GEOMETRIC RECTIFICATION OF EUROPEAN HISTORICAL ARCHIVES OF LANDSAT 1-3 MSS IMAGERY

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ABSTRACT

This paper describes the development of a method for the geometric correction of Landsat 1-3 MSS scenes from the ESA archives. The method is based on a rigorous orbital/attitude model, which poses some special problems since the orbital and attitude data recorded in the telemetry are no longer available in the ESA archives. The result from testing the method demonstrates the possibility to orthorectify MSS scenes to 1/2-pixel accuracy. The method was used for the production of an ortho-image historical database of Landsat 1-3 MSS data covering all of Sweden.

1. INTRODUCTION

The European Space Agency (ESA) stations reception of Landsat MSS images started in 1975. There are now 700,000 scenes in the ESA archives from the period 1975 – 1983, acquired by the Landsat 1-3 satellites. When Landsat 4 was launched in 1982, the new TM instrument made the MSS sensor less interesting. The archives of MSS images from 1975 – 1983 are, however, a unique source of information from this time period. Combined with recent imagery from other satellites, they make possible the study of changes in the European landscape over a 20 years period.

Still, the potential of Landsat 1-3 MSS scenes is very seldom used. One reason may be the difficulty in producing geometrically corrected images of good enough quality. Quantitative change detection requires a very good geometrical match between the old and the new images. To achieve this, a rigorous orbital/attitude model is required which makes orthorectification using a DEM possible. This has become even more difficult in the last years, since ESA, during the transcription of the old MSS archive tapes, discarded the telemetry information that contained the orbital data and attitude measurements from the satellite.

This paper describes the development of such a model. It also presents the results from evaluation tests, using a number of MSS scenes over Scandinavia.

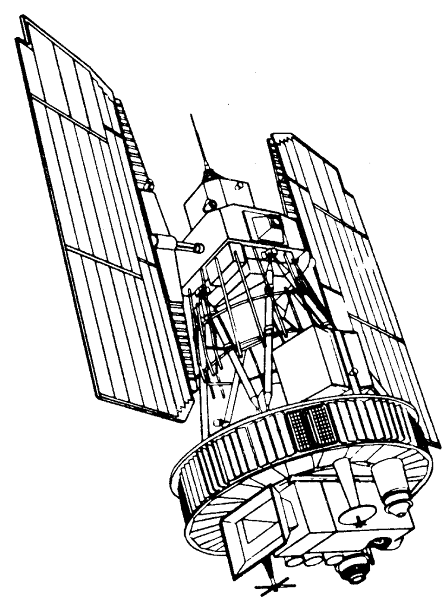

FIGURE 1. The Landsat 1-3 platform

2. MSS SENSOR CHARACTERISTICS

The first three satellites in the Landsat series carried two types of instruments, the Return-Beam Videcon (RBV) and the multispectral scanner (MSS). The RBV was never very successful, but the MSS performed above expectations. This chapter will give an overview of the MSS instrument characteristics. For more detailed descriptions, see the Landsat Data Users Handbook (USGS, 1979) or Freden & Gordon, 1983.

TABLE 1. Spectral response for Landsat MSS

Band	Spectral Response
4	0.5 – 0.6 µm
5	0.6 – 0.7 µm
6	0.7 – 0.8 µm
7	0.8 – 1.1 µm

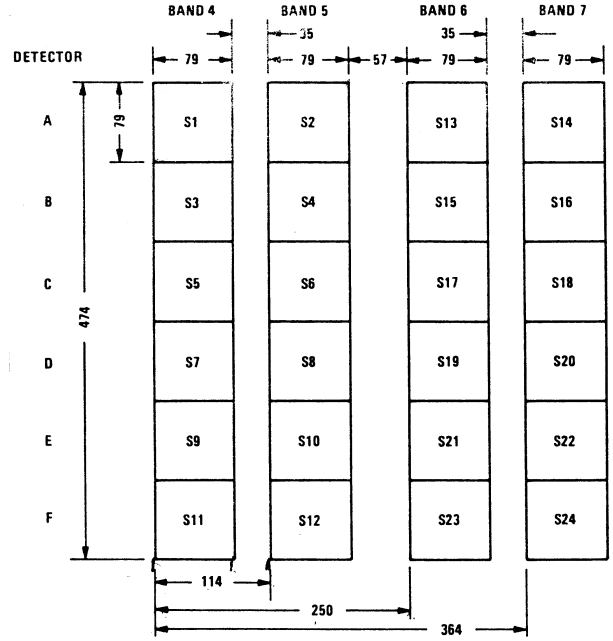

FIGURE 2. Detector layout projection on ground

The MSS instrument has 4 spectral bands in the visible – near IR range (table 1). Each spectral band is sensed by 6 detectors. The detector layout in the focal plane is shown in figure 2. This also shows the instantaneous projection and dimensions of the detectors on the earth surface. Each detector covers an area of 79 x 79 m on the ground.

