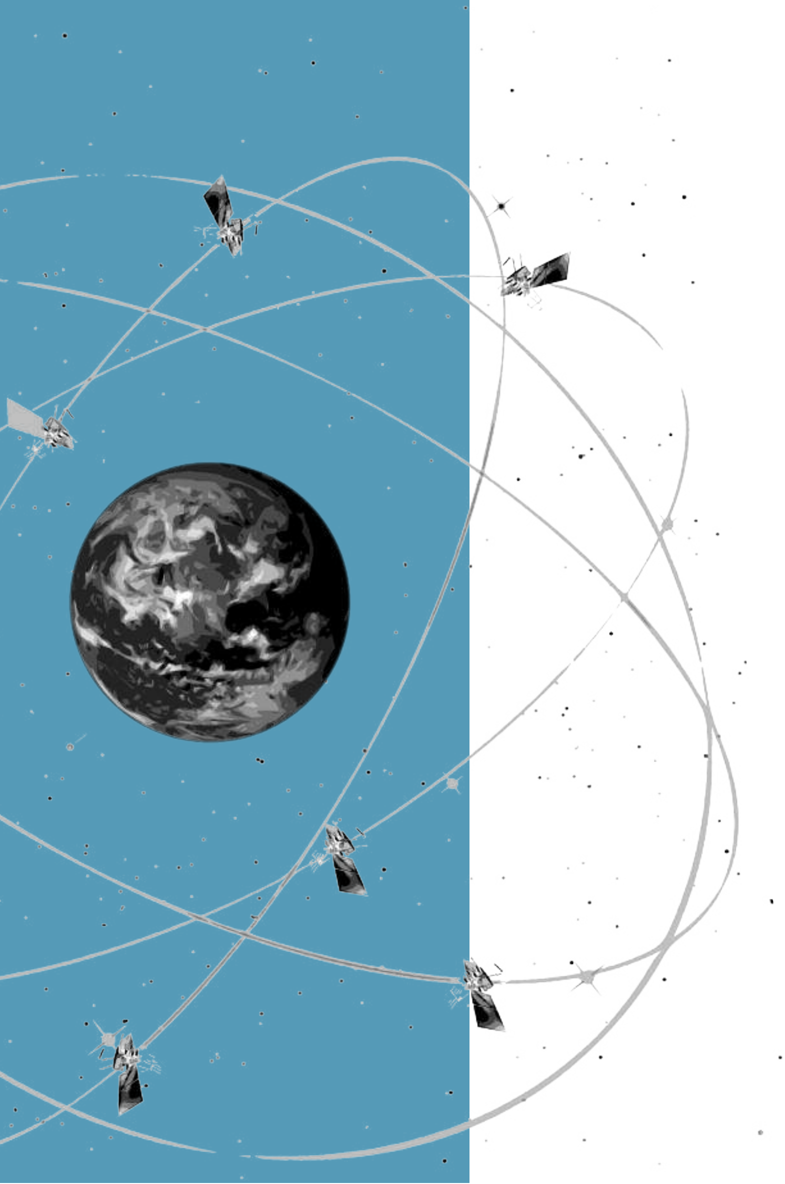
IGS INTERNATIONAL GNSS SERVICE

TECHNICAL REPORT
2016



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SIRGAS Regional Network Associate Analysis Centre Technical Report 2016

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1 Introduction

The SIRGAS Reference Frame is currently composed of 411 continuously operating GNSS stations (Figure 1). It comprises two hierarchy levels (Brunini et al. 2012): a core network (SIRGAS-C, Sánchez et al. (2015a)) 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. The SIRGAS reference stations are processed by 10 SIRGAS processing centres (Cioce et al. 2016a):

- Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (Germany), Sánchez (2016)
- 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), Moya et al. (2016)
- CPAGS-LUZ: Centro de Procesamiento y Análisis GNSS SIRGAS de la Universidad del Zulia (Venezuela), Cioce et al. (2016b)
- IBGE: Instituto Brasileiro de Geografia e Estatistica (Brazil)
- IGAC: Instituto Geográfico Agustń Codazzi (Colombia)
- IGM-Cl: Instituto Geográfico Militar (Chile), Parra (2016)

