Detecting Volcanic Ash Plume Components from Space using Machine Learning Techniques

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Abstract

During an explosive eruption, large volumes of ash and gases are ejected into the atmosphere, forming a volcanic plume which is transported by the wind. The dispersion of volcanic ash in atmosphere represents a threat for aviation safety, whereas the tephra fallout, together with gas emission, may strongly affect population health and damage to environment and infrastructure as well. Volcanic monitoring from space offers now a powerful tool to quantify hazards on both population and air traffic and gain insight into processes and mechanism of violent explosive eruptions. Here we propose a machine learning (ML) algorithm that exploits the Thermal Infrared (TIR) bands of the images acquired by the sensor Spinning Enhanced Visible and InfraRed Imager (SEVIRI), on board Meteosat Second Generation (MSG) geostationary satellite, to identify the components of ash and SO2 gas in a volcanic plume. The detection and assessment of volcanic ash clouds has been performed applying the brightness temperature difference (BTD) approach, between bands at 10.8 µm and 12.0 µm, which highlights the presence of thin volcanic ash, while the algorithm for the SO2 retrieval is based on the contributions given by the bands at 10.8 µm and 8.7 µm. Combining the latter two bands with the 10.8 µm band in the RGB channels, it is possible to create an Ash RGB image, used both day and night for the detection and monitoring of volcanic ash and sulphur dioxide gas. The advantage of the machine learning algorithm is to detect and extract automatically these features from an Ash RGB image. As test cases, we considered the sequence of explosive eruptions occurred at Etna volcano (Italy) in early 2021, which produced very long and high plume columns. Thanks to the high temporal resolution of SEVIRI (one image every 15 minutes), it was possible to visualize and to follow the plumes, from their formation to their complete dispersion in the atmosphere. The comparison of our ML algorithm with the consolidated procedure based on a RGB channels combination in the visible (VIS) spectral range showed a good agreement.

