Accurate DEM reconstruction from Permanent Scatterers and multi-baseline interferometry

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Abstract *— The application of the Permanent Scatterers (PS) Technique in multi-temporal data-sets, namely the identification and exploitation of sparse coherent targets, has shown that it is possible to estimate and remove interferometric phase components due to atmospheric effects and orbital fringes. So far, the application of the PS technique has been focused on the extraction of the motion field of the area of interest. However, it is also known that PS relative elevations can be estimated with sub-meter precision while smooth errors can be removed using a coarse resolution DEM or the data of the Shuttle Radar Topography Mission (SRTM). In this paper, we describe a new approach combining the PS Technique and standard interferometry to improve the quality of InSAR DEM's. ERS Tandem interferograms are exploited to increase the number of coherent pixels, while atmospheric effects are estimated and subtracted by means of the sparse PS grid. Prior information and PS elevation are used to reduce the probability of phase-unwrapping errors. Preliminary results are reported and the key-factors for its successful application (e.g. the number of Tandem acquisitions available, PS density) are discussed.*

Keywords- Multi-baseline DEM; Permanent Scatterers.

I. INTRODUCTION

As well known, SAR interferometry (InSAR) is a remote sensing technology that exploits the phase difference of two SAR scenes gathered at different times with different incidence angles over the same area of interest for recovering high-resolution topographic profiles [1]. Main limitations of InSAR are temporal and geometrical decorrelation [2] as well as atmospheric effects (a space-variant phase delay caused by the atmospheric water vapor at the time of the acquisition [3]). In order to improve the quality of InSAR DEM's, ESA ERS-1 and ERS-2 tandem acquisitions (with 24 hours revisit interval) were exploited taking advantage of the low temporal decorrelation [4], whereas many independent interferograms were combined for mitigating atmospheric artifacts [5]. The Permanent Scatterers (PS) Technique [6] developed at POLIMI in the late nineties exploits long series of SAR data both for filtering out atmospheric artifacts and for improving the accuracy of the results. By means of a wide range of baselines, the relative 3D positioning accuracy of single targets achievable with the PS technique is less than 1m [7]. A drawback of the PS technique is to provide a sparse set of height estimates, only in correspondence of targets (usually but not necessarily corresponding to man-made objects) that stay coherent for a long time-span.

Aim of this paper is to show the first results of the joint exploitation of the PS Technique together with conventional interferometry applied to tandem interferograms for generating high-resolution DEM's. The main products of the PS Technique can be used successfully for driving a multi-baseline approach. The atmospheric phase screen (APS), estimated through the PS analysis, can be removed from the tandem interferograms, significantly reducing the difficulties related to atmospheric artifacts. The DEM can then be obtained by means of a multi-baseline estimate, showing much better results than without removal of APS. Moreover, the sparse set of PS heights can be exploited for steering the DEM estimate. The developed prototypal algorithm has shown promising results that however deserve future research efforts.

II. DEVELOPED ALGORITHM

The algorithm developed for DEM reconstruction through the combination of a PS analysis with multi-baseline interferometry consists in three main steps. First a PS analysis is carried out with a data-set that includes tandem acquisitions. The APS estimated in the PS analysis is then removed from the tandem images and tandem interferograms are generated. The interferograms are then flattened and filtered. Finally, a multi-baseline technique is applied and the DEM is retrieved.

A. PS analysis and APS removal

The PS analysis is carried out exploiting a common master image, selected to minimize the dispersion of the normal baseline values of all the interferograms. All the acquisitions are registered on the common master grid. PS candidates (PSC) are selected setting a threshold on the amplitude stability index [6]. For each PSC the phase terms connected to the relative elevation and to the linear motion are then jointly estimated and removed. Thus, phase residuals depend only on the atmosphere and noise. The APS is estimated from phase residuals exploiting its spatial correlation. In this way, each estimated APS is relative to the Master acquisition. The Tandem images are then selected and the respective tandem interferograms are generated. Tandem APS are created in order to remove the dependency on the Master image and subsequently removed from the interferograms. Tandem interferogram phase residuals should then depend on topography, possible displacements, noise and atmospheric residuals, where not correctly estimated.

