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PS-InSAR TECHNIQUE FOR LANDSLIDE DEFORMATION IN THE THREE GORGES RESERVOIR AREA USING ENVISAT ASAR DATA STACKS

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ABSTRACT:

This technique is well-known for its applications in subsidence of landslide monitoring analysis. However, practical applications of D-InSAR are limited by major drawbacks such as geometric and temporal decorrelation, as well as atmospheric disturbances. With the PS-InSAR techniques, a long time series of SAR images is combined to identify point-like stable reflectors (PSs), which can overcome the problems for traditional D-InSAR technique so as to improve the accuracy and reliability of deformation measurements. However, its application in landslide deformation monitoring has just become a hot topic of research in recent years. Landslide monitoring in the Three Gorges areas with PS-InSAR techniques is difficult due to environmental conditions such as strong terrain relief, dense vegetation cover, and complicated atmospheric variation/ condition. Such problems may hinder the PS-InSAR analysis.

InSAR is a powerful technique that exploits phase information of SAR images to measure ground surface movements. Landslide deformation and monitoring using D-InSAR technique with millimetre accuracy is an important application of satellite SAR data acquired in repeat-pass mode. To solve these such problems, B.M. Kampes, R.F. Hanssen and P. Marinkovic developed the DORIS to make use for SAR interferometric processing, DEM generation- creation of digital elevation model and using the created DEM obtaining an interferometric containing displacement information. Andy Hooper and David Bekaert developed the StaMPS to make use of spatial-temporal filtering to extract deformation components from time-series interferometric phase signal.

In this study, I have used D-InSAR and PS-InSAR techniques for landslide movement detection and deformations and monitoring by time series data and analysis at the Three Gorges Reservoir area. With ENVISAT ASAR 09 images of multiple tracks acquired during the period 08th February 2004 to 12th June 2005 years were used as test data. Using PS-InSAR method, identified areas with high risks of slope failure at the Three Gorges area and detect time-series deformation at landslide bodies.

1. INTRODUCTION

Synthetic-Aperture Radar Interferometry (InSAR) is a powerful technique that exploits phase information of SAR images to measure ground surface movements. An important application of satellite SAR data acquired in repeat-pass mode is the deformation monitoring using Differential SAR interferometry (D-InSAR) technique with millimetre accuracy.

To solve these such problems, the DORIS (the Delft Object-Oriented Radar Interferometric Software) for Interferometric SAR processing software. And StaMPS (Stanford Method for Persistent Scatterer) is a software package that implements an InSAR Persistent Scatterer (PS) method developed to work even in terrains devoid of man-made structures and/or undergoing non-steady deformation.

In this study project, I am investigated the application of D-InSAR and PS-InSAR techniques that uses radar signals from a satellite to accurately measures ground and landslide displacement and movement detection and monitoring by time series data and analysis at the Three Gorges Reservoir area. In this study project, both D-InSAR and PS-InSAR techniques will be used to measure landslide deformations in the Three Gorges Reservoir area.

With Environmental Satellite (ENVISAT) Advanced Synthetic Aperture Radar (ASAR) datasets of 09 images of multiple tracks acquired during the period 08th February 2004 to 12th June 2005 years are used as test data. Using PS-InSAR method, I am identify areas with high risks of slope failure at the Three Gorges area and detect time-series deformation at landslide bodies. PS-InSAR is an improved and more accurate analysis algorithm compared to the InSAR method. PS-InSAR technique is a widely used for to detect & monitor slow terrain movements, with millimetric accuracy from satellite data like SAR data and its accuracy measures ground displacement.

2. AIM AND OBJECTIVE FOR STUDY NEED

2.1. Aim

In this study project, to identify the areas with high risks of slope failure at the Three Gorges reservoir area and detect time-series deformation at landslide bodies and both D-InSAR and PS-InSAR techniques will be used to measure landslide deformations in the Three Gorges Reservoir area.

2.2. Objective

To implement the D-InSAR and PS-InSAR techniques for interferogram generation, to DEM generation, landslide deformations monitoring and for time series plotting and deformation of landslide respectively.

3. STUDY AREA AND TEST DATASETS

3.1. Study Area

As the largest hydro-electric project in the world, the Three Gorges Project (TGP) was fully working in 2009. The Three Gorges Reservoir situated on 175 m above sea level. Nowadays, the reservoir water level fluctuates between 145 m and 175 m billion annually during each storage-discharge cycle. Such a big and frequent variation will inevitably affect slope stability along the Yangtze River and its tributaries in the Three Gorges Region, including reactivation of some old landslide and triggering new slope failures. Therefore, landslide monitoring will always be a task of major concern in the post-TGP era. The area divided in two main groups, i.e., the middle Triassic group (T_2b) and the lower Triassic Jialingjiang group (T_1J) along Yangtze River, is taken as my project study area.

All old towns has been demolished and submerged due to water level rise along with the TGP construction. Most of all new towns are built along a steep river bank, the impact of water level variation in the Three Gorges reservoir is of great concern. Therefore, slope instability in near the Three Gorges Region is induced by various kinds of triggering factors, such as rainfall, human activity, and geological environment change.

Its landscape indicates that one of the most significant geomorphological characteristic is the strata dip toward the bank of the Yangtze River. Buildings located on this slope are affected by potential slope instability.

