The Velocity Model for SIRGAS 2010-2015 (VEMOS2015)

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Symposium SIRGAS, Quito, Ecuador, 16-18 November 2016

Tectonic frame in Latin America and the Caribbean: Plate boundaries (Bird 2003), motions (Drewes 2012)

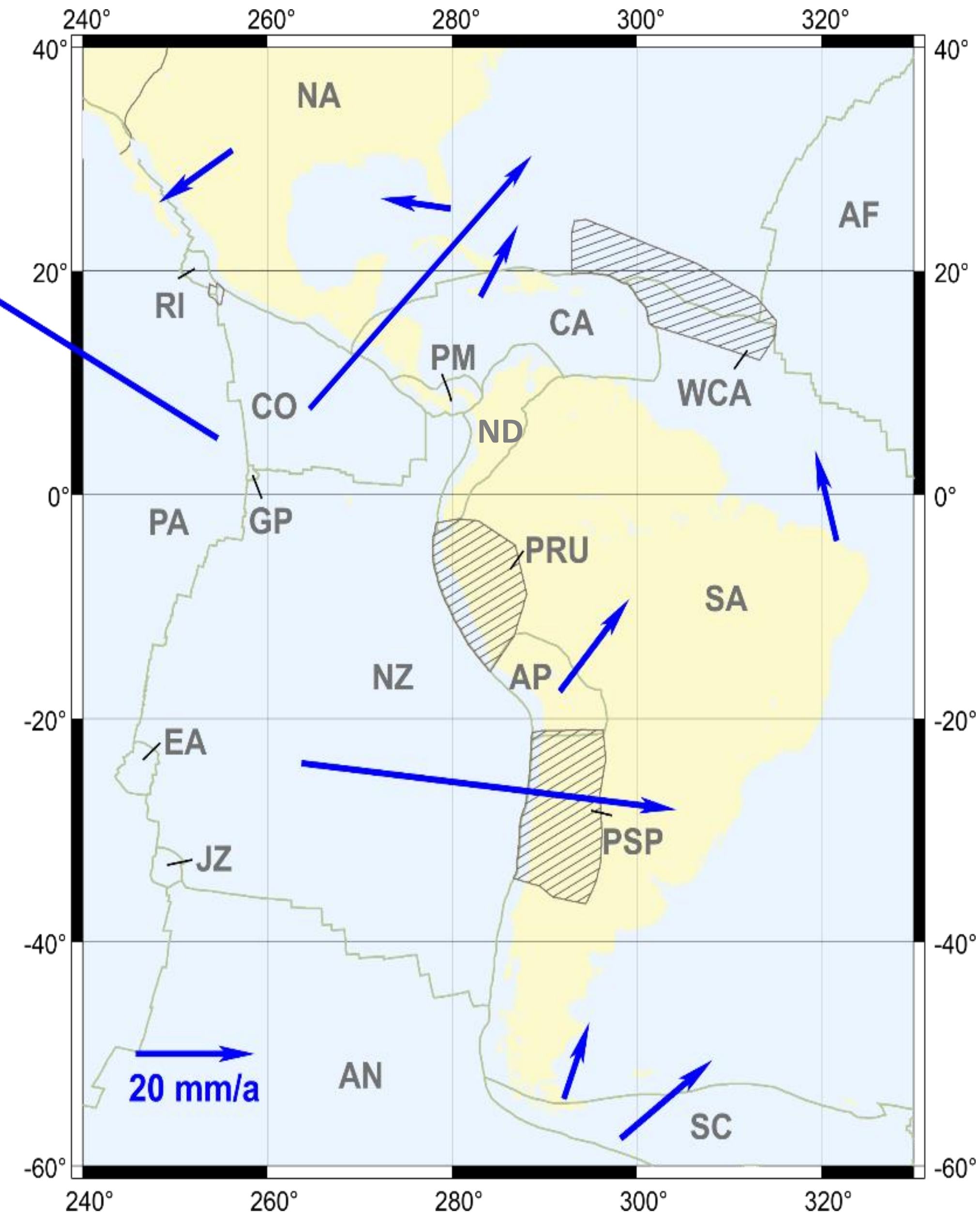
The standard tectonic models distinguish tectonic plates and deformation zones (orogenes).

<u>Plates</u>:

NA	N America	AF	Africa
RI	Rivera	CA	Caribbean
PM	Panama	ND	North Andes
CO	Cocos	GP	Galapagos
PA	Pacific	EA	Easter Island
NZ	Nazca	AP	Altiplano
SA	S America	JZ	Juan Fernandez
AN	Antarctica	SC	Scotia

<u>Orogenes</u>:

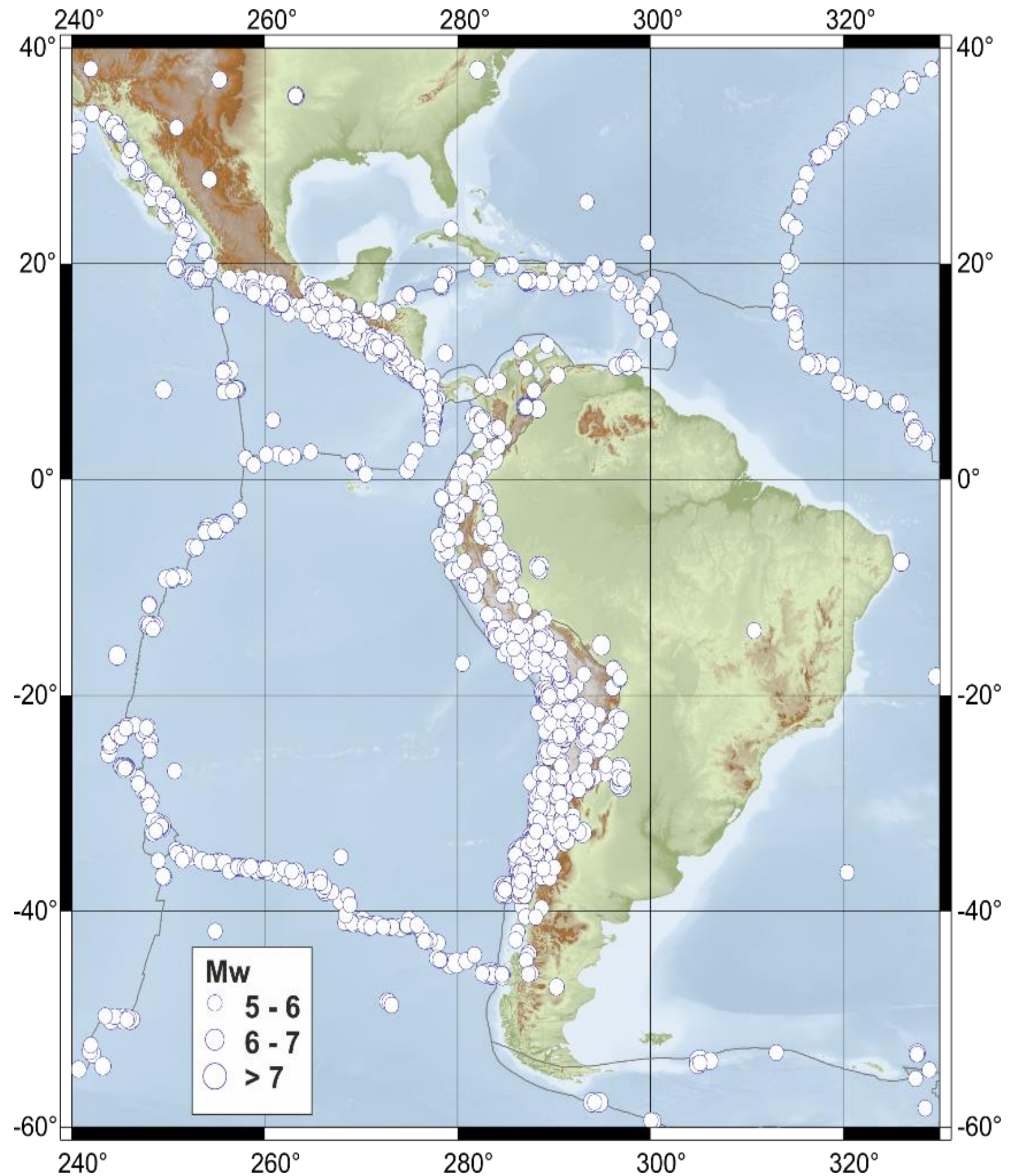
WCA	West Central Atlantic
PRU	Peru
PSP	Puna-Sierras Pampeanas



