Red GNSS del Centro Sismológico Nacional de Chile, aplicaciones a terremotos

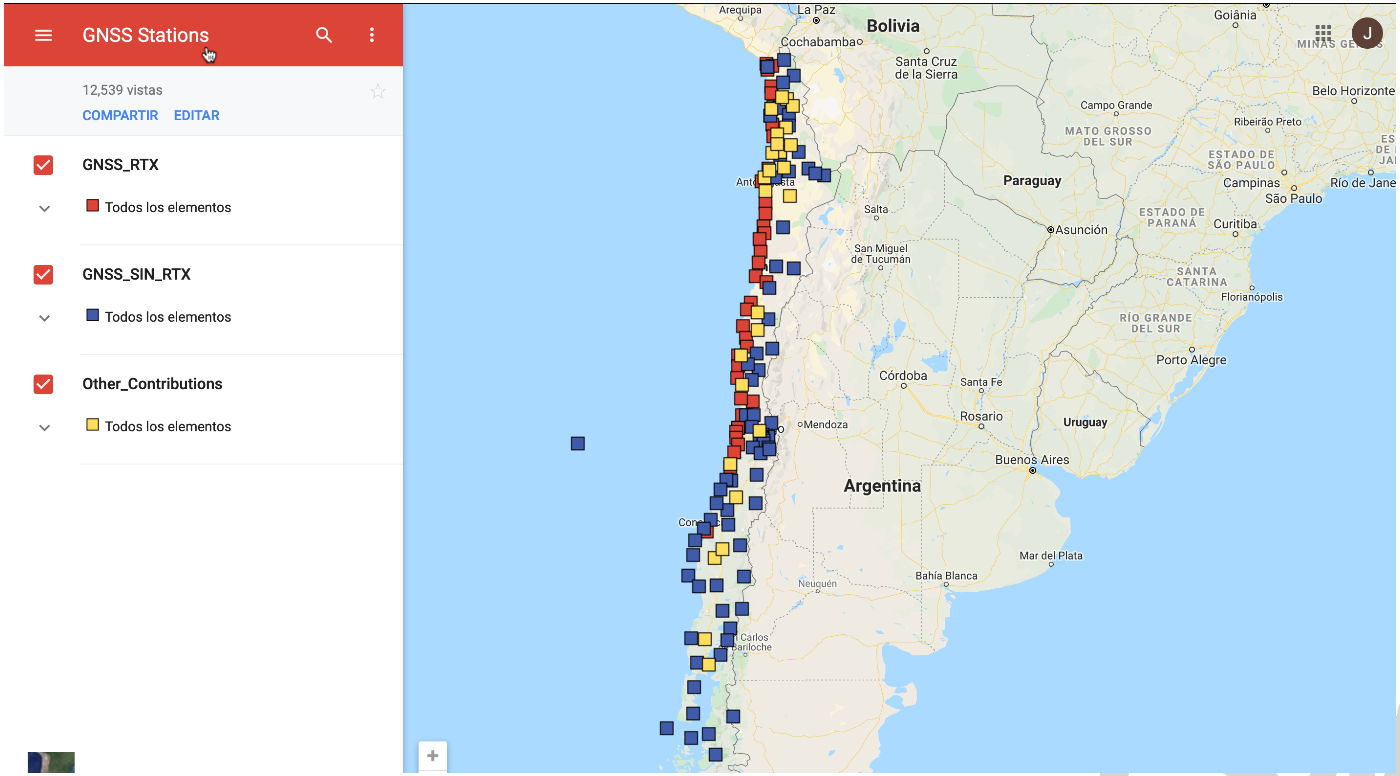
Báez J.C., Del-Campo F., Pineda D., Leyton F., Ruiz S., CSN team

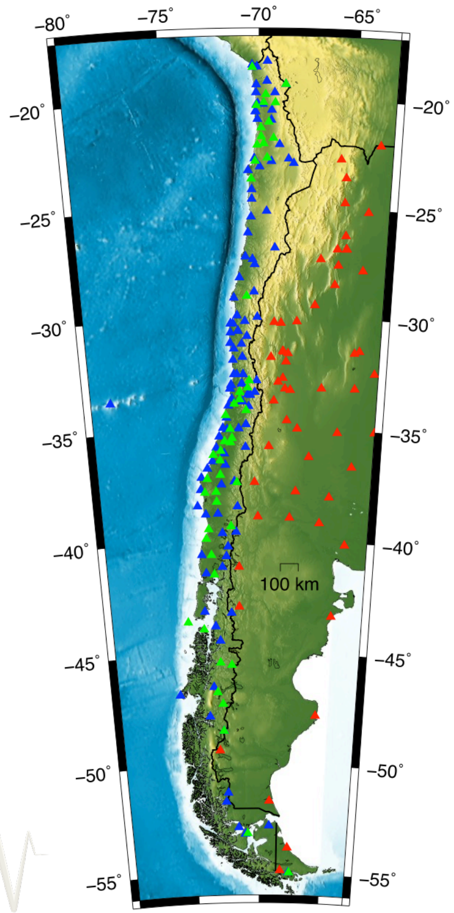
jcbaez@csn.uchile.cl

Geodetic Applications for Earthquake Studies

Motivation:

GNSS network from CSN (> 130)



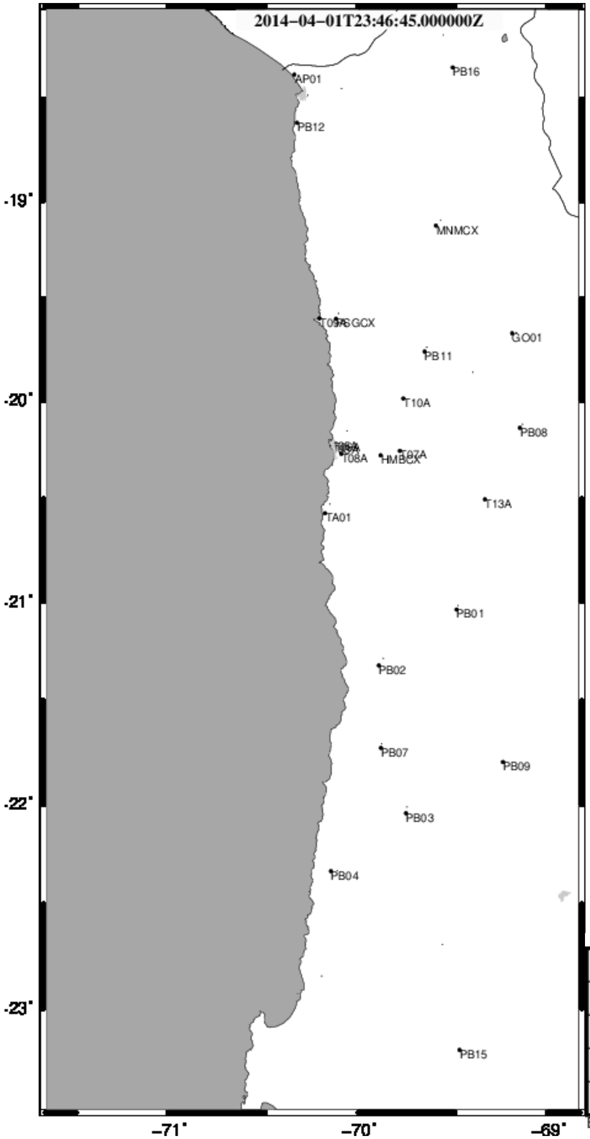


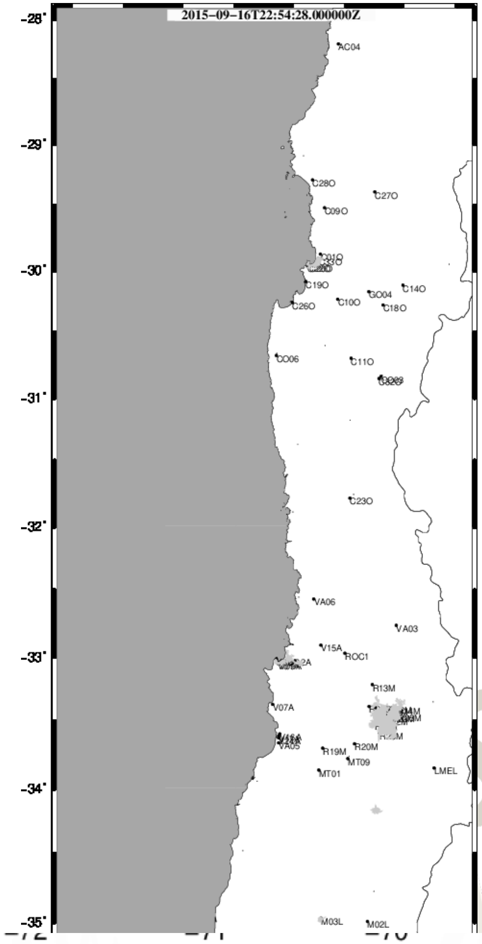
See http://gps.csn.uchile.cl

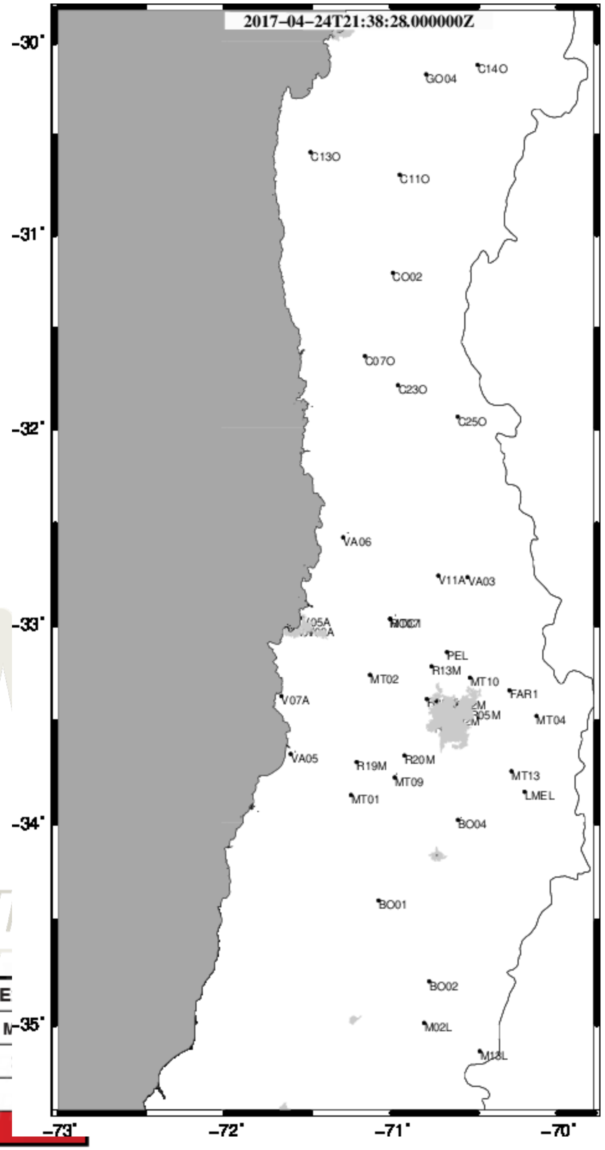
Task 1
Install, operate and maintain a GNSS network to develop applications for seismology

Motivation:

Acceleration and displacement of EQ



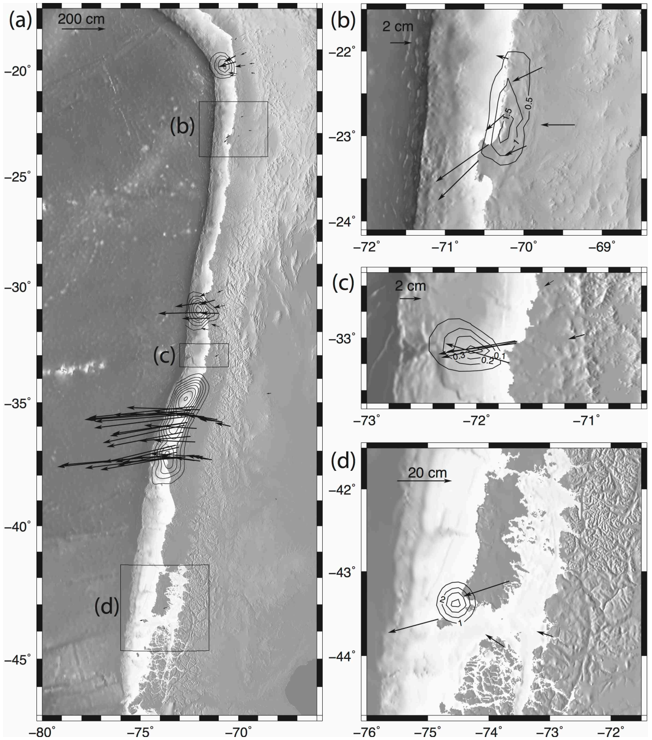


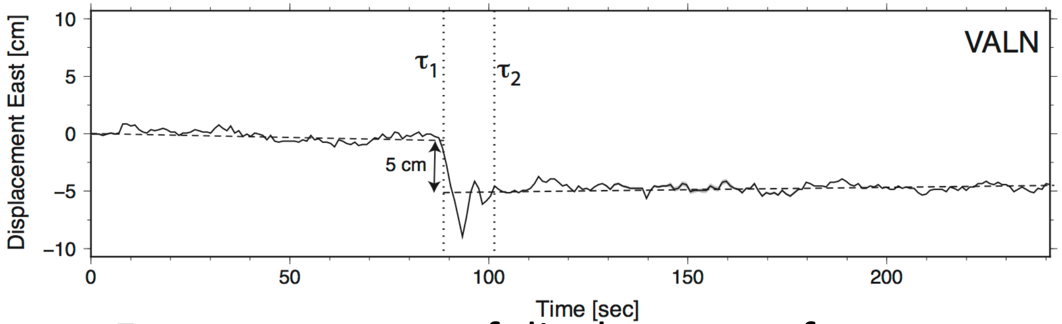


Percepción	No sensible	Débil	Suave	Moderado	Fuerte	Muy Fuerte	Severo	Violento	E
Daño Potencial	Ninguno	Ninguno	Ninguno	Muy poco	Poco	Moderado	Moderado a Alto	Alto	M
Acel Max (%g)	<0.19	1.9	4.4	13	24	44	83	156	
Vel Max (cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	
Intensidad Instrumental	I	II–III	IV	V	VI	VII	VIII	IX	

Escala basada en Worden et al. (2011)

Motivation:





East component of displacement for Valparaiso Mw6.9, 2016

Ⓔ

DATA MINE

The Chilean GNSS Network: Current Status and Progress toward Early Warning Applications

by J. C. Báez, F. Leyton, C. Troncoso, F. del Campo, M. Bevis, C. Vigny, M. Moreno, M. Simons, E. Kendrick, H. Parra, and F. Blume

ABSTRACT

Chile is one of the world's most seismically active regions and is therefore extensively studied by the earthquake sciences. The great length of the country hosts a variety of measurement systems allowing for the characterization of earthquake processes over a wide range of timescales and in different phases of the seismic cycle. Starting in the early 1990s, several research groups began to deploy continuously operating geodetic networks in Chile, forming the core of the modern network of Global Navigation Satellite Systems (GNSS) receivers used to monitor geodynamics from the southern tip of the Americas to the central Andes. Today, the Centro Sismológico Nacional (CSN) of the Universidad de Chile maintains and improves this network, increasing its coverage and spatial density while greatly reducing solution latency. We present the status of the GNSS network, its data streams, and the real-time analysis system used to support real-time modeling of earthquakes. The system takes 2 s, on average, to collect raw data, estimate positions, and stream results. Such low latency is essential to enabling early warning of earthquakes and tsunamis in Chile.