Location - Latitude and Longitude Position of Study Area

Latitude: **30^0 N. to 32^0 N.**
Longitude: **110^0 E. to 112^0 E.**

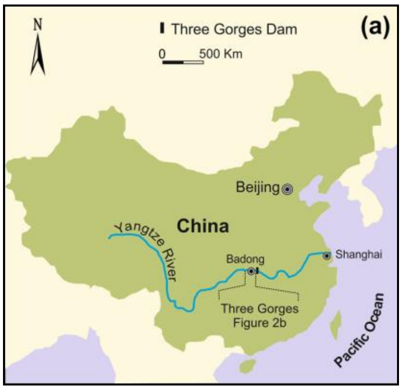


Figure 1: Location Map of Study Area (a)

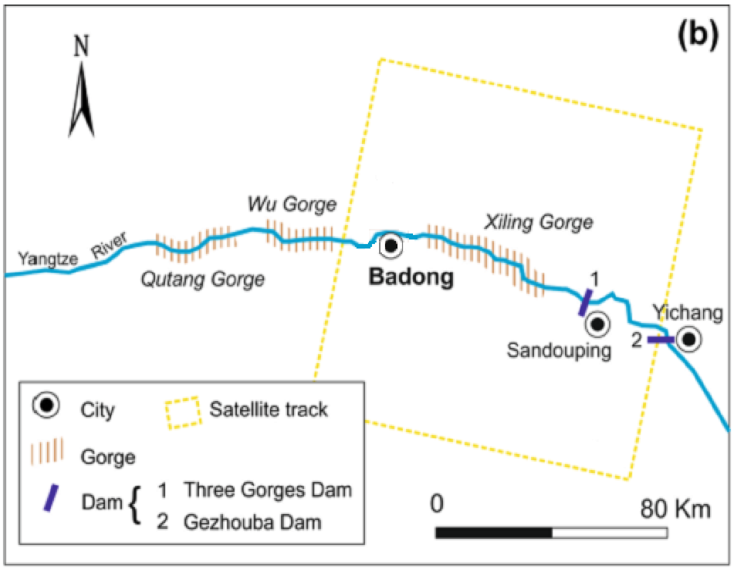


Figure 2: Location Map of Study Area - Three Gorges (b)

3.2. Test Datasets

In the project experiments, I am used 09 InSAR image data stacks covering the same area to detect landslide deformation in the Three Gorges Reservoir area. I am used a stack of 09 images acquired by the ENVISAT ASAR data from descending pass orbit direction during the period 08th February 2004 to 12th June 2005 are provided by ESA.

Table 1: Date Wise Envisat ASAR Dataset

Sr. Nos.	Date Wise Dataset
1	08-February-2004 (Master File)
2	23-May-2004 (Slave File)
3	27-June-2004
4	01-August-2004
5	19-December-2004
6	27-February-2005
7	03-April-2005
8	08-May-2005
9	12-June-2005

3.2.1. Introduction to Envisat Satellite

Launched in 2002, Envisat is the largest Earth Observation spacecraft ever built. It carries ten sophisticated optical and radar instruments to provide continuous observation and monitoring of the Earth's land, atmosphere, oceans and ice caps. Envisat data collectively provide a wealth of information on the workings of the Earth system, including insights into factors contributing to climate change. Furthermore, the data returned by its suite of instruments are also facilitating the development of a number of operational and commercial applications.

Envisat largest single instrument is the Advanced Synthetic Aperture Radar (ASAR), operating at C-band. This ensures continuity of data after ERS-2, despite a small (31 MHz) central frequency shift. It features enhanced capability in terms of coverage, range of incidence angles, polarisation, and modes of operation. Some Envisat ASAR data information are as below:

Table 2: Envisat ASAR Specifications and Data Information

Sr. Nos.	Specifications	Data Information
1	Accuracy	Radiometric Resolution in Range: 1.5 - 3.5 dB,
2	Radiometric Accuracy	0.65 dB
3	Spatial Resolution	Approx. 30 m x 30 m.
4	Wide Swath Mode	Approx. 150 m x 150 m.
5	Global Monitoring Mode	Approx. 1000 m x 1000 m.
6	Swath Width	Image and Alternating Polarization Modes: Up To 100 km.
7	Wave Mode	5 km.
8	Wide Swath and Global Monitoring Modes	400 km. or More
9	Waveband	Microwave: C-Band, With Choice of 5 Polarization Modes (VV, HH, VV/HH, HV/HH or VH/VV)
10	Earth Topics	Land (Landscape Topography), Snow and Ice (Snow and Ice), Ocean and Coast (Ocean Currents and Topography) [Ref. 2]

4. METHODOLOGY FOR SYNTHETIC-APERTURE RADAR INTERFEROMETRY (INSAR) FOR LANDSLIDE MONITORING/ DEFORMATION

4.1. Differential Synthetic-Aperture Radar Interferometry (D-InSAR) Techniques

D-InSAR data processing can be implemented in several ways. Most commonly used is the two-pass method, i.e., one is Ascending Pass method and second is Descending Pass method, which uses two SAR images for interferogram generation and then removes the topographic phase estimated from an existing digital elevation model (DEM).

D-InSAR can detect millimetre-level accurate deformation. However, its performance for landslide monitoring application is reduced due to the loss of coherence between the two observations as well as atmospheric screen. Furthermore, other factors may degrade the quality of differential interferogram, such as the DEM error or the error in image co-registration.

