InSAR Operational and Processing Steps for DEM Generation

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Key words: InSAR, DEM, Processing steps, ENVISAT, DORIS

SUMMARY

Digital Elevation Models (DEMs) are used in many applications in the context of earth sciences such as in topographic mapping, environmental modelling, rainfall-runoff studies, landslide hazard zonation, seismic source modelling, etc. During the last years multitude of scientific applications of Synthetic Aperture Radar Interferometry (InSAR) techniques have evolved. It has been shown that InSAR is an established technique of generating high quality DEMs from spaceborne and airborne data, and that it has advantages over other methods for the generation of large area DEM.

However, the processing of InSAR data is still a challenging task. For each selected image pair, several processing steps have to be performed. One of the current challenges of the InSAR application is to bring the techniques to a level where DEM generation can be executed on an operational basis. This is important not only for commercial exploitation of satellite InSAR data, but also for many government and scientific applications.

This paper describes InSAR operational steps and processing chain for DEM generation from Single Look Complex (SLC) SAR data. The operational steps are performed in three major stages: Data Search, Data Processing, and product Validation. The Data processing stage is further divided into five steps of Data Pre-Processing, Co-registration, Interferogram generation, Phase unwrapping, and Geocoding. The Data processing steps have been tested with ENVISAT data using Delft Object-oriented Interferometric (DORIS) InSAR processing software. Results of the outcome of the application of the described processing steps to real data set are presented.

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1. INTRODUCTION

Synthetic Aperture Radar Interferometry (InSAR) is a technique where two SAR images acquired with a nearly identical incidence angle (one usually regarded as master and the other slave) are combined to produce a phase interference image called an interferogram (Dixon, 1994; Massonnet, 1997; Zebker and Goldstein, 1986). SAR images consist of both magnitude (brightness) and phase values. Often the phase information is thrown away; however, if it is retained, the SAR image is described as being complex (Henderson and Lewis, 1998). The phase in a complex SAR image is a coherent signal containing information about the distance between a resolution cell on the ground and the radar antenna, as well as information about the texture of terrain within a resolution cell. Using the phase information in the interferogram, it is possible to extract topographic height information (DEM), height change information, and fine scale temporal change measurements(Burgmann et al., 2000; Okeke, 2005).

Topographic maps have a long history, starting with qualitative expressions of hills, valleys, and mountains on general maps and continuing with quantitative topographic contour maps. The advent of stereo aerial photography in the first part of the twentieth century made possible photogrammetric measurements of elevations over substantial areas, and many regions have been mapped at various scales by these means. Stereo images or photographs taken by satellites are also used to construct topographic maps. A major problem for optical imagery in tropical areas like Nigeria is cloud cover that prevents imaging of the ground surface from space. To measure the topography and monitor deformation of earth surface, traditional geodetic measurements, geotechnical instrumentation, GPS-based systems, and many other geodetic techniques are also available. However, most of them are point-based measurement techniques and are too costly if a very large area needs to be monitored. InSAR (Interferometric Synthetic Aperture Radar) technique has emerged as the state-of-the art technique of measuring dense points in an area accurately, economically, conveniently and efficiently, and without any effect from cloud cover (Gabriel et al., 1989) (Biegert et al., 1997; Massonnet et al., 1993). Studies have demonstrated the potential of the interferometric technique to produce high-resolution topographic maps with relative height errors of 5m or less, as found by Zebka (1994) tests with 3-day repeat-pass ERS-1 imagery.

However the processing of interferometric SAR data for monitoring Earth surface is still a challenging task. Classical InSAR processing is known to be computationally laborious (Marinkovic et al., 2004). The amount of data to be handled is enormous, the input data often expensive, the data quality a priori unknown, and the algorithms require fast computers. For each selected image pair several pre-processing steps (co-registration, interferogram generation, flat earth removal, etc) have to be performed. A typical scene of ERS data for instance occupies about 650 Mbytes of computer storage. Also the quality requirements for these pre-processing steps are generally high. For instance co-registration accuracy for InSAR applications must be of the order of a tenth of a pixel (Marinkovic et al., 2004). Also flat-earth removal has to rely on accurate orbital modeling to avoid long wavelength errors.

