Assessment of South America Mid-Plate Strain Rates through GNSS Velocities Estimated from SIRGAS-C Time Series

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November 24, 2022

Abstract

We are investigating terrain deformations of long range and persistence that take place on continental scale over the stable shield of continental South America. The crustal deformation is being investigated by correlating with velocities and directions obtained from time series of approximately 60 GNSS stations deployed in Brazil and neighboring countries that take part of the Continuous network of the Geocentric Reference System for the Americas (SIRGAS-C). We attempt to estimate velocities and mid-plate strain rates using the best GNSS stations located in the stable South America mid-plate. The velocities have been estimated by Least Square Estimation (LSE) using SIRGAS weekly time series with a stochastic model composed of white noise plus flicker or random walk noises. Variance Component Estimation (VCE; Amiri-Simkooei et al., 2007) has been applied to classify the type of noise and compose the time series stochastic model. In addition, the time series breaks and offsets are taken into account in the LSE. The noises were classified as white plus flicker noise in approximately 70% of the horizontal component and most of random walk appears for stations located in the Amazon and Pantanal basins or near the coastal zones. The estimated formal precision reach about 0.10 mm/year with RMS of residual near 1.5 and 4.5 mm respectively for horizontal and vertical velocities. The estimated velocities by LSE were also computed by using the MIDAs code (Blewit et al 2015) and the results show an agreement of the order of 0.30 mm/y. The computed strain rates in the central part of Brazil indicate shortening, consistent with the predominance of reverse faulting mechanisms. When a station pair includes one station near the coast, the linear strain rates indicate extension. However, strain rates do not clearly indicate a preferred principal direction and do not seem compatible with the stress patterns derived from the focal mechanisms. In addition, the rate of seismic moment release indicates strain rates from earthquake occurrence two to three orders of magnitude lower than the observed strain rates from the geodetic network. Assessment of South America linear strain rates computed through estimated GNSS velocities will be discussed.

ASSESSMENT OF SOUTH AMERICA MID-PLATE STRAIN RATES THROUGH GNSS VELOCITIES ESTIMATED FROM SIRGAS-C TIME SERIES

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AGU 100 FALL MEETING
Washington, D.C. | 10–14 Dec 2018
G23C-0627

INTRODUCTION

We are investigating terrain deformations of long range and persistence that take place on continental scale over the stable shield of continental South America. The crustal deformation is being investigated by correlating with velocities and directions obtained from time series of approximately 60 GNSS stations deployed in Brazil and neighboring countries.

The velocities have been estimated by Least Square Estimation (LSE) using SIRGAS-C (Continuous Geocentric Reference System for the Americas) weekly time series with a stochastic model composed of white noise plus flicker (WH+FL) or white plus random walk (WH+RW) noises [1]. The noises were classified by the LS-VCE (Least Square Variance Component Estimation) and the estimated velocities by LSE were compared against SIRGAS (VEMOS) and MIDAS.

The strain rates where computed between pair of stations. In the central part of Brazil the strains rate indicate shortening, consistent with the predominance of reverse faulting mechanisms. When a station pair includes one station near the coast, the linear strain rates indicate extension. However, strain rates do not clearly indicate a preferred principal direction and do not seem compatible with the stress patterns derived from the focal mechanisms. Optimal estimation of velocities and assessment of South America linear strain rates is discussed in this presentation.

FUNCTIONAL AND STOCHASTIC MODELS FOR GNSS COORDINATE TIME SERIES

Functional:

$$y(t) = y_0 + rt + \sum_{k=1}^{q}\left[a_k \cos(\omega_k t) + b_k \operatorname{sen}(\omega_k t)\right] + \delta(t) + \nu_y \quad (1)$$

where:
$y(t)$ - observed time series (y) at time t;
y_0 and r - intersection and slope;
a_k and b_k - coefficients of the trigonometric terms (harmonic function);
w_k - harmonic frequency;
$k = 1,\dots,q$ - number of seasonal terms;
$\delta(t)$ - represents a breakpoint occurring at time t;
ν_y - time series residual.