In this study, the Delft object-oriented radar interferometric software (DORIS) is used for Differential Interferometric SAR processing. Because the DORIS Software only support Single Look Complex format (SLC) data.

D-InSAR is the commonly used term for the production of interferograms from which the topographic contribution has been removed. However, the term may occasionally be misleading, because on the one hand interferometry is a differential technique right from the beginning, and on the other hand, the subtraction process can be pushed further as well as in other directions (e.g. subtraction of an expected geophysical contribution through landslide, earthquake, volcano dynamic modelling, and etc.). [*Ref. 2*]

4.2. Persistent Scatterer Synthetic-Aperture Radar Interferometry (PS-InSAR) Techniques

PS-InSAR is an advanced technique to derive information of terrain motion. This technique uses multiple SAR acquisitions of the same area to build a stack of interferograms, from which point-like stable reflectors, *i.e.*, the so-called Persistent Scatterer (PS), are identified.

The coherent measurements on PS's allow a terrain movement estimation with millimetre accuracy. After the interferogram formation, used the StaMPS Software to identify PS points and estimate the displacements at these points. PS-InSAR can overcome the limitations of geometrical and temporal decorrelation as well as atmospheric disturbance.

One of the main difficulties encountered in D-InSAR applications is temporal and geometric decorrelation. The main goal of this section is the identification of single pixels (called Permanent Scatterer, PS) that are coherent over long time intervals and for wide look-angle variations.

In fact when the dimension of the PS is smaller than the resolution cell, the coherence is good (the speckle is the same) even for image pairs taken with baselines greater than the decorrelation length. On those pixels, sub-meter DEM accuracy and millimetric terrain motion detection can be achieved, even if the coherence is low in the surrounding areas. Reliable elevation and deformation measurements can then be obtained on this subset of image pixels that can be used as a 'natural' GPS network.

Although this is rarely the case, there are pixels where one scatterer dominates the echo and which behave somewhat like point scatterers, so that decorrelation is greatly reduced. This is our model for a PS pixel. One can thus obtain useful data from all image pairs enabling the formation of a series of interferograms, all referenced to the same "master" scene. The atmospheric delay signal can then be estimated and removed by filtering of the resulting phase time series obtained for each of the PS pixels.

5. PROCESSING SOFTWARE'S

5.1. The Delft Object-Oriented Radar Interferometric Software (DORIS)

To solve such problems, B.M. Kampes, R.F. Hanssen and P. Marinkovic are developed the Delft Object-Oriented Radar Interferometric Software (DORIS) to make use for SAR interferometric processing, DEM generation- creation of digital elevation model and using the created DEM obtaining an interferometric containing displacement information.

In study, the DORIS was used for Interferometric SAR processing. Because the DORIS Software only support Single Look Complex format (SLC) data.

DORIS philosophy is to use simple format definitions, and a single main program that keeps track of the processing. There are 6 small ASCII files that are used to store relevant parameters on the master image, the slave, and on the products. Each processing step can read and write to these files, updating them with the latest available results.

DORIS software is made available for non-commercial applications only and can be downloaded from: http://enterprise.lr.tudelft.nl/DORIS/:DORIS_v4.01.tar.gz.

5.2. The Stanford Method for Persistent Scatterer (StaMPS)

Andy Hooper and David Bekaert are developed the Stanford Method for Persistent Scatterers (StaMPS) to make use of spatial-temporal filtering to extract deformation components from time-series interferometric phase signal. After the interferogram formation, used the Stanford Method for Persistent Scatterers (StaMPS) to identify PS points and estimate the displacements at these points.

There are two pre-processing steps before getting to the PS processing proper. The first is to focus the raw data, and the second is to form interferograms. ROI PAC is used for focusing and DORIS for interferogram formation. If starting with SLC images, rather than raw data, the focusing step can be skipped and the images imported directly into DORIS. Both the ROI PAC and DORIS processing are non-standard and various shell scripts, MatLAB scripts and programs are included in this package to produce interferograms that are PS friendly.

StaMPS / MTI is made available for non-commercial applications only and can be downloaded from: http://homepage.see.leeds.ac.uk/~earahoo/stamps/ *(Ref. Hooper et al. [2012]).* It is compliant with StaMPS/MTI Version 3.3b1.

StaMPS (Stanford Method for Persistent Scatterer) is a software package that implements an InSAR Persistent Scatterer (PS) method developed to work even in terrains devoid of man-made structures and/or undergoing non-steady deformation. StaMPS/MTI (Multi-Temporal InSAR) is an extended version of StaMPS that also includes a small baseline method and a combined multi-temporal InSAR method.

5.3. MatLAB

DORIS and StaMPS software's are working on MatLAB programming platform. The PS processing itself includes C++ programs and MatLAB scripts to identify PS pixels, and to extract the deformation signal for these pixels.

6. RESULTS AND ANALYSES OF STUDY PROJECT

6.1. Differential Synthetic-Aperture Radar Interferometry (D-InSAR) Process Analysis

6.1.1. Analysis of Coherence SLC Images

The DORIS Software only support Single Look Complex format (SLC) data. Coherence SLC data is an indicator of InSAR data quality, is estimated from the complex cross-correlation coefficient of the SAR image pair. In this study, to examine some interferometric pairs from each InSAR data stack for my study comparison i.e. time interval pair. Coherence SLC images associated with the interferograms from the some InSAR datasets pairs are as shown in below Figures 3 & 4.

