A new sulphur dioxide retrieval from IASI: results for recent eruptions and possible volcanic degassing.

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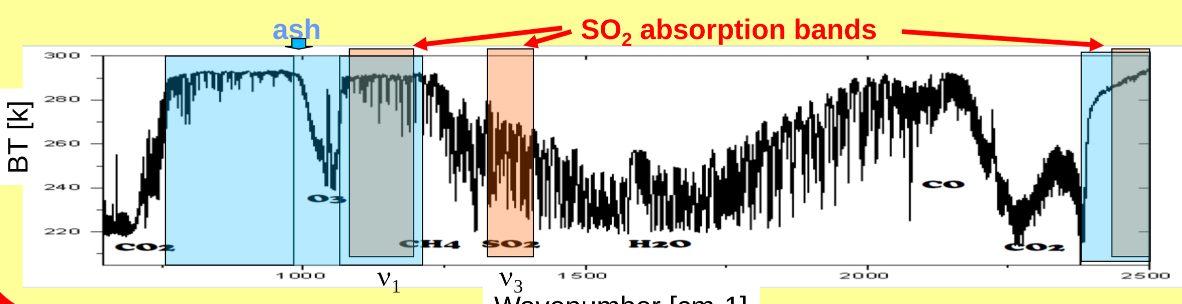
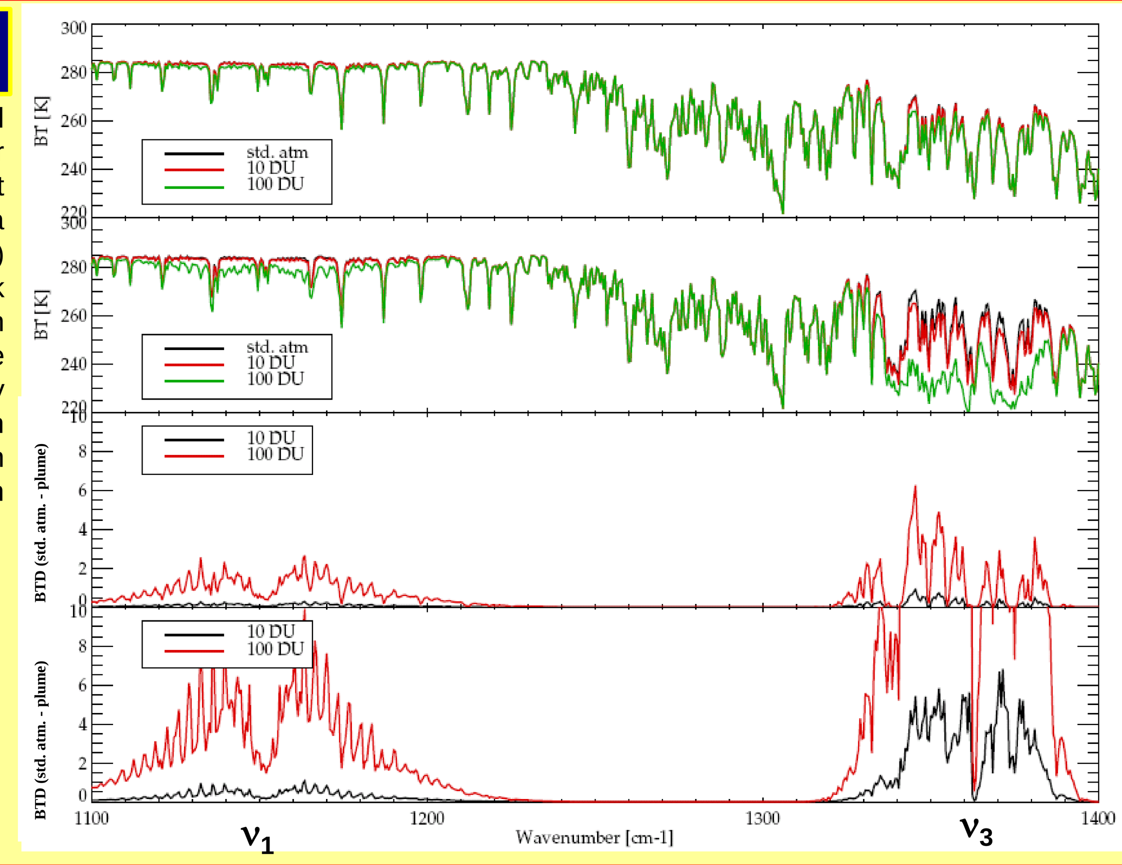
ABSTRACT: The results from a new algorithm for the retrieval of sulphur dioxide (SO_2) from the Infrared Atmospheric Sounding Interferometer (IASI) data will be presented. This retrieval scheme determines the column amount and effective altitude of the SO_2 plume with high precision (up to 0.3 DU error in SO_2 amount if the plume is near the tropopause) and can retrieve information in the lower troposphere.
The scheme uses the IASI channels around the ν1 and ν3 SO_2 absorption bands centred at about 7.3 and 8.7 microns (i.e. the spectra between 1000-1200 and 1300-1410 cm^{-1}). The retrieval assumes a Gaussian distribution for the vertical SO_2 profile and returns the SO_2 column amount and the altitude of the plume. The scheme is based on the optimal estimation (OE) method (Rodgers, 2000). Within this scheme simulated spectra (constructed using a forward model) are compared with measured spectra. The simulations are based on RTTOV (Saunders et al.,1999) and ECMWF meteorological data.
A comprehensive error budget for every pixel is included in the retrieval. This is derived from an error covariance matrix that is based on the SO_2-free climatology of the differences between the IASI and forward model spectra. Within the simulation of the IASI spectra it is possible to include a cloud or ash layer. This feature is used to illustrate: (1) it is possible to discern if ash (or other atmospheric constituents not included in the climatological variability) affect the retrieval using quality control based on the fit of the measured spectrum to the forward model spectrum; (2) the SO_2 retrieval is not affected by underlying cloud. In this work we present the results for recent volcanic eruptions (Monserrat, Eyjafjallajokull, Grimsvotn, Puyehue, Nabro, Etna) and compare the results against other satellite data.
Finally we will demonstrate the potential to monitor quiescent degassing from some volcano.

