SO_2 AND ASH VOLCANIC PLUME RETRIEVALS FROM THE 24 NOVEMBER 2006 Mt. ETNA ERUPTION USING MSG-SEVIRI DATA: SO_2 VALIDATION AND ASH CORRECTION PROCEDURE

S. Corradini(1), L. Merucci(1), A. J. Prata(2), C. Spinetti(1), M. Silvestri(1), M. Musacchio(1), M. Burton(1), T. Caltabiano(1), M. F. Buongiorno(1)

(1) Istituto Nazionale di Geofisica e Vulcanologia, Italy
(2) Norwegian Institute for Air Research, Norway

Istituto Nazionale di Geofisica e Vulcanologia

Estimation of the daily trend of sulfur dioxide and ash from the thermal infrared measurements of the Spin Enhanced Visible and Infrared Imager (SEVIRI), on board the Meteosat Second Generation (MSG) geosynchronous satellite, has been carried out. The SO_2 retrieval is validated vicariously by using satellite sensors and with ground measurements. The 24 November 2006 tropospheric eruption of Etna volcano is used as a test case. MSG-SEVIRI is an optical imaging radiometer characterized by 12 spectral channels, a high temporal resolution (one image every 15 minutes), and a 10 km^2 footprint. The instrument's spectral range includes the 7.3 and 8.7 μm bands (channels 6 and 7) used for SO_2 retrieval and the 10.8 and 12.0 μm (channels 9 and 10) split window bands used for ash detection and retrievals. The SO_2 columnar abundance and ash are retrieved simultaneously by means of a Look-Up Table least squares fit procedure for SO_2 and using a Brightness Temperature Difference algorithm for ash. The SO_2 retrievals obtained using different satellite sensors such as AIRS and MODIS have been carried out and compared with SEVIRI estimations. The results were validated using the permanent mini-DOAS ground system network (FLAME) installed and operated by INGV on Mt. Etna. Results show that the simultaneous presence of SO_2 and ash in a volcanic plume yields a significant error in the SO_2 columnar abundance retrieval in multispectral Thermal Infrared (TIR) data. The ash plume particles with high effective radius (from 1 to 10 μm) reduce the top of atmosphere radiance in the entire TIR spectral range, including the channels used for the SO_2 retrieval. The net effect is a significant SO_2 overestimation. To take this effect into account a novel ash correction procedure is presented and applied to the retrieval.

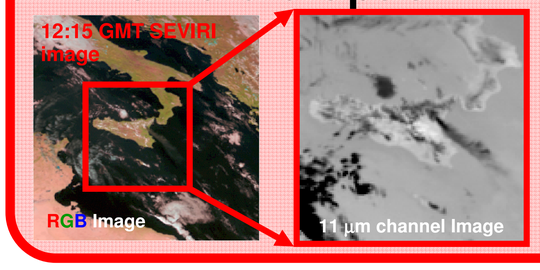
Spinning Enhanced Visible and InfraRed Imager (SEVIRI)

The most important sensor on board MSG satellite is SEVIRI. This sensor is a 50 cm diameter aperture, line-by line scanning radiometer, which provides image data from VNIR to TIR.

Its main peculiarity is the **repeat cycle of 15 minutes**. SEVIRI characteristics allow to obtain close time-spaced maps, useful in the study of temporal fluctuations of different atmospheric parameters over a specific area.

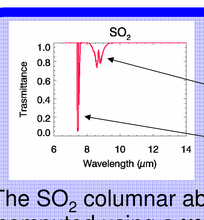
	Channel No	Central Wavelength (μm)	Spatial Resolution (km)
	1	0.6	3
	2	0.8	3
	3	1.6	3
	4	3.9	3
	5	6.2	3
SO_2	6	7.3	3
SO_2	7	8.7	3
	8	9.7	3
Ash	9	10.8	3
Ash	10	12	3
	11	13.4	3
	12	0.8	1

Test Case: 24/11/2006 Mt. Etna eruption



Mt. Etna is located in the eastern part of Sicily (Italy) and is one of the major degassing volcanoes in the world. From September to December 2006 many eruption episodes occurred. **The 24 November 2006 eruption** started at about 03:00 GMT and ended at about 17:00 GMT; it took place at the SE crater located in the southern flank of Mt. Etna. The wind was blowing from the N-NW direction creating **major problems** for the "Fontanarossa" International Airport of Catania which was subsequently closed to air traffic.

