Volcanic emission into the atmosphere measured by satellite

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Who are we?

- Earth Observation Data Group in Atmospheric, Oceanic & Planetary Physics, University of Oxford
  - *Elisa Carboni*, Gareth Thomas, Andy Sayer, **Don Grainger**:
  - satellite aerosol/cloud retrieval (AATSR, SEVIRI…). **Ash**
  - Dan Peters, Adam Povey:
  - laboratory measurements/LIDAR **Ash refractive index** **Ash vertical profile**
  - *Elisa Carboni*, Joanne Walker, **Anu Dudhia**
  - trace gas retrieval (infrared spectrometer: IASI…) **SO2**

Remote Sensing Group at Rutherford Appleton Laboratory

Richard Siddans, Caroline Poulsen

Web page: *http://www.atm.ox.ac.uk/project/eyja/*

http://www.atm.ox.ac.uk/project/NCEO/nceot6.html

Satellite data available for volcanic emission

Volcanic ash

Limb/occultation instruments:

SAGE
SAGE II (1984)
HALOE (1991)

MIPAS (ENVISAT 2002)
? HIRDLS (AURA 2004)

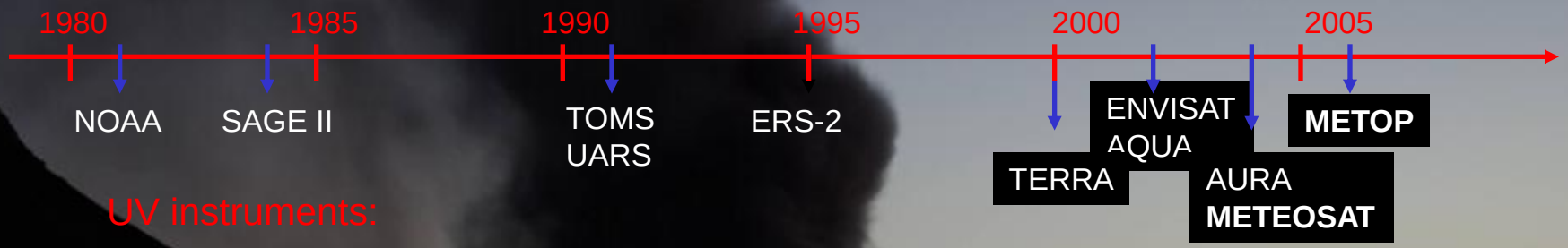
Polar orbit

Imagers:

AVHRR (NOAA-1979, 1981)
ATSR-2 (ERS-2 1995)
AATSR (ENVISAT 2002)
MODIS (TERRA 2000, AQUA 2002)
GOSAT (2009)

Geostationary

SEVIRI (METEOSAT 2004)



Volcanic SO_2

UV instruments:

TOMS (Meteor3 1991)
OMI (AURA 2004)

CALIOP (CALIPSO 2006)

MLS (?) (UARS 1991, AURA 2004)

UV-VIS spectrometers

GOME (ERS-2 1995)
SCIAMACHY (ENVISAT 2002)
GOME-2 (METOP 2006)

Polar orbit

Different daily coverage

IR instruments:

ASTER (TERRA 2000)
HIRS (NOAA)
AIRS (AQUA 2002)
TES (AURA 2004)
IASI (METOP 2006)

Underline = both products ash and SO_2.

ORAC AEROSOL PROCESSOR

ORAC (Oxford RAL Retrieval of Aerosol and Cloud) is a optimal estimation retrieval algorithm for retrieving aerosol (and cloud) from ATSR and SEVIRI.
http://www.atm.ox.ac.uk/project/orac

ORAC is being used in the GRAPE and Globaerosol project.
http://www.atm.ox.ac.uk/project/grape
http://www.globaerosol.info/

Standard ORAC retrieval

FM extended to IR is a function of 5 parameters:
Aerosol optical depth (AOD),
Aerosol effective radius (Re)
Surface reflectance at 550nm (Rs)
Surface temperature (Ts)
Aerosol effective height (H)

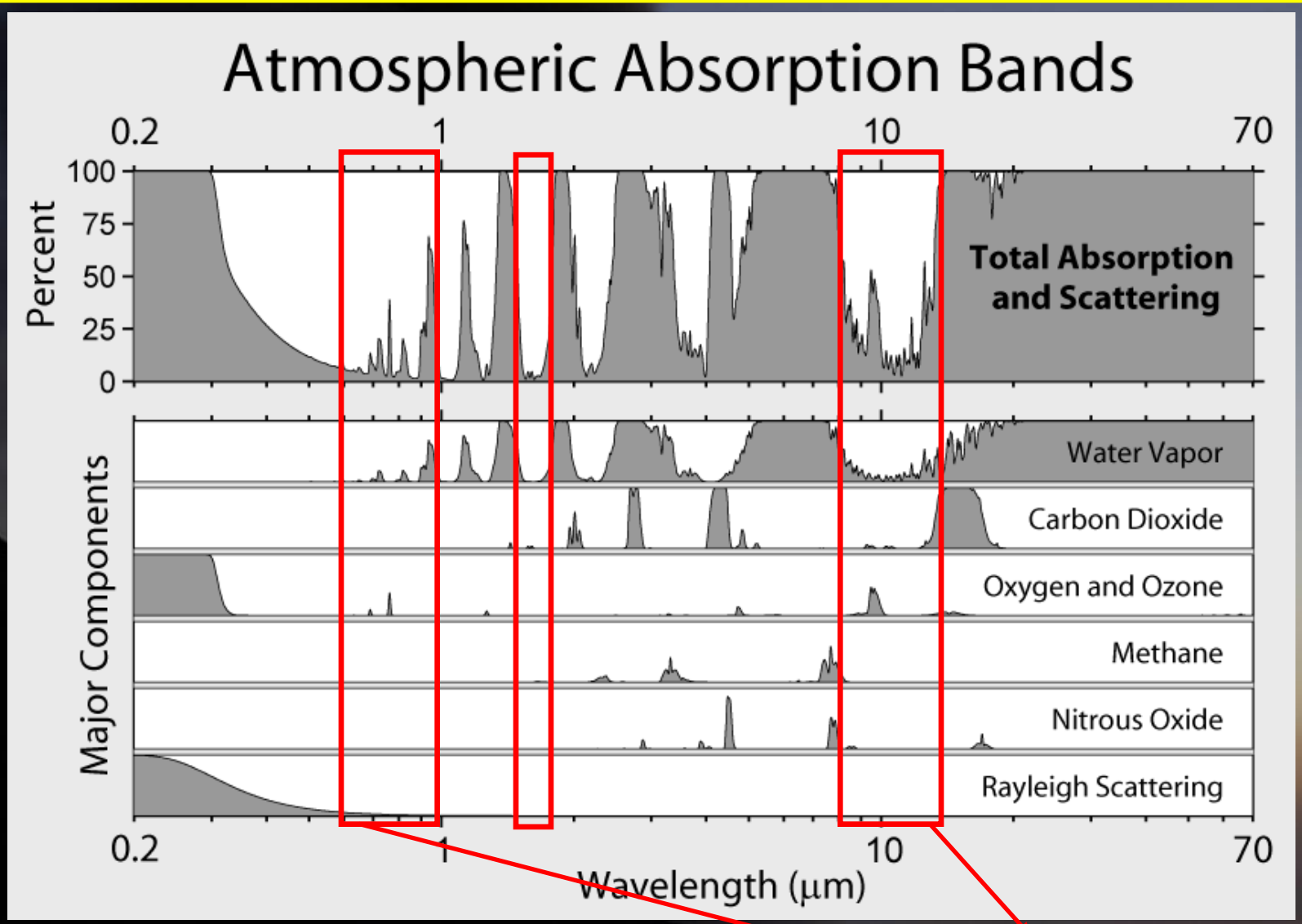
The addition of the infrared channels add sensitivity to the aerosol vertical distribution, surface temperature and atmospheric profile.

Instruments

SEVIRI – (Meteosat Second Generation)
Geostationary satellite, spatial resolution 3 km, 15 min time resolution.
12 channels in the 0.6-14 μm range.
we use VIS-NIR + IR channels centered at 0.640,0.809,1.64, 10.78, 11.94,13 μm
from February 2004

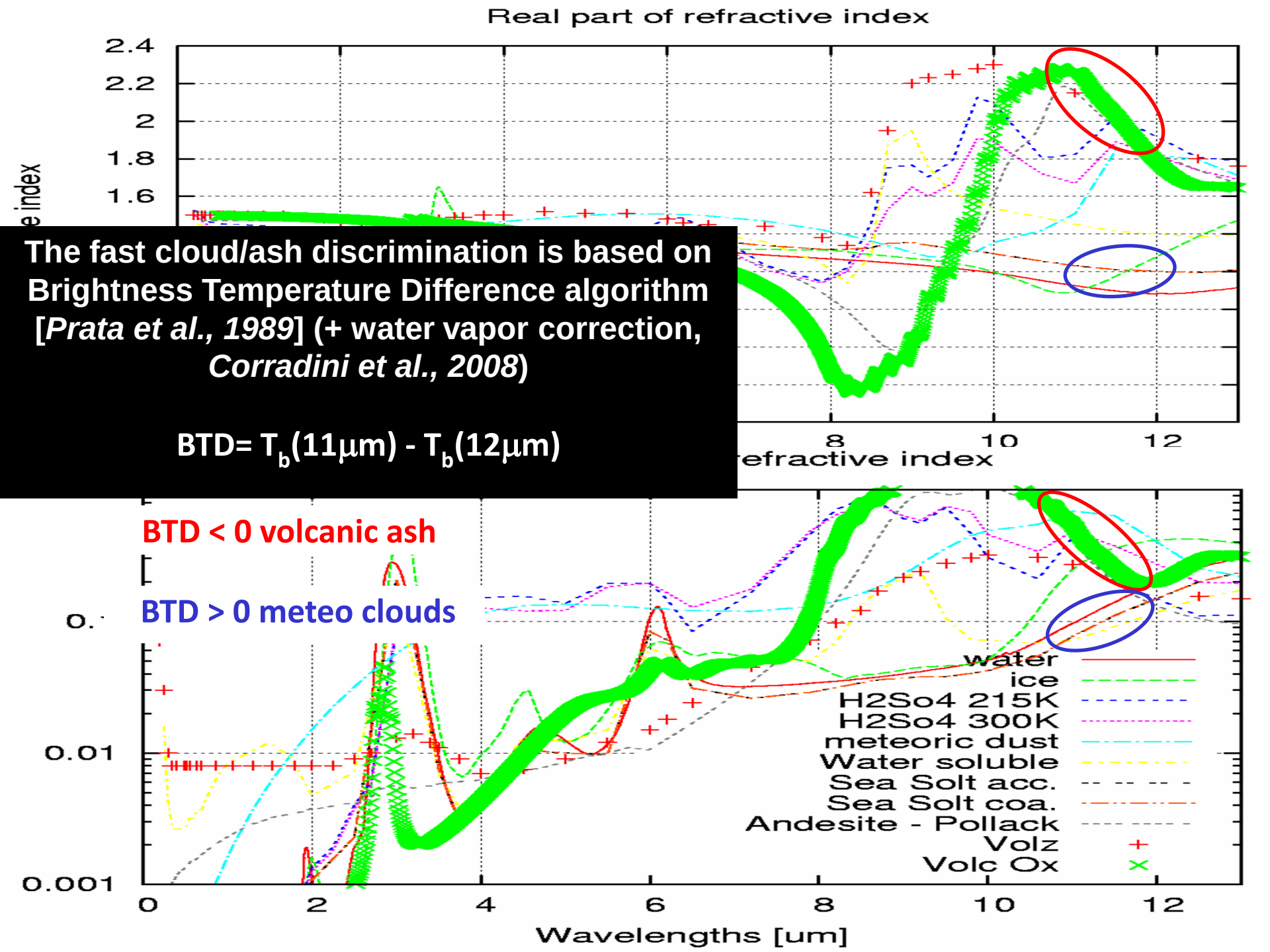
ATSR-2 and **AATSR** (ERS-2 – ENVISAT)
Polar orbit, spatial resolution 1 Km
3 days global coverage
7 channels in the 0.5-14μm range
we use 3-4 VIS-NIR centred at
0.66,0.86,1.6, 11,12 [μm],
and
0.56,0.66,0.86,1.6 [μm]

