USING LOW-EARTH-ORBIT SATELLITES TO PROVIDE EARLY-WARNING AND DISASTER-ASSESSMENT MESSAGING FOR EMERGENCY MANAGEMENT

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ABSTRACT: There is a need for warning of impending hazardous conditions and reliable assessment of post-disaster conditions as crucial elements in Emergency Management. Low-Earth-Orbit (LEO) satellite systems can fill this need by relaying status messages from small, low-cost, low-power transmitters, through LEO satellites, to control centers. Such systems are independent of common carrier communication systems and are resistant to disruption during disasters. An existing system, Argos, is already used for one-way messaging and geo-positioning in applications such as prediction of volcanic eruptions, indication of seismic station status, hydrographic station monitoring, and hazardous materials tracking. A specific case study of an existing system for early warning of volcanic eruption is presented. A new satellite system, Starsys, will soon provide two-way messaging and geo-positioning worldwide.

Introduction

North American Collection & Location by Satellite can now provide timely warning of increased volcanic activity to civil authorities and the airline industry. We are putting together a coalition of governments, international industries, and scientists to implement a simple system, low in cost, to allow monitoring of many volcanoes that pose a hazard to civil aviation and local populations.

For early warning of volcanic eruption to have much utility to aviation, monitoring must be done on many volcanoes. The cornerstone to such wide spread volcano monitoring is affordable instrumentation coupled with global coverage. We have developed affordable instrumentation that can be deployed anywhere in the world. This instrumentation uses the Argos satellite system as the telemetry link.

Argos monitoring stations are self-contained and may be left unattended for one year or more. Hourly seismic event summaries are transmitted from each monitored site every day. This helps to detect increased volcanic activity, prompting organization of further field campaigns or remote observation. Permanent monitoring can be offered without range limit, because the Argos system has worldwide coverage.

For two years, CLS / Argos has worked to offer a complete system, made of 1) two types of stations (seismic recorder and physical-chemical parameters), 2) the Argos data transmission link, 3) the dedicated software for data readout. This system, which has been extensively tested on Etna and Kelut volcanoes, can provide warning of increased volcanic activity at a low enough cost to permit instrumentation on many volcanoes.

This document gives more information about the global system for volcano observation, now available from CLS/Argos. There is also information on how both the Argos and the new Starsys LEO satellite systems work.

Volcano monitoring

Most aviation experts agree that volcanoes should be more widely monitored. Three jumbo jets experienced engine flameout and nearly crashed in the 1980's. But the significant eruptions in the 1980's were mostly on volcanoes with few previously-observed eruptions. This is why

many experts are now calling for permanent systems on more volcanoes. Continuous volcano observation would provide a way of detecting early signs of activity. Monitoring more volcanoes would increase the probability of observing eruptions. It would help to protect aviation and civilian populations and to provide data for scientific studies.

When volcanologists study actively erupting volcanoes, they usually demand sophisticated observing stations, with high investment and maintenance costs. It is not feasible to establish permanent, sophisticated observatories on each volcano that poses a potential threat to aviation. Remotely monitored data collection platforms are a cost-effective alternative to large observatories. Argos-based platforms have many particularly attractive features: because they are reliable and drain little power, they can be left unattended for a year or more and transmit data several times per day. It is easy to protect and install the little equipment that is needed. In addition to geophysical parameters, they also transmit housekeeping data, i.e. their operational status and maintenance needs.

Data are relayed through low-earth orbit satellites for further processing. Increases in volcanic activity can be remotely monitored, and more intensive observations can then be made, initially using satellite images, and later, by installing additional instruments. This early detection system is of benefit to local populations, to scientists, and also to the aviation industry. The system is designed to be affordable in order to be installed on the vast majority of volcanoes that do not have manned observatories.

CLS Argos has worked with seismologists and volcanologists to define a basic volcano monitoring system. Some of these experts have now been using Argos data transmission for 10 years (INSU, French Institute for Sciences of the Universe). They have helped define the detection criteria for seismic events, as well as the short but significant data to be sent through Argos. The system includes field stations with Argos transmitters and dedicated software to access the data.

