An automatic algorithm for the detection and the characterization of cloud boundaries from BAQUNIN LIDAR signals

Anna Maria Iannarelli[1], Marco Cacciani[2], Stefano Casadio[1], Gabriele Mevi[1], Annalisa Di Bernardino[2]

(1) SERCO SpA, Frascati, Italy (Annamaria.Iannarelli@serco.com); (2) Sapienza University of Rome, Department of Physics, Rome, Italy

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 height of clouds from LIDAR signal, are obtained by the retrieval of the temporal averaged LIDAR signal profiles. The mean signal assures a good signal to noise ratio but a decrease in the temporal resolution occurs. 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 on the system characteristics. Moreover, several (or all) profiles of the measurement session can be analyzed in the same time, ensuring easy and quick-results.

Method

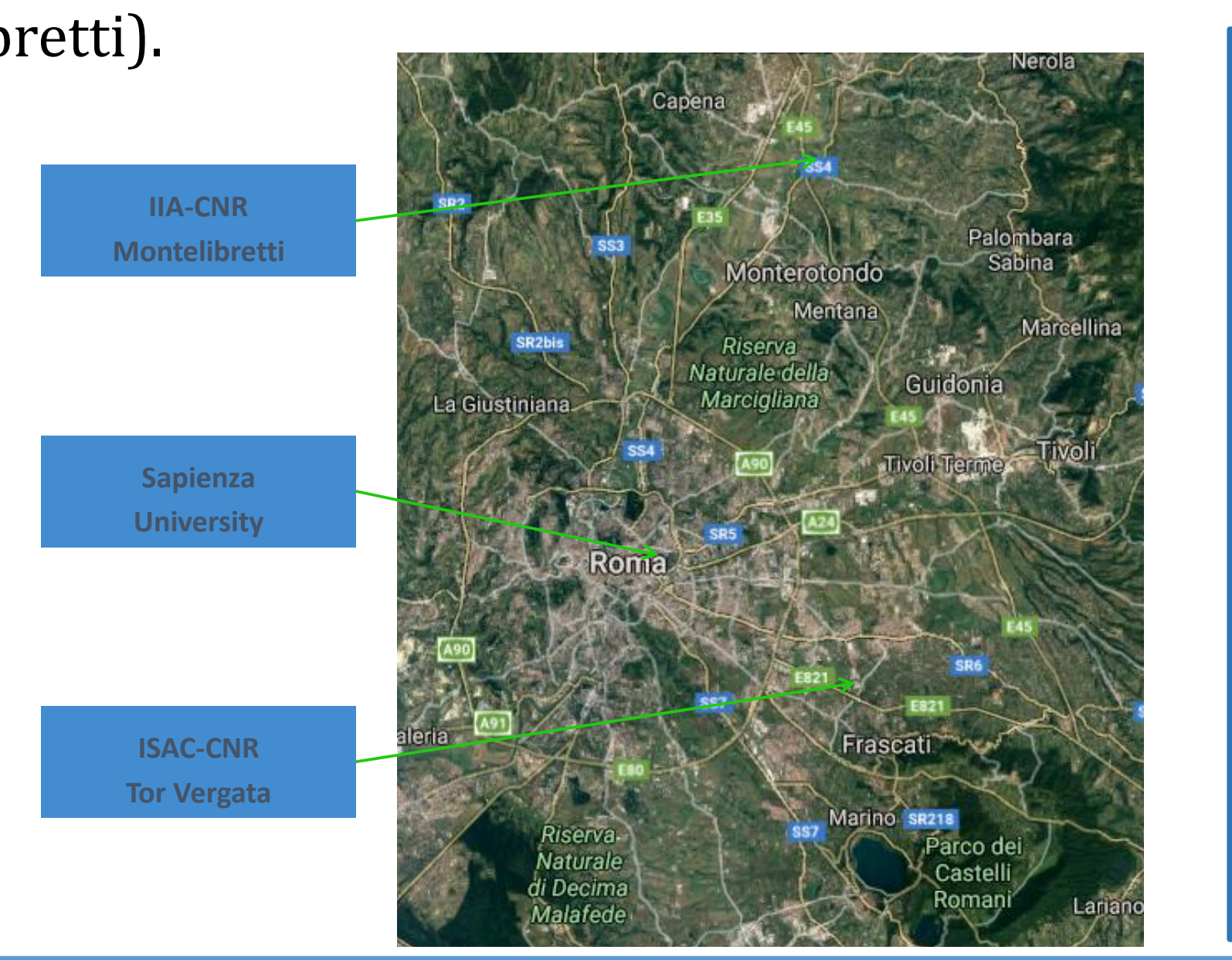
The approach has been tested using the BAQUNIN LIDAR–measurements.This system permits to acquire signal with a temporal and spatial resolutions of 30 seconds and 7.5 meters, respectively (3000 bins for each profiles), using 3 different wavelengths of 355, 532 and 1064 nm. This means that we can obtain top and bottom heights of clouds each 30 seconds instead of 5 or 10 minutes, which is the temporal resolution after the meaning process. The method uses a minimum threshold value of the signal in order to identify the presence of clouds, and the height of the aerosol layer to discern between aerosol and cloud in the lower parts of the atmosphere. Both these parameters are derived from the algorithm, and not imposed a priori.

