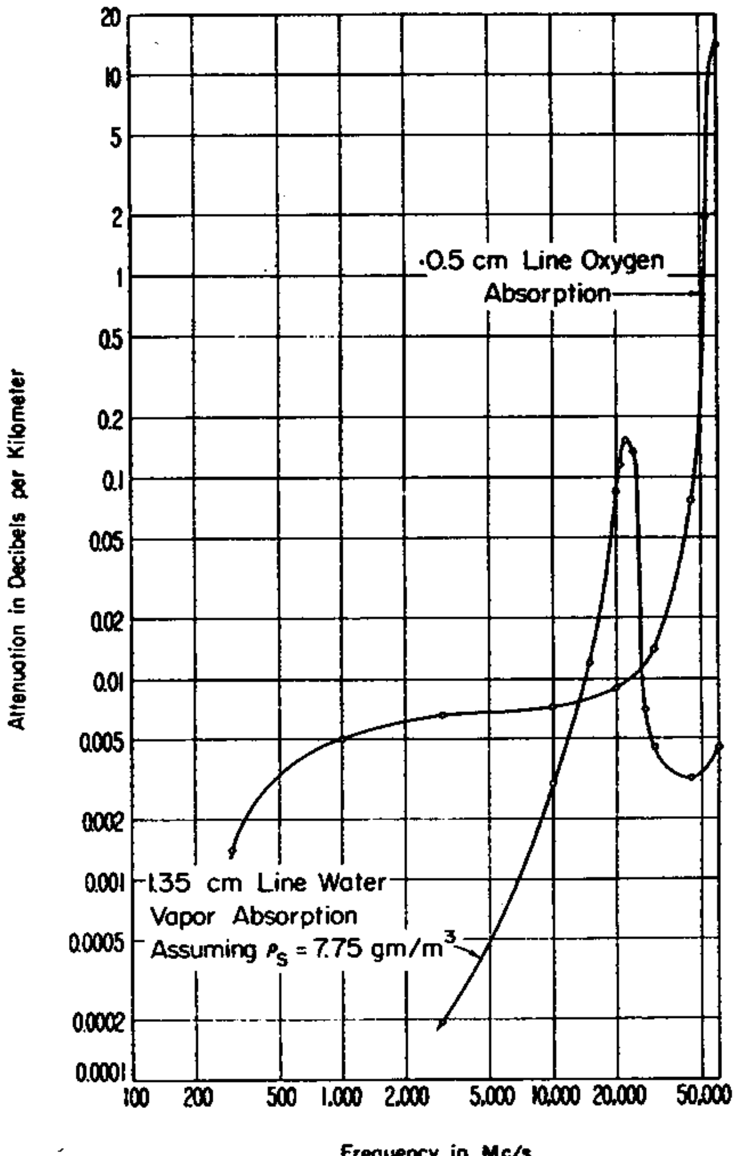
MET 4410 Remote Sensing: Radar and Satellite Meteorology
MET 5412 Remote Sensing in Meteorology

Lecture 17: Attenuation of Radar Echoes & Spaceborne Radars

Attenuation

- **Definition**: EM radiation passing through any medium is reduced in power by an amount that depends upon the kind of material present and its density. **In free space, there is no attenuation.**
- **Atmosphere, cloud, rain, snow, and hail can all cause attenuation of radar return power.**
- **Attenuation is caused by absorption and scattering out.**
- **Attenuation is a function of distance**. The longer the distance that radar beam travels, the larger the attenuation is.
- **Attenuation coefficient** *K* is defined as the Decibels per kilometer (dB/km). A one-way attenuation of 0.01 dB/km over a path of 100km will production a total of 1 dB attenuation. Since radar works by transmitting a signal and receiving an echo back, the path traveled by the radar waves will be twice this distance, therefore producing for our example a total of 2 dB of two-way attenuation.
- **Attenuation is also a function of wavelength**. The attenuation problem is more severe for shorter wavelength radars.

Atmospheric Attenuation



Frequency in GHz

- Among all atmospheric gases, only **oxygen and water vapor** can cause attenuation at radar wavelengths.
- For radar frequencies below 10 GHz (wavelength > 3 cm), atmospheric attenuation is small (k<=0.01 dB/km) and can be neglected.

