SMASH overview and related ash projects at University of Oxford

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SMASH team

SMASH overview

Summary of SMASH products delivered:

GOME-2 SO_2 amount DLR
OMI SO_2 height (assimilation) FMI
MODIS VIS & TIR ash and SO_2 INGV & CGS
IASI ash and SO_2 (OE retrieval and fast) Oxford

Validation case study:

Together SMASH& SACS-2

Eyjafjallajökull: April_May 2010
Grimsvötn: May 2011

Thessaloniki (SACS-2)

Earlinet: ash AOD & height
Aircraft: ash AOD & height,
(if time concentration, r_{eff})
Brewer spectrometer: SO_2 column
CALIPSO: ash AOD & height

Etna 2011_2013

INGV (SMASH)

IR camera: ash source altitude
FLAME: SO_2 total amount

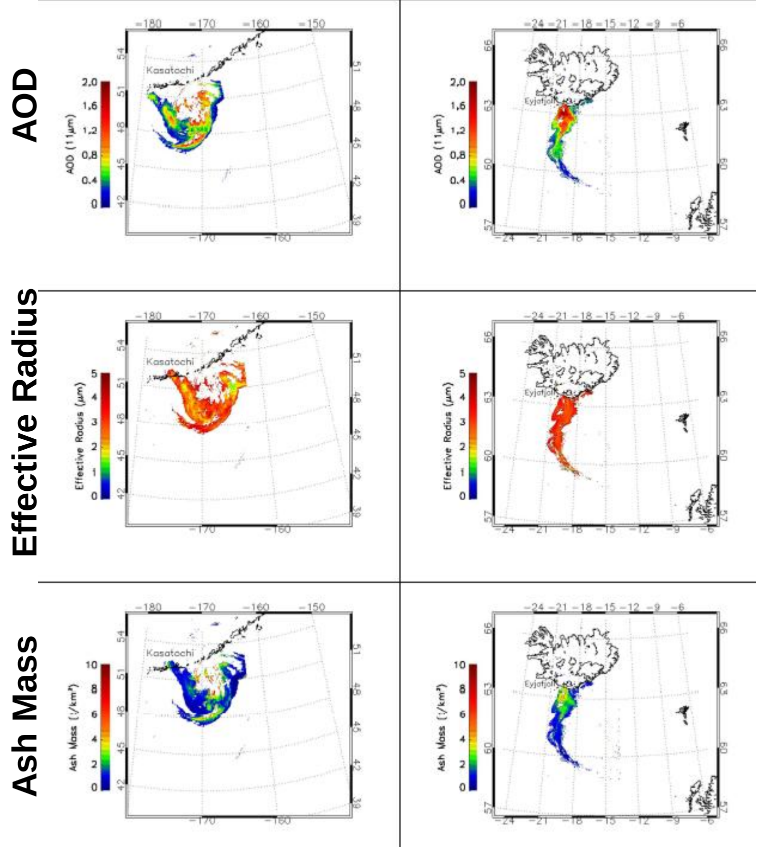
Credit: Corradini, Merucci (INGV), Di Nicolantonio, Cacciari (CGS)

See poster P-12

MODIS Ash and SO_2 retrievals

Standard MODIS-TIR products

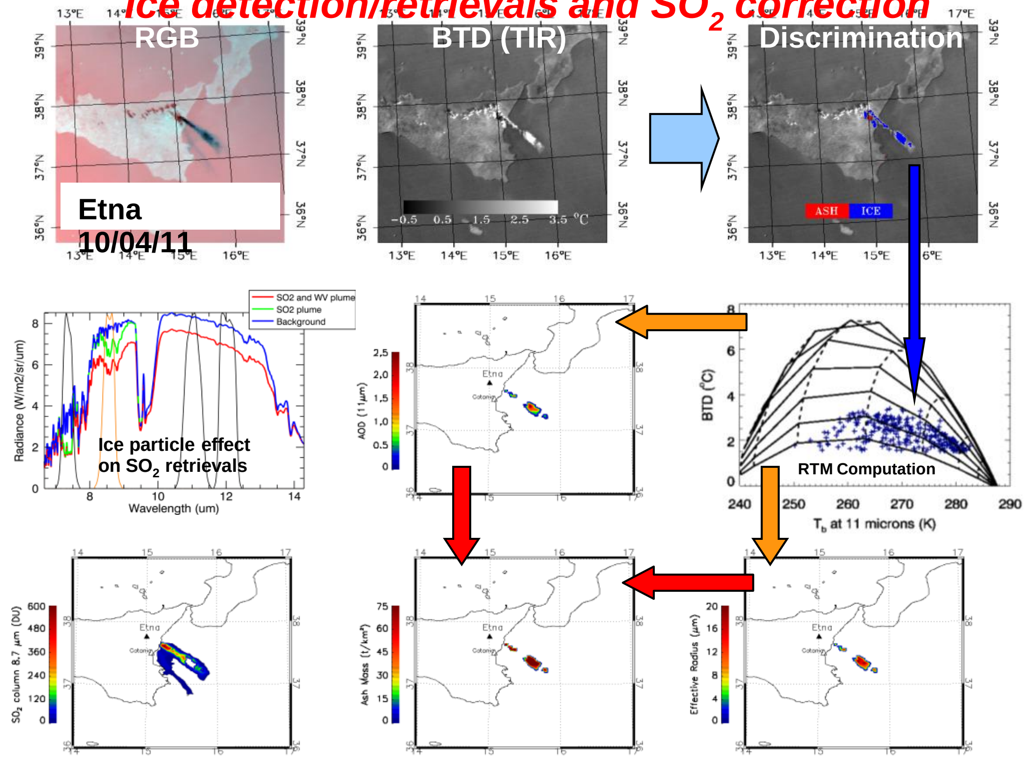
Kasatochi (Alaska) 2008	Eyjafjalla (Iceland) 2010
MODIS-Aqua	MODIS-Terra
9 August 2008, 00:50 UTC	19 April 2010, 14:55 UTC



INGV

New MODIS-TIR Products

Ice detection/retrievals and SO_2 correction



New MODIS-TIR-VIS Products

Ash Detection and Retrievals

INGV

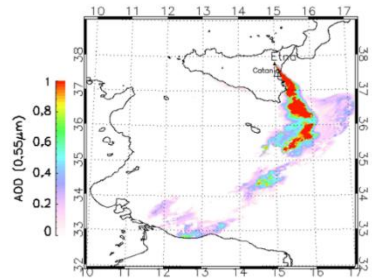
OHB CGS

RGB

Ash detection (TIR)

Ash detection (TIR+VIS)

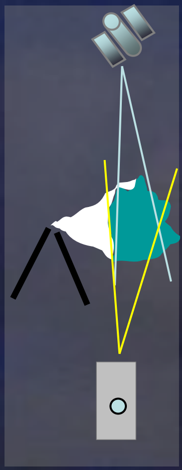
Ash retrieval (TIR+VIS)



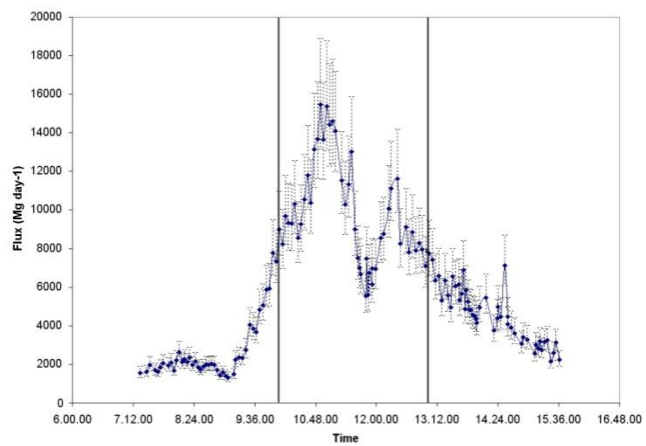
ESA-Smash Validation Activities

The validation concerns the IASI, MODIS, GOME-2 SO_2 mass retrieved

Test cases selected are the 2011 Mt. Etna paroxysmal activities, Italy (lava fountains) using ground SO_2 flux measurements from FLAME monitoring network

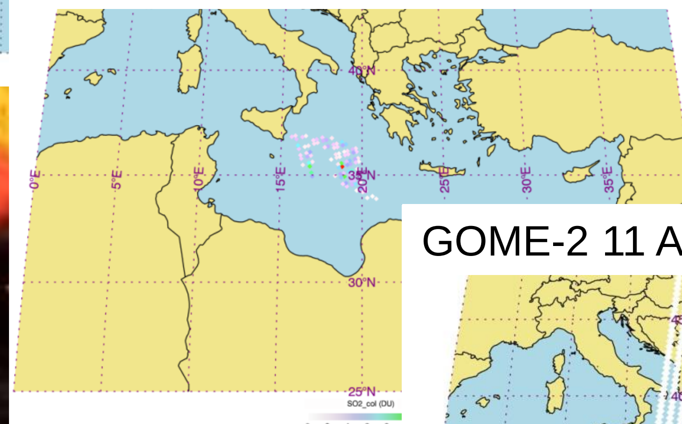


FLAME SO2 measurements of 10 April 2011 Lava fountain

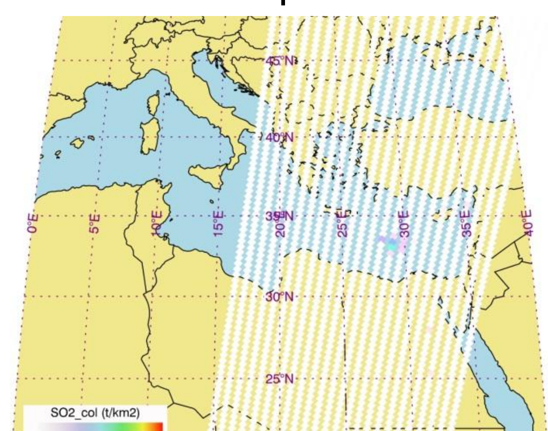


MODIS 10 April 1230 UTC

IASI 10 April 1942 UTC



GOME-2 11 April 0744 UTC

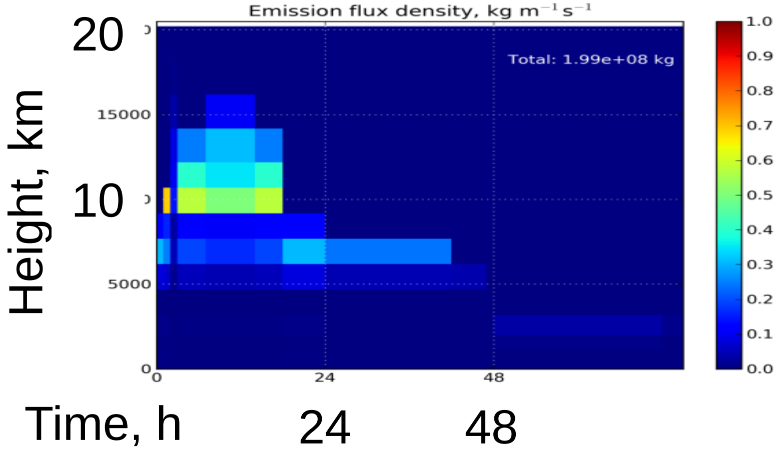


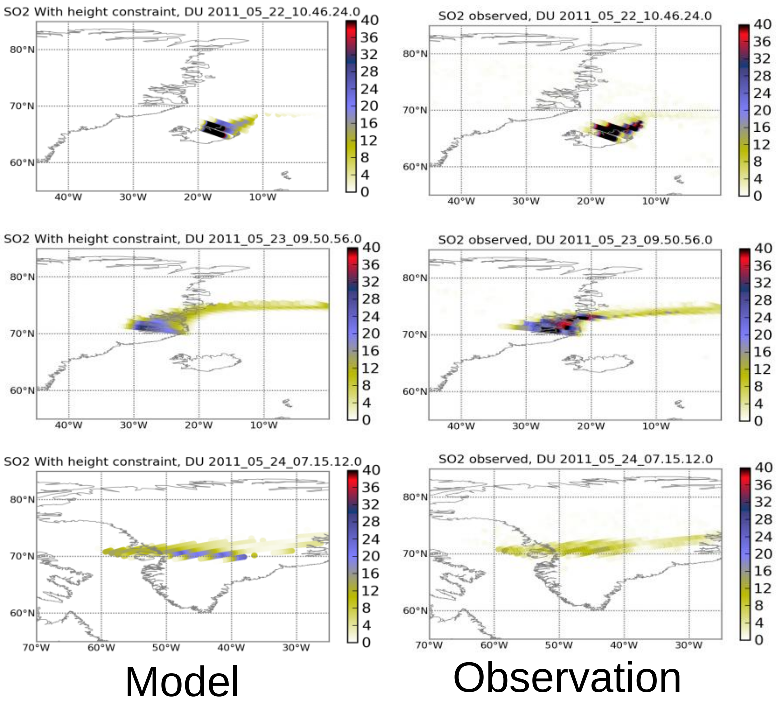
Credit: C. Spinetti (INGV)

