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Digital Satellite Image Mapping of Antarctica

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Summary: It is current practice to use geodetic control for the rectification and absolute orientation of digitally recorded satellite image data. In Antarctica this control regularly can be represented by nunataks or other stationary topographic features.
However, normally we lack sufficient ground control. Fixed points are often determined in various, independent coordinate systems. Vast areas containing no control at all have to be bridged. Points are often moving or changing.
A method is outlined with which in general it will be possible to overcome the abovementioned problems and which is based only on digital processing. Results are demonstrated by recently published satellite image maps composed of Landsat-1 and 2 imagery at 1:1.000.000 and 1:250.000 scales.
Furthermore, we report on a project in which 74 Landsat-5 and four Landsat-1 MSS scenes, mainly covering the region of Filchner-Ronne-Schelfeis and Coats Land are treated in an overall block adjustment. In that area, extending over about 1500 km by 2000 km, geodetic control was only available for some 30 localities.

Zusammenfassung: Es ist gängige Praxis, für die Entzerrung und absolute Orientierung digital aufgezeichneter Satellitenbilddaten geodätische Festpunkte zu verwenden. In der Antarktis sind dies normalerweise Nunatakker oder andere topographische Objekte.
In der Regel herrscht in der Antarktis aber ein Mangel an hinreichenden Festpunkten vor. Oft sind diese Punkte in verschiedenen, voneinander unabhängigen Koordinatensystemen bestimmt. Ausgedehnte Gebiete, ohne jeglichen Festpunkt, müssen überbrückt werden. Häufig bewegen oder verändern sich die Punkte.
Es wird eine Methode beschrieben, mit der die oben angeführten Probleme bewältigt werden können und die ausschließlich auf digitaler Verarbeitung beruht. Als Beispiele werden Ergebnisse diskutiert, die kürzlich bei der Herstellung von Satellitenbildkarten im Maßstab 1:250.000 und 1:1.000.000 aus Landsat-1, 2-Bilddaten erzielt wurden.
Weiterhin wird über ein Projekt berichtet, bei dem 74 Landsat-5- und vier Landsat-1-MSS-Szenen in einem Gesamtblock ausgeglichen worden sind. Die Bilder erfassen auf einer Fläche von etwa 1500 km x 2000 km nahezu das gesamte Filchner-Ronne-Schelfeis und Teile des Coats Land. In diesem Gebiet standen für die geometrische Entzerrung und Orientierung der Bilder lediglich etwa 30 Festpunkte zur Verfügung.

1. INTRODUCTION

Satellite images have become an essential aid worldwide for various tasks of scientific research, planning purposes or other thematic applications. Because of the outstanding potentialities of satellite imagery to demonstrate and unveil extended glaciological correlations of difficult or inaccessible areas, this is all the more valid for the Antarctic (WILLIAMS et al. 1982, SWITHINBANK & LUCCHITTA 1986, LUCCHITTA et al. 1987).

However, though an increasing number of nations and scientists are involved in research in Antarctica and, though the operational imaging satellite system Landsat has been in orbit since 1972, satellite image maps ar still lacking for very large parts of Antarctica.

Topographic line mapping has been done systematically for nearly all mountainous regions in Antarctica at 1:250.000 scale, either by conventional terrestrial methods or by aerial photogrammetry.

This, however, makes up only the smallest part of Antarctica. The reasons for this are obvious. The making of maps requires the availability of sufficient geodetic ground control (fixed points) which generally will be provided by nunataks or other stationary topographical features.

These fixed points are an absolutely necessary prerequisite for providing a definite and unique scale and for constructing a definite graticule for the map.

In Antarctica we are confronted by the problems that
1. we lack sufficient ground control.
2. fixed points are often determined in isolated ranges which are not or could not be tied together by geodetic observations.
3. we have to bridge vast snow and ice covered areas of many hundreds of square kilometers containing no fixed point, and
4. surface features are often moving or changing.

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In this paper a method is outlined by which in general it will be possible to overcome the problems mentioned above and which is based only on digital processing.

