INSAR DEM CALIBRATION FOR TOPOGRAPHIC MAPPING IN EASTERN UGANDA

Siefko SLOB[*]**, François KERVYN**[**]**, Johan LAVREAU**[**]**, John ODIDA**[***]** and David KYAGULANYI**[***]

[*]International Institute for Aerospace Survey and Earth Sciences, Delft, Netherlands
slob@itc.nl
[**]Royal Museum for Central Africa, Tervuren, Belgium
fkervyn@africamuseum.be; jlavreau@africamuseum.be
[***]Geological Survey and Mines Department, Entebbe, Uganda
gsurvey@starcom.co.ug

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ABSTRACT

The main objective of this study is to demonstrate how Space-borne Radar Interferometry (InSAR) techniques using ERS-1 and ERS-2 satellite data can be used as a routine tool for creating topographic information. In this project InSAR techniques are used to construct a Digital Elevation Model (DEM) for an area in the eastern part of Uganda, in the Southern Karamoja region. Landsat TM satellite imagery is used as visual backdrop for the topographic information that will be derived from the InSAR data. A Differential Global Position System (DGPS) is used in the field as a tool to obtain reference data in order to calibrate the satellite data. GIS is used to integrate the information and present the information in the form of maps.

1 INTRODUCTION

1.1 Scope

After many years of civil war and political unrest, Uganda is now one of the countries in Central and East Africa that experiences a rapid reconstruction of the economic and technical infrastructure. For proper planning of these reconstruction initiatives in certain areas, it is necessary to have detailed and reliable information on these areas. A serious problem is that much of the information about the country, especially in the shape of maps, has been outdated or is simply lost. Application of new technologies, such as described in this paper, may hold the answer to the rapid updating and replacement of regional topographic information in developing countries [1].

1.2 Objectives

This project was carried out in the framework of the ESA/ESRIN Data User Programme (DUP)

The main objective of this DUP project was to demonstrate the use of the ERS system as a routine tool for topographic document production and upgrading of existing basic local topographic documents in Africa, under local operational conditions.

This demonstration has been executed in an area in the northeastern part of Uganda, in the South-Karamoja region. The objective was to create a comprehensive series of topographic and thematic map sheets at different scales which cover the area between 34 and 35 degrees Eastern longitude and 1.5 to 2.5 degrees Northern latitude.

The final objective was to continue the capacity building initiative of the Ugandan Geological Survey and Mines Department (UGSMD) in the field of remote sensing and digital cartography techniques. This new technique of radar interferometry will be introduced and through this project the potentials and limitations of this technique will be demonstrated.

2 SAR DATA GATHERING AND DATA PROCESSING

2.1 ERS-1 and ERS-2 tandem mission data

ERS data is presently the easiest data to work with for interferometry. The ERS-1 and ERS-2 orbits are well maintained, so that there are many InSAR pairs available from this data. A baseline larger that 400 metres is usually not suitable for interferometry, while a baseline smaller than metres may not be suitable for DEM mapping [2]. A total of 3 ERS interferometric couples have been acquired and processed, more or less covering the entire extent of the project area.

2.2 InSAR processing and DEM generation

2.2.1 Processing steps

In the InSAR processing for the generation of a DEM three important steps can be distinguished.

A. Coregistration: The main purpose of the coregister-processing step is to resample the 'slave' SAR image to be coregistered with the 'master' SAR image (for example of intensity image see Figure 7).

B. Interferogram generation: The main functions of this processing step are to:
Generate the interferogram
Calculate a phase coherence map (see Figure 6)
Enhance the interferogram phase in preparation for the phase unwrapping
Generate an unwrapping control mask
Apply a data reduction

C. Phase to Height Conversion: The main functions of this processing step are to:
Unwrap the interferogram phase
To generation a DEM (height image) from the phase (see Figure 9)

2.2.2 Coherence problems

One of the main problems that occurred during the InSAR processing was that for large areas no interferometric fringes and thus no height information could be calculated due to lack of coherence. Particularly in mountainous terrain, where layover, foreshortening and shadowing phenomena take place, no height information could be obtained. Low coherence in these areas may not have been only due to the steepness of the terrain, but probably also due to the fact that these mountain areas are densely vegetated. Vegetation also adversely affects the interferometric coherence.

