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Advances in the modernization of the height reference systems in Latin America and their integration to the International Height Reference System (IHRS)

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ABSTRACT: One of the main objectives of SIRGAS (**SI**stema de **R**eferencia **G**eocéntrico para las **A**mérica**S –** www.sirgas.org) is the establishment of a unified height reference system for its country members within a global frame. The central purpose is to refer all existing geopotential numbers (or physical heights) to the equipotential surface defined by the W_0 value adopted by the IAG in July, 2015. Thus, a present challenge is the transformation (or integration) of the existing height systems into the International Height Reference System (IHRS). To advance in this direction, initial actions concentrated on the co-location of the national vertical datums with the geocentric reference frame SIRGAS (densification of the International Terrestrial Reference Frame – ITRF – in Latin America) and the continental adjustment of the Vertical Reference Frame (VRF) in terms of geopotential numbers. To determine the relationship between the global and the local reference levels, we are evaluating different geodetic boundary value problem (GBVP) formulations in three different approaches: at the reference points (tide gauges) of the classical height datums, in the marine areas close to the tide gauges, and at fiducial stations of the geometrical reference frame SIRGAS. The kernel of the intended realization of the unified vertical reference system will be a continental set of very good (reproducible) benchmarks with ITRS/ITRF geometric coordinates as well as known global geopotential numbers and anomalous potential values. These stations should contribute to the establishment of the Global Geodetic Reference System and Frame (GGRS/GGRF). In this work, we report about several goals already obtained and promising ongoing activities like the connection of local VRF to the reference level of the global IHRS.

1. NATIONAL VERTICAL REFERENCE SYSTEMS AND FRAMES IN THE SIRGAS CONTEXT

In the last twenty years, the central activities of SIRGAS Working Group III – Datum Vertical (SIRGAS-WGIII) were directed towards the modernization of all national VRS and respective frames based on geopotential numbers and their connection to the geometric SIRGAS continuously operating GNSS stations. Several activities were developed to face the challenges associated with the unification of vertical networks in the SIRGAS region. The respective main aspects to be considered are the heterogeneities of criteria for establishing and maintaining each national VRF, lack of geodetic data as well as difficulties for planning necessary activities. The efforts, initially concentrated in South America (FIG. 1) are now extended to Central America (FIG. 2).

2. SIRGAS-WGIII PROTOCOLS

Nowadays, the following main protocols are considered in the SIRGAS-WGIII: Strategies to realize VRF by physical heights [$H_P = f(C_P)$] with C_P as the geopotential number given by $C_p = W_0 - W_P$; connection of the national VRF to the SIRGAS continuously operating GNSS stations; Adjustment of the national VRF in terms of geopotential numbers; Approaches for referring the SIRGAS VRF to the W_0 value of IHRS; Association to an specific epoch by considering the realization epoch and temporal variations in the coordinates; Planning of activities for establishing a GGRF/IHRF station profile in the SIRGAS region; Future link of SIRGAS VRF to a profile of GGRF/IHRF stations.

FIG. 1. National Vertical Reference Frames and border connections in South America. Adapted from Brunini et al. (2011).

3. CURRENT STATUS OF NATIONAL VRF IN THE SIRGAS CONTEXT

Three countries accomplished to adjust their VRF in terms of geopotential numbers: Argentina, Brazil and Uruguay. Their networks represent more than 60% of first order leveling points in South America (Argentina ≈ 18 000 points; Brazil ≈ 70 000 points; Uruguay ≈ 1 500 points). Most countries in the region have on course related activities advised by SIRGAS-WGIII. However, several problems remain. Among these: the lack of international connections between countries to form consistent loops for simultaneous adjustment; the unavailability of original leveling measurements in some countries; and isolated vertical datums (each VRF refer to different reference tide gauges).

4. SIRGAS-WGIII ACTIVITIES RELATED TO THE IHRS/IHRF

Since the creation of the IAG/GGOS 0.1.2. Working Group on Strategy for the Realization of the International Height Reference System (IHRS) in 2016, SIRGAS-WGIII is inserted in its activities. At the beginning of 2017, SIRGAS proposed a set of 22 IHRF stations distributed in South America, Central America and the Caribbean carefully selected by national referents (Fig. 2). Since then, SIRGAS-WGIII is contributing with numerical experiments oriented to evaluate different approaches for the determination of reference coordinates at those stations. Two initiatives merit emphasis: The connection of Ecuadorian Vertical Datum to the IHRS accomplished in 2017 with basis on two experimental approaches (Carrión, 2017); and the insertion of two South American research groups linked to SIRGAS in the Colorado Experiment organized by the IAG/GGOS 0.1.2. Working Group. This experiment is related to the development of the strategies for the establishment of IHRS stations. The experiment is now running by considering the Molodensky approach to solve the GBVP (see Flowchart 2). Some provisional results related to the six Brazilian IHRF stations are now available.

