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THE CHILEAN NATIONAL SEISMIC NETWORK

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Abstract

Chile, along 3000 km of it 4200 km long coast, is regularly affected by very large earthquakes (up to magnitude 9.5) resulting from the convergence and subduction of the Nazca plate beneath the South American plate. These megathrust earthquakes exhibit long rupture regions reaching several hundreds of km with fault displacements of several tens of meters.

Minimum delay characterization of these giant events to establish their rupture extent and slip distribution is of the utmost importance for rapid estimations of the shaking area and their corresponding tsunamigenic potential evaluation, particularly when there are only few minutes to warn the coastal population for immediate actions.

The task of a rapid evaluation of large earthquakes is accomplished in Chile through a network of sensors being implemented by the National Seismological Center of the University of Chile. The network is mainly composed approximately by one hundred broad-band and strong motion instruments and 130 GNSS devices; all connected in real time. Forty units present an optional RTX capability, where precise satellite orbits and clock corrections are sent to the field device producing a 1-Hz stream at 4-cm level. In the other units, raw data will be sent in real-time to be later processed at the central facility. Hypocentral locations and magnitudes are estimated after few minutes by automatic processing software based on wave arrival; for magnitudes less than 7.0 the rapid estimation works within acceptable bounds. For larger events, automatic detectors and amplitude estimators of displacement have been developed from the real time GNSS streams. This software has been tested for several cases showing that, for plate interface events, the minimum magnitude threshold detectability reaches values within 6.2 and 6.5 (1-2 cm coastal horizontal displacement), providing an excellent tool for earthquake early characterization from a tsunamigenic perspective.

Keywords: Seismic Networks, large earthquakes, seismic observation

1. Introduction

Chile is amongst the most seismically active countries in the world. Since the arrival of the Spaniards, who started the written record in mid-1500s, a magnitude 8 -or larger- earthquake has taken place every dozen of years, as an average. In the last 100 years, more than ten events with magnitudes around 8 or larger have taken place in this part of world [1] (Beck et al., 1998). Three events with M>8 have taken place only in the last six years. Historical records of local damage, reports of tsunami heights recorded in Japan and recent paleoseismological studies [2,3] have evidenced several earthquakes of this sequence with magnitudes close to 9 and above. Among them is the 1960 event, the largest earthquake ever recorded since the beginning of instrumental seismology [4]. Such extreme seismic activity is the result of the interaction of the Nazca, Antarctic, Scotia and South American plates in southwestern South America where Chile is located. As shown in Fig. 1 most of the seismicity is the direct result of the interaction of the Nazca and South American plates.

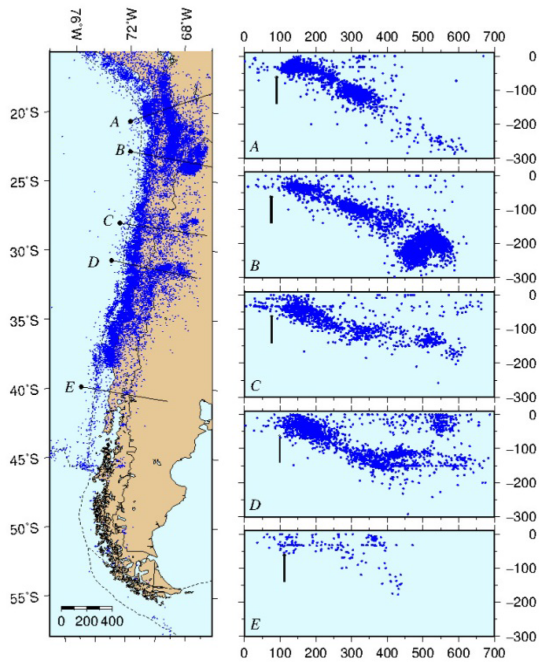

Fig. 1. Five profiles (right panels) show the depth distribution of earthquakes as a function of distance from the trench. The catalog includes three sources of information SISRA [5] (1900-1981), USGS (1982-1999), CSN (2000-2015

