LAND SUBSIDENCE MONITORING IN THE SOUTHERN SPANISH COAST USING SATELLITE RADAR INTERFEROMETRY

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ABSTRACT

Over the last decades, coastal areas in many parts of Spain have undergone a continuous urban expansion because of the growth of cities and development of new residential areas. The invasion of the sea, as a consequence of the rise of sea level and the subsidence of populated areas, may result in serious problems to many constructions situated in the coastline. This has an important impact on the economy, environment and society, representing a considerable natural hazard. This paper investigates the applicability of InSAR in studies of coastal dynamics. We study the spatial and temporal evolution of some subsidence areas revealed from the SAR observations, an ERS SAR data set from 1992 to 2000 over the southern Spanish coast. After a preliminary processing using persistent scatterer (PS), small baseline (SBAS) and a combined multi-temporal InSAR time-series methods, we detect, for the first time, some subsidence areas that may be at risk.

Keywords: SAR Interferometry, Permanent Scatterer Interferometry, coast, land-subsidence, MTI

1. INTRODUCTION

In Spain, great part of the population and the model of economic and social development are found to be intimately connected with the coast. Their living and future depend on it. The shape of a coast directly depends on the effects of the environmental and anthropic changes. At sand beaches for example, the more characteristic types of the south and east Spanish coasts, the changes happen in short periods of time, although, to priori, the rocky coasts present greater resistance to the changes, being these visible only long-term.

Another problem of the Spanish coasts is related to the possible rise of the medium sea level, mainly due to the climatic change. The climatic change is a factor of pressure for environment in general and for coasts particularly ([1], [2]). According to recent studies of Ministerio de Medio Ambiente (Spanish Ministry of Environment), it is estimated that the combined effect of the increase of the sea level, the own backward movement of the line of coast and the increase of the energy and the variation of direction of the swell, can come important backward movements in some coastal sections.

The Spanish National Plan of Adaptation to the Climatic Change (PNACC) identified that the main problems of the climatic change in the coastal zones are related to the possible rise of the medium level of the sea (NMM) what would be able to imply a flood of them. Although this effect is being studying during years, the capacity of showing their existence from a scientific point of view does not remain clearly reflected. Nevertheless, the scientific investigation in this sense goes growing united to the increment of the precision and reliability of the measurements.

The study of the coastal strip should be undertaken from an ambitious project to guarantee their sustainability with a view toward the future and requires of a knowledge permanently brought up to date on the effects that are being produced at the local level. For it, it is indispensable to apply methodologies that permit to study its effects as part of an evolutionary process. The acquisition of spatial information related to environmental places, such as coasts, is essential to evaluate the environmental effects on these areas. Traditionally, the studies on coastal evolution to great detailed scale have been carried out from surveying. Nevertheless, the methods of positioning and registration of spatial data have suffered all a revolution in recent years due to data processing technological advances. At present, the utilization of global positioning systems (GNSS) ([3], [4]) or altimetric airborne laser (LIDAR) ([5]), are two of the better technological options to be applied in studies of coastal erosion. The capture of new available forms of spatial information and the software tools developed for data processing permit to quantify the erosion from the experienced volumetric changes by the coast.

The environmental applications of global positioning systems have neither gone unnoticed, charging special importance their employment in agriculture of precision, in the monitoring of deformations of the land and their application in the prediction of natural catastrophes or in the control of erosion in zones with steep slopes ([6]).

The gradual increase of sea level is causing the coastline to retreat inland by 0.3 m/year. Many urbanized areas may disappear under the sea. Due to their geological/geomorphological features, many constructions situated in the coastline can be affected by subsidence and land deformations, mainly collapse deformations.

The advantages of using satellite radar interferometry technology instead of conventional techniques such as levelling, classical networks or GPS, make InSAR an essential tool to study different areas at the same time, providing with large spatial coverage. In Spain, no study of this kind using InSAR has ever been carried out over coastal areas, therefore the application of this technique is a pioneering one, and it might state its potential application in other areas.

