The Velocity Model for SIRGAS 2010-2015 (VEMOS2015)

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

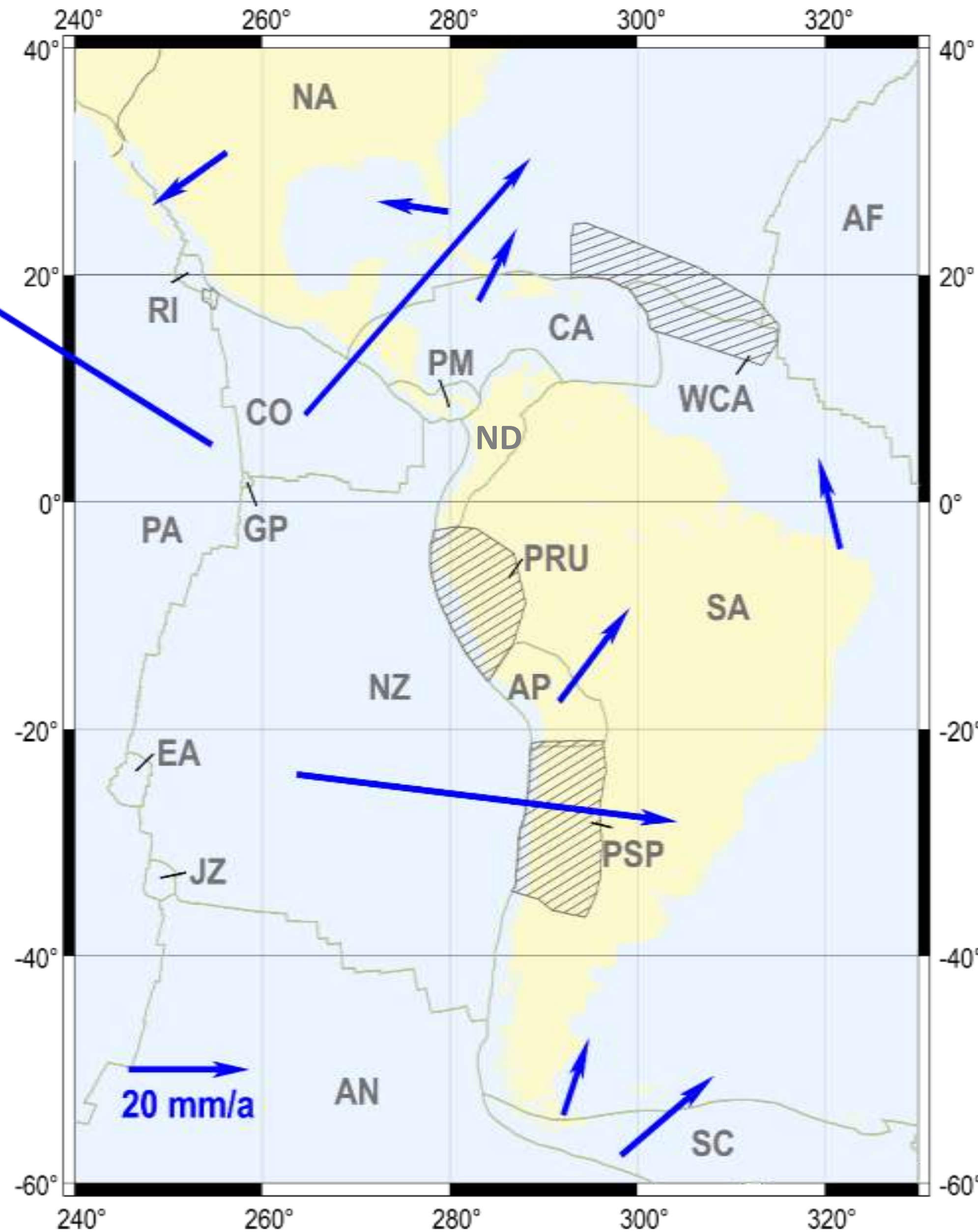
The standard tectonic models distinguish tectonic plates and deformation zones (orogenes).

Plates:

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

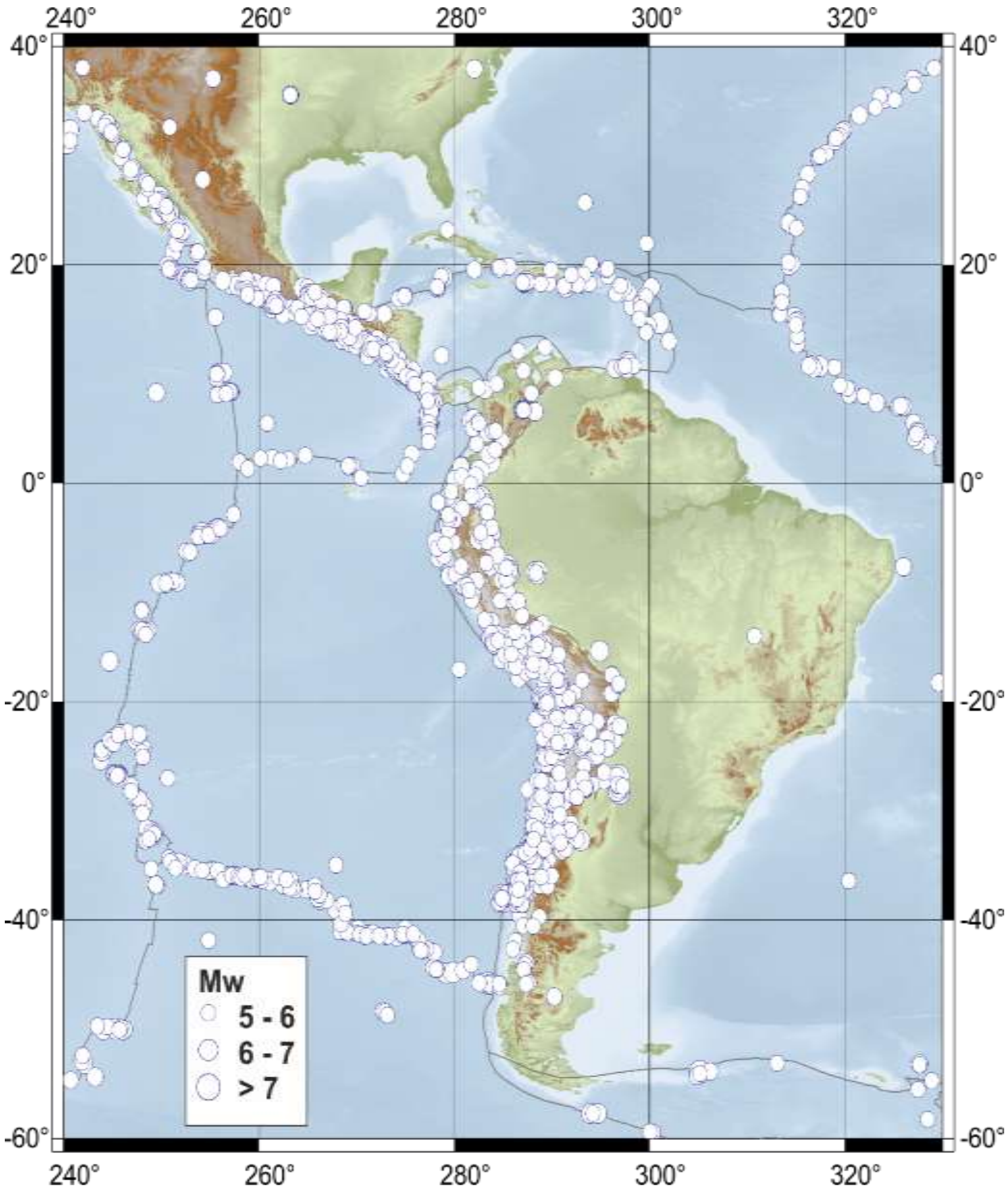
Orogenes:

