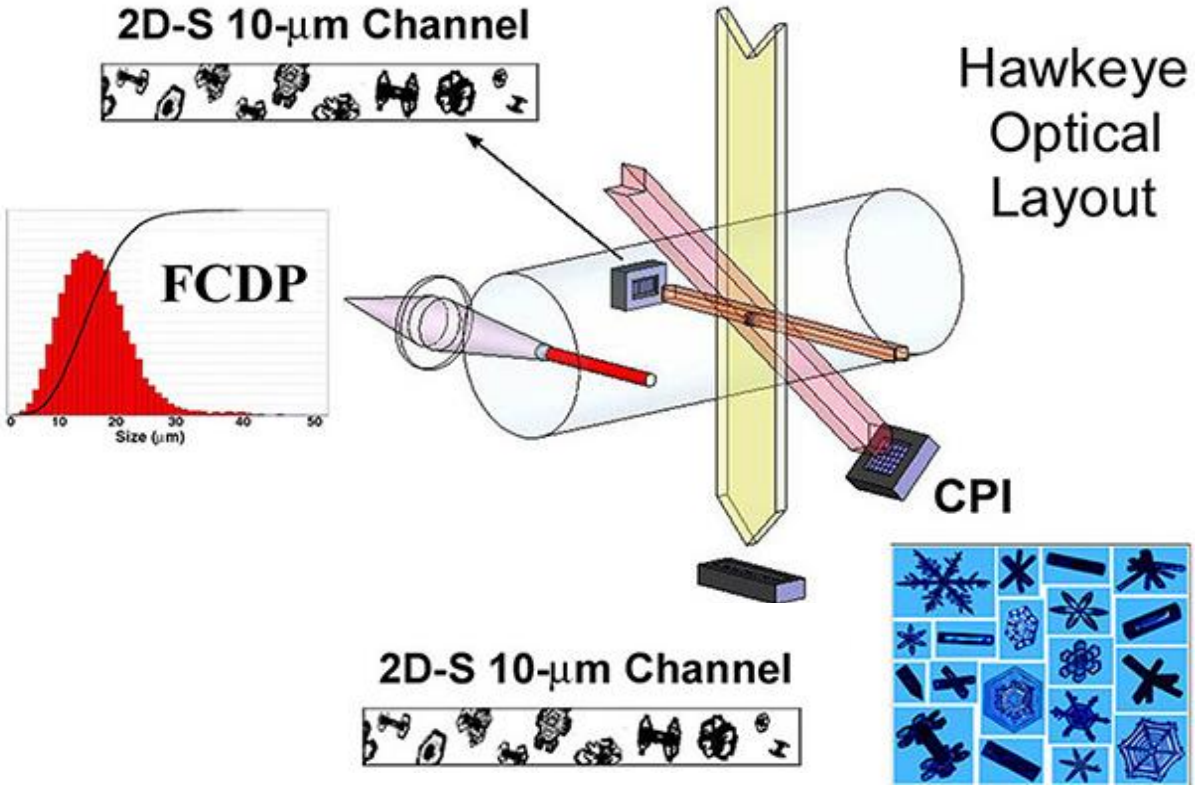
RF01, 12-13 February

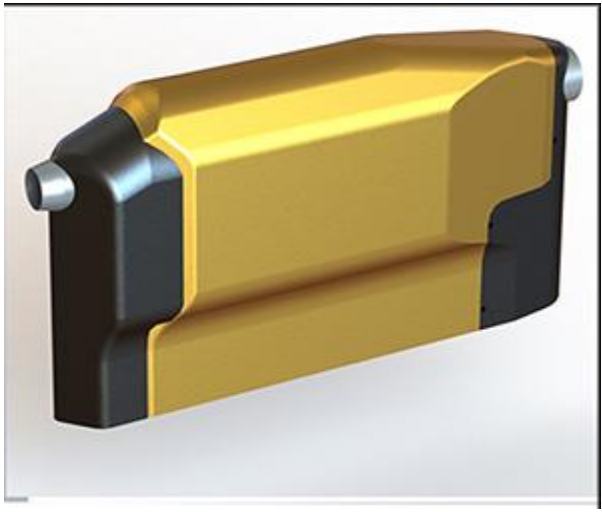
RF05, 9-10 March

30
20
10
0
-10

130 135 140 145 150 155 160 165 170 175 180

Instrument	Resolution	Measurement Range	Measurement Technique
Hawkeye-CPI (Cloud Particle Imager)	2.3 um	2.3 um - 2.36 mm	CCD (camera)
Hawkeye-FCDP (Fast Cloud Droplet Probe)	2 um	1 um - 50 um	Forward Scattering
Hawkeye-2D-S (2-D Stereo Probe)	10 um	10 um - 1.28 mm	Diode Array (128)