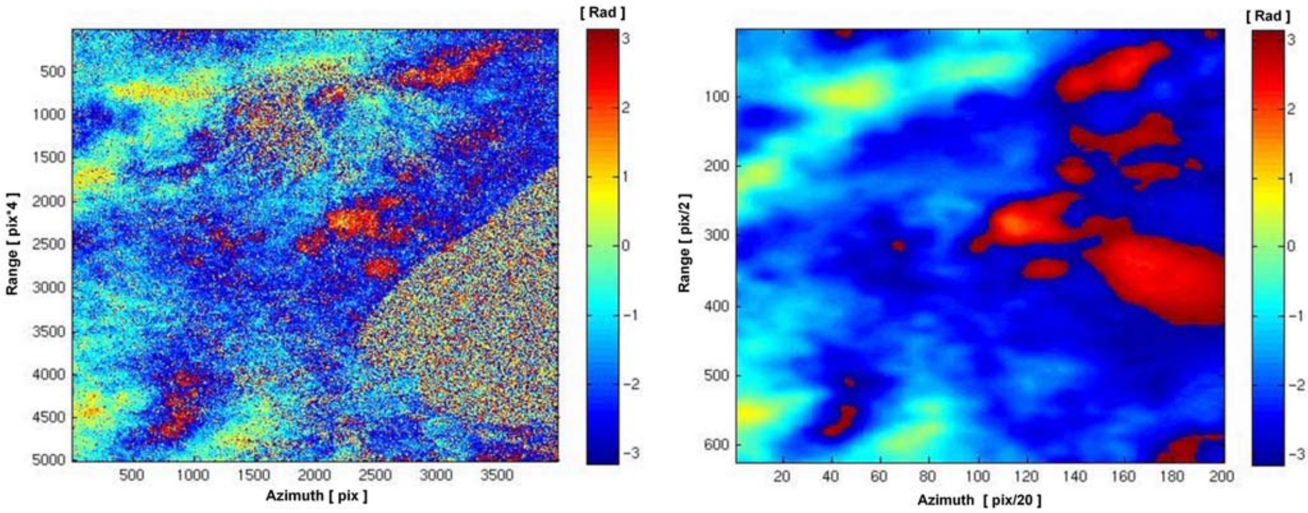

Figure 1. Example of the effects of atmospheric artifacts on a differential interferogram (tandem pair 19990421-19990422, with –97m normal baseline) of an area around Naple. Left: differential tandem interferogram. Right: APS of the same area (relative to the same pair of images) estimated by means of the PS tecnhique. As clearly visible, most of the interferometric fringes derive from atmospheric effects.

B. *Differential interferogram Filtering*

Because coarse resolution DEM's (as SRTM data) are almost worldwide available, it is reasonable to foresee their exploitation. Moreover, the height estimated through the PS analysis on a sparse set of targets can improve the quality of the coarse DEM [7]. By combining SRTM and PS data we then obtain a first DEM that we use for flattening the interferograms, already compensated for the estimated APS. *Differential* phase residuals can now be easily filtered to reduce the impact of phase noise. In order to preserve the resolution even in high coherence areas, we chose to implement the modified Goldstein radar interferogram filter presented in [8]. Such filter is adaptive and takes into account the interferogram spatial coherence. Filtered phase residuals will depend on spatially correlated quantities such as DEM errors, possible displacements, residual APS.

