Post-seismic crustal deformations after the 2010 earthquakes in Latin America

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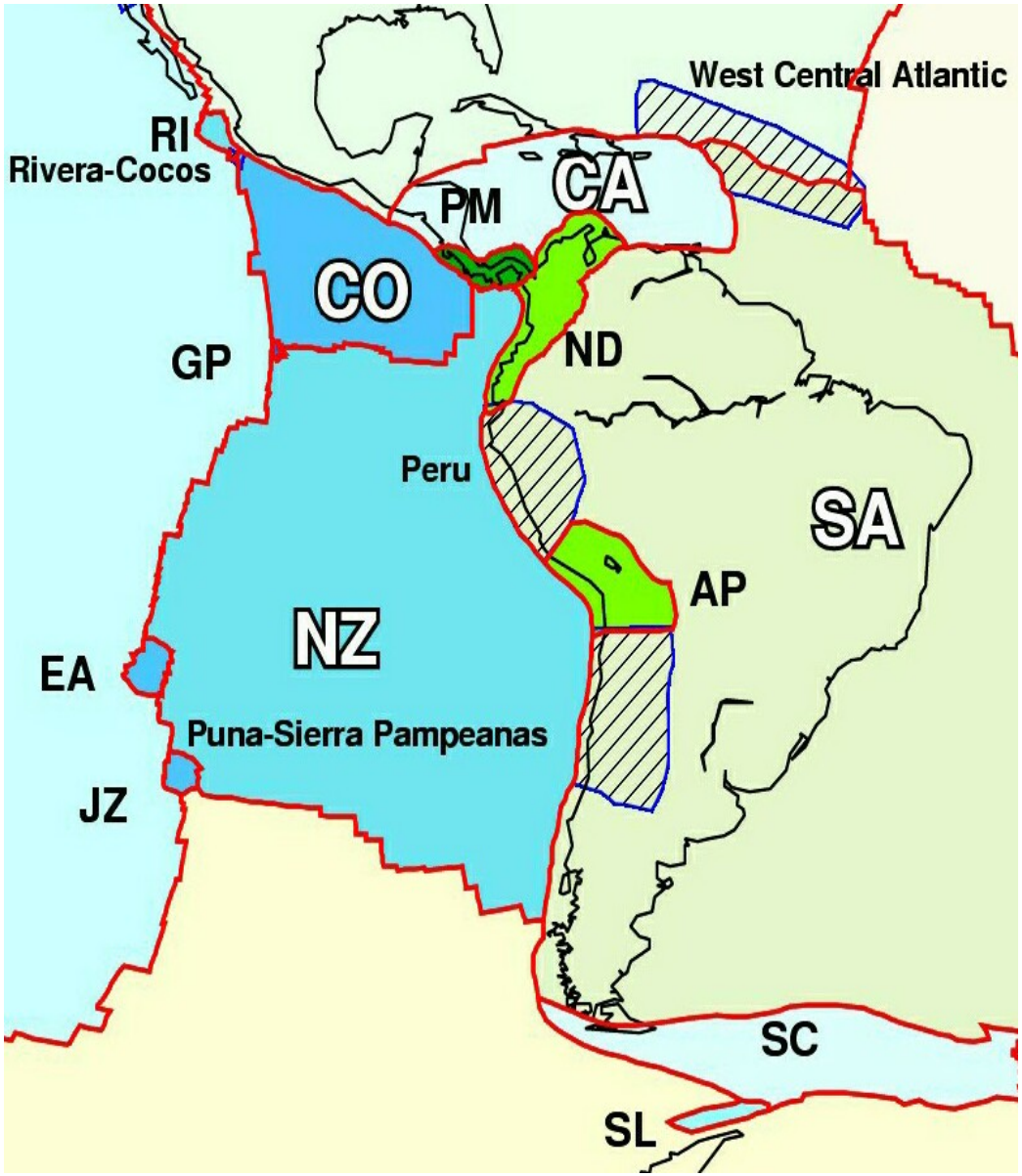
SIRGAS: Geocentric Reference System for the Americas

Tectonics in Latin America

- The Western part of Latin America is located in the plate boundary zone between
  - the North American and Caribbean plates in the North,
  - the Pacific, Cocos and Nazca plates in the West, and
  - the South American plates in the East.



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

Earthquakes in Latin America since January 2010 with magnitudes > 5

- The interaction of these moving plates causes an extremely high seismic activity in this area, generating episodic station movements and deformations in the geodetic reference frames (like ITRF and its regional densification SIRGAS).

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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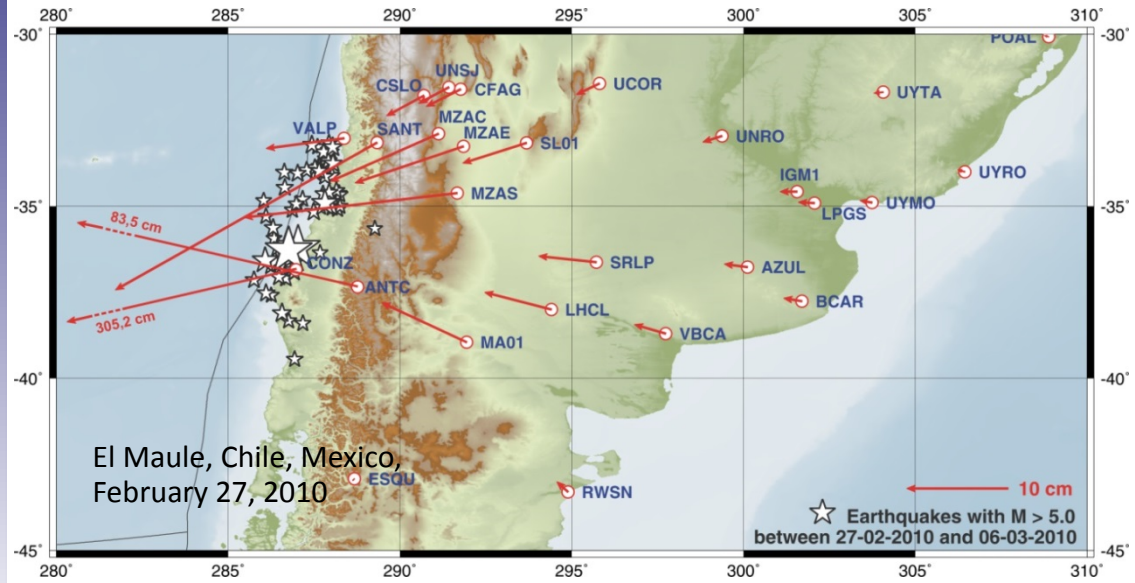
Seismic deformations in reference frames



Co-seismic displacements in Chile/Argentina (Feb. 2010) and Guatemala (Nov. 2012)

The precise determination and modelling of the co-seismic and post-seismic displacements is necessary to guarantee:

1) The reliability of the positions 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.