These call for a well articulated processing steps and organizational workflow similar to those in Photogrammetry and optical remote sensing, and to the level where, for instance, InSAR topographic maps are generated on an operational basis. This is important not only for commercial exploitation of satellite InSAR data, but also for many government, scientific, and industrial applications. Presently, there is dire need for up-to-date topographic data for most developing countries. Production of accurate and timely DEM by InSAR method will surely promote better land administration and therefore good governance.

This paper describes an InSAR operational steps and processing chain for DEM generation from SAR data which is suitable for adaptation in an organization for both industrial and scientific applications. Each processing step can be automated in an organizational workflow to make for efficiency. In particular, this paper aims to provide InSAR processing steps that will:

- Implement an approach for organizing the sequence of image processing steps
- Minimize disk access, RAM access, and image cache size, as well as minimize inter-process communication and message passing between different steps.
- Support and take full advantage of low-cost computing hardware (e.g., PC Pentium)
- Provide a complete environment for batch processing.
- Take advantage of the best of the open source software.

The overall operational workflow described in this paper consists of three major stages, namely Data Search, Data Processing, and Product validation. The Data Processing Stage is further sub-divided into five steps, which are data pre-processing, co-registration and resampling, computation of Interferogram, Phase un-wrapping, and Geocoding. The data processing steps have been tested with the Bam, Iran data set using DORIS InSAR processing software. The resulting interferogram and contour map generated from this data are presented.

2. PROPOSED INSAR PROCESSING STAGES

The proposed overall InSAR processing stages are Data Search, Data Processing, and Data Validation (figure 1). Description of each component of the processing stage follows.

Figure 1: Overall InSAR Processing Stages

2.1 Data Search

The data search stage consists of searching for appropriate data that will ensure adequate data quality and capable of yielding optimal result for the InSAR processing. The search is usually made to agencies responsible for SAR data provision. Currently there are two agencies operating SAR satellites in the civilian sector, the Canadian Space Agency (CSA) and the European Space Agency (ESA). CSA has had one SAR satellite, RADARSAT-1 in orbit since 1996. ESA launched its third SAR satellite, ENVISAT, in 2002. Its predecessors, ERS-1 and ERS-2 collected SAR images from 1992 to 2000 and from 1995 to present, respectively. Both CSA and ESA satellites have collected a large database of archival SAR images. In addition, the National Space Development Agency of Japan (NASDA) operated a SAR satellite from 1993-1998. The SAR images collected by this satellite are also available. There are satellite radar missions planned for the future. These include Canadian RADARSAT 2 (C-Band), Japan ALOS (L-Band), German TerraSAR (X-Band). Table 1 gives summary of past and current satellite radar missions

Table 1: Satellite radar missions

Mission	**SEASAT**	**JERS-1**	**ERS-1**	**ERS-2**	**ENVISAT**	**RADARSAT 1**
Owner	JPL	Japan	ESA	ESA	ESA	CSA
Launch Date	June 07, 1978	Feb. 11, 1992	July 16, 1991	April 20, 1995	2002	1995
Ended Date	Oct '10, 1978	Oct' 12, 1998	2000			
Band	L(23.5 cm, 1.275 GHZ)	L(23.5 cm, 1.275 GHZ)	C(5.7 cm, 5.25 GHZ)	C(5.7 cm, 5.25 GHZ)	C(5.7 cm, 5.25 GHZ)	C(5.7 cm, 5.35 GHZ)
Polarization	HH	HH	VV	VV	All	HH
Look angle	20 (23)	35^{o} (38^{o})	20-26	20-26	16-45	20-50
Swath	100km	75 km	100km	100km	50km-400km	45-500km
Range resolution	25	18 m	20m	20m	20m	10-100m
Azimuth resolution	25	18 m	30m	30m	30m	10-100m
Left/Right looking		Right	Right	Right	Right	Right
Looks	4	3	4	4	4	
Orbit	Altitude: 800 km in near polar orbit	Altitude: 568km, inclination: 98 degrees	Altitude: 785km, inclination 98.5 degrees	Altitude: 785km, inclination 98.5 degrees	Altitude: 785km, inclination 98.5 degrees	Altitude: 798 km, Inclination 98.6 degrees.

