MULTI-TRACK PS ANALYSIS IN SHANGHAI

Daniele Perissin(1), Claudio Prati(1), Fabio Rocca(1), Deren Li(2) and Mingsheng Liao(2)

(1) Politecnico di Milano, Via Ponzio 34/5, 20133 Milano, Italy, Email: daniele.perissin@polimi.it
(2) LIESMARS, Wuhan University, China

ABSTRACT

It is known that several areas in Shanghai town are affected by strong subsidence and many studies are being carried on for monitoring its ground motion. Moreover, the city is growing more and more both in extension and height, and this fact can be connected to the subsidence phenomena. In this work, carried out within the ESA Dragon project, all the available data acquired by ESA satellites ERS and Envisat over Shanghai are jointly exploited in order to get the full story of the ground motion and of the city growth. The results obtained by analyzing an area of about 1,000 km^2 around Shanghai city-center are shown. They are in good agreement with leveling data collected in in-situ surveys. Moreover, for the first time a PS analysis has been carried out exploiting jointly data acquired by the satellite flying along parallel tracks.

1. INTRODUCTION

Built on coastal sand and clay that lie 70 meters below the ground surface, Shanghai is suffering from creeping subsidence, like Los Angeles, Mexico City, New Orleans, Osaka and Venice. Local experts have agreed that the overuse of underground water remains a main cause of the city's subsidence. Shanghai started exploiting its underground water in 1860 when international traders poured in and began to turn the small town into a metropolis. As the granite high-rise buildings of banks and business centers rose up to form the imposing riverside Bund district, the city's population grew to about 5 million in the 1940s. As early as 1921, geologists discovered that Shanghai was sinking. Since the 1920s, the city's 600-square-kilometre central area has sunk by 2 meters on average and even 3 meters in some areas. As the most urbanized metropolis on the Chinese mainland, the land of Shanghai now shoulders more than 2,000 high-rise buildings of at least 100 meters in its 600 square kilometer central area. Thus, in addition to the overuse of underground water, experts believe that the mushrooming of skyscrapers in central Shanghai has also contributed to the city's creeping subsidence.

Thus, as the European Space Agency (ESA), together with the National Remote Sensing Center of China (NRSCC) decided to run a three-year (2004-2007) cooperation program in Earth Observation science and technology (the Dragon project), the Shanghai case was chosen as a test-site for developing remote sensing procedures to monitor deformation phenomena from spaceborne SAR data.

The procedure here adopted to tackle the study of the ground motion affecting Shanghai city is the Permanent Scatterers (PS) technique [1], a powerful technology developed at POLIMI to process spaceborne SAR data. The PS technique is capable of accurately measuring the differential movement of vast numbers of “natural radar targets” distributed across the Earth’s surface. PS typically correspond to objects on man-made structures such as buildings, bridges, dams, water pipelines, antennae, as well as to stable natural reflectors (e.g. exposed rocks). When PS remain coherent within a multi-temporal radar data-set, it is possible to detect and measure millimeter variations in the sensor-target distance, over time. Thus the PS comprise a sort of “natural geodetic network” for accurately monitoring surface deformation phenomena (e.g. subsidence, uplift, landslides, seismic faults, etc.), as well as the stability of individual structures.

2. AVAILABLE DATA

All data acquired by ESA spaceborne SAR sensors (ERS1-2 and Envisat) have been distributed to the Dragon scientific community to retrieve information on the subsidence in Shanghai. Around the city center of Shanghai, 4 different swaths imaged by the radar in 4 different satellite orbits cross: 2 parallel ascending (Tracks 268 and 497) and 2 parallel descending passes (Tracks 275 and 3), as visible in Figure 1a. Unfortunately, ERS1 and ERS2 collected an amount of 43 images in the period 1992-2003 (17 acquired by ERS1 and 26 acquired by ERS2) only along Track 3. On the other side, the Envisat satellite has been taking data since it was launched in orbit (year 2002) in all 4 tracks, but, due to conflicts in the request of different acquisition modes (i.e. the natural counterpart of the desired instrument flexibility), after 5 years of

