Final Report

ERS-1/ Almaz SAR Project

"Russian Spaceborne SAR Data: Comparative Analysis with ERS-1 Imagery"

ESA-ESRIN, 1994

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RUSSIAN SPACEBORNE SAR DATA: COMPARATIVE ANALYSIS WITH ERS-1 IMAGERY

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ABSTRACT

The present case study is devoted to the comparative analysis of information and metric properties of Russian spaceborne SAR data and ERS-1 imagery for use in large-scale topographic and land-use mapping. Original image data obtained over Italy during the winter and summer seasons of 1991 to 1993 were preprocessed, interpreted, transformed into the same projection and synthesized into colour images.

A final interpretation of the colour images was performed to retrieve land-use information. The accuracies achieved were reported and discussed. A statistical approach was used to analyse likeness of laws for pixel values distribution and to evaluate the number of looks for available image data. The promising results as to the high potential of Russian radar data and their joint analysis with ERS-1 data should encourage further studies.

1. INTRODUCTION

The Russian Almaz satellite was in operation from March 31, 1991, until October 17, 1992. During this period the on-board SAR system collected a wealth of radar data of the Earth's surface within a strip ranging from 73°N to 73°S. The highest ground resolution to be achieved with this system was reported to be about 5 meters ("Mechanical Engineering" Corporation product information. 1993).

One year ago Russian spaceborne SAR data were made available on the international remote sensing market. "Mechanical Engineering" Corporation (Reutov, Mosc. region, Russia Gerbert A. Yefremov, General Constructor) is the main official distributor of Almaz image data in Russia and abroad.

Only rare examples are known of practical applications using these image data for large-scale thematic mapping, and very little effort has been made to put them to commercial use in the West. The main reasons are probably insufficient marketing programmes, difficulties of handling digital data specified and standardized in Russian as well as the traditional lack of communication between East and West.

In contrast, ERS-1 radar image data are internationally reputed for their successful application to different areas such as geoscience, cartography, disaster monitoring, maritime traffic, etc. Good results in three-dimensional terrain modelling and large-scale mapping were achieved by means of computer-based joint analysis of ERS-1 radar data and imagery obtained by optical-electronic scanners installed on LANDSAT and SPOT satellites.

This case study is one of the first attempts to analyze and compare potentials of both kinds of SAR data with regard to large-scale cartography (right up to a scale of 1:25 000).

The main objective of the present investigation was the development of an automated technique for the joint processing of Almaz and ERS-1 imagery for use in topographic and land-use mapping of agricultural areas in the Tiber valley, Italy. The study was expected to yield an argument for recommending such an analysis and to give an evaluation of the accuracies to be achieved.

The investigation was carried out during three weeks (February - March, 1994) at ESRIN, Frascati, Italy, in the framework of an ESA-supported international programme of scientific cooperation between Russia and ESA.

2. DESCRIPTION OF EXPERIMENTAL DATA SET

The collected multitemporal cartographic and remote sensing data set covers the agricultural test area of 25 square kilometers in size, situated in the Tiber valley, in the vicinity of Fonte di Papa, Italy. The situation of the test site characterized by flat relief is shown in Figure 1.

The investigation is based on all sheets of topographic maps available for this territory at 1:25,000 and 1:200,000 scales, aerial stereo photographs at 1:20,000 scale obtained on 09.10.1984, terrestrial photographs as well as spaceborne radar image data obtained by Almaz and ERS-1 satellites during 1991-1992. The list of digital radar data used in the experiments is given in Table 1.

Table 1. List of digital radar data.

N	File name	Date	Satellite	Note
1.	1M12RF. LAN	20.07.1991	Almaz	Oriented, averaged (3x3)
2.	R2605R.LAN	26.05.1992	ERS-1	Oriented, fast delivery product
3.	R0301R. LAN	03.01.1992	ERS-1	Oriented, precision image
4.	1M21RF. LAN	08.01.1992	Almaz	Oriented, averaged (3x3)
5.	R1501R. LAN	15.01.1992	ERS-1	Oriented, precision image

The pixel size of the original Almaz data was about 5 meters across and along track. After averaging it was increased up to 15 meters. Pixel depth was 16 bits.

The pixel size of the ERS-1 fast delivery product was 20 meters across and 16 meters along track, while the pixel size of the precision image data was 12.5 meters both across and along track with a pixel depth of 16 bits.

All data were obtained from descending orbits with right-looking view and oriented with projection in ground range. The mid swath incidence angle was about 50° for Almaz data and 23° for ERS-1 data. The wavelength of the Almaz radar is somewhat larger than the one of the ERS-1 radar. H-H polarisation is typical for Almaz radar in contrast to V-V polarisation for ERS-1 SAR ("Mechanical Engineering" Corporation product information. 1993; ERS User Handbook, 1993).

3. METHODOLOGY AND TOOLS FOR RADAR DATA PROCESSING

Experimental work was carried out on the computer-based workstation equipped with "Erdas. Version 7.5, 1991" software in a standard environment (Compaq Deskpro 386/20 processor, image and symbol monitors, Tektronix 4693 DX printer). This system incorporates the functions of both remote sensing image data processing and raster GIS.