WCA	West Central Atlantic
PRU	Peru
PSP	Puna-Sierras Pampeanas



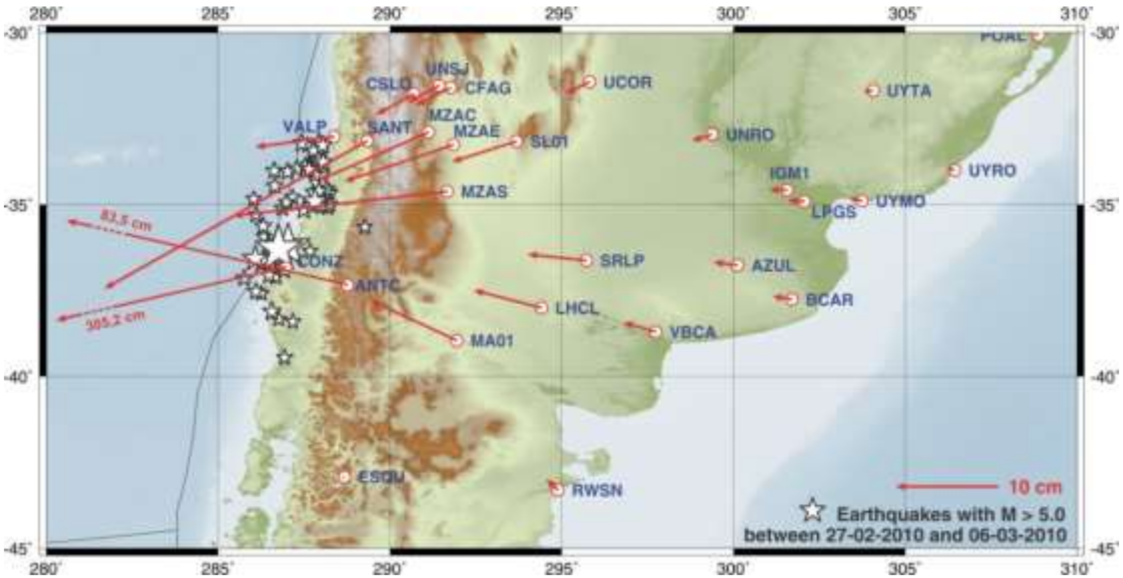
Earthquakes in the SIRGAS region since January 2010 with magnitudes > 5

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)



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

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 study and fix:

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

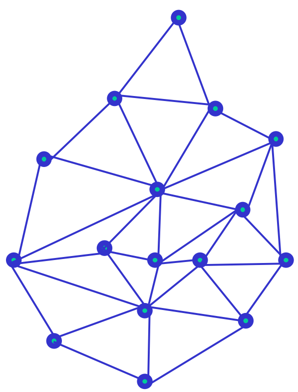
Input data: velocities based on cumulative solutions of GNSS weekly normal equations

SIRGAS 2011

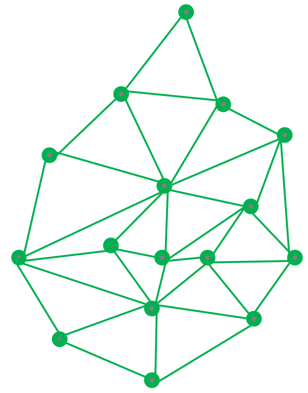
SIRGAS 2015

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

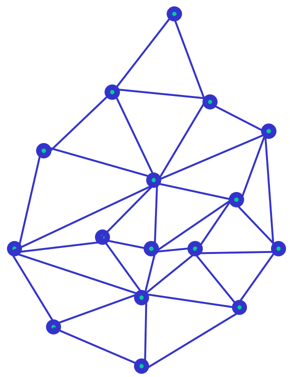
Reference networks without deformation:



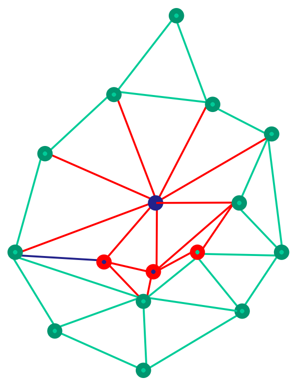
Similarity transformation



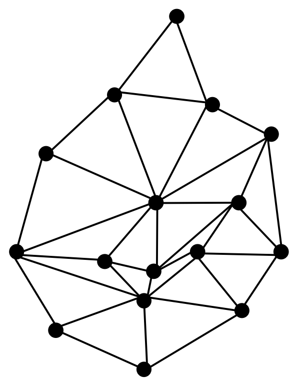
Reference networks with deformation:



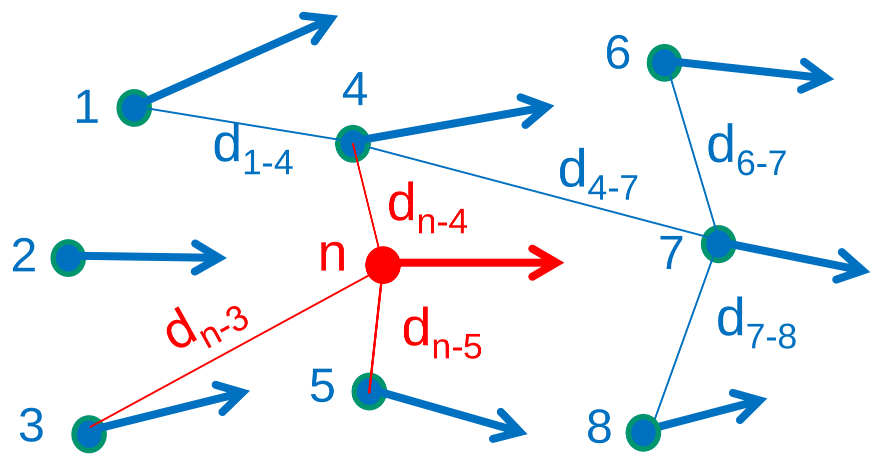
deformation model

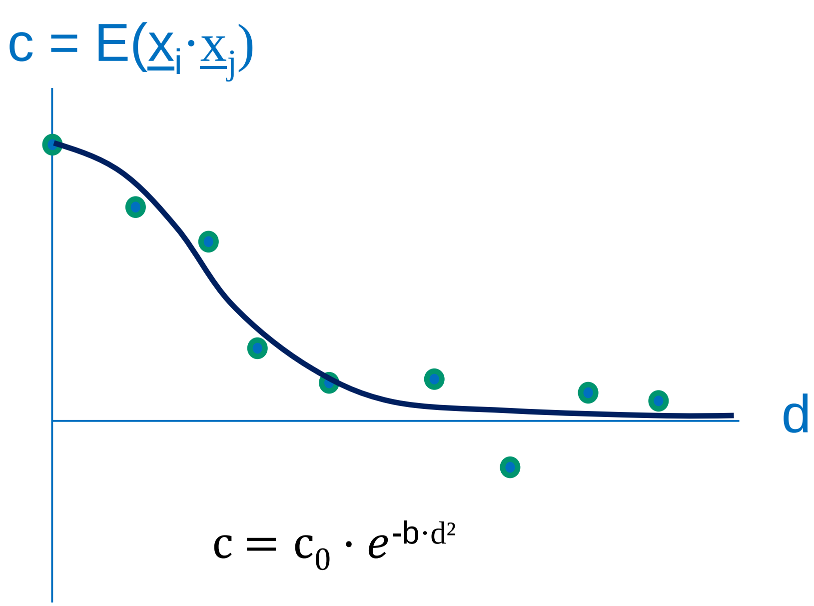


transformation



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

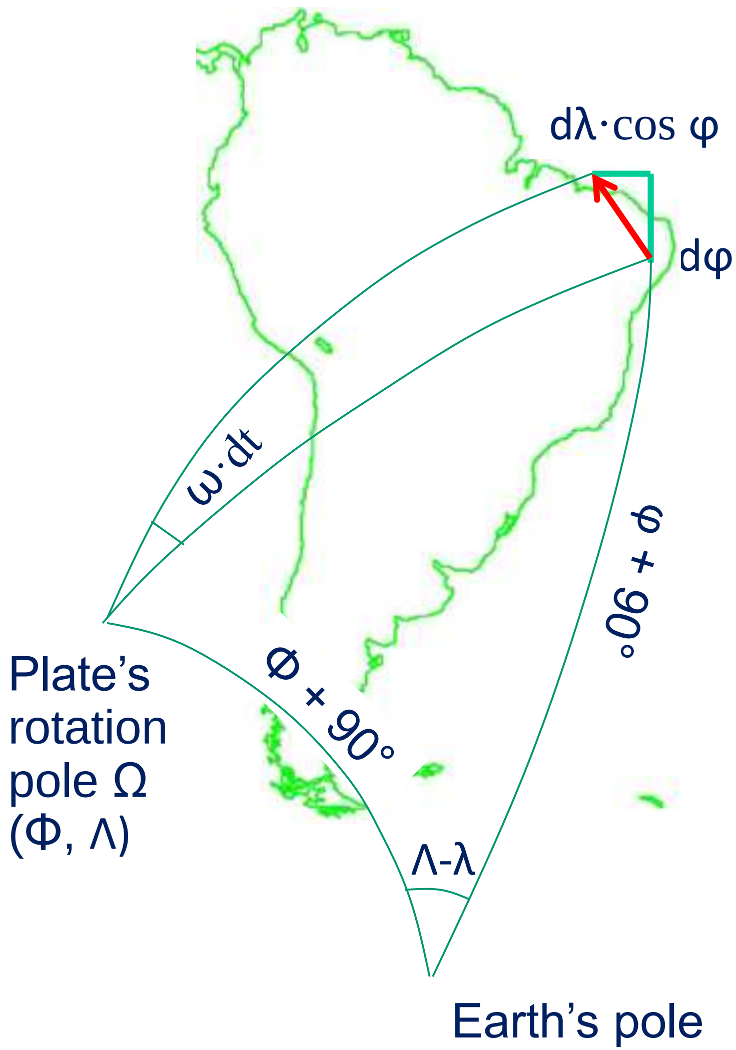
$\underline{\mathbf{C}}_{obs}$= correlation matrix between observed vectors (C_{NN}, C_{EE}, C_{NE})

