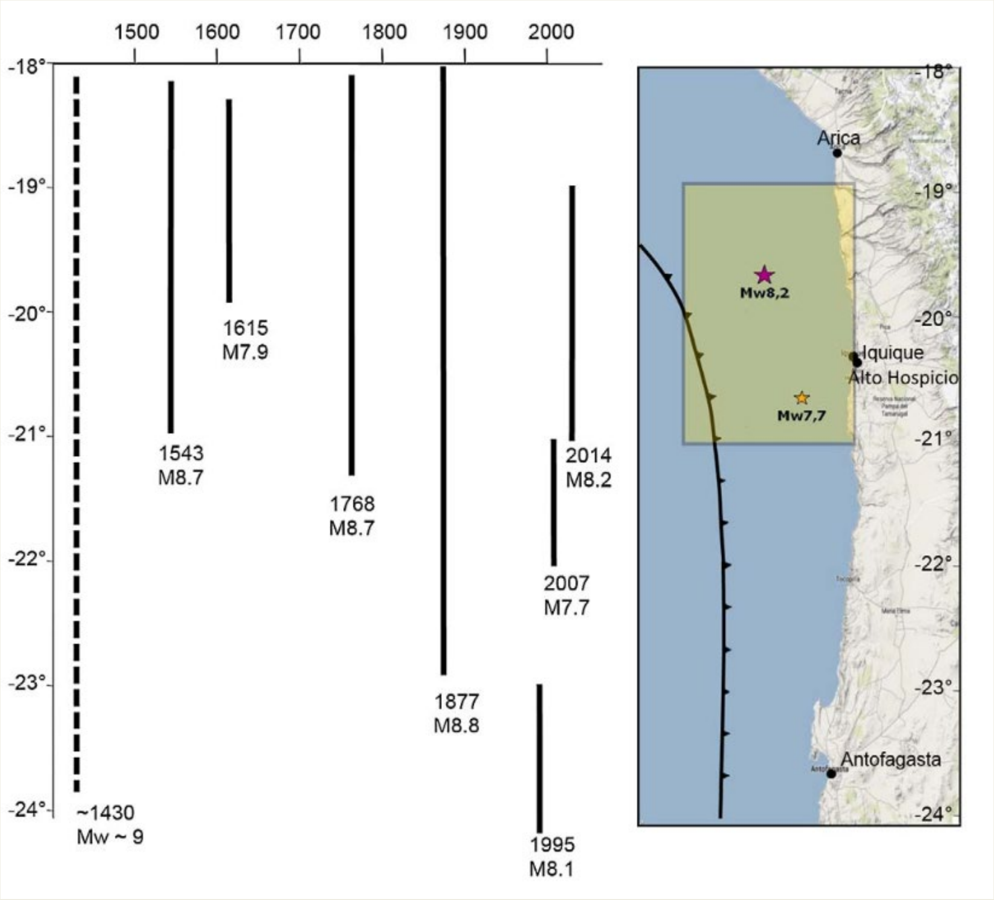
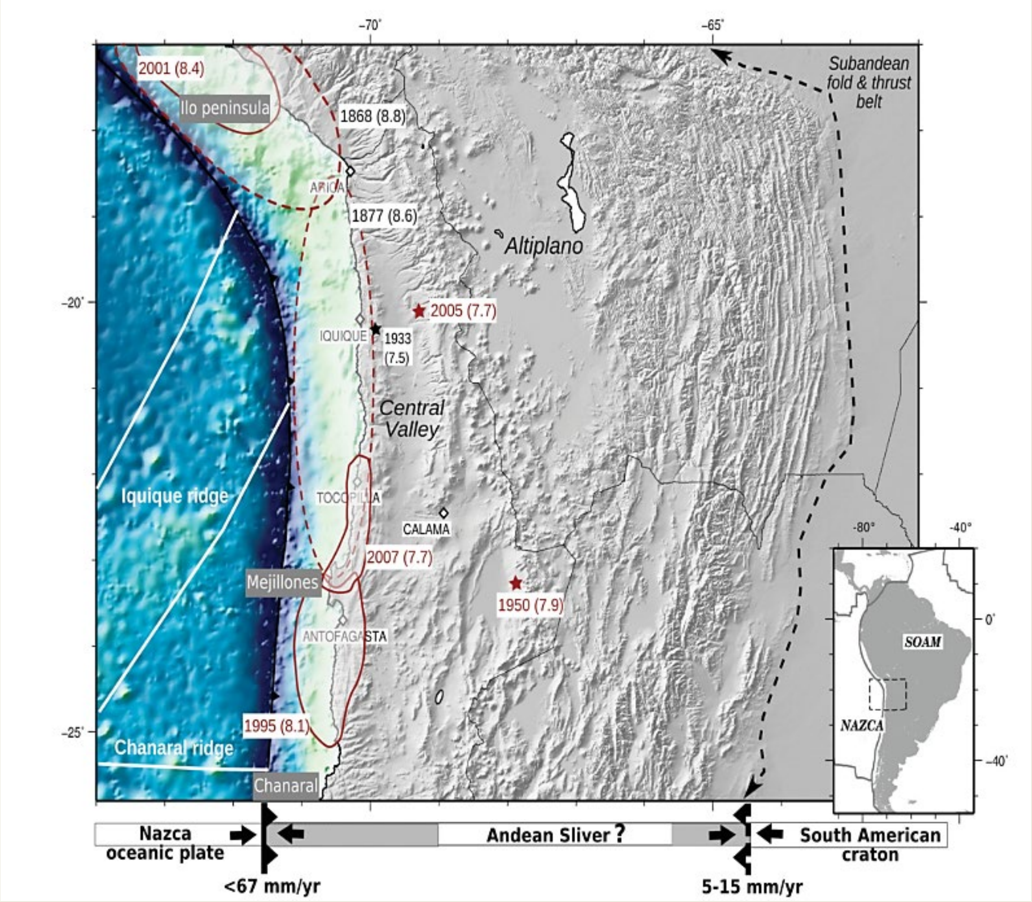
Tsunami source of the 2014 Iquique – Chile earthquake

