Proceedings of ERAD 2006

A dual-wavelength polarimetric method to identify cloud component in warm precipitating systems

Jean-François Georgis, Olivier Pujol, and Henri Sauvageot

Université Paul Sabatier, Laboratoire d'Aérologie, Toulouse (France)

1 Introduction

Well known, and systematically disregarded, attenuation of radar waves by clouds (non precipitating part of the condensed atmospheric water) can lead to a biased interpretation of the backscattered signal by the illuminated volume. This term can significantly affect the information about physical characteristics of clouds and precipitation, as water content or precipitation intensity usually deduced from reflectivity. Consequences can be dramatic for instance for civil aviation.

Contrary to precipitation, few studies were proposed to estimate cloud attenuation, the difficulty being that clouds are difficult to identify due to their low reflectivity. In this work, an algorithm of identification of warm clouds, i.e. composed only of water droplets, is suggested.

2 Degradation of reflectivity by cloud component

Clouds can produce a strong attenuation at operational microwave frequencies although they are characterized by low reflectivity values which prevent their detection by radar. To illustrate this fact, a meteorological target consisting in warm clouds associated with rain or drizzle have been modelled and simulations of radar observations have been performed.

Clouds and rain fields are both defined by their respective liquid water content M_c and M_r which are represented by a spatial two-dimensional function derived from observations. Fig. 1 is a vertical cross-section of the total liquid water content $M_c + M_r$ in the case of a cumulus cloud associated with a rain field reaching the ground (the horizontal black line delimit the cloud base). The target modelling is completed by taking into account the microphysical characteristics through the size distributions of the hydrometeors. The cloud droplet size distribution (CDSD) and raindrop size distribution (RDSD) are respectively computed from the Khrgian and Mazin (1952) gamma distribution and the two parameter modified gamma distribution suggested by Ulbrich (1983).

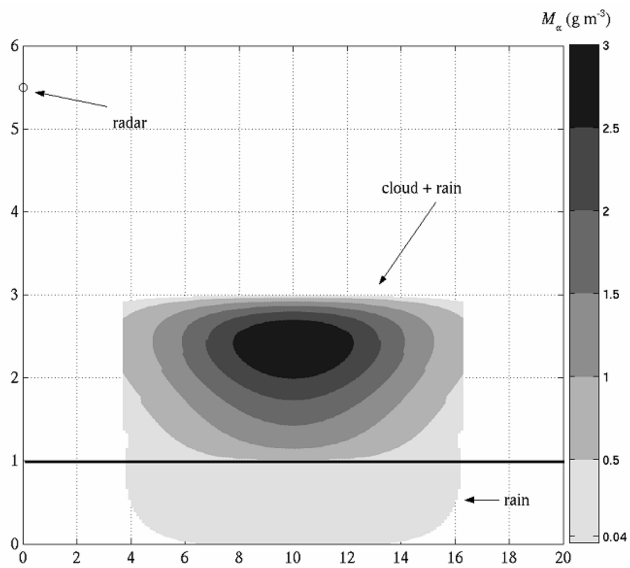


Fig.1. Vertical cross-section of the total liquid water content for a precipitating cumulus cloud of 2 km height and 12 km of horizontal extension.

Radar observations have been simulated at different wavelengths by considering common characteristics (beamwidth $\theta_{3\mathrm{dB}} = 1.8°$, range gate spacing $\Delta r = 0.15$ km) of an airborne radar located at $(x, y) = (0, 5.5\ \mathrm{km})$. The computational procedure consists in calculating for a given resolution volume the non-attenuated equivalent reflectivity factor Z_e due to the hydrometeors present in this volume and the two-way cloud attenuation a_c from the Mie formulas which provide backscattering and attenuation cross sections of spherical scatterers. The "measured" or degraded equivalent reflectivity factor Z_m(dBZ) is then given by:

Correspondance to: Dr. Jean-François Georgis.

geojf@aero.obs-mip.fr

$$Z_m(dBZ) = Z_e(dBZ) - \int_0^r a_c \, dr \qquad (1)$$

It is to be noted that, since cloud particles are in the Rayleigh scattering region, the intrinsic Z_e value does not depend on the radar wavelength. It is displayed on Fig.2.

