# Non-Precipitating Stratus Cloud Characterization Using a Ground-Based Microwave Doppler Radar

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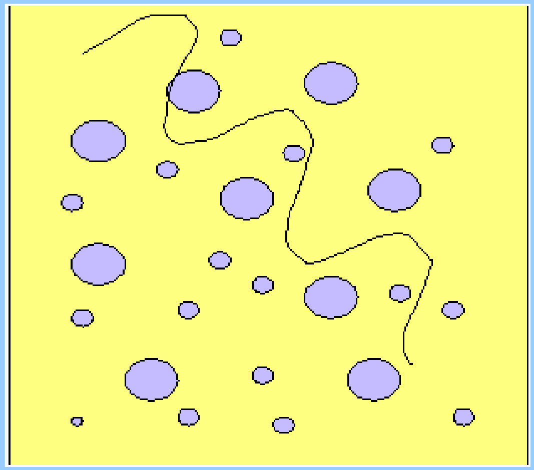
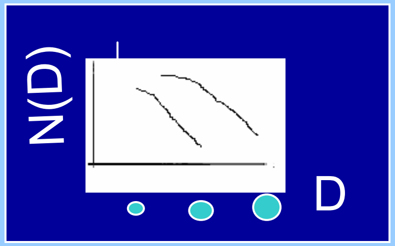
# Cloud's Microphysical Properties

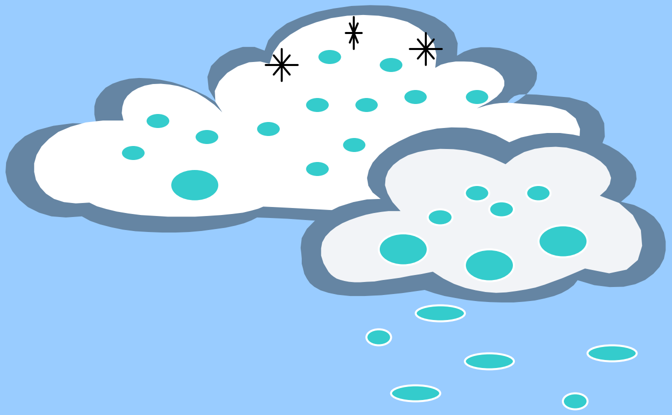
Rayleigh Scattering

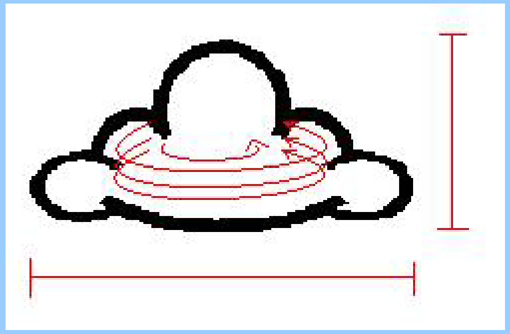


Exponential Distribution

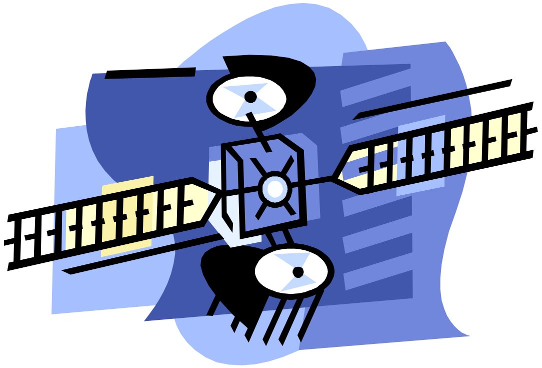



Suspended Water Droplets

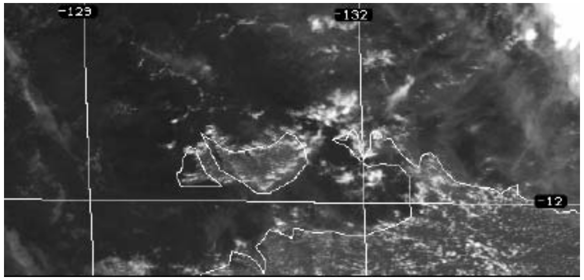




# Clouds Types on the Atmosphere



# Problem

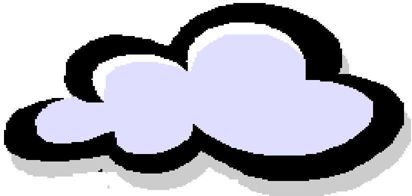


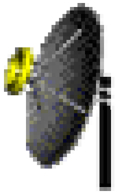

## Atmospheric Correction

Knowing the cloud's macrophysical and microphysical properties the  attenuation due to the cloud can be known, with this the cloud can be removed from satellite imagery

## Meteorology

Knowing the microphysical and macrophysical and microphysical properties for weather and global change studies.





# Objectives

- Estimate the microphysical properties of non precipitating stratus cloud
  - Retrieve drop size distribution *parameters* of a stratus cloud
  - Extract the liquid water content
- Validate the exponential size distribution by Marshall and Palmer.

