Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section), 89 (1990) 263–267
Elsevier Science Publishers B.V., Amsterdam

Global data collection and the surveillance of active volcanoes

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(Received by publisher July 30, 1990)

ABSTRACT

Ward, P.L., 1990. Global data collection and the surveillance of active volcanoes. Palaeogeogr., Palaeoclimatol., Palaeoecol. (Global Planet. Change Sect.), 89: 263–267.

Data relay systems on existing earth-orbiting satellites provide an inexpensive way to collect environmental data from numerous remote sites around the world. This technology could be used effectively for fundamental monitoring of most of the world's active volcanoes. Such global monitoring would focus attention on the most dangerous volcanoes that are likely to significantly impact the geosphere and the biosphere.

Introduction

The International Geosphere/Biosphere Program (IGBP) will require "a long-term coordinated network of marine, and land-based measurements" (SCIGBP, 1988, p. 103) and a global network of observatories is anticipated. Some data will be collected by trained observers, but much of the data can be collected automatically by remote sensors. The primary purpose of this paper is to highlight the existence of an international network of satellites that can be used to relay these data rapidly and inexpensively from remote sites around the world to research laboratories in many different countries. One application of this network that relates to the IGBP would be to monitor the level of activity of the majority of the potentially active volcanoes of the world. Such monitoring would provide a basis for identifying those volcanoes most likely to erupt and would provide critical baseline data that could be used in conjunction with more detailed studies to try to predict the time and size of specific eruptions. The technology exists and can be exported easily and inexpensively to all countries. What is needed is development of the required international organization and a method for multi-national funding.

Satellite data relay systems

A wide variety of data relay channels exist on currently orbiting satellites. The system most suitable for economical collection of small amounts of data from a large number of remote sites scattered throughout the world is operated in the United States by the National Oceanic and Atmospheric Administration (NOAA) and utilizes a minimum of two Geostationary Operational Environmental Satellites (GOES) (McCallum and Nestlebush, 1983). Similar satellites are operated by the European Space Agency and the Japanese Meteorological Satellite Center. The Hydrometeorological Service of the USSR plans to launch a satellite in 1989. These 5 satellites will give complete global coverage except near the poles. Relay of environmental data is provided free of charge for appropriate users.

Data Collection Platforms (DCP) for use in the field are available from several manufacturers in the United States and Canada. These

0921-8181/90/$03.50

systems in their simplest configuration cost about (US) $3,000 and use a 12 V battery with an average current drain of around 30 mA. They can be powered at most latitudes by solar cells. The standard data channels allow transmission of at least 450 bytes of digital data once every 3 h. The global system can relay data from 100,000 DCPs. As of early 1989, 5600 DCPs were using the NOAA satellites relaying data on stream flow, water level, rainfall, temperature, radiation, magnetospheric activity, ground tilt, magnetic field, earthquake activity, etc. Many DCPs are contained in ocean buoys. DCPs are also available that receive as well as transmit, so that limited amounts of data can be sent back to individual remote sites to directly involve local personnel. More typically all of the data are received at a satellite tracking station and relayed over ground lines to the users. Local receiver sites, using a fixed dish antenna 5 m in diameter, can be built for under (US) $100,000 to receive the whole data stream. A new system is planned in the U.S. that will relay this data stream from a NASA tracking station back through a commercial satellite, DOMSAT, and then to receivers similar to those used to receive television channels from satellites that can be installed complete with decoding computer for under (US) $10,000. Thus data can be collected from remote sites throughout the world and relayed essentially instantaneously to many different receiver sites for rapid analysis. The GOES system is installed, tested, and proven with over a decade of experience. NOAA plans to launch several replacement satellites to extend the life of this system well into the next century.

Silverman et al. (1989) describe the use of the GOES telemetry system for routine and reliable collection of creep, strain, tilt, magnetic field and water level data from 100 DCPs in the western U.S. and the southwest Pacific. They modified the data rate to send small amounts of data every 10 min. The data are received directly from the satellite in Menlo Park, California, and processed by computer. If the computer notes abnormal changes in the data, it notifies the appropriate scientist using a standard beeper paging system. The scientist can then dial into the computer and evaluate the situation. This approach is being used in California in a unique experiment to try to predict the occurrence of a major earthquake (Bakun et al., 1987).

Bernard et al. (1988) describe use of the GOES system not only for collecting seismic and water level data to record and warn of tsunamis, but also for relaying the warning to local personnel within 2–3 min of detection of a critical threshhold by a central computer. Such immediate response is obtained by using a data channel on the satellite designated for immediate transmission of sporadic emergency data rather than regular, timed transmissions.

Satellite telemetry is typically much easier to use than land-based methods that often require line-of-sight between transmitters and receivers. At moderate latitudes the satellite antenna is pointed well above the horizon, even in mountainous terrain. Thus sensors can be placed with little concern for topography. There is little problem of radio interference or dealing with land-lines connected through many different telephone companies. Yet the data can be collected rapidly in a central location. Our experience has proven the satellite system more reliable than a complex system of land-based communication and much easier to install and operate.

The GOES satellites are in a stationary orbit high above the equator and provide continuous relay of data except possibly for a few minutes during a few days per year if available power is low during the vernal and autumnal equinoxes when the spacecraft is in eclipse. Polar orbiting satellites such as ERTS (Endo et al., 1974), which is no longer in use, and those that are part of the Argos system (Den and Hunter, 1988) relay data only when the satellite is visible from the remote site, typically for short periods of time every 6–12 h apart. These satellites fly at a lower altitude than the stationary ones so that the remote transmitters need less power and smaller antennas. The relayed data can only be received on relatively expensive antennas that track the path of the satellite.