In order to assess the evolution of coasts and quantify changes in coastal morphology, we have designed a multidisciplinary project which integrates between others satellite radar interferometry and active GNSS networks. The development of this project will provide with a methodology of monitoring coasts, by means of the execution of a base research, along with a series of experiments based on active GNSS networks and the analysis of time series of SAR images using PS-InSAR technology. In this way, the environmental, social and economic impact can be analyzed. Research results will also permit us to resolve very interesting issues as detect the areas of greatest subsidence in the southern peninsular coast and asses the consequences of such deformation.

In this paper, we present the results of a preliminary PS-MTI processing in the southern Spanish coast for monitoring land subsidence. For this analysis we used 31 ERS1&2 SAR images of track 230 and frame 729 acquired between 1992 and 2000 which cover almost the entire province of Málaga.

2. STUDY AREA

The study area, the province of Málaga, is located at the southern coast of Spain, in the Autonomous Community of Andalusia. It is bordered by the Mediterranean Sea to the south (Fig. 1). The capital, Málaga, is the southernmost large city in Europe. It lies on the Costa del Sol (“*Coast of the Sun*”) of the Mediterranean Sea.

The study area is also situated at the southern Betic Cordillera (southern Spain). The topography is quite rough from 0 meters up to 2000 meters high (Fig. 2).

Málaga, together with the following adjacent towns and municipalities: Rincon de la Victoria, Torremolinos, Benalmadena, Fuengirola, Alhaurin de la Torre, Mijas, Marbella y San Pedro Alcántara form the urban area with a population of 1,046,279 on 827.33 km² (density 1,264 hab / km²) – 2009 data. The urban area stretches mostly along a narrow strip of coastline. The Málaga metropolitan area (Fig. 3) includes additional municipalities located mostly in the mountains area north of the coast and also some on the coast: Cártama, Pizarra, Coín, Monda, Ojén, Alhaurín el Grande and

Estepona on west; Casabermeja on north; Totalán, Algarrobo, Torrox and Vélez-Málaga eastward from Málaga. The population is concentrated mainly in the metropolitan area of Málaga and throughout the coastal area.

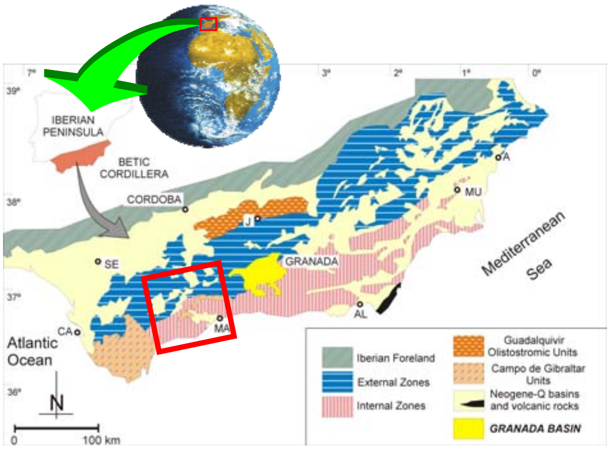


Figure 1. Location of the study area and simplified geological map of the Betic Cordillera (southern Spain). The corresponding frame of the study area is shown as a red box.

Figure 2. Topographic map of the province of Málaga.

Figure 3. The metropolitan area of Málaga.

3. DATA AND METHOD

The province of Málaga is covered by 31 ERS-1/2 SAR images from the ascending track 230 and frame 729 (Fig. 1). The SAR images cover the time period from October 1992 to November 2000. A Shuttle Radar Topography Mission (SRTM) C-band DEM with resolution of 3 arc-seconds (90 m) was used as an external DEM in this study to remove the topographic phase from the differential interferograms. Precise orbit data for ERS-1/2 satellite, which enable the removal of the reference phase from the differential interferograms were provided by TU Delft ([7]).

