EPJ Web of Conferences **119**, 07002 (2016) DOI: 10.1051/epjconf/201611907002
ILRC 27

SIGNAL TO NOISE RATIO ESTIMATIONS FOR A VOLCANIC ASH DETECTION LIDAR. CASE STUDY: THE MET OFFICE.

George Georgoussis [1], Mariana Adam[2], George Avdikos[1*]

[1]*Raymetrics S.A., Spartis 32,Metamorfosis, Greece *Email: gavdikos@raymetrics.gr*

[2]*Observations, Met Office, Exeter, Devon EX1 3PB, United Kingdom*

ABSTRACT

In this paper we calculate the Signal-to-Noise (*SNR*) ratio of a 3-channel commercial (Raymetics) volcanic ash detection system, (LR111-D300), already operating under Met Office organization. The methodology for the accurate estimation is presented for day and nighttime conditions. The results show that *SNR* values are higher than 10 for ranges up to 13 km for both nighttime and daytime conditions. This is a quite good result compared with other values presented in bibliography and proves that such system is able to detect volcanic ash over a range of 20 km.

1. INTRODUCTION

The Eyjafjallajokull eruption started on 20 March 2010, for almost 30 days resulted in large amounts of volcanic ash being injected into the atmosphere [1]. This event strongly affected the European and global air transport industry since volcanic ash (VA) plumes were subjected to long-range transport and carried over large areas in Central Europe due to strong westerly winds. Although volcanic ash is composed of materials with very small dimensions, the damages it may cause can be significant because, after expelled in the atmosphere to a very high altitude (kilometers), it is scattered and usually falls on large surfaces. In all cases, volcanic ash at high altitudes in the atmosphere can pose a serious hazard to aircraft engines [2]. VA has a highly corrosive effect, primarily on gas turbines of the aircrafts as they get temporarily or definitively blocked after aspirating the dust, which melts at high temperatures inside the combustion chamber, and then cools down and solidifies on the cooler parts of the engine. Such a situation can cause sudden and permanent engine failure. VA poses a hazard also to gas turbine blades and causes friction scratches on the windshield, resulting in poor visibility [3]. Monitoring and detecting VA particles remains a difficult task since aerosol particles are highly inhomogeneous and vary in time and space. Consequently, aerosol observations and measurements have to be global, continuous and systematic. Ground-based aerosol remote sensing instruments such as lidar can contribute significantly to the understanding of aerosols properties and potential associated impacts, thanks to their distribution. Among lidar systems, those which have the capability of detecting aerosols' type (depolarization lidar systems) are appropriate for detecting and distinguishing volcanic ash [4]. In several European countries, meteorological agencies decided to develop lidar networks (e.g. Met Office) in order to support decision-making in the case of volcanic ash events. In our paper we aim to show that automatic, depolarization lidar systems with routine operation can be a quite powerful tool for detecting volcanic over a range of 20 km or more. The paper is structured as follows: Sect. 2 is dedicated to the description of the Raymetrics lidar system and to the methodology for the estimation of *SNR* values including the error propagation. In Sect. 3 we present the results of the *SNR* analysis for both nighttime and daytime conditions. In the last section, we conclude with the most important results arising from the *SNR* values.

2. METHODOLOGY

The Met Office lidar network consists of two Raymetrics depolarization Raman lidars, located in Camborne. In the near future, 8 new systems will be dispersed at several locations over UK and operate as a lidar network of 10 systems. For more information please see Adam et al. [5]. The Raymetrics lidar system is a portable, 3-channel (355p, 355s and 387nm) *eye-safe depolarization Raman lidar system* suitable for detection of any volcanic ash, fully automated including a lot of sensors, electronics sub-systems and interlocks (which block the operation at emergency situations). It can work 24 h per day outdoors in an unattended mode under almost any weather conditions (Fig. 1). A pulsed laser beam at 355 nm is emitted into the atmosphere. The energy per emitted pulse is 53 mJ, while the pulse duration is ~ 10 ns. A beam expander is used at the emission unit in order to expand the laser beam by a factor of 7, so that the eye safety is completely fulfilled. The repetition rate is 20 Hz. The backscattered radiation is collected by a Cassegrain telescope of 300mm in diameter and having an f-number of 5 (focal length f = 1500 mm). The collected radiation is spectrally analyzed (using beam splitters), filtered (using narrow band interference filters) and focused on photomultiplier tubes (PMTs) which are used to detect the received lidar signals in the analog and the photon counting mode. The corresponding raw signal spatial resolution is 7.50 m. For this study the raw temporal resolution of the retrieved aerosol profiles was set at 1 min, while the spatial resolution was 15 m. The full overlap of the instrument is achieved for altitudes higher than ~250m.