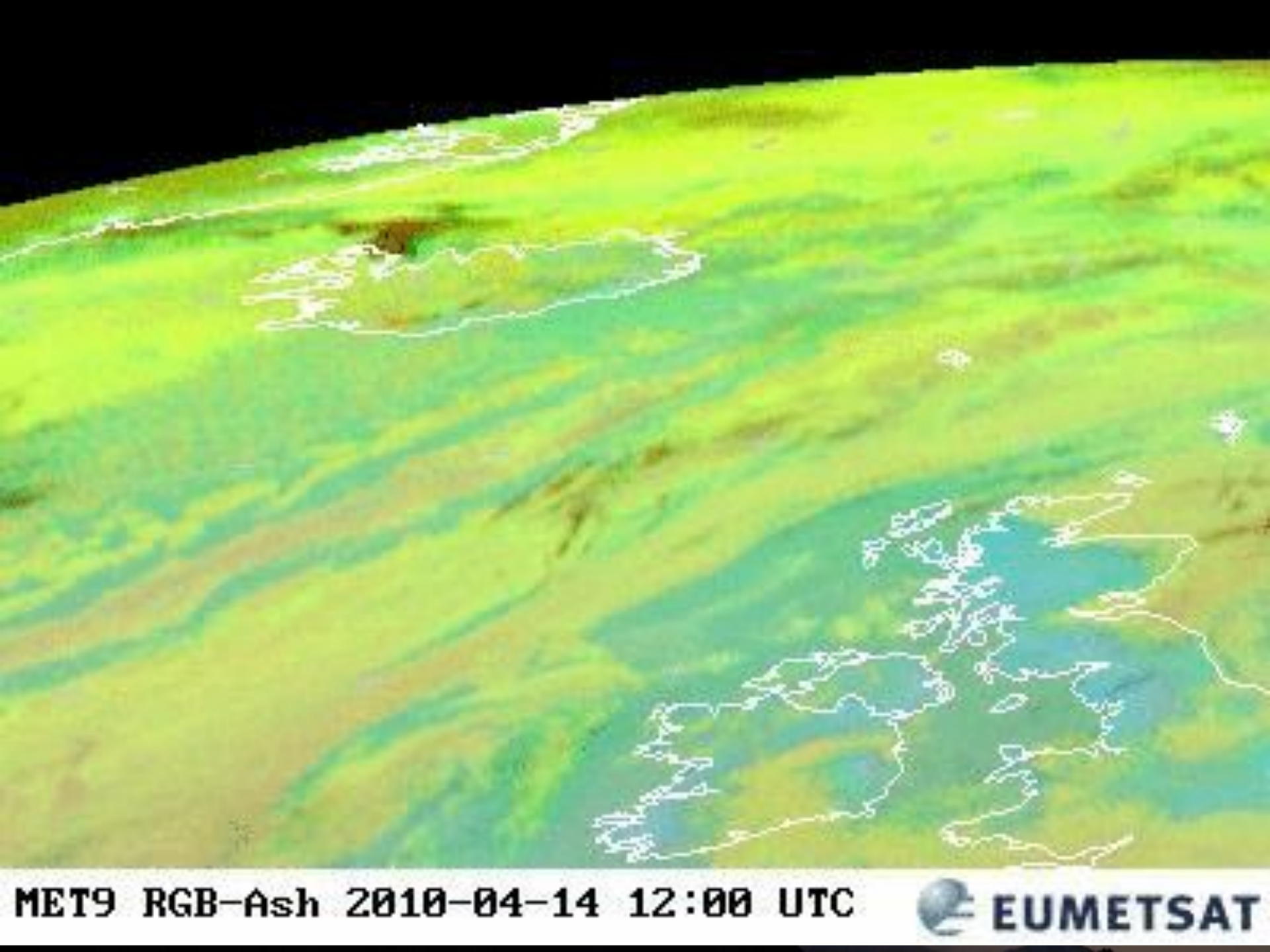
Volcanic products from satellite data: ash

