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Reference systems of maps and geographic information systems of Antarctica

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Abstract: The necessity for uniform reference systems for conventional maps (analogue) and geographic information systems (digital) is discussed. It is recommended that the following scales and projections are used for Antarctic maps: general maps at scales smaller than 1:1 000 000 should use a stereographic projection. Maps up to a scale of 1:1 000 000 should be compiled according to the specifications of the International Map of the World (IMW) 1:1 000 000. Ellipsoids are used as reference surfaces for the various map projections. Differences of the ellipsoidal parameters of the WGS72 and WGS84 systems have to be considered if accuracies better than 10 m are required. Geographic information systems may store data in vector or raster format and in geographic or in geodetic coordinates. For a raster format which is referred to the geographic (spheroidal) grid the term of 'geographic raster' is introduced, in contrast to the 'geodetic raster' which is referred to a plane cartesian coordinate system. The Institut für Angewandte Geodäsie (IfAG) is establishing the 'Geocoded Information System Antarctica' (GIA) using digital satellite image recordings. Internal storage of data in the GIA is in the form of the geodetic raster (and not by spheroidal coordinates). For the scale range 1:250 000 to 1:1 000 000 the size of the raster element is 60 m × 60 m. For smaller scales, satellite image data of a raster width of 240 m × 240 m are preferred.

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Key words: geocoding, geodetic raster, geographic information system, geographic raster, image map, International Map of the World (IMW) 1:1 000 000.

'All cartographers' trouble began with the abolition of the flat-Earth theory '

Introduction

One important aid for the representation of spatial terrain-related geoscientific data in the Antarctic is their cartographic reproduction in thematic maps. Unfortunately, the maps are often based on different scales, reference systems, and projections, rendering comparison more difficult. This has proved a major obstacle in interdisciplinary work.

As a consequence, the geoscientific world has called on cartographers to issue recommendations and guidelines for a single map projection to cover the widest possible range of uses and users. However, since the spherical shape of the Earth cannot be reproduced without distortion on a flat surface, it is impossible to produce only one map sufficient for all needs.

Compromises in the choice of map projections are inevitable, particularly when the Antarctic is the subject of global problems (e.g. ecological control on a world-wide basis). The recommendations for the production of Antarctic maps outlined in this paper are based therefore on the concept of the International Map of the World at 1:1 000 000 scale. This was also the basis for the recommendations suggested by the 'Scientific Committee on Antarctic Research (SCAR) Working Group on Geodesy and Cartography' for the Antarctic in 1959.

This need for uniformity is becoming increasingly urgent in view of the rapid proliferation of geographic information systems. With the digital form of data acquisition and processing, coordinate systems and map projections will naturally hold a key position.

The question is addressed as to how far the call for a universal coordinate system can be achieved in geographic information systems, and what role international guidelines for the production of Antarctic maps will play in the future.

Map projection

General characteristics

A map is a representation of the curved surface of the Earth projected on to an image plane or on to a portrayal surface which can be developed into the plane. The method of 'flattening' is called map projection. Since flattening can never be absolutely free of distortion, Earth map projection must be adapted to a particular use. This also means that there cannot be one single ideal projection to satisfy all requirements, not even for the Antarctic.

The various forms of projection can be categorized according to

the type of the projection surface in
- azimuthal projections (Fig. 1a),
- cylindrical projections (Fig. 1b),
- conical projections (Fig. 1c), and
- other analytic projections,

their position in relation to the Earth's axis in
- normal projections (see Figs 1a–c),
- transverse projections,
- oblique projections,

and according to the characteristics of projection in
- equidistant projections (for selected directions),
- equivalent projections, and
- conformal (orthomorphic) projections (in the differential sense).

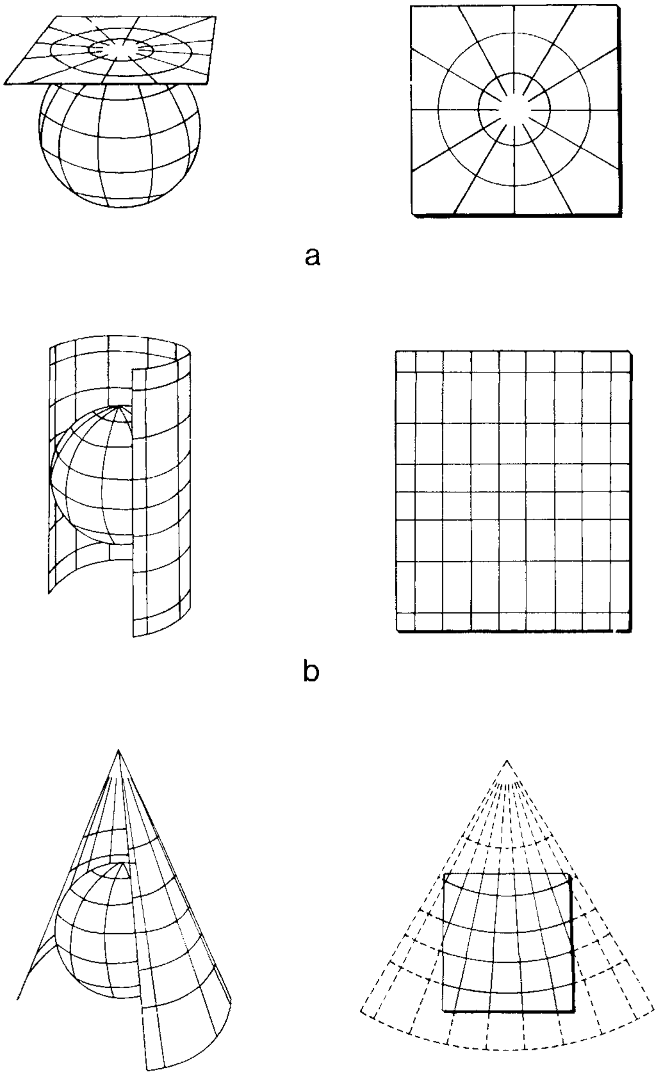


Fig. 1. Main types of map projection (after Arnberger & Kretschmer 1975): **a.** Azimuthal projection. **b.** Cylindrical projection, **c.** Conical projection.

Prerequisites for the Antarctic

The selection of the type of map projection is generally based on
- minimum distortion of the projection,
- projection characteristics (e.g. appearance of the parallels and meridians),
- shape, position and size of the area to be projected,
- map scale, and
- purpose of the map.

In the case of the Antarctic, certain considerations must be observed, which limit *a priori* the possible number of map projections.

Conformal projections are to be preferred for all measuring tasks, particularly for navigational purposes. Angles are presented differentially free of distortion and circles are shown as circles. Thus, conformal projection achieves the best results with low incidence of distortion for the major navigational lines (either great circle, which is the shortest distance between any two points, or rhumb line, which is the line of constant bearing).