The basis of the methodology for the *SNR* estimation is similar to that described in [6]. At instrumental level, data processing includes correction such as background sky irradiance, which is measured by averaging lidar signal at high altitude range (above 49 km). Finally, lidar profiles within 10 min were accumulated and signal-to-noise ratio is estimated according to the procedure that follows.

For *N* laser shots, the counts per bin number

$$C'^{n}_{m} = \sum_{n=0}^{Nshots} C^{n}_{m} \quad \text{m} \tag{1}$$

(m memory bin from 0 to 8000). In case that we have a resolution of 15 meters it is like sampling every 10 MHz, so

$$M^{n}_{m}(Hz) = \frac{10*10^{6}*C^{n}_{m}}{Nshots} \Rightarrow M^{n}_{m}(MHz) = \frac{10*\sum_{n=0}^{Nshots} C^{n}_{m}}{Nshots} \tag{2}$$

Thus, if we want convert back to Counts per bin (which is the sum of counts for *Nshots*) we simply reverse the above equation:

$$C'^{n}_{m} = \frac{Nshots * M^{n}_{m}(MHz)}{10} \tag{3}$$

Figure 1. Raymetrics volcanic ash detection system installed and operated by Met Office

If we assume that an electronic system can average 12000 shots (e.g. 10min data at 20Hz) then we should get

$$M^{n}_{m} = \frac{10*C'^{n}_{m}}{12000} = \frac{10*\sum_{n=1}^{12000} C^{n}_{m}}{12000} \tag{4}$$

In that case, if we like to go back to Counts we should get

$$C'^{n}_{m} = \frac{12000*M^{n}_{m}}{10} \tag{5}$$

During nighttime, the background for photon counting is almost zero such that it can be neglected. However, in case there is some noise (e.g. during daytime) we proceed as following

$$C'^{n}_{m} \equiv C_{total} = C_{sig} + C_{bg} \Rightarrow C_{sig} = C_{total} - C_{bg} \tag{6}$$

From error propagation law, we obtain:

$$\Delta C_{sig} = \sqrt{(\Delta C_{total})^{2} + (\Delta C_{bg})^{2}} \tag{7}$$

leading to

$$SNR = \frac{C_{sig}}{\Delta C_{sig}} = \frac{C_{sig}}{\sqrt{(\Delta C_{total})^{2} + (\Delta C_{bg})^{2}}} \tag{8}$$

For photon counting the signal noise follows the Poisson statistics. The error of a counting rate is equal to its square-root. Hence, we get:

$\Delta C = \sqrt{C}$ and then $\Delta C_{total} = \sqrt{C_{total}} \Rightarrow$

DOI: 10.1051/epjconf/201611907002

$(\Delta C_{total})^2 = C_{total}$ and similar $(\Delta C_{bg})^2 = C_{bg}$

Finally,

$$SNR = \frac{C_{sig}}{\Delta C_{sig}} =$$

$$\frac{C_{sig}}{\sqrt{(\Delta C_{total})^2 + (\Delta C_{bg})^2}} = \frac{C_{sig}}{\sqrt{C_{sig} + 2C_{bg}}} \quad (9)$$

3. RESULTS

In this section we present the results of the methodology previously described. The analysis involves data processing for both daytime (noisy) and nighttime (noiseless) conditions, depicted in Figs 2 and 3 respectively. First, we processed the data for daytime conditions. To do this, we averaged 10 profiles, each one corresponding to 1 minute data. In all cases, the alignment was checked by fitting with molecular atmosphere. The Range Corrected Signal (*RCS*) for 355-parallel channel (analog mode) during daytime is depicted at Fig. 2 (upper plot). In order to carry out a more accurate analysis, we performed gluing analysis (by plotting photon counting versus analog signal with background correction in order to convert the analog to photon counting) (Fig. 2, middle plot). Finally, the *SNR* values were calculated by using equation (9) from the previous section (Fig. 2, bottom plot).

