The varying surface kinematics in Latin America: VEMOS 2009, 2015, and 2017

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SIRGAS: Sistema de Referencia Geocéntrico para Las Américas

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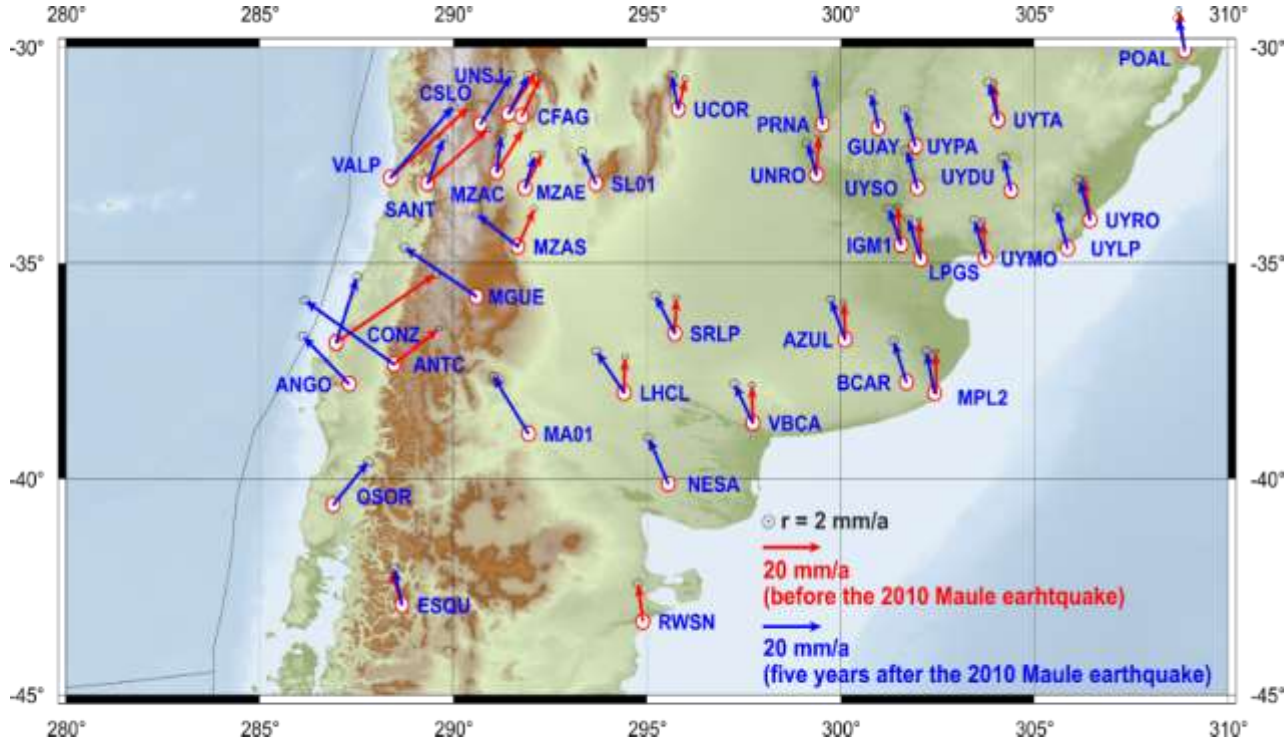
Motivation

Surface deformation models are the basis for computing coordinates of any point at any time from a time-dependent reference frame (positions & velocities). They must

- provide a high-spatial resolution in order to reflect all regional effects;
- consider regional deformation patterns and not only global (plate tectonic) models;
- be updated after any major abrupt deforming event (e.g. strong earthquakes).



Station velocities determined before and five years after the 2010 Maule earthquake. Velocities were oriented about N45°E before and N40°W after the event (~20 mm/a).

Tectonic settings

Tectonics in the SIRGAS area: Plate boundaries (Bird 2003) and motions (Drewes 2017)

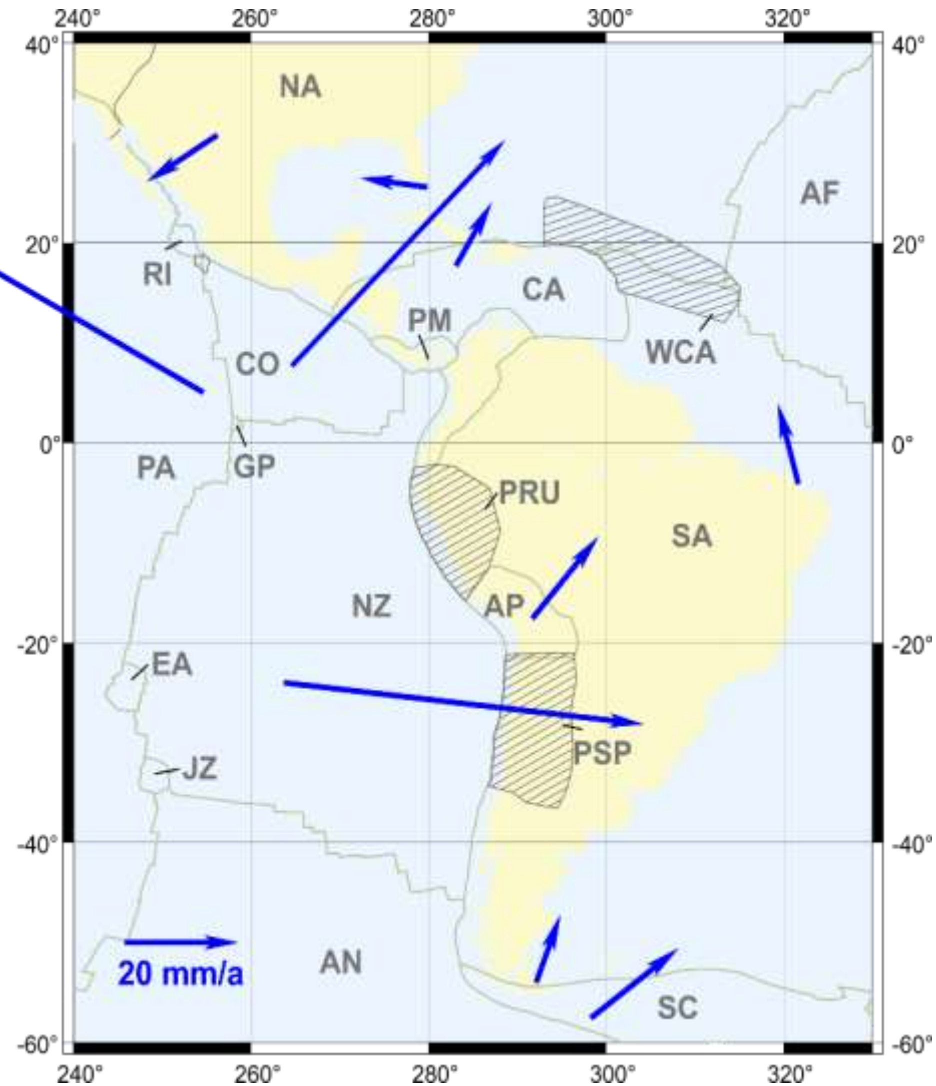
Standard tectonic models distinguish plates and deformation zones (orogens).

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

Orogens:

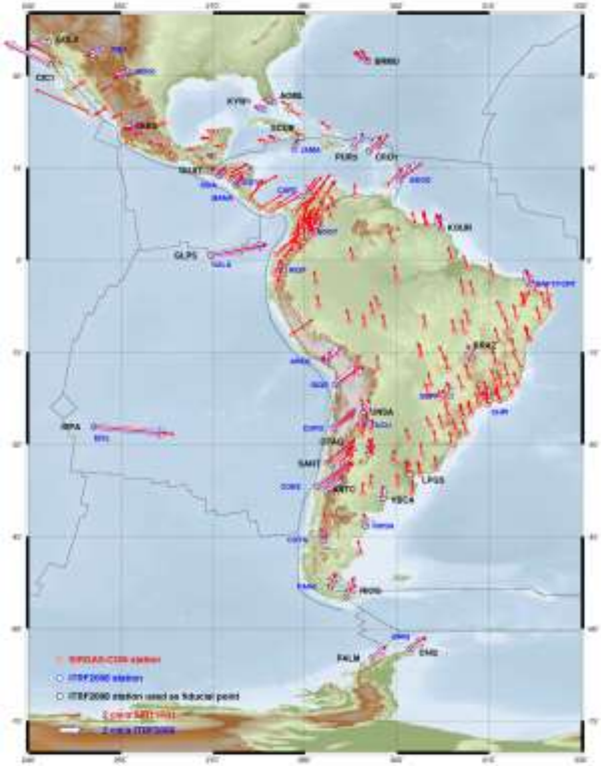
WCA	West Central Atlantic
PRU	Peru
PSP	Puna-Sierras Pampeanas