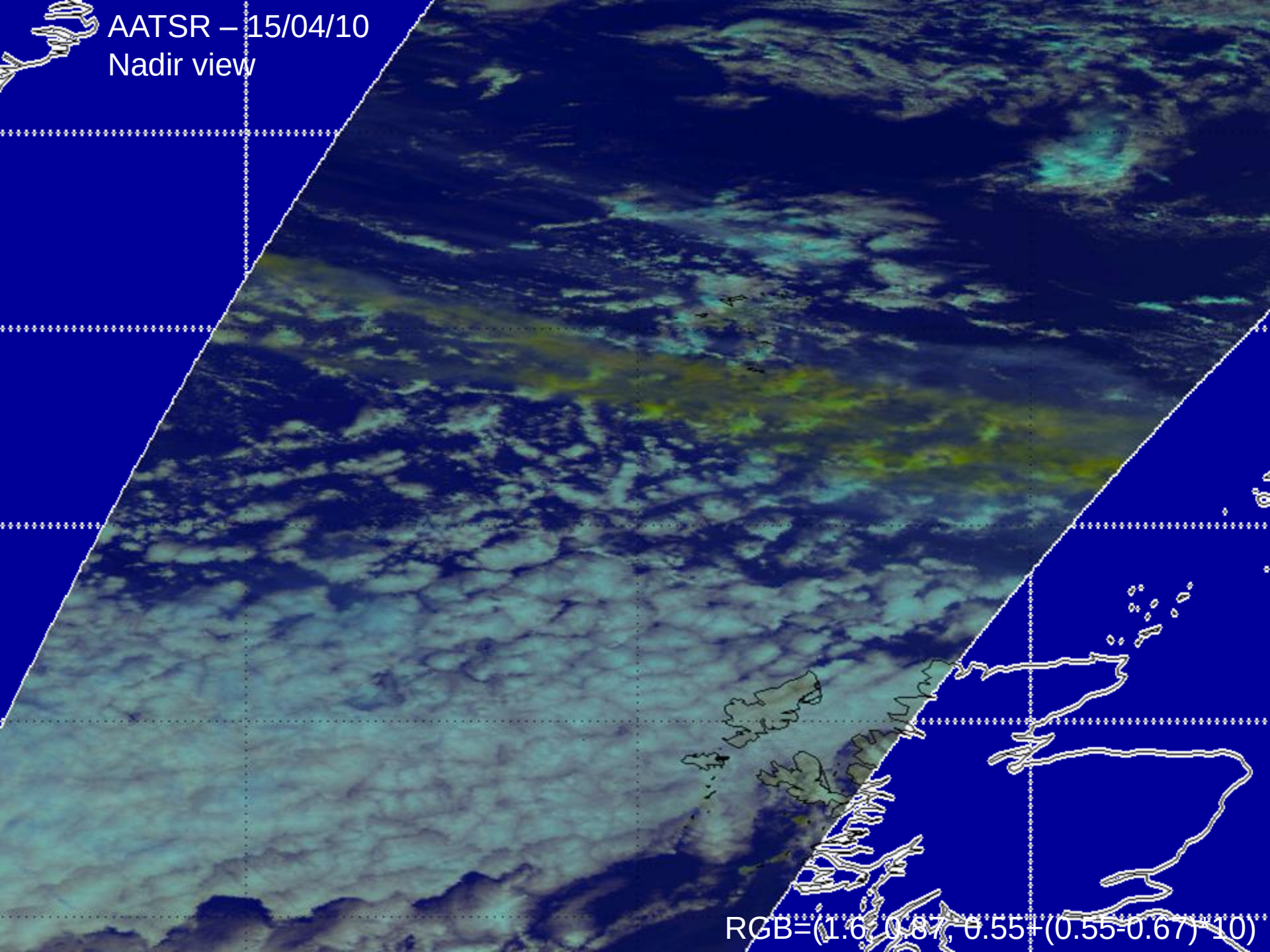


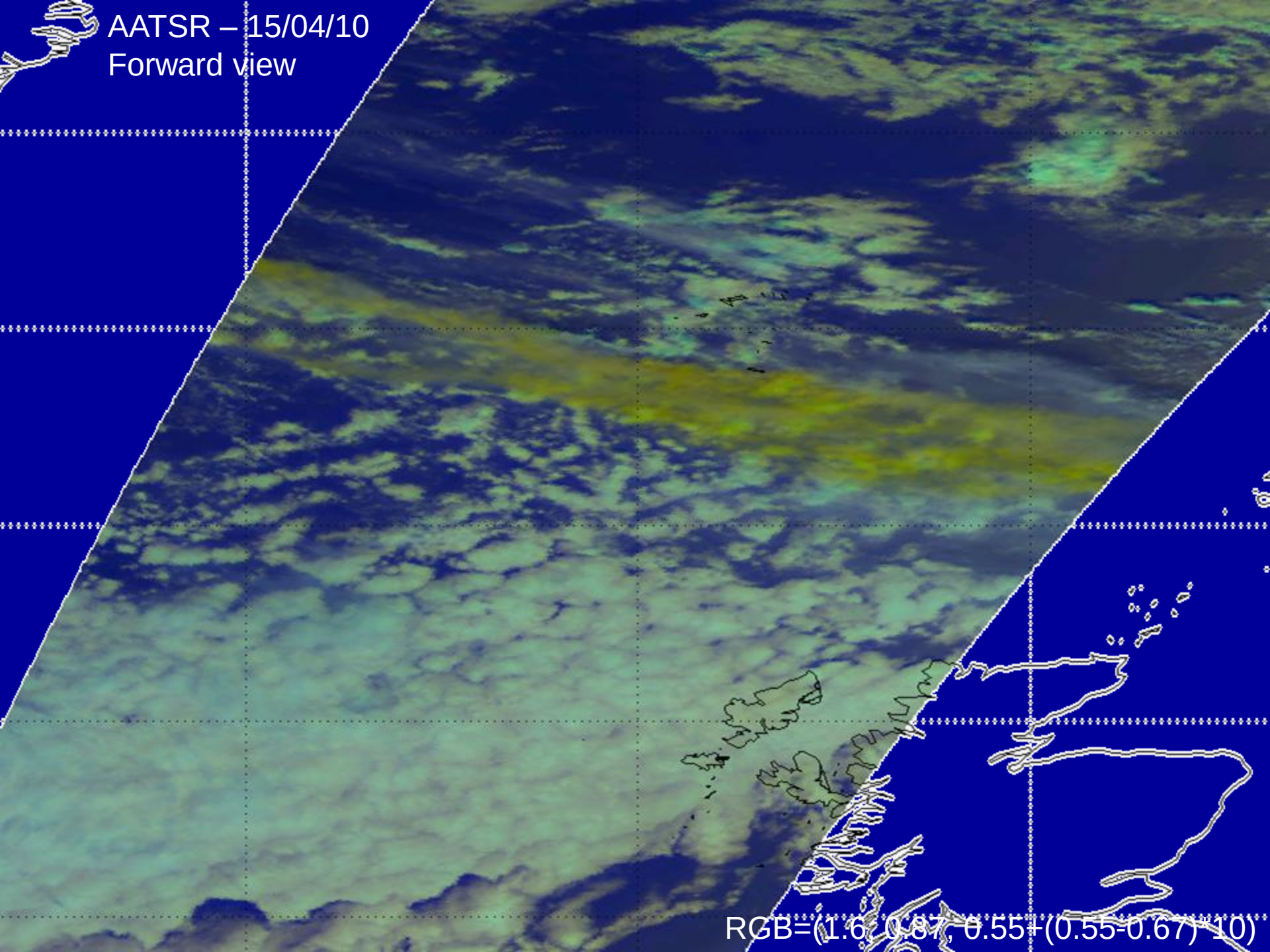
Aerosol retrieval is possible in atmospheric windows

Volcanic ash retrieval


Real part of refractive index
2.4
2.2
2
1.8
1.6
8
10
12
efractive index
The fast cloud/ash discrimination is based on Brightness Temperature Difference algorithm [*Prata et al., 1989*] (+ water vapor correction, *Corradini et al., 2008*)
BTD= $T_b(11\mu m) - T_b(12\mu m)$
BTD < 0 volcanic ash
BTD > 0 meteo clouds
0.01
0.001
water
ice
H2So4 215K
H2So4 300K
meteoric dust
Water soluble
Sea Solt acc.
Sea Solt coa.
Andesite - Pollack
Volz
Volc Ox
0
2
4
6
8
10
12
Wavelengths [um]

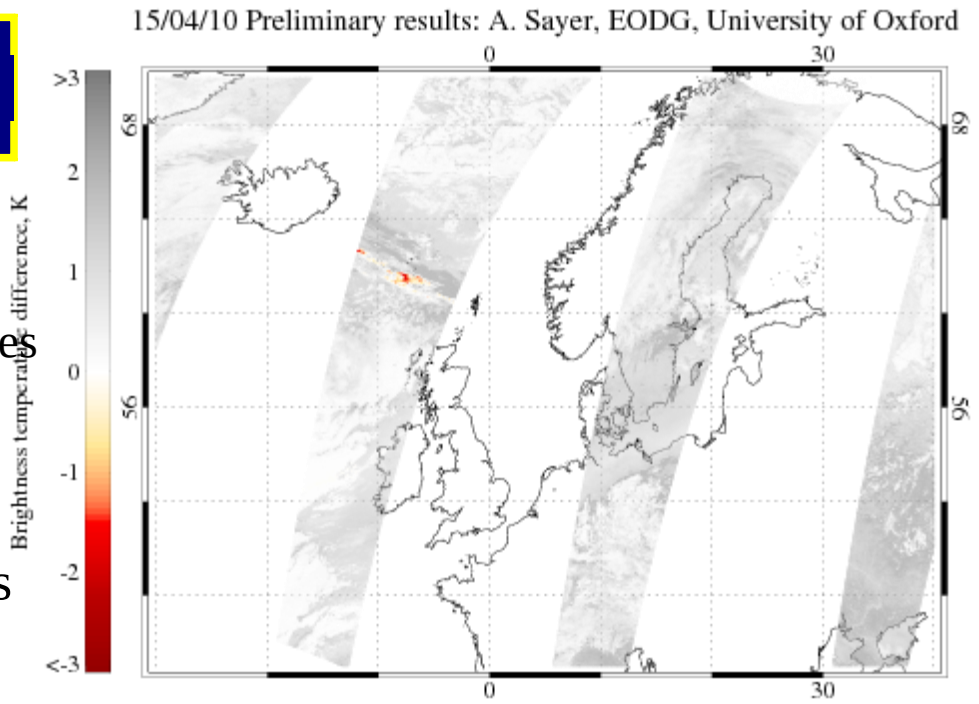

MET9 RGB-Ash 2010-04-14 12:00 UTC
EUMETSAT

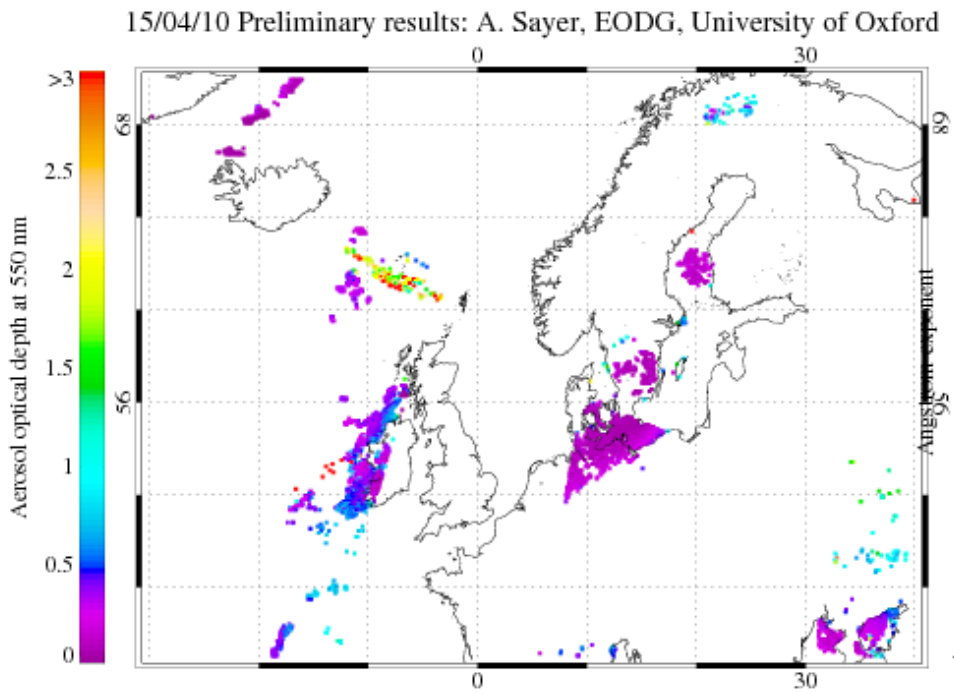

AATSR – 15/04/10
Nadir view
RGB=(1.6, 0.87, 0.55+(0.55-0.67)*10)

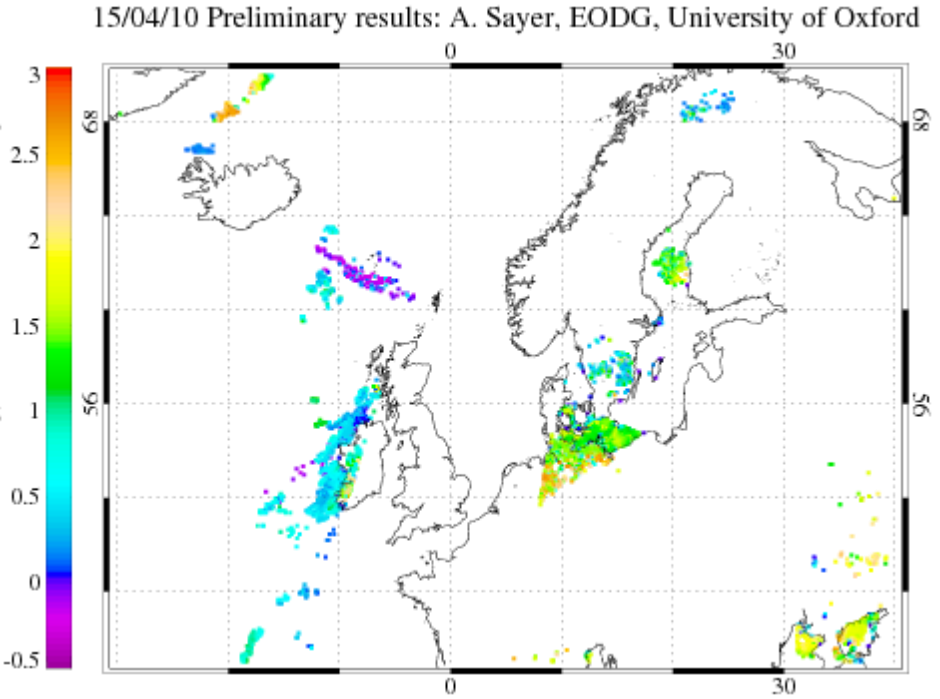

AATSR – 15/04/10
Forward view
RGB=(1.6, 0.87, 0.55+(0.55-0.67)*10)

AATSR ORAC ash retrieval

- Aerosol/cloud optical depth at 550 nm, effective radius, Angstrom exponent
  - Quality control and uncertainty estimates
  - Also cloud-top pressure for clouds
  - Data ~4 km (clouds), 10 km (aerosols)
- Also visible/IR composites at 1 km
- Ash plume well-fit by refractive indices measured in-house (Dan Peters)