Stations

The stations we have developed have:

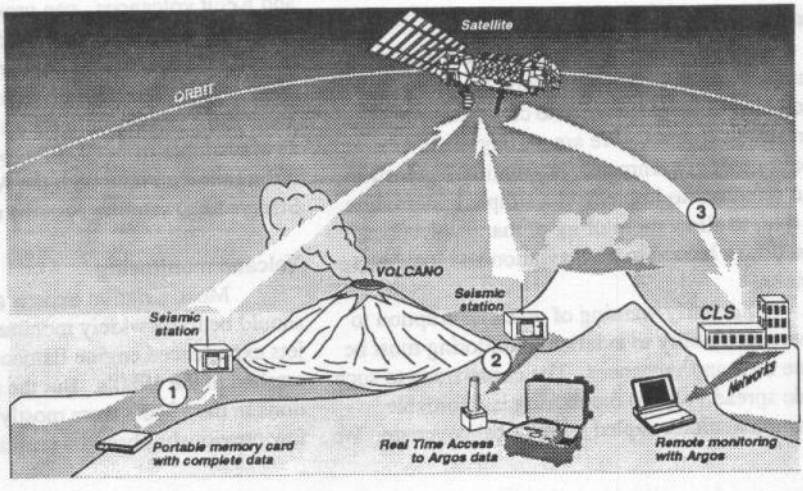
- high memory capacity so that data can be accessed on site,
- power supply by external batteries or solar panel,
- Argos transmitter for remote monitoring, with low power drain,

Three ways to access to data:

1- locally: full data set on removable memory card,

2- in line of sight and real time (several miles away from the platform), with radio receiver on Argos frequency,

3- with Argos satellite worldwide dissemination.



• transmission of housekeeping parameters.

The SISMO1 station is a stand-alone seismic station. The MONOA and the TAD 808 record slow-varying physical or chemical parameters using either off-the-shelf or custom-made sensors. SISMO1 is described in moderate detail. Further details on other hardware are available from the author.

Access to data

The system provides dual access to data locally, either by recovering the removable memory card (1), or by real-time, line-of-sight radio link using a receiver on the Argos frequency (2). All stations have programs for configuring the instruments and retrieving data. This can be done on site, using a portable PC, or in the observatory. Remote access to all your data is obtained from global and regional Argos processing centers (3). Data from a large number of stations can be read with a single program. The same platforms can be monitored from several places (even on different continents), by collaborative groups.

Advantages of the Argos transmission link

a) permanent access to data, in near-real time (results available in less than fifteen minutes when the platform is served by "regional processing" mode),

b) it tells that the station is working properly (housekeeping parameters),

c) it tells when critical events occur, so that imagery can be acquired,

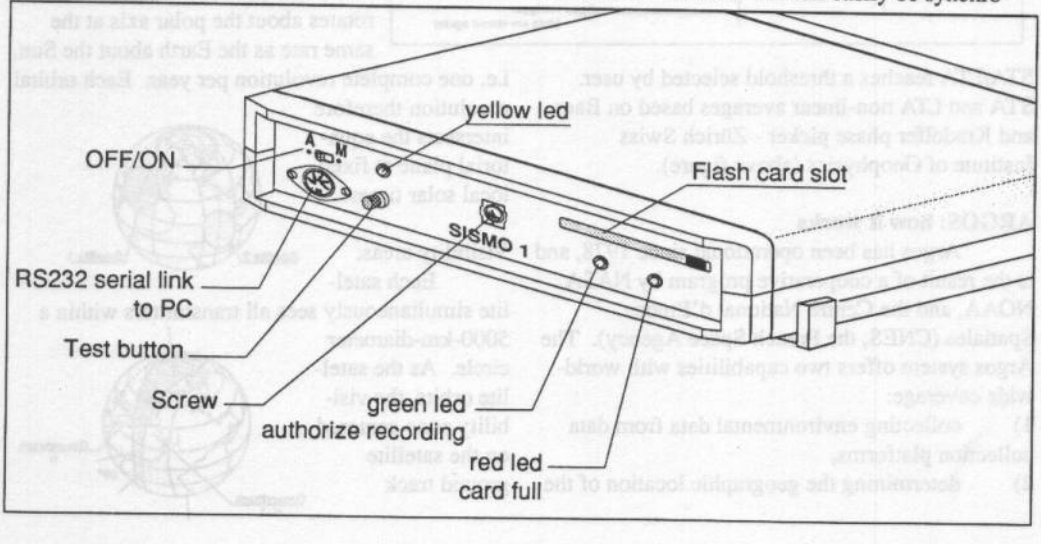
d) data are confidential but can be shared world-wide among authorized users.

