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OGS MAPS OF SOUTH CIRCUMPOLAR AREAS

Abstract. Map information is a basic tool in earth science data analysis and must satisfy certain requirements for easy consultation and comparison. Thus, a suitable projection, (Polar Stereographic with a contracting factor k=0.95 at the South Pole) and a convenient sheet format were chosen at OGS for planning, presentation and evaluation of the marine geophysical cruises in Antarctica under the Italian Antarctic Project, with an eye to possible future devolopments. A polynomial in latitude is given to provide easy transformation from geographic to plane coordinates and viceversa.

INTRODUCTION

In recent years, the Osservatorio Geofisico Sperimentale of Trieste (OGS) has collected a large quantity of geophysical data along marine profiles in various areas around the Antarctica under the Italian National Program for Antarctic Research, organized by ENEA.

The initial task was a systematic exploration of the Ross Sea but, from year to year, other projects were added, so that the number of areas in Antarctica has increased. Furthermore, measurements were also taken on the way to and from these areas. This conspicuous increase in data necessitated a collation of all the explorations, including those carried out by other investigators, for a proper planning of the research, and for subsequent data evaluation.

In order to assemble these data (profiles, points, contours) on maps, it is necessary to assume a cartographic base which is sufficiently extensive as to cover all the areas of interest with connecting sheets, in order to uniformly represent a large portion of the southern circumpolar areas, and thus allowing the insertion of particular studies into the more general picture.

It is well known that it is not feasible to project the entire earth's surface onto a plane using the same projection system, and different projection systems must be used to map the areas concerned.

Unfortunately, no international agreement has so far been enforced: various maps have been produced using different projections and various scales for publishing purposes, and few general maps are available. Data comparison for integration and interpretation is thus not immediately possible, and in many cases a digitization of the data is required when projection (and scale) conversion are to be done.

It was therefore necessary to establish some criteria for mapping the data needed at OGS for evaluation and planning of our geophysical activity in Antarctica and bordering regions.

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DISCUSSION OF POSSIBLE SOLUTIONS

Basic requirements for the choice of a unified cartography and suitable sheet formats are well known and can be summarized as follows:

- the projection is to be conformal, which means that for every point the same scale applies in all directions and the angles on the map are equal to the real ones;

- the largest area should be represented without excessive deformation of relative scale (within a map);

- it must be possible to join adjacent maps to assure continuity of representation along edges, which should be as long and convenient as possible;

- dimensions of individual maps should be not too large for easy handling (say, not more than about one meter per side).

For our needs, the limits of this unified area should extend from the South Pole to about 45-50°S latitude.

In order to allow easy insertion of relevant data (coasts and ice shelfs or glaciers, bathymetric contours, gelogical maps), the projection adopted should be that in which most of the existing maps containing the above mentioned features are already drawn, so that only the simplest transformations are involved (e.g., photoreduction). At OGS, digitized geographical coordinates of the coastlines from the general maps of Antarctica are already available.

The most commonly adopted projections for mapping large areas are the Lambert conic (LCP), the Mercator (nautical, MP) and the polar stereographic (PSP) projections. They belong to the same family, as is shown by the exponential nature of the analytical relationships for coordinate conversion (see, e.g., Tomelleri and Vettore, 1987).

The PSP is less familiar to the ordinary user, at least when the areas are large, since he is accustomed to looking at an "up-down" north-south direction and a "left-right" west-east direction, and this is not always true in PSP maps if they are very near to the pole, or include it. This is the only drawback, and it disappears when smaller areas not including the pole are mapped.

Since most of the areas of interest are covered by oceans, and seabed features are shown on nautical maps (in MP), we do not consider the LCP of great interest in our case, especially since we have no tradition with LCP in Italy. Also, nautical (MP) maps cannot be extended to cover areas around the poles, which are most conveniently represented by PSP.

To analyse the fidelity of the MP and PSP representations (both widely employed in these areas), we can compare the modules of linear deformation, i.e., the ratio k between the length of an (infinitesimal) segment measured on the map and the same corresponding length on the earth.

We note again that these projections are conformal, i.e., they keep real and map angles equal (bearings are altered by the so-called convergence of the meridians: in the PSP, the convergence is equal to the longitude, taken with opposite sign in the southern hemisphere); furthermore, scale deformations at every point are constant in all directions.