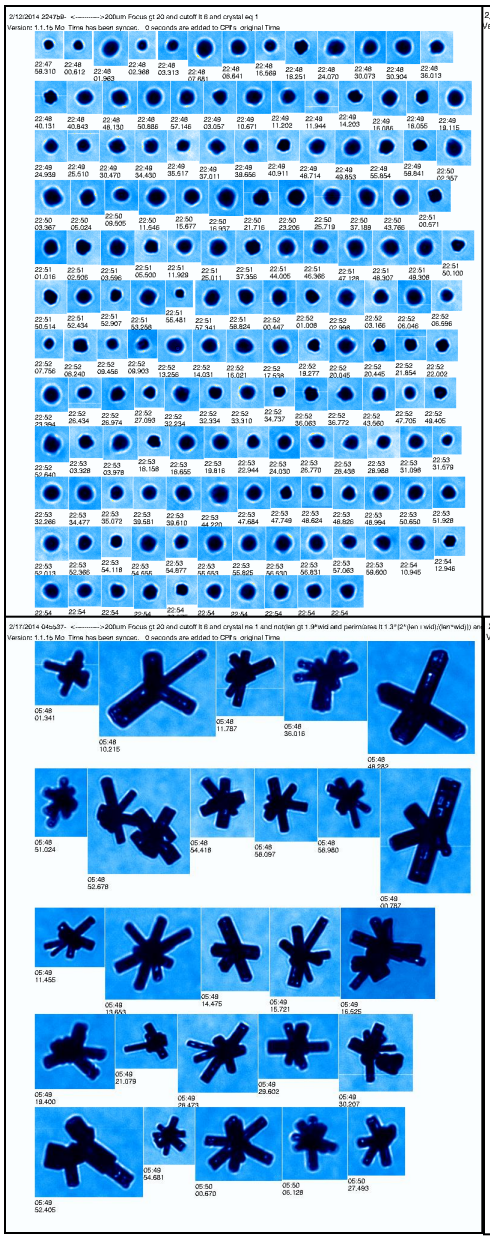


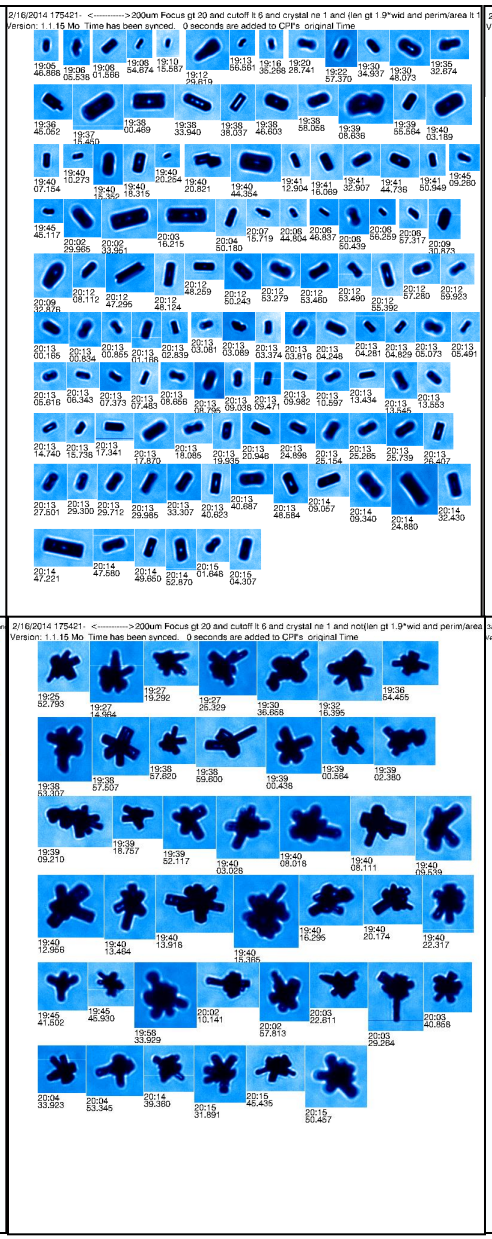
Spheroids

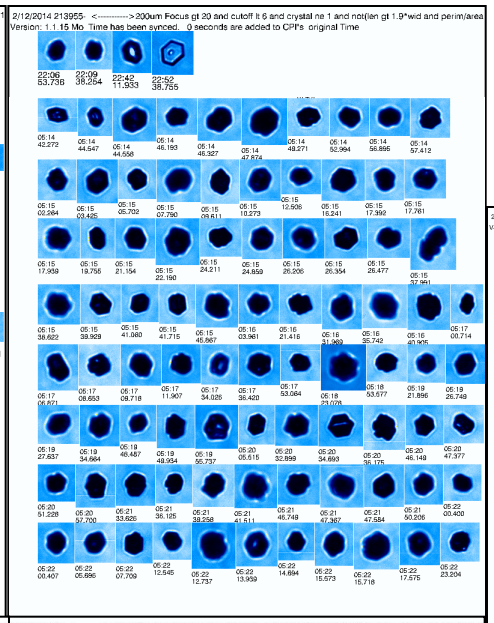
Columns

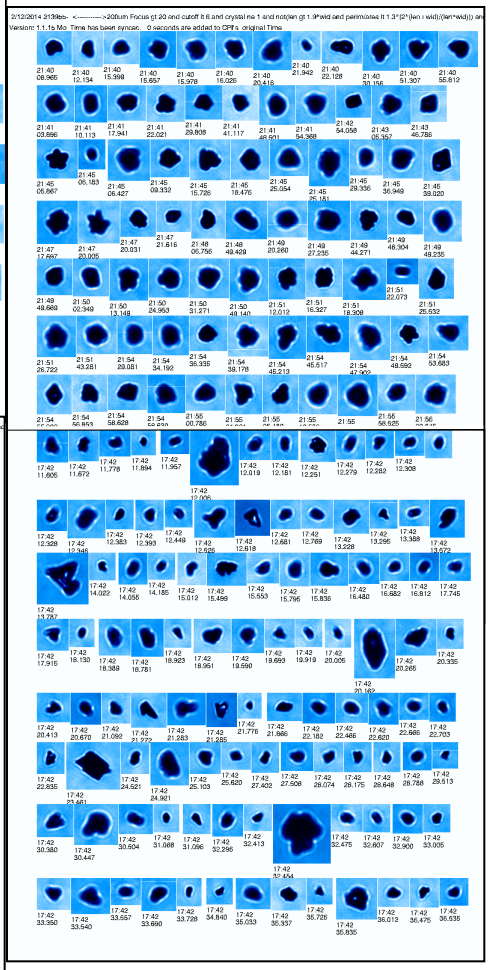
Plates

200 um





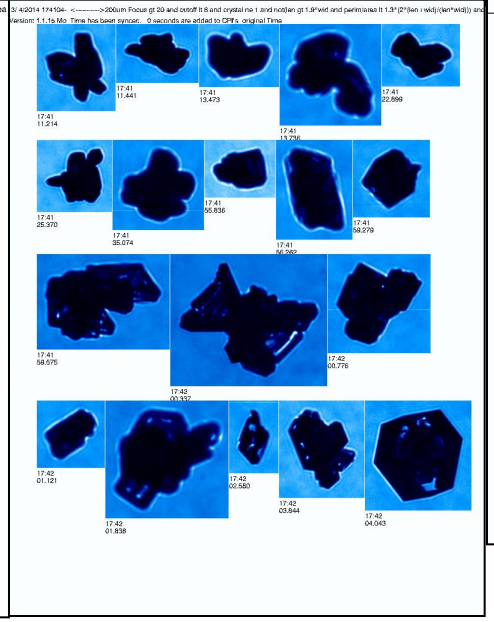




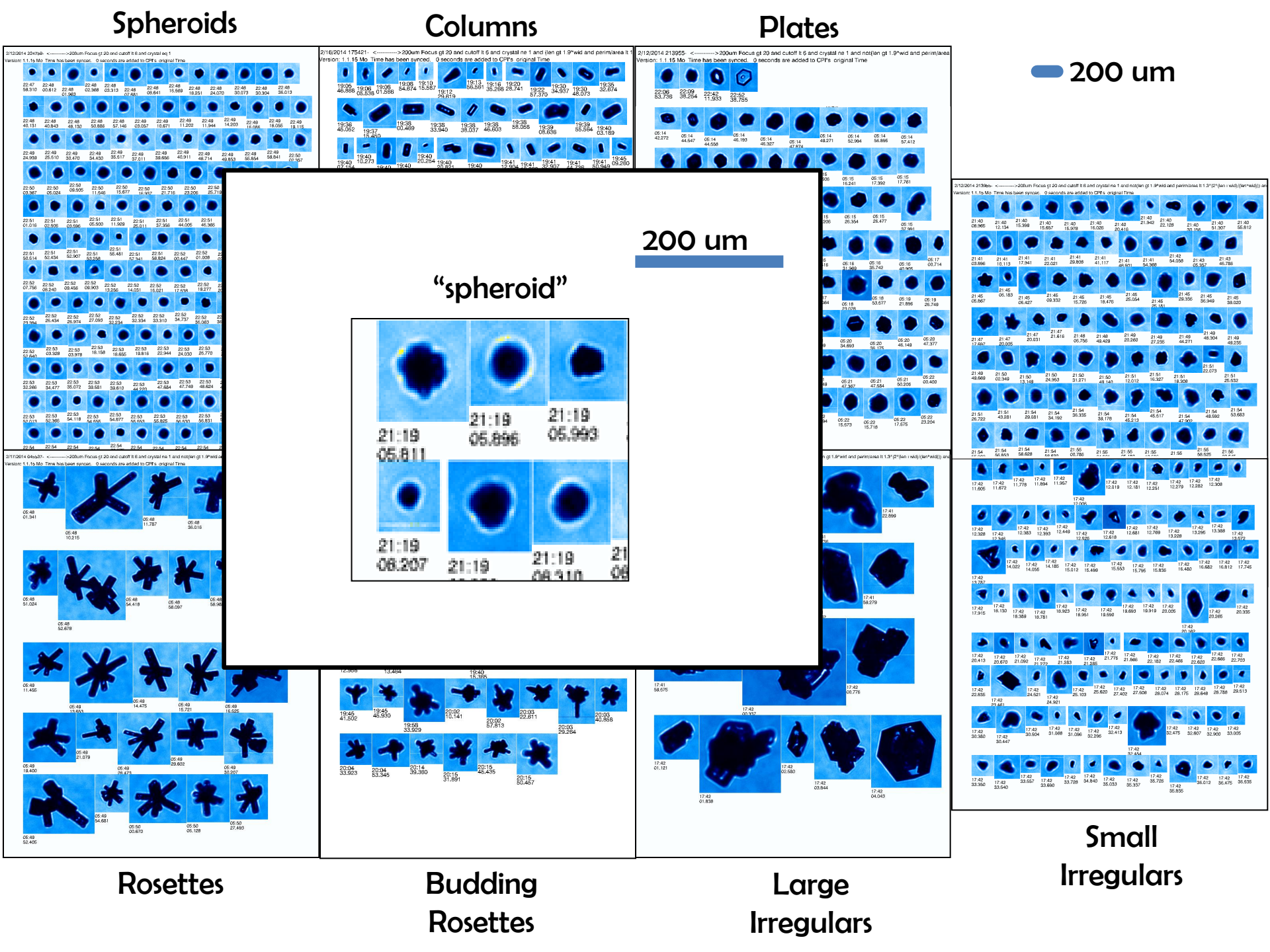
Small Irregulars

Rosettes

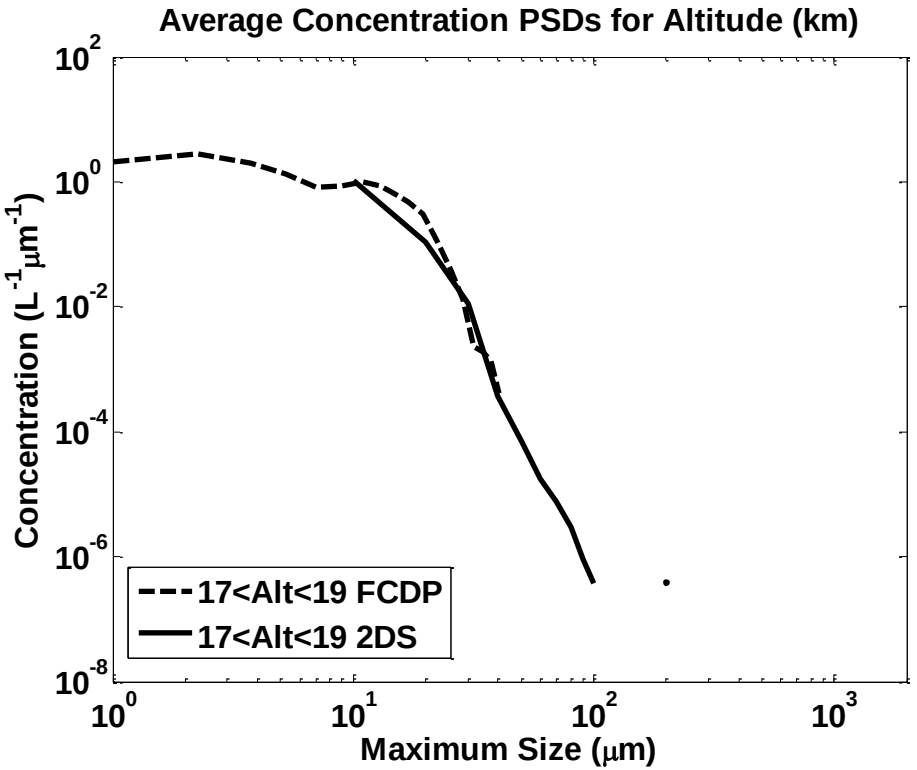
Budding Rosettes

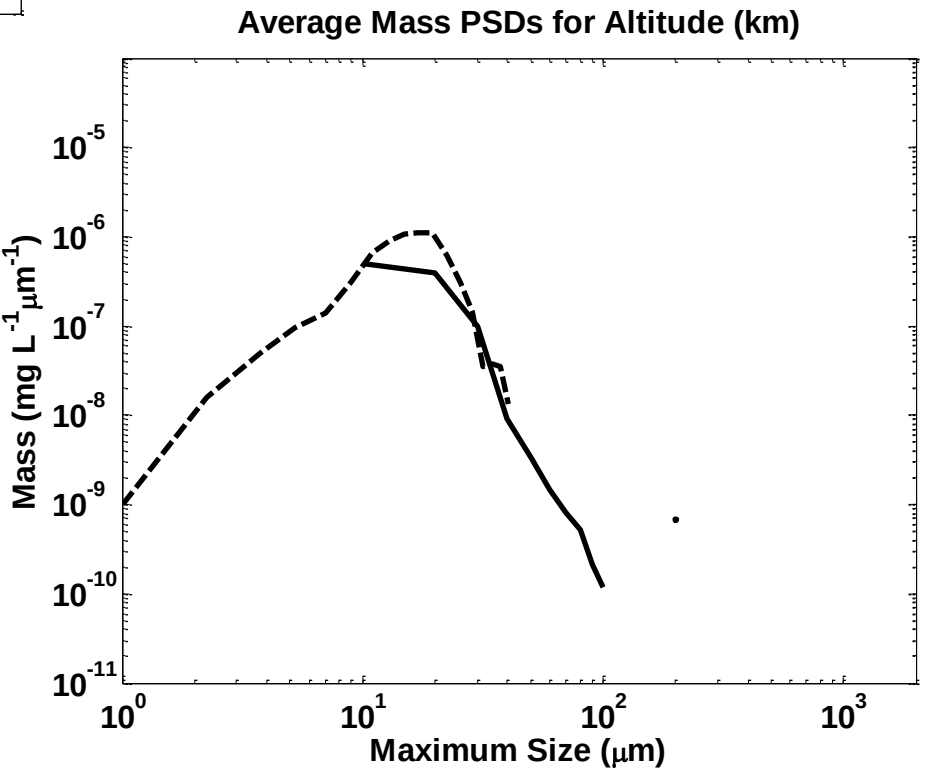


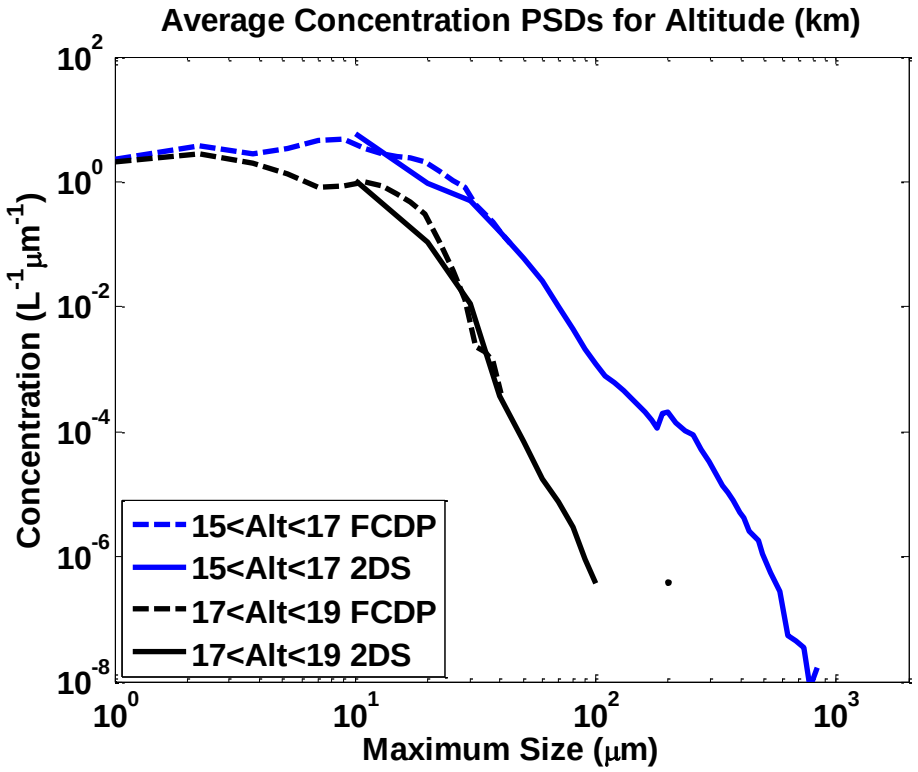
Large Irregulars

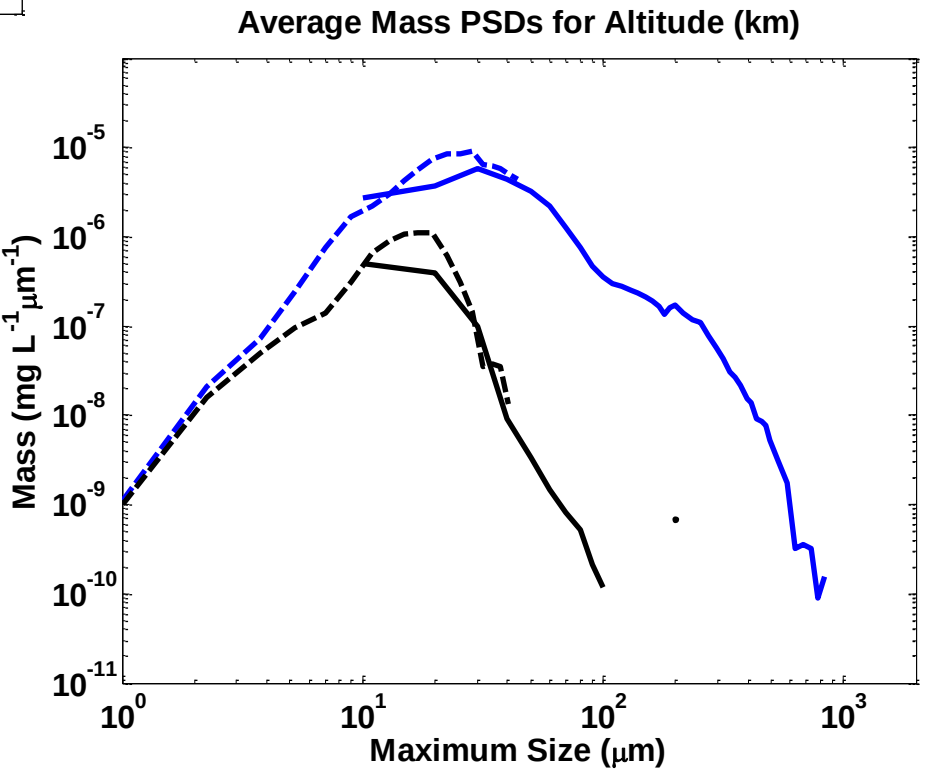

Spheroids
Columns
Plates
200 um
"spheroid"
200 um
Small Irregulars
Rosettes
Budding Rosettes
Large Irregulars

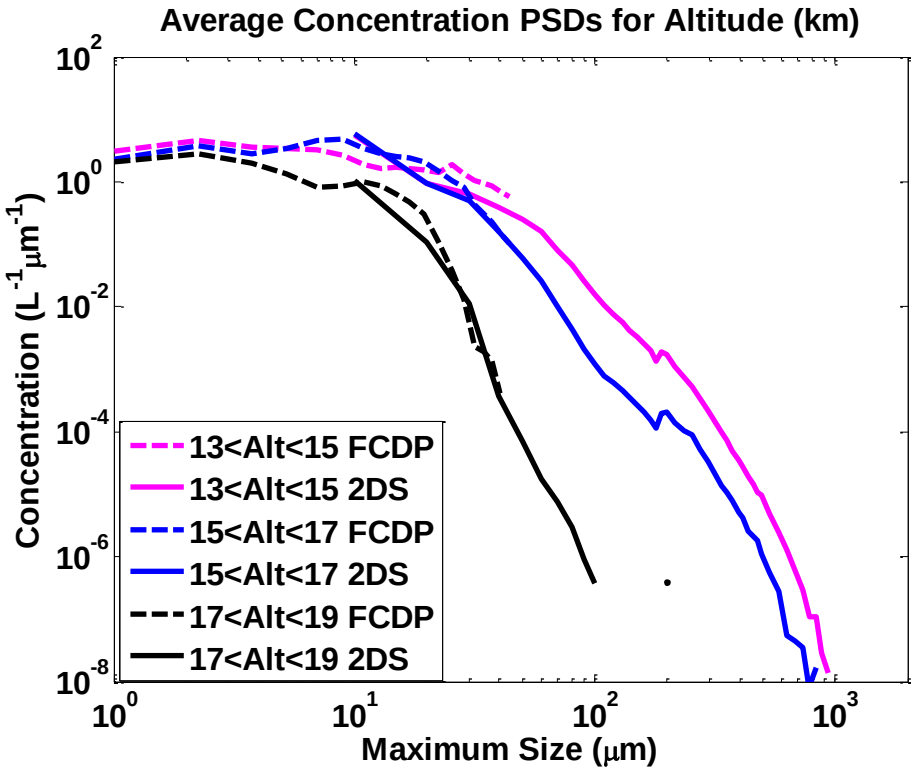
How do particle concentration, mass, size and shape vary with ***altitude***?