2. CARTOGRAPHIC SPECIFICATIONS

The Institut für Angewandte Geodäsie, Frankfurt am Main, intends to publish a series of satellite image maps at scales of 1:1.000.000 and partly at 1:250.000 of parts of Neuschwabenland, Coats Land, and Filchner-Ronne-Schelfeis. With reference to the „Recommended Technical Specifications for Antarctic Mapping" of SCAR Working Group on Geodesy and Cartography, the planned map series is based on the following specifications:

— Horizontal datum: World Geodetic System 1972 (WGS 72),
— Lambert Conformal Conic Projection with two standard parallels,
— Sheet line system as shown in Fig. 1,
— Metric system.

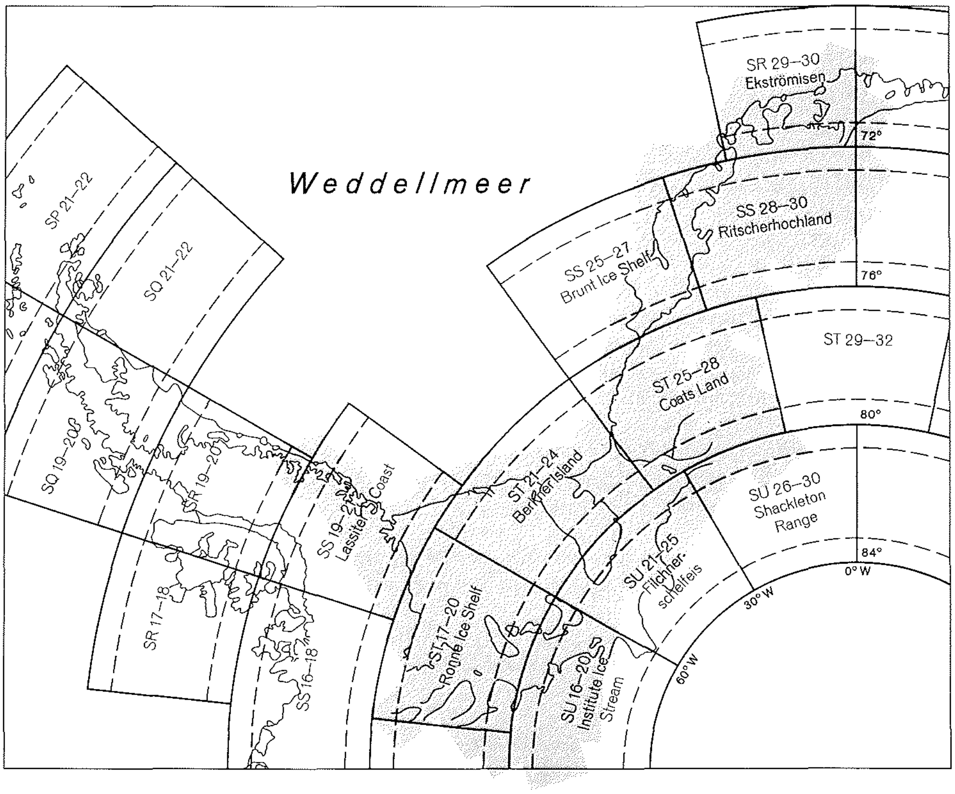

Fig. 1: Index to adjoining sheets 1:1.000.000. Sheet numbering system based on International Map of the World 1:1.000.000. Broken lines = standard parallels of Lambert Conformal Conic Projection. Each Lambert zone of 4° latitude has two standard parallels both 40' apart from the map sheet lines. Landsat-MSS archive held at IfAG (screened area).

Abb. 1: Blattübersicht 1:1.000.000. Blatteinteilung nach Internationaler Weltkarte 1:1.000.000. Gestrichelte Linien = Bezugsbreiten der konformen konischen Abbildung (Lambertabbildung). Jede "Lambertzone" von 4° Breite besitzt zwei Bezugsbreiten, die von den Blattgrenzen einen Abstand von 40' aufweisen. IfAG-Landsat-MSS-Archiv (gerasterte Fläche).

