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SIRGAS: THE GEOCENTRIC REFERENCE FRAME FOR THE AMERICAS

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SIRGAS (Sistema de Referencia Geocéntrico para las Américas) is in charge of the definition, realization, and maintenance of the geocentric reference system for Latin America and the Caribbean, including a gravity field-related vertical reference system. The SIRGAS activities are coordinated by three working groups: The SIRGAS-WGI (Reference System) is committed to establish and maintain a continental-wide geocentric reference frame as a regional densification of the ITRF (International Terrestrial Reference Frame). This objective was initially accomplished through two continental GPS campaigns in 1995 and 2000, comprising 58 and 184 stations, respectively. Today, it is realized by the SIRGAS Continuously Operating Network (SIRGAS-CON), which includes more than 230 permanent GNSS stations. The SIRGAS-CON network is weekly processed by the SIRGAS Analysis Centres providing weekly station positions aligned to the ITRF as well as loosely constrained weekly solutions for further combinations of the network. The SIRGAS-WGII (Geocentric Datum) supports the adoption of SIRGAS in the Latin American and Caribbean countries by means of national densifications of the continental network. This also includes the development of adequate tools to modernize the geo-data referring to the old horizontal datums and to promote the use of SIRGAS as reference frame in practical and scientific applications at national level. The SIRGAS-WGIII (Vertical Datum) is dedicated to the definition and realization of a unified vertical reference system within a global frame. Its central purpose is to refer the geopotential numbers (or physical heights) in all countries to one and the same equipotential surface, which has to be defined globally. This also considers the transformation of the existing height datums into the new system. In addition to the issues covered by the three working groups, based on the observational infrastructure provided by the SIRGAS-CON network, initiatives related to the atmospheric modelling and the implementation of real time applications have been strongly developed in the last three years. According to this, the present contribution describes the main achievements and new challenges taken under consideration by SIRGAS to continue providing a long-term stable and high-precise reference frame for Latin America and the Caribbean.

The SIRGAS Reference Frame

SIRGAS as a reference system is defined identical with the ITRS (International Terrestrial Reference System, IERS 2004). It is realized by means of a regional densification of the global ITRF in Latin America and the Caribbean. SIRGAS has three realizations: two by means of episodic GPS campaigns (Fig. 1) and one by means of a network of continuously operating GPS stations. The first realization of SIRGAS (SIRGAS95) refers to the ITRF94, epoch 1995.4. It is given by a high-precision GPS network of 58 points distributed over South America (SIRGAS, 1997). In 2000, this network was re-measured and extended to the Caribbean, Central and North American countries. This second realization (SIRGAS2000) includes 184 GPS stations and refers to the ITRF2000, epoch 2000.4 (Drewes et al. 2005). The third realization of SIRGAS (the SIRGAS-CON network, Fig. 2) is at present composed by more than 230 permanently operating GPS sites and is weekly computed by the SIRGAS Analysis Centres; main products of this computation are (Brunini et al. 2010): loosely constrained weekly solutions for station positions to be included in the IGS (International GNSS Service) global polyhedron and in multi-year solutions of the network; weekly station positions aligned to the ITRF for further applications in Latin America; and multi-year solutions providing station positions and velocities for high-precise practical and scientific applications. The SIRGAS-CON weekly positions refer to the observation epoch and to the current frame in which the GPS satellite orbits (i.e. IGS final orbits, Dow et al. 2009) are given, at present the IGS05, the IGS realization of the ITRF2005 (see IGSMAIL 5447, http://igscb.jpl.nasa.gov/). The coordinates of the multi-year solutions refer to the latest available ITRF and to a specified epoch, e.g. the most recent SIRGAS-CON multi-year solution SIR10P01 refers to ITRF2008, epoch 2005.0 (Seemüller et al. 2010). The relationship between the different SIRGAS realizations is given by the transformation parameters between the corresponding ITRF solutions they refer and by taking into account the station position variations with time through a velocity (deformation) model (Drewes and Heidbach 2010). In this way, realizations or densifications of SIRGAS associated to different ITRFs and reference epochs materialize the same reference system and, after reducing them to the same frame and epoch, their positions are compatible at the mm-level. The SIRGAS reference frame is extended to the countries through national densifications (Fig. 3, Table 1), which provide accessibility to the reference frame at national and local levels (Sánchez and Brunini 2009).

