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DIAGNOSIS OF CYLINDRICAL PROJECTIONS AND ANALYSIS OF SUITABILITY FOR THE TERRITORIAL AREA OF SOUTH AMERICA

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ABSTRACT:
Cartographic Projection can be defined as the mathematical relationship between the position of a model of the terrestrial surface and the flat surface. Cylindrical projections are employed around the world, taking into consideration their properties and special characteristics. The purpose of this study was to identify the cartographic projection that best represents South America terrestrial surface, focusing mainly on the area of the continent, determined by the South American Defense Council. Initially, the projections were selected based on a bibliographic review. Subsequently, a suitability judgment was made for South America applying Tissot Indicatrix, Isolines of Maximum Angular Distortion and Region of Acceptable Distortion. Finally, an assumption was drawn up among the best results. The study control was performed using the software Flex Projector and ArcGIS 10.1, computational resources of great use in Cartography. The study provided a clear, simple and objective understanding of how different projections behave. The motivation comes from the insufficiency of detailed information and applied to the choice of map projection in regions of large areas.

Keywords: Cylindrical Projections, Feasibility Analysis, Flex Projector, South America

UNIFESSPA Universidade Federal do Sul e Sudeste do Pará
FAPESPA Fundação Amazônia Paraense de Amparo à Pesquisa

1. INTRODUCTION

Cartography is responsible for the representation of the Earth's surface, in a clear and objective way, where the spatial variables can be interpreted by the users. There are several forms to represent the terrestrial surface, such as reduced models, globes, maps and charts, digital terrain models and others. According to (Thofehrn, 1980) globes exhibit a great advantage in a description, because they can show the user a realistic illustration, but they have only a few practical applications. One complication in the globes application is the planimetric scalar dimensions (X and Y) that cannot be settled with height (Z).

Since the Earth's surface is not flat, cartography uses mathematical methods to represent a curved surface in a plane. Cartographic projections are methods applied in the portrayal of the Earth, considering the distortions. Map projections can be defined as mathematical functions that relate the points on a surface used as a reference (sphere or ellipsoid) to a projection surface (plane, cone, cylinder).

There are different ways to set a classification for cartographic projections, but according to Lapaine (2015), projections are classified according to their geometry, shape, special properties, projection parameters and nomenclature. The main properties of the projections are described in Table 1.

Table 1: Properties and Characteristics of Map Projections

Method	Geometric	Geometry principles
	Analytical	Mathematical formulation
Projection Surface	Azimuthal	Earth surface over a plane
	Conic	Earth surface in a cone
	Cylindrical	Earth surface in a cylinder
Properties	Poli superficial	Earth surface represented in more than one projection surface
	Conformal	It preserves the angles
	Equivalent or Equal-area	It preserves the areas
	Equidistant	It does not present linear distortions
	Affiliated	Absence of the other properties
Point of contact	Tangent	Projection surface is tangential to the reference surface
	Secant	Projection surface cuts the reference surface

The decision to adopt a particular type of projection will depend on several factors, such as location, shape, dimensions and purpose of the work in relation to the globe. Some mappings present some characteristics that make this decision even more challenging, either because they provide a continental location, or with a considerable variation of longitude and latitude, or areas whose purpose implies in the variation of scales. All these obstacles related to the cartographic projection must be analysed taking into account the current technological advances.

2. SOUTH AMERICA AND ITS TERRITORIAL EXTENSIONS

South America is composed of the southern portion of the American continent, its location occurring predominantly in the southern hemisphere, in the western intertropical zone. It is surrounded to the east by the Atlantic Ocean, to the west by the Pacific Ocean and to the North by the Antilles Sea, also known as the Caribbean Sea. It has 13 territories and 12 countries. The members of the continental part include Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay and Venezuela. The territory of French Guiana, whose capital is Cayenne, belongs to France.

Brazil is the largest country in South America regarding territorial extension followed by Argentina and Peru. Table 2 displays the area of each South American country according to South American Defense Council (CDS, in Portuguese). CDS was established in 2008, targeting to consolidate South America as a zone of peace and create conditions for political stability and economic and social development; as well as establishing a South American defense identity to generate an agreement able to help strengthen cooperation on the continent, BRAZIL (2017).

