ASSESSMENT OF THE POTENTIAL OF JERS-1 FOR RELIEF MAPPING USING OPTICAL AND SAR DATA

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ABSTRACT:

The Japanese Earth Resources Satellite-1 (JERS-1) is equipped with a multispectral optical sensor (OPS-VNIR) in visible and near infrared as well as a microwave synthetic aperture radar (SAR) sensor. The optical sensor additionally includes a capability for in-orbit acquisition of stereoscopic image data. This paper focuses on the geometric treatment of JERS-1 image pairs, both from the optical and the SAR imaging mode. In general, the aspect of topographic information extraction based on stereoscopic images is treated. The potential mapping accuracy is analysed for JERS-1 image pairs with regard to geometric modelling, stereo model set-up and relief mapping. These activities have been part of the research project „Assessment of the Potential of JERS-1 for Thematic and Relief Mapping Using Optical and SAR Data", which has been defined and accomplished by the Institute for Digital Image Processing in its role as a Principal Investigator within the JERS-1 mission.

1. INTRODUCTION

The Japanese Earth Resources Satellite-1 (JERS-1) is the first remote sensing satellite with a multisensoral imaging capability, as it carries a multispectral optical sensor as well as a microwave synthetic aperture radar (SAR) sensor in L-band on board. The optical sensor comprises 4 spectral bands each in visible and near infrared (OPS-VNIR) as well as in short wavelength infrared (OPS-SWIR).

The OPS-VNIR instrument can acquire in-orbit stereo data as a combination of spectral bands 3 and 4. One image of the stereo pair is represented by spectral band 3 (wavelength 0.71 - 0.91 μm) of the JERS-VNIR sensor, whereas its stereo partner, i.e. spectral band 4, is achieved through simultaneous imaging of the terrain with a forward looking sensor, the tilt angle being about 15 degrees. This imaging mode can be specifically used for the extraction of 3D terrain information.

Based on optical and SAR image data acquired by the JERS sensor various experiments related to relief mapping have been carried out for the *Ötztal* test area. This area is located in the Austrian Alps and shows high mountainous and partly glaciated terrain reaching from about 1750 to more than 3700 meters above sea level. The test site has been selected as the major test site within the JERS-1 research activity „Assessment of the Potential of JERS-1 for Thematic and Relief Mapping Using Optical and SAR Data" of the Institute for Digital Image Processing of JOANNEUM RESEARCH. Besides, this test area has also been designated as a primary test site for glaciological experiments within the SIR-C/X-SAR mission and has been used within other investigations in the field of geocoding or stereo mapping. Related work is for instance presented in Almer et al. (1991) or Raggam et al. (1991).

The work presented in this paper comprises the use of JERS-1 optical and SAR image pairs in order to extract topographic information stereoscopically. Based on inter-comparison of achieved results and proper reference data a thorough analysis of the quality of achieved results is given.

The following JERS-1 image pairs have been considered for investigations on their potential for relief mapping:

- a stereoscopic JERS-1 optical image being acquired on August 18, 1992, with a nominal pixel resolution of 18 meters on ground. The respective image pair is denoted as OPS-1 and OPS-2 in the following (see Figure 1).
- a pair of JERS-1 L-band SAR images, being acquired from 2 adjacent orbits on 22nd and 23rd of October, 1993 (denoted as SAR-1 and SAR-2, see Figure 2). These images are acquired with a nominal pixel resolution of 12.5 meters and an off-nadir looking angle of about 35 degrees. The SAR-1 image, however, unfortunately covers only a minor part of our area of interest.

For the optical and the SAR image pair it was intended to extract topographic relief using stereoscopic mapping procedures. Therefore, preparatory processing and analyses have been performed like geometric modelling of the image data and investigation of monoscopic and stereoscopic mapping accuracy.