The MSS is a line-scanning device, and the scanning is accomplished in the cross-track direction by an oscillating mirror. Six lines are scanned simultaneously when the mirror sweeps the ground projection of the six detectors across-track (figure 3). Only the west to east scan is active. The nominal scan mirror frequency is 13.62 Hz. This, together with the nominal satellite ground-track velocity of 6.456 km/s, aligns the sweeps at 474 m (6x79 m) intervals (figure 4).

A detector is sampled every 9.958 µs. In this time the detector ground projection has advanced 56 m in the sweep. Thus, the data is about 40% oversampled in the cross-track direction, and the effective sampled pixelsize is considered to be 56 x 79 m. The individual detectors are not sampled simultaneously. Instead, each detector is sampled in a sequence (S1-S24 as defined in figure 2) with 0.3983 µs intervals.

The active scan sweep time is 33 ms. It results in about 3300 samples per line. The effective cross-track FOV becomes 11.56 degrees, corresponding to about 185 km on the ground.

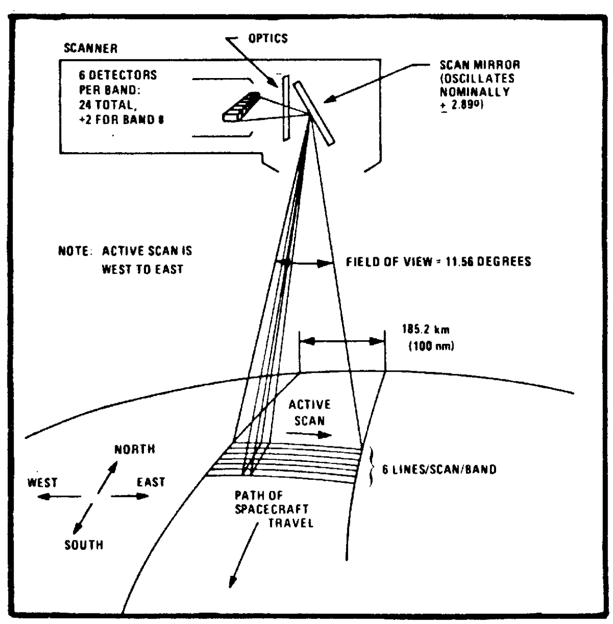

FIGURE 3. The MSS scanning arrangement

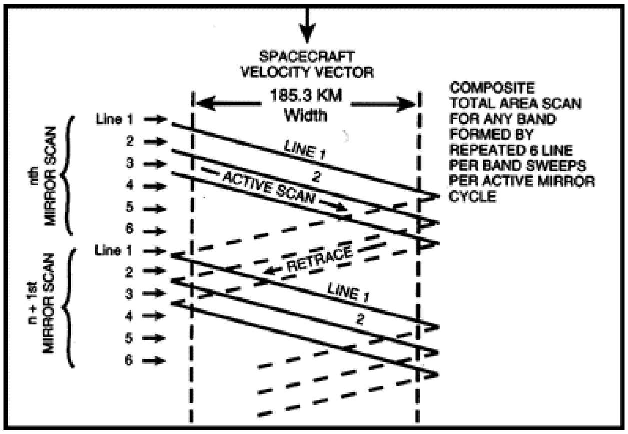

FIGURE 4. Ground scan pattern

Each detectors analog output is encoded as a six-bit digital word. In addition to this, signal compression is generally employed to improve the signal-to-noise ratio in bands 4,5 and 6. The different available A/D conversion functions are illustrated in figure 5.

