Research Regarding Aerosol Properties of the Grimsvötn Ash by Applying Sun Photometry

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This paper gives the aerosol columnar properties above Timisoara, Romania, informing about the possibility to detect particles dispersion originated from thousands of kilometers distance. Volcanic ash has a peculiar chemical composition and it affects, as demonstrated by this article, much extended areas, far away from the source of origin. The novelty brought by the article addresses a specific episode, over Romania, due to a phenomenon that occurs at major distance, over which until now, one could not suppose normal dispersion of pollutants, and still it exists and is active and out of human control. The study was achieved by end of May 2011, when the Grimsvötn volcano erupted in Iceland, by means of photometry. The sun photometer observations results, consisting of aerosol optical depth (AOD), Angstrom coefficients, fine and coarse mode concentration and size distribution, allow identifying the volcanic aerosols. The single scattering albedo was detected to be between 0.75 and 0.85, at 440 nm.

Keywords: volcanic ash, aerosol, sun photometer, aerosol optical depth (AOD)

It is known that volcanic eruption may eject large amounts of ash (aerosols – in function of the types of magma, in special SiO_2) and trace gases such as sulphur dioxide (SO_2) into the atmosphere. The principal gases released during volcanic eruption are H_2O, CO_2, SO_2, H, CO, HCl, NH_3, H_2S, and HF [1]. These ejects can have considerable impact on the visibility and human health [2], and also reduce solar radiation reaching the surface.

The effects of volcanic ash depend on the grain size, mineralogical composition and chemical coatings on the surface of the ash particles [3]. The eruption of the Grimsvötn volcano in South - East Iceland (64.41 N, 17.33 W) began on 21th May 2011 at 19:25 GMT [4].

Disruption of the air travel commenced on 22 May starting from Iceland, and reached other locations such as Greenland, Scotland, Norway, Svalbard and a small part of Denmark, on subsequent days.

On 24th May the disruption spread already to Northern Ireland and to airports in northern England.

On 25th May the disruption arrived to Northern Germany, as consequence airports at Hamburg and Bremen were closed for a few hours.

On 27th May Greenlandic airspace was closed due to a concentration of ash over Greenland and the North Atlantic. Ash chemical composition from Grimsvötn eruption on 22nd May is presented in table 1.

Sample GR11-01 from Kirkjubæjarklaustur, was collected during the onset of fallout just after midnight 22nd May, 00:58 GMT. Sample GR11-02 was collected in the morning of 22th May, 08:45 GMT from Horgsland / Sida. Based on chemical composition, the ash classifies as tholeiite-basalt, with no significant difference between samples GR11-01 and GR11-02 [5].

More information on the Grimsvötn eruption, such as description of the eruptive phases, plume heights, size distribution analysis, etc. can be found in the website of the Institute of Earth Sciences (http://earthice.hi.is).

The aim of this paper is to investigate the optical, chemical and microphysical properties of the volcanic aerosols based on the AERONET sun photometer observations in the Timisoara city from Romania during 26 – 29 May 2011. Timisoara is located in the Western part of Romania, thus it is one of the first areas where the result of the eruption consequences from Iceland were observed.

Experimental part

The sun photometer is located on the roof of the Mechanical Engineering Faculty of “Politehnica” University of Timisoara (fig. 1, right), with coordinates: 43.74 N; 21.22 E and 122 m altitude. The sun photometer from Timisoara is connected at AERONET site [6], position 645.

Figure 1 presents the sun photometer components. This is composed from an optical head, electronic box and a robot [6].

<table>
<thead>
<tr>
<th>Sample</th>
<th>GR11-01</th>
<th>GR11-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO_2</td>
<td>50.54</td>
<td>51.01</td>
</tr>
<tr>
<td>Al_2O_3</td>
<td>13.73</td>
<td>13.46</td>
</tr>
<tr>
<td>FeO</td>
<td>13.14</td>
<td>13.25</td>
</tr>
<tr>
<td>MnO</td>
<td>0.23</td>
<td>0.28</td>
</tr>
<tr>
<td>MgO</td>
<td>5.69</td>
<td>5.77</td>
</tr>
<tr>
<td>CaO</td>
<td>10.12</td>
<td>9.86</td>
</tr>
<tr>
<td>Na_2O</td>
<td>2.87</td>
<td>2.81</td>
</tr>
<tr>
<td>K_2O</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>TiO_2</td>
<td>2.73</td>
<td>2.67</td>
</tr>
<tr>
<td>P_2O_5</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>Ba</td>
<td>0.0112</td>
<td>0.0111</td>
</tr>
<tr>
<td>Co</td>
<td>0.0070</td>
<td>0.0069</td>
</tr>
<tr>
<td>Cr</td>
<td>0.0035</td>
<td>0.0026</td>
</tr>
<tr>
<td>Cu</td>
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<tr>
<td>La</td>
<td>0.0013</td>
<td>0.0010</td>
</tr>
<tr>
<td>Ni</td>
<td>0.0058</td>
<td>0.0044</td>
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<tr>
<td>Sc</td>
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<tr>
<td>Sr</td>
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<td>0.0079</td>
</tr>
<tr>
<td>V</td>
<td>0.0155</td>
<td>0.0129</td>
</tr>
<tr>
<td>Y</td>
<td>0.0008</td>
<td>0.0007</td>
</tr>
<tr>
<td>Zn</td>
<td>0.0066</td>
<td>0.0060</td>
</tr>
<tr>
<td>Zr</td>
<td>0.0018</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

