Combined Use of Satellite Data and Machine Learning for Detecting, Measuring, and Monitoring Active Lava Flows at Etna Volcano

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Abstract

Despite significant advances in monitoring of the development of active lava flow fields, many challenges remain. Timely field surveys of active lava flows could improve our understanding of the development of flow fields, but data of sufficient accuracy, spatial extent and repeat frequency have yet to be acquired. Satellite remote sensing of volcanoes is very useful because it can provide data for large areas with a variety of modalities ranging from visible to infra-red and radar. Satellite sensing can also access remote locations and hazardous regions without difficulty. Radar and multispectral satellite sensing data have been shown that can be combined to map heterogeneous lava flows using machine learning techniques, but a robust general model trained with several different lava compositions has to be developed. Here, we propose a robust, automatic approach based on machine learning techniques for analysing open-access satellite data in order to map lava flows in near-real time applicable to different kind of lava with different thermal components (i.e., incandescent, cooling and cooled lava component). We built a neural network model and trained it with a set of satellite images (e.g., Sentinel-1 SAR, Sentinel-2 MSI and Landsat 8 OLI/TIRS) of recent lava flows, and the relative labels of the lava and background regions. In this way, the trained model becomes capable to detect and map lava flows and to classify any new image, when available. The relative output is a segmented image with lava and background classes, obtained without an analysis made by a human operator. This approach allows to segment lava flows with both hot spot and cooling parts, and to recognize lava flows with different characteristics in near-real time. The results obtained during the long sequence of short-lived eruptive events occurred at Mt. Etna (Italy) between 2020 and 2021 are shown.

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ABSTRACT

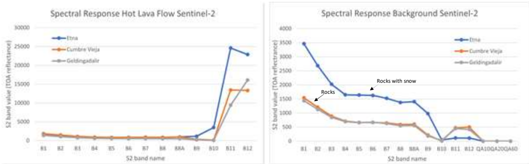
Despite significant advances in monitoring of the development of active lava flow fields, many challenges remain. Timely field surveys of active lava flows could improve our understanding of the development of flow fields, but data of sufficient accuracy, spatial extent and repeat frequency have yet to be acquired. Satellite remote sensing of volcanoes is very useful because it can provide data for large areas with a variety of modalities ranging from visible to infra-red and radar. Satellite sensing can also access remote locations and hazardous regions without difficulty. Radar and multispectral satellite sensing data have been shown that can be combined to map heterogeneous lava flows using machine learning techniques, but a robust general model trained with several different lava compositions has to be developed. Here, we propose a robust, automatic approach based on machine learning techniques for analysing open-access satellite data in order to map lava flows in near-real time applicable to different kind of lava with different thermal components (i.e., incandescent, cooling and cooled lava component). We built a neural network model and trained it with a set of satellite images (e.g., Sentinel-1 SAR, Sentinel-2 MSI and Landsat 8 OLI/TIRS) of recent lava flows, and the relative labels of the lava and background regions. In this way, the trained model becomes capable to detect and map lava flows and to classify any new image, when available. The relative output is a segmented image with lava and background classes, obtained without an analysis made by a human operator. This approach allows to segment lava flows with both hot spot and cooling parts, and to recognize lava flows with different characteristics in near-real time. The results obtained during the long sequence of short-lived eruptive events occurred at Mt. Etna (Italy) between 2020 and 2021 are shown.

INTRODUCTION & MOTIVATIONS

During a volcano eruption, mapping lava flow field and assessing the hazard is of extreme importance in the manage of the damage. Exploiting the potentiality of the Big Data and the automatic approaches, we introduce an automatic method to detect the volcanic activity and to segment the lava flow, combining machine learning and deep learning techniques and a variety of open-access satellite data (ESA Copernicus Sentinel-1 (S1) SAR, ESA Copernicus Sentinel-2 (S2) MSI and NASA&USGS Landsat 8 (L8) OLI/TIRS.

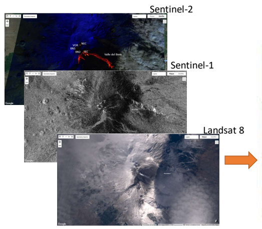
Automatic algorithm

Input: vector **x**=(x_1, x_2, …x_n) of features → x_i , with i=1,..,n is the value of reflectance of the pixel in a portion of the satellite image spectrum. The model exploits the different spectral response of each component of the image to distinguish and detect active lava flows and background (normalizing with mean and standard deviation).



Specific chemical and physical characteristics of the lava identify the type of response in the spectrum.