SISMO1: the seismological platform

SISMO1 (shown below) is a portable datalogger that digitizes, processes and stores the ground velocity signal recorded by a geophone. It also transmits significant data via Argos. It is for two types of applications:

• long-term monitoring: one to three stations per volcano, with transmission of mean energy, number of seismic events relative to given thresholds, duration of tremors relative to given thresholds. The full data set is stored on credit-card size removable memory boards, with storage capacity of 1 to 4 megabytes.

• short-term comprehensive seismic studies: installation of a network for locating and tracking seismic events. The network can easily be synchro-



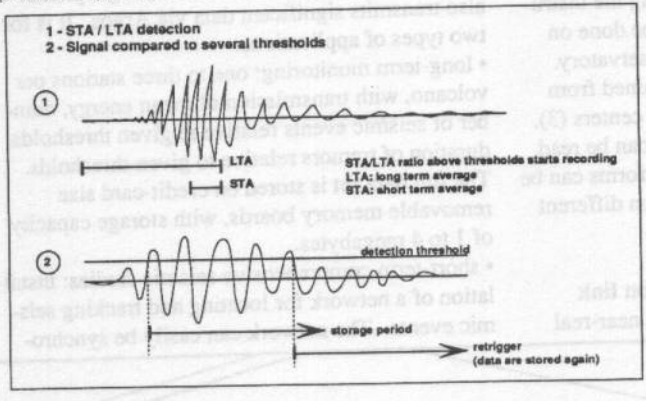
nized by Argos satellite accurate time-coding.

Event Detection

The signal is continuously digitized, stored in a ring-buffer, and compared to detection criterion. All criteria selected by user. Event and pre-event are stored in memory. Automatic gain is latched during event detection. Events are time tagged within 1/200 second.

There are three recording modes:

- continuous upon remote start-up
- continuous upon pre-defined time slots
- short term to long term average ratio criterion (STA/LTA): SISMO1 starts recording when



STA/LTA reaches a threshold selected by user. STA and LTA non-linear averages based on Baer and Kradolfer phase picker - Zürich Swiss Institute of Geophysics (above figure).

ARGOS: how it works

Argos has been operational since 1978, and is the result of a cooperative program by NASA, NOAA, and the Centre National d'Etudes Spatiales (CNES, the French Space Agency). The Argos system offers two capabilities with world-wide coverage:

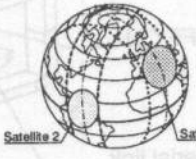
1) collecting environmental data from data collection platforms,
2) determining the geographic location of the platforms.

The space segment

The first satellite was launched in 1978, and new satellites are launched every one or two years. The space segment comprises two NOAA satellites in simultaneous low earth orbit. They receive all transmissions from platforms in visibility during the entire orbital revolution. The signals are stored by tape recorders on board the satellite, and downloaded when the satellite passes above one of the ground stations. The onboard equipment also retransmits the data in real time. Presently, three satellites are in operation (NOAA-F, NOAA-H, NOAA-D), and one other is in backup.

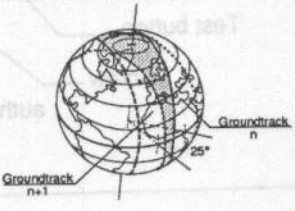
The satellite orbits:

- Worldwide coverage with polar orbits
- Altitude: 830 km and 870 km for the two satellites.
- Period: approximately 101 minutes. That makes 14 orbital revolutions per satellite per day.
- Sun-synchronous: the orbital plane rotates about the polar axis at the same rate as the Earth about the Sun, i.e. one complete revolution per year. Each orbital revolution therefore intersects the equatorial plane at fixed local solar times.



Visibility areas:

Each satellite simultaneously sees all transmitters within a 5000-km-diameter circle. As the satellite orbits, the visibility zone centered on the satellite ground track



sweeps a 5000-km swath around the Earth that passes over the North and South poles.

As a result of the Earth's rotation, the ground tracks and swath shift 25° west (2800 km at the Equator) about the polar axis from one revolution to the next. There is therefore sidelap between successive swaths.