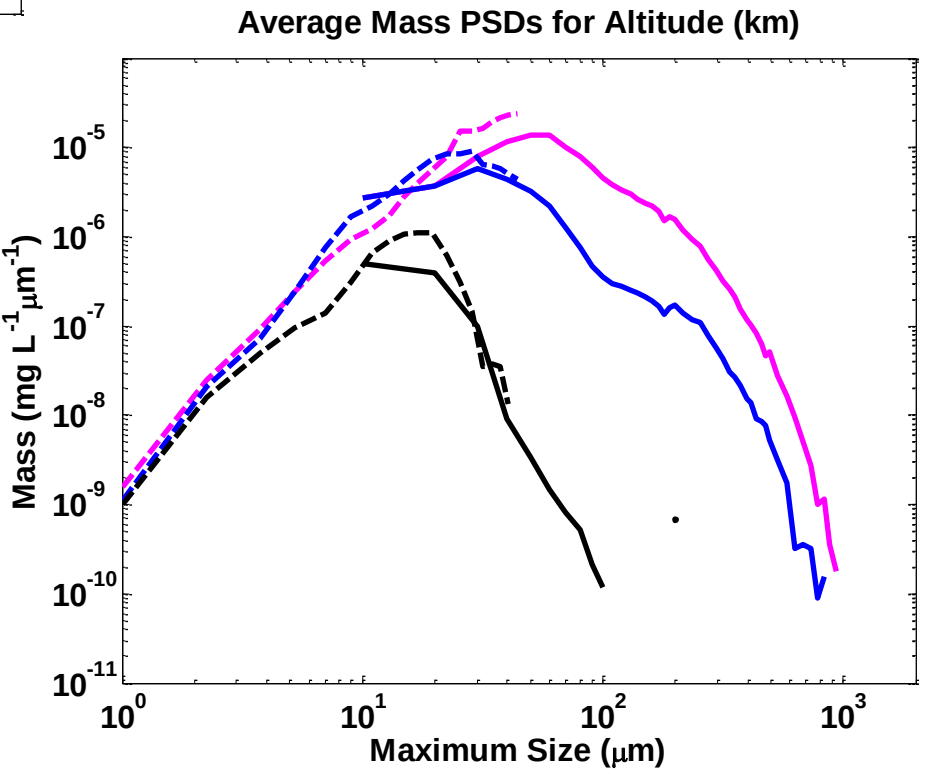

Average Concentration PSDs for Altitude (km)
Concentration (L-1μm-1)
Maximum Size (μm)
17<Alt<19 FCDP
17<Alt<19 2DS

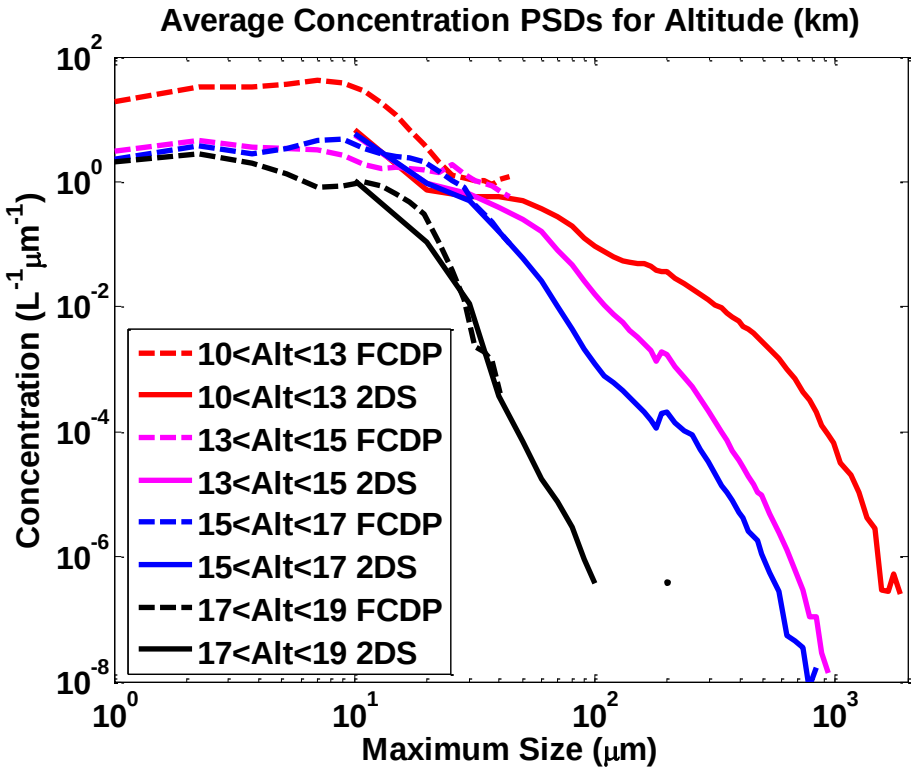

Average Mass PSDs for Altitude (km)
Mass (mg L-1μm-1)
Maximum Size (μm)

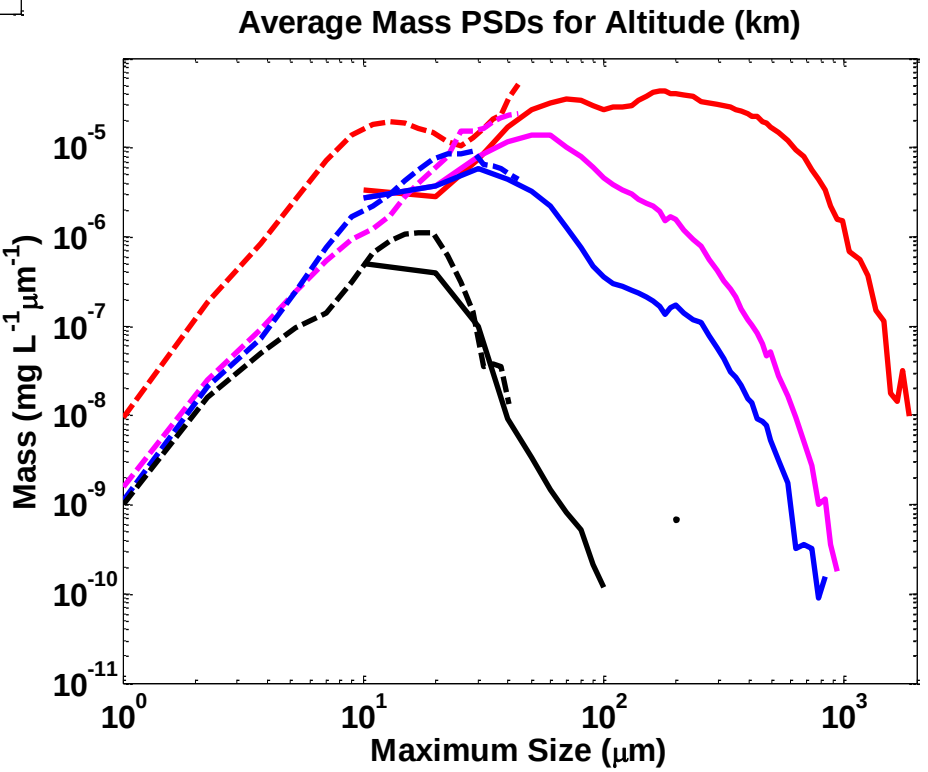

Average Concentration PSDs for Altitude (km)
Concentration (L-1μm-1)
Maximum Size (μm)
15<Alt<17 FCDP
15<Alt<17 2DS
17<Alt<19 FCDP
17<Alt<19 2DS

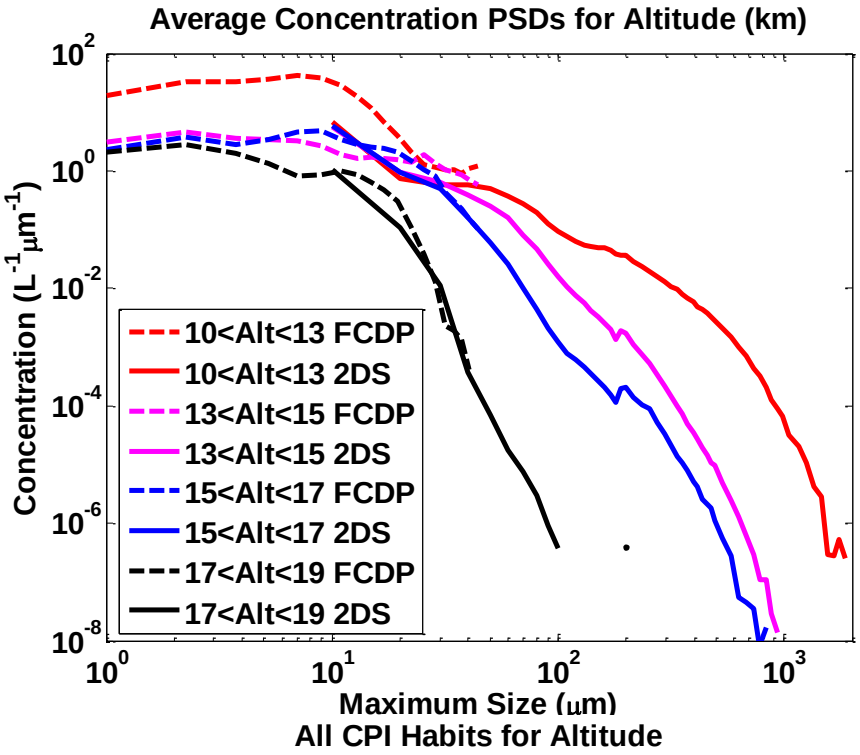

Average Mass PSDs for Altitude (km)
Mass (mg L-1μm-1)
Maximum Size (μm)

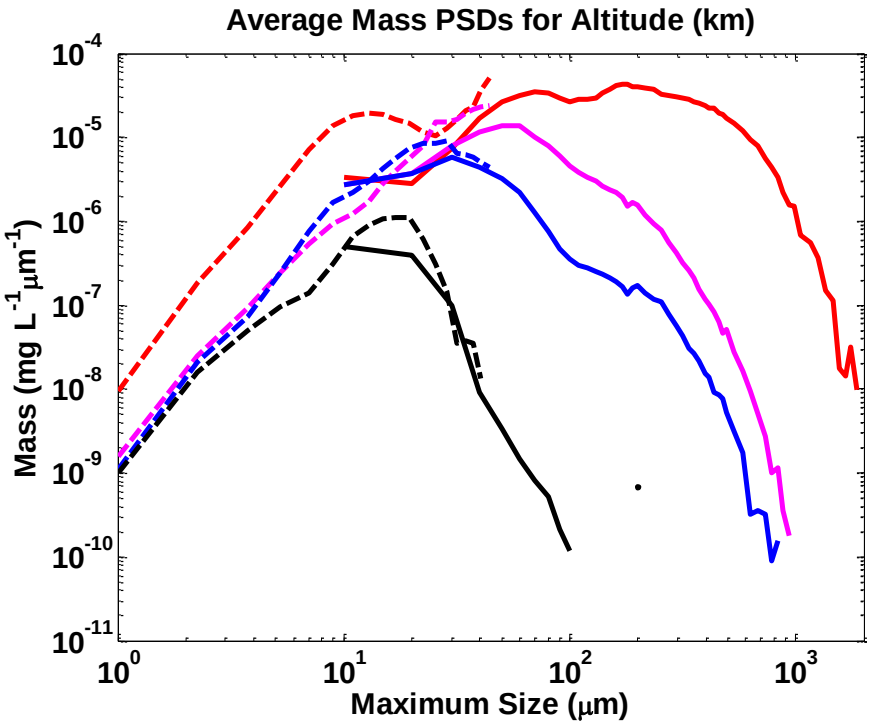

Average Concentration PSDs for Altitude (km)
Concentration (L-1μm-1)
Maximum Size (μm)
13<Alt<15 FCDP
13<Alt<15 2DS
15<Alt<17 FCDP
15<Alt<17 2DS
17<Alt<19 FCDP
17<Alt<19 2DS

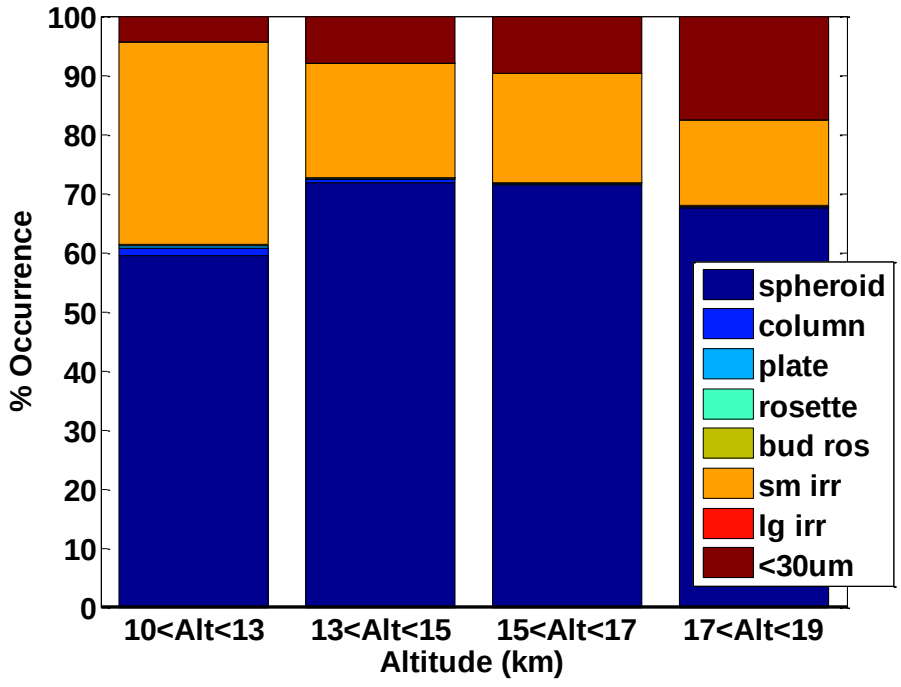

Average Mass PSDs for Altitude (km)
Mass (mg L-1μm-1)
Maximum Size (μm)

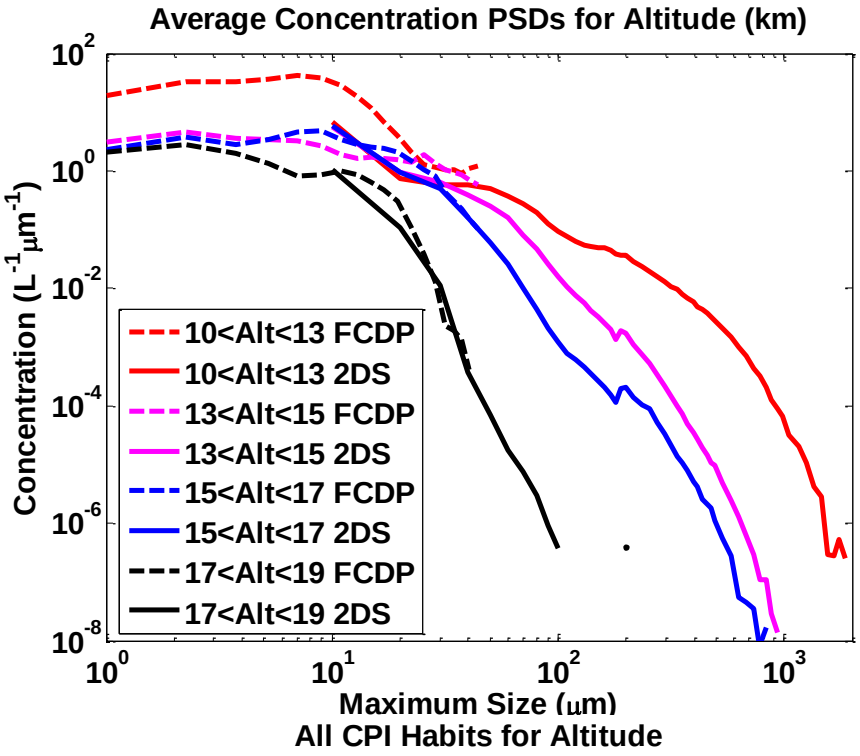

Average Concentration PSDs for Altitude (km)
Concentration (L-1μm-1)
Maximum Size (μm)
10<Alt<13 FCDP
10<Alt<13 2DS
13<Alt<15 FCDP
13<Alt<15 2DS
15<Alt<17 FCDP
15<Alt<17 2DS
17<Alt<19 FCDP
17<Alt<19 2DS

