Comparing GPS, Optical Leveling and Permanent Scatterers

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Abstract

Subject of this paper is the comparison of the results obtained exploiting the Permanent Scatterers (PS) Technique on ERS DInSAR data with displacement measurements carried out by means of optical leveling and GPS.

1 The PS Technique

The PS Technique has been developed at POLIMI [1], [2] and allows high accuracy measurements of deformation phenomena occurring at individual radar targets that are phase coherent (Permanent Scatterers). PS are not affected by either geometrical or temporal decorrelation and can be identified by means of a statistical analysis of their amplitude and phase returns, exploiting a large number of SAR data (> 25). Whenever a sufficient PS spatial density (> 10 PS/km^2) is available, the different phase contributions (i.e. effects of the atmospheric phase screen, slightly different orbits, phase errors due to topographic effects joint with large baselines, and motion) can be carefully separated at individual PS. The main results of the PS analysis are:

(1.) Average Line of Sight (LOS) deformation rate of single PS with accuracy ranging from 0.1 to 1 mm/yr.

(2.) Full LOS displacement time series of each PS. Accuracy on single measurements amounts to $1 \div 3$ mm.

(3.) High precision elevation at each PS. Accuracy is better than 1 m.

The accuracy of deformation and elevation measurements depends on the number of available SAR images and on the phase coherence of the PS at hand. Both displacement and height values are relative to a reference point supposed motionless. Moreover, accuracy decreases with the distance from the reference radar target.

PS can be considered as benchmarks of a geodetic network. In urban areas the PS spatial density is extremely high (100-300 PS/km^2). In rural areas the PS Technique can still be used as long as the number of phase stable radar targets (e.g. man made structures and exposed rocks) is high enough (> 10 PS/km^2).

2 PS vs. optical leveling

A first comparison has been carried out on the Italian coast South-West of Ancona. The area is well known to be affected by a slow evolving landslide phenomenon and is monitored since 1983 with optical leveling techniques. The PS analysis has been carried out in the context of the European Commission MUSCL project [3] exploiting 60 ERS acquisitions relative to the time span from June 1992 to Nov. 2000. About 650 PS (square markers) have been identified in the area showed in Fig. 1 A (around $3 \times 3.5\,\mathrm{km}^2$). 12 PS are in the (rural) landslide descent front area, several dozens in the two urbanized ascent front areas. Some of the main benchmarks used for optical leveling survey campaigns are localized by large circular white markers [3]. Leveling (vertical) displacement values have been projected along the ERS LOS for being compared with the time series of the nearest PS. Corresponding plots are showed in Fig. 1 B and C and denote a perfect agreement.

A further interesting result was obtained by studying a single-building deformation phenomenon induced by the excavation of a new underground railway tunnel in Milan. 64 ERS scenes, acquired between May 1992 and Nov. 1999, were used. PS are represented with their average deformation rate in a GIS environment [4] in Fig. 2 A. The track of the underground tunnel is showed as well (dotted lines) in Fig. 2 A. A sudden "step-wise" subsidence phenomenon of about 1 cm occurred to the building (marked 1 in Fig. 2 A) on the crossroad Via Giustiniano - Viale dei Mille in June 1995, due to the excavation of the underlying part of the main tunnel. The deformation can be appreciated in the displacement time series (Fig. 2 D) of the corresponding PS, even though, unfortunately, measurements are quite noisy ($\sigma \approx 3.2\,\mathrm{mm}$). Good agreement was found with displacement values detected at a leveling benchmark within a few meters from the radar target (confidential data). Structural damages are evident (Fig. 2 B, C). On the other side of the crossroad, the building hosting the school "Istituto Magistrale Virgilio" (marked 2 in Fig. 2 A) does not show any deformation, Fig. 2 E.

Main advantageous characteristics of optical leveling are high accuracy (a realistic value is 0.1 mm for leveling lines between benchmarks within 100 meters), possibility to choose the position of benchmarks and to schedule freely surveying campaigns. On the other hand, reg-

