SIRGAS Regional Network Associate Analysis Center Technical Report 2014

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1 Introduction

The IGS Regional Network Associate Analysis Center for SIRGAS (IGS RNAAC SIR) was established in June 1996 under the responsibility of the Deutsches Geodätisches Forschungsinstitut (Seemüller and Drewes 1998), since January 2015 integrated into the Technische Universität München. The main objective of the IGS RNAAC SIR is the permanent analysis of the SIRGAS reference frame. The present activities of the IGS RNAAC SIR concentrate on (Sánchez 2014)

- the computation of loosely constrained weekly solutions for further combinations of the network (e.g., integration into the IGS polyhedron, computation of cumulative solutions, etc.). These solutions are weekly delivered to the IGS in SINEX format to be combined together with those generated by the other IGS Global and Regional Analysis Centers. They are named `sirwwww7.snx` (`wwww` stands for the GPS week);
- weekly station positions aligned to the same reference frame in which the IGS GNSS orbits are given, i.e., the IGS reference frame. These positions are applied as reference values for surveying applications in Latin America. Their name is `siryyPwwww.crd` (`yy` indicates the last two digits of the year).
- multi–year solutions providing station positions and constant velocities to estimate the kinematics of the reference frame and as support for applications requiring time–dependent coordinates. They are identified by `SIRyyPnn.SNX` (`nn` being the number of the cumulative solution computed in one year).

2 The SIRGAS reference frame

The SIRGAS reference frame was regularly computed by the IGS RNAAC SIR as only one common network until August 31, 2008 (GPS week 1495) (Seemüller et al. 2012). Afterwards, due to the increasing number of stations (about 400 in December 2014), different sub–networks were defined and, at present, the analysis strategy is based on the combination of individual solutions including (Brunini et al. 2012)

- one core network (SIRGAS–C) composed of a set of geographically well–distributed and consistently reliable reference stations (Fig. 1). The main objective of the SIRGAS–C network is to ensure the long–term stability of the reference frame, and it is understood as the primary densification of the ITRF in Latin America and the Caribbean.
- national reference networks (SIRGAS–N) realizing densifications of the core network (Fig. 1). The central purpose of these densifications is to provide accessibility to the reference frame at national and local levels and to facilitate its extension by assimilating new reference stations (mainly those installed by the national agencies responsible for the local reference networks).

3 SIRGAS analysis centers

The SIRGAS–C network is processed by DGFI–TUM as IGS RNAAC SIR. The SIRGAS–N networks are computed by the SIRGAS Local Processing Centers, which operate under the responsibility of national Latin American organizations. At present, the SIRGAS Local Processing Centers are:

- CEPGE: Centro de Procesamiento de Datos GNSS del Ecuador, Instituto Geográfico Militar (Ecuador)
- CNPDG–UNA: Centro Nacional de Procesamiento de Datos GNSS, Universidad Nacional (Costa Rica)
- CPAGS–LUZ: Centro de Procesamiento y Análisis GNSS SIRGAS de la Universidad del Zulia (Venezuela)
- IBGE: Instituto Brasileiro de Geografia e Estatistica (Brazil)
- IGAC: Instituto Geográfico Agustín Codazzi (Colombia)
- IGM–Cl: Instituto Geográfico Militar (Chile)
- IGN–Ar: Instituto Geográfico Nacional (Argentina)