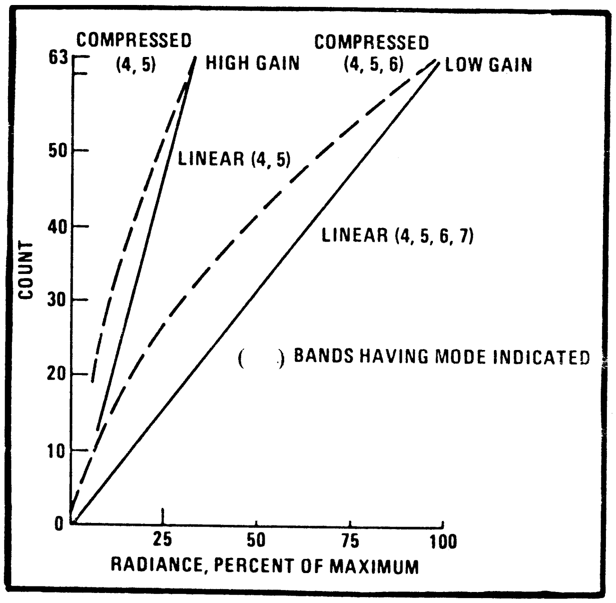

FIGURE 5. A/D conversion functions

3. MSS SCENES FROM ESA ARCHIVES

The European Space Agency (ESA) archives of Landsat MSS scenes dates back to 1975, when the Fucino station in Italy started its reception. Later, in 1978, Esrange in Sweden was added to the European network of Landsat receiving stations. There are now about 700,000 scenes from Landsat 1-3 in the ESA archives, covering the time period 1975 – 1983. They constitute a unique source of historical data about the European landscape, as no other high-resolution satellite sensors are available from this time period

Landsat MSS scenes from ESA are today delivered on CD-ROM media, but are still produced in the old data format from 1975 (ESA, 1979). It is rather complicated to read, with the metadata coded in EBCDIC, and with a somewhat irregular record structure for the bands in the image data file. The image data can be produced by ESA in two processing levels: as raw data or system corrected. In this study, only raw data has been used, to be able to develop a rigorous geometrical model for the data.

The metadata content is rudimentary. The only data of practical use was found to be:

- Track/Frame identifier
- Latitude and longitude of scene center
- Date and time of scene acquisition

Originally, the CCT's produced by ESA also contained the raw telemetry data file, which could be used to extract some information on the ephemeris and attitude for the satellite pass. Unfortunately, the possibility to deliver telemetry data was lost when the ESA station processing systems were upgraded in the middle of the 90'ies. Today we have no way of getting information on the satellite ephemeris and attitude measurements.

4. GEOMETRICAL MODEL

The geometrical model selected for the modelisation of MSS scenes can be divided into different parts. The exterior orientation includes a satellite orbit model and an attitude variation model. The interior orientation includes a scan mirror model and the detector position and sampling sequence.

4.1 Satellite orbit model

The satellite model is based on the six Kepler parameters (figure 6). These, together with the constant second-degree zonal component (J_2) of the earth gravitational potential, are able to describe the satellite motion with high enough precision for the Landsat MSS correction requirements.

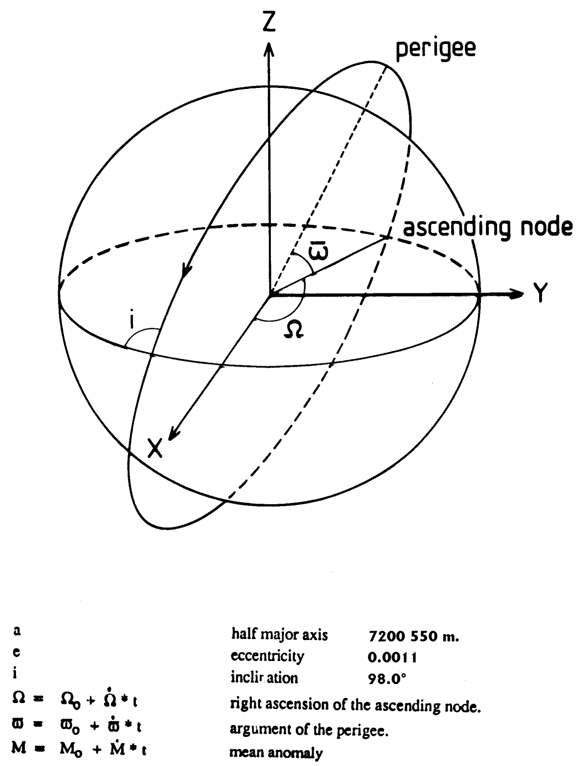

FIGURE 6. Satellite orbit parameters

4.2 Attitude model

The attitude angles are modeled by 3'rd degree polynomials in time.

$$roll = a_0 + a_1 * t + a_2 * t^2 + a_3 * t^3$$
$$pitch = b_0 + b_1 * t + b_2 * t^2 + b_3 * t^3$$
$$yaw = c_0 + c_1 * t + c_2 * t^2 + c_3 * t^3$$

where the coefficients a_i, b_i and c_i remains to be determined. It is assumed that a 3'rd degree polynomial will be sufficient for the modelisation of the time interval of a complete scene.