Dra. Ignacia Calisto
Geophysics Department
University of Concepcion
Observatory of Environmental Risk – ORA
Millennium Nucleus CYCLO

UNESCO-IOC Meeting of Experts on tsunami sources and hazard in southern Peru and northern Chile
22-25 August 2023 -Arica, Chile

Before the 2014 Earthquake

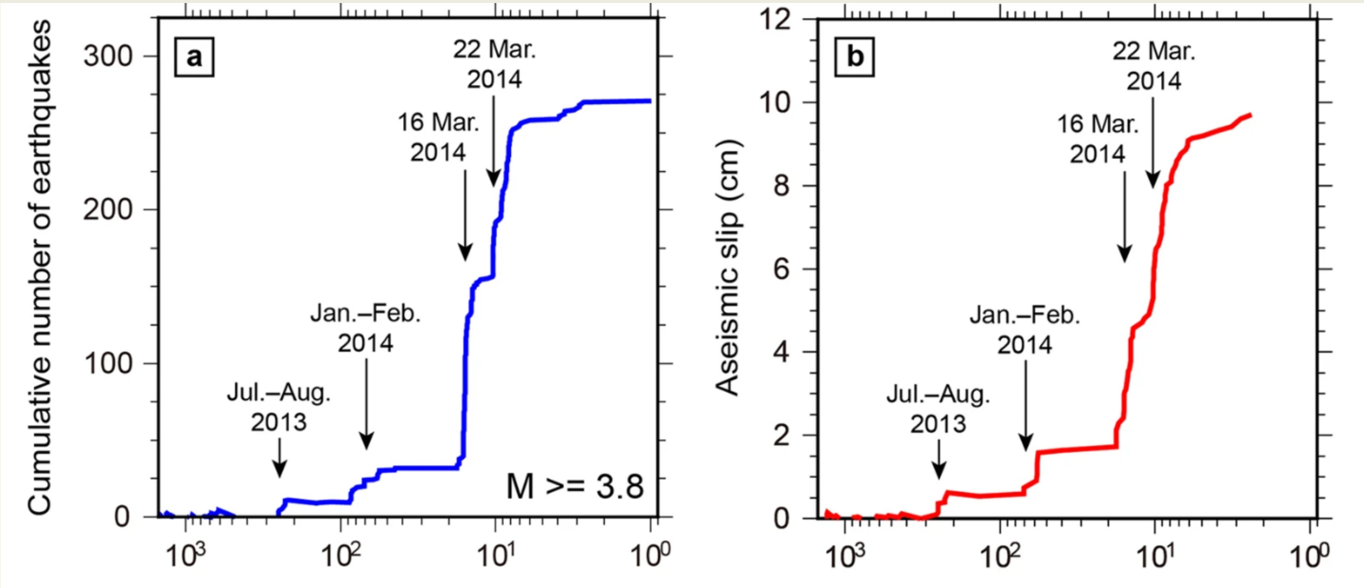


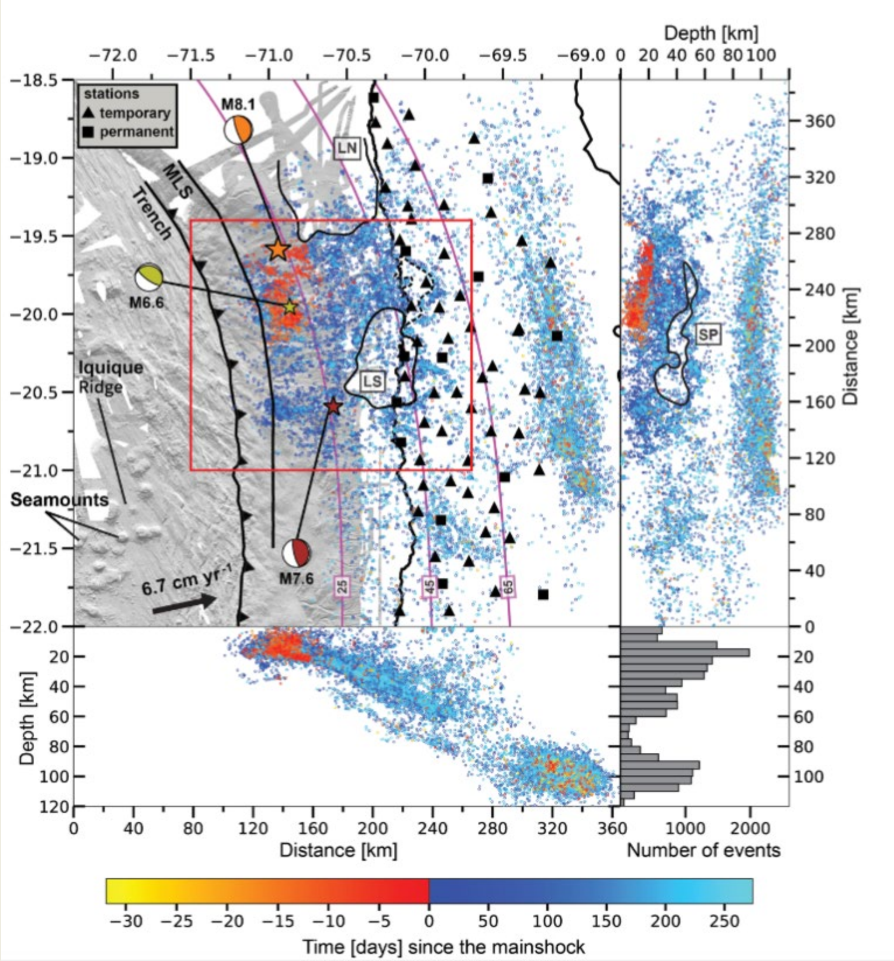


Becerra et al., 2016
Metois et al., 2013

Before the 2014 Earthquake

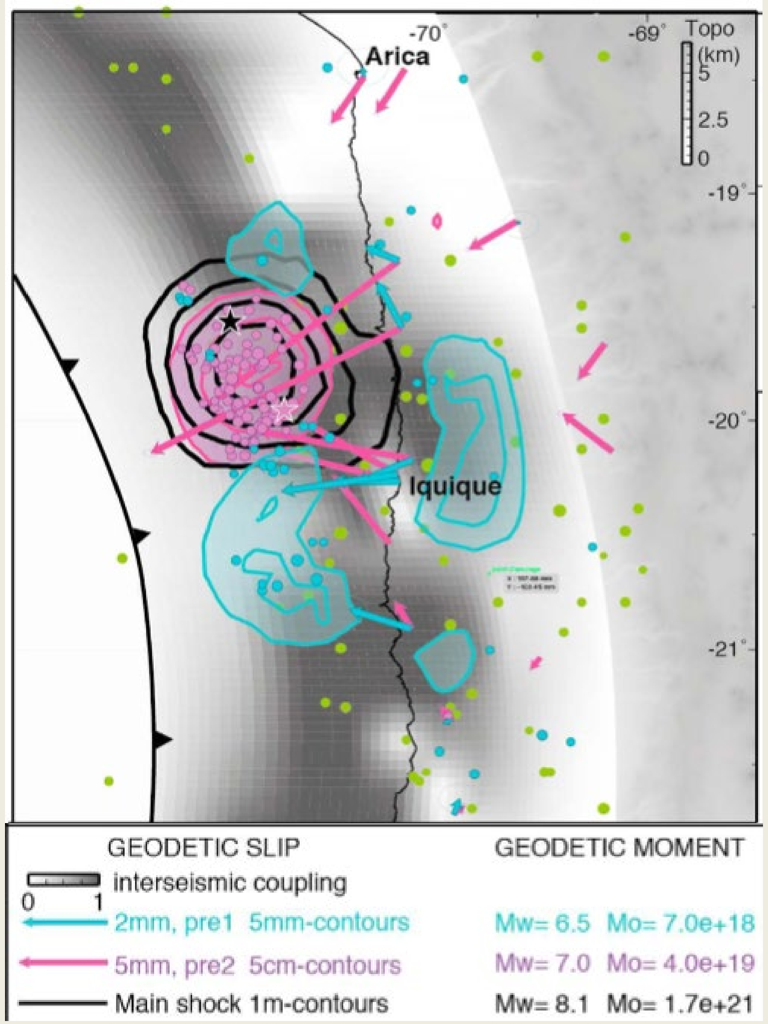
- Series of earthquake swarms beginning in July 2013
- Seismicity is around a small portion of the gap