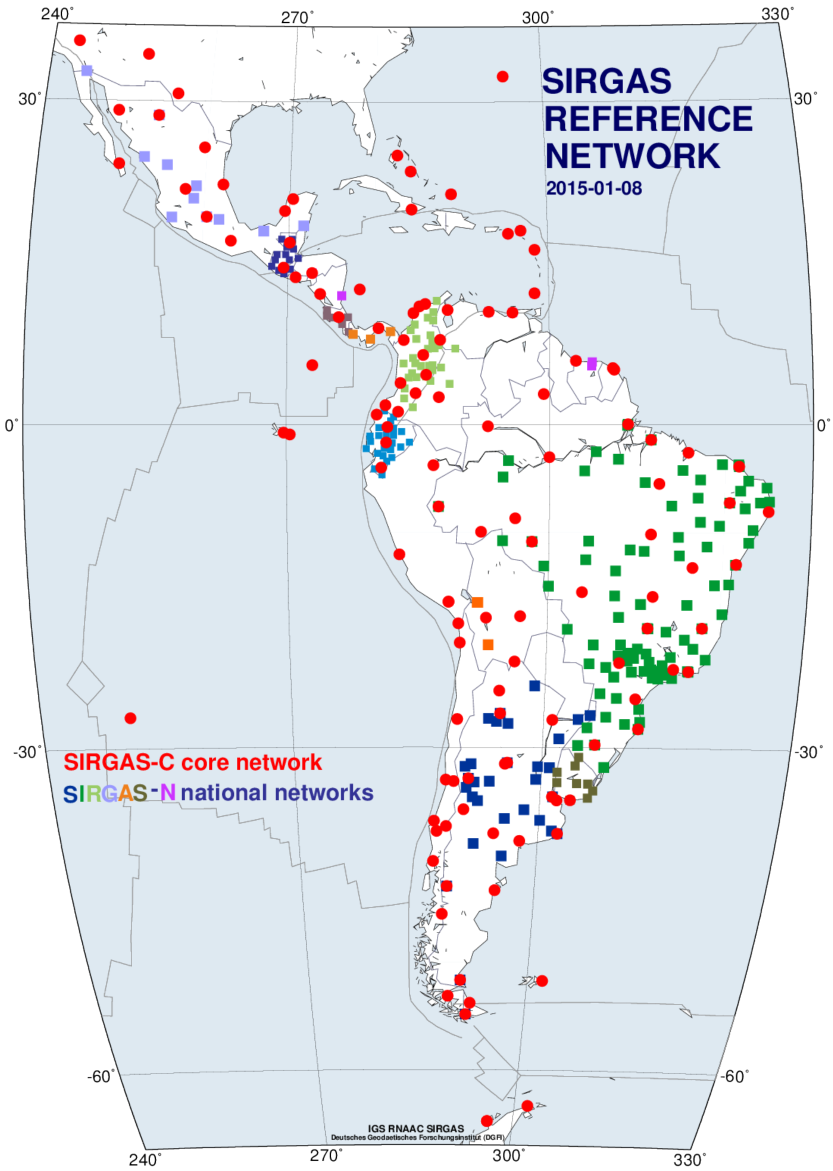

Figure 1: SIRGAS reference network (as of January 2015).

- INEGI: Instituto Nacional de Estadística y Geografía (México)
- SGM: Servicio Geográfico Militar (Uruguay)

These processing centers deliver loosely constrained weekly solutions for the SIRGAS–N national networks, which are combined with the SIRGAS–C core network to get homogeneous precision for station positions and velocities. The individual solutions are combined by the SIRGAS Combination Centers currently operated by DGFI–TUM (Sánchez et al. 2012) and IBGE (Costa et al. 2012).

4 Routine processing of the SIRGAS reference frame

The SIRGAS processing centers follow unified standards for the computation of the loosely constrained solutions (Sánchez et al. 2013). These standards are generally based on the conventions outlined by the IERS and the GNSS–specific guidelines defined by the IGS; with the exception that in the individual SIRGAS solutions the satellite orbits and clocks as well as the Earth orientation parameters (EOP) are fixed to the final weekly IGS values (SIRGAS does not compute these parameters), and positions for all stations are constrained to ± 1 m (to generate the loosely constrained solutions in SINEX format). INEGI (Mexico) and IGN–Ar (Argentina) employ the software *GAMIT/GLOBK* (Herring et al. 2010); the other local processing centers use the *Bernese GPS Software* Ver. 5.2 (Dach et al. 2007, 2013).

