FIRST RESULTS FROM OPERATIONAL VOLCANO MONITORING IN THE CANARY ISLANDS

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ABSTRACT

Indra Espacio and the Spanish Volcanic Research Network have started a project for operational volcano monitoring demonstration in the Canary Islands in the frame of an ESA contract using ERS interferometry. The new service shall complement the information derived from field deployed instrumentation in the archipelago and shall be used for decision making in volcanic risk linked to the Civil Protection Authorities. The preliminary results from the service, those obtained from the processing of a selection from the ERS historical archive of the last decade, have unveiled unknown displacements out of the areas traditionally being monitored by field instrumentation. These results have conditioned the development of new surveying campaigns and are revolutionising the way the volcano monitoring is being performed in the archipelago and of course shall pave the way for the achievement a self-sustained service beyond the ESA funding.

INTRODUCTION

The application of space technologies for the management of emergency situations has a huge development potential. However, there is still a real need to bridge the gap between the space data service providers and a collection of “end users” –civil and governmental authorities- involved in risk management that can clearly benefit from such technologies.

The advantages of using satellite systems to facilitate Decision Making for emergency or natural hazard management can readily be demonstrated using to-day satellites and it is a key step for the definition of dedicated future missions. In particular, the well known differential interferometry (DINSAR) is a straight-forward application [1], and one of the best suited for its operational application.

Within this context, ESA has launched a project for the promotion of space technologies for supporting the management of natural disasters. Indra Espacio in collaboration with the RIV (Spanish Volcanic Research Network) was awarded the DECIDE-VOLCANO project in order to demonstrate the feasibility of using Earth Observation technologies for operational decision support demonstration at a volcanic risk scenario like the Canary Islands. An extended description of the project scope can be found in [2].
DECIDE-VOLCANO PROJECT OVERVIEW

DECIDE-VOLCANO project was started in September 1999 and it is currently on-going. This project is expected to bridge the gap between the Satellite technology users group (the satellite ground segment and the value added companies) and the potential end user of this technology in the frame of decision making upon the management of volcanic risk (Civil Protection Authorities and volcanology research teams) in the Canary Islands.

The project consortium includes two branches. By one side, Indra Espacio (the prime contractor and value added company) which provides its expertise in Earth Observation technology and by the other side the Spanish Volcanologic Network, RIV, as the end user, responsible (by law) for the monitoring of the Canarian volcanoes, in close co-operation with the Civil Protection Authorities, which has not used EO technology up to date.

The goal of the project is to commit the end user, the volcano specialist, to use the EO technology on an operational basis for decision making. INDRA’s role will be to transfer the SAR technology to the end users, customising it to his needs, and supporting them during the execution of the project as shown in Fig. 1. For this purpose, INDRA has set up a customised version of its INSAR commercial software EPSIE 2000 at the RIV facilities and taken care of the training so that RIV’s personnel is able to operate the system on their own.

The RIV has proven to be a truly committed end user, and after the completion of the project, they are willing to operate the EO system on its own on a regular basis. The achievement of a self-sustained status is guaranteed by the operational status and the results achieved during the project execution as it will be shown in the following sections.

DECIDE project is organised in three phases, each one lasting 6 months:

- Service specification, integration and training of RIVs system operators.
- Pre-operational service. Processing of historical archive and system validation.
- Exploitation phase. Steady state operational monitoring of volcanic risk.

**Future scenario after DECIDE**

Fig. 1. Future scenario after the DECIDE project: the decision making chain has adopted EO technology on an operational basis.
THE SCENARIO AND THE CURRENT MONITORING SYSTEM

The Canary Islands—with a population about 1.6 million people—are a well known volcanic area, i.e. there is a high probability of future volcanic eruptions over their territory. In historical times, there have been reported a dozen eruptions in the Islands of La Palma, Tenerife and Lanzarote, being the last one Teneguía volcano (La Palma, 1971). In the other Islands—save for La Gomera—there have been many recent eruptions although beyond the short 500 years historical register of the Islands.

Usually, any kind of volcanic eruption is preceded (weeks, days) by some precursors (Earth tremors, ground deformations, gravimetry and electromagnetic variations, chemical modifications in smoke emissions, etc.) which can be detected by especially on-site deployed equipment as shown in Fig. 2. The interpretation of the data from these instruments requires a deep knowledge of the volcanism mechanism of the area under study along with the knowledge of the instrument response in previous eruptions or crisis.