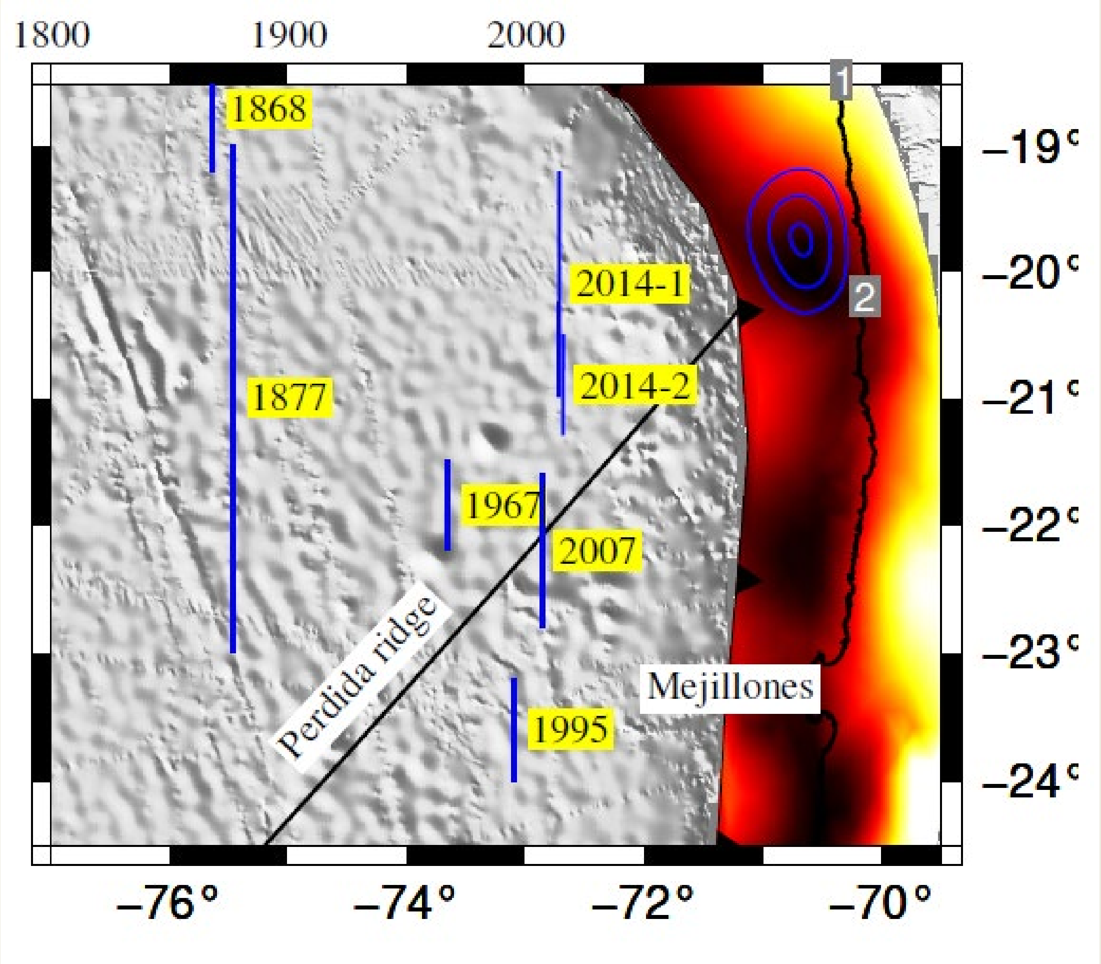




Kato et al., 2016
Soto et al., 2019

Before the 2014 Earthquake

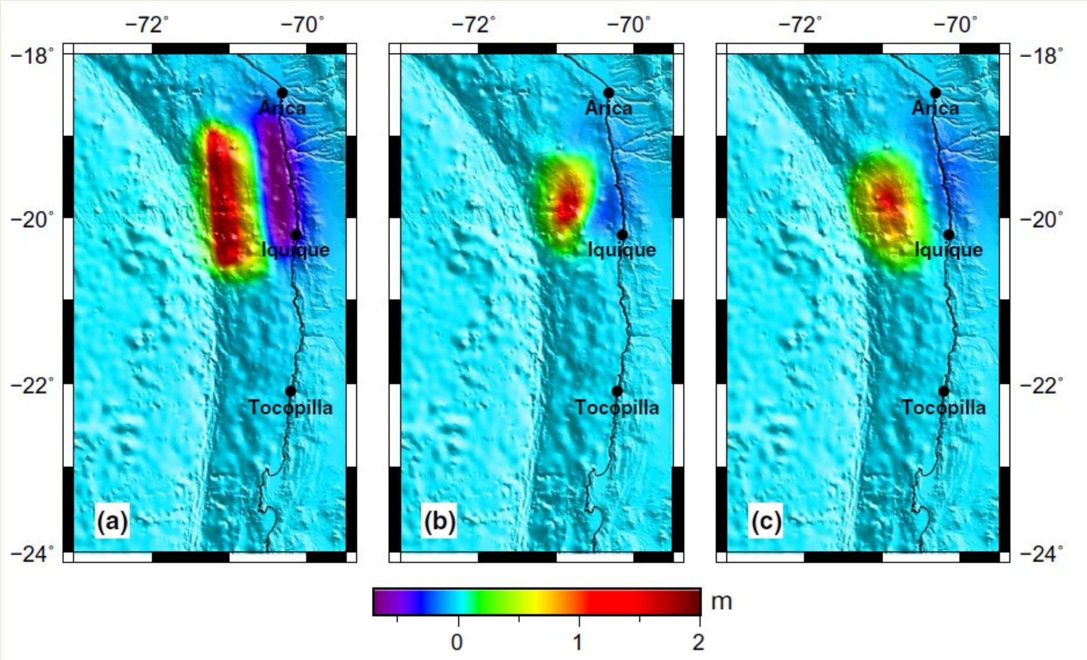




Socquet et al., 2017
Drapela et al., 2021 (Moreno et al., 2010)

The 2014 Source: heterogeneous vs homogeneous

Source models



(a) Homogeneous	(b) Lay et al, 2014	(c) Schurr et al, 2014
Mw 8.1 (1)	54 subfaults (1)	69 subfaults (1)
Strike 355° (1)	14.44 x 11.48 km2 (1)	16.49 x 16.61 km2 (1)
Dip 15° (1)	Lon, Lat, slip, rake (1)	lon, lat, slip (1)
Rake 106° (1)	Dip, strike (2)	Rake 102.96° (2)
Depth 21.6 km (1)		Strike, dip, depth (3)
(19.70 S, 70.81 W). (1)		
184 x 76 km2 (2)		
Slip 4.5 m (3)	(1) Lay et al, 2014 (2) Klotz et al, 2001	(1) Schurr et al, 2014 (2) Nuvel 1A DeMets et al, 1994 (3) Hayes et al, 2012
(1) (http://www.globalcmt.org/) (Dziewonski et al, 1981; Ekstrom et al. 2012) (2) Papazachos et al. (2004) (3) Kanamori and Anderson (1975)	Short-period teleseismic P wave backprojections and inversion of deepwater tsunami wave recordings	Inversion of static three-component GPS displacement data for the final fault slip and then teleseismic and local strong-motion waveforms for the time-dependent kinematic rupture process. Finally a joint inversion of the waveform and GPS data is performed.

