

Real-time product: Feature mask, aerosol extinction and mass concentration

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1 Introduction

Eruptions in the past emphasised the importance of the observation and precise forecast of volcanic ash plumes for society and economy. Observations from space (geostationary satellites) and dense ceilometer networks can provide a good spatial coverage of the horizontal and vertical distribution of aerosol layers.

Continuous ground-based remote sensing at Mace Head, at the West coast of Ireland (53.33° N, 9.90° W, 21 m above sea level) provides information on the vertical distribution of possible volcanic ash layers in near real-time (every 15 minutes). The location of the site relative to Europe is another advantage in case of future volcanic eruptions in Iceland.

Plots of the products described here are provided at <http://macehead.nuigalway.ie/rt/feature> (updated every 15 minutes). The automatic retrieval of the extinction and mass concentration has been set up on 28/04/2015. Archive data exists since that date. Before, only feature mask plots are available.

2 Remote sensing instruments

The instruments used for this retrieval algorithm are operated automatically and continuously at Mace Head.

2.1 Ceilometer

The ceilometer (Jenoptik, model CHM15K) uses the lidar technique and is measuring at 1064 nm. It is used to detect aerosol layers and clouds up to about 15 km above ground level. In case of clouds however, the detection limit depends on the cloud optical depth. Furthermore, the detection efficiency of (weak) aerosol layers decreases with increasing altitude.

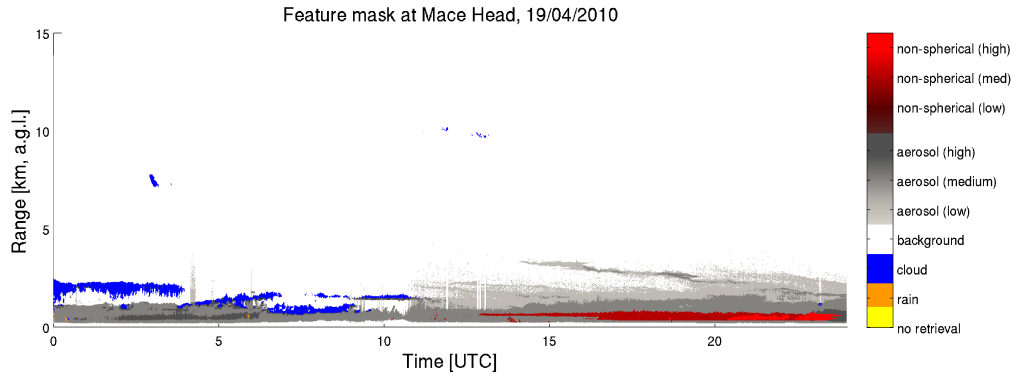


Figure 1: Feature mask from Mace Head, detected on 19 April 2010, after the eruption of Eyjafjallajökull, Iceland.

2.2 Cloud radar

Co-located with the ceilometer is a Doppler cloud radar measuring at 35 GHz (Metek, model MIRA36). The radar signal is reflected by larger atmospheric particles like cloud droplets, ice crystals, insects, and very large aerosol particles. Hence, the radar is not capable of detecting aerosol layers.

2.3 Microwave radiometer

The radiometer (RPG, model HATPRO) is a passive remote sensing instrument detecting microwave radiation in 14 different channels. It is measuring humidity and temperature profiles, which are used for the inversion and calibration of the ceilometer signal.

3 Methods

This document describes the retrieval of the feature mask (section 3.1), the aerosol extinction coefficient (section 3.2) and the aerosol mass concentration (section 3.3) from a combination of ground-based remote sensing observations performed at Mace Head.

3.1 Feature Mask

The classification of the different atmospheric features bases on the combination of data from the ceilometer and the cloud radar. From the ceilometer, the background- and range-corrected backscatter signal is used for the feature analysis. The radar data are used to supplement the ceilometer measurements with cloud information.

First, all clouds are flagged using the cloud products provided by the radar (blue in figures 1 and 2). The radar also provides information on the presence of rain, which

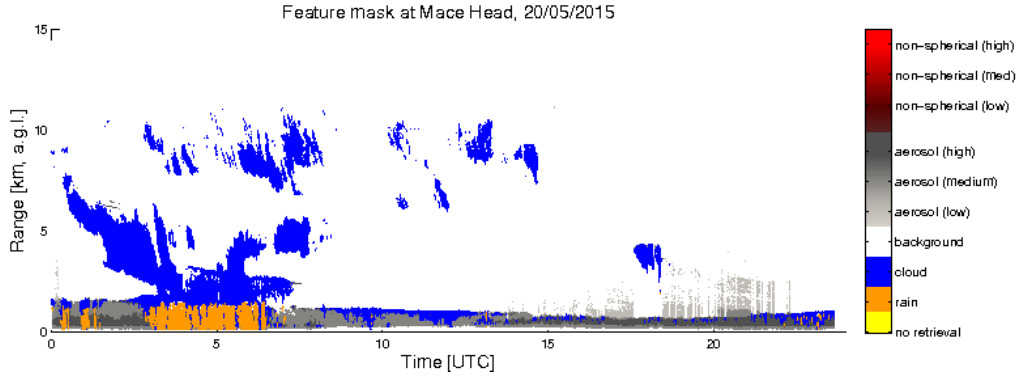


Figure 2: Feature mask from Mace Head, detected on 20 May 2015.

is flagged as well (orange on colour scale of figures 1 and 2). Periods when no aerosol retrieval is possible are flagged yellow.

