# Comparison of Simulated Hurricane Dorian CRTM Microwave Brightness Temperatures with GMI Observations

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Department of Meteorology and Atmospheric Science

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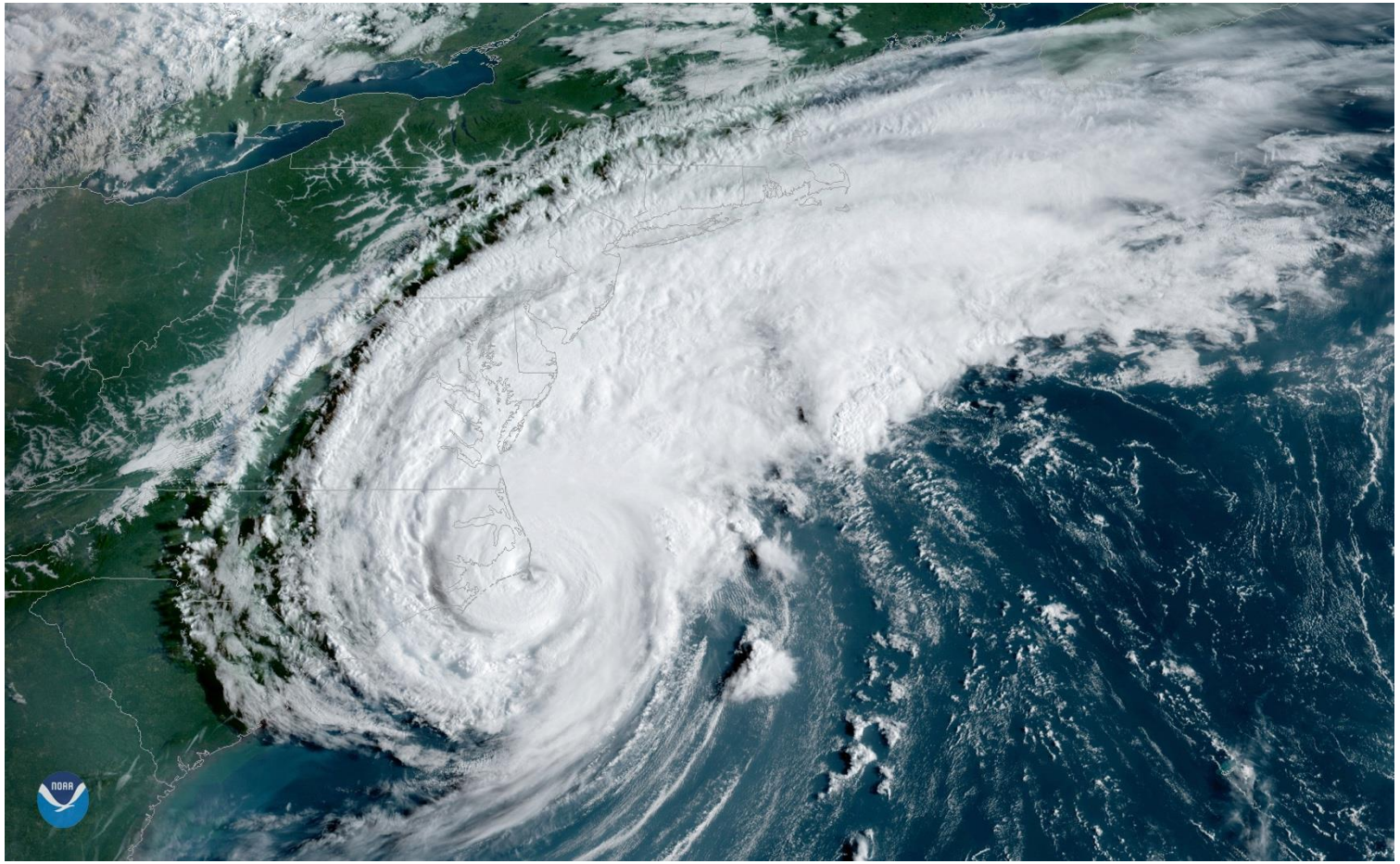
# Improving WRF simulation of a Hurricane

- WRF model
  - Bulk microphysics schemes estimate hydrometeors.

- Main uncertainty stems from the estimation of frozen hydrometeors (Ice, Snow, Graupel) in the eyewall and rainbands.

- Constraining the knowledge of ice particle type using a Radiative Transfer Model and Microwave Satellite Observations.

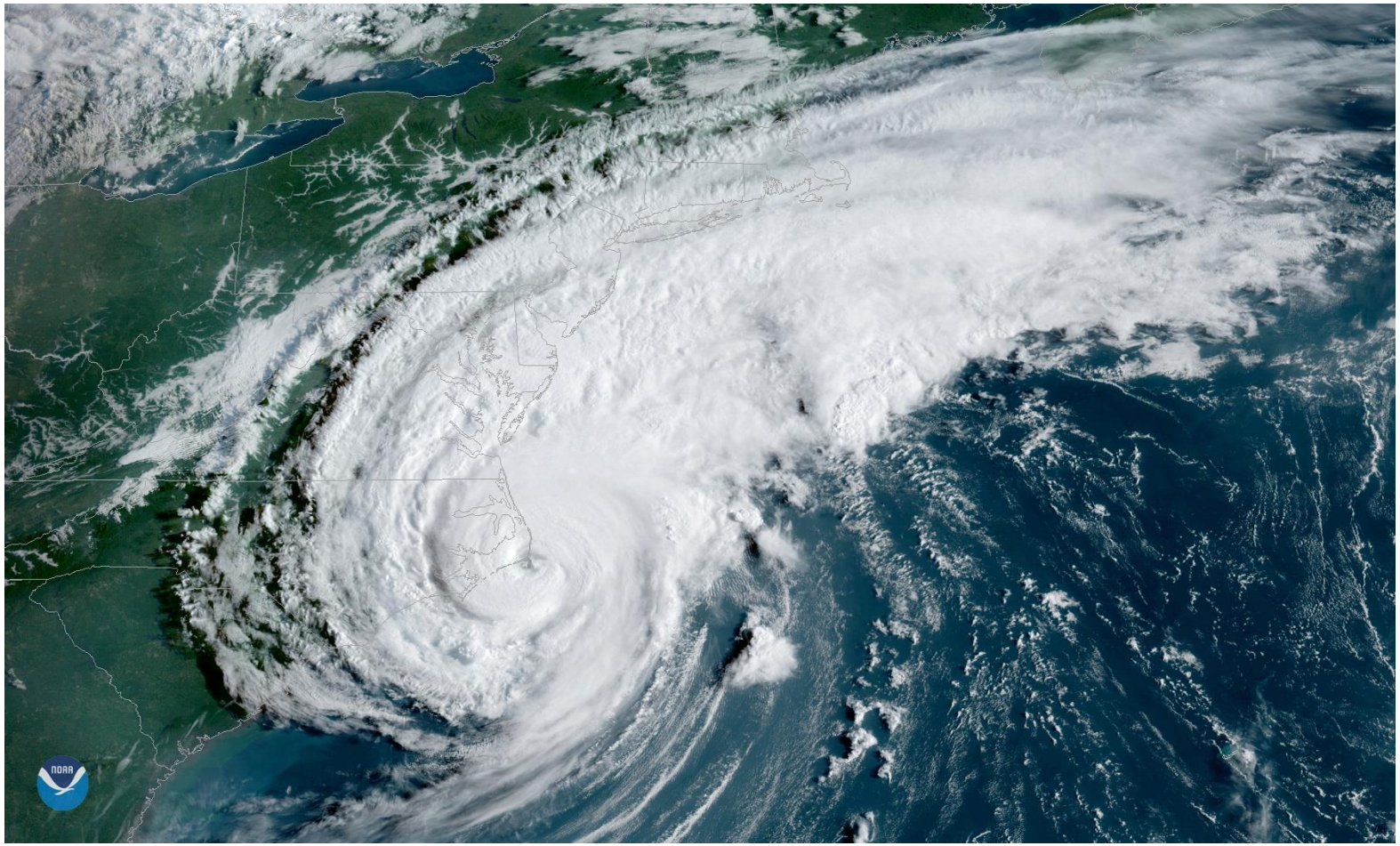
GOES Visible Image of Hurricane DORIAN



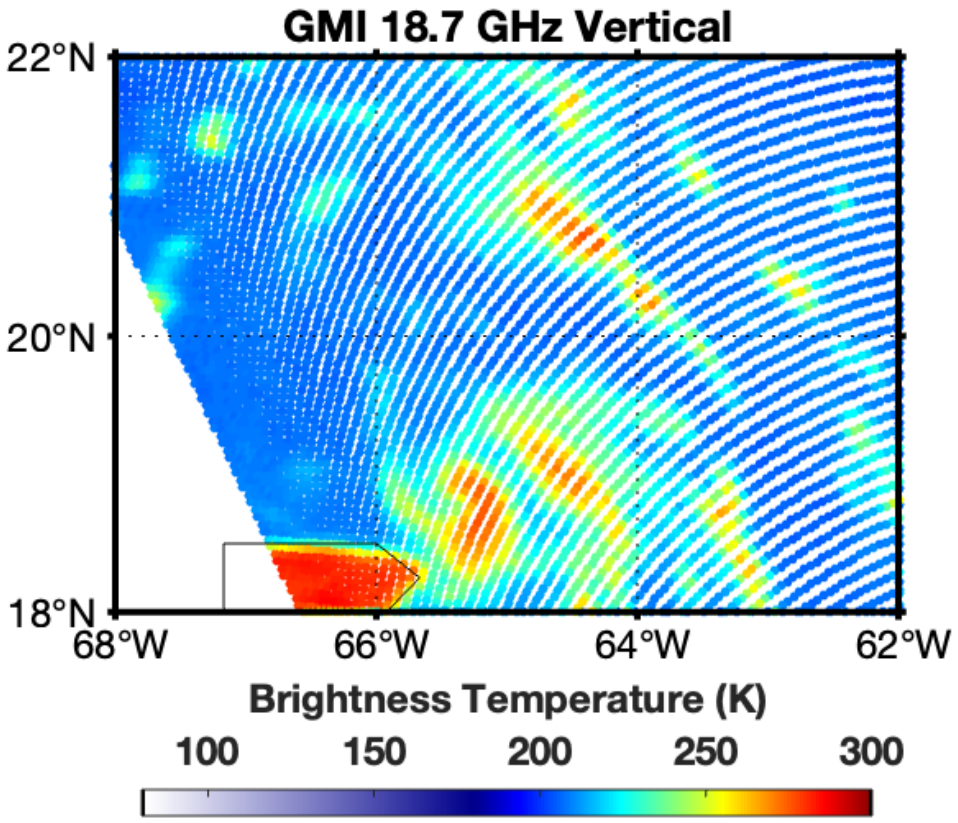
# Using Microwave Observation

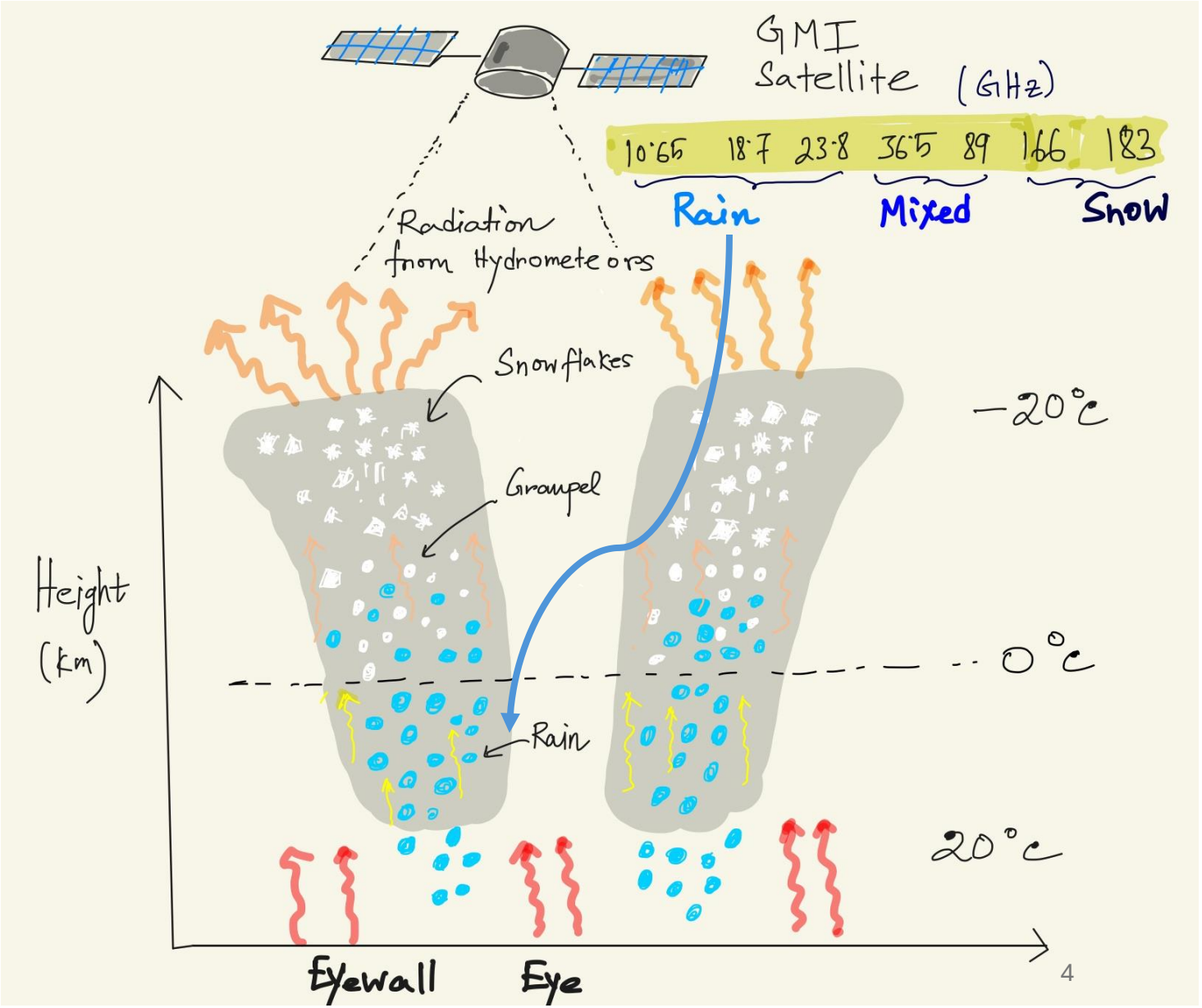
- How do the Microwave Channels measure Radiances at the different level of Hurricane eyewall and rainbands?

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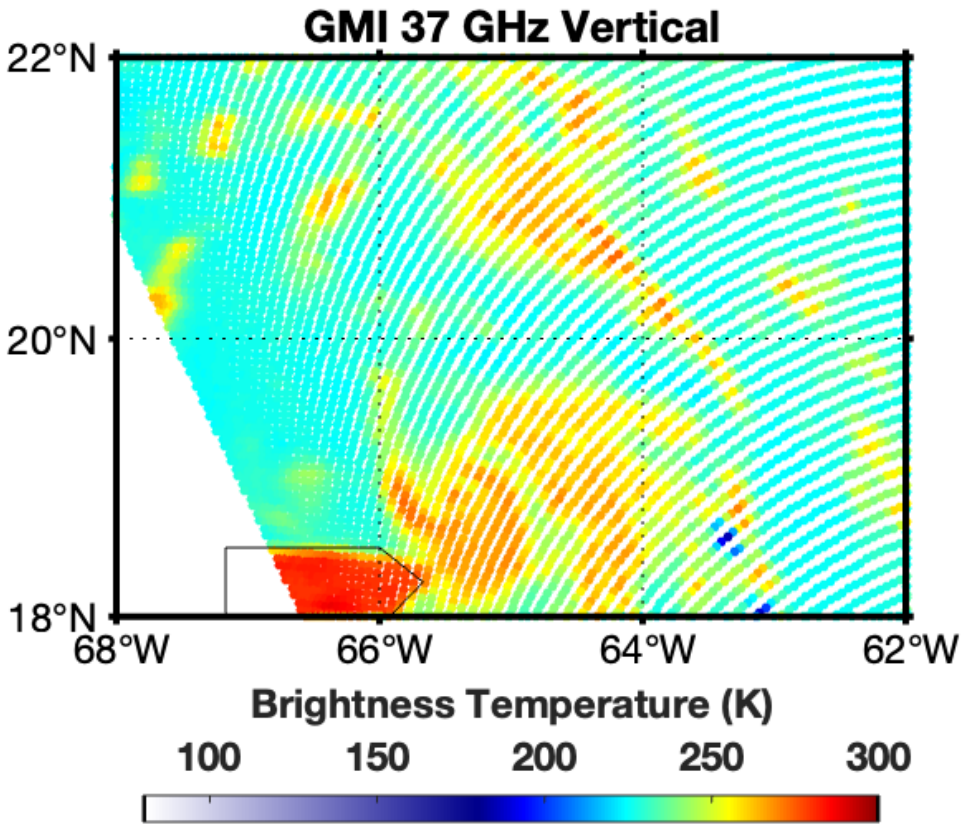


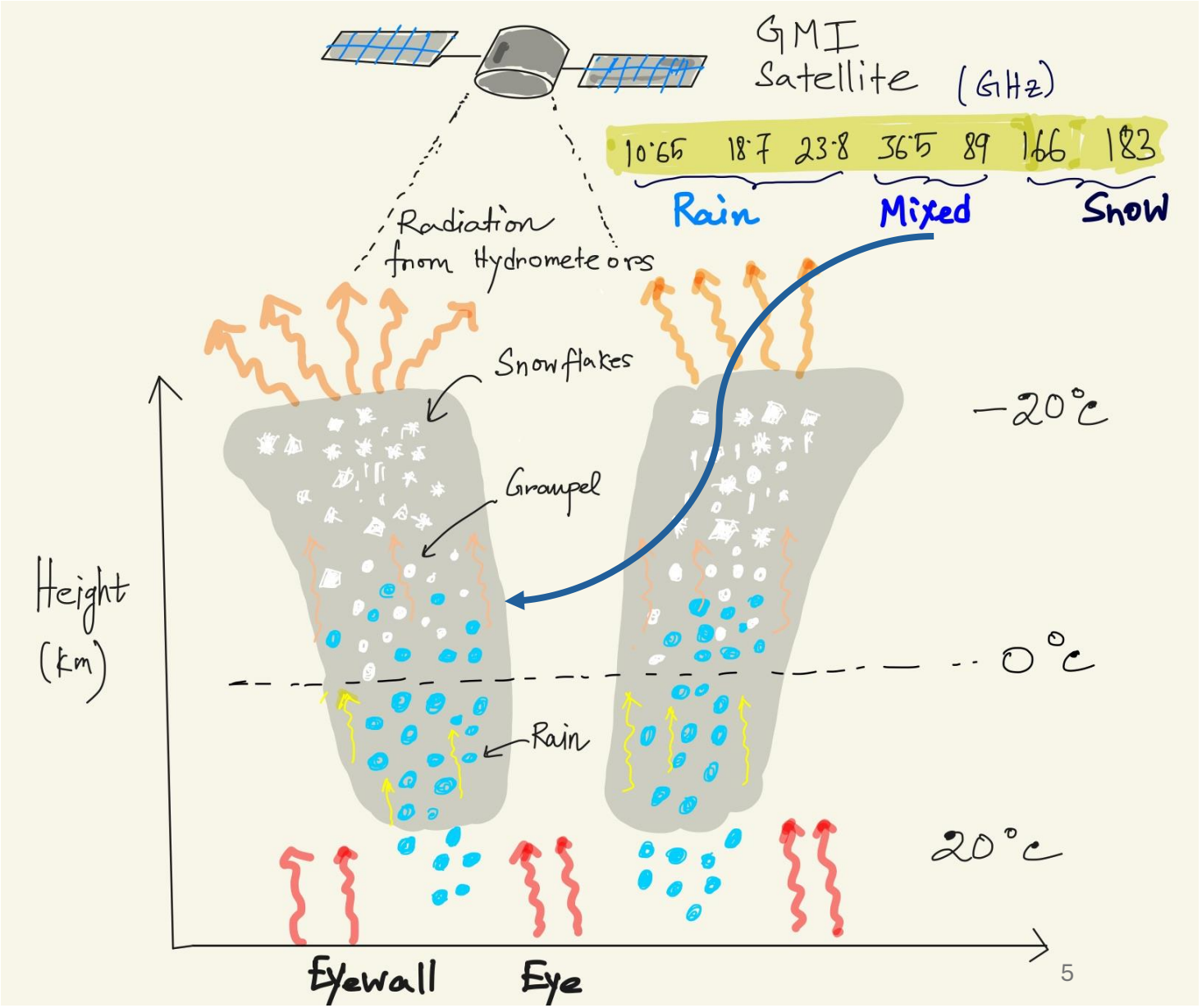
# GMI (GPM Microwave Imager) Observation



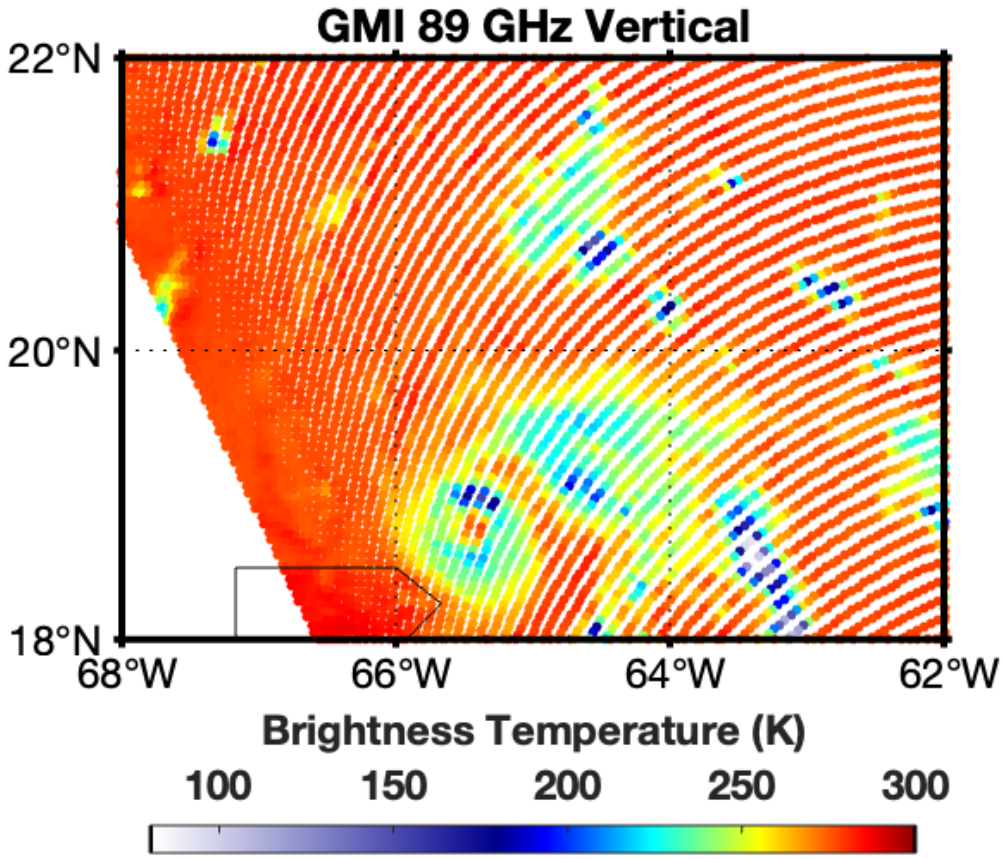



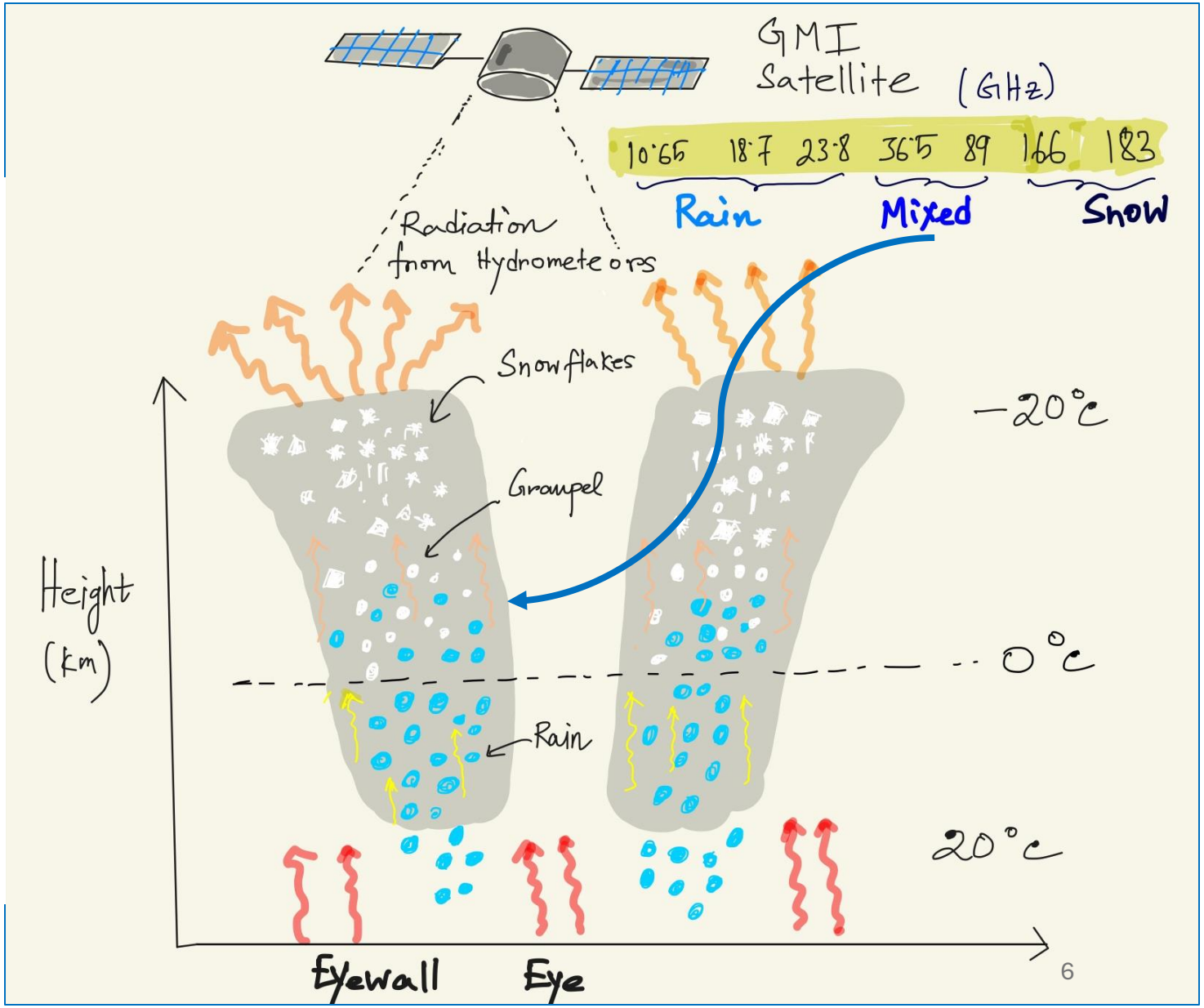
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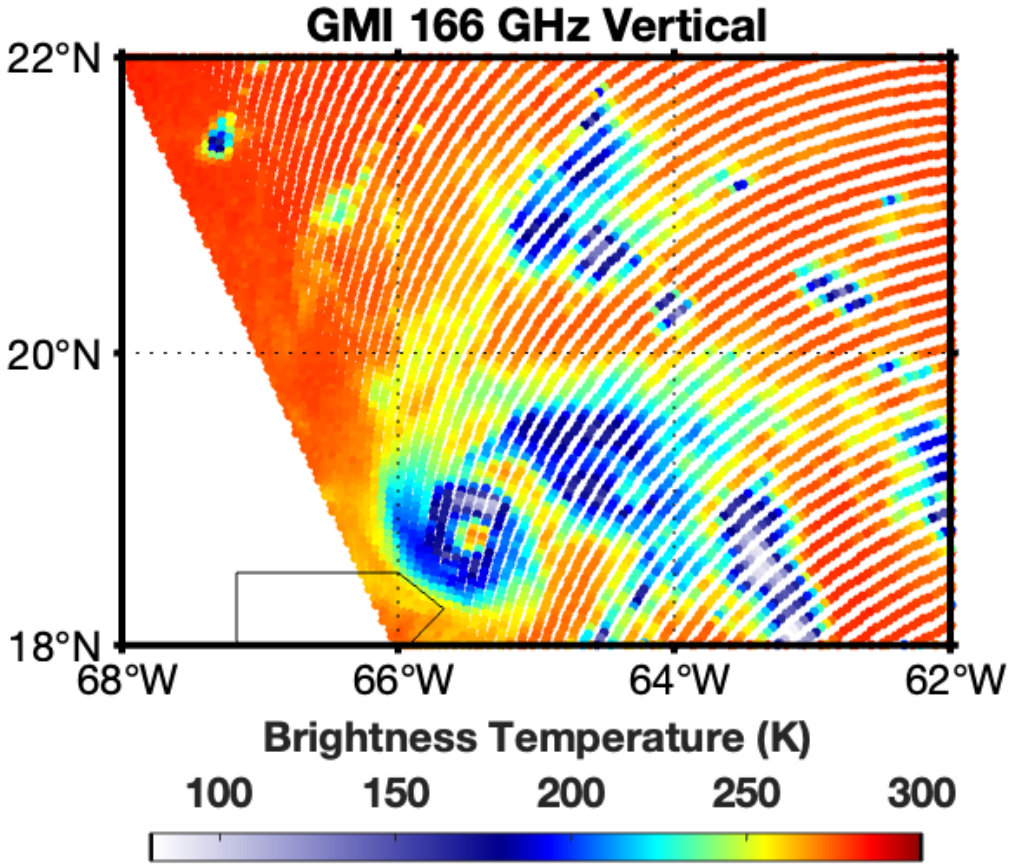



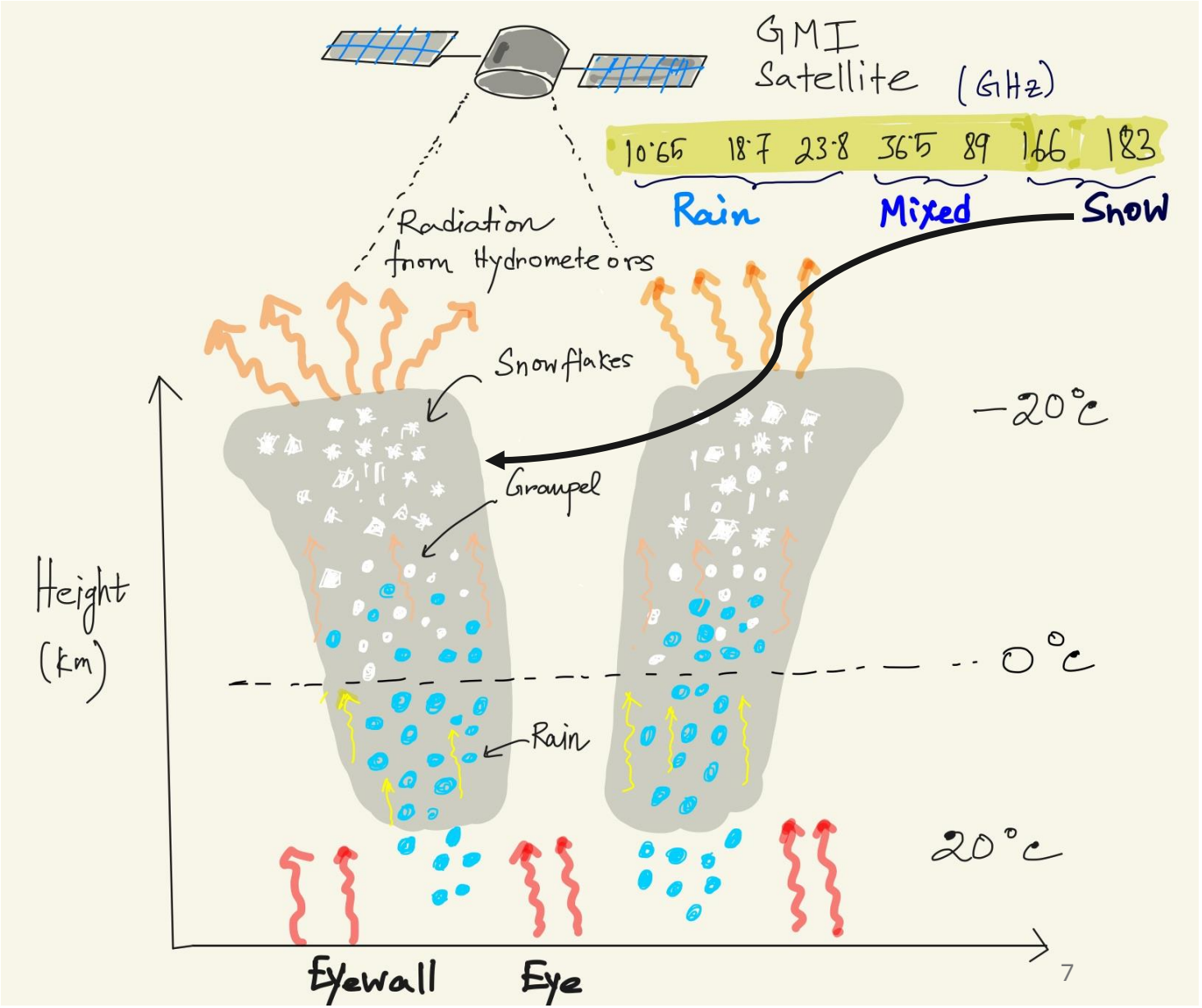
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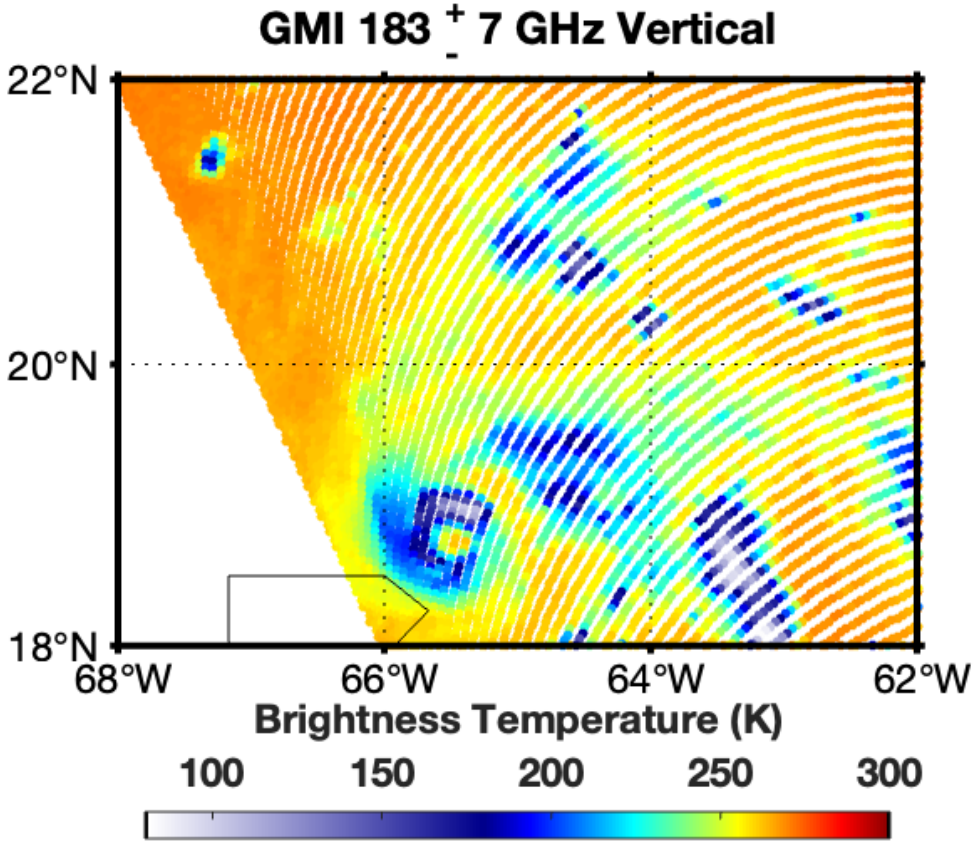