3. DIGITAL SATELLITE DATA ACQUISITION

The geometric and spectral resolution of Landsat Thematic Mapper (TM) and of the French satellite SPOT (Satellite pour l'Observation de la Terre) open up unexpected possibilities to produce satellite image maps even at 1:25.000 scale. The data quality of these sensors, however, has to be paid for: by the high purchase cost of the original data and by the handling of enormous quantities of data.

In the Antarctic there is a demand for maps at small scales. On the one hand, we are far away from a continuous map series at 1:1.000.000 scale and on the other hand Antarctic maps have to accomplish other requirements than is the case in industrialized countries. For Antarctica, at present the most important aim is to produce maps giving synoptic representations of extended areas. For that purpose satellite image maps at 1:1.000.000 scale are ideally suited.

Some 20 scenes covering an area of 185x185 km^2 are required to produce one map sheet at 1:1.000.000 scale. If only one spectral band is being used (one-coloured reproduction), about 160 Mbyte data of MSS have to be managed (see Table 1). One has to cope with a quantity of 760 Mbyte when dealing with TM and 1.7 Gbyte or 7 Gbyte respectively in the case of operating with SPOT data. A coloured reproduction (three spectral bands) trebles the quantities quoted.

At present, therefore, digital recordings of Landsat MSS may be the only meaningful tool for producing satellite image maps at 1:1.000.000 scale. This is valid all the more because in Antarctica objects of a size of about 100 m (equal to 0.1 mm on the map) are being imaged identifiably. Imagery of the Antarctic digitally recorded by SPOT and TM, therefore, will be applied by IFAG mainly to some detailed large-scale investigations.

	Landsat MSS	Landsat TM	SPOT multi-spectral	SPOT pan
area covered [km^2]	185 x 185	185 x 185	60 x 60	60 x 60
pixel size [m^2]	60 x 80	30 x 30	20 x 20	10 x 10
spectral bands	4	7	3	1
number of pixels [Mbyte] per band	8	38	9 85*	36 342*
number of pixels [Mbyte] for one map sheet at 1:1.000.000 scale (1 band)	160	760	1700	70

Tab. 1: Comparison of digital Landsat/SPOT data quantities to be processed. * extrapolated to a covered area of 185 x 185 km^2 without considering any necessary side overlap of the mosaicked scenes.

Tab. 1: Vergleich der zu verarbeitenden digitalen Satellitenbild-Datenmengen von Landsat und SPOT. * Umgerechnet auf eine Gebietsdeckung von 185 x 185 km, ohne Berücksichtigung einer notwendigen Seitenüberlappung der zusammenzufügenden Szenen.

3.1 Satellite Scanning System

Landsat-4 and -5 orbit the earth on a near-polar, sun-synchronous path with an inclination of 98°.1. Both satellites scan about 100 km further south than the earlier Landsat-1, 2 and 3. The southern most area covered is at approximately 82°45'S.

Paths of different orbits of Landsat are shown schematically in Fig. 2. The continuous scanning and recording process is perpendicular to the path of the satellite. Therefore, scan lines of adjacent Landsat scenes do not run parallel, but intersect each other. That is, all the different path/scanning coordinate systems have to be transformed to a single system (see Fig. 3). Owing to the extent of the area dealt with, some problems are created regarding the data processing, the data management, and the archiving.

To conduct the abovementioned programme to produce satellite image maps at scales of 1:1.000.000 and 1:250.000 the following specifications have been agreed upon:
— the 0°-Meridian corresponds with the positive x-axis of all Lambert systems,
— the pixel size of the resampling is 60 x 60 m^2.

