Real-Time Data Received from Mount Erebus Volcano, Antarctica

Internal and eruptive volcano processes involve complex interactions of multi-phase fluids with the solid Earth and the atmosphere, and produce diverse geochemical, visible, thermal, elastic, and anelastic effects. Multidisciplinary experimental agendas are increasingly being employed to meet the challenge of understanding active volcanoes and their hazards [e.g., Ripepe et al., 2002; Wallace et al., 2003].

Mount Erebus is a large (3794 m) stratovolcano that forms the centerpiece of Ross Island, Antarctica, the site of the principal U.S. (McMurdo) and New Zealand (Scott) Antarctic bases. With an elevation of 3794 m and a volume of ~1670 km$^3$, Erebus offers exceptional opportunities for extended study of volcano processes because of its persistent, low-level, strombolian activity (Volcano Explosivity Index 0–1) and exposed summit magma reservoir (manifested as a fluidic lava lake). Key scientific questions include linking conduit processes to near-field deformations [e.g., Aster et al., 2003], eruption physics [e.g., Johnson et al., 2003], magmatic differentiation and residence [e.g., Kyle et al., 1992], and effects on Antarctic atmospheric and ice geochemistry [e.g., Zreda-Gostynska et al., 1997]. The close proximity of Erebus (35 km) to McMurdo, and its characteristic dry, windy, cold, and high-elevation Antarctic environment, make the volcano a convenient test bed for the general development of volcano surveillance and other instrumentation under extreme conditions.

Integrated Surveillance Instrumentation

During the 2002–2003 and 2003–2004 Antarctic field seasons, a major research instrumentation grant awarded to the New Mexico Institute of Mining and Technology (NMT) by the U.S. National Science Foundation (NSF) Office of Polar Programs supported the design and deployment of a five-station Integrated Surveillance Instrumentation (ISI) network of sensors, data acquisition, and telemetry hardware (Figures 1 and 2). ISI stations are designed to deliver real-time, year-round data streams to McMurdo, NMT, and worldwide via the Internet, while augmenting a pre-existing, year-round network of short-period, FM-telemetered seismic stations and continuous single-frequency Global Positioning System (GPS) receivers.

The primary objectives are to acquire diverse multi-year observations about the physical conditions of Erebus, and to develop instrumentation for general multidisciplinary volcano data collection in remote and hostile environments. An important objective was to integrate the geoedetic data from a dual-frequency GPS receiver into the seismic data stream with a minimum of redundant hardware. The integration of geodesy with seismology is essential to understanding the full spectrum of deformational processes in volcanic and tectonic environments as, for example, in the EarthScope program [van der Vink, 2002].

ISI instrumentation consists of a broadband seismometer, digitizer, dual-frequency GPS receiver, and 9000-MHz spread-spectrum radio modem. Additional sensors deployed at selected stations include infrasonic microphones, infrared radiometers, tiltmeters, gas sensors, and weather instruments (temperature, wind speed/direction, humidity, and barometric pressure). Component and battery temperatures, current, and voltage are further monitored to assess overall system performance. A time-stamped video camera allows observations of lava lake and other vent activity. Station design was dictated by scientific goals, environmental robustness, helicopter transportability, and by moderate power consumption (10–15 W) and cost ($35,000/station).

Signals are digitized using a Guralp Systems CMG-DM24 digitizer incorporating hardware and software modifications developed at Guralp to accommodate a continuous GPS data stream. Digitizers feature either three or six 24-bit channels (40 samples/s) for seismic, infrasound, and infrared signals, and eight 16-bit channels (four samples/s) for tilt, environmental, and system performance signals. The GPS receiver supplies National Marine Electronics Association (NMEA) time sentences and a 1 pulse/s signal to timestamp data packets.