LIDAR ash observations Chilbolton Observatory

The Robust and Compact Environmental Lidar system

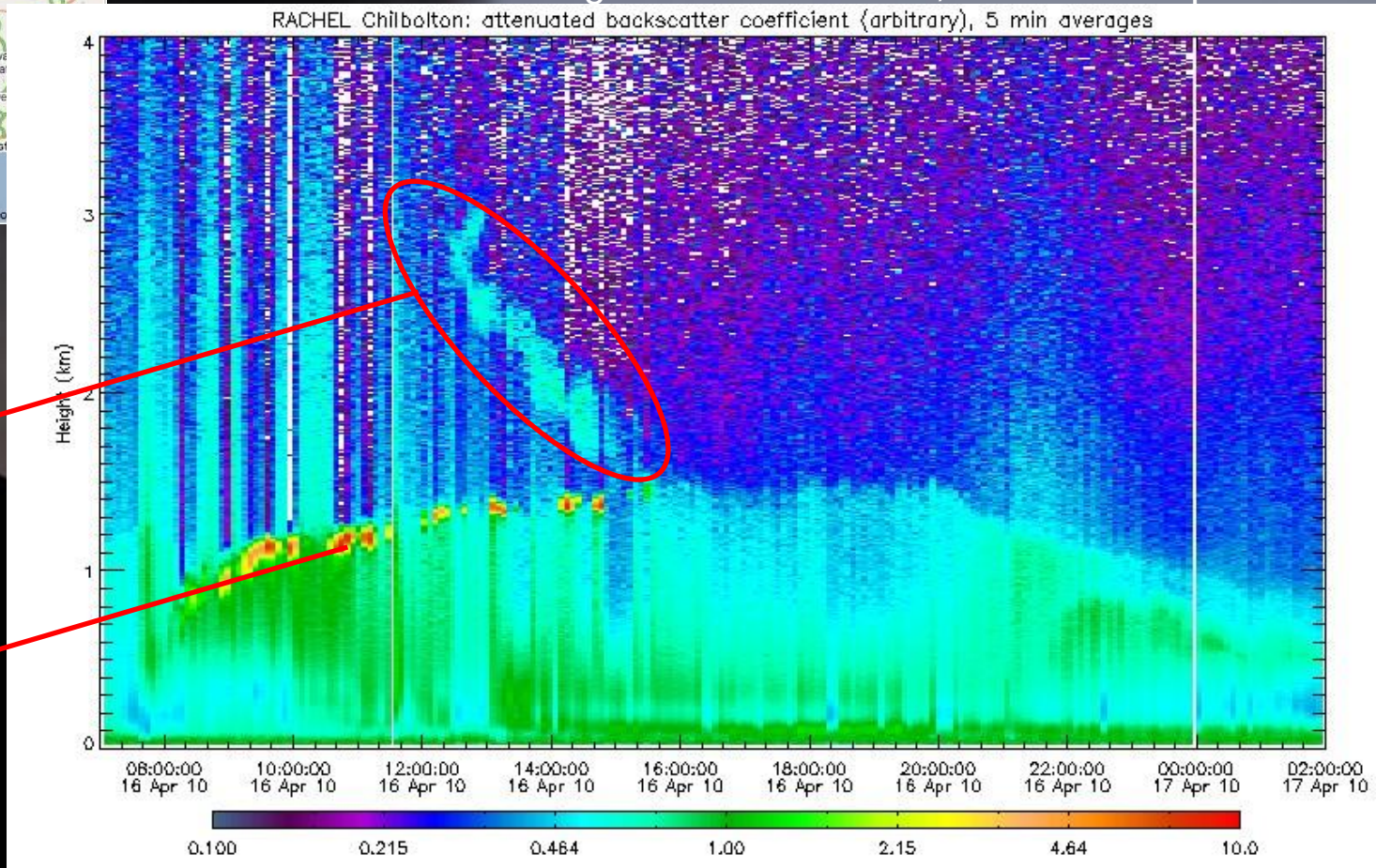
355 nm Raman lidar **RACHEL**

- Elastic backscatter
- Nitrogen and water vapour Raman backscatter

- Designed for continuous, unattended operation

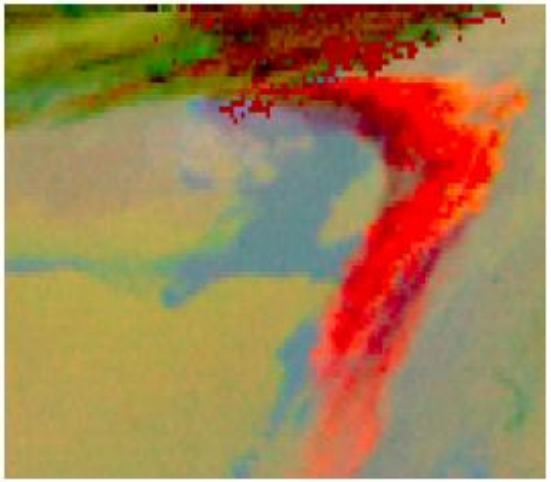
Ash

Meteorological cloud



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

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



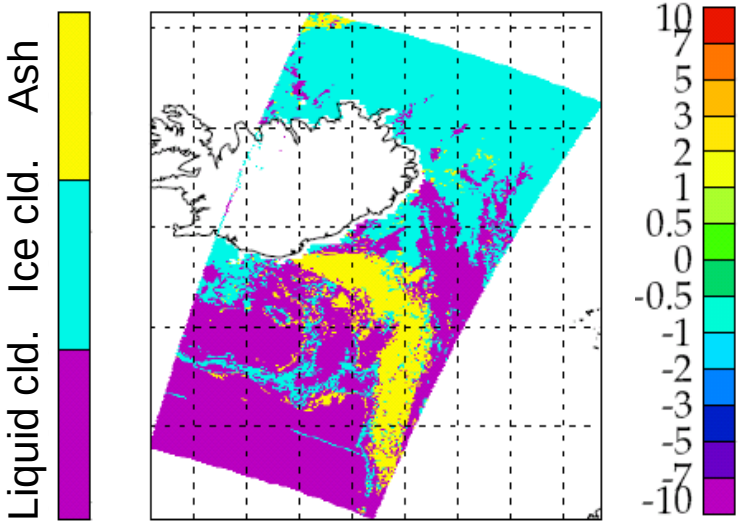
National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL

Oxford-RAL Retrieval of Aerosols and Cloud (ORAC):
Visible/near-ir/mid-ir retrievals from AATSR on 6 May 2010.

