The BAQUNIN Super-Site Lidar: Features and Retrieval Algorithms

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PURPOSE

Presenting the LIDAR system employed at BAQUNIN (Boundary-layer Air Quality-analysis Using Network of Instruments) Super site, its features and retrieval algorithms.

BAQUNIN SUPERSITE

BAQUNIN Super-Site includes ground based active and passive remote sensing instruments operating in synergy, offering quantitative and qualitative information
for a wide range of atmospheric parameters for atmospheric chemistry (satellite) validation activities and Planetary Boundary Layer (PBL) studies. The instruments are located in three different sites: an urban component, at the Physics Department of Sapienza University, a sub-urban and a rural component located at CNR-ISAC and CNR-IIA, respectively. The LIDAR system is an integral part of BAQUNIN instrumental suite. It is located at the BAQUNIN urban component (Lat 41.902, Lon 12.516, 75 m a.s.l.), in the centre of Rome, Italy, together with many other atmospheric remote sensing devices (**Fig 1**).

Fig 1

MAIN PRODUCTS AND ALGORITHMS

LIDAR data retrieval software has been developed by BAQUNIN personnel; two algorithms are adopted for backscattering and extinction retrieval: the iterative method described in Di Girolamo et al., 1999, to calculate the backscattering coefficient profile at 1064 and 532 nm, while the UV backscattering coefficient is calculated applying the algorithm described in Ansmann et al., 1992, using the ratio between elastic 355 nm signal and the RAMAN 386 nm profiles.

When the BAQUNIN sun-photometers measurements of aerosol optical depth (AOD) are available (clear sky and daytime), the quality of the aerosol retrieval can be improved constraining the lidar AOD values to the AOD measured by the sun-photometers (CIMEL, POM and MFRSR). In the AOD calculation the backscattering coefficient value is extrapolated to the ground from the value at the overlap altitude. The synergy between photometers and lidar measurements allows the estimation of aerosol Lidar Ratio (LR) using an iterative algorithm. **Fig. 4 to 7** on the right panels show a measurement collected at 27/09/2019 in which the CIMEL AOD have been used to estimate the aerosol LR. **Fig. 4** shows a 5 minutes integrated signal and uncertainty at 532 nm. **Fig. 5** shows the AOD estimated using an a-priori LR value of 50 and the CIMEL (Giles et al., 2019) AOD respectively; the yellow dots represent the contribute of the layer below the overlap altitude to the lidar AOD. The backscattering coefficient retrieved with its uncertainty contributes is displayed in **Fig. 6**. In **Fig. 7** the LR values retrieved combining lidar and CIMEL measurements are represented with their uncertainty: LR greatly differs from the a-priori value of 50 at 11:00 and 12:10 Ut, corresponding to the larger difference between the Fig. 5 timeseries. **Fig. 8** shows the extinction coefficient profiles retrieved at 11:00 Ut using the a-priori LR and the LR retrieved using the CIMEL AOD.
The synergy between LIDAR measurements and sun-photometers during clear sky and daytime allows the retrieval of aerosol LR, in order to provide a more accurate estimation of the aerosol extinction coefficient. During the same day the LR can change more than about 100%, for this reason the use of fixed value of LR introduces larger systematic errors to the values of extinction and backscattering coefficients. Moreover, the time evolution of LR can be used to study the daytime changing of the aerosol behavior in the boundary layer.

The **Water Vapor Mixing Ratio** is retrieved through the ratio of Raman signals at 407 and 387 nm. System calibration constant is obtained by the comparison with the values measured in the free atmosphere by closest in time and distance radiosounding (Pratica di Mare, 41.65 lat, 12,43 lon). A result obtained with this procedure is shown in **Fig. 9**.

Top and bottom altitudes of cloud layers are retrieved by an image analysis software. **Fig. 10 and 11** display examples of signal collected in term of counts number as function of time and altitude on which the cloud layers have been identified (highlighted in blue in the pictures). If the signal is not completely absorbed by a lower cloud layer, the algorithm is able to retrieve multiple clouds (Fig 11).

We are actually working on the development of the **aerosol depolarization** retrieval.

Quality assurance procedures adopted to characterize LIDAR performances and errors follow the indications for the EARLINET LIDARs (Freudenthaler et al., 2018).