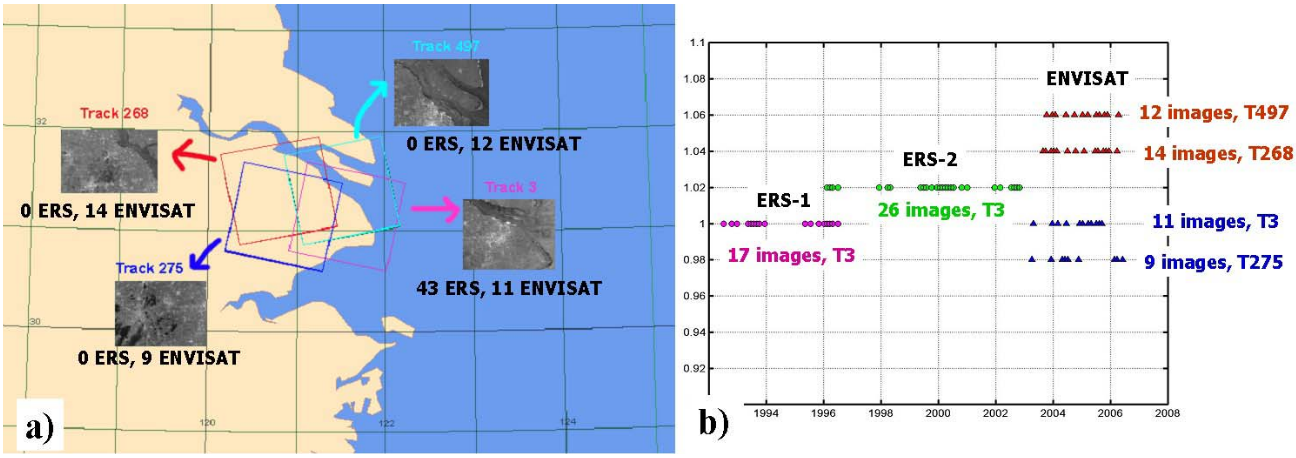

Figure 1. ESA SAR available data around the city center of Shanghai. a) Strips imaged by the ESA spaceborne radars along 4 different orbits, 2 descending (T3, T275) and 2 ascending (T268, T497). b) Temporal distribution of the available data.

operations it has acquired only 14 images in Track 268, 12 images in Track 497, 11 images in Track 3 and 9 images in Track 275. Figure 1b shows all the available data as a function of the acquisition time.

Given the dataset shown in Figure 1b, an ad hoc procedure to exploit all the available images had to be studied. The PS technique in fact, can produce reliable results when applied to a dataset of at least 20 images [1]. ERS1-2 data can then be used together within an analysis covering the time span 1992-2003. But none out of the 4 tracks acquired by Envisat has a sufficient number of images to carry out a PS analysis on Envisat data only. A possible solution to exploit more images is the combination of ERS and Envisat data, as published in [2]. The main difference between ERS and Envisat acquisitions is a shift between the carrier frequencies of 31MHz (5.3 GHz for ERS and 5.331 GHz for Envisat) that causes the loss of about 30% of coherent targets. If we adopt this solution only the Envisat data acquired along Track 3 (along which ERS data were taken) could be exploited, leaving the other 3 tracks unused. Furthermore, in Shanghai the use of data acquired in the nineties together with data of the last years is made more difficult due to the high trend of buildings construction. As an example, in Figure 2 the reflectivity maps of a 4km^2 area are shown before and after year 1999: the whole area changed for the built up of a ring and surrounding buildings. An alternative solution to use the Envisat data is the combination of parallel tracks (268 together with 497 or 275 together with 3) in a joint PS analysis. Up to now parallel tracks (as well as ascending and descending passes) have been combined on a common geographic layer, after estimating the targets height and deformation trend in separate analysis [3]. Here the goal is the identification