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The optical head has two channel systems: the sun collimator, without lens, and the sky collimator with lenses. The sun tracking is equipped with a 4-quadrant detector.

The electronic box contains two microprocessors for real time operation for data acquisition and motion control. A ‘wet sensor’ detects precipitation in automatic mode, and forces the instrument to park and to protect the optics. The robot is moved by step-by-step motors in two directions: in the zenith and azimuth planes.

A sun photometer is an optical instrument for the measurement of the spectral solar radiation. The spectral resolution depends on the number of channels. The range of wavelength is between 0.34 - 1.65 μm. The sun photometer accomplishes two basic measurements, either direct sun or sky, both within several programmed sequences. The direct sun measurements are made in nine spectral bands (340, 380, 440, 500, 670, 870, 940, 1020 and 1640 nm) requiring approximately 10 seconds. The 940 nm channel is used for column water abundance determination [7].

Sky measurements are performed at 440 nm, 670 nm, 870 nm, and 1020 nm. Two basic sky observation sequences are recorded: the “almucantar” and the “principal plane” [7].

Results and discussions

The aerosol optical depth is obtained applying the Beer-Lambert-Bouger law to irradiance data and by removing the contribution due to Rayleigh scattering and absorption of atmospheric gases.

The accuracy of the AERONET aerosol optical depth measurements is 0.01 - 0.02 for the wavelength ≥ 440 nm and the uncertainty in measured sky radiances due to calibration error is 0.5% [8]. Analysis of aerosol optical thickness (aerosol optical depth) in Timisoara from AERONET observations have been accomplished in several other papers [9, 10].

Figures 2 (a – d) present the aerosol optical depth (AOD) on 26th, 27th, 28th and 29th of May 2011, for different wavelengths. On 26th May 2011 the AOD value is increased which indicates the presence of intrusions in atmosphere. The time scale is given by GMT (Greenwich Mean Time).

Fig. 3 presents the average of the total, fine and coarse mode aerosol optical depth. From figure it is observed as dominated by fine mode. On 28th of May one observed that the value corresponding to 500 nm was higher, with an average of 0.501 and an error of 0.1 %. The coarse particle predominance was also observed on 28th May, with an average of 0.07.

Value of Angstrom parameter (α) smaller that <1 indicate size distributions dominated by coarse mode aerosols, which can be associated with dust and sea-salt aerosols, while Angstrom parameter >1 would indicate
the presence of fine mode particles, that can be associated with urban pollution and in same cases with biomass burning [8].

Figure 4 shows that for all days Angstrom parameter is greater that 1, meaning the presence of fine particles in atmosphere (fig.4).

The volcanic ash intrusion induces a variation of these parameters, as follows: an increase in aerosol optical depth (AOD), decrease of the Angstrom parameter and decrease of the water vapor.

The Angstrom turbidity ($\alpha$) is related to the particles concentration. $\alpha$ values of less than 0.1 are associated with a relatively clear atmosphere, and values greater that 0.2 are associated with a relatively hazy atmosphere. For the period studied values of Angstrom turbidity coefficient are in the range 0.06 – 0.23 (fig. 5).

The AOD is related the amount of particles and $\alpha$ to the size, thus it can be considered as a relevant information to individuate aerosols with different properties and of different types. Three main groups of particles can be identified:

(i) the first one includes data with large values of AOD ($0.3 \leq \text{AOD} \leq 0.6$) and low values of $\alpha$ ($\alpha \leq 0.6$) for the dust aerosol;

(ii) the second one contains points with low values of ($0 \leq \text{AOD} \leq 0.2$) and large values of $\alpha$ ($1 \leq \alpha \leq 2$) for the marine aerosols and

(iii) the third group is formed of values $0.2 \leq \text{AOD} \leq 0.9$ and $1.2 \leq \alpha \leq 2$. It is known that the third group is typical of urban-industrial, biomass burning aerosols and volcanic aerosol [13].