3.2 Data Archive

Figure 1 also shows the area (shaded) over which IFAG has procured CCT's of Landsat MSS. Three regions are

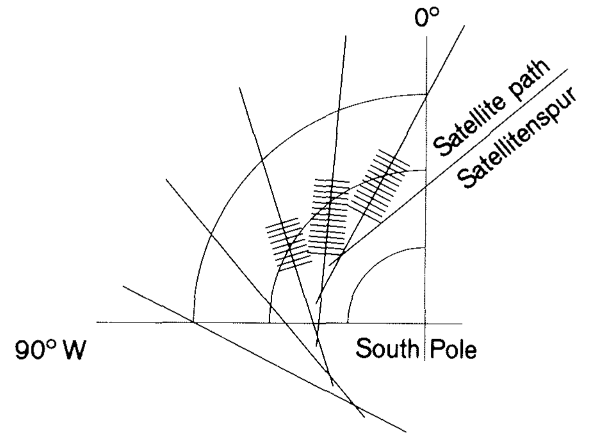

Fig. 2: Varying Landsat MSS scanning coordinate systems.

Abb. 2: Von der Satellitenbahn abhängige Koordinatensysteme des Landsat-MSS-Abtastsystems.

involved, with three periods of data acquisition between 1973 and 1988:

— R i t s c h e r h o c h l a n d (71° — 76°S, 0° — 20°W),
18 scenes, Landsat-1, -2, February 1973 — November 1975,

— F i l c h n e r - R o n n e - S c h e l f e i s , C o a t s L a n d (72° — 83°S, 15°W — 90°W),
9 scenes, Landsat-1, -2, November 1973 — January 1974,
74 scenes, Landsat-5, February/March 1986,
19 scenes, Landsat-4, -5, October 1987 — March 1988,

— F i m b u l - , J e l b a r t - , E k s t r ö m i s e n (69° — 73°S, 5°E — 15°W),
14 scenes, Landsat-5, October 1987,

The scenes cover a range of longitude of more than 90°. The maximum extents are 2000 km and 1500 km.

4. CONCEPT OF MOSAICKING

The satellite image maps are being produced from digital data of Landsat MSS available in Computer Compatible Tape (CCT) format. At present only a black and white map version has been published for which spectral band 3 or 4 (or band 6/7 respectively of Landsat 1, 2 and 3) are being used. Each scene has been digitally processed to maximize geometric fidelity and radiometric information while minimizing inevitable contrast differences between adjacent scenes.

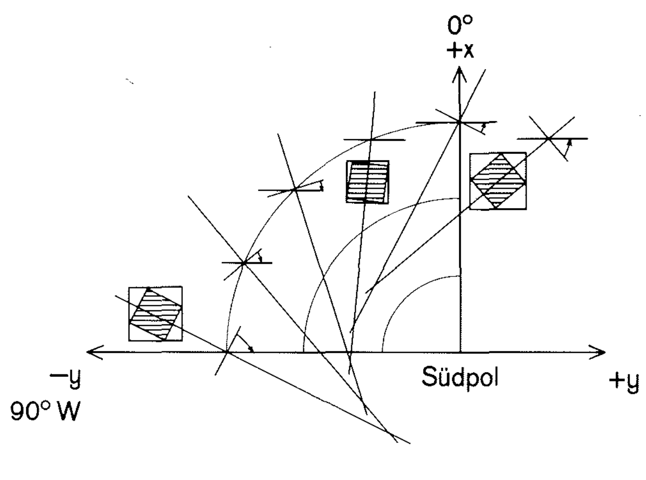

Fig. 3: Uniform resampling x, y-coordinate system.

Abb. 3: Einheitliches x-, y-Koordinatensystem.

A) Single-scene processing	B) Block adjustment using tie points	
A	B1	B2
Original digital raw data	Original digital raw data	Original digital raw data
Preprocessing	Preprocessing	Preprocessing
	Selection of tie points	Selection of tie points
Digital measurement of image coordinates of — ground control	Digital measurement of image coordinates of — ground control — tie points	Digital measurement of image coordinates of — ground control — tie points
Single-scene adjustment of all ground control referred to a **specified map projektion**	**Block** adjustment of all ground control and tie points referred to a **specified map projection**	**Block** adjustment of all ground control and tie points referred to an **ellipsoid**
Result: 1 set of transformation parameters for 1 **single** scene	Result: Sets of transformation parameters **simultaneously** adjusted for **each** scene	Result: Sets of transformation parameters **simultaneously** adjusted for **each** scene
Resampling of 1 single scene to the **specified** map projection = geocoding	Resampling of each scene to the **specified** map projection = geocoding	Resampling of each scene to **any optional** reference system or map projection = geocoding
Interactive-digital geometric and radiometric mosaicking	Interactive-digital geometric and radiometric mosaicking	Interactive-digital geometric and radiometric mosaicking

Tab. 2: Concepts of digital satellite image mosaicking.