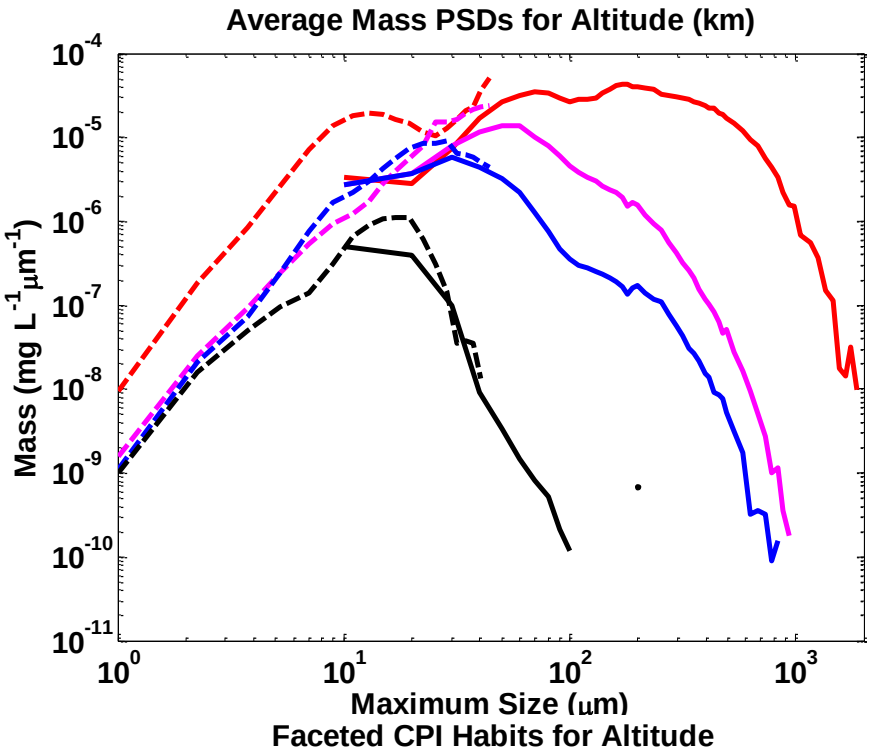

Average Mass PSDs for Altitude (km)
Mass (mg L-1μm-1)
Maximum Size (μm)

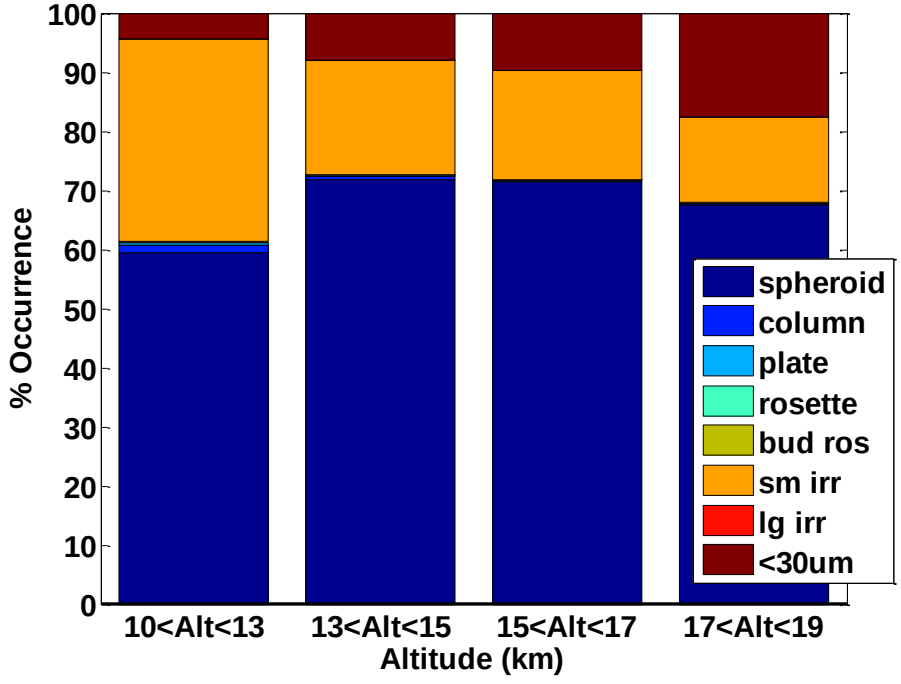

Average Concentration PSDs for Altitude (km)
Concentration (L-1μm-1)
Maximum Size (μm)
10<Alt<13 FCDP
10<Alt<13 2DS
13<Alt<15 FCDP
13<Alt<15 2DS
15<Alt<17 FCDP
15<Alt<17 2DS
17<Alt<19 FCDP
17<Alt<19 2DS

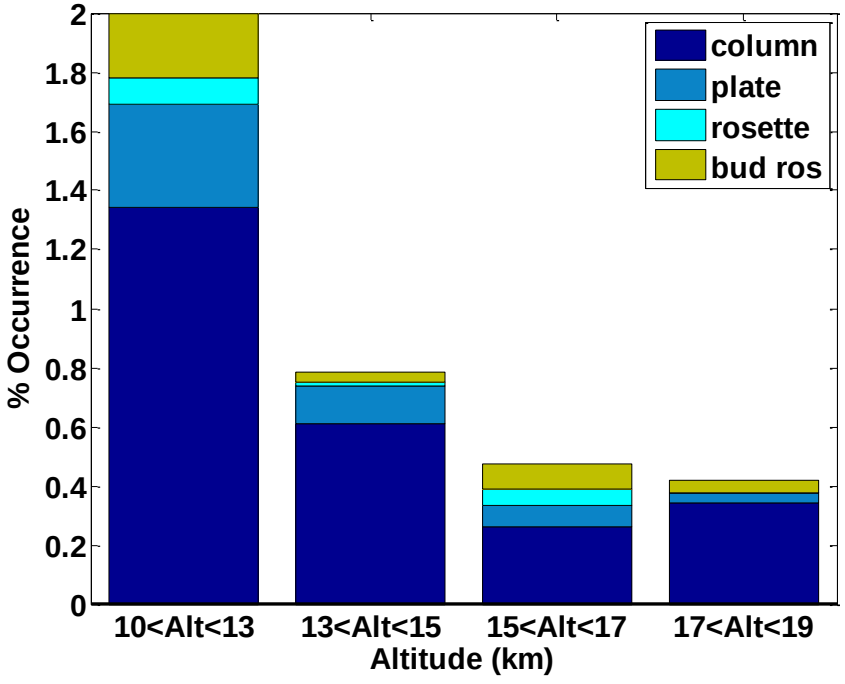

Average Mass PSDs for Altitude (km)
Mass (mg L-1μm-1)
Maximum Size (μm)


All CPI Habits for Altitude
% Occurrence
Altitude (km)
10<Alt<13
13<Alt<15
15<Alt<17
17<Alt<19
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

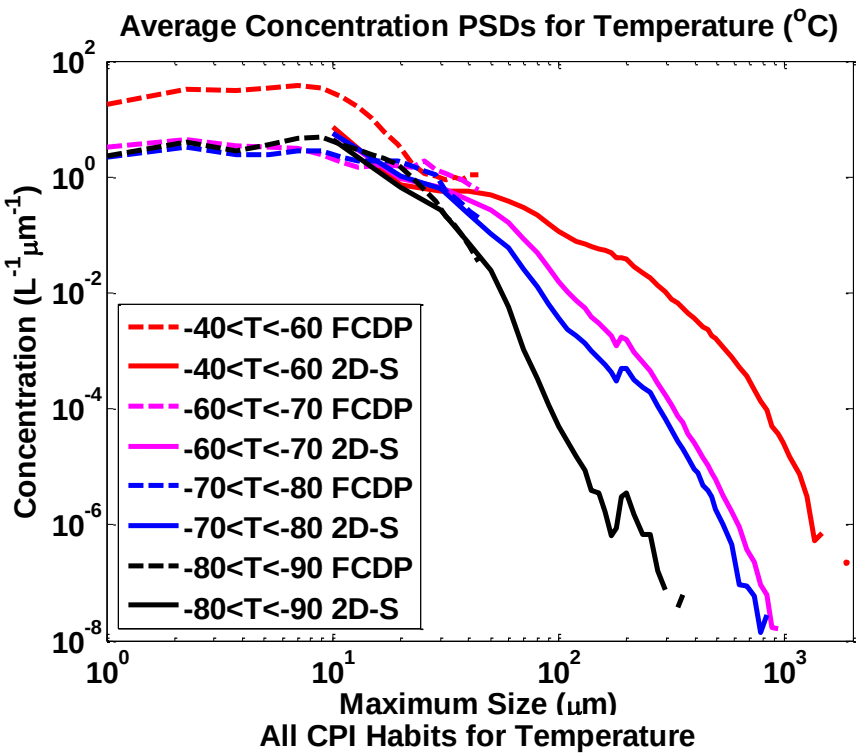

Average Concentration PSDs for Altitude (km)
Concentration (L-1μm-1)
Maximum Size (μm)
10<Alt<13 FCDP
10<Alt<13 2DS
13<Alt<15 FCDP
13<Alt<15 2DS
15<Alt<17 FCDP
15<Alt<17 2DS
17<Alt<19 FCDP
17<Alt<19 2DS

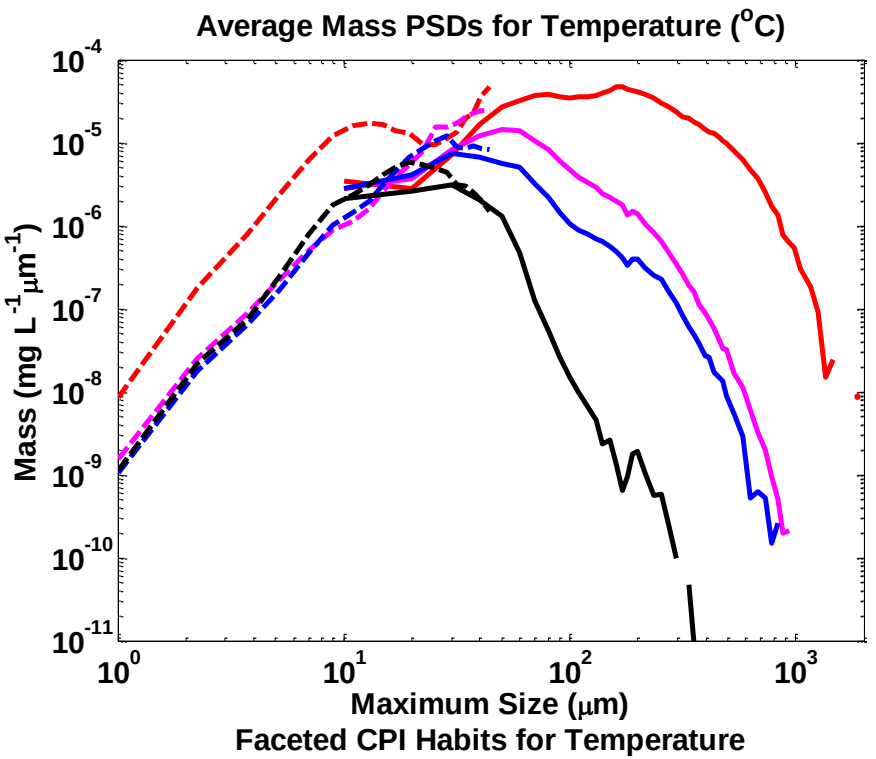

Average Mass PSDs for Altitude (km)
Mass (mg L-1μm-1)
Maximum Size (μm)

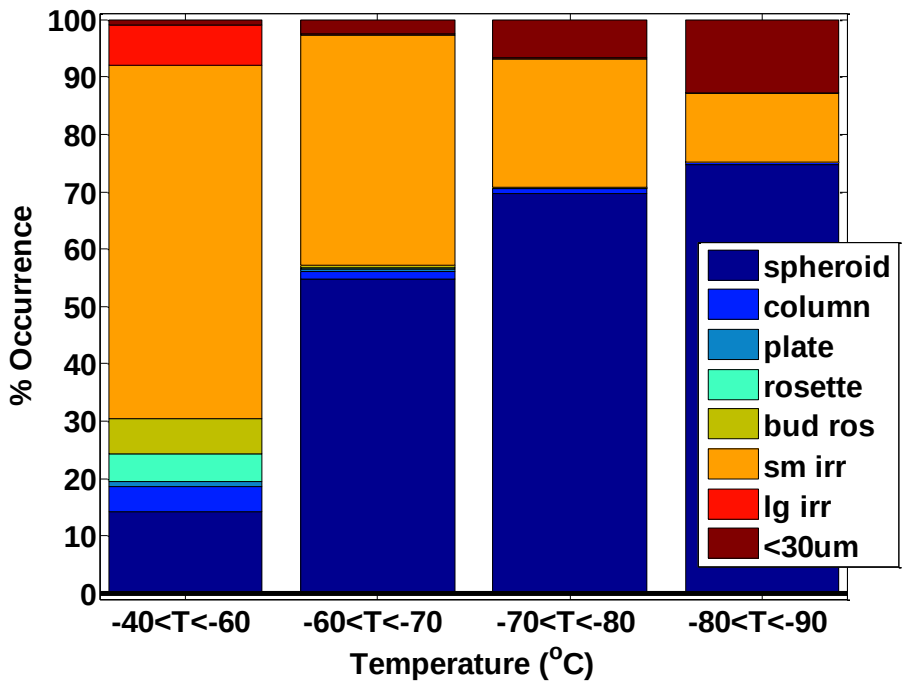

All CPI Habits for Altitude
% Occurrence
Altitude (km)
10<Alt<13
13<Alt<15
15<Alt<17
17<Alt<19
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

