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SIRGAS-WGIII activities for unifying height systems in Latin America

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Resumen

Desde 1997, SIRGAS (Sistema de Referencia Geocéntrico para las Américas) está actuando para establecer la unificación del Sistema de Referencia Vertical SIRGAS (SRVS) en América Latina y el Caribe. Los estándares, procedimientos y actividades que buscan la definición y realización del SRVS están actualmente dirigidos a cumplir los requerimientos internacionales modernos de integración dentro de un Sistema de Referencia Vertical Global (SRVG), con la finalidad de apoyar las necesidades de los Sistemas de Observación Terrestres. Estas aseveraciones implican la unificación de los Sistemas de Referencia Vertical Nacionales (SRVN) existentes, cada uno con su respectivo Marco (MRVN) y Datum Vertical (DVN) realizados en el espacio geopotencial. El estudio de algunas nuevas posibilidades para conectar los SRVN en una base global está en el contexto de las principales actividades de la Asociación Internacional de Geodesia (IAG por sus siglas en inglés). Sin embargo, muchos de los nuevos requerimientos para la construcción del SRVS no son aplicables aún, debido a las diferencias de definición y realización de cada SRVN en la región SIRGAS. En este trabajo es presentada una revisión acerca del estado de los SRVN, MRVN y DVN en Sudamérica. Los aspectos más importantes para la unificación de los SRVN en un contexto global como también los principales problemas relacionados son presentados. Algún énfasis es dado a las actividades del SIRGAS-Grupo de trabajo III, dirigidas a solventar los problemas de integración en Sudamérica. La pobre disponibilidad de datos, discrepancias desconocidas entre SRVN, diferentes estrategias para levantamiento y procesamiento de datos en el establecimiento de las redes, y otras fuentes de error son discutidas. En este contexto las posibilidades provenientes de nuevas estrategias y herramientas modernas son dis-

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cutidas, principalmente considerando las nuevas misiones, bases de datos y herramientas modernas de la Geodesia.

Palabras clave: *SIRGAS, SIRGAS-GTIII, Marcos y Sistemas de Referencia Vertical.*

Resumo

Desde 1997 o SIRGAS (Sistema de Referência Geocêntrico para as Américas) atua para o estabelecimento de um Sistema Vertical de Referência para o SIRGAS (SVRS) na América Latina e Caribe. Os padrões, procedimentos e atividades visando à definição e realização do SVRS estão agora dirigidos de encontro aos requisitos internacionais de integração em um Sistema Vertical de Referência Global (SVRG) para suportar as necessidades dos Sistemas de Observação da Terra. Estas condições implicam na unificação de Sistemas Verticais de Referência Nacionais (SVRN), cada qual com sua Rede (RVRN) e *Datum* Vertical (DVN) realizado no espaço do geopotencial. O estudo de novas possibilidades para conectar os SVRN em bases globais está no contexto das principais atividades da Associação Internacional de Geodésia (IAG para sua sigla em inglês). No entanto os requisitos mais modernos para estabelecer o SVRS não são imediatamente aplicáveis devido as diferenças nas concepções e realizações de cada SVRN na região do SIRGAS. Neste trabalho é apresentada uma visão geral acerca das características dos SVRN, das RVRN e respectivos DVN na América do Sul. São apresentados os preceitos mais importantes para unificação dos SVRN em base global bem como os problemas mais importantes a serem encarados. É dada alguma ênfase às atividades do Grupo de Trabalho III do SIRGAS voltadas para a solução dos problemas de integração referidos. A pobre disponibilidade de dados, o desconhecimento das discrepâncias entre os SVRN, as diferentes estratégias para aquisição e processamento de dados utilizados no estabelecimento das RVRN e outras fontes de erros são discutidos. As possibilidades advindas das novas estratégias e ferramentas modernas são discutidas principalmente com base nas novas missões e bases de dados globais da Geodésia.

