Validation of retrieved volcanic ash properties from the Infrared Atmospheric Sounding Interferometer (IASI)

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Introduction

Interest in the ability to detect and characterise volcanic ash plumes has increased following the eruption of Eyjafjallajökull. The characteristics of the IASI instrument make it a useful tool for the observation of larger aerosol particles (e.g. desert dust and volcanic ash) and the tracking of volcanic plumes. To retrieve the properties of ash plumes, IASI brightness temperature spectra are analysed using an optimal estimation retrieval scheme. Here we present results for the Eyjafjallajökull and Grimsvötn eruptions, along with a method of validating the retrieved parameters using the CALIOP instrument and FAAM aircraft.

Optimal Estimation Retrieval Algortihm

- An ash detection procedure, based upon departures of IASI spectra from an expected background covariance, is carried out on each IASI pixel. If the pixel contains a positive ash (or SO_2) signal then the full retrieval is subsequently calculated.
- The IASI brightness temperature spectra are analysed using optimal estimation, which aims to minimise the cost function,

$$\chi^2 = [\mathbf{y} - \mathbf{F}(\mathbf{x},\mathbf{b})]^{\mathrm{T}} \mathbf{S}_y^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x},\mathbf{b})] + [\mathbf{x} - \mathbf{x}_a]^{\mathrm{T}} \mathbf{S}_a^{-1} [\mathbf{x} - \mathbf{x}_a]$$

where y is the measurement vector, F(x,b) is the forward model, x is the state vector, S_y and S_a are the measurement and *a priori* error covariance matrices.

- A best estimate of the state vector is produced with a full error budget:

$$\mathbf{S}_x = \left(\mathbf{K}^{\mathrm{T}} \mathbf{S}_\epsilon^{-1} \mathbf{K} + \mathbf{S}_a^{-1}\right)^{-1}$$

- The forward model is based on RTTOV; the RTTOV output for a clean atmosphere (containing atmospheric gases but not cloud or aerosol/ash) is combined with a single ash layer using the same scheme as for the Oxford-RAL Retrieval of Aerosol and Cloud (ORAC) algorithm (Thomas *et al.* 2009).

- Retrieved Parameters: Ash Optical Depth (AOD) at 550nm
  Effective Radius, R_{eff} [µm]
  Plume Altitude, h [mb]
  Surface Temperature, T_s [K]

Measurement Error Covariance Matrix

Figures 1 and 2. The covariance matrices created using IASI data from clear-sky and cloudy scenes respectively, for the latitude band 30°N-60°N.