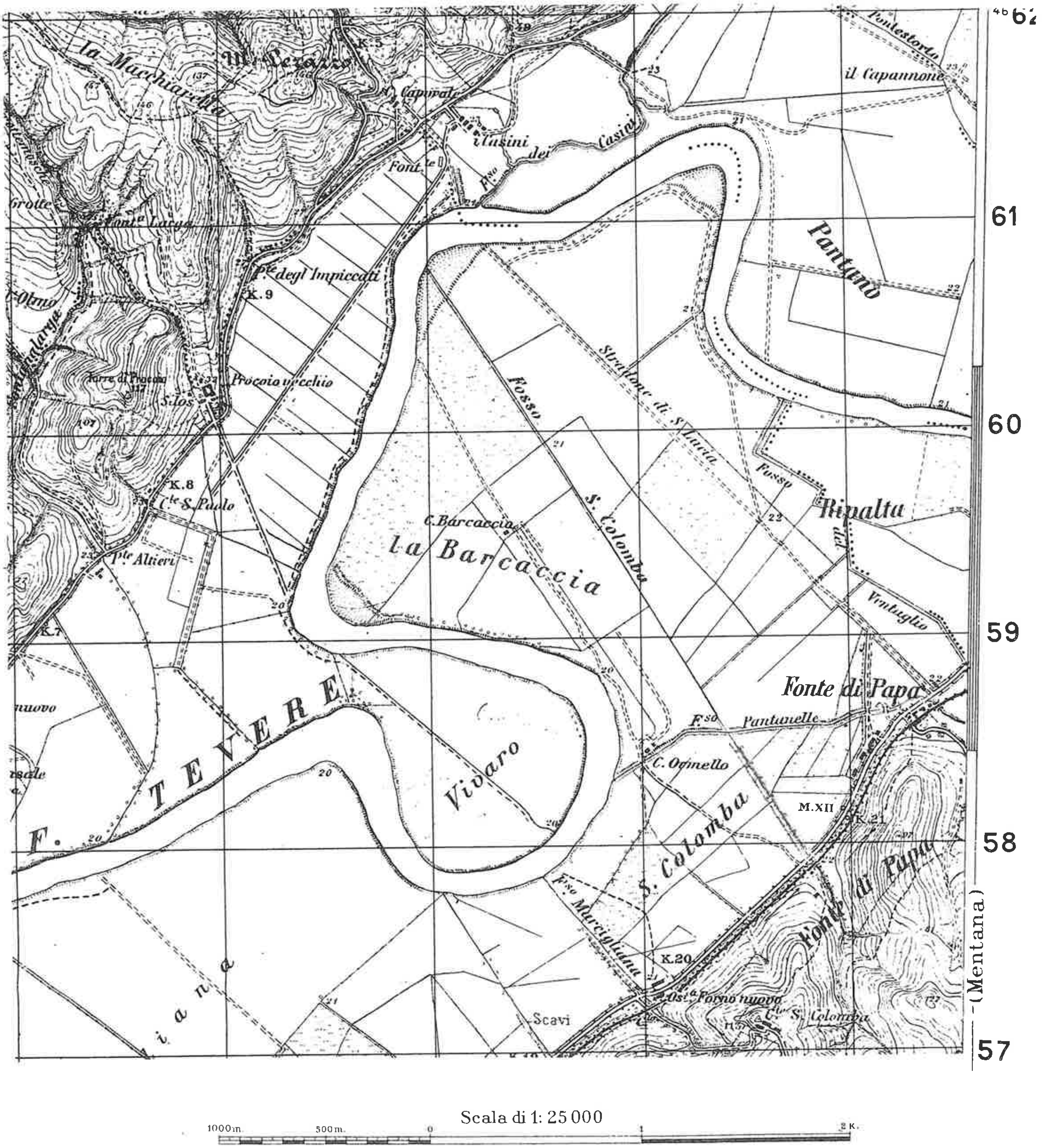

Figure 1: Location of the test site in the Tiber valley north of Rome.

As a first step, a visual interpretation of all spaceborne images was performed on the basis of terrestrial photographs and cartographic data. Artificial objects of high contrast (buildings, cross-roads, bridges, agricultural field corners) were recognized and selected for ground control.

For convenient comparison with ERS-1 SAR data the Almaz imagery was preprocessed and transformed into the same projection. Then the preprocessed Almaz radar data obtained in the summer of 1991 were compared with the ERS-1 fast delivery image and the winter data provided by Almaz (08.01.1992) were successively compared with two precision images of ERS-1 obtained on 03.01.1992 and 15.01.1992.

All these image data were integrated into two synthesized colour images, corresponding to the summer and winter state of the test area. First-order statistics (mean value, standard deviation, their ratio and histogram) were calculated for whole image frames and small fragments taken from homogeneous areas corresponding to agricultural fields and settlements. These values were taken into account for thematic analysis of synthesized colour images and for the production of a large-scale (1: 25 000) land-use image map.

