Overview of results of project 10665 over the last year

Qiming Zeng (PKU) and Jan-Peter Muller (UCL-MSSL)
Overview

• Team Composition
• Study Sites
• Objectives
• Highlights from consortium partners
• Poster “quickie” talks
• Luyi Sun
Joint Team – European Side

- Prof. Jan-Peter Muller (UCL)
  Mullard Space Science Laboratory, Dept. of Space and Climate Physics, University College London, UNITED KINGDOM

- Prof. Dr. Wolfgang Niemeier, (TUB)
  Institute of Geodesy and Photogrammetry, Technische Universität Braunschweig, Braunschweig, GERMANY

- Prof. Zhenhong Li (NU)
  School of Civil Engineering and Geosciences
  Newcastle University, UNITED KINGDOM

- Dr. Jean-Philippe Malet (US)
  CNRS-IPGS / University of Strasbourg, FRANCE
Joint Team – Chinese Side

group leaders from each institution

– Prof. Qiming Zeng (PKU)
Institute of Remote Sensing and GIS, Peking University, Beijing

– Prof. Jingfa Zhang (ICD)
Institute of Crustal Dynamics, CEA, Beijing

– Prof. XiuFeng He (HHU)
College of Civil Engineering, Hohai University, Nanjing, Jiangsu

– Prof. Denrong Zhang (HZNU)
Hangzhou Normal university, Hangzhou, Zhejiang

– Prof. Guoqing Zhou (GLUT)
Guilin University of Technology, Guangxi, Guangxi

– Dr. Jinghui Fan (AGRS)
China Aero Geophysics and Remote Sensing Centre for Land Resources
Objectives

- Investigate the complementarity and possible synergy of GPS and SAR methods for better monitoring of large area line-of-sight earth surface motion
- Assess the role of ASTER GDEMv2 and TanDEM-X DEMs to predict unstable slopes, validated by ground measurements
- Develop a robust and reliable method, which can be validated, for monitoring ground deformation in the Three Gorges, Guilin, Tibet and South China
- Assess the potential of GOCE & GRACE measurements to be combined with DEM for monitoring the effect of the additional water volume in dammed areas on surface stability
- Goal is to build a more operational system for landslide monitoring in order to be able to predict when landslides will occur based on SAR and weather monitoring especially spaceborne precipitation measurements
WorkPlan & Responsibilities

- WP1. Methods: PKU, UCL, NU
- WP2. DEM: UCL, PKU, NU
- WP3. Three Gorges: NU, UCL, AGRS, US, TUB
- WP4. Daduhe and Putaogao: HHU, TUB
- WP5. Mining area Xishan: TUB
- WP6. Southeast China: HZNU, PKU
- WP7. Tibet: ICD, NU, UCL, PKU, TUB
Assessment of the potential of TerraSAR-X Staring Spotlight data for monitoring ground deformation in densely vegetated terrain in the Three Gorges Region of China

Luyi Sun ¹, Jan-Peter Muller ¹, Qisong Jiao ², Tengfei Xue ², Jingfa Zhang ²

¹ Imaging Group, Mullard Space Science Laboratory, University College London, UK
² Institute of Crustal Dynamics, Chinese Earthquake Administration, Beijing, PRC
Shuping and Tanjiahe landslide sites are located on the south bank of the Yangtze River, about 49km and 56 km upstream from the Three Gorges Dam.
2. Data

- TerraSAR-X Staring Spotlight
- Resolution: 0.85~m × 0.24m
- Extension: 7.5km × 2.5km

Shuping landslide site
13/02/2015 – 23/05/2015

Tanjiahe landslide site
04/12/2014 – 18/05/2015
After the first impoundment of the Three Gorges Reservoir in June 2003, obvious deformation occurred in the two blocks. This was 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 time window from May to August every year (Li et al., 2011).


In previous work, sub-Pixel Offset Tracking (sPOT) method has been applied to high resolution SAR data to derive centimetre-level landslide rates in this region. (Singleton et al., 2014)

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

The landslide rates show a consistent seasonal pattern with a dramatic increase of landslip from May to August in both 2009-2010 and 2012-2013.