Electronic Supplement: Figures showing schema of communication from the stations to the servers used at Centro Sismológico Nacional (CSN), comparison between velocities derived from real-time Global Navigation Satellite Systems (RT-GNSS) data, kinematic finite-fault inversion results and waveform comparison, and results of the estimation of M_w as a function of time, and tables of station locations and estimated total coseismic displacement.

INTRODUCTION

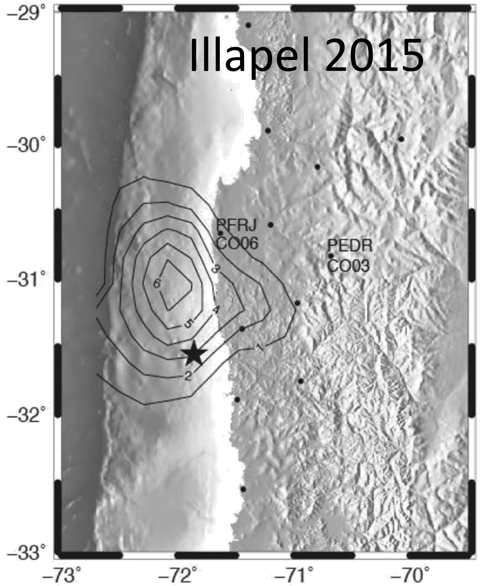
Deformation rates of the Earth's surface, derived from modern space geodesy, constitute the observational basis for physical models of the earthquake deformation cycle, providing key information to describe the processes leading up to and following great events (e.g., Vigny *et al.*, 2011; Ruiz *et al.*, 2014; Schurr *et al.*, 2014; Duputel *et al.*, 2015; Melnick *et al.*, 2017). Along the Chilean subduction zone, the Chilean network of Global Navigation Satellite Systems (GNSS) has been steadily growing from the early 1990s to the present day, with the earliest stations coming from different international research projects and institutions such as the central Andes Global Positioning System (GPS) project (CAP) (Bevis *et al.*, 1999; Kendrick *et al.*, 1999), the German Research Centre for Geosciences (GFZ), the currently active Integrated Plate Boundary Observatory Chile (Angermann *et al.*, 1999; Klotz *et al.*, 2017; Moreno *et al.*, 2017), the French National Research SUBChile project by Institute de Physique du Globe de Paris and École Normale Supérieure in Paris, France (Ruegg *et al.*, 2009; Vigny *et al.*, 2009), and the Central Andean Tectonic Observatory Geodetic Array of the California Institute of Technology (Caltech) (Simons *et al.*, 2010; Bejar-Pizarro *et al.*, 2013).

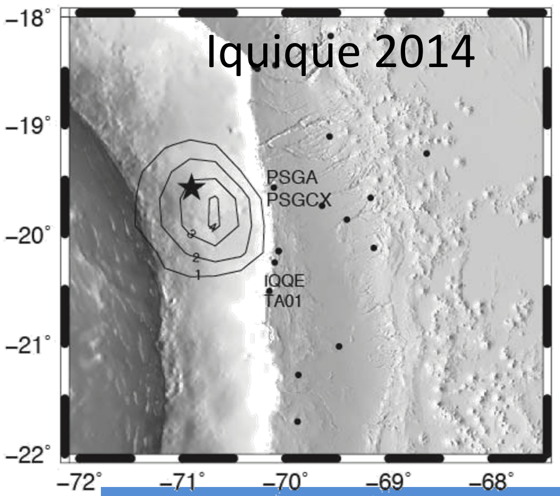
At the end of the twentieth century, GNSS data from continuous and campaign observations were primarily used in Chile and neighboring countries to estimate plate motion and interseismic deformation (Norabuena *et al.*, 1998; Angermann *et al.*, 1999; Bevis *et al.*, 1999, 2001; Kendrick *et al.*, 1999, 2003, 2006; Brooks *et al.*, 2003; Ruegg *et al.*, 2009; Moreno *et al.*, 2011; Bejar-Pizarro *et al.*, 2013; Metois *et al.*, 2013; Melnick *et al.*, 2017). The GNSS network now provides good spatial coverage throughout Chile's seismogenic zone, enabling the observation of the complete seismic cycle, including the coseismic deformation caused by the M_w 8.8 giant Maule event in 2010 (Vigny *et al.*, 2011; Moreno *et al.*, 2012; Lin *et al.*, 2013), and by events in Iquique (M_w 8.1) in 2014 (Ruiz *et al.*, 2014), Illapel (M_w 8.3) in 2015 (Duputel *et al.*, 2015; Melgar, Crowell, *et al.*, 2015; Ruiz *et al.*, 2016), and Chiloé (M_w 7.4) in 2016 (Melgar *et al.*, 2017; Ruiz, Aden-Antoniow, *et al.*, 2017; Ruiz, Moreno, *et al.*, 2017). The GNSS network also records the postseismic transients caused by these events (Bedford *et al.*, 2013, 2016; Klein *et al.*, 2016). Several researchers proposed the use of real-time GNSS (RT-GNSS) data to estimate not only the magnitude of an event but also its rupture geometry

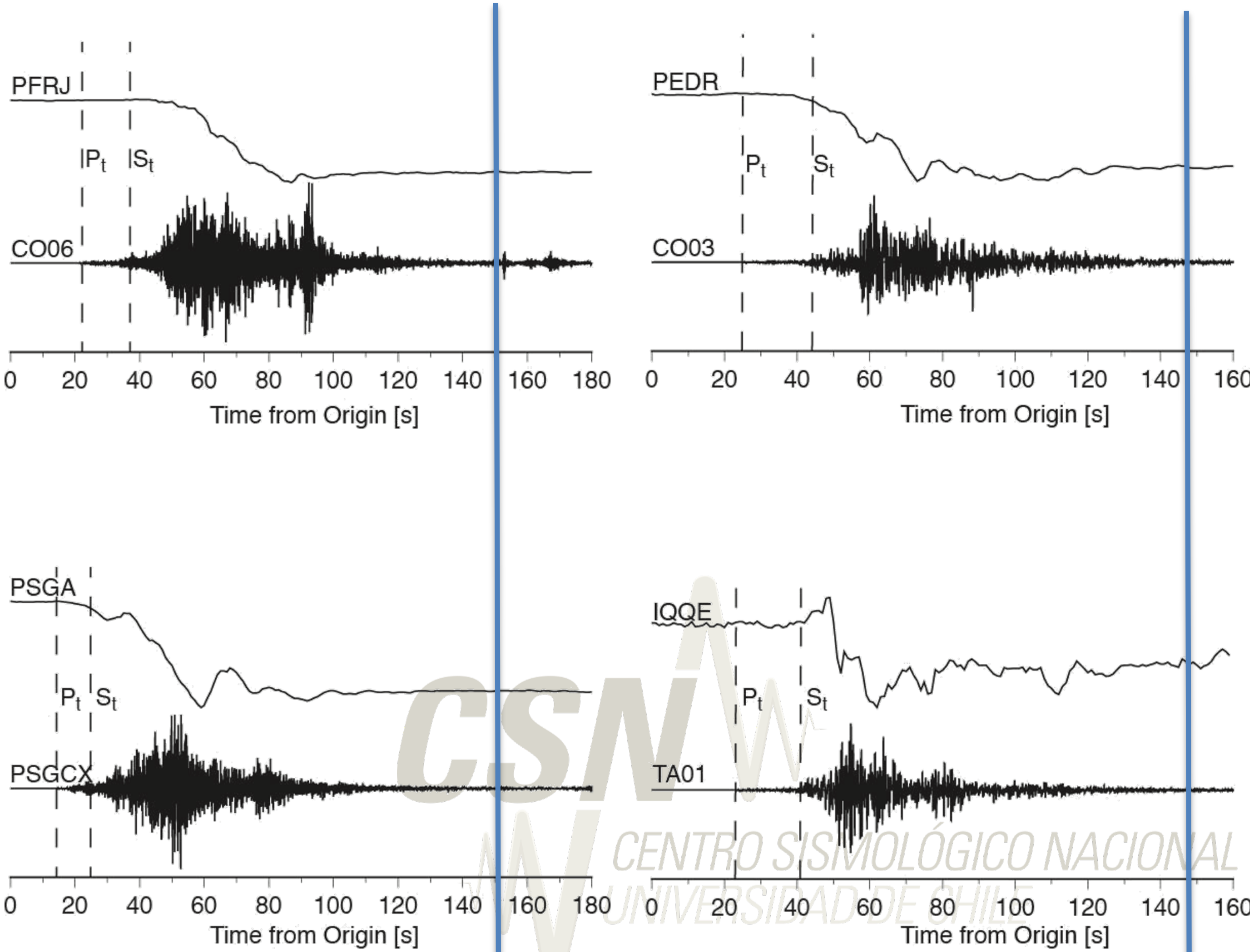
Task 2

Estimate moment magnitude and slip distribution of earthquake, ASAP!!, with displacement from GNSS observations.

Motivation: earthquakes







(Leyton et al. 2018)

Estimation of Mw from PGD

CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL078991

Key Points:

- We calibrate coefficients from earthquake early warning methodologies to do a fast estimation of magnitude for subduction earthquakes
- These methodologies are able to robustly estimate the magnitude for small-to-moderate events (Mw ≤ 7.0) ~30 from origin time
- Large events (Mw ≥ 7.5) required data from GNSS to perform the magnitude estimation ~70 s from origin time

Supporting Information:

- Supporting Information S1

Correspondence to:
F. Leyton,
leyton@csn.uchile.cl

Citation:
Leyton, F., Ruiz, S., Baez, J. C., Meneses, G., & Madariaga, R. (2018). How fast can we reliably estimate the magnitude of subduction earthquakes?. *Geophysical Research Letters*, *45*. https://doi.org/10.1029/2018GL078991

Received 30 MAY 2018
Accepted 4 SEP 2018
Accepted article online 10 SEP 2018

How Fast Can We Reliably Estimate the Magnitude of Subduction Earthquakes?

F. Leyton[1], S. Ruiz[2], J. C. Baez[1], G. Meneses[3], and R. Madariaga[3]

[1]Centro Sismológico Nacional, Universidad de Chile, Santiago, Chile, [2]Departamento de Geofísica, Universidad de Chile, Santiago, Chile, [3]Laboratoire de Géologie, CNRS, University Paris Science Letters and Ecole Normale Supérieure, Paris, France

Abstract Fast and reliable characterization of earthquakes can provide vital information to the population, even reducing the effects of strong shaking produced by them. In this study, we explore the minimum time required to estimate the magnitude for subduction earthquakes. Using traditional *P* wave earthquake early warning parameters and considering a progressively increasing time window, we are able to estimate magnitude for subduction earthquakes ~30 s from the origin time (with an average residual of 0.01 ± 0.28). However, estimations for larger events (Mw ≥ 7.5) present larger errors (average residual of −0.70 ± 0.30). We complement our data with Global Navigational Satellite System observations for these events, enabling magnitude estimations ~70 s from the origin time (average residual of −0.42 ± 0.41). We propose that rapid estimations of magnitude should consider, initially, *P* waves in a progressively increasing time window, and complemented with GNSS data, for large events.

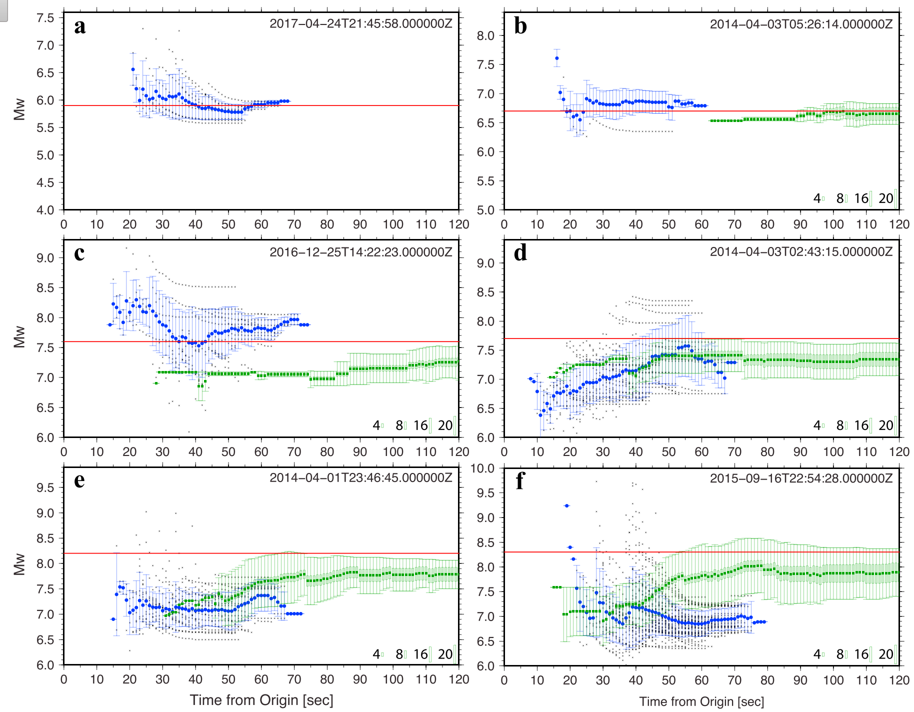
Plain Language Summary Fast and reliable magnitude estimation of earthquakes enables the preparation of the public to reduce its impact. Here we test known methods to rapidly estimate the magnitude of subduction earthquakes. We found encouraging results, taking a few tens of seconds to provide reliable values. However, results for larger events tend to underestimate the real magnitude. Hence, we propose the combination with other sources of information, such as Global Positioning System, that are able to resolve these larger events.