The black curve corresponds to 355-parallel signal (glued signal) whilst the red curve to 355-perpendicular signal (glued signal). As it can be easily seen, the *SNR* is equal to 10 at about 11.5 km for the 355-perpendiclur signal and 13 km for the parallel signal, which is a quite good result as compared with other references [6]. For comparison reasons, we made the same analysis for nighttime conditions (Fig. 3). The value of *SNR* of 10 was found to be at ~ 17.8 km and 18.7 km for parallel and perpendicular channel respectively. The green curve (Figure 3, bottom plot) corresponds to *SNR* values for the Raman channel (387 nm).

4. CONCLUSIONS

By processing daytime and nighttime routine lidar measurements, calculation for the Signal-to-Noise Ratio was feasible. According to our analysis, the

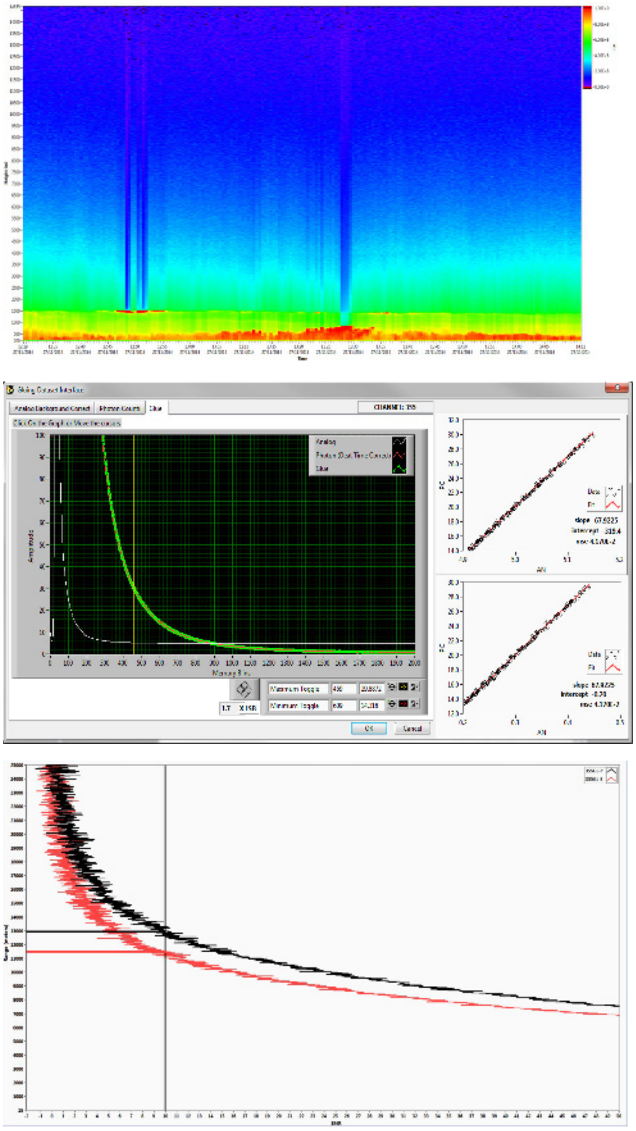

Figure 2. Daytime conditions (27/11/2014): *RCS* for 355nm (Analog) (top). GUI interface of Gluing procedure for 355-parallel signal (middle). *SNR* values versus range (bottom).

SNR can reach the value of 10 at the range of 11.5 km and 13.0 km for both 355 nm channels leading to a very promising result. We showed that the system is capable of detecting volcanic ash (VA) aerosols for ranges up to 20 km or more. A network of 10 lidar systems across UK could provide very useful information in case that an event similar to that of 2010 takes place.

ACKNOWLEDGEMENT

The authors would like to thank Met Office for giving us the permission to use the system picture and for providing the data for processing.