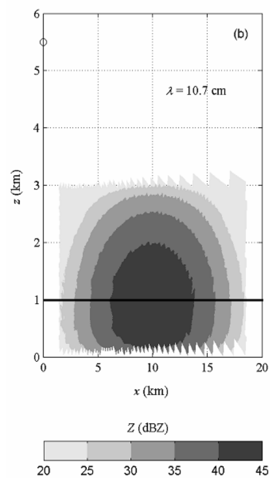
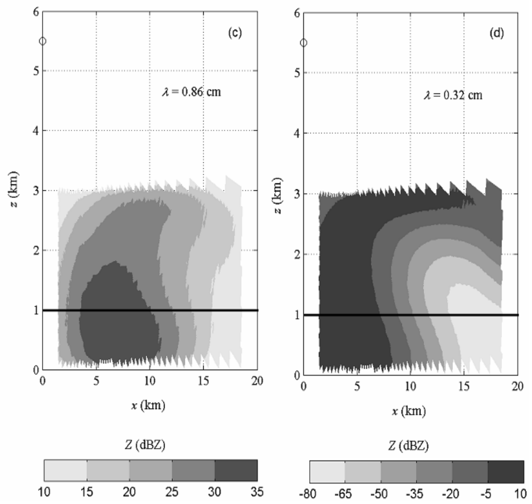


Fig.2. Representation of the intrinsic Z_e values for the considered warm precipitating system.

Figure 3 displays the "observed" reflectivity fields Z_m(dBZ) at 0.86 cm (a) and 0.32 cm (b). This clearly shows the importance of cloud attenuation since reflectivity fields are highly distorted, especially when observations are conducted with short wavelengths.



(a) (b)

Fig.3. Reflectivity fields degraded by cloud attenuation at 0.86 cm (a) and 0.32 cm (b).

3 Cloud water content estimation from combined polarimetric X-band and non-polarimetric Ka-band observations

The proposed method to identify the cloud component in warm precipitating systems is based on the attenuated polarimetric method (APM) developed by Sauvageot (1996) and summed up in Box A in Fig. 4.

APM consists in determining the corrected rain rate R distribution in each range gate. From the single polarization X-band radar reflectivity factor, $Z_{H,X}$ a first estimation of R is calculated via an empirical $Z(R)$ relation: $Z = aR^b$ where b is a mean climatological constant and a an adjustable coefficient. For that, the step by step iterative rain attenuation correction scheme proposed by Hildebrand (1978) is used. Then, a summation along the ray path of R, I_1, is obtained with an error due to the uncertainty in a. A second estimation of this quantity (I_2) is calculated from the cumulative differential polarimetric attenuation $A_{DP} = Z_{DR} - Z_{DR,S}$ where Z_{DR} is the attenuated differential reflectivity observed at the end of the ray path and $Z_{DR,S}$ the non-attenuated corresponding value computed from R and an assumed raindrop size distribution (RDSD). Precisely, I_2 is calculated from A_{DP} by considering an empirical $A_R(R)$ relation $A_R = kR^\gamma$ where A_R is the single polarization attenuation coefficient in rain and k and γ are well known wavelength-dependent coefficients. Since data have to be self-consistent, I_1 and I_2 are iteratively recalculated by modifying the a-value coefficient as long as they differ from a fixed value ε. When $|I_1 - I_2| \leq \varepsilon$, the fitted a and, consequently, the R distribution at each range gate are determined and APM is achieved. It is to be noted that the X-band reflectivity data have been then corrected by taking into account only the attenuation by precipitation.

In order to determine the cloud attenuation, the first step consists in calculating both the "true" reflectivity Z_{Ka} and the rain attenuation $A_{R,\mathrm{Ka}}$ for the Ka-band radar sensitive to the non-Rayleigh effects. For that, the previously assumed RDSD is used. The difference between the measured Ka-band reflectivity $Z_{m,\mathrm{Ka}}$ and the calculated Z_{Ka} provides the total attenuation $A_{t,\mathrm{Ka}}$ due to rain ($A_{R,\mathrm{Ka}}$) and cloud ($A_{C,\mathrm{Ka}}$). $A_{C,\mathrm{Ka}}$ is then given by $A_{C,\mathrm{Ka}} = A_{T,\mathrm{Ka}} - A_{R,\mathrm{Ka}}$. Since $A_{C,\mathrm{Ka}}$ is related to the cloud water content M_c by a proportionality coefficient depending only on the wavelength and the temperature, M_c is easily determined and can be used to calculate the cloud attenuation $A_{C,\mathrm{X}}$ for the X-band radar. This parameter can be finally used to correct the initial value of $Z_{H,\mathrm{X}}$.

This process continue until $A_{C,\mathrm{X}}$ changes by less than 1 dB from the previous iteration as suggested by Hildebrand (1978) for the rain attenuation correction. At the end of the procedure, M_C, the corrected R distribution, and the both radars corrected reflectivity are expected to be determined in the whole observation volume.

It is important to note that this procedure can be theoretically applied to only the polarimetric X-band radar without considering the Ka-band radar. But, since the X-band radar is less affected by cloud attenuation than the Ka-band radar, the determination of M_C would be far less precise.

