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Ice Crystal Simulation for Comparison with Microwave Radar

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Abstract- *In this work, we model the ice crystals mostly found in cirrus clouds: bullet and bullet rosettes, with programs previously done with data measured by an airborne instrument, known as the Video Ice Particle Sampler (VIPS), from the National Center for Atmospheric Research (NCAR)[1]. With such programs we can obtain results for the backscattering of the ice crystals we wish to analyze. Our ultimate goal is to retrieve the ice particle's size distribution N(D), using real reflectivity measurements and simulated backscattering from the bullet rosettes, in order to compare it with real values of particles size distribution*.

INTRODUCTION

Clouds are classified in certain categories, such as stratus, cumulus and cirrus clouds, according to the heights of their base. For this study, we chose cirrus clouds, which belong to the high clouds group. They distinguish themselves from others because they are composed of ice crystals as opposed to water particles[2]. In addition of providing a visible indication of what is going on in the atmosphere, clouds play an important roll in the study of different systems because they have a great effect on the earth's radiation budget. For that, scientists have encountered a need for creating models to help them visualize different parameters that influence the study of atmospheric and climatic events.

BACKGROUND

In order to develop this research, certain considerations and assumptions were taken.

Since we use the Ka and W bands, corresponding to 33 and 95 GHz respectively, it should be pointed out that for 33 GHz, Rayleigh approximation was used to analyze the backscattering, since the wavelength at this frequency is much smaller than the particle's size. When analyzing particles at 95 GHz, the Rayleigh approximation is no longer the adequate one to use since the particle's size becomes comparable with the wavelength. Therefore, for 95 GHz, we must use Mie Theory.

Many studies haven been developed in which constant densities for the ice crystals found in clouds are assumed. For our research development, we use a more appropriate density function that varies with the length of the bullet.

This assumption is closer to the densities that correspond to the temperatures at the cirrus clouds' altitude.

$$\rho = 0.78L^{.0038}(gcm^{-3}) \qquad (1)$$

For every longitude we must also compute a complex index of refraction.

In order to state this report as easy as possible so that anyone can read it, I would like to define the technical terms used in our research:

- Backscattering – how much of the power that is incident on a particle, rebounds and is captured back in a receiver. When there is no receiver, it is just said that the particle "scatters". We study this property because the ice particles in clouds scatter microwave radiation with negligible absorption or emission[3]. So, incident radiation on clouds is reduced by scattering energy out of the beam as it passes through regions containing ice particles.

Reflectivity - $Z = \int_0^\infty N(D)D^6 dD \qquad (2)$

Is a radar term for the backscattering cross-section per unit volume[6]. This factor depends on the particle's size distribution N(D) which correspond to the number of scatterers per unit volume with diameters in dD.[3]

- Or $Z = \frac{10^{12}\lambda^4}{4\pi^4 |K_w(\lambda)|^2} \int_0^\infty \xi_b(D,\lambda,\rho) N(D) D^2 dD$

  Where ξ_b is the Mie backscattering coefficient and K_w is the dielectric factor. In our case Z is measured by the radar.
- Particle's size distribution *N(D)* –
  Property that tells us how many particles of each size there are.

DATA SETS

The data we are trying to analyze is different from the data that was used to develop the programs. It comes from an experiment conducted in the Southern Great Plains site in Spring 2000. Two of the primary objectives of this experiment were to quantify the ability of algorithms to estimate the 3D properties of the cloud field, and to examine the relationship between volumetric distributions of cloud microphysical properties and the transfer of radiation through the cloudy atmosphere[7]. In that month of March, pure ice clouds (cirrus) among other types of clouds were captured and documented with ground-based radars and airborne instruments. The data was downloaded from the Atmospheric Radiation Measurement (ARM) Program web site. The two sets of data that we are using come from:

- UMASS Cloud Profiling Radar System (CPRS)-95/33 GHz Radar.

  Data gathered by Dr. Sekelsky, from the University of Massachusetts. This data comes in a special format in a compressed file (cdf). In order to decompress the file and be able to read the data, we made two programs in the IDL software that obtains the variables from the compressed file and assigns new names to those variables from the radar. Next, we are capable to load the data to analyze it. Since we have many days of data, the program let's the user select which day the he wants to load.

- CPI (Cloud Particle Imager) – instrument that goes in an airplane which is flown into the clouds. This device separates ice crystal from interstitial gases, and then evaporates the crystals within a nitrogen sample stream. Then, the particle number concentrations are measured downstream. Data gathered by Dr. Andrew Heymsfield, from the National Center for Atmospheric Research. This data comes in a text file with data such as time, pressure, temperature, latitude, longitude and altitude of the airplane at the time specified, and total concentration of the particles in the spectrum, which was divided in bins (see Fig.1).

