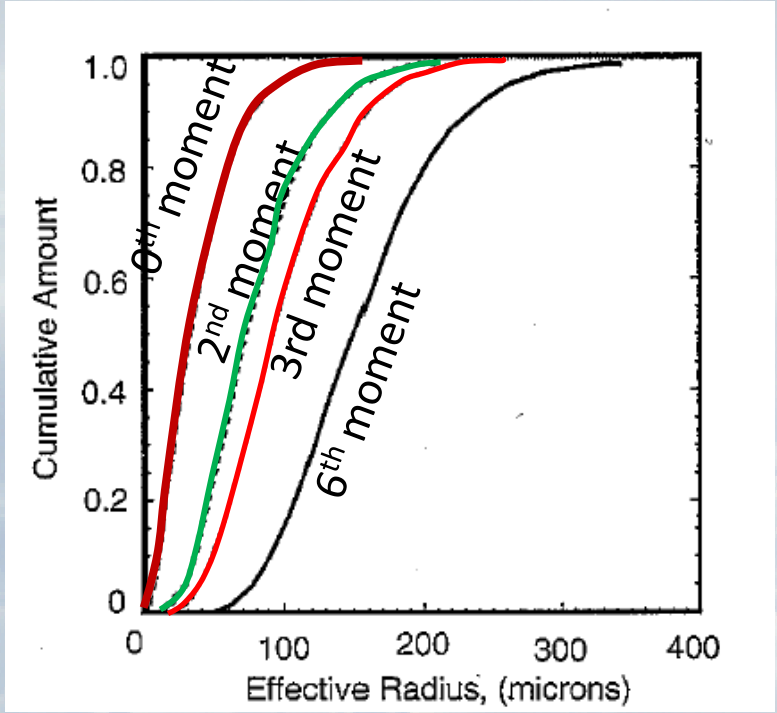
Some Thoughts on What the New ARM Instruments Will Contribute to Cloud Retrievals

In general – an atmospheric column contains multiple cloud layers that are often composed of two phases of water in size distributions that are often multi modal (require multiple simple functions to describe).

So in the general case, the microphysics of a cloudy volume contain 4-6 independent degrees of freedom.

Therefore, to characterize clouds, measurements must address **unique moments** of the PSD.