This figure shows that **Yichang, Sandouping and Badong** is study area which shows more intensity and coherence of SLC images. Red circles shows more landslide intensity of displacement area in my study area.

These SLC image shows intensified or coherence area near to Yangtze River. White pixels (dots) shows intensity of image. All images shows same output of intensity images and **white dots** shows more coherence or intensity of landslide displacement on the particular image.

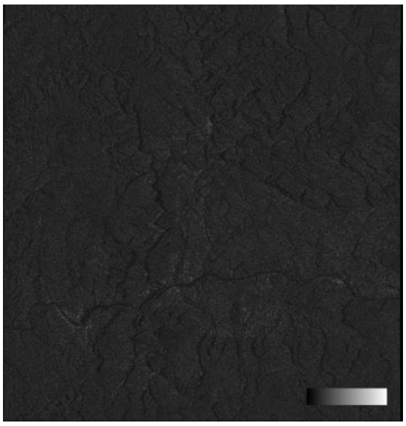


Figure 3: 23rd May 2004

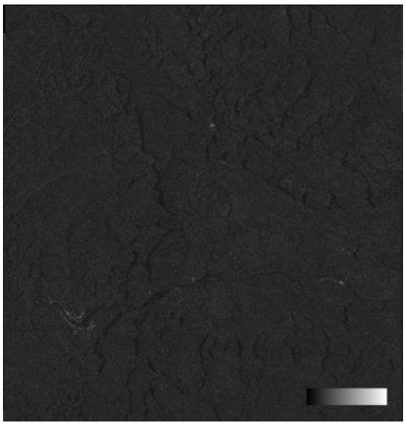


Figure 4: 12th June 2005

6.1.2. Analysis of Interferograms Images

The interferometric phase is produced from phase difference calculation between two SAR images pixel by pixel. In this study after removing the topographic phase from the interferograms, landslide fringes (slope) should only show up at areas with a high deformation rate. Location of landslide deformation in the large scale can be roughly identified by analysis of fringe (slope) density in differential interferograms.

From Figure 5 to 8 shows that all differential interferograms with small normal baselines can show Three Gorges Reservoir areas landslide, a large landslide located on the riverbank of the Yangtze River. The interferometric amplitude and phase are shown in figures. In the results of the ENVISAT ASAR data stacks, dense landslide displacement or deformation were detected only along the riverbank of Yangtze River and displacement or deformation of landslide were distributed all over the Three Gorges Reservoir area.

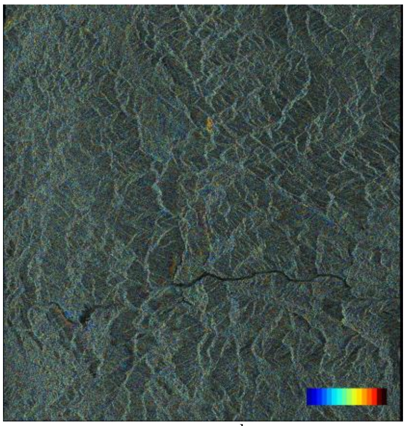


Figure 5: 23rd May 2004

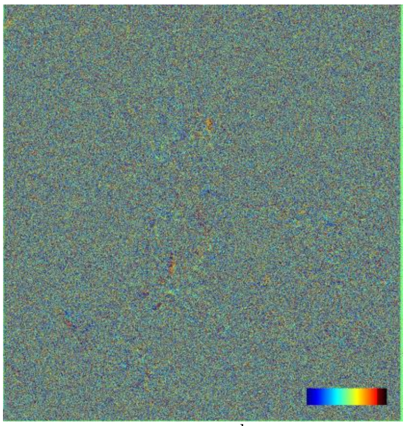


Figure 6: 23rd May 2004

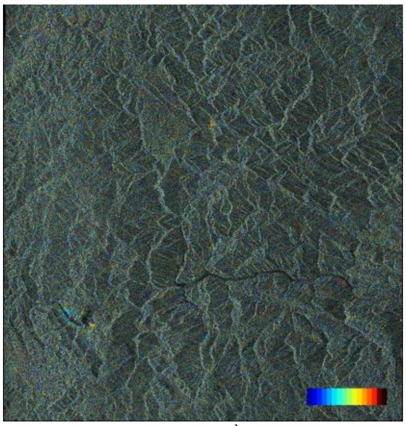


Figure 7: 12th June 2005

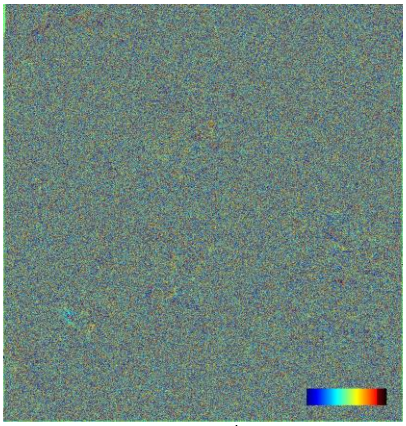


Figure 8: 12th June 2005

6.2. Persistent Scatterer Synthetic-Aperture Radar Interferometry (PS-InSAR) Process Analysis:

The spatial distribution of PS points identified from these data stacks. The PS point density of the ENVISAT ASAR dataset is quite high and distributed evenly across the area. In the results of the ENVISAT ASAR data stacks, dense PS points can be detected only along the riverbank of Yangtze River and the distribution of PS points is spread all over the Three Gorges Reservoir Region area. In this study Deformation velocities at PS points in the Three Gorges Reservoir areas identified by PS-InSAR from ENVISAT ASAR descending datasets.