5 New processing standards for the SIRGAS reference frame

Since January 2014, the SIRGAS processing centers apply the standards of the IERS Conventions 2010 (Petit and Luzum 2010) and the characteristics specified by the IGS for the second reprocessing of the IGS global network. The main changes with respect to the previous processing strategy are (Sánchez et al. 2015):

- Reference frame: IGS08/IGb08 (Rebischung et al. 2012)
- Antenna phase center model: igs08.atx (Schmid 2011)
- Tropospheric zenith delay modelling based on the Vienna Mapping Function 1 (VMF1, Böhm et al. 2006) with a priori values (∼dry part) from the gridded coefficients provided by J. Böhm at `http://ggosatm.hg.tuwien.ac.at/DELAY/GRID/VMFG` and refinement through the computation of partial derivatives with 2–hour intervals within the network adjustment
- Tidal corrections for solid Earth tides, permanent tide, and solid Earth pole tide as described by Petit and Luzum 2010. The ocean tidal loading is reduced with the

FES2004 model (Letellier 2004) and the atmospheric tidal loading caused by the semidiurnal constituents S1 and S2 is reduced following the model of van Dam and Ray 2010. The reduction coefficients for the ocean tidal loading are provided by M.S. Bos and H.–G. Scherneck at `http://holt.oso.chalmers.se/loading`. The reduction coefficients for the atmospheric tidal loading are provided by T. van Dam at `http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html`.

- Non–tidal loadings like atmospheric pressure, ocean bottom pressure, or surface hydrology are not reduced.

At present, the SIRGAS processing centers are recomputing the daily normal equations backwards until January 1997 applying these new standards.

6 Modelling post–seismic deformations in the SIRGAS region

The Maule 2010 earthquake in Chile generated the largest displacements of geodetic observation stations ever observed in terrestrial reference frames (Sánchez et al. 2013). Coordinates changed by up to 4 m, and deformations were measurable in distances of up to more than 1000 km from the epicenter. The station velocities in the regions adjacent to the epicenter changed dramatically after the seism; while they were oriented eastward with approximately 2 cm/y before the event, they are now directed westward with about 1 cm/y (Sánchez 2014; Sánchez et al. 2015). The 2010 Baja California earthquake in Mexico caused displacements on the dm level also followed by anomalous velocity changes. The main problem for geodetic applications is the fact that there is no reliable reference frame available in the region. To overcome this inconvenience, DGFI–TUM, acting as the IGS–RNAAC–SIR, computed a new multi–year solution for the SIRGAS reference frame (Fig. 2) considering only the four years after the seismic events (mid–2010 ... mid–2014). The obtained station positions and velocities refer to the IGb08 reference frame, epoch 2013.0. The averaged rms precision is ±1.4 mm horizontally and ±2.5 mm vertically for the station positions at the reference epoch, and ±0.8 mm/y horizontally and ±1.2 mm/y vertically for the constant velocities. Based on this solution (called `SIR14P01`), a new continuous deformation model for SIRGAS was computed (Fig. 3) following the strategy implemented by Drewes and Heidbach 2012. It is clear that the tectonic structure in South America has to be redefined. The area south of 35°S to 40°S was considered as a stable part of the South American plate. Now we see that there are large and extended crustal deformations.

7 Outlook

The present SIRGAS activities concentrate on the reprocessing of the weekly SIRGAS normal equations backwards until January 1997 applying the new standards. The IGS