Infrared Atmospheric Sounding Interferometer - IASI

IASI in on board of METeorological OPerational satellite program (METOP), an European meteorological satellite that is operational from 2007. METOP is the first of three polar satellite system (EPS) that will cover fourteen years. It cross the equator at the local time of 9.30 am. IASI is a Fourier transform spectrometer, that measures the spectral range 645 to 2760 cm^{-1} (3.62−15.5μm) with a spectral sampling of 0.25 cm^{-1} and a apodised spectral resolution of 0.5 cm^{-1}. Radiometric accuracy 0.25-0.58K. The IASI field of view (FOV) consists of four circles of 20 km diameter (at nadir) inside a square of 50 x 50 km, step-scanned across track (30 steps). It has a 2000 km swath and nominally can achieved the **global coverage in 12 hours** (although there are some gaps between orbits at the equatorial tropical latitudes). Radiances are collocated with the Advanced Very High Resolution Radiometer (AVHRR) that can be potentially useful, with complementary visible/near infrared channel, for cloud and aerosol retrieval. IASI make nadir observation of the earth simultaneously with Global Ozone Monitoring Experiment (GOME-2) also on board of METOP. GOME-2 is an UV spectrometer that contain also the SO_2 signature in the UV absorption band and have been used for both DOAS and Optimal estimation retrieval of SO_2.



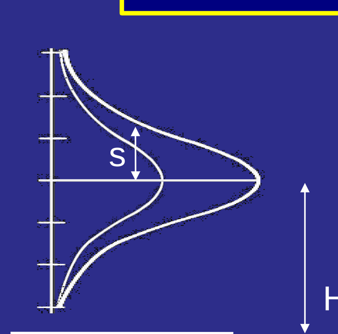


The 7.3 μm feature (ν_3) is the strongest, it is inside a strong water vapour absorption band and so:
(1) it is not very sensitive to surface and the lower atmospheric layer;
(2) the different spectral shapes of the water vapour and SO_2 absorption features provide valuable information on the vertical profile of SO_2.

The 8.7 μm absorption feature (ν_1) contains SO_2 information also in the case of lower tropospheric plumes. It is in an atmospheric window (relatively high transmittance to the surface), but by itself does not contain significant spectral information about the plume altitude or plume profile. Nevertheless, it is probably the most useful region for monitoring those volcanoes characterized by continuous quiescent degassing.

- **IASI is sensitive to both the amount of SO_2 and the altitude of the plume, amount and altitude have different spectral signature => we attempt to retrieve both**
- **Note that getting the altitude correct is important not just for itself, but also in order to get the correct *amount* of SO_2, since the signal depends strongly on altitude.**

Retrieval scheme



State vector:
- Total column amount of So2
- Altitude H
- ~~Thickness~~ s
- Surface temperature Ts

\+ ECMWF profile (temperature, h2o, p, z)

F(x) Forward model: fast radiative transfer (RTTOV + SO2 RAL coefficients)

IASI simulated spectra

IASI measurements → OE retrieval

$$J = (\mathbf{y} - F(\mathbf{x}) - \mathbf{b})^T \mathbf{S}_\epsilon^{-1} (\mathbf{y} - F(\mathbf{x}) - \mathbf{b}) + (\mathbf{x} - \mathbf{x}_a)^T \mathbf{S}_a^{-1} (\mathbf{x} - \mathbf{x}_a)$$

y is the measurement vector, **x** the state vector, **F(x)** forward model, **Sy** error covariance matrix

best estimate of stare vector: SO2 amount, plume altitude, Ts

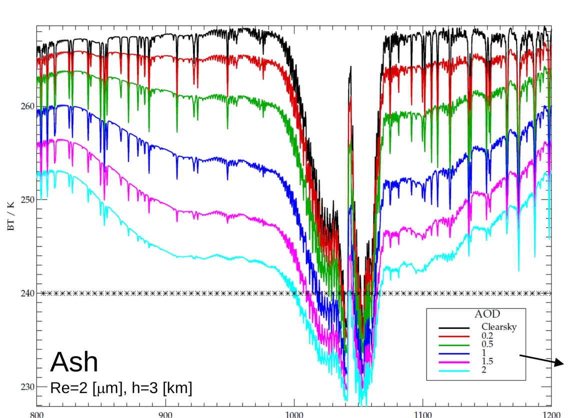
$$S_y(i,j) = \langle (y_{mi}-y_{si})-\overline{(y_{mi}-y_{si})} \rangle \langle (y_{mj}-y_{sj})-\overline{(y_{mj}-y_{sj})} \rangle$$

$y_s = F(SO_2=0)$

Sy Computed with billions pixels

We compute the error covariance $\mathbf{S_y}$ using similar conditions but when we know there is no SO_2 in the atmosphere. This will give an error covariance which allows deviations due to cloud and other trace-gases but still enables the SO_2 signature to be detected.