2.2.3 Residual phase - tilt problems

The DEM is calculated in (relative) meters using the baseline parameters. Because of slight errors in the baseline parameters, a substantial residual phase could be observed on the intereferograms on all processed couples. Only in those images where a good elevation reference exists (e.g. shore of a lake along which the elevation remains constant) a visual correction of the baseline parameters could be carried out. This is an interactive process where the baseline parameters are corrected until the interferogram has parallel fringes along the shoreline. Ortho-correction (correction of the lay-over and fore-shortening) of the SAR imagery is automatically achieved, except of course in those areas where no topographic information is generated due to unwrapping errors because of low interferometric coherence. Where there was no reference information present, additional reference data had to be acquired to correct for this residual tilt in the DEM. This is discussed in 3.3.

3 SAR DATA CALIBRATION

3.1 Reference data gathering (DGPS survey)

Differential GPS is a technique used to improve positioning or navigation accuracy by determining the positioning error at a known location and subsequently incorporating a corrective factor (by real-time transmission of corrections or by post-processing) into the position calculations of another receiver operating in the same area and simultaneously tracking the same satellites [3].

The system that was used in the field is a wide-area differential GPS service, with many widely spaced Base Stations used in a multi-site solution [4]. This system consists of a single receiver, which receives both GPS signal (up to 8

satellites) and the differential signal without the requirement to maintain a reference base station in the field. For the fieldwork that had to be carried out, this type of equipment was preferred, because a large general survey had to be carried out, covering the entire project area and beyond. Because no base station had to be maintained, the whole system becomes much simpler, the mobility is higher and less manpower is required (only 1 field team instead of 2).

With the system sub-meter positioning is achievable over most of Europe and surrounding countries. However, because in Africa the base stations are more widely spaced, the DGPS signal is less precise. Still an accuracy can be achieved of 2-4 meters. The vertical precision is roughly half the horizontal precision, i.e. 4-8 meters

3.2 Horizontal calibration (georeferencing)

What is apparent on the SAR intensity images are the typical high-intensity reflections. These are in most cases caused by large buildings or buildings with (corrugated iron) roofs that are located such that due to their orientation act as a 'mirror' to the radar beam (see Figure 1). Such a particularly strong response can look like a bright cross in a SAR intensity image. One of the tasks in the data validation was therefore to attempt to locate these objects in the field and measure the exact location with the DGPS equipment. With the exact position of these buildings that caused the strong reflection, the InSAR data can be georeferenced very accurately.

In principle only 4 GCP's per tandem scene need to be located in order to achieve a satisfactory georeferencing. Nevertheless, as much GCP's as possible was necessary to measure in the field, because many of them still had to be eliminated in the georeferencing process based on poor effect to the overall RMS error and lack of confidence in the reliability of the particular GCP. Below is a summary of the accuracy of the georeferencing process (see Table 1).

Table 1. Horizontal calibration report.

ERS tandem frame	RMS error (in pixels and metres)			# GCP's
	X	Y	Distance	
0027	0.32 (6.4 m)	0.23 (4.6 m)	0.39 (7.8 m)	13
3573	0.71 (14.2 m)	0.07 (1.4 m)	0.72 (14.4 m)	5
3555	0.47 (9.4 m)	0.82 (16.4 m)	0.95 (19.0 m)	5
overall	0.50 (10.0 m)	0.37 (7.4 m)	0.62 (12.4 m)	23

Figure 1. Small building that yielded a strong reflection on the SAR image because of the specific orientation of the corrugated iron roof (mirror-effect).

3.3 Vertical calibration (tilt correction)

Two of the main difficulties in processing satellite InSAR data are obtaining accurate satellite/earth geometry models for the two SAR images and phase unwrapping the interferogram. The geometry models are used to calculate the orientation and magnitude of the line of separation or baseline between the satellite positions. The baseline is a required parameter to convert the unwrapped phase to topographic height.

Even small errors in the baseline estimation can result in serious errors in the DEM. Typically, uncorrected DEM's exhibit 'tilt': elevations along shorelines are not constant and rivers seem to be flowing in the wrong direction. One way to eliminate the errors in the baseline estimation before the creation of the InSAR DEM is to correct the baseline parameters until no fringes will be observed in flat terrain or that fringes run parallel to shorelines. The best control is to have reference data in the form of an existing DEM for example to calibrate the InSAR DEM.