Lay et al., 2014 (Published in May)
Schurr et al., 2014 (Published in August)
Calisto et al., 2015

The 2014 modelation: Methodology

- COrnell Multi-grid Couple Tsunami Model (COMCOT) v1.7. (Liu et al., 1998)
- Explicit staggered leapfrog finite difference schemes to solve shallow water equations (linear and non-linear)
- Nested grid system. Uniform grid size ($\Delta x = \Delta y$)
- The water surface displacement is the same as the deformation of the sea floor
- The sea floor displacement is computed using finite fault plane theory (Okada, 1985)
- 6 hours simulation using a time step of 0.3 s, which satisfies the Courant stability condition
- Bottom friction coefficient of 0.025 (Masamura, 2000)
- 4 virtual tide gauges to compare with observed data from SHOA (Chilean Navy Hydrographic and Oceanographic Service)

	Latitude	Longitude
Arica	18.4758 S	70.3232 W
Iquique	20.2046 S	70.1478 W
Tocopilla	22.0937 S	70.2117 W
Talcahuano	36.6953 S	73.1063 W

The 2014 modelation: Grids

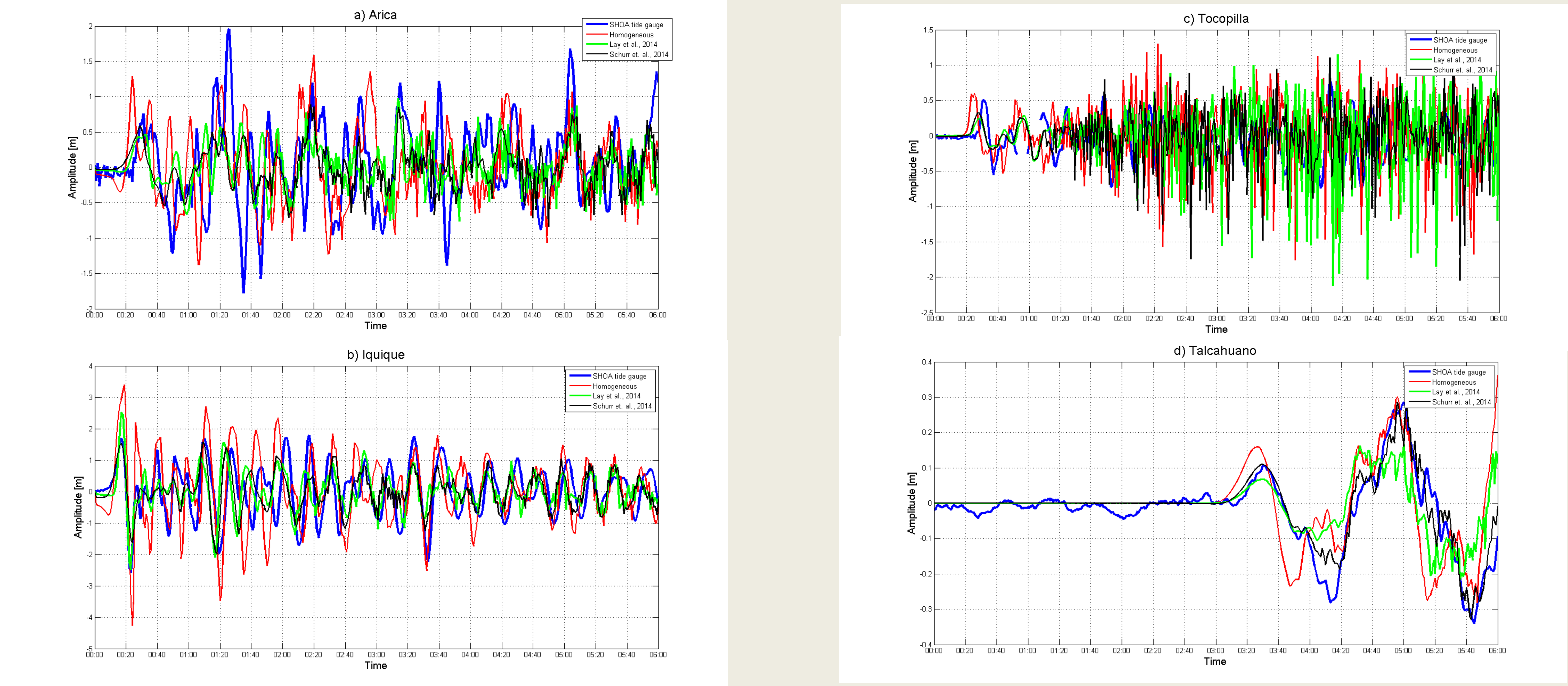
11 grids

- 1st level: 2’ resolution (3700 m). From Arica to Concepcion Bay
- 2nd level: 0.5’ resolution (930 m). From Arica to Tocopilla and around Concepcion Bay
- 3rd level: 0.1’ resolution (190 m). Arica, Iquique, Tocopilla and Talcahuano coastal areas
- 4th level: 0.016’ resolution (30 m). Arica, Iquique, Tocopilla and Talcahuano coastal areas

- Level 1 and 2 grids: SRTM30 (NASA Shuttle Radar Topogrpahy Mission; Becker et al., 2009).
- Level 3 and 4 grids: Bathymetry data from SHOA, (www.shoa.cl metadatos CENDHOC) and topography from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) which is a product of METI (http://gdem.ersdac.jspacesystems.or.jp/) and NASA (http://asterweb.jpl.nasa.gov).

