Inverting for high temporal resolution SO$_2$ flux using satellite imagery and chemistry-transport modelling: application to the 2010 Eyjafjallajökull eruption

Marie Boichu [1], Laurent Menut [1], Dmitry Khvorostyanov [1], Lieven Clarisse [2], Cathy Clerbaux [2,3], Solène Turquety[1], Pierre Coheur [2]

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[2]*Université Libre de Bruxelles,* [3]*IPSL, LATMOS*

Volcanic SO_2 source

Knowledge of the volcanic SO_2 source is crucial:
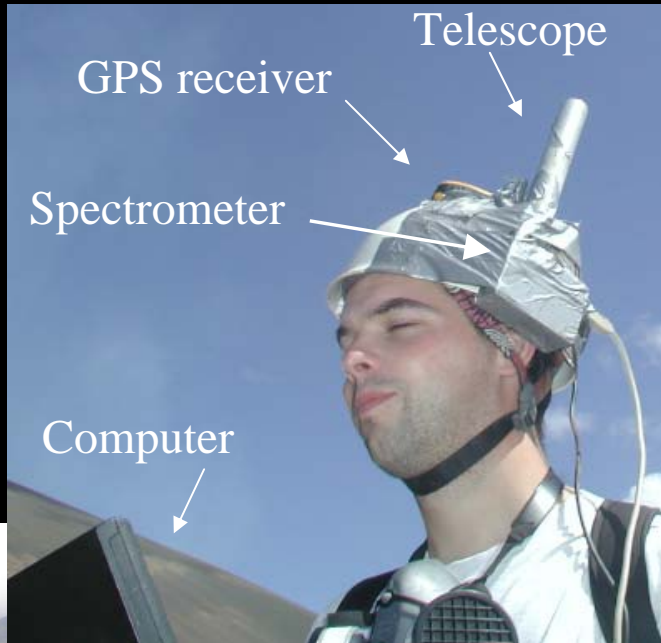
1) for atmospheric scientists:

   1.a) SO2 is a good proxy for ash (often easier satellite retrieval)

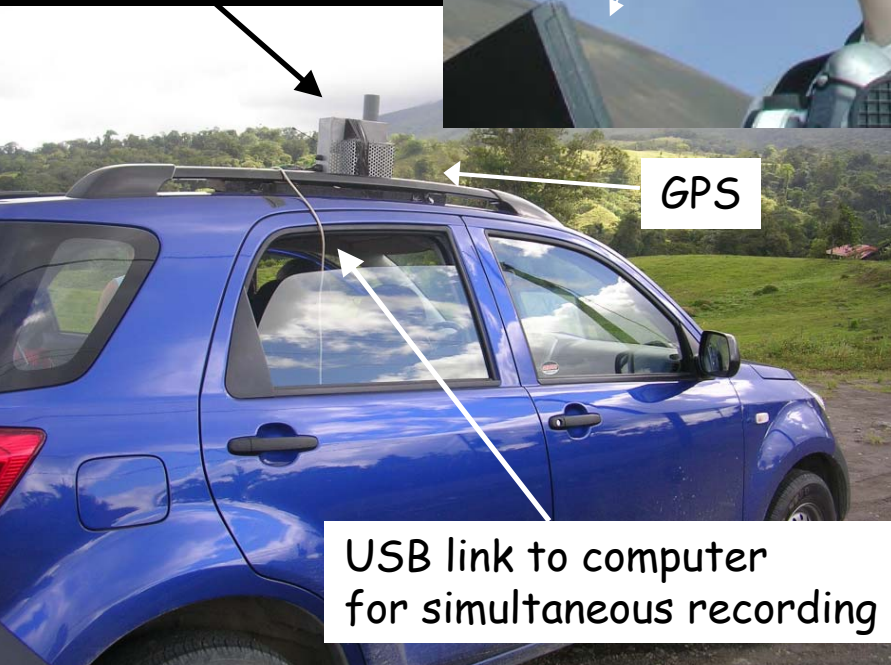   -> Simulation & forecast of volcanic plume transport/dispersion (air traffic)

   1.b) Impact on climate on longer-term

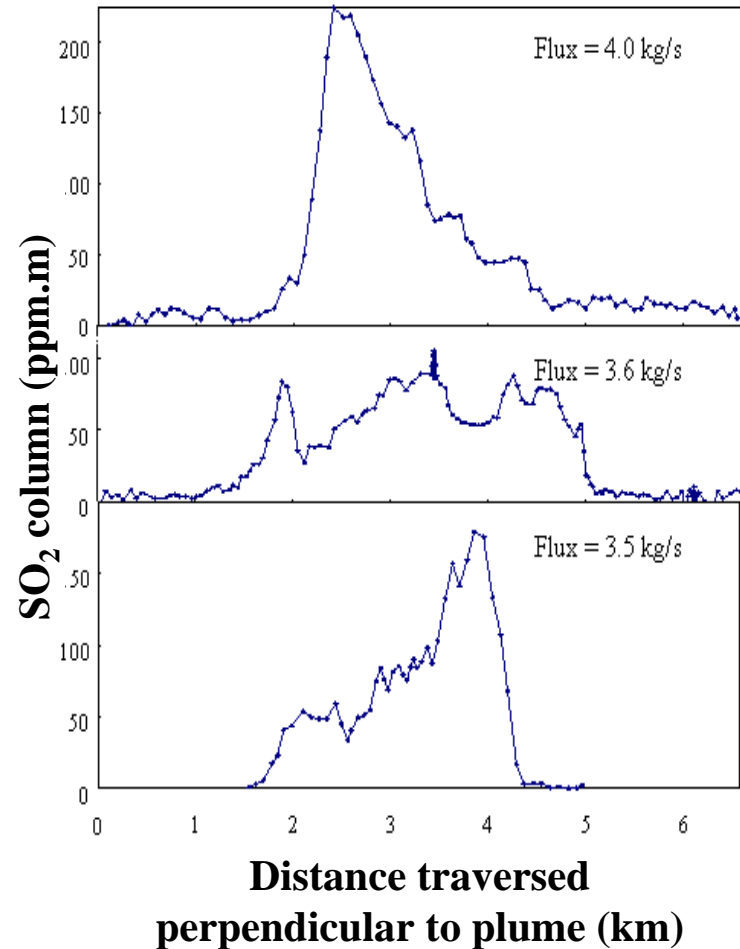2) for volcanologists (SO_2 flux = indicator of volcanic activity)

SO₂ flux from traverses using a mobile UV-DOAS spectrometer

GPS receiver

Telescope

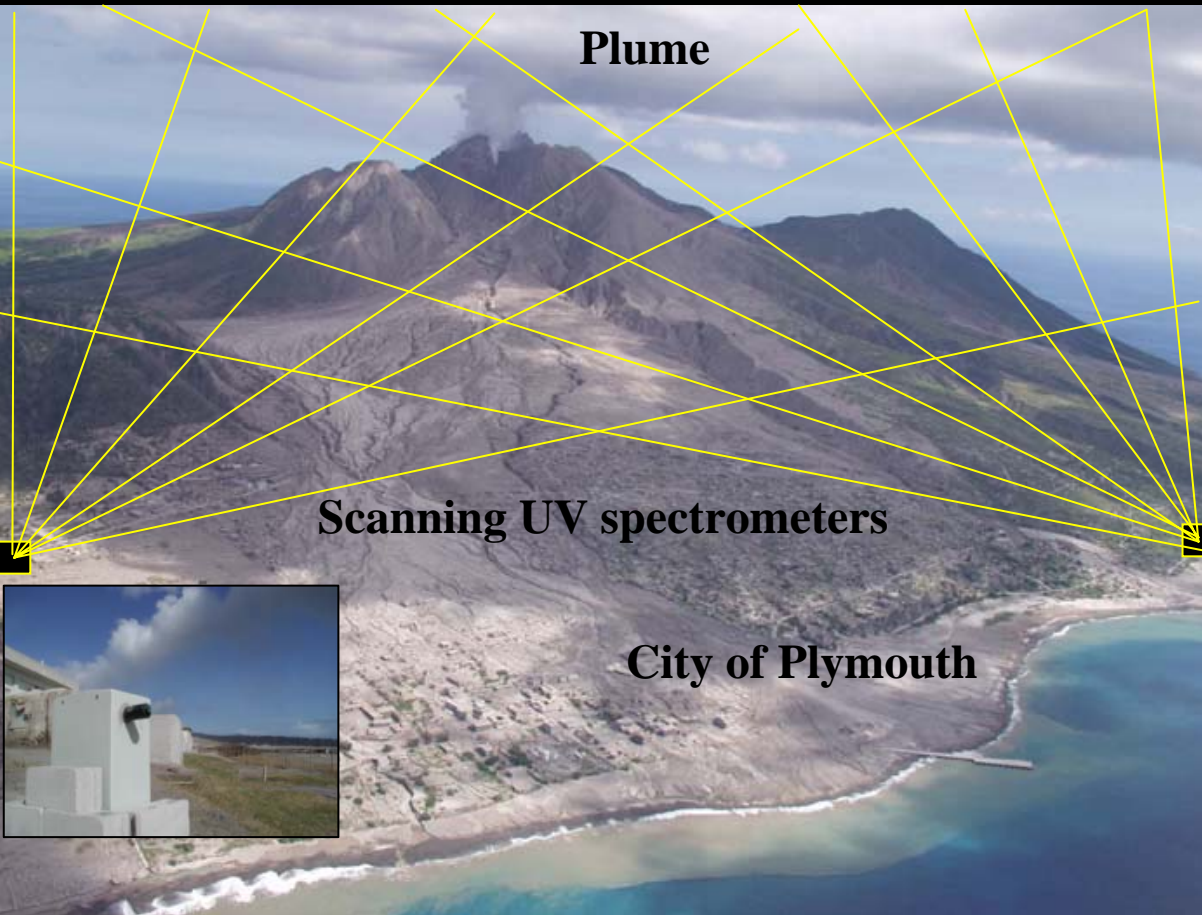Spectrometer

Computer

Thermo-controlled DOAS spectrometer

GPS

USB link to computer for simultaneous recording

SO₂ flux retrieval

Flux = 4.0 kg/s

Flux = 3.6 kg/s

Flux = 3.5 kg/s

SO_2 column (ppm.m)

Distance traversed perpendicular to plume (km)

SO$_2$ flux from automated scanning UV spectrometers and more recent techniques

Soufrière Hills Volcano

Plume

Scanning UV spectrometers

City of Plymouth

Edmonds et al., 2003

Erebus Volcano

Plume

Dual-wide field of view DOAS

dX ~ 810m

dY ~ 72m

Lenses

Goniometer

Upper   Lower

Spectrometers
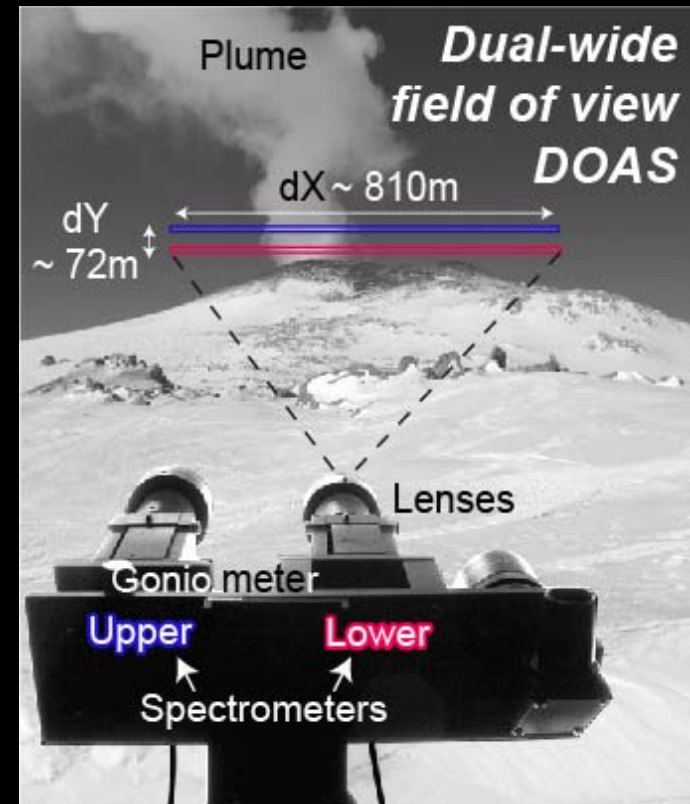
Boichu et al., 2010

DOAS network on 24 volcanoes today
(Galle et al. 2010)

Limits of ground spectroscopic methods

- Most active volcanoes are still too poorly instrumented !
- Limited when ash-rich emissions (plume opaque to UV)
- Mobile DOAS measurements difficult and not safe during major eruptions...

And from satellite observations ?

IASI SO$_2$ CA images of the 2010 Eyjafjallajökull plume

8 May AM

+ 0.0 day

8 May PM

+ 0.5 day

9 May AM

+ 1.0 day

+ 1.5 day

9 May PM

DU
5 10 15 20 25
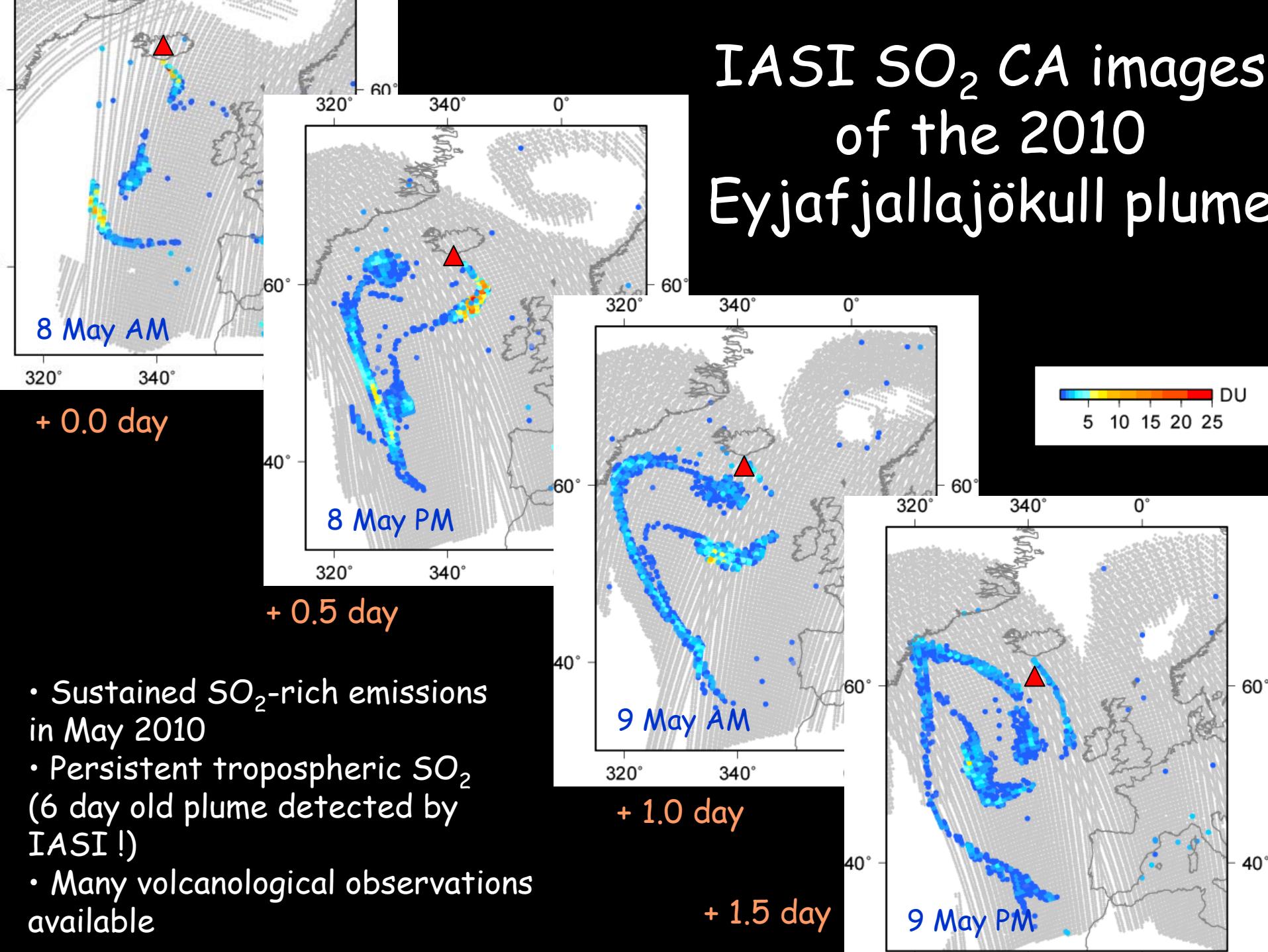
• Sustained SO$_2$-rich emissions in May 2010
• Persistent tropospheric SO$_2$ (6 day old plume detected by IASI !)
• Many volcanological observations available