Sensor	Date Time	SO_2 Mass Max Min (tons)	D Error Ground-Sensor/Ground
FLAME	10/04/2011 10.05-12.30 10.05-12.47	5714 ÷ 3455 5753 ÷ 3479	-
MODIS	10/04/2011 12.30	4946 ÷ 3656	- 3%
IASI	10/04/2011 19.42	6049 ÷ 4517	+ 19%
GOME-2	11/04/2011 07.44	3496 ÷ 2506	- 32%

SO2 emission inversion for the 2011 Grimsvötn eruption using the OMI satellite observations

- **The atmospheric SO2 release in the 2011 Grimsvötn eruption is reconstructed with inverse modeling:**
    - OMI SO2 column observations assimilated into the SILAM dispersion model
    - 4D-Var algorithm yields temporal and vertical emission profiles
    - emission top constrained by in-situ observations; no prior information on emitted amounts
- **~200 kt SO2 emitted mainly between 10-12 km ASL, shown below:**

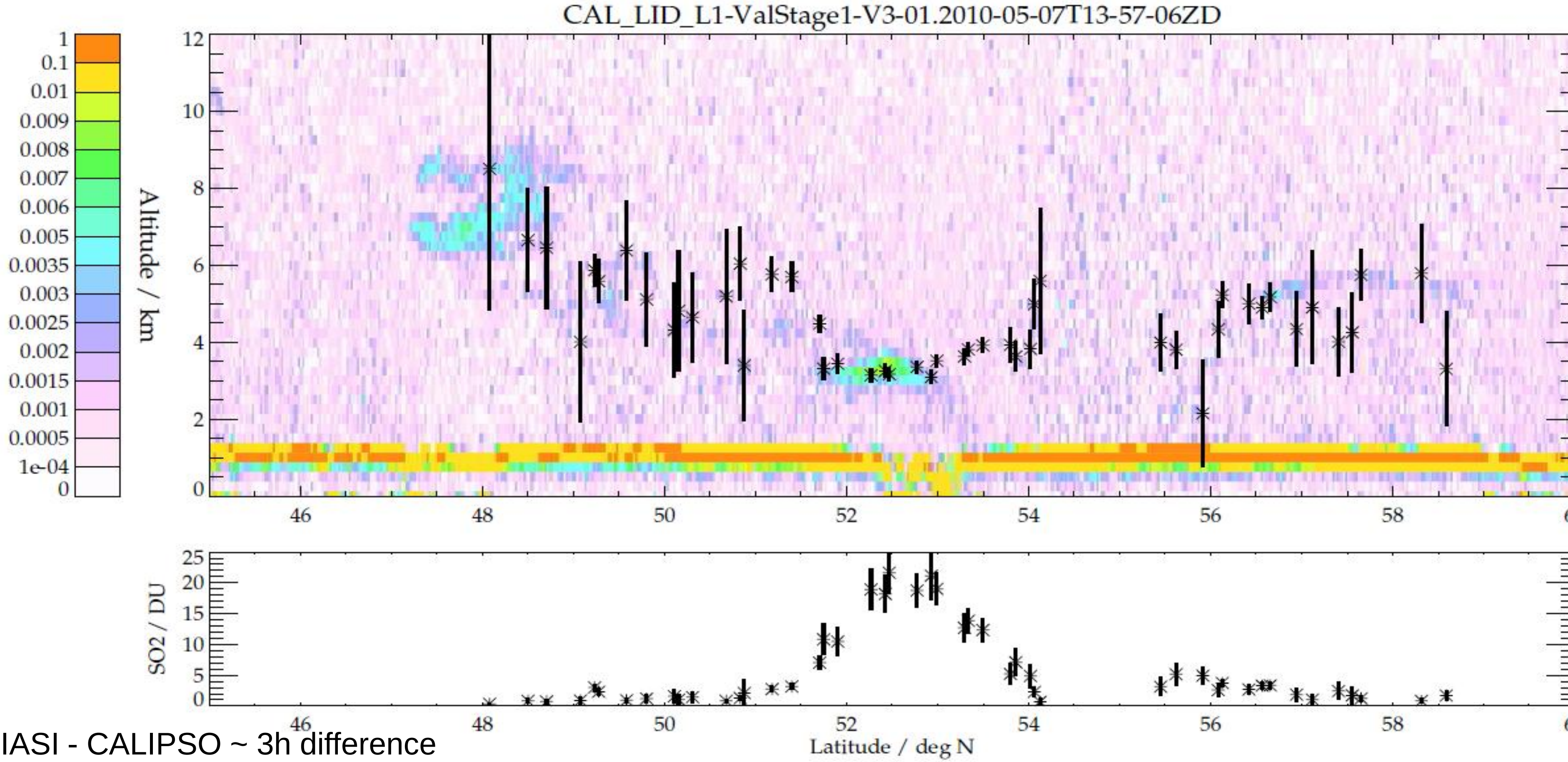




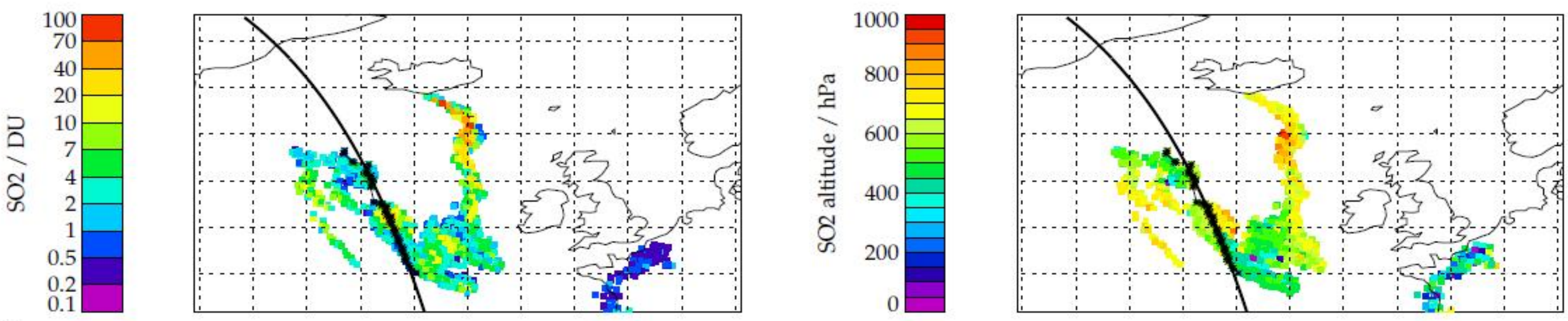
The simulated (after inversion) and observed SO2 column density (DU) in May 22-24, 2011

Credit: Julius Vira (FMI)

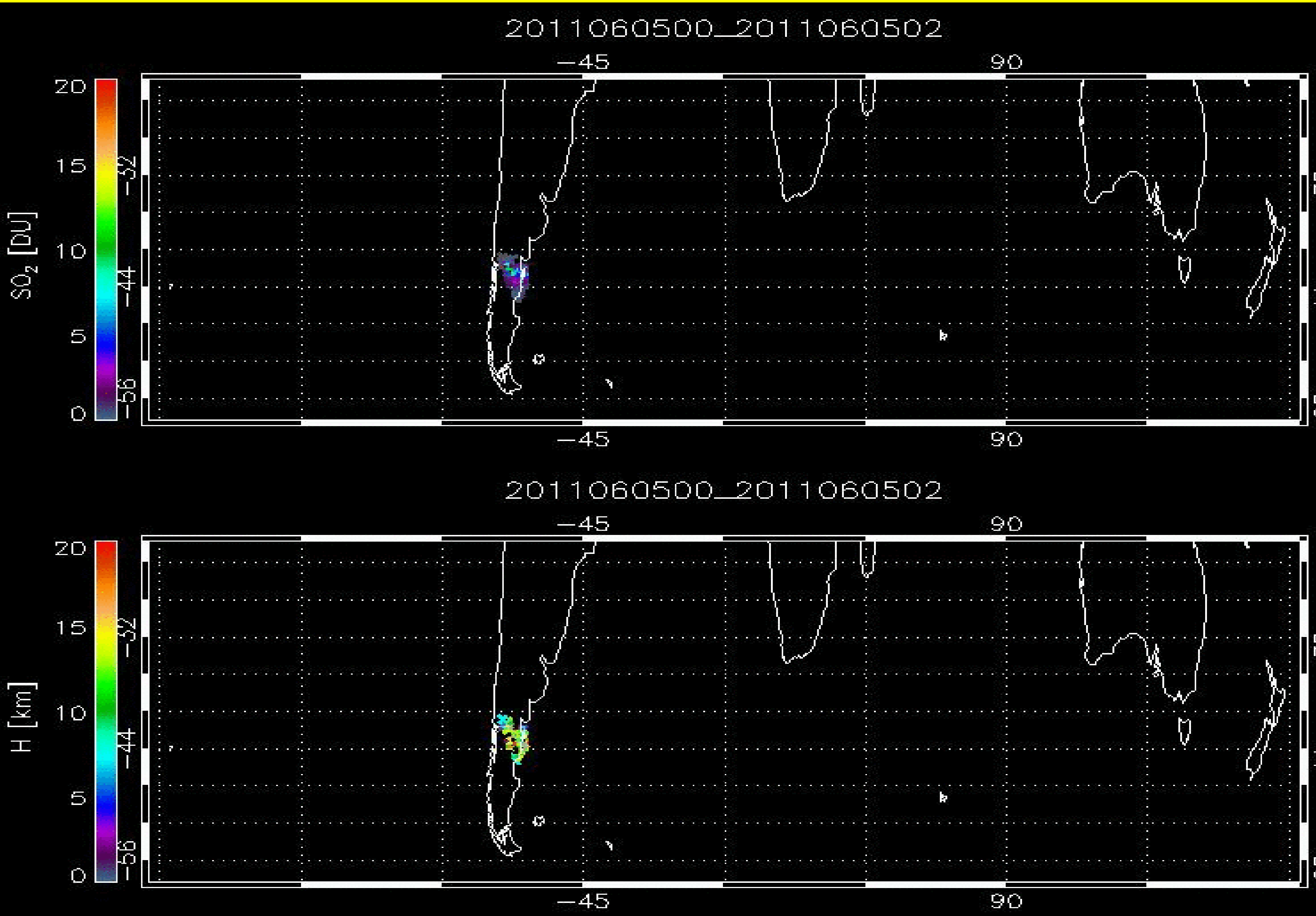
IASI - SO_2



IASI - CALIPSO ~ 3h difference



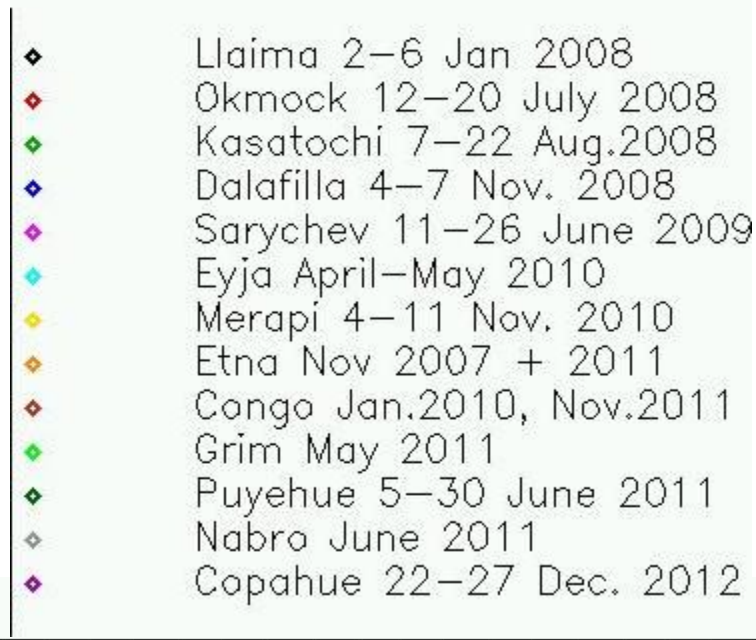
IASI SO_2 - Puyehue-Cordón Caulle eruption 5 - 30 June 2011

