Evaluation of the use of the sub-Pixel Offset Tracking method with conventional dInSAR techniques to monitor landslides in densely vegetated terrain in the Three Gorges Region, China

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1. Study Area

Shuping landslide area is located on the south bank of the Yangtze River, about 49km upstream from the Three Gorges Dam, with centre coordinates, $30.996^\circ \text{N}$, $110.609^\circ \text{E}$.
2 Shuping Landslide

- After the first impoundment of the Three Gorges Reservoir in June 2003, obvious deformation occurred at the two blocks.
- This is confirmed by GPS measurements obtained 6 months after the first impoundment. (Sassa et al., 2006)
- Most of the landslides in Shuping appear to occur in the same period (approximately May to August) every year (Li et al., 2011).


According to previous work (Singleton et al., 2014), limited by the Maximum Detectable Displacement (MMD) of dInSAR, the large phase gradients induced by fast slope movements in Shuping landslide were underestimated by dInSAR even when using 1m resolution SAR data.

As an alternative method, offset tracking has recently been employed to derive centimetre-level landslide rates in this area using high-resolution (≤3m) space-borne SAR imagery (Li et al., 2011; Singleton et al., 2014).

It is found (Singleton et al., 2014) that accurate deformation magnitude can be measured from artificial Corner Reflectors using 1m-3m resolution TSX SAR data.

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4. Outline of this study

- Evaluation of Cosi_corr vs SARSCAPE sPOT results
- Correlation between the deformation pattern and water level changes of the Three Gorges Reservoir
- Assessment of non-Corner Reflector points (i.e. natural scatterers) for tracking offsets in areas where no CRs are present
- On-going work on the assessment of TSX Staring Spotlight data and Terrestrial Laser Scanning (TLS) measurements on the ability of obtaining “bare earth” observations
5. Data

- TerraSAR-X High-resolution Spotlight
- Resolution: 1m
- Extension: 10km × 5km
6. Workflow of sub-Pixel Offset Tracking

Processing flow of sub-Pixel Offset Tracking
7. Evaluation of time series sub-Pixel Offset Tracking results measurements from Corner Reflectors

- Due to the lack of ground truth measurements, evaluation was carried out by comparing the offsets derived by SARScape (provided by A. Singleton) and the results produced by COSI_Corr.

- Subsets of landslide sub-areas were cropped from 35 pairs of TerraSAR-X Spotlight images acquired from 02/21/2009 – 15/04/2010 and 19 pairs from 02/01/2012 – 23/02/2013.

- sub-Pixel Offset Tracking was applied to every pair of subsets using COSI_Corr with respect to the same master image for every annual time series (i.e. 2009-2010 and 2012-2013).

- deformation magnitudes of Corner Reflectors were extracted for time series analysis.

**Table 1. Settings of the Normalized Cross Correlation of COSI_Corr and SARScape**

<table>
<thead>
<tr>
<th></th>
<th>COSI_Corr</th>
<th>SARScape</th>
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</thead>
<tbody>
<tr>
<td>Searching window Size</td>
<td>32*32</td>
<td>31*31</td>
</tr>
<tr>
<td>Searching step</td>
<td>2 pixels</td>
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<tr>
<td>Correlation window size</td>
<td>10*10</td>
<td>8*8</td>
</tr>
<tr>
<td>accuracy</td>
<td>1/10 pixel</td>
<td>1/16 pixel</td>
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</table>
Location of Corner Reflectors in Shuping landslide area shown on geocoded TSX image exported to Google Earth with the red boundary corresponding to the two landslide blocks.