Ash and cloud effects?



To test if the retrieval is sensitive to ash/cloud etc...

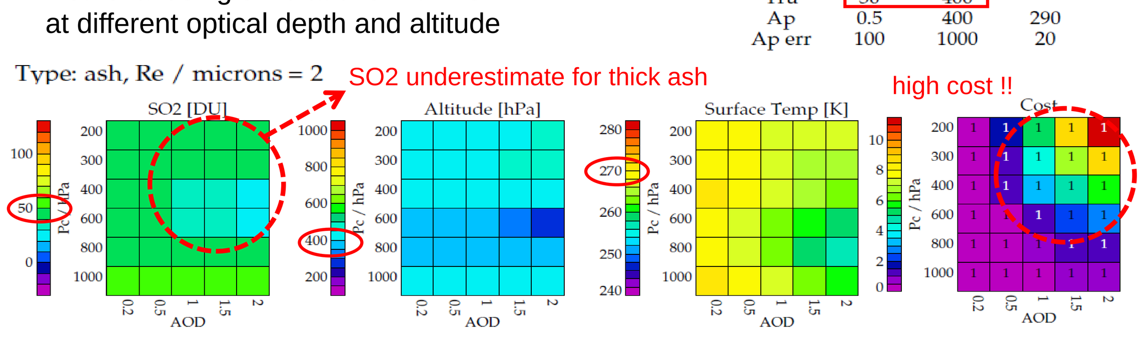
IASI forward model can include aerosol and cloud.

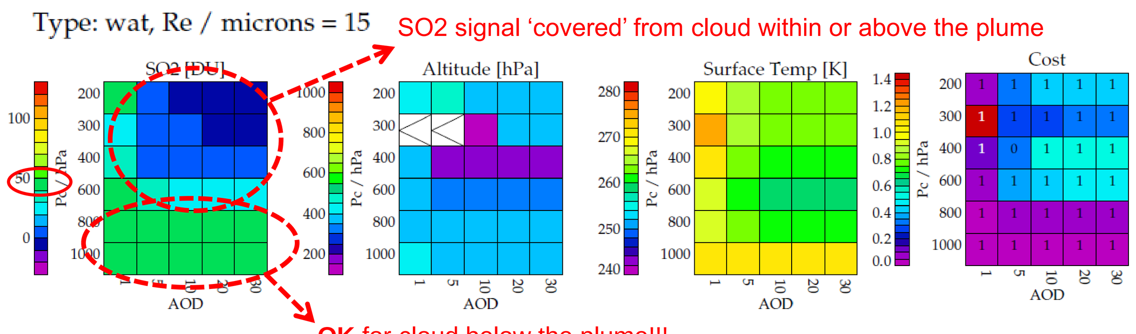
Obtained with refractive index measured by Daniel Peters (see poster VA-5).

Sensitivity of retrieval to presence of ash and cloud

Retrieval using simulations with ASH at different optical depth and altitude

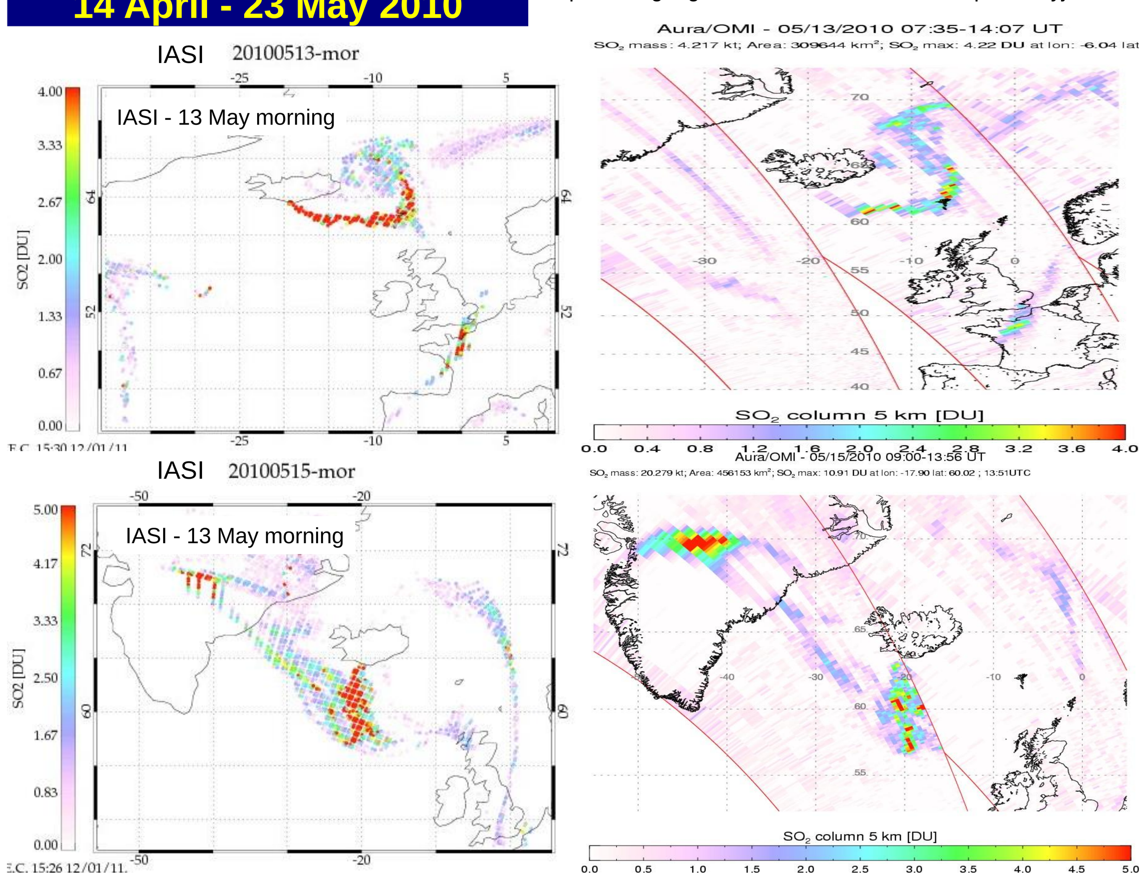
	DU	hPa	T [K]
Tru	50	400	290
Ap	0.5	400	290
Ap err	100	1000	20





