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MODIS volcanic ash retrievals *vs* FALL3D transport model: a quantitative comparison

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Abstract **Satellite retrievals and transport models represents the key tools to monitor the volcanic clouds evolution. Because of the harming effects of fine ash particles on aircrafts, the real-time tracking and forecasting of volcanic clouds is key for aviation safety. Together with the security reasons also the economical consequences of a disruption of airports must be taken into account. The airport closures due to the recent Icelandic Eyjafjöll eruption caused millions of passengers to be stranded not only in Europe, but across the world. IATA (the International Air Transport Association) estimates that the worldwide airline industry has lost a total of about 2.5 billion of Euro during the disruption. Both security and economical issues require reliable and robust ash cloud retrievals and trajectory forecasting. The intercomparison between remote sensing and modeling is required to assure precise and reliable volcanic ash products. In this work we perform a quantitative comparison between Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals of volcanic ash cloud mass and Aerosol Optical Depth (AOD) with the FALL3D ash dispersal model. MODIS, aboard the NASA-Terra and NASA-Aqua polar satellites, is a multispectral instrument with 36 spectral bands operating in the VIS-TIR spectral range and spatial resolution varying between 250 and 1000 m at nadir. The MODIS channels centered around 11 and 12 μm have been used for the ash retrievals through the Brightness Temperature Difference algorithm and MODTRAN simulations. FALL3D is a 3-D time-dependent Eulerian model for the transport and deposition of volcanic particles that outputs, among other variables, cloud column mass and AOD. Three MODIS images collected the October 28, 29 and 30 on Mt. Etna volcano during the 2002 eruption have been considered as test cases. The results show a general good agreement between the retrieved and the modeled volcanic clouds in the first 300 km from the vents. Even if the modeled volcanic cloud area is systematically wider than the retrieved area, the ash total mass is comparable and varies between 35 and 60 kt and between 20 and 42 kt for FALL3D and MODIS respectively. The mean AOD values are in good agreement and approximately equal to 0.8. When the whole volcanic clouds are considered the ash areas and the total ash masses, computed by FALL3D model are significantly greater than the same parameters retrieved from the MODIS data, while the mean AOD values remain in a very good agreement and equal to about 0.6. The volcanic cloud direction in its distal part is not coincident for the 29 and 30 October 2002 images due to the difference between the real and the modeled local wind fields. Finally the MODIS maps show regions of high mass and AOD due to volcanic puffs not modeled by FALL3D.**

THE Mt. ETNA 2002 ERUPTION

Mt. Etna [37.73°N, 15.00°E], a massive stratovolcano (3330 m a.s.l.) located in the eastern part of Sicily (Italy), is one the major degassing volcanoes in the world. Etna's general quiescent state is periodically interrupted by eruptive crises during which significant emissions of gases and ash occur. Ash fallout periodically reaches the surrounding areas affecting the local population and disrupting the nearby Catania, Sigonella, and Reggio Calabria airports.

The Mt. Etna 2002 eruption began on the evening of 26 October with a swarm of earthquakes recorded by the Italian National Institute of Geophysics and Volcanology (INGV). The seismic swarm preceded and accompanied explosive activity in the NE and S volcano flanks and strombolian activity in the summital area. The explosive activity increased during the following days reaching a paroxysm during 28-31 October, with a fairly sustained eruptive column that rose up to 7 km a.s.l. Ash fallout caused many problems to the surrounding population and infrastructures, including the closure of the Catania Fontanarossa (27 October) and the Reggio Calabria (31 October) airports. Prevailing winds directed the ash cloud towards the African coast, causing a light fallout in Libya (700 km from Mt. Etna) during the subsequent days.

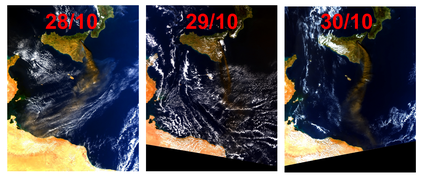
In this work the **28, 29 and 30 October 2002** images collected at 12:15, 9:45 and 12:05 UTC respectively by MODIS-Aqua (28 and 30 October) and MODIS-Terra (29 October), have been considered as test cases.