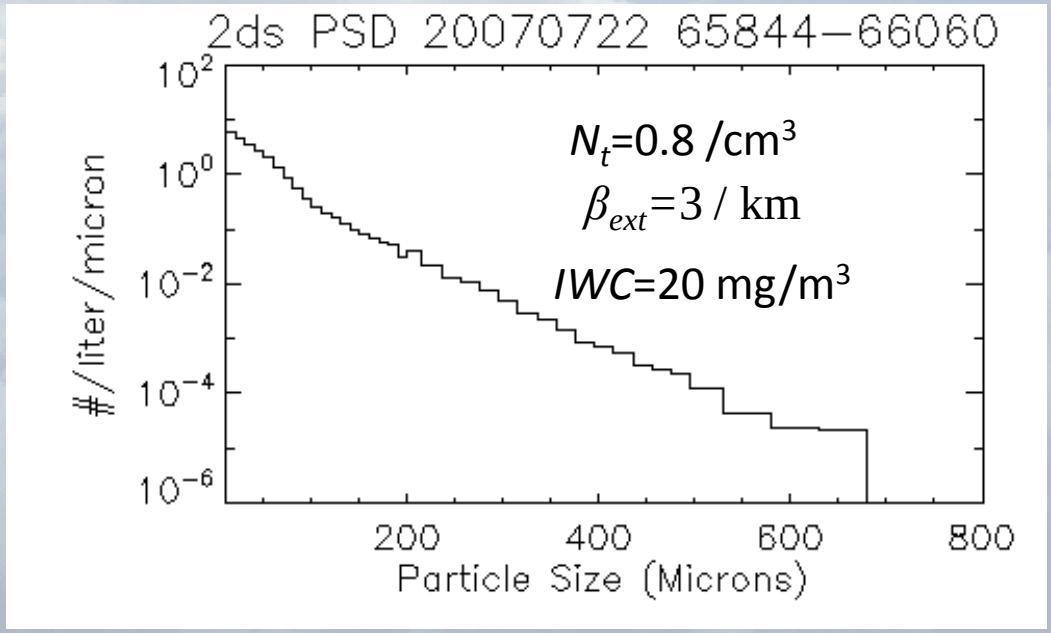
Photo Credit: Steve Dinardo



$$N_T = \int N(D)dD$$

$$Area = \frac{\pi}{4}\int D^2 N(D)dD$$

$$Mass = \frac{\rho}{3}\int D^3 N(D)dD$$



Remote Sensing 101

$$V(D) \propto \frac{Mass}{Area} \qquad \beta_{ext} \propto \int D^2 N(D)\, dD$$

$$Z = \int D^6 N(D)\, dD$$

$$V_d^{Radar} = \frac{1}{Z} \int D^6 \; V(D) N(D) dD$$

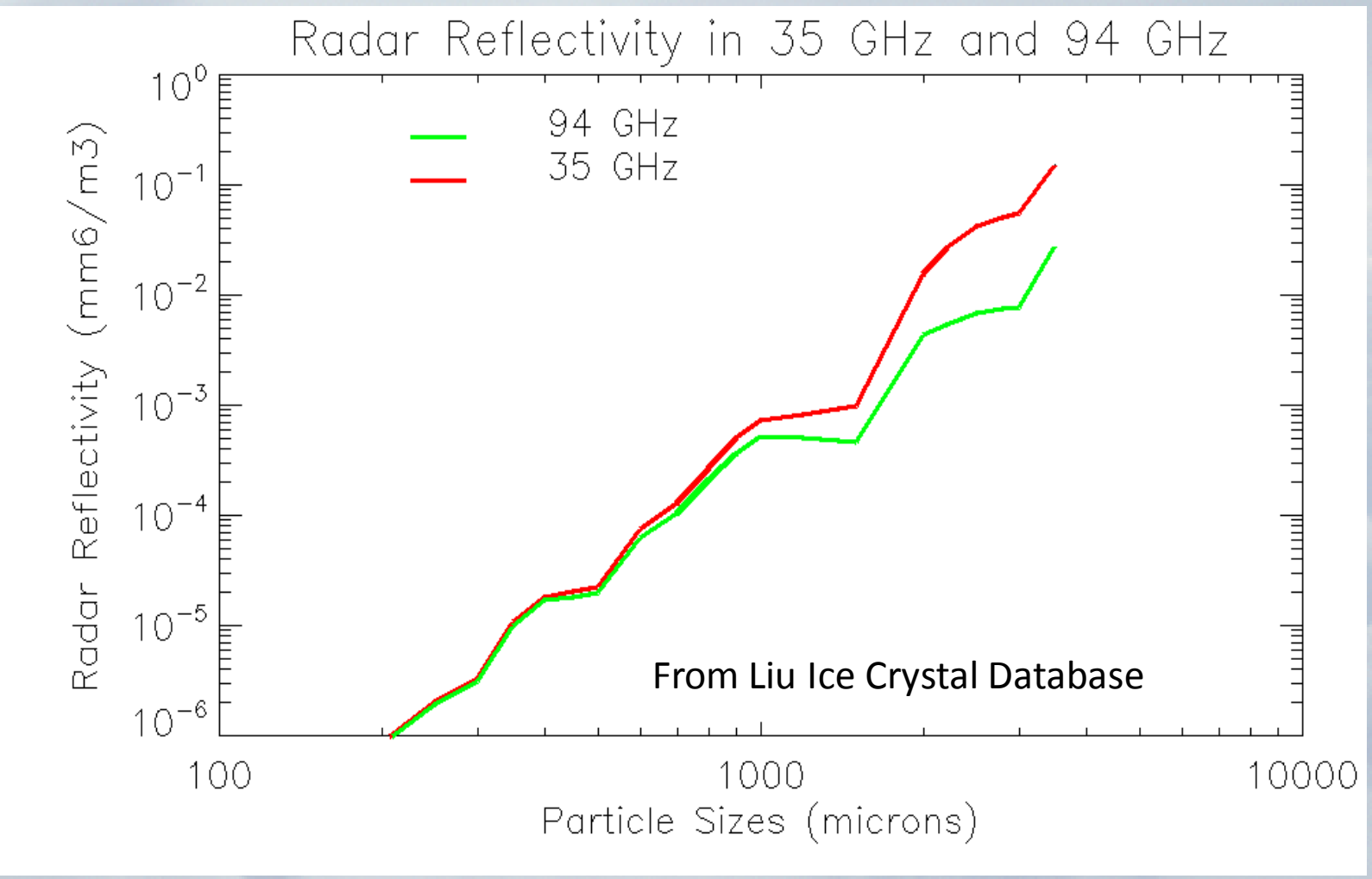
$$S_{Lidar} = C\beta_{back} \exp\left(-2 \int \beta_{ext} dr\right)$$

$$V_d^{lidar} = \frac{\pi}{2ext} \int D^2 \; V(D) N(D) dD$$

Critical passive measurements include:

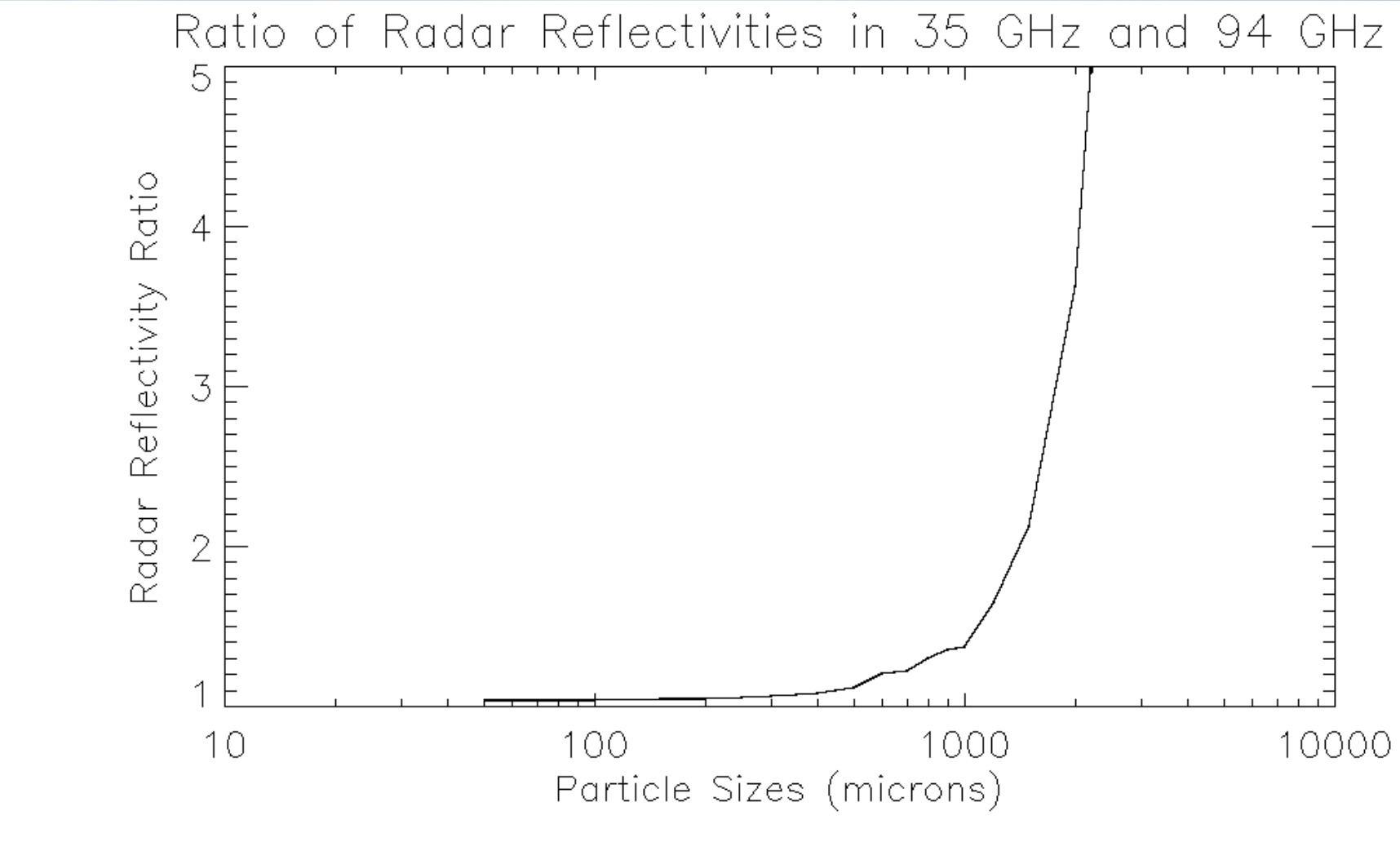
1. Integrated liquid from passive microwave
2. Optical depth and emissivity from vis and IR radiances from MFRSR and AERI

Multi Frequency (Ka and W) Doppler Radar Measurements



Beyond sizes of 600 microns, the backscatter cross sections of W and Ka differ providing significant information regarding mass and cross sectional area from reflectivity and Doppler velocity differences.