- IGN-Ar: Instituto Geográfico Nacional (Argentina)
- INEGI: Instituto Nacional de Estadística y Geografía (Mexico)
- SGM: Servicio Geográfico Militar (Uruguay), Suárez (2016)

2 Routine processing of the SIRGAS reference frame

The SIRGAS processing 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 individual SIRGAS solutions the satellite orbits and clocks as well as the Earth orientation parameters (EOP) are fixed to the final weekly IGS, and positions for all stations are constrained to ±1 m (to generate the loosely constrained solutions in the SINEX format). INEGI (Mexico) and IGN-Ar (Argentina) employ the software GAMIT/GLOBK (Herring et al. 2010); the other local processing centres use the Bernese GPS Software V. 5.2 (Dach et al. 2015). The processing standards applied at present are described in (Sánchez and Drewes 2016). The individual solutions are combined by the SIRGAS combination centres operated by the DGFI-TUM (Sánchez et al. 2012; Sánchez 2016) and the IBGE (Costa et al. 2012). In charge of the IGS Regional Network Associate Analysis Centre for SIRGAS (IGS RNAAC SIRGAS), DGFI-TUM processed the entire SIRGAS reference network from June 1996 until August 2008 (Brunini et al. 2012; Sánchez et al. 2012). Now, it is responsible for

- processing the SIRGAS-C core network (Figure 1), Sánchez (2016)
- combining the core network with the national reference networks (Figure 2 and 3), Sánchez (2016);
- ensuring that the SIRGAS processing strategy meets the IERS standards and IGS guidelines;
- developing strategies to guarantee the reliability of the reference frame over time, this includes the estimation of the reference frame kinematics (Figure 4) and modelling crustal deformation in the SIRGAS region (Figure 5), Sánchez and Drewes (2016);
- making available the SIRGAS products via `www.sirgas.org` and `ftp.sirgas.org`.

At present, the SIRGAS efforts are concentrated on the second reprocessing of the reference network backwards until January 1997 using the IGS14 as the reference frame.