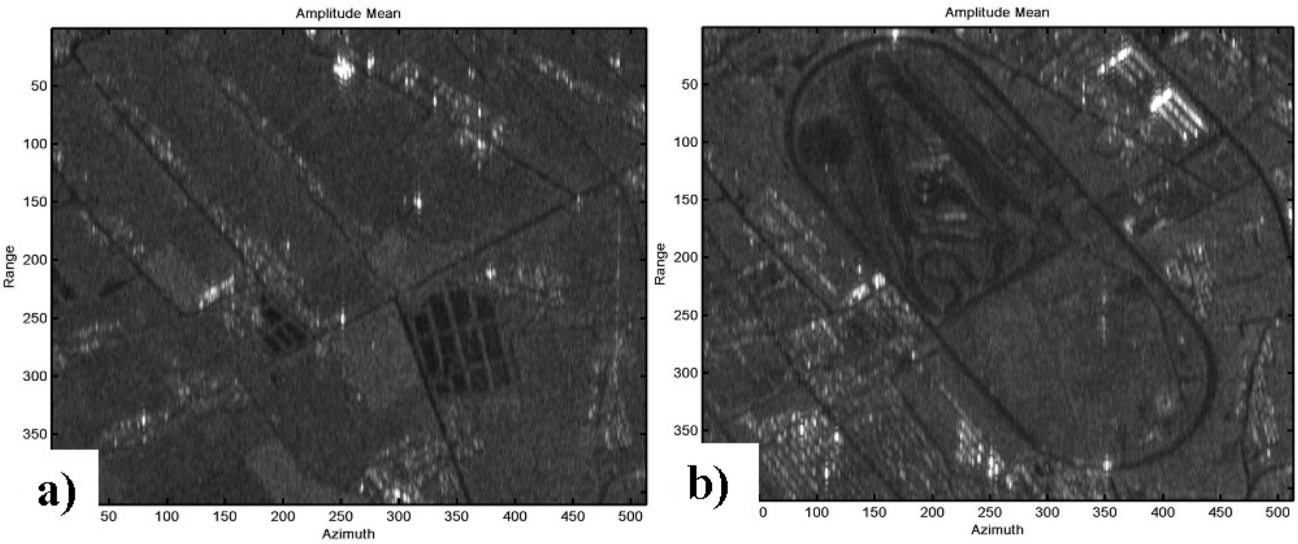

Figure 2. Example of the city growth in Shanghai. The images show the reflectivity map (amplitude incoherent mean) relative to the same ground area estimated in two different periods: a) using images acquired between 1992 and 1999; b) using images acquired between 1999 and 2006. Data have been taken by ERS and Envisat along Track 3.

