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Radargrammetric Point Determination „Proradam"

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1. Introduction

The present paper reports on the Colombian mapping project PRORADAM. This name stands for „Projecto Radargrametrico del Amazonas" and refers to a reconnaissance type of mapping project using airborne sidelooking radar imagery, covering southern Colombia, about 360,000 km² (see figure 1). The prime cartographic product was to be a set of mosaics in the Colombian **Gauss-Krueger** projection at a scale of 1 : 200,000.

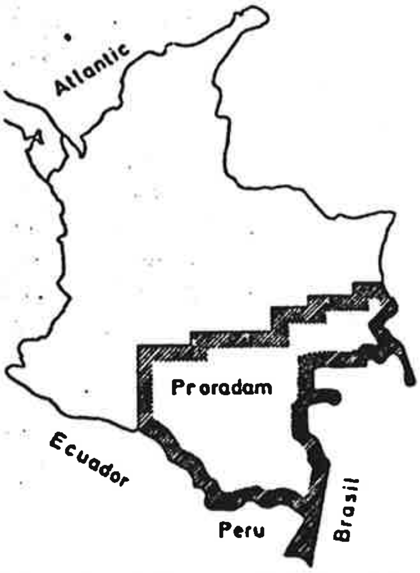


Figure 1 Project area PRORADAM within Colombia, covering nearly 400000 km².

By now the entire Amazonas basin is covered by SLAR imagery. However, compared to the Brazilian, Venezuelan and Peruvian projects, the Colombian PRORADAM represented a novelty as for the first time the metric base for mosaicking was produced through a block adjustment with the SLAR imagery. In other projects, the Brazilian or Peruvian, precise auxiliary data (aircraft tracking by SHORAN) were considered to render such adjustment superfluous; or, as in Venezuela, mosaics were simply uncontrolled.

In Colombia the previously mentioned auxiliary data were not measured. But a 60 % sidelap between adjacent image strips, as well as the presence of 44 ground control points, made it very logical to attempt an adjustment. The work was carried out by the International Institute for Aerial Surveys and Earth Sciences (ITC, Enschede, Netherlands) under a contract with Aero Service Corp. of Philadelphia. This company acquired the imagery and prepared the mosaics.

In particular, the paper will consist of an account of the procedures used and problems encountered in the adjustment. The procedures were chosen in view of a rather severe time constraint; this constraint resulted from the fact that an adjustment was not planned initially. The actual adjustment was split into an internal and external one, preceded by initial strip formation and correction of systematic image deformations.

2. Image Acquisition

Goodyear's synthetic aperture radar was used in Aero Service's Caravelle jet. Image scale in this system is always 1 : 400,000. Flight lines were spaced 13.7 km. directed NS, and imaging was always in the same direction (see figure 2). Flying height a.m.s.l. was 12.5 km. Seventy flight lines were planned but 30 reflights were necessary (40 %). These reflights had to replace images with serious defects due to electronic failure, heavy rain or turbulence [3].

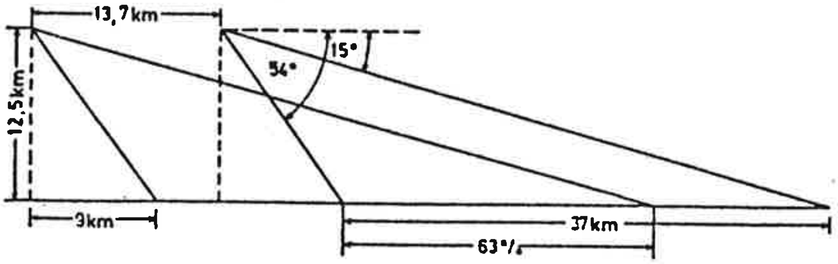


Figure 2 SLAR imaging geometry to obtain 60 % overlap.

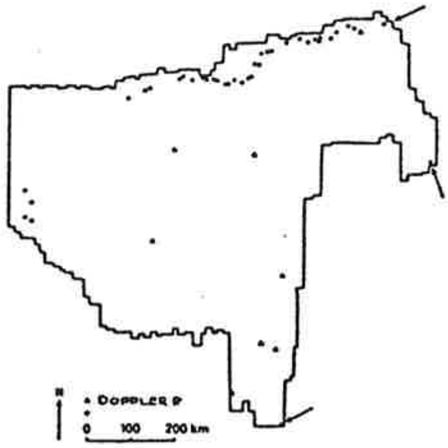


Figure 3 Distribution of ground control. The points marked by an arrow were only available in the ultimate phase of the computations. The figures 7a and 7b do not use information from these points.

