Multidimensional Cloud Images Retrieval From Dual- Frequency Millimeter-Wave Radar

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***Abstract* -- In order to obtain a better understanding of the dynamics of heat transfer in our planet's atmosphere, we need to develop better and more accurate climate models for the hydrometeor distribution within clouds. A better insight into the microphysical structure of clouds will be helpful to several meteorological and climate prediction models [1, 5, 6, 9]. In this work, stratus clouds are studied using dual-frequency radar. Liquid stratus clouds are found in the lower part of the atmosphere and have a profound impact on the earth's radiative budget because of their high albedo and large global coverage. These clouds are difficult to study and quantify with visible and IR remote sensors due to their high optical extinction rate. In this work, we retrieve stratus cloud properties in two dimensions using a dual-frequency millimeter-wave radar. This work is a joint project between UMass and UPRM.**

I. Introduction

IN THIS WORK we use radar scans of cloud reflectivity at 33 GHz and 95 GHz to produce multi-dimensional cloud images of the liquid water content within the cloud. Such data can be applied to meteorological models such as the General Circulation Models (GCMs)[9]. The cloud reflectivity was measured with the Cloud Profiling Radar System (CPRS) developed by the University of Massachusetts (UMass) at the Microwave Remote Sensing Laboratory (MIRSL). The vertical resolution attained with this system is quite high, varying from 8.7 m to 131 m for the 33 GHz channel and from 3.14 m to 47 m for the 95 GHz channel [8]. The higher resolution is at 1 km height and the lowest is at 15 km in the troposphere. A physical-based retrieval algorithm that uses the difference in 33 GHz and 95 GHz extinction is employed to estimate the liquid water content in the cloud. These scans are the first multidimensional plots of microphysical properties of clouds using co-located 33 GHz and 95 GHz radar data.

CPRS is a portable ground-based polarimetric radar that works as two independent subsystems at two different frequencies, 33 GHz (Ka Band) and 95 GHz (W band) using a single lens 1-meter antenna to avoid pointing errors [8].

To retrieve liquid water profiles, we first compute the Differential Extinction (*DE*) since it is an indirect measurement of liquid water content profile in the cloud. *DE* is calculated as the slope of the difference (rates of change with altitude) of the raw 33 GHz and 95 GHz reflectivity data. The amount of liquid water content (*W*) is derived using Liebe's model for cloud extinction and knowledge of the temperature inside the cloud [4,7].

$$DE(r_0) = \frac{Z_{33}(r_0+\Delta r)10^{A_g,33(r_0+\Delta r)}}{Z_{95}(r_0+\Delta r)10^{A_g,95(r_0+\Delta r)}} \times \frac{Z_{,95}(r_0)10^{A_g,95(r_0)}}{Z_{33}(r_0)10^{A_g,33(r_0)}} \times \frac{1}{\Delta r} \tag{1}$$

In the above equation, r_o is the distance to the center of the range resolution cell, A_g is the gas attenuation due to water vapor and oxygen, Z is the radar reflectivity at the given frequency, and Dr is the length of the radar resolution cell.

The radar reflectivity is given by

$$Z_f = \frac{10^{10}\, l^4}{p^5 \left|K_w{}^2\right|} \int_0^\infty x_b D^2 N(D) dD \qquad (2)$$

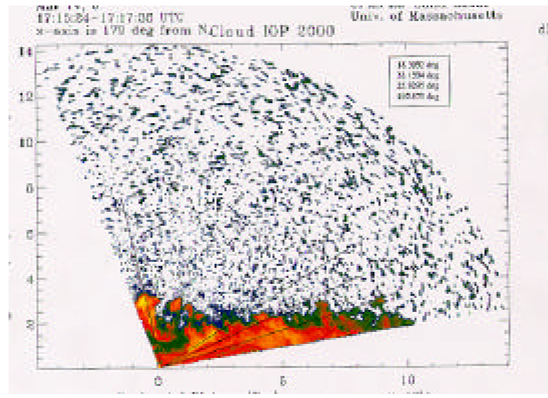
where D is the diameter of the water hydrometeors within the cloud and $N(D)$ is the particle size distribution. The constant K_w is related to the index of refraction of water at low frequencies as given in [8] and l is the wavelength in free space corresponding to the frequency f. The liquid water content, W, in the cloud is estimated using the *DE* measurements and cloud temperature together with an algorithm derived from Liebe's cloud extinction model [4].

