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UNAVCO Conference Explores Advances in Volcanic Geodesy

Volcanic eruptions are among Earth's most spectacular surface phenomena. However, attempts to understand their basic physics face the challenge that the key processes occur at great depth and are difficult to observe. Thus volcanologists have been interested for years in using ground deformation measurements to study active volcanoes and predict their behavior during extended volcanic crises, such as the dramatic six weeks in 1980 between the initial and major eruptions of Mt. Saint Helens.

The advent of new technologies in recent years—in particular the Global Positioning System (GPS) and Interferometric Synthetic Aperture Radar (INSAR)—has shown potential for significant advances in volcano studies. Progress in this direction was explored at a conference organized by the University Navstar Consortium (UNAVCO) on September 15-17, 1999, with financial support from the National Science Foundation (NSF), NASA, and the U.S. Geological Survey (USGS). The meeting aimed to assess the status of various geodetic technologies and their potential to address crucial scientific and social needs in volcanic science and monitoring, as well as to develop recommendations on ways to spur further progress in these areas.

Based on various presented examples, participants concluded that geodetic data offer great potential for fundamental advances in volcanology because ground deformation occurs almost inevitably before volcanic eruptions. Evidence from many volcanoes shows that it is possible to detect ground motion reflecting magma rising from depth, sometimes months or weeks before the magma glow leads to earthquakes or other eruption precursors. Geodetic monitoring thus complements seismic monitoring by extending the study of volcanic phenomena from seconds to years, providing details of growth of magma bodies within the volcano.

The 3-day workshop included 48 participants representing research institutions in the United States, Mexico, Japan, United Kingdom, France, Iceland, New Zealand, and Australia, and was conducted in a "retreat setting" at Jackson Hole, Wyoming, USA. The site was chosen for its proximity to the Yellowstone volcanic system; a high point of the meeting was a field trip to explore volcanic and tectonic structures associated with the Yellowstone hotspot.

The conference participants considered a number of emerging technologies—with a special focus on GPS and INSAR—together with borehole strain and tilt measurements. Results were presented for a range of volcanic types, including volcanoes in California, Hawaii, Alaska, the Yellowstone hotspot, Iceland, the Philippines, the Galapagos, the Caribbean, Costa Rica, and Sicily.

Presentations focused on four principal scientific and technical themes.

- Volcano Science: What are the critical issues in volcanology that can be addressed by crustal deformation measurements? How can geodetic observations be used to accurately identify magma sources and their temporal variability? What are the mechanics of triggering volcanic eruptions, and what are the critical measurements that can be used to observe these phenomena? What can we contribute to improve the reliability of volcanic predictions?
- Volcano Geodesy Techniques: Which methods of measuring volcanic deformation provide maximum resolution in both space and time? What are the most promising new technologies for volcano monitoring? How can space-based and terrestrial deformation measurements be integrated? What are the best means of reducing errors in volcano geodesy? What is the most effective way to partition resources between different technologies when designing a monitoring network?
- Volcanic Source Models: What are the most promising methods for inferring magmatic sources from surface deformation measurements? How can more realistic models of volcanic source geometries and material properties of the deforming medium be incorporated into modeling techniques?
- Volcano Monitoring: What are critical scientific and technical issues related to volcanic prediction? How can GPS and other geodetic techniques be incorporated into near-real-time monitoring systems? What are critical logistical issues in deploying and operating a volcanic deformation monitoring system? How can deformation measurements be translated rapidly into realistic, time-variable volcanic source models?

The new technologies are evolving well. The UNAVCO-designed L1 (single-frequency GPS) system is now being tested successfully at several volcanoes. Similar systems are under development in Australia and at the USGS Cascade Volcano Observatory. These systems provide high-quality data at far lower cost than previously possible, allowing deployment of dense deformation monitoring systems, more accurate images of the spatial variability of the

Fig. 1. David Okita deploys a GPS receiver near Pu'u O'o, Hawaii—Kilauea volcano's most active vent. Scientists from Stanford University and the U.S. Geological Survey, with equipment and logistical support from UNAVCO, have taken GPS measurements on Kilauea since 1987. The goal of the experiment is to better understand the kinematics and mechanics of the deformation associated with Hawaiian volcanism. (Photo: Peter Cervelli).