4.3 Scan mirror model

The basic scan model is a line-of-sight vector, which is perpendicular to, and rotates around, the satellite platform x-axis (roll-axis). The oscillating scan mirror should ideally have a constant angular velocity during the active scan. In reality, there is speeding up at the beginning and slowing down at the end of the scan. This makes the velocity profile look more like a sine function. The shape of this function is important for the interior scene geometry. In the beginning of the 80'ies, Swedish Space Corporation put a lot of effort in calibrating the exact shape of these profiles for each satellite. This was done by the measurement of a large number of very precise ground control points. The velocity profiles are tabulated, and applied during modelisation. Figure 7 shows an example of a mirror angle correction profile.

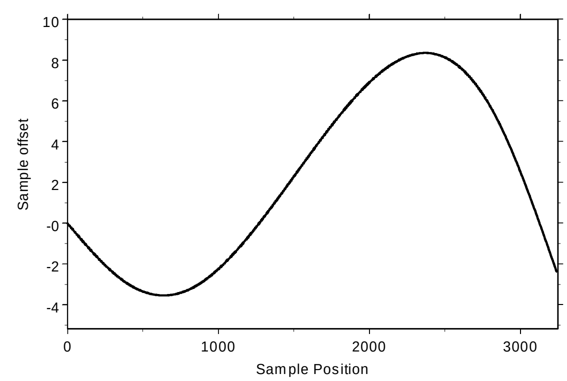

FIGURE 7. Scan mirror correction profile

4.4 Detector position and sampling sequence

The exact detector positions in the focal plane, and the detector sampling sequence are considered and applied as documented in the Landsat Data Users Handbook (USGS, 1979).

5. MODEL PARAMETER ADJUSTMENT

To be able to achieve a high precision model for a specific scene, the model parameters have to be estimated and refined by the use of ground control points. The parameter adjustment follows the method developed in the paper by Westin, 1990. It is a least-squares adjustment, with the possibility to weight the parameters. The parameter weights are used to determine which parameters are to participate in the adjustment.

Only the exterior orientation parameters are adjusted. Of the six Kepler parameters, two are kept constant. Due to the very small eccentricity of the orbit, the eccentricity and argument of perigee can be kept constant without significant loss of accuracy. Of the 12 attitude parameters, only a subset is adjusted. There is a trade-off between stability and precision in the result that has to be considered when deciding which of them to keep constant.

The adjustment method requires *a priori* values for the parameters. This poses some problems, as the ephemeris and attitude data for the acquisition is unavailable. The attitude coefficients can simply be set to zero, as this is the expected output of the satellite attitude control system. But start values for the satellite ephemeris has somehow to be calculated. This is achieved by the following steps and assumptions:

- Assume that the nominal Landsat satellite orbit (table 2) is valid, except for the mean anomaly (M) and the right ascension of the ascending node (Ω) parameters.
- Find the mean anomaly for the nominal orbit, which makes the satellite nadir point fall on the latitude of the scene center. This can be calculated by an iterative process.
- Adjust Ω so that the satellite nadir point falls on the scene center longitude.

The result is an approximate orbit, which may have up to about 10 km radial error in the sub-satellite point (due to inaccuracy in the scene center coordinate given in the metadata). The orbit is, however, good enough to fall within the pull-in range of the least-squares adjustment method.

TABLE 2. Nominal orbit parameters for Landsat

	Landsat-1	Landsat-2	Landsat-3
Semi-major axis	7285438m	7285989m	7285716m
Inclination	99.906°	99.210°	99.117°
Eccentricity	0.001070	0.001019	0.001330
Argument of perigee	0°	0°	0°

6. EVALUATION

The model was evaluated by the use of a scene with the following data:

Satellite	Landsat-2
Scene	208/18
Date	1978-05-29

The scene covers the Stockholm area in Sweden (figure 8). This area has a type of terrain that is suitable for the extraction of high precision control points.