One of the main goals that faces volcanologists who are researching an active volcano area instrumentally observed, is to define the most suitable monitoring system, a task that is particularly difficult in the absence of recent activity. The task not only takes into account the technical optimisation of the monitoring systems, but also their economic and scientific profitability. Traditionally, observations of seismic, hydrologic, or fumarolic activity have proven useful. Yet, in the light of the IAVCEI’s recommendations regarding routine monitoring, geodetic measurements are being used more and more extensively in active volcanoes and have been shown to be a reliable eruption precursor.

However, it becomes harder to predict future eruptions when their likelihood is not limited to a specific volcano but to a wide active volcanic region. This is the situation in the Canary Islands, where there is an active stratovolcano, the Teide (Tenerife), and monogenetic historic volcanism scattered over several islands. This is a typical case in which the volcanic monitoring system must be carefully designed. The system must be efficient, but must also make full use of existing facilities and have acceptable installation and running costs, in line with the current inactivity.

These facts make the volcano monitoring in the Canary Islands a very demanding issue which requires the collaboration of all the institutions (scientific and political at all levels—central, regional and municipal government—).

The monitoring of a volcanic area cannot be limited to a single warning factor but it has to take into consideration the data from different origins; in particular, it should be considered: Seismic activity (Earth tremors), ground deformation (geodesy), geomagnetic field and fumarolic activity. Present volcano monitoring in the Canary Islands relies mainly on the seismic and geodetic networks, which cover the whole archipelago, but with a higher density over the most probable eruption scenarios. An eruption may take place at any island, although Lanzarote, Tenerife, La Palma and El Hierro do have a higher probability. Furthermore, an explosive eruption is feasible in Mt. Teide in Tenerife.

RIV’s reporting to Civil Protection Authorities is based upon the analysis of the data extracted from the volcanic precursors measurement. Present deployed equipment includes dense seismic networks, water tube clinometers, magnetometers, etc. This equipment is networked with a high reliability satellite telemetry provided by INDRA. Besides of the permanent deployed equipment, extra information is generated from periodic—and expensive—surveying campaigns over the geodetic networks (precision levelling and GPS).

Fig. 2. Artist’s view of the present volcano monitoring equipment in the Canary Islands, including satellite telemetry.
THE EARTH OBSERVATION APPROACH ADVANTAGE

Up to now, the volcano monitoring systems did not include any EO technology. So, what could be the benefits of SAR interferometry for volcano monitoring in the Canary Islands? Next item list describes the advantages of the new technique over the selected scenario:

- SAR differential interferometry delivers information on ground deformation with a centimetric accuracy. This is a well-known volcanic precursor since observation of ground deformation allows the detection of re-activation at mid and long term and can be used as a clue in order to predict future eruptions.
- Remote sensing allows monitoring of areas during eruption, when using field deployed instrumentation becomes unfeasible or hazardous.
- Whereas geodetic surveying measurements provide information only over some selected points, SAR interferometry provides wide area images (100x100 km) showing the deformation field trends along all the area of interest allowing the extrapolation of the field measurements. Such images are geocoded and can be easily fed into a GIS for analysis purposes.
- SAR imaging allows continuos monitoring of the areas of interest. Present ERS-2 configuration allows 35-day revisit time. Furthermore, if ascending/descending or overlapping passes are considered, the periodicity can be increased even up to 4 images every month.
- SAR imaging allows the monitoring of sparse volcanism scenarios like the Canary Island. Furthermore, the island’s dimensions perfectly match the ERS frame structure as shown in the coverage image in Fig. 3.
- DINSAR can be a very cost-effective tool to monitor active volcano in remote areas without deployed instrumentation and difficult access.
- DINSAR allows long-term stability analysis, which is one of the recommended techniques for volcano monitoring. Weather and land cover (scarce vegetation) of the area a most suitable for long time baseline DINSAR.
- Finally, we must state that the yearly operation cost of an INSAR system is quite under an order of magnitude of the cost of a traditional field based instrumentation monitoring system (not to say of the initial cost!)