CONCLUSIONS

BAQUNIN LIDAR is an integral part of the instrumental suite composing supersite. The use of custom-made components allows the BAQUNIN personnel to constantly developed and improved the system, adapting it to measurement needing. LIDAR retrieval software is also constantly updated, allowing to directly control each analysis step.
Presently the BAQUNIN LIDAR system, in synergy to the other BAQUNIN equipment, is involved in the CAL/VAL SENTINEL 5P activity and in the DIVA project.
The instrument is also used for the study of Urban Boundary Layer (UBL), in particular to retrieve the evolution of aerosol loading and humidity, the height of Mixing Layer as well as the interaction between UBL and Free Atmosphere.

LIDAR FEATURES

BAQUNIN LIDAR has been designed and assembled using both custom-made and commercial equipment (**Fig. 2**). Laser source, sensors, electronics and optics are commercial items, while frames and opto-mechanics were designed and built in the mechanical workshop of the Physics Department. The controlling software has been developed by the laboratory personnel. This modular approach allows a regular upgrading of each component and gives the possibility to add to the basic instrument new acquisition channels, in order to improve the system performance. Presently the system includes a large power pulsed laser, emitting 3 wavelengths, 4 receivers and 12 acquisition channels. LIDAR can be operative in no-rain day and night conditions. **Table 1** summarize the LIDAR general features. A **Quanta Ray Pro-290-30 laser** produces pulses at three wavelengths, 1064, 532 and 355 nm, all emitted along the same beam path. The 355nm-beam is separated from the others by a Harmonic Separator (HS) beam splitter before leaving the laser. **Table 2** displays laser features and **Fig. 3** shows a scheme of the laser beams emission. The 1064nm and 532nm beams are then separated by another HS outside the head. The three beams are directed to the vertical direction by adjustable mirrors and prisms. For safety reason and to prevent that laser light leakages could be picked up by the receivers, the beams travel inside black enclosures throughout the path from the laser head to the hatch in the roof. The lidar signals are collected by **four receivers** whose characteristics are described in **Table 3.** The **acquisition system** is based on 6 **Transient Recorders TR20@LICEL**. Each TR20 is equipped with an ADC as well as a Photon counter. Altogether 12 channels are available for the signals acquisition. The analogic channels are dedicated to the acquisition of the stronger elastic backscatter signals, while the photon counting is the method to digitalize the weak Raman backscattering from atmospheric water vapour and molecular nitrogen.

Fig 3

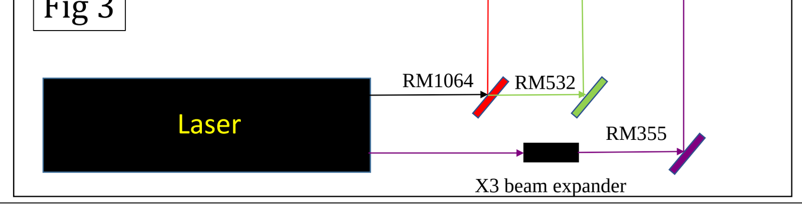


Table 1

Position (lat., lon., alt.)	41.90°N, 12.52°E, 75 m a.s.l.
Max Vertical Resolution	7.5 m
Max Time Resolution	10 s
Max Vertical Range	30000 m a.s.l.
Min Overlap Height (Elastic)	150 m a.s.l.
Min Overlap Height (Raman)	1000 m a.s.l.
Emitted wavelenghts	355, 532,1064 nm
Received wavelengths	
Elastic backscattering	355±1.5 nm
	532±0.18 nm
	1064±1.07 nm
N2 Raman Backscattering	386±0.31 nm
H2O Raman Backscattering	407±0.25 nm