The most important risks to the InSAR data quality are temporal decorrelation and atmospheric effects (Henderson and Lewis, 1998). Temporal decorrelation is indicated as low coherence image. It has been established that there is a clear correspondence in tropical regions between high values of the Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) and low coherence (Solaas and Gatelli, 1996). In order to avoid the problem of temporal decorrelation, care must be taken in the selection of the SAR data. The selection of the images can be made on the basis of baseline length and the time period between two image acquisitions. Depending upon the application and the spatial resolution of the data, the baseline length can be chosen. For example, in the case of ERS–1 and 2, the baseline may be taken as 150 to 300m for topographic applications, 30 to 50m for surface change detection and up to 5m for surface feature movement studies such as crustal deformations, lithospheric movements, movement of glaciers etc (Burgmann et al., 2000). Also, the time gap between two passes of satellite may not be kept large as there may be some changes in the scene that may lead to temporal decorrelation. A number of procedures can be applied to minimize data quality risks. These include:

- Assessment of topography, climate and weather conditions during the SAR acquisitions.
- Assessment of the impact of seasonal vegetation cover on temporal decorrelation. This can be based on predicted phase coherence levels of SAR data for the world based on AVHRR NDVI mosaics.

In addition, the ERS Interferometric Quick Look processor developed by ESA has made it possible to examine the interferometric coherence of ERS data for land use application on a world wide bases (Walker et al., 2005). The Interferometric Quick Look system has been designed to rapidly process complete strips of ERS SAR data and many examples covering a wide range of land surfaces have been processed at ESRIN and can be viewed at their web site http://earth1.esrin.esa.it/INSI. The coherence of the data can readily be assessed and hence the suitability of interferometric techniques for the particular region of the world covered by the image.

2.2 Data Processing

The data processing stage consists of five distinct steps (figure 2): Data pre-processing, Co-registration and Resampling, Computation of Interferogram, Phase un-wrapping, and Geocoding. In this work, the data processing stage is performed using Delft Object-oriented Interferometric Software (Doris), (Kampes, 2005a; Kampes et al., 2003; Kampes and Usai, 1999). Doris is chosen because it is fully functional interferometric processing software in the public domain. Doris follows the classic UNIX philosophy that each tool should perform a single, well-defined function, and complex functions should be built by connecting a series of simple tools into a pipeline. Doris consists of series of programs (modules) that perform different interferometric tasks. More details on Doris are provided in (Kampes et al., 2003; Kampes and Usai, 1999).

Doris has been successfully installed in the department of Geoinformatics and Surveying of the University of Nigeria, Enugu Campus, and running in a Mandrake Linux 10.1 operating system environment, in a PC (Pentium 4). Doris uses other public domain software to perform dedicated tasks that can be handled well by these programs. These software have also been installed independently in the same computer in the department. These includes *getorb* which is for getting precise orbital data records for the ERS satellites (getorb, 2005; Scharroo and Visser, 1998), SNAPHU for phase unwrapping (SNAPHU, 2005), GMT for general plotting and gridding (GMT, 2005), and PROJ.4 for coordinate transformations (USGS, 2005).

2.2.1 Step 1. Data input, data cropping, and oversampling

This first step in the Data Processing stage consists of input of both master and slave data sets for the InSAR processing. Only Single Look Complex (SLC) data are processed. This excludes the pre-processing of the raw data, both radar and orbit. In this stage orbit data downloaded from the g*etorb* Web site for the computation of precise orbit are also read. From the input files Doris then the SLC leader, volume and header data file as well as relevant parameters. Oversampling of data and amplitude calibration is also performed at this step.

