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COMPARISON OF CIRRUS CLOUD CHARACTERISTICS AS ESTIMATED BY A MICROPULSE GROUND-BASED LIDAR AND A SPACEBORNE LIDAR CALIOP DATASETS OVER LILLE, FRANCE (50.60 °N, 3.14 ° E)

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ABSTRACT

Our goal is to establish a climatology of cirrus cloud properties over Lille, France (50.60°N, 3.14 °E) using a ground-based lidar. A statistical analysis of mid-latitude cirrus clouds from lidar data in Lille over the period 2008-2013 is presented and discussed. The macrophysical properties (cloud base altitude, cloud top altitude, geometrical thickness, mid-cloud temperature) and optical properties (cloud optical thickness and lidar ratio) are evaluated and compared between the ground-based and the spaceborne lidar CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) measurements for the period 2008-2013. We found similar results of macrophysical properties derived from both lidars. In addition a difference in the optical properties results is due to the multiple scattering and the heterogeneity of the observed scenes.

1. INTRODUCTION

Cirrus clouds are classified by the World Meteorological Organization (WMO) as high altitude clouds, detached in the form of delicate filaments and composed of ice crystals. Because of their high altitudes, cirrus clouds play an important role in the climate system with two opposite effects. They trap the outgoing infrared radiation, but at the same time, they can reflect the incoming solar radiation back out to space. The balance between these two radiative processes, the greenhouse and albedo effects, determines the net impact of cirrus on our climate system. Each contribution depends on the cirrus clouds microphysical and macrophysical properties (Stephens et al., 1990) [1]. Many active remote sensors are used to study high level clouds such as lidars and radars. Moreover several methods have been developed over time to determine and characterize geometrical and optical properties of cirrus clouds using ground-based or spaceborne lidars measurements. The objectives of this study are: (1) to establish a methodology of detection and characterisation of cirrus clouds using a micropulse lidar (MPL) data, (2) to retrieve cirrus clouds properties using the MPL database from 2008-2013, in order to construct a cirrus cloud climatology over Lille, (3) to compare the retrievals properties with CALIOP measurements, and finally (4) to evaluate the potential of the MPL to study high level clouds.

2. METHODOLOGY

First, we present the instrumentation and datasets characteristics used in this work. Then a basic description of the methodology used in this study to determine the macrophysical and optical properties of cirrus clouds using the MPL in Lille and CALIOP, is presented.

2.1. Ground-based lidar

A micropulse lidar has been installed in the Laboratoire d'Optique Atmosphérique (LOA), at University of Lille (France) since 2006. This lidar is operating in automatic mode 24 hours per day, 7 days per week. This MPL uses a Qswitch active ND: yag laser which emits a light pulse of ~ 15 ns at 532 nm. The repetition rate is 4.7 kHz with a pulse energy of 14 μJ. The photons are collected by a 200 mm diameter telescope with an altitude resolution of 15 m. A 1 minute integration time is used. This MPL is not equipped with a polarizing detector; hence the information of ice crystals size or phase of cirrus clouds cannot be obtained.

2.2 Spaceborne lidar CALIOP

The CALIPSO mission (Cloud Aerosol and Infrared Pathfinder Satellite Observations) was launched in April 2006 to measure global profiling of clouds and aerosols. The CALIOP lidar is a two-wavelength (532 nm and 1064 nm) polarization-sensitive lidar set on CALIPSO satellite. CALIOP is a three-channel elastic backscatter lidar. The vertical resolution of

CALIPSO data is 30 m from the surface to 8.2 km and 60 m from 8.2 km to 20.2 km. The layer products are generated at three different spatial resolutions: 1/3, 1 and 5km. The temperature used in CALIOP products is derived from the GEOS-5 data product. In order to compare cirrus clouds properties obtained from CALIOP measurements to those obtained from the ground-based lidar over Lille from 2008 to 2013, we used the CALIOP Level 2 v3.01, 3.02 and 3.30, 5km cloud layer products with a spatial domain of ± 1.5 ° in latitude and longitude round the ground site. We obtained 725 overpasses in this zone (day & night).

2.3. Methodology basic description

The first step of the methodology is to identify the presence of cirrus clouds, by using the method proposed by Platt et al., (1994) [2]. Hence the following geometrical properties are found: cloud base altitude, cloud top altitude and geometrical thickness. The second step is to determine the cirrus cloud optical parameters, which are the Cloud Optical Thickness (COT) and the lidar ratio (LR). The LR corresponds to extinction-to-backscatter ratio, assumed constant within the cloud. This ratio depends on crystal shape, size and orientation. Hence the effective optical depth of cirrus cloud is determined by using the transmittance method (Chen et al., 2002) [3]. This method consists to apply two linear fits of backscattering signals just below and above the cloud layer. The derived effective lidar ratio implies an iterative process, for the COT obtained by applying klett inversion forward method (Klett, 1985) [4] coincide with the COT obtained by the transmittance method. These two effectives parameters are corrected by the multiple scattering parameter η. It is still poorly known, as well as it depends on factors including cloud optical and microphysical properties and lidar configuration (field of view of the receiver, laser beam divergence).

