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DUST MASS CONCENTRATIONS FROM THE UK VOLCANIC ASH LIDAR NETWORK COMPARED WITH IN-SITU AIRCRAFT MEASUREMENTS

Martin Osborne*[1], Franco Marenco[2], Mariana Adam[2], Joelle Buxmann[2], Jim Haywood[2]

[1]*Univeristy of Exeter, UK, *martin.osborne@metoffice.gov.uk*
[2]*Met Office, UK*

ABSTRACT

The Met Office has recently established a series of 10 lidar / sun-photometer installations across the UK, consolidating their ash / aerosol remote sensing capabilities [1]. In addition to this network, the Met Office have acquired the Civil Contingency Aircraft (MOCCA) which allows airborne in-situ measurements of ash / aerosol scattering and size-distributions. Two case studies are presented in which mass concentrations of Saharan dust are obtained remotely using lidar returns, and are then compared with those obtained in-situ. A thorough analysis of the mass concentration uncertainty will be provided at the conference.

1 INTRODUCTION

The UK Met Office acts as the London Volcanic Ash Advisory Centre (VAAC) and is responsible for issuing forecasts and safety information in the event of a volcanic eruption in the North Atlantic region. Data from the new lidar network (fig 1) and the instrumentation carried on MOCCA will be used by expert forecasters to supplement modelling and satellite data. This could be particularly useful where cloud is obscuring satellite products.

This study aims to provide an initial assessment of the estimates of aerosol mass concentration retrieved using the new lidar network by using Saharan dust as a proxy for volcanic ash. The assessment is made by comparing remotely retrieved estimates of mass concentrations with in-situ airborne measurements made using MOCCA.

2 LIDAR NETWORK AND MOCCA

The new lidar network consists of nine fixed locations and one mobile facility (fig 2). The lidars (Raymetrics LR111-300) operate at 355nm and have N2 Raman and depolarization (polar and co-polar) channels. Data is transmitted to the Met Office HQ and can be accessed and visualized in near real time

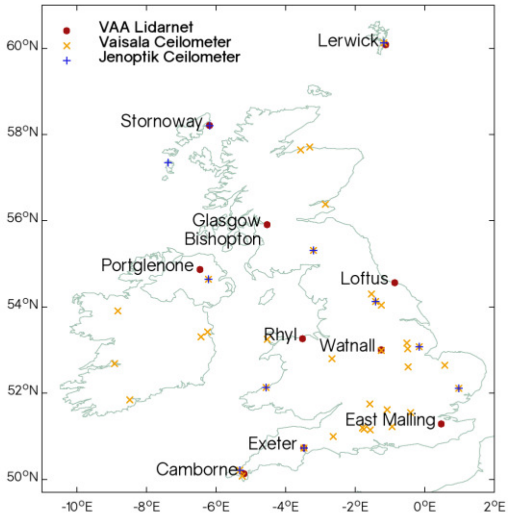

Figure 1.The Met Office Lidar-sunphotometer operational network. Also shown are the location of the operational ceilometers.

MOCCA is a Cessna 421 light aircraft equipped with a three wavelength nephelometer and an optical particle counter (Cloud and Aerosol Spectrometer (CAS)). MOCCA also carries a Leosphere ALS450 backscatter / depolarization lidar operating at 355nm. This can be positioned to point upwards or downwards before takeoff.

3 METHODOLOGY

3.1 In – situ mass estimate

Figure 2 upper and lower show output from the Met Office operational numerical weather prediction (NWP) model for dust aerosol optical depth (AOD) for the 1st and 25th November 2016 respectively. On both occasions AODs of around 0.1 – 0.2 were forecast. The output for the model also suggested that the skies over Camborne in the South West of the UK would be relatively cloud free. On each of these days, MOCCA was directed to make flights over the Camborne lidar site (fig 3) in order to perform in-situ measurements with the nephelometer and the CAS. During both flights, the dust layers were first mapped using the on board Leosphere lidar, and from this data altitudes were chosen for in-situ sampling runs. The data from the CAS were processed using an assumed refractive index for desert dust. The resulting volume size distributions were multiplied by a nominal density for desert dust of 2.6 μg cm^{-3} to arrive at an estimated mass concentration.