PROCESSING OF THE HISTORICAL ARCHIVE

After the system installation in March’2000, the processing of the image archive started at the RIV’s facilities by their own personnel. This archive consists of 30 images acquired since 1991 over the three islands selected for the project (Tenerife, Lanzarote and La Palma). During the last 6 months, the processing of this data set has addressed the following objectives:

- Assessment of long term stability coherence. This was easily achieved thanks to the volcanic nature of the archipelago. Fig. 4 shows two examples of coherence; notice the superb coherence in exposed rocks area in Lanzarote’s Timanfaya Natural Park and in Tenerife in Las Cañadas surrounding Teide. Quality interferograms have been delivered in Tenerife with over 8 years time span.
- Cross check of the INSAR data information collected by the field instrumentation during the last years. Mainly the geodetic networks in Tenerife and the data from the Geodynamics laboratory in Lanzarote. During the last years, the instruments yielded no movement and this was assessed by the SAR.

Fig. 3. This image shows an example of ERS coverage (from ESA’s DESC software) over the Canary Islands. Some descending ERS frames have been highlighted over Lanzarote, La Palma and Tenerife.
• The historical archive is needed in order to have images available from the full perpendicular-baseline-dead-band in order to have always a suitable mate for any future incoming image during the operational processing. As an example of the achieved coverage, Fig. 5 shows the distribution of baselines along time covering a 700m orbit gap in the frame corresponding to Tenerife.

• Extension of the area under monitoring. The field instrumentation covers only a part of each island leaving a large area uninspected. The SAR provides the full picture and this has yielded an unexpected result: movements were detected out of the reach of traditional field instrumentation as described in the following section.

• Overall system performance validation.

• Analysis of atmospheric artefact impact. It has been assessed the need for many images in order to avoid their impact since the displacement detected are small (<10cm).

FIRST RESULTS: DETECTION OF UNEXPECTED MOVEMENTS

The processing of the SAR data set over Tenerife has allowed the detection of two unexpected movements in the island that were out of the reach of the traditional geodetic network that up to date were deployed only in the surroundings of Teide every 2 years. Fig. 6 shows the location of the traditional monitoring network in Teide and the movements detected in the Northwestern ridge, in a recent colada with eruptions in 1909 (Chinyero) and 1706 (Arenas Negras).

The two detected spots have yielded 10 and 3cm vertical displacement in 8 years respectively. Such movements are having a large impact in the monitoring strategy. As a first consequence, an exceptional field campaign was made this summer by reobserving a GPS network (first deployed in 1995 around the whole island by the National Geographic Institute) and densifying it around the new areas of interest. The results from the campaign, not processed yet, shall be used as an enforcement and validation of the SAR data.

The detected displacements are small and very local, i.e. the two covered areas are about 3 and 15km² respectively. This means, that a geodetic network designed not to miss such a deformation would have had to have a huge density (Tenerife has 2034 km²). This fact highly enforces the need for INSAR as an operational monitoring tool in the area.

Fig. 4. Sample coherence images with over a year time span. Left: Tenerife; notice the high coherence in Teide Caldera, Las Cañadas, in the center of the island and the coladas in the Northwestern ridge. Right: Lanzarote; notice the high coherence in Timanfaya (left) and La Corona (up right).

Fig. 5. Perpendicular baseline vs. time.
CONCLUSIONS AND ON-GOING ACTIVITIES

The project is having a large impact and it is revolutionising in the volcanic risk monitoring strategy in the archipelago. Not only the feasibility of the technique has been assessed, but also it has been demonstrated that it can operationally yield results that could not be achieved by other means. In brief, the results from the GPS campaign will be available and full geophysical analysis of the data will be performed. Furthermore, the last phase of the project shall be initiated and the operational processing of a new SAR image will be performed every 35 days.

The obtained results guarantee the continuation of the service beyond ESA funding and the achievement of a self-sustained state by granting funding from Civil Protection Authorities.

In a second stage of the project, a Southamerican project extension is envisaged to start in Ecuador in collaboration with CLIRSEN (Centro de Levantamientos Integrados de Recursos Naturales mediante Sensores Remotos) for the monitoring of Ecuadorian volcanoes applying the same methodology than in the Canary Islands.

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REFERENCES


Fig. 6. Left: location of the traditional monitoring network in the surroundings of Teide (yellow) and the two spots detected in the Northwestern ridge. Center: zoom of the area of interest showing the two deformation spots. Right: one of the deformation spots detected in Tenerife (the Northern one, in Garachico). Each colour fringe represents 2.8cm ground displacement in the satellite line of sight.