ProGriD: The Transformation Package for the Adoption of SIRGAS2000 in Brazil

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Abstract

Brazil adopted SIRGAS2000 in 2005. This adoption called for the provision of the relationships between SIRGAS2000 and the previous reference frames used for positioning, mapping and GIS, namely, the Córrego Alegre (CA) and the South American Datum of 1969 (SAD 69). Two programs were designed for this purpose. The first one, TCGeo, provided the relationships based on three-translation Similarity Transformation parameters. TCGeo was replaced in December 2008, by ProGriD. ProGriD offers, besides the same similarity transformation as TCGeo, a set of transformations based on modelling the distortions of the networks used in the various realizations of CA and SAD 69. The distortion models are represented by a grid in which each node contains a transformation value in terms of difference in latitude and in longitude. The grid follows the same specifications of the NTv2 grid, which has been used in other countries, such as Canada, USA and Australia. This paper presents ProGriD and its main functionalities and capabilities.

109.1 Introduction

Historically, two geodetic reference systems have been officially and widely used in Brazil in support of surveying and mapping. By 'officially' it is meant that they were regulated by specific legislation. The first one, the Córrego Alegre (CA), started to be developed in the 1950s and was used as the official system until 1983 when it was replaced by the South American Datum of 1969 (SAD 69). Different realizations of Córrego Alegre and SAD 69 exist. Both systems have co-existed for mapping applications. In 2005, Brazil adopted SIRGAS2000 as its official reference system (IBGE 2005). A period of 10 years, which started in 2005, was suggested. During this period all components of government and private sector should start using SIRGAS2000 in their activities and should start

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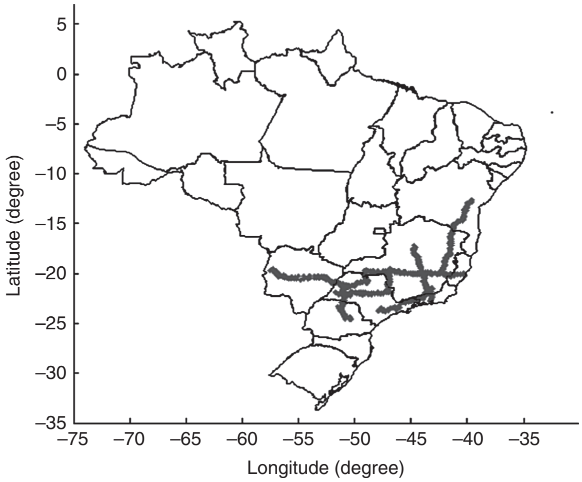