New approach: inverse modelling
(Boichu et al., subm., ACPD)

$$d \quad = \quad G \quad\quad\quad\quad m$$
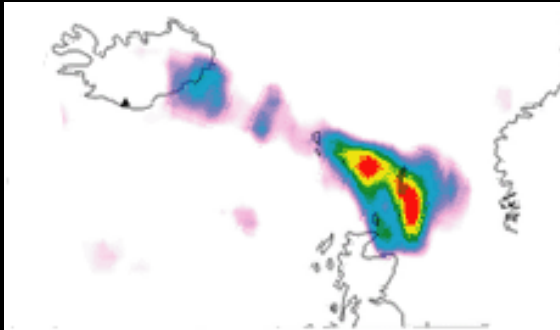
d for data

Needs a description of:
- Transport/mixing
- Diffusion
- Deposition
- Wet scavenging
- Chemistry…
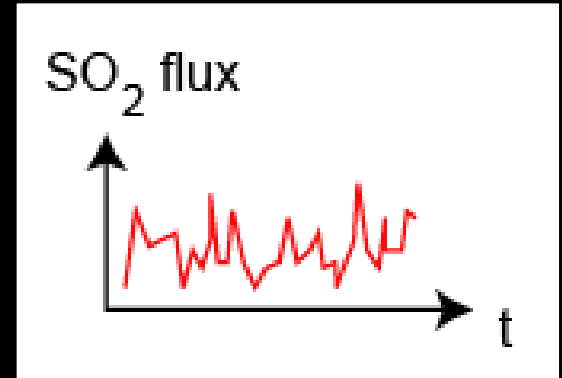
m for model

… from the volcano to the observation point !

Forward model: $\quad\quad\quad\quad d = G\, m$

Inverse problem: $\quad\quad\quad m^* = G^{-g}\, d$

A posteriori prediction: $\quad d^* = G\, m^*$

Inverse modelling

- G: CHIMERE: Regional chemistry-transport model

  – Eulerian model
  – Grid: 25 km horizontal resolution
  – 18 vertical layers up to 200 hPa (~ 10 km)
    (~ 1km vert. resol. above 5 km)
  – Forced with WRF meteorological field
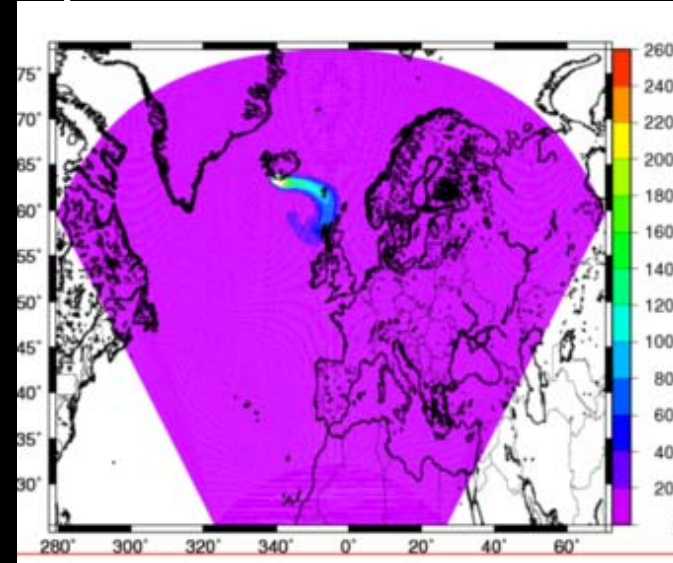
- d: IASI (Infrared Atmospheric Sounding Interferometer)

  – Abord the polar-orbiting MetOp-A
  – Infrared (645 cm–1 to 2760 cm –1)
  $\Rightarrow$ 2 overpasses per day (9h30; 21h30 LT)

  – Spatial resolution : (12 km x 12 km) pixel at nadir
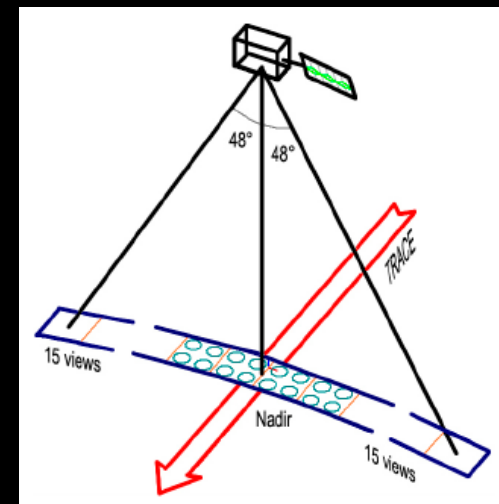
(Clerbaux et al. 09)

Forward model: $d = G\,m$

t_0

t_0+dt
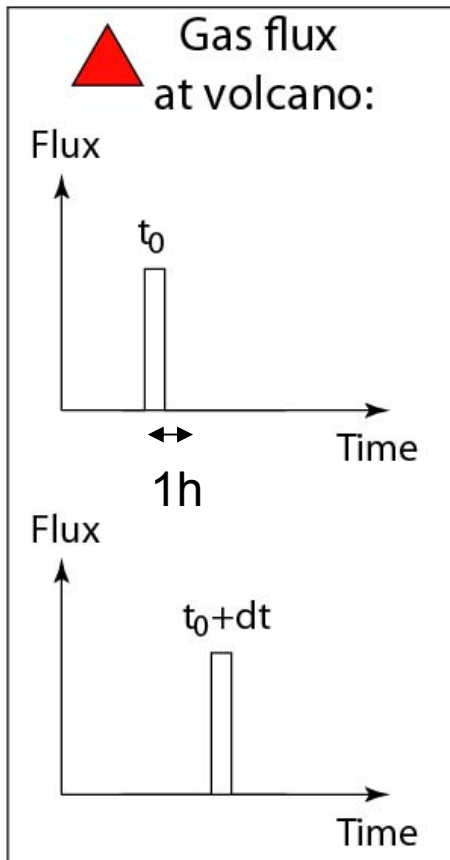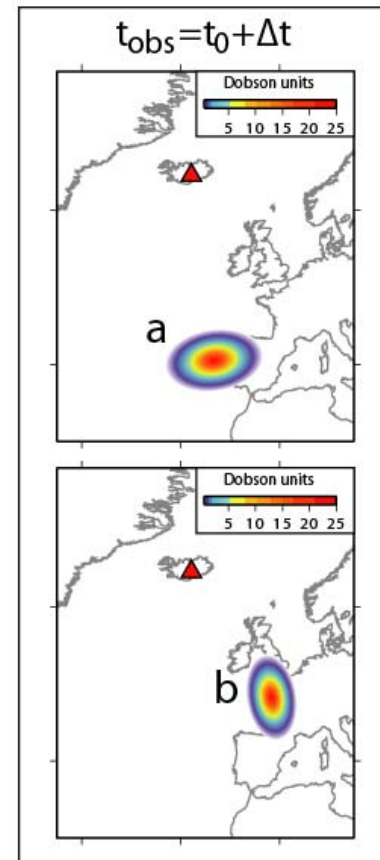
t_{obs}
=
$t_0+\Delta t$

m

Prerequisites
on source term:
- Emission altitude (2010 Eyjaf.: fixed to 7 km)
- Emission profile (Gaussian)
- Elemental function (1h-long rectangular pulse here)

Inversion scheme: m* = G⁻ᵍ d

IASI SO$_2$ CA map
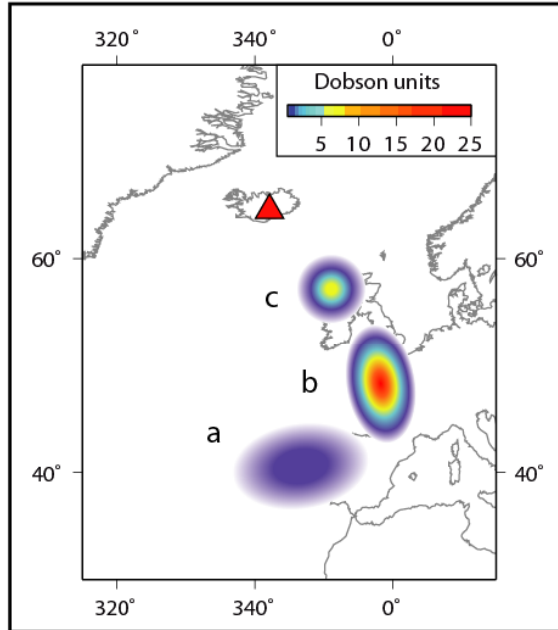
d
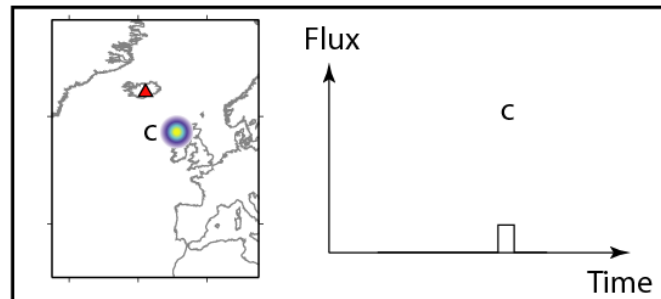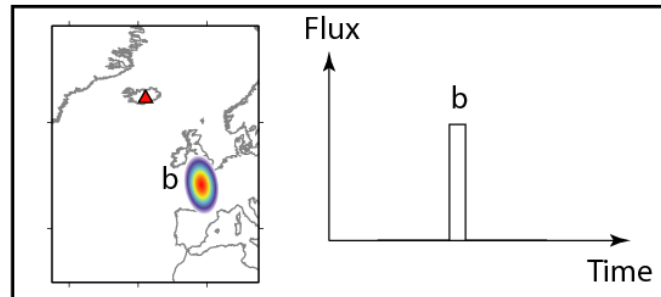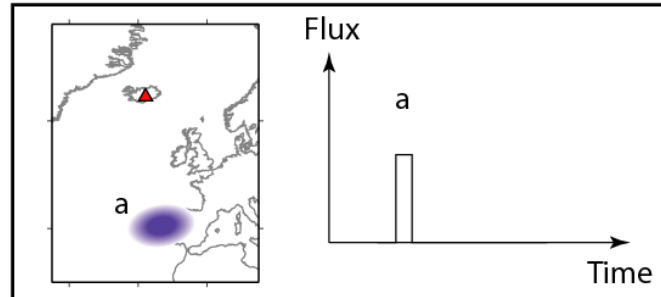
Emitted SO$_2$ flux
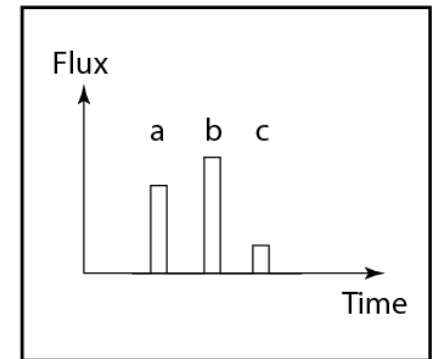
m*

Inversion scheme:
- least squares inversion
- non-negativity of solution
- no a-priori on source (!)
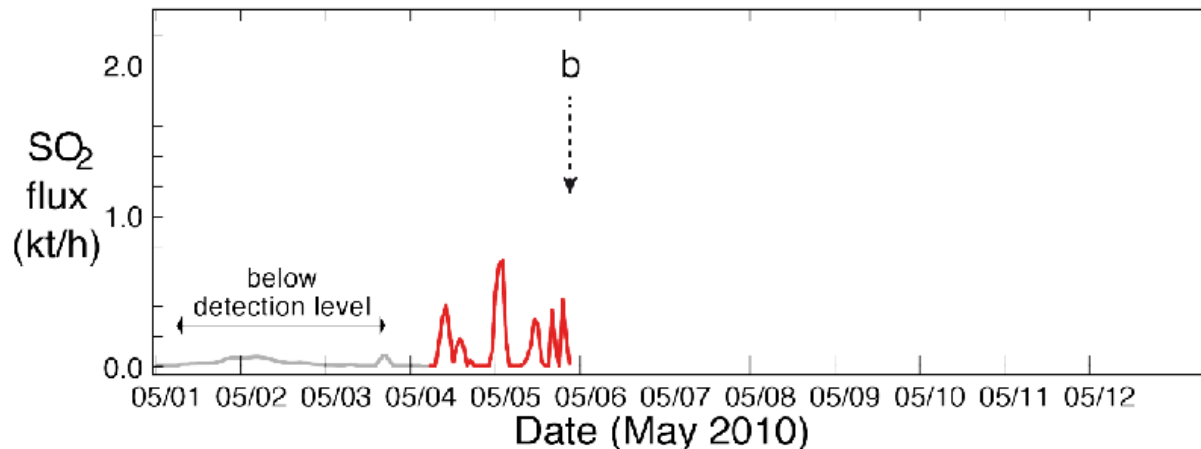
Retrospective analysis (1 => 12 May 2010)
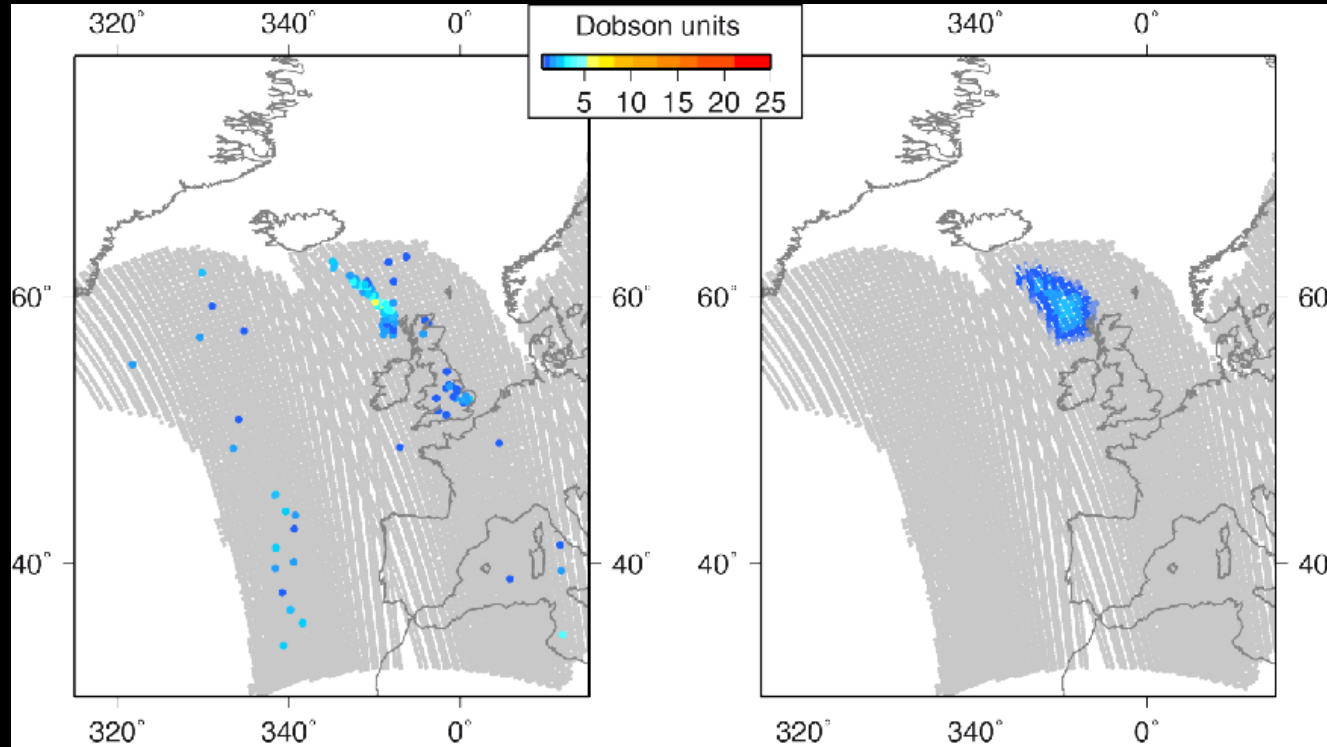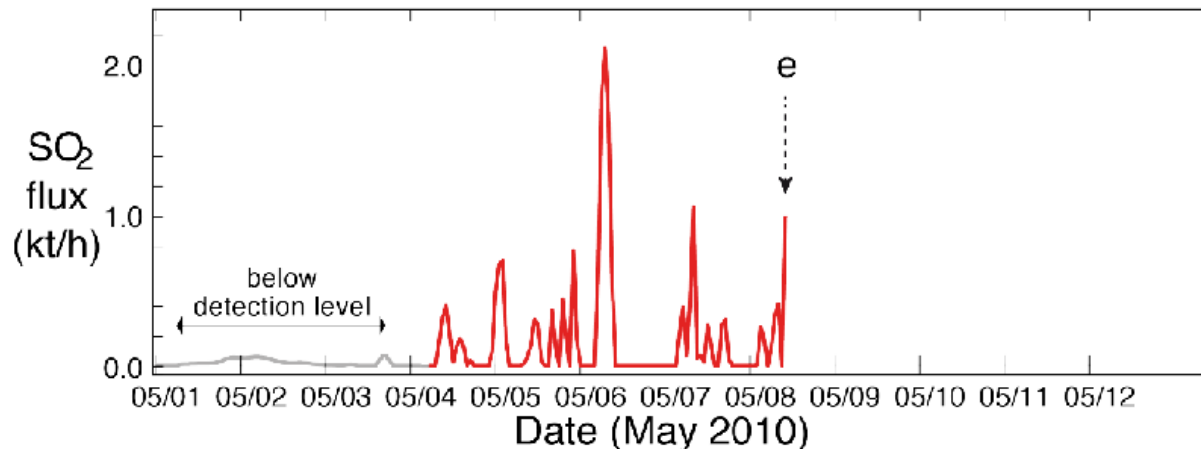