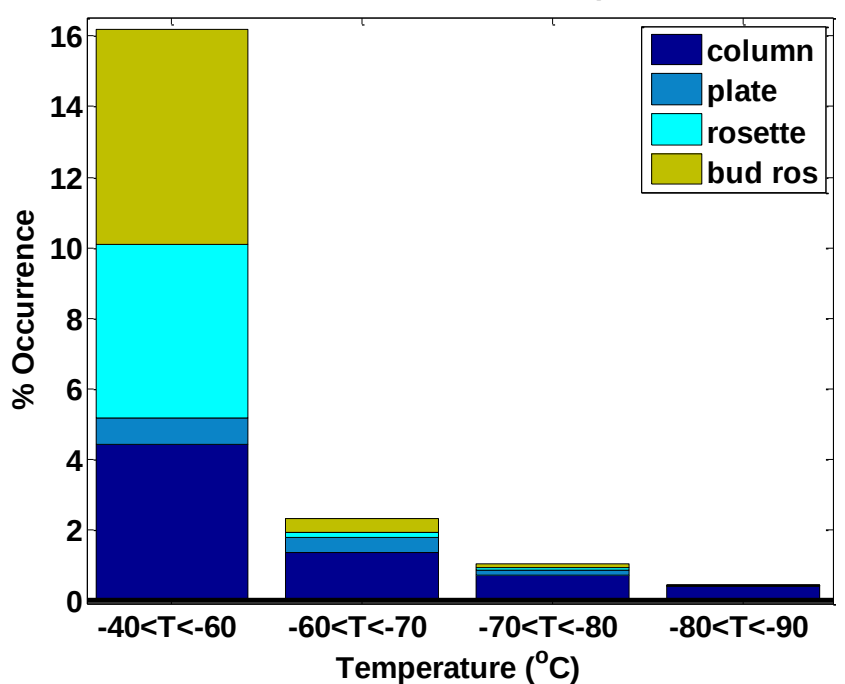

Faceted CPI Habits for Altitude
% Occurrence
Altitude (km)
10<Alt<13
13<Alt<15
15<Alt<17
17<Alt<19
column
plate
rosette
bud ros

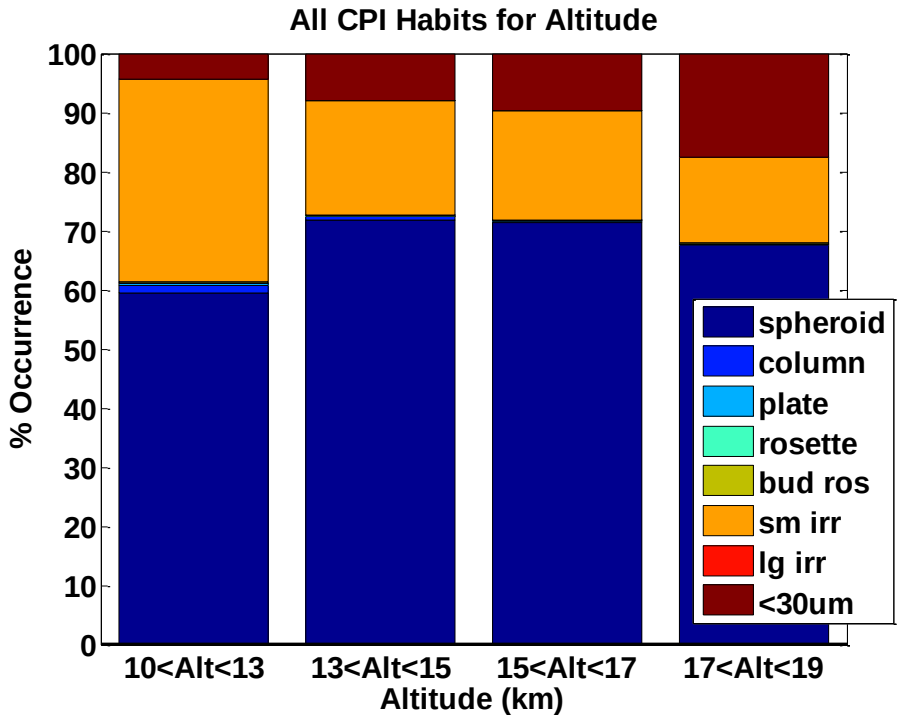
How do particle concentration, mass, size and shape vary with ***temperature***?

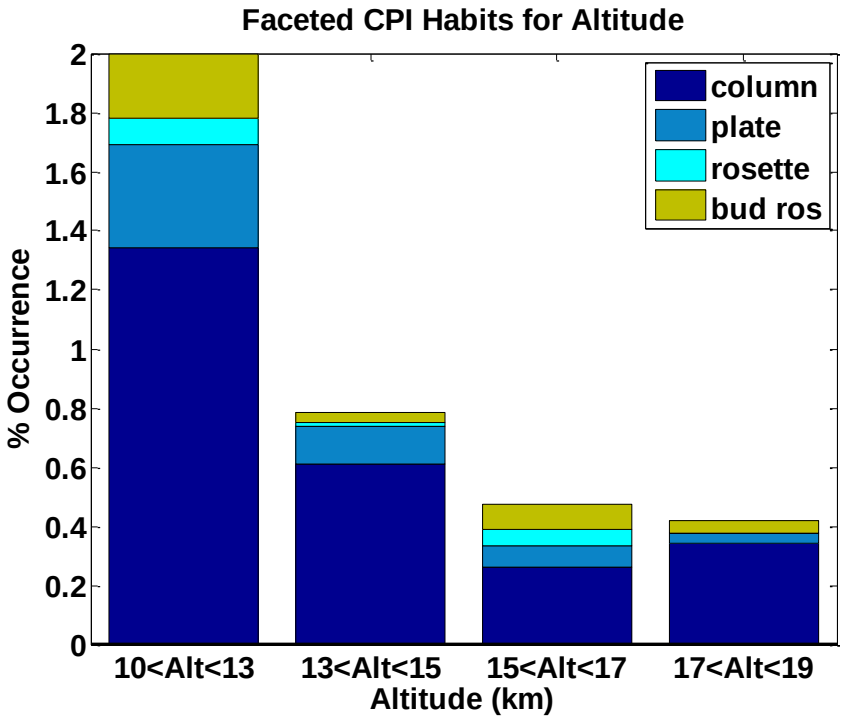

Average Concentration PSDs for Temperature (°C)
Concentration (L⁻¹μm⁻¹)
Maximum Size (μm)
-40<T<-60 FCDP
-40<T<-60 2D-S
-60<T<-70 FCDP
-60<T<-70 2D-S
-70<T<-80 FCDP
-70<T<-80 2D-S
-80<T<-90 FCDP
-80<T<-90 2D-S

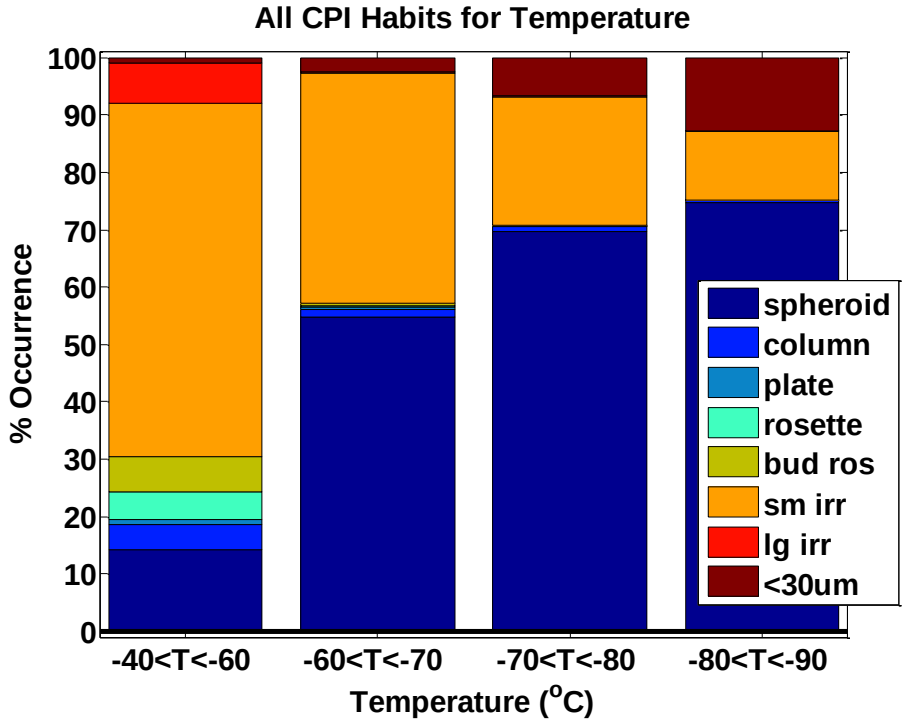

Average Mass PSDs for Temperature (°C)
Mass (mg L⁻¹μm⁻¹)
Maximum Size (μm)

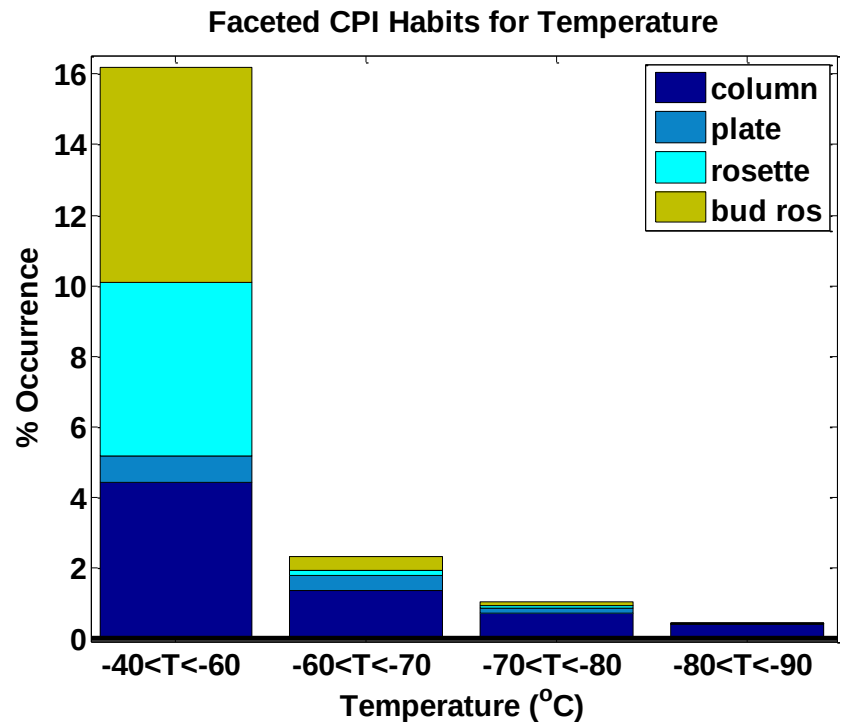

All CPI Habits for Temperature
% Occurrence
Temperature (°C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um


Faceted CPI Habits for Temperature
% Occurrence
Temperature (°C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
column
plate
rosette
bud ros

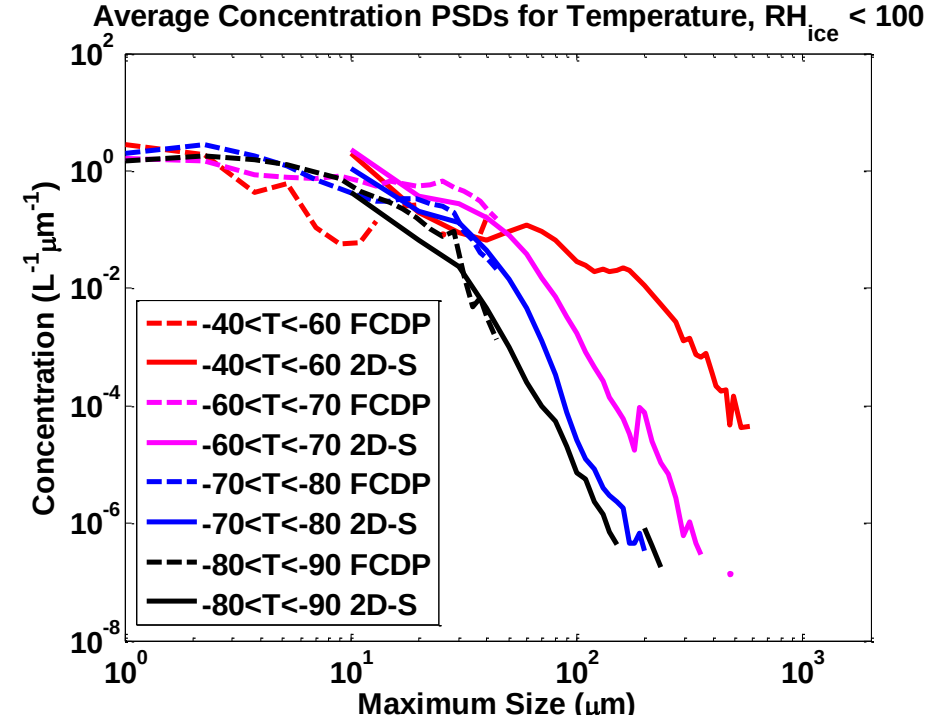

All CPI Habits for Altitude
% Occurrence
Altitude (km)
10<Alt<13
13<Alt<15
15<Alt<17
17<Alt<19
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

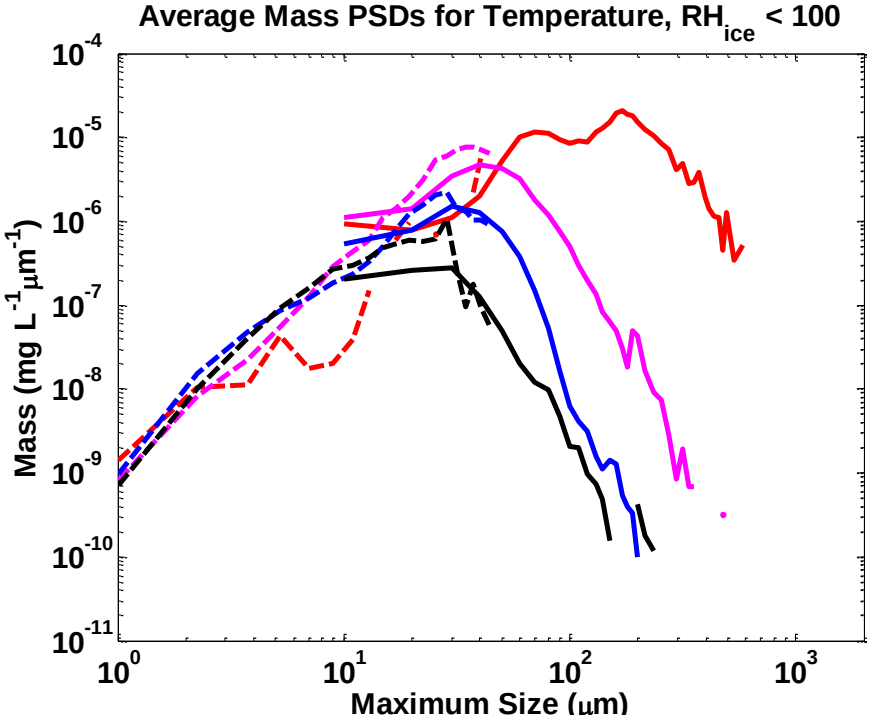

Faceted CPI Habits for Altitude
% Occurrence
Altitude (km)
10<Alt<13
13<Alt<15
15<Alt<17
17<Alt<19
column
plate
rosette
bud ros

