SIRGAS – GGOS Session

**SIRGAS Working Group III (Vertical Datum):
Past, Present and Future**

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CONTENTS

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1 - Some Historical Remarks

o A quick development was experienced by national geometric tridimensional networks in South America after the SIRGAS 1995 GPS unified campaign.

o However no immediate possibilities were evidenced at that time in relation to the modernization and unification of vertical networks in the continent. In general, the main problems were:

  ➢ No physical meaning for heights;
  ➢ No homogenization and connection at international context;
  ➢ Different vertical datums.

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1 - Some Historical Remarks

o Aiming to face those difficulties, the SIRGAS Directing Council established the SIRGAS - Working Group III (Vertical datum) during the IAG Scientific Assembly held in Rio de Janeiro in 1997.

o The initial insights were directed to diagnose in each national vertical system involving their networks and datums, and the related problems for promoting their modernizations by considering the characteristics and status of each:

  ➢ Networks and datums characteristics;
  ➢ Current status and available data;
  ➢ Necessary actions for promoting their modernization.

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1 - Some Historical Remarks

o The definition of the unified SIRGAS Vertical Reference System (SVRS) for South America with physical meaning was discussed during a Workshop of SIRGAS WG III in Santiago de Chile, August 1998:

> ➢ The central strategy was how to face the associated problems of each national vertical networks and datums in agreement with a unified height system in a continental basis;

> ➢ The integration of continental vertical networks with the SIRGAS/ITRF network was considered.

o The SIRGAS GPS campaign 2000 put new perspectives for the WG III because the inclusion of GPS stations linked to reference tide gauges and in national boarders associated with connection points among national vertical networks (Luz et al. 2002).
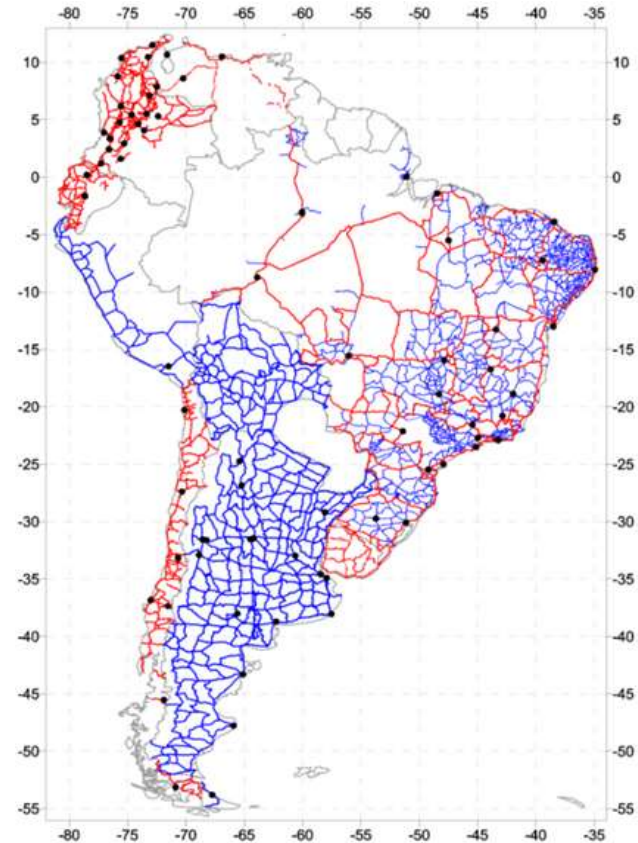
1 - Some Historical Remarks

o The SIRGAS WGIII milestones were consolidated in the IAG Vertical Reference System Symposium held in Cartagena, Colombia, 2001. The main aspects related to the SIRGAS Vertical Reference System (SVRS) were established as:

➢ to define a modern Vertical Reference System (VRS) for SIRGAS with physical meaning;

➢ to establish the corresponding reference frame;

➢ to transform the existing classical height datums to the new system (DREWES et al, 2002);

➢ how to realize physical connection among National Vertical Reference Networks (De Freitas et al., 2002);

➢ the SVRS be based on two types of heights: the ellipsoidal and the normal heights;

➢ also, dynamic aspects were considered as necessary for defining and maintaining the SVRS.

