Post-seismic crustal deformations after the 2010 earthquakes in the SIRGAS region

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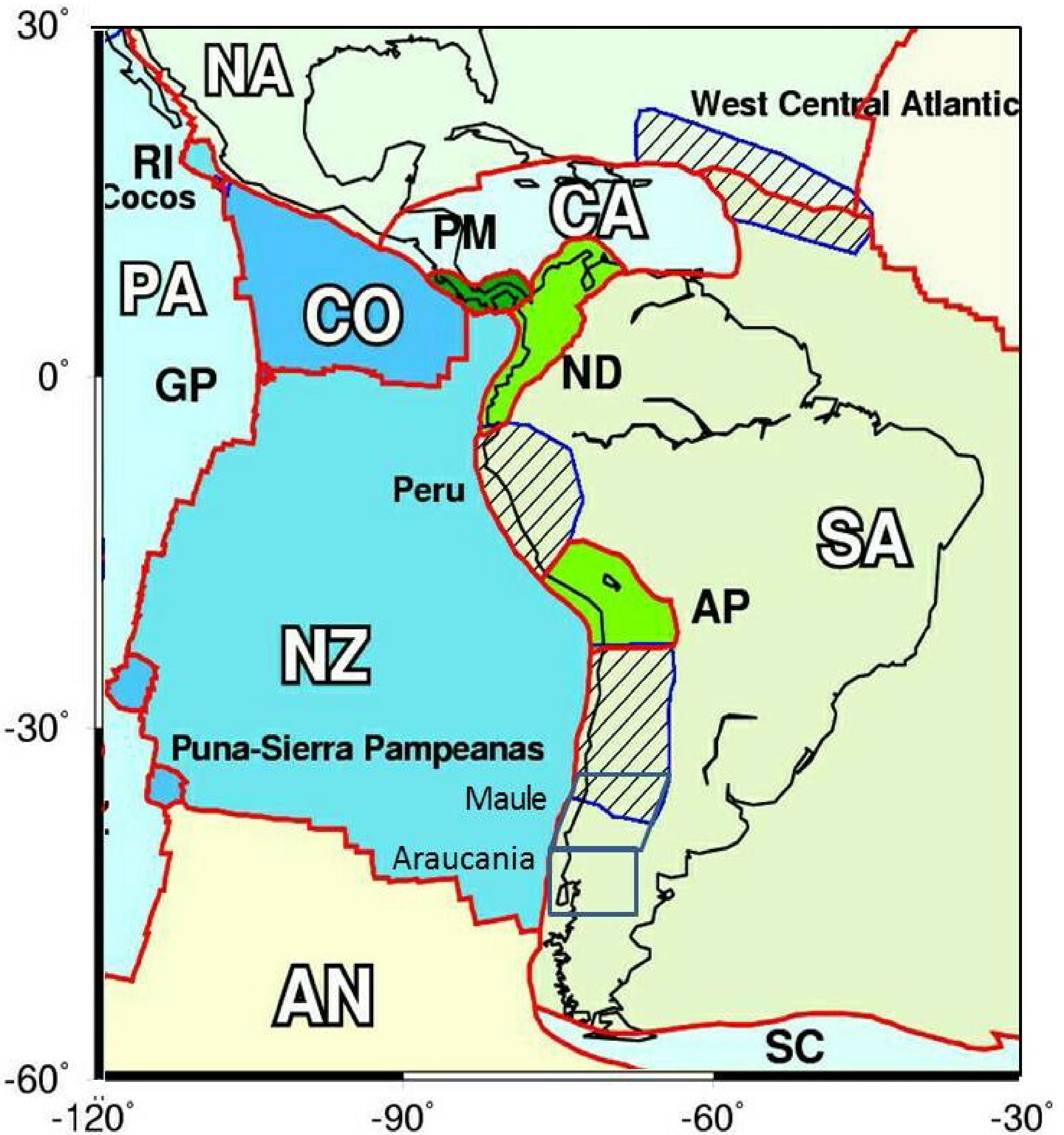
SIRGAS: Geocentric Reference System for the Americas

Tectonics in the SIRGAS region

The SIRGAS region is located in the boundary of (Bird 2003)

- the major tectonic plates: North America, Caribbean, Pacific, Cocos, Nazca, South America, and Antarctica;
- the smaller tectonic blocks: Rivera, Panama, Galapagos, Northern Andes, Altiplano, and Scotia; and
- the deformation zones: West Central Atlantic, Peru, and Puna-Sierra Pampeanas.

We add Maule and Araucania (see following investigation).



Extract of model PB2002 (Bird 2003) for the Latin American region

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

Symposium SIRGAS2015, Santo Domingo, Dominican Republic
November 18-20,2015

The interaction of these moving tectonic units causes an extremely high seismic activity generating episodic station movements and deformations in the geodetic reference frames (ITRF, its continental densification SIRGAS and the national densifications).

Earthquakes in Latin America since 2010-01-01 with magnitudes > 5, source: IRIS: Incorporated Research Institutions for Seismology, www.iris.edu

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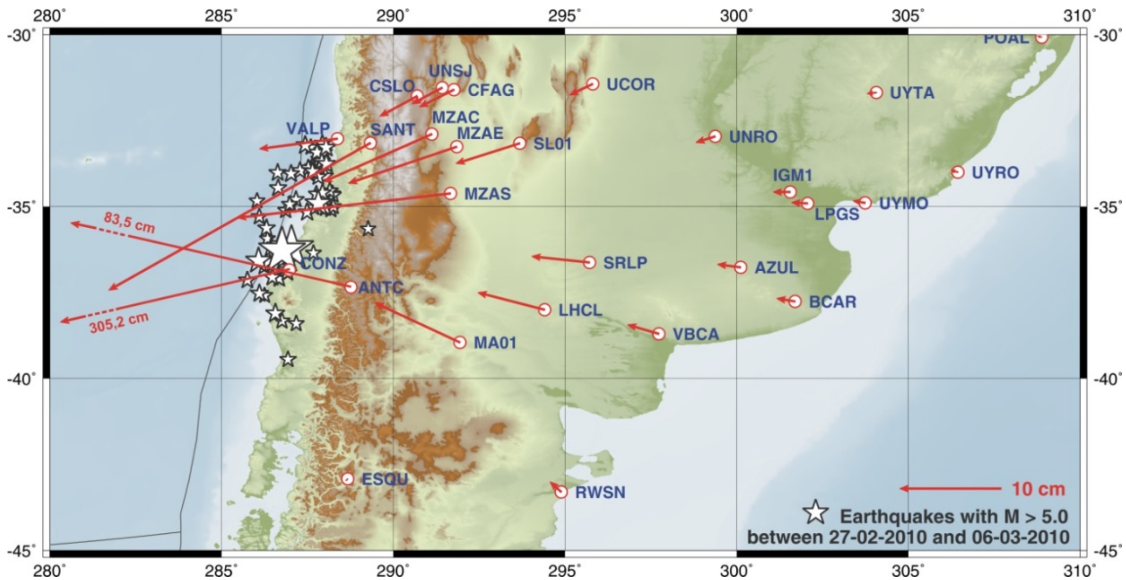
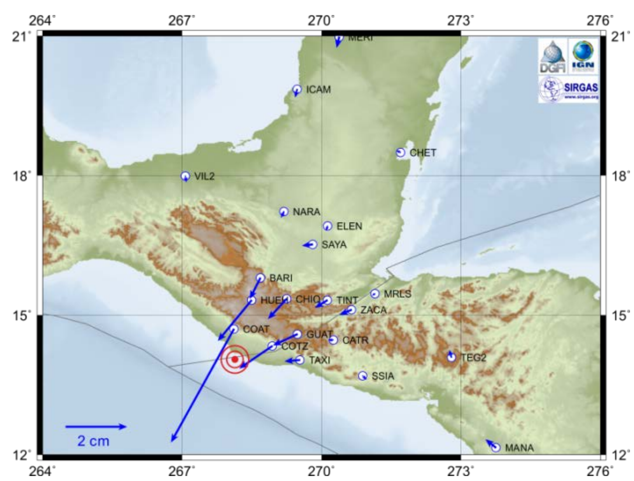
www.sirgas.org