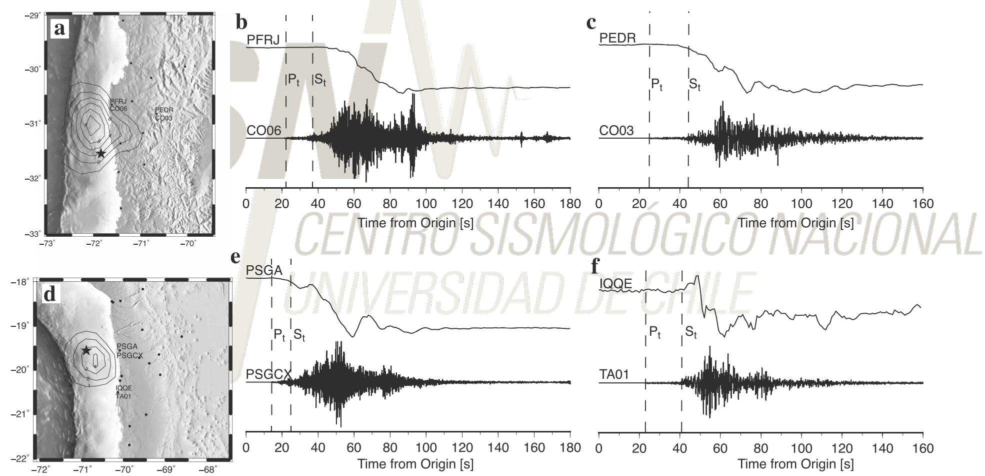
1. Introduction

Recent advances in communication and automatic processing of seismic data have enabled fast and reliable earthquake source estimation, improving the rapid response of public and private agencies as well as the general public (Kanamori, 2005; Satriano et al., 2011). Indeed, fast estimations of the location, magnitude, and expected ground motions are the basis of the present Earthquake Early Warning Systems (EEWS) aimed to prevent losses produced by earthquakes (Colombelli & Zollo, 2016; Heaton, 1985; Satriano et al., 2011). In general, these systems aim to provide a few seconds warning in advance of the destructive seismic waves of an earthquake, based on a continuous, real-time, seismic monitoring (Colombelli et al., 2015).

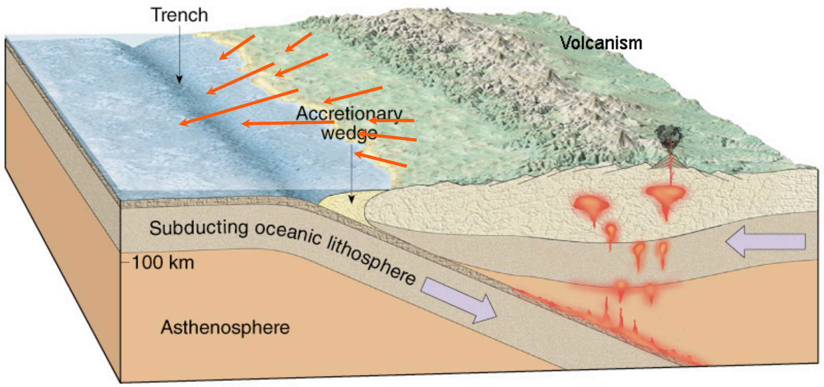
The main principle in usual EEWS is that the information from few seconds of the *P* wave can provide information regarding the magnitude and location of an earthquake (Allen & Kanamori, 2003), and given that these waves travel faster than the potentially destructive waves, this can provide an actionable warning to the population to reduce the impact of shaking (Colombelli & Zollo, 2016). However, there always will be a trade-off between the warning time and the reliability of the information: larger time windows should enable better knowledge of the event, while giving less time to prepare for its impact; this concept has lead to a general use of continuous updates in EEWS (Colombelli et al., 2012, 2015; Satriano et al., 2011). Moreover, Minson et al. (2018), using simple seismological relations, discussed the minimum time required to estimate the possibility of having strong ground shaking due to an earthquake: they showed that there is a limit given by the required time for the earthquake to evolve into a large event.

Indeed, a key aspect that remains controversial is whether a few seconds of the *P* wave can predict the earthquake's size over a wide range of magnitudes: some authors suggest that an initial rupture will develop into a large earthquake only if it has enough fracture energy to break across several heterogeneities (Olson & Allen, 2005). In this case, the Deterministic model, the final seismic moment is determined by the initial rupture (Ellsworth & Beroza, 1995; Zollo et al., 2006). However, as pointed out by Rydelek & Horiuchi (2006), it is not clear by which mechanism the information between these heterogeneities is transmitted across large





Magnitude and slips distribution



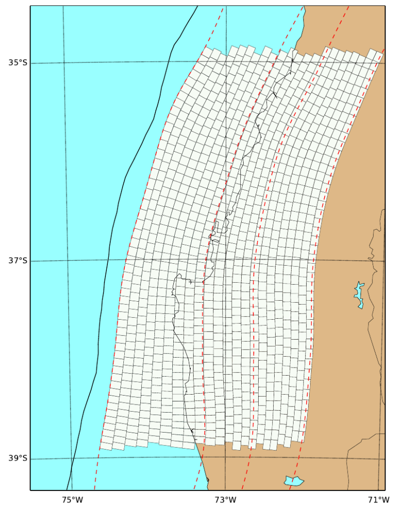
1.- Physic model e.g. Okada (1985)

2.- discretization of contact

3.- Inversion method

Physic model: (Okada, 1985)

Assumptions
- Semi space geometry
- Homogenous media
- Elastic linear response



SLAB1 (Hayes et al.2012)

Estados de información

≡ Estimación bayesiana en este caso

p.d.f. *a-priori* de **x**

p.d.f. de **d** dado **x**

$$p(\mathbf{x}|\mathbf{d}) = \frac{p(\mathbf{x})p(\mathbf{d}|\mathbf{x})}{p(\mathbf{d})}$$

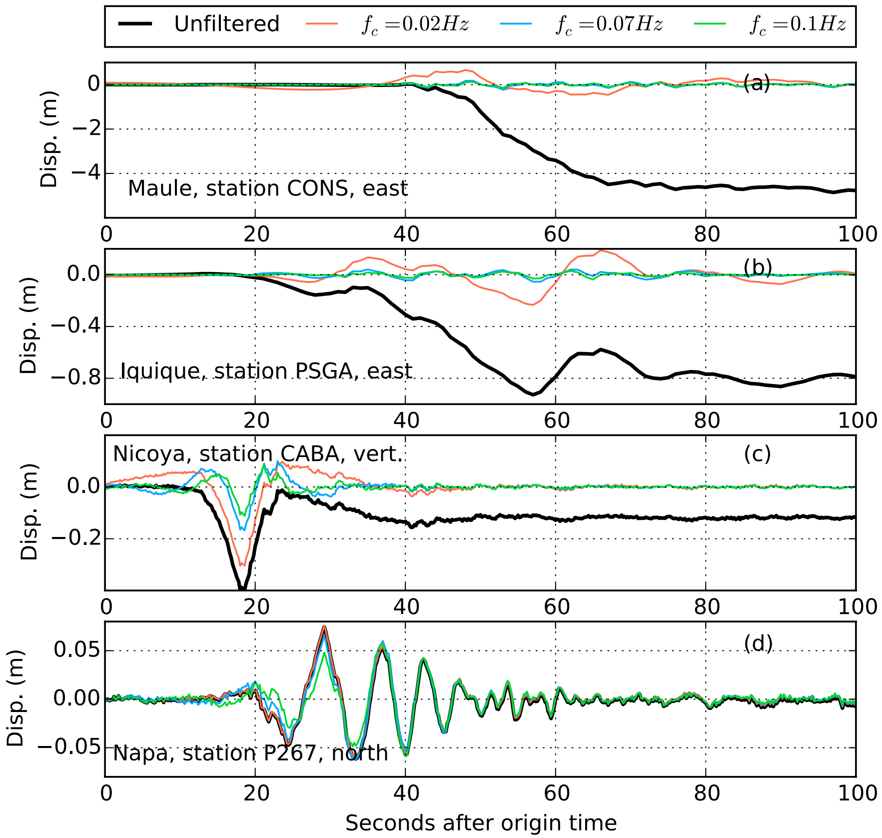
p.d.f. *a-posteriori* de **x**

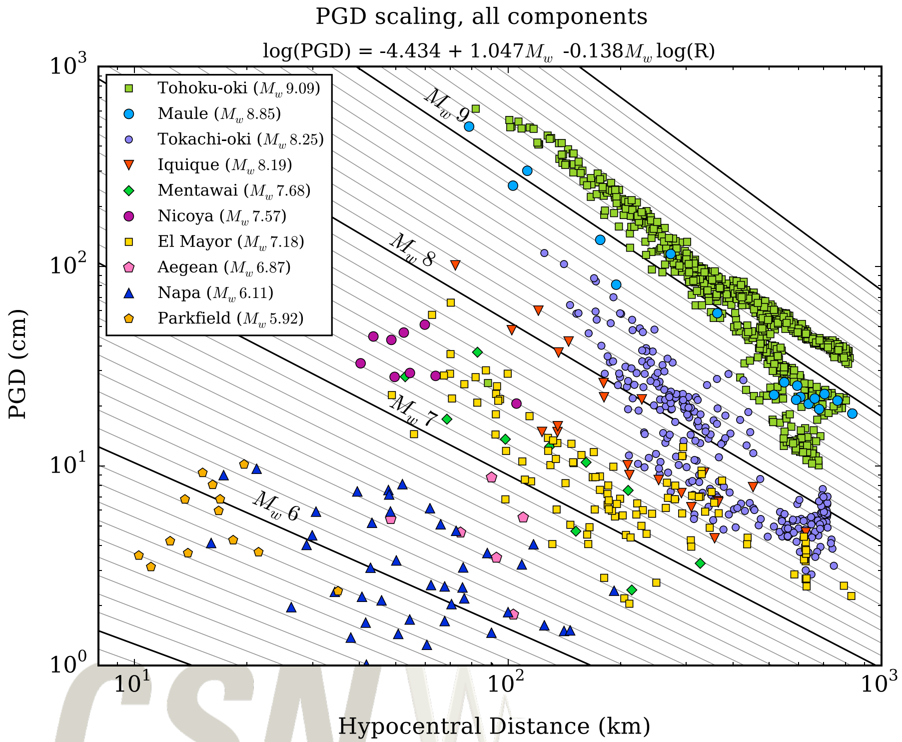
p.d.f. *a-priori de* **d**

- A. Tarantola, B. Valette. Inverse Problems = Quest for Information. Journal of Geophysics, 1982, 50, p. 159–170

It should work with just one station!!!