MODIS

Moderate Resolution Imaging Spectroradiometer
(http://modis.gsfc.nasa.gov/)

Aboard the **Terra** and **Aqua** polar orbit satellites
36 bands from VIS to TIR
Repetition cicle: 1/2 days
TIR Spatial resolution : 1 km

The TIR channels 31 and 32, centered around 11 and 12 μm respectively, have been used for the ash mass and AOD at 0.55 μm retrievals by means the **BTD procedure** [*Prata, 1989, Wen and Rose, 1994*] and **MODTRAN simulations** [*Corradini et al., 2008, 2009*].



The volcanic dust optical properties with log-normal size distribution and particle density equal to 2500 kg/m^3 have been considered.

FALL 3D

3-D time-dependent Eulerian model for the transport and deposition of volcanic particles [*Costa et al., 2006; Folch et al., 2009*].

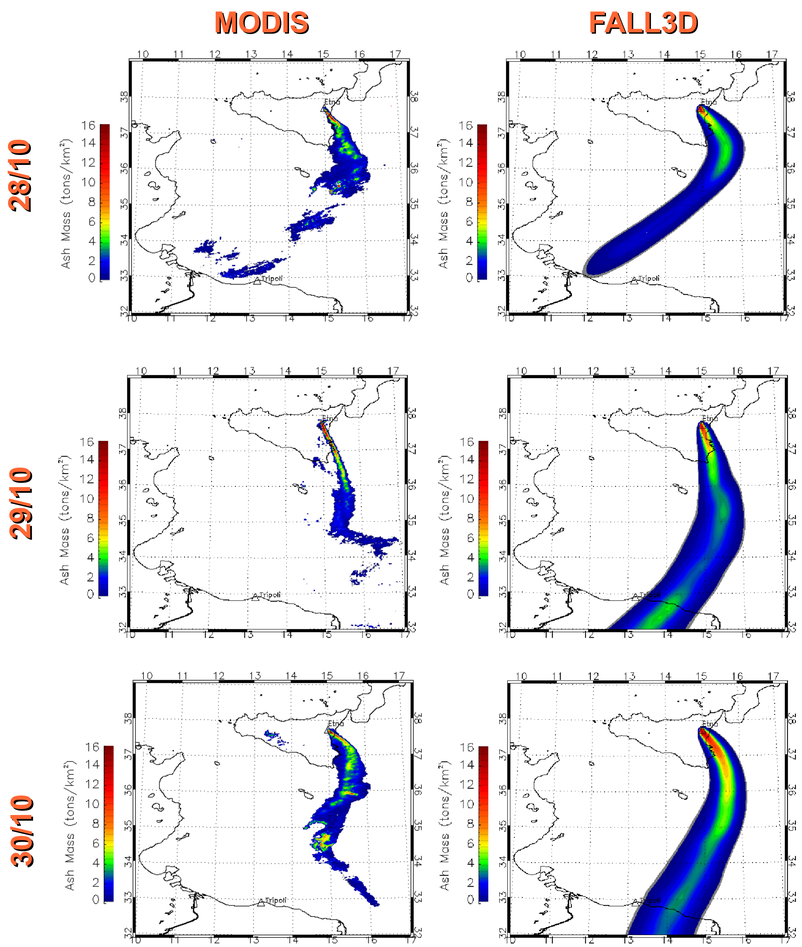
The model solves an Advection-Diffusion-Sedimentation (ADS) equation for each particle class, characterized by its diameter, density and shape factor. The main volcanological inputs are the plume Column Height, the Mass Eruption Rate (MER) and the Total Grain Size Distribution (TGSD).

Event	Time Interval [h after 00UTC]	Column Height [m a.v.]	Averaged MER [kg/s]
28 Oct 2002	00:00-06:00	3750	1.6×10^5
	06:00-12:00	4000	2.2×10^5
	12:00-18:00	4250	3×10^5
	18:00-24:00	4000	3×10^5
29 Oct 2002	00:00-06:00	3500	2×10^5
	06:00-12:00	3000	1.5×10^5
	12:00-18:00	3250	2×10^5
	18:00-24:00	3500	2×10^5
30 Oct 2002	00:00-06:00	3750	2.1×10^5
	06:00-12:00	4000	2.3×10^5