Input data: VEMOS multi-year velocity solutions

2000.0 ... 2010.1	2010.2 (2012.2) ... 2015.2	2014.0 ... 2017.1

2000.0 ... 2010.1



Stations: 230

Accuracy positions

Hor.: ±1.5 mm, Vert.: ±2.4 mm

Accuracy velocities

H.: ±0.7 mm/a, V.: ±1.1 mm/a

2010.2 (2012.2) ... 2015.2

Stations: 456

Accuracy positions

Hor.: ±0.8 mm, Vert.: ±3.5 mm

Accuracy velocities

H.: ±0.7 mm/a, V.: ±1.6 mm/a

2014.0 ... 2017.1

Stations: 515

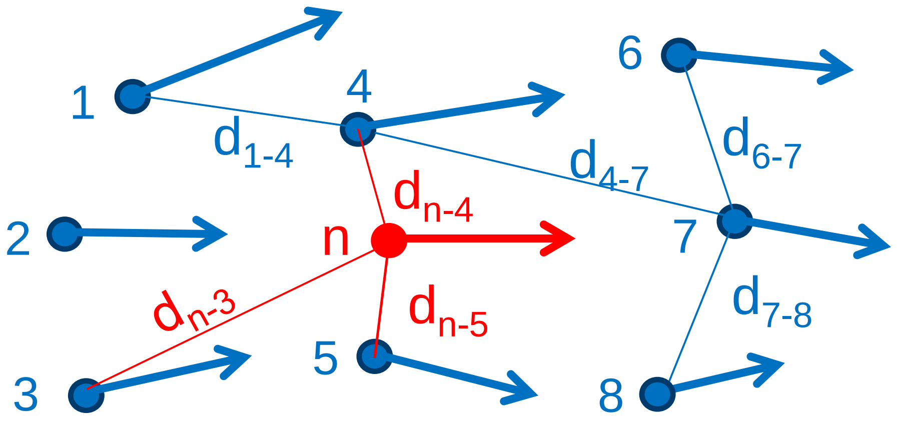
Accuracy positions

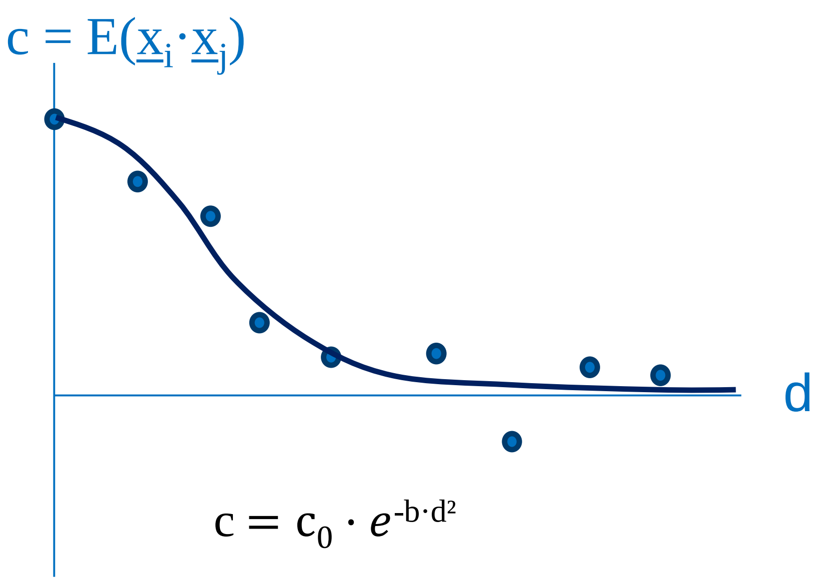
Hor.: ±0.8 mm, Vert.: ±2.5 mm

Accuracy velocities

H.: ±0.7 mm/a, V.: ±1.1 mm/a

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





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 regular grid

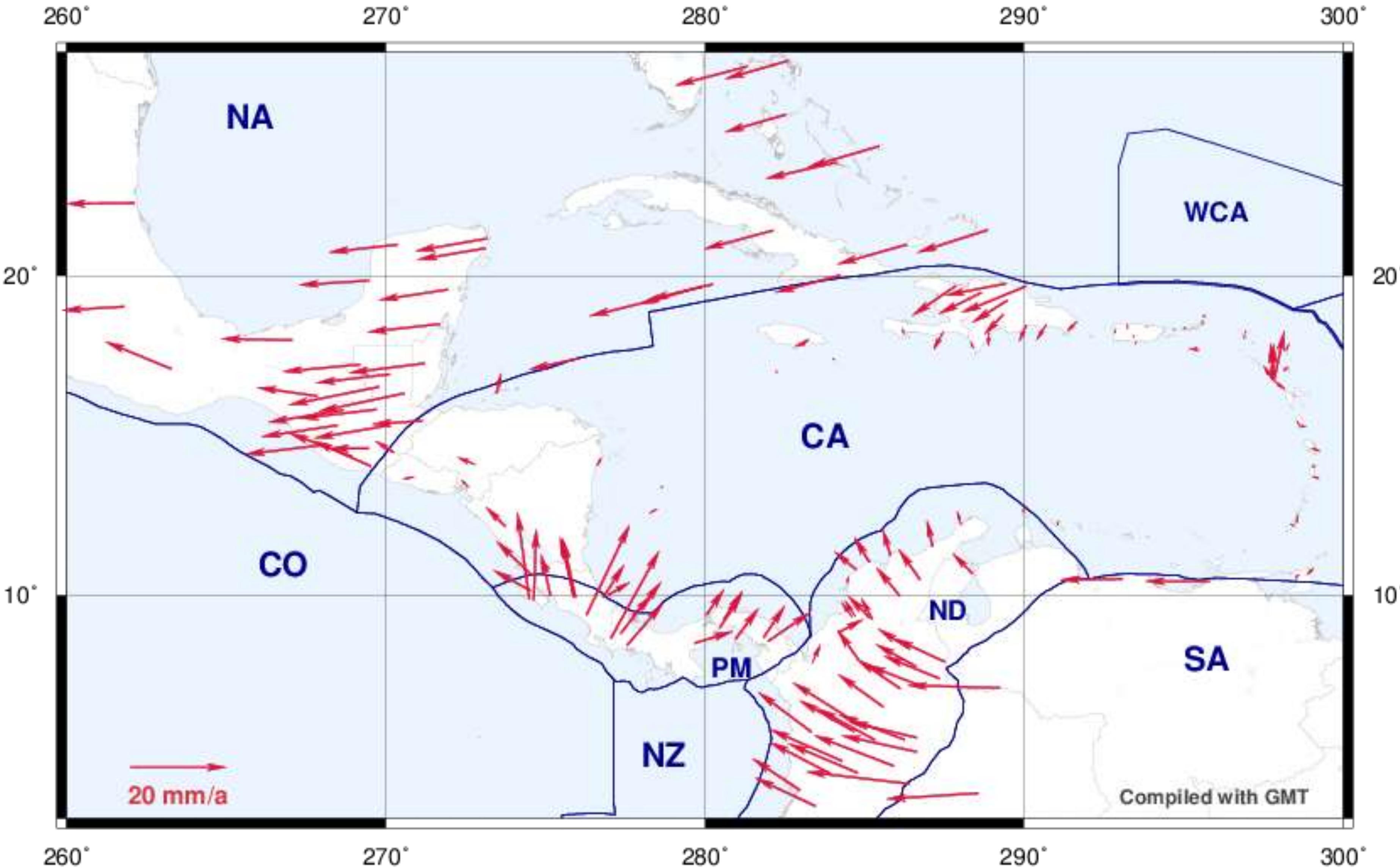
$\underline{\mathbf{C}}_{obs}$ = correlation matrix between observed vectors (C_{NN}, C_{EE}, C_{NE})