The data was processed using the Stanford Method for Persistent Scatterers - Multi-Temporal Interferometry (StaMPS-MTI) ([8], [9], [10], [11], [12]) to determine Line-Of-Sight (LOS) displacements. StaMPS (Stanford Method for Persistent Scatterers) is a software package that implements an InSAR persistent scatterer (PS) method developed to work even in terrains devoid of man-made structures and/or undergoing non-steady deformation. StaMPS/MTI (Multi-Temporal InSAR) is an extended version of StaMPS that also includes a small baseline method and a combined multi-temporal InSAR method. StaMPS PS analysis uses primarily spatial correlation of the phase to identify phase-stable pixels, as opposed to temporal correlation, and it does not assume any approximate model of displacements (e.g. [13], [14]). A requirement is that the displacement gradients in space and time should not be steep for proper unwrapping. In addition, SBAS (Small BASeline) analysis ([15]) aims to detect pixels whose phase decorrelates little over short time intervals. Finally, StaMPS-MTI combines both sets of results to improve phase unwrapping and the spatial sampling of the signal of interest.

For a premilinary processing we processed the full frame selecting orbit 12108 (1997/08/13) as master scene (Fig. 4). Due to ERS-2 gyroscope failure on January 2001, only images until 2001 were selected in order to avoid Doppler centroid differences of more than 700 MHz. Fig. 5 shows the Doppler centroid differences respect to the master scene

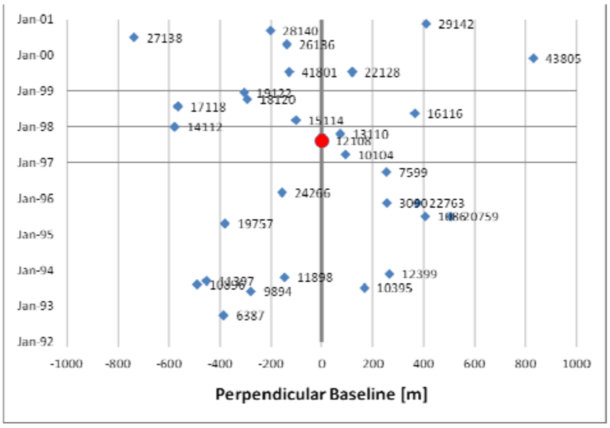


Figure 4. Perpendicular baseline distribution for the ERS-1/2 data set used in this study. Master image is shown as a red dot.

For the SBAS processing, 82 differential interferograms were formed.

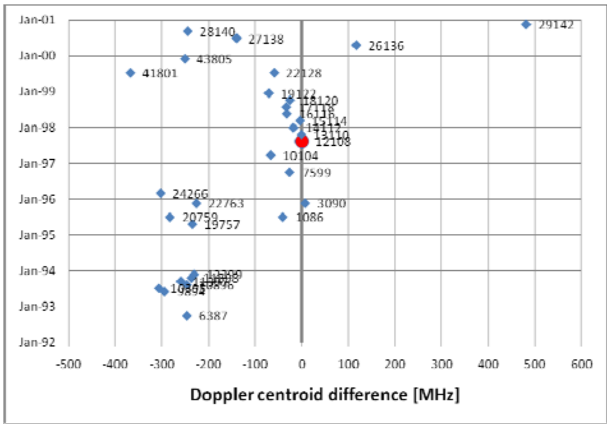


Figure 5. Doppler centroid difference distribution for the ERS-1/2 data set used in this study. Master image is shown as a red dot.