In the initial InSAR data processing phase some of the tilt in the InSAR DEM data had already been eliminated using (visual) residual phase removal in the interferogram. As mentioned before, this is quite a subjective procedure without accurate estimation of the precision of the result. In the InSAR processing software some elevation control points had been added manually in order to subsequently correct the InSAR DEM for the absolute elevation. However, proper reference information in the form of accurate topographic maps or existing DEM's for this area does not exist. It was therefore decided to use the elevation measurements from the DGPS track data to calibrate and compare the InSAR DEM's.

No information exists however on the accuracy of the DGPS elevation measurements itself. The company that operates the worldwide DGPS network could not suggest an estimate of this value. It was advised to apply the rule-of-thumb, that the accuracy of the vertical measurement is roughly half the horizontal accuracy. The horizontal (absolute) accuracy of their system in Africa is around 2-4 metres for the specific DGPS receiver used; therefore the vertical accuracy should be around 4-8 metres. According to our own observations, the relative accuracy is believed to be much higher than that value. The horizontal and vertical DGPS measurements were very stable, especially while tracking. Only when static measurements where taken, some 'swerving' of the measurements was observed.

Therefore, in order to calibrate the residual tilt in our InSAR DEM's, two assumptions were made:

1. The DGPS elevation measurements is a stable reference source, i.e. there is no systematic error in the elevation measurements.
2. The relative elevation of the InSAR DEM is correct, while the only error in the InSAR DEM is a linear tilt. The InSAR DEM should therefore be corrected with a plane tilt surface.

The entire procedure has been carried out in ArcInfo making use of the modules GRID. Most of the procedures could also have been carried out using the PCI image processing software, except for the procedure to determine a trend surface through a series of points. This is the procedure TREND in GRID. According to our second assumption, with this function a linear and 1st order polynomial regression is performed to fit a least-squares surface to the set of input points. The RMS error of the interpolation is also returned. The more closely the interpolated surface represents the input points, the lower the RMS error reported.

Height trend correction is also possible in the InSAR processing software (EarthView) but only a limited number of height control points can be added and the points have to be added manually, not feasible with thousands of reference points. By utilising all the DGPS measurements in the procedure using the ArcInfo software a much more reliable statistical correction can be performed.

The following procedure was followed to make the tilt correction:

1. First, after the horizontal correction each individual InSAR DEM (for the project area three InSAR DEM's from different ERS couples were calculated) was subtracted from the DGPS measurements.
2. Through the difference values a linear trend surface is calculated. The reported RMS errors give an indication of the accuracy of the InSAR DEM's with respect to the DGPS measurements (see Table 2).
3. This trend surface is subsequently added to the InSAR DEM and the calibration is completed (the histograms of the remaining error are displayed in Figure 2 to Figure 5).

The only procedure left was that three individually calibrated DEM's now had to be merged in order to create a DEM for the entire project area. However, After merging it was observed that some serious differences existed between the different InSAR DEM's at the edges where the DEM's were joined. It was therefore decided to calibrate two of the DEM's to the InSAR DEM to the best calibrated DEM (frame 3573), merge them again and afterward compare the merged result with the DGPS data (see Table 2 and Figure 5). In this way the overall accuracy outcome may be worse than the individual calibration results, but the inconsistencies at the edges is then mainly eliminated.

Table 2. DEM vertical calibration report.

ERS tandem frame	RMS error Z (m)	Difference(m)			# Height control pnts.
		min	max	mean	
0027	10.567	-35	113	0	17049
3573	6.889	-27	24	0	9568
3555	8.481	-31	54	0	7721
overall	13.380	-44	113	0	25032

Histogram of difference in elevation between calibrated InSAR DEM and DGPS measurements - ERS tandem frame 0027

Figure 2

Histogram of difference in elevation between calibrated InSAR DEM and DGPS measurements - ERS tandem frame 3573

