STEREO-RADARGRAMMETRIC EVALUATION OF ERS-1 SAR IMAGES: A CASE STUDY IN SOUTHERN ITALY

V. Kaufmann[1], W. Mattner[1], J. Raggam[2], A. Almer[2], and J. Schnell[2]

[1]Institute for Applied Geodesy and Photogrammetry, Graz University of Technology, Austria;
[2]Institute for Digital Image Processing, Joanneum Research Graz, Austria

ABSTRACT

This paper describes two methods of unconventional mapping using overlapping ERS-1 SAR Precision Images. The first method is a hybrid one using classical ways of photogrammetric mapping based on analog images which have been derived from radiometrically enhanced digital SAR data. Whereas the second method was supposed to semi-automatically derive 3-dimensional topographic information by means of image correlation techniques. A case study was carried out in the badlands of the Sant 'Arcangelo Basin in Southern Italy in order to investigate the potential of ERS-1 SAR image stereopairs, i.e., two overlapping same-side stereopairs from ascending and descending orbits, for topographic/ geomorphometric mapping, especially for obtaining a digital elevation model (DEM). The critical points of the stereo mapping procedure for both methods are highlighted. Furthermore, the overall quality of the derived DEMs has been assessed using an existing high-resolution DEM derived from airborne photographic data and an additional DEM from a panchromatic SPOT-1 stereopair.
Keywords: ERS-1, SAR, radargrammetry, topographic mapping, geomorphometric mapping, stereo image matching.

1. INTRODUCTION

The evaluation of optical image data, e.g., photographic images or line scanner images, is already well understood, whereas the evaluation of synthetic aperture radar images for extracting 3-dimensional information is still under investigation (Refs. 1 and 2). The basic objective was to apply radargrammetric mapping procedures on overlapping ERS-1 SAR images which were aquired from adjacent orbits. Two methods of stereo-radargrammetric mapping procedures were investigated:

1. Hybrid method using film transparencies with an analytical stereo plotting device,
2. Semi-automatic method using image correlation techniques.

The applicability of the proposed methods to ERS-1 SAR data should be proved in a case study. The main task was to generate a digital elevation model (DEM) of a study area using ERS-1 SAR data. As it will be shown in comparison to optical image data, the treatment of SAR images is much more complicated due to the SAR specific geometric and radiometric distortions, which are induced by the terrain topography, and the SAR inherent speckle noise. These effects cause problems for various sub-tasks to be performed in the course of SAR stereo mapping, which will be discussed.

2. STUDY AREA

As shown in Figure 1, the study area is located in Southern Italy and covers an area of approx. 300 km^2 and is drained by the Sauro river in the northern part and the Agri river in the southern part. The study area belongs to the geological setting of the Sant 'Arcangelo Basin (Ref. 3) and is very much affected by landsliding and soil erosion. The two main river valleys, a hilly area with long slopes in the SE, a hilly to mountaineous landscape with several quasi-vertical slopes in the NW are identified as the major geomorphological units in the study area. The elevations raise from 120 m to 980 m.

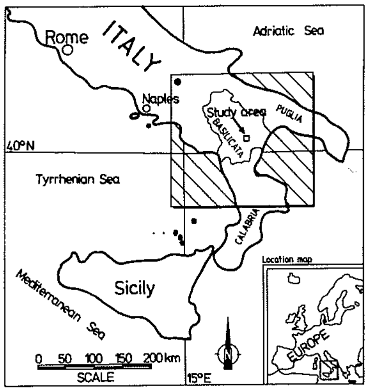

Figure 1. The location of the study area in Southern Italy.

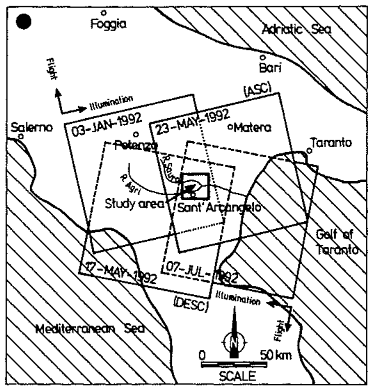

Figure 2. Location map showing coverage of ERS-1 images.