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6

1 - Some Historical Remarks

o Global needs for unifying VRS were introduced in 2003 by the IAG/GGOS. Related to this subject, GGOS established as its central Theme 1 - the Unified Height System. Following this aspect, some key-works for organizing the SIRGAS WG III activities were developed:

➢ the Report 2005 by Sánchez (2005) where, besides a clear discussion about the scientific foundations for SVRS, it was presented a relevant first inventory about the National Vertical Reference Systems (NVRS) in South America;

➢ Besides a deep analysis of BVRS/F, a thesis containing a road- map for inventory, analysis and modernization of VRS and respective networks was developed by Luz (2008);

o Since then, a lot of pro-active actions was developed by the SIRGAS WG III for establishing the SVRS.

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2 –Diagnostic Related to SVRS/F

Several VDs and big áreas without VRN

Source: http://www.sirgas.org

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2 –Diagnostic Related to SVRS/F

o The present SIRGAS-WGIII diagnostic of the existing height system and datums in Latin America expose that still remain the following aspects to be surpassed with an effective participation of authorities of member countries (SIRGAS, 2019):

➢ The reference level of the Latin American height datums is realized mainly by the mean sea level registered at individual tide gauges over different periods, i.e. they refer to different epochs;

➢ The vertical networks were extended over each country using mainly spirit levelling methods, but in general the levelled heights have not been corrected by the gravity effects;

➢ They do not take into account the variation of heights and reference levels with time, i.e. they are static;

➢ These vertical datums present big discrepancies between neighboring countries, they do not permit data exchange neither in continental nor in global scale, and they are not able to support practical height determination with GNSS techniques in combination with precise geoid models.

3 – The IAG/GGOS Age

The conception of the Global Geodetic Observing System (GGOS) is based on the integration of several global geodetic platforms and systems for data acquisition and monitoring. GGOS has support in the IAG Services which support the pillars of Geodesy, base for generating products directed to environmental control and mitigation of natural hazards effects.

SOURCE: http://www.ggos.org/

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3 – The IAG/GGOS Age

o From the new paradigms introduced by the GGOS came:

- ➤ The IAG Inter Commission Project ICP 1.2 - World Height System-Pilot Project (ICP1.2 – WHS-PP) developed until 2011 the foundations of a global unified Vertical Reference System/Frame inside the GGOS Theme 1 (Idhe, 2011);

o The consecution of IAG/GGOS activities since 2003 and the term 2011-2015 of the GGOS Focus Area Unified Height System (GGOS-FA-UHS) resulted in the IAG Resolution 1 "Definition and realization of an International Height Reference System (IHRS)" in July, 2015:

- ➤ IHRS in the geopotential space with a height reference surface constrained by the geopotential value W_0 = 62 636 853,4 m²s^{-2} and the geopotential number $C_P = -\Delta W_P = W_0 - W_P$ as primary physical vertical coordinate (IAG, 2015).

11

4 - Strategies of SIRGAS WG III According to GGOS

○ Several fundamental aspects that influenced the development of SIRGAS WG III related activities were based in the new paradigms introduced by the IAG /GGOS (Sánchez, 2012).

➢ The IAG stablished in 2016 the "Joint Working Group 0.1.2. on Strategy for Realization of the International Height Reference System (IHRS)" inserted in the GGOS Theme 1. The SIRGAS WG III participates in the JWG 0.1.2 since its creation;

➢ De Freitas (2015) presents an overview about the foundations and strategies for modernizing the VRS in the SIRGAS context considering the IHRS;

➢ Several activities of SIRGAS WG III for modernizing the VRS can be found in http://www.sirgas.org/en/publications/ or … /presentations/.

4 - Strategies of SIRGAS WG III According to GGOS

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o The present protocols of SIRGAS WG III related to the National Vertical Networks of member countries refer to (De Freitas, 2017):

➢ Strategies for realizing Vertical Networks based on physical heights $[H_P = f(C_P)]$;

➢ Link of National Vertical Networks to the SIRGAS GNSS Continuous Stations;

➢ Integration of National Vertical Networks of members countries in the geopotential space;

➢ Approaches for referring the SIRGAS Vertical Network to the W_0 value of IHRS;

➢ Association to a specific epoch by considering the realization epoch and temporal variations in coordinates;

➢ Planning of activities for establishing a GGRF/IHRF station profile in the SIRGAS region;

➢ Future link of Vertical SIRGAS Network to a profile of GGRF/IHRF stations.

5 - On Going Activities of SIRGAS WG III Related to SVRS

○ Since 2011 SIRGAS-WGIII concluded that there were several implicit problems associated with the establishment of the SVRS based on the unification of NVRS by adjusting geopotential numbers (De Freitas, 2015):

➢ The heterogeneity in knowledge by people involved in the respective national institutions responsible for NVRS with respect to the scientific foundations of modern VRS and modern tools for realizing the respective frames;

➢ The general deficiency related to the organization of consistent databases needed for data interchanges and use in common multinational projects.