Measuring volcanic activity

Over 500 volcanoes erupted in historic time and more than 1400 volcanoes have been active in the past 10,000 years (Simkin et al., 1981). The largest of these eruptions have significantly impacted the geosphere and the biosphere, but all of these events were at least an order of magnitude smaller that eruptions recorded in the geologic record within the past million years. Where and when will the next major eruption occur? Only a few dozen volcanoes are monitored intensively; hundreds are not monitored at all. Yet population is increasing rapidly near volcanoes where soil is fertile and the views are scenic. The 1980 eruption of Mt. St. Helens in Washington reminds us of the potential violence of nature. The 1985 eruption of Nevado del Ruiz in Columbia shows how devastating to man even a small eruption can be. Early warning of volcanic eruptions is made difficult by the large number of volcanoes around the world, the lack of continuous monitoring systems, and particularly the lack of baseline data. Scientists often must try to interpret evidence of a potential eruption without any clear data on when this volcano began reawakening.

Volcanoes become active when magma moves toward the surface typically along fractures. Movement of magma often causes deformation of the ground surface, small changes in the gravitational, magnetic, or electrical fields, and changes in ground temperature or the content of gases emitted. The greatest change associated with most eruptions, however, is a significant increase in the number of earthquakes and the amount of seismic energy released per unit time. Typically weeks to months before significant eruptions, there is an increase in local seismicity by as much as several orders of magnitude (Shimozuru et al., 1971; Endo et al., 1981). These changes may occur more rarely just hours before or as much as a year before an eruption. All major increases in seismicity, though, are not followed by eruptions. Thus seismicity alone rarely can be used to predict specific eruptions, but it does provide a reliable indication of the level of activity of a volcano and some estimate of the likelihood of an eruption. Careful mapping of earthquakes in the upper 10 km of the crust under volcanoes appears to provide an outline of the magma plumbing system (Ryan et al., 1981; Endo et al., 1981; Klein et al., 1987) suggesting that these earthquakes result from stresses caused primarily by the upward movement of magma and gases. Thus measuring the seismic energy release of these events does appear to reflect fundamental processes related to eruptions. Seismic activity can be measured by one or more sensors in the vicinity of a volcano. Most other potential precursors of activity must be measured high on the flanks of volcanoes or else within known vents where logistical problems can be severe.

Beginning in 1972, Endo et al. (1974) installed earthquake counters on 15 volcanoes in western North America, Iceland, and Central America The data were relayed via the Earth Resources Technology Satellite (ERTS) to Menlo Park, California. Ground tilt was also measured at 5 volcanoes. An order of magnitude increase in seismic activity was observed prior to the eruption of volcan Fuego in Guatemala in 1973. This experiment demonstrated the feasibility of a global volcano surveillance system. The ERTS system provided for relay of only 8 bytes of data that were reliably received only twice per day. Seismic data, however, is normally recorded continuously at rates of 100–200 bytes per second. Thus Endo et al. (1974) developed a simple event counter that counted the number of earthquakes of 4 different sizes. Far more sophisticated systems have been developed to compress seismic data (Massinon and Plantet, 1976; Stewart, 1977; Allen, 1978; Johnson, 1979). With the amount of data that can be relayed by GOES, it should be relatively easy to develop a seismic detector that will measure the seismic energy release per unit time from both local earthquakes and harmonic tremor in a manner similar to that being developed by Murray and Endo (1987). Additional data on specific earthquakes such as distance, azimuth, and angle of incidence of the waves might also be determined. Such systems, in quantity, might be packaged with the data transmitter, batteries, and solar panels for (US)$6000 to 10,000 each and could be shipped worldwide for installation by local personnel. For perhaps twice the cost, a more complete monitoring system might be built using a volumetric strainmeter installed in a shallow borehole (Sachs et al., 1971; Johnson et al., 1986).

Thus the technology exists to monitor most of the world's potentially active volcanoes. Such a system would provide important baseline data and could be used to focus limited scientific resources on the most dangerous volcanoes. What is needed is to develop the sensor and remote processing system and then to find an appropriate international program or organization to coordinate multinational funding and distribution. Each country could buy systems for their volcanoes or for volcanoes in other countries of interest. Thus such a global surveillance system could be built without a major infusion of funding from one country or agency. The data might be relayed simultaneously to local personnel and to several volcanology groups around the world.

Conclusions

Satellites can be used to relay data from thousands of remote sites around the world to many different research laboratories. Such systems might be of key importance to the IGBP and could be used to monitor efficiently the world's potentially active volcanoes.

Acknowledgements

I wish to thank Malcolm Johnston, Carl Mortenson, Mike Nestlebush, and Stan Silverman for information on the GOES system and Dave Harlow and Chris Newhall for reviewing the manuscript. Any use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey. Information on GOES is available from Chief, Data Collection and Direct Broadcast Branch (E/SP21), National Environmental Satellite Data and Information Service, National Oceanic and Atmospheric Administration, Washington, D.C. 20233. Information on Argos is available from Service Argos, 16 Avenue Edouard-Belin, 31055 Toulouse Cedex, France or Service Argos, 1801 McCormick Drive, Suite 10, Landover, Maryland 20785.

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