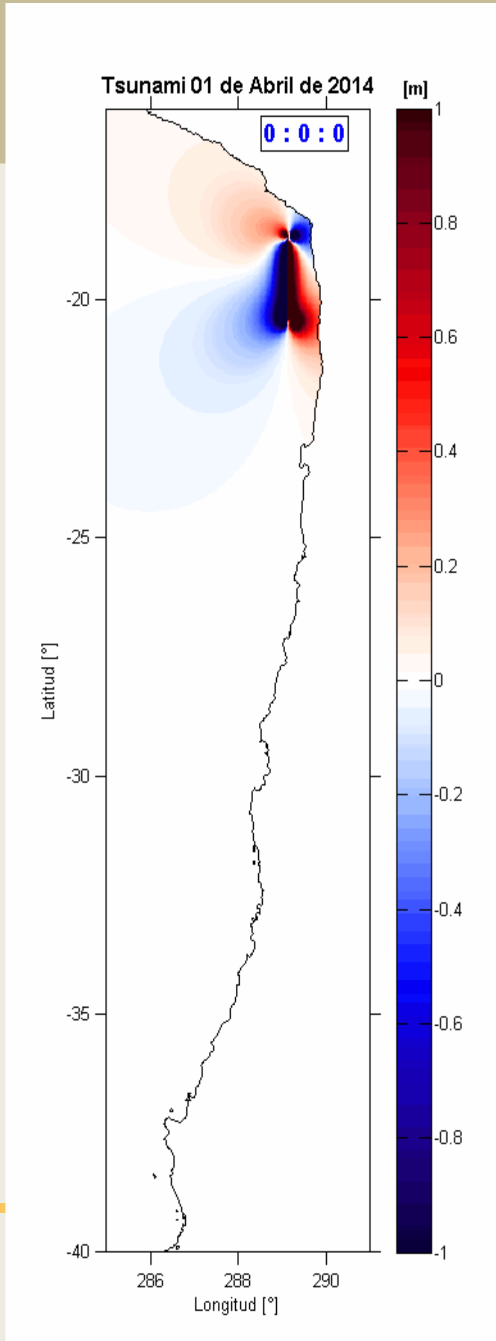
- For the data manipulation: Generic Mapping Toolkit (Wessel et al. 2013).

The 2014 modelation: Tsunami

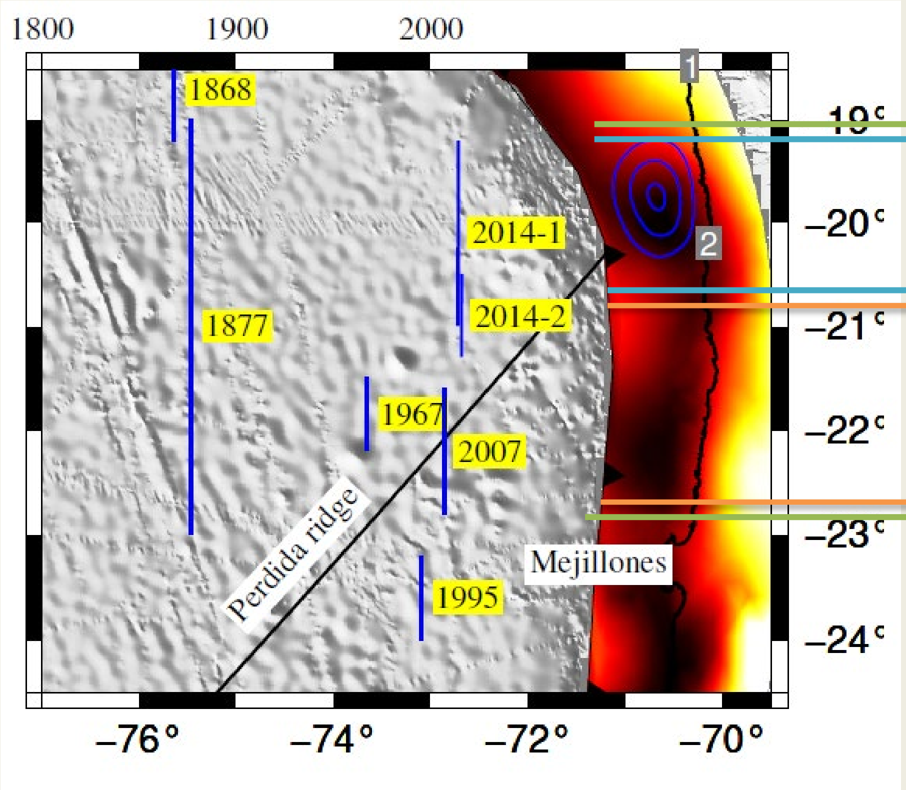


Results

- Both hereogeneous models reconstructed the tsunami signal better than the homogeneous one.
- The coseismic slip models, generated with different techniques and data sets, show very similar features, with a large and a smooth slip patch.
- The homogeneous model could be calculated much more quickly than the coseismic models using inversion methods (at that moment).
- The homogeneous model could be used to give us a rapid response but could underestimate the wave height in front of the main slip patch and overestimate the tsunami height in coastal areas beyond the rupture limits.
- The observed lack of the sea withdrawal before the initial wave was accurately modeled only for the heterogeneous models.



Discussion: Locking model used as a possible heterogeneous source?



How are the slip deficit and the recurrence time considered to calculate the slip using the locking degree?

How could different sectors in the seismic gap break at the same time, and under what conditions?

Drapela et al., 2021

Discussion: what features control the rupture?

