Remote Sensing and GIS Application in Antarctica

Heinz Bennat & Jörn Sievers

Institut für Angewandte Geodäsie
Richard-Strauss-Allee 11 - D-6000 Frankfurt/Main 70

ABSTRACT

Antarctica is the last great wilderness on Earth. Even today, more than 80 years after the beginning of research in Antarctica we have little topographic information about this continent and we are not able to close this gap with traditional methods. But accurate maps are essential for studying and monitoring environmental changes.

The development of spaceborne remote sensing technologies from the 1960s onward offered new data sources for the mapping of Antarctica. Together with airborne remote sensing, satellite imagery provides a massive volume of data which renders its organization into a digital database vitally necessary. IfAG is establishing the "**Geocoded Information System Antarctica (GIA)**" as a tool to manage the huge amount of data from remote sensing technologies as well as information gathered in conventional ways. In the first step the Antarctic region covered reaches from 10°E to 90°W. GIA shall support topographic and thematic mapping of Antarctic regions. In addition, modern GIS technologies offer the possibility to support geoscientific research by combining different layers of information, enabling new insights to be gained into our understanding of the environment.

Different types of data are to be handled within GIA: Raster data from satellite image recordings, vector data from field measurements, image interpretation and digitized maps, and alphanumeric data describing additional nonspatial information. Therefore, GIA will consist of separate management systems conceived to handle these different data types. On top of GIA a relational database system will be built containing descriptions of all data stored within GIA. The function of this central database ("a database of databases") could be compared with a "catalogue" in a library. Within GIA all data will be available in a form geocoded to a uniform reference system which is the prerequisite for universal utilisation of information.

After preprocessing and geocoding the digital satellite image data the images are mosaicked and radiometrically adjusted. These mosaics are used to produce topographic maps at scales of 1 : 1.000.000 and 1 : 250.000. Map projection parameters are used in accordance with the recommendations of the SCAR working group on "Geodesy and Geographic Information". To offer maximum information for further visual interpretation only the geographic graticule, selected place names and spot height information are superimposed.

The georeferenced imagery serves as a basis for scientific interpretation. Within the discussion about global change in general and the influence of changing climate on polar ice caps, it is necessary to get detailed knowledge about the outline of Antarctica. Therefore, IfAG prepared a digital coastline together with other digital data (inland glacial features, ice fronts, etc.) derived directly from satellite imagery. More than 80 geocoded Landsat MSS images were interpreted at IfAG and digitized at AWI to serve as a basis for navigational, glaciological and other scientific purposes. Additionally, these databases were intended as the German contribution to the "Antarctica Digital Database Project" initiated by the World Conservation Monitoring Centre (WCMC), British Antarctic Survey (BAS) and Scott Polar Research Institute (SPRI) and supported by SCAR Working Group on Geodesy and Geographic Information. This information is stored in vector format using software of 'ARC/INFO' and within GIA also available in raster format for direct overlay on geocoded imagery.

INTRODUCTION

Antarctica is the last great wilderness on Earth. It is the coldest, the highest and the least known continent. The Antarctic continent is mostly overlain by a huge mass of ice which is estimated to represent about 91% of all ice on

Earth. The effect of the Antarctic ice sheet on global climate is undoubtedly immense. On the other hand, the evolution of the world's climate will alter the mass balance of this ice sheet. But not only for climatology Antarctica is of growing scientific interest. It's modulating effect upon many other physical and biological systems of our planet means that Antarctica plays a key environmental role that extends well beyond the borders of the continent.

It is clear that accurate topographic information (in form of printed or digital maps) will be invaluable for studying and monitoring environmental changes as well as for geological investigations, biological inventories, the planning of expeditions, etc. However, many details on important problems, such as snow accumulation, ice motion and the ultimate removal of the ice at the coast, are largely unknown due to the immense size, remoteness, and harsh environment of these areas. Only for a small portion of the total area of Antarctica maps are available. To close this gap remote sensing technologies are used.

An up-to-date review about remote sensing applications and remote sensing-related activities in Antarctica was presented by MASLINK and BARRY (1990). Therefore, we will give only some examples of IfAG activities in Antarctic research.

1. ACTIVITIES OF IfAG IN ANTARCTICA

After the signing of the Antarctic Treaty by the Federal Republic of Germany in 1979, and as a consequence of the building of the permanent German research station "Georg von Neumayer" in 1981, a boom in German research activities in Antarctica was initiated. The German Antarctic research programme is carried out by the Alfred Wegener Institute for Polar and Marine Research (AWI) at Bremerhaven, the "Bundesanstalt für Geowissenschaften und Rohstoffe" (BGR) at Hannover, and by scientists of different universities and institutions. Within this programme IfAG is engaged in the fields of photogrammetry, remote sensing and cartography and is also named as the "National Antarctic Mapping Centre of the Federal Republic of Germany".

IfAG started remote sensing activities by producing NOAA-AVHRR mosaics of "Western Neuschwabenland 1:3 000 000" (1981), "Neuschwabenland 1982 1:3 000 000" and "Antarctica between 110°W to 90°E" 1:6 000 000 (Schmidt-Falkenberg 1983, 1984a, 1984b, 1987, Göpfert 1984, 1985). The map at a scale of 1:6 000 000, published in 1984, was the first satellite image map showing more than half of the continent. It took another 5 years before a NOAA-AVHRR mosaic covering Antarctica in total was completed by a joint project of NOAA, the United States Geological Survey (USGS) and the National Remote Sensing Centre (NRSC, UK) (Merson 1989).

