USE OF SATELLITE TELEMETRY FOR MONITORING ACTIVE VOLCANOES, WITH A CASE STUDY OF A GAS-EMISSION EVENT AT KILAUEA VOLCANO, DECEMBER 1982

By Kenneth A. McGee, A. Jefferson Sutton, *and* Motoaki Sato

ABSTRACT

A telemetry system using geostationary satellites for data relay has several advantages over ground-based systems that are widely used as a means for relaying geophysical and geochemical data from volcanoes. The National Oceanic and Atmospheric Administration's NESDIS (National Environmental Satellite, Data, and Information Service) maintains two operating Geostationary Operational Environmental Satellites (GOES) to monitor the Earth's weather systems. These satellites are part of a worldwide network of meteorological satellites, and each is equipped to relay data transmissions from networks of data-collection platforms. A degassing event at Kilauea Volcano in December 1982, observed and recorded some 9,000 km away, is cited as an example of how satellite telemetry can be a viable alternative for monitoring potentially active volcanoes.

INTRODUCTION

Radio telemetry is widely used as a means for relaying geophysical and geochemical data from active volcanoes to observatories or other data-collection centers. Most existing telemetry networks are ground based and are constrained by topographic conditions. In order to extend the range of the telemetry, repeater stations may be installed or telephone lines leased. However, the cost of maintaining these systems adds substantially to the total cost of the operation. Moreover, the complexity of the system increases and the flow of data becomes more vulnerable to equipment failure as more links are added to the data-relay chain.

A telemetry system using geostationary satellites for data relay has advantages over ground-based systems (McGee and Sato, 1982). The need for repeaters, multiple telemetry links, and dedicated telephone lines is eliminated. Although the initial cost of the transmitters may be higher, the elimination of repeater stations and leased telephone lines reduces the operational costs and, more importantly, extends the potential useful range to thousands of kilometers. Since the telemetry antennas must be pointed skyward at a high angle (30° to 60° depending on latitude), the elevation and local topography of the monitoring site become less important. Also, because satellite-relayed telemetry systems operate at higher radio frequencies than typical ground-based systems they have shorter antenna element lengths and fewer interference problems. Smaller antenna systems in turn reduce the vulnerability of monitoring sites to damage from wind or ice. Finally, a telemetry system using geostationary satellites for data relay allows more than one observatory or laboratory to collect data from volcanoes scattered across continents or oceans.

DESCRIPTION OF A SATELLITE DATA-COLLECTION SYSTEM

The National Oceanic and Atmospheric Administration's NESDIS (National Environmental Satellite, Data, and Information Service) operates a series of Geostationary Operational Environmental Satellites (GOES) to image and monitor the Earth's cloud cover and weather systems (National Oceanic and Atmospheric Administration, 1983). These satellites, placed in orbits coincident with the Earth's equatorial plane at an altitude of about 35,500 km, rotate at the same speed as the Earth and appear from the Earth to be in a fixed position. Unlike earlier polar-orbiting satellites, these geostationary or geosynchronous satellites, which are part of a worldwide network of meteorological satellites, have nearly a full hemisphere of continuous view (fig. 34.1). NESDIS maintains operational satellites at 75° and 135° west longitudes. One or more older satellites, located about midway between these two operational sites, are used if one of the primary satellites fails. These in-orbit spares can be turned on and moved to the operational location to provide continuity of coverage.

Each of the satellites is equipped to relay data transmissions from networks of data-collection platforms to one or more receiving sites. The onboard instrumentation that performs the relay function is a satellite transponder, which is a combination radio receiver and transmitter that receives data and instantaneously retransmits it back to Earth with no change except for frequency. Each of the two NESDIS satellites can relay environmental data from as many as several thousand individual data-gathering devices located at virtually any point in the Western Hemisphere. Likewise, the large beam width of the satellite transmitter antenna permits reception of the signal from the satellites over the same wide area.