- New boundary identified from dInSAR (Singleton et al., 2014)
- Corner Reflector 1 - 6 are located on the stable ground outside the landslide boundary.
7.1 Time series landslide rates measured from CRs

Time series deformation magnitudes of Corner Reflectors in Shuping landslide area in 2009-2010 derived by COSI_Corr with azimuth deformation in upper panel and range deformation in lower panel.
7.1 Time series landslide rates measured from CRs

Time series deformation magnitude of Corner Reflectors in Shuping landslide area in 2009-2010 derived by SARScape with azimuth deformation in upper panel and range deformation in lower panel.
7.1 Time series landslide rates measured from CRs

Time series deformation magnitude of Corner Reflectors in Shuping landslide area in 2012-2013 derived by COSI_Corr with azimuth deformation in upper panel and range deformation in lower panel.
7.1 Time series landslide rates measured from CRs

Time series deformation magnitude of Corner Reflectors in Shuping landslide area in 2012-2013 derived by SARScape with azimuth deformation in upper panel and range deformation in lower panel.
7.2 Time series landslide rates measured from CRs: Difference of COSI_Corr and SARScape measurements

Difference of COSI_Corr and SARScape measurements (2009-2010) with mean difference in upper panel and standard deviation in lower panel.
7.2 Time series landslide rates measured from CRs: Difference of COSI_Corr and SARScape measurements

Difference of COSI_Corr and SARScape measurements (2012-2013) with mean difference in upper panel and standard deviation in lower panel.
8. Water level measurements of Three Gorges Reservoir

Daily water level of the Three Gorges Reservoir can be accessed from the Three Gorges Corporation website: http://www.ctg.com.cn/inc/sqsk.php
8. Water level measurements of Three Gorges Reservoir

- The water level measurements corresponding to every acquisition date show a consistent seasonal pattern.
- The 2 annual time series show a lower water level in the flooding season and normal levels in other seasons.
- This is strongly correlated with the active period of the Shuping landslide.
A big number of areas along the river bank on the risk of landslides

Not everywhere have CRs installed

Question: can offset tracking measure the deformation range and pattern in densely vegetated areas where no CRs available?
9.1 Histogram analysis of measurements derived from Corner Reflectors vs natural scatterers

Histograms of range (left panel) / azimuth (right panel) deformation derived from 21/02/2009 and 15/04/2010 pair via COSI_Corr from natural scatters vs CRs inside the landslide boundary

Using offset tracking method, the same range of deformation was derived from natural scatterers and Corner Reflectors.
9.2 Time series histograms of 2D offsets derived by offset tracking

We can see the centroid stayed at the coordinate origin during Feb – May 2009, and then showed an obvious move since May as well as a wider distribution of deformation magnitude. Since Aug 2009 the centroid stopped moving with few changes of distribution.
9.2 Time series histograms of 2D offsets derived by sPOT method

- Similar results
- The histogram of 20120524 starts showing a slightly different distribution
- The centroid moved since May and stopped after August 2012.
9.3 Conclusions of this assessment

- The offset tracking method is able to measure ground deformation range in densely vegetated terrain.

- From changes of the histogram centroid, the active period of the Shuping landslide can be identified, which agrees well with the measurements derived from the artificial Corner Reflectors.

- In the vast majority of regions where CRs are not installed, the offset tracking method should be able to independently measure ground deformation in terms of the 2D deformation range, landslide pattern and distribution of measurements from all scatterers in the whole landslide area.

- The statistical analysis implies that a big number of pixels still reflect the bare earth deformation trend.

- To distinguish the bare ground deformation and the offsets resulted from vegetation changes, further study is required to identify scatters showing bare earth deformation.
10. Assess TSX Staring Spotlight data and TLS measurements on the ability of obtaining “bare earth” observations.

TSX Staring Spotlight image superimposed on an InSAR DEM generated from a pair of TSX High-resolution Spotlight images, landslide boundary is marked in red.
Bare ground points extracted from TLS measurements

DTM generated from bare ground points of Shuping landslide area

Photo of Shuping landslide area with ongoing earth-work, Nov 2014
11. Way forward

- Evaluate the TSX Staring Spotlight mode and local Terrestrial Laser Scanning (TLS) observations to assess whether further “bare earth” observations can be obtained on landslide rates and deformation patterns.

- Compare the potential and limitations of sub-Pixel Offset Tracking and dInSAR techniques on TSX Staring Spotlight data over other test sites with different deformation rates, topographies and weather.
Thank you!