Multi Frequency (Ka and W) Doppler Radar Measurements



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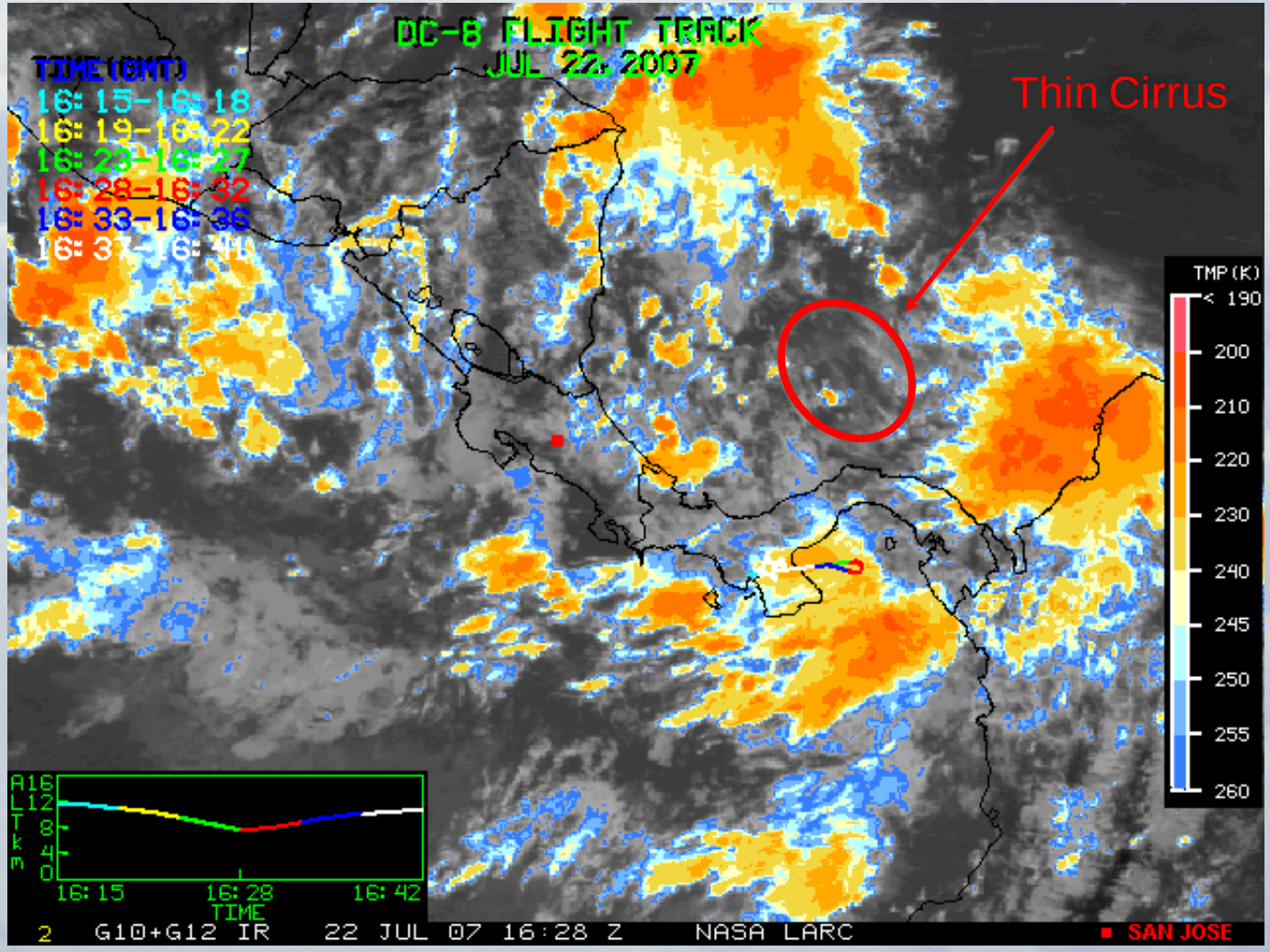
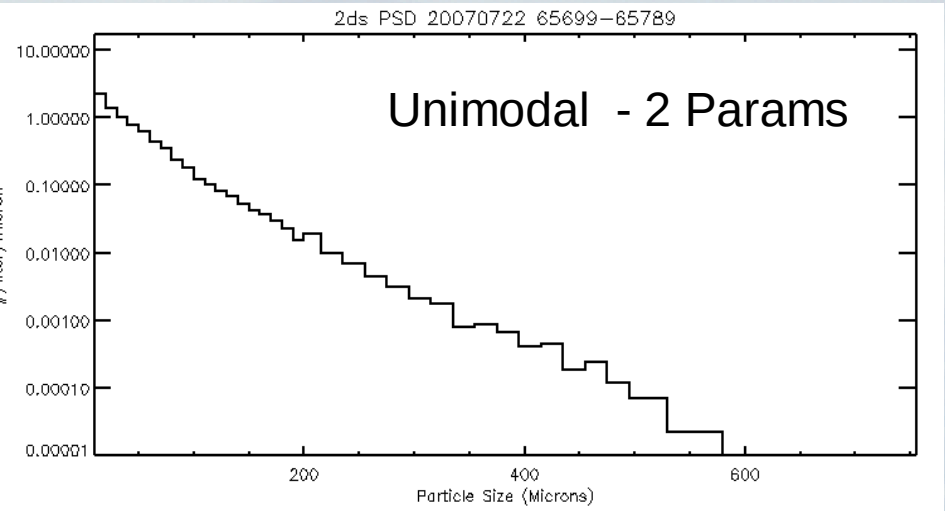
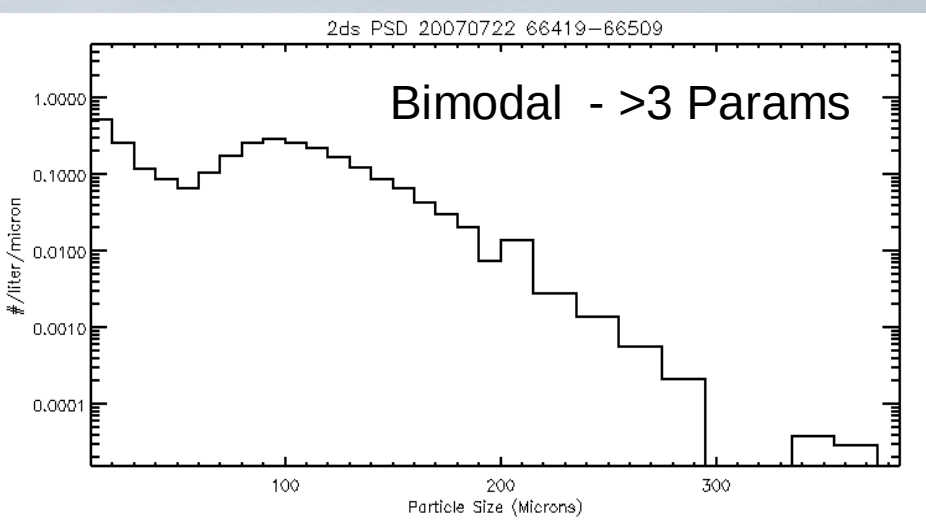
Instrument	Measurement/Primary Retrieved Quantity	PSD Moment	Additional Information
HSRL Lidar	Extinction	2^{nd}	MUST have independent Extinction
Lidar Doppler	Vd	2^{nd} Moment Weighting	To optical depth 2 or so.
94 GHz Radar	Z	6^{th} d<0.6 mm	Combo of multi freq. Doppler will constrain the large particle modes very precisely
	Vd	$2^{nd}/3^{rd}$ weighted by 94 GHz Z	
35 GHz Radar	Z	6^{th} d< 2 mm	
	Vd	$2^{nd}/3^{rd}$ weighted by 35 GHz Z	
Low Freq Microwave (MWR)	Column Liquid	3^{rd}	Column constraint
Visible Fluxes (MFRSR)	Vis Tau/re	2^{nd}	Column constraint (Day)
Thermal IR Radiances (AERI)	IR Emissivity	2^{nd} to Emiss=1	Column constraint (day and night)
Solar and IR Flux			Radiative Closure Column constraint