Acquisition of geoscientific data in the Antarctic by satellite, aircraft or snow vehicle is carried out almost exclusively with reference to the system of geographical coordinates. Plane Cartesian coordinate grids, normally used in large-scale maps as UTM or Gauss-Krüger grids, are therefore of secondary importance for geoscientific purposes.

'Large-scale' maps (1:25 000, 1:50 000) are not widely used and are limited to the snow-free and ice-free mountainous regions or the immediate environs of research stations. Generally maps are required at medium scales (1:250 000, 1:500 000) and small scales (1:1 000 000 or smaller) for clear presentation of regional spatial and thematic correlations. The geographical position of geoscientific data can be emphasized, increasing the importance of the geographical net and its representation on the map.

In view of the above-mentioned prerequisites, it is recommended that Antarctic maps be based on an existing map series at a scale of 1:1 000 000.

International Map of the World 1:1 000 000

The International Map of the World (IMW) system at 1:1 000 000 scale was first proposed by the German geographer A. Penck in 1891. Guidelines for the production of the IMW were laid down at international conferences in 1909 (London) and 1913 (Paris). They were subsequently updated and extended at the United Nations Technical Conference on the International Map of the World on the Millionth Scale held in Bonn in 1962 (United Nations 1963, see also Knorr 1962). These guidelines specify the sheet line and map numbering system for map representation and map projection. They also constitute part of the 'Recommended Technical Specifications for Antarctic Mapping', published by the SCAR Working Group on Geodesy and Cartography (1961) and since then have been established as Standing Resolutions Gd-2, Gd-3 and Gd-4 of that Working Group.

Between 84°N and 80°S the globe can be divided into parallel zones of 4° of latitude using the Lambert Conformal Conic Projection with two standard parallels. An approximation of the Earth's surface is thus achieved by a system of 41 spherical zones, each projected on a different cone. The polar caps have to be shown in polar stereographic projection. The division and numbering of map sheets for the Southern Hemisphere between 60°S and 90°S is given in Fig. 2.

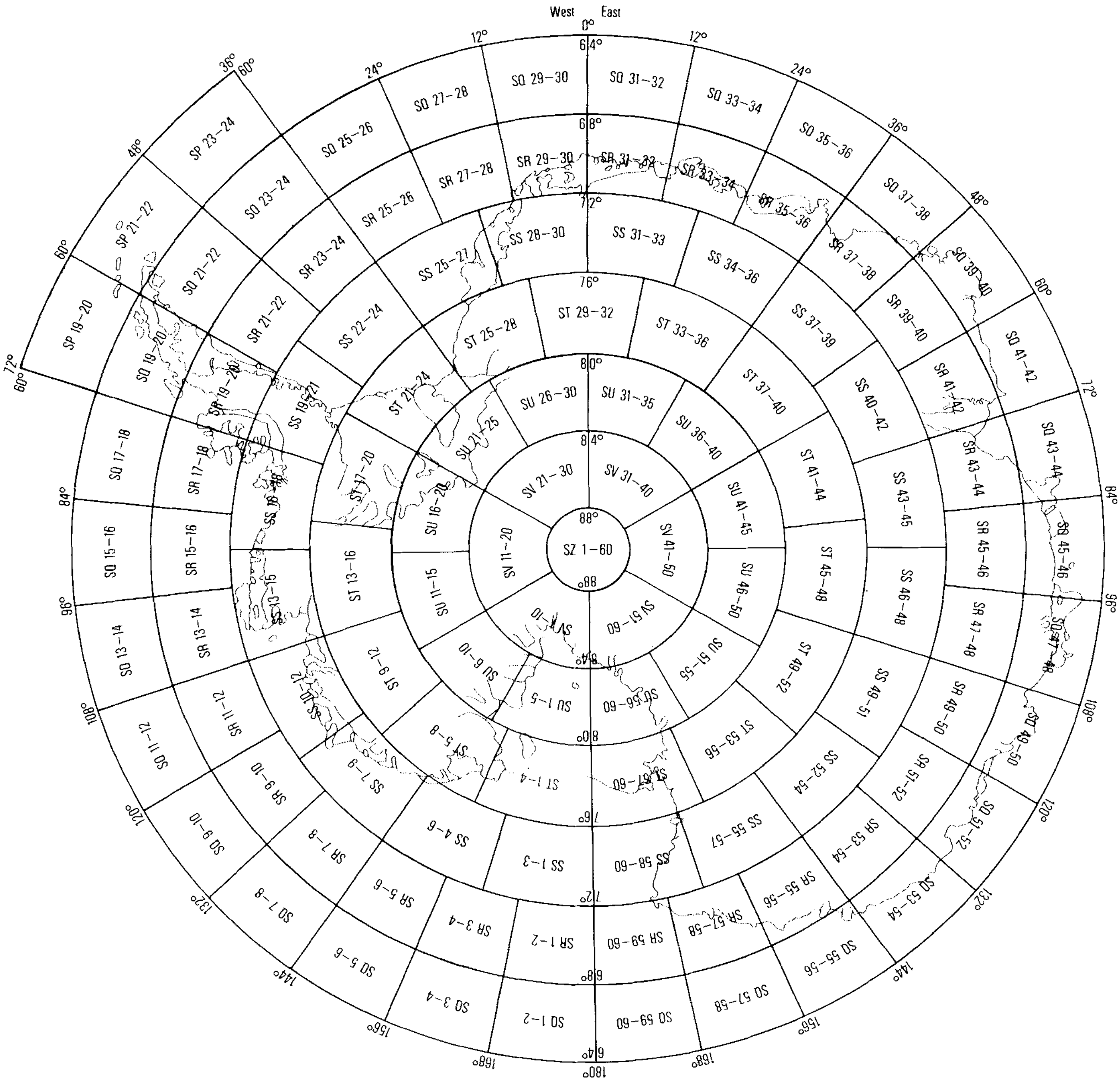


Fig. 2. Sheet division and numbering system of the Southern Polar Region according to the IMW 1:1 000 000. Beginning at the equator, the Earth's surface is divided into 22 parallel zones of 4° of latitude, labelled A to V. The polar cap is labelled Z. These labels are preceded in the Northern Hemisphere 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 on one sheet.

The Lambert Conformal Conic Projection with two standard parallels. The mathematical formulae for a conformal conic projection of the spheroid are given in Appendix 1. According to the specifications of the International Map of the World (1:1 000 000), each Lambert zone of 4° of latitude has two standard parallels, both at a distance of 40' from the map sheet lines (Fig. 3).

