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METHODS AND ACCURACY OF OPERATIONAL DIGITAL IMAGE MAPPING WITH AIRCRAFT SAR

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ABSTRACT

An airborne sidelooking Synthetic Aperture Radar (SAR) system, STAR-1, has been complemented by processing techniques to create a new type of cartographic product: a 1:50,000 radar image map with 100m contour lines. This product is denoted as STARMAP. The paper describes the system, processing steps and some results.

1. INTRODUCTION

Remote sensing imagery increasingly serves the creation of image maps. Widespread examples concern Landsat MSS and TM. The images are digitally rectified with ground control points and mosaicked. Limited cultural detail and names may be added to such image maps. The images are typically assumed to be unaffected by terrain relief; therefore no differential rectification is provided to remove terrain relief displacements.

Using analogue processes, airborne radar imagery (from real aperture and synthetic aperture side-looking airborne radars) has been mosaicked and registered to ground, typically at scales of 1:250,000 or less. Recently, digital imagery from INTERA's STAR-1 radar has been digitally mosaicked and ground registered (in press). In these examples, however, no account has been taken of relief displacement effects, which can displace a target pixel by several hundred meters per kilometer of target elevation above the average terrain.

This paper reports on a refined radar mapping product in analogy to classical photogrammetric ortho-photo maps. The product takes the form of a true radar image map at scale 1:50,000. with contour lines. The terrain elevation data are obtained from radar image pairs using stereo-mensuration. The result is a digital elevation model (DEM). Individual images are then differentially rectified using the DEM. The ortho-image is combined with computed contour lines into an image map. We have previously reported on this capability (Mercer et al., 1986). We review in the current paper the available input data with additional evaluation of accuracies.

2. RADAR AND CONTROL DATA

The radar image map was produced form a set of 5 overlapping Synthetic Aperture Radar (SAR) images in a configuration illustrated in Figure 1. The system used is STAR-1*, a digital fully focussed x-band SAR (Nichols et. al, 1986). Geometric resolution is 6 m in range and 8 m in azimuth.

In the configuration used, coherent speckle is minimized by averaging 7 looks. The aircraft typically flies at an altitude of 10 Km A.S.L. Look angles range from 51° to 75° off nadir.

Processing of the raw radar signal is done in real-time in an onboard digital processor. The resultant image is recorded aboard the aircraft on High Density Digital Tape (HDDT) for subsequent transcription to Computer Compatible Tape (CCT). Aboard the aircraft the iamgery is also viewed in real-time for quality control purposes and may also be downlinked to ground stations in certain applications such as ice mapping in support of Arctic drilling or maring transport activities (Mercer et al 1986).

The application referenced in this paper is topographic mapping, and for this purpose an area about 1000 km² was imaged in April 1986. The area, about 200 km north-west of Calgary, includes the Brazeau Mountain mountain range and a variety of topographic relief. Moreover, there is a reasonable set of ground control points which can be extracted from existing topographic maps as described below.

The imaged area is 24 kms x 24 kms. The images cover a swath of 24 kms and have an overlap of 16 kms. However, stereo models are formed by non-adjacent images that have an overlap of 8kms to provide large stereo intersection angles. These average from 11°7 to 21°. The 5 images form 3 stereo models as follows: images 1+3, 2+4, 3+5. Figure 2 illustrates the density and distribution of about 60 ground control points. These were taken from 4 existing official Canadian NTS maps at scale 1:50,000. Each individual stereo model covered only a portion of the control points. Navigation data were not available for aircraft the project except for the flight log.

3. DECISION ON PRESENTATION SCALE

Considerations about the presentation scale depend on geometric accuracy and a resolution of details. It is frequently argued, for example by Colvocoresses (1986) that about 3 pixels should be presented in a millimeter. This is why Landsat-MSS data are shown at scale 1:250,000, Thematic Mapper data at 1:100,000 and SPOT at 1:50,000. If we consider classical orthophotography, the argument is made that enlargements between the original negative and the final presentation should not exceed a factor of 11. Assuming an equivalent pixel size in an original aerial made that enlargements between the original negative and the final presentation should not exceed a factor of 11. Assuming an equivalent pixel size in an original aerial photograph of 10μm, the enlargement would place 9 pixels in a millimeter. The space image consideration would suggest that a radar image with 6 m pixels can be presented at a scale 1:25,000. The orthophoto consideration would suggest a scale of 1:50,000.