Examine Particle Size Distributions, Physical Properties, and Remote Sensing Properties



Thin Cirrus Particle Size Distributions From Aged Anvil





DC8 TC4 Data 20070722 65699-65789 18.25-18.27
Water Content: 0.0107500 g/m^3
Extinction: 0.397460 1/km
Concentration: 0.234099 1/cc
Effective Radius: 40.5701 microns

35 GHz Ze and Vd (cm/s): -24.7376 30.475503
94 GHz Ze and Vd (cm/s): -24.8305 30.183258
Lidar Vd (cm/s): 10.778739

DC8 TC4 Data 20070722 66419-66509 18.45-18.47
Water Content: 0.0122200 g/m^3
Extinction: 0.344062 1/km
Concentration: 0.0729008 1/cc
Effective Radius: 53.2752 microns

35 GHz Ze and Vd (cm/s): -30.7224 14.937320
94 GHz Ze and Vd (cm/s): -30.7228 14.909728
Lidar Vd (cm/s): 10.710044

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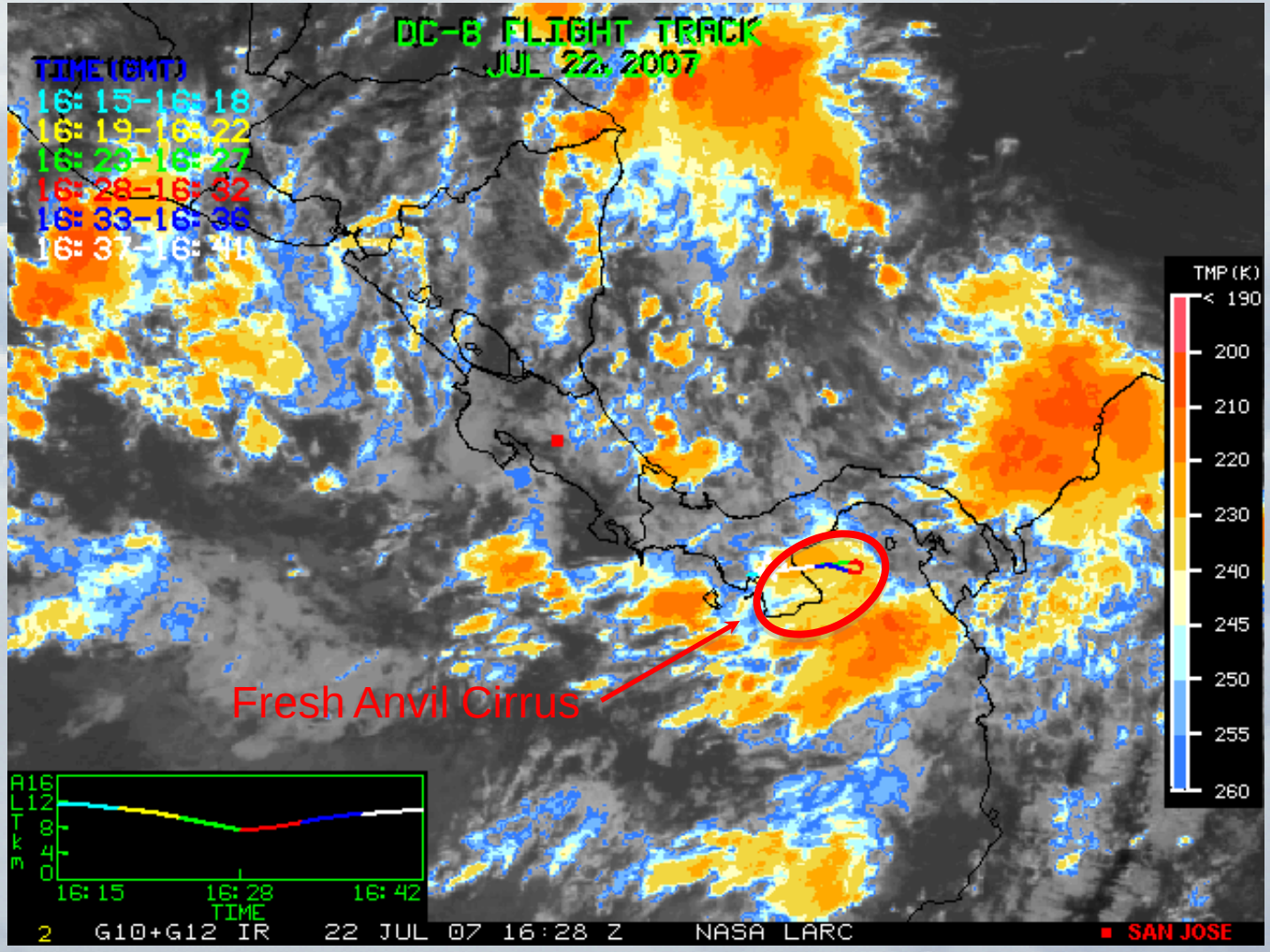
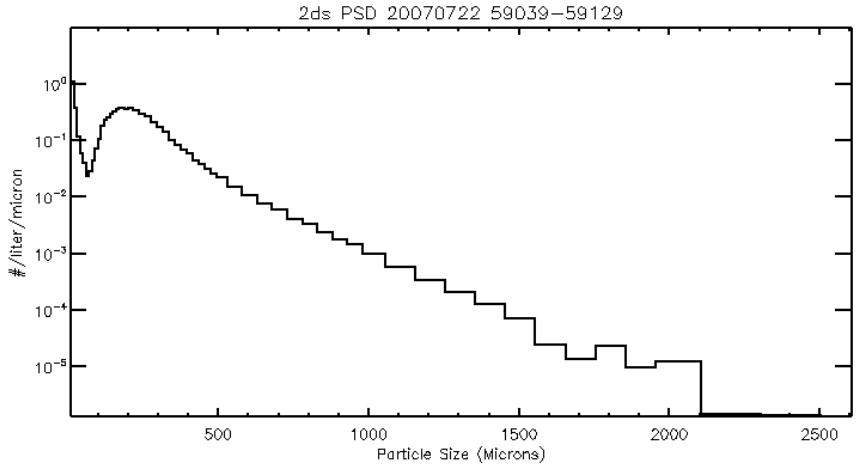
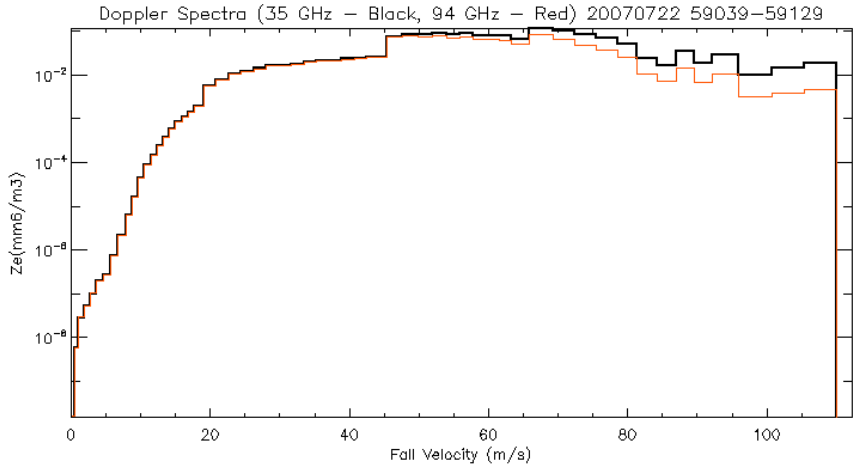
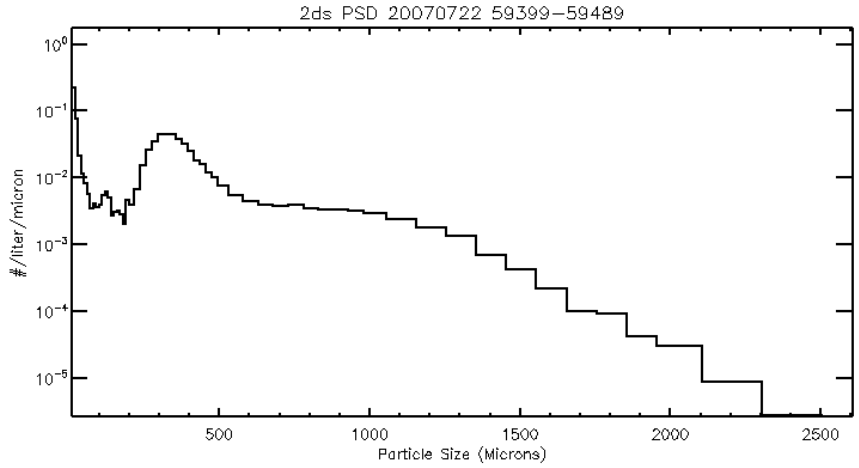