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3. AVAILABLE DATA

Two same-side ERS-1 SAR stereopairs, acquired from ascending and descending orbits, respectively, have been selected for this case study. The ground coverage of the 4 SAR images is shown in Figure 2. The January ERS-1 image was acquired during a 3-day repeat cycle (ice) phase, and the other 3 images during a 35-day repeat cycle (multi-disciplinary) phase. For the purpose of this study also a panchromatic SPOT-1 P stereopair (Level 1B, incidence angles 21.1° to the left and 21.7° to the right) was available in digital format, as well as a high-resolution DEM of the area with a grid spacing of 2.5 m derived from aerial photographs. Overlapping sub-windows covering the area of interest have been extracted from both the ERS-1 SAR scenes and the SPOT-1 scenes in order to form appropriate stereopairs (see Figures 7-9).

4. HYBRID METHOD

The proposed method uses the classical way of photogrammetric mapping based on analog images (Ref. 4). The general approach of this method is outlined in Figure 3. As an initial step the digital image data were radiometrically enhanced for optimal visual perceptance. Special attention was paid to the filtering process of the radar images in order to reduce its inherent speckle noise. After this, transparencies on 35-mm film were produced using a matrix film-recorder. The geometric fidelity of which was checked by repetitive exposures and high precision measurements of a regular grid. The distortions are less than 10 µm in both coordinate directions. Parallax free stereo vision was achieved by means of rigorous radargrammetric methods implemented for radar images on an analytical plotter DSR-1 of Kern (Ref. 5). The results of the stereo model set-up for both the ERS-1 models and the SPOT-1 model are summarized in Table 1.

Model	RMS East	RMS North	RMS Height
SPOT-1 P	+/- 9 m	+/- 10 m	+/- 7 m
ERS1-1 ASC	+/- 54 m	+/- 34 m	+/- 29 m
ERS1-1 DESC	+/- 25 m	+/- 27 m	+/- 13 m

Table 1. Accuracy of model set-up for the hybrid method.

This table also confirms the better stereo disposition of the descending ERS-1 (DESC) against the ascending ERS-1 (ASC) stereopair, as the latter has a significant smaller base length. Several hours of training were necessary to get acquainted to the stereoscopic viewing of the SAR data and to 3-dimensional model movement of the floating mark. On-line 3-dimensional relief mapping in 1:50.000 scale was done with a GP1-plotter from Kern. Contour lines at an interval of 50 m were digitized, as well as drainage lines, ridge lines, break lines and spot heights. These data were entered into a software package for creation of a digital elevation model. The grid spacing was selected with 20 m. In order to check the overall quality of the two digital elevation models, which have been derived from the two SAR stereopairs, the SPOT stereopair was taken to generate a reference DEM which itself was checked by a high-resolution DEM derived from aerial photographs. Axonometric views of the DEMs derived from SPOT-1 and ERS-1 are shown in Figures 10-12, the heights being exaggerated with a factor of 4. The respective DEMs were substracted and the distribution of the height differences were plotted as shown in Figure 13. Figures 4 and 6 should illustrate the feasibility of relief mapping with ERS-1 SAR data in comparison to SPOT-1 P.

5. SEMI-AUTOMATIC METHOD

This method is based on digital image data only and can be split up into 3 global sub-procedures as follows (see also Figure 5 and Ref. 6):

1. Stereo-radargrammetric model set-up using the same rigorous radargrammetric methods as indicated in the hybrid method. Also in this case, an a-priori mapping accuracy may be estimated from the GCPs.
2. 3-dimensional data extraction based on automatic image correlation using epipolar image data. The correlation results may be converted into 3-dimensional ground coordinates.
3. Generation of a DEM, which can be basically achieved through triangulation of irregularly distributed points and subsequent interpolation of a regular point raster.

The above mentioned stereo mapping methodology is implemented in the software package RSG, which has been developed at the Institute for Digital Image Processing of Joanneum Research Graz. The software runs under MS-DOS, UNIX and VMS, and handles not only radar images but also line scanner data as well as any type of digitized photographs. The results of the a-priori mapping accuracy for all of the three stereopairs are shown in Table 2.

