# A post-seismic deformation model after the 2010 earthquakes in Latin America

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## Motivation

The tectonics of the eastern Pacific region is characterised by the boundary zones between the Pacific, North American, Caribbean, Cocos, Nazca, and South American plates. It is an extremely active seismic area causing strong co-seismic and post-seismic crustal deformations and affecting severely the geodetic reference frames. The Maule 2010 earthquake in Chile generated the largest displacements of geodetic observation stations ever measured in terrestrial reference frames, i.e. the global ITRF (*International Terrestrial Reference Frame*) and its regional densification SIRGAS (*Sistema de Referencia Geocéntrico para las Américas*). Coordinate changes came up to 4 m, and deformations were measurable in distances up to more than 1000 km from the epicentre (Fig. 1).

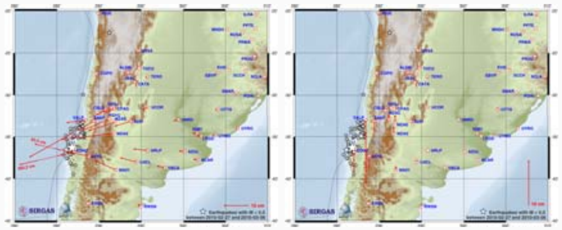

*Fig. 1. Station displacements caused by the Maule earthquake on 2010-02-27.*

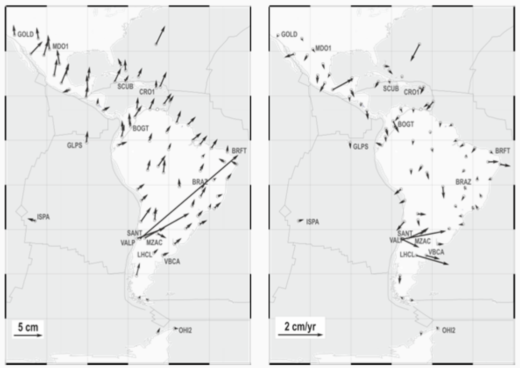

*Fig. 2. Horizontal position difference vectors (left) and horizontal velocity difference vectors (right) between SIRGAS multi-year solutions computed before and after the earthquakes in 2010.*

The station velocities in the area between latitudes 30° S and 40° S changed dramatically after the seism extending over the entire continent. In the Andes region they were oriented eastward with approximately 2 cm/a before the event, now they are directed westward with about 1 cm/a (Fig. 2). A similar pattern is presented from the Baja California earthquake 2010 in Mexico with displacements in the decimetre-level, also followed by anomalous velocity changes (Fig. 3).

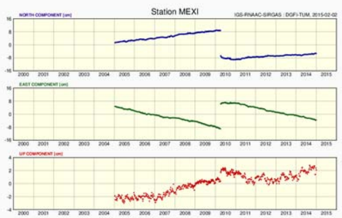


*Fig. 3. Station position series at the SIRGAS station in Mexicali, Mexico.*

## Modelling continuous post-seismic deformations

The main problem in geodetic applications is that there is no reliable reference frame to be used after an earthquake. For geophysical applications we have to redefine the tectonic structure in affected areas. E.g. the area from $\varphi$ = 35°S to $\varphi$ = 40°S was considered as a stable part of the South American plate (e.g. Bird 2003). Now we see that there are large and extended crustal deformations.

Crustal velocity models for South America and the Caribbean were computed by geophysical finite elements and geodetic least squares collocation before the seismic events based on station velocities observed in the SIRGAS frame from 2000 to 2009 and various geodynamic projects (Drewes and Heidbach 2012). The combined model is shown in Fig. 4.


*Fig. 4. Velocity model for South America and the Caribbean from 2000 to 2009 (Drewes and Heidbach 2012).*

## Post-seismic station velocity model for Latin America

A new velocity solution for the SIRGAS reference frame was computed covering the four year time span from two months after the February 2010 Maule earthquake to mid-2014 (SIR14P01). Because most of the South American stations included in the ITRF, which serve for the global geodetic datum realization, were affected by this earthquake, further stations in North America, Oceania, Europe, and Africa, were added.

