A tool for automatic detection and characterization of cloud boundaries from BAQUNIN Lidar signals

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Introduction

The LIDAR system is widely used in atmospheric aerosol and boundary layer (BL) studies, and for the detection of cloud boundaries. However automatic and accurate identification of cloud top and bottom heights and BL height presents some difficulties, especially for low signal to noise ratio values, and when aerosol layers are observed at the top of BL. In addition, the disentanglement of cloud and aerosol contribution to LIDAR signal is not trivial.

In this work, a signal threshold approach is presented, starting from the range corrected signal (RCS) and using its spatial and temporal variations. Usually top and bottom heights of clouds from LIDAR signal retrieved analyzing profiles obtained mediating the signals acquired over the time. The mediate signal assure a good signal to noise ratio but decrease the temporal resolution, in addition each profile has to be analyzed to have cloud boundaries. In our approach, we use the Range Corrected signal (RCS) of each profile acquired, so the temporal resolution depends only by the system characteristics. Moreover, several or all profiles of the measurement session can be analyzed in the same time, allowing to have easily and quickly the results.

Method

The approach has been tested using the BAQUNIN Lidar measurements.

This system allows to acquired signal with a temporal and spatial resolutions of 30 seconds and 7.5 meters respectively (3000 bins for each profiles), using 3 different wavelengths 355, 532 and 1064 nm. This means that we can obtain top and bottom heights of clouds each 30 seconds instead of 5 or 10 minutes, which is the temporal resolution after the mean process. **[1]**

First step

The method is based on the visualization of color graph of the RCS signal calculated using the following equation

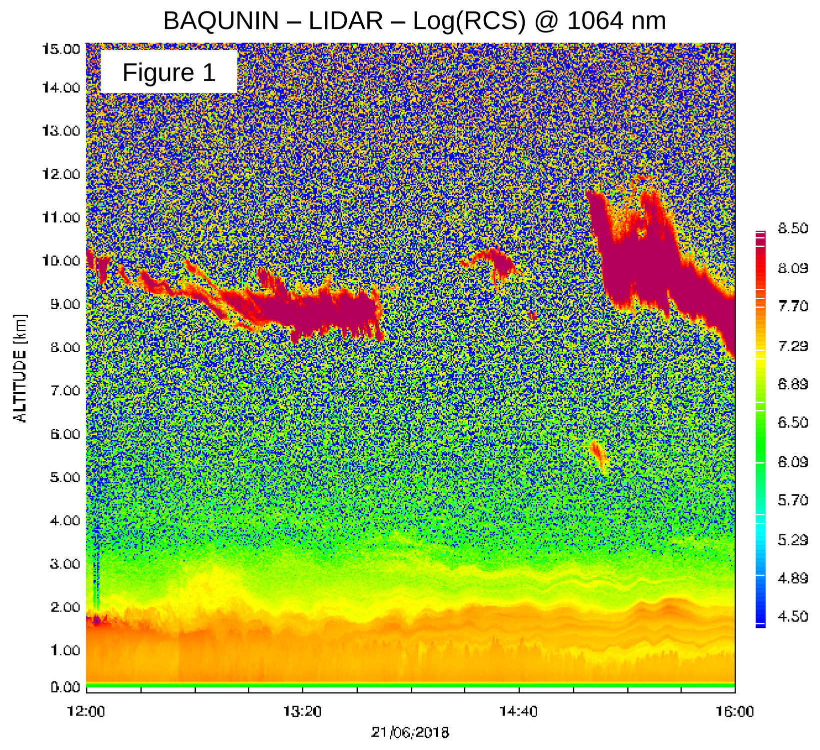
$$RCS[t,z] = Log((S[t,z]-B)\times r[z]^2)$$

