

A SYSTEMATIC RETRIEVAL OF ICE CLOUD MICROPHYSICAL AND RADIATIVE PROPERTIES USING A SYNERGETIC RADAR/LIDAR ALGORITHM

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1. INTRODUCTION

Representation of clouds in climate or forecast model is done (depending on the scale of the model) by using variables such as ice water content or effective radius. On the other hand dynamical variables (such as falling velocity) are used in order to get a realistic cloud life cycle. However due to a lack of observations these parameter can be over/under estimated by a factor of two.

In the framework of the CloudNET project vertically pointing Doppler cloud radar and lidar are continuously operated from three sites in Europe (SIRTA (France), Chilbolton (UK) and Cabauw (Netherlands)) and at the same time outputs of four operational models (ECMWF, UKMO, Météo-France and RACMO) are stored at the measurement points.

A synergetic algorithm, combining radar/lidar measurements (Tinel *et al.*, 2004) in order to obtain an accurate retrieval of microphysical and radiative parameters and algorithms making use of the radar Doppler signal to derive dynamical properties (Protat *et al.*, 2002, Bouniol *et al.*, 2004) have been developed. Since retrieval of dynamical properties (falling velocity and vertical air velocity) is here the subject to another paper, this paper is more focussed on the microphysical and radiative properties determination.

As a first step the principle of radar/lidar synergetic algorithm is recalled, then this algorithm is applied to data collected on one site of the CloudNET project, finally some conclusions and perspectives are given.

2. PRINCIPLE OF THE RETRIEVAL OF MICROPHYSICAL AND RADIATIVE PARAMETERS

The principle of the radar/lidar algorithm is completely described in Tinel *et al.* (2004) for airborne instrument. It has been validated and compared to another algorithm making use of the same measurements (Donnovan *et al.*, 2000) in Hogan *et al.* (2004) for a space configuration. In this

paper, it is applied to measurements from ground-based instruments.

This algorithm lies on the hypothesis that the radar reflectivity (Z) and lidar backscattering coefficient (β_a) can be related to each other and then related to microphysical parameter such as ice water content (IWC) and radiative parameter, such as effective radius (r_e) using statistical relationships derived from in-situ measurements. However if one tries to derive a statistical relationship between for instance Z and IWC a large scatter is observed which makes hard a statistical relationship to be derived with accuracy. In order to reduce the dispersion, it is rather looked for relationships between Z/N_0^* and IWC/N_0^* (see Delanoë *et al.* for details), where N_0^* is a normalization parameter of the drop size distribution (see Testud *et al.* (2001) for derivation of this parameter). The set of equations relating the measurements to the parameter to be retrieved and the measurements of the two instruments is called the inverse model. This inverse model as been determined by Delanoë *et al.* (2004) on a large number of microphysical data set and they show that it does not depend of the geographical location of the measurements and of the cloud type or altitude.

The first step of the processing consists in relating the two measurements. This is done by using an integral constraint, written as followed and assuming as a first step a constant profile of $N_0^*(r)$.

$$\int_{r_1}^{r_0} \alpha(s) ds = \int_{r_1}^{r_0} a N_0^*(s)^{(1-b)} Z(s)^b ds \quad (1)$$

where α is the lidar extinction coefficient, r_0 and r_1 are the upper and lower limits respectively of the common sampling area of radar and lidar and a and b are the coefficients relating α and Z within the inverse model. This equation can be rewritten as $\alpha(r_0) = f(\alpha(r_0))$ and solved. Then the $\alpha(r_0)$ value found is introduced within the Klett (1981) solution rewritten as a function of extinction:

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

This leads to a new profile of $\alpha(r)$ and then by using

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the α/Z law of the inverse model to a new profile of $N_0^*(r)$ which is re-introduced within Eq. 1. This process is carried on up to the convergence to a $N_0^*(r)$ profile. Once this profile is obtained it is introduced within the inverse model and then IWC and r_e profiles are computed.