Seismic deformations in reference frames





Co-seismic displacements in Chile (Feb. 2010) and 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 guarantee:

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

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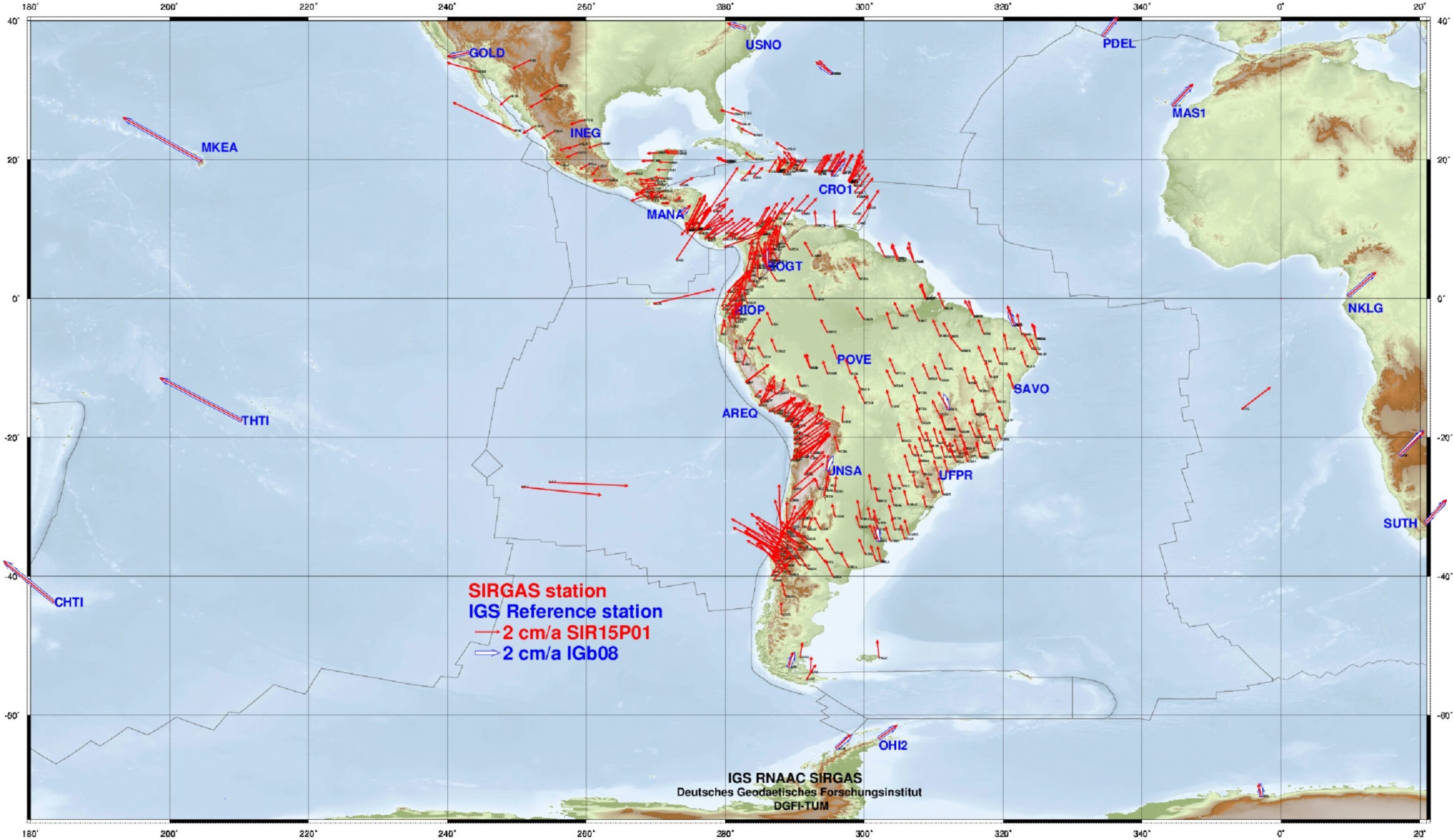
- Weekly normal equations (according to IERS/IGS/SIRGAS standards);
- Time span: 2010.2 (2012.2) - 2015.2; 471 stations;
- Frame: IGb08 epoch 2013.0; Accuracy: N - E = ±1.0 mm/a, h = ±1.2 mm/a