$\underline{\mathbf{C}}$ 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 [$\mathbf{v} = \boldsymbol{\Omega}(\Phi,\Lambda,\omega) \times \mathbf{X}$] 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

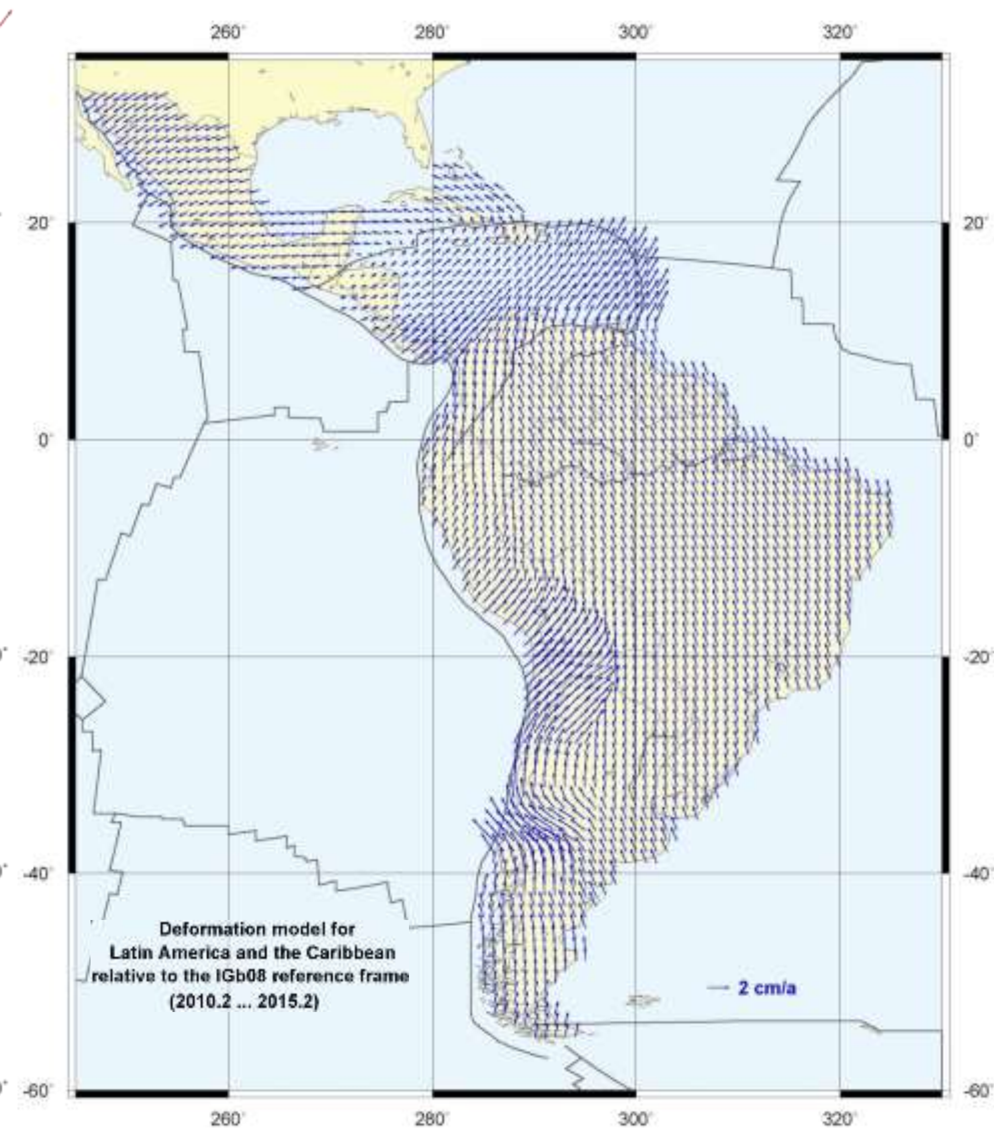
Plate	Φ [°]	Λ [°]	ω [mas/a]
NA(VEMOS15)	-0.2 ± 1.0	270.1 ± 1.1	0.82 ± 0.03
(APKIM2008)	- 5.8 ± 0.5	272.5 ± 0.2	0.68 ± 0.01
CA(VEMOS15)	26.4 ± 0.9	270.4 ± 2.2	1.21 ± 0.07
(APKIM2008)	28.0 ± 1.3	250.9 ± 2.7	0.75 ± 0.06
NZ(VEMOS15)	44.1 ± 1.3	258.0 ± 0.3	2.21 ± 0.02
(APKIM2008)	45.9 ± 0.6	257.6 ± 0.3	2.28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