Model	RMS East	RMS North	RMS Height
SPOT-1 P	+/- 14 m	+/- 13 m	**+/- 8 m**
ERS1-1 ASC	+/- 77 m	+/- 20 m	**+/- 35 m**
ERS1-1 DESC	+/- 85 m	+/- 23 m	**+/- 38 m**

Table 2. Accuracy of model set-up for the semi-automatic method.

Comparing Table 1 with Table 2 it can be seen that the accuracy derived by the hybrid method is better than the one obtained in the semi-automatic method. This is due to the stereoscopic measurement of image coordinates in the hybrid method which gives of course better results in comparison to the monoscopic measurement of homologue points in the digital images. The results of the quality analysis of the DEMs derived from ERS-1 and SPOT-1, respectively, are graphically shown in Figure 14.
As a result of this case study the following conclusions can be drawn.

6. CONCLUSIONS

An experiment on practical elevation data generation and topographic/ geomorphometric mapping using ERS-1 SAR Precision Images is documented in this paper. Two different approaches, i.e., a hybrid and a semi-automatic method, were considered. For both methods a sufficient stereo model set-up accuracy was obtained. With regard to stereo mapping, a poor a-priori stereo mapping accuracy is achieved due to the bad ERS-1 stereo disposition comprising steep look angles and rather small intersection angles of only some 3 degrees. Therefore, even small pixel errors induce considerable errors into the determination of 3-dimensional ground coordinates. The dominating errors are caused by range errors, which yield a lateral displacement on ground. Accordingly, the height accuracy is superior to the planimetric accuracy (approx. a factor of 2 to 2.3). Having an ERS-1 SAR Precision Image stereopair, a measurement error in range direction of +/- 1 pixel causes an error of +/- 118 m to +/- 98 m in range

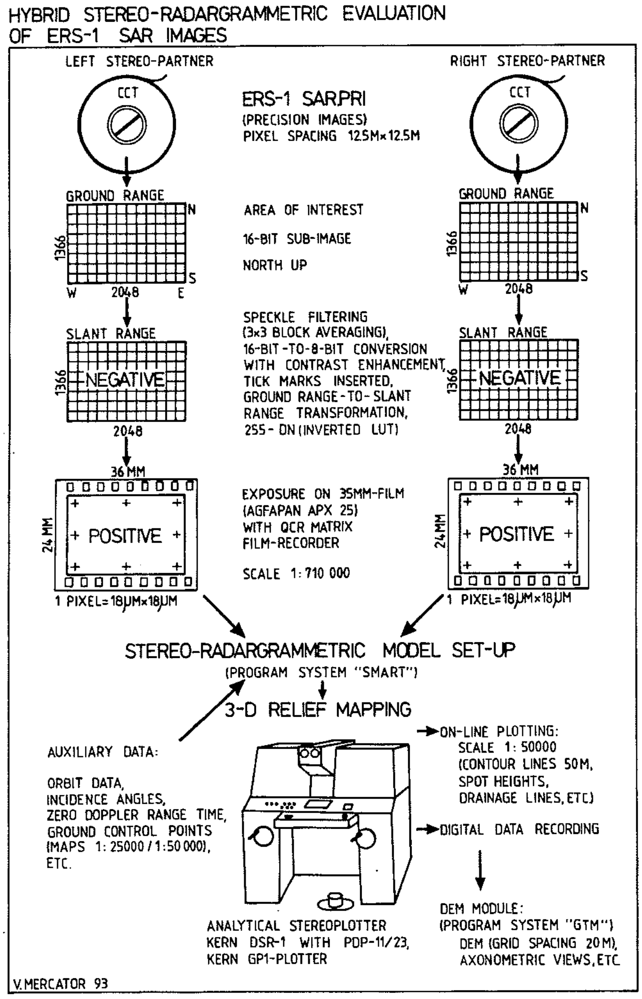

Figure 3. Procedure for stereo-radargrammetric mapping using analog ERS-1 SAR images (hybrid method).