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deformation field, and the deployment of GPS receivers in high-risk sites during volcanic crises. The L1 system accuracy is degraded by ionospheric activity, and optimal data reduction techniques—including the combination of sparse dual-frequency data and dense single-frequency systems—are being investigated.

INSAR can identify deformation at volcanoes without any ground-based observations, an especially valuable feature in remote and hazardous areas. It appears that SAR works in places with vegetation, although it still seems to have limited utility in densely vegetated tropical areas and will not operate in snow-covered regions.

The new technologies are natural candidates for integration with borehole strain and tilt, which currently offers the only proven real-time deformation monitoring system. Real-time GPS data reduction is being tested at Long Valley Caldera, California, and on Kilauea and Mauna Loa in Hawaii. Combining real-time data with optimized forward and inverse source modeling algorithms could provide details of intrusive events as they occur.

A key theme that emerged was that by combining the different—and often complementary—techniques discussed at the conference, and by integrating geodetic observations with other volcanologic approaches, it will be possible to make fundamental advances in understanding both volcanic processes and the mechanics of volcanism. Moreover, such integration will enable volcanologists to significantly enhance real-time volcano monitoring, which shows great promise in predicting many volcanic eruptions. These powerful new volcano monitoring technologies and the recent successes in volcanic prediction make this an especially auspicious time to initiate university and multiagency discussions on the future of both volcanic geodesy and volcano science in general.

The group recommended both technological and organizational measures to advance volcanic geodesy toward its full potential. The highest priority was given to continued development of volcanic GPS technology, including the low-cost single-frequency UNAVCO GPS system being tested successfully at several volcanoes. Also deemed crucial was the continued development of the data communications infrastructure—via new low-cost satellite telemetry—for returning GPS and other data inexpensively from remote locations.

Another high priority was acquiring SAR data for all active volcanoes with repeat intervals of several months, via either a dedicated scientific SAR satellite or arrangements for use of other satellites carrying SAR systems. Results to date indicate that this is better accomplished using a longer wavelength (L band) radar than the C band commonly used at present. This goal should be a priority for NASA, the European Space Administration (ESA), and the Japanese space development agency (NASDA). Participants expressed concern that the satellites scheduled to succeed ERS-2 after the end of its nominal mission next year may not devote sufficient time to acquiring radar data for interferometric monitoring of volcanoes and earthquakes. There is also the need to standardize data to allow data sharing.

A second set of recommendations concerned data analysis. First, it is important to develop techniques to combine GPS and SAR data with data from strainmeters, tiltmeters, seismometers, and volcanic gas sampling to identify, monitor, and study hazardous volcanoes. SAR could provide an overview, assessing large numbers of volcanoes remotely; those that show significant ground motion can then be studied with GPS and other ground-based instruments. Second, improved methods are needed for using geodetic, seismic, and other data to better understand the geometry, location, and motion of magma sources, as well as the mechanics of volcanic processes. Similarly, real-time analysis algorithms are needed to interpret data in real time and provide public authorities with useful information during volcanic crises.

Finally, organizational changes could significantly advance volcanic geodesy. The group urged initiation of a national volcanic hazards program—comparable to the National Earthquake Hazards Reduction Program—in order to coordinate efforts and funding between university scientists, federal scientific agencies, and other interested parties, including emergency management agencies. The workshop participants also favored identifying volcanoes within the western United States and Alaska for intensive study as part of the proposed Plate Boundary Observatory Program. In conclusion, they recommended formulating joint plans with U.S. and foreign scientists spanning a broad spectrum of relevant interests and disciplines to promote integrated geological and geophysical studies on selected volcanoes around the world.

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