2. The Observation System

The National Seismological Center of the Universidad de Chile (CSN), continuation of the Seismological Service, started operations in March, 2013. The main task of this recently created agency is to install, maintain, and operate a seismic network composed by 65 multi-parametric stations (broad-band seismometers, accelerometers, and GNSS devices) plus 65 GNSS devices recently acquired in addition to the existing University network and those resulting from international collaborations. The broadband and accelerographic signals are transmitted in real time to the central headquarters in Santiago, the rest -GNSS- is planned to be completed throughout 2016. Complementary to these devices, 297 accelerographs, to record strong motion associated with medium to large earthquakes (triggering threshold at 5%g, acceleration of gravity) have been deployed by the Oficina Nacional de Emergencia (ONEMI, Office of Disaster Management) in cooperation with the Ministry of Housing and Urban Planning. Currently, these devices are being transferred to the CSN for their operation and maintenance. The locations of these devices as of December, 2015, are shown in Fig. 2; the 297 strong motion instrument locations are those reported by ONEMI.

The Integrated Plate Boundary Observatory Chile (IPOC, http://www.ipoc-network.org/) is a major effort conducted in northern Chile initiated in 2007 primarily by GeoForschungsZentrum Potsdam (16 stations), part of a Helmholtz Center, and Institut de Physique du Globe de Paris (4 stations) while the GRO undertaking is the result of National Science Foundation (NSF)-funded effort to both IRIS and Universidad de Chile starting in 2011 as a consequence of the 2010 (Mw=8.8) Maule earthquake.

Twenty IPOC stations are composed by displacement (Leica), velocity (STS-2, Streickeisen) and acceleration (Episensor, Kinemetrics) sensors with Quanterra acquisition systems. Environmental variables (temperature, pressure) are also included in the data streams.

The ten GRO stations, part of the C network (https://www.iris.edu/hq/projects/chile), are equipped with velocity (Trillium 240, Nanometrics), acceleration (Episensor, Kinemetrics) with Quanterra 330 acquisition systems. These instruments are complemented with infrasound (Chaparral) together with environmental sensors (temperature, rain gauge, and pressure).