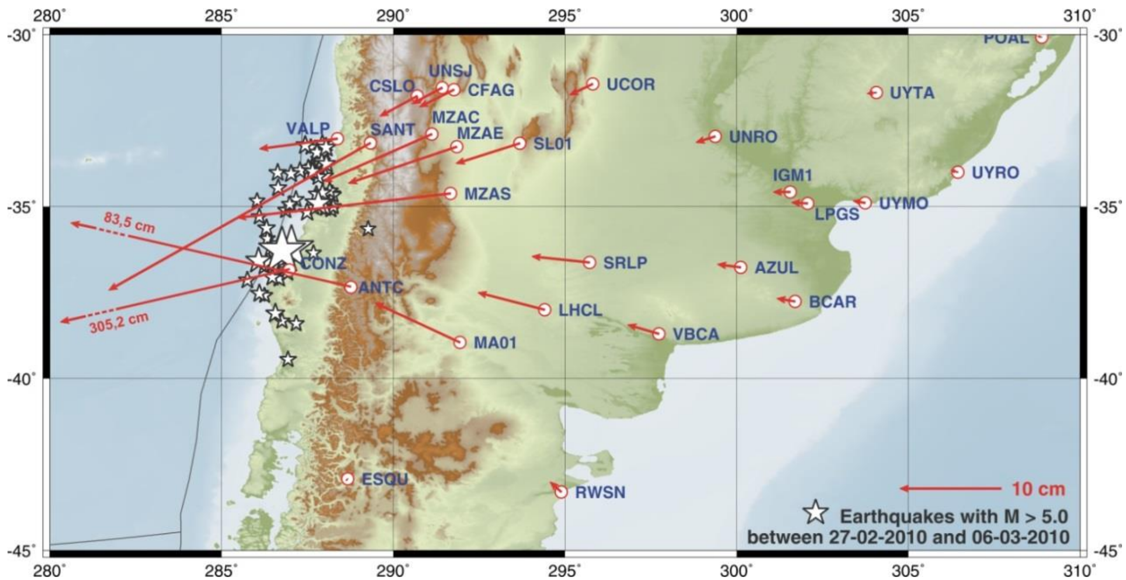
Earthquakes in the SIRGAS region since January 2010 with magnitudes > 5

The interaction of these moving tectonic units causes a very high seismic activity (earthquakes) which generates episodic crustal movements and long-term crustal deformation affecting geodetic reference frames (ITRF, continental densification SIRGAS and all the national densifications).

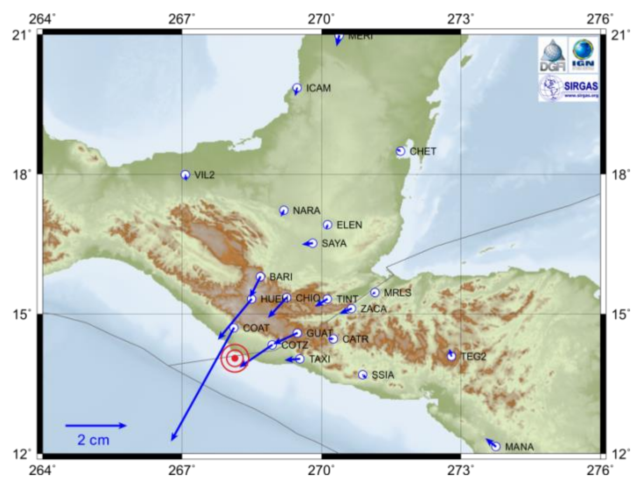
Earthquakes with magnitudes > 5
in Latin America and the Caribbean
from January 2010 to April 2015.
Source: IRIS: Incorporated Research Institutions for Seismology, www.iris.edu



Seismic deformations in reference frames (e.g. SIRGAS)



The precise determination and modelling of the co-seismic and post-seismic displacements and changes in the surface velocities over the entire affected area is necessary to guarantee:

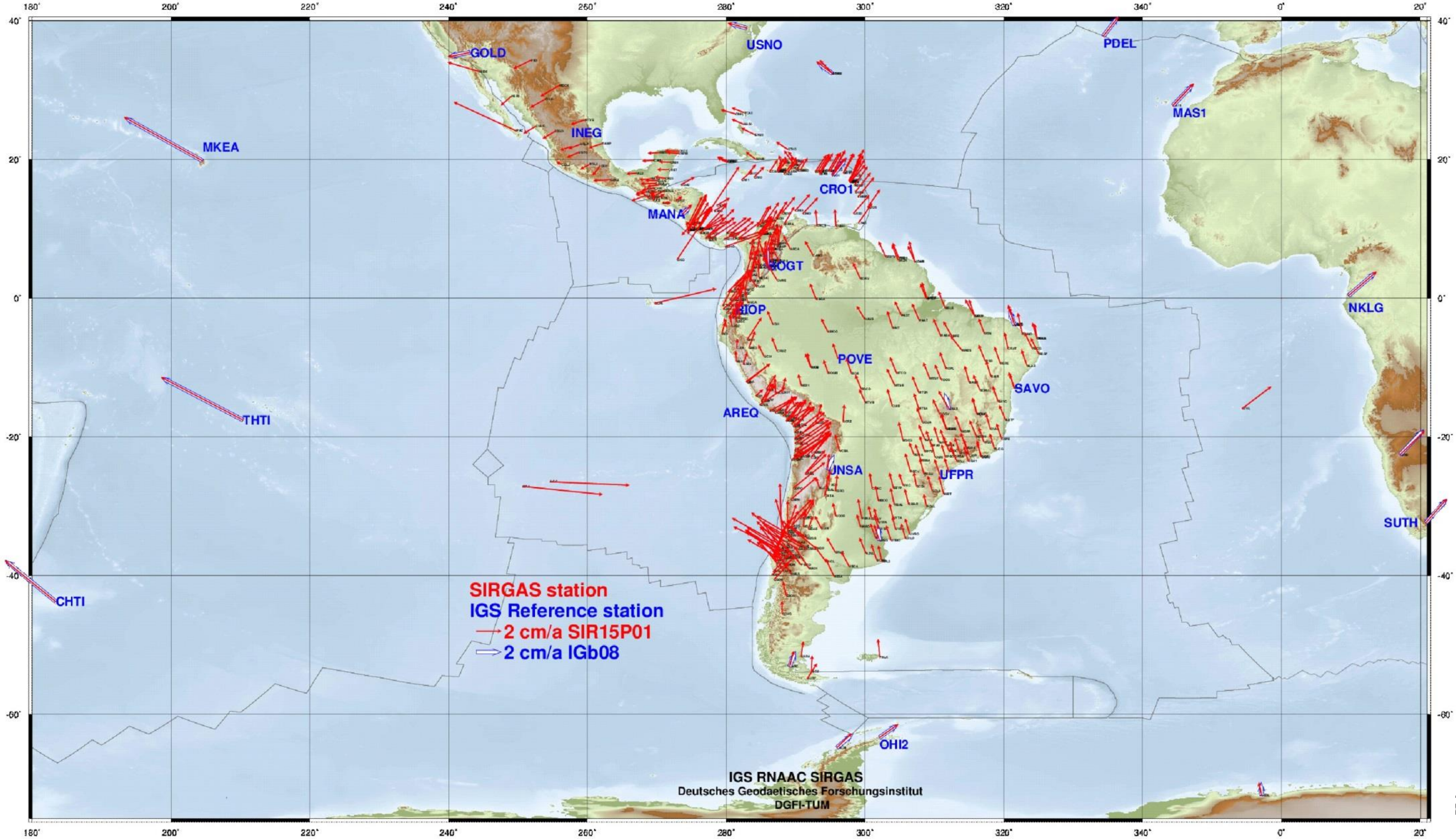


Co-seismic displacements caused by the large earthquakes in Chile (Feb. 2010) and in Guatemala (Nov. 2012)

1) The reliability of all the positions in the adopted reference frame estimated for the week when a seismic event occurs;
2) The appropriate transformation between the pre-seismic and the post-seismic (deformed) reference frame;
3) The long-term stability of the geodetic reference frames to be obtained by the corrections of the seismic displacements.