Aerosol size is a key parameter to separate natural from man-made aerosol. The anthropogenic aerosol is dominated by fine-mode particles, while natural aerosol contains a substantial component of coarse-mode particles. The AERONET inversion algorithm allows retrieving volume particle size distributions and all particles with radius $0.06 \mu \text{m} \leq r < 0.6 \mu \text{m}$ are considered fine, while those with $0.6 \mu \text{m} \leq r \leq 8.8 \mu \text{m}$ are considered coarse.

The particle size distributions are shown in figure 6 for different dates of interest. The shape of the volume size distribution on 26-29 May is a bimodal lognormal size distribution, with a strong peak at $r = 0.1 \mu \text{m}$ (27\textsuperscript{th} of May 2011) and a secondary peak at $r = 3.9 \mu \text{m}$ (29\textsuperscript{th} of May 2011). The volcanic ash aerosol presents a bimodal size distribution (accumulation and coarse mode), whereas the mineral dust has an only one maximum (coarse mode).

The volcanic ash is relatively large (>1 $\mu \text{m}$) and the sulphate resulting from volcanic eruption it is a fine mode, with radius around 0.1 $\mu \text{m}$.

The single scattering albedo ($\omega$) as a function of wavelength is depicted in figure 7. This representation is very useful to identify aerosol types, following the climatology reported by Dubovik [8, 13, 14]. Incident light is scattered and absorbed by the particle. The quantity of the absorbed light is directly related to the single scattering albedo ($\omega$) [15]. If $\omega$ is 1, one considers that the particle only scatters, and in the case that $\omega$ is 0, one concludes that the particle is a perfect absorber. The single scattering albedo is retrieved only then when the aerosol optical depth
decreases with increasing wavelength. On 27th May the single scattering albedo was high (0.85 at 440 nm around 16:07 UTC).

Figure 8 presents the results of continuous measurements of aerosol optical properties from whence is extracted amount of water vapour over Timisoara. On 27 May the water vapour of atmosphere decreases.

Average imaginary part of the refractive index was 0.027 at 440 nm, this value is corresponding for a strong absorption (0.06). The refraction index is dependent on the chemical composition of the particle, the wavelength and relative humidity.

Other model was concerning and proposing for concentration prediction of inorganic airborne pollutants (particle matter with an aerodynamic diameter of 10 µm or less) from a risk area (two industrial areas) and an urban area from Constanta [16]. For Bucharest area was analyzed air pollution (NO₂) using an other method [17].

Conclusions
Volcanic ash intrusion from Grímsvötn volcano in South - East Iceland (64.41 N, 17.33 W) over Timisoara has been analyzed. One demonstrated that by means of sun photometry investigation of the optical, chemical and microphysical properties of volcanic aerosols is possible, generating information about the momentum dispersion situation of a volcanoes plum, originated in the far West of Europe.

The episode is known as generating main disturbances in the air traffic. The results indicate indeed that the data generated by the measurements are informing about the event and the presence over Romania, of different particles (episode on 26th and 28th of May 2011). In the second part of the 28th of May 2011 precipitations occurred, and this is the reason for less recorded data. Values of single scattering albedo < 0.9 lead to warming, while single scattering albedo > 0.9 indicate a cooling of the climate system.

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References
5. OSKARSSON, N., SVERRISDÓTTIR, G. http://earthice.hi.is
7. *** Sun photometer - User Manual, version 4.6

Fig. 9. Forecast model: Met Office London VAAC on 26.05.2011, 00:00GMT [18]

The Met Office London Volcanic Ash Advisory Centre (VAAC) is responsible for the calculation of the ash dispersion by means of atmospheric models and provides forecast guidance up to 24 h for flight. This used a range of technologies (Lidar, Radar) and expertise to predict the movement of volcanic ash [18].

Met Office predicts ash cloud intrusion in North - West Romania at FL 200 (Flight Level) at 00:00 GMT (fig. 9).

SiO₂ concentration on 26 and 27th May had values between 0.6 – 0.8 D.U (Unit Dobson) and was calculated with IASI model [19].

SiO₂ and SO₂ concentration for Grímsvötn area is 14.94 mg / L and respectively 223.79 mg / L reported by [5]. Also it contains a high concentration of Na 47.25 mg / L, Ca 32.17 mg / L and Mg 11.56 mg / L. For Timisoara area it can be observed that accumulation mode is predominant. This mode is specific to atmospheric gases. Due to loading with aerosols can be formed acid rain. Relationships between major ion concentrations and for different ionic constituents and precipitation depth was analyzed for urban and mountain site from Romania [20].

A similar study was completed by Cazacu [21] for the city of Iasi, and Vetres [22] for the Timisoara city.

Based on the experimental data and the analysis, one concludes that on 26-29.05.2011; at the Timisoara station, a special episode occurred, as fine dust of fine volcanic ash was present, dispersed from far away by meteorological conditions.
18. *** http://www.metoffice.gov.uk/aviation/vaac
19. *** http://sacs.aeronomie.be

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