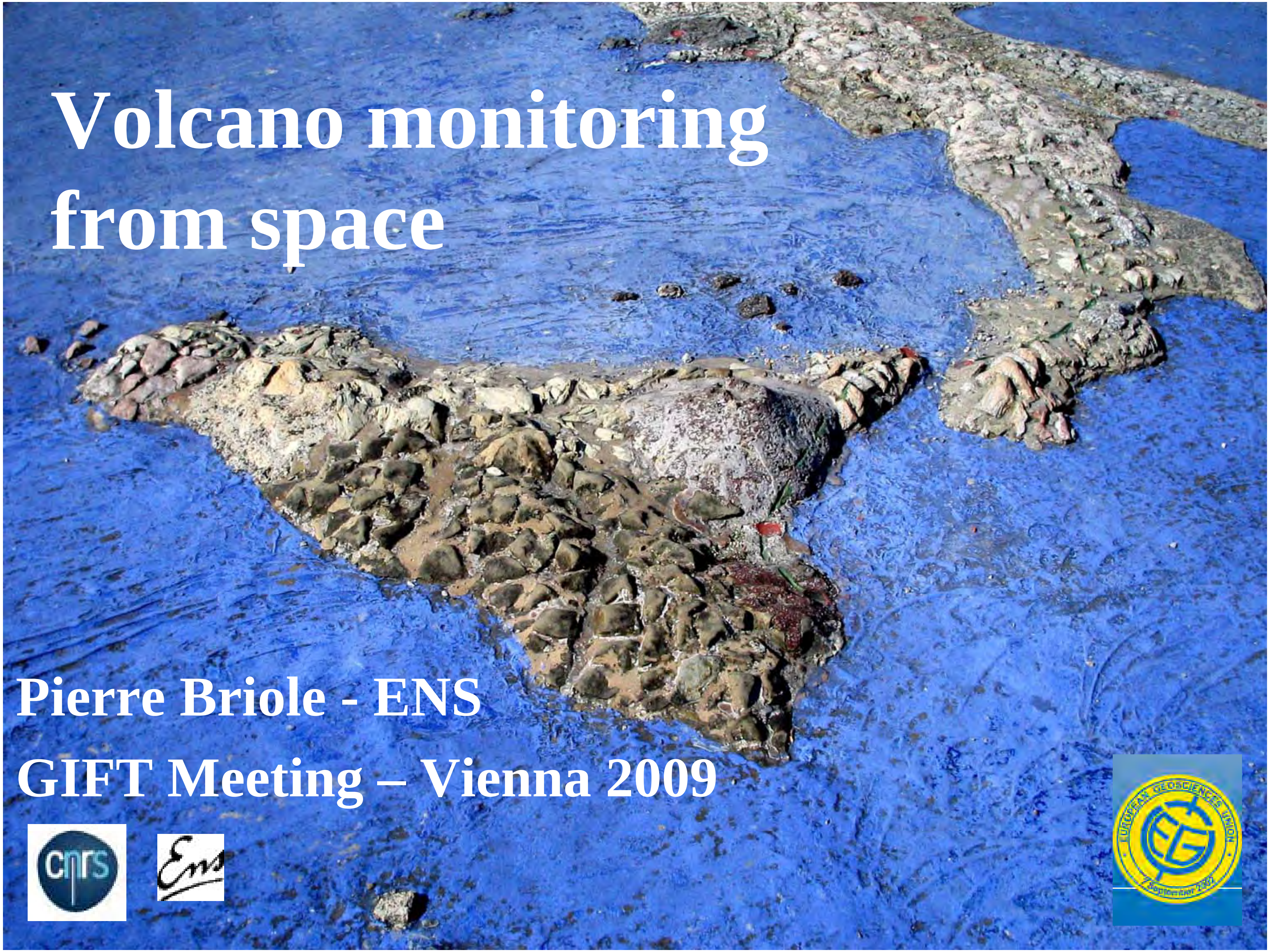


Volcano monitoring from space

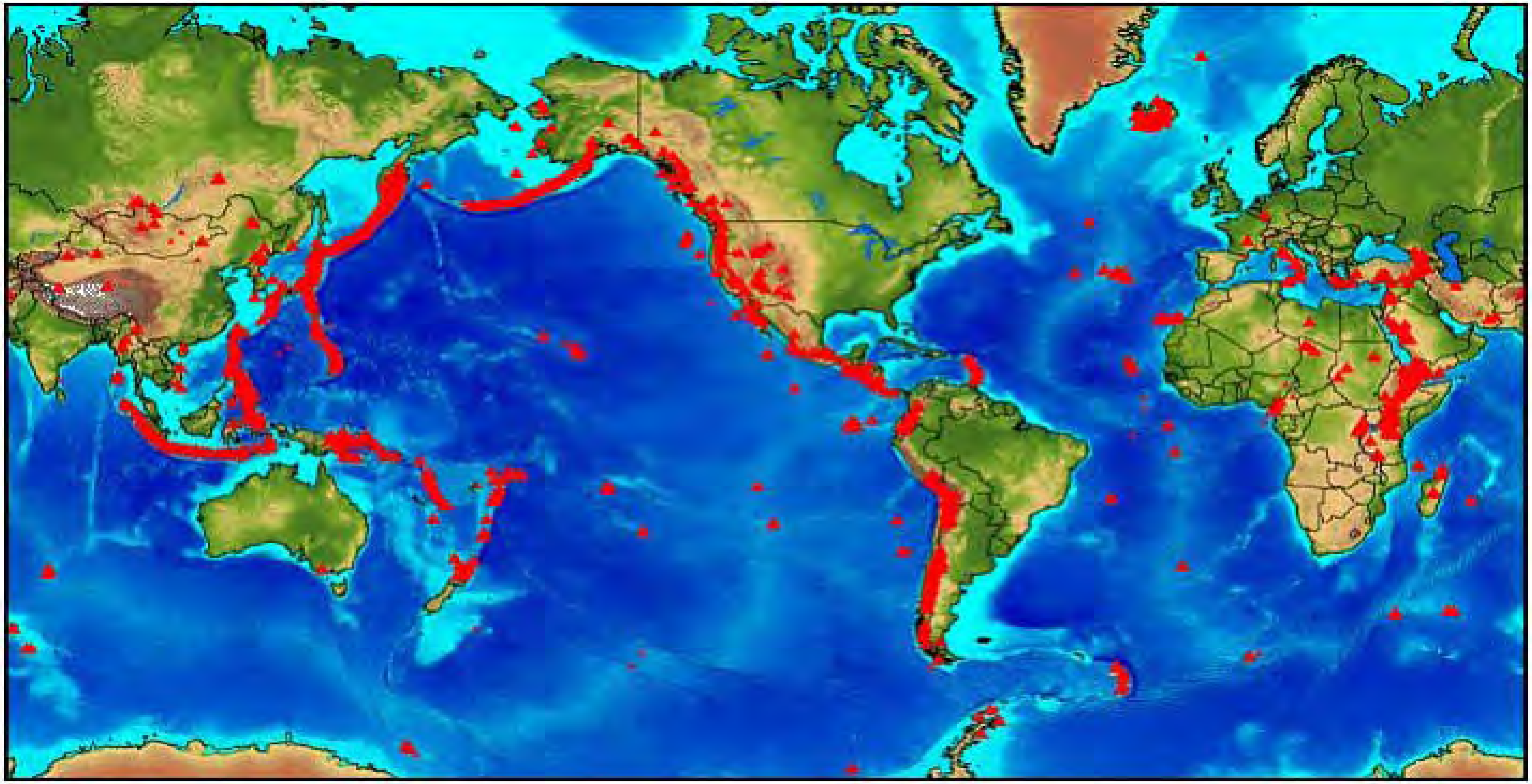
Pierre Briole - ENS

GIFT Meeting – Vienna 2009

Summary

- 1: Volcanoes on Earth
- 2: Volcanic hazards
- 3: Volcano monitoring from the ground
- 4: Volcano monitoring from space
  - 4a: C and L-band radar (deformations)
  - 4b: Infra-red (plume, thermal)
  - 4c: Visible (thermal, mapping)
  - 4d: Ultra-violet (plume: sulfur dioxide)

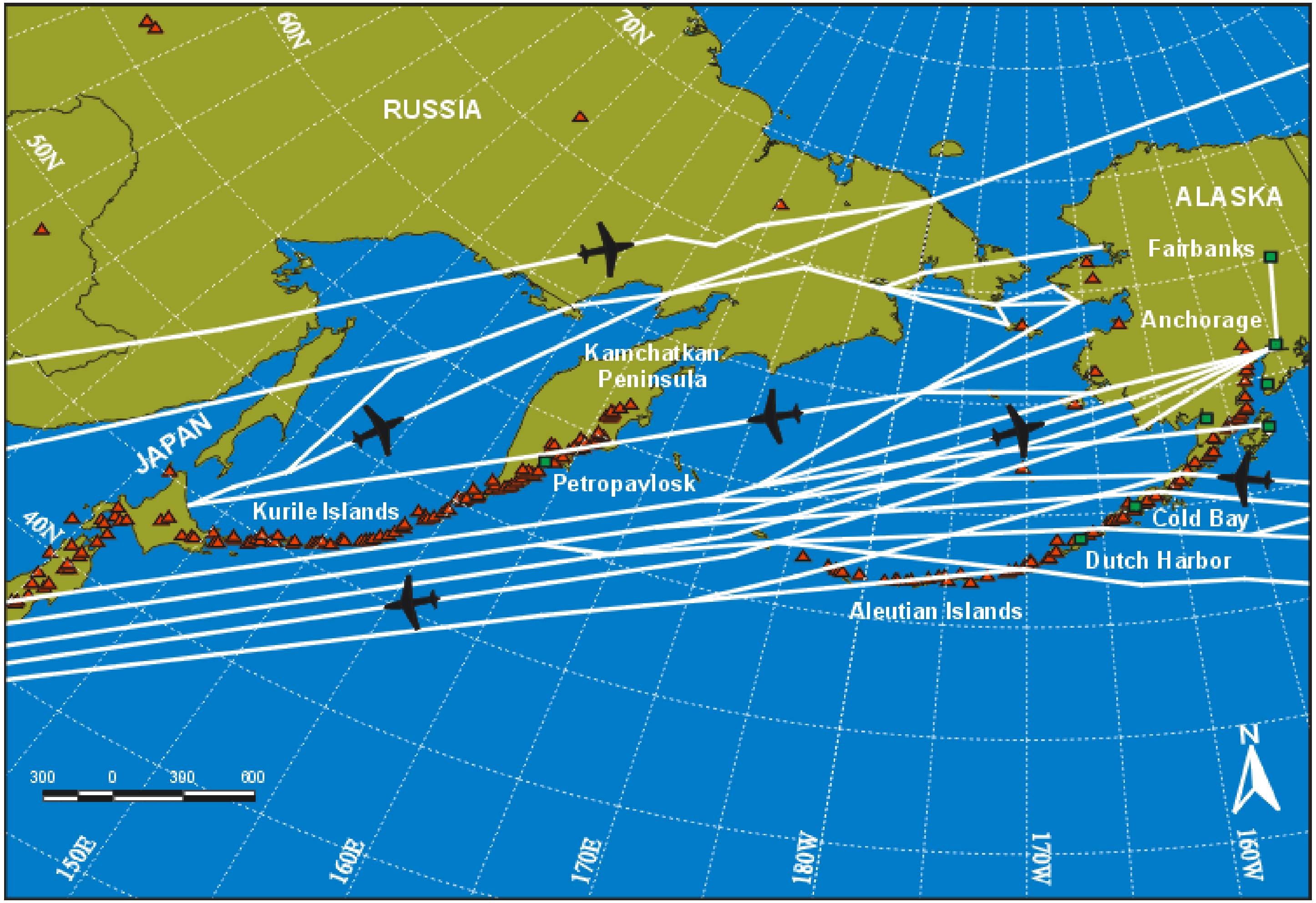
Active volcanoes on Earth



More than 1500 volcanoes on the Earth are potentially active. About 70 are presently erupting.

10% of the world population is living in areas threatened by volcanoes, without considering the effects of eruptions on climate or air–traffic.

