Surface Clutter Due to Antenna Sidelobes for Spaceborne Atmospheric Radar

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1. Introduction

- Spaceborne atmospheric radars must detect relatively weak targets (clouds and rain) in the presence of both thermal noise and clutter.
- Clutter is primarily from the surface through antenna sidelobes.
- Because of the brightness of the surface relative to atmospheric targets, surface clutter must be accurately calculated for proper system design.
- Previous work in this area has dealt with clutter due to the same pulse as that illuminating the atmosphere.
- The method presented here includes effects of all contributing transmit pulses, Doppler shifting, finite receiver bandwidth, and curved earth's surface.

2. Atmospheric Signal

- The atmospheric backscatter power is calculated by the Probert-Jones equation:

$$P_a(r) = \frac{P_t \lambda^2 G^2 \theta_1^2 \Delta \eta}{512\pi^2 \ln 2 r_a^2}$$

- P_t is the transmitter power, λ is the wavelength, G is the antenna gain, θ_1 is the antenna half-power beamwidth, Δ is range resolution, r_a is the range to the atmospheric target, and η is the reflectivity.

- In this equation and our subsequent derivations, we assume that the pulse shape is nearly constant over the resolution Δ and zero outside.

- This equation also assumes a Gaussian-shaped antenna pattern.

3. Clutter Signal

- In addition to the signal from the atmosphere, the radar will simultaneously receive echoes from all targets which differ in range by $nc/2PRF$.
- Here, n is an integer, c is the speed of light, and PRF is the pulse repetition frequency.
- n corresponds to the pulse number relative to the pulse being received from the atmospheric target, with positive n denoting previous pulses and negative n denoting subsequent pulses.
- The surface return P_s for a particular n is given by the following expression:

$$P_s(r) = \frac{P_t \lambda^2 G^2}{64\pi^3} \int_S \frac{g^2 \sigma^0}{r_s^4} dS$$

- S denotes the surface illuminated by the pulse, σ^o is the normalized radar cross section of the surface, and g is the antenna pattern.
- The range to the surface r_s is equal to $r_a + nc/2PRF$.
- For a rectangular pulse, the surface clutter through sidelobes for a given n is due to an annulus on the earth's surface.

4. Signal-to-Clutter Ratio

- The previous expression for P_s can be simplified by writing dS as $\sin\gamma d\gamma d\phi$, where γ is the angle subtended by the earth's surface from nadir to the annulus.
- Then g^2, σ^o, and r_s are assumed constant over the width of the annulus and brought outside the γ integral.
- The signal-to-clutter ratio (SCR) can be found as the ratio of the atmospheric power to the sum of the clutter power over all pulses (or annuli):

$$SCR = \frac{\pi\theta_1^2\eta\Delta(R_e + h)}{4\ln 2 r_a^2 R_e \Sigma}$$

$$\Sigma \equiv \sum_n \frac{\sigma^o(r_2^2 - r_1^2)}{r_s^4} \int_0^{2\pi} g^2(\theta_n, \phi) w(\phi) d\phi$$

- $r_1 \equiv r_s - \Delta/2$, the distance to the inner annulus edge, and $r_2 \equiv r_s + \Delta/2$, the distance to the annulus outer edge.
- R_e is the earth's radius, and h is the spacecraft altitude.
- θ_n is the angle between nadir and the nth annulus.

5. Computational Details

- Since the receiver has a finite bandwidth, the return from a direction ϕ must also be weighted by $w(\phi)$ the receiver output for a Doppler shifted input.
- An antenna pattern g is also needed; we use a Gaussian shaped mainbeam with sidelobes which fall off at a user-specified rate.
- For the surface backscatter σ^o, we use a function which decreasese linearly in the log-domain.
- For a spherical earth, the maximum n corresponds to a propagation vector that is tangent to the earth's surface.
- The minimum n is 0 for a nadir looking system but can be negative when the antenna is scanned off-nadir.
- Rather than computing SCR, it is more convenient to solve for the reflectivity giving an SCR of unity:

$$\eta_m = \frac{r_a^2 4 \ln 2 R_e \Sigma}{\pi \theta_1^2 \Delta (R_e + h)}$$

- The minimum detectable reflectivity factor, $Z_m \equiv \lambda^4 \eta_m 10^{18} / \pi^5 |K|^2$, is then found.
- K is the dielectric constant factor for the atmospheric target.