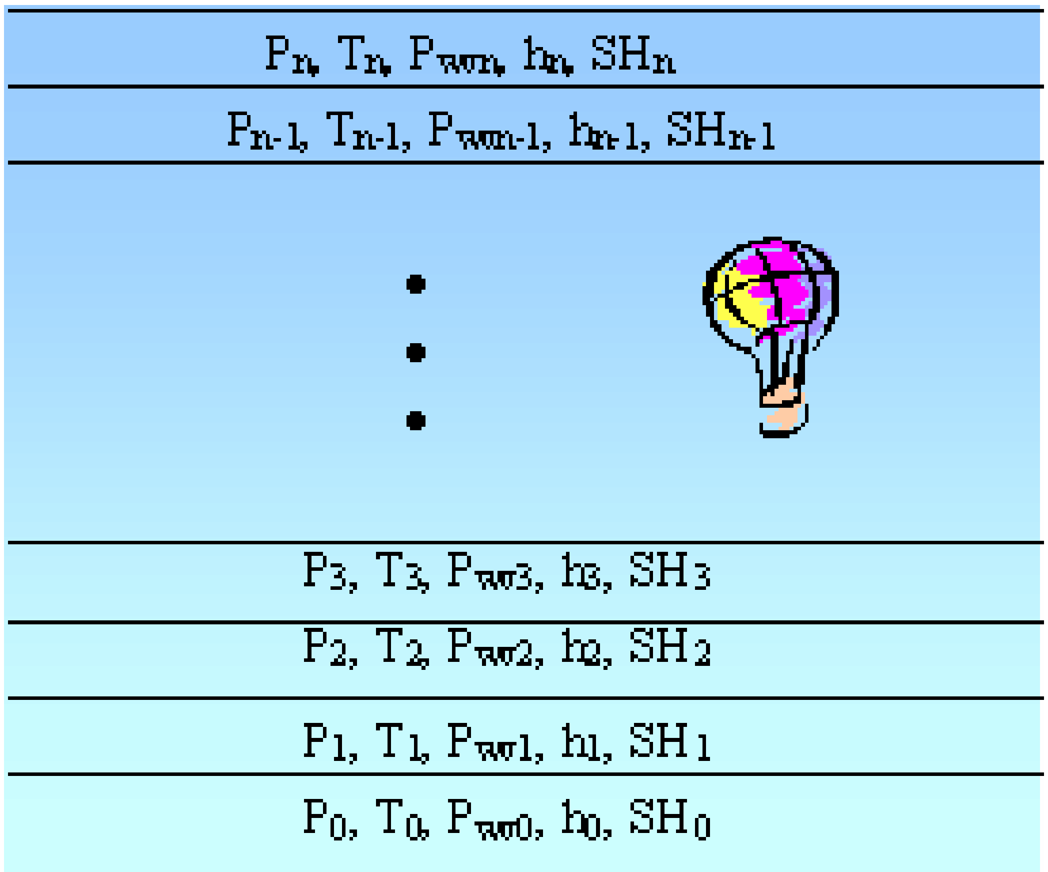
# Cloud Profiling Radar System

Developed by UMass 1994

Field Experiment
SPG Cart Site, Lamont Oklahoma

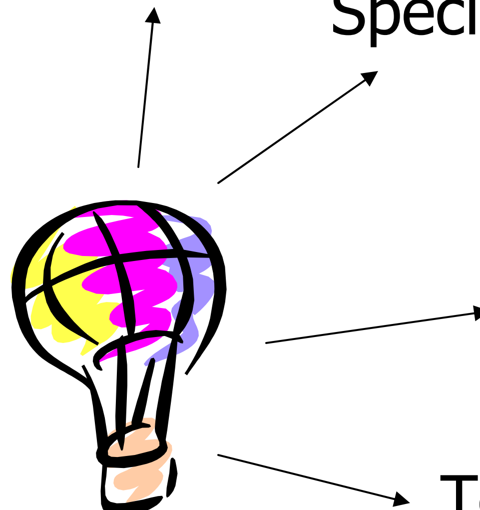
Spring 2000

# Horizontally Stratified Atmosphere




Height

Specific Humidity vs. Height



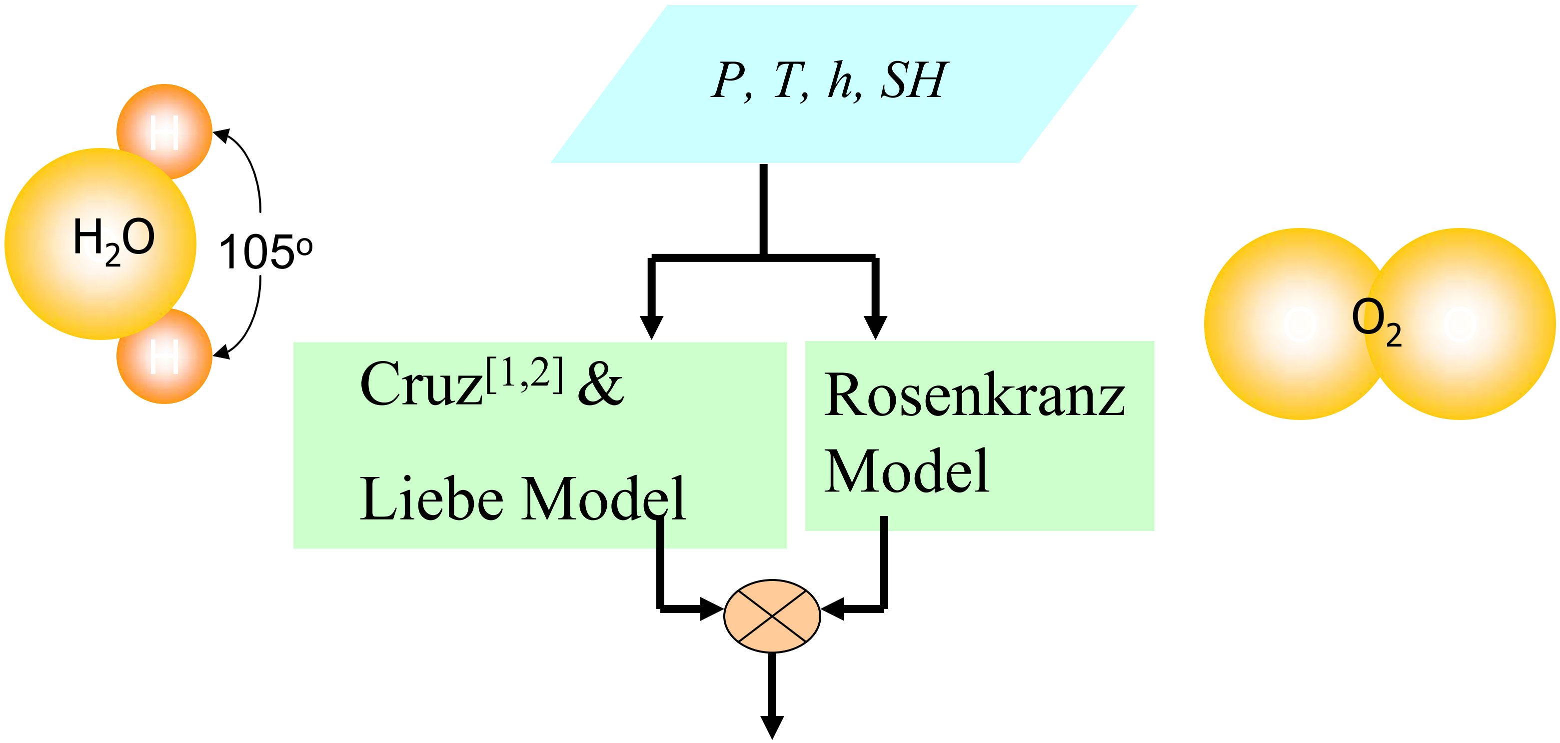
Pressure vs. Height

Temperature vs. Height

Dual-channel microwave Radiometer

Total integrated or column water vapor and liquid water