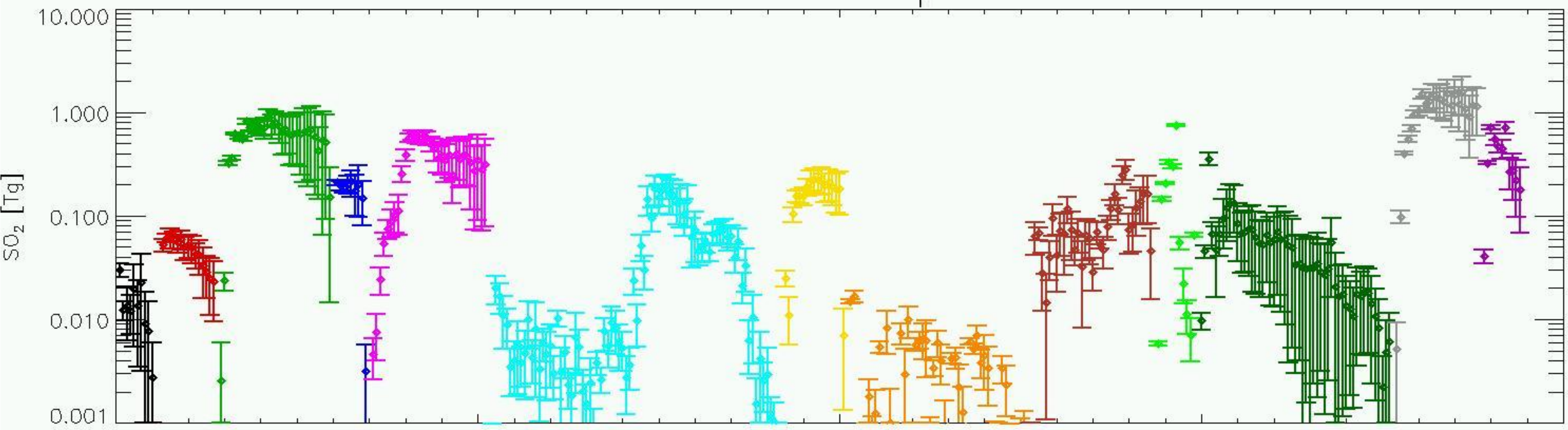


Total mass of SO_2 from IASI (period 2007-2012)

The total SO_2 mass present in the atmosphere is obtained summing all the values of a regularly gridded map of SO_2 amounts.
Points are separated by ~12 hours.

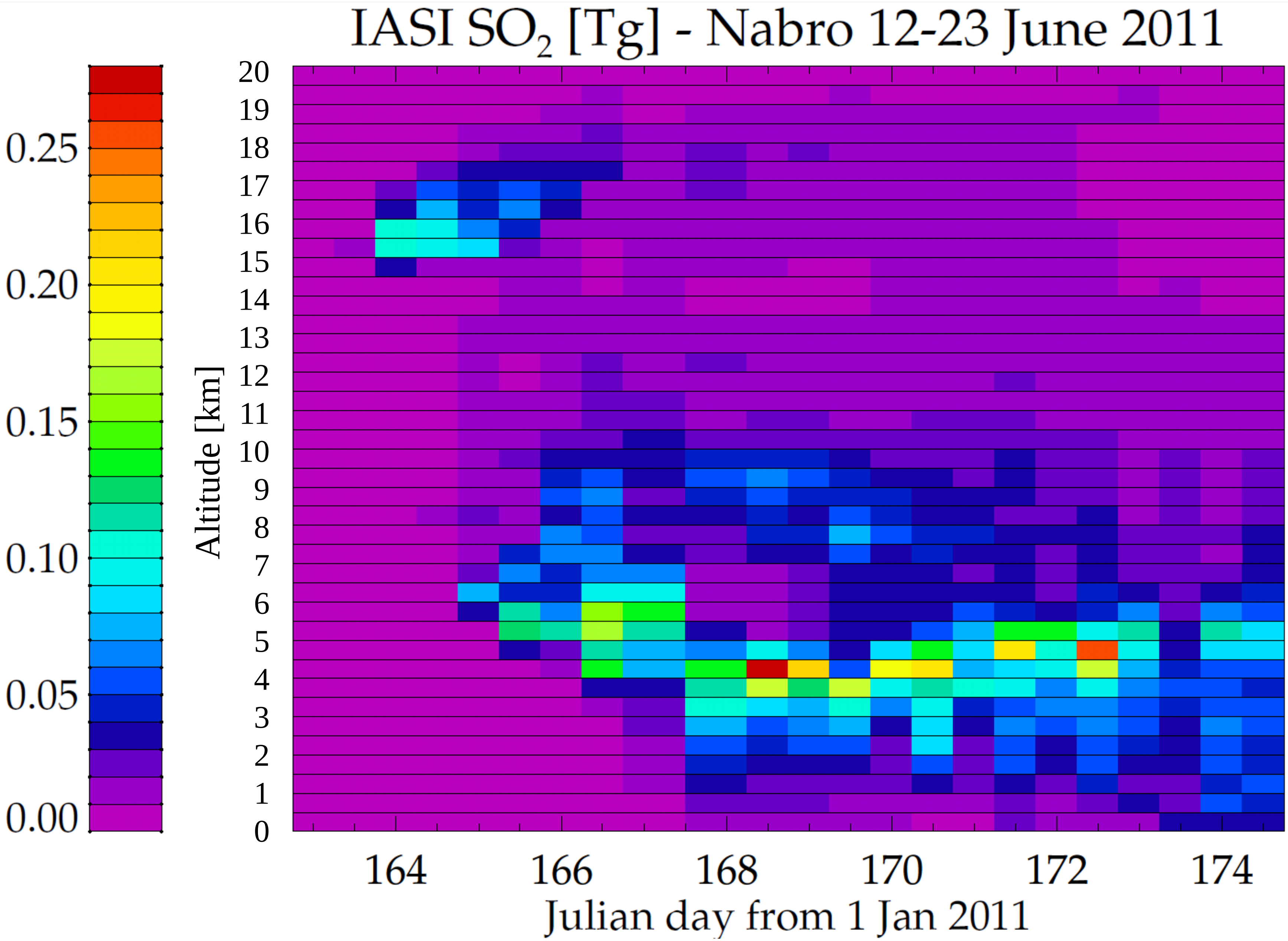
Nabro produces the largest amount of SO_2 plume observed by IASI with a maximum of up to ~2 Tg of SO_2.



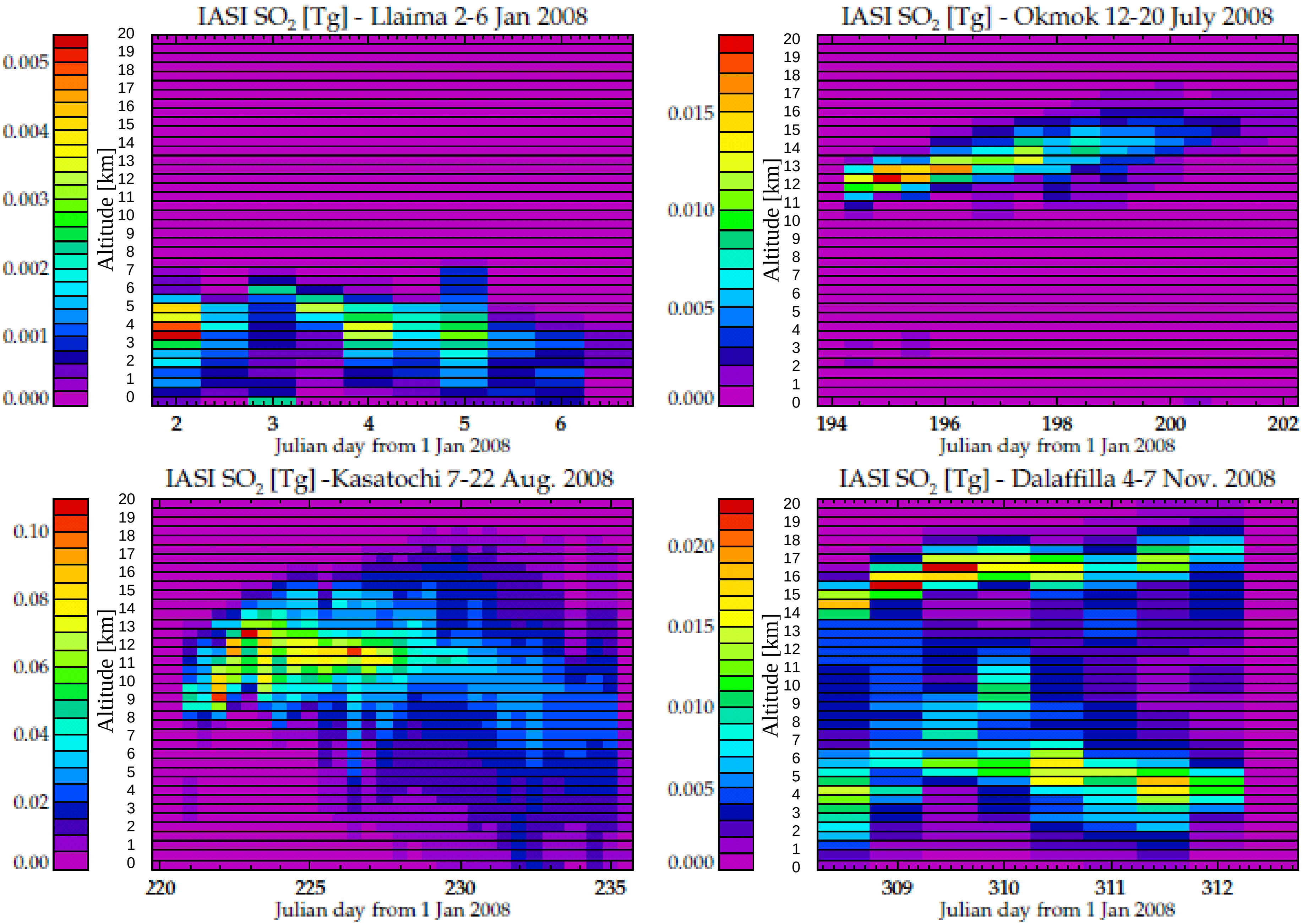


SO_2 retrieved from IASI data. The values are the measured amount on a particular day and vary with volcanic emission, gas removal and satellite sampling. Points are separated by ~12 hours.