4. PREVIOUS VISUAL ANALYSIS

The main objectives of this stage were to evaluate the general situation, to study the representation of topographic objects and to select ground control points. The first step was to recognize natural objects, such as the hydrographic network, as well as relief and vegetation features.

4.1. REPRESENTATION OF NATURAL OBJECTS

The wide Tiber river is represented by black and dark-grey tones on all image data and can be interpreted quite easily. Small rivers flowing into the Tiber are discernable only on aerial and Almaz image data due to higher ground resolution.

White narrow strips along rivers are probably caused by the joint influence of steep slopes and - to a certain degree - vegetation, as e.g. groups of willows. The clearer reproduction of this effect on Almaz imagery is due to the larger incidence angle of radar illumination. Extended ravins are detectable on Almaz imagery right up to 15 meters in width, whereas it is sometimes not possible to trace them on ERS-1 image data.

Single trees as well as groups of trees were distinctly discernable on Almaz summer data and sometimes only indistinctly visible on winter ERS-1 and Almaz imagery. Bare uncultivated lands are bright on all image data, but subsatellite information is necessary for exact interpretation.

4.2. RECOGNITION OF ARTIFICIAL OBJECTS

Artificial ponds, drains, channels as well as ditches and sand-pits are detectable on all image data depending on their size. Edges of these objects are usually sharper on ERS-1 imagery.

The railway running on a high embankment is represented by two strips, one of which bright and the other one dark due to shadowing. The motorway is dark, but is well detectable on all radar images due to its linear form. Small roads, cross-roads and streets in settlements are better represented on Almaz imagery.

In contrast, ERS-1 radar data are more useful for recognizing large single houses and metallic constructions such as drags, tanks, ships, etc. Large bridges are well discernable on both kinds of radar data. (See Figures 2-5).

Boundaries and corners of agricultural fields are well visible only on Almaz data, especially when they are marked by roads or small forms of relief. Different conditions of agricultural fields in winter characterized by varying surface roughness are represented on Almaz data in higher contrast. The summer image obtained from the Almaz satellite is much better suitable for crops recognition than the fast delivery product of ERS-1.

It should be noted that the most accurate and detailed results can be obtained only in conjunction with subsatellite information and fieldwork data.

Thus, a first visual analysis has shown that Almaz imagery is in no way inferior to ERS-1 SAR data in the field of land-use mapping. Both of them complement each other with topographic information. Therefore, it is useful to integrate them into a single synthesized image.

5. RECTIFICATION OF RADAR IMAGE DATA

To be able to compare radar images of both kinds pixel by pixel and integrate them into one single image, Almaz image data must conform to ERS-1 imagery. Moreover, for convenient matching imagery must be oriented in a way, that the north direction corresponds to the top of the image. Since ERS-1 precision radar images are already oriented and rectified into usual map projection we chose them as our reference system.

The rectification of image data, which is also known as image-to-image registration, involves the following general steps: location of ground control points, computation and test of a transformation matrix, creation of an output image file and finally integration.

5.1. COLLECTION OF GROUND CONTROL POINTS (GCPs)

Accurate ground control points are essential to an accurate rectification. They should be located throughout the scene and should be clearly visible on each image. The more dispersed the GCPs are the more reliable will be the rectification. For easier selection of homogeneous points on both kinds of radar images, we have averaged original Almaz image data with a window of 3x3 pixel size, thereby also reducing "speckle" noise.

In total, 28 GCPs well recognized on aerial images were selected on all radar image data. They included intersections of roads, bridges, buildings, corners of agricultural fields, bends and confluences of rivers. The position of the GCPs is shown on the Almaz summer image (20.07.1991) given in Figure 6.

Plane reference coordinates of GCPs were measured on the ERS-1 images obtained on 26.05.1992 and 03.01.1992, respectively. Source coordinates of GCPs were fixed on the Almaz images obtained on 20.07.1991 and 08.01.1992, respectively. Coordinates were measured with the accuracy of one pixel and subsequently entered by means of the keyboard.

5.2. COMPUTATION OF THE TRANSFORMATION MATRIX: ACCURACY TEST

Transformation matrixes corresponding to summer and winter images were computed from the GCPs by means of the least squares regression method. They consist of coefficients which are

Figure 2: Almaz radar image dated from 20.07.1991 (summer).
Histogram superimposed.

