# Cirrus Clouds Millimeter-Wave Reflectivity Comparison with *In-Situ* Ice Crystal Airborne Data

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Abstract

**In an effort to evaluate scattering models for particle size distributions of ice crystals within cirrus clouds, simultaneous data was collected during the Department of Energy (DoE) Atmospheric Radiation Measurement (ARM) Cloud Intensive operational period (Cloud IOP) at the Cloud and Radiation Testbed (CART) site in Lamont, Oklahoma, from the NCAR Video Ice Particle Sampler (VIPS) and UMass 33GHz/95GHz Cloud Profiler Radar System (CPRS) in March 2000. Data collected simultaneously from both sensors was used to retrieve and compare the equivalent radar reflectivity at Ka band (33GHz). The equivalent reflectivity is measured by the ground-based, zenith-looking, CPRS radar at Ka band and compared to the reflectivity computed from the airborne VIPS samples of particle size distribution, *N(D),* using Mie theory. In addition, equivalent reflectivity was calculated with ice particles model of bullet rosettes shaped crystals developed with DDSCAT software and compared with the Mie (sphere shape) results. "Results from the two sensors data sets compare the equivalent reflectivity obtained with the bullet rosettes model as opposed to the sphere model for ice particles. (change this when actual results are found)"**

## Introduction

Cirrus clouds play an important role in the balance of Earth's energy dynamics. These clouds cover about 20% of Earth and are mainly composed of ice particles. They cool the Earth by reflecting solar radiation back to space and warm it by trapping infrared radiation emitted from the surface and lower atmosphere [**].

In order to evaluate the accuracy of the current climate models precise millimeter-wavelength radar measurements of clouds microphysical properties for developing the cloud parameterization are needed. Several experiments have been done in the past two decades to improve the understanding of the relationship between microphysical and radiative properties of cirrus clouds (FIRE-I, FIRE-II and ARM). In addition, similar studies have been done in the past where radar and in situ measurements were analyzed and compared. Chandrasekar, Bringi and Strapp have documented comparisons for graupel and hail [ ]. All of these experiments employed various types of instruments, such as radars and in-situ devices whose measurements result too expensive and also cover a limited region of the sky which in turn reinforces the intention of validating radar data [ ] .

Appropriate radars for studying clouds such as cirrus clouds are millimeter wavelength radars like the UMass Cloud Profiler Radar System (CPRS), because they are sensitive enough to study particles smaller than one millimeter [wx]. For the in-situ measurements the NCAR Video Ice Particle Sampler (VIPS) was used. The CPRS operating frequencies are 33 and 95 GHz which is near to the atmospheric window making it useful for studying the microphysical properties of clouds [ ]. Although Rayleigh approximation is applicable at 35GHz, in this work we used the full Mie equations to calculate the backscattering from individual crystals. [@]. It is known that the shape of the particles found in cirrus clouds are not spherical (bullets and bullet rosettes are the most common) yet for many applications the use of Mie scattering which assumes a sphere shape for is a good approximation. To evaluate its applicability in crystal ice particle simulations, discrete dipole approximation (DDA) is employed to compare the bullet shaped crystals response with the Mie results [@]. Data from both instruments were obtained on March 2000 from the ARM experiment at the Southern Great Plains (SGP) site in Oklahoma

[http://www.arm.gov/iops/2000/sgp2000sprcloud/afteriop_cloud2000.html], a satellite photo of the area is shown in Figure 4; this was for March 3rd.