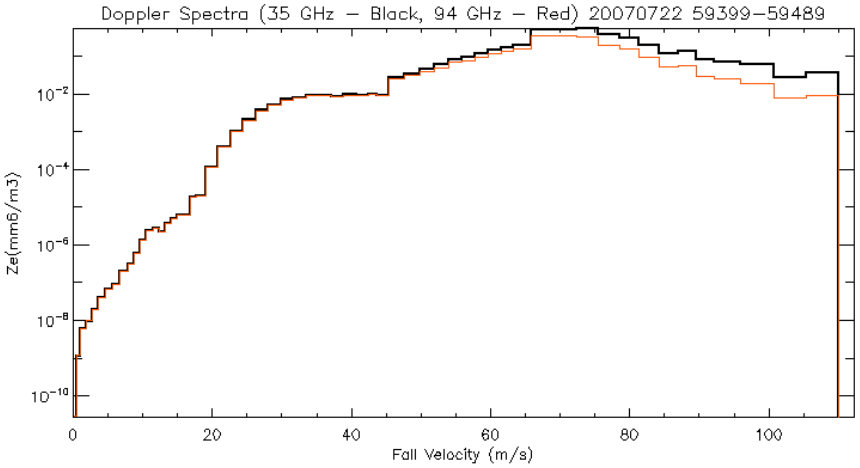




DC8 TC4 Data 20070722 59039–59129 16.40–16.42
Water Content: 0.249158 g/m^3
Extinction: 7.08765 1/km
Concentration: 0.193520 1/cc
Effective Radius: 52.7307 microns

