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

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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**
  - 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:

\[ \mathbf{v}_{\text{pred}} = \mathbf{C}_{\text{new}} \mathbf{C}_{\text{obs}}^{-1} \mathbf{v}_{\text{obs}} \]

\( \mathbf{v}_{\text{pred}} \) = predicted velocities \((v_N, v_E)\) in a regular grid

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

\( \mathbf{C}_{\text{new}} \) = correlation matrix between predicted and observed vectors

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

\( \mathbf{C} \) 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 $\Delta v$
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

**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.