Airborne and satellite observations of volcanic ash from the Eyjafjallajökull eruption

Stuart Newman and co-authors

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Photo credit: Arnar Thorisson 17.4.10
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Stuart Newman
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Talk contents

• FAAM aircraft and instrumentation
• Case study from 17 May 2010
• Radiative transfer modelling of infrared spectra
• IASI retrievals of ash mass concentration (ULB)
• Choice of ash refractive index
FAAM aircraft and instrumentation
ARIES interferometer (Bomem MR200)
Radiances: spectral range 550-3000 cm\(^{-1}\)
HgCdTe and InSb detectors
Max. resolution 1 cm\(^{-1}\) (0.5 cm\(^{-1}\) sampling)
Multiple viewing geometries (up and down)
Field of view 44 mrad (full angle)
Table 1: Nominal specifications of the ALS450 lidar system.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitted wavelength</td>
<td>354.7 nm</td>
</tr>
<tr>
<td>Receiver bandwidth</td>
<td>0.36 nm</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>16 mJ</td>
</tr>
<tr>
<td>Pulse repetition Frequency</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>4 ns</td>
</tr>
<tr>
<td>Pulse-to-pulse stability</td>
<td>5–7%</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>2.5 mm (laser), 30 mm (beam exp.)</td>
</tr>
<tr>
<td>Beam divergence</td>
<td>≤ 1 mrad (laser), 0.2 mrad (beam exp.)</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Overlap range</td>
<td>150 m (95%), 300 m (100%)</td>
</tr>
<tr>
<td>Maximum range</td>
<td>user defined, typ. ≤ 15 km</td>
</tr>
<tr>
<td>Integration time</td>
<td>user defined, typ. 5 – 30 s</td>
</tr>
<tr>
<td>N.D. filter optical density</td>
<td>0.7 ‖, 0.3 ⊥</td>
</tr>
<tr>
<td>Channel 0</td>
<td>analog, ‖</td>
</tr>
<tr>
<td>Channel 1</td>
<td>analog, ⊥</td>
</tr>
<tr>
<td>Channel 2</td>
<td>photon count, ‖</td>
</tr>
<tr>
<td>Channel 3</td>
<td>photon count, ⊥</td>
</tr>
<tr>
<td>Flashlamp lifetime</td>
<td>30 · 10^6 shots (415 hours operation)</td>
</tr>
<tr>
<td>Coolant</td>
<td>water, or ethylene glycol 20% solution</td>
</tr>
<tr>
<td>Coolant freezing point</td>
<td>0°C or -8.9°C, respectively</td>
</tr>
<tr>
<td>Eye-safety compliance</td>
<td>EN60825-1</td>
</tr>
</tbody>
</table>
## Particle measuring instrumentation on FAAM BAe 146

<table>
<thead>
<tr>
<th>Particle counter name</th>
<th>Effective size range</th>
<th>Aircraft flown on</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPS/CAS</td>
<td>0.5 – 50 µm</td>
<td>FAAM BAe146-301</td>
</tr>
<tr>
<td>PCASP</td>
<td>0.1 – 3 µm</td>
<td>FAAM all</td>
</tr>
</tbody>
</table>

**CAPS** probe was essential to capture the larger particles
Case study from 17 May 2010
Case study
North Sea event on 17 May 2011

TERRA MODIS imagery
(thanks to Jim Haywood)
SEVIRI
“dust”
RGB imagery
Flight tracks
FAAM and DLR aircraft sampled the same event
Around 98% particles by mass were found in the coarse mode, around 2% in the fine mode.

DLR size distribution has mean diameter of approx. 9.6 μm, larger than estimated by CAS on FAAM BAe 146 (3.6-4.5 μm).

Some support for CAS size distribution from ground-based AERONET retrievals.
Lidar: Franco Marenco
Radiative transfer modelling of infrared spectra
Radiative transfer modelling

- **Infrared airborne radiances**: use Havemann-Taylor Fast Radiative Transfer Code (HTFRTC). Based on singular value decomposition of spectral information to speed up calculations. Ability to treat scattering by clouds and aerosol particles.