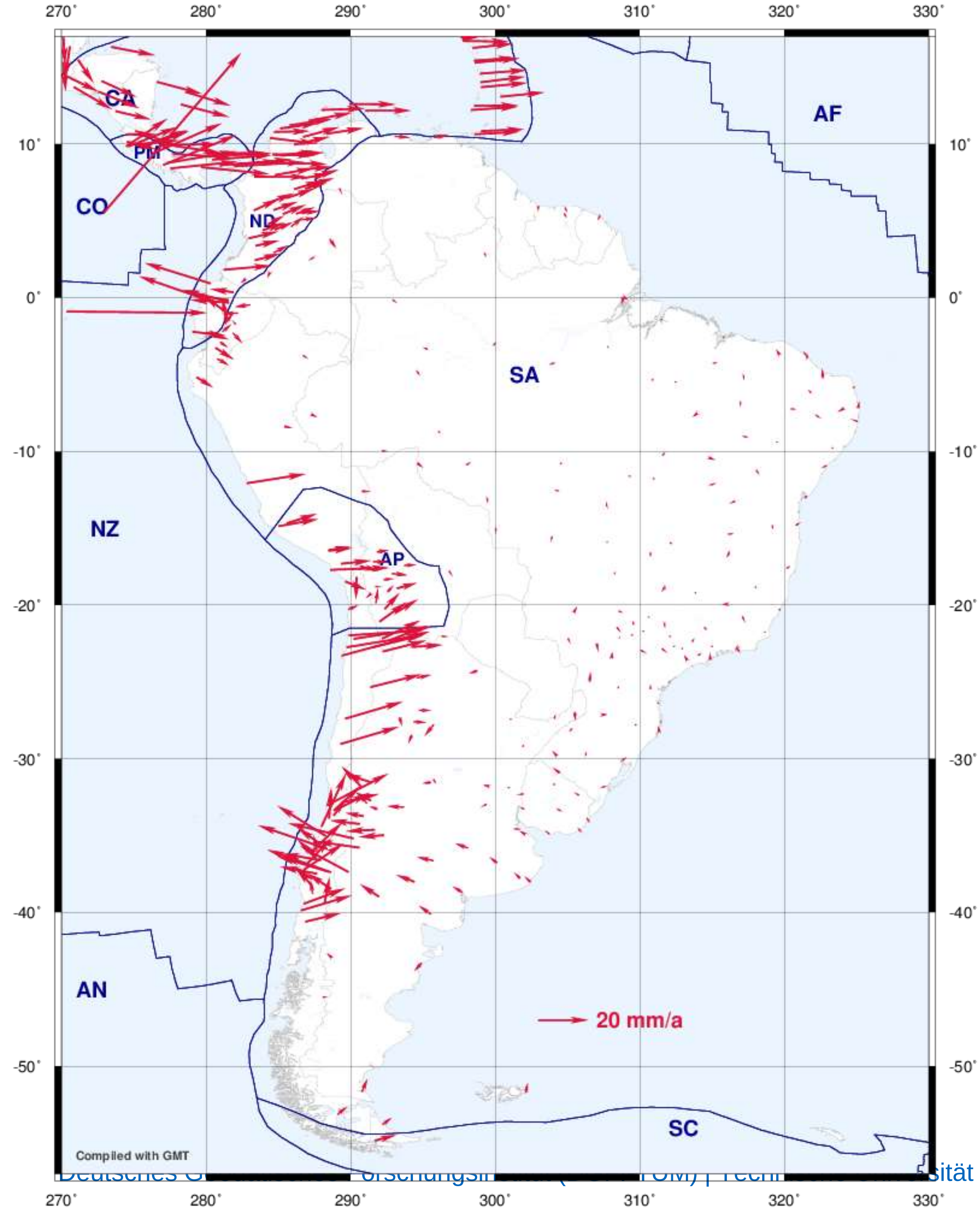
$\underline{\mathbf{C}}_{new}$ = correlation matrix between predicted and observed vectors

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

$\underline{\mathbf{C}}$ matrices are built from empirical isotropic, stationary covariance functions. To fulfil these conditions, trends in velocities must be reduced.

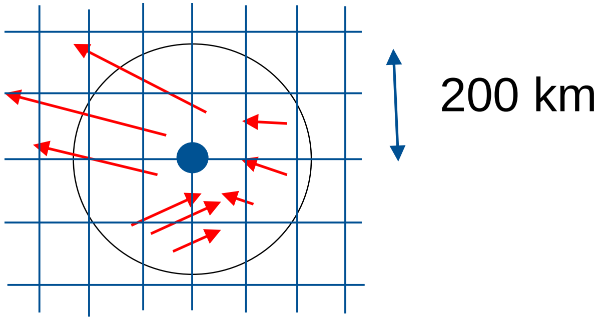
Reduced velocities w.r.t. the Caribbean Plate