Concerning photogrammetric activities IfAG participated in 5 expeditions during which more than 10000 aerial photographs, mainly of mountainous regions in Western Neuschwabenland, in the Shackleton Range, and of parts of the Antarctic Peninsula were obtained. Additional photographs were taken near the Georg von Neumayer Station and the German summer station (Filchnerstation) on the Filchner-Ronne-Schelfeis (see Fig 1). The problems of aerial photogrammetry in Antarctica due to the special geographic conditions (low sun angle, high reflection of snow and ice, sharp contrasts between rock outcrop and snow, etc.) were discussed by Sievers and Walter (1984).

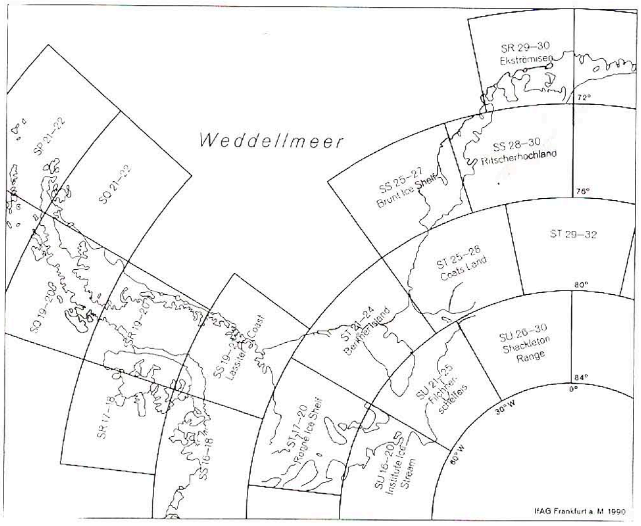

Fig. 1 - Areas covered by IfAG aerial photographs.

By conventional photogrammetric methods the aerial photographs of Borgmassivet, Heimefronfjella and the Shackleton Range were used to derive digital elevation models (DEM), contour plots and orthophotos. Until today a total area of more than 15.000 km^2 has been covered by these three terrain models. The orthophotos and contour plots of Borgmassivet were used for geomorphological and glaciological investigations by Brunk (1989). The data of Heimefrontfjella served as basis for further geophysical and glaciological measurements (Herzfeld & Holmlund 1988). A geological map using a mosaic of orthophotos as background information is in preparation.

2. THE GEOCODED INFORMATION SYSTEM ANTARCTICA (GIA)

In parallel with these photogrammetric activities, IfAG became more and more involved in the field of spaceborne remote sensing using data sources with higher spatial and radiometric resolution, like LANDSAT MSS. The increasing volume of data and the evolution of data analysis methods forced IfAG to find new strategies of data organization. As a result it was decided to establish an information system called 'Geocoded Information System Antarctica (GIA)' which is financially supported by the German Research Ministry (Bundesministerium für Forschung und Technologie, BMFT).

GIA shall support the geoscientific analysis of remote sensing data as well as the production of all kinds of maps using modern GIS-technologies (Schmidt-Falkenberg 1987, 1990).

GIA will consist of data bases encompassing aerial photos, control points, maps, geographical names, digital elevation models and geoscientific data, as for example geophysical measurements of ice thickness, ice flow velocities or meteorological data. But the greatest amount of data will be built by satellite image data of the various systems, like NOAA-AVHRR, LANDSAT MSS, LANDSAT TM, SPOT HRV, COSMOS, and ERS-1.

These different types and sets of data comprised by GIA can be arranged in three groups:
- alphanumeric data: i.e. the information about control points or geographical names,
- vector data: i.e. the digitized coastline of Antarctica and
- raster data: i.e. the satellite images.

Owing to the different kinds of data to be managed the term "GIA" does not apply to a singular system but to a group of data bases and geographic information systems and to the organizational context. The logical scheme of GIA, visualized in Fig. 2 as a set of triangles, consists of a catalogue surrounded in the centre by three management systems in accordance with the different data types.

Raster data are handled using facilities of the image analysis systems **ARIES III of DIPIX Technologies**, Ottawa, Canada, and **DVS/IntegRIS**. DVS is a development of IfAG (Weber, 1983), which was first used on PDP 11/34 computers. In the meantime, the software has been revised and adopted to VAX-workstations and supplemented by modules of the IntegRIS-GIS software (Göpfert, 1991) of the Technical University of Darmstadt. In general, the ARIES system with its sophisticated image analysis capabilities is used for geoscientific investigations and the development of new methods, while the DVS-package is used for standard applications like preprocessing of image raw data, building of mosaics, etc. DVSroutines are also used for long-time archiving of image data on optical disks because of the optimized I/O-performance characteristics suited for accessing large data sets.

