INSAR X-BAND ATMOSPHERIC WATER VAPOR ANALYSIS AND COMPARISON IN HONG KONG

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ABSTRACT

The persistent 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. On the contrary, PS technique could also be used 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 (TSX) data and PS technique in Hong Kong. We will present some of the preliminary results as well as the discussions over the stratification and turbulence estimation.

Index Terms— *InSAR, X-Band, Atmospheric Phase Screen*

1. INTRODUCTION

Space-borne Synthetic Aperture Radar Interferometry (InSAR) has been proved a very powerful technique to monitor ground motions and to recover Digital Elevation Models (DEM). Due to the coherent nature of the radar signal, images can interfere with each other revealing possible millimetric displacement of the observed terrain (and thus detecting landslides, subsidence, earthquake precursors, building stability etc.). Depending on the characteristics of different sensors, areas of several thousand square kilometers can be imaged at once, with up to one meter resolution.

However, one of the major sources of noise in InSAR is the water vapor 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]. The intensity of atmospheric effects is depending on local atmospheric conditions [2], and in sub-tropical regions as Hong Kong, the noise power is particularly high, exceeding several centimeters in C-band over few hundred square kilometers. As a consequence, to successfully apply interferometric techniques, the atmospheric water vapor delay must be estimated and removed from radar data.

Till now, the main approach used for studying the atmospheric delay problem remains to be modeling the slow space-variant residual phase in interferograms. The approach, that has by all means generated many good works, improved greatly our knowledge on the matter. One of the major limitations of the mentioned approach lies within separating the different components of the interferometric phase. For example, 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 sometimes quite difficult to distinguish between non-linear movement and water vapor accumulation. Moreover, residual interferometric phase possibly caused by orbits uncertainties can look very much similar to atmospheric phase. 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 TerraSAR-X/Tandem-X SAR data in Hong Kong. The preliminary results of high resolution water vapor field analysis are presented.

2. METHODOLOGY

The PS technology that exploits long series of SAR data to separate the different contribution of the interferometric phase of selected targets is adapted for estimating APS in this analysis. 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 PS technique is implemented through the following 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 neighbor targets that have good probability to be coherent. It is worth mentioning that, for Hong Kong, due to its unique co-habitation of highly vegetated and highly urbanized feature and its peninsular characteristic, is a very particular case, in which finding adjacent coherent targets that eventually link the whole city will turn out to be very challenging.

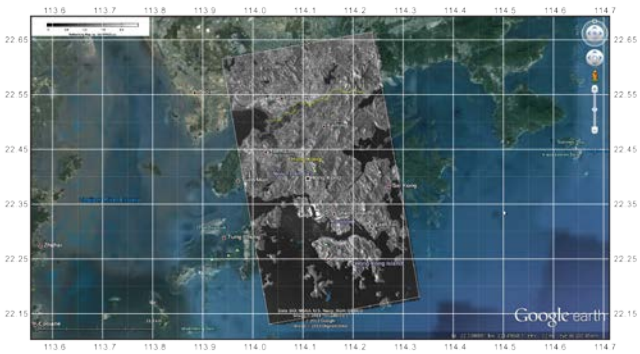

Figure 1 the average amplitude map of Hong Kong, or what we referred as the reflectivity map for one whole frame of TerraSAR-X/TanDEM-X stack of images.

Figure 1 shows the reflectivity map of one whole frame of analyzed TerraSAR-X data in Hong Kong and geocoded in GE. Black areas (as the sea) correspond to low reflection and white areas (as buildings) to high reflection. In particular, one can note the high reflection generated by containers aligned in the harbor.

For the next step, an ensemble of connections between neighbor PS candidates (PSC) is created. 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 neighbor targets. Then the integration of the small atmospheric contributions through the spatial graph is conducted by doing spatial unwrapping of phase residuals. The result is thus a sparse estimate of the atmospheric phase delay in the analyzed area for each interferogram, commonly referred as APS. The third step of the algorithm is re-sampling APS on a regular grid by means of interpolation process that takes into account the distance between the spatial data and the sample to be fitted to recalculate the APS. For the last step, the estimated APS will be compared with different sources of weather data.

3. APS SEPARATION

The phase residuals of the detected PSC collect every possible phase delay that cannot be compensated by removing the topographic and linear movement terms. In other words, all possible image-dependent spatially-variant phase delay can be included in the estimated APS [4][5]. As a consequence, one of the biases in APS could be 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, where geographic and SAR coordinates can be precisely calculated. An orbital error of an acquisition can be estimated 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 factors 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 influence localized phase gradient in both flat and mountainous regions.