The following characteristics are evident:
- all meridians are shown as straight lines,
- all parallels are represented by circular arcs,
- for navigational purposes a linear approximation to great circles is adequate,
- scale error is less than $\pm 4 \times 10^{-4}$ (see Fig. 3 as well as Figs 8 and 9 for comparison with stereographic projection),
- all map sheets show the same degree of distortion.

If the individual latitudinal zones, which are projected onto various cones, are developed into the plane, the result is a series of divergent annular zones, shown schematically in Fig. 4. Adjoining map sheets will meet without gaps in an east–west direction, but in a north–south direction they will only meet along one meridian, which can nevertheless be selected freely. Fig. 5 shows the size of the gaps between map sheets for the region between 60°S and 88°S.

Stereographic Projection. The mathematical formulae for conformal projection of the ellipsoid onto a sphere and for

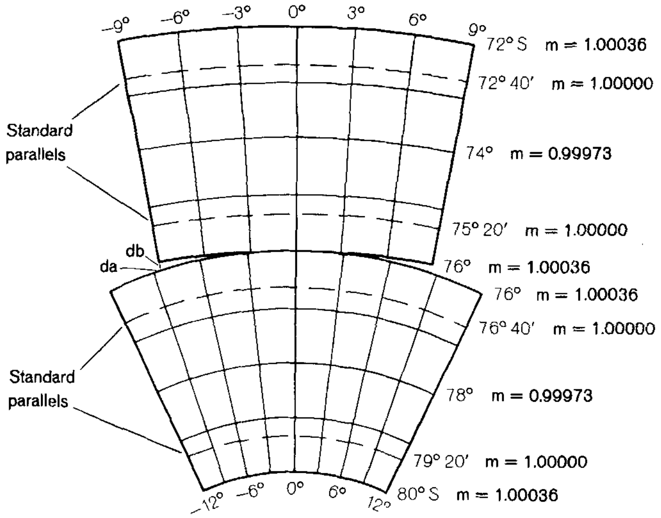


Fig. 3. Scale error (m) of conformal conic projection with two standard parallels. Example: map sheets at 1:1 000 000 scale between 72°–76°S and 76°–80°S with standard parallels drawn in at 72°40' and 75°20', and 76°40' and 79°20'. Scale error remains constant along the parallels as described in the text and changes along the meridians. The distortions are the same in all map sheets. Values for gaps (da) and (db) between adjacent map sheets are given in Fig. 5.

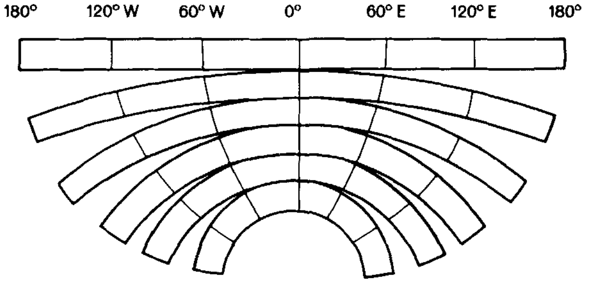


Fig. 4. Projection scheme of several latitudinal zones on various cones with subsequent development into the plane (after Arnberger & Kretschmer 1975). On the maps all meridians are shown as straight lines. In a north–south direction, all meridians can be represented as unbroken straight lines if adjacent zones touch each other along these meridians (shown here for the 0°-meridian).

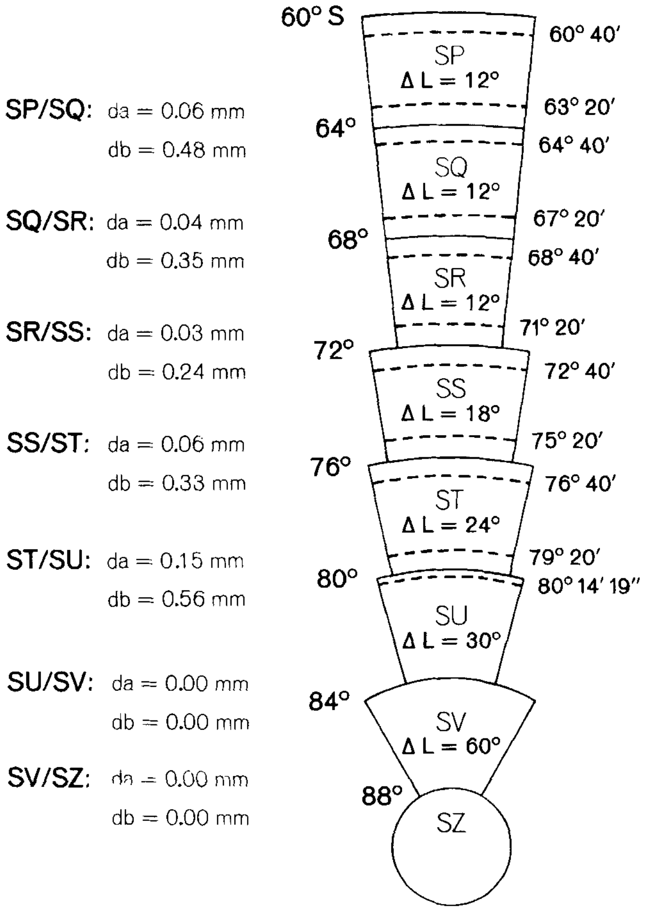


Fig. 5. Gaps (da) and (db) between adjacent map sheets of 4° latitudinal zones for conformal conic projection with two standard parallels (see Fig. 3). Adaption of map sheets to the mean meridian. Values for da and db refer to the map scale 1:1 000 000. There are no gaps between adjacent sheets in an E–W direction (not shown). Sheets SU, SV and SZ fit perfectly, since they have a common, uniform refrence system of stereographic projection according to the IMW convention. ΔL is the size of a single map sheet in an E–W direction.

stereographic projection of a sphere onto a plane are given in Appendix 2.

There are two reasons for considering stereographic projection for cartographic representation of the Antarctic. Firstly, it is a method ideally suited for small-scale uniform representations of the whole continent with a single coordinate system. Secondly, stereographic projection is an accepted standard for the International Map of the World 1:1 000 000.

In the IMW system, stereographic projection is used to represent the polar caps north of 84°N and south of 80°S. It is characterized by the following:

- all meridians are shown as straight lines,
- all parallels are represented as closed circles or circular arcs,
- great circles are shown as circular arcs but may be approximated to straight lines for navigational purposes,
- distortion scales (Fig. 6) are less favourable (by a factor of 10) in comparison with the Lambert projection,
- as a result of scale matching to 80° latitude, between 80°S and 90°S a standard parallel is computed at 80°14'19" (valid for the WGS 72).