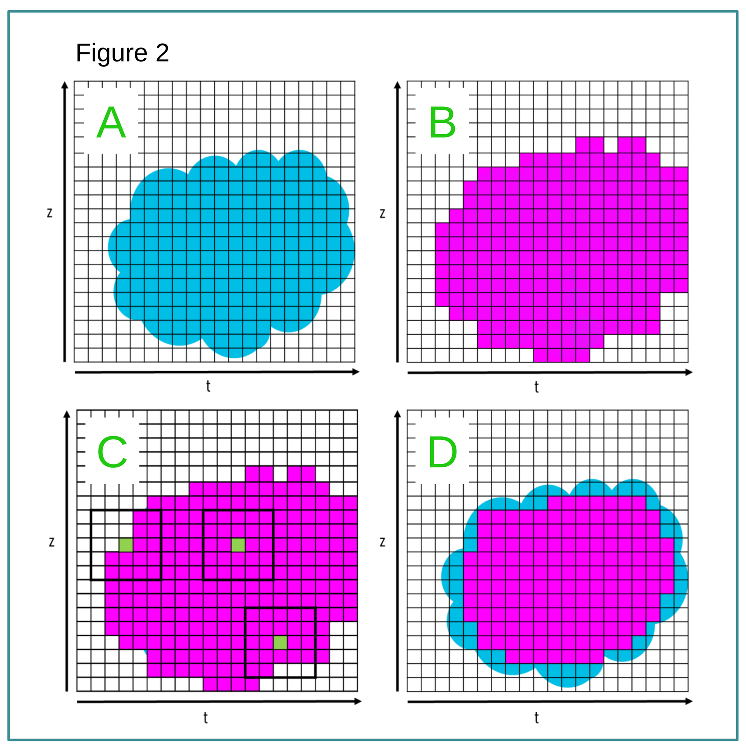
S is the acquired signal, B the background noise obtained mediating S over the last 100 bins, r is the altitudes a.s.l., finally the indices *t* and *z* allow to run along the time and altitude.

To improve the visualization of the lidar imagery we take the log of the attenuated backscatter. Any missing values, infinite values, or not-a-number (NaN) values are then set to the daily minimum value.

An example of the color graph of the RCS is show in Fig.1. The color scale is customized according to better visualized the signal, it depends on the LIDAR system characteristics and the selected wavelength.

BAQUNIN – LIDAR – Log(RCS) @ 1064 nm





Second step

Observing RCS plot, a threshold value is selected to distinguish between cloud and molecular or aerosol backscatter signal. For the RCS obtained from the backscattered signal of the wavelength 1064 nm shown in Fig.1, the threshold is 7.5. This threshold depends on the characteristics of the specific Lidar: analyzing almost 100 hours of LIDAR measurements (temporal resolution 30 seconds), we noted that the same value can be used if the receiver conditions do not change significatively.

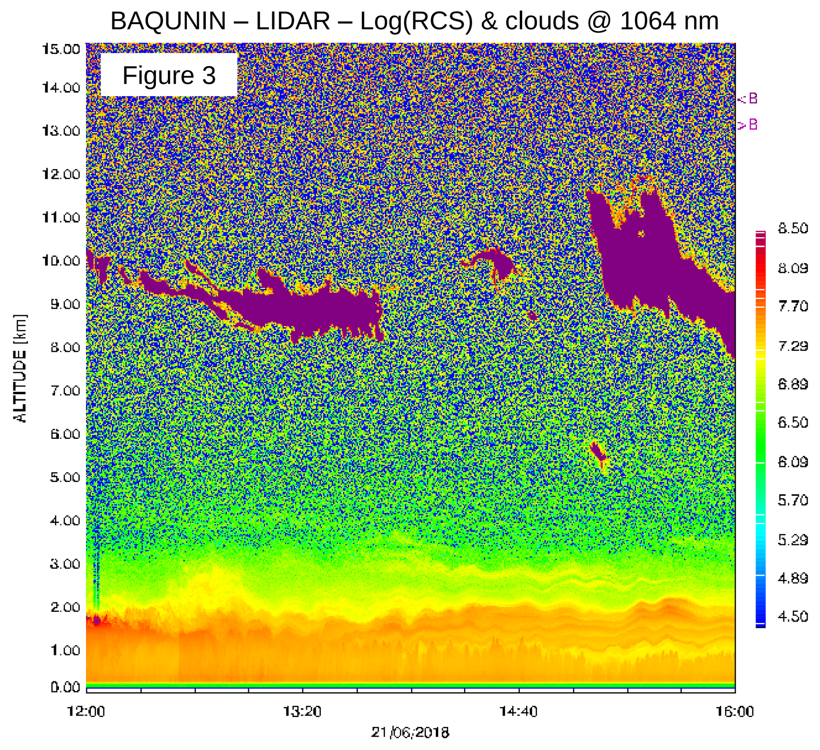
Considering the RCS as a matrix (Fig.2-A), with altitude and time as dimensions (indices t and z in the equation before), the elements of this matrix which have a value greater than the selected threshold are "labeled" as possible cloud elements (Fig.2-B).