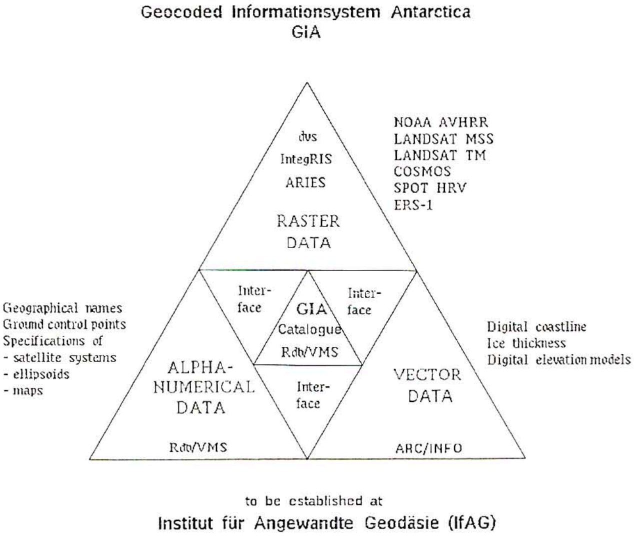

Fig. 2 - Schematic structure of GIA.

Vector data are stored using the GIS-software of ESRI's ARC/INFO. This well known product offers all necessary modules for data capture, storage, display and analysis. Via the IfAG network data transfer to the Image Mapper of Kartoplan for hybrid processing of raster and vector data is possible.

Alphanumeric data are managed using the relational data base software Rdb/VMS of Digital Equipment. This software product is also used to build the catalogue. Between the catalogue and the different management systems interfaces have to be established to support data exchange and format conversion.

The catalogue will offer an overview of all available information. Therefore this data base will only contain the heading information which is necessary to select a special satellite image file, for example. The description will consist of the name of the area covered, the corner coordinates, date and time of acquisition, sensors and spectral ranges recorded, and of the medium and address where the information is stored.

Maps, for example, may be available in three forms: analogue in the IfAG map library, scanned in raster format

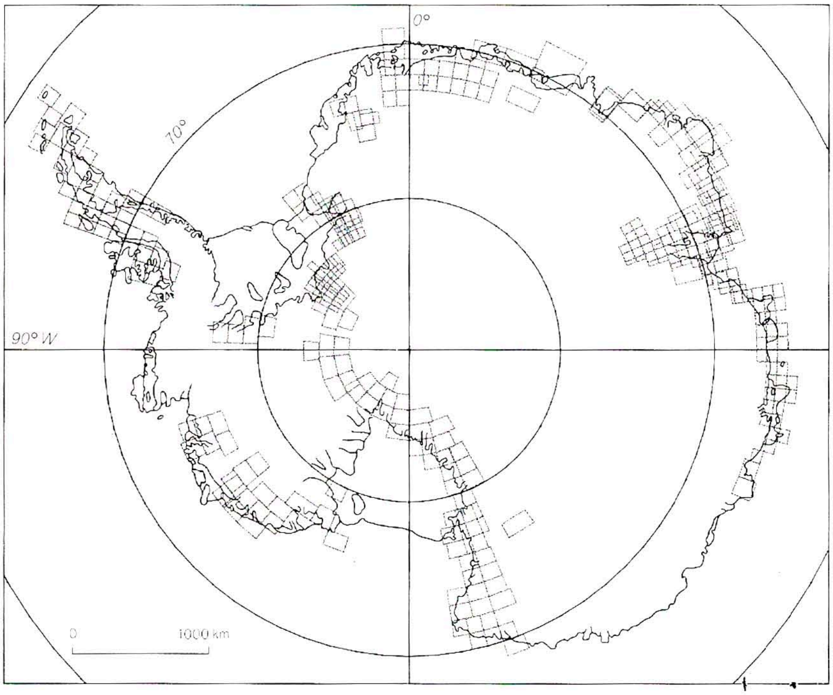

Fig. 3 - Map coverage of Antarctica with topographic maps at a scale of 1 : 250.000. Data source: Scar (ed.) (1988): Antarctica - A Catalogue of Maps and Charts. (From: Bennat 1991).

or digitized in vector format. We therefore get three sets of data describing the same map, which are only different in the field referring to the storage medium.

To avoid problems with copyright of satellite imagery data GIA is at the moment not designed for external online access.

One of the main tasks of GIA consists in supporting the compilation of topographic and thematic Antarctic maps.

3. MAPPING OF ANTARCTICA

Until today only about 20% of Antarctica is covered by topographical maps at a scale of 1:250 000 or larger (Fig. 3), which is the minimum scale usable for glaciological purposes (Swithinbank 1988). Even at scales of 1:1 000 000 or 1:500 000 only the coastal regions are mapped. If one tried to complete the map coverage by traditional methods, one would never come to an end.

The development of spaceborne remote sensing technologies from the 1970s onward offered new data sources for the mapping of Antarctica. Only 15-20 Landsat MSS images, instead of 12,000 conventional vertical aerial photographs, are required to cover the area of a 1 : 1.000.000 scale map of the International Map of the World (IMW) (Lucchitta et al, 1987).

Swithinbank (1988) pointed out that for Antarctica, "Satellite images generally yield the first-ever reliable data not only on many glacier margins but also on the very existence of a great variety of features never seen before". The advantage of satellite images to show features on the Earth's surface in their correct relative positions caused a more or less uncritical handling of this data. In many papers hardcopies of single scenes with none or minor geometric and radiometric corrections were used to interpret glaciological features and to publish the results as annotated photographs, often called maps. But most of these sometimes very spectacular looking products are of limited value for further geoscientific research, because the satellite images were not referred to any map projection, which especially in Antarctica is the presupposition to use contemporary satellite images to measure changes in various ice sheet parameters.

