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AN AIRBORNE RADAR AND LIDAR COMBINATION TO DOCUMENT MICROPHYSICAL AND RADIATIVE PARAMETERS OF CLOUDS

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1. INTRODUCTION

Clouds are an important component of the Earth'climate system. However their parametric representation in large scale circulation model is recognized as insufficient.

Earth CARE (Earth Cloud Aerosol Radiation Explorer) is an ESA mission aiming to address this question. It plans to combine on the same spaceborne platform a cloud radar and a lidar to retrieve the microphysical and radiation properties of clouds. RALI (RAdar-LIdar) developed at IPSL (France), which combines the 95 GHz cloud radar RASTA of the CETP and the 0.5 µm wavelength backscattering lidar LEANDRE of the Service d'Aéronomie, is an airborne demonstrator for this mission.

The first tests of RALI were successfully accomplished during the last CARL 2000 and CLARE 2001 field projects (in November 2000 in Brest and in March 2001 in Bretigny-sur-Orge, France), where both instruments were mounted on board the french ARAT aircraft. The Meteo-France MERLIN aircraft, instrumented with microphysical probes of the GKSS (Germany) for CARL 2000 and of the LAMP (France) for CLARE 2001, was simultaneously flying below the ARAT.

We will present in this paper the principles of the algorithm combining lidar and radar data. Then we will show some simulation results taking account the natural variability of the intercept parameter distribution.

2. RADAR LIDAR SYNERGY

2.1 Synergy algorithm inputs

The radar lidar algorithm is based on three important elements:

- the apparent reflectivity Ze from the radar,
- the apparent backscattering coefficient βe from the lidar,
- an inverse model consisting of microphysical power laws relating clouds parameters to instruments parameters.

2.2 Inverse model

The inverse model, as explained in Tinel et al (2000), is funded upon a set of power laws relationships relating the radar parameters (attenuation K and reflectivity Z), the lidar parameters (backscattering coefficient β and extinction coefficient α) and the normalized distribution parameter N0* . The power laws are:

$$K = a\left[N_0^*\right]^{1-b} Z_e^{\,b} \qquad (1)$$

$$\alpha = c\left[N_0^*\right]^{1-d} K^{d} \qquad (2)$$

$$IWC = p\left[N_0^*\right]^{1-q} K^{q} \qquad (3)$$

$$\beta = f\alpha \qquad (4)$$

The coefficients of these power laws are established from microphysical data sets. In the present study we used the Clare98 microphysical data set. This field project, which associated airborne radar and lidar data and microphysical in-situ measurements took place in Chilbolton, UK, in autumn 1998. In future we are planning on using more data sets to build up some detailed comparison study.

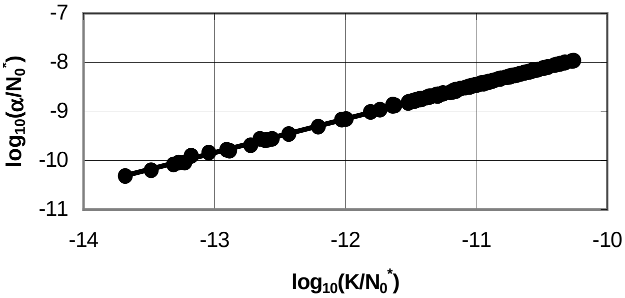

Fig 1. : The **Fig. 3:** The α/N_0^* versus K/N_0^* relationship for the CLARE microphysical data set and for a 95GHz radar.

Fig 1. shows that it is possible to set a relation between α/N0* and K/N0*, confirming the equation (2).

2.3 Retrieval Method

Thanks to the similarity between reflectivity and backscattering coefficient exact expressions (written respectively by Hitschfeld and Bordan, 1954 and Klett, 1981), it is possible to write the exact expressions of the radar attenuation and lidar extinction as written by Testud et al, 2000.

$$K(r) = \frac{K(r_0) Z_a{}^b(r)}{Z_a{}^b(r_0) + 0.46 b K(r_0) \int_r^{r_0} Z_a{}^b(s) ds} \quad (5)$$

$$\alpha(r) = \frac{\alpha(r_0)\beta_a(r)}{\beta_a(r_0) + 2\alpha(r_0)\int_r^{r_0} \beta_a(s) ds} \quad (6)$$

where r is the distance from the radar and r_0 and r_1 the extreme boundaries of the integration length.

To retrieve those two last profiles, the values of K and α at r_0 are set from the following constraint:

$$\int_{r1}^{r0} \alpha(s)ds = c\left[N_0{}^*(r)\right]^{1-d} \int_{r1}^{r0} K^d(s)ds \quad (7)$$

Combining (5), (6) and (7), it is possible to retrieve $\alpha(r_0)$ and $N_0{}^*(r_0)$ through an iterative process initiated with a first guess of $N_0{}^*(r_0)$. The iteration process converges to the value of $\alpha(r_0)$ and the knowledge of $N_0{}^*$ allows to calculate $K(r_0)$ from (2).

Once we obtain the K and α profiles, it is possible to retrieve a N0* profile from (2), and subsequently IWC and effective radius (r_e) profiles.

The present method is an improvement version of Tinel et al, 2000, as $N_0{}^*$ varies along the retrieved profile (and consequently temperature and particles aggregation).