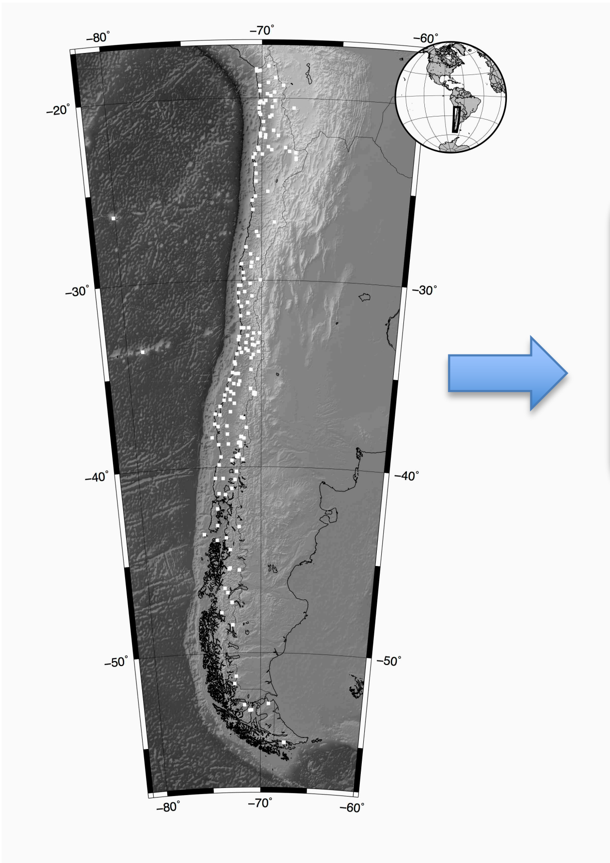
Magnitude with pick ground displacement

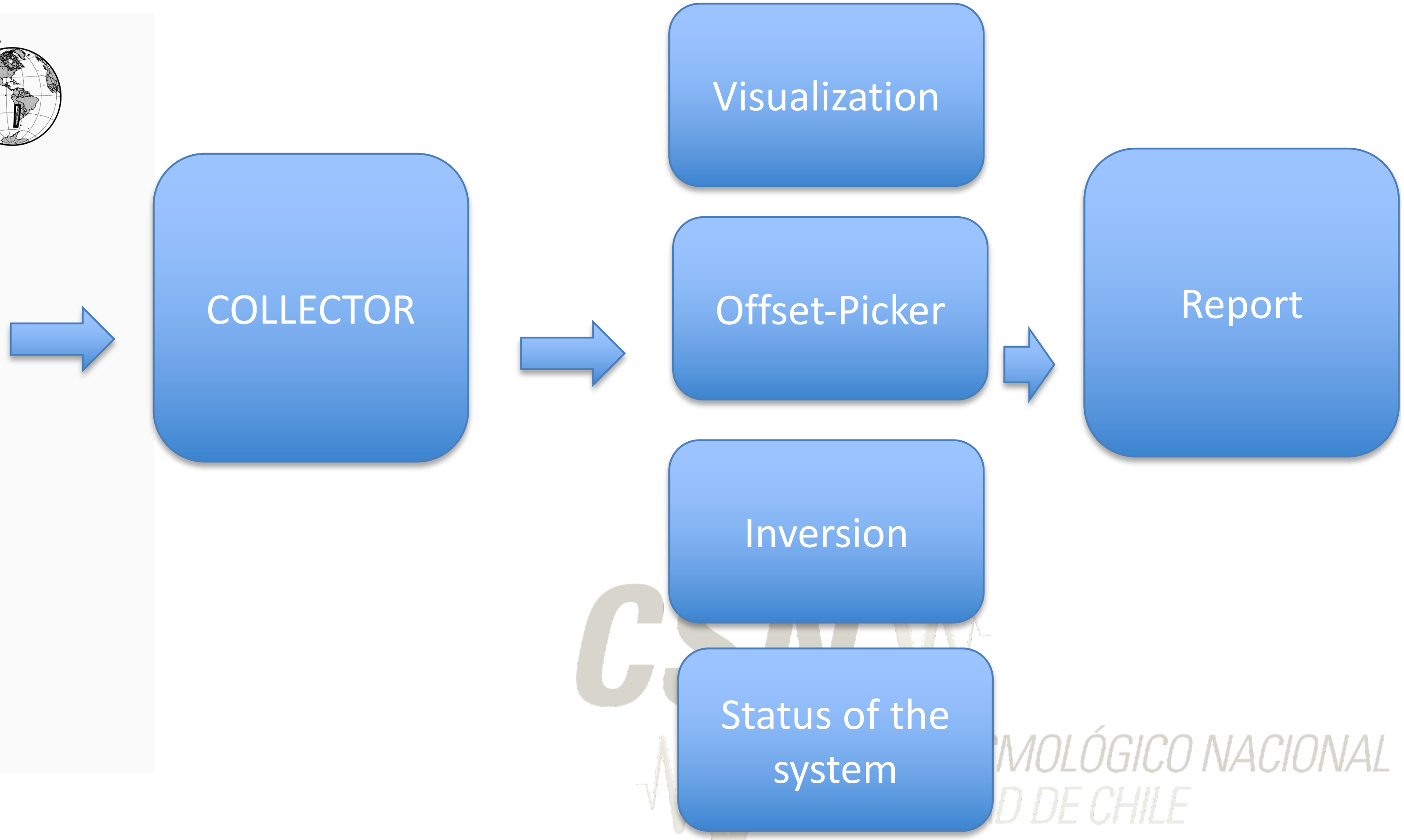




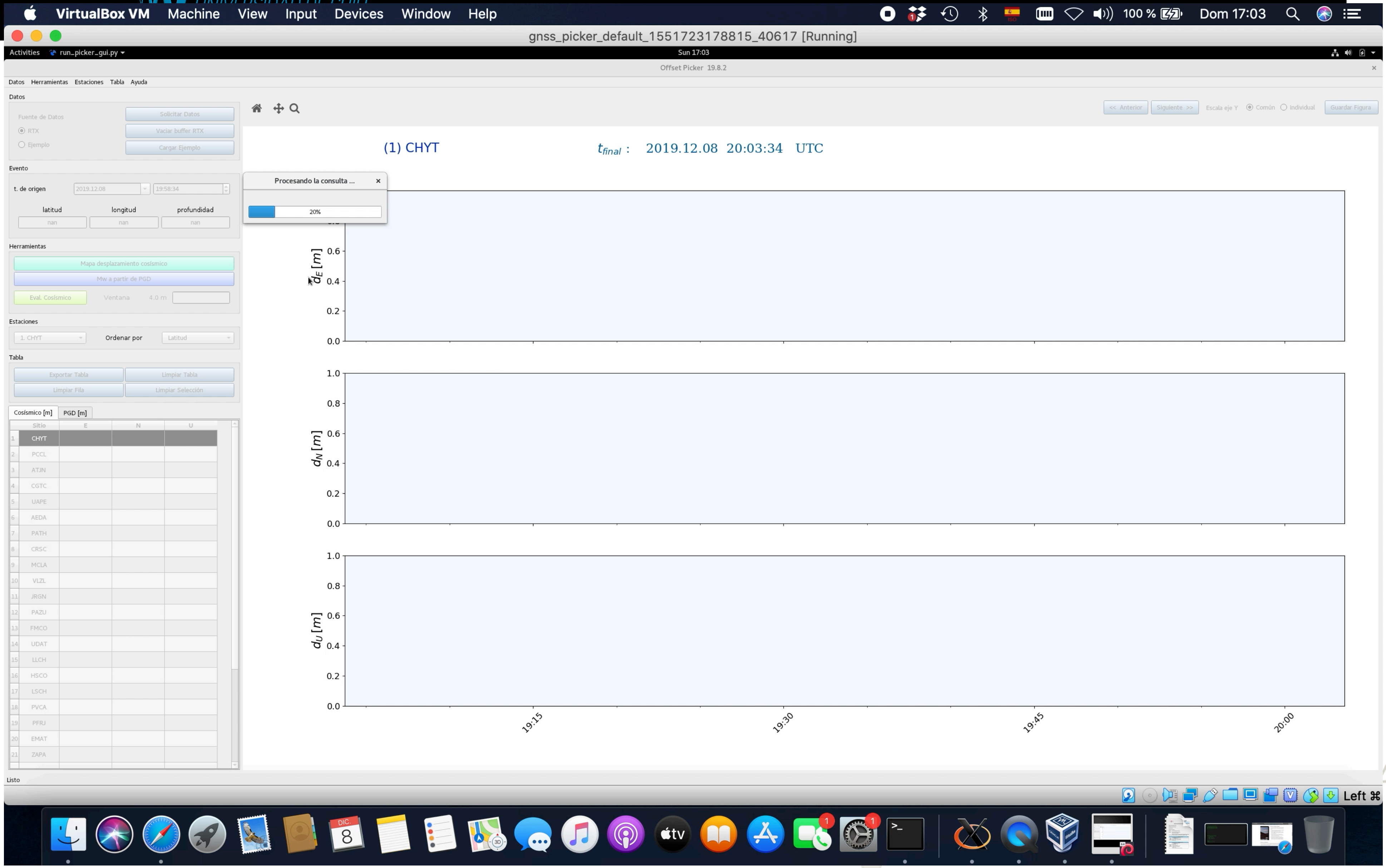
$$\log(\mathrm{PGD}) = A + B \cdot M_w + C \cdot M_w \cdot \log(R).$$