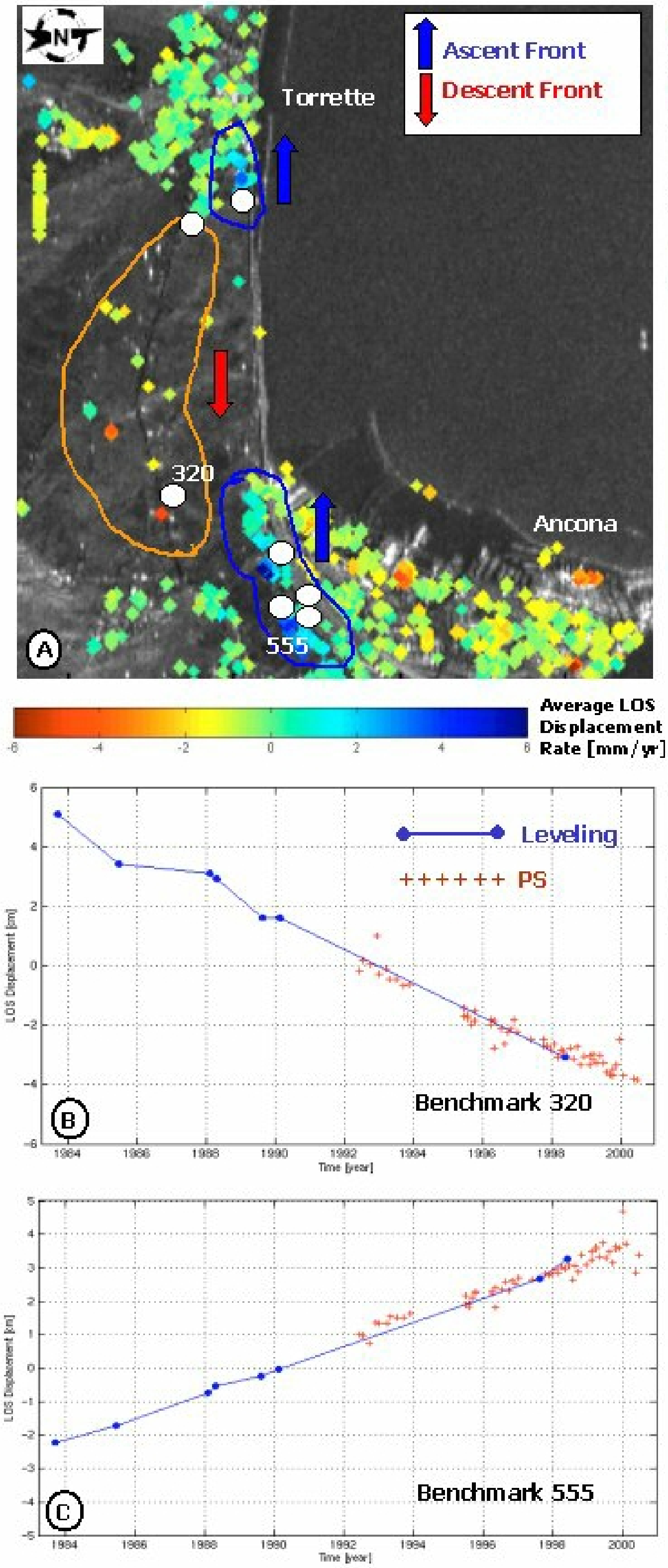

Figure 1: A. The Ancona landslide. Position of identi¯ed PS (square markers) and optical leveling benchmarks (circular markers). B., C. Displacement along ERS LOS at benchmarks 320 and 555 compared with results at the respectively closest PS.

