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RADAR IMAGE SIMULATION AS A TOOL TO ANALYZE TOPOGRAPHIC EFFECTS ON GEOMETRY AND RADIOMETRY OF RADAR IMAGERY

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I. ABSTRACT

To be able to deal with the huge quantities of digital radar data to be expected from the radar satellites in the 1990's (ESA-ERS-1, RADARSAT, J-ERS-1, VRM) tools must be ready to prepare global image scenes for subsequent applications. This paper describes the image simulation as a tool to analyze the effect of topographic variation on the geometry and radiometry of the radar image. Preliminary conclusions are drawn by comparing the resulting preprocessed image to thematic maps of a pilot application.

II. INTRODUCTION

Radar Image Simulation can provide new capabilities to characterize the geometric and radiometric properties of real radar imagery and to study the characteristics of proposed acquisition configurations under controlled conditions. Due to the critical response of radar imaging systems to terrain topography, exploitation of digital elevation model data over varied terrain is required for the analysis of single radar images and stereo radar imagery. Simulation offers a natural way to relate a digital elevation model to a radar image and thus serves as a powerful tool for interpretation and understanding of radar radiometry and geometry.

In comparison to other simulators, e.g. the Kansas Simulator (Holtzman et al., 1977; Ulaby et al., 1981), the simulator implemented at the Research Center Graz emphasizes the analysis of the geometric and topographic aspects of the radar imaging process. The system has been used so far for investigations into optimal stereo configurations (Domik et al., 1983; and Domik, 1984) and rectification processes (Domik et al., 1984).

III. DESCRIPTION OF TEST SITE

Requirements for a suitable testsite were the availability of radar imagery over an area with topographic variation and the presence of topographic and thematic maps on the same area. The choice was made for the Eastern part of the island Sardegna, Italy, which was imaged during the SIR-A mission in November 1981. Available for the study area were also a topographic map in a scale 1 : 25 000, which was used to create a digital elevation model (DEM), and a geological map with lithological information.

The originally optical SIR-A data was digitized by an Optronics device for further digital processing. A low pass filter was applied to remove the speckle effect and thus enhanced the image quality. Thereby the specific test area was made to fit into the refresh memory of a 512 x 512 pixel DeAnza image array processor IP6400 by using a pixel size of 100 x 100 m^2. The three data sets used for the following investigations are presented in Figure 1.

IV. ELIMINATING THE EFFECT OF TOPOGRAPHIC VARIATION ON GEOMETRY AND RADIOMETRY IN RADAR IMAGES

A. GEOMETRIC RECTIFICATION

The radar image geometry is characterized by layover, foreshortening and radar shadow; these effects depend on flight and imaging parameters (e.g. flight height, elevation angle) and the topography of the imaged area. Many applications of single radar imagery (e.g. cartography) or use of synergistic data sets (e.g. radar data combined with Landsat-MSS or -TM data or/and data from maps) require the use of a geometrically corrected radar image; radar images that display the geometry of a map rather than the layover and foreshortening distortions of the original radar geometry (be it slant range or ground range geometry) are denoted as "Radar Ortho Images".

Naraghi and Stromberg (1981) presented a method to create geometrically rectified radar imagery using a digital elevation model. A similar multi step rectification procedure subsequently involving image simulation, relative registration between real and simulated image and use of the correspondence between object addresses (image coordinates) established during the simulation is presented in this paper.

The flight and imaging parameters used as input to the simulation are extracted from the SIR-A protocoll (Cimino and Elachi, 1982) and displayed in Table I. A homogenous backscatter function for the whole testsite was assumed. Using the digital elevation model (Fig. 1b) and the above mentioned additional information, the simulator models all geometric aspects of the SIR-A sensor, including layover, foreshortening, radar shadow and outputs grey values as a function of the corresponding local angle of incidence. The resulting simulation is displayed in Figure 2. Additionally to the synthetic grey value image a file containing the relation between each object coordinate and corresponding image location is established.