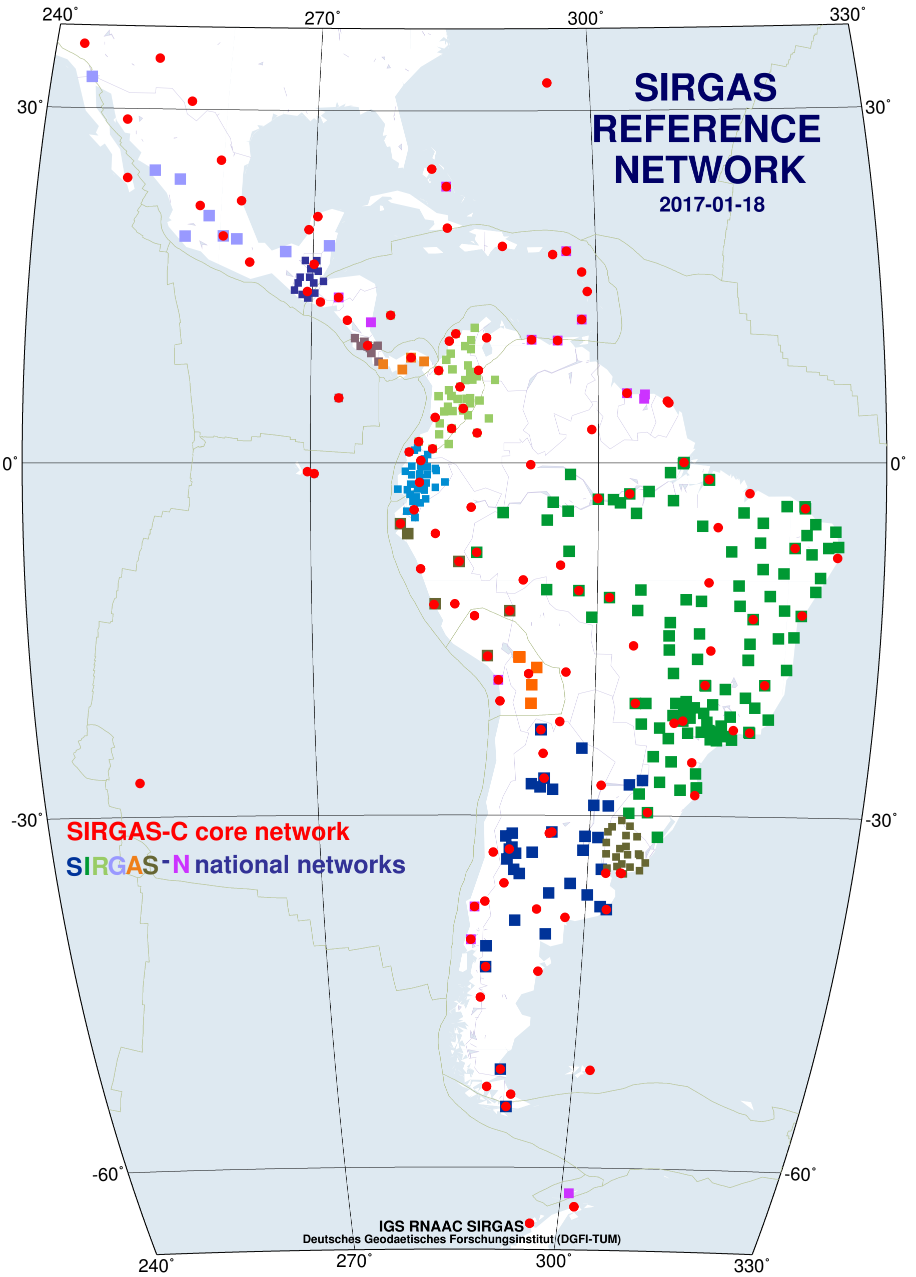


Figure 1: Core and national networks within the SIRGAS Reference Frame (January 2017)

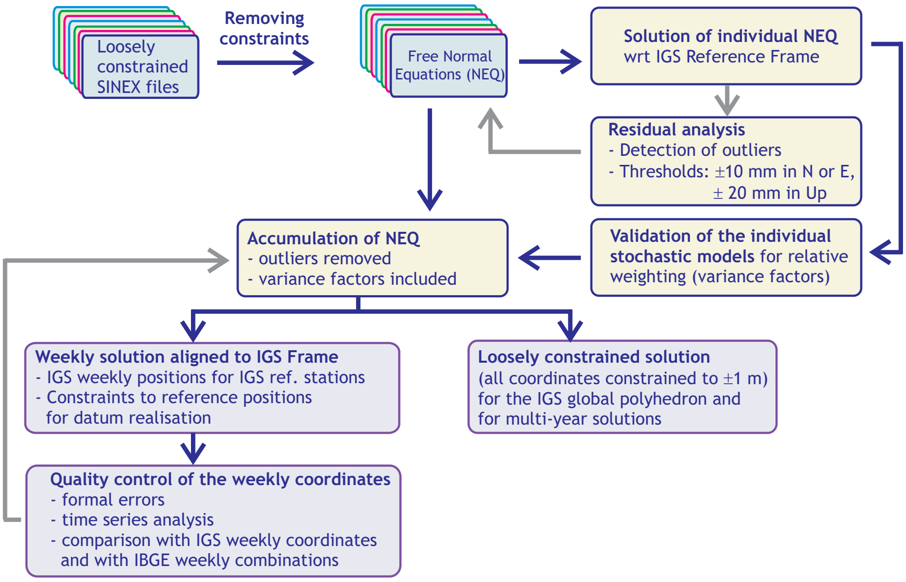
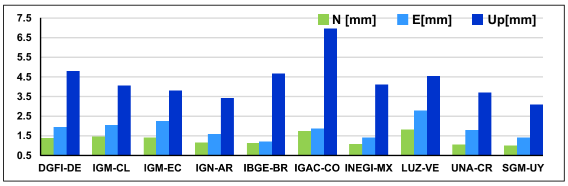


