Observations of warm and cold clouds using the airborne backscattering lidar LEANDRE 1 during CLARE, part 1 : data presentation

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INTRODUCTION

A large variety of crystal size and shape is very often found from in situ measurements in cold clouds. If cloud temperature is warmer than –40°C, supercooled water droplets can be found in a variable quantity. As radiative properties of water and ice particles are significantly different, and for ice depend on crystal shape, cloud radiation budget may be strongly affected by the spatial variability of cloud properties. The retrieval of optical and microphysical properties of cloud layers in cloud systems is thus of importance to better assess the radiation budget of the earth-atmosphere system.

Dual polarization backscattering lidar has the potential to provide information on cloud structure, cloud extinction and phase, especially in semi-transparent layers as will be presented here. Measurements were taken in both nadir and zenith viewing to analyze low and mid-level clouds as well as upper level clouds. Observations performed during the CLARE'98 campaign with the airborne backscatter lidar LEANDRE 1 are introduced in this first paper. Analysis methods are discussed in part 2, where examples of the retrieved cloud optical and microphysical parameters are given. The airborne radar Kestrel (see Guyot et al., this report) has been flown at the same time onboard the ARAT (French Atmospheric Research Aircraft, a Fokker F27), and made simultaneous observations of lower clouds in nadir viewing. First results from a direct combined analysis will be presented in the third paper, including ground-based radar measurements for cold clouds observed in zenith viewing. A complementary analysis is discussed in another paper (Guyot et al., this report).

LIDAR OBSERVATIONS

LEANDRE 1 is a backscatter lidar based on the use of a Nd-Yag laser source operating in the visible (532 nm) and near infrared (1064 nm) (Pelon et al., 1990). The signal emitted at 532 nm is linearly polarized and the backscattered signal is analyzed at both vertical and horizontal polarizations.

LEANDRE 1 was installed onboard the ARAT also equipped with radiometry and the Kestrel radar from University of Wyoming (Guyot et al., this report). In most cases lidar data were taken in nadir viewing simultaneously with the Kestrel radar. In some cases, zenith measurements have been taken in the most interesting situations when cold clouds were observed above the aircraft. Table 1 summarizes the ARAT flights.

Date	Mission	LEANDRE 1 pointing	Nr of legs	Cloud Type
07 Oct 98	M1	Nadir	9	Sc (single layer)
13 Oct 98	M2	Nadir	5	Cu-Sc-As/Ac (multilayer)
14 Oct 98	M3	Nadir + Zenith	6 + 2	Cu+Sc-clearing, then Ci
15 Oct.98	MC	-		Inter-Comparison
20 Oct 98	M4	Nadir	5	Sc+As/Ac
20 Oct 98	M4	Nadir	7	Sc +As/Ac
21 Oct 98	M5	Nadir + Zenith	4 + 1	Cu+Sc+As+ Ci

Table 1 : ARAT flights over Chilbolton

LIDAR CALIBRATION

Lidar signal is due to scattering by atmospheric molecules and particles. Scattering by molecules and droplets (or crystals) correspond to different regimes. Rayleigh scattering by molecules can be used as a reference in the visible as the corresponding signal can be easily measured.

Only signals obtained in the two channels operated at 532 nm are used. In the parallel polarization channel (polarization identical as the emitted one) the lidar signal is normalized to atmospheric scattering at an altitude close to the aircraft, using onboard nephelometer measurements (Flamant et al., 1998). This method cannot be used if the aircraft is flying in cloud, and the existence of an aerosol free area must be assumed to reference signal to molecular scattering.

Depolarization signal is also referenced to molecular depolarization taken as equal to 2.8 % (Young, 1980). In dense clouds depolarization is mainly due to multiple scattering. In semi-transparent cold clouds, the occurrence of ice can be better identified if their optical thickness remains small (say below 1).

LIDAR SIGNAL ANALYSIS

For an ideal detection system, the normalization procedure allows to derive the so-called attenuated backscattering coefficient β_a, defined as the real atmospheric backscattering coefficient β not corrected from transmission

$$\beta_a(\lambda, z) = \beta(\lambda, z) T^2(\lambda, z, z_a) \quad (1)$$

where z_a is the altitude of the airborne lidar. $T(\lambda, z, z_a)$ is the atmospheric transmission between z and z_a.

However, water clouds (such as stratocumulus) are usually dense media. Extinction becomes very large and signal can only be obtained from the first layers the laser beam penetrates. In this case, the apparent backscattering coefficient is altered by the detection time response and can be strongly reduced as compared to its true value (Pelon et al., 1999). This point will be further discussed in part 2. Furthermore, due to the large optical thickness of water clouds, multiple scattering contributes very significantly to the signal amplitude in both polarizations.