In addition to the spacecraft itself, a satellite data-collection system is made up of four major parts: (1) sensors; (2) data-collection platforms; (3) Earth receiving stations; and (4) a data processing and storage system (fig. 34.2). Because NESDIS operates a central Earth Receiving Station, the user need only

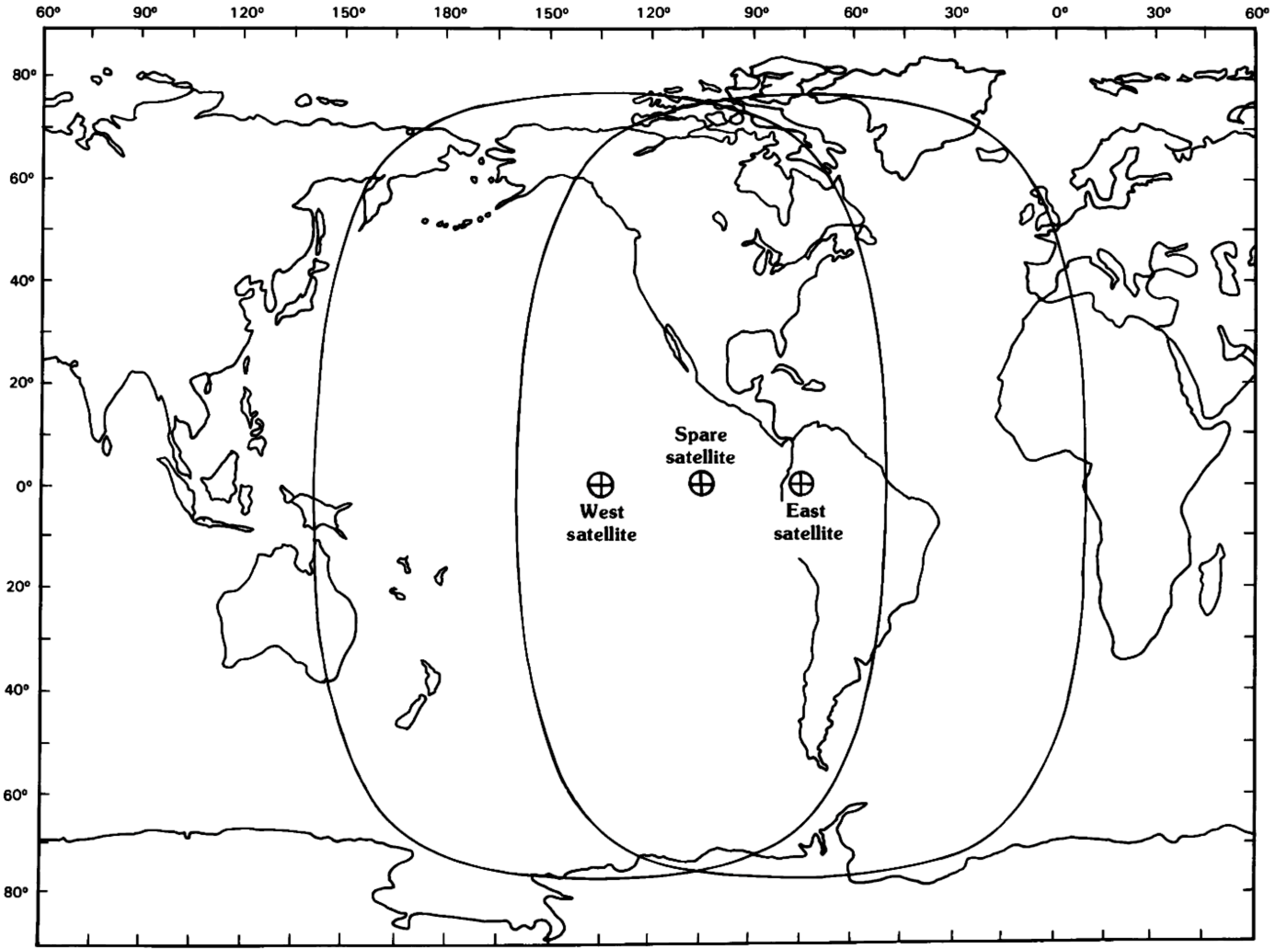

FIGURE 34.1.—Areal coverage of the Earth's surface by geostationary satellites located at long 75° and 135° W. (from National Oceanic and Atmospheric Administration, 1983, fig. 1-2, p. 4).

supply the remaining three parts. In a minimum network configuration (1–20 monitoring sites), the user provides only the sensors, data-collection platforms, and some sort of data processing and storage system. As the number of monitoring sites increases, it may be beneficial to acquire a direct-readout ground receiving station.