Figure 8.6 Atmospheric attenuation from water vapor and oxygen at standard pressure (1013.25 mb) as a function of frequency. The water vapor curve assumes an absolute humidity of 7.75 g/m^3. From Bean and Dutton (1968)

Cloud Attenuation

- Cloud attenuation is variable because clouds themselves are variable, from very thin to very thick clouds.
- Attenuation from clouds depends upon whether the clouds are composed of water droplets or ice particles.

One-way attenuation coefficient K in clouds in (dB/km)/(g/m^3)

	Temp. (°C)	Wavelength (cm) 0.9	1.24	1.8	3.2
Water	20	0.647	0.311	0.128	0.0483
	10	0.681	0.406	0.179	0.0630
	0	0.99	0.532	0.267	0.0858
	-8	1.25	0.684	0.34*	0.122*
Ice	0	0.00874	0.00635	0.00436	0.00246
	-10	0.00291	0.00211	0.00146	0.00081
	-20	0.00200	0.00145	0.00100	0.00056

- Attenuation from ice clouds is negligible.
- For water clouds, the amount of attenuation cannot be ignored for most radar wavelengths if the clouds are dense and/or extensive.
- For liquid water content=4 g/m^3, at 25km distance, at wavelength=3.2 cm, the two way total attenuation would be 10 dB.

Rain Attenuation

- Attenuation by rain is stronger than that from clouds.
- Rain attenuation can be related to rain rate R or radar reflectivity dBZ.

One-way rain attenuation coefficient K in (dB/km)/(mm/h). From Wexler and Atlas, 1963.

λ (cm)	M-P (at 0°C)	Modified M-P (0°C)	Mueller-Jones (0°C)	Gunn & East (18°C)
0.62	0.50-0.37	0.52	0.66	
0.86	0.27	0.31	0.39	
1.24	$0.117R^{0.07}$	$0.31R^{0.07}$	0.18	$0.12R^{0.06}$
1.8				$0.045R^{0.11}$
1.87	$0.0045R^{0.10}$	$0.050R^{0.10}$	0.065	
3.21	$0.011R^{0.15}$	$0.013R^{0.15}$	0.018	
4.67	0.005-0.007*	0.0053	0.0058	$0.0074R^{0.31}$
5.5	0.003-0.004*	0.0031	0.0033	
5.7				$0.0022R^{0.17}$
10	0.0009-0.0007*	0.00082	0.00092	0.0003

- For 100 mm/h rain at 10km distance, the total two-way attenuation would be 36 dB.

Snow Attenuation

- Attenuation by snow is generally negligible because for ice the refractive index parameter $|K|^2$ is small and the melted precipitation rate for snow is usually small.

Table 8.5 One-way attenuation coefficients (dB/km) by low-density snow at 0°C calculated from: $k_s = 3.5 \cdot 10^{-2} R^2/\lambda^4 + 2.2 \cdot 10^{-3} R/\lambda$ (Battan, 1973).

λ (cm)	Precipitation rate R (mm/h) 1	10	100
1.8	0.0046	0.344	33.5
3.2	0.0010	0.040	3.41
5.4	0.00045	0.0082	0.45
10.0	0.00022	0.0026	0.057

- A 50-km two-way path through snow of 10 mm/h precipitation rate would produce only 2 dB attenuation for a wavelength=3.2 cm radar.

Correcting for Attenuation

- It is possible to correct for attenuation by estimating the amount of attenuation if we know the conditions (i.e. rain rate or reflectivity)
- Gas attenuation is small & easy to correct
- Complex algorithms are needed to correct radar attenuation in cloud and precipitation.

