MicroPulse Lidar and Ceilometer inter-comparison during Saharan dust intrusions over the Canary Islands

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Abstract — **This study presents an inter-comparison between a Vaisala CL51 ceilometer and a Micro Pulse Lidar (MPL) of both the Boundary Layer (BL) and the Saharan Air Layer (SAL) top heights during Saharan dust events from January to April 2011. This inter-comparison was performed at the Santa Cruz de Tenerife Observatory in Tenerife, Canary Islands, within the Marine Boundary Layer. From January to April the Saharan dust intrusions usually occur at lower altitudes within the BL. One of the main goals of this study is to determine whether the CL51 ceilometer is capable to detect mineral dust within the SAL. To our knowledge, this is the first time this kind of study is attempted on a site close to Saharan dust sources.**

The BL and SAL heights were determined using the gradient method. The BL and SAL heights correspond respectively, to the first and subsequent measurable minima of the derivative of the MPL and CL51 backscatter signals.

Our results have been analyzed using ancillary information: 1) HYSPLIT 4 and ECMWF backtrajectories; 2) simulations of vertical profiles of dust concentrations from the BSC-DREAM8b dust model; 3) analysis of temperature, pressure, humidity and wind vertical profiles from radiosonde at the Güimar radiosonde station in Tenerife; 4) aerosol optical depth from Izaña and Santa Cruz de Tenerife AERONET stations ; 5) MODIS and MSG satellite imagery analysis; 6) particulate matter concentrations PM10.

We have found a good agreement between the Vaisala CL51 ceilometer and the MPL in the determination of the BL and SAL height, noting that in the winter season it is more challenging for the MPL to detect dust layers because they travel at lower altitudes.

Keywords— **African dust, Saharan Air Layer, Boundary Layer, ceilometer, lidar**

I. Introduction

The Boundary Layer (BL) is a subject widely investigated [Hayden *et al*., 1997; Hägeli *et al*., 2000]. BL is directly influenced by Earth's surface and responds to surface forcing by frictional drag, evaporation and transpiration, and is sensitive to heat transfer with a timescale of an hour or less. The top of the BL can be determined in several ways, e.g., sodar data, wind-profiling radar, lidars and ceilometer [Beyrich, 1997; Cohn and Angevine, 2000; Seibert *et al*., 2000; Emeis *et al*., 2004; Wiegner *et al*., 2006].

Originally, the ceilometers were conceived for cloud height detection. There are case studies of multilayer cloud base height [Martucci *et al*., 2010]. Novel methods for determination of the BL height based on ceilometer measurements [Eresmaa *et al*., 2006; Emeis *et al*., 2008; Kamp *et. al*., 2010] have been described and tested against commonly used classical methods.

Lidar permits the detection of the BL top with vertical and temporal resolution in the range of a few meters and seconds, respectively. Continuous lidar observations of the top height of the BL have been performed by some authors [Melfi *et al*., 1985; Baars *et al*., 2008]. Different methods to determine the BL height have been described by Flamant *et al*. (1997), Menut. *et al*. (1999), Sicard *et al.* (2006), Amiridis *et al*. (2007) and Martucci *et al*. (2007). Also several studies about BL and dust layer (DL) height evolution using lidar have been performed [De Tomasi and Perrone, 2006]. A comparison of the determination of both the BL and aerosol layers height using lidar and Vaisala CL31 ceilometer was performed by McKendry *et al*. (2009).

In this study we focused on determining and comparing the BL and SAL top with a Vaisala CL51 ceilometer and the Micro Pulse Lidar (MPL), using the Gradient Method (GM) and verifying our results with ancillary information. The study site is characterized by frequent and occasionally very intense African dust outbreaks. As far as we know, this is the first time that the Vaisala CL51 ceilometer is used to detect the Saharan Air Layer (SAL).

The study is structured as follows: first we describe the study site and the instrumentation. Secondly, we explain the

BL and SAL height determination method. Then results are shown and discussed and, finally, the conclusions.