# Radiosonde Data Processing




$$K_{Gaseous}(i,f) = K_{WaterVapor(i,f)} + K_{O_2}(i,f)$$

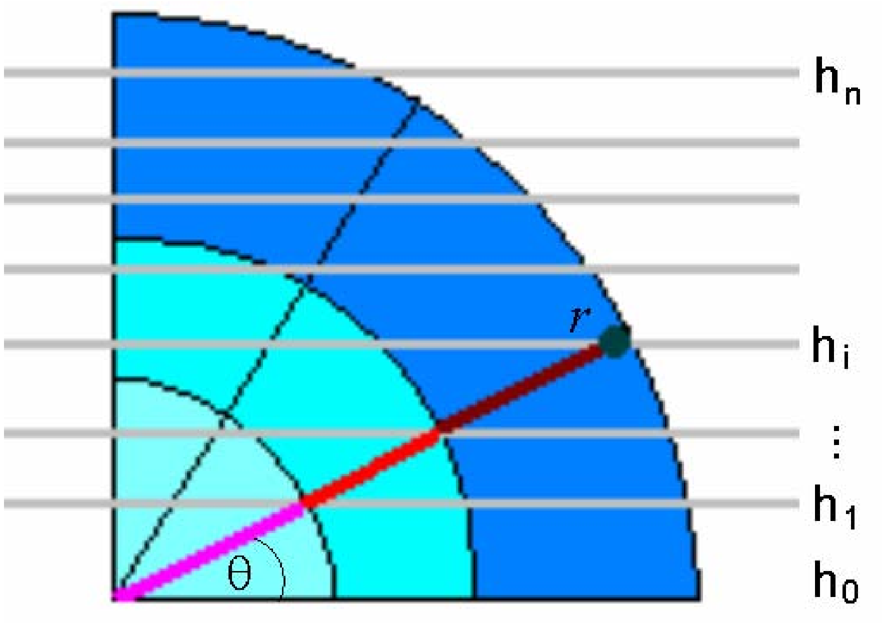
[1] *Keihm et al., IEEE Trans. On Geoscience and Remote Sensing, June 2002*

[2] *Cruz-Pol et al., "Improve Atmospheric Absorption Model…", Radio Science, 2000*

# Cumulative Gaseous Attenuation

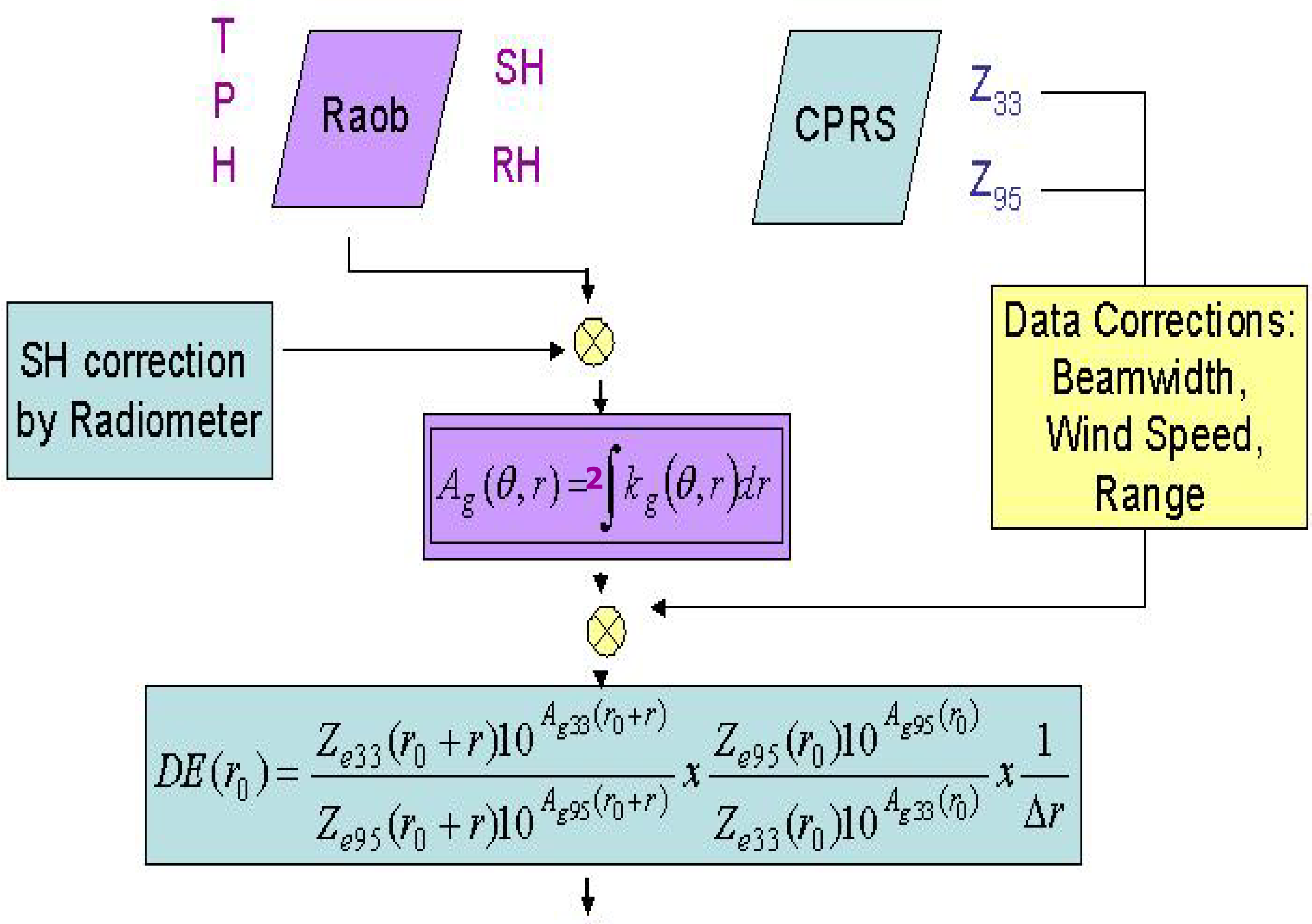
Accumulative attenuation is calculated for every radar radius at a fixed angle.