Crowell et al. 2013, Melgar et al. 2015

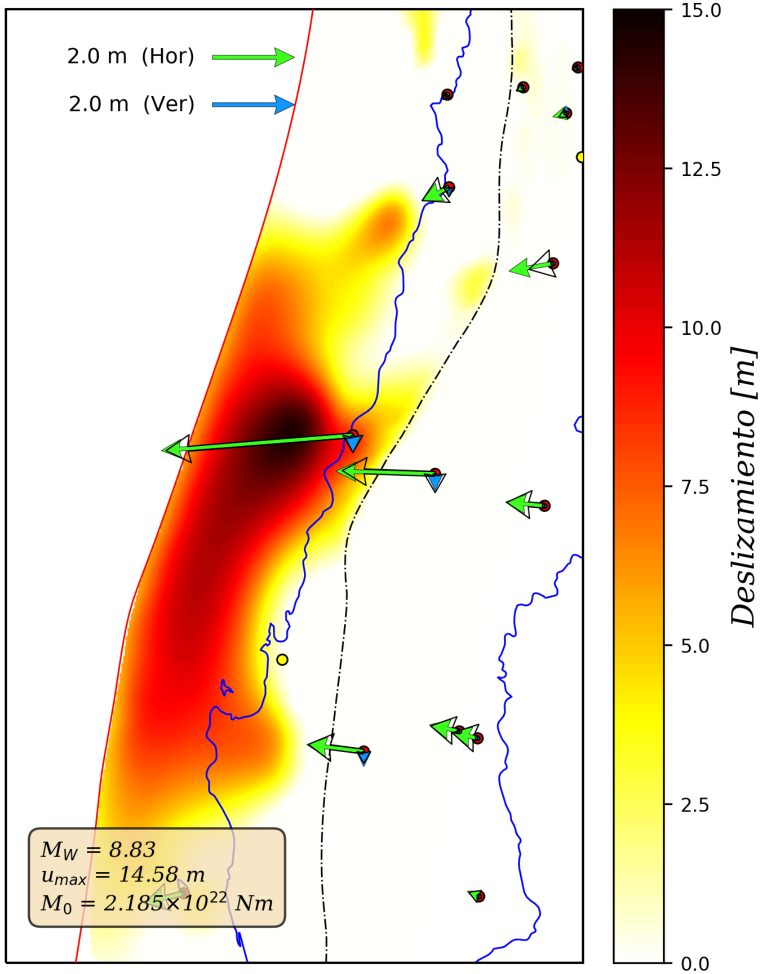

−80°
−70°
−60°
−20°
−30°
−40°
−50°

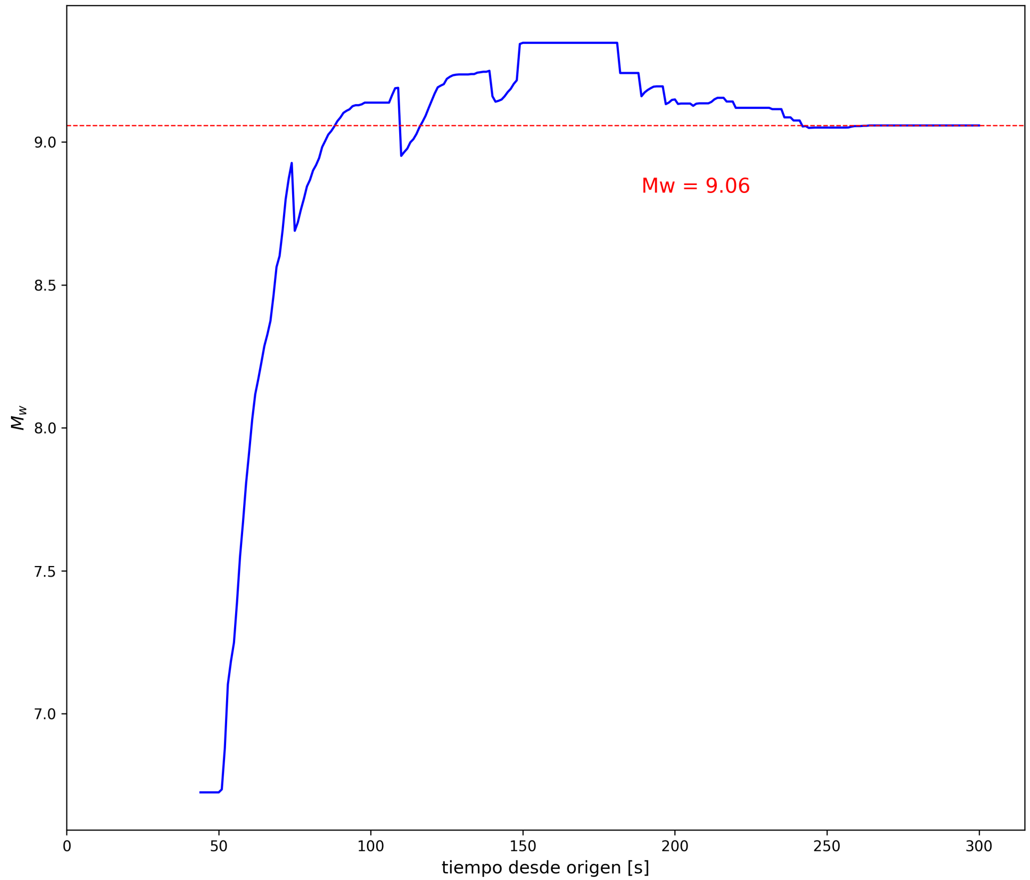

COLLECTOR
Visualization
Offset-Picker
Inversion
Status of the system
Report

CENTRO SISMOLÓGICO NACIONAL

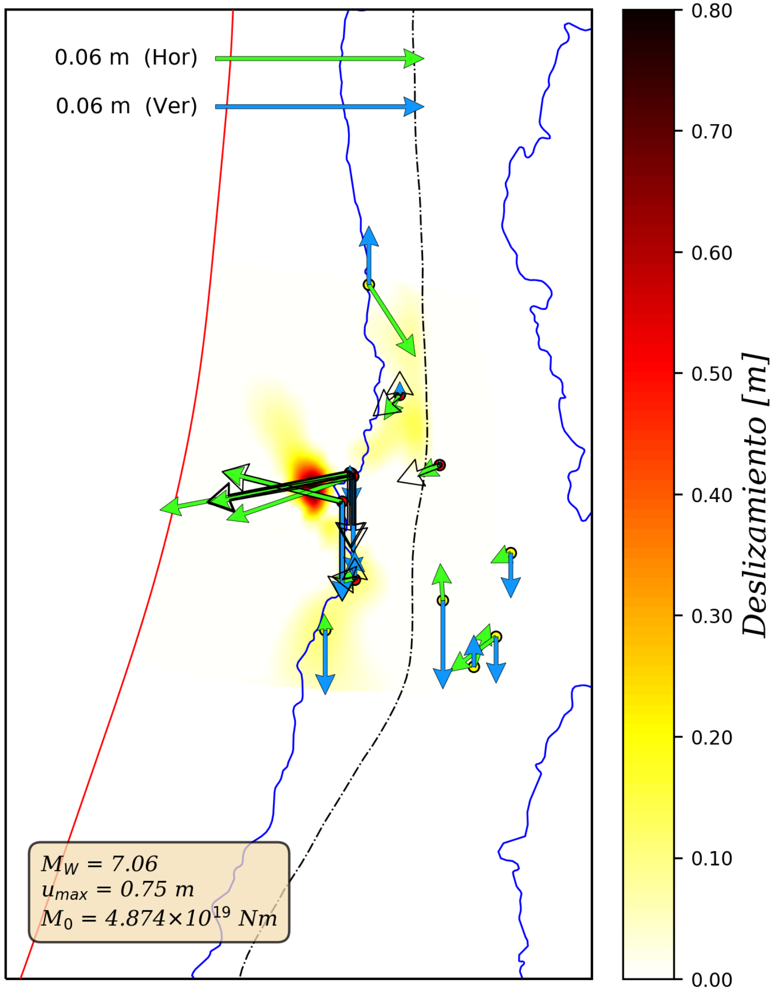


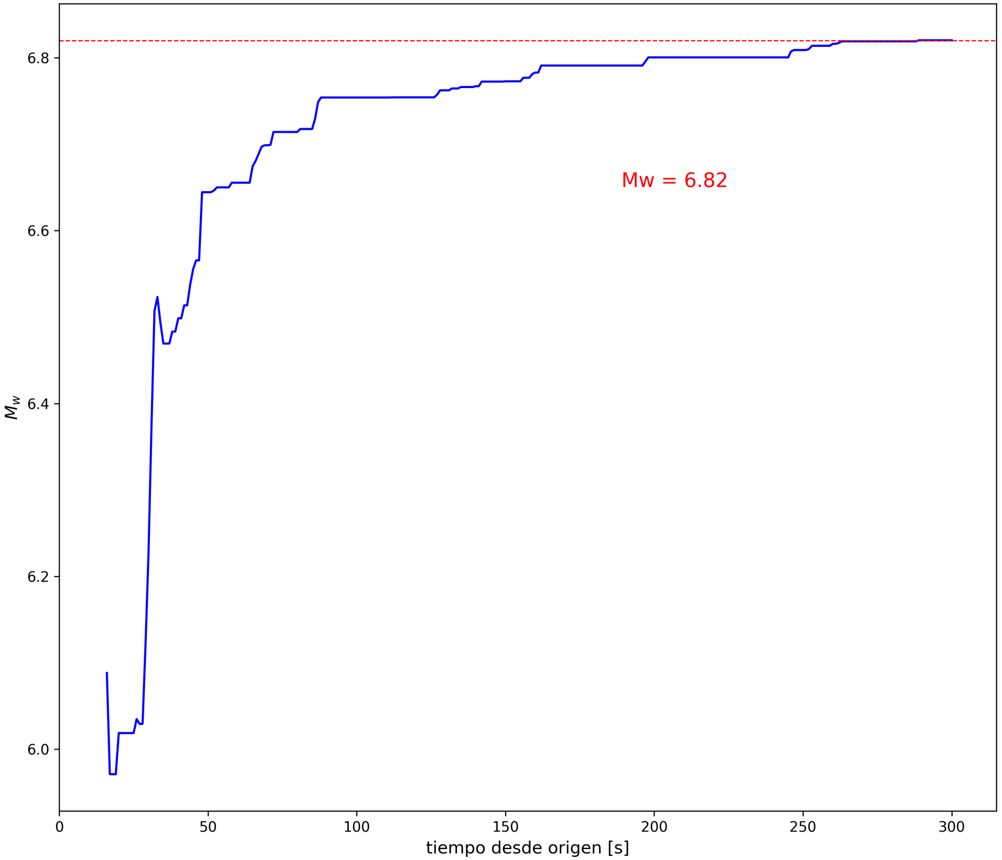
Example 1: Maule Mw8.8 2010





Example 2: Valparaiso Mw 6.9 2017





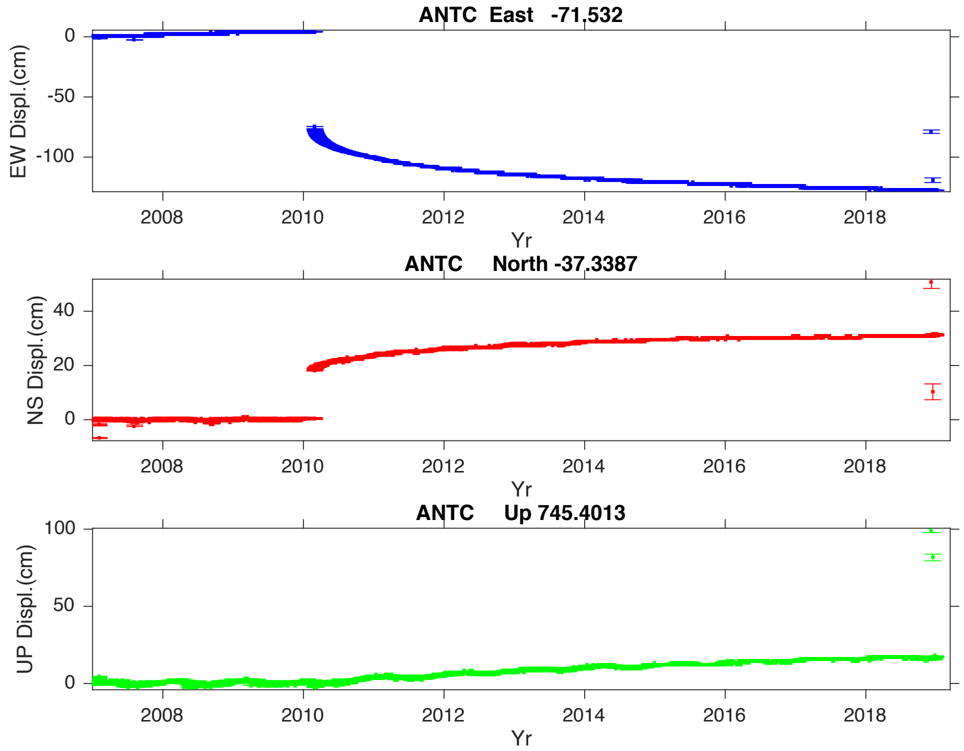
Trajectory

CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

$X_l = X_0 + V(t_i - t_0) + \Sigma_r$

$X_l = X_0 + V(t_i - t_0) + C_s + P_s + S + T + SL + e$

Bevis and Brown 2014
Bedford and Bevis 2018

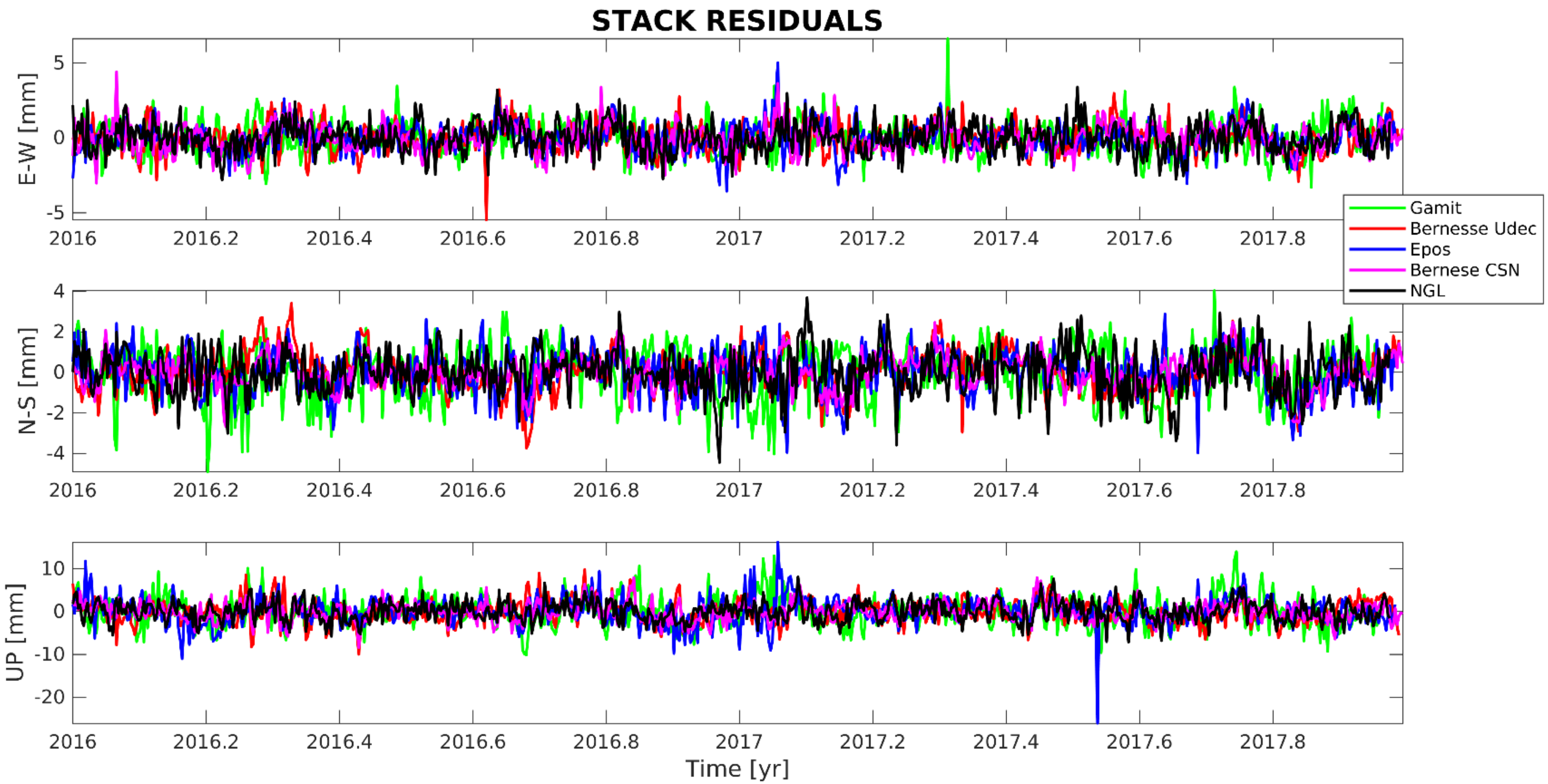


Trajectory

$X_l = X_0 + V(t_i - t_0) + \Sigma_r$

$X_l = X_0 + V(t_i - t_0) + C_s + P_s + S + T + SL + e$

Solutions from different AC

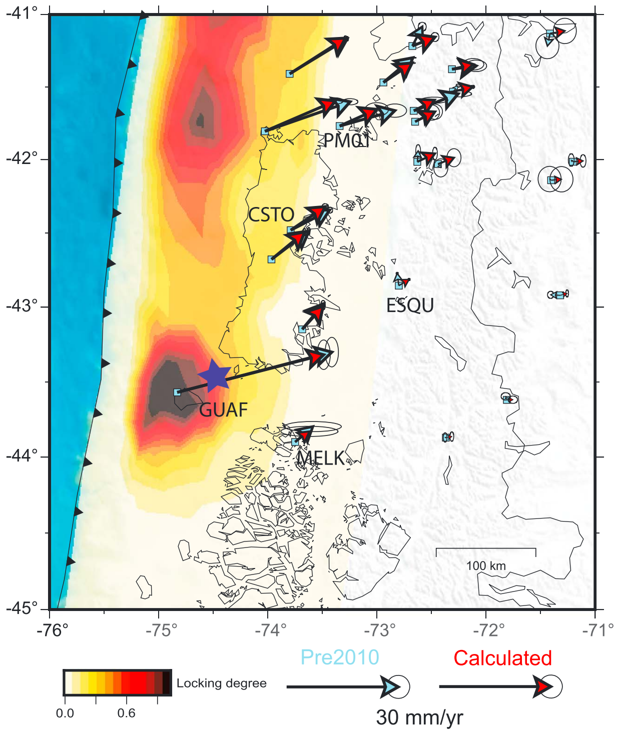


(Báez and Moreno, 2020, in preparation)

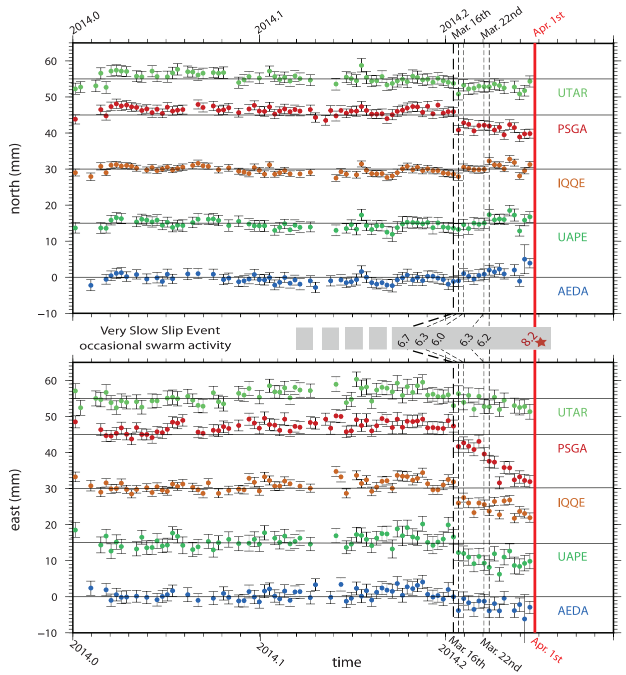
Research Projects

Ruiz S., Báez, J.C., Madariaga R., FONDECYT Nº1170430

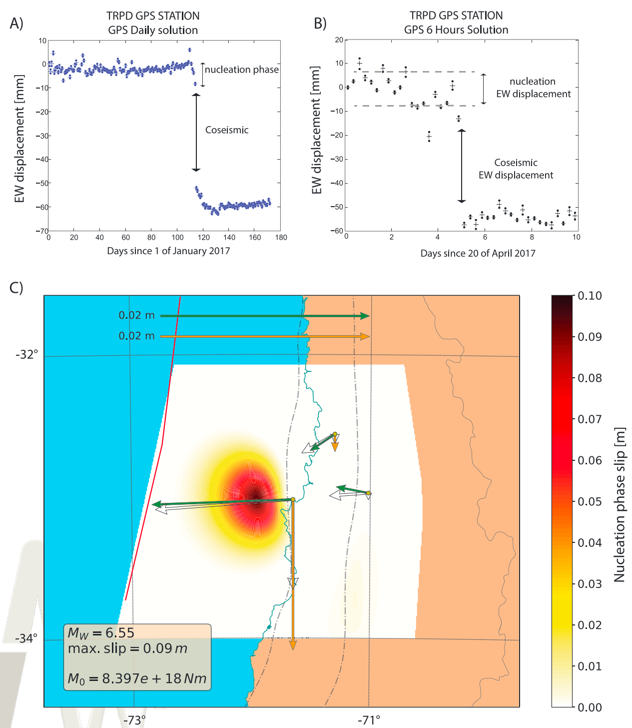
The relation among small, large and mega-earthquakes in central Chile