Fig. 109.1 Córrego Alegre 1961

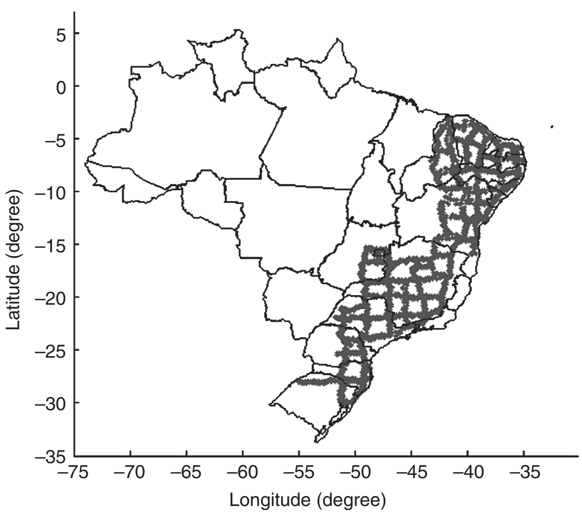

Fig. 109.2 Córrego Alegre 1970 + 1972

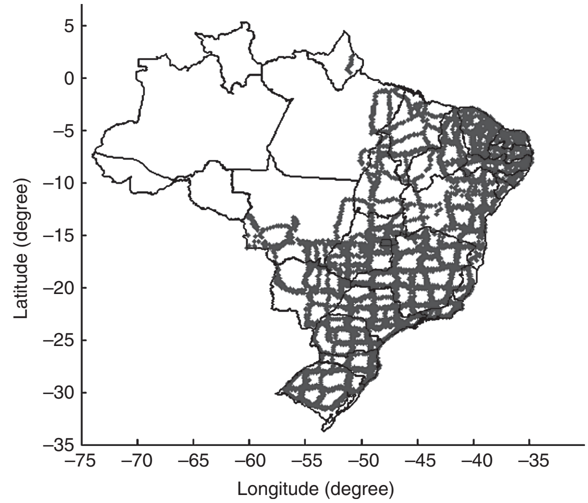

Fig. 109.3 SAD 69

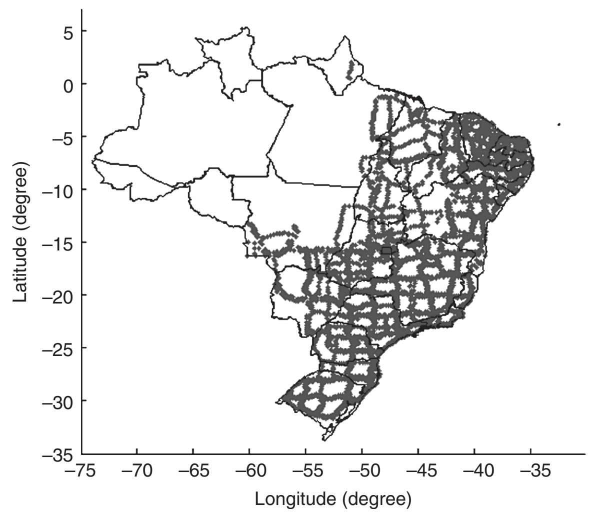

Fig. 109.4 SAD 69/96

migrating into SIRGAS2000 all their databanks currently in either Córrego Alegre or SAD 69.

Córrego Alegre is a classical datum, developed during the 1960s and the 1970s, which uses Hayford (Torge 2001) as its reference ellipsoid. There were three realizations of Córrego Alegre, in 1961, in 1970 and in 1972. Figures 109.1 and 109.2 show the coverage of Córrego Alegre 1961 and of Córrego Alegre 1970 and 1972 put together, respectively. It can be seen that Córrego Alegre 1961 was mostly present in the Southeast part of the country. Córrego Alegre 1970 and 1972 increased the southeastern coverage as well as grew towards the South and the Northeast. The North and the Center-West are big empties.

SAD 69 is a classical datum, developed during the 1980s and the 1990s, which uses the GRS 67 as its reference ellipsoid (IAG 1971). There were two realizations of SAD 69, the original and another one released in 1996. Figure 109.3 and 109.4 show these two realizations. It can be noted the network is vastly enhanced, with several points in the Northern part of the country (the Amazon) most of them determined using NNSS receivers in absolute mode.

The topocentric origin of both Córrego Alegre and SAD 69 are located in different geodetic markers, albeit very close to each other, in the state of Minas Gerais. The distance between the (non-geocentric) centers of each ellipsoid to the center-of-mass is around 150 m.

There were instances of local datums being implemented in remote areas devoid of geodetic infrastructure in the past to serve as basis for hydrographic operations, and exploration of oil and other minerals. These numerous local datums are out of the scope of this paper, either for not being used any more, or for lack of documentation, or, as in the case of a couple of them, for requiring a specific treatment.

The adoption of SIRGAS2000 by Brazil, to satisfy traditional activities related to surveying and mapping plus more recent ones such as GIS and Spatial Data Infrastructure, created the need for a consistent computational tool to help users in their transition efforts from the 'old' frames to SIRGAS2000. This need has been addressed initially with the release of a program named TCGeo, in 2005. TCGeo was capable of performing a three parameter similarity transformation between SAD 69 and SIRGAS2000, using the parameters published by IBGE (IBGE 2005). Finally, in 2008, a program named ProGriD was released, allowing for the modelling of the distortions remaining from the similarity transformation, resulting in a more accurate transformation. Besides SAD 69, ProGriD can also handle Córrego Alegre.

For the sake of completeness, SIRGAS2000 network is shown in Fig. 109.5.