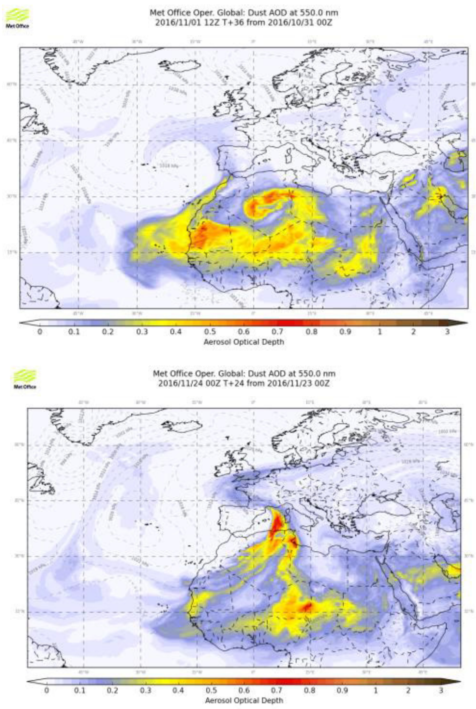

Figure 2. Dust AOD forecasts from the Met Office NWP model . Upper 1/11/16 and lower 25/11/16

3.2 Lidar mass estimate

Using the average of ~ 3hours of Raman channel data from the night before each flight, the methods described in [2] & [3] were applied to data from the lidar at the Camborne installation. The resulting profiles for extinction and backscatter were used to calculate mean lidar ratios (LR) both in and out of the dust layers. The LR uncertainty was determined as the STD over the 3h of measurements during night time. In order to obtain aerosol extinction & backscattering profiles from the elastic channel during day light hours, this lidar ratio was then used in Fernald / Klett retrievals [3,4]. It was assumed that the dust layer during day time had the same optical properties as during the night and thus the same LR. We feel this is justified as the dust had been transported from the source over 4 to 5 days, and there is no reason to assume that it had modified significantly in the ~ 12 hrs between the night time retrievals and those during the day. We did not consider the Raman channel during day time due to the high level of noise. The particle depolarization ratio (PDR) was then calculated using the resulting backscatter profiles and the depolarization channel.

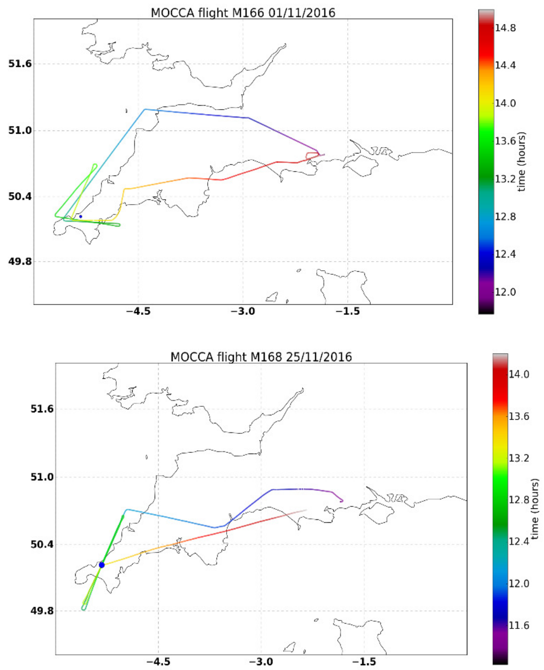

Figure 3. MOCCA flight tracks for (a) 1/11/16 and (b) 25/11/16. Camborne is shown in blue

Table1: Parameters used in lidar retrievals

Parameter	**Value**
Lidar ration in dust layer	01/11= 45 sr ± 6.9
	25/11= 65 sr ± 18.0
Lidar ratio below dust	01/11 = 20 sr ± 3
	25/11= 20 sr ± 6.5
Dust density	2.6 μg cm^{-3}
Non-dust density	1.5 μg cm^{-3}
Specific extinction dust	0.6 m^2g^{-1}
Specific extinction non-dust	0.16 m^2g^{-1}
Particle depolarization ratio dust	0.2
Particle depolarization ratio non-dust	0.001

Finally, using the methods described in [5] mass concentration estimates were obtained for dust, and non-dust aerosols. The values of parameters used in these retrievals are summarized in table 1. Molecular scattering was calculated using temperature and pressure profiles from the Met Office UKV 1.5km NWP model.

4 RESULTS

Figure 4 upper and lower show ~ 24 hours of data from the elastic and depolarization channels of the Camborne lidar, recorded on 1st and 25th November 2016 respectively.

