Draft du 6 avril-2009, submitted (and rejected) to Advances in Space Research

Chilean-French cGPS Operations along the Subduction Trench in Chile, South-America

Christophe Vigny[1], Anne Socquet[2], Alain Rudloff[1], Jean-Claude Ruegg[2], Alexandre Nercessian[2], Sylvain Morvan[1], Raul Madariaga[1], Arthur Delorme[2], Olivier Charade[2,3], Jean-Bernard de Chabalier[2], Daniel Carrizo[2,4], Jaime Campos[4], Carolina Bermejo[4], Marta Bejar[2], Sergio Barrientos[4], Carlos Aranda[4],

[1]Laboratoire de Géologie, Ecole Normale Supérieure (ENS), CNRS, Paris, France

[2]Institut de Physique du Globe (IPGP), Paris, France

[3]Division Technique de l'INSU, Meudon, France

[4]Departamento de Geofísica (DGF), Universidad de Chile, Santiago, Chile.

Abstract:

The subduction in Chile is very active with in average a Mw 8 event every ten years along the coast. This activity is the result of the fast convergence (~ 7 cm/yr) of the Nazca plate subducting under the American plate (Norabuena et al., 1999; Angermann et al., 1999; Kendrick et al., 2003, Altamimi et al., 2007; Vigny et al., 2009). The subduction zone in Chile is segmented, and each segment alone can produce large earthquakes similar to those of Concepcion (1835), Valparaiso (1906, 1985), La Serena (1880, 1943), Vallenar (1819, 1922), Arica (1877), Antofagasta (1995) (eg. Barrientos, 1995; Comte et al., 1986; Ruegg et al., 1995 for recent earthquakes, Beck et al, 1998;; Lomnitz, 1971 for historical earthquakes). Occasionally, the rupture connects several segments in one larger magnitude 9+ earthquake like the event of 1730 which seemed to have ruptured the whole central part of Chile, from Concepcion to LaSerena (Beck et al. 1998); or the Valdivia mega-thrust event of 1960: the largest earthquake ever recorded (eg. Cifuentes 1989).The recent earthquake of Tocopilla (2007) could be an indication of the preparation of a larger rupture on this particular section of the fault -the gap of Arica (). It could also be that the intra-plate events of Chillan 1939 ~35°S, Punitaqui 1997 ~30°S (Pardo et al., 2002b), Tarapaca 2005 ~20°S (Peyrat et al, 2006), are an indication of the preparation of the subduction interface for a major rupture. Based on parsimonious historical data, several seismic gaps (i.e. areas where large earthquakes happened in the past, but not recently) have been identified (eg. Kelleher, 1972). Three seismic gaps in North and Central Chile were identified by the French and Chilean teams as being close to rupture: In two of these gaps, no major earthquakes has been recorded since the last 130 years (eg Campos et al., 2002; Conte and Pardo, 1991). We report here on the installation of a Chilean-French cGPS network in Chile, which aim is to monitor crustal deformation during the seismic cycle and possibly capture the triggering processes of large subduction earthquakes.

Network:

We installed the very first cGPS station in Iquique, north Chile in 1995. Since then, and until the beginning of the new century, some stations were installed but remained very few and very sparce. Starting in 2003 and during the next 5 years, we installed 11 additional stations in northern Chile between Arica and Antofagasta (18°S-27°S) and 24 new stations in central Chile, between Concepción and La Serena (37°S-30°S). Additionally, some older stations have been upgraded to improve the coherence and the quality of the network. Today, the network is composed of 37 stations, among which

27 are recording at 1 Hz and 21 are daily transmitting (table 1, figure 1). The data are archived in Chile (http://www.dgf.uchile.cl) and in France (http://gpscope.dt.insu.fr) where they are made available to the community upon request.

Scientific results:

The network is designed to monitor crustal deformation associated to accumulation of elastic deformation in the overriding continental plate. This deformation is due to the convergence between the two plates (the oceanic Nazca plate subducting under the continental South-American plate) and the fact that because of friction on the interface the motion is currently locked. At the end of the seismic cycle, a sudden earthquake releases instantaneously (1-10 minutes) the deformation that has been accumulated for centuries. Then, a post-seismic deformation occurs, releasing additional deformation, possibly over decades for the biggest earthquakes. The pattern of surface deformation is related to the geometry of the subduction interface (dip angle, width, length, depth), the velocity of plate tectonics, and the friction properties on the interface. Hence, its quantification is a key point for understanding earthquake nucleation.

