Performance of Scanning Millimeter-Wave Radar in a Tropical Environment

Jorge M. Villa and Sandra L. Cruz-Pol
Electrical and Computer Engineering Department
University of Puerto Rico, Mayagüez Campus
Mayagüez, PR. 00681-5000, email: jorgemvg@ece.uprm.edu and SandraCruzPol@ieee.org

Stephen M. Sekelsky
Microwave Remote Sensing Laboratory, University of Massachusetts at Amherst
Amherst, MA. 01003, email: sekelsky@mirls.ecs.umass.edu

Abstract-**The minimum detectable radar reflectivity (dBZemin) is computed for the University of Massachusetts 33 GHz/95 GHz Cloud Profiling Radar System (CPRS) under humid tropical conditions. Extinction by water vapor and oxygen are calculated for a horizontally stratified atmosphere as a function of range and scan angle for both radar frequencies. Combined radiosonde and dual- frequency microwave radiometer measurements are used to model radar signal extinction for the Maritime Continent Thunderstorm Experiment (MCTEX), which was conducted in northern Australia. These data are compared with CPRS radar measurements to evaluate the performance of both frequencies for sensing clouds and precipitation versus elevation angle.**

I. CHARACTERIZATION OF WATER VAPOR PROFILE

The data obtained by the radiosonde and corroborated by radiometer data show that the experiment was made under moderated humidity weather conditions with a specific humidity of 8.4 gm^{-3}, 0.48 dB of two-way total attenuation to 15 Km from zenith for the K_a band (33 GHz) with a variance of 0.016 dB. While for the W band (95 GHz) the total attenuation was 2.91 dB with variance of 0.37 dB.

II. ATTENUATION STATISTICS

A. Equations relating humidity profiles and microwave radiometer data to attenuation

Radiosonde profiles of air temperature, pressure and specific humidity are used as inputs for the gaseous attenuation models. This data is necessary for atmospheric correction. Assuming a horizontally stratified atmosphere, the gaseous attenuation due to oxygen, $K_{O2}(l)$, and gaseous attenuation due to water vapor, $K_{wv}(l)$, for every height and for each radar frequency, 33 GHz and 95 GHz[1]. The oxygen absorption model used is defined by Rosenkranz [2].

The total gaseous attenuation in a layer is the sum of the attenuation due to water vapor plus the attenuation due to oxygen particles in that layer.

$$K_g = K_{wv} + K_{O_2} \qquad (1)$$

After calculating the gaseous attenuation in each layer, we can obtain the absorption due to gases, where the absorption in a determined layer (A_g), is defined as the sum of the gaseous attenuation of the inferior layers, l, to a specific one plus the attenuation in the layer, l_0.

$$A_g(l_0) = 2\int_0^{l_0} k_g(l)dr \text{ (Np)}. \qquad (2)$$

B. Scan Equations

The path loss, A_g, varies depending on the frequency being used. For frequencies where the path loss degrades the signal strongly, higher power should be used to minimize this effect.

After calculating the atmospheric attenuation for every height, a projection of that attenuation was made for every radar radius at a fixed angle. A matrix of radius times angles was used to save the projected attenuation. Then the cumulative attenuation for specific angle and radius is calculated

$$A_g(\theta,h) = \sum_{i=0}^{n-1} k(i)\left[h(i) - h(i+1)\right]\sin\left(\theta\right) \qquad (3)$$

Finally with the cumulative attenuation for every radius at a specific angle the total path loss, l, can be calculated. Using the path loss and the radar equation the reflectivity in dBZ can be determined [3].

$$l = e^{-A_g} \qquad (4)$$

$$Z_e = P(r_0)\frac{6.75\times 2^{14}\lambda^2 {r_0}^2 \ln(2)}{\pi^5 10^{-17} P_t g^2 g_s \tau\theta_1^2 \left|K_w\right|^2 l^2 l_r} \qquad (5)$$

For this system the radar uses the same antenna to transmit the pulses and to receive the echoes where the peak power transmitted is P_t (mW). With an antenna gain g, and one system power gain g_s, with λ (m), as the wavelength of the transmitted pulse, τ (s) is the duration of the pulse, the pattern of the antenna has the same beamwidth on azimuth and on elevation. The constant ln(2) is found in the equation because it was assumed that the antenna radiation pattern is circularly symmetric and with Gaussian shape [3]. θ_l (radians) is the half power beamwidth of the antenna, the range of the target is r_o (m), l^2 is the two way attenuation through the atmosphere and l_r^2 are the losses on the receiver given a finite beamwidth, and from the index of refraction of water is obtain $|K_w|$.