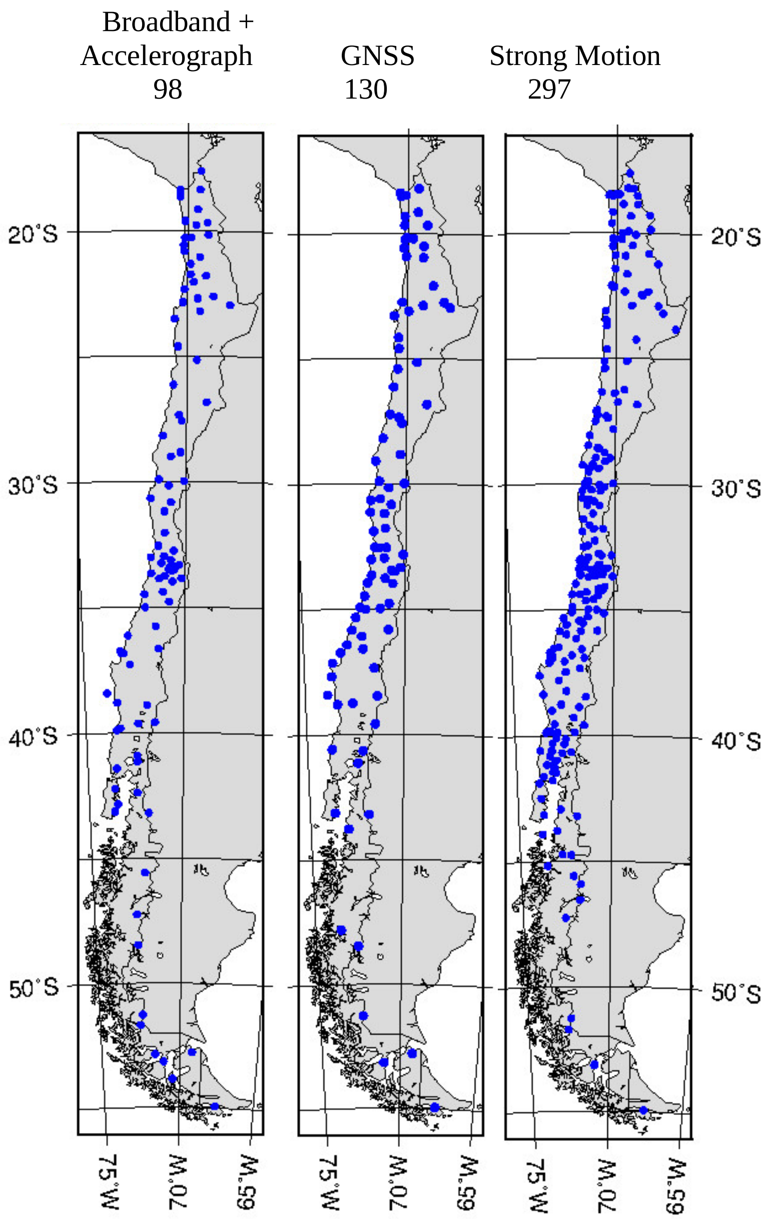

Fig. 2. Distribution of 98 multiparametric (broadband + accelerographic) stations (left panel), 130 GNSS devices (central panel) and 297 strong ground motion instruments (right panel). The 297 strong motion instruments are being transferred to the CSN. Important role in this network is played by 20 Integrated Plate Boundary Observatory Chile (IPOC, CX network) in northern Chile, ten Geophysical Research Observatories (GRO, part of the C network), three GSN stations (LCO, LVC and RPN) and two GEOSCOPE stations (PEL and COY), all included in the left panel.

The C1 network is composed by 65 new stations including broadband velocity (Trillium 120) and acceleration (Guralp 5T) sensors with Quanterra 330 acquisition systems together with GNSS devices (Trimble NetR9).

Additional stations of the C network (LMEL, ROC1) are sampled at standard configuration 100-40-1 for broadband channels and 100 s/s for the acceleration streams.

Data from all these instruments are transmitted in real time to a central headquarters in Santiago where they are processed, analyzed, distributed and archived. Currently, the software packages EarlyBird, SeisComP and Seisan are being used to produce preliminary and final estimations of location and magnitude of earthquakes in Chilean territory within 5 to 20 minutes from origin time, respectively.

The location of each station of these three major elements: a) 98 BB+SGM, b) 297 SGM and c) 130 GNSS stations are shown in Fig, 2.The inter-sensor separation for element a) is about 80 – 90 km, element b) is highly concentrated in different basins where cities have been built.

The 130 GNSS Trimble receivers are also part of the network. The system is currently being deployed in the field. Nearly 100 of them are already storing 1-Hz files with connectivity in progress. Forty of these devices include additional RTX capabilities; this is the Precise Point Positioning vendor algorithm executed at the receiver by integration of the satellite-transmitted orbits and clocks corrections

Initial testing of the RTX system in April 2014 allowed the capture of the first-ever record of the Earth´s surface displacement produced by an earthquake. The first Trimble RTX device was installed at the Iquique airport. Data were transmitted through Dirección General de Aeronáutica Civil (DGAC, Chilean Aviation Administration) communications system to Santiago, where they are processed, analyzed, distributed and archived.