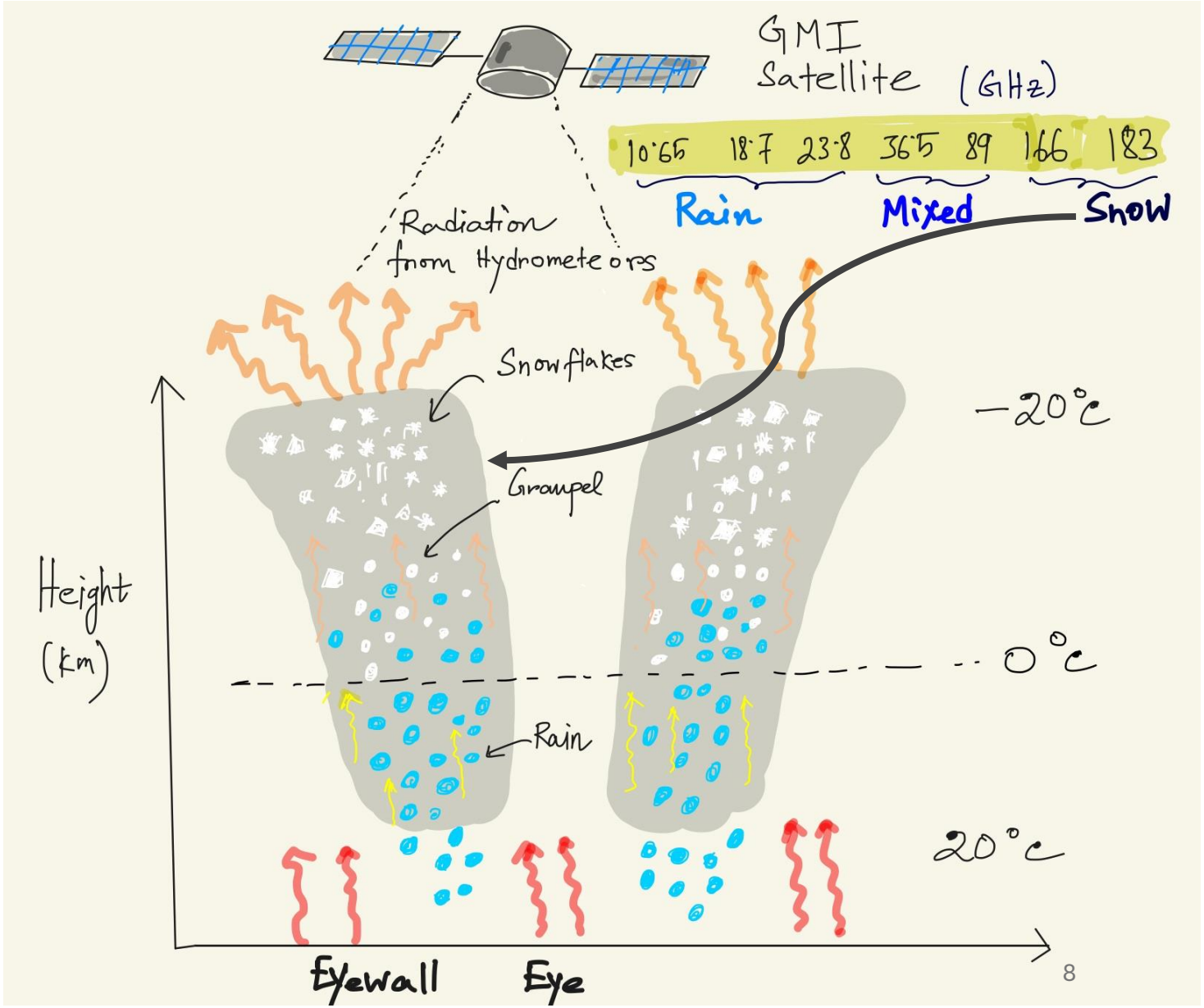
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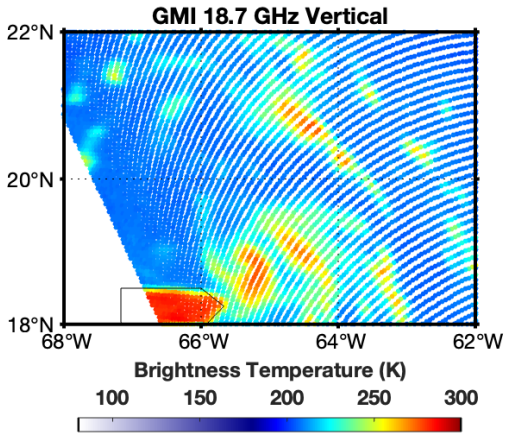



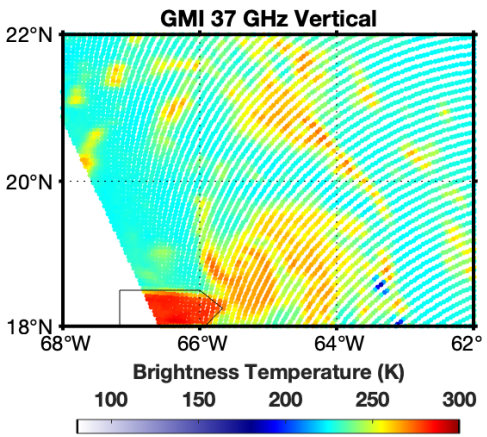
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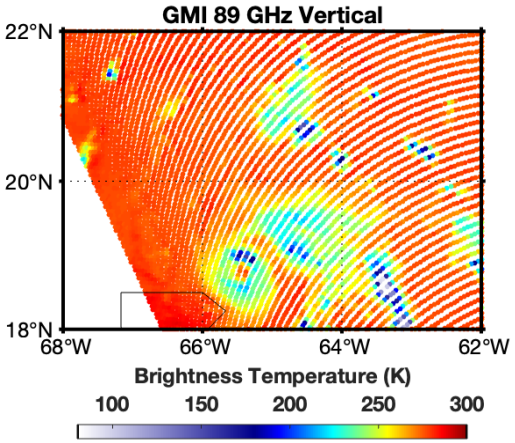


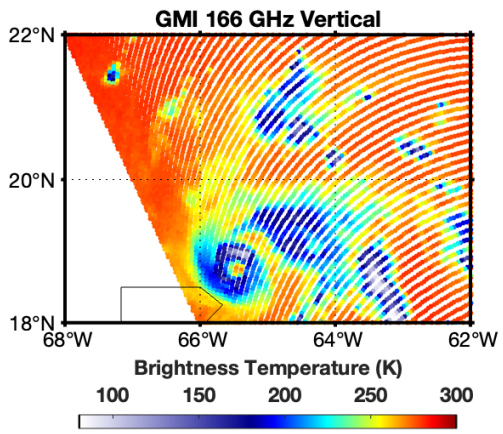



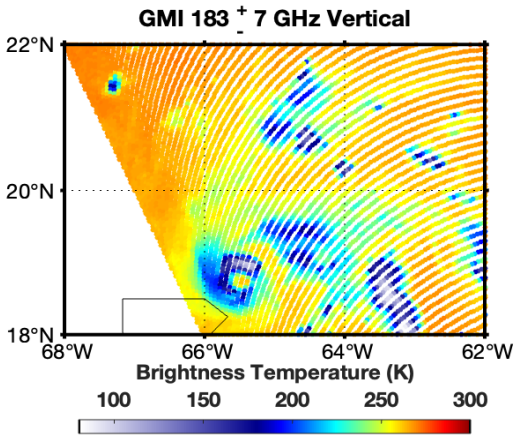
# How can we simulate Brightness Temperature?



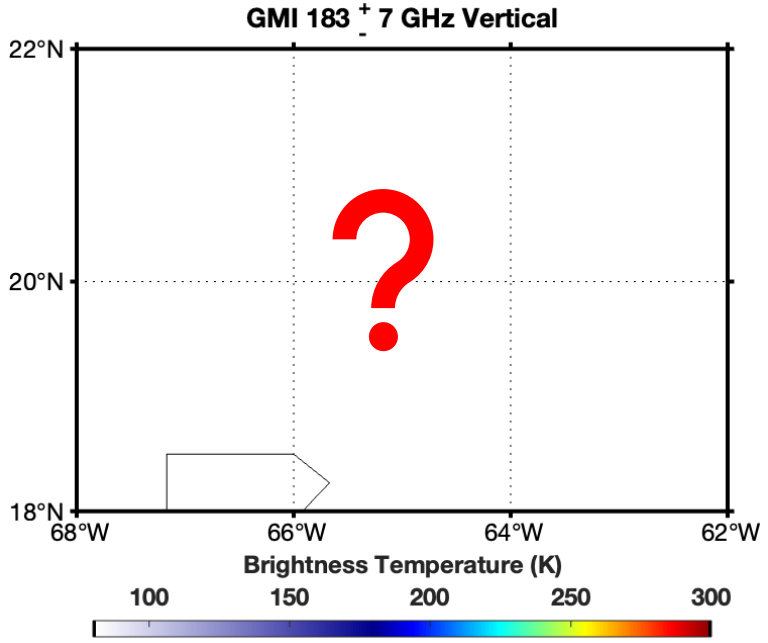




Simulation of Brightness Temperature



# WRF Output of Hurricane DORIAN

- 3-hour Forecasts of Hurricane Dorian from identical initial conditions.

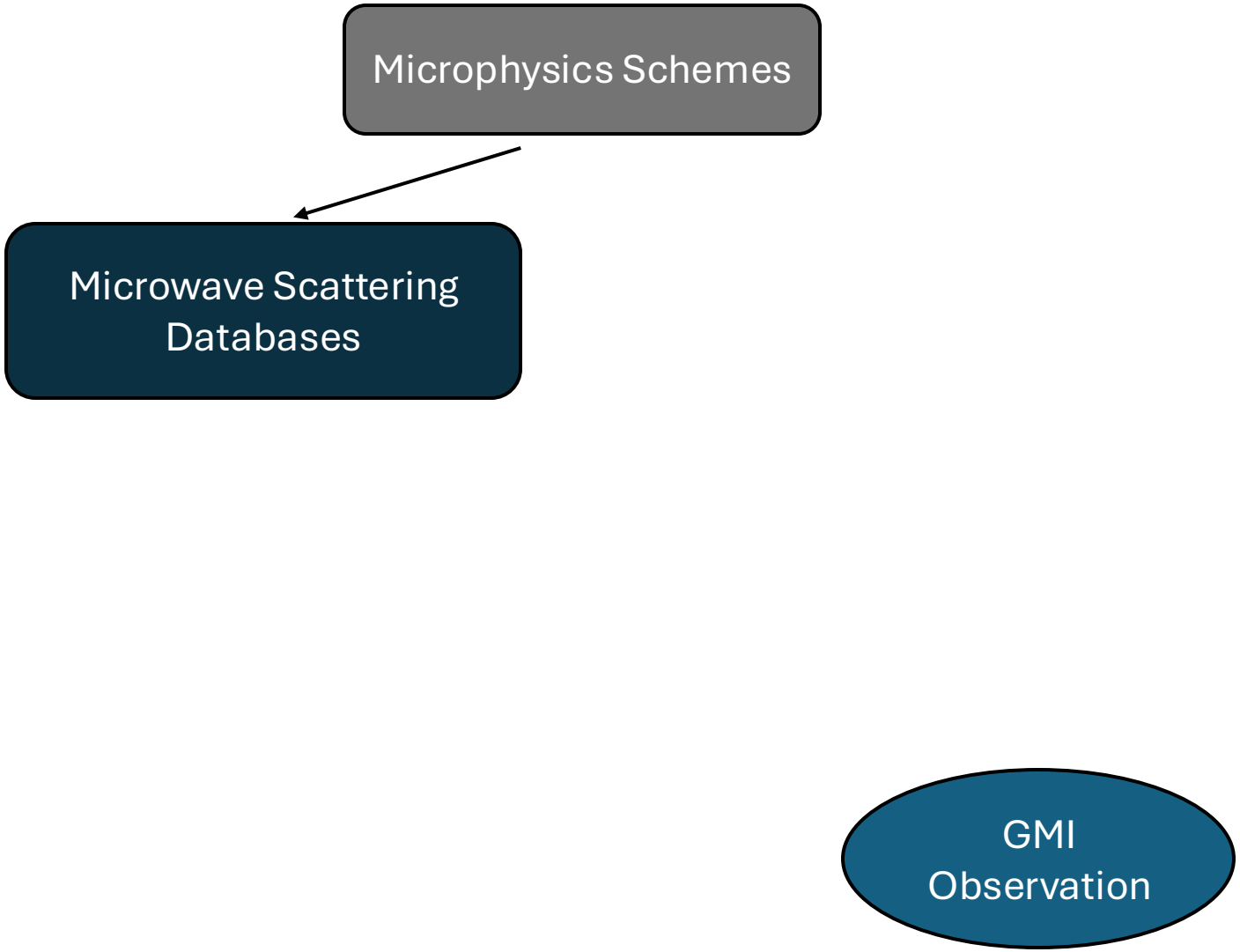
- Microphysics Schemes
  - WSM6, Thompson, NSSL

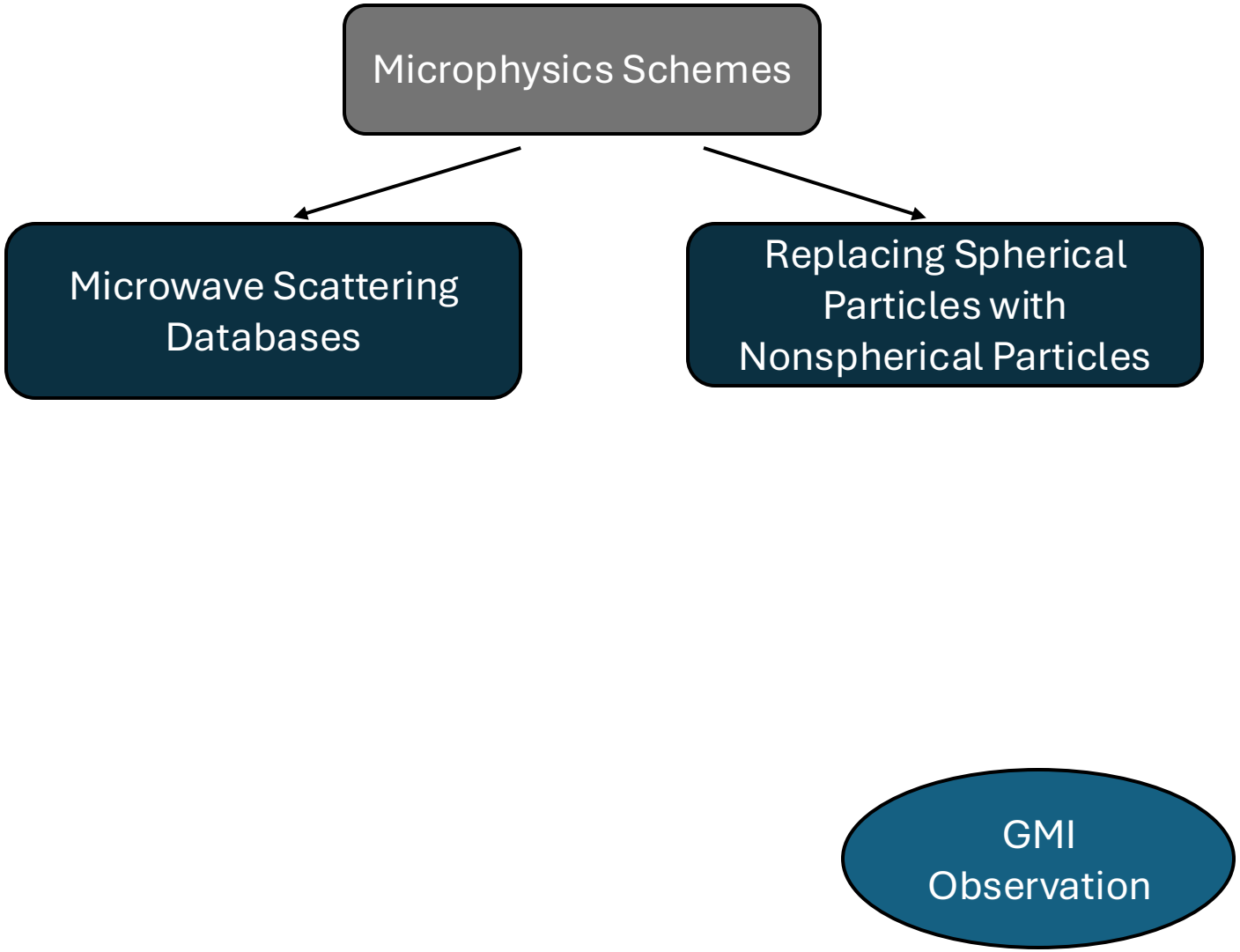
# Simulation of Brightness Temperature

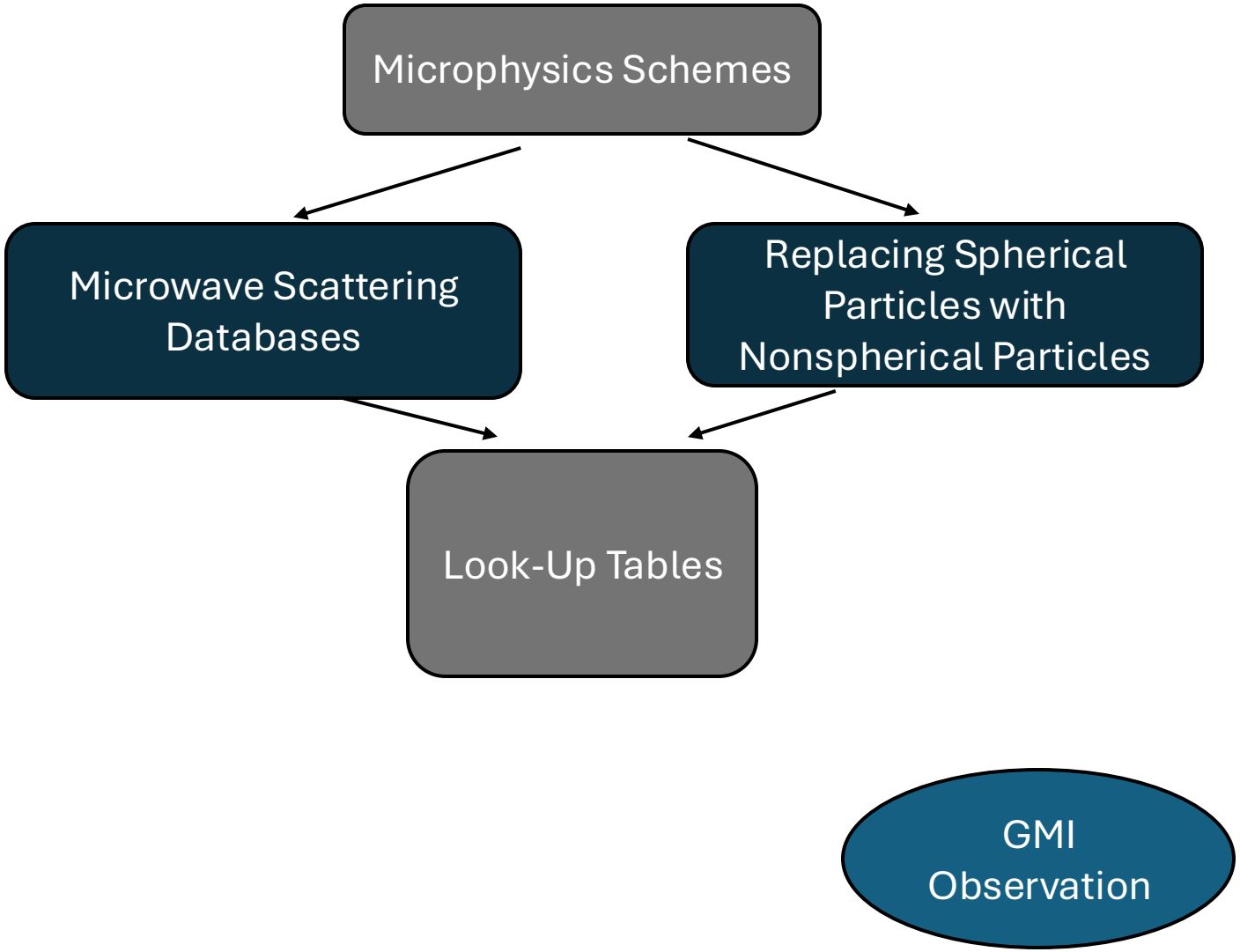
- Community Radiative Transfer Model (CRTM) is used to simulate upwelling radiance using WRF outputs.
- CRTM requires Cloud Optical Properties for simulating radiance.
- Cloud Optical Properties are incorporated in Look-Up (LUT) tables.

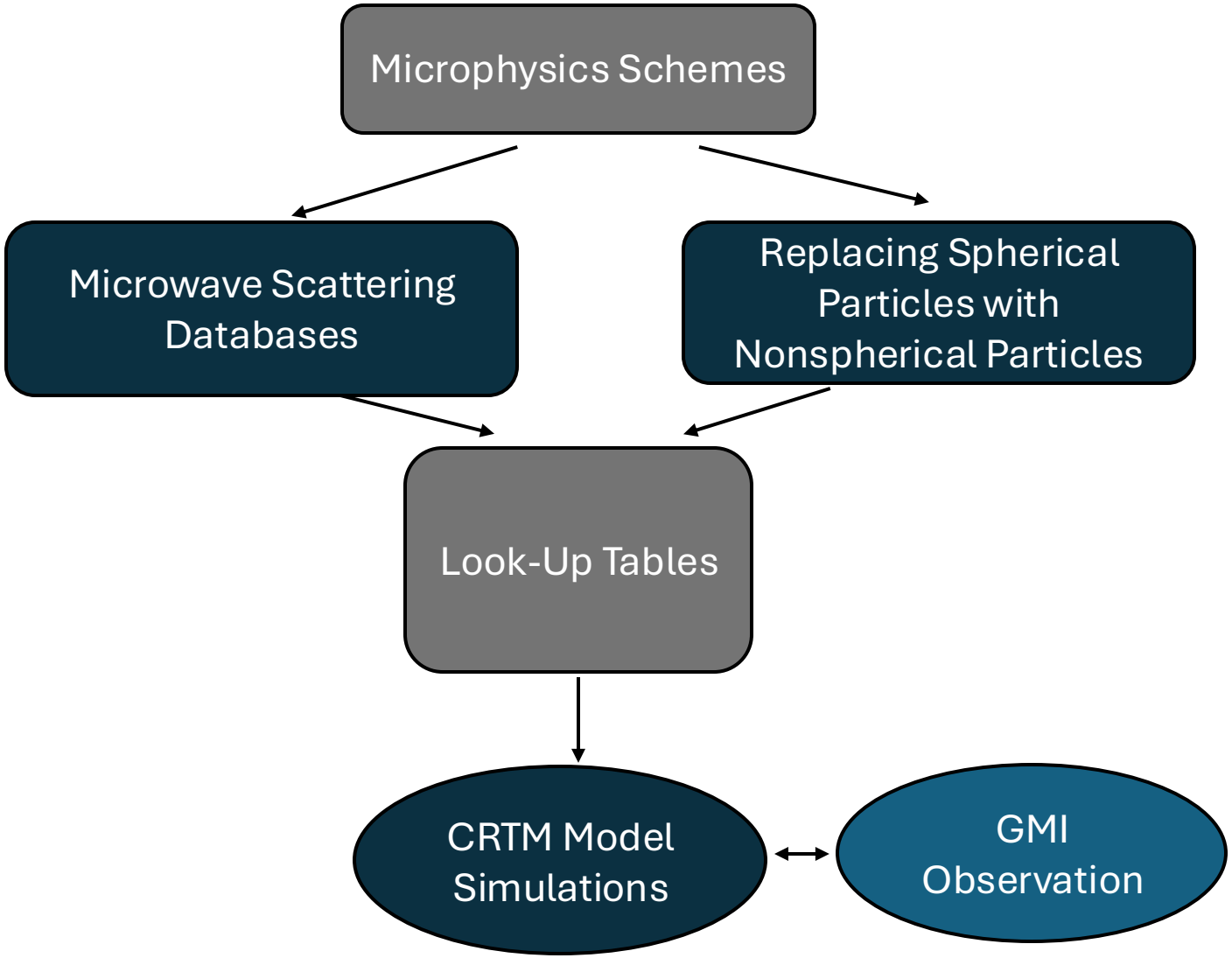
Microphysics Schemes

GMI
Observation


Microphysics Schemes
Microwave Scattering Databases
GMI Observation


Microphysics Schemes
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Replacing Spherical Particles with Nonspherical Particles
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Microphysics Schemes
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Look-Up Tables
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Microphysics Schemes
Microwave Scattering Databases
Replacing Spherical Particles with Nonspherical Particles
Look-Up Tables
CRTM Model Simulations
GMI Observation

# Microphysics Schemes

- WSM6

  Rain, Snow, Graupel (Exponential Distribution)

- Thompson

  Rain, Graupel (Exponential Distribution)

  Snow (Summation of Exponential and Gamma Distribution)

- NSSL

  Rain and Snow (Gamma Distribution)

  Graupel (Exponential Distribution)

# Bulk Optical Property

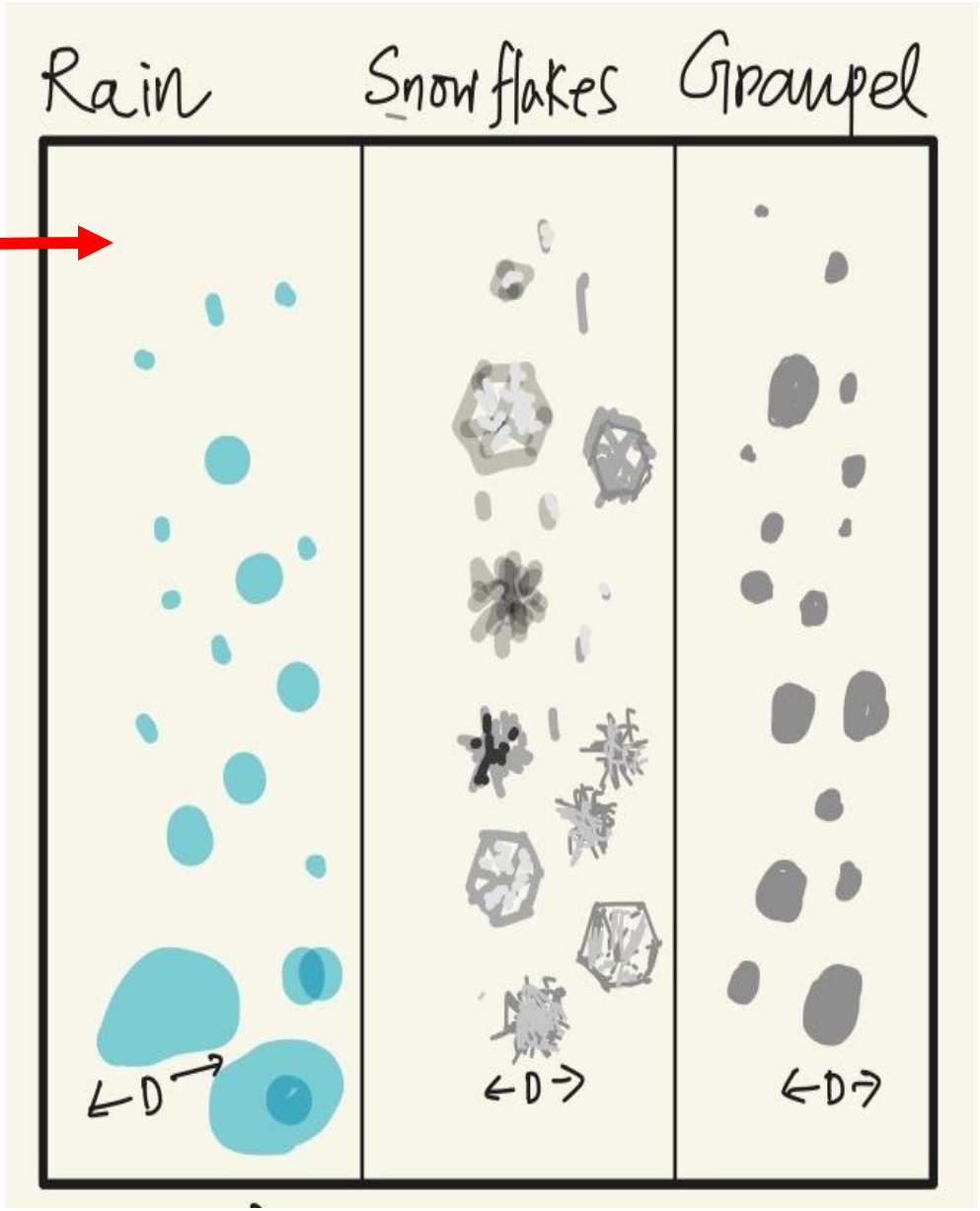
- Hydrometeor Bulk Optical Properties are developed as a function of Effective Radius (*Re*).
- *Re* is related to Particle Size Distribution and Particle Size.
- Different Particle Size Distribution affects the Bulk Optical Properties.

# Effective Radius (*Re*)

- $Re = \frac{1}{2} \frac{\int D^3 N(D) dD}{\int D^2 N(D) dD}$

- *N(D)* is hydrometeor size distribution

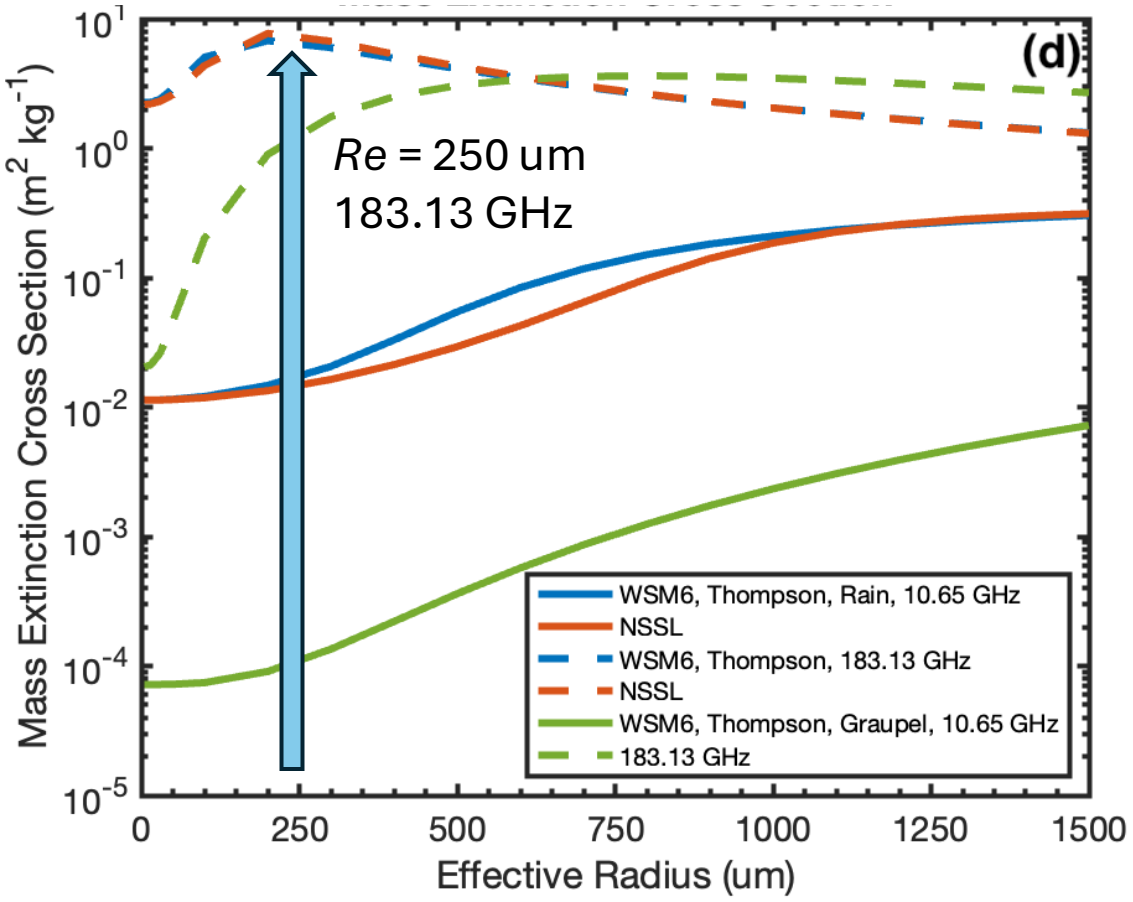
- $N(D) = N_0 e^{-\lambda D}$ (WSM6)



