# SIRGAS: the core geodetic infrastructure in Latin America and the Caribbean


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## SIRGAS reference frame

The primary objective of SIRGAS (*Sistema de Referencia Geocéntrico para las Américas*) is the determination and maintenance of a reliable reference frame in Latin America and the Caribbean as a densification of the ITRF and as a regional realisation of the ITRS. The SIRGAS reference frame is currently composed of 418 continuously operating GNSS stations (Fig. 1). It comprises two hierarchy levels: a core network (SIRGAS-C) providing the primary link to the global ITRF; and national reference networks (SIRGAS-N) improving the geographical density of the reference stations to ensure the accessibility to the reference frame at national and local levels. Given that most of the existing ITRF stations in South America are affected by the strong seismic activity in this region, further stations located in Europe, Africa, Oceania and North America are included in SIRGAS to increase the availability of fiducial points.

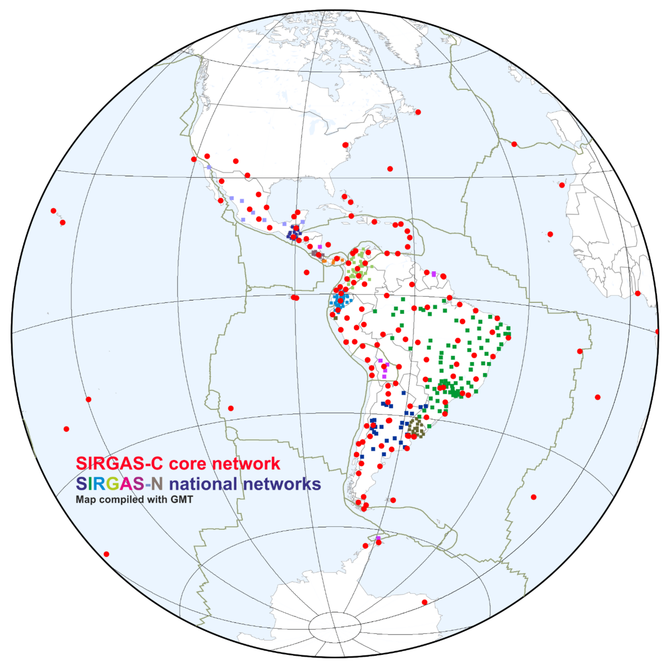


***Fig. 1*** *SIRGAS reference frame (as of July 2017).*

## Routine processing of the SIRGAS reference frame

The SIRGAS-C network is processed by DGFI-TUM (Germany) as IGS RNAAC SIRGAS (IGS Regional Network Associate Analysis Centre for SIRGAS). The SIRGAS-N networks are computed by the SIRGAS local analysis centres, which are operated by CEPGE (Ecuador), CNPDG-UNA (Costa Rica), CPAGS-LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGM (Chile), IGN (Argentina), INEGI (Mexico), and SGM (Uruguay). The SIRGAS analysis centres follow unified standards for the computation of loosely constrained weekly solutions for the station positions. 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 SIRGAS solutions the satellite orbits and clocks as well as the Earth orientation parameters (EOP) are fixed to the final weekly IGS products, and positions for all stations are constrained to ±1 m. The individual solutions are combined by the SIRGAS combination centres operated by the DGFI-TUM and the IBGE.

The main SIRGAS products are: (a) Loosely constrained weekly solutions in SINEX format for further combinations of the network (e.g., SIRGAS multi-year solutions or integration into the IGS polyhedron); (b) weekly station positions aligned to the IGS reference frame (to provide reference values for surveying in Latin America); and (c) multi-year solutions for applications requiring time depending positioning.

## Kinematics of the SIRGAS reference frame

To estimate the kinematics of the SIRGAS reference frame, a cumulative (multi-year) solution is computed (updated) every year, providing epoch positions and constant velocities for stations operating longer than two years. The latest SIRGAS multi-year solution (SIR17P01, Fig. 2) covers the period from April 17, 2011 (GPS week 1632) to January 28, 2017 (GPS week 1933) and includes only weekly solutions referring to the IGS08/IGb08 reference frame. This new SIRGAS cumulative solution has been aligned to the IGS14 reference frame and it is consistent with the igs14.atx ground antenna calibrations. This was achieved by applying corrections to the positions of stations with updated ground antenna calibrations. When available, the applied corrections were taken from the station-specific estimates published by the IGS; otherwise, they were computed from the latitude-dependent models recommended by the IGS. SIR17P01 includes positions and velocities for 345 stations referring to the IGS14, epoch 2015.0. Its estimated precision is ±1,2 mm (horizontal) and ±2,5 mm (vertical) for the station positions at the reference epoch, and ±0,7 mm/yr (horizontal) and ±1,1 mm/yr (vertical) for the velocities.