The Argos platform

An Argos platform is a data acquisition module (or datalogger), which sends data through a transmitter. Each platform transmits a short message (less than 0.92 s) by phase modulating a carrier frequency of 401.650 MHz. This frequency must remain very stable, because the location of mobile platforms is based on a Doppler effect calculation. Each platform repeats its message regularly, for example every 200 seconds. The message starts with an identification number, to make each platform unique. The message generally stays the same for a set period, to insure that it will be collected. Message length is selectable from 32 to 256 bits per message. Presently, over 4,000 Argos platforms are active world-wide.

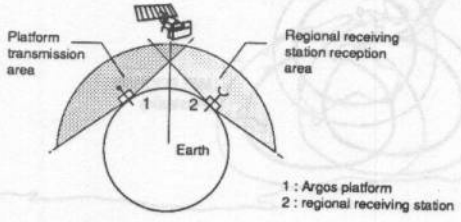
How data are relayed by the satellite

The Argos onboard equipment receives all messages transmitted by platforms within the satellite visibility area. Messages are received, processed and transmitted to ground in real time. They are also stored on an onboard recorder, and the full data set is retransmitted to each of the three ground stations: Lannion (France), Wallops (Virginia, USA), Fairbanks (Alaska, USA).

When data are available to users

Regional coverage:

The realtime downlink is for platforms close to receiving stations: the satellite sees the platform and the station simultaneously. In other words, the platform and station visibility circles overlap, and the satellite ground track crosses the overlap area. Data from platforms processed in regional mode are available to users more quickly. These platforms are also processed in Global coverage mode. Platforms within the heavy lines on the map are received in regional coverage mode.



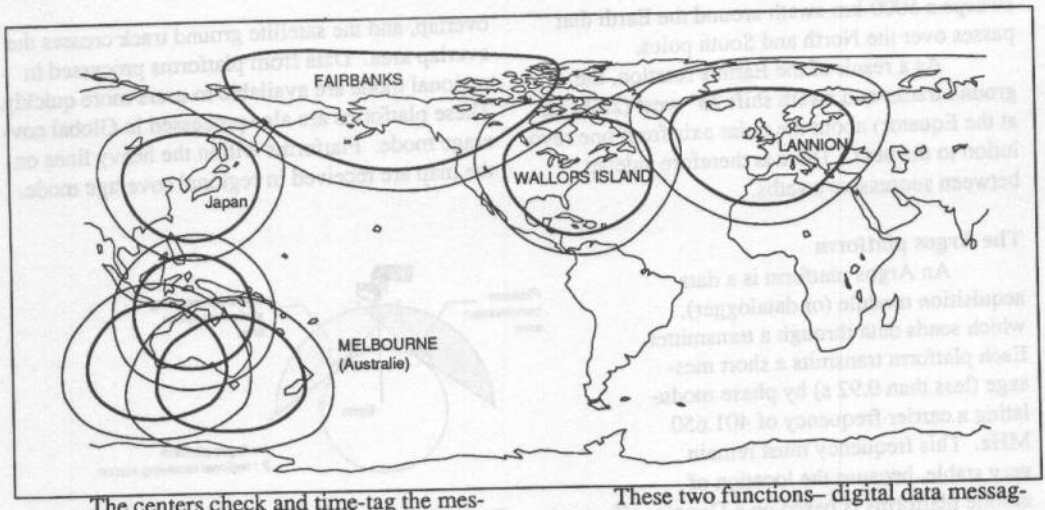
Global coverage:

When the platform is not in a regional coverage area, only recorded data are available. They are downloaded when the satellite passes above a ground station, then transmitted to one of the Argos processing centers.

Throughput time (delay from when message is received by satellite to when it is available to users) improves constantly. In global mode, 60% of messages are available in less than two hours. In regional mode, 60% of data are available in less than 15 minutes.

The Argos processing centers

The data received at the ground stations are relayed to two Argos data processing centers. These are designed for maximum availability and minimum data loss. One center is in Toulouse (France), the other in Landover (MD, USA). Centers in Tokyo and Melbourne have recently been opened, and provide regional coverage for platforms in the south-west Pacific. Each center operates around the clock, every day of the week. Each has three identical computers and thus offers internal redundancy: users' data can be processed even if only two computers are operating.