The simulated image (Figure 2) differs from the real one (Figure 1a) in the grey value distribution, because the synthetic image does not account for thematic variation within the image. Differences in the geometries of the two images are quite small and derive from errors in the digital elevation model, lack of knowledge for simulation input parameters, e.g. exact sensor location at imaging time, and processing errors in the real image. These differences are erased using a relative registration procedure to correlate the real image to the geometry of the simulated one. Subsequently, the geometric rectification of the registered SIR-A image is performed by resampling the radar grey values at the terrain cell addresses that can be accessed through the additional address file. The resulting "Radar Ortho Image" (Fig. 3) displays the geometry of the digital terrain model. Thus it also corresponds to the additional thematic data.

This preprocessed data was further used by geologists who evaluated hard copies of the digital products. Besides the advantage of using registered data sets they found the creation of a synthetic stereo model (original radar data and radar ortho image) useful for their investigations.

B. RADIOMETRIC RECTIFICATION

The radar backscatter values are dependent on characteristics of the terrain (e.g. slope, texture, water content) and of the sensor (wavelength, polarization, elevation angle). Whereas wavelength and polarization are identical for all SIR-A images, and thus in particular for one SIR-A scene, only the elevation angle and the terrain properties vary within the image. In contrary to this, the simulator models the grey values with the use of standard backscatter curves, only depending on the incidence angle, which is defined as a function of elevation angle and terrain slope. By substracting the real image from the simulated one, effect of the slopes in the terrain - strongly backscattering foreslopes versus darker backslopes - is decreased, and the thematic features enhanced. In other words, the result is a map of radar brightness with the topographic effects removed. This process is denoted as "radiometric correction" of the radar image.

Removing the effects of topographic slopes from radar images proves the ability for lithological mapping, as different rock types can frequently be identified by their radar scattering characteristics, if the incidence angle has not complicated the scattering distribution. By comparison with the existing lithological map, a small amount of classes could be separated in the corrected radar images by their corresponding grey level.

Figure 4 displays an image, where the real radar gey values were substracted from the corresponding synthetic grey value numbers. Comparing the result to the lithological map shows a differentiation between two geologic classes, denoted with C and G, respectively, by their grey values.

V. INFLUENCE OF THE ELEVATION ANGLE AND TOPOGRAPHY ON THE INFORMATION QUANTITY OF RADAR IMAGES

The specification of future radar sensors for spacecraft raises the question of optimal flight and imaging parameters for various applications. One of the image quality parameters to be investigated is the elevation angle as it influences the information quantity of radar images and thus also its quality.

The elevation angle is defined as the angle between a vector from the sensor position to the nadir and the line connecting sensor position and terrain point. For any specific terrain, layover and foreshortening are high if imaged from near range (low elevation angle) and low if imaged from far range. The opposite is true for radar shadowing: high elevation angles create a bigger amount of shadow. Optimal elevation angles minimize these effects. For spaceborne imaging the value of the elevation angle between near and far range is quite constant (e.g. variation of approximately 6 degrees in SIR-A and SEASAT). The elevation angle of $47^o \pm 3$ used for SIR-A created comparatively low effects of the above mentioned distortions even in rather mountainous areas. A simulation study was performed over the former described test site of Sardegna to evaluate more exactly the loss of information by layover, foreshortening and shadow, which one must expect by using various elevation angles when imaging from the approximate height of the space shuttle.

For this study, ten simulated radar images were created with varying elevation angles ranging from 20 to 80 degrees off nadir. The sensor altitude at imaging time was chosen to be 260 km (app. altitude of Space Shuttle). The amount of each distortion was calculated during the simulation process. Table II gives an overview of the loss of information for the total area. As expected, the high amount of layover and foreshortening with low elevation angles compensates the loss through shadow with high elevation angles. For this specific test site and flight altitude the optimal elevation angle was 60 degrees to the first data point with an information loss of only 15 per cent. Figures 5 to 7 show simulation products using subsequent elevation angles of 20, 65 , and 80 degrees.

VI. CONCLUSIONS

Radar image simulation was used to create a relationship between radar image coordinates and corresponding terrain properties (object address, height, slope). The radar images could be corrected for geometric and radiometric distortions that were due to these terrain properties. Thus preprocessed radar data aid in the application oriented interpretation of radar images. For the example given in this paper, two thematic classes could be visuelly differentiated after geometric and radiometric rectification.

