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BEYOND Center of Excellence: geophysical activity 'seen' from space

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Abstract

BEYOND Center of Excellence primarily builds upon state-of-the-art optical remote sensing technologies, differential interferometry techniques and Persistent Scatterer methods. The resulting products are integrated with in-situ observations from the National Seismological Network, the NOANET GPS network, and the ENIGMA magnetometer network established at NOA, to monitor the geodetic activity in Greece and beyond, interpret geophysical phenomena, assess and map damages after catastrophic events. Characteristic examples of studies that have been conducted in the framework of BEYOND are highlighted in this work. Using satellite radar interferometry techniques we observed the geophysical activity that took place at Santorini volcano in early 2011, and detected and estimated a clear and large inflation signal in the line-of-sight direction, with a radial pattern outward from the center of the caldera. We have also estimated crustal deformation associated with the mainly right-lateral 3.2.2014 Cephalonia earthquake (Mw5.9) with high resolution TerraSAR-X and COSMO-SkyMed imagery. These measurements are correlated with post-earthquake damage assessment activities using UAV flights over the inflicted area. Finally, we present a time-series analysis using ERS and Envisat Synthetic Aperture Radar data for mapping diachronic ground motions in Athens/Attica, to showcase the significance of the accurate, seamless and consistent monitoring of subsidence in an urban environment.

Keywords: Radar interferometry; geo-hazards; PSI, damage assessment

1. INTRODUCTION

The onset of the new Millennium, found remote sensing scientists, geophysicists, geodesists, and engineers equipped with powerful new tools for measuring crustal deformation via Earth Observation. The growing flow of satellite data, along with the development of innovative algorithms and processing chains, have allowed the systematic mapping of surface deformation, pertinent to earthquakes, volcanic eruptions, landslides and ground subsidence occurring from manmade activities, leading to the enhancement of our knowledge and understanding of the manifestation of several geophysical phenomena and the processes that govern them.

Radar interferometry has highlighted the value of remote geodetic measurements for estimating ground displacement with unprecedented spatial coverage and accuracy. Interferometry is based on the simple idea that by sensing the same object or scene twice, in separate times, one can identify the changes that the observed object or scene has undergone between these two distinct time instants. The radar transmits successive pulses to the Earth from a distance, from two slightly different locations and at different times, and collects the backscattered echoes, leading to an interference pattern, analogues to classic physics experiments. This pattern has an invaluable geodetic measurement potential.

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Initially, radar interferometry was applied to measure deformation that was inflicted after abrupt catastrophic events, like an earthquake, or rapidly deforming calderas [1]. In time, new techniques emerged, which exploit time series of satellite observations to generate maps depicting surface displacement rates. The Persistent Scatter Interferometry concept [2, 3] is based on the detection of stable targets that do not change their scattering characteristics over time and remain coherent under all imaging geometries. Hence, the methodologies have evolved to such a level that radar interferometry can be used as if a very dense network of precise ground-based geodetic instruments was deployed.
These technologies are primarily used in the framework of BEYOND Center of Excellence which is discussed in the following section. These techniques, integrated with measurements from in-situ geodetic and seismological observations, lead to the generation of high scientific value products. An indicative selection of such products is presented herein, representative for the monitoring of different geophysical phenomena, namely volcanic activity, earthquake- related deformation, and surface displacement in an urban environment.

2. BEYOND CENTER OF EXCELLENCE FOR MONITORING GEOPHYSICAL DISASTERS

The recently established Centre of Excellence for Earth Observation based monitoring of Natural Disasters in south-eastern Europe, BEYOND [4] aims primarily to set up innovative integrated observational solutions to operate space borne and ground-based monitoring networks in a complementary, unified and coordinated manner. The research portfolio covers a broad spectrum of phenomena, addressed under the three research domains of BEYOND: meteorological and human induced hazards, geophysical hazards, and atmospheric pollution and air quality.