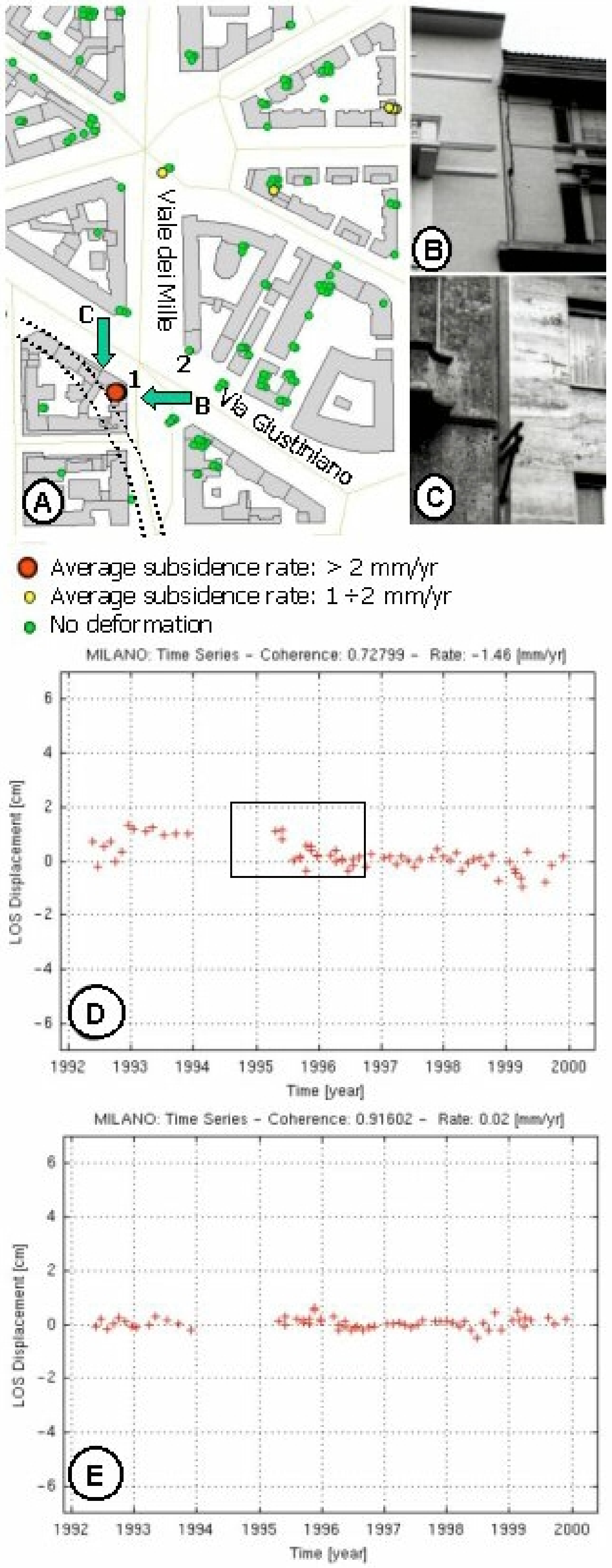

Figure 2: A. PS in GIS environment [4]. Track of the underground tunnel, positions from which photos B and C have been taken. B. Fissuring started 1989 when the pilot tunnel was excavated. C. Structural damages are less evident due to recent restorations. D., E. LOS displacement time series relative respectively to PS marked 1 and 2 in A.

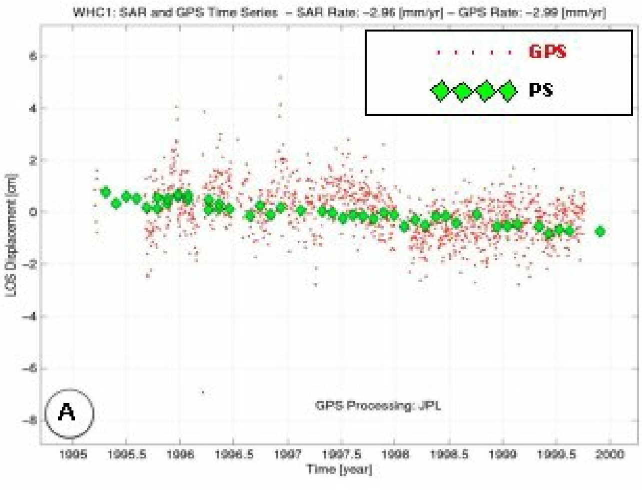

Figure 3: A. PS and GPS time series along ERS LOS direction. The scatterer is within few tens of meters from the GPS station WHC1 at the Whittier College, Whittier, Los Angeles basin.

ular monitoring of wide areas is extremely expensive, campaigns are often too spread in time (e.g. Ancona, Fig. 1: 1983-1985-1988-1988-1989-1990-1998, as well as Bologna: 1983-1987-1992-1999, [5]) to give a good description of displacement phenomena and cannot be used for an e®ective real time risk assessment.

3 PS vs. GPS

A detailed comparison of PS results has been carried out with GPS deformation data gathered by the Southern California Integrated GPS Network (SCIGN) [6] and processed at JPL [7]. Preliminary results were shown already at the IGARSS 2000 [8]. 55 ERS SAR acquisitions (June 1992 - Nov. 1999) were exploited.

GPS data relative to 11 permanent stations operating at least since 1996 in the Los Angeles basin have been projected along ERS LOS and the regional common-mode term (mainly due to the drift towards West of the whole of the LA basin) has been estimated and removed. GPS data were compared with time series relative to PS in the immediate neighborhood (possibly within 100 m), highlighting good agreement (Fig. 3). Vertical accuracy of GPS solutions amounts to 5-10 mm [7] and PS benchmark spatial density is orders of magnitude higher than the GPS one. On the other hand GPS provides daily (at permanent stations only) full 3D deformation data.

4 Conclusions

PS displacement measurements are in good agreement with corresponding results of optical leveling and GPS surveys. Moreover, the three techniques have di®erent and, to some extent, complementary characteristics that call for a synergistic use. PS analysis is extremely advantageous for wide area deformation monitoring, in particular in highly urbanized regions. Furthermore ERS SAR data allow to retrieve past deformation since the ESA ERS archives gather acquisitions since late 1991. GPS is indispensable for assessing 3D displacement data. Optical leveling is still the most accurate and versatile monitoring instrument as long as it is employed on small areas (up to a couple of km^2). The planning of optical leveling investigations could take signi¯cant advantage from PS and GPS results in order to concentrate resources on localized areas (with remarkable economical bene¯ts) and enhance the frequency of surveying campaigns. We are convinced that reliability and quality of surface deformation monitoring could be strongly improved combining the three techniques and integrating the results in a GIS (Geographic Information System) environment.

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