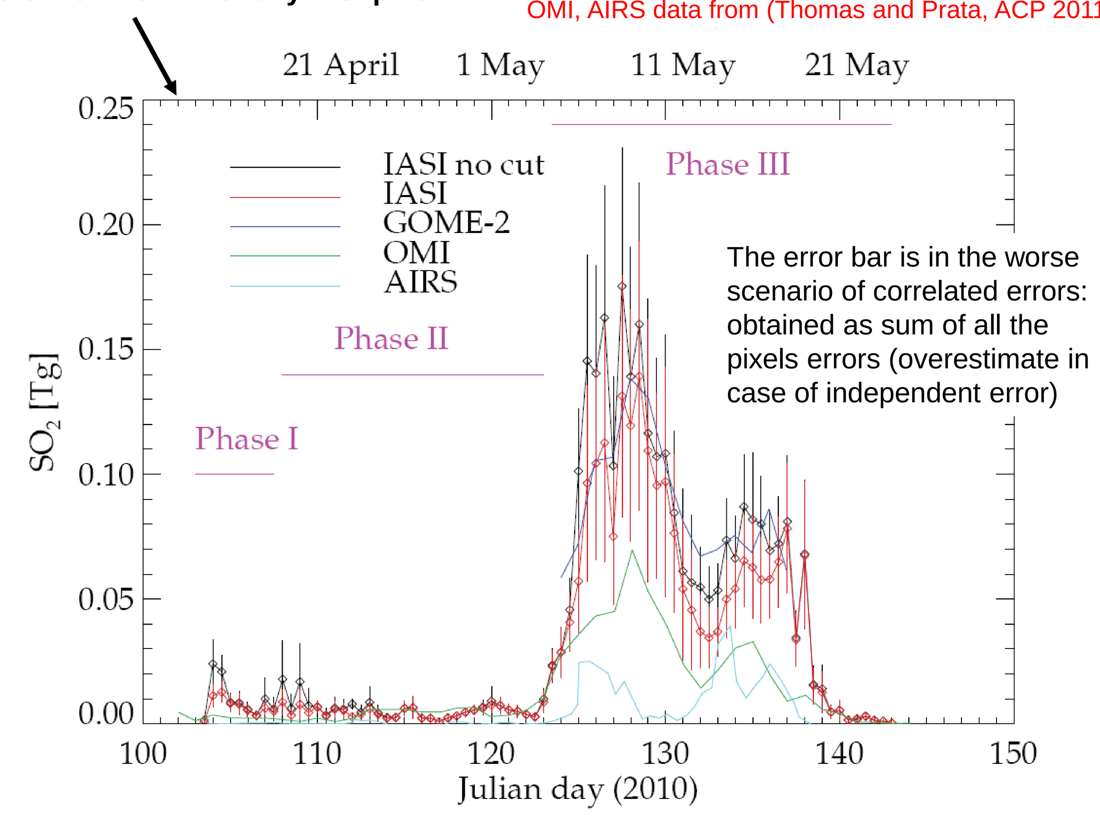
Eyjafjallajökull eruption 14 April - 23 May 2010

OMI data from IAVCEI web page (Simon Carn): http://sites.google.com/site/iavceirscweb/eruptions/eyja