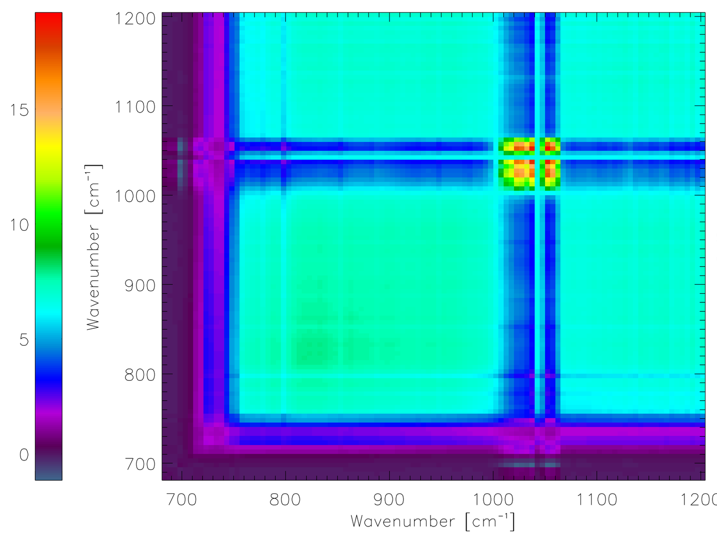


Figure 1

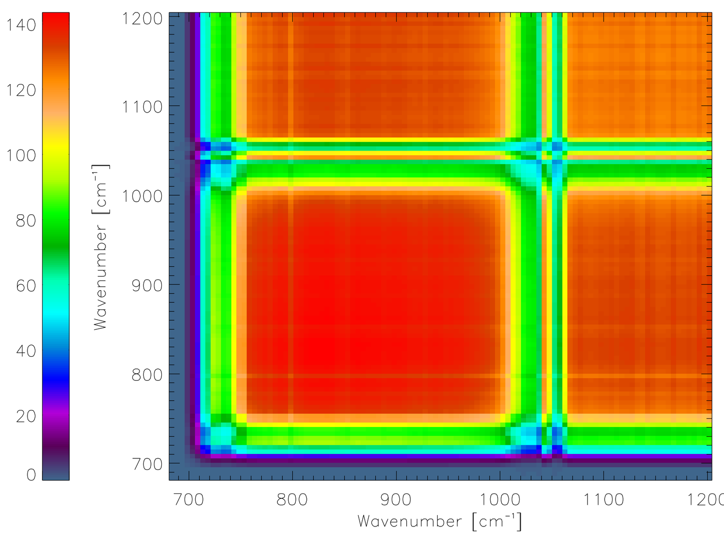


Figure 2

- S_y is built up from an ensemble of difference spectra, which capture the spectral variability between the IASI data and the simulated radiative transfer model calculations, for example, the impact of clouds or errors in the spectroscopy or atmospheric profiles.
- Separate covariance matrices are created using clear-sky and cloudy scenes.
- Initially, the retrieval uses the `clear' covariance. However, if the output does not pass the quality control, the retrieval is repeated with the `cloudy' covariance.

Comparisons to aircraft observations

- Retrieved values of effective radius are compared to in situ airborne observations taken by the FAAM and DLR operated aircraft on 17th May 2010.
- Values given in Turnbull *et al*. (2012) for the geometric mean diameter and spread have been converted to effective radius, combining the fine and coarse particle modes, and are shown in Table 1.
- Figure 3 shows the peak R_{eff} retrieved for the same scene compares well to the aircraft measurements.