Palavras chave: *SIRGAS, SIRGAS-GTIII, Marcos e Sistemas de Referência Vertical.*

Abstract

Since 1997 SIRGAS (Geocentric Reference System for the Americas) is acting for establishing a unified SIRGAS Vertical Reference System (SVRS) in Latin America and the Caribbean. The standards, procedures and activities aiming the definition and realization of the SVRS are now directed to meet the modern international requirements of integration into a Global Vertical Reference System (GVRS) to support the needs for Earth Observation Systems. These statements imply in a unification of the existing National Vertical Reference Systems (NVRS), each one with its respective Frame (NVRF) and Vertical *Datum* (NVD) realized in the geopotential space. The study of new possibilities for connecting NVRS in a global basis is in the context of the International Association of Geodesy (IAG) main activities. However, most of modern requirements are not immediately applicable for building the SVRS because the differences in the conception and realization of each NVRS in the SIRGAS region. In this work an overview about the status of NVRS, NVR Fand NVD in South America is presented. The most important characteristics for unifying NVRS in a global context as well as the main related problems are presented. Some emphasis is given on the activities of SIRGAS-Working Group III directed for facing the integration problems in South America. The poor data availability, unknown discrepancies among NVRS, different data collecting and processing strategies for establishing the networks, and other error sources are discussed. The possibilities coming from new strategies and modern tools are discussed mainly by considering new missions and global data basis of Geodesy.

Key words: *SIRGAS, SIRGAS-WGIII, Vertical Reference Systems and Frames*.

Introduction

Among the main Geodesy activities in the present global context are those for supporting spatial databases directed for Earth Observing Systems. This is the central purpose of the Global Geodetic Observing System (GGOS) inside of IAG structure. In the GGOS/IAG kern there is the global geodetic infrastructure formed by the terrestrial geodetic reference systems, frames, platforms and models, associated data and activities. In this infrastructure there are the continuous observing stations for several parameters as well as the dedicated spatial missions based on artificial satellites, data centers, analysis and combination centers, and international cooperation projects. Several planetary monitoring processes in the GGOS context present relative precision requirements on the spatial referencing tasks in the order of one part per billion —1ppb (Plag *et al.*, 2009). This is the case of needs related to a Global Vertical Reference System (GVRS). The GVRS became fundamental for monitoring the physical process related to the changes in Earth's System, mainly because masses redistribution effects. In general these effects must be described by their vertical movements in the geopotential space in association with the related level surfaces. However, more than a hundred of independent National Vertical Reference Systems (NVRS) exist in the world. Each NVRS has its own Vertical Datum (NVD) and Frame (NVRF) realized with different methods and standards, and, in general, without physical meaning. These facts impose an implicit requirement related to gravity field information for realizing and integrating each NVRS to a GVRS. Considering these aspects, conventions and standards for definition and realization of GVRS are now under consolidation in the GGOS/IAG context (Kutterer *et al.*, 2012; Sánchez *et al.*, 2013; IUGG, 2015).

According to the SIRGAS web page <www.sirgas.org>

> The 26th of February, 2015 General Assembly of the United Nations adopted its first Resolution on the Global Geodetic Reference Frame for Sustainable Development. With this Resolution, it is recognized the importance of a globally–coordinated approach to Geodesy: the science focused on accurately measuring the shape, rotation and gravity field of planet Earth. SIRGAS, as the responsible for the reference frame in Latin America and the Caribbean, contributes to this initiative together with the International Association of Geodesy (IAG), the Pan-American Institute for Geography and History (PAIGH), the Regional Committee of the United Nations Global Geospatial Information Management for the Americas (UN-GGIM: Americas) and GeoSur.

SIRGAS is part of IAG through the Sub-Commission 1.3b -"Regional Reference Frames" and it is a Working Group of the PAIGH Cartography Commission. SIRGAS has as one of its objectives to define a geocentric reference system for the Americas with the vision of standardizing its realization and maintenance, and therefore, its continuous modernization. Within SIRGAS there are three Working Groups, which are essential for developing its activities: SIRGAS-WGI-Reference System; SIRGAS-WGII-SIRGAS at National Level; and SIRGAS-WGIII-Vertical Datum. Nowadays, SIRGAS-WGIII is looking for the definition of a modern unified SIRGAS Vertical Reference System (SVRS) and for establishing their corresponding reference frame (SVRF) based on geopotential numbers related to a GVRS. The regional integration of NVRS considering their respective NVRF and each corresponding Vertical Datum must be based on a GVRS. To perform this integration, it is necessary to know the characteristics of each local network at different countries in the SIRGAS region. To align to this purpose, SIRGAS-WGIII is looking for the standards related to the SVRS by considering the integration of its geometric and physical components. The geometrical component corresponds to ellipsoidal heights referred to the SIRGAS GNSS Continuous Network (SIRGAS-CON) and the physical component is given in terms of geopotential numbers for assuring physical meaning for heights and in accordance with a GVRS. This means the choice of an equipotential surface expressed by its geopotential value W_0 as a reference level and geopotential numbers as primary coordinates given by (Hofmann-Wellenhof and Moritz, 2005):