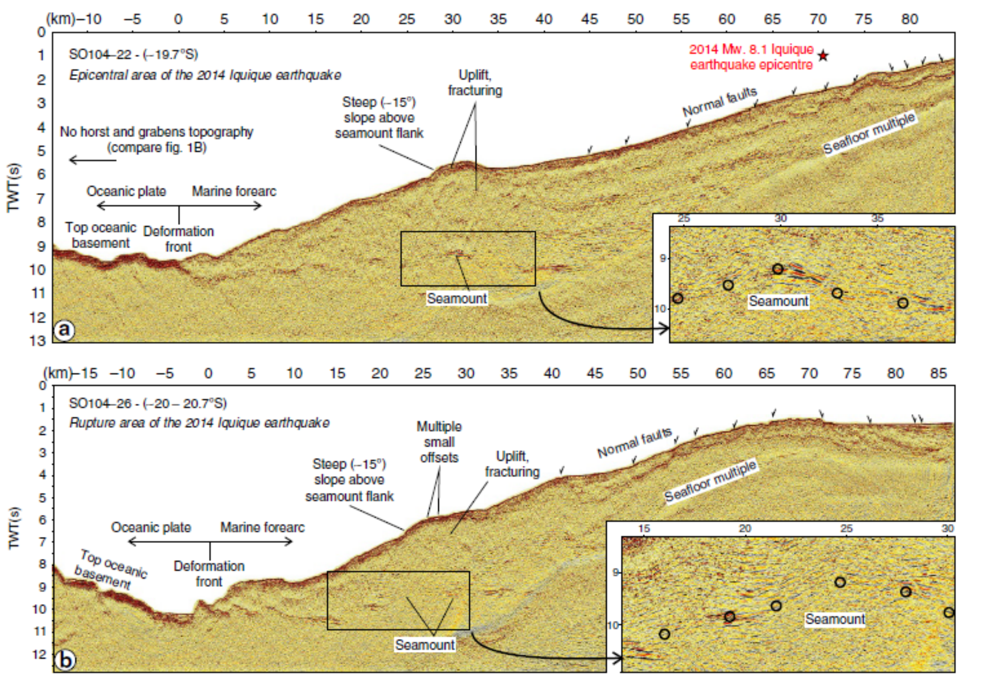
nature COMMUNICATIONS

ARTICLE

Received 18 Mar 2015 | Accepted 4 Aug 2015 | Published 30 Sep 2015 DOI: 10.1038/ncomms9267 OPEN

Subducting seamounts control interplate coupling and seismic rupture in the 2014 Iquique earthquake area

Jacob Geersen[1], César R. Ranero[2], Udo Barckhausen[3] & Christian Reichert[3]

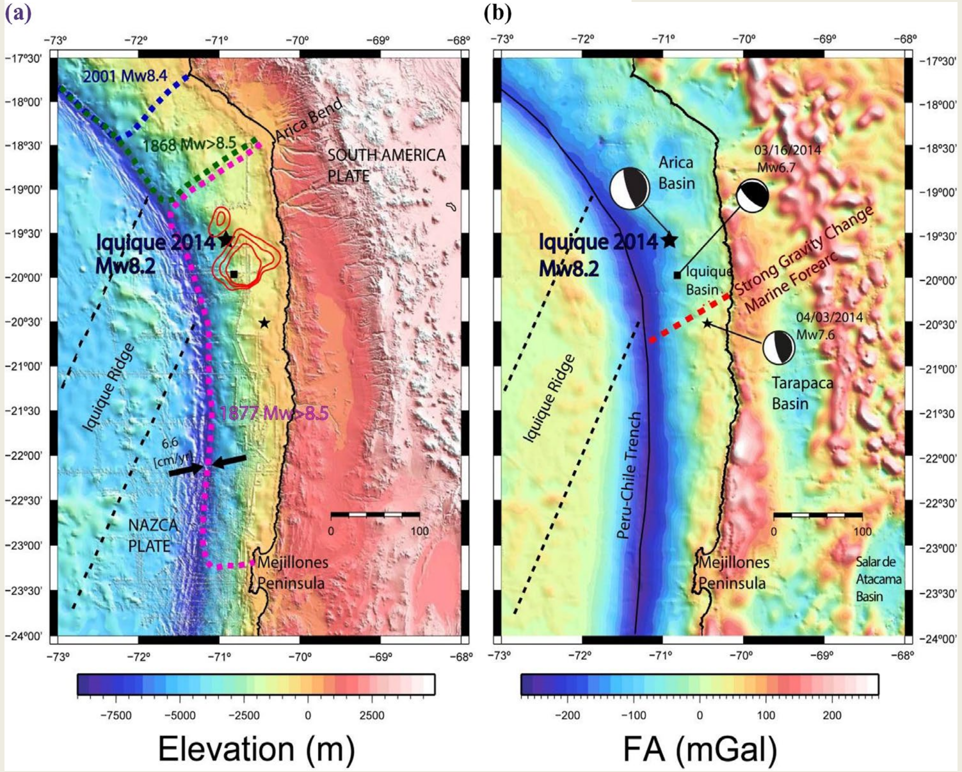


JOURNAL ARTICLE

Heterogeneous structure of the Northern Chile marine forearc and its implications for megathrust earthquakes FREE

Andrei Maksymowicz, Javier Ruiz, Emilio Vera, Eduardo Contreras-Reyes, Sergio Ruiz, César Arraigada, Sylvain Bonvalot, Sebastián Bascuñan