5 - On Going Activities of SIRGAS WG III Related to SVRS

o As general strategy, SIRGAS WG III decided by the training the involved staff of the institutes responsible by the NVRS in a way for allowing each member country as protagonist in solving the associated problems with each NVRS. The strategies were based on Workshops and Schools on Vertical Reference Systems:

➤ SIRGAS-WGIII Workshop in Rio de Janeiro, Brazil, 2012;

➤ SIRGAS WG III School on Vertical Reference Systems in La Paz, Bolivia, 2014;

➤ SIRGAS-WG III School/Workshop in Curitiba, Brazil, 2015;

➤ SIRGAS WG III School/Workshop in Quito, Ecuador, 2016. In this event were introduced the aspects related to the IHRS/IHRF and the SIRGAS WG III presented the protocols referred in a previous slide;

➤ SIRGAS WG III School/Workshop in Heredia, Costa Rica, 2017;

➤ SIRGAS WG III Workshop in Aguas Calientes, Mexico, 2018.

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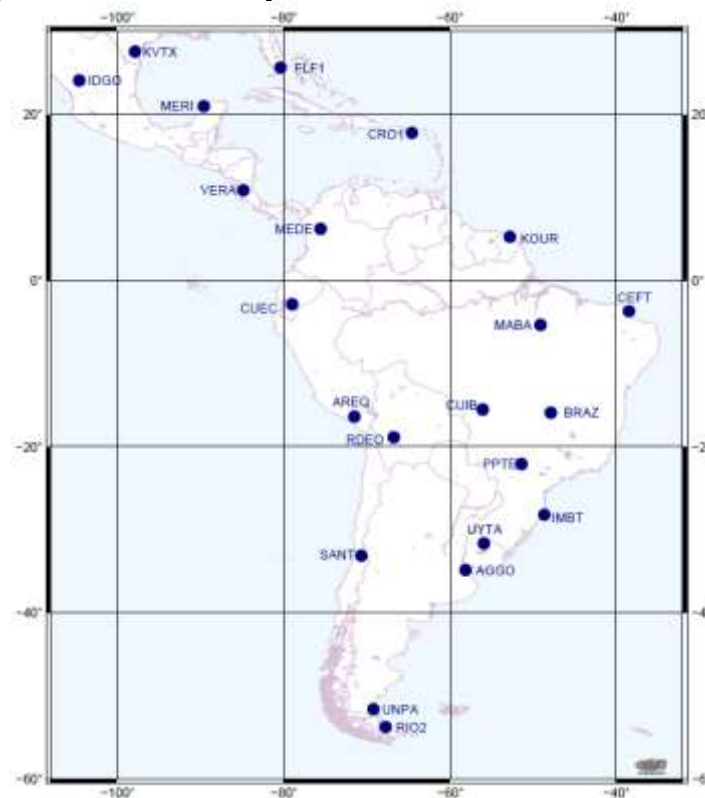# 5 - On Going Activities of SIRGAS WG III Related to SVRS

o In the Workshops and Schools were involved most of two hundred people from national institutes, enterprises working in related areas, professors of related faculties, and some students already working in related projects;

o Always were involved recognized experts in the area as instructors and two software packages for supporting all the practical activities: One developed by Hon. Prof. Dr. Hermann Drewes and Dr. Laura Sánchez from TUM/DGFI - Germany and other by Prof. Dr. Roberto T. Luz from IBGE – Brazil;

o Almost two hundred people were involved in the Workshops/Schools.

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6 - Present Focus Related to SVRS/F

➢ Gravity (interpolated or observed *in-situ*) + observed level differences + GNSS/LEV;

➢ Standardization of national networks in the geopotential space: geopotential numbers adjustment (in a same permanent Earth tide system) vertical datums zones aiming the generation of free normal equations;

➢ Free normal equations combination by using the estimated discrepancies in each vertical datum ΔW_i ;

➢ Determination of adjusted discrepancies among the national and global vertical reference systems ⟹ Spatialization of conversion parameters with basis in the IHRF stations;

➢ Cinematic aspects under consideration. If $H \approx h - N$, then

dH/d$t \approx$ dh/dt – {(dN/dt) or (dζ/dt)};

7 - The Future IHRF in the Context SIRGAS

➢ 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 - WG III is inserted in its activities.