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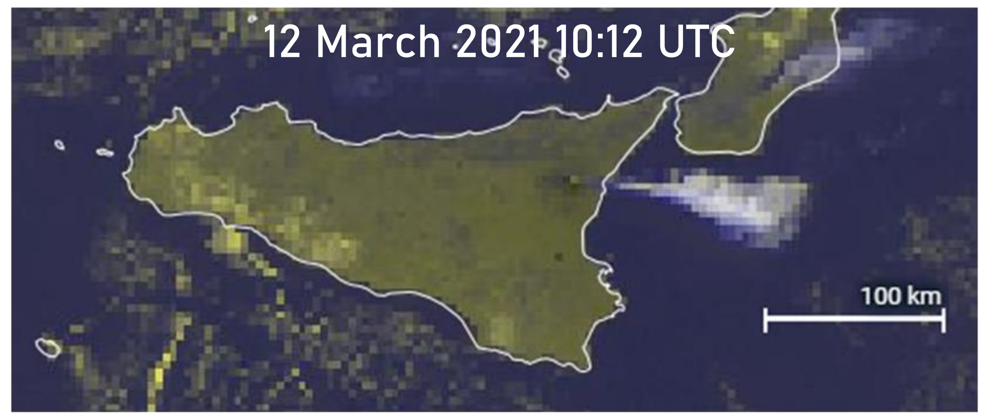
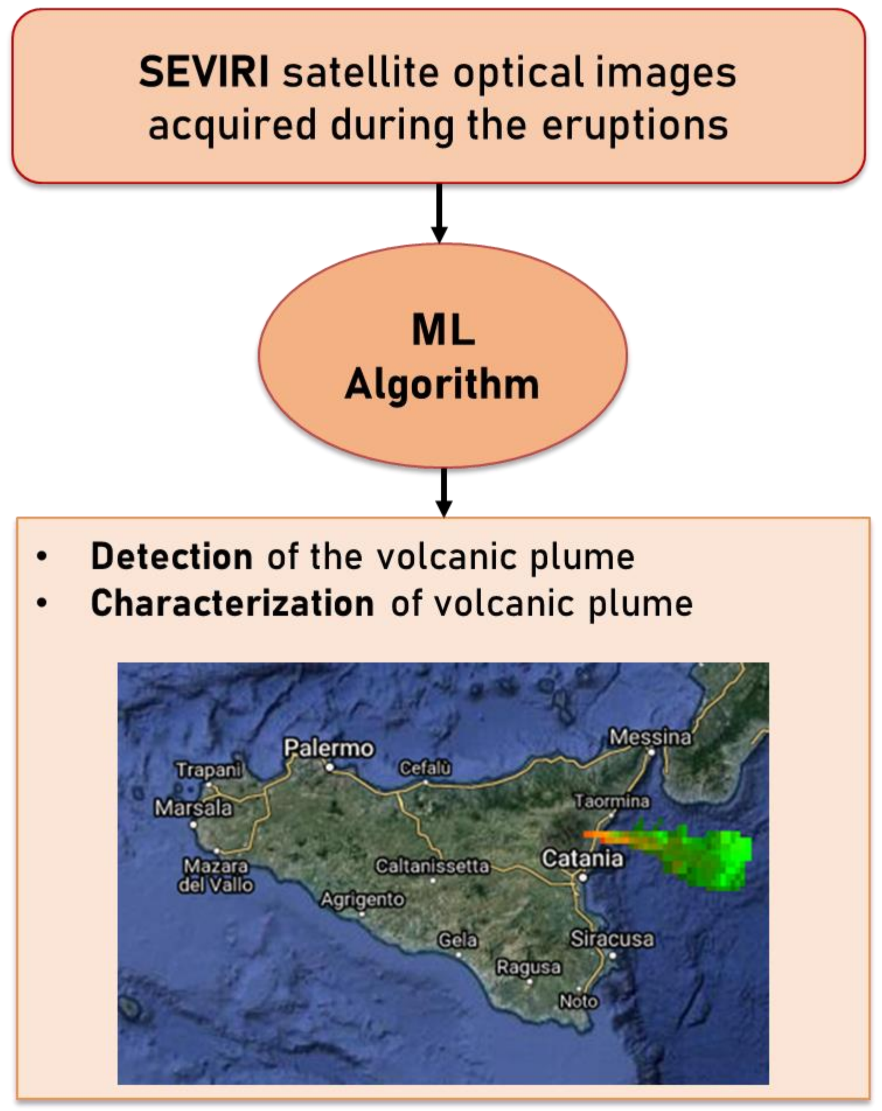
INTRODUCTION

During an explosive eruption, large volumes of ash and gases are ejected into the atmosphere, forming a **volcanic plume** which is transported by the wind. The dispersion of volcanic ash in atmosphere represents a threat for aviation safety, whereas the tephra fallout, together with gas emission, may strongly affect population health and damage to environment and infrastructure as well. Volcanic monitoring from space offers now a powerful tool to quantify hazards on both population and air traffic and gain insight into processes and mechanism of violent explosive eruptions.

Here we propose a **machine learning (ML)** algorithm which exploit the **Thermal Infrared (TIR) bands** of the images acquired by the sensor **Spinning Enhanced Visible and InfraRed Imager (SEVIRI)**, on board Meteosat Second Generation (MSG) geostationary satellite, to identify a volcanic plume and to retrieve its content of ash and SO_2.



