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Crustal Deformation in South America from GPS and VLBI

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Abstract

The western coast of South America is a tectonically active convergent margin, where the Nazca and Antarctic plates subside under the South American continent. We present contemporary crustal deformation obtained from GPS and VLBI data. A network of 20 permanent GPS stations, mainly on the west coast, was analyzed using the Precise Point Positioning (PPP) strategy with the GIPSY/Oasis II software. The movement of the stations during more than five years, starting in late 1999, was derived and the corresponding strain rate field was calculated. Station velocities were compared to corresponding results from VLBI analyses.

1. Introduction

The analysis of GPS and VLBI observational data provides important crustal deformation results for geophysical research. Crustal deformation in terms of station velocities and strain rate fields can be derived. Zones of deformation, where tectonic plates converge, are of special interest, due to the variety of geological processes that occur there.

2. Background - The Tectonic Setting in South America

The subsidence of the oceanic Nazca and Antarctic plates beneath the South American continental plate creates the Andean subduction zone (ASZ). It represents the longest convergent margin in the world, stretching for over 7500 km along the South American west coast from Colombia to the south of Chile. Due to the active plate margin, the Andes comprise high mountain peaks and volcanoes, and most parts of the area have been struck by earthquakes.

The relative convergence vector between the Nazca and South American plates is 65 mm/yr [1]. The total relative plate motion in the ASZ can be divided into different components controlling crustal deformation [2]. Roughly half of the motion accumulates in the locked parts of the plate interface, leading to transient elastic deformation, which is released in large thrust earthquakes. Some motion is expected to occur as stable sliding at the interface, since the slip rate of large subduction earthquakes is generally less than the convergence rate. The vertical crustal thickness of the Andes and its root implies that some of the motion also causes permanent crustal shortening and mountain building.

3. GPS and VLBI: Data, Analysis and Results

The area of investigation is enclosed by 16°S in the north and 54°S in the south and stations are located on both sides of the Andes. The majority of the 20 GPS stations chosen for this study are IGS sites. Additionally, GPS data from a station operated at the ALMA site at Chajnantor in Northern Chile at about 5000 m height [4] are included. Five permanent GPS sites in eastern South America were added for reference. The station locations are listed in Table 1, together with the location of the few VLBI sites in South America.

GPS data from this network between late 1999 and mid 2005 were downloaded from SOPAC GPS data archive [3]. The data were analyzed using the GIPSY/Oasis II software [5] with the Precise Point Positioning strategy [6] and a non-fiducial approach. The daily coordinate results were transformed to ITRF2000 using transformation parameters provided by IGS and JPL, respectively.

VLBI data were not analyzed by ourselves; instead we used the velocity solution of the combined VLBI Terrestrial Reference Frame (VTRF2005) [7].

3.1. Station Velocities

GPS station velocities were derived by a least-squares fit to the time series of topocentric station positions. Examples for time series are shown in Fig. 1. Row one shows the west coast station SANT in Chile, row two shows the west coast station AREQ in southern Peru that was affected by a strong earthquake in 2001, the third row shows the station CHAJ in northern Chile on the altiplano at about 5000 m height, and the last row shows the station BRAZ in the eastern part of South America.

Outliers were removed in two steps, based on the formal standard deviations and simple outlier tests. Topocentric station velocities were determined by fitting offset, linear trends, and annual signals to the time series. For the station AREQ in southern Peru, which suffered from a M_w=8.4 earthquake in June 2001, parameters of a post-seismic relaxation model for the horizontal displacement were also determined. The best fit relaxation times were 0.26 and 1.04 years for the North and East component, respectively. Table 1 lists the results for topocentric GPS station velocities, as well as the velocities of the few VLBI stations in South America.

We find that the west coast stations move landward in a NE direction. This is due to coupling at the thrust interface during an inter-seismic phase. The velocities are highest at the coast, close to the trench, and decrease further away from it. Horizontal velocities for stations in the ASZ are on the order of 10-35 mm/yr and in the eastern part around 10 mm/yr. The horizontal VLBI velocities agree reasonably well with the GPS derived velocities. However, the vertical velocities do show significant discrepancies.