After this, graphics from calculations of the dBZ_{emin}, for every radio and each angle at 33 and 95 GHz are plotted

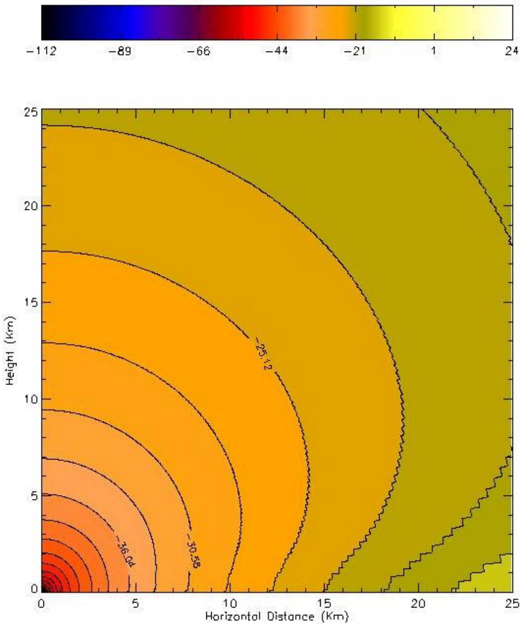

Fig. 1. Minimum detectable dBZ for 33GHz

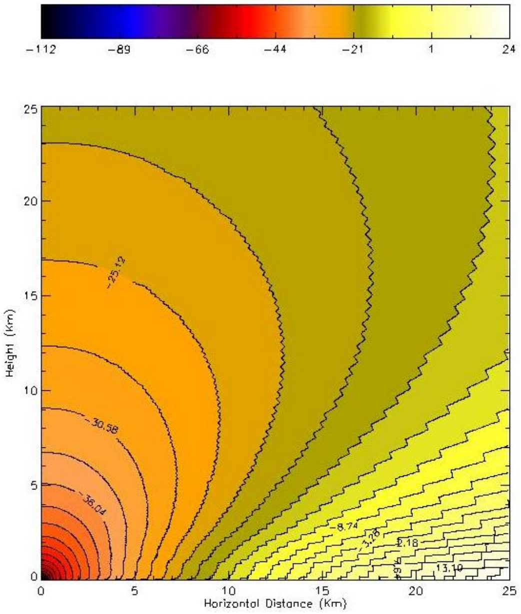

Fig. 2. Minimum detectable dBZ for 95GHz

In Figures 1 and 2 the delta between two lines of the contour is 2.73dB. As can be seen in Figure 2 the 95 GHz signal suffers more attenuation than the 33 GHz signal (Figure 1). This is because the higher frequency 95 GHz suffers greater attenuation due to the water vapor encountered in the lower layer of the atmosphere. As the scanning angle increases from the vertical (zenith) a higher portion of the path traveled by the signal propagates thought the lower layers (higher in water vapor concentration).

Plotting real data of the reflectivity taken November 23th of 1995 in Australia under MCTEX by CPRS in the Ka and W bands with a scanning mode from 10 to 110 degrees, measured from the horizon (Figures 3 and 4). In the same date radiosonde and radiometer data were taken, which were used to calculate the values of the Figures 1 and 2

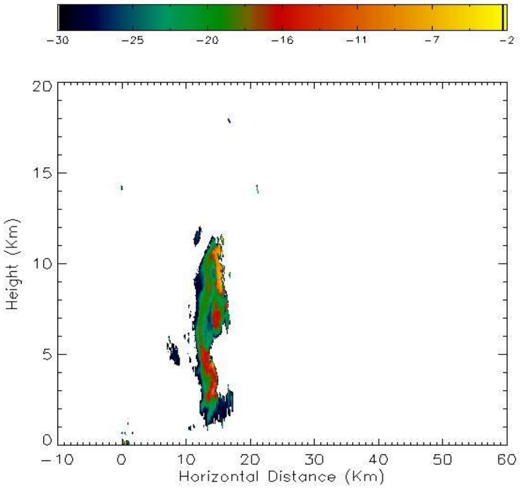

Fig. 3. CPRS Data of dBZ (33GHz).