## Surface deformation modelling within SIRGAS

Based on GNSS measurements gained after the strong earthquakes occurred in 2010 in Chile and Mexico, a new continental continuous crustal deformation model for the SIRGAS region was computed. It is based on a multi-year velocity solution for a network of 456 continuously operating GNSS stations and covering a five years period from March 14, 2010 to April 11, 2015. This deformation model, called VEMOS2015 (Velocity Model for SIRGAS 2015), is computed using the least square collocation (LSC) approach with empirically determined covariance functions. The results make evident that the tectonic structure in South America has to be redefined: The area between the latitudes 35° S and 40° S was usually considered as a stable part of the South American plate; now it is obvious that there is a large and extended crustal deformation zone (Fig. 3). Comparisons with reference frames solutions based on measurements before the 2010 earthquakes (like the ITRF2008 or former SIRGAS solutions) and with the previous model VEMOS2009 show the strong deformation caused by these earthquakes and highlight the necessity of updating accordingly reference frames and deformation models in the affected regions. At present, an updated deformation model based on GNSS data gained from January 2014 to January 2017 is being computed.

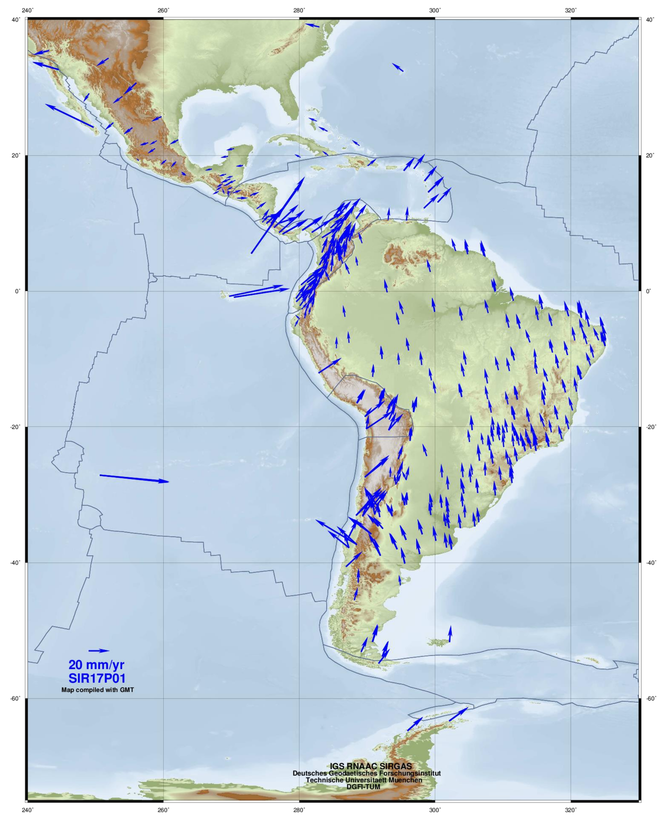

***Fig. 2*** *Horizontal velocities of the SIRGAS multi-year solution SIR17P01.*

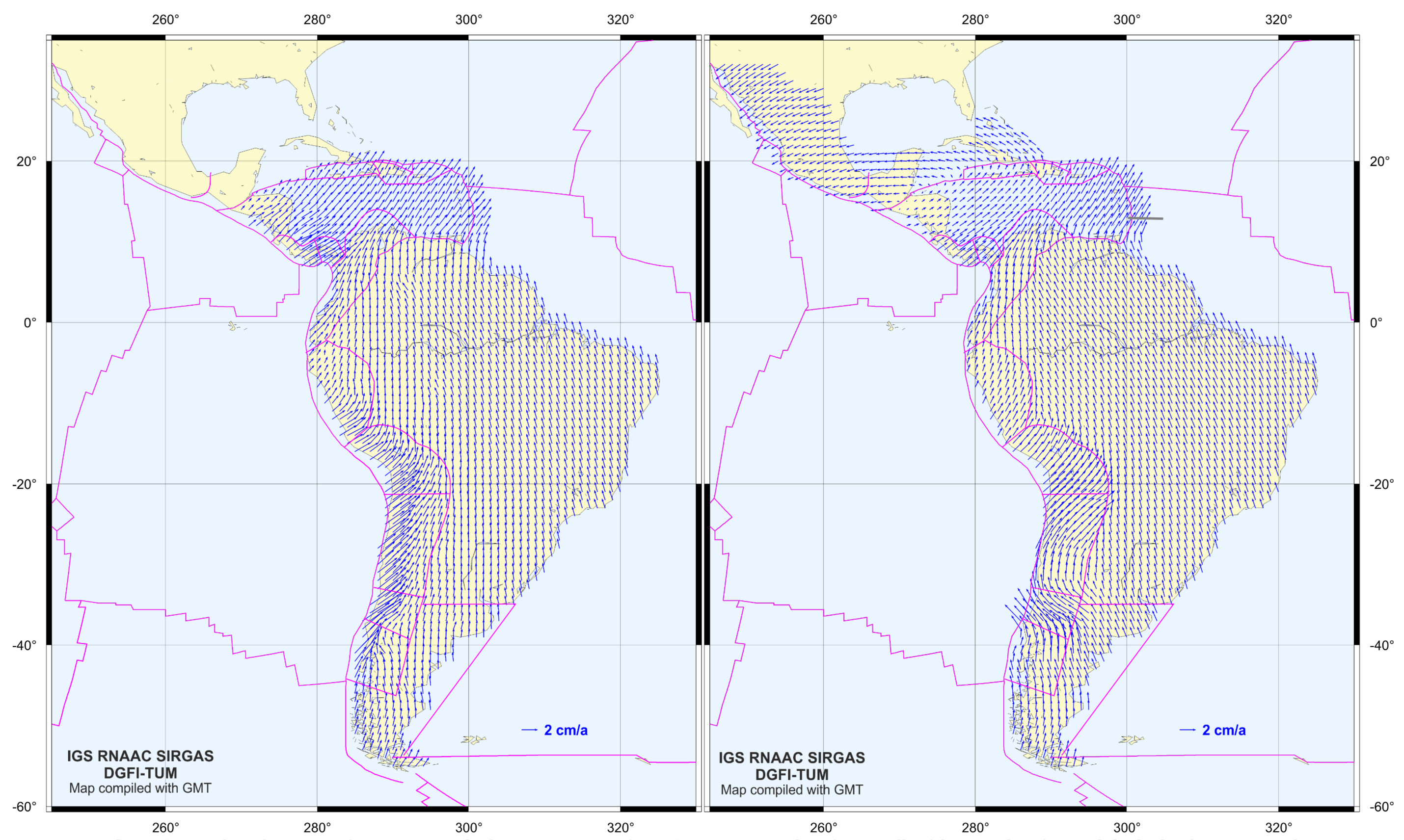


