DEFORMATION MONITORING BY LONG TERM D-INSAR ANALYSIS IN THREE GORGES AREA, CHINA

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ABSTRACT

After the Three Gorges Dam began to function in China in 2003, the water level of the Yangtze River in Three Gorges area raised more than 100 meters. The impact of the man-made reservoir caused by the dam on the surroundings is becoming object of several studies. In this paper we make use of two long term D-InSAR techniques, Quasi-Permanent Scatterer technique (QPS) and Stanford Method for Persistent Scatterer (StaMPS), to measure the deformation trends in Badong, Three Gorges area, China. The results obtained by the two processing tools with the same focused and co-registered data sets are analyzed and compared. Two subsidence areas are identified by both techniques. However, since the QPS analysis is able to process partially coherent targets, much more points are extracted than in StaMPS, and more information can be retrieved.

Index Terms**—**Differential interferometry, geodetic measurements, synthetic aperture radar (SAR)

1. INTRODUCTION

Three Gorges Dam, in Hubei province, China is the largest dam in the world. The dam began to function in 2003; as a consequence, the water level of the Yangtze River in Three Gorges area raised more than 100 meters. Then, the largest man-made reservoir (600 kilometers long) was formed in the upriver part of the dam. Although lots of benefits come out from the power generation and flood control functions of the project, the raising of the water changed the natural terrain and flooded the basements of the mountains in this area. Moreover, due to the weight of the reservoir on the riverbed, there is potential rock instability in the gorges along the river. The regional assessment of landslide impact in the upriver areas of the dam has been reported in [1].

In order to assess the impact of the project on the ground stability of upriver area, it’s necessary to measure and analyze the deformation in this region. Temporal Differential Interferometric Synthetic Aperture Radar (D-InSAR) technique is one of the most suitable tools for getting measurements in such case [2, 3].

The main limitations of D-InSAR technique are geometrical and temporal de-correlations with repeat-pass satellite mode [4]. Even though the coherence of the two radar signals is high enough, the atmospheric phase screen (APS) difference between master and slave images still reduces the accuracy of the final results [5]. Aiming at the above restrictions, Ferretti et al. presented the Permanent Scatterers Technique (PS) [6] in the late 1990s. Instead of extracting information from the whole SAR image, PS InSAR technique identifies natural point-like stable reflectors i.e. PSs from long temporal series of interferometric SAR images. The coherence on PS is good enough to obtain sub-meter accuracy DEM and millimetric terrain motion [7]. The applications of PS InSAR technology have been successfully achieved especially in urban areas [8].

In order to take advantage of all the coherent targets, partially coherent analysis was also developed in Politecnico di Milano (POLIMI), named Quasi-PS technique (QPS) [9]. Different from classical PS technique, QPS analyzes the multi-temporal SAR images that allow to extract information also from partially coherent targets. The benefit of QPS is that the density of points with measured deformation trends increases significantly in non-urban areas. In the mean while, A. Hooper developed the Stanford Method for Persistent Scatterer (StaMPS) [10]. Without knowing the deformation model, StaMPS filters the phase in spatial and temporal dimensions separately to divide the correlated interferogram phase into incidence angle error, APS difference, deformation trends and noisy parts. After that, the deformation series are unwrapped, exploiting different algorithms according to the complexity of the phenomena at hand.

The objective of this case study is to present the preliminary results of deformation monitoring in Badong, Three Gorges area by two different kinds of long term D-InSAR analysis i.e. Quasi-PS technique and StaMPS. The available data have been acquired from ERS and Envisat satellites in the time span from 1992 to 2007. More than 70 scenes of SAR images in two tracks of Badong test site have been processed. ERS and Envisat images have been kept separate, due to the different carrier frequencies and the big temporal changes of the analyzed area. Here we will report the most significant results we obtained, that refer to a single Envisat track. The few available images and the low coherence prevented from achieving more information from the other data-sets.

2. TEST SITE AND DATA SETS

Badong County is selected as our test site, which is a county settled on the banks of the Yangtze River, in Hubei province, China. It is located just east of the Wuxia Gorge in the Three Gorges region. The old town of Badong has a history of more than 1500 years. Due to the construction of the Dam, this town was going to be under the flood water level. Therefore, the emigration of the whole town was organized in the summer of 1997. Almost all the buildings of the old town were demolished in order not to affect the channel. A totally new city began to grow up at the same time more than 5 km west from the old one.