## Experiment Setup

We focus on the cirrus clouds on March 13, 2000, in which past studies found that the dominant crystal type found is the bullet rosettes, with an average of five bullets per rosette as shown in Fig.xe[a]. Different crystal structures are more dominating in a cirrus cloud depending of the diameter. Particles of less than a 100um are more likely to have a spherical shape [c]. The flight pattern for that day was a series of legs at various altitudes rather than a single descent, and the location of the radar is represented by a blue dot in Fig. xx.
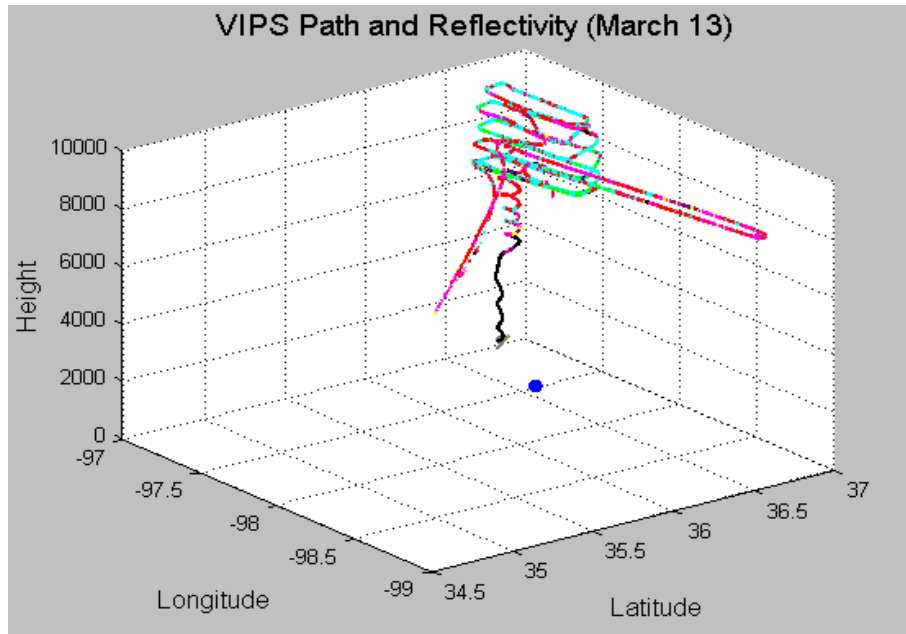


*Fig. xx Airplane flight track pattern for March 13, 2000.*
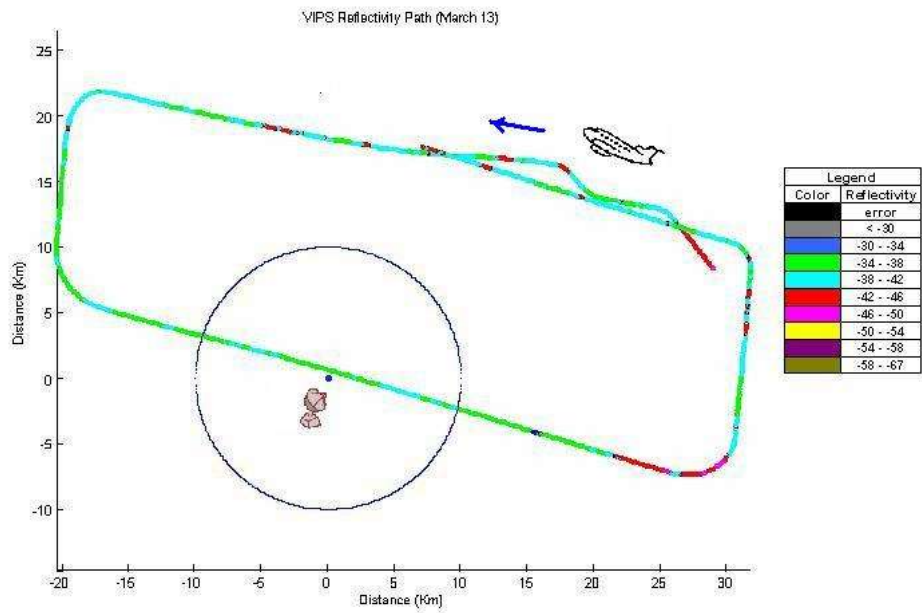*The blue dot iindicates the position of the CPRS radar.*

Fig 11 Diagram depicting the radar position, and the trace of the flight of the VIPS instrument.



a)

b)