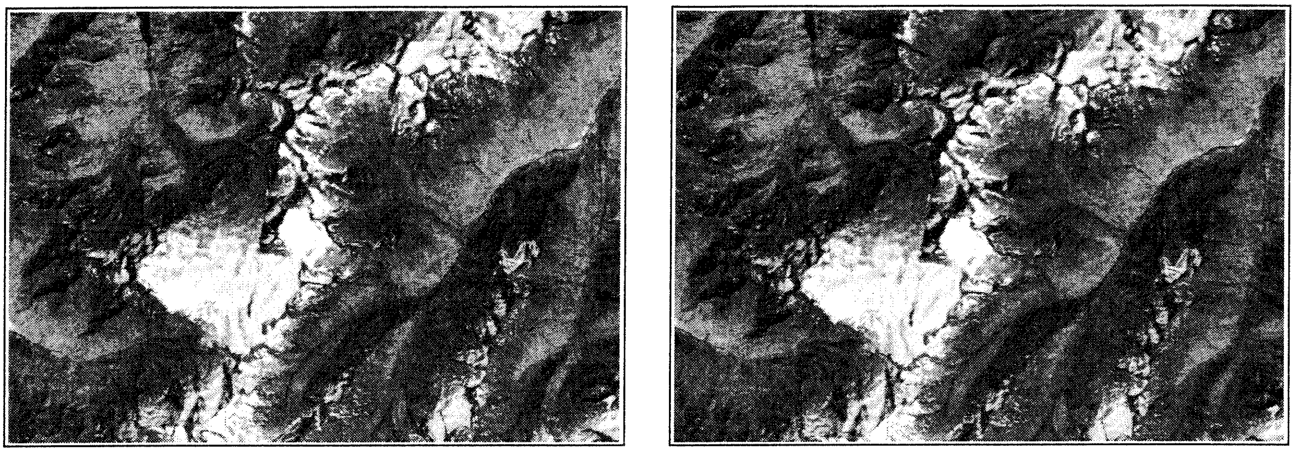

Figure 1: Sub-images of optical JERS-1 image pair: nadir view OPS-1 (left) and forward view OPS-2 (right).

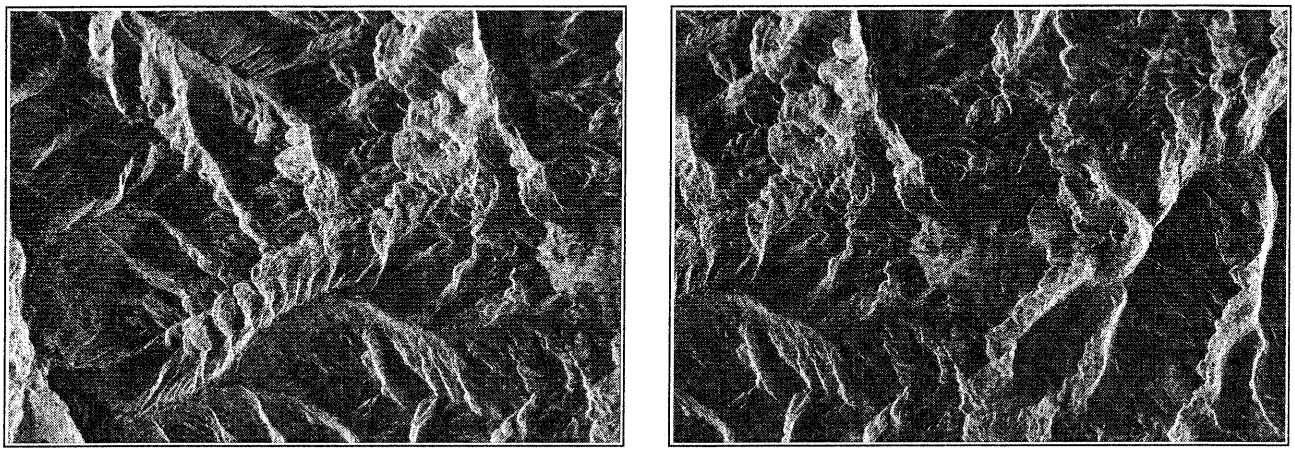

Figure 2: Sub-images of JERS-1 SAR image pair: SAR-1 (left) and SAR-2 (right).

