EPJ Web of Conferences **362**, 08016 (2026) https://doi.org/10.1051/epjconf/202636208016
ILRC31/CLRC22-2024

Using BeCOOL microlidar for satellite calibration/validation

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Abstract: BeCOOL is a microlidar designed to monitor high clouds from stratospheric balloons. From October 2021 to January 2022, three of these instruments have been flown along the equator, gathering hundreds of hours of high-resolution nighttime lidar profiles. Case studies of collocated observations with CALIOP, and statistical comparisons, highlight the very good agreement between the two lidars and the enhanced sensitivity of BeCOOL to ultra thin clouds. Future observation campaigns involving this instrument could be an opportunity for calibration/validation of upcoming space-borne lidar missions such as Earthcare or AOS.

1 Introduction

BeCOOL (Balloon-borne Cirrus and convective overshOOT Lidar) is a nadir-pointing microlidar designed to study cirrus optical properties and convective overshoots [1,2]. During the first Strateole-2 campaign (October 2021 - January 2022), three BeCOOL microlidars have been flown onboard super-pressure balloons along the equator, just a few kilometers above the clouds, gathering 700 hours of nighttime observations [3]. These observations compare very well to CALIOP's, both from case studies and from a statistical point of view. Moreover, BeCOOL benefits from a higher signal-to-noise ratio (SNR) thanks to the long integration time (1 minute) allowed by the low speed of the balloons. Hence, this instrument has a unique sensitivity to ultra thin cirrus clouds.

2 Instrument and processing

The microlidar has been designed and built at LATMOS. Its main technical characteristics are summarized in Table 1. BeCOOL only operates during nighttime, with a duty cycle of 10 min ON / 10 min OFF, due to thermal constrain onboard the gondola. Each 1 minute profile is normalized using ERA5 temperature and pressure assuming pure molecular conditions in the near-field (between 1 and 2 km below the instrument). After a 10 minutes averaging, optical properties of clouds are retrieved using the classical Fernald/Klett inversion method [4].

Table 1 : BeCOOL technical specs

Weight	< 7kg
Power	< 10 W
Wavelength	802 nm
Pulsed energy	10 µJ
Pulse repetition rate	4700 Hz
Integration time	60 s

Similarly to what is done for CALIOP [5], optical depth retrieval of the thicker clouds (optical depth $\tau > 3{\cdot}10^{-2}$) can be constrained with the two way transmission through the clouds. Optical depth retrievals of the thinner clouds rely on *a priori* lidar ratio derived from CALIOP over the same region and period. Constrained retrievals need to be further corrected from multiple scattering [6]. The correction factor $\eta = 0.88$ has been determined as the scaling factor that reconciles BeCOOL's "apparent" and CALIOP's "true" optical depth distributions for constrained retrieval.

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3 Two case studies

Collocated BeCOOL/CALIOP observations allow a fine comparison of both lidars' performances. Two case studies of such coincident measurements are detailed in the following.

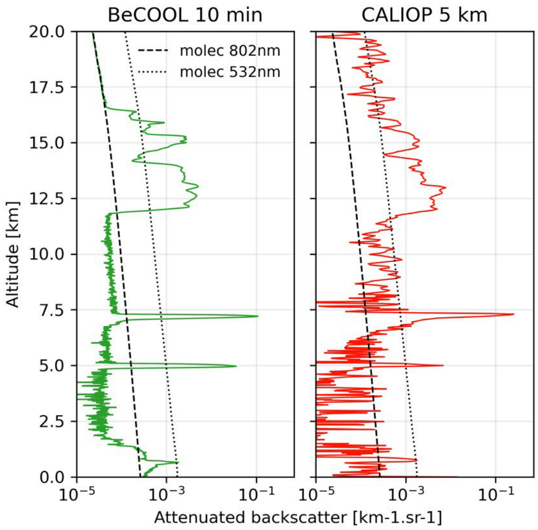

Figure 1. Collocated thick cirrus observations

Figure 1 shows collocated observations (attenuated backscatter profiles) of a thick cirrus over the Pacific Ocean. On this figure, CALIOP's horizontal resolution is 5 km (15 laser shots, 0.7 s). BeCOOL's profile is integrated over 10 minutes (about 3 million laser shots) and is of comparable horizontal resolution. The closest BeCOOL 10 minute profile displayed on the figure has been measured 7 min before the satellite overpass. A complex multilayered scene is captured by both lidars : a thick cirrus cloud extends from 11 to 16.5 km over two mid-level clouds at 5 and 7.5 km that have small vertical extension, strong backscatter, and are likely to be pure liquid clouds. BeCOOL's lower noise level (at these resolutions) clearly appears on this figure. Furthermore, due to the strong wavelength dependency of Rayleigh scattering, the contrast between the clouds and the surrounding molecular atmosphere is higher at 802 than 532 nm.