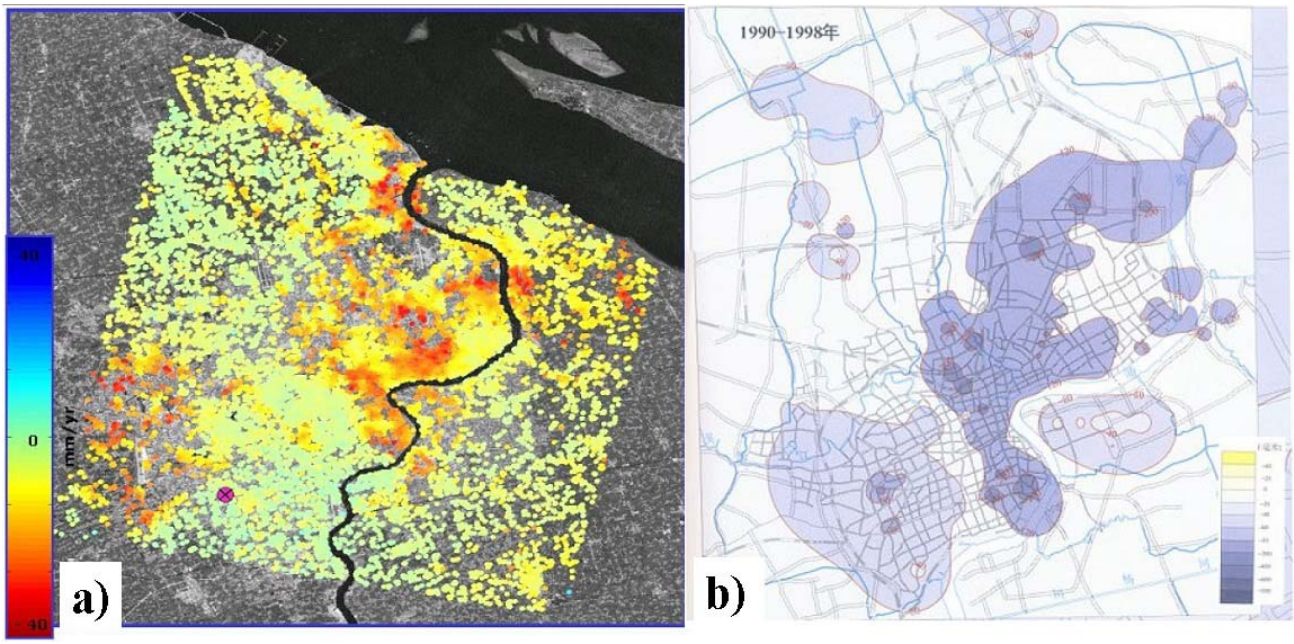

Figure 3. Subsidence maps estimated in Shanghai. a) Velocity field of ERS PS (Track 3 data). Color scale: -40 ÷ 40 mm/year. b) Deformation map prodiced by the China Geological Survey using optical leveling data.

of common targets, visible from both the different viewing angles of the two tracks (about 4 degrees), in order to estimate their height and displacement using jointly the two datasets. In the following we analyze first the results of the classical PS analysis carried out on ERS data only and then the results obtained by the combination of the Envisat parallel tracks.

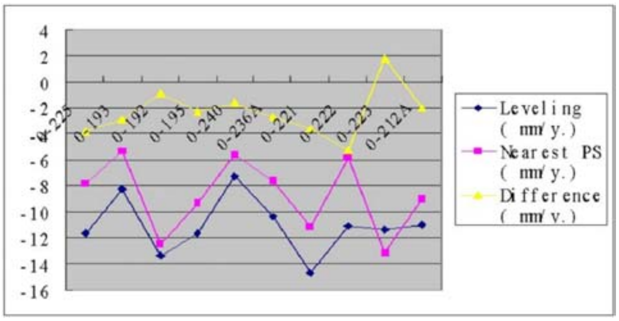

Figure 4. Comparison between displacement time series estimated by means of SAR and optical leveling data. The vertical scale is in [mm]. The time span is 1992-1998.

3. ERS PS ANALYSIS AND VALIDATION BY MEANS OF LEVELING DATA

The main result of the PS analysis carried out on the 43 ERS data, acquired in the 1992-2003 time-span is shown in Figure 3a. Each colored point in the image corresponds to a Permanent Scatterer (about 30,000 in 1,000 km^2) and its color shows the estimated linear deformation trend. The color scale range is -40 ÷ 40 mm/year. The red areas in the image identify the zones of Shanghai with the highest subsidence rate. Figure 3b reports the subsidence map produced by the China

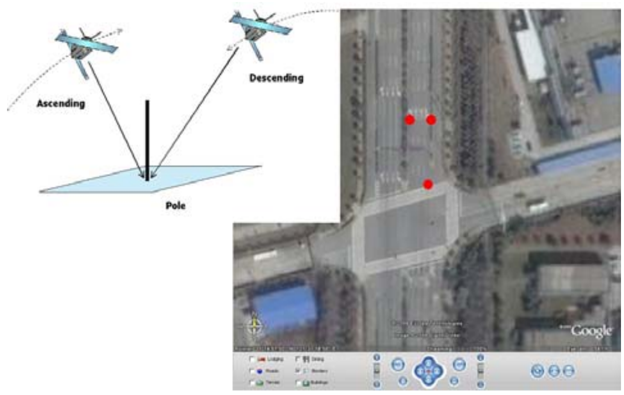

Figure 5. Example of target recognition in Shanghai by means of SAR data. The red spots on the optical image taken from Google are SAR PS recognized as poles. Poles are a very useful urban target typology because of their simmetric dihedral-type peculiarity.

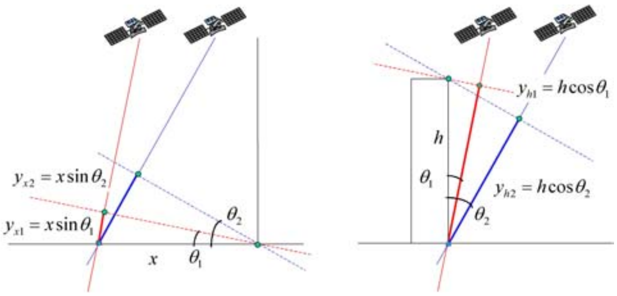

Figure 6. Simple scheme for the acquisition geometry of two parallel tracks. Left: slant range projection of 2 ground points x meters away. Right: slant range projection of 2 points at different heights (0, h).