IASI (d)

Simu (d*)

4 May PM
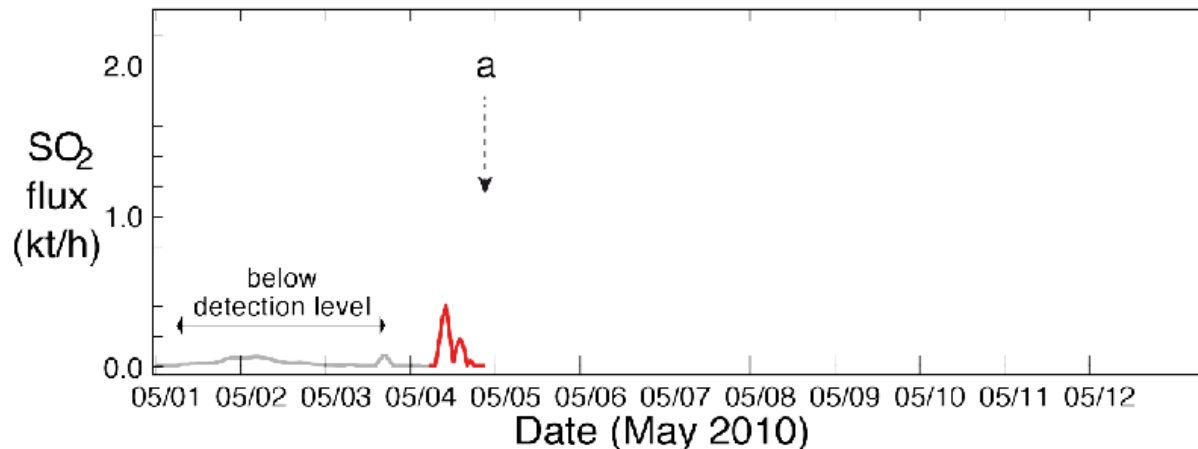
Source (m*)

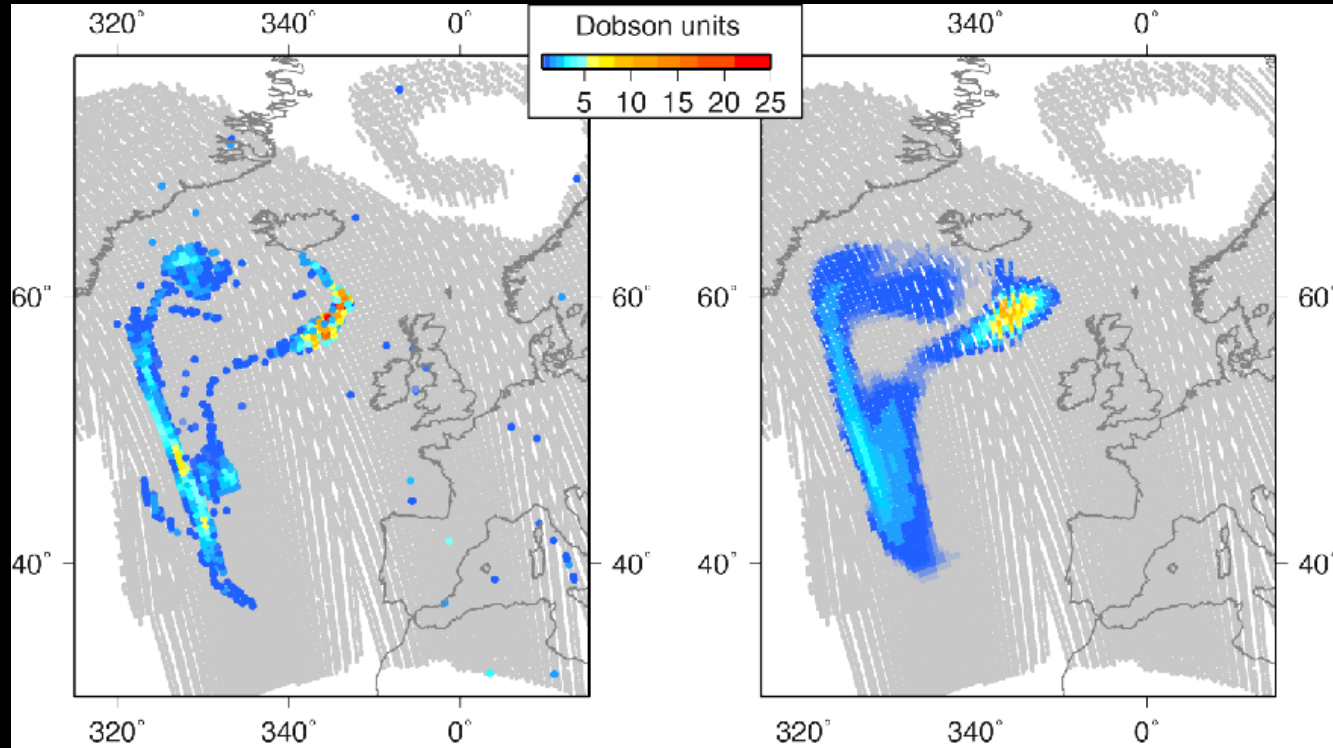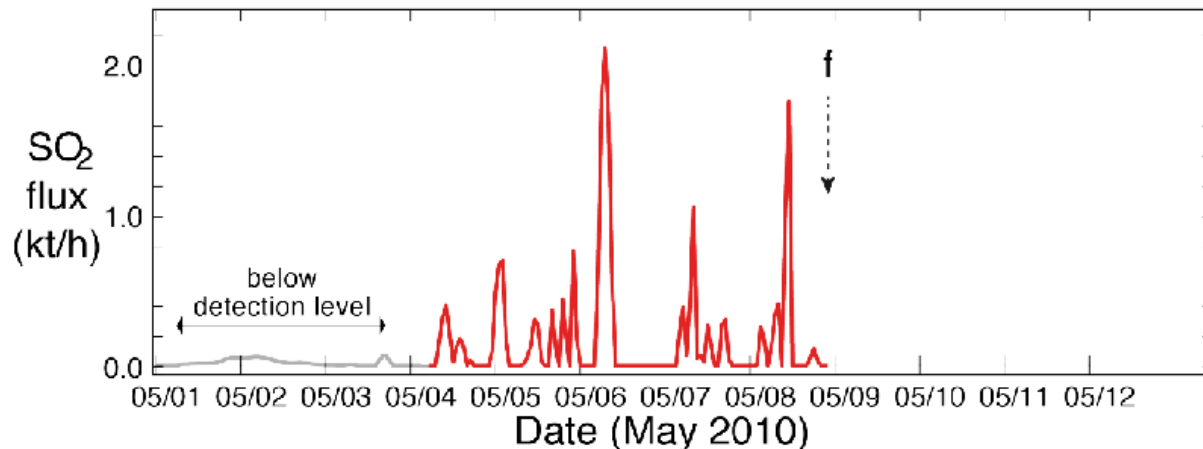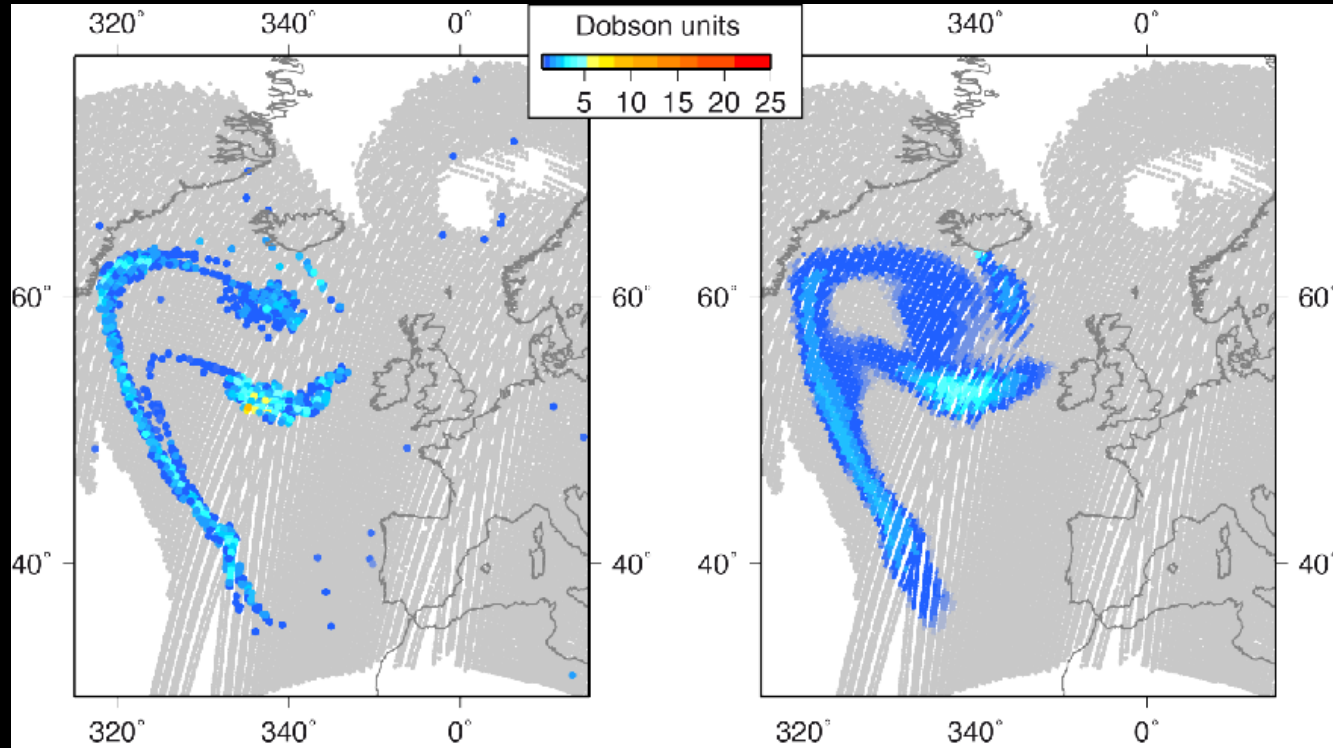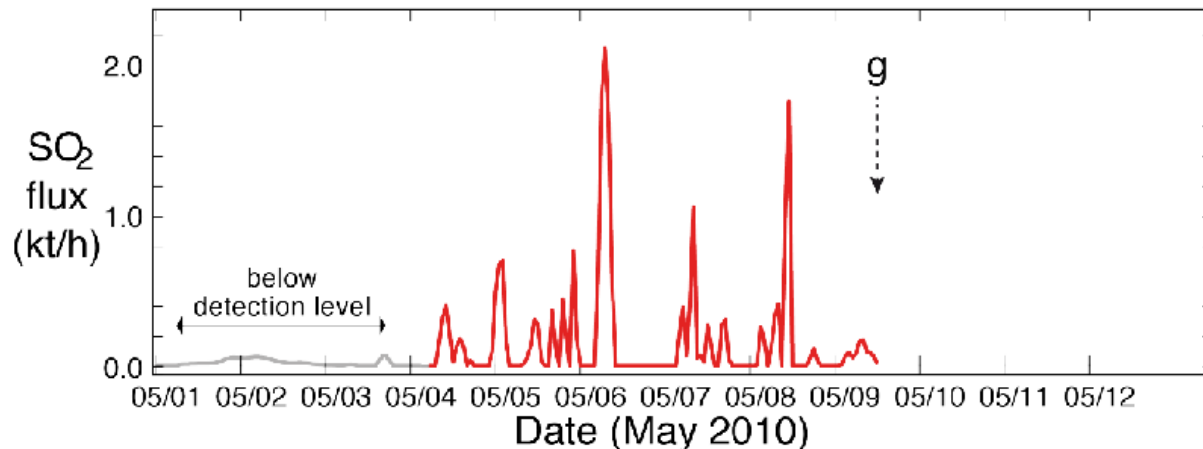# Retrospective analysis (1 => 12 May 2010)
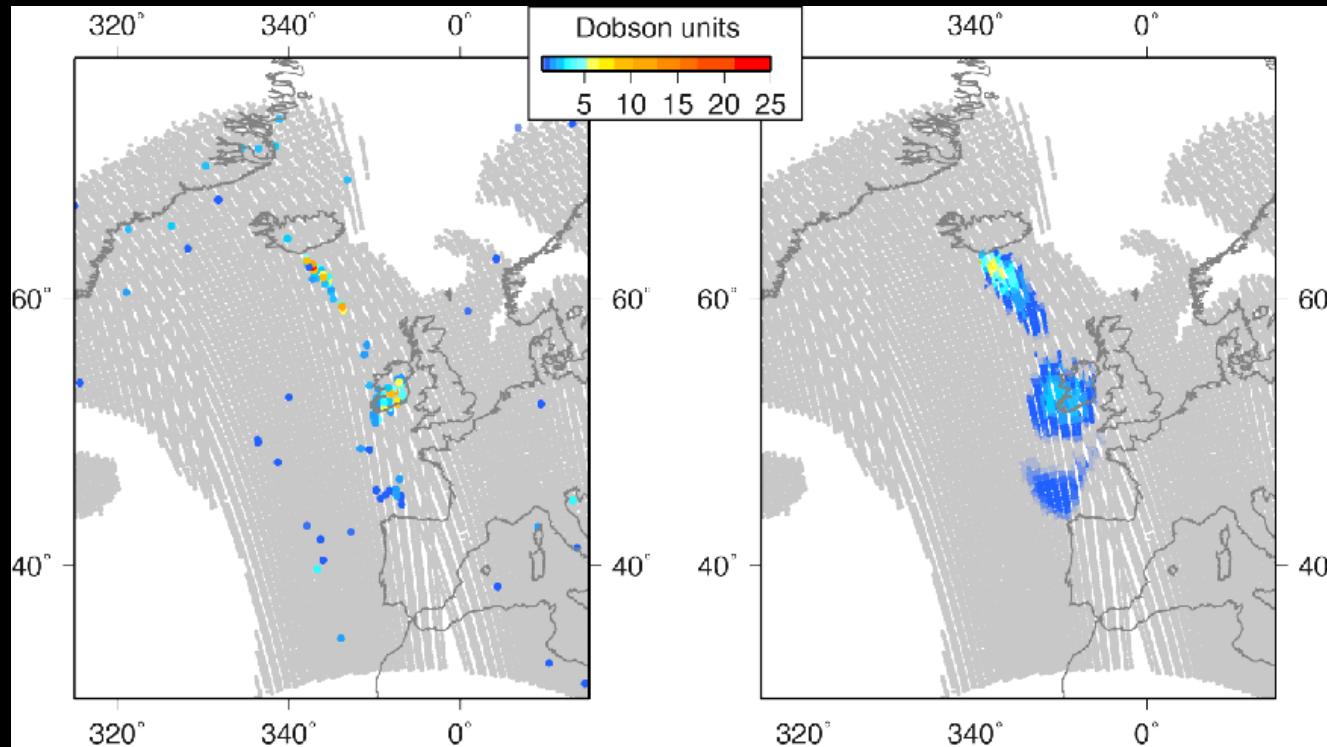
IASI
(d)