This is the reason to select a scale 1:50,000 for the radar image map. It needs to be investigated whether planimetric accuracy supports that choice. If we permit an r.m.s. planimetric error of $\pm$0.75 mm to exist in the image map we need to achieve an accuracy of $\pm$37 m on the ground. We will show that this accuracy has been surpassed in the mapping process.

4. THEORETICAL CONSIDERATIONS

The limits to SAR mapping accuracy are currently not well understood. Experimental data are dominated by the results of Space Shuttle Imaging Radar SIR-B work. However, the resolution, look angles and speckle are entirely different from STAR-1. SIR-B coordinate accuracies are typically about 5 resolution diameters.

Accuracy limitations can be studied by propagating the range error into an error of the stereo model coordinates. This is a limiting error in the sense that it assumes that all other errors are negligible apart from the uncertainty implicit in the range measurement. In reality, there are other effects that appear to dominate, such as irregular platform motion, uncertainties in pointing to homologue points of interest in the stereo pair and uncertainties of matching ground control with radar features. As will be shown below, these translate into observed inaccuracies somewhat larger than the theoretical expectation. The common method of expressing this error is the following, based on the two look-angles off-nadir, θ', θ'':

$$\sigma_{height} = \sigma_{range} \, (\sin^2\theta' + \sin^2\theta'')^{1/2} / \sin(\theta' - \theta'')$$

$$\sigma_{crosstrack} = \sigma_{range} \, (\cos^2\theta' + \cos^2\theta'')^{1/2} / \sin(\theta' - \theta'')$$

This expression is widely used for radargrammetric work. It has been recently discussed by Leberl et al. (1986).

Table 1 contains numerical values for the STAR-1 stereo configuration. The look angles θ', θ'' are chosen at the near-range and far-range edges of the stereo-overlay. The stereo-intersection angle $\Delta\theta$ ranges from 11.7° to 21°.

The standard error of slant range, σ_{range}, is not identical with range resolution. In the absence of accepted statements on this relationship it is assumed that σ_{range} is 1/2 of the range resolution, or $\pm$3m.

Therefore the theoretical limit to the STAR-1 height accuracy would be ±10m in the near range and ±19m at the far range; the cross-track accuracy would be ±6m to ±7.5m.

A major factor in not achieving such accuracies is the thematic disparity of the two overlapping images: this disparity of course is caused by the difference of illumination, the very element that is needed to obtain relevant geometric disparities. No quantitative data exist to explain the trade-off between good geometric disparity and undesirable thematic disparity.

5. STEREO MAPPING AND DIFFERENTIAL RECTIFICATION

The digital STAR-1 pixel arrays (4000 x 4000 pixels to cover 24 kms x 24 kms) are preprocessed for various data defects: missing lines, gray value artifacts, scale differentials, etc. and converted to film images. The film is used in a photogrammetric stereo plotting instrument for collection of a DEM grid and terrain break lines. Data collection consists of the definition of an inner orientation, stereo model set-up using ground control, and actual measurements of surface points.

Stereo model set-up is based on the computer program SMART for stereo mapping with radargrammetric techniques and has for example been described by Leberl et al. (1986).

The DEM measurements are somewhat irregular and therefore need to be interpolated into a dense regular grid of terrain heights; in addition contour plots of the area are created (Figure 3). The contour interval can be selected arbitrarily. However, accuracy considerations lead one to select a 100 m interval. We supplement this with 50 m intermediate contours for a more continuous description of terrain shape.

The DEM grid is the basis for a digital image rectification system: The SAR pixels are matched with the DEM so that then a resampling step can remove the effects of topographic relief displacement. The rectified pixel array is again written onto film and subsequently combined with the contour lines and a map frame to create the final radar image map.

6. ACCURACIES AND DISCUSSION

Figure 4 presents the final "STARMAP*" which is the radar image map described above. Both the height and planimetric accuracies can be evaluated by comparing the radar map with a traditional map at scale 1:50,000.

