COMPARISON BETWEEN SAR ATMOSPHERIC PHASE SCREENS AT 30' BY MEANS OF ERS AND ENVISAT DATA

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ABSTRACT

The Permanent Scatterers (PS) technique is able to estimate atmospheric artifacts that delay the SAR interferometric phase over pointwise targets. In this work, for the first time, the Atmospheric Phase Screen (APS) estimated with ERS data is compared to the APS retrieved with Envisat data at 30' time delay. The goal of the comparison is to add new insights to the phase delay that affects InSAR measurements. Preliminary but interesting real data results have been obtained over the city of Milan.

1. INTRODUCTION

SAR interferometry is theoretically capable of measuring millimetric displacements of radar targets that are coherently imaged by the radar at different times [1]. However, phase delays induced by the water vapor content in the atmosphere can prevent from reaching the theoretical accuracy [2]. Thus, atmospheric effects must be removed from interferograms in order to fully exploit the potentiality of InSAR [3]. At the moment, no instrument can estimate the atmospheric delay with spatial resolution comparable to that of spaceborne SAR. The atmospheric delay can be estimated only from long series of SAR images (as in the Permanent Scatterers (PS) technique [4]), by exploiting its statistical behavior in space and time. The Atmospheric Phase Screen (APS) estimated by the PS technique gather then all phase delays that do not depend on the target elevation and on the adopted deformation model. Thus, APS can also include e.g. orbital errors or unknown (or not considered) spatially-dependent phase terms.

The density of PS in urban sites can reach some hundreds of points per km^2 and decreases up to few points in vegetated areas. How would it be possible to validate the effective dependence of the APS on local atmospheric conditions in urban areas? The answer would also be useful to check the feasibility of correcting SAR interferograms by means of independent measures of the local atmospheric parameters. Usually the main problem is the very low spatial density of meteo stations that provide pressure, temperature and humidity measurements. Alternative instruments are in situ devices such as radiosondes (costly, low horizontal resolution [5]) or spaceborne sensors: passive remote sensing systems such as microwave radiometers and infra-red (IR) sensors mounted onboard orbiting satellites (again with low resolutions and other drawbacks [5]). Then, also the exploitation of GPS receivers to estimate the water vapor content of the atmosphere is increasing in the last years. Works have been developed to retrieve the zenith wet delay by combining data acquired by different ground stations [6], and research is being carried out on the tomographic reconstruction of the atmosphere [7]. Also in these cases the main problem is the availability of a dense network of ground stations to explore the atmospheric volume with the desired resolution.

In this work for the first time a comparison between APS estimated at 30' delay by means of SAR data is provided. In terms of spatial resolution and temporal distance, the experimental data here reported represent a unique contribution to better understand the impact and the variability in space and time of atmospheric effects on electromagnetic signals.

2. PS CHARACTERIZATION AND CLASSIFICATION

The first problem to be tackled in the attempt of carrying out the comparison here proposed is the exploitation of ERS high Doppler Centroid (DC) data [8] together with Envisat images acquired with a different carrier frequency [9]. Distributed targets, in fact, lose coherence when observed under different acquisition geometries [10]. On the contrary, very point-wise targets are expected to be coherently imaged also in squinted images.

Recently, the physical nature of SAR urban targets has been subject of study [11] and algorithms for the identification of their scattering typology have been developed [12]. Based on target characteristics that can be estimated by means of radar data (height with respect to street level, geometrical dimensions, resonance attitude, bounces parity-disparity), urban SAR PS's have been classified in 6 main typologies: ground level resonating scatterers as floor metal gratings, elevated (roof-level) scatterers as tiled or corrugated roofs, dihedrals, resonating dihedrals as metal fences, poles and trihedrals.