➢ In the beginning of 2017 SIRGAS proposed a set of 22 IHRF stations distributed in the South America, Central America and Caribbean regions carefully selected by national referents.
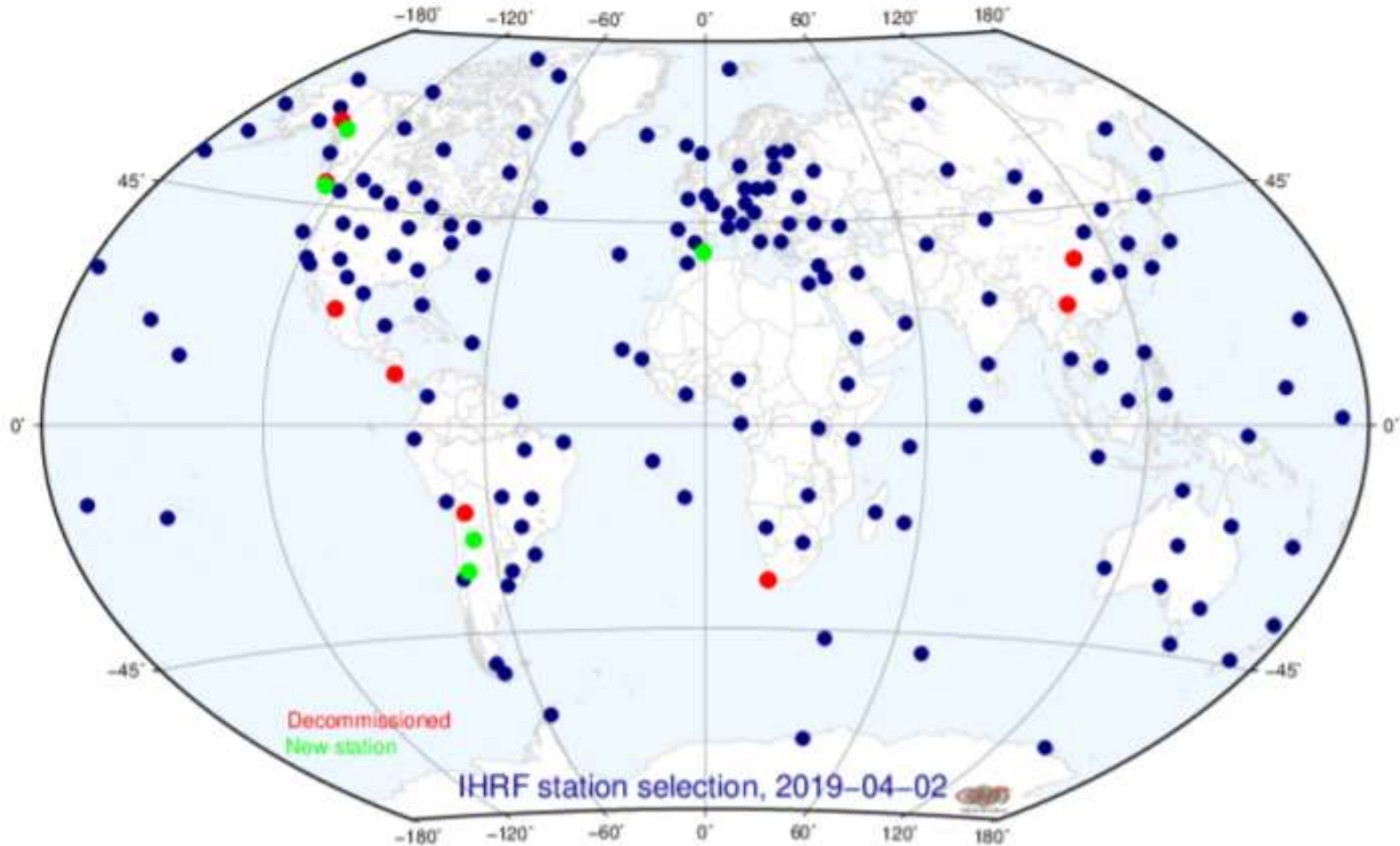

Source: SÁNCHEZ, 2018

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18

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7 - The Future IHRF in the Context SIRGAS

o The activities for realizing the IHRS in the SIRGAS context is coordinated by Dra. Laura Sánchez. Until now there are several achieved results like:

➢ National authorities mobilization regarding GGRF/IHRF;

➢ Studies and planification of new stations according the road-maps of "IAG/GGOS WG 0.1.2 *on the Strategy for the Realization of the* IHRS"*;*

➢ Preliminary results and stations re-planning or decommission.