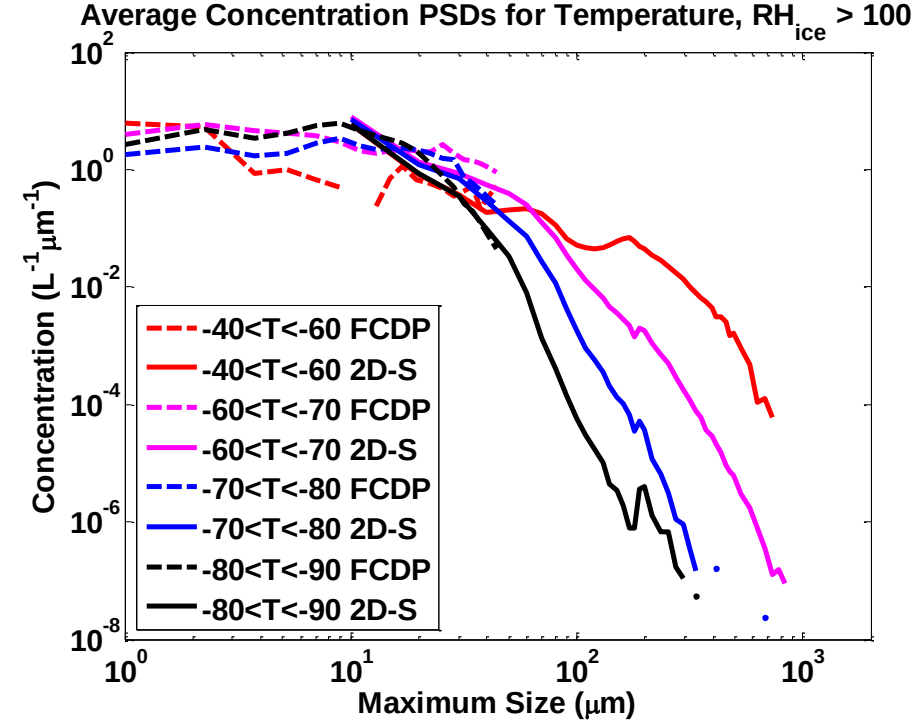

All CPI Habits for Temperature
% Occurrence
Temperature (°C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

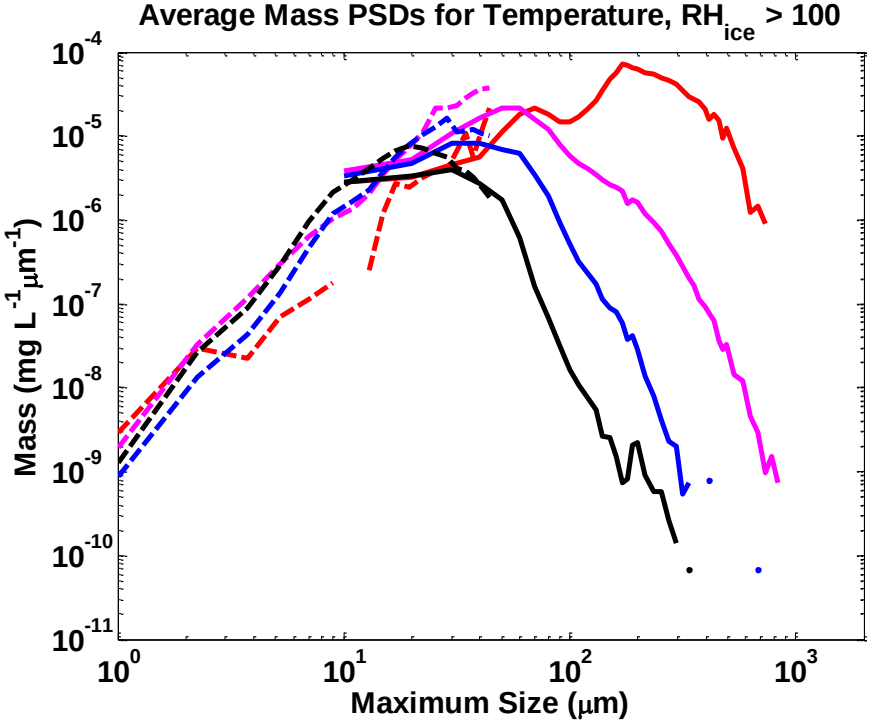

Faceted CPI Habits for Temperature
% Occurrence
Temperature (°C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
column
plate
rosette
bud ros

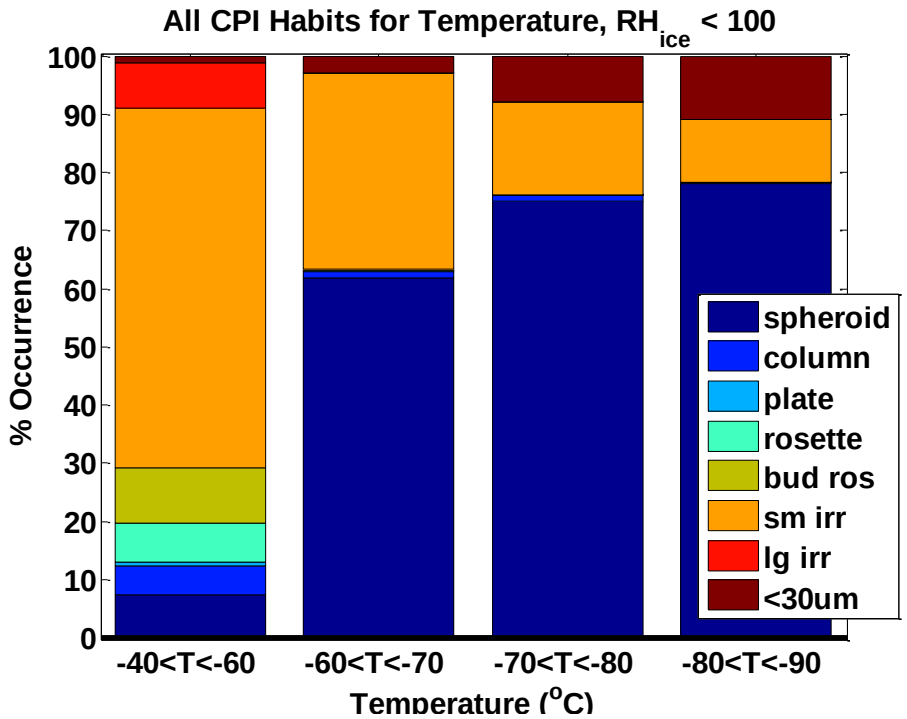
How do particle concentration, mass, size and shape vary with ***temperature*** *when* ***supersaturated***?

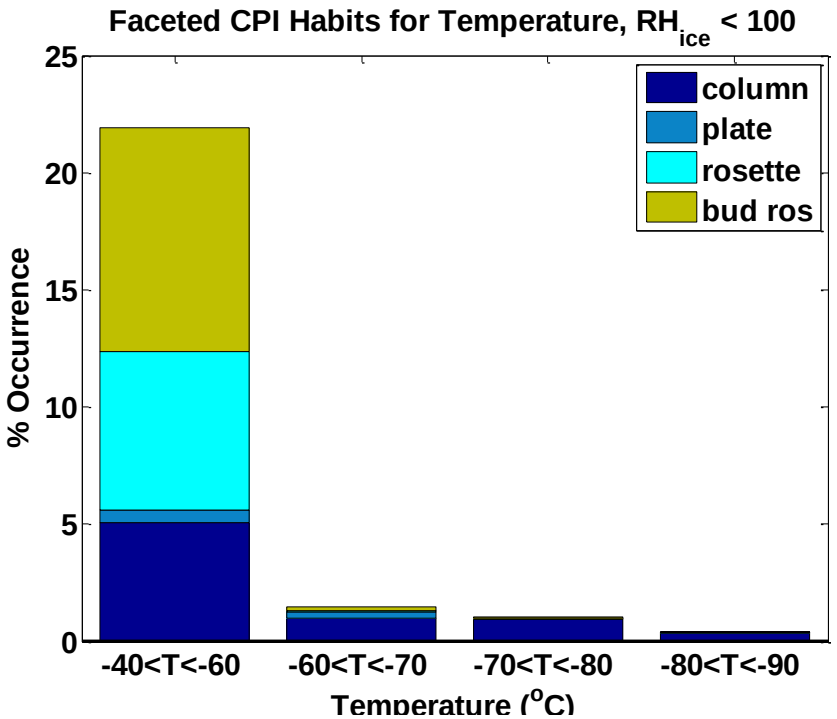

Average Concentration PSDs for Temperature, RH$_{ice}$ < 100
Concentration (L^{-1}μm^{-1})
Maximum Size (μm)
-40<T<-60 FCDP
-40<T<-60 2D-S
-60<T<-70 FCDP
-60<T<-70 2D-S
-70<T<-80 FCDP
-70<T<-80 2D-S
-80<T<-90 FCDP
-80<T<-90 2D-S

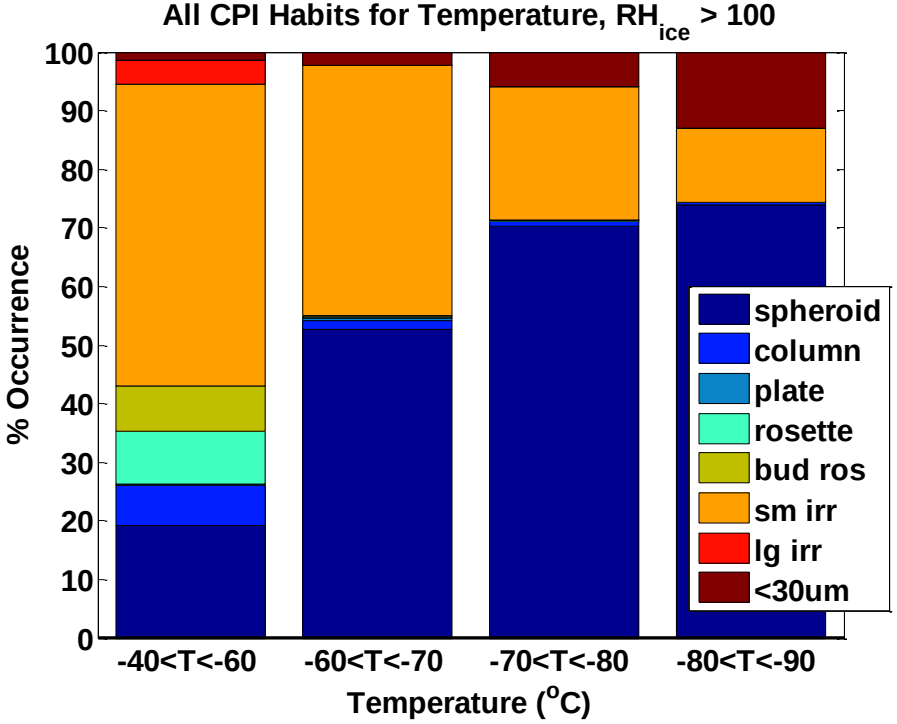

Average Mass PSDs for Temperature, RH$_{ice}$ < 100
Mass (mg L^{-1}μm^{-1})
Maximum Size (μm)

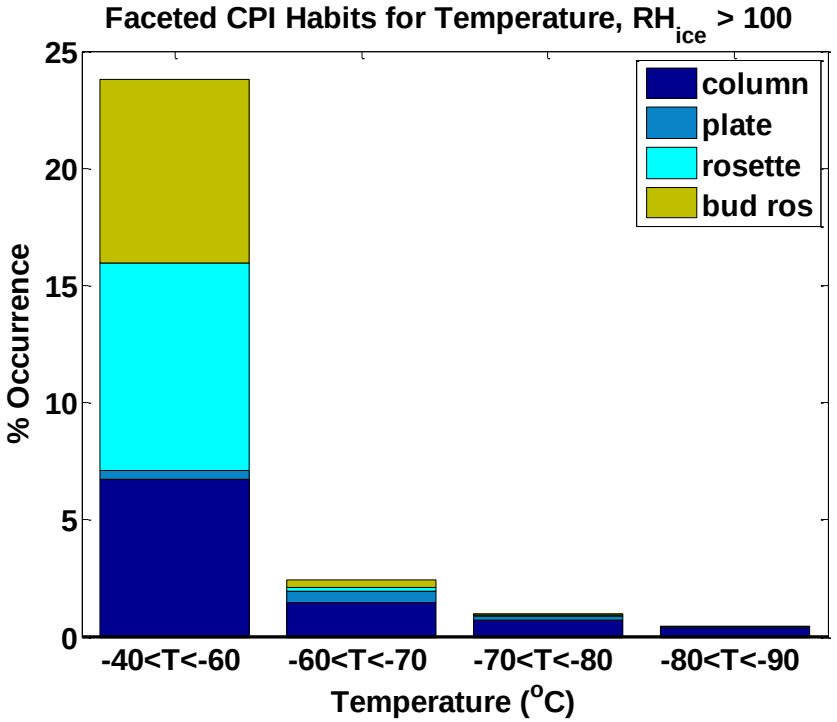

Average Concentration PSDs for Temperature, RH$_{ice}$ > 100
Concentration (L^{-1}μm^{-1})
Maximum Size (μm)
-40<T<-60 FCDP
-40<T<-60 2D-S
-60<T<-70 FCDP
-60<T<-70 2D-S
-70<T<-80 FCDP
-70<T<-80 2D-S
-80<T<-90 FCDP
-80<T<-90 2D-S


Average Mass PSDs for Temperature, RH$_{ice}$ > 100
Mass (mg L^{-1}μm^{-1})
Maximum Size (μm)