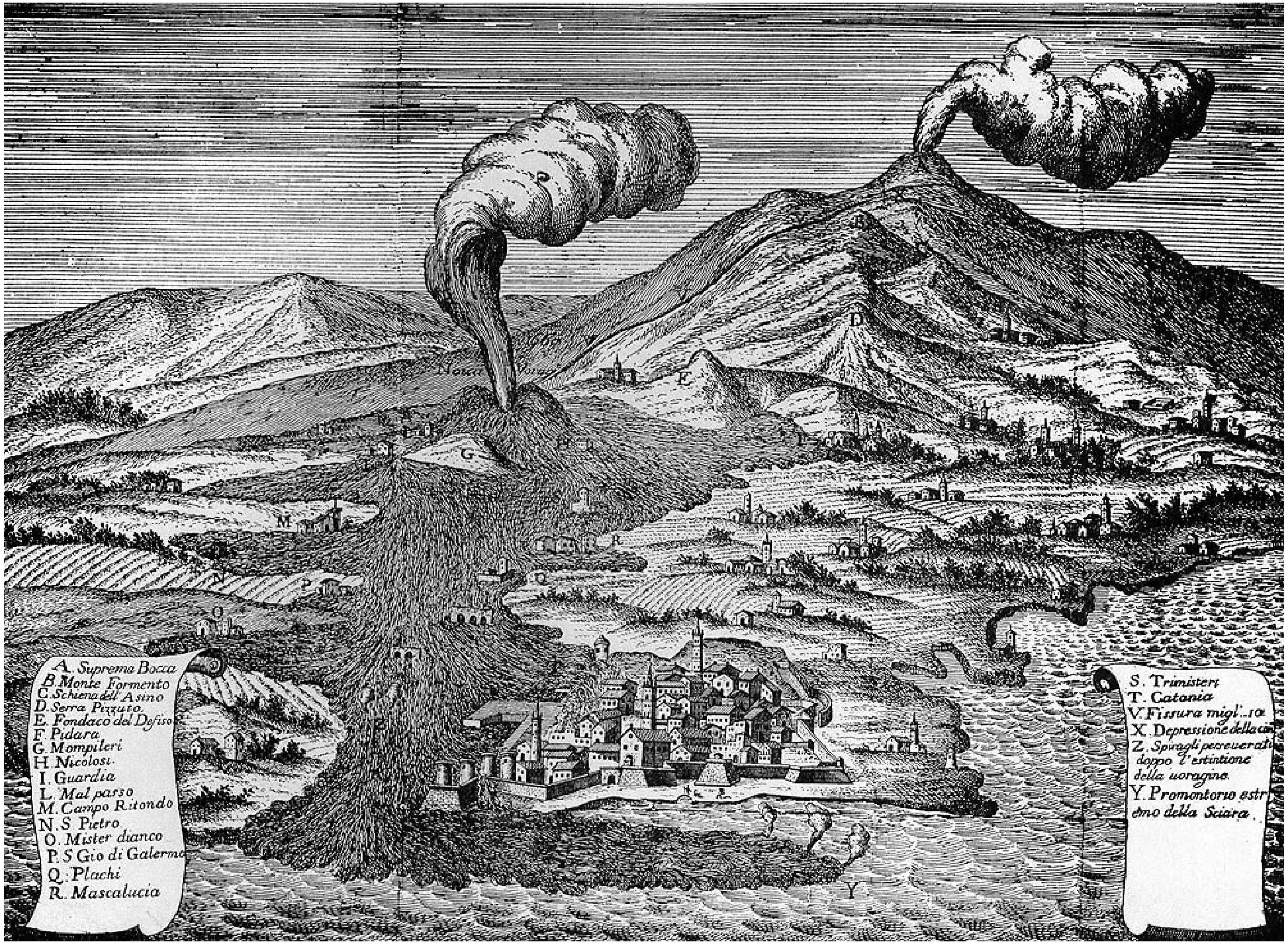
Volcanoes and the security of air traffic



Routes of some of the 100000 flight per year in the Alaska-Aleoutians area


• 2: Volcanic hazards
• 3: Volcano monitoring from the ground
• 4: Volcano monitoring from space

Lava flows



The large 1669 eruption of Etna

Lava flows produce irreversible damages to the land.
In general the velocity of lava flow is slow and the population can escape.
The flow extension depends on slope, effusion rate, duration of the eruption

Lava domes and pyroclastic flows

Merapi, 1995
© Mangin

Mount St Helens © USGS

Soufriere Hills Montserrat, 2000
and the city of Plymouth
© G. Boudon

Eruptions of explosive volcanoes are often preceded by the growth of a lava dome.
The eruption occur when the amount of gas becomes so high that the lava dome explodes.
Pyroclastic flows are a mix of hot gas and lava blocks. They can be very fast.

Ash fall / mud flows

Ash fall and roof collapses during the 1992 eruption of Pinatubo, Philippines © USGS

Armero destroyed by a mudflow after the melting of ice on the Nevada del Ruiz volcano in 1985 © USGS

Near Pinatubo, Philippines, 1991 © USGS

Gaz

Lake Nyos, Cameroun © Smithsonian

Soufrière de Guadeloupe, 2000
© JC Komorowski

Sakurajima, 2000
© P. Briole

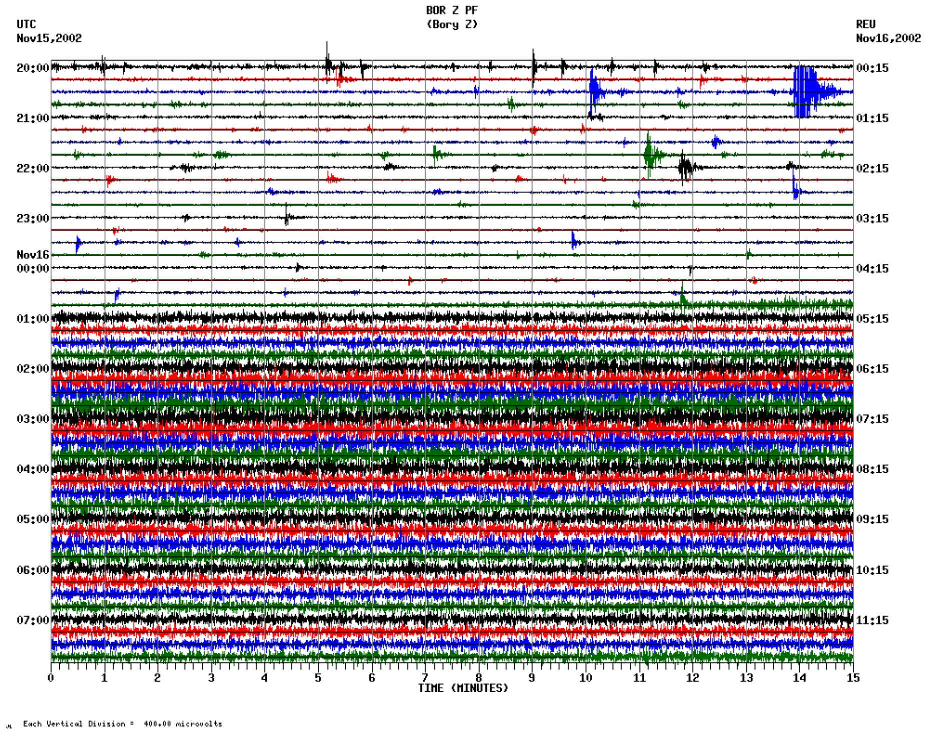
Volcanoes inject in the troposphere H2O, CO2, SO2, H2, CO and in lower quantities H2S, HCl, HF, He, …
Those gases can be responsible of acid rains, pollution of aquifers, ….
The volcanic plumes have also an impact on the climate. Some historical eruptions have induced colder climate during years.

- 3: Volcano monitoring from the ground
- 4: Volcano monitoring from space

Seismicity

Seismic sensors are the basic tool in volcano observatories

Seismometer

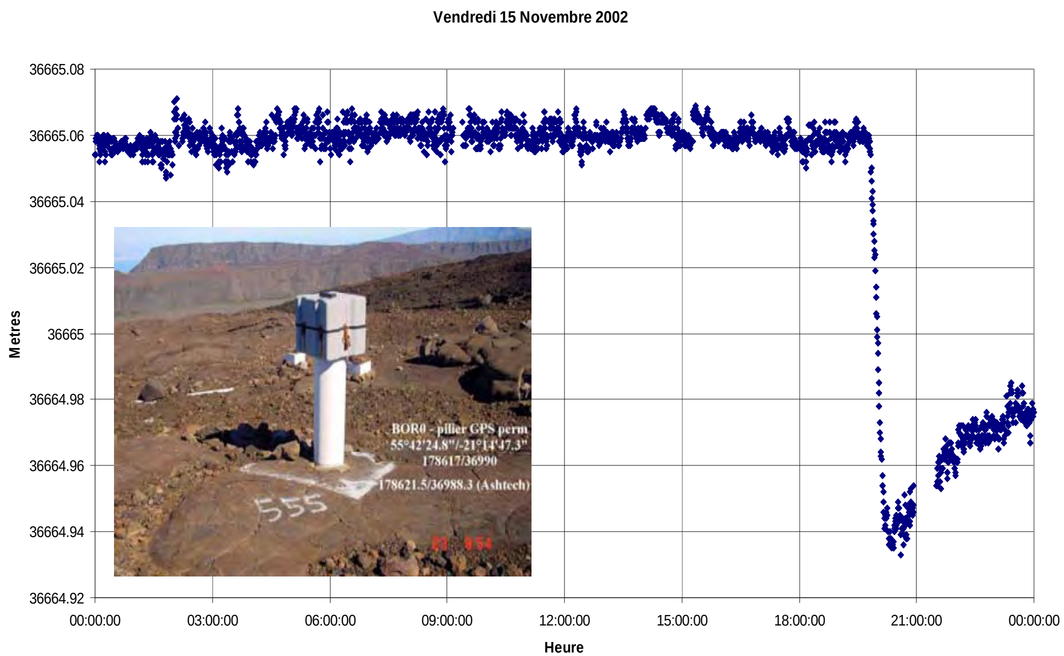


Seismicity at the beginning of an eruption at Piton de la Fournaise

Strainmeter

Tiltmeter

Ground deformations



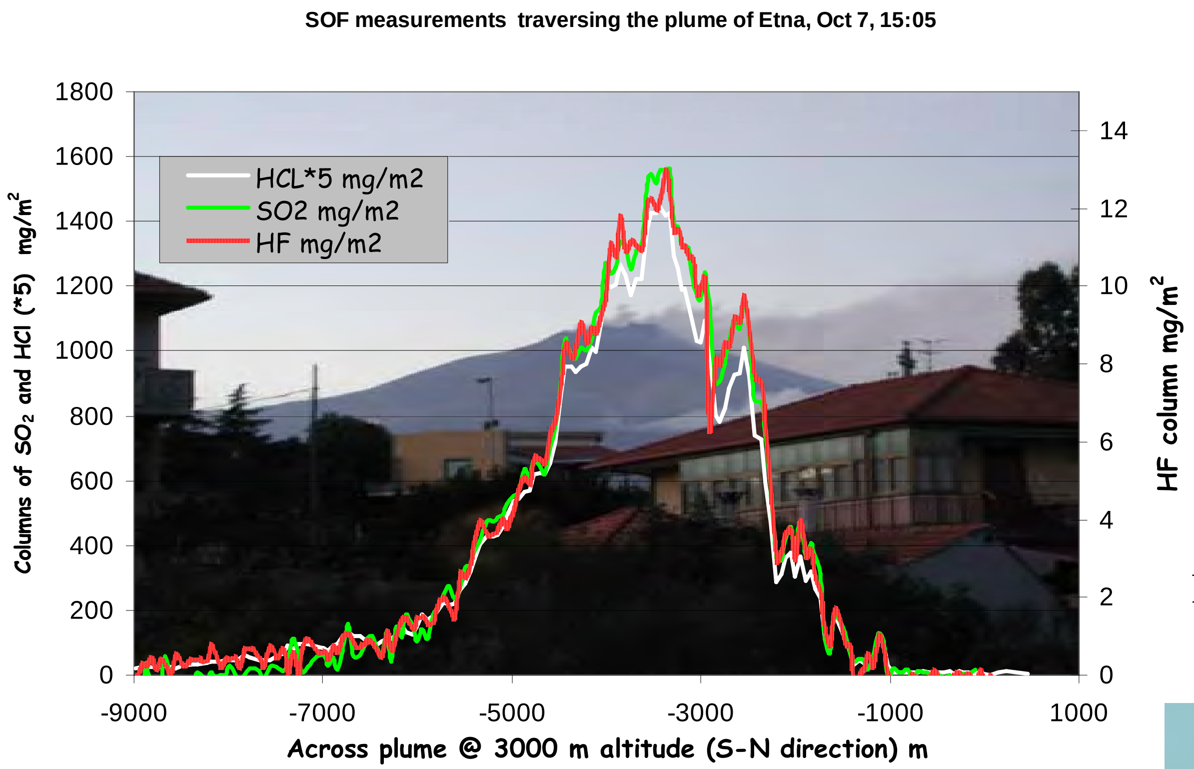
Ground deformation at a GPS station during the beginning of the November 15, 2002 eruption
© P. Briole and Piton de la Fournaise volcano observatory