3. RESULTS

In our study, only clouds with cloud base temperature colder than -25 °C are considered to ensure the majority composition of ice crystals. In Lille, this threshold corresponds to a typical cloud base altitude above 6300 m. The atmospheric temperature measurements are obtained from radiosondes launched in Brussels (50.75°N, 4.77°E) at 00:00 UTC, while the MPL lidar in Lille is approximately 115 km from Brussels station.

3.1. Geometrical and temperature characteristic

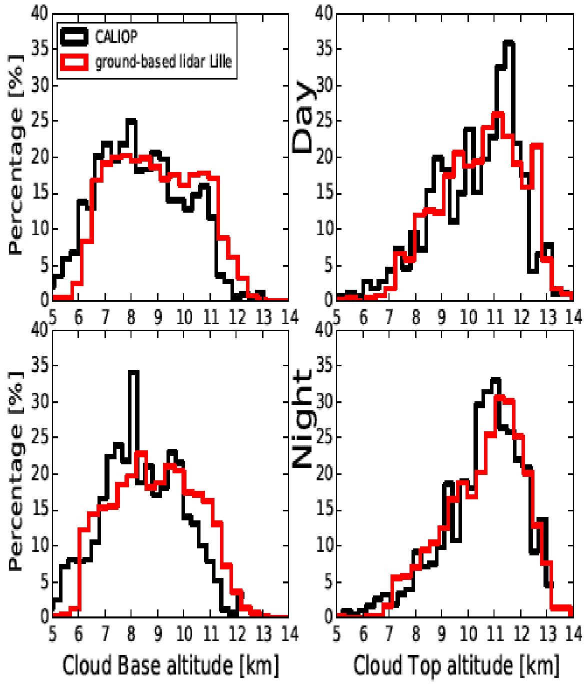

Figure 1: *Distribution of cloud base and cloud top altitude. Black and red lines correspond respectively to CALIOP and ground-based lidar data. The upper two figures correspond to the results obtained during the night and the lower ones to these obtained during the day.*

The MPL is very sensitive to the solar background noise, therefore we separate between nighttime and daytime lidar measurements. Figure 1 shows the distribution of cloud base altitude, and cloud top altitude obtained by the MPL and CALIOP. Cirrus clouds base altitudes are generally observed from 7 to 11 km, and top cloud altitudes from 8 to 14 km with a peak at 11 km. Similar results are obtained from both lidars. There is generally close agreement between results obtained for the cloud top altitudes during night. Also, 87% of total cases studied have a geometrical thickness between 0.5 and 2.5 km. Figure 2 shows the mid-cloud temperature, i.e. the temperature at the geometric midpoint of the cloud layer. Mid-cloud temperatures range from -30 to -70 °C, with a maximum of cases between -45 and -55 °C.

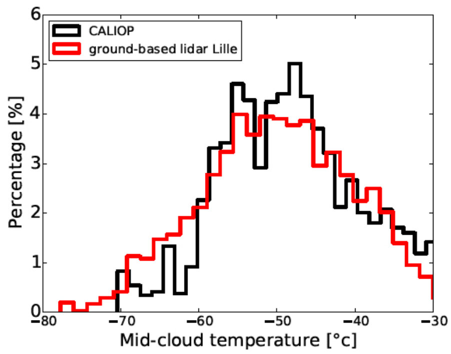

Figure 2: *Distribution of mid-cloud temperature for nighttime measurements.*

The average retrievals of macrophysical properties are presented in table 1, with a mean difference varying between 0.1 and 0.5 km. Table 1 shows that the cirrus clouds detected during night have slightly higher cloud top altitude, colder mid-cloud temperature, and are geometrically thicker, than cirrus clouds detected during day. Besides no remarkable diurnal difference for the cloud base altitudes is found.

Parameters	Day	night
Cloud base altitude (km)	8.92 ± 1.65 (8.39 ± 1.65)	8.91±1.60 (8.38 ± 1.57)
Cloud top altitude (km)	10.46±1.59 (10.25 ± 1.62)	10.62±1.50 (10.55 ± 1.51)
Mid-cloud temperature(°C)	-49±10 (-47 ± 10)	-50±9 (-48 ± 9)
Geometrical thickness (km)	1.54±0.91 (1.86 ±1.55)	1.71±0.93 (2.17 ± 2.01)

Table 1. *Average and standard deviation of macrophysical properties of cirrus clouds over Lille obtained from the MPL lidar and CALIOP (in parentheses) during daytime and nighttime measurements.*