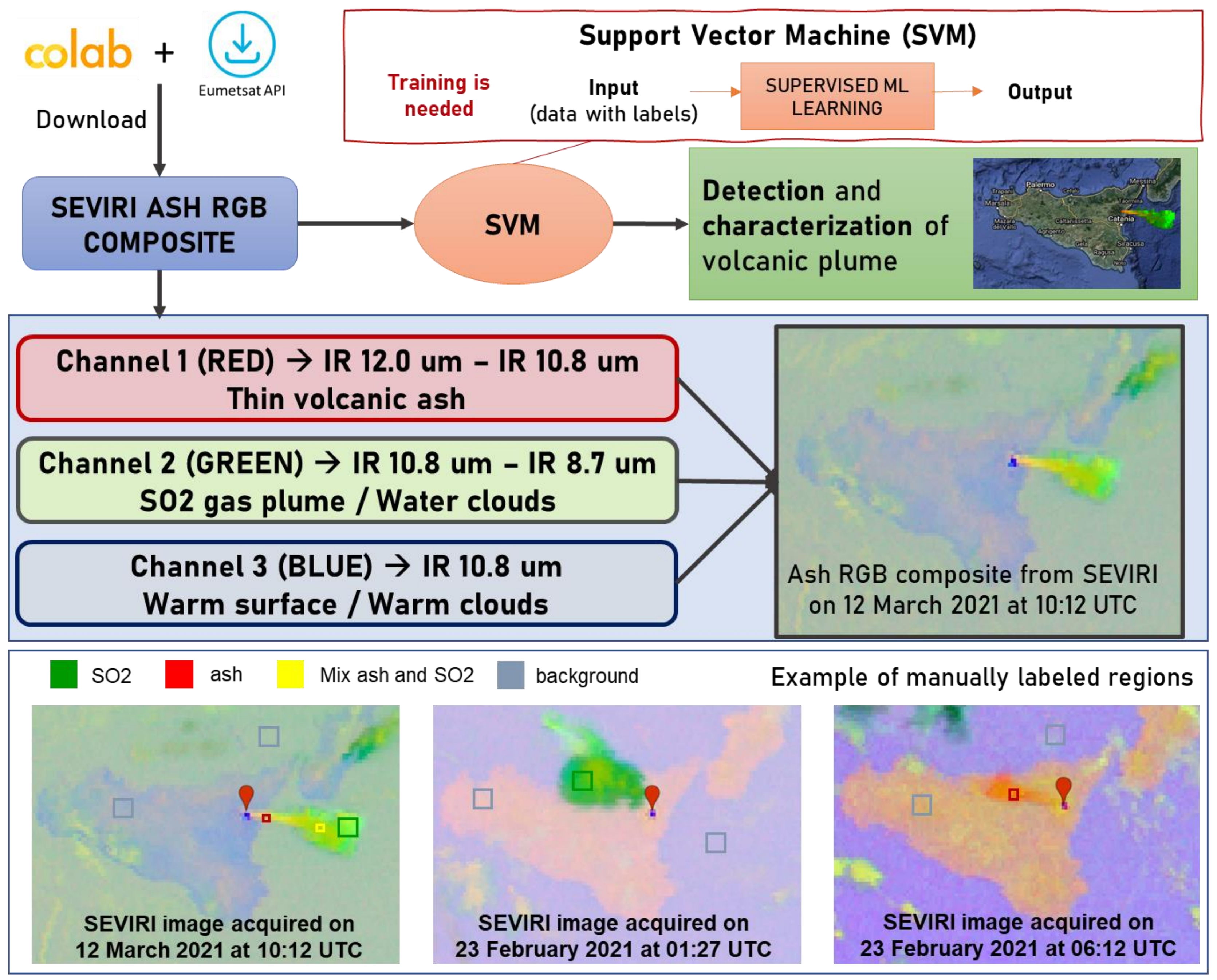
Visible ash cloud appearance in SEVIRI HRV RGB



MATERIALS & METHOD

The **detection of a volcanic plume** is performed exploiting the **TIR bands** of SEVIRI images: **IR 8.7 um, 10.8 um, 12.0 um**. The brightness temperature difference (BTD) between bands at 10.8 µm and at 12.0 µm highlights the presence of thin volcanic ash, whereas the difference between bands at 10.8 µm and 8.7 µm emphasizes the presence of SO2. Combining the latter two bands with the 10.8 µm band in the RGB channels, it is possible to create an **Ash RGB image**, used both day and night for the detection and monitoring of volcanic ash and sulphur dioxide gas.

A **Machine Learning (ML) algorithm** which exploits the TIR bands of SEVIRI images was developed to identify a volcanic plume and to retrieve its content of ash and SO2. This algorithm exploits some manually labeled image regions from four SEVIRI images of reference (19 February 2021 at 10:12 UTC, 23 February 2021 at 01:27 UTC and at 06:12 UTC, 12 March 2021 10:12 UTC), in order to train the classifier. This trained classifier is able to distinguish the plume from the background and to discriminate the three main components of the plume: pure ash, pure SO2 and the mixture of the two.

