The retrieval of 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 plume altitude using the CALIOP instrument.

Optimal Estimation Retrieval Algorithm

- 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).
- S_y is built up from an ensemble of difference spectra, which capture the variability between the IASI data and the radiative transfer model calculations, i.e. S_y contains the spectral variability caused by any inability of the forward model to correctly simulate the IASI measurements, for example, errors in the spectroscopy or errors in the atmospheric profiles.

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

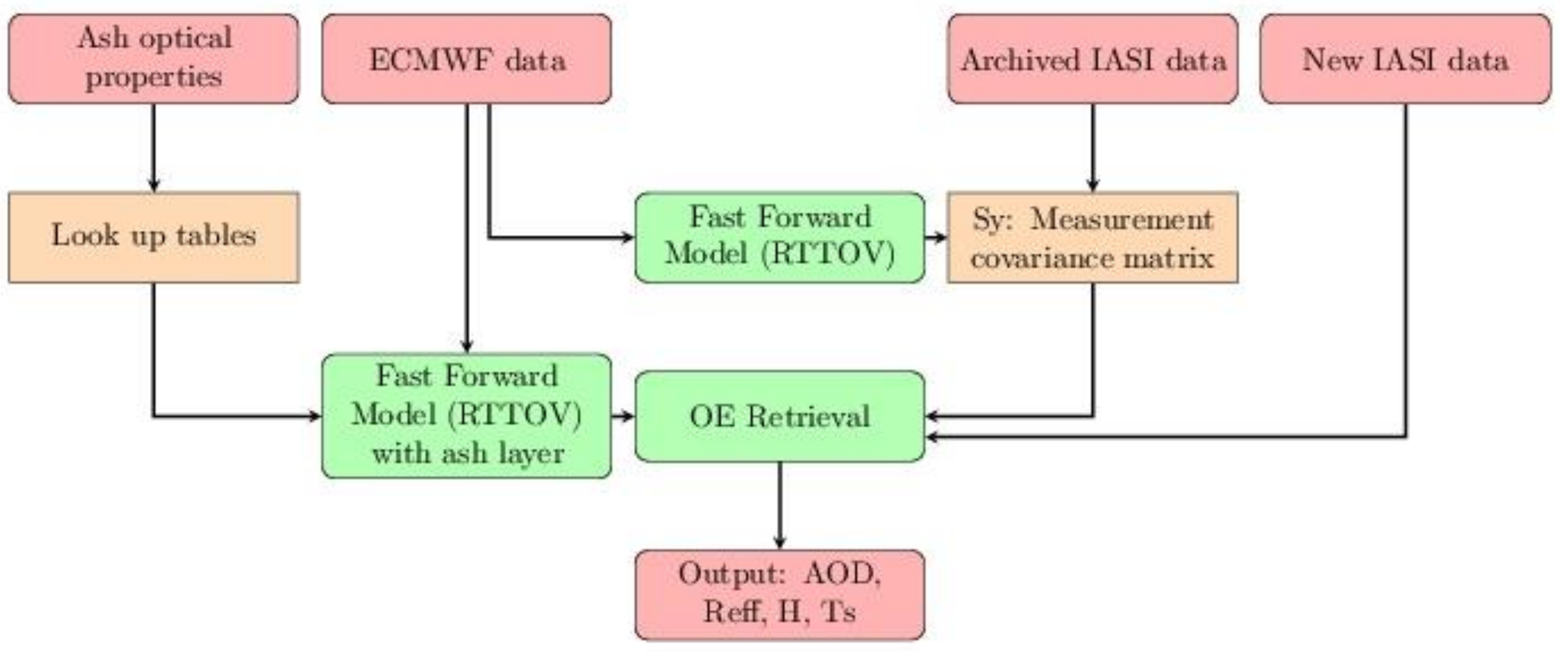


Figure 1. Flow chart outlining the key features of the retrieval scheme

Example: Grimsvötn Eruption 23rd May 2011

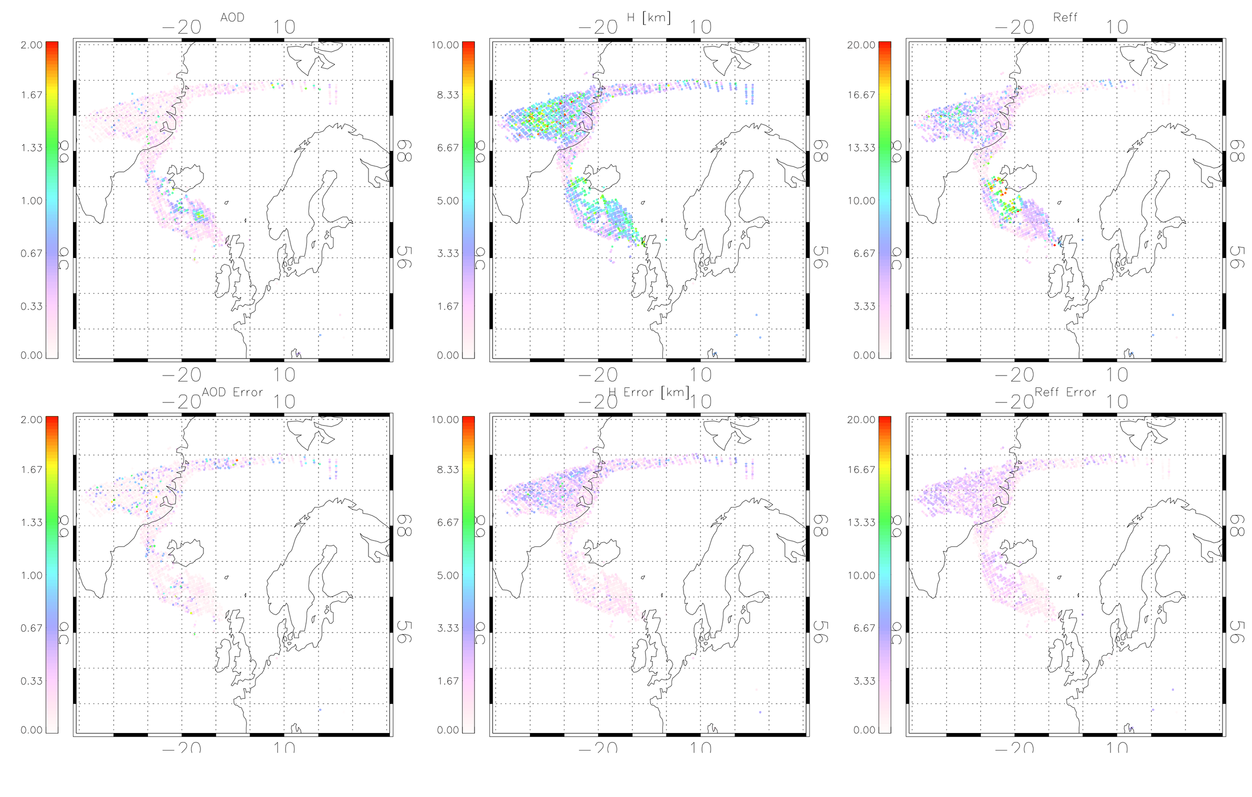
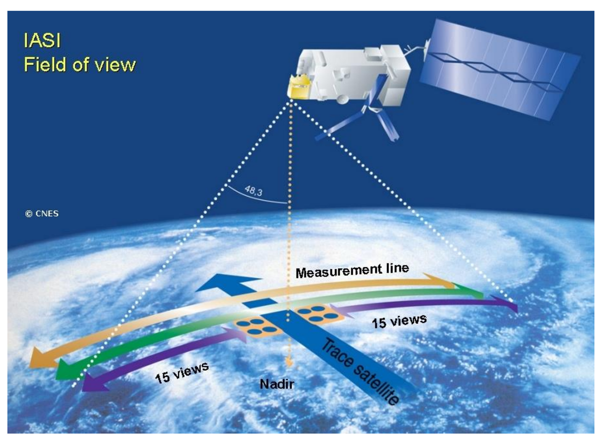
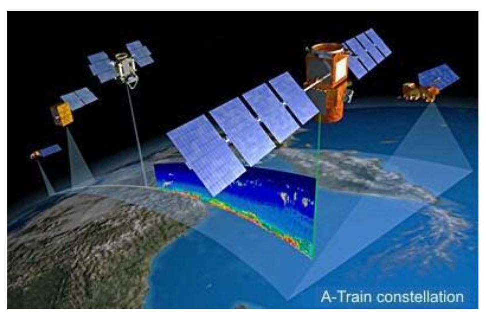


Figure 2. Example of the retrieval products and their associated errors for the 23rd May 2011

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) pixels
- 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
- Colocation is assumed if measurements are within 50 km and 1.5 hrs of each other