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

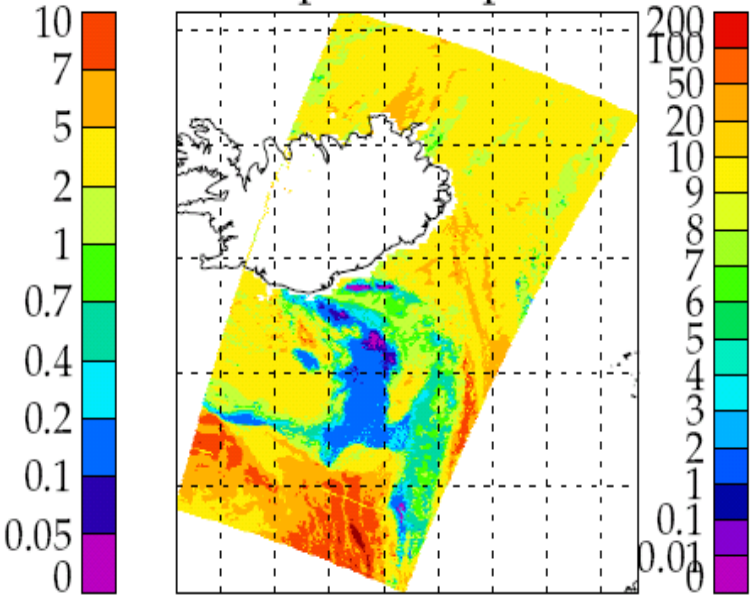
Particle type



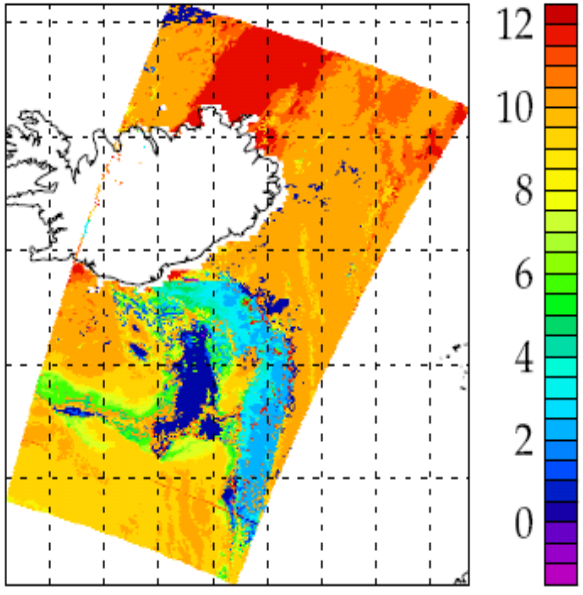
Measured 11-12μm BT/K

Simulated 11-12μm BT/K

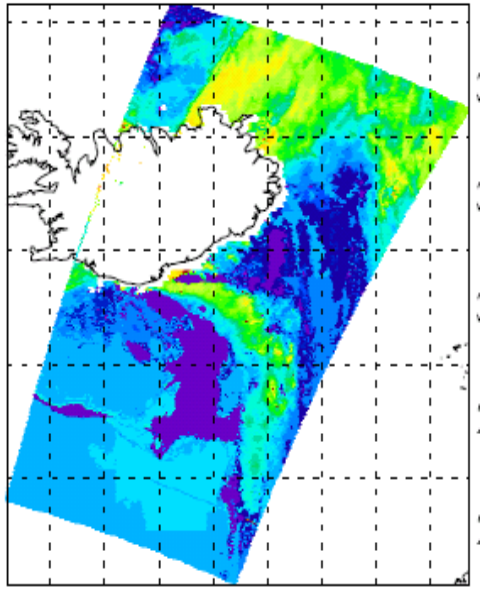
Optical depth



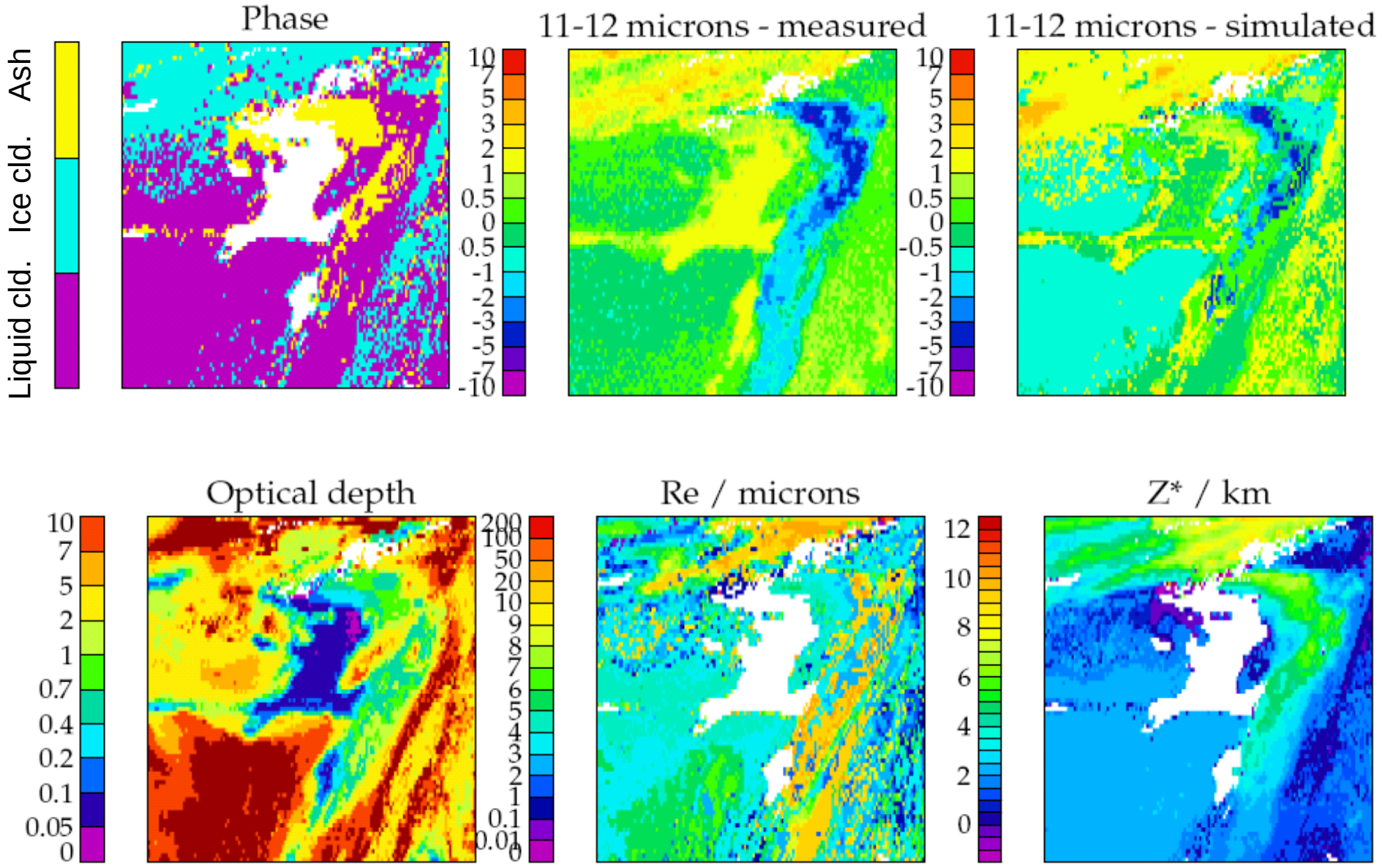
Effective Radius / microns



Altitude / km



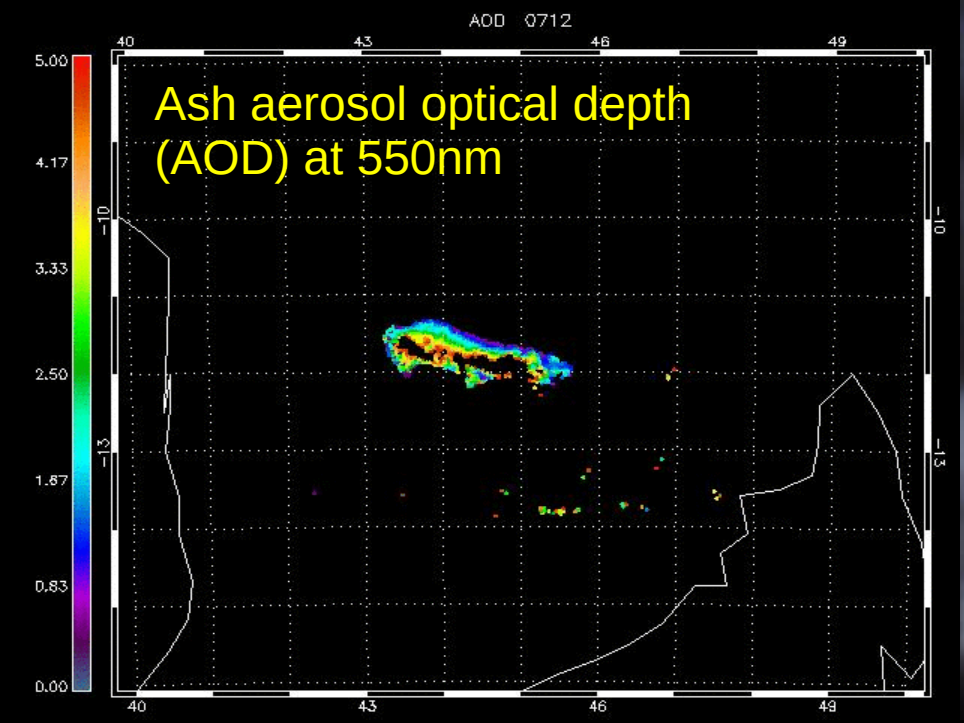
SEVIRI Retrieval 6 May 2010

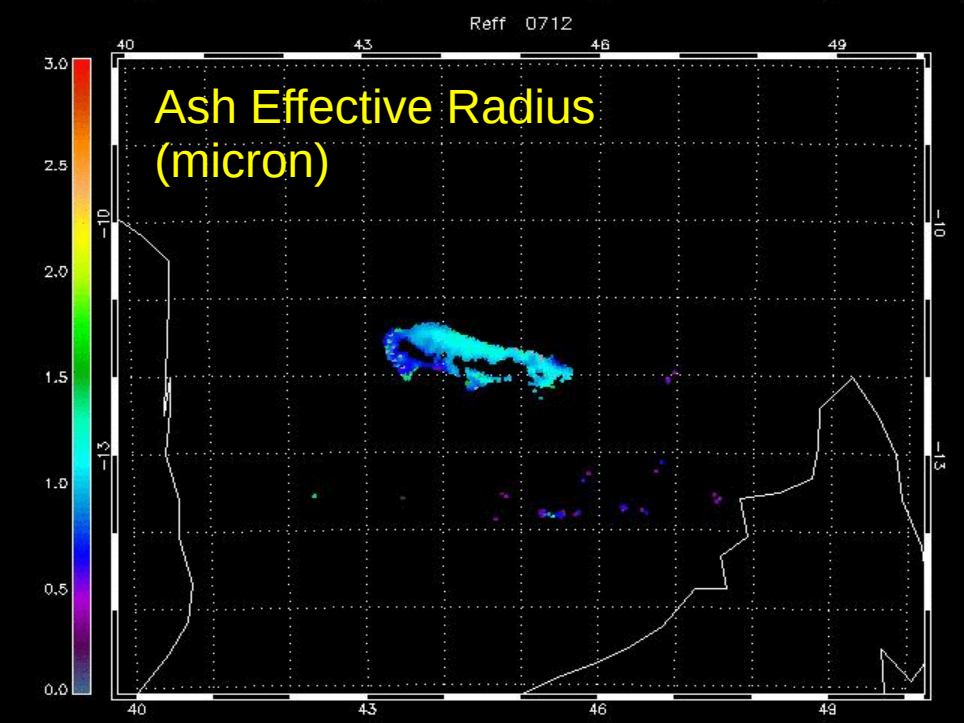


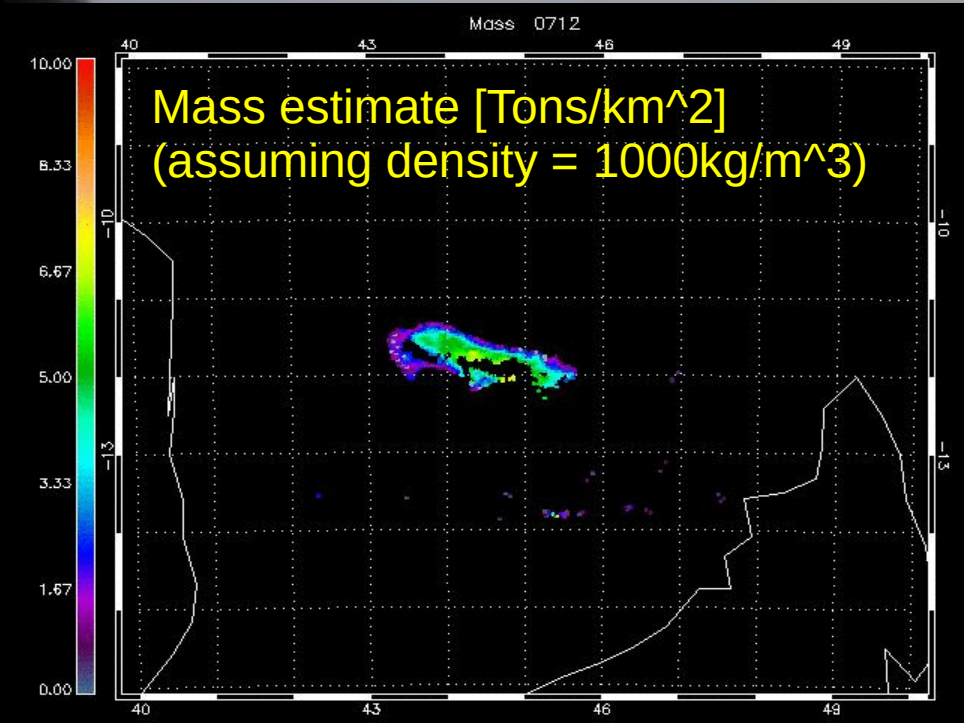
Oxford-RAL retrieval (ORAC) algorithm using VIS and IR channels

Karthala eruption (25 Nov. 2005)

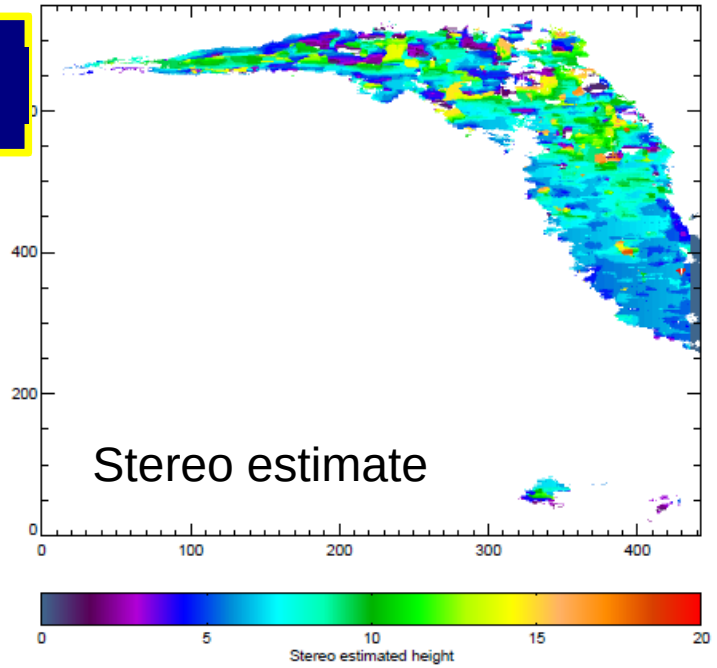
To study this eruption the ORAC algorithm have been extended to use both visible and infrared channels and have been applied to the volcanic ash plume.

