remote sensing

Editorial

Volcanic Processes Monitoring and Hazard Assessment Using Integration of Remote Sensing and Ground-Based Techniques

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The monitoring of active volcanoes is a complex task based on multidisciplinary and integrated analyses that use ground, drones, and satellite monitoring devices. Over time, and with the development of new technology and increasing frequency of acquisition, the use of remote sensing to accomplish this important task has grown enormously. This is especially so with the use of drones and satellites for classifying eruptive events, detecting the opening of new vents, the spreading of lava flows on the surface or ash plumes in the atmosphere, the fallout of tephra on the ground, the intrusion of new magma within the volcano edifice, and the deformation preceding impending eruptions, and others besides. The main challenge in using remote sensing techniques is to develop automated and reliable systems that may assist the decision-maker in volcano monitoring, hazard assessment, and risk reduction. The integration with ground-based techniques represents a valuable additional aspect that makes the proposed methods more robust and reinforces the results obtained. This collection of papers is focused on several active volcanoes, such as Stromboli, Etna, and Vulcano in Italy; the Long Valley caldera and Kilauea volcano in the USA; and Cotopaxi in Ecuador. The authors make use of several different methods to predict and forecast the volcanoes' future behavior, using insights from the available data or from new automated routines applied to the analysis of existing data. The aim is to enable rapid assessments of the state of a volcano, discovering the connection between variables apparently not related to each other and to the state of the volcano. The development of new or automated routines is an important step forward in the process of forecasting eruptive activities, and this collection comprises several such examples.

This Special Issue on the monitoring of active volcanoes using an integration of remote sensing and ground-based techniques comprises twelve papers. Three are focused on the results obtained for Stromboli volcano (Italy), where eruptive activity varies from moderate Strombolian, often accompanied by summit overflows, to highly explosive paroxysms, which are very dangerous both for the local population and for the many tourists who frequently visit the island. The first paper [1] presents the precursors of the paroxysmal and devastating explosive eruptions occurring in 2019. This paper applied an unsupervised analysis of seismic and infrasonic data, comprising a dataset of 14,289 Strombolian explosions occurring over 10 months, using a Self-Organizing Map (SOM) neural network to recognize changes in the eruptive patterns preceding the paroxysms. The SOM analysis identified three main clusters indicating a clear change in Stromboli's eruptive style before the paroxysm of 3 July 2019. The main clusters were then compared with the recordings of the fixed monitoring cameras and with the Ground-Based Interferometric Synthetic Aperture Radar measurements, showing that they were associated with different types of Strombolian explosions and different deformation patterns of the summit area.

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The second paper, dealing with the Stromboli volcano [2], proposes a new classification system based on multidisciplinary volcanological and geophysical data coming from the 12 explosive events occurring at Stromboli between 25 June 2019 and 6 December 2020. The authors used images of the monitoring camera network, seismicity, and ground deformation data, to characterize, classify and distinguish paroxysms (impacting the whole island) from major explosions (that affect the summit of the volcano above 500 m elevation) and from the persistent, mild explosive activity that normally has no impact on the local population.

The third paper, dedicated to the Stromboli volcano [3], considers an eruptive period from 28 March to 1 April 2020, when the Stromboli volcano erupted overflows from the crater rim that spread along the NW slope and reached the sea. Satellite, GBInSAR, and seismic data, enabled the reconstruction of the volcanic event, which involved several small collapses of the summit cone and the generation of pyroclastic density currents (PDCs) spreading along the slope and on the sea surface. Satellite monitoring allowed for the mapping of the lava flow field and the quantification of the erupted volume, and GBInSAR continuous measurements detected the crater widening and the deflation of the summit cone caused by the last overflow. The characterization of the seismicity made it possible to identify the signals that were associated with the propagation of PDCs along the volcano flank and, for the first time, to recognize the signal that was produced by the impact of the PDCs on the coast.

The following set of three papers focuses on the results regarding the recent extraordinary sequence of lava fountains at Etna volcano (Italy). From December 2020 to February 2022, a sequence of 66 lava fountains occurred. Eruptive columns and ash plumes caused by these paroxysmal events resulted in several infrastructural problems to the urban areas and the villages around Etna's flanks and in general to the eastern part of Sicily. Moreover, they were of great concern since the ash plumes often caused the closure of the Catania international airport, and also because they expanded well beyond Italian territory.

