Some Experiments on Relief Mapping from Space Using Microwave and Optical Image Data: Looking at the Badlands in Southern Italy

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ABSTRACT

This paper describes the methods employed in and results obtained from experiments on relief mapping using panchromatic SPOT-1, ERS-1 SAR, and spectrozonal KFA-1000 stereopairs, as well as a single high-resolution KVR-1000 image. The experiments have been carried out in order to investigate the potential of the above-mentioned spaceborne images for geomorphometric mapping. The emphasis is on generating digital elevation models (DEMs) and detecting relief changes.

In principle, two stereo mapping methods have been considered and analyzed: a classical/hybrid method using analogue images with an analytical plotter and a semi-automatic method using digital images and image correlation techniques. Analogue images may be either original ones or may be derived from radiometrically enhanced digital image data exposed on film.

A badland prone area in the Basilicata region, Southern Italy, was chosen as a study area to convey the practical work. As a reference for accuracy analysis large-scale aerial photographs were taken.

INTRODUCTION

The study area, 300 km^2, is located in the Basilicata region, Southern Italy, at 40°10' N latitude and 16°20' E longitude (figure 1). For many years it has served as a site for geomorphological survey and mapping exercises by ITC students (Verstappen, 1983). Furthermore, in 1990 this area has been selected by the Institute for Applied Geodesy and Photogrammetry as a study area for geomorphometric and topographic mapping in order to investigate new methods of mapping using terrestrial, airborne and spaceborne image sources.

The main part of the study area is confined in the N by the Sauro river, and in the S by the Agri river. The landscape, severely affected by soil erosion, landslides and other mass movements, is hilly to gently undulated and includes also some vertical cliffs in the W. Elevations rise from between 120 to 980 m. Main settlements are Sant' Arcangelo and Aliano.

Due to various reasons, e.g., geology, earth quakes, soil type, Mediterranean climate and human impact, this area

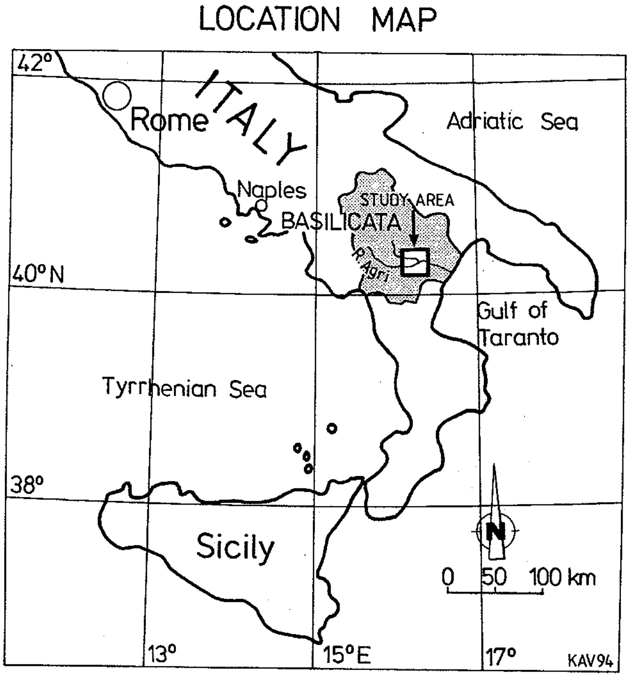

Figure 1 - Location map.

has to a great extent turned into a so-called "badland" with its characteristic morphology, e.g., earth cones and piping gullies, (Alexander, 1982; Guerricchio and Melidoro, 1982). Lack of vegetation, steep slopes, high drainage density, shallow to non-existing regolith, and rapid erosion rates inhibit agricultural use in badland areas (Howard, 1994). In the framework of a large irrigation project, the chaotic badland topography is smoothed out systematically by means of bulldozers in order to increase the arable land. In November 1980 a fatal earthquake occurred in Southern Italy which also hit this area and drove the inhabitants of the small village Alianello from their homes. New settlements were built at safer places.

A digital elevation model (DEM) of the study area has to be generated in order to facilitate geomorphological studies, e.g., hazard zone mapping, and to obtain relief information for precise rectification of the available remotely sensed data. In the framework of this study topographic mapping, especially map up-dating, has also been accomplished. Time series of airborne and spaceborne photographs show how the landscape has changed in the course of the past 40 years. The biggest changes took place in the past 10 years.

