

Perspective

Early warning systems and ground-based monitoring in detecting active volcanoes

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ABOUT THE STUDY

Volcanoes are among the most dynamic and dangerous natural phenomena on Earth. Their eruptions can have catastrophic impacts on human life, infrastructure, and the environment. However, technological advancements have significantly improved our ability to monitor and predict volcanic activity, providing early warnings and minimizing risks.

Remote sensing technologies

One of the most significant advancements in volcanic monitoring is the use of remote sensing technologies. Satellites equipped with various sensors can monitor volcanoes from space, providing data that is important for understanding volcanic activity. These technologies include:

Infrared imaging: Infrared sensors on satellites can detect heat emanating from volcanoes. This capability allows scientists to monitor temperature changes in volcanic regions, which can indicate rising magma or increased geothermal activity. For example, the ModIS (Moderate resolution Imaging Spectroradiometer) on NASA's Terra and Aqua satellites provides thermal imagery that helps in detecting hot spots and lava flows.

Synthetic Aperture Radar (SAR): These satellites, like the European Space Agency's Sentinel-1, emit radar waves to create detailed images of the Earth's surface. By comparing images over time, scientists can detect ground deformation, which often precedes volcanic eruptions. Ground deformation occurs when magma moves beneath the surface, causing the ground to swell or crack.

Optical imaging: High-resolution optical satellites, such as those operated by the United States Geological Survey (USGS), provide visual imagery of volcanic landscapes. These images help in mapping volcanic features, monitoring changes in crater morphology, and assessing the extent of lava flows and ash deposits.

Ground-based monitoring

While remote sensing provides a broad overview, ground-based monitoring offers detailed and localized data necessary for real-time analysis. Key ground-based technologies include:

Seismometers: These are important for detecting volcanic earthquakes, which often precede eruptions. By analyzing the frequency, intensity, and location of these earthquakes, scientists can infer magma movement and pressure buildup. Dense networks of seismometers, such as those deployed by the USGS Volcano hazards program, provide continuous monitoring and early warning capabilities.

Gas sensors: Volcanoes emit various gases, including Sulfur Dioxide (SO₂), Carbon Dioxide (CO₂), and Hydrogen Sulfide (H₂S). Monitoring these gases helps scientists understand volcanic degassing processes and magma dynamics. Ground-based gas sensors and airborne instruments, such as drones equipped with gas analyzers, measure gas concentrations and fluxes, offering insights into the likelihood of an eruption.

GPS and InSAR: Global Positioning System (GPS) receivers installed around volcanoes measure ground displacement with high precision. When combined with Interferometric Synthetic Aperture Radar (InSAR) data, scientists can create detailed maps of ground deformation. This information is essential for understanding magma chamber dynamics and potential eruption sites.

Early warning systems

The integration of remote sensing and ground-based data into comprehensive early warning systems has revolutionized volcanic hazard management. These systems, often developed by national and international agencies, aim to provide timely alerts to at-risk communities. Key components of these systems include:

Data integration: Advanced software platforms integrate data from various sources, including satellites, seismometers, gas sensors, and GPS receivers. This integration allows for real-time analysis and visualization of volcanic activity. Tools like the Volcano Disaster Assistance Program (VDAP) developed by the USGS and the USAID allow the rapid assessment of volcanic hazards and the dissemination of information.

Communication networks: Effective communication is important for early warning systems. Automated alert systems send notifications *via* text messages, emails, and social media to authorities and the public.

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These systems also rely on traditional media outlets and community networks to spread warnings quickly and efficiently.

Community engagement: Technology alone is not sufficient; Community engagement is necessary for effectively minimizing hazards. Public education campaigns and community drills help residents understand the risks and respond appropriately to warnings. Collaborations between scientists, emergency managers, and local communities enhance preparedness and resilience.

Technological advancements have transformed our ability to monitor active volcanoes, providing valuable data that improves our understanding and response capabilities. Remote sensing technologies offer broad, continuous monitoring from space, while ground-based instruments provide detailed, real-time data. Integrating these technologies into comprehensive early warning systems has proven effective in minimizing volcanic hazards and protecting communities.