Geological Survey by means of optical leveling data collected between years 1990-1998. The good spatial correlation found is a first validation of the used technique. In order to quantify the accordance between the two measures, the displacement time series of 10 leveling benchmarks have been compared to those of the PS closest to them. The standard deviation between the two measures turned out being less than 2mm/year. Figure 4 shows an example of time series of the two measures and the relative difference.

Besides the deformation trend, for each PS detected in Shanghai also the height with respect to the ground and useful hints on its physical nature (as the scattering pattern) have been estimated. Such information have been used to produce a first recognition of the PS scattering typology, as described in [4]. In Figure 5 an example of PS recognized as poles is shown. For their cylindrical symmetry, poles are very useful to combine data acquired from ascending and descending orbits.

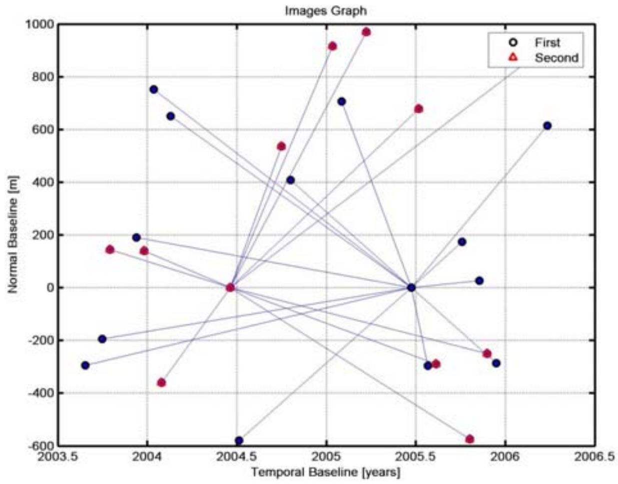

Figure 7. Scheme for the combination of data acquired from parallel tracks. Each point denotes an acquisition in the normal-temporal baselines space. The data of the two tracks are referred to two different master acquisitions.

4. ENVISAT PARALLEL TRACK PS ANALYSIS

The main task of a joint combination of data acquired from parallel tracks for carrying out a PS analysis is the identification of multi-angle targets. The physical analysis described in [4] here in not applicable because of the low number of available data. The pixel selection for PS candidates (PSC) has then to be developed without a-priori information. Similarly to the classical PS technique, a possible procedure for the PSC selection is to look for pixels showing sufficient

