DINSAR INTERFEROMETRY OF RADAR SATELLITE IMAGES: QUANTITATIVE ASSESSMENT OF VERTICAL GROUND DEFORMATIONS IN THE GUADALFEO RIVER VALLEY AND METROPOLITAN AREA (GRANADA, SOUTH OF SPAIN)

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ABSTRACT

A Differential Interferometric SAR (DInSAR) analysis of RADAR satellite images of landslides in the Guadalfeco River basin (South of Granada, Spain) is here presented based on ERS1 and ERS2 images following a methodology with two main steps: a first basic treatment of SAR SLC focused images to obtain differential interferograms with the
wrapped phase using a Digital Elevation Model (DEM) of the study zone. The second step includes elaborations of theses interferograms with a specific DInSAR technique to assess the average annual velocity in the landslide masses. The obtained results are first evidences of the activity of these landslides which are potentially affecting villages (Albuñuelas, 1070 inhabitants; Lanjarón, 3796 inhabitants) or the Guadalfeo river with is over villages as Vélez de Benaudalla, 2800 and Motril, 57895, which could be affected by flash flooding after a landslide dam failure situation. Despite the interest of assessing the risks derived from the activity of these landslides no instrumentations were available and from these the great interest of using DInSAR interferometry techniques may be easily understood.

The landslide activity assessment resulting from these research shows annual average vertical velocities for the period 1993-2000 of 6mm/yr for Tablones landslide, 7mm/yr for the Lanjarón landslide and up to 13mm/yr for the Albuñuelas landslide.

The quantitative assessment of landslide activity is introduced in a GIS application to landslide hazard and risk mapping of the Guadalfeo River Valley in which a database of landslides, along with digitized information about element of the territory and the analysis of correlation between determinant factors of the slope stability are combined with triggering data concerning rainfall, earthquake activity and also landslide activity. The main outputs of the GIS application are in terms of susceptibility, hazard and risk maps of the region at variable scales from a pixel resolution of 10 m.

1.-Introduction

In the last few years differential interferometry of RADAR images has become one of the most accurate remote sensing techniques in assessing during natural or anthropically induced landslide activity related to natural hazard or natural resources studies (Massonet1998, Crosetto2005b).

In this paper first results from the application of this technique to different environments of the Granada province, South of Spain, are presented (Figure 1) which allow for the assessment of different types of movement affecting both land-use planning and natural resources.
The first results concern to the Guadalfeo River Basin, where abundant landslides were inventoried in a SIG application. These landslides were previously identified (Chacón et al 1994; Jiménez et al 2005) including its different features as slope, orientation, lithological composition, areal extension, etc. Nevertheless no instrumental quantification of the landslide activity was available and only considering morphological criteria and direct observation, they were considered as dormant or very slow active landslides.

A second study zone corresponding to the Granada metropolitan area is presented were no previous information about any vertical movement existed.

By using differential interferometry SAR (DInSAR) we have qualitatively obtained first assessment of vertical movements in processes affecting landslides slopes in the Guadalfeo River Basin and also land vertical movements in the alluvial Quaternary sediments at the West and South of the Granada metropolitan area, respectively.

2.-Methodology and data

The research is based on a set of descending and ascending ERS1 and ERS2 images comprising the period from December 1993 to January 2000. The processing chain is applied to the descending and the ascending stack images separately.
SAR Data

The research is based on a set of descending and ascending ERS1 and ERS2 images. Each image covers 100 x 100 km comprising the period from December 1993 to January 2000. A set of differential interferogram was used for each trajectory of the satellites. The interferograms were selected considering criteria of perpendicular baseline and temporal gap.

The descending data were used to the study of the Mezquerina and Serreta Slides and Granada-Metropolitan area and the ascending images for the Albuñuelas one.

In the case of the descending images, we part from 25 images, to use a stack of 72 interferograms. For the ascending data we part from 15 SAR images, to select 48 interferograms.

Methodology

The DInSAR process includes 2 main stages: a general and a specific stage. The first one refers to basic elaborations starting with Single Look Complex (SLC) images to compute the differential interferograms with the wrapped phase. The second arises with specific DInSAR elaborations from the selection of wrapped interferograms to the interpretation of the obtained results and, finally, its integration into a GIS application. The methodology followed in this research is summarized in Figure 2.
The General Stage includes all the basic elaborations for any DInSAR analysis for every type of applications and therefore it is a common stage to other methodologies (Hanssen, 2001). In this stage a reference image is selected in order to add the same geometry to all the resting images. This particular process is known as coregistration and the reference image is the *Supermaster*, usually the oldest image.

Once all the images are coregistered, the mean amplitudes image is calculated. With the coregistered images and a DEM, the differential interferograms are obtained in two steps. The first consists in the elaboration of a complex interferogram from two coregistered images (*master* and *slave*). The second step is a simulation of a synthetic interferogram from a DEM. Finally the simulated interferogram is subtracted from the complex interferograms obtaining the wrapped differential interferograms.

The Specific Stage starts with a selection of the differential interferograms for the calculation of the deformation velocity image, expressed in mm/year for the considered temporal interval. This part of the research was made in cooperation with the Remote Sensing Unit of the Institute of Geomatics of Barcelona (Spain) by means of a new no commercial software developed in that unit (Crosetto et al, 2005a). This part is based on
the use of not an only interferogram or a few, but a stack of interferograms that are processed together semi-automatically. In this process it is obtained a numerical estimation of the velocity of the movement in the line of sight (LOS) expressed in millimetres per year.