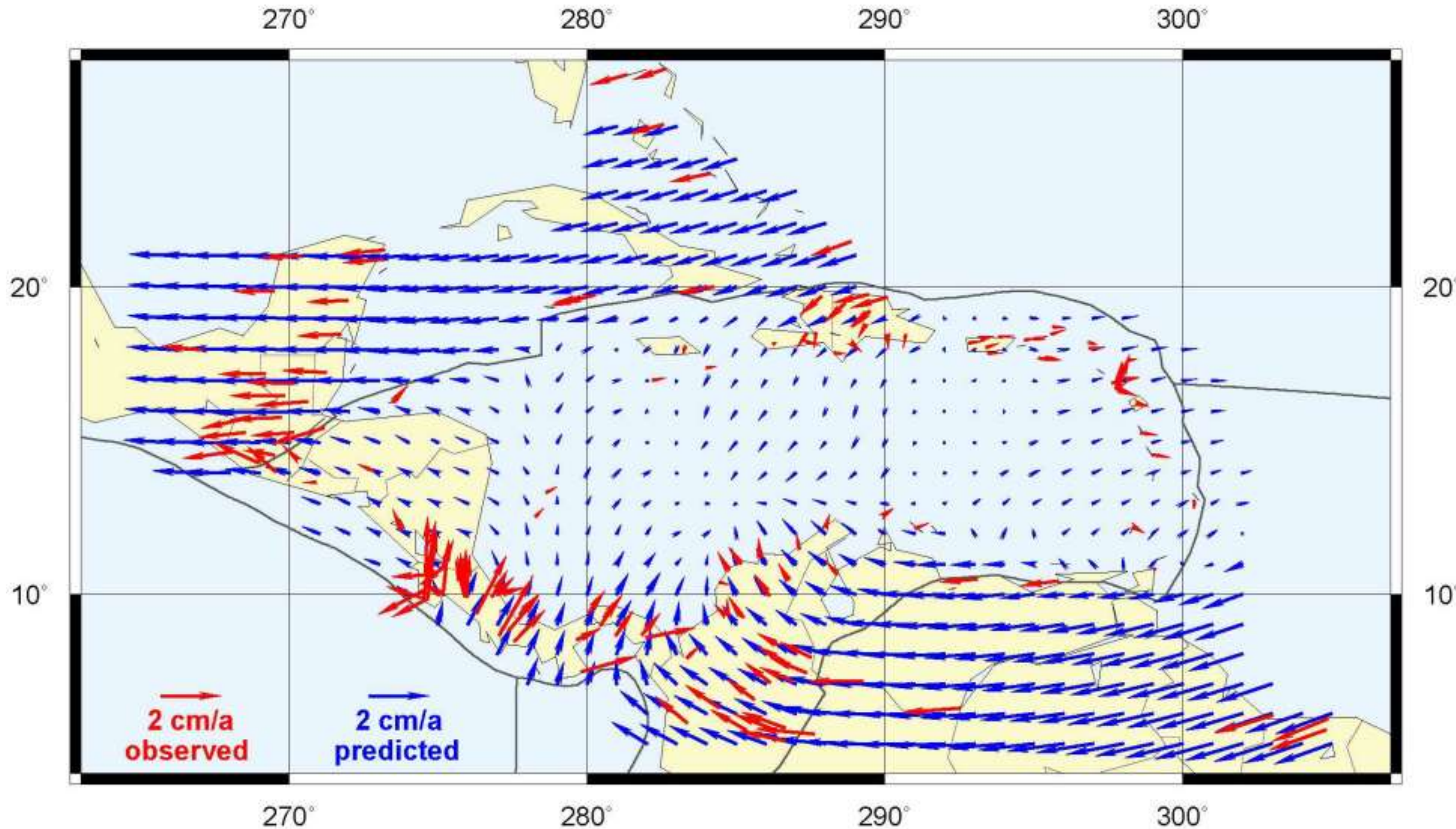
… deformation zones

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

Observed and predicted velocities

