The SARPROZ InSAR tool for urban subsidence/manmade structure stability monitoring in China

Daniele Perissin[a] , *Zhiying Wang*[b*], *Teng Wang*[c]

[a] Institute of Space and Earth Information Science, Chinese University of Hong Kong, Hong Kong, daniele.perissin@cuhk.edu.hk
[b] Harbin Institute of Technology Shenzhen Graduate School, China, zhiying.wang@hitsz.edu.cn
[c] King Abdullah University of Science and Technology, Jeddah, Saudi Arabia, wang.teng@gmail.com

ABSTRACT

In this work we introduce a very flexible research tool for processing Interferometric Synthetic Aperture Radar (InSAR) data. The software, called SARPROZ, is able to perform different multi-temporal analysis like Permanent Scatterers (PS), Quasi-PS (QPS) and much more. SARPROZ has been intensively used for analyzing several test-sites in China with different spaceborne SAR data. Here we show results recently obtained in Shanghai, Tibet and Hong Kong.

Keywords Synthetic Aperture Radar Interferometry, Permanent Scatterers, Terrain Motion, Digital Elevation Models

1. INTRODUCTION

Nowadays China is facing the problem of monitoring the stability of terrain and structures against phenomena like water over-extraction, sub-ways excavation, high-rate urbanization, high-speed railways construction and so on. Within the Dragon project, funded by the European Space Agency and the National Remote Sensing Centre of China, the problem has been studied with the aid of Synthetic Aperture Radar Interferometry. To study ground deformation in time, series of SAR data have been processed with advanced techniques that allow separating the different interferometric phase components (motion, ground elevation, atmospheric delay). The core idea behind multi-image analysis is the Permanent Scatterers (PS) technique (Ferretti 2001), developed in Milan in the 90'. But the implementation of the PS technique strongly depends on the characteristics of the problem at hand and on the used data. Different strategies have to be chosen e.g. for processing areas containing simple towns, natural terrain or metropolises full of skyscrapers. The targets life-time must be considered for obtaining reliable estimates in developing areas. Different radar carrier frequencies have different sensitivities to motion and atmospheric effects. Finally, different models or algorithms are needed to detect non-linear motions. In this work, three Chinese case studies, analyzed with three different sensors (ALOS, Cosmo SkyMed, TerraSAR-X), are shown. SARPROZ (Perissin, 2009), a very flexible research tool that implements the PS technique and many derivatives, has been exploited for processing the SAR data. Different approaches have been selected in relation with the treated problems and with the available data.

2. THE SARPROZ SOFTWARE

The SARPROZ tool is an extremely versatile software for processing InSAR data, written in Matlab. Originally, the code was developed for solving the specific problem of combining coherently data with different carrier frequencies, in particular ERS and Envisat, through an advanced PS technique (Perissin, 2006a). Such problem is strictly related to the physical nature of radar targets and to their capability of being "visible" under different looking angles/illuminating frequencies. Thus, the software tool was equipped with a module for target characterization and recognition, able to process and extract information also from the amplitude of radar images (Perissin, 2007). As a side-effect, using amplitude time-series the tool became able to deal with temporary targets (Ferretti, 2003). Moreover, the recognition of a radar target implies a precise localization, and within SARPROZ several techniques for improving the height estimation and the consequent geocoding process were developed (Perissin, 2006b). As a consequence, algorithms for DEM and DSM extraction from sparse points were included (Perissin 2006b and Perissin 2008). The problem of increasing the density of PSs in extra-urban areas was then faced and the QPS algorithm was studied and implemented (Perissin 2010). Currently, SARPROZ provides many different options for combining long series of data, and the user can choose which set of interferograms to process and with which techniques. The software includes then some auxiliary functions like classification and change detection. Finally, a whole section is dedicated to data visualization and exportation. Several smart tools have been developed in particular to geocode sparse and extended results in Google Earth.

SARPROZ is a research tool and for this reason it is continually under development. Moreover, being it written in Matlab, it gives to the user the chance to access the data very easily and to make his own modifications. At the same time, thanks to the powerful Matlab toolboxes, SARPROZ can face extensively very heavy computational burdens and process

* corresponding author

** This works has been partially funded by the CUHK Direct Grant 2021032. Cosmo data in Shanghai have been provided by Eastdawn, Beijing. ALOS data in Tibet have been provided under the ESA-NRSCC Dragon project. TSX data in Hong Kong have been partly provided by Infoterra, Germany.