2. GEOMETRIC MODELLING

2.1. Geometric Accuracy Assessment

Parametric mapping models have been determined for the SAR as well as for the optical image data. A-priori parameter information was obtained from given and/or known tracking parameters of the sensor. These a-priori mapping models were further optimised by means of least squares parameter adjustment techniques being based on ground control point (GCP) measurements. The accuracy of the achieved mapping models can be assessed by statistical parameters of the adjustment residuals like RMS, minimum or maximum values.

These statistical parameters are summarised in Table 1 for the optical and for the SAR image data, respectively, showing both residuals in along and across track *(x/y)* as well as nominally in East and North *(E/N)*. Besides, the length of the residuals, denoted by $|xy|$ and $|EN|$, is given. It can be seen from Table 1, that for the optical data an RMS-accuracy of less than 1 pixel in along and across track and about 1 pixel in length is achievable, the latter being equivalent to some 20 meters on ground with reference to the pixel resolution of the images.

Image		Image Pixel Residuals			Nominal Ground Residuals		
		x	*y*	$\|xy\|$	*E*	*N*	$\|EN\|$
OPS-1	RMS	0.7	0.8	1.0	15.0	11.0	18.7
	MIN	-1.2	-1.9	0.2	-34.6	-22.3	3.4
	MAX	1.3	1.5	2.0	27.6	20.2	36.3
OPS-2	RMS	0.8	0.9	1.2	17.1	13.5	21.8
	MIN	-1.8	-2.1	0.1	-38.6	-26.5	1.4
	MAX	1.5	1.9	2.3	35.3	26.4	41.1
SAR-1	RMS	1.6	1.7	2.3	19.1	20.0	27.7
	MIN	-3.9	-3.8	0.4	-38.5	-39.7	5.0
	MAX	3.0	3.5	4.4	46.8	47.2	52.8
SAR-2	RMS	1.6	1.6	2.2	18.9	19.5	27.2
	MIN	-3.8	-3.1	0.1	-40.4	-44.7	0.9
	MAX	3.3	3.3	4.1	37.0	47.9	51.4

Table 1: Statistics on set up accuracy for the JERS-1 image data, given in image pixels as well as nominally in meters on ground.

For the SAR data the achieved accuracy is worse, as documented by the RMS residuals being about twice as much as for the optical images. Due to the nominal pixel resolution of about 12.5 meters for the JERS-1 and ERS-1 SAR images, RMS residual lengths of about 30 meters result therefrom.

2.2. Stereoscopic Accuracy Assessment

An a-priori stereo mapping accuracy may be evaluated from residuals between measured GCP coordinates and intersected 3D ground control point coordinates, the latter being calculated in a 3D stereo intersection procedure from the respective stereo pixel measurements (Raggam et al., 1990 [2]). Again, statistics of the individual 3D point residuals may serve for a stereoscopic accuracy assessment.

The respective statistical values of the resulting coordinate differences, such as minimum, maximum or RMS-residuals, are summarised in Table 2. For the optical JERS-1 stereo model the resulting RMS height residuals are 54 meters. For image pairs of the SPOT sensor comparative values may be around some 10 meters for panchromatic image data and stereo dispositions with a base-to-height ratio of around 1.0 (Raggam et al., 1993). The worse accuracy of JERS-1 results from a worse pixel size (18 meters versus 10 meters) and a worse bas-to-height ratio, which is around 0.3.

Model	Residual Statistics			
		E	*N*	*H*
OPS-1 / OPS-2	RMS	12.9	10.7	54.4
(Ω=~15°)	MIN	-21.9	-21.0	-83.6
	MAX	29.2	20.9	102.6
SAR-1 / SAR-2	RMS	169.5	35.9	139.4
(Ω=~2.5° - 3°)	MIN	-503.4	-57.1	-275.9
	MAX	318.8	91.6	399.6

Table 2: Statistics of a-priori stereo mapping for the optical (above) and the SAR (below) stereo model.