6.2.1. PS Points in the Three Gorges Reservoir Region Identified by Multilooked Interferogram

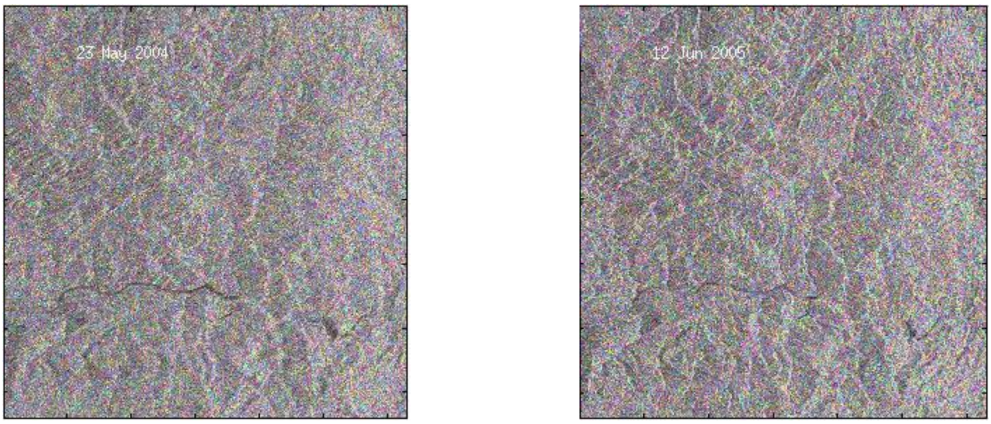
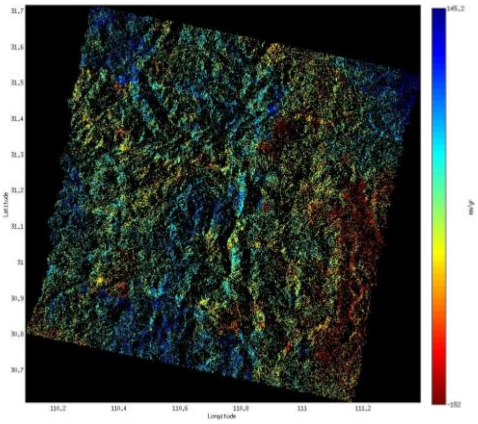


Figure 9: Particular Date Wise Deformation Velocities at PS points in the Yangtze River Area. Plots Multilooked Interferogram Images. Similar work has been performed on some more data stack.

6.2.2. PS Plots on ENVISAT ASAR Descending Pass Datasets



Plots values for each selected pixel, on various backgrounds, for chosen interferograms.
ps_plot(v-d,0): ‘v’ means LOS velocity (MLV) in mm/yr minus ‘d’ means spatially correlated DEM error, 0 means black background, longitude/latitude axes.

Figure 10: PS Plots for mean velocities at PS points using Black Background

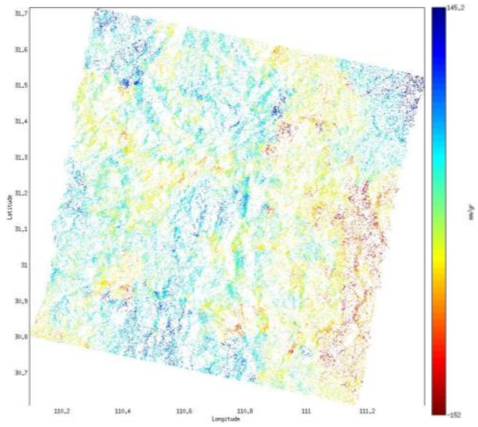


Figure 11: PS Plots for mean velocities at PS points using white Background

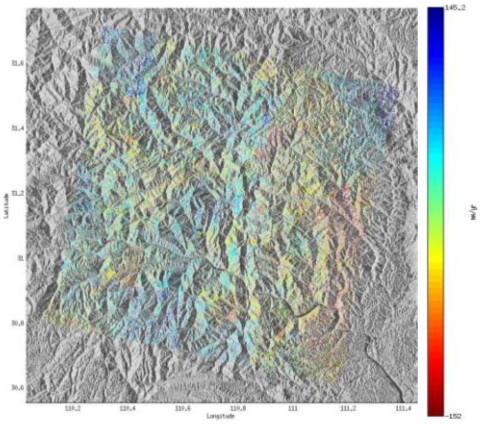
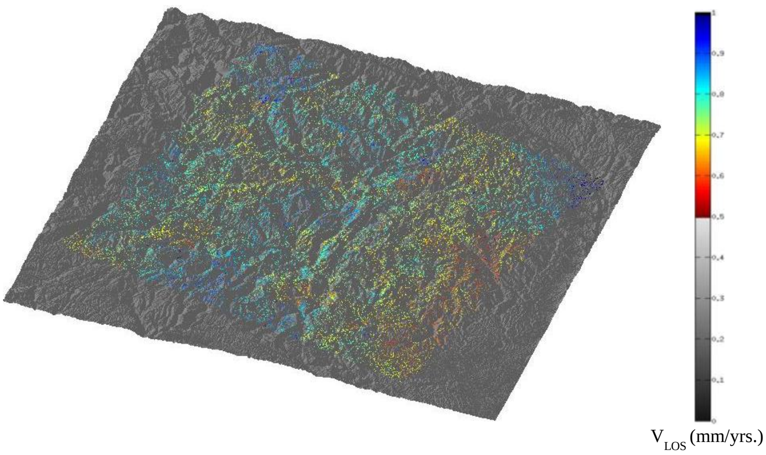


Figure 12: PS Plots for mean velocities at PS points using Shaded Relief Topology

Plots values for each selected pixel, on various backgrounds, for chosen interferograms.

