Eyjafjallajökull volcano ash plume operational monitoring all over Europe with ground based and airborne mounted Lidars

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1. Introduction

Volcanic emissions comprising steam, ash, and various gases are injected into the atmosphere and produce effects affecting Earth's climate. Volcanic ash is composed of non-spherical mineral particles spanning a large size range. The largest ones are likely to sediment quickly not far from the eruption site. The ash component, and sulphate particles formed by subsequent oxidation of the SO_2 emission, pose a variety of hazards to humans and machinery on the ground, as well as damage to aircraft that fly inadvertently through ash plumes [1]. To mitigate such hazards, a network of nine backscattering ALS Lidars, produced by LEOSPHERE, provided plots of range corrected backscatter signal hourly to different agencies, and to VAAC coordinated by UK Met Office. The network, together with airborne mounted Lidar test flights, offered a fundamental support to the different civil aviation agencies in making decisions regarding flight safety. Recent determination of the extinction to mass conversion factor by optical modelling of ash cloud data allows estimating plume mass density from the Lidar measurements.

2. Presentation of the instrument

ALS Lidar is a ground-based optical remote sensing instrument designed to determine the vertical and horizontal properties of the atmosphere. The physical principle is the same as for radar: a short pulse of laser light is transmitted to the atmosphere. As the pulse travels along, part of it is scattered by molecules, anthropogenic particles, water droplets, or other objects in the atmosphere. The greater the scatterers are in number or size, the greater the light fraction scattered. A small portion of the scattered light is directed backwards, collected by the telescope, and detected. Signal recording ion at 10 ns time resolution allows to resolve scatter distance at 1.5 m according to the pulse travel time, creating a range profile for each light pulse. A larger aerosol surface density appears as an increase or spike in the backscattered signal profile. Moreover, the depolarization detection channel provides particle shape information discriminating spherical droplets from other scatterers such as mineral dust or ice crystals [4].

The ALS Lidar uses a tripled pulse laser source ND:YAG at 355 nm wavelength with a pulse energy of 12mJ emitted during 7ns and repetition frequency of 20 Hz. Both analog and photon counting detection schemes are available. The Lidar system provides a real time measurement of backscattering and extinction coefficients, Atmospheric Optical Depth (AOD), automatic detection of the Planetary Boundary Layer (PBL) height, depolarization ratio, and clouds base and top height from 50 m up to 20 km. Table 1 summarizes the instrument characteristics.

Table 1 ALS Lidar Technical Specifications

PERFORMANCES	ALS_{300}	ALS_{450}
Range min (without overlap corection)	0.15 to 12 km	0.4 to 20 km
Accumulation time	30s	30s
Vertical resolution	1.5/15m	1.5/15m
Options	3D Scanning, cross-polarisation, Nitrogen Raman auto-calibration	
ELECTRICAL	ALS_{300} / ALS_{450}	
Power supply	100/240V AC 50-60 Hz	
Power consumption	750 W max with heaters	
ENVIRONMENTAL		
Temperature range	-35°C to 40°C (with heat condionning option)	
Humidity	0-100% (IP65)	
OPTICS, ELECTRICAL AND MECHANICS		
Laser type	Nd-Yag solid state	
Eye-safety compliance	EN60825-1 / ANSI-Z136.1-2007	
Emitted Wavelength	355nm	
Output Pulse Energy	12mJ	
Pulse repetition Rate	20 Hz	
Scanning Range	Horizontal: 0°-178° with 6°/second Vertical: 0°-89,9° with 6°/second	
Angular Accuracy	1°/10°	
Casing Certification	Three levels : IP40 to IP65	
WEIGHT / DIMENSIONS (FOR BASIC CASING)		
Optical Head	16 kg / 700*160*200mm	
Electronics	20 kg / 480*500*300mm	
DATA		
Data Format	ASCII/HDF/BINARY	
Data transfert	Ethernet or GSM/GPRS	

3. Operational Lidar Data Network

The volcanic eruption started on 14 April 2010 at 3:00 UTC. The Moderate Resolution Imaging Spectroradiometer (MODIS) satellite picture clearly visualizes the signature of ash plume following the global circulation and propagating eastward on 15 April, 11.39 UTC (Figure 1)