Among these target typologies, poles are a very special kind of scatterers. Poles indeed are dihedrals with cylindrical symmetry. This means that poles are visible by sensors with different incidence angles, attitudes and also from ascending and descending passes [13]. Such a

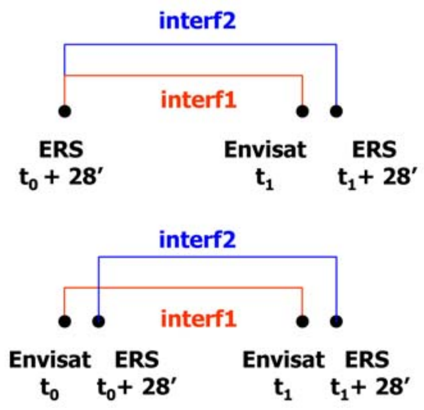

Figure 1. Different strategies to generate interferograms for comparing ERS Envisat APSs at 30'

peculiarity has been used to precisely combine results obtained from different orbits [14] but also to develop PS analysis estimating height and deformation trend by jointly combining parallel tracks [15]. Here the goal is to exploit poles to reduce decorrelation effects due to different DC and carrier frequencies and to obtain the desired APS.

3. PROBLEM STATEMENT AND PROCESSING CHAIN

Let us assume Envisat acquires an image at time t_0 with frequency f_0 + 31MHz (repeat cycle 35 days). ERS flies then over the same ground area at time t_0 + 28' and works at frequency f_0.

Two possible configurations can be adopted for the comparison here proposed, as sketched in Fig. 1. In the first case, a common ERS image acquired at time t_0 + 28' is chosen as Master. Two interferograms are generated between the Master image and the Envisat and ERS acquisitions at time t_1 and t_1 + 28' respectively. Such configuration can be useful to directly compare the two ERS and Envisat APS that can be retrieved from the interferograms. The drawback of this approach is the contemporaneous presence of decorrelation due to different DC and carrier frequencies. In the second case, two interferograms are generated with two different Master acquisitions (Envisat at t_0 with Envisat at t_1 and ERS at t_0 + 28' with ERS at t_1 + 28'). Here the decorrelation can be strongly reduced, but the APS to compare have different references. As we will see from the results retrieved in Milan, in first approximation the APS are still comparable even in this case.

The developed processing chain to estimate the APS consists in the following steps:

- A PS analysis is carried out by means of stable acquisitions (limited normal baselines and DC frequencies). Height and deformation trend are estimated for the detected PSs [4].
- Poles are identified by means of the acquired radar data, exploiting their scattering characteristics [12].
- Poles are then precisely geocoded and cross-checked with ground measurements [14].

At this point a precise geocoded ground network of poles is available. 3D geographical coordinates (1m tolerance [16]) and possible displacement (few mm [4]) are known. Given then a new image (be it squinted or acquired with a different frequency or even with different resolution or geometry), after a first rough geocoding, poles can be found visible in it. The matching of the new image with the ground network of