1. STEREOSCOPIC RELIEF MAPPING

Topographic mapping and orthophoto production using aerial photographs have been well-understood techniques for metric and thematic documentation of the earth's surface since many decades. Nowadays, satellite-borne earth observation systems offer the possibility of monitoring and mapping the earth in various spectral bands, different spatial and radiometric resolutions, and in repetitive time intervals. In regard to availability and spatial resolution of spaceborne image data not only small-scale but also large-scale mapping is getting more and more exciting, in particular when working in the digital domain.

Three experiments have been conducted in the study area based on spaceborne microwave and optical image stereopairs. The main goal has been to generate a digital elevation model which could be used later on for rectifying the image data itself. A DEM is also required for various geoscientific applications as discussed in (Buchroithner, 1993).

Two different methods in stereo mapping from space were investigated in detail (Kaufmann, 1993):

1. Classical or hybrid method using film transparencies with an analytical plotter,
2. Semi-automatic method using digital images and image correlation techniques.

1.1 Classical or hybrid method

This method is based on the conventional photogrammetric evaluation of stereopairs using analogue images (photographic film or paper print). The classical method uses original film material or equivalent copies, whereas in the hybrid method the original, digitally acquired image data has to be recorded on film first. The digital data set may be geometrically corrected and cleared of systematic errors or any other known image distortions as well as radiometrically enhanced before digital-to-analog conversion. The hybrid method offers some convenient advantages: e.g., existing hard- and software can be used, no digital photogrammetric workstation is needed, the area of interest can be selected freely, and the desirable image scale can be determined to a certain extent.

In the presented study a KFA-1000 stereopair was evaluated in the classical way, two ERS-1 stereopairs and a SPOT stereopair were treated applying the hybrid method. The hybrid stereo-photogrammetric as well as the stereo-radargrammetric evaluation have already been described in detail (Kaufmann *et al.*, 1994; Raggam, 1984; Raggam *et al.*, 1987). It is important to mention that the digital-to-analogue conversion in this study was not performed on a high-performance film writer. Instead, transparencies on 35-mm film were produced at a low price using a Quick Color Recorder (QCR-Z) from Matrix Instruments Inc.

The geometric fidelity of this recorder has been investigated carefully. Repeatedly, a regular grid was exposed on 35-mm film for calibration purposes. Its image coordinates were measured by means of a monocomparator. Since the implemented software on the DSR-1 of Kern only takes systematic affine image distortions into consideration, an affine transformation was selected to analyze the image distortion. Unfortunately, the observed distortions on the left-hand side of the slide are quite large, some 70 µm. Because of this, the area for stereo compilation had to be restricted to the dashed line as shown in figure 2. Within this area the expected film/image distortions are less than 1 pixel (≅ 17.5 µm) in both coordinate directions.

The parameters of the model set-up with the analytical plotter are then directly used in the rectification process

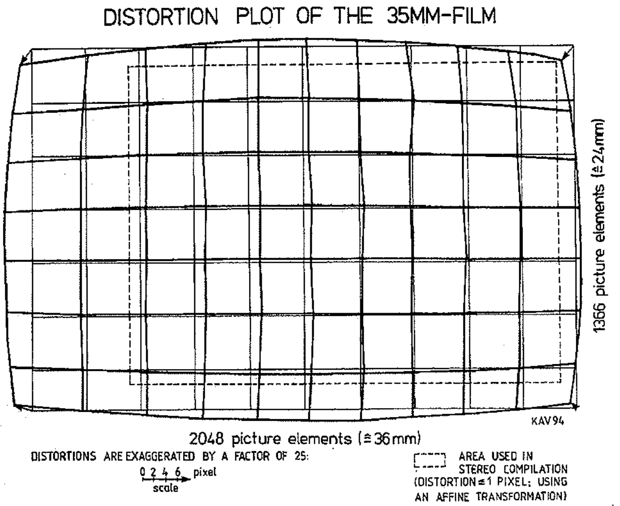

Figure 2 - Image distortion plot of the 35mm film.

of the digital image data. If a digital orthoimage of an analogue image is needed, the given image has to be scanned first.