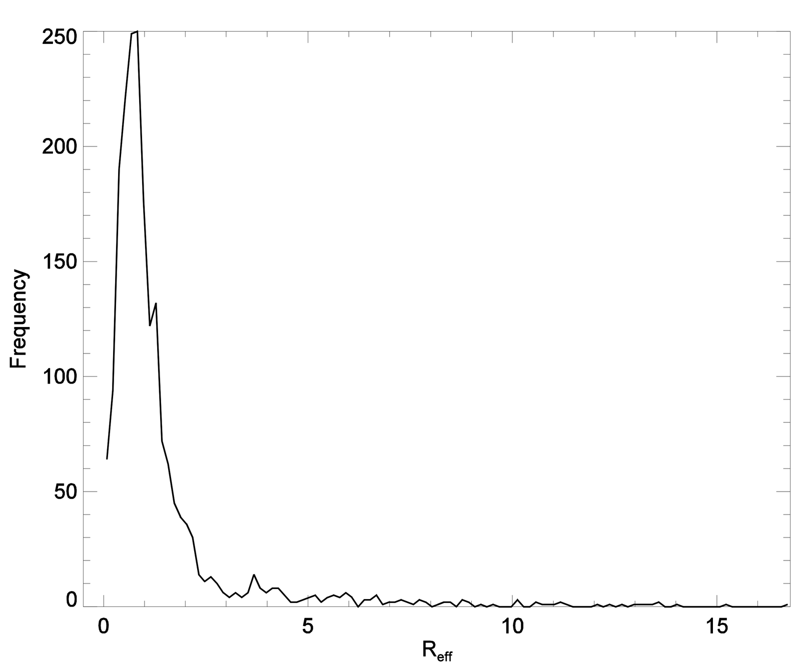


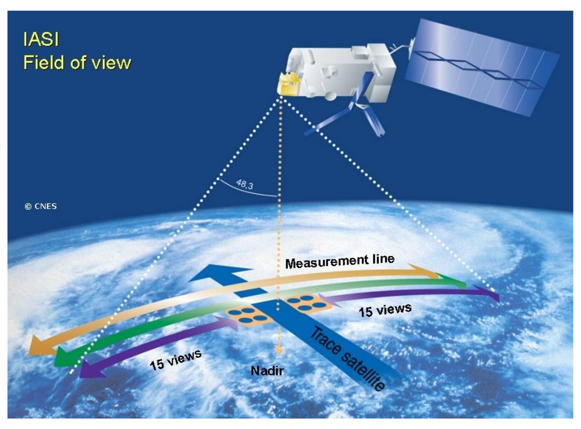
Figure 3. A histogram of the retrieved values of R_{eff} for each IASI pixel on 17th May 2010.

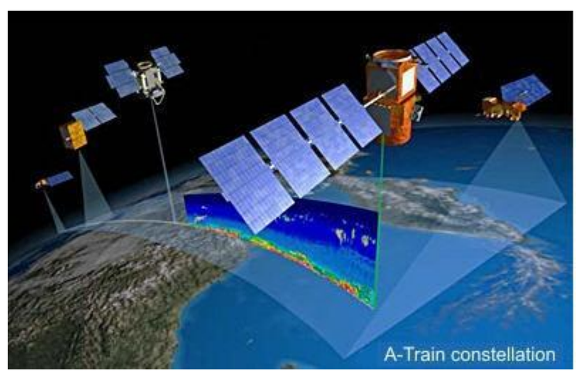
	FAAM Irregulars	FAAM Spheres	FAAM as DLR Case M	DLR Case M	IASI
Reff	0.87	0.98	1.19	1.12	0.83

Table 1. The effective radius measured by the FAAM and DLR aircrafts , and the retrieved IASI value for the same scene.

IASI (Infrared Atmospheric Sounding Interferometer)

- Nadir viewing Fourier Transform Spectrometer
- Onboard MetOp-A and MetOp-B
- Spectral Range: 645 to 2760 cm^{-1} (3.62–15.5µm)
- Spectral Resolution: 0.25 cm^{-1} (unapodised)
- FOV: 2x2 matrix of 12 km (diameter) circles
- Each IASI instrument provides near global coverage every 12 hours





CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization)

- Two wavelength polarization sensitive lidar
- Spatial Resolution: 333m
- Vertical Resolution: 30-60m
- Backscatter at 532nm and 1064nm

Comparisons to CALIOP

- Retrieved IASI plume altitudes are compared to cloud-top heights from CALIOP
- The CALIOP height is calculated as the altitude at which atmospheric extinction passes a given threshold, see Figure 4.
- Colocation is assumed if measurements are within 50 km and 1.5 hrs of each other