Considering geophysical applications, BEYOND primarily builds upon state-of-the-art optical remote sensing technologies, differential interferometry techniques and Persistent Scatterer methods. The resulting products are integrated with in-situ observations from the National Seismic Network [5], the NOANET GPS network [6], and the ENIGMA magnetometer network [7] established at NOA, to monitor the geodetic activity in Greece and beyond, interpret geophysical phenomena, assess and map damages after catastrophic events (Figure 1, left). The aim is to become a focal point as a regional observational network for monitoring geophysical activity, based on an integrated and interdisciplinary approach.

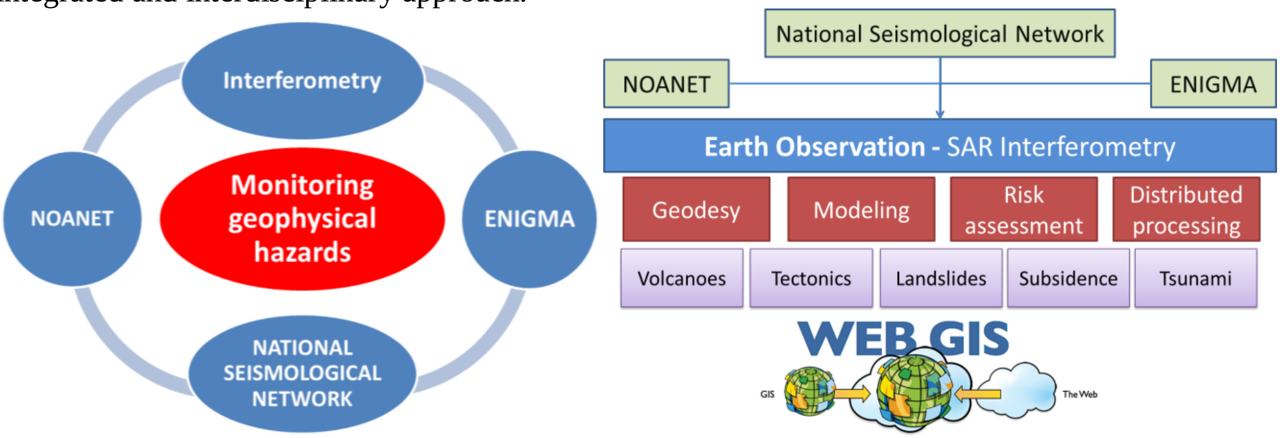

Figure 1. The observational infrastructure available in BEYOND (left) and key activities foreseen in BEYOND (right).

The key priorities of BEYOND are depicted in Figure 1, right. Through the effective integration of space-based information using Synthetic Aperture Radar (SAR) imagery, with ground-based information of the in-situ monitoring networks, BEYOND is generating products and services to serve a wide base of institutional stakeholders and the scientific user community. The four research pillars addressed include satellite geodesy, the modeling of the geophysical phenomena and the processes that govern them, the estimation of geophysical hazards and the distributed processing of

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the big archives of SAR imagery using leading edge cloud computing and GPU processing technologies. The phenomena which are being studies include volcanic eruptions, tectonic motion and earthquakes, landslides, man-made subsidence and tsunamis. It is envisaged that the total set of products, flagged with an either operational or pre-operational status, will be disseminated via a dedicated web-GIS platform, currently under development.

3. PRODUCTS AND SERVICES

This section contains a series of indicative products that have been generated in the framework of BEYOND Center of Excellence and a brief presentation of the main services which are available in the same context.

3.1 The Santorini inflation episode

Recent studies have indicated that, for the first time since 1950, intense geophysical activity is occurring at the Santorini volcano [8, 9]. Analysis of satellite interferometry data was performed using well-established techniques PSI techniques, producing dense line-of-sight ground deformation maps. The displacement field was compared with GPS observations from ten continuous sites installed on Santorini. Results show a clear and large inflation signal, up to 150 mm/yr in the LOS direction, with a radial pattern outward from the center of the caldera (Figure 3). The deformation inferred from GPS and InSAR is modeled using a Mogi source located north of the Nea Kameni island, at a depth between 3.3 km and 6.3 km and with a volume change rate in the range of 12 million m^3 to 24 million m^3 per year. The latest InSAR and GPS data suggest that the intense geophysical activity has started to diminish since the end of February 2012 [10].