Fig 2

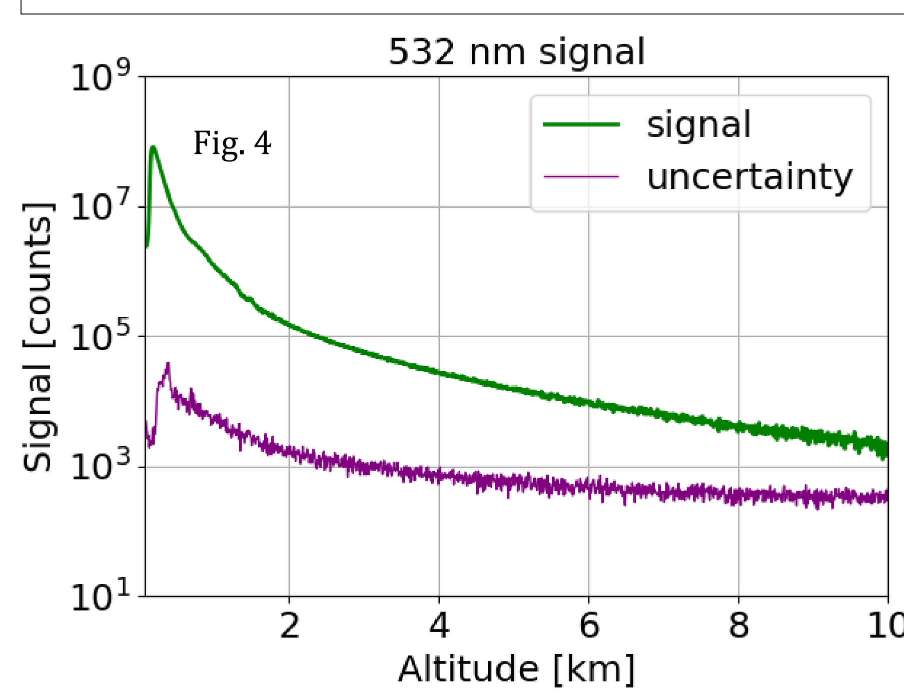
Table 2

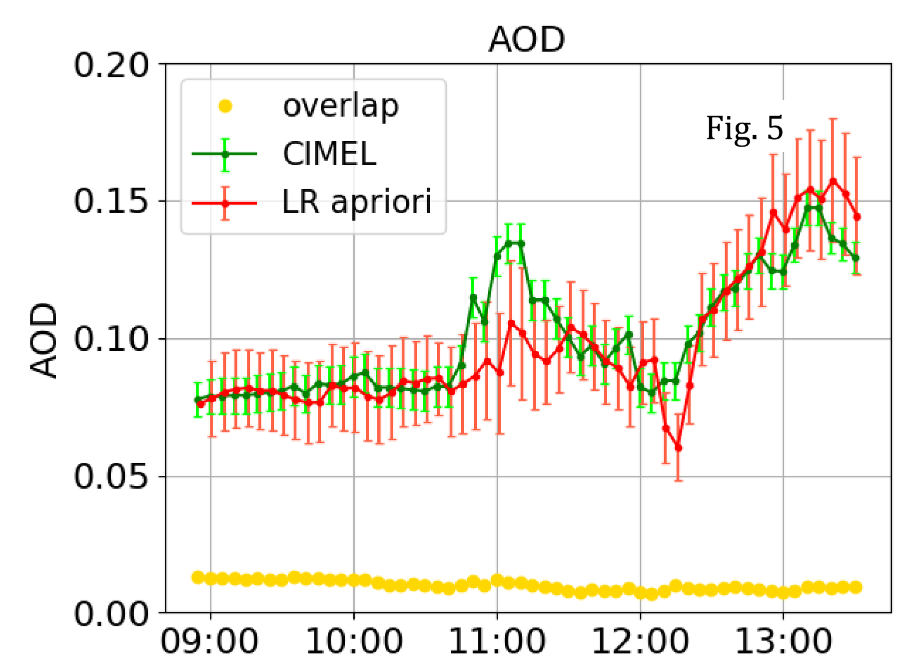
Wavelength [nm]	355	532	1064
Repetition frequency [Hz]	30	30	30
Pulses Energy [mJ]	800	375	1600
Beam divergencies [mrad]	0,15	0,5	0,5