Occasionnaly, a cGPS network captures an earthquake. Several studies have been dealing with the recent earthquake that occurred on the subduction in North Chile: the 14 November 2007, Mw 7.6, Tocopilla earthquake (Bejar et al. 2009). The rupture of the Tocopilla earthquake is shown to propagate North to South, and activating along 130 km two main asperities, localised at a depth between 30 to 50 km at the base of the coupled zone. These two asperities have been independently confirmed by a detailed study of the GPS data and the InSar images. However, this earthquake has only partially ruptured the South and deep part of the North Chile seismic gap. Will the remaining part of this segment rupture in recurring ~Mw8 earthquakes, or was the Tocopilla earthquake a preparation for a mega-thrust event rupturing the whole segment at once ?

Additionally, the high sampling instruments demonstrated their capacity to record seismic waves, even at very large distances from the epicentre. The cGPS station of BTON (Tongoy), located 850 km due south of Tocopilla shows very clearly surface waves (Love and Rayleigh) arriving at distinct times on the different components (fig 2). The East-West component is affected by the Love wave, polarized orthogonally to propagation and travelling at approximately 4 km/s. The North-South and vertical components are affected simultaneously by the Rayleigh wave, polarized circularly along the direction of propagation and travelling at approximately 3 km/s. The records match extremely well those of a broadband station located at Las Campanas observatory (~100 km away).

Finally, in our standard processing we estimate one tropospheric vertical delay parameter per station every 3 hours. These can be extracted routinely from the solutions and used as a proxy of the tropospheric water vapor contains. They clearly show variations related to climate and allow to quantify them in time and space. Should these reveal useful for meteorological models, we could easily set up a second routine process of our data, dedicated to meteorological application, with 15 minutes sampling for example.

Acknowledgment:

The cGPS network was developed and installed under the umbrella of an international collaboration. An International Associated Laboratory (LIA) “Montessus de Ballore” was created in 2006 by the CNRS(DRI), associating the CNRS/INSU and the University of Chile (departments of geophysics and geology). In November 2006, the LIA was officially launched during the workshop Montessus de Ballore in Santiago. Our geodetic project is sponsored by CNRS/INSU programs (PICS, ACI Catnat) and the French National Research Agency (ANR) in France; and by "Nucleo Milenio en Sismotectónica y Peligro Sísmico" in Chile.

References:

Altamimi, Z., X. Collilieux, J. Legrand, B. Garayt, and C. Boucher (2007), ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters , *J. Geophys. Res*., 112, B09401, doi:10.1029/2007JB004949.

Angermann, D., J.Klotz, and C.Reigber, (1999), Space geodetic estimation of the Nazca-South America Euler vector, *Earth Planet. Sci. Lett.* 171, 329-334.

Barrientos, S.E., (1995), Dual seismogenic behavior: the 1985 Central Chile earthquake, *Geophys. Res. Lett*., 22, 3541-3544.

Beck, S.L., Barrientos, S., Kausel, E., and Reyes, M., (1998), Source characteristics in historic earthquakes along central Chile subduction zone, *J. S. Am. Earth. Sci*., 11, 115-129.

Campos, J., Hatzfield, D., Madariaga, R., Lopez, G., Kausel, E., Zollo, A., Ianaconne, G., Fromm, R., Barrientos, S. and Lyon-Caen, H., (2002), A seismological study of the 1835 seismic gap in South Central Chile, *Phys. Earth Planet. Int.,* 132, 177-195.

Cifuentes, I.L., (1989), The 1960 Chilean earthquake, *J. Geophys. Res.,* 94, 665-680.

Comte, D., Eisenberg, A., Lorca, E., Pardo, M., Ponce, L., Saragoni, R., Singh, S.K. And Suarez, G., (1986), The Central Chile earthquake of 3 March 1985: a repeat of previous great earthquakes in the region? *Science,* 233, 449-453.

Comte, D. and Pardo, M., (1991). Reapprisal of great historical eathquakes in Northern Chile and Southern Peru seismic gaps, *Nat. Hazards*, 4, 23-44.

Kelleher, J., (1972) Rupture zones of large South American earthquakes and some predictions, *J. Geophys.Res.* 77, 2087-2103.