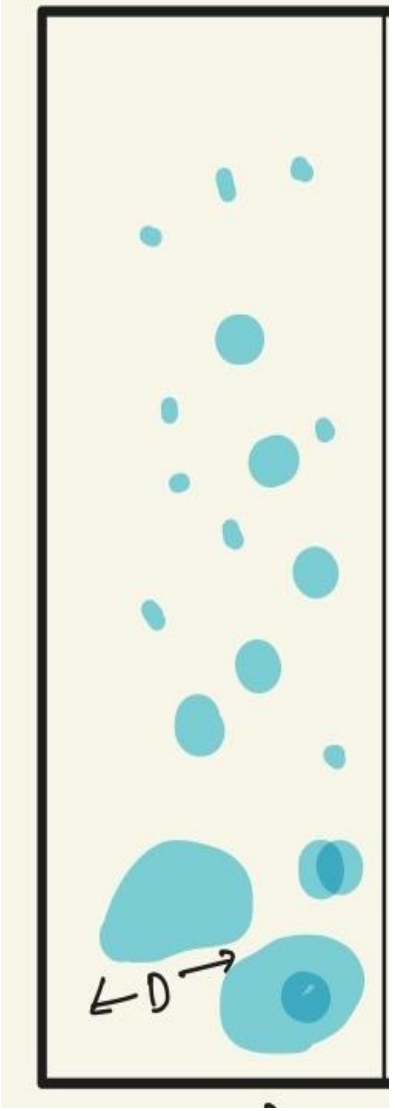

Rain Re Snow Re Graupel Re

# Re effect on Extinction by Rain

$$\sigma_{me} = \frac{\int \sigma_e(D)\, N(D)\, dD}{\int m(D) N(D)\, dD}$$



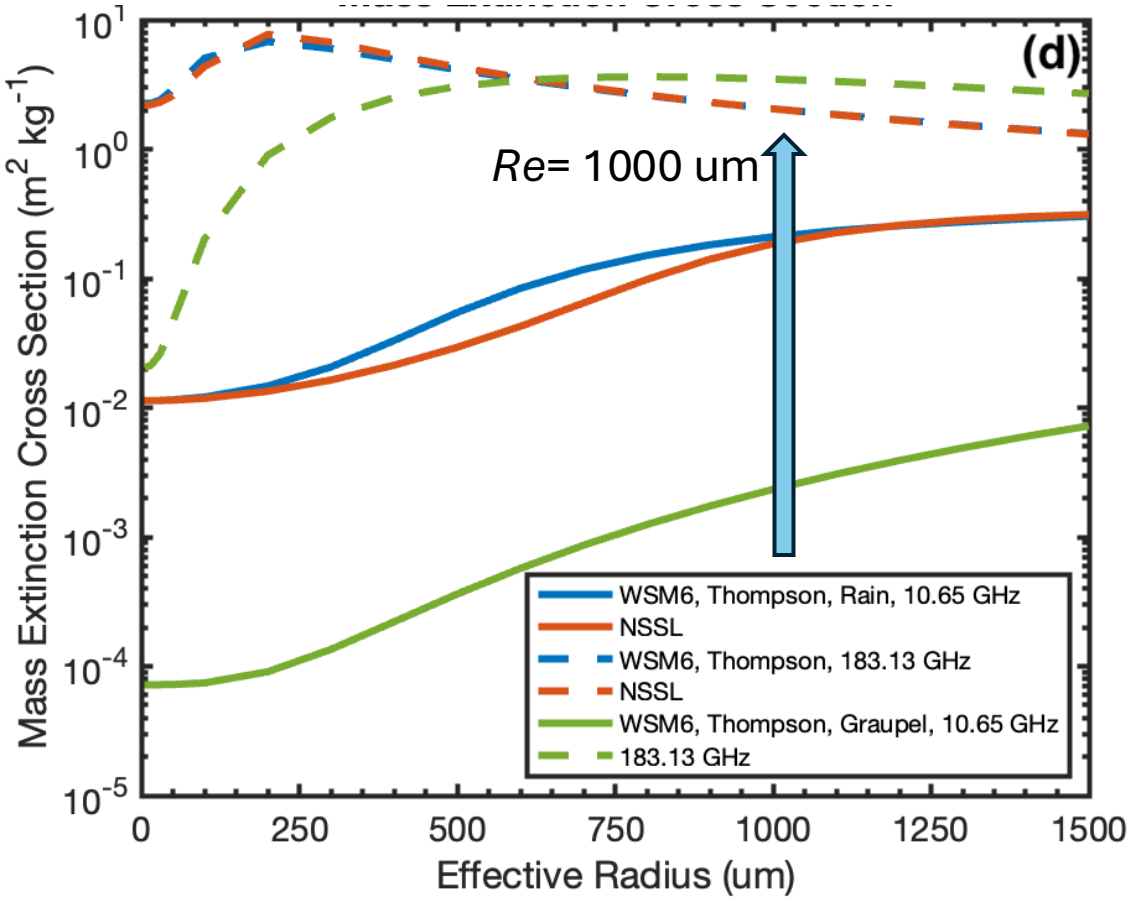

*Re* = 250 um



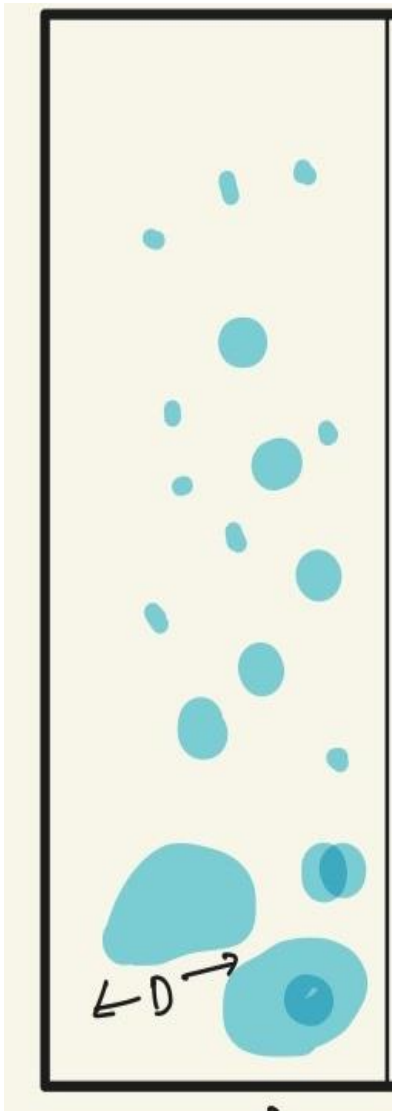
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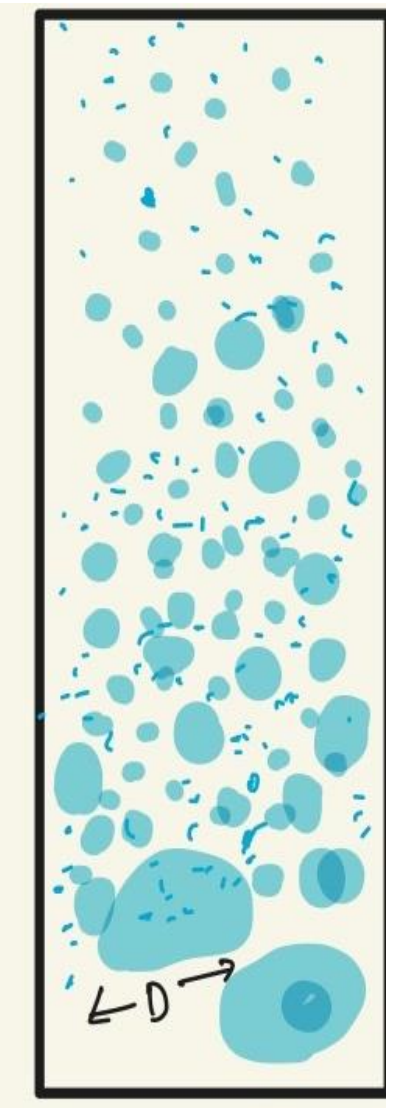
m(D)- mass




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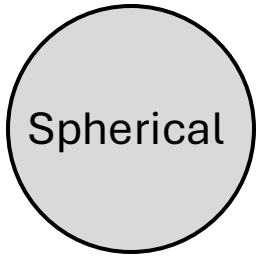



*Re* = 1000 um

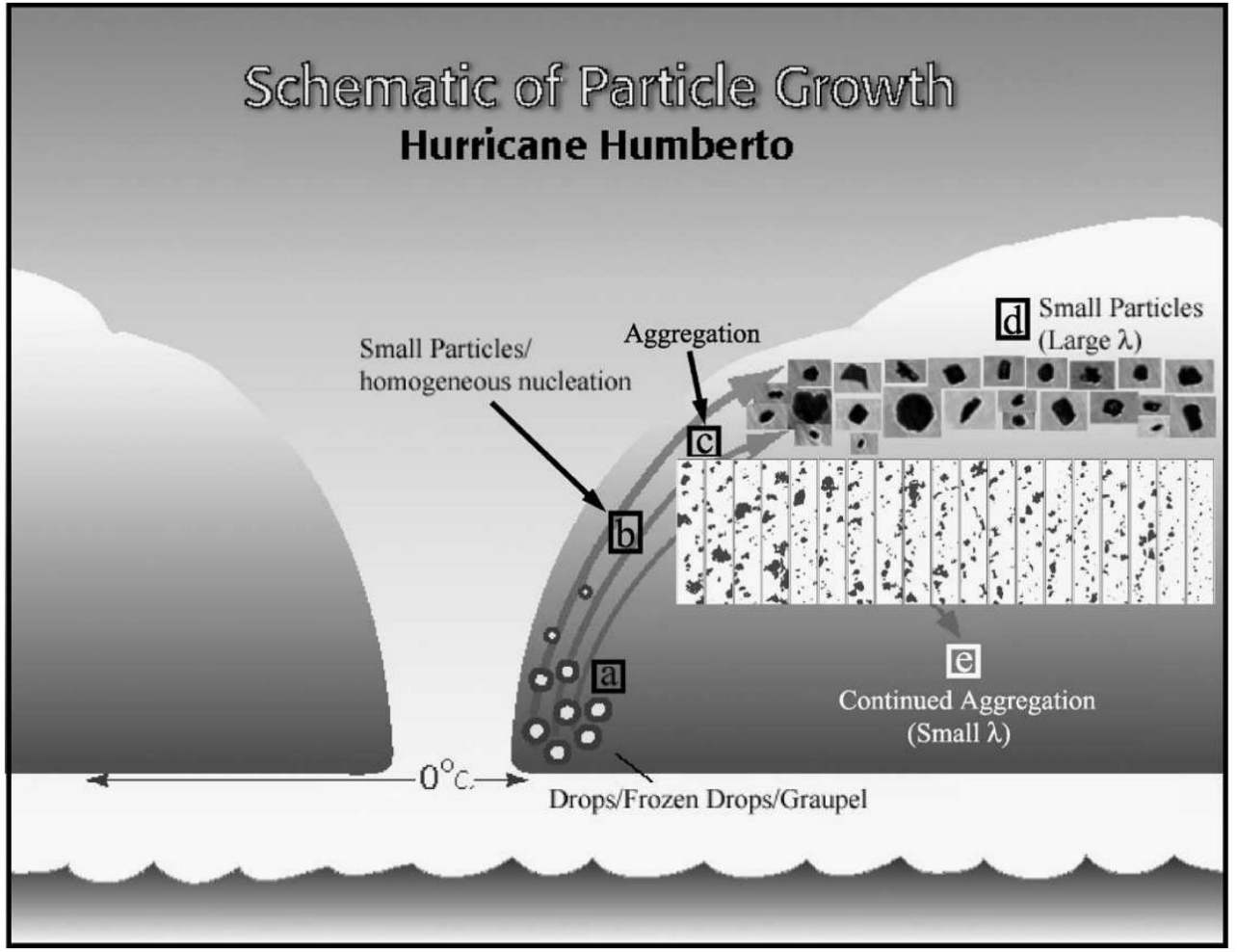


# Nonspherical Snow Particle

- Microphysics Schemes consider Snow Particle as Spherical.




- Observations show that Snow Particles grow with different shapes.




Heymsfield et al., 2004

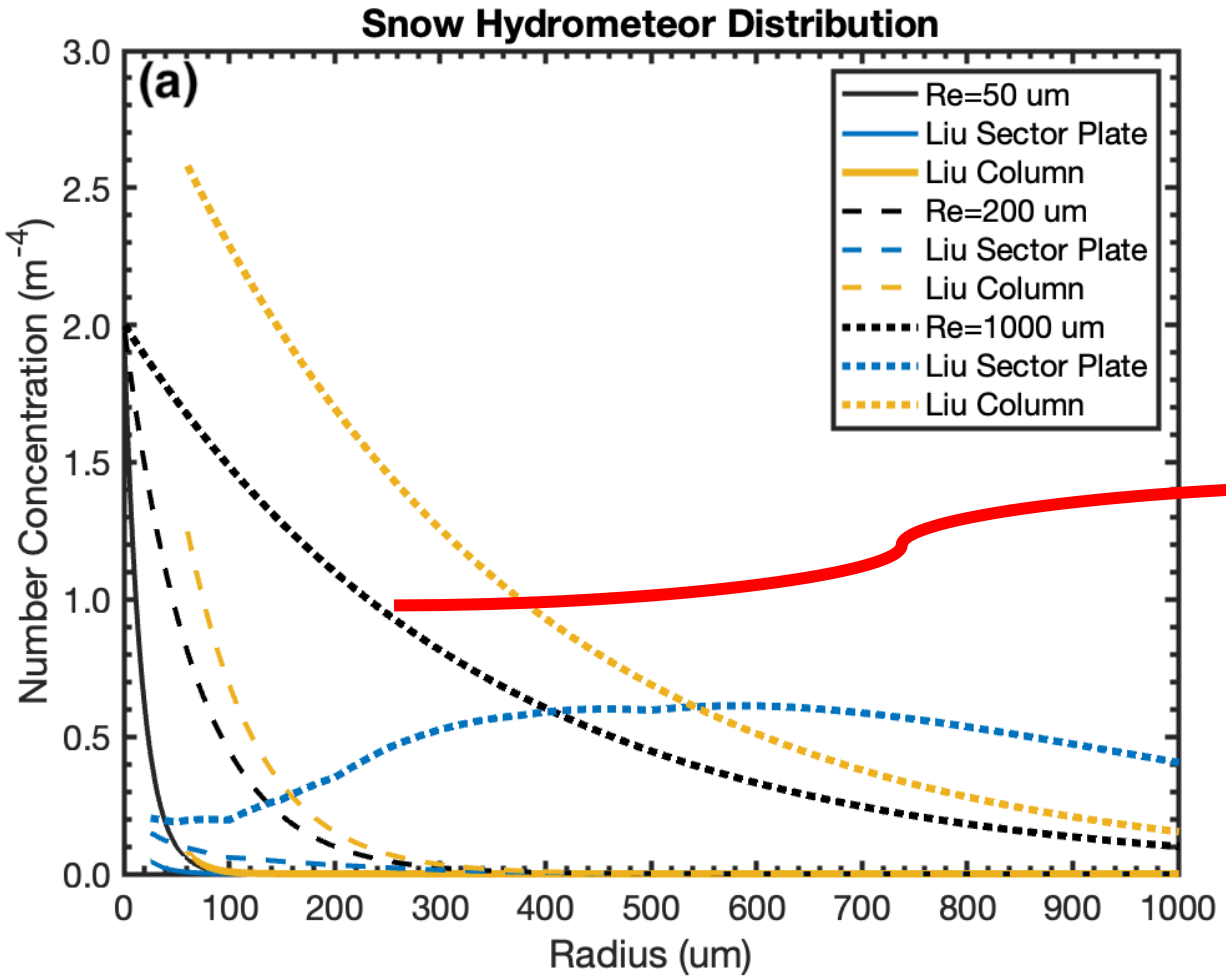
# Replacing Spherical Particles with Nonspherical Particles

$$N(D_{spherical})m(D_{spherical}) = N(D_{nonspherical})m(D_{nonspherical})$$

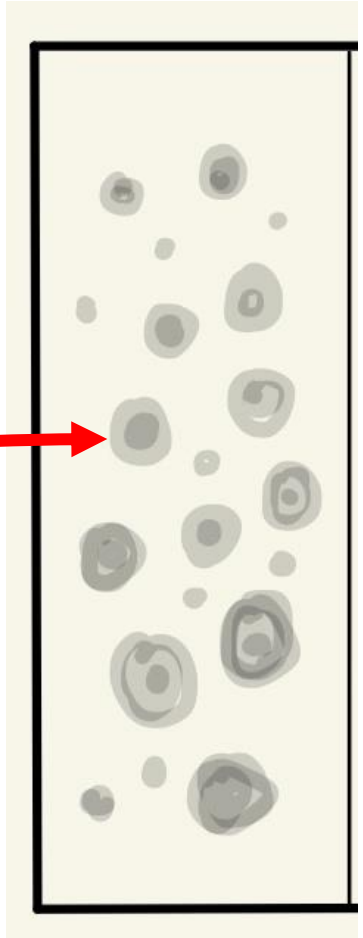
$$N(D_{nonspherical}) = \frac{N(D_{spherical})\, m(D_{spherical})}{m(D_{nonspherical})}$$

$$\sigma_{mass\ extinction\ cross\ section} = \frac{\int \sigma_e(D)\ N(D)dD}{\int m(D)\ N(D)dD}$$

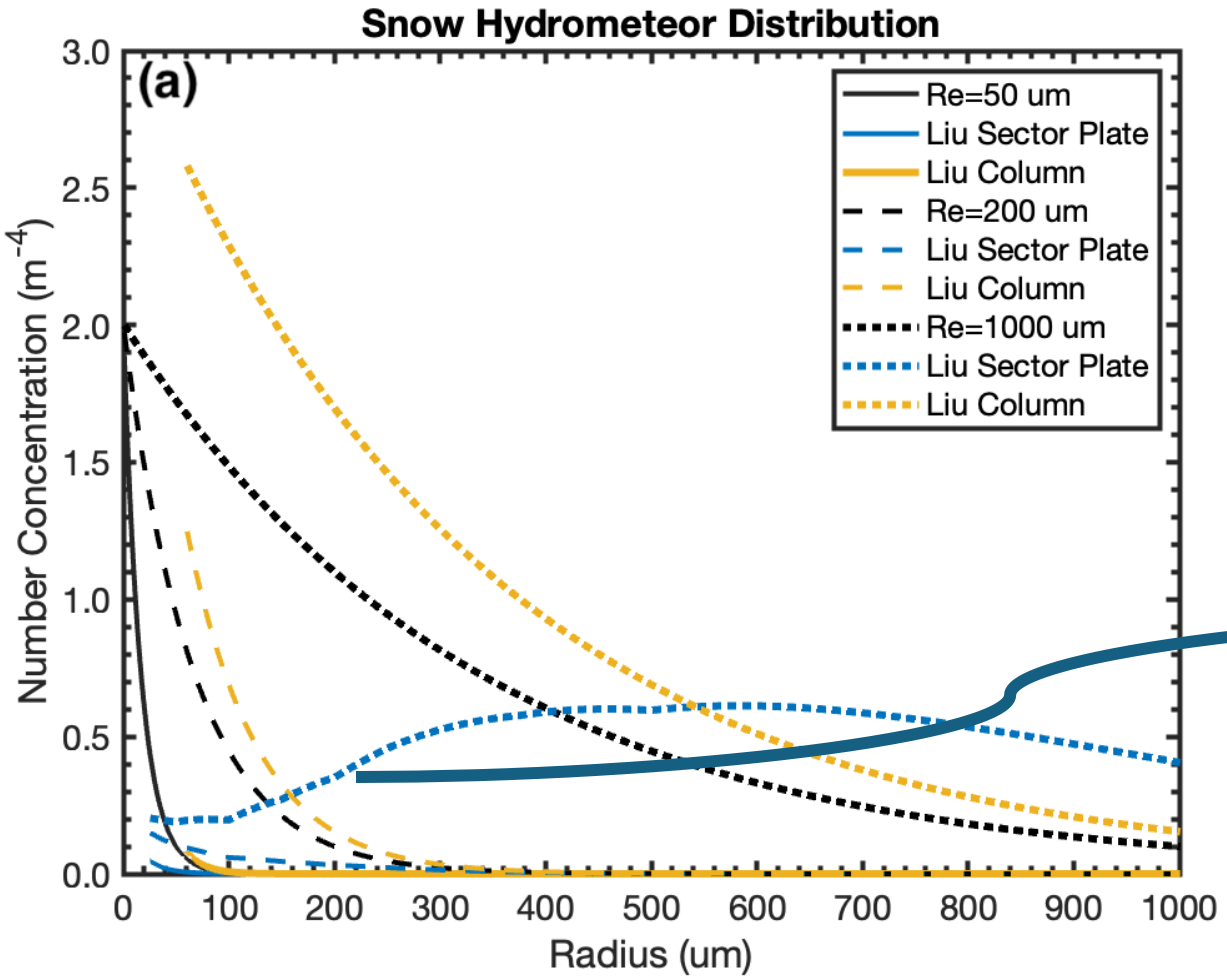
# Sector Plate and Column Particle Representation

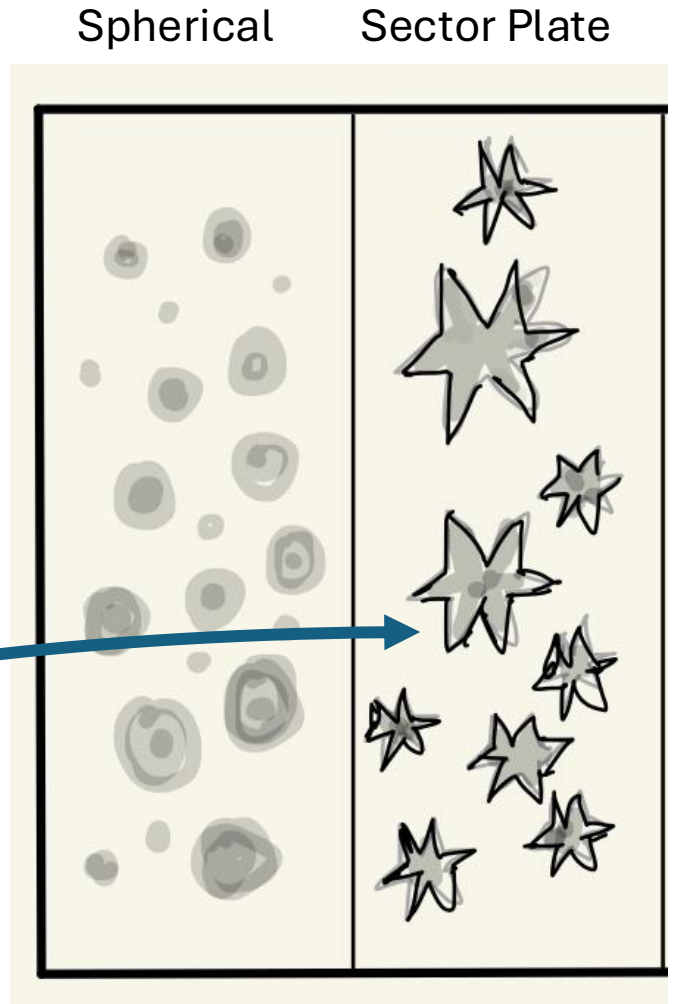



Spherical

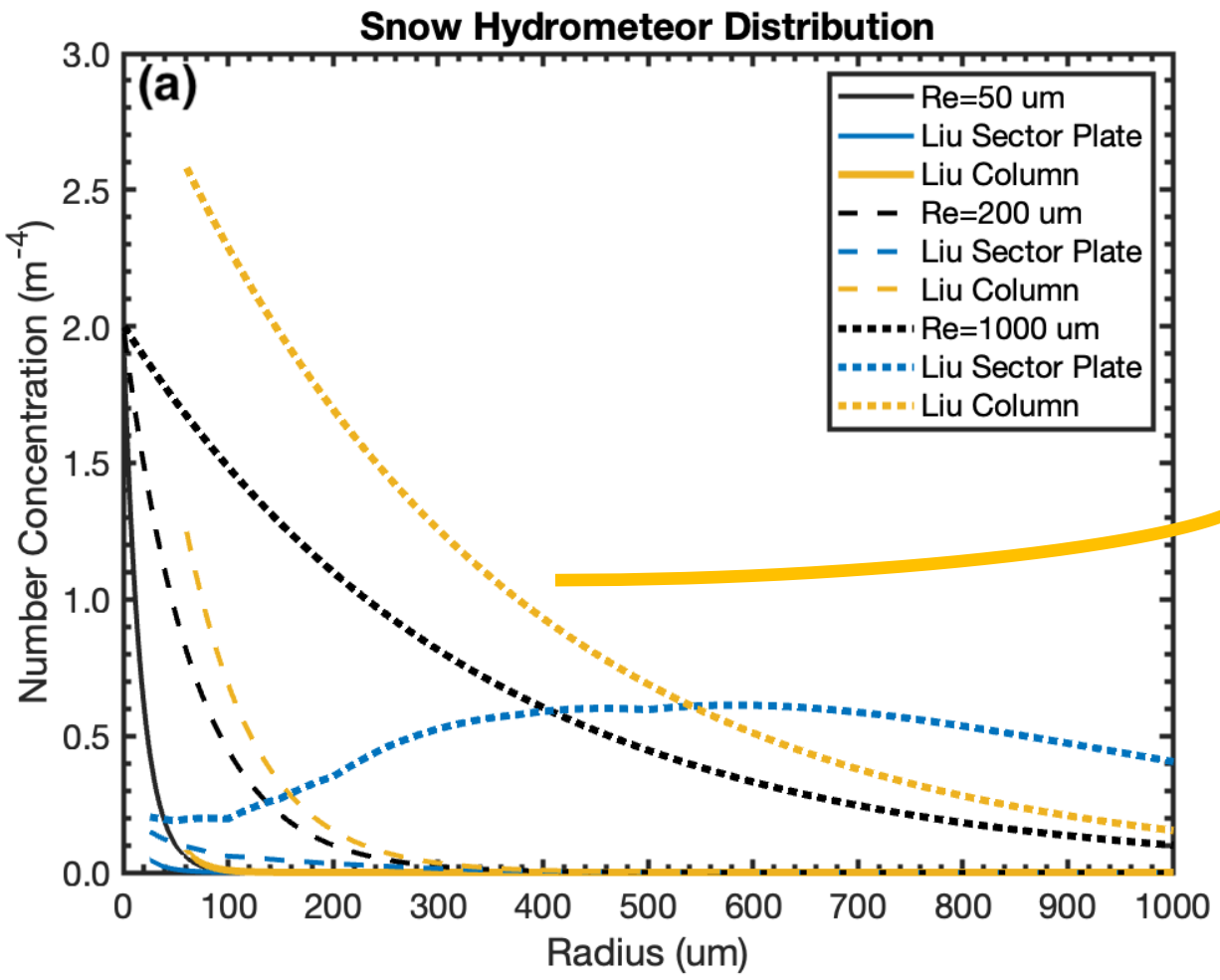


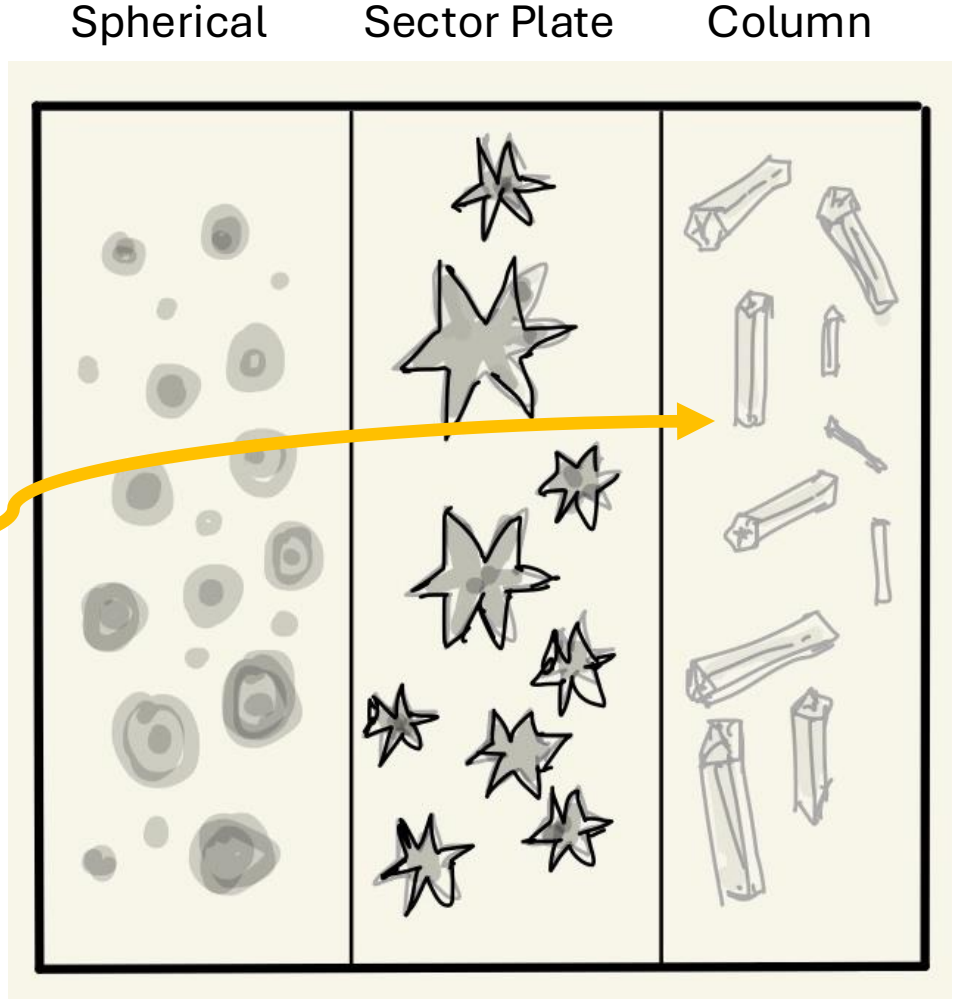
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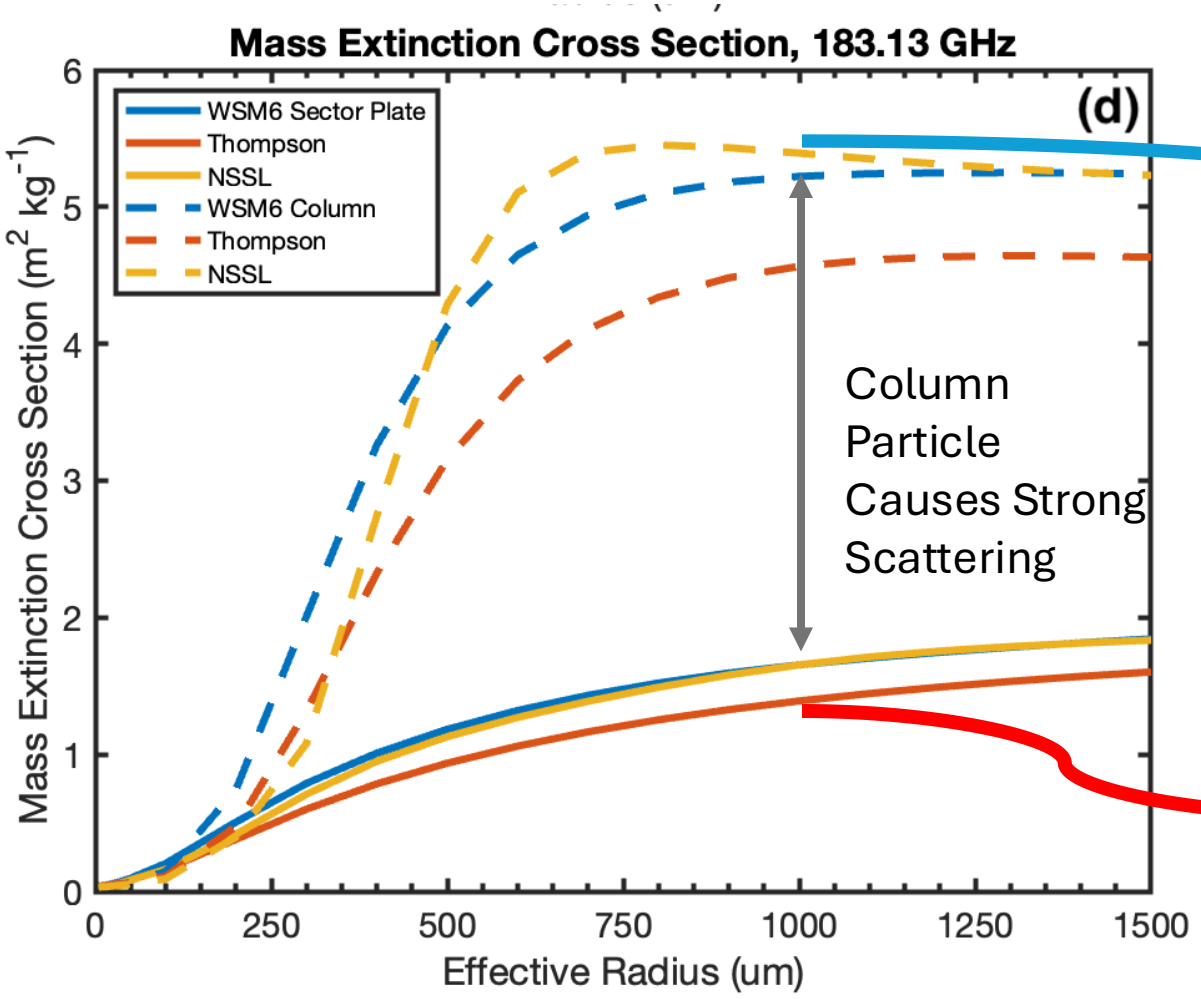



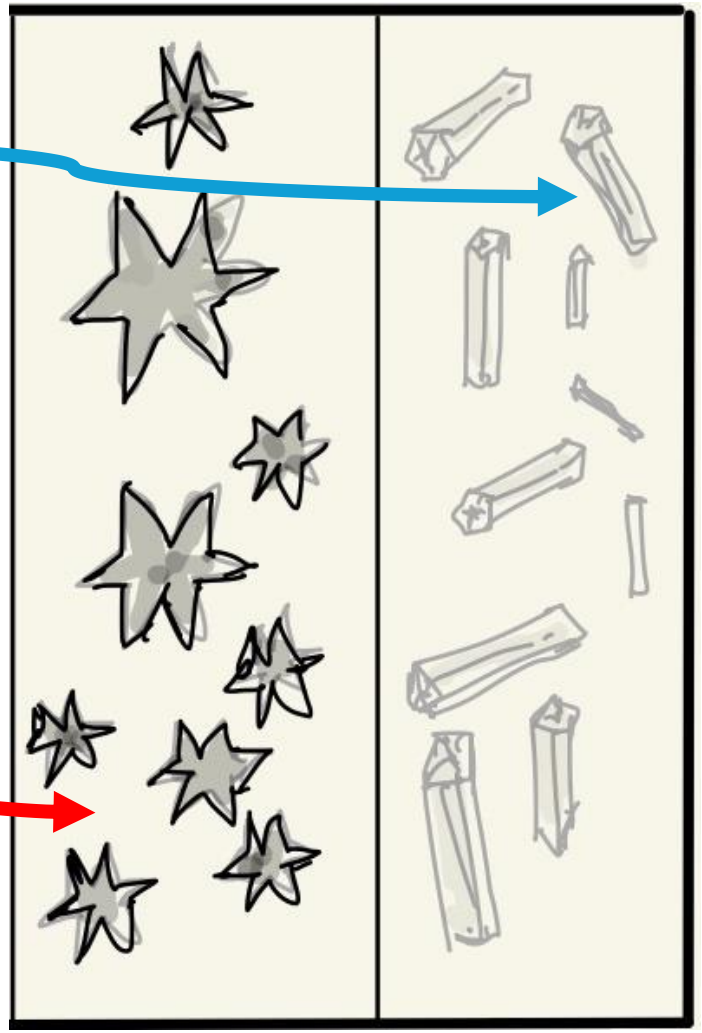
# Sector Plate and Column Particle Representation



# Snow Mass Extinction Cross Section



# Bulk Optical Property of Liu Database

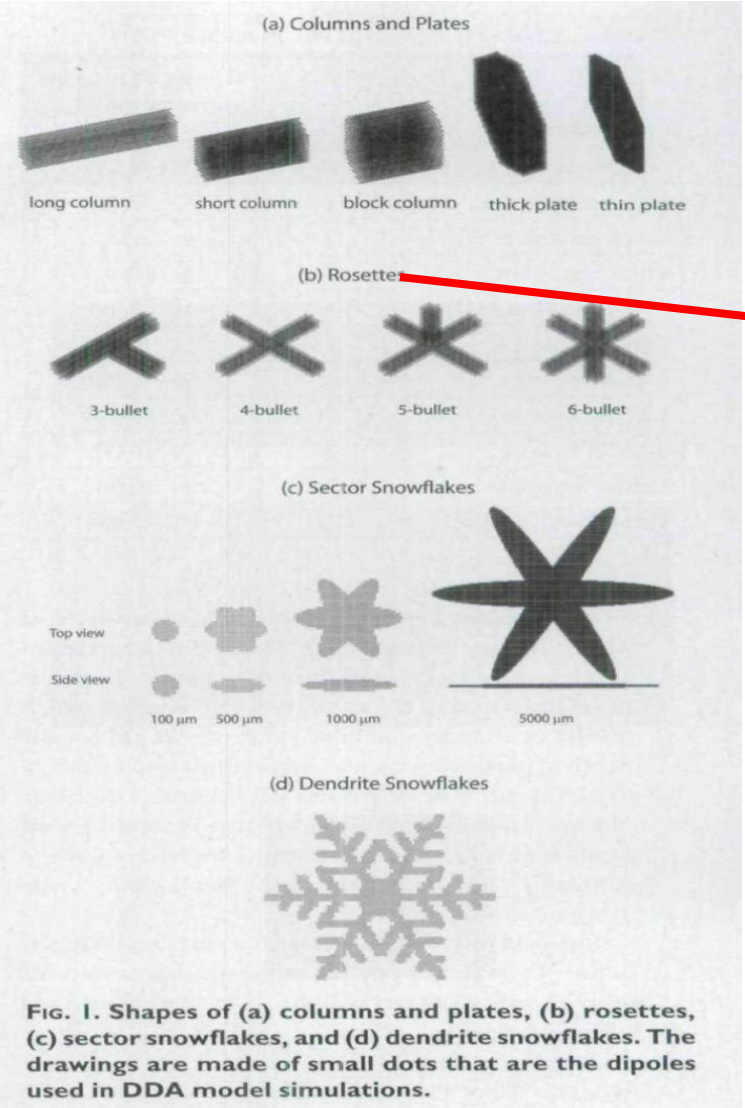
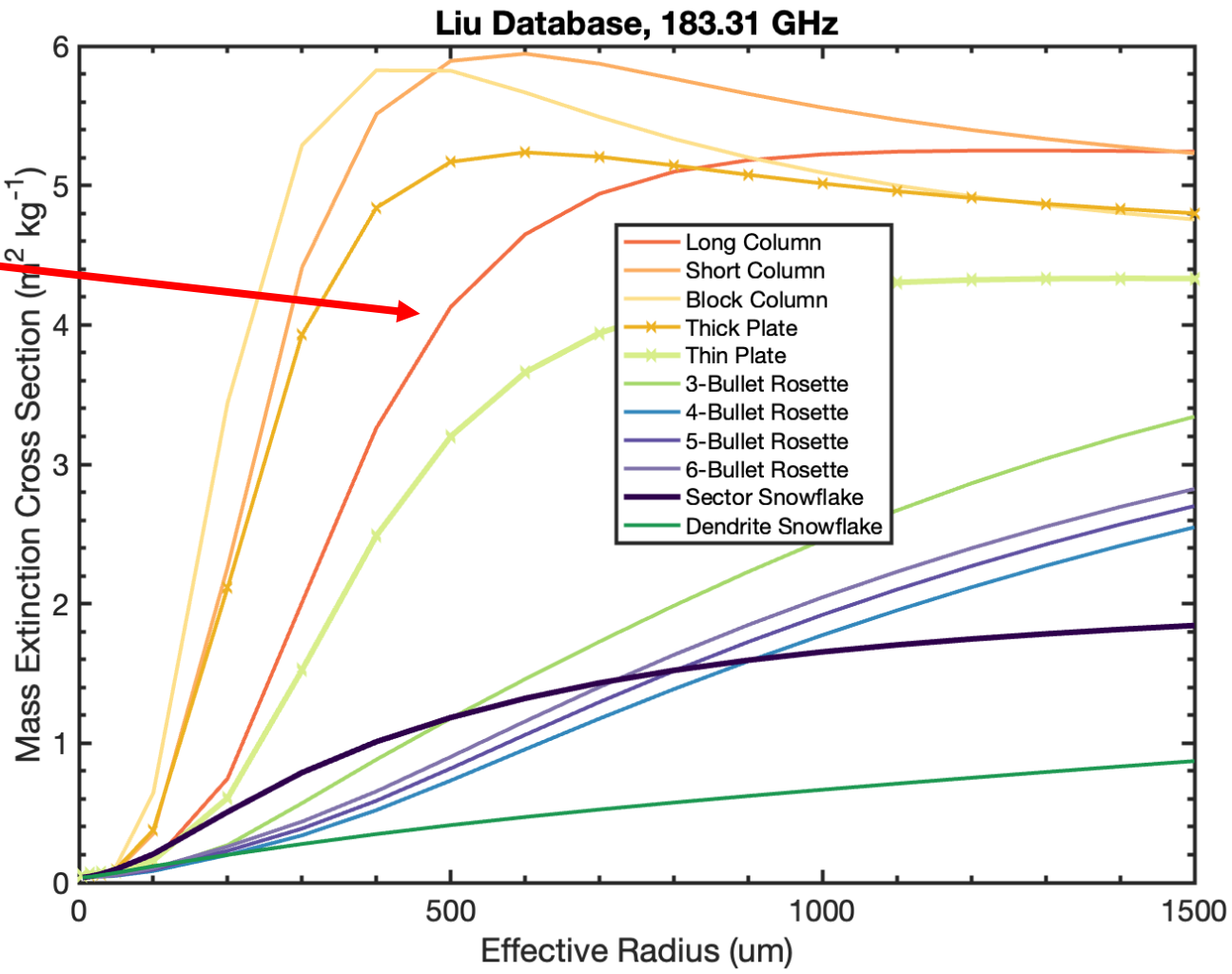



FIG. 1. Shapes of (a) columns and plates, (b) rosettes, (c) sector snowflakes, and (d) dendrite snowflakes. The drawings are made of small dots that are the dipoles used in DDA model simulations.