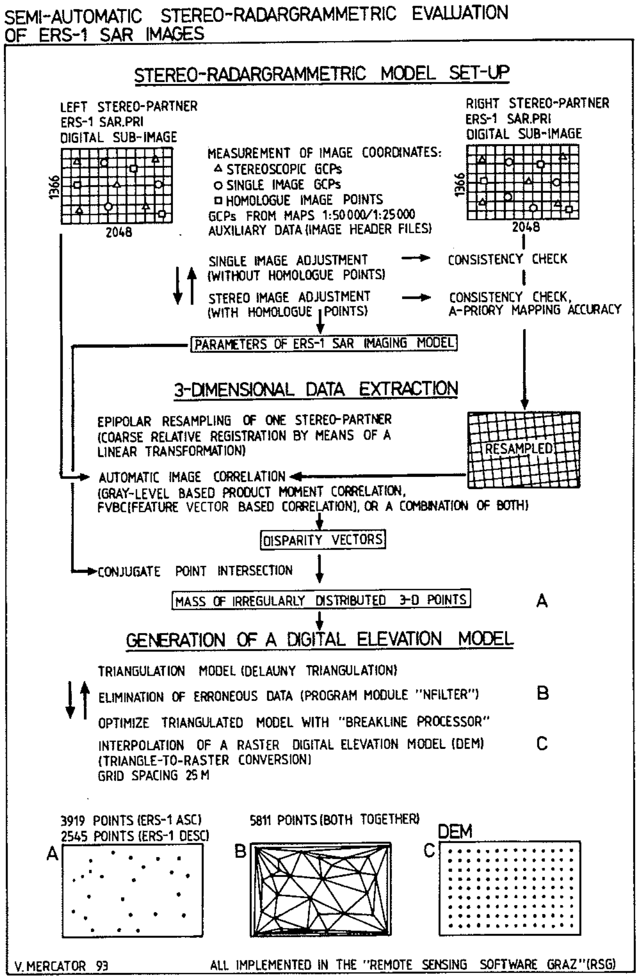

Figure 5. Procedure for stereo-radargrammetric mapping using digital ERS-1 SAR data (semi-automatic method).

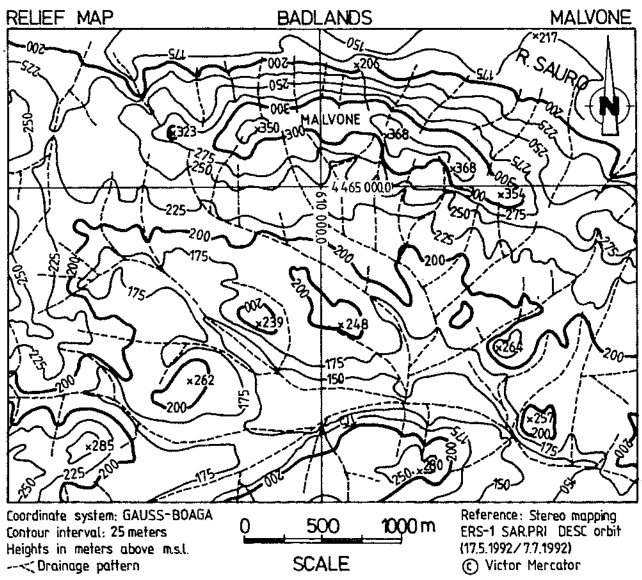

Figure 4. Relief map derived from the descending ERS-1 SAR image stereopair using the hybrid method.

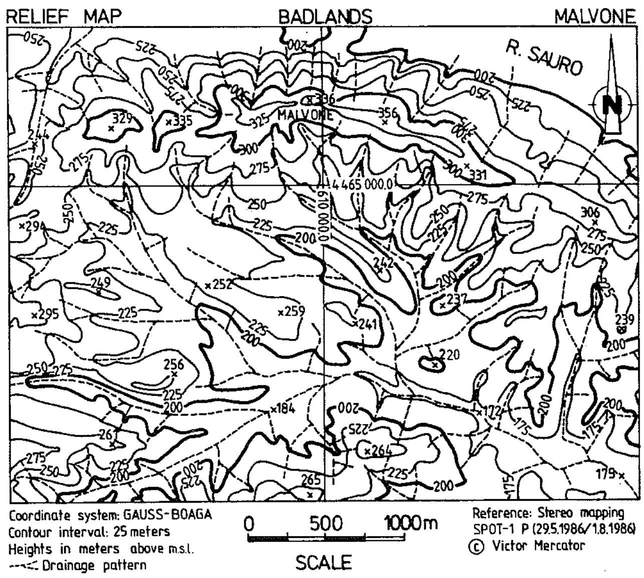

Figure 6. Relief map derived from the SPOT-1 P image stereopair using the hybrid method.