In other parts of the World like Europe it is possible to rectify and to match single scenes of different satellite sensors or/and recording times with each other because satellite imagery is characterized by heterogeneous texture pattern and a lot of identifiable objects with well-known coordinates. In contrast to this in the case of Antarctica we have to deal with quite different surface characteristics. It is estimated that less than 3% of this continent is free of snow and ice. The remainder is moving more or less fast and its surface is represented in satellite images by homogeneous grey values. In the regions of the ice streams and glaciers the surface topography is constantly but unpredictably changing. Velocities of ice flow reaching more than 1 km per annum are determined. Crevasses to be seen in an image recorded this year might have been disappeared in the next year due to the moving ice or the stormy wind which is equalizing all surface features. Therefore, only the few nunataks can serve as reliable ground control points (GCP), but not all of them are known with their coordinates.

This means that only in exceptional cases the rectification of single scenes is possible. Therefore, techniques of image triangulation have to be applied to transform all data to a uniform reference system. For this transformation of spatial data into a uniform coordinate system the terms "geocoding" and "georeferencing" are sometimes incorrectly used as synonyms.

According to Swann et al. (1988) there are three levels of geometric correction appropriate to satellite imagery. First, the imagery can be corrected to an 'ideal satellite projection', i.e. the effects of the satellite's changing altitude and irregularities in its orbit have to be eliminated. In the second step, called "georeferencing" the remaining perspective distortions are corrected and the image is transformed to a map projection. In the next step of processing, the "geocoding", the imagery is rotated to align the scanlines with the map projection grid, and is resampled to a standard rectangular pixel size which is fundamentally necessary for universal utilization of data.

Geocoded imagery offers several advantages. It can be directly overlaid with other digital data, like geocoded imagery from other satellite sensors or digitized map data. Therefore, geocoded imagery is an ideal data source for building a Geographic Information System, like GIA.

Figure 4 shows the area of Filchner-Ronne-Schelfeis, Coats Land and Neu schwabenland overlaid by a location diagram of more than 100 LANDSAT MSS-Scenes to illustrate the irregular distribution of the few suitable GCPs (indicated by crosses) within this large area (approx. 2700 km x 1300 km).

The image data, with few exceptions acquired in February and March 1986, were rectified using the method of block adjustment with tie points as described by SIEVERS et al (1989). This method enables us to transform the imagery to a coordinate system requiring only sparse geodetic control, as shown in Fig. 4.

As standard reference system for geocoding within GIA we use the specifications of the International Map of the

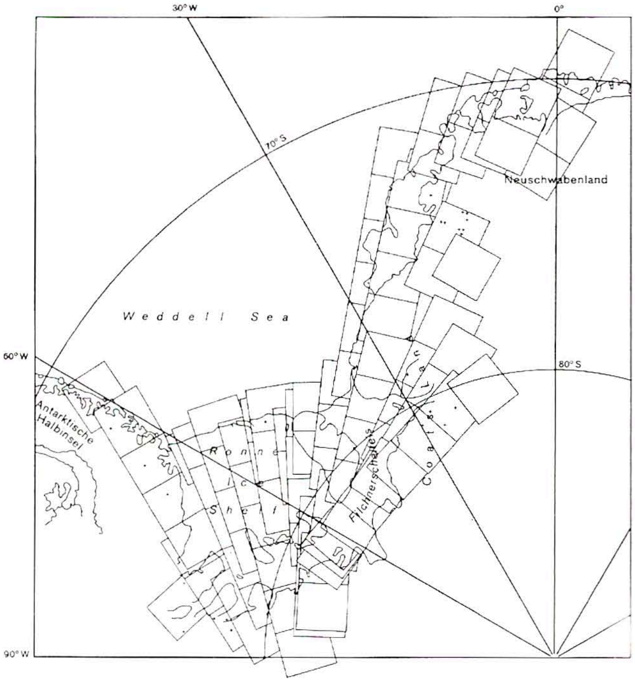

Fig. 4 - Imagery coverage diagram of Landsat MSS mosaic "Filchner-Ronne-Schelfeis, Coats Land and Neuschwabenland". Indicates geodetic control by GPS or Doppler satellite positioning used for the southern part (After: Sievers et al. 1989, Heidrich et al. 1991).

World (IMW) 1:1 000 000 as recommended by the SCAR Working Group on Geodesy and Geographic Information (Sievers & Bennat 1989). The reference spheroid is WGS72 or WGS84.

The division and numbering of map sheets for the Southern Hemisphere between 60°S and 90°S is given in Fig. 5.

For synoptic small scale representation of very large regions or the whole continent the polar stereographic projection (standard parallel 71°S) is used which is unsuitable for measuring purposes because of the high distortion.

Therefore, geocoding of Landsat MSS data has been done for two scale ranges:

- for large and medium scales to 1:1 000 000 with a raster element size of 60 m x 60 m in reference systems according to the IMW 1:1 000 000
- and for scales less than 1:1 000 000 with a raster width of 240 m x 240 m in stereographic projection.