An additional study based soley on simulation investigated the influence of the elevation angle on a specific testsite that can be classified as "rough terrain". The conclusion could be drawn, that the loss of image information due to layover, foreshortening and radar shadow would be minimized using an elevation angle as high as 60 degrees at a flight height of 260 km (average space shuttle altitude).

VII. ACKNOWLEDGEMENT

The above documented results were obtained as part of a study on "The Use and Characteristics of SAR for Geological Applications / Radargrammetric Aspects" sponsered by the ESA/ESOC under contract number 5443/83/D/IM(SC). The topographic and thematic map of the Sardegna testsite were placed at our disposal by Dr. Jaskolla and Mr. Rast from the Institute for Applied Geology of the University Munich. The digital elevation model was created by the system GTM (Graz Terrain Model) at the Research Center Graz.

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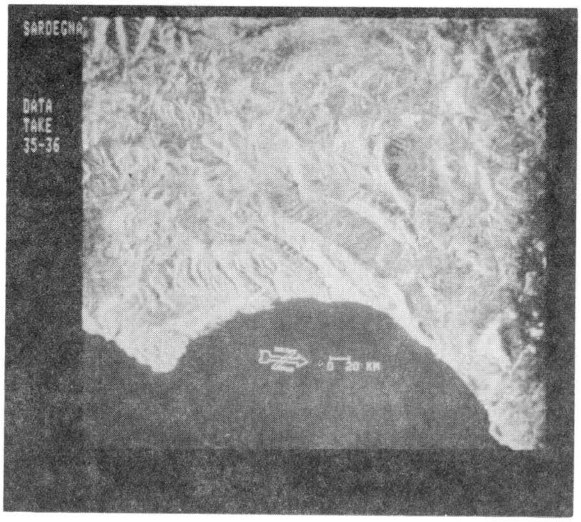

Figure 1a. Digitized SIR-A image of Eastern Sardegna, Italy.

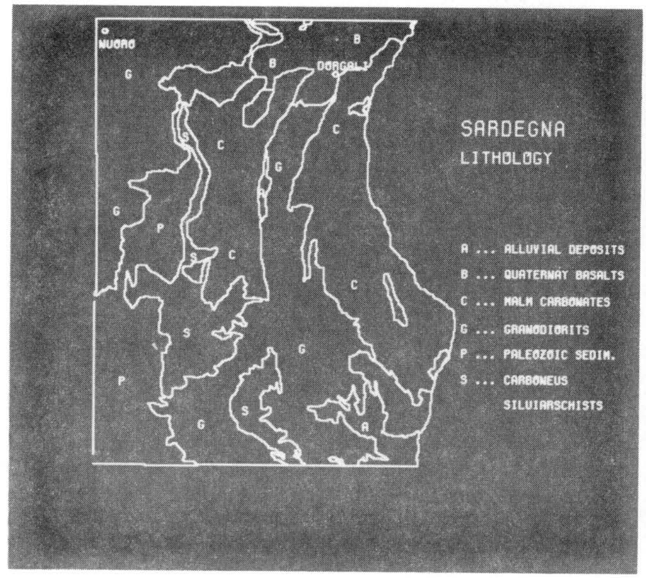

Figure 1c. Lithological map of Eastern Sardegna, Italy. North is up. Same scale as in Figure 1a.

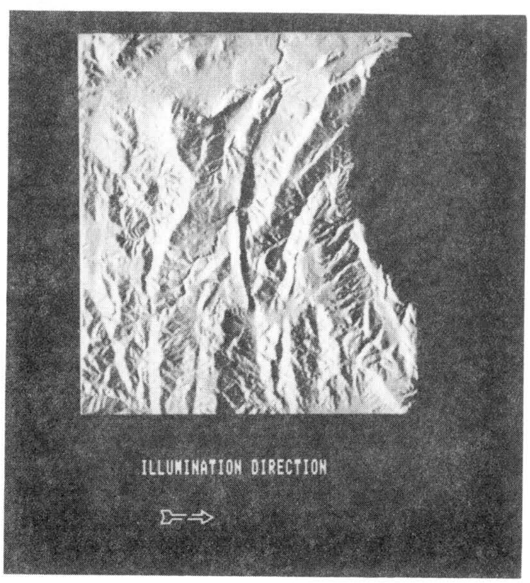

Figure 1b. Illuminated elevation model of subarea of Figure 1a. North is up. Same scale as in Figure 1a.