II. Methodology

A. Measurements sites

This study was performed in the Santa Cruz Observatory (SCO). SCO is a coastal urban background station (28.5ºN, 16.2ºW, 52 m a.s.l.) in Tenerife (Canary Islands), within the marine boundary layer (MBL). SCO is managed by the Izaña Atmospheric Research Centre (CIAI) of the Spanish Meteorological State Agency (AEMET). This station is a NASA/AERONET, NASA/MPLNET (MicroPulse Lidar NETwork, http://mplnet.gsfc.nasa.gov/) and SPALINET (Spanish and Portuguese Aerosol Lidar NETwork, http://www.lidar.es/spalinet/) site.

Radiosoundings were performed at Güimar station (GS; 60018; 28.32ºN, 16.38ºW, 115 m a.s.l.) in Tenerife (Canary Islands).

B. Instruments

The Micropulse Lidar version 3 (MPL-3, SES Inc., USA) system is the standard MPL currently in operation within NASA/MPLNET. MPL is a robust system with high-pulse (2500 Hz) and low-energy (~ 7μJ) 'eye-safe' Nd:YLF laser at 523 nm, operational in full-time continuos mode.

The vertical resolution of the lidar backscattered signal is 75 m. It is registered in 1-minute integration time.

Several corrections were applied to the raw signal in order to take into account those factors affecting the instrument [Campbell *et al*., 2002]. In order to increase the signal-to-noise ratio (SNR), the corrected profiles are hourly averaged. A full overlap is reached at 3 km height. Above 600 m a.s.l. the errors in the data range between 10% to 40%. Below 600 m a.s.l. intrinsic limitation of the system configuration exists resulting in large errors in the data.

The Vaisala Ceilometer CL51 uses pulsed diode laser LIDAR technology. The laser diode is 'eye-safe' InGaAs at 910 nm, a pulse of 6.5 kHz and 3.0 μWs energy (Vaisala, 2010). The CL51 is the latest model of Vaisala. It is equipped with a larger lens and a more powerful laser transmitter module than CL31. The SNR increases with this new configuration. The vertical resolution of the ceilometer backscattered signal is 10 m. It is registered in 16-seconds integrated time. The backscatter profiles are range and overlap corrected. The full overlap is reached at 30 m (Münkel and Roininen, 2010).

C. Experimental procedure

In this study the BL and the SAL heights were determined using the gradient method (GM) (Flamant *et al*., 1997; Menut *et al*., 1999) with both MPL-3 and CL51 backscatter profiles.

In the GM, the first derivative of corrected lidar and ceilometer backscatter signals with respect to height is used. The corrected profiles for both instruments were hourly averaged and the derivative of the signals was visually inspected and smoothed with a box-averaging over 5 points. The BL top is indicated by the minimum gradient. Subsequent measurable minima indicate different structures, including the top of the SAL.

The results of the determination of the BL heights were compared with those given by the Vaisala Boundary Layer View Software (BL-View), radiosoundings data and the BL height simulated by the ECMWF model (data provided by the operational ECMWF Data Server). The BL-View uses the Mixing Height Algorithm, which consists on the determination of the local minimum of the backscatter coefficient gradient.

Ancillary information, namely HYSPLIT 4.0 and ECMWF backtrajectories, Moderate resolution Imaging Spectroradiometer (MODIS) and Meteosat Second Generation (MSG; EUMETSAT) satellite imagery, aerosol optical depth (AOD) and Angström exponent at Izaña Observatory (IZO, 28.31ºN, 16.5ºW, 2373 m a.s.l.) and SCO, particulate matter concentration (PM10) at SCO, and vertical profiles of dust concentration at SCO simulated by BSC-DREAM8b model (http://www.bsc.es/projects/earthscience/DREAM/), see section III. AOD is the standard parameter measured by sunphotometers as those operating in AERONET (Holben *et. al*., 1998). AOD was used in order to corroborate the presence of African dust over the study site during the case study periods.

III. Results and discussion

The CL51 measurements campaign was conducted in SCO from January 17 to April 4, 2011. Four African dust intrusion episodes occurred during this period. Two of these episodes, which have been objectively identified, are shown and discussed in this study. The first case study occurred on February 20-25, 2011 and the second case on March 31-April 3, 2011. During these episodes, warm and very dry air masses were observed between 800 and 2000 m height.