New ground deformation techniques have been implemented at volcanoes in the last two decades

Automated geodimeter at Piton de la Fournaise volcano © P. Briole

GPS measurements at Piton de la Fournaise © P. Briole

Gas monitoring



Etna, 2005 – COSPEC measurements of the SO2 in the volcanic plume © INGV Catania

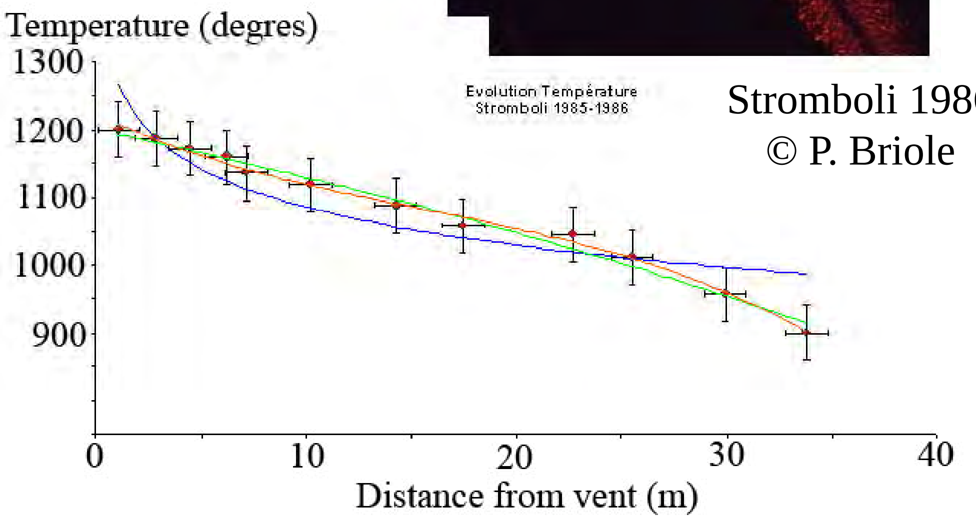
Poas, 1985, gas sampling in a fumarole © JL Cheminée

Stromboli, 1985, aerosols sampling for the analysis of radon daughters short lived radio-nuclides © P. Briole

Lava flow emission monitoring

Lava sampling at Piton de la Fournaise
© T. Staudacher

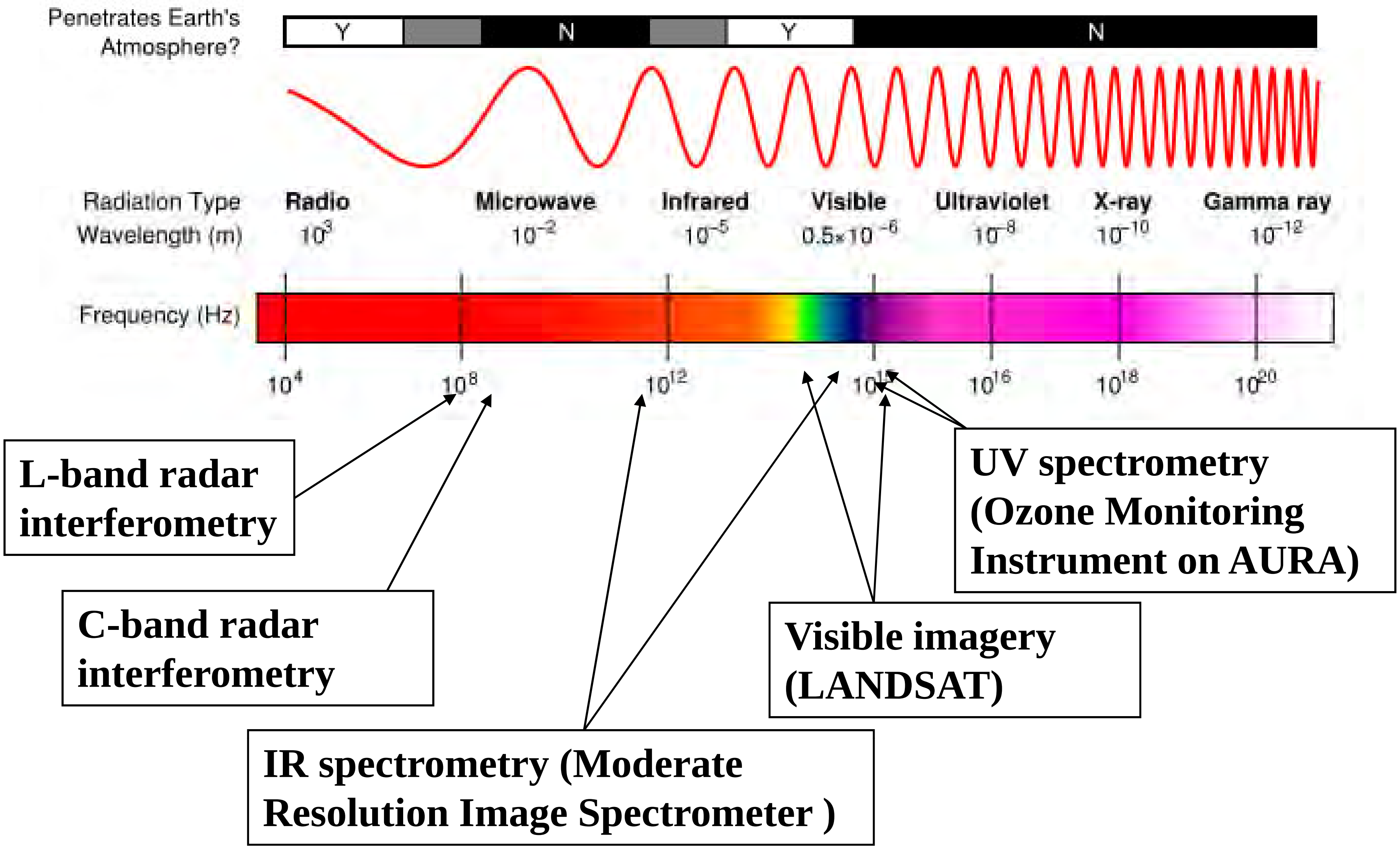
Stromboli 1986
© P. Briole

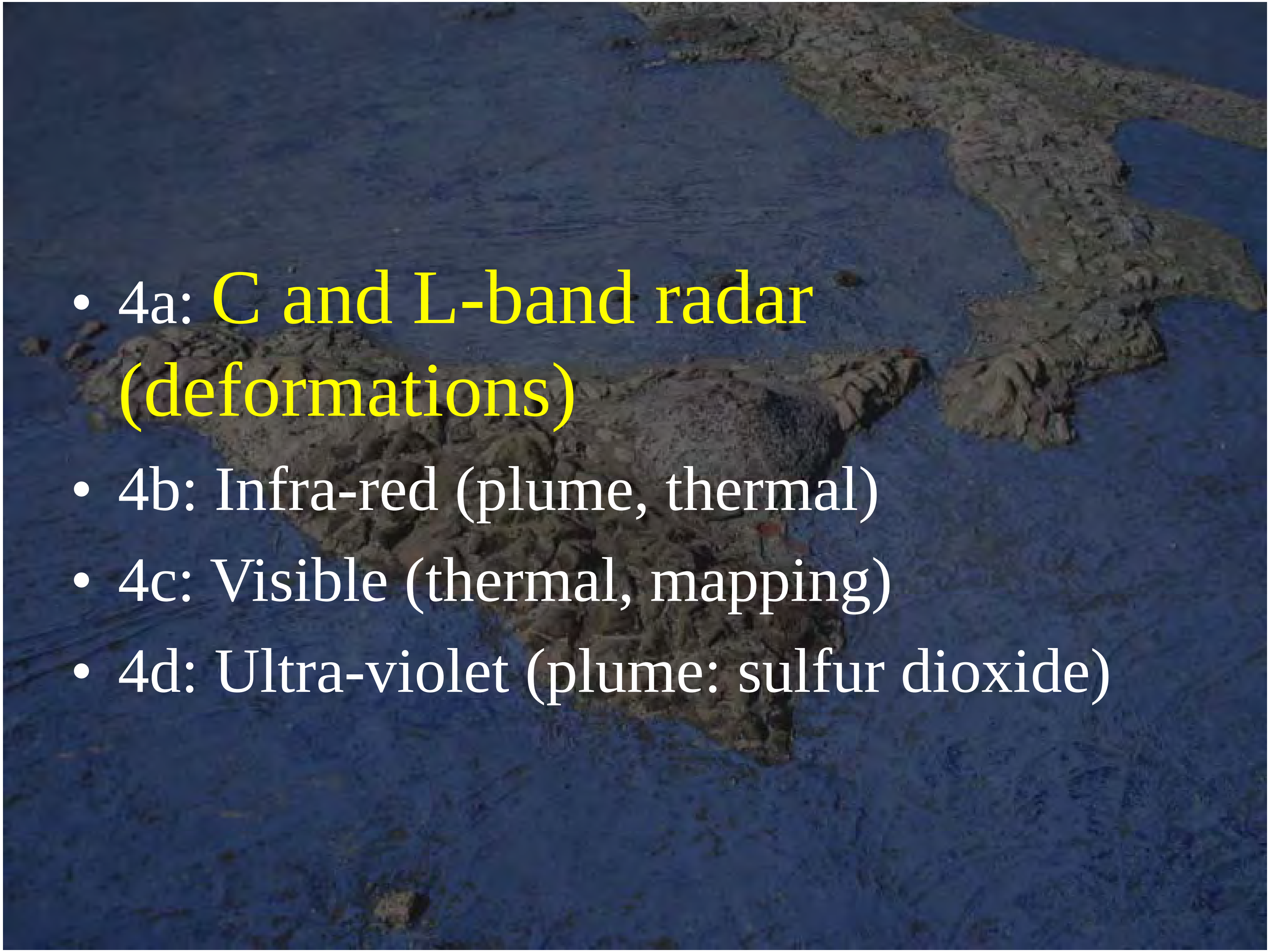


Doppler radar at Etna volcano
© OPGC Clermont-Ferrand

- 4: Volcano monitoring from space
  - 4a: C and L-band radar (deformations)
  - 4b: Infra-red (plume, thermal)
  - 4c: Visible (thermal, mapping)
  - 4d: Ultra-violet (plume: sulfur dioxide)

The electromagnetic spectrum



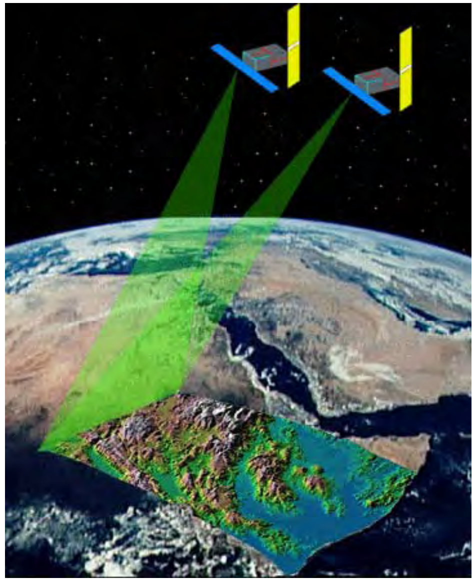


- 4a: C and L-band radar (deformations)
- 4b: Infra-red (plume, thermal)
- 4c: Visible (thermal, mapping)
- 4d: Ultra-violet (plume: sulfur dioxide)