Spaceborne Weather Radars

- **Spaceborne weather radars** have only been operational since 1997.
- Technological advances in signal processing, power requirements, and antenna design brought the cost to feasible levels during the 1990s.
- The first spaceborne weather radar is the **precipitation radar (PR) on the Tropical Rainfall Measuring Mission (TRMM) satellite, which was launched in 1997 and stopped in usage in 2013. TRMM PR** is a Ku-band (frequency = 14 GHz, wavelength = 2.2 cm) scanning radar.
- **CloudSat is the first spaceborne cloud radar** (launched in 2006), which allows the mapping of clouds and light precipitation beyond the capabilities of TRMM. CloudSat is a W-Band (frequency = 95 GHz, wavelength = 3 mm) nadir pointing system.
- **The Global Precipitation Mission (GPM) dual-wavelength precipitation radar (DPR): is a successor of TRMM PR. The** GPM satellite successfully launched in 1:37 p.m. EST, Feb. 27, 2014. DPR has two frequencies at Ku (same frequency as TRMM) and Ka (frequency = 35 GHz, wavelength = 8.5 mm), which will allow retrieval of the drop size distribution through dual-wavelength techniques, will have higher sensitivity at Ku band. This will allow improved rainfall retrievals.

Comparison between spaceborne and ground-based radars

- Compared with ground-based radar, spaceborne radar has the same principle, but less infrastructure
- Due to smaller wavelengths, space radars are more subject to attenuation problems.
- Spaceborne radars are in low earth orbit, so the radar height from the earth surface is 350/403km for TRMM PR, 407 km for GPM DPR, and and 750 km for CloudSat radar
- Spaceborne radar generally has:
  - Lower transmit power
  - Lower sensitivity
  - Lower azimuthal resolution, higher vertical resolution
  - No Doppler or Polarimetric Capability (yet)
  - Moving at 10s of km/s, so only get snapshots of precipitation (vs. volume scans)
  - Cross-track scanning (TRMM PR & GPM DPR), or nadir (straight down, CloudSat radar) pointing angles