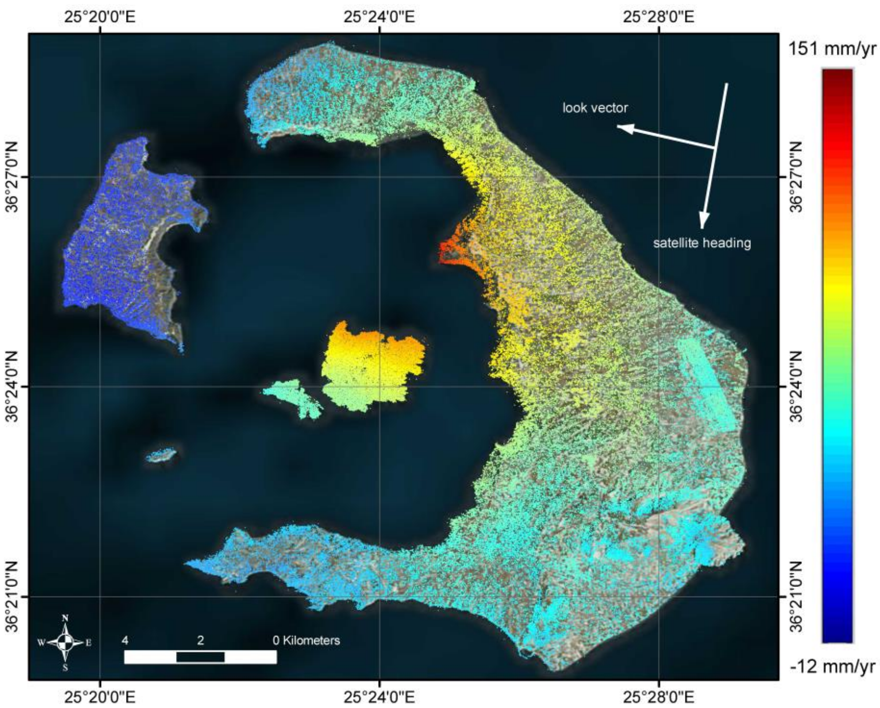

Figure 3. Line-of-sight velocities of the persistent scatterers, estimated for the time span March 2011 – April 2012.

In the same direction, a complimentary modeling application for the simulation of volcanic ash dispersion has been customized for Santorini. This system is based on a detailed daily weather forecast model accompanied by a Lagrangian dispersion model and it has been designed to provide an early warning system for volcanic ash. This information is of particular interest for aviation safety, health and weather and climate studies. Figure 4 depicts a simulated scenario of volcanic ash dispersion for Santorini. The hypothesis assumes 60 hours of continuous emissions at a 1.5 km height column.

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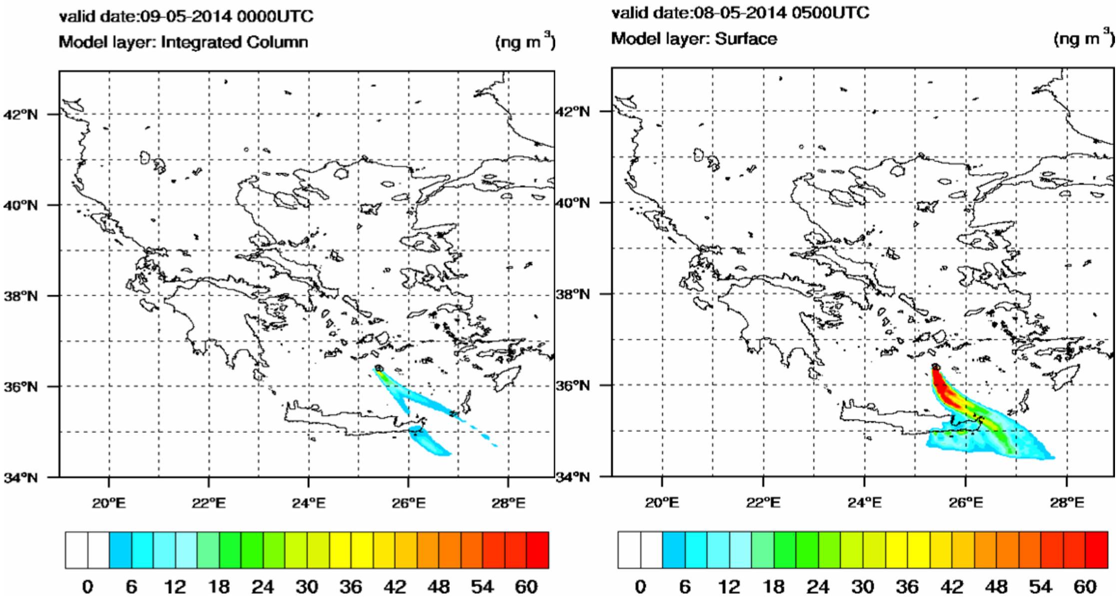