$$C_P = W_0 - W_P \tag{1}$$

Where W_P is the geopotential value in the considered point P. Heights with physical meaning could be obtained from geopotential numbers in a general way by:

$$H_P^K = \frac{C_P}{G_m} \tag{2}$$

Where G_m is a mean value of gravity. Considering the reference surfaces in the geopotential space in the Figure 1, the three main kinds of heights with physical meaning are (De Freitas and Blitzkow, 1999): *Orthometric* is the distance P_0P along the plumb line (simplified by the ellipsoid normal in the Figure 1) from the geoid to the point at the surface. G_m is equal to the mean value of gravity g_m between the point P and the geoid - the reference surface is the geoid and points at the same level surface in general have differences in orthometric heights. The distance $Q_0P_0=N$ is called geoid height; *Dynamic* is the distance obtained when G_m is equal to the mean value of normal gravity[1] $\gamma_{\varphi m}$ (e.g. for a mean latitude $\varphi= 45°$) – it is not represented in the Figure 1 because there is no reference surface to it and points on the same level surface have the same dynamic height; *Normal* is the distance Q_0Q along the normal from the level ellipsoid to the telluroid Σ or the distance $Q'P$ from the quasigeoid to the point P. G_m is equal to the mean value of theoretical gravity γ_m between a point Q where the normal potential U_Q is defined to bee qual to the geopotential at W_P in a point P at the surface[2] – the reference surface is the quasigeoid and points at the same level surface in general does not have the same normal height.

At most of NVRF in the SIRGAS context, it is only possible to determine geopotential differences among small quantity of points where gravity data exists and because each NVD is on a local equipotential surface W_{0i}, in general different of a global adopted value W_0. The NVD are, in general, associated with local Mean Sea Level affected by local disturbances, and referred to an arbitrary epoch t_0. Besides, each NVRF has its own characteristics and internal distortions along with leveling lines (De Freitas *et al.*, 2002).

Considering these precedent aspects, the main present objective of SIRGAS-WGIII is to establish a unified gravity-field related SVRS that meets the GGOS requirements on long-term stability and homogenous high-reliability. In this manuscript the foundations of modern Vertical Reference Systems and the activities developed by the SIRGAS-WGIII for establishing the SVRS as well as the obtained results until now are presented.

1 Theoretical value of gravity produced by the normal Earth based on the level reference ellipsoid.

2 The set of points which accomplish this property form a surface Σ in the Figure 1 (telluroid). The distance ζ from the telluroid to the surface is called height anomaly. The quasigeoid is the surface determined by the corresponding height anomalies over the level ellipsoid.

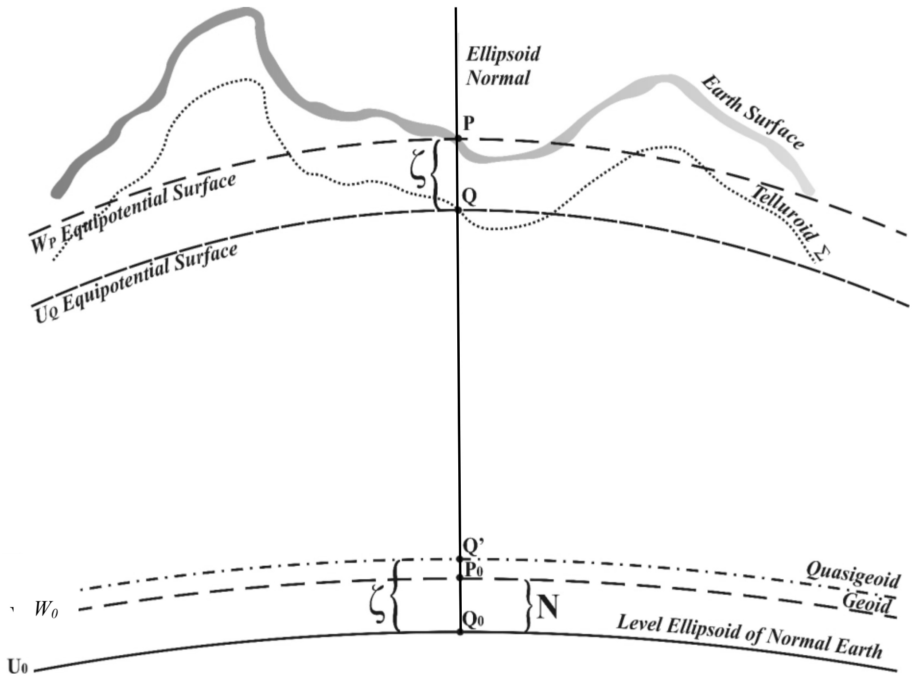

Figure 1. Reference surfaces for heights in the geopotential space

The GGOS/IAG Global Vertical Reference Systems and the SVRS

According to (Sánchez *et al*., 2013):