Third step

Then spatial and temporal variations of the RCS are considered: if the neighbor elements of a selected "labeled" element [t,z] are also "labeled" (green elements in Fig.2-C), then the selected element is confirmed to be a cloud signal (Fig.2-D). This procedure excludes "single bin" cloud or aerosol elements in the RCS, possibly due to instrumental noise.

The number of elements to be considered for the 2-D analysis depends on the spatial and temporal resolution of the Lidar. In our case, these are 7.5 m and 10 s, therefore we selected a grid of 5x5 elements centered on the selected elements. This algorithm is applied to the complete set of Lidar measurement session, producing a matrix of "labeled" elements.

BAQUNIN – LIDAR – Log(RCS) & clouds @ 1064 nm



Finally, the bottom and top heights of the layers are detected as the height of first and last labeled groups of elements, this allows to detect more than one cloud in the profile.

Fig.3 shows the obtained results for the RCS signal in Fig.1, the clouds are well identified and there is also an estimation of the retrieval indicated with two different colors light or dark violet according if the robustness of the results. If the backscattered signal over the cloud is grater than the background signal, it is possible to affirm that the method estimate well cloud boundaries, if not it means that there is a grater uncertainty of the result due to the major extinction of laser beam in the cloud.

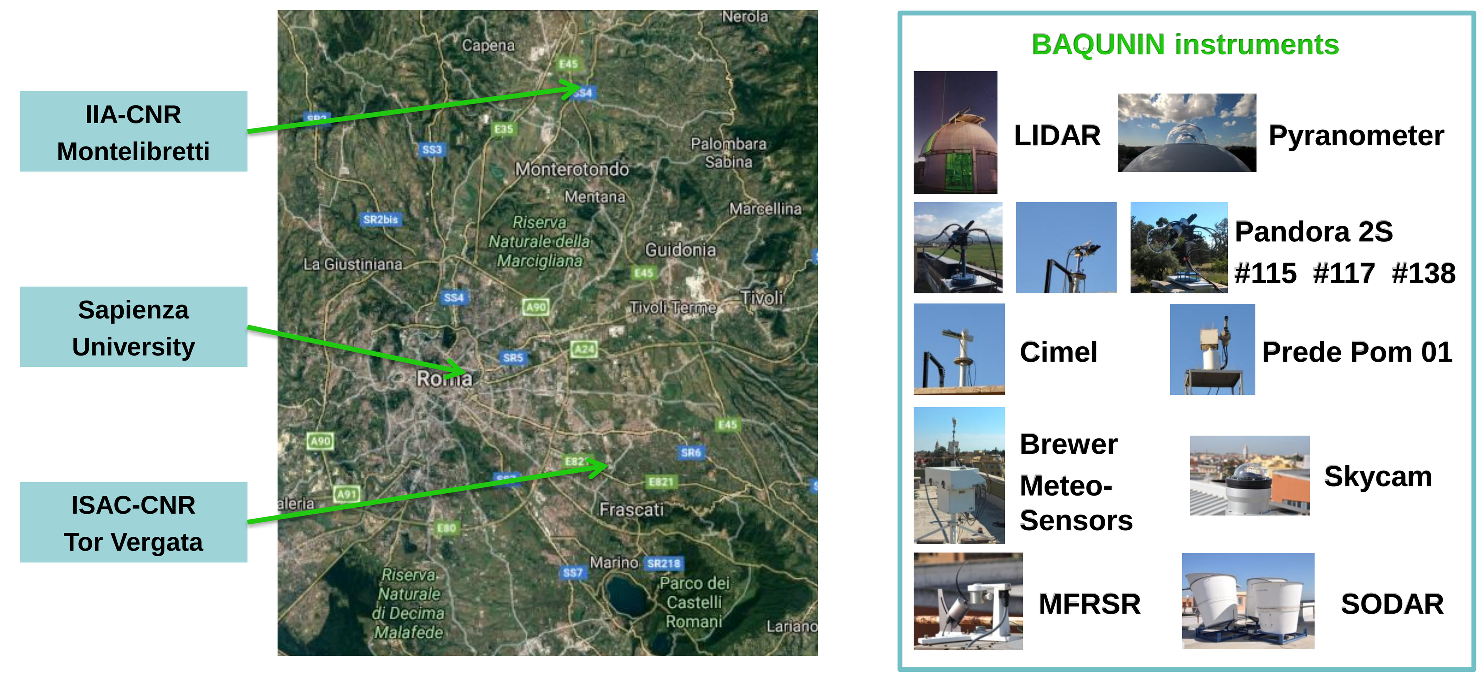
Clouds at 5,5 Km and from 8 to 11 km are identified, the higher cloud with greater uncertainty respect to the lower one (dark and light violet).

