SMALL SCALE LINEAR DEFORMATION DETECTION USING PERMANENTS SCATTERERS TECHNIQUE APPLIED TO THE GULF OF CORINTH (HELLAS)

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ABSTRACT

The Permanent Scatterers (PS) technique, invented by Politechnico di Milano research team, is an approach that minimises the undesirable noise components in the classic InSAR technique, such as spatial and temporal decorrelations, signal delay due to tropospheric and ionospheric disturbances, orbital errors as well as topographical errors. This approach is suitable for the measurement of near vertical displacements of the order of ~1 mm per year. It exploits almost all of the available SAR interferometric data over an area and requires availability of natural and/or artificial permanent scatterers. In this study we describe the implementation of the PS technique, called PerSePHONE (Permanent Scatterers Project Held by the Observatory, National, of Hellas). Its development has been based on a number of algorithmic adaptations, as well as new approaches in PS candidate selection. An example of this implementation is shown for the case of the Corinth Rift area (Hellas).

1. INTRODUCTION

Classic InSAR technique has offered a great deal of reliable measurements of ground deformation. These measurements suffer from undesirable components mainly due to spatial and temporal decorrelations, signal delay due to tropospheric and ionospheric disturbances, orbital errors as well as topographical errors (related to DEM artefacts). Many techniques have been proposed to minimise some of these components. The most promising approach is the so-called Permanent Scatterers (PS), invented by Politechnico di Milano (POLIMI) research team [5]. This technique integrates a large series of SAR data, forming interferometric pairs with a selected master image, including those with large temporal and geometrical baselines. In addition, it requires availability of natural and/or artificial permanent scatterers. The PS approach is ideal for measuring small-scale ground deformations due to seismic precursor activity, urban subsidence as well as displacements in active fault zones. The motivation for the implementation of the PS technique was the study of a geophysically active area, such as the Gulf of Corinth.

The Gulf of Corinth study area (covers ~3350 Km^2 and extends from NW 22º04'E, 38º38'N to SE 22º57'E, 38º14'N) shown in Fig. 1 has been long identified as a site of major importance due to its intense geophysical activity. It is one of the world's most rapidly extending continental regions and it has one of the highest seismicity rates in the euro-Mediterranean region. It has also produced a number of earthquakes with magnitude greater than 5.8: Alkyonides (February 1981, *M*=6.7), Aigio (June 1995, *Mw*=6.1), and Galaxidi (November 1992, *Mw*=5.8). Moreover, GPS campaigns using a dense network of permanent GPS stations have shown a 1.5 cm per year of north-south extension [2]. This reported rifting mechanism often leads to submarine slope failures and to damaging tsunamis. On land, the same fault system causes landslides.

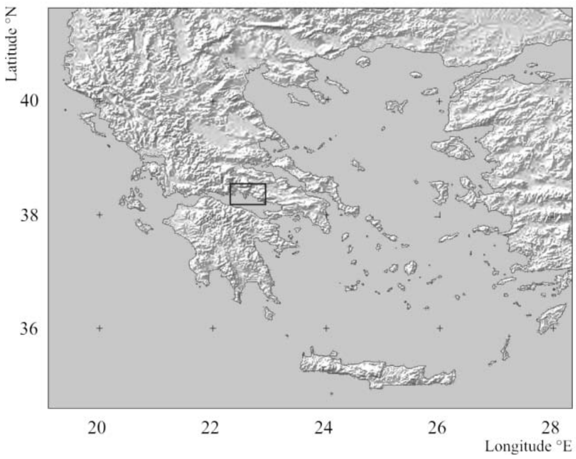

Figure 1. Location of the study area in Hellas.

