Time evolution of the SIRGAS reference frame

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SIRGAS reference frame

The present realisation of SIRGAS (*Sistema de Referencia Geocéntrico para las Américas*) is a network of about 450 continuously operating GNSS stations (Fig. 1), data of which are processed on a weekly basis to generate instantaneous weekly station positions and multi-year (cumulative) reference frame solutions aligned to the ITRF. The instantaneous weekly positions are especially useful when strong earthquakes cause co-seismic displacements or large relaxation motions at the SIRGAS stations invalidating the previous coordinates. The multi-year solutions provide the most accurate SIRGAS station positions and velocities. They are used for the realisation and maintenance of the SIRGAS reference frame between two releases of the ITRF. While a new ITRF is published approximately every five years, the SIRGAS reference frame multi-year solutions are updated every one or two years (Fig. 2). Occasionally, the historical SIRGAS GNSS data are reprocessed to take into account new analysis standards or models introduced by the IERS and the IGS.

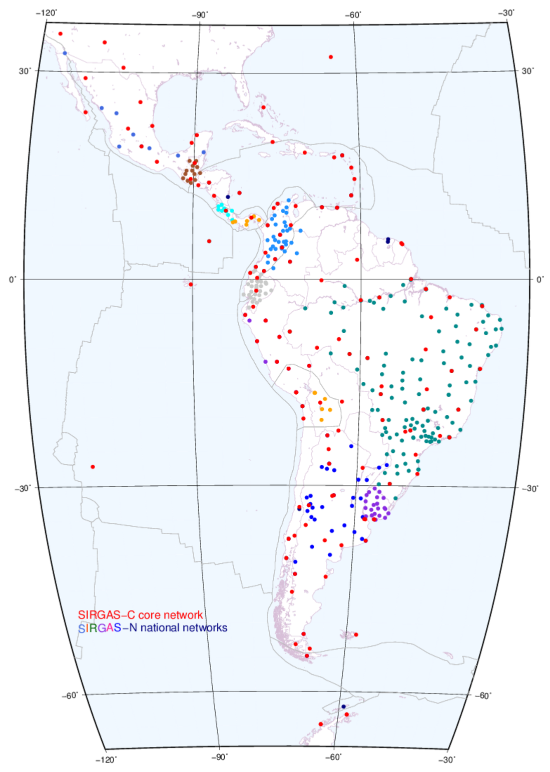


Fig. 1 *SIRGAS reference frame (as of July 2018).*

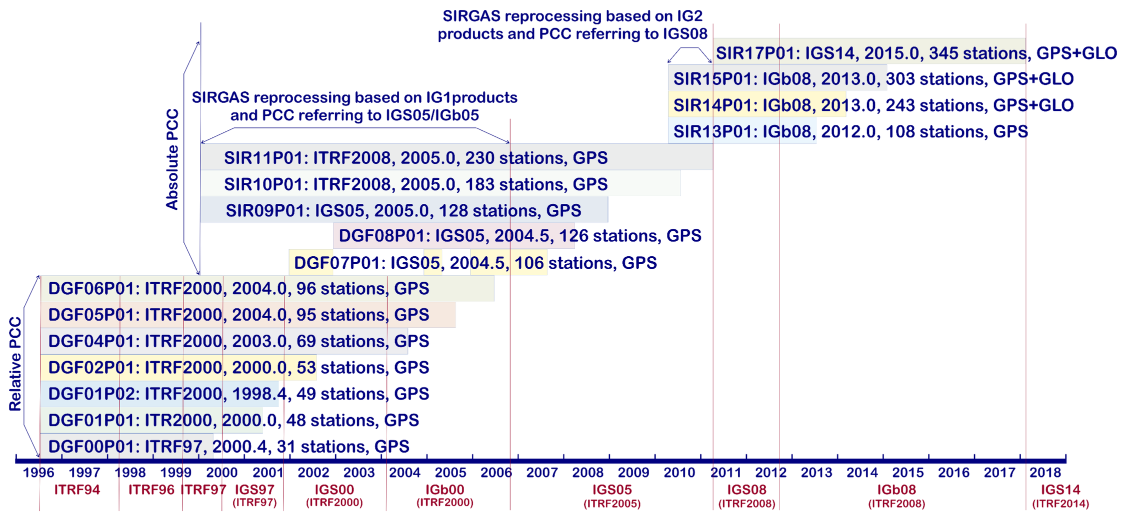


Fig. 2 *Multi-year solutions computed for the SIRGAS reference frame. Coloured bars represent the time-span covered by each solution. The reference epoch for the station positions, the number of stations, the considered observations (GPS and GLONASS (GLO)) as well as the reference frame (ITRFyy/IGSyy) are shown. The figure also displays when relative or absolute corrections to the antenna phase centre variations (PCC) were applied, and which weekly solutions were reprocessed following the IGS reprocessing campaigns IG1 and IG2.*