> The GGOS/IAG established in 2010 its Theme 1: Unified Height System. The main purpose is to provide a global gravity field-related vertical reference system that (1) supports a highly-precise (at cm-level) combination of physical and geometric heights worldwide; (2) allows the unification of all existing local height datums; and (3) guarantees vertical coordinates with global consistency (the same accuracy everywhere) and long-term stability (the same order of accuracy at any time). The primary coordinates of this height system are geopotential numbers referring to one and the same reference level realized globally by its geopotential value W_0.

Studies developed since the creation of the SIRGAS-WGIII pointed out some singular characteristics of NVRF and available gravity data in Latin America and the Caribbean. Each of these networks has specific features related to their definitions and realizations as well different approaches for their maintenances. These aspects implies in some important distinctions such as: differences in the NVD due the variability of the mean sea level at different locations and the reference epoch of the tide gauge records or arbitrary reference levels for land-locked countries; the partial or complete lack of correction from gravity field effects on leveled heights; the no-consideration for geodynamics effects. Because of these aspects, the heterogeneity of the information obtained is evident, and generates height discrepancies between neighboring countries. As main consequence the NVRF do not permit data exchange neither in continental nor in global scale. In short, the present networks in the SIRGAS region do not allow the exchange of consistent vertical geographic information. They are not able to support practical height determination with Global Navigation Satellite System (GNSS) techniques in combination with existing tailored geoid or quasi geoid models in the continent, usually affected by non-modeled indirect effects coming from each NVD (Gatti *et al.*, 2012) as well as effects coming from implicit deformations in the networks by disregarding local gravity field effects. With this, a new challenge for SIRGAS arises, which is the vertical data interoperability through the creation and updating of standards and conditions mainly by taking into account gravity field effects on vertical networks. Along with this big challenge there is another important point to be considered: the modernization of the employed techniques and new existing tools in a global context for obtaining spatially referenced information. Considering these two important referred precedent aspects, the present objective of SIRGAS-WGIII is establishing a unified gravity-field related SVRS that meets the GGOS requirements on long-term stability and homogenous high-reliability, as previously pointed out in this manuscript.

Basic concepts on geopotential numbers in local and global systems

Classical NVRF were by more than a century established based on spirit leveling in general along roads or railroads because the limitations of the technique. Even considering the modern digital levels and rods, the spirit leveling remains a very expensive technique in terms of time and efforts for accomplishing results. However, considering the modern spring gravimeters, it is possible to easily associate gravity observations with classical leveling. Nowadays other possibilities for leveling with physical meaning appear. This happened after the full operation of the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS). They allow new possibilities for leveling associated with gravity observations elsewhere. The present possibilities are reinforced by new products of Geodesy like modern Global Geopotential Models (GGMs) and Digital Elevation Models (DEMs) improved in accuracy, consistency and spatial resolution by satellite-based observations.

Geopotential numbers in local Systems

The geopotential numbers C_{Pi} along with conventional leveling lines in NVRF could be determined with basis on equation (1) by:

$$C_{Pi} = W_{0i} - W_P = \int_{0i}^{P} g dn \cong \sum g_{mj} \Delta n_j \tag{3}$$

In equation (3) g is the gravity value, g_{mj} is the mean value of gravity in a leveling section j (e.g. ~ 3km) and Δn_j is the observed level difference between the extremes of the section.

Geopotential numbers in a global System

In a modern approach, other possibilities coming from the solution of the Geodetic Boundary Value Problem (GBVP) can be considered, when the geometry of the Earth's surface is known. This possibility arises from the modern tools of Geodesy for positioning and gravimetry (Ferreira and De Freitas, 2011). It is possible in this case to assume that in each point the only unknown is the geopotential W_P if the Earth's surface is used as a contour surface (Heck, 2011). In this case, it is important to consider the possibilities coming from gravity observations associated with GPS/GNSS positioning for determining gravity disturbances:

$$\delta g_P = g_P - \gamma_P \tag{4}$$

In equation (4) g_P is the observed gravity in P and γ_P is the normal gravity reduced to P by considering the observed ellipsoidal height and by applying the gradient of the normal gravity which is discussed in the next section.