To prevent this landslide from threatening the Three Gorges dam, Chinese authorities decided to mitigate the landslide by denuding the landscape (orange trees & houses) and moving a big amount of Earth.

This earth work started in August 2014 and finished in February 2015 before Chinese new year.
4. Workflow of sub-Pixel Offset Tracking

Processing flow of sub-Pixel Offset Tracking

- Master image
- Slave image
- Co-registration
- Sub-pixel Normalized Cross Correlation
- Deformation fields along range / azimuth direction
- Statistical analysis
Deformation magnitudes of Corner Reflectors were extracted for time series analysis.

Subsets of landslide sub-area were cropped from 4 pairs of TerraSAR-X Staring Spotlight images acquired from 13/02/2015 – 23/05/2015.

Sub-Pixel offset Tracking was applied to every pair of subsets with respect to the same master image (i.e. 2015-02-13, which is the first acquisition after the earth works).

**Table 1. Settings of the Normalized Cross Correlation in offset tracking**

<table>
<thead>
<tr>
<th>Searching step</th>
<th>2*12 pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation window size</td>
<td>16*96</td>
</tr>
<tr>
<td>accuracy</td>
<td>1/32 pixel</td>
</tr>
</tbody>
</table>
5b. Corner Reflectors assisted time series analysis of Shuping landslide

- All data were acquired in right-looking and descending mode
  - The positive scale of azimuth deformation corresponds to the reverse along-track direction (predominantly to the North)
  - The positive scale of range deformation is away from the sensor (predominantly to the West)

- To reduce the background noise, CR1 is taken as a reference point, so the deformation magnitudes of CR1 were subtracted from all time series magnitudes of CR2-11 in the results.
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.
5c. Time series deformation magnitude measured from CRs in Shuping landslide area
6. Initial Assessment of TSX Staring Spotlight data and TLS measurements on the potential to obtain “bare earth” observations

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

DTM generated from bare ground points of Shuping landslide area
Zoom up of landslide area on TSX-ST intensity acquired on 28 November 2014

Zoom up of landslide area on TLS point cloud
7a. Tanjiahe Landslide

Aerial map of Tanjiahe landslide

geomorphic map of Tanjiahe landslide area with GPS monitoring points (Xue et al., 2014)

7b. Tanjiahe Landslide

Cumulative displacement obtained by GPS measurements (Xue et al., 2014)

- reactivated landslide since the impoundment of Three Gorges Dam reservoir;
- Continuous displacement occurring on the slope, with higher landslide rate when the reservoir level rises or after heavy rainfall. (Xue et al., 2014; Wang et al., 2015)
The centroid stayed at the coordinate origin with very few offsets in the order of correlation accuracy (up to 0.1 pixel)

In the time series the histogram showed a slightly wider distribution but no split peaks.
9. Conclusions and Way forward

- Sub-Pixel offset tracking (SPOT) applied to TSX Staring Spotlight mode imagery time series over Shuping landslide area indicates stabilisation of the landslide area but too early to say if Three Gorge dam operation will result in any landslip.

- SPOT applied to Tangjiahe landslide does not yet indicate any landslip but early days for definitive conclusion.

- Using local Terrestrial Laser Scanning (TLS) observations to assess whether “bare earth” observations can be obtained and identified from TSX ST datasets. This includes 3D point cloud matching and detection of bare patches in TSX-ST SAR amplitude data.

- Comparing 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.

- Assessment of Sentinel-1 TOPS data over entire Yantgze to detect areas for higher resolution acquisitions in future.
HUANGTUPO LANDSLIDE


LOCATION

Three Gorges (China)
SAR INTERFEROMETRY

(a) Vertical displacements (b) N-S displacements

Envisat ASAR images:
- 41 img. 2003-2010 (T075)
- 31 img. 2004-2010 (T347)
- 13 img. 2008-2010 (T068)
TRIGGERING FACTORS

Wavelet analysis →
InSAR displacements vs rainfall:
- In antiphase in the lower part
- In phase in the higher part
Wavelet analysis → InSAR displacements vs reservoir water level:

- In antiphase in the higher part
- In phase in the lower part
RIVER WATER LEVEL & RAINFALL vs. InSAR DISPLACEMENTS

LOWER PART OF THE LANDSLIDE

UPPER PART OF THE LANDSLIDE
BEHAVIOUR

General trend: Burger’s creep model: \( f(t) \)

\[
\delta = A \left( 1 - e^{-\frac{t}{B}} \right) + K \cdot t + C
\]

Seasonal changes (correlated with rainfall & water level)
Time Series Interferometry Analysis combined Point-like Scatters and Distribute Scatters

Sheng Gao, Qiming Zeng, Jian Jiao, Qingxi Tong
Institute of Remote Sensing & GIS, Peking University
Two categories of stable scatters could be used by time series interferometry analysis

Stable scatter candidates (SSC) selecting methods:

- Dispersion of Amplitude, \(DA\), \((Ferreti, 2000)\)
  \[D_A = \frac{\sigma}{A_s} \approx \sigma_\phi = \frac{1}{\sqrt{2r}} = \frac{\sigma^2}{\sqrt{I_s}}\]

- Dispersion of Intensity, \(DI\)
  \[D_I = \frac{\sigma_I}{\langle I \rangle} = \frac{2\sigma_\phi}{1 + 2\sigma_\phi^2} \sqrt{1 + \sigma_\phi^2}\]

- Rice Distribution

- Gauss Distribution

\(\sigma_\phi \approx \frac{1}{\sqrt{2r}}\)
\(r = \frac{I_s}{2\sigma^2}\) Ration of signal to cluster
Comparison between by DI and by DA

25 scenes ASAR, 6000R*1800C, 27 km*36 km, Dongguan city, Guangdong

When phase deviation (DA) is small, they are highly correlated.
SSC numbers are almost same when phase deviation is small, but selection result is not same; however along with threshold relax, SSC numbers increase rapidly, but by DA is faster than by DI, that percentage of commonly selected is stable by DI, rather one by DA decrease. That means PSC selected by DI has high quality than by DA.
Distribute stable scatter candidates identifying and phase estimation

Statistically Homogeneous Pixels (SHP) identify by using Goodness of fit testing (Kolmogorov-Smirnov test), then coherence of distribute scatters in a given window have been only averaged on neighbored SHPs, and it is been proved to be unbiased best estimation

Kolmogorov-Smirnov test threshold $D$ value is a function of given confidence and sample number $N$ (interferogram stack number)
Time Series Interferometric Analysis
combined PS and DS

23 ASAR IM from 20061024-20100615, Bp<400m
StaMPS PS-InSAR

StaMPS Combined-MTI

CDPS-InSAR

(a) StaMPS PS-InSAR  (b) StaMPS Combined-MTI  (c) CDPS-InSAR

Pixel numbers

- Initial pixels
- Final pixels

38
Space born repeat pass differential Interferometry atmospheric correction based on WRF model and data Assimilation

Ye Yun, Qiming Zeng, Jian Jiao
Institute of Remote Sensing & GIS, Peking University
3D variation assimilation test
Atmospheric Correction based on WRF and Assimilation with Ensemble Karlman Filtering

Observation assimilated: GPS (also as verification) and MODIS PWV
### Verification result with GPS (mm)

<table>
<thead>
<tr>
<th>干涉对</th>
<th>校正前</th>
<th>WRF-NODA</th>
<th>EnKF</th>
<th>EnKF-GPS</th>
<th>EnKF-MODIS-for</th>
<th>EnKF-MODIS-ana</th>
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<tr>
<td>20080816-20081025</td>
<td>12.17</td>
<td>9.04</td>
<td>N/A</td>
<td><strong>7.23</strong></td>
<td>10.01</td>
<td>11.49</td>
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<tr>
<td>20080816-20090627</td>
<td>17.19</td>
<td>18.48</td>
<td>N/A</td>
<td><strong>16.04</strong></td>
<td>19.14</td>
<td>18.68</td>
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<td>干涉对</td>
<td>校正前</td>
<td>WRF-NODA</td>
<td>EnKF</td>
<td>EnKF-GPS</td>
<td>EnKF-MODIS*-for</td>
<td>EnKF-MODIS*-ana</td>
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<td>20080712-20080816</td>
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<td><strong>10.04</strong></td>
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<td>20080712-20081025</td>
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<td>20080712-20090627</td>
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<td>8.95</td>
<td>9.01</td>
<td><strong>8.70</strong></td>
<td>9.32</td>
<td>9.79</td>
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</table>
Advantages

