# Atmospheric Phase Screen Estimation with TerraSAR-X Data in Hong Kong

**Ling Lei  Daniele Perissin  Yuxiao Qin**

Institute of Space and Earth Information Science

The Chinese University of Hong Kong, Shatin, Hong Kong

E-mail: leiling25@hotmail.com

**Abstract**. The permanent scatterers (PS) technique is a powerful remote sensing technology that exploits a long series of synthetic aperture radar data for monitoring ground deformations with millimeter accuracy on a high spatial density of ground targets. One of the major limitations of this technique is due to atmospheric effects, and in particular to high Water Vapor (WV) variability. As a consequence, to successfully apply interferometric techniques, the atmospheric WV delay must be estimated and removed from radar data. On the contrary, this PS technique could be explored as a tool to study high-resolution spatial-temporal water vapor characteristics. In this work, we investigate the atmosphere effects with a series of high-resolution TerraSAR-X data and PS-InSAR technique in Hong Kong. We will present some of the preliminary results as well as the discussions over the stratification and turbulence estimation.

## 1. Introduction

Spaceborne Synthetic Aperture Radar Interferometry (InSAR) has become nowadays a very powerful technique to monitor ground motions and to recover Digital Elevation Models (DEM). The microwave signal sent by satellites can penetrate clouds and does not need the light of sun to record pictures of the ground. But one of the major sources of noise in InSAR results is the water vapour content of the atmosphere. The radar signal can in fact penetrate it but it is slightly delayed resulting in a distortion of the detected ground displacement [1][2]. Till now, the main approach used for studying the atmospheric delay problem has been modelling slow space-variant residual phase in interferograms. The approach, that has by all means generated many good works, improving greatly our knowledge on the matter, has been limited by the availability of data and of processing algorithms. One of the major limitations of the mentioned approach lies in separating the different components of the interferometric phase. Residual terrain elevation, not well resolved by a Digital Elevation map, could in fact be easily taken as atmospheric delay. At the same time, it could be quite difficult to distinguish between a local subsidence and a WV accumulation as a thick isolated cloud. Moreover, long spatial wavelengths of the residual interferometric phase could be caused by orbits uncertainties and look like very similar to atmospheric wavefronts moved by wind. A correct separation of all these effects is mandatory for an effective atmospheric analysis and correction. In this paper, the Atmospheric Phase Screen (APS) has been estimated with the Persistent Scatterers technique by using 72 TerraSAR-

X/Tandem-X SAR data in Hong Kong. The preliminary results of high resolution water vapor field analysis are presented.

## 2. PS-InSAR Technique

In the last decade, new perspectives have been added by advanced techniques for processing multi-temporal InSAR data. The pioneer of all is the Permanent Scatterers technique developed in Politecnico di Milano. The PS technology exploits long series of SAR data to separate the different contribution of the interferometric phase of privileged targets. The interferometric phase depends on the acquisition geometry, possible displacements and atmospheric effects. Only by estimating and removing the geometrical and movement components it is possible to achieve the delay induced by the water vapor in the atmosphere [3].

The methodology for solving the atmospheric inverse problem by means of InSAR is implemented through three main steps. Firstly, height and deformation trend of the targets are estimated by reducing as much as possible the humid contribution. The goal is obtained by analyzing neighbour targets that have good probability to be coherent. An a-priori index (usually the amplitude stability index) is used for the initial selection of the PS Candidates (PSC). Hong Kong, due to its unique co-habitation of highly vegetated and highly urbanized areas, is a very particular case, in which the application of PSInSAR techniques turns out being very challenging. Figure 1 shows the PSCs we detected in the whole Hong Kong area. Then an ensemble of connections between neighbour PSC's is created (a spatial graph where the vertex are the PSC's). The temporal phase series associated to each connection is inverted searching for the relative height and deformation trend. The variance of the phase residuals is used to quantify the correctness of the estimate. The phase residuals depend on noise and atmospheric changes between the analyzed neighbour targets. The second methodological step of the algorithm is then the integration of the small atmospheric contributions through the spatial graph. The problem relates to the spatial unwrapping of phase residuals in presence of noise and it is solved due to the high over-determination given by the redundancy of connections of the graph (many connections for each PSC). The result of the spatial phase unwrapping is thus a sparse estimate of the atmospheric phase delay in the analyzed area for each interferogram, commonly called APS. The third step of the algorithm is re-sampling the APS on a regular grid. The operation is implemented by means of a kriging/interpolation process that takes into account the distance between the spatial data and the sample to be fitted to recalculate the APS.