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

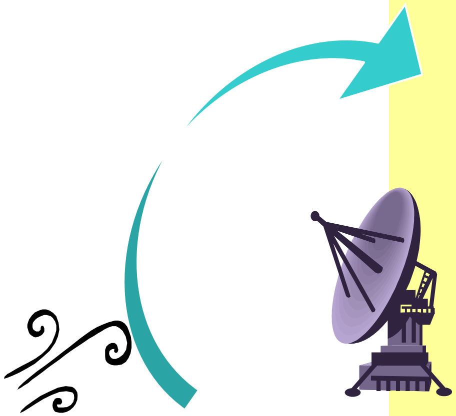



$$\Delta r(i) = \left[h(i+1) - h(i)\right]\sin(\theta)$$

# Flow Diagram



# Wind Speed Correction



**Effective Wind Velocity**

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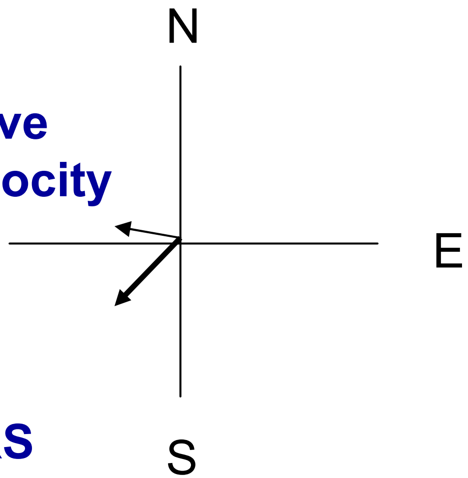
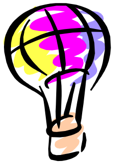
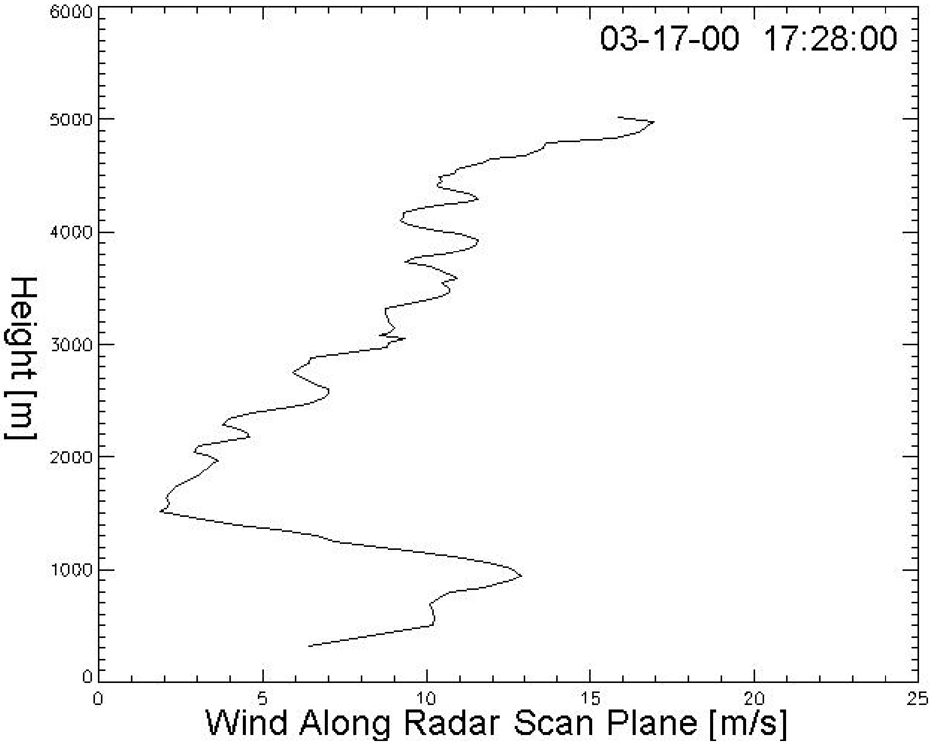


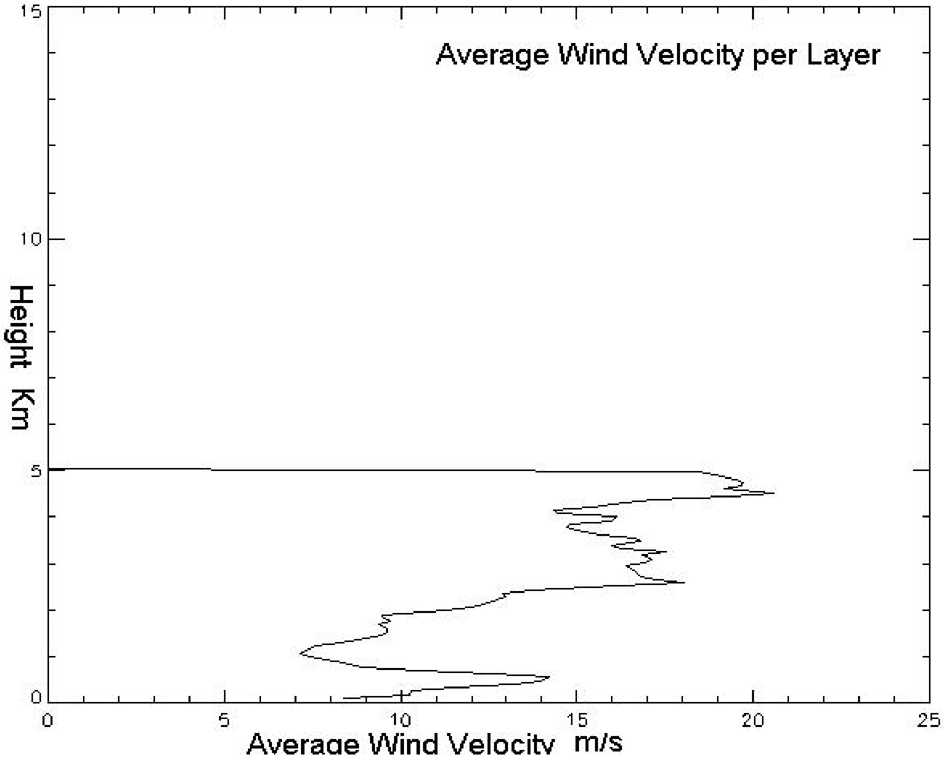

**CPRS**
**220° from N**

N Component
E Component



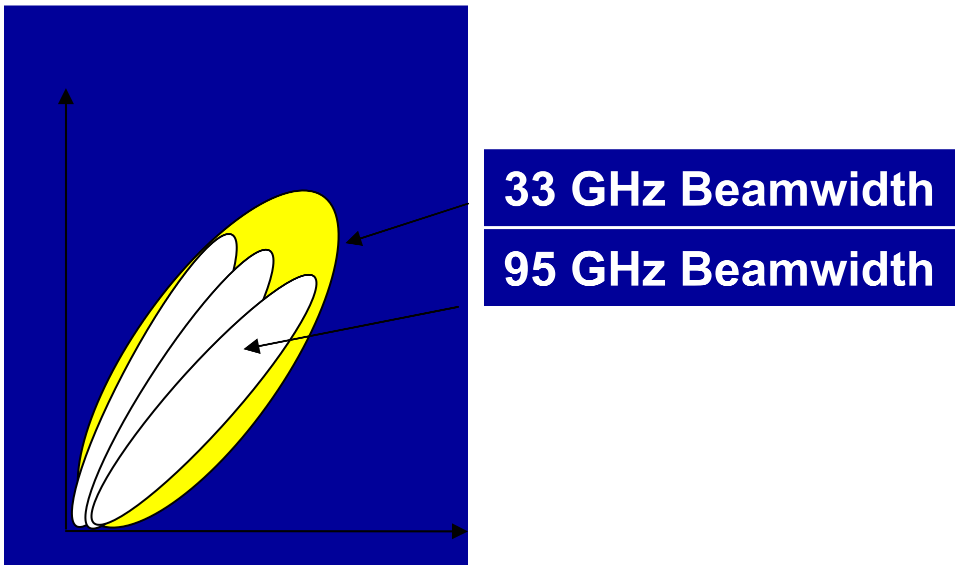
# Effective Wind Velocity



# Beamwidth Correction

$$erf\left(2\sqrt{\ln 4}\,\frac{\phi}{\theta_1}\right)-erf\left(\frac{2\sqrt{\ln 4}\left[\phi-\alpha MT_s\right]}{\theta_1}\right)-\frac{1}{2}erf\left(\sqrt{\ln 4}\,\frac{\alpha MT_s}{\theta_1}\right)=0$$