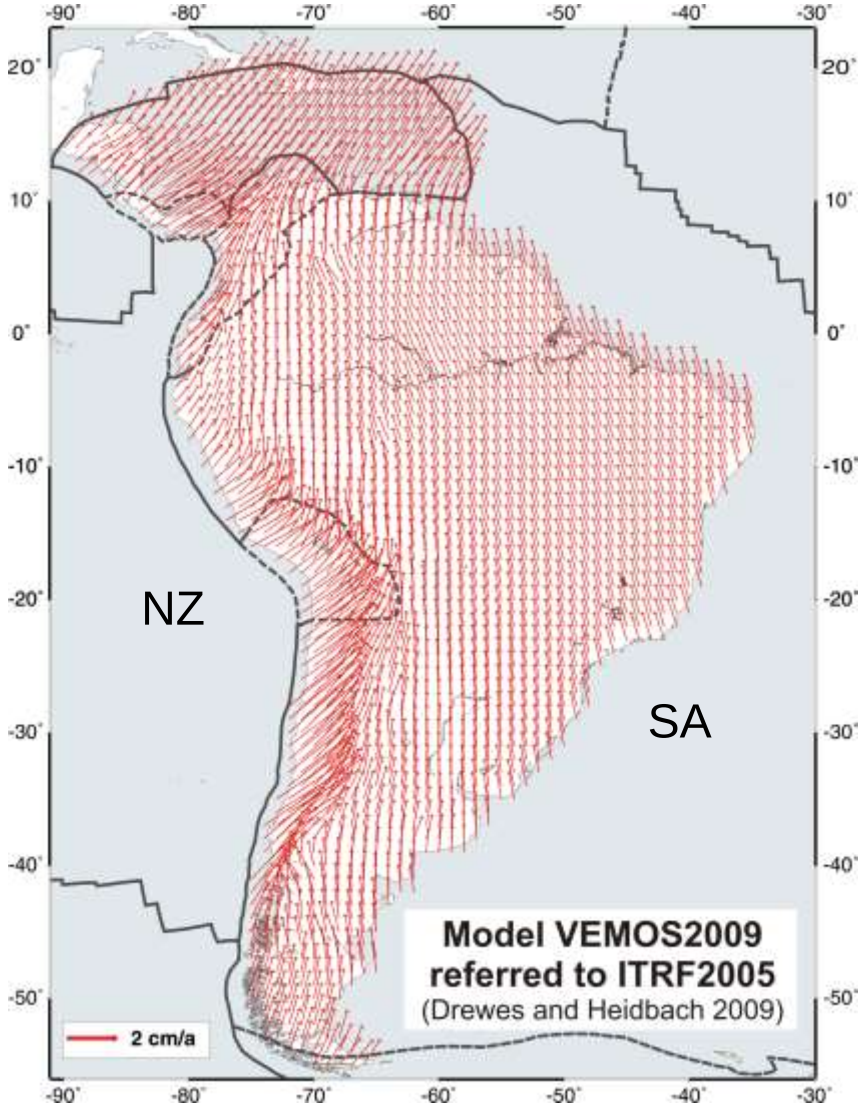


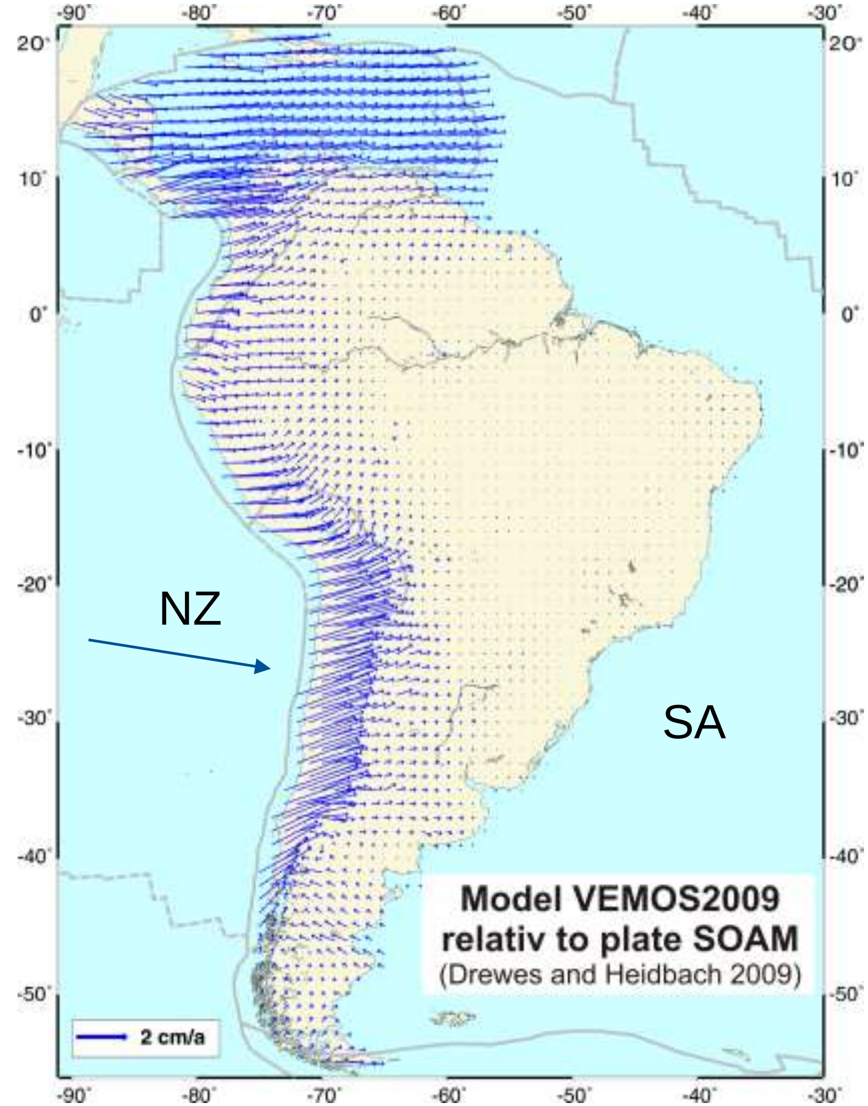
Reduced velocities w.r.t. the South American Plate

In order to fulfil the isotropy and stationarity condition in areas outside the reference plates (South American or Caribbean) the average velocities in the LSC prediction domain (in general 200 km around the prediction point) are removed before LSC and restored after.

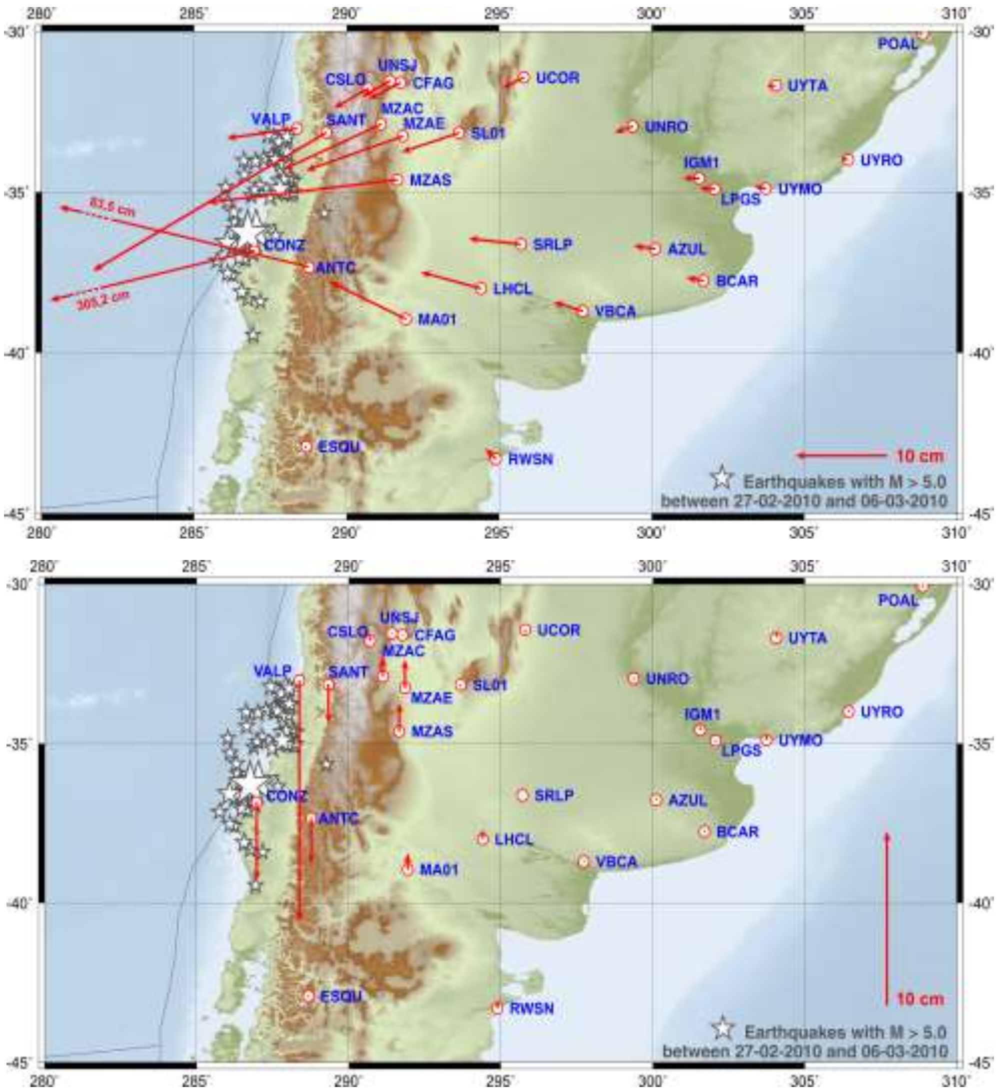


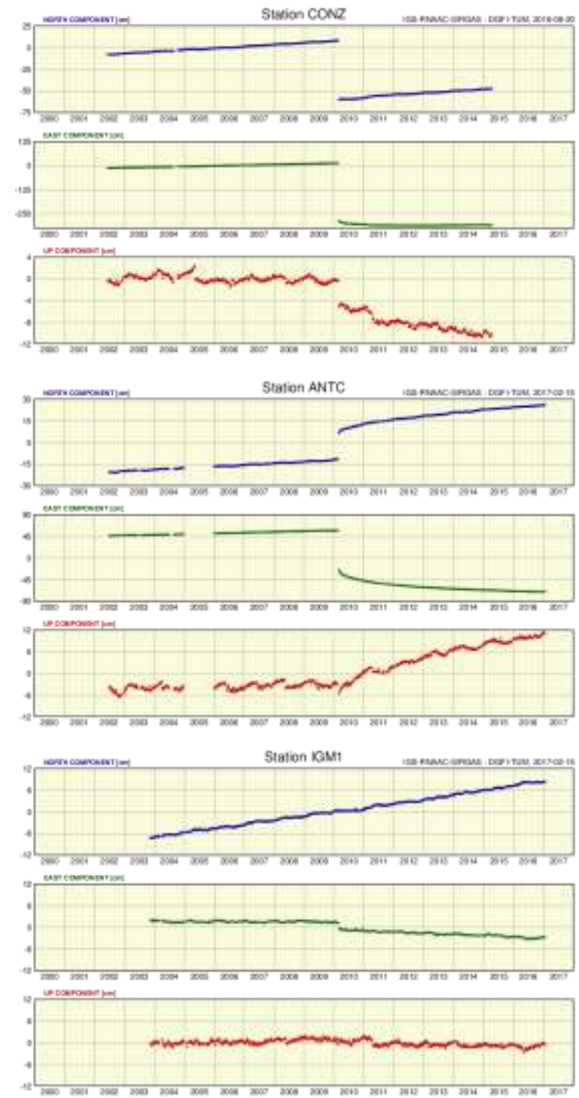
Surface kinematics and deformation model prior to the 2010 Maule earthquake: VEMOS2009 (2000.0 ... 2009.6)



