Detecting Debris Flows Using Ground Vibrations

Debris flows are rapidly flowing mixtures of rock debris, mud, and water that originate on steep slopes. During and following volcanic eruptions, debris flows are among the most destructive and persistent hazards. Debris flows threaten lives and property not only on volcanoes but far downstream in valleys that drain volcanoes where they arrive suddenly and inundate entire valley bottoms. Debris flows can destroy vegetation and structures in their path, including bridges and buildings. Their deposits can cover roads and railways, smother crops, and fill stream channels, thereby reducing their flood-carrying capacity and navigability.

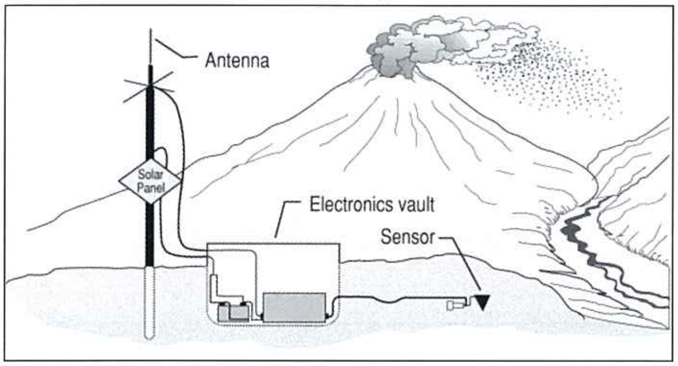
Large debris flow triggered by a small, explosive eruption at Mount St. Helens on March 19, 1992. Most of the flow went down the North Fork Toutle River, eventually reaching the Cowlitz River, 50 miles (80 kilometers) downstream. (Photo by Thomas J. Casadevall, March 21, 1982)

Detection of debris flows close to their sources can provide timely warnings to people in downstream areas if adequate communication systems exist. Unlike some other volcano hazards that are not constrained by topography, such as ashfalls and pyroclastic flows, debris flows are usually contained in valley bottoms and follow predictable paths along stream channels. In 1985, a relatively minor eruption of Nevado del Ruíz, Colombia, melted snow and started debris flows which entrained ash, soil, and debris. Within hours, the ensuing debris flows had traveled nearly 100 km down stream channels, left more than 23,000 people dead, and destroyed more than 5,000 homes. Similar, although smaller, tragedies are caused repeatedly by debris flows at volcanoes throughout the world. Thousands of lives might have been saved at Nevado del Ruíz, and hundreds around Mount Pinatubo, Philippines, had people received warning of approaching debris flows and known where to seek safety.

Previous Instrumental Monitoring of Debris Flows

Several approaches using electronic instruments have been used in the past to detect and monitor debris flows at active volcanoes. Trip wires are lengths of wire that are broken by a passing flow, and have been used with only limited success. If installed at different levels up the side of a valley, they can detect the maximum depth of a flow according to the level of the highest wire that has been broken. If installed at successive downstream sites, they can detect the progress and speed of the flow front. Such trip wires are difficult to install and are subject to vandalism and accidental breakage by animals or falling rocks. They cannot provide information about subsequent flows after they have been broken, and they must be reset each time a flow passes.

Debris flows have been observed with conventional seismographs that were deployed for earthquake detection. However, because conventional seismographs record earth tremor signals in the range of 0.5 to 20 Hz, they do not detect the strongest vibrations of debris flows and floods which occur at higher frequencies, and cannot pinpoint the exact location where a debris flow is flowing. Furthermore, conventional seismographs cannot distinguish debris flows from other sources of persistent noise at volcanoes, such as high wind, heavy rain, or fumarole activity.



A typical installation of an automated, debris-flow sensing station includes an antenna with a solar panel attached, a buried electronics vault, and a sensor buried 50 to 500 meters above a stream channel.

Researchers in Japan and China used high-frequency accelerometers in separate studies of debris flows. They reported that debris flows with dissimilar composition and dissimilar channel characteristics caused similar ground vibrations, in particular, the frequency, amplitude, and duration of vibration.

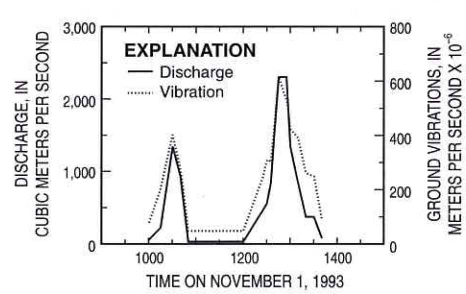
The Acoustic Flow Monitor

Scientists at the U.S. Geological Survey Cascades Volcano Observatory have developed an inexpensive, durable, portable, and quick-to-install system to detect and continuously monitor the arrival and passage of debris flows and floods in valleys draining active volcanoes. This automated system, known as the Acoustic Flow Monitor (AFM), senses and analyzes ground vibrations with a compact, solar-powered unit that is installed near specific channels. It uses an inexpensive geophone and an on-site microprocessor to continuously analyze vibration signals and detect debris flows and floods on the basis of frequency composition, amplitude, and duration of the vibration signal. A two-way radio system communicates between each sensing unit and a base station.

The geophone can sense ground vibrations with frequencies ranging from 10 Hz to 300 Hz. Most debris flows cause the ground to vibrate at a peak frequency of 30 Hz to 80 Hz, whereas watery floods cause ground vibrations with a peak frequency of more than 100 Hz.

The microprocessor-controlled instrument measures the amplitude of the vibration signal every second and sends data by radio to the base station at regular intervals, typically 30 minutes. If the instrument measures vibrations that exceed a certain threshold value (adjustable for each individual site) for longer than 40 seconds, the AFM transmits immediate alert messages. It continues to send alert data at 1-minute intervals for as long as the signal remains above the threshold level. When the signal drops below the threshold level, the AFM resumes normal operation, transmitting at less-frequent intervals. The AFM can detect increased ground vibrations several minutes (as much as a kilometer) before a debris flow or flood reaches the station, and continues to record vibrations above background level until the tail of a debris flow or flood has passed. The speed of approaching flows can be determined by detecting arrival times at sequential sensing sites along stream channels. In addition, continuous monitoring of the passage of floods and debris flows allows estimation of the volume of water and debris that is passing the sensing unit. At Pinatubo Volcano, Philippines, AFM signals have been used to estimate debris-flow discharges ranging from 10 to 1,800 cubic meters per second.

The AFM system has distinct advantages over previous debris-flow detection systems: (1) the geophone and microprocessor are set to analyze the peak vibrations typically produced by debris flows and floods, and screen out other noise or tremor that would affect normal seismographs; (2) flows are monitored as they approach, and recede from individual monitored sites, and (3) the equipment is ready to detect subsequent flows immediately without any maintenance.



Graph showing the relation between discharge and ground vibration during passage of two lahars on the Sacobia River near Pinatubo Volcano, Philippines on November 1, 1993.

This new technology is available and ready to deploy at the next sign of unrest at any volcano in the United States. The AFM system already has been installed and tested at Mount St. Helens and Mount Rainier, Washington; Redoubt Volcano, Alaska; Unzen Volcano, Japan; Cotopaxi Volcano, Ecuador; and Pinatubo Volcano, Philippines. The system can be used to alert emergency officials to the approach of debris flows and large floods emanating from volcanoes or other steep terrain. If properly calibrated to local conditions, it can also provide estimates of the magnitude of the flows. The AFM has the potential to save many lives from one of the most dangerous hazards posed to people who choose to live near these volcanoes.

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