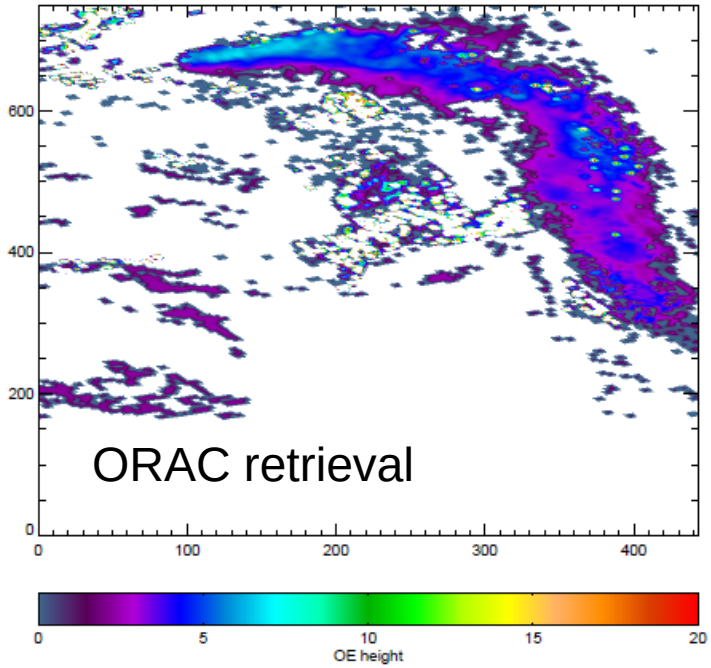






ash height

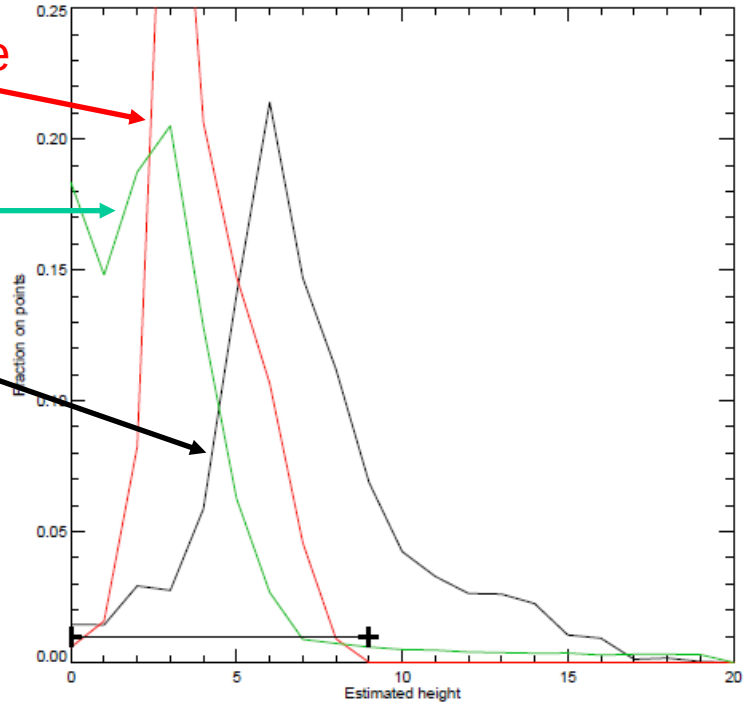


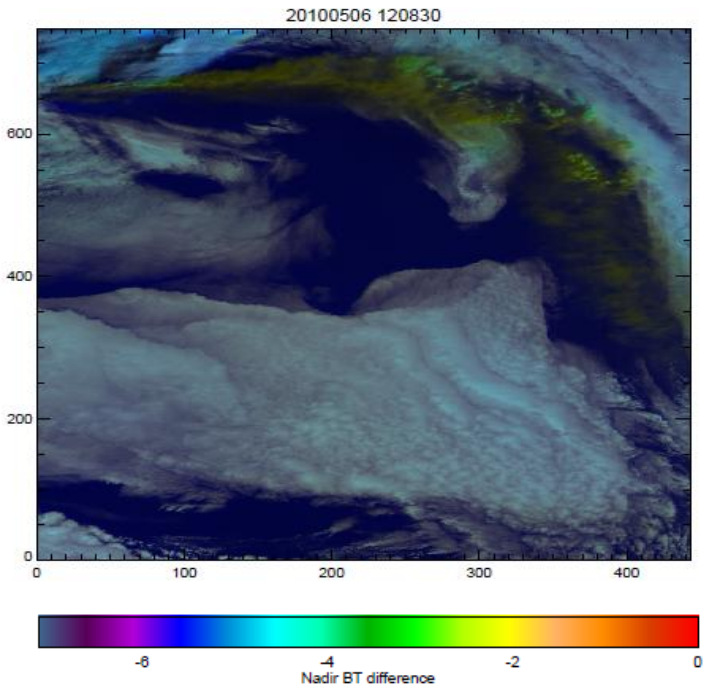


BT + ecmwf profile

ORAC

Stereo





METeorological OPerational satellite programme (MetOp)

European polar-obiting meterological satellite.
Operational in May 2007
First of tree polar satellite system (EPS) that will cover 14 years
Equator crossing time 9:30 local time

Advanced Very High Resolution Radiometer (AVHRR/3) NOAA
6-channel visible/IR (0.6-12 µm) imager, 2000 km swath, 1 x 1 km resolution.
Global imagery of clouds, ocean and land. 35 kg, 622/39.9 kbit/s (high/low rate), 27 W.

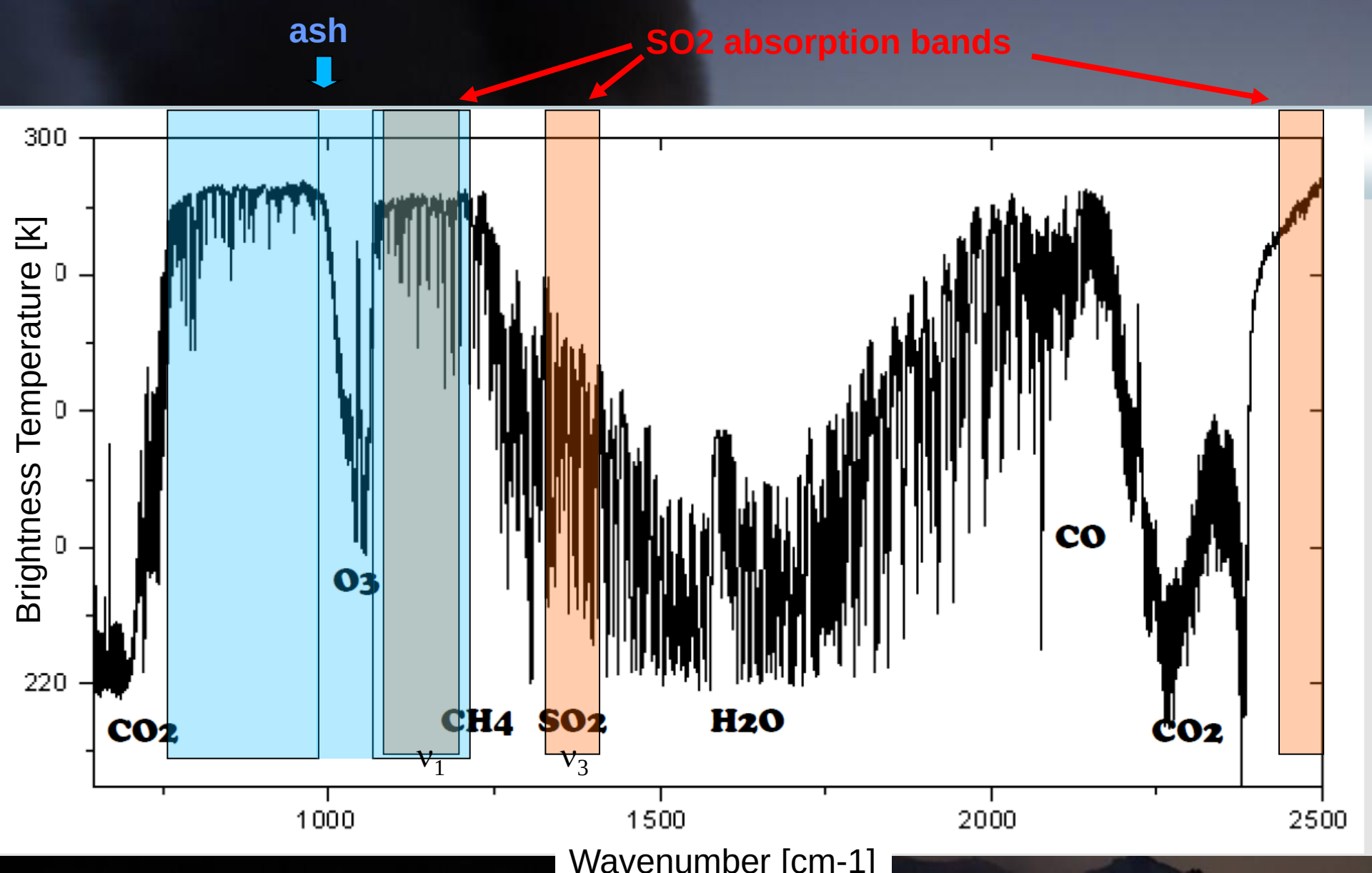
http://www.esa.int/

Global Ozone Monitoring Experiment (GOME-2) ESA/EUMETSAT
Scanning spectrometer, 250-790 nm, resolution 0.2-0.4 nm, 960 km or 1920 km swath, resolution 80 x 40 km. Global coverage can be achieved within one day.