✓ PWV information at time point identical with SAR acquisition, but in case of no strong wind, positive and negative 15 minutes is acceptable
✓ Spatial resolution of PWV could up to 300~500m, and could used for medium spatial resolution interferometry application, but some detailed small scale weather structure maybe not reliable in case of no enough high resolution weather observations
✓ Simulation including rich weather variables information, could benefit to explain some strange phase pattern

Limitations

✓ Correction result could be worse when two simulation errors in opposite direction
✓ Spatial resolution of WRF model currently used and assimilated weather observations could not fulfill requirement for high resolution SAR interferometry application
Ye Yun, Qiming Zeng, Benjamin Green, and Fuqing Zhang. Mitigating atmospheric effects in InSAR measurements through high-resolution data assimilation and numerical simulations with a weather prediction model. International Journal of Remote Sensing. 2015, 36(8): 2129-2147

Gao Sheng, Zeng Qiming, Jiaojian, Tong Qingxi, A Review on Persistent Scatterers Interferometry, REMOTE SENSING TECHNOLOGY AND APPLICATION, accepted, (in Chinese)

LI Xin, LI ZENG Qiming†, WANG Xinyi, HUANG Jianghui, JIAO Jian, A Soil Moisture Co-Retrieval Approach Based on AMSR-E and ASAR Data, ACTA SCIENTIARUM NATURALIUM UNIVERSITATIAS PEKINENSIS, accepted, (in Chinese)

2 PhD students and 1 Master student graduated, obtain their academic degree

2 students will attend IGARSS 2015
Mapping Bedrock Elevation in Arid Regions by Using ALOS/PALSAR InSAR-derived DEMs

Siting Xiong a, Jan-Peter Muller a, b, *

a Imaging Group, Mullard Space Science Laboratory (MSSL), University College London, Department of Space & Climate Physics, Holmbury St Mary, Dorking, Surrey, RH5 6NT, UK

b Chair, “Terrain Mapping Sub-Group”, CEOS WG on Calibration & Validation

Email: sitting.xiong.14@ucl.ac.uk  j.muller@ucl.ac.uk
**Objects and Study Area**

- Laboratory measurements: Skin depth ranges from 1.5 to 6 m depending on rel. perm.
- Field observations: 0.8 to 2 m.
- Studies on InSAR derived DEMs over eastern Sahara by using ALOS/PALSAR datasets and comparing them with SRTM DEM to analyse InSAR geometry caused by refraction of radar signal at the sand-rock interface, which is different from the conventional InSAR method.

**Table 1. InSAR image pair used in this study.**

<table>
<thead>
<tr>
<th>Image</th>
<th>Date</th>
<th>Platform/Sensor</th>
<th>Level</th>
<th>Polarisation</th>
<th>Orbit</th>
<th>Frame</th>
<th>Asc./Desc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master</td>
<td>Aug. 13, 2007</td>
<td>ALOS/PALSAR</td>
<td>1.0</td>
<td>HH</td>
<td>8268</td>
<td>450</td>
<td>A</td>
</tr>
<tr>
<td>Slave</td>
<td>Sep. 30, 2008</td>
<td>ALOS/PALSAR</td>
<td>1.0</td>
<td>HH</td>
<td>14307</td>
<td>450</td>
<td>A</td>
</tr>
</tbody>
</table>
In this study, we use JPL’s open source InSAR processing software (ROI_pac) to generate flattened and differential interferograms, and updated baseline by using a quadratic model between unwrapped total phase and height in radar coordinates. Then the updated flattened interferogram is converted to height.
Results and Analyses

Figure 4. Comparisons of interferograms with and without updated baseline.