In the following steps, the remaining ceilometer data is classified according to the signal strength. This can be used as an indication for low/medium/high aerosol load (grey scale in figures 1 and 2) and background noise. This is not suitable for an absolute quantitative evaluation. The particle backscatter and extinction coefficients or the aerosol mass can only be obtained from ceilometer data under certain assumptions (see section 3.2 and 3.3).

Volcanic ash particles are non-spherical and therefore depolarising. From ceilometer data alone it is not possible to distinguish non-spherical particles from spherical ones. The cloud radar data can help making this distinction. However, as mentioned before, it is limited to large particles and likely to miss free-tropospheric aerosol plumes. The use of the depolarisation ratio is implemented in the generation of the feature masks. Aerosol layers with sufficiently large non-spherical particles are classified as such (red scale in figure 1). This does not mean, that all other aerosol layers consist of spherical particles only. It rather indicates, that the other particles are too small to be detected by the radar. On the other hand, the presence of non-spherical particles does not necessarily indicate volcanic ash. Other non-spherical aerosol types with large scatterers can be observed as well, for example desert dust.

3.2 Aerosol extinction

The feature mask is used to limit the extinction retrieval to time periods and height regions with aerosol. Clouds, rain and background are excluded in order to save computational time. The following procedure is illustrated on the example of 20 May 2015. The feature mask is shown in figure 2.

The ceilometer signal is Rayleigh calibrated using a calibration constant obtained from clear night-time measurements (see section 4.1). The calibration constant is calculated whenever possible and the constant used for the retrieval described here is updated

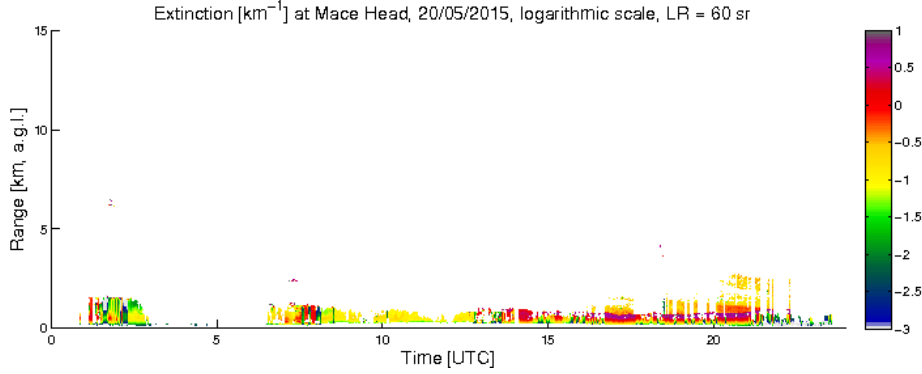


Figure 3: Aerosol extinction coefficient profiles on 20 May 2015.

accordingly using an average value of a number of previous calibrations.

The aerosol backscatter coefficient profiles are calculated using the so-called Klett algorithm. Assuming a fixed extinction-to-backscatter ratio (or lidar ratio) of 60 sr, the extinction coefficient profiles are derived. Lidar ratios in this range were found for volcanic ash from Eyjafjallajökull at the wavelength 355 and 532 nm using sophisticated multi-wavelength Raman lidars (*Ansmann et al.*, 2010). The aerosol extinction coefficient profiles of the example case are shown in figure 3.

However, the calibration constant is not valid for daytime measurements, as the instrument changes its sensitivity in order to protect the sensitive detectors from overload due to high background radiation. It is even further reduced in case of very low optically thick clouds due to the sudden peak in the received backscattered radiation. A daytime calibration of the ceilometer is necessary to correct for changes in the sensitivity. This is not implemented yet. Therefore, the daytime extinction coefficient is subject to large uncertainties. The effect of the change in sensitivity on the extinction data can be seen in figure 3 at around 13:00 UTC.

3.3 Aerosol mass concentration

Profiles of the aerosol mass concentration are derived from the aerosol extinction coefficient using the mass-to-extinction ratio $\eta = \rho/\alpha$, with ρ being the mass concentration and α being the extinction. *Hervo et al.* (2012) found this ratio to be 1.57 g/m² for volcanic ash from Eyjafjallajökull and 0.33 g/m² for local aerosol. When no volcanic ash alert has been issued, η is set to 0.33 g/m². After a volcanic eruption with air mass advection towards Ireland, the value will be changed manually to 1.57 g/m². The value of the mass-to-extinction ratio used to produce the plots is given in the plot title (MER, see figure 4). As the mass is directly derived from the extinction profiles, the change in sensitivity of the ceilometer is also visible in the mass profiles.