C. *Multi-Baseline Phase Unwrapping*

Topography-dependent phase residuals (height not resolved by the coarse DEM used for interferogram flattening) are the only residual phase term correlated with normal baseline. By unwrapping accordingly the phase residuals, the associated

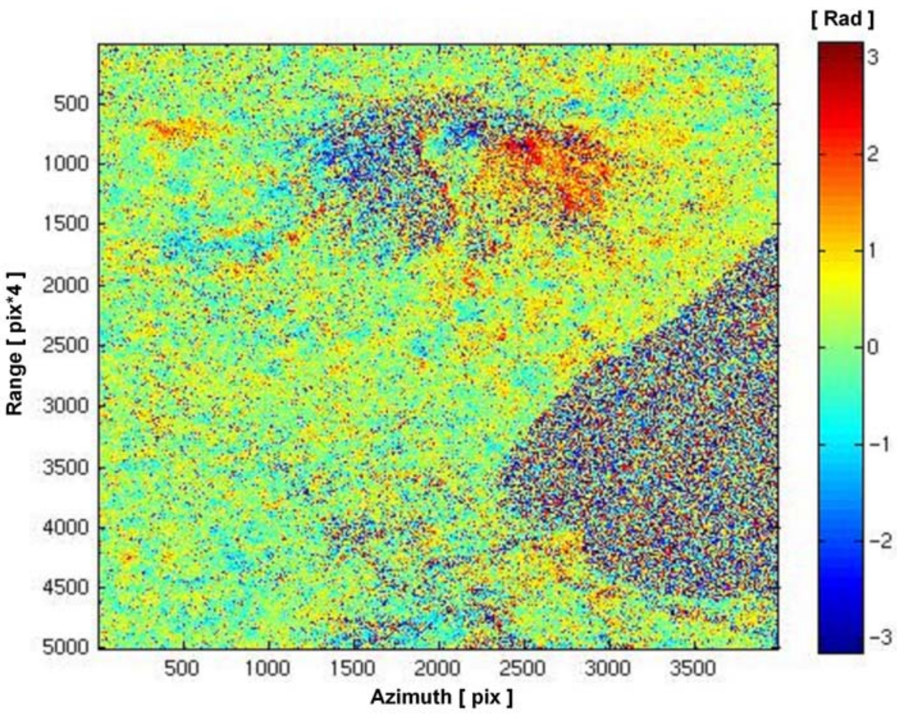

Figure 2. Differential Tandem interferogram 19990421-19990422, with –97m normal baseline, after removal of APS estimated by means of the PS analysis. Residual fringes are mostly due to SRTM DEM errors.