Half-Power Beamwidth

33 GHz = 0.18 degrees
95 GHz = 0.06 degrees

To degrade the resolution of the 95 GHz to match the sampling volume at 33GHz

# Range Correction

To reduce the mismatch, reflectivity data was convolved with the range weighting function of the other frequency.

$$a = \frac{\pi}{2\sqrt{\ln 2}}$$

Pulse Width

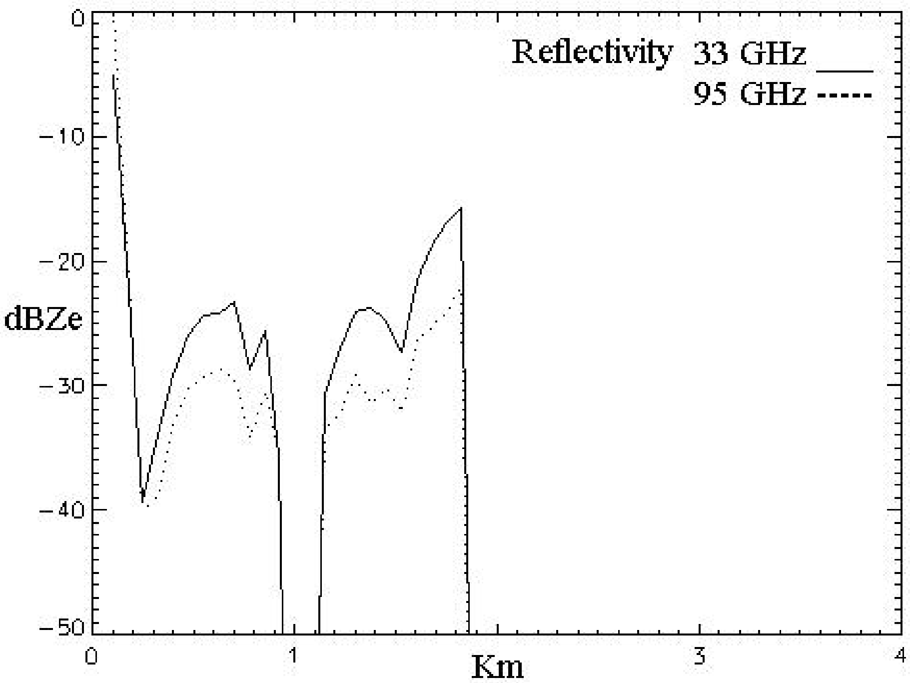
Bandwidth within 6 dB

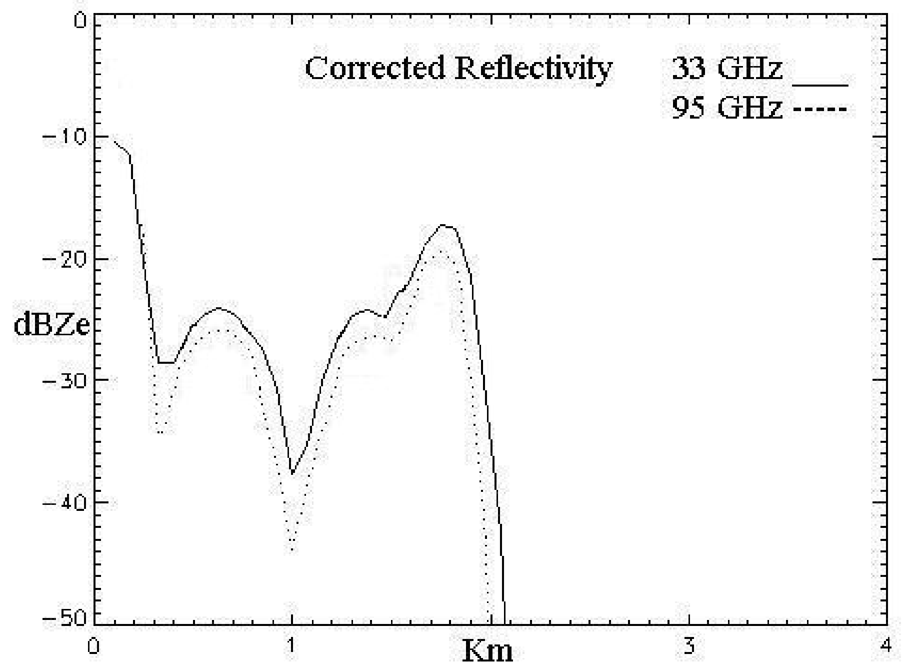
$$W(r) = \frac{1}{2}\left\{ erf\left[\left(\frac{2aB_6}{c}\right)\left(r_0 - r + \frac{c\tau}{4}\right)\right] - erf\left[\left(\frac{2aB_6}{c}\right)\left(r_0 - r - \frac{c\tau}{4}\right)\right]\right\}$$