Due to resolution of the CRT, each image strip is presented in two parts. This would correspond in aerial photography to photography cut into two pieces. There is, however, a slight overlap of 5 % between the pieces of an image strip. One piece corresponds to the range nearer the flight line, the other piece to the range farther from the flight line. Therefore, the 2 pieces are called "near range" and "far range view". Geometrically, the 2 pieces can be considered as one unit.

Apart from the NS flight lines, there were 3 EW transverse flights flown, producing so called "tielines". This was done at a time when it was expected that no ground control would be available. But in the progress of the project it turned out that the Interamerican Geodetic Survey was about to measure Doppler Satellite points in the mapping area. Consequently there were ground control points available for mosaicking as shown in figure 3.

3. Strip Formation

The purpose of the adjustment was to interpolate radargrammetric points in between the given ground control points as a basis for mosaicking. The basic unit for the adjustment is an image strip. Since the mapping area is flat, there was no requirement to form stereo models. Tiepoints had to be selected to connect the individual strips to form a block. These tiepoints had to be transferred stereoscopically, the ground control points identified, and all these image points measured.

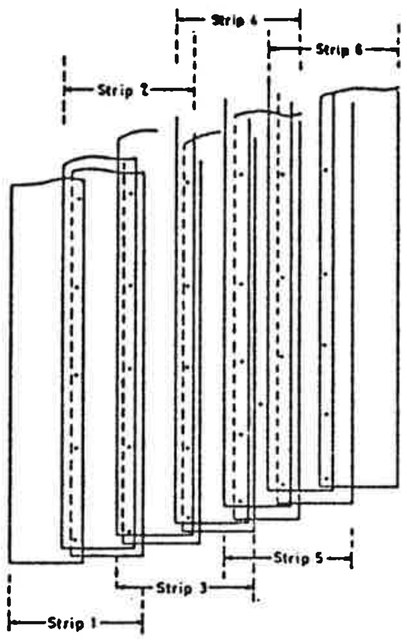
A single SLAR strip, however, extends up to 250 cms. Measurement on a coordinatograph had therefore to be in parts. This and the fact that each strip was given as a near (NR) and far (FR) range view necessitated the initial step of "strip formation" in which all the piecewise measurements of a strip are transformed into a common strip system.

An effective selection of tiepoints was found to be in the small zone of 5 % overlap between NR and FR views of an image strip (see figure 4). Due to the 60 % overlap between adjacent strips, each tiepoint had to be measured at least 4 times.

Transformation of the piecewise measurements of a strip into a strip system was of course always overdetermined. This enabled an estimate of the combined error of point transfer and measurement, showing a root mean square value of ± 0.33 mm at image scale.

4. Predictable Image Errors

Before block formation, it is essential to eliminate significant predictable image deformations from the individual strips. However, as the imagery of PRORADAM is in ground range presentation, and



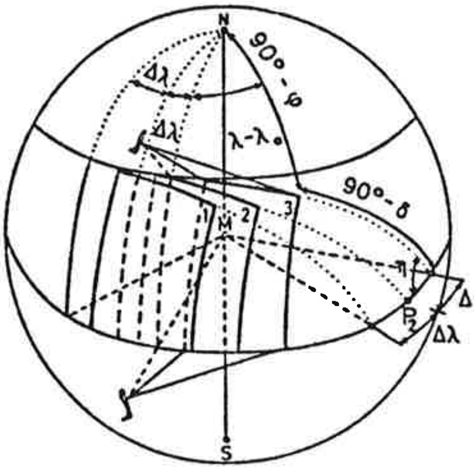


Figure 5 Projection deformation in SLAR imagery.

Figure 4 SLAR strips with 60 % overlap, but split into near range and far range views through the use of 2 cathode ray tubes (CRTs). Indicated are the locations of tiepoints in the common overlap between the two views of a strip.

as the terrain is flat, the only predictable deviation of an image from a desired map projection is just due to this projection. This poses an interesting problem which is illustrated in figure 5.