In cold clouds, optical thickness is smaller so that signal analysis can be usually performed using a second order scattering approximation (Ruppersberg et al., 1997). In such clouds, crystals are much larger than the wavelength, and diffraction must be accounted for in the analysis of the cloud optical properties. As this does not modify polarization, the depolarization ratio (defined as the ratio of the signals measured in the two polarizations) can be measured directly from the signals in the two visible channels to better characterize crystal shape (Chepfer et al., 1999).

Multiple scattering and diffraction are accounted for using a simple formalism proposed by Platt (1979), who introduced a parameter η (η<1) in the transmission term

$$T(\lambda, z, z_a) = \exp\left[-2\int_{z_a}^{z} \eta\alpha(\lambda, z')dz\right] \quad (2)$$

The same formalism can be used for all cloud types.

RADIOMETRY

Simultaneous radiation flux measurements were made onboard the ARAT with broadband visible Eppley pyranometers. Calibration flights performed with the C130 and the Falcon 20 of DLR allowed to compare flux measurements made by the three aircraft. The plane albedo A_A of the surface-cloud-atmosphere system was deduced from the ratio of the upward and downward shortwave flux F_{SW} measured by the upward and downward looking pyranometers as the ARAT flew over the stratocumulus layer

$$A_A = \frac{F_{sw}\uparrow}{F_{sw}\downarrow} \quad (3)$$

As a first approximation, a plane-parallel cloud model assuming no absorption and relying on two-stream radiative transfer calculations show that the cloud optical thickness τ can be deduced from the total plane albedo A_A as (Meador and Weaver, 1980)

$$\tau = \frac{A_A}{\gamma(1 - A_A)} \quad (4)$$

where γ is a parameter depending on the radiation model used. In the case of the Eddington scheme the value of γ is ¾(1-g), where g is the asymmetry factor of the cloud droplet distribution. As g = 0.85 for water spheres, we obtain γ = 8.8.

RESULTS

Examples of lidar cross-sections are shown on Figure 1 for the stratocumulus case of 7 October. Attenuated backscatter profiles obtained in nadir pointing show that the lidar signal is rapidly attenuated in such dense clouds.

One can notice that he maximum attenuated backscatter coefficient value in the stratocumulus is about 0.5 km^{-1}, which is much smaller than the expected value, as can be obtained from radiometry measurements.

In fact, the optical thickness of the cloud estimated from radiometric measurements using Eq. (4) and (3) is larger than 30 as shown in Figure 2. Given the cloud depth of 300 m deduced from the temperature measurements during ascent and assuming a linear increase of the extinction coefficient with height as a first approximation, one can estimate the extinction at cloud top to be of the order of 0.2 m^{-1}.

The true backscatter coefficient at cloud top is thus about 0.01 m^{-1}. sr^{-1} (10 km^{-1}), which is about 20 times larger than the observed value. This point will be further discussed in part 2.

It is however to be noted that the cloud base cannot be retrieved during this leg. In following measurements, as the cloud deck was breaking, the optical thickness was strongly decreasing in downdrafts, allowing to detect the surface.

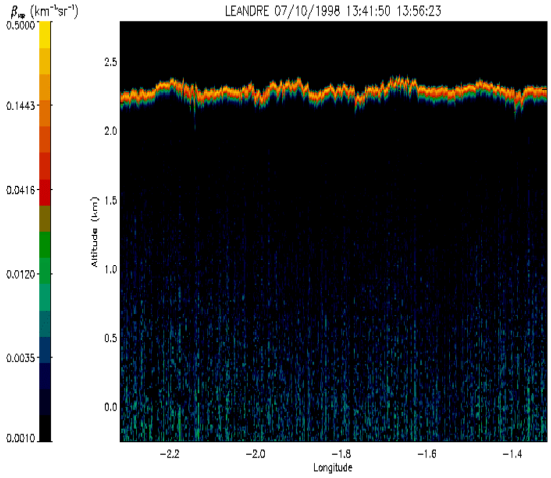

Figure 1 : Attenuated backscatter cross-section obtained during leg 2 over the stratocumulus deck overflown during mission 1.

A fairly good estimate of the cloud base height can be obtained in this case, as multiple scattering contribution apparently coming from below cloud base is small.

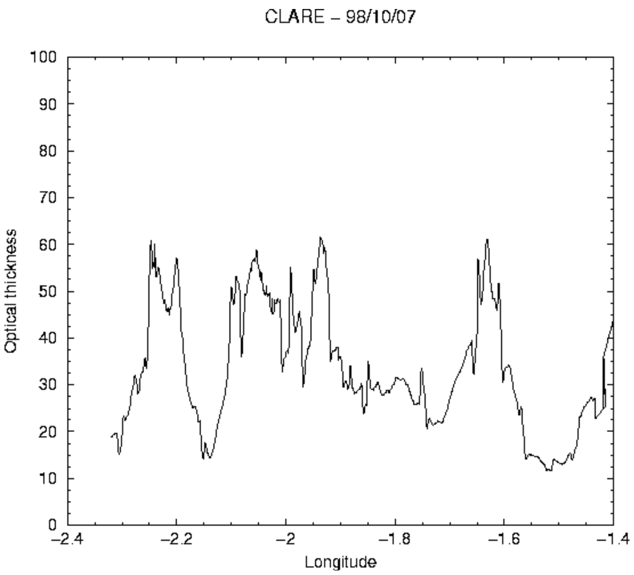

Figure 2 : Cloud optical thickness estimated from radiometry for the same stratocumulus case as in Fig. 1.