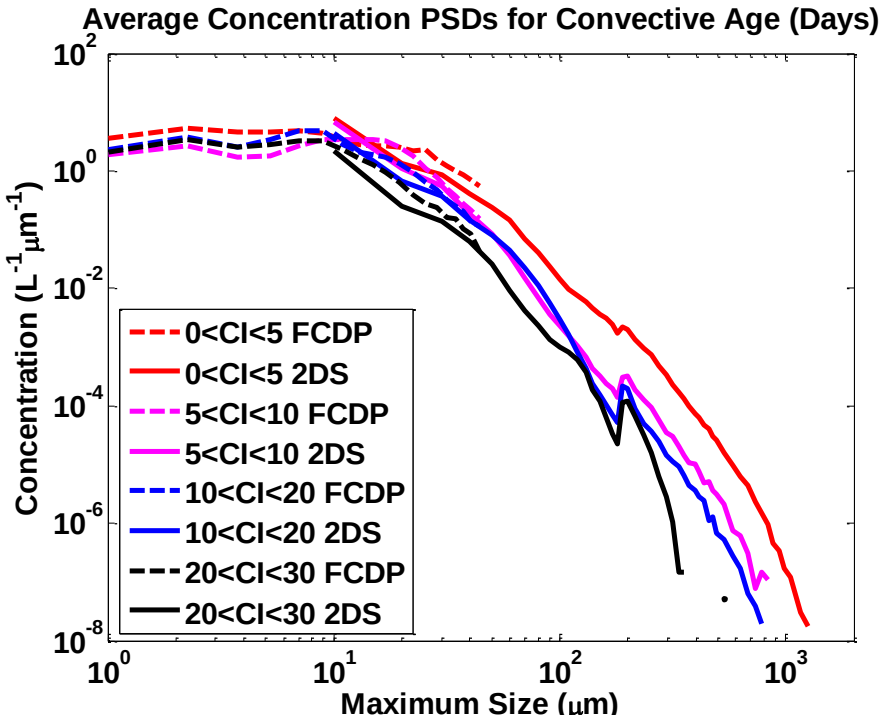

All CPI Habits for Temperature, RH$_{ice}$ < 100
% Occurrence
Temperature (^{o}C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

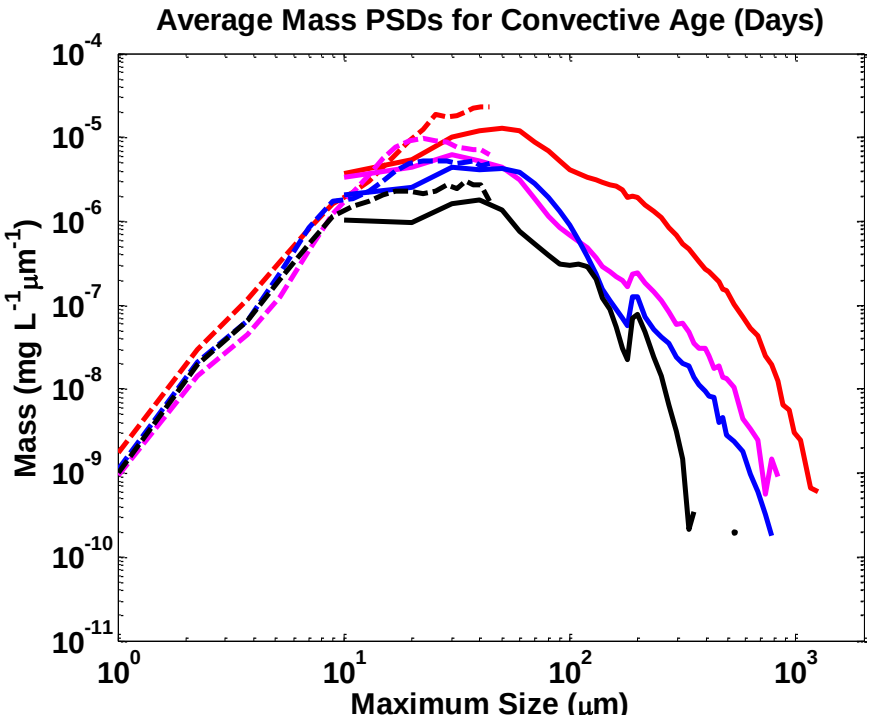

Faceted CPI Habits for Temperature, RH$_{ice}$ < 100
% Occurrence
Temperature (^{o}C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
column
plate
rosette
bud ros

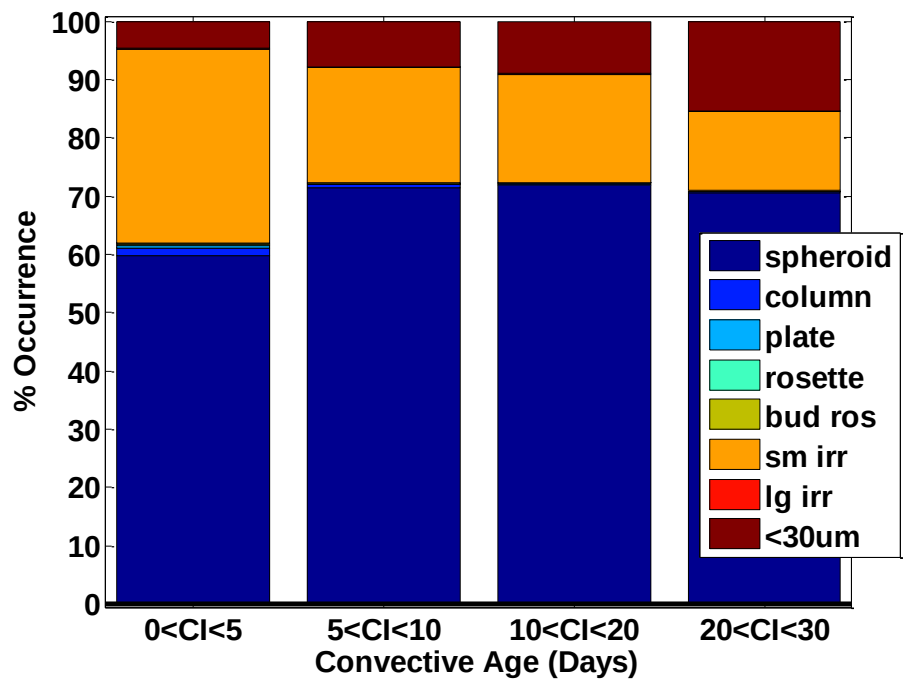

All CPI Habits for Temperature, RH$_{ice}$ > 100
% Occurrence
Temperature (^{o}C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

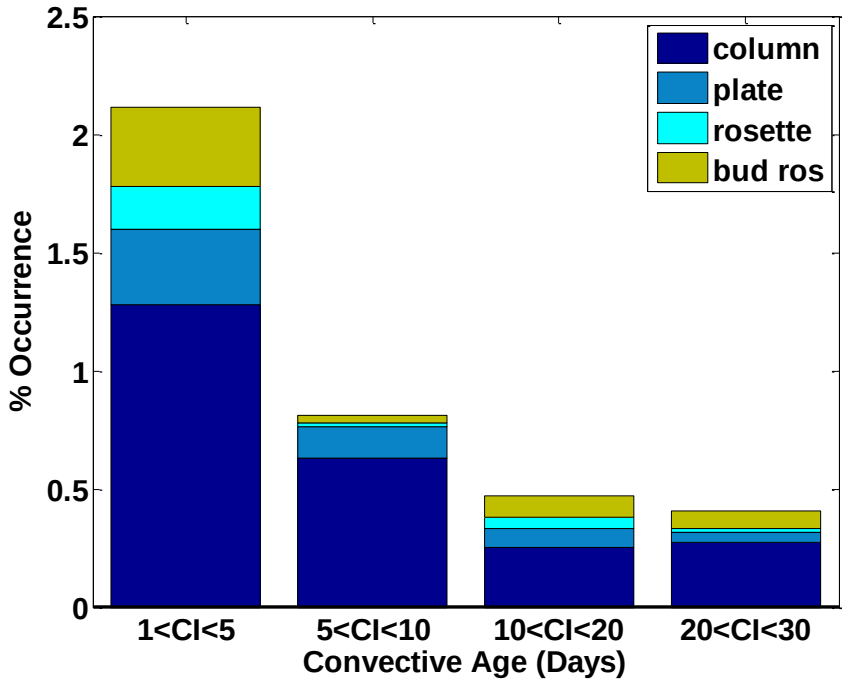

Faceted CPI Habits for Temperature, RH$_{ice}$ > 100
% Occurrence
Temperature (^{o}C)
-40<T<-60
-60<T<-70
-70<T<-80
-80<T<-90
column
plate
rosette
bud ros

How do particle concentration, mass, size and shape vary with ***age since convection***?


Average Concentration PSDs for Convective Age (Days)
Concentration (L-1μm-1)
Maximum Size (μm)
0<CI<5 FCDP
0<CI<5 2DS
5<CI<10 FCDP
5<CI<10 2DS
10<CI<20 FCDP
10<CI<20 2DS
20<CI<30 FCDP
20<CI<30 2DS

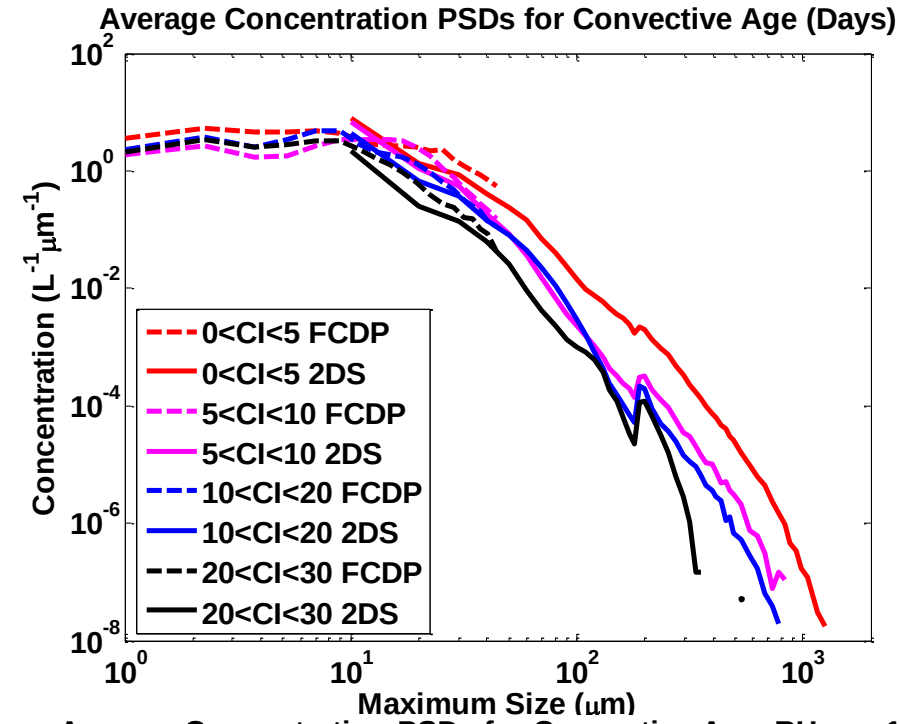

Average Mass PSDs for Convective Age (Days)
Mass (mg L-1μm-1)
Maximum Size (μm)

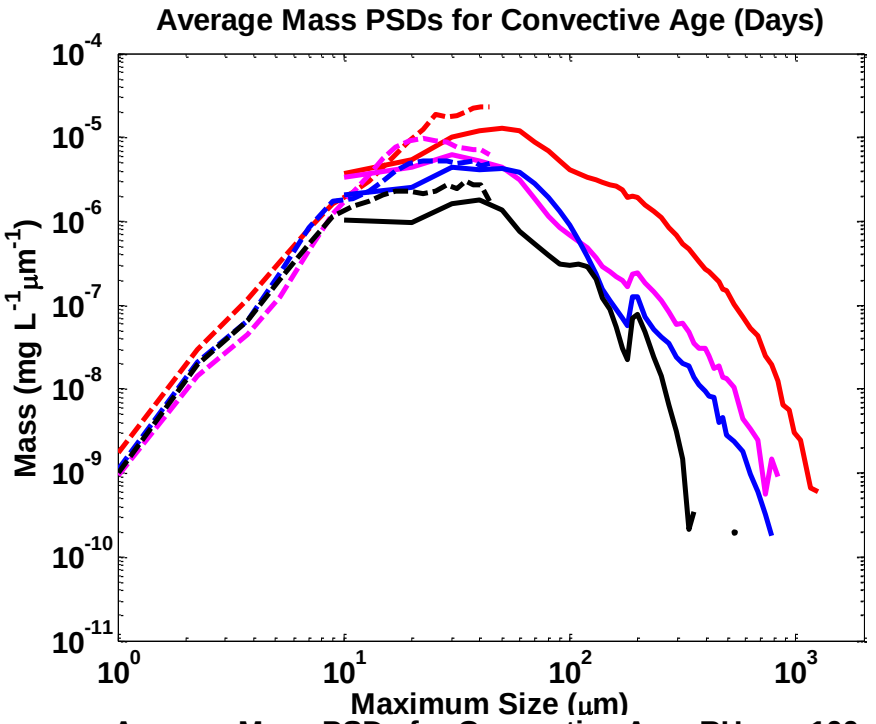

All CPI Habits for Convective Age
% Occurrence
0<CI<5
5<CI<10
10<CI<20
20<CI<30
Convective Age (Days)
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um