SAR interferometry satellites

- **ERS 1** 1992-2000 – C-band
- **ERS 2** 1995-2001 – C-band
- **ENVISAT** 2002-? – C-band
- **RADARSAT 1** 1995-? – C-band
- **RADARSAT 2** 2007-?– C-band
- **ALOS** 2006-? – L-band
- **TERRASAR X** 2007-? – X-band
- **COSMO** 2007-? – X-band
- **SENTINEL 1** (GMES, 2011) – C-band

ENVISAT before launch © ESA



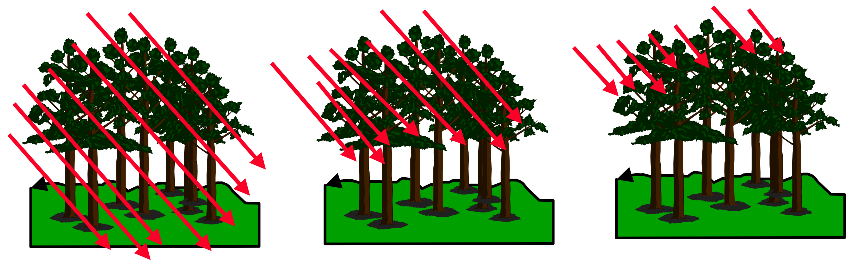
Repeat time:
16 to 35 days

Artist vue of
ALOS © JAXA

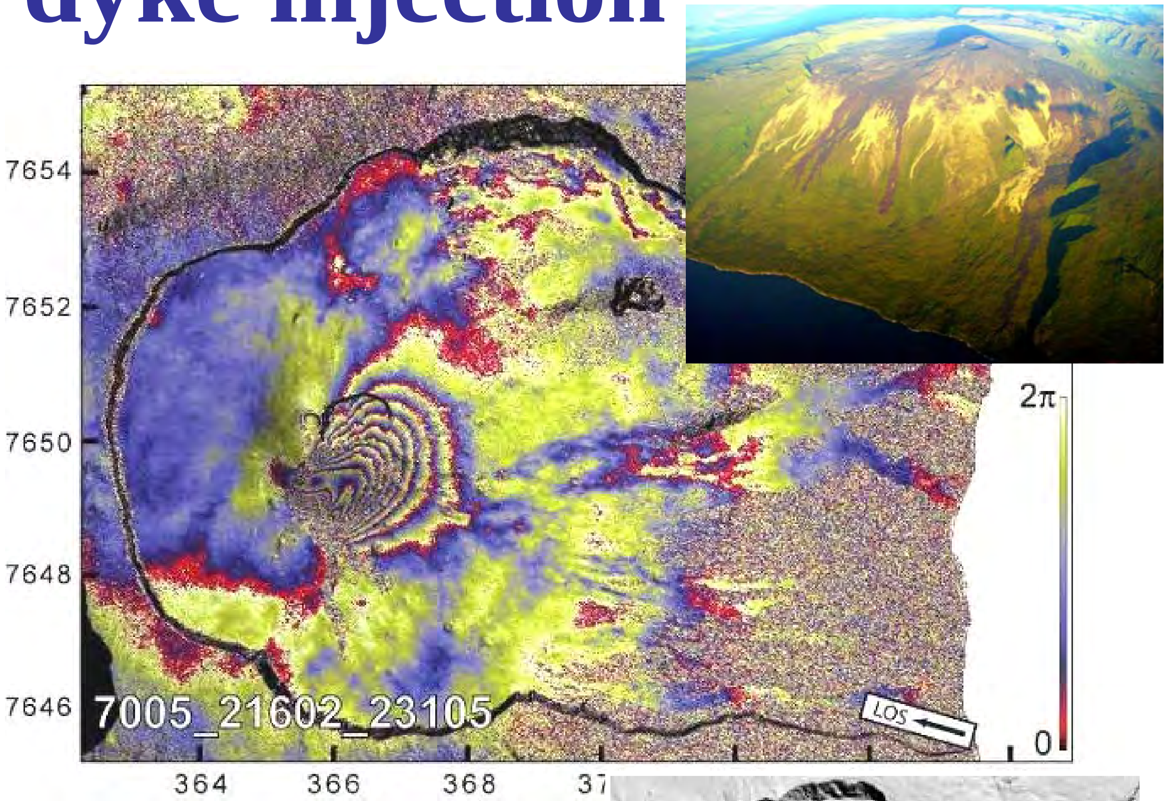
L band λ = 23 cm

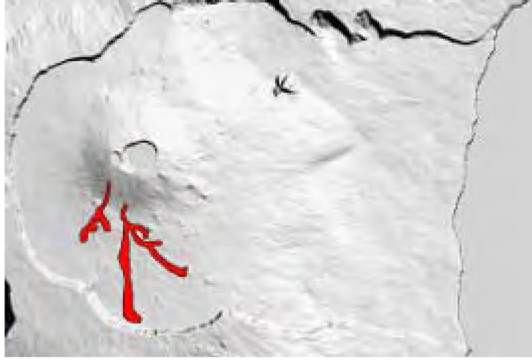
C band λ = 6 cm

X band λ = 3 cm

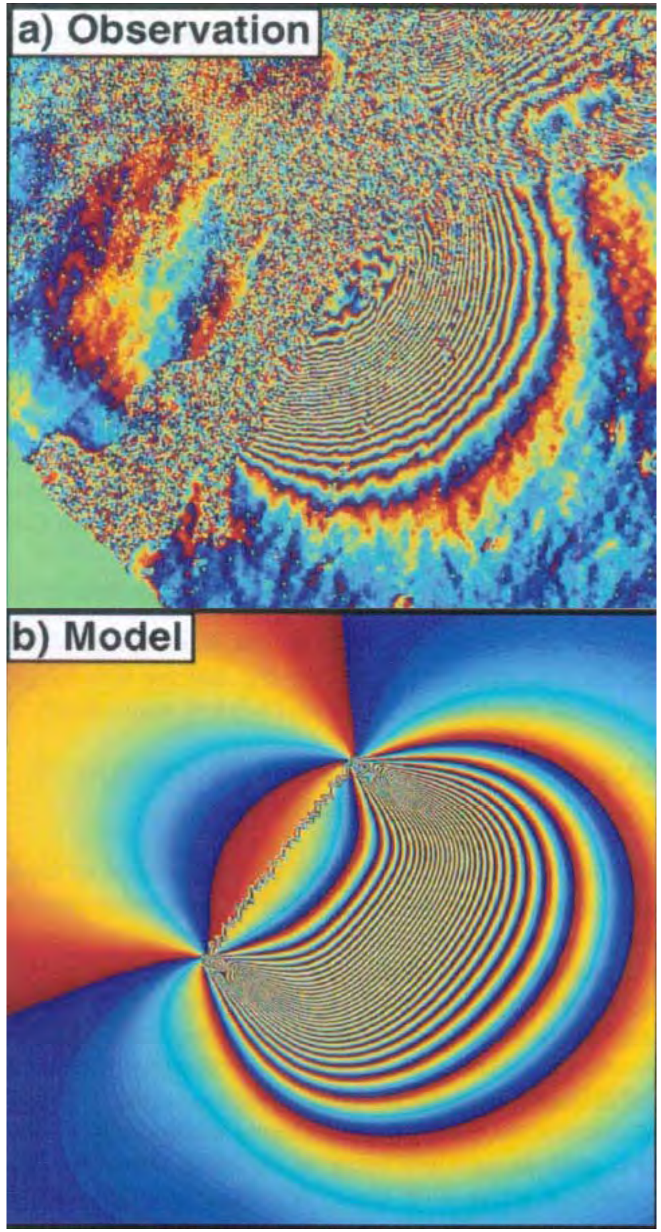


Deformation due to dyke injection



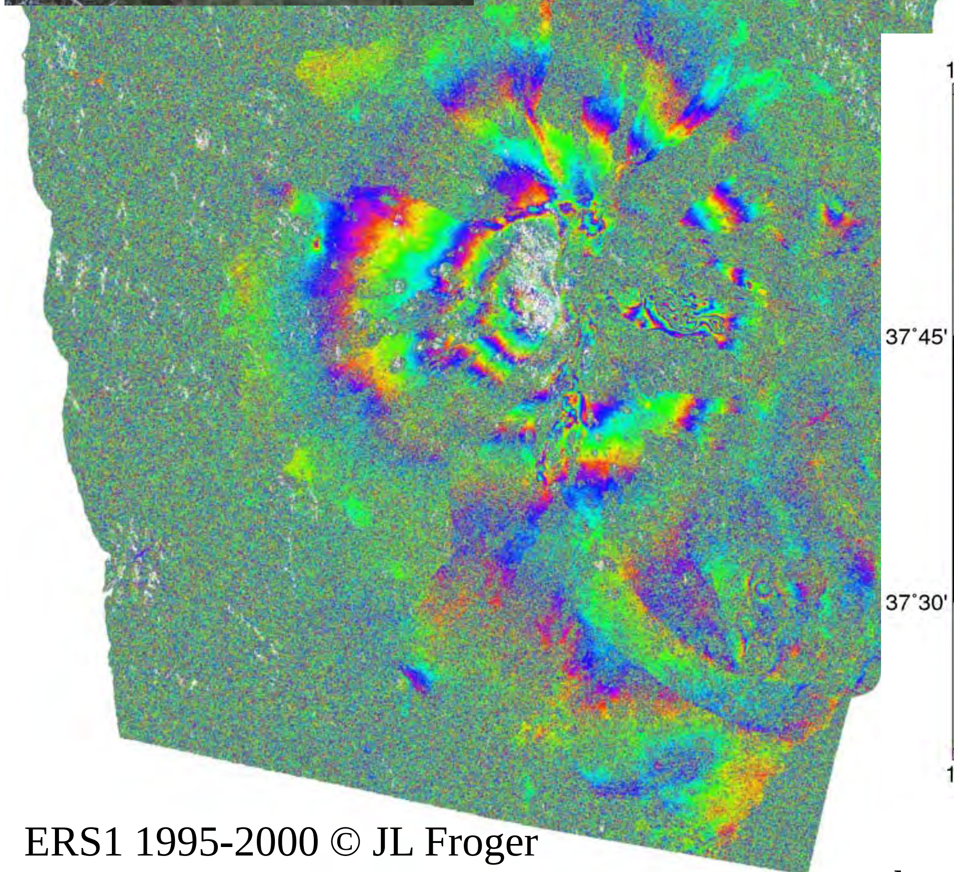


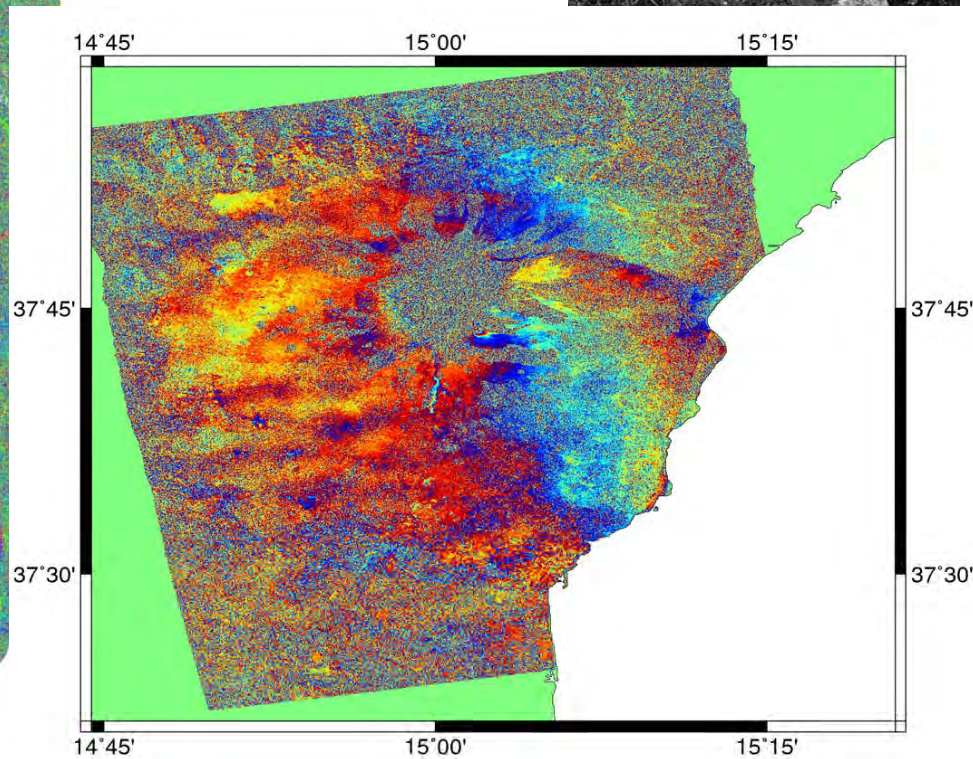
July 2006 eruption of Piton de la Fournaise
© OPGC Clermont-Ferrand



1995 eruption of Fernandina, Galapagos © Jonnson et al.