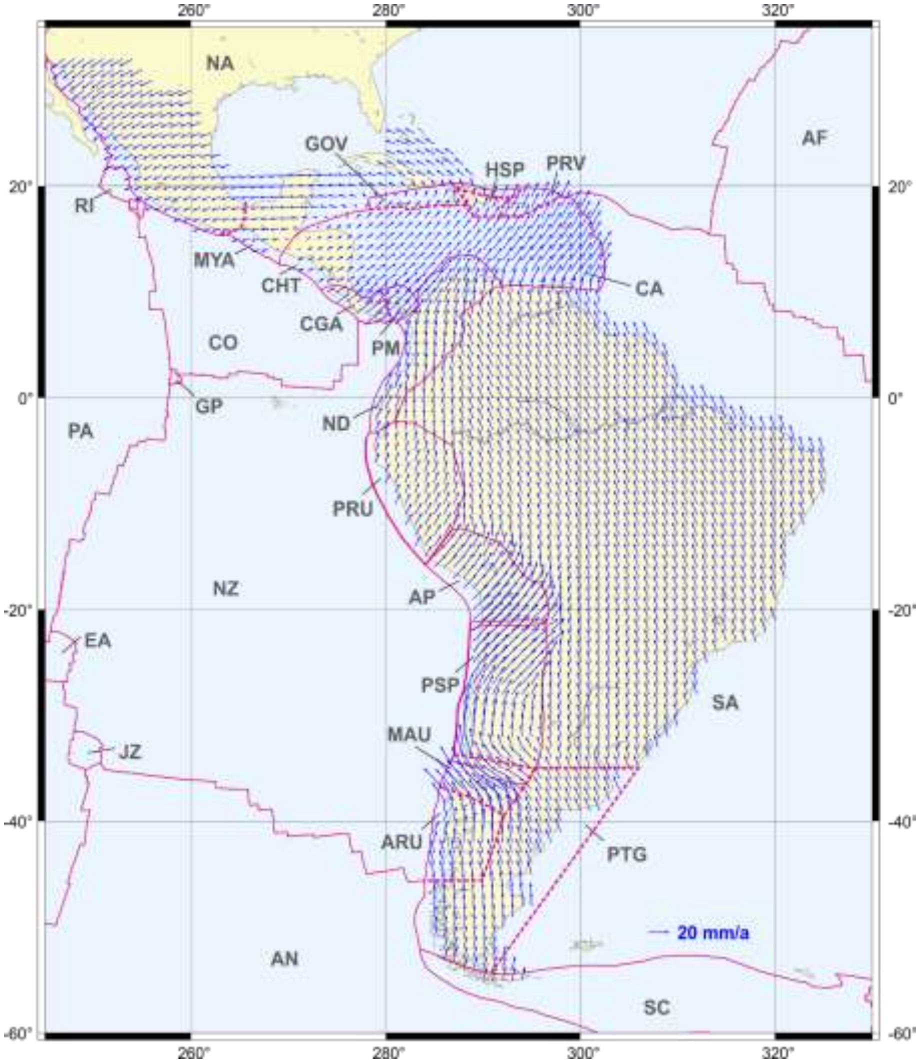


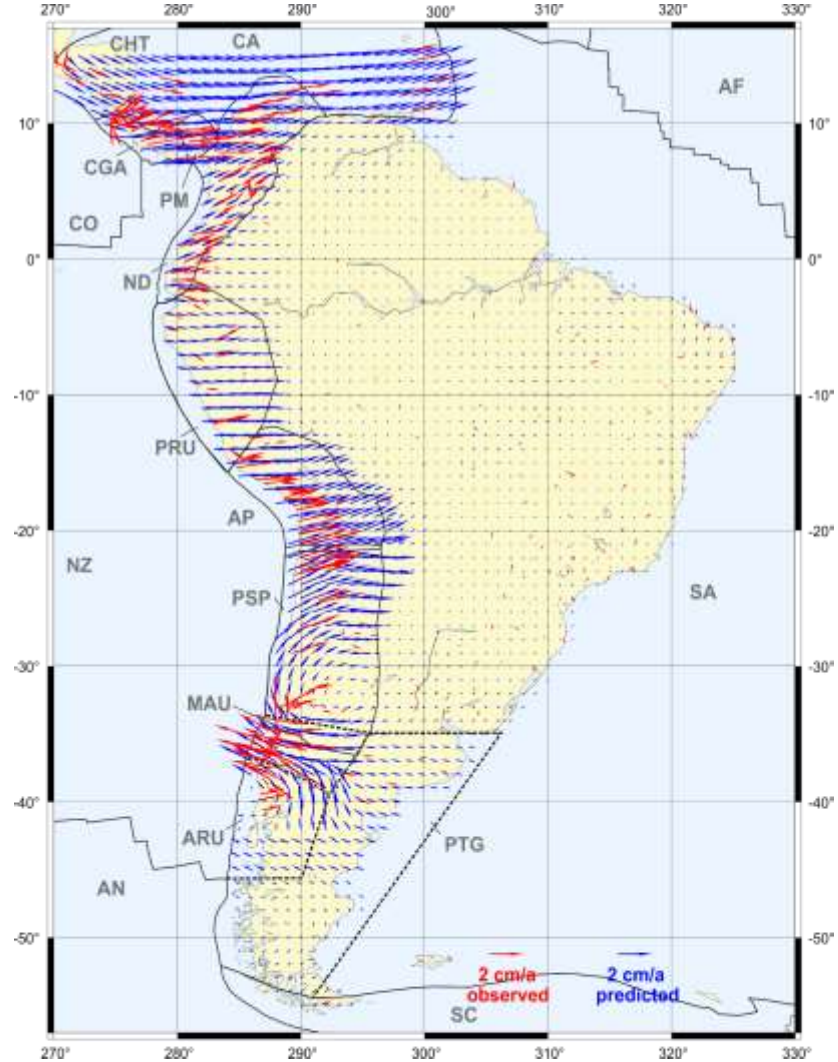
Co-seismic impact of the 2010 Maule earthquake the SIRGAS reference frame



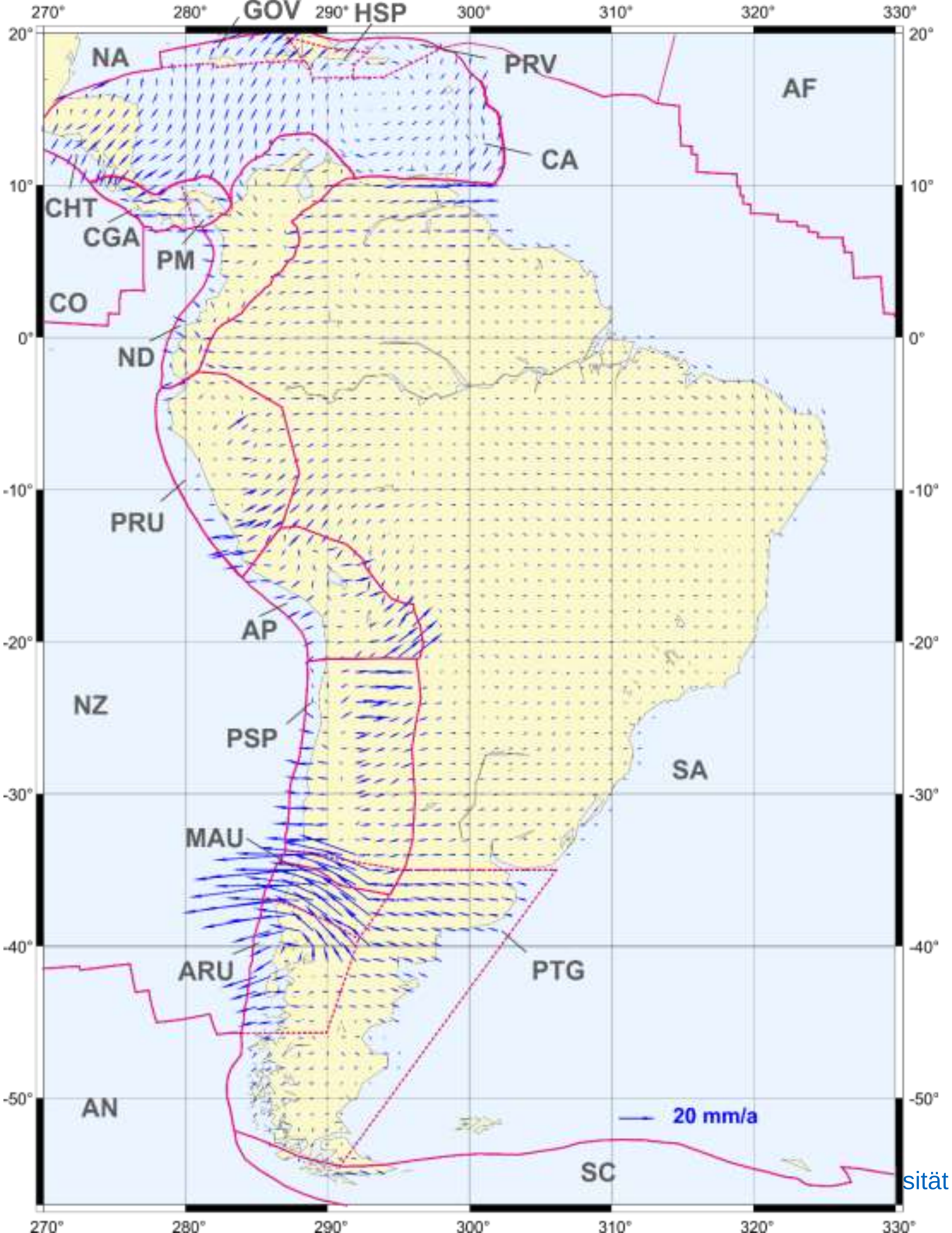


Surface kinematics and deformation model within 5 years after the 2010 earthquake: VEMOS2015 (2010.2 ... 2015.2)