BAQUNIN

Boundary-layer Air Quality using Network of Instruments Supersite is born in June 2016, thanks to the collaboration with ESA. 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.

https://www.baqunin.eu/



First step

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

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

where S is the acquired signal, B the background noise obtained meaning S over the last 500 bins, r is the altitudes a.s.l. and finally the indices t and z permit to run overtime and altitude.

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

Figure1 shows an axample of the RCS visualization.

Figure 1

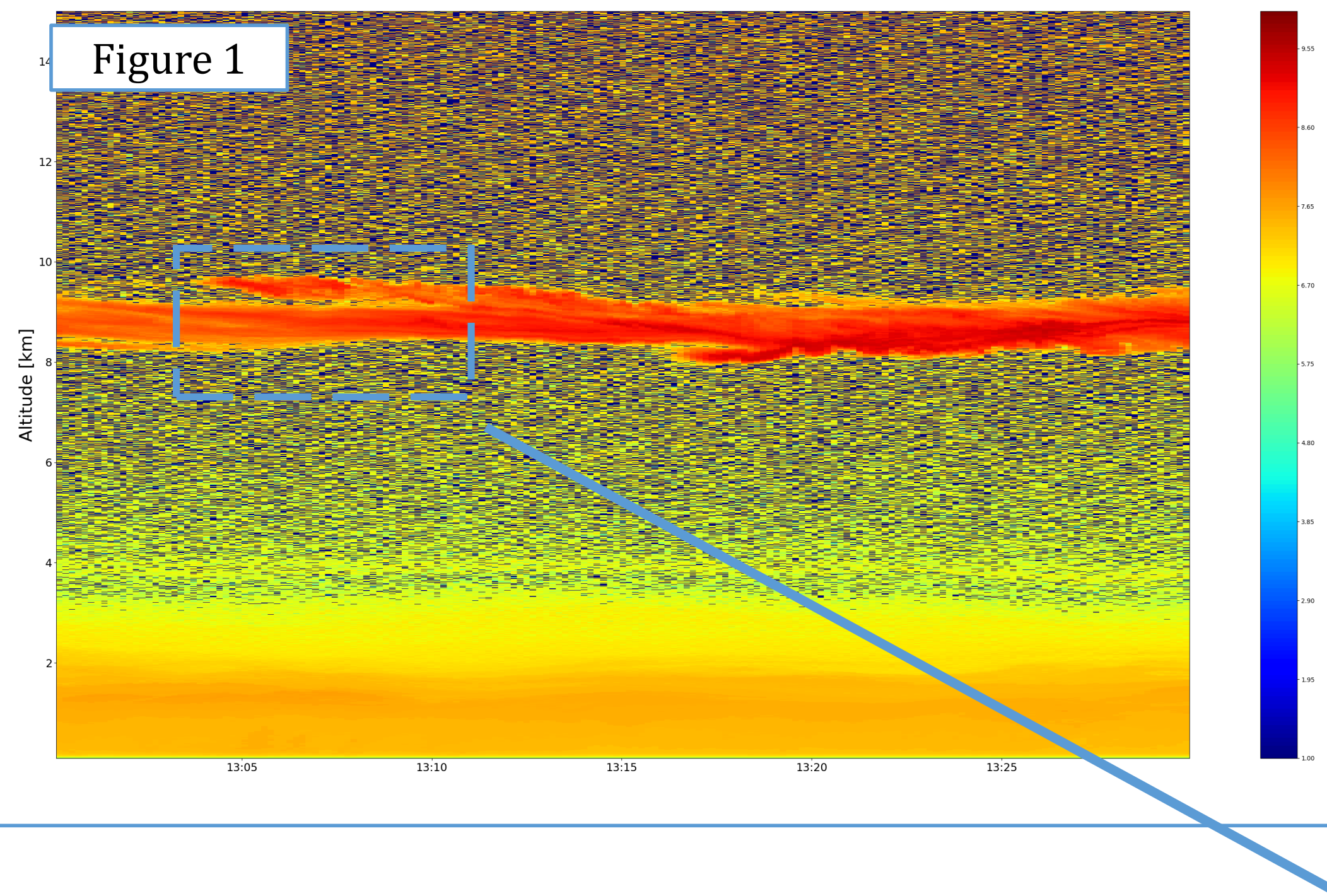
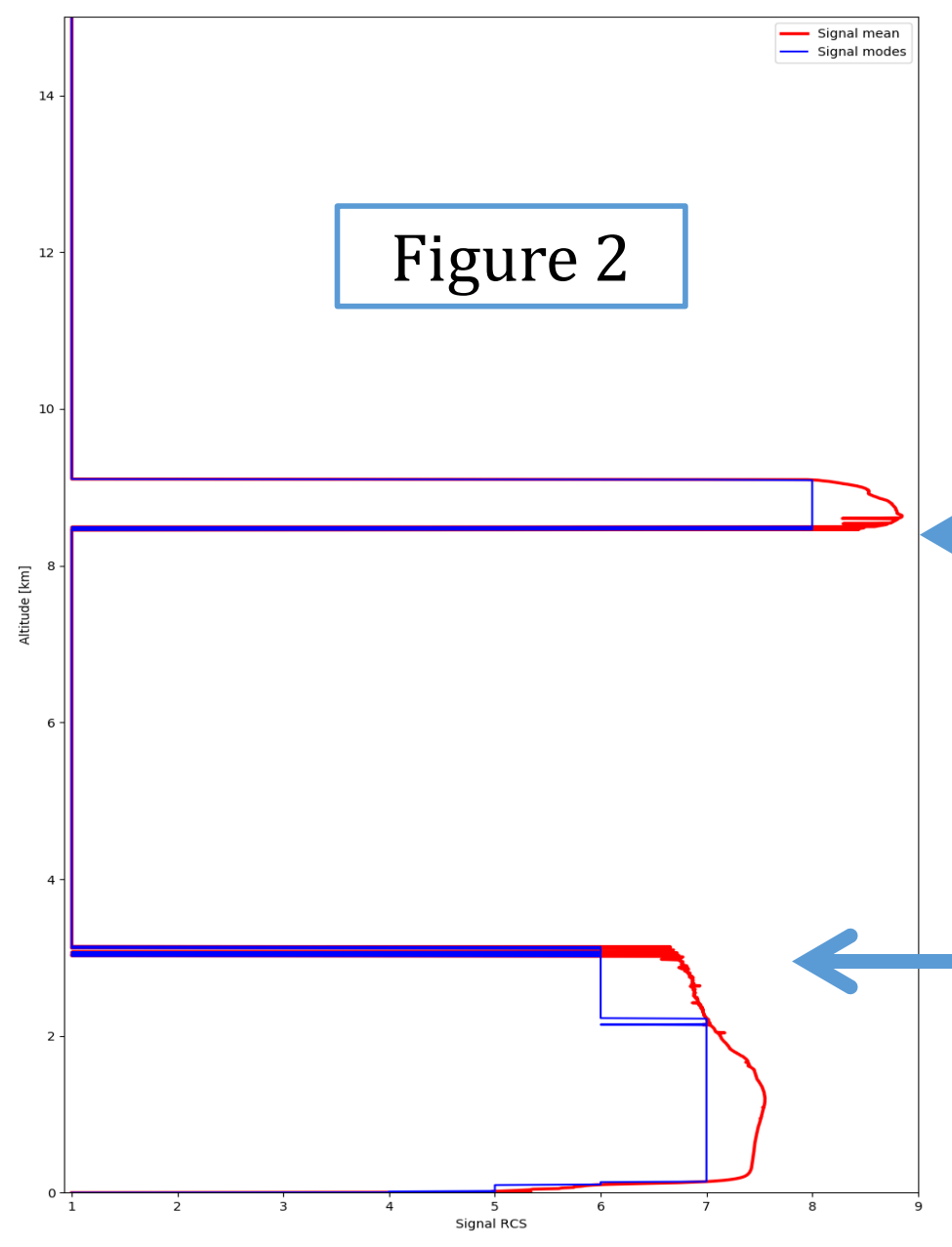