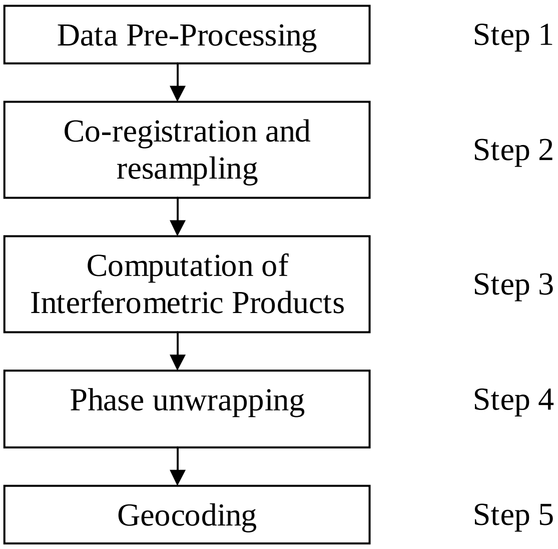

Figure 2: Flowchart of the processing steps of the Data Processing Stage

2.2.2. Step 2: Co-registration and resampling

In this step the co-registration polynomial that describes the transformation of the slave to master image, which is subsequently used for the resampling of slave image to the master grid is determined. This is performed in 4 steps in Doris. First the orbital data of master and slave are used to compute a single coarse offset on pixel level between master and slave image. The estimate for this offset is then improved using a cross correlation performed on the intensity data of master and slave on a small number of relatively large patches. The initial offset is taken from the previous computed coarse offset based on the orbits. In the third step, the fine co-registration, the offset vectors between master and slave are computed at a large number of small patches (64 by 64 pixels) also using a cross correlation of the intensity data. Finally using the estimated polynomial, the slave image is resampled to the master grid.

2.2.3 Step 3: Computation of interferometric products

In this step the complex interferogram and the coherence image are generated. In Doris, interferogram is by default computed using a multilook factor of 5 in azimuth and 1 in range.

The interferometric phase is corrected for the phase of a reference body. The WGS84 ellipsoid or an external can be used to compute the reference phase.

Doris can also compute the coherence image that can be used as input for the cost function computations in the unwrapping program. Phase filtering can be applied using different methods. Doris uses different variety of methods for the computation of coherence image, which include simple pre-defined spatial averaging kernel, 2D convolution kernels, or the Goldstein filter (Baran et al., 2003; Goldstein and Werner, 1998).

2.2.4 Step 4: Phase Unwrapping

This is the reconstruction of the original phase from the wrapped phase representation. Doris calls the SNAPHU phase unwrapping software (SNAPHU, 2005) for the phase unwrapping computations. SNAPHU phase unwrapping software is described in (Curtis and Zebker, 2000). It is a modern, sophisticated phase unwrapping program that uses information on the expected smoothness of the unwrapped phase, and can use the interferometric amplitude and/or coherence image to compute the cost functions.

2.2.5 Step 5: Geocoding

In this step the unwrapped phase is converted to a height, and the pixel co-ordinates are geo-referenced. The output of this step is the height for a large number of pixels at an irregular grid of (longitude, latitude) pair. These output matrices however are gridded using the GMT tools, while the PROJ.4 software is used for transformation to the desired coordinate system.

2.3 Product Validation

This stage includes all aspect of quality assessment of the InSAR products through comparison with reference models obtained from independent sources.

3. PROCESSING ENVISAT DATA SET

In order to test the processing steps described in section 2, we computed the topography of Bam area in Iran. The ENVISAT ASAR data of Bam area in Iran was kindly provided by ESA in order to promote the ENVISAT ASAR data for use in seismology and to highlight the value of the ASAR data archive collected over seismic areas. The Bam ENVISAT ASAR data were supplied in a DVD of about 3.5Gbytes. The two ASAR SLC (master orbit 9192, 03 DEC 2003; slave orbit 9693, 07 JAN 2004) images, which span the earthquake event, were read directly into Doris via the DVD ROM. Details of the processed scenes as determined by the Doris software are listed in tables 2 and 3. The temporal baseline is only 35 days, resulting in minimal temporal decorrelation for this area.

Table 2: Image parameters for the processed master and slave ASAR SLC.

Image Parameters	**Master**	**Slave**
Frame number	22	23
Orbit number	9192	9693
Acquisition date	03-Dec-2003	07-Jan-2004
Acquisition Time [UTC]	06:13	06:13
Number of lines	26897	26580
Number of range pixels	5167	5167
Radar wavelength (m)	0.0562356	0.0562356
Sensor Platform Mission Identifier	ENVISAT-ASAR-SLC	ENVISAT-ASAR-SLC
Product Type	ASAR	ASAR

Table 3: Product parameters for the Interferogram.