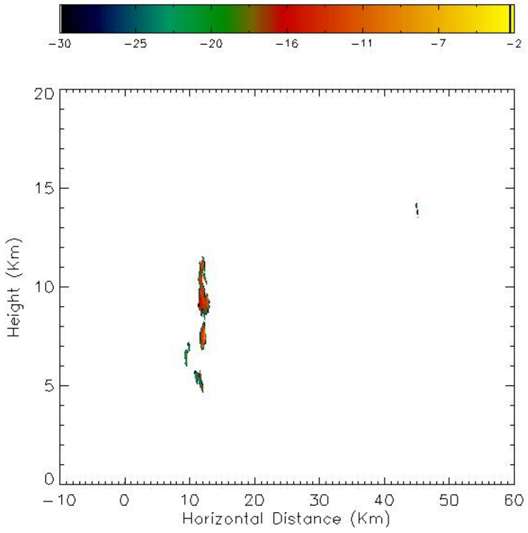

Fig. 4. CPRS Data of dBZ (95GHz).

The radar begins to detect the cloud from a radius of 8.2Km and from an angle between 15 and 36 degrees. To the W band the cloud is much smaller than the one showed by the Ka band. This data validates the simulation and confirms the effect of the attenuation of the W band in angles smaller than 50 degrees (Figure 2).

III. RADAR SYSTEM CHARACTERISTIC AND MCTEX EXPERIMENT LAYOUT

A. Maritime Continent Thunderstorm Experiment (MCTEX)

The MCTEX experiment was performed in the North Coast of Australia, and in the Bathurst and Melville Islands. The principal objective of this experiment was to understand better the physical processes, such as humidity balance over tropical islands on a maritime continent. For this reason, the experiment was realized between November 13 and December 10, 1995; season on which the transition phases occurs between the dry and wet seasons. The data of this experiment were collected with different sensors. One set was collected by means of the Cloud Profiling Radar System (CPRS). This one, collected data on the Ka frequency band (33.12 GHz) and W frequency band (94.92 GHz). Data from the W frequency band, 95 GHz, also was collected by the Airborne Cloud Radar. The NOAA radar collected data on the S frequency band, at 2.8 GHz.

B. Radar Hardware of Cloud Profiling Radar System (CPRS)

The CPRS is a dual-frequency polarimetric Doppler radar system that works with two sub-systems at 33 and 95 GHz. This was fully developed by the University of Massachusetts' Microwave Remote Sensing Laboratory (MIRSL).

TABLE I
CPRS PARAMETERS

	W band	Ka band
Frequency (GHz)	95	33
Peak power (Kw)	1.5	120
Average power (w)	15	120
Pulse width (ns)	500	200
Range gate spacing (m)	60	30
Pulse repetition freq. (KHz)	10	5
Noise figure (dB)	13	11
Profile averaging period (s)	2	2
Bandwidth (MHz)	2	5
Beam width (deg)	0.18	0.50

The CPRS has a programmable structure that allows working in different modes of scanning. It has a high-speed VXI-bus-based data acquisition and digital signal processing (DSP) system. A radome protects the system from atmospheric effects. Both the 33 and 95 GHz sub-systems simultaneously transmit and receive by means of a single aperture and not producing pointing errors between both frequencies. Table I shows other typical characteristics of the CPRS operation.

The CPRS measures can obtain the reflectivity (Z_e), mean fall velocity ($\bar{u}$) linear depolarization ratio (LDR), velocity spectral width (σ_v), and the full Doppler spectrum ($S(v)$) [4], [5].

IV. CONCLUSIONS

In this work, we demonstrated that the higher attenuation exhibited at angles away from zenith for the 95 GHz (Fig. 4) is due to the atmospheric attenuation as shown by the simulation (Fig. 2) since at these angles the signal travels longer path trough the lower layer of the atmosphere.

Minimum signal extinction is observed when the radar points at zenith, which corresponds to the shortest path through the moist boundary layer. For the MCTEX data, the average atmospheric two-way path extinction between the surface and tropopause (approximately 20 km) is 30.79 dB and 36.37 dB, at 33 GHz and 95 GHz, respectively and both radar channels have nearly the same minimum detectable reflectivity. However, 95 GHz signal extinction rapidly increases as the radar is scanned away from zenith. At low elevation angles (between 0° and 55° where 0° points to horizontal) the 95 GHz signal experiences significant attenuation and the minimum detectable reflectivity is severely degraded.

While pointing horizontally (0° elevation angle) the average extinction rates for the MCTEX data are 1.78 dB/km and 2.96 dB/km at 33 GHz and 95 GHz respectively.

At higher elevation angles the MCTEX data shows that the 95 GHz channel is still sufficiently sensitive to detect clouds at horizontal distances of 10 km or further. In contrast, MCTEX data shows that the 33 GHz channel detects clouds and precipitation at all elevation angles to distances in excess of 50 km. Scanning from horizon-to-horizon a swath in excess of 100 km can be covered at 33 GHz.

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