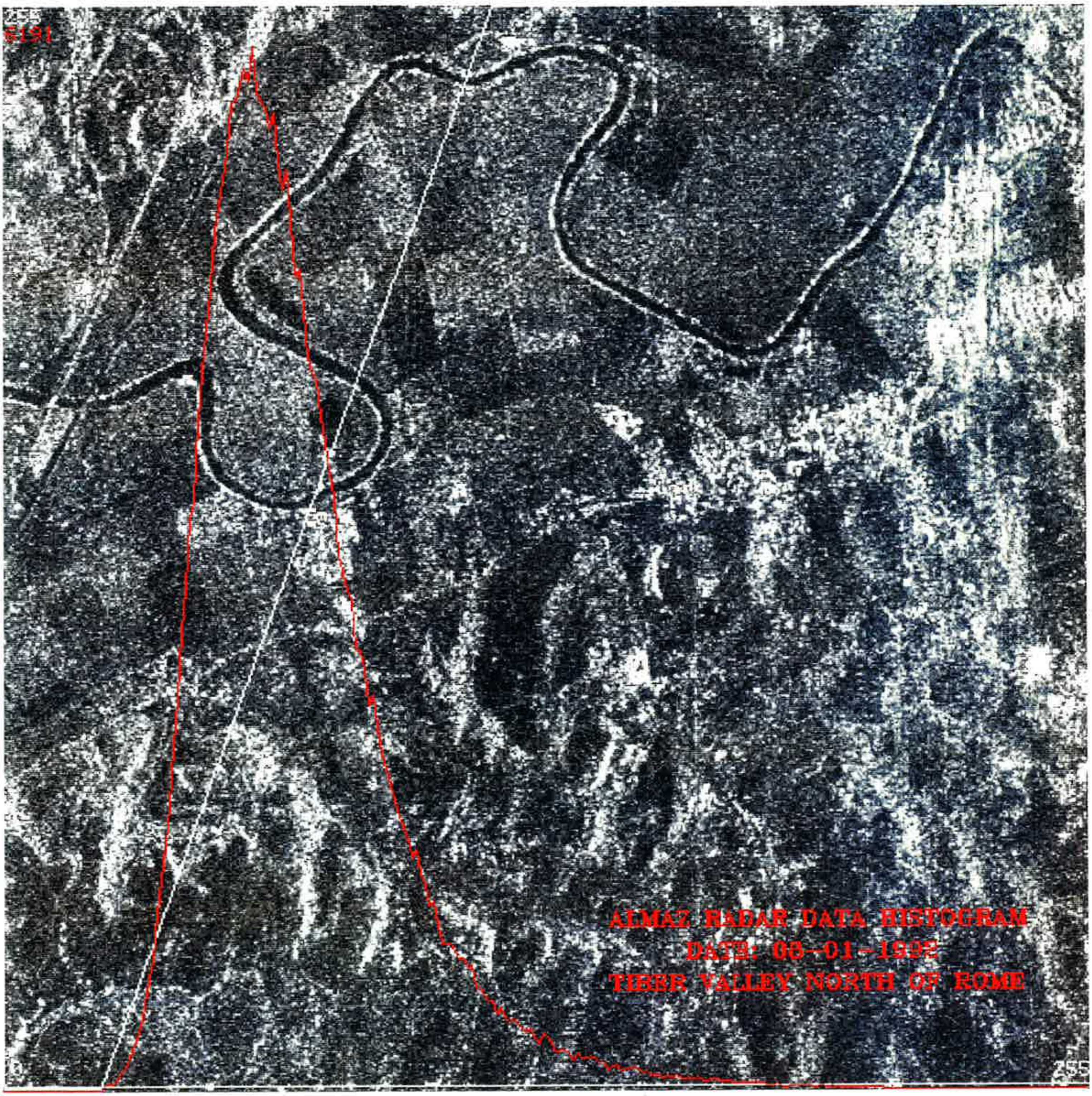

Figure 3: Almaz radar image dated from 08.01.1992 (winter).
Histogram superimposed.

Figure 4: ERS-1 radar image dated from 03.01.1992 (winter).
Histogram superimposed.