Eyjafjallajökull

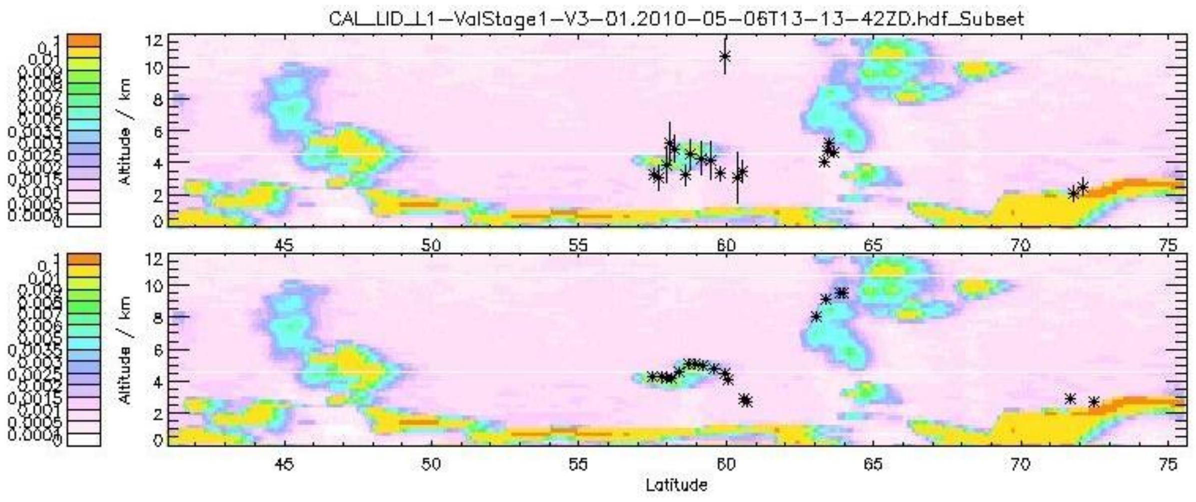
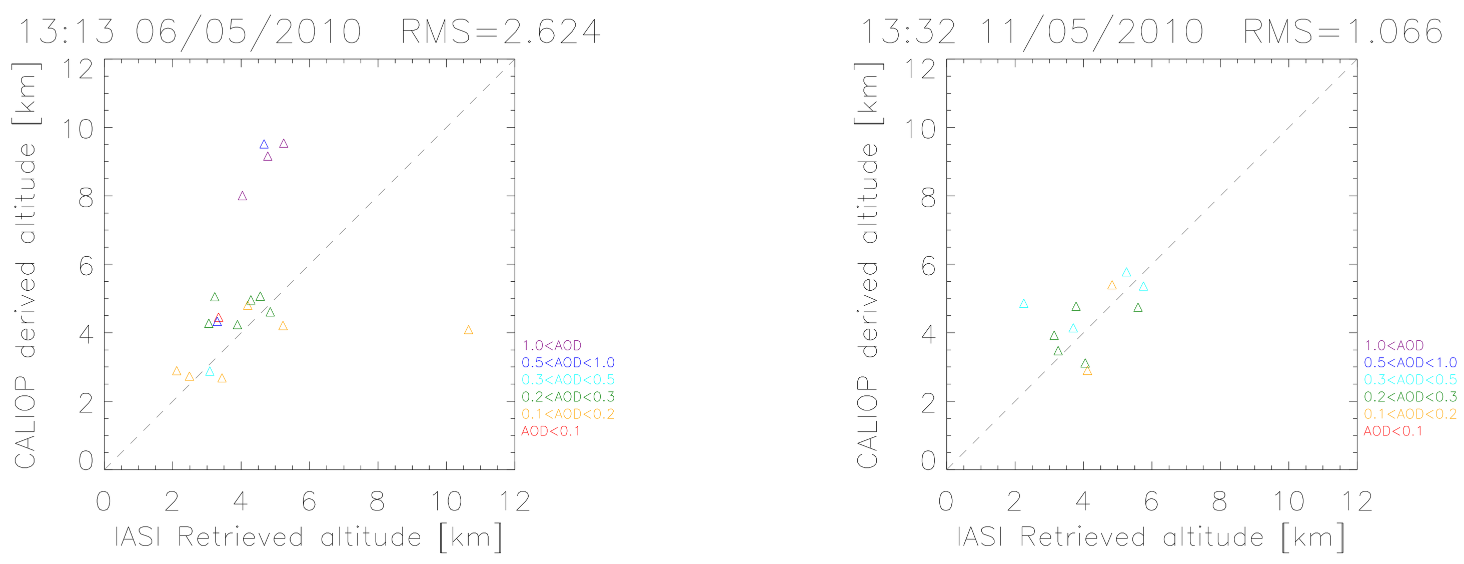


Figure 3. CALIOP backscatter profiles with retrieved IASI altitudes (top) and CALIOP derived altitudes (bottom) for 6th May 2010



Figures 4 and 5. Examples of IASI/CALIOP altitude comparisons for scenes during the Eyjafjallajökull eruption