The geometric disposition of JERS-1 SAR data does not propose a high accuracy. Due to the small intersection angles Ω of about 3 degrees maximum the range geometry is very sensitive to even small pixel errors, which cause serious displacements in across track direction, i.e., mainly in Easting and Height. For the JERS-1 SAR stereo model the respective RMS accuracies are 170 and 140 meters. For comparison, accuracies of some 80 meters in planimetry and around 40 meters in height were achieved in a similar experiment related to ERS-1 SAR stereo models (Raggam et al., 1993).

2.3. Sensitivity Analysis

Numerical simulation was used to analyse the effects of certain pixel errors in the stereo images, as they are usually evident from manual point measurement as well as automatic image correlation, onto the accuracy of corresponding ground coordinates, being achieved from 3D intersection of projection lines. Disparities of +/-1 pixel were assumed in along-track and across-track for the left and/or the right image of the stereo pairs. These errors basically cause a shift of the projection lines/curves to be intersected for the determination of the ground coordinates.

The point displacements resulting from the numeric simulation are summarised in Table 3. From this Table one basically can deduce a verification of the values given in Table 2 for the a-priori stereo mapping accuracy. The most severe effects are caused by the pixel errors corresponding to the orientation of the stereo baseline, which is in along-track (Δx) for the optical and in across track (Δy) for the SAR stereo data. For instance, 1-pixel disparities cause height errors of 65 meters for the optical and more than 100 meters for the SAR data. In the second case also a considerable displacement in Easting of around 120 meters is achieved.

Comparative values were elaborated for SPOT and ERS-1 stereo models in a similar experiment (Raggam et al., 1993). For SPOT again a height displacement of only some 10 meters was achieved, while the height errors for ERS-1 SAR stereo models were around 30 meters. Hence, SPOT and ERS-1 image pairs in general show a superior geometric imaging disposition than optical and SAR data from JERS-1.

Model	Disparities	Point displacement ΔE	ΔN	ΔH
OPS	Δx_l = +/- 1	-/+ 6.9	-/+ 16.7	-/+ 65.5
	Δy_l = +/- 1	+/- 8.8	-/+ 1.8	-/+ 0.6
	Δx_r = +/- 1	+/- 3.6	-/+ 1.1	+/- 65.4
	Δy_r = +/- 1	+/- 8.9	-/+ 1.6	+/- 0.6
SAR	Δx_l = +/- 1	-/+ 16.0	-/+ 3.4	+/- 13.1
	Δy_l = +/- 1	-/+ 117.4	+/- 22.3	+/- 108.2
	Δx_r = +/- 1	+/- 13.8	-/+ 9.0	-/+ 13.0
	Δy_r = +/- 1	+/- 128.9	-/+ 23.9	-/+ 107.5

Table 3: Coordinate mismatch (in meters) caused by one-pixel errors in the course of stereo-intersection.

3. IMAGE CORRELATION PERFORMANCE

Automatic matching procedures are used to find corresponding points in the images and to determine the respective 3D ground coordinates therefrom. In the present experiment a straightforward grey value based correlation was applied, including backward correlation as a first quality control mechanism.

For the JERS-1 stereo models a more or less coarse grid of points was correlated to determine representative accuracy parameters for 3D data extraction. The elevations of the extracted data were compared to the corresponding reference elevations extracted from the reference DEM. Statistics on the resulting height differences are summarised in Table 4 together with the percentage of points having been matched under consideration of the specified correlation criteria.

Concerning the optical data we first of all note a good stereoscopic performance of the pure JERS-1 stereo model. The achieved height accuracy of 51 meters RMS error is even slightly better than proposed within the geometric modelling. In the experiment related to SPOT panchromatic stereo data, on the other hand, we have achieved an RMS height accuracy of around 26 meters. Hence, the resulting height accuracy achieved from the JERS data is fairly reasonable if stereo disposition and pixel resolution are considered, both of them being significantly worse in comparison to SPOT.