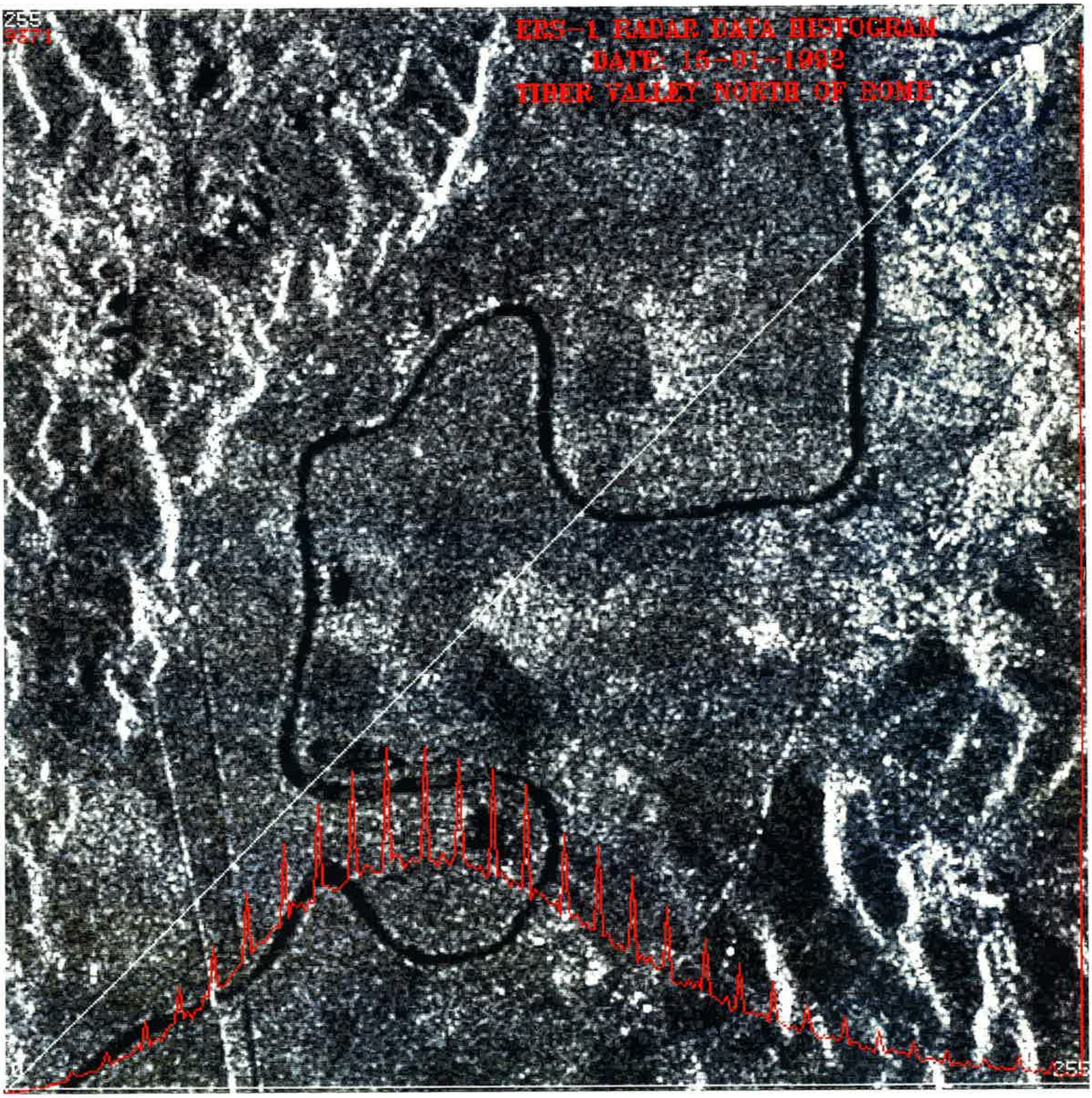

Figure 5: ERS-1 radar image dated from 15.01.1992 (winter).
Histogram superimposed.

Figure 6: Location of ground control points (GCPs).

Order of transformation is 1

```
 0.6344527E+00-0.5082490E+00
 0.3386638E+01 0.2382283E+01
-0.1322276E+01 0.2604699E+01
```

These are the computed results of the matrix above:

Point Count	Point Number	Image X Pixel	X Pixel Residual	Image Y Pixel	Y Pixel Residual
1	1	90.61	-0.3923E+00	961.51	0.5134E+00
2	2	227.29	0.4287E+01	1022.05	-0.4953E+01
3	3	577.68	0.6766E+00	970.77	0.9767E+01
4	4	660.74	-0.6261E+01	1093.50	0.3495E+01
5	5	1099.08	-0.5919E+01	666.85	0.2847E+01
6	6	748.45	-0.8552E+01	458.78	-0.1221E+01
7	7	1150.11	0.6113E+01	588.98	-0.3016E+01
8	15	888.68	0.2682E+01	979.82	-0.8176E+01
9	9	1048.21	0.3208E+01	756.69	0.2693E+01
10	10	132.14	-0.8595E+00	967.98	0.3977E+01
11	11	332.34	-0.4658E+01	1080.12	-0.6882E+01
12	12	856.38	0.3377E+01	787.45	0.4473E+00
13	13	256.73	0.3728E+01	614.42	-0.1578E+01
14	17	291.57	0.2570E+01	900.09	0.2087E+01

X RMS error= 4.43663 Y RMS error= 4.59360

Total RMS error= 6.38630

Point Count	Point Number	Error	Error Contribution by Point
1	1	0.6461	0.1012
2	2	6.5510	1.0258
3	3	9.7901	1.5330
4	4	7.1708	1.1228
5	5	6.5684	1.0285
6	6	8.6388	1.3527
7	7	6.8163	1.0673
8	15	8.6051	1.3474
9	9	4.1888	0.6559
10	10	4.0687	0.6371
11	11	8.3098	1.3012
12	12	3.4068	0.5335
13	13	4.0483	0.6339
14	17	3.3105	0.5184

Table 2: Results of the geometric transformation of the summer Almaz radar image into the ERS-1 SAR geometry (FDP).