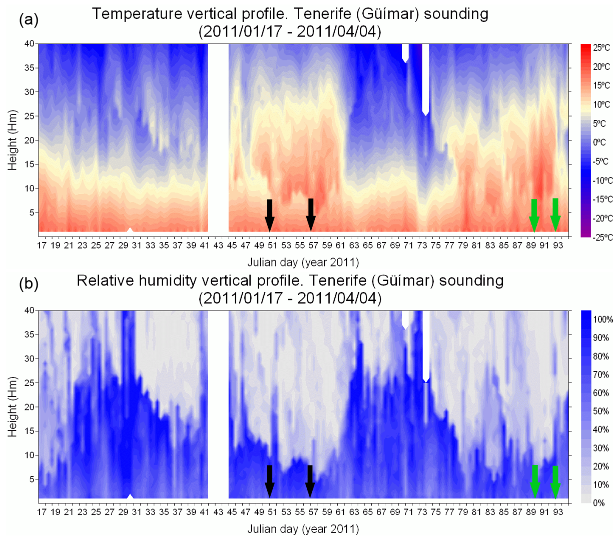

Fig. 1. Temperature (a) and relative humidity (b) cross sections from sounding at Güimar for the period January 17-April 4, 2011. Black arrows indicate the first and last day of the first case study. Green arrows indicate the first and last day of the second case study.

A. Fist case study: February 20-25, 2011

During this case study an African dust intrusion over SCO occurred (February 21-24, 2011). Backtrajectory analysis showed a North African origin for the air masses reaching SCO (not shown for brevity). BSC-DREAM8b vertical profiles revealed high concentrations $\geq 100\mu/m^3$ below 2000 m. a.s.l.. Daily means of PM10 at SCO ranged between 9.5 $\mu g/m^3$ (February 20, 2011) and 24.0 $\mu g/m^3$ (February 23, 2011). PM10 daily means during this African episode were higher than PM10 background for SCO (around 10 $\mu g/m^3$). The Angström exponent was lower than 0.05 and coarse mode AOD at 500 nm was higher than 0.12. These values are indicative of an African dust intrusion over the study site, with a high coarse particles content.

Figures 2a, b show the range corrected signal of the CL51 and MPL-3 for the whole study period respectively. The first 24 hours were characterized by the presence of clouds. An African dust layer can be distinguished as high intensities after 24 h, above 1000 m.

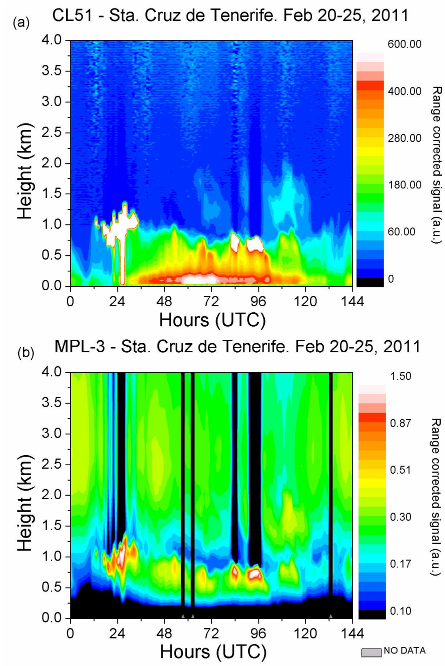

Fig. 2. Temporal evolution of the range corrected signal in arbitrary units obtained by CL51 (a) and MPL-3 (b) respectively. The relationship between backscatter intensity and color code is presented by color bar.

An example of a full 24-h period (February 24, 2011) of CL51 and MPL-3 is displayed in Figure 3a, b respectively. The BL top is located at heights slightly lower than 1000 m a.s.l., and the SAL top is located at heights around 2000 m a.s.l.. BL height mainly oscillates between 620 and 870 m a.s.l. in hours of maximum insolation, and then rapidly decreases at sunset. The temporal evolution of the BL and SAL heights observed with both instruments is in good agreement ($r^2 = 0.8$ and $r^2 = 0.4$, respectively), see Figure 3a, b, and Figure 4.