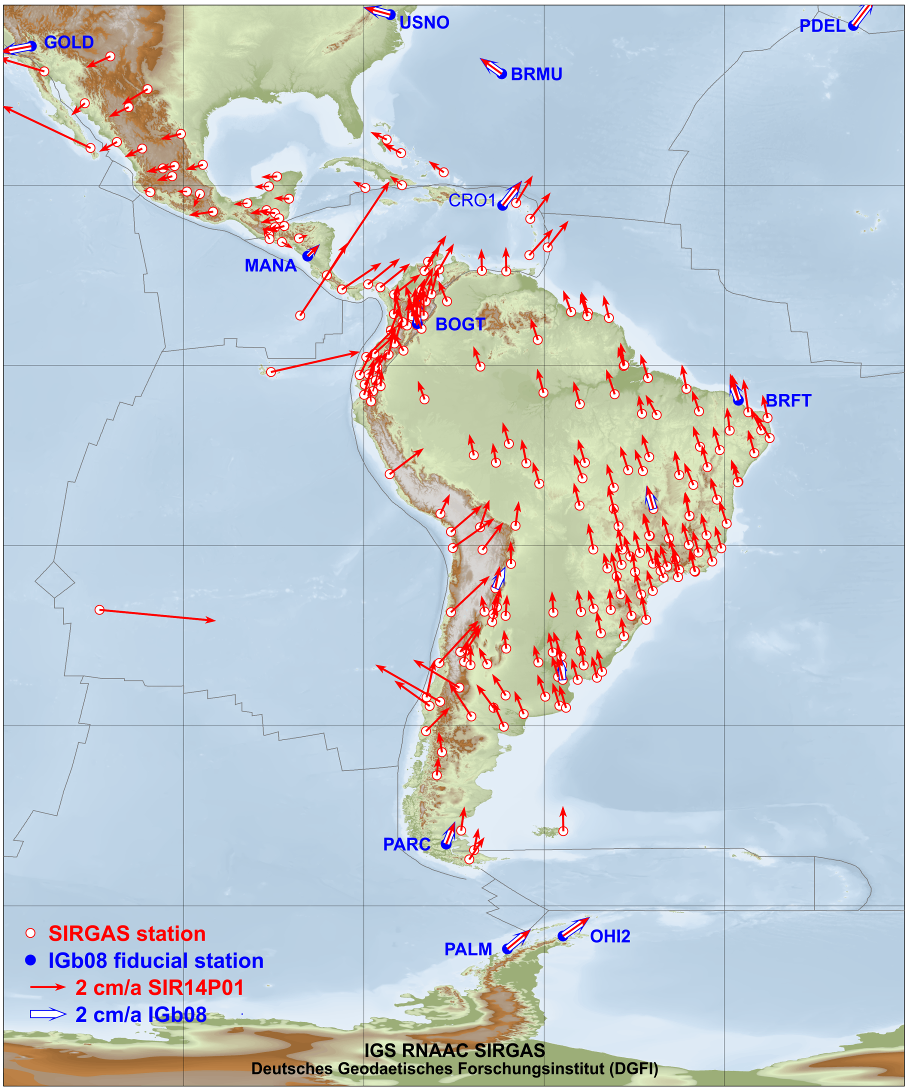

Figure 2: Horizontal velocities of the multi–year solution SIR14P01 (IGb08, 2013.0).