White Background: ps_plot(v-d,1): ‘v’ means LOS velocity (MLV) in mm/yr minus ‘d’ means spatially correlated DEM error, 1 means white background, longitude/latitude axes.

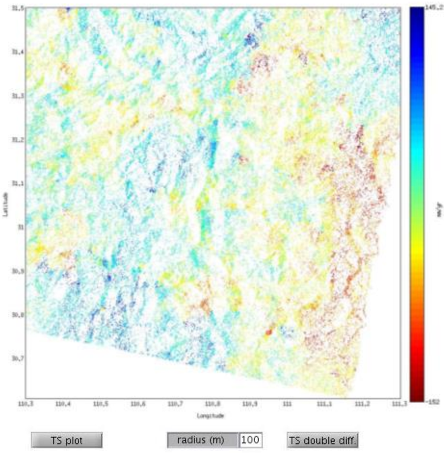
Shaded Relief Topology: ps_plot(v-d,2): ‘v’ means LOS velocity (MLV) in mm/yr minus ‘d’ means spatially correlated DEM error, 2 means shaded relief topology, longitude/latitude axes.



Plots values for each selected pixel, on various backgrounds, for chosen interferograms.
ps_plot(v-d,3): ‘v’ means LOS velocity (MLV) in mm/yr minus ‘d’ means spatially correlated DEM error, 3 means 3 dimensional topology, longitude/latitude axes.

Figure 13: PS Plots for mean Velocities at PS points using 3 Dimensional Topology

6.2.3. PS-InSAR Time Series Plotting



For. Example:
ps_plot(‘v-d’,1,0,0,[], 0,0,0,[], [110.3 111.3], [30.6 31.5], ‘ts’)
Meaning of value:
ps_plot(value_type,background,phase_lims,ref_ifg,ifg_list, n_x,...cbar_flag,textsize,textcolor,lon_rg,lat_rg)
Plot velocity for the subset defined by longitude and latitude and generates TS plots, these values are default values for using TS plots.

Figure 14: PS Plots for mean velocities at PS points using White Background with XY axis.