Further a very high correlation success rate of 82.6% was achieved for JERS-1, whereas the comparative rate for SPOT was 53% only. With regard to the image matching performance it can be seen therefrom, that the simultaneous in-orbit stereo data acquisition of the JERS sensor has a distinct advantage versus the multitemporal data acquisition of the SPOT sensor.

The SAR images were processed in an adequate manner and, in particular, without any preprocessing (e.g. speckle filtering) of the image data. Due to the SAR specific speckle noise and the radiometric peculiarities like particularly layover the correlation step is significantly more problematic for these data. This is immediately documented by the low percental rate of successful correlation of 17% only. For ERS-1 stereo data, for comparison, similar correlation rates of up to some 20% have been achieved.

We can note, however, a fairly high height accuracy of some 80 meters for the JERS-1 SAR stereo pair, whereas the respective accuracy achieved from stereoscopic modelling (Table 2) amounts only to about 140 meters. Hence we can conclude that the stereoscopic correlation together with the criteria used for this process is more accurate than the interactive measurement of (control) points, which has been done monoscopically in the individual images.

It can be assumed, that the height accuracy resulting from JERS-1 SAR stereo data in general may be improved through a proper preprocessing like speckle filtering of the image data. Then similar accuracies like those achieved in experiments related to ERS-1 SAR stereo data, i.e. some 50 meters RMS height errors, should be feasible, as the geometric prerequisites like pixel resolution or stereo intersection angle are around the same.

	OPS-Model	SAR-Model
Corr. Rate (%)	82.6	17.1
RMS	50.8	77.8
Mean	-18.8	-22.0
Std.Dev	47.2	74.6
Minimum	-136.6	-257.9
Maximum	128.6	183.1

Table 4: Statistical values of stereo mapping accuracy analysis (given in meters).

4. RELIEF MAPPING

4.1. DEM Generation

The correlation results of the optical JERS-1 stereo data were used in a next step in order to generate a stereoscopically derived digital elevation model (DEM). First, 3D ground coordinates were determined for the matching points through intersection of the respective projection lines. Then a triangulation procedure was applied to the 3D point data resulting from the correlation and intersection procedure. Erroneous correlation data manifest themselves usually as irregular peaks or holes, i.e. up-/down-pyramids, in the triangulated network. An automatic filtering mechanism was applied to identify and eliminate such outliers, which considers the slope of triangle edges coinciding at a triangle point. Finally, a regular raster of elevations was interpolated from the triangle net with a specified frame and mesh size. Smoothing procedures were used to eliminate the triangular terrain shapes in the raster DEM.

This resulting stereo-derived DEM is shown in Figure 3 in a grey level coded presentation. For topographic reference a DEM with a cell size of 12.5 is available, which has been generated from topographic maps in a scale of 1 : 25000. This DEM is shown in Figure 4. For ease of comparison selected height levels are indicated by contour lines. For a detailed quality assessment of the stereo-derived DEM the height differences to the reference DEM have been calculated and presented in Figure 5. In this Figure respective contour lines indicate height errors larger than +/- 50 meters (dark and bright areas). The statistical values calculated for this difference DEM compare well to the values given in Table 4. For instance, basically the same standard deviation of 47.8 meters or mean value of -18.8 meters have been determined.

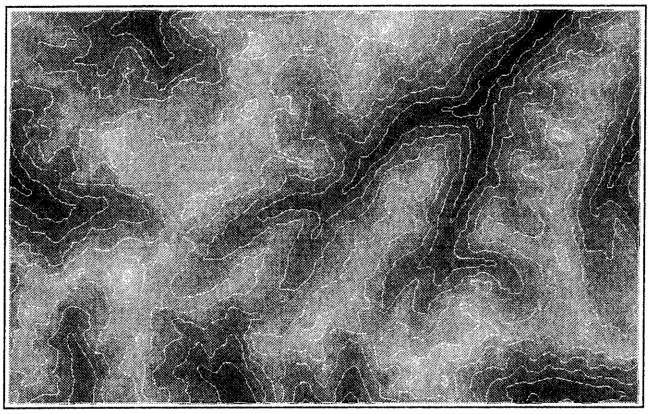

Figure 3: Stereoscopically derived DEM.