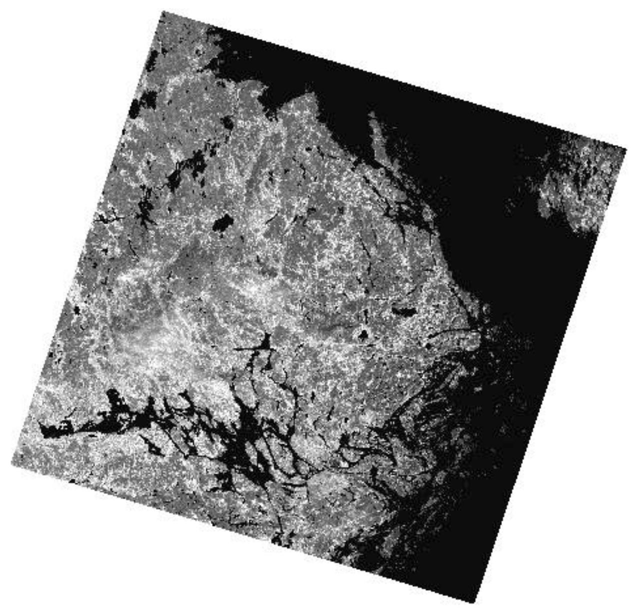

FIGURE 8. Landsat MSS scene over the Stockholm area, used for model evaluation.

The geodetic reference used in this case was a set of SPOT XS scenes, orthorectified to the Swedish national grid system. The estimated rms planimetric error in the SPOT scenes is 5-10 m. Control point features were extracted from the SPOT scenes, and identified in the Landsat MSS scene. A total number of 81 control points were extracted and measured. Figure 9 shows the distribution of control points over the scene.

FIGURE 9. Control point distribution over the Landsat MSS scene.

The control point measurements were used for least-squares adjustment of the model parameters for the scene. The residual errors in the adjustment were then analyzed to determine the model fidelity. An important aspect to investigate was to determine which coefficients in the attitude polynomial model that need to be present. This was analyzed by repeating the adjustment with 0'th, 1'st, 2'nd and 3'rd order coefficients present, and then analyzing the different results.

It was assumed that the main contribution to the residuals in the adjustment would come from the attitude variations in roll and pitch. The yaw variation is less important because its effect on the residuals is only 1/10'th of the roll and pitch contributions.

The pitch variation contribution to the residuals can be analyzed by plotting the residuals in along-track direction as a function of the line number in the raw image. Similarly, the roll variation contribution to the residuals can be analyzed by plotting the residuals in cross-track direction as a function of the line number in the raw image.

Finally, the fidelity of the scan mirror model can be analyzed by plotting the residuals in cross-track direction as a function of the column number in the raw image.

7. RESULTS

The scene was adjusted 4 times, with different sets of model parameters. In all cases, 4 parameters for the satellite orbit were used (as defined in paragraph 5). The set of attitude coefficients used was varied as follows:

0'th order: a_0, b_0, c_0
1'st order: $a_0, b_0, c_0, a_1, b_1, c_1$
2'nd order: $a_0, b_0, c_0, a_1, b_1, c_1, a_2, b_2$
3'rd order: $a_0, b_0, c_0, a_1, b_1, c_1, a_2, b_2, b_3$

The overall residual errors in the scene for the different adjustment cases are presented in table 3.

TABLE 3. Overall RMS residual error as a function of the number of coefficients used in the attitude model.

Order of attitude polynomial	Total number of model parameters	RMS residual X	RMS residual Y
0'th	7	35 m	77 m
1'st	10	18 m	29 m
2'nd	12	14 m	25 m
3'rd	13	14 m	20 m

The results can be further analyzed by plotting the residuals versus the raw line number. Figure 10 and 11 shows the residual pitch and roll variation effect in the residuals for the 0'th order attitude model. It is obvious from figure 10 that a strong linear drift in pitch is causing most of the image errors.

Figure 12 and 13 show the result for the 1'st order attitude model. Systematic 2'nd and 3'rd order trends in pitch and roll are still visible, but with amplitudes of less than ½ pixel.

Figure 14 and 15 show the result for the 2'nd order attitude model. A systematic 3'rd order trend is still visible in pitch, the roll variation looks fairly random.