SO_2 vertical distribution

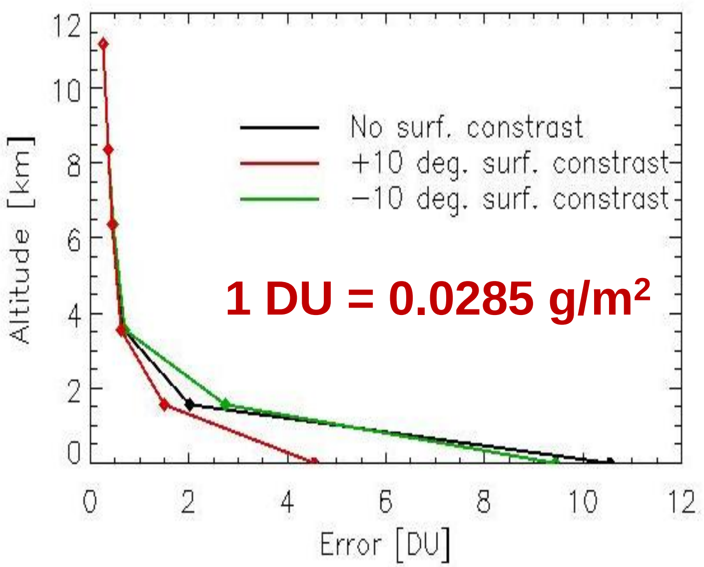


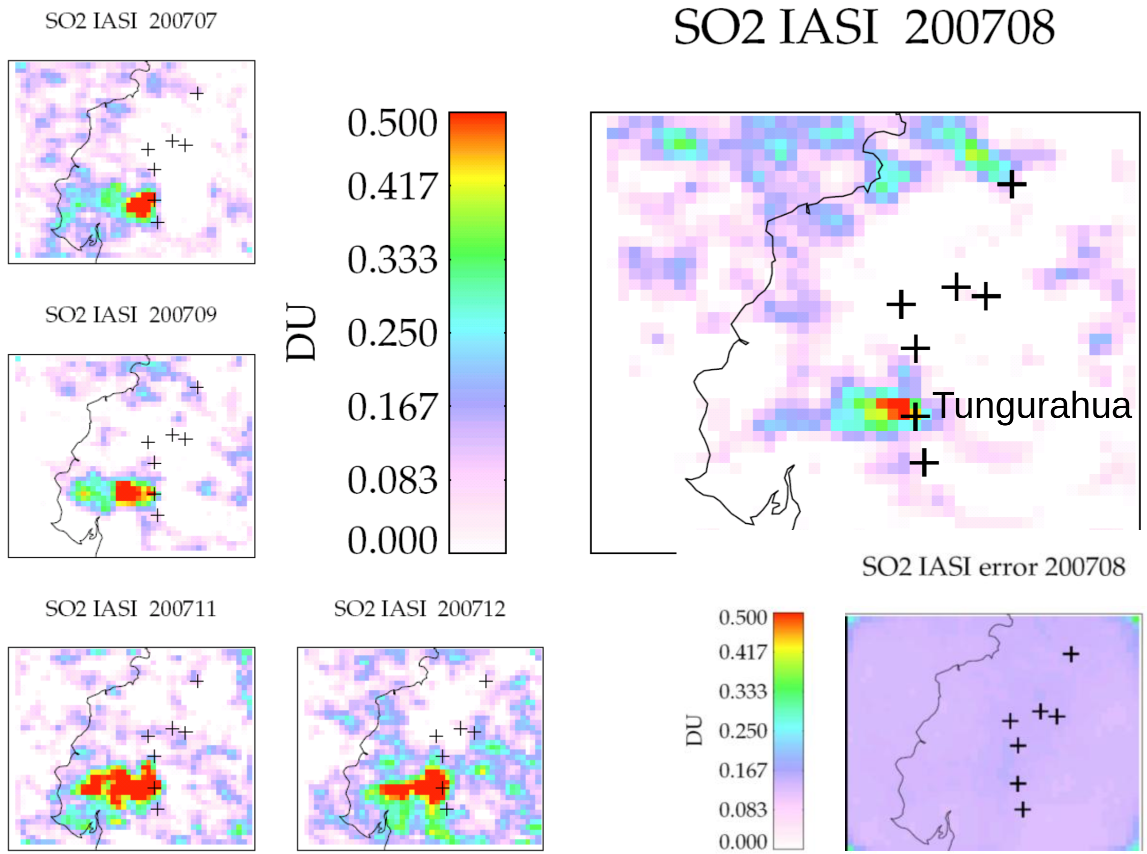
SO_2 vertical distribution



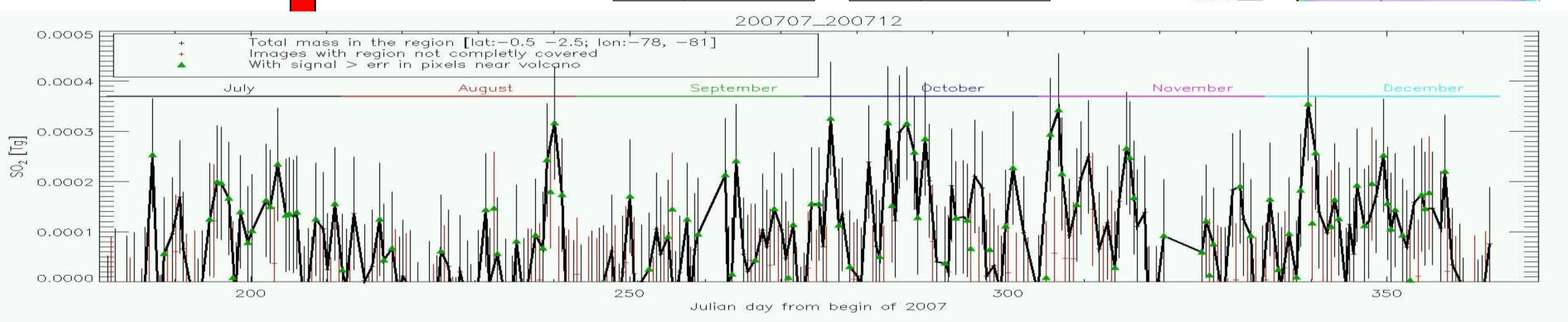
SO_2 Degassing

Minimum error

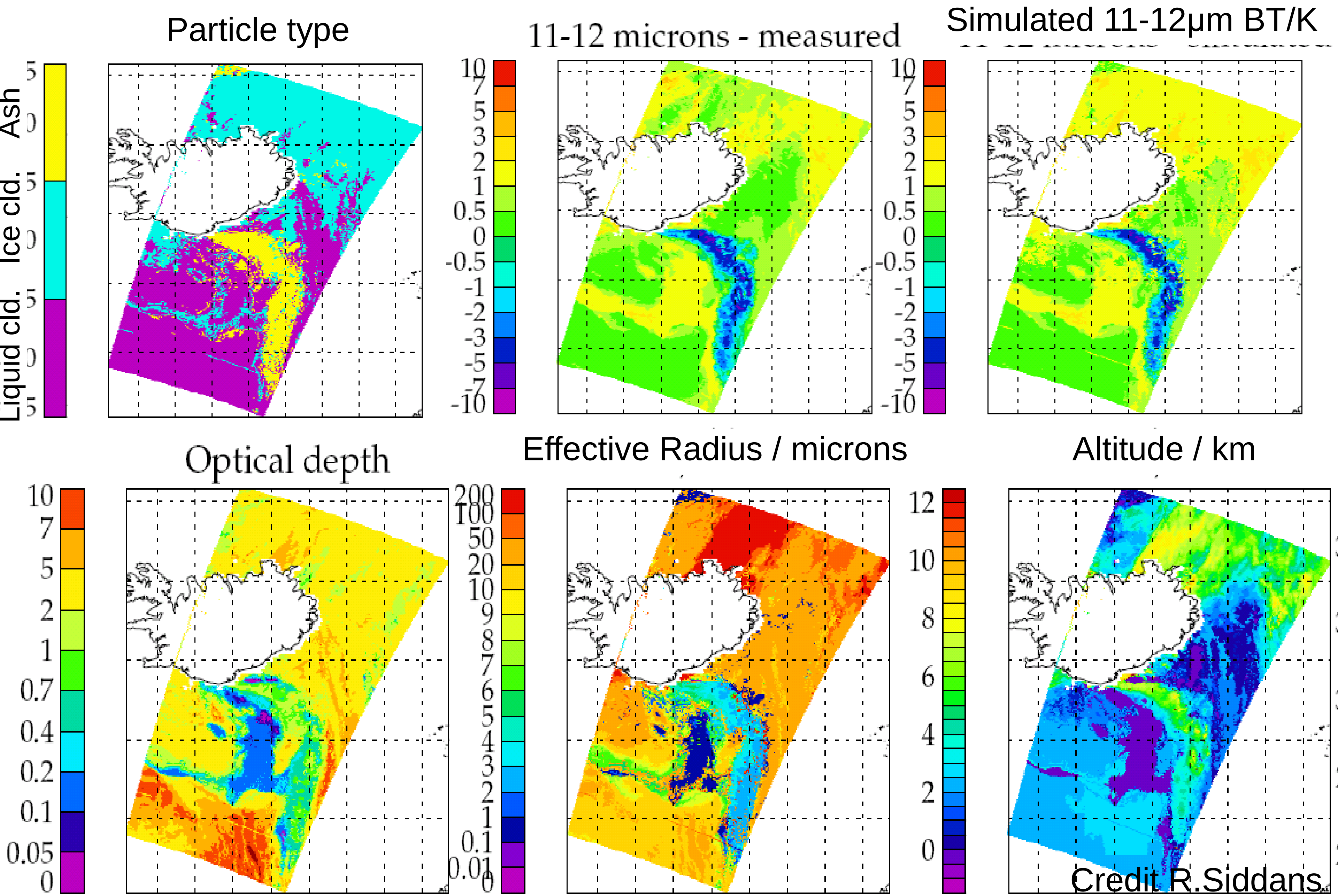




Time series of the SO_2 column amount integrated over a box around Tungurahua. July – December 2007



ORAC Ash retreival- VIS/NIR/TIR from AATSR on 6 May 2010



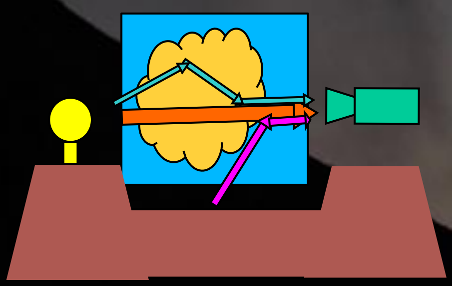
SHIVA: Spectrally High resolution Infrared measurements for the characterisation of Volcanic Ash

→ to better understand the volcanic process that control eruptive activity.

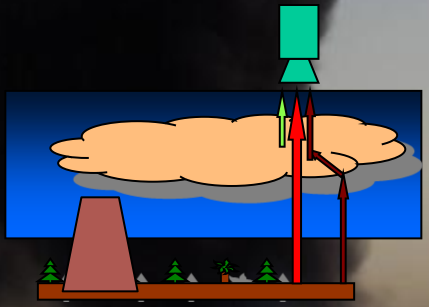
Optimal estimation approach (Rodgers, 2000) to retrieve ash composition and possibly size from infrared spectral measurements.
We will study ash formed from different magmas and at different stages of evolution within a volcanic plume.

one-to-one correspondence between refractive index spectra, compositions and remote sensing measurements.

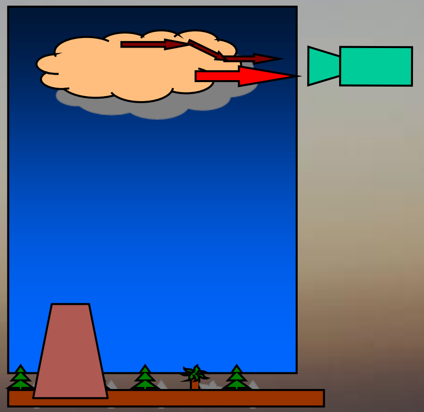
FTIR



IASI



MIPAS

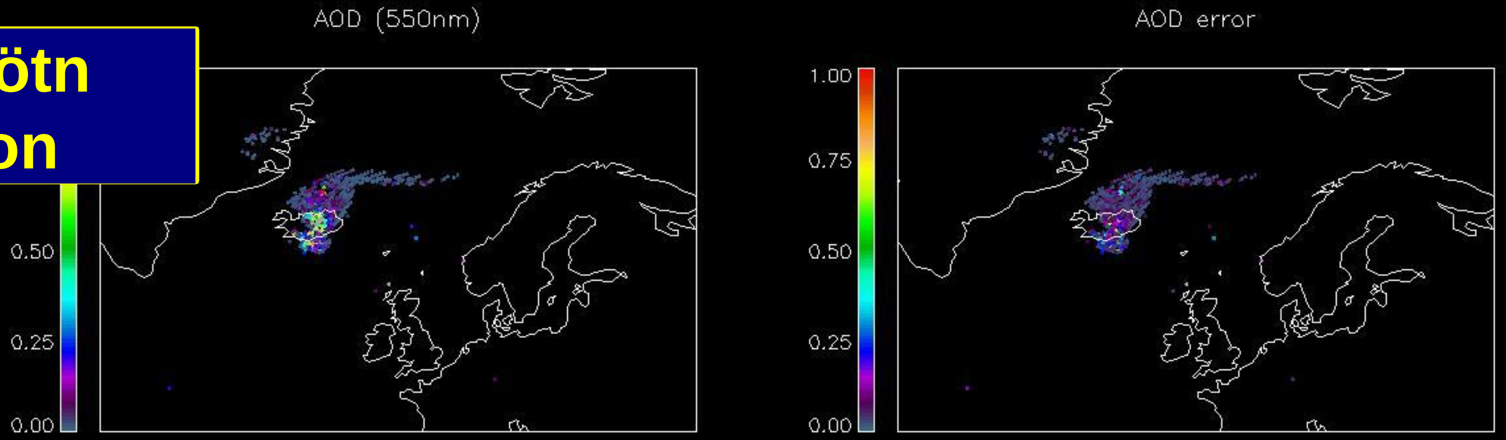


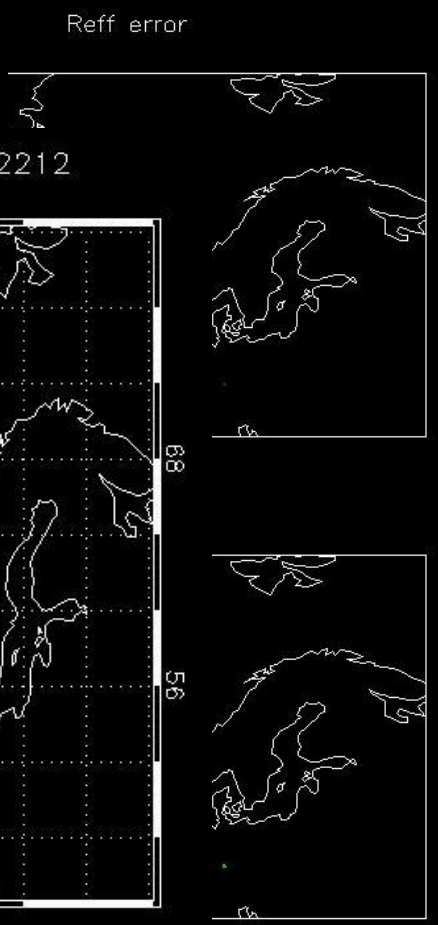
\+ Ash sample analysis

ground and satellite retrievals → ash type/composition (with different size distributions) to be compared with the geochemical and petrological analysis done on ash sample for the same volcanic plume.