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

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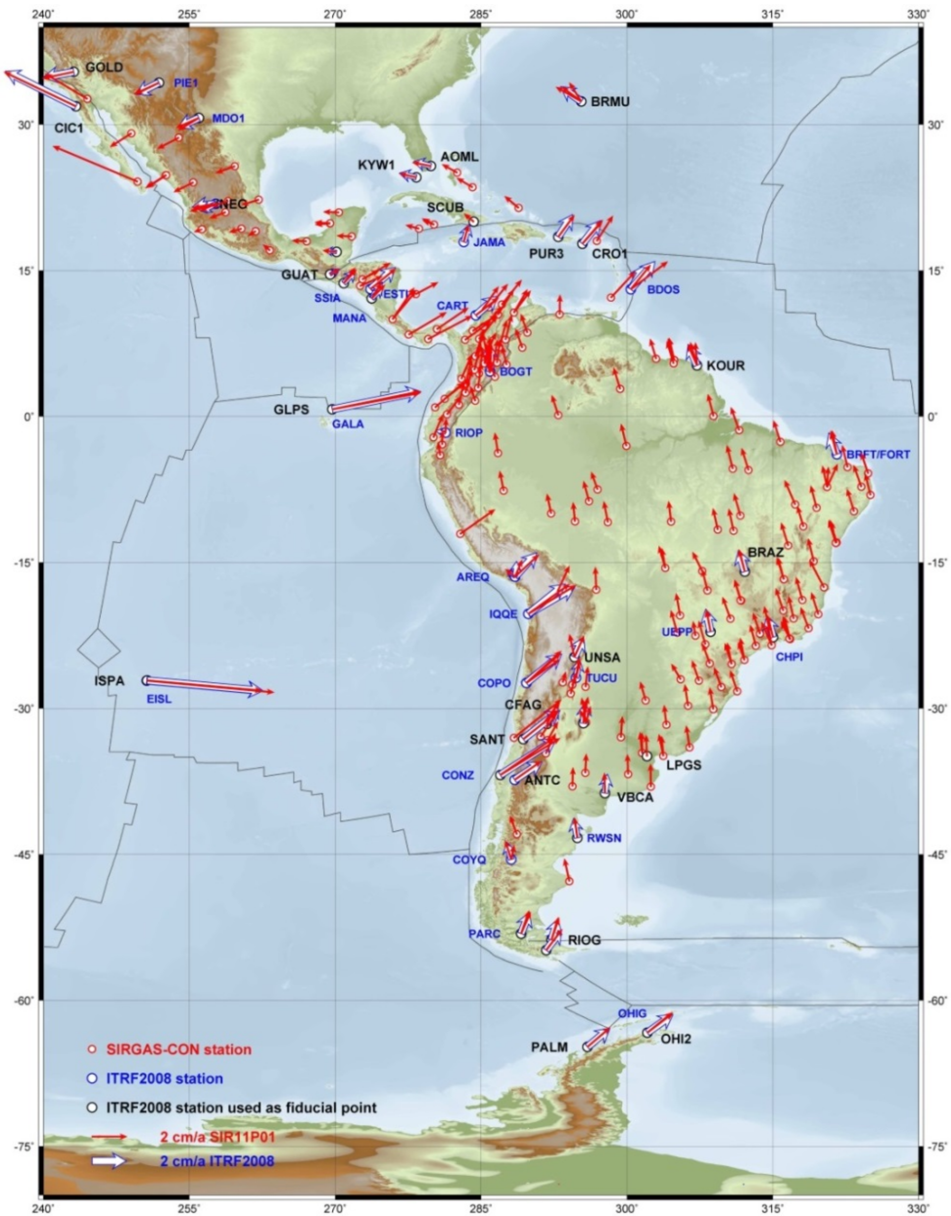
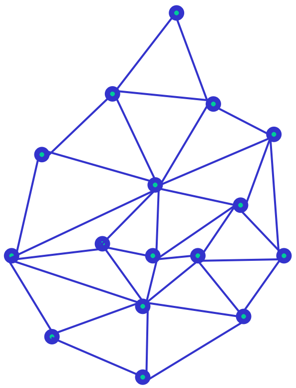
SIRGAS 2011



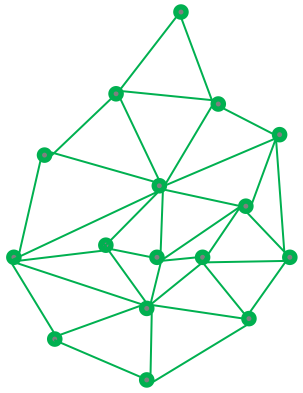
SIRGAS 2015

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

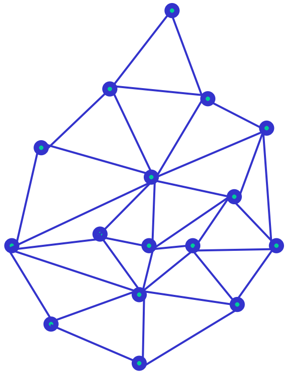
Reference networks without deformation:



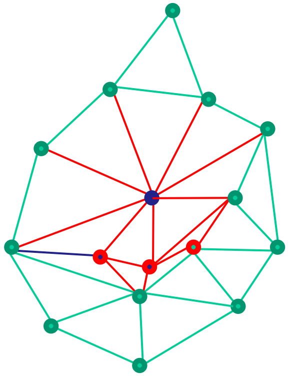
Similarity transformation



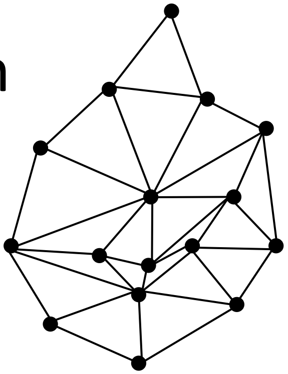
Reference networks with deformation:



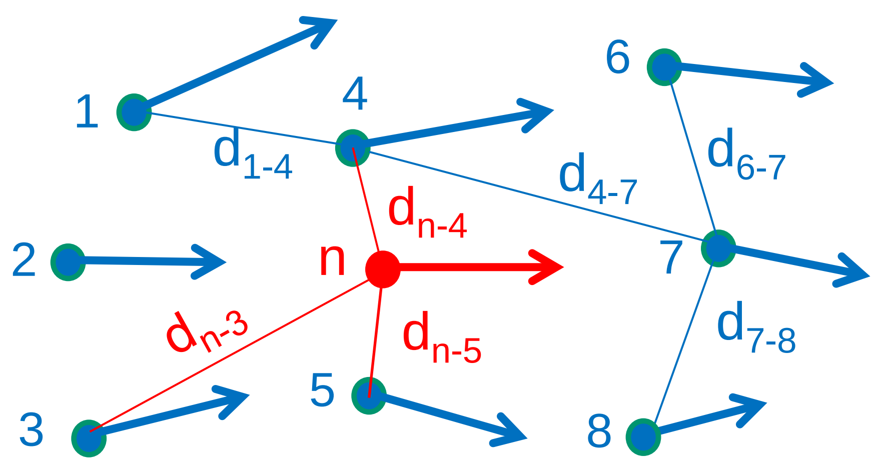
deformation model

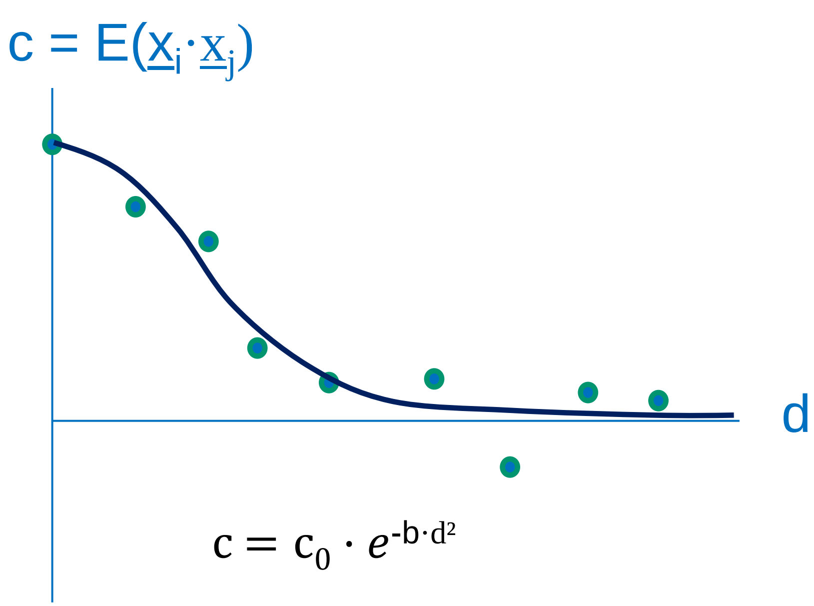


transformation



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})