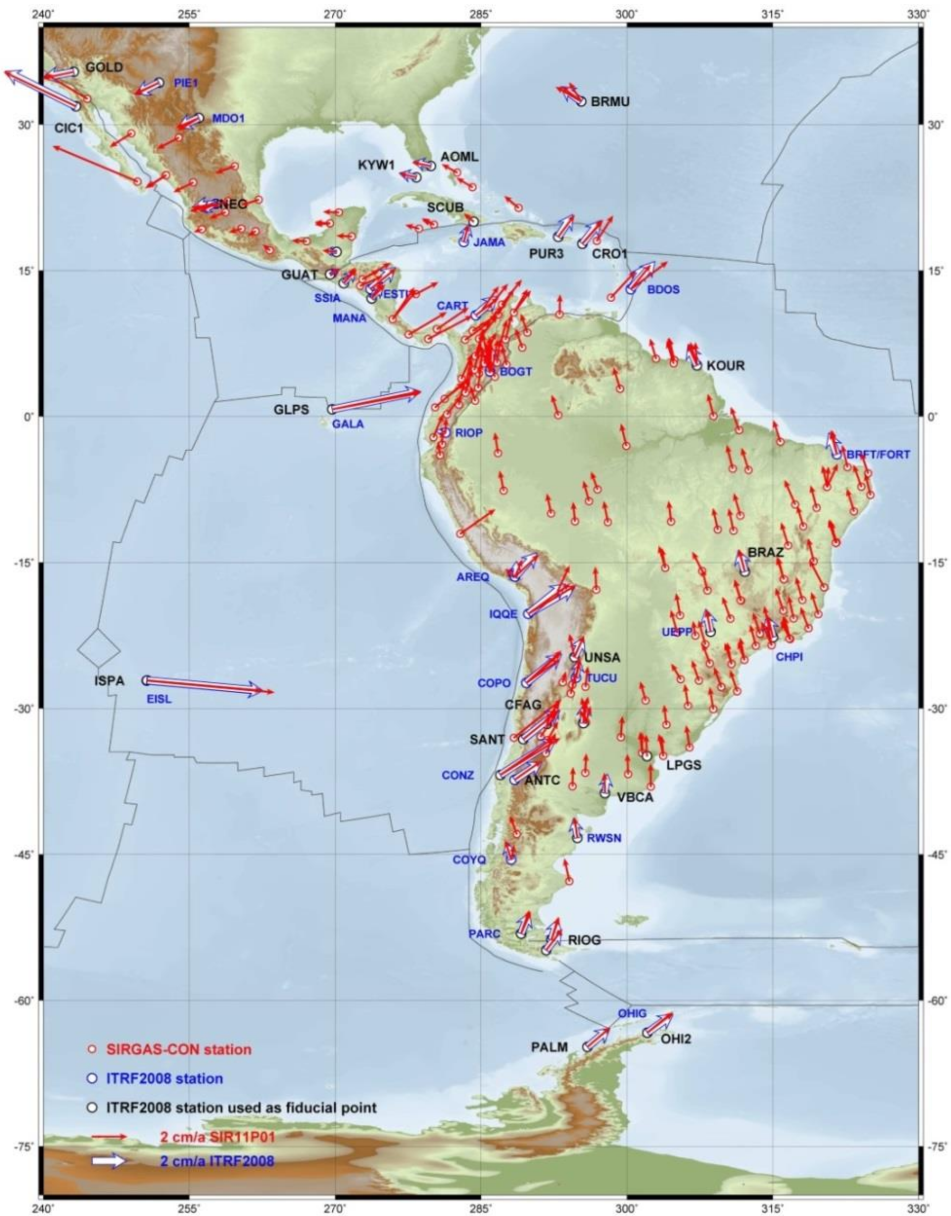
Input data: velocities based on cumulative solutions of GNSS weekly normal equations

- Weekly normal equations (according to IERS/IGS/SIRGAS standards);
- Time span: 2010.2 (2012.2) - 2015.2; 471 stations;
- Frame: IGb08 epoch 2013.0; Accuracy: N - E = ±1.0 mm/a, h = ±1.2

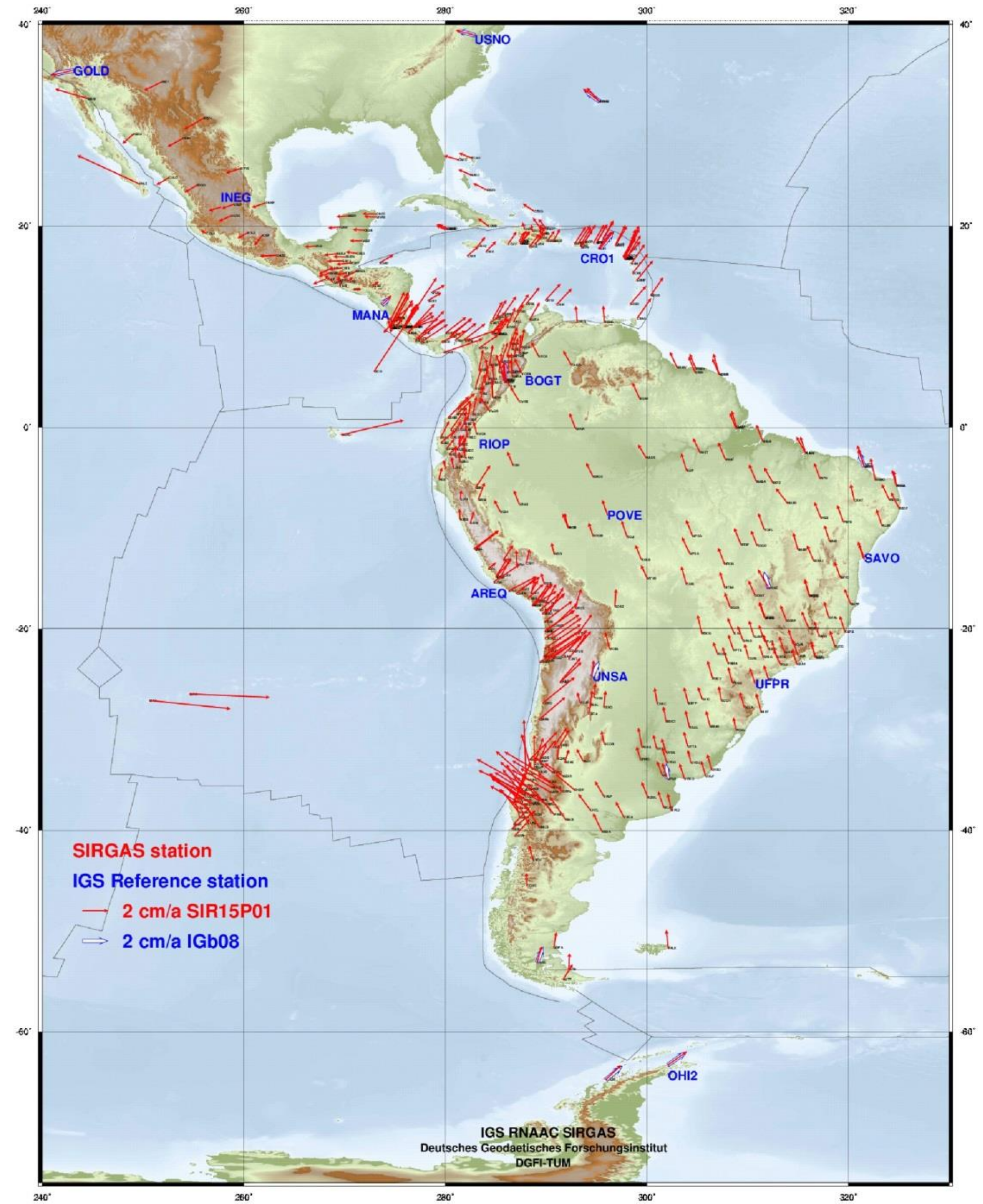


Input data: velocities based on cumulative solutions of GNSS weekly normal equations

SIRGAS 2011

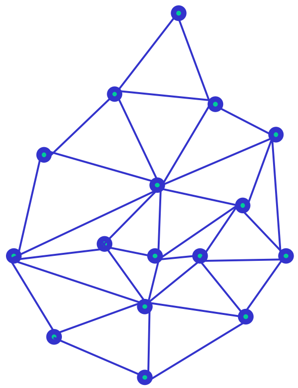


SIRGAS 2015

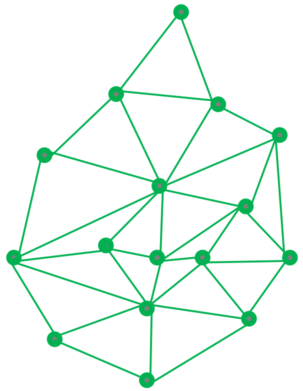


Pre-seismic and post-seismic (deformed) reference frames

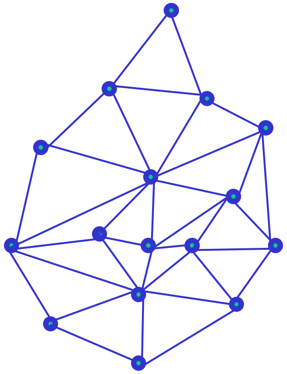
Reference networks without deformation:



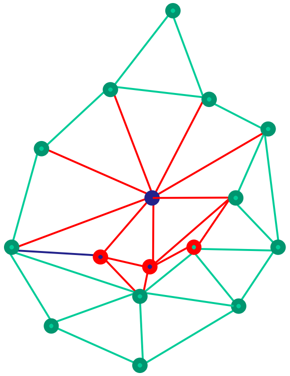
Similarity transformation



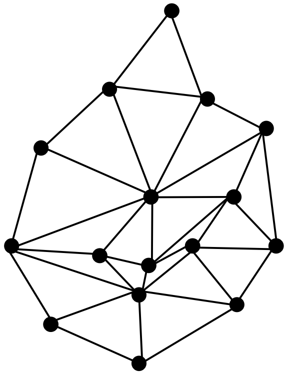
Reference networks with deformation:



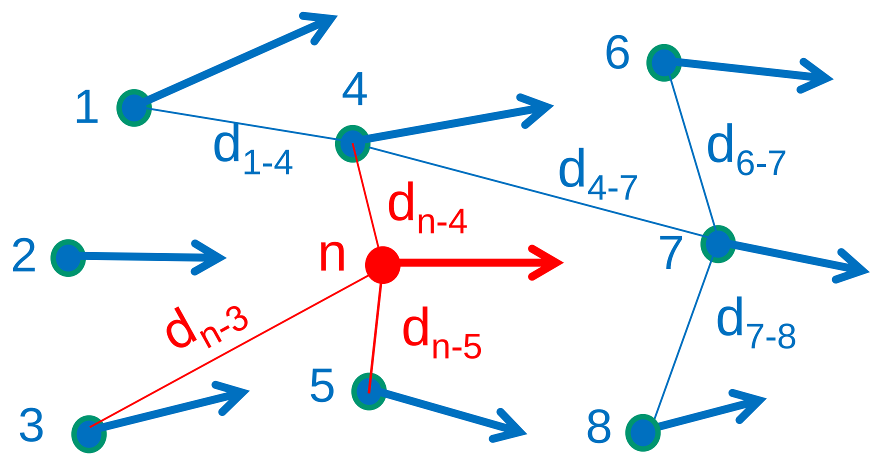
deformation model

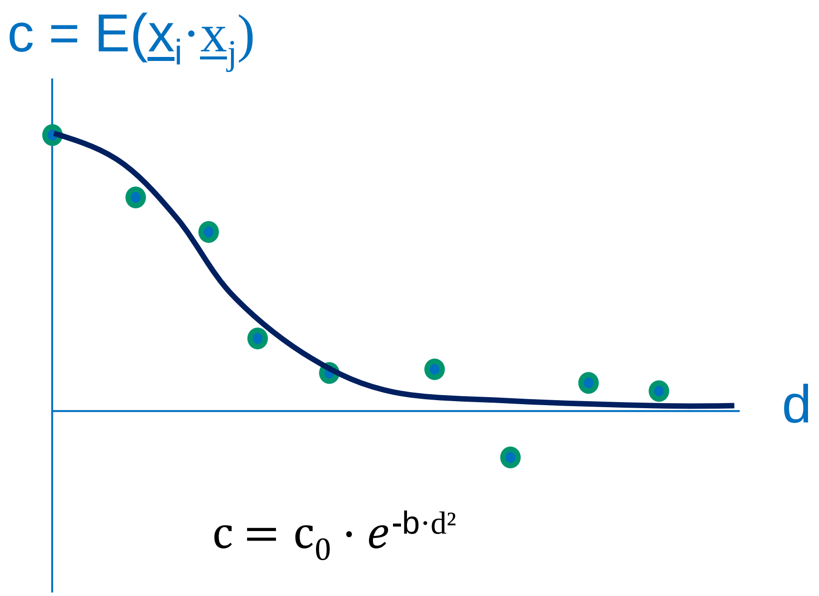


transformation



Modelling of deformations based on the geodetic Least Squares Collocation Approach (LSC)





2D-vector prediction:

$$\underline{\mathbf{v}}_{pred} = \underline{\mathbf{C}}_{new}^{T}\, \underline{\mathbf{C}}_{obs}^{-1}\, \underline{\mathbf{v}}_{obs}$$

$\underline{\mathbf{v}}_{pred}$ = predicted velocities (v_N, v_E) in a 1°× 1° grid

$\underline{\mathbf{v}}_{obs}$ = observed velocities (v_N, v_E) in geodetic stations

$\underline{\mathbf{C}}_{new}$= correlation matrix between predicted and observed vectors

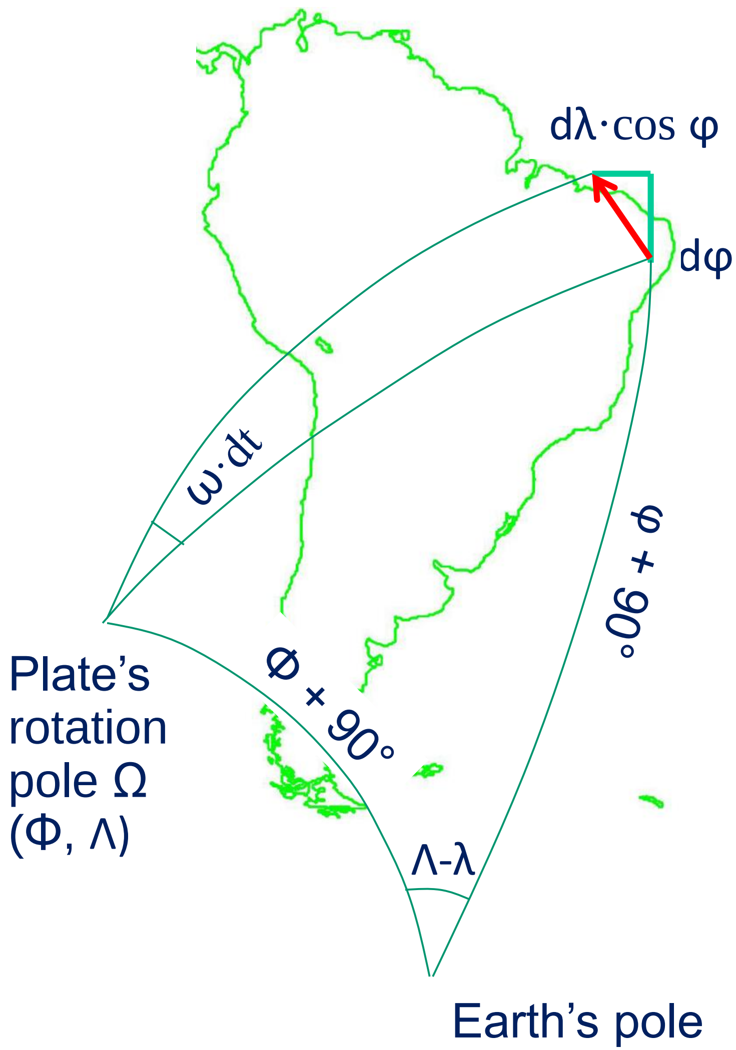
$\underline{\mathbf{C}}_{obs}$= correlation matrix between observed vectors (C_{NN}, C_{EE}, C_{NE})

$\underline{\mathbf{C}}$ matrices are built from empirical isotropic, stationary covariance functions.