Simu
(d*)

5 May PM

+1.0 day

Source
(m*)

Retrospective analysis (1 => 12 May 2010)
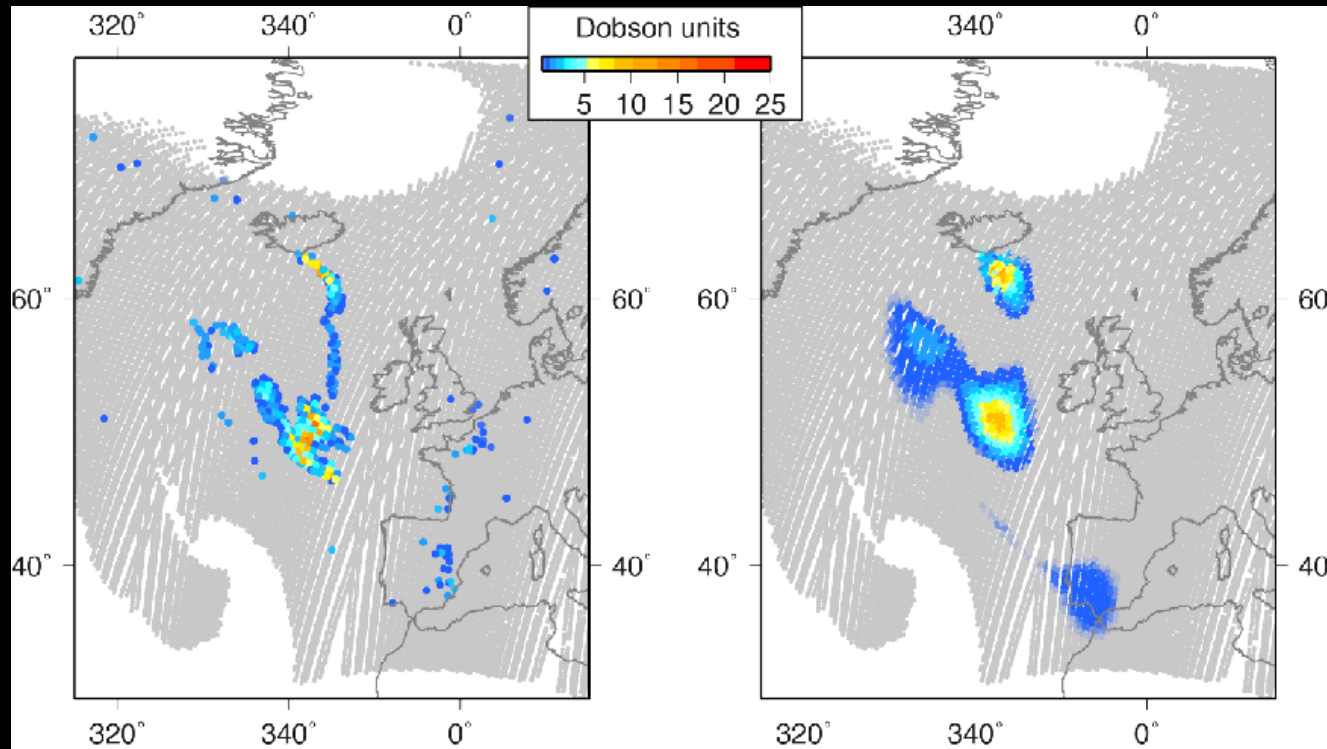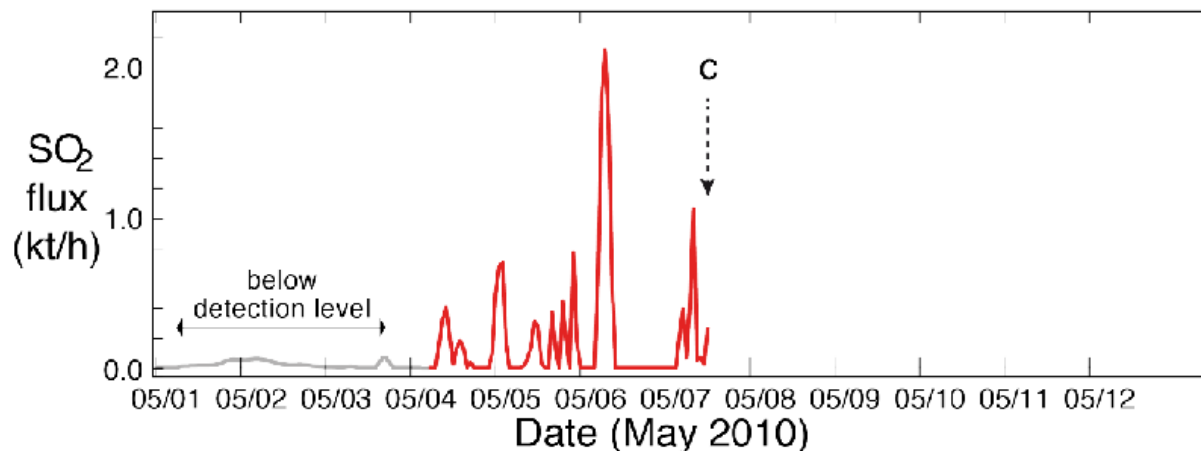
IASI (d)

Simu (d*)

7 May AM

+2.5 day

Source (m*)

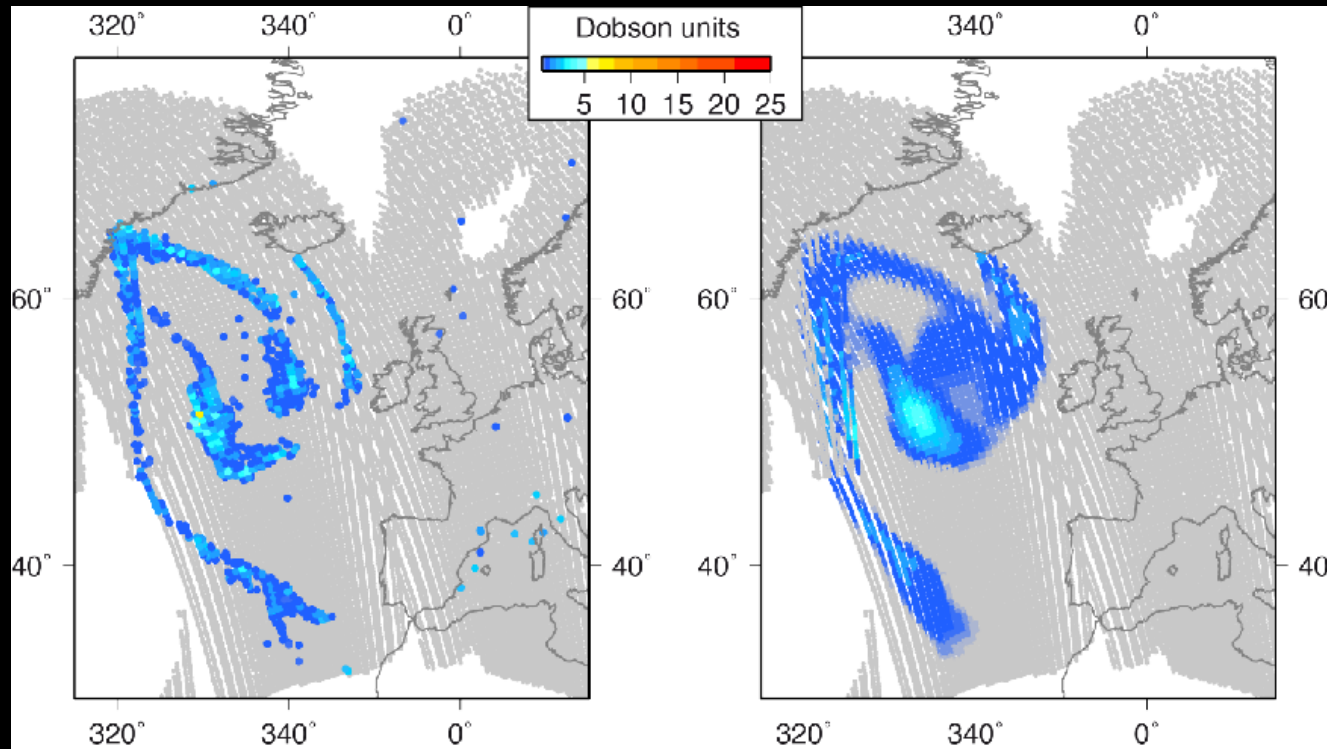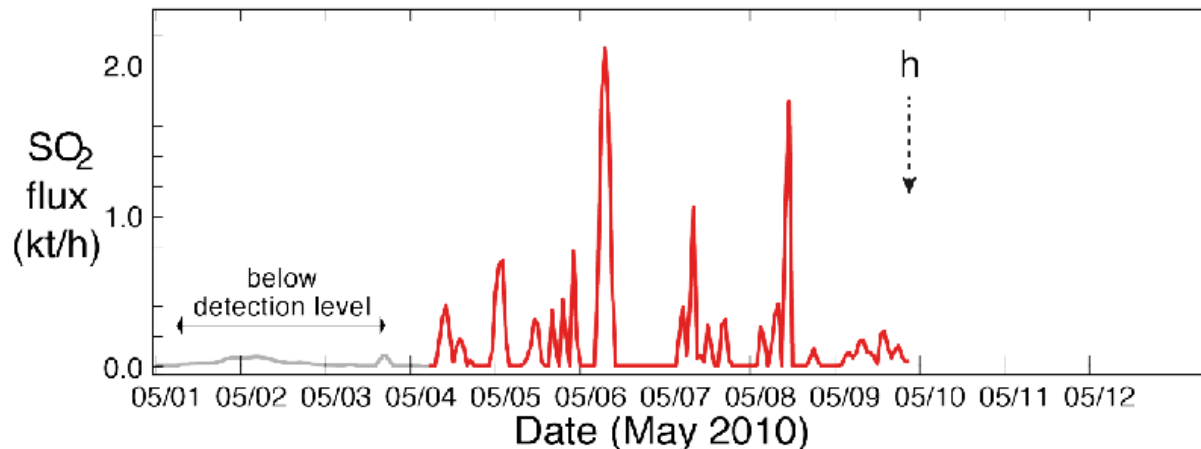# Retrospective analysis (1 => 12 May 2010)
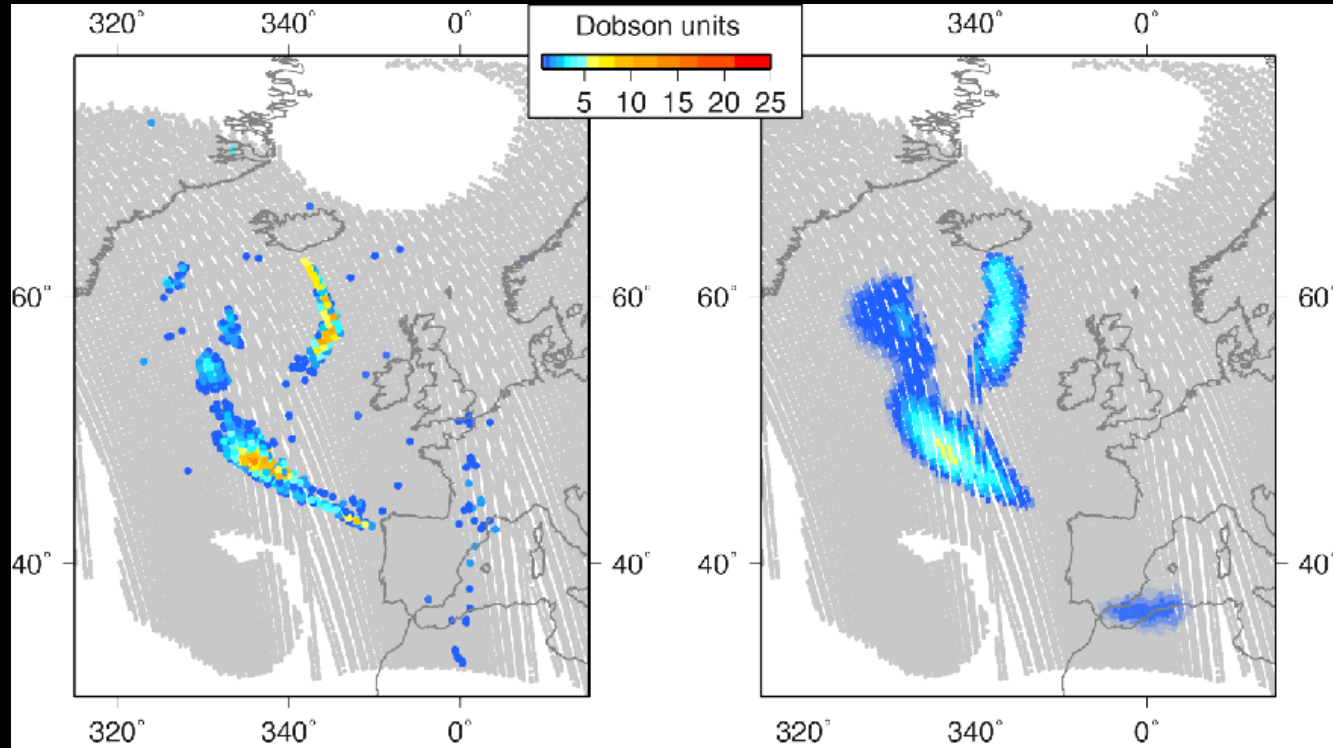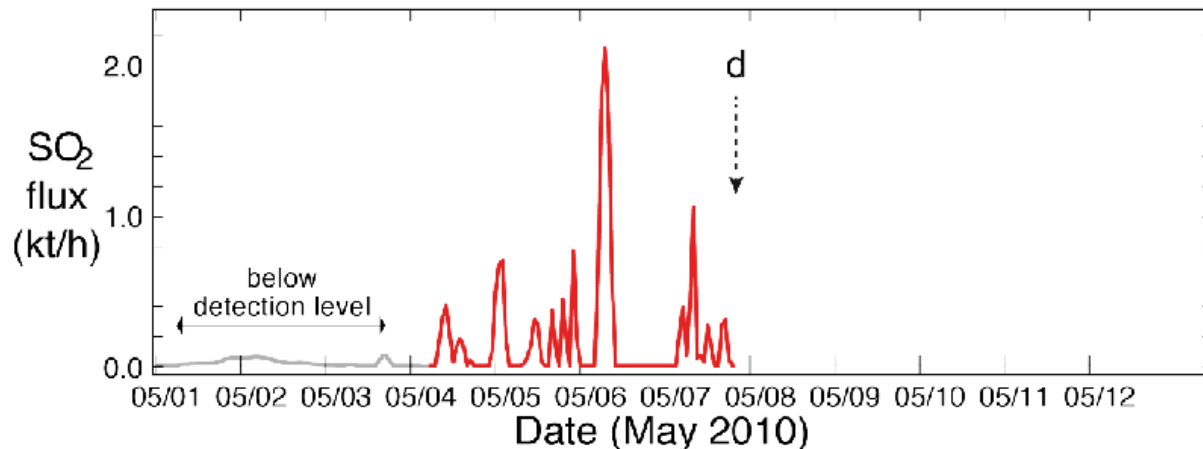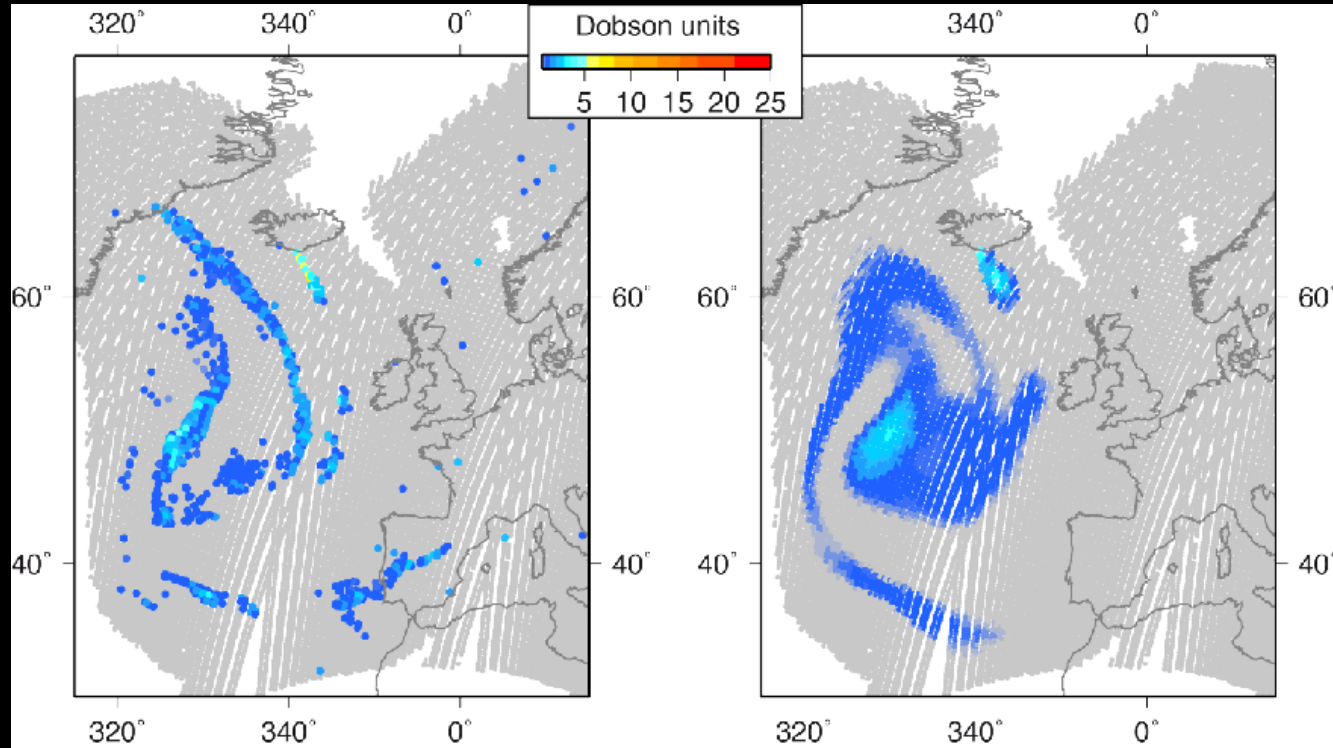