1.2 Semi-automatic method

This method employs digital image data only. The concept of this method is described in (Kaufmann *et al.*, 1994; Raggam *et al.*, 1993; Schnell, 1993). The stereo model set-up for radar and optical images is basically the same as mentioned earlier. Three-dimensional data extraction is based on automatic image correlation techniques. This stereo mapping methodology is implemented as RSG software at the Institute for Digital Image Processing of Joanneum Research Graz, Austria.

In the following, the results of three experiments are presented.

2. PANCHROMATIC SPOT-1 STEREOPAIR

A panchromatic SPOT-1 stereopair was acquired on May 29, 1986 (26.1° L incidence angle), and on August 1, 1986 (21.7° R incidence angle), respectively. The image data was made available as digital Level 1B product. A stereo intersection angle of 47.8° leads to a base-height ratio (B/H) of about 0.9. Since the images were acquired at an interval of two months, significant radiometric differences can be observed, which should hamper not only the three-dimensional space perception of the observer but also the performance of the digital image correlation. Image subsets covering the study area and a smaller test area within the study area were exposed on black-and-white negative 35-mm film at scales of 1:568,000 and 1:284,000, respectively. Parallax free stereo vision was achieved on an analytical plotter DSR-1 of Kern using ground control points from 1:50,000 and 1:25,000-scale topographic maps, and a 1:5,000-scale geomorphological map. The results of the stereo model set-up are summarized in table 1, which also lists the results obtained using the semi-automatic method.

Table 1 - Accuracy of model set-up for SPOT-1

Method	RMSE (Northing)	RMSE (Easting)	RMSE (Height)
hybrid using 1:568,000-scale images	±10 m	±9 m	±7 m
hybrid using 1:284,000-scale images	±5 m	±8 m	±3 m
semi-automatic	±13 m	±14 m	±8 m

Concerning the hybrid method, on-line three-dimensional relief mapping was performed using a Kern GP1-plotter. Contour lines, drainage lines, ridge lines, breaklines and spot heights were digitized in order to establish a digital elevation model, whereas the semi-automatic method yields the DEM by triangulation of irregularly distributed points derived from image correlation. The software package GTM (Graz Terrain Model), which has been developed at the Institute for Image Processing of Joanneum Research Graz, was used to generate the DEMs. The overall quality of the DEMs has been checked within the test area using a high-resolution DEM derived from aerial photographs (dating from 1976) of 1:16,000 scale with a grid spacing of 2.5 m. The respective DEMs were subtracted from each other, numerical results are given in table 2. In addition, axonometric plots of the DEMs confirmed evidently that the DEMs obtained applying the hybrid method are of better quality. In figure 3 a vertical profile through a representative part of the terrain is shown for the DEMs derived using the hybrid method.

Table 2 - Mean shift in height for the SPOT-1 DEM and remaining standard deviation of height differences

Method	Mean Vertical Shift	Standard Deviation
hybrid, 1:568,000 scale	-14 m	±10 m
hybrid, 1:284,000 scale	-3 m	±7 m
semi-automatic	+12 m	±18 m

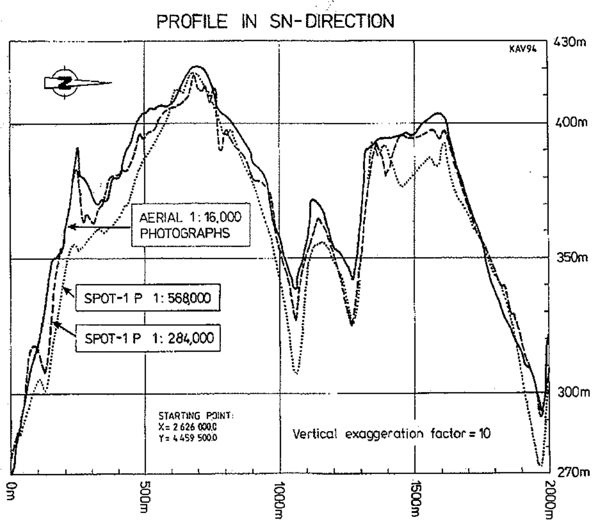

Figure 3 - Vertical profiles derived from SPOT-1 and aerial survey.