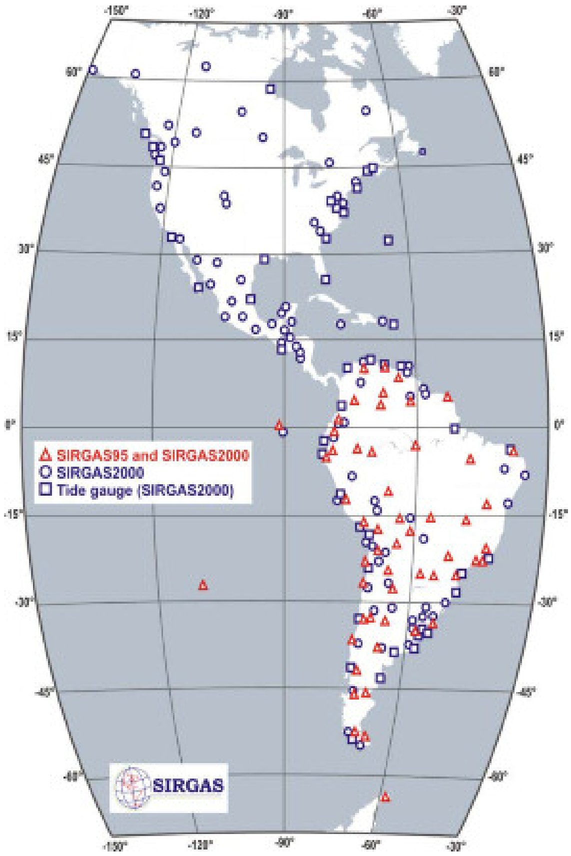

Fig. 1. *SIRGAS95, SIRGAS2000: SIRGAS realizations by means of GPS campaigns.*

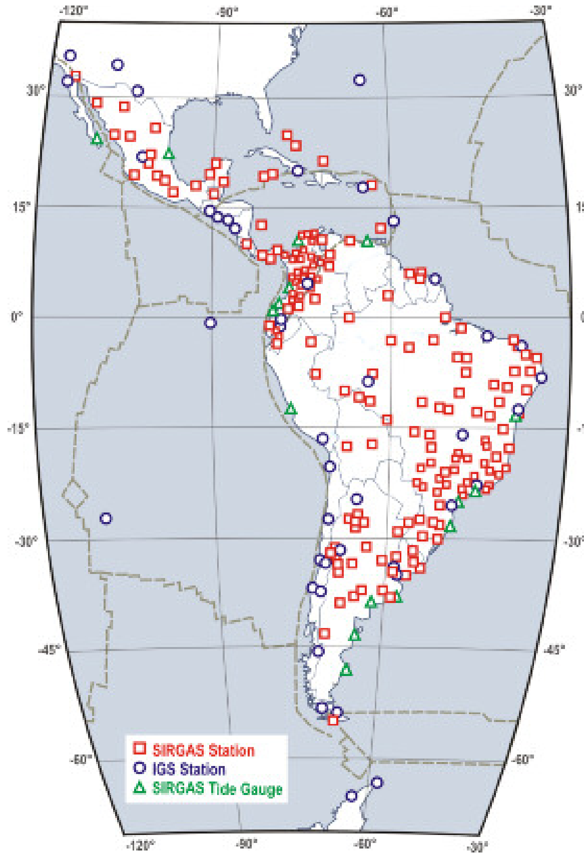

Fig. 2. *SIRGAS-CON: SIRGAS realization by means of continuously operating GNSS stations.*

