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Remote sensing measurements of the volcanic ash plume over Poland in April 2010

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ABSTRACT

This work provides information on selected optical parameters related to volcanic ash produced during the eruption of the Eyjafjöll volcano in Iceland in 2010. The observations were made between 16 and 18 April 2010 at four stations representative for northern (Sopot), central (Warsaw, Belsk) and south-eastern (Strzyzow) regions of Poland. The largest ash plume (in terms of aerosol optical thickness) over Poland was observed at night of 16/17 April 2010 in the layer between 4 and 5.5 km a.s.l. The highest values of the aerosol extinction coefficient reached 0.06–0.08 km^{-1} at 532 nm (based on lidar observations in Warsaw) and 0.02–0.04 km^{-1} at 1064 nm (based on ceilometer observations in Warsaw). The corresponding optical thickness due to volcanic ash reached values of about 0.05 at 532 nm and about 0.03 at 1064 nm. These values are similar to those reported for the Belsk station based on lidar observations. The ash mass concentration estimated based on the maximum aerosol extinction coefficient reached 0.22 ± 0.11 mg m^{-3}. This value is significantly lower than the limit (2 mg m^{-3}) for the aircraft operation.

1. Introduction

Volcanoes are among most important natural sources of atmospheric pollution. They emit dust and gases, which undergo chemical reactions in the atmosphere producing aerosols (McCormick et al., 1995). Similar to desert dust, particles produced as a result of fires or industrial combustion processes, volcanic aerosols may influence meteorological conditions e.g. surface solar radiation, visibility, and other. For example the Tambora volcano eruption in April 1815 caused a year with no summer in Indonesia in 1816 (Trigo et al., 2009). The climatic impact of volcanic eruptions is usually less spectacular, however, very important and can also be observed (Hansen et al., 1992; Parker et al., 1996; Kirchner et al., 1999).

Particle size distribution of volcanic aerosols tends to be multimodal, suggesting multiple processes of formation. The finest particles result from the condensation of volatiles, and gas phase reactions (Mather et al., 2003). The accumulation mode includes also the smallest tephra particles, while the coarse mode includes fragmented magma, and erosion particles (Mather et al., 2003). Impact of volcanoes on global climate results from a relatively long life of fine particles in the atmosphere. The residence time of fine particles (mainly sulfuric compounds) in the stratosphere varies in a wide range from months to years. In case of volcanic ash, the climate effect is usually smaller, because particles have a maximum residence time in the troposphere of few weeks. Only the finest tephra particles remain in the stratosphere for up to few months, but they have only minor climatic effect. Volcanic aerosols mainly scatter solar radiation, however, small absorption rate which occurs in upper atmospheric layers has an important impact on local radiation balance (Myhre et al., 2001; Harshvardhan, 1979) and as a consequence, on air temperature (Parker et al., 1996; Kirchner et al., 1999). An indirect influence of volcanic aerosols on climate is related to their impact on microphysical cloud properties (Durant et al., 2008).

The motivation for this study was a several day long closing of the European air space (IATA, 2010) after the eruption of the Eyjafjöll volcano in April 2010. Such situation resulted from the lack of consistent volcanic ash monitoring over Europe. This work provides information on spatial and temporal evolution of the aerosol optical properties such as aerosol optical thickness (AOT) and aerosol extinction and backscatter coefficients related to

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volcanic ash produced during the eruption of the Eyjafjöll volcano which was observed over Poland between 16 and 18 April 2010. It is worth mentioning that other volcanic ash episodes, not reported in this work, were observed over central Poland as well (Pietruczuk et al., 2010; Mona et al., 2010; Campanelli et al., 2012; Thomas and Prata, 2010).

2. Methods

2.1. Instrumentation

The volcanic ash optical properties were measured with the use of the remote techniques at 4 stations in Poland (Fig. 1).

The EUSAAR Sopot station is based in the Institute of Oceanology Polish Academy of Sciences (www.iopan.gda.pl) on the coast of the Baltic Sea (54° 26′N, 18° 33′E, 2 m a.s.l.). The laboratory is equipped with Microtops II sunphotometers (5 wavelengths), lidar, nephelometer, and particle counters. For the purpose of this paper only sun photometer data were used (Table 1).

The University of Warsaw Radiative Transfer Laboratory (http://www.igf.fuw.edu.pl) is based on the platform on the roof of the university building (52° 21′N, 20° 98′E, 110 m a.s.l.). The instrumentation involves a CHM-15K ceilometer made by JenOptik and a Microtops II sunphotometer. Additionally, a 510M lidar of the Faculty of Physics of the University of Warsaw was employed for measurements during the measurement period. This lidar is based on the Nd–YAG laser generating beams at its three harmonics: 1064, 532 and 355 nm, where energies of the light pulses are 170, 90 and 60 mJ, respectively. During the Eyjafjoll volcanic event setup of the 510M lidar contained only 532 nm wavelength. The measurements were taken with pulse repetition frequency of 10 Hz.