Ruiz et al. 2017



Ruiz et al. 2014



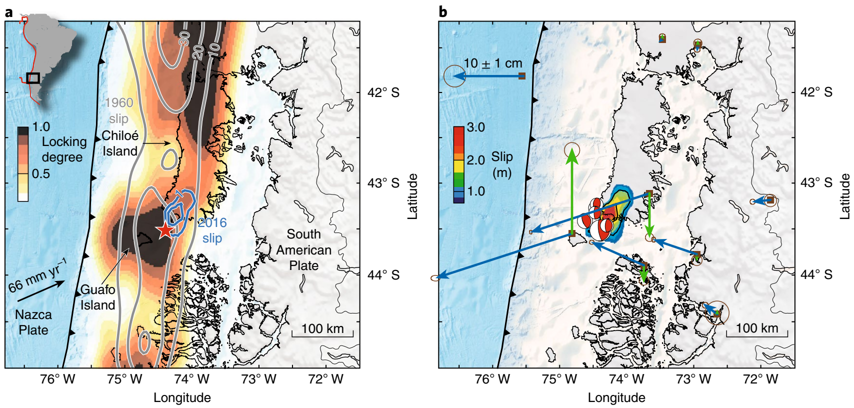
Ruiz et al. 2017

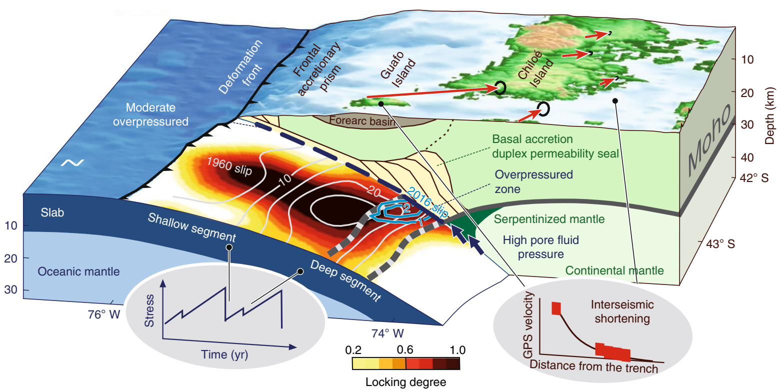
CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

Research Projects

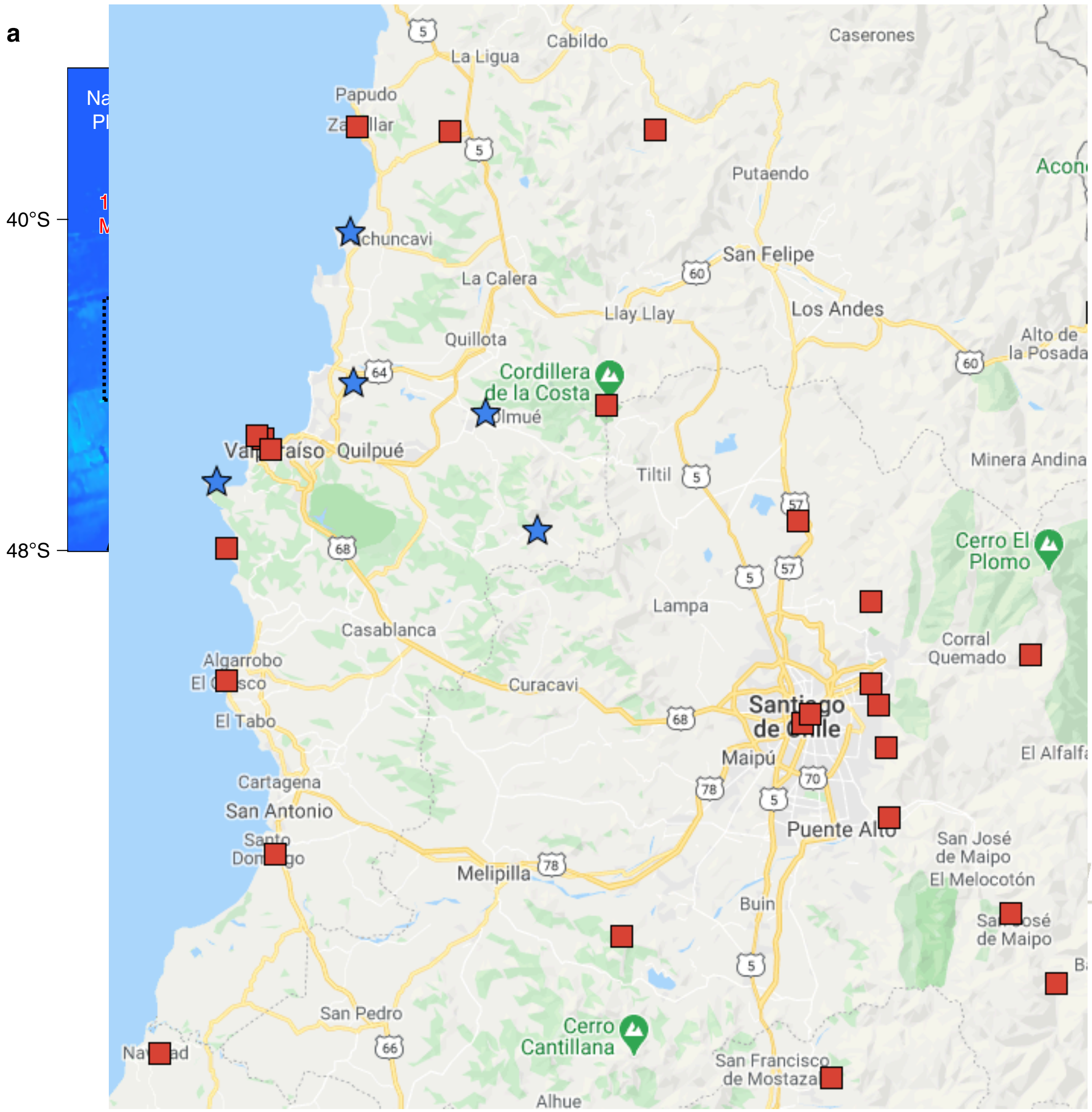
Moreno M., Cisternas M., Báez, J.C., Ortega F., Melnick D., FONDECYT Nº1181479

Investigation the feedback between megathrust eq. and continental plate faulting: Consequences for seismic hazard in Metropolitan Chile

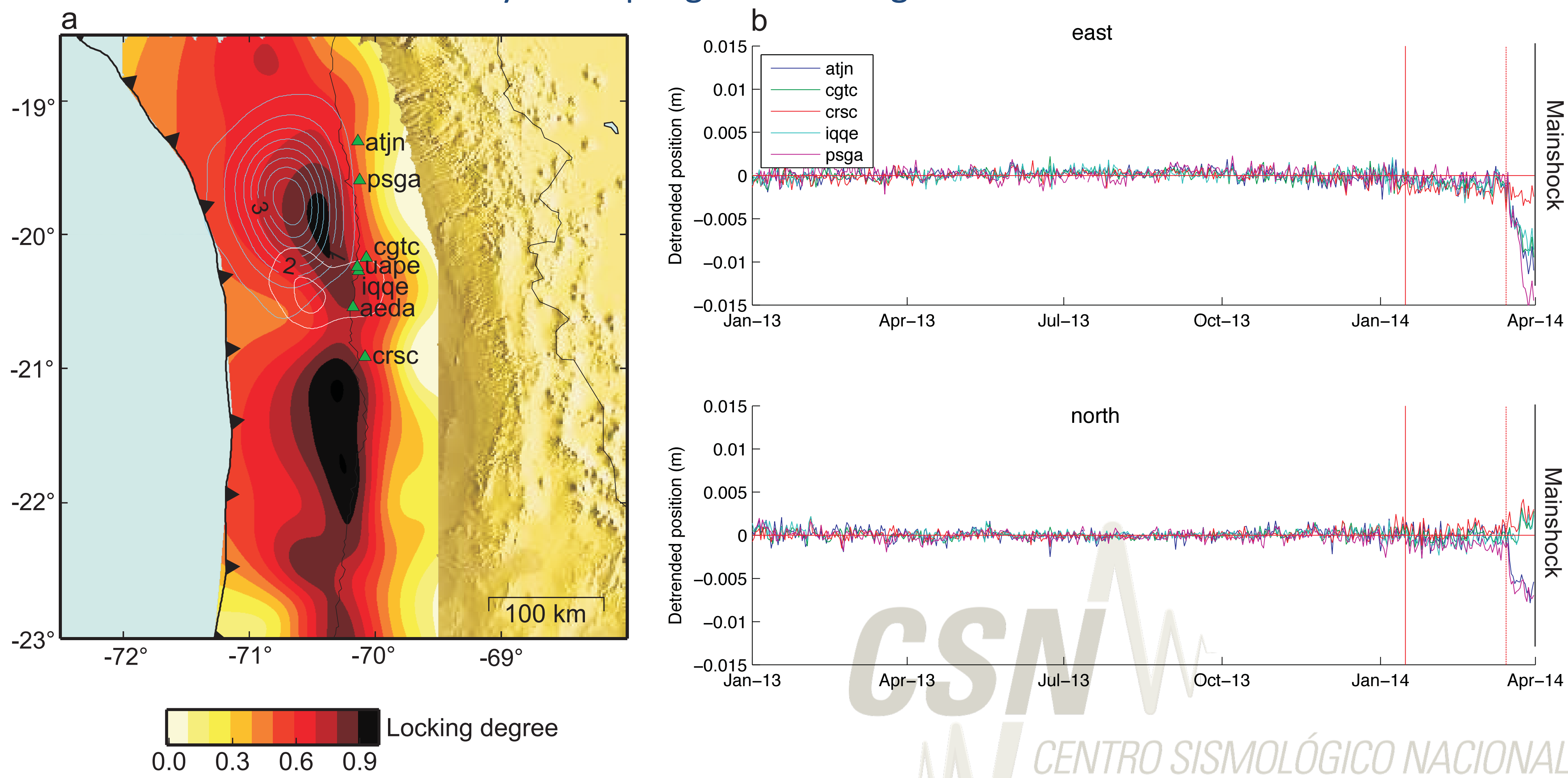




Moreno et al., 2018



Transitory decoupling before Pisagua 2014 EQ



Schurr et al., 2014

nature

Explore our content | Journal information | Subscribe

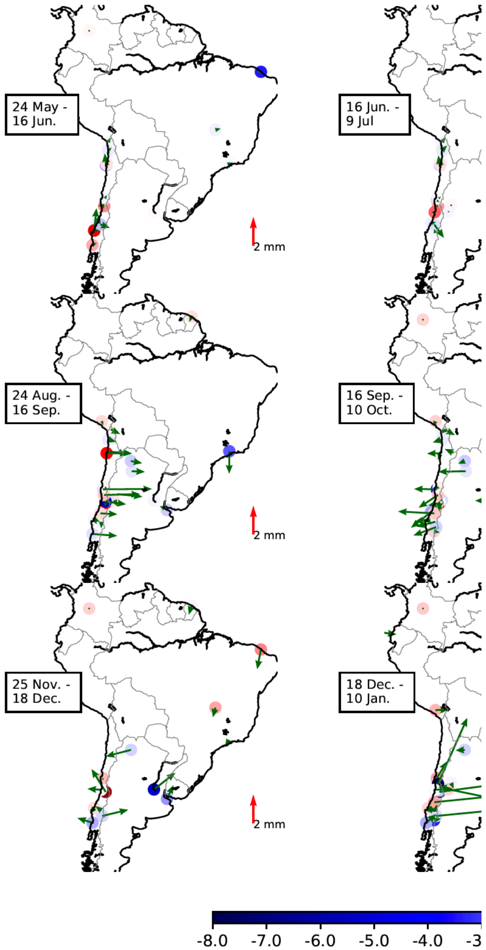
nature > articles > article

Article | Published: 29 April 2020

Months-long thousand-kilometre-scale wobbling before great subduction earthquakes

Jonathan R. Bedford, Marcos Moreno, Zhiguo Deng, Onno Oncken, Bernd Schurr, Timm John, Juan Carlos Báez & Michael Bevis

Nature **580**, 628–635(2020) | Cite this article



Abstract

Megathrust earthquakes are responsible for some of the most devastating natural disasters[1]. To better understand the physical mechanisms of earthquake generation, subduction zones worldwide are continuously monitored with geophysical instrumentation. One key strategy is to install stations that record signals from Global Navigation Satellite Systems[2,3] (GNSS), enabling us to track the non-steady surface motion of the subducting and overriding plates before, during and after the largest events[4,5,6]. Here we use a recently developed trajectory modelling approach[7] that is designed to isolate secular tectonic motions from the daily GNSS time series to show that the 2010 Maule, Chile (moment magnitude 8.8) and 2011 Tohoku-oki, Japan (moment magnitude 9.0) earthquakes were preceded by reversals of 4–8 millimetres in surface displacement that lasted several months and spanned thousands of kilometres. Modelling of the surface displacement reversal that occurred before the Tohoku-oki earthquake suggests an initial slow slip followed by a sudden pulldown of the Philippine Sea slab so rapid that it caused a viscoelastic rebound across the whole of Japan. Therefore, to understand better when large earthquakes are imminent, we must consider not only the evolution of plate interface frictional processes but also the dynamic boundary conditions from deeper subduction processes, such as sudden densification of metastable slab.