A dedicated software has been developed for this retrieval, it allows to visualize the RCS graph, select the threshold, temporal and spatial range for the analysis, and the results are saved (matrix of labeled elements and top and bottom heights of the clouds) in a netcdf file.

Further improvements of this approach will be able to detect aerosol layers and clouds, determining automatically threshold to apply according to the temporal/spatial variation of the intensity of the signal.

BAQUNIN

Inside the Physic Department of Sapienza University two research groups involved in atmospheric and climate studies are present since 30 years ago. During the years, a lot of researchers were formed there, some of which still today work in these sectors. Thanks to the collaboration with ESA, in June 2016 the BAQUNIN (Boundary-layer Air Quality using Network of Instruments) Supersite is born. In the last years, the suite of the instruments present in the Physics Department has expanded and so also the collaboration with other research agencies.



The great part of the BAQUNIN Super Site instrumentation is located at Sapienza University, in the city center. Other two instruments (Pandora) are located in semi-rural areas:

- The ISAC-CNR Rome Atmospheric Supersite, southeast of the city (Tor Vergata)
- The IIA-CNR Institute for Atmospheric Pollution, northeast of the city (Montelibretti)

In the Supersite are located 12 ground based remote sensing instruments, operating in synergy, offering quantitative and qualitative informations for a wide range of atmospheric parameters for Planetary Boundary Layer (PBL) studies and for validating the satellite atmospheric composition and optical products.

