Ka-band Radar Observations at AFRL

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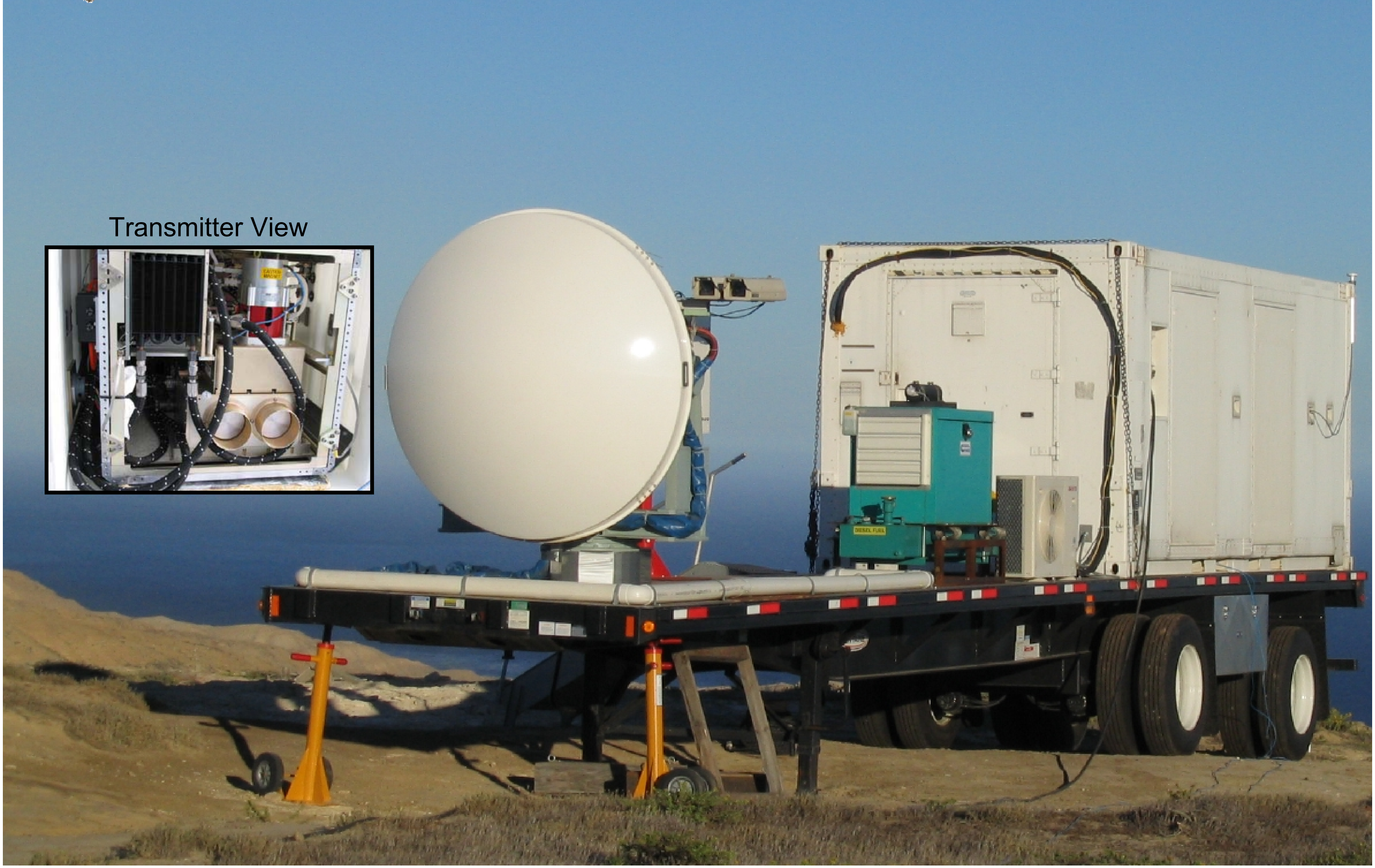
Air Force Cloud Profiling Radar (AFCPR)
Ka-band Doppler radar, 35 GHz, 8.56 mm



Transmitter View

AFCPR Ka-Band Radar Characteristics

Wavelength	35.05 GHz, 8.56 (mm)
Transmitter	Liquid cooled Klystron, 1.5 kW peak, 5% duty 16 W average (pulse mode) 80 W average (chirp mode)
Receiver noise figure	3.2 dB
Antenna	1.8m Cassegrain, 54 dBi gain, Max sidelobes 19.5 dB down
Beamwidth	0.35º, 6.1 milliradians
Range resolution	75 m
Polarization	Linear: H transmit; H or H&V receive
Parameters	Backscatter, Doppler velocity, spectrum width, linear depolarization ratio (LDR)
Nyquist velocity	43 m/s pulse mode; 8 m/s chirp mode
Positioner	AzEl yoke mount, computer or joystick controlled, 0.05º accuracy

Ka-band Sensitivity

Ka-band: 26.5 – 40 GHz (11.3 – 7.5 mm)

Ka-band well suited to cloud detection. Most clouds are within sensitivity realm. Some exceptions: fair weather cumulus and marine fog, due to small droplet sizes (~5μm radius)

Dust particles and insects provide suitable backscatter in boundary layer for altitudes generally <2km AGL. Can be used as tracers of the wind.