- **IASI mass retrievals**: code developed at ULB. Optimal estimation for simultaneous retrieval of trace gases, aerosol size and concentration. Treats multiple scattering in spherical geometry.
Can we model the infrared ash signature?

Lidar extinction profile has been used as input to forward calculation along with representative temperature and humidity profiles. Aerosol properties are based on measured size distribution and dust refractive index due to Balkanski et al. (2007)

Agreement is (surprisingly) good

Increasing ash concentration

(a) Irish sea, lidar O.D. = 0.06

(b) North sea, lidar O.D. = 0.28

(c) North sea, lidar O.D. = 0.61
ARIES: mineral dust refractive index is a better match than andesite or obsidian for 17 May 2010

IASI: mineral dust refractive index is a good match here too

<table>
<thead>
<tr>
<th>Name</th>
<th>RMS of residual (in W m(^{-2}) m sr(^{-1}))</th>
<th>Mass (in % of first)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral Dust</td>
<td>5.5 (10^{-6})</td>
<td>100</td>
<td>Balkanski et al., 2007</td>
</tr>
<tr>
<td>Obsidian</td>
<td>7.2 (10^{-6})</td>
<td>79</td>
<td>Pollack et al., 1973</td>
</tr>
<tr>
<td>Basalt</td>
<td>1.6 (10^{-5})</td>
<td>65</td>
<td>Pollack et al., 1973</td>
</tr>
<tr>
<td>Andesite</td>
<td>1.5 (10^{-5})</td>
<td>63</td>
<td>Pollack et al., 1973</td>
</tr>
<tr>
<td>Pumice</td>
<td>1.4 (10^{-5})</td>
<td>73</td>
<td>Volz, 1973</td>
</tr>
<tr>
<td>Rained out dust</td>
<td>1.5 (10^{-5})</td>
<td>159</td>
<td>Volz, 1973</td>
</tr>
</tbody>
</table>

Spectral residual of fit to IASI observations
IASI retrievals of ash mass concentration
IASI ash retrievals

ULB IASI ash mass loadings (g/m²) for 17 May am and pm overpasses

Lidar and IASI distribution of column loadings over same advected part of ash plume area
Choice of ash refractive index
Why does mineral dust refractive index match ash cloud spectra?

- Large particles are dominated by silicates on 17 May 2010
- This is less evident on 2 May 2010
Summary and conclusions

• Airborne and satellite infrared radiances can be accurately modelled based on the in situ measured size distribution and a mineral dust refractive index

• Retrievals of ash mass column loading using IASI observations are in accord with lidar-derived mass estimates, giving a verification for the hyperspectral ash retrieval method

• Modelling of ARIES and IASI ash-affected spectra demonstrates the importance of accurately specifying the refractive index

• There is evidence that the composition of airborne ash from the Eyjafjallajökull eruption varied within the same event

• It was recognised in the UK that there is a requirement for a well instrumented airborne facility to be able to monitor ash concentrations – the Met Office now operates a twin piston engine aircraft for civil contingency use
Questions and answers
Other eruptions: Puyehue in Chile and Grímsvötn in Iceland as seen by IASI
But ash particles are NOT spheres!

Electron microscope images of ash collected on filters during FAAM flight B526
But ash particles are NOT spheres!

SID2h scattering patterns for hydrated sea-salt aerosol (spherical)
• Other refractive indices: Balkanski mineral dust gives best agreement

• Other choices (andesite and obsidian) fail to match observations
ARIES looking up under the ash…

With scaled extinction profile agreement of simulation with measured brightness temperature is good
Aerosol scattering properties

Aerosol refractive index

Representative particle size distribution

Mie theory

Scattering properties at IR wavelengths

Normalised extinction

Single scattering albedo

Asymmetry parameter

(calculations by Ben Johnson)