SO_2 and Ash retrievals



The SO_2 columnar abundance is computed using a χ^2 procedure [*Realmuto et al., 1994*]:

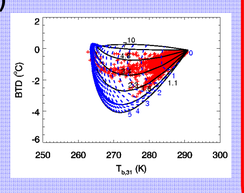
$$\chi^2_{cs} = \sum_{i=1}^{n} \left[\frac{R_{s,i} - R_{m,i}(c_s, 0, 0)}{R_{s,i}} \right]^2 w_i$$

Sensor radiance **Simulated radiance**

The ash detection is based on Brightness Temperature Difference algorithm applied on **11** and **12 μm** channels [*Prata, 1989*].

BTD= T_b(11μm)-T_b(12μm)
BTD < 0 volcanic ash
BTD > 0 meteo clouds

The retrieval is based on computing the simulated inverted arches curves "BTD-T_b(11μm)" varying the AOT and the particles effective radius [*Wen and Rose, 1994*]



The **TOA simulated Radiances (R_m)**, needed for SO_2 and Ash retrievals, have been computed using MODTRAN 4 RTM

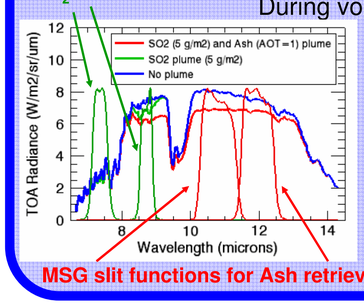
$$R_{m,i}(c_s, AOT, R_{eff})$$

- **21 values of c_s (0 to10 g/m^2, step 0.5 g/m^2)**
- **11 values of AOT (0 to 5, step 0.5)**
- **8 values of R_{eff} (0.4 to 10 μm, constant step in a logarithmic scale)**

Ash correction procedure for SO_2 retrieval

Why the ash correction?

During volcanic eruptions, SO_2 and ash are emitted simultaneously. The plume ash particles reduce the top of atmosphere radiance in the entire TIR spectral range. The net effect is a significant SO_2 overestimation in particular when the 8.7 μm channel is used for the retrieval.

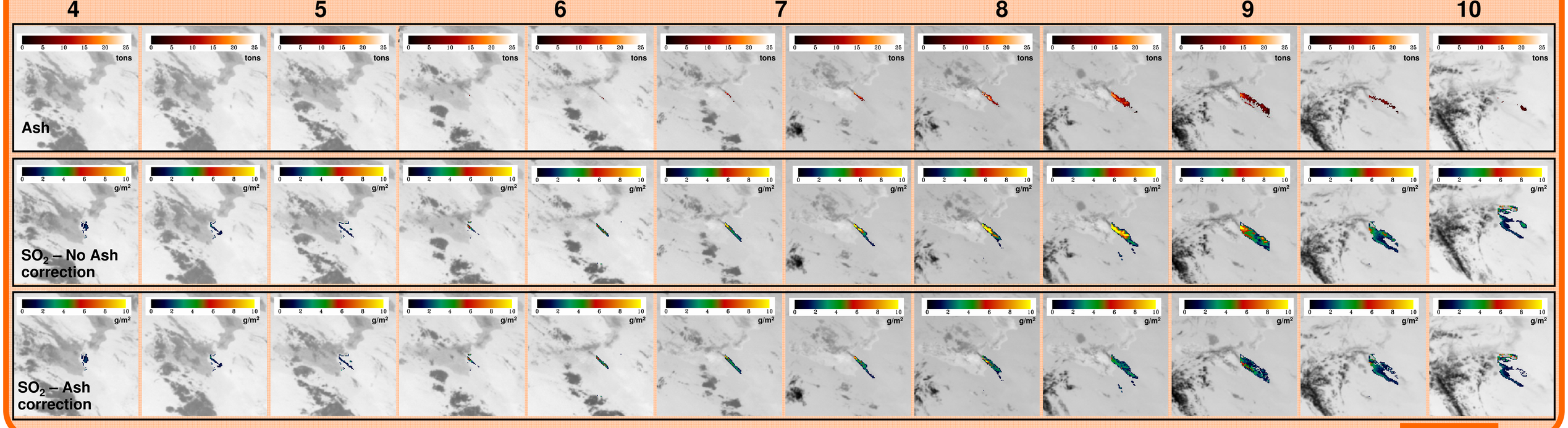


Procedure

For each image pixel, containing both SO_2 and Ash, the least square fit procedure is applied with a simulated radiance interpolated using the AOT and the effective radius of the pixel itself.

$$\chi^2_{cs} = \sum_{i=1}^{n} \left[\frac{R_{s,i} - R_{m,i}(c_s, AOT_k, R_{eff,k})}{R_{s,i}} \right]^2 w_i$$

MSG-SEVIRI SO_2 and Ash Retrievals



Instrument used for SEVIRI SO_2 validation

Ground Instruments

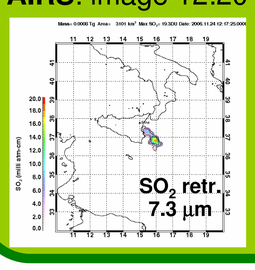
FLAME network of scanning DOAS instruments

The Etna FLAME network was deployed in 2003 and consists of 5 scanning ultraviolet spectrometers used to automatically measure the flux of SO_2 emitted from Mt. Etna. Each station consists of an Ocean Optics S2000 spectrometer, a scanning mirror and a PC. Data are collected and analysed in real-time, with results sent via GSM modem to the observatory.