IASI (d)

Simu (d*)

7 May PM

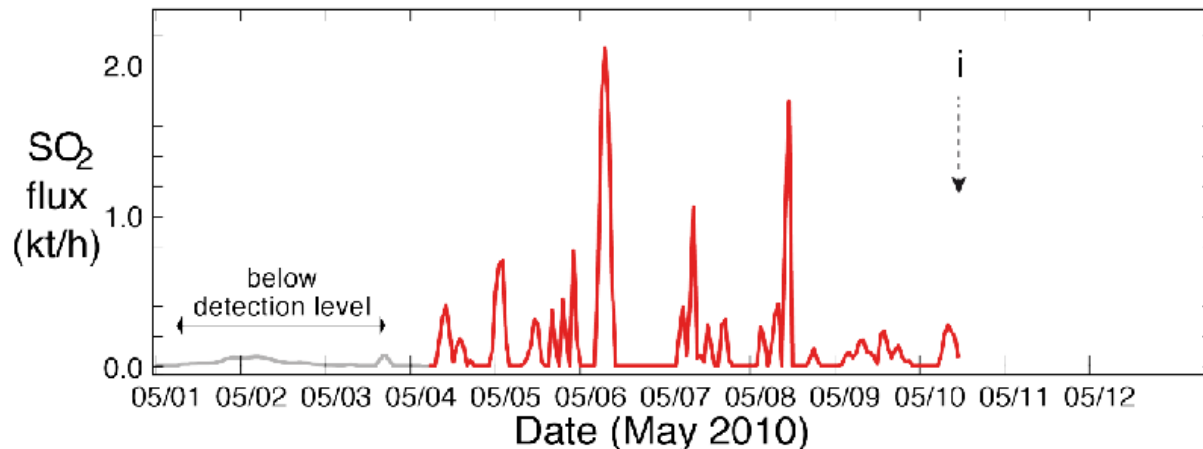+3.0 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)
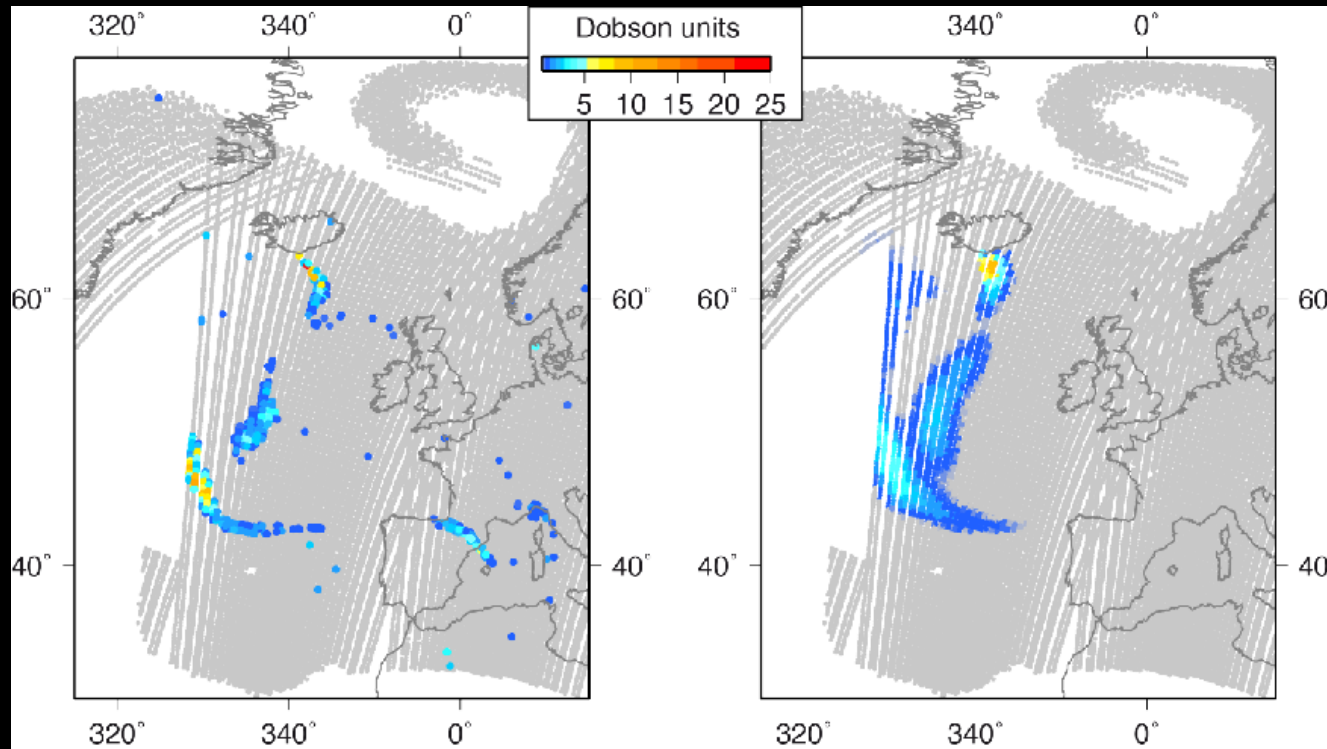
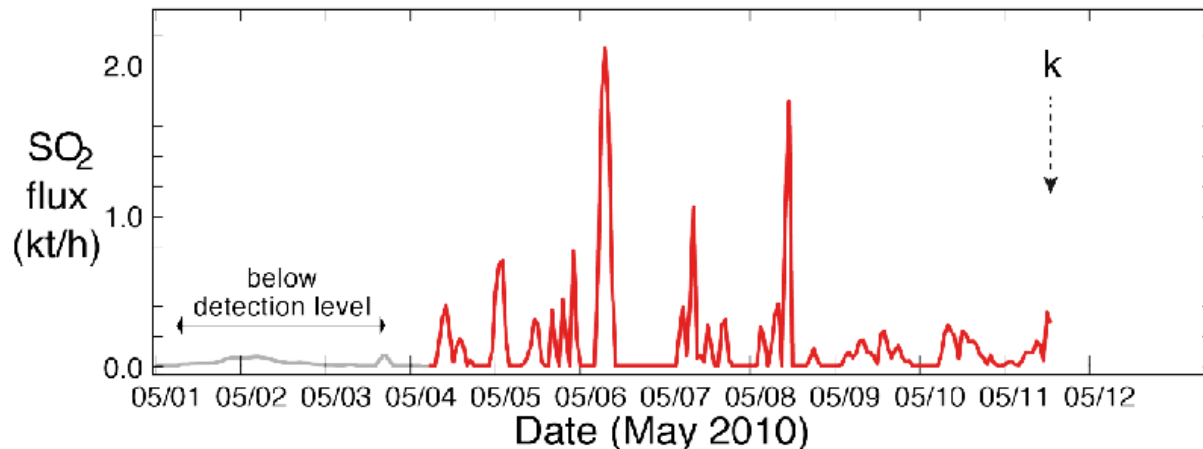IASI (d)

Simu (d*)

8 May AM

+3.5 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)

IASI (d)

Simu (d*)

8 May PM

+4.0 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)

IASI (d)

Simu (d*)

9 May AM

+4.5 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)

IASI (d)

Simu (d*)

9 May PM

+5.0 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)

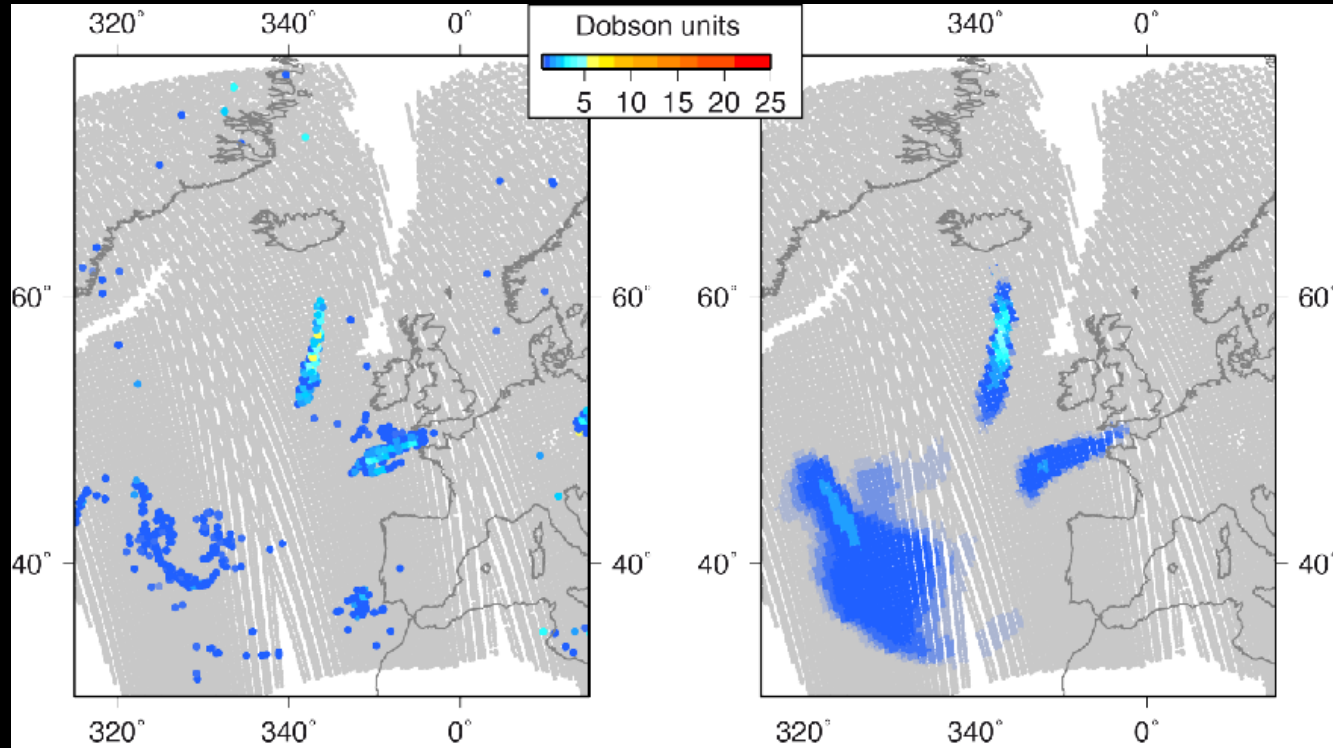IASI (d)

Simu (d*)

