TERRAIN MONITORING IN CHINA VIA PS-QPS INSAR: TIBET AND THE THREE GORGES DAM

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ABSTRACT

In this paper we report the results of two analyses carried out by the Topographic Measurement Team (Project ID 5297) within the European Space Agency (ESA) and National Research Center of China (NRSCC) Dragon 2 cooperation program. In the first analysis, the DEM of a small area in the Tibetian Plateau has been estimated processing 11 L-band ALOS images with the Quasi-Permanent Scatterers (QPS) technique, proving the capability of the technique to extract elevation maps from small sets of coherent interferograms. In the second study, several small landslides have been identified by processing X-band Cosmo SkyMed images around the Three Gorges Dam, from ascending and descending orbits, using the Permanent Scatterers approach. The results here reported contribute in assessing the usefulness of multi-temporal Synthetic Aperture Radar Interferometry (InSAR) analyses for terrain monitoring in China.

Index Terms— ***Tibet; Three Gorges Dam; PSInSAR; QPSInSAR; ALOS; Cosmo SkyMed***

1. INTRODUCTION

The Dragon Programme is a cooperation between ESA and the Ministry of Science and Technology (MOST) of the P.R. China. The 1st Dragon Programme commenced in 2004 and was completed in April 2008. The 2nd Dragon Programme started at the 2008 Beijing Symposium and terminated in June 2012.

The topographic measurement group (Project ID 5297) was lead by scientists from the Polytechnic of Milan (Italy) and from Wuhan University (China) and focused on the exploitation of SAR images to estimate terrain height and to monitor its movements.

During the 4 years of the project, several studies were carried out, among which an analysis of the Three Gorges Dam with Envisat data [1], studies of the deformation in Tianjin [2,3], the monitoring of the Shanghai subsidence with ERS and Cosmo data [2,4]. In this paper, we report the last achievements obtained in Tibet (with ALOS data) and on the Three Gorges Dam (with Cosmo SkyMed images).

To retrieve the results here presented, the SARPROZ software has been used [5,6]. SARPROZ is a very versatile software, implemented in Matlab, that allows the user to choose among many multi-temporal processing techniques to analyze stacks of SAR images. The software has a graphical user interface, it is fully parallelized and it can be compiled, running independently of Matlab. The interested reader can contact the author for further details [6].

2. THE TIBET CASE STUDY

The Qinghai-Tibet Plateau is located in the western part of China. The area we analyzed is close to the Beilu River (see Figure 1) and it covers a small section of the Qinghai-Tibet railway, which connects Golmud with Lhasa. The area is characterized by permafrost and strong seasonal phenomena modify the terrain surface [7]. Such movements may affect the railway. It is therefore of great interest to assess the capability of InSAR to monitor the terrain in the region, estimating its elevation and detecting possible movements that may cause problems to the railway line.

2.1 The QPS analysis

To analyze the Tibetian Plateau we made use of 11 L band ALOS images provided by the Japanes Space Agency via ESA within the Dragon program. The low number of available images and the complex changes of the terrain surface suggested to adopt the Quasi-PS technique [8] to process the dataset.

The core idea of the QPS technique is to relax the strict conditions imposed by the PS analysis [9] in order to retrieve information also from partially coherent targets. In short, the QPS technique processes the most coherent interferograms given the available dataset and weights each interferometric phase with the corresponding interferometric coherence. Is this way, each pixel of the radar image is processed using the best subset of interferograms, and the subset can be different from one pixel to the other.

