J1.3 **COMBINED RADAR AND LIDAR OBSERVATIONS FOR THE RETRIEVAL OF RADIATIVE AND MICROPHYSICAL PROPERTIES IN ICE CLOUDS**

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1. INTRODUCTION

To appreciate the radiative impact of clouds in the dynamics of the global atmosphere, it is important to deploy from space, from aircraft, or from ground, instruments to describe the cloud layering and to document the cloud characteristics (namely liquid and/or ice water content, and effective radius.

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. The same combination (radar -lidar) will be also launched with the Afternoon-train of Cloudsat (NASA cloud radar) and Calipso (CNES lidar).

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 completed during the last Carl2000 and Carl2001 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 Carl2000 and of the LAMP/Météo-France (France) for Carl2001, was simultaneously flying within the clouds below the ARAT.

We will present in this paper the principles of the algorithm that combines lidar and radar data. Then we will show some simulation results taking into account the natural variability of the intercept parameter of the particle size distribution and we will also present results of this algorithm applied to data from Carl2001.

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2. RADAR LIDAR SYNERGY

2.1 Synergy algorithm inputs

The radar lidar algorithm is based on three essential 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 instrumental parameters.

2.2 Inverse model

The inverse model, as explained in Tinel et al (2000), is funded upon a set of power law 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 N_0^* . 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 plan in a near future to use more data sets in order to build up some detailed comparison study.

We calculated the reflectivity, the ice water content, the radar attenuation and the optical extinction from in-situ measurements (Clare98). When plotting one of those parameters versus another, the dispersion of the points makes any regression impossible. Once normalized by N_0^* as in tinel et al (2000), the same plot becomes a straight line as illustrated in Figure1.

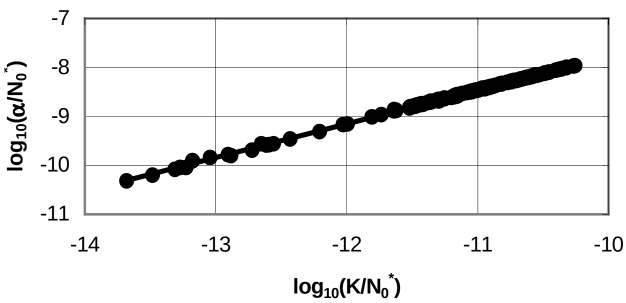

Fig 1. : The α/N_0^* versus K/N_0^* relationship for the CLARE98 microphysical data set and for a 95GHz radar

It is then easy to compute a robust regression with a set of constant coefficients to obtain a series of power laws relationships. These relations connect the instrumental parameters to the microphysical ones as in (1), (2) and (3).

This inverse model will be used in the synergetic algorithm

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:

$$\int_{r_1}^{r_0} \alpha(s) ds = c \left[N_0^*(r) \right]^{1-d} \int_{r_1}^{r_0} K^d(s) ds \quad (7)$$

Combining (5), (6) and (7), it is possible to retrieve $\alpha(r_0)$ through an iterative process initiated with a first guess of N_0*. We assume in this calculation that N_0* is constant between r_0 and r_1. $[r_0, r_1]$ is the integration length corresponding to a distance equal to 5 instrumental gates. The iteration process converges toward a value of $\alpha(r_0)$. We also assume that the reflectivity attenuation is negligible in ice clouds. The knowledge of $\alpha(r_0)$ and Z(r0) allows to calculate the value of $N_0^*(r_0)$ (from the power law relationships), which is equal to the value of $N_0^*[r_0, r_1]$.

Once we obtain the α profile, and an IWC profile, (from Z and N_0*), it is possible to retrieve an effective radius (r_e) profile.

The present method is an improved version of Tinel et al, 2000, as the value of N_0* is segmented along the retrieved profile (because of the variation of temperature with altitude 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, we calculate the Z and α profiles from the combination of (1), (2), (3) and (5). An assumption is made on the f parameter which is set to a constant value of 0.05 (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 in calculating the attenuated backscattering coefficient profile which is one of the three input parameters of the algorithm. We consider that reflectivity is not attenuated. It is then possible to apply the algorithm.

3.2 Parameters retrieval

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

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

The segmentation provides well retrieved profiles even if slight differences appear. Mean standard deviations have been calculated. The values are:

$$\begin{aligned} &\sigma(\alpha) = 0.315 \\ &\sigma(re) = 5.257 \\ &\sigma(\beta) = 0.016 \\ &\sigma(IWC) = 0.0116 \\ &\sigma(\log(N_0^*)) = 0.185 \end{aligned} \quad (8)$$

These values are small and correspond approximately for all parameters to a 10% relative error. This would be acceptable for radiative transfert calculations.