Figure 3

Histogram of difference in elevation between calibrated InSAR DEM and DGPS measurements - ERS tandem frame 3555
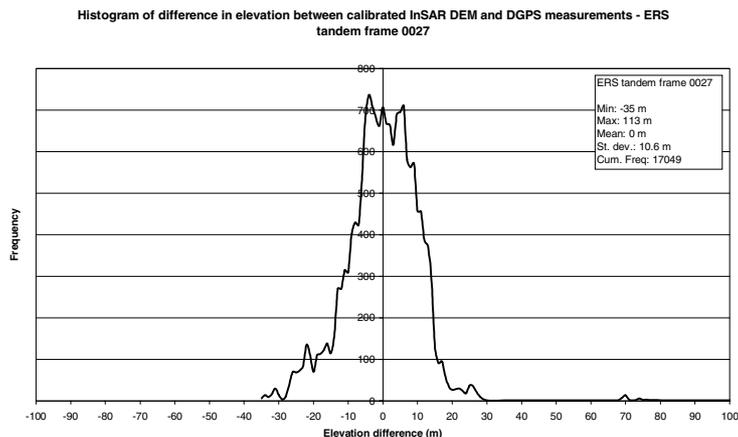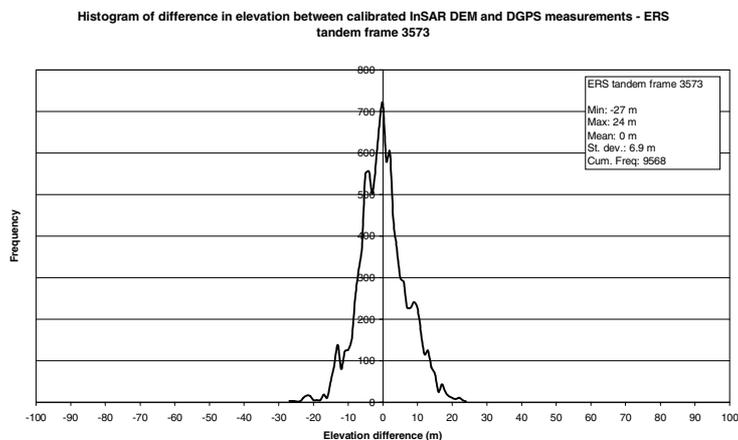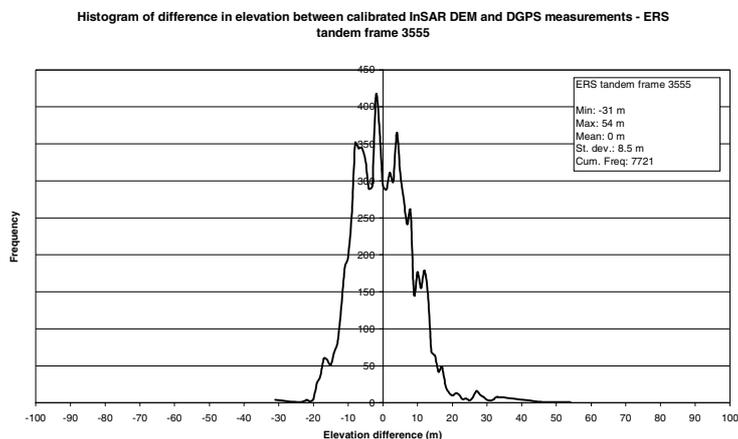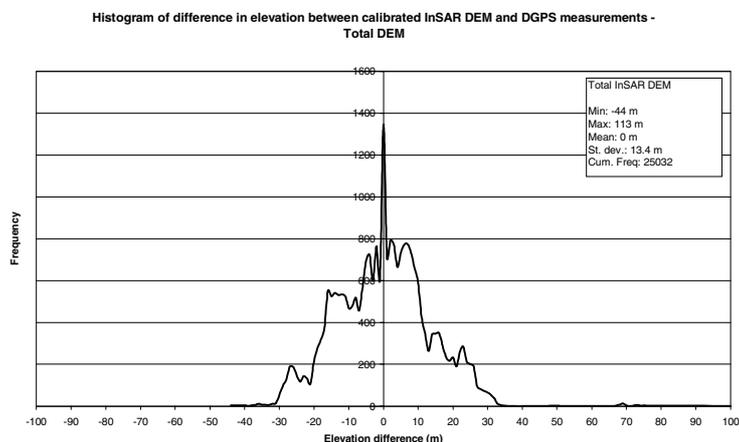
Figure 4

Figure 5

4 CONCLUSIONS

InSAR DEM's offer good complementary topographic information to the existing 1:50,000 topographic map sheet coverage in Uganda. In mountainous terrain the InSAR method performs poorly, while in relative flat and non-vegetated terrain the method yield very detailed topographic information. The topography depicted on the existing topographic map sheets is obtained using traditional photogrammetric methods. This gives good results in mountainous terrain, but poor results in the flat areas. Integration of both data types will render greater accuracy than the individual data types.