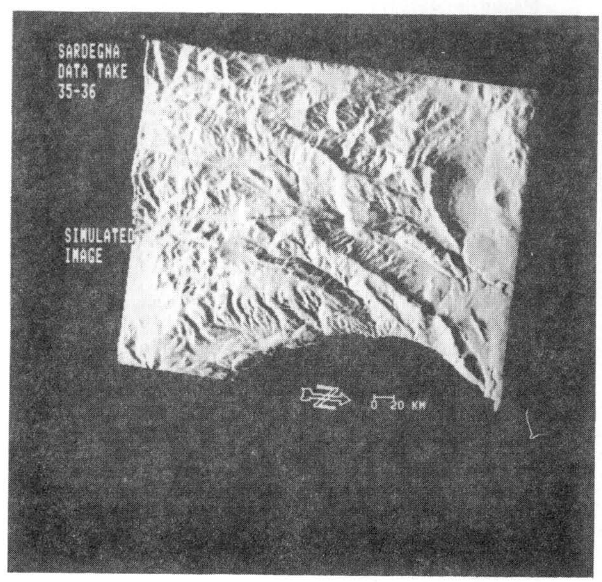

Figure 2. Simulated radar image using input data from Table I and Figure 1b.

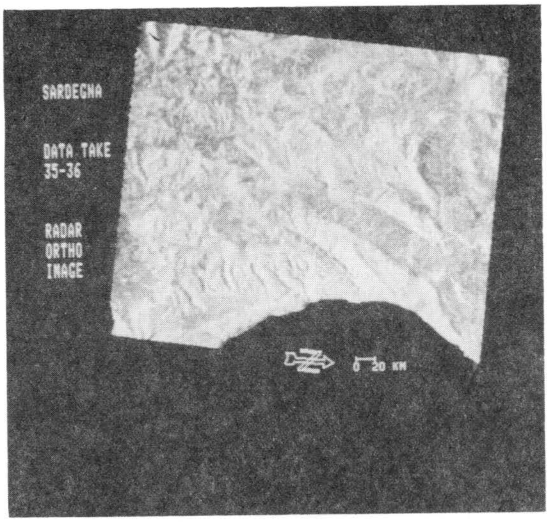

Figure 3. Geometric correction of radar image in Figure 1a.

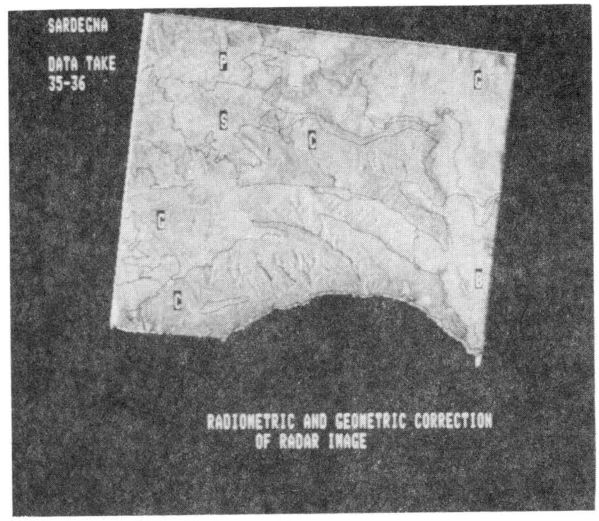

Figure 4. Radiometric and geometric correction of radar image in Figure 1a. Same scale and North direction as in Figure 3.

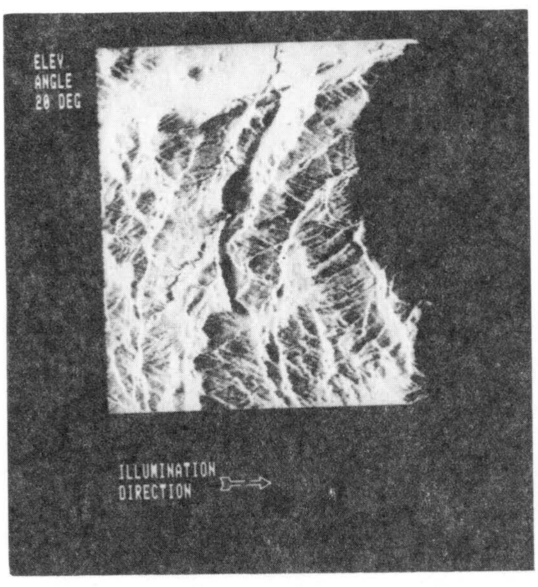

Figure 5. Simulated radar image using input data from Figure 1b and the following additional information: elevation angle 20°