Product Parameters	Value
Scene size [km]	100 x100
Scene center longitude [deg]	58.5219
Scene center latitude [deg]	29.1385
Perpendicular baseline [m]	520.6
Parallel baseline [m]	269.1
Height ambiguity [m]	15.1
Temporal baseline [day]	35
Base line orientation [deg]	-7.1
Look angle [deg]	20.1
Incidence angle [deg]	22.8

Figure 3 shows the computed offset vectors, which are used in forming the polynomials for projecting the slave image on top of the master image. Only vectors, which have correlation larger than 0.4 are plotted using the software GMT that is automatically called by Doris.

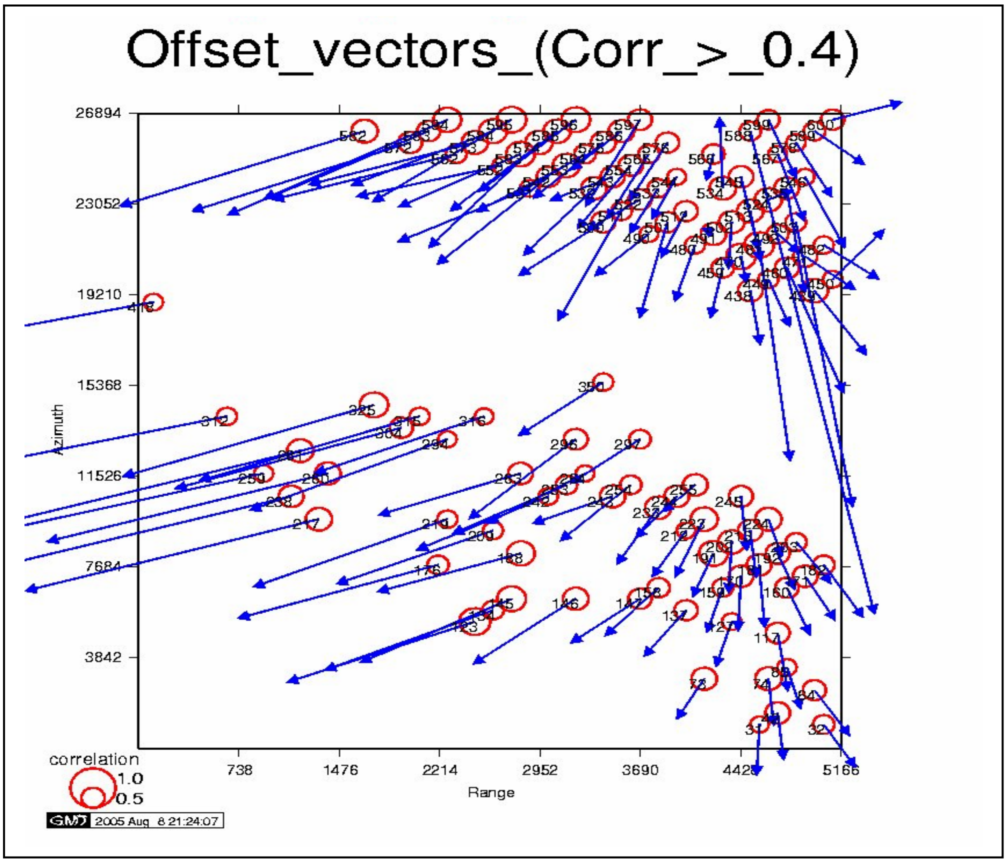

Figure 3: The estimated offsets

The interferogram was computed using a multilook factor of 5 in azimuth and 1 in range.
The interferometric phase was corrected for the phase of a reference body here taken as the WGS84 ellipsoid. The resulting topography interferogram created from two ASAR SLC images (master orbit 9192 and slave orbit 9693) is shown in figure 4. Contour lines at 100-meter interval of the project site are shown in figure 5.