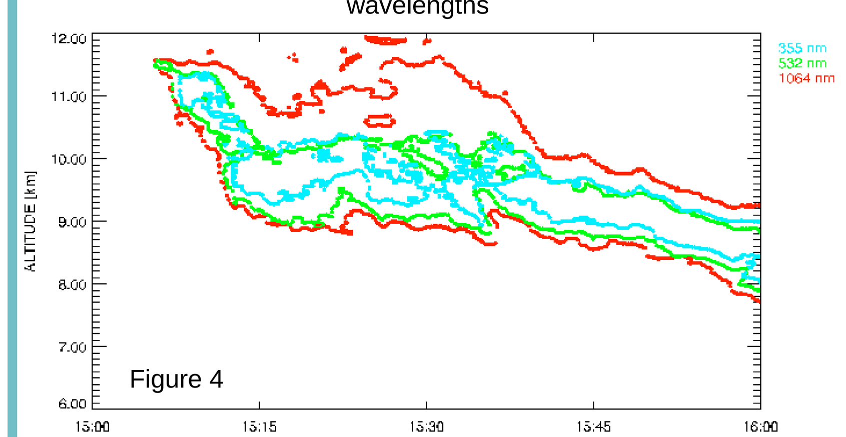
Results

This method was tested for different atmospheric conditions and wavelengths, and the results were compared with those obtained using the standard approach of LIDAR data analysis.

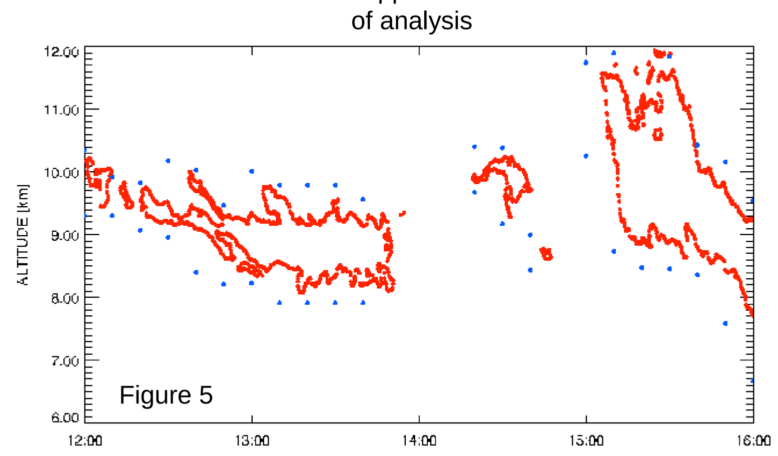
In Fig.4 are shown the comparison of the cloud boundaries retrieved using the three wavelength of the aerosol BAQUNIN LIDAR system. The graph refers to the cloud retrieved in Fig.3 starting from 15.00. There are a good agreement of the bottom of the cloud between all wavelengths, instead some differences are present for top heights estimation, due to different extinction of laser beams inside the cloud.

Fig.5 shows the comparison between the results obtained using the threshold method described (red dots) and the standard LIDAR method (blue dots). In the second case, the 10 minutes mediate signal is used. There is an improvement of the temporal resolution of the clouds boundaries using the threshold method, and also the contours are ore detailed.

BAQUNIN – LIDAR – Clouds boundaries: comparison between results of the analysis obtained using three wavelengths