After several years of construction, in 2002, the new city which covers about 7.3 km^2, with more than 50,000 residences began to be formed. A bridge over the Yangtze River was also built to connect the south and north parts of the city. Since the city is built along the steep river bank, many consolidation works were settled for landslide protection. Therefore it's very important to identify the potential landslides areas near the city, especially after the rising water of the Yangtze River.

Another reason for selecting Badong as our test site is that the new city of Badong is observed by 2 tracks of data sets, i.e. track 75 and 347, so it's possible to take advantage of more data sets and/or cross validate the subsidence measurements from two tracks. The available data information is listed in TABLE I.

TABLE I DATA SETS INFORMATION

Track/Frame: 75/2979		
ERS	May,1992 – Nov, 2000	11 scenes
Envisat	Aug, 2003 – June, 2007	34 scenes
Track/Frame: 347/2979		
ERS	Mar, 1993 – Nov, 2000	15 scenes
Envisat	Jan, 2004 – June, 2007	21 scenes

Since the ERS and Envisat data are acquired before and after the construction of the dam, the changes of the river in this area can be observed from the reflectivity maps of the data sets from two sensors. Fig 1 (a) and (b) shows the incoherent average reflectivity maps of ERS (a) and Envisat (b) data, the Yangtze River is much wider in the Envisat image, and the urban changes due to the population migration can be seen in Fig 1, where indicated in the red rectangle.

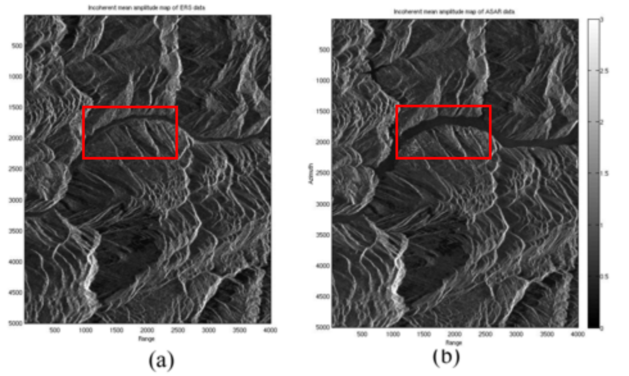

Figure 1 Reflectivity maps of Track 75 Frame 2979, from (a) ERS images and (b) Envisat images. The red rectangle indicates the new city of Badong, which is brighter in the Envisat image because of the urbanization.

3. DATA PROCESSING

Two processing tools are used to extract deformation trends information from the data set, namely, QPS tool from POLIMI and StaMPS open source software. The raw data of the test site are firstly focused and co-registered, and then processed by both processing tools.

3.1 QPS data Processing

QPS connects the images for the minimum best coherent graph, and then creates a set of interferograms from a given data-set. Fig. 2 shows the image connection graph of track 75 data set. Then the deformation trends, DEM errors and APS are estimated in this multi-master system, the PSs are selected by setting the temporal coherence threshold as 0.8. Finally, 74618 PSs are selected with the deformation trends shown in Fig 3(a).

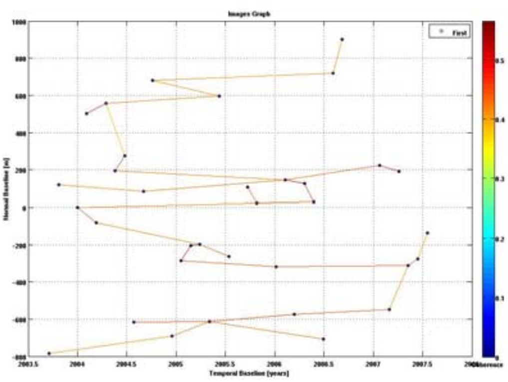

Figure 2 Images connections graph of the data set. Horizontal axis: image acquisition time. Vertical axis: spatial baseline. Each dot indicates one image; each line represents one interferogram between the two endpoints. The color bar indicates the spatial coherence of each interferogram.