The GOES system is particularly suited to monitoring slowly varying parameters. In a volcanic region, parameters of interest may include tilt, magnetic field strength, self-potential, gas emissions, fumarole temperatures, and meteorological data. In some instances, it is possible to transmit higher frequency data through the system if some onsite preprocessing is done. For example, seismicity, in the form of earthquake counts, can easily be accommodated. This might have particular application to remote volcanoes where recording the number of earthquakes may be more pertinent to assessing the level of activity than recording the actual waveforms. GOES data-collection platforms (DCP's) typically require sensors with analog voltage outputs in the range 0–5 V, although other output ranges and certain sensing devices with digital outputs can often be accommodated.

GOES DCP's are small, battery-powered, 402-megahertz radio transmitters that transmit data to the satellite at a rate of 100 bits per second (National Oceanic and Atmospheric Administration, 1984). Higher data rates are possible though not currently used. The major components of a DCP are the sensor interface, programmable microprocessor, memory, radio, clock, and antenna. Many GOES DCP's operate in the self-timed mode, which requires the platform periodically to transmit its data under the command of a precise timer. In this self-timed mode, the platform, under control of the timer and microprocessor, scans its sensor interface. A typical DCP sensor interface can accommodate as many as 16 sensors. Data from each scan may be stored in the memory of the DCP until the prescribed transmission interval. Some DCP's are capable of performing preliminary data manipulation including data conversion, averaging, slope computation, and warning-level assessment, for emergency transmissions. Reliable, environmentally hardened DCP's are commercially available from a number of sources. A complete site installation, exclusive of sensors, can be performed in less than four hours.