Routine processing of the SIRGAS reference frame

The SIRGAS reference frame comprises two hierarchy levels (Fig. 1): 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 enable the accessibility to the reference frame at national and local levels. The SIRGAS-C network is processed by DGFI-TUM (Germany) as the IGS RNAAC SIRGAS (IGS Regional Network Associate Analysis Centre for SIRGAS). The SIRGAS-N networks are computed by the SIRGAS local analysis centres operated by IGM-Ec (Ecuador), UNA (Costa Rica), LUZ (Venezuela), IBGE (Brazil), IGAC (Colombia), IGM-Cl (Chile), IGN (Argentina), INEGI (Mexico), and SGM (Uruguay). The SIRGAS analysis centres follow the standards of the IERS and the most-recent GNSS processing guidelines issued by the IGS. The only modification is that satellite orbits and clocks as well as Earth orientation parameters are not estimated within the SIRGAS processing, but fixed to the final weekly IGS values. The individual solutions are combined by the SIRGAS combination centres operated by IBGE and DGFI-TUM.

Kinematics of the SIRGAS reference frame

A main objective of the SIRGAS multi-year solutions is to monitor the kinematics and deformation of the reference frame. The latest SIRGAS multi-year solution (SIR17P01, Fig. 3) covers the period from April 17, 2011 (GPS week 1632) to January 28, 2017 (GPS week 1933). It includes only weekly solutions referring to the IGS08/IGb08 reference frame. This new SIRGAS solution is 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 of 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/a (horizontal) and ±1.1 mm/a (vertical) for the velocities.

Fig. 3 *SIR17P01 horizontal station velocities. Blue labels identify the fiducial stations.*

Surface deformation modelling within SIRGAS

As the western margin of Latin America is one of the seismically most active regions in the world, the maintenance of the SIRGAS reference frame implies the frequent computation of present-day (updated) surface deformation models to predict coordinate changes where no geodetic stations are installed. These models are called VEMOS (Velocity Model for SIRGAS) and have been computed in 2003 (data from May 1995 to Dec. 2001), 2009 (data from Jan. 2000 to Jun. 2009), 2015 (data from Mar. 2012 to Mar. 2015), and 2017 (data from Jan. 2014 to Jan. 2017). The comparison of these models makes evident that the present-day surface deformation in the SIRGAS region is highly influenced by the effects of major earthquakes. While the earthquakes in Champerico and Nicoya modified the aseismic deformation regime in Central America up to 5 and 12 mm/a (Fig. 4), respectively, recent earthquakes in the Andes caused changes up to 35 mm/a in magnitude and almost 140° in the orientation of the deformation vectors (Fig. 5). A common kinematic process is observed: Before the earthquakes, the deformation vectors are roughly parallel to the direction of plate subduction and their magnitudes diminish with the distance from the subduction front. After the earthquakes, the deformation vectors are NW directed and describe a progressive counter clockwise rotation south of the epicentres and a clockwise rotation north of the epicentres. The strain fields inferred from the different VEMOS models show that this complex kinematic pattern slowly disappears following the post-seismic relaxation process that brings the uppermost crust layer to the aseismic NE motion (Fig. 6).