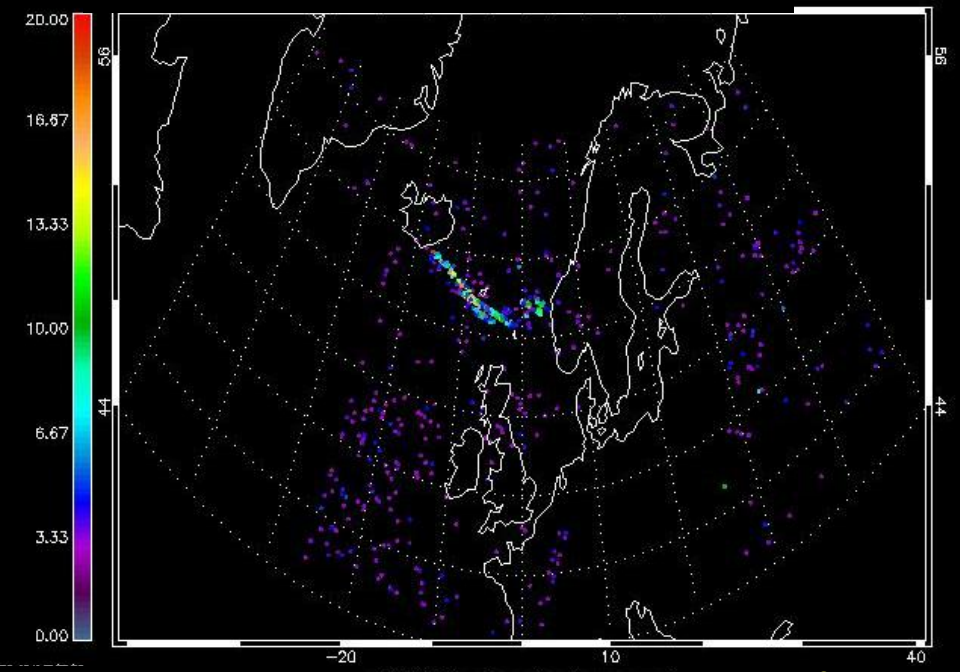
High-resolution Infra-Red Sounder (HIRS/4) NOAA
20-channel optical/IR filter-wheel radiometer, 2000 km swath, IFOV 17.4 km (nadir). 35 kg, 2.9 kbit/s, 21 W. Replaced on MetOp-C by IASI.

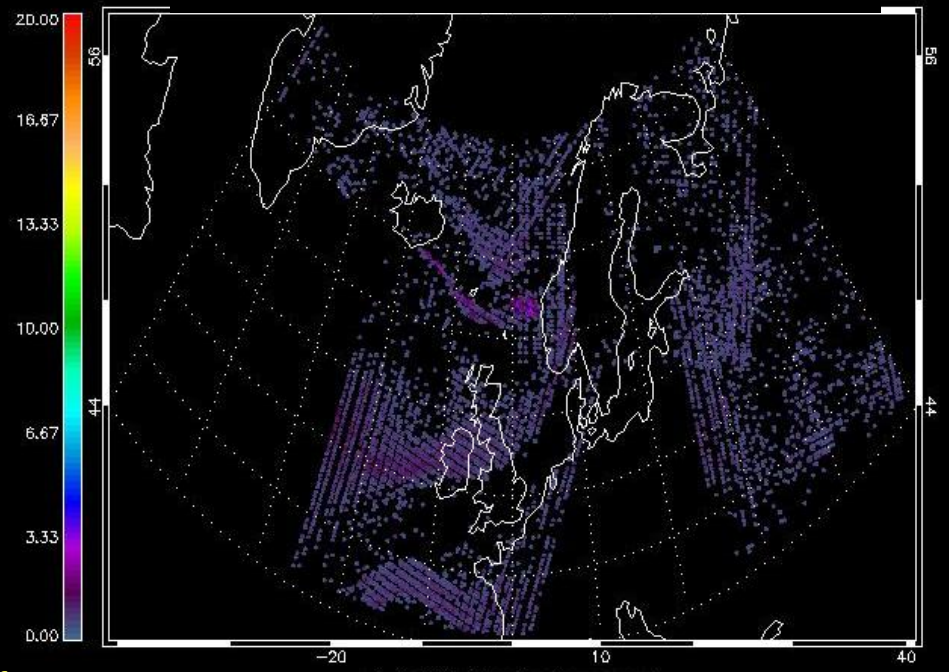
Infrared Atmospheric Sounding Interferometer (IASI) CNES/EUMETSAT
Fourier-transform spectrometer, 3.62-15.5 µm in three bands. Four IFOVs of 20 km at nadir in a square 50 x 50 km, step-scanned across track (30 steps), synchronised with AMSU-A. 2000 km swath. Resolution 0.5 cm-1. Radiometric accuracy 0.25-0.58K. Global coverage will be achieved in 12 hours.

Volcanic products from satellite data: SO2

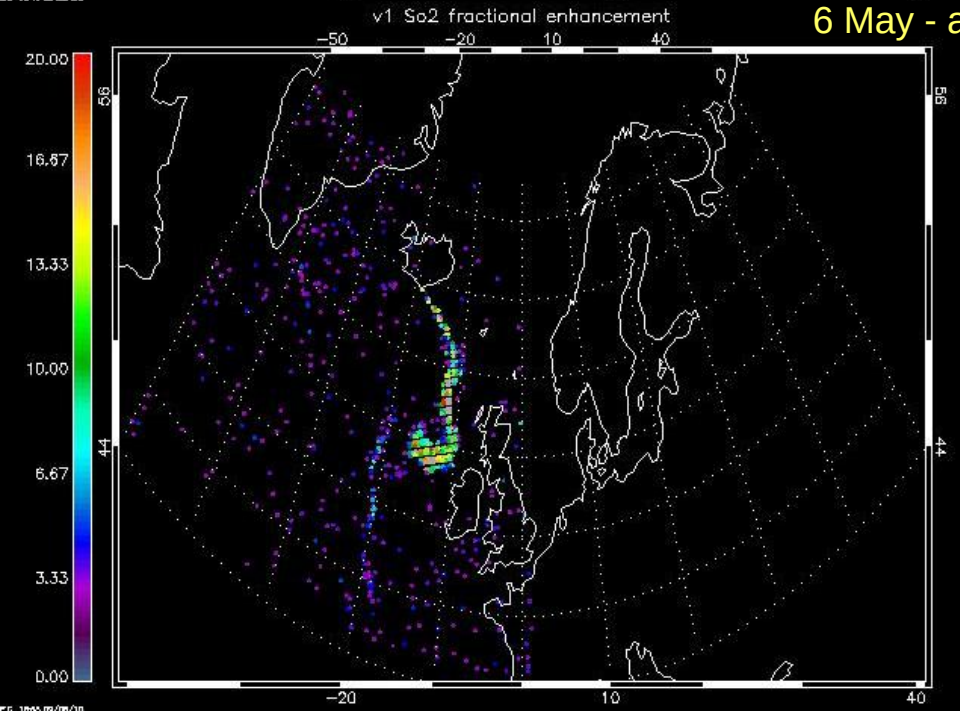


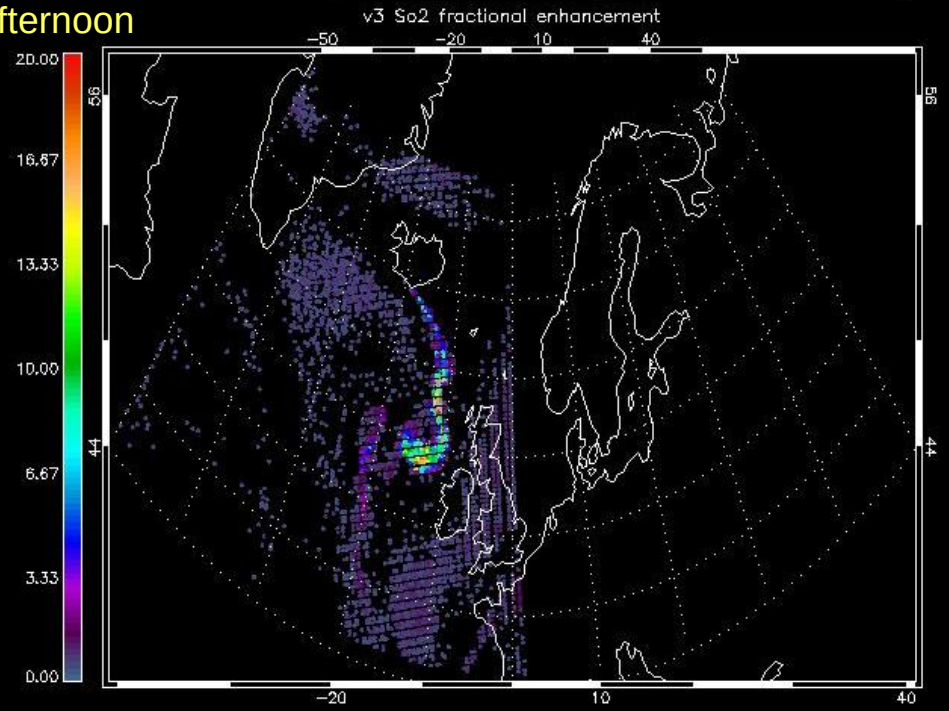
v1 SO2 fractional enhancement 15 April - morning v3 SO2 fractional enhancement