Figure 6. Comparing ALOS/PALSAR InSAR derived DEM with SRTM DEM.

Figure 7. Profiles analyses of ALOS/PALSAR InSAR derived DEM comparing with SRTM DEM.
Accuracy Assessment of SRTM 1, ASTER G-DEM and TanDEM-X I-DEM over the UK and its implications for China

L. Feng 1, L. Sun 1, J.-P. Muller 1,2

1 Imaging Group, Mullard Space Science Laboratory (MSSL), University College London, Department of Space & Climate Physics, Holmbury St Mary, Surrey, RH5 6NT, UK

http://www.ucl.ac.uk/mssl/imaging

lang.feng.14@ucl.ac.uk luyi.sun.12@ucl.ac.uk j.muller@ucl.ac.uk

2 Chair, “Terrain Mapping Sub-Group, CEOS WG on Calibration & Validation
The datum varies in OSGB36 national grid

<table>
<thead>
<tr>
<th>comparision</th>
<th>min</th>
<th>max</th>
<th>Mean(m)</th>
<th>Stdev(m)</th>
</tr>
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<tbody>
<tr>
<td>Odn-osgb36 ellipsoid</td>
<td>-0.372</td>
<td>15.398</td>
<td></td>
<td></td>
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</tbody>
</table>
Analysis areas in UK

- Birmingham
- MSSL, Surrey
- Wales
- Swanage, Dorset

Conclusion: The penetration ability of IDEM X band is weaker than SRTM C band in tree areas (canopy density) and land areas according to soil moisture and land roughness. In urban areas, IDEM, SRTM, ASTER are higher than Bluesky. Visible optical wavelength can penetrate coastline water.
## The statistics info & accuracy of DEM products of UK

<table>
<thead>
<tr>
<th>DEM Product</th>
<th>Min(3σ)</th>
<th>Max(3σ)</th>
<th>Mean(m)</th>
<th>Stdev σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDEM30m-bluesky 30m</td>
<td>-21.951</td>
<td>41.819</td>
<td>1.136</td>
<td>7.274</td>
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<td>SRTM30m-bluesky30m</td>
<td>-21.778</td>
<td>41.582</td>
<td>1.739</td>
<td>6.512</td>
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<tr>
<td>Aster30m-bluesky</td>
<td>-30.587</td>
<td>42.490</td>
<td>0.406</td>
<td>10.214</td>
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<tr>
<td>TanDEM-X IDEM 30m</td>
<td>30m</td>
<td>30m</td>
<td>30m</td>
<td>30m</td>
</tr>
<tr>
<td>IDEM30m-Aster30m</td>
<td>41.598</td>
<td>26.683</td>
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<td>SRTM30m-Aster30m</td>
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<td>IDEM30m-SRTM 30m</td>
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<table>
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<tr>
<th>DEM Product</th>
<th>Horizontal matching numbers</th>
<th>Absolute Horizontal RMSE (pixels)</th>
<th>Matching numbers for Vertical RMSE</th>
<th>Absolute Vertical RMSE (m)</th>
<th>Control point data</th>
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<td>TanDEM-X IDEM</td>
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<td>SRTM 1</td>
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<td>ASTER G-DEM</td>
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<td>132931709</td>
<td>8.366</td>
<td>Blue Sky</td>
</tr>
</tbody>
</table>
Areas of investigation in China

- Mining area Xishan
- Catchment dynamics at Lake NamCo
- Baota landslide behaviour
Xishan coal mine area

- Area of eight active mines with a total coverage of 304.8 km²

ROI be divided into two parts, the western part with five mines and eastern part with three mines. In this research, we will study the western part only.
Three-quarters of this area feature large mountains with steep slopes and ravines, which are mainly composed of Carboniferous, Permian sandstone, shale and Quaternary loess. Landslides, debris flows and avalanches are quite common in this area. Altitude: 979 m to 1518 m.
<table>
<thead>
<tr>
<th>Acquisition Date</th>
<th>Spatial baseline (m)</th>
<th>Temporal baseline (days)</th>
</tr>
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<td>2008.02.04</td>
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<td>2008.12.22</td>
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<td>2010.02.09</td>
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<table>
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<td>2009.10.04 (master)</td>
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<td>2010.02.21</td>
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<td>2010.07.11</td>
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<tr>
<td>2010.08.15</td>
<td>177.955</td>
<td>315</td>
</tr>
</tbody>
</table>
• ALOS pair 2009.12.25-2010.02.09 vs. ENVISAT pair 2009.10.04-2010.02.21.