4. RESULTS AND DISCUSSION

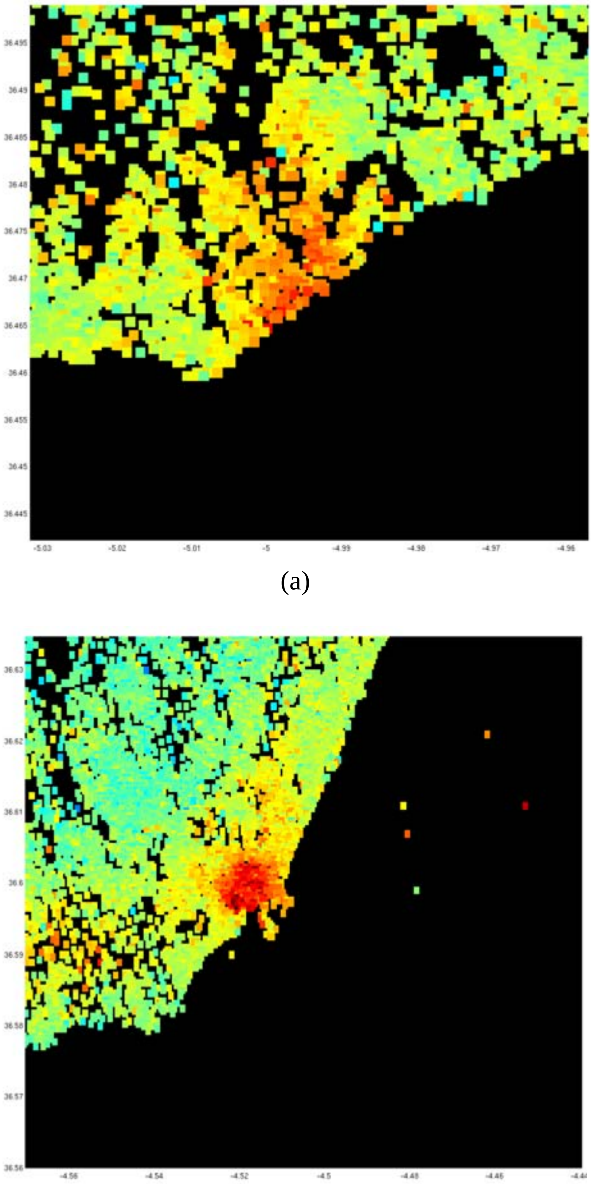
After the preliminary MTI processing, 385713 coherent targets were detected for the full scene. In general, the area is stable although three zones of subsidence were identified at the coast (Fig. 6). The first one is located at Guadalmina area (Fig. 7a), a residential zone located to SW of San Pedro de Alcántara village. The second one is Puerto Marina area (Fig. 7b), in Benalmádena village. Finally, the third one is located to SW of Málaga city corresponding to two different zones, an industrial park and a residential area in the coastline (Fig. 7c).

This InSAR-MTI processing shows some subsidence processes in all the three areas with velocities around 5-6 mm/yr (Fig. 7).

Figure 6. Location of three subsidence areas detected at the coast (metropolitan area of Málaga). The areas correspond to: 1.- Guadalmina, 2.- Puerto Marina and 3.- Guadalhorce. The areas are enlarged in Fig. 7.

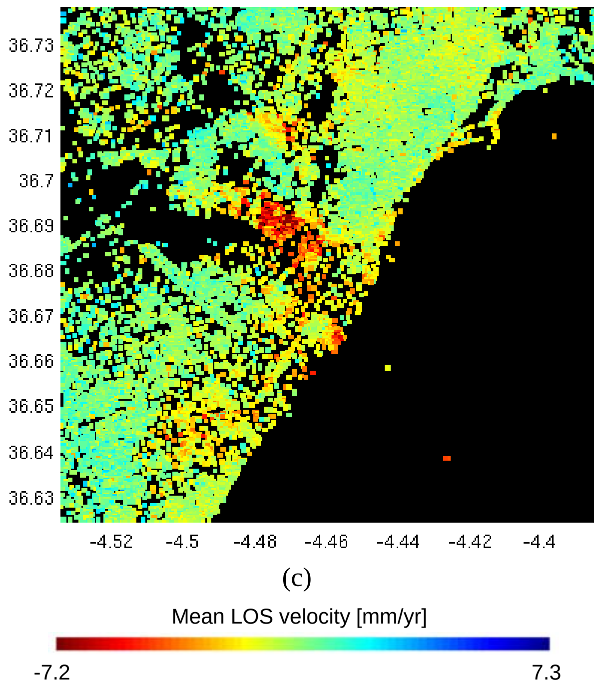
Further investigation is needed to find the origin of these detected subsidences although an initial cause at Guadalmina (Fig. 7a) and Puerto Marina (Fig. 7b) areas could be their infrastructural developments leading to soil compaction as well as intensive extraction of underground water originated by the increase of population in the last years. Fig. 8 shows the PS from MTI processing superimposed to Google Earth. The Guadalmina area is represented in Fig. 8a. The Puerto Marina area is shown in Fig. 8b, and enlarged in Fig. 8c and 8d. In these two areas many swimming pools can be seen which could be a reason for intensive extraction of underground water apart from own consumption.