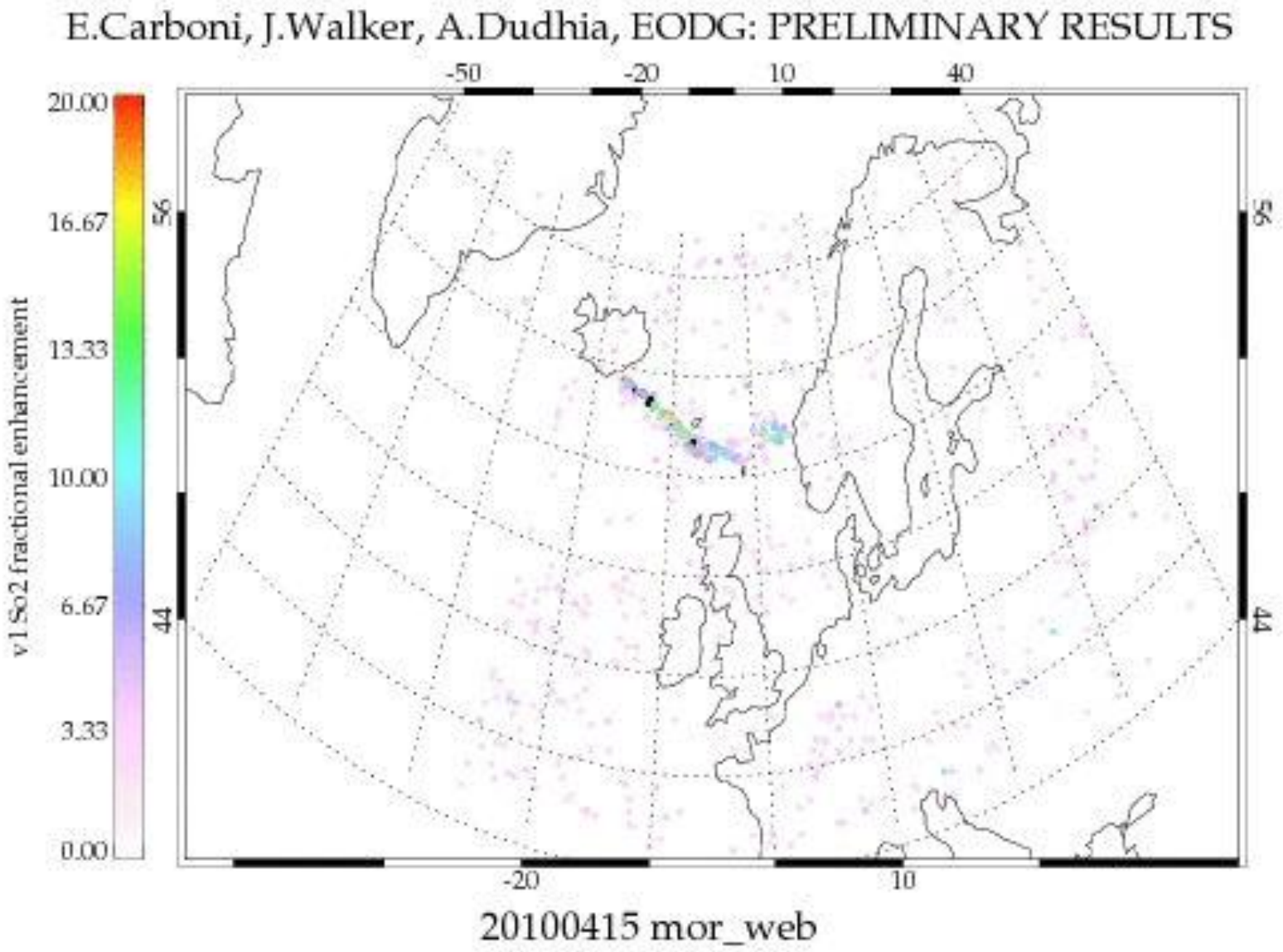


6 May - afternoon

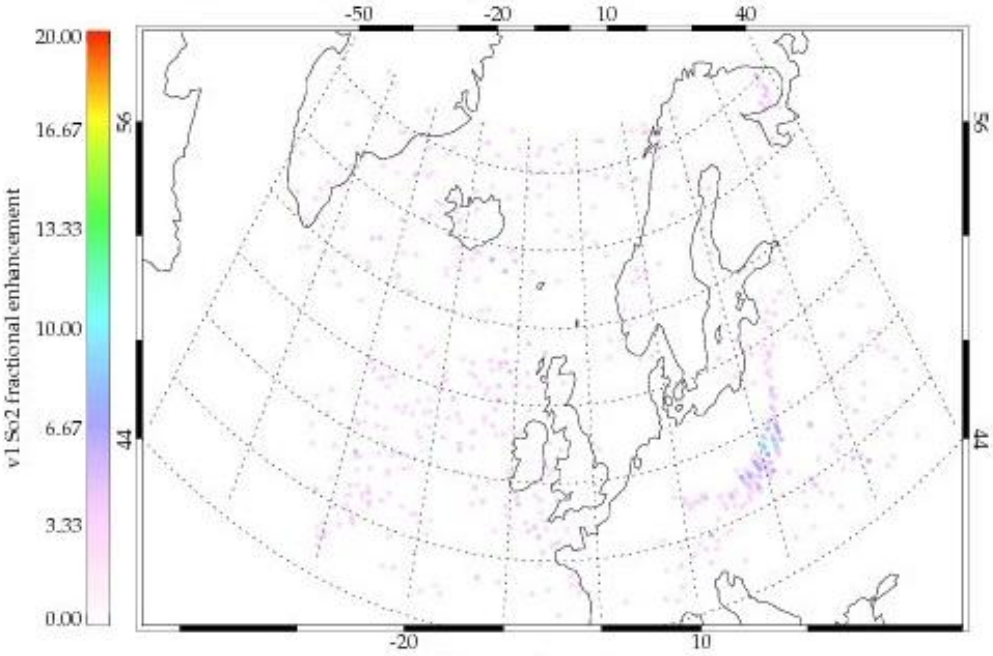


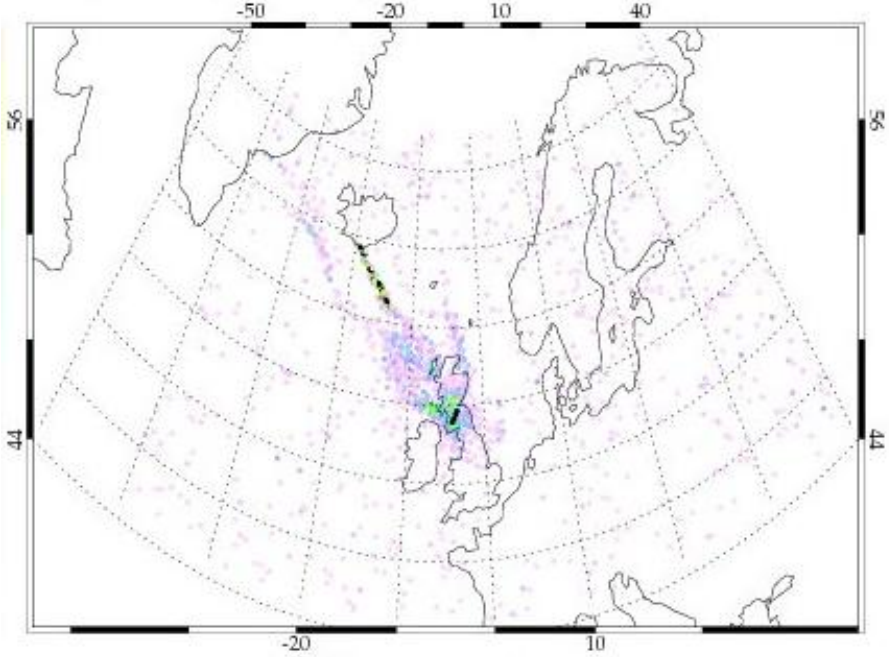


IASI - SO2 fractional enhancement



SO2 fractional enhancement

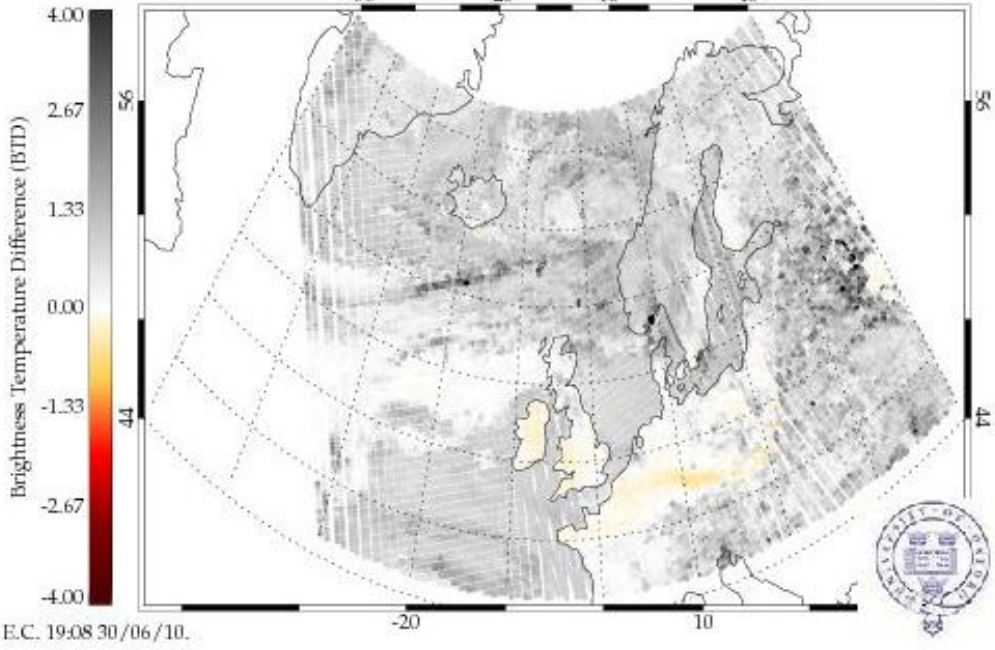


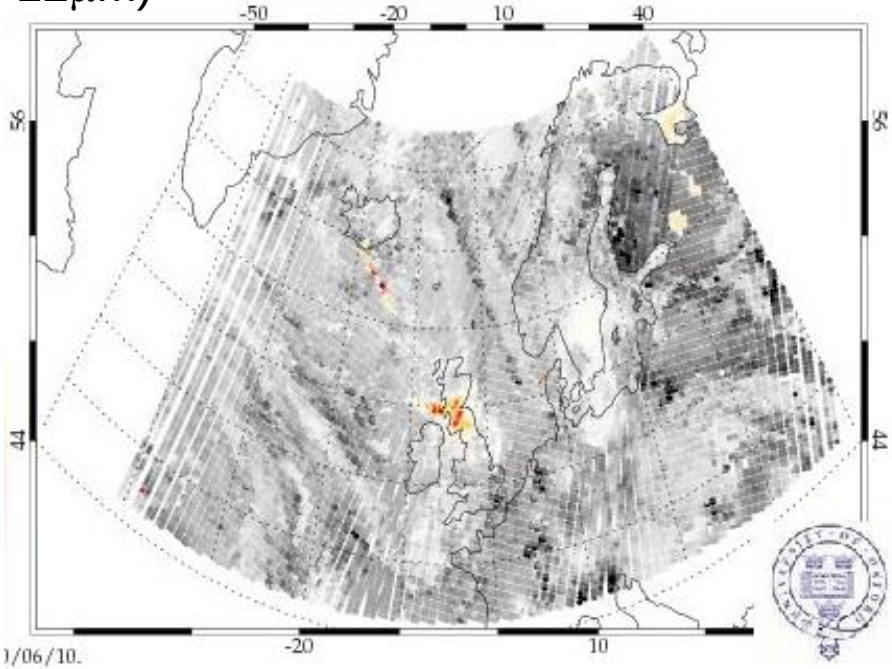


20100416 aft_web

(BTD: 11-12μm)

20100516 mor_web





Conclusion

Eyja erruption was observed by satellites capable of retrieving valuable Information on the emission of ash and SO2

Methods to optimally exploit this information are under development

Ash amount (optical depth), size, mass and height can be obtained using the ORAC Scheme applied to AATSR (small pixel size) or SEVIRI (15 min sampling)

Remains considerable difference between such quantities retrieved using different techniques. NB uv vs vis vs ir (refr. Index), stereo vs ir height etc
-> further intercomparison, validation, retrieval development needed

Metop (GOME-2 + IASI) a powerful new system for observing (&discriminating) both SO2 and ash, including sensitivity to height of SO2

Detection of SO2 from IASI well demonstrated, now moving to quantification (but will be challenging!)