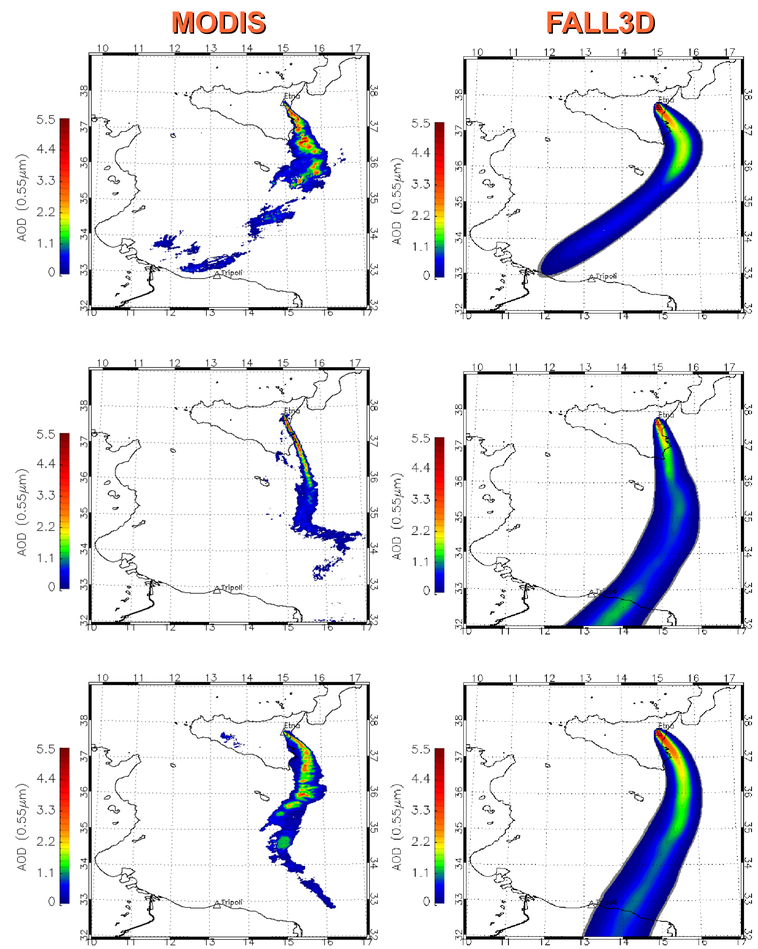
The MER and plume column height derive from Andronico et al., [*2008*]. In order to obtain the meteorological variables, we coupled FALL3D with the WRF model [*Folch et al., 2009*].

For consistency with the MODIS satellite retrievals, the same ash optical properties have been considered and only the particles between 1 and 10 μm have been modeled.

Ash Mass



Ash Optical Depth (0.55 μm)



Date	MODIS Area [km^2]	MODIS T_M [kt]	MODIS $\overline{AOD}$	FALL3D Area [km^2]	FALL3D T_M [kt]	FALL3D $\overline{AOD}$	% cloud overlap AOD $\geq$ 0.1	% cloud overlap AOD $\geq$ 1
28 Oct 2002	26700	63.0 ± 25.2	0.62 ± 0.19	43700	90.0	0.62	55	66
	15600	41.9 ± 16.8	0.80 ± 0.24	19300	61.0	0.97	82	70
29 Oct 2002	13700	30.3 ± 12.1	0.57 ± 0.17	61400	106.9	0.53	74	23
	5300	19.4 ± 7.8	0.91 ± 0.27	15100	33.8	0.67	95	23
30 Oct 2002	24300	59.5 ± 23.8	0.59 ± 0.18	62900	125.8	0.61	82	62
	13100	36.9 ± 14.8	0.78 ± 0.23	16900	51.8	0.93	95	64

Table: **The red boxes indicate, for each image, the values obtained considering the first 300 km from the vents**

Conclusions

First 300 km from the vents:

the retrieved and modeled ash clouds are essentially collocated;
the MODIS retrieval highlight regions of high AOD and total ash mass not captured by FALL3D;
the total ash mass varies between 20 and 45 kt and between 35 and 60 kt for MODIS and FALL3D respectively;
the mean AOD is in good agreement and equal to about 0.8

Whole image

as expected the FALL3D modeled masses are significantly greater than those retrieved from MODIS data (in the plume distal part the ash signal is too low to be detected by MODIS);
the mean AOD remain in good agreement and equal to about 0.6;
the directions of the retrieved and modeled clouds in their distal parts are not coincident. This is probably due to the difference between the real and the modeled local wind fields.

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