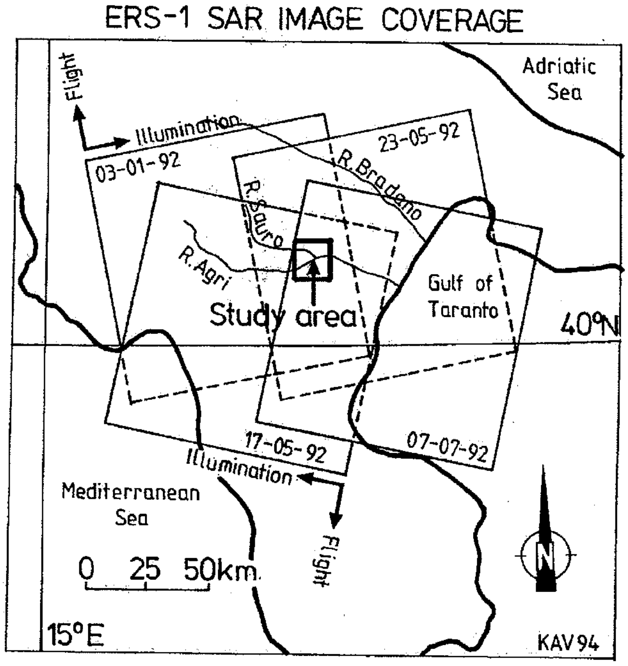

Figure 4 - Coverage of ERS-1 SAR image stereopairs.

3. ERS-1 SAR IMAGE STEREOPAIRS

Three methods can be applied to create DEMs from Synthetic Aperture Radar (SAR) obtained in the imaging mode, i.e., interferometry, shape from shading, and stereo-radargrammetry (Leberl, 1990). In this paper stereo-radargrammetry is considered as a feasible tool for extracting geometric information from amplitude (intensity) radar images. The procedure of stereo-radargrammetric evaluation of gray scale radar images does not differ much from the well-known stereo-photogrammetric one, except for the fact that the underlying imaging geometry is different. Only a limited number of reports have been published on ERS-1 SAR stereo-radargrammetric work (Dowman, 1993; Raggam, *et al.*, 1993; Dowman, 1994; Kaufmann *et al.*, 1994). Various applications in geology and geomorphology (Chorowicz, 1994; Kaufmann, 1993) utilizing ERS-1 SAR stereopairs show that there is a demand for stereo-radargrammetric mapping in order to georeference, e.g., drainage patterns, lineaments, faults, etc., especially in (high)-mountain regions where image distortions are quite large.

Two same-side ERS-1 SAR stereopairs covering the study area, acquired from ascending and descending orbits, respectively, have been selected and were provided in digital format as ESA specified ERS-1 SAR Precision Images with a pixel spacing of 12.5 m. The ground coverage of the four SAR scenes is shown in figure 4.

The January ERS-1 image was acquired during a 3-day repeat cycle (ice) phase, and the other three images during a 35-day repeat cycle (multi-disciplinary) phase. The respective radar stereograms of the study area are documented in (Kaufmann *et al.*, 1994). A multitemporal radar image (figure 5) referring to the same orbit and frame number as given for the image from May 23, 1992, shows the terrain very impressively.

The stereo model set-up of the appropriately filtered ERS-1 SAR sub-scenes has yielded the following results for both the hybrid and the semi-automatic method (see table 3).

For both ERS-1 SAR stereo models contour lines at an interval of 50 m, as well as drainage patterns, ridge lines, other geomorphologically prominent ridges, and spot heights, were digitized in the three-dimensional space of

Table 3 - Accuracy of model set-up for ERS-1 SAR

Model/ Method	RMSE (Northing)	RMSE (Easting)	RMSE (Height)
ascending/ hybrid, 1:710,000 scale	±34 m	±54 m	±29 m
ascending/ semi-automatic	±20 m	±77 m	±35 m
descending/ hybrid, 1:710,000 scale	±27 m	±25 m	±13 m
descending/ semi-automatic	±23 m	±85 m	±38 m