Deformation model based on a geodetic Least Squares Collocation Approach (LSC)

To satisfy the isotropy condition, the plate motions [$\mathbf{v} = \mathbf{\Omega}(\Phi,\Lambda,\omega) \times \mathbf{X}$] are reduced from observations:

$$(d\varphi/dt)_k = \omega_i \cdot \cos \Phi_i \cdot \sin(\lambda_k - \Lambda_i)$$
$$(d\lambda/dt)_k = \omega_i \cdot (\sin \Phi_i - \cos(\lambda_k - \Lambda_i) \cdot \tan \varphi_k \cdot \cos \Phi_i)$$



Comparison of rotation vectors Ω

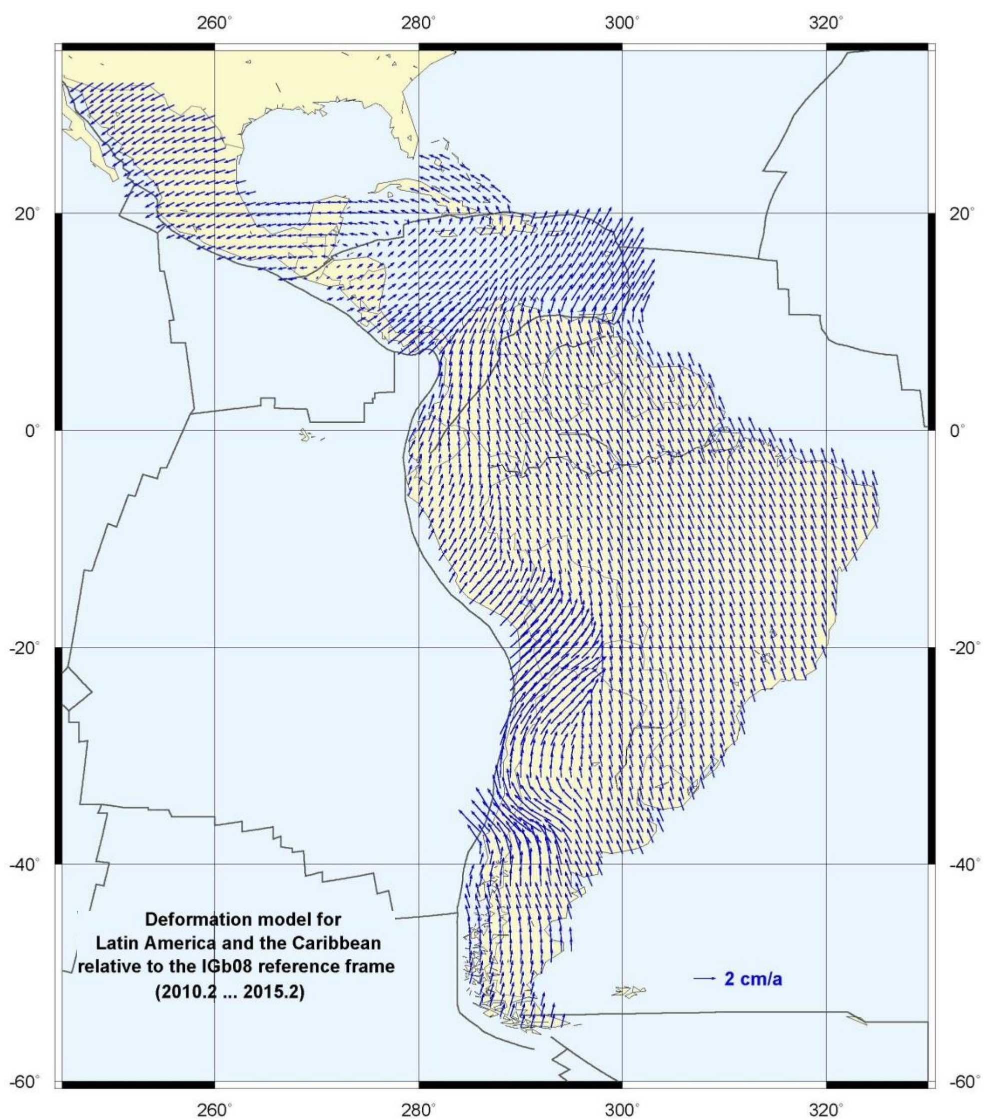
Plate	Φ [°]	Λ [°]	ω [mas/a]
NA(VEMOS15)	-0.2 ± 1.0	270.1 ± 1.1	0.82 ± 0.03
(APKIM2008)	- 5.8 ± 0.5	272.5 ± 0.2	0.68 ± 0.01
CA(VEMOS15)	26.4 ± 0.9	270.4 ± 2.2	1.21 ± 0.07
(APKIM2008)	28.0 ± 1.3	250.9 ± 2.7	0.75 ± 0.06
NZ(VEMOS15)	44.1 ± 1.3	258.0 ± 0.3	2.21 ± 0.02
(APKIM2008)	45.9 ± 0.6	257.6 ± 0.3	2.28 ± 0.02
SA(VEMOS15)	-22.2 ± 0.6	226.9 ± 1.7	0.44 ± 0.01
(APKIM2008)	-19.4 ± 1.0	237.8 ± 1.5	0.46 ± 0.01

... smaller blocks

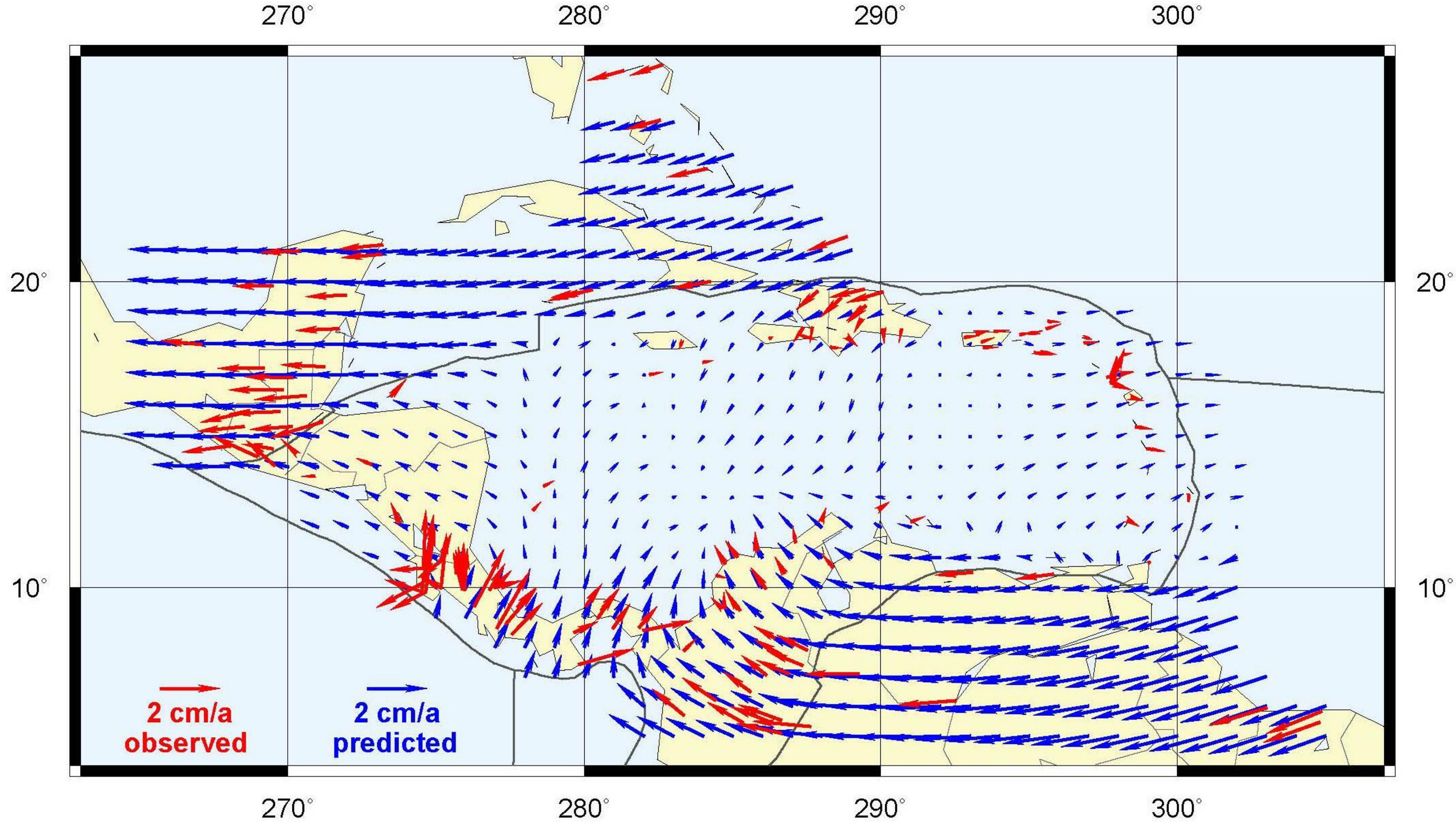
... deformation zones

After the collocation procedure, the plate motions are added to the interpolated velocities again (remove-restore).