➢ In course activities aiming to understand the relationship among national VDs with the IHRS (e.g. Carrión et al. 2018).

7 - The Future IHRF in the Context SIRGAS

Recent changes in the selection of IHRF reference stations

IHRF station selection, 2019-04-02

Decommissioned
New station

Source: SÁNCHEZ. GGOS Focus Area Unified Height System: Status report, ongoing activities, outlook. GGOS Coordinating Board Meeting. Vienna, Apr 6, 2019

7 - The Future IHRF in the Context SIRGAS

The **IHRS** has as primary coordinates the geopotential numbers, i.e.,

$$C_P = W_0 - W_P$$

The metrics heights in a *K* system with physical meaning are done by:

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

In a local vertical system *i* is possible to express:

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

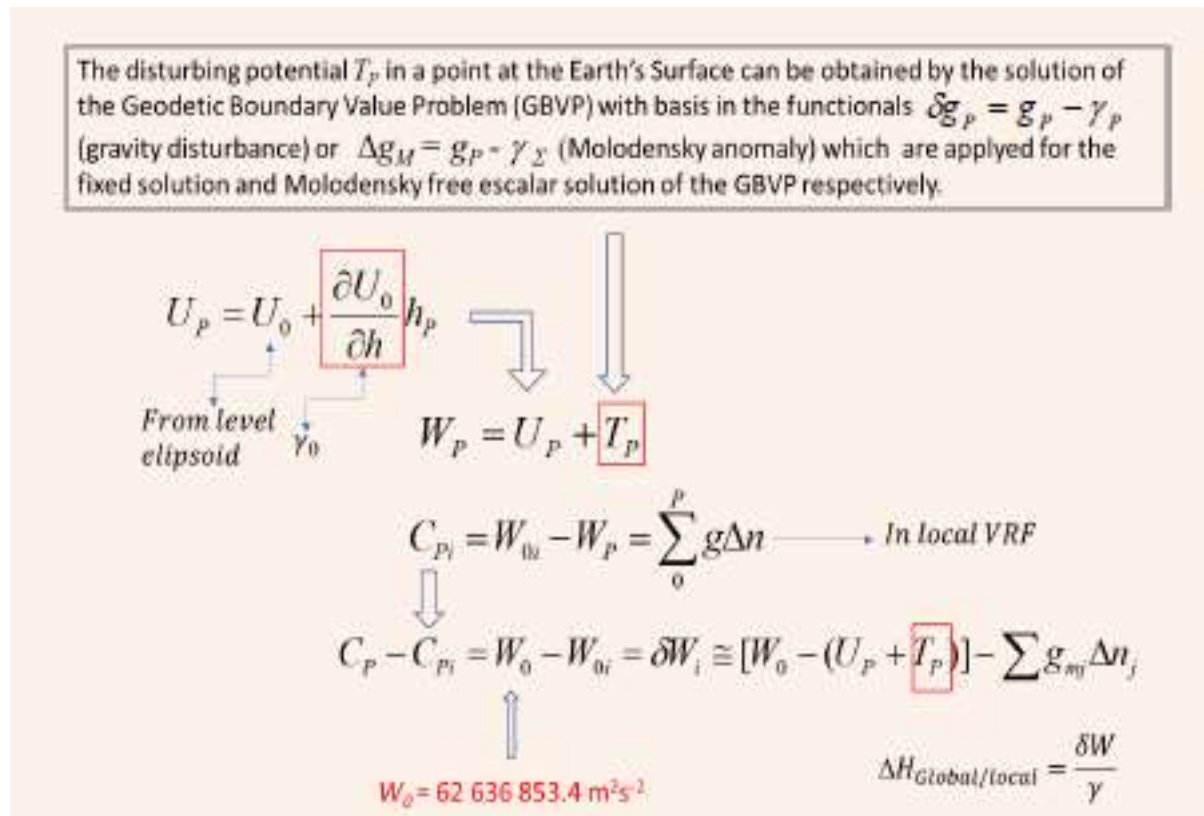The discrepancies related to IHRS are done by:

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

Where T_P is obtained, e.g. with the fixed solution GBVP:

$$T_P = \frac{R}{4\pi} \iint_S (\delta g + g_1 + \dots) H(\psi) \cdot ds$$

21

7 - The Future IHRF in the Context SIRGAS

o In synthesis, the central aspect associated with the referred protocols is the connection of each NVRS in the geopotential space with the IHRS by means of IHRF stations in agreement with the Figure:

The disturbing potential T_P in a point at the Earth's Surface can be obtained by the solution of the Geodetic Boundary Value Problem (GBVP) with basis in the functionals $\delta g_P = g_P - \gamma_P$ (gravity disturbance) or $\Delta g_M = g_P - \gamma_\Sigma$ (Molodensky anomaly) which are applyed for the fixed solution and Molodensky free escalar solution of the GBVP respectively.