Single breakpoint or exponentially decay post-seismic motion

$$\delta = \sum_{j=1}^{n_g} g_j H\left(t_i - T_{g_j}\right) + \sum_{j=1}^{n_h} h_j H\left(t_i - T_{hj}\right)t_i + \sum_{j=1}^{n_k} k_j e^{\left[1-\left(\frac{t_i - T_{k_j}}{t_j}\right)\right]} H\left(t_i - T_{k_j}\right) \quad (2)$$

Where H denotes the Heaviside step function. The first term in equation 2 corrects for the number n_g offsets, each one with magnitude g_j at epoch T_{gj}. The next terms allow modelling post-seismic motion as rate change h_j and/or exponential decay with magnitude k_j for Earthquake occurred at epoch T_{hj} and T_{kj}.

Stochastic:

The observations variance-covariance matrix (Qy) can be represented by the following linear combination [6], [1] and [2]:

$$Q_y = Q_0 + \sum_{k=1}^{p} \sigma_k^2 Q_k = Q_0 + \sigma_w^2 I + \sigma_f^2 Q_f + \sigma_{rw}^2 Q_{rw} \quad (3)$$

σ_w^2, σ_f^2 and σ_{rw}^2 are unknown parameters

Composition of WH+FL or WH+RW is based on statistical w-test [1] and [2].

The elements of Q_f (σ_{ij}^f) and Q_{rw} are computed as:

$$\sigma_{ij}^f = \begin{cases} 9/8 & if\ \tau = 0 \\ 9/8(1 - (\log\tau/\log 2) + 2/24) & if\ \tau \neq 0 \end{cases}$$

$$Q_{rw} = f_s^{-1}\begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & 2 & \cdots & 2 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 2 & \cdots & n \end{bmatrix} \quad \text{with } f_s = (m-1)/T$$

GEODETIC INFRASTRUCTURE

SIRGAS-C is a monitoring geodetic network formed by approximately 400 sites distributed along the Latin America and Caribbean region.

Several GNSS stations have been installed by IBGE/INPE with support of FAPESP. Although, there are few years of data from these stations, the main objective is for geodynamic monitoring.

Fig 1: GNSS stations belonging to the SIRGAS network
Fonte: http://www.sirgas.org/pt/sirgas-con-network/stations/ (Accessed: sept 2018)

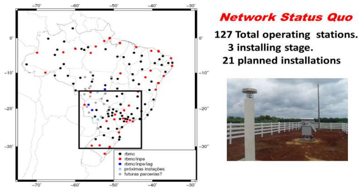


Fig 2: Stations for geodynamic monitoring installed by IBGE/INPE in the context of FAPESP thematic project

METHODOLOGY

SIRGAS time series were retrieved form SINEX files taking account 40 stations located in the most stable part of the South American plate. The time series span for the chosen stations vary from minimum of approximately 5 years until approximately 18 years. The procedure involved data cleaning from statistical analysis, discontinuities detections, stochastic model estimation through LS-VCE, optimal velocity estimation account for trend, seasonal and breaks and finally the strain rate computation between pair of stations. The estimated velocities based on our adopted strategy was denominated 'LS+' and comparisons were accomplished against velocities coming from SIRGAS [4] and MIDAS [3].

EXPERIMENTS

Stochastic Model - Noise variance component estimation

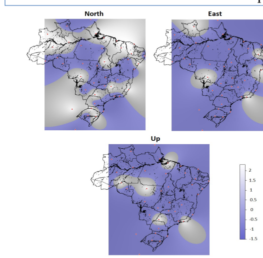


Fig 5: Geographic distribution of noise for SIRGAS stations (FL: k=-1 and RW: k=2)

Time series adjusted in the LS+

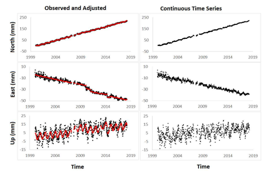


Fig 6: Observed and adjusted time series for POAL station

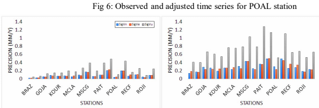


Fig 7: Precision due to application of only diagonal or full (time correlation) covariance matrix of observations

- Stations more susceptible to affected by WH+RW are located in the Amazon basin, regions nearest to the Andes and in the Coastal zones.
- The stochastic models in most of cases are composed by WH+FN being approximately 60% for North and 85% for East and Up coordinates.
- For cases with diagonal covariance matrix of observations, the average velocity precision reached near 0.09 mm/year and 0.22 mm/year, respectively, for horizontal and vertical velocities. However, considering the case of full observation covariance matrix (time correlation) , the average reached values of approximately 0.29 mm/year and 0.73 mm/year, respectively, for horizontal and vertical velocities precisions.