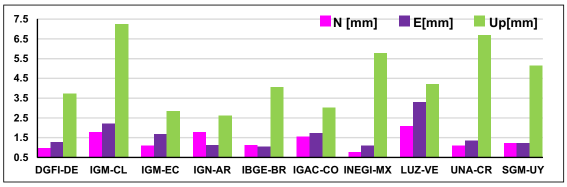
Figure 2: DGFI-TUM strategy for the combination of the weekly solutions delivered by the SIRGAS processing centres

3 Crustal deformation and surface kinematics after the 2010 earthquakes in Latin America

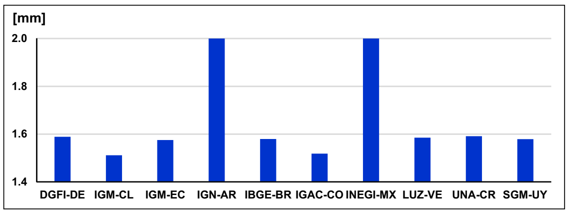
The Maule 2010 earthquake in Chile generated the largest displacements of geodetic observation stations ever observed in terrestrial reference frames (Sánchez et al. 2013). Coordinates changed by up to 4 m, and deformations were measurable in distances of up to more than 1000 km from the epicentre. The station velocities in the regions adjacent to the epicentre 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 et al. 2015a). The 2010 Baja California earthquake in Mexico caused displacements on the dm level also followed by anomalous velocity changes. To ensure the long-term stability of the SIRGAS reference frame, the transformation of station positions between different epochs requires the computation of reliable continuous surface deformation (or velocity) models. To achieve this objective, DGFI-TUM, acting as the IGS RNAAC SIRGAS, computed a new continental continuous crustal deformation model for Latin America and the Caribbean inferred from GNSS (GPS+GLONASS) measurements gained after the strong earthquakes occurred in 2010. It is based on a multi-year velocity solution for a network of 456 continuously operating GNSS stations and covering a five years period. This new deformation model, called VEMOS2015 (Velocity Model for SIRGAS 2015), is computed using the least square collocation (LSC) approach with empirically determined covariance functions as shown in Sánchez and Drewes (2016). The result is summarised as follows: While the effects of the Baja California earthquake can



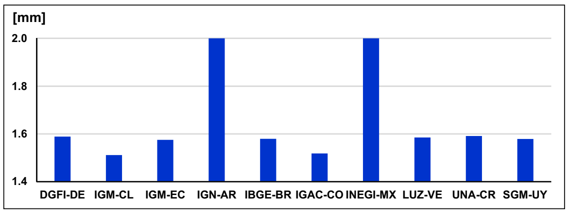
a) Mean RMS values for the weekly repeatability of the station positions within the SIRGAS processing centre solutions: about ± 1.8 mm in the North and the East, and ± 3.5 mm in the height. Large values in the IGAC solutions are unclear.



b) Mean RMS values of the station position residuals for each analysis centre with respect to the IGS weekly final solutions. This comparison allows to assess the accuracy of the individual solutions: about ± 1.3 mm in the North and the East, and ± 4 mm in the vertical component. Large values in the vertical component presented by the INEGI-MX, LUZ-VE and UNA-CR solutions are caused by Mexican stations processed by the IGS with a wrong antenna model. Large residuals in the IGM-CL solutions are caused by a lack of IGS reference stations in the southern part of the SIRGAS region.



c) Standard deviation of station positions after solving the individual solutions with respect to the IGS reference frame. These values represent the formal errors of the individual solutions. Individual standard deviations agree quite well: ± 1.51 mm (IGM-CL, IGAC-CO), ± 1.58 mm (DGFI-DE, IGM-EC, IBGE-BR, LUZ-VE, UNA-CR, SGM-UY), ± 2.0 mm (IGN-AR, INEGI-MX).