Research Projects

CSN CENTRO SISMOLÓGICO NACIONAL UNIVERSIDAD DE CHILE

Proyecto "Precursor"

Hacia la comprensión de la deformación sísmica transitoria a precursora en Chile

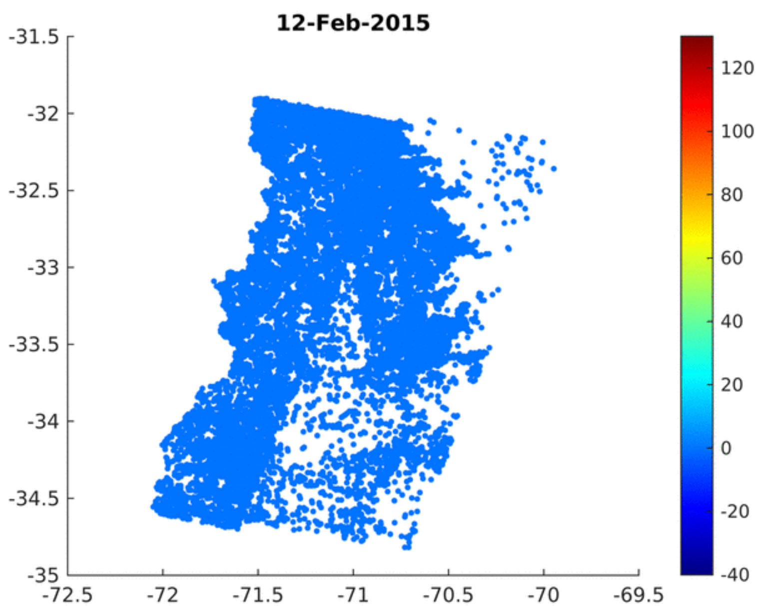
L1: Observational line, focused on providing displacement time series from spatial geodesy data (GNSS and SAR), and from seismicity catalogs