3.2. Strain Rate Field

Knowing the GPS station positions and velocities, the strain rate field was calculated for almost the entire South American continent. A Delauney triangulation was used to densify the network into a finite element structure. The velocity field of this finite element structure was calculated with a least-squares collocation method. Then, three dimensional strain rate tensors were determined for all finite elements [8]. Figure 2 shows the tangential part of the strain rate tensors. A band of extensive compressional deformation along the west coast between latitude 20°S and 40°S is clearly visible. The average compression is on the order of 5-15 nanostrain/yr with peak values of up to 100 nanostrain/yr, while extension directly east of the Andes is about 5-10 nanostrain/yr. The average compression and extension in the eastern part of South America are both on the order of 1 nanostrain/yr with peak values of up to 6 nanostrain/yr.

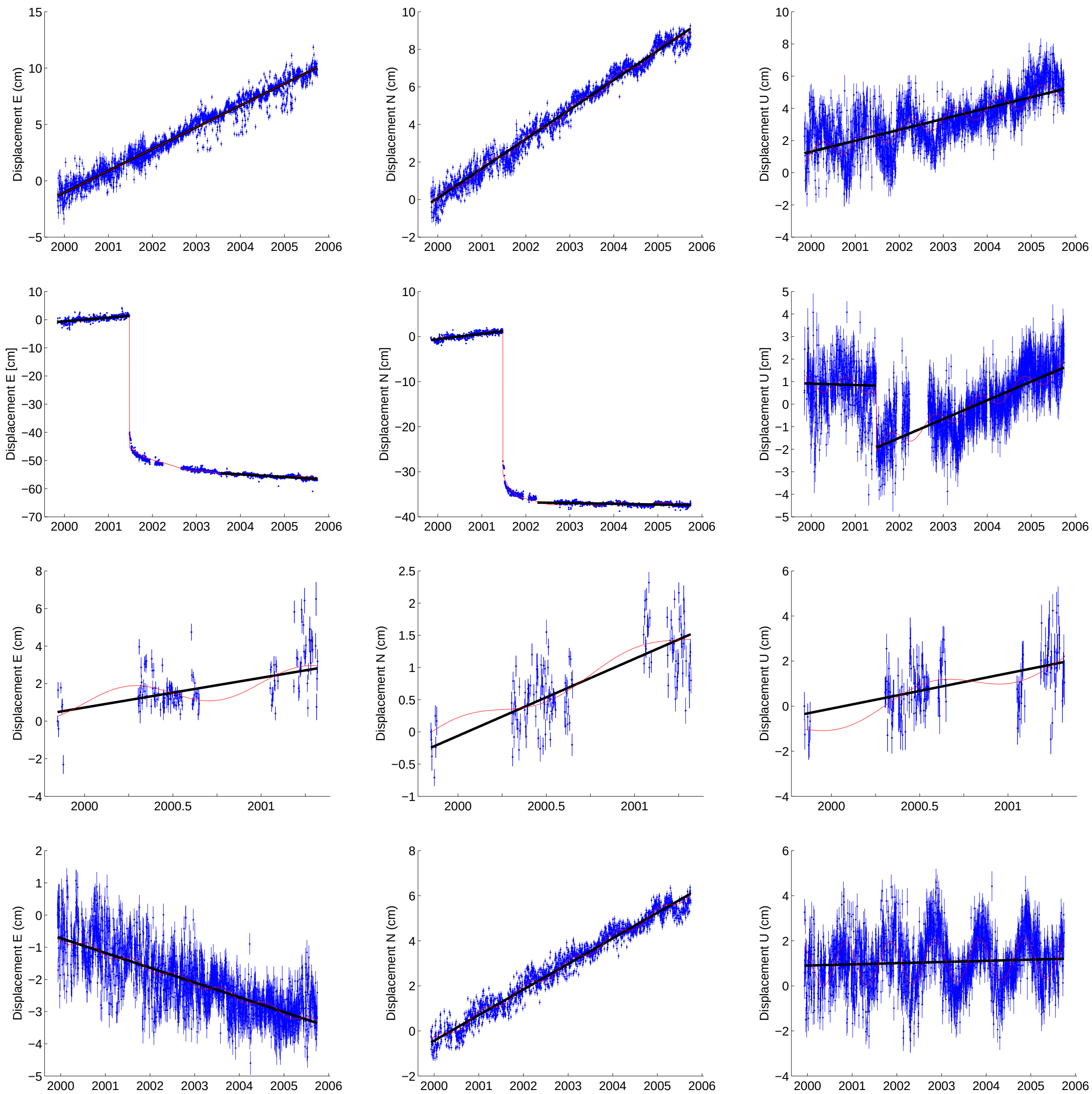

Figure 1. Examples of GPS derived time series of topocentric station positions in South America. Row 1–4 show the stations SANT, AREQ, CHAJ and BRAZ, and column 1–3 the East, North and Up components, respectively. The estimated linear station velocities are shown as straight lines whereas the sinusoidal curves represent seasonal components. For the horizontal motion of the station AREQ an exponential relaxation model was applied.