It should be noted that most of these phenomena in the specific area have been monitored for over a decade in the framework of several national and EU funded projects, with the use of Permanent GPS stations, GPS campaigns, in situ observations, as well as with classic InSAR [1, 2]. These techniques present limitations for near vertical (~23° from zenith) movement rates

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estimation with sufficient accuracy. This is encountered through PS processing.
In this study we describe the implementation of the PS technique, called PerSePHONE (Permanent Scatterers Project Held by the Observatory, National, of Hellas) which has been developed in the Institute for Space Applications and Remote Sensing of the National Observatory of Athens.

2. DATA PREPROCESSING

When selecting the time span of the data to be processed, the presence of strong non-linear phenomena, such as the June 1995 Aigion earthquake, was avoided. Moreover, taking into account the PS technique requirement for uniform distribution of both the normal baselines in the interferometric pairs and the acquisition dates of the scenes, the ERS-1 scene acquired on 19^{th} June 1995 (orbit No 20536, track 007 and frame 283) was selected to be the common master scene for interferogram formulation. Thus, the data set consisted of 2 ERS-1 (20536 and 22039) and 18 ERS-2 scenes, having a time span of 6½ years, from June 19^{th}, 1995 to October 16^{th}, 2001 (Fig. 2).
Before advancing to the PS analysis, some necessary pre-processing of the data took place. This relates to image focusing, cropping of the scene to the study area

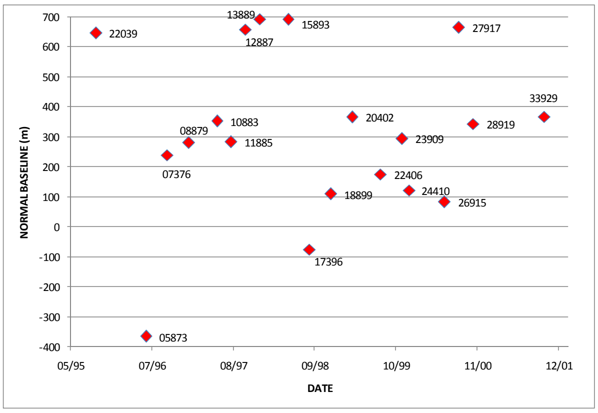

Figure 2. Normal baselines versus the acquisition dates of the scenes. The labels indicate the orbit number of each scene.

and compensating for zero Doppler centroid. In addition, an important step at this stage is the radiometrical correction of the amplitude images in order to achieve better cross-correlation statistics for image registration. This was performed through histogram equalisation.
Finally, a customised version of the CNES DIAPASON software [9] was used to produce the interferometric phases and other by-products necessary for PS processing. The 19 interferograms had a cell size of ~4m in azimuth and ~20m in range and were created from the single look images, without applying any pixel averaging techniques. Moreover, the precise orbital files were produced by the Delft Institute. The Digital Elevation Model came from digitising the 20m contours from 1:50000 topographic maps with estimated vertical accuracy of ±10m. Parts of the DEM having no height information were filled with resampled SRTM-3 data.

3. METHODOLOGY

PerSePHONE development has been based on a number of algorithmic adaptations, for PS and PS Candidates (PSC) selection. An initial modification was that the normalization of the amplitude image values, used for the calculation of the Dispersion Index (DI) and thus for the first selection of PSCs, was performed through histogram matching between the master scene and each one of the slave scenes (instead of using the calibration factor K for ERS satellites, as in [5]). The test area was divided in 800 tiles each having dimension of 500 pixels in azimuth and 100 pixels in range, covering an area of ~$4Km^2$. About 200,000 targets having DI<0.33 where identified from all tiles as a first selection of PSCs (denoted as $PSCs^{(1)}$, with index indicating the PSCs set emerging from the first successive refinement step as described below and it ranges from 1 to the total number of refinement steps, n). Atmospheric phase screen (APS) contribution was calculated in each tile separately through solving a non linear system, by means of an iterative algorithm [5], since interferometric phase values are known in modulo-2π. The selection of the PSCs was strengthened by identifying and removing those that obstruct the algorithmic convergence due to either low accuracy of the corresponding DEM value (which was used for interferometric calculation) or due to the fact that its motion leads to aliasing and cannot be approximated by the constant velocity model (second and fourth factor, according to [5]). Thus the standard deviation of the correction values at each advanced iteration step of the unknowns (velocities and DEM errors) was calculated. This quantity was used as a criterion for keeping those PSCs (from $PSCs^{(1)}$) which presented low dispersion of their correction values in the advanced iteration steps. The resulted PSCs set ($PSCs^{(2)}$) was fed again in the iterative algorithm and the forth mentioned procedure was repeated until either the algorithm converged or the number of $PSCs^{(n)}$ became lower than a minimum threshold value. That value was set to 20. The algorithm finally converges if apart from the forth mentioned factors, the space-time distribution of the scenes is uniform and the dimensions of each tile is small enough so that APS and orbital fringes can be well approximated by linear phase components (first and third factor according to [5]). Moreover non linear atmospheric disturbances of low frequency were isolated from the phase residuals