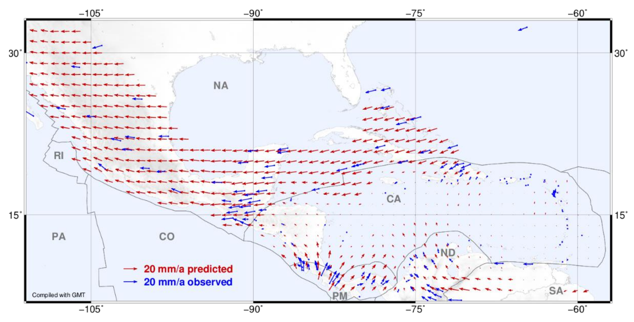


Fig. 4a *VEMOS2017: Surface deformation model relative to the Caribbean plate.*

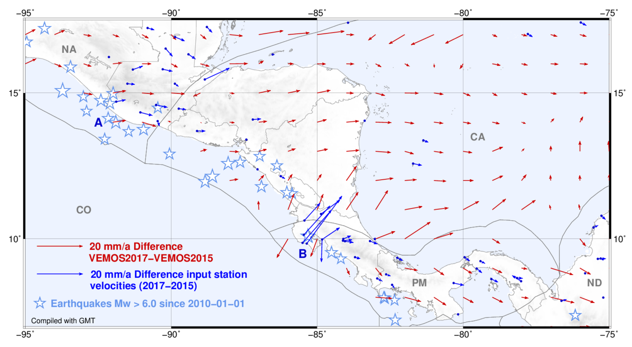


Fig. 4b *Differences between station velocities and the deformation models VEMOS2015 and VEMOS2017. Earthquakes: (A) Champerico, Mw7.4, 2012-11-11; (B) Nicoya, Mw7.6, 2012-09-05.*

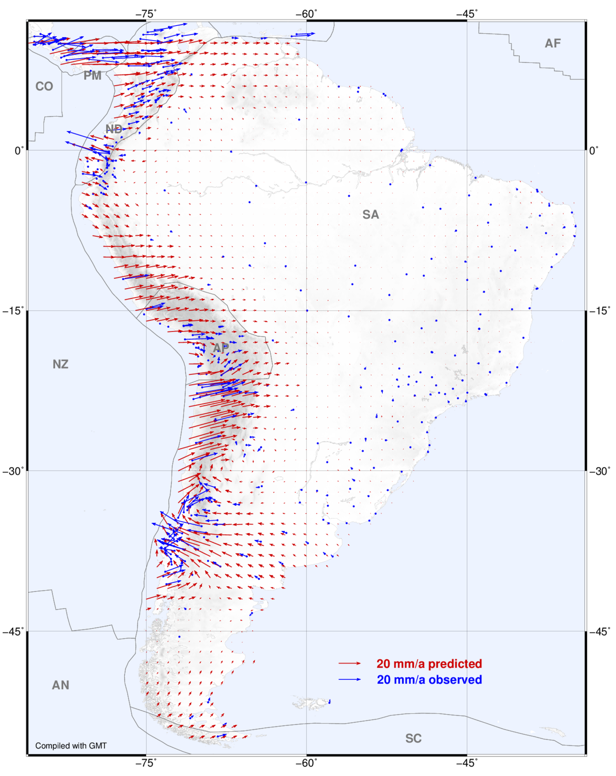


Fig. 5a *VEMOS2017: Surface deformation model relative to the South American plate.*