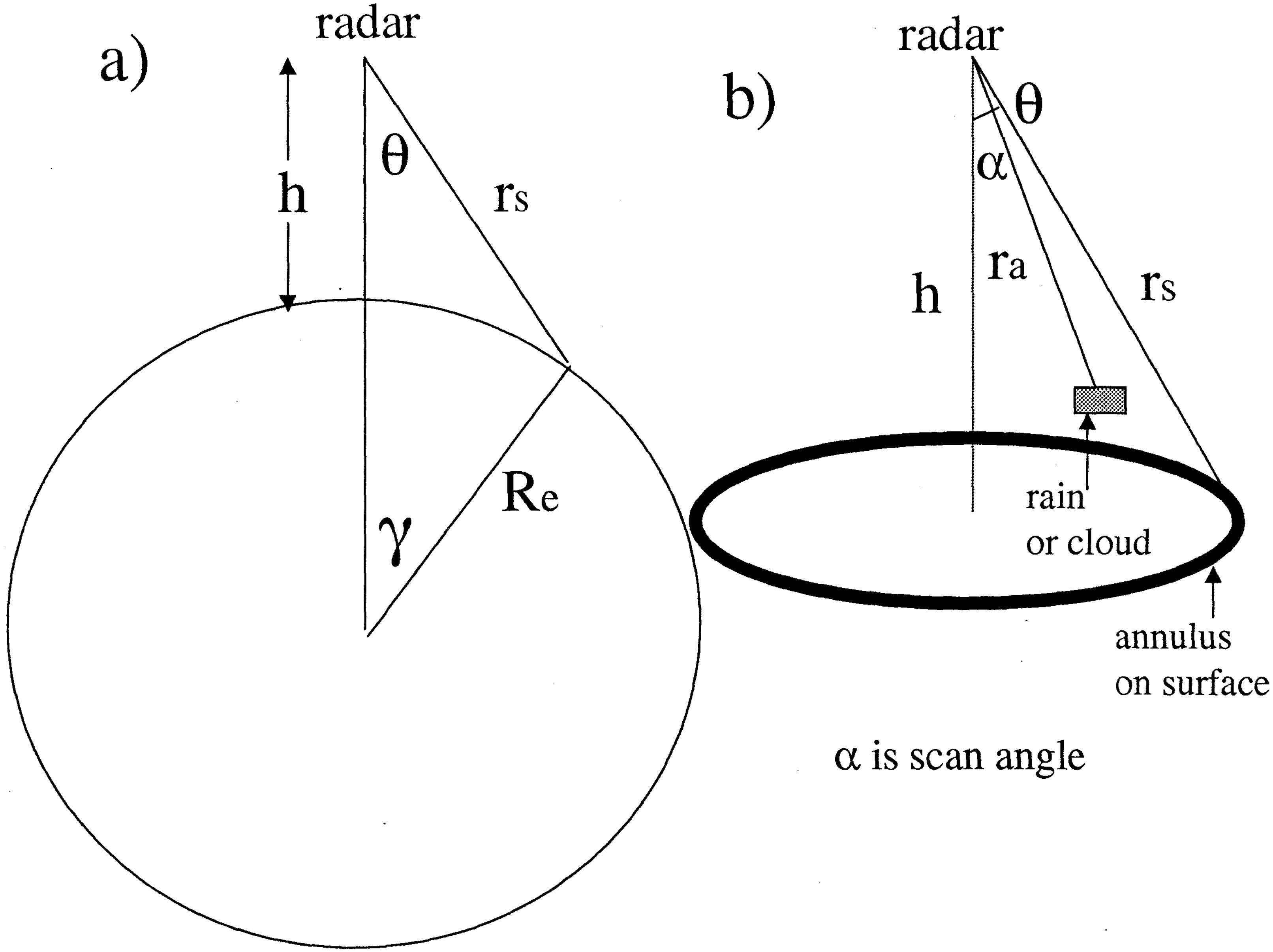
6. Application to TRMM

- The TRMM Precipitation Radar (PR) has been in operation since late 1997.
- The figure shows clutter data acquired by the TRMM PR over the Indian ocean at 17^o incidence angle (clear conditions).
- Also shown in the figure are calculations of Z_m due to clutter using the method developed here.
- Agreement between the calculated and observed Z_m is generally good; differences are most likely due to differences between the ocean σ^o model and the actual ocean σ^o and between the antenna pattern model and the actual pattern.
- The clutter contribution to atmospheric targets from just above the surface to a slant altitude of about 15 km is dominated by same-pulse clutter (i.e., $n = 0$).
- At nadir (not shown) the $n = 0$ pulse does not contribute to range bins above the surface; we find that Z_m due to $n \geq 1$ is nearly constant with altitude, having a value near -3 dBZ.
- This value is well below the TRMM PR sensitivity due to thermal noise and cannot be observed.