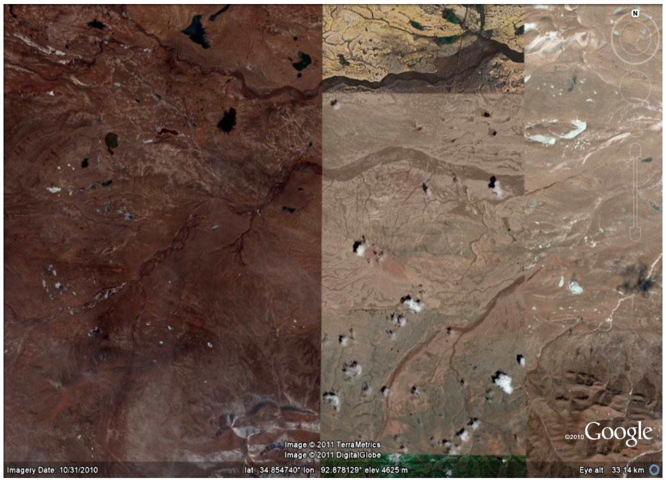

Figure 1. The Tibetian Plateau in the analyzed area as visible from Google Earth.

The QPS technique has great advantages w.r.t the PS one in non-urban areas [8]. However, it is also affected by drawbacks like loss of precision. In particular, since the subset of interferograms is pixel-dependent, also the estimated motion can have a different reliability pixel by pixel. Therefore, the interpretation of QPS results is not trivial and it requires a deep analysis of the estimation process and of the data used for the estimate.

2.2 Preliminary Results

The results of the QPS analysis in the selected area are shown in Figures 2 and 3. In particular, in Figure 2 the estimated terrain height (the residual height after removing the freely accessible SRTM DEM) is plotted in geographic coordinates over the Google Earth optical imagery. From Figure 2 we can observe the height of the analyzed area in a range that mostly spans -20 20m. Some outlier in the distribution of height is found in correspondence of the topographic relieves included in the area, highlighting a slight misregistration between SRTM and the SAR images. Figure 2 also shows many topographic details which were not included in SRTM, assessing the capacity of multi-temporal techniques like QPSInSAR to retrieve topographic information.

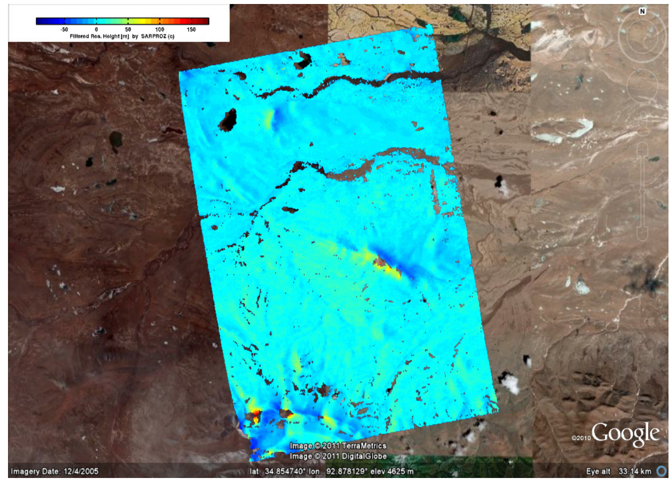

Figure 2. The DEM estimated by processing 11 ALOS images with the QPS technique.

Figure 3 reports in addition the movements estimated in the area of interest by the QPS technique. We can observe a wide range of detected deformations, both with positive and negative signs. However, the explanation of such trends should not be found simply in subsidence or uplift because of the peculiarity of the adopted technique. As previously mentioned, in fact, the seasonal character of the backscattering properties of the analyzed terrain can drive the QPS technique to estimate only portions of the seasonal motions characterizing the area, which appear simply as positive or negative ramps.

It is in any case very interesting to observe that all the river beds included in the analyzed area appear as blue (a positive trend in the corresponding subset of interferograms), which describes the process of freezing of the soil with a consequent expansion. We have then the central area, with smoother topography, which is affected by negative movements (again highly probably determined by the seasonal compaction of the ground). Finally, we note a couple of wider areas on steep slopes, corresponding with good probability to landslides.

The work here carried out represents only the first step of a longer analysis required to understand the phenomena happening in the region. However, the estimated maps shown in Figures 2 and 3 clearly demonstrate that InSAR is able to catch information otherwise impossible to observe with common monitoring techniques. Our group is trying to build stronger cooperation with local scientists to carry forward the interpretation of the results.