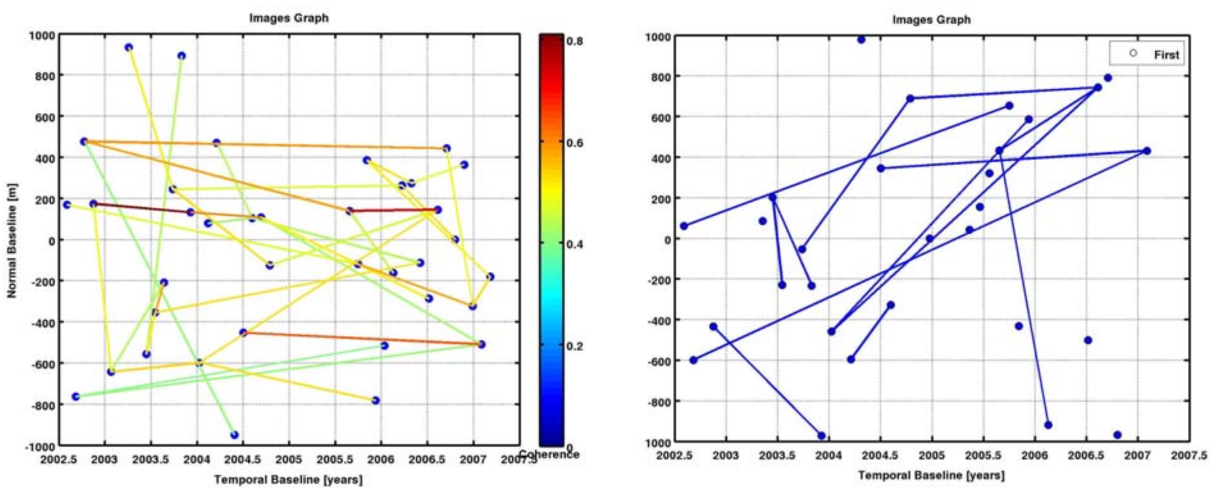

Figure 2 .Left: Minimum graph among ERS high DC images obtained by maximizing the interferometric coherence. Right: corresponding Envisat interferograms. The two images are in the normal-temporal baselines space.

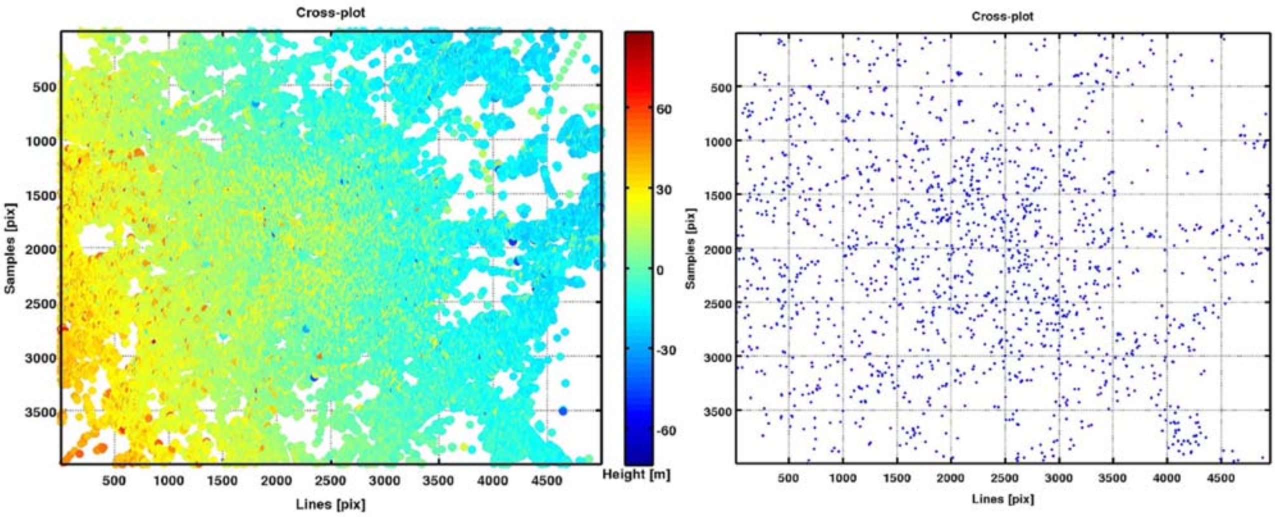

Figure 3. Left: 60,000 PSs detected in Milan. Color scale: estimated height. Right: 2,000 selected poles.

poles allows then the following operations:

- Precise coregistration (squinted ERS and Envisat images are aligned on a common Master grid)
- Generation of interferograms
- Orbital corrections (estimation of the offsets due to inaccurate closest approach and acquisition time of the first sample, removal of cross-orbits phase ramps)
- Interferogram puncturing in correspondence of poles (extraction of their interferometric phase)
- Compensation of the interferometric phase for the known height and deformation trend

Finally, a set of interferometric phase residuals is available for the detected poles. The space-correlated component of the interferometric residuals is then interpreted as APS. The power of the uncorrelated residuals is an index of the coherence of the single interferogram. The deviation of the residuals for a single pole with respect to the phase history in the stable acquisitions is an index of the pole reliability.

