Icelandic Holuhraun plume: balloon borne measurement of aerosol size distribution

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Summary
Volcanic eruptions have enormous societal and economic consequences. In Iceland, one of the best known examples is the Laki eruption (1783-84 CE) which caused the deaths of >20% of the Icelandic populations and likely increased European levels of mortality through air pollution. The recent fissure eruption at Holuhraun (31 August 2014 – 27 February 2015) was a major source of gaseous and aerosol and caused both local and European-wide deteriorations to air quality.

The capability of atmospheric models to predict volcanic impacts is limited by uncertainties in the near-source plume state. Most in-situ measurements of the elevated plume involve interception of more aged plumes that have already chemically or physically evolved, and for this reason, we present balloon borne observations of plume conditions.

The RV Polarstern is a research vessel of the Helmholtz Centre for Ocean Research Kiel (GEOMAR). It is a 65 meter long polar research vessel, operated by the Alfred-Wegener-Institut (AWI) in Bremerhaven, Germany. GEOMAR is part of the Helmholtz Association (Helmholtz-Gemeinschaft), which is a collection of 18 research organizations in Germany.

Eruption overview

Holuhraun “Young” plume state caught by a balloon

Ballon borne results from LOAC

During the balloon ascent, we intercepted two plume layers, 8 km from the crater. The first one is identified as the plume in a non-condensed phase and the second above is the same plume turned in a cloud phase. Altitude, optical properties and particle size distribution for both of these layers is presented, alongside conditions above and below the plume.

Plume altitudes
2 layers measured:
- Condensed phase: From 2.3 to 3.1 ± 0.1 km
- Non-condensed phase: From 2.0 to 2.3 ± 0.1 km

Plume altitude retrieved from LOAC data
LOAC shows an altitude of 5.1 ± 0.1 km above the sea level. Two layers were observed, a non-condensed lower layer and a condensed upper layer. The lower layer of 4000m thick was characterized by a modus of fine particles centered on 0.2µm in diameter and a second modus centered on 2.9 µm. The total particle concentration around 100 particles per cubic centimetre. The upper layer of 4000m thick was a cloud like signal, with droplets centered on 20 µm in diameter and a fine modus, the total particle concentrations 10 times higher than the first layer. The plume top height was determined between 2.7 and 3.1 km, the plume height is in good agreement with an estimate made by modelling of IASI satellite remote sensing data, thus demonstrating in-situ validation of this recent satellite algorithm (Carboni et al. 2015).

This experiment shows that under such difficult field campaign conditions (strong wind, low temperatures, snow, rain and hail, close to the launch site) it is possible to launch meteorological balloons with novel payloads to directly sample in-situ the near-source plume, determine the plume altitude, identify dynamically phases of the plume and document the size distribution of particles inside a plume which is only a quarter of an hour old.

Acknowledgments
- Icelandic Meteorological Office

Eruption key-points:

- Six-month effective eruption duration
- Largest eruption in Iceland for 200 years
- Lava emitted:
  - Total of 1.6 ± 0.3 km³
  - Average of 100 m³/s
- SO₂ emitted:
  - Total of 11 ± 5 Tg
  - Average of 400 kg/s

The altitude given by the Carboni algorithm is closest measurement from the crater is 3.8 ± 0.5 km

The altitude and size of the particles allow us to better understand the source plume, determine the plume altitude for a specific localization

- Balloon instrumentation - LOAC

Measurers at 2 scattering angles (field of view of a few degrees)
- 12°, low sensitivity to the refractive index of the particles (mainly diffraction)
- 60°, strongly sensitive to the refractive index of the particles

Concentration for 18 size classes in the 0.2 – 10 µm diameter range
Weight of 18g: electric consumption of 3 W

SO₂ Dobson units from IASI: Physico-chemical Earth

Comparison with other datasets & flux estimation

Establishing ratios between gas measurements and aerosols is a big challenge. This kind of information can be used in models in order to retrieve the aerosol emissions from a volcano.

Using the concentration measured by LOAC in the non condensed plume phase (from 2.6 to 2.3 km), assuming a relative homogeneity of the plume in time and space (omitting the condensed phase layer) we calculate a ratio of 500 SO₂ mass per number of particles around 10³ – 10⁴ kg/m³ in the near source plume.

Measurements with LOAC and gas sensors on a previous campaign on the Mount Etna by Roberts et al (2015) shows similar ratios of 3LA, but not aerosol particles

We estimated that a total of 6 x 10⁶ volcanic particles in the range of 0.2 to 10 µm have been emitted on the day of the flight and between 10¹⁴ and 10²⁴ particles in the same size range for the whole eruption. This ratio remains highly uncertain due to the constant evolution of aerosols along the plume.

Perspectives

- Tests in Bermuda (South of France) have demonstrated that a LOAC can be deployed by Renard et al (2016). McManus (2008) demonstrated that a smoke-laden plume with SO₂ and CO₂ sensors can fly into a volcanic vents, which Roberts et al (2015) shows good correlation between LOAC particle and volcanic SO₂. The future association of a LOAC with gas sensors on a drone in a volcanic plume can allow to spatially quantify the local volume of plume altitude, plume evolutions and dispersion.

- Flights with a LOAC under meteorological conditions have been made from Reunion Island (diameter between 2.5-150 km) through the stratospheric part of Calbuco plumes. These studies are presented on Louter’s poster session: X.7.1 session: Atmospheric aerosols, volcanic eruptions and their radiative effects (RS 2013-02575-05) (14th April 2016 ROSE)

- Partnership with volcanological offices from France and Iceland has been set up and several instruments are ready to be launched in case of volcanic eruption. The goal is to provide a better knowledge to air traffic regulators on the concentrations and size distributions of aerosols to allow a better knowledge on air traffic risks due to volcanic particles.

Aerial view of the eruption December 2014 Credits: EgillVíknisson


2. References: A. Carboni, D. Ingólfssón, D. Vignelles, E. Ilyinskaya, J. Jerolmack, J. Ruddick, S. Hall, J. Smith, O. Hidalgo, D. Hall, J. Renard, R. Smith, A. Koulakov, A. Boutilier, J. Aspinall, C. Frehaut, and N. Hidalgo, as well as CNRS and the Inter-University Centre for Astronomy and Its Development (CIIA) for their support. The dataset is freely available for scientific purposes upon request to the corresponding author.