***Fig. 3*** *Velocity surface model VEMOS for SIRGAS before (left) and after (right) the Maule earthquake Mw8.8 in February 2010.*

## Geocentric datum realisation in the weekly SIRGAS solutions

Due to the strong seismic activity in Latin America, the fiducial points used for the geodetic datum realisation often present discontinuities and they are no longer suitable as reference stations. In addition, the weekly solutions suffer from the convention that the geometric reference frames model only linear station position changes, so that the geocentricity of the SIRGAS network is lost when seasonal or abrupt episodic variations occur. Thus one of the present SIRGAS objectives is to design a new strategy for the geocentric realisation of the SIRGAS reference frame. The basic idea is to extend the GNSS network beyond the SIRGAS region including SLR/GNSS and VLBI/GNSS co-located stations to perform a multi-technique combination and to transfer the datum from SLR/VLBI optimally to the regional network. To initiate the empirical experiments, the existing regional SIRGAS network was extended by globally distributed co-location and all available IGS core stations (Fig. 4). Based on this network configuration, different processing strategies are being evaluated. As an example, Fig. 5 shows the differences between the SIRGAS weekly positions and those obtained within the global network using GNSS observations with orbit and EOP determination for the first week of June 2014. The computation of the regional reference frame within a global network may change its station positions some millimetres. In the case of SIRGAS, it seems the network "moves" to the north about 3 mm.

It is necessary to extend the computations to the wintertime in the north hemisphere (e.g. December) to identify if these discrepancies are caused by seasonal effects. Additionally, to reduce the computation time, the same experiment should be repeated using a smaller number of global IGS stations.