Large scale deformations (Etna)

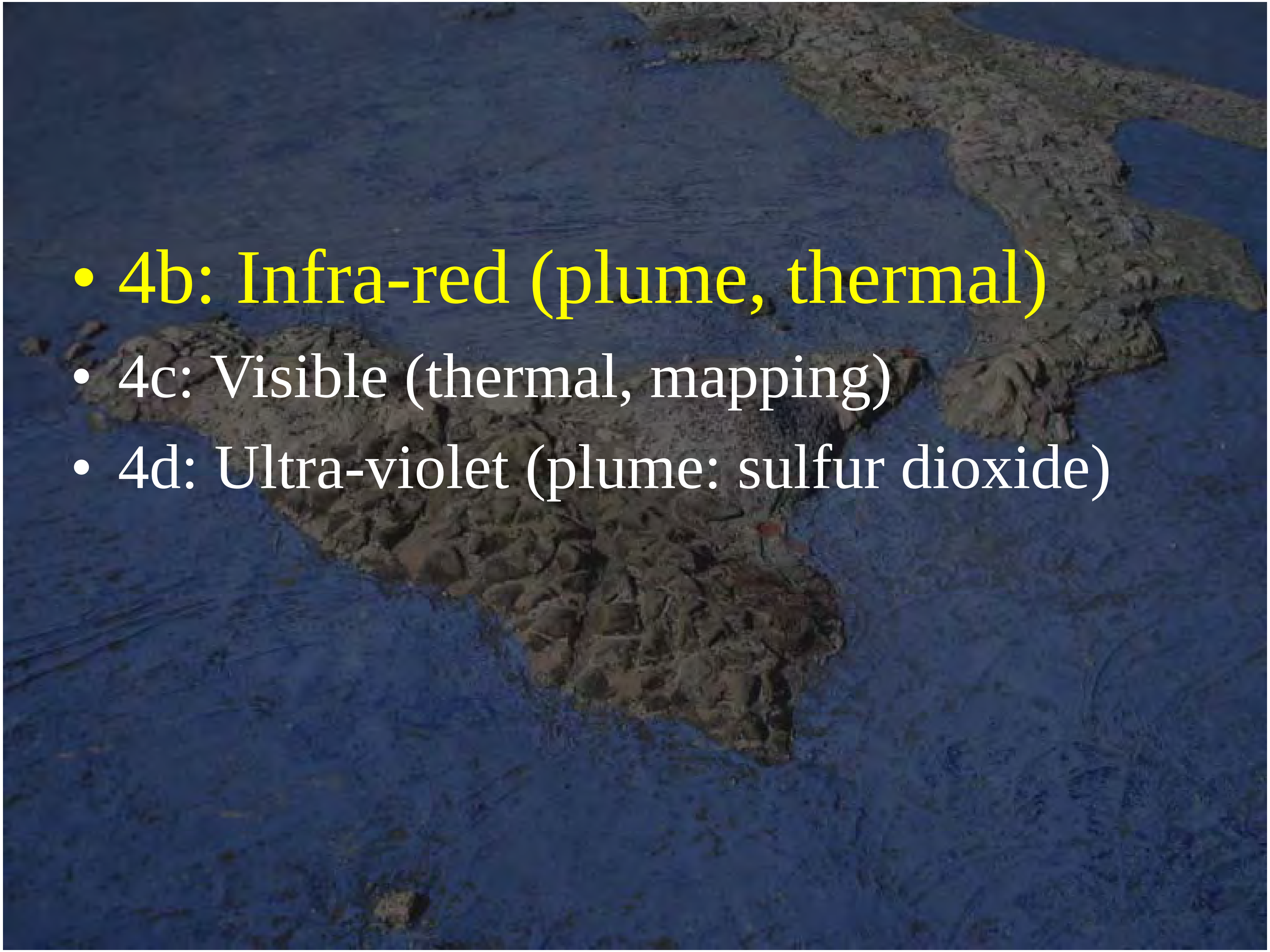




ERS1 1995-2000 © JL Froger

ALOS, 2007-2008 © P. Elias

Photos © P. Briole



- 4b: Infra-red (plume, thermal)
- 4c: Visible (thermal, mapping)
- 4d: Ultra-violet (plume: sulfur dioxide)

Volcano monitoring in the infra red

The MODIS Rapid Response System:
http://rapidfire.sci.gsfc.nasa.gov

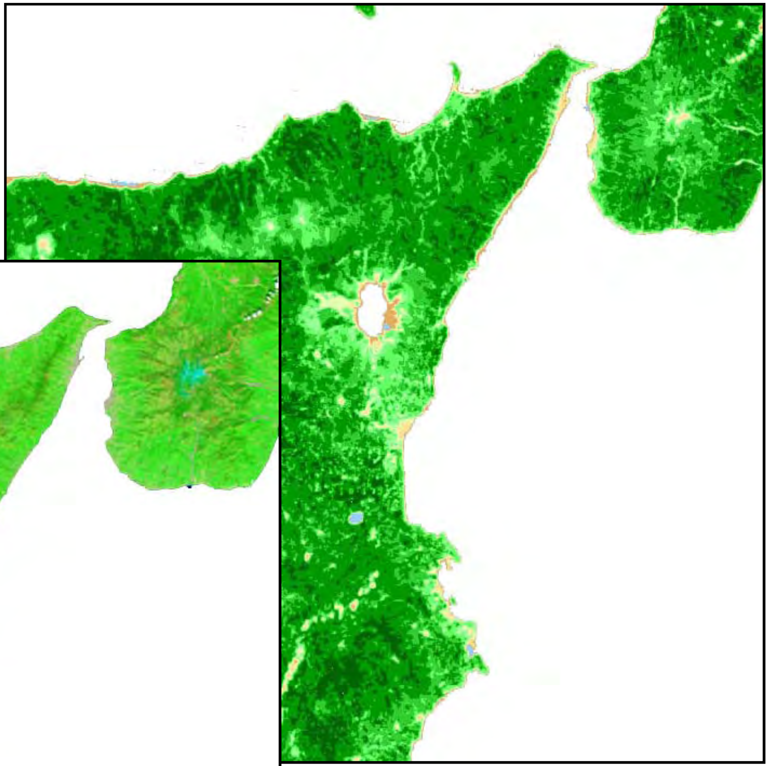
Band	Bandwidth [μm]	Use for volcanology
1	0.620 - 0.670	Plume RGB: 1-4-3
2	0.841 - 0.876	
3	0.459 - 0.479	Plume RGB: 1-4-3
4	0.545 - 0.565	Plume RGB: 1-4-3
5	1.230 - 1.250	
6	1.628 - 1.652	
7	2.105 - 2.155	
21	3.929 - 3.989	Hot-Spot
22	3.929 - 3.989	Hot-Spot
31	10.780 - 11.280	Plume, Hot-Spot
32	11.770 - 12.270	Plume, Hot-Spot

MODIS bands

The case of MODIS (Moderate Resolution Imaging Spectrometer)

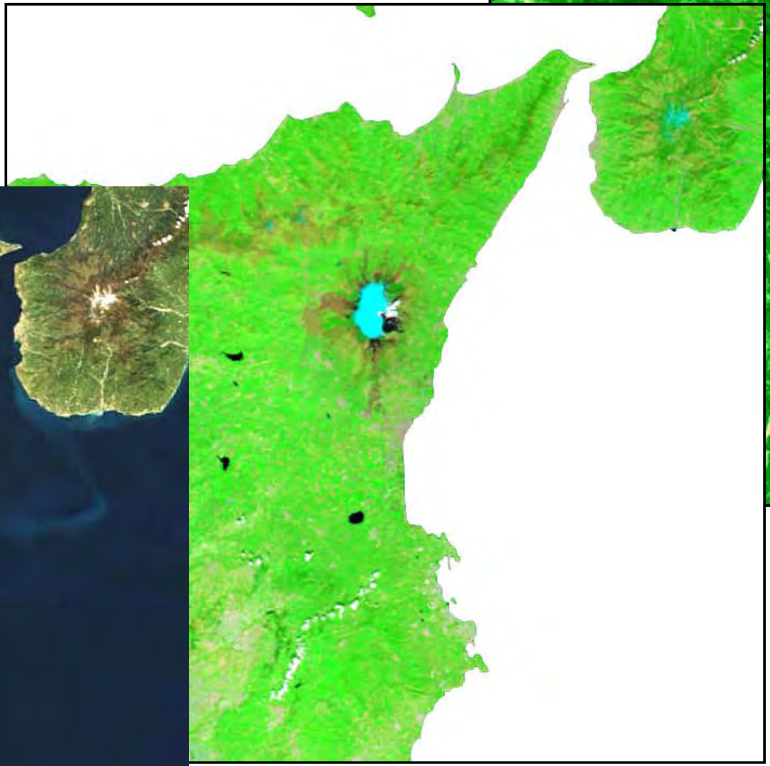
- **2 NASA satellites: Terra (since 1999), Aqua (since 2002)**
- **Spatial resolution = 1km (some bands available in 250m and 500m)**
- **Temporal resolution = 1 day- and 1 night pass of each satellite every 48 hours = 4 observations in 2 days).**
- **36 bands: visual, near-IR, mid-IR, thermal IR**

Bands combination



NDVI composition

NDVI = Normalized Difference Vegetation Index = (NIR-RAD)/(NIR+RAD)