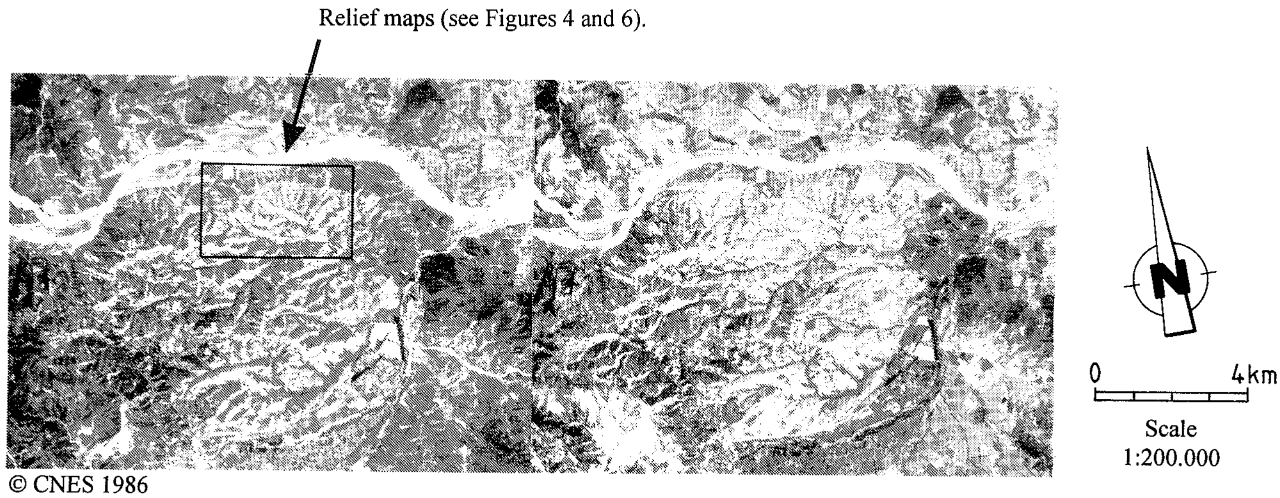

Figure 7. SPOT-1 P stereopair.

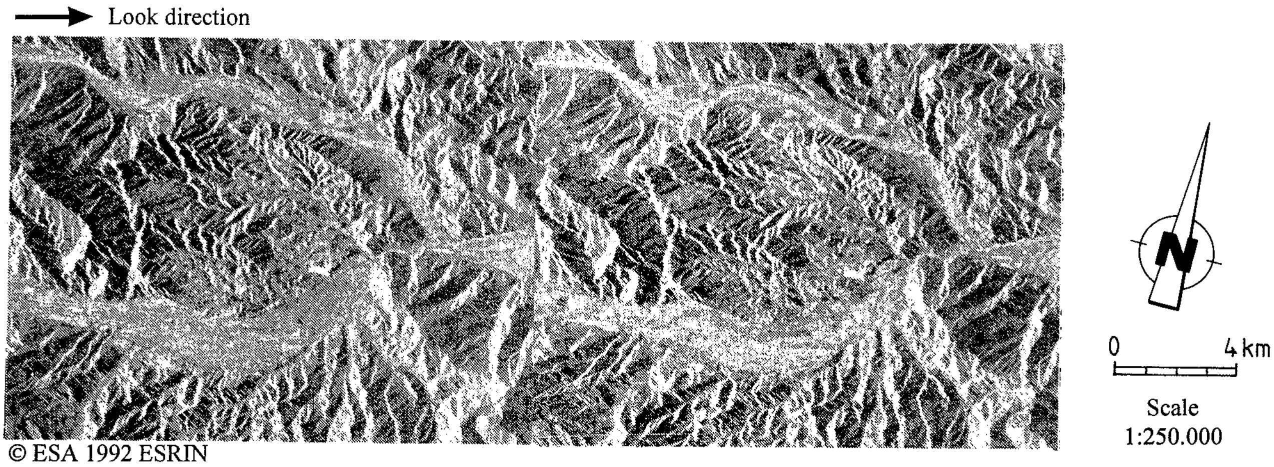

Figure 8. Ascending ERS-1 SAR stereopair (ASC).

