Monitoring of Volcanic Activity by the MSG Satellite
Case study: Icelandic eruption

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Outline

- Area of study
- Data Specifications, Atmospheric simulation, Temperature and BRF
- Method
- Results
- Conclusion
Area of study

The volcano erupted, for the first time since 1821, on 20 March and started erupting for a second time on 14/04/2010. The volcano, under the glacier ice, has caused ice melt and subsequent flooding and damage locally.

The eruption of the Eyjafjallajökull glacier in southwest Iceland has led to the closure of airports throughout the UK and Scandinavia, with further disruption in northern Europe expected later today.

Requirement for detection and monitoring of eruptions/ash clouds

Volcanic Ash shows up well in MSG imagery
Geostationary satellites

Allow a continuous surveillance of wide regions of the Earth surface;

Suitable for those remote sensing applications (Ash Volcanic detection) that, besides requiring the monitoring of large spatial scale events, do not need a high observation detail;

The satellite images processing allow studying the temporal evolution of the phenomenon and its environmental impact;

MSG images have been considered for analysing the huge ash cloud generated in the recent eruption of the volcano Eyjafjallajokull;

MSG images are directly acquired to the Centro di Ricerca Progetto S. Marco (CRPSM) of the “Sapienza, University of Rome”
SEVIRI image data

Data in 15-min repeat cycles

Full spatial resolution in 12 spectral channels

SEVIRI data consist of geographical arrays of various sizes of image pixels, each pixel containing 10 data bits, representing the received radiation from the earth and its atmosphere in the following 12 spectral channels:
**MSG BAND**

1. Visible band centred on 0.6μm
2. Visible band centred on 0.8μm
3. Near-infrared band centred on 1.6μm

<table>
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<th>Channel No.</th>
<th>Channel ID</th>
<th>$\nu_c$</th>
<th>A</th>
<th>B</th>
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<tr>
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<td>12</td>
<td>HRV0.7</td>
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</table>

Conversion from Radiances to Brightness Temperatures
### Method

**Pre-processing**

1. **MSG image**
2. **RAD, Ref conversion**
3. **Band selection**
   - Reflectance in B1 (0.6 \( \mu \)m) > 0.5
   - \( BT(\text{IR10.8}) < 290 \) K
   - \(-0.5 \ K < (\text{IR10.8} - \text{IR12.0}) < 1.5 \) K
4. **Cloud mask**

**Ash detection**

1. **Masked image**
2. **DBT1 = BT7 - BT10**
3. **DBT2 = BT9 - BT10**
4. **DBT3 = BT7 - BT9**
5. **Threshold value**
6. **Ash plume map**
Conversion from Counts to Radiances

The relation between the binary pixel value and the physical radiance is fully defined for each spectral band by the relation:

$$R = \text{CAL\_offset} + \text{CAL\_slope} \times \text{Count}$$

R = spectral radiance in $\text{mWm}^{-2}\text{sr}^{-1}(\text{cm}^{-1})^{-1}$
Conversion from Radiances to Brightness Temperatures

The following analytic relation between the equivalent brightness temperatures ($T_b$) and the SEVIRI radiances ($R$) is adopted:

$$T_b = \left[ \frac{C_2 \nu_c}{\log\left( \frac{C_1 \nu_c^3}{R} + 1 \right)} - B \right] / A$$

With:  
\[ C_1 = 1.19104 \times 10^{-5} \text{ mW m}^{-2} \text{ sr}^{-1} (\text{cm}^{-1})^{-4} \]
\[ C_2 = 1.43877 \text{ K} (\text{cm}^{-1})^{-1} \]
\[ \nu_c = \text{central wavenumber of the channel} \]
\[ A, B \text{ coefficients (see next slide)} \]
Surface can reflect different intensities of radiation into different directions, with the intensity varying with changes in both the sun’s location and the view perspective. The function that describes this reflectance characteristic for all sun and view angles is the bidirectional reflectance distribution function (BRDF).

This term relates the reflectance from a target surface to the reflectance that would be observed from a Lambertian surface located at the target:

$$BRF = \frac{\pi \cdot r \cdot d^2}{R_{TOA} \cdot \cos \beta}$$

- $r$ is the reflectance
- $d$ is Earth-Sun distance
- $R_{TOA}$ is radiance at the top of atmosphere
- $\beta$ is the sun zenith angle.
(at 10.8 μm the clouds are characterized by a higher BT value with respect to 12 μm, where a stronger water vapour absorption occurs).
Result of BRF function of 15/04 13:00 and relative cloud mask (red colour).
numerical simulations

A preliminary study based on numerical simulations (to estimate the surface and atmospheric contributions to the total radiance reaching the sensor, in standard and free-cloud atmospheric conditions), was done using PC Modwin (numerical models Modtran).

The figure shows the atmospheric transmittance as function of the wavelength (in μm), in the 8.5-12.2 μm.