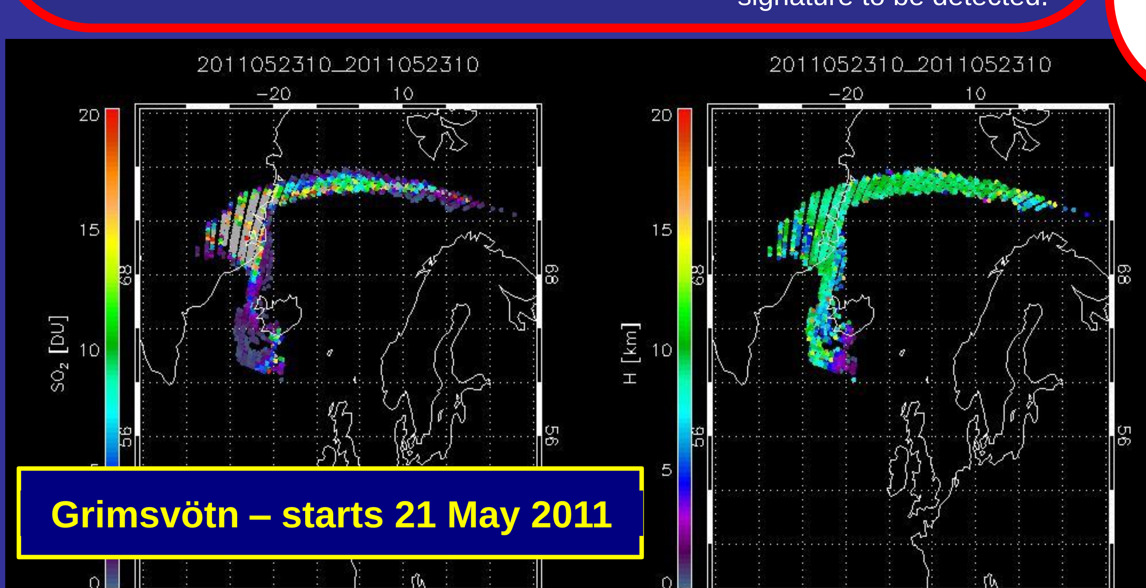
Total mass of SO_2 assuming an average area of 25 x 25 km for any IASI pixel

GOME-2 data from (Rix et al, JGR 2012)
OMI, AIRS data from (Thomas and Prata, ACP 2011)

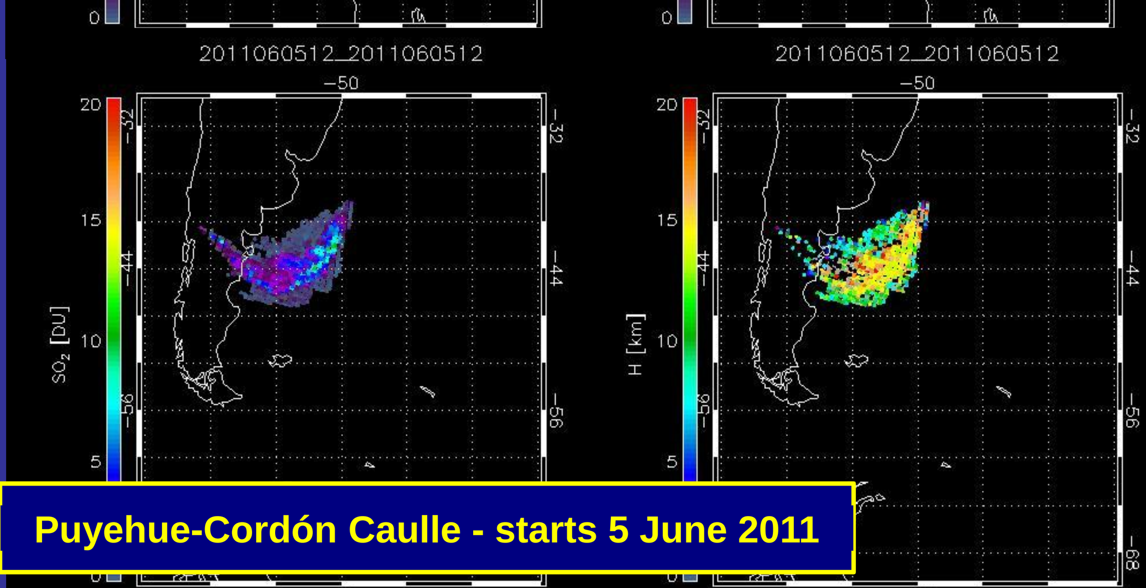


The error bar is in the worse scenario of correlated errors: obtained as sum of all the pixels errors (overestimate in case of independent error)