Kendrick, E., M. Bevis, R. Smalley, B. Brooks, R Vargas, E. Lauria, and L. Souto-Fortes (2003), The Nazca-South America Euler vector and its rate of change. *Journal of South American Earth Sciences, 16, pp125-131*

Lomnitz, C., '1971), Grandes terramotos y tsunamis en Chile durante el periodo 1535-1955, *Geofis. Panamericana*, 1, 151-178.

Norabuena, E., T. Dixon, S. Stein, and C.G.A Harrison (1999), Decelerating Nazca-South America and Nazca-Pacific Plate Motion, *Geophys. Res. Lett.*, 26, 3405-3408.

Pardo, M., D. Comte, T. Monfret, R. Boroschek and M. Astroza, (2002b), The October 15, 1997 Punitaqui Earthquake (Mw=7.1): a destructive event within the subducting Nazca plate in central Chile, *Tectonophysics*, 345, 199-210.

Peyrat, S., Campos, J., de Chabalier, J.B., Perez, A., Bonvalot, S., Bouin, M.-P., Legrand, D., Nercessian, A., Charade, O., Patau, G., Clévédé, E., Kausel, E., Bernard, P., and Vilotte, J.-P., (2006), Tarapaca intermediate depth earthquake (Mw 7.7, 2005, northern Chile): a slab-pull event with horizontal fault plane constrained from seismologic and geodetic observations, *Geophys. Res. Lett.*, 33, L22308, doi:10.1029/2006GL027710.

Ruegg, J.C., J. Campos, R. Armijo, S. Barrientos, P. Briole, R. Thiele, M. Arancibia, J. Cañuta, T. Duquesnoy, M. Chang, D. Lazo, H. Lyon-Caen, L. Ortlieb, J.C. Rossignol, and Serrurier, L. (1996), The Mw=8 1 Antofagasta (North Chile) earthquake July 30, 1995 : first results from teleseismic and geodetic data. *Geophys. Res. Lett.*, 23, 917-920.

Vigny, C., A. Rudloff, J.C. Ruegg, R. Madariaga, J. Campos, M. Alvarez (2009), Upper plate deformation measured by GPS in the Coquimbo gap, Chile, *PEPI,* 10.1016/j.pepi.2008.02.013