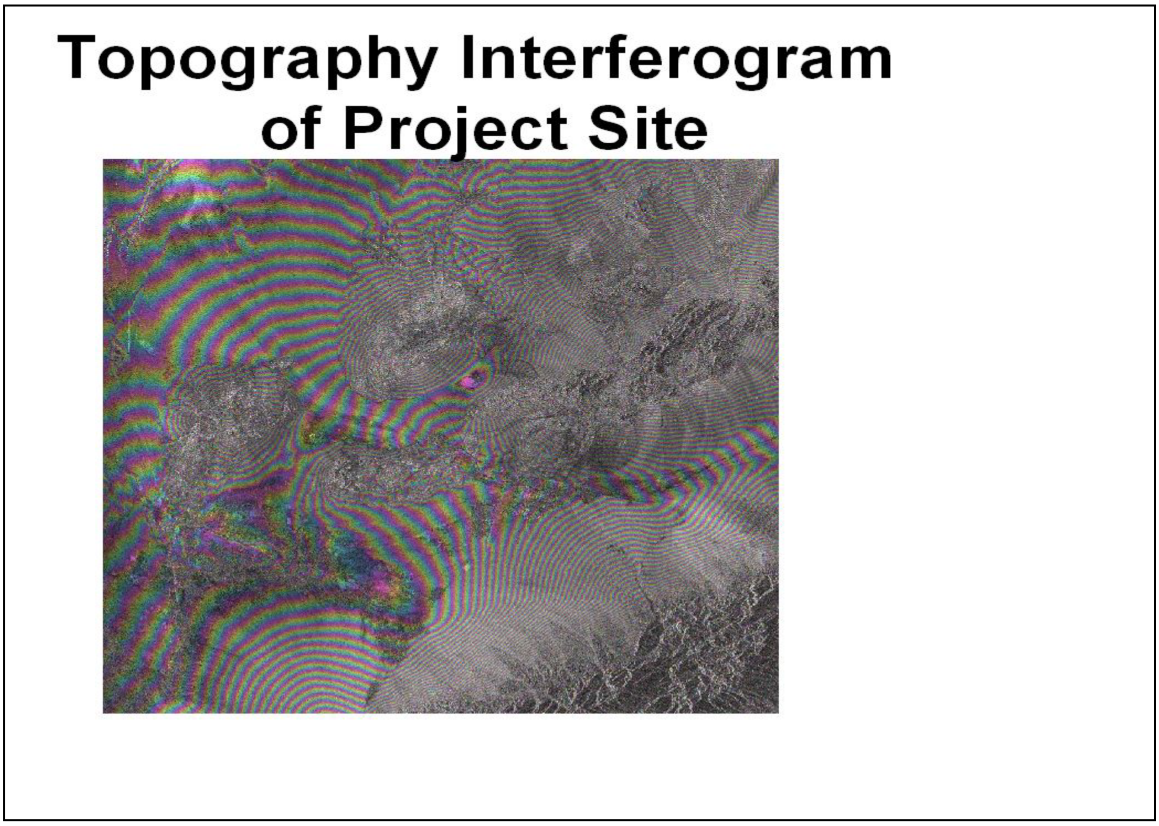

Figure 4: Topography interferogram of the project site

4. CONCLUSIONS

This paper has presented steps for processing InSAR data for DEM generation using SLC data. It has implemented a sequential approach for organizing SAR image processing steps in a way to minimize disk space, RAM access, and image cache size, as well as minimize inter-process communication and message passing between different steps. It has been implemented in a PC (Pentium 3), thereby taking full advantage of low-cost computing hardware. Also it provides a complete environment for batch processing, and utilizes one of the best of the open source InSAR software (Doris).

Practical application of the InSAR processing steps described in this paper has been tested with the processing of the Bam Iran ENVISAT ASAR data set to yield DEM of the area. The InSAR processing steps described in this work can be adapted to form a data processing workflow for an organization for both commercial exploitation of SAR data and for scientific investigation, using any software capable of InSAR processing.