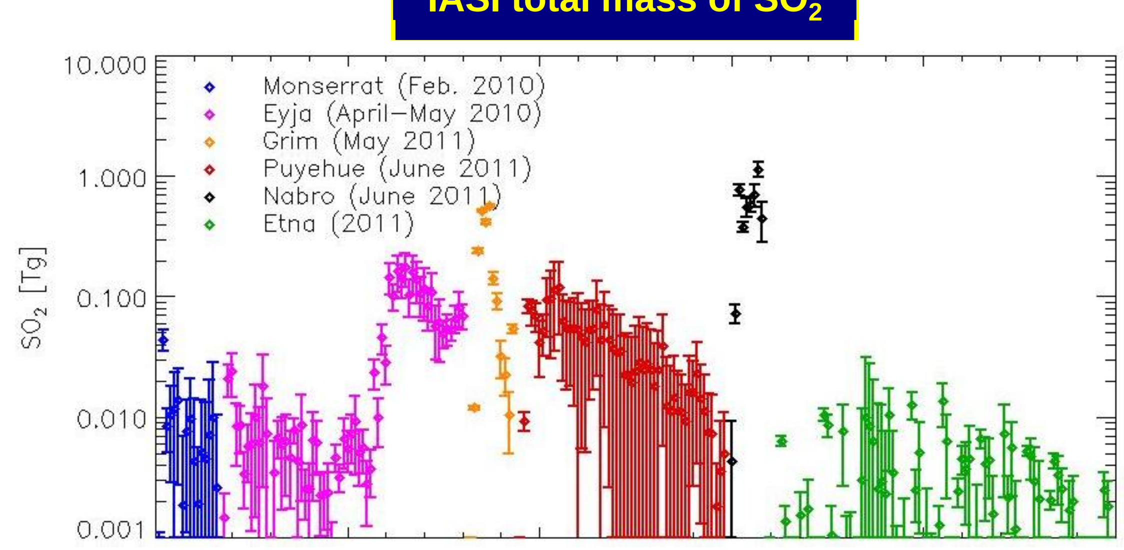
Grimsvötn – starts 21 May 2011



Puyehue-Cordón Caulle - starts 5 June 2011

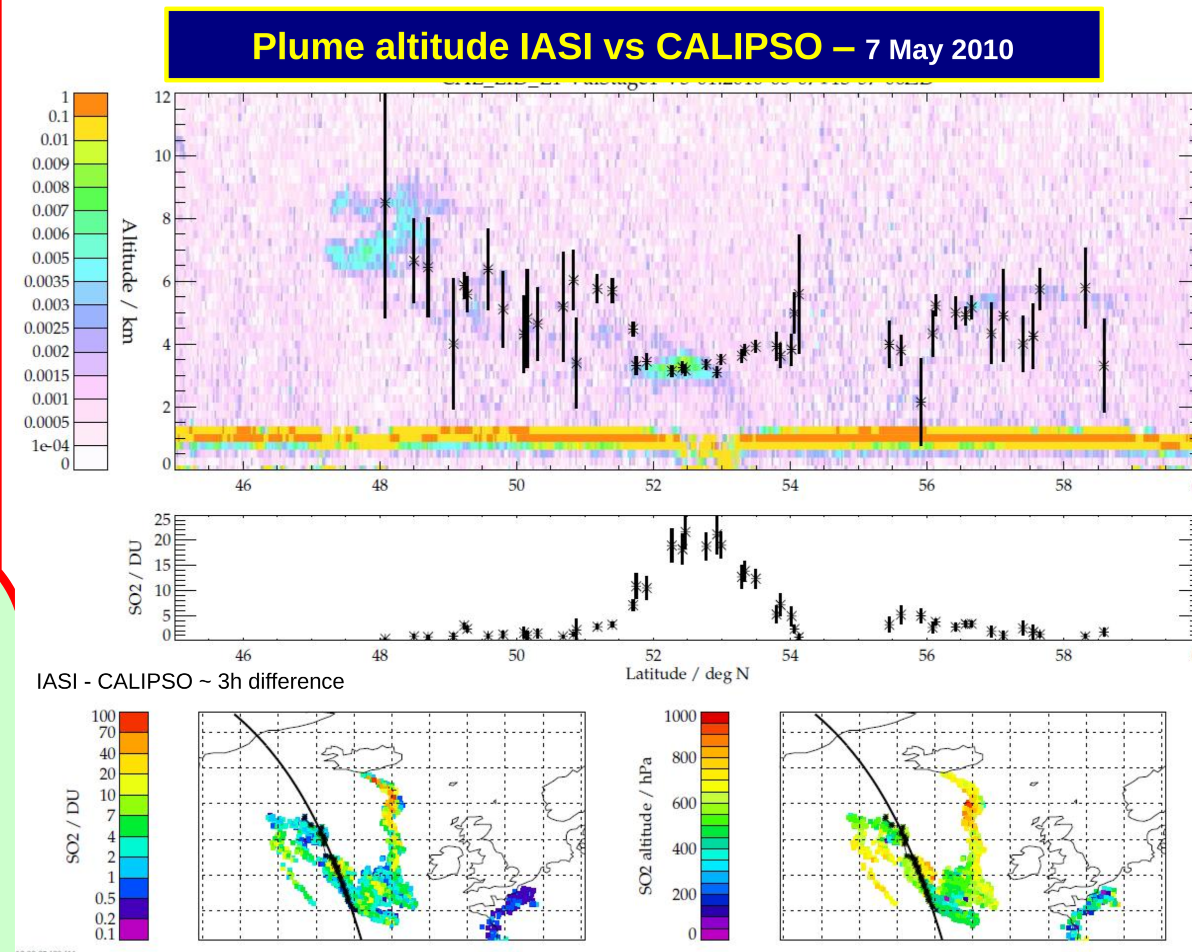


IASI total mass of SO_2

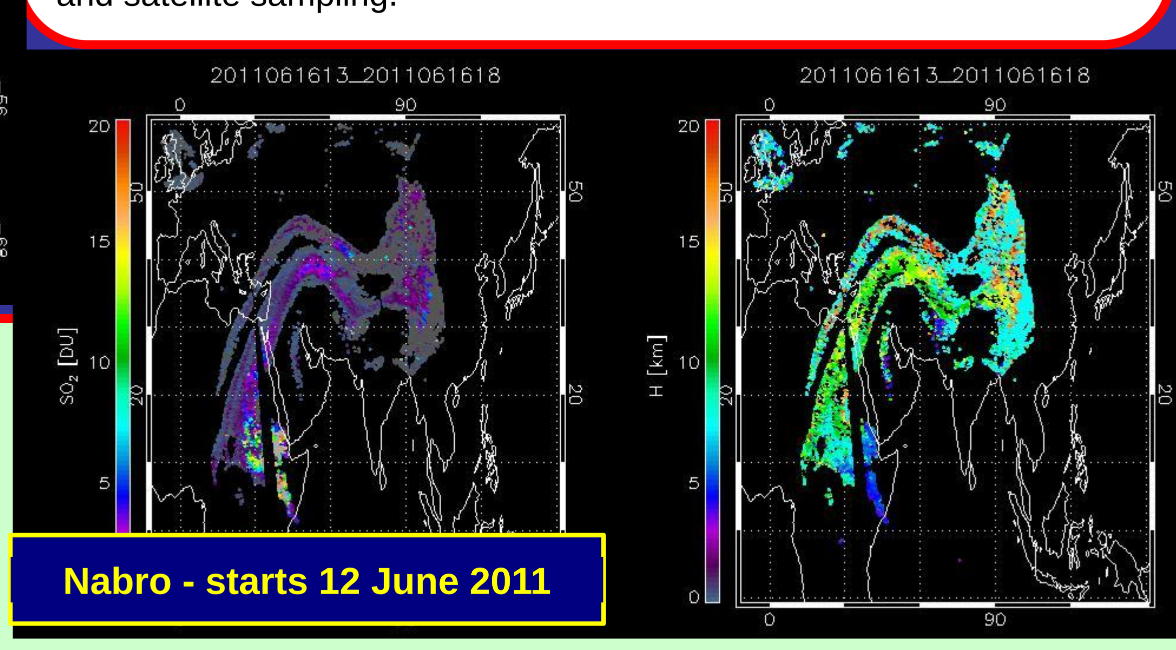


Amount of SO_2 retrieved from IASI data. The values are the measured SO_2 on a particular day and vary with volcanic emission, gas removal and satellite sampling.