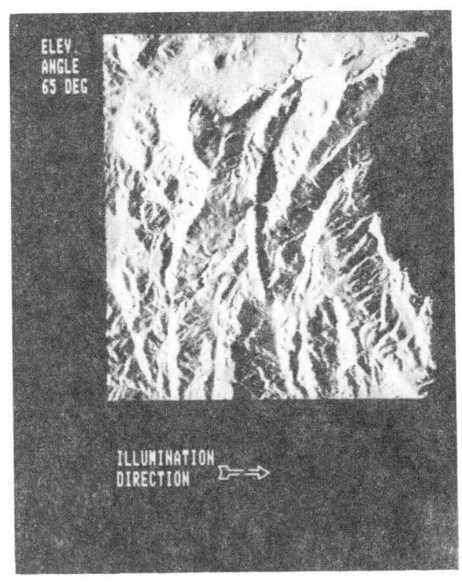

Figure 6. Simulated radar image using input data from Figure 1b and the following additional information: elevation angle 65°

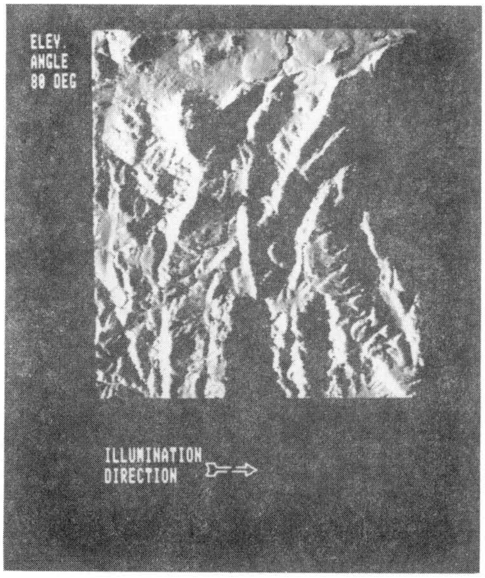

Figure 7. Simulated radar image using input data from Figure 1b and the following additional information: elevation angle 80°.

Flight Altitude	261.21
Number of Sensor Positions	2
Flight direction	97.034° clockwise from North
Digital elevation model Grid cell size	100 m x 100 m
Elevation angle to first data point	45.64°
Slant range to first data point	373.58 km
Slant or ground range presentation	slant range presentation
Backscatter curve	homogen Kosinus
Squint angle	0°

Table I. Sensor and imaging parameters extracted from SIR-A flight protocoll.

EFFECT OF ELEVATION ANGLE ON LAYOVER, FORESHORTENING AND SHADOW

SARDEGNA	Total Area	Relevant Area
%	100	app. 85
km**2	1245	1058.25
Pixel	124500	105825

Elev.Angle (Deg.)	Layover (%)	Foresh. (%)	Shadow (%)	Sum of loss (%)	Sum of loss (km**2)
20	5.03	43.29	0.00	48.32	601.58
30	1.35	35.18	0.06	36.59	455.55
40	0.47	26.36	0.24	27.07	337.02
45	0.12	22.16	0.69	22.95	285.73
50	0.08	18.25	0.97	19.30	240.28
55	0.03	14.65	2.07	16.75	208.54
----60	0.01	11.43	3.48	14.92	185.75
65	0.00	8.53	7.82	16.35	203.56
70	0.00	6.10	13.12	19.19	238.92
80	0.00	2.30	35.97	38.27	476.46
45.64 (SIR-A Data Take 35-36)	0.26	22.65	0.30	23.21	288.96
45.57 (SIR-A Data Take 37A)	0.30	22.07	0.24	22.61	281.50
15.45 (Seasat)	9.66	50.24	0.00	59.90	745.76

Flight Altitude for SEASAT: 795 km
other : 260 km

Table II. Comparison of image quality as a function of elevation angle.