Normal gravity

According Clairaut's formula, the normal gravity for the latitude φ at the level ellipsoid is given by (Hofmann-Wellenhof and Moritz, 2005):

$$\gamma = \gamma_e (1 + \beta \sin^2 \varphi + \beta' \sin^2 2\varphi) \tag{5}$$

In the equation (5) γ_e is the normal gravity at the equator and the other involved parameters are:

$$\beta = \frac{5}{2} m - f - \frac{17}{14} mf \tag{6}$$

$$\beta' = \frac{f^2}{8} - \frac{5mf}{8} \tag{7}$$

$$m = \frac{a\omega^2}{\gamma_e} - \frac{3}{2} m^2 \tag{8}$$

In the previous equations ω is the angular velocity of the Earth, $f = (a - b)/a$ is the geometrical flattening with a and b being respectively the major and minor semi-axes of the level ellipsoid.

Other equivalent possibility for computing the normal gravity is to consider the Somigliana formula:

$$\gamma = \frac{a\gamma_e \cos^2\varphi + b\gamma_p \sin^2\varphi}{(a^2\cos^2\varphi + b^2\sin^2\varphi)^{1/2}} \quad (9)$$

In the equation (9) γ_p is the normal gravity at the pole. In Table 1 numerical values for associated parameters related to the Geodetic Reference System 1980 (GRS1980) are presented.

The normal gravity above the level ellipsoid is obtained by considering the gradient of the normal gravity above the level ellipsoid as proposed by Bruns (details in Hofmann-Wellenhof and Moritz, 2005, p. 81-82). Considering the ellipsoidal height h in a rigorous form,the normal gravity above the level ellipsoid is given by:

$$\gamma_h = \gamma - \frac{2\gamma_e}{a}(1 + f + m - 2f\sin^2\varphi)h + \frac{3\gamma_e}{a^2}h^2 \quad (10)$$

By considering a simplification given by the mean value for the gradient of normal gravity, the normal gravity above the level ellipsoid is given by:

$$\gamma_h = \gamma - 0.3086h \quad (11)$$

Table 1
Numerical values for GRS1980

Parameter	*Symbol*	*Value*
Major semi-axis	a	6378137 m
Minor semi-axis	b	6 356 752.3141 m
Flattening	f	1:298.257222 101
Angular velocity	ω	7 292 115 x 10^{-11} rad/s
Geocentric gravitational constant	GM	398 600.5 x 10^9 m^3s^{-2}
Equatorial rate of specific forces	m	0.00344978600308
Tide free Earth dynamic form factor	$J2$	108 263x 10^{-8}
Normal gravity at the equator	γ_e	9.7803267715ms^{-2}
Normal gravity at the pole	γ_p	9.8321863685 ms^{-2}
Normal potential at the level ellipsoid	U_0	62636860.850 m^2s^{-2}

Source: Hofmann-Wellenhof and Moritz (2005, pp. 84-86).

The geopotential at a point *P* in the Earth' surface is given by:

$$W_P = U_P + T_P \tag{12}$$

In the equation (12) U_P is the normal potential at P given by:

$$U_P = U_0 + \frac{\partial U_0}{\partial h} h_P \tag{13}$$

Then, considering equation (1), the gravity disturbance could be used for solving the GBVP and obtaining the disturbing potential T_P at Earth's surface points. The knowledge of T_P allows the direct computation of C_P in a GVRS as:

$$C_P = W_0 - W_P = W_0 - \left(U_P + T_p\right) \tag{14}$$

For this, it is necessary to consider the fundamental limit condition:

$$\frac{\partial T}{\partial h} = -\delta g \tag{15}$$

In consequence, the disturbing potential could be determined from the formula based on a Brovar type solution for the GBVP fixed at the Earth's surface and considering the Brun's equation $\zeta = T_P/\gamma$ (Heck, 2011):

$$T_P = \zeta\gamma = \frac{R}{4\pi} \iint_s (\delta g + g_1 + \ldots) H(\psi) \cdot ds \tag{16}$$

where R is the mean Earth's radius, ζ is the height anomaly, γ is the normal gravity and $H(\psi)$ is the Hotine-Koch's function based on the geocentric angular distance ψ (Hofmann-Wellenh of and Moritz, 2005, p. 115) given by:

$$H(\psi) = \frac{1}{\sin\left(\frac{\psi}{2}\right)} - \ln\left(1 + \frac{1}{\sin\left(\frac{\psi}{2}\right)}\right) \tag{17}$$