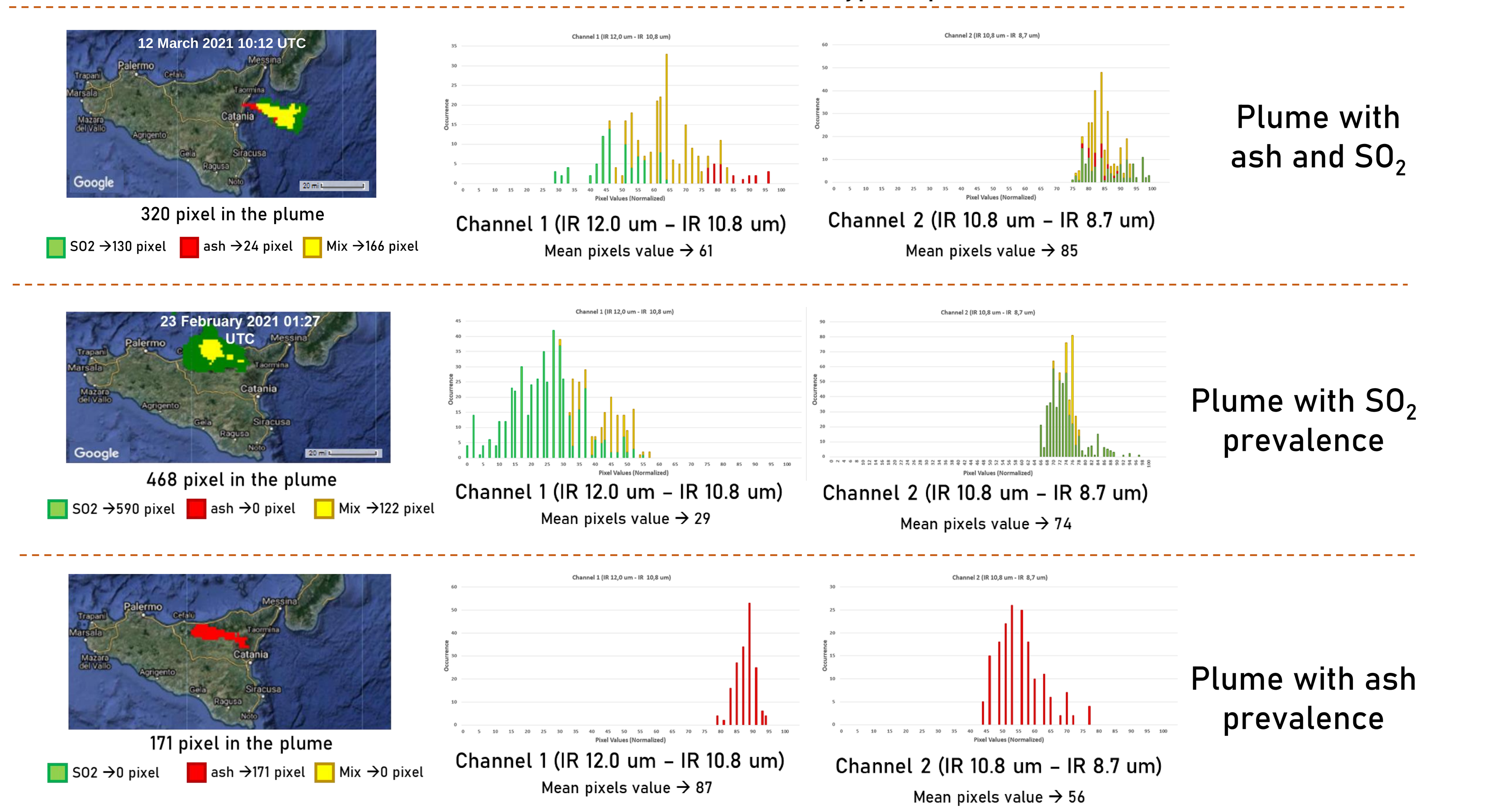


RESULTS

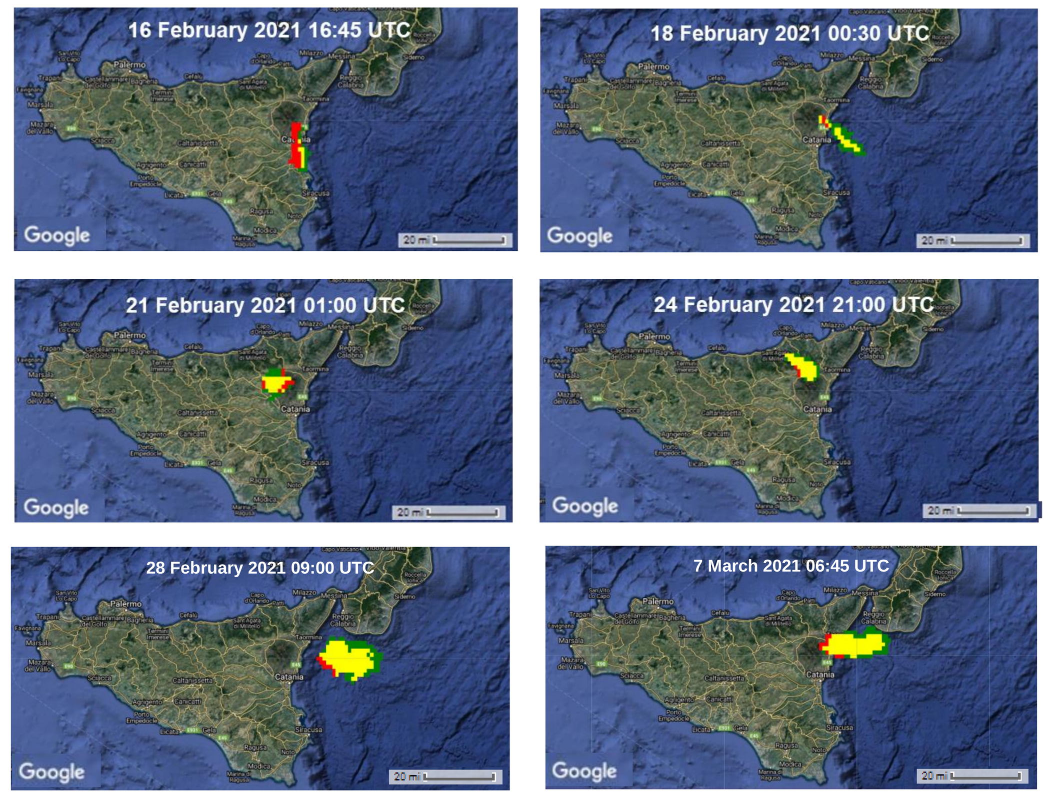
After the training phase, the classifier is ready to be applied to new images. Some study cases occurred on February-March 2021 are considered as testing phase (thus no training is performed), in particular the eruptive events of 16, 18, 21, 24, 28 February 2021 and of 7 March 2021. The discriminations of the components has led to satisfying results.

Once the ML algorithm is applied, the detected plume region is used to calculate the number of pixel inside the plume and the areal extent, related also to each component of the plume. Moreover, a statistical analysis was conducted to establish if a plume is ash-rich, SO_2-rich or characterized by both ash and SO_2. Taking into account the SEVIRI Channel 1 (BTD 12.0 – 10.8 µm) and SEVIRI Channel 2 (10.8 – 8.7 µm), it is calculated how many times a certain value of pixel is repeated inside the same channel, in order to construct two histograms, one for the Channel 1 and one for the Channel 2. Before performing this calculation, the values of both channels are normalized between 0 and 100, in order to be comparable.