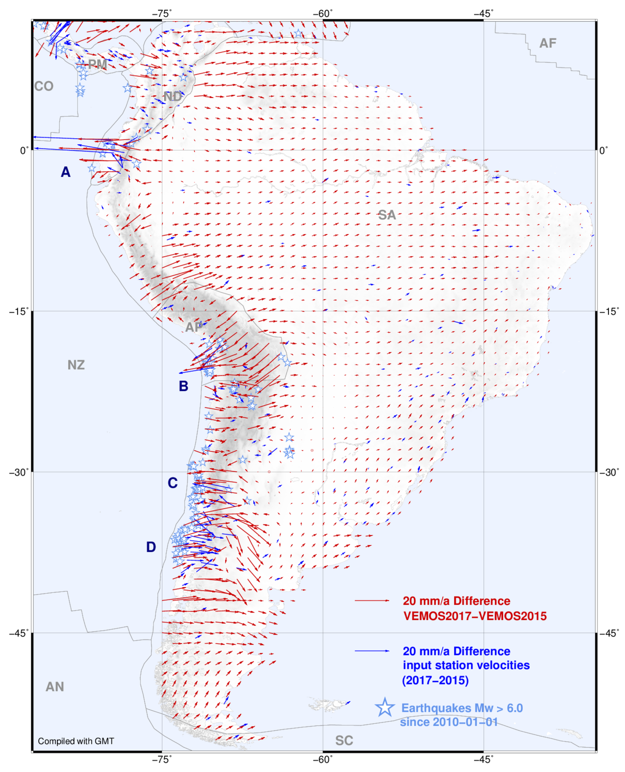
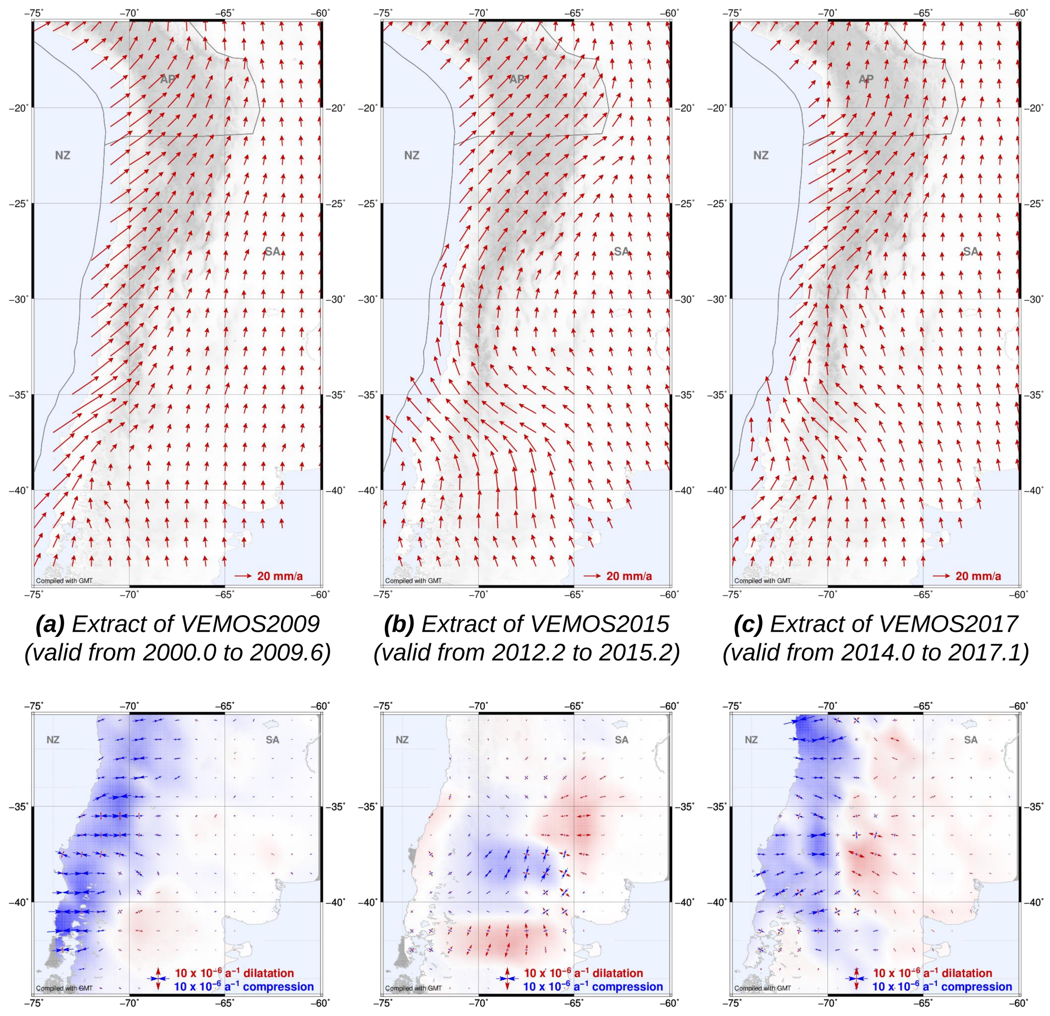


Fig. 5b *Differences between station velocities and the deformation models VEMOS2015 and VEMOS2017. Earthquakes: (A) Pedernales, Mw7.8, 2016-04-16; (B) Pisagua, Mw8.2, 2014-04-01; (C) Illapel, Mw8.3, 2015-09-16; (D) Maule, Mw8.8, 2010-02-27.*



(a) Extract of VEMOS2009 (valid from 2000.0 to 2009.6)
(b) Extract of VEMOS2015 (valid from 2012.2 to 2015.2)
(c) Extract of VEMOS2017 (valid from 2014.0 to 2017.1)
(d) Strain field inferred from VEMOS2009
(e) Strain field inferred from VEMOS2015
(f) Strain field inferred from VEMOS2017