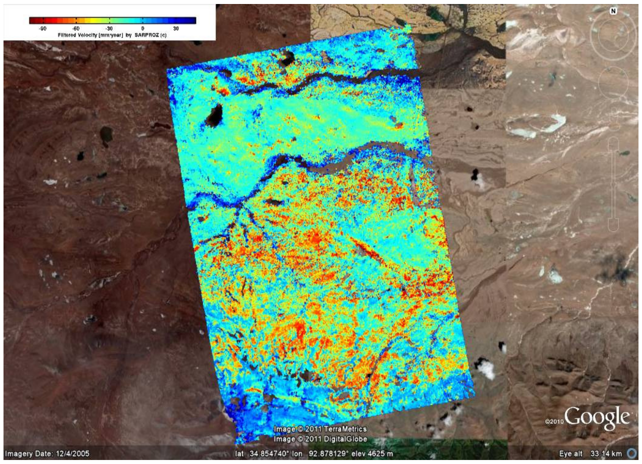

Figure 3. The linear deformation estimated by processing 11 ALOS images with the QPS technique. Notice that, due to the QPS peculiarity, the map here reported corresponds in fact to short gradients of seasonal movements caused by freezing and melting of the ground soil

3. THE THREE GORGES DAM

The Three Gorges Dam along the Yangtze River in China is the largest hydroelectric project in the world. 2.3 km long, the dam is 185m high and it created a water reservoir 660km long. Its power generator is the largest in the world, having a huge impact on economy, environment, civil protection of the region, with both positive and negative consequences [10, 11].

The stability of the Dam is clearly a key and extremely sensitive factor for the Hubei province and for the whole Chinese country. Several instruments are installed on the Dam structure and new technologies are continuously investigated to provide new and complementary measurements [12-15]. Synthetic Aperture Radar Interferometry (InSAR) has been proved to be an economic and convenient way for this task.

The authors of this paper worked in the past 5 years on the topic adopting InSAR technologies to study the stability of the Dam [1,2]. However, the works that have been carried out till now were based on small archives of Envisat images, with a ground resolution of about 20m and a revisit time of 35 days. High Resolution (up to 1m) and high revisit-time (up to few days) Cosmo SkyMed data started being available in 2010, and offer new interesting potentialities.

The analyzed area is about 50 sqkm centered around the Three Gorges Dam. It includes the dam itself and surrounding buildings, the towns of Zigui and Sandoupingzhen and a couple of topographic relieves. An overview of the area of interest in shown in Figure 4.

Figure 4. The Three Gorges Dam and surroundings as seen from Google Earth.

3.1 The Cosmo SkyMed Dataset

Cosmo SkyMed is a constellation of Satellites launched by the Italian Space Agency providing Synthetic Aperture Radar images in interferometric mode in X band with a resolution of 3m and revisit time of a few days.

The dataset used in this work is formed by two Cosmo SkyMed tracks, one ascending and the other one descending, 29 images each. The data have been acquired by all Cosmo satellites, from February to August 2011. The acquisitions are stripmap in interferometric mode.

3.2 Preliminary Results

The reflectivity maps of the area of interest are shown in Figures 5 and 6, for the Ascending and Descending orbits respectively. The High Resolution SAR signal intensity itself is very interesting for appreciating the topography of the area and the Dam structure. The images reported in Figures 5 and 6 are in fact the geocoded reflectivity maps. The Height used for the geocoding process in SRTM DEM, which has a quite poor resolution in the imaged area. Unfortunately, it was not possible to retrieve better local information due to the sensitivity of the target. The reflectivity maps have been geocoded and visualized in Google Earth by SARPROZ [5,6], a software tool written by the authors to process series of interferometric SAR data. The optical data shown in the background are taken from Google Earth.