Figure 16 shows the result in pitch for the 3’rd order attitude model. Now there is only random variation visible.

Figure 17 demonstrates the fidelity of the scan mirror model by only displaying random variation of residuals.

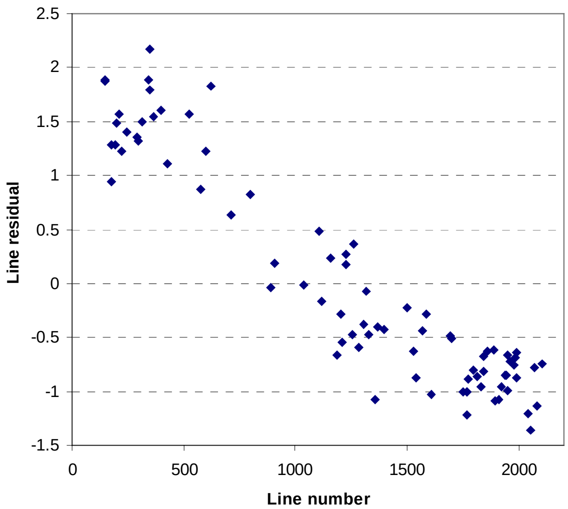

FIGURE 10. Along-track residuals for 0’th order attitude model

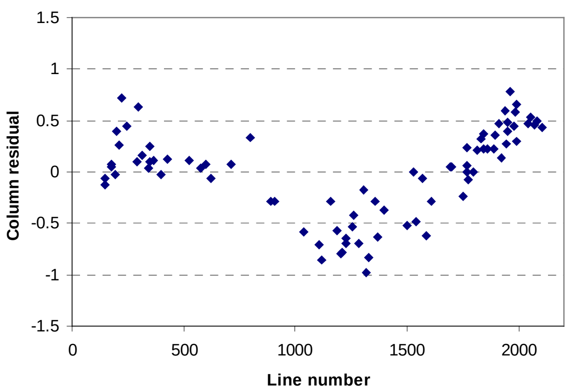

FIGURE 11. Cross-track residuals for 0’th order attitude model

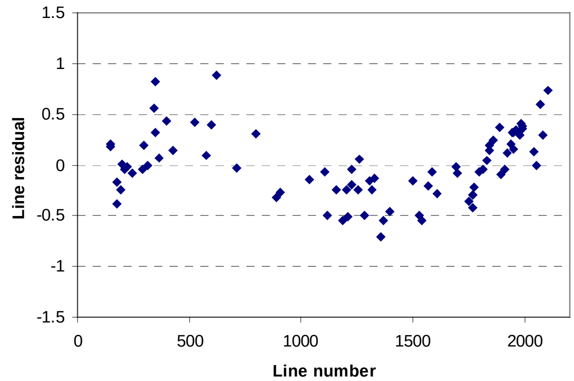

FIGURE 12. Along-track residuals for 1’st order attitude model

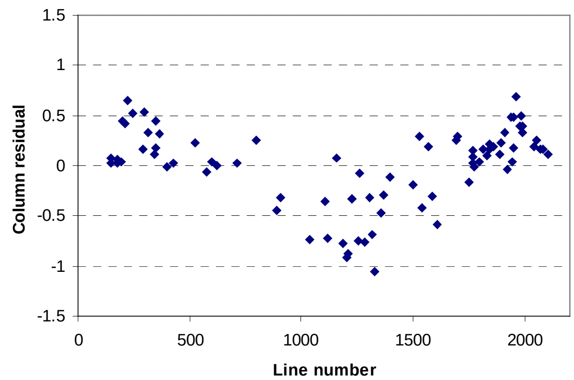

FIGURE 13. Cross-track residuals for 1’st order attitude model

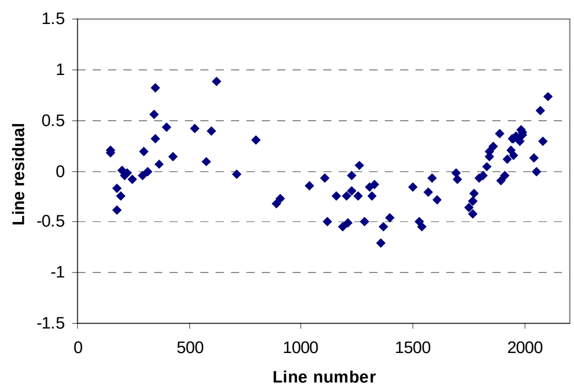

FIGURE 14. Along-track residuals for 2’nd order attitude model

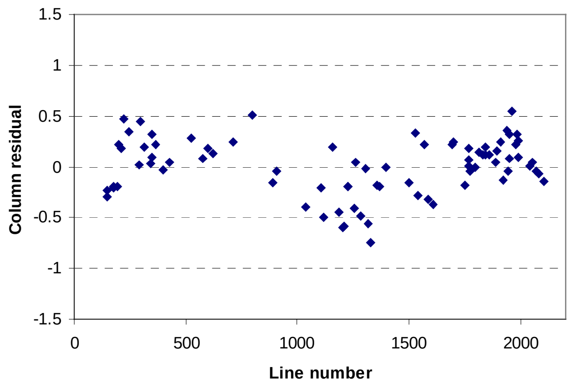

FIGURE 15. Cross-track residuals for 2'nd order attitude model

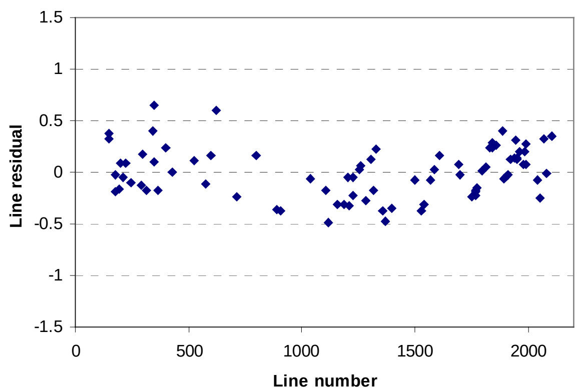

FIGURE 16. Along-track residuals for 3'rd order attitude model

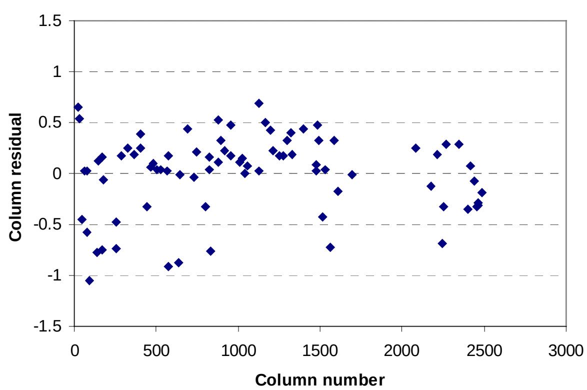

FIGURE 17. Cross-track residuals for 1'st order attitude model , plotted cross-track.

8. PRODUCTION EXPERIENCES

The model for Landsat MSS correction has been implemented in the production systems at Satellus. It was used in a full-scale project, covering all of Sweden with 51 orthorectified Landsat MSS scenes (6 from Landsat-1, 34 from Landsat-2 and 11 from Landsat-3). In this case, the control points were extracted from the