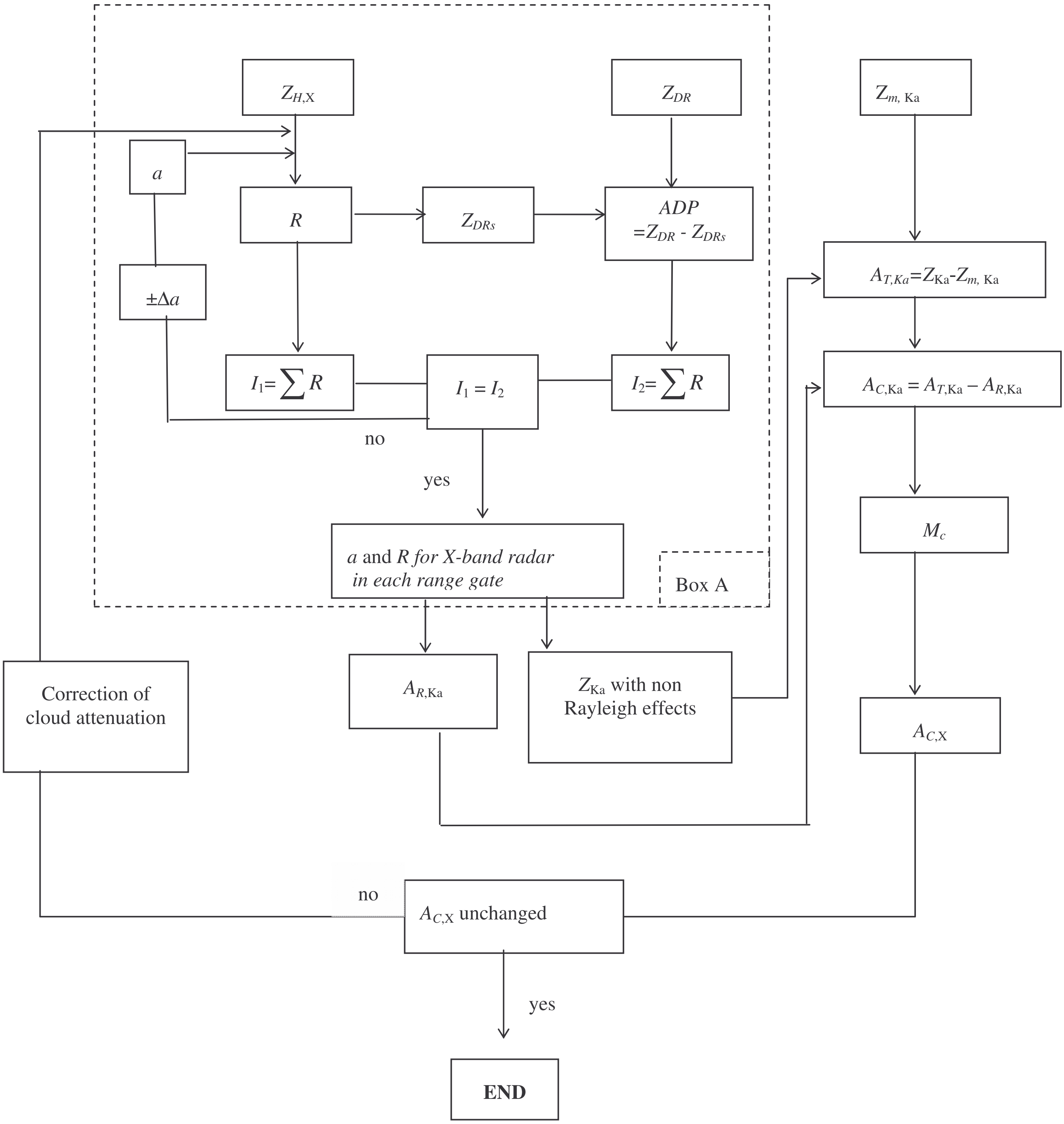


Fig.4. Flow chart of the method

References

Hildebrand, P.H., 1978: Iterative correction for attenuation of 5 cm radar in rain. *J. Appl. Meteor.*, **17**, 508-514.

Khrgian, A.Kh., and I.P. Mazin, 1952: The size distribution of droplets in clouds. *Trudy TsAo*, **7**.

Sauvageot, H, 1996: Polarimetric radar at attenuated wavelengths as a hydrological sensor. *J. Atmos. Oceanic Technol.*, **13**, 630-637.

Ulbrich, C. W.., 1983: Natural variations in the analytical form of the raindrop size distribution. *J. Climate Appl. Meteor.*, **22**, 1764-1775.