Differential GPS provides fast and accurate reference data for the horizontal and vertical calibration of ERS SAR data and InSAR DEM's. Although no reliable data exist on the absolute accuracy of the utilised DGPS equipment, particularly the accuracy of the elevation measurements, it is concluded that the measurements provide a stable reference source for the elimination of residual tilt in the InSAR DEM. The best horizontal calibration of one InSAR data pair had a RMS error in the order of 8 metres. The best vertical calibration of one InSAR DEM had a RMS error in the order of 7 metres.

ACKNOWLEDGEMENTS

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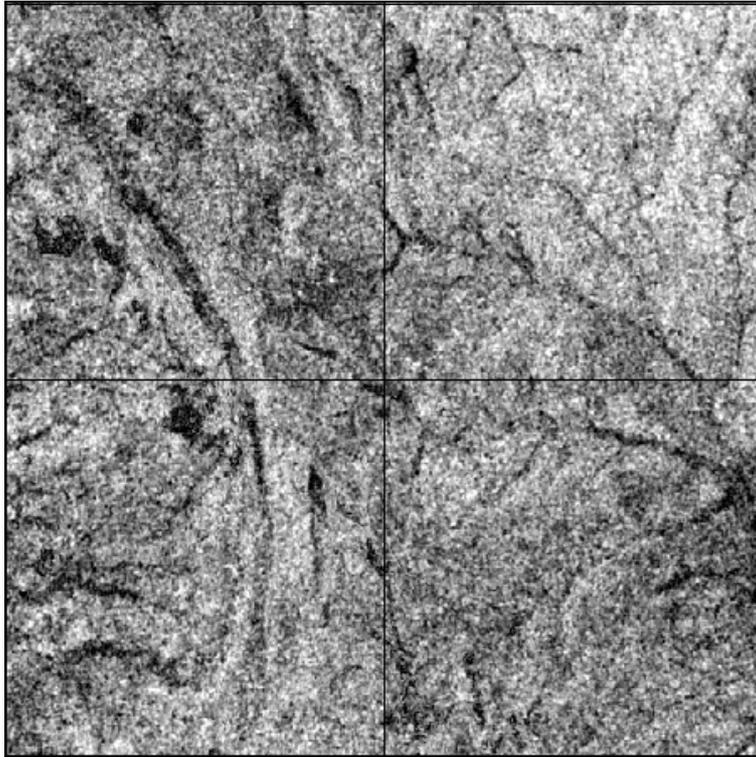