Geometry and spatial sampling considerations for TRMM

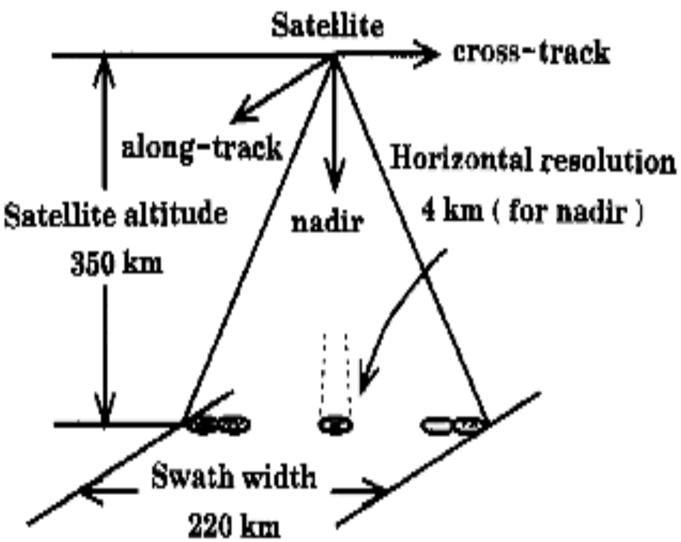
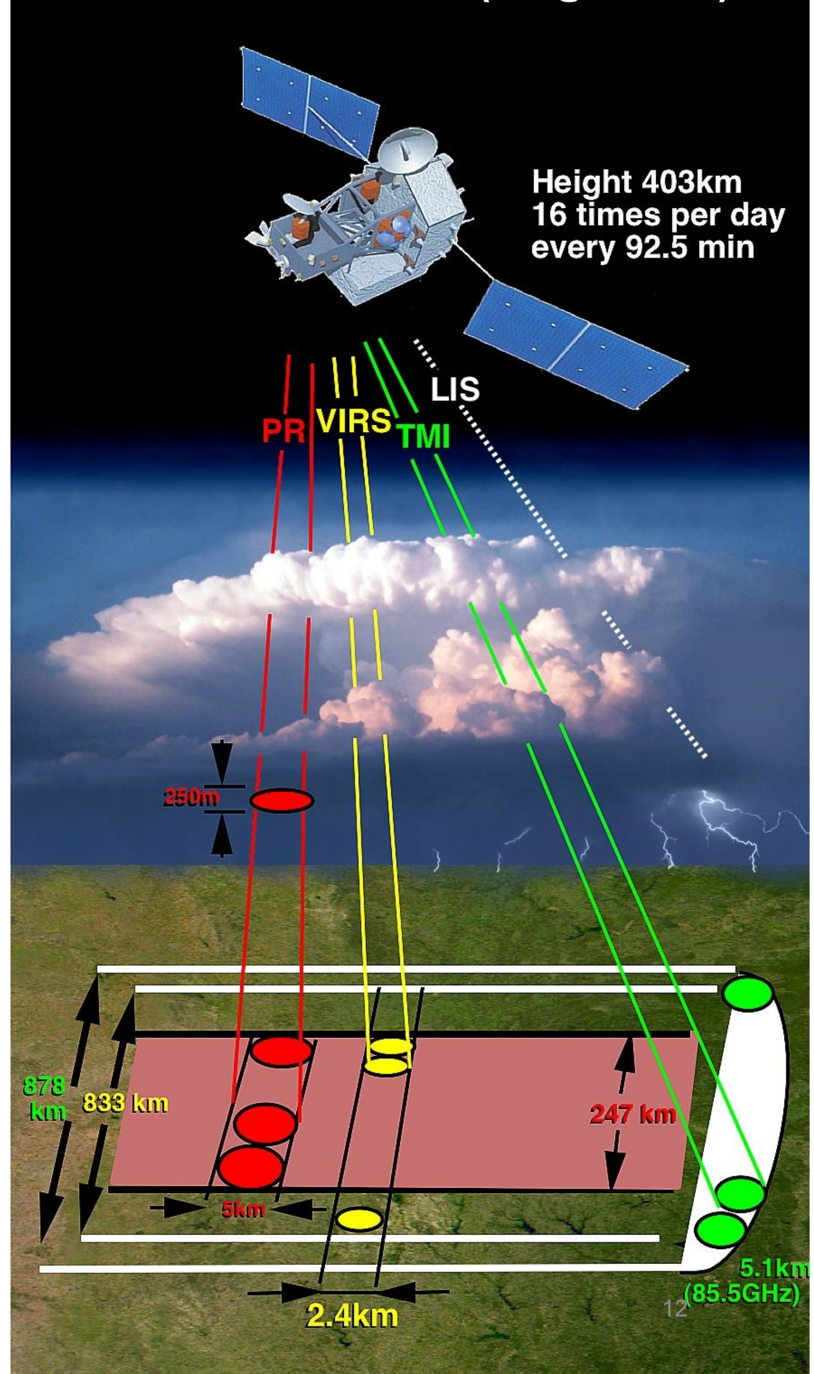


Fig. 1. Mission requirements of TRMM (=Tropical Rainfall Measuring Mission).

Before TRMM Boost (Aug. 2001)

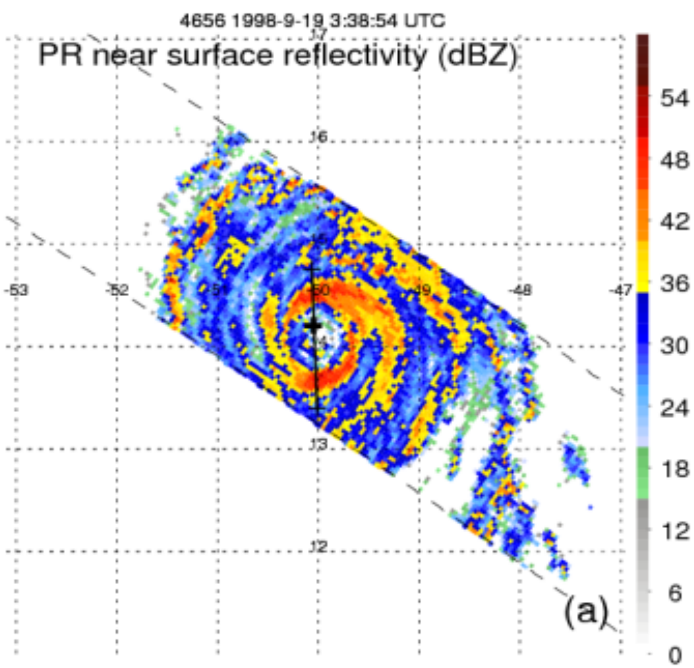
After TRMM Boost (Aug. 2001)