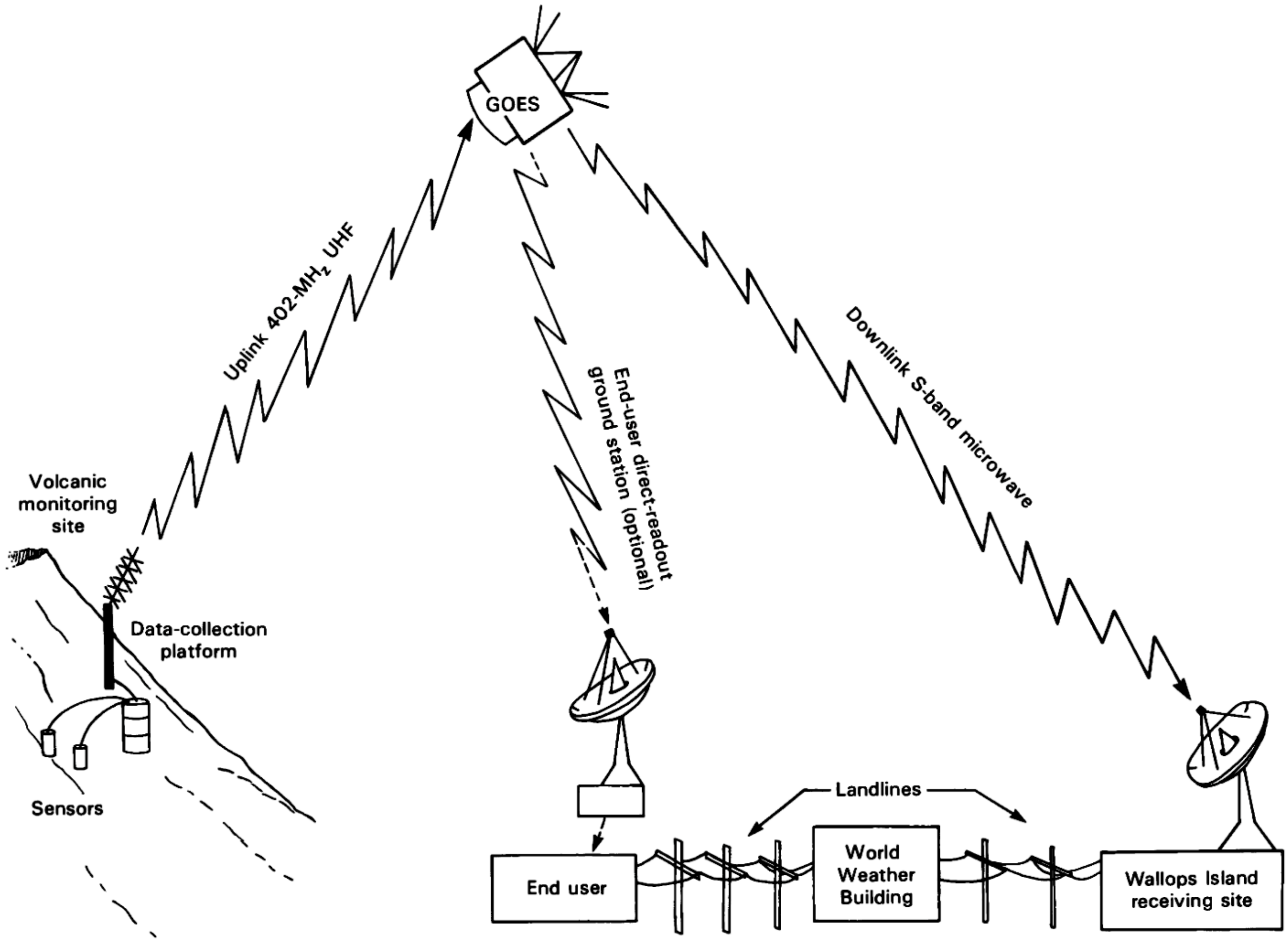

FIGURE 34.2.—Diagram of Geostationary Operational Environmental Satellite (GOES) data-flow path from remote site through satellite to end user.

Each satellite can support more than 250 radio channels, many of which are dedicated to self-timed platforms. The technique for defining the schedule of DCP reporting is called frequency-division multiple access with time-shared channel occupancy. A GOES platform typically uses a 1-min time interval every 3 h on its assigned radio channel for transmission of its data to the satellite. Sensor data can be collected as often as every 10 min and stored in memory until the prescribed transmission interval. Depending on the number of sensors and data points, transmission message lengths average about 30 s. In addition to self-timed transmission, two other modes of DCP transmission initiation are possible in the GOES system: (1) interrogation by the satellite, and (2) emergency transmission because of a predetermined sensor-threshold value being exceeded. The latter capability can be useful in providing warnings of imminent floods or mudflows.

NESDIS operates only one Earth receiving site, located at Wallops Island, Va., for the GOES satellite data-collection system. This receiving site performs a number of functions including command and control of the spacecraft, reception of data, and monitoring of signal quality. From the Wallops Island location, NESDIS forwards data from the satellites to a computer in the World Weather Building at Camp Springs, Md. From there, the data are distributed to users via the telephone system using either dedicated circuits or dial-in lines. Many users of the GOES system, in an effort to reduce system complexity and dependence on land lines, are establishing their own local direct-readout ground station terminals. These terminals are becoming less expensive and can provide a user with immediate access to the data transmitted from the satellite.

Because NESDIS does not store data in its computer for longer than a few days, it is necessary for the user to transfer the data regularly to his own computer system for processing and storage. Collecting data from one sensor at 10-min intervals produces more than 52,000 data points in a year. A network of several DCP's, each with several sensors, can thus produce a large data base. In addition, since the data are in numerical form, a mechanism for converting the data to graphical form for viewing is a must. Frequent visual inspection of the recorded data for significant sensor variations is necessary to take full advantage of the nearly real-time nature of satellite-relayed telemetry. An optimum computer system for end users of the GOES system would include screen and hard-copy graphics capability and several megabytes of online data-storage capacity.

EXAMPLE OF A WIDE-AREA NETWORK FOR MONITORING VOLCANOES

The current U.S. Geological Survey network of volcanic-gas monitoring stations at several widely scattered volcanoes is an excellent example of a wide-area network using satellite telemetry. In the summer of 1981, satellite-relayed hydrogen-gas monitoring stations were installed at Mount Baker and Mount St. Helens, Wash., and Lassen Peak, Calif. Similar monitoring stations were installed in 1982, at Long Valley Caldera, Calif., and Kilauea, Hawaii, and in 1983 at Mauna Loa, Hawaii, and Coso Hot Springs, Calif. Until mid-1984, data from all of these stations were scrutinized and recorded at the U.S. Geological Survey National Center in Reston, Va. (more than 4,000 km from the nearest monitoring site). In June 1984, the responsibility for collecting data from these stations was transferred to the Cascades Volcano Observatory in Vancouver, Wash. This change of recording facility was completed without the necessity for a single visit to any field site and clearly demonstrates the extreme flexibility of a satellite-relayed telemetry system.