a. Single Time Series Plotting

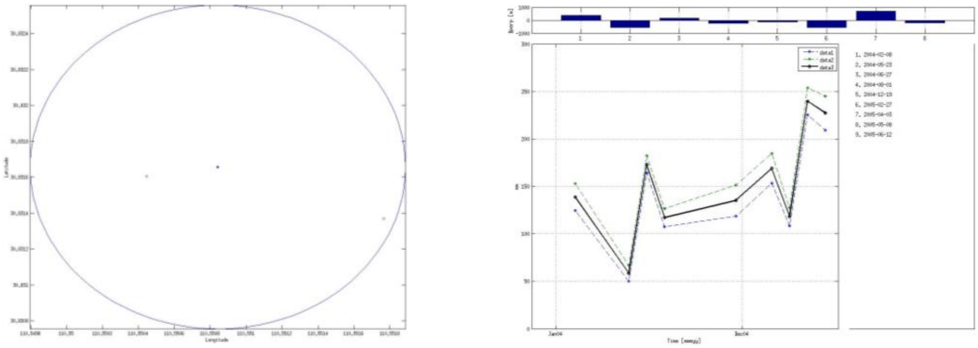


Figure 15: TS Plots between 100 m (v-d) Radius with Landslide Deformation Graph

b. Double Difference Time Series Plotting

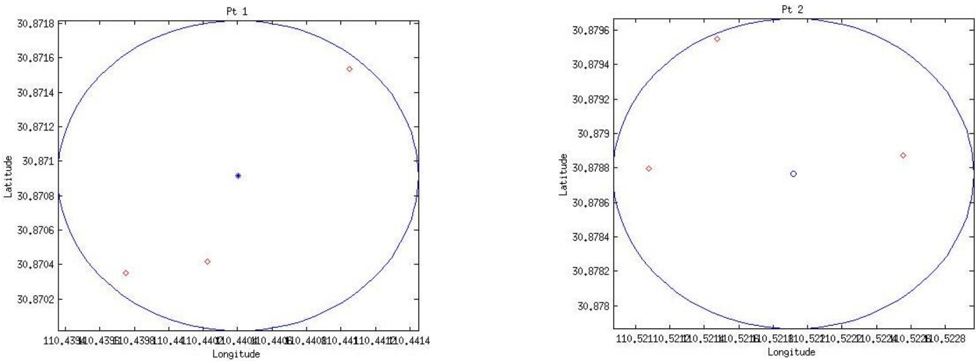


Figure 16: TS Plots in 100 m (v-d) Radius between Two PS Points

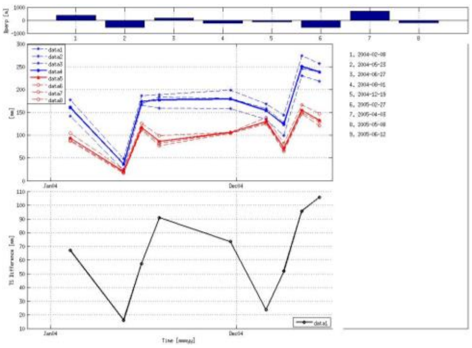


Figure 17: TS Plots Landslide Deformation Graph

7. DISCUSSION

The landslide deformation in the Three Gorges reservoir area is analyzed in four aspects of the experimental results, *i.e.*, coherence images, phase interferograms, PS distributions and mean deformation velocity of PS.

The experimental results indicates that D-InSAR and PS-InSAR techniques can be used to observe displacement areas in the Three Gorges reservoir. The InSAR data quality in repeat-pass interferometry can be evaluated using coherence. Coherence in vegetated area is not only related with time interval and normal baseline of data pair but also depends on radar wavelength.

Moreover, only the differential interferograms in the case of the Three Gorges reservoir area, with steep topography and dense vegetation, the dissimilar system configurations of each dataset greatly impact the number and spatial distribution of PS points. The system of longer wavelength is more coherent and could usually produce a larger number of PS points. These areas of large displacement in the Three Gorges reservoir area are monitored by the SAR datasets for landslide assessment.

The mean deformation velocities in the areas are −152 to 145.5 mm/yr estimated using PS-InSAR technique. Using the ENVISAT ASAR data acquired from a descending stack three high displacement areas can be identified. Using satellite acquisitions from descending orbits, it is possible to overcome the problem of incompleteness in identification of potential landslide risk using just one data stack. The algorithm for identifying PS pixels in a series of interferograms is based primarily on phase characteristics and finds low amplitude pixels with phase stability that are not identified by the existing algorithms.

8. CONCLUSIONS

Remote sensing technique is a proficient tool to extract spatial information for hazard analyses especially radar instruments which provide day and night data and seldom affected by atmospheric conditions.

In complex areas, data fusion technique by using multiple SAR datasets from different data sensors is more effective and reliable than use only one platform data.

In this study, detected some significant deformations in the Three Gorges reservoir area using the D-InSAR technique. However, the deformation detection with this technique is effective only for those data pairs with relatively short time intervals and small normal baselines. Thus, this technique is difficult to be applied for long-term monitoring.

Using PS-InSAR technique, limitations due to geometrical and temporal decorrelation, as well as atmospheric disturbances, can be overcome, and time series monitoring are implemented.

These significant deformation in the Three Gorges reservoir areas are detected by using PS-InSAR technique. In this way the reliability and accuracy of deformation monitoring can be improved in areas with complex topography and vulnerable geological conditions. Finally, cross-validation is carried out among the PS-InSAR results from the data stacks by projection of LOS velocity onto down-slope direction for unification.

REFERENCES

1. Zonation of the landslide hazards in the forereservoir region of the Three Gorges Project on the Yangtze River, - Shuren Wu, Ling Shi, Reijiang Wang, Chengxuan Tan, Daogong Hu, Yingtang Mei, Ruichun Xu, Engineering Geology 59 (2001) 51 – 58.
2. InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation, - European Space Agency, TM-19, February 2007.
3. Radar Interferometry With Public Domain Tools, - Bert M. Kampes(1;2), Ramon F. Hanssen(2), Zbigniew Perski(3)
4. Delft Object-oriented Radar Interferometric Software User’s manual and technical documentation Version: v4.02, Delft Institute of Earth Observation and Space Systems (DEOS) Delft University of Technology, This document is typeset in LATEX2e. Delft, December 2008.
5. Radar Interferometric processing with the Doris software The Cookbook; B.M. Kampes, R.F. Hanssen and P. Marinkovic; Satellite Radar Interferometry Course, CONIDA. Lima, Peru 24-28 October 2011.
6. Liao, M.; Tang, J.; Wang, T.; Balz, T.; Zhang, L. Landslide monitoring with high-resolution SAR data in the Three Gorges region. *Sci. China Earth Sci.* 2012, *55*, 590–601.
7. Li, T.; Liu, J.; Liao, M. Monitoring City Subsidence by D-InSAR in Tianjin Area. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Anchorage, AK, USA, 20–24 September 2004.
8. Wang, T.; Perissin, D.; Liao, M.; Rocca, F. Deformation Monitoring by Long Term D-InSAR Analysis in Three Gorges Area, China. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Boston, MA, USA, 8–11 July 2008.