The height comparison is achieved with the help of a map-derived DEM. Figures 5a and b show perspective views of the radar and map DEM. Differences can be quantified by subtracting the heights. One will notice that height errors are larger where radar shadows exist. We present therefore the r.m.s. height differences in smaller windows as shown in Fig. 6 . The differences are less than ±30m if no shadows exist in the radar data.

A North American mapping standard requires that 90% of all points interpolated from a contour map should be in error by less than one-half of the contour interval. Relating this statement to the R.M.S. error of ±30m, suggests the foremetioned contour interval of 100 meters as appropriate for this radar image map. Fifty meter sub-intervals are also computed. Because this is an image map, fine scale fluctuations of terrain elevation of much lesser amplitude than the contour intervals are readily apparent.

While the uncertainties quoted relate to absolute vertical coordinates, it was demonstrated that on a relative scale, 10-15 meter elevation accuracies could be achieved in localized areas.

A separate planimetric accuracy evaluation is based on a set of check points that one extracts from both STARMAP and a classical topographic map. Based on 16 check points the random horizontal differences amount to:

Error of north = ±29m r.m.s.
Error of east = ±33m r.m.s.

A concern in STARMAP is the dense grid of ground control points. This will be eliminated in an ongoing developmental phase by use of inertial navigation and global positioning data for the aircraft. We will report on those results as they become available.

7. CONCLUSION

A unique and previously unavailable cartographic product has been presented: a radar image map at scale 1:50,000 with 100m contour interval and 50 m supplemental contours. The usefulness of this product is seen in areas of poor photographic coverage and of a need for rapid mapping results. The planimetric resolution of 8 pixels/mm and accuracy of ±30m fully justify a choice of scale 1:50,000. The height accuracy of ±30m permits one to present a 100m contour interval. The stereoradar height accuracy is certainly sufficient to support the differential rectification for acceptable planimetric accuracy. The 100m contour interval is large for a scale of 1:50,00. However, one should realize that radar presents a very distinct enhancement of topographic expression in the image. The contour lines have not been a common feature of Landsat image maps. Therefore the 100m contour lines (with 50m supplements) supports height measurements off the radar image map in a manner unavailable from Landsat image maps.

An additional technological development that is being integrated into the production chain is the use of inertial navigation and global positioning data for decreased reliance on expensive ground control.

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REFERENCES

Colvocoresses, A. (1982) "Image Mapping with the Thematic Mapper." Photogrammetric Engineering and Remote Sensing, Vol. 52, No. 9, pp. 1499-1505.

Leberl F., G. Domik, J. Raggam, J. Cimino, M. Kobrick, (1986) "Radargrammetric Experiments with Space Shuttle SIR-B Imagery." Proceedings of the ISPRS - Commission II Symposium, Baltimore, USA.

Mercer J.B., R.T. Lowry, F. Leberl, G. Domik (in print) "Digital Terrain Mapping with STAR-1 SAR Data." Proceedings of IGARSS '86, Zurich.

Mercer J.B., E. Leavitt, R. Lowry and G. McAvoy (1986), "Advanced Radar Systems for Support of Arctic Marine Operations", Proc. Intnl. Polar Transportation Conference (in press), Vancouver, British Columbia.

Nichols, A.D., J.W. Wilhelm, T.W. Gaffield, D.R. Inkster and S.K. Leung (1986). "A SAR for Real-time Ice Reconnaissance", IEEE Trans. on Geoscience and Remote Sensing, Vol. GE-24(3), p. 393-389.

Roessel, J. van and R. de Godoy (1974) "SLAR Mosaics for Project RADAM," Photogramm. Eng., XL.

Table 1: STAR-1 theoretical accuracies based on propagation of range error due to limitation of the range resolution.