Fig. 6 *Deformation model and strain field series in the Central and South Andes: VEMOS2009 (left), VEMOS2015 (centre) and VEMOS2017 (right). Blue shades represent compression; red shades represent dilatation.*

Modelling seasonal displacements at SIRGAS stations

As many SIRGAS stations present strong seasonal motions (Fig. 7), 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 observations. Although gravity changes over the surface are due to atmospheric, non-tidal ocean and hydrological mass variations, the hydrological contribution holds the main role in the SIRGAS region. 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 elasticity parameters, namely, Poisson's ratio and Young's modulus. The empirical experiments combine (a) the NEQ calculated on a weekly basis for the SIRGAS reference frame over 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. 8.

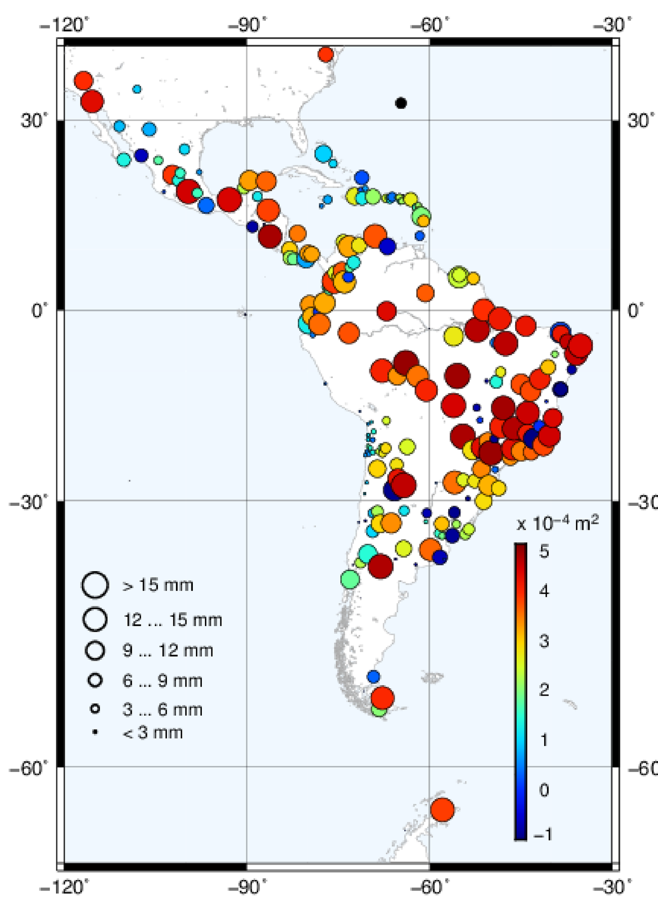


Fig. 7 *Comparison of the seasonal station motions observed with GNSS and those inferred after modelling non-tidal effects within the GNSS NEQ. Stations represented with large circles are strongly affected by non-tidal effects (and vice-versa); red-coloured stations present a high-correlation between the geometric (GNSS) and the predicted loading-induced displacements; dark blue-coloured stations represent a poor correlation or even an anti-correlation..*

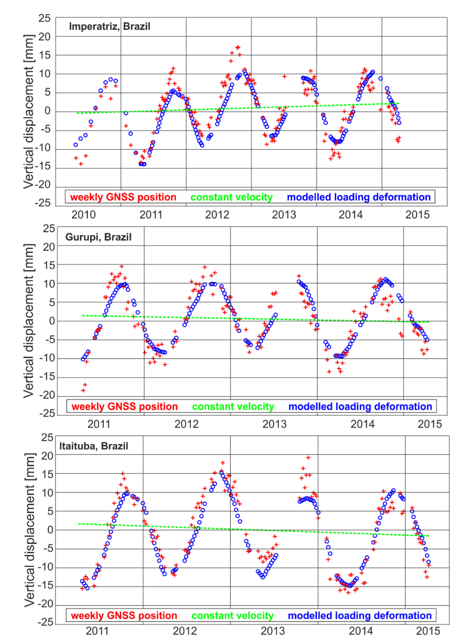


Fig. 8 *Vertical loading deformation by combining GNSS geometric movements and GRACE-inferred equivalent water heights at the normal equation level.*

Further reading

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