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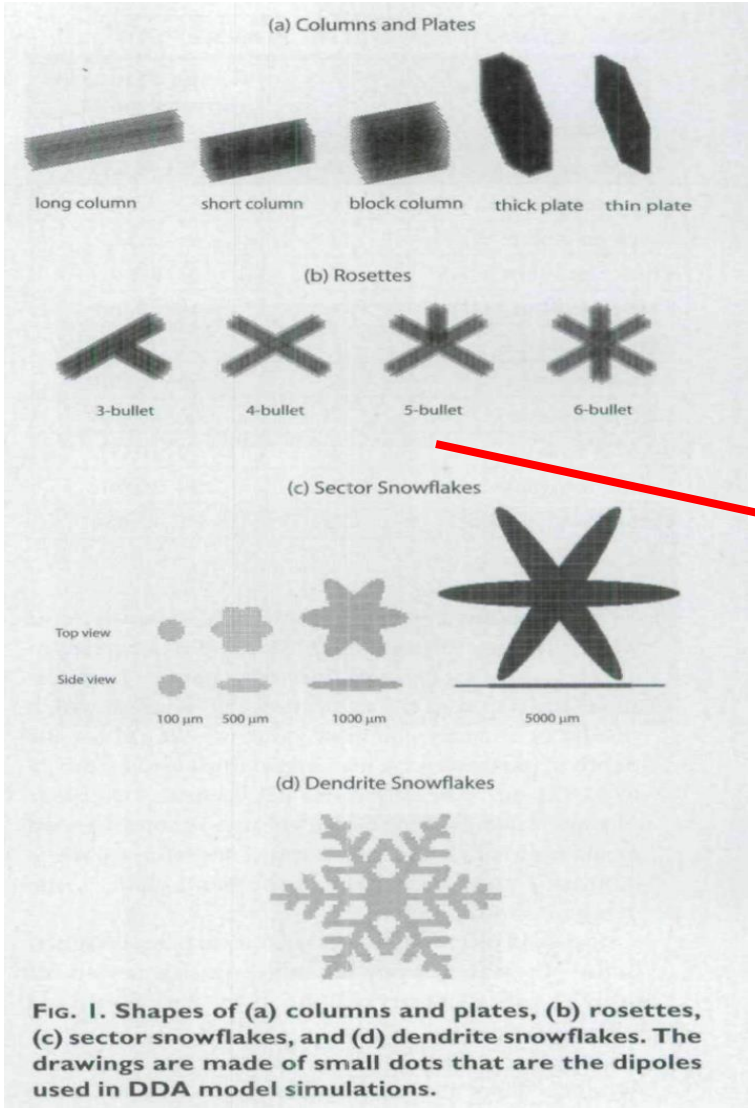
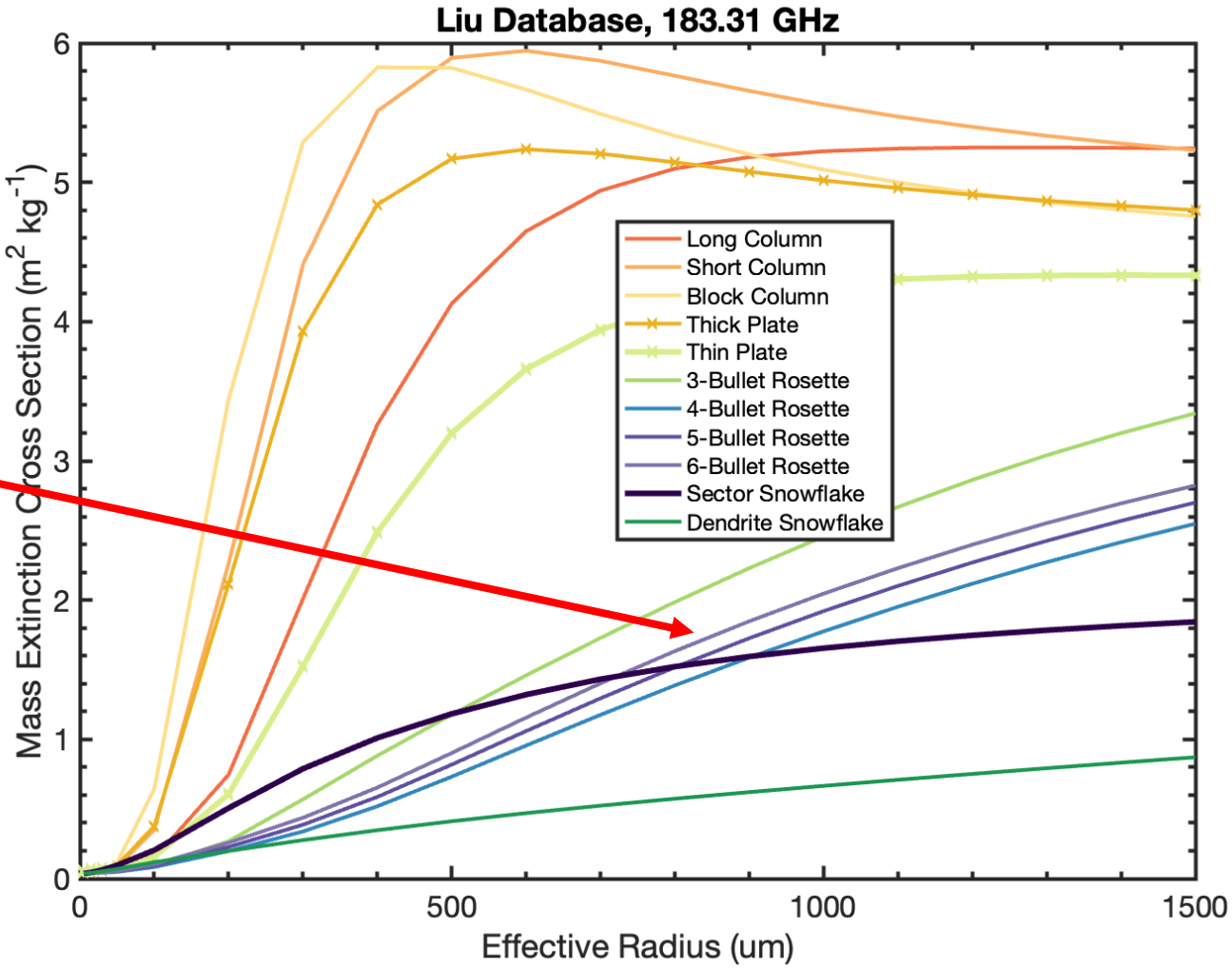



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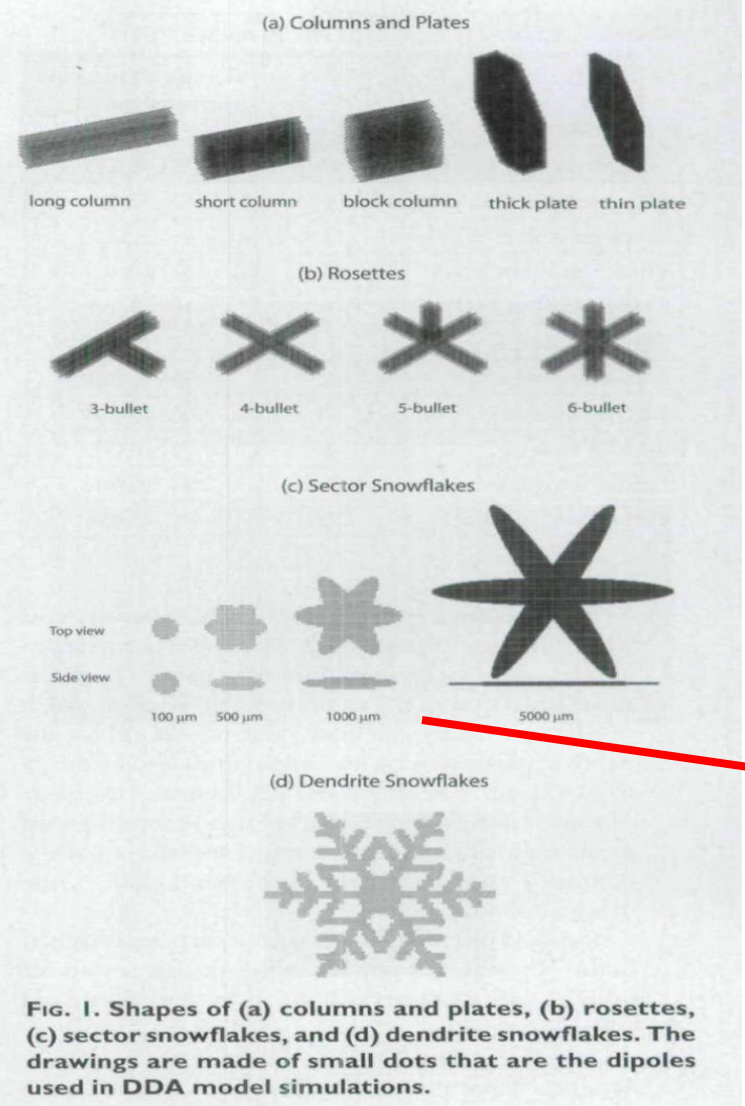
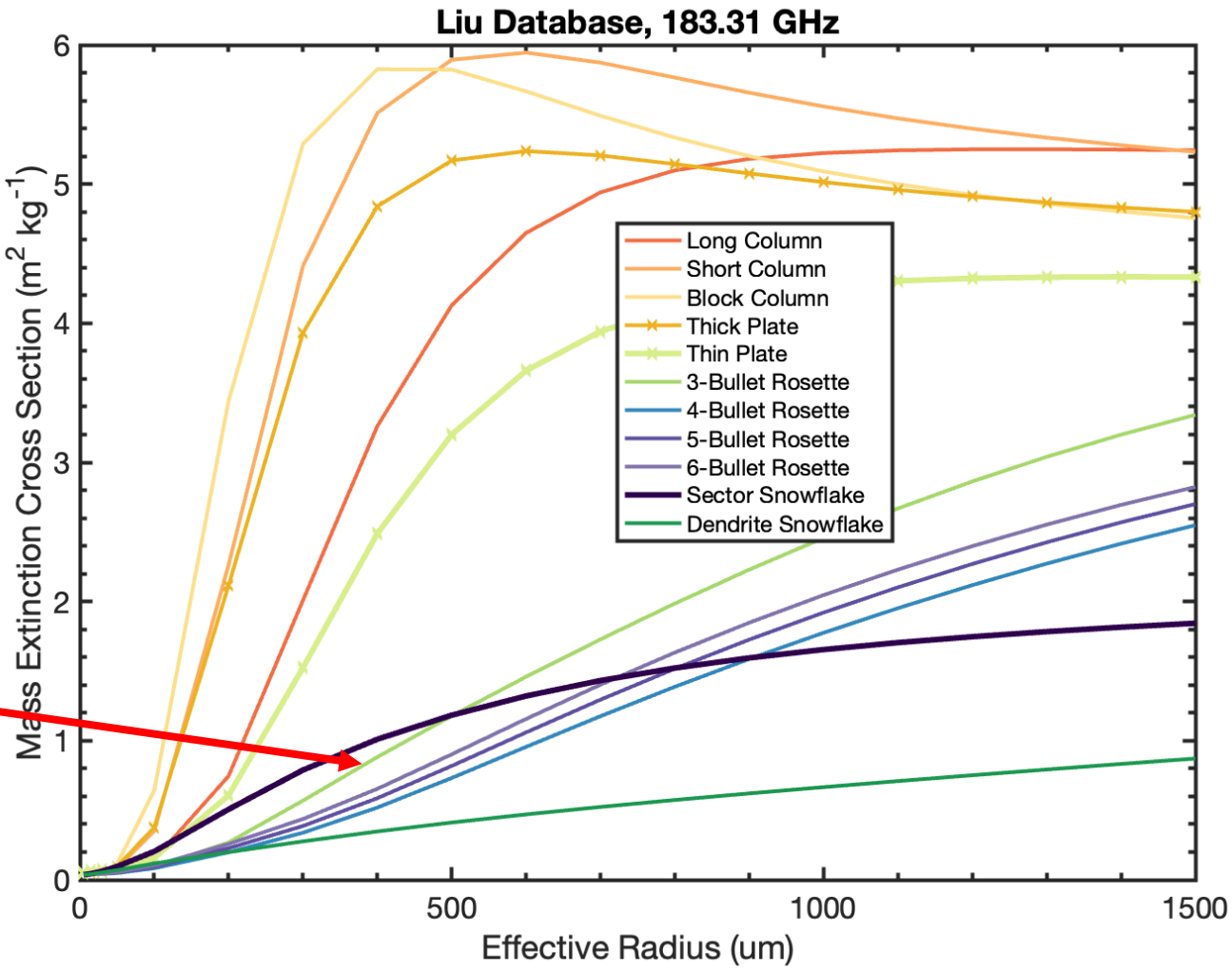



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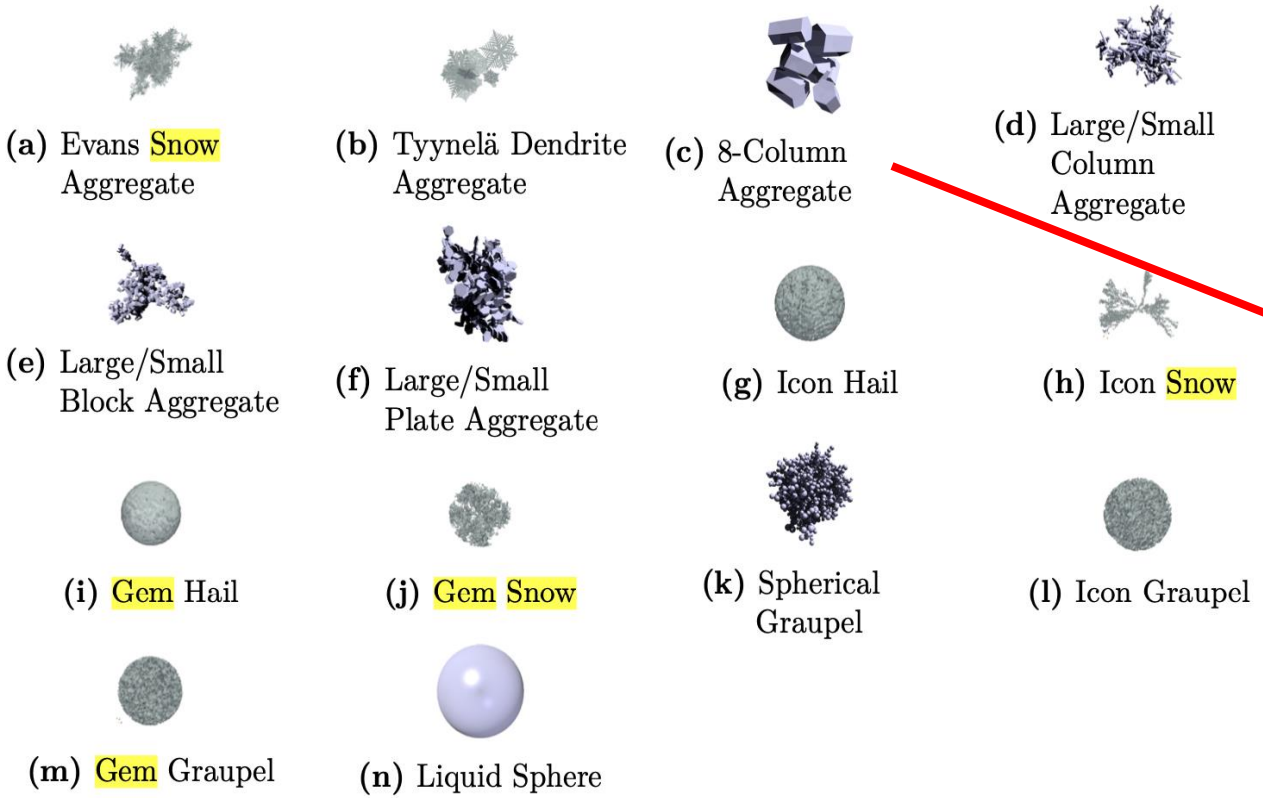
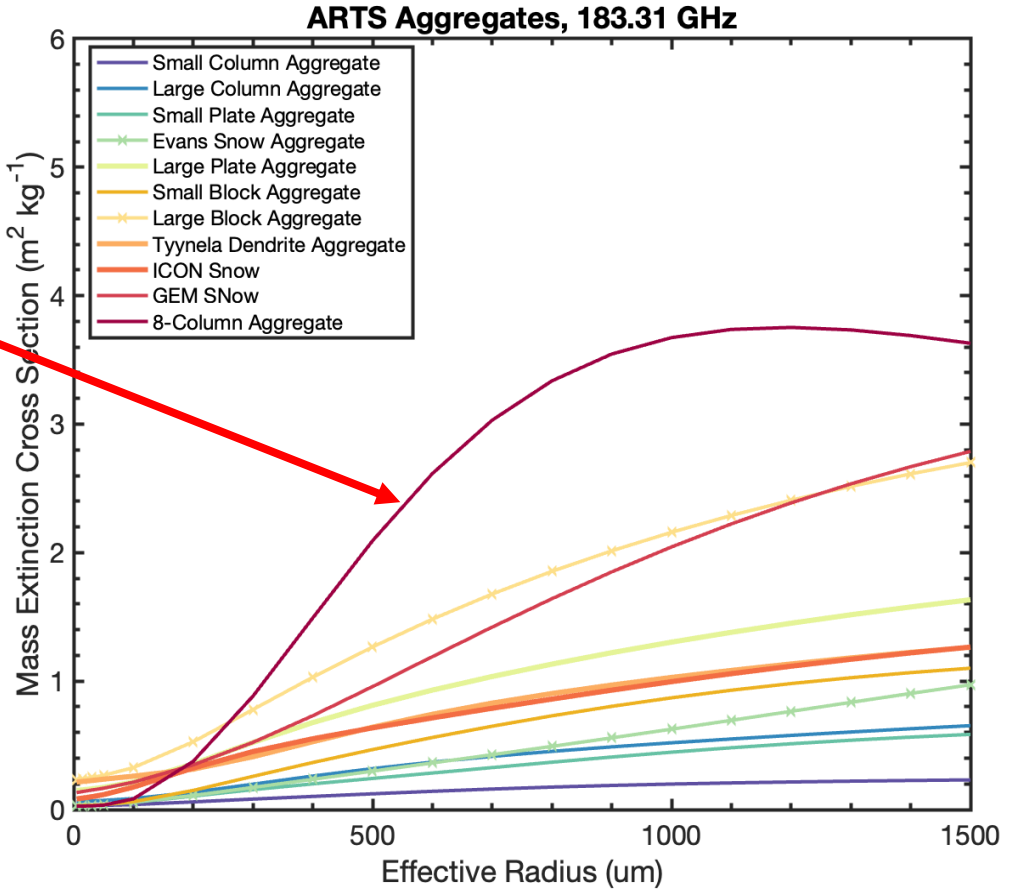



**Table 5.4.:** Aggregate habit figures. The liquid sphere has been included also.



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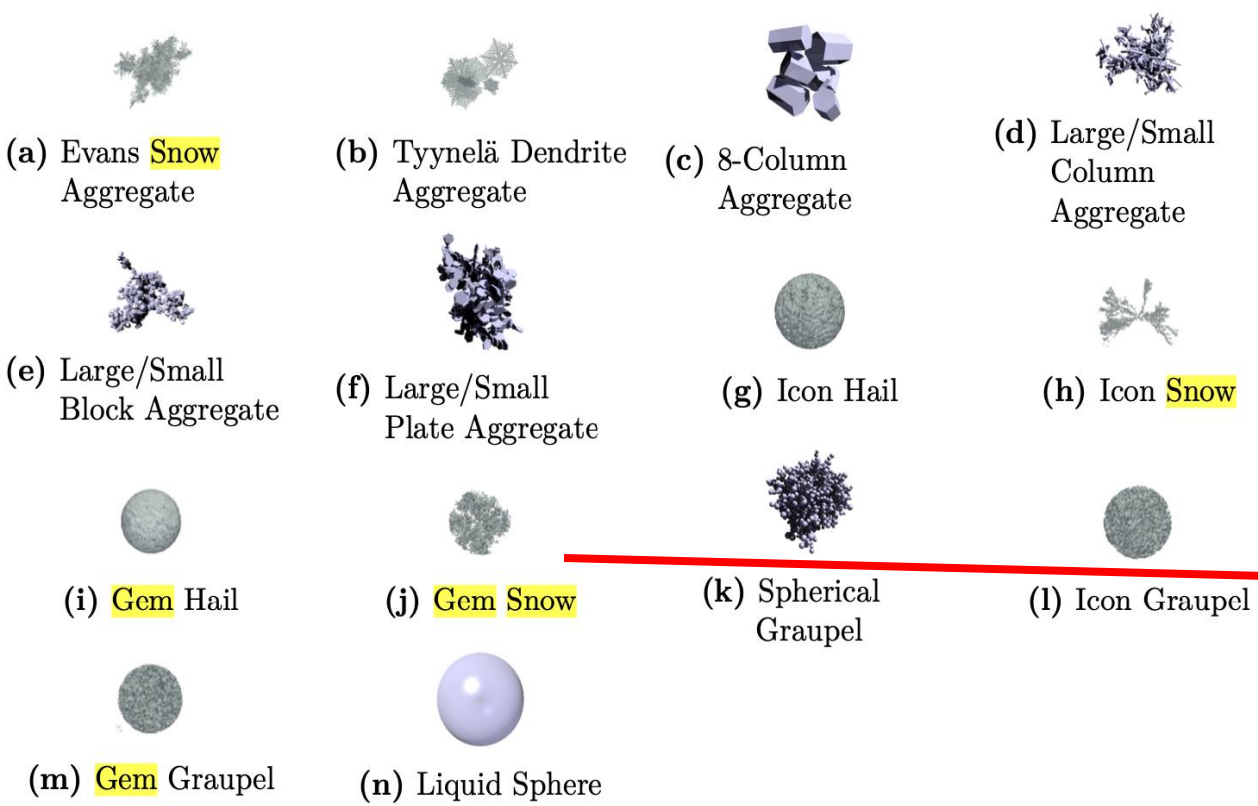
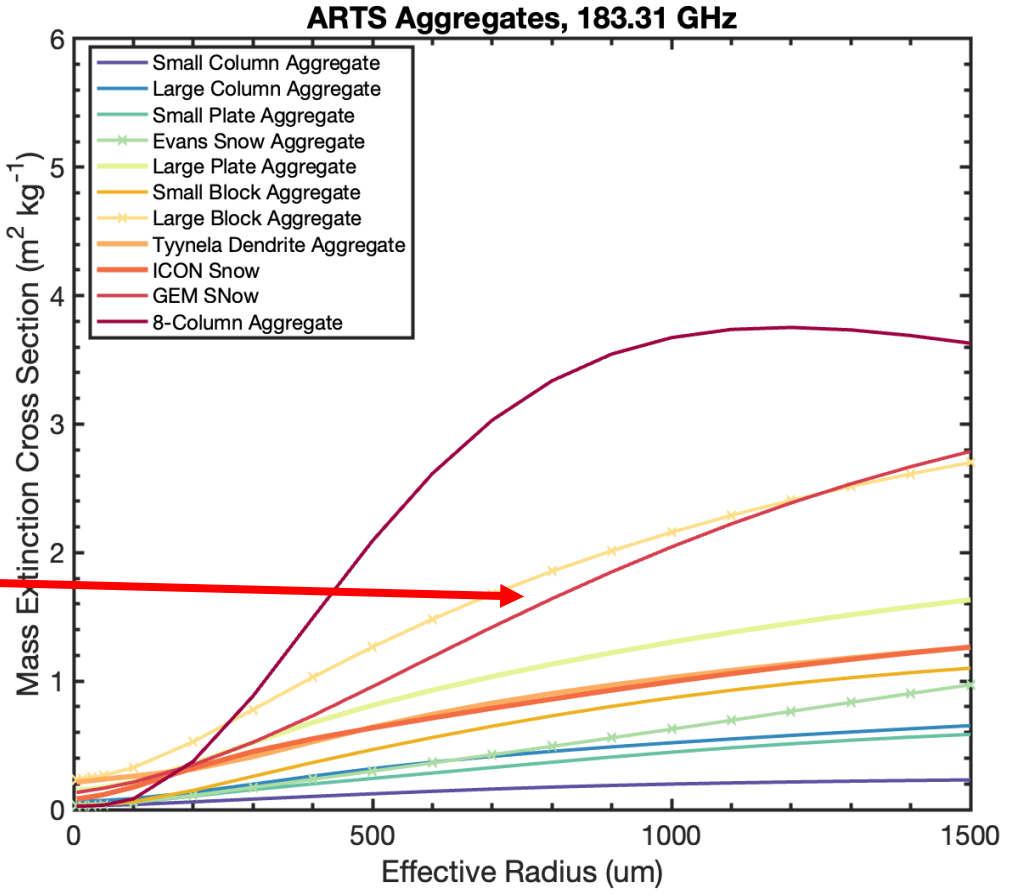



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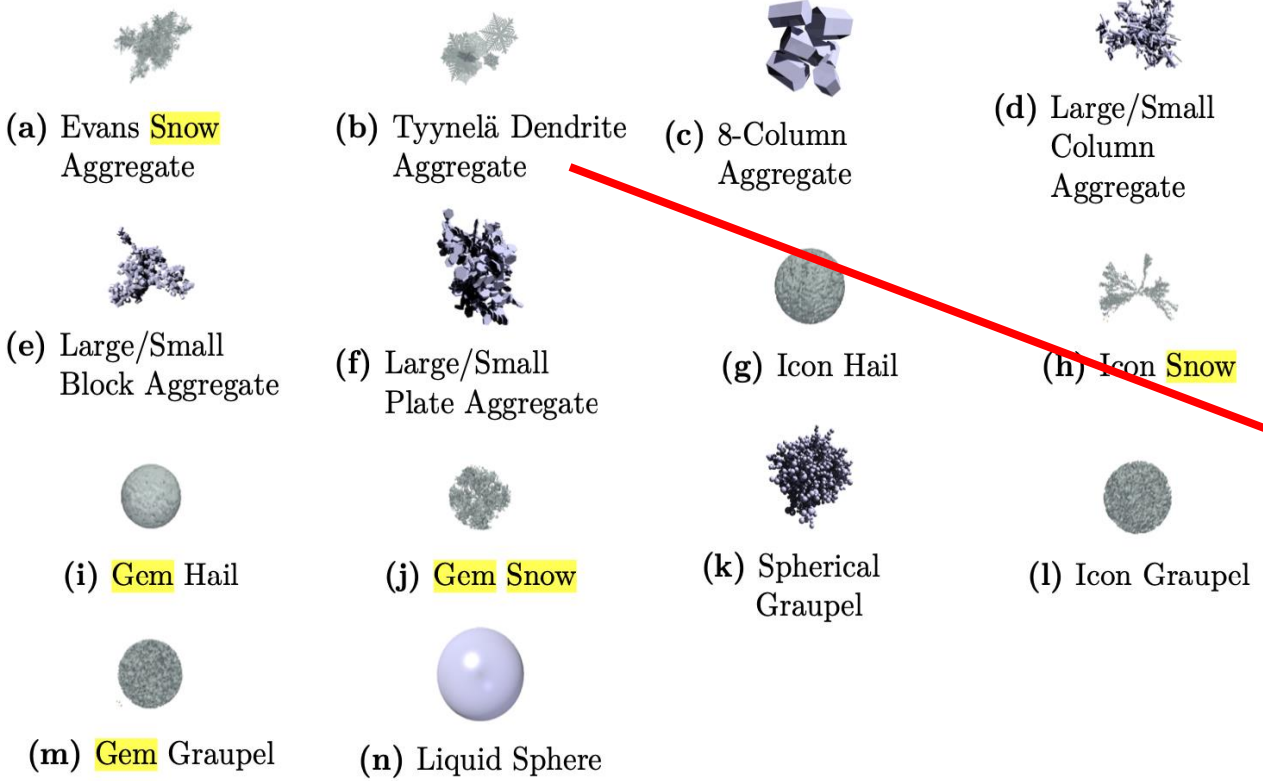
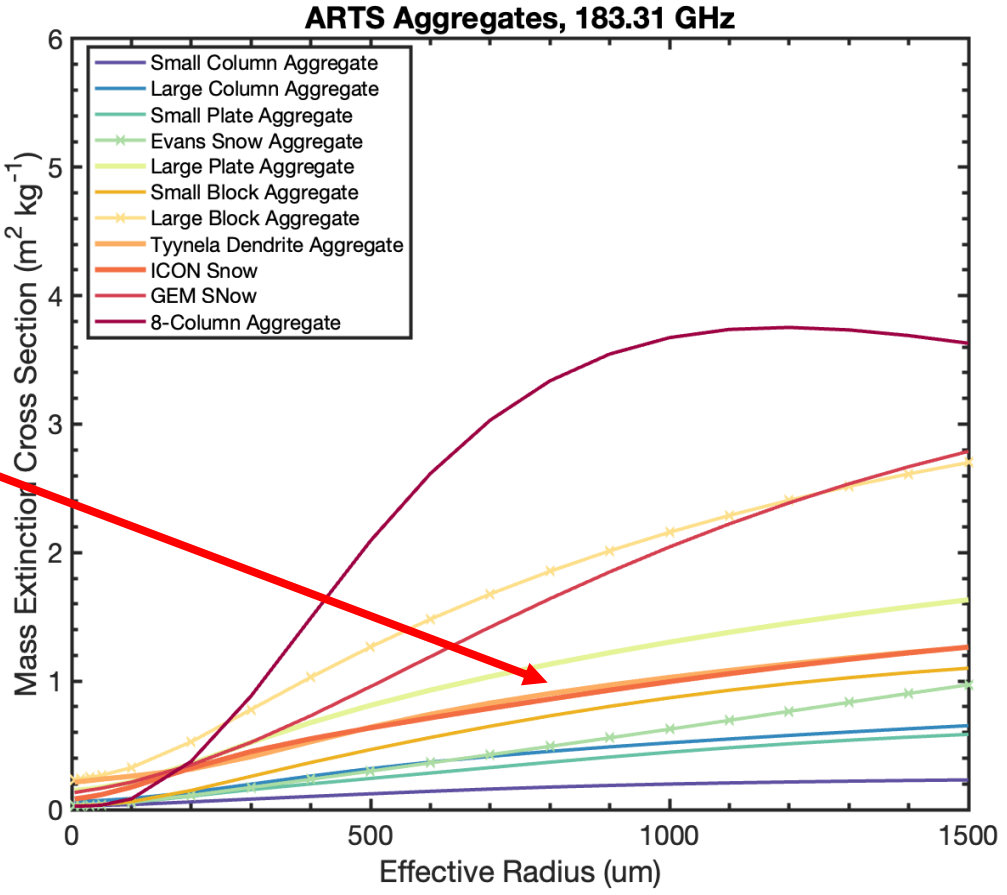