Table 2. Territorial área of South american countries Área dos territórios da América do Sul

País	Capital	Área (km²)
Argentina	Buenos Aires	2.780.400
Bolivia	La Paz	1.098.581
Brazil	Brasília	8.514.877
Chile	Santiago	756.102
Colombia	Bogotá	1.138.910
Ecuador	Quito	283.561
Guyana	Georgetown	214.969
French Guiana	Cayenne	83.534
Paraguay	Assunção	406.752
Peru	Lima	1.285.216
Suriname	Paramaribo	163.820
Uruguay	Montevídeo	176.215
Venezuela	Caracas	912.050
TOTAL		**17.814.987**

Fonte: BRAZIL (2017)

3. METHODOLOGY

The methodology applied in the research made use of exploratory and inductive approaches. KOBASHI et. al, (2006) model was established to guide the steps for the development of a scientific research in the field of Cartography:

- Definition of the analysis chain and the bibliographic elements to be considered in the study;
- Characterization of the areas of study;

- Investigation of analysis parameters; and
- Results discussion

3.1 Bibliographic Investigation

A bibliographic survey of the cartographic projections used around the world was made to establish criteria that could contribute to the proposed research. During the theoretical background, academic studies were identified over the years. In this phase, Werner (1993) and Šavrič et. al, (2016) made several discussions of the main projections applied globally. They carried out a survey of map users and professionals to choose the best projection to be used. 496 people and nine cartographic projections were involved.The pairing comparison test evaluated each element of a projection with all the other projections. The nine cartographic models analyzed were: Robinson, Eckert IV, Winkel Tripel, Wagner VII, Mollweide, Goode Homolosine, Plate Carrée, Interrupted Mollweide and Mercator, all illustrated in Figure 1.

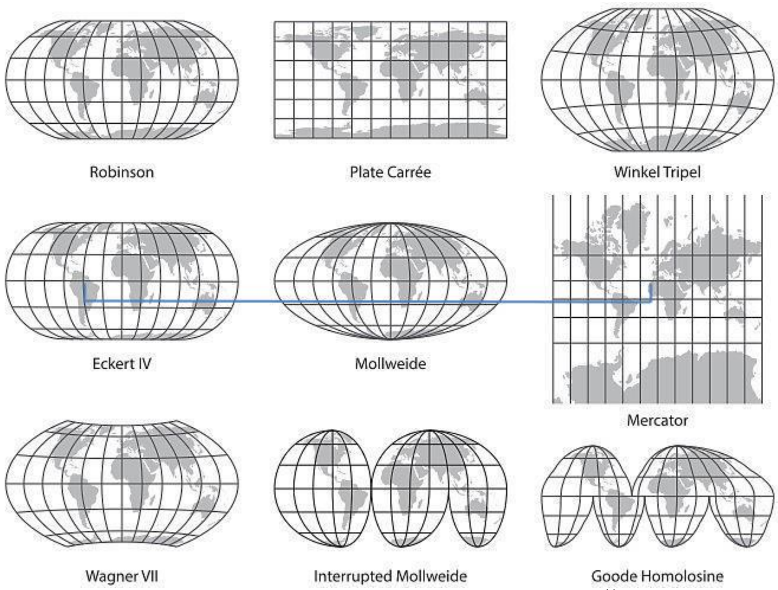

Figure 1 - Small-scale projections investigated. Source: Šavrič et al, (2016)

The hierarchical results of preference are shown in Table 3.

Table 3 - The most conventional projections applied by cartographers and other user

	1(%)	2(%)	3(%)	4(%)	5(%)	6(%)	7(%)	8(%)	9(%)
1. Robinson		68	77	71	77	74	84	78	95
2. Winkel Tripel	32		49	57	72	65	70	76	90
3. Eckert IV	23	51		55	62	66	68	76	84
4. Mollweide	29	43	45		54	61	70	70	81

5. Wagner VII	23	28	38	46		53	67	67	81
6. Plate Carrée	26	35	34	39	47		56	57	89
7. Mollweide Int	16	30	32	30	33	44		69	71
8.Goode Homolosine	22	24	24	30	33	43	31		68
9. Mercator	5	10	16	19	19	11	29	32	

Table 3 shows that the projection most used in constructing maps is Robinson's projection. The projection of Mercator is the least employed, despite of being the most known. Cylindrical projections are essentially recommended in the mapping of the two hemispheres and the construction of world maps. This fact can be explained due to the minimal distortions obtained in the equatorial region.

