

Special issue

Artificial Intelligence for Volcanology

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Article history: received May 17, 2025; accepted May 19, 2025

Preface

When a volcano erupts, it is essential to provide timely and accurate information on hazardous volcanic phenomena, their impacts, and the duration of the eruptive activity. However, volcanic eruptions are inherently complex processes governed by the interaction of multiple physical and chemical phenomena, often nonlinear and stochastic. The many uncertainties in key parameters make precise forecasting of eruptions in time and space particularly challenging – volcanic events can be intrinsically unpredictable. Despite these limitations, significant progress has been made in forecasting volcanic hazards, and in specific circumstances, in developing predictive models. These advances are closely tied to the growing availability of large volumes of data collected through enhanced monitoring systems, including Earth observation satellites, and to the rapid development of computational resources. This has encouraged the widespread adoption of data-driven approaches – particularly artificial intelligence (AI) techniques – to support decision-making in volcanology. AI technologies, which allow computers to learn from data, are increasingly used to monitor, analyze, and forecast volcanic activity. They support both real-time surveillance and retrospective hazard assessments through modeling tools. Looking ahead, combining AI with physical constraints represents a promising strategy to enhance the interpretability and reliability of predictions. Hybrid approaches – blending physics-based simulations, machine learning, and data fusion – are being actively developed to fully exploit computational power and improve flexibility in modeling complex volcanic dynamics.

This Special Issue reflects the growing integration of AI with satellite and ground-based monitoring systems. It includes eight contributions illustrating the application of machine learning and deep learning methods to detect thermal anomalies, track volcanic clouds, simulate lava flow behavior, and model eruptive processes.

Presented below are the eight articles featured in this volume, each addressing different perspectives on Artificial Intelligence for Volcanology.

Di Bella presents a multi-sensor fusion strategy integrating AI algorithms and Earth Observation data to monitor Etna's 2022–2023 effusive eruption. Volcanic parameters such as VRP, TADR, and erupted volume are estimated using data from MODIS, VIIRS, SLSTR, SEVIRI, and Sentinel-2 MSI.

Malaguti applies a Random Forest model implemented in Google Earth Engine to Sentinel-2 data to detect and map lava flows from the 2023-2024 Sundhnúkur eruption, showing strong generalization and sensitivity to subtle thermal anomalies.

Cariello develops a cascading AI pipeline using Sentinel-2 imagery to classify volcanic thermal features at Etna, Stromboli, and Pacaya, offering insights into spatial patterns and changes during periods of volcanic unrest.

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Torrise proposes an integrated machine learning approach using SEVIRI data to detect and characterize volcanic clouds generated by Etna's lava fountains between 2020 and 2022, including ash and SO₂ components and plume height estimation.

Amato uses SPH-based numerical simulations to study how different effusion rates – derived from satellite data – influence lava flow evolution and eruptive styles, from effusive to explosive regimes.

Zago presents a refined SPH model to simulate two-way fluid-solid phase transitions in lava, incorporating realistic thermal thresholds and validating results with benchmark tests.

La Spina et al. explore the application of Cellular Nonlinear Networks (CNNs) to solve partial differential equations in fluid dynamics, demonstrating their capability to model geophysical flows with efficient parallel computation.

Corradino offers a broad conceptual overview on how AI and Earth Observation are reshaping volcano monitoring, introducing key ML and DL techniques such as feature engineering, attention mechanisms, and transfer learning.

List of papers of the Special Issue

Di Bella (2025). Multi-sensor fusion for thermal activity. *Annals of Geophysics*, this volume.

Malaguti (2025). Sentinel-2 mapping of lava flows. *Annals of Geophysics*, this volume.

Cariello (2025). Classification of volcanic patterns. *Annals of Geophysics*, this volume.

Torrise(2025). Tracking volcanic clouds with ML. *Annals of Geophysics*, this volume.

Amato (2025). Effect of effusion rate in SPH simulations. *Annals of Geophysics*, this volume.

Zago (2025). Phase transitions in lava with SPH. *Annals of Geophysics*, this volume.

La Spina et al. (2025). CNNs for geophysical fluid modeling. *Annals of Geophysics*, this volume.

Corradino (2025). Conceptual framework integrating AI and EO. *Annals of Geophysics*, this volume.

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