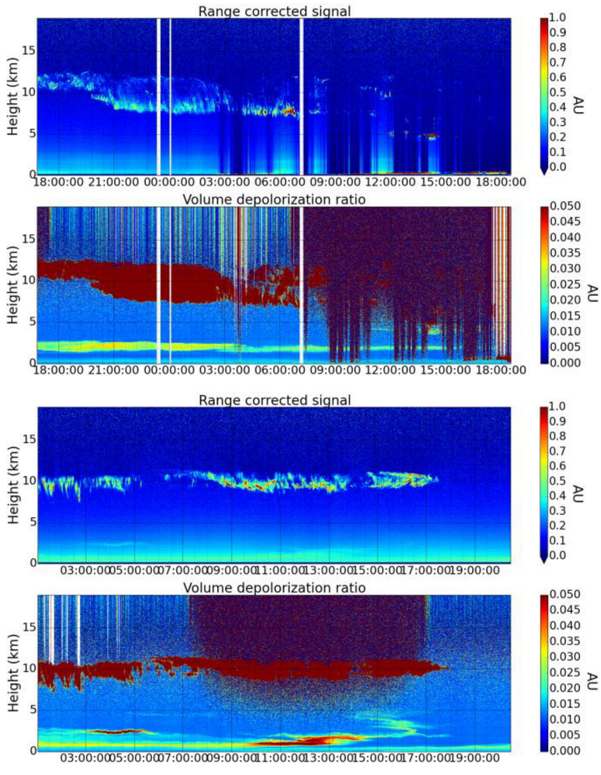

Figure 4.Range corrected signals for Camborne lidar elastic channel and volume depolarization ratio. Upper 1st November 2016 and lower 25th November 2016 .

Clear depolarizing layers can be seen in the depolarization channel on both days at between ~ 1 and ~2 km. Given this clear depolarization, and the prediction of Saharan dust made by the Met Office NWP model, we identify this layer as desert dust.

4.1 Lidar mass concentrations

Figure 5 upper and lower show the mass estimates arrived at using the process outlined above. The PDR in the dust layer on the 1st November is lower than expected. This is potentially due to the dust being polluted and becoming hydrated. The relative humidity recorded by MOCCA was ~ 80% in the dust layer.

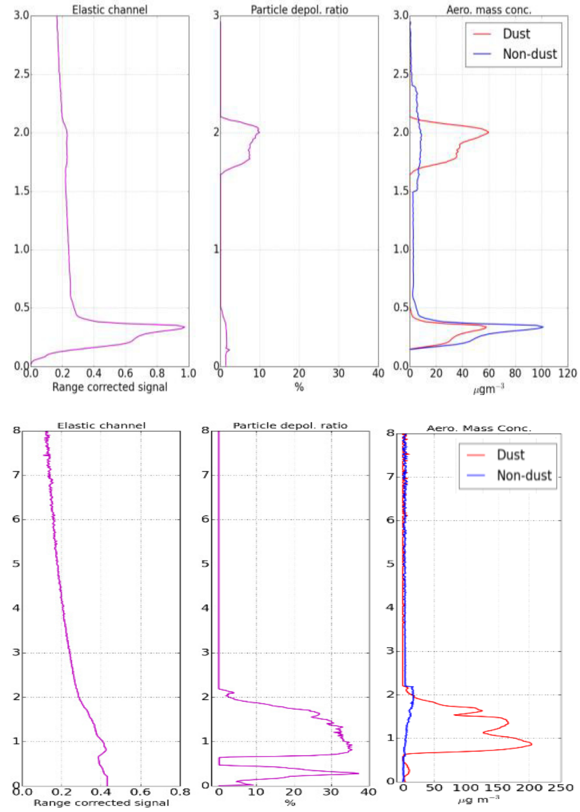

Figure 5. Lidar mass concentrations. Upper 1/11/16 and lower 25/11/16

The relative humidity recorded by MOCCA was ~ 80% in the dust layer. The PDR in the dust layer on the 25th November is more in line with values reported in the literature for desert dust. The relative humidity in this layer was around 40%.

4.2 In-situ mass concentrations.

Figure 6 upper and lower show the in-situ mass concentrations obtained using the CAS on the 1st and 25th of November 2016 respectively. In Fig 6 upper, the two peaks in the mass concentration correspond to MOCCA flying into and out of a highly in-homogeneous dust layer. In the dust layer the CAS mass concentrations are often between 40 and 70 μgm^{-3}, showing some agreement with the 40 to 60 μgm^{-3} obtained in the lidar retrievals. Figure 6 lower shows CAS mass concentrations between 100 and 200 μgm^{-3}, again, showing some agreement with the lidar retrievals. Based on estimates in [7], we expect a factor of two uncertainty for the mass derived from CAS.