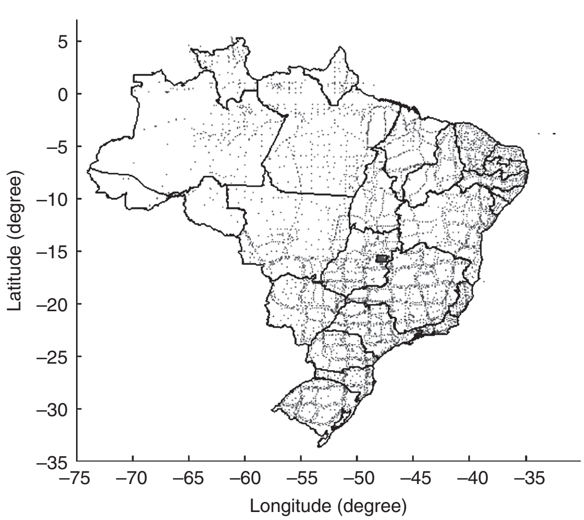

Fig. 109.5 SIRGAS2000

109.2 ProGriD

As said before, ProGriD is a computational tool that performs coordinate transformations among realizations of Córrego Alegre, SAD 69 and SIRGAS2000. ProGriD is based on grids that contain the shifts between pairs of realizations. These grids follow the National Transformation Version 2 (NTv2) format (Junkins 1998). This format was chosen because several other countries (e.g., Canada, the USA, and Australia) have done so before, and many GIS software packages are already capable of handling it.

The shifts contained at the nodal points of the grids represent the value to be used in the transformation from Córrego Alegre and SAD 69 to and from SIRGAS2000. These transformation values are a result of a distortion model. Oliveira et al. (2008) described the effort of several research groups in developing different distortion models for the Brazilian situation. The outcome of this effort showed that the developed models yielded results similar to the NTv2 model (Junkins and Farley 1995; Nievinski 2006), in a certain way validating its choice.

NTv2 relates two reference frames by applying a Helmert transformation and a "grid" calculation, the latter being a correction that models the distortions derived from the materializations of the reference systems. The distortions are computed according to an exponential weight function, which is a function of distance between point of interest and its neighbouring network points. This allows the creation of a grid of corrections (shifts) for latitude and longitude. A file containing these shifts in the form of a grid was created for each one of the 2D classical reference frames or interest, therefore, called as the shift grid files. To determine the shift values from the grid, a bi-linear interpolation is used.

The realizations of Córrego Alegre and SAD 69 supported by ProGriD are:

- Córrego Alegre 1961 (CA61).
- Córrego Alegre 1970 and 1972 put together (CA70 + 72).
- SAD 69 original including only the *classical* network (SAD 69).
- 1996 realization of SAD 69 (SAD 69/96) including only the *classical* network.
- SAD 69 points established by space geodetic techniques.

Further explanation is required about the list presented above.

During the data analysis it was realized that two of the realizations of the Córrego Alegre (1970 and 1972) were exactly the same, differing only in the coverage of the respective networks. Therefore, it was decided to merge them into a single one.

During the data analysis it became clear that the classical points integrating the SAD 69 have very distinct distortion behaviour than those determined by geodetic space techniques (Doppler and GPS). Classical points are inherently two dimensional whereas space geodetic points are three dimensional quantities. If treated together it would make the distortion modelling very difficult to accomplish with the risk of resulting in an unrealistic model. For example, Fig. 109.6 shows the different level of distortions of triangulation and GPS points in the southern tip of Brazil in SAD 69/96 (distortion here defined as the difference between the SAD 69/96 coordinates transformed into SIRGAS2000 by a three-parameters transformation 'minus' the adjusted coordinates in SIRGAS2000). The long arrows show the distortion of the triangulation points. The dots show the distortion of the GPS points. In reality, the dots representing the distortion of the GPS points are arrows too, but their magnitudes are so much smaller than the distortion of the triangulation points that they can be barely identified as arrows. If looking carefully, it can also be seen that several "dots" fall in the middle of the "arrows." Moreover, it should be considered that the users, in their surveying and mapping applications, would have used either classical (2D) points or space-determined (3D) points separately. These facts led to the conclusion that the 2D and the 3D points should be treated separately as two independent networks. The points determined via space geodetic techniques were then removed from the SAD 69, forming an independent group of points been referred to as *SAD 69 Doppler or GPS Technique*.

In a nutshell, the networks of distinct nature (classical and space geodetic) are treated by ProGriD differently. The classical networks relates to SIRGAS2000 by grid shift files that model their distortions. The space network relates to SIRGAS2000 by three translation parameters.