D.Moreno

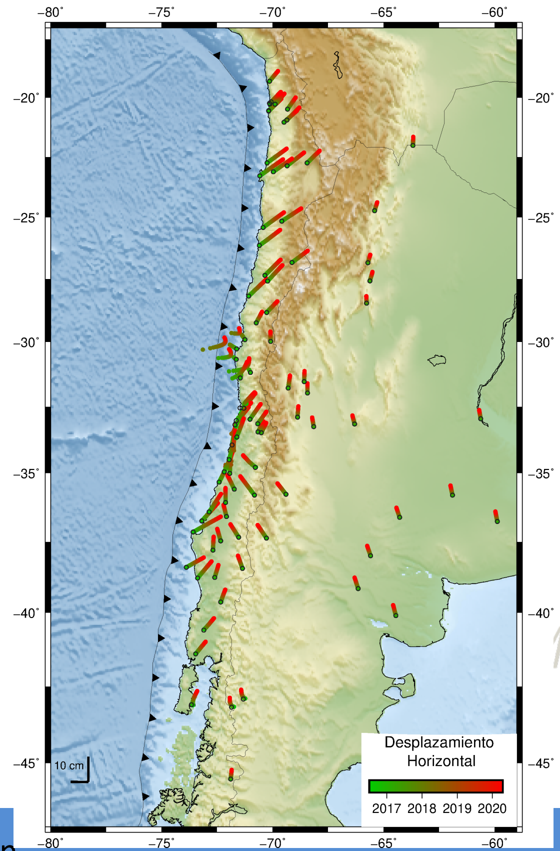
M.Moreno

J.C. Báez

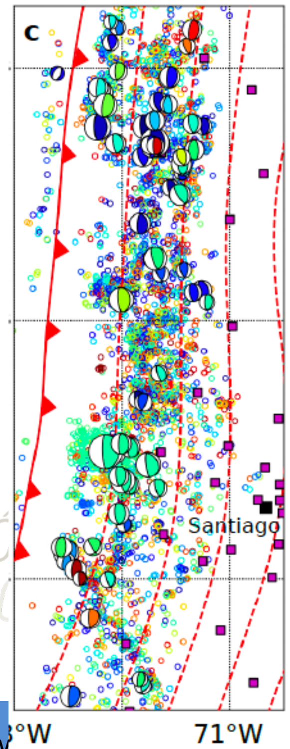
InSAR time-series Central Chile



Displacements 2016-2019

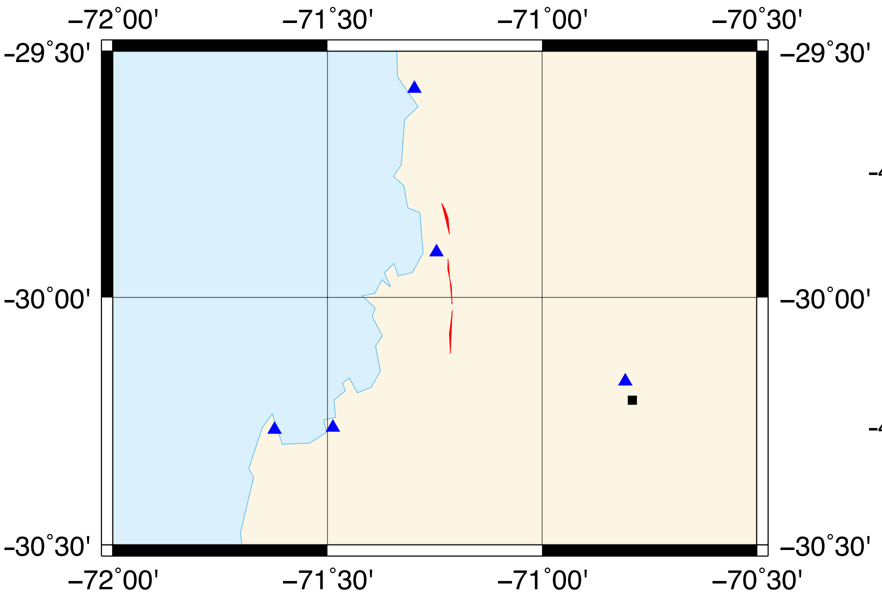


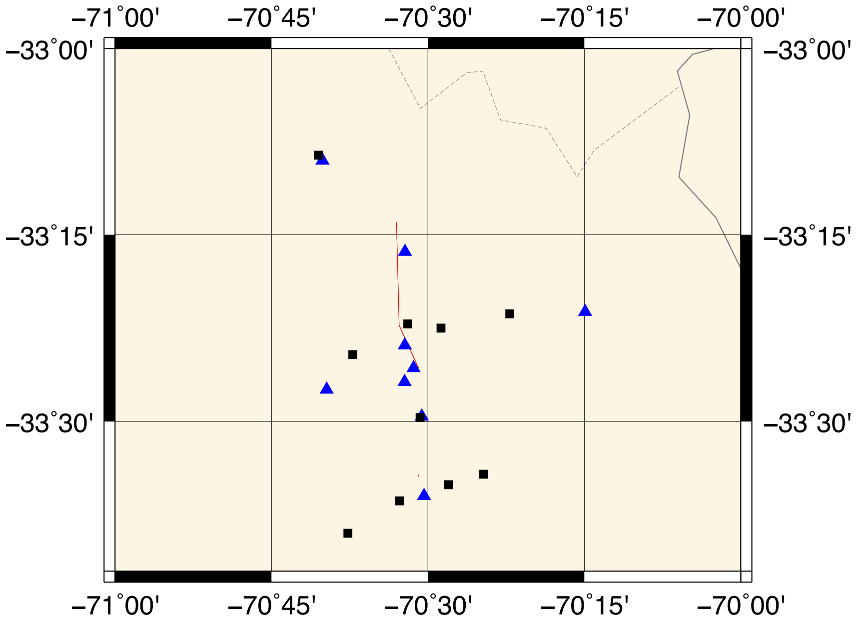
Seismicity 2014-2018

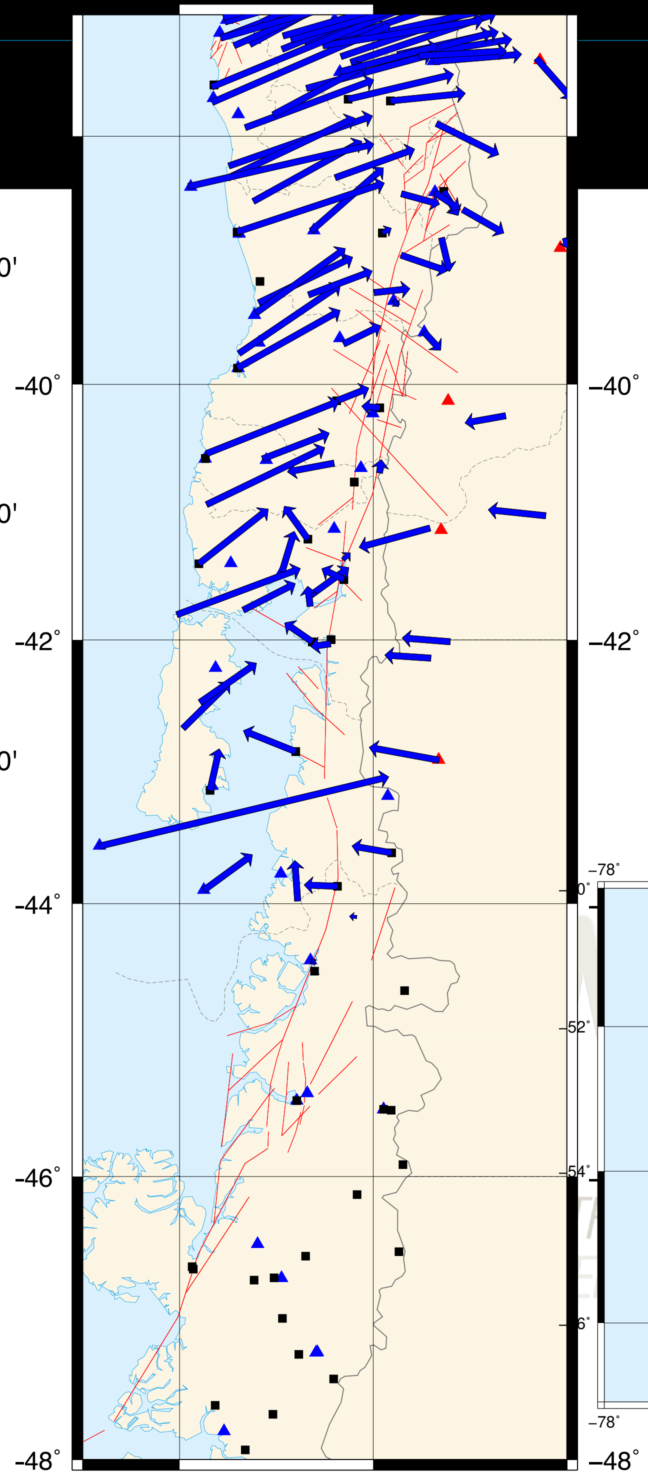


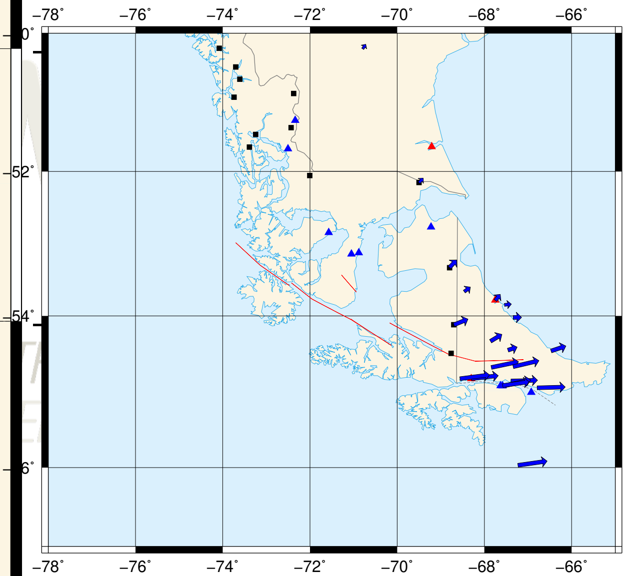
CSN Faults

CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

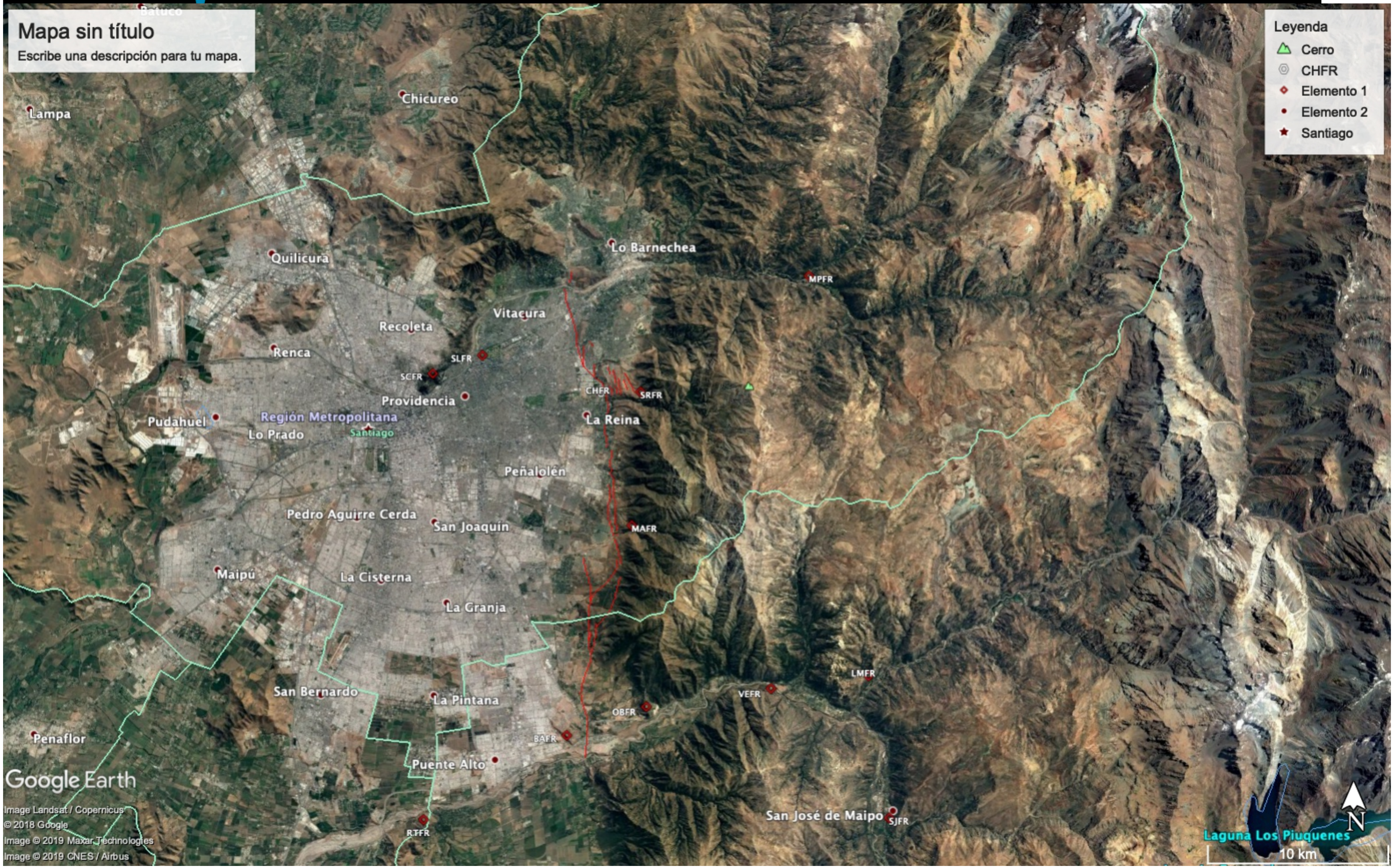






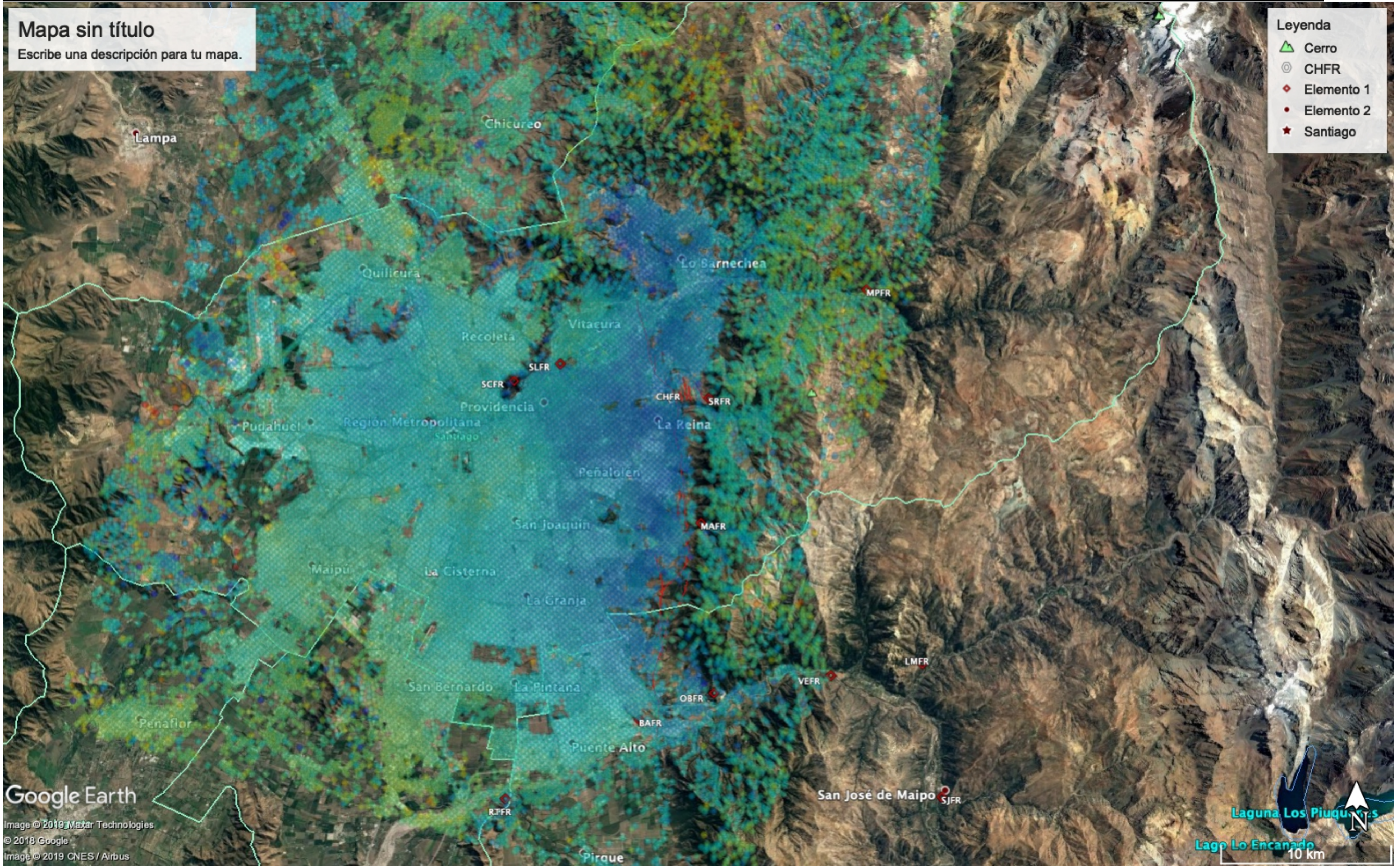


CSN
Faults
CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE



Faults

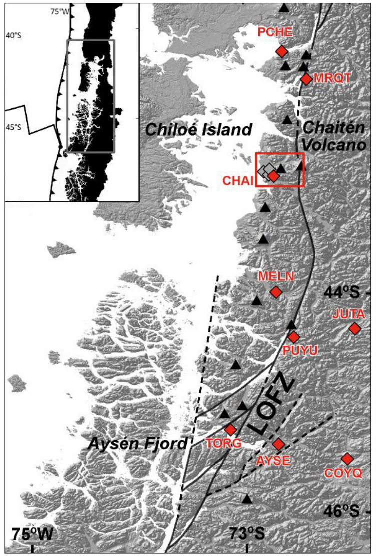
CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

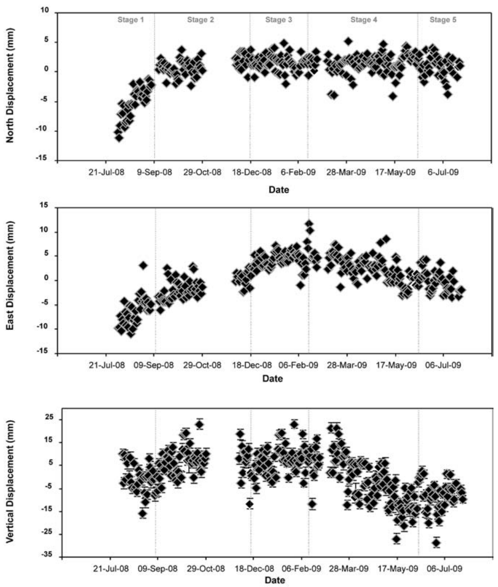


CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

Volcanoes

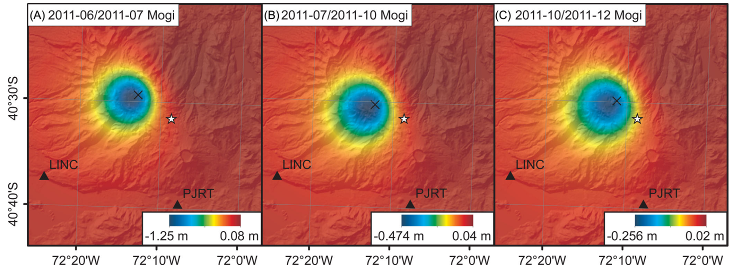
Chaitén

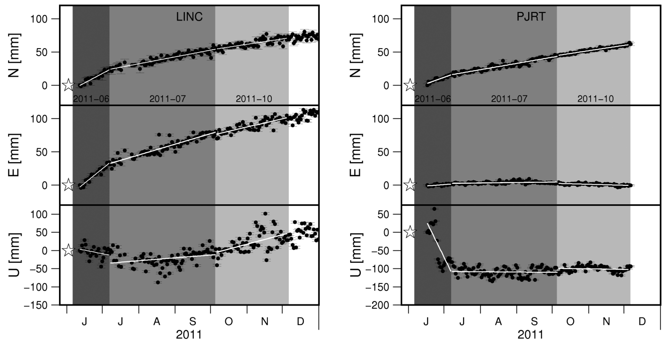




Piña et al., 2009, Andean Geology

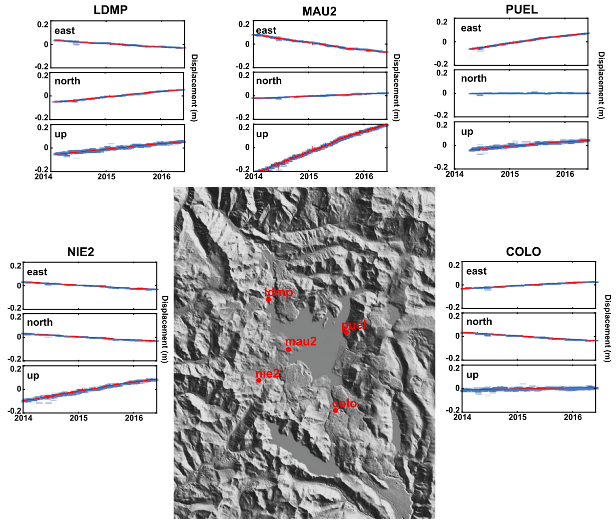
Cordón del Caulle

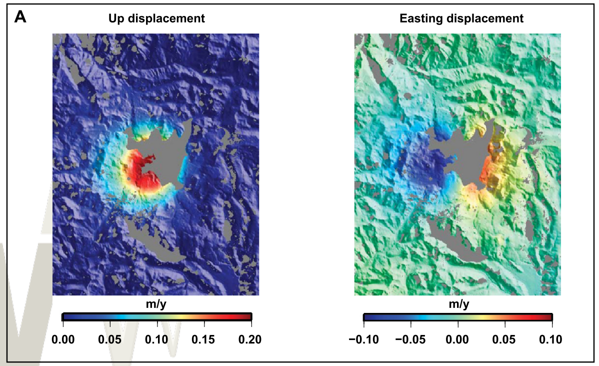


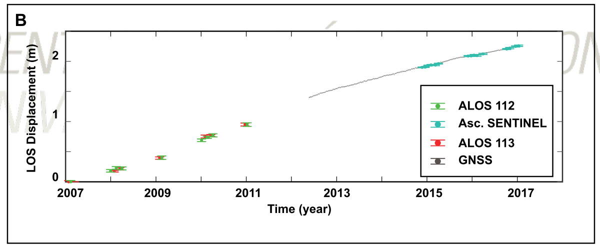


Went et al., 2017, GJI

Laguna del Maule





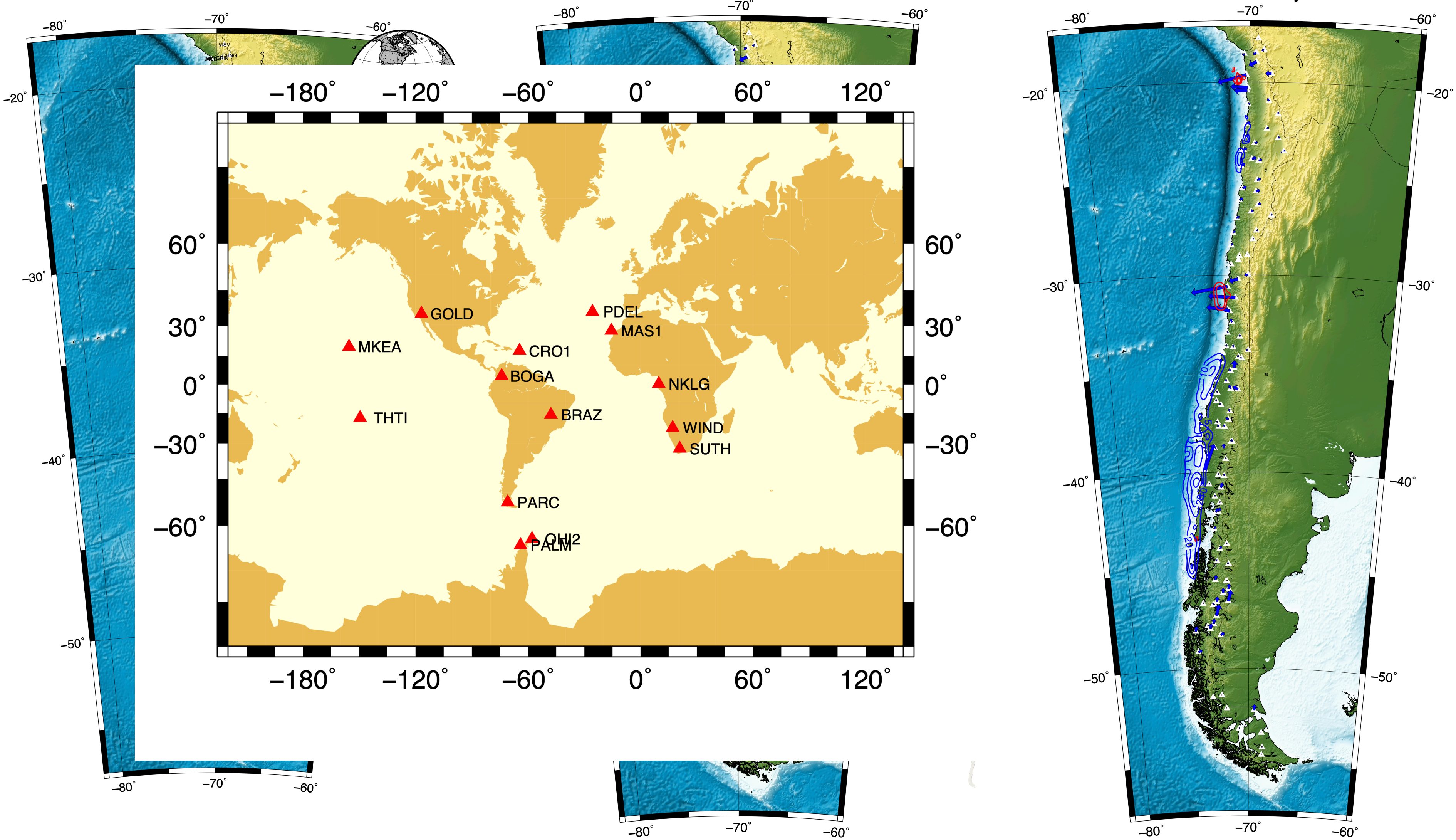


Novoa et al., 2019, EPSL

Impact into GRF

CENTRO SISMOLÓGICO NACIONAL
UNIVERSIDAD DE CHILE

SIRGAS-CHILE SIRGAS-CHILE 2013-2016 SIRGAS-CHILE/ EQ



The Helmert transformation does not work in Chile, even the use of velocities to transform epochs, due to deformation and earthquakes.

Final Remarks

- We developed an integrated system to obtain moment magnitude and slip distributions with GNSS observations;

- Next step will be to include intraplate and fault system EQ and also a combination between displacement from GNSS and data from accelerometers to characterize large EQ;

- We generate high-quality observations, which are available in an ftp for the use of the general public. We also keep the observations of the IGS stations in Chile;

- We participate in several multidisciplinary research project, national and international, to better understand the seismic cycle in Chile and, a relation between faults system and earthquakes.

https://scholar.google.com/citations?user=TeLKryYAAAAJ&hl=es

Thank you for your attention!