In the first paper, Freret-Lorgeril et al. [4] investigate multi-sensor strategies for the real-time determination of eruptive source parameters of explosive eruptions, useful for accurately forecasting both tephra dispersal in the atmosphere and deposition on the ground. The authors analyze and compare data acquired by two Doppler radars, ground- and satellite-based infrared sensors, one infrasound array, visible video-monitoring cameras, as well as data from tephra-fallout deposits. A second paper by Calvari et al. [5] considers a case study by selecting and analyzing the 12 March 2021 episode, which was one of the most powerful (and best recorded) lava fountain events over the entire eruptive sequence. The authors used remote sensing data from the ground and satellite to characterize the formation and growth of the lava fountains, integrated and related with ground deformation data recorded by a high precision borehole strainmeter to infer the decompression of the source. Moreover, the authors provided an estimation and comparison of different components of the erupted volumes (pyroclasts plus lava flows) with the total erupted volume inferred from the volcano deflation recorded by the borehole strainmeter.

A further paper [6] analyzes the entire lava fountains sequence by using a new approach. This consists of a software routine able to automatically detect the start and end time of each lava fountain, the area of the hot pyroclasts, the elevation reached by the lava fountains over time, and to calculate in real-time the erupted volume of pyroclasts, giving results close to the manual analysis but more focused on the sustained portion of the lava fountain, which is also the most dangerous.

The next two papers deal with general approaches for the modeling of eruptive parameters and processes. Pulvirenti et al. [7] present a 3D finite element model that includes topography and crust heterogeneities to characterize the nature of the intrusion in the Long Valley Caldera (USA). Joint numerical inversions of uplift and Electronic Distance Measurement baseline length change data were used to infer the deformation-source size, position, and overpressure. Successively, this information was used to refine the source overpressure estimation, compute the gravity potential and infer the intrusion density from the inversion of deformation and gravity data. Pailot-Bonnétat et al. [8] use the cloud-height-from-shadow technique to model the plume emitted during the 26 October 2013 event at Mount Etna. The authors used a single Landsat-8 Operational Land Imager image to extract the cloud altitude time-series, allowing them to document the ascent and dispersion history of a plume–cloud system produced by a fountaining event. The results were validated through a comparison with the proximal plume height time-series obtained from fixed monitoring cameras, finding a good agreement.

Two papers explore methods and tools to monitor volcanic activity. Inguaggiato et al. [9] present the results obtained by the long-term monitoring of three extensive parameters measured at Vulcano Island (Italy): the SO_2 flux in the volcanic plume, the soil CO_2 flux, and the local heat flux, monitored in the mild thermal anomaly located to the east of the high-temperature fumarole. The time variations of these parameters showed a cyclical trend in the volcanic degassing and a general increase in the pattern since June 2021. Corsa et al. [10] provide a differential interferometric SAR (DInSAR) time series and integrated it with GNSS data to create a fused dataset with enhanced accuracy of 3D ground motions over Hawaii island from 2015 to 2021, giving new estimates of the spatial and temporal dynamics of the 2018 Kilauea volcanic eruption. The methodology presented can easily be repeated over any region of interest where an SAR scene overlaps with GNSS data, giving a contribution to the classification of volcanic eruption precursors and the advancement of early warning systems.

Finally, the last two papers focused on methodologies to detect and map the deposits of volcanic products, which are fundamental for hazard assessment studies. In the first paper, Andrade et al. [11] provide a detailed cartography of the lahar deposits from the 26 June 1877 event in Cotopaxi (Ecuador). The cartography was performed through a combination of geological fieldwork with the analysis and interpretation of high-definition imagery obtained by drone surveys, which produced 25 cm-pixel ortho-mosaics using Structure from Motion. These data were subsequently exploited to map the deposits with the help of remote-sensing techniques and in correlation with field data. The second paper [12] reconstructs the dynamics of the 2014 effusive eruption at Stromboli (Italy) through the main morphological changes of the entire Sciara del Fuoco area. This was constructed by integrating multisensor remote sensing data, such as lidar, photogrammetric, and bathymetric surveys coupled with SAR amplitude images collected before and after the eruption. The results highlighted the importance of integrated submarine and subaerial studies to monitor active volcanoes, providing a comprehensive view of the main processes (constructive vs. destructive) associated with eruptive dynamics.

From this brief summary, it is clear how these studies included in the Special Issue confirm the growing importance of remote sensing in the complex and multidisciplinary monitoring of active volcanoes and demonstrate how its integration with classic ground-based techniques represents an essential approach for a deeper understanding and interpretation of how volcanoes work.

Conflicts of Interest: The authors declare no conflict of interest.

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