3.2 Analysed Projections

According to Lopez (2015), cylindrical projections are useful for cartographic representation of world maps, however, these projections present a distortion nuisance in high latitude areas. Comparisons and specific properties among these projections can be found in Table 5.

Table 5 - Comparisons and main properties of the nine most employed projections by professionals for the representation of world maps

Projection	**Property**	**Area**
Robinson	Affiliated Cylindrical	Low distortion between parallels ± 45 ° and Equator
Winkel Tripel	Affiliated Cylindrical	Moderate distortion except in the polar regions along the outer meridians
Eckert IV	Equivalent Pseudocylindrical	Equivalent
Wagner VII	Modified Azimuthal	Equivalent
Plate Carrée	Cylindrical	Distortions magnified as it moves away from standard parallels
Mollweide	Pseudocylindrical	Equivalent
Goode Homolosine	Interrupted Pseudocylindrical	Equivalent

Mercator	Cylindrical	Larger distortions at the polar regions
Mollweide Int.	Pseudocylindrical	Equivalent

In the equidistant cylindrical projection, distortion in the parallels can be observed defined by the scale factor, while the meridians remain undistorted. As a result, the areas are also distorted. To compensate the area deviation, projections which keep the proportion of areas can be formed by manipulating and modelling the scale factor between meridians and parallels. From the nine projections in Table 4, the ones that best fit the field of study were used, selected by their properties and parameters of interest (Table 5) related to the equivalence of the areas and the representation of deformations, and are displayed in Table 6. However, Mercator's projection was applied in the research even not being included in the selective criteria, since it is widely adopted in South American due to historical factors.

Table 6 - Projections to be evaluated in the study

Projection	Scale	Continental Scale	Area	Continental Area
Eckert IV	0.36	0.45	0	0
Goode Homolosine	0.46	0.46	0	0
Mercator	-	-	-	-
Mollweide	0.39	0.43	0	0
Wagner VII	0.37	0.4	0	0
Winkel Tripel	0.26	0.26	0.18	0.26

3.3 Software appliance

Some software products are currently available in the market for manipulating parameters from cartographic projections and data files in the shapefile format. The chosen programmes for the study were *Flex Projector and Arcgis 10.1*.

In Flex Projector the projections are able to be manipulated through sliders, in addition to the creation of a new projection from another already existing one. The software has four groups of cursors to adjust the length of the parallels, vertical distribution, bending, and meridian distribution. Through an interactive table, it is possible to have an entire view of the distortions in the modified projection.

The procedure to evaluate and classify the selected projections was based on the results achieved with Flex Projector. The case study was carried out using shapefile formats of the projections, Tissot Indicatrix (TI), Isolines of Maximum Angular Distortion (IMAD) and Region of Acceptable Distortion (RAD).