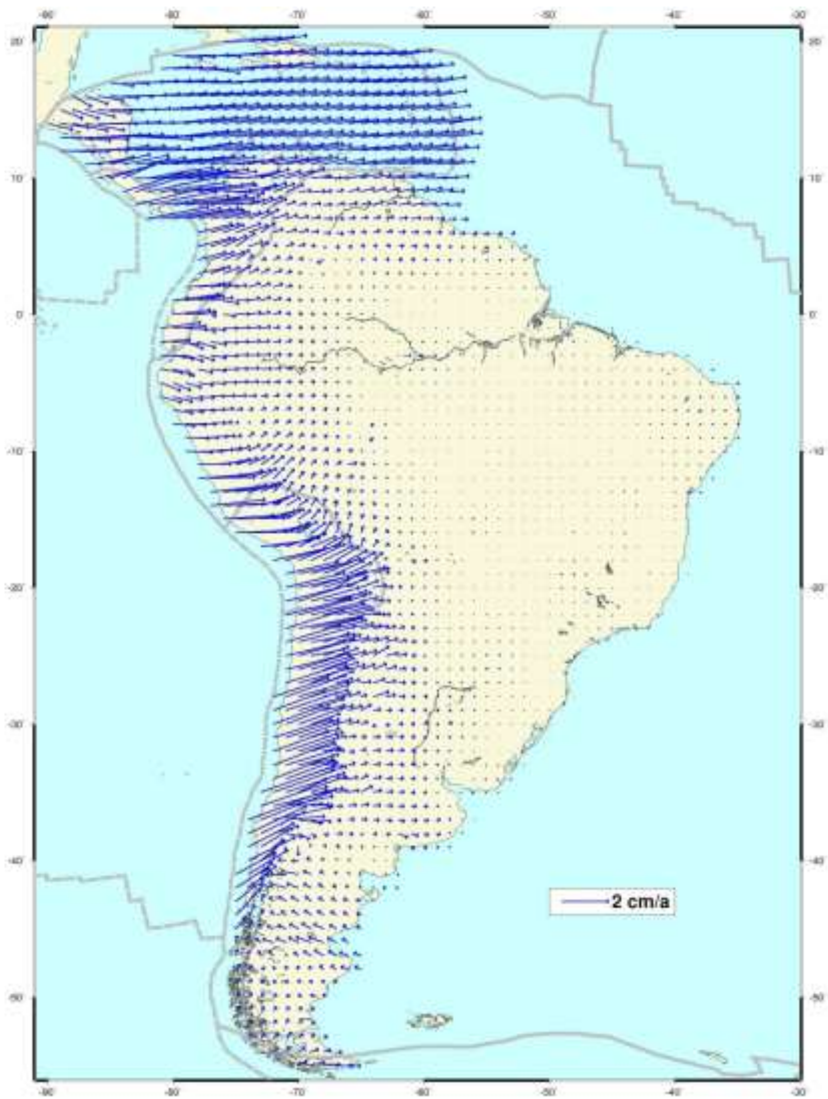


Deformation relative to the Caribbean Plate

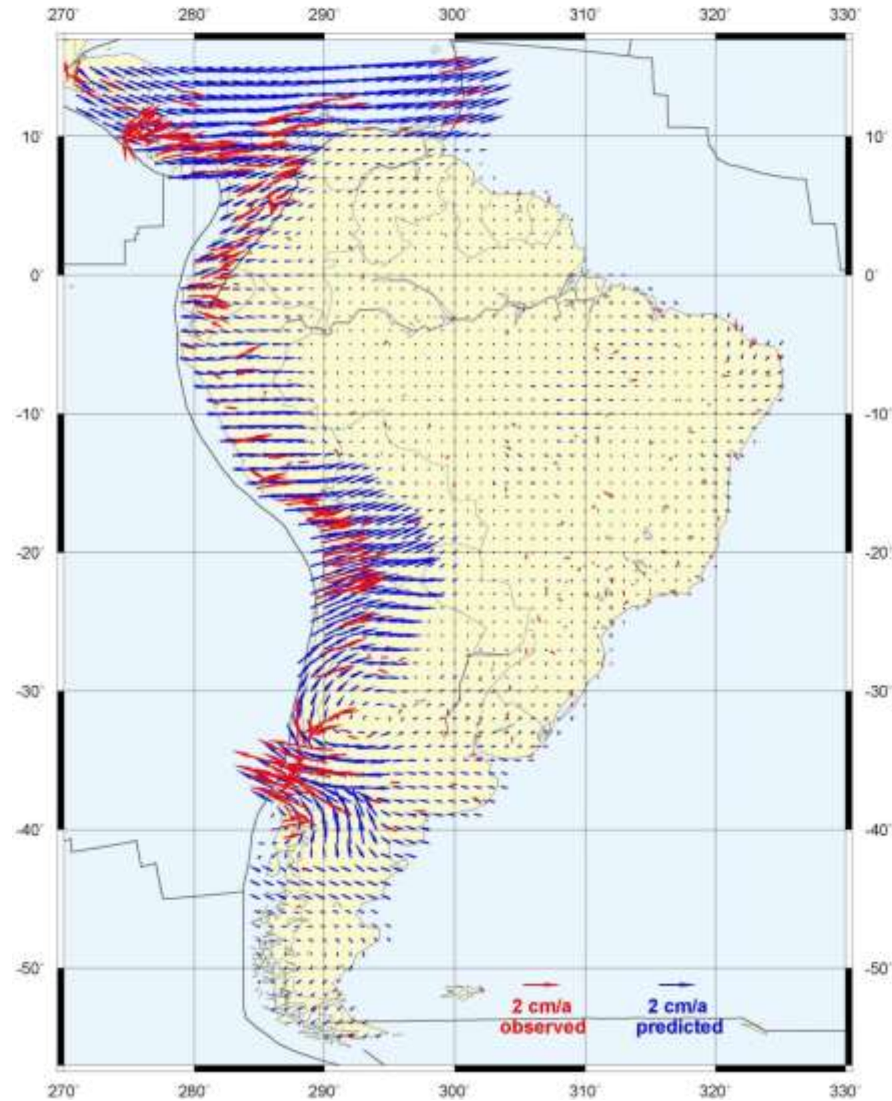


Deformation relative to the South American Plate