Figures 3 and 4 show the derived attenuated backscatter coefficient for the two cold cloud cases of 14 and 21 October, respectively. Cross-sections have been obtained with a vertical resolution of 15 m and an horizontal resolution of 100 m, corresponding to an acquisition time of 1s (12 laser shots). It is seen that comparable maximum values of the attenuated backscatter coefficient are obtained. The vertical structure is however very different although it corresponds to a fairly similar meteorological situation (see Illingworth et al., this report).

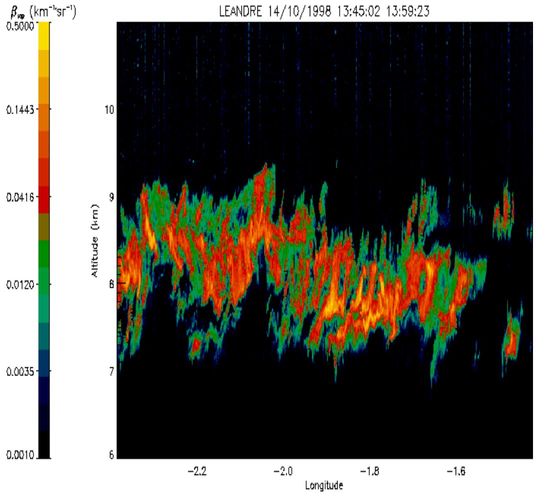

Figure 3 : Attenuated backscatter cross-section obtained during leg 5 of mission 3.

Average depolarization values obtained are comparable for the Sc and cold cloud cases. They are in all cases about 10 to 25 %. However, depolarization in Sc is due to multiple scattering, whereas it is mainly due to scattering by non-spherical particles in the cold cloud cases. Depolarization values for the 14 October are within 20 to 25%, those for the 21 October are within 10%. Such low values for elevated clouds are comparable to the ones obtained at warm temperatures (about -35°C for the 14 October and -15 °C for the 21 October as observed with the C130 -see Francis et al., this report-) in previous measurements (Platt et al., 1987)..

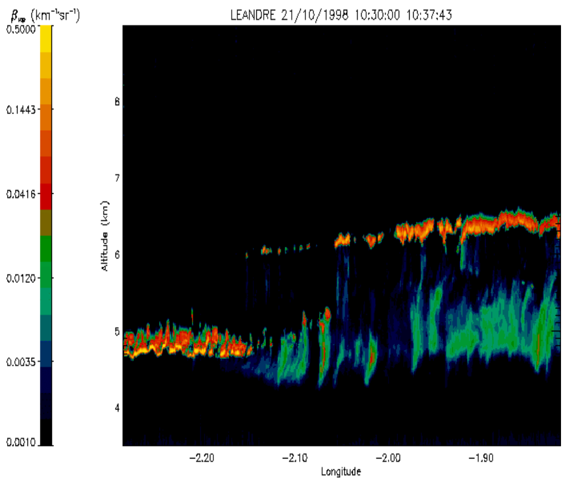

Figure 4 : Attenuated backscatter cross-section obtained during leg 5 of mission 5.

The cold cloud case of 14 October shows the occurrence of streaks, possibly associated to falling crystals. On the 21 October a particular vertical structure is observed with a thin layer above a broader one. Larger values of the attenuated backscatter coefficient associated to low depolarization coefficient are measured in the upper layer. Such a result may be representative of an upper cloud layer with super-cooled water droplets (small droplets strongly scattering and weakly depolarizing light) and large simple shaped ice crystals below. Note the difference in scattering in the lower level layer when the upper layer is not present. Similar observations of enhanced backscattering in a thin cloud layer were made on the 20 October.

CONCLUSION

ARAT flights performed during CLARE'98 have allowed to perform Lidar observations on different types of clouds. Multi-layered cloud structure was frequently observed. Thin layers of enhanced backscattering have been observed in cold clouds, which were attributed to the presence of super-cooled water. Measurements cannot be interpreted directly in terms of optical parameters and require specific analysis method adapted to the optical thickness and particle type in the cloud. This topic will be discussed in the second paper.

ACKNOWLEDGMENTS

The ARAT/F27 flights were funded by the European Space Agency which is acknowledged. The ARAT/F27 is a research aircraft of CNRS, CNES, Meteo-France and IGN.

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