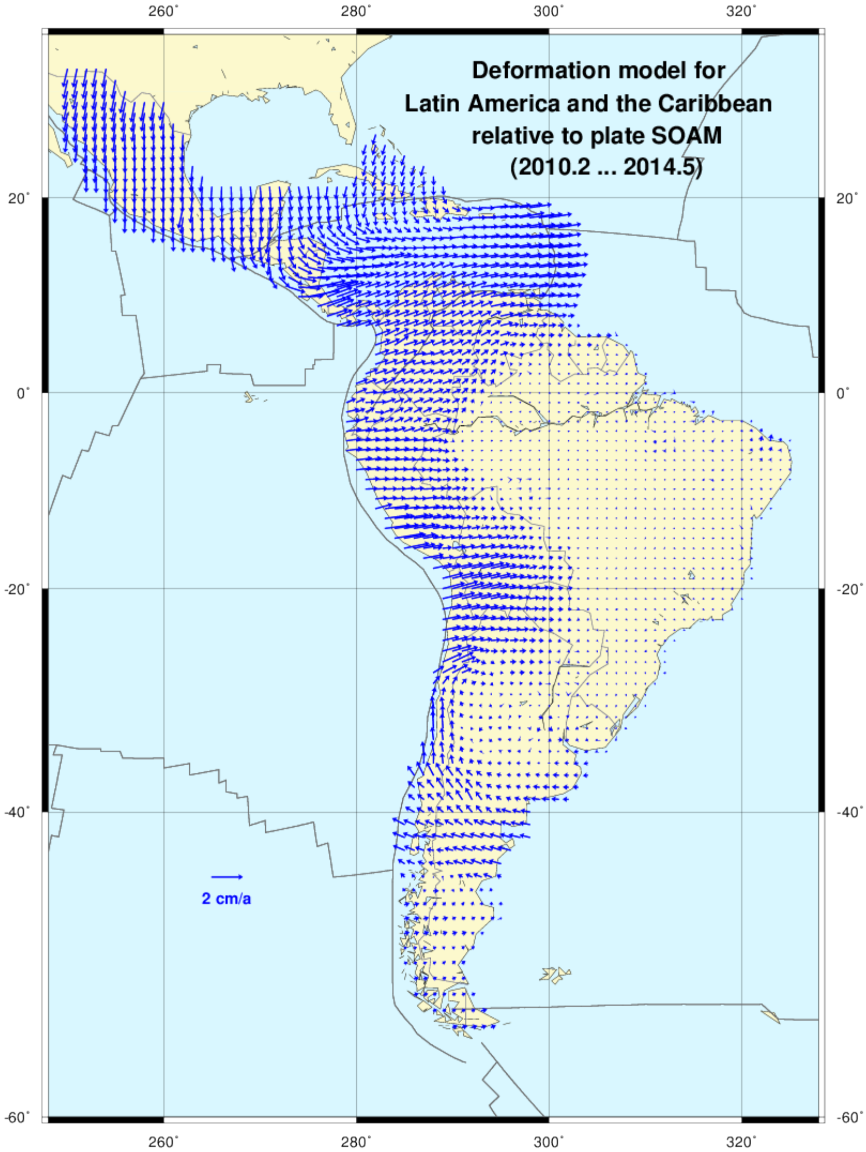

Figure 3: Post–seismic deformation model after the 2010 earthquakes in Latin America.

RNAAC SIR takes care of the computations from 1997 until August 2008, when the first SIRGAS Local Processing Centers started operating. From September 2008 until December 2013, the reprocessing includes the combination of the individual (reprocessed) solutions delivered by the SIRGAS Local Processing Centers for the SIRGAS–N national networks. Once the reprocessing is completed, a cumulative solution for the SIRGAS reference frame including time series analysis and seismic effects shall be computed.

8 Acknowledgements

The operational infrastructure and results described in this report are only possible thanks to the active participation of many Latin American and Caribbean colleagues, who not only make the measurements of the stations available, but also operate SIRGAS analysis centers processing the observational data on a routine basis. This support and that provided by the International Association of Geodesy (IAG) and the Pan–American Institute for Geography and History (PAIGH) is highly appreciated. More details about the activities and new challenges of SIRGAS, as well as institutions and colleagues working on can be found at www.sirgas.org.

References

Böhm, J., B. Werl, and H. Schuh. Troposphere mapping functions for GPS and very long baseline interferometry from European Center for Medium–Range Weather Forecasts operational analysis data. *J. Geophys. Res.*, 111, B02406, 2006. DOI:10.1029/2005JB003629

Brunini, C., L. Sánchez, H. Drewes, S.M.A. Costa, V. Mackern, W. Martinez, W. Seemüller, and A.L. Da Silva. Improved analysis strategy and accessibility of the SIRGAS Reference Frame. In: S. Kenyon, M.C. Pacino, and U. Marti (Eds.). *Geodesy for Planet Earth*, IAG Symposia, 136:3–10, 2012.