Table 1. Station names, geographic positions, and topocentric velocities of South American GPS stations. (1) Results only before the June 2001 earthquake. (2) Results only after the June 2001 earthquake. (3) Results only before June 2005. (4) Results only before May 2005.

Station	λ °E	ϕ °N	v_E (mm/yr)	σ_{v_E} (mm/yr)	v_N (mm/yr)	σ_{v_N} (mm/yr)	v_U (mm/yr)	σ_{v_U} (mm/yr)
AREQ[1]	−71.49	−16.47	13.13	0.17	12.14	0.05	−0.62	0.48
AREQ[2]	−71.49	−16.47	−9.34	0.76	−1.61	0.01	8.33	0.12
CFAG	−68.23	−31.60	5.19	0.01	11.40	0.01	0.30	0.11
CHAJ	−67.79	−22.90	10.70	0.78	10.82	0.20	20.67	1.40
CORD	−64.47	−31.53	−0.68	0.04	10.77	0.01	2.01	0.11
PARC	−70.88	−53.14	3.41	0.04	12.18	0.03	−0.82	0.12
RIOG	−67.75	−53.79	2.76	0.02	11.46	0.01	6.03	0.06
SANT	−70.67	−33.15	19.31	0.03	15.82	0.01	6.96	0.07
TUCU	−65.23	−26.84	0.20	0.05	9.89	0.02	3.92	0.14
IQQE[3]	−70.13	−20.27	22.86	0.04	13.79	0.02	7.86	0.17
COPO	−70.34	−27.38	17.41	0.05	13.46	0.02	11.97	0.15
UNSA	−65.41	−24.73	2.98	0.03	10.38	0.01	3.36	0.10
VALP	−71.63	−33.03	27.65	0.16	21.47	0.08	−1.27	0.52
CONZ[4]	−73.03	−36.84	28.91	0.04	19.50	0.02	8.40	0.18
ANTC	−71.53	−37.34	12.91	0.12	9.76	0.06	9.30	0.36
COYQ	−71.89	−45.51	−4.01	0.09	9.96	0.05	0.46	0.27
BRAZ	−47.88	−15.95	−4.60	0.04	11.40	0.01	0.55	0.08
FORT	−38.43	−3.88	−4.37	0.11	11.02	0.02	2.15	0.18
CHPI	−44.99	−22.69	−4.51	0.09	9.78	0.04	3.22	0.32
LPGS	−57.93	−34.91	−3.14	0.03	10.54	0.02	5.25	0.10
KOUR	−52.81	5.25	−6.07	0.03	12.23	0.01	3.88	0.09
VLBI station locations and topocentric velocities [7]								
FORT	−38.43	−3.88	−4.41	0.20	11.89	0.11	−0.24	0.09
TIGO	−73.03	−36.84	30.38	1.12	20.32	0.68	4.39	1.26
SANT	−70.67	−33.15	19.84	0.54	15.75	0.15	5.03	0.50

4. Discussion and Conclusions

The results of this study agree with previous investigations [9], [10]. During inter-seismic periods velocities in the ASZ are generally landward and greatest close to the trench, up to 35 mm/yr, induced by the motion of the incoming Nazca and Antarctic plates. On occasions of fault slip, like the one close to Arequipa, Peru, in 2001, the crust suddenly moves seawards and the post-seismic signal shows slow continued movement in the same direction.

The horizontal velocity of the GPS station at Chajnantor is comparable to other GPS station on the altiplano [2].

The few available VLBI velocities in general confirm the findings of this GPS study.

The strain rate field is, as expected, highly pronounced along the South American west coast. In this area it is dominated by compression with values from 10-100 nanostrain/yr. Some regions east of the Andes experience smaller extension of about 5-10 nanostrain/yr. The eastern part of South America is dominated by a strain rate field with values on the order of 1-6 nanostrain/yr.