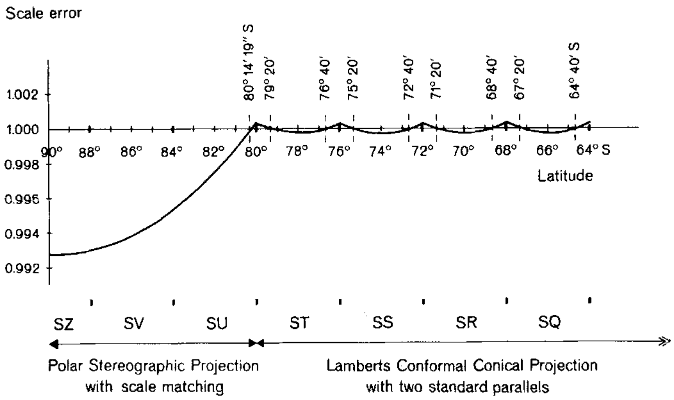


Fig. 6. Scale error (m) in the IMW 1:1 000 000 for Stereographic Projection between 90°S and 80°S, $\Delta m = 7.7 \times 10^{-3}$, and Lambert's conformal conic projection between 80°S and 64°S, $\Delta m = 0.6 \times 10^{-3}$ (see also Fig. 3). Identified latitudes are (equidistantly projected) standard parallels. For map sheet designations SZ, SV, etc. see Fig. 2.

Characteristics and advantages of the IMW. Utilization of the IMW 1:1 000 000 specifications for Antarctic mapping offers the following advantages:

- The IMW, on which the 'World Aeronautical Chart — ICAO 1:1 000 000' of the International Civil Aviation Organization is based, constitutes the only map series which has been defined and accepted throughout the world.
- The IMW has been defined for the whole of the Earth's surface and consists of a total of 43 projection and coordinate systems.
- The *Antarctic* region is covered by five spherical zones between (60°S and 80°S) using Lambert's conformal conic projection and the polar cap (south of 80°S) in stereographic projection.
- Each individual map sheet is based on a single Cartesian coordinate system.
- The sheet line system ensures that the area covered by each sheet is approximately the same size.
- Distortion scales are low and evenly distributed throughout the individual map sheets.
- All map sheets (with the exception of the polar caps) contain the same degree of distortion.
- All meridians are shown as straight lines.
- For navigational purposes great circles can be shown as straight lines to a good approximation.

Map projections at scales smaller than 1:1 000 000

For Antarctic mapping at scales smaller than 1:1 000 000 the SCAR Working Group on Geodesy and Cartography (1961) recommended the use of a stereographic projection with equidistant reproduction of the standard parallel at 71°S.

This map projection is used to represent coherently extended areas covering several 4° latitudinal zones on one map sheet. This is not possible with the conformal conic projection described above, due to the resultant gaps between the latitudinal zones (see Figs 3, 4, 5).

Characteristics for meridians, parallels and great circles at small scales are similar to those outlined above for stereographic projection within the concept of IMW, except that distortion scales rapidly decrease with increasing distance from the Pole. Between 90°S and 60°S the difference in the scale factor is 7×10^{-2}. In comparison with the conformal conic projection this means an increase in distortion by more than a factor of 100.

This is clearly illustrated by the following example (see Fig. 7). At a scale of 1:2 000 000 a distance of 100 mm

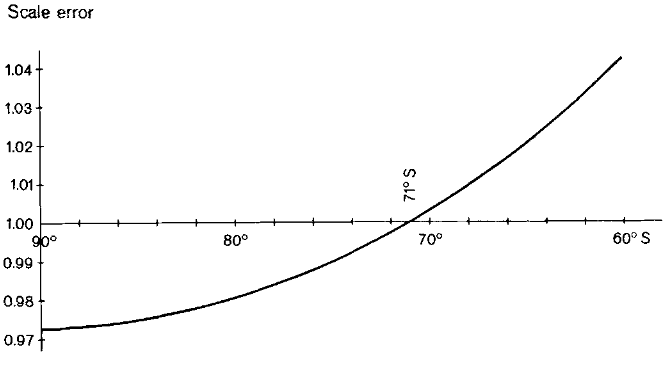


Fig. 7. Scale error (m) of polar stereographic projection with standard parallel at 71°S. Distances marked on a map have to be divided by a factor of 1.04 at 60°S, and multiplied by 1.03 at 90°S. The projection defined by these specifications is used solely for map scales smaller than 1:1 000 000.

measured on the map at 60°S corresponds to an actual distance on the ground of 192 km, at 71°S to 200 km and at 90°S to 206 km. With the specifications given here (projection area between 60°S and 90°S, and standard parallel at 71°S), the stereographic projection is unsuitable for measuring purposes because of the high distortion, particularly for maps at medium and large scales. Therefore, it does not fulfil the initial requirement for one single map projection which satisfies all uses and users. But it is ideally suited for synoptic small-scale representations of very large regions of the whole continent.

Map projections at scales larger than 1:1 000 000

The SCAR Working Group on Geodesy and Cartography recommends using conformal projections for maps at scales larger than 1:1 000 000. The sheet lines are based on subdivisions of the IMW 1:1 000 000.

It is recommended here that the conformal conic projection and the parameters described above are used for map scales of 1:500 000 and 1:250 000, as well as all larger scales.

This means that each spherical zone of 4° of latitude contains two standard parallels at a distance of 40' from the sheet line parallels within the zone. Sheet division and numbering for maps at scales of 1:500 000 and 1:250 000 are explained with examples in Fig. 8.

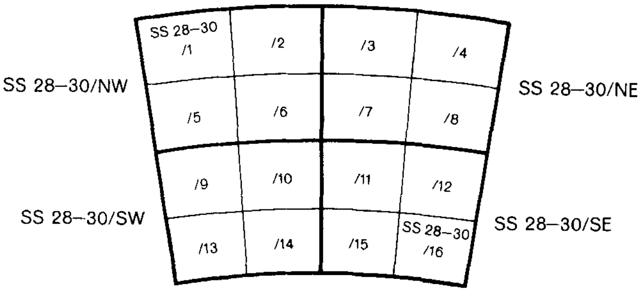


Fig. 8. Numbering system of map sheets at 1:250 000 and 1:500 000 scales. Example: Subdivision of an IMW sheet 1:1 000 000 (SS 28–30) into 16 map sheets at 1:250 000 scale and four map sheets at 1:500 000 scale.

Reference ellipsoids

If maps are to be used for taking measurements, accuracy requires that those greater than 1:2 000 000 must be based on an ellipsoid (Hake 1982). For smaller scales the Earth may be considered as a sphere.