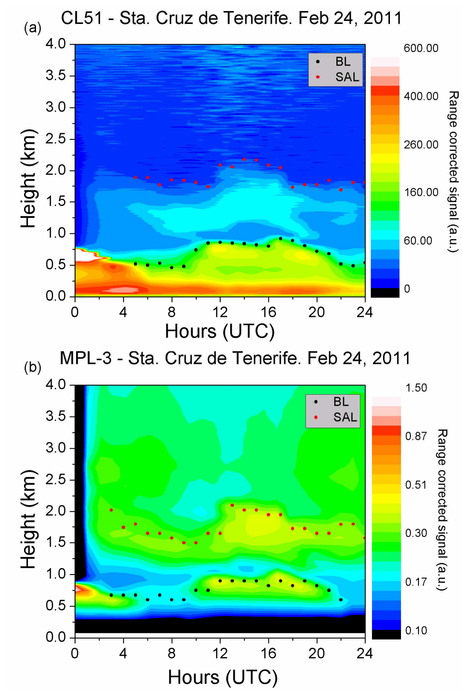

Fig. 3. Temporal evolution of the range corrected signal in arbitrary units obtained by CL51 (a) and MPL-3 (b) respectively for 24-h. (February 24, 2011). Black circles correspond to BL top and red circles to SAL top.

In Figure 4 BL top heights resulting from BL-View are depicted, which shows a good correlation with our results obtained by MPL-3 (r^2=0.9) and with those obtained by CL-51 (r^2=0.9). BL top heights obtained by radiosoundings and ECMWF model are also shown in Figure 4, which are in agreement with our results.

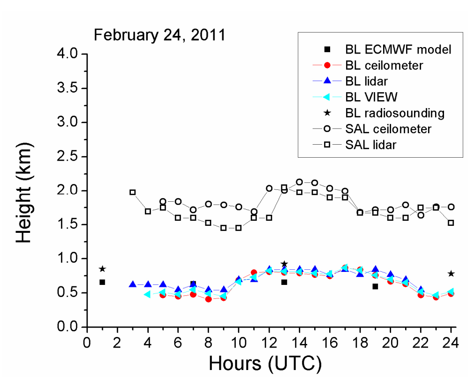

Fig. 4. Temporal evolution for 24-h of the BL (CL51, MPL-3, radiosoundings, ECMWF and BL-View) and SAL (CL51, MPL-3) top heights.

B. Second case study: March 31-April 3, 2011

For the overall study period, 2 days (April 1-2, 2011) of African dust intrusion over SCO was confirmed. Backtrajectory analysis reveals the North African region as the source of the dust (not shown for brevity). BSC-DREAM8b vertical profiles show high concentrations ≥ 100μ/m^3 below 2000 m a.s.l.. MODIS revealed an African dust plume over the Canary Islands. Daily means of PM10 at SCO ranged between 11.4 μg/m^3 (April 3, 2011) and 27.4 μg/m^3 (March 31, 2011), those concentrations are higher than those of the first case study. The values of coarse mode of AOD at 500 nm and Angström exponent indicated the presence of both coarse and fine particles.

Figures 5a and b show the range corrected signal of the CL51 and MPL-3 for the whole study period respectively. The first half of March 31, 2011 data were not recorded by the CL51. April 3, 2011 is characterized by a significant presence of clouds, as seen with both instruments.