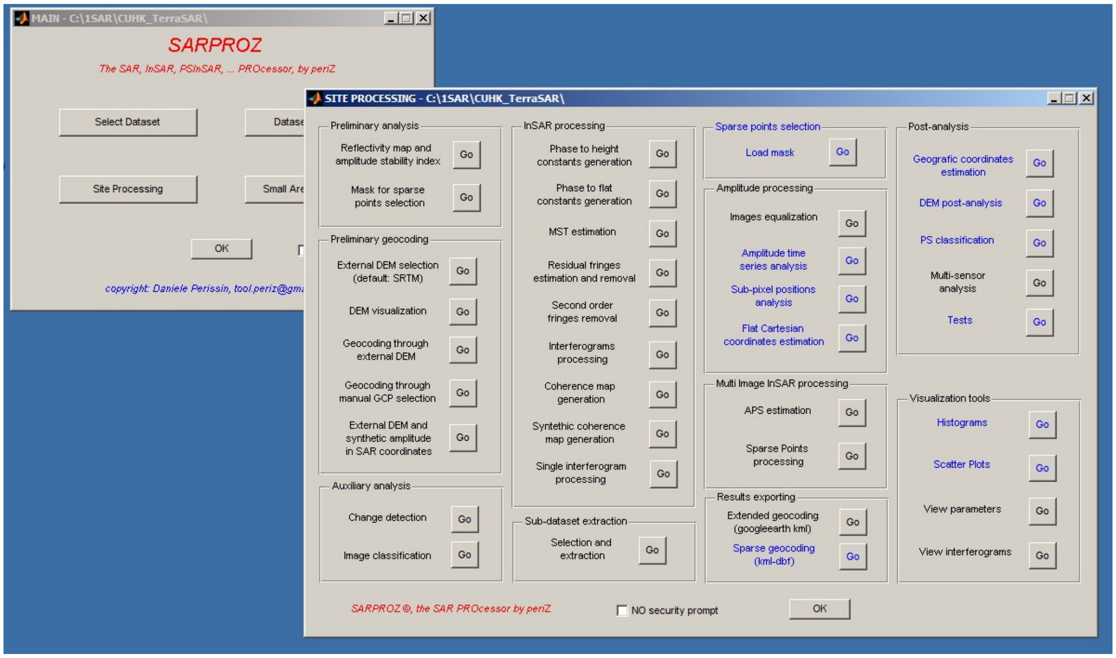

Figure 1. Example of the SARPROZ interface. From the main window, a list of functions can be accessed through the "site processing" module. Functions are divided into preliminary analysis, preliminary geocoding, InSAR processing, amplitude processing, multi-image InSAR processing, post-analysis, results exporting, visualization tools. Functions written in black are relative to extended operations, those in blue to sparse points analysis.

easily multiple SAR frames on multiple-CPUs or computer clusters.

An example of how the interface of SARPROZ looks like is shown in Figure 1. Unless advanced modifications are needed, no coding is required to run the tool. Each module can be accessed through different windows which contain buttons and menus for the possible options. Figure 2 shows as second example the module for Atmospheric Phase Screen (APS) estimation. As visible from Figure 2, the steps for APS retrieval are quite common (Ferretti 2001) (PS Candidates PSC selection, graph creation, parameters estimation, APS retrieval). However, many options can be chosen. Beside linear deformation trend and height (Ferretti 2001), other parameters can be estimated as azimuth sub-cell position (Perissin 2006b), a constant phase gap (as for ERS-Envisat combination, Perissin 2006a), and seasonal trend (Perissin 2006b). Moreover, non-linear polynomial deformation (Ferretti 2000) and more scattering centers (Ferretti 2005) are also implemented. Parameters can be estimated through the classical PS algorithm (Ferretti 2001) as well as through the QPS one (Perissin 2010). In the end, APS can be estimated through different algorithms for the graph inversion.

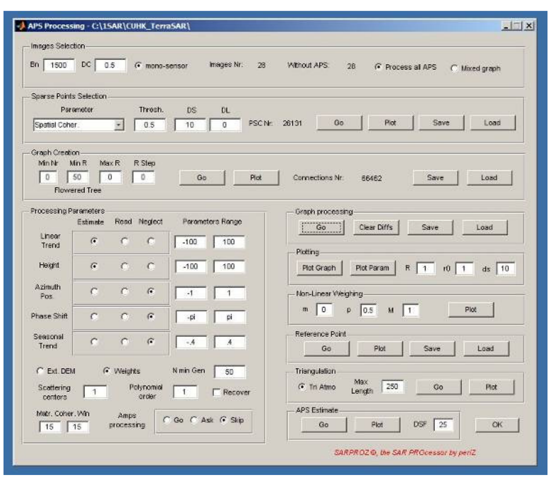

Figure 2. Example of APS estimation module in SARPROZ. Through this function, PS Candidates can be selected, a graph created, parameters estimated and finally residuals are used to retrieve the atmospheric phase delay.