Turbulence: measure dissipation rate of turbulent kinetic energy through Doppler velocity spectrum. Turbulence detection requires a backscatter medium such as clouds.

There is no suitable backscatter mechanism for clear-air turbulence

Complex Index of Refraction (m) of Water and Ice at 35 GHz*

m=n-ik; n is ordinary refractive index, k is absorptive coefficient

	Temperature (C)	Complex index of refraction (m)	$\|K\|^2 = \left\|\frac{m^2-1}{m^2+2}\right\|^2$	Im(-K)
water	20	5.09-2.69i	0.902	0.070
water	10	4.51-2.57i	0.891	0.088
water	0	3.94-2.32i	0.867	0.114
water	-8	3.50-2.06i	0.835	0.141
ice	0	1.78-0.0024i	0.176	9.6×10^{-4}
ice	-10	1.78-0.0079i	0.176	3.2×10^{-4}
ice	-20	1.78-0.0055i	0.176	2.2×10^{-4}

*Adapted from Gunn and East, 1954, *Quart. J. Roy. Meteor. Soc.*, Vol. **80**, 522-545

Radar Backscatter

Mie scattering theory describes backscattering cross section (σ) of a spherical drop:

$$\sigma = \frac{\pi r^2}{\alpha^2}\left|\sum_{n=1}^{\infty}(-1)^n(2n+1)(a_n - b_n)\right|^2$$

where size parameter is $\alpha = 2\pi r / \lambda$

Rayleigh backscatter:

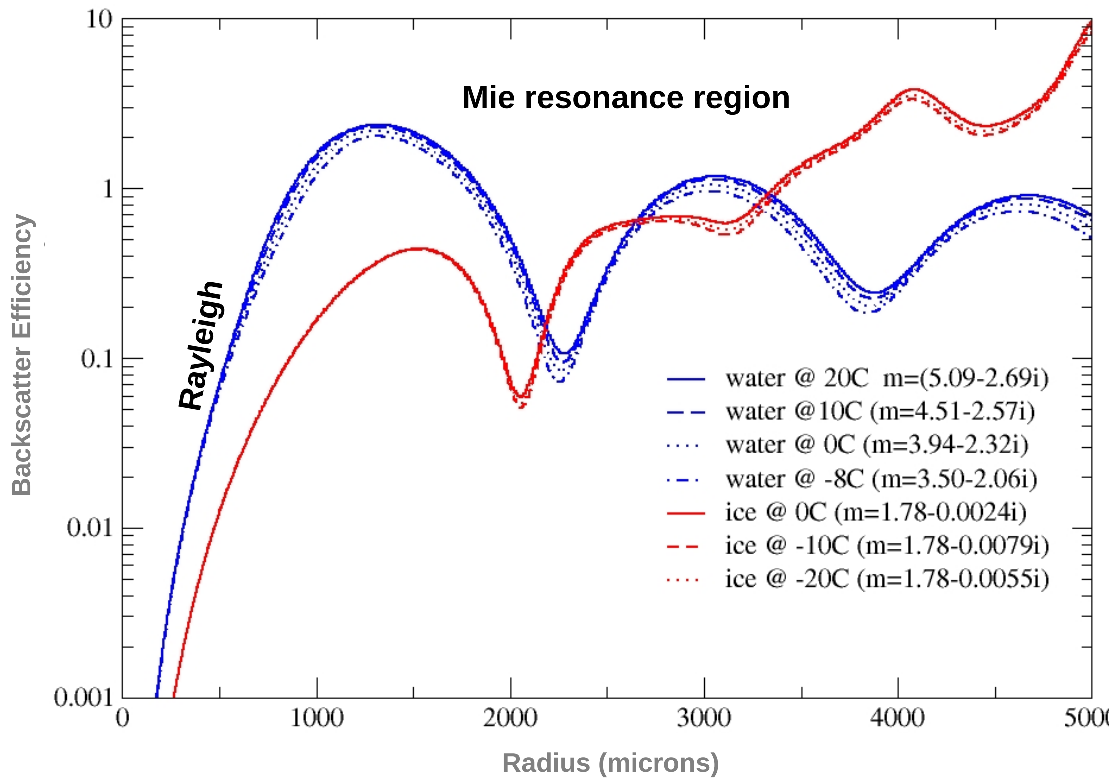
$$\sigma_i = \frac{\pi^5}{\lambda^4}|K|^2 D_i^6$$