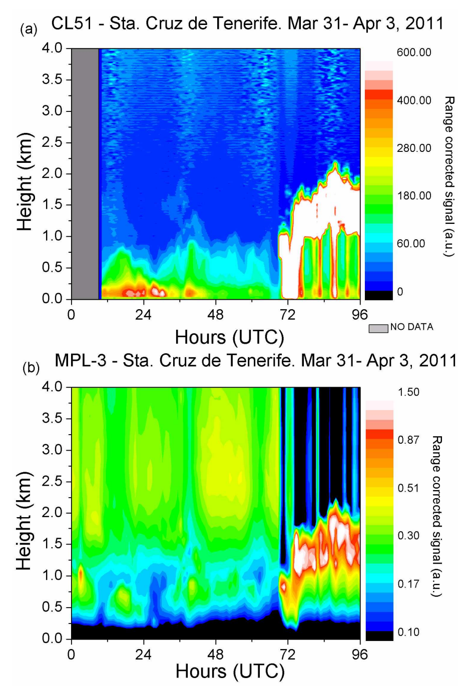

Fig. 5. Temporal evolution of the range corrected signal in arbitrary units obtained by CL51 (a) and MPL-3 (b) respectively. The relationship between backscatter intensity and color code is presented by color bar.

The April 1, 2011 (full 24-h period) case is shown in Figure 6 a, b, where the range corrected signal from CL51 and MPL-3 is observed respectively. BL and SAL heights are also marked in Figure 6a, b. The BL top is located at heights between 500 m and 100 m and the SAL top is located at heights between 1 and 1.5 km. As occurred in the previous case study, the temporal evolution of the BL and SAL top heights obtained with CL51 and MPL-3 are in good agreement (r^2= 0.5 and r^2= 0.9), see Figure 6a, b, and Figure 7.

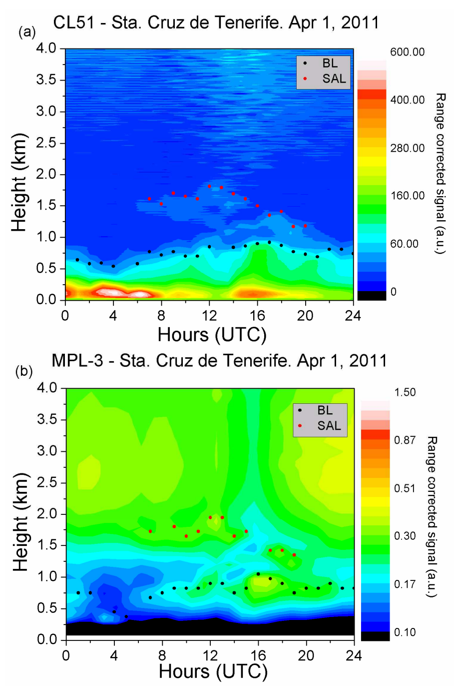

Fig. 6. Temporal evolution of the range corrected signal in arbitrary units obtained by CL51 (a) and MPL-3 (b) respectively for 24-h (April 1, 2011). Black circles indicates BL top and red circles SAL top.

BL top heights resulting from BL-View and ECMWF model are in good agreement with our results, as observed in Figure 7.

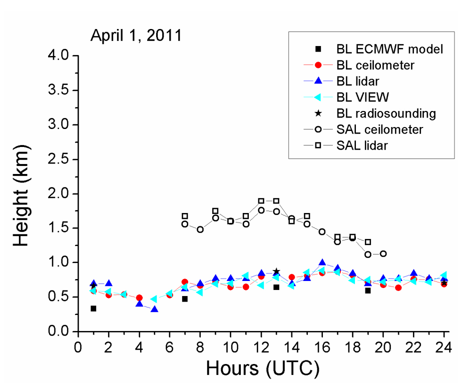

Fig. 7. Temporal evolution for 24-h of the BL (CL51, MPL-3, radiosoundings, ECMWF and BL-View) and SAL (CL51, MPL-3) top heights

IV. Conclusions

This study has shown that the Vaisala CL51 ceilometer is able to detect the dust layer during a winter African dust episode, being appropriate to monitor vertical structure of the SAL.

Despite the intrinsic limitations of the MPL-3, we have found that this instrument is also capable of detecting the BL and the SAL.

The results obtained in this study indicated that the MPL-3 and CL51 are in good agreement in the determination of both the BL and SAL heights, noting that in the winter season it is more challenging for the MPL-3 to detect dust layers because they travel at lower altitudes. BL height obtained by BL-VIEW, ECMWF model and radiosoundings are in agreement with our results.

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