Observed and predicted velocities

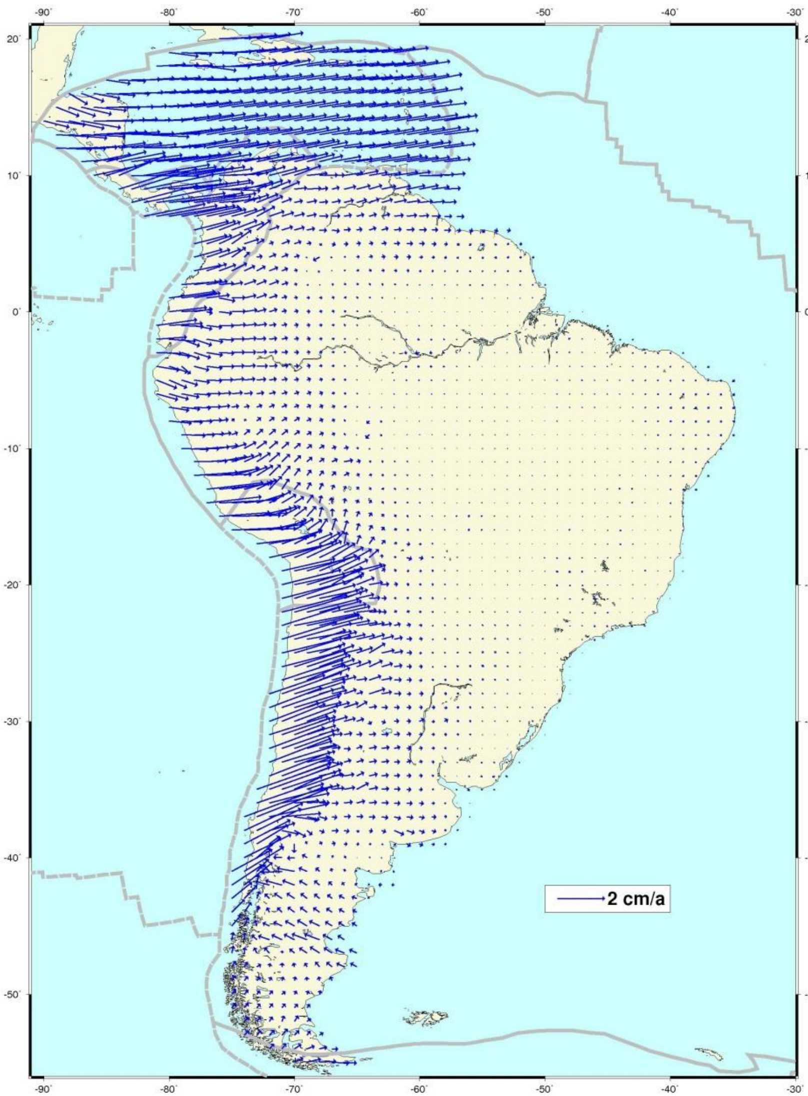


Deformation relative to the Caribbean Plate

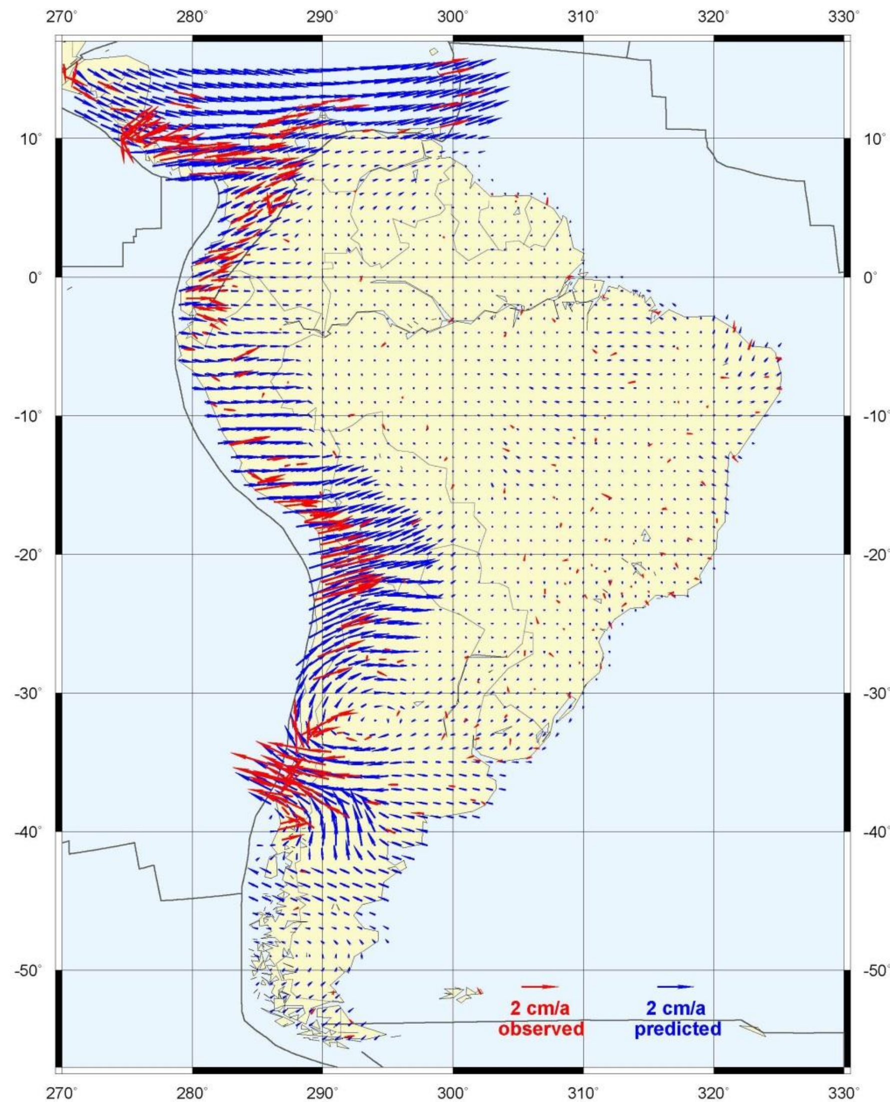


Deformation relative to the South American Plate

VEMOS 2009

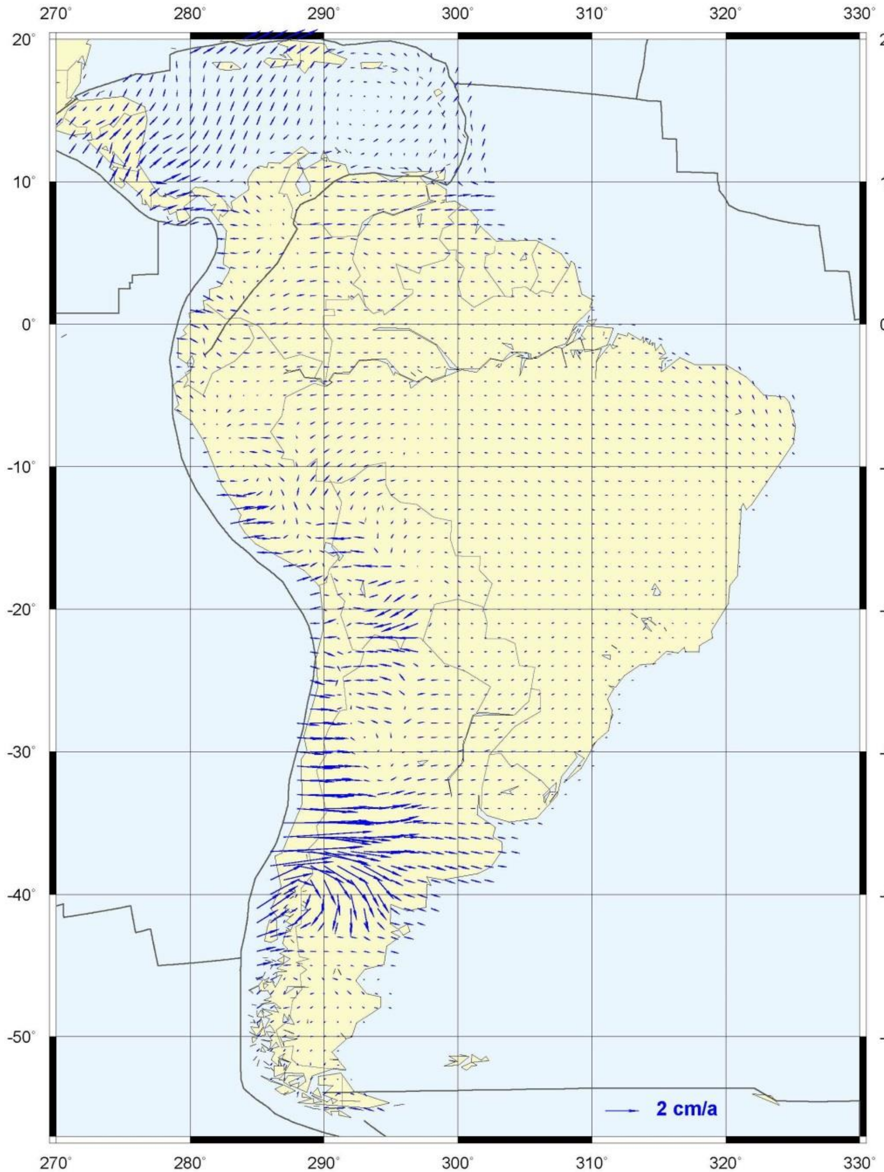


VEMOS 2015

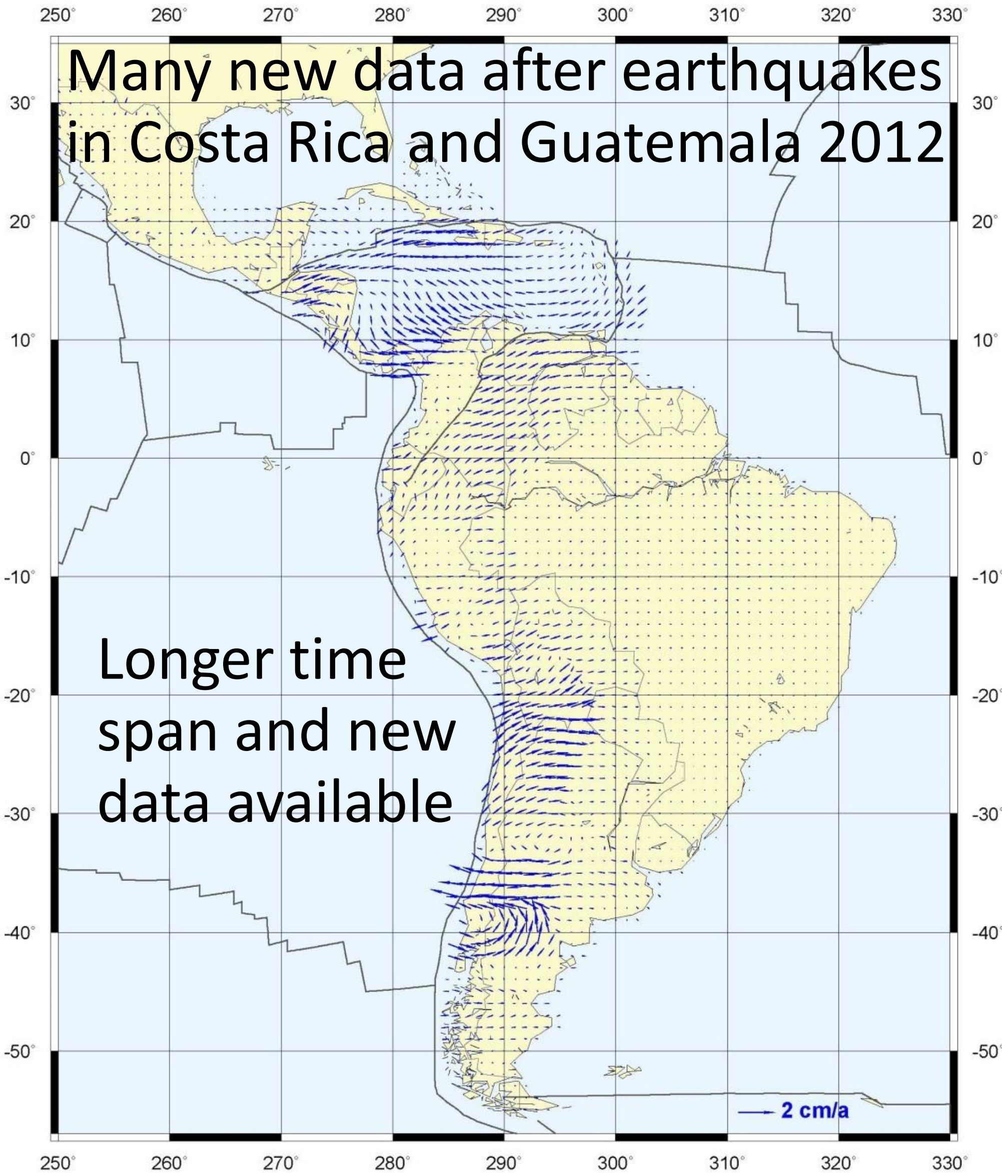


Differences with previous deformation models

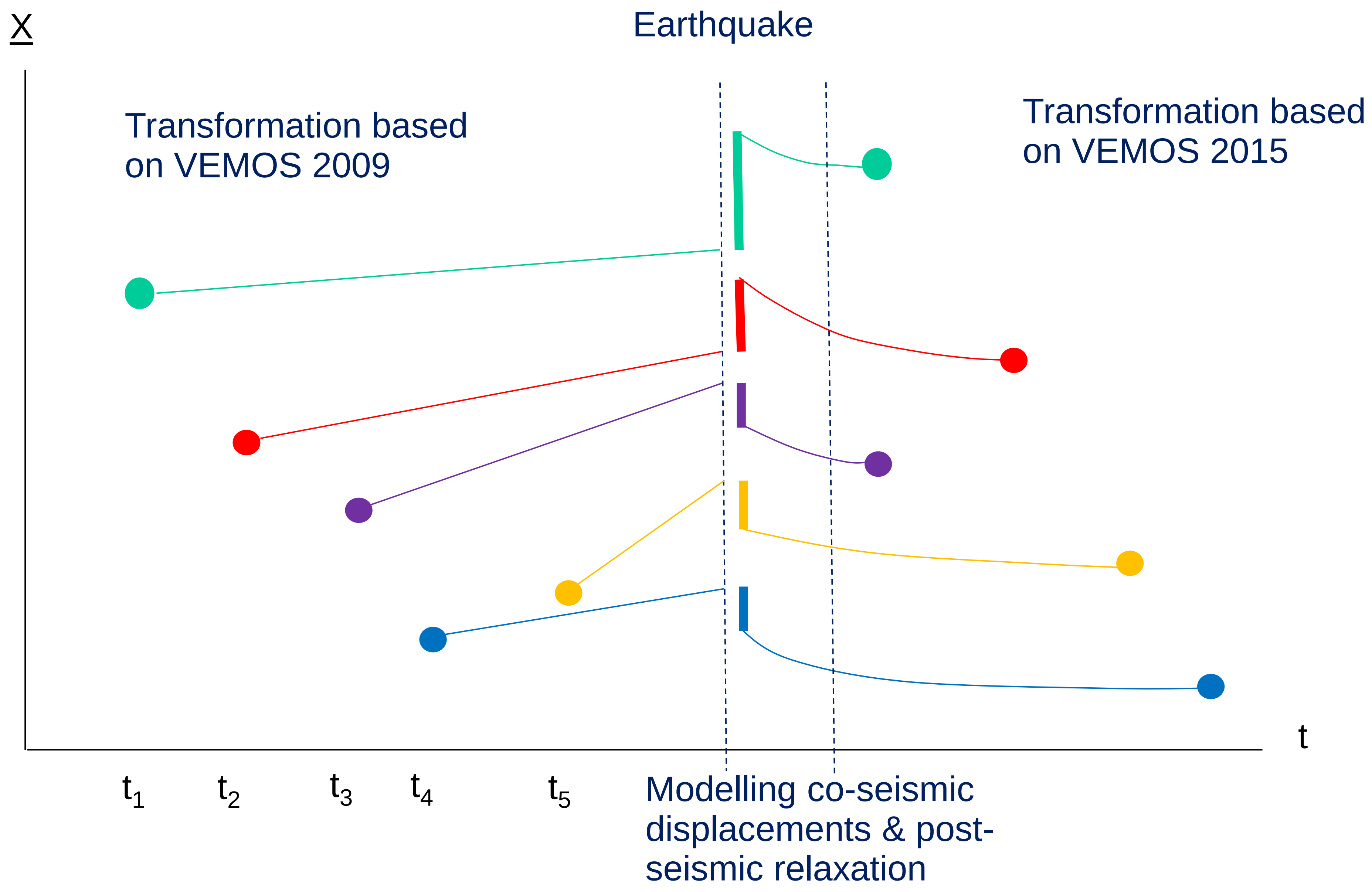
VEMOS 2015 - VEMOS 2009



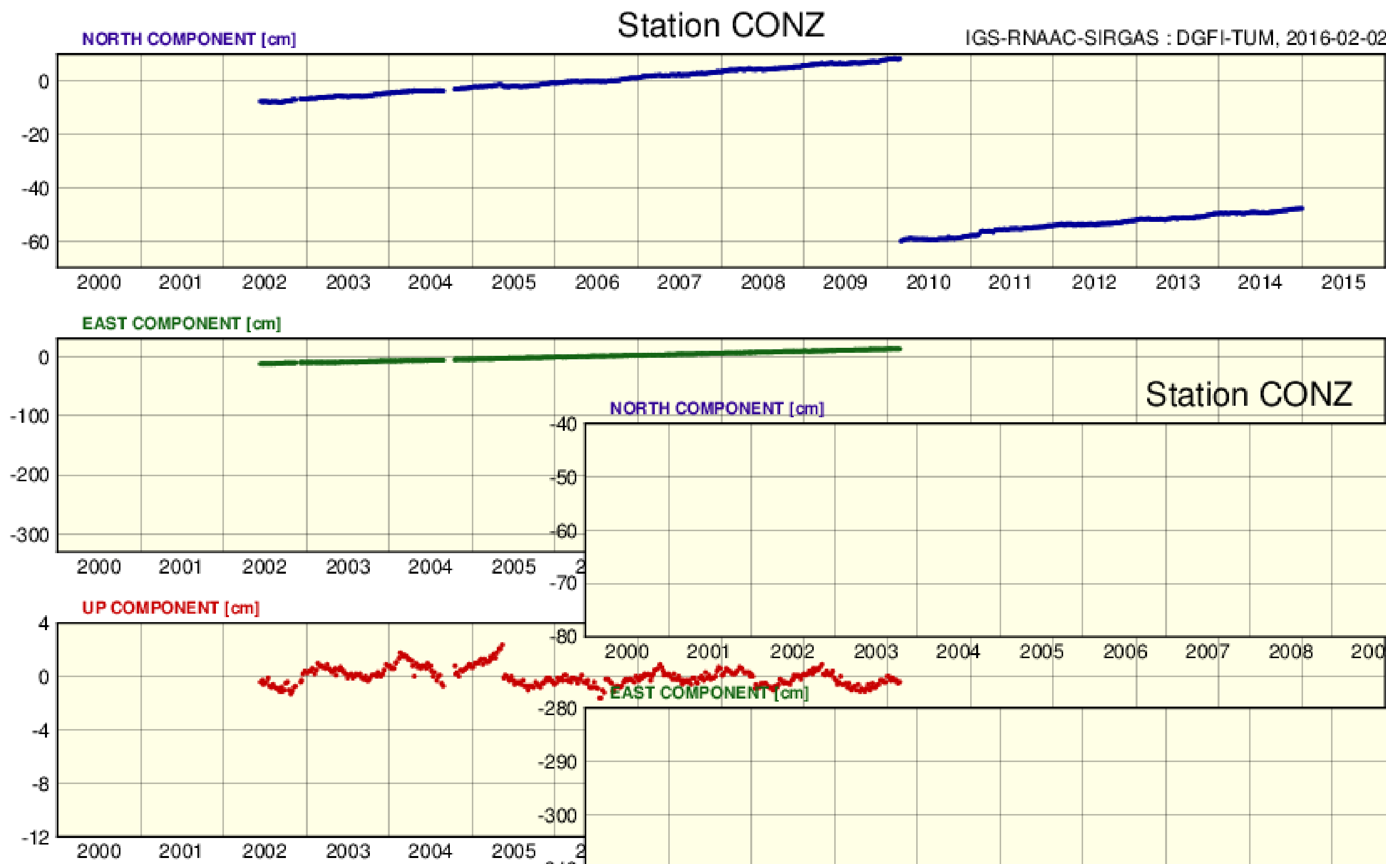
VEMOS 2015 – VEMOS 2014