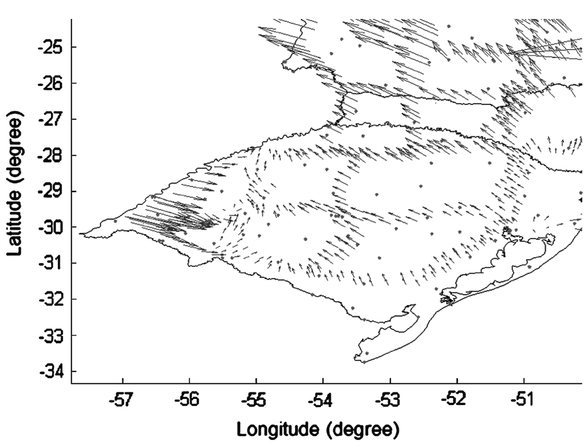

Fig. 109.6 Different distortion levels of triangulation and GPS points

109.3 Transformations Treated by ProGriD

ProGriD was designed to handle a number of transformations between the geodetic frames presented before, allowing the use of different coordinate types.

Figure 109.7 indicates the flow of transformations. One can relate any one of the reference frames through SIRGAS2000. For example, ProGriD permits coordinate transformation between Córrego Alegre 1961 (CA61) and SAD 69 via SIRGAS2000. It is important to say that the relation between CA61, CA70 + 72, SAD 69 and SAD 69/96 to SIRGAS2000 is 2D, being done via the NTv2 grid. The relation between the network of 3D points determined by space geodetic techniques (TE) and SIRGAS2000 is done using the official three translations as published by IBGE (IBGE 2005).

Figure 109.8 illustrates the type of coordinates handled by two-dimensional transformations, i.e., transformations that involve any one of the classical

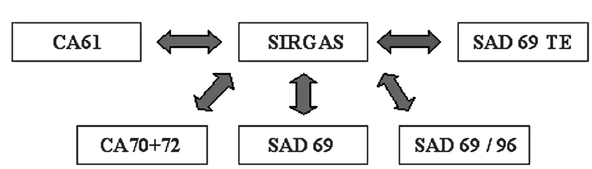

Fig. 109.7 Flow of transformations

Fig. 109.8 Coordinates used in 2D transformations

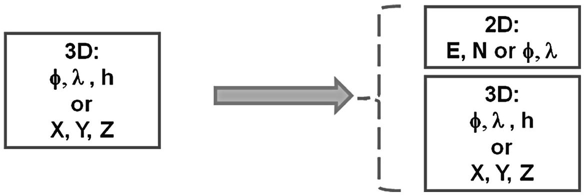

Fig. 109.9 Coordinates used in 3D transformations

reference frames. In this case, only geodetic latitude ϕ and longitude λ and UTM E and N coordinates can be used.

Figure 109.9 portrays the type of coordinates handled by three-dimensional transformations, i.e., transformations that involve 3D points (included in *SAD 69 Doppler or GPS Technique*) and SIRGAS2000. In this case, not only geodetic latitude ϕ and longitude λ and UTM E and N coordinates can be used but also Cartesian coordinates and geodetic height *h*. In the case of mixed-type transformations (ones involving any one of the classical 2D frames and the 3D *SAD 69 Doppler or GPS Technique*) the geodetic height information will be either treated or ignored during the process.

The user has the option to input the coordinates in any order he/she wants, in either decimal or in degrees, minutes and seconds, for the geodetic coordinates.

As far as heights are concerned, ProGriD handles only geodetic heights. Orthometric height must be appropriately transformed before running ProGriD. Another program, MAPGEO2004, must be used to handle these height transformations. It is very important to realize that ProGriD does not identify a wrong input. If the wrong height type is used, ProGriD will treat it as geodetic height.

109.4 Uncertainties

ProGriD handles the uncertainties associated with the transformations as follows.

The standard deviation σ_G of the nodal points of the grid represents transformations involving only classical networks from/to SIRGAS2000. They come from a specific grid shift file. Each individual value σ_G is obtained as a weighted average among the standard deviation of neighbouring classical points around a particular nodal grid point. The weight is a function of distance between the classical point and the grid. A radius of 500 km was used. They reach maximum values of 0.7 m for Córrego Alegre 1961 and 1970 + 1072, and 0.5 m for most of the SAD 69, except for an area in the State of Amapá, in the Amazon, where it reaches 6 m (an open electronic traverse).

The standard deviation σ_T of the transformations involving *SAD 69 Doppler or GPS Technique* and SIRGAS2000 correspond to the estimated standard deviation of the three official translations. Its value is at cm-level for the three translations.