Finally, the third area is shown in Fig. 8e. The industrial park (upper part of Fig. 8e) is enlarged in Fig. 8f. No reason, a priori, explains the subsidence in this zone. A field reconnaissance is needed to investigate the cause of such a subsidence. The lower part of Fig. 8e shows a residential area which is shown in a 3D view in Fig. 8g.



(a)

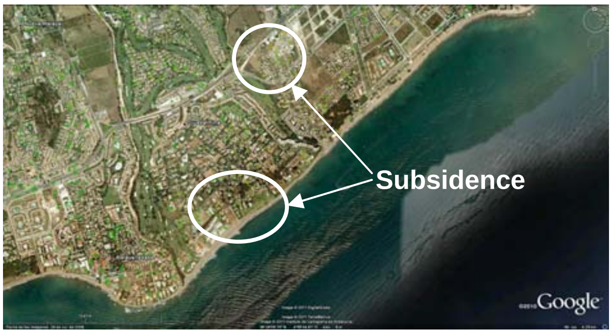
(b)



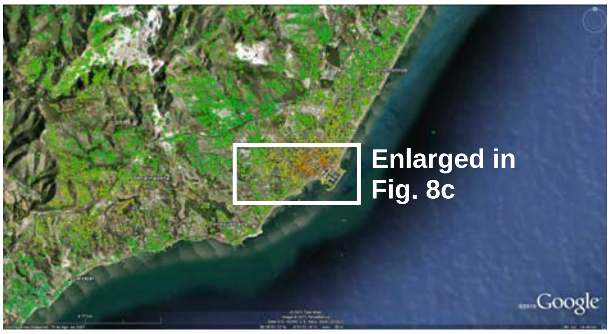
(c)

Figure 7. Mean LOS velocity maps of the three areas located at Fig. 5. (a) 1.- Guadalmina. (b) 2.- Puerto Marina and (c) 3.- Guadalhorce.

The detected subsidence in this last area could be motivated by the same reasons that for Guadalmina and Puerto Marina ones. That is, great infrastructural developments leading to soil compaction as well as intensive extraction of underground water. It can be seen that this subsidence area is in the same coastline so with a very high risk.



(a)



(b)

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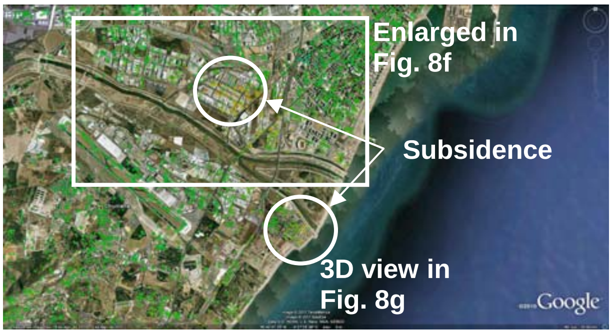

(e)

(f)

(g)

Figure 8. Visualization over Google Earth of the PS from MTI processing of the different subsidence areas detected in this study. (a) Guadalmina area (b), (c) and (d), Puerto Marina. (e), (f) and (g) Guadalhorce.

5. CONCLUSION

This is the first attempt for detecting land subsidence zones at the Spanish southern coast using satellite radar interferometry. In this study, we present the results of a preliminary processing of 31 ERS-1/2 SAR ascending acquisitions over 10,000 square kilometers. For that, a time period of 9 years, from 1992 to 2000, is analyzed. Data were processed using StaMPS-MTI. Due to the existence of this data sets and wide area coverage many coherent points can be detected. The analysis of them, after a preliminary processing, identifies three main subsidence zones, for the first time, at the Málaga metropolitan area verifying the potential of satellite InSAR technique for deformation monitoring at coastal areas.

Further investigations will study the causes and analyze the evolution of these land subsidence.

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