The Geophysical Observatory in Belsk is equipped with an aerosol backscatter LIDAR and a Sun-scanning photometer. The Belsk LIDAR, a part of EARLINET network, has a Nd:YAG laser with three harmonics. Aerosol backscatter coefficients at wavelengths 1064, 532 and 355 nm are calculated by means of a standard Fernald procedure and are available through the EARLINET database (http://earlinet.org). Collocated Sun-photometers CIMEL CE 318, is federated in European SkyRad users' network (ESR) and AErosol RObotic NETwork (AERONET) networks respectively.

The EUSAAR SolarAOT private station (established by K. Markowicz in 2003 http://www.igf.fuw.edu.pl/meteo/stacja/) in Strzyzow, in the south-east part of Poland (49° 86′N, 21° 87′E, 443 m a.s.l.) uses a Multi-Filter Rotating Shadowband Radiometer (Model MFR-7) (Harrison et al., 1994).

Fig. 1. Location of Polish stations.

The volcanic ash analyses were supported with satellite data from (Moderate Resolution Imaging Spectroradiometer) (MODIS) mounted on Terra and Aqua satellite and Spinning Enhanced Visible and Infra-red Imager (SEVIRI) onboard of theMeteosat Second Generation (MSG). The authors analyzed data provided by the AErosol RObotic NETwork (AERONET) at different stations placed on the route of the volcanic ash plume. In addition, we used the Lagrangian particle dispersion model FLEXPART (Stohl et al., 1998) and the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) (Draxler and Rolph, 2010).

2.2. Retrieval techniques

To obtain vertical profiles of the aerosol extinction from ceilometer signals we used three different retrieval methods (Frey et al., 2010; Heese et al., 2010; Flentje et al., 2010; Markowicz et al., 2008). These require additional information about aerosol optical properties such as a lidar ratio (ratio of particle extinction to backscatter coefficient) and/or aerosol optical thickness (AOT). The first method used in this study, called the Porter approach (Porter et al., 2000, revised by Markowicz et al., 2008) is based on the forward-stepping algorithm which requires information about the single scattering albedo and the backward phase function or the lidar ratio, as well as the lidar calibration coefficient. The latter quantity was obtained using the lidar auto-calibration technique (O'Connor et al., 2004), which we modified for 1064 nm. This method had to be applied to signals detecting a persistent low level and not too-thick Cumulus cloud system, which causes complete attenuation of the ceilometer signal but without causing its saturation. Another Porter method (Porter et al., 2002) does not require knowledge of the lidar calibration coefficient (because it is constrained using sun photometer measurements) but we did not use this method. The two other methods applied to the ceilometer signals were the standard backward Klett–Fernald–Sasano approach (Klett, 1985; Fernald, 1984; Sasano et al., 1985) and the seldom used forward Klett–Fernald–Sasano approach. For the three evaluation approaches the lidar ratio was assumed constant with altitude. However, for the Klett–Fernald–Sassano approach the lidar ratio was calculated as an adjustment of an integrated ceilometer extinction coefficient profile to the total AOT measured by the sun photometer. By using additional information, such as the value of the integrated aerosol optical thickness from sun photometer, the Klett–Fernald–Sasano technique, can reduce the error of the derived extinction profiles to ± 0.005 km^{-1} (Welton and Campbell, 2002). On the other hand an assumption of the lidar ratio constant with altitude may lead to significant uncertainties (Sasano et al., 1985). In case of the Porter approach we assumed the lidar ratio of 50 sr constant with altitude and time, a value typical for volcanic ash particles (Wang et al., 2008; Papparlardo et al., 2010; Ansmann et al., 2010).

In the case of the two forward approaches the initial aerosol extinction coefficient (at 0.25 km) was assumed 0.01 km^{-1} at 1064 nm. However, during the consecutive iterations this value varied, so that the final aerosol extinction coefficient at 0.25 km may differ from the starting value. Assuming an error of 2% of the molecular extinction coefficient calculated from the radiosounding data, which is accounted to a daily variation of temperature and pressure, the error of the retrieved aerosol extinction coefficient is about 10% (Stachlewska and Ritter, 2010).

As the total optical thickness measurements with sun photometers are not possible at night the AOT used for the aerosol extinction coefficient retrieval was obtained by the interpolation of