- ALOS data are ascending while ENVISAT are descending.
- ALOS pair detected decimeter-level but ENVISAT pair showed only centimeter-level movements.
ROI in amplitude image of TerraSAR-X
<table>
<thead>
<tr>
<th>Pairs</th>
<th>master</th>
<th>slave</th>
<th>/day</th>
<th>/m</th>
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<td>2012-04-15</td>
<td>2012-04-26</td>
<td>11</td>
<td>141</td>
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<tr>
<td>3</td>
<td>2012-04-15</td>
<td>2012-05-07</td>
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<tr>
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<td>10</td>
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<td>2012-05-07</td>
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<td>2012-05-18</td>
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</table>
Time series analysis was carried out when 22 scenes of interferogram were ready. The first acquisition, 20120404, was used as the reference (the start point of time series analysis). Therefore, the deformation phases on all other dates are related to that on 4th April, 2012. A sequence of cumulative subsidence phases were estimated and then converted into height changes.
Time Series from TSX

- 2012.04.05-2012.04.27
- 2012.04.05-2012.05.08
- 2012.04.05-2012.05.30
- 2012.04.05-2012.06.21
- 2012.04.05-2012.07.02
- 2012.04.05-2012.07.13
subsidence caused by underground mining processes

2012.04.05-2012.11.22

Unit: mm
Baota landslide

- occurred: 18th July 1982
- position: Lat: 30° 57′ N, Lon: 108° 54′
- left bank of the Changjiang (Yangtze river).
- located in the middle of the Three Gorges Reservoir, 223km upstream of TGR Dam site, 388km downstream of Chongqing

- 1900m length, 800 – 1300m width, 450m height difference
- 15° surface gradient
- 70m thickness of landslide deposits
- 4000 people live on the landslide
3sec-SRTM-DEM Changjiang (Yangtze river)

- SRTM 3"-DEM input data set
- Colour cycle change in height of 500m
- Quarter scene (50km*50km)
- Image pair: 23424_06256
- **satellites: ERS1 and ERS2**
- Date of image acquisition: January – July 1996
- Baseline $B_{perp} = 23$ m
- Precise ephemeris
Baota landslide interferogram

max. movement rates in line of sight of 10mm in 6 months
Geodetic network Baota

- 5 stable control points
- 12 monitoring points

January and November 1997

GPS campaigns with conventional survey
- Rogue 8000 receivers
- EDM: Wild DI 2002

Movement rates up to 25mm

Under the assumption of linear approximation
INSAR (1996) results are in good coincidence to GPS results (1997)
Combination of different data types with Support Vector Machines for behaviour modelling
Velocity field with Support Vector Machines Modelling

- topography
- slope
- max. curvature
- min. curvature
- NDVI
- classified surface
- 12 GPS-vectors
• Limitations on Baota landslide

• including the neighboured slope

• without limitation
Investigation on landslide acceleration caused by water level rise of Three Gorges dam

- Use of 13 Envisat scenes from January 2009 to October 2010
- Reduction of data set to smaller baseline length
- Use of SBAS approach
Result of SBAS-processing for Baota

Mean Velocities 3-12mm/a

=> No significant slope acceleration in comparison to 1997
Investigation on catchment dynamics in the vicinity of Lake NamCo in Tibet

Main objectives:
- Estimation of a time series of high resolution DEMs based on ERS, ENVISAT and Tandem-X data analysis
- Mapping of seasonal surface changes based on DEM time series
- Estimation of glacier volumes and velocities

Area of investigation shown by radar data, Lake NamCo is located 100km north of Lhasa.

The estimated height values along the red transect in the figure above are derived from Envisat data processing of 2008, 2009 and 2010.