Plume altitude IASI vs CALIPSO – 7 May 2010



Nabro - starts 12 June 2011



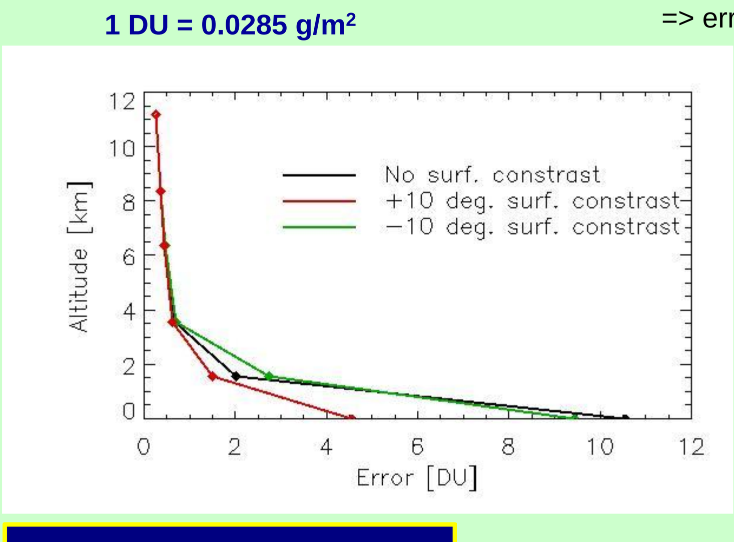
Minimum error estimate

surface contrast = skin temperature - temperature of the first atm. layer

std. atm. profiles
assumption: we know the altitude of the plume.

considering 60 overpass a month => error reduced of 1/sqrt(60)

