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)
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 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.
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 Nevado del Ruiz volcano in 1985 © USGS

Near Pinatubo, Philippines, 1991 © USGS
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

Strainmeter

Tiltmeter

Seismicity at the beginning of an eruption at Piton de la Fournaise
© Piton de la Fournaise volcano observatory
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

SOF measurements traversing the plume of Etna, Oct 7, 15:05

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

Stromboli 1986 © P. Briole

Doppler radar at Etna volcano © OPGC Clermont-Ferrand

Lava sampling at Piton de la Fournaise © T. Staudacher
• 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

- L-band radar interferometry
- C-band radar interferometry
- IR spectrometry (Moderate Resolution Image Spectrometer)
- UV spectrometry (Ozone Monitoring Instrument on AURA)
- Visible imagery (LANDSAT)
- 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

Repeat time: 16 to 35 days

L band $\lambda = 23\text{ cm}$
C band $\lambda = 6\text{ cm}$
X band $\lambda = 3\text{ cm}$
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)
• 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

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

### MODIS bands

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

- **NDVI composition**
  - NDVI = Normalized Difference Vegetation Index = \( \frac{\text{NIR} - \text{RAD}}{\text{NIR} + \text{RAD}} \)

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

**MODIS on TERRA – View of Etna on 16 April 2009**

- True (visible) colours
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)
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

<table>
<thead>
<tr>
<th>ETM+ Bands</th>
<th>μm</th>
<th>Resolution</th>
</tr>
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<tbody>
<tr>
<td>Band Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.45-0.515</td>
<td>30 m</td>
</tr>
<tr>
<td>2</td>
<td>0.525-0.605</td>
<td>30 m</td>
</tr>
<tr>
<td>3</td>
<td>0.63-0.69</td>
<td>30 m</td>
</tr>
<tr>
<td>4</td>
<td>0.75-0.90</td>
<td>30 m</td>
</tr>
<tr>
<td>5</td>
<td>1.55-1.75</td>
<td>30 m</td>
</tr>
<tr>
<td>6</td>
<td>10.4-12.5</td>
<td>60 m</td>
</tr>
<tr>
<td>7</td>
<td>2.09-2.35</td>
<td>30 m</td>
</tr>
<tr>
<td>8</td>
<td>0.52-0.9</td>
<td>15 m</td>
</tr>
</tbody>
</table>

Merapi 2006, ASTER © NASA
Evolution of the vegetation after a large eruption

- 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

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

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

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 (SO₂ content) by Ozone Mapping Spectrometers.