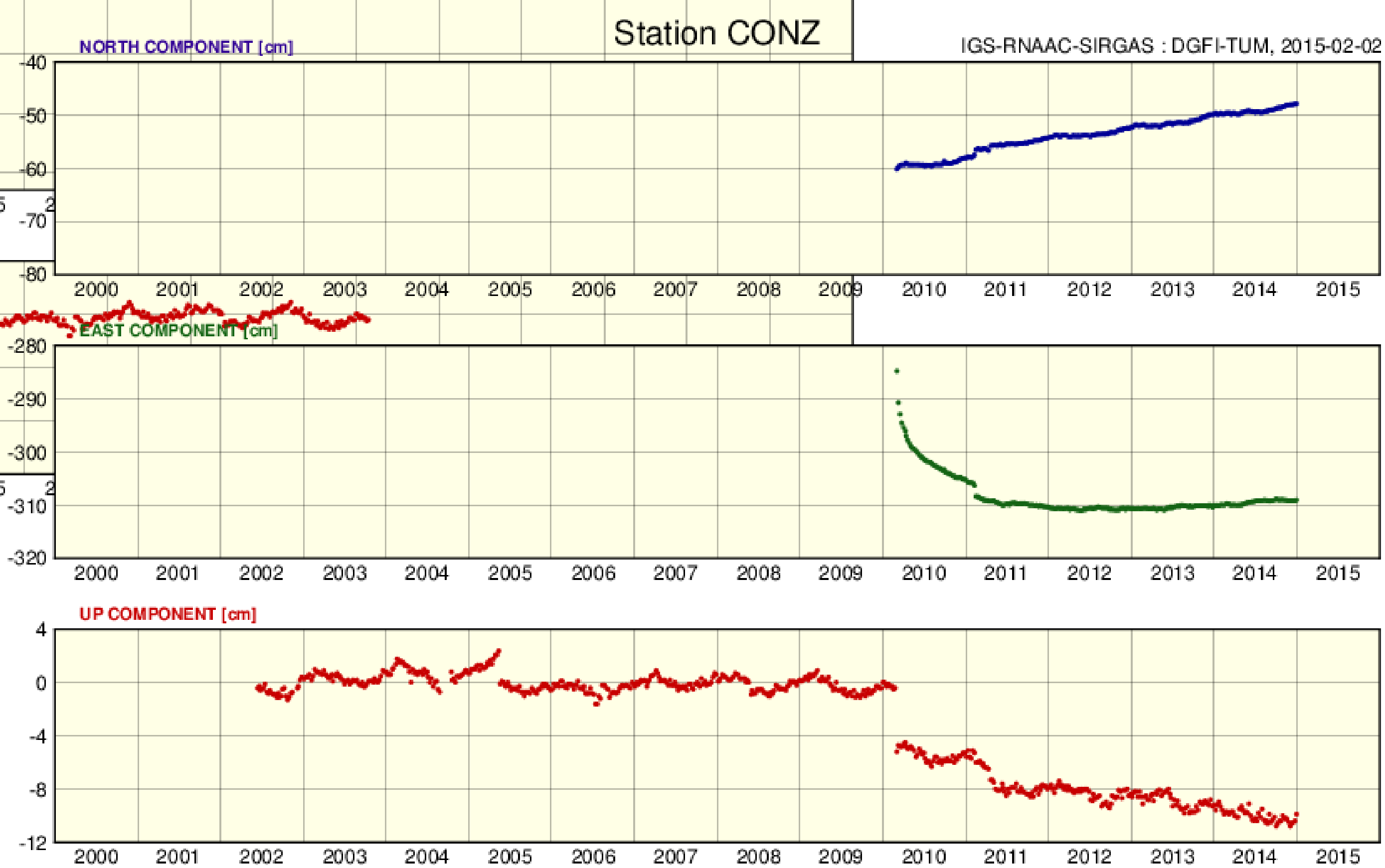
Transformation between pre- and post-seismic frames



Co-seismic displacements and velocity changes



Displacement at earthquake 2010



Velocity change after event 2010

Conclusions

- The earthquakes in Latin America since 2010 produced co-seismic displacements of up to 3 m in the SIRGAS reference frame.
- The surface velocity field in Central and South America has changed dramatically after these seismic events.
- Consequently the involved countries cannot use the official national reference frame (referring to the pre-seismic epoch) for scientific studies and practical applications.
- The predicted 1° x 1° velocity grid allows the interpolation of station positions and velocities in the considered time span (2011-2015) and transformations to previous epochs.
- The co-seismic displacement has to be modelled (→ MoNoLin)
- The computation of the velocity field has to be repeated until the velocities have come to a “normal” behaviour. This may take years.
- Thank you very much for your attention!