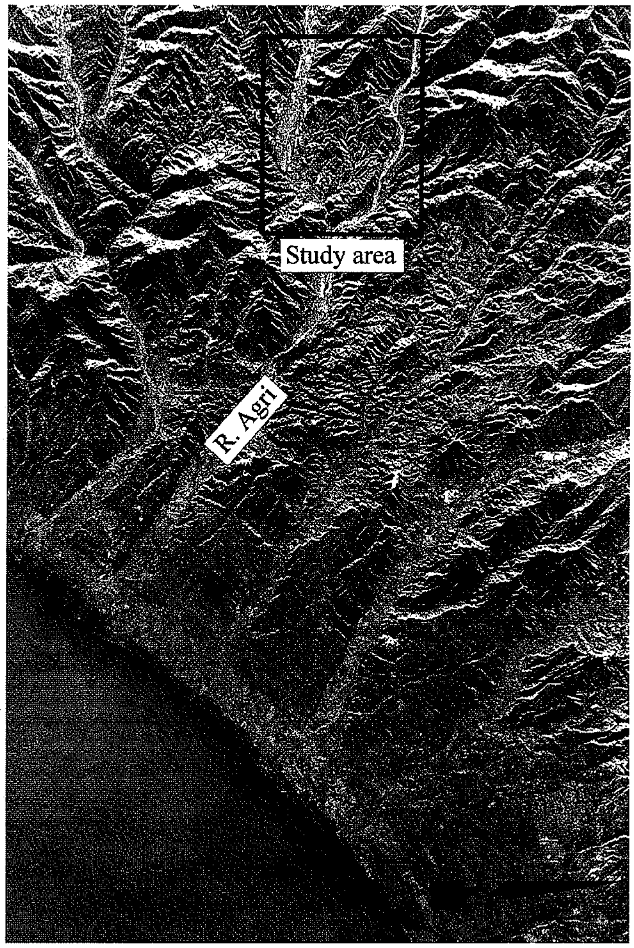

Figure 5 - Multitemporal ERS-1 SAR image. Part of a poster prepared by the I-PAF and presented at the 2nd ERS-1 Symposium, Hamburg, 1993. Courtesy of I-PAF.

the Italian Gauss-Boaga coordinate system. Respective DEMs were interpolated. DEMs were also generated using the semi-automatic method (Schnell, 1993). Problems with bad stereo matching and blunders have been reported (Raggam *et al.*, 1993). The overall quality of the DEMs has been checked on the basis of the DEM derived from SPOT-1. The statistics of the obtained height differences is summarized in table 4. Errors in planimetry significantly contribute to the absolute height accuracy obtainable. Because of the insufficient accuracy of the DEMs the radar images were rectified using the DEM from SPOT-1.

Due to the ERS-1 SAR inherent geometry and speckle noise the errors in planimetry and height observed in line maps and DEMs are obviously quite large. Nevertheless, these errors can be accepted if small-scale mapping, e.g. 1:250,000, is an issue, and even more, if there is no other source of information, e.g., optical data, available.

Table 4 - Mean shift in height for the ERS-1 DEMs and remaining standard deviation of height differences

Model/Method	Mean Vertical Shift	Standard Deviation
ascending/hybrid using 1:568,000-scale images	-54 m	±34 m
ascending/semi-automatic using image correlation	+26 m	±32 m
descending/hybrid using 1:568,000-scale images	-29 m	±32 m
descending/semi-automatic using with image correlation	+6 m	±27 m

4. SPECTROZONAL KFA-1000 STEREOPAIR

The date of survey of the KFA-1000 stereopair is August 22, 1992. The photographs (30 x 30 cm^2, 1:240,000 scale) were taken in low-oblique angle (8°) to the right hand side in flight direction. Because of the small base-height ratio of 0.14 topographic mapping in respect to relief was not performed with the analytical plotter. Instead, the following procedure can be recommended:

- Generation of copies on 23 x 23 cm^2 format film, always including 3 fiducial marks and the study area.
- Relative orientation of these photographs using the given asymmetric radial lens distortion.
- Absolute orientation of the stereo model using ground control points which are located in the study area.
- Scanning of the respective areas in the original photographs.
- Digital rectification using the absolute orientation parameters, lens distortion values and the DEM derived from SPOT.