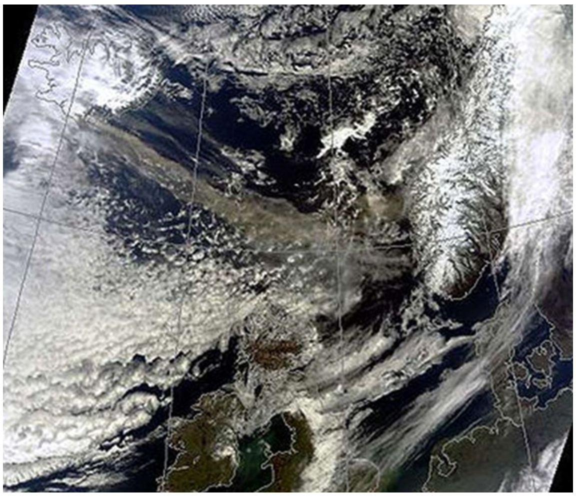

Figure 1. MODIS satellite 15 April 2010 11:39 UTC. The ash plume is clearly visible, moving eastward from Iceland up to northern Scotland

From 16 April to 1 May 2010 nine ALS Lidars operated continuously from north of Denmark to south of France. Due to the strong depolarization, the ash plume was detected in the depolarization channel in most cases.

Quick-looks of the range corrected backscatter signal were provided in real time to the Volcanic Ash Advisory Centers (VAAC) coordinated by UK Met Office

The station situated at Orsay (48.8N 2.2E), detected a thick depolarizing layer from 17 April until 21 April (Fig. 2). The ALS Lidar situated in Cabauw (51.9N, 4.9E), The Netherlands, revealed a strong aerosol layer on 18 April (Fig. 3).

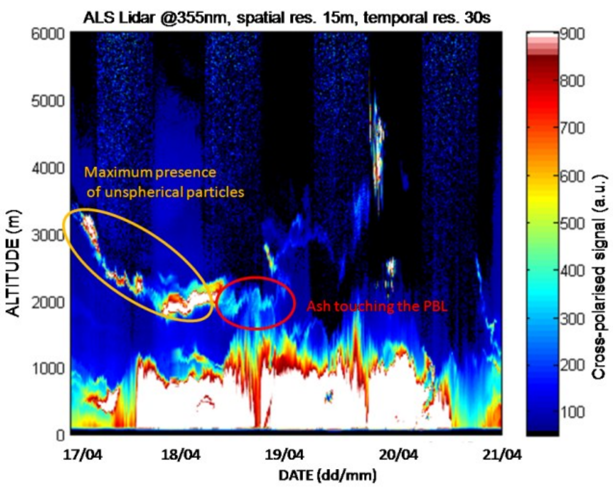

Figure 3 Perpendicular range corrected backscatter signal at Orsay (48.8N, 2.2E) from 17 to 21 April 2010. A thick depolarizing layer is present at about 3.3 km on the 17 April. This layer mixes with the PBL on 19 April.

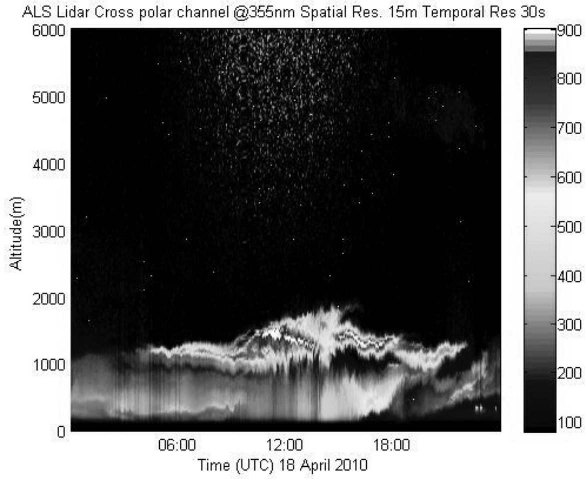

Figure 3 Perpendicular range corrected backscattered signal at Koninklijk Nederlands Meteorologisch Instituut (KNMI), 48.8N, 2.2E on 18 April 2010. A thick depolarizing layer is present at about 1.3km that mixes into PBL on 19 April.

4 From optical backscattering to mass concentration

On 17 April, a COBALD (Compact Optical AerosoL Detector) backscatter radiosonde was launched from ETH Zurich. COBALD is based on similar principles as the sonde of Rosen and Kjome [2], which was successfully used for observations of the Mount Pinatubo cloud [3]. Figure 4 shows the vertical profile of this sounding. In addition to temperature (black curve) and SnowWhite hygrometer relative humidity (light-green), the backscatter ratios at two wavelengths are presented (455 nm and 870 nm, labelled BSR450 and BSR870 respectively). The enhanced signal below 5 km characterizes a distinct aerosol layer, which in conjunction with the relative humidity of 30 % is identified as the volcanic ash layer above Zurich.