Speed of Light

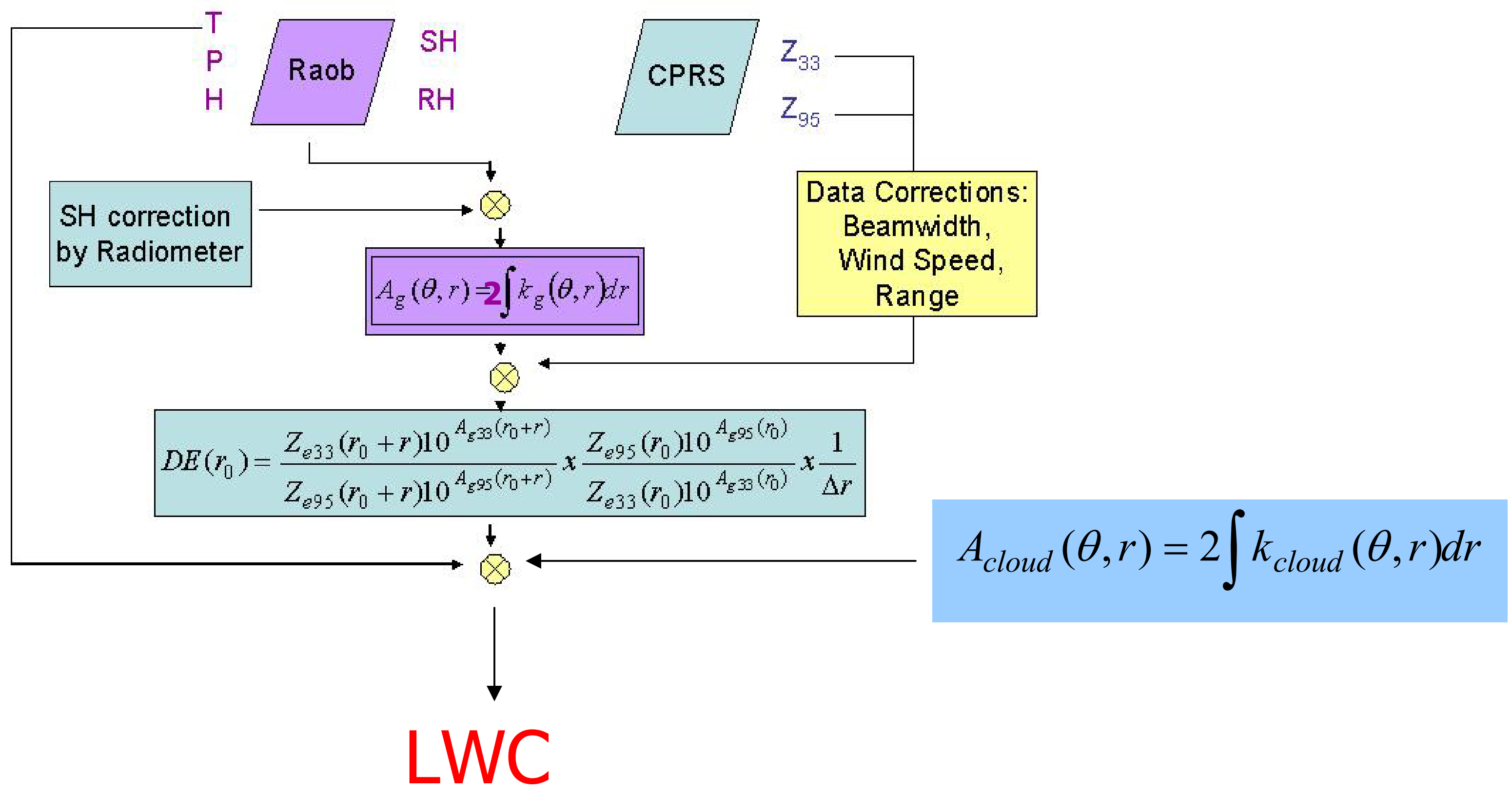
Scatterer’s Maximum Weight Received at

# After Data Correction …



# Flow Diagram



# Look Up Table To Find LWC

Cloud Attenuation
From Liebe's
Model
For Suspended
Water Droplets
at Both
Frequencies

T

DE

| | | | |
|---|---|---|---|
| LWC | LWC | LWC | |
| LWC | LWC | | |
| | | | |

# Cloud Characterization Parameters

Newton's Method for Solving Non-Linear Equations Systems

Effective Diameter

Drop Size Distribution

$$N(D) = N_0 D^{\mu} e^{-3.67 D / Do}$$

Peak Number Concentration

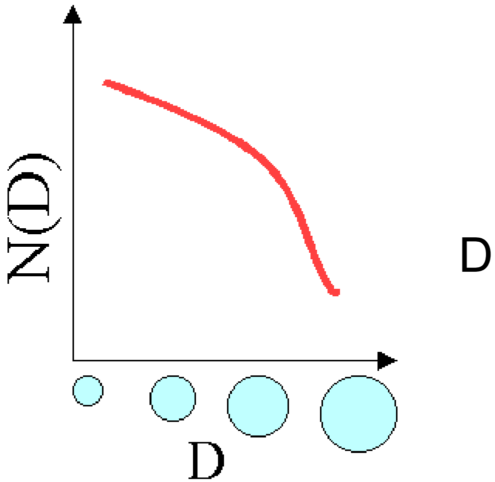
Reflectivity [dBZe]

$$Z = \int_0^{\infty} N(D) D^6 dD$$

Liquid Water Content [g/m³]