The deformation velocity image may be over imposed to the average amplitude image, obtaining in this way a general image from which it is possible to get to a quick approximate location of the landslide area with reference to the estimated strain rate.

By the geocodification of the deformation velocity image a precise location of the moving areas is obtained with its corresponding speed, over imposed this image to maps or orthoimages.

Finally an interpretation of the obtained result is made considering all the related data and its GIS integration.

3.-Results

The assessed values in the following figures refer to estimations along the LOS, near the verticality, and taking as positive values those related to land subsidence.

3.1 The Guadalfeo River Basin

From the abundant landslides in this region only results from three areas were obtained: Mezquerina Creek in Lanjarón, the Serreta de Tablones and Albuñuelas.

The Mezquerina Creek site shows evidences of slope instability affecting Triassic limestone and interlayered gypsum bodies although it is unclear whether the vertical deformation is related to landsliding or to direct subsidence resulting from gypsum karstic erosion. Landslide evidences are related to the deformed aspect of the slope, the appearance of open cracks, bodies of failed limestone blocks, and the lack of morphological hierarchy in the drainage network. The unstable slope is limited by the main regional road and therefore a potential risk is associated to the slope movements. The lack of instrumental data of the slope movements leads to consider this slope also as a probable dormant landsliding area. The results obtained from DInSAR give values of activity of 7mm/year in a small area close to the main road, showing a slow velocity instead the dormant stage previously considered. In the period of about 7 years of DInSAR analysis the deformation attains 5 cm (Figure 3).
Figure 3: The Mezquerina Creek site (Lanjarón, Granada). At the left frontal view of the landsliding area. At the right results obtained by DInSAR plotted into an orthoimage of the area. The red pixels correspond to a maximum subsidence of 7 mm/year.

The La Serreta de Tablones translational slide was considered in a dormant stage because of the lack of evidences of current deformations onto the slope or river morphology. It is composed by a block of Triassic marble sliding on a Upper Palaeozoic phyllite unit. The values obtained by DInSAR evidence deformations in the period 1993 to 2000 with a maximum vertical displacement of 6mm/year what amounts about 4 cm in that period. Pixels showing DInSAR displacements cover almost all the mass. (Figure 4)
The estimated slide activity on slope limiting a river channel (Figure 4) is being analysed in relation to the risks associated to its final collapse and consequent damming and flooding which could damage nearby villages and infrastructures.

Albuñuelas village (1070 inhabitants) was deeply damaged during a large regional earthquake in 1884. A third part of the village with some 500 houses are currently settled under an old landslide scarp were a layer 20 m thick of Tortonian bioclastic calcarenites is cropping out below yellow to red silts and clays. The observation of widespread distributed tilting of the houses with values between 1 and 6° leads to consider the possibility of a rotational activity in the mass surrounded by the scarp (Figure 5). DInSAR assessment of vertical movements confirmed the existence of activity, showing an average rate of vertical subsidence in central and western part of the village, surrounded by the scarp, of 8mm/year with a maximum rate of 13mm/year. Currently a detailed study is being made in order to assess the City Council about the process and introduce a program of risk control and surveillance.
3.2.-Results in Granada- Metropolitan area

This study area was accomplished by analysing several different smaller areas with centre in some of the abundant villages, and a final overlapping of the partial results into the final map of the whole area.

Because of the absence of any previous data on active subsidence assessment in the region the DInSAR technique was used first as a tool for the identification of areas affected by subsidence and then for the quantification of the observed processes.

The observed ground deformations are concentrated around two different points (Figure 6). One is the village of Santa Fe (14600 inhabitants) settled on Holocene alluvial deposits, where rates of vertical deformation up to 8mm/year are observed with maximum values at the centre of the urban area and decreasing values toward its peripheral border (Figure 7). The only process which could be related to the subsidence is an intensive aquifer
overexploitation.

Figure 6: Distribution of ground deformations in the Granada basin showing all the Metropolitan Area in a mean of amplitude SAR image. Two zones are identified to the centre Santa Fé and at the south east Otura. The legend bar shows rates in mm/year measured in the area.

The second zone corresponds to the Otura municipality (5470 inhabitants) where Upper Pleistocene to Upper Tortonian conglomerates and marls are cropping out (Figure 7). DInSAR assessed rates of ground deformation attain 12mm/year and amount 8.4 mm in the period 1993-2000. In this area also aquifer overexploitation exist but given the overconsolidated soil layers affected by the deformation and the regional context in the Betic Cordillera and the vicinity of Sierra Nevada affected by active faults (Keller et al., 1994, 1996) also some influence from local active tectonics is being considered.

4.-Conclusions

The first application of DInSAR technique to the Andalusia region leads to interesting results showing:

- A first qualitative assessment of local sites in the Granada province affected by ground deformations previously unknown
- The confirmation of active very slow movement in landslide areas and the quantification of the rate of vertical deformation.
- The confirmation of active ground deformations in the Granada metropolitan area with a quantification of its rate.

These results permit the preparation of new projects for the control and surveillance of the observed deformations as the proposal of recommendations to the local authorities in order to a better control of water pumping and houses tilting.

Figure 7: Detailed images of the two zones with observed ground subsidence in the Granada Metropolitan Area. Left: Santa Fe village showing rates up to 8mm/year. Right: Otura village with values up to 12mm/year. The legend and scale bars give the distribution of pixel with vertical subsidence obtained from DInSAR techniques.

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6.-References