The KFA-1000 photographs are of good quality, the fiducial marks, however, are not well defined, especially in areas with dark background. Rms-errors between 5 and 15 μm were obtained. Contrary to aerial cameras, which are more or less distortion free, the KFA-1000 camera is subject to quite large distortion values (figure 6). Radial lens distortions of up to 1000 μm in the edges of the frame have to be accounted for in the photogrammetric evaluation process. The relative orientation yielded y-parallaxes in the order of 5 μm, the absolute orientation of the stereo model was performed using 30 control points. The residuals are less than 5 m in planimetry and less than 10 m in height. The actual vertical accuracy of height measu-

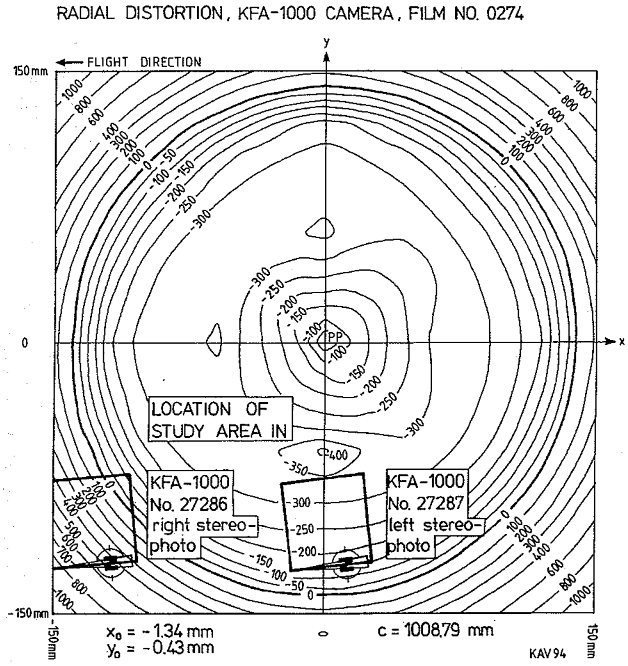

Figure 6 - Asymmetric radial lens distortion of the KFA-1000 camera.

rements is indeed worse than the value specified above (Sirkiae and Laiho, 1989; Jacobsen, 1992).

The original transparencies were scanned using the VX3000 Image Scanning System with a pixel size of 12.5 µm (≅ 3 m ground resolution). Digital rectification has been performed with the software system GAMSAD (Kaufmann, 1984). The pixel spacing of the orthophoto was selected at 2.5 m. Due to the existing relief displacements a projective image-to-object transformation does not fulfill the requirements for high-precision rectification with accuracies in the order of the given ground resolution. If the area of interest covers larger areas or maybe the whole KFA-1000 stereo model, the local geoid, earth curvature and map projection have to be taken into consideration as well (Gross, 1991). The final quality control of both orthophotos derived from the stereopair has been performed stereoscopically. It should be noted that hardly any digital photogrammetric workstation can compensate for asymmetric radial lens distortion.

5. MONOSCOPIC RELIEF MAPPING

Due to the limited spatial resolution of the previously mentioned spaceborne images, the rugged meso-relief of the badland, consisting of earth cones and piping gullies, cannot be identified directly by its gray tone representation in the image. Badland areas were outlined to a certain extent through visual interpretation using texture and radiometric information, i.e., high albedo, in accordance with relief impression and collateral knowledge. High-resolution images from the Russian KVR-1000 photographic system (Marek and Weigelt, 1993), and recently also from the KFA-3000 system (Soellner, 1993), offer new possibilities in large-scale mapping from space (Riess *et al.*, 1993; Kostka and Sharov, 1993; Sulzer, 1993; Marek *et al.*, 1994; Kostka *et al.*, 1994).

5.1 High-resolution KVR-1000 image data

On December 30, 1990, a KVR-1000 photograph was acquired over the study area. The respective part, 169 km^2, of the panchromatic black-and-white photograph was scanned and provided in digital format (DD-5) by the Russian State Center "Priroda". The digital data was also recorded on film. In a first step photographic enlargements of the film were produced on paper up to a scale of 1:5,000. Unfortunately, long shadows are present in the image due to the very low sun elevation at the time of acquisition. However, the badland forms, e.g. the earth cones, which are restricted more or less to the southward facing slopes, are very much emphasized by the illumination of the sun. Such images have always been excellent sources for geologists and geomorphologists. In order to study the changes in topography in more detail a rectification of the digital data into the Gauss-Boaga coordinate system has been performed.

5.2 Orthoimage through Helmert transformation

Little is known about the KVR-1000 camera system and the image geometry itself. Therefore this image was considered as coming from a "black box". As a reference system for geocoding, a GPS-controlled stereotriplet of 1:36,000-scale aerial photographs (1990) was used. 24 evenly distributed control points were measured in both systems. Subsequently, three coordinate transformation models were considered and evaluated. Its results are given in table 5. The ground resolution has been determined as 2.9 m.