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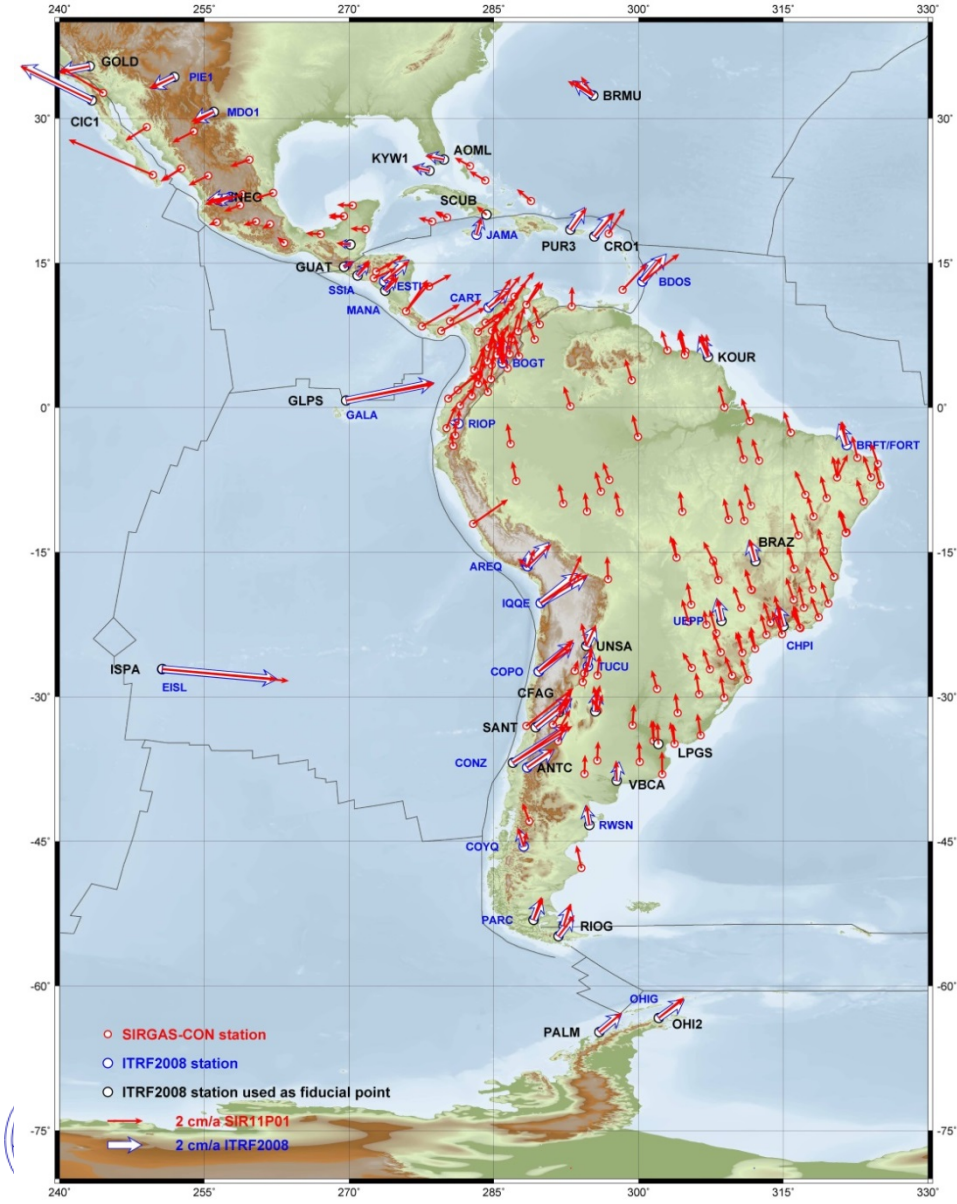
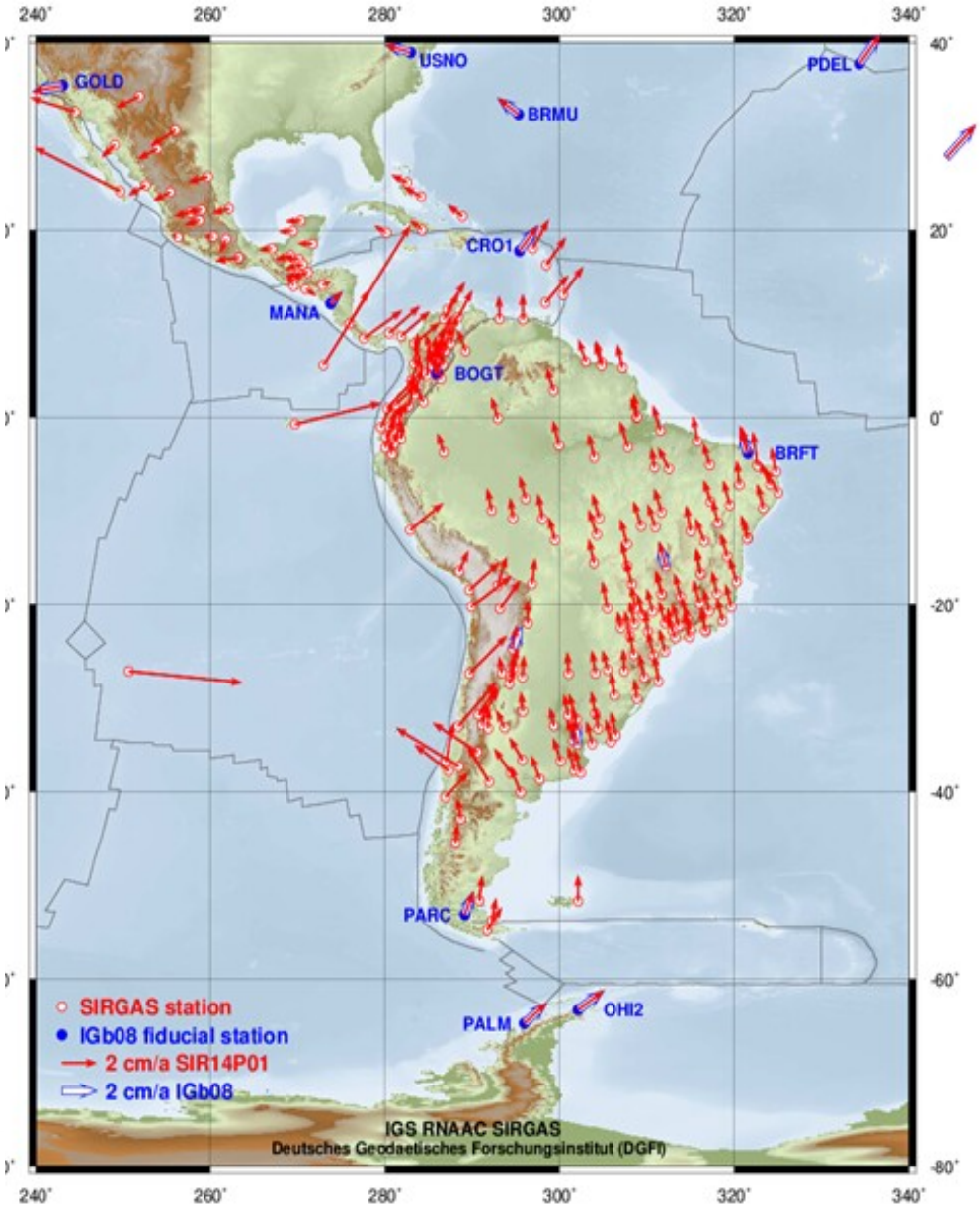
Input data: velocities based on cumulative solutions of GNSS weekly normal equations