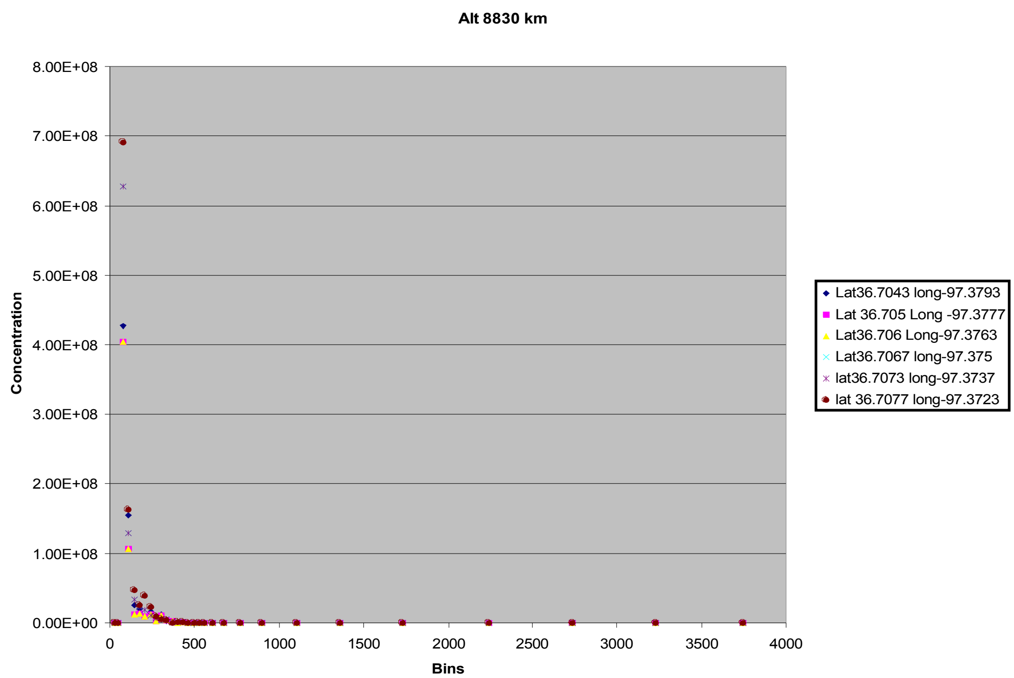

Fig. 1 Concentration of ice particle as measured by the airborne instrument as several locations. 1

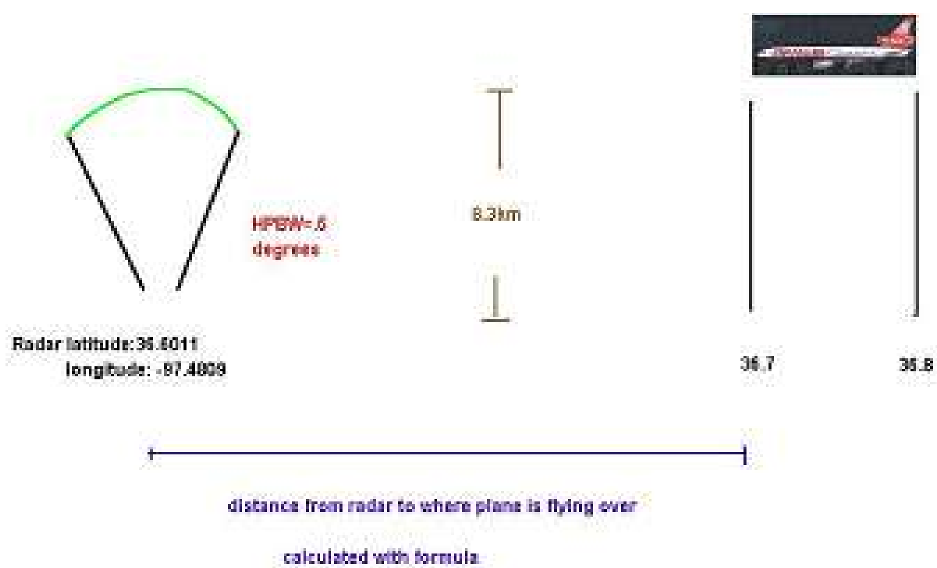

Fig. 2 Experimental set up.

Our first approach was to limit the airborne data by eliminating those points were the airplane flew too far from Blackwell Airport at lat. 36.7451158 and long. –97.3495997 because at those coordinates the radar was located stationary. We filtered all data that was not between latitude 36.7 and 36.8. After eliminating a large part of the original data, there was still a large amount remaining. We decided to look for the distances from each of the coordinates to where the radar was located. For this (See Fig.2), we changed the coordinates to distances in kilometers with the following formula:

$$D = E * [\cos^{-1}\{(\sin(a)) * \sin(b) + \cos(a) * \cos(b) * \cos(P_1 - P_2)\}]$$

where: E= Earth Radius=6367.3 km
a= latitude of 1st point=36.6011
b= latitude of 2nd point
` P_1=longitude of 1st point = 97.4809
P_2=longitude of 2nd point

Having the airplane flying at an approximated altitude of 8.3 km, the air scanning area of the radar seems to be:

$$S = r\theta = (8.3\,km) \times (0.5° * \frac{\pi}{180°}) = 72.4\,m \qquad (4)$$

where 0.5° is the antenna beamwidth and *S* is the diameter of the "footprint" in the air path. After making the calculations, the data from the airplane seemed to be too far from the place where the radar was located, which indicates that the airplane did not fly close to the radar when it was collecting the data we downloaded.