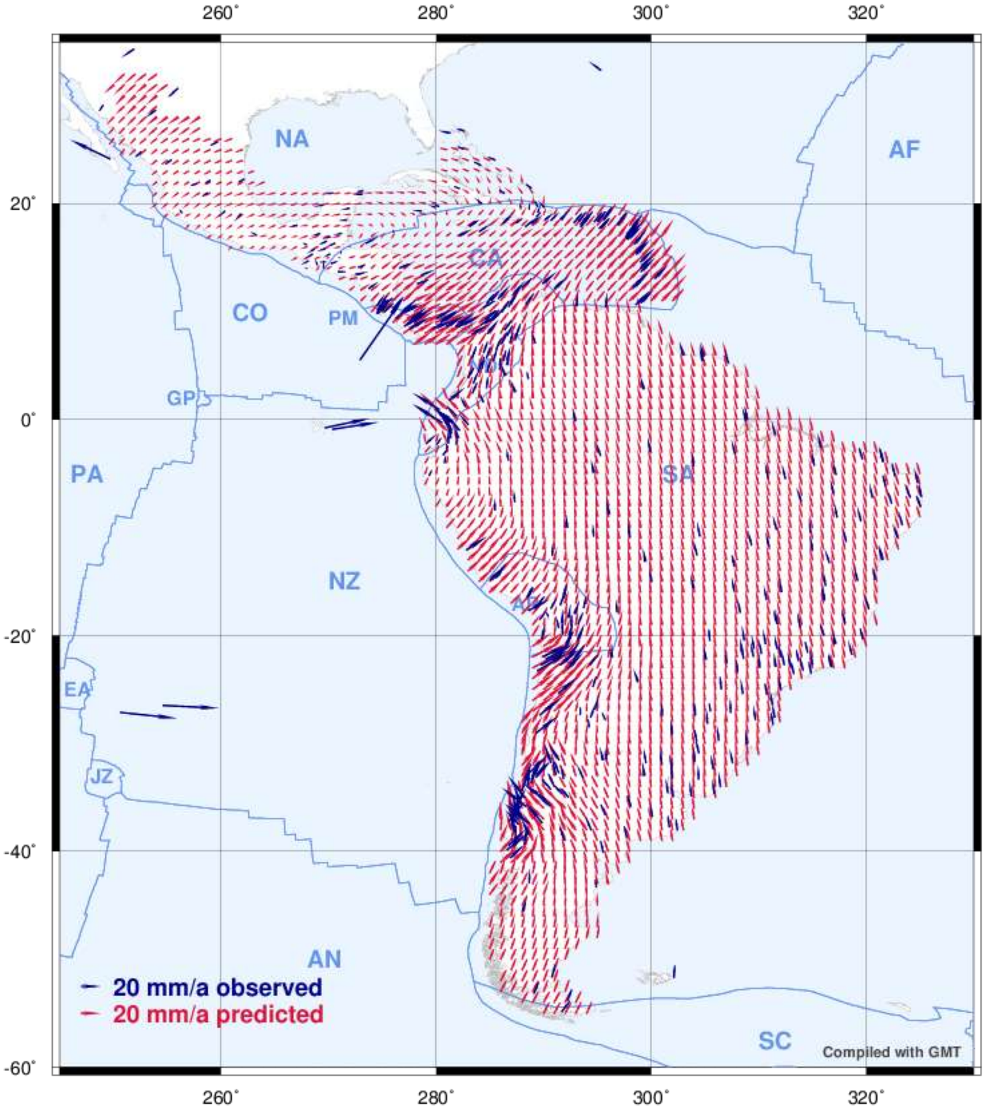


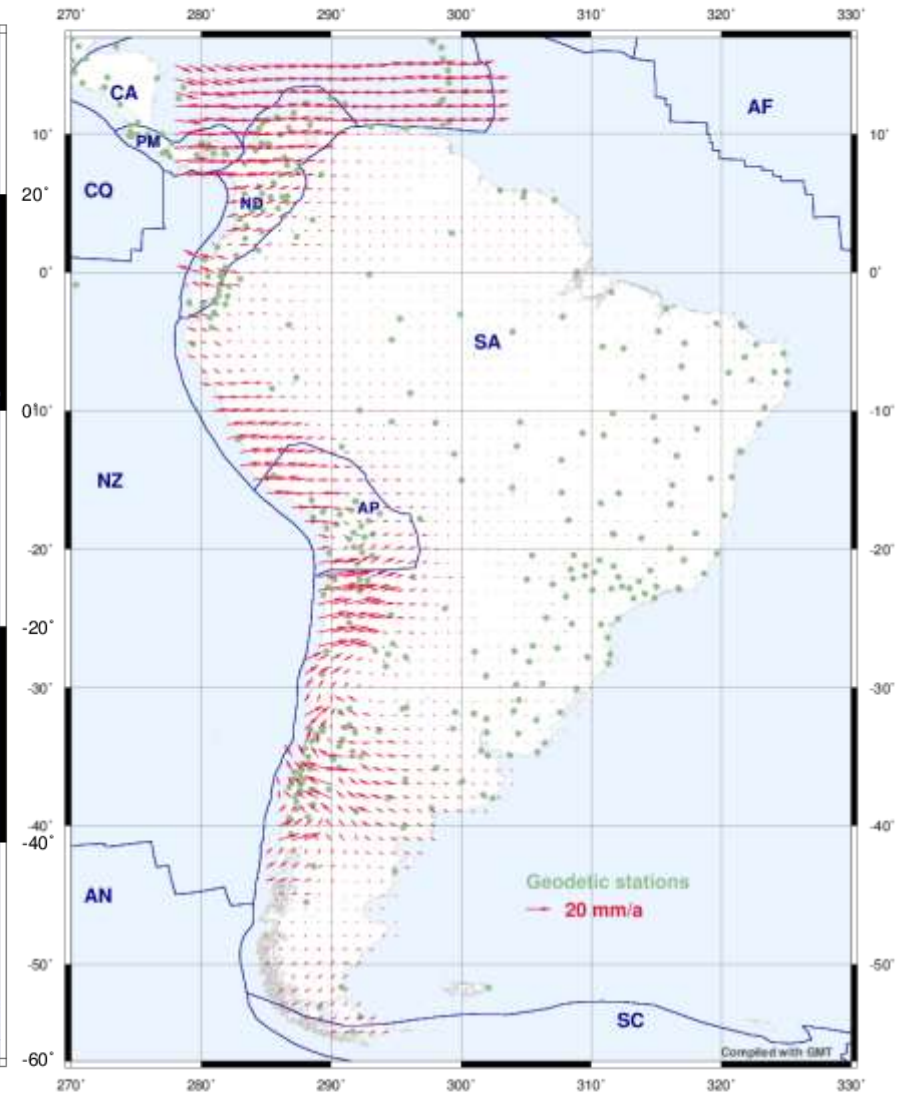


Difference Δv
VEMOS2015 minus
VEMOS2009

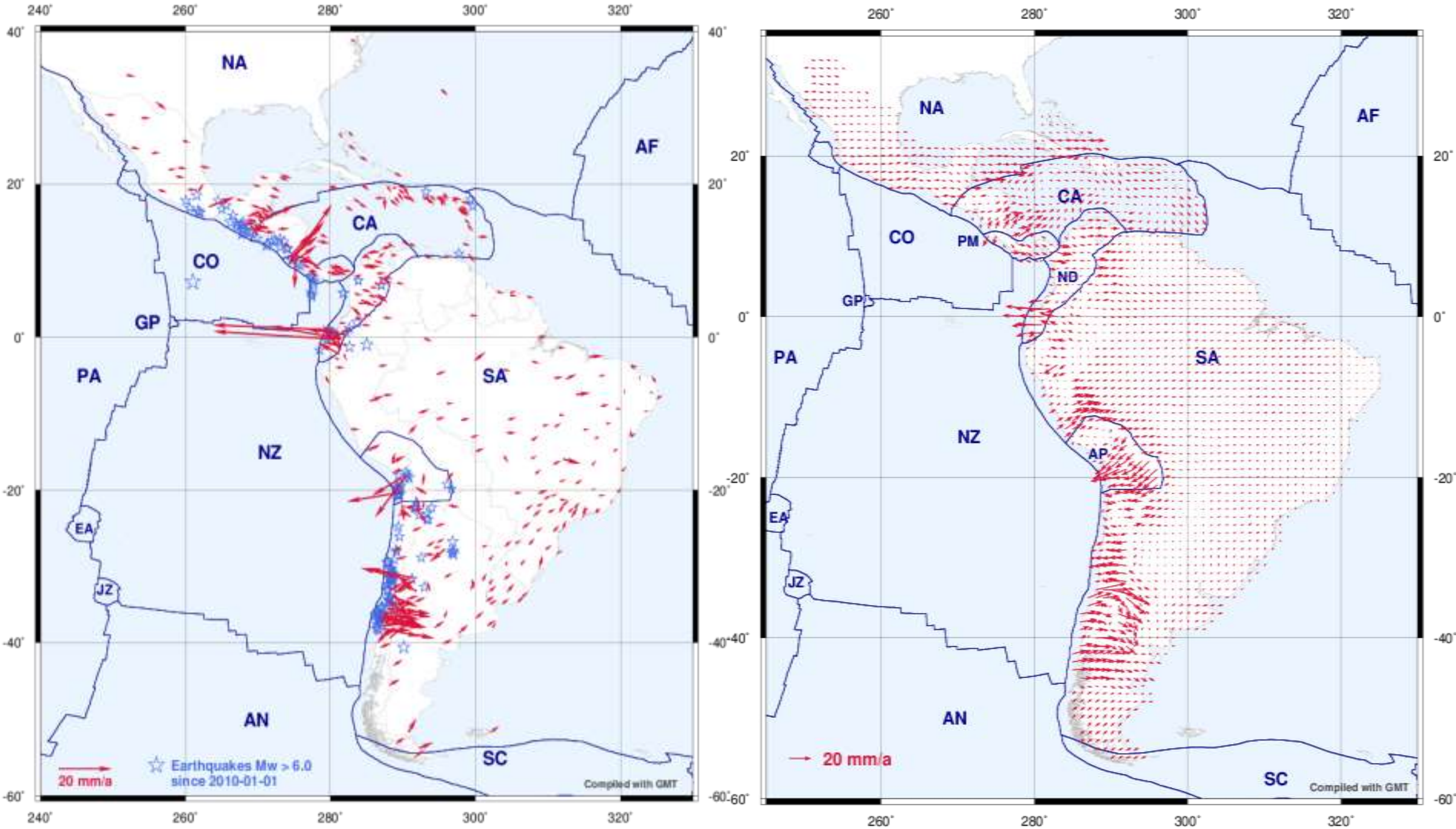


Surface kinematics and deformation model from January 2014 to January 2017: VEMOS2017