3. APPLICATION TO DATA COLLECTED AT SIRT

As mentioned in the introduction a cloud Doppler radar and a lidar are implemented on three sites in Europe and in particular at SIRT in France. There the RASTA 94GHz Doppler is continuously operated at the same time with the dual-wavelength (532 and 1024 nm) LNA lidar operated in case of dry weather.

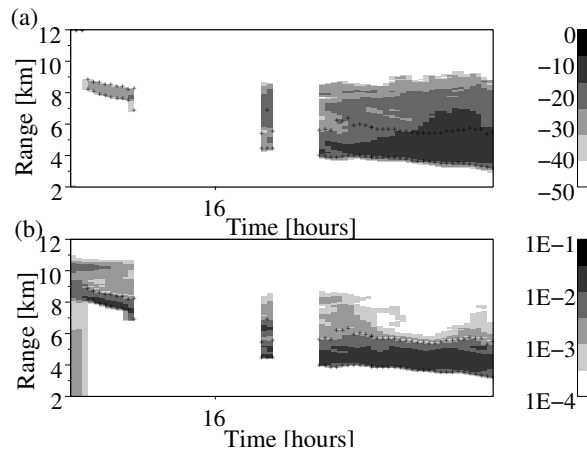


FIGURE 1: Time series of (a) radar reflectivity in [dBZ] and (b) lidar backscatter coefficient in [$\text{km}^{-1} \text{sr}^{-1}$] as a function of range in [km] observed at SIRT on the 13 november 2002. The crosses on both figures delimited the common sampling area of the two instruments.

Figure 1 shows the data collected at SIRT on the 13 november 2002 by (a) the radar and (b) the lidar. The overlap of the sampling of the two instruments is showed by the crosses on the two figures. These area is determined on lidar data by thresholding the signal. These observations are corresponding to a case of pre-frontal situation, where before 16UTC some cirrus clouds at about 9 km arrive above the site and afterwards the clouds become thicker leading to precipitations within the evening. These data also clearly illustrate the complementarity between radar and lidar observations, with a lidar more sensitive within thin clouds such as within the cirrus clouds. On the other hand when the clouds become thicker the lidar is rapidly attenuated while the radar is able to sample the whole cloud depth. This kind of cloud system is very commonly observed at SIRT latitude.

These data are ingested within the synergetic algorithm which leads to the results depicted on Fig. 2. Figure 2(a) shows the IWC values obtained

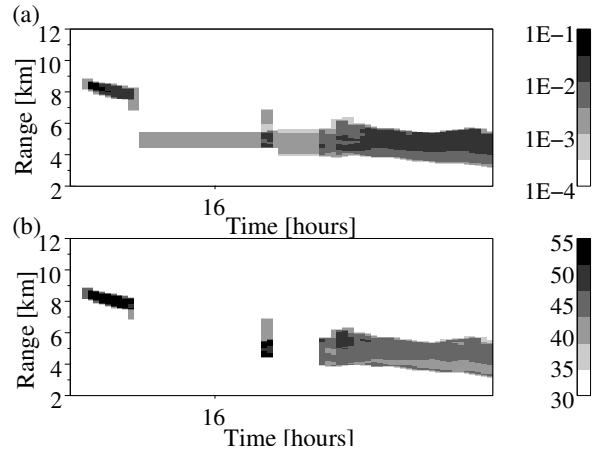


FIGURE 2: Time series of (a) IWC in [g m^{-3}] and (b) r_e in μm as a function of range in [km] deduced from the data showed on Fig. 1 by using the synergetic algorithm.

for this day with values in the range [$5 \cdot 10^{-3} - 1 \cdot 10^{-1}$] g m^{-3} . These values are in agreement with the one obtained by using other instruments such in-situ probes for instance. What can also be observed is that the IWC is decreasing towards the lower cloud edge, which can be explained by the evaporation of ice particles falling within a dryer environment. The corresponding r_e values are shown on Fig. 1(b) and fall within the range [$30 - 55$] μm which is also the range they are expecting for this kind of cloud.