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# ARTS Aggregates

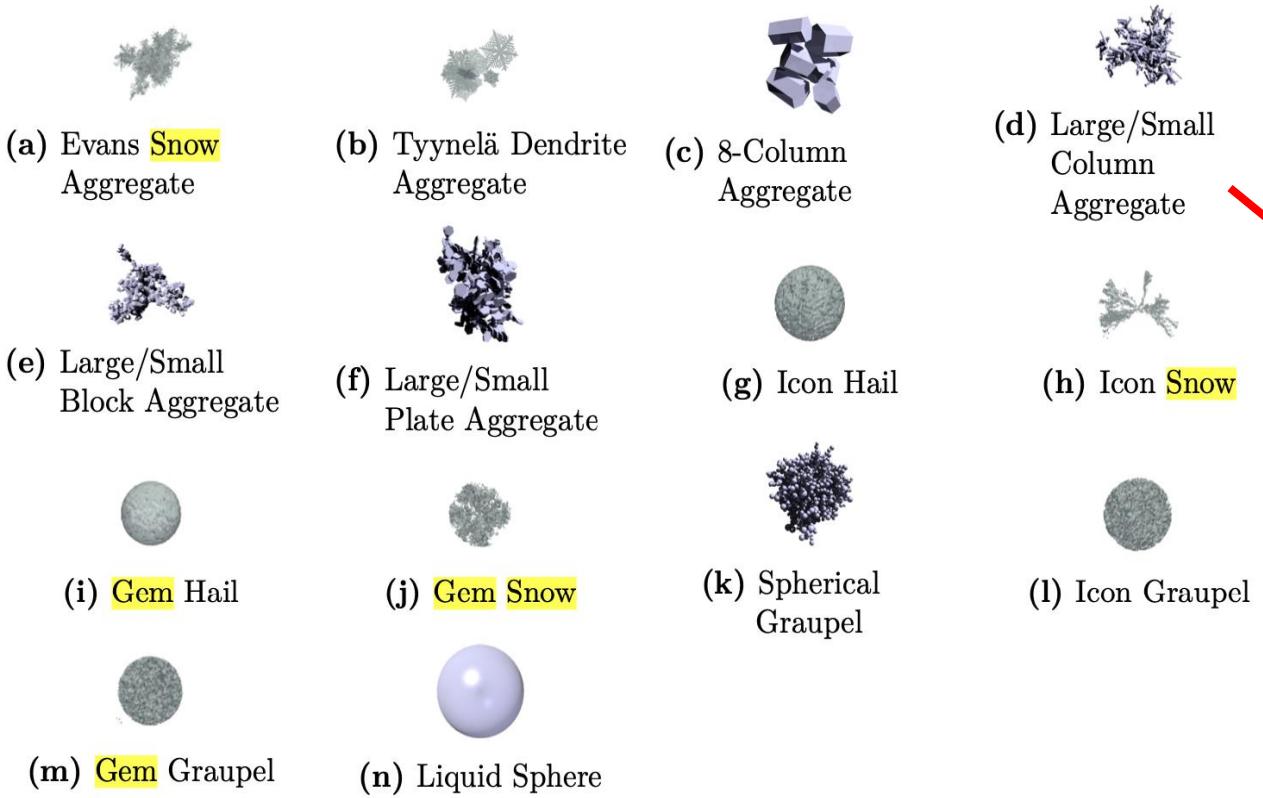
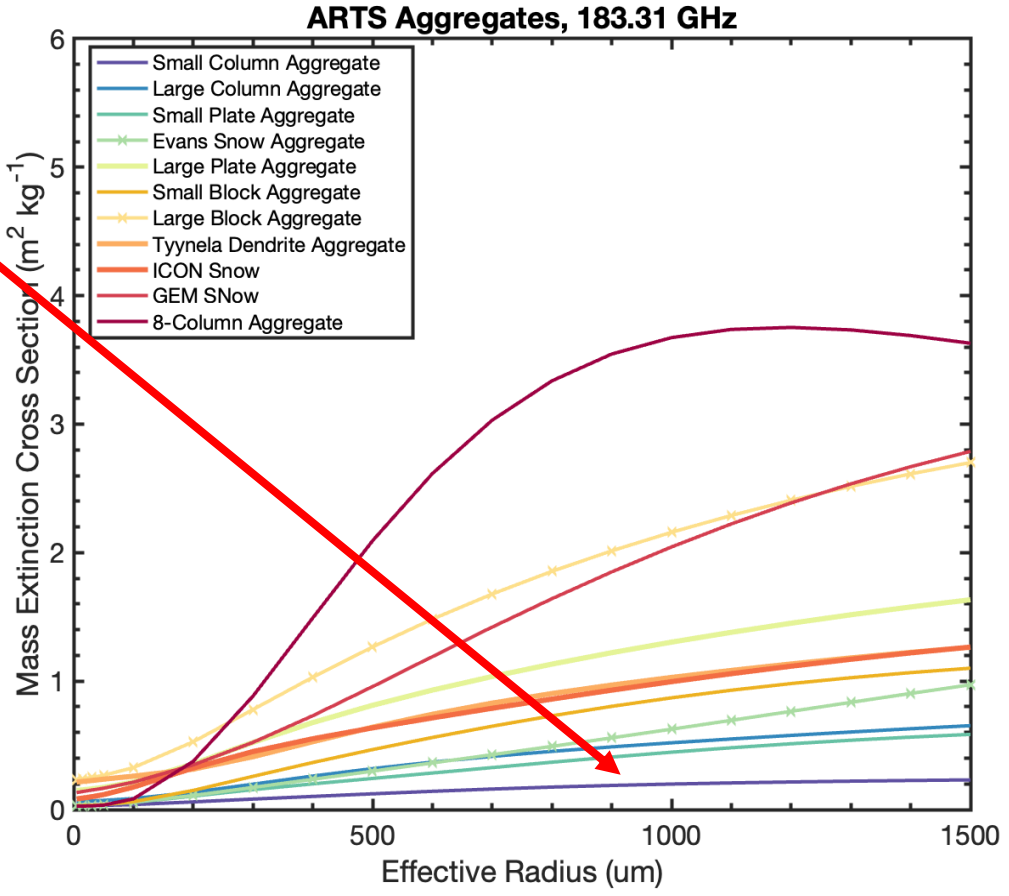
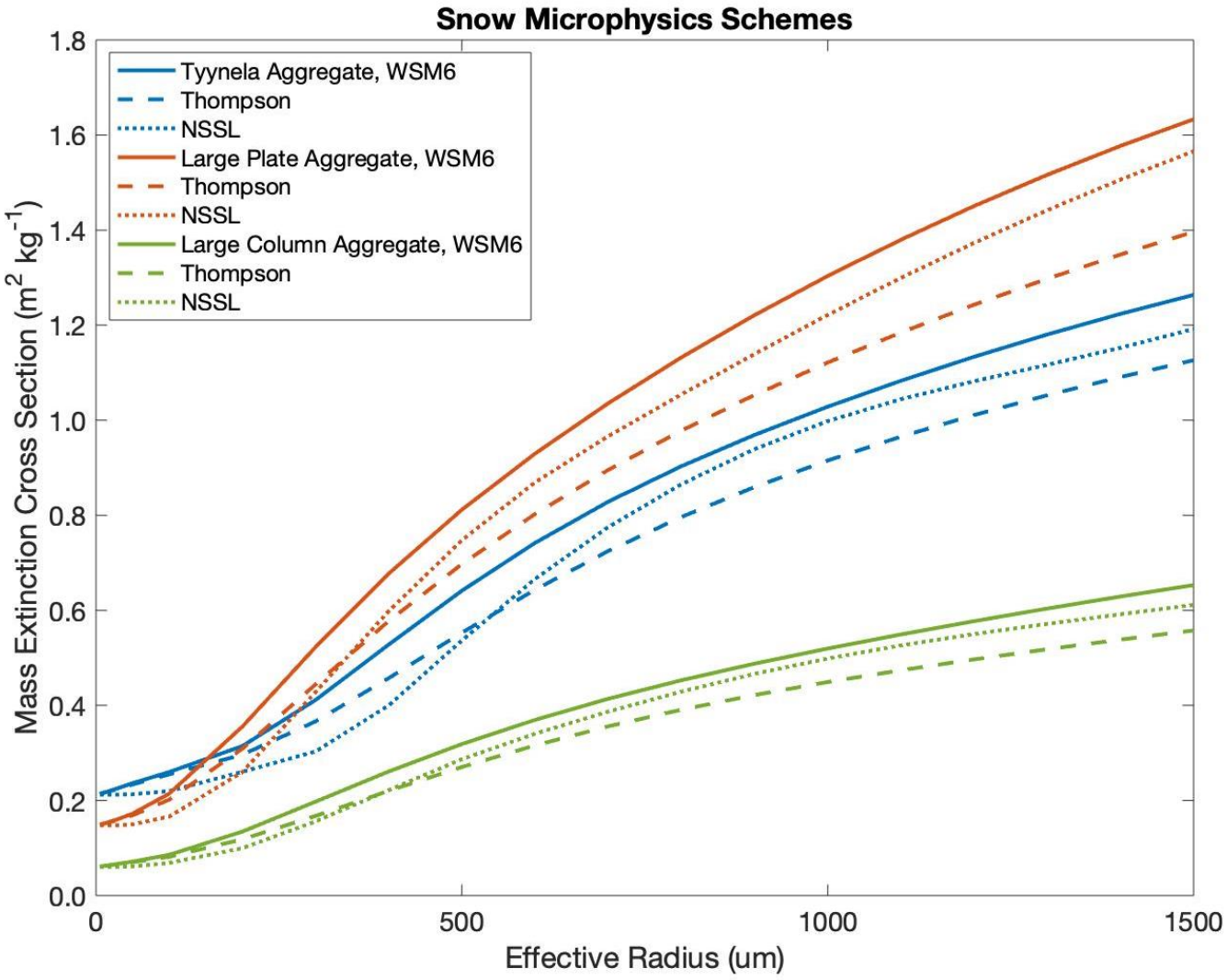


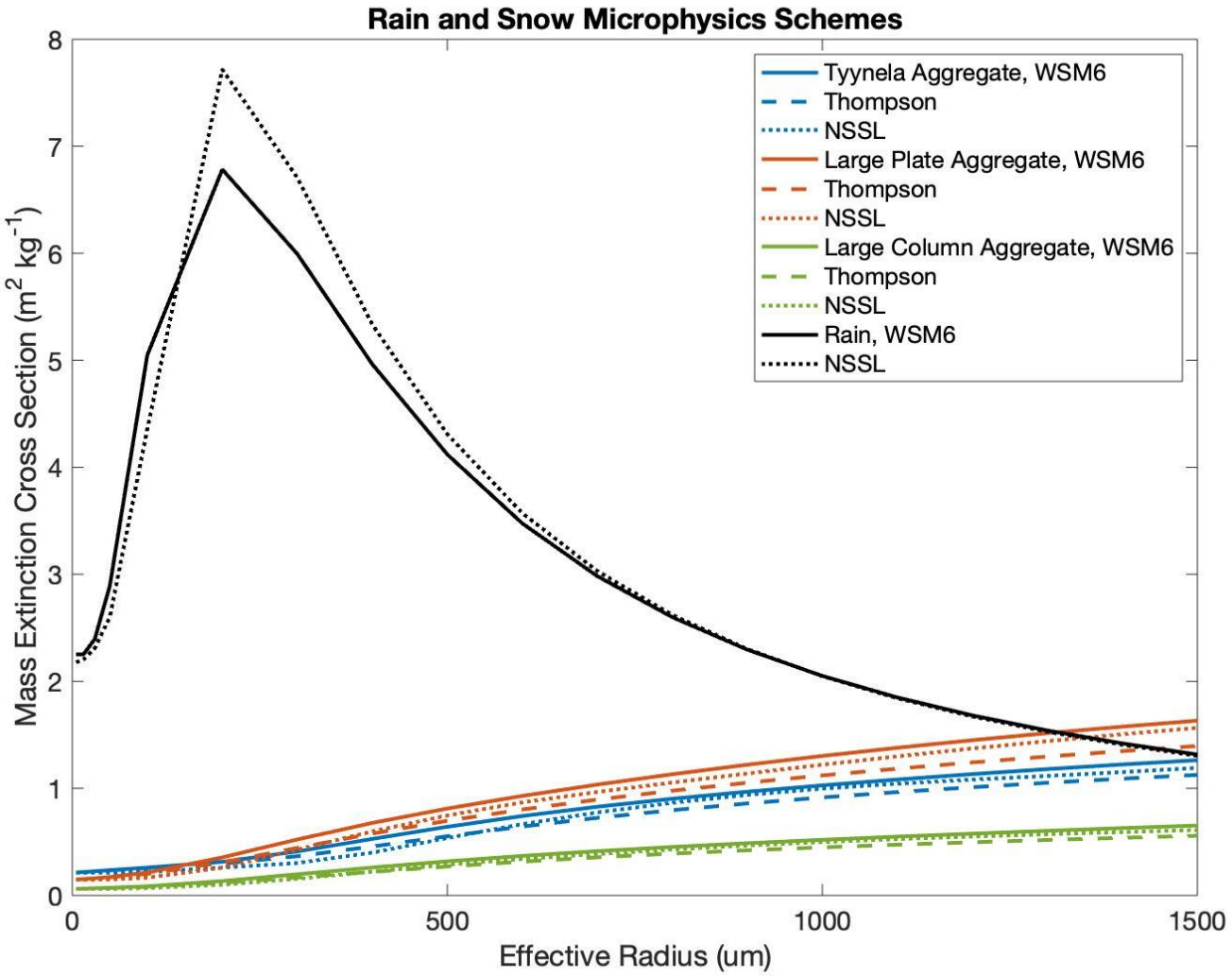

**Table 5.4.:** Aggregate habit figures. The liquid sphere has been included also.

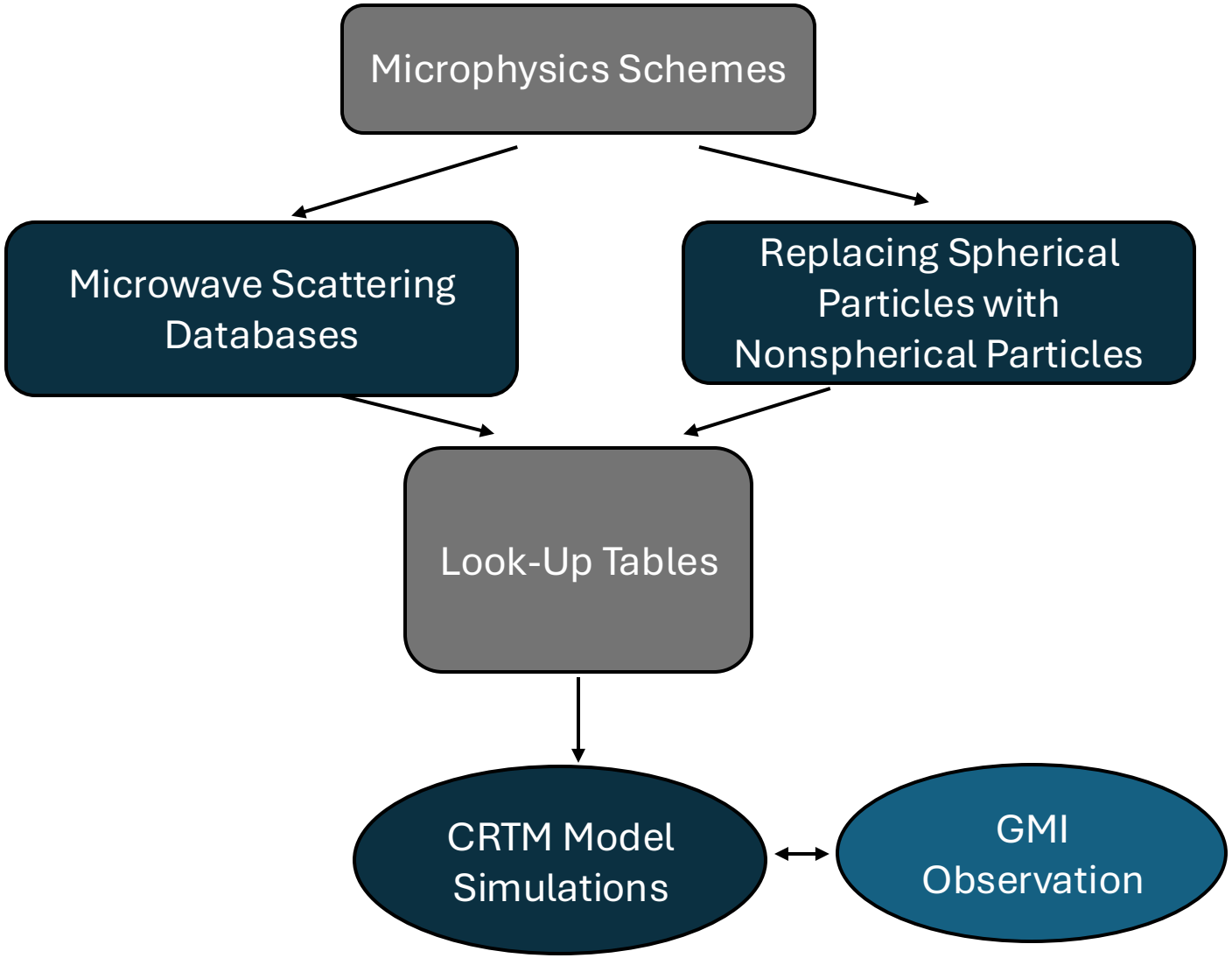


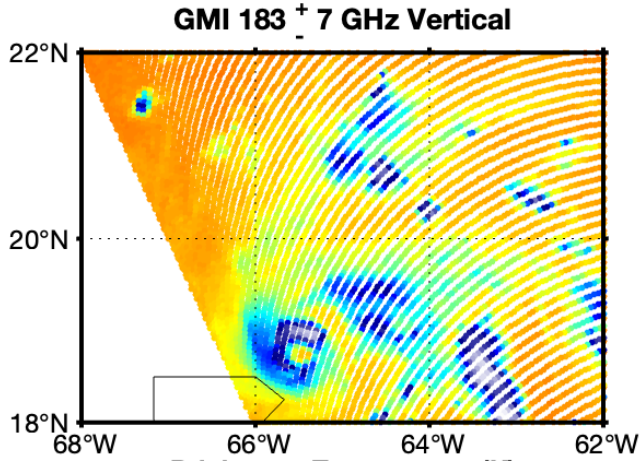
# Microphysics Schemes and Bulk Optical Properties

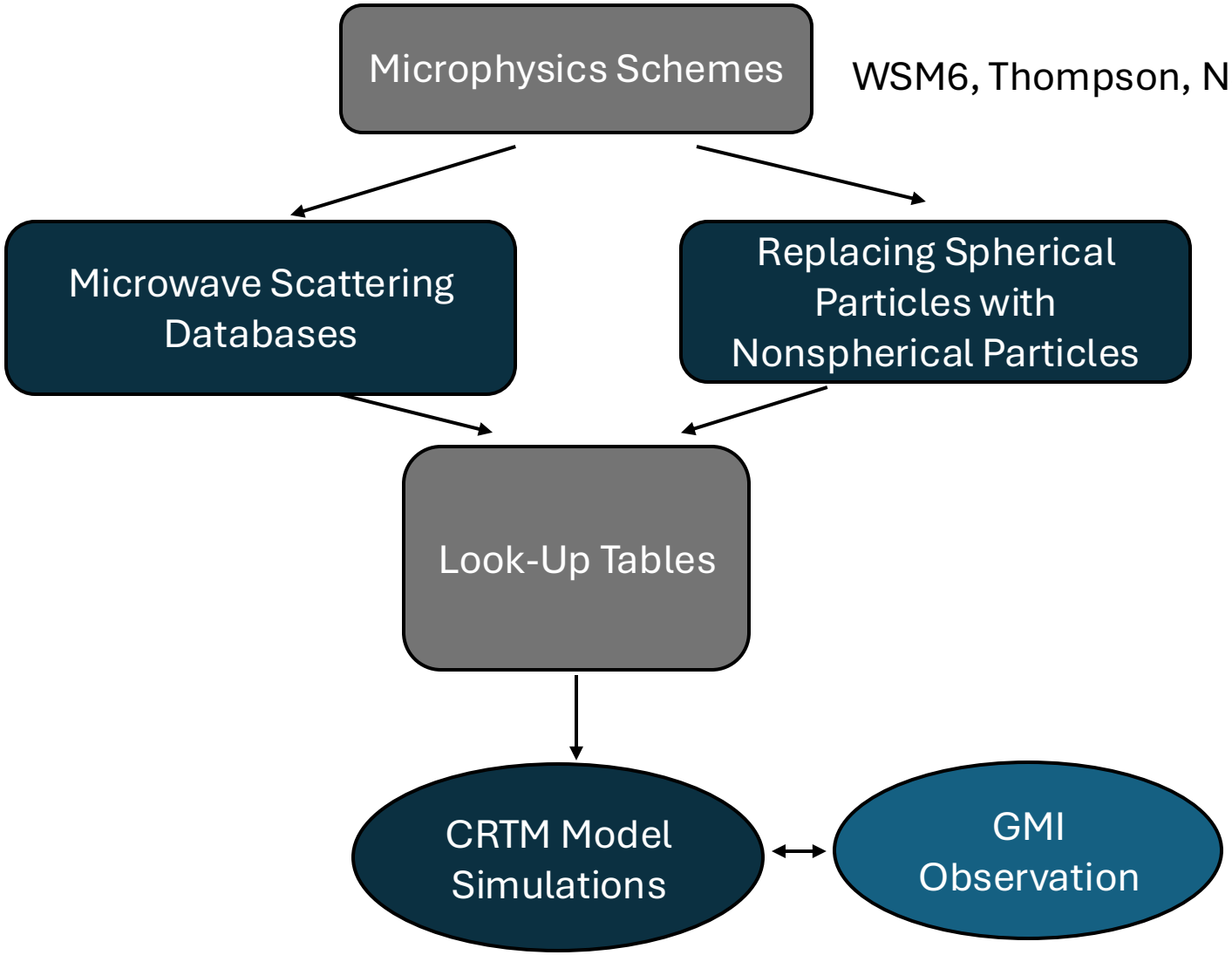


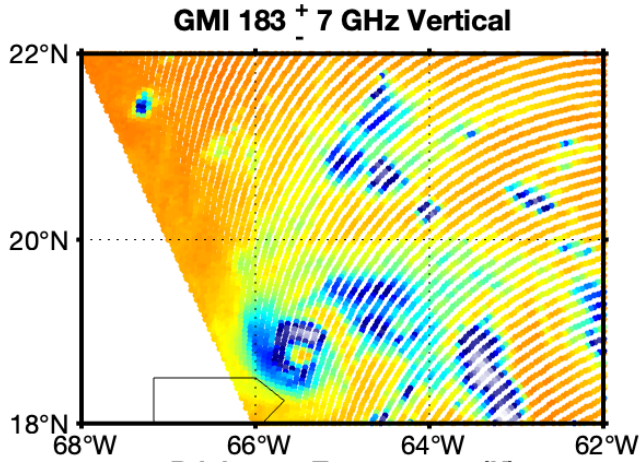
# Microphysics Schemes and Bulk Optical Properties




Microphysics Schemes
Microwave Scattering Databases
Replacing Spherical Particles with Nonspherical Particles
Look-Up Tables
CRTM Model Simulations
GMI Observation


GMI 183 ± 7 GHz Vertical
22°N
20°N
18°N
68°W
66°W
64°W
62°W


Microphysics Schemes
WSM6, Thompson, NSSL
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Microphysics Schemes

WSM6, Thompson, NSSL

Liu Database
ARTS

Microwave Scattering Databases

Replacing Spherical Particles with Nonspherical Particles

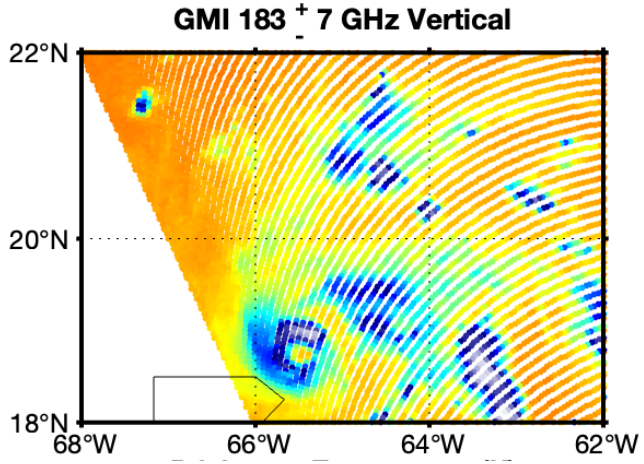
Particle Size Distribution changes

Look-Up Tables

Mass Extinction Cross Section
Single Scattering Albedo
Asymmetry Parameter
Phase Functions

CRTM Model Simulations

GMI Observation



Microphysics Schemes

WSM6, Thompson, NSSL

Liu Database
ARTS

Microwave Scattering Databases

Replacing Spherical Particles with Nonspherical Particles

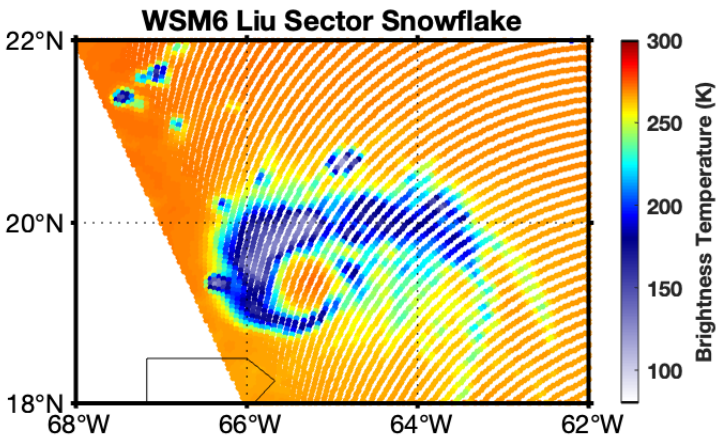
Particle Size Distribution changes

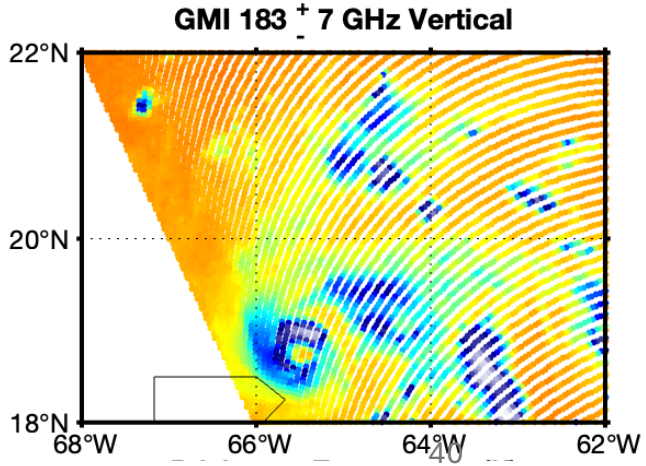
Look-Up Tables

Mass Extinction Cross Section
Single Scattering Albedo
Asymmetry Parameter
Phase Functions

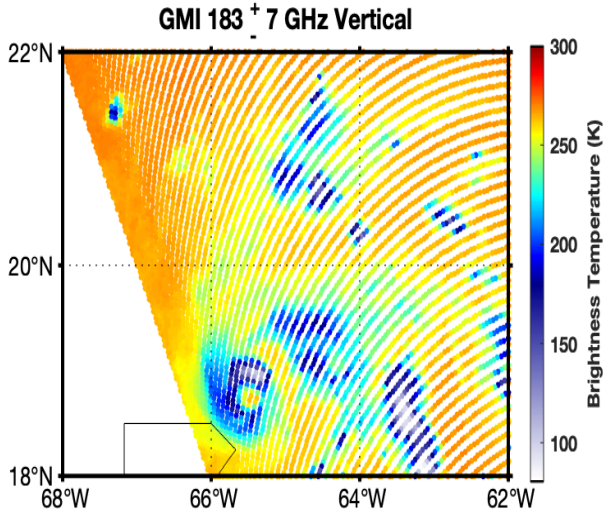
CRTM Model Simulations

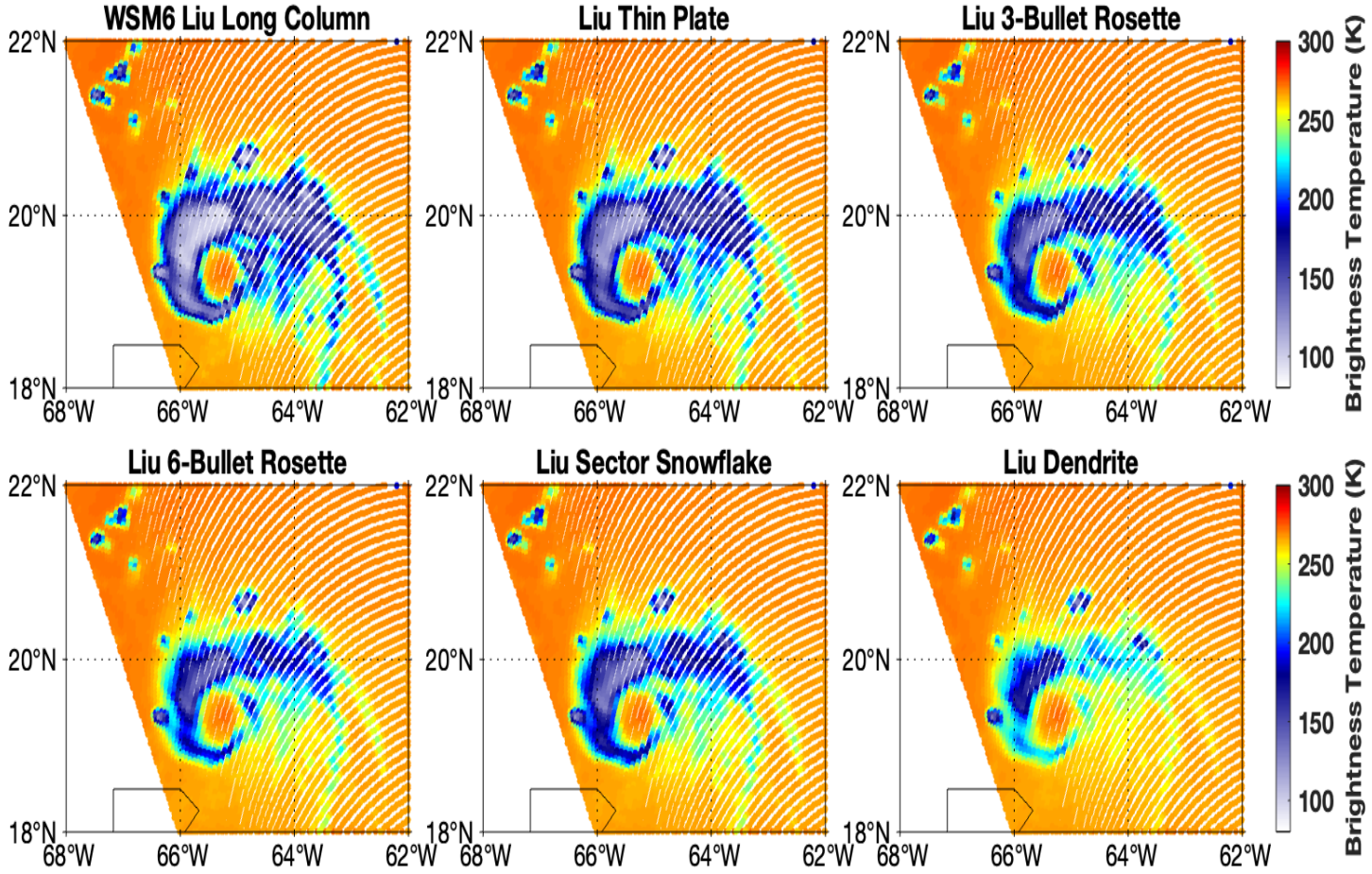
GMI Observation



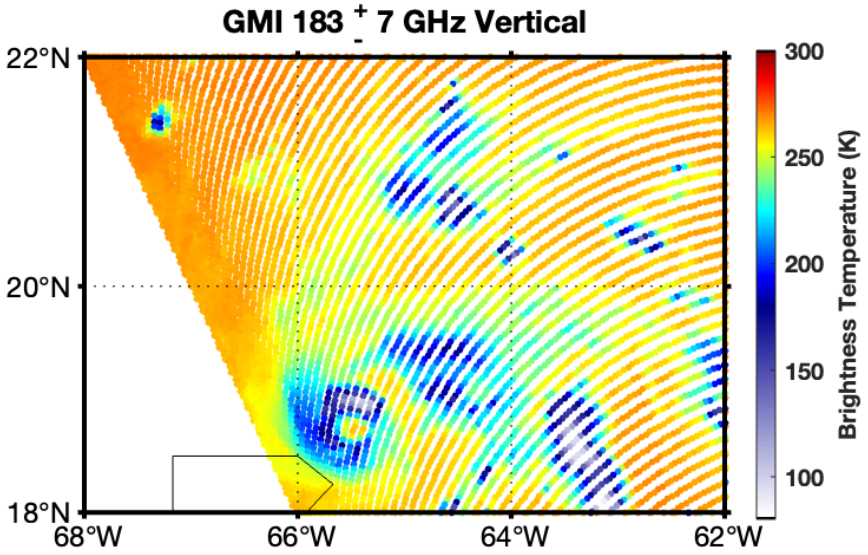



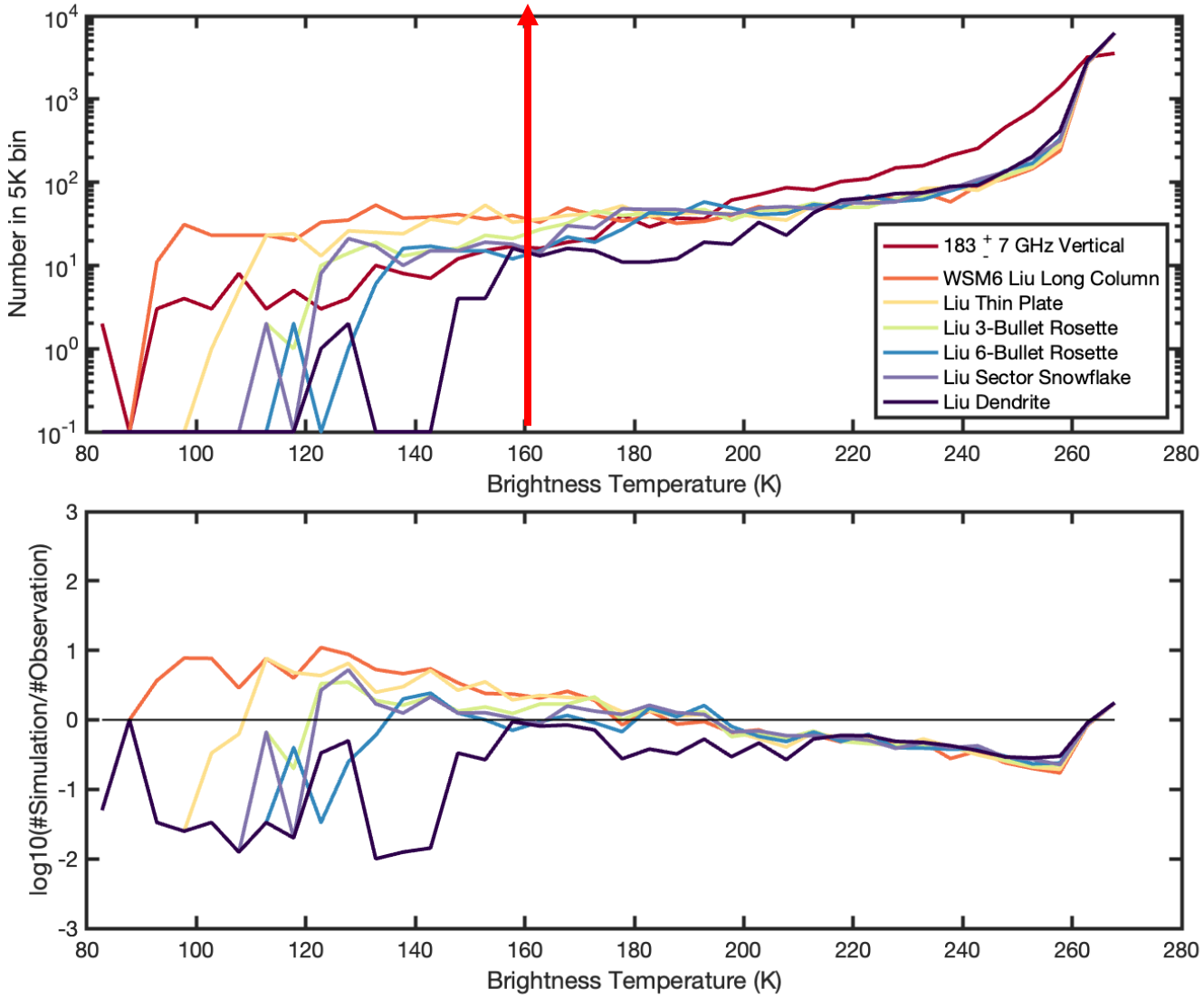
# Observation vs WSM6 Simulations, Liu Particles