code	Name	Lat. S	Long. W	altitude	rec. type	Sampling rate	data transfer	operational since
UTAR	Univ. Tarapaca, Arica	18.490	70.296	87	Ashtech ZXtrem	30s	internet	03-dec-2003
MNMI	MiniMini	19.131	69.595	2351	TopCon GB-1000	1Hz	Satellite	28-mar-2007
COLC	Colchane	19.276	68.638	3777	TopCon GB-1000	1Hz	manual	04-nov-2007
PSGA	Pisagua	19.597	70.123	1002	TopCon GB-1000	1Hz	Satellite	30-mar-2007
PCHA	Pachica	19.869	69.432	1682	Ashtech ZXtrem	30s	manual	03-jun-2003
UAPE	Univ. Arturo Prat, Iquique	20.241	70.141	56	Ashtech ZXtrem	30s	internet	21-may-2005 (init 1995)
HMBS	Humberstone	20.278	69.887	1208	TopCon GB-1000	1Hz	Satellite	29-mar-2007
PICC	Pica	20.485	69.321	1376	TopCon GB-1000	1Hz	manual	03-nov-2007(init 1999)
MICA	Cerro Mica	21.714	69.827	1675	Trimble Net-RS	1Hz	manual	16-dec-2007
URCU	Punta Urcu	21.763	70.152	0	Trimble Net-RS	1Hz	manual	04-dec-2007
RADO	Radomiro tomic mine	22.082	68.926	0	Trimble Net-RS	1Hz	manual	08-dec-2007
PCAL	Calama	22.456	78.929	2300.2	Ashtech ZX-trem	30s	manual	29 nov 2008
PMEJ	Punta Mejillones	23.100	70.448	48	Ashtech ZXtrem	30s	internet	29-nov-2003
UCNF	Univ. Cat. Norte, Antofagasta	23.680	70.410	72	Trimble Net-RS	1Hz	internet	03-dec-2003
VALL	Vallenar	28,572	70,764	378	Trimble Net-RS	1Hz	manual	12-jun-2008
CRZL	Carizalillo	29,101	71,409	84	Trimble Net-RS	1Hz	manual	15-nov-2008
SILL	La Silla	29,254	70,738	2323	Trimble Net-RS	1Hz	internet	13-jun-2008
LSCH	La Serena	29,908	71,246	77	Trimble Net-RS	1Hz	internet	20-nov-2006
JUNT	Junta El Toro	29,976	70,093	2138	Trimble Net-RS	1Hz	manual	14-dec-2007
TOLO	El Tololo	30,169	70,806	2229	Trimble Net-RS	1Hz	internet	11-may-2005
BTON	Tongoy	30,263	71,487	39	Trimble Net-RS	1Hz	internet	16-nov-2006
OVLL	Ovalle	30,603	71,203	248	Trimble Net-RS	1Hz	internet	26-avr-2004
PFRJ	Parc Fray Jorge	30,674	71,635	206	Trimble Net-RS	1Hz	manual	18-nov-2006
PEDR	Pedregal	30,838	70,689	881	Trimble Net-RS	1Hz	manual	21-nov-2006
EMAT	Caletta El Maiten	31,146	71,662	46	Trimble Net-RS	1Hz	manual	08-may-2007
CMBA	Combarbala	31,188	70,998	963	Trimble Net-RS	1Hz	manual	08-may-2007
CNBA	Canela Baja	31,398	71,457	316	Trimble Net-RS	1Hz	internet	21-nov-2006
SLMC	Salamanca	31,777	70,962	547	Ashtech MicroZ	30s	manual	28-jul-2003
LVIL	LosVilos	31,909	71,513	29	Ashtech MicroZ	30s	manual	28-jul-2003
PORT	Portillo	32,835	70,130	2925	Ashtech UZ-12	30s	internet	11-dec-2002
ROBL	Roble	32,976	71,015	2255	Trimble Net-RS	1Hz	internet	28-oct-2008
VALN	Valparaiso SHOA	33,027	71,635	119	Ashtech ZXtrem	30s	internet	01-jan-2005
VNEV	Valle Nevado	33,353	70,249	3097	Ashtech UZ-12	30s	internet	08-jan-2003
DGF1	U-Chile, Santiago	33,457	70,664	581	Ashtech ZXtrem	30s	internet	01-jan-2004
RCSD	Roca Santo Domingo	33,654	71,613	66	Trimble Net-RS	1Hz	internet	16-Oct-2008
CONS	Constitucion	35,330	72,412	39	Trimble Net-RS	1Hz	internet	29-avr-2003
SJAV	San Javier	35,595	71,733	119	Trimble Net-RS	1Hz	internet	24-jun-2003
MAUL	Laguna del Maule	35,809	70,821	1184	Trimble Net-RS	1Hz	manual	22-dec-2003