Look Angles θ'	θ''	$\Delta\theta$	$\sigma_{height}/\sigma_{range}$	$\sigma_{cross}/\sigma_{range}$
71.6	50.5	21	3.4	2.0
75.3	63.6	11.7	6.5	2.5

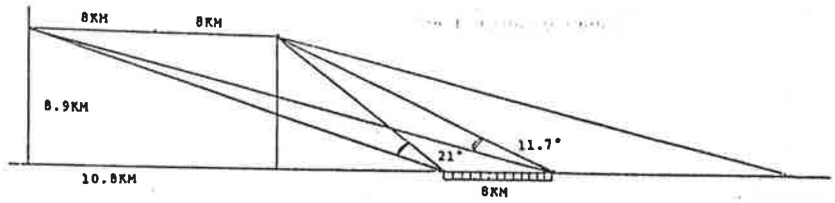

Figure 1: STAR-1 imaging configuration for stereo radargrammetry.

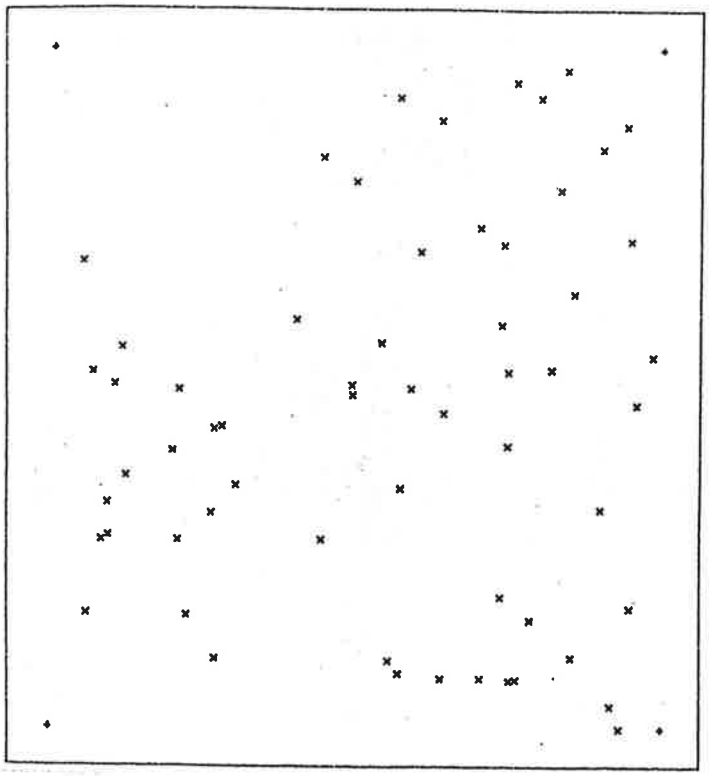

Figure 2: Distribution of ground control points in the Brazeau area, covering about 30 kms x 25 kms.