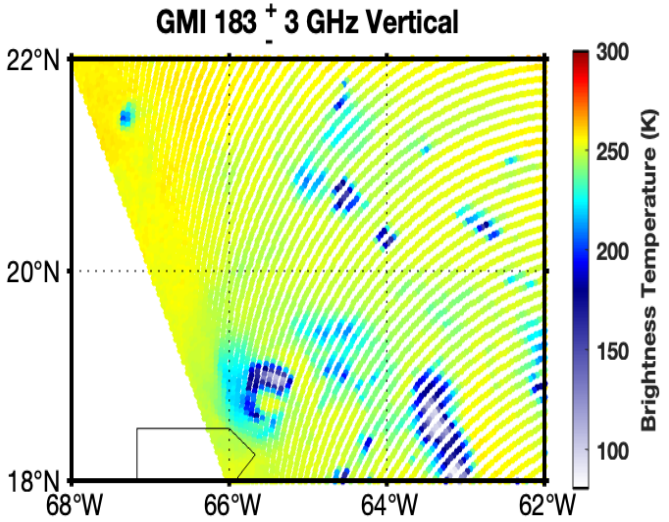
# 183+/-7 GHz, Histogram

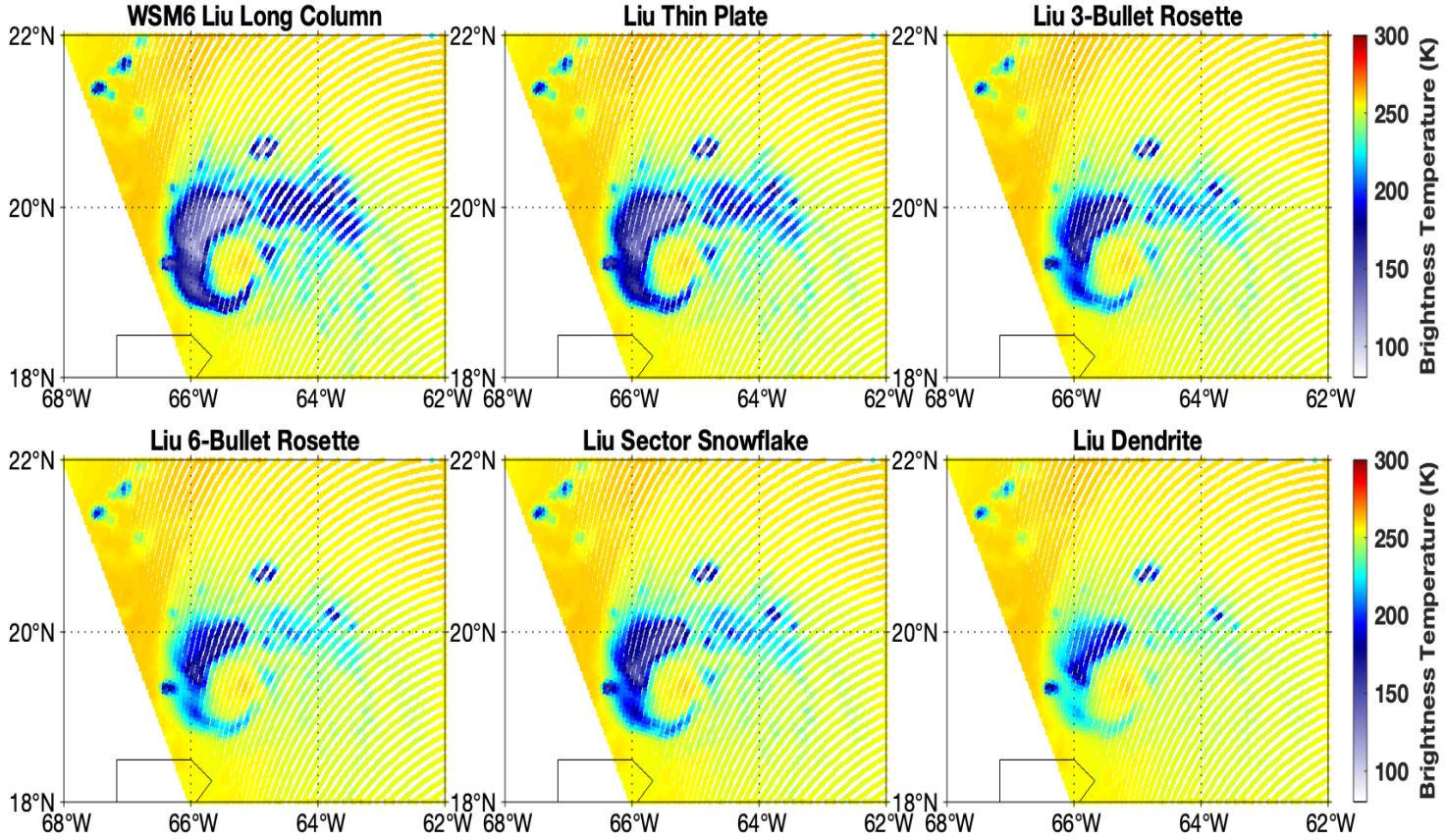


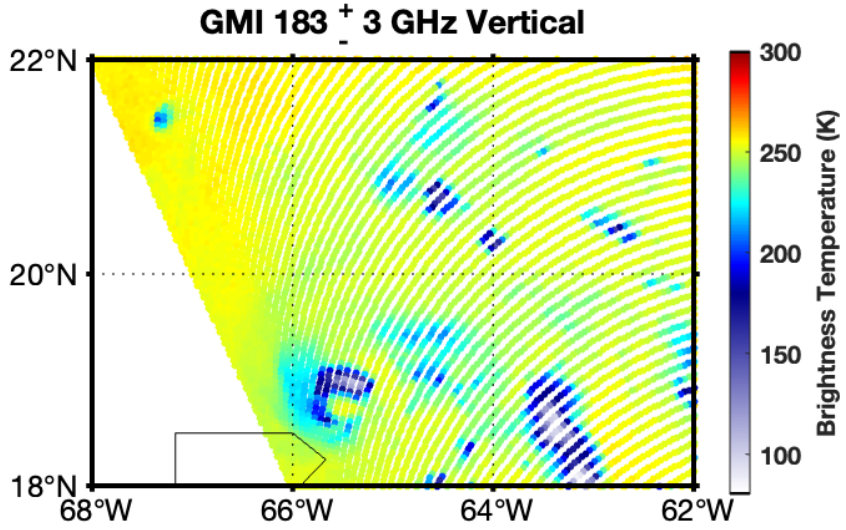

$$\log_{10}\frac{\#Simulation}{\#Observation}=\log_{10}\frac{10^3}{10^3}=0$$

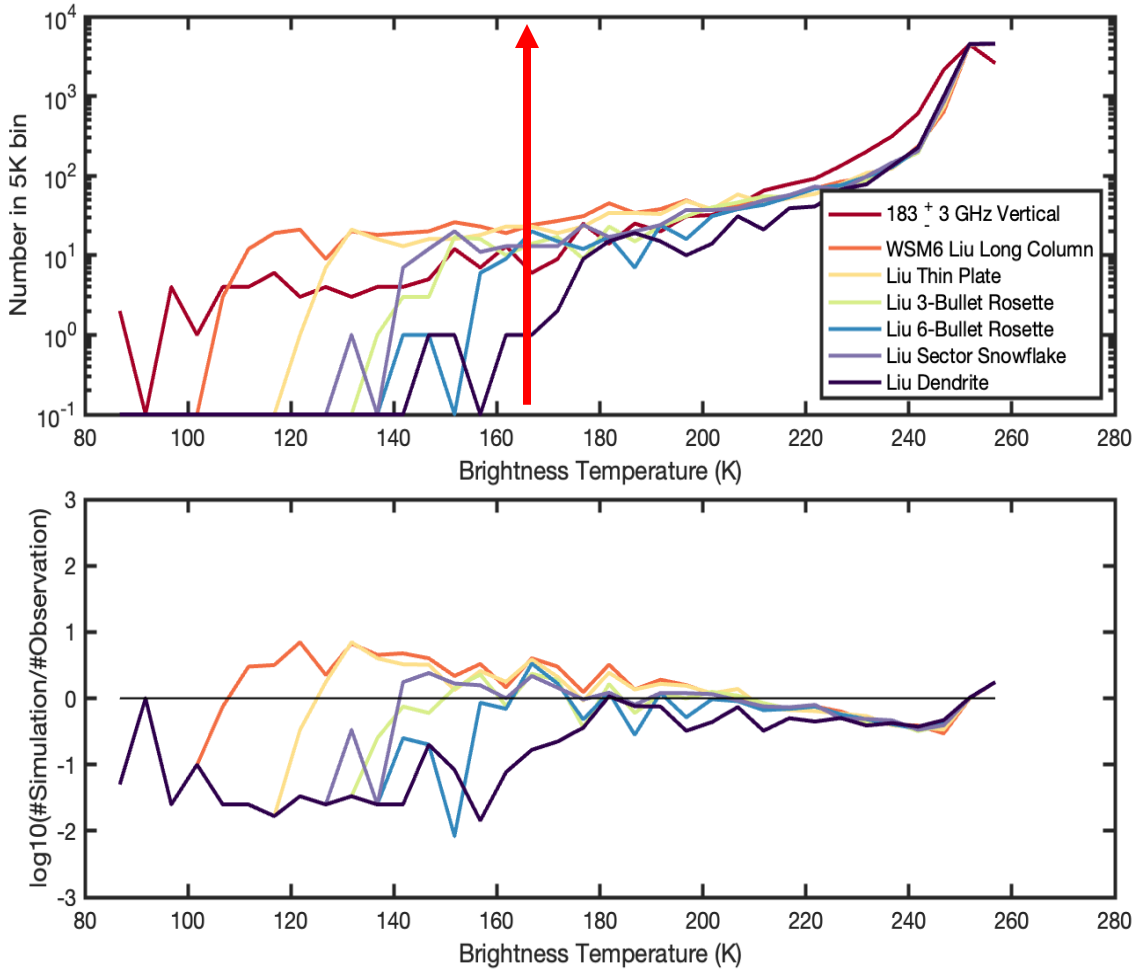
# 183+/- 3 GHz, Brightness Temperature



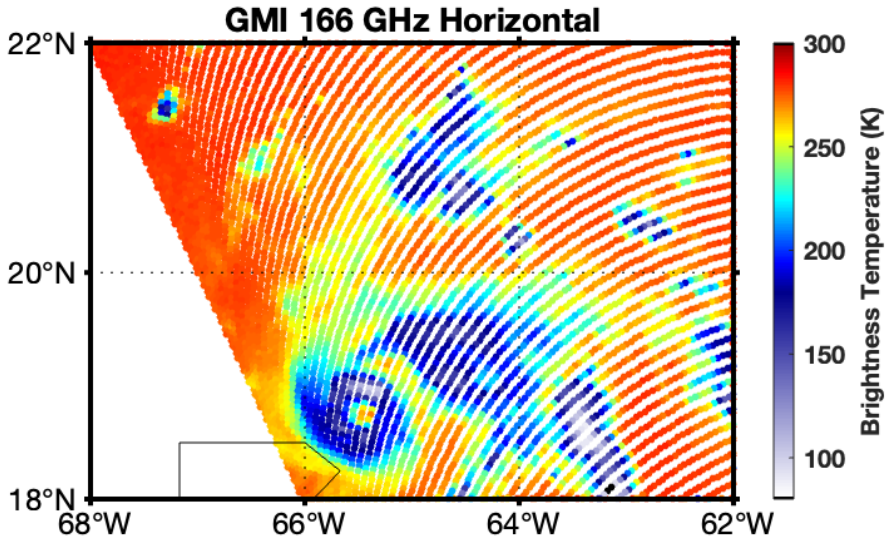



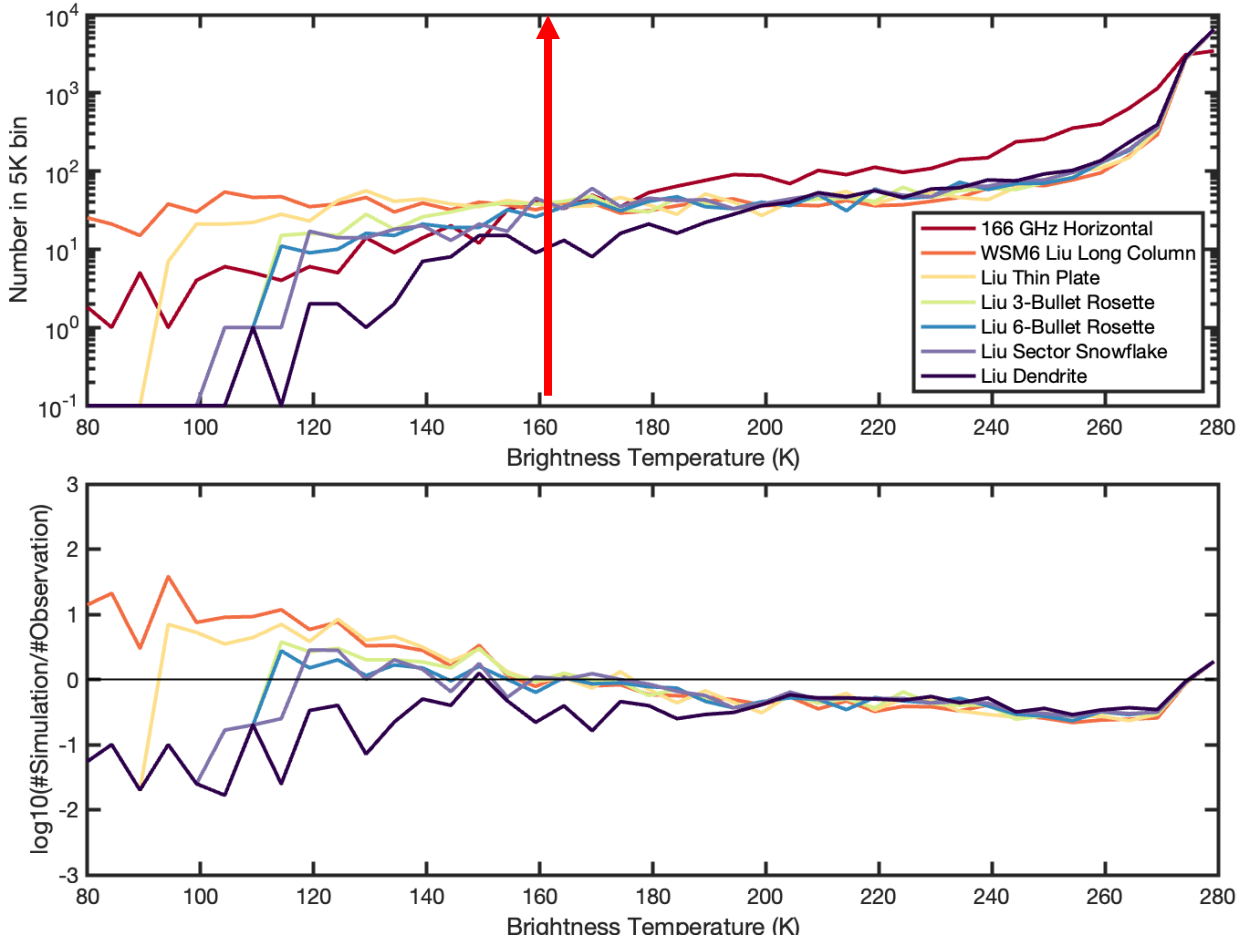
# 183+/-3 GHz, Histogram



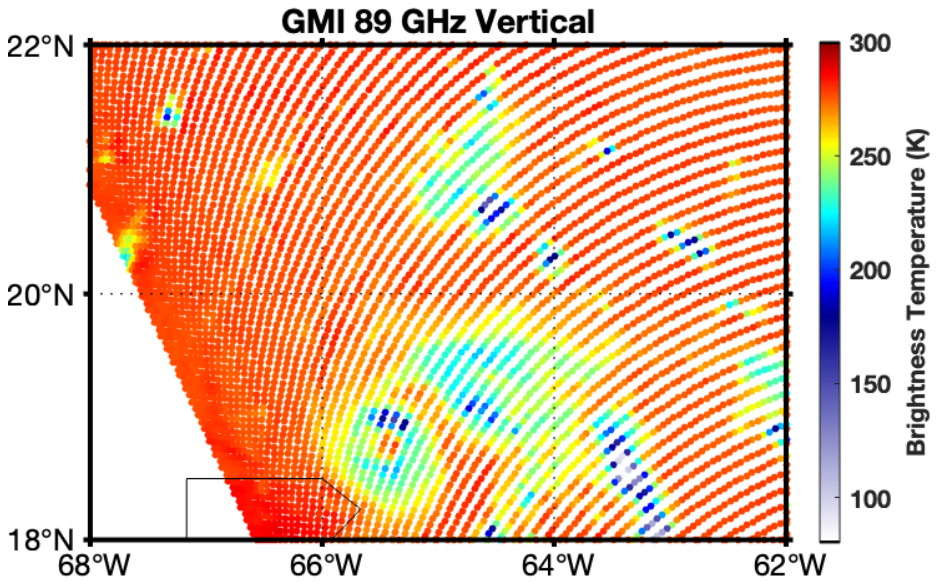



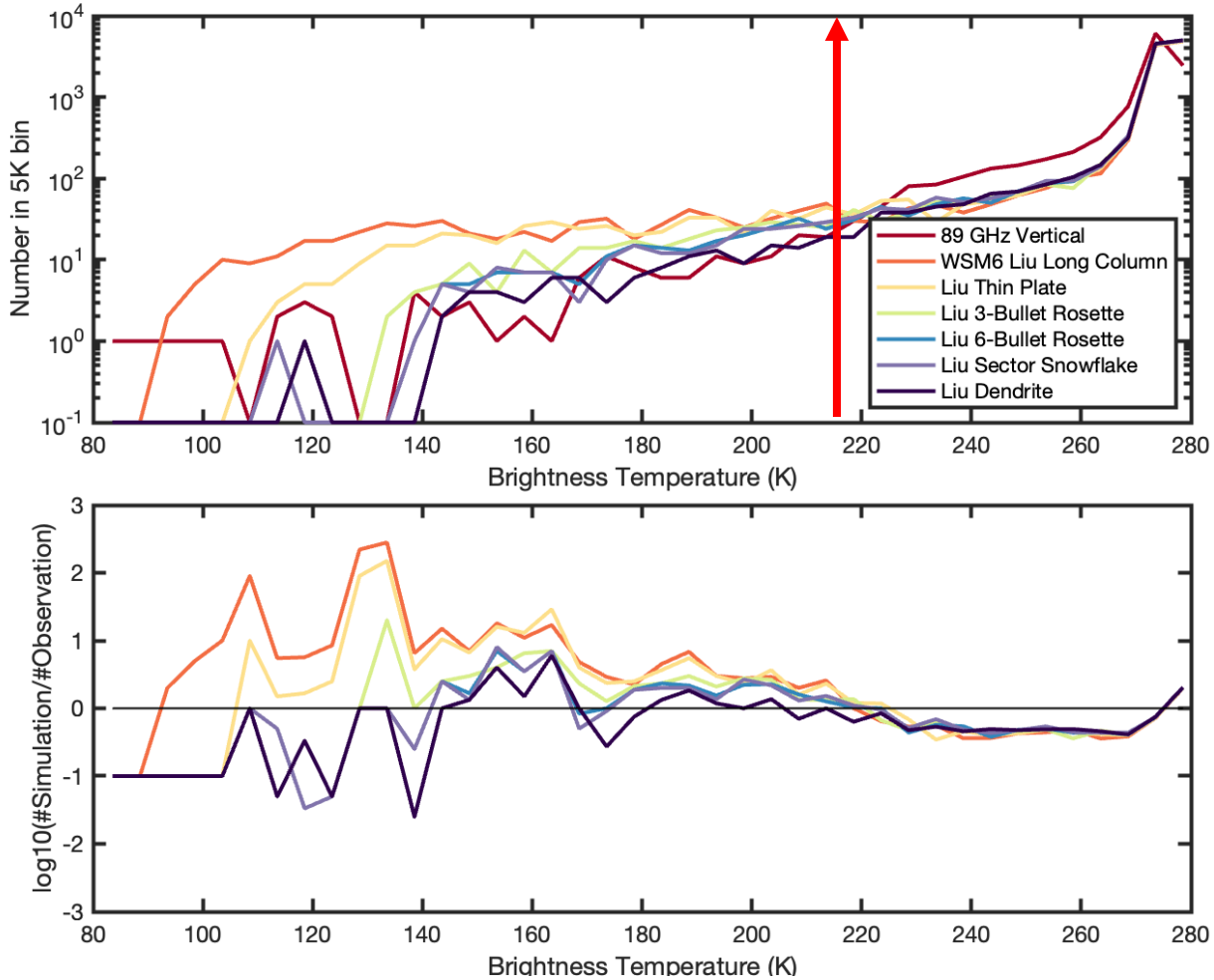
# 166 GHz, Histogram



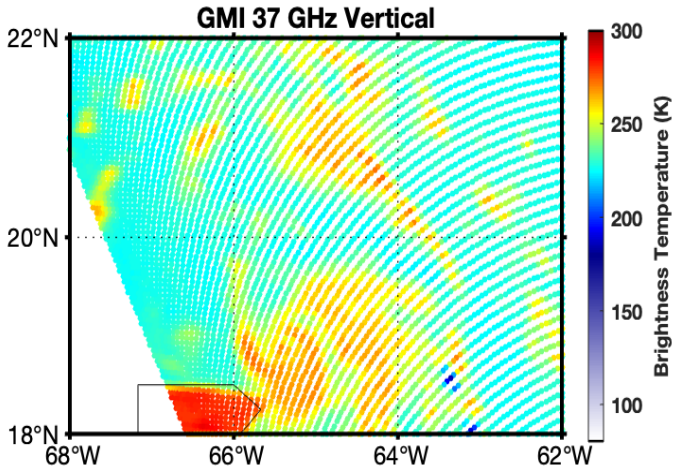



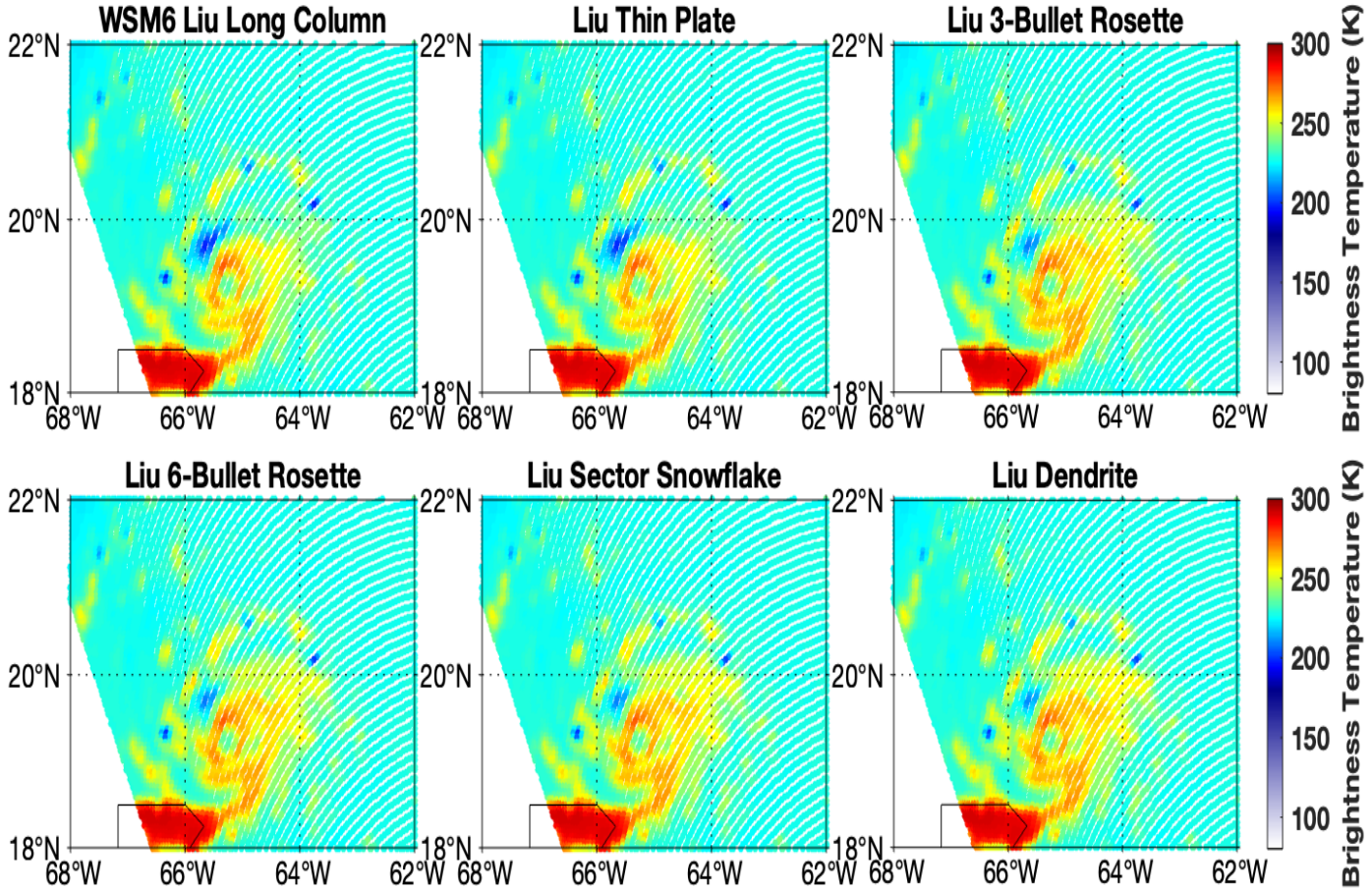
# 89 GHz, Histogram



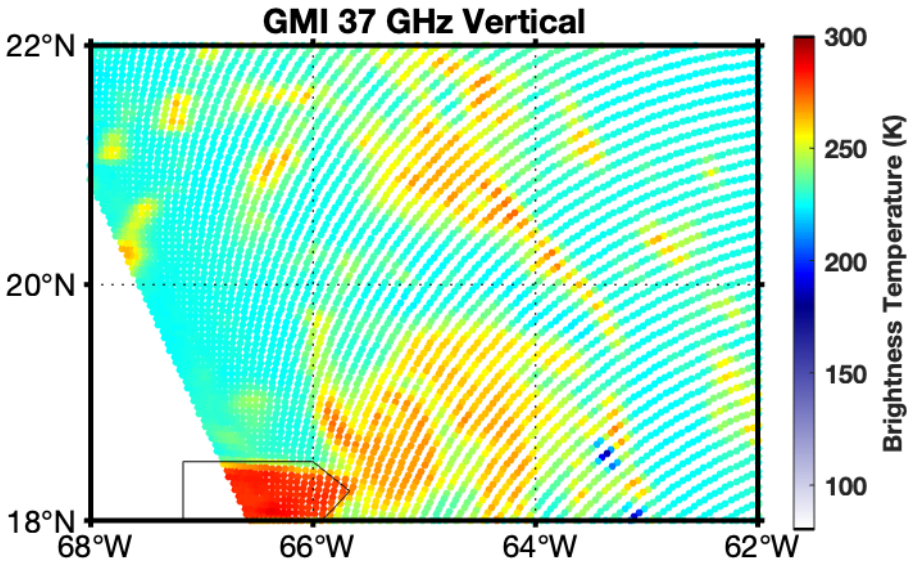



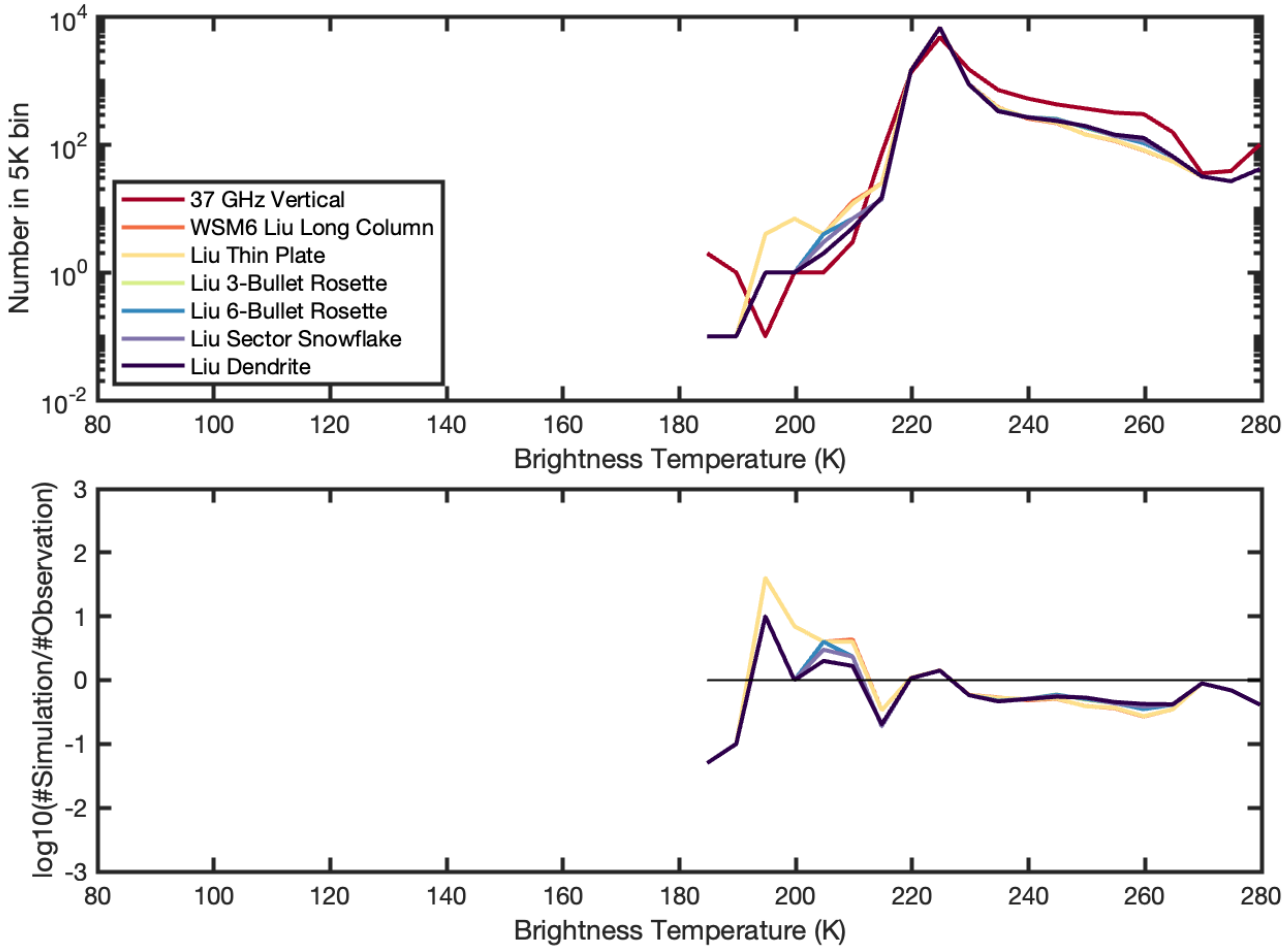
# 37 GHz, Brightness Temperature



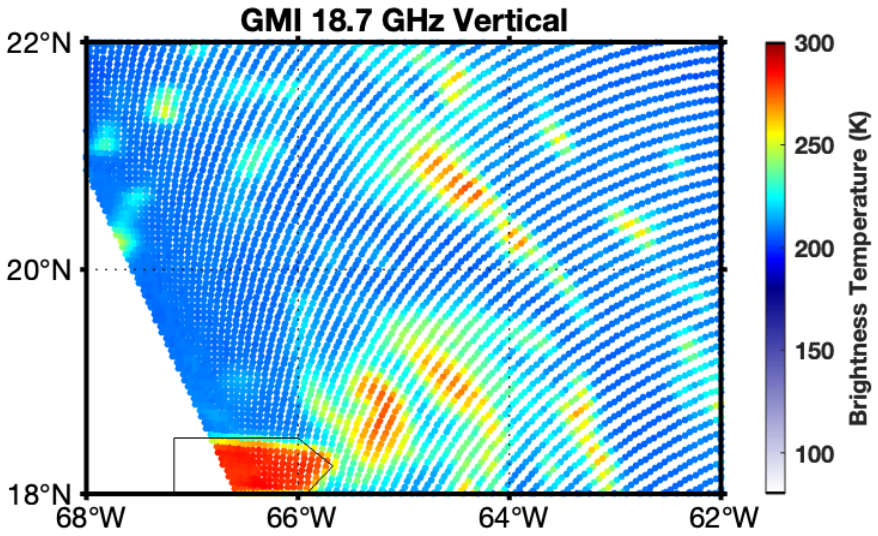



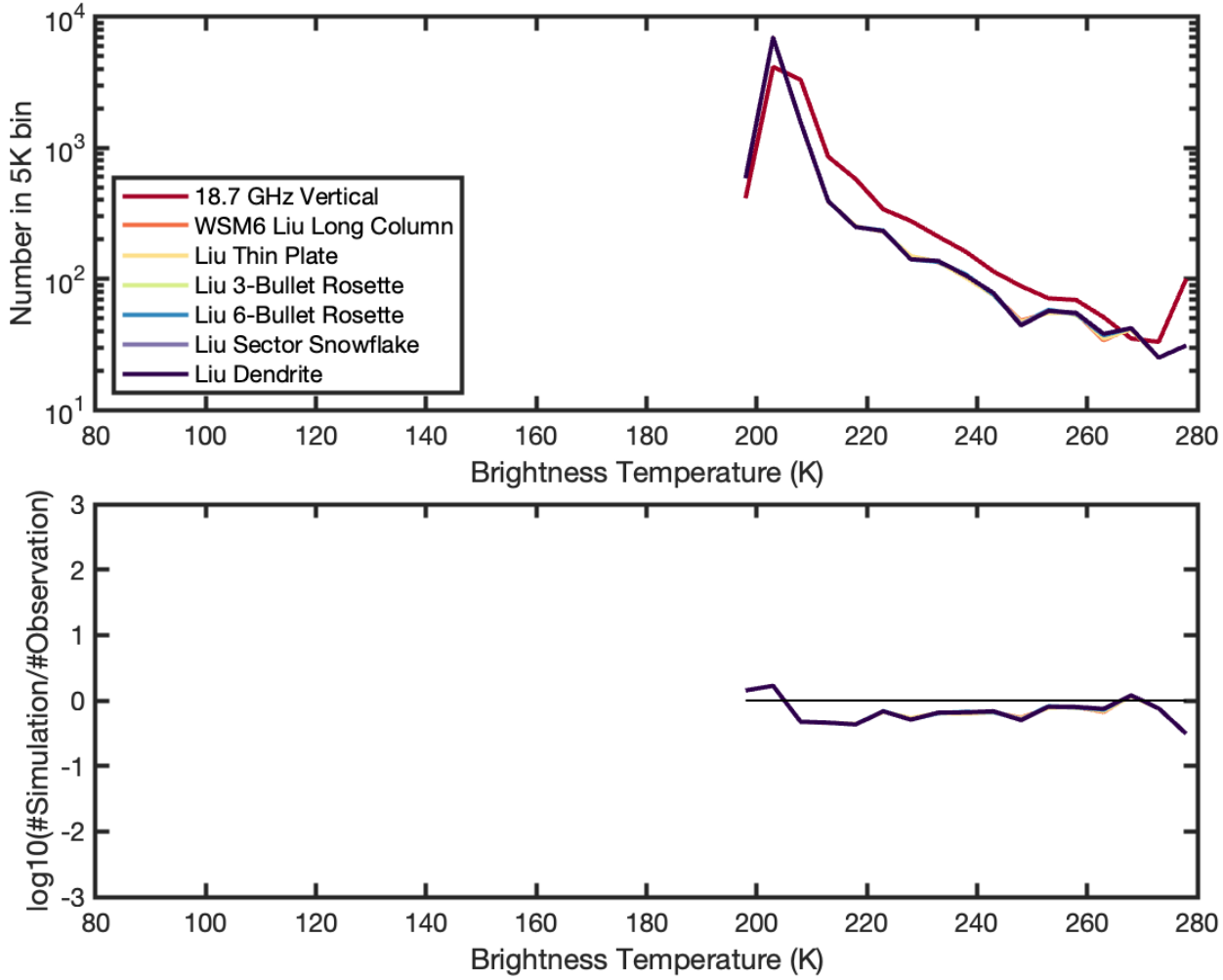