national 1:50,000 and 1:100,000 topographic maps. The estimated map planimetric accuracies are 25-50 m (rms error). On the average, 40 points per scene were measured. The scenes were adjusted using only the 1'st order attitude polynomial coefficients. This decision was based on the wish to prioritize robust solutions over high precision, for the cases were control could not be well distributed over the scenes. Still, the results are satisfactory. On average the RMS residuals in the map control points were 53 m in X and 55 m in Y.

9. CONCLUSIONS

The result of the evaluation of the correction model shows that Landsat MSS scenes from the ESA archives can be corrected to better than ½ pixel accuracy. This could be achieved by using a simple linear attitude model because the amplitude of the attitude variation was small enough compared to the IFOV. Still, a 3'rd order attitude model is warranted if precision is prioritized.

10. REFERENCES

ESA 1979. Format specification for Landsat MSS system corrected computer compatible tapes produced at Kiruna. EPO/80-545/SB/gg. 22 p.

Freden, C. S. and F. Gordon, 1983, Landsat Satellites. In *Manual of Remote Sensing*, American Society of Photogrammetry. 2nd ed. Part 1, Ch 3, pp. 517-570.

USGS, 1979. Landsat Data Users Handbook. US Geological Survey.

Westin, T., 1990: Precision rectification of SPOT imagery. Photogrammetric Engineering & Remote Sensing, Vol. 56, No 2, pp. 247-253.