The figure highlights that the atmospheric extinction values in the bands 7, 9, and 10 of SEVIRI are quite similar. It means that the BT differences computed in the aforesaid bands are small in absence of a volcanic eruption; therefore strong BT variations can be related to a significant gas-aerosol concentration due to a volcanic eruption.
Ash Detection

Particles and clouds presence can be detected, in appropriate spectral intervals of the thermal infrared region, by measuring the BT variations.

BTD (Brightness Temperature Difference) method was applied to a temporal series of images (April 15, 17 and 19), using bands 7 (8.7 \( \mu \text{m} \), in the \( \text{SO}_2 \) absorption band) 9 and 10 of the sensor SEVIRI (the band 10 is more sensible to the water vapour absorption with respect to the band 9)

Volcanic Ash shows up well in MSG imagery calculating Channel 9 (10.8 \( \mu \text{m} \)) and Channel 10 (12.0\( \mu \text{m} \)) Both channels are IR

Three indices were used for Volcanic Ash detection

\[
\text{BTD1} = \text{BT} (8.7 \text{ mm}) - \text{BT} (12 \text{ mm})
\]
\[
\text{BTD2} = \text{BT} (10.8 \text{ mm}) - \text{BT} (12 \text{ mm})
\]
\[
\text{BTD3} = \text{BT} (8.7 \text{ mm}) - \text{BT} (10.8 \text{ mm})
\]
Yellow-red region (high positive values):
Emission by volcanic SO$_2$ aerosols in a no-thermal equilibrium condition with the surrounding atmosphere (high temperature particles), capable to increase the BT at 8.7 $\mu$m.

Emission by volcanic H$_2$O gas in a thermal equilibrium condition, capable to reduce the BT at 12 $\mu$m.

Less significant: radiation extinction due to volcanic aerosols scattering higher at 12 $\mu$m than at 8.7 $\mu$m.

Dark blue region (low negative values):
Emission by volcanic SO$_2$ aerosols in a thermal equilibrium condition, capable to reduce the BT at 8.7 mm.

Emission by volcanic H$_2$O gas in a no-thermal equilibrium condition, capable to increase the BT at 12 mm.

Less significant: radiation extinction due to volcanic aerosols scattering higher at 8.7 $\mu$m than at 12 $\mu$m.
Yellow-red region (high positive values):
Emission by volcanic H$_2$O gas in a thermal equilibrium condition, capable to reduce the BT at 12 $\mu$m more significantly than at 10.8 $\mu$m. In a standard condition positive values are also obtained but not so high as in this test case.

Less significant: radiation extinction due to volcanic aerosols scattering higher at 12 $\mu$m than at 10.8 $\mu$m.

Dark blue region (low negative values):
Emission by volcanic H$_2$O gas in a no-thermal equilibrium condition, capable to increase the BT at 12 mm more significantly than at 10.8 mm.

Less significant: radiation extinction due to volcanic aerosols scattering higher at 10.8 mm than at 12 mm.
Yellow-red region (high positive values):
Emission by volcanic SO$_2$ aerosols in a non-thermal equilibrium condition, capable to increase the BT at 8.7 $\mu$m.
Less significant: emission by volcanic H$_2$O gas in a thermal equilibrium condition, capable to reduce the BT at 10.8 $\mu$m.
Less significant: radiation extinction due to volcanic aerosols scattering higher at 10.8 mm than at 8.7 mm.

Dark blue region (low negative values):
Emission by volcanic SO2 aerosols in a thermal equilibrium condition, capable to reduce the BT at 8.7 mm.
Less significant: emission by volcanic H2O gas in a no-thermal equilibrium condition, capable to increase the BT at 10.8 mm.
Less significant: radiation extinction due to volcanic aerosols scattering higher at 8.7 $\mu$m than at 10.8 $\mu$m.
temporal evolution of the ash plume on April 15 at 7, 7:30, 12 a.m, 1 p.m; the plume has reached the northern coast of England.

http://www.esa.int/esaCP/SEMKD...
This is a false-colour image from NOAA-17, derived from differencing the two far-infra-red channels, with a colour palette applied to emphasise the volcanic ash/dust.
This methodology can detect the presence of atmospheric particles.

Atmosphere behaviour in standard conditions (absence of volcanic eruptions) has been carried out.

Techniques based on the BTD (Brightness Temperature Difference) measurement have been evaluated to detect volcanic ash.

The shape of volcanic plume at least in accordance with the result presented in the ESA web site:

http://www.esa.int/esaCP/SEMKDU9MT7G_index_0.html
Different choices can be done in order to specialise and optimise the results in accordance with the particular optical behaviour of the particles under study (taking into consideration both the absorption-emission phenomena, depending on the gas-aerosol chemical composition, and the scattering phenomena, depending on the size of the particles).

To better investigate the difference behaviour between clouds and volcanic plume (use atmospheric numerical simulation)

This is a preliminary study....need to be continued and doing more tests

➢ Conclusion 2
Questions?
Comments?

Спасибо!
Thank You!
Paldies!