# 37 GHz, Histogram



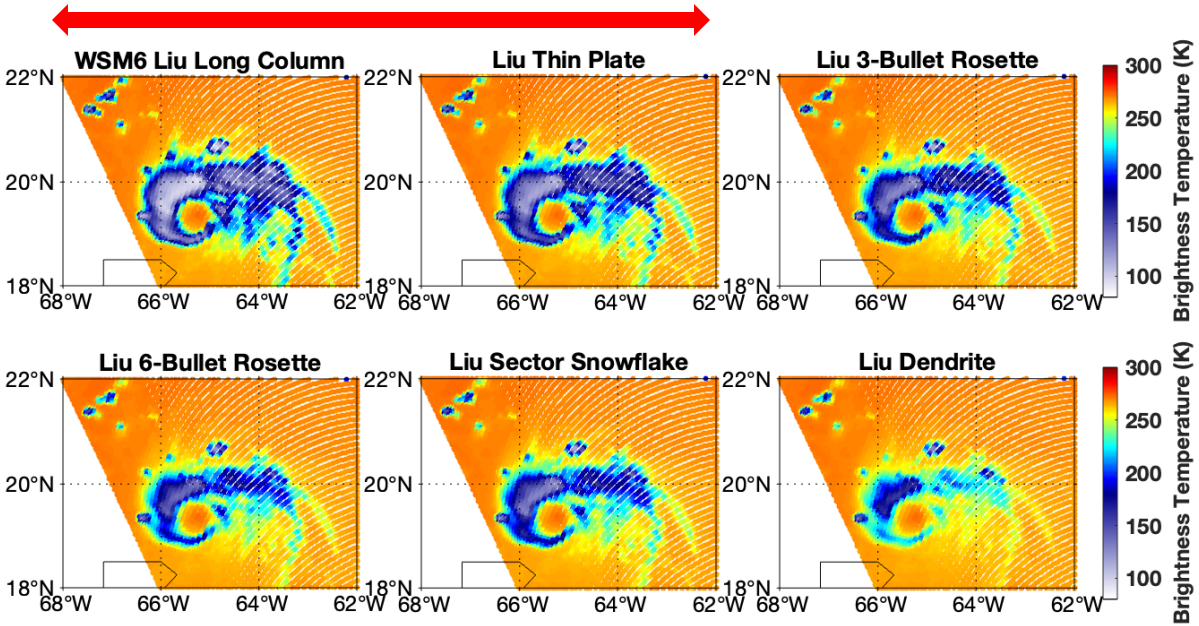



# 18.7 GHz, Histogram

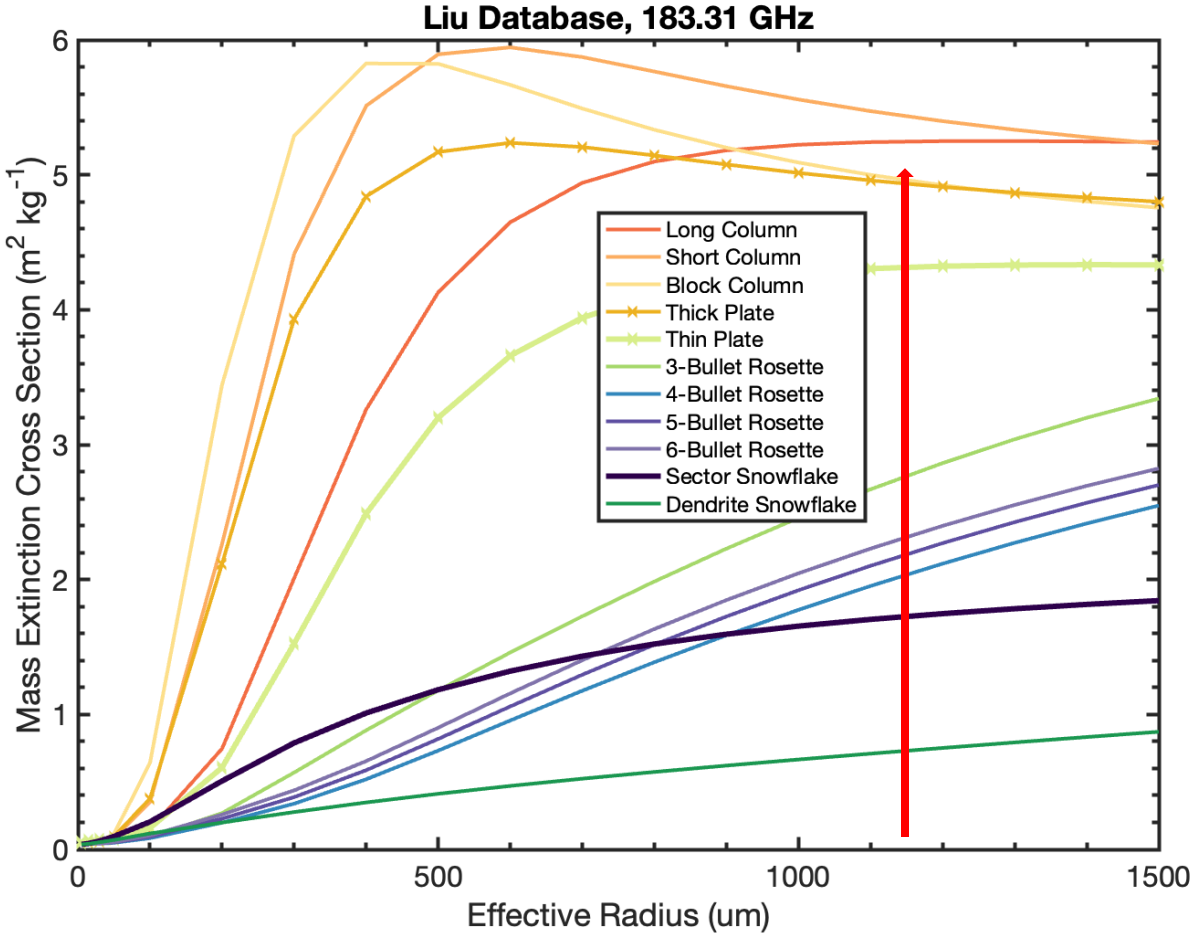


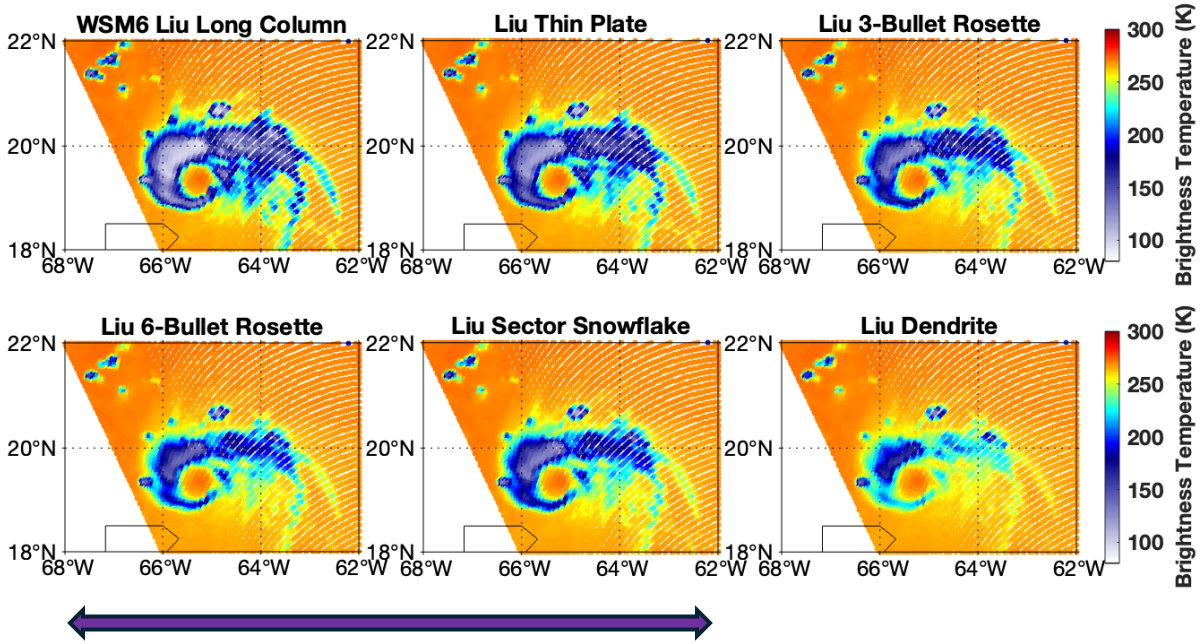
# Liu Particles Behaviour, 183+/-7 GHz



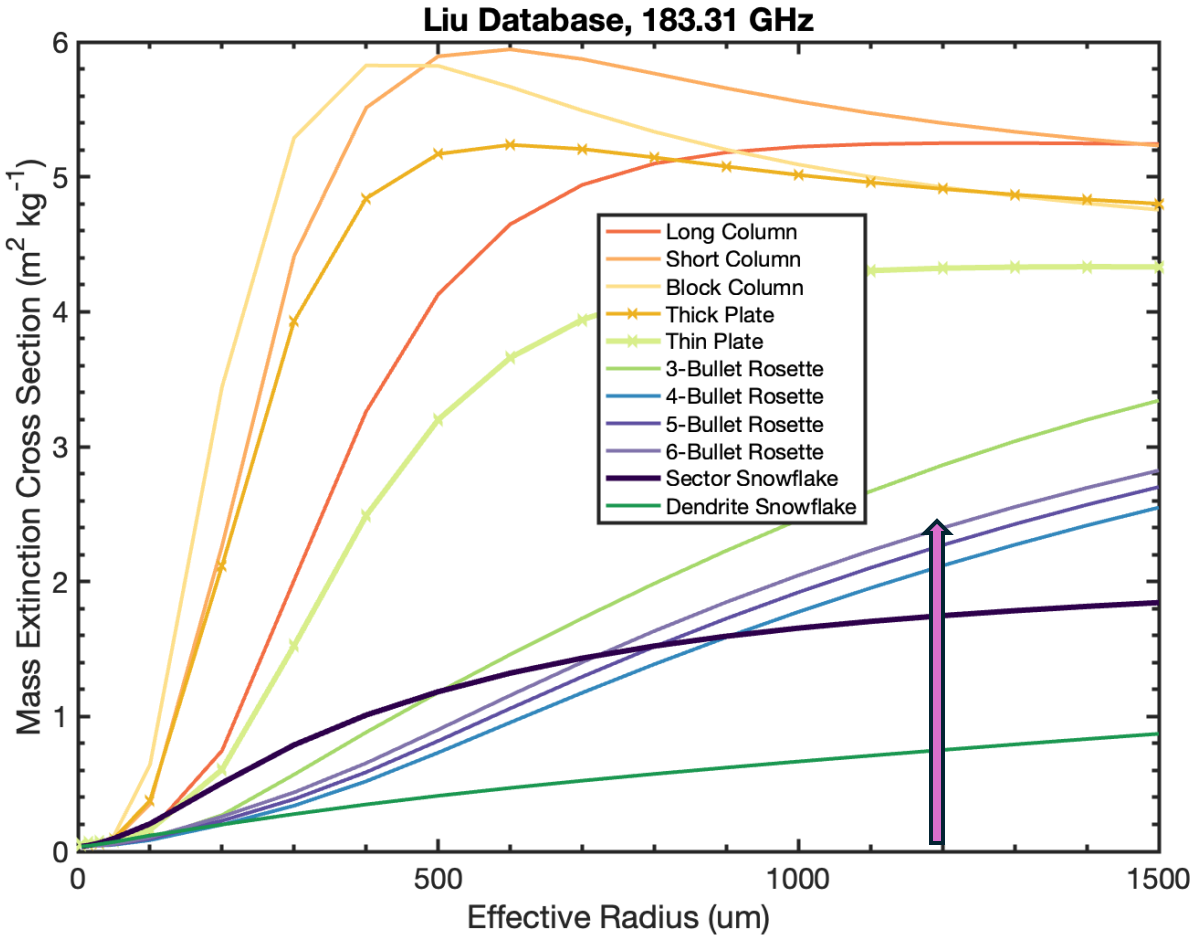

Liu Long Column
Liu Thin Plate



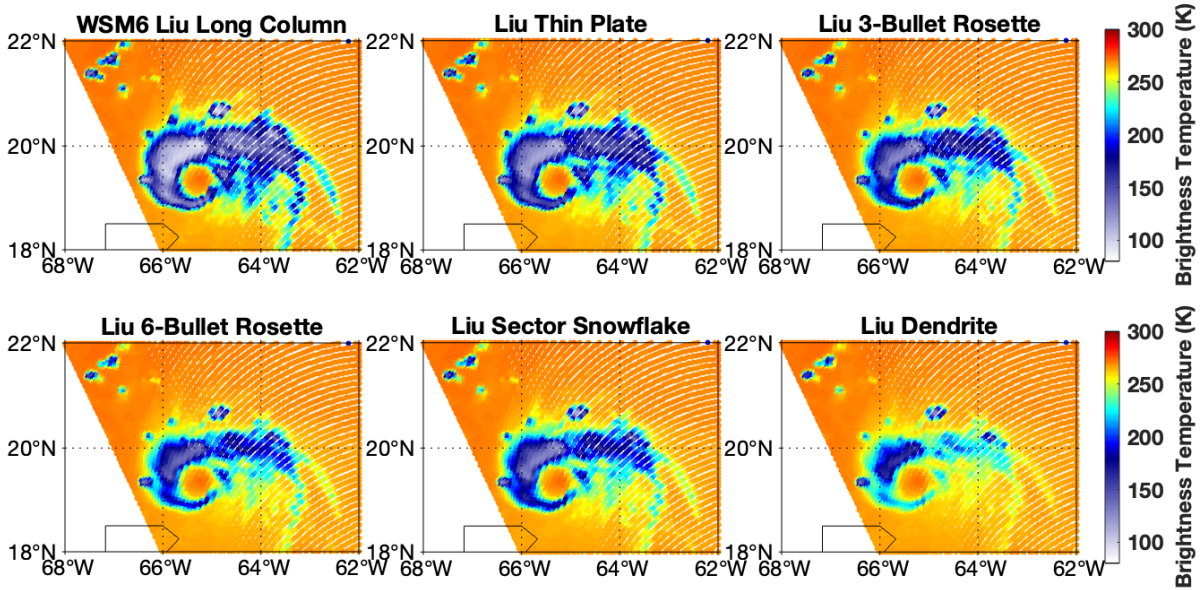
# Liu Particles Behaviour, 183+/-7 GHz



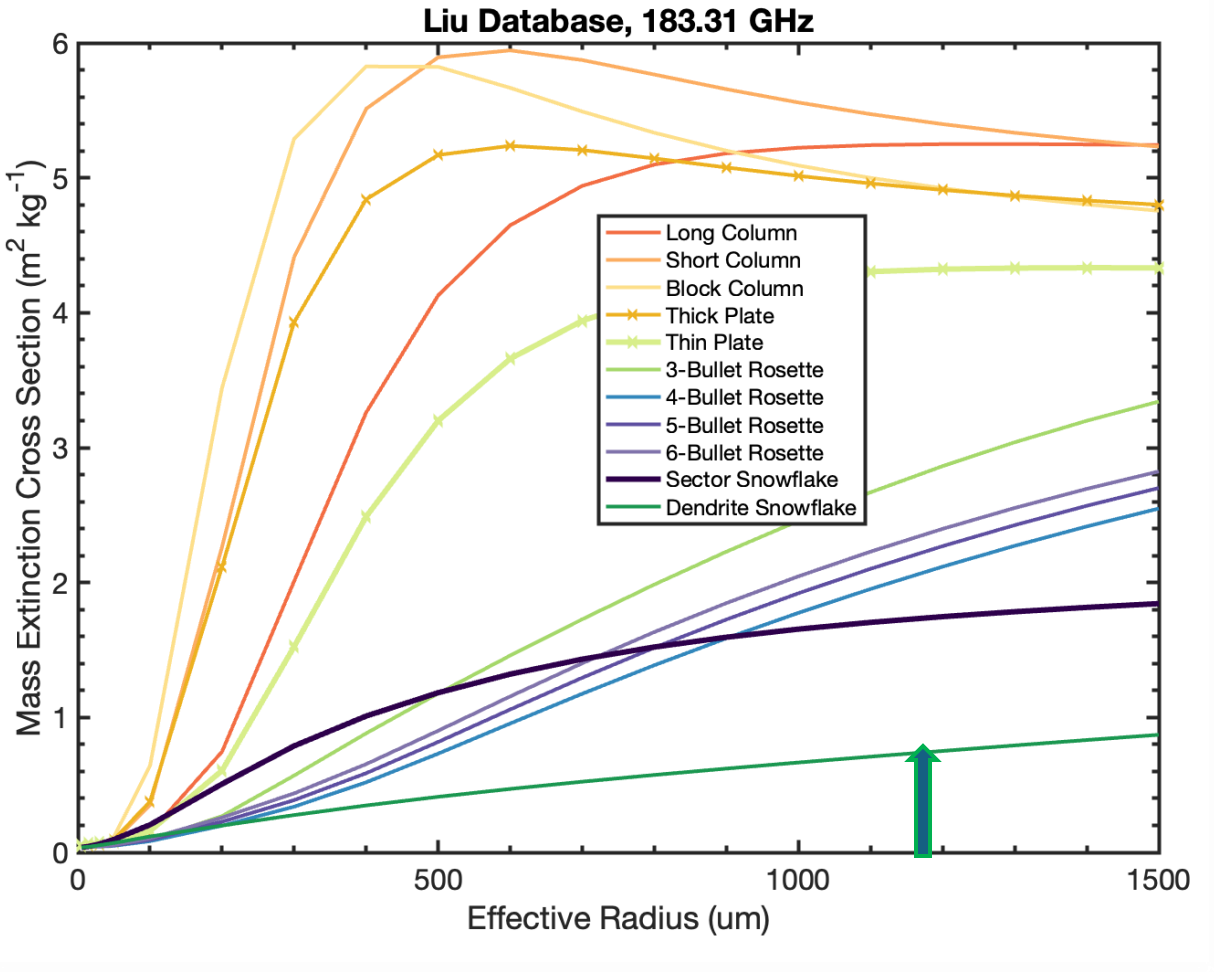

6-Bullet Rosette
Sector Snowflake



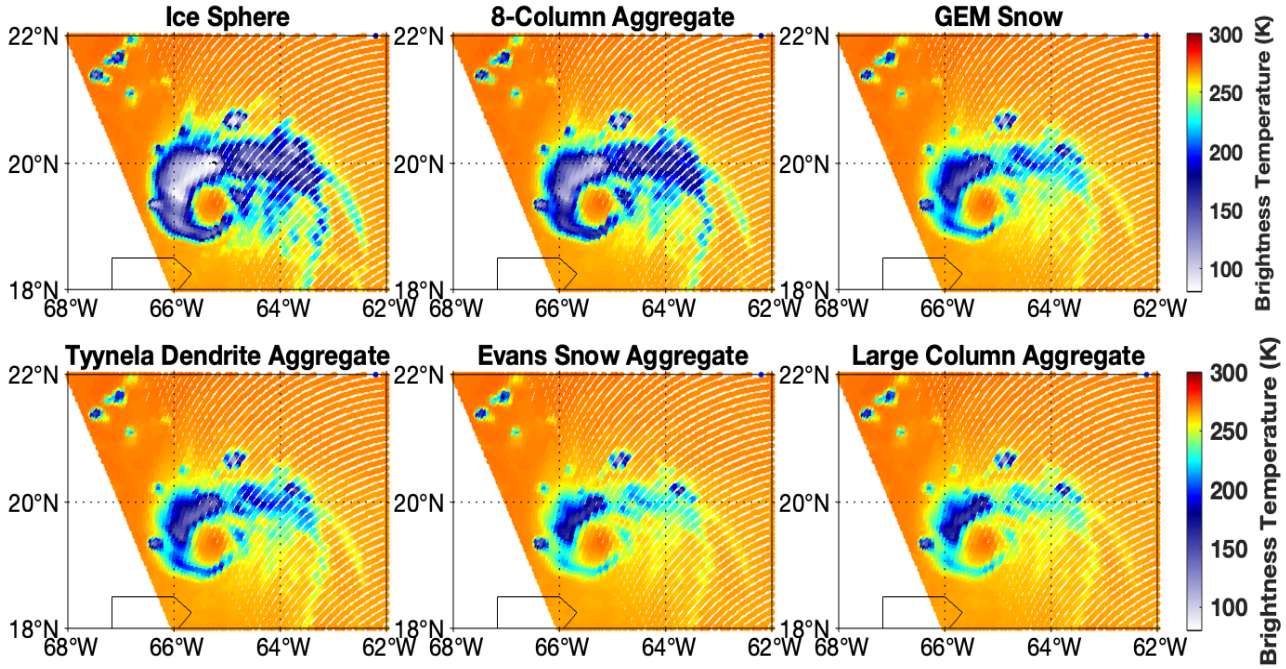
# Liu Particles Behaviour, 183+/-7 GHz

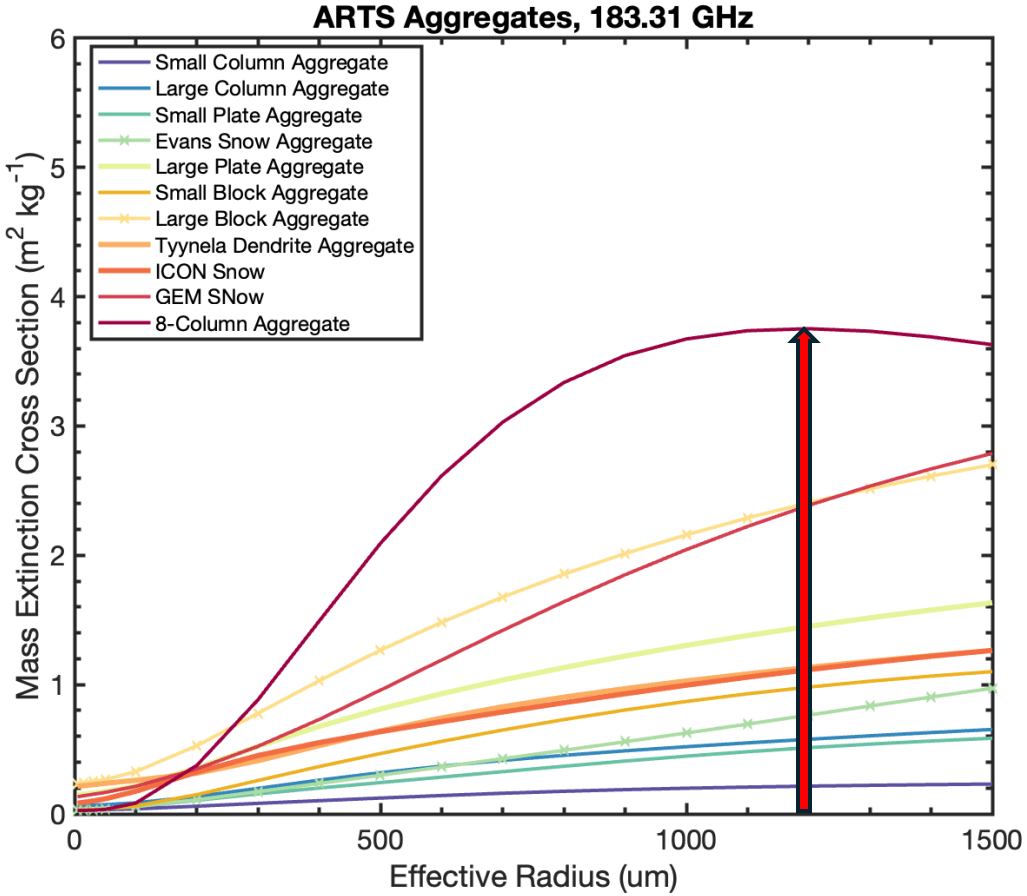



Dendrite



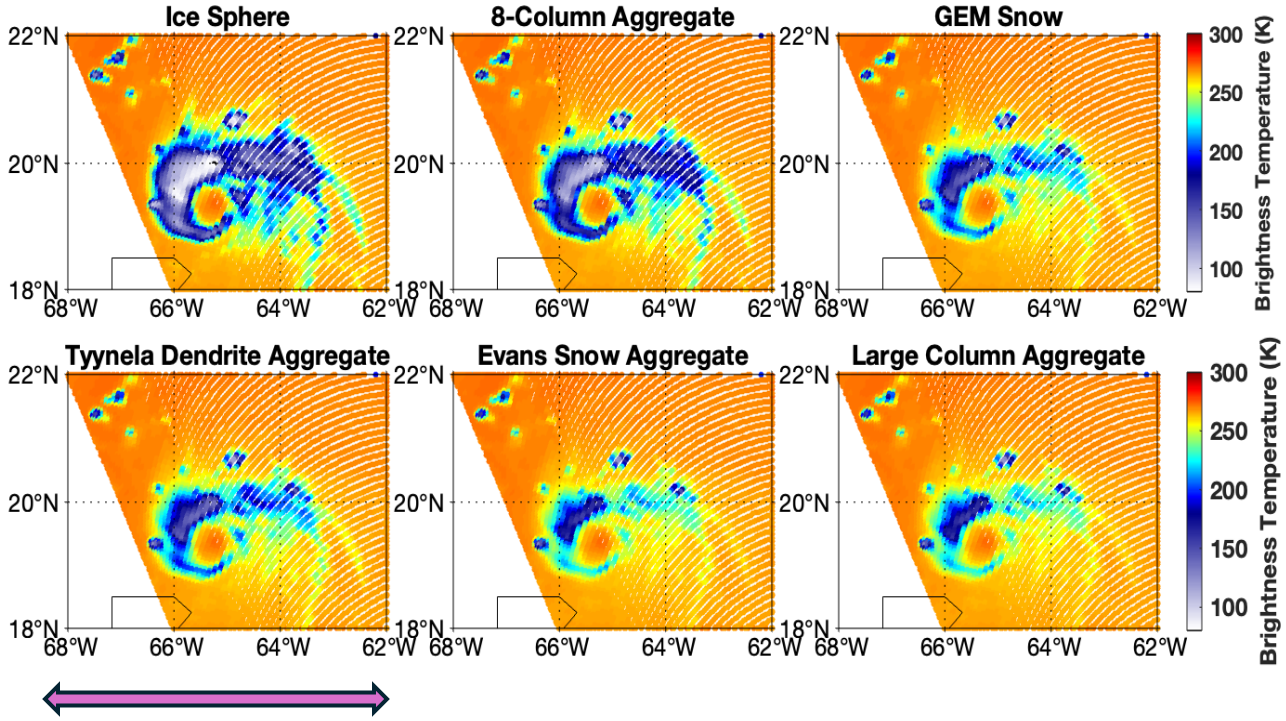
# ARTS Aggregates



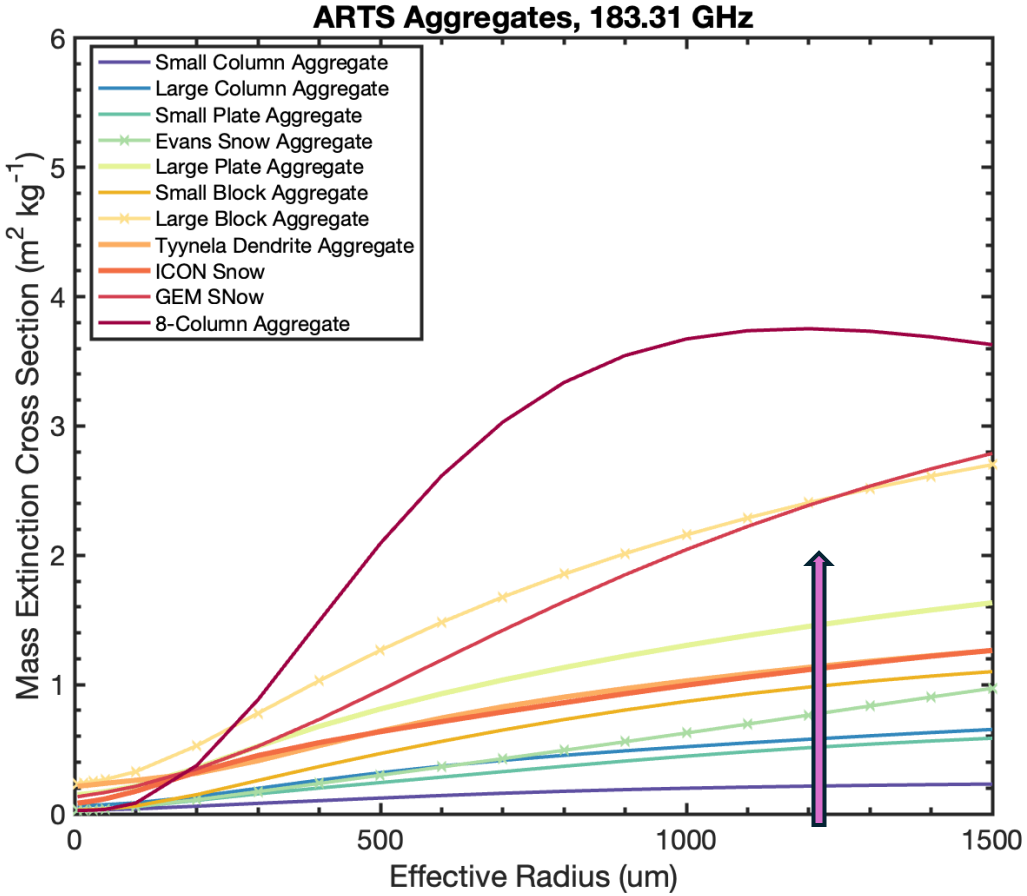




Ice Sphere
8-Column Aggregate

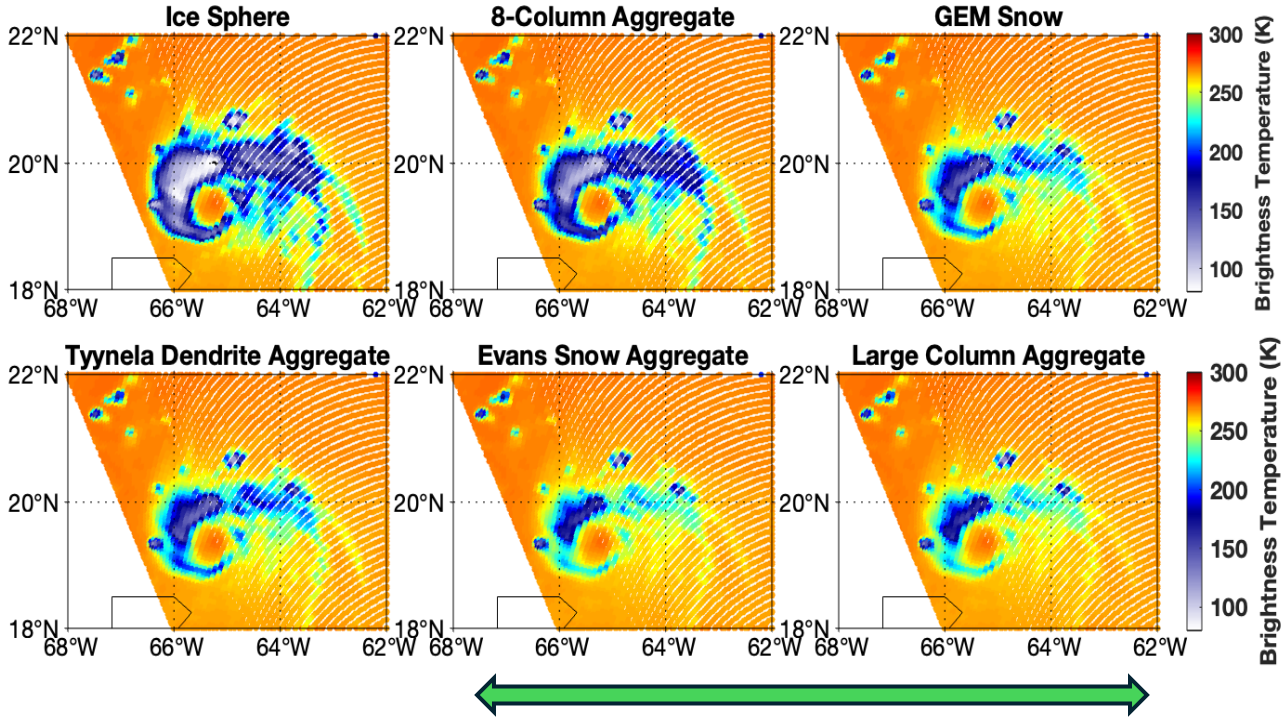
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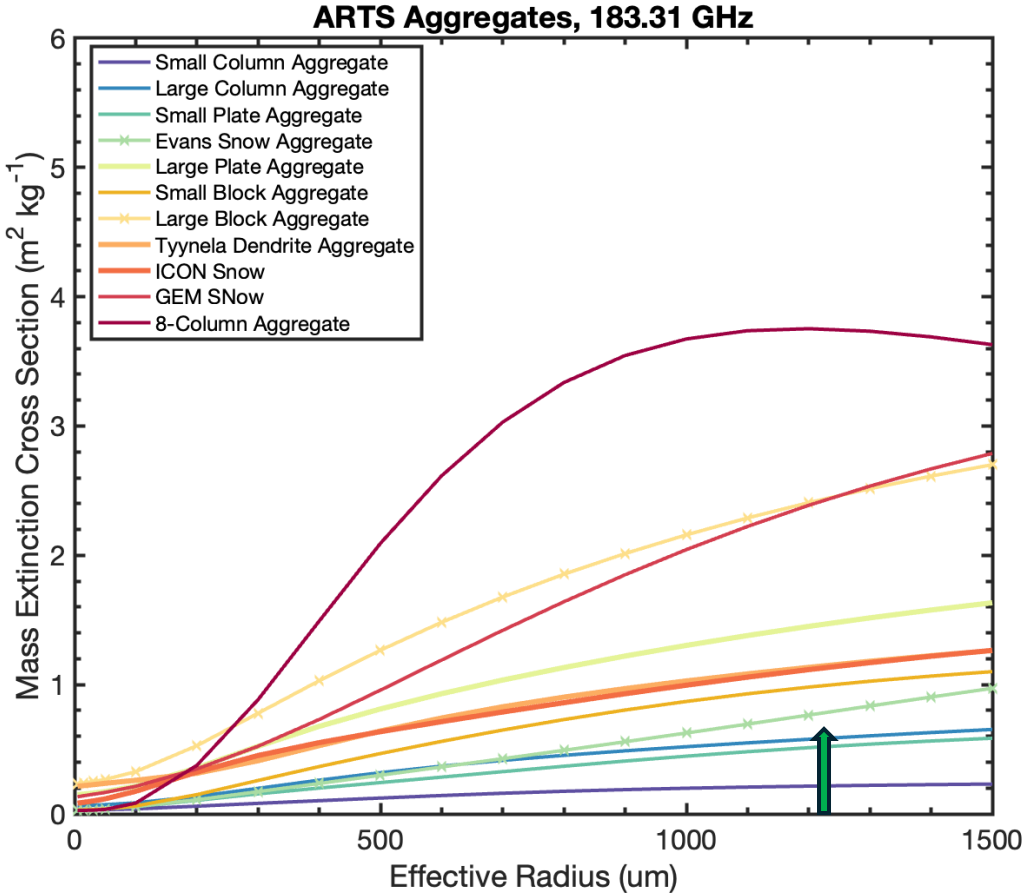