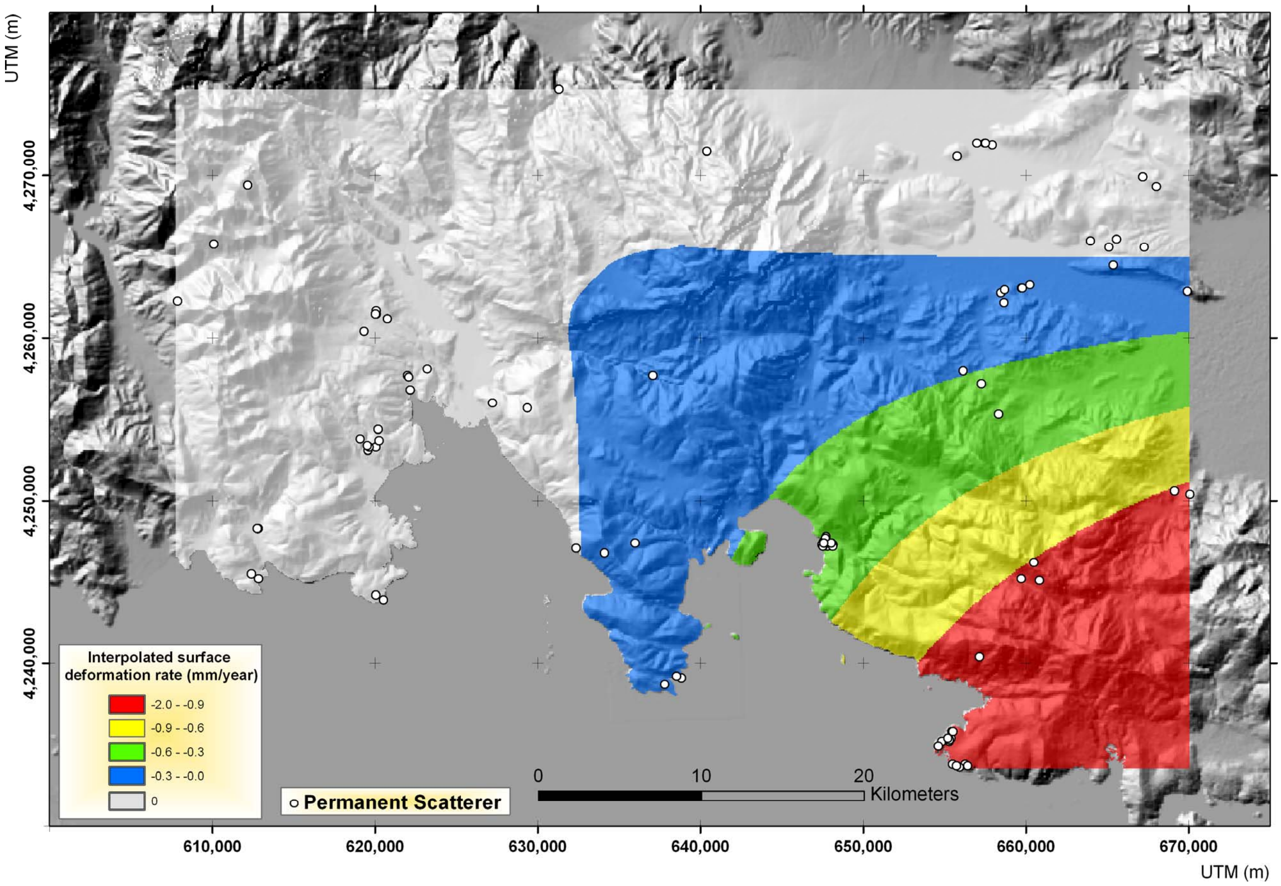

Figure 3. The PSs and the bilinear surface.

(the phase signal after APS removal) by using a Kriging filter [8] and were added to the APS.

By the end of the convergence, 56 tiles fulfilled the forth mentioned factors and further participated in the calculations. A total number of 1599 PSCs$^{(n)}$ were kept, having a density of ~28.5 PSCs per tile or ~6 PSCs per Km^2. This value is low in comparison with high populated urban areas. Note though, that some tiles with large number of PSCs$^{(n)}$ had a density of up to 22 PSCs per Km^2.

Advancing to the PS selection step, the first criterion was the Ensemble Phase Coherence (EPC), which refers to the stability of the phase value (in absence of APS, orbital, first estimation of deformation rates and DEM errors) of each target throughout all the scenes.

After removal of the APS and orbital errors from each interferometric pair, the calculation of the final velocities and DEM errors is thought as a nonlinear inverse problem [5], solved by means of scanning a 2-D parametric space (the velocity and DEM error) and maximising the coherence index, which in our case is the Phase Coherence (PC). This index refers to the phase stability of the target, emerging from the final velocities and DEM errors, after removing the APS from the differential interferometric values. The Maximum value of each target was used as a second criterion for PS selection, called MPC. The applied threshold values for EPC and MPC criterion of 0.2 and 0.69 respectively, resulted in a total number of 107 PSs in 49 tiles.

Finally, it should be noted that the code has been written in Matlab and executed by using the Matlab Distributed Computing Engine for parallel processing of the tiles.

The above mentioned PS technique, together with the adaptations and the existing processing capabilities for interferogram calculation (using CNES DIAPASON), as well as projection to a common cartographic system, were integrated in a single robust processing chain.

4. RESULTS

Since the identified PS density was very low, surface interpolation over the study area was considered imperative. A number of interpolated surfaces were tested estimating the gradient of the velocity field either by filtering out the local anomalies or by emerging them. This trial and error procedure resulted in two surfaces that corresponded to two approaches.

The first approach, which wiped out the local anomalies (Fig. 3), is a bilinear surface with equation $z=a+bx+cy+dxy$, where z is the calculated surface and a, b, c and d are the parameters emerged from the available PS set. The root mean square (rms) error between the actual PS velocities and the interpolated