PROCESS

For the simulations, two programs are used:

- DDScat Software – with this program we create the particle we want to analyze, in our case, bullet and bullet rosettes, with certain parameters that we input to the program, such as wavelength, diameter and others. The program uses the DDA (Discrete Dipole Approximation) Method, filling that volume the user created with dipoles and then calculating the electric field due to each dipole. With the total electric field being the contribution of all the individual electric fields from each dipole, certain coefficients such as scattering (or backscattering) and absorption are calculated.
- IDL software – program used to calculate the complex index of refraction for each wavelength and length of particle, which will serve as an input parameter to DDScat. We also use it when we want to calculate the reflectivity from the simulated backscattering.

The whole process is as we see in Fig.3. The simulated backscattering values that DDScat outputs, and the radar reflectivity measurements is what we will be trying to use to derive the particle's size concentration N (D).

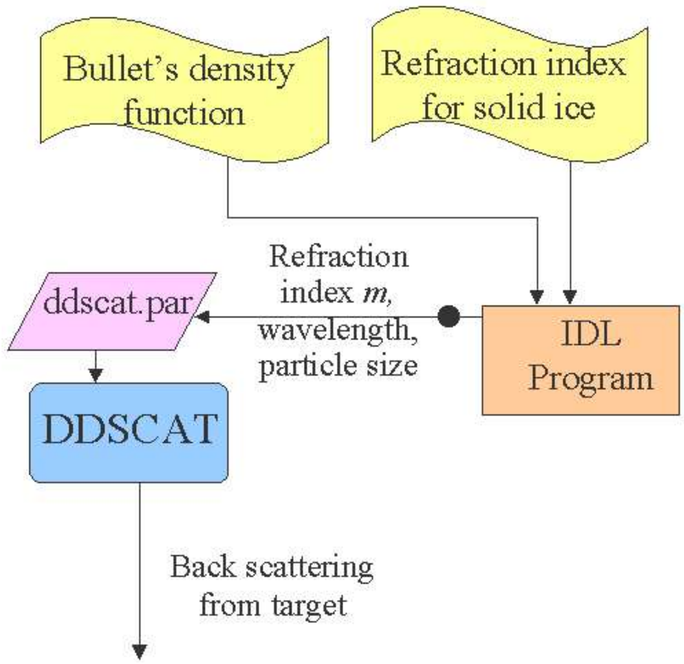

Fig..3 Process for simulation

The results for the backscattering of a bullet look as we see in Figure4.

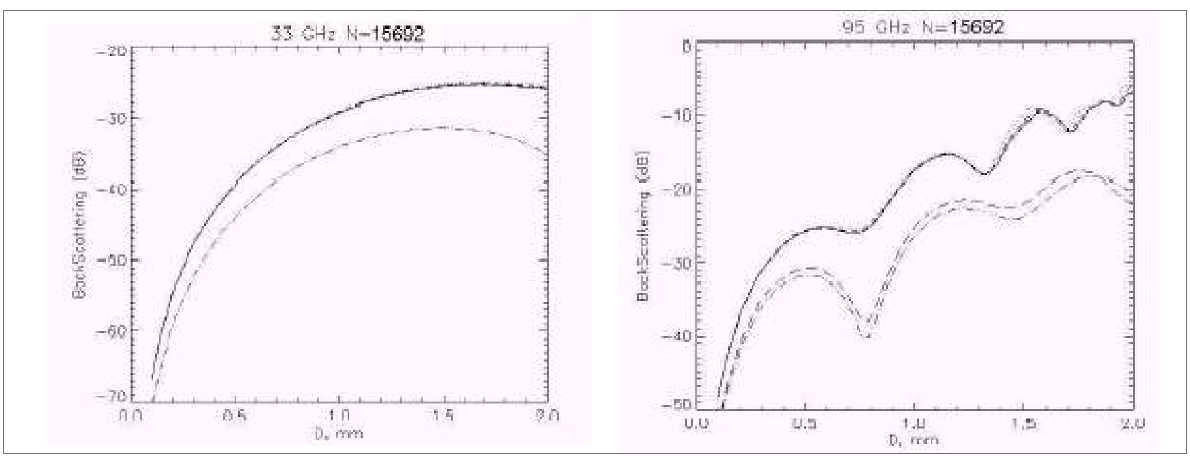

Fig. 4. Backscattering coefficients from Mie in dB for 33 and 95 GHz.

CONCLUSIONS

From this whole research, certain conclusions have been drawn. As we noticed, the backscattering coefficient is influenced by the decision of taking a variable density function vs. a constant density for the bullet rosettes. This tells us that assuming a density of 0.9 gcm^{-3} for the bullet rosettes does not correspond to the typical shape of the bullet and temperature at that altitude.

This semester's work is not finished and more work will be needed with the new data, since we've been having certain problems with the distances, and none of the people concerning this data have been available to help.

ACKNOWLEDGMENT

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REFERENCES