3. THE SHANGHAI CASE STUDY

Shanghai is built on the deltaic deposit of the Yangtze river, and has experienced a very high construction and expansion rate in the last 40 years. Moreover, underground water is extracted since the beginning of last century. As a consequence, it is well known that Shanghai is affected by strong subsidence, and many works were published on the subject (Monjoie, 1992).

In this context, for the opening of the Expo in 2010 and for developing an advanced transportation network, Shanghai built and is still building a large number of subways.

To monitor with millimetric accuracy an area as wide as Shanghai, the only cost-effective technique is InSAR. However, several problems need to be faced in order to apply successfully InSAR techniques in Shanghai. The first is the high developing rate of the city, which needs to consider temporary targets in the analysis. The second one is the high humidity that causes strong artifacts on interferograms, even more the shorter the used wavelength.

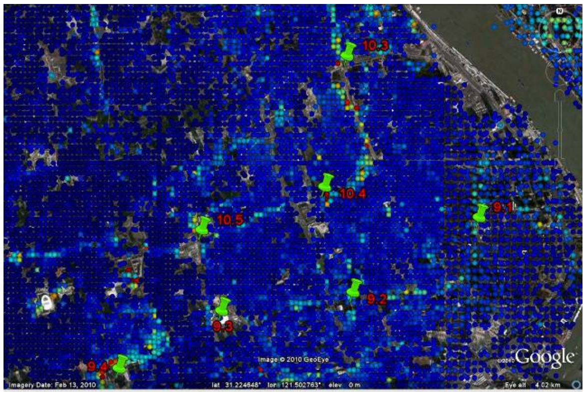

Figure 3. Linear subsidence rate estimated by SARPROZ in Shanghai with CosmoSky-Med data. Colorscale: -20÷0 mm/year (red-blue). Points are interpolated on a regular grid. Yellow placemarks are in correspondence of Metro stations. It is evident to distinguish the subway tracks (lines 9 and 10) from the surface subsidence.

In this analysis, we processed 35 Cosmo Sky-Med stripmap images with SARPROZ. The area is about 600 sqkm wide, and the tool detected 1.2 million of targets. Figure 3 shows a particular of the estimated linear deformation rate. Stable targets are plotted in blue color in Figure 3, yellow corresponds to -10mm/year and red to -20 mm/year. In Figure 3 targets have been interpolated on a regular grid, to reduce the number of points visualized in Google Earth at that particular level of zoom. In the image in Figure 3 some numbered placemarks are shown as well in correspondence of metro stations of the new Shanghai lines 10 and 9. As visible in the picture, a strip of subsiding points is detected right in correspondence of the newly excavated subway tunnels. Cosmo SkyMed data, processed with SARPROZ, can reveal a 20-30 meter wide subsiding surface strip at a rate of 10-20 mm per year, perfectly following the path of the underground metro line. The result is impressive and such particulars in Shanghai have never been published by using InSAR analysis.

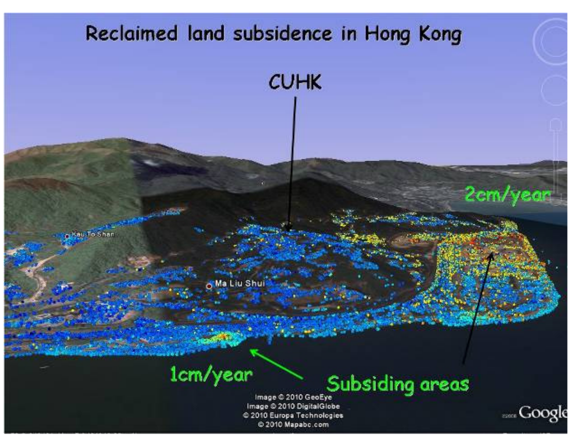

Figure 4. Quasi-PS detected in Hong Kong, around the CUHK campus, with TerraSAR-X data. Colorscale: -20÷0 mm/year (red-blue). On the right the reclaimed land appears evident. An other subsiding area is visible slight on the left of the image middle.