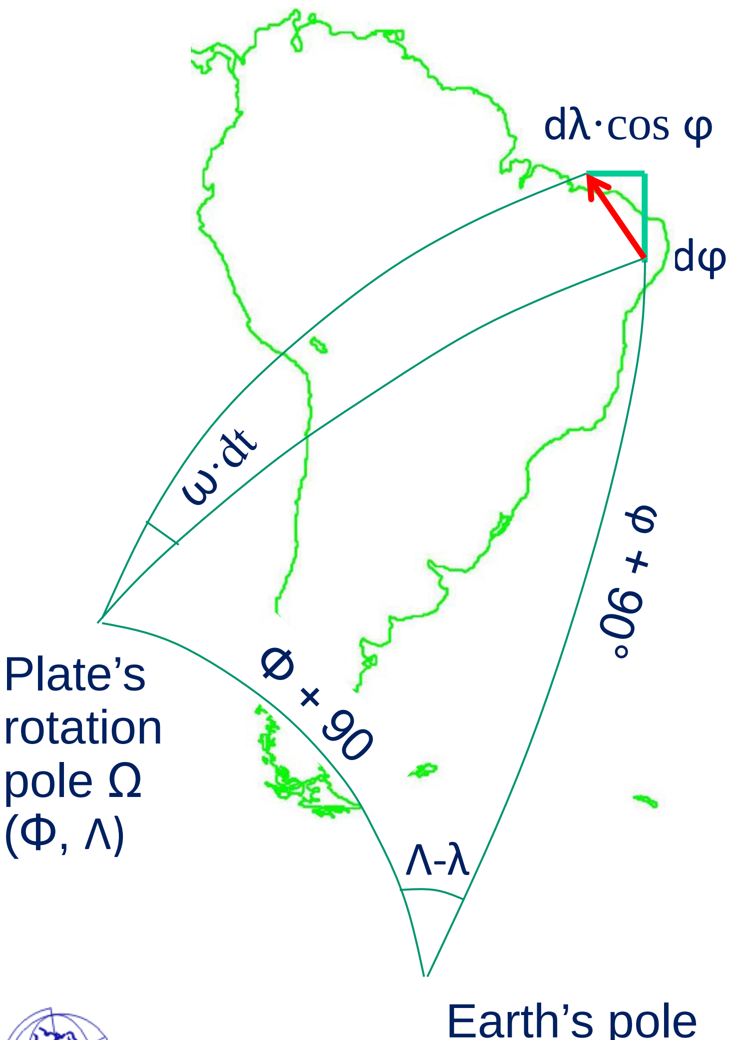
$\underline{\mathbf{C}}$ matrices are built from empirical isotropic, stationary covariance functions.

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

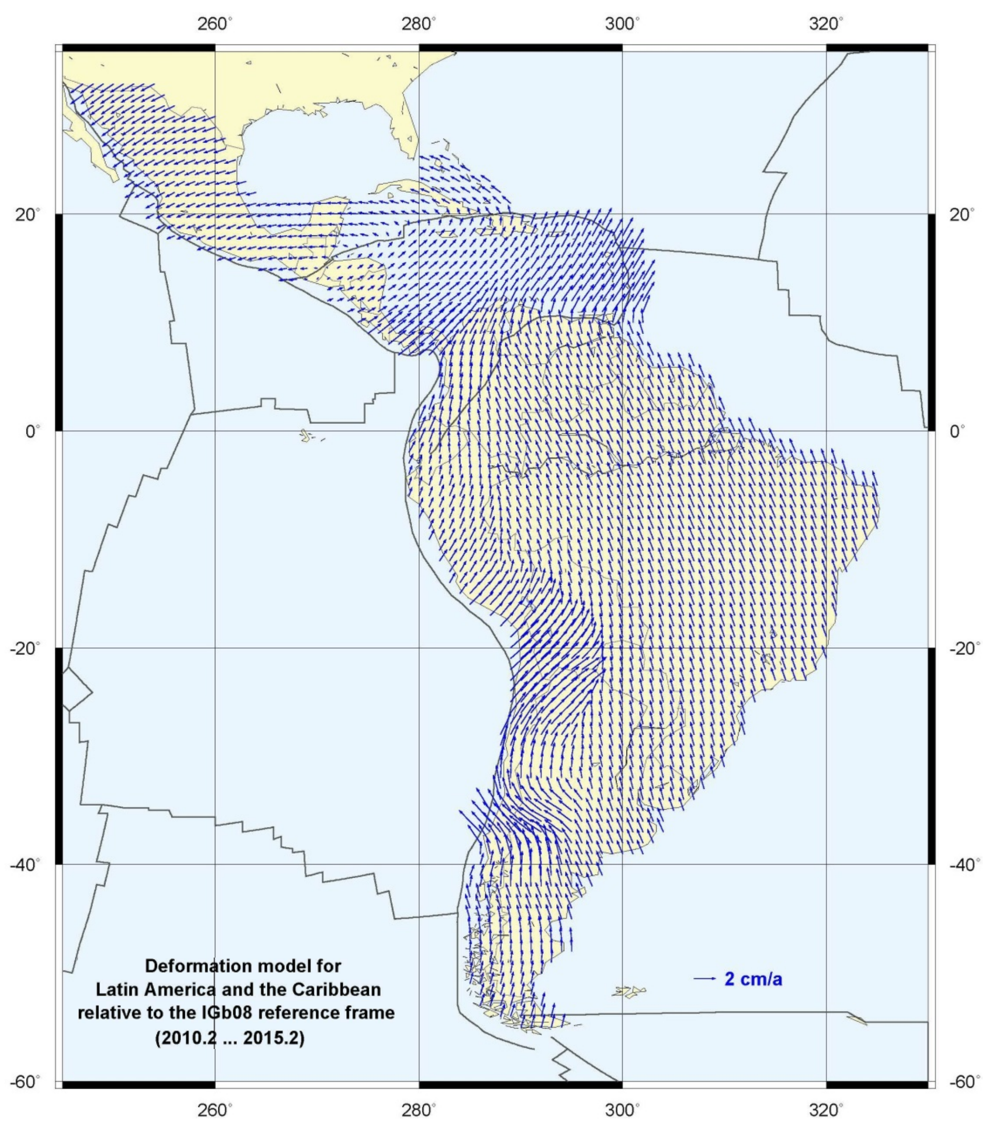
Plate	Φ [°]	Λ [°]	ω [mas/a]
NA(VEMOS15)	-0.2 ± 1.0	270.1 ± 1.1	0.82 ± 0.03
(APKIM2008)	- 5.8 ± 0.5	272.5 ± 0.2	0.68 ± 0.01
CA(VEMOS15)	26.4 ± 0.9	270.4 ± 2.2	1.21 ± 0.07
(APKIM2008)	28.0 ± 1.3	250.9 ± 2.7	0.75 ± 0.06
NZ(VEMOS15)	44.1 ± 1.3	258.0 ± 0.3	2.21 ± 0.02
(APKIM2008)	45.9 ± 0.6	257.6 ± 0.3	2.28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