Ka Rayleigh range:

r<200 μm for water

r<400 μm for ice

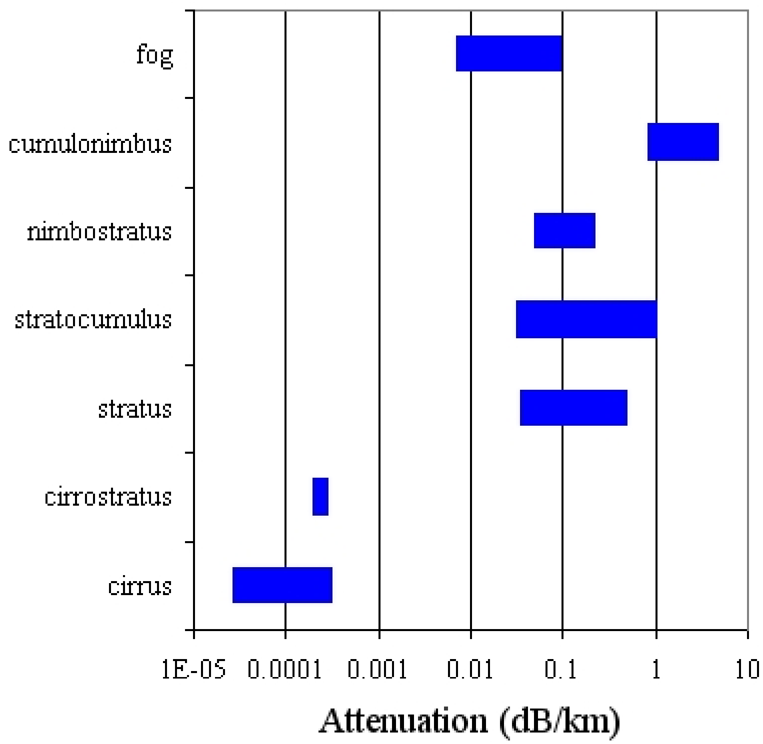
Ka-band backscatter efficiency for water and ice spheres



Attenuation by Clouds and Rain

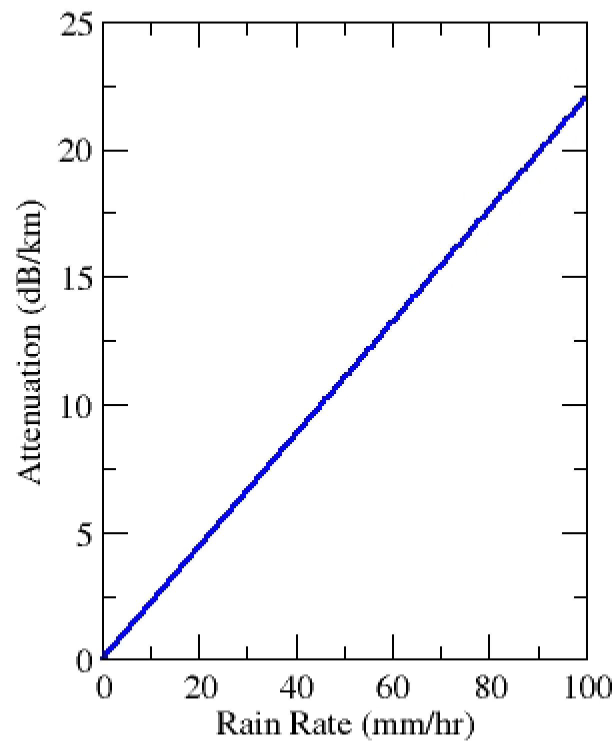
Attenuation by clouds proportional to liquid water content:

$$A(dB/km) = 2.604\frac{\pi M}{\lambda\rho}\text{Im}(-K)$$



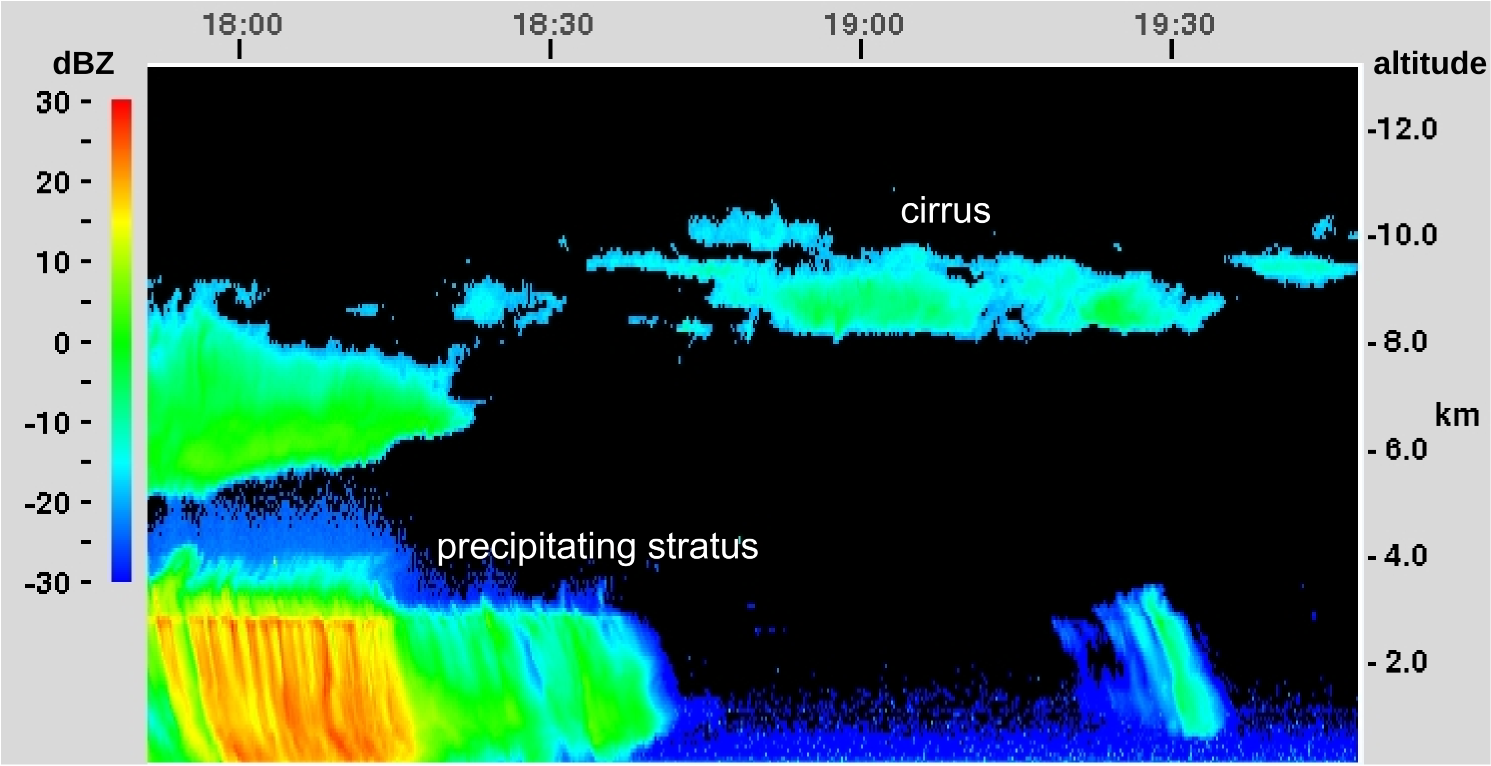
Approximation for attenuation by rain at 35 GHz :