35 GHz Ze and Vd (cm/s): 2.21737 60.116742
94 GHz Ze and Vd (cm/s): 1.09719 56.127650
Lidar Vd (cm/s): 33.029364

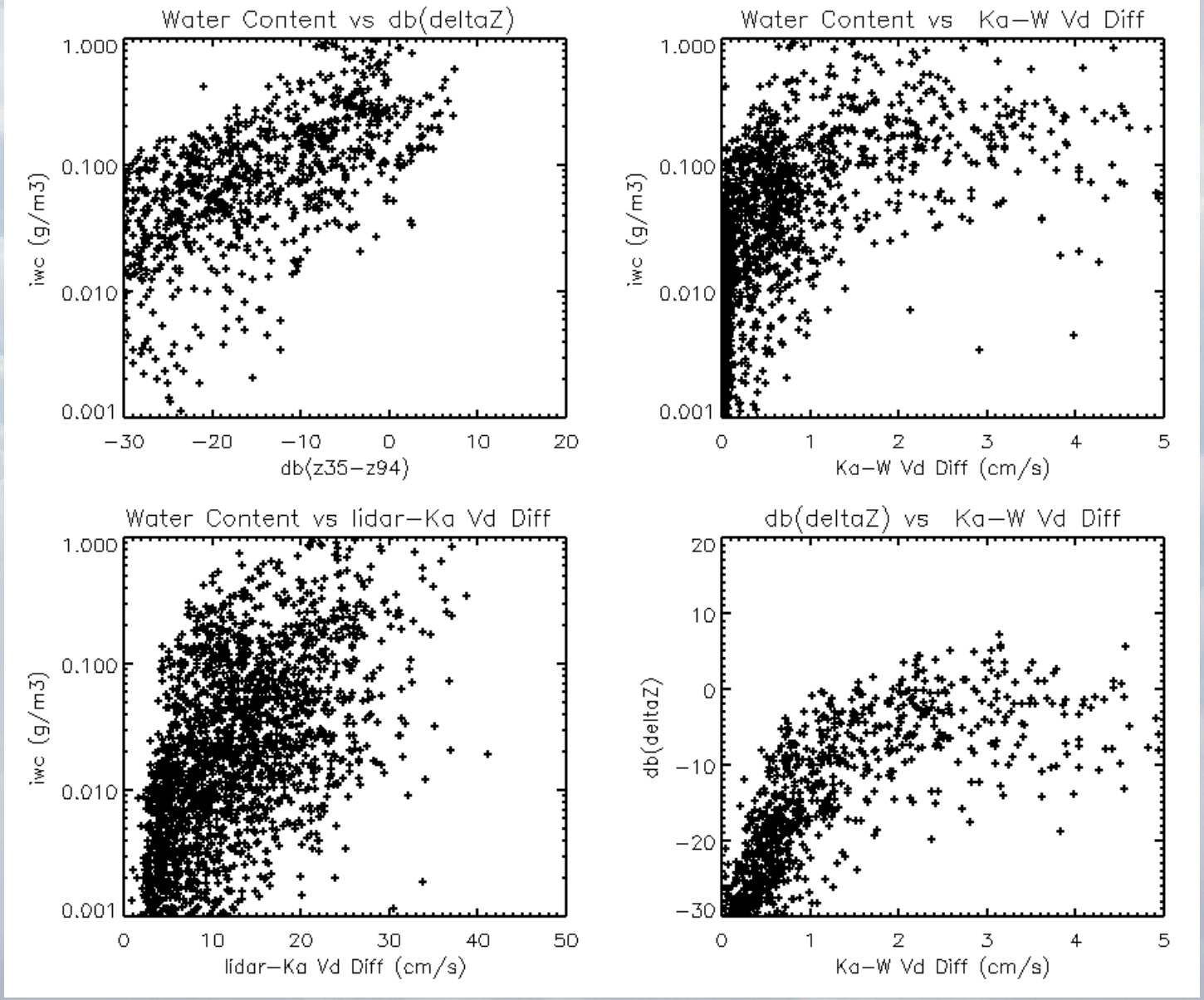




DC8 TC4 Data 20070722 59399–59489 16.50–16.52
Water Content: 0.269960 g/m^3
Extinction: 3.30410 1/km
Concentration: 0.0310458 1/cc
Effective Radius: 122.557 microns