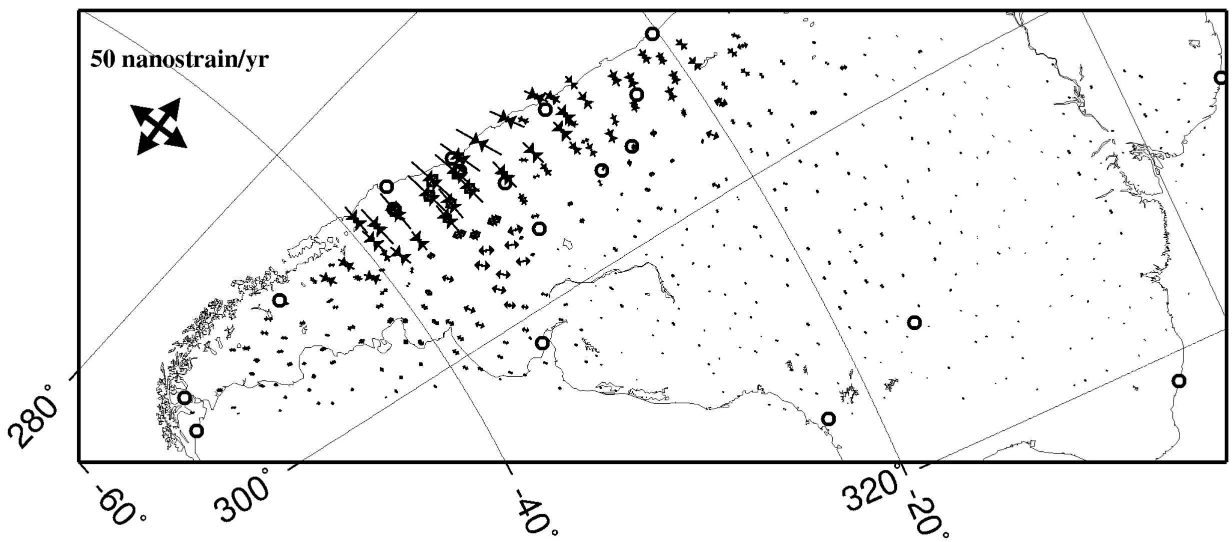

Figure 2. The GPS-derived strain rate field in South America. The circles mark GPS sites.

References

[1] Angermann, D., Klotz, J., and Reigber, C.: Space-geodetic estimation of the Nazca-South American Euler Vector. *Earth Planet. Sci. Lett.*, **171**, 329–334, 1999.

[2] Norabuena, E., Leffler-Griffin, L., Mao, A., Dixon, T., Stein, S., Sacks, S., Ocola, L., and Ellis, M.: Space-geodetic Observations of Nazca-South American Convergence Across the Central Andes. *Science*, **279**, 1998.

[3] `ftp://garner.ucsd.edu/pub/rinex`

[4] Gradinarsky, L. P., Johansson, J. M., Elgered. G., and Jarlemark, P.: GPS site testing in Chajnantor in Chile. *Phys. Chem. Earth*, **26(6–8)**, 421-426, 2001.

[5] F.H. Webb and J.F. Zumberge: An introduction to GIPSY/OASIS-II. *JPL Publication D-11088*, Jet Propulsion Laboratory, Pasadena, 1993.

[6] J.F. Zumberge, M.B. Hefflin, D.C. Jefferson, M.M. Watkins, and F.H. Webb: Precise point positioning for the efficient and robust analysis of GPS data from large networks. *J. Geophys. Res.*, vol. 102(B3), pp. 5005–5018, doi:10.1029/96JB03860, 1997.

[7] Nothnagel, A.: VTRF2005 A combined VLBI Terrestrial Reference Frame. In: *Proc. 17th Work. Meet. Euro. VLBI Geodesy and Astrometry*, 118-124, 2005.

[8] Haas, R., Scherneck, H.-G., Gueguen, E., Nothnagel, A., and Campbell, J.: Large-scale strain-rates in Europe derived from observations in the European geodetic VLBI network. *EGU Stephan Mueller Special Publication Series*, **2**, 139–152, 2002.

[9] Klotz, J., Khazaradze, G., Angermann, D., Reigber, C., Perdomo, R., and Ciuentes, O.: Earthquake cycle dominates contemporary crustal deformation in Central and Southern Andes. *Earth Planet. Sci. Lett.*, **193**, 437-446, 2001.

[10] Khazaradze, G., and Klotz, J.: Short and long-term effects of GPS measured crustal deformation rates along the South-Central Andes. *J. Geophys. Res.*, **108(B4)**, doi:10.1029/2002JB001879, 2003.