1 DU = 0.0285 g/m²

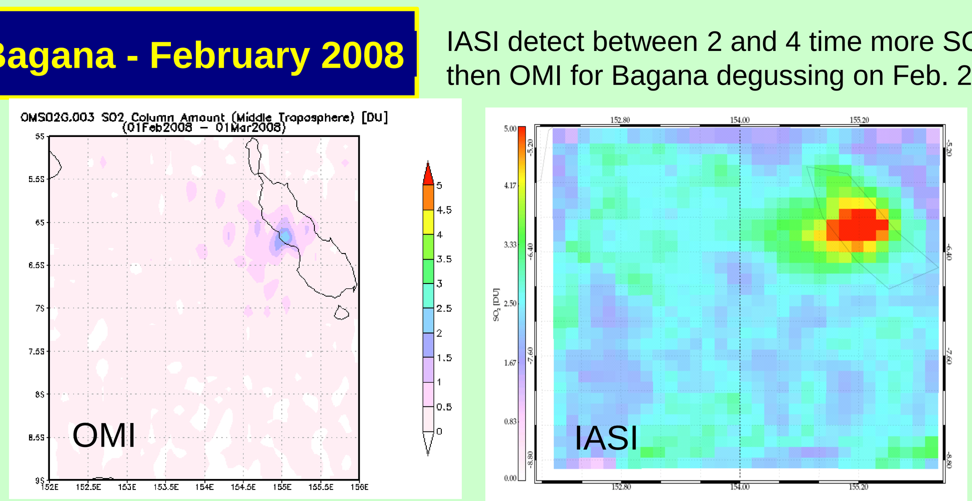


SO_2 monthly errors

[km]	[g/m2]
11	9 10-4
8.3	13 10-4
6.4	17 10-4
3.5	24 10-4
1.5	73 10-4
0	388 10-4

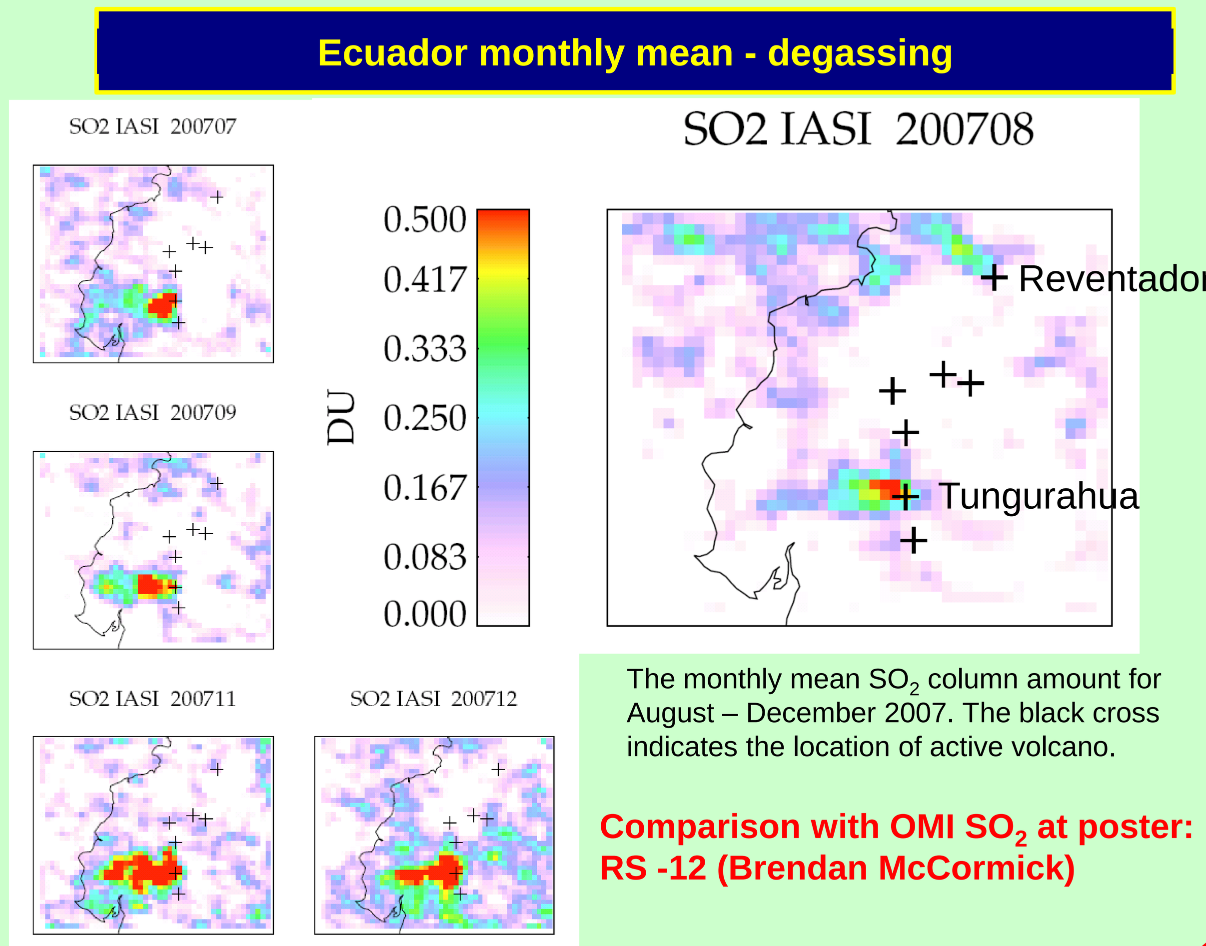
Bagana - February 2008

IASI detect between 2 and 4 time more SO_2 then OMI for Bagana degussing on Feb. 2008



OMI monthly mean is produced with the Giovanni online data system, developed and maintained by the NASA GES DISC: http://gdata2.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=omil2g

Ecuador monthly mean - degassing



The monthly mean SO_2 column amount for August – December 2007. The black cross indicates the location of active volcano.

Comparison with OMI SO_2 at poster: RS -12 (Brendan McCormick)

Conclusions

IASI SO2 scheme retrievs the height and amount of SO_2 and provides a comprehensive error budget for every pixel.

Uses the detection scheme (Walker et al. 2011) applied to pixels for the full retrieval.

Initial results seem to compare reasonably to other observations. Though sometimes see much larger SO_2 amounts then uv methods

Thick ash can affect the retrieval, recognizable from cost >2
Underlying cloud don't affect the retrieval, cloud at the same altitude or above the plume mask the SO_2 signal.
Retrieving the ash and cloud (optical depth, altitude and effective radius properties is possible and subject of parallel work at AOPP & RAL.

Related references

Retrieval scheme and Eyjafjallajökull eruption :
Carboni, E., Grainger, R., Walker, J., Dudhia, A., and Siddans, R.: A new scheme for sulphur dioxide retrieval from IASI measurements: application to the Eyjafjallajökull eruption of April and May 2010, Atmos. Chem. Phys. Discuss., 12, 11861-11897, doi:10.5194/acpd-12-11861-2012, 2012.

Detection scheme:
Walker, J.C., E. Carboni, A. Dudhia, R.G. Grainger: Improved Detection of Sulphur Dioxide in Volcanic Plumes using Satellite-based Hyperspectral Infra-red Measurements: Application to the Eyjafjallajokull 2010 Eruption, J. Geophys. Res., 117, doi:10.1029/2011JD016810, 2012.