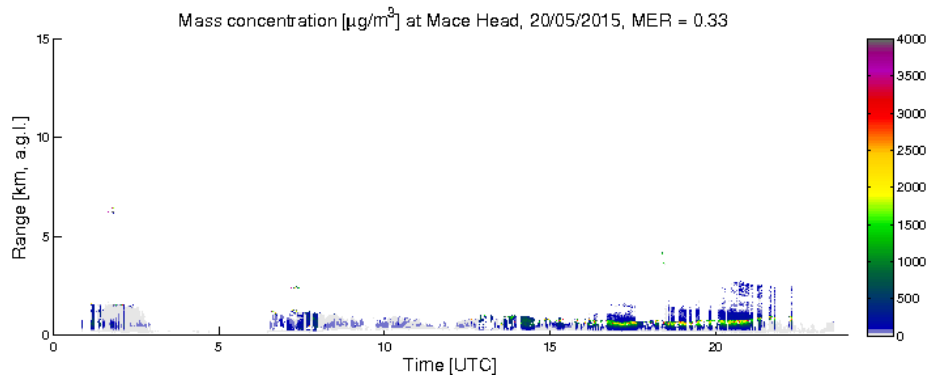


Figure 4: Aerosol mass concentration on 20 May 2015.

4 Uncertainties

With the combination of ceilometer and cloud radar we are able to locate aerosol layers and distinguish them from clouds with high accuracy. The derived aerosol properties however, are subject to large uncertainties.

4.1 Ceilometer calibration

To obtain backscatter coefficient profiles a Rayleigh calibration of the ceilometer has to be done regularly. The calibration of the ceilometer has been performed 112 times in a period of five years. The data were averaged over clear night periods of at least 1 hour duration (average of 2.7 hours), and over a height range of at least 300 m (average of 1000 m). The mean calibration constant (logarithmic) of all these calibrations was -27.88 with a standard deviation of 0.09 , a minimum of -28.12 and a maximum of -27.61 . The median was very close to the mean value with -27.89 . Deviation from the mean calibration constant by 0.3 , as estimated from the extrema, results in an error in the backscatter coefficient of about 1% . During daytime, the uncertainties are much larger, due to the uncorrected change in sensitivity of the ceilometer.

4.2 Lidar ratio

Many studies exist on the extinction-to-backscatter ratios, or lidar ratios, of different aerosol types. Typical values range from about 20 sr for marine aerosol up to 100 sr for strongly absorbing aerosol types. The assumption of a lidar ratio of 60 sr for volcanic ash is in accordance with literature for wavelengths 355 and 532 nm. As the wavelength dependency is small, it can be used at 1064 nm as well.

The lidar ratio is used for the retrieval of the backscatter coefficients using the Klett method as well as for the calculation of the extinction coefficient. The influence of an inappropriate lidar ratio on the backscatter coefficient is small at longer wavelengths. For the conversion from backscatter to extinction however, the lidar ratio is directly

used. Due to the large spread in lidar ratios, high uncertainties can be introduced for aerosol types other than volcanic ash. For the marine site Mace Head, generally a lower lidar ratio is expected close to the ground. A difference in the true lidar ratio from the assumed one of 40 sr propagates to an error in the extinction coefficient of 70%.

4.3 Extinction-to-mass ratio

Similar considerations are true for the extinction-to-mass ratio. There are well defined values published. However, the range is large, depending on the aerosol type. The assumption of one value for all aerosol types introduces large uncertainties. A deviation of the assumed extinction-to-mass ratio from the true one of 1 g/m^2 can lead to an error in the mass concentration of 60%.

5 Summary

This document describes a procedure to process ceilometer and cloud radar data in near real-time with the objective of volcanic ash detection and quantification. The use of continuously operating instruments are a great asset. The remote sensing suite of instruments at Mace Head allows the detection of aerosol layers as well as a rough estimation of the extinction and mass concentration. To achieve this, a number of assumptions were necessary which can lead to large uncertainties. The algorithm has been set up to minimise the uncertainties for volcanic ash quantification at night time. The extinction-to-mass ratio for the calculation of the mass concentration can and will be adjusted in case of an volcanic ash alert.

References

- Ansmann, A., et al. (2010), The 16 April 2010 major volcanic ash plume over central Europe: EARLINET lidar and AERONET photometer observations at Leipzig and Munich, Germany, *Geophysical Research Letters*, **37**, doi:10.1029/2010GL043809.
- Hervo, M., et al. (2012), Physical and optical properties of 2010 Eyjafjallajökull volcanic eruption aerosol: ground-based, Lidar and airborne measurements in France, *Atmospheric Chemistry and Physics*, **12**, 1721–1736, doi:10.5194/acp-12-1721-2012.