Tab. 2: Methoden zur digitalen Bildung von Satellitenbildmosaiken

The process of mosaicking can generally be conducted by two methods (ZOBRIST et al. 1983, GÖPFERT 1984, ALBERTZ et al. 1987):

Method A (see Table 2) is based on the processing and rectification of single scenes. Geometric discrepancies in the seams between adjacent scenes are neglected. An overall adjustment of all image coordinates measured in all single scenes is not carried out.

The method is easily and expediently applicable if sufficient ground control is available (generally four to nine points for each single scene) drawn from maps or positioned on the ground.

In Antarctica about 20 Landsat MSS scenes ar necessary to produce a satellite image map at 1:1.000.000 scale. The procedure of tying together single scenes rectified independently of each other cannot be used for that task. Mostly we lack sufficient ground control or even we are failing the possibilities of positioning control points.

Method B, two variants of which are reported here (see Table 2), is based mainly on the measurement of image coordinates of features appearing in the overlap between adjacent Landsat scenes. Ground coordinates for these common points, also called "tie points" or "seam points", are not known. To adjust the mosaic to a coordinate system, only sparse geodetic ground control is required, as shown in Fig. 5.

An overall block adjustment is applied to all image coordinates measured in all scenes of the mosaic. The results are sets of transformation parameters for each scene. In variant B1, the adjustment is conducted with reference to the specified map projection from the beginning of the processing. In variant B2 the block adjustment is carried out relative to a spheriod.

It is common to all methods described that various effects of the dynamic scanner/spacecraft geometry have to be compensated for. In some cases it is necessary to apply the corrections to the original unprocessed image geometry, notably the elimination of regular striping patterns (six band noise) and the correction of variable scanline length.

Other effects can be treated simultaneously in the block adjustment as it is performed in method B2. The effects are mainly spacecraft motion and earth rotation during the scanning process, earth curvature, panorama distortion, variable scanning mirror velocity, and instability of satellite attitude.

Two mosaics have been compiled after applying the methods of block adjustment using tie points, for which results are reported in the following chapters.

4.1 Satellite Image Map SS 28-30 "Ritscherhochland" 1:1.000.000

In November 1986 the Institut für Angewandte Geodäsie published the first satellite image map digitally processed at 1:1.000.000 scale. The map is composed of a mosaic of 15 scenes of Landsat-1 and 2 acquired from February 1973 to November 1975.

Figure 4 shows the satellite imagery coverage diagram of the mosaic. 25 GPS- or Doppler satellite positioned localities are available bunched together to three main groups. This represents a rather disadvantageous distribution of ground control. With the aid of topographic maps at 1:250.000 scale additional control points could be determined. Transformation of these points to WGS 72 was not possible in all case with the same certainty. The standard deviation of the ground control positions obtained using the broadcast ephemeris is estimated to be ± 30 m. The standard deviation of points determined on the maps is about ± 100 m.

The selection of tie points proves to be difficult for this mosaic. The seam between scene B and C is too small (about 70 scanlines) to choose a sufficient number of identical points in both images. The cirumstances are even worse in the overlapping area of scenes C and F and the situation is additionally aggravated by clouds in scene C. Further problems are resulting from the large time interval between adjoining images (there is a three year