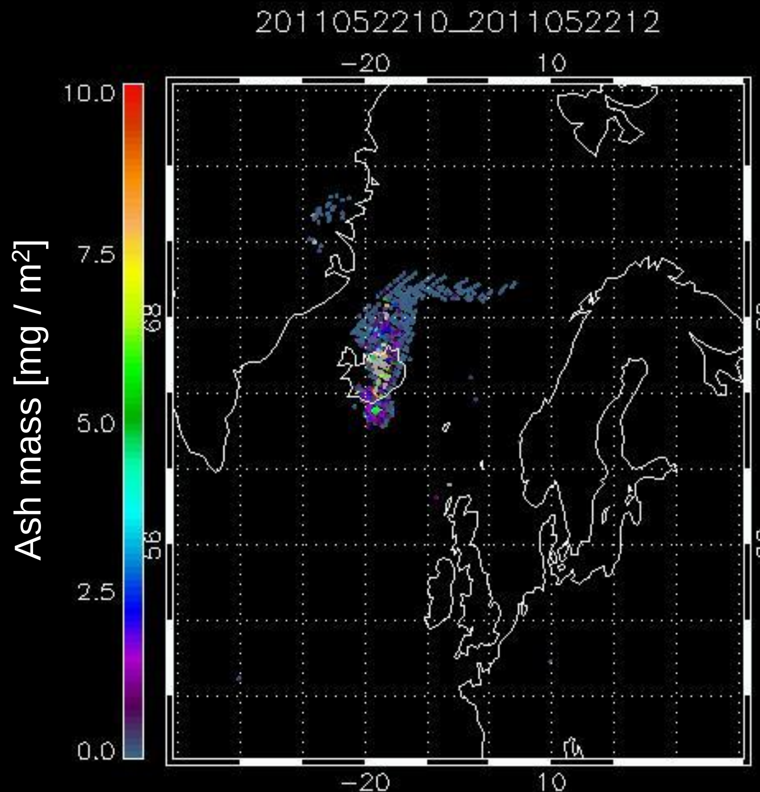
Grimsvötn eruption

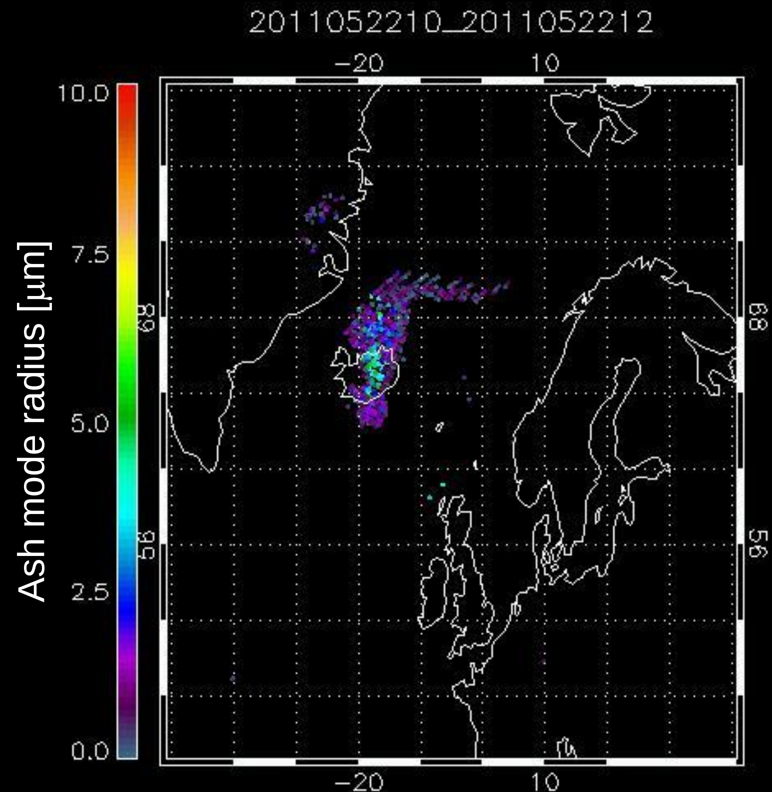
22 May 2011
morning orbits



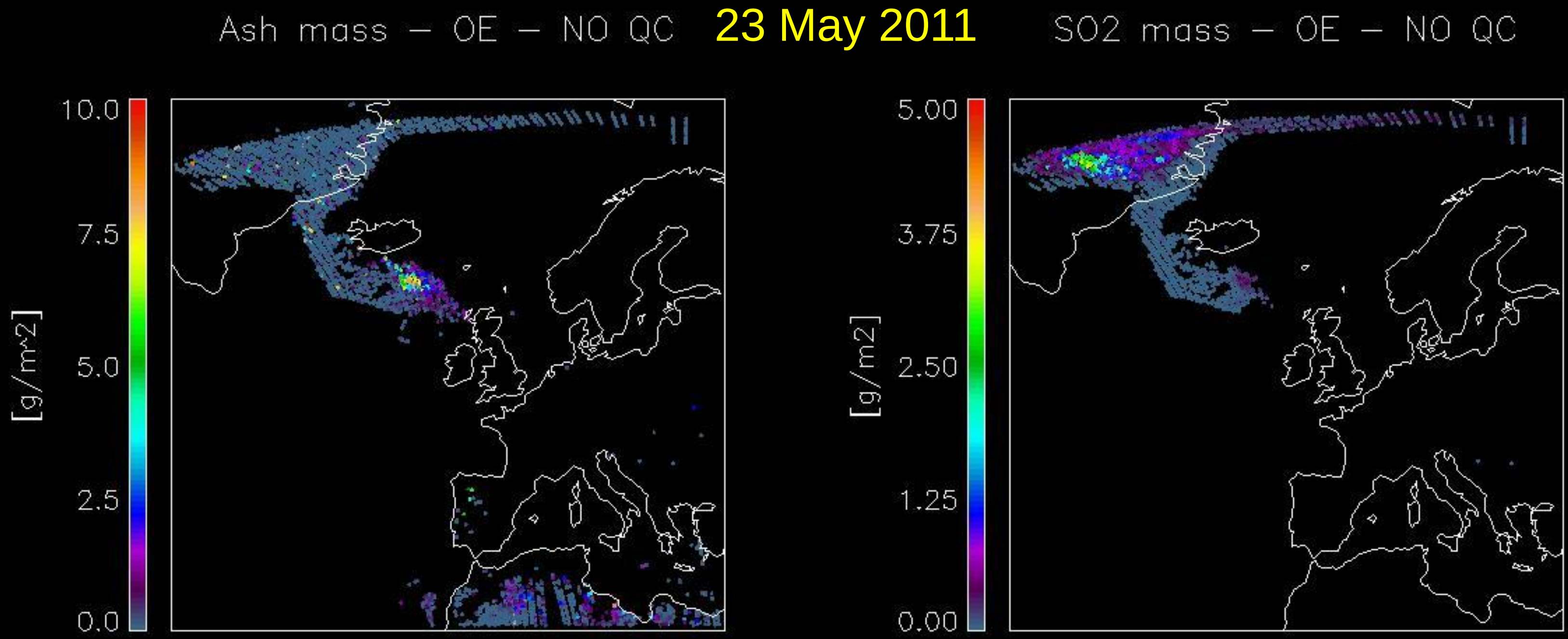


From AOD and Reff we compute the total mass and mode radius

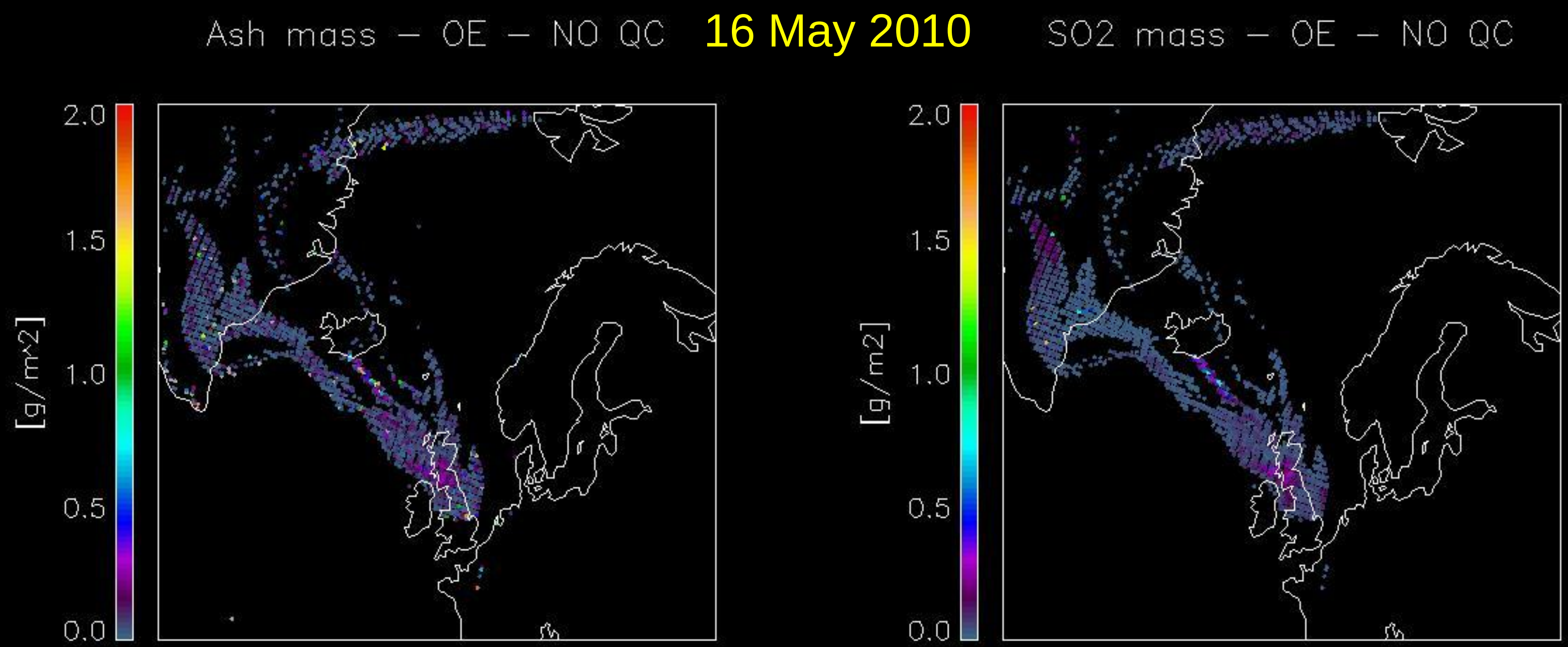




23 May 2011



16 May 2010



Summary

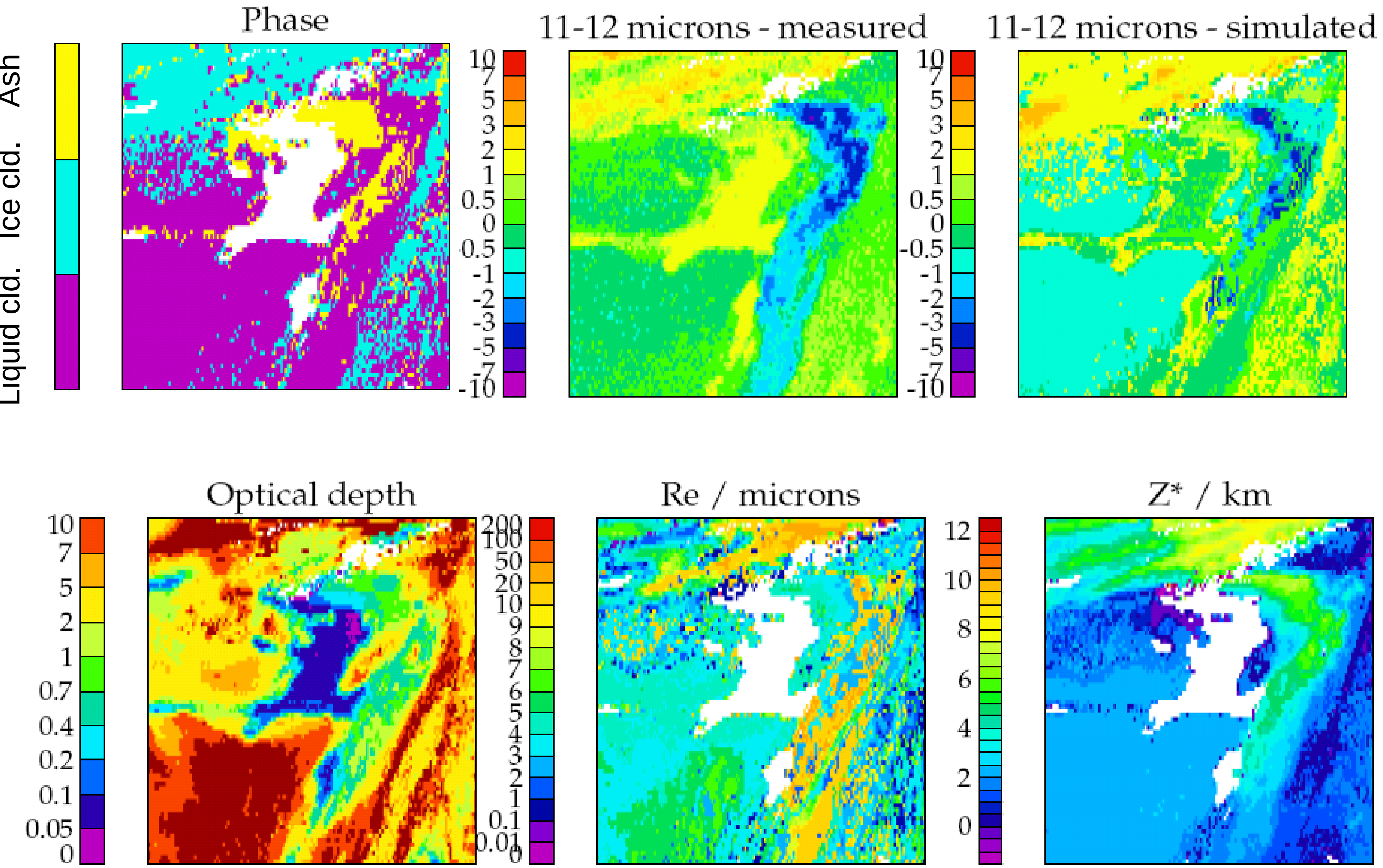
- **SMASH** aims to improve source term characterisation by improving satellite retrieval of ash & SO2 from UV & TIR spectrometers and radiometers.
- Validation for Eyja, Girmm and Etna case study

- **IASI SO_2** scheme retrieves the **height and amount of SO_2** and provides a **comprehensive error budget for every pixel**.
- Uses the detection scheme (Walker et al. 2011, Walker et al. 20122) applied to pixels for the full retrieval (Carboni et al 2012).
- Retrieved uncertainties increase with the decreasing of altitude, nevertheless it is possible to retrieve information in the **lower troposphere and monitor volcanic degassing**.
- 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.
- Comparison with other satellite retrievals is undergoing

- **ORAC** (radiometer and IASI) scheme retrieves **ash optical depth, effective radius** (from which mass and Mode radius are estimate), **and height**.
- Preliminary results show the possibility to exploit the IASI spectra in order to **discern between different ash model**.
- Full optimal estimation retrievals of ash is currently under development. The IASI ash retrieval scheme development will be carried out within the new NERC SHIVA and FP7 APHORISM projects.

This work has been supported by COMET+ (National Center for Earth Observation NCEO-NERC Geohazard theme), SMASH (ESA) and SHIVA (NERC).

ORAC Ash retreival- VIS/NIR/TIR from SEVIRI on 6 May 2010



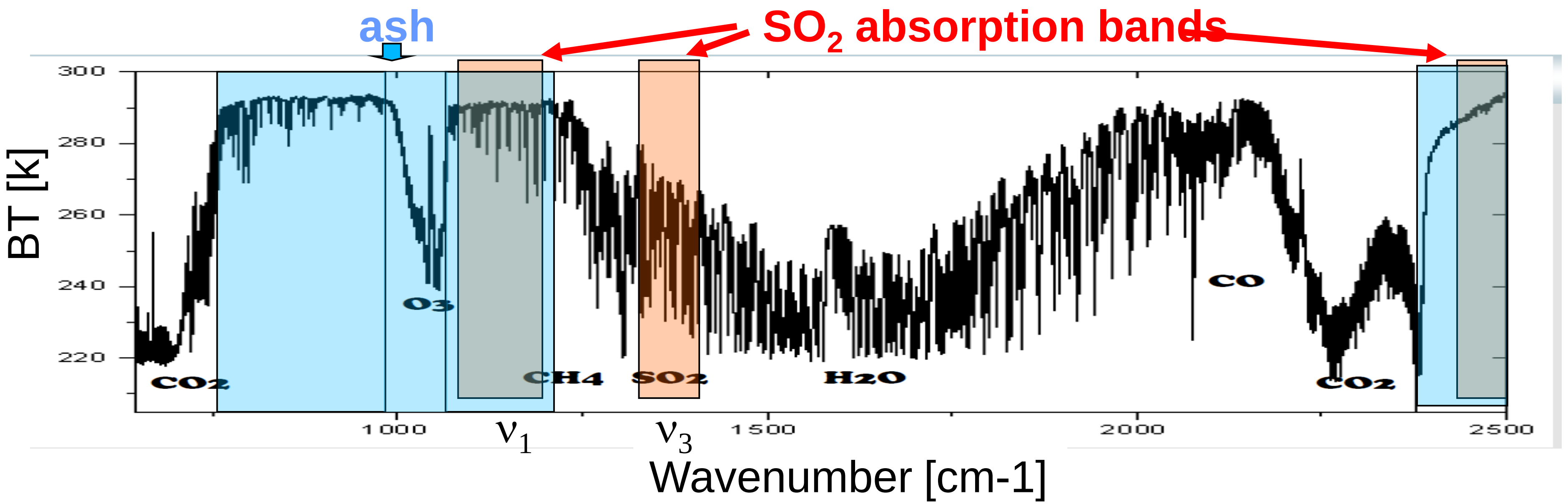
Credit R.Siddans

Infrared Atmospheric Sounding Interferometer - IASI