Table 5 - Results of image-to-map transformations

Transformation	RMSE (Northing)	RMSE (Easting)	max. Residuals (Northing)	max. Residuals (Easting)
Helmert	±2.0 m	±4.0 m	5.3 m/-3.3 m	7.9 m/-7.9 m
affine	±1.8 m	±3.9 m	4.7 m/-2.4 m	7.0 m/-8.8 m
projective	±2.2 m	±3.3 m	5.5 m/-4.7 m	6.8 m/-9.4 m

Finally, a digital KVR-1000 orthoimage of the study area was computed based on a pixel spacing of 2.5 m. For this procedure a Helmert transformation (scaling, rotation and shifting) was used and found to be appropriate. Figure 7 shows a perspective view of the study area using the DEM derived from SPOT-1 and the texture information from the KVR-1000 orthoimage, respectively. At least for the given example it can be stated that possible distortions induced by the imaging system and the relief do not show significant effects concerning image geometry which is more or less an orthogonal projection.

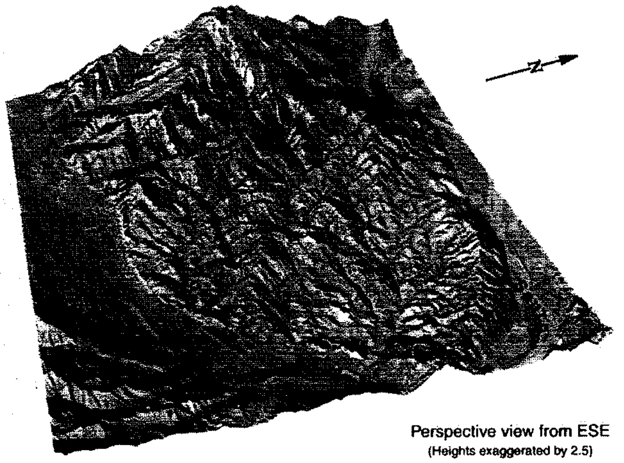

Figure 7 - Perspective view of the study area. The KVR-1000 orthoimage has been draped on the DEM derived from SPOT-1.

5.3 Quality control and map up-dating

The planimetry of the KVR-1000 orthoimage was checked twofold:

- Stereoscopic fusion with orthophotos derived from, e.g. previously mentioned stereotriplets,
- Superimposition of a digital 1:5,000 geomorphological map using CAD-Overlay GSX (Image Systems Technology).

By the way, mixed stereopairs consisting of either a SPOT-1 image or an aerial photograph together with the KVR-1000 image as stereopartner at the same scale can be viewed stereoscopically without problems.

The geomorphological map (situation of 1976) of a badland area east of Alianello available in AutoCAD DXF-format was superimposed on the KVR-1000 orthoimage. In areas with good contrast the existing map could be updated easily, e.g., roads, buildings and smoothed out badland areas (figure 8 and figure 9). As a result, a geomorphological base map at 1:50,000 scale and another study map at 1:10,000 scale are in print.

Figure 8 - KVR-1000 orthoimage showing badland areas east of Alianello. Relief changes are clearly revealed.