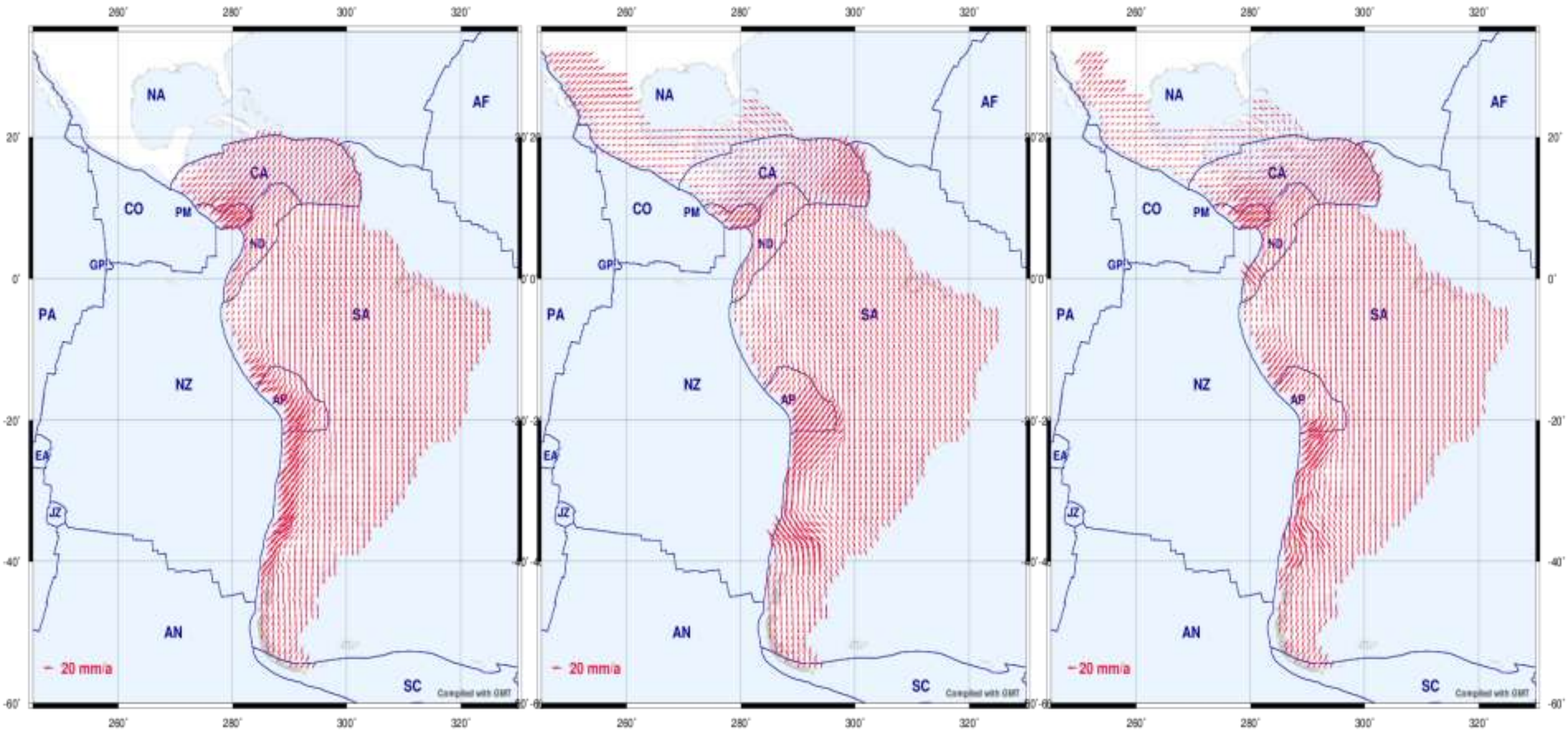


VEMOS2017 minus VEMOS2015



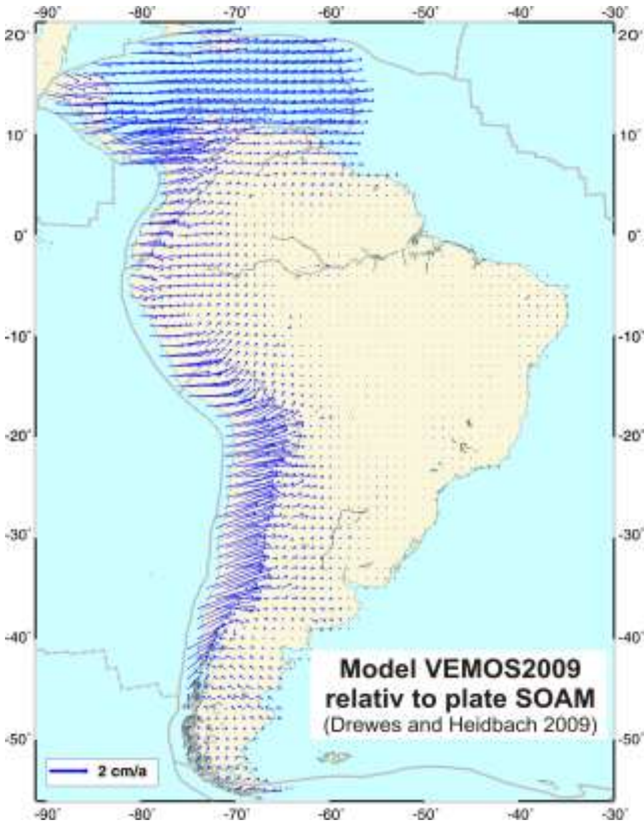
Recent surface kinematics in Latin America

VEMOS2009 (ITRF) [2000.0 ... 2009.6]	VEMOS2015 (ITRF) [2010.2 (2012.2) ... 2015.2]	VEMOS2017 (ITRF) [2014.0 ... 2017.1]