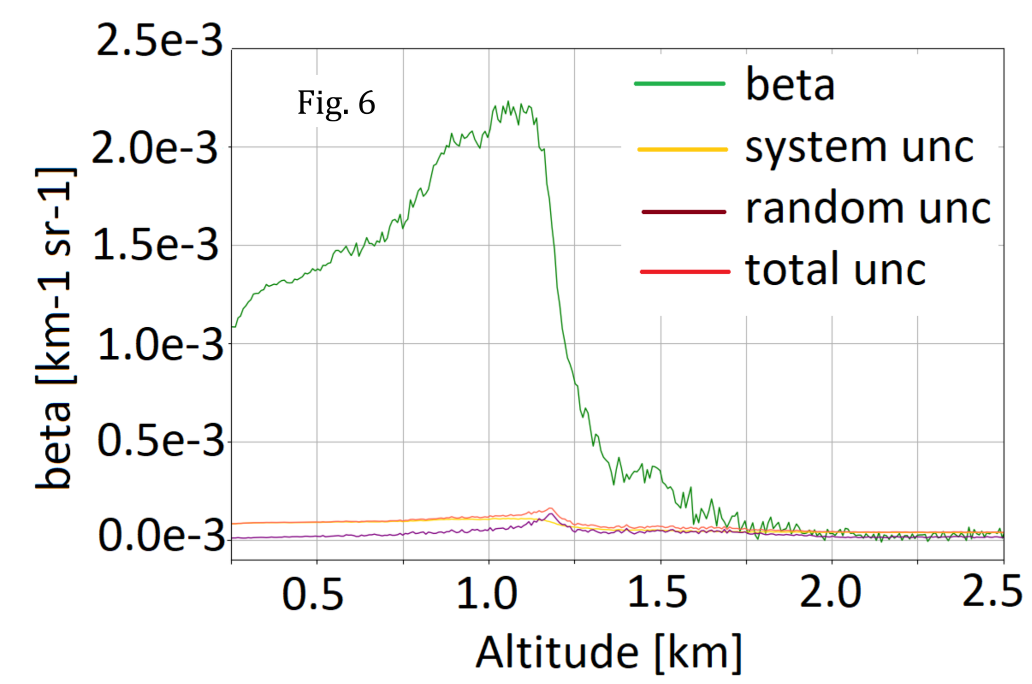
Table 3

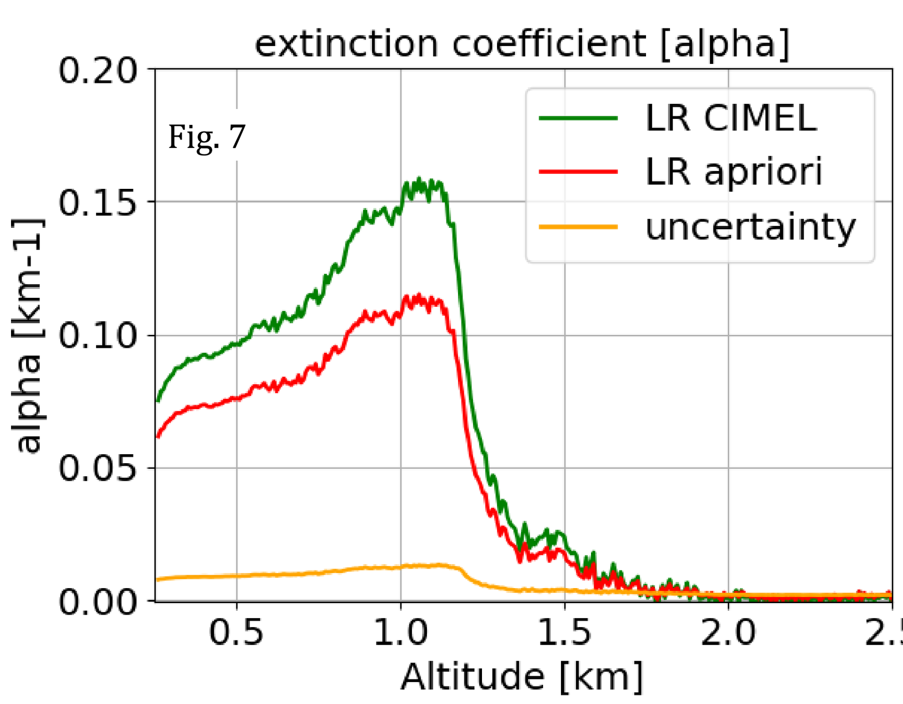
Receiver	Configuration	Primary lens/ mirror	Overlap altitude [m a.s.l.]	Signals collected and polarization
1	Cassegrain	500 mm	5000	355 nm total, 386 nm N2 RAMAN total, 407 nm H2O RAMAN total
2	Cassegrain	100 mm	750	Far range, 532 nm total and parallel
3	Cassegrain	100 mm	300	1064 nm total
4	Refractive	50 mm	220	Short range, 532 nm total