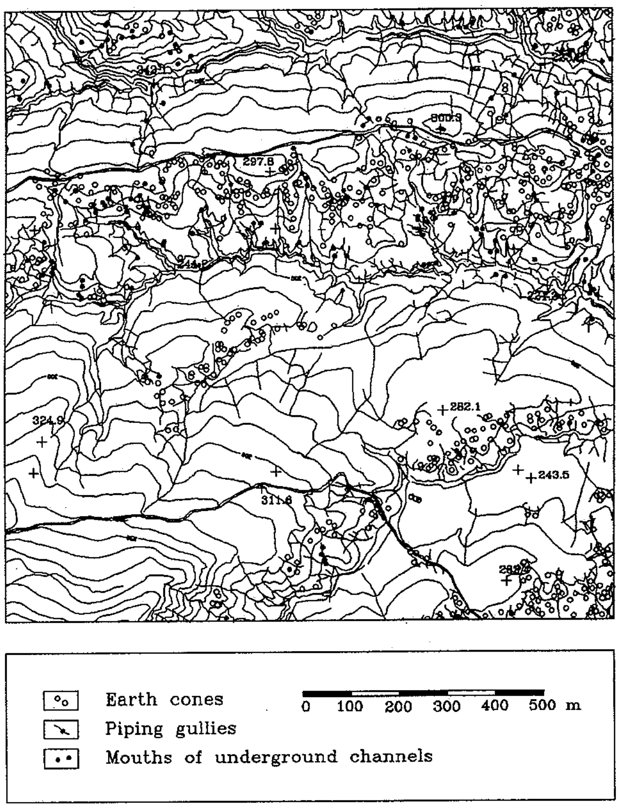

Figure 9 - Modified geomorphological map indicating earth cones and mouths of underground channels. Same area as in figure 8.

5.4 Acquisition time and relative height information

Since the exact acquisition time of the KVR-1000 image was not available from the Russian authorities, it has been estimated by means of astronomy using shadow information obtained from the orthoimage and ephemeries of the sun (The Astronomical Almanac, 1990). The geodetic azimuth direction of more than 10 distinct shadow lines (tall trees, columns of bridges, etc.) were determined in the orthoimage. Using an elevation-azimuth plot of the sun for the day of acquisition, the acquisition time can be interpolated (figure 10). Its accuracy is about ±3 minutes. In the same way the sun elevation may be considered as well, but the measurements are subject to larger errors. Instead, the interpolated sun elevation from figure 10 and the given astronomical azimuth were taken to define the viewing direction, which is identical to the illumination direction of the sun, of an axonometric view of an area where the KVR-1000 orthoimage was draped on a high-resolution DEM with a grid-spacing of 2.5 m. This axonometric view confirmed the derived acquisition time, because all shadows disappeared in the axonometric view as they should. Furthermore, heights of houses, trees and other construction works can be estimated with the given sun elevation.

CONCLUSIONS

Currently, a multitude of earth observation systems each year acquire thousands of images of the earth's surface. As to what type of remotely sensed data has to be selected for a certain mapping project depends on many parameters, e.g, availabilty, resolution, cost and time factor, software and hardware requirements, etc. It has been shown that topographic mapping (in particular relief mapping) from space, utilizing classical, hybrid or digital methods, can be an alternative to conventional aerial photo mapping, always keeping in mind the limitations caused by poor ground resolution and sometimes instable imaging geometry.

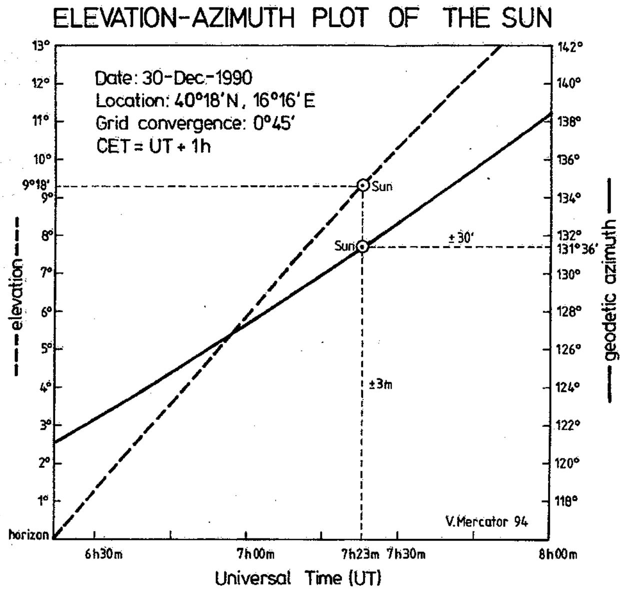

Figure 10 - Elevation-azimuth plot of the sun.

Digital orthoimages from SPOT, KFA-1000 or KVR-1000 are ideal sources for map up-dating in scales ranging from 1:50,000 to 1:10,000. The applicability of DEMs derived from ERS-1 SAR using stereo-radargrammetric methods is limited, whereas the accuracy should be sufficient to georeference mapped features, such as lineaments or drainage lines, to fit a common map projection.

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The ERS-1 SAR images were made available free of charge through the Earthnet Programme Office of the European Space Agency at ESRIN, Frascati, Italy.

The KFA-1000 images were scanned at the Institute for Computergraphics (Head Prof. Dr. F.W. Leberl) of the Graz University of Technology with the help of M. Gruber.

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