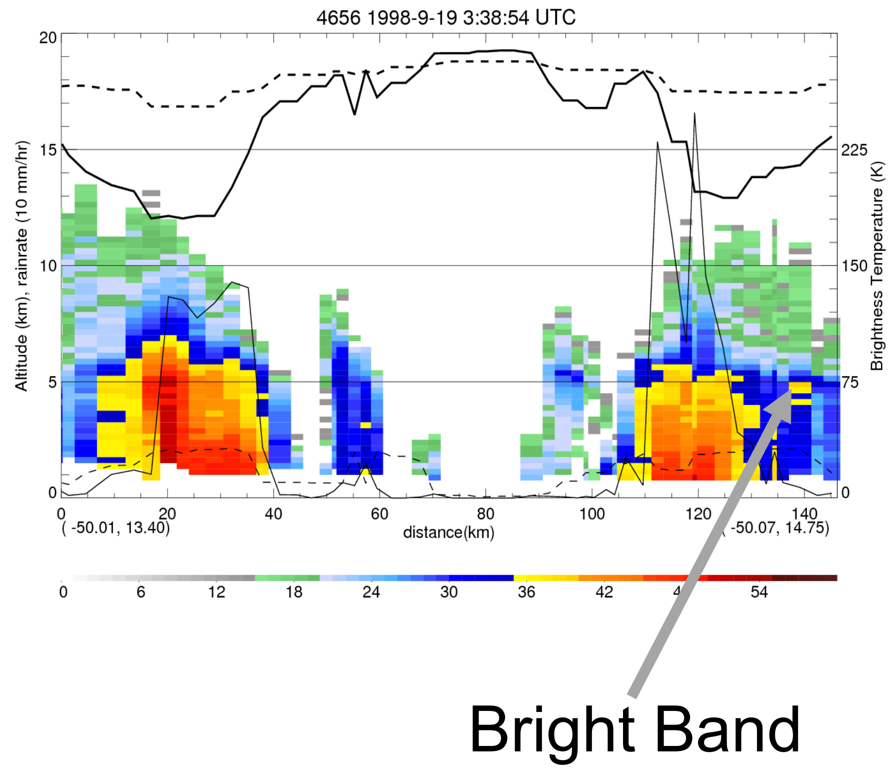
Satellite-borne (downward looking) Radar Display Example: TRMM Precipitation Radar (PR)

Hurricane Georges (1998):

Horizontal View:



Vertical Radar Cross Section



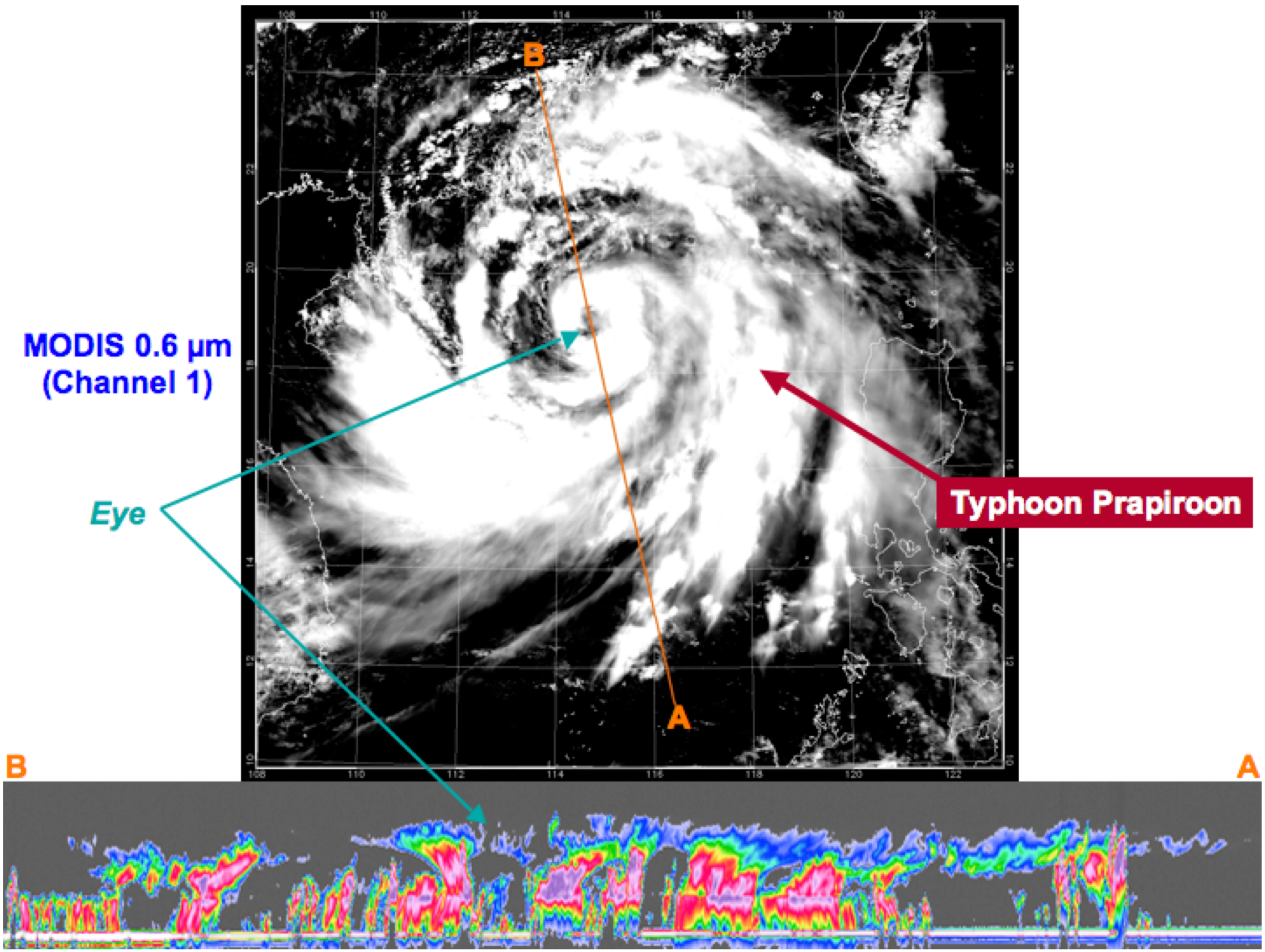
Estimating Precipitation from TRMM radar

- Need to invert reflectivity factor *Z* to rain rate *R* (use Z-R relationship $Z = a R^{b}$)
- *Z* is attenuated (by gases, cloud, and precipitation), so it needs to be corrected
- Use surface reference technique (estimate path integrated attenuation or PIA and redistribute attenuation coefficient k in vertical) or k-Z relationship to correct Z for each assumed hydrometeor type
- Then use corrected Z to estimate R via Z-R relationship (with adjustment from attenuation correction if available)
- Reference: Iguchi et al. (2000, Journal of Applied Meteorology)

CloudSat Radar

- While TRMM PR has been a successful precipitation radar, its 17-18 dBZ minimum detectable signal does not allow views of light precipitation and/or clouds (except some anvils) due to wavelength and sensitivity
- Going to a higher frequency (therefore smaller wavelength) increases sensitivity to smaller particles (D^6)
- However, Mie effects are more likely to occur, so there is some tradeoff
- W-Band (mm wavelength) is an attractive option, since it is sensitive to many large cloud particles
- Attenuation and Mie effects in precipitation limit the maximum retrievable rain rate (depending on the DSD) of W-band radar to about 15-25 dBZ

Typhoon Prapiroon (2006) viewed by CloudSat Radar



http://www.cloudsat.cira.colostate.edu/dpcstatusQL.php

Typhoon Prapiroon (2006) viewed by the Cloud Radar on CloudSat