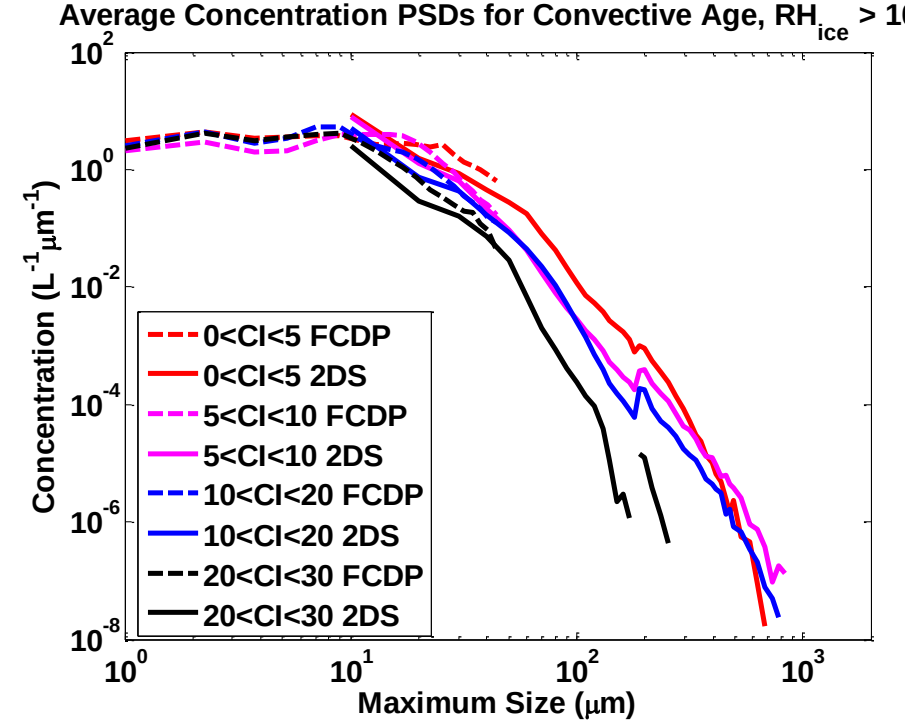

Faceted CPI Habits for Convective Age
% Occurrence
1<CI<5
5<CI<10
10<CI<20
20<CI<30
Convective Age (Days)
column
plate
rosette
bud ros

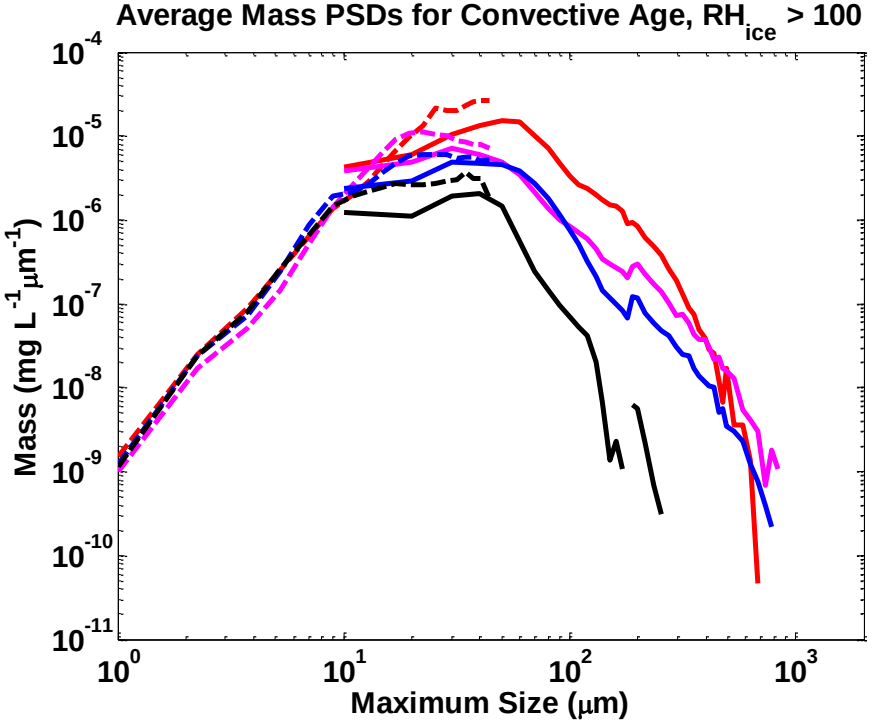
How do particle concentration, mass, size and shape vary with

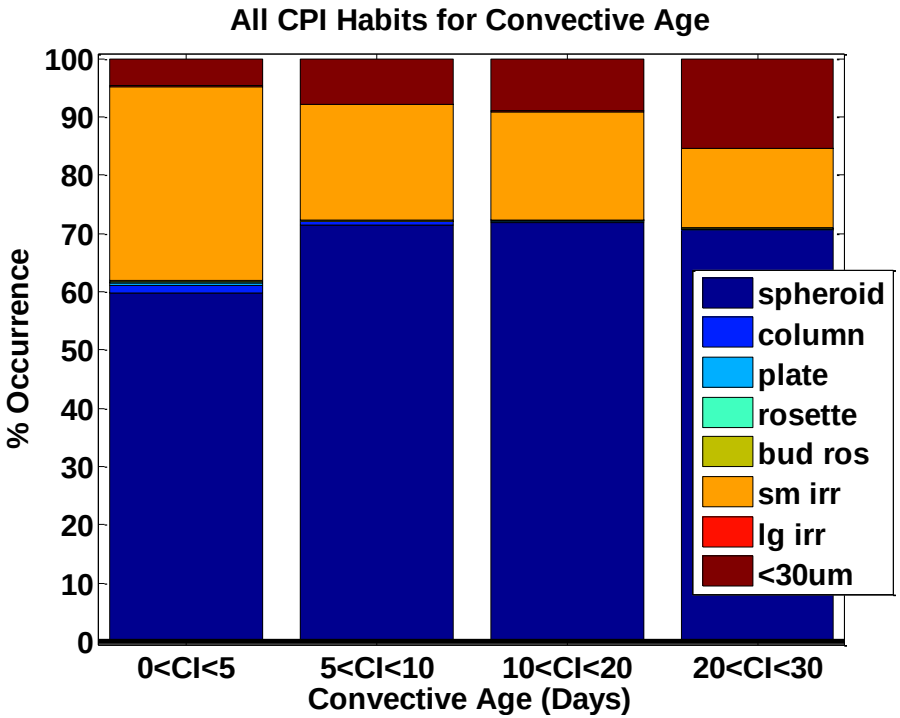
age since convection *when* ***supersaturated***?

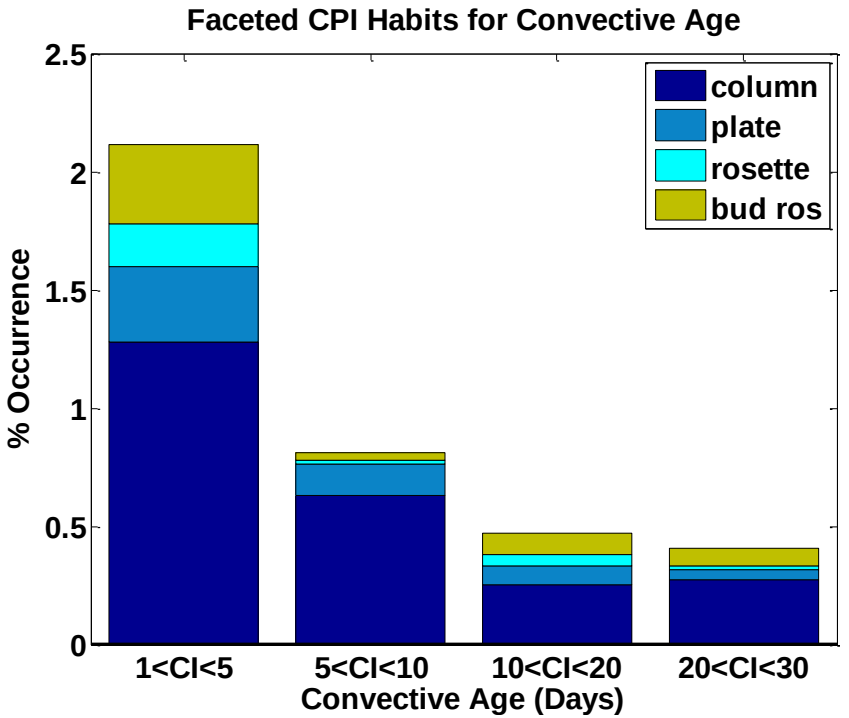

Average Concentration PSDs for Convective Age (Days)
Concentration (L^{-1}μm^{-1})
Maximum Size (μm)
0<CI<5 FCDP
0<CI<5 2DS
5<CI<10 FCDP
5<CI<10 2DS
10<CI<20 FCDP
10<CI<20 2DS
20<CI<30 FCDP
20<CI<30 2DS

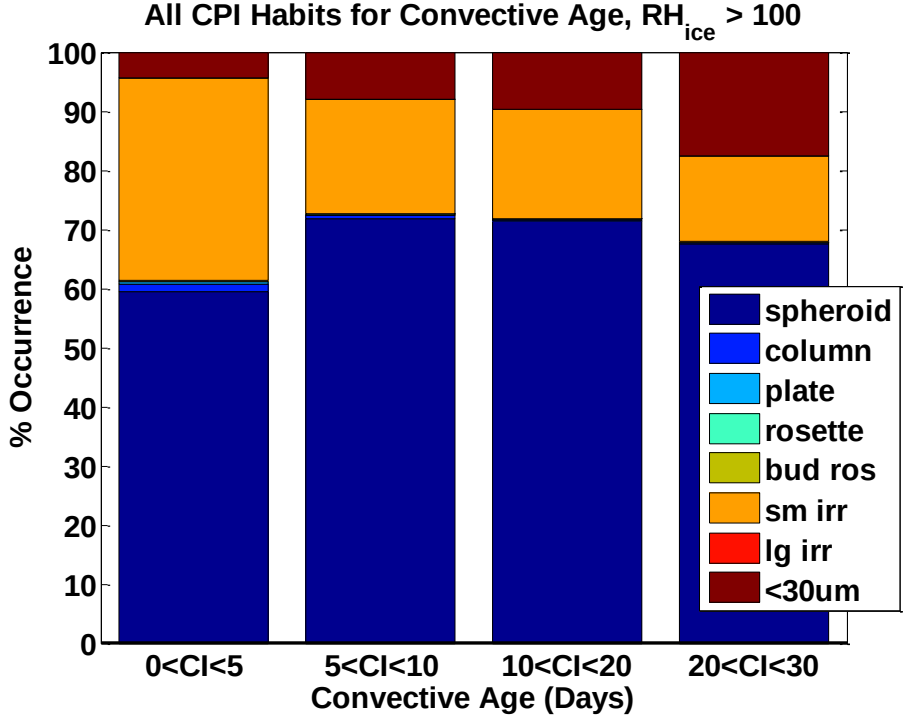

Average Mass PSDs for Convective Age (Days)
Mass (mg L^{-1}μm^{-1})
Maximum Size (μm)

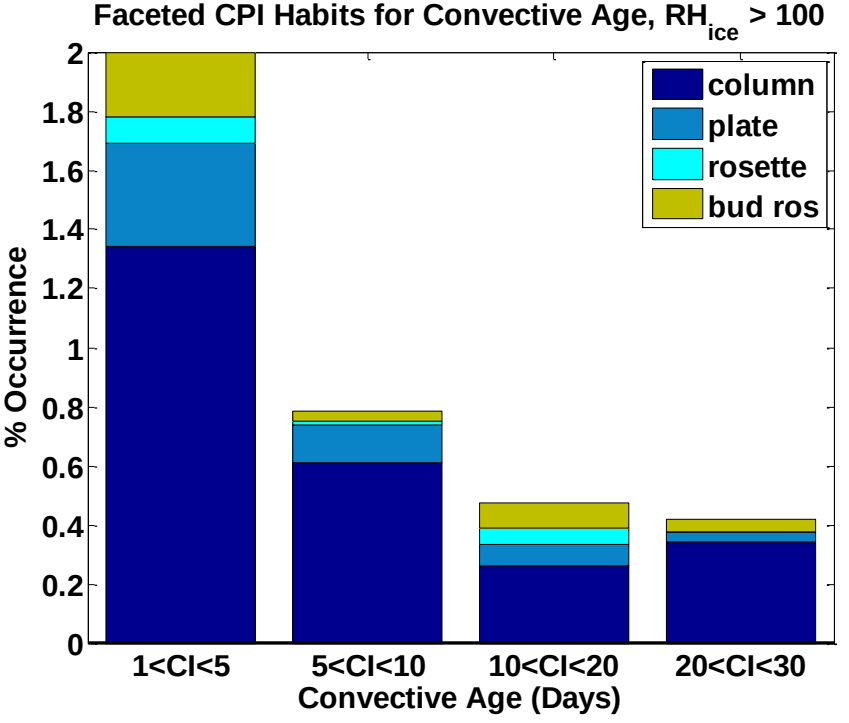

Average Concentration PSDs for Convective Age, RH$_{ice}$ > 100
Concentration (L^{-1}μm^{-1})
Maximum Size (μm)
0<CI<5 FCDP
0<CI<5 2DS
5<CI<10 FCDP
5<CI<10 2DS
10<CI<20 FCDP
10<CI<20 2DS
20<CI<30 FCDP
20<CI<30 2DS


Average Mass PSDs for Convective Age, RH$_{ice}$ > 100
Mass (mg L^{-1}μm^{-1})
Maximum Size (μm)


All CPI Habits for Convective Age
% Occurrence
Convective Age (Days)
0<CI<5
5<CI<10
10<CI<20
20<CI<30
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um


Faceted CPI Habits for Convective Age
% Occurrence
Convective Age (Days)
1<CI<5
5<CI<10
10<CI<20
20<CI<30
column
plate
rosette
bud ros


All CPI Habits for Convective Age, RHice > 100
% Occurrence
Convective Age (Days)
0<CI<5
5<CI<10
10<CI<20
20<CI<30
spheroid
column
plate
rosette
bud ros
sm irr
lg irr
<30um


Faceted CPI Habits for Convective Age, RHice > 100
% Occurrence
Convective Age (Days)
1<CI<5
5<CI<10
10<CI<20
20<CI<30
column
plate
rosette
bud ros

Summary

- **Habit classification**
  - Predominantly spheroid, followed by small irregulars
  - Low percentages of faceted habits (columns, plates, rosettes, budding rosettes)
    - Faceted habits had highest percentages when separated by temperature
- **Temperature and Altitude**
  - Highest concentrations of the larger (> 50 μm) sized particles are found in the warmer temperature regions and lower altitudes (broader concentration and mass size distributions)
  - Percentages of spheroids & smallest (<30 μm) particles increase with decreasing temperature
  - Percentages of faceted habits & irregulars decrease with decreasing temperature (increasing altitude)
- **Convective influence**
  - More recent convective influence correlates with slightly higher concentrations in the larger sized particles (slightly broader concentration and mass size distributions)
  - Percentages of smallest (<30 μm) particles increases with increasing time since convective influence
  - Percentages of faceted habits & irregulars decrease with increasing time since convective influence
- Trends hold with only small variation for under- vs super-saturated conditions

Future Work

- Include 2013 ATTREX FCDP and 2015 ATTREX/CAST Hawkeye analysis
- Habit size distributions
- Case studies comparing the microphysics lifecycle of cases with similar mesoscale features close to convection and downwind of convection