Although some of the field sites in the gas network are located near existing ground-based telemetry systems, many of the monitoring locations are in remote areas where there is no possibility of linking into a ground-based telemetry system or telephone line. That any data can be collected at all from these sites in nearly real-time fashion is a tremendous accomplishment. Clearly, the wide-area gas monitoring network owes its existence to the availability of satellite telemetry.

CASE STUDY—EVIDENCE FOR A WIDESPREAD GAS EVENT AT KILAUEA VOLCANO, DECEMBER 1982

Hydrogen gas sensors were strategically deployed in or near fumaroles at the Kilauea summit caldera ('71 Fissure and Halemaumau West), along the east rift zone (Mauna Ulu and Puu Kiai), and on the southwest rift zone (Kau Desert) in the late 1970's with conventional ground-based telemetry used at each site to transmit the data to the Hawaiian Volcano Observatory for recording (McGee, 1979). In mid-December 1982, a GOES satellite data-collection platform was interfaced with the receivers of the land-based telemetry system to produce an integrated telemetry system. Previous data acquisition involved the mailing of strip-chart recordings to a distant laboratory for analysis (months later). This marriage of ground-based and satellite telemetry allowed a wide area of Kilauea to be monitored using a single central DCP for data relay to the satellite.

On December 23, 1982, a degassing event was recorded at both Kilauea summit stations and at Mauna Ulu in the upper east rift zone (fig. 34.3). Although the distance between the summit monitoring sites and the Mauna Ulu site is about 8 km, the onset time and duration (2 days) of the gas event are essentially concurrent at the three locations. In addition, hydrogen sensors with on-site recording at two nearby locations, Puhimau and a different fumarole at Mauna Ulu, recorded similar peaks. On December 26, a distinct gas event that had rapid onset and lasted only a few hours was recorded at Puu Kiai. This event is noteworthy because it is the only hydrogen gas event ever recorded at that location. Puu Kiai is located about 13 km down the east rift zone from Mauna Ulu.

Other independent evidence also points to a widespread gas release during this time period. Friedman and Reimer (chapter 33, part I) report a distinct helium anomaly at Sulfur Bank in late December 1982. In addition, a substantial radon peak was observed near the western rim of Kilauea's caldera at about the same time (Donald Thomas, oral commun., 1984). It is likely that this widespread gas release was a precursory manifestation of the intrusion of a large body of magma into the Kilauea summit area. Subsequent injection of this magma into the east rift zone resulted, on January 3, 1983, in the first of a long series of east-rift eruptions.

The crucial point to note here is that the degassing event, as detected in satellite-relayed data from the hydrogen-monitoring stations, was identified and recorded 9,000 km away almost instantly, leaving ample opportunity for telephone notification of personnel near the site of the event before the onset of eruptive activity. This episode illustrates the utility of using satellite telemetry for monitoring pertinent parameters of potentially active volcanoes from long distances.

CONCLUSIONS

The potential for utilizing geostationary satellites for monitoring remote and widely scattered volcanoes has not yet been fully realized. The techniques recently developed are directly applicable to many areas of the world where real-time data on natural hazards are required. The availability of low-cost and reliable data-collection platforms and direct-readout ground stations can provide a data-telemetry system free from the usual communications infrastructure (Shope and Paulson, 1981). The United States, the European Space Agency, and the Japanese Meteorological Agency all currently operate geostationary satellites capable of data relay. There are few areas in the world where potential users could not gain access to a geostationary satellite. The example cited earlier clearly demonstrates that satellite telemetry is now a viable alternative to other types of data-collection systems for monitoring potentially active volcanoes.

REFERENCES CITED

McGee, K.A., 1979, An analog data telemetry system for remote monitoring applications, version II: U.S. Geological Survey Open-File Report No. 79–946, 11 p.