Statistics to establish the type of plume

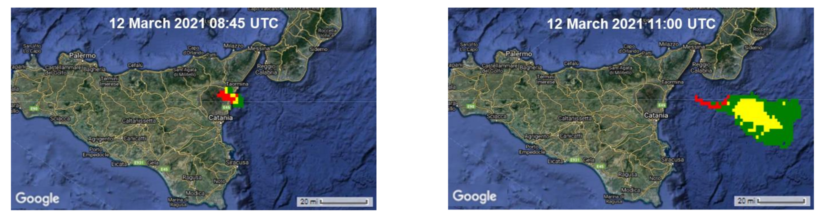


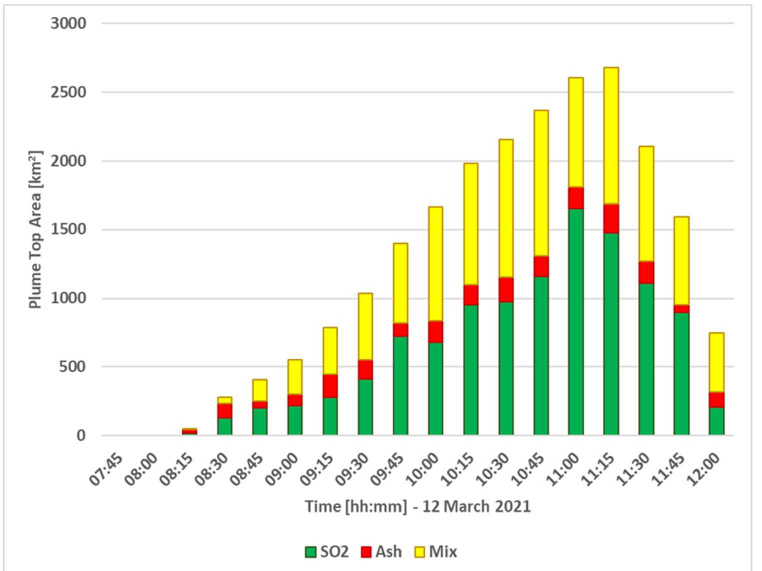
TESTING IMAGES



Tracking

Thanks to the high temporal resolution of SEVIRI, which provides a new earth image every maximum 15 minutes, it was possible to visualize and to follow the volcanic cloud dispersion in the atmosphere during the eruptive episode. An example is reported in the figures beside, which represent the detection and characterization of the plume on 12 March 2021 at 08:45 and 11:00 and an histogram of the plume top area during 12 March 2021 from 07:45 to 12:00. The plume is visible by SEVIRI at 08:15; its area increases until 11:15 and then starts decreasing and dispersing in the atmosphere.





CONCLUSIONS

- A **machine learning (ML) algorithm** which exploits the **TIR bands** of the images acquired by the sensor **SEVIRI**, on board Meteosat Second Generation (MSG) geostationary satellite, was developed. Sample regions are chosen and labeled in order to train a classifier, which is able **to detect a volcanic plume and to identify its components of ash and SO_2 gas.**
- The advantage of the machine learning algorithm is **to detect and extract automatically** these features from an Ash RGB image.
- The classifier was tested to new images not considered during the training phase and resulted well suitable for the detection and the characterization of different volcanic plumes erupted by Mt. Etna
- Thanks to the **high temporal resolution of SEVIRI**, which provides a new earth image every maximum 15 minutes, it was possible to visualize and to follow a volcanic plume, from its formation to its complete dispersion in the atmosphere.

References:

Gouhier M, DeslandeGouhier M, Deslandes M, Guéhenneux Y, Hereil P, Cacault P, Josse B. Operational Response to Volcanic Ash Risks Using HOTVOLC Satellite-Based System and MOCAGE-Accident Model at the Toulouse VAAC. *Atmosphere*. 2020; 11(8):864. https://doi.org/10.3390/atmos11080864s M, Guéhenneux Y, Hereil P, Cacault P, Josse B. Operational Response to Volcanic Ash Risks Using HOTVOLC Satellite-Based System and MOCAGE-Accident Model at the Toulouse VAAC. *Atmosphere*. 2020; 11(8):864. https://doi.org/10.3390/atmos11080864

Lorenzo Guerrieri, Luca Merucci, Stefano Corradini, Sergio Pugnaghi, Evolution of the 2011 Mt. Etna ash and SO2 lava fountain episodes using SEVIRI data and VPR retrieval approach, Journal of Volcanology and Geothermal Research, Volume 291, 2015, Pages 63-71, ISSN 0377-0273

Corradino C, Ganci G, Cappello A, Bilotta G, Hérault A, Del Negro C. Mapping Recent Lava Flows at Mount Etna Using Multispectral Sentinel-2 Images and Machine Learning Techniques. Remote Sensing. 2019; 11(16):1916. https://doi.org/10.3390/rs11161916

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