Table 1: list, location, and principal characteristics of cGPS stations

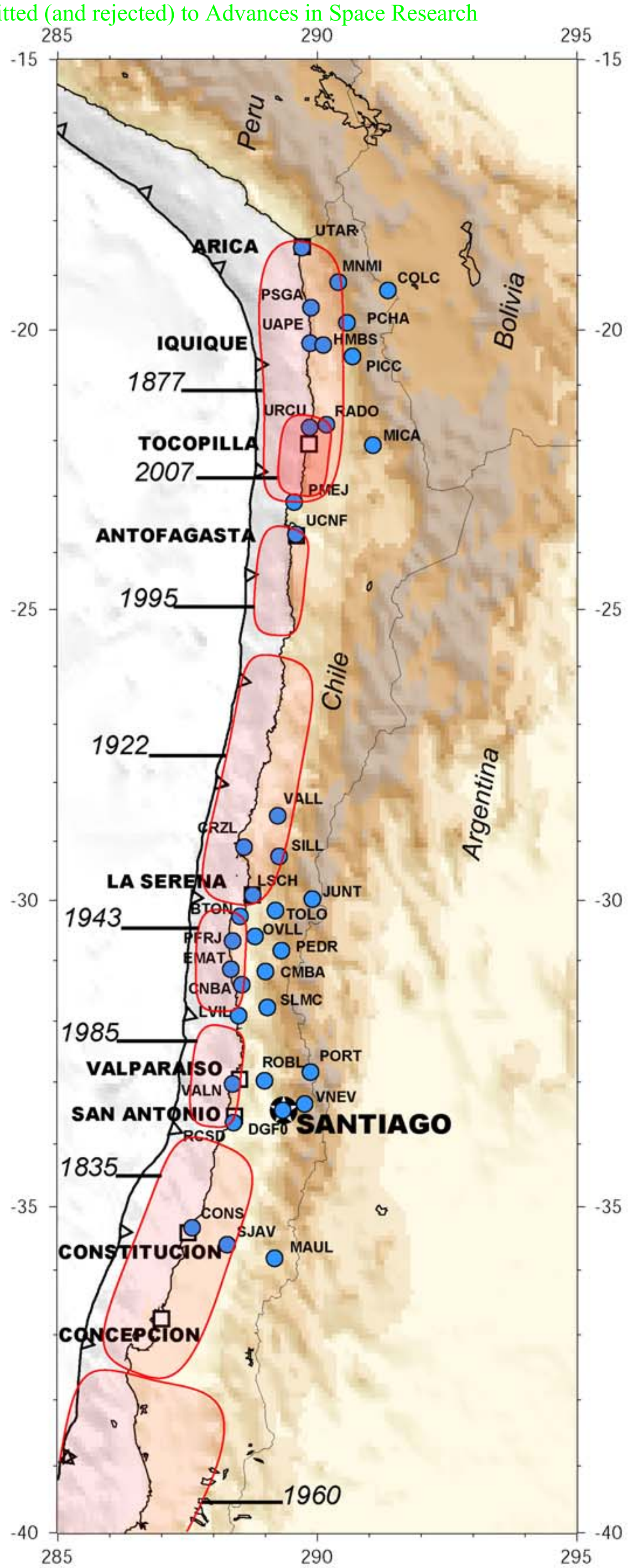

Figure 1: cGPS network in Chile. Blue dots depict cGPS stations. Red patches depict recent and historical earthquake ruptures

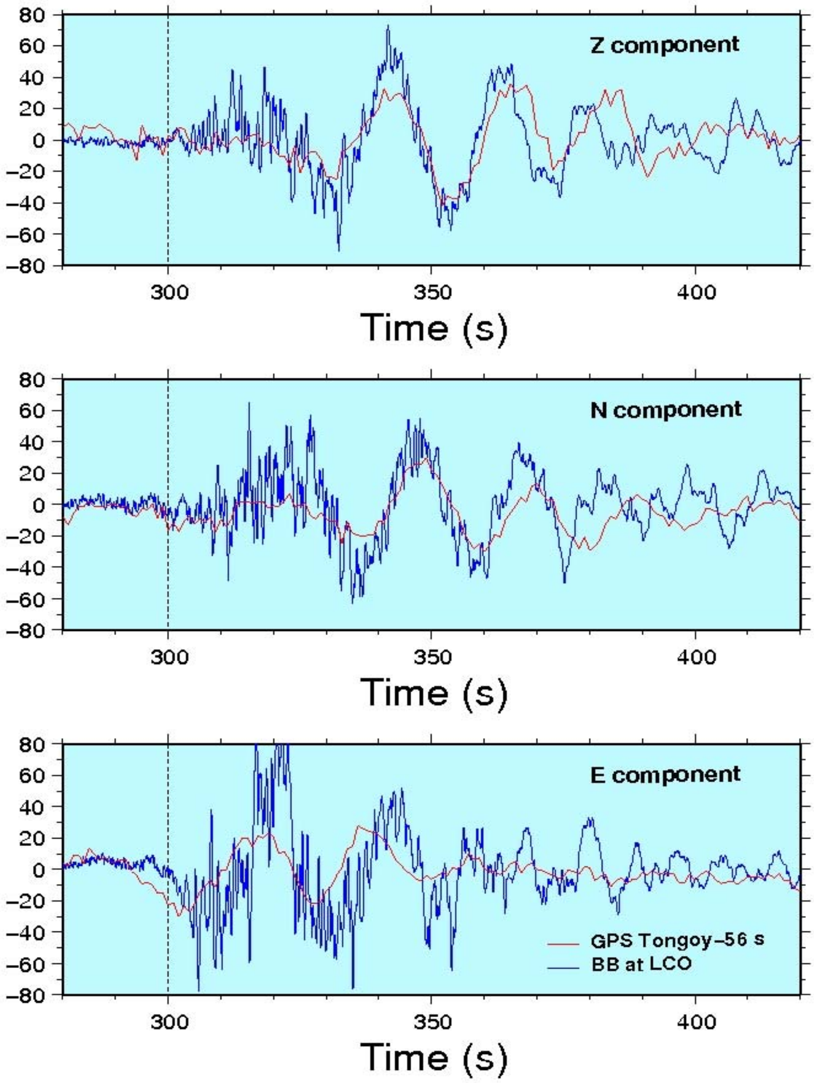

Figure 2: comparison of 1-Hz cGPS records at BTON and integrated seismograms at LCO