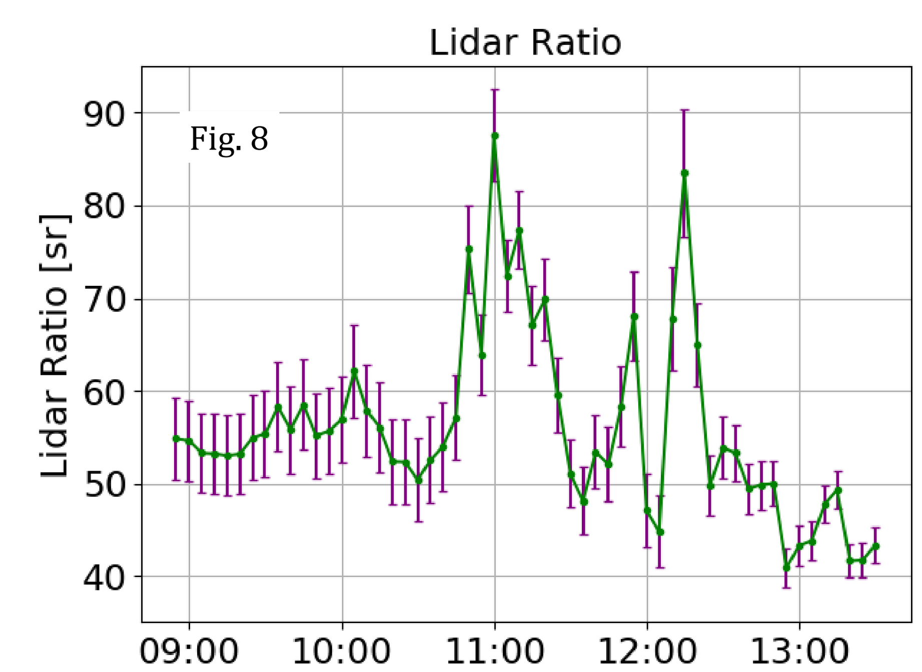
AOD AND WATER VAPOR ALGORITHMS

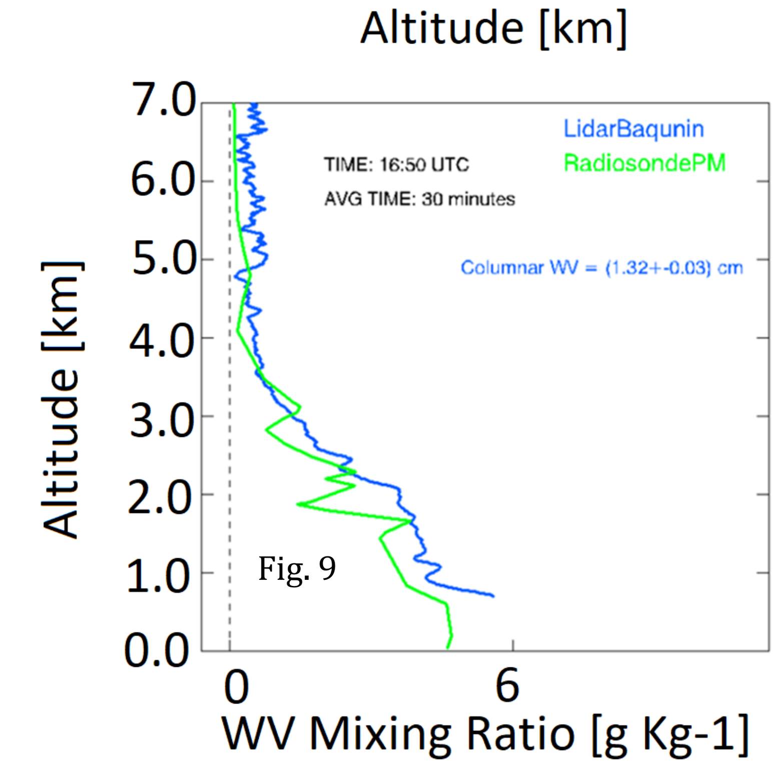




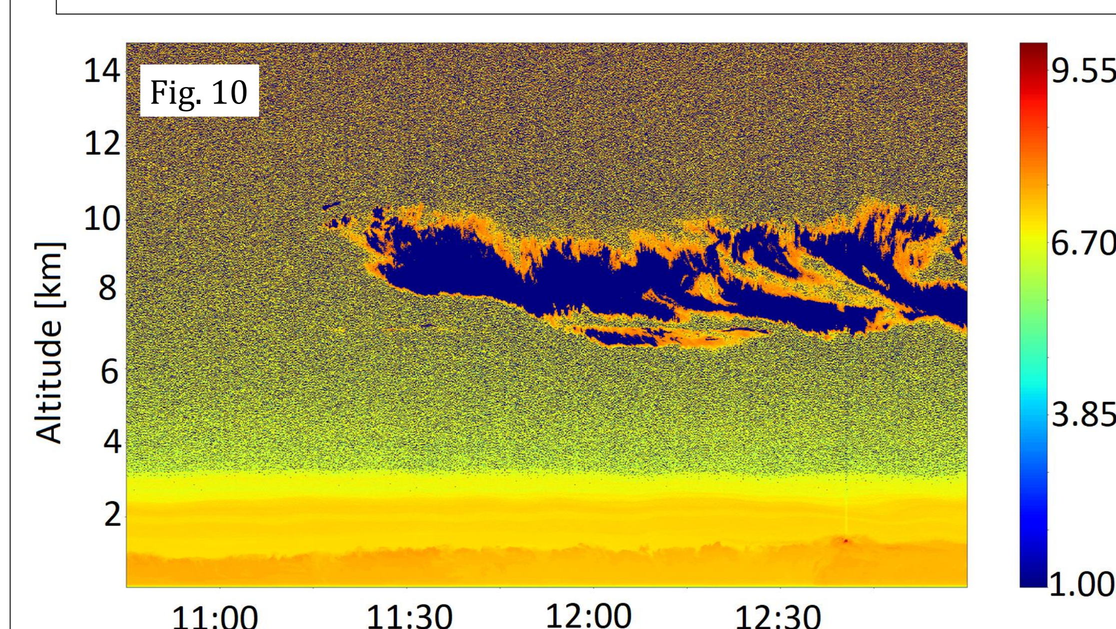