This algorithm is systematically applied when common measurements are available. As a first step for model/observation comparison, probability density functions are built and are illustrated on Fig. 3. Figure 3(a) shows the probability density function of IWC and Fig. 3(b) of r_e . A first observation, which at this stage cannot be generalized is that the probability density functions seems to be slightly asymmetric with more small values than large for IWC. The shape is inverted for r_e with more large values than small one.

Figure 4 shows the same probability density functions but for another day where a more significant amount of data is present. This case is also for a frontal case and it seems that the same results can be found for IWC but in this case the probability density function for r_e is more symmetric. This result can be partly explained by the fact that on this case the lidar is penetrating deeper within the cloud and smaller r_e are more expected within the upper part of the cloud. For the same reason the range of IWC values is extending toward lower values.

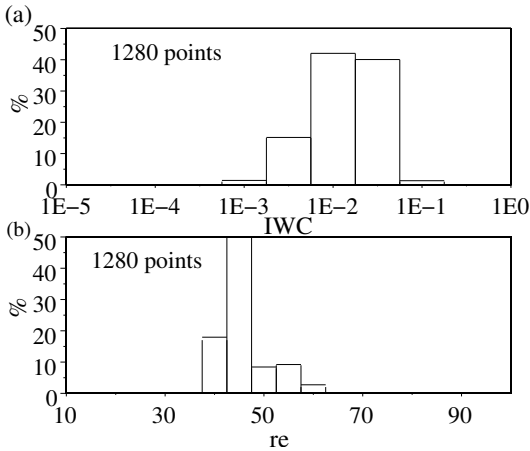


FIGURE 3: Probability density function of (a) IWC in $[g m^{-3}]$ and (b) r_e in μm for the frontal system observed on the 13 november 2002

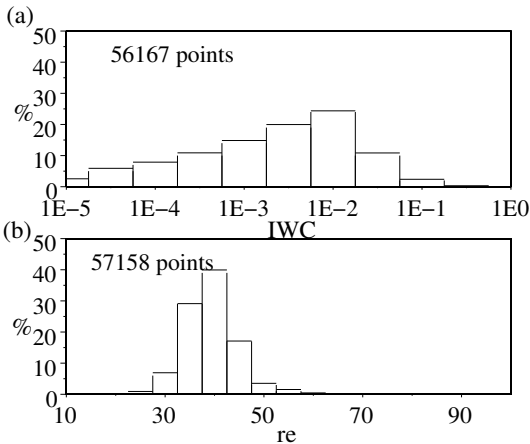


FIGURE 4: Same as Fig. 3 but for the 16 may 2003

4. CONCLUSION

A radar/lidar synergetic algorithm is runned at SIRTa in order to monitor as continuously as possible the microphysical and radiative properties of ice clouds. This algorithm is an iterative process which includes a set of statistical relationships, normalized by the N_0^* parameter, which relies the measurements and the measurements to the parameter to be retrieved. IWC and r_e are then retrieved within the common sampling area. This point needs to improve indeed the common area is often rather small compared to respective amount of data of each instrument. This algorithm should then be completed with two other (one lidar alone and one radar alone) using the results found in the common areas to document the ice cloud properties when only one instrument is available.

Once the microphysical and radiative param-

eters are determined one can expect to make comparisons with models outputs. A first step has been presented here which consists in building probability density functions from the observations. Since this paper was focussed only on two cases, no robust conclusions can be made. The following step is then to compare the obtained distributions to the one coming from models.

Another interesting point is to use the Doppler capability of the radar to retrieve dynamical properties of ice cloud. Studies of dynamical and microphysical/radiative interactions can be performed and parametrisation linking for instance falling velocity to IWC can be derived and compare the existing one, usually derived from in-situ measurements or theoretical works.

5. ACKNOWLEDGEMENT

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