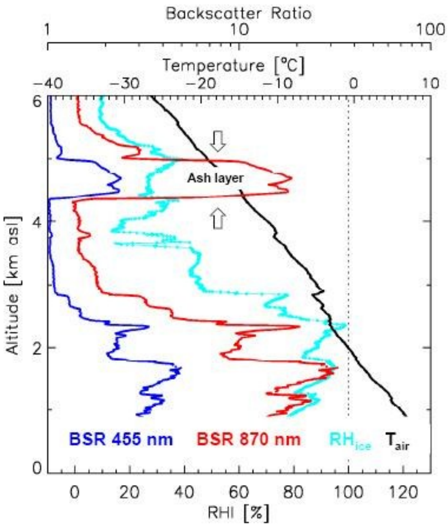

Figure 4 Vertical profiles of temperature (*T*, black), relative humidity with respect to ice (RHI, light green) and backscatter ratios above Zurich obtained by balloon sounding, 17 April 2010, 0:36 UTC. Arrows mark volcanic aerosol layer

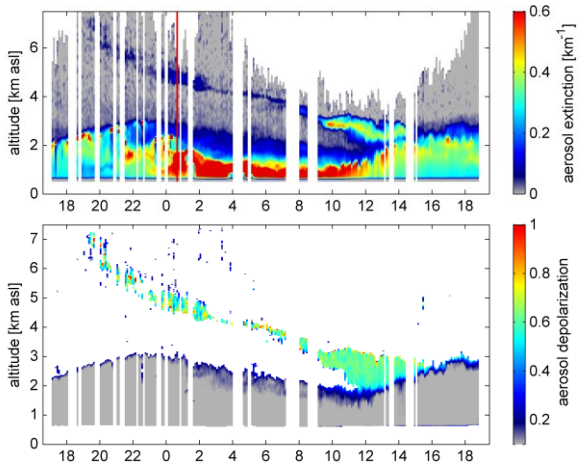

Figure 5 Lidar observation time series over Zurich (47.4N, 8.5E), 16 to 17 April 2010, time in UTC. Red vertical line marks the sounding displayed in Fig.4. The extinction maximum observed noontime 17 April is 4 times higher as compared to during the sounding. Aerosol depolarization remains uniform in the ash cloud.

Simultaneously to the sounding an ALS Lidar recorded data from the launch site (Fig. 5.) The descending signature above the PBL is located in dry environment (less than 40% RHi) as verified from COSMO-2 analysis data and thus identified as of volcanic origin. Despite the high extinction variability the aerosol depolarization remains fairly constant which allows attributing the extinction changes to mass density changes. An extinction to mass conversion factor was obtained by optical modelling based on the simultaneous, collocated extinction and backscatter measurement at three different wavelength on 17 April 0:36 UTC. The statistical approach [5] is based on a bimodal particle size distribution, as suggested by various ground-based and airborne observations, representing a sulphate and an ash plume component. Parameters of this distribution (number densities and mode radii, lognormal width, refractive indices including an imaginary part for the ash mode) are varied in order to comply with the optical properties measured. The ash mode is represented as spheroids and cylinders with varying aspect ratios.

Despite the large number of degrees of freedom most of the fit results (over 60000 in total) constrained by the optical measurements yield a mass density between 80 and 150 µg/m^3 and a conversion factor in the range of 0.65 to 1 g/m^2 for the extinction at 355 nm [5]. This value is lower as compared to those used in the literature for plume mass estimates, which is explained by the fact that the effect of the sulphate mode – only marginal in mass, but significantly contributing to the 355 nm extinction – is not attributed in the values adopted from ordinary mineral dust. The noontime extinction peak on 17 April, four times higher than during the sounding, is consequently associated with a maximum mass density of 600 µg/m^3.

5. Conclusion and perspectives

- ALS Lidar with depolarization channel has been used intensively in 5 countries in Europe, with 9 systems and 2 airborne versions (British FAAM and French FALCON).

- It gave a great support to the Met agencies during the crisis.

- ALS Lidar provided verification of dispersion models and satellite products.

- An immediate operational network was set up.

- Optical modeling based on simultaneous Lidar and balloon measurements using a reasonable ash particle description allows estimating extinction to mass conversion factor to calculate plume mass density from the Lidar measurements.

In the future, simple one wavelength new ALS Lidar (Raman N2, with depolarization) can integrate Lidar super sites with research proposals as operational tool for ash dust events surveillance and trans-boundary pollution studies

6. References

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