A comparison of the above mentioned modules of linear deformation (coordinate scale factors, k, for WGS84) is given in the following Table 1:

To reduce scale deformation in PSP, it is customary to apply a factor $k_0 \ll 1$ to the plane coordinates. The choice of this reduction factor depends on how large is the latitude range which is to be mapped: in our case, the areas of interest extend to 55°S.

Maps drawn in PSP have the advantage that for rescaling from one map to another it is sufficient to compute a single scale factor (ratio) to account for the difference in scale, and therefore for the reference parallel: hence only a photographic reduction is needed.

In the case of a Mercator projection, however, the modulus of linear deformation has the opposite trend, since it increases with the absolute value of the latitude. When large portions of the earth are to be represented in connecting maps, the same scale at a given latitude must be adopted; but in this case very high deformations (deviations from the true nominal scale)

Table 1 - Comparison of PSP and MP scale factors.

	Latitude	k_{PSP}	k_{MP}
Pole	90°	1.000 000	infinity
	85°	1.001 906	11.43
	80°	1.007 654	5.740
	75°	1.017 328	3.851 6
	70°	1.031 079	2.915 15
	65°	1.049 118	2.359 69
	60°	1.071 732	1.994 973
	55°	1.099 292	1.739 527
	50°	1.132 266	1.552 665
	45°	1.171 235	1.411 845
	40°	1.216 921	1.303 607
	35°	1.270 215	1.219 430
	30°	1.332 215	1.153 734
	25°	1.404 287	1.102 718
	20°	1.488 128	1.063 761
	15°	1.585 866	1.035 044
	10°	1.700 791	1.015 324
	5°	1.834 5	1.003 724
Equator	0°	1.943	1.000 000

are introduced, if they span a large latitude interval.

An example is given by the GEBCO set of worldwide bathymetric maps which, to get connecting maps, present the following changes of scale:

at Equator	1:10,000,000	(reference scale), which
at lat. 20°	becomes	1: 9,400,626
at lat. 40°		1: 7,671,106
at lat. 60°		1: 5,012,626
at lat. 72°		1: 3,099,608

These relative scale deformations are much greater than those which should occur in a single PSP map, even if extended from the pole to the equator!

Beyond 60°S latitude, PSP is employed in GEBCO charts: the maps for lower latitudes (in MP) cannot be joined to the maps (in PSP) around the poles, so they are given in both projections, over the 60°-72°S interval, in order to display the whole sea-floor topography.

Another example is given by the International Map of the World (IMW) at the 1:1,000,000 scale, where the portion of the earth between 84°N and 80°S is projected onto maps each covering 4° of latitude, and from 4° (at the equator) to 30° (northern hemisphere) or 24° (southern hemisphere) in longitude to account for the meridian convergence toward the poles. The projection is the LCP with two standard parallels chosen inside each map, both 40' from the boundary latitudes. In the areas around the poles, the PSP is used again. This mapping was recommended in 1961 by the SCAR Working Group on Geodesy and Cartography (WGGC) as part of the Antarctic mapping system. But these maps cannot be exactly joined in latitude sequence, and the change in projection near the poles makes this inconvenience much worse.

THE OGS SOUTH POLAR MAP SERIES

As a result of the preceding analysis, the polar stereographic projection has been adopted at OGS to represent to south polar areas in all phases of planning and evaluation.

Our need is to represent the area around Antarctica to latitudes of nearly 60°S, where measurements have already been made. A contraction is therefore to be applied at the pole in order to balance the deformations due to the PSP as latitude decreases.

In Fig. 1 some values for the scale factor are plotted as a function of latitude. The curve