*Fig. xe Most common shape found in cirrus clouds. a) One bullet per rosette. b) Five bullets per rosette*
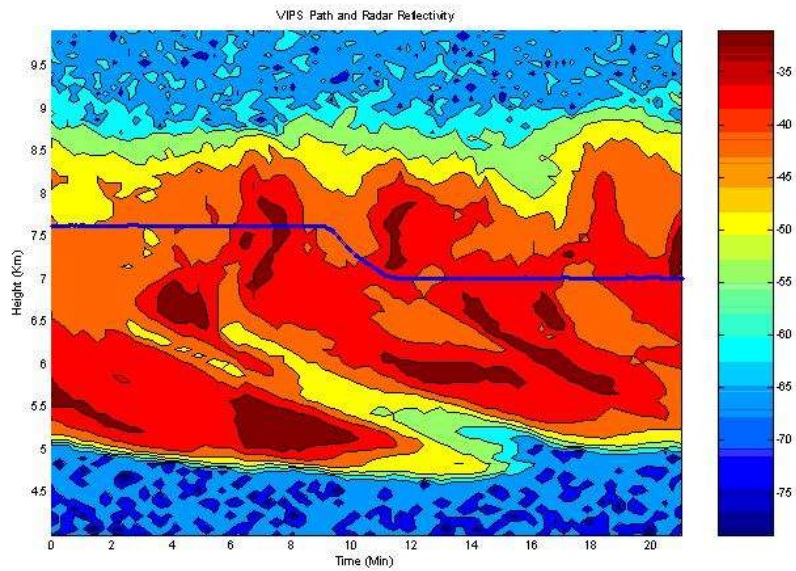


Fig 22. CPRS reflectivity plot versus time showing the trajectory of the airplane through the cirrus cloud.

The ice particle's models was developed using the measured parameters of the particle's shape given by A. Heymsfield from the National Center for Atmospheric Research (NCAR) [*Mitchell and Arnott*, 1994]. Measurements were collected with the Video Ice Particle Sampler (VIPS). This is an airborne instrument that flies inside cirrus clouds, and takes samples of the cirrus cloud particles sizes up to 5 μm in size. The VIPS have an electro-optical and imaging unit that is in charge of collecting data, and another part designated to record data. The particles' images are recorded in two formats, one is at 30 Hz on high-resolution Hi-8 VCRs, the other format is at 1 Hz, digitized in real-time in an Apple PowerPC [*Heymsfield*, 2000].

Various shapes of the bullet rosettes are observed (see Fig. 3.1). Each bullet has a longitude relation [*Heymsfield*, 1972], $L$ (mm), versus wide, $w$ (mm), (twice times the apothem) for temperatures between –18° and –20 °C given by

$$w = 0.25L^{0.7856} \text{ [mm]}, \qquad (1)$$

for bullets with $L \leq 0.3$ mm, and

$$w = 0.185L^{0.532} \text{ [mm]}, \qquad (2)$$
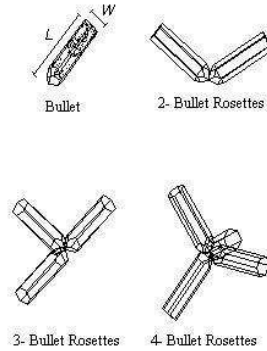
for bullets with $L \geq 0.3$ mm



FIGURE 3.1 Bullet and Bullet Rosettes with different angles of junction

In this way the equations were determined for the bulk density, $\rho$, of the bullet, considering the solid ice density as 0.9 g cm-3 and using the volume of ice in individual crystals

$$\rho = 0.78L^{0.0038} \quad (\text{g cm}^{-3}) \quad (3)$$

As the Wiener's theorem states the complex index of refraction, $m$, depends of the bulk density when dealing with dry ice particles:

$$m = \frac{2 + n_i^2 + 2f_i\left(n_i^2 - 1\right)}{2 + n_i^2 + f_i\left(-n_i^2 + 1\right)}$$

(4)

where $f_i$ represents a non-dimensional fraction of the volume of air and ice and it is defined as:

$$f_i = \frac{\rho}{\rho_i} \qquad (5)$$

with $\rho_i$ as the solid ice density (0.9 g cm-3) and where $n_i$ is the complex index of refraction of solid ice which is different for every frequency (33 and 95 GHz). Using the above equations, we obtained an index of refraction for each frequency and each bullet size [*Villa* et al., 2002].
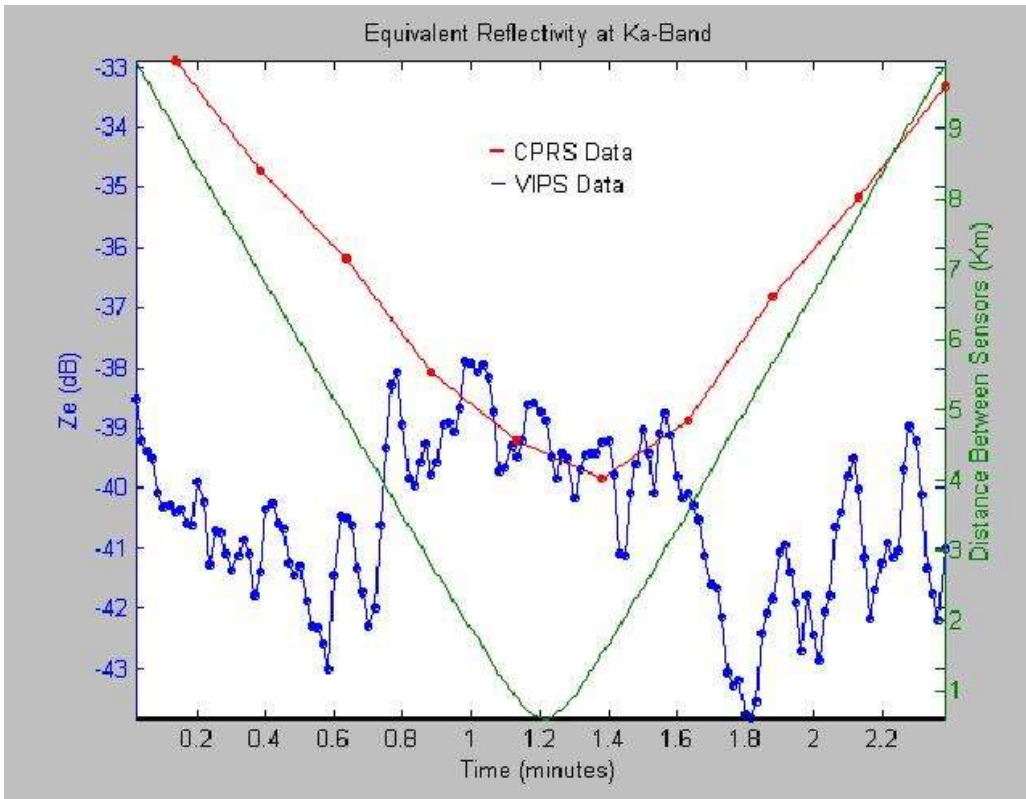
Fig 33. Plot showing on the left scale the radar reflectivity from the CPRS and the computed reflectivity from the VIPS particle size distribution and on the right the distance between the radar and the airplane position. Obviously the best agreement occurs at the center of the graph where the distance is minimum.
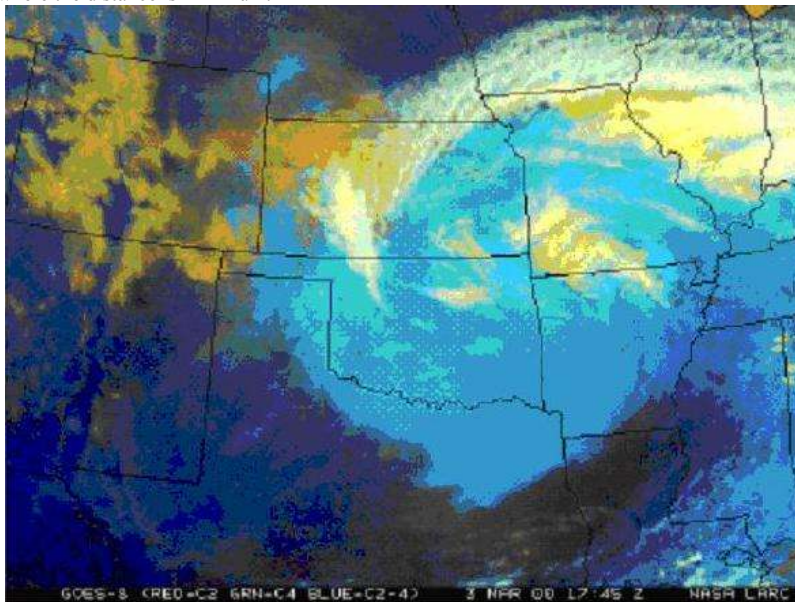


Fig. 777 GOES satellite false color image of the cloud field over the ARM site on 3 March 2000. During this time, 3 surface radars and three aircrafts were sampling cloud layers. Terra passed directly overhead of the CART central facility at 1740 UTC. [Courtesy of NASA?]

