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Atmospheric Measurement Techniques
Discussions

Interactive comment on "Dual-wavelength light scattering for selective detection of volcanic ash particles" *by* Z. Jurányi et al.

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We are very thankful to Referee #1 for the constructive suggestions.

General Comments:

1. Comment:

Former work on instruments of that type, in particular by Beswick et al. (2014) on the Backscatter Cloud Probe (BCP) which is quite similar to presented design, and then by Rosen and Kjome (1991) and Groß et al. (2013) on the use of multi-wavelength information for classifying aerosol particles should be discussed adequately. In particular, the differences and similarities to the BCP instrument should be highlighted.

Answer:

The following text was added to the manuscript:

"Measuring the scattered light simultaneously at two different wavelengths can provide information on the average aerosol particle size. Assuming no strong wavelength dependence of the refractive index, the ratio of the scattered light intensity changes with the mean particle size monotonically in the sub-micron size range. Rosen and Kjome (1991) have developed a backscatter sonde which measures simultaneously at 490 and 940nm wavelengths the backscattered light around 173° scattering angle, and the ratio of the red to blue backscattered light is used to estimate the mean particle size. This instrument does not measure single particles as it has an effective sensitive volume of the order of 1mˆ3. Inspired by this backscatter sonde the Compact Optical AerosoL Detector has been developed in 2008 using high power LEDs at comparable wavelength for cirrus cloud analysis (Brabec et al., 2012, Cirisan et al., 2014) with a tenfold mass reduction down to 0.5 kg.

Multi-wavelength Lidar measurements have shown that different aerosol types (biomass burning, Saharan dust, marine aerosol and anthropogenic pollution) have different backscatter ratios measured at 532 and 1064nm wavelengths (Gross et al., 2013)."

"The BCP uses a single wavelength of 658 nm and measures the scattered light of single particles at a solid angle range of 144-156°. This light-weight instrument is able to detect particles with optical diameters in the range of 5-75um. If this instrument is equipped with the optional polarisation detector, the polarisation ratio of the measured particles indicates whether the particle is spherical or not. With this feature, it might be possible to differentiate between water droplets and significantly non-spherical volcanic ash particles. The Cloud and Aerosol Spectrometer with Polarization (CASPOL) is another new instrument to characterize atmospheric aerosols. It measures the aerosol light scattering (at one wavelength) in forward and backward directions, with an additional polarized detector in the backward direction. Glen and Brooks (2015) have shown that it can characterize optical properties of various dust particles on a particle-by-particle basis."

2. Comment:

The theoretical evaluation of the instrument used Mie theory and thus assumed spherical particles only. However, all considered aerosol types (mineral dust, volcanic ash) are irregularly shaped. In addition, the theoretical evaluation is limited to water droplets whereas volcanic ash particles in the atmosphere may be embedded in cirrus clouds, but not water clouds. This topic is not discussed but may have a major influence on the determined capabilities of the instrument. A first impression of expected effects may be gained from an intercomparison of the theoretically expected response ratio of the instrument to different aerosol types and the measured values shown in Fig. 6. Since the respective size distributions were recorded, this intercomparison should be straightforward. Another aspect refers to the fact that in the case of irregularly shaped particles, the angular distribution of scattered light depends not only on the particle geometry but also on the orientation of the particle with respect to the scattering geometry of the instrument. Since the instrument detects scattered light over a very narrow angular range, this issue is of high relevance and should be discussed in detail. See also the paragraph on page 8713, lines 10–17. Here, the application of the T-Matrix method (Mishchenko, 1990) may be appropriate. Codes are available from Mishchenko's website.

Answer:

We added a new section to the manuscript where we show some examples how the non-sphericity of the volcanic ash particles influences the R-value. Here we also investigated the influence of the particle orientation. As these calculations are very time-consuming only a limited number of examples were calculated. We used particles with different ellipsoid form to model the non-sphericity of the dust-like particles. A new ta-

ble (Table 2) summarizes the obtained results and the following text was added to the manuscript:

"In this section we show some examples, how the non-sphericity of dust-like particles influences our calculations. We do not know the exact, non-spherical shape of the particles which, of course, differs from particle to particle as well. Therefore, the following assumptions were made: The shape of the non-spherical particles were chosen to be ellipsoid because in a recent publication (Merikallio et al., 2015) it was shown that the light scattering properties of volcanic ash particles can be well described assuming a particle population with different ellipsoid forms. Due to the complexity and the very high computational time demand of the problem, we were only able to calculate a few examples. For this calculation, we have used the open source, discrete-dipole-approximation code from Yurkin and Hoekstra (2011). We did the calculations for 5 different ellipsoid shapes, all having a volume equivalent diameter of 5 um, and we have investigated the influence of the particle orientation on the scattering with the help of one of these ellipsoids having axis ratios of 1.25 and 2 as well. The R values were calculated following Eq.1, using the same refractive indices as for the volcanic ash Mie calculations (see Tab. 1.) and the same scattering angle ranges. We have chosen the z-axis as the direction of the incident light propagation. The obtained results and the shape and orientation of the particles are summarized in Table 2.

Changing the particle shape from spherical to ellipsoid increases the visible light scattering compared to the IR and as a consequence increases the R value. Among our examples, the highest R value of 3.00 was found for a highly non-spherical ellipsoid with axis ratios of 1.25 and 2. This R value is more than 10 times higher than the value of an equivalent sphere having the same volume. The effect of the particle orientation was investigated on this ellipsoid and the derived R values of the rotated ellipsoid can be also found in Table 2. As expected, the orientation of the particle influences the R value as well, however, this effect seems to be still moderate for our chosen examples, we see both increase and decrease. The encountered highest R value is 4.67, which is almost a factor 20 higher than for the equivalent sphere. However, if we look at Figure 2 we see that the R value of the spherical water droplets is ∼35, and, therefore, a differentiation should still be possible for non-spherical dust particles. Of course, we cannot exclude that dust particles at other sizes and/or with exotic shapes will not have R values in the range where water droplets are found. However, we believe that the fraction of these particles is negligible compared to the number of the total dust particles and a successful particle differentiation using the two wavelengths is still possible. In the following we will experimentally investigate the problem of the water droplet and dust like particles differentiation."

Regarding the question about ice crystals, it is already mentioned in the conclusion, that we would need a slightly different wavelength of 2790 nm instead of the currently used 2750 nm to have the best separation for both ice and water droplets from dust particles; unfortunately a proper laser at that wavelength was not available. However, the currently used laser wavelength should also be sufficient to separate ice form dust particles. Mie calculations (assuming spherical ice particles, bringing uncertainty to these calculations) show that ice has slightly lower R values than water. This calculation is newly added to Figure 2 and the refractive index of ice was added to Table 1. We did not have the facility to grow ice particles in our lab and, therefore, no experimental data is available on ice. Further ambient tests at the high alpine site Jungfraujoch and on the board of an aircraft will offer the possibility to test experimentally whether the separation of ice is possible or not. We also hope that in a future cooperation with Fraunhofer Institute a suitable IR laser with the target wavelength of 2790nm will be available, where the gap between the R values of water/ice and dust is higher. In this respect, parts of the text were modified:

"The refractive index of ice slightly differs from the one of liquid water, and therefore, the R values (dashed turquoise line in Fig. 2) are lower with an average value of 30, which is still much higher than the one for dust and there is no overlap between the single R value ranges either (turquoise and orange shading in Fig. 2)."

3. Comment:

Key references describing physical and optical properties of volcanic ash particles during the Eyjafjallajökull eruption should be referenced, in particular Schumann et al. (2011) and Turnbull et al. (2012) for size distributions, and Weinzierl et al. (2012) for optical properties and visibility.

Answer: The requested literature was included in the manuscript

Specific Comments:

1. The title seems incomplete, how about: "Dual-wavelength light scattering technique for selective detection of volcanic ash particles"?

The title was changed to: What about: Dual-wavelength light scattering technique for selective detection of volcanic ash particles in the presence of water droplets

2. Page 8715, line 12: This sentence seems incomplete, please check.

The paragraph was rewritten now it reads: "If we combine the two laser beams having the same beam diameter and center position with a suitable dichroic mirror, then the particles passing by the lasers will experience the same fraction of the maximal, central incident laser intensities and, therefore, much narrower R value distribution is expected. The size dependence of the single particle scattering at the visible wavelength can be used for particle sizing. However, the incident laser power inhomogeneity is a problem here. Applying a similar inversion algorithm as done for the BCP (Beswick et al., 2014) is a possibility to make particle sizing possible in the future."

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