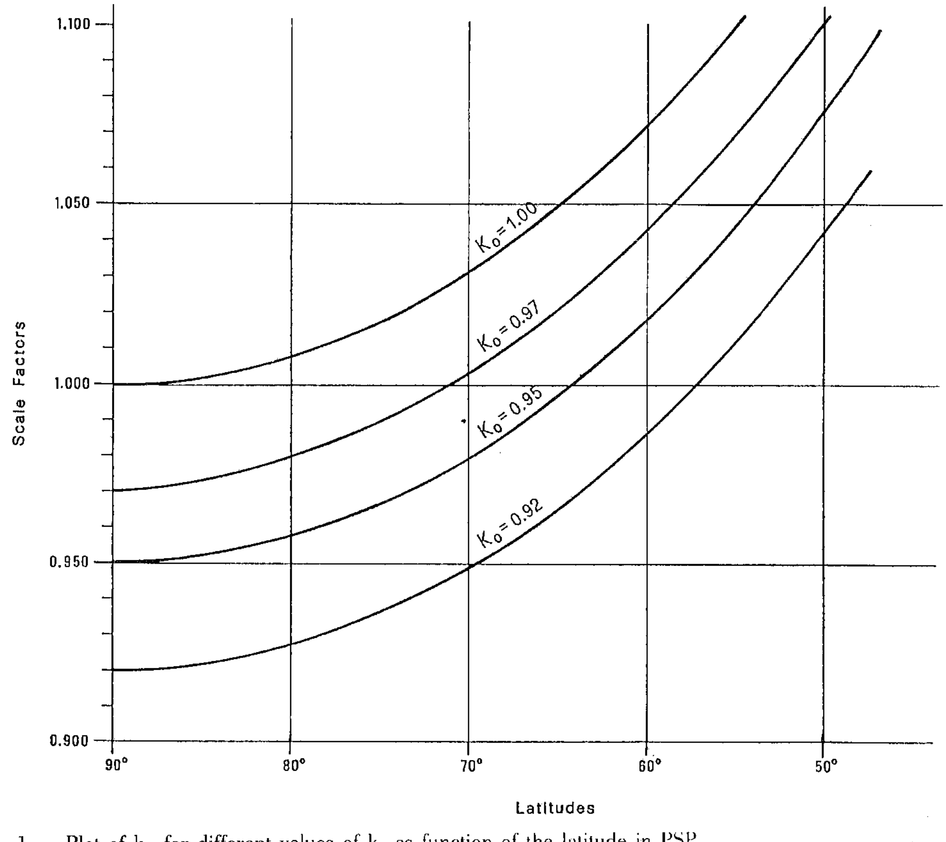


Fig. 1 — Plot of k_φ for different values of k_0 as function of the latitude in PSP.

for scale factor 1.0 at 71° is plotted as a special case, since it was recommended by the WGGC at the SCAR for use at scales smaller than 1:1,000,000 (see, e.g., Sievers and Bennat, 1989): it is equivalent to assuming $k_0=0.97275$ for the contracting factor at the pole, and to remain within ±27.3 m/km of scale deformation in the area from the pole to 63.3°S; it can be seen that the scale factor becomes as large as about 1.07 at the latitude of 55° in this mapping system!

The OGS polar cruises cover interesting geological features up to latitudes of nearly 60°, so that mapping is required northward to say 55°. Let us consider therefore that, by setting $k_0=0.95$ at the pole, we admit a maximum scale deformation within about ±5% (i.e., to ±50 metres per km) over the whole area to 54°S latitude. This corresponds to putting k=1 exactly, at latitudes of about 64°09', and this was assumed in drawing the OGS maps. The relationship between k_0 , k and φ is shown in Fig. 2.

We observe that (1) the largest area that can be mapped onto perfectly connecting maps is still well suited to our needs and (2) the fact that distances cannot be precisely measured on these OGS maps is not relevant, since the accuracy is still adequate for planning and comparison purposes. If greater accuracy is required, numerical computation must be done; (3) if absolutely necessary for the overall picture, the area represented can be extended to the borders of the World Map, which lies at 48°S, with less than 10% deformation.

The other advantages remain also, since they are related to the projection itself. Details presented in other PSP maps can be easily inserted into these OGS maps since, as already mentioned, only a photographic reduction is needed. To insert details from maps in other projections, they have to be digitized, analytically converted from plane to geographical coordinates, and then transformed into plane polar stereographic coordinates.

Until 1990, due to the extensive use of mainly Transit satellite navigation, the adopted