The imagery geocoded to 240 m x 240 m pixel size will serve as a basis for a cooperative project between the UK, the USSR, Norway and Germany to produce a series of topographic-glaciologic maps of Filchner-Ronne-Schel-

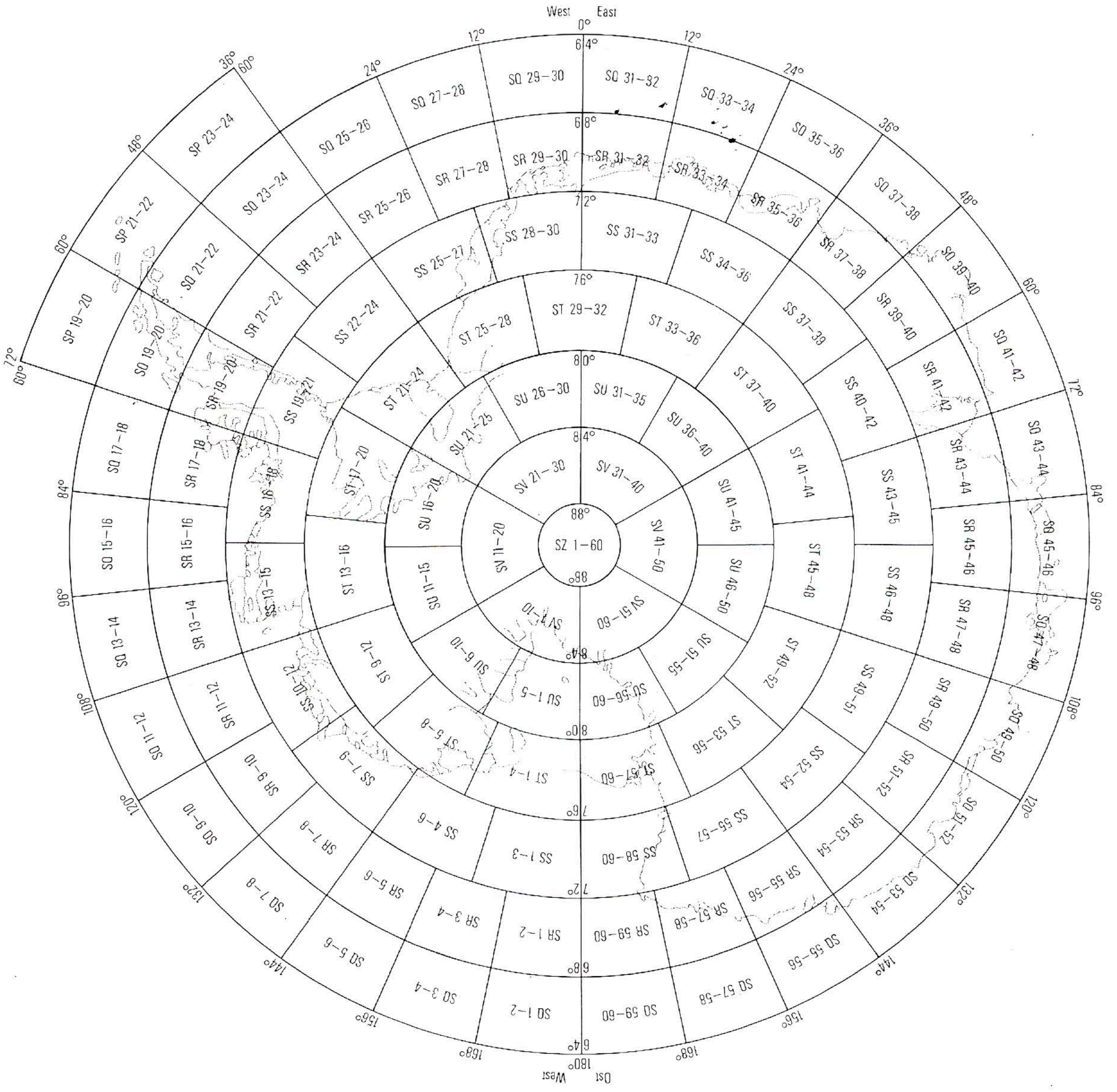

Fig. 5 - Sheet numbering system of the Southern Polar Region according to the International Map of the World (IMW) 1 : 1.000.000. Beginning at the equator, the Earth's surface is divided into 22 parallel zones of 4° of latitude, labelled A to V. The polar cap is labelled Z. These labels are preceded in the Northern Hemisphere by the letter N; in the Southern Hemisphere by the letter S. Meridional zones of 6° are drawn longitudinally and marked by numbers 1-60. Due to the convergence of the meridians, south/north of 60° latitude two or more sheets of the same parallel zone are combined in one sheet. The polar caps are shown in one sheet. (From: Sievers & Bennat 1989).

feis at a scale of 1:2 000 000. Data collected from field measurements or information derived from airborne and spaceborne geophysical observations about surface elevation, ice thickness, sea bottom topography and glaciological features will be presented in printed maps, but shall be available in digital form also.

The mosaicking was carried out in cooperation between IfAG and the Technical University of Darmstadt (THD). After geometric adjustment local and global radiometric corrections were applied. The local operations smooth the differences between adjacent scenes. The global correction using histogram equalization is necessary to eliminate the influence of different illumination caused by the changing sun angle from west to east. In general, this correction will cause new distortion in the imagery. A new method developed during the preparation of this mosaic by Dipl.-Ing. Lin Wei (THD) and Dipl.-Ing. (FH) A. Grindel (IfAG) avoids traces of the primary correction. In a secondary global processing a filter function based on randomly distributed frequency variations is applied. The result is a homogeneous background image for mapping.