Figure 4. Volcanic ash dispersion in Santorini, airborne (left) and deposited (right).

3.2 The Cephalonia earthquake

On Jan. 26, 2014 st 13:55 UTC an Mw 6.0 earthquake struck the island of Cephalonia, Greece, followed only five hours later by a Mw 5.3 aftershock, and by an Mw 5.9 event on Feb. 3, 2014 at 03:08 UTC. Extensive structural damages and widespread environmental effects were induced throughout the Paliki peninsula and along the eastern coast of the Gulf of Argostoli. Three-dimensional crustal deformation estimated with high resolution TerraSAR-X and COSMO-SkyMed imagery and associated with the mainly right-lateral 3.2.2014 Cephalonia earthquake is presented in Figure 5 [11].

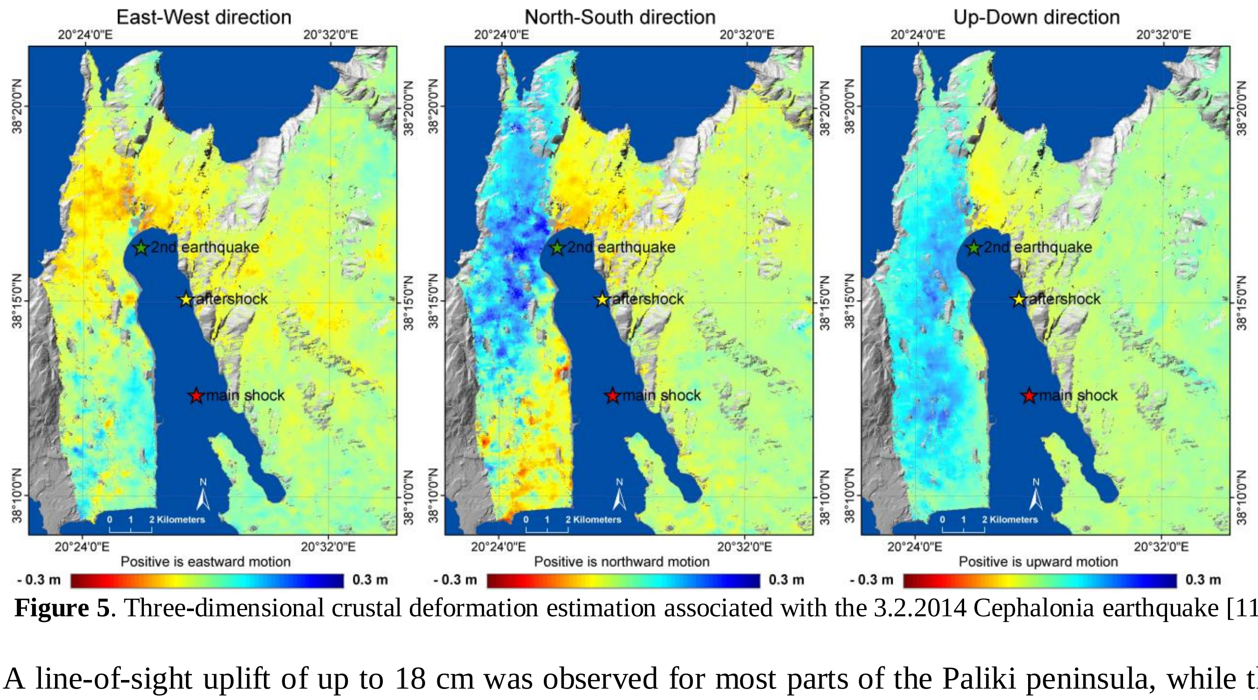

Figure 5. Three-dimensional crustal deformation estimation associated with the 3.2.2014 Cephalonia earthquake [11].