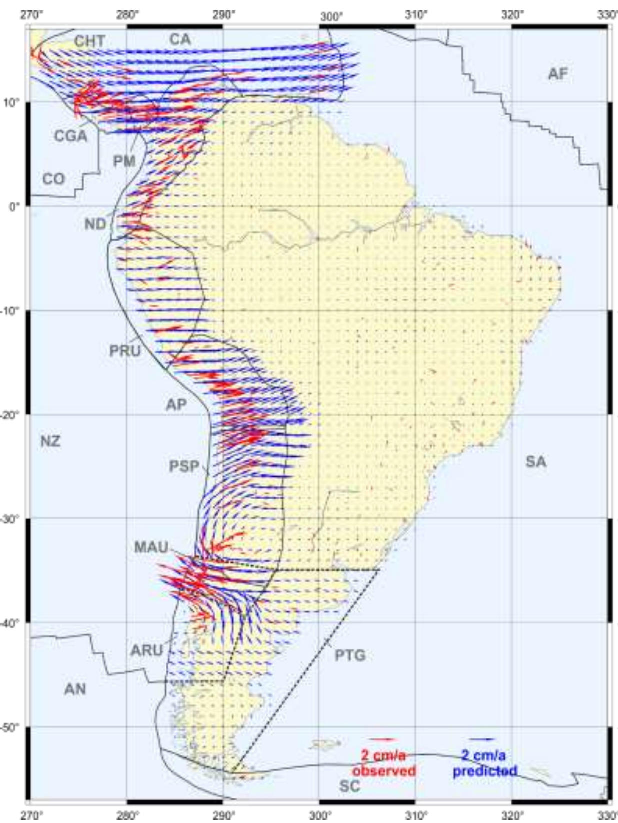


Recent surface deformation in Latin America

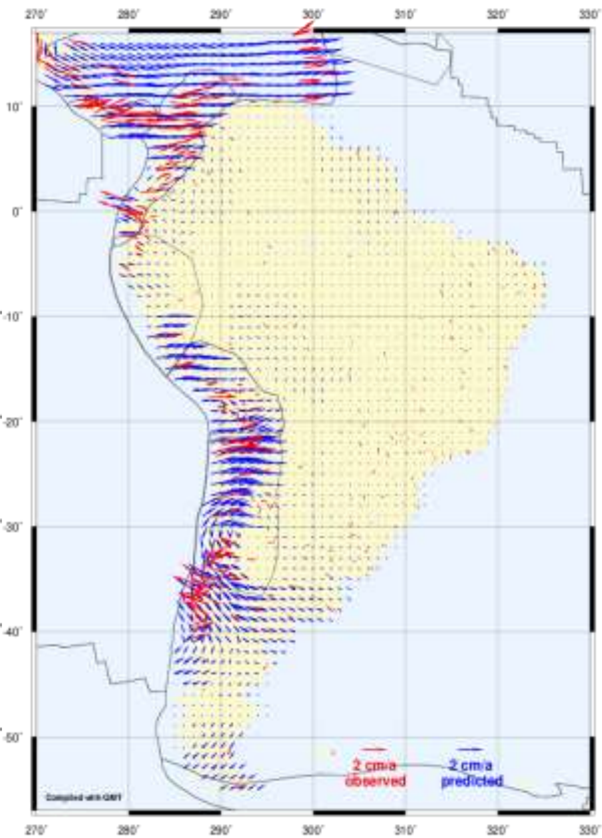
VEMOS2009
(2000.0 ... 2009.6)
reduced to South
American Plate



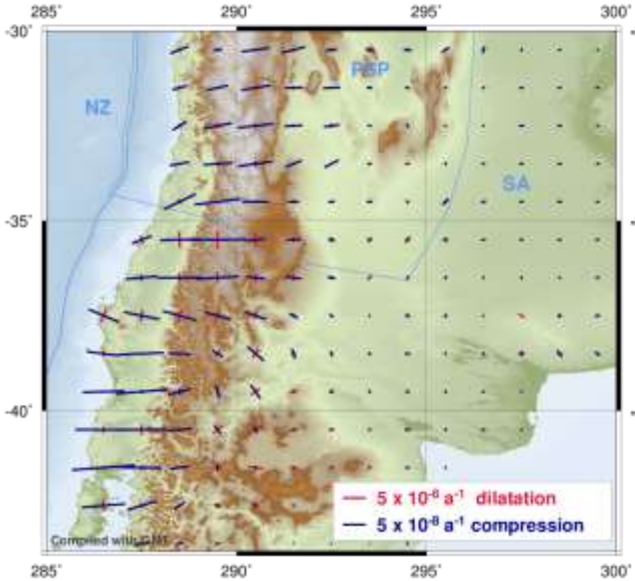
VEMOS2015 (ITRF)
2010.2 (2012.2) ... 2015.2
reduced to South
American Plate



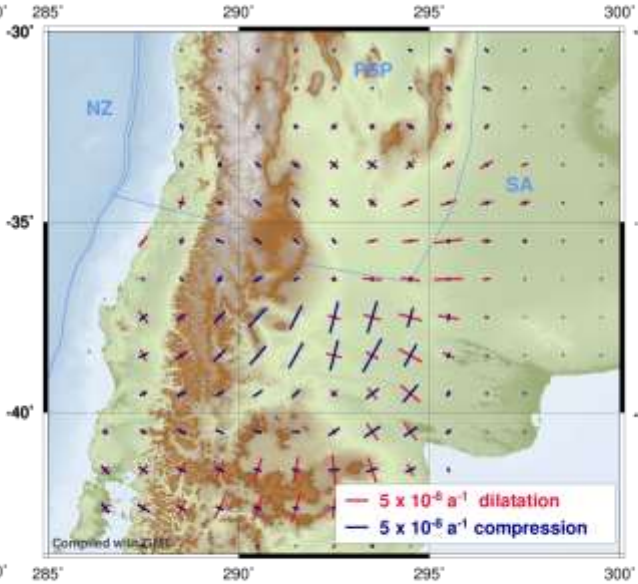
VEMOS2017 (ITRF)
2014.0 ... 2017.1
reduced to South
American Plate



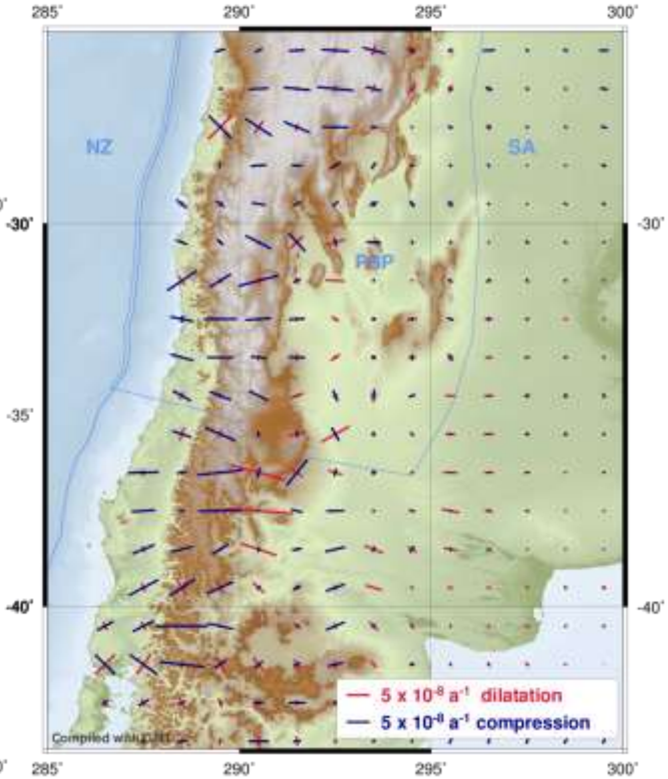
Maule strain field before and after 2010



VEMOS2009



VEMOS2015



VEMOS2017

Before the earthquake:

– strong west-east compression between the latitudes 38°S and 44°S;

– extensional strain rates in the north-south direction.

After the earthquake:

– maximum extensional strain rate south of latitude 40°S;

– north of 35°S extension to Maule zone (S45°W) with smaller rates;

– largest compression between Maule and Patagonia; it returns to the *usual* motion.

Closing remarks

– The modelled surface kinematics was inferred from GNSS velocities only; i.e. physical properties or dynamical environments were not included.

– Station velocities as well as the deformation models represent the mean displacements (deformation) along the defined periods (VEMOS2009: 2010.0 to 2009.6; VEMOS2015: 2010.2 to 2015.2; VEMOS2017: 2014.0 to 2017.1)

– The tectonic settings in the Caribbean and Central America are based on the combination of geophysical/geological interpretations/models with GNSS results.

– The deformation zones in the southern part of South America are defined in accordance with the geometry given by the GNSS station velocities in this study.

– The deformation caused by the 2010 Maule earthquake extends up to latitude 45°S and to the Atlantic coast in Argentina. Therefore, one could conclude that the southern part of Patagonia is deformable and does not belong to the stable part of the South American plate.

– The computation of the velocity field for SIRGAS has to be repeated until the velocities have come to a *usual* behaviour. This will take some more years.