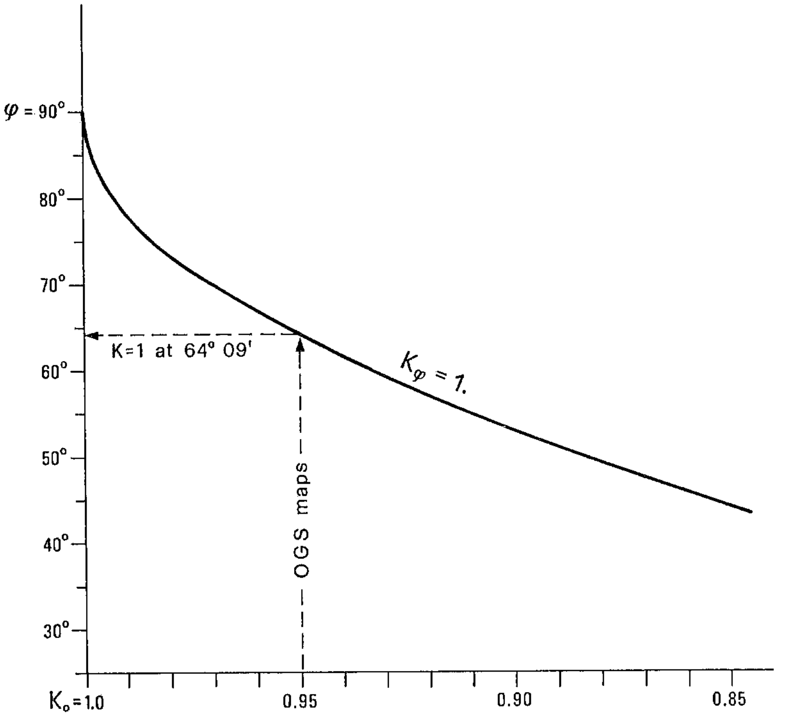


Fig. 2 — Latitude at which the scale factor is $k_{\varphi}=1.0$ as a function of the value of k_0 at the pole.

reference ellipsoid in navigation postporcessing (by nearly all observers) was the WGS-72 with the following parameters:

a=6 378 135.000 b=6 356 750.520	1/f=298.26	(e^2=0.006 694 317 778)

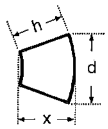
Subsequently, the GPS constellation was implemented and now positioning can be achieved nearly 24 hours a day. GPS is therefore the present (and future) standard, and the WGS-84 reference has been adopted for OGS maps, with the following parameters (AIG, 1980; DMA, 1991):

a=6 378 137.000 b=6 356 752.3142	1/f=298.257 223 563	(e^2=0.006 694 379 99)

Conversions from WGS-72 into WGS-84 may be carried out by simple transformation. However, at small scales (1: 100,000 or smaller) it is practically immaterial which reference ellipsoid is used in computation: position differences are less than 15 meters, so that only the numerical data are affected. It should also be noted that current GPS technology in marine kinematic positioning gives error estimates of the same magnitude: to achieve ± 1 meter accuracy requires inertial reference, pitch- and roll-control, differential techniques and proper software to integrate the corresponding information.

For the sake of simplicity, the assumed contracting coefficient at the pole is mentioned together with the reference ellipsoid, when giving the identification of the OGS cartographical system as OGS PSP 0.95 on WGS84.

As far as size and scale are concerned, we have assembled a basic map series at the 1:1,500,000 scale, as indicated in Fig. 3, where the sizes of the 31 maps from the boreal cap to latitudes of 57°S are indicated by A, B, C, to which an annulus of D size maps may



	φ	$\Delta\lambda$	nr. of sheets	Dimensions (cm) at 1:1.500.000 scale h	d	x
A	90°–80°	90°	4	70.9	100.3	70.9
B	80°–70°	40°	9	72.0	97.7	76.2
C	70°–57°	20°	18	97.0	83.3	105.6
D	57°–45°	20°	18	95.3	116.4	98.9

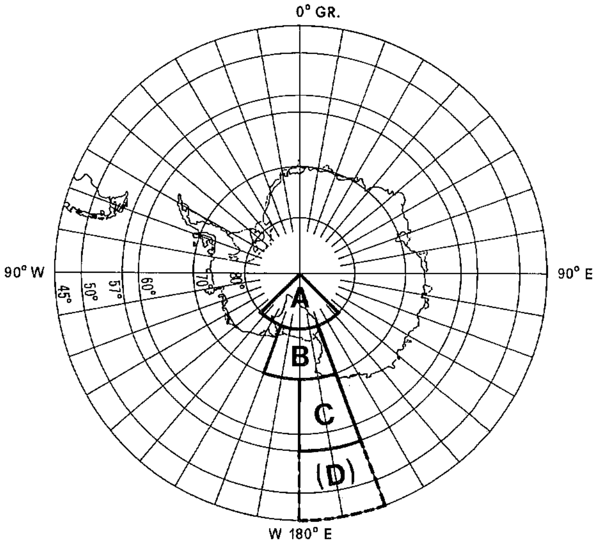


Fig. 3 — Layout of OGS circumpolar maps of Antarctica.

be added to extend the area. Actual dimensions are also shown in the same Figure.