d) Quality evaluation of the combined SIRGAS solutions: The coordinate repeatability of the weekly combinations provides an estimate for the accuracy (internal consistency) of the weekly combinations of about ± 1.2 mm in the horizontal component and about ± 3.2 mm in the vertical one. The RMS values derived from the time series for station positions and with respect to the IGS weekly coordinates indicate that the reliability of the network (external precision) is about ± 1.5 mm in the horizontal position and ± 4.2 mm in the height. The differences with respect to the IBGE weekly combinations are at the expected level (less than 0.5 mm).

Figure 3: Quality control of the individual solutions delivered by the SIRGAS processing centres as well as of the combined solutions computed by the IGS RNAAC SIRGAS (mean values from 01-09-2015 to 10-10-2016, 58 weeks).

be considered as local, the effects of the Maule earthquake changed the surface kinematics of a large area (between the latitudes 30°S - 45°S from the Pacific to the Atlantic coasts). Before the Maule earthquake, the strain rate field in this area showed a strong west-east compression with maximum rates of about 0.40 μstrain/a between latitudes 38°S and 44°S (Figure 6). In accordance, the deformation vectors were roughly parallel to the plate subduction direction and their magnitudes decreased with the distance from the subduction front. After the earthquake, the largest compression (0.25 μstrain/a) occurs between the latitudes 37°S and 40°S with a N30°E direction. The maximum extensional strain rate (0.20 to 0.35 μstrain/a) is observed in the Sub-Andean zone in the Patagonia south of latitude 40°S. The extensional axes rotate from a N30°E direction in the central Araucania zone to a westerly direction of N72°W in the western part of Patagonia. In the northern region of parallel 35°S, the extension is also directed to the Maule zone (S45°W) but with quite smaller rates ($<$ 0.06 μstrain/a). This complex kinematics causes a large counter clockwise deformation pattern rotating around a point south of the epicentre (35.9° S, 72.7°W). The magnitude of the deformation vectors varies from 1 mm/a close to the rotation point up to 22 mm/a near the 2010 earthquake epicentre. The direction of the largest deformation vectors points to the epicentre. VEMOS2015 covers the region from 55°S, 110°W to 32°N, 35°W with a spatial resolution of 1° x 1°. The average prediction uncertainty is ±0.6 mm/a in the north-south direction and ±1.2 mm/a in the east-west direction. The maximum is ±9 mm/a in the Maule deformation zone while the minimum values of about ±0.1 mm/a occur in the stable eastern part of the South American plate.

Station coordinates, station position time series as well as velocity and deformation fields computed by the IGS RNAAC SIRGAS within the model VEMOS 2015 are available through the PANGAEA (Data Publisher for Earth and Environmental Science) platform at: `https://doi.pangaea.de/10.1594/PANGAEA.835100` and `https://doi.pangaea.de/10.1594/PANGAEA.863131`.