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

From level elipsoid γ_0

$$W_P = U_P + T_P$$

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

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

$$W_0 = 62\ 636\ 853.4\ \text{m}^2\text{s}^{-2}$$

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

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8 - Outlook

o The SVRS/F is still under construction. New paradigms were introduced in 2015 with IHRS/F as consequence of IAG/GGOS developments:

➢ It is clear that several activities must be realized in the context of the SIRGAS WG III. However, with the present approaches based on the answers of national institutes as protagonists, only three countries in the SIRGAS context partially accomplished the tasks related to the modernization of their NVRS/F;

➢ New hopes were introduced with IHRS/F. The scientific and practical aspects related the transition from local VRS without physical meaning to a GVRS with physical meaning were considered in the referred Workshops and Schools;

➢ A new conceptions must be introduced in WG III by considering the aspects of Vertical Datum, networks based on geopotential numbers and the modeling of gravity field for supporting the integration with IHRS/GGRS and practical applications (e.g. how recover W_P or how to obtain H_P with sufficient precision departing from GNSS positioning?).

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We invite the SIRGAS national representants, people involved with national vertical networks and the new IHRF profile as well as the WG III members for participating in the Working Group meeting to be realized Thursday, 14th , 12:30 to 14:00h, in the room H CDHP/ENCE

THANK YOU VERY MUCH!!!

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9 - References

➢ Carrión, J.L., De Freitas, S.R.C., Barzaghi, R. (2018). Offset evaluation of the Ecuadorian Vertical Datum related to the IHRS. Bol. of Geod. Sciences, 24(4), 503-525. https://dx.doi.org/10.1590/s1982-21702018000400031

➢ De Freitas S.R.C., Medina A.S., De Lima S.R.S. (2002). Associated problems to link South American vertical networks and possible approaches to face them. In: Drewes H., Dodson A.H., Fortes L.P.S., Sánchez L., Sandoval P. (eds) Vertical Reference Systems. International Association of Geodesy Symposia, vol 124: 318-323. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-04683-8_59

➢ De Freitas S.R.C. (2015) SIRGAS-WGIII Activities for unifying height systems in Latin America. Revista Cartográfica, v. 91, p. 75–92. Instituto Panamericano de Geografía e Historia (IPGH). http://publicaciones.ipgh.org/rca/rca091.pdf

➢ De Freitas S.R.C. (2017) Report on the SIRGAS Working Group III "Vertical Datum" Workshop 2016, Quito, Ecuador. IAG Newsletter, January, 2017, pp. 10-11.

➢ Drewes H., Sánchez L., Blitzkow D., De Freitas S. (2002) Scientific Foundations of the SIRGAS Vertical Reference System. In: Drewes H., Dodson A.H., Fortes L.P.S., Sánchez L., Sandoval P. (eds) Vertical Reference Systems. International Association of Geodesy Symposia, vol 124: 297-301. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-04683-8_55

➢ Ihde J, Sánchez L (2005) A unified global height reference system as a basis for IGGOS. J Geodyn 40(4–5):400–413. https://doi.org/10.1016/j.jog.2005.06.015

➢ Luz R.T., Fortes L.P.S., Hoyer M., Drewes H. (2002). The vertical reference frame for the Americas - The SIRGAS 2000 GPS campaign. In: Drewes H., Dodson A.H., Fortes L.P.S., Sánchez L., Sandoval P. (eds) Vertical Reference Systems. International Association of Geodesy Symposia, vol 124: 302-305. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-04683-8_56

➢ Sánchez (2005). Report 2005 SIRGAS WG III. Available in: http://www.sirgas.org/fileadmin/docs/Boletines/Bol09/23_Sanchez_ReporteGTIII.pdf

➢ Sánchez L (2012) Towards a vertical datum standardization under the umbrella of global geodetic observing system. J Geod Sci. 2(4):325-342. https://doi:10.2478/v10156-012-0002-x

➢ SIRGAS (2019). http://www.sirgas.org/en/organization/working_groups/sirgas-wgiii-vertical-datum/