[aq]

# Hardware

a. UMass Cloud Profiling Radar System (CPRS)

CPRS operates at 33 and 95 GHz frequencies and. in this experiment the radar was operating in a vertically looking position so that it was looking at zenith at all times. Although both frequency channels were on at the time of the over flight of the airborne VIPS system, it was later discovered that the 95GHz channel was not properly working during this time (see Figure #44), so only data from the 33 channel is used for this work.
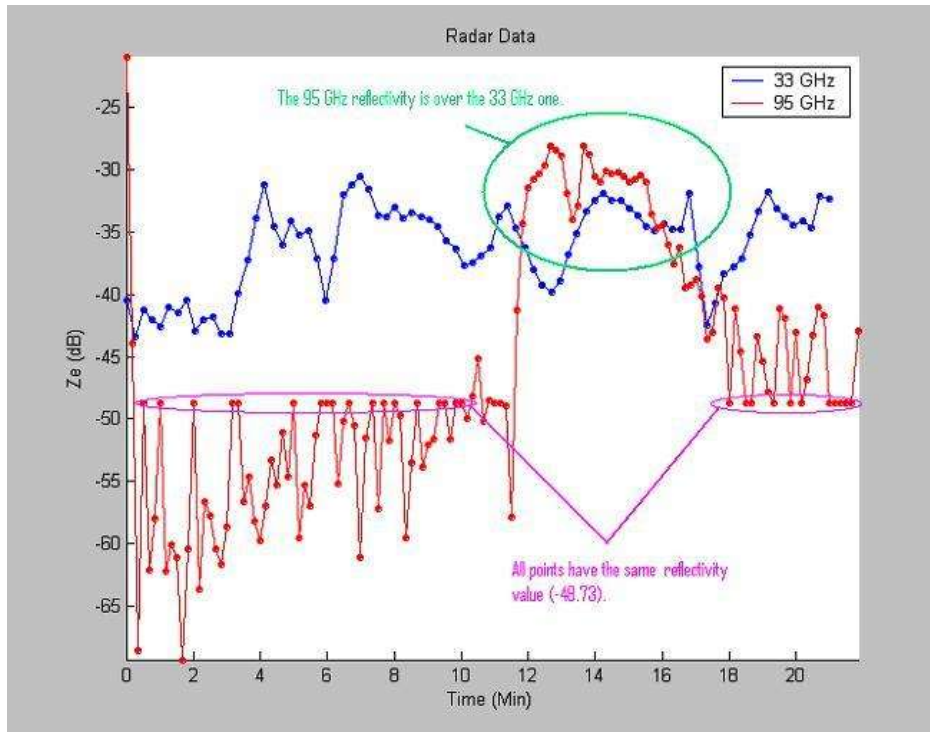


Fig 44. Time trace of the data showing the radar reflectivity of the two channels of CPRS data during the time when the airplane over flew over the radar. The 95 GHz channel shows a miss-operation during this time, therefore only 33GHz data was used in this work.

The data already processed by this radar was obtained from the ARM website [arm] and is in NetCDF format; these files were opened using IDL software. From this data we used the range (distance to the radar), the time of the measurement and the equivalent reflectivity.

b. NCAR Video Ice Particle Sampler (VIPS)

This device uses an electro-optical instrument used to collect and record a continuous sample of cloud particles down to 5 μm. Particles are collected continuously on a looped belt coated with silicone oil. [ ]

The VIPS system is composed of two parts: (1) an electro-optical collection and imaging unit mounted in a standard particle measurement system (PMS) can, and (2) data acquisition and recording components. Aperture width of the collection subassembly is adjustable for varying flight conditions. The CCD imaging cameras are coupled with inline, high detail video enhancers.