4 Acknowledgements

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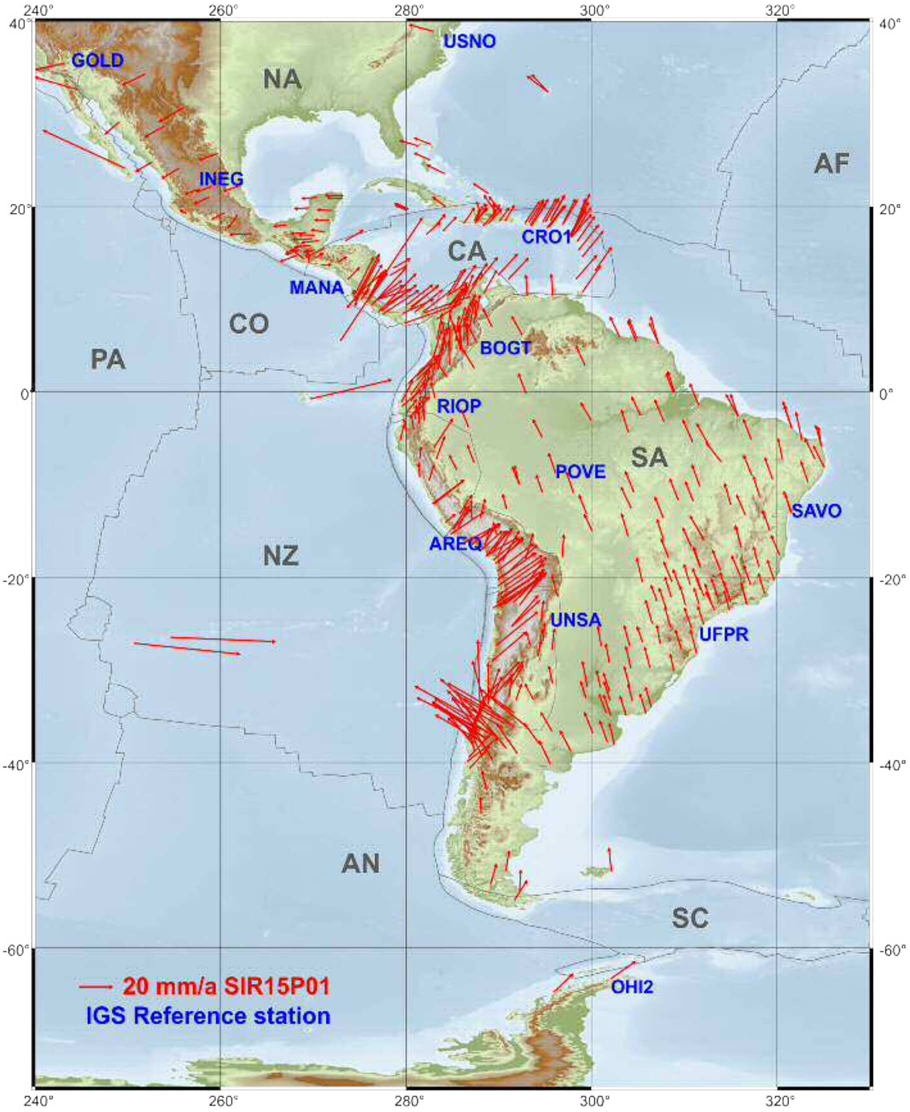

Figure 4: Kinematics of the SIRGAS reference frame. Station coordinates refer to the IGb08 frame, epoch 2013.0. Averaged RMS precision for the considered 456 stations is ±1.8 mm for the station positions, and ±1.0 mm/a for the velocities (taken from (Sánchez and Drewes 2016)).