VEMOS 2009



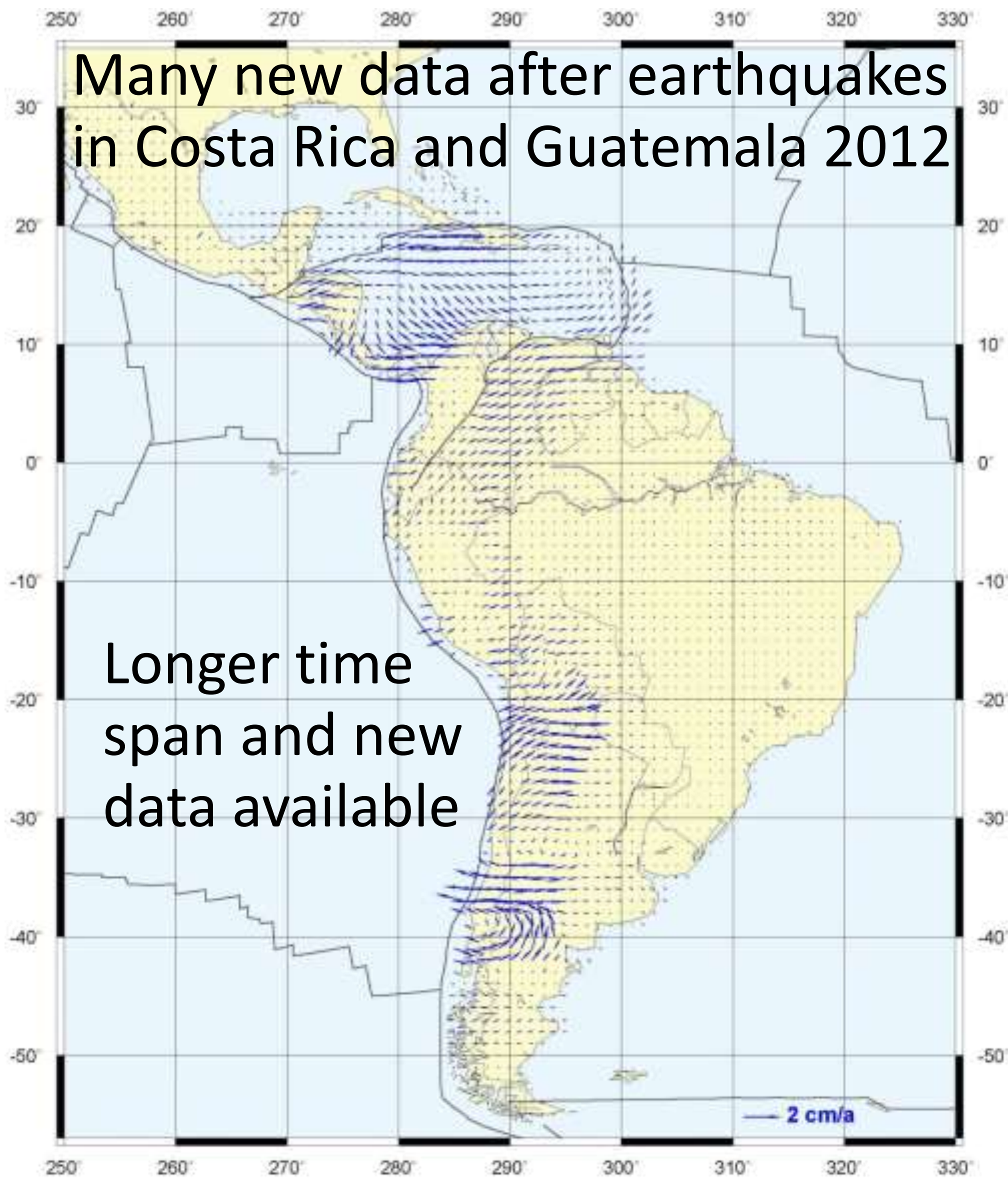
VEMOS 2015



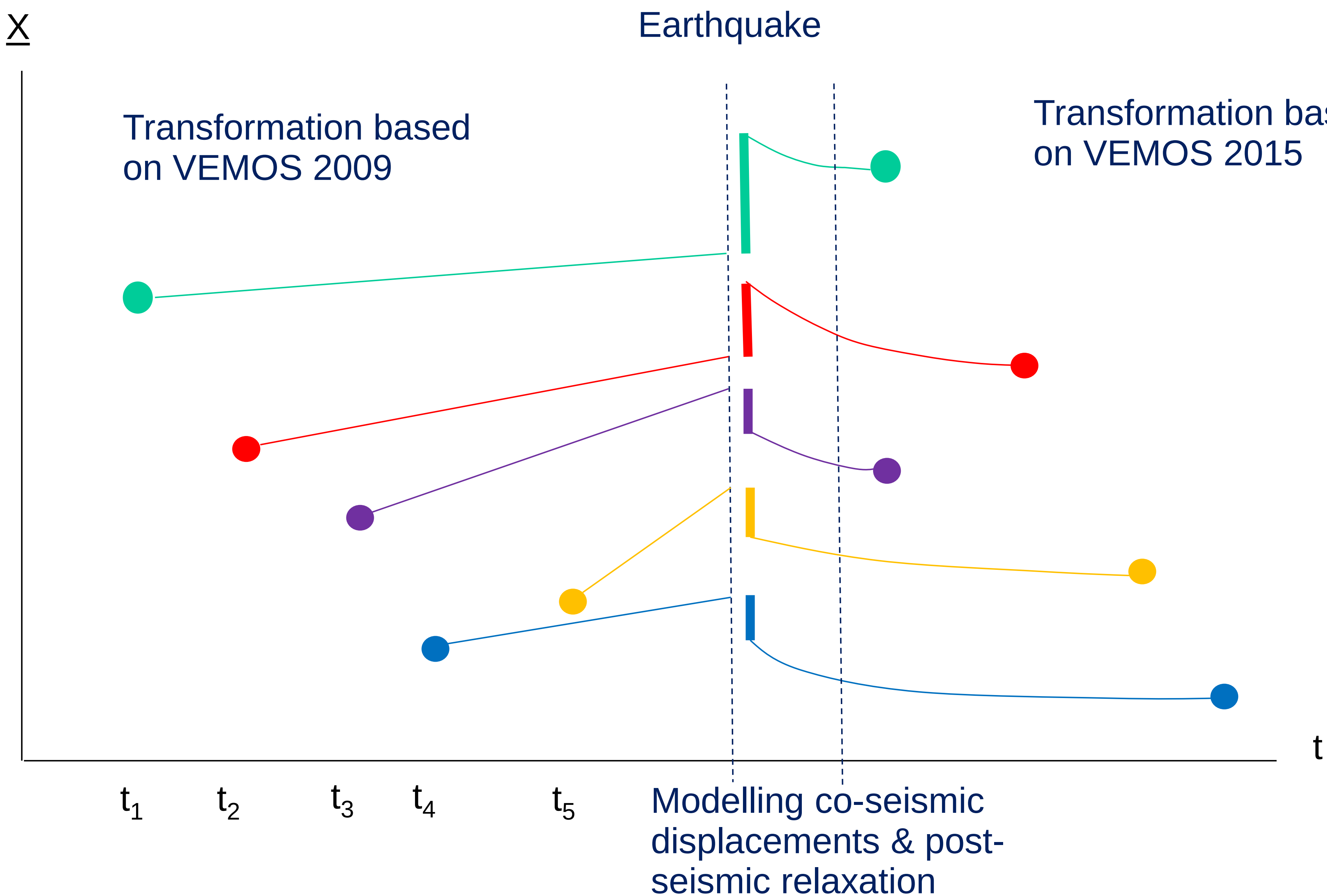
Differences with previous deformation models