II. Preliminary Results and Discussion

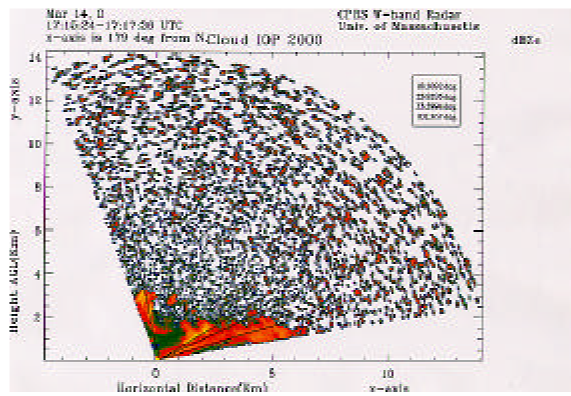
With the combination of two millimeter-wavelength backscattering signals, 33 GHz (λ=9mm) and 95 GHz (λ=3.16mm), microphysical properties inside the cloud can be retrieved. This is achieved because each radar signal experiences a different extinction as it propagates through the cloud. Once the differential extinction is computed from the reflectivity, the particle size and liquid water content can be estimated.

Processed radar scans at the two frequencies are shown in Fig. 1(a) and (b). From Fig. 1, we can compare the two responses to the two frequencies. Fig. 1b shows that the W-band signal is noisy due to the fact that its signal to noise ratio degrades at higher altitudes. Fig. 1a shows the response to Ka Band (33 GHz). It can be seen that this frequency penetrates deeper into the clouds and its signal to noise ratio is better at high altitudes. The liquid water content is then estimated from the *DE* to create the image of the stratus cloud [7].

Fig. 2 presents a multidimensional image of the estimated liquid water content in a stratus cloud. The y-axis is the height while the x-axis is the scan angle in degrees. The minimum and maximum scan angles were 10^o and 110^o, respectively. Part of the cloud was missed from the image because we did not scan low enough.



(a)



(b)

Fig 1. Scanning Plots of radar reflectivity for stratus clouds after atmospheric correction for water vapor and oxygen for the (a) Ka Band and (b) W band. Observe that Ka -band can penetrate further into the cloud while W band can see smaller particles like ice, the melting layer and the rain region. The radar was scanned from an angle of 10^o to 110^o.

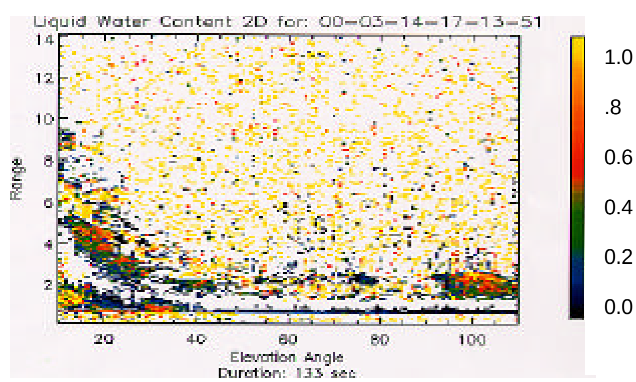


Fig 2. Liquid water content estimated from DE and Liebe's model for cloud extinction.

III. FUTURE PLANS

Future work includes the use of a calibrated water-vapor absorption model developed by Cruz-Pol and Ruf [2]. It will be incorporated to the cloud reflectivity code, originally developed at UMass and modified as a result of this work, in order to obtain better accuracy. Uncertainties in this improved model for atmospheric absorption were significantly improved over previous published models. The RMS difference between modeled and measured thermal emission by the atmosphere, in terms of the brightness temperature, was reduced by 23%, from 1.36 K to 1.05 K, compared to one of the most currently used atmospheric models [2].

In addition, liquid water content on clouds will be computed from the dual-frequency ratio ($DWR = Z_{33(dB)} - Z_{95(dB)}$.) using a procedure outlined in [6] to be compared to the current retrieved values.

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