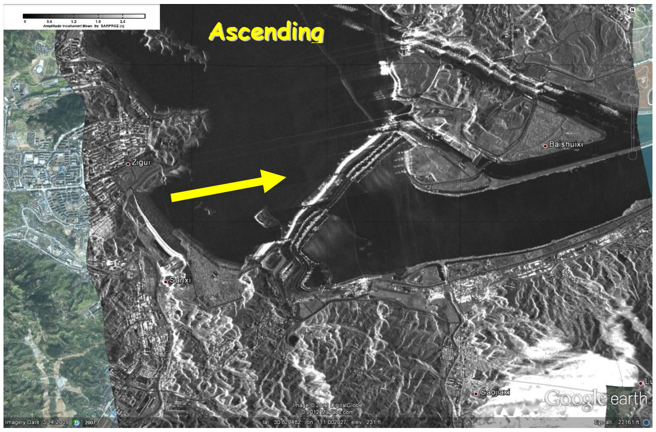

Figure 5. Reflectivity map of the area of interest, Ascending Cosmo dataset.

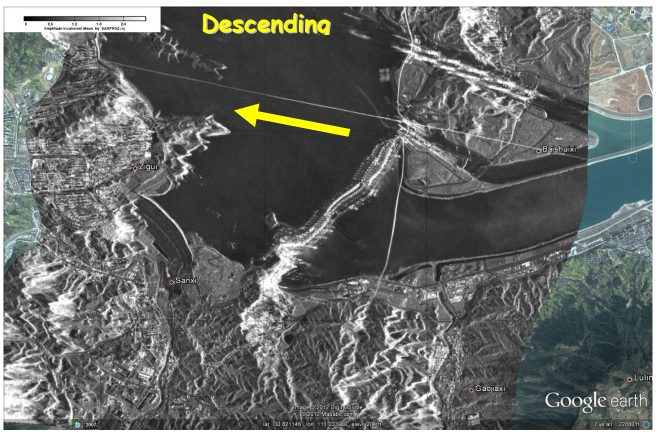

Figure 6. Reflectivity map of the area of interest, Descending Cosmo dataset.

To retrieve the terrain deformation, PSInSAR analyses were carried out in both datasets. The technique implemented to perform the study is the classic one easily found in literature [9]. Two main results have been extracted, the targets height and the linear displacement rate.

Figures 7 and 8 display the main outcome of the analysis, namely the terrain displacement rate observed in the analyzed time span. The colorscale of the two pictures ranges values from -60 to 20mm/year.

Figure 7 shows the linear deformation map obtained from the ascending dataset. It is very interesting to notice a series of subsiding areas along the riverbanks. The moving areas have been surrounded by circles to drive the reader's attention. In particular, we notice a strong subsidence on the south west of the dam body.

Figure 8 is the corresponding map for the Descending case. The first macroscopic detail we notice is the identification of the same macro-subsiding area on the south west of the dam body, in good agreement with the Ascending case. Several details are then less visible, due to the different acquisition geometry. Also the motion intensity is slightly different, as a consequence of the different viewing angles. Though, even with different intensities it appears evident from both geometries that e.g. the down river banks have an opposite motion w.r.t. the upriver sides. Both upriver sides of the dam are in fact consisting of rocks, while the downriver sides are constituted of sand and soil.

A very interesting behavior has been observed and reported in Figure 9. In the picture, 4 vertical structures are revealed by the presence of PSs on their top. From the Google imagery, shadows are found in correspondence of the structures, recognized as power pylons. The color of Figure 9 represents the target displacement, and the top of the pylons appear as uplifting. Such behavior should be surprising, but it finds its explanation in the thermal dilation of the structures. The analyzed time span is in fact only a few months, and a seasonal displacement is almost linear in such a period. It becomes then almost impossible to distinguish between thermal effects and actual terrain movement by observing too short times.