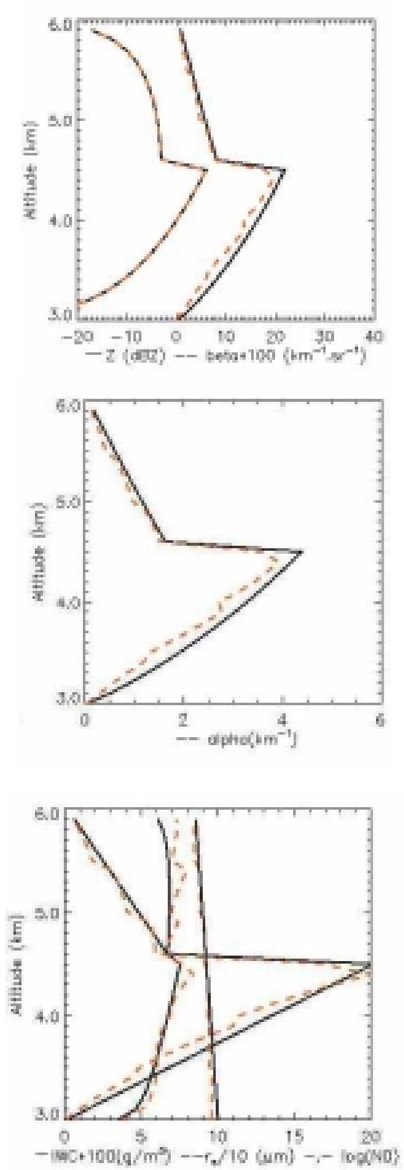

Figure 2 : expected and retrieved parameters from top to bottom:
(a) radar reflectivity and lidar backscattering coefficient
(b)radar attenuation and lidar extinction
*(c)Ice water content, effective radius and N0**

This simulation is a really first test of the algorithm. It has been made to prove that it is possible to retrieve a nearly-variable N_0* 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 Carl2001 in march 2001 campaigns.

The synergetic algorithm has been applied to those data. Figure 3 shows the results of the algorithm for one straight flight pattern on the 10^h of November 2000. That shows a good penetration of the lidar and radar beam into the upper cloud layer (iced stratus). 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. Thin supercooled layers are also seen by the lidar (at an altitude ranging from 3.9 km to 4.2 km).

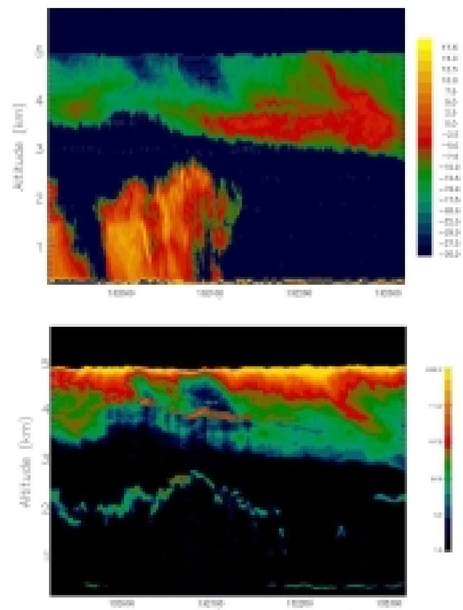

Figure 3: Illustration of apparent reflectivity (top) of RASTA radar and apparent backscattering coefficient (bottom) of LEANDRE lidar during Carl2000 on the 10^{th} of November 2000.

The presence of those supercooled layers is confirmed by the in-situ measurements. The Merlin was flying within the cloud at an altitude of about 4-4.2 km, and the measurements of the TW probe onboard the aircraft indicates the presence of cloud water in this part of the cloud.

Figure 4 shows the retrieved microphysical and radiative parameters from the synergetic algorithm. The segmentation of N0* has been done on 8 instrumental gates (about 120 meters). This is why N_0* values seem to be broken up. Effective radius values range from 60 to 100 µm in the ice cloud, and lower values are found (from 13 to 45 µm) in the supercooled layer as expected (Francis et al., 1998). Values of the ice water content are ranging from 0.001 to 0.04 g.m-3 in the ice part of the cloud. In this present case effective radii are calculated with the hypothesis of the presence of ice only. Thus we plan to apply two different algorithms on this supercooled layer: the first one will only take into account the reflectivity. Since the N0* value is not really different below and above the supercooled layer, we will use this value and the reflectivity to calculate the ice water content of this layer (from the power law relationship). The second algorithm will concern the liquid water content. Since liquid water is mainly seen by the lidar, we will consider an inverse model which takes into account the only lidar measurements. This should be more representative of the truth.

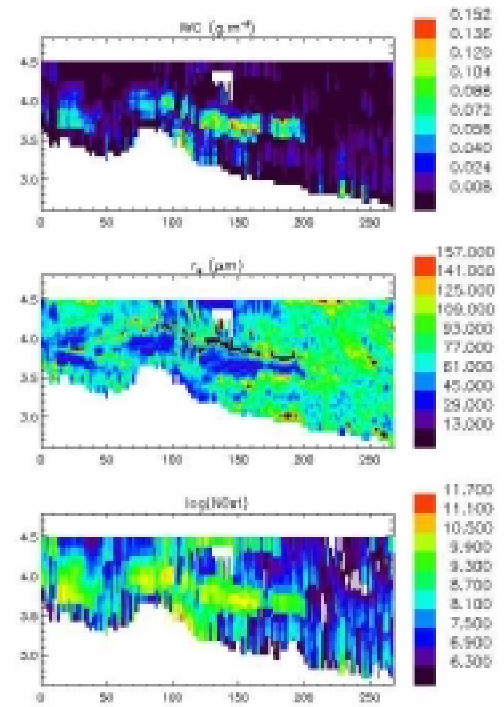

Figure 4: from top to bottom: retrieved ice water content, effective radius and N0 parameters from the synergetic algorithm for the iced stratus.*

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 relationships expressions,

The simulation will be extended with the introduction on noise instrument and the variation of f parameter,

The new power law relationships retrieved and the improvement of the algorithm due to the simulation study is currently applied to the database set from Carl 2000 and Clare 2001.

A segmentation of the algorithm between liquid and ice phases is planned as described above.

A dynamical approach, as explained in Protat et al (2002) will be applied to these data to study the dynamics to microphysics interactions.

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