$$LWC = \frac{\pi \rho_w}{6} \int_0^{\infty} D^3 N(D) dD$$

Exponential Distribution



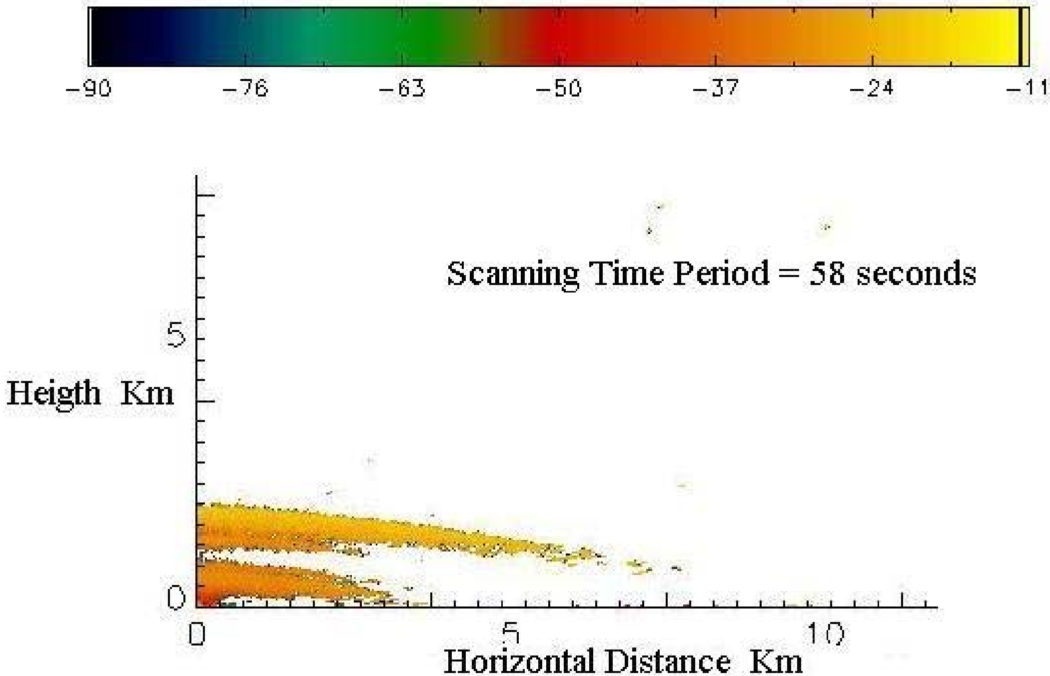

Effective Drop Diameter

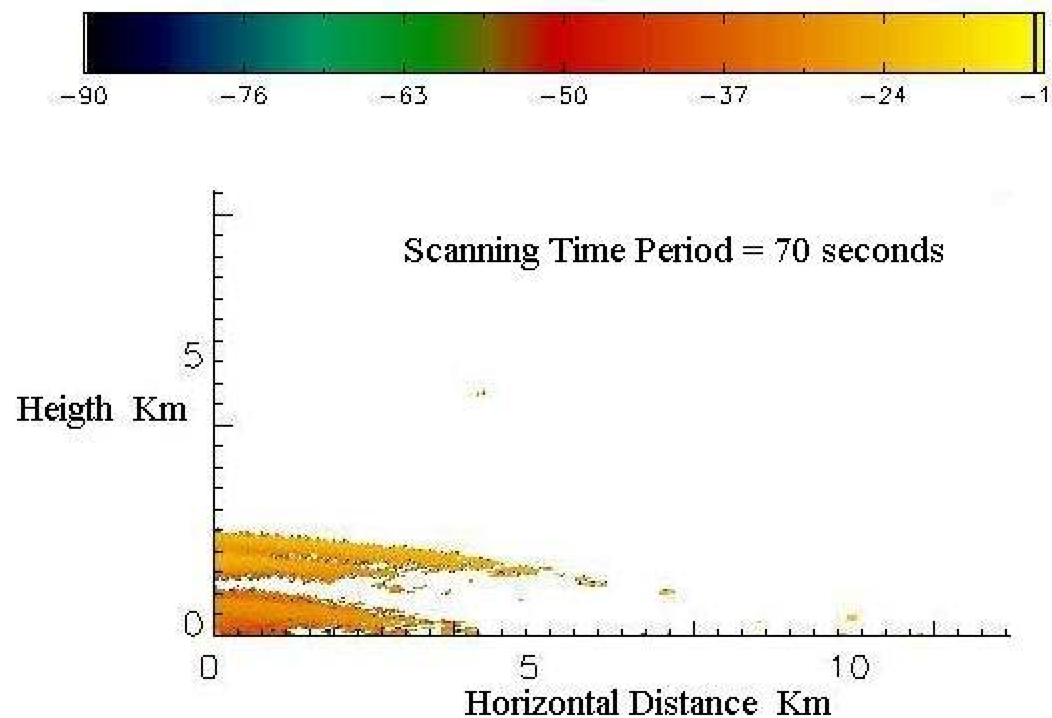
# Newton Method for Solving Non Linear System Equations

$$\begin{pmatrix} \left(\dfrac{\partial Z(N_0, D_0)}{\partial N_0}\right) & \left(\dfrac{\partial Z(N_0, D_0)}{\partial D_0}\right) \\ \left(\dfrac{\partial LWC(N_0, D_0)}{\partial N_0}\right) & \left(\dfrac{\partial LWC(N_0, D_0)}{\partial D_0}\right) \end{pmatrix} \begin{pmatrix} \Delta N_0 \\ \Delta D_0 \end{pmatrix} = -\begin{pmatrix} Z(N_0, D_0) \\ LWC(N_0, D_0) \end{pmatrix}$$

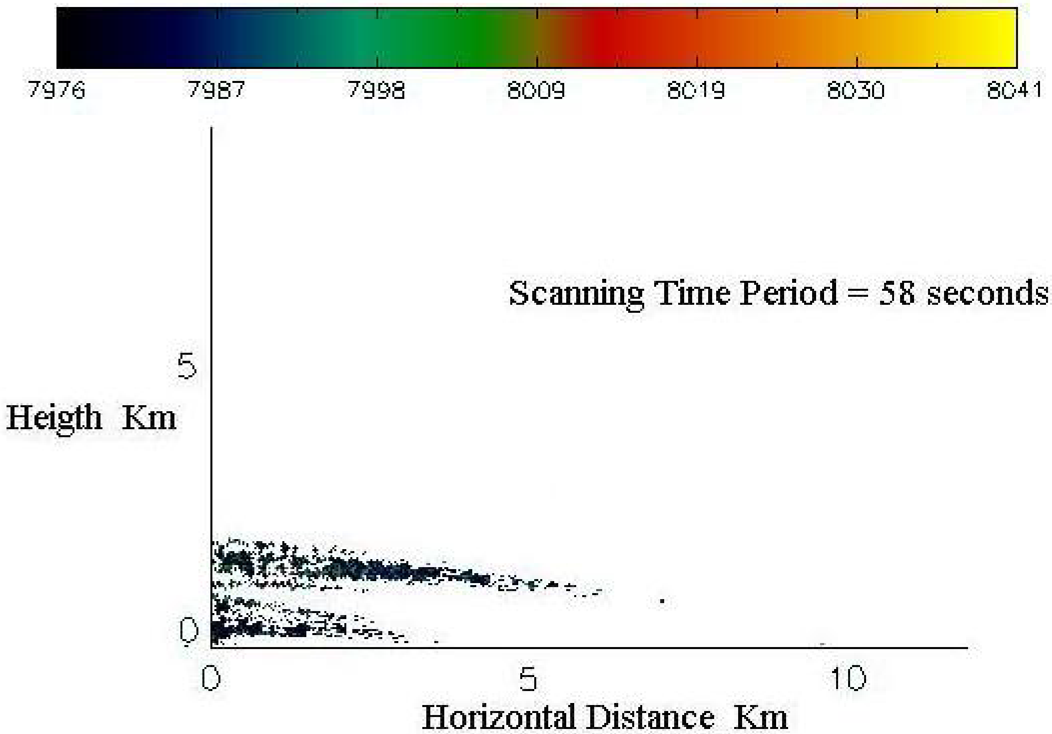
Minimizing the Error

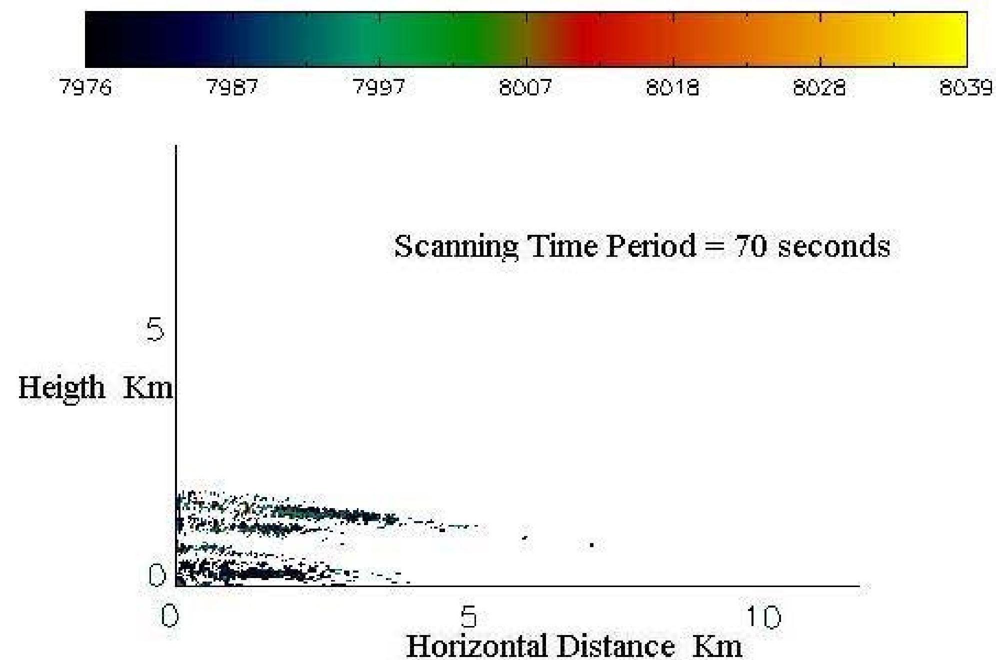
# $Z_{33}$ [dBZ]