Table 1. SIRGAS densifications in Latin America

Country	SIRGAS/ITRF densification	No. od stations passive/CON
Argentina	ITRF2005, 2006.6	178 / 33
Bolivia	SIRGAS95, 1995.4	125 / 8
Brasil	SIRGAS2000, 2000.4	1903 / 79
Chile	SIRGAS2000, 2002.0	269 / 13
Colombia	SIRGAS95, 1995.4	70 / 37
Costa Rica	ITRF2000, 2005.8	34 / 1
Ecuador	SIRGAS95, 1995.4	135 / 8
El Salvador	IGS05, 2007.8	34 / 1
F. Guiana	ITRF93, 1995.0	7 / 1
Guatemala	ITRF2005, 2009,6	0 / 17
México	ITRF92, 1988.0	0 / 20
Panamá	ITRF2000, 2000.0	20 / 4
Peru	SIRGAS95, 1995.4	47 / 3
Uruguay	SIRGAS95, 1995.4	17 / 5
Venezuela	SIRGAS95, 1995.4	156 / 5

CON: Continuously operating stations

Fig. 3. *SIRGAS densifications in Latin America by means of passive stations (monuments).*

Kinematics of the SIRGAS Reference Frame

Multi-year (cumulative) solutions for estimating the kinematics of the SIRGAS-CON network are regularly performed. The station positions (associated to a reference epoch) and velocities are estimated by constraining selected ITRF stations existing in the region to their reference values. Given that IGS standards include absolute calibration values for the antenna phase centre corrections since GPS week 1400, the SIRGAS-CON weekly solutions from January 2000 to November 2006 computed with relative phase centre corrections and referred to former ITRF solutions were completely reprocessed applying absolute phase centre corrections and the IGS05 as reference frame. Based on this reprocessing, a new multi-year solution (SIR10P01) covering the time period from January 2, 2000 (GPS week 1043) to June 6, 2010 (GPS week 1586) was computed (Fig. 4). It refers to the ITRF2008 at epoch 2005,0 and provides positions and velocities for 183 SIRGAS-CON stations operating more than two years. Its precision was estimated to be ~±0,5 mm (horizontal) and ~±0,9 mm (vertical) for the station positions at the reference epoch, and ~±0,2 mm/a (horizontal) and ~±0,4 mm/a (vertical) for the linear velocities (Seemüller et al. 2010).