The computation was done with the Bernese software V5.2 (Dach et al. 2013) using reprocessed weekly normal equations based on the latest standards released by the IERS (*International Earth Rotation and Reference Systems Service*) and the IGS (*International GNSS Service*). The datum is realized by applying no-net-rotation and no-net-translation conditions w.r.t. the positions and linear changes (constant velocities) of selected IGS core stations referring to IGb08, epoch 2013.0 (Fig. 5). The estimated precision is ±1.8 mm (horizontal) and ±3.1 mm (vertical) for the station positions at the reference epoch, and ±0.6 mm/a (horizontal) and ±1.1 mm/a (vertical) for the constant velocities.

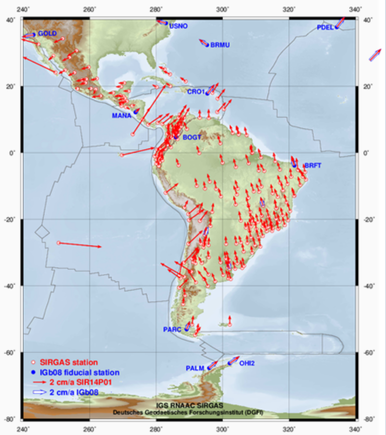

*Fig. 5. Horizontal velocities of the post-seismic SIRGAS solution 2010-2014*

## Crustal deformation model for Latin America

The post seismic continuous crustal deformation model for Latin America is based exclusively on the cumulative velocity solution SIR14P01 covering only the period after the major earthquakes in Latin America from April 2010 to mid-2014. In total 236 horizontal velocities were available in the region. The least squares collocation (LSC) method was used for interpolation of the velocities to a 1°x1° grid. To fulfil the conditions required by the LSC (isotropy and stationarity), the station velocities were first reduced by the systematic effects (trend reduction, in this case global plate motions), and an empirical covariance function was computed for each domain of stations surrounding the 2277 grid points to be predicted. The result is shown in Fig. 6 (relative to the North American plate) and Fig. 7 (relative to the South American plate).

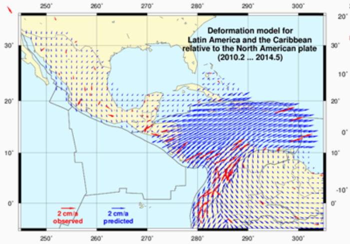


*Fig. 6. Continuous deformation model (velocity model) for Latin America and the Caribbean 2010-2014 (VEMOS2014) relative to the North American plate.*

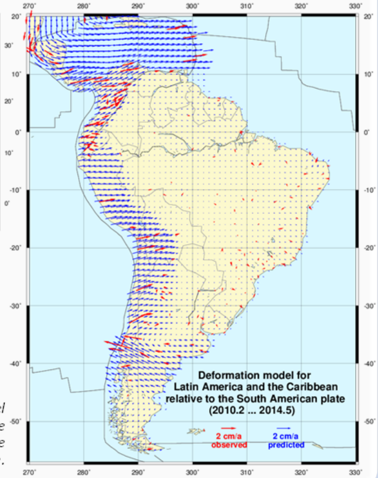


*Fig. 7. Continuous deformation model (velocity model) for Latin America and the Caribbean 2010-2014 (VEMOS2014) relative to the South American plate.*

## Interpretation and conclusions

The model shall be interpreted in comparison with the pre-seismic model VEMOS2009 (Fig. 4). In a first glance we clearly see the reversed direction of velocities between 35° and 40° southern latitude extending from the Pacific to the Atlantic coast. North of this region the velocities are smaller along all the Pacific coast, i.e. the subduction zone of the Nazca plate, than before the earthquake. This obviously shows the post-seismic relaxation process.

The conclusion for geodetic applications is that the reference frames presently available (ITRF2008 and national SIRGAS densifications like SIRGAS-Chile 2002 and regional frames in western Argentina) can no longer be used. New post-seismic reference frames have to be established. As the velocities are not constant, they have to be renewed frequently.

The conclusion for geophysical application is that the stable part of the South American plate is reduced to Brazil and Paraguay; all the other regions have to be considered present-day deformation zones. In Mexico we have no comparison with pre-seismic velocity models, but it seems that there is an ongoing deformation w.r.t. to the stable North American plate after the 2010 Baja California seism.

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