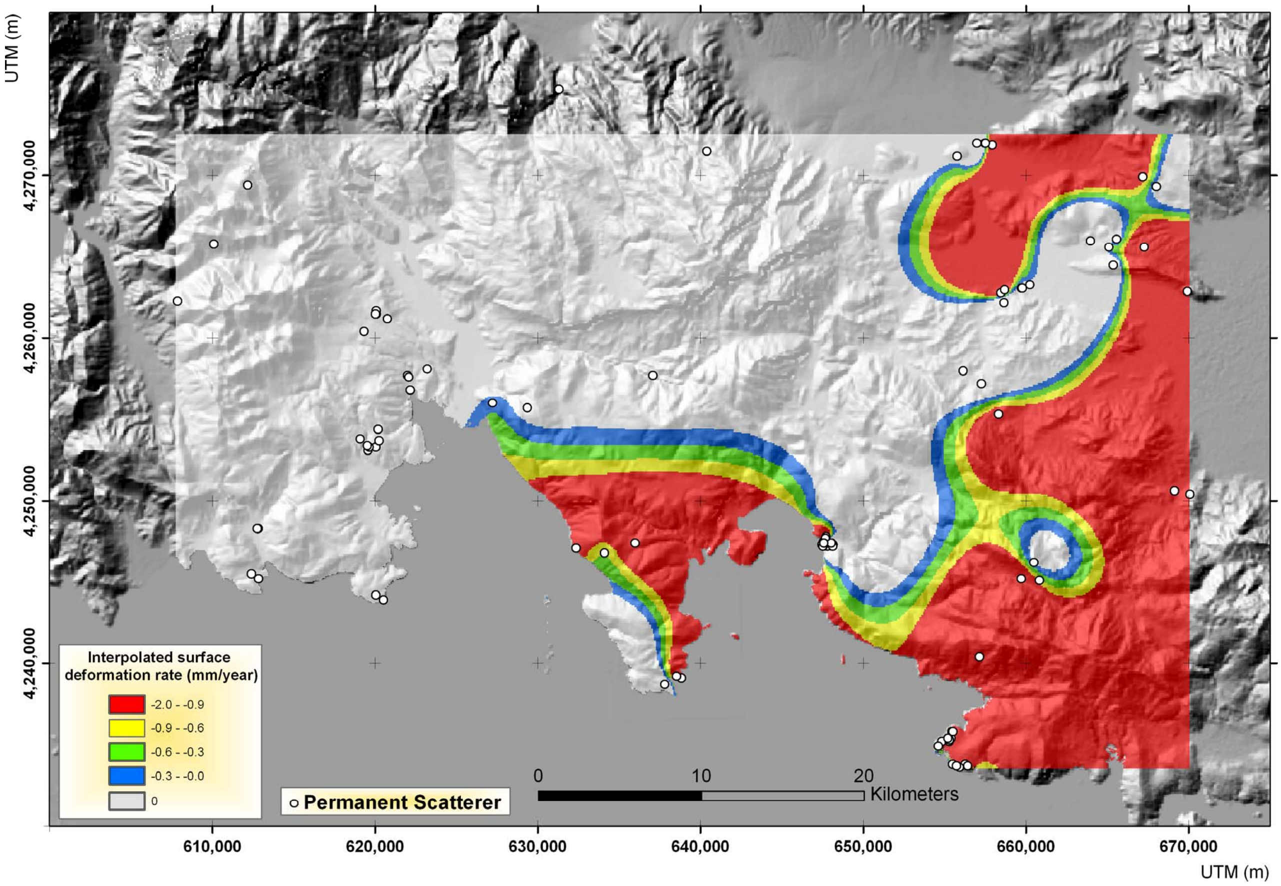

Figure 4. The PSs and the minimum curvature surface.

surface is 1.1mm per year. In this approach a subsidence trend of ~2mm per year, located in the NW part of the area is clearly visible.

The second approach, which retained the local anomalies (Fig. 4), is a minimum curvature surface. The rms error between actual PS velocities and the interpolated surface is 0.4mm per year. In this approach a subsidence trend of ~2mm per year, focused in the northwest and north of the area is evident.

5. CONCLUSION

In general due to land cover conditions (high vegetation, lack of rocky and urban areas), as well as high cloud coverage and rainfall characterising the Gulf of Corinth area, it is considered as a rather challenging example case for PS identification and measuring.

The PerSePHONE analysis, though, identified regions with adequate number of PSs and indicated a subsidence trend. Reference [6], which states that the northern margin of the Gulf of Corinth seems to be under regional subsidence, confirms the outcome of the presented study.

6. ACKNOWLEDGEMENTS

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