SIRGAS 2011

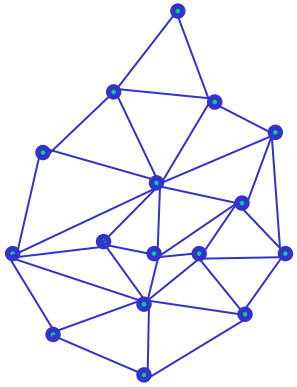


SIRGAS 2014

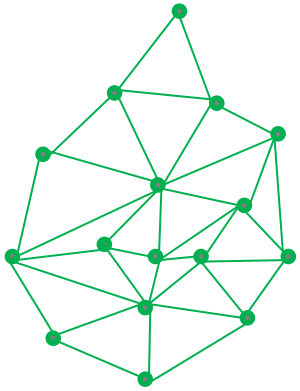


Pre-seismic and post-seismic (deformed) reference frames

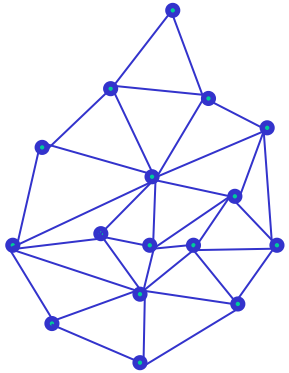
Reference networks without deformation:



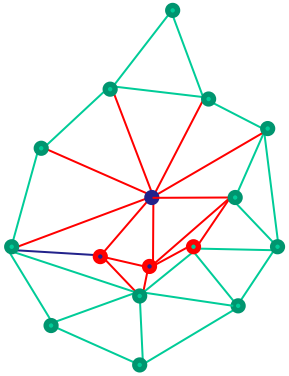
transformation



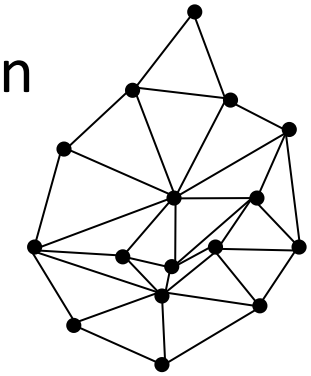
Reference networks with deformation:



deformation model

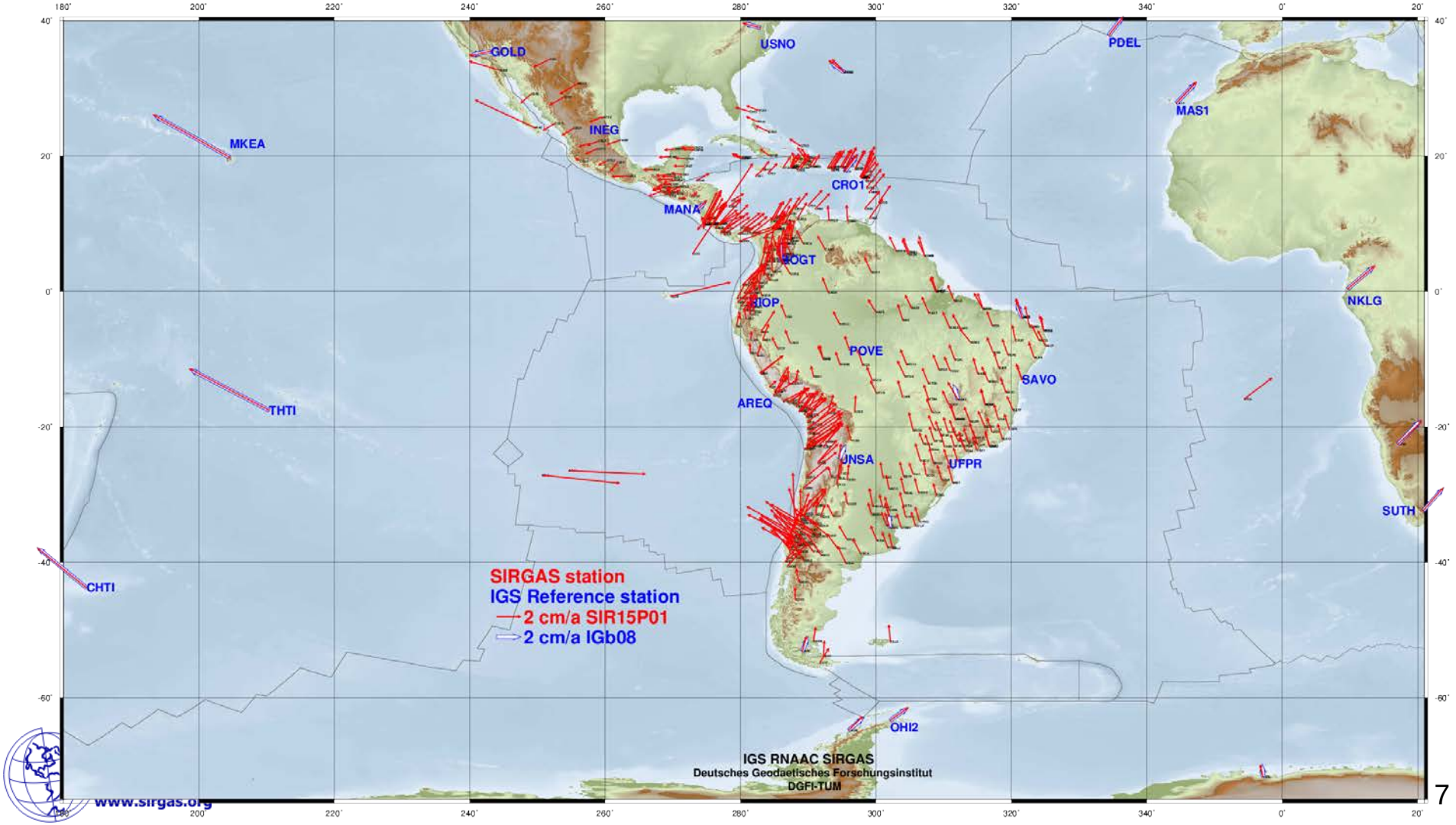


transformation

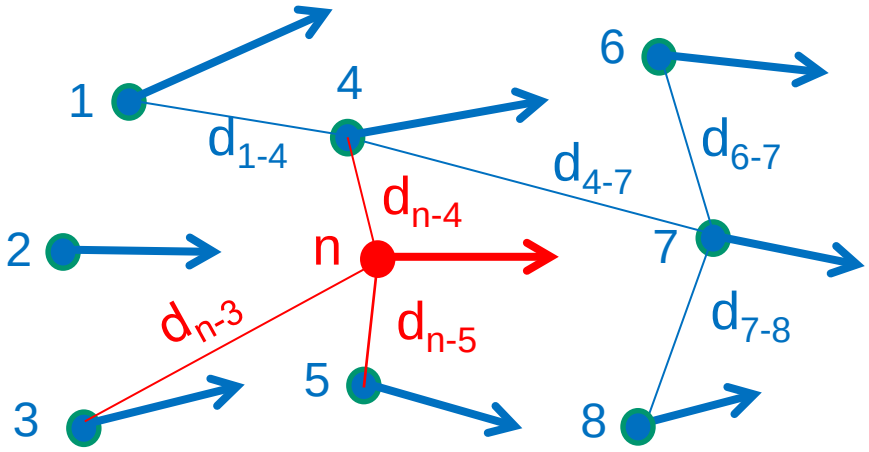


Input data: velocities based on cumulative solutions of GNSS weekly normal equations

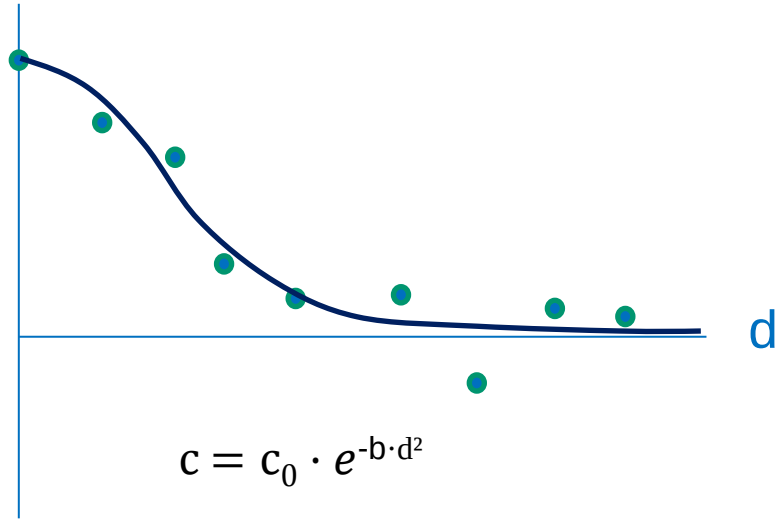
- Weekly normal equations (according to IERS/IGS/SIRGAS standards);
- Time span: 2010.2 (2012.2) - 2015.2; 471 stations;
- Frame: IGb08 epoch 2013.0; Accuracy: N - E = ±1.0 mm/a, h = ±1.2 mm/a



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



$c = E(\underline{x}_i \cdot \underline{x}_j)$



$c = c_0 \cdot e^{-b \cdot d^2}$

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

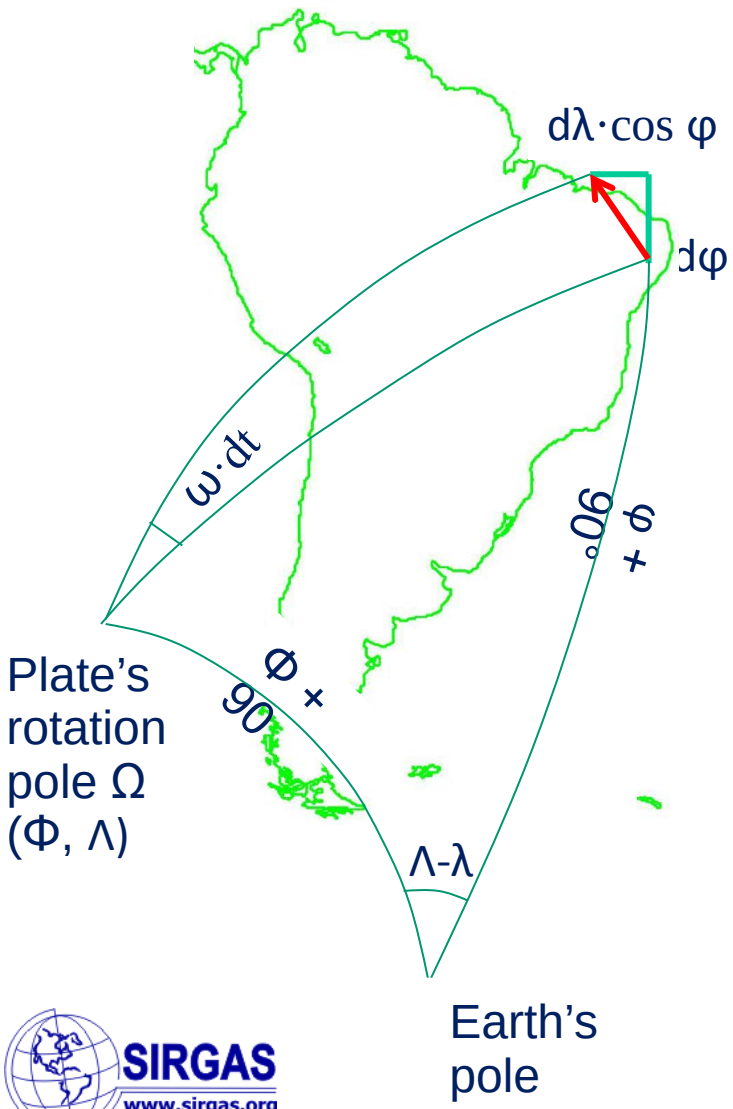
$\underline{\mathbf{C}}_{new}$ = correlation matrix between predicted and observed vectors

$\underline{\mathbf{C}}_{obs}$ = 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 the observations:



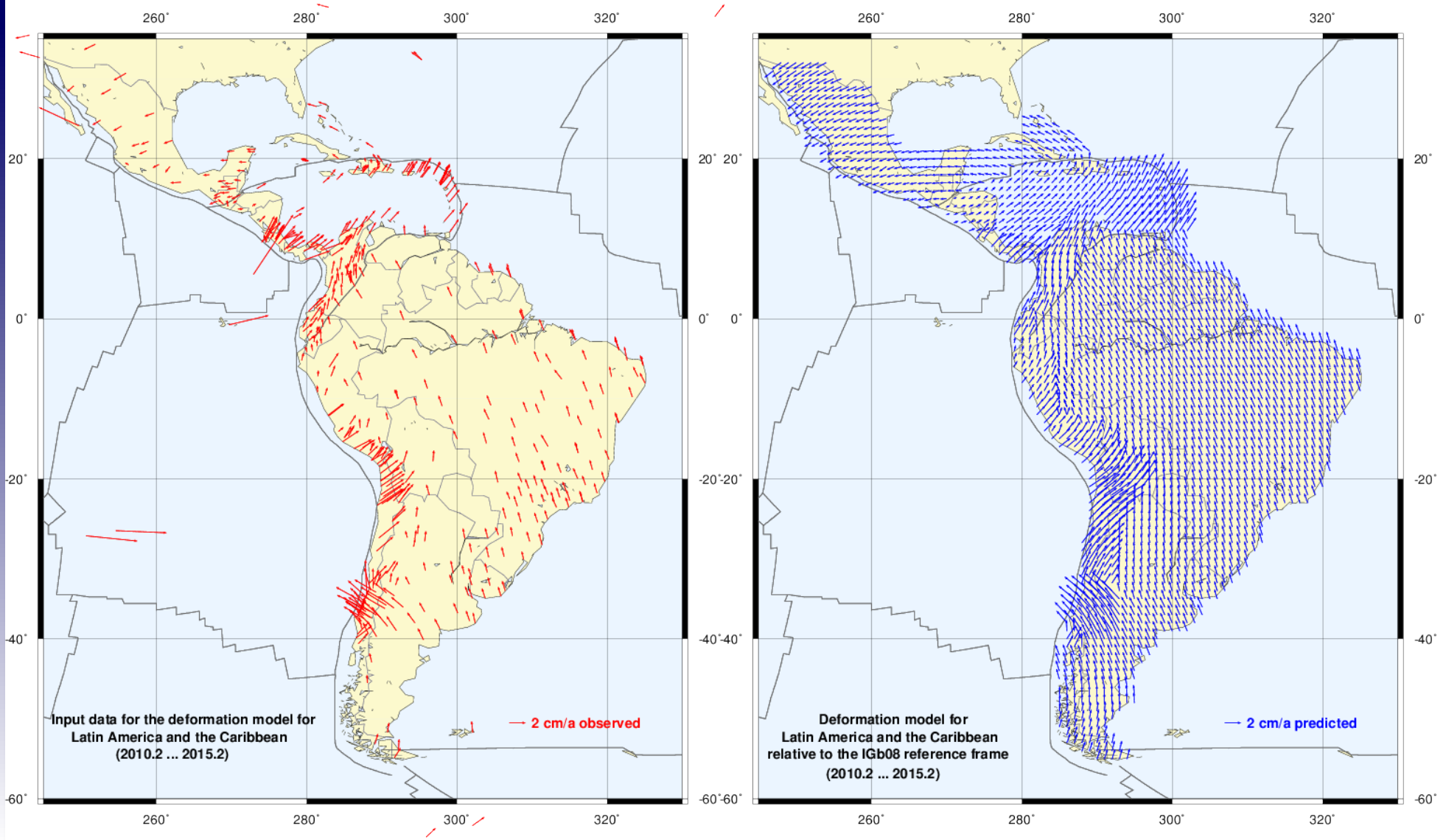
$$(d\varphi/dt)_k = \omega_i \cdot \cos\Phi_i \cdot \sin(\lambda_k - \Lambda_i)$$
$$(d\lambda/dt)_k = \omega_i \cdot (\sin\Phi_i - \cos(\lambda_k - \Lambda_i) \cdot \tan\varphi_k \cdot \cos\Phi_i)$$

Rotation vectors Ω (from observations)

Plate	Φ [°]	Λ [°]	ω [°/Ma]
NOAM(VMS15)	-5.2 ± 2.3	270.2 ± 0.9	0.187 ± 0.014
(APKIM2008)	-5.8 ± 0.5	272.5 ± 0.2	0.189 ± 0.001
CARB (VMS15)	26.4 ± 0.6	270.4 ± 1.3	0.336 ± 0.018
(APKIM2008)	28.0 ± 1.3	250,9 ± 2.7	0.208 ± 0.018
SOAM (VMS15)	-20.7 ± 1.1	226.9 ± 3.3	0.117 ± 0.002
(APKIM2008)	-19.4 ± 1.0	237.8 ± 1.5	0.127 ± 0.002