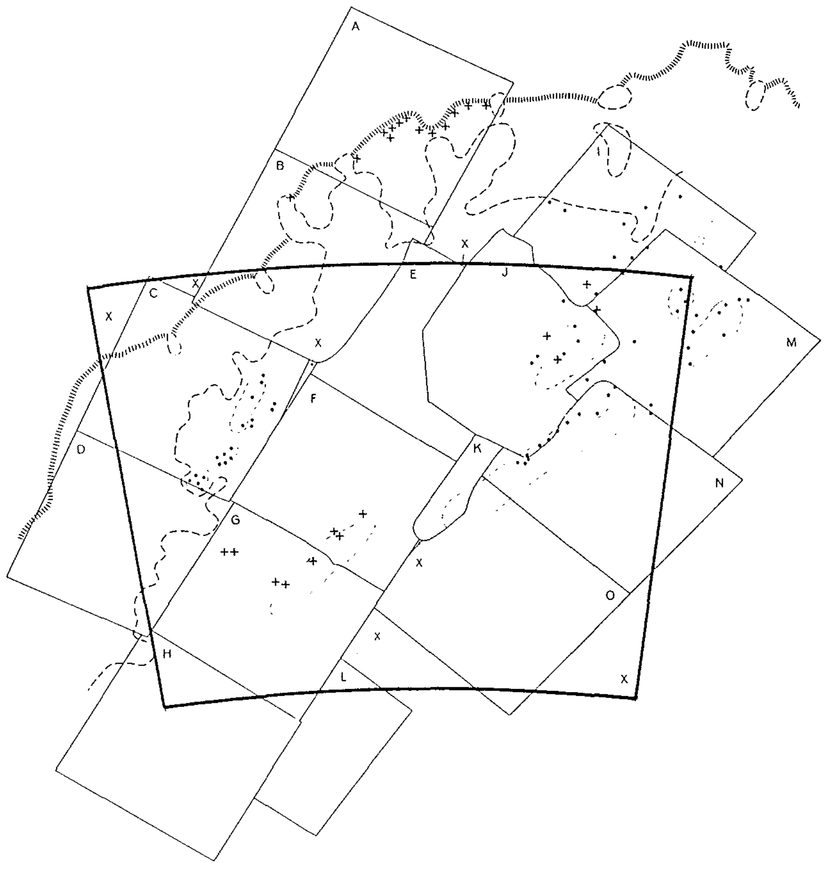

Fig. 4: Imagery coverage diagram of Satellite Image Map SS 28-30 "Ritscherhochland" 1:1.000.000. + geodetic control by GPS- or Doppler satellite positioning; • geodetic control by terrestrial triangulation; A-O satellite imagery used; X no satellite imagery available.

Abb. 4: Bildübersicht der Satellitenbildkarte SS 29-30 "Ritscherhochland" 1:1.000.000. + Paßpunkte, bestimmt durch GPS- oder Dopplerbeobachtungen, • Paßpunkte, bestimmt durch terrestrische Triangulation, A-O verwendete Satellitenbilder, X keine geeigneten Satellitenbilder verfügbar.

interval between scenes I and M). Other difficulties result from seasonal changes of objects in the course of the year. Above all this is a source of complication and misinterpretation.

About 260 image coordinate readings of control and tie points in the 15 scenes of the mosaic were made. The adjustment is based on a linear, affine polynominal model. The compilation is conducted in the system of the respective Lambert projection zone. The approximated values of the exterior orientation of the satellite, normally listed in the header files of each CCT (SIAT files) have not been used.

Standard deviations s_x and s_y of the x- and y-coordinate are calculated from the residual errors in each of the 15 scenes. The s_x, s_y range from ± 60 m to ± 150 m. The average standard deviation of point position is ± 138 m.

4.2 Digital Satellite Image Mosaic "Filchner-Ronne-Schelfeis, Coats Land"

In collaboration between the Institut für Angewandte Geodäsie (IfAG), Frankfurt am Main and the Institut für angewandte Geowissenschaften (IFG), Offenbach a mosaic comprising 78 Landsat MSS scenes was produced and digitally tied together in May 1988 (in 1987 an analogue mosaic of that area was assembled and served as a basis for a glaciological satellite image interpretation. This work is published as a line map (SWITHINBANK, BRUNK & SIEVERS 1987)).