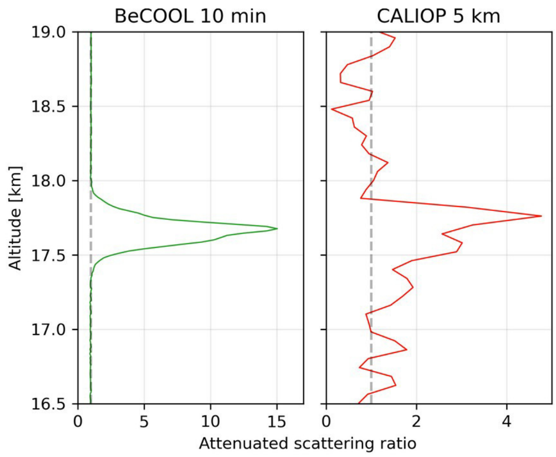

Figure 2. Collocated thin cirrus observations

Due to both effects (noise level and spectral dependency of Rayleigh scattering), BeCOOL has a unique sensitivity to very thin clouds, as illustrated with a second case study displayed on Figure 2. It shows collocated profiles of attenuated scattering ratio (ASR) over an very thin cirrus at 17.7 km above the coast of Indonesia. BeCOOL's ASR peaks at 15 with very low noise on the molecular baseline while CALIOP's peaks below 5 over a noisy baseline. This thin cirrus cloud's optical depth at coincidence is $5 \cdot 10^{-3}$ (about CALIOP's detection lower limit), it is only partially detected by CALIOP which does not resolve its full horizontal extent.

4 Statistical comparison

Figure 3 shows the optical depth distributions for all clouds above 5 km from BeCOOL (blue) and from CALIOP's Level 2 nighttime profiles over the same period and region (red).

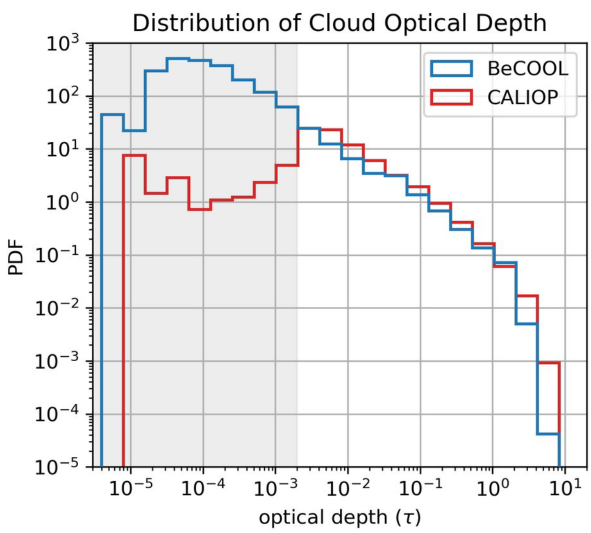

Figure 3. Cloud optical depth distributions

A clear optical depth cut-off appears in CALIOP's distribution at $\tau = 2{\cdot}10^{-3}$. Both distributions compare very well above this threshold value, exhibiting a τ^{-1} slope up to $\tau = 1$. For BeCOOL, this power law relation extends down to $\tau = 10^{-4}$ while CALIOP's distribution diverges below $\tau = 2{\cdot}10^{-3}$. Ultrathin clouds with an optical depth below $2{\cdot}10^{-3}$ are reported in less than 1 % of CALIOP's profiles while they appear in more than 30 % of BeCOOL's, mainly within the Tropical Tropopause Layer (above 14 km, 23 % of the profiles). They share characteristics with laminar cirrus reported by Winker & Trepte from LITE space-borne lidar observations [7] and with Ultrathin Tropical Tropopause clouds reported by Peter et al. from airborne observations [8]. Such clouds play a role in the dehydration of air masses transported upward to the stratosphere [9].

5 Perspectives

CALIPSO mission ended during summer 2023, before the launch of the next generation of space-borne lidars (Earthcare, AOS). Several BeCOOL flights are scheduled during the second Strateole-2 scientific campaign (boreal winter 2025-2026), it could be an opportunity for calibration/validation of upcoming satellite missions.

Ongoing instrumental developments (notably to enable daytime measurements) include a 532 nm version and a dual-wavelength version of the microlidar. Deployments of these instruments in synergy with radars and/or infrared radiometers are planned, both in the tropics and at higher latitude.

6 References

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