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

Observed and predicted



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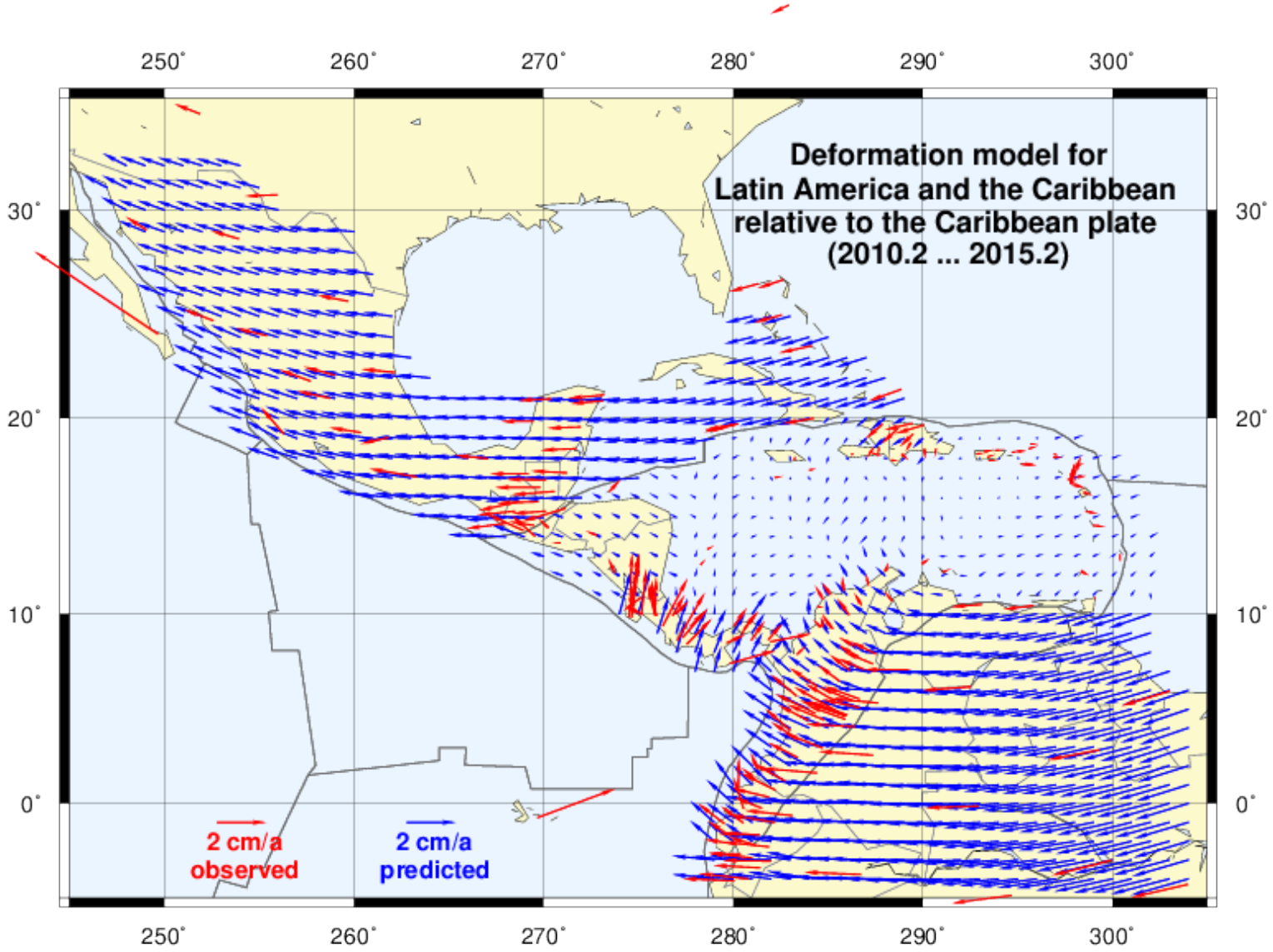
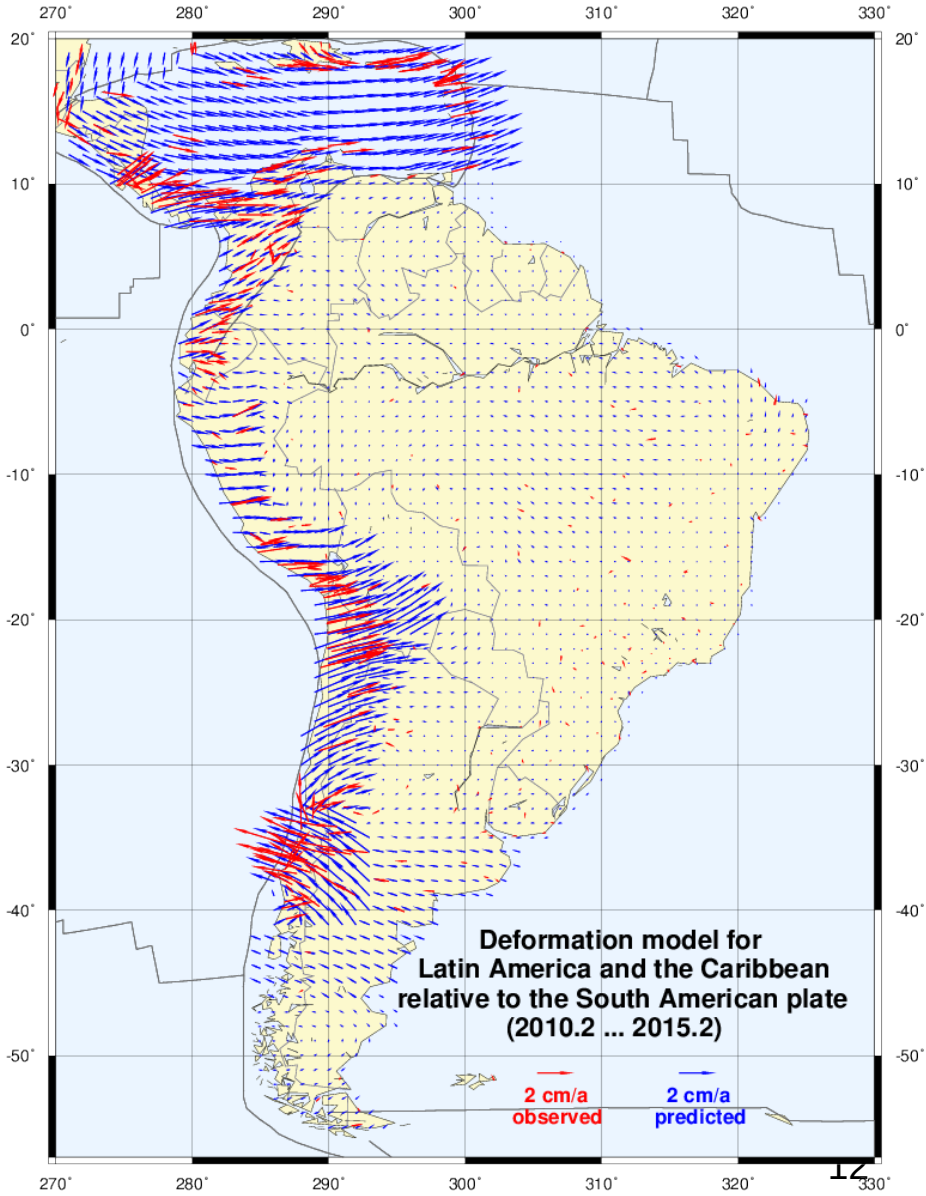
Deformation relative to the Caribbean Plate



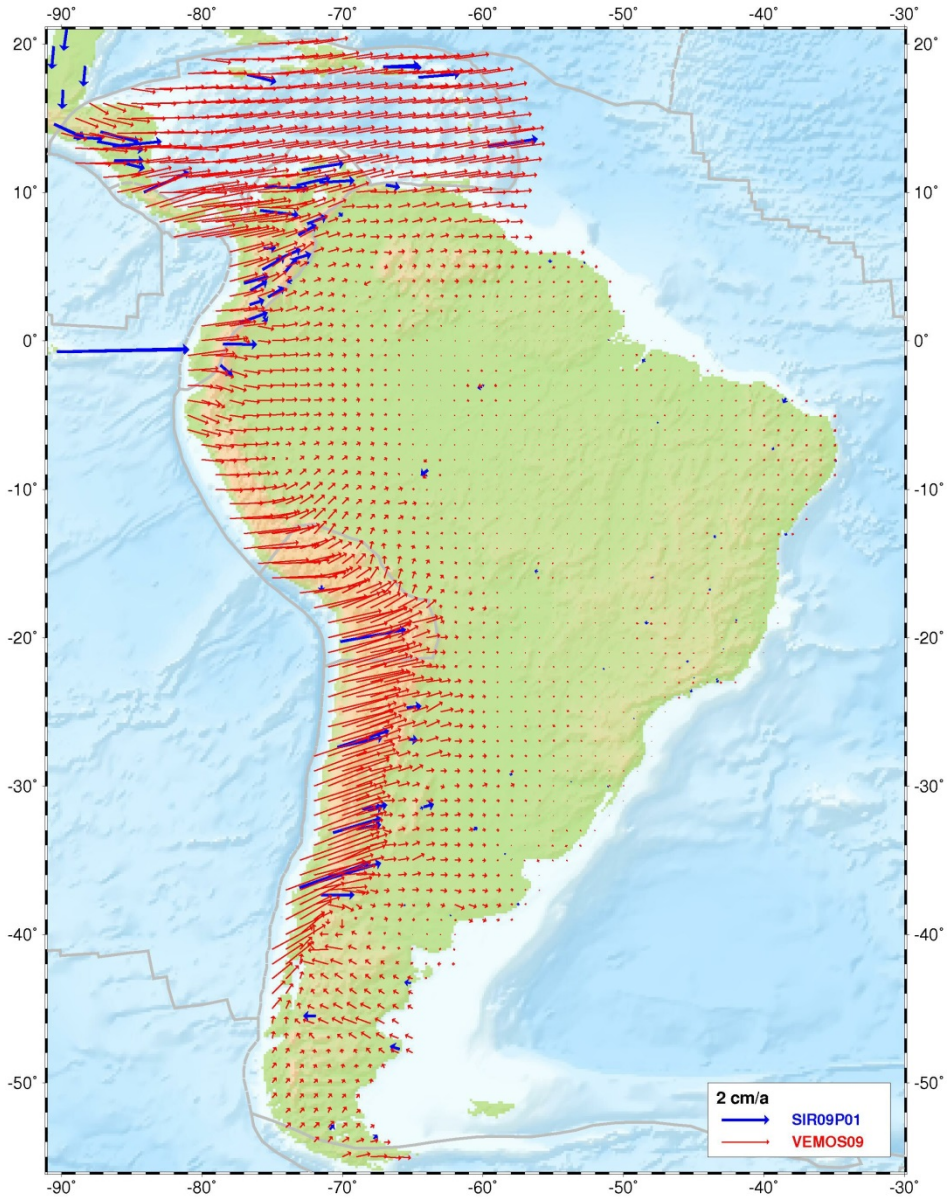
Deformation relative to the South American Plate