3 APPLICATION OF THE ALGORITHM TO A SIMULATED CASE

3.1 Hypothesis of the simulation.

This simulation is a first case simulation which does not take into account the instrument noise and the multiple scattering of particles. The power laws used in this simulation are from the Clare98 (field campaign in Chilbolton, autumn 1998) microphysical data set.

The principle is the following. We start with two variable profiles of IWC and N0* for a 3 km height field. Once we get those two profiles, it is easy to calculate the Z, K and α profiles from the combination of (1), (2), (3) and (5). An assumption is made on the f parameter which is set to the 0.05 constant value (it is assumed in the literature that f varies from 0.01 to 0.1 in iced clouds). It is then possible to calculate an effective backscattering coefficient β profile. It is also assumed in this simulation that the atmospheric temperature ranges from -9° C to -15°C.

The next step consists of the calculation of attenuated reflectivity and backscattering coefficient profiles which are two of the three input parameters of the algorithm. It is then possible to apply the algorithm.

3.2 Parameters retrieval

Figure 2 represents the expected and retrieved parameters through the simulation.

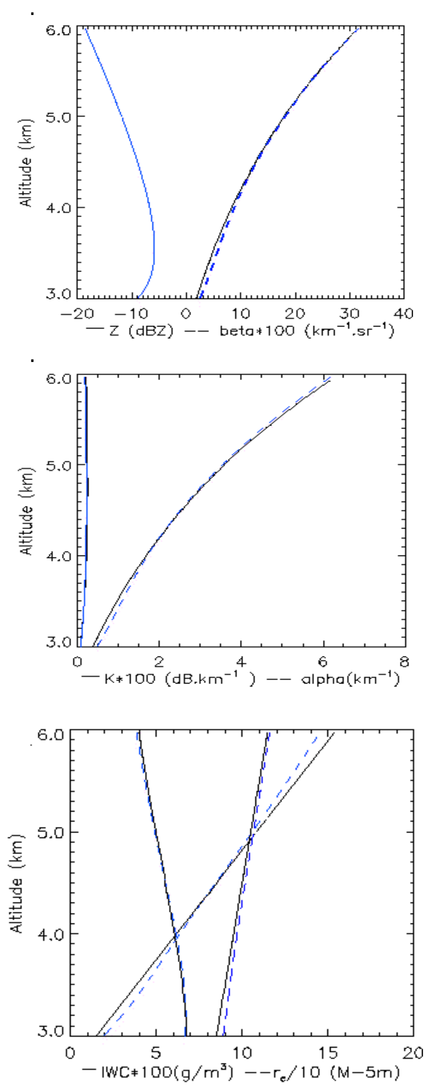

Figure 2 : expected and retrieved parameters from top to bottom:
(a) radar reflectivity and lidar backscattering coefficient
(b)radar attenuation and lidar extinction
(c)Ice water content, effective radius and N0*

The solid lines represent the expected parameters and the dashed lines the retrieved parameters.

The attenuation and reflectivity profiles are well retrieved. A slight divergence is observed in the lower and upper parts of the lidar extinction profile. It implies a divergence in N0* profiles and so, IWC and β profiles

This simulation is a really first simulation. It has been made to prove that it is possible to retrieve a variable N0* profile

4 APPLICATION OF THE ALGORITHM TO REAL DATA

The two last field campaigns which combined airborne radar and lidar were the CARL2000 in november 2000 and CLARE 2001 in march 2001 campaigns.

The synergetic algorithm will soon be applied to those data. Figure 3 illustrates one leg of the case of the 10^{th} of November 2000. That shows a good penetration of the lidar and radar beam into the upper cloud layer. The lower cloud layer, which is a precipitating layer, is well described by the radar. The backscattered power of the lidar shows the top of this precipitating layer.

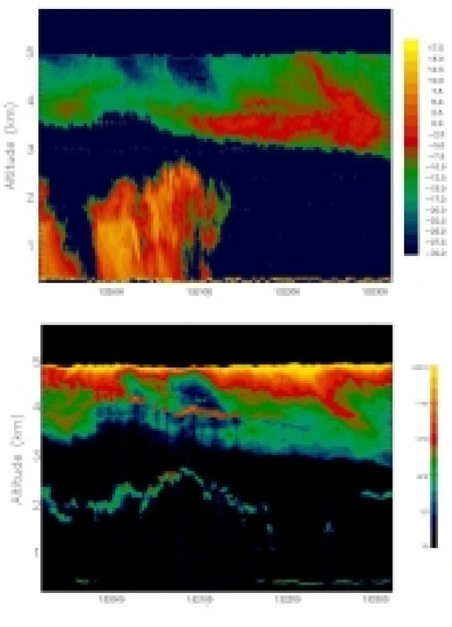

Figure 3: Illustration of apparent reflectivity (top) of RASTA radar and apparent backscattering coefficient (bottom) of LEANDRE lidar during CARL 2000 on the 10^{th} of November 2000.

We will process data from this experiments with the synergetic algorithm, taking into account the N0* variation along the altitude.

5 FURTHER WORK

The next step will be to study:

- the extension of the microphysical database set which will allow us to generalize the power realationships expressions,
- The simulation will be extended with the introduction on noise instrument,
- The new powerlaws retrieved and the improvement of the algorithm due to the simulation study will be applied to the important database set from Carl 2000 and Clare 2001.

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