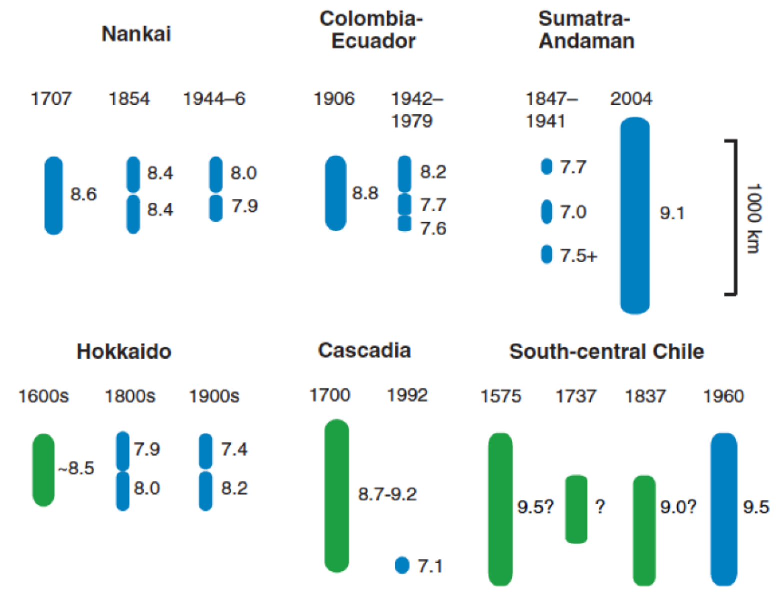
Geophysical Journal International, Volume 215, Issue 2, November 2018, Pages 1080–1097, https://doi.org/10.1093/gji/ggy325
Published: 06 August 2018 **Article history ▾**

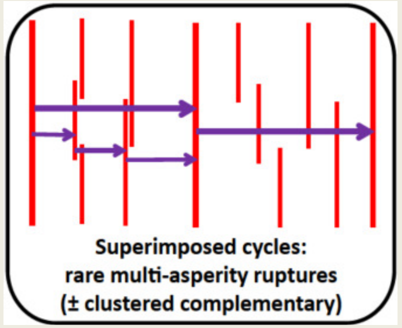


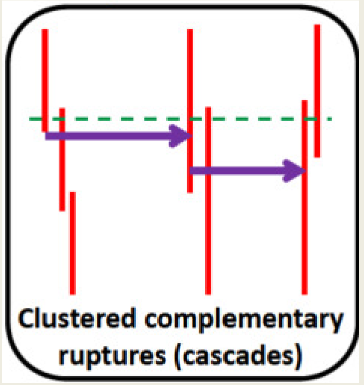
DGEO Universidad de Concepción milenio INICIATIVA CIENTÍFICA CYCLO ORA

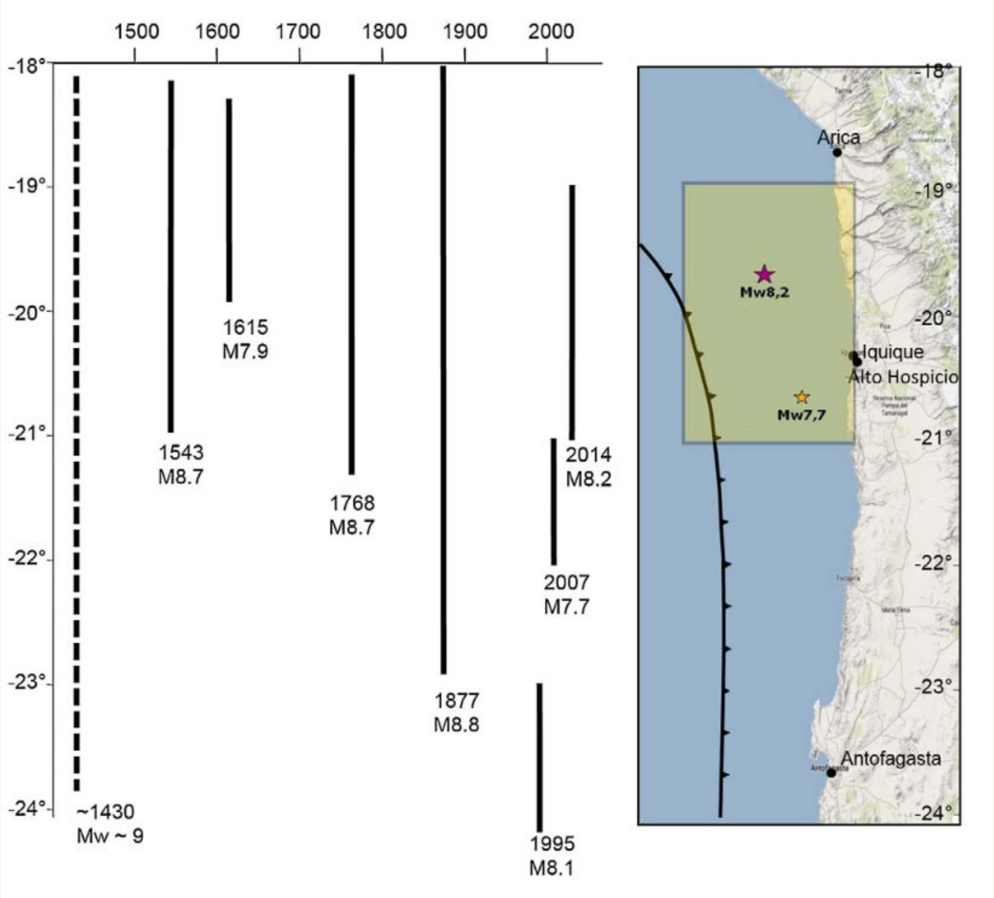
Geersen et al., 2015
Maksymowicz et al., 2018

Discussion: seismic cycle and recurrence interval