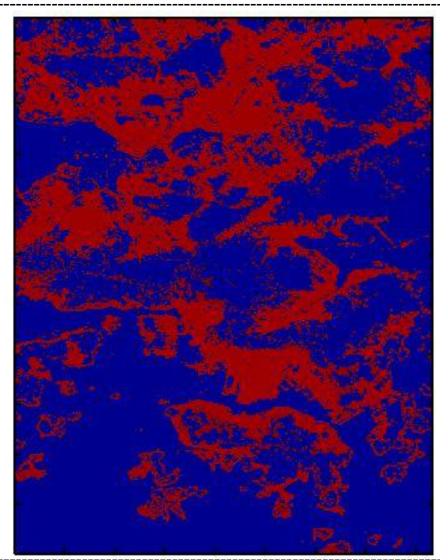


**Figure 1.** PS candidates detected in Hong Kong.

## 3. APS separation

In order to make the APS estimated from InSAR data comparable to normal water vapor maps, we have to deal with the correlation between the unwrapped phase residuals and the water vapor content of the atmosphere. The phase residuals of the detected PSC collect every possible phase delay that cannot be compensated by removing the topographic and movement terms. In other words, all possible image-dependent spatially-variant phase delay can be included in the estimated APS [4][5]. The more probable source of such a bias is the orbital uncertainty. A SAR sensor orbit error has two main consequences: a phase term correlated to the flat earth (for small regions a phase plane) and a phase term correlated to the topography. An orbital error affecting the master image can be corrected in urban sites by finding ground control points, whose geographic and SAR coordinates can be precisely estimated and forced to agree. An orbital error of an acquisition other than the master is more difficult to compensate, but it can be achieved by finding a correlation between the residual phases and the topography.

Besides orbital error, the residual caused by localized water vapor is often considered the most important parameter causing artifacts in SAR interferograms [6][7]. Water vapor is mainly contained in the near-ground surface troposphere (up to about 2 km above ground), where a strong turbulent mixing process occurs. Turbulent mixing can result in three-dimensional spatial heterogeneity in the refractivity and can cause localized phase gradient in both flat and mountainous regions. Besides turbulent mixing, atmospheric process with clear physical origin is the stratification of the atmosphere [8]. Atmospheric stratification considers variation of the refractivity along the vertical height. Stratification of the atmosphere into layers of different vertical refractivity causes additional atmospheric delays in mountainous regions, changes in pressure between two acquisitions can generate a bigger tropospheric delay signal than humidity variation.

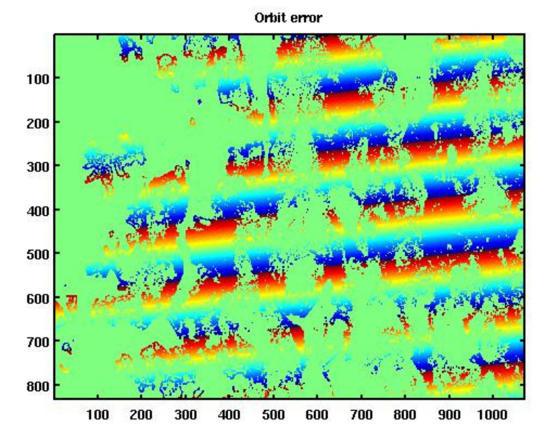
Overall, the APS should be divided into three parts which are linear trend orbital error, stratification and turbulent atmosphere.