Each SLAR strip represents an equidistant cylinder projection. The flight line is the reference meridian of the cylinder. Across track image lines represent great circles on the sphere with this reference meridian as an equator and the intersection of the great circles as a pole. Each SLAR strip, however, represents a projection onto a different cylinder. Necessary conversion of alongtrack coordinate x and acrosstrack coordinate y into a Marinus projection with coordinates X, Y amounts to:

$$\delta = k \cdot (x - x_0)/R \qquad \tan(\lambda - \lambda_0) = \tan\delta \cdot \cos\eta$$

$$\eta = k \cdot (y - y_0)/R \qquad X = \varphi \cdot R$$

$$\sin\varphi = \cos\delta \cdot \sin\eta \qquad Y = (\lambda - \lambda_0) \cdot R$$

k . . . scale factor
R . . . radius of earth
φ . . . longitude
λ . . . latitude
λ_0 . . . reference latitude
x_0 . . . image x of equator
y_0 . . . image y of flight line

Evaluation of these formulae reveals that corrections of SLAR image coordinates will always be less than 3 in 10,000.

5. Internal Adjustment

Block formation, or internal adjustment, should now produce a single pair of coordinates for each tiepoint, of which coordinates are at this point available in 3 adjacent SLAR strips. Due to unpredictable (random) image errors, there must be some discrepancies expected. Analysis leads to the conclusion that there are two main defects of image geometry: variation of along track scale and curvature of flight lines (see figure 6).

Block formation was done by starting from an initial image and transforming successively each adjacent image into the previous one. One thus progresses from the initial image throughout the whole block. One can compare this with photogrammetric strip formation where the role of individual models is taken over by the SLAR images.

The transformation was basically linear conformal, with correction terms for differential scale and curvature. The correction terms were set up as spline functions.

The fact that this block formation is sequential rather than simultaneous simplified numerical problems and was a consequence of the stringent time constraints. It is expected that simultaneous internal adjustment will produce a slightly superior block.

The result of the block formation can be evaluated to some extent from the discrepancies left in the tiepoints. These are shown as root mean square values in mm at photoscale (table 1). They represent discrepancies between internally adjusted tiepoints and transformed tiepoints.

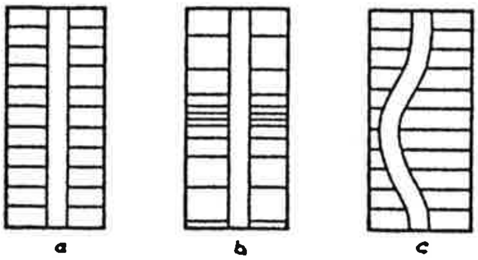


Figure 6 The grid of fig. (a) is deformed to (b) due to variations an along track scale, and to (c) due to a curvature of the flight line.

Four computational alternatives were computed for the block formation: with and without correction of projection deformation and with or without splines in addition to linear conformal transformation of strips. Table 1 shows clearly that discrepancies are much smaller using spline corrections but that projection deformation is not significant.

An independent comparison of the block with the tielines shows that both are fairly consistent. It can be expected that the block deformation relative to ground control is of the same order of magnitude.

Table 1 Internal root mean square discrepancies in mm at image scale, after block formation. 1: without correction for projection deformation; 2: with correction for projection deformation; A: without splines; B: with splines

		A 1	A 2	B 1	B 2
N-S LINES	RMSE X	1.12	1.13	0.66	0.65
	RMSE Y	1.17	1.18	0.68	0.68
TIE-LINES	RMSE X	1.20	1.20	1.30	1.30
	RMSE Y	1.10	1.50	1.40	1.31

6. External Adjustment

Beginning external adjustment with a linear conformal transformation into the control point net reveals rather much larger block deformations than expected; and their order of magnitude does not vary, whether or not spline corrections or projection corrections are used (see table 2).

An attempt to explain the obvious discrepancy between two independent evaluations of block deformation has initially and still focuses on the fact that the complex inertial navigation was initialized at the airport of Bogota at 2700 m with rather unusual deviations of the local vertical. It is suspected that this led to a distorted frame for the inertial navigation above flat and low Amazonas. If this suspicion is correct, then this would explain why the tielines fit so well with the NS lines, and why, at the same time, the NS lines do not fit with the ground control.

Error vectors describing the block deformations appear to be largely systematic. This is confirmed by computing the covariance functions for deformations in northing and easting.

Table 2 External root mean square discrepancies in mm at image scale, after 4-parameter similarity transformation of SLAR block into geodetic control

	A 1	A 2	B 1	B 2
RMSE X	4.07	3.93	4.89	5.15
RMSE Y	3.68	3.50	5.95	4.75

Correction of these deformations is an interpolation problem. Various methods can be and were used for the purpose. Only the results of two are presented here: of a polynomial, independent for errors of northing and easting; and of linear prediction. Application of linear prediction was by a combination of moving average and linear prediction proper. The moving average has the role of trend function in this application.