35 GHz Ze and Vd (cm/s): 6.02379 71.870583
94 GHz Ze and Vd (cm/s): 4.07676 68.781476
Lidar Vd (cm/s): 54.993215

Summary of IWC and Measureable Quantities From Cirrus on July 22, 2007



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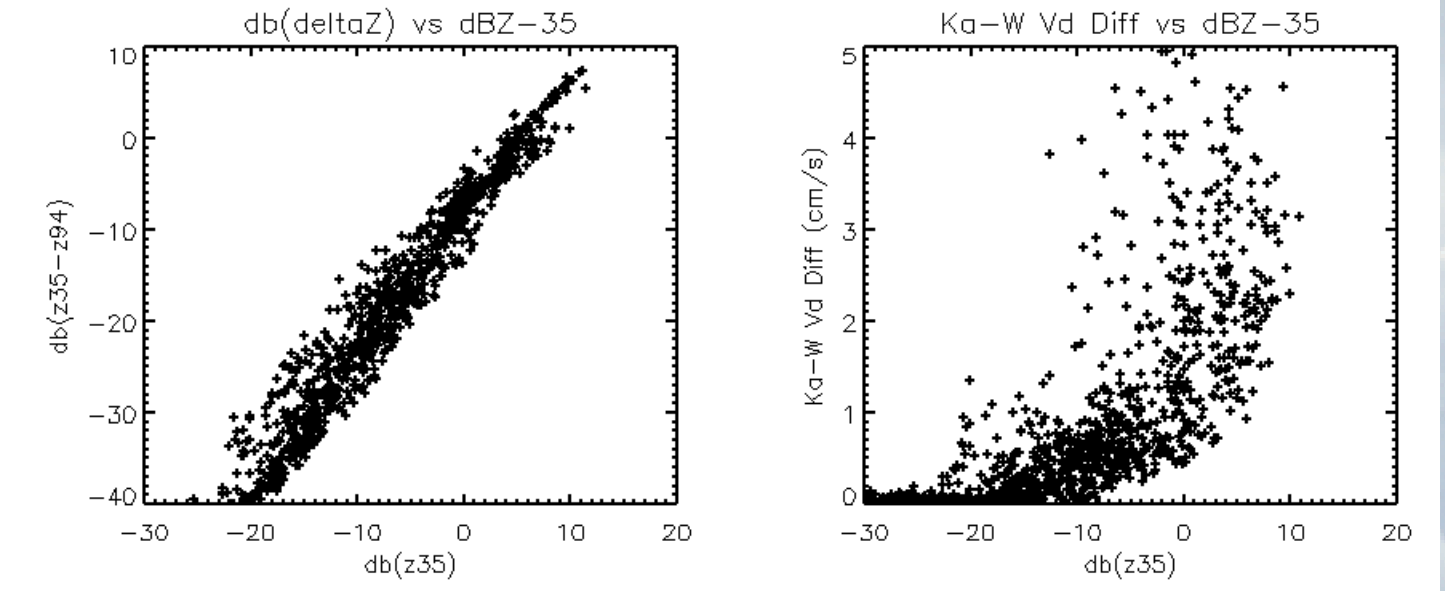
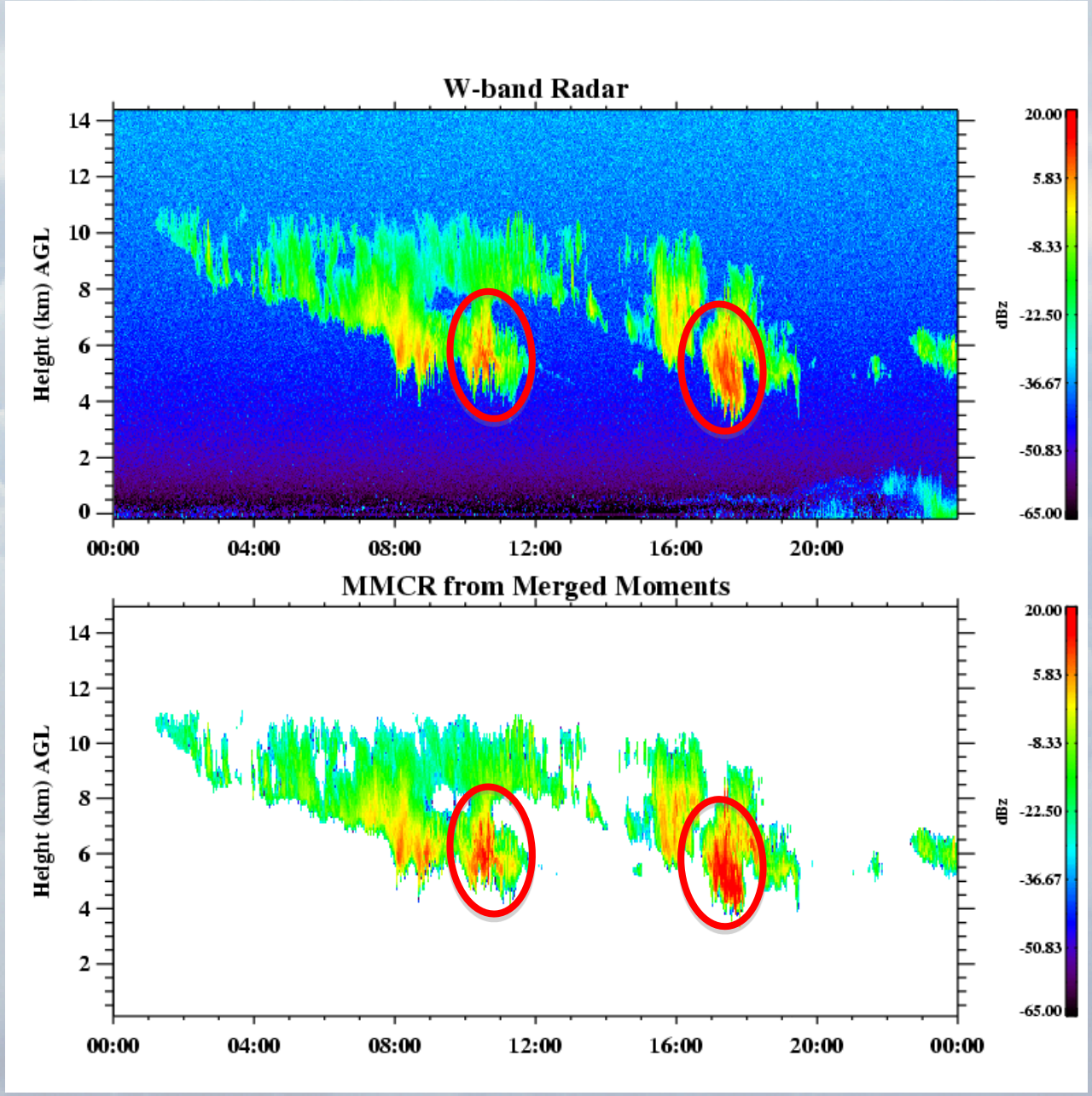
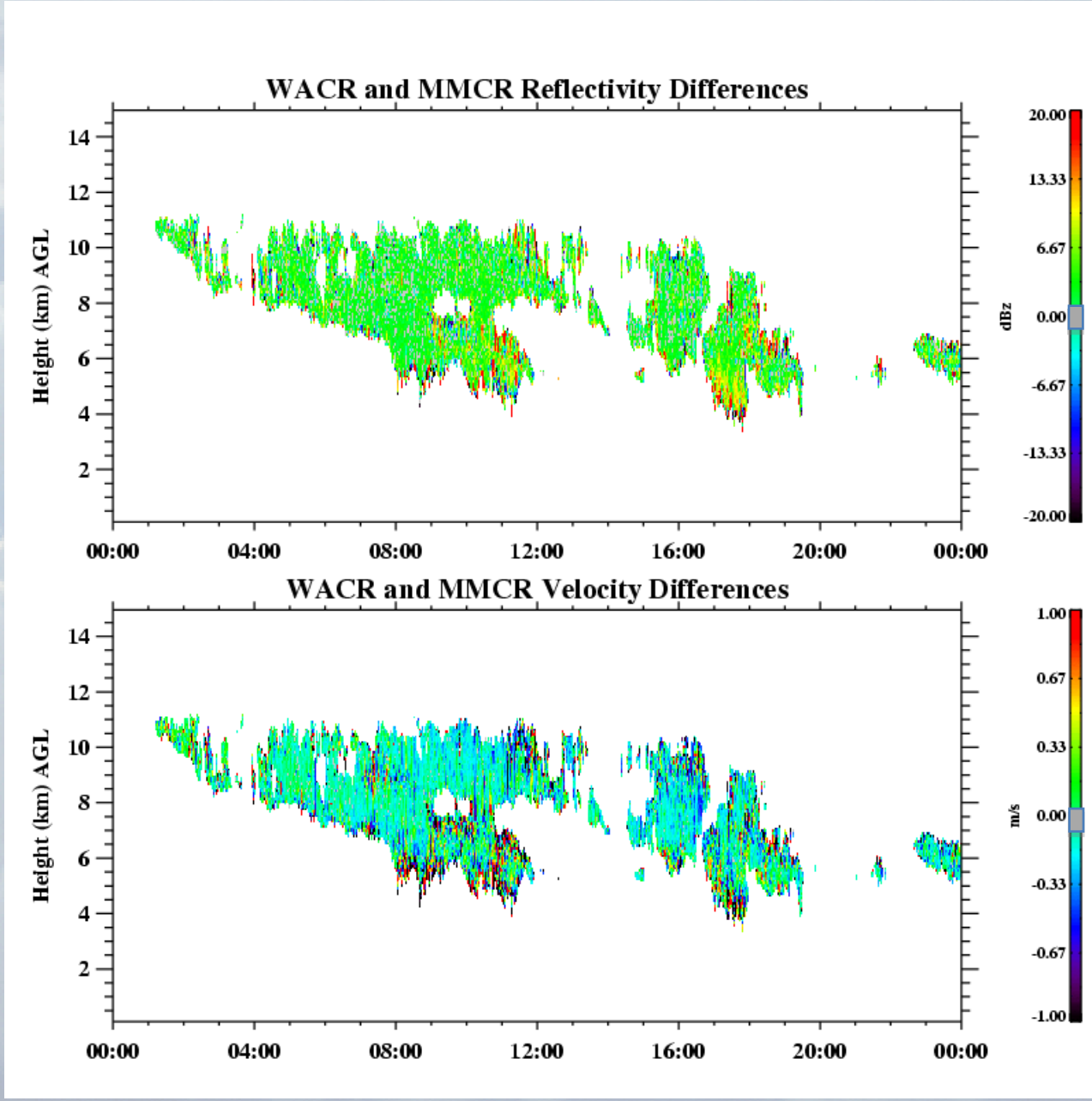