And the contribution from anomalous elements in terrain is:

$$g_1 = \frac{R^2}{4\pi}\iint_s \left(\frac{h - h_P}{\ell_0^3}\right)\delta g \cdot ds \tag{18}$$

In equation (18) ℓ_0 is the Euclidian distance from the computation point P to the disturbing element at the Earth's surface given by (Hofmann-Wellenhof and Moritz, 2005, p. 115):

$$\ell_0 = 2R\sin\left(\frac{\psi}{2}\right) \tag{19}$$

An equation like (16) is adequate to be solved with basis on the Fast Fourier Transform (FFT) technique (Sideris and Schwarz, 1986). This approach allows the spectral decomposition of the disturbing potential in the so called Remove-Restore process (Forsberg and Tscherning, 1981). The solution by spectral decomposition allows using related gravimetric information coming from different sources. It is the case where it is possible to integrate observed gravity disturbances, predict values from modern Global Geopotential Models (GGM) and values for gravity disturbances deduced from terrain effects like in the Residual Terrain Model (RTM) based on Digital Elevation Models (Forsberg, 1984; Hirt *et al.*, 2010). In this sense it is possible to consider by spectral decomposition (Ferreira and De Freitas, 2011):

$$\delta g_{RES} = \delta g_{OBS} - \delta g_{GGM} - \delta g_{RTM} \tag{20}$$

The integral (16) is solved by using only the small residual gravity disturbance given by equation (20). Then, it is possible to compute T_{RES} and the whole disturbing potential is obtained in a composition process by:

$$T = T_{RES} + T_{GGM} + T_{RTM} \tag{21}$$

In equation (21) the terms at the right side are all known.

In a preliminary approach, it is possible to obtain the discrepancy between the Global Vertical Datum (GVD) and the National Vertical Datum (NVD) in terms of the geopotential number. The difference between equations (14) and (3) at the same point results:

$$C_P - C_{Pi} = W_0 - W_{0i} = \delta W_i \cong (U_P + T_P) - \sum g_{mj}\Delta n_j \tag{22}$$

Indeed, the difference between the geopotential numbers at any point must represent the discrepancy between the global and local vertical datums (GVD and LVD) represented by δW_i. The discrepancy between the GVD and LVD in units of length could be given by:

$$\delta H = \frac{\delta W_i}{\gamma_i} \tag{23}$$

However, there are implicit observation errors in leveling, positioning and gravimetry, as well as commission and omission errors in GGM and DEM associated to the determination of parameters in the right-hand side of equation (22). Hence estimations of δW_i must be done by a least square adjustment of observed geopotential differences along the NVRF on a large number of points where T_P was determined in the GVRS or by solving the GBVP at the vertical datum region where distortions in the leveling lines could be considered under the intended precision.

Activities of SIRGAS–WGIII and the present status of the SVRS

The SIRGAS–WGIII was established in 1997 during the IAG General Assembly at Rio de Janeiro aiming to define a modern unified vertical reference system for SIRGAS, to establish the corresponding reference frame, and to transform the existing classical height datums to the new system. Since its foundation most of activities have been directed to inventory and diagnostic tasks, and attempts to form a database. The present status of database in South America consisting of leveling lines associated with existing gravity observations is displayed in Figure 1. This database is essential for a first attempt to adjust geopotential numbers.

There are some activities developed by the SIRGAS-WGIII which support the determination of the geometric and physical components of the SVRS. In the SIRGAS observing campaign of 2000 the basis of the geometric component were established by GPS observing stations associated with NVD, points on benchmarks of NVRF and connection points at national borders. Nowadays, most of these stations are in the SIRGAS Continuous GNSS network (SIRGAS-CON). Following the SIRGAS 2000 campaign, there was an expressive participation of people involved in the SIRGAS-WGIII in the IAG Symposium "Vertical Reference System" (VeReS) that happened in Cartagena, 2001. From this participation resulted eight scientific papers published in the IAG Symposia Series, vol. 124 (VeReS, 2002). The scientific foundations of the SVRS were established there (Drewes *et al.*, 2002).