A line-of-sight uplift of up to 18 cm was observed for most parts of the Paliki peninsula, while the eastern part of Cephalonia remained stable with subsidence identified near the raptured fault. Moreover, the potential for fast and accurate post-earthquake damage assessment using a UAV at Lixouri has emerged as an important and useful service. BEYOND conducted eight dedicated UAV flights over several critical sites in Cephalonia, collecting a series of images. These images were analysed at a post-processing stage to map earthquake related damages, as depicted in Figure 6.

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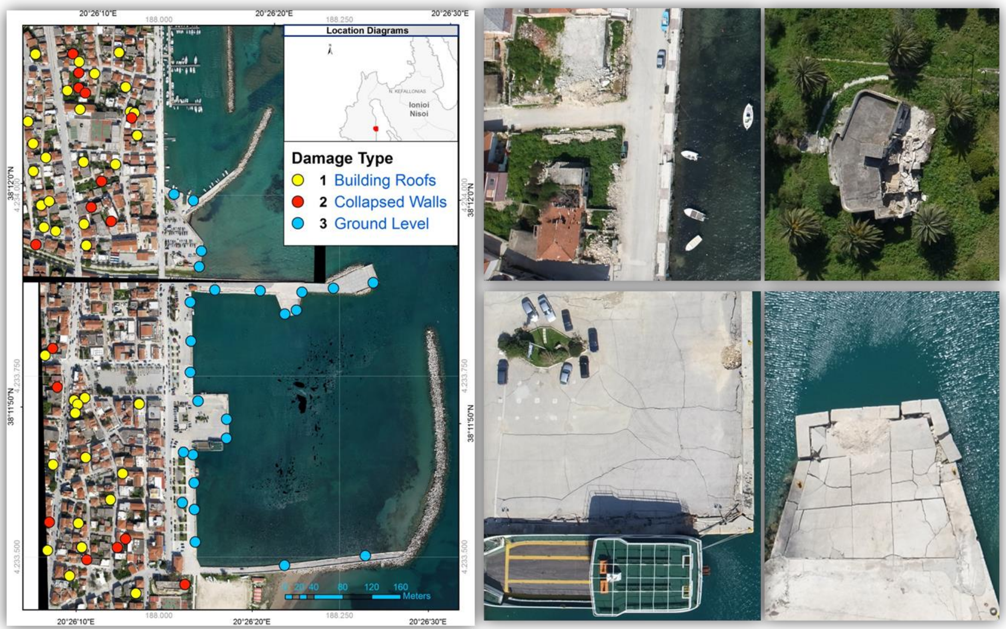

Figure 6. UAV based earthquake damage assessment for the town of Lixouri.

3.3 Ground motion in greater Athens

The wider Athens metropolitan area presents a challenging and quite an interesting setting for the implementation of radar interferometric techniques. On the one hand there are complex regional geotectonic characteristics with several active and blind faults, one of which gave the deadly M_w 5.9 Athens earthquake on September 1999, on the other Athens is heavily urbanized in the sense that intense construction activities have been taking place in the last fifteen years in the framework of the 2004 Olympic games and following urban planning for sustainable European cities. The area is covered by a rich dataset of SAR data, consisting of both ascending and descending tracks, originating from ERS-1, ERS-2 and Envisat satellite platforms, and spanning from May 1992 up to September 2010. The multi-track dataset available provides a unique opportunity for decomposing the generated velocities to their vertical and horizontal components [12]. Results of the thorough time-series analysis indicate that a large area containing the Kifisia municipality has been subsidizing in the period 1992-1999 and has been uplifting since 2002 (Figure 7). This is attributed to water extraction activities that took place in the first period and ceased in late 1995. Since then the region is on a restoration phase.