Figure 2



Second step

The identification of the threshold to be used is carried out by looking for the characteristics of the mediated signal. If, during the acquisition, the atmospheric conditions remain constant (height of the aerosol layer does not vary, no aerosol fronts carried by the wind appear) the signal averaged over time Mt(z) is calculated throughout the acquisition; otherwise, different time intervals are considered. Once the average is obtained, the modal trend is computed, in order to highlight the characteristics of the signal: this allows us to identify both the value of the signal at the cloud layer, and the altitude in which the aerosol layer disappears. [Figure2] Threshold used to identify the cloud later correspond to the max value of the identified modes. The aerosol layer top correspond to the height of the main mode.

Third step

the cloud. Considering the RCS as a matrix (Fig.3-A), with altitude and time as dimensions (indices t and z in the equation above). The identified threshold value T_c is applied to the RCS values allows detecting the presence of a cloud layer. RCS values obtained for each acquired profile and altitude could be considered as a two-dimensional matrix M. As first step the elements $M_{ij} > T_c$ of this matrix are labeled as possible cloud elements (Fig.3-B). Then spatial and temporal variations of the RCS are considered: the algorithm excludes from the calculation the elements M_{ij} corresponding to spike values or affected by high noise considering the spatial and temporal variations of the RCS. A labeled element (green elements in Fig.3-C), is confirmed to be a cloud element if the number of its labeled neighbors is above a selected percentage threshold T_{perc} (Fig.3-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 select a grid of 5x5 elements centered on the investigated element. This algorithm is applied to the complete set of LIDAR measurement session, producing a matrix of "labeled" elements. The accuracy of the results depends on the spatial and temporal resolution of the acquired signal, considering the BAQUNIN LIDAR characteristics the best accuracy is 15 m and 20 s.