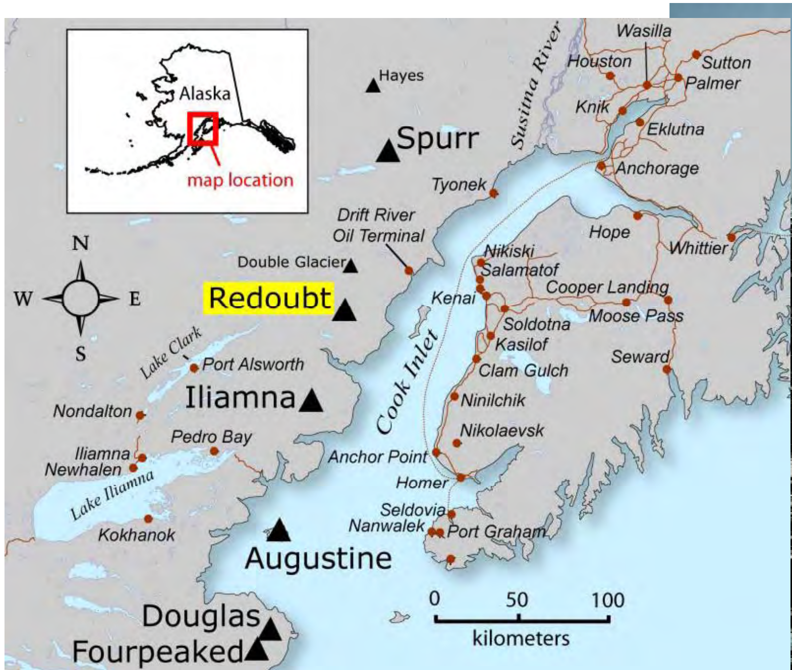


Composition 7-2-1: used to detect burned areas

True (visible) colours

MODIS on TERRA – View of Etna on 16 April 2009

Plume and deposits observed by MODIS

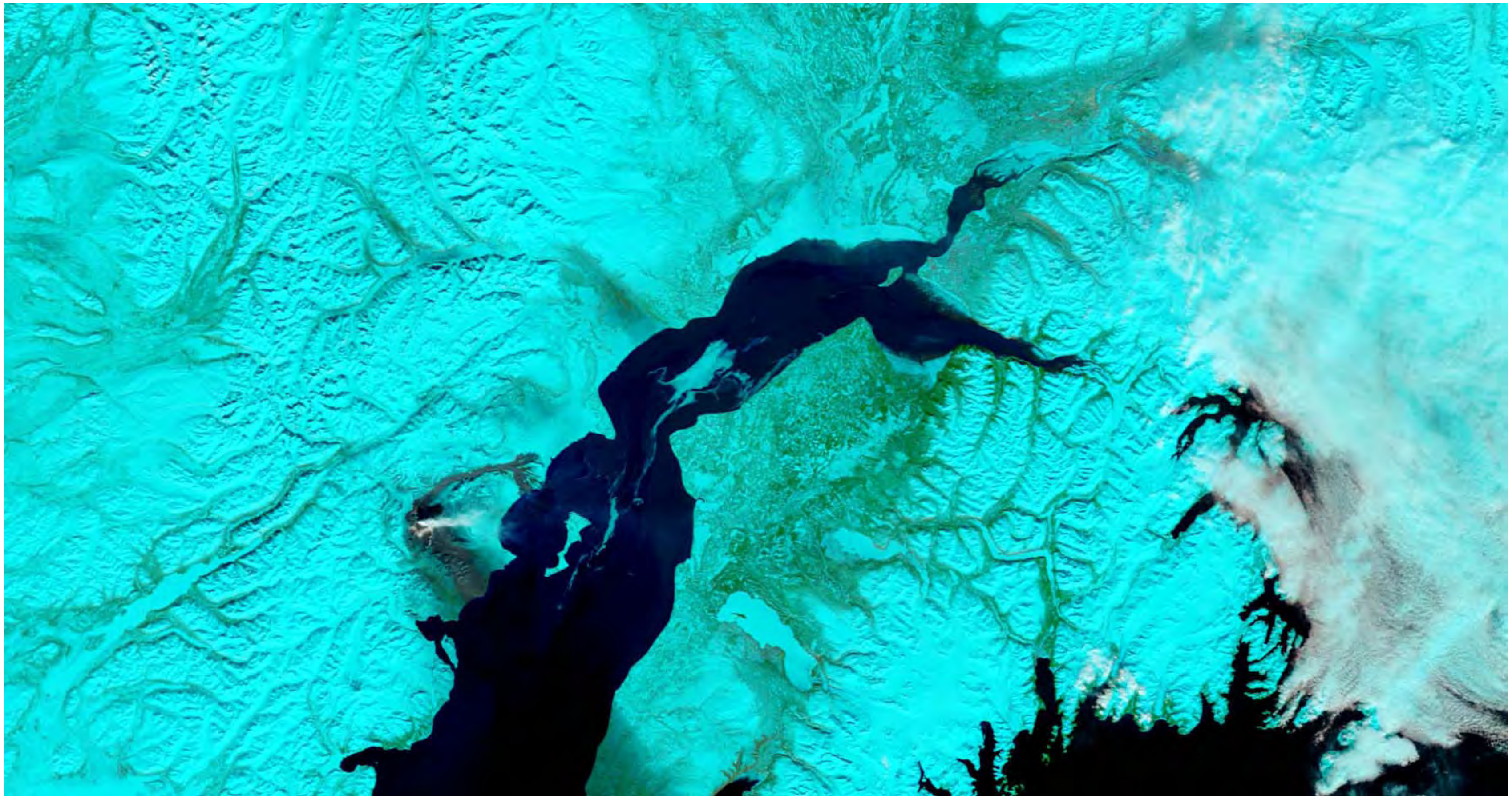


Redoubt volcano, Alaska, 16 April 2009

5 April – True colours

Redoubt Alaska 5 April 2009 (MODIS on Terra – 250m – True colours)

5 April – Composition 721

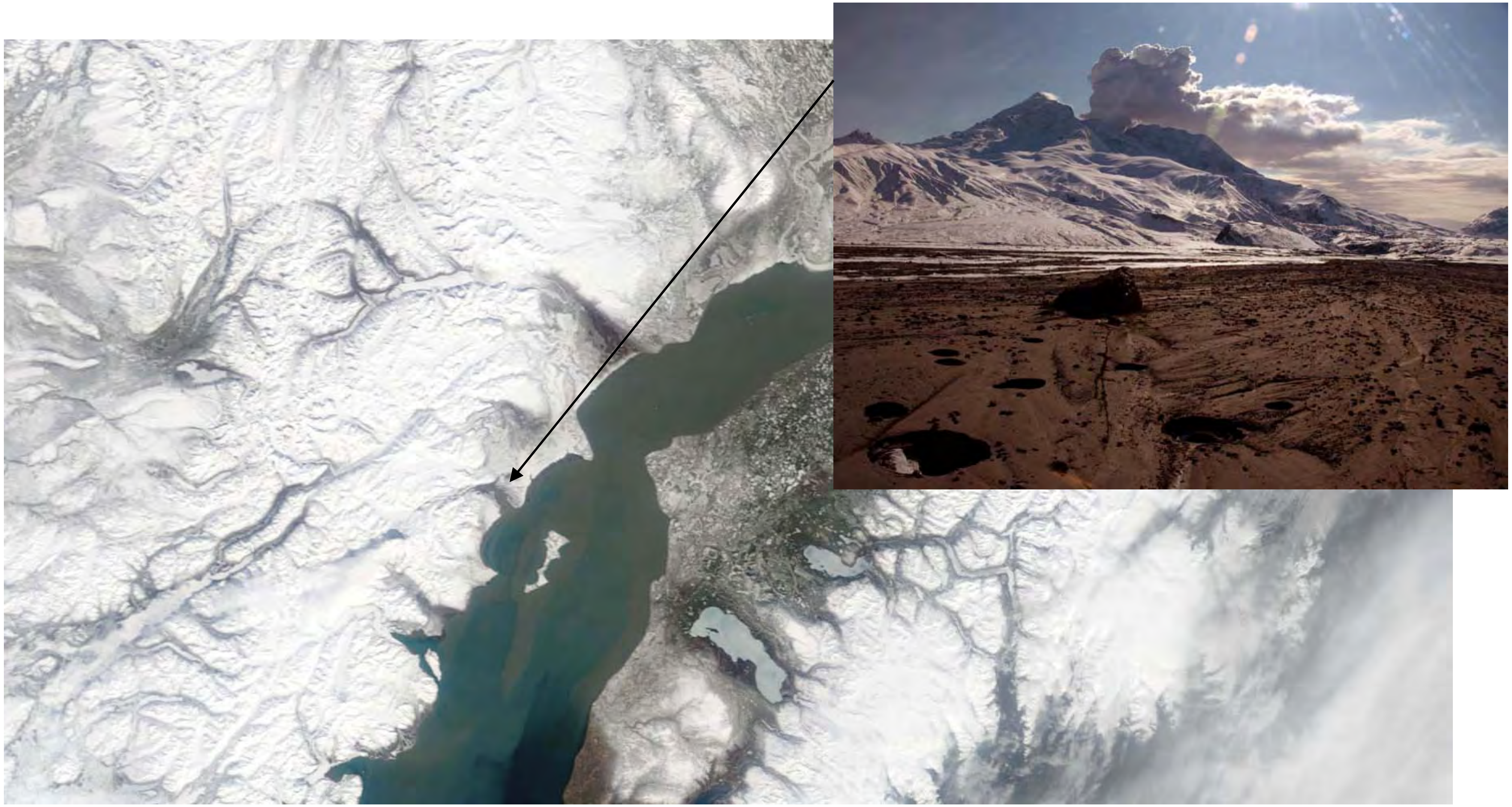


Redoubt Alaska 5 April 2009 (MODIS on Terra – 250m – composition 721) © NASA

16 April – True colours

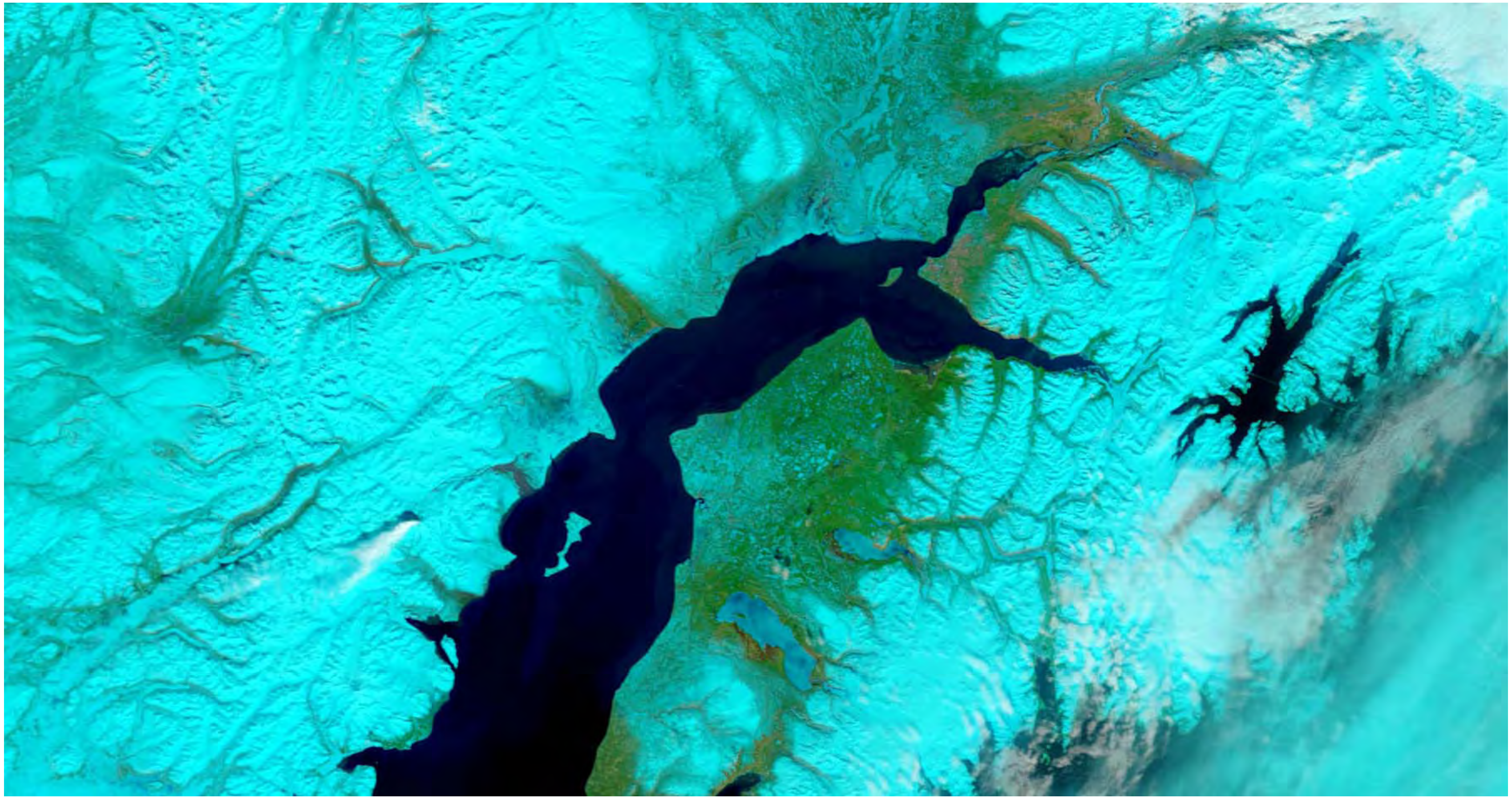
Redoubt Alaska 16 April 2009 (MODIS on Terra – 250m – True colours)