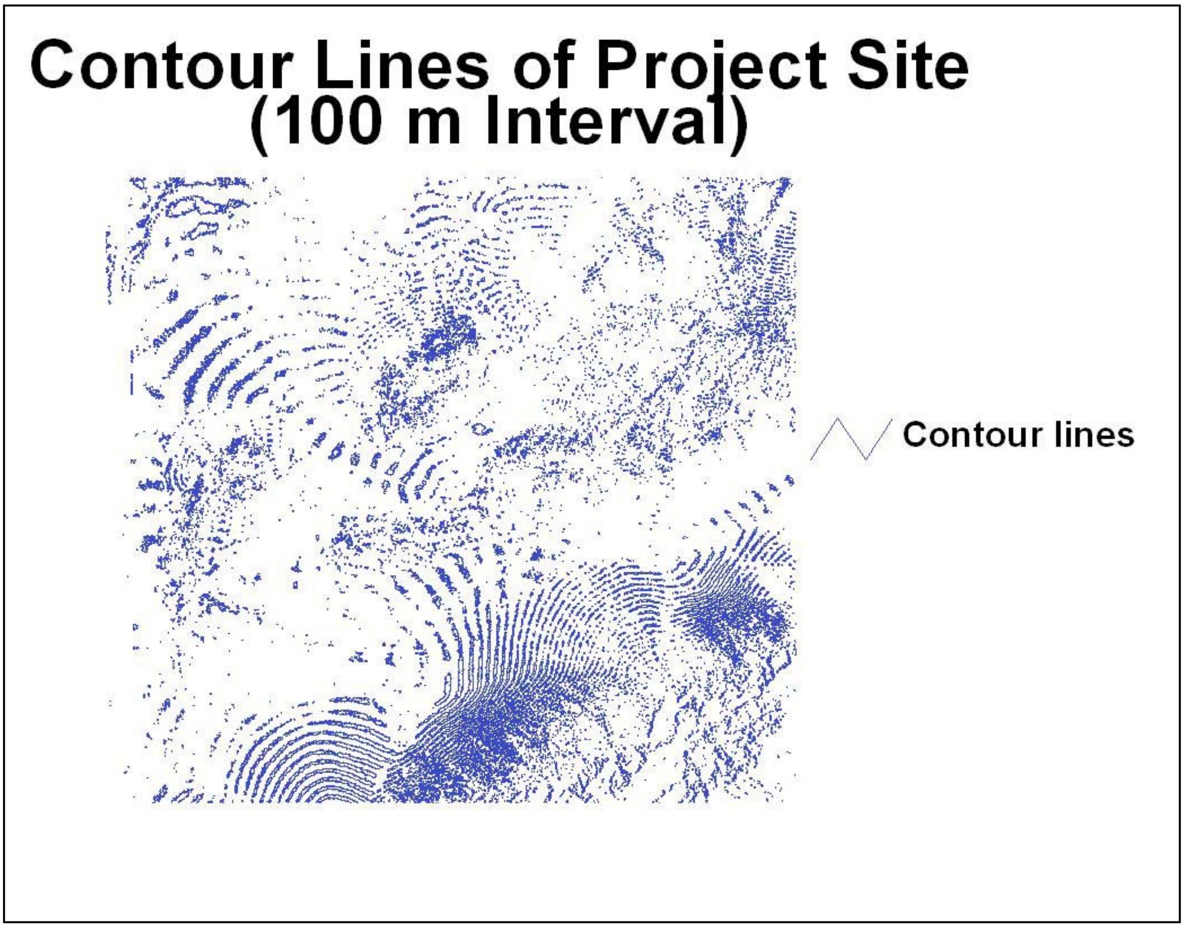

Figure 5: Contour lines of project site at 100m interval

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REFERENCES

Baran, M.P., Stewart, B., Kampes, B.M., Perski, Z. and Lilly, P., 2003. A modification to the Goldstein radar interferogram Filter. IEEE Transactions on Geoscience and Remote Sensing, 41(9): 2114-2118.