On Erebus, Guralp CMG 40-T 30 s–50 Hz seismometers were used, which were found to be especially robust for Antarctic transportation and operation in the Antarctic. The seismometer is crucial for studying lava lake strombolian eruptions [Roube et al., 2000; Aster et al., 2003], which generate very long-period signals with energy at periods as great as 25 s, volcanic tremor, mega-iceberg signatures [Vulandier et al., 2002], icequakes, and earthquakes at local to teleseismic distances. Bidirectional communications allow for in situ reconfiguration of digitizers and seismometer calibration.

Infrasonic (≤20 Hz) monitoring is a fundamental tool for studying vigorous volcanic degassing [e.g., Ripepe et al., 2002; Johnson et al., 2003]. Infrasonic recordings are especially valuable for examining near-surface source processes, in part because atmospheric Green’s functions are simpler than seismic Green’s functions, especially given the structural complexity common at volcanoes. A 3-station, 4-sensor, Erebus infrasound network facilitates precise determinations of explosion location, eruptive time history, energy, and gas volume release, and is also generally useful for discriminating between non-eruptive and eruptive sources.

Infrasonic sensors on Erebus are reference-calibrated microphones composed of four electret condenser elements. These microphones provide useful data at frequencies as low as 0.05 Hz (the 3 dB attenuation corner frequency is approximately 0.5 Hz and the system can record pressures as large as ±50 Pa, with a dynamic range of more than 80 dB and a noise floor of ~1 mPa).

Geodetic measurements complement seismic observations by showing detecting strain changes at periods far longer than the seismic band. Erebus geodetic instrumentation consists of a biaxial tiltmeter (Applied Geomechanics model 701-2A) sampled at four samples/s with 16-bit dynamic range and a dual-frequency GPS receiver (Trimble 4700). The BINEX GPS data stream is incorporated into the native Guralp compressed format (GCF) via a “byte pipe” hardware modification that renders the digitizer capable of accepting a general RS232 data stream. Guralp Seismometer Configuration Real-Time Acquisition and Monitoring (SCREAM) software segregates the byte pipe stream into day volumes at McMurdo. The continuous GPS data complements and enhances ongoing campaign GPS surveys [Bartel et al., 2003].
During the 2002–2003 field season, five of the six planned ISI stations were deployed. A sixth station, near the top of Ray's Gully (RAY) on the eastern crater rim, was installed in January 2004. Because RAY will frequently be within the volcano plume, this station incorporates CO$_2$, HCl, and SO$_2$ sensors to monitor the degassing of the summit system.

Power Systems

Year-round power systems in Antarctic conditions are a significant challenge. Assessing environmental and system power conditions is thus an important component of the ISI effort. Auxiliary four sample/s data streams are used to assess interactions between environmental and instrumentation conditions (for example, system temperatures, wind and solar charging currents, and battery voltage). Environmental and electronic variables sensed are wind speed and velocity (R.M.Young model 05103VM Wind Monitors), external and internal temperatures, humidity, barometric pressure, system voltage, and system and wind generator currents. At the latitude of Erebus (78°S), the Sun is below the horizon between late April and late August, and air temperature on the summit plateau ranges between ~ -10° to -60°C [the lowest temperature noted during the 2003 winter was -58°C at Truncated Cones (CON)]. The charging system incorporates 400 W Air 403 Industrial wind generators and 150 W solar panel arrays with ~2000 A-H of deep-cycle adsorbed glass mat lead-acid battery capacity. Charging is regulated by a temperature-compensated system controlled by a battery box temperature probe (necessary lead-acid battery charging voltage increases significantly with decreasing temperature). Usable lead-acid battery capacity decreases rapidly with temperature, so battery boxes are thickly insulated with foam. During the 2003 winter, internal dissipation during wind-charging intervals was sufficient to heat the batteries by up to 10°C above the outside temperature. Four of the five stations deployed in the first field season lost power or telemetry before the end of the 2003 winter, primarily due to reduced capacity, wind generator damage, a charge controller failure, and blow-down of a relay tower with LEH and NKB repeaters (Figure 1). CON continued to operate intermittently through the winter. Tower and wind generator problems were exacerbated by ice riming and storms with winds in excess of 140 km/hr. The 2003–2004 field season efforts were largely concentrated on repairing damaged components and on reducing the vulnerability of the power and exposed telemetry components to rime and wind loading.