All areas of interest, already investigated or under project, namely the Ross Sea, the Scotia Arc, the Antarctic Peninsula, and the area from Prydz Bay to Kerguelen Island, can therefore be displayed in homogeneous maps, from the South Pole to latitude 45°S. However, details can be extracted and presented in any convenient scale and size (e.g., for publication purposes) directly from digital data bases.

The basic transformation algorithm, as given in the literature (AMS, 1958), is as follows.

The radius, from the pole, is given by:

$$R = \frac{2\,k_o\,a}{(1-e^2)^{1/2}} \left[\frac{1-e}{1+e}\right]^{e/2} \tan\,(p/2) \left[\frac{1+e\,\cos p}{1-e\,\cos p}\right]^{e/2},$$

where

$$k_o = 0.95$$
$$p = \text{colatitude.}$$

To avoid negative coordinates in numeric treatmet, a false easting and a false northing, both of 5,000,000 meters, are applied to the plane coordinates. Thus, we have:

$$X = 5\ 000\ 000 + R\ \sin l$$
$$Y = 5\ 000\ 000 + R\ \cos l,$$

where

$$l = \text{longitude.}$$

Conversion of the above exponential expression into a truncated polynomial form, with the coefficients computed for the WGS84 and including the factor 0.95 at the pole, gives the following result, where p is expressed in radians:

$$R = 6\ 079\ 613.9446\ p + 486\ 147.7261\ p^3 + 50\ 767.0024\ p^5$$
$$+ 5\ 020.5802\ p^7 + 515.485\ p^9 + 51.65\ p^{11} + 5.5\ p^{13}$$

Table 2 — Elements for OGS maps from 45° to 90° (WGS 84).

Latitude	R (m)	k
45°	5 026 602.692	1.112 673 3
46°	4 903 379.290	1.104 782 7
47°	4 780 997.474	1.097 140 9
48°	4 659 430.237	1.089 742 2
49°	4 538 651.205	1.082 581 2
50°	4 418 634.604	1.075 652 6
51°	4 299 355.242	1.068 951 4
52°	4 180 788.482	1.062 472 8
53°	4 062 910.220	1.056 212 2
54°	3 945 696.860	1.050 165 3
55°	3 829 125.296	1.044 327 7
56°	3 713 172.890	1.038 695 5
57°	3 597 817.454	1.033 264 8
58°	3 483 037.225	1.028 031 9
59°	3 368 810.855	1.022 993 2
60°	3 255 117.386	1.018 145 4
61°	3 141 936.236	1.013 485 3
62°	3 029 247.179	1.009 009 7
63°	2 917 030.335	1.004 715 7
64°	2 805 266.149	1.000 600 6
65°	2 693 935.374	0.996 661 6
66°	2 583 019.064	0.992 896 3
67°	2 472 498.550	0.989 302 1
68°	2 362 355.435	0.985 876 9
69°	2 252 571.571	0.982 618 4
70°	2 143 129.055	0.979 524 6
71°	2 034 010.209	0.976 593 6
72°	1 925 197.571	0.973 823 5
73°	1 816 673.879	0.971 212 6
74°	1 708 422.065	0.968 759 2
75°	1 600 425.236	0.966 462 0
76°	1 492 666.667	0.964 319 4
77°	1 385 129.789	0.962 330 1
78°	1 277 798.176	0.960 493 0
79°	1 170 655.535	0.958 806 9
80°	1 063 685.694	0.957 270 8
81°	956 872.596	0.955 883 8
82°	850 200.281	0.954 645 0
83°	743 652.880	0.953 553 6
84°	637 214.606	0.952 609 2
85°	530 869.740	0.951 810 9
86°	424 602.624	0.951 158 5
87°	318 397.647	0.950 651 4
88°	212 239.241	0.950 289 4
89°	106 111.865	0.950 072 4
90°	0.000	0.950 000 0

The radius computed with this polynomial agrees to one millimeter or better with the result of the rigorous formula over the interval 48°-90°.

The inverse transformation is straightforward since, by letting

$$x = X - 5\ 000\ 000 \quad \text{and} \quad y = Y - 5\ 000\ 000,$$

we get the longitude

$$l = arc\ tan \frac{x}{y} ,$$

and the radius

$$R = x / sin\ l = y / cos\ l = \sqrt{x^2 + y^2},$$

from which the latitude can be easily computed by iterative interpolation (only the first term of the polynomial, applied on successive differences from values of R computed with the complete polynomial, is needed).

Table 2 is presented to help decisions in map planning: the values of R and k are listed in one-degree steps.

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