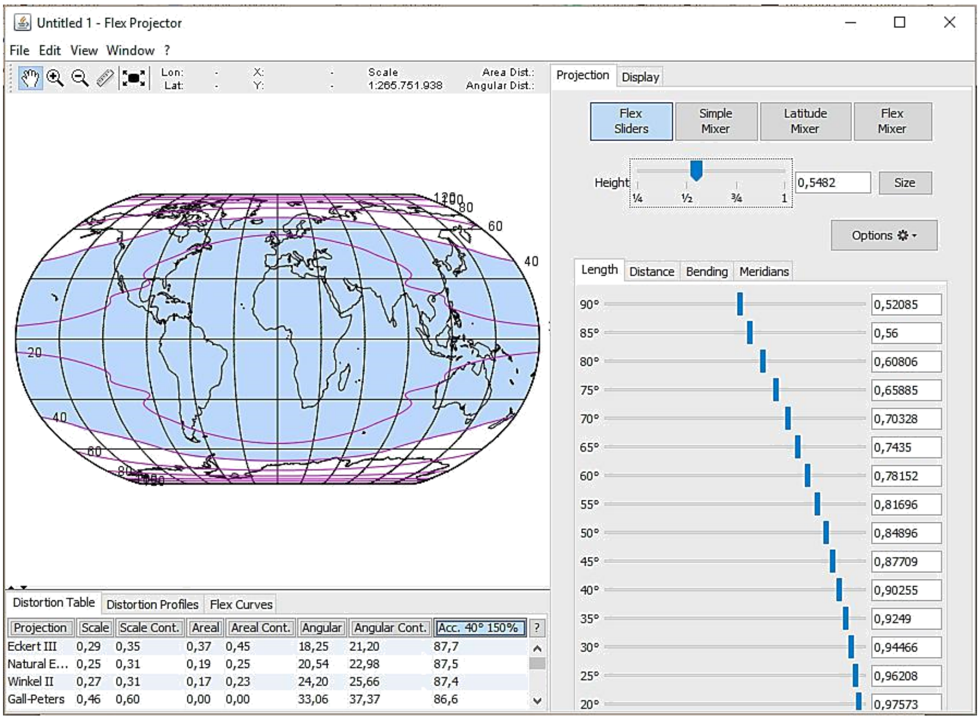

Figure 2**:** *Flex Projector* graphical user interface

3.4. Area analysis

In order to present the results of the areas, shapefiles were generated in *Flex Projector* for each one of the models. In the ArcGIS, manipulations of these files exported from Flex Projector were executed. In the software attribute table, the areas of each projection were calculated. The tables provide the information referring to the properties of an attribute, thus, quantitative, qualitative, textual and numerical information. The results are shown in Table 7.

Table 7. **A**reas obtained from shapefiles data in ArcGIS 10.1

Projection	**Calculated Area** (km²)	**Official known área (km²)**	**Area difference (km²)**
Mollweide	17,883,957		68,971
Wagner Vll	17,884,161		69,175
Eckert lV	17,884,357		69,371
Goode Homolosine	17,885,457	**17,814,987**	70,471
Winkel Tripel	15,565,318		-2,249,669
Mercator	20,865,481		3,050,494

As it can be seen from the table, the results obtained indicated that the Mollweide projection achieved the best fitting to the official area defined by CDS, as shown in Table 7.

3.4.2 Shape Analysis

Equivalent or equal-area projections modify the original shape of the continents. In order to evaluate the similarity of the South American continent and which of the projections represent more accurately the terrestrial reality, we examined TI, IMAD and RAD parameters for the studied models.

TI estimates the distortion of an Earth's surface projection. Through calculations, it reaches the deformations at a given point of an infinitesimal circle with ds radius, centred at a point P on the ellipsoid, and can be converted into a circle according to the type of projection. Figure 3 displays the behaviour of the deformations in the studied projections from South America with a 30º distance between the error ellipses.

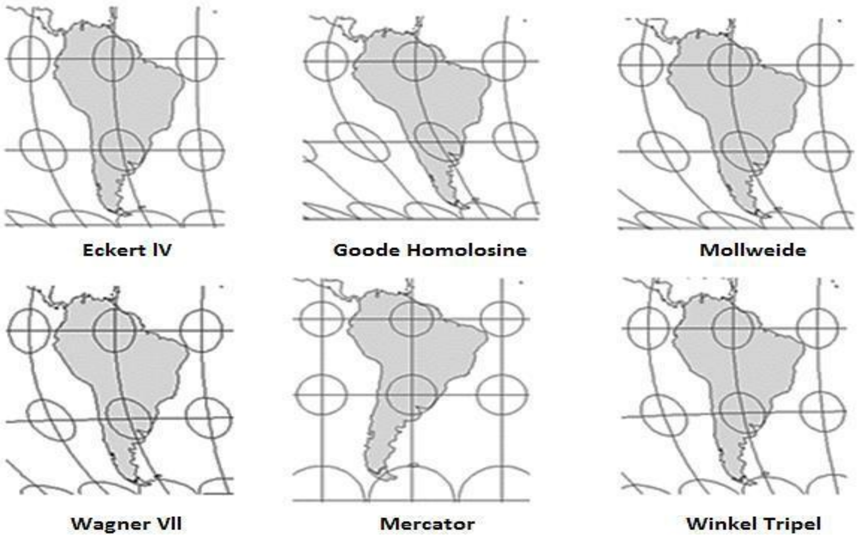

Figure 3. Tissot Indicatrix for six studied projections

The largest deformations demonstrated by TI analysis occurred in the direction of the meridians and at the poles, as expected. Mercator projection proved to be the best one to represent the terrestrial reality, due to its conformity properties, but the distortion at the pole is remarkable.