The centers check and time-tag the messages, and sort them by platform. On request, sensor data can be converted into physical values. Users access their results via an on-line dissemination system, supplying the last four days of data plus the current day. Data are also archived and can be recovered off line (tapes and floppies). Most users get their data via the Internet, but some connect to the centers through packet switched public networks (X25 protocol) or automatically receive updates by fax.

Introduction to Starsys

There is a need for two-way, rapid messaging of a sort that Argos is not designed to provide. To meet this need NACLS has joined Hughes-STX, to develop Starsys Global Positioning, Inc. The mission of Starsys is to develop a low Earth orbit (LEO) mobile satellite service (MSS) for providing low-cost, two-way, wireless transfer of data messages between mobile terminals and distant fixed-position ground stations. In addition to data messaging, the system will also be able to provide customers with accurate locations of their remote radio transmitters, thereby allowing tracking of mobile goods, vehicles, and individuals.

These two functions– digital data messaging and position determination, individually or combined– enable a wide variety of applications which are both useful and valuable for business, industry, government, and private use.

The low-cost design and operation of the Starsys system is expected to make Starsys services available and affordable to millions of users throughout the world. This low cost solution to a broad communications need will create strong demand for low Earth orbit mobile satellite service.

Starsys System Overview

Starsys Global Positioning, Inc., was formed to provide inexpensive, satellite data communications services for very large markets in a variety of applications. The system will transfer via satellite brief digital data messages between mobile radio transmitter/receivers (mobile user terminals) and distant ground stations. Through ground computer processing of radio signals, Starsys will also be able to determine the geographic location of transmitting mobile user terminals.

The company is an applicant to the United States Federal Communications Commission

(FCC) for a license to operate this system. License approval is anticipated early in 1994, with initial operations beginning within two years of licensing. Commercial operations will begin with two satellites in 1996, rapidly increasing to five to six satellites on orbit.

The development plan calls for twenty-four satellites to comprise the full constellation. The full constellation, with overlapping footprints, will provide near constant coverage, assuring that the mobile terminals are almost always able to contact, or to be contacted by, a ground station immediately.

Starsys system capabilities will:

- Let industry or government routinely check the environmental conditions of remote areas or sites; let utilities quickly gather remote meter data
- Allow security and status evaluations of remote sites and equipment
- Allow remote control of valves, switches, and other control mechanisms to regulate power and utility functions
- Allow individuals to send and receive personal and emergency messages
- Allow shippers or receivers to check the condition of goods in transit, or locate and track the movement of special interest cargos
- Enable quick position determination for recovery of lost or stolen vehicles
- Permit very low-cost two-way message traffic between fleet operators and mobile units at virtually any time at any location.

The very low cost Starsys global positioning and two-way data transfer system uses relatively simple low Earth orbiting satellites to relay digital data transmissions between distant communicating entities. Inexpensive, low-power, battery-operated remote radio receiver-transmitter units can originate data messages automatically, or can respond to "polling" by the ground station to originate a message.

These transceivers can allow Emergency Managers to: 1) receive early warning of changes in nominal levels of hazardous activities or events; 2) assess post-event status of infrastructure or ambient environmental conditions. The system can be entirely free of regional post-event conditions that can degrade ground-based communications systems.

Ground stations collocated in the satellite "footprint" with the transmitting unit send data to and receive it from the remote unit. All Starsys message traffic to and from remote terminals goes through the ground-based processing and analysis center which encodes the messages for spread-spectrum frequency transmission, and decodes the incoming signals for message routing.

Starsys progress

As part of its ongoing development process, Starsys has completed an initial satellite experimental program using S80/T, which was launched in August 1992. The experimental program was designed to test and validate the Starsys spread-spectrum transmission concept and verify operational capabilities in the allocated frequencies. Initial results have confirmed the viability of the spread-spectrum transmission mode, allowing further progress toward development of the system.

A full description of the Starsys concept is available from the author.

Conclusions

The need for regional or global networks for both early warning of disasters and rapid post-disaster assessments can be met now with data messaging through Argos, a low Earth orbit satellite system. Argos has a proven track record, with over 4,000 data collection platforms monitored world-wide today. A high-capacity, low-cost, two-way data messaging system, called Starsys, is under development, and will be available in 1996.