Order of transformation is 1

```
 0.5620346E+00-0.5837648E+00
 0.2083381E+01 0.1491087E+01
-0.1521744E+01 0.2120054E+01
```

These are the computed results of the matrix above:

Point Count	Point Number	Image X Pixel	X Pixel Residual	Image Y Pixel	Y Pixel Residual
1	1	69.74	-0.2565E+00	557.37	-0.1631E+01
2	2	431.69	-0.1309E+01	465.01	0.5012E+01
3	3	239.99	0.1992E+01	202.65	-0.2346E+01
4	4	867.89	-0.3114E+01	100.06	0.6372E-01
5	5	832.68	-0.8322E+01	204.03	0.2034E+01
6	6	687.92	-0.7859E-01	800.03	0.1031E+01
7	7	1419.44	0.5439E+01	42.32	-0.3681E+01
8	8	647.57	0.1569E+01	34.65	0.3646E+01
9	9	256.55	0.3549E+01	523.39	-0.2613E+01
10	10	271.53	0.5308E+00	524.48	-0.1518E+01

X RMS error= 3.60029   Y RMS error= 2.72875

Total RMS error= 4.51754

Point Count	Point Number	Error	Error Contribution by Point
1	1	1.6511	0.3655
2	2	5.1805	1.1468
3	3	3.0772	0.6812
4	4	3.1146	0.6894
5	5	8.5669	1.8964
6	6	1.0342	0.2289
7	7	6.5671	1.4537
8	8	3.9691	0.8786
9	9	4.4068	0.9755
10	10	1.6077	0.3559

Table 3: Results of the geometric transformation of the summer Almaz radar image into the ERS-1 SAR geometry (PRI).

used in polynomial equations for coordinate conversion. The size of matrixes depends upon the order of transformation.

We used the first-order transformation (linear transformation), which produced the desired results.

Computed results are given in Tables 2 (for summer images) and 3 (for winter images). The root mean square errors (RMS) obtained in the location of GCPs on rectified Almaz data as compared to ERS-1 imagery are presented in values of original Almaz pixel size.

If we take its values into account (4.8 meters along the track (Y) and 5.2 meters across the track (X)), then we obtain

X RMS error = 23 m   Y RMS error = 21 m   Almaz data as compared to fast delivery product of ERS-1 data

and

X RMS error = 19 m   Y RMS error = 13 m   Almaz data as compared to precision ERS-1 imagery.

These values are in good correspondence with radargrammetric theory (F. Leberl, 1989). The use of a higher order transformation resulted in an insignificant increase in accuracy.

5.3. CREATION OF OUTPUT IMAGE FILES

Two output image files (IM12TR.LAN and IM21TR.LAN) were created with the new coordinate information in the header. The pixels were resampled by means of the nearest neighbor method to conform to the new grid.

Rectified Almaz images (cyanic color) were overlaid on ERS-1 radar image (red color) as is shown in Figures 7 (summer images) and 8 (winter images). Good coincidence of contours is visible for the flat Tiber valley, whereas double contours prevail in mountainous areas. These synthesized images, especially the latter, were used in the following experiments.

6. STATISTICAL ANALYSIS OF RADAR IMAGE DATA

For efficient data handling a statistical analysis of easily comparable winter radar images was performed. General 1st-order statistics (range, mean value, standard deviation and histogram) were calculated for all winter scenes. Results are shown in Figures 3 to 6 and in Table 4.

N	Statistics / File	IM21TR.LAN	RO301R.LAN	R1501R.LAN
1.	Minimum data value	0	21	25
2.	Maximum data value	232	5475	3265
3.	Mean value MV	52.44464	279.8851	284.1299
4.	Standard deviation SD	36.29829	154.2459	142.057
5.	Ratio MV / SD	1.45	1.82	2.00
6.	Number of looks, n	1	3	4

Table 4. General 1st-order statistics of radar image data.