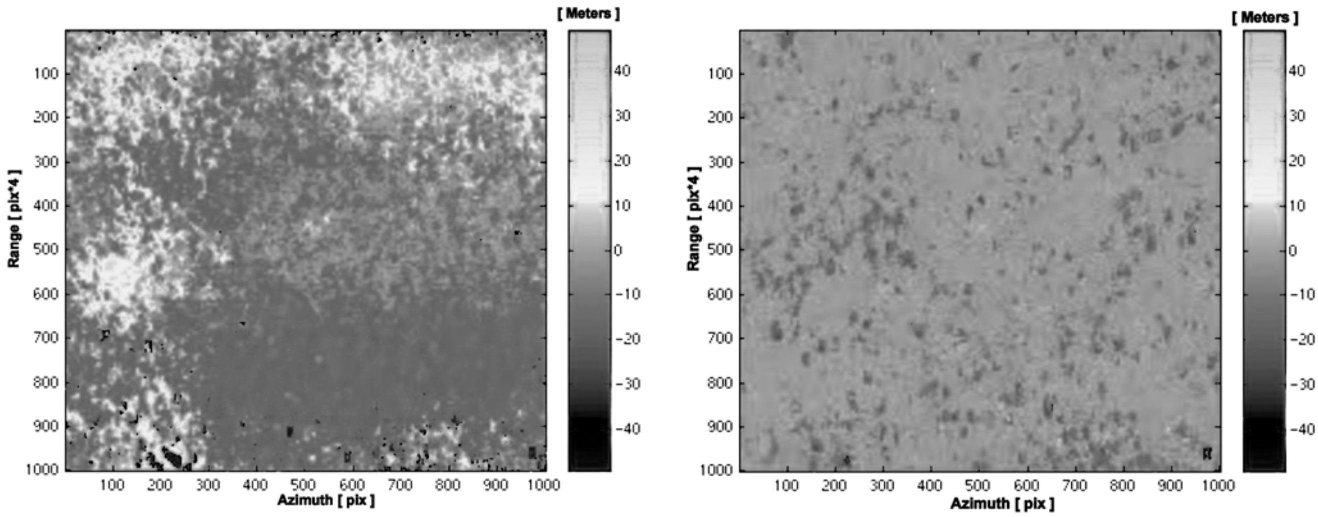

Figure 3. Example of height measure improvement derived from the estimate and removal of atmospheric artifacts. Left: height estimated by means of MBPU using tandem interferograms (flattened with SRTM and PS data) without APS removal. Right: height estimated by means of MBPU with the same differential interferograms after removing the PS APS.

DEM error can be directly derived. A method for implementing such operation is the Multi-baseline Phase Unwrapping (MBPU) [9]. The core idea of MBPU is to build the a-priori p.d.f of the height of a pixel in a differential interferogram, given the phase difference with respect to a reference point, the interferogram normal baseline and the spatial coherence associated to the pixel. By multiplying more p.d.f. relative to the same pixel in more independent interferograms, we get the a-posteriori distribution, whose maximum identifies the height that best fits the phase residuals. The reference point plays an important role, and it can be chosen from among the most coherent PS's identified in the area. The estimate re-iterated on the whole image provides the DEM error with respect to the initial coarse DEM. At the end of the processing, the final result is then the sum of the DEM error estimated by the MB approach and the coarse DEM used to flatten the data.

The accuracy of the final height estimate can be derived from the a-posteriori p.d.f., as reported in [9]. However, it can be stated that the variance of the height estimate is directly proportional to the phase noise and inversely proportional to the baseline squared dispersion and to the number of the exploited tandem interferograms. The variance of the height estimate depends also on the reliability of the tandem APS estimate. As derived in [10], the standard deviation of the single APS estimate is directly proportional to the absolute value of the interferogram normal baseline. Thus, a good compromise for baseline values of tandem interferograms should be found. The variance of the single APS estimate depends also on the baseline dispersion of all the images exploited for estimating it. A high dispersion of normal baselines in a PS analysis allows a precise estimate of PS height and thus a better APS estimate [10]. The ideal data-set for the proposed technique consists of a varied ensemble of images, also at high normal baselines, and the highest available number of tandem acquisitions (the minimum would be 3 pairs) with limited normal baseline values. Finally, it has to be noted that the reliability of the APS estimate depends also on the spatial density of PS's (at least ten PS's per km^2 for estimating a locally plain surface).

III. RESULTS ON REAL DATA

The results reported in this section are relative to an area of about $400 km^2$ around Naples (Italy). 79 ERS-1/2 (Track 36, Frame 2781) images have been exploited in the PS analysis. 12 tandem pairs are available. Figure 1 shows an example of the effects of atmospheric artifacts on an interferogram. The image on the left hand side of Figure 1 is a tandem interferogram compensated for the *a priori* DEM: the interferogram has been flattened exploiting SRTM (~90m posting) and PS data. Most of the fringes on the differential interferogram are not due to DEM errors but to atmospheric disturbances. This is clearly visible comparing the interferogram with the APS estimated by means of the PS technique on the same area (reported on the right-hand side). Note that the uncorrelated area on the right part of the interferogram is over the sea. Clearly the APS estimated on it is not reliable. Figure 2 shows the same interferogram after removal of the estimated APS: most of the error power is concentrated on the Vesuvius volcanic area.

Figure 3 shows an example, relative to a limited area, that highlights the importance of the APS compensation before applying the MBPU. The image on the left is the height estimated by means of the MB approach using all available tandem (differential) interferograms without APS removal. The image on the right is the height estimated by means of MB algorithm using the same data-set but after removing the APS. The expected result is between –10m and 10m, the tolerance of the initial coarse DTM exploited for interferogram flattening. The reference point is approximately in the centre of this area in both pictures.