Figure 6. Interferometric coherence image (black=low coherence, white=high coherence)
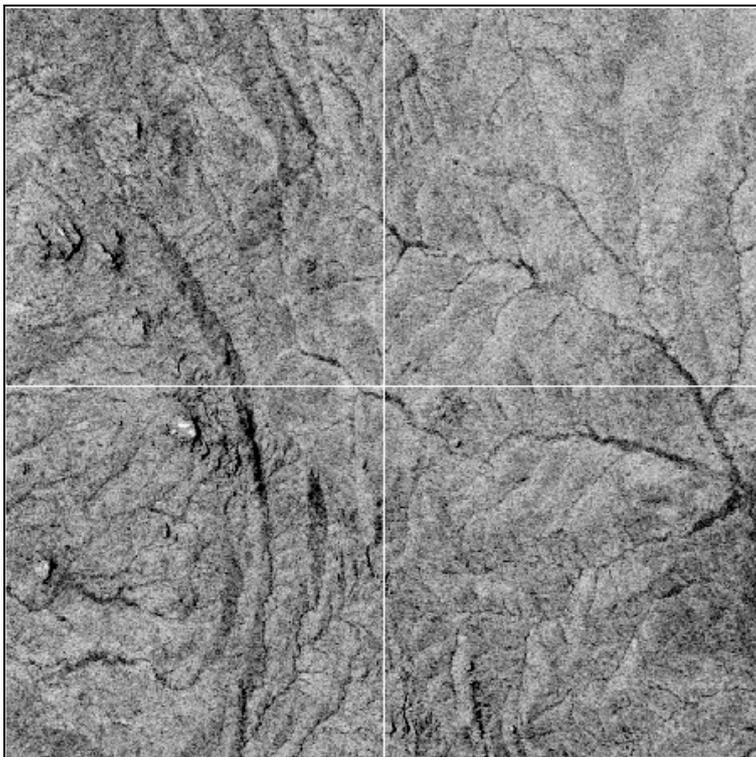
Figure 7. SAR (ERS-1, September 1997) intensity image (black=high intensity, white=low intensity)
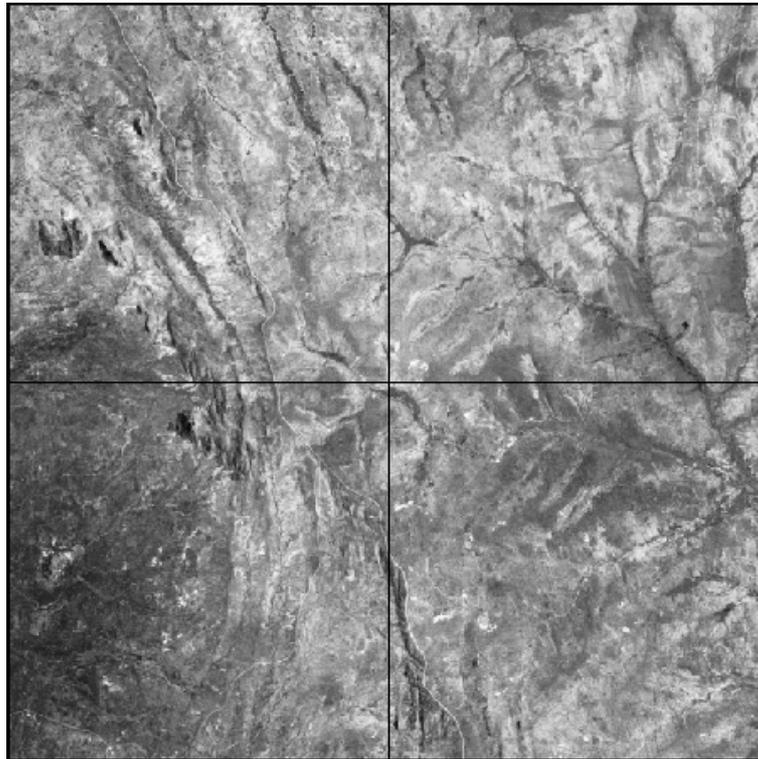
Figure 8. Landsat TM image - September 1984 (channels 4,5,7 as R,G,B). Used as backdrop image for the 'spacemap' products (TM image overlain with InSAR-derived topographic contours).
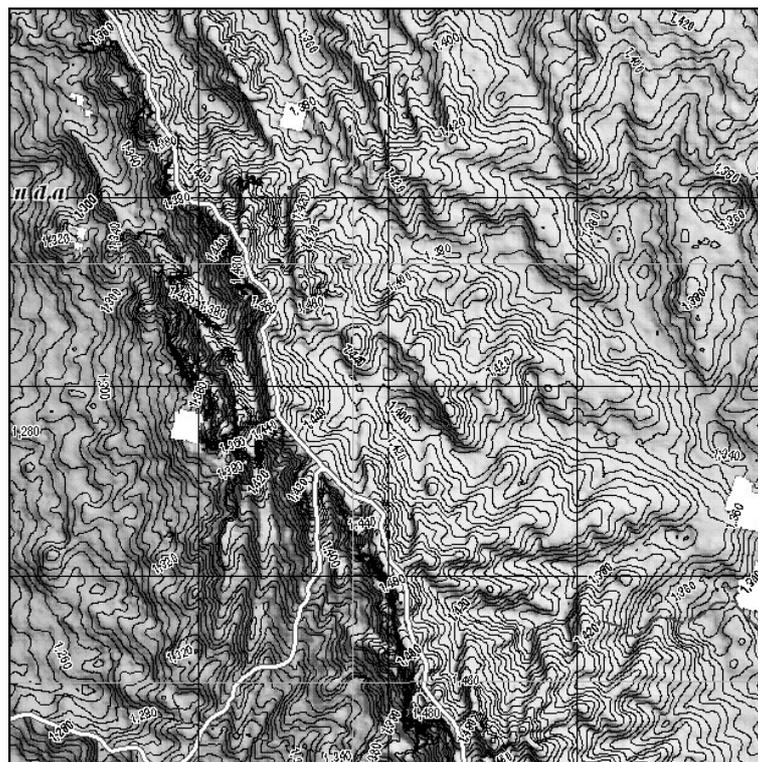

Figure 9. Interferometric DEM, shown as hillshaded relief model with topographic contours (every 5 m.) and roads as example of the quality of the final map product.