IMAD analysis permits to verify different regions that share a common value. Every isoline tries to illustrate the spatial variation of a phenomenon. It calculates and represents the differences between the angles measured on the reference surface and on the projection, ranging from 0º (without deformation) to 180º. Isolines were generated at 5º intervals. The results are shown in Figure 4.

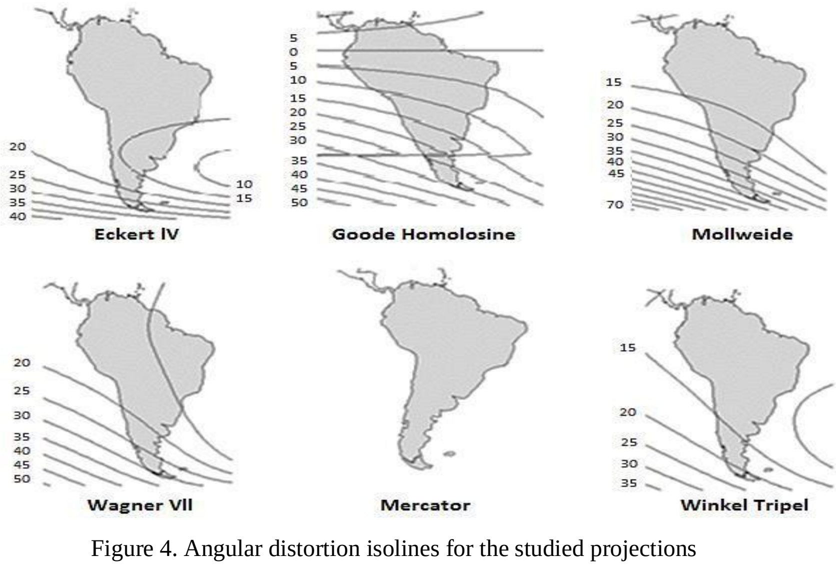

Figure 4. Angular distortion isolines for the studied projections

The maximum angular distortion considered was 20º. The highest deformations were obtained in the Goode Homolosine model. The poles presented distortions in all the projections analysed, as expected. The Winkel Tripel projection exhibited the slightest distortions. Mercator projection could not be evaluated for IMAD.

From RAD analysis it is possible to verify the regions where the deformations appear according to the projection. In Figure 5, it can be observed that Goode Homolosine is not recommended to reproduce South America projection, while the Winkel Tripel model presented to be the most suitable for the mapping of the study area. The other models exhibited distortions at the poles

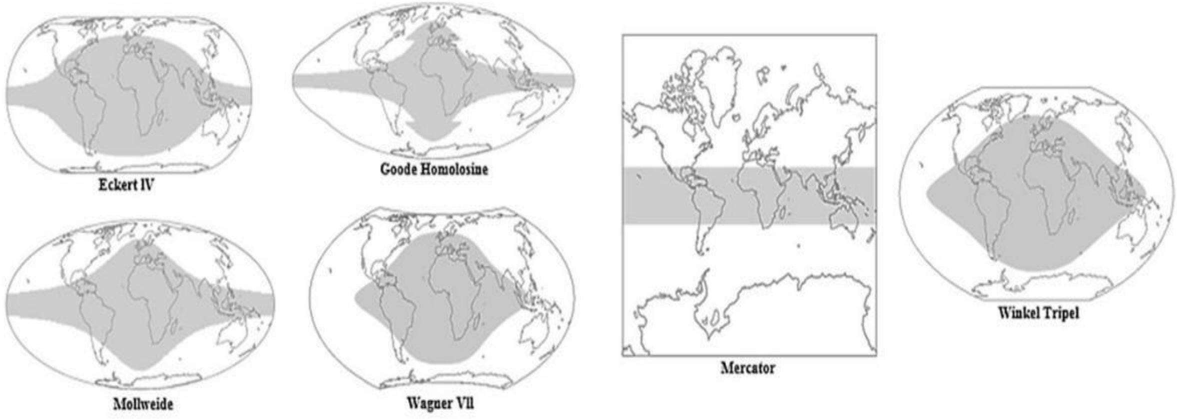

Figure 5. Distortion areas of the projections

Table 8 summarizes a relative evaluation of the studied parameters. A scale was created to define the most suitable projection for the South America mapping in three levels: Good, Reasonable and Bad. The evaluation showed that the projection with the lowest distortion associated with the shape of the South American continent was the Winkel Tripel projection.