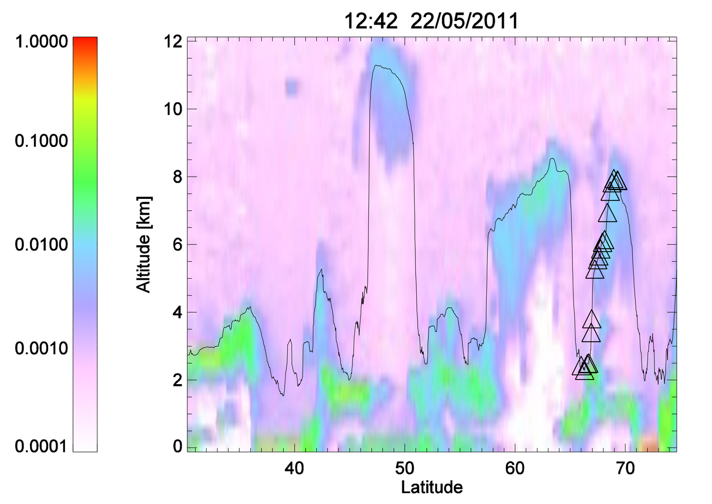
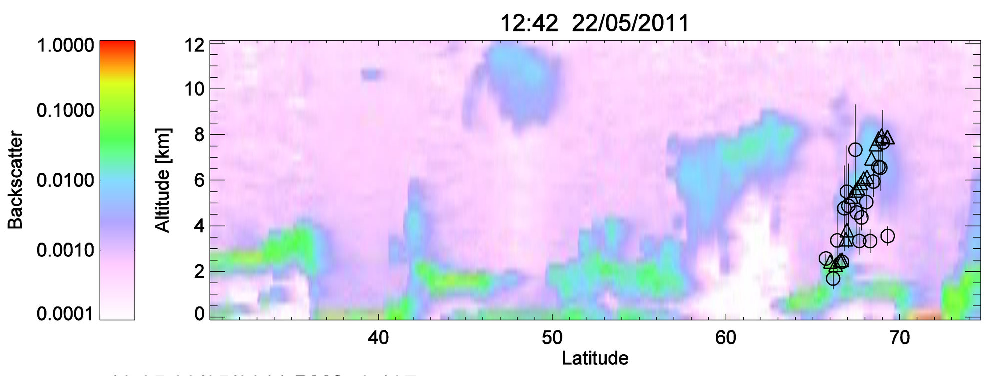
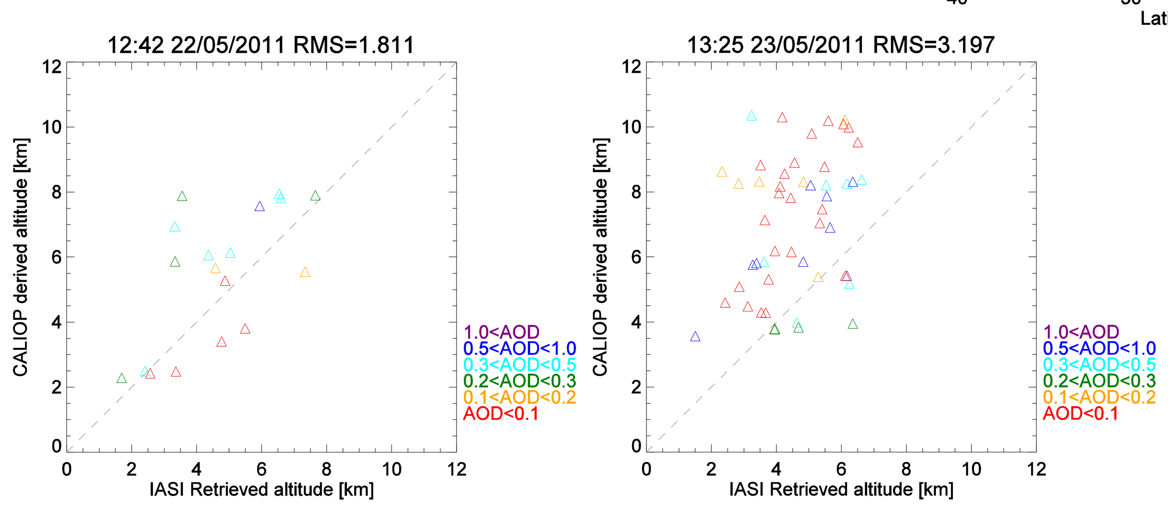


Figure 4. Example of the plume height derived from a CALIOP scene (solid line). Triangles indicate colocation with an IASI pixel.

Grimsvötn

Figure 5. CALIOP backscatter profiles with retrieved IASI altitudes (circle) and CALIOP derived altitude (triangle) for 22th May 2011