16 April – True colors



Redoubt Alaska 16 April 2009 (MODIS on Terra – 250m – True colours)

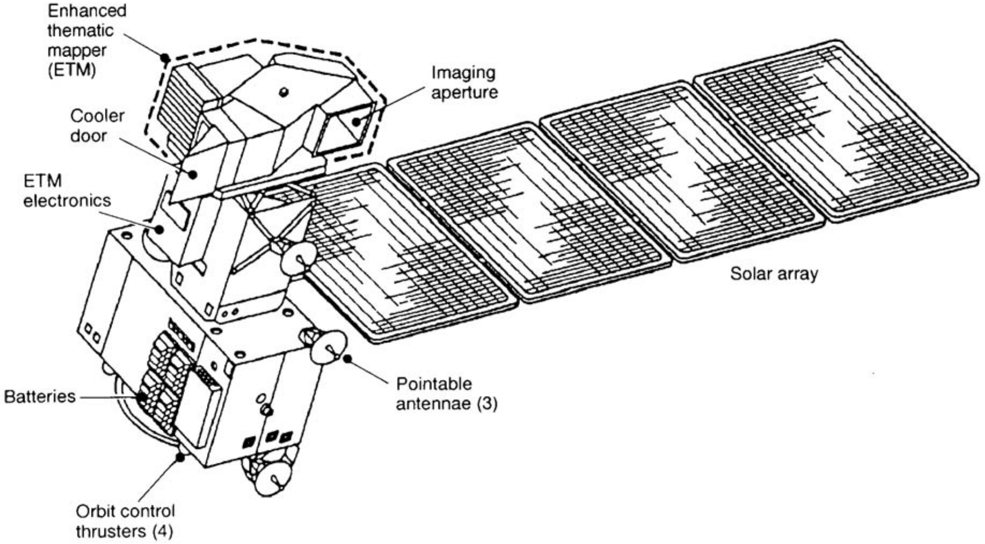
16 April – Composition 721



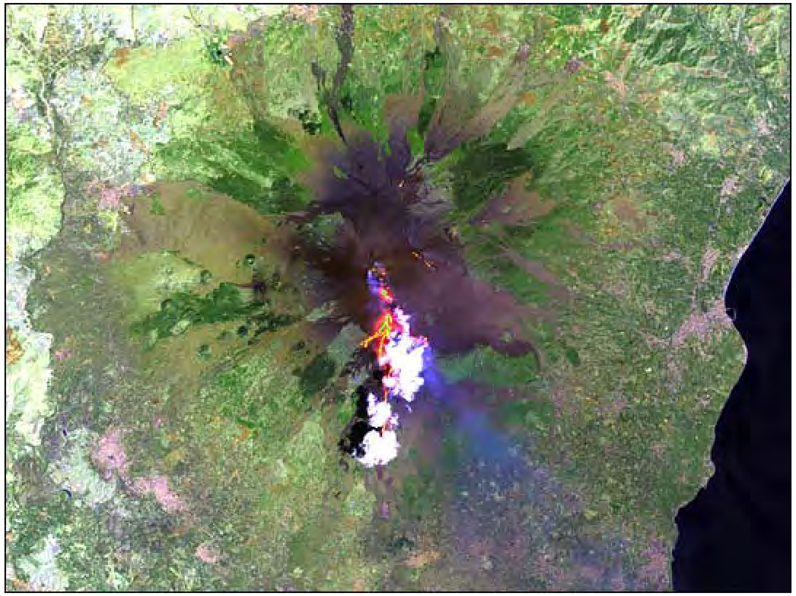
Redoubt Alaska 16 April 2009 (MODIS on Terra – 250m – composition 721) © NASA

- 4c: Visible (thermal, mapping)
- 4d: Ultra-violet (plume: sulfur dioxide)

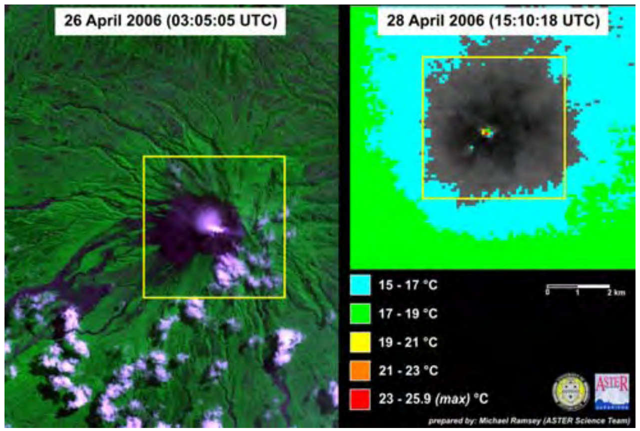
Volcano monitoring in visible band



Landsat and the Enhanced Thematic Mapper (ETM) © EOSAT



Etna, 2001 – LANDSAT 7



Merapi 2006, ASTER © NASA

ETM+ Bands

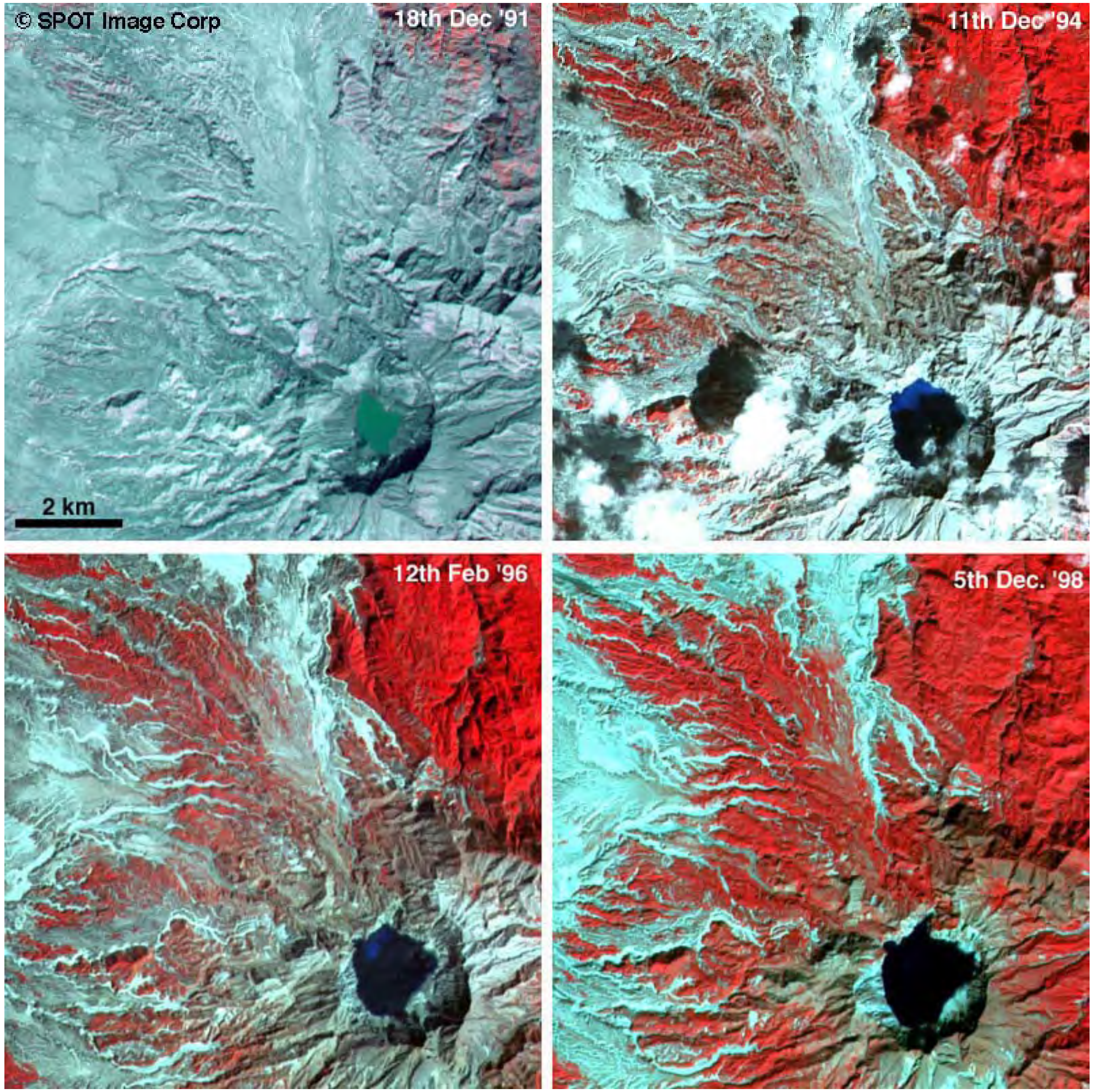
Band Number	µm	Resolution
1	0.45-0.515	30 m
2	0.525-0.605	30 m
3	0.63-0.69	30 m
4	0.75-0.90	30 m
5	1.55-1.75	30 m
6	10.4-12.5	60 m
7	2.09-2.35	30 m
8	0.52-0.9	15 m

Evolution of the vegetation after a large eruption

-Pinatubo: comparison of SPOT data
acquired between
1991 and 1998

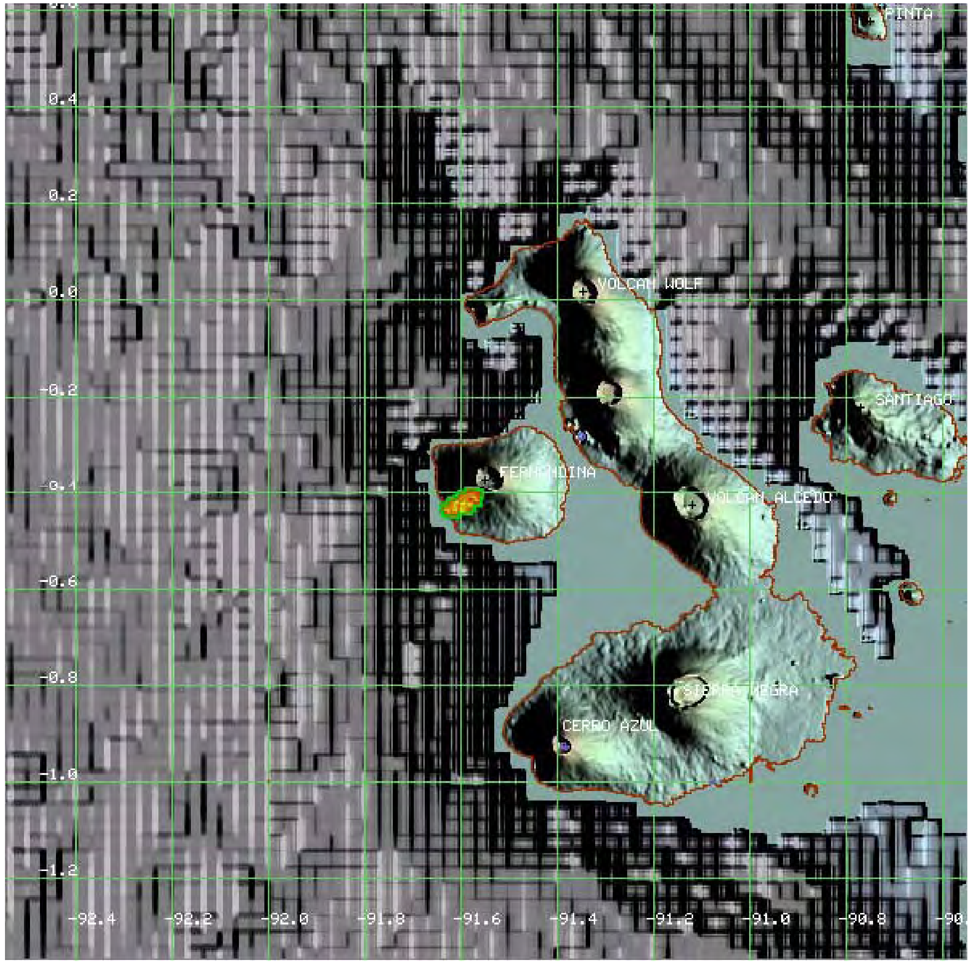
- Red shows vegetation,
the ash deposits
are light blue