9. Tantianuparp, P.; Balz, T.; Wang, T.; Jiang, H.; Zhang, L.; Liao, M.; Analyzing the Topographic Influence for the PS-INSAR Processing in the Three Gorges Region. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Munich, Germany, 22–27 July 2012.
10. Rosen, P.A.; Hensley, S.; Joughin, I.R.; Li, F.K.; Madsen, S.N.; Rodriguez, E.; Goldstein, R.M. Synthetic aperture radar interferometry. *Proc. IEEE* 2000, *88*, 333–382.
11. Nagler, T.; Rott, H.; Kamelger, A. Analysis of Landslides in Alpine Areas by Means of SAR Interferometry. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Toronto, ON, Canada, 24–28 June 2002.
12. Chini, M.; Atzori, S.; Trasatti, E.; Bignami, C.; Kyriakopoulos, C.; Tolomei, C.; Stramondo, S. The May 12, 2008, (Mw 7.9) Sichuan earthquake (China): multiframe ALOS-PALSAR DInSAR analysis of coseismic deformation. *IEEE Geosci. Remote Sens. Lett.* 2010, *7*, 266–270.
13. Jiang, K.; Wang, C.; Zhang, H.; Chen, W.; Zhang, B.; Tang, Y.; Wu, F. Damage Analysis of 2008 Wenchuan Earthquake Using SAR Images. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Cape Town, South Africa, 12–17 July 2009.
14. Perissin, D.; Wang, T. Time-series InSAR applications over urban areas in China. *IEEE J-STARS* 2011, *4*, 92–100.
15. Ferretti, A.; Prati, C.; Rocca, F. Permanent scatterers in SAR interferometry. *IEEE Trans. Geosci. Remote Sens.* 2001, *39*, 8–20.
16. Zhang, Y.; Gong, H.; Li, X.; Liu, T.; Yang, W.; Chen, B.; Li, A.; Su, Y. InSAR Analysis of Land Subsidence Caused by Ground Water Exploitation in Changping, Beijing, China. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Boston, MA, USA, 8–11 July 2008.
17. Colesanti, C.; Wasowski, J. Investigating landslides with space-borne Synthetic Aperture Radar (SAR) interferometry. *Eng. Geol.* 2006, *88*, 173–199.
18. Herrera, G.; Gutiérrez, F.; García-Davalillo, J.C.; Guerrero, J.; Notti, D.; Galve, J.P.; Fernández-Merodo, J.A.; Cooksley, G. Multi-sensor advanced DInSAR monitoring of very slow landslides: The Tena Valley case study (Central Spanish Pyrenees). *Remote Sens. Environ.* 2013, *128*, 31–43.
19. Holbling, D.; Fureder, P.; Antolini, F.; Cigna, F.; Casagli, N.; Lang, S. A semi-automated object-based approach for landslide detection validated by persistent scatterers interferometry measures and landslides inventories. *Remote Sens.* 2012, *4*, 1310–1336.
20. Bovenga, F.; Wasowski, J.; Nitti, D.O.; Nutricato, R.; Chiaradia, M.T. Using COSMO/SkyMed X-band and ENVISAT C-band SAR interferometry for landslides analysis. *Remote Sens. Environ.* 2012, *119*, 272–285.
21. Liu, P.; Li, Z.; Hoey, T.; Kincal, C.; Zhang, J.; Zeng, Q.; Muller, J. Using advanced InSAR time series techniques to monitor landslide movements in Badong of the Three Gorges region, China. *Int. J. Appl. Earth Obs. Geoinf.* 2013, *21*, 253–264.
22. Hooper, A.; Zebker, H.; Segall, P.; Kampes, B. A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. *Geophys. Res. Lett.* 2004, *31*, L23611.
23. Zhang, R.; Liu, G.; Yu, B.; Li, T.; Jia, H. Multi-Platform Persistent Scatterer SAR Interferometry Time Series Analyzing. In Proceedings of Second International Workshop on Earth Observation and Remote Sensing Applications, Shanghai, China, 8–11 June 2012.
24. Ye, R.; Niu, R.; Zhao, Y.; Jiang, Q.; Wu, T.; Deng, Q. Integration of LIDAR Data and Geological Maps for Landslide Hazard Assessment in the Three Gorges Reservoir Area, China. In Proceedings of IEEE International Conference on Geoinformatics, Beijing, China, 18–20 June 2010. *Remote Sens.* 2013, *5* 2719
25. Wu, S.; Shi, L.; Wang, R.; Tan, C.; Hu, D.; Mei, Y.; Xu, R. Zonation of the landslide hazards in the forereservoir region of the Three Gorges Project on the Yangtze River. *Eng. Geol.* 2001, *59*, 51–58.
26. Wu, S.; Wang, H.; Han, J.; Shi, J.; Shi, L.; Zhang, Y. The Application of Fractal Dimensions of Landslide Boundary Trace for Evaluation of Slope Instability. In *Landslide Disaster Mitigation in Three Gorges Reservoir, China*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 465–474.
27. Liu, J.G.; Mason, P.J.; Clerici, N.; Chen, S.; Davis, A.M. Landslide Hazard Assessment in the Three Gorges Area of the Yangtze River Using ASTER Imagery. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Toulouse, France, 21–25 July 2003.
28. Xia, Y.; Kaufmann, H.; Guo, X. Differential SAR Interferometry Using Corner Reflectors. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, Toronto, ON, Canada, 24–28 June 2002.
29. Ferretti, A.; Savio, G.; Barzaghi, R.; Borghi, A.; Musazzi, S.; Novali, F.; Prati, C.; Rocca, F. Submillimeter accuracy of InSAR time series: Experimental validation. *IEEE Trans. Geosci. Remote Sens.* 2007, *45*, 1142–1153.
30. Cascini, L.; Fornaro, G.; Peduto, D. Advanced low- and full-resolution DInSAR map generation for slow-moving landslide analysis at different scales. *Eng. Geol.* 2010, *112*, 29–42.