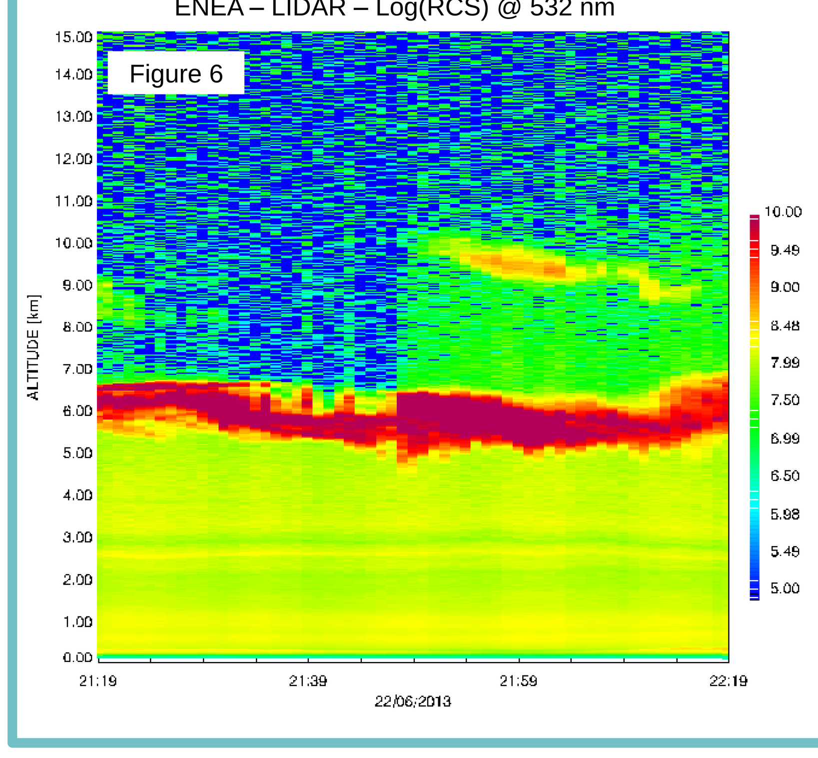
BAQUNIN – LIDAR – Clouds boundaries: comparison between the threshold approach and standard method of analysis



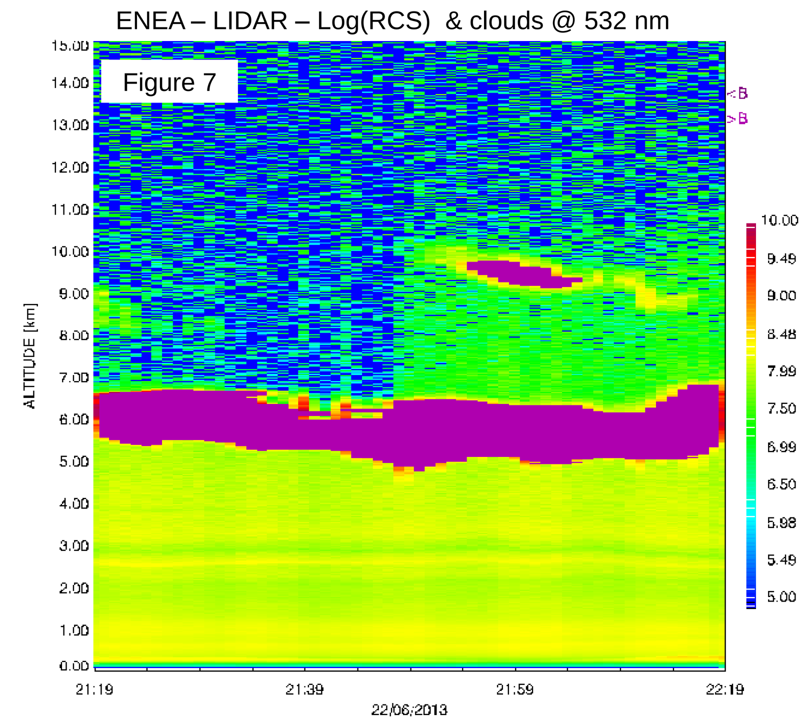
This method was also tested using data acquired by the LIDAR system installed in the ENEA Station for Climate Observations on the island of Lampedusa. For this system the temporal and spatial resolutions are 1 minute and 7,5 meters respectively, the wavelength used is 532 nm.

Fig.6 and Fig.7 show the RCS signal and the retrieved clouds using our method. Also in this case the threshold approach give good results.

ENEA – LIDAR – Log(RCS) @ 532 nm



ENEA – LIDAR – Log(RCS) & clouds @ 532 nm



[1] More technical information on BAQUNIN LIDAR system in the poster ***The Elastic/Raman LIDAR contribution to the Boundary-layer Air Quality Using Network of INstruments (BAQUNIN) project***, M. Cacciani.

Thanks to the research group of the ENEA Station for Climate Observations on the island of Lampedusa for LIDAR data.