3.2 StaMPS data processing

StaMPS uses amplitude dispersion (Da) [6] to select PS Candidates (PSCs). Since our test site is not in urban area, the Da threshold is set higher than usual to get enough PSCs. Then StaMPS filters PSCs in small patches to estimate the incidence angle errors, APS and deformation trends. The thresholds for selecting PSs are determined by calculating the PS probability of every PSCs, which considers both the temporal coherence [6] and Da value. After that, the phase series of the PSs are unwrapped by a three-dimensional unwrapping algorithm. Finally, 1618 PSs are selected from the data set with the deformation trends shown in Fig 3(b).

4. RESULTS AND DISCUSSION

Two subsidence regions in the south river bank of Badong city are identified by both techniques. One is in the west part of the city, which is about 400m above the Yangtze River. Another region is in the east part of the city near the river. But with much more PSs, the borders of residence areas are easier to be identified from the QPS result. Furthermore, in non-urban areas, more subsidence regions can be seen, for instance the area in the south east direction from the city. Because of too few points from the result of StaMPS, no reliable deformation measurements can be obtained in non-urban areas.

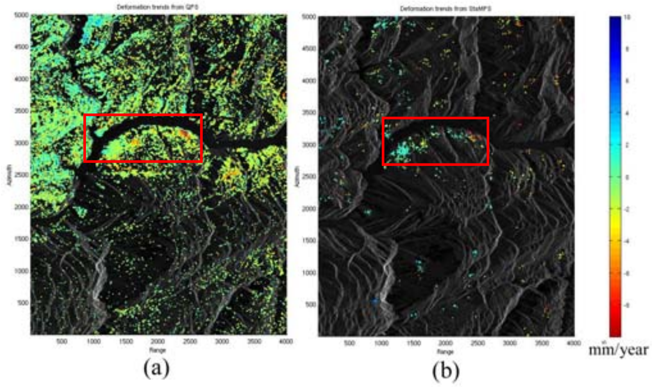

Figure 3 deformation trends from (a) QPS and (b) StaMPS, the red rectangle indicates the city of Badong.

Since the two results are obtained from the same co-registered data set, common PSs are easily selected by searching the nearest points in a small window, here we use the window with 9 in azimuth and 3 in range. Fig.4 (a) and (b) show the distribution and the value of deformation trends of common PSs. More than 500 points are selected to cross validate the results. Because there is no ground truth or reference points in this test site, the deformation trends we got have only a relative meaning. As shown in Fig.4 (a), most of the common PSs are located in the west subsidence area. Their deformation trends values are shown in Fig. 4(b). Further validations will be carried out as soon as ground truth in the test site will be available.

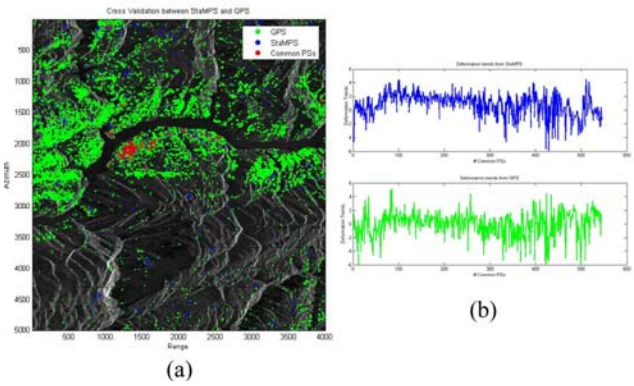

Figure 4 (a) Superposition of PSs from QPS (green) and StaMPS (blue). Red points: common PSs. (b) Deformation trends (vertical axis) on common PSs. Green: QPS. Blue: StaMPS.

For what about the APS estimation, the QPS technique interpolates a map in the whole image, whereas StaMPS estimates the APS only on PSs. In our test site, the APS low frequency feature is very difficult to be identified from StaMPS results. From the APS results of QPS, we find that the atmosphere distribution relates to the topography, for instance the APS difference between the data acquired on 4th March, 2007 and 23rd January, 2005 that is shown in Fig 5. The APS difference along the Yangtze River can be distinguished from which is on the mountainous areas. That is the particular feature of water vapor distribution in such area. Also, in the south bank of the river, the APS difference changes with the increasing of the elevation.