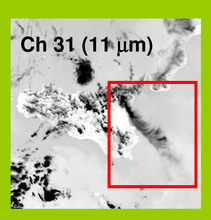
The spectrometer measures between 295 and 380nm, with a resolution of 1.1nm. Data analysis is performed using a custom-built DOAS-style retrieval with artificial clear-sky background spectrum.

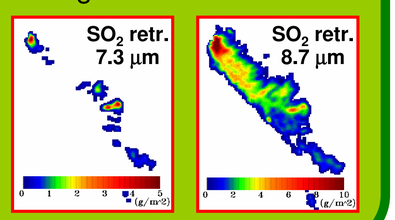
Satellite Instrument

AIRS: image 12:20 GMT



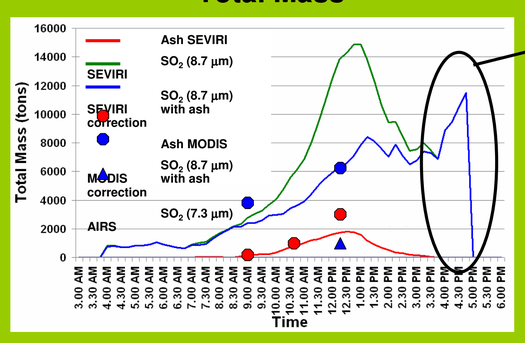
MODIS: image 12:20 GMT





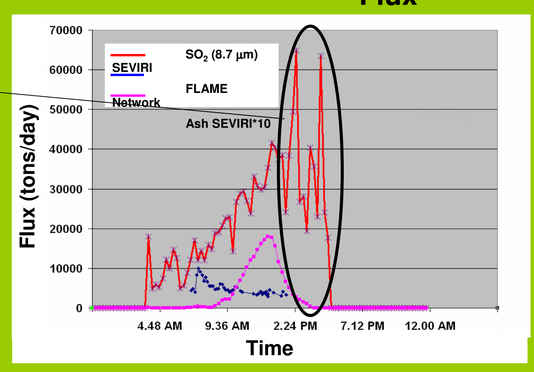
SO_2 retrieval validation

Total Mass



Due to clouds presence (see SO_2 retrieval pictures at 15 pm)

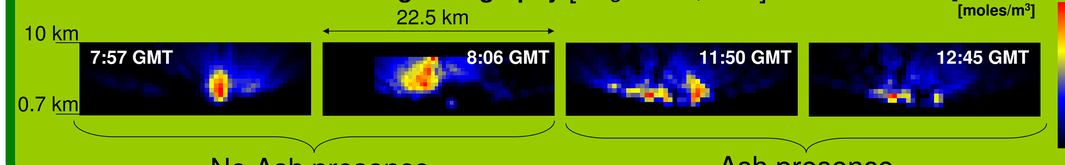
Flux



- The SEVIRI SO_2 flux retrieval is significantly greater than the SO_2 flux retrieved by FLAME: a possible cause is the absorption of the plume water vapor particles not considred in the simulations

- The FLAME network shows a meaningful SO_2 underestimation in concomitance with ash emission

UV scanning tomography [*Wright et al., 2008*]:



Gas above 3 km appears to be poorly represented, suggesting that attenuation of UV radiation by ash is inhibiting ground detection of SO_2

CONCLUSIONS

- Results show the importance of the ash correction on SEVIRI SO_2 retrieval at 8.7 μm; the total mass corrected by the ash influence, can be less than half the values retrieved without the correction.
- The MODIS SO_2 and ash retrievals are in good agreement with the SEVIRI estimations.
- The AIRS SO_2 retrieval is significantly underestimated. The main reason is due to the use of the 7.3 μm SO_2 absorption feature: in case of tropospheric eruptions (our case), the 7.3 μm band is severely affected by atmospheric water vapor absorption.
- The FLAME network SO_2 flux is significantly lower than the flux retrieved by SEVIRI. The lowest values occur in concomitance with ash emission.
- The plume vertical cross section reconstructed by means of Flame network data tomography, suggest that UV radiation is attenuated by ash, thus inhibiting the ground detection of SO_2.
- A possible cause of a SEVIRI SO_2 overestimation is the presence of water vapor particles in the volcanic plume, that was not modeled in the atmospheric correction simulations.

References

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