4. THE HONG KONG CASE STUDY

Hong Kong is in someway similar to Shanghai, at least for what about construction rate and humid weather conditions. The main difference between the two cities is that Hong Kong has a very limited area, and the density of buildings is one of the highest in the world. Moreover, Hong Kong grows up in a beautiful natural park, and notwithstanding the incredible urbanization plan, most of its territory is still characterized by beautiful hills covered by vegetation. Even more, Hong Kong is composed by more than 250 islands, making its landscape unique.

The limited territory of Hong Kong pushed his engineers to study techniques for gaining land from the sea. Several newly built areas belong indeed to reclaimed land, and as easily understandable they need to be monitored to check the stability of the whole structure.

Also in the Hong Kong case, in particular when dealing with construction sites, it turns out sub-optimal to base the analysis on permanent targets. At the same time, a construction site can show a much more complex behavior than a simple new building, that appears basically as temporary target.

We applied then a QPS analysis in this site, weighing each interferogram with its spatial coherence in order to select the informative phase. As a consequence, the estimated deformation trend is the average linear trend that better explains the data at hand (Perissin 2010). The data used are 28 TerraSAR-X stripmap images. Figure 4 shows as example the linear deformation rate in an area around the Chinese University of Hong Kong. The colorscale ranges again -20 ÷ 0 mm/year (from red to blue). QPS are geocoded on Google Earth. The yellow-red area on the right, facing the sea, corresponds exactly to reclaimed land. The area is under construction and presents no permanent targets. QPS turn out then particularly useful to identify such an area and to give an indication of the average displacement rate. At the same time, QPS are still able to detect subsidence in a normally urbanized area, as visible in a spot slightly on the right of the middle of the image.

5. THE TIBET CASE STUDY

As last example we report an analysis carried out in Tibet. The analyzed area belongs to the Tibet plateau that lies at about 4600 m over the sea level. The area is totally lacking manmade structures, apart the Qinghai-Tibet railway that runs across. For the rest we have some topographic relieves, two riverbeds, vegetation and bare rocks. Moreover, the area is covered in good part by permafrost, which causes big seasonal changes in the reflectivity of the terrain.

The area was analyzed with ALOS data, that thanks to the long wavelength show good coherence even in such a complex environment. Unfortunately, the limited dataset (11 images) and the long revisit time (46 days), together with the complexity of the terrain, do not allow to retrieve meaningful results of the motion of the terrain. Still, by using a QPS-like approach, it is possible to estimate the height of the terrain.

Figure 5 shows the obtained result. Due to the ALOS high coherence and to the QPS weighing process, about 1.5 million coherent pixels were detected in nearly 15*20km. Figure 5 shows a snapshot of one of the visualization tools of SARPROZ, that allows plotting, resampling, adjusting the dataset parameters, on the most suitable set of pixels, selected posing the desired thresholds after evaluating the parameters distribution. Figure 5 reports in particular the estimated height with respect to the SRTM DEM. The colorscale is about -150 ÷ 50m (from blue to red). Considering the complexity of the scattering terrain, the result is quite impressive. A possible slight misregistration can be deducted by observing higher height differences in correspondence of the mountain peaks, on the upper right and in the lower middle of the image. At the same time, it is possible to detect the railway path, going from the left to the right in the lower part of the image, drawing a couple of curves on the left and at the bottom of the central peak. Also the two riverbeds are slightly visible on the right of the image, going from the top to the bottom of the image.

6. CONCLUSIONS

In this work we introduced the SARPROZ software, a research tool for processing long series of InSAR data. The tool is written in Matlab –and thus very easy to integrate- and is provided with an user-friendly interface. At the same time, the software makes use of the parallel computing toolbox of Matlab and is totally parallelized, being capable of running on multiple CPU workstations as well as on computer clusters. In this paper, we show three successful case studies (Shanghai, Hong Kong and Tibet) retrieved with CosmoSky-Med, TarraSAR-X and ALOS data.

ACKNOWLEDGEMENTS

The authors would like to thank ESA, in particular Yves Louis Desnos and Andy Zmuda; Eastdawn, in particular Zikuan Zhou and Robert Li; Infoterra Germany, in particular Ralf Duering.