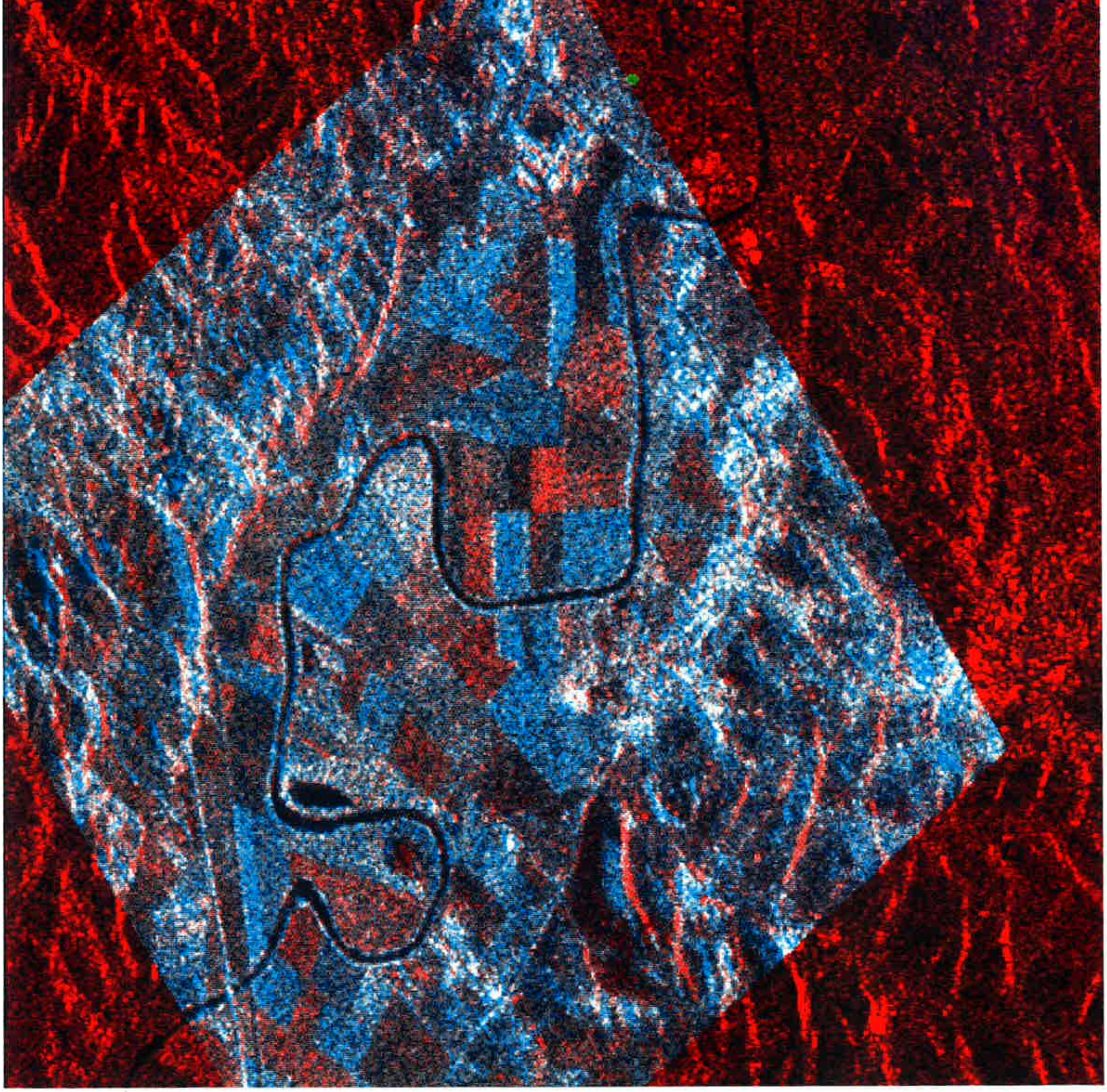

Figure 7: Superimposition of Almaz with ERS-1 radar data (winter images).
Geometry of ERS-1 SAR fast delivery product (FDC).