$$A_r(dB/km) = 0.22R^{1.0}, R(mm/hr)$$



Ka-Band Radar Observations Through Precipitating Clouds

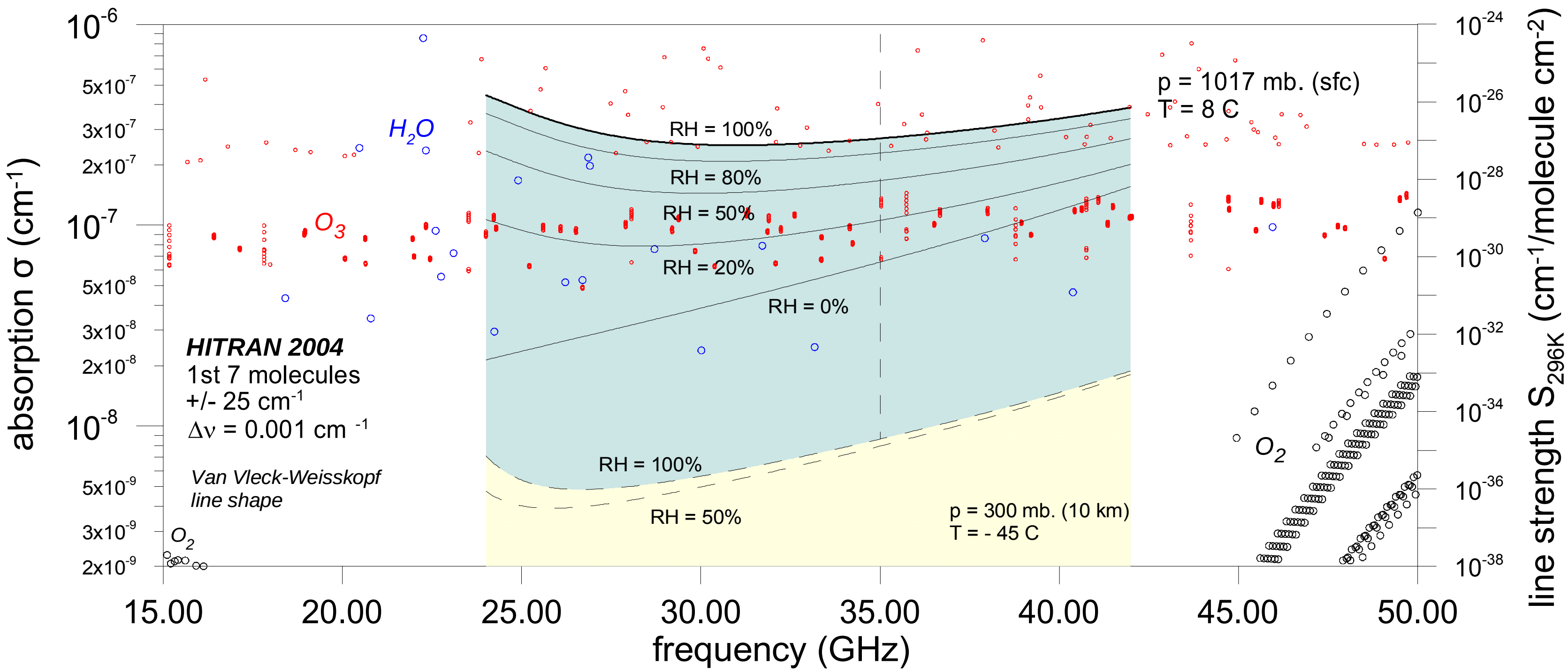
ORCLE (10/12/2004) Hanscom AFB



Attenuation by Gases in Ka-band

HITRAN used to characterize absorption considering H_2O, CO_2, CO, CH_4, O_2, O_3, and N_2O molecules