The block contains four scenes of Landsat-1 aquired in October/November 1973, two scenes of Landsat-5 of January 1985, and 72 Landsat-5 scenes recorded from January to March 1986. The imagery covers large parts of Coats Land and nearly the entire Filchner-Ronne-Schelfeis. Only small parts of the ice shelf beyond the orbital limit of Landsat-5 (82°45'S) are not imaged. The whole area extends from 10°W to 90°W and from 71°S to 82°45'S. The maximum extents of the mosaic are 2000 km and 1500 km.

Figure 5 shows the satellite imagery coverage diagram of the mosaic. Only 28 ground control points are available, bunched together to some 15 irregularly distributed groups. The entire Filchner-Ronne-Schelfeis, about 900x500 km^2 in area contains just one geodetic locality (at 50°W, 77°S). The southern boundary of the mosaic is without any reference points. Most of the control has been positioned by survey campaigns of the U.S. Geological Survey and the British Antarctic Survey from 1975 to 1978. Values of positioning accuracy have been reported by RENNER (1982). Standard deviations are estimated to be ± 10—20 m.

No particular intricacy arose from selecting the tie points, apart from an organizational problem encountered as a result of the large number of tie points. Seasonal changes of the appearance of objects did not occur within the short period of data acquisition. Similarly movement of the snow and ice features is negligible in the most cases. Insufficient overlapping only occurs at two places.

The mosaic presents a specific characteristic. In some cases sequences of consecutive images have been recorded continuously and are consisting of as many as six scenes. Such sequences can be tied together with absolute certainty. This is of particular significance for the stability of the block in the block adjustment.

Altogether 1460 image coordinate readings of ground control and tie points have been made. Of that number less than 20 readings (about 1%) had to be eliminated because of obvious misinterpretation or wrong numbering.

The block adjustment is based on a mathematical model of third order polynomials for which the interior geometry of each scene is considered indiviually. The model comprises all parameters of the dynamic scanning geometry of the satellite: spacecraft motion, earth rotation and curvature, panorama distortion, variable scanning mirror velocity, and instability of satellite attitude. The adjustment has been perfomed with two-dimensional ellipsoidal coordinates and is referred to the reference spheroid WGS 72. An adjustment referred to a planimetric coordinate system of a map projection is not considered because:

— the mosaic covers several 4°-zones of the Lambert projection,
— ellipsoidal coordinates are much easier to transform to other reference systems and map projections rather than planimetric coordinates.

Standard deviations s_x, s_y of all 78 scenes are calculated from the residuals for each scene. The s_x, s_y vary from ± 40 m to ± 200 m, from which an average standard deviation of point position of ± 125 m is calculated.

Fig. 5: Imagery coverage diagram of Landsat MSS mosaic "Filchner-Ronne-Schelfeis, Coats Land". + geodetic control by GPS or Doppler satellite positioning; map sheet line system based on International Map of the World 1:1.000.000.

Abb. 5: Bildübersicht des Landsat-MSS-Mosaiks „Filchner-Ronne-Schelfeis, Coats Land". + Paßpunkte, bestimmt durch GPS- oder Dopplerbeobachtungen. Eingetragene Kartenblattbegrenzungen nach Internationaler Weltkarte 1:1.000.000.

5. CONCLUSION

The lack of geodetic ground control in the Antarctic demands particular procedures for the digital preparation of satellite image maps at 1:1.000.000 scale. Digital mosaicking based on the method of block adjustment with tie points is demonstrated on two examples of mosaics assembled from 15 or 78 Landsat MSS scenes respectively with maximum extents of 2000 km and 1500 km. The major advantage of the method applied is that even extremely large areas (900 x 500 km^2) containing no ground control can be bridged geometrically.

Compared with simpler procedures applied to single scenes, additional expenditure is incurred for the preparation and organization of the digital image coordinate measurement. Furthermore considerable computer capacity is required. However, without employing the block adjustment the production of satellite image maps of the Antarctic at 1:1.000.000 scale presently cannot be performed to cartographic quality standards.

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