Meanwhile, we have built a stock of more than 140 LANDSAT MSS images covering the area between 10°E and 60°W (Fig. 6). About 50 more LANDSAT TM scenes showing the region of the Antarctic peninsula are currently geocoded. Because of the heterogeneous topography and the higher resolution of TM-imagery, DEM parameters will be included in the transformation algorithm. The DEM will be derived from 250 m contours to be delivered from British Antarctic Survey (BAS). An alternative approach to compute DEM's directly from TM-imagery, as described for example by Konecny et al. (1986), Ehlers (1987) or Ehlers & Welch (1988), could not be applied due to manpower problems.

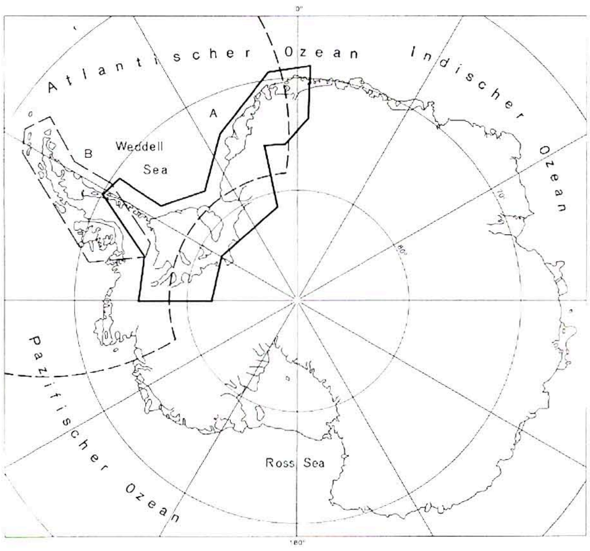

Fig. 6 - Area covered by Landsat MSS & Landsat TM imagery geocoded by IfAG. The dashed circle indicates the observation area of the German recieving station for ERS-1 data at O'Higgins (After: Heidrich et al. 1991).

4. GEOSCIENTIFIC APPLICATION OF THE INFORMATION SYSTEM GIA

Not only the interior of Antarctica, even the coastline is not well known. One reason is the fact that the coastline is constantly changing since approx. 40% of it consists of floating ice shelves. Tabular icebergs with dimensions reaching from several kilometres to several hundreds of kilometres in size calve episodically.

In spring 1990, IfAG and AWI started in a cooperative exercise the preparation of a digital Antarctic topographic database of the coastal regions of Western Neuschwabenland, Coats Land and Filchner-Ronne-Schelfeis (Heidrich et al. 1991, Sievers & Heidrich 1991). Instead of digitizing existing topographic or thematic maps, IfAG and AWI used about 80 recent geocoded satellite images to directly trace topographic and glaciologic features. The following table summarizes the features classified and digitized. Fig. 7, showing the vicinity of the Georg von Neumayer Station illustrates the appearance of some of them in a satellite image.

Table 1 - Topographic-glaciologic features of IfAG/AWI Antarctic digital coastline data base

coastline
at ice front, ice wall, ice rise, ice rumple, fast ice, rock outcrop

grounding line
at main land, ice rise, ice rumple, ice plain

ice stream/glacier
on main land and ice shelf

rock outcrop
as single nunatak or mountain range

significant features
like ridges, steps, rifts, etc.
on the main land, ice rise and ice shelf

Their classification, however, varying between certainty and informed speculation is documented as an attribute in the data base. To allow comparative evaluation of imagery to be expected in future, all features are linked with an attribute indicating the time of observation.

The data base covering an area of about 2 million km^2 excels by a high level of geometric accuracy and by superior homogeneity of the topographic survey.

The digital coastline will be used for further scientific applications by IfAG and AWI, and because of its up-to-date character for navigation on board of the German research vessel "FS Polarstern".

The data set is also the German contribution to the project "Antarctic Environmental Database", carried out by BAS, Scott Polar Research Institute (SPRI) and the World Conservation Monitoring Centre (WCMC), in cooperation with several SCAR member nations, to get a database of the entire Antarctic. It shall be available on CD-ROM in 1992.

CONCLUSION AND OUTLOOK

Remote sensing is a remarkable step forward in the reconnaissance and the mapping of Antarctica. But most work was carried out in the visible and near-infrared band of the electromagnetic spectrum. Extensive cloud cover, long periods of darkness and lack of reliable discrimination between ice and especially light and thin clouds are limiting factors for geoscientific applications of this kind of data.

With new data sources from ERS-1 it is expected to get new insights into the Antarctic environment, even to the extent of monitoring processes during the Antarctic winter. Therefore, IfAG will include ERS-1 SAR data in its further activities.