Finally, Figure 4 shows the final estimated DEM in a small area on the slopes of Vesuvius volcano. The area covers a square of about 2km side and the height range is almost 300m.

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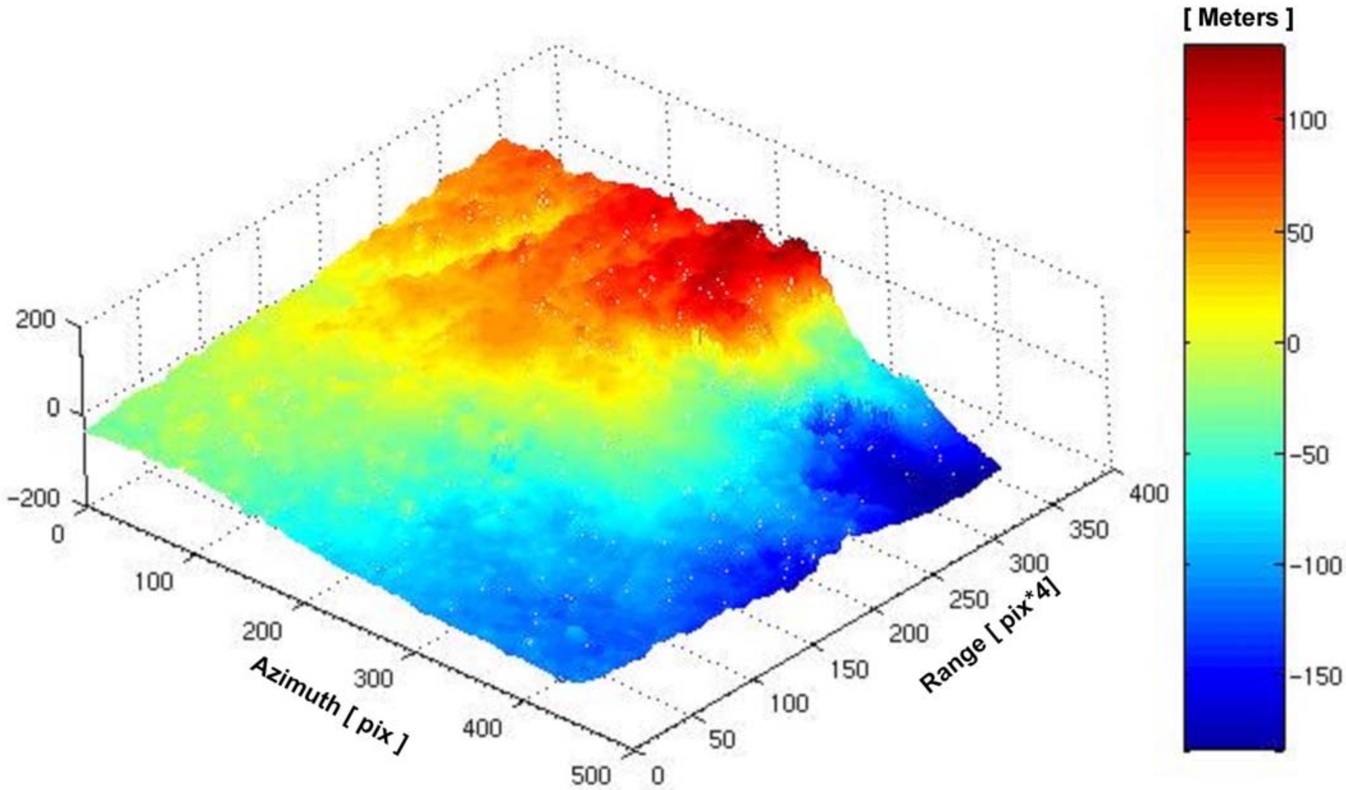

Figure 4. Example of DEM retrieved by means of the joint combination of MBPU and PS Technique. The exploited Tandem differential interferograms have been compensated for the APS estimated through the PS technique.