IASI is on board of METeorological OPerational satellite program (METOP-A and METOP-B), a European meteorological satellite that has been operational since 2007.

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 an apodised spectral resolution of 0.5 cm^{-1}. Radiometric accuracy is 0.25-0.58K. The IASI field of view (FOV) consists **of four circles of 12 km diameter (at nadir) inside a square of 50 x 50 km.**

It has a 2000 km swath and nominally can achieved **global coverage in 12 hours** (although there are some gaps between orbits at tropical latitudes). Radiances are collocated with the Advanced Very High Resolution Radiometer (AVHRR) that provides complementary visible/near infrared channel, for cloud and aerosol retrievals.



OPTIMAL ESTIMATION RETRIEVAL

Bayesian theory -> OPTIMAL ESTIMATION [Rodgers 2000]

Initial state estimate: x_0 *A priori*: x_a

Run forward model: $f(x_i)$

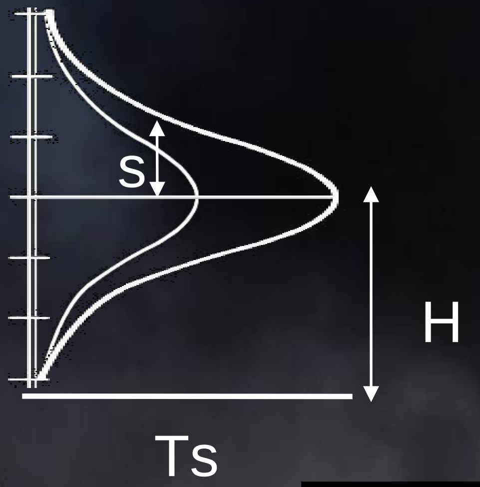
Compare to measurements (y): $J = [y - f(x_i)]S_e^{-1}[y - f(x_i)] + [x_i - x_a]S_a^{-1}[x_i - x_a]$

Update state: $x_i \rightarrow x_{i+1}$ (Levenburg-Marquardt)

Stop when: □J is small , or when i is large.

NB Optimal estimation method provides **error estimate** and quality control

SO_2 Retrieval scheme



State vector:
- Total column amount of SO_2
- 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

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

$$J = (y - F(x))^T S_y^{-1} (y - F(x)) + (x - x_a)^T S_a^{-1} (x - x_a)$$

best estimate of stare vector:

SO_2 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

S_y, is defined to represent the effects of atmospheric variability not represented in the forward model (FM), as well as instrument noise (cloud and trace-gases…).

The matrix is constructed from differences between FM calculations (for clear-sky) and actual IASI observations for wide range of conditions, when we are confident that negligible amounts of SO_2 are present.

Error analysis

linear error on the 'true' state obtained as:

$$S_x = (K^T S_y^{-1} K + S_a^{-1})^{-1}$$

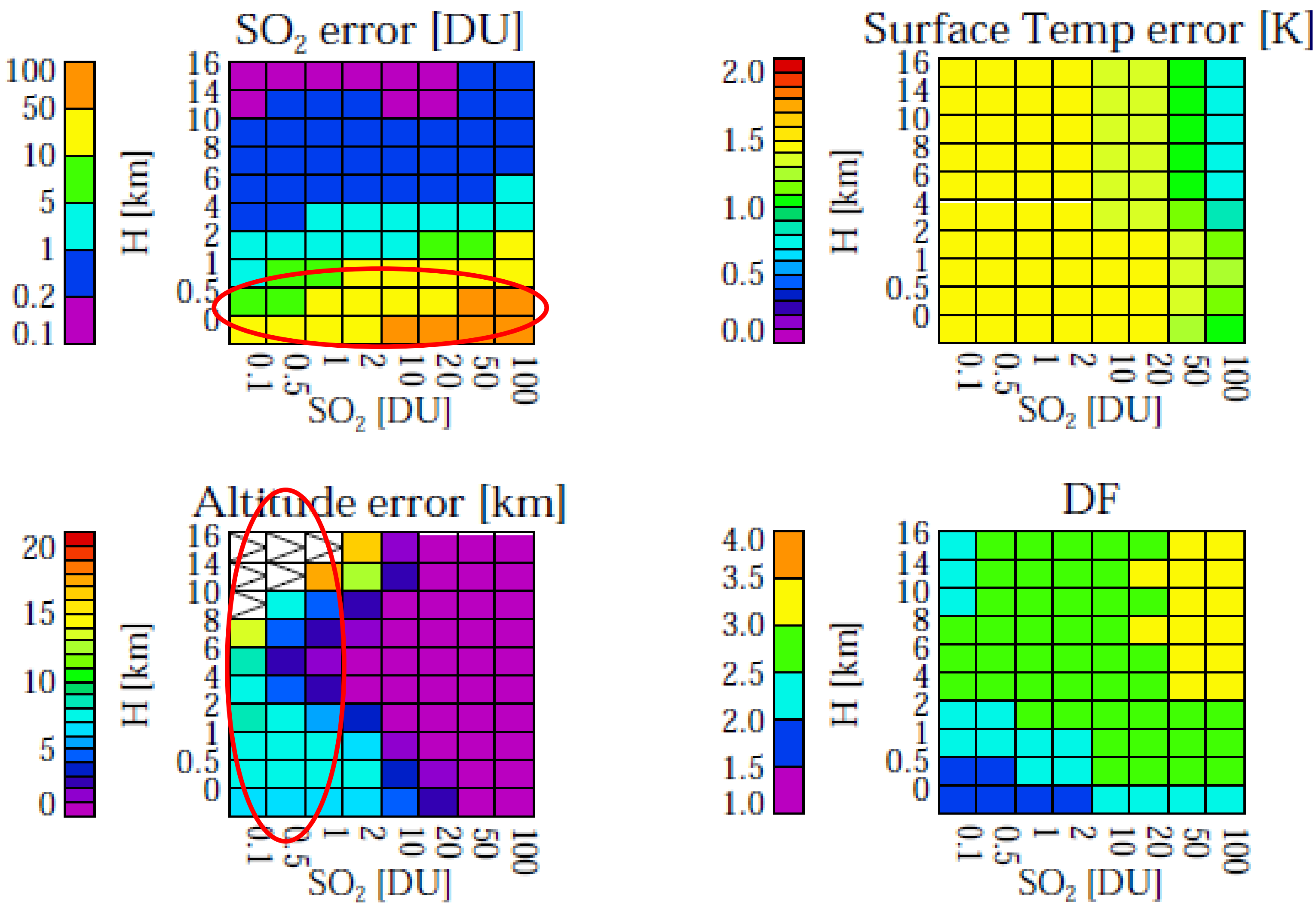
$$A = S_x S_x^{-1} - S_a^{-1}$$

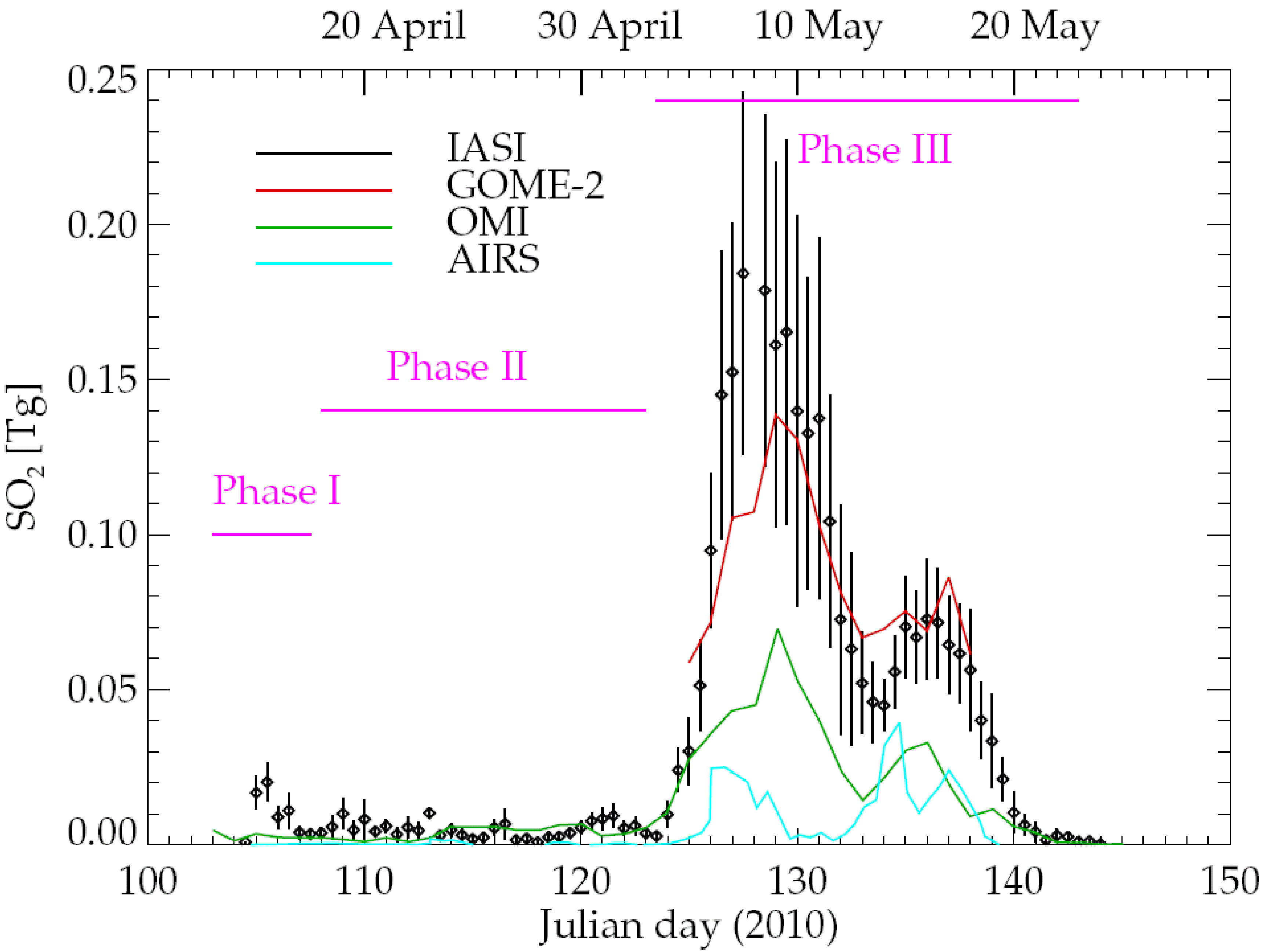
A priori values

SO2, H, s, Ts

Xa=[0.5, 400, 100, 290]

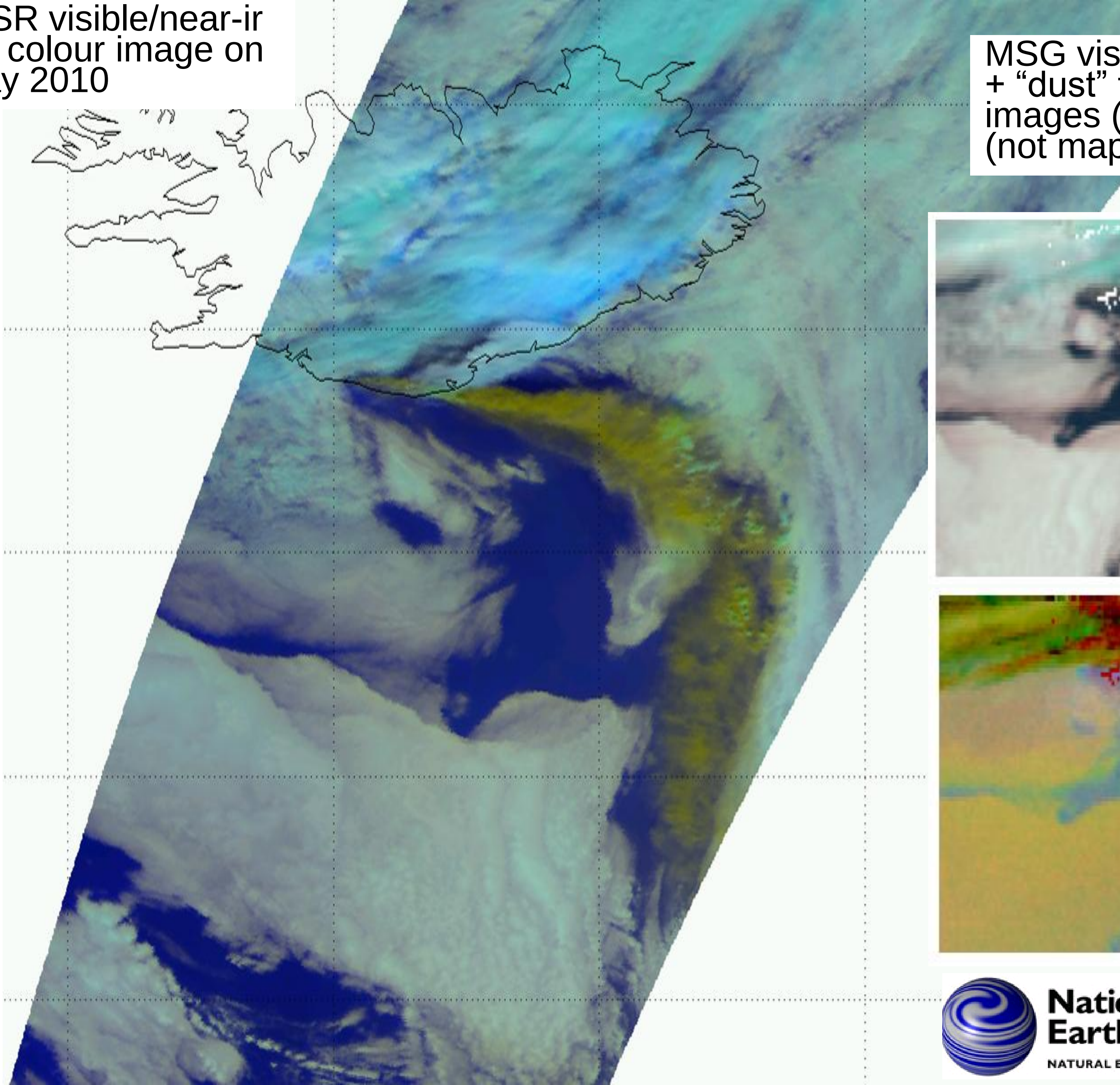
DXa=[100, 1000, 1, 20]



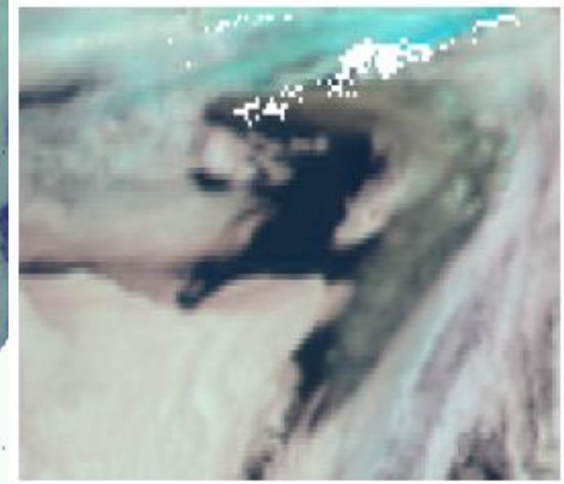


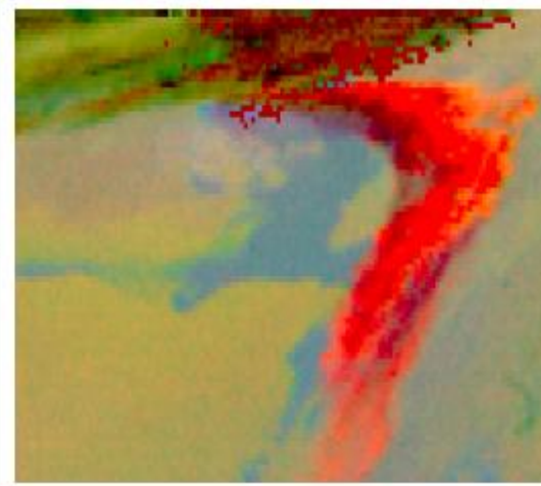
OMI, AIRS (Thomas and Prata, ACP 2011) GOME-2 (Rix et al, JGR 2012) [Carboni et al ACP 2012]

AATSR visible/near-ir false colour image on 6 May 2010



MSG visible/near-ir + “dust” false colour images (12 UT) (not map-projected)





National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL

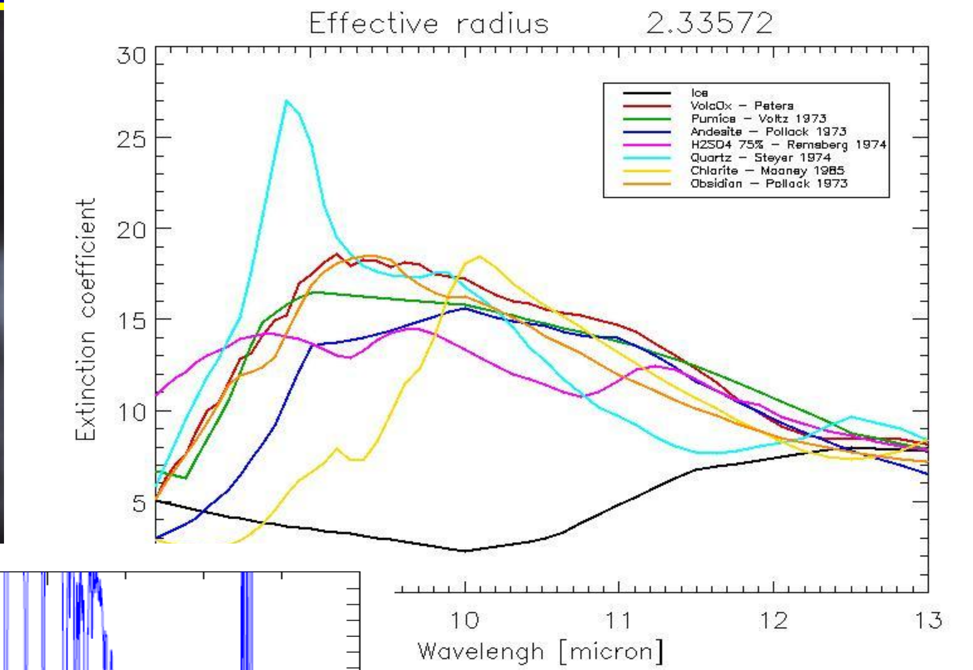
Ash composition from thermal infrared spectrometer