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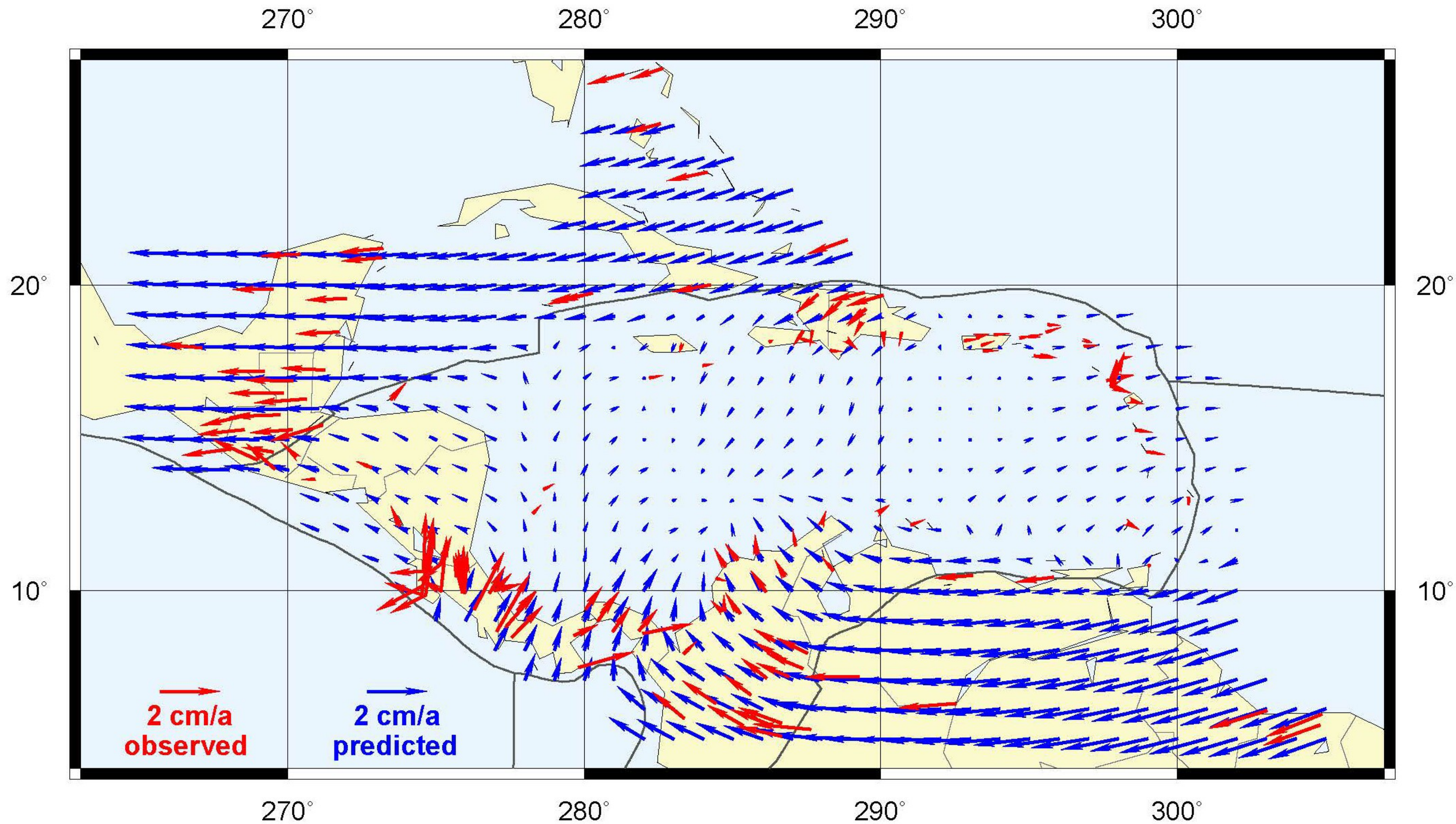
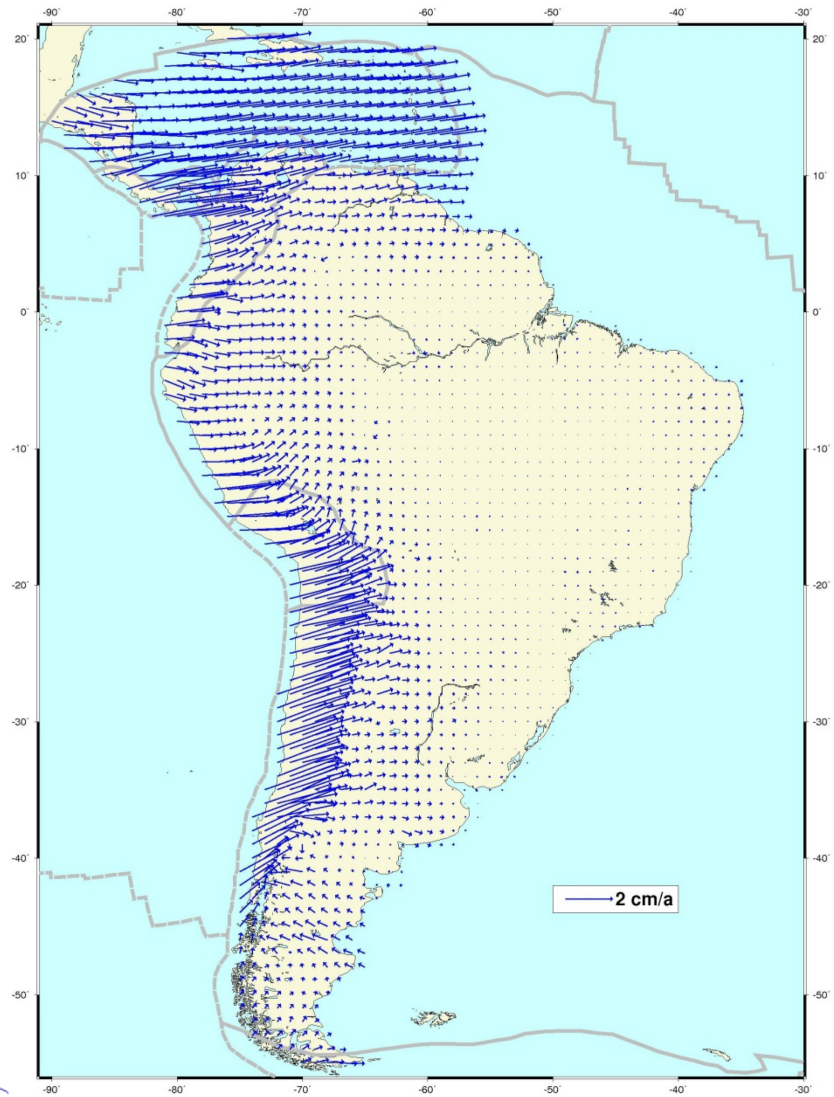
Deformation relative to the Caribbean Plate