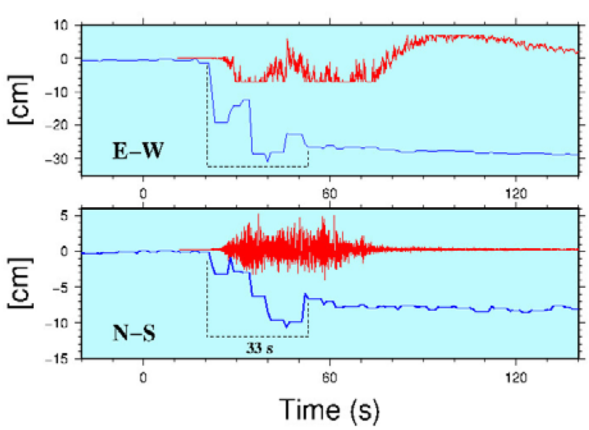

Fig. 3. First ever real-time detection of co-seismic displacement by the RTX capability of a Trimble GNSS device. The easting and northing components, sampled at 1 s/s, reach 30 and 8 cm respectively. On top of the Easting component, the clipped E-W broadband component is plotted (red trace). Similarly, the N-S acceleration component is plotted above the N-S displacement. Assuming that the fault displacement takes place on the subduction interface, for this type of events, due to the geometry of the station-source, it is possible to estimate the magnitude –and the slip location- with just one observation point. The permanent static displacement is reached 33 s after the first pulse.

The first ever real time record of a large earthquake with the Trimble RTX technique corresponding to the largest aftershock of the 2014 Iquique earthquake shows about 30 cm of permanent displacement to the West and about 8 cm to the South, after 33 sec of arrival of the P wave (Fig. 3).

3. Network Objectives

Because the seismological observation system developed by the CSN is the only system at a country level, there are several objectives that must be fulfilled.

a) The network must be capable of providing enough information to rapidly characterize large earthquakes in Chile and its impact, particularly to estimate acceleration levels reached at the surface (such as Shakemap) and to evaluate the potential generation of tsunamis in the near field; this is not a simple task because large magnitude earthquakes (M>7.5) take place very close to the observation network. Systems based on broad-band seismometry are saturated in the near field while recorded acceleration, integrated twice, is often unstable because it requires accurate baseline corrections and proper estimations of rotations and tilts [6, 7, 8, 9] (Kinoshita and Takagishi, 2011; Wang et al., 2011; Colombelli et al., 2013, Melgar et al-, 2013).

b) A second objective is to define –to the best possible extent- the seismogenic zones that are responsible for the earthquake hazard in Chile. The network must have enough sensitivity to detect earthquakes of magnitude 3 and above within the country. It is recognized that even smaller earthquakes could provide a better definition of these sources in compressed time intervals but the existing network of roughly 85 km sensor inter-spacing can indicate regions where to concentrate future efforts with denser arrays.

c) The 297 strong motion instruments, build and deployed by the Ministry of Housing and Urban Planning and the Office of Disaster Management of the Interior Ministry (Onemi) are being transferred to the CSN to provide a sound data base of strong motion records (accelerations) produced by large earthquakes for engineering purposes.

4. September 16, 2015 earthquake

To better estimate the fault slip distribution of large earthquakes, real-time GNSS observations have been incorporated as an integral part of the seismological network.

Along these lines, local GNSS data rapidly available allowed the estimation of the preliminary slip distribution associated with the 16 September 2015 (Mw=8.4) Illapel earthquake (Fig. 4). Only 33 hours after the earthquake, a first estimation was published; this is because the stations were not connected in real time, a task that is currently being carried out. During the later days, more data were included in the inversion scheme and the solution presented a more concentrated patch of slip, roughly maintain the north-south rupture extension; the moment magnitude increased from 8.29 to 8.35.