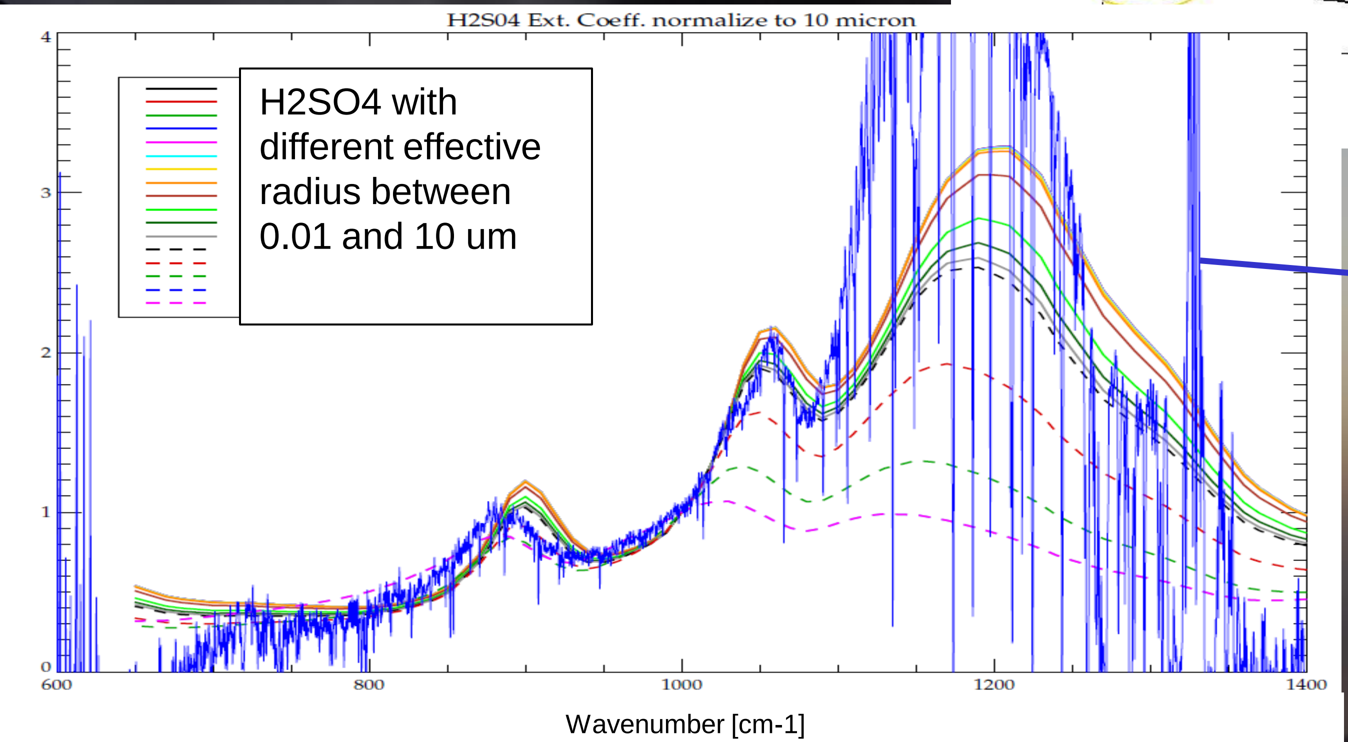
relationship between ash features and styles of explosive activity.

. **Basaltic** ➡ **Andesitic** ➡ **Rhyolitic**

Increasing SiO_2 %

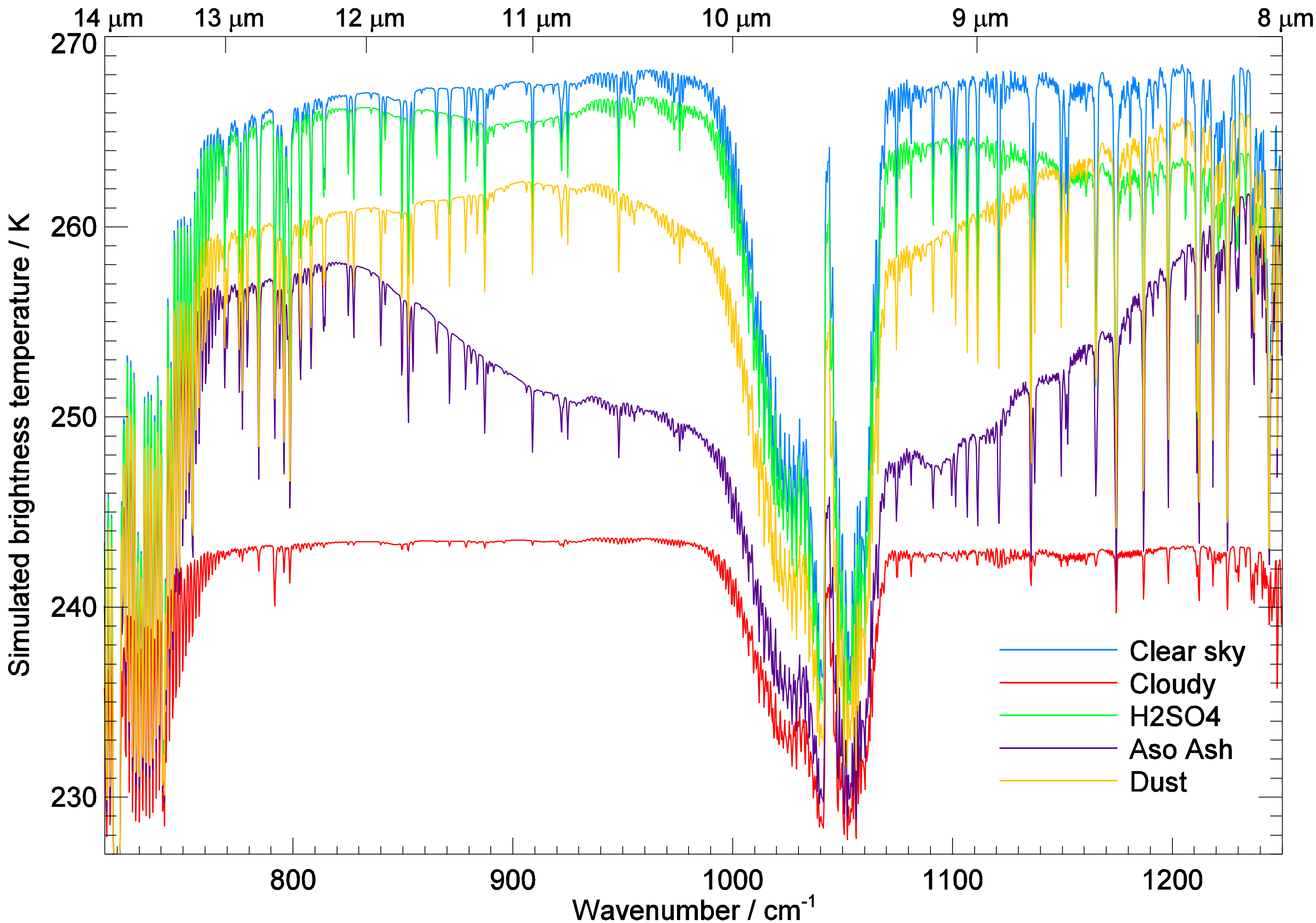
Extinction coefficients obtained for ice, volcanic ash (Peters, 2012), pumice, andesite, H_2SO_4, quartz, obsidian.





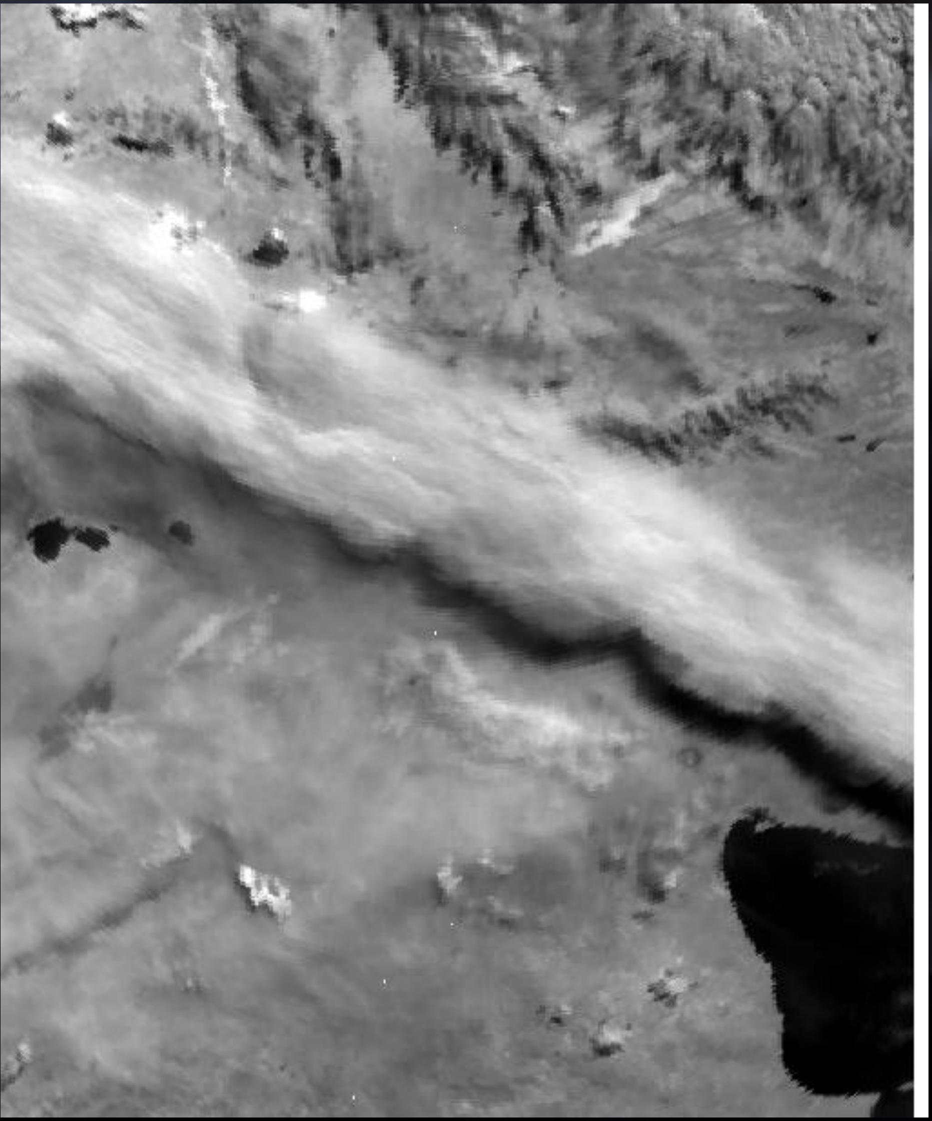
FTIR spectra measured at Masaya volcano in Nicaragua (Mike Burton).

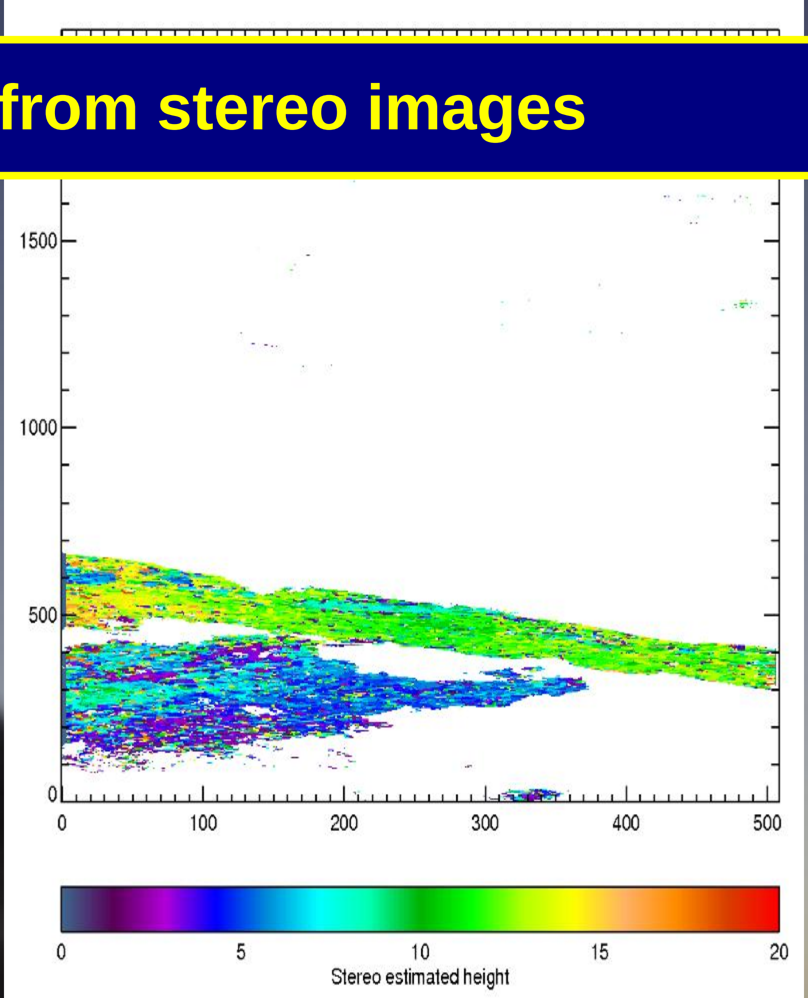
IASI simulated spectra



Volcanic plume altitude from stereo images

AATSR nadir view





The main plume appears at about 15 km but descends to about 12 km quite quickly. The plume to the south is much lower - typically around 5 km in altitude.

Credit G.Thomas