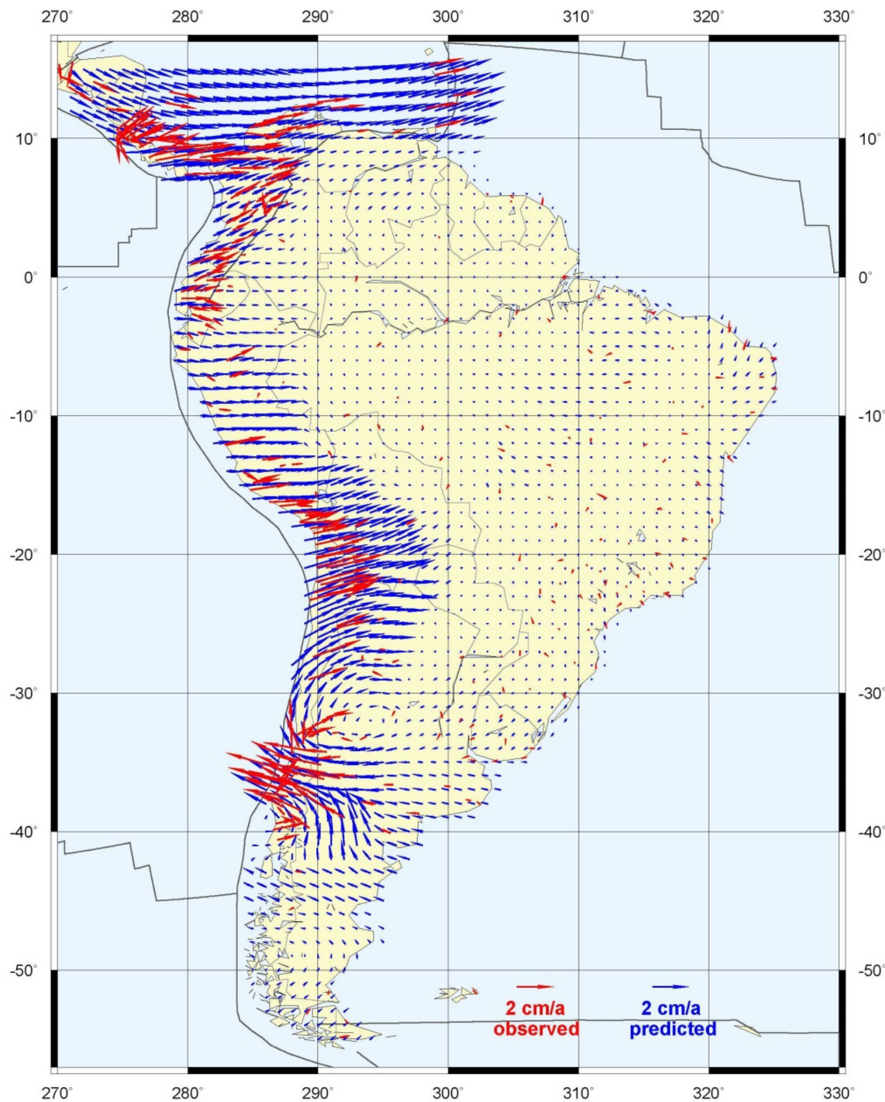


Deformation relative to the South American Plate

VEMOS 2009



VEMOS 2015



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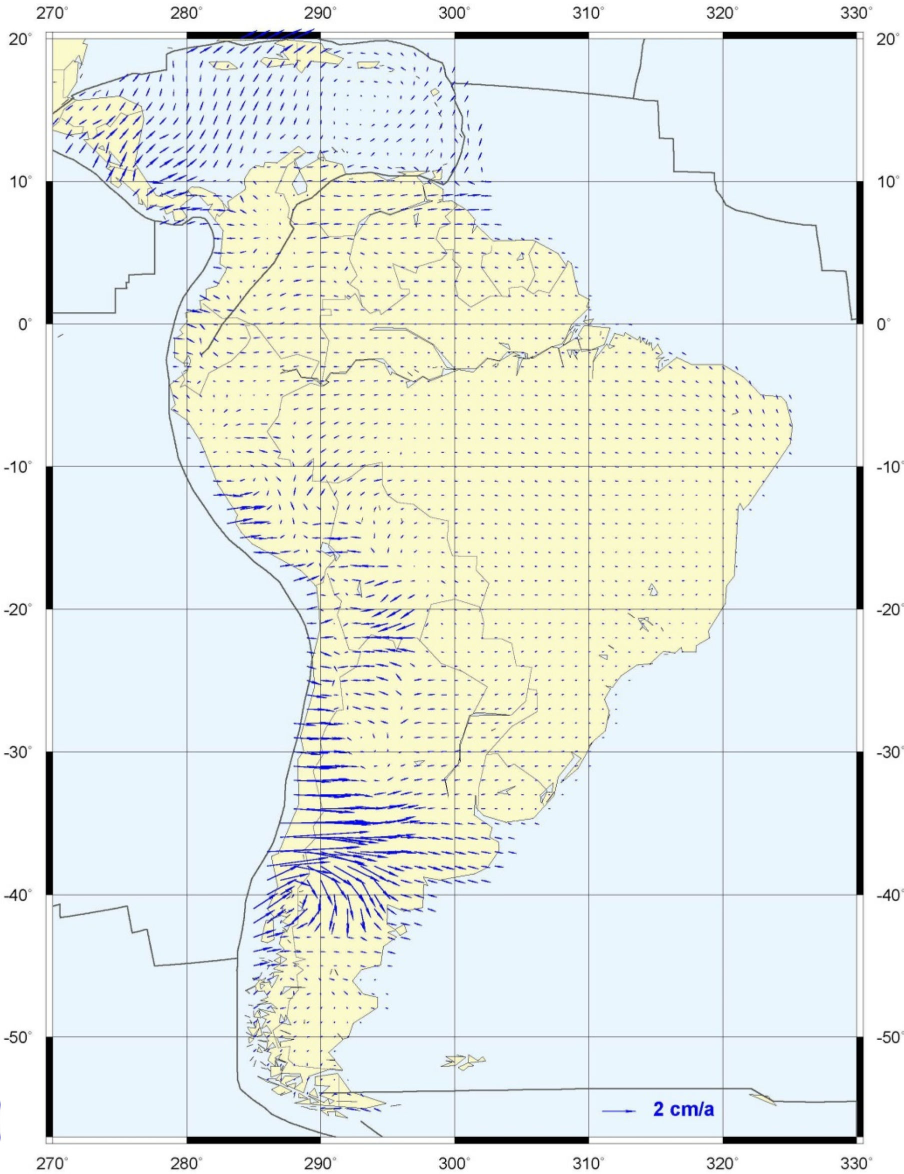
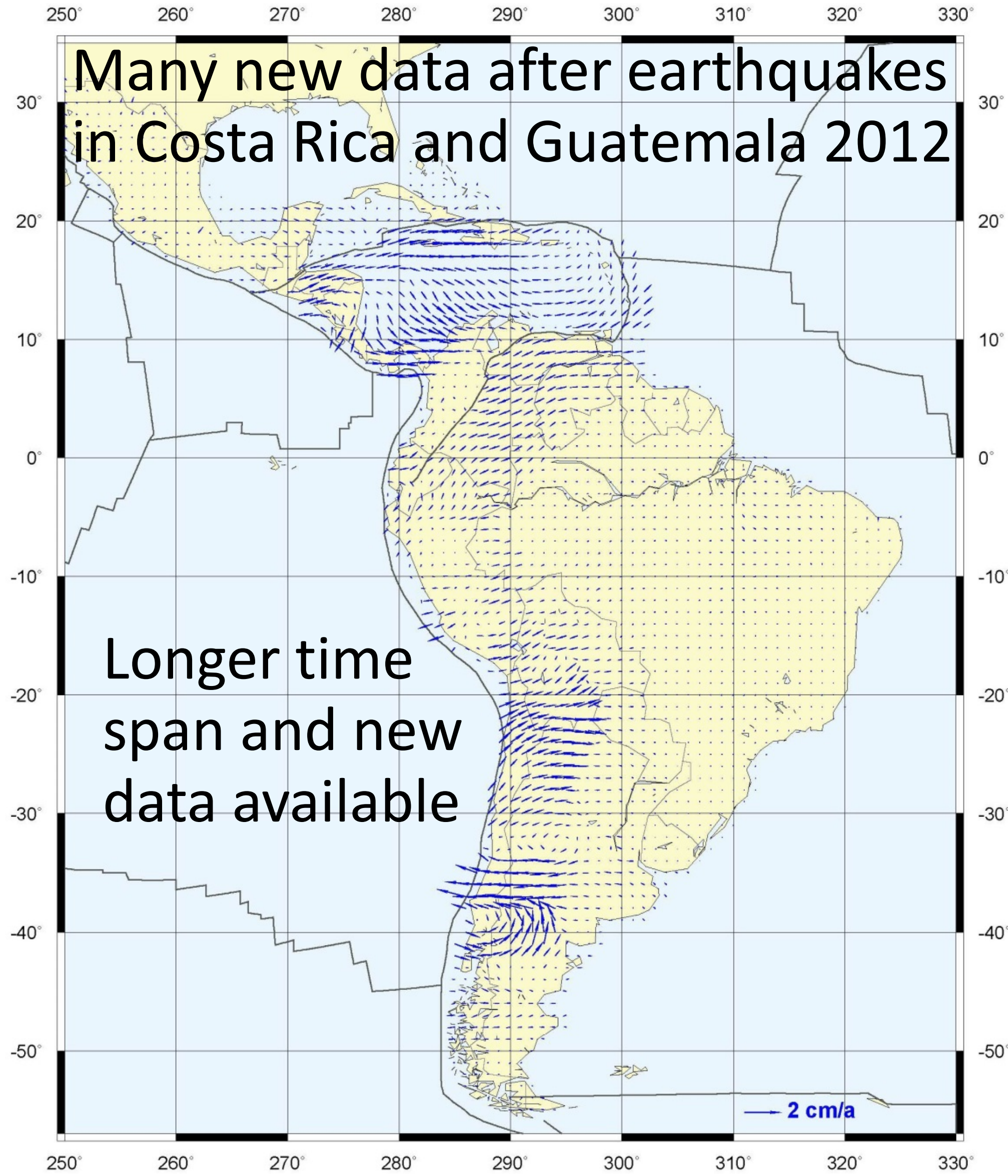
Differences with previous deformation models