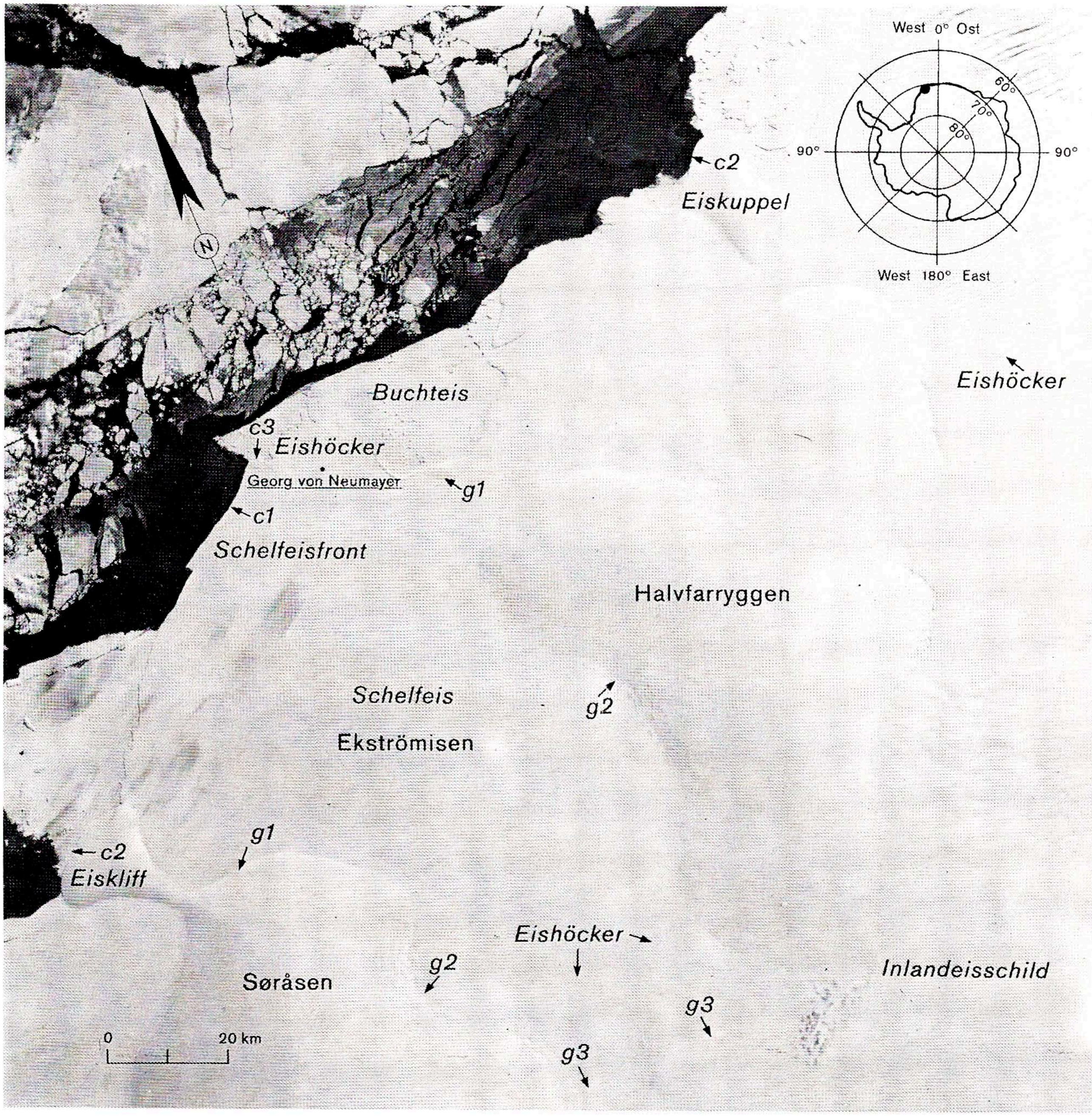

Fig. 7 - Topographic-glaciologic features in the vicinity of Georg von Neumayer Station visible in Landsat MSS. Coastline: cl = Ice front, c2 = Ice wall at mainland or ice rise, c3 = Ice front at ice rumples. "Grounding line", detectable as break in slope on the image with varying degrees of certainty: g1 = certain, g2 = uncertain, g3 = very uncertain ("informed speculation"). (Image data: Landsat MSS, path/row 178/110, 13 Oct. 1987, centre coordinates: 8°W, 71°S). (From Sievers & Heidrich 1991).

REFERENCES

Bennat, H. (1991), "Der Stand der kartographischen Erfassung der Antarktis". Nachrichten aus dem Karten - und Vermessungswesen, Reihe I, Heft 107 (in press) - Frankfurt/Main.

Brunk, K. (1989), "Geomorphologisch-glaziologische Detailkartierung des arid-hochpolaren Borgmassivet, Neuschwabenland, Antarktika". Berichte zur Polarforschung 66. - Bremerhaven.

Ehlers, M. (1987), "Integrative Verarbeitung von digitalen Bilddaten der Satellitenphotogrammetrie und fernerkundung im Rahmen von Geogra phischen Informationssystemen". Wissenschaftliche Arbeiten der Fach richtung Vermessungswesen der Universität Hannover, Nr. 149, 139 Seiten. Hannover.

Ehlers, M. und Welch, R. (1988), "Kartographische Leistungsfähigkeit von Landsat-TM-Aufnahmen". Bildmessung und Luftbildwesen 56, Heft 4, S. 138-148 und Heft 5, S. 157-166. - Karlsruhe.

Göpfert, W. (1984), "NOAA-7 AVHRR Satellitenbildkarten der Antarktis". Internationales Archiv der Photogrammetrie und Fernerkundung, Band XXV, Part A 3A, Kommission III, pp. 320-325.