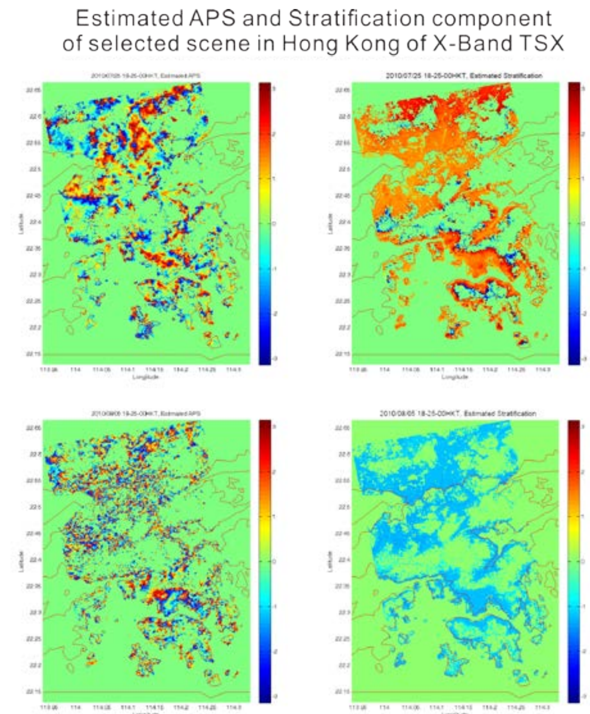

Figure 2 the estimated APS and stratification in Hong Kong for TSX images. Upper: APS estimated for 25th July, 2010; Down: APS estimated for 5th August, 2010. For each scene, the left indicate the APS estimated, and the right is the stratification component estimated and derived from APS. Stratification is linked to the local terrain.

Apart from the turbulent mixing term, atmospheric distribution component also follows clear physical rules, in this case the stratification of the atmosphere [8]. Stratification layers, having different vertical refractivity, causes additional atmospheric delays in mountainous regions, changes in pressure between two acquisitions and correlated with height, can generate a bigger tropospheric delay signal than humidity variation.

Overall, the APS should be divided into three parts, namely the linear trend orbital error, stratification and turbulent atmosphere. As mentioned above, the stratified tropospheric delay caused by hydrostatic atmosphere and water vapor is assumed to be a linear function of elevation.

4. INITIAL OUTCOME

For the analysis, 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 PS-InSAR processing has been carried out using SARPROZ software [9]. For each scene, the estimated APS along with orbital error, stratification and turbulence maps is achieved. Due to the humid weather in Hong Kong, the atmospheric effects could be significant in some of the scenes. Here we show one specific example of the outcome with a significant influence coming from precipitation.

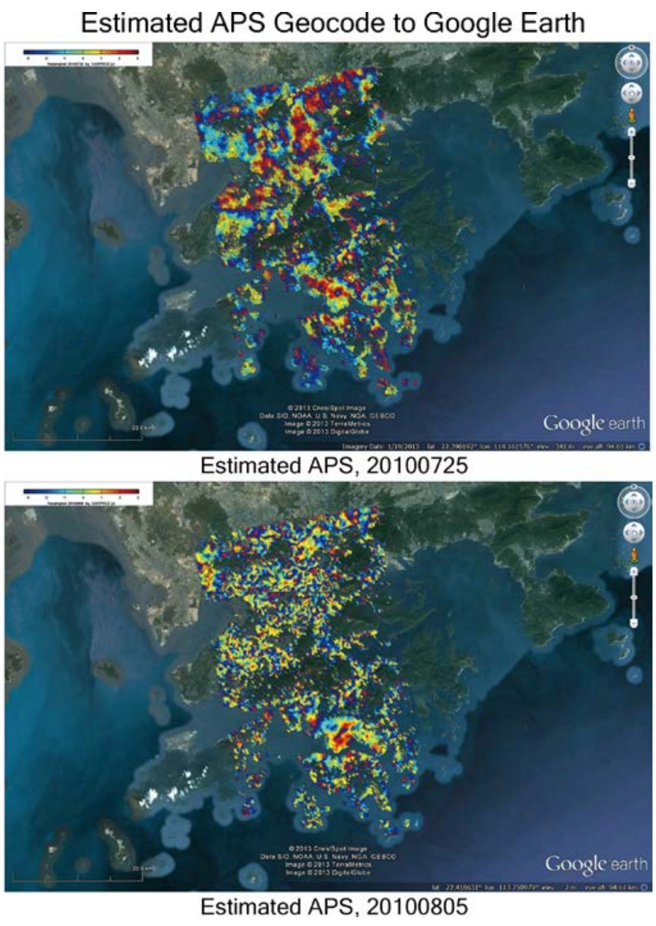

Figure 3 the estimated APS geocoded to Google Earth. The APS fringe shows a better spatial correlation in 25th July than in 5th August. For the estimated APS in 5th August, it indicated that the storm can covered the north part of Hong Kong including New Territories and Kowloon, but not yet arrived at the Island.