$$APS_i(x, y) = Ax + By + k_i q + \varepsilon_i \quad (1)$$

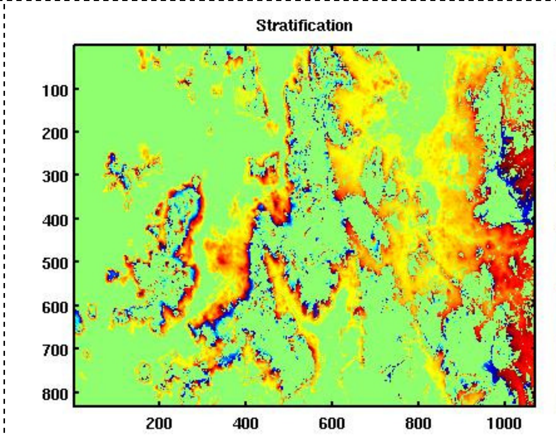
Where $A$ and $B$ are coefficients for orbit error estimation, $k_i$ is the tropospheric delay coefficient, $q$ is the local DEM, $\varepsilon_i$ is the turbulent term. High pass phase ramp accounts for ionospheric delay and residual orbit errors. Stratified tropospheric delay caused by hydrostatic atmosphere and water vapor, is assumed to be a linear function of elevation. The residual phase is the turbulent atmosphere with zero mean superposed on the stratified troposphere.

## 4. Discussion of results

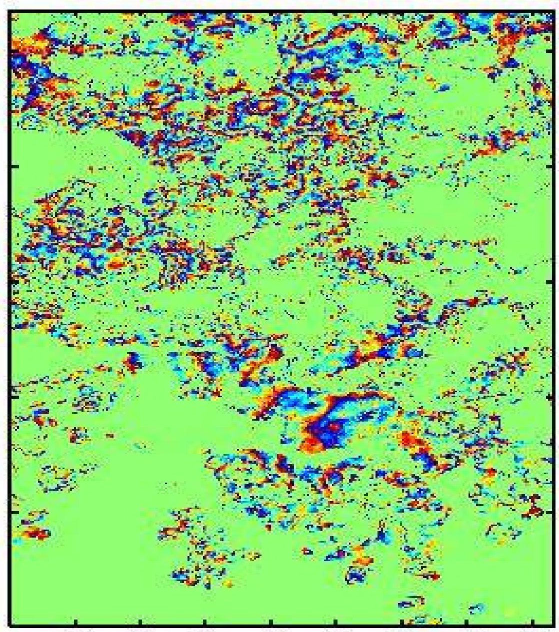
We apply PS-InSAR technique to 72 scenes of data including 61 TerraSAR-X and 11 TanDEM-X images acquired between October 2008 and June 2012. The TSX sensor acquires images over Hong Kong at about 6:25pm, along an ascending orbit with an incidence angle of approximately 37 degrees. The PS-InSAR processing has been carried out using SARPROZ software [9] and the orbital error maps as well as the stratification, turbulence maps on each acquisition date were achieved (Figure 2). Due to the humid weather in Hong Kong, the atmospheric effects could be significant in many of the dates in the year around. Some of the maps show very interesting results. Take the residual errors/turbulence map on Aug 5$^{th}$, 2010 as an example; we observed the corrupted phase into many fringes in northern Hong Kong as seen in Figure 2(c). We checked the weather satellite data [10] and it showed a big storm was coming from south China to Hong Kong on that day. Around the TSX data acquisition time, the storm had gone to New Territories which is in the northern part of Hong Kong but not to Hong Kong island which is in the south yet. It corresponds well with the contribution in turbulent atmosphere which we assume to be caused by the storm. The residuals fringes were visible because nearby storms produced excessive turbulence during the acquisition and the topographic variation is smaller the residual signal.