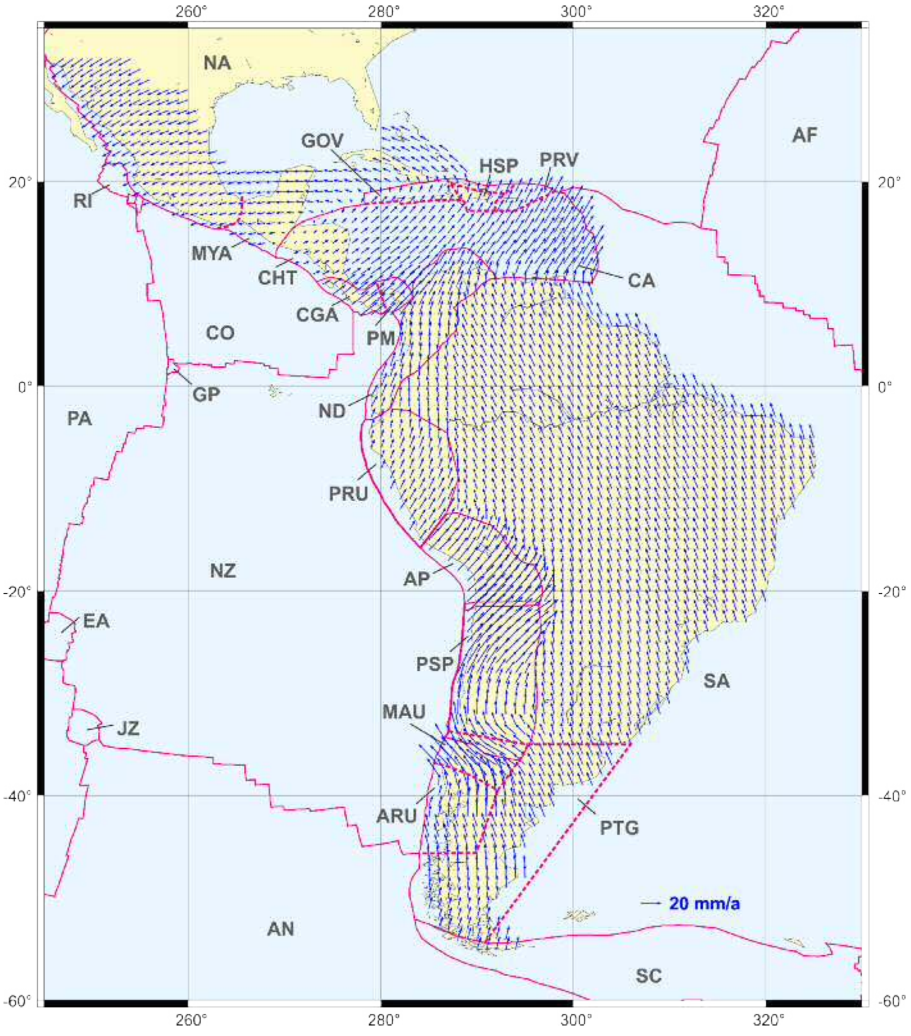

Figure 5: Velocity field VEMOS2015 (taken from (Sánchez and Drewes 2016)). AF: Africa, AN: Antarctica, AP: Altiplano, CA: Caribbean, CO: Cocos, EA: Easter Island, GP: Galapagos, JZ: Juan Fernandez, NA: North America, ND: North Andes, NZ: Nazca, PA: Pacific, PM: Panama, RI: Rivera, SA: South America, SC: Scotia, GOV: Gonave, HSP: Hispaniola, PRV: Puerto Rico and Virgin Islands, MAY: Maya, CHT: Chortis, CGA: Chorotega, PRU: Peru, PSP: Puna-Sierras Pampeanas, MAU: El Maule, ARU: Araucania, PTG: Patagonia.

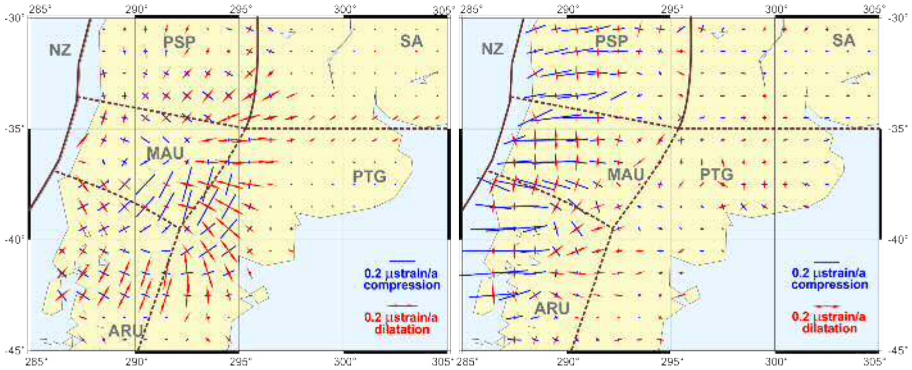

Figure 6: Strain field after (2010 to 2015, left) and before (2000 to 2008, right) the Maule 2010 earthquake (taken from (Sánchez and Drewes 2016)). NZ: Nazca, SA: South America, PSP: Puna-Sierras Pampeanas, MAU: El Maule, ARU: Araucania, PTG: Patagonia.

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