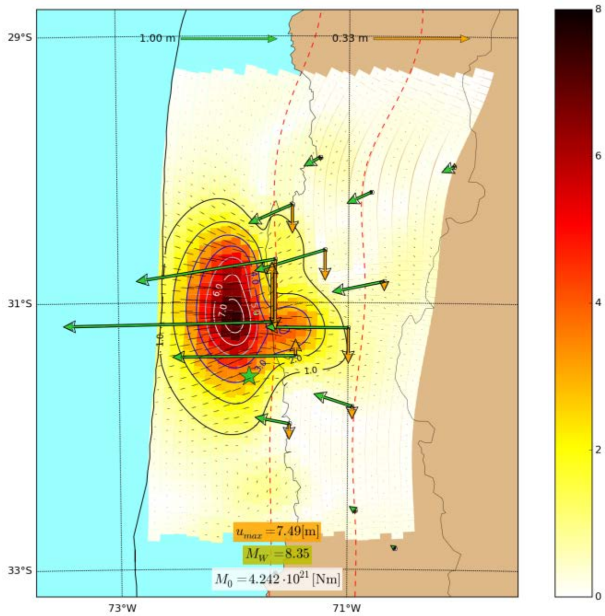

Fig. 4. Final (right) estimation of slip distribution of the 2015 Illapel earthquake from displacement data observed at the surface [10]. The first estimation was obtained after 33 hours of origin time. The goal is to diminish this number to few minutes, considering the source duration.

Because the near field terms of the displacement at the surface of a half-space decay as r^{-4}, it is extremely desirable that GNSS stations are located as close as possible to the source. In the case of Chile, as presented in the section above, the majority of the sources of large earthquakes are located along the coupling region of the Nazca and South American plates, between the coast and the trench. Therefore, the GNSS stations are being deployed roughly every 40-km along the coast. This allows an inter-sensor spacing of the same order of the depth to the seismogenic region, this is, 40 - 50 km. Inland, coarser deployment of stations is possible, complementing instrumentation at the recently installed BB stations.

Additionally, because surface displacement associated with large earthquakes does not saturate in the near field when observed by GNSS devices, as it is the case of the integrated broadband signals, Riquelme et al. [11] have developed a methodology to rapidly estimate the fault geometry as well as the magnitude of the source in the near field by means of direct observations of displacement through the W-phase methodology. The initial results of application of this method to the large Chilean earthquakes such as Maule, 2010; Iquique 2014 and Illapel 2015, show promising results.
Another significant development reached within the implementation of the new network, is the collection of strong motion data and their rapid publication. These stations are not connected to the main acquisition system yet, but they are available few days after the event. As an example, Fig. 5, prepared by Leyton [12], shows the strong motion data of the September 2015 Illapel earthquake.

Strong motion records for other significant earthquakes taking place in Chile since May, 2010, can be downloaded from http://evtdb.csn.uchile.cl/.