VEMOS 2015

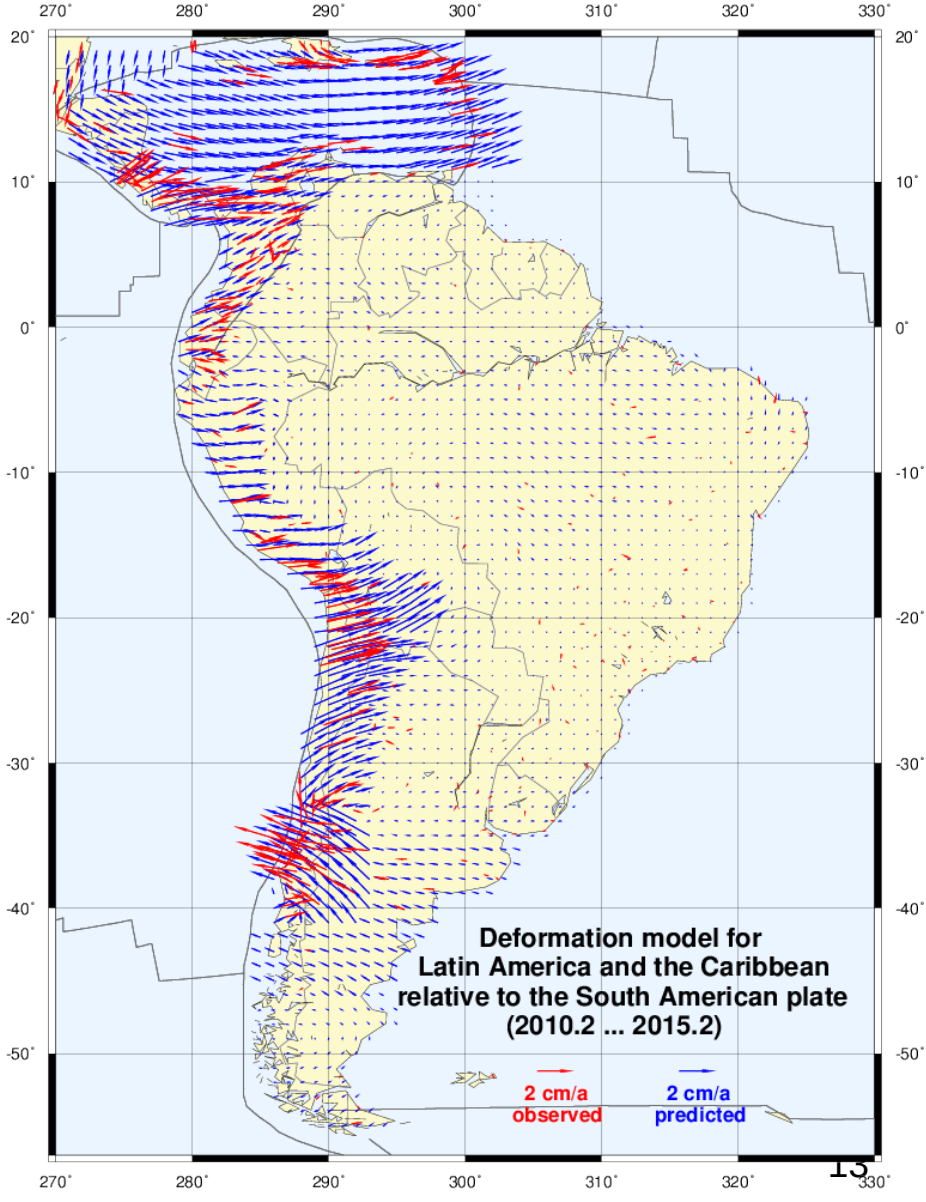


Deformation relative to the South American Plate

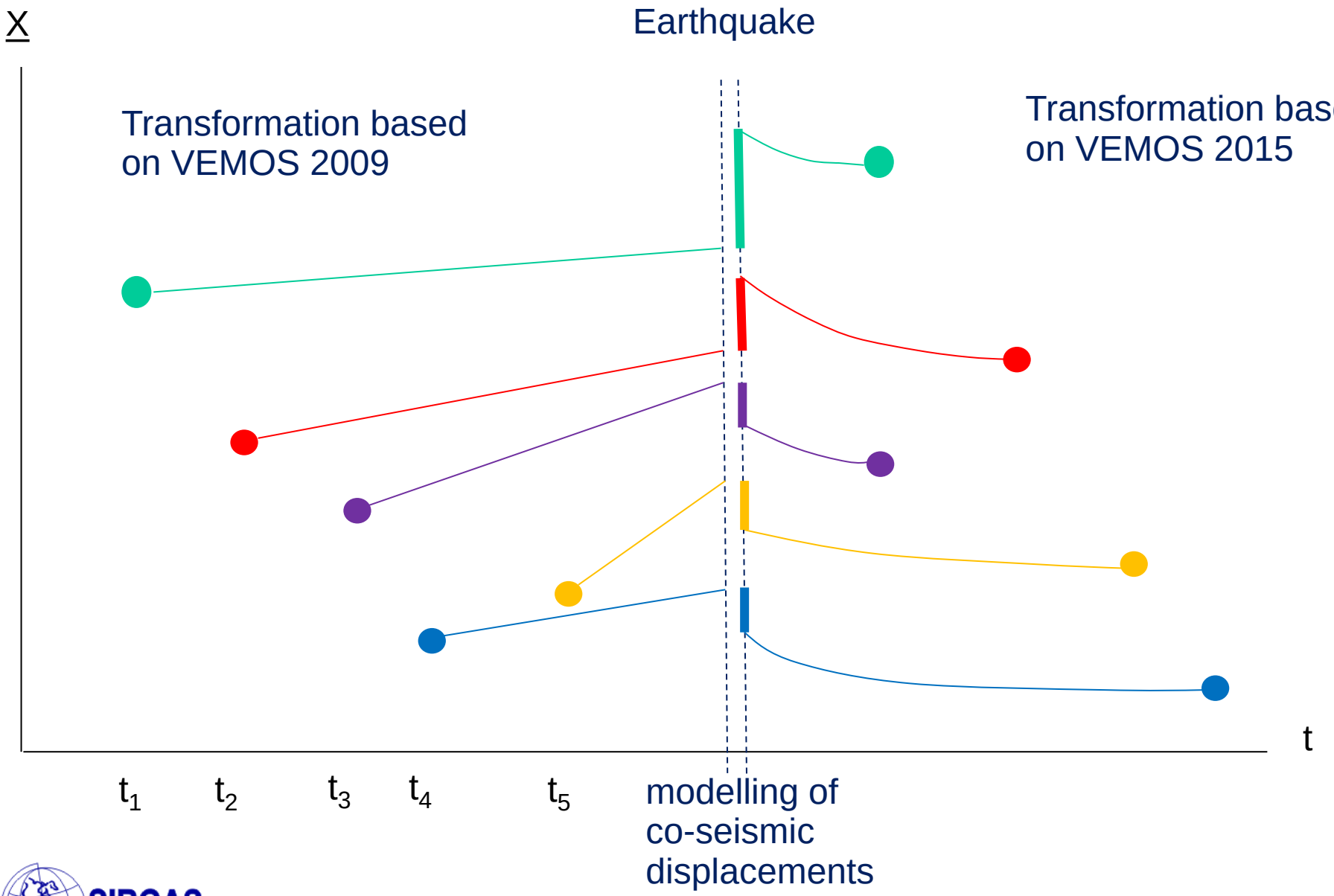
VEMOS 2009



VEMOS 2015

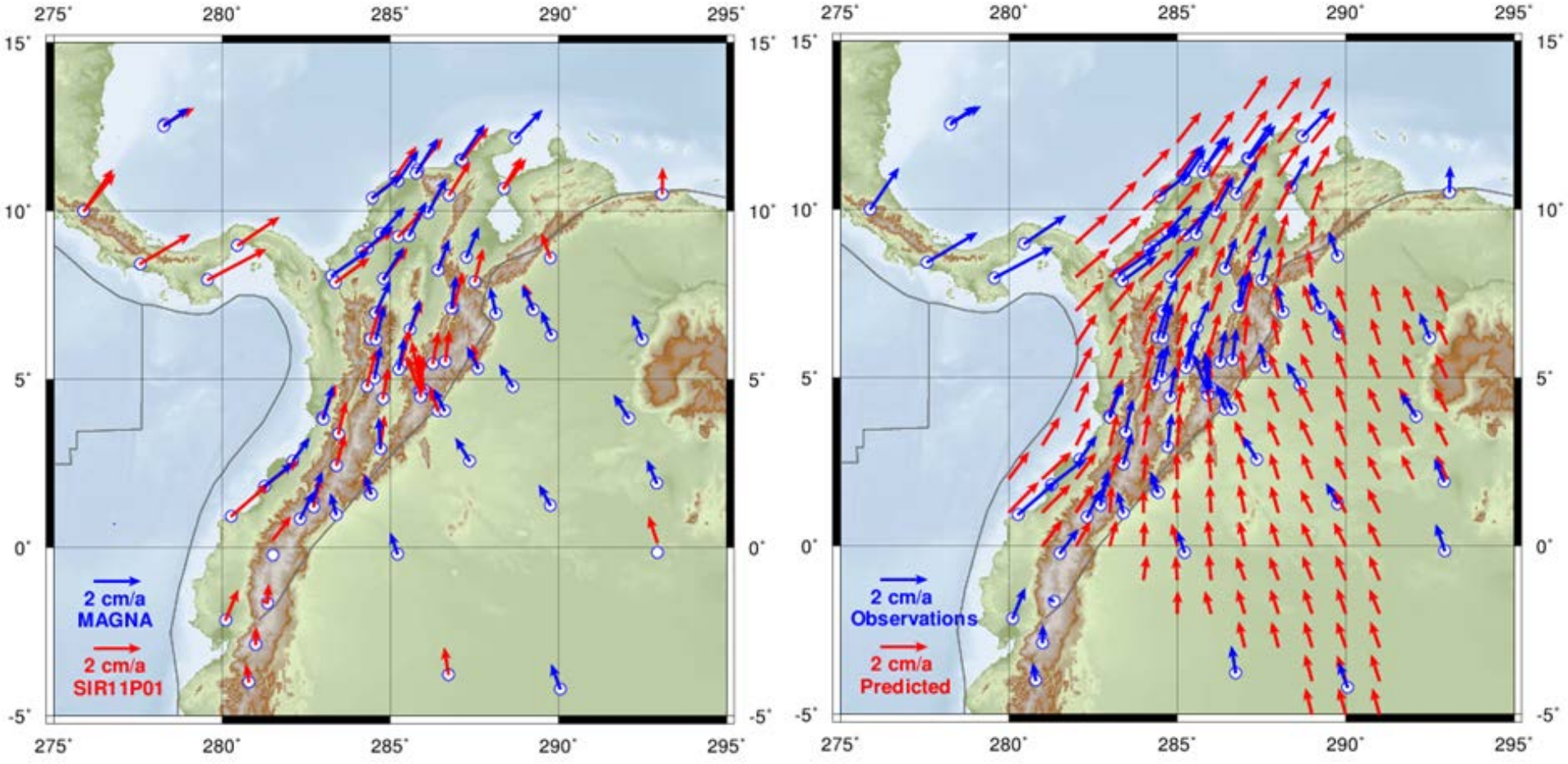


Transformation between pre- and post-seismic frames



Higher spatial resolution based on GNSS campaigns

Deformation model in Colombia (observed and from least squares collocation) using SIRGAS continuous observations and repeated campaigns of the Colombian reference frame in 1995 and 2011.



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Conclusions

- The earthquakes in Latin America since 2010 produced co-seismic displacements of up to 4 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 computation of the velocity field has to be repeated until the velocities have come to a “normal” behaviour. This may take some more years.

Conclusions