Costa, S.M.A., A.L. Silva, and J.A. Vaz. Report on the SIRGAS–CON combined solution by IBGE Analysis Center. *Geodesy for Planet Earth*, 136:853–857, 2012. DOI: 10.1007/978–3–642–20338–1_107

Dach, R., U. Hugentobler, P. Fridez, and M. Meindl (Eds.). Bernese GPS Software Version 5.0 (User Manual). Astronomical Institute, University of Bern, 2007.

Dach, R. Bernese GPS Software: New features in version 5.2. Astronomical Institute, University of Bern, 2013. Available at http://www.bernese.unibe.ch.

Drewes, H. and O. Heidbach. The 2009 horizontal velocity field for South America and the Caribbean. In: S. Kenyon, M.C. Pacino, and U. Marti (Eds.). *Geodesy for Planet Earth*, IAG Symposia 136:657–664, 2012. DOI:10.1007/978–3–642–20338–1_81

Herring, T.A., R.W. King, and S.C. Mcclusky. Introduction to GAMIT/GLOBK, Release 10.4. Massachusetts Institue of Technology, 2010. Available at http://www-gpsg.mit.edu/~simon/gtgk/Intro_GG.pdf.

Letellier, T. Etude des ondes de marée sur les plateux continentaux. Thèse doctorale, Université de Toulouse III, Ecole Doctorale des Sciences de l'Univers, de l'Environnement et de l'Espace, 2004.

Petit, G. and B. Luzum (Eds.). IERS Conventions (2010). IERS Technical Note, 36. Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt a.M., 2010.

Rebischung, P., J. Griffiths, J. Ray, R. Schmid, X. Collilieux, and B. Garayt. IGS08: the IGS realization of ITRF2008. *GPS Solutions*, 16(4):483–494, 2012. DOI: 10.1007/s10291–011–0248–2.

Sánchez, L., H. Drewes, C. Brunini, and M.V. Mackern. SIRGAS core network stability. IAG Symposia 143 (in press), 2015.

Sánchez, L., W. Seemüller, H. Drewes, L. Mateo, G. González, A. Silva, J. Pampillón, W. Martinez, V. Cioce, D. Cisneros, and S. Cimbaro. Long–term stability of the SIRGAS Reference Frame and episodic station movements caused by the seismic activity in the SIRGAS Region. In: Z. Altamimi and X. Collilieux (Eds.): Reference Frames for Applications in Geosciences, IAG Symposia, 138:153–161, 2013. DOI:10.1007/978–3–642–32998–2_24

Sánchez, L., W. Seemüller, and M. Seitz. Combination of the weekly solutions delivered by the SIRGAS Processing Centers for the SIRGAS–CON Reference Frame. In: S. Kenyon, M.C. Pacino, and U. Marti (Eds.), *Geodesy for Planet Earth*, IAG Symposia 136:845–851, 2012. DOI:10.1007/978–3–642–20338–1_106

Sánchez, L. IGS Regional Network Associate Analysis Center for SIRGAS (IGS RNAAC SIR). Report of activities 2013. International GNSS Service Technical Report 2013, pp.103–114, 2014.

Schmid, R. Upcoming switch to IGS08/igs08.atx – Details on igs08.atx. IGSMAIL–6355 (http://igs.org/pipermail/igsmail/2011/006347.html), 2011.

Seemüller, W. and H. Drewes. Annual report 1997 of the RNAAC SIRGAS. In: IGS 1997 Technical Reports, 173–174, IGS CB, JPL Pasadena, 1998.

Seemüller, W., M. Seitz, L. Sánchez, and H. Drewes. The new multi–year position and velocity solution SIR09P01 of the IGS Regional Network Associate Analysis Center (IGS RNAAC SIR). In: S. Kenyon, M.C. Pacino, and U. Marti (Eds.). *Geodesy for Planet Earth*, IAG Symposia 136:877–883, 2012. DOI:10.1007/978–3–642–20338–1_110.

van Dam, T. and R. Ray. S1 and S2 atmospheric tide loading effects for geodetic applications. 2010. Data set accessed 2013–06–01 at http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html.