A first formal diagnosis of the NVRS and NVRF status in the SIRGAS-WGIII context was generated in 2005. It resulted in a detailed report which emphasizes

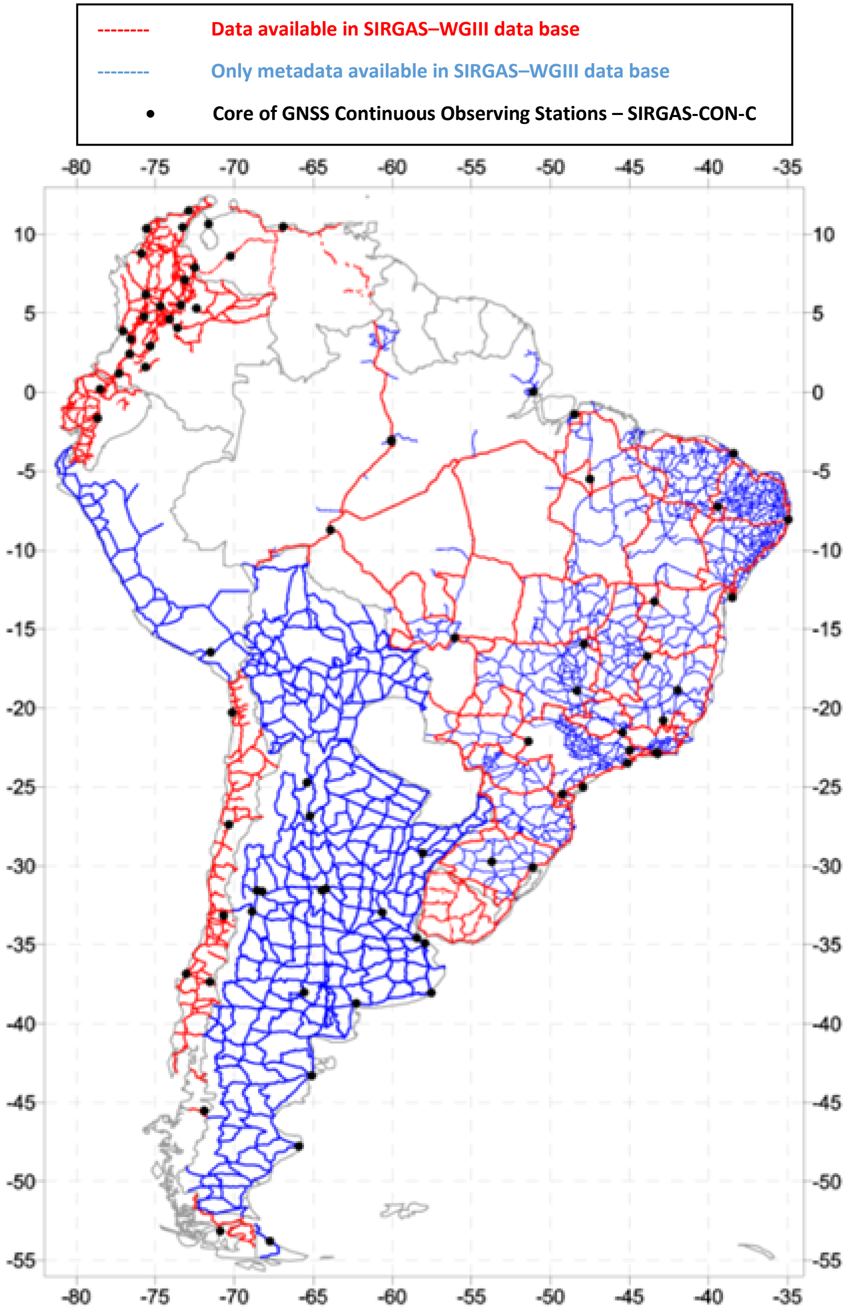

Figure 2. Eveling lines with gravity observation in South America available for SIRGAS-WGIII (Brunini *et al.*, 2011).

that NVD in Latin America refer to different reference levels and different epochs; besides, in most of the countries the vertical networks were established and adjusted without considering information coming from gravity reductions of the leveled heights. It is possible to observe large discrepancies among heights in the same point considering the NVRS of neighboring countries. A serious implication is that the mentioned discrepancies coming from datums referred to different reference surfaces and distortions along leveling lines do not permit data exchange neither in continental nor in global scale. Another aspect inside the problem is that the NVRS do not take care of the height and reference level variations with time. In general, the adopted standards for system, vertical datum and frame realization differ from country to country. A synthesis of the main problems related to SVRS was presented in the Report 2010-2011 of SIRGAS (Brunini *et al.*, 2011).