If the transformation involves more than one network, it can be computed as:

(a) If the transformation involves any one of the 2D classical networks and the 3D *SAD 69 Doppler or GPS Technique* network, it entails the uncertainty from a grid σ_G and the uncertainty from the transformation parameters σ_T. The uncertainty given by ProGriD is computed as:

$$\sigma_{PG} = \sqrt{\sigma_G^2 + \sigma_T^2}. \qquad (109.1)$$

(b) If the transformation involves any two of the 2D classical networks, it entails the uncertainty from a grid σ_{G1} and a from a grid σ_{G2}. The uncertainty given by ProGriD is computed as:

$$\sigma_{PG} = \sqrt{\sigma_{G1}^2 + \sigma_{G2}^2}. \qquad (109.2)$$

ProGriD has no control over the uncertainty associated to the coordinates input by the users. In other words, the user cannot input the uncertainty associated with the coordinates desired to be transformed. If the final uncertainty of the transformation σ_F is desired, it must be computed by the user combining the uncertainty given by ProGriD σ_{PG} with the uncertainty of the user's input coordinates σ_U, contained in the user's data base, as:

$$\sigma_F = \sqrt{\sigma_{PG}^2 + \sigma_U^2}. \qquad (109.3)$$

109.5 Practical Considerations

Users of ProGriD must realize that there are several decisions that depend on them. They include, for example, the proper choice of the network being dealt with, if either Córrego Alegre 1961 or Córrego Alegre 1970 + 1972, if either SAD 69 or SAD 69 realization 1996, and if either SAD 69 (2D) classical network or SAD 69 (3D) Doppler or GPS network. This is very important because the software cannot distinguish between networks. Erroneous solutions of up to a few metres will arise if users by mistake:

– Treat Córrego Alegre 61 as 70 + 72 and vice-versa
– Treat SAD 69 as SAD 69 realization 1996 and vice-versa
– Treat a "satellite" point as classical point and vice-versa

A common misconception that exists among users is that, somehow, the quality of their coordinates will improve when migrated from a classical network into SIRGAS2000. As a matter of fact, the transformation does not improve the quality of the original coordinates.

Other examples of what ProGriD does not do are summarized in the paragraphs that follow.

ProGriD does not distinguish vertical coordinate type. In other words, the user must make sure that geodetic heights are input instead of any other height type. ProGriD will always treat any input height as geodetic height.

Until recently, the relationship between the classical frames used in Brazil and the early ones used in space geodesy (e.g., WGS72 and the earlier realization of WGS84) was treated by means of translation parameters. These parameters were official, i.e., they were published by IBGE. With the new paradigm created by the more rigorous distortion modelling handled by ProGriD there is no need to rely on those parameters any more. Therefore, ProGriD does not transform any of the classical networks into SIRGAS2000 using official translation parameters.

ProGriD does not handle points outside the predefined limit areas. This limitation was implemented in order to avoid the use of the software for areas outside the continental Brazil.

ProGriD does not handle non-official frames. As mentioned earlier in this paper, besides the two official classical 2D reference frames, Córrego Alegre and SAD 69, Brazil has had in its geodetic history many other 'non-official' frames were developed to satisfy different reasons. One of them is the frame Aratu. Aratu is a series of local frames joined together over the years, developed by the Brazilian Petroleum S.A. (Petrobras) in support of its exploration and production activities. Other local frame developed over the years is the one known as SICAD. This frame was developed and has been used in the mapping of Brazil's Federal District, where the city of Brasília is located. Aratu, SICAD, or any other non-official frame must go through a particular treatment to establish the proper relation with SIRGAS2000.

109.6 Concluding Remarks

This paper presents ProGriD, the transformation program package developed to handle coordinate transformation between realizations of Córrego Alegre and SAD 69 to SIRGAS2000 in Brazil. It overviews the major characteristics of ProGriD, including a brief discussion on the model used for the modelling of the distortions of the 2D frames, NTv2. It also describes that the 3D points were separated from their SAD 69 parent frame to form an independent network, which relates to SIRGAS2000 by means of three translation parameters. ProGriD provides error estimates of the transformations. It concludes with a few practical considerations dealing with situations where the misuse of ProGriD may cause unwanted errors.

Currently, a desktop version of ProGriD can be downloaded from IBGE's web site at ftp://geoftp.ibge.gov.br/programa/Transformacao_de_Coordenadas/. A web version is planned to be released early in 2010.

The desktop version of ProGriD was released in December 2008. It has been widely used by the community at large, including the transformation of large data sets, such as the whole spatial database of the State of Espírito Santos (GEOBASES).

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