Long-term stability of the SIRGAS Reference Frame and episodic station movements caused by the seismic activity in the SIRGAS region

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Motivation

The western part of the SIRGAS region (Fig. 1), 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 1), which influence the long-term stability of the SIRGAS frame. For instance, the earthquake in Chile on 2010-02-27 moved 23 reference stations between 1 cm and 3 m to the west (Fig. 2). The earthquake in Mexicali, Mexico (on 2010-04-04) caused a jump of 24 cm in the south-east direction of the station MEXI (Fig. 3).

Table1. Seismic events with high impact in the SIRGAS frame 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. 2
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

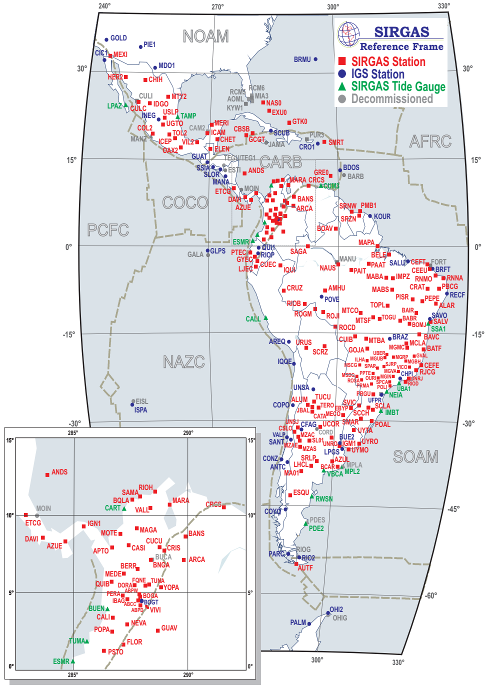

Fig.1. SIRGAS Reference Frame

Modelling seismic effects within the reference frame

The network deformation due to these events has to be determined in order to guarantee the long-term stability, i.e. the transformation between the pre-seismic and the post-seismic coordinates. This cannot be done by usual approaches (like Helmert transformation) because the deformed networks do not fulfil the similarity condition.

Earthquakes of big magnitudes generate not only jumps in the position of the reference stations, but also change their "normal" movement (constant velocities). When a reference station shows a non-linear behaviour after the earthquake (e.g. AREQ after 2001-06-23, Fig. 4), the post-seismic period is habitually cut into short time intervals ΔT_i to model the movement by a sequence of constant velocities V_i (Fig. 4). To transform the station positions before and after the seismic event, one has to sum up all the intervals ($\Delta X = \ V_i * \Delta T_i$). This approximation is insufficient for SIRGAS because:

- The national reference frames contain a high percentage of non-continuously operating stations and the sequence of velocities after an earthquake cannot be reliably determined;
- The SIRGAS reference frame is composed by almost 250 continuously operating stations; nevertheless, their geographical distribution does not provide the required density (coverage) to interpolate (model) the effects of the seismic events with high accuracy for other stations.

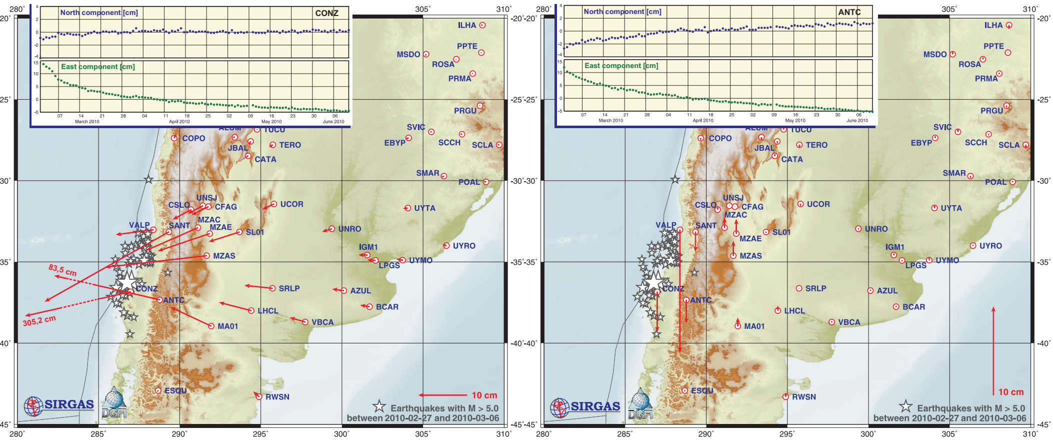

Fig. 2. Displacements caused by the earthquake in Chile on 2010-02-27. Time series show post-seismic movements in stations CONZ and ANTC.

Recommendations

To mitigate the impact of seismic events in the use of SIRGAS, it is necessary:

- To improve the national reference frames by installing more continuously operating GNSS stations in order to precisely monitor possible deformations;
- The reference networks composed by non-continuously operating stations must be replaced as far as possible by continuously operating stations. If this is not possible, they have to be re-measured inmediately after a strong seism;
- The transformation between the pre-seismic and the post-seismic frame realizations must be based on a deformation model derived from discrete (weekly) station positions. The Helmert transformation cannot be applied;
- In stations not observed continuously, the post-seismic coordinate changes can be interpolated from the deformation model;
- In precise positioning, users have to apply epoch (weekly or monthly) positions as reference coordinates instead of those derived from a reference epoch and (a sequence of) velocities.

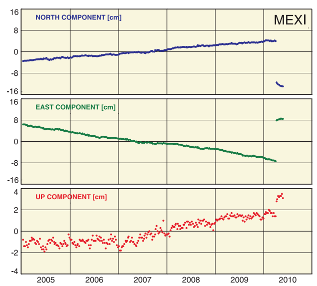

Fig. 3. Time series of station MEXI (Mexicali, Mexico). Displacements caused by the earthquake on 2010-04-04 are shown.

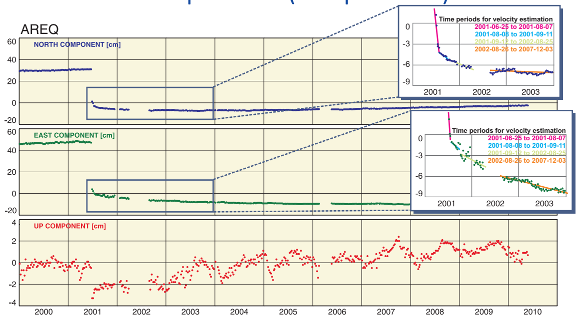

Fig. 4. Time series of station AREQ. Velocities for post-seismic displacements are displayed.

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