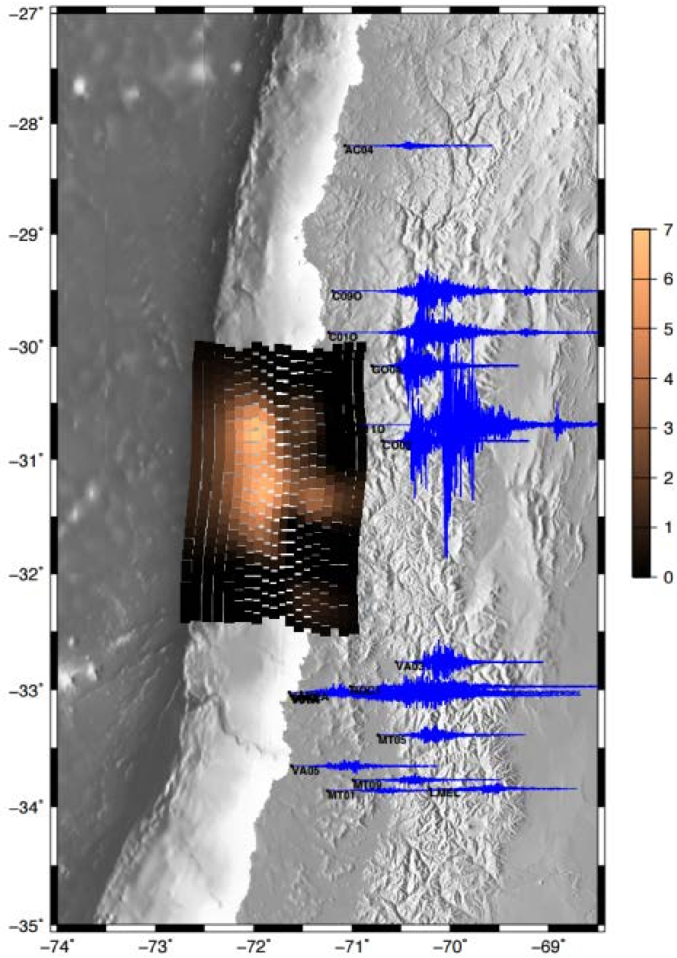

Fig. 5. Strong motion records associated with the 15 September (Mw=8.4) Illapel earthquake. Maximum accelerations of the order of 60%g were recorded at stations directly inland of the major displacement along the rupture plane (SLAB1.0 model, [13]).

It is expected that during 2016 most of the instruments will be connected to the Data Center located in Santiago. Currently, the implementation of a 16-station-core with robust communications should be completed within the first part of 2016.

5. Acknowledgments

Most of the figures were made using Generic Mapping Tools (www.soest.hawaii.edu/gmt, Wessel and Smith, [14]). This work would have not been possible without the continuous and dedicated effort of the CSN personnel.

6. References

[1] Beck, S., S. Barrientos, E. Kausel and M. Reyes (1998): Source characteristics of historic earthquakes along central Chile subduction zone. *Jour. South Am., Earth Sciences* **11** (2) doi:10.12/S0895-9811(98)00005-4.

[2] Cisternas, M., F.Torrejón,Sawai, Y.,Machuca G., M. Lagos, Eipert A., Youlton C., Salgado I., Kamataki T.,Shishikura M.,Rajendran C.P.,Malik J.K.,Rizal Y. and Husni M. (2005): Predecessors of the giant 1960 Chile earthquake, *Nature*, **437**, 404-407.

[3] Moernaut, J., M. Van Daele, K. Heirman, K.Fontijn, M. Strasser, M. Pino, R. Urrutia and M. De Batist (2014): Lacustrine turbidites as a tool for quantitative earthquake reconstruction: New evidence for a variable rupture mode in south central Chile, *J. Geophys. Res.* **119**, 3, 1607-1633.

[4] Kanamori, H., The energy release in great earthquakes (1977): *J. Geophys. Res*. **82**, 20, 2981-2987.

[5] SISRA, Proyecto Sismicidad y Riesgo Sísmico en la Región Andina (1985): CERESIS.

[6] Kinoshita, S., and M. Takagishi, Generation and propagation of static displacement estimated using KiK-net recordings(2011):, *Earth Planets Space*, **63**, 779–783, doi:10.5047/eps.2011.05.003.

[7] Wang, R., B. Schurr, C. Milkereit, Z. Shao, and M. Jin (2011): An improved automatic scheme for empirical baseline correction of digital strong motion records, *Bull. Seism. Soc. Am.,* **101**(5), 2029–2044, doi:10.1785/ 0120110039.

[8] Colombelli, S., R. Allen and A. Zollo (2013): Application of real-time GPS to earthquake early warning in subduction and strike-slip environments, *J. Geophys. Res*. **118**, 3448-3461.

[9] Melgar, D. S., Bock, Y., Sanchez, D. and Crowell, B. C (2013): On robust and reliable automated baseline corrections for strong motion seismology, *J. Geophys. Res*., **118,** 1177-1187, doi:10.1002/jgrb.50135.

[10] Del Campo, F., Personal Communication

[11] Riquelme, S., F.Bravo, D. Melgar, R. Benavente, J. Geng, S. Barrientos and J. Campos (2015): W-phase source inversion using high-rate regional GPS data for large earthquakes, submitted to *Geophys. Res. Lett*. 2015.

[12] Leyton, F., Personal Communication

[13] Hayes, G., Wald, D., Johnson, R., (2012): Slab1.0: A three-dimensional model of global subduction zone geometries, *J. Geophys. Res*. **117**, B01302, doi:10.1029/2011JB008524.

[14] Wessel, P. and W. H. F. Smith (1998). New, Improved version of Generic Mapping Tools released, EOS Trans. AGU, 79, 579, 1998.