In 1959 the International Ellipsoid was proposed by the SCAR Working Group on Geodesy and Cartography (1961) as the reference surface for the Antarctic. Since the utilization of transit satellites for positioning purposes and the introduction of the World Geodetic System 1972 (WGS72), the WGS72 has been used as the reference surface for the Antarctic instead of the International Ellipsoid. However, this system can no longer be used for satellite observations because the World Geodetic System 1984 (WGS84) is already in use for the Global Positioning System (GPS) satellites.

The parameters of some Earth ellipsoids are given in Appendix 3. Variations of the ellipsoidal parameters cause scale variations in the geographic graticule as well as changes in the geographic coordinates of objects.

Scale variations of the graticule are affected by different radii of polar curvature. The factors of these scale variations (k), compared with WGS72, are given in Appendix 3. Because of differences in k, a distance of 3000 km on WGS72 is about 150 m longer on the International Ellipsoid and only 0.9 m longer on WGS84.

The variations of the geographic coordinates which occur with the change from WGS72 to WGS84 are calculated according to the formulae given in Appendix 3. For the geographic longitude a constant shift of $\Delta L = 0.554''$ can be ascertained which, for the latitudinal shift, amounts to a maximum of 0.08" in the geographic object coordinates as far as 60°S. In any case these deviations do not exceed 10 m. It may be concluded from these facts that a change from WGS72 to WGS84 will not affect scale differences in the graticule or differences in the position of topographic objects as far as cartographic (analogue) applications are concerned.

However, in a GIS coordinates are stored and processed digitally, and for this reason differences in scale and coordinates should be born in mind. It is demonstrated below that even a GIS based on image data cannot be established to any degree of accuracy. By introducing raster (areal) elements, the resolution of a GIS for the Antarctic will at present be limited to 60 m and in the future may be improved to 10 m. Hence, transformation of WGS72 coordinates into the WGS84 system is currently unnecessary. Equations for transforming the International Ellipsoid to WGS72 or to WGS84 are not known with regard to the Antarctic.

Geographic Information Systems (GIS)

Tasks of the GIS

The term GIS applies to spatial digital data and to methods of systematic acquisition, updating, processing and conversion of such data. In GIS, geographic objects are described by two partial attributes. The position attribute determines the spatial position of the object within a coordinate system, and the thematic attribute describes the non-spatial characteristics of the object such as shape, colour, size, age, formation, etc. Geographic objects with common thematic attributes are combined in thematic groups (information levels).

The particular importance of GIS is due to the generation of a logical connection between different levels, thus enabling us to gain new comprehensive information which will ultimately improve our understanding of geoscientific correlations. The prerequisite is a uniform spatial reference system, which should support universal utilization of GIS with regard to data processing and data exchange.

Maps and GIS

The application of GIS has changed the function of traditional maps. Analogue maps are simultaneously a medium for information storage and representation. This has the disadvantage that, because of limited space, only selected subject matter can be depicted.

In order to justify the high production costs, map contents are usually selected to meet the demands of a wide variety of users. A relatively long period of time elapses between data acquisition and map printing because of the work-intensive cartographic editing process. This means that the contents are already out of date on the day of map publication.

GIS eliminates the double function of the map, i.e. information storage and representation medium. In a GIS a map is only one representation medium of the information stored together with other output forms such as tables and diagrams.

Therefore, even with GIS, maps will retain their particular importance as a pictorial medium which instantly shows the spatial distribution of specific contents in context. According to the degree of abstraction from the real world, data in a GIS is called a geographic model (i.e. objects are stored with exact positions and detailed descriptions close to reality) or a cartographic model derived therefrom (i.e. objects are stored in a generalized and distorted form with regard to cartographic requirements, as e.g. map scale and map projection).

Output in map format begins after the geographic model has been converted into cartographic models (dependent on various scales). However, the problems described above, pertaining to flattening of the Earth's spherical surface, still remain.

The choice of cartographic models and map projections will be determined by the requirements of the GIS users. In the case of the geographic model, this means that the coordinates have to be collected in a way which allows for flexible and rapid transformation into all possible map projections. However, this aim of universality is countered by the demand for uniformity and comparability of results, needed for the production of analogue maps.

Data structures in GIS

Two different data structures are used for storage in GIS: vector and raster format. A detailed description of these formats can be found, in, e.g. Burrough (1986).

Vector data. In the vector form, the coordinates of a discrete point can be described by a pair of real numbers.This offers the advantage of determining point positions to a higher degree of accuracy than can be achieved by integer values. The other two basic types of geographic objects, lines and areas, are defined as a sequence of points or as a sequence of limiting line segments.

The thematic attributes coupled to the positional attribute may also contain explicit information on the type and arrangement of the objects (topological structure) as well as on the geometric relations of the various objects to each other. The vector format is used for digital representation of irregularly distributed objects, e.g. contents of thematic maps or individual measurements at various discrete points. Areas without thematic information are not described.

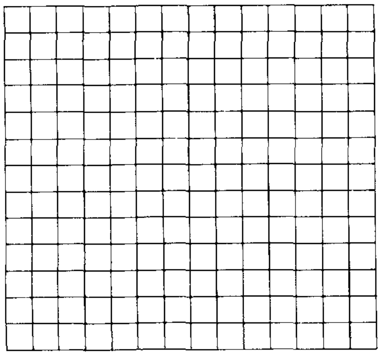
For a vector-based GIS, geographic coordinates provide an ideal, universal reference system. Digital storage and processing is initially free of any limitations regarding map projection or scale. However, these parameters have to be considered as soon as a cartographic representation of the results (e.g. on screen or as an analogue map) is required. Therefore it is also usual to use vector data in all GIS modules (data recording, storage, processing, presentation) referred to plane cartesian coordinate systems.

Raster data. In raster representations, the Earth's surface has to be imagined to be covered with an array of regular areal grid cells (also called raster elements, picture elements or pixels). The line and column numbering of the array form an integral right-angled coordinate system. The thematic attributes of the geographic objects are referred to the grid cells. The grid spacing determines the accuracy of the planimetric resolution — doubling resolution increases the amount of data to be stored by four times.

Normally, a two-dimensional Cartesian coordinate system is selected for the raster. This gives the individual raster meshes a quadratic (or rectangular) plane form (Fig. 9a). Storage in a GIS for this method means the Earth's spherical surface must be projected onto a flat surface, with all the resultant problems of 'flattening' as described above. By analogy with the terms 'geodetic coordinate system' and 'geodetic map projection', this pattern of equally sized, plane, and rectangular raster elements is called a 'geodetic raster'.