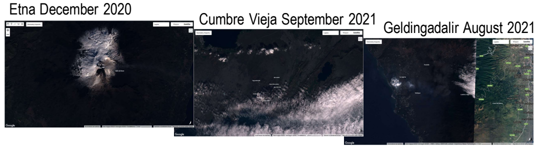
Machine learning with satellite remote sensing data



Training samples: lava/background

Maps of segmented lava flows (December 2020 - March 2021 Etna Activity)

(a) 14 December 2020, (b) 22 December 2020, (c) 17 January 2021, (d) 18 January 2021, (e) 16 February 2021, (f) 18 February 2021, (g) 21 February 2021, (h) 23 February 2021, (i) 24 February 2021, (l) 28 February 2021, (m) 02 March 2021



Etna December 2020 — Cumbre Vieja September 2021 — Geldingadalir August 2021

Mapping of lava flows

Machine Learning (ML) techniques:
- K-Means,
- Support Vector Machine,
- Classification and Regression Trees,
- Minimum Distance.

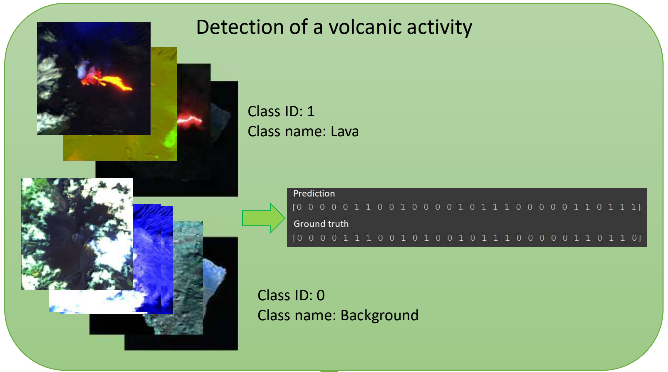
In Google Earth Engine (GEE).

Satellite data in the bands of:
- SWIR and TIR, mostly;
- Visible and NIR, a little.

The aim of this work is to generalize the technique that uses a portion of the image like input and segments all the rest. Here, we train a model with different images for the training, to make it ready for when images never seen before become available, exploiting the potentiality of the automatic techniques to elaborate quickly Big Data, with cloud computing.

MODEL

Generalization with Machine Learning and Deep Learning



1° step: Detection

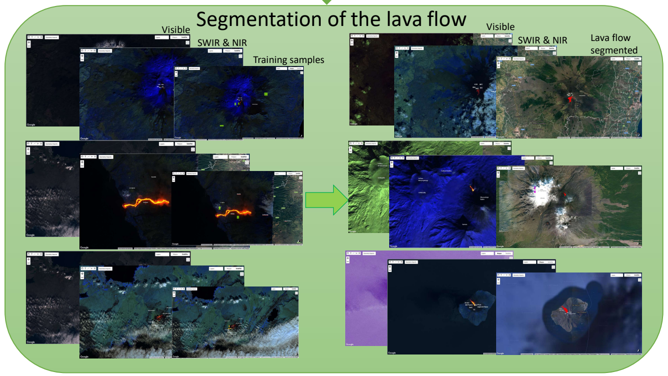
Detection of the volcanic activity, recognizing scenes where an eruption is in development.
Satellite images with activity and lava flows (class: 1) and with no activity and no lava flows (class: 0).

Deep Learning techniques:
SqueezeNet 1.0 (readjusted + fine-tuning)

In Google Colaboratory (Colab)

Satellite data:
ESA Copernicus Sentinel-2, NASA&USGS Landsat 8 (NIR, SWIR bands)
Etna, Cumbre Vieja, Geldingadalir, Kilauea, Stromboli.

Detection: Background → 0
Lava → 1



2° step: Segmentation

Segmentation of background and lava flow, mapping lava flows in the scene.

Machine Learning technique:
- Random Forest

In Google Earth Engine (GEE)

Satellite data:
ESA Copernicus Sentinel-2, NASA&USGS Landsat 8

Bands: Visible, NIR, SWIR

Training set: Etna, Cumbre Vieja, Geldingadalir volcanoes images.
Test set: Etna, Kljucevskaja Sopka, Stromboli volcanoes images.

CONCLUSION

Combining satellite images and automatic models, it is possible to detect and map lava flow fields. This kind of methods exploits the specific characteristic of the objects detected, through the spectral response of the satellite acquisitions. A model based on machine learning and deep learning techniques, trained with a set of images, becomes capable to apply all the knowledges learned in the training phase to new images never seen before. In this way, it is possible to monitor a volcanic activity in near real-time, when new images are available.
Researches in progress are aimed to an improvement of the cooled lava points detection and mapping, using visible, NIR and SWIR bands.

ACKNOWLEDGEMENTS

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