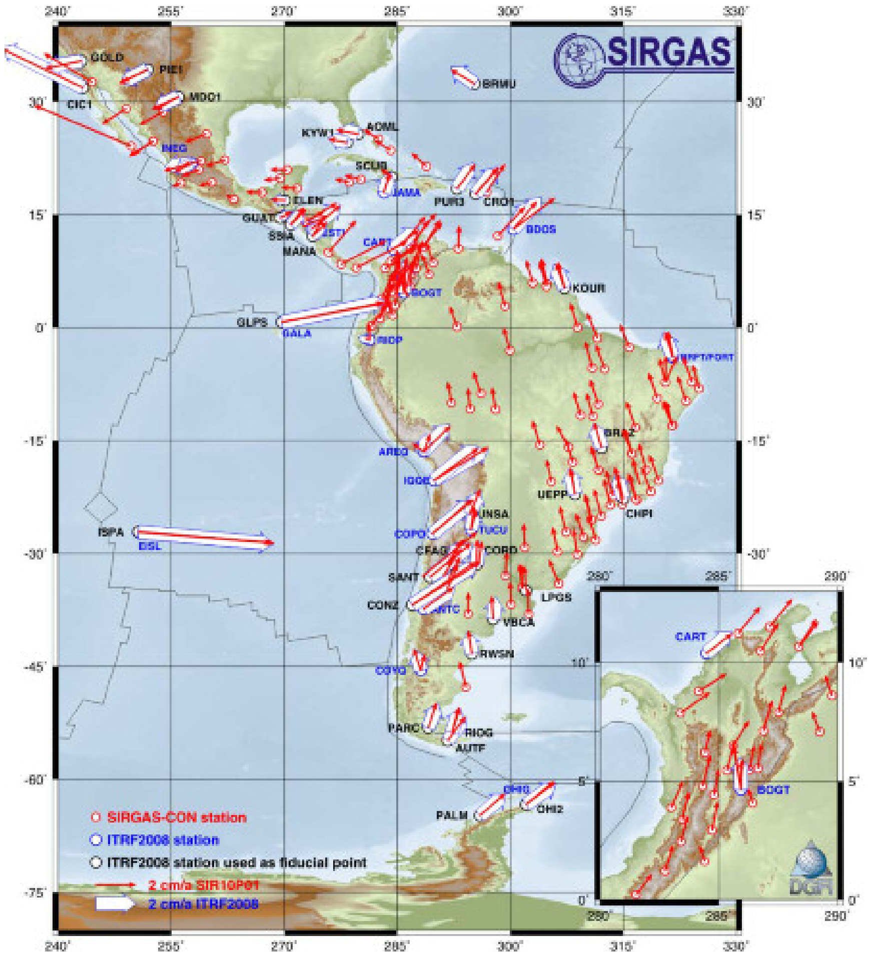

Figure 4. *Horizontal velocities of the SIR10P01 multi-year solution. Velocities of ITRF2008 stations are included for comparison.*

Although the reliability of the estimated positions and velocities of the SIRGAS reference stations as well as its compatibility through time are guaranteed, it is necessary to give special care to the reference frame deformations caused by seismic events. It is well known that the western part of the SIRGAS region, i.e. the plate boundary zone between the Pacific, Cocos, and Nazca plates in the west and the North American, Caribbean, and South American plates in the east, is an extremely active seismic area. The frequent occurrence of earthquakes causes episodic station movements (Table 2), which influence the long-term stability of the SIRGAS reference frame (Sánchez et al. 2010). For instance, the recent earthquake in Chile on 2010-02-27 moved 23 reference stations between 1 cm and 3 m to the west (Fig. 5). To mitigate the impact of this kind of events in the sustainability of SIRGAS, it is necessary the permanent monitoring of the (continental and national) reference networks by means of continuously operating GNSS stations and the consequent modelling of the caused deformations (Sánchez et al. 2010).

Table 2. *Seismic events with high impact in SIRGAS since 2000.*

Location	Date	M	Coordinate Change	Affected Stations
Mexicali, Mexico	2010-04-04	7,2	23 cm	MEXI
Chile	2010-02-27	8,8	1 cm - 3 m	See Fig. 6
Costa Rica	2008-01-08	6,1	2 cm	ETCG
Martinique	2007-11-29	7,4	1 cm	BDOS, GTK0
Copiapo, Chile	2006-04-30	5,3	2 cm	COPO
Tarapaca, Chile	2005-06-13	7,9	6 cm	IQQE
Managua, Nicaragua	2004-10-09	6,9	1 cm	MANA
Arequipa, Peru	2001-06-23	7,9	61 cm	AREQ