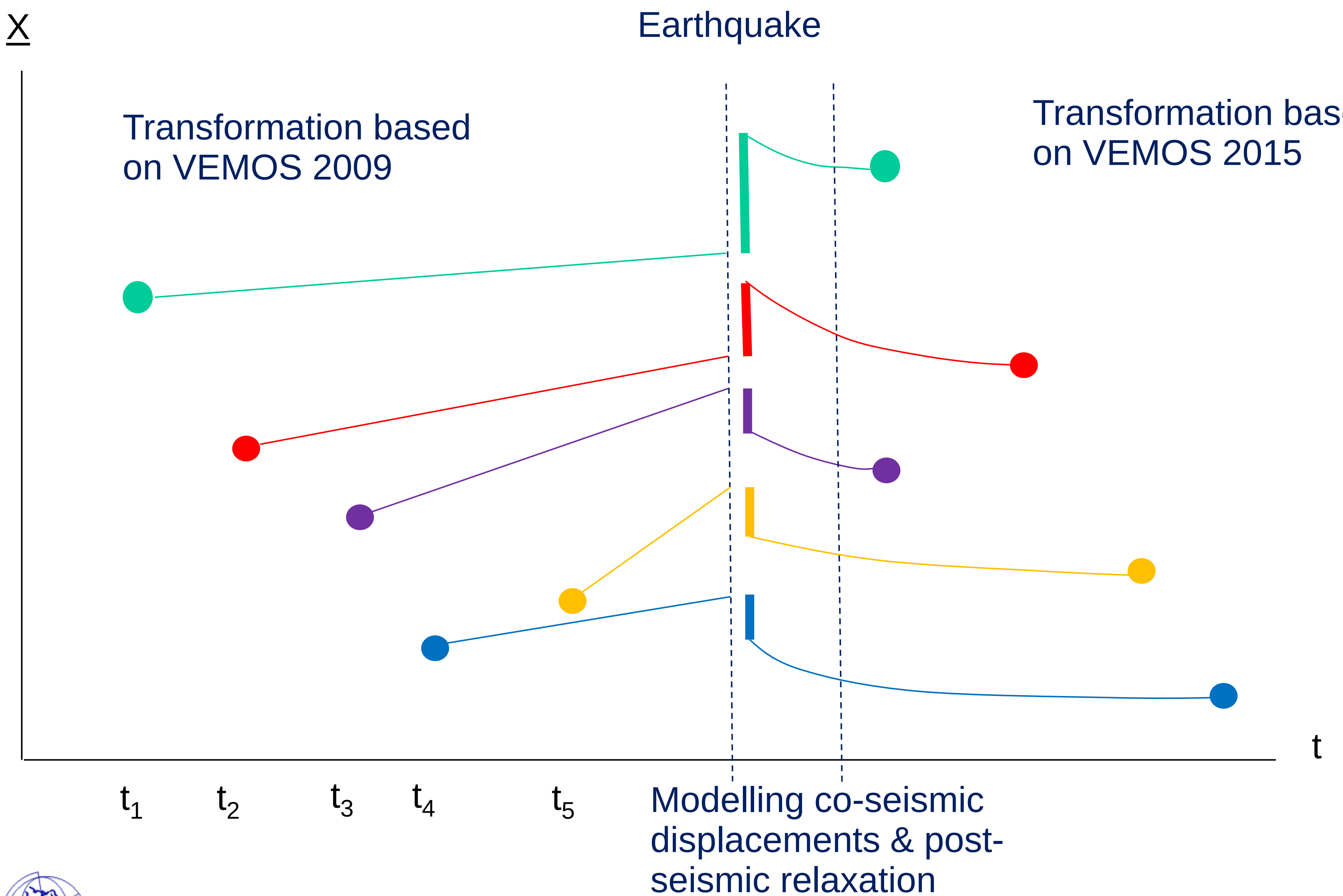
VEMOS 2015 - VEMOS 2009



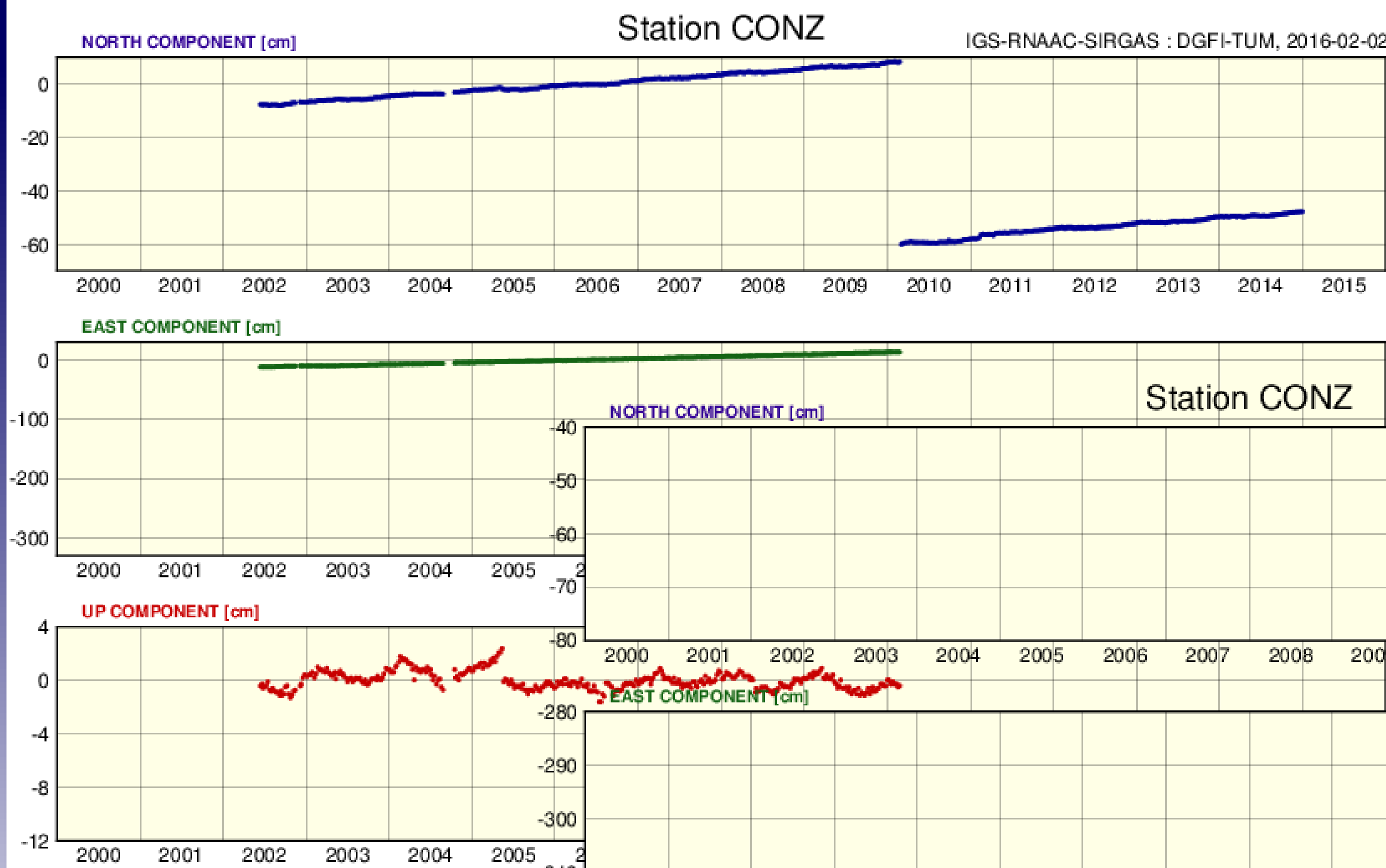
VEMOS 2015 – VEMOS 2014



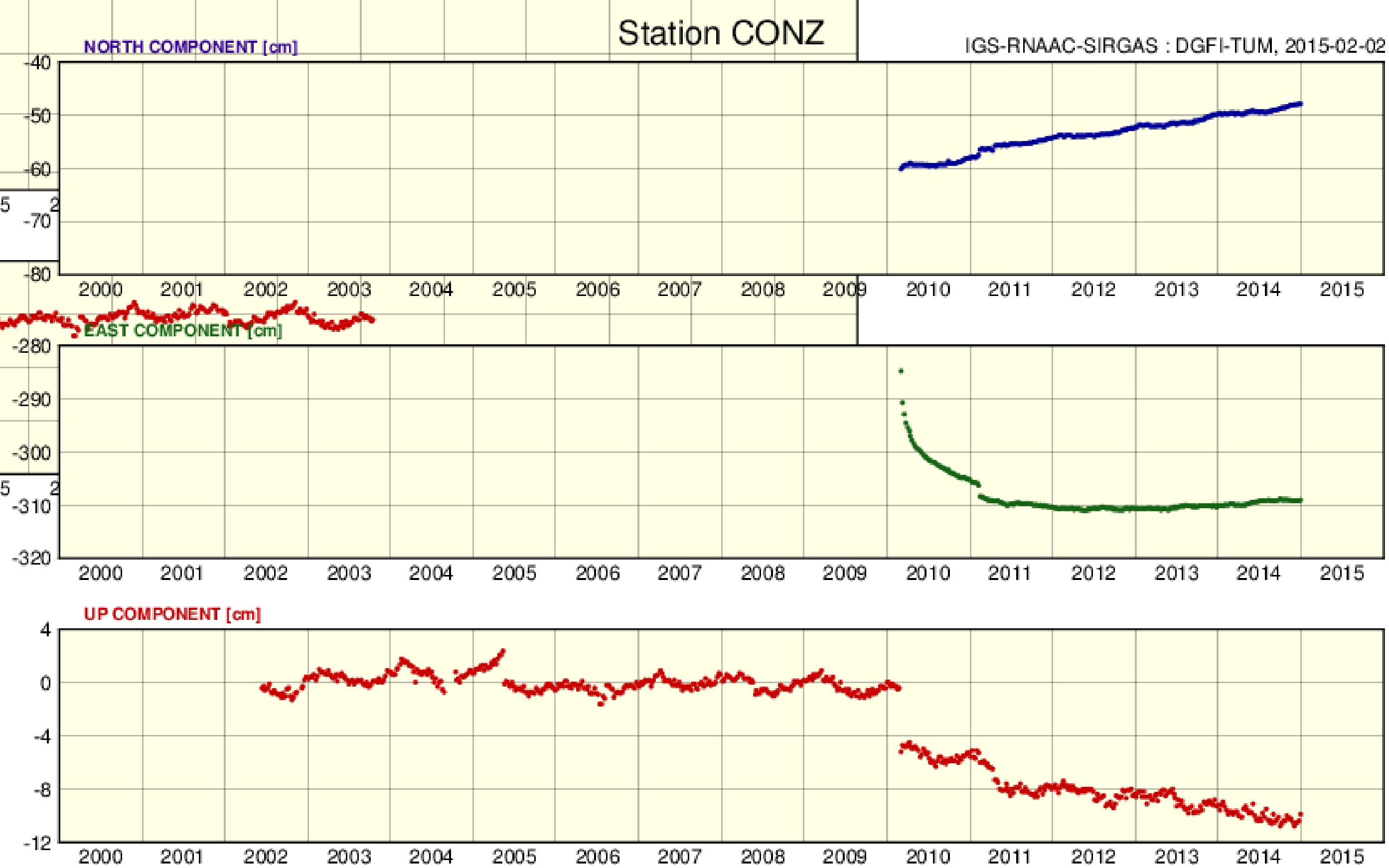
Transformation between pre- and post-seismic frames



Co-seismic displacements and velocity changes



Displacement at earthquake 2010



Velocity change after event 2010

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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!