2. RESULTS

The processing chain above described has been applied to a data-set acquired by the ESA sensors ERS and Envisat over the city of Milan between 1992 and 2007. 116 ERS images are available, out of whom 39 have DC absolute values greater than half a PRF replica. The Envisat images are 29 since 2002. Only 3 ERS and Envisat tandem pairs could be used for interferometry, according to the standard criteria, whereas a total number of 20 pairs is available.

How to chose which interferograms to analyze? Again, here the bottle neck is the decorrelation due to high DC (it is worth to remember here that high DC frequencies affect also the reliability of the focusing process). Thus we search for the minimum graph that connect the selected 20 ERS images and maximizes the interferometric coherence (Fig. 2 on the left). In this way we can analyze the most coherent independent APSs. In second instance, we extract the corresponding Envisat pairs (Fig. 2 on the right). At the end, 14 Envisat-Envisat t_0- t_1 and 14 ERS-ERS t_0+28’- t_1+28’ interferograms are generated. As visible from Fig. 2, normal and temporal baselines of the selected interferograms are not negligible. As a consequence, the compensation of the interferometric phase for the estimated height and deformation trend described in the previous section becomes mandatory.

In Fig. 3 on the left the 60,000 PSs detected in Milan are showed in SAR coordinates, the color indicating the estimated height. Besides, the 2,000 targets recognized as poles are reported.

Fig. 4 shows the final result of the work (the best 10 pairs have been chosen). In the first and third columns Envisat APSs are reported, besides in the second and fourth columns there are the corresponding ERS APSs. Thus the comparison is to be done between horizontal side images. As visible at first glance, the two corresponding APSs look similar for each pair. Some of them are more noisy (e.g. the ERS ones in the fourth line), in particular where few poles are present on the right of the image grid (as visible from Fig. 3). The variance of the atmospheric disturbance varies from less than 1rad^2 to about 6rad^2 for the worst APS. In the first, third and fifth lines, first two columns, the APSs have similar low variance for each pairs (mostly winter acquisitions, in accordance with [17]). But it can be noted that the higher spatial frequencies (due to turbulence effects) are different. On the other side, two pairs in the first two lines have common more complicated features (summer acquisitions, again [17]). In particular, first line, third and fourth columns, the APSs are characterized by similar longitudinal fringes.

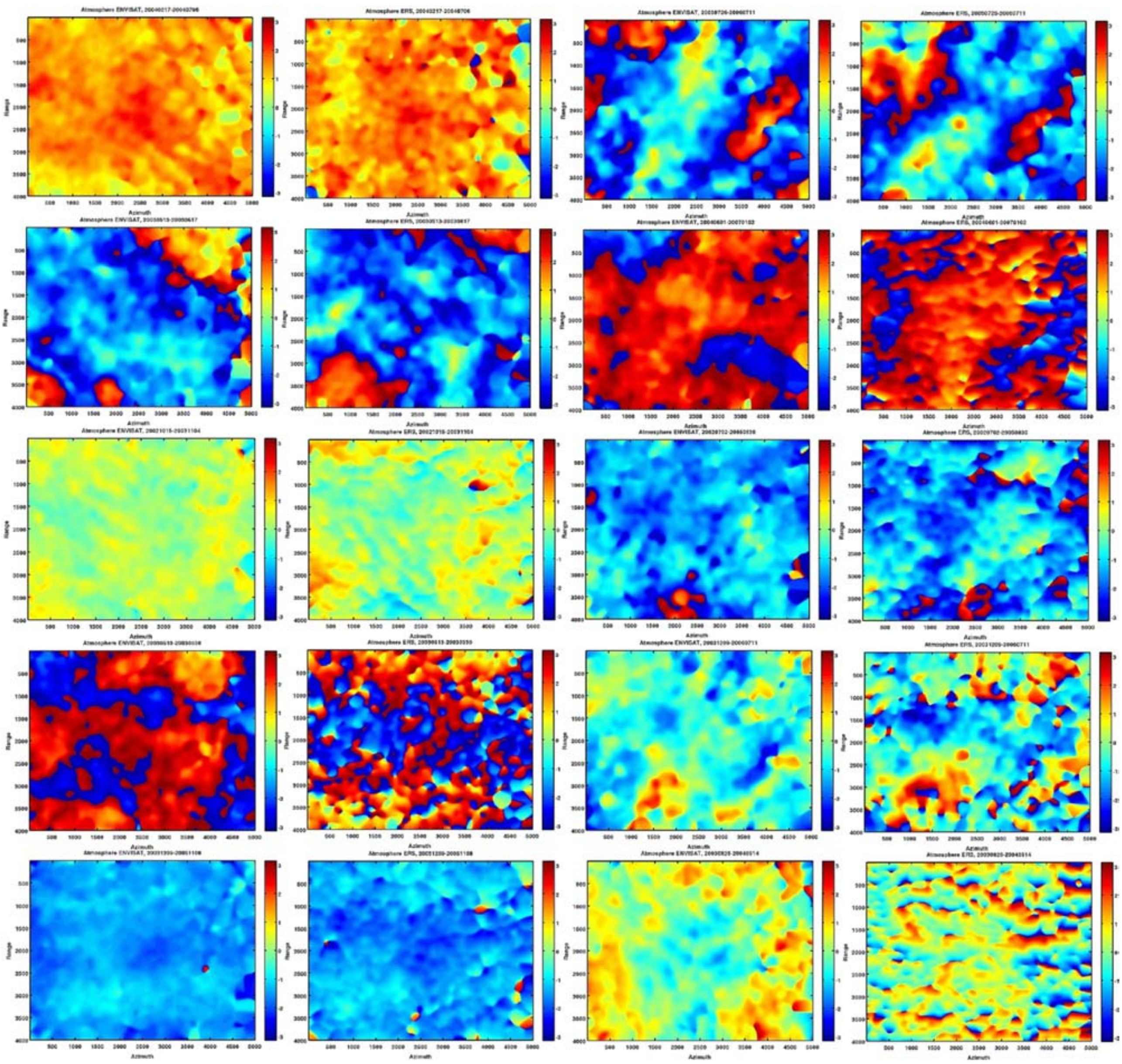

Figure 4. APSs estimated in Milan. First and third columns: Envisat APSs. Second and fourth columns: corresponding ERS APSs. Corresponding ERS-Envisat APSs at 30' stay side by side horizontally.

From a preliminary analysis of spatial cross-correlations, the correlation radius varies from about 200m (summer) to 5km (winter). Moreover, the turbulence shows often a periodical character.

Finally, an attempt to compare possible recognizable shifts of the clouds with the measured direction and intensity of the wind has been carried out. Indeed, some weak correlation has been observed (at least the magnitude of the wind is in accordance with the observed shifts), but the complexity of the problem deserves more future efforts to better understand the phenomenon.

4. CONCLUSIONS

In this work, for the first time, the Atmospheric Phase Screen (APS) estimated with ERS data is compared to the APS retrieved with Envisat data at 30' time delay. The result of the comparison over a small set of images in Milan show that atmospheric low frequencies look similar after 30'. High frequencies are on the contrary dependent on local conditions and have different levels and types of correlation.

The work has been carried out with the aid of poles, multi-frequency multi-geometry targets that can be exploited to successfully generate interferograms between high DC ERS-2 and Envisat images.

5. ACKNOWLEDGEMENTS

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