Geophysical Research Abstracts
Vol. 21, EGU2019-11276, 2019
EGU General Assembly 2019

Review of the use of synthetic aperture radar to monitor volcano slope instability

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Volcano slope instability manifests in many forms, ranging from steady state to punctuated movement, or shallow erosion to deep-seated spreading. The interplay of gravity, magmatic or hydrothermal fluids, and often active tectonics, results in complex spatial and temporal variations in deformation kinematics; deformation from magma rise or variations in hydrothermal systems may be inseparable from deep-seated and persistent flank motion. Similarly, shallow or localized ground motion may overlap with thermal contraction or subsidence of newly emplaced lava or tephra deposits. While this makes the recognition, assessment, and monitoring of volcano slope instability challenging, advancements in Synthetic Aperture Radar (SAR) technology have accelerated our knowledge of instability phenomena and our ability to assess their hazards. SAR amplitude images are powerful tools for mapping areas of geomorphological changes, which can be combined using Interferometric SAR (InSAR) to create multi-temporal deformation maps that provide unique information on the evolution of slope failures. Space-borne InSAR has become an economic way to detect changes at volcanoes at very high resolution. Ground-Based InSAR (GBInSAR) can produce frequent SAR images, propelling InSAR from monitoring to surveillance and early-warning applications. Various InSAR techniques have been used to measure persistent, transient, or surficial slope movement of at least ten volcanoes, some of which have had several periods or instances of flank motion.

To highlight the utility of SAR for measuring and monitoring mass movements, studies at Stromboli (Italy) and Pacaya (Guatemala) volcanoes are reviewed in detail, where recent instability events, persistent volcanic activity, and ground truth constraints have resulted in excellent case-histories in applying SAR imagery to understand these potentially hazardous slope instabilities. At Stromboli, years of monitoring with GBInSAR has led to an operational approach to mitigate landslide risks by defining a relationship between measured displacement rates and associated instability and eruptive hazards. This aided in anticipating a flank eruption 11 hours in advance in 2014. At Pacaya, the combined use of aerial and satellite InSAR time series successfully measured a large transient co-eruptive event in 2010. This was determined to have initiated a new stage of rifting, implicating new potential hazards for future eruptions.

Monitoring slope instability over the world's volcanoes will continue to increase with new radar satellites schedule to launch around 2020-2022, including ALOS-4 PALSAR by JAXA, NISAR by NASA-India, and SAOCOM by Argentine Space Agency. These satellites will provide more frequent images and improved coherence and coverage than previous sensors, with the potential to move from observing and explaining volcanic slope instability to tracking and forecasting failures. However, this enhanced mitigation potential relies on the manageability, rapidity, and fusing of these large datasets, and the integration of measured persistent or flank unrest into emergency planning.