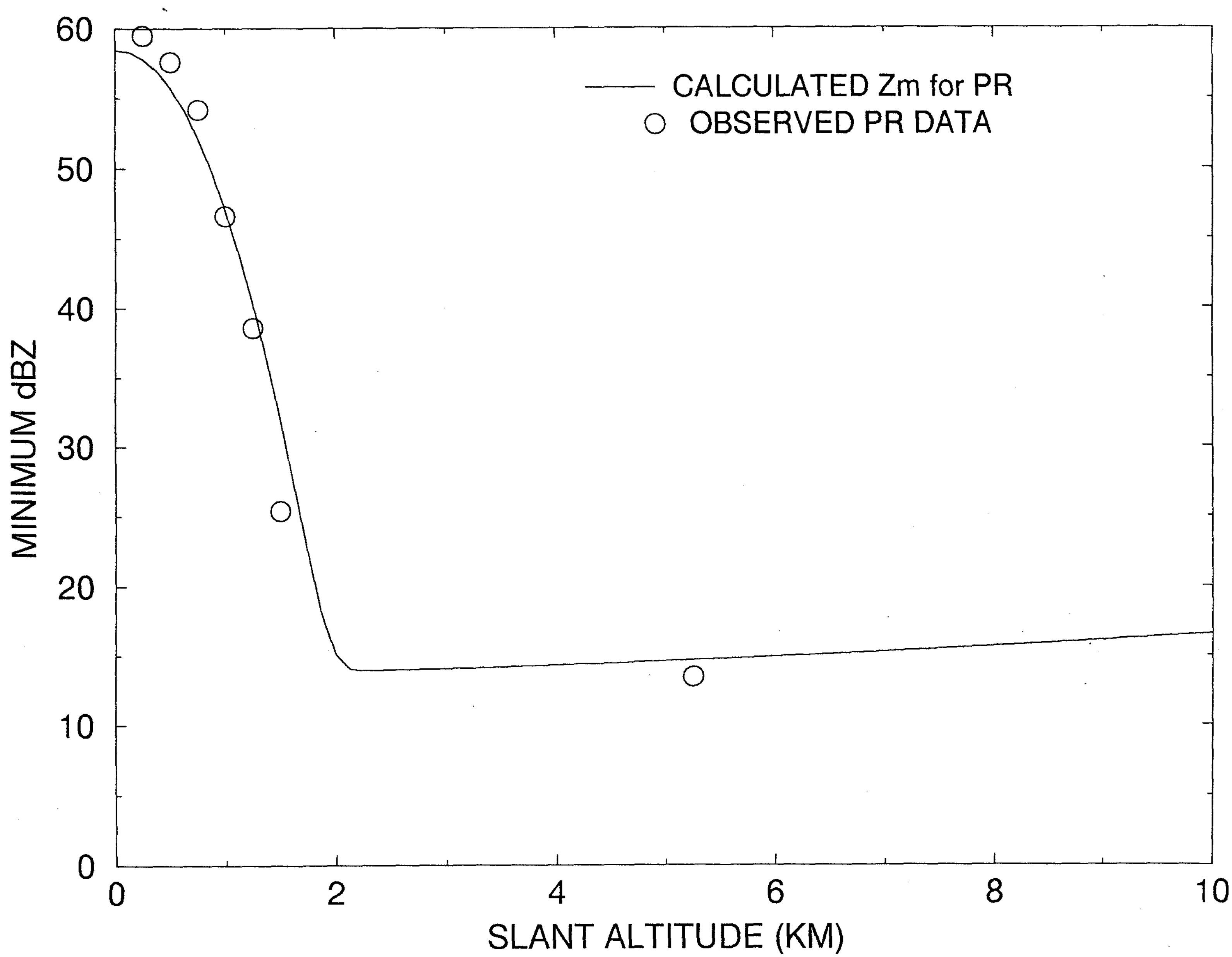
7. Application to Cloud Radar

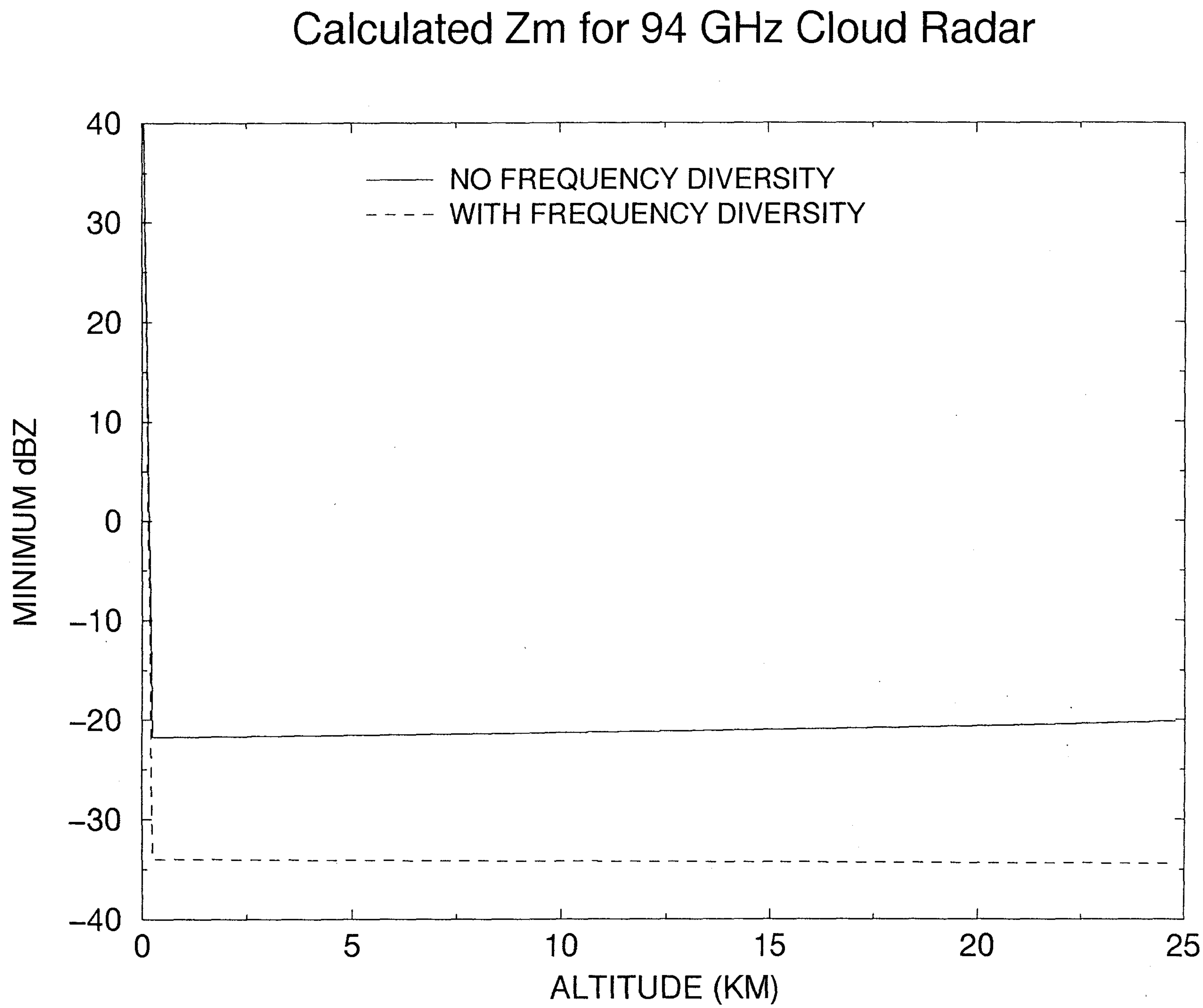
- Cloud radars must measure targets substantially weaker than precipitation (e.g., -25 dBZ versus +25 dBZ).
- The figure shows a calculation for a 94 GHz cloud radar with antenna sidelobes of -38 dB; the resulting Z_m is near -20 dBZ.
- Improvement can be found by using frequency diversity; a sequence of transmit frequencies is used, varying pulse-to-pulse.
- The receiver tracks the transmit frequency with a delay corresponding to the pulse roundtrip time.
- The figure shows results with the same antenna but using 2 MHz spacing between frequencies and 16 frequencies; Z_m is lowered to -34 dBZ.
- The next figure shows the contribution of each annulus to the received clutter at 25 km altitude, both without and with frequency diversity.
- For the case without frequency diversity, the Doppler spectra of all annuli are centered on the receiver passband.
- When frequency diversity is used, the annuli have center frequencies shifted by 2 to 30 MHz, reducing the power in the receiver passband.