The 'geographic raster' is predefined by the geographic grid of the Earth's surface (Fig. 9b) and hence qualifies as a universal reference system which is free of limitations regarding scale and method of projection. However, it should be noted that the geographic raster format no longer contains plane and equally sized meshes. Due to convergence of the meridians, the area of the raster meshes decreases, particularly in the Antarctic, in relation to the geographic latitude. A raster mesh at 60°S is only half as large as at the Equator, at 80°S only one sixth as large and at the Pole it is equal to zero.

The varying size of the raster meshes means inhomogeneous variations in the level of accuracy and resolution



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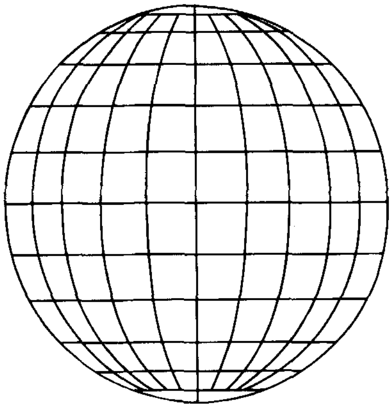

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Fig. 9. Grids for the representation of raster data: **a.** equally sized, planar, and rectangular cell array of the 'geodetic raster', **b.** unequally sized, spheroidal cell array of the 'geographic raster'.

within a data set. Additional algorithms would be needed to allow for the correction of this problem.

A direct graphic representation of the geographic raster (on screen or as a map) is not possible, since the individual raster elements are not plane or rectangular. By this stage, the geographic raster format has to be transformed into a plane Cartesian coordinate system. By analogy with the term 'geographic coordinate system' this pattern of curved and unequally sized raster elements on the ellipsoid is called 'geographic raster'.

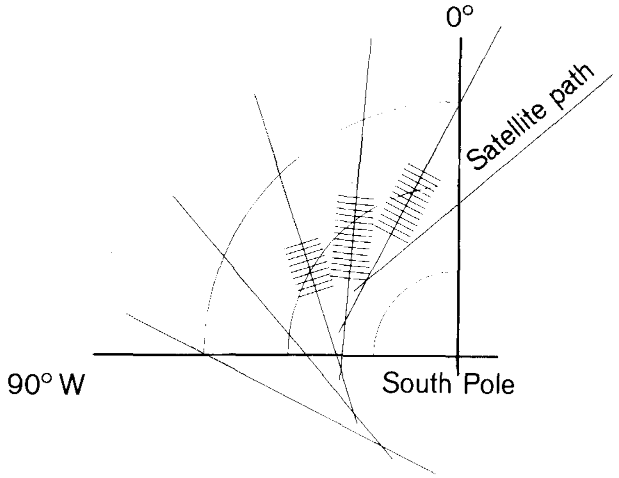
Utilization of the geographic raster format is at present limited to small-scale applications with low resolution, e.g. planetary research (Planetary Cartography Working Group 1987) or the topographic model of the Earth (ETOPO 5).

Geocoded Information System Antarctica (GIA)

The Institut für Angewandte Geodäsie (IfAG) is establishing a 'Geocoded Information System Antarctica' (GIA) as a contribution to the Antarctic research program of the Federal Republic of Germany. The database will consist mainly of satellite image data, i.e. that the dominant part of the GIS data has to be handled in raster format.

Satellite image data. Satellite image recordings are of particular importance for the Antarctic since large, inaccessible areas can be covered in chronological sequence and with a high repetition rate.

In view of the variable orbit paths of satellites, each satellite scene has been given its own recording coordinate system (Fig. 10a). A mosaic of adjacent scenes requires transformation of all images into a uniform coordinate system (Fig. 10b). This is called 'geocoding'.



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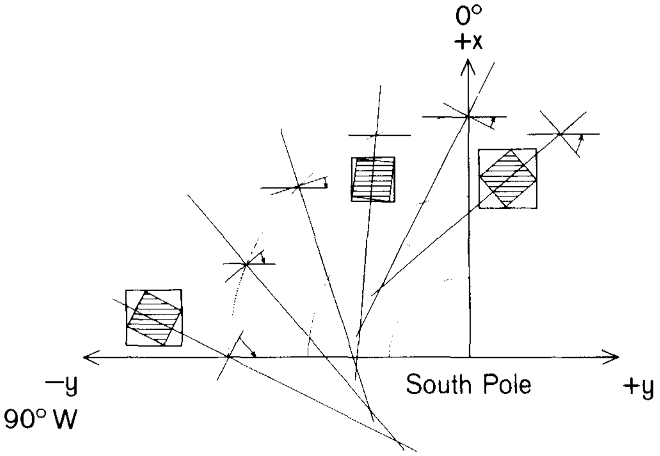

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Fig. 10. Coordinate systems of satellite data acquisition and of geocoded data (from Sievers *et al.*, in press). **a.** The coordinate system, fixed in relation to the satellite track is variable with respect to the principal coordinate system. **b.** The uniform x, y-cordinate system of the geocoded satellite image recordings.

Geocoding of image data in raster format may be carried out both in the geographic coordinate system as well as in a plane Cartesian coordinate system. The following reasons prompted our decision to carry out geocoding for the GIA initially in geodetic raster format. Firstly, digital data storage and processing in this format is at present much simpler than in geographic raster format. Secondly, the overwhelming amount of image data stored in GIA means that the use of GIA is predetermined to produce results primarily in image or map form. However, this entails the same demands and problems as in analogue map production (see above).

Geocoding for GIA is therefore conducted in two scale ranges: for large and medium scales up to 1:1 000 000 with a raster element size of 60 m x 60 m; for small scales less than 1:1 000 000 with a raster width of 240 m x 240 m.

Scale of 1:1 000 000 or larger. According to IMW regulations, six projections with their own coordinate systems are needed for cartographic representation of the Antarctic between 60°S and 90°S. An integral Cartesian grid of 60 m mesh width has been superimposed on each of the six projections (Fig. 11).

Within each Lambert sector of 4° of latitude, the intersection of the Greenwich meridian with the southern (equidistantly projected) standard parallel represents the origin of each reference system. With the polar system (80° to 90°S), which is stored in stereographic projection, the South Pole constitutes the origin of the cartographic reference system. To simplify computation, the origins are displaced by an additional constant so that only positive values occur for easting and northing (not shown in Fig. 11).

The annular shape of the individual Lambert sections means that large areas between two sections contain no information (Fig. 4). Therefore, a sensible solution is to manage the total area in blocks. This saves storage space and raises access speed for individual areas.

Within adjacent areas of two Lambert sections the geocoded data must be stored in the coordinates of both systems (Fig. 11). This enables areas which extend beyond one Lambert zone to be processed provisionally in one system and imaged on screen as well. However, in order to conform with the aims of uniformity and comparability of maps, the ultimate cartographic representation has to be carried out in the sheet line system in accordance with the IMW convention.