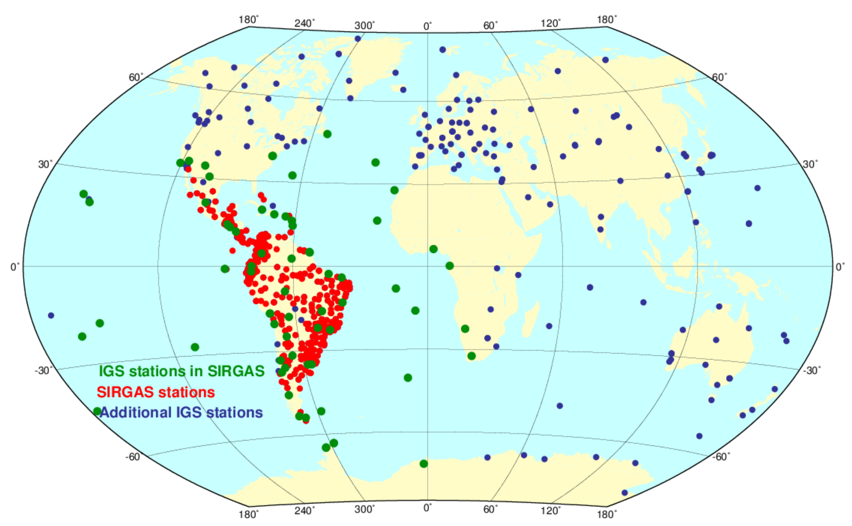


***Fig. 4*** *Global GNSS network used for the geocentric datum realisation of the SIRGAS frame. Green dots represent the IGS stations currently included in the routine SIRGAS processing. Blue dots represent the additional IGS stations considered to realise a global network. Map compiled with GMT.*