For comparing the APSs estimated by the two techniques, the different way to combine the images has to be taken into account. In fact, StaMPS exploits a single-master configuration, whereas the QPS technique processes a more complex set of interferograms. Moreover, the comparison has to be carried out on a set of common points. Since QPS produces interpolated APS maps, we sampled the APS values on the location of StaMPS points. Then, the APS values are referred to the same master image (temporal dimension) and to the point with highest coherence (spatial dimension). The phase series are wrapped and then plotted for each image as in Fig 6 (QPS on the left and StaMPS on the right). One example of the APS difference on PSs between the data acquired on 30th November, 2003 and 23rd January, 2005 is shown in Fig. 6 (a) and (b). Only in the area corresponding to the city of Badong, the APSs retrieved by the two techniques are comparable (bottom of Fig 6). In the rest of the mountain areas, StaMPS points are not enough to allow a reliable comparison.

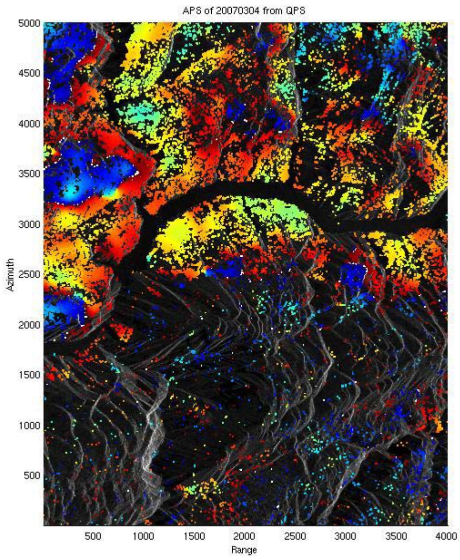

Figure 5 APS difference between the data acquired on 4th March, 2007 and 23rd Jan, 2005. The correlation between APS and topography can be clearly observed.

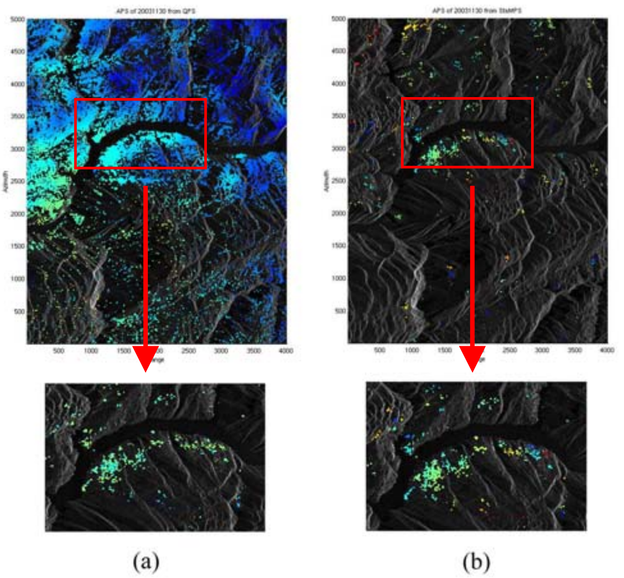

Figure 6 APS difference on PSs between the data acquired on 30th Nov, 2003 and 23rd Jan, 2005 derived by QPS (a) and StaMPS (b). On the bottom, the zoom-in views over the Badong area.

5. CONCLUSION

In this case study, the long term D-InSAR analysis in Badong, Three Gorges area, China is carried out by implementing StaMPS and QPS techniques. The results, obtained by processing the same focused and co-registered data set, have been jointly analyzed. QPS algorithm takes advantage of partially coherent targets and elaborates the best coherent interferograms, whereas StaMPS finds only targets that stay coherent in the whole time span. Two subsidence regions are identified by both techniques in Badong city. However, the PS density of QPS is much higher than StaMPS. The StaMPS three-dimensional phase unwrapping method is not useful in this case since no complex motion is present. Future work will be focused on the combination of the two parallel tracks data sets to get more information about the ground deformation before and after the Three Gorges Dam construction.

6. ACKNOWLEDGEMENTS

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