Figure 2 shows the estimated APS and the derived stratification component of two TSX acquisition dates, namely the 25th July and 5th August 2010. Take the estimated APS on 5th August as an example; we observed strongly corrupted phase into many fringes in northern Hong Kong as seen in down-left of Figure 2. As a comparison, the estimated APS in 25th July showed a relatively good spatial coherent over the region with less corrupted phase fringes. The same scenario is also shown in Figure 3, where the estimated APS is geocoded to Google Earth for a better understanding the case.

As an initial analysis, we assume it very likely to be caused by the storm. While in most cases, precipitation do not contribute much to APS component, however, when the precipitation becomes heavy, it could produce excessive turbulence during the acquisition due to the very wet surface, and the topographic variation will be smaller than the residual signal.

5. COMPARISON WITH WEATHER DATA

The assumption for the acquisition of the image in the middle of a heavy storm is also compared with weather data. In this case, we will compare with both weather satellite data [10] and the numerical weather prediction (NWP) model. As shown in Figure 4, the infrared remote sensing images that reveal the low surface cloud movement caught clearly the whole process of the heavy storm approaching and falling in Hong Kong on the 5th of August. 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.

With the help of Weather Research and Forecasting (WRF) model analysis in Hong Kong, we can also simulate the atmospheric conditions on each day the Radar images are acquired. In this research project, we adapt to the model for estimating the atmospheric conditions, and a set of variables including water vapor content, precipitations, temperatures and others are being well estimated to a spatial resolution of 1km and temporal resolution of 1 hour. In Figure 5 we plot one of the variables estimated from the model, namely the accumulated total grid scale precipitation. The WRF model outcome was consistent with the primary analysis derived from SAR images and IR4 images, where the accumulated total grid scale precipitation revealed the same process of the storm.

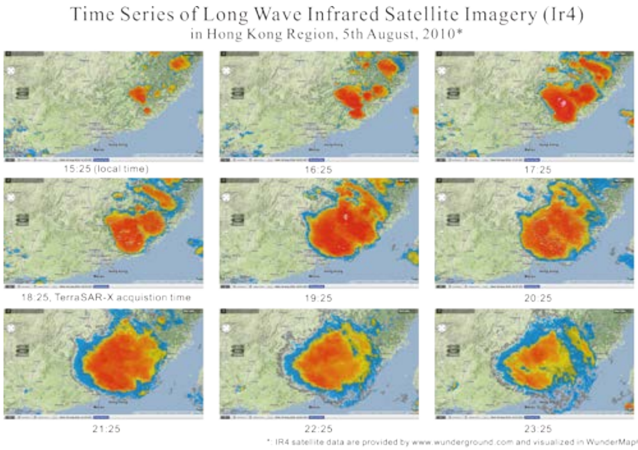

Figure 4 the weather data, IR4 satellite data that reveals the low surface cloud movement on the 5th of August from 15:25 local time to 23:25, is showing clearly the big storm approaching and falling in Hong Kong on the 5th of August.

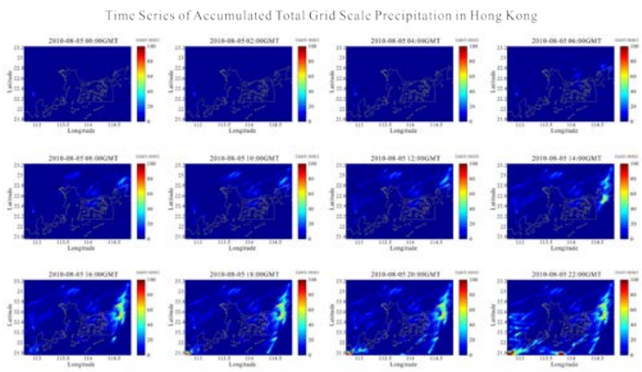

Figure 5 the time series of accumulated total grid scale precipitation in Hong Kong on the date on 5th August 2010 derived from WRF model. From the time series we can clearly observe a heavy rain/storm coming from northeast of Hong Kong and hit most part of Hong Kong from approximately 1600HKT.

6. 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 NWP models to do further investigation.

7. ACKNOWLEDGMENT

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