MMCR and WACR on 2006/10/30



(Ka-W) dBZ

(Ka-W) Vd



(Ka-W) dBZ

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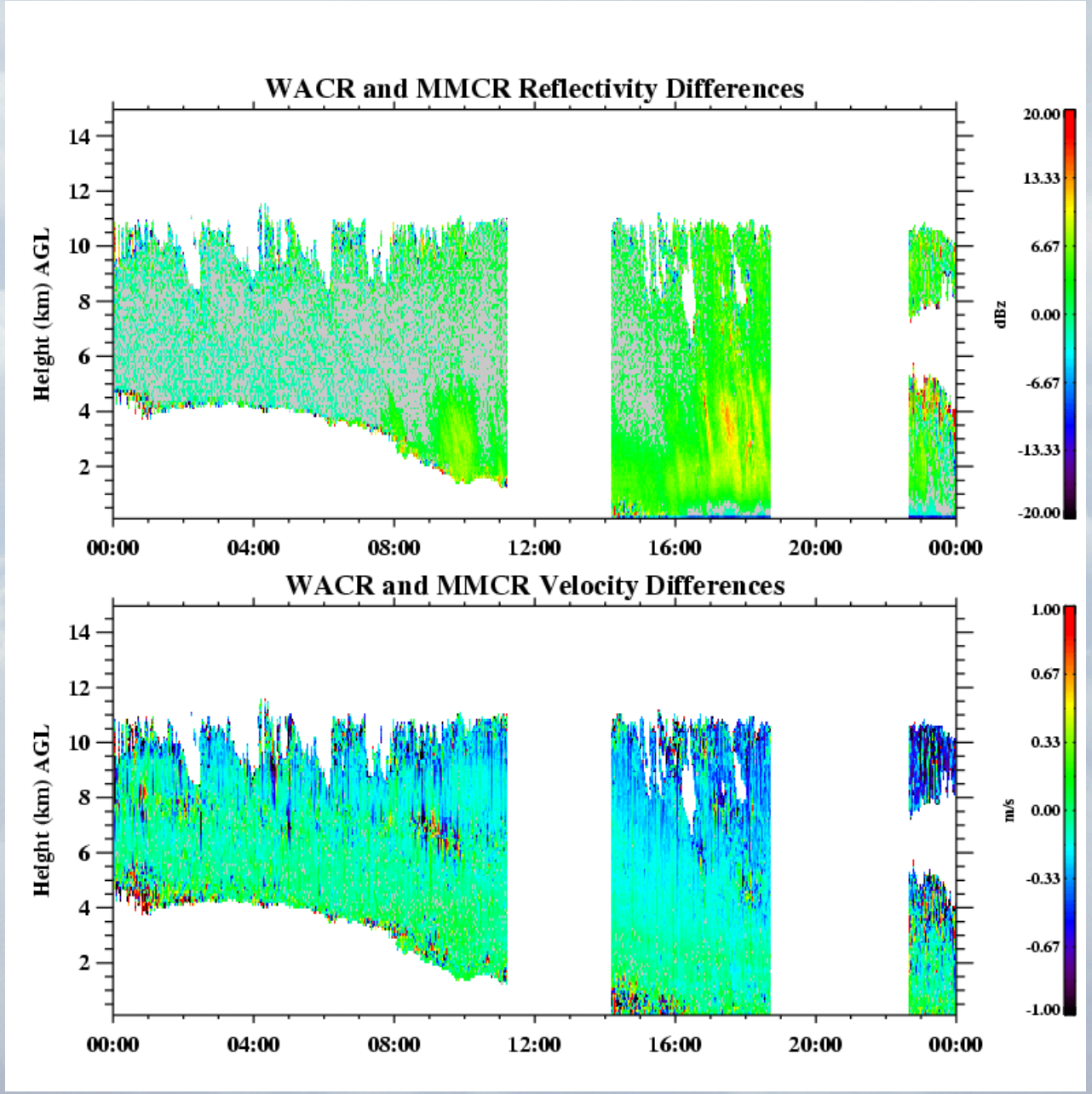


Summary:

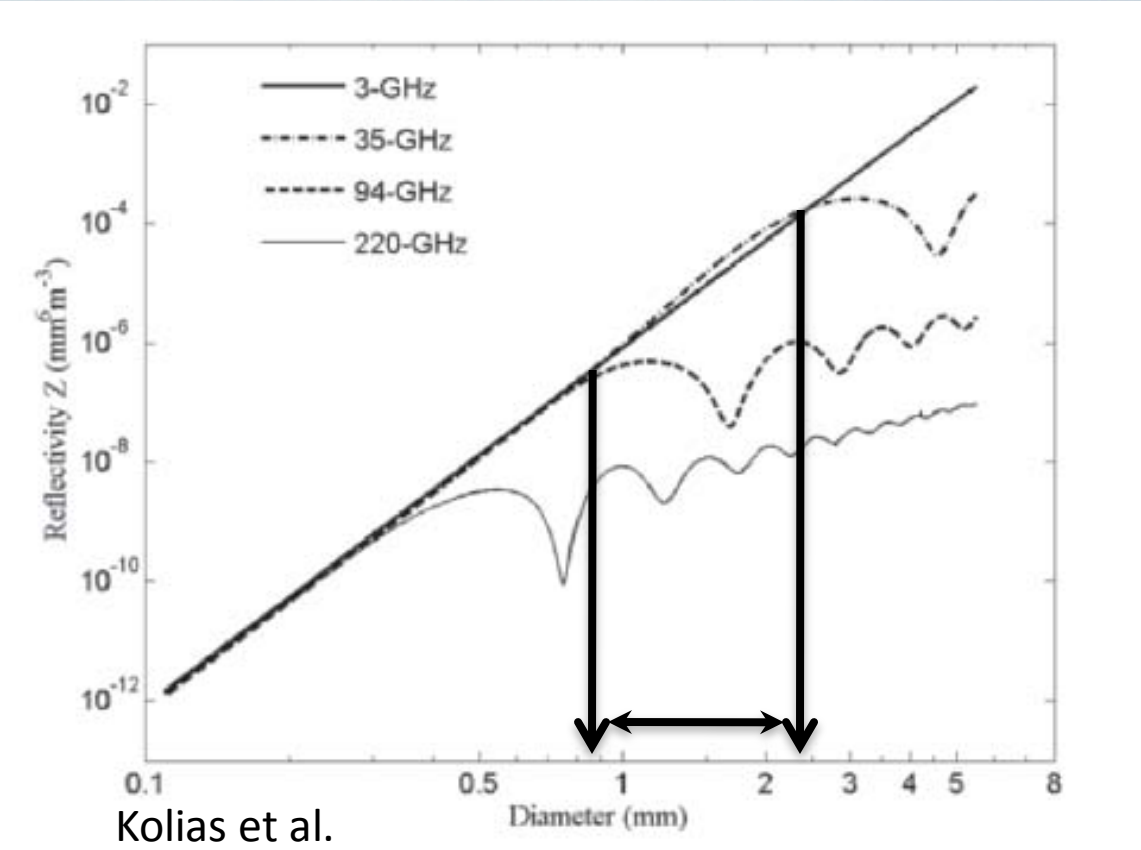
- For non precipitating clouds, dual frequency (W and Ka) are significant for heavy ice clouds such as alto stratus and anvil cirrus.

- Lidar Doppler velocity provides provides significant independent information for thin clouds

- Dual Frequency (Ka-W) Doppler spectra provides the most specific information.

- Given the very small dynamic range that the Ka and W band provide in non-precipitating clouds, calibrations to within 0.5 db and 0.005 m/s and precise volume/beam matching are critical and must be an integral aspect of the new radars.

Multi Frequency Doppler Radar Measurements



Kolias et al.

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