GEM Snow
Tyynela Dendrite



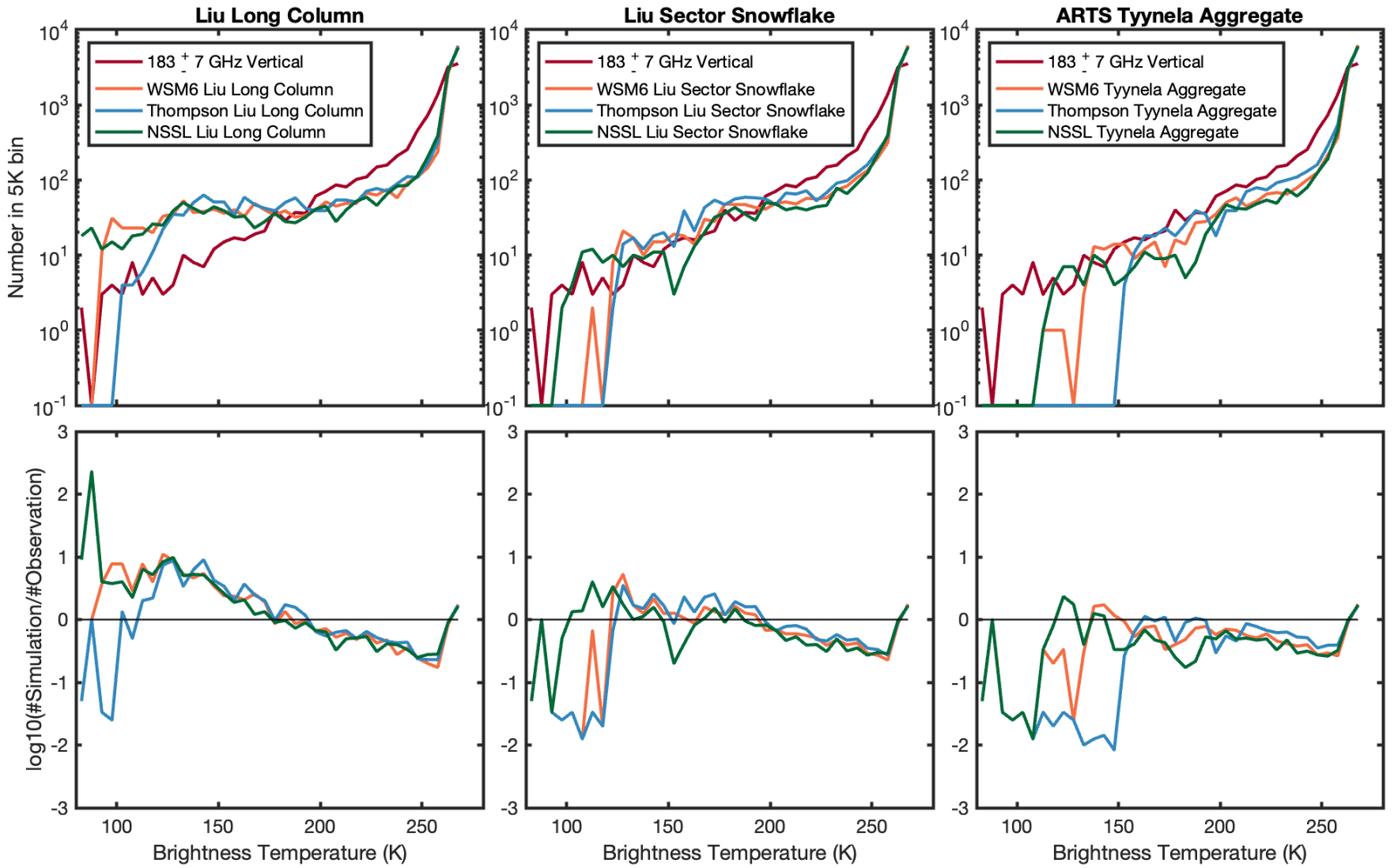
# ARTS Aggregates



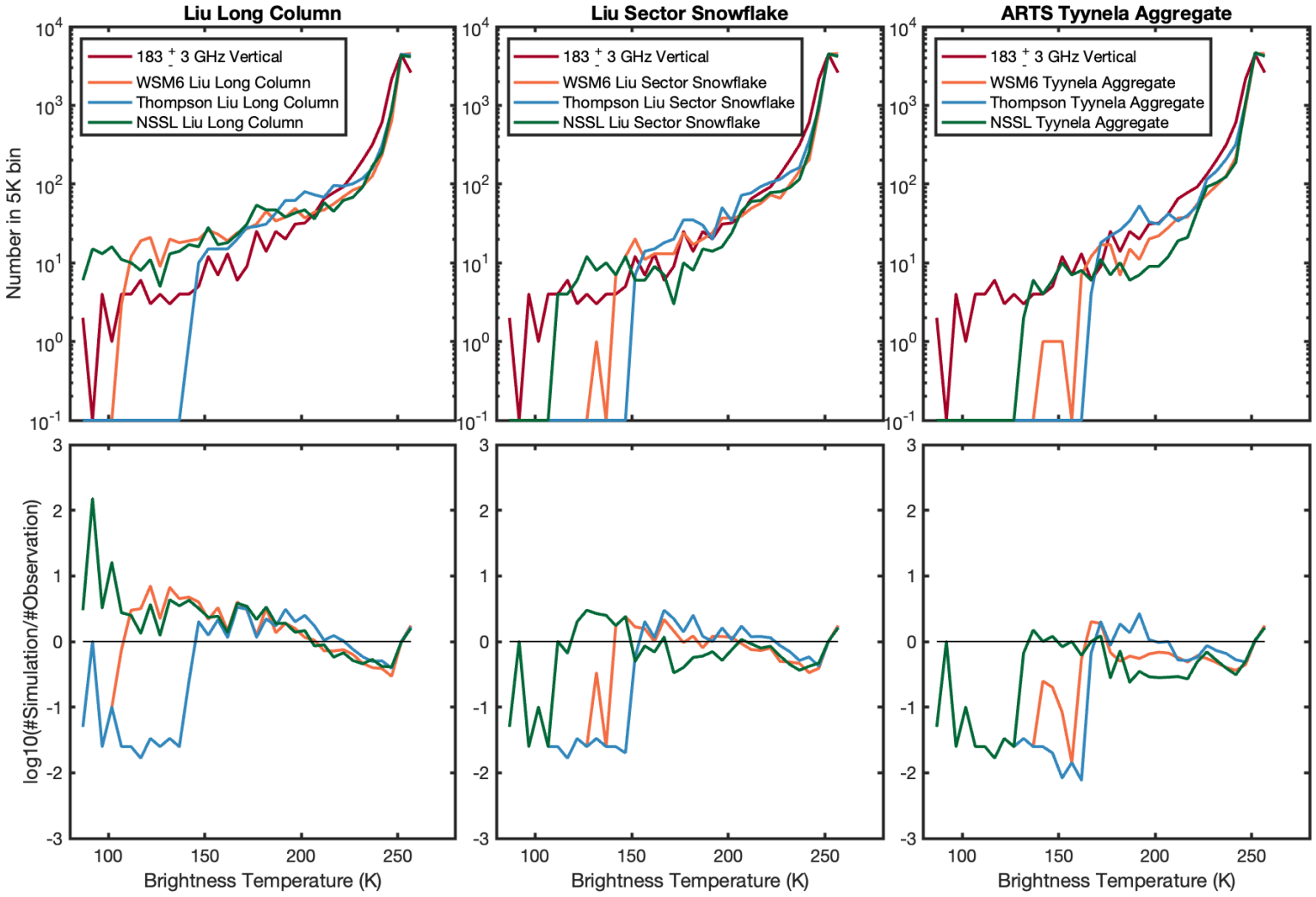

Evans Snow Aggregate
Large Column Aggregate



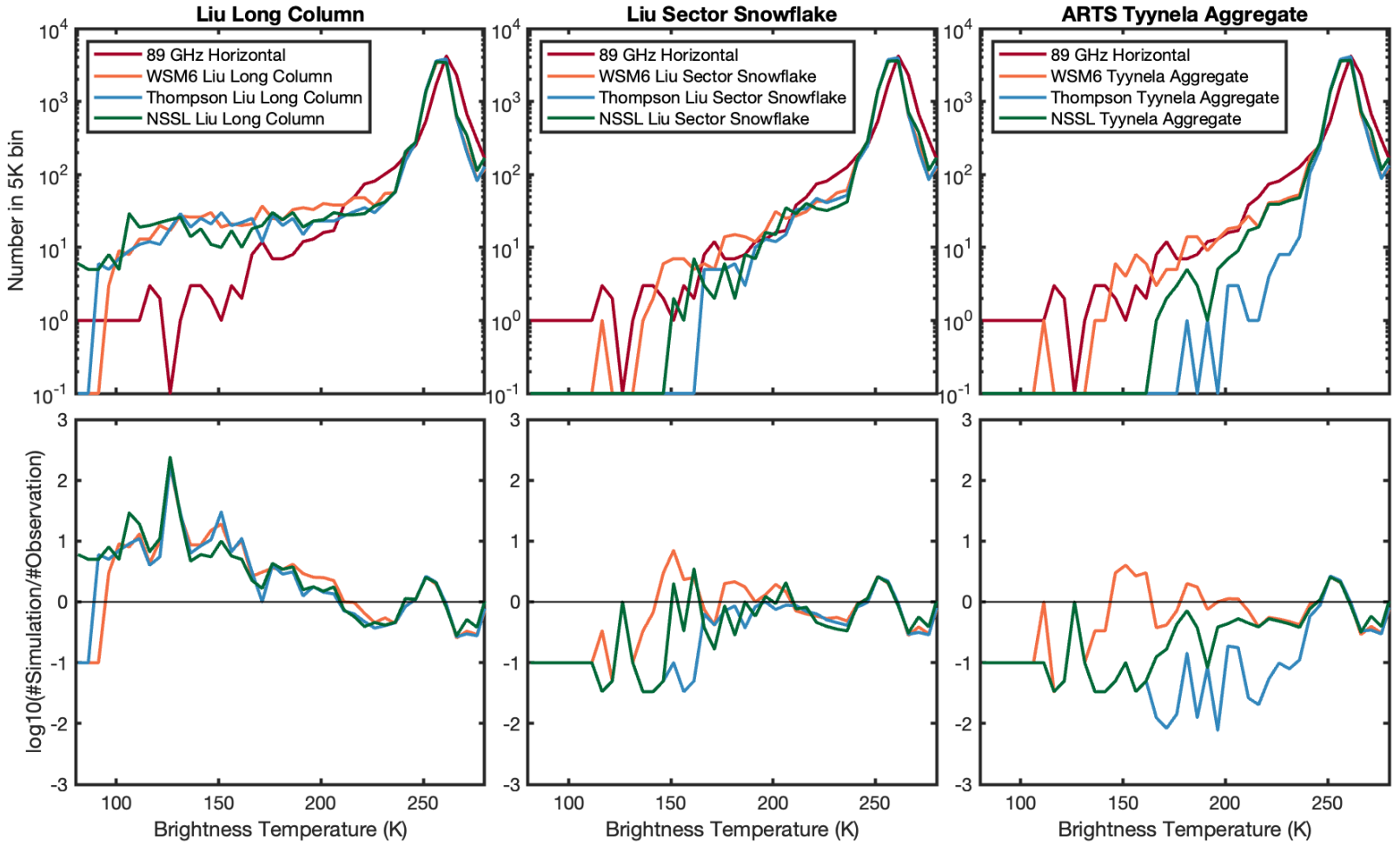
# 183+/-7 GHz


Liu Long Column
Liu Sector Snowflake
ARTS Tyynela Aggregate
183 ± 7 GHz Vertical
WSM6 Liu Long Column
Thompson Liu Long Column
NSSL Liu Long Column
WSM6 Liu Sector Snowflake
Thompson Liu Sector Snowflake
NSSL Liu Sector Snowflake
WSM6 Tyynela Aggregate
Thompson Tyynela Aggregate
NSSL Tyynela Aggregate
Number in 5K bin
log10(#Simulation/#Observation)
Brightness Temperature (K)

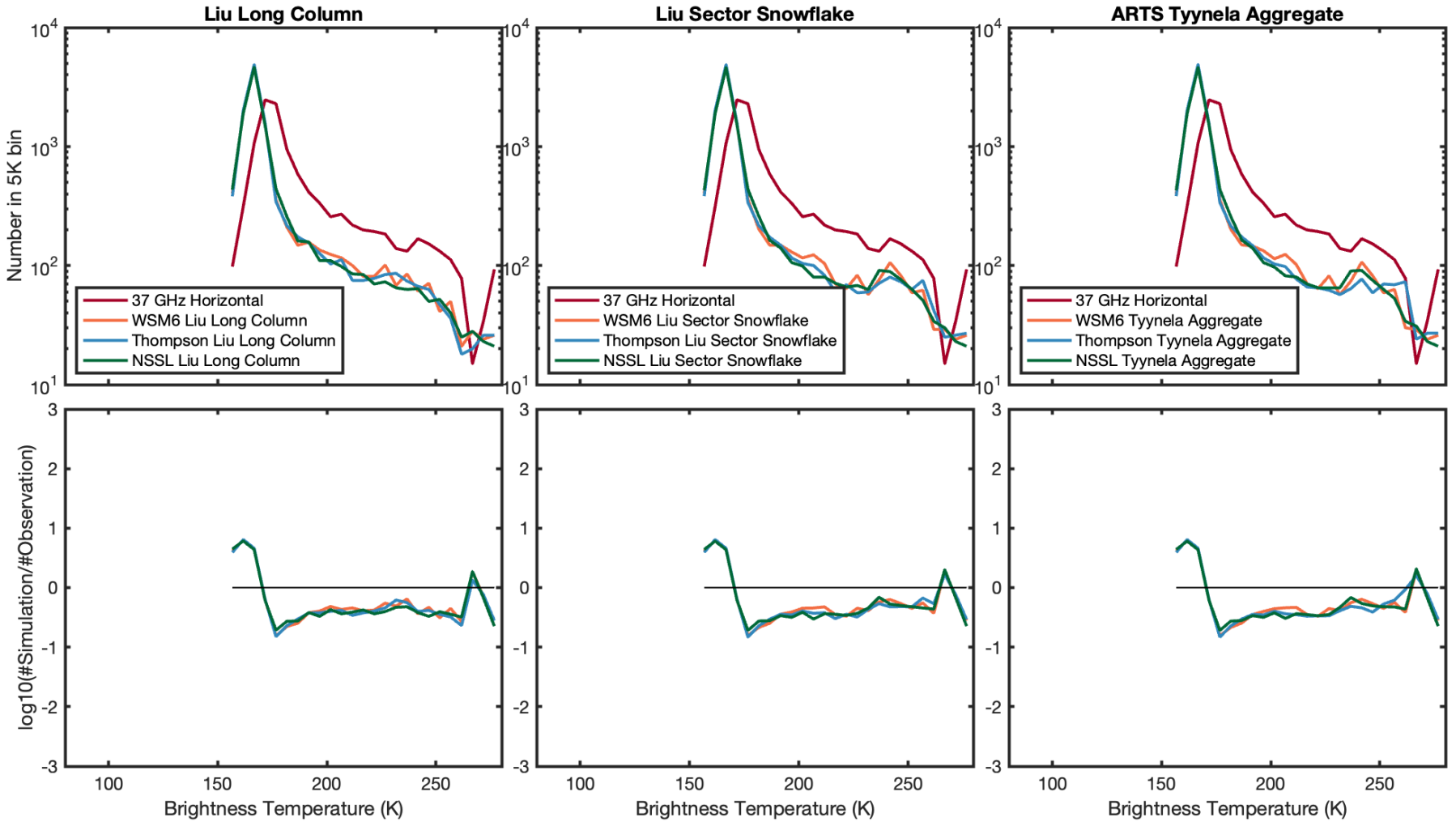
# 183+/-3 GHz


Liu Long Column
Liu Sector Snowflake
ARTS Tyynela Aggregate
183 ± 3 GHz Vertical
WSM6 Liu Long Column
Thompson Liu Long Column
NSSL Liu Long Column
WSM6 Liu Sector Snowflake
Thompson Liu Sector Snowflake
NSSL Liu Sector Snowflake
WSM6 Tyynela Aggregate
Thompson Tyynela Aggregate
NSSL Tyynela Aggregate
Number in 5K bin
log10(#Simulation/#Observation)
Brightness Temperature (K)

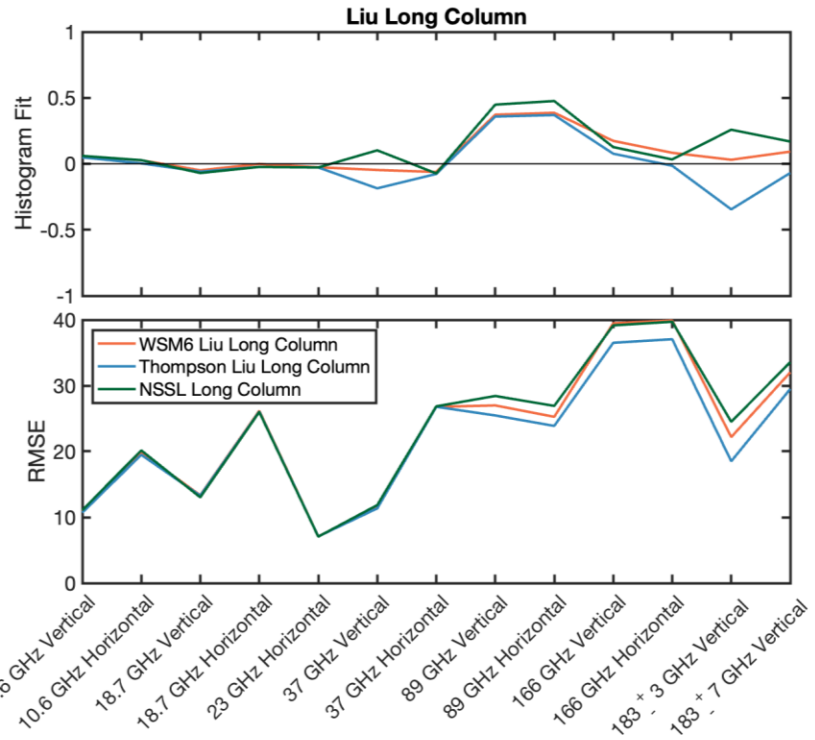
# 89 GHz Horizontal



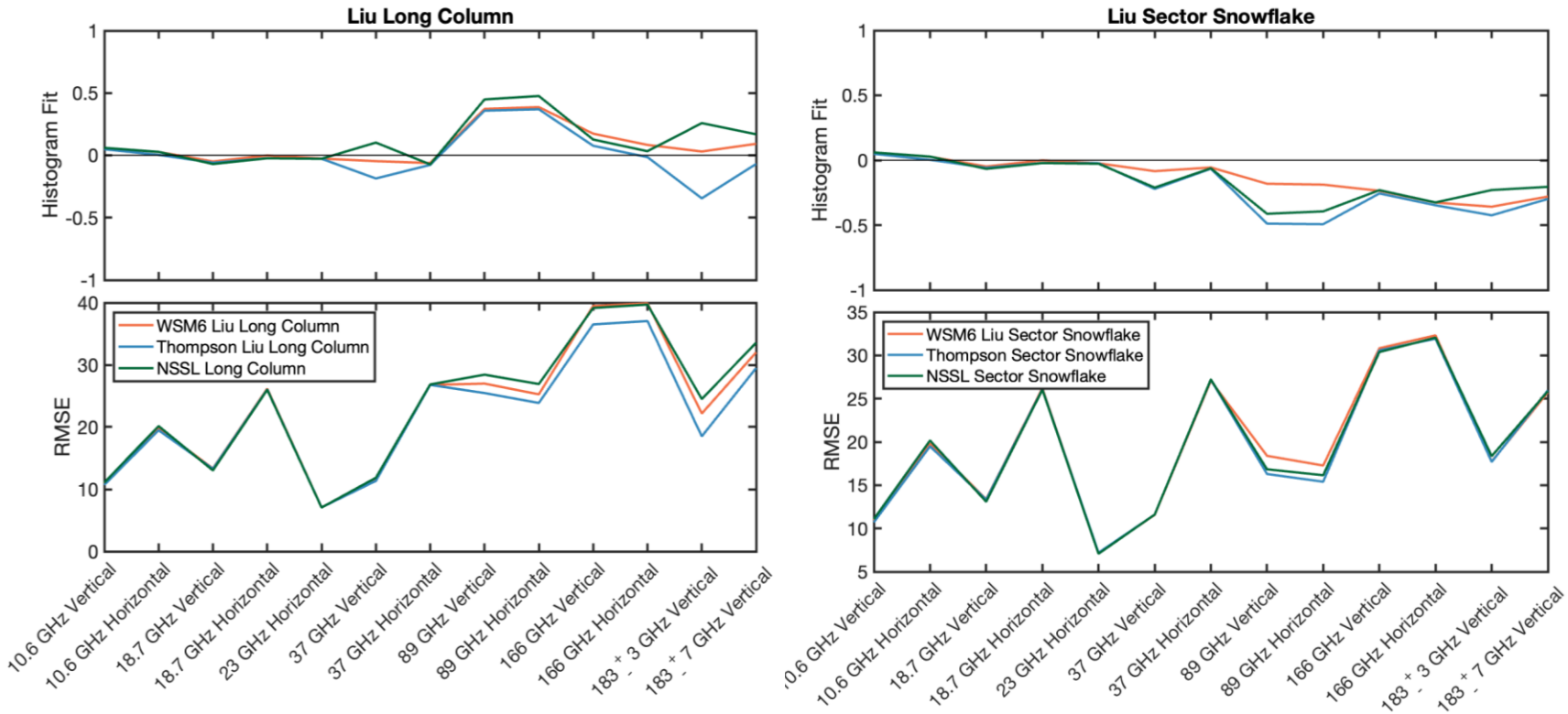
# 37 GHz Horizontal



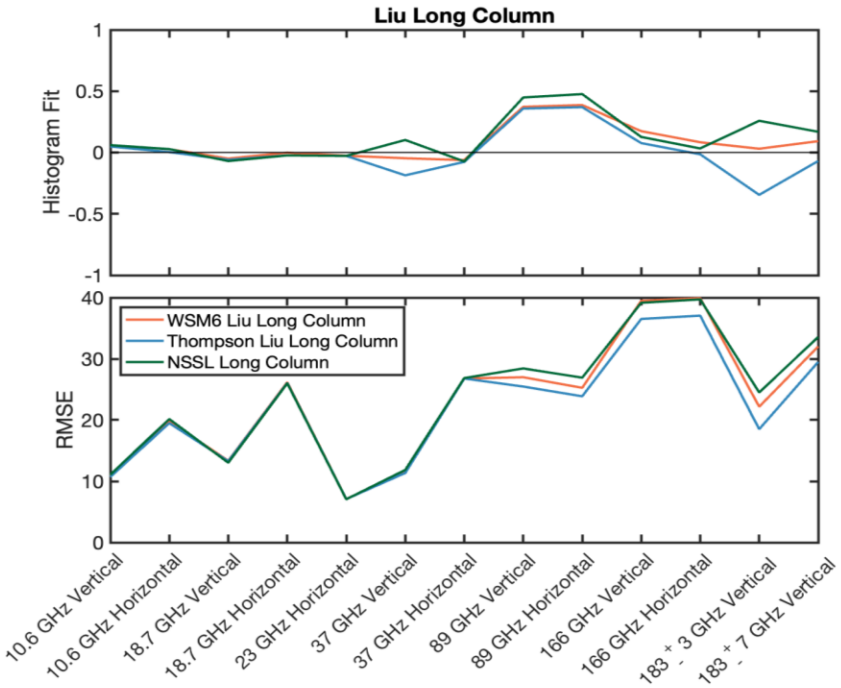
# Histogram Fit

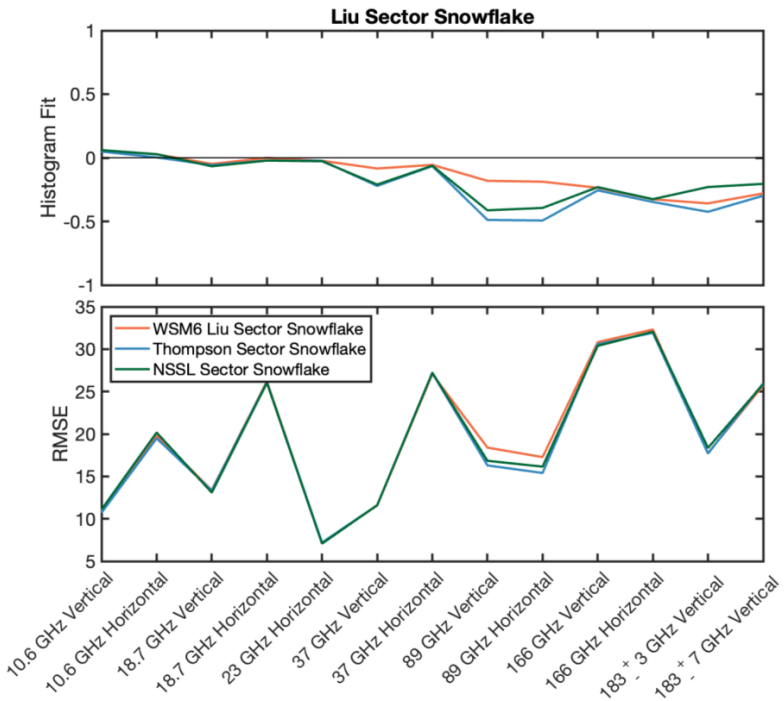


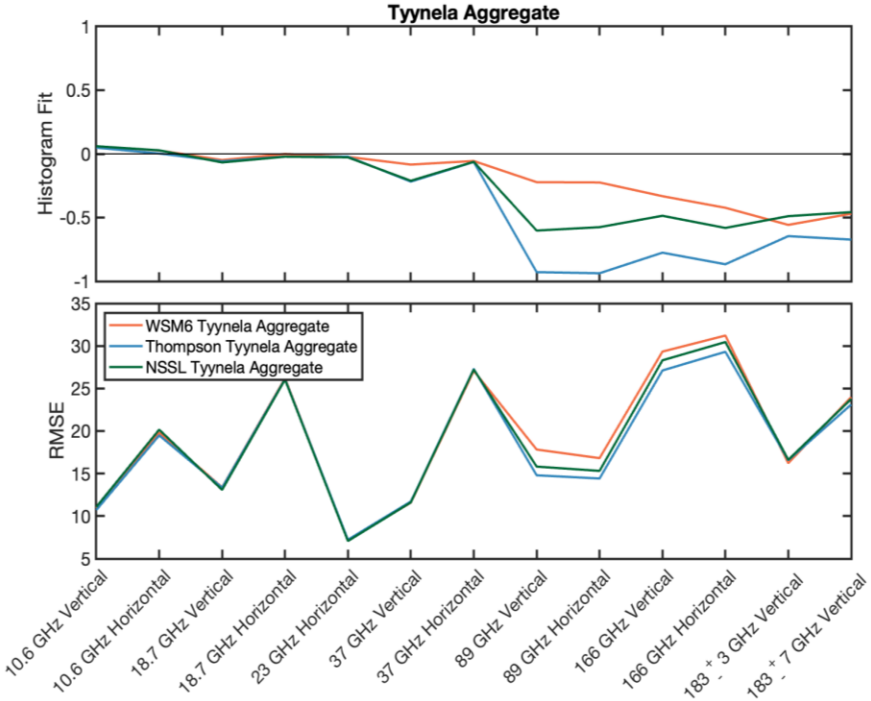
# Histogram Fit



# Histogram Fit



# Conclusions

- Ice particles having higher mass extinction cross section produce higher number of colder Brightness Temperatures.

  Liu Long Column, Ice Sphere, 8-Column Aggregate

- Ice particles having lower mass extinction cross section produce higher number of warmer Brightness Temperatures.

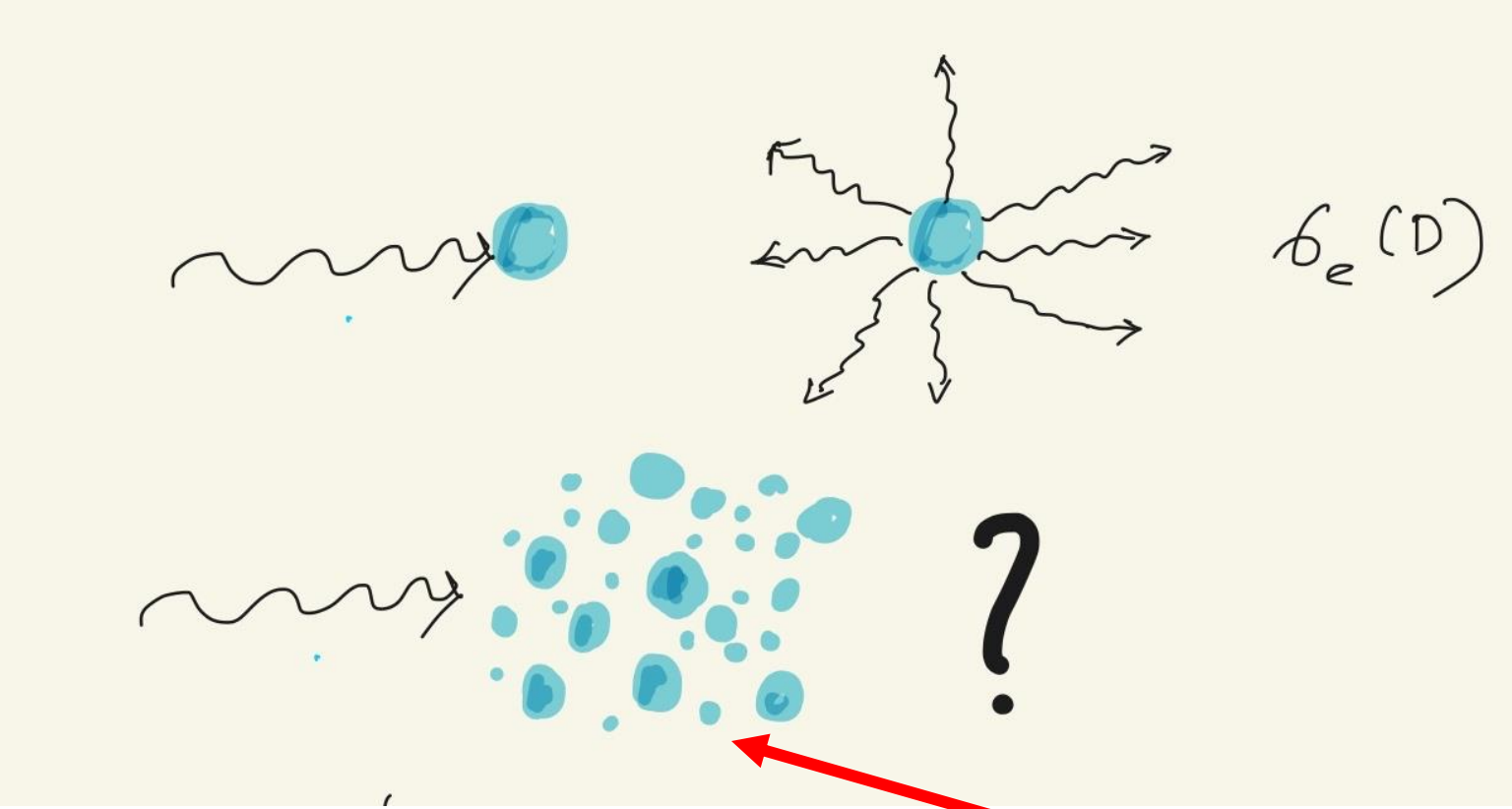
  Liu Dendrite, Evans Snow Aggregate, Column Aggregate

- WSM6 and NSSL schemes with Liu Sector Snowflake and Tyynela Aggregate produce Brightness Temperature similar to Observations in the Eyewall.

- More Tropical Cyclones need to be studied using these LUTs and Microphysics Schemes.

# THANKS

# Microwave Bulk Optical Property




Mass Extinction Cross Section$= \frac{\int \sigma_e(D)\, N(D)\, dD}{\int m(D) N(D)\, dD}$

*m(D)*- Mass of a hydrometeor of size *D*

# Effective Radius (Re)

- $Re = \frac{1}{2} \frac{\int D^3 N(D) dD}{\int D^2 N(D) dD}$

- *N(D)* is hydrometeor size distribution.

  $N(D) = N_0 e^{-\lambda D}$ (WSM6)

- *N(D)* is Microphysics Scheme dependent.