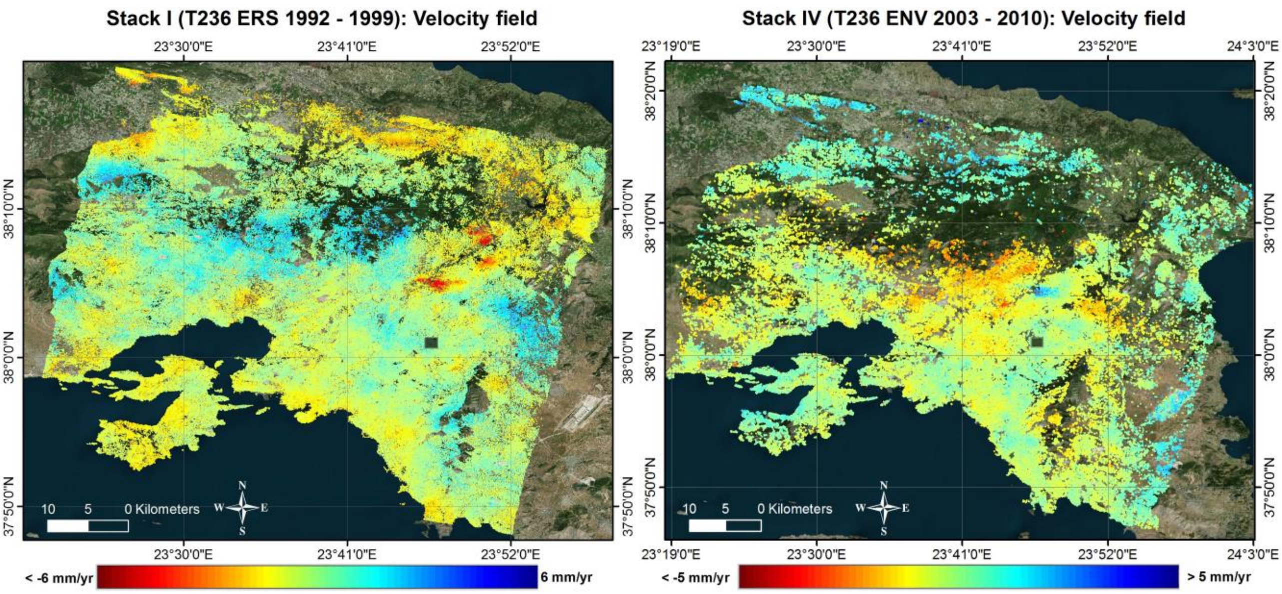

Figure 7. Line-of-sight ground motion in greater Athens, for two time periods [12].

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4. CONCLUSIONS

BEYOND has showcased a diverse set of products and services for monitoring geophysical activity, based on the use of satellite data and state-of-the-art Earth Observation technologies. Crustal deformation and UAV based damage assessment associated with earthquakes is provided on an operational basis to the end-user community, while long term time series interferometric analysis can provide valuable information on the diachronic ground motion patterns in critical sites.

In BEYOND we aspire to build upon this well-established expertise. To this end, the Center of Excellence has been granted access to large volumes of SAR data of different spatial, spectral and temporal resolutions, through the submission of competitive proposals. Hence, we can exploit TerrSAR-X (DLR-German Space Agency), COSMO-SkyMed (ASI-Italian Space Agency), Radarsat-2 (CSA-Canadian Space Agency), ERS-1,2 and Envisat (European Space Agency) data for the seamless geophysical monitoring of southeastern Europe. More importantly, the National Observatory of Athens, to which BEYOND belongs, has signed an agreement with ESA to establish at our premises an ESA mirror site, for the collection, management, distribution and processing on a real-time basis, of data and products from the Sentinel family of satellites. Such facility has the potential to play a vital role for cutting-edge remote sensing research pertinent to geophysical applications.

Acknowledgement

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