To be reduced to 75% of present size

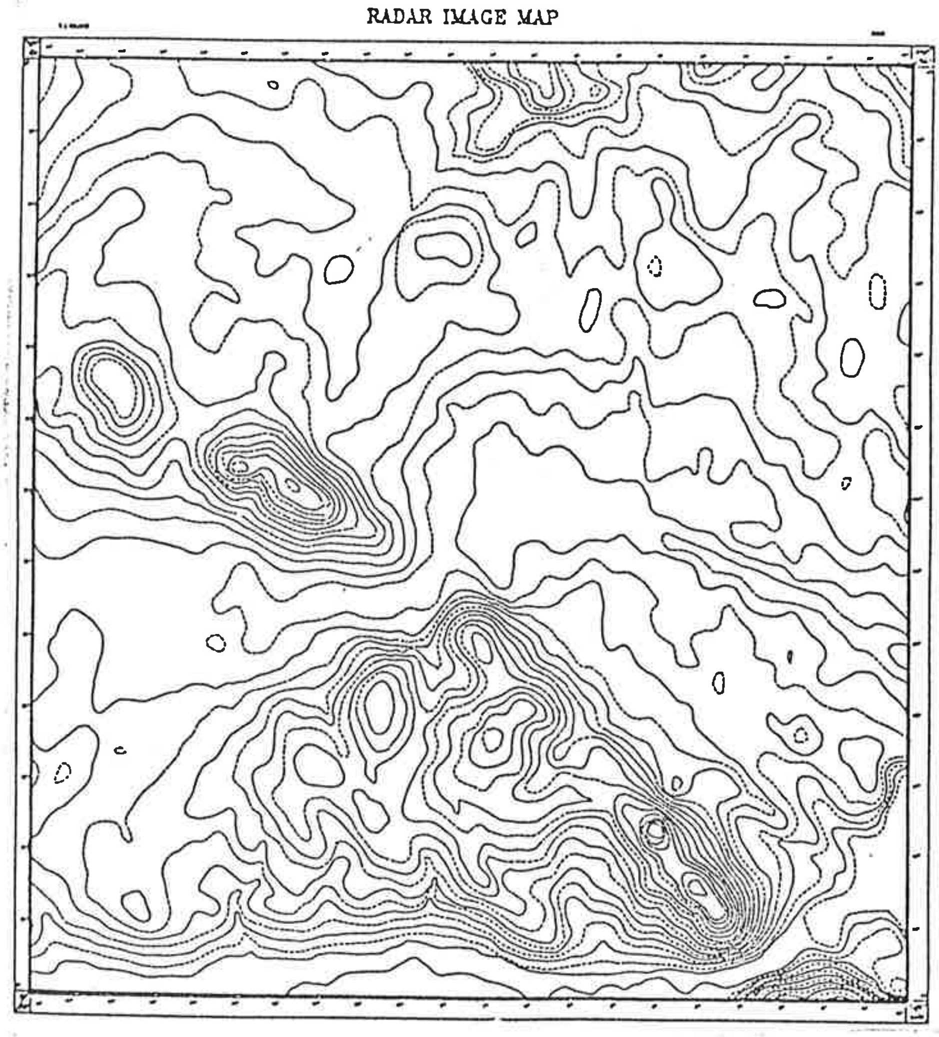

Figure 3: Contour plot at 100 m interval (with 50m supplementals) produced from the digital elevation model that was measured from STAR-1 stereo radar.

RADAR IMAGE MAP

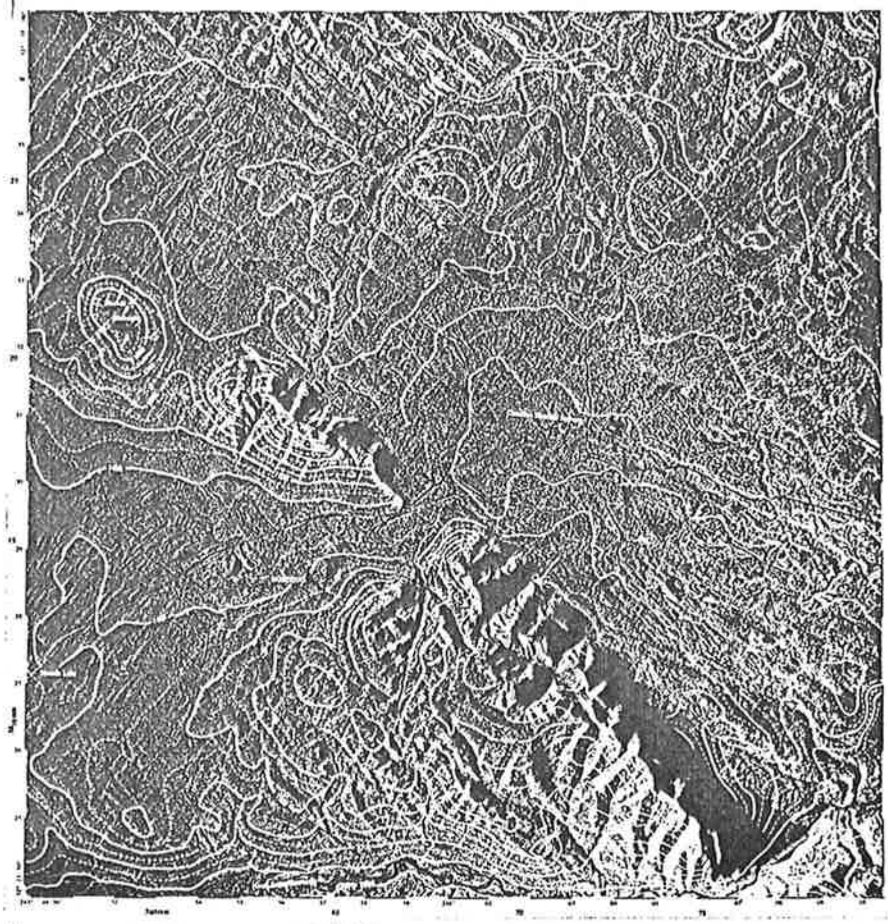

Figure 4: STAR MAP of the area near the Brazeau range, 200 kms North of Calgary, Alberta. Radar image taken with STAR-1, 3cm wavelength.

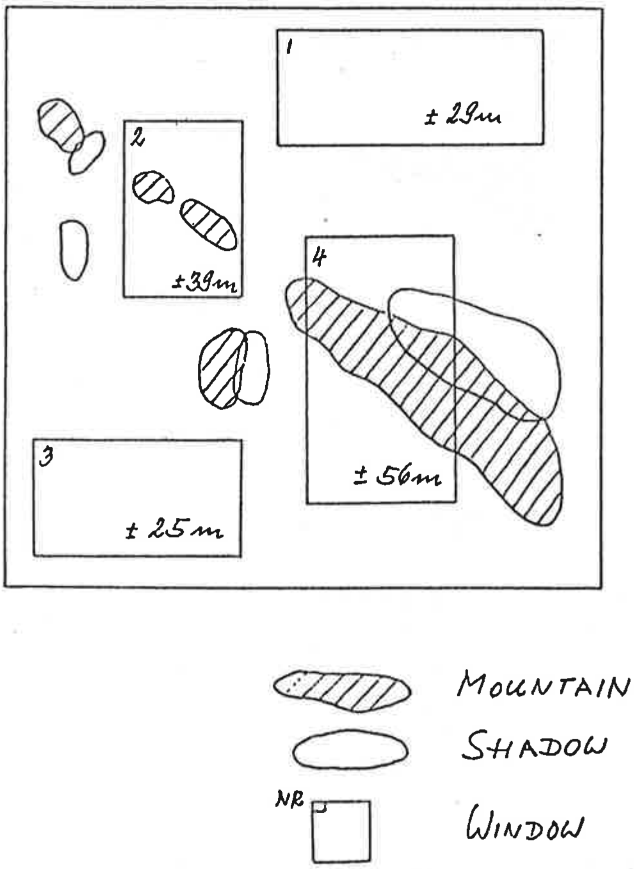

Figure 6: Differences in meters (r.m.s.) between radar- and map-derived DEM.

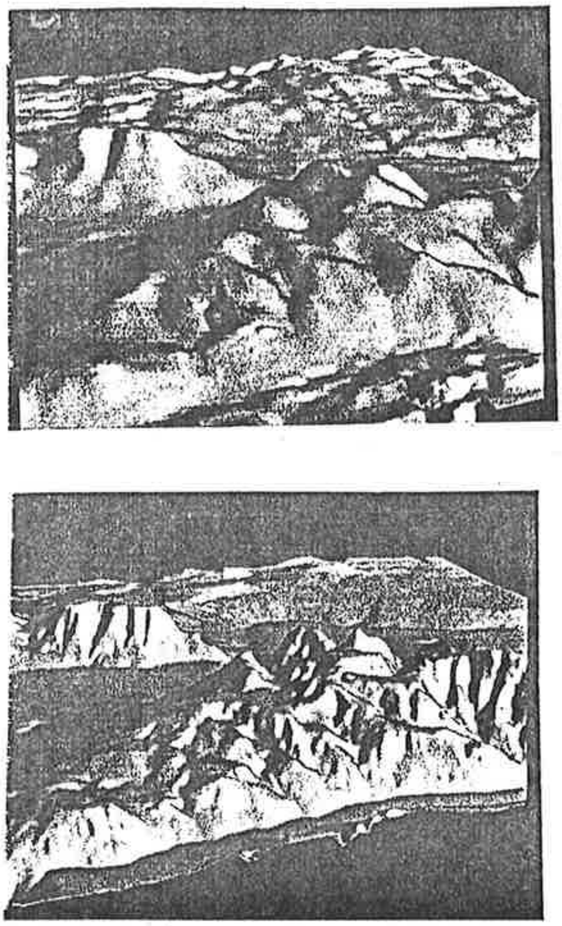

Figure 5: Perspective views of (a) the radar-derived DEM, (b) the map derived DEM.