- Numerous O_3 lines have low molecular number densities
- 99.9% of absorption due to O_2 and water vapor



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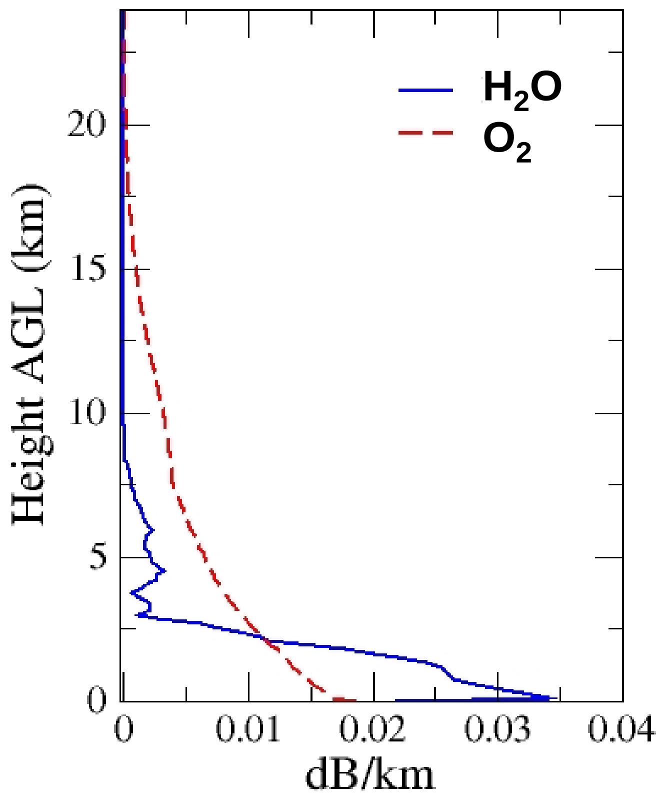
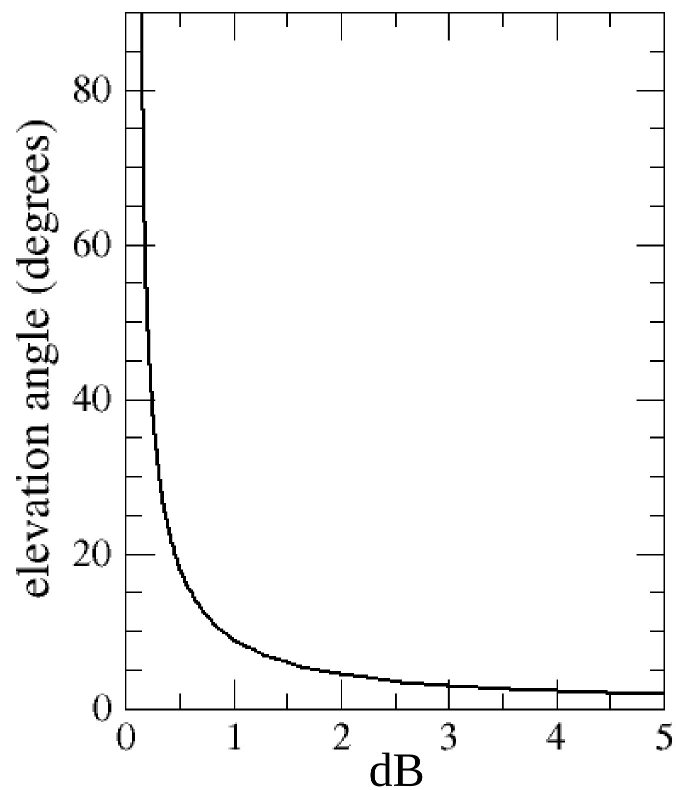
Attenuation by Gases (Cont.)