*Fig. ax VIPS used to...*

The data we have from this instrument are in table for... ...he altitude of the airplane, the diameters and concentration of par... ...diameters. Also to compare in time and space with the radar... ...d and the coordinates of the airplane were used.
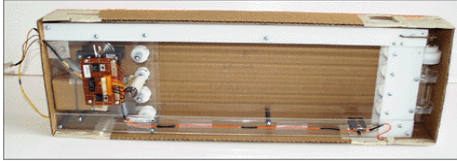
Simulation of Bullet Rosettes

Mie theory is used to obtain the backscattering coeffic... ...rticles are spherical or randomly oriented in a way that their sca... ...a spherical shape. But this assumption lead to incorrect scatt... ...olarization parameters are even neglected [bs].
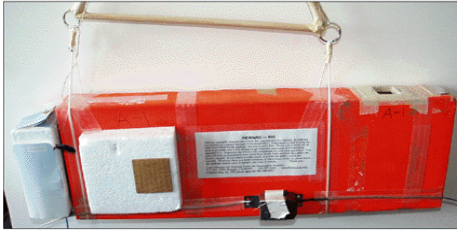
$$Z_e = \frac{\lambda^4}{\pi^5 |K|^2} \int_0^{D_{max}} \sigma(D) N(D) dD \quad [mm^6 m^{-3}]$$

where σ is the Mie radar backscattering cross section...
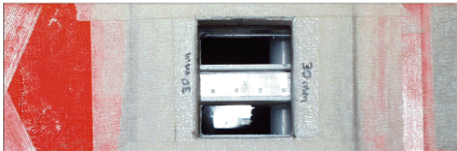
Discrete Dipole Approximation (DDA)

The basic idea of DDA is the representation of an random particle by a finite array of N dipolar subunits arranged on a cubic lattice as shown in Fig. wx.
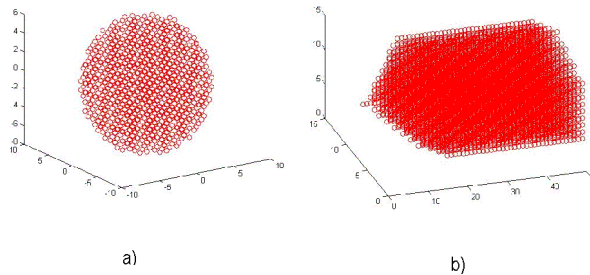


a)                                         b)

*Fig. wx Dipole representation of particles. a) Spheric shape. b) Bullet shape*

**Acknowledgements**

References:
[**]http://nit.colorado.edu/mwcirrus/remsentalk/slide1.html

[@] Clifton Dungey "Backscattering by nonspherical Hydrometers as calculated by the coupled-dipole method: an application in radar meteorology"

[a] Lewis L., Heymsfield A., Twohy C., Poellot M. "*In-situ Microphysical Measurements of Cirrus Properties During ARM 2000 IOP.*"

[b] "*The development of midlatitude cirrus models for MODIS using FIRE-I, FIRE-II, and ARM IN-Situ Data*". Journal of Applied Meteorology. Vol.41, March 2002.

[c]  "*Use of In-Situ observations to characterize cloud microphysical and radiative properties: application to climate studies*". Thirteenth ARM Science Team Proceedings, Broomfield, Colorado, March 31-April 4, 2003.

[wx] Sekelsky, S. M., R. E. McIntosh, "Cloud observation with a polarimetric 33 GHz and 95 GHz radar"., Meteorology and Atmospheric Physics.  Vol. 58, 123-140, 1996.

[aq] Mace G. and Sassen K., "Cloud property and surface radiation observations and diagnostics in support of EOS; CERES, MODIS, and MISR validation efforts". May 26, 2000.

 [arm] http://www.arm.gov/docs/iops/2000/sgp2000sprcloud/afteriop_cloud2000.html

[bs] Lemke H., Quante M., Danne O., Raschke E. "Backscattering of radar waves by non-spherical atmospheric ice crystals: An application of the discrete dipole approximation".

[] Villa, J. M., S.L. Cruz-Pol, and S.M. Sekelsky, "*Modeling, Simulation and Comparison Study of Cirrus Clouds Ice Crystals*", SPIE 9th International Symposium on Remote Sensing, Crete, Greece, 2002.