5. RELATIONSHIP BETWEEN THE GLOBAL AND THE LOCAL REFERENCE LEVELS

Even considering that a national VRF (i) is realized with basis on geopotential numbers $C_{pi} = W_{0i} - W_P$ (being W_{0i} the potential value at the local vertical datum i and W_P the potential value at a point P), these geopotential numbers C_{pi} differ from those C_p referred to the global reference W_0 by a value expressed as the offset $\delta W = W_0 - W_{0i}$. The correspondent metric offset is given by $\Delta H = \delta W / \gamma_0$, where γ_0 is the normal gravity at the level ellipsoid. Flowcharts 1 and 2 summarize the handling of these discrepancies to achieve the integration of local VRF into the IHRS.

6. FLOWCHART 1: CONNECTION OF LOCAL VERTICAL DATUMS WITH THE GLOBAL IHRS

The disturbing potential T_P at a point P on the Earth's surface can be obtained by the solution of the Geodetic Boundary Value Problem (GBVP) using gravity disturbances ($\delta g_P = g_P - \gamma_P$) or the so-called Molodensky anomaly ($\Delta g_M = g_P - \gamma_\Sigma$). These two functionals are separately used for the fixed solution and for the free scalar solution of the GBVP, respectively.

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

From level ellipsoid γ_0

$$W_P = U_P + T_P$$

$$C_{Pi} = W_{0i} - W_P = \sum_0^P g\Delta n \longrightarrow \textit{In local VRF}$$

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

W_0 = 62 636 853.4 m²s⁻²

$$\Delta H_{Global/local} = \frac{\delta W}{\gamma}$$

7. FLOWCHART 2: MOLODENSKY'S SOLUTION OF THE GBVP

Observed Gravity

Δg_{OBS} (Molodensky)

Remove

$\Delta g_{RES} = \Delta g_{OBS} - \Delta g_{GGM} - \Delta g_{RTM}$

GBVP free escalar solution

$$\zeta = \zeta_0 + \zeta_1 + \zeta_2 + \ldots\ldots$$

$$T_0 = \zeta_0 \gamma = \frac{R}{r\pi}\int_\sigma Z_0 S(\Psi) d\sigma \qquad T_1 = \zeta_1 \gamma = \frac{R}{r\pi}\int_\sigma Z_1 S(\Psi) d\sigma$$

$$Z_0 = \Delta g_M$$

$$Z_1 = \frac{R^2}{2\pi}\int_\sigma \frac{h - h_P}{l^3}[\Delta g_M + \frac{3\bar{g}}{2R}\zeta_0] d\sigma$$

$$\zeta = \frac{GM}{r\gamma}\left[\sum_{n=2}^{n_{max}}\left[\frac{a}{r}\right]^n \sum_{m=0}^{n} \bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\cos m\lambda \sin m\lambda\right]\bar{P}_{nm}(\sin\varphi)$$

Restore

$$\zeta_P = \zeta_{RES} + \zeta_{GGM} + \zeta_{RTM}$$

$$\zeta_{prism} = \frac{V_{RTM}}{\gamma_Q} \quad ; \zeta_{RTM} = \sum_{i=1}^{k} \zeta_{prism\,i}$$

W_0 = 62 636 853.4 m²s⁻²

$$Bias = \delta W = W_0 - W_{0i}$$

$$W_P = T_P + U_P$$

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

$$T_P = \zeta_P \gamma_0$$

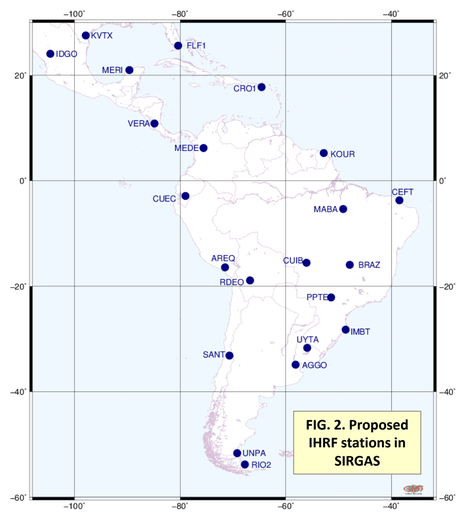

FIG. 2. Proposed IHRF stations in SIRGAS

8. OUTLOOK

Present efforts continue concentrating on the modernization of the national vertical networks existing in the SIRGAS region by determining adjusted geopotential values and by connecting them to the IHRS/IHRF.

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