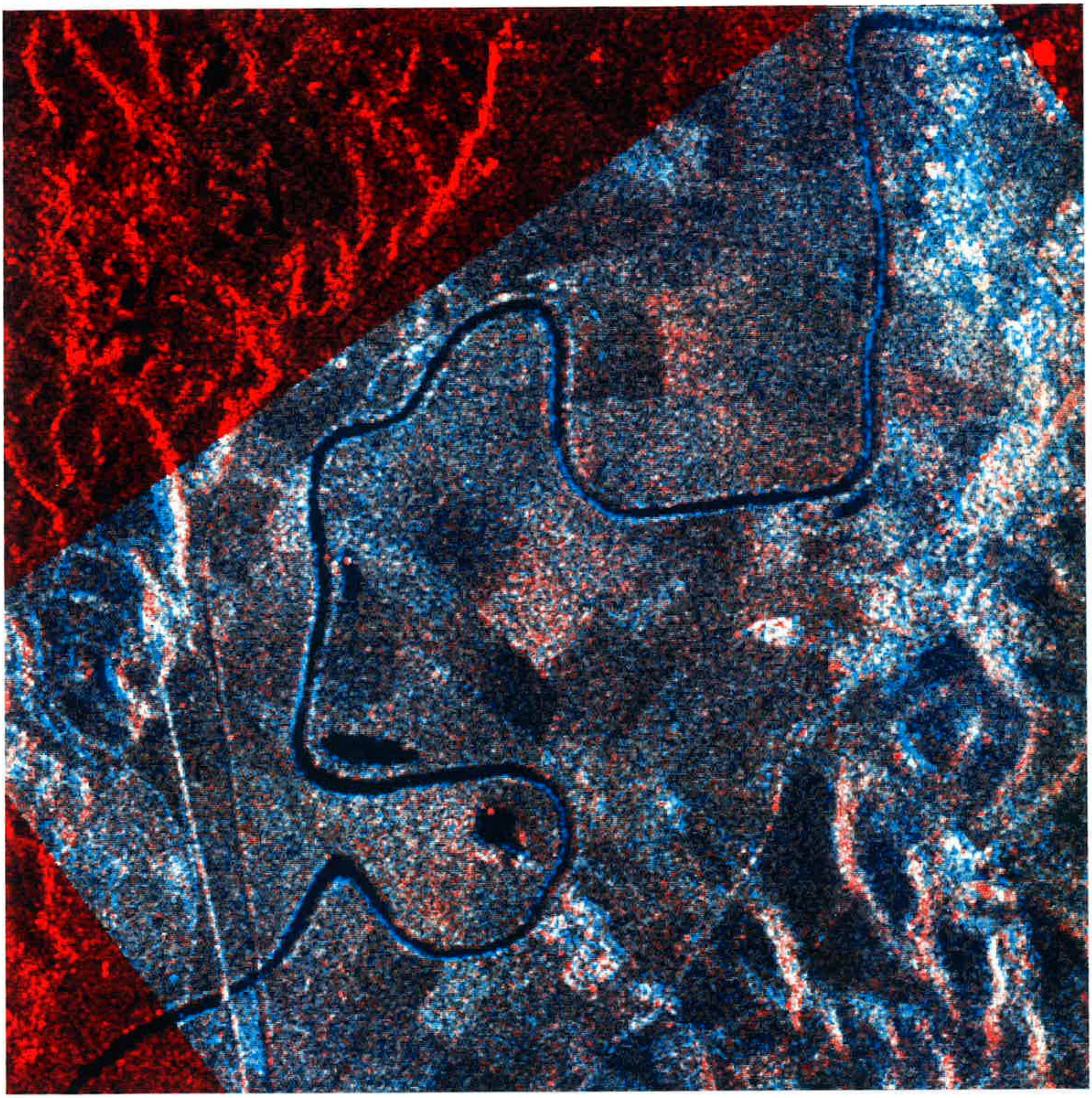

Figure 8: Superimposition of Almaz with ERS-1 radar data (summer images).
Geometry of ERS-1 SAR precision image (PRI).

The number of looks **n** for averaged radar image data can be obtained from the following equation

$$1/\sqrt{n} = \textbf{Standard Deviation / Mean Value.}$$

For Almaz image data the number of looks equals 2, that is true. For ERS-1 radar data **n** is between 3 and 4.

Feature 1st-order statistics were defined for some winter scene fragments corresponding to single agricultural fields and settlements.

We have selected the same 8 typical fragments (the first 6 of them are agricultural fields) from each winter scene. The position of the fragments is shown in Figure 6. Calculated results are presented in Table 5.

a)

N	Fragment Statistics	1	2	3	4	5	6	7	8
2.	Max	914	458	545	812	526	557	2415	1576
3.	Mean	194.65	88.00	121.92	183.70	103.73	112.73	317.55	187.25
4.	SD	214.73	97.04	132.35	131.19	125.56	125.14	424.28	240.23
5.	Mean/SD	0.91	0.91	0.92	1.40	0.91	0.90	0.75	0.78
6.	n	1	1	1	2	1	1	1	1

b)

1.	Min	0	0	0	0	0	0	0	0
2.	Max	161	160	115	212	119	132	232	231
3.	Mean	36.45	26.18	28.88	42.64	26.27	30.54	57.31	42.18
4.	SD	39.09	28.66	30.60	30.22	30. 65	32.38	63.13	50.50
5.	Mean/SD	0.93	0.91	0.94	1.41	0.86	0.94	0.91	0.83
6.	n	1	1	1	2	1	1	1	1

c)

1.	Min	0	0	0	0	0	0	0	0
2.	Max	773	658	628	777	611	604	2240	1298
3.	Mean	177.89	109.21	142.20	199.12	101.20	122.49	255.28	157.46
4.	SD	196.90	125.60	155.84	147.85	125.29	135.12	360.46	197.92
5.	Mean/SD	0.90	0.87	0.91	1.34	0.81	0.91	0.71	0.80
6.	n	1	1	1	2	1	1	1	1

Table5. Feature 1st-order statistics for winter radar image data:
a) R0301R.LAN (ERS-1, 03.01.1992) P1-P8 (band 1);
b) IM21TR.LAN (Almaz, 08.01.1992) F1-F8;
c) R1501R.LAN (ERS-1, 15.01.1992) P1-P8 (band 3).

From the evaluation of calculated statistics and graphic histograms it can be concluded that the statistical laws of values distribution is similar for Almaz and ERS-1 data. Both of them are close to the Reley's law of distribution.

7. CONCLUSION

Geometric, information and statistical characteristics of Almaz and ERS-1 radar image data were defined and analysed. The results obtained have shown that joint analysis of both kinds of imagery is possible and expedient after data preprocessing and image-to-image registration.

The integration of rectified image data into a single synthesized colour image is a useful approach to detailed land-use interpretation in combination with collateral non-image data. The accuracy achieved using precision image data was better than 20 meters, which makes possible the generation of land-use maps for flat areas at a scale of 1:50,000 and their revision right up to a scale of 1:25,000.

Studies should be continued to investigate some interesting effects, such as edge migration, shadow differences or change in the reflectance properties of an object with changing incidence angle of radar radiation. Further investigations should also include detailed land-use mapping and crop discrimination with the support of fieldwork data.

AKNOWLEDGEMENTS

I am most grateful to my scientific leader at ESRIN, Jurg Lichtenegger, whose fruitful ideas and constant encouragement served as a basis for this investigation. I'd also like to thank V. Kaufmann (Graz University of Technology, Austria) for his kind support.

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