Tabela 8: Results obtained with Flex Projecton files

Projection type	**Tissot Indicatrix**	IMAD	RAD
Mollweide	Bad	Bad	Reasonable
Wagner Vll	Bad	Bad	Reasonable
Eckert lV	Reasonable	Reasonable	Good
Goode Homolosine	Bad	Bad	Bad
Winkel Tripel	**Reasonable**	**Good**	**Good**
Mercator	Good	-	Reasonable

The Winkel Tripel projection was developed in 1921 by Oswald Winkel (1873 - 1953). Tripel is a German term meaning a combination of three elements. Winkel chose the name because the projection is affiliated: it does not eliminate distortions of area, direction or distances, but minimizes the sum of the three. It was adopted in 1998 by the National Geographic Society as the standard model for world maps.

4. CONCLUSIONS

The research evaluated cylindrical projections with respect to the area and shape of South America. The results showed that in relation to the surface area, Mollweide model is the closest to the known territorial area. Regarding to the shape of the continent, Winkel Tripel provided the greater conformity. Despite it has smaller deformations of area and shape, Eckert IV reached the closest result for the total official area. The decision was made based on Table 7 results. The developments of the models were personal contributions from their authors based on theoretical information and on their perceptions, experiences, interests and knowledge of cartographic projection systems. The decision of which model should be used is in the hands of the human beings. The role of the map model is basically to assist the specialists, ensuring quality, organization and documentation of the decision analysis process, validating value judgments, investigating conflicting goals, sharing understanding about issues, and often promoting consensus. According to the exposed facts, it could be concluded that the mapping results were satisfactory and supported the use of methodologies and the usage of the software Flex Projection and ArcGIS in the analysis of the representation of a particular region of the terrestrial surface.

REFERENCES

BRASIL, Conselho de Defesa Sul Américano – CONASUL. Fortalecendo a defesa, a confiança mútua e desenvolvimento da região sul-americana. Available at: http://www.defesa.gov.br/arquivos/relacoes_internacionais/unasul/informativo_unasul.pdf. Last access: 20/06/2017

M. HERBEI . The analysis of cartographic projections used in romania .Research Journal of Agricultural Science, 45 (2), 2013

KENNEDY, M., Koop, S.: Understanding map projections. GIS by Environmental System Research Institute (1994)

KOBASHI, N. Y., SANTOS, R. N. M. Scientific research institutionalization in Brazil: thematic and social network cartography by means of bibliometric techniques. TransInformação, Campinas, 18(1):27-36, jan./abr., 2006

LAPAINE, M. Proyecciones cartográficas y sistemas de referencia. Croacia y E. Lynn Usery, Estados Unidos 2015.

ŠAVRIČ, B., B. Jenny, T. Patterson, D. Petrovič, and L. Hurni. 2011. "A Polynomial Equation for the Natural Earth Projection." Cartography and Geographic Information Science 38 (4): 363–372. doi:10.1559/15230406384363.

SLUTER, R. C, Firkowski, H. Cartografia Geral e Projeções Cartográficas. Curso de Especialização em Geotecnologi DGEOM – UFPR (2014). Availableat:
https://docs.ufpr.br/~firk/pessoal/projcart/Cap%204%20ProjCart.pdf

ROCHA, R. S. da. Algumas considerações sobre as projeções cartográficas utilizadas no Brasil para mapeamentos em grandes escalas. In:· CONGRESSO BRASILEIRO DE CADASTRO TÉCNICO MULTIFINALITÁRIO. Florianópolis. 1998. Anais... Florianópolis, 1998. Last access: 1/04/2008.

THOFEHRN, Hans Augusto. Alguns Aspectos do Uso da Cartografia. Revista do Seite. Ano 1, N. 1. Sistema Estadual de Informação Técnica e Estatística. Govemo do Estado do Rio Grande do Sul. Porto Alegre. 1980.

WERNER, R. J. 1993. "A Survey of Preference Among Nine Equator-Centered Map Projections." Cartography and Geographic Information Science 20 (1): 31–39. doi:10.1559/152304093782616733.