Retrieving volcanic ash properties from 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 eruption with methods to validate the retrieved parameters using MODIS, CALIOP and the FAAM aircraft. (Ventress *et al*., 2016, submitted to *Atmos. Chem. Phys.*)

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,

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

  where **y** is the measurement vector, **F**(**x**,**b**) is the forward model, **x** is the state vector, $\mathbf{S}_y$ and $\mathbf{S}_a$ are the measurement and *a priori* error covariance matrices.
- A best estimate of the state vector is produced with a full error budget:

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

- 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]

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 that the peak R_{eff} retrieved for the same scene compares well to the aircraft measurements.

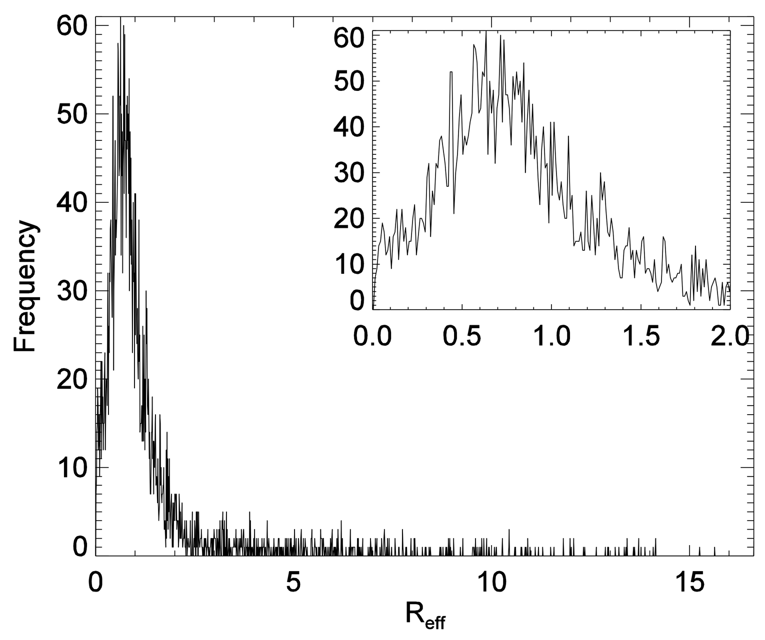


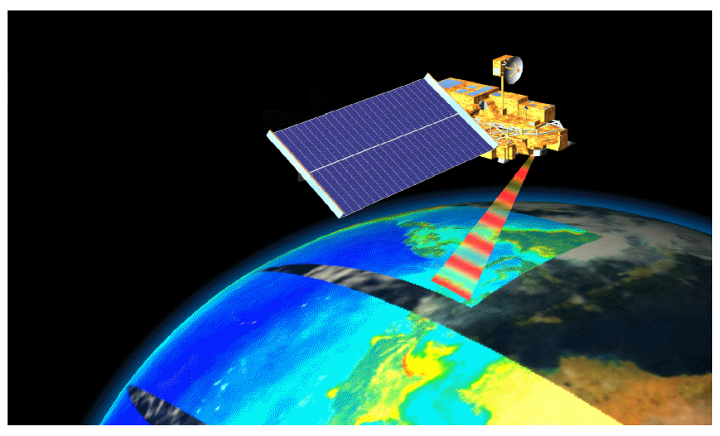
Figure 3. A histogram of the retrieved values of R_{eff} for each IASI pixel on 17th May 2010.

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

Table 1. The effective radius measured by the FAAM and DLR aircrafts.

MODIS (MODerate-resolution Imaging Spectroradiometer)

- Onboard NASA Terra and Aqua
- 36 bands from 0.41-15µm
- Spatial resolution: 250m (2bands), 500m (5bands), 1km (29bands)
- Swath width: 2330km