Comparisons LS+ versus MIDAs and VEMOS17 (Velocity Model for SIRGAS)

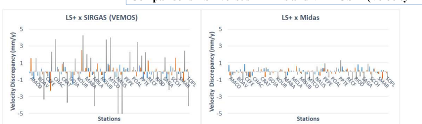


Fig 8: LS+ versus SIRGAS (VEMOS) and MIDAS

Table 1: Statistics for velocity discrepancies

	dVn	dVe	dVu
LS+ versus SIRGAS			
Mean	-0.094	0.108	-0.140
Standard Deviation	0.584	0.788	2.814
RMS	0.592	0.795	2.818
LS+ versus MIDAS			
	dVn	**dVe**	**dVu**
Mean	0.099	-0.038	-0.290
Standard Deviation	0.355	0.318	0.681
RMS	0.368	0.320	0.740

The largest difference for LS+ versus SIRGAS (VEMOS), can be due to SIRGAS velocities estimation in different periods, as for example, the two periods for NAUS given, respectively by 2011/04/17 until 2013/04/06 and 2014/08/31 until 2016/11/18 [5].

Assessment of stresses for South America mid plate

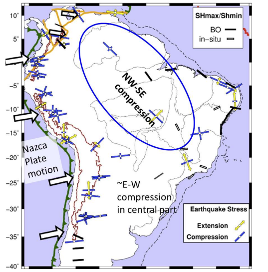


Fig 9: Stress patterns (stress inversions from foc. mechs.)

Strain rates Range from:
-1.0 E-9/y to +0.4 E-9/y

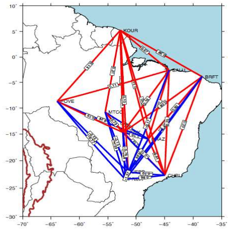
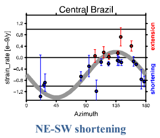
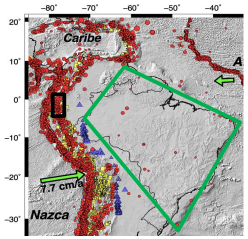
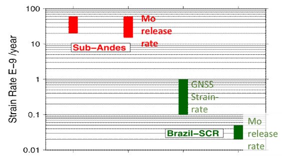


Fig 10: Strain Rates between all pairs of stations



Intraplate seismicity





In mid-plate Brazil, seismic moment release is one order of magnitude lower than deformation rate

COMMENTS AND CONCLUSIONS

In this work strain rate is being analyzed by using optimal velocities estimated from SIRGAS time series. The adopted methodology involves variance component estimation to form the stochastic model and accounting for trend, seasonal effects and breaks. RMS of time series residuals reach the order of 1.5 and 4.5 mm respectively for horizontal and vertical coordinates. The estimated velocities by LS+ were also computed by using the MIDAs code [3] and the results show an agreement of the order of 0.30 mm/y.

The computed strain rates in the South America mid plate (central part of Brazil) indicate shortening, consistent with the predominance of reverse faulting mechanisms. When a station pair includes one station near the coast, the linear strain rates indicate extension. However, strain rates do not clearly indicate a preferred principal direction and do not seem compatible with the stress patterns derived from the focal mechanisms. In addition, the rate of seismic moment release indicates strain rates from earthquake occurrence two to three orders of magnitude lower than the observed strain rates from the geodetic network.

The topic under investigation requires answer to what causes NE-SW shortening rate in South America mid-plate and possibly extensional rates along the coast. The strain rates can be explained by Global Glacial Isostatic Adjustment, relaxation after large Andean Earthquakes or decadal deep hydrological cycles?

ACKNOWLEDGMENTS

The authors would like to thanks the FAPESP by financial support through processes 2017/02968-3 and 2013/24215-6.

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