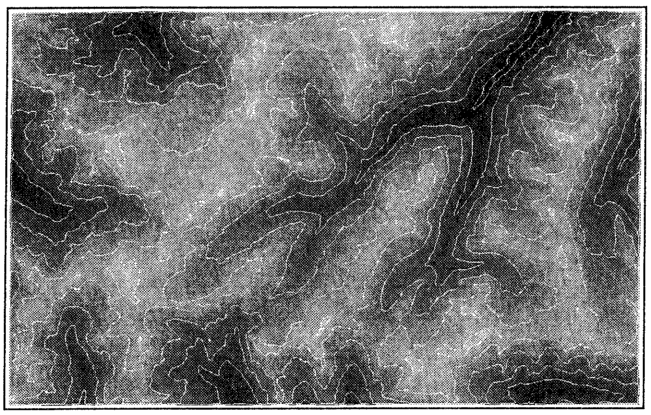

Figure 4: Map derived reference DEM.

Figure 5: Height differences between map-derived and stereo-derived DEM.

4.2. Data Geocoding

Based on the parametric mapping models and on the map-derived as well as the stereo-derived DEM JERS-1 image data were geocoded. An intercomparison of geocoded images produced with map-derived and stereo-derived DEM, respectively, was made in order to further conclude on the usefulness of the stereo-derived DEM. The respective results are presented in Raggam et al. (1995). In this context only the geocoded OPS-2 and the geocoded SAR-2 image are comparatively presented in Figure 6 in order to show the global information characteristics of JERS-1 image data.

Beside the JERS-1 data, a geocoded multispectral SPOT image as well as an ERS-1 SAR image are shown in Figure 7 to demonstrate the radiometric but also the geometric differences to the JERS-1 images. While the optical data present themselves very similar, it can be seen for the SAR data that the shapes of the layover areas are completely different and much more extended in the ERS-1 data. Consequently, for mountainous terrain the content of useful information in ERS-1 images is significantly reduced in comparison to JERS-1 SAR images.

Moreover, for data from the steep looking ERS-1 sensor it happens more frequently, for instance, that extended dark patterns occur inside a geocoded layover area. Such patters arise already from small error effects and in fact this kind of geocoding errors is less severe than anticipated from the visual impression.

5. CONCLUSION

For the high alpine testsite *Ötztal*, a multisensoral image data set comprising optical images from JERS and SPOT as well as SAR images from JERS and ERS-1 was used for stereoscopic investigations and for the production of geocoded images. Based on the achieved results the following conclusions can be made:

- From a radiometric point of view optical JERS data provide a good performance for stereo mapping, as a stereoscopic image pair is acquired during one overflight. In this concern JERS data are superior to SPOT stereo pairs being collected in separate overflights and with a certain temporal difference.
- From a geometric point of view the JERS stereo disposition is limited to a stereo intersection angle of some 15 degrees. The resulting base-to-height ratio of about 0.3 is insufficient to obtain a high accuracy in height, in particular in comparison to image pairs from the SPOT sensor with respective values of even more than 1.0.
- SAR stereo images of the JERS sensor in general provide a worse potential for stereo mapping, as the stereo intersection angles are very small. In comparison to ERS-1, however, the JERS sensor produces less layover. This is of high benefit for the stereo mapping task, because the areas excluded from successful image matching are significantly smaller.
- Sometimes, systematic errors may be resulting from stereo mapping, as expressed by mean height errors deviating significantly from 0. These effects have to be further investigated. In this concern, other correlation algorithms may be helpful.