Geometry for Clutter Calculations

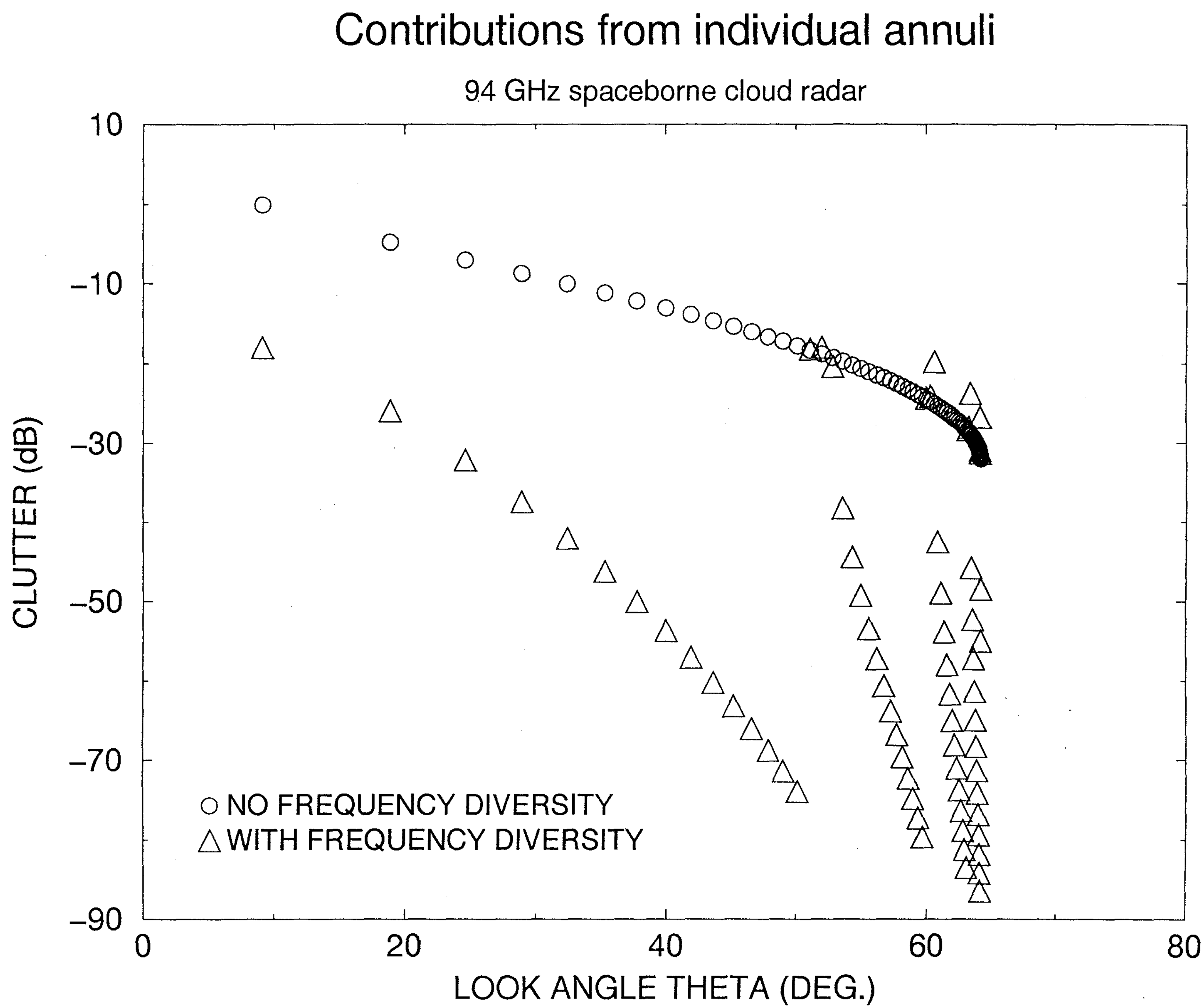


OBSERVED AND CALCULATED Zm for TRMM PR





Calculated Zm for 94 GHz Cloud Radar
NO FREQUENCY DIVERSITY
WITH FREQUENCY DIVERSITY
MINIMUM dBZ
40
30
20
10
0
−10
−20
−30
−40
0
5
10
15
20
25
ALTITUDE (KM)



Contributions from individual annuli
94 GHz spaceborne cloud radar
10
−10
−30
−50
−70
−90
CLUTTER (dB)
0
20
40
60
80
LOOK ANGLE THETA (DEG.)
○ NO FREQUENCY DIVERSITY
△ WITH FREQUENCY DIVERSITY