Grimsvötn

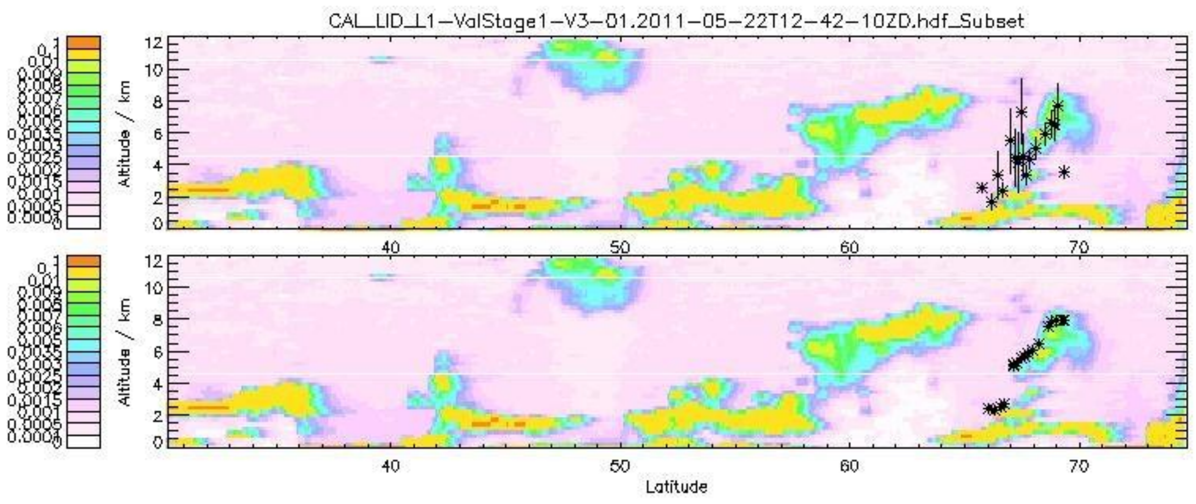
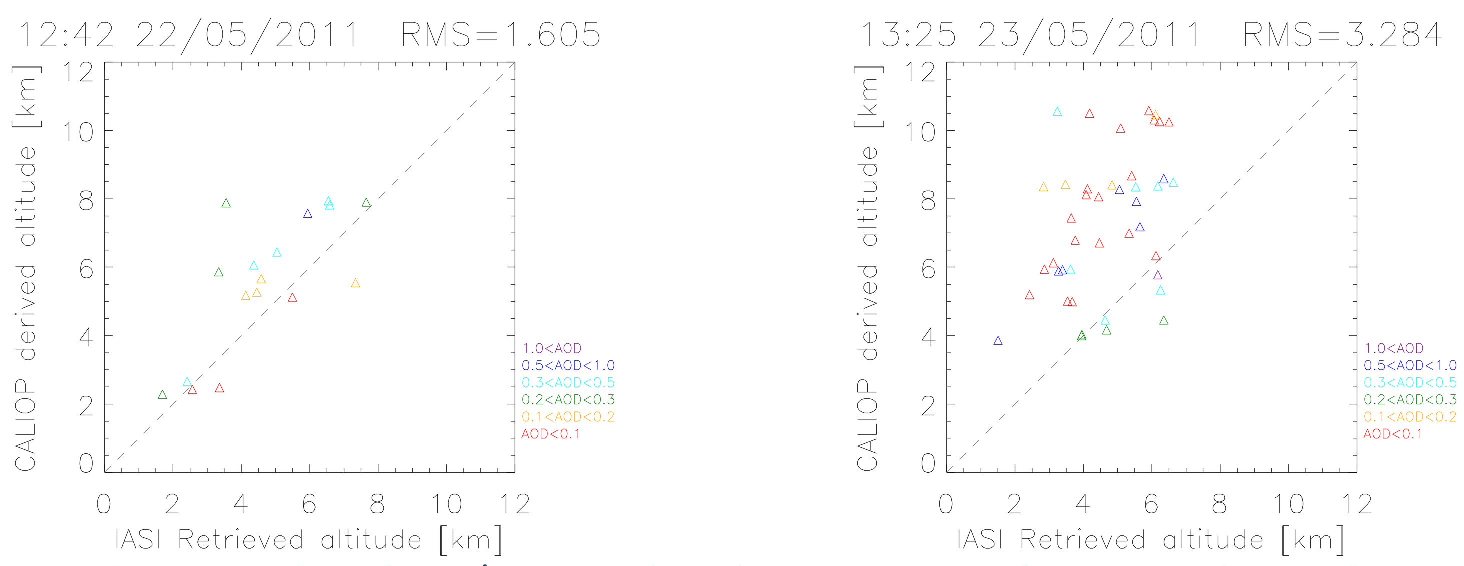


Figure 6. CALIOP backscatter profiles with retrieved IASI altitudes (top) and CALIOP derived altitude (bottom) for 22nd May 2011



Figures 7 and 8. Examples of IASI/CALIOP altitude comparisons for scenes during the Grimsvötn 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.

References

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)