VEMOS 2015 - VEMOS 2009

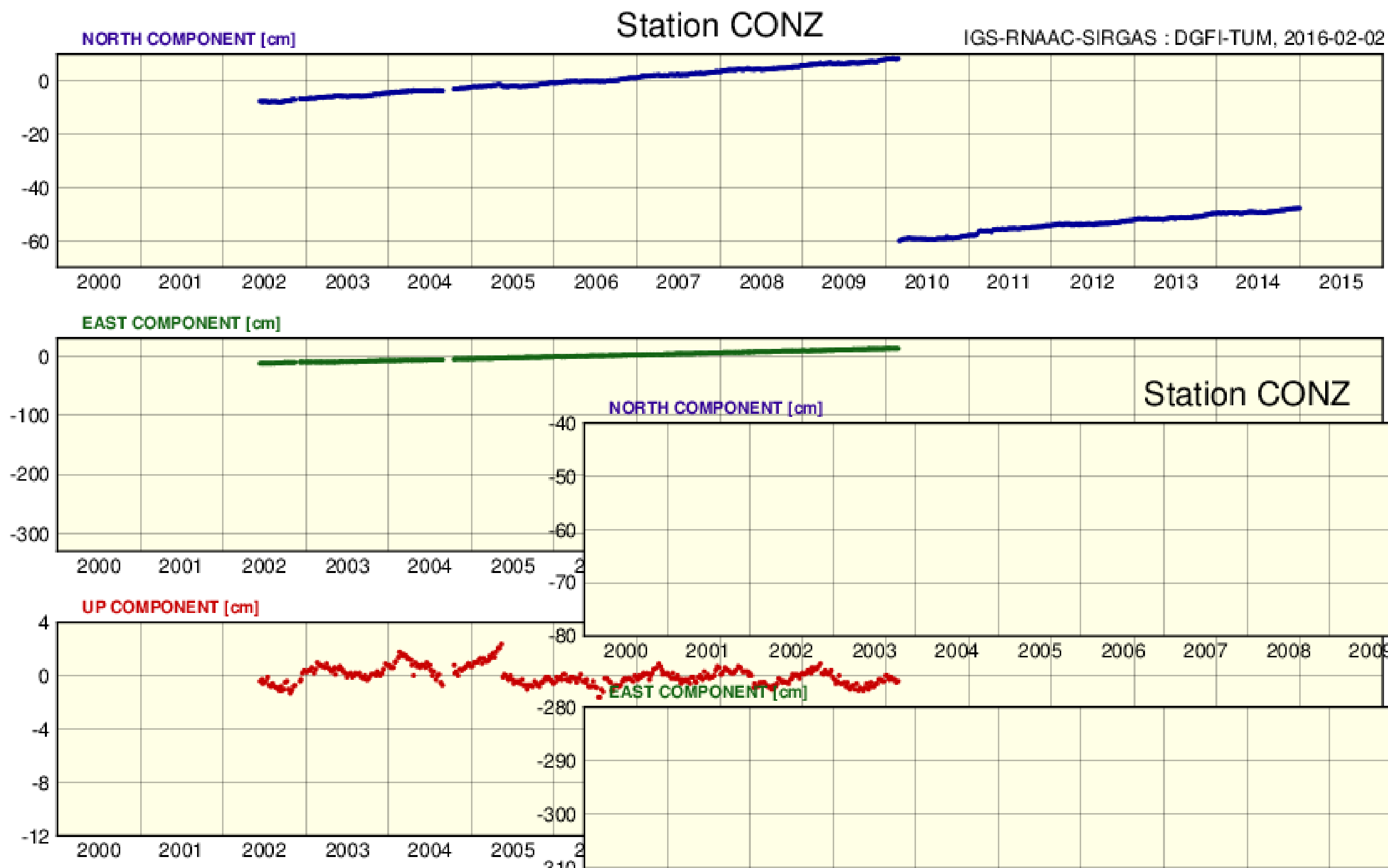
VEMOS 2015 – VEMOS 2014



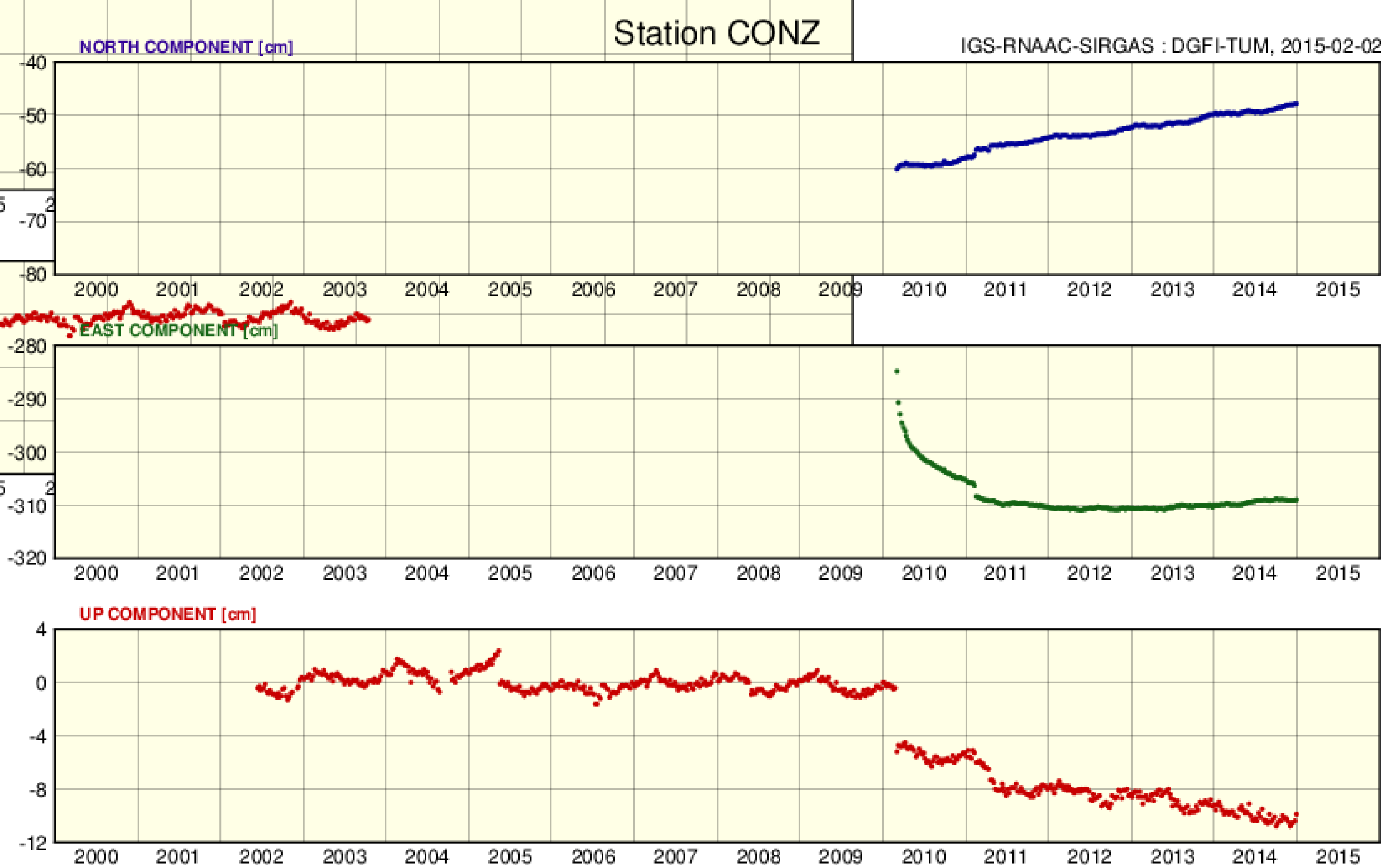
Transformation between pre- and post-seismic frames



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!
  ¡Muchas gracias por su atención!