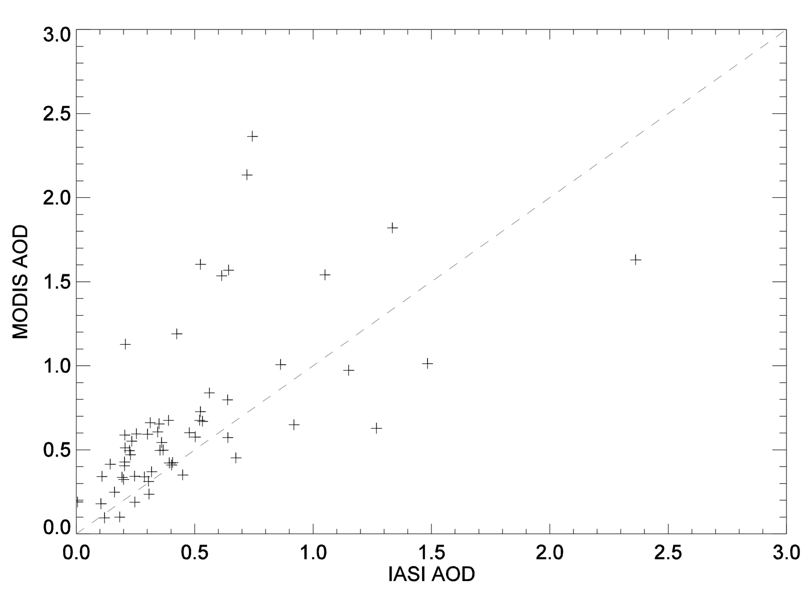


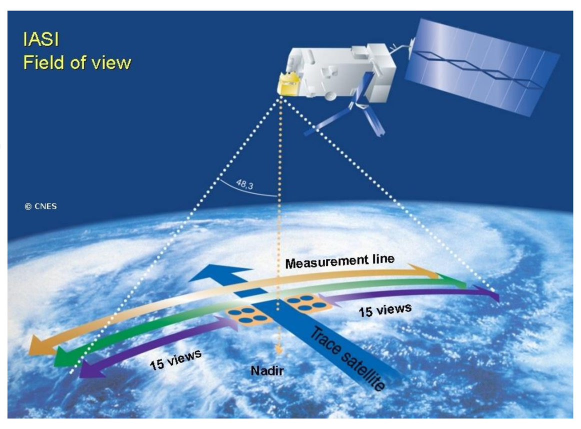
Figure 8. Comparisons of AOD at 11µm retrieved from IASI and MODIS Terra.

Comparisons to MODIS

- AOD retrievals from MODIS Terra, computed using the ORAC algorithm (Thomas *et al.* 2009), are compared to the IASI retrievals.
- Results of AOD at 11µm are shown in Figure 8 for the Eyjafjallajökull eruption.
- MODIS results were aggregated to IASI resolution. All pixels must have been flagged as ash and within 1hr and 50km of IASI pixel.
- The RMS for all points is 0.46, but reduces to 0.2 (for AOD<1) and 0.15 (for AOD<0.5).

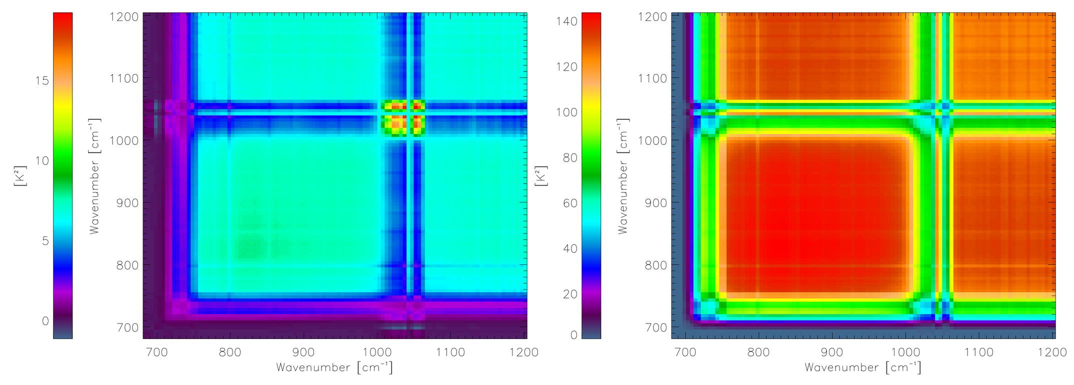
IASI (Infrared Atmospheric Sounding Interferometer)

- 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

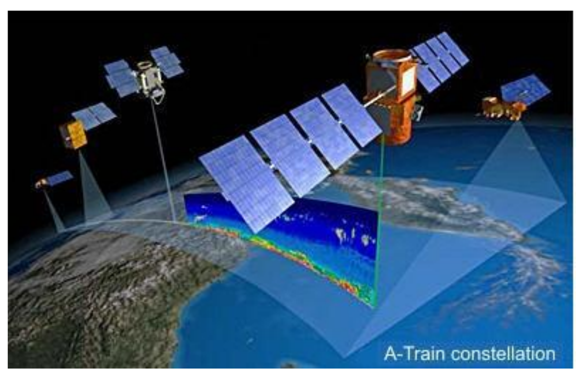


Measurement Error Covariance Matrix

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



- $\mathbf{S}_y$ is built up from an ensemble of difference spectra to capture the spectral variability between IASI data and simulated radiative transfer model calculations, e.g. the impact of clouds or errors in the spectroscopy or atmospheric profiles.
- The retrieval uses the clear covariance. However, if the output does not pass quality control, the retrieval is repeated with the `cloudy' covariance.