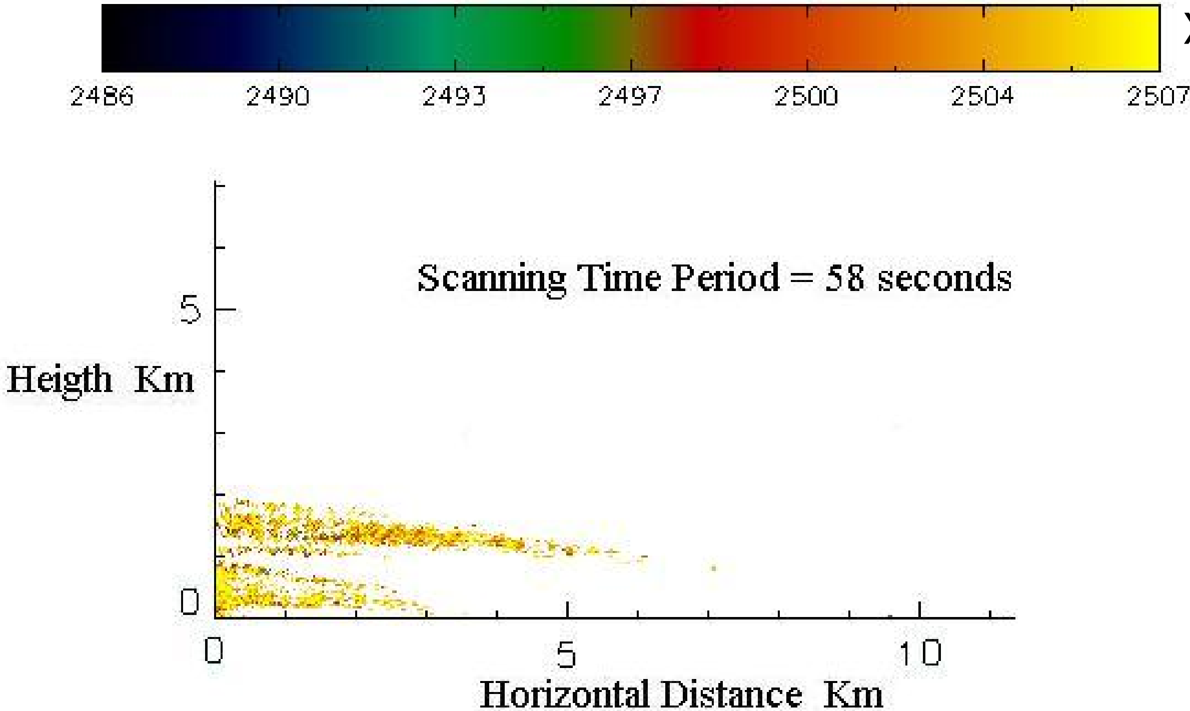

-90
-76
-63
-50
-37
-24
-11
Scanning Time Period = 58 seconds
Heigth Km
5
0
0
5
10
Horizontal Distance Km


-90
-76
-63
-50
-37
-24
-11
Scanning Time Period = 70 seconds
Heigth Km
5
0
0
5
10
Horizontal Distance Km

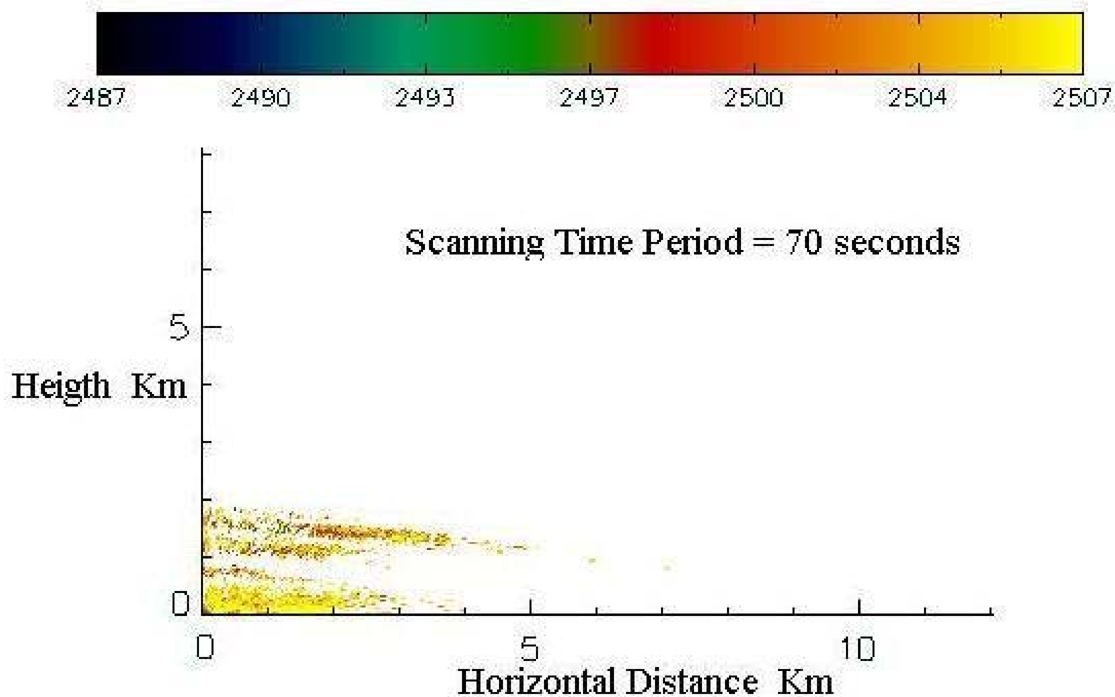
$N_o \approx 8,000$






$D_o \approx 2.5\mu m$



# Conclusions

- Radar reflectivity was used to retrieve cloud's microphysical properties, *N(D)*.
- A clear improvement in the W-band and $K_a$-band reflectivity after correcting
- The drop size distribution as well as the peak number concentration was estimated using Newton's method for non-linear system of equations.
- $N_o$ and $D_o$, were in excellent agreement with the model by Marshall and Palmer

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