Scales smaller than 1:1 000 000. If the relevant working area covers considerably more than 4° of latitude, processing and representation of geoscientific data will be at a scale which is normally less than 1:1 000 000. Therefore, for 'small scale cases', further geocoding of satellite image data is planned (Fig. 12) with the following features:

- a raster width of 240 m x 240 m,
- stereographic projection with equidistantly projected standard parallels at 71° latitude,

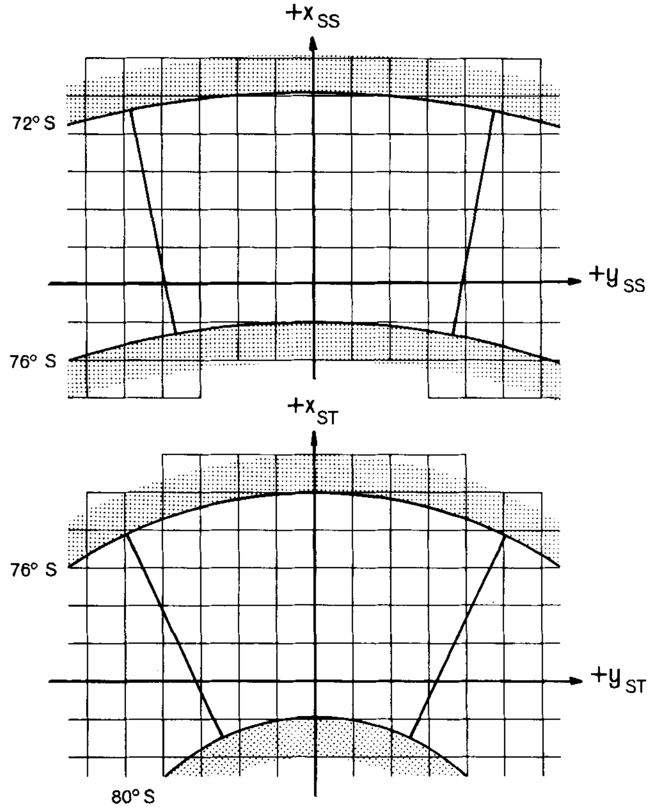

Fig. 11. 'Geodetic raster' for scales of 1:1 000 000 or larger. The schematic example shows parts of the IMW zones SS (72°S to 76°S) and ST (76°S to 80°S) with the relevant x, y-coordinate systems. One mesh of the superimposed grid is approximately 60 km x 60 km, and contains 1024 x 1024 raster elements 60 m x 60 m. The shaded zones indicate areas for which the data have been geocoded in two reference systems and stored in the GIA.

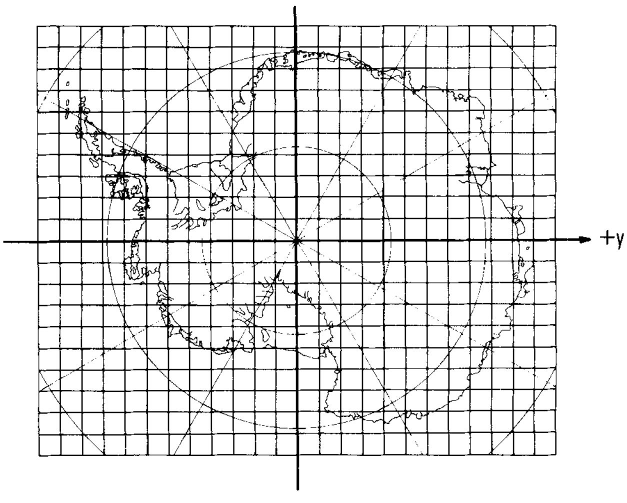

Fig. 12. 'Geodetic raster' for scales of smaller than 1:1 000 000. One mesh of the superimposed grid is approximately 250 km x 250 km, and contains 1024 x 1024 raster elements 240 m x 240 m.

- the South Pole as origin of a plane Cartesian x,y-coordinate system, and
- the 0°-meridian as positive x-axis.

In areas where satellite image data are available, such data are managed in GIA in sections of 1024 × 1024 raster elements (equivalent to *c*. 250 km × 250 km).

Conclusions

In the Antarctic, in particular, multi-disciplinary and international cooperation is a prerequisite for the promotion of geoscientific research. The call for increased comparability of results means that specialists in the fields of geodesy, photogrammetry and cartography must recommend uniform reference systems and map projections for the Antarctic.

For map scales larger than or equal to 1:1 000 000 the adoption of the specifications of the International Map of the World (IMW) 1:1 000 000 is recommended. Smaller scale maps should be represented in stereographic projection.

The requirements of uniform map projections, however, are in apparent opposition to the flexibility offered by Geographic Information Systems (GIS). In view of the purely digital approach in a GIS, it is intended to establish a universal database which is not limited to specific scales and map projections. Geographic coordinates provide the ideal reference system.

But even in a GIS the final processing of the results must normally be represented on a map (plane) and at a particular scale. At this stage problems arise with planar representation of the Earth's spherical surface. For many reasons it would be simpler at present to keep the digital GIS database in the projections and scales already recommended for the production of analogue maps.

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Further reading

The following works are a useful source of information on map projections and geographic information systems.

Göpfert, W. 1987. *Raumbezogene Informationssysteme*. Karlsruhe: Herbert Wichmann Verlag, 278 pp.

Parry, R.B. & Perkins, C.R. 1987. *World mapping today*. London: Butterworths, 583 pp.

Snyder, J.P. 1987. Map projections — a working manual. *US Geological Survey Professional Paper*, **1395**, 383 pp.

Appendix 1

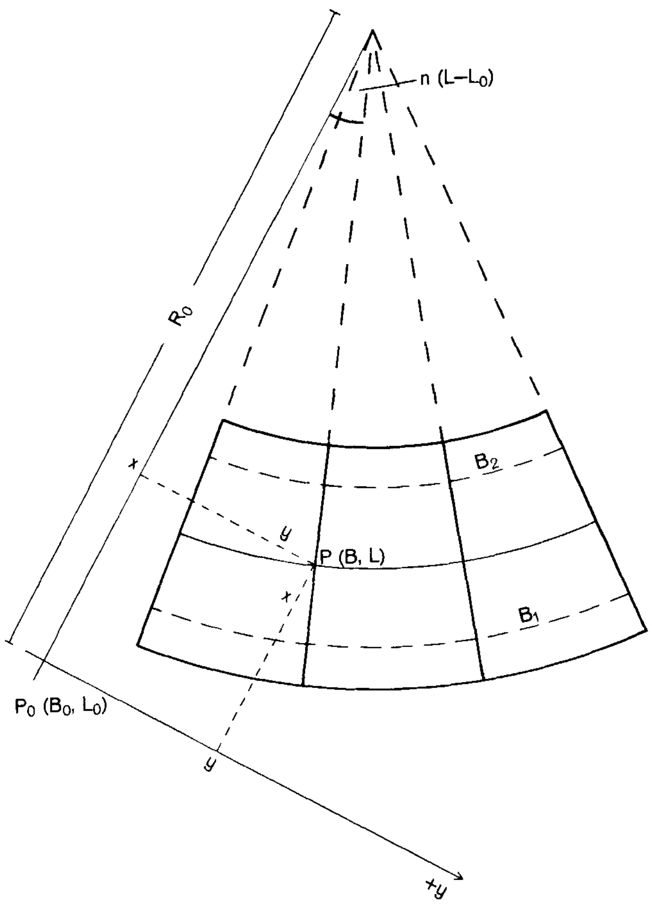
Conformal conic projection of the ellipsoid with two (equidistantly projected) standard parallels ('Lambert's 2nd Conformal Conic Projection') (after Grossmann 1962).