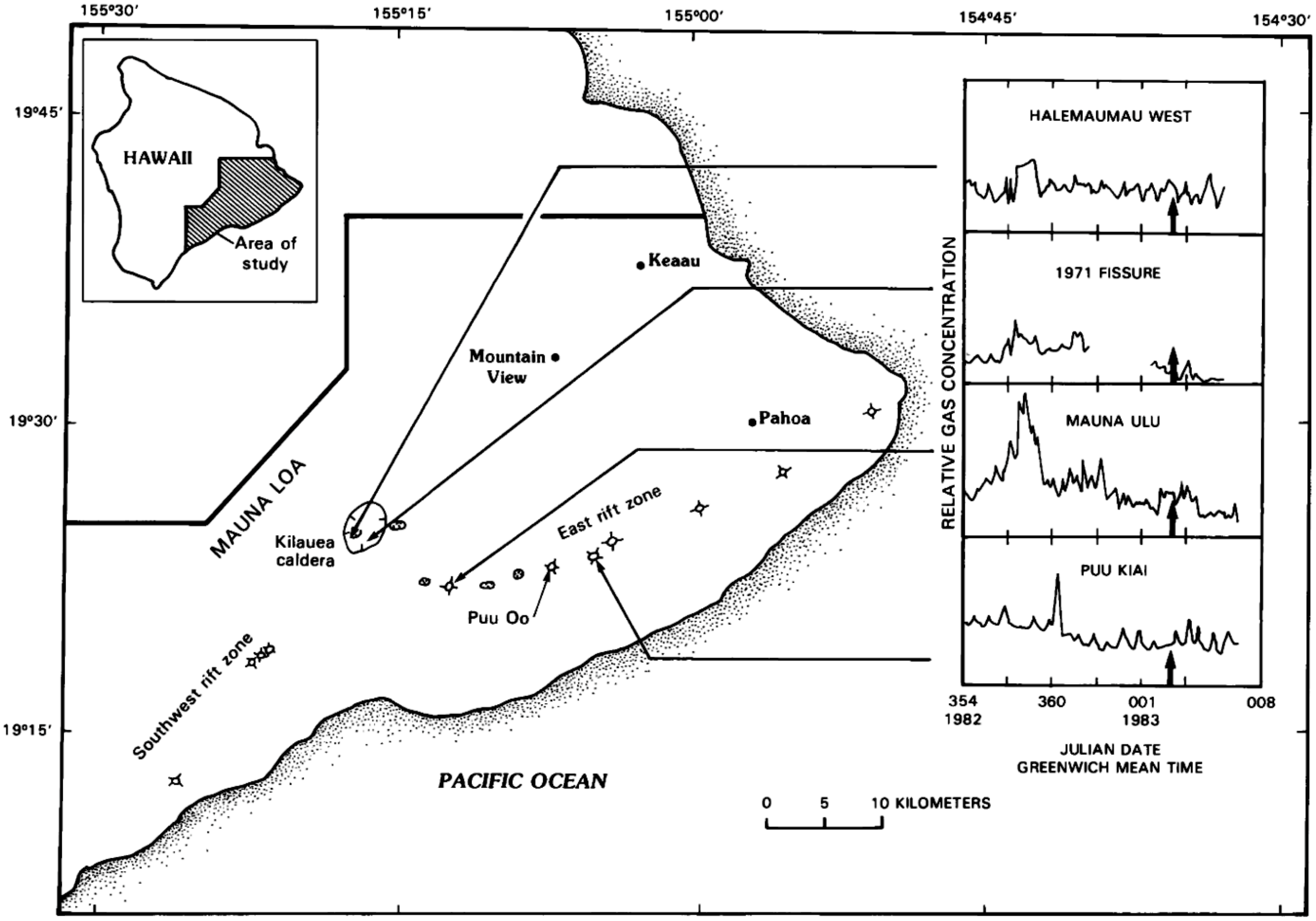

FIGURE 34.3.—Results from satellite-telemetered gas monitoring stations at Kilauea for late December 1982 to early January 1983. Occurrence of gas-emission event is essentially simultaneous at the two caldera stations and Mauna Ulu. Vertical arrow marks onset of eruptive activity at Puu Oo.

McGee, K.A. and Sato, Motoaki, 1982, The use of satellite telemetry for monitoring active volcanoes [abs.]: International Association of Volcanology and Chemistry of the Earth's Interior, Symposium on the Generation of Major Basalt Types, Reykjavik, Iceland, 1982, Proceedings, p. 109.

National Oceanic and Atmospheric Administration, 1983, The geostationary operational environmental satellite data collection system: Washington, D.C., National Oceanic and Atmospheric Administration Technical Memorandum National Environmental Satellite Data and Information System 2.

———1984, GOES data collection system and data processing system: Washington, D.C., National Environmental Satellite Data and Information System User Interface Manual, 132 p.

Shope, W.G., and Paulson, R.W., 1981, Data collection via satellite for water management: Transportation Engineering Journal, American Society of Civil Engineers, 107, no. TE4, p. 445–455.