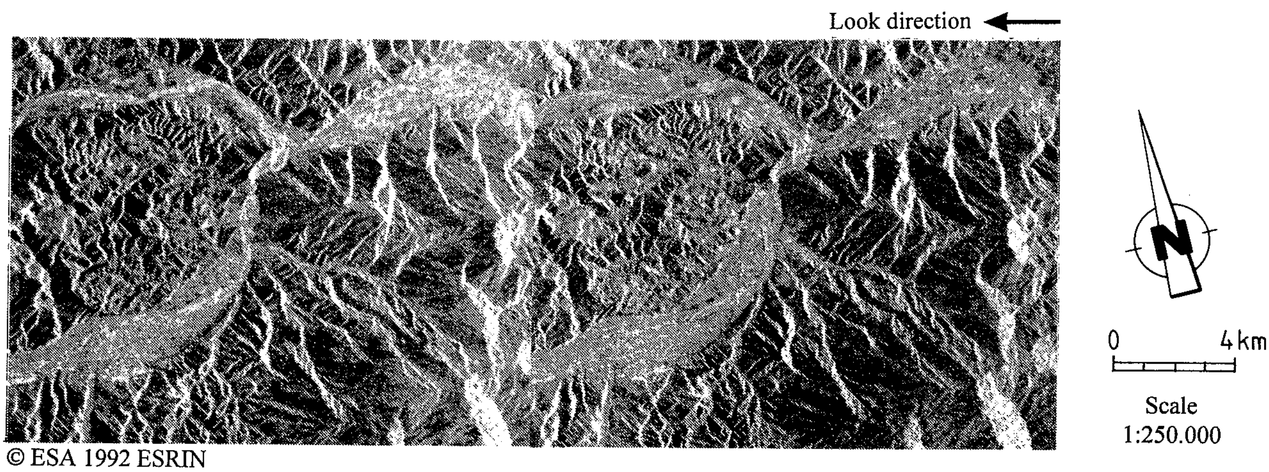

Figure 9. Descending ERS-1 SAR stereopair (DESC).

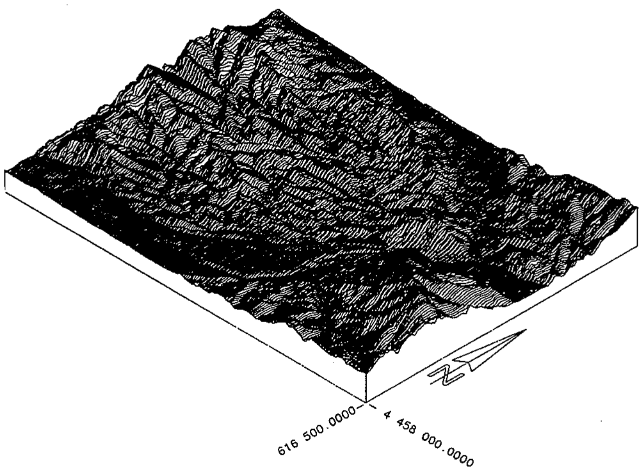

Figure 10. Axonometric view of the DEM derived from SPOT-1 P image stereopair using the hybrid method.