REFERENCES

A. Ferretti, C. Prati, F. Rocca, "Non-linear subsidence rate estimation using permanent scatterers in Differential SAR Interferometry", IEEE TGARS, Vol. 38, no. 5, 2000.

A. Ferretti, C. Prati, F. Rocca, "Permanent Scatterers in SAR Interferometry", IEEE Trans. Geosci. Remote Sens., Vol. 39, no. 1, 2001.

A. Ferretti, C. Colesanti, D. Perissin, C. Prati, and F. Rocca, "Evaluating the effect of the observation time on the distibution of SAR Permanent Scatterers", Proceedings of FRINGE03, Frascati (Italy), December 2003.

A. Ferretti, Bianchi, M., Prati, C. and Rocca, F. Higher-order permanent scatterers analysis. Eurasip Journal on Applied Signal Processing, 2005

A. Monjoie, R. Paepe and He Yuan Su, Land subsidence in Shanghai (R.P. of \ China), Bulletin of the engineering geology and the environment, Vol.46, Number 1, 5-7, Doi:10.1007/BF02595028, pp:3-5, 1992.

D. Perissin, C. Prati, M. Engdahl, Y.-L. Desnos, "Validating the SAR wave-number shift principle with ERS-Envisat PS coherent combination", IEEE Transactions on Geoscience and Remote Sensing, Volume 44, Issue 9, Sept. 2006, Pages: 2343 - 2351.

D. Perissin, F. Rocca, "High accuracy urban DEM using Permanent Scatterers", IEEE Trans. Geosci. Remote Sens., Volume 44, Issue 11, Pages: 3338 -- 3347, 2006.

D. Perissin, A. Ferretti, "Urban target recognition by means of repeated spaceborne SAR images", IEEE Trans. Geosci. Remote Sens., Volume 45, Issue 12, December 2007, Pages: 4043 - 4058.

D. Perissin, "Validation of the sub-metric accuracy of vertical positioning of PS's in C band", IEEE Geoscience and Remote Sensing Letters, vol. 5, pp. 502-506, 2008.

D. Perissin, 2009, SARPROZ software manual http://ihome.cuhk.edu.hk/~b122066/manual/index.html

D. Perissin, T. Wang, "Repeat-pass SAR Interferometry with Partially Coherent Targets", submitted to TGARS, 2010.

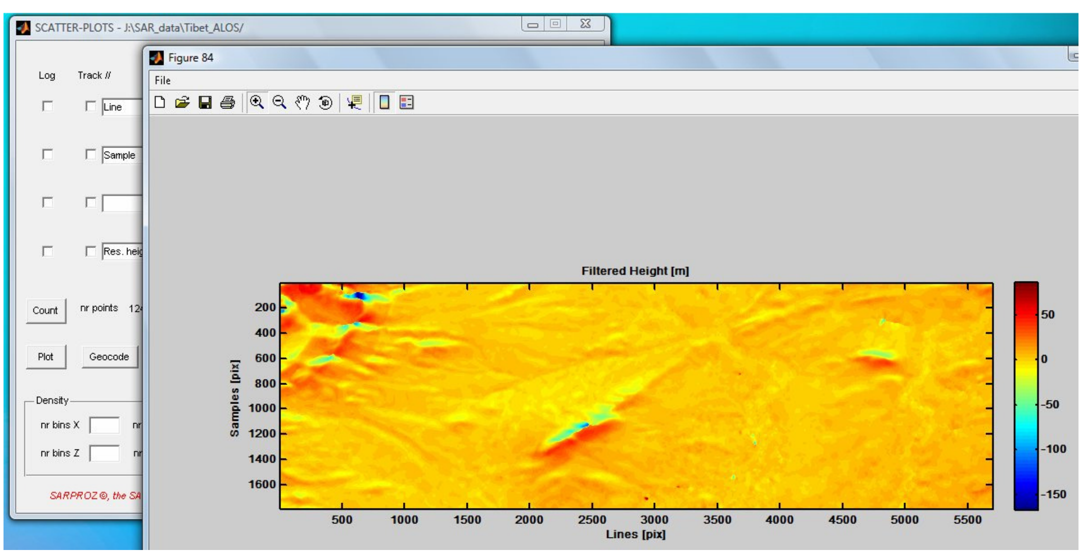

Figure 5. Residual height (w.r.t SRTM) estimated by SARPROZ in the Tibet region form 11 ALOS images. On the background, one of the data visualization modules of SARPROZ. From the image, the railway path can be seen from the left to the right, in the lower part of the plot.