Biegert, E.K., Berry, J.L. and Oakley, S.D., 1997. Oil field subsidence monitoring using spaceborne Interferometric SAR: a Belridge 4-D case history, Atlantis Scientific Inc, http://www.atlsci.com/library/papers/Oil_field_Subsidence_Monitoring_using_Space b

Burgmann, R., Rosen, P.A. and Fielding, E.J., 2000. Synthetic Aperture Radar Interferometry To Measure Earth's Surface Topography And Its Deformation. Annual Review Earth Planetic Sciences, 28: 169-209.

Curtis, W.C. and Zebker, H.A., 2000. Network approaches to two-dimensional phase unwrapping: intractability and two new algorithms. Journal of the Optical Society of America, A 17(3): 401-414.

Dixon, T.H., 1994. SAR Interferometry and Surface Change Detection, Report of a Workshop, Boulder, Colorado, USA.

Gabriel, A.K., Goldstein, R.M. and Zebaker, H.A., 1989. Mapping small elevation changes over large areas: differential radar interferometry. Journal of Geophysical Research, 94(B7): 83-91.

getorb, 2005. Get Orbit (getorb), http://enterprise.lr.tudelft.nl/doris/tools/getorb/

GMT, 2005. Generic Mapping Tools (GMT), University of Hawaii, http://gmt.soest.hawaii.edu/

Goldstein, R.M. and Werner, C.L., 1998. Radar Interferogram Filtering for Geophysical Applications. Geophysical Research Letters, 25(21): 4035-4038.

Henderson, F.M. and Lewis, A.J. (Editors), 1998. Principles and Application of Imaging Radar. Manual of Remote Sesnsing, 2. John Wiley and Sons, New York, 886 pp.

Kampes, B.M., 2005a. Delft Object-oriented Interferometric Software (DORIS), Bert Kampes, TU, Delft, http:enterprise.lr.tudelft.nl/doris

Kampes, B.M., Hanssen, R.F. and Perski, Z., 2003. Radar Interferometry With Public Domain Tools, FRINGE 2003 Workshop. ESA/ESRIN, Frascati, Italy.

Kampes, B.M. and Usai, S., 1999. Doris: the Delft Object-oriented Radar Interferometric Software, 2nd International Symposium on Operationalization of Remote Sensing, Enschede, The Netherlands.

Marinkovic, P.S., Hanssen, R.F. and Kampes, B.M., 2004. Utilization Of Parallelization Algorithms In Insar/Ps-Insar Processing, 2004 Envisat & ERS Symposium. ESA SP-572, Salzburg, Austria.

Massonnet, D., 1997. Satellite radar interferometry. Scientific American, 276(2): 46-53.

Massonnet, D. et al., 1993. The displacement field of the Landers Earthquake mapped by radar interferometry. Nature, 364: 138-142.

Okeke, F.I., 2005. Integrating InSAR, GRACE Mission Data and Traditional measurements for Topographic Mapping and Earth Surface Deformation Monitoring for Nigeria, 1st International Conference on Geodesy and Geodynamics, Toro, Nigeria.

Scharroo, R. and Visser, P., 1998. Precise Orbit Determination and Gravity Field improvement for the ERS Satellites. Journal of Geophysical Research, 103(C4): 8113-8127.

SNAPHU, 2005. Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping (SNAPHU), Stanford University, http://www-star.stanford.edu/sar

Solaas, G.A. and Gatelli, F., 1996. Initial Testing of ERS Tandem Data Quality for InSAR Applications (Examples from Taiwan, Madagascar, Zaire, Ivory Coast, Mali and Greenland), ESA Report No. RS/ED96.D002/1.0.

USGS, 2005. PROJ.4, USGS, http://www.remotesensing.org/proj/

Walker, N.P., Mica, S. and Laur, H., 2005. The ERS Interferometric Quick Look Processor: a Powerful System to Assess and Exploit the ERS Tandem Archive for Land-Use Information Retrieval, http://earth1.esrin.esa.it/INSI

Zebker, H., Werner, C., Rosen, P. and Hensley, S., 1994. Accuracy of topographic maps derived from ERS-1 Interferometric radar. IEEE Transactions on Geoscience and Remote Sensing., 32: 823-836.

Zebker, H.A. and Goldstein, R.M., 1986. Topographic Mapping from Interferometric SAR Observations. Journal of Geophysical Research, 91(B5): 4993-4999.

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