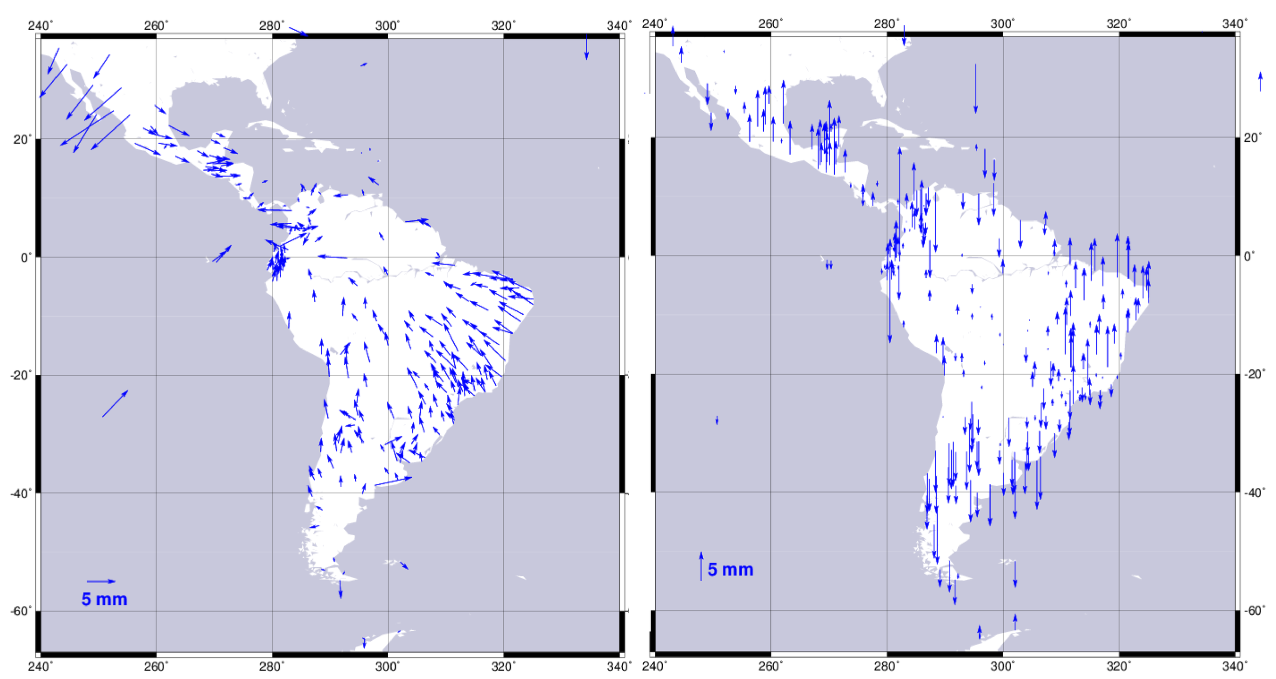


***Fig. 5*** *Horizontal (left) and vertical (right) differences between the SIRGAS weekly positions and those obtained within a global network using GNSS observations with orbit and EOPs determination. Differences in*
*latitude (N): Mean value = 0.0029 ± 0.0018 m, Min = -0.0064 m, Max = 0.0073 m*
*longitude (E): Mean value = 0.0007 ± 0.0014 m, Min = -0.0111 m, Max = 0.0092 m*
*height (h): Mean value = 0.0009 ± 0.0032 m, Min = -0.0225 m, Max = 0.0246 m.*
*Maps compiled with GMT.*

## Modelling seasonal displacements at SIRGAS stations

As many SIRGAS stations present strong seasonal motions, an investigation is being conducted to model these motions using vertical load values as additional parameters in the accumulation of the weekly SIRGAS normal equations (NEQ). The proposed model relates the response of the Earth's crust (as measured by GNSS) to the vertical load inferred from GRACE. Although gravity changes over the surface are due to atmospheric, non-tidal ocean and hydrological mass variations, in the SIRGAS region the hydrological contribution holds the main role of the overall contributions. Our method is based on a numerical solution of the static equilibrium equation for an elastic medium (i.e. the Earth's crust) characterized by an elastic parameter. The elastic parameter relies on the combination of Poisson's ratio and Young's modulus. The empirical experiments combine (a) the NEQ calculated on a weekly basis for the SIRGAS reference frame along five years, with (b) monthly grids of equivalent water height (EWH) derived from GRACE for the same time span. The solution of the combined NEQ leads to the common adjustment of seven parameters per GNSS station; namely, three position coordinates at a certain epoch, three constant velocity coordinates, and one elastic parameter. The vertical positions predicted with this method agree with the SIRGAS weekly positions within ±3 mm at the one sigma level. Some examples are shown in Fig. 6.

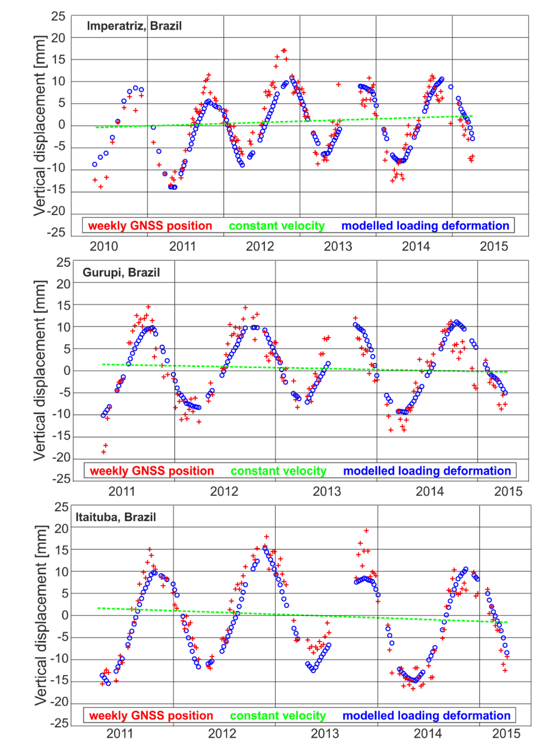


***Fig. 6*** *Vertical loading deformation by combining GNSS geometric movements and GRACE-inferred equivalent water heights at the normal equation level.*

## Further reading


Sánchez L, Drewes H, Brunini C, Mackern MV, Martínez W (2015) SIRGAS Core Network Stability, IAG Symposia, 10.1007/1345_2015_143.

Sánchez L, Drewes H (2016) Crustal deformation and surface kinematics after the 2010 earthquakes in Latin America. J. Geodyn, 10.1016/j.jog.2016.06.005.

Galván R, Gende M, Brunini C (2016) Regional model to estimate vertical deformations due to hydrological load, IAG Symposia, 10.1007/1345_2015_101.

Brunini C, Sánchez L, Galván R, Drewes H, Gende M (2017) Modelling vertical displacements due to hydrological load at stations of the Geocentric Reference System for the Americas (SIRGAS), IAG-IASPEI 2017, July 30 – August 4, 2017, Kobe, Japan.