Göpfert, W. (1985), "Digital image mapping of Antarctica using NOAA-7 AVHRR imagery". Nachrichten aus dem Karten und Vermessungswesen, Reihe II, 42 (Teil I, II), S. 11-16. - Frankfurt/Main.

Göpfert, W. (1991), "Ein raumbezogenes Informationssystem für Raumordnung und Umweltplanung auf der Grundlage rechnergest zter Kartographie und Fernerkundung". Kartographische Nachrichten, 41. Jg. Nr. 1, 1-9. - Bonn.

Heidrich, B., Sievers, J., Thiel, M. & Schenke, H.W. (1991), "Digitale topographische Datenbank Antarktis - Die Küstenregionen vom westlichen Neuschwabenland bis zum Filchner-Ronne-Schelfeis interpretiert aus Satellitenbildern". Nachrichten aus dem Karten und Vermessungswesen, Reihe I, H. 107 (in press). - Frankfurt/Main.

Herzfeld, U.C. & Holmlund, P. (1988), "Geostatistical analysis of radio-echo data from Scharffenbergbotnen, Dronning Maud Land, East Antarctica". Zeitschrift für Gletscherkunde und Glazialgeologie, Bd. 24, H. 2, S. 95-110.

Konecny, G., E. Kruck und P. Lohmann (1986), "Ein universeller Ansatz für die geometrische Auswertung von CCD-Zeilenabtasteraufnahmen". Bild messung und Luftbildwesen 54, Heft 4, S. 139-146. - Karlsruhe.

Lucchitta, B.K., Bowell, J.A., Edwards, K.L. Eliasion, E.M. & Ferguson, H.M. (1987), "Multispectral Landsat Images of Antarctica". U.S. Geol. Surv. Bull. 1696. - Washington, DC.

Maslink, J.A. & Barry, R.G. (1990), "Review - Remote sensing in Antarctica and the Southern Ocean: applications and developments". Antarctic Science, Vol. 2, No 2, pp. 105-121. - Cambridge.

Merson, R.H. (1989), "An AVHRR mosaic image of Antarctica". International Journal of Remote Sensing, 10, No. 4/5 pp. 669-674.

Scar (ed.) (1988), "Antarctica - A Catalogue of Maps and Charts". Scientific Committee on Antarctic Research, 5th Edition - Canberra, Australien.

Schmidt-Falkenberg, H. (1983), "Ausschnitt aus der Antarktis-Satellitenbildkarte 'Neuschwabenland'". Geogr. Rundschau 35, H. 3, S. 108-109. Braunschweig.

Schmidt-Falkenberg, H. (1984a), "Deutsche Beiträge zur Kartographie der Antarktis mittels Photogrammetrie und Fernerkundung". Zeitschrift für Vermessungswesen 4, S. 141-154.

Schmidt-Falkenberg, H. (1984b), "German contributions to the Cartography of Antarctica by means of photogrammetry and remote sensing". Nachrichten aus dem Karten und Vermessungswesen, Reihe II, Nr. 42, S. 29-48. - Frankfurt/Main.

Schmidt-Falkenberg, H. (1987), "Die Fernerkundungskartographie in der Antarktisforschung". Münchner Geogr. Abh. Band B 4, S. 67-85. - München.

Schmidt-Falkenberg, H. (1990), "OEA-Wissenschaftsplan". - Interdisziplinäres Forschungsvorhaben unter Einbeziehung von Radarbildaten der Europäischen Fernerkundungssatelliten ERS-1 und ERS-2 - Frankfurt/Main.

Sievers, J. (1990), "Glaciological Satellite Image Map Series Filchner - Ronne-Schelfeis 1 : 2.000.000". Filchner Ronne Ice Shelf Programme, No 4, S. 84-85. - Bremerhaven.

Sievers, J. & Bennat, H. (1989), "Reference systems of maps and geographic information systems of Antarctica". Antarctic Science, Vol. 1, No. 4, pp. 351-362. - Cambridge.

Sievers, J., Grindel, A. & Meier, W. (1989), "Digital Satellite Image Mapping of Antarctica". Polarforschung Vol. 59 (1/2), S. 25-33. - Bremerhaven.

Sievers, J. & Heidrich, B. (1991), "Digital Coastline of Filchner-Ronne-Schelfeis: Interpretation of high quality satellite imagery". Filchner-Ronne Ice Shelf Programme, No 5 (in press). - Bremerhaven.

Sievers, J. & Walter, H. (1984), "Photogrammetrie 1983/84 im westlichen Neuschwabenland". Berichte zur Polarforschung 19, S. 156-164 - Bremerhaven.

Swann, R. & Hawkins, D. & Westwell-Roper, A. & Johnstone, W. (1988), "The potential for Automated Mapping from Geocoded Digital Image Data". Photogrammetric Engineering and Remote Sensing, Vol. 54, pp. 187-193.

Swithinbank, C. (1988). In: Williams, R.S. JR & Ferrigno, J.G. (ED), "Satellite Image Atlas of Glaciers of the World: Antarctica". U.S. Geol. Surv. Prof. Pap. 1386-B - Washington, DC.

Weber, W. (1983), "Ein Datenverwaltungssystem für digitale Rasterkarten". Nachrichten aus dem Karten - und Vermessungswesen, Reihe I, Heft Nr. 91, S. 77-95, Frankfurt/Main.