**(a)** Orbital error map




**(b)** Stratification map



**(c)** Turbulence map

**Figure 2.** Atmospheric maps on Aug. 5th, 2010.

## 5. Conclusion

In this work, we investigate the atmospheric phase residuals with PS-InSAR technique and 72 TerraSAR-X/Tandem-X data in Hong Kong. We separate the APS which we got from PS analysis into orbital error, stratification and turbulence successfully. Some of the turbulence results show clearly the areas where weather fronts and storms were because the phase delay patterns were not continuous and corrupted into many fringes. It corresponds well with the storm distribution of weather satellite data. For future work, we would like to analyze the water vapor maps quantitatively and utilize Numerical Weather Prediction (NWP) models to do further investigation.

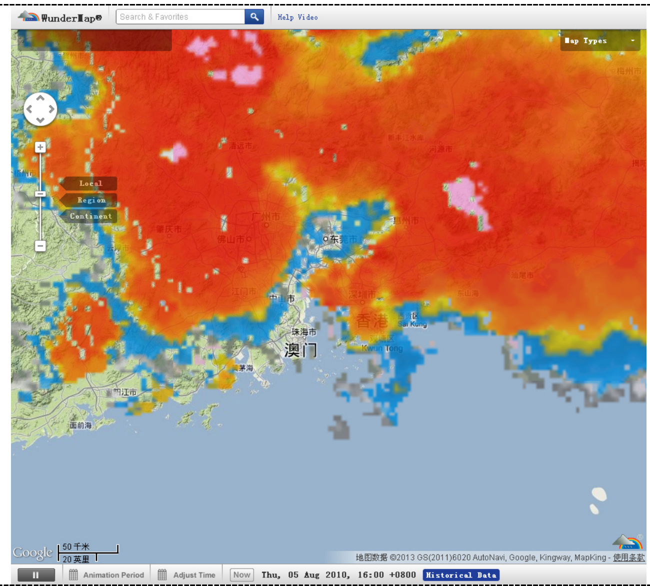



**Figure 3.** Satellite map of storm distribution on Aug. 5th, 2010.

## 6. Acknowledgment

We thank Infoterra Germany, through the cooperation with Ralf Duering, Beijing for providing us TerraSAR-X data in this project. This work was partially supported by the Research Grants Council (RGC), General Research Fund (GRF) (Project Reference no. 415911) of HKSAR.

## References

[1] Ding, X., et al., Atmospheric effects on InSAR measurements and their mitigation. Sensors, 2008. 8(9): p. 5426-5448.

[2] Even, M., et al. Atmospheric phase screen-estimation for PSInSAR applied to TerraSAR-X high resolution spotlight-data. in Geoscience and Remote Sensing Symposium (IGARSS), 2010 IEEE International. 2010: IEEE.

[3] Ferretti, A., C. Prati, and F. Rocca, Permanent scatterers in SAR interferometry. Geoscience and Remote Sensing, IEEE Transactions on, 2001. 39(1): p. 8-20.

[4] Li, Z., et al., Quantitative study of atmospheric effects in spaceborne InSAR measurements. Journal of Central South University of Technology, 2005. 12(4): p. 494-498.

[5] Li, Z., X.L. Ding, and G. Liu, Modeling atmospheric effects on InSAR with meteorological and continuous GPS observations: algorithms and some test results. Journal of Atmospheric and Solar-Terrestrial Physics, 2004. 66(11): p. 907-917.

[6] Perissin, D., et al., Mitigation of Atmospheric Water-vapour Effects on Spaceborne Interferometric SAR Imaging through the MM5 Numerical Model. PIERS Online, 2010. 6(3): p. 262-266.

[7] Pierdicca, N., et al. Atmospheric water-vapour effects on spaceborne Interferometric SAR imaging: data synergy and comparison with ground-based measurements and meteorological model simulations at urban scale. in Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on. 2009: IEEE.

[8] Hanssen, R.F., Radar interferometry: data interpretation and error analysis. Vol. 2. 2001: Springer.

[9] SARPROZ software manual: http://ihome.cuhk.edu.hk/~b122066/manual/index.html

[10] Weather data http://www.wunderground.com/