WSMR, NM, Tula-G site radiosonde, 11/18/2004

Attenuation profile at 35 GHz



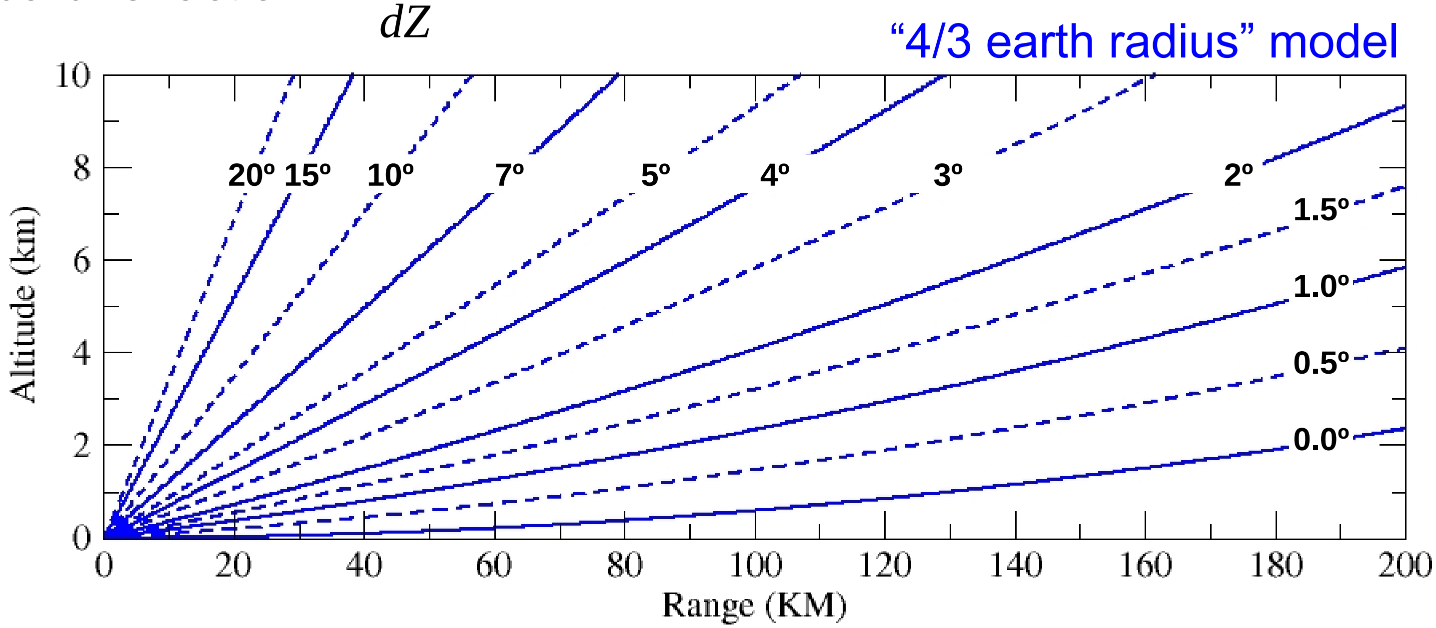
Total 1-way path attenuation



Refractivity

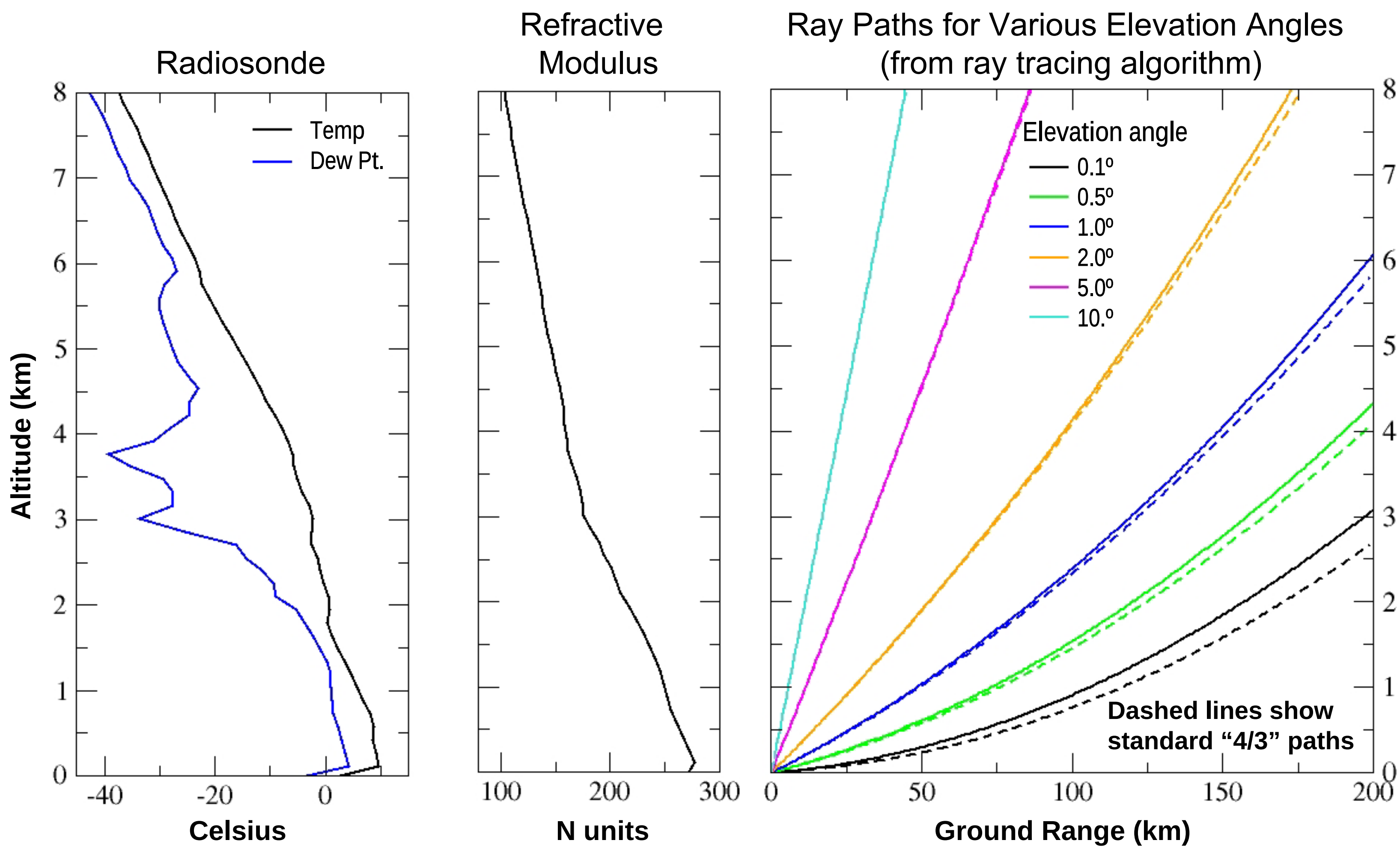
Radio refractivity $N = (n-1)10^6, \quad N = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right)$