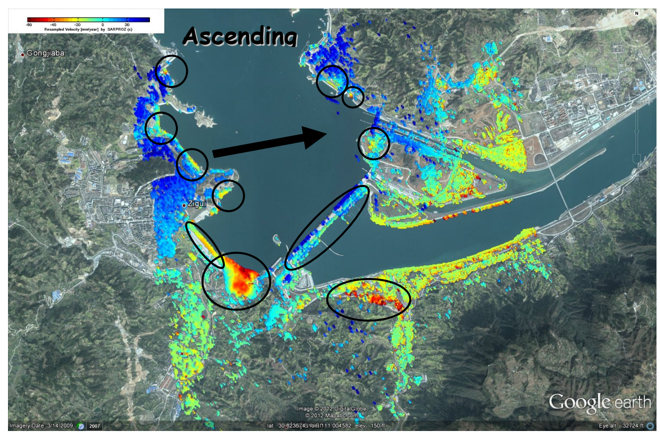

Figure 7. Linear deformation trend detected via PSInSAR analysis with Ascending Cosmo data over the Three Gorges Dam area

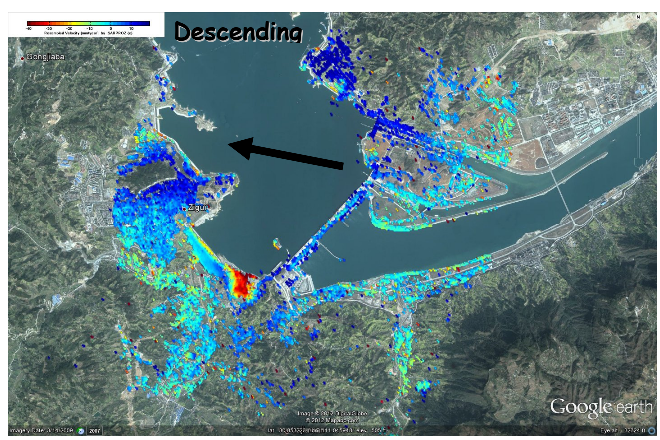

Figure 8. Linear deformation trend detected via PSInSAR analysis with Descending Cosmo data over the Three Gorges Dam area

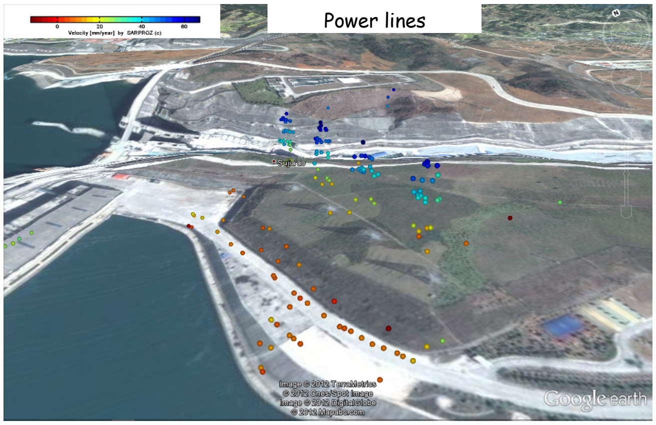

Figure 9. Example of a close up of the linear displacement trend around a target of interest: 4 power pylons right beside the Dam structure (shadows are visible on the optical picture). The top of the pylons seem uplifting, but the detected movement is actually thermal dilation. Due to the limited time span, it is very difficult to distinguish between linear and seasonal motions.

4. CONCLUSIONS

In this paper, two case studies analyzed in the Dragon program have been reported. In the first case, we show how a few L band images can be successfully processed with the QPS technique to retrieve ground height and movements. In the second one, we analyzed 60 High Resolution Cosmo Skymed SAR images around the Three Gorges Dam along ascending and descending passes to retrieve information on the terrain displacement. The preliminary results show important movements of the river banks, landslides and a relative stretch between up and down river sides. The main challenge of the study has been the impossibility of separating seasonal movements from linear displacement due to the very short observed time. Works are still ongoing on both studies, but the preliminary results show how promising are multi-temporal InSAR analysis in China for monitoring purposes.

5. ACKNOWLEDGEMENT

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