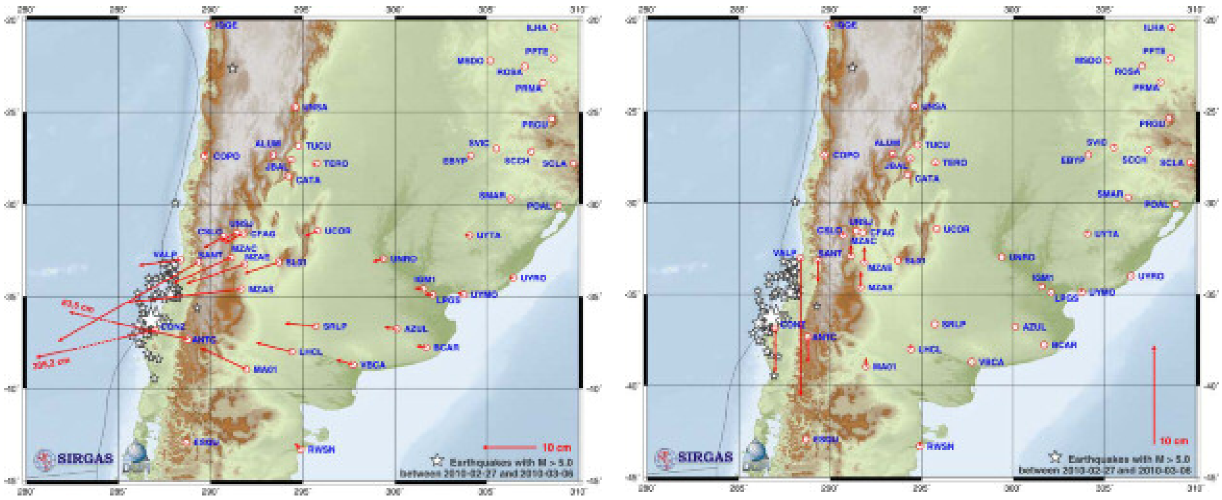

Figure 5. *Station displacements caused by the earthquake occurred on 2010-02-27 in Chile.*

The SIRGAS Ionospheric Analysis

The ionosphere over the Central and South American areas presents a particularly complex behaviour because the free electron distribution is strongly affected by the Equatorial Anomaly and the distortion of the geomagnetic field (with respect to its dipolar approximation). The high-quality dual-frequency GNSS observations provided by the SIRGAS-CON network constitute an invaluable source of information for continuously monitoring this complex phenomenon. According to this, since July 2005 hourly maps of vertical total electron content (vTEC) for the SIRGAS region are routinely computed (Brunini et al. 2008). The twenty four daily maps are presented in graphical and numerical formats (grids of 1°×1° in latitude and longitude) and complemented by daily movies. They are available, together with the other SIRGAS products, at the SIRGAS web site (www.sirgas.org). SIRGAS maps of vTEC are being applied for different kind of studies such as validation of the International Reference Ionosphere (IRI) over the South America, improvement of positioning with single-frequency GPS receivers, and the feasibility of computing ionospheric corrections for a satellite based augmentation system (SBAS) for the region (Brunini and Azpilicueta, 2009).

Closing remarks

The organizational structure of SIRGAS is based on an Executive Committee composed by a national representative of each member country, which approves the official SIRGAS policies and recommendations and promotes their adoption between the national bodies responsible for the local geodetic reference systems. The scientific activities are coordinated by the working groups in close cooperation with the SIRGAS Scientific Council and representatives of IAG (International Association of Geodesy) and PAIGH (Pan-American Institute for Geography and History). The operational infrastructure of SIRGAS is based on the voluntary contribution of more than 50 Latin American organizations, which install and operate permanent stations, drive SIRGAS Analysis Centres and, in general, support SIRGAS initiatives, activities, and projects.

SIRGAS is the backbone for all projects based on the generation and use of geo-referenced data in a national as well in an international level in Latin America. Besides to provide the reference coordinates for the development of practical applications such as engineering projects, digital administration of geographical data, geospatial data infrastructures, etc., SIRGAS is also the platform for a wide range of scientific applications such as the monitoring of Earth's crustal deformations, vertical movements, sea level variations, atmospheric studies, etc. The use of SIRGAS as reference frame in the countries of the region is complemented by different capacity building activities oriented to provide users with fundamental concepts needed for the appropriate generation and application of reference geodetic data. This includes capacitation on geodetic reference systems, precise coordinate determination using GNSS, relationship between heights obtained from GNSS and those based on spirit levelling, and spreading and application of the SIRGAS products.

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