Figure 3

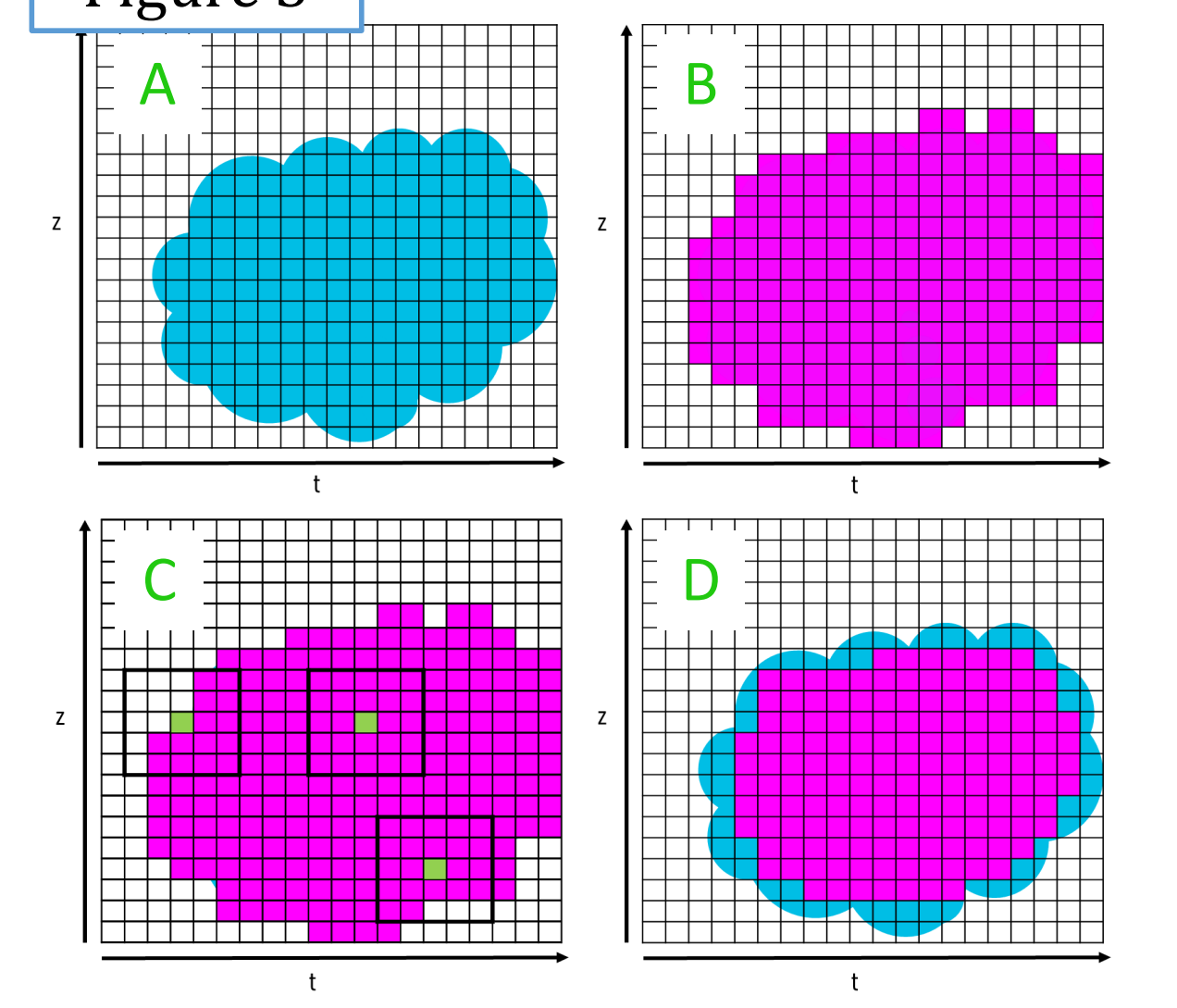
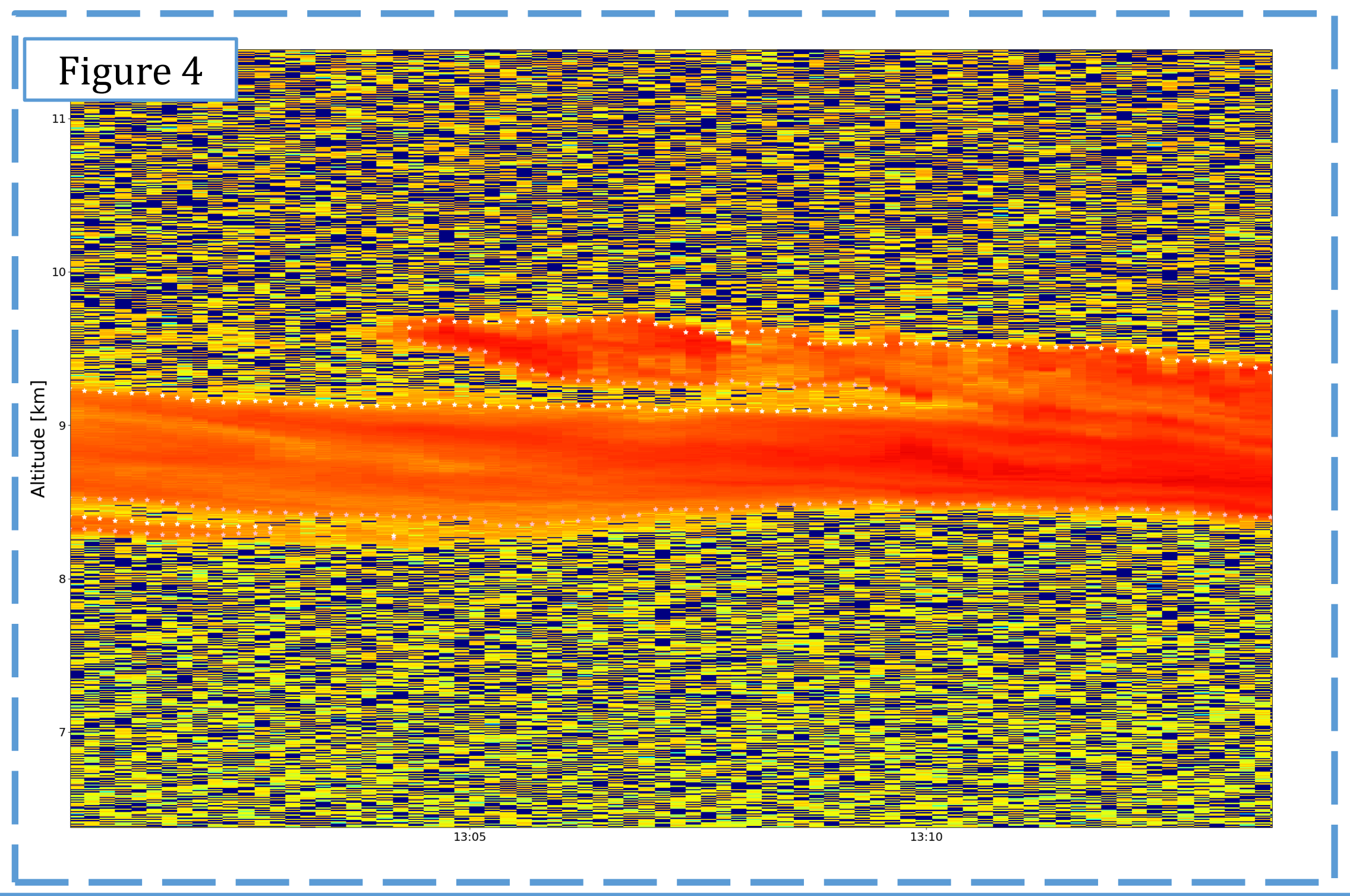


Figure 4



Fourth step

Bottom and top heights of the layers are detected as the altitude of the first and last labeled groups of elements, permitting the more than one cloud in a single profile.

Fig.4 shows the obtained results for the RCS signal in Fig.1: the clouds are well identified, and white dots show top and bottom heights identified. The algorithm permits also an estimation of 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 well estimate 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.

Results

This method was tested for different atmospheric conditions, and the results were compared with those obtained using the standard approach of LIDAR data analysis. This algorithm will be integrated with the LIDAR analysis software permitting to automatized the data analysis.

Some examples for different atmospheric conditions are shown in the following figures. Identified clouds are highlight in blue.

Figures 5, 6 and 7 show results, respectively single cloud, multilayer clouds and thin cloud in the aerosol layer.