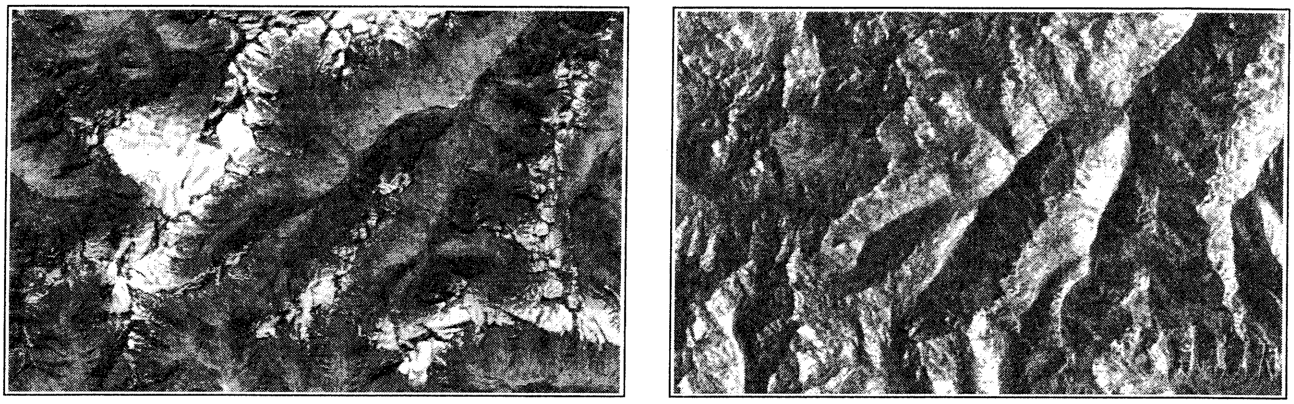

Figure 6: Geocoded image data: optical JERS image OPS-2 (left) and JERS SAR-2 image (right).

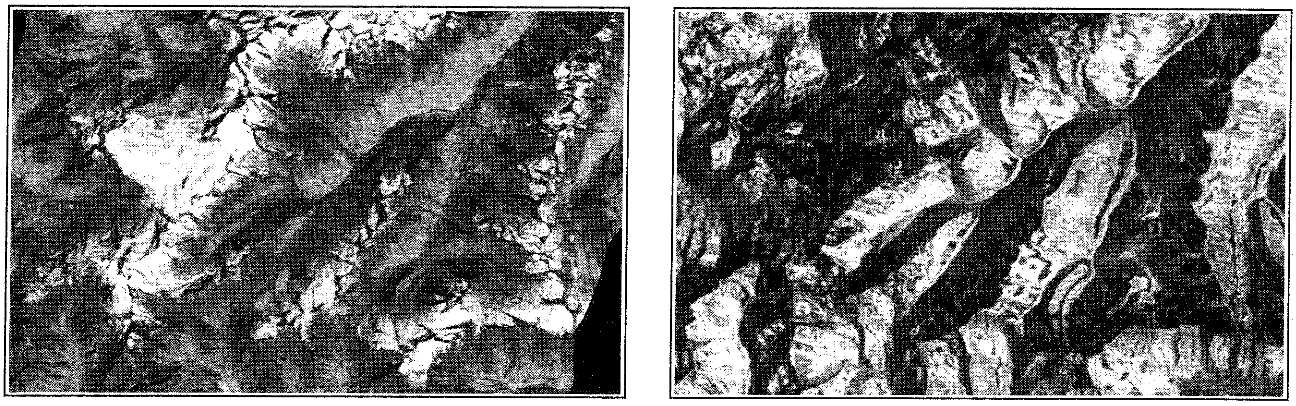

Figure 7: Geocoded image data: multispectral SPOT XS, spectral band 3 (left) and ERS-1 SAR image (right).

Certain improvements of achieved results seem feasible through a more sophisticated processing of the data. In particular, future activities will be related to the implementation of alternative image matching algorithms. Emphasis shall be put on their applicability for SAR stereo pairs including images from different SAR sensors. Filter mechanisms for SAR image data have to be considered in order to reduce the SAR speckle noise and to provide better conditions for automatic SAR image matching.

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