It is possible to note in Figure 2 that the vertical data distribution in South America is heterogeneous, with large regions without related information like in the Amazon. If considered only the Brazilian case, there are more than 65 thousand benchmarks linked by about 160 000 km of leveling lines. It is clear that it is almost impossible to cover the empty regions with leveling lines using a conventional leveling approach.

As result of several discussions, mainly during the SIRGAS 2011 meeting (see Sánchez and Luz, 2011), the SIRGAS-WGIII concluded that there are other implicit problems associated with the establishment of the SVRS based on the unification of NVRS by adjusting geopotential numbers. Among them there is the heterogeneity in knowledge by people involved in the respective national institutions responsible for NVRS with respect to the scientific foundations of modern vertical reference systems and modern tools for realizing the frames. Also, it is possible to observe a general deficiency related to the organization of consistent databases needed for data interchanges and use in common multinational projects. A first attempt of SIRGAS-WGIII for overcoming these problems was the organization of the SIRGAS Workshop on Vertical Datum Unification, held in 2012 in Rio de Janeiro, Brazil. This workshop was focused on basic concepts about vertical reference systems and strategies for data processing. The first SIRGAS School on Vertical Reference Systems happened in La Paz, Bolivia, in 2014, in conjunction with the SIRGAS 2014 meeting. This school covered scientific and practical aspects related to modern height systems, GVRS, least square adjustment, gravimetry, geopotential numbers, data inventory and databases, new tools of Geodesy and modern approaches for solving the GBVP. The implications of connecting networks, determination of conversion parameters and vertical datum unification were also discussed. The school was repeated in Curitiba, Brazil, in May 2015, as part of the SIRGAS-WGIII Workshop on Consolidation of strategies for unifying NVRS of SIRGAS Member Countries. In this workshop a first attempt for least square adjustment of geopotential numbers in the SIRGAS region has been tried. However, because the different status of countries data bases development and people capabilities this first solution was not achieved in full.

In synthesis, the main statements for SVRS up dated until now can be extracted from <www.sirgas.org/index.php?id=56&L=2>. They are:

- To refers to a unified global reference level W_0
- To be realized by proper physical heights (derived from spirit levelling in combination with gravity reductions)
- To be connected to the SIRGAS geometrical reference system; and
- To be associated to a specific reference epoch, i.e. it should consider the coordinate and frame changes with time.

The official recommendation of SIRGAS about the physical heights is to adopt normal heights. However, since some countries want to use orthometric heights, it was decided to define the new vertical reference system in terms of geopotential quantities (W_0 as a reference level and geopotential numbers as primary coordinates), and then, in the realization, each country can introduce the desired physical heights with their respective reference surface: the geoid or the quasi geoid.

Conclusions

This manuscript described the main foundations and some steps considered fundamental for integrating the National Vertical Reference Systems (NVRS) into the SIRGAS Vertical Reference System (SVRS). The main developed activities of SIRGAS-WGIII for establishing the SVRS were presented. A basic conclusion is that SVRS and its realization can be obtained from the integration of each NVRS into a Global Vertical Reference System (GVRS) under the Global Geodetic Observing System (GGOS)'s Global Vertical Reference System (GVRS) conventions.

There is a lack of height and gravity information in large areas in Latin America. Where such kind of data exist, they are in part misorganized and, in consequence, inadequate for determining physical heights consistent with a GVRS. One of SIRGAS-WGIII aims is training people as protagonist in database organization and processing following the specifications of the Regional Committee of the United Nations Global Geospatial Information Management for the Americas (UN-GGIM: Americas) for building a future Spatial Data Infrastructure for the Americas, base for spatial data interchanging among countries and of GGOS/IAG. The continuous inventory of data in each country is fundamental for establishing solution strategies in regional integration of NVRS and a link to a GVRS.

It is almost impossible to fill in vertical and gravity data gaps in the SIRGAS region by the expensive conventional leveling methods. As other possibilities for obtaining height with physical meaning based on satellite based systems exist, SIRGAS-WGIII has established activities for training involved people for using such new possibilities.

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