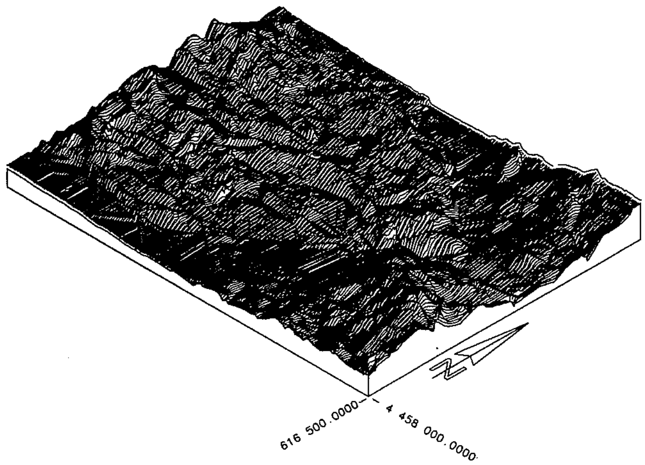

Figure 11. Axonometric view of the DEM derived from the ascending ERS-1 SAR stereopair using the hybrid method.

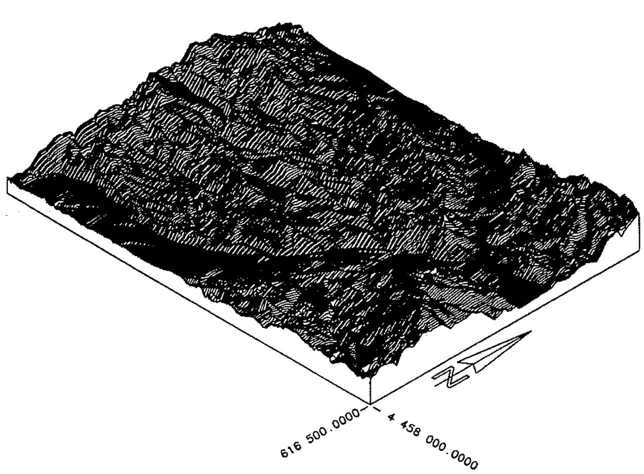

Figure 12. Axonometric view of the DEM derived from the descending ERS-1 SAR stereopair using the hybrid method.

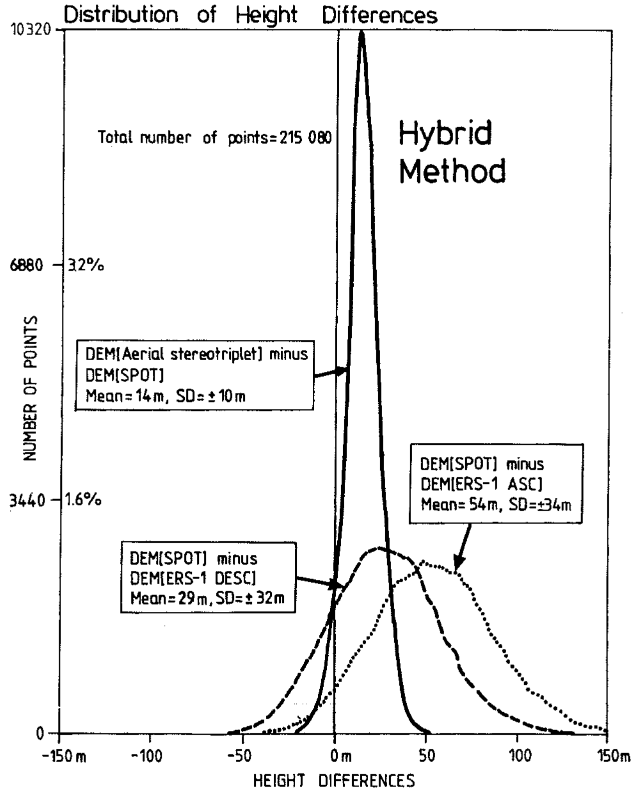

Figure 13. Distribution of height differences for the hybrid method.