Standard refraction: $-\frac{dN}{dZ} = 39/km$



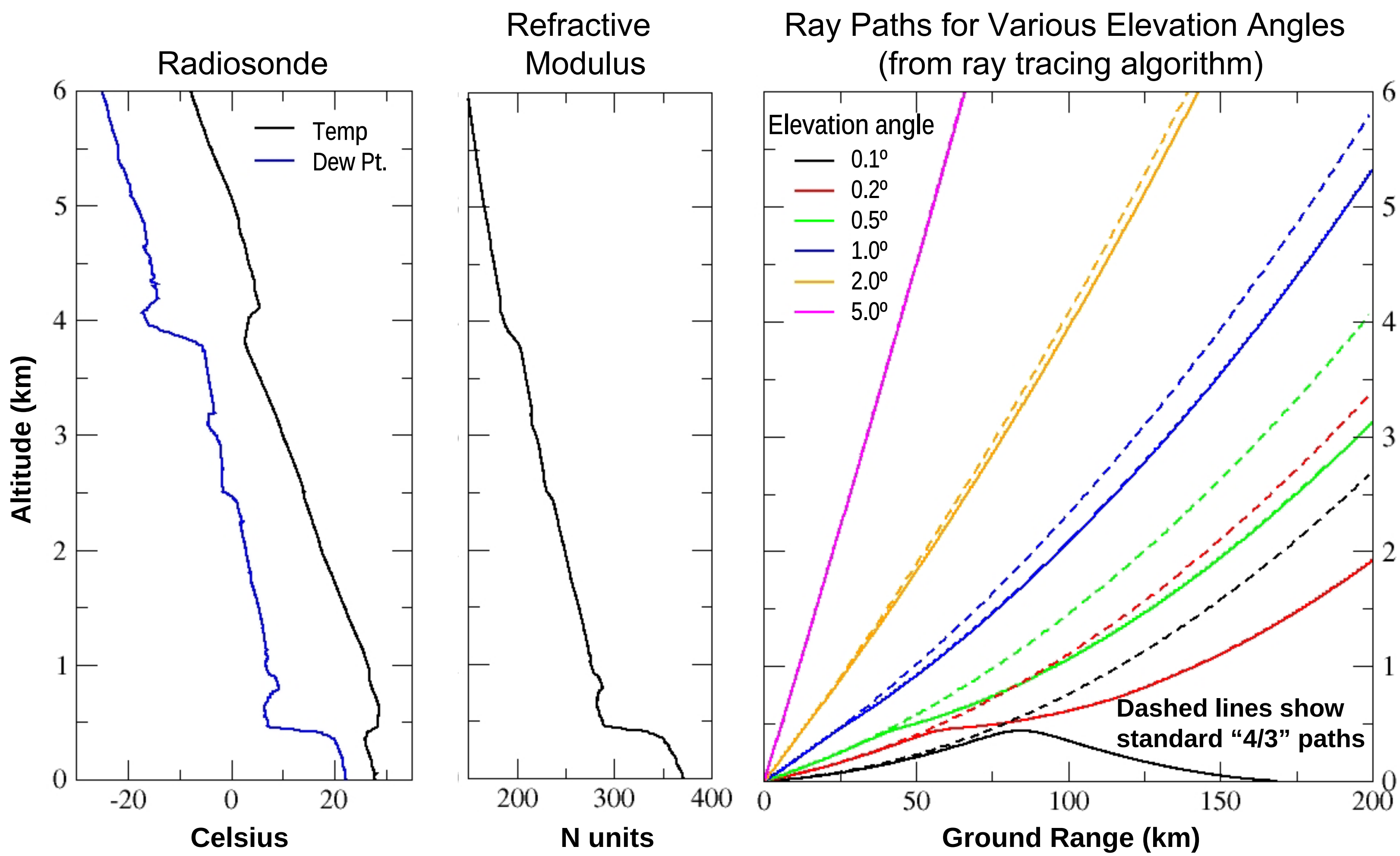
- Super refraction and anomalous propagation occur for $-\frac{dN}{dZ} > 39/km$
- Refraction primarily related to moisture gradient
- More accurate refractivity estimates achieved with a ray tracing algorithm

Refractivity Gradient Impact on Radar Propagation-Subrefraction



18 Nov 2004 WSMR, NM Tula G

Superrefraction



22 Oct 1999 Doha, Qatar

Ka-Band Performance Summary

- Backscatter source is from particulates such as clouds, precipitation, insects and large (>100 µm) dust particles
- Attenuation from non-precipitating clouds at zenith is generally small (< 5 dB) but can be large for liquid clouds at low elevation angles and long path lengths
- Attenuation from rain can be very large and is proportional to the rain rate
- Oxygen and water vapor are the primary absorptive gases
- Attenuation from atmospheric gases is very small at zenith (<1 dB), but increases substantially for low (<5º) elevation angles
- Refraction is generally small for elevation angles above 5º
- Accurate Ka-band refractivity modeling/propagation assessment requires detailed measurement of the vertical water vapor structure