Abstract – The Permanent Scatterers (PS) technique is an advanced tool for processing series of interferometric SAR data aiming at millimetric precision ground deformation mapping. The approach is based on a joint time-space-acquisition geometry analysis that is carried out at individual point-wise radar targets. The aim of this paper is twofold: (1) describe the main issues related to the precision of PS products; (2) show preliminary PS results obtained using, instead of ESA-ERS scenes, data acquired by other spaceborne SAR platforms characterized by different acquisition parameters (namely RADARSAT and JERS).

I. PRECISION ASSESSMENT
The estimation of the precision of PS output products (Line of Sight (LOS) displacement measurements, average deformation rate and PS elevation) is not an easy task to perform. The three main factors impacting on the precision of PS measurements are:

1. atmospheric phase artifacts (tropospheric and ionospheric delays), creating the so-called Atmospheric Phase Screen (APS) superimposed on each SAR acquisition;
2. state vectors errors, creating the so-called “orbital fringes” (low order phase polynomials) on the differential interferograms;
3. temporal and geometrical decorrelation, affecting individual PS.

A full statistical characterization of these contributions is not straightforward [3], here it will suffice to recall that tropospheric phase components are characterized by high spatial correlation, baseline errors and ionospheric effects usually generate phase pattern well fitted by means of a low order phase polynomial, and decorrelation phenomena give rise to phase noise that is uncorrelated both spatially and temporally. In the following, we will briefly discuss how important is the use of a multi-interferogram approach to improve DInSAR data quality and we will highlight the major statistical features of PS results.

One of the first steps of PS Technique is the generation of N differential interferograms with respect to the same master acquisition [1][2]. This operational strategy allows one to carry out the interferometric analysis in a simple, effective, and elegant mathematical framework, where the user can find useful tools also for accuracy and precision assessment. Problems related to optimum data selection and clustering (which data should I use? How many and what interferograms should I generate?) as well as the difficulties related to the correlation of partial results (most of the times data coming from different interferograms cannot be considered independent, since they have common images) are no more present.

For each interferogram $i$, the phase can be modeled as:

$$\varphi_i = K_1 \cdot B_n + K_2 \cdot B_T + \varphi + \mu_{NL} + \alpha_i + n_i$$

where $B_n$ represents the normal baseline, $B_t$ the time difference (in days) between the acquisition of master and slave images, $\epsilon$ the error in the reference DEM, $\nu$ the LOS velocity field of the area of interest, $\mu_{NL}$ is a possible deformation pattern due to non-linear motion components, $\alpha$ the phase shift due to atmospheric effects and orbital fringes and $n$ is the noise contribution.

Let us now suppose that we know the unwrapped phase values on a sub-set of image pixels slightly affected by decorrelation phenomena and we have selected a reference point $P_0$ assumed to be motionless and of known elevation.

As a matter of fact, the first part of the PS strategy (PS candidates selection, joint estimation of relative velocity and elevation between pairs of PS candidates not too far apart, integration of the local variations) can be thought of as a multi-interferogram phase unwrapping algorithm, properly taking into account the different phase contributions [2]. Once phase values are unwrapped (at least on a sub-set of PS) we can have a chance to properly estimate atmospheric and orbital fringes and start a powerful pixel-by-pixel analysis of the data-set.

Considering the unwrapped phase difference between $P_0$ and a generic PS candidate it is possible to write a linear system of $N$ equations:

$$\varphi_{uw} = K_1 \cdot B_n + K_2 \cdot B_T \cdot \nu + \mu_{NL} + \alpha + n$$

where $\nu$ includes atmospheric, orbital and noise components as well as non-linear terms for the current image and $\alpha$ represents the atmospheric contribution of the master acquisition, common to all differential interferograms. We can then solve this system for the three unknowns $\nu$, $\epsilon$, and $\mu_{nl}$ and estimate the precision of the results in the LMS mathematical framework. The variance of $w$ can be estimated directly from the data as the power of the phase residues with respect to the linear model we have adopted.

Due to the nature of the disturbance ($w$), which is mainly due to atmospheric effects and spurious orbital fringes, the variance of $w$ increases as far as we move away from the...
reference point $P_0$ and the phase residues with respect to the model adopted are characterized by high spatial correlation. Thus we expect that the pattern of the \textit{a posteriori} variance of the unknowns (e.g., the velocity) should reflect these features. This is exactly what we measure on real data every time we carry out this kind of estimation on the sparse grid of the so-called PS candidates (PSC). This precision assessment procedure is very important for PS processing: as a matter of fact, atmospheric and orbital fringes are estimated and removed basing on the estimation of the motion and topographic components of the PSC.

In Figs. 1 and 2 the estimated standard deviation of the velocity values (mm/yr) obtained from the procedure outlined above. The analysis has been performed on ESA-ERS SAR data acquired over Japan from November 1992 up to December 2000. Thanks to the use of more than 40 acquisitions, the precision (1-sigma) is always better than 1.25 mm/yr even before any filtering of atmospheric and/or orbital phase components and considering PS more than 30 km apart from the reference benchmark $P_0$. It should be pointed out that, in general, a very strong contribution of the variance of the phase residues stems from spurious phase ramps superimposed on the data and so the values we measure strongly depend on state vectors precision. Once linear phase components are systematically removed from all interferograms, the maximum value of the standard deviation drops to less than 0.5 mm/yr (typical value for areas less than 2,500 sqkm wide). Of course, in this case, we are renouncing to estimate the regional gradient in the velocity field.

In general, the analysis of the precision of a PS velocity field in terms of one simple figure, e.g., the maximum standard deviation, is misleading. The precision strongly depends on the distance between the reference radar benchmark and the generic PS. It is the study of the variogram (or the autocorrelation function) of the phase components that can give us a more complete statistical characterization of the results. Indeed, if we are not interested in low-frequency spatial components of the deformation pattern the multi-temporal PS analysis can be extremely accurate. In fact, on the sparse PS grid, phase dispersion due to decorrelation phenomena can be extremely low and the main actors become atmospheric effects and orbital fringes. As a matter of fact, locally (e.g. less than 4-5 km apart from the GCP and considering 8 years of ERS acquisitions) the precision can be even better than 0.1 mm/yr. Things get more difficult when seeking for regional phenomena (e.g., the post-glacial rebound of the Scandinavian peninsula with typical gradients of 3 mm/yr/100 km). In that case the information coming from the analysis outlined above can give some important indications about the reliability of the conclusions we draw at the end of the PS analysis. The use of different data-sets coming from acquisition geometries (ascending, descending orbits, parallel tracks, etc.) or even multi-platform analyses can help in further clarifying the scenario.

**II. MULTI-PLATFORM ANALYSIS**

Recently the PS Technique has been tested also on JERS and RADARSAT data. Here we wish to show very briefly the first preliminary results obtained on part of the urban area of Tokyo (~35 sqkm), that has been analyzed both with ERS and RADARSAT data (Standard Image Mode, beam S1, having a nominal acquisition geometry very similar to the ERS one, even though, of course, polarization is horizontal and Doppler Centroid values are strongly different). Only 12 RADARSAT images, gathered in the years 2000-2001, are available. Aiming at making comparable PS analyses carried out on the two different platform data sets, 12 ERS images (1993-2000, out of the 45) have been selected paying attention to get an ERS sub-data set with a distribution of the normal baseline values the more similar to

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**Figure 1:** PSC velocity standard deviation [mm/year]: Tokyo bay area, Japan (SAR coordinates). 45 images processed, descending mode. Area extension: 30x60 sqkm.

**Figure 2:** PSC velocity standard deviation [mm/yr]: Yoshiwara area, Japan (SAR coordinates). 49 images processed, ascending mode. Area extension: 50x34 sqkm.
the one of the RADARSAT data (see Figure 3), in order to keep similar also the effect of geometric decorrelation. The whole PS processing has been carried out both on the ERS and RADARSAT data, assuming a constant velocity model for LOS deformation. The main goal was to demonstrate that RADARSAT data are suitable for a PS analysis and to start comparing the PS populations relative to the different data sets. As expected, the PS approach works on RADARSAT data, even though the low number of images as well as the purpose of comparing results obtained with different data sets required adopting adequate criteria to identify PS with reasonable confidence (Further details are discussed in [4]). Limiting our attention to the spatial distribution of the PS (i.e. to their position), we could appreciate that the PS densities are comparable. Furthermore, PS are (mainly) hosted by different sampling cells and, therefore, correspond to different features. Similar results have been obtained on a different test site (Yoshiwara) comparing ERS and JERS PS results.

III. CONCLUSIONS
In this paper we focused on two important aspects related to the Permanent Scatterers technique: the PS data precision assessment and the possibility to extend this processing strategy to other platforms, in particular to RADARSAT. We have outlined a simple procedure that can help in the evaluation of PS results and we have pointed out the importance of the statistical characterization of all phase disturbances. The PS approach can achieve impressive precision figures as long as a sufficient number of data is available and regional deformation patterns are corrected using prior information (e.g. GPS values), wherever available. As we expected, the PS approach can be extended to other sources of SAR data with no major changes. PS distribution and density depends on acquisition geometry, polarization, operating frequency. The optimization of the joint use of different radar sources is currently an active research topic.

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