a, b = semimajor, semiminor axis of the Earth's ellipsoid,
B_0, L_0 = geographic coordinates of the (freely selected) origin of the plane cartesian coordinate system,
B_1, B_2 = geographic latitude of standard parallels,
N = radius of curvature in the prime vertical of the ellipsoid,
Q = isometric latitude.

Computation of isometric latitude Q

$$Q = \ln\tan\left(45° + \frac{B}{2}\right) + \frac{\bar{e}}{2}[\ln(1 - \bar{e} \times \sin B) - \ln(1 + \bar{e} \times \sin B)]$$

with $\bar{e} = \left(\frac{a^2 - b^2}{a^2}\right)^{1/2}$.



Computation of transformation parameters n and R_0

$$n = \frac{\ln(N_1 \times \cos B_1) - \ln(N_2 \times \cos B_2)}{\mathcal{Q}_2 - \mathcal{Q}_1},$$

$$R_0 = \frac{1}{n} \times N_1 \times \cos B_1 \times e^{n(\mathcal{Q}_1 - \mathcal{Q}_0)}$$

$$= \frac{1}{n} \times N_2 \times \cos B_2 \times e^{n(\mathcal{Q}_2 - \mathcal{Q}_0)}$$

with e as base of natural logarithm.

Computation of plane Cartesian coordinates x, y and scale error m

$$x = R_0\left(1 - e^{-n(\mathcal{Q} - \mathcal{Q}_0)} \times \cos[n(L - L_0)]\right),$$

$$y = R_0 \times e^{-n(\mathcal{Q} - \mathcal{Q}_0)} \times \sin[n(L - L_0)],$$

$$m = \frac{N_1 \times \cos B_1}{N \times \cos B} \times e^{-n(\mathcal{Q} - \mathcal{Q}_1)}$$

$$= \frac{N_2 \times \cos B_2}{N \times \cos B} \times e^{-n(\mathcal{Q} - \mathcal{Q}_2)}.$$

Appendix 2

Conformal polar azimuthal projection of the ellipsoid ('Streographic Projection') (after Grossmann 1962)

B, L = geographic coordinates of the ellipsoid,
r, λ = geographic coordinates of the image sphere,
x, y = plane, Cartesian coordinates.

Conformal projection of the ellipsoid onto an image sphere with radius $R = N_0$ and the requirements $B_0 = \phi_0$ and $L = \lambda$.

$$R = N_0 = c \times (1 + e'^2 \cos^2 B_0)^{-1/2}$$

with $c = \dfrac{a^2}{b}$ as radius of polar curvature,

$$\tan\left(45° + \frac{\phi}{2}\right) = \frac{1}{k} \times \tan\left(45° + \frac{B}{2}\right) \times \left[\frac{1 - \bar{e} \times \sin B}{1 + \bar{e} \times \sin B}\right]^{\bar{e}/2}$$

with $k = \left(\dfrac{1 - \bar{e} \times \sin B_0}{1 + \bar{e} \times \sin B_0}\right)^{\bar{e}/2}$, $\bar{e} = \left(\dfrac{a^2 - b^2}{a^2}\right)^{1/2}$,

and $e'^2 = \dfrac{a^2 - b^2}{b^2}$.

Stereographic projection of the image sphere into the plane

$$-x = \frac{2R}{m_0} \times \tan\left[\frac{1}{2}(90 - \phi)\right] \times \cos\lambda,$$

$$y = \frac{2R}{m_0} \times \tan\left[\frac{1}{2}(90 - \phi)\right] \times \sin\lambda$$

with $m_0 = \left[\cos^2\left(45° - \dfrac{\phi_0}{2}\right)\right]^{-1}$.

Scale error at any point is calculated by

$$m = \frac{1}{m_0} \times \left[\cos^2\left(45° - \frac{\phi}{2}\right)\right]^{-1}.$$

The South Pole is origin of the plane, Cartesian coordinate systems.

Appendix 3

Parameters of reference ellipsoids (Table I)

B, L = geographic coordinates,
a, b = semimajor, semiminor axis,
f = flattening = $\dfrac{a - b}{a}$,
c = radius of polar curvature = $R_{90} = \dfrac{a^2}{b}$,

Table I. Parameters of reference ellipsoids.

Ellipsoid	a (m)	b (m)	$1{:}f$	c (m)	k
International 1924	6 378 388.0	6 356 911.94613	297	6 399 936.6	$1+5\times 10^{-5}$
Krasovskij	6 378 245.0	6 356 863.0188	298.3	6 399 698.9	$1+2\times 10^{-5}$
WGS72	6 378 135.0	6 356 750.5199	298.26	6 399 591.4	1
WGS84 = GRS 1980	6 378 137.0	6 356 752.31414	298.26	6 399 593.6	$1+3\times 10^{-7}$
Sphere	6 370 000.0	6 370 000.0	∞	6 370 000.0	$1-5\times 10^{-3}$

$$k = \frac{c}{c_{\mathrm{WGS72}}}.$$

Transformation formulae of change of ellipsoid from WGS72 to WGS84 (after Seeber 1989)

$$\Delta B = \frac{4.5 \times \cos B}{a_{\mathrm{WGS72}} \times \sin 1''} + (\Delta f \times \sin 1'') + \frac{\Delta f \times \sin 2B}{\sin 1''},$$

$$\Delta L = +0.554'' = \text{constant},$$

$$\Delta f = 0.3121057 \times 10^{-7},$$

$$B_{\mathrm{WGS84}} = B_{\mathrm{WGS72}} + \Delta B,$$

$$L_{\mathrm{WGS84}} = L_{\mathrm{WGS72}} + \Delta L.$$