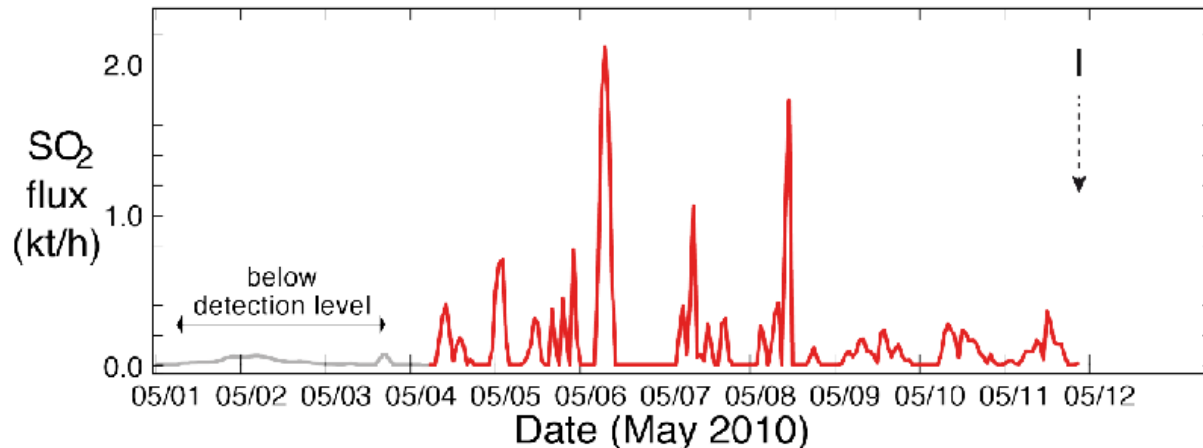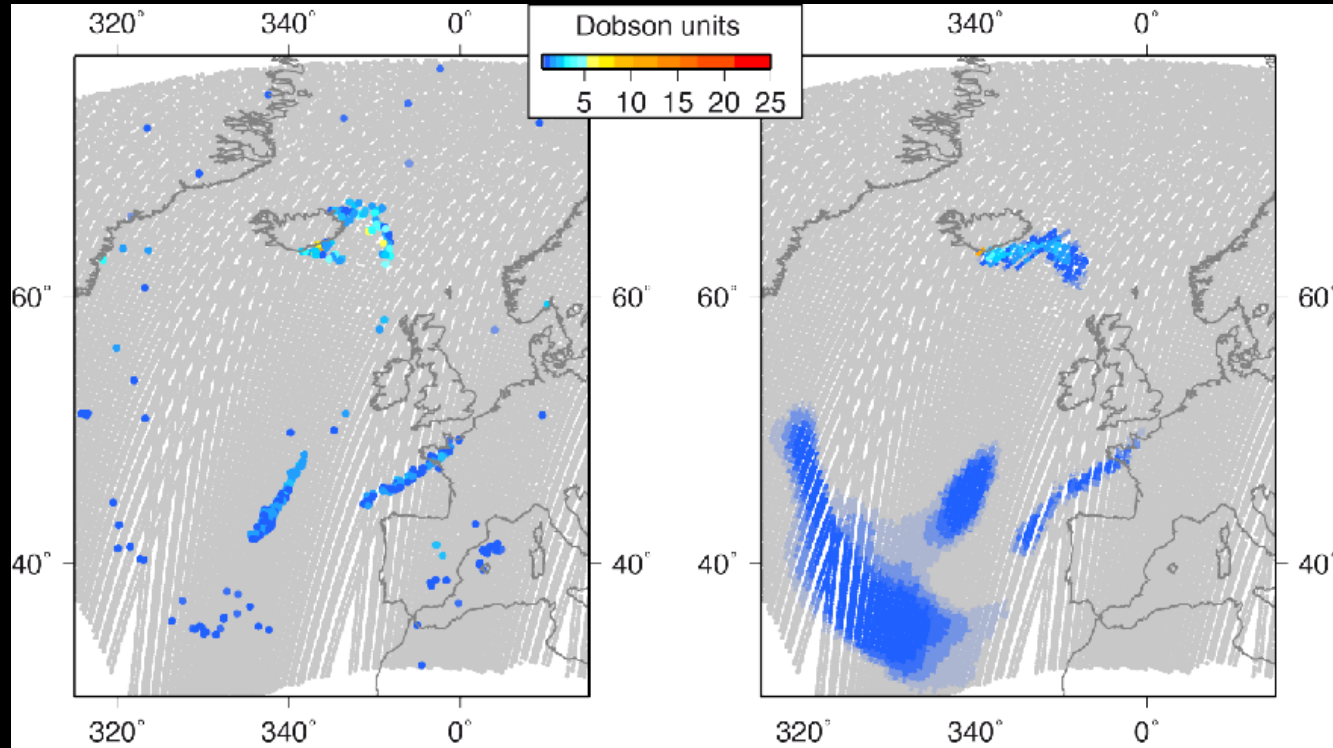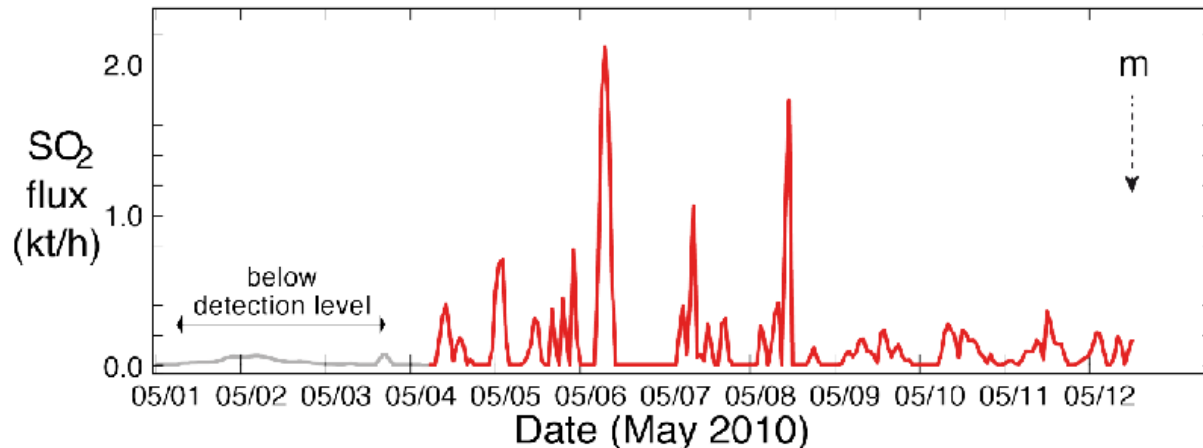10 May AM

+5.5 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)

IASI (d)

Simu (d*)

10 May PM

+6.0 day

Source (m*)

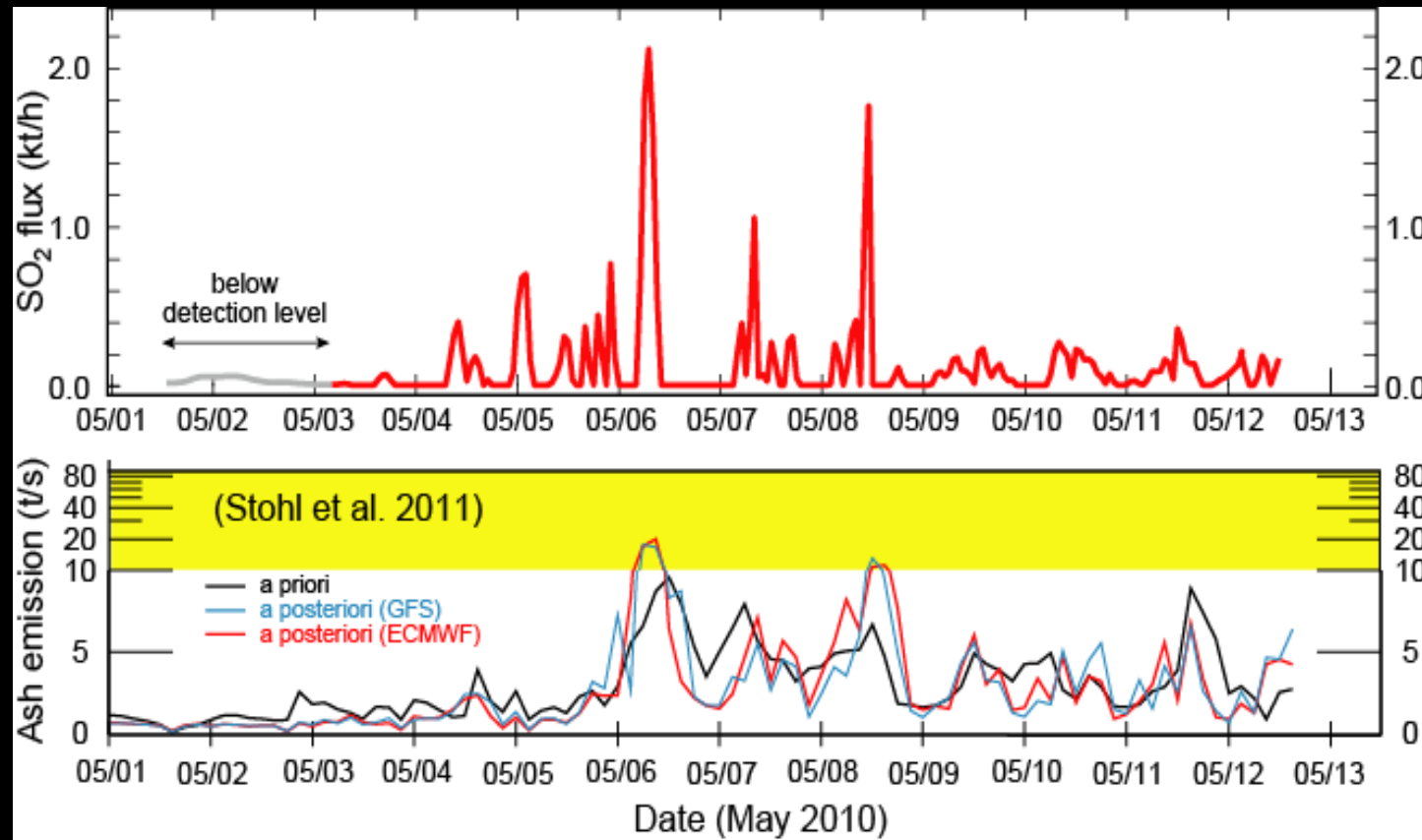# Retrospective analysis (1 => 12 May 2010)
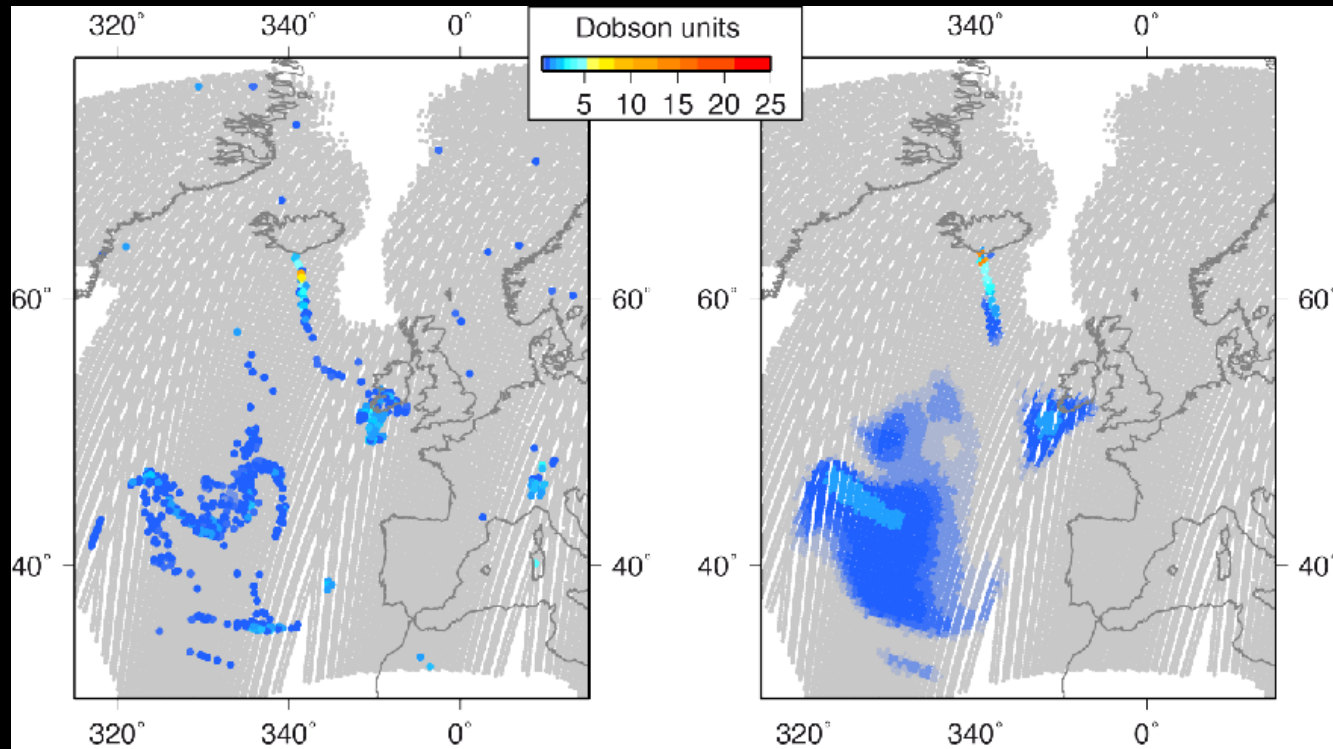
IASI
(d)

Simu
(d*)

11 May AM

+6.5 day

Source
(m*)

Retrospective analysis (1 => 12 May 2010)

IASI (d)

Simu (d*)

11 May PM

+7.0 day

Source (m*)

Retrospective analysis (1 => 12 May 2010)

IASI (d)