3.2. Optical properties of cirrus clouds

The CALIOP cloud products use a multiple scattering factor of 0.6 and a fixed lidar ratio (LR) of 25 sr, which is one of the causing differences in the optical parameters obtained by the MPL and CALIOP. Sassen and Comstock (2001) [5] assumed a multiple scattering factor of 0.9 for sub-visible cirrus clouds, of 0.8 for relatively thick clouds and 0.6 to 0.7 for optically thick clouds. Because the multiple scattering factor depends on many factors as cited before and in order to find this factor for the MPL lidar, we determine η as the ratio of the COT obtained by CALIOP and the COT obtained by the MPL before correction, i.e. effective COT; we found a variable multiple scattering factor with a mean value equal to 0.75. Figure 3 shows the distribution of different classes of cirrus clouds according to their optical thickness. Visible cirrus clouds, characterized by their COT between 0.03 and 0.3 as defined by Sassen and Cho, (1992) [6] reach 67 % of the total observed cirrus clouds by the MPL before the correction of multiple scattering effect. It is reduced to 56 %, after the correction (figure 3).

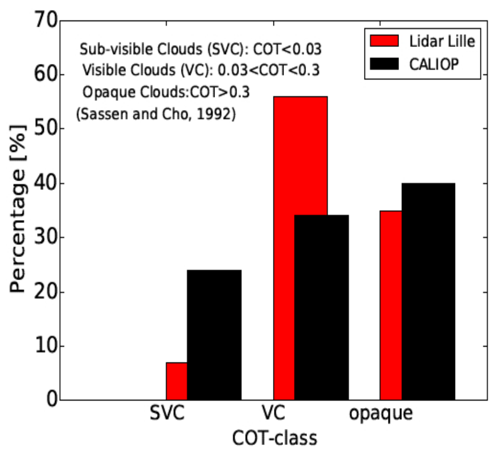

Figure 3: *Different classes of cirrus clouds obtained by MPL and CALIOP. Red histograms correspond to the results obtained by the MPL after the correction of the multiple scattering effect (η=0.75).*

3.3. Monthly variation of cirrus clouds

Figure 4 shows the monthly variation of altitudes of cirrus clouds over Lille cumulated for the 6 years. It shows a similar shape variation obtained from both lidars. Lille has a temperate oceanic climate; furthermore four seasons are generally recognized. Cirrus clouds are more frequently observed in autumn (September till November)

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with 37 % of total cases (figure 4, a). The mean value of the tropopause during the six years is at 11.3 ± 1.4 km with a mean temperature of -59 ± 6 °C. The cloud top altitudes tend to track the tropopause (figure 4, b). However cirrus clouds are higher during summer (June till August) than during winter (December till February).

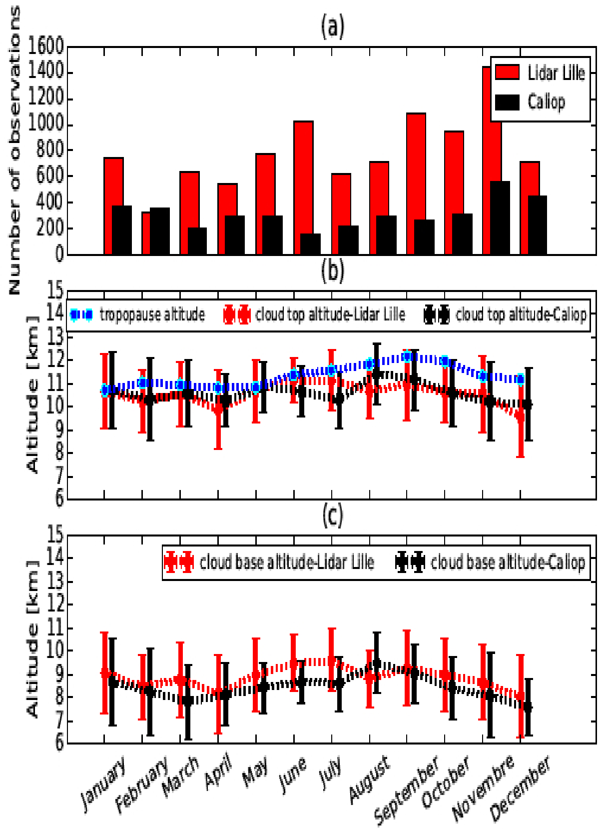

Figure 4: *(a) Histogram of the number of observations of cirrus. (b) Mean and standard deviation of cirrus top altitude and mean tropopause altitude. (c) Mean and standard deviation of base cirrus altitude obtained from ground-based and CALIOP lidar.*

4. CONCLUSIONS

This study provides an analysis of macrophysical and optical properties of cirrus clouds over Lille. An agreement was found between the results obtained by the ground-based and spaceborne lidar especially for the macrophysical properties. A slightly difference is obtained for the optical properties due to the multiple scattering and the impact of cirrus clouds heterogeneities on the retrieved COT. This study shows the potential of the micropulse lidar to study high clouds and to create a climatology of mid-latitude cirrus clouds. However, with some limits: a maximum value of retrieved cirrus COT is 1.2, the solar background noise and the presence of thick lowest cloud creates difficulties in the detection of cirrus clouds.

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