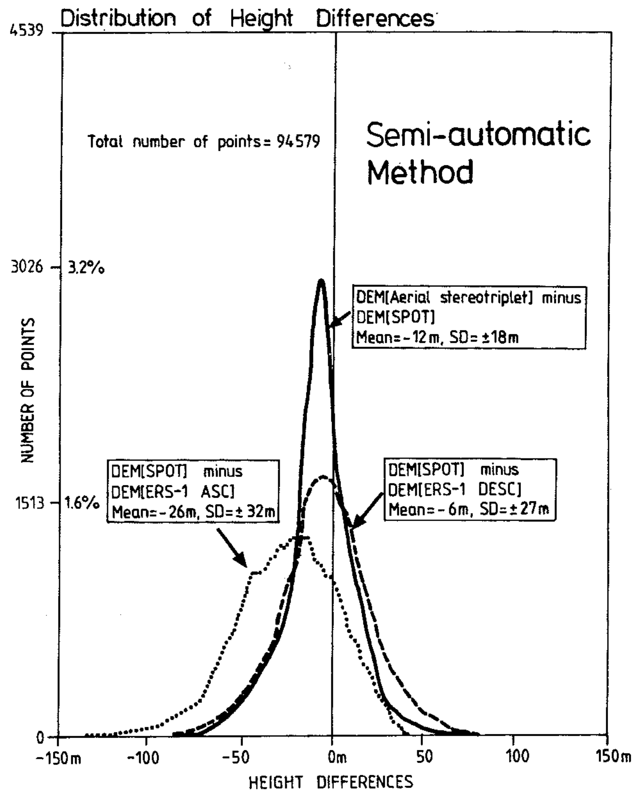

Figure 14. Distribution of height differences for the semi-automatic method.

direction and +/- 52 m to +/- 43 m in elevation for the intersected point on ground depending on the length of the stereo base, i.e., 52 km to 61 km. DEMs derived from stereoscopic ERS-1 SAR data showed a variable systematic shift in height against a DEM derived from SPOT-1. The standard deviations of height differences are about +/- 27 to +/- 34 m. From this a radar matching accuracy of approx. +/- 1 pixel is achieved. This is valid for both methods. Mapping of drainage patterns with the hybrid method revealed also a systematic planimetric shift in both coordinate directions of up to 200 m as can be seen in Figure 4. The phenomena of systematic shifts in height and planimetry needs further investigations.
In the following some more comments on both methods in respect to ERS-1 SAR images are given:

Hybrid method:

- Stereo viewing of overlapping same-side ERS-1 radar images is possible, whereas no stereo fusion of cross-over (convergent) ERS-1 radar images is possible.
- Vertical exaggeration factor of ERS-1 stereopairs is 2.1.
- Due to relief displacement the viewed stereo model is geometrically very much distorted. Image brightness is mainly modulated by topography, at least in our case study. Proper relief impression is disrupted in foreshortening and layover areas ("floating clouds above ground").
- Decorrelation of image brightness in all rather flat areas, such as river valleys and gentle rolling hills has been observed. Here only limited stereoscopic measurements were possible. Therefore, ruggedness of the imaged terrain is ideal. Applicability in high mountain regions has still to be proved. Nevertheless, the operator should be familiar with the topography of the area of interest.
- Radar image stereopairs should not differ to much in acquisition time, like 2 or 5 months as in the case study.
- Special attention should be addressed to speckle filtering for visual perception.
- The identification of proper ground control points needs an experienced operator.
- Drainage patterns and prominent geomorphological features could be mapped to a great extent in comparison with SPOT. Merging of 3-dimensional data from ascending and descending orbits in respect to ERS-1 radar geometry has still to be studied.
- Derived DEMs from ERS-1 SAR do not fulfill the requirements for high precision SAR geocoding, but may be used for coarse geocoding to remove systematic effects in image geometry. Proposed mapping scales may range between 1:250.000 up to 1:100.000 at maximum.
- Synergism between optical and geomorphometric information derived from ERS-1 radar, e.g. merging a single Landsat TM image with drainage patterns derived from ERS-1, may facilitate the interpretation of Landsat TM images.

Semi-automatic Method:

- The proposed (standard) image matching algorithms have not proved to be optimal.
- Alternative preprocessing (speckle filtering, segmentation) and matching methods, which are better applicable to SAR images, have to be identified and used for this task.
- A new algorithm for detection of blunders in radar image correlation is still under investigation.
- Knowledge-based systems (radar geometry, geomorphology) may be of advantage.
- A proposed digital stereo-radargrammetric workstation should be fully automatic, at least with the help of an operator, as it already exists for mapping with digitized aerial photographs (softcopy photogrammetry).

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