Simu (d*)
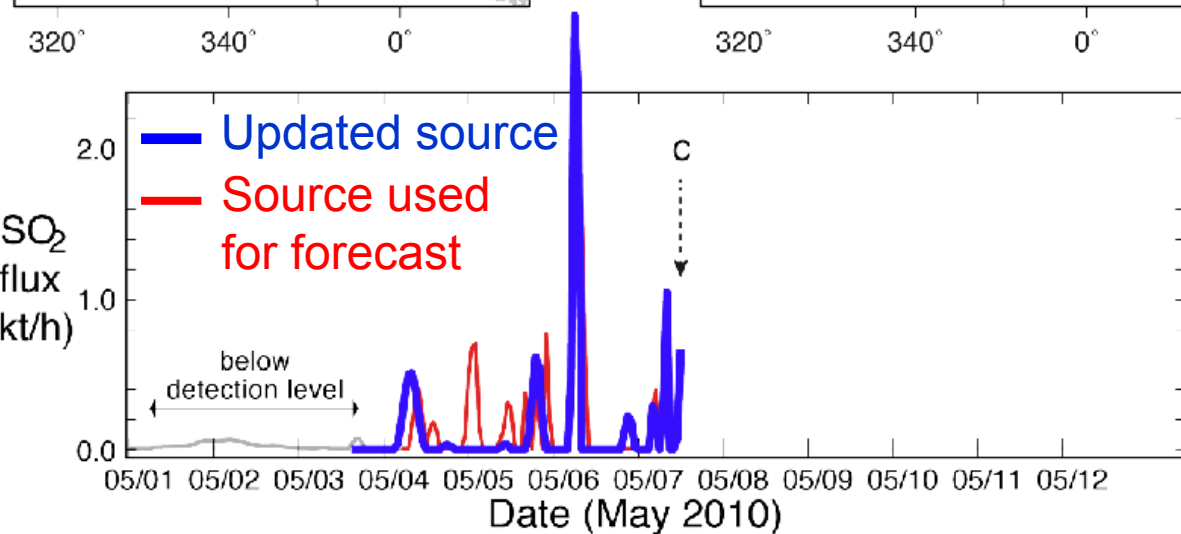
12 May AM
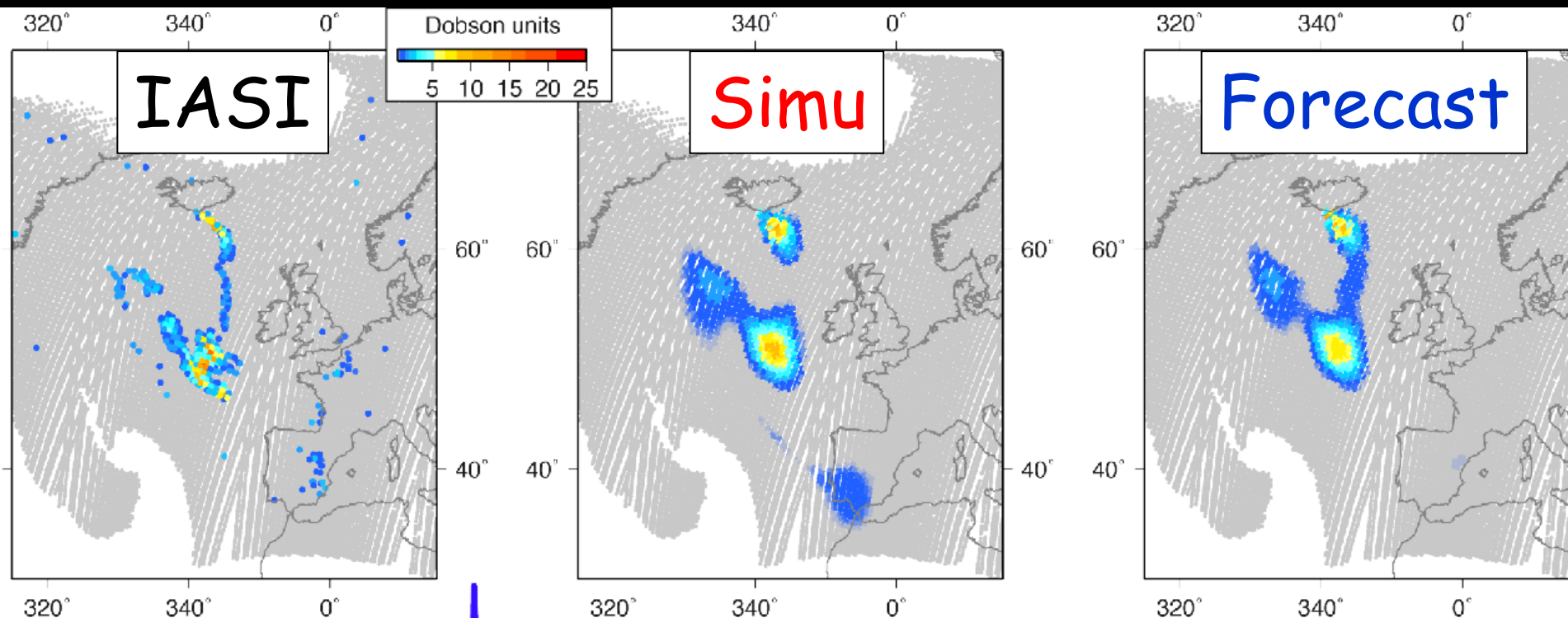
+7.5 day

Source (m*)

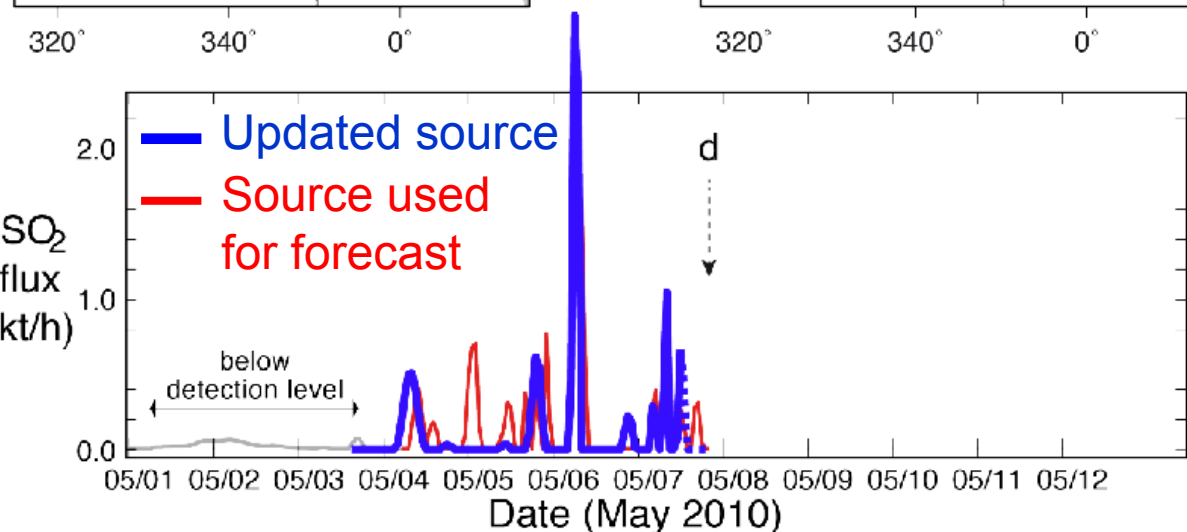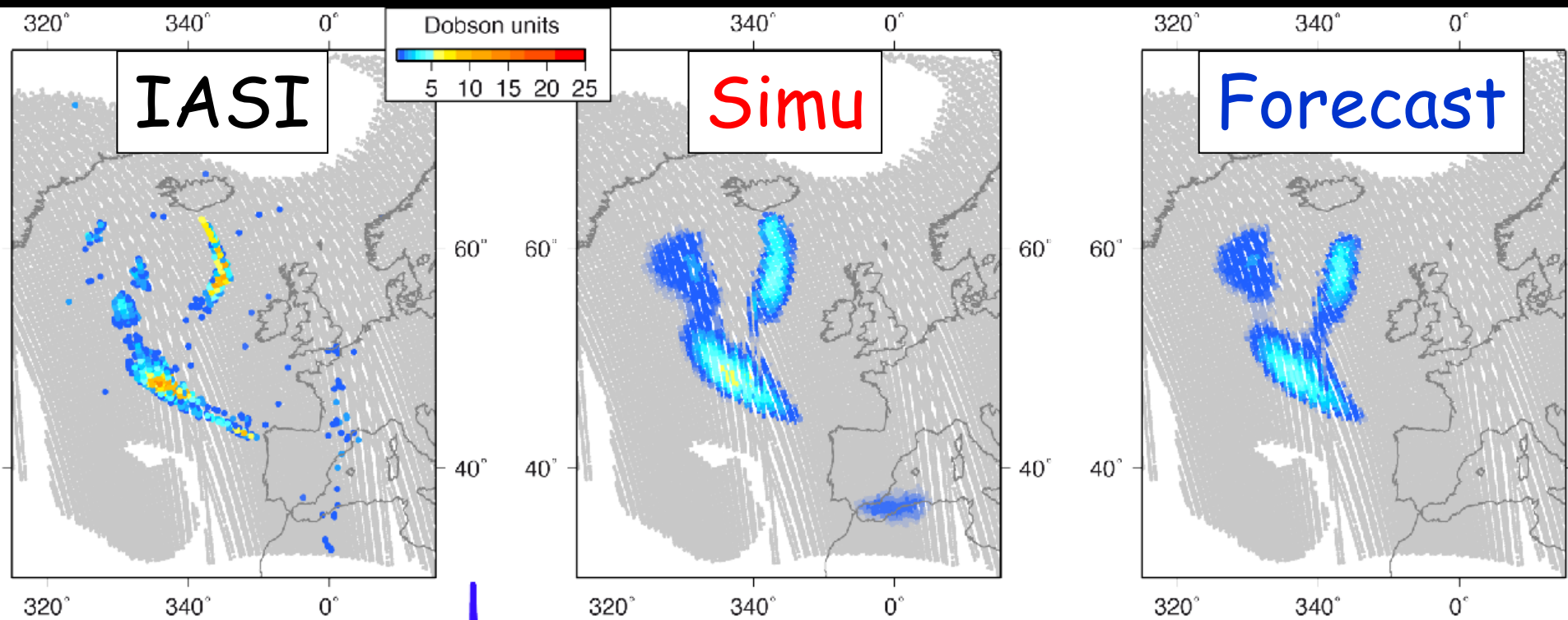# Comparison with other available observations of the volcanic source

SO$_2$
(IASI)
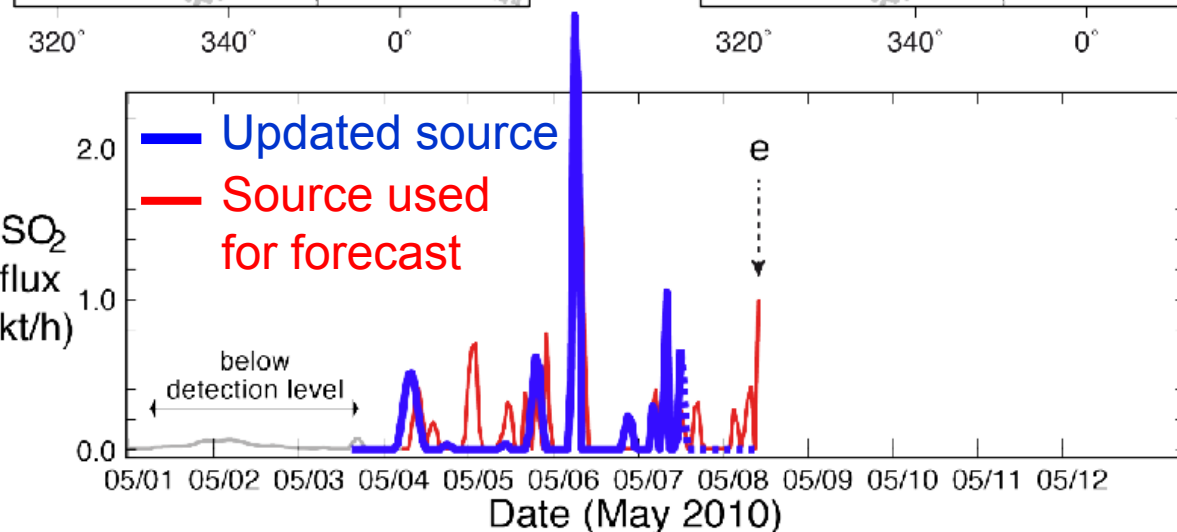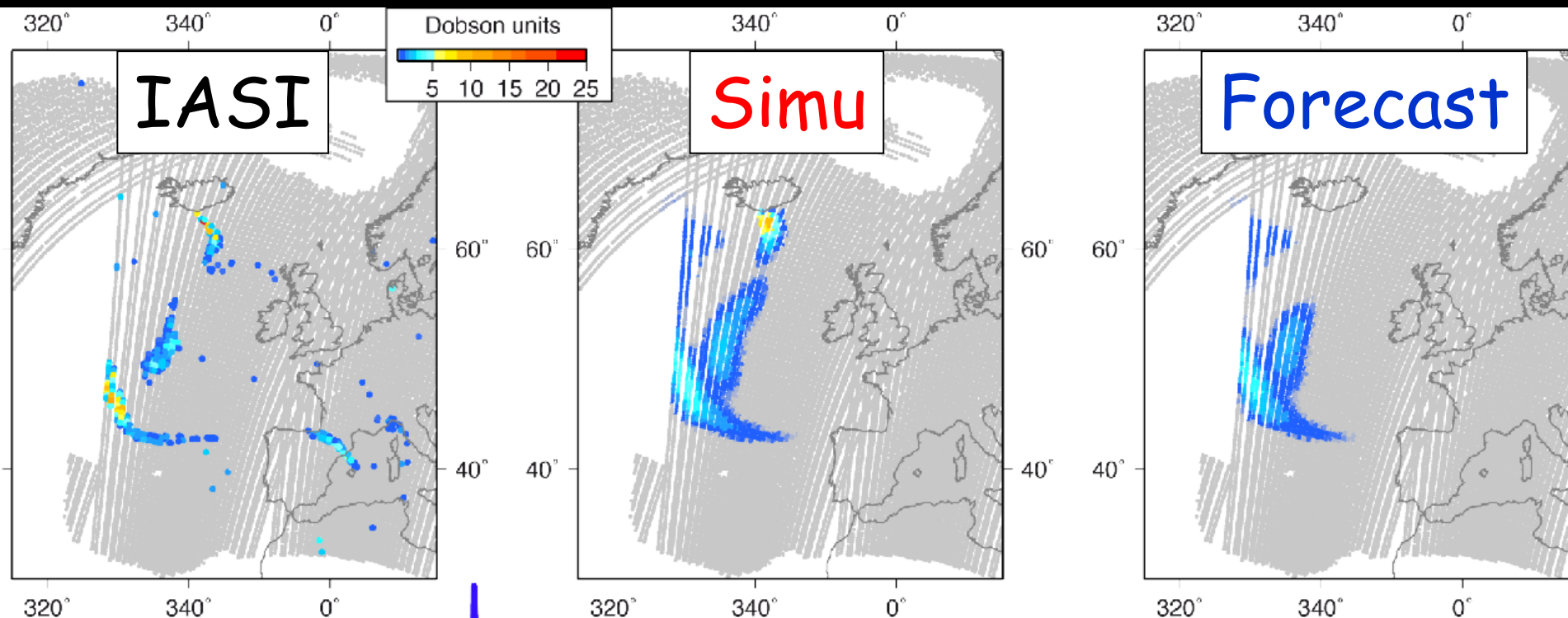[This study]

Ash
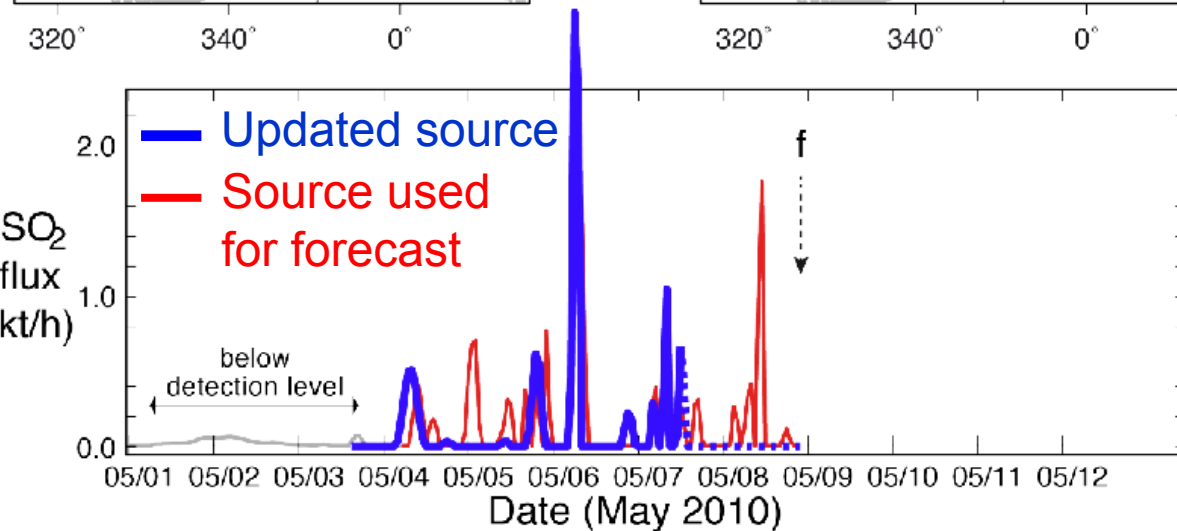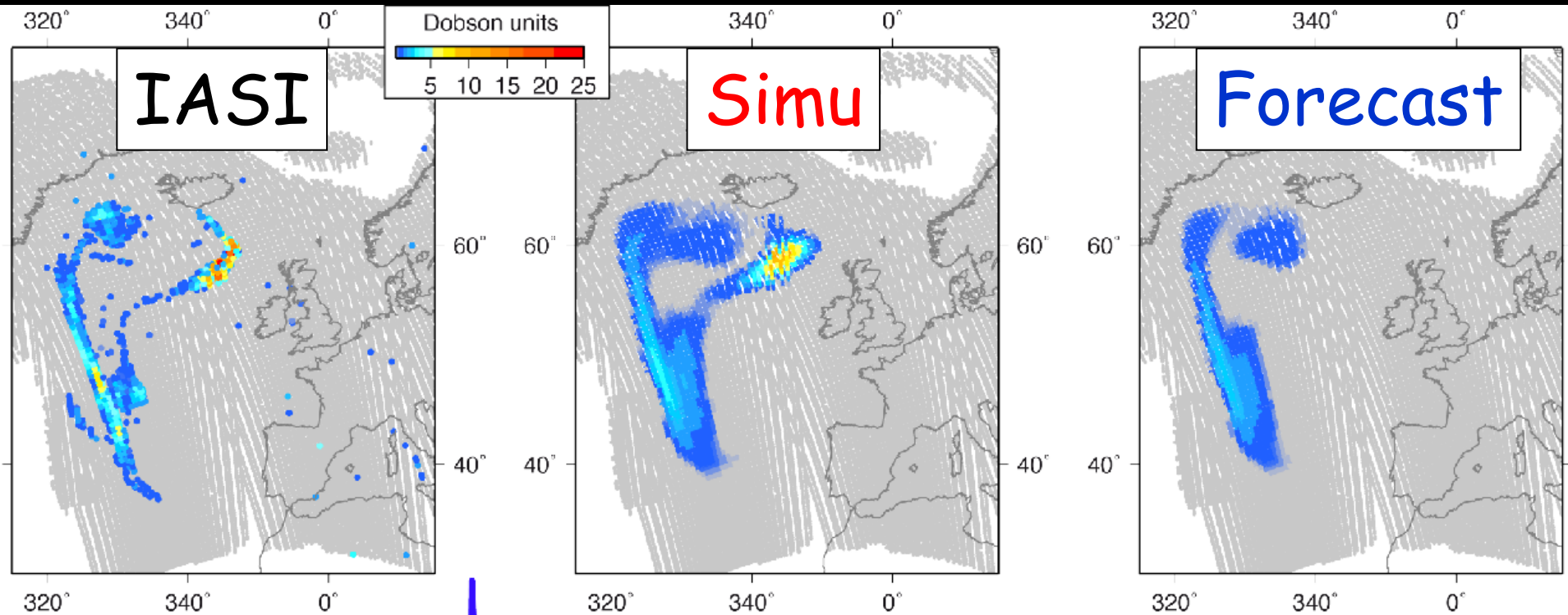(SEVIRI)
[Stohl et al. 2011]