- Summit is at lower right



Near real time monitoring of hot spots

http://modis.higp.hawaii.edu/

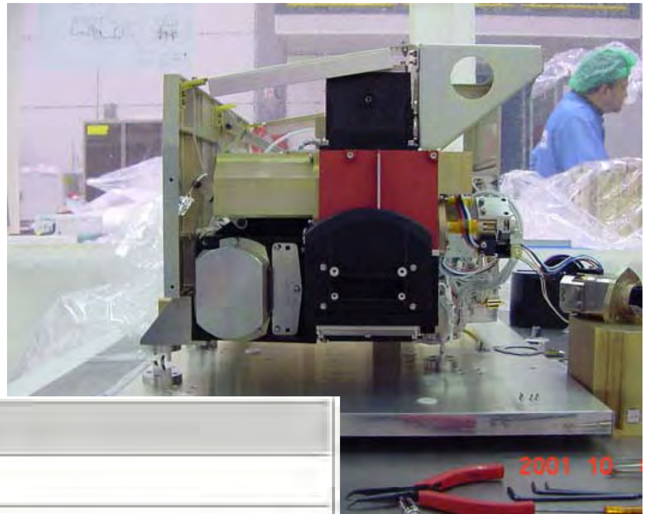


MODIS at Fernandina 11 April 2009 © NASA

Fernandina lava flow on 19 April 2009 © NASA

- 4d: Ultra-violet (plume: sulfur dioxide)

Volcano monitoring in the ultraviolet

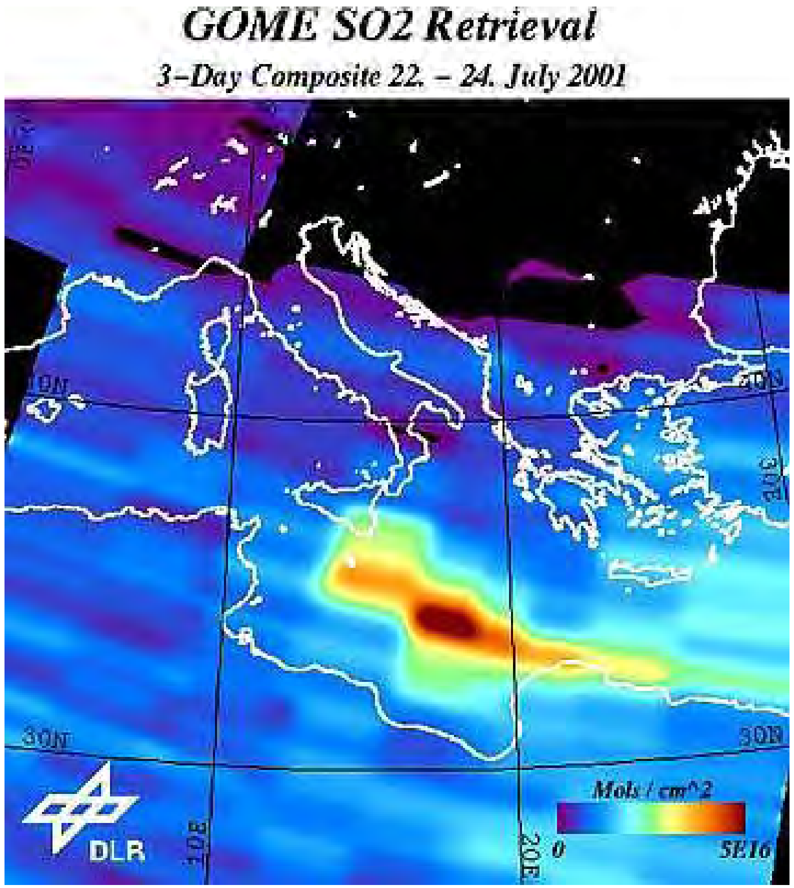


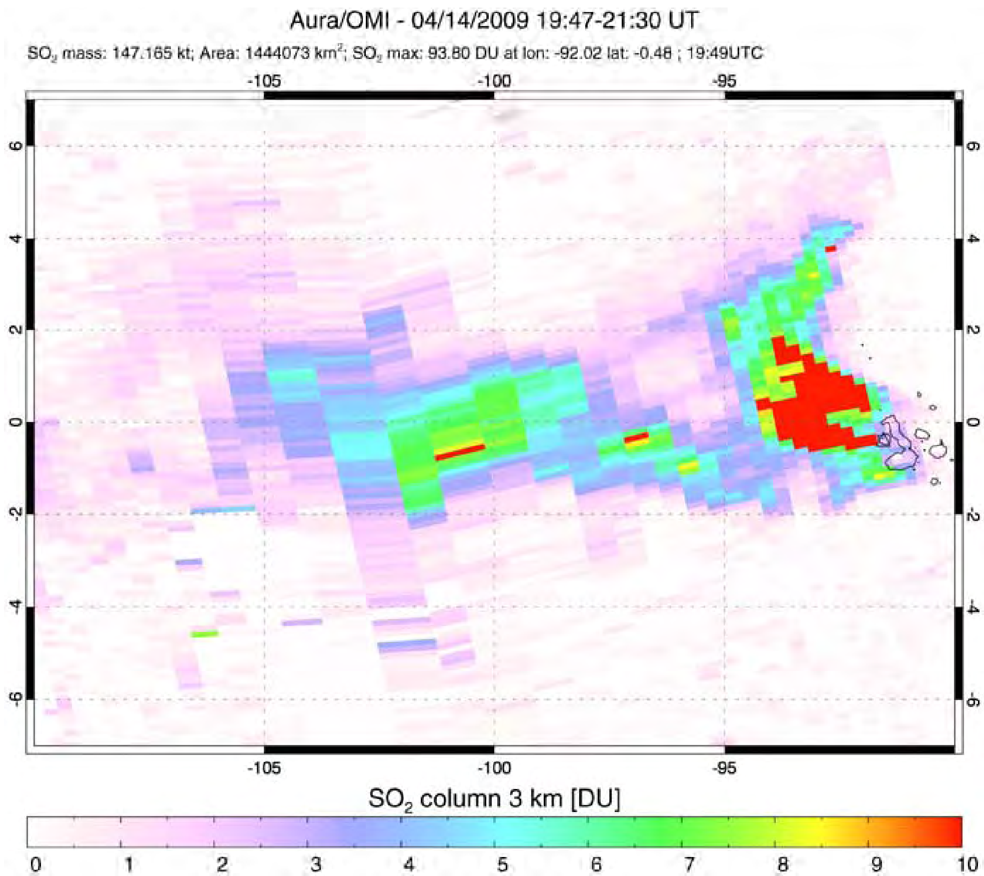
The Ozone Monitoring Instrument on AURA
© NASA

Item	Parameter
Wavelength range:	
Visible:	350 - 500 nm
UV:	UV-1, 270 to 314 nm, UV-2 306 to 380 nm
Spectral resolution:	1.0 - 0.45 nm FWHM
Spectral sampling:	2-3 for FWHM
Telescope FOV:	114Å (2600 km on ground)
IFOV:	3 km, binned to 13 x 24 km
Detector:	CCD: 780 x 576 (spectral x spatial) pixels
Mass:	65 kg
Duty cycle:	60 minutes on daylight side
Power:	66 watts
Data rate:	0.8 Mbps (average)

AURA satellites during its building
© NASA

Monitoring of volcanic plumes

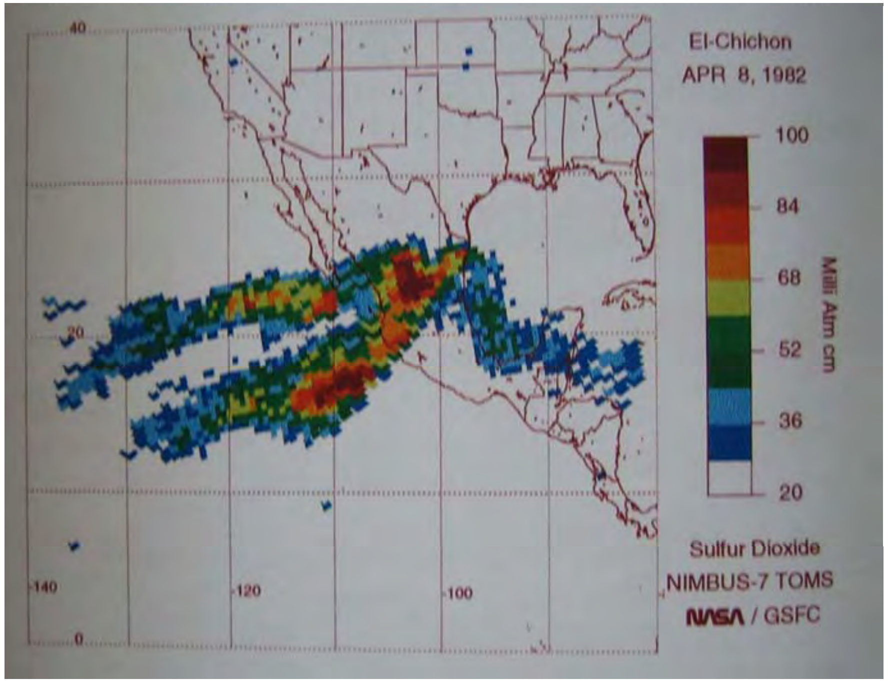




SO_2 at Etna in 2001 measured by GOME on ERS2 © DLR-ESA

SO_2 at Fernandina measured on 14 April 2009 by the OMI (Ozone Monitoring Instrument) on board of AURA © NASA

Large volcanic plumes



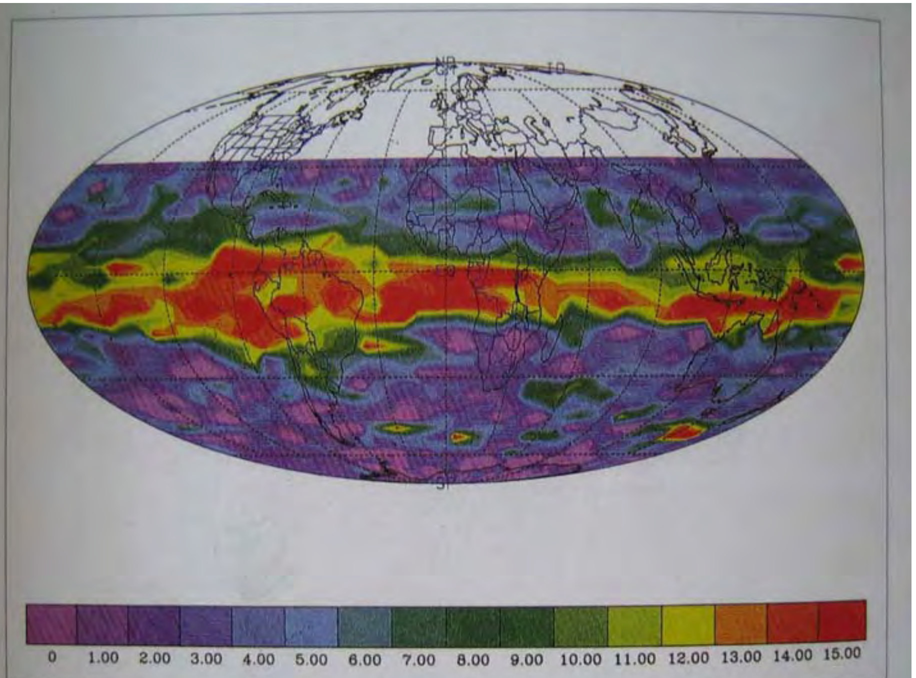


Plate VI Figure 18.10 The global distribution of sulphur dioxide at the 26 km level on September 21, 1991, approximately three months after the Pinatubo eruption (Read *et al.* 1993). The colour bar units are in parts per billion by volume

The two eruptions with stronger impact on the climate in the last 30 years were the 1982 El Chicon (Mexico) and the 1991 Pinatubo (Philippines) eruptions. Both could be accurately observed (SO_2 content) by Ozone Mapping Spectrometers


The end