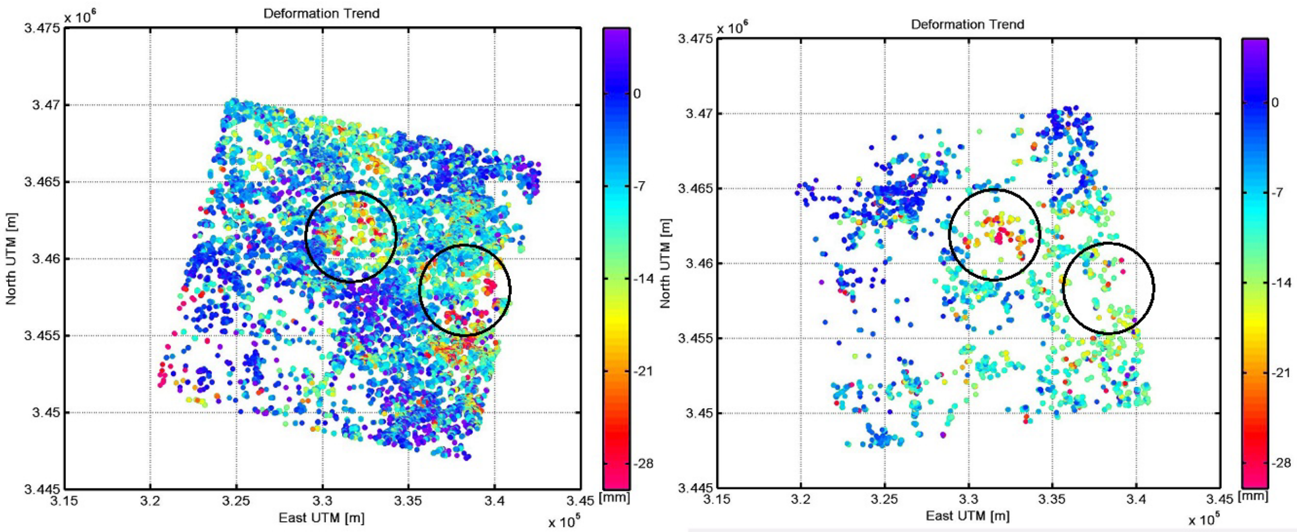

Figure 8. Comparison between PS velocity field estimated with ERS data (left) and Envisat data acquired from the parallel tracks 268 and 497 (right). Black circles identify the two areas with the highest subsidence rate.

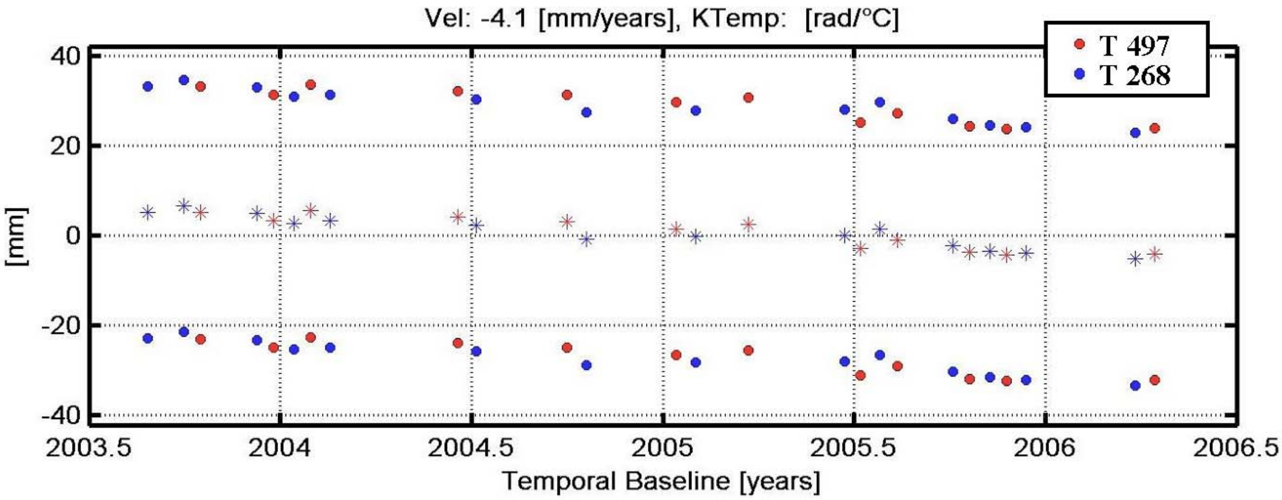

Figure 9. Example of displacement time series estimated from two different parallel tracks with Envisat data. Blue dots Track 268, red dots Track 497.

amplitude stability in both datasets. To do this, a very precise co-registration of the two SAR systems must be performed. Core idea of the process that we implemented is the co-registration of a sparse set of points instead of a whole-image co-registration. The co-registration process can be summarized in the following main points:

- First PSC are selected separately in the two datasets by means of the amplitude stability index [1].
- The offsets of the orbital data (closest approach and acquisition time of the first sample) are precisely corrected in both datasets using ground control points.
- Exploiting an a-priori DEM (such as SRTM or the DEM estimated with ERS data) PSC of both datasets are georeferenced.
- Points with similar geographical coordinates in the two datasets are selected (distance < 10-15m).
- Fine coregistration is performed by better aligning the two clouds of selected points.

The results of the whole analysis strongly depend on the precision of the co-registration process and this is strictly linked to the precision of the available a-priori DEM. Furthermore, the impact of the residual height of a PS with respect to the used DEM has to be evaluated. To this aim in Figure 6 a very simple case is sketched. Assuming a perfect compensation for the local topography, the impact of residual PS height h on the misregistration in slant range Δy_h can be approximated in

$$\Delta y_h = h\left(\cos\theta_1 - \cos\theta_2 \frac{\sin\theta_1}{\sin\theta_2}\right) \qquad (1)$$

where θ_1 and θ_2 are the incidence angles of the two tracks. In the Shanghai case, to guarantee a slant range misregistration less than 5m (corresponding to ~10m on the ground) the residual PS height must be less than 25m. Considering that most PS in urban sites lie on the ground [5], and in particular dihedral-type PS [4], such number is fully acceptable. Moreover, also the SRTM height tolerance (~10m) should guarantee the feasibility of co-registering the two tracks.

Once PSC are selected, the parallel track analysis can be carried out as in the standard PS analysis. The only difference that has to be taken into account is the use of a double-master configuration: the images of the two datasets cannot be referred to the same master acquisition but to two different ones, one for each track, as sketched in Figure 7. Consequently, assuming constant target velocity, the well known [1] model for the interferometric phase of a target with respect to a reference point in the whole dataset becomes the following:

$$\underline{\Delta\phi} = \frac{4\pi}{\lambda R}\Delta h \underline{B_n} + \frac{4\pi}{\lambda}\Delta v \underline{B_t} \qquad (2)$$

where Δh and Δv are height and velocity of the PS and

$$\underline{B_n} = \begin{bmatrix} B_{n,1} - B_{n,M_1} \\ \dots \\ B_{n,N_{I_1}} - B_{n,M_1} \\ B_{n,N_{I_1}+1} - B_{n,M_2} \\ \dots \\ B_{n,N_{I_1}+N_{I_2}} - B_{n,M_2} \end{bmatrix}, \underline{B_t} = \begin{bmatrix} B_{t,1} - B_{t,M_1} \\ \dots \\ B_{t,N_{I_1}} - B_{t,M_1} \\ B_{t,N_{I_1}+1} - B_{t,M_2} \\ \dots \\ B_{t,N_{I_1}+N_{I_2}} - B_{t,M_2} \end{bmatrix}$$

the normal and temporal baselines. N_{I1}, N_{I2} are the number of images in the two datasets and M_1, M_2 denote the two master indexes.

The preliminary results of the novel technique are shown in Figure 8. The results have been obtained by processing the ascending tracks 268 and 497. The image on the right reports the detected multi-track PS (about 5,000 in 400 km^2) in geographic coordinates with a color proportional to the estimated deformation trend. The image on the left shows the results of the ERS PS technique previously described (descending Track 3) in the same area. The subsidence detected in the two independent analyses is pretty congruent. Finally, an example of displacement time series is plotted in Figure 9. The combination of data acquired from parallel tracks allows the reduction of the revisit time of the sensor (about 16 days).

5. CONCLUSIONS

In this work we exploited all the available ESA SAR data to study the deformation phenomena affecting the city of Shanghai. The results obtained processing 43 ERS acquisitions by means of the POLIMI PS technique have been validated by optical leveling data collected in-situ by the China Geological Survey. Moreover, for the first time Envisat data acquired from adjacent parallel tracks have been jointly used for estimating height and deformation trend of SAR targets visible from the two geometries.

6. ACKNOWLEDGMENT

The authors are very thankful to ESA for providing ERS and Envisat data under the Dragon project (id. C1F.2567) and to TRE –TeleRilevamento Europa for focusing the SAR images.

REFERENCES

[1]. Ferretti A., Prati C., Rocca F., (2001). Permanent Scatterers in SAR Interferometry, *IEEE TGARS*, Vol. 39, no. 1, 2001.

[2]. Perissin D., Prati C., Engdahl M., Desnos Y.-L., (2006). Validating the SAR wave-number shift principle with ERS-Envisat PS coherent combination, *IEEE TGARS*, Vol. 44, Issue 9, Pages: 2343 - 2351.

[3]. Colesanti C., Ferretti A., Prati C., Rocca F., (2002). Full exploitation of the ERS archive: multi data set permanent scatterers analysis, Proceedings of IGARSS 2002 Volume 2, 24-28 Page(s):1234 – 1236.

[4]. Ferretti A., Perissin D., Prati C., (2005). Spaceborne SAR anatomy of a city, Proceedings of FRINGE 2005.

[5]. Perissin D., Rocca F., (2006) High accuracy urban DEM using Permanent Scatterers, *IEEE TGARS*, Volume 44, Issue 11, Pages: 3338 – 3347.