Following [6], we expect an uncertainty of around 40% for lidar derived mass concentrations.

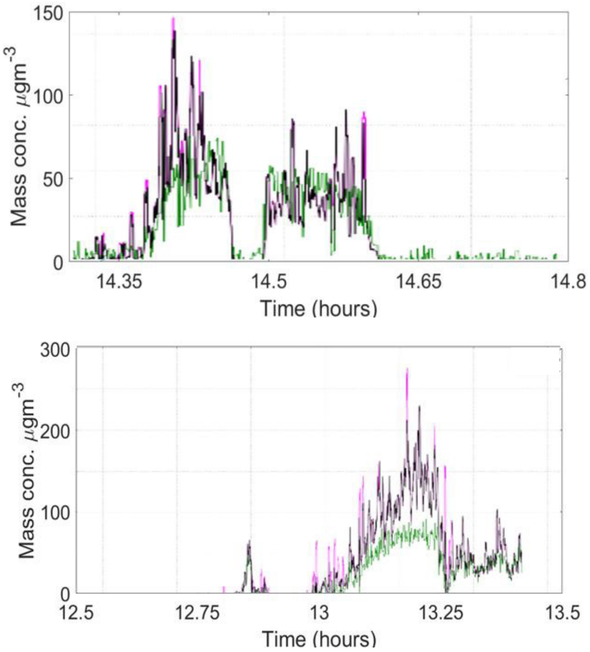

Figure 6. In-situ mass concentrations recorded by the CAS on board MOCCA (Black lines). Upper 1/11/16 and lower 25/11/16.

5 CONCLUSIONS

Estimates of mass concentration of Saharan dust were obtained remotely using data from a new volcanic ash lidar network. A height resolved lidar ratio was derived using N2 Raman channel data, and separate masses for dust and non-dust aerosols were obtained using data from elastic and depolarization channels. The results were compared with those obtained in-situ using the MOCCA aircraft and found to show some agreement. Such estimates for ash mass concentration are of interest to many users (including VAAC and ICAO) [8], and given that model uncertainty is estimated at a factor of 1.5 [9], even uncertain estimates would be invaluable to VAAC forecasters. Detailed analysis of the two case studies described above (including a thorough analysis of the mass concentration uncertainties), and further case studies in which Sun-photometer data and data from the aircraft nephelometer are utilized, will be presented at ILRC.

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References

[1] Adam, M., Buxmann, J., Freeman, N., Horseman, A., Salmon, C., Sugier, J, Bennett, R,: 2017: The UK Lidar-Sunphotometer operational volcanic ash network, 28 *ILRC*

[2] Ansmann, A., Riebesell, M., Weitkamp, C., 1990: Measurement of atmospheric aerosol extinction profiles with a Raman lidar, *Opt. Lett*. **15**, pp. 746-748.

[3] Ansmann, A., Muller, D., Lidar and atmospheric aerosol particles. In: Weitkamp, C., 2006: Lidar: Range-Resolved Optical Remote Sensing of the Atmosphere, 1st edition. Singapore: Springer Science & Business, p. 105 – 138.

[4] Fernald, F. G., 1984: Analysis of atmospheric lidar observations: some comments, *Appl. Optics*, **23**, pp. 652–653.

[5] Klett, J. D., 1985: Lidar inversion with variable backscatter/extinction ratios, *Appl. Opt*., *24*, pp 1638–1643.

[6] Ansmann, A., Tesche, M., Seifert, P., Gross, S., Freudenthaler, V., Apituley, A., Wilson, K. M., Serikov, I., Linne, H., Heinold, B., Hiebsch, A., Schnell, F., Schmidt, J., Mattis, I., Wandinger, U., Wiegner, M., 2011: Ash and fine-mode particle mass profiles from EARLINET-AERONET observations over central Europe after the eruptions of the Eyjafjallajokull volcano in 2010, *Journal of Geophysical Research*, **116** pp. 1-15.

[7] Johnson, B., et al. (2012), In situ observations of volcanic ash clouds from the FAAM aircraft during the eruption of Eyjafjallajökull in 2010, J. Geophys. Res., 117, D00U24.

[8] Martucci G. and A. Haefele, 2014: Review of Requirements for a European network of Automatic LIDARs and Ceilometers for cloud, aerosol and volcanic ash monitoring (http://eumetnet.eu/).

[9] Webster, H. N., et al. (2012), Operational prediction of ash concentrations in the distal volcanic cloud from the 2010 Eyjafjallajökull eruption,J. Geophys. Res., 117 D00U08.