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.

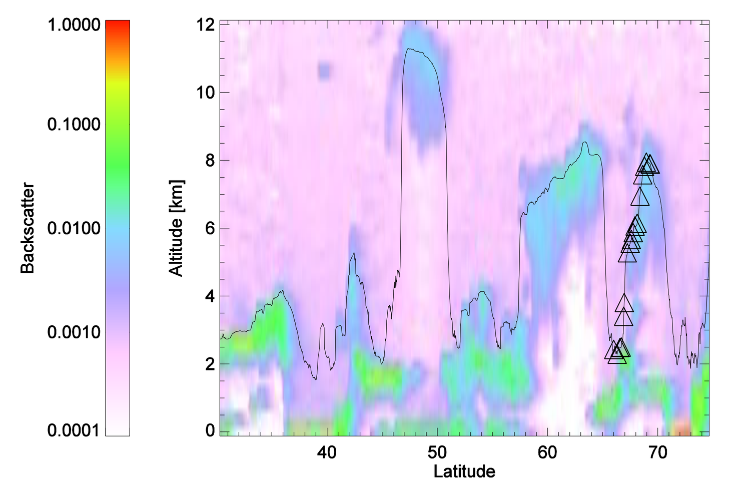
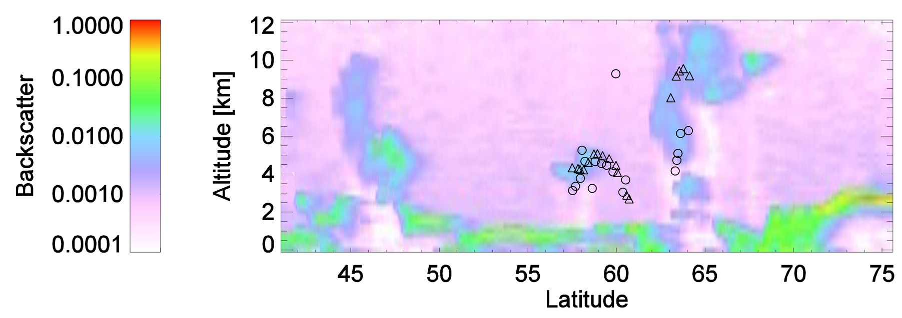


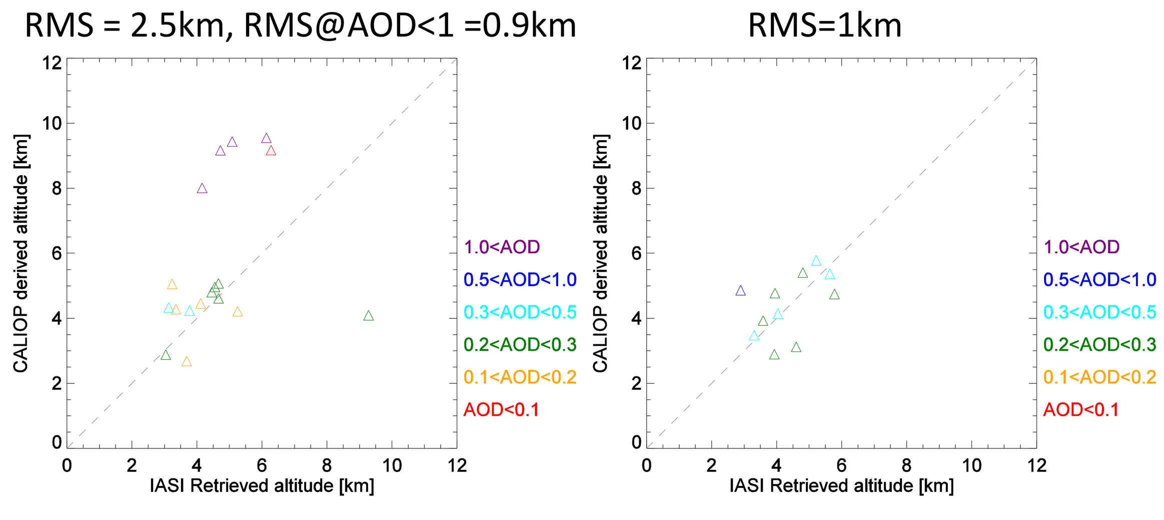
Figure 4. Example of the plume height derived from a CALIOP scene (solid line). Triangles indicate colocation with an IASI pixel.

Eyjafjallajökull

Figure 5. CALIOP backscatter profiles with retrieved IASI altitudes (circle) and CALIOP derived altitudes (triangle) for 6th May 2010.



RMS = 2.5km, RMS@AOD<1 =0.9km   RMS=1km



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

Conclusions

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

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)