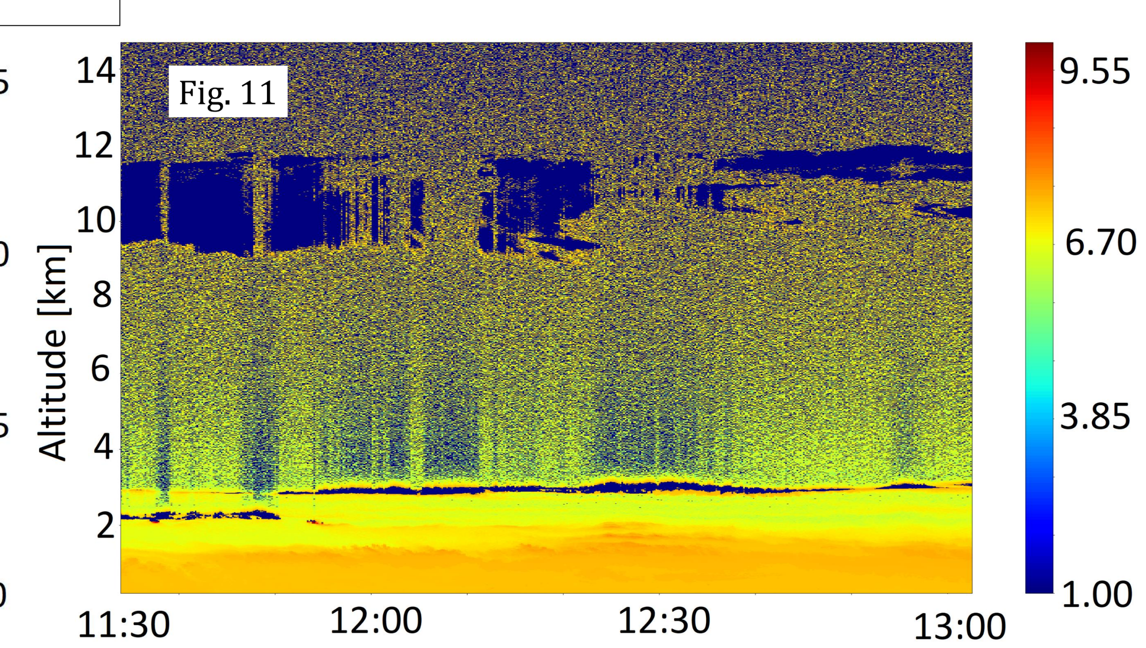






CLOUD DETECTION ALGORITHM





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