Data Telemetry

Telemetry to McMurdo is accomplished using bi-directional, 900 MHz Freewave radios in point-to-point, masterslave configuration. At the McMurdo Arrival Heights receiver site, a complement of Freewave radios sends data to the serial ports of an NT personal computer running SCREAM. This PC then exports its data, using the U.S. Geological Survey Earthworm.
module called LavaLake2.0, to a McMurdo Sun Earthworm system. The Sun system merges data from the ISI network with data from the FM-telemetered, short-period stations (received at a different McMurdo site) and maintains a McMurdo data archive. McMurdo to U.S. Internet connectivity relies on a sub-T1 capacity geosynchronous satellite data link with Brewster, Washington. Erebus data streams are exported from Antarctica to NMT using a compression algorithm, where they are retrieved and rearchived by a Sun Earthworm system, and are re-exported to the IRIS Data Management Center in Seattle for independent archival and general community access (Network Code ER). Internet downtime or heavy use can introduce dropouts into the compressed Earthworm transfer from McMurdo to NMT, so the open source rsync utility (http://samba.anu.edu.au/rsync) is used to synchronize NMT and McMurdo data archives hourly. GPS BINEX data are forwarded to UNAVCO in day volumes for archival and processing.

Video Surveillance

The spectacularly exposed Erebus lava lake (Figure 2) offers unique opportunities for close visual monitoring of an erupting volcano. A video system is installed on the north crater rim approximately 300 m from the lava lake (Figure 1, Figure 2), powered in association with the NKB ISI site, and using an Extreme CCTV camera coupled with VideoComm Technologies 2.4 Ghz telemetry. At McMurdo, video data are time-stamped and recorded on VHS tape, and a decimated (one sample/s) stream is exported using QuickTime Broadcaster software.

Visual observations of erupting volcanic vents can be valuably complemented by infrared radiometric measurements [Ripepe et al., 2002]. The camera site incorporates two infrared radiometers (Omega Engineering model OS 493) directed at the lava lake with narrow (2°) and wide (15°) respective fields of view. Radiometer signals are sampled at 40 samples/s and incorporated into the ISI system at NKB. Another (2°) sensor was installed at RAY in January 2004. Representative seismic, acoustic, and lava lake irradiance data from a lava lake eruption are shown in Figure 3.

Future Opportunities

ISI is one realization of moderate-power and cost multidisciplinary instrumentation suitable for deployment at remote volcanoes. All sensor and data collection hardware, with the exception of the infrasonic microphones (constructed from off-the-shelf parts and calibrated by J. Johnson) are commercially available. The integration of seismic, GPS, tilt, infrasound, infrared, gas, environmental system state-of-health, and other data streams in easily transportable and deployable packages highlights the possibility of large-scale standardized data gathering on active volcanoes worldwide. When combined with growing Internet connectivity and the development of openly accessible archival systems such as the IRIS Data Management Center, this presents new opportunities for more quantitative and systematic study of global volcanic activity.

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References


Fig. 3. (a) Sample ESI data from Erebus. Short period-filtered (1–5 Hz) seismic velocity, infrasound, and radiometer records from a strombolian explosion on 19 February 2003 are shown. Note the simplicity of the acoustic Green’s function relative to the seismic Green’s function and the prolonged infrared radiometer signals (both wide and narrow field) recording lava lake disruption and refill. (b) A very long period (VLP) broadband seismic displacement stack from strombolian explosions recorded at E1S is shown. VLP signals persist for several minutes during the refill period following the explosive evisceration of the lava lake [Aster et al., 2003]. (c) This tremor signal (possibly of mega-iceberg origin; Talandier et al. [2002]) recorded over a 2.5 hr period at CON on 3 April 2003 shows complex variability in source characteristics, including a multi-source episode around 150 min recognized by independently tracking sets of harmonics. Broadband transients are from local glacial icequakes.

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