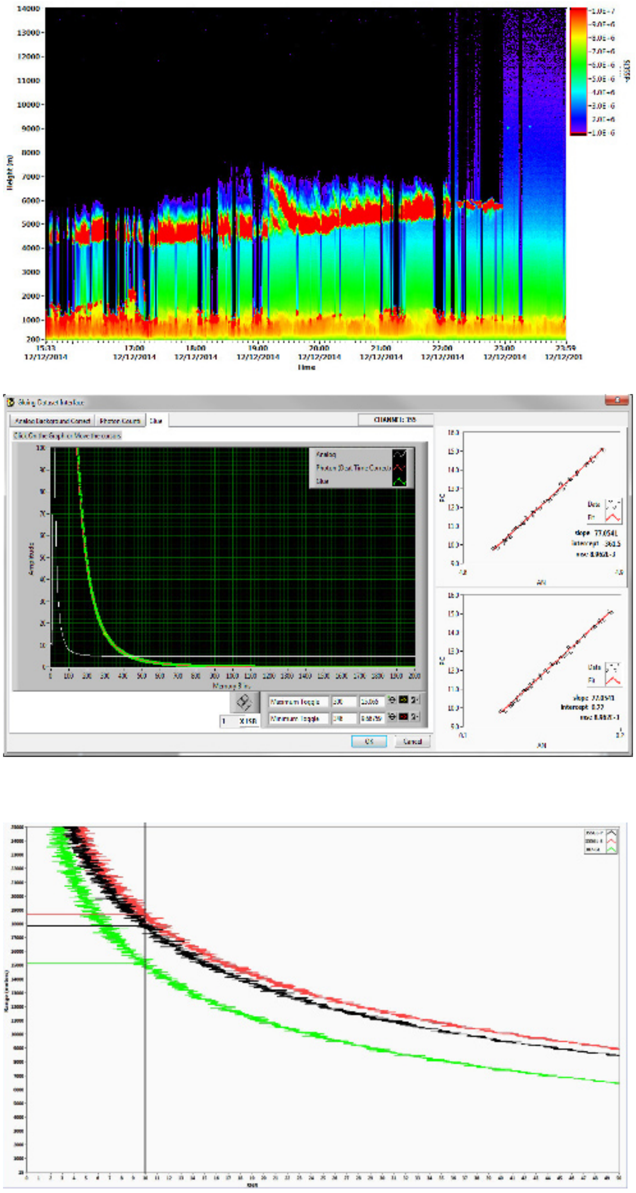

Figure 3. Nighttime conditions (12/12/2014): *RCS* for 355nm (Analog) (top). GUI interface of Gluing procedure for 355-parallel signal (middle). *SNR* values versus range (bottom).

REFERENCES

[1] Sigmundsson, F., Hreinsdottir, S., Hooper, A., Arnadottir, T., Pedersen, R., Roberts, M. J., O'skarsson, N., Auriac, A., Decriem, J., Einarsson, P., Geirsson, H.,Hensch, M., O´ feigsson, B. G., Sturkell, E., Sveinbjornsson, H., and Feigl, K. L. 2010: Intrusion triggering of the 2010 Eyjafjallajokull explosive eruption, *Nature*, **468**, 426–430.

[2] A. Mortier, P. Goloub, T. Podvin, C. Deroo, A. Chaikovsky, N. Ajtai, L. Blarel, D. Tanre1, and Y. Derimian 2013: Detection and characterization of volcanic ash plumes over Lille during the Eyjafjallajokull eruption, *Atmos. Chem. Phys*., **13,** 3705–3720.

[3] Ajtai, N., Stefanie, H., Stoian, L. C., and Oprea, M. G.: The volcanic ash and its impact on European air transport industry 2010: A case study on the detection and impact of the the Eyjafjallajokull volcanic ash plume over North-Western Europe between 14 and 21 April 2010, *AES Bioflux,* **2**, 57–68.

[4] Muller, D., Ansmann, A., Mattis, I., Tesche, M., Wandinger, U., Althausen, D., and Pisani, G. 2007: Aerosol-type-dependent lidar ratios observed with Raman lidar, *J. Geophys. Res*., **112**, D16202, 1-11.

[5] Adam, M. et al. 2015: From operational ceilometer network to operational lidar network, *27 ILRC* – Coordinated lidar networks and applications.

[6] B. Heese, H. Flentje, D. Althausen, A. Ansmann, and S. Frey 2010: Ceilometer lidar comparison: backscatter coefficient retrieval and signal-to-noise ratio determination, *Atmos. Meas. Tech*., **3**, 1763–1770.