Plume forecast

Plume forecast

Plume forecast

Plume forecast

Plume forecast

Plume forecast

IASI Simu Forecast

Dobson units
5 10 15 20 25

Updated source
Source used for forecast

t = +2.5 days

SO_2 flux (kt/h)

below detection level

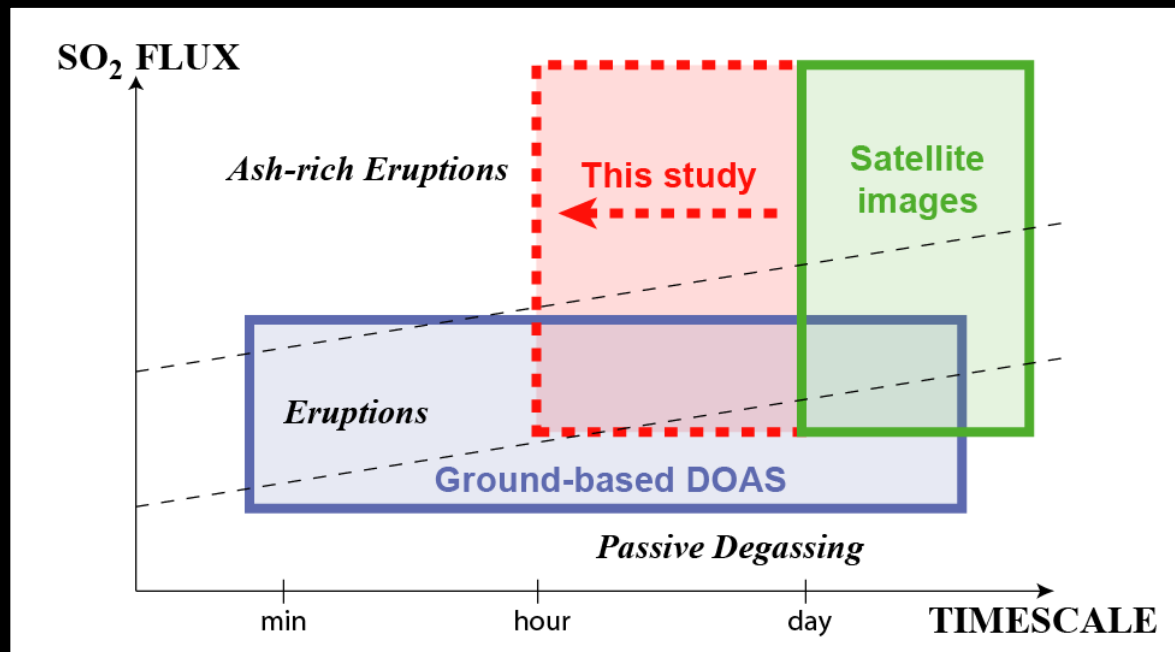Date (May 2010)
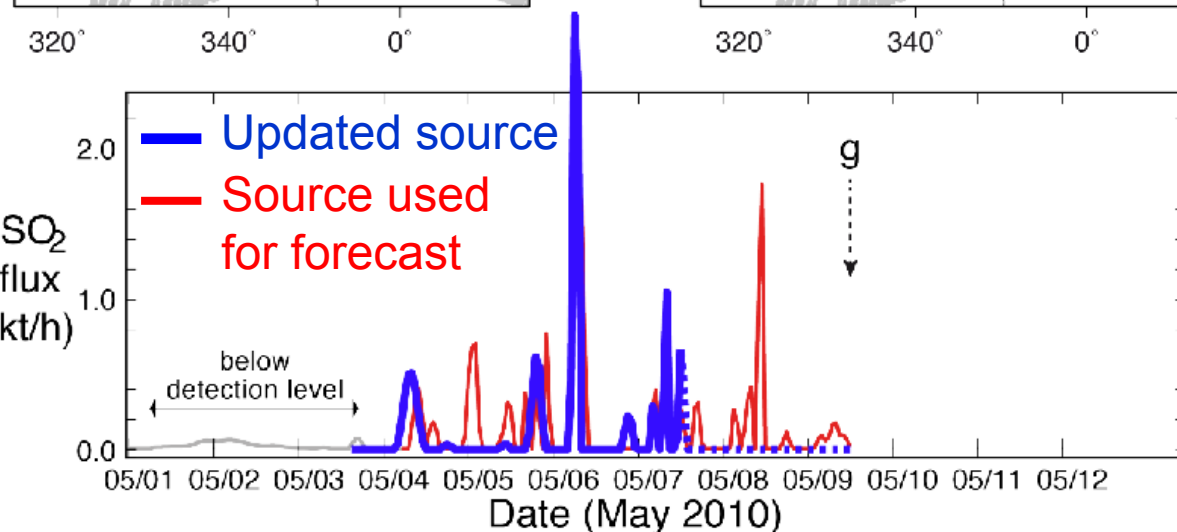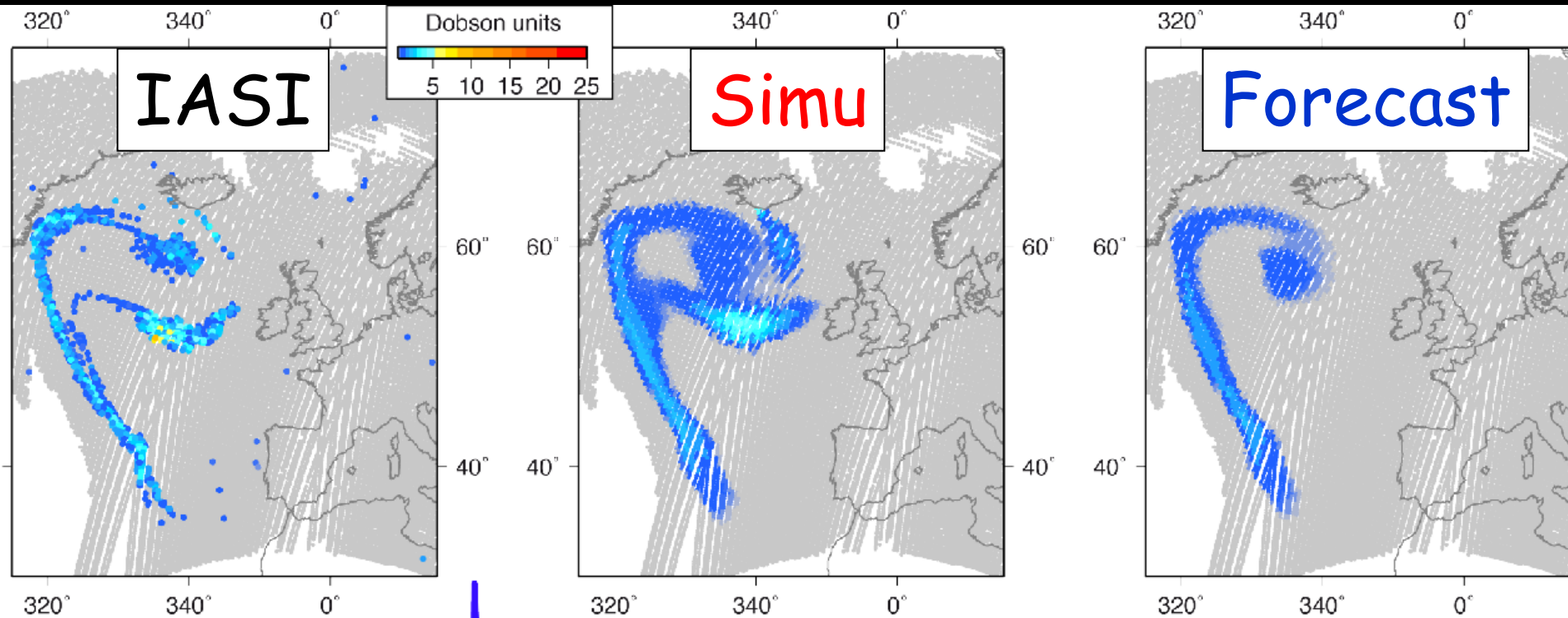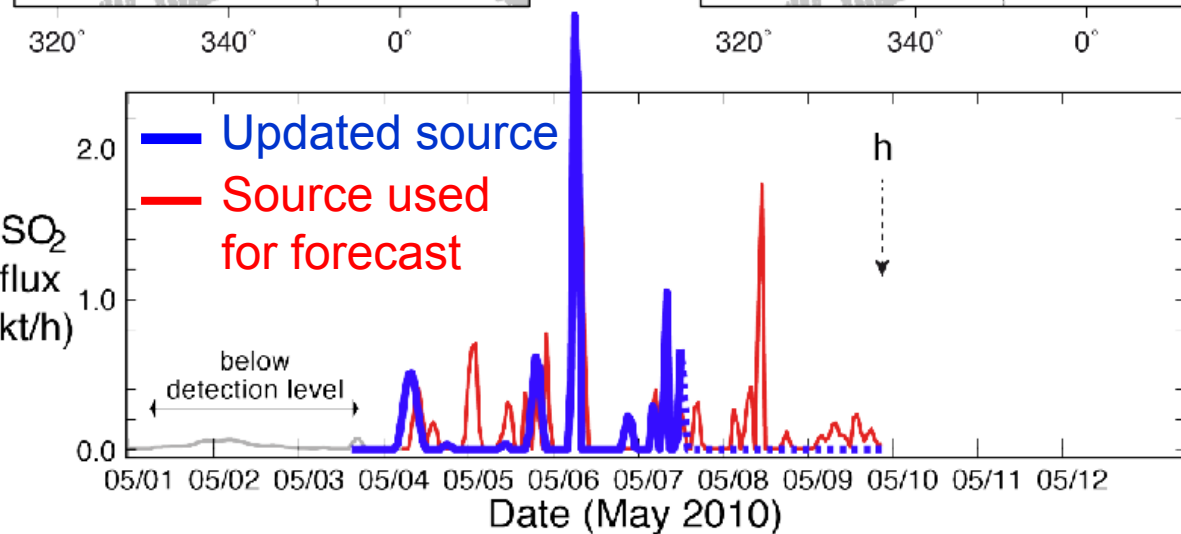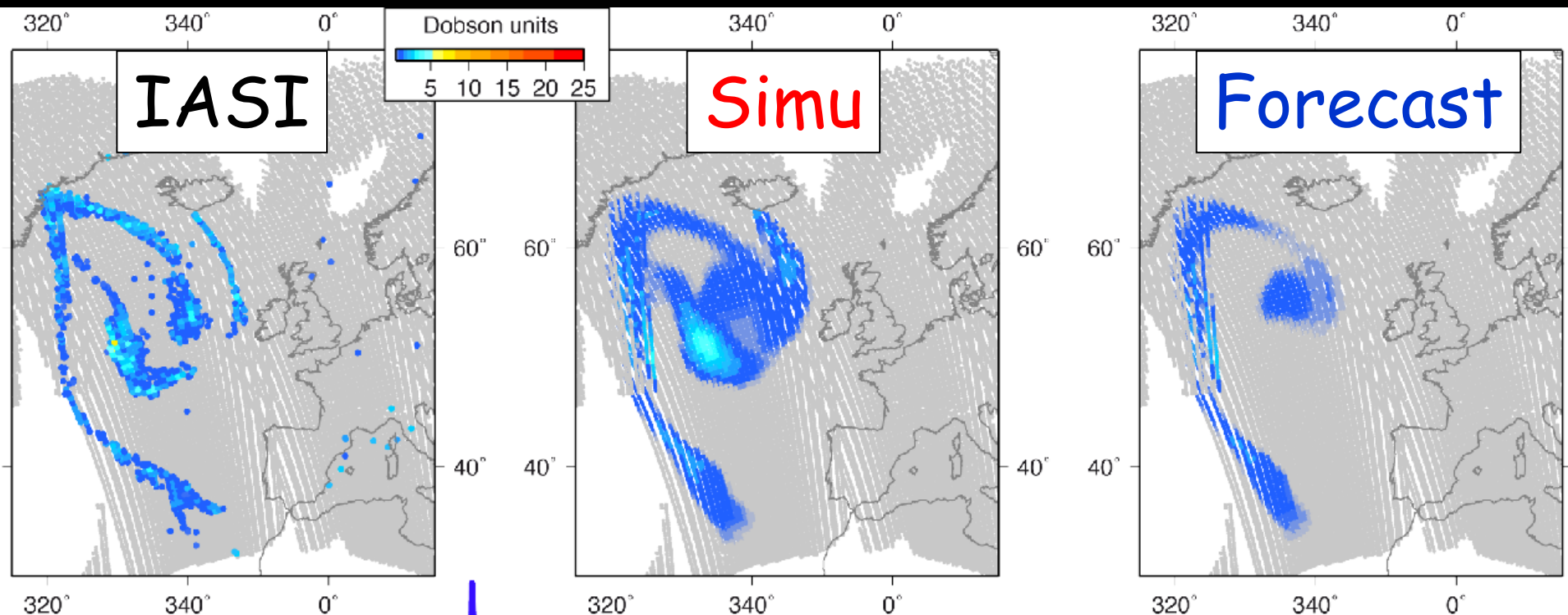
Conclusions

- Reconstruction of hourly-resolved volcanic SO_2 flux:
  - For volcanology:
    - Crucial complement to ground observations
    - Insight into volcanic activity and magma/volatile dynamics

  - For atmospheric sciences:
    - Improve the quality of plume simulations/forecast
    - Opens operational perspectives: use of this method of satellite data assimilation during an eruptive crisis as a plume forecasting tool

Thanks for your attention..