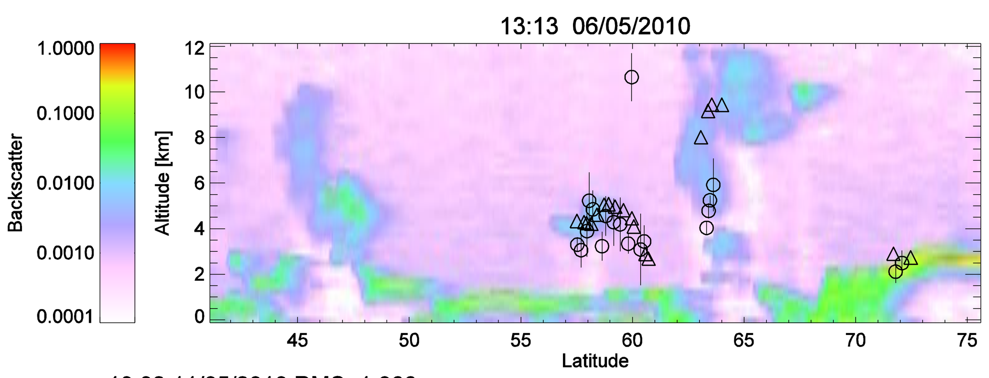


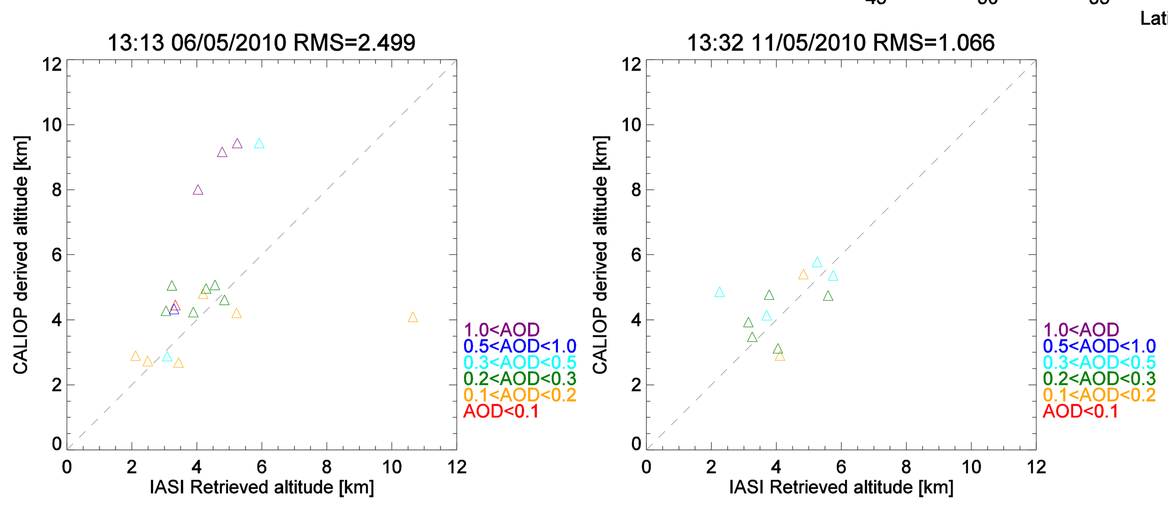


Figures 6 and 7. Examples of IASI/CALIOP altitude comparisons for scenes during the Grimsvötn eruption

Eyjafjallajökull

Figure 8. CALIOP backscatter profiles with retrieved IASI altitudes (circle) and CALIOP derived altitudes (triangle) for 6th May 2010





Figures 9 and 10. Examples of IASI/CALIOP altitude comparisons for scenes during the Eyjafjallajökull eruption

Conclusions

- We have a working retrieval algorithm producing estimates of AOD, R_{eff} and plume altitude with associated errors.
- Despite temporal differences in the measurements, comparisons to CALIOP have proved promising and a metric has been created which can be used to test future improvements made to the retrieval.
- Work is still needed to improve the retrieved IASI height for thin ash plumes over meteorological water cloud.
- Values of effective radius compare favourably to aircraft measurements despite their sensitivities to particles of different sizes.

References

1. Thomas, G.E, E Carboni, A.M. Sayer, C.A. Poulsen, R. Siddans, R.G. Grainger, Oxford-RAL Aerosol and Cloud (ORAC): aerosol retrievals from satellite radiometers, in Satellite Aerosol Remote Sensing Over Land, Springer Verlag (2009)

2. Turnbull, K., B. Johnson, F. Marenco, J. Haywood, A. Minikin, B. Weinzierl, H. Schlager, U. Schumann, S. Leadbetter, and A. Woolley, A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 1. In situ airborne observations, J. Geophys. Res., 117 (2012)