Two vector diagrams show an essential difference of the applicability of the two methods for the purpose (figure 7). Diagram (a) refers to the interpolated corrections using a 10 coefficient polynomial (3rd order). The other (b) uses linear prediction. It is obvious that in certain areas corrections obtained from polynomials degenerate to very large values. This is in areas of extrapolation. With linear prediction, no degenerated corrections are obtained. Table 3 demonstrates that correction size is the same as of the original deformations in control points.

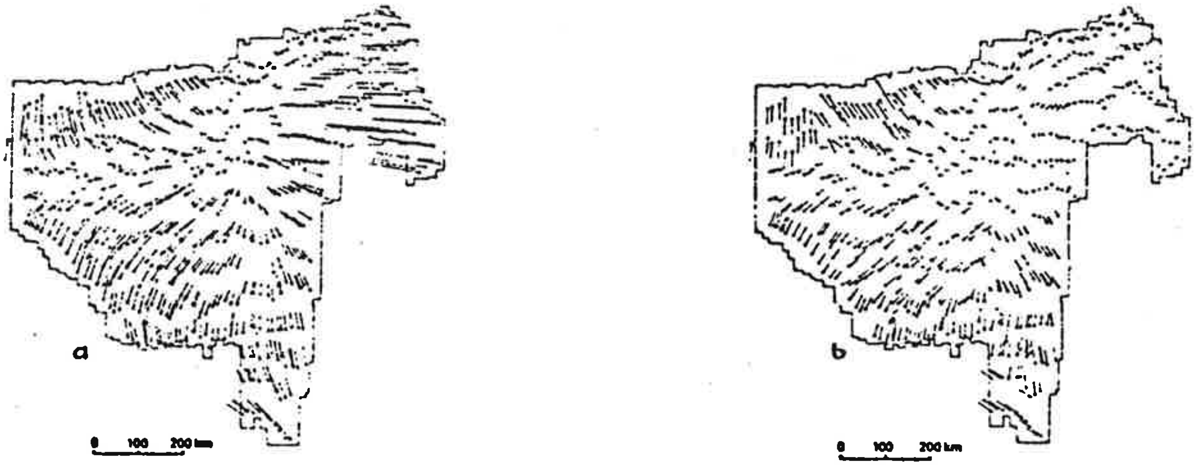


Figure 7 Corrections computed with polynomial (a) and linear prediction (b). In the North East and South West of the area, extrapolation leads to very large correction with the polynomial.

Table 3 Residuals at control points (without brackets), and corrections at radargrammetric points (in brackets), after external adjustment with linear prediction. Values in mm at image scale. Correlation function: Gov (d) = $0.9/(1 + d^2/500^2)$.

	A 1	A 2	B 1	B 2
RMSE X	0.56 (3.75)	0.55 (3.58)	0.56 (3.96)	0.59 (4.08)
RMSE Y	0.70 (3.39)	0.69 (3.25)	0.71 (4.52)	0.61 (3.65)

7. Accuracy of SLAR Block, Evaluated with ERTS-MSS-Imagery

From table 3 no reliable estimate is possible of the actual precision of radargrammetric points, but availability of ERTS-1-MSS imagery is used to obtain an independent estimate of this accuracy. ERTS images are available in about 50 % of the mapping area; only half of this is not covered by clouds. Therefore, only 25 % of the area is also shown on ERTS imagery. For the simple reason of lack of time, these remaining ERTS data were only used as a check rather than as control.

The check is only possible using drainage lines. From inspection of many ERTS images it can be concluded that at this state SLAR shows much more detail and for this reason is superior to ERTS imagery (see figure 8). The drainage lines are actually the only recognizable detail in most of the ERTS images of the Amazonas area but, due to a year's difference between taking ERTS and SLAR, some changes have occurred. This might to some extent make the ERTS images of this area less reliable than in other cases. Reported ERTS image deformations are of the order of magnitude of 170 to 400 m (0.3 to 1 mm at SLAR image scale) [1], [2].

Table 4 shows the root mean square coordinate differences between seven ERTS images and the adjusted SLAR block. The overall root mean square discrepancy amounts to ± 1.5 mm, representing the sum of deformations of ERTS and SLAR.

Table 4 Root mean square discrepancies between ERTS-1-MSS images and SLAR block PRORADAM. Values in mm at scale 1 : 400000. MSS-channel 7 used.

Nr.	RMSE-X	RMSE-Y	Nr. of points	Date of Acquisition
1	1.06	0.51	9	Oct. 1972
2	0.80	0.69	10	Oct. 1972
3	2.77	2.85	11	Oct. 1972
4	1.32	1.26	7	Oct. 1972
5	1.08	0.71	18	Febr. 1973
6	2.29	1.35	12	Febr. 1973
7	1.15	1.35	22	Febr. 1973
Total	1.58	1.41	89	

This value allows the tentative conclusion that the relative accuracy of the adjusted SLAR block is about equivalent, or perhaps a little inferior, to ERTS accuracy. This suggests for future work that ERTS imagery in SLAR mapping projects should not be disregarded.

8. Conclusion

An internal and external block adjustment for planimetry was numerically carried out with SLAR imagery for the Colombian project PRORADAM. The mapping area consisted of the Colombian Amazonas Basin (400,000 km^2). Forty-four ground control points were available.

Time constraint necessitated a rather simple solution for the problem. After sequential block formation, the consistent SLAR block was transformed into the set of ground control points. Residual block deformations at ground control points were used to interpolate corrections in radargrammetric points. The interpolation method was linear prediction.

Comparison of the adjusted SLAR block with independent ERTS-MSS-images reveals root mean square coordinate discrepancies of 1.5 mm at image scale.

The methods which were used for the adjustment were simple of necessity. It is expected that more rigorous methods of computation will improve results. ERTS imagery should be incorporated as external constraint in the adjustment.

Summary

PRORADAM (Projecto Radargrametrico del Amazonas) is a Colombian reconnaissance type mapping project of about 360,000 km², using airborne sidelooking radar (SLAR). The paper deals with the procedures used and problems encountered in a planimetric adjustment of the block of SLAR image strips, making use of 44 ground control points. The adjustment was split into 2 steps: block formation and external adjustment. Accuracies obtained could be evaluated by comparing the adjusted block with independent ERTS-MSS images. Root mean square discrepancies between ERTS and SLAR amount to ± 1.5 mm at image scale 1 : 400,000.

Zusammenfassung

PRORADAM ist ein kolumbianisches Project zur raschen vorläufigen Kartierung eines Gebietes von 360,000 km². Hierfür wurde ein Seitwärts-Radar-Aufnahmesystem (SLAR) benutzt. Der Bericht beschreibt die Methoden und Probleme, die in einer planimetrischen Ausgleichung des Blocks von Radaraufnahmen eine Rolle spielten. 44 Paßpunkte standen zur Verfügung. Die Ausgleichung wurde in 2 Schritten ausgeführt: interne und externe Ausgleichung. Die erreichte Genauigkeit konnte anhand unabhängiger ERTS-MSS-Bilder beurteilt werden: mittlere Abweichungen zwischen ERTS und SLAR sind ungefähr ± 1.5 mm im Bildmaßstab 1 : 400,000.

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Topographic accuracy of side-looking radar imagery

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Introduction

The objective of this investigation was to ascertain the accuracy by which the planimetric position and elevation of points can be determined from side-looking airborne radar (SLAR) imagery. The test material used consists of two strips of SLAR imagery of Phoenix, Arizona and vicinity, flown by the Goodyear Mapping System 1000 (GEMS) at a scale of 1 : 400000. The lines were flown in a North-South direction at an altitude of 12,040 m. The positions and elevations of ground control points were determined from 1 : 24,000 scale topographic maps at the Institute of Photogrammetry in Hannover.

These strips overlap in an opposite-side configuration. For Strip 1 the ground range delay is 5 nautical miles (9,266 m) while for Strip 2 it is 15 nautical miles (27,800 m). The first range marks appearing are those at 10.0 and 17.5 nautical miles (18,532 m and 32,431 m) slant range respectively. The spacing of the marks is 2.5 nautical miles slant range and the presentation is in ground range.

Measurements and preparatory tests

The image coordinates of the test points were measured in a Zeiss PSK comparator under 8 times magnification and in two independent sets. Stereo vision is extremely difficult on opposite-side overlaps, therefore, the measurements were performed monocularly. The standard error of one measurement as computed from the double measurements was 11 μm and 15 μm for the x coordinates, and 16 μm and 18 μm for the y coordinates in Strip 1 and Strip 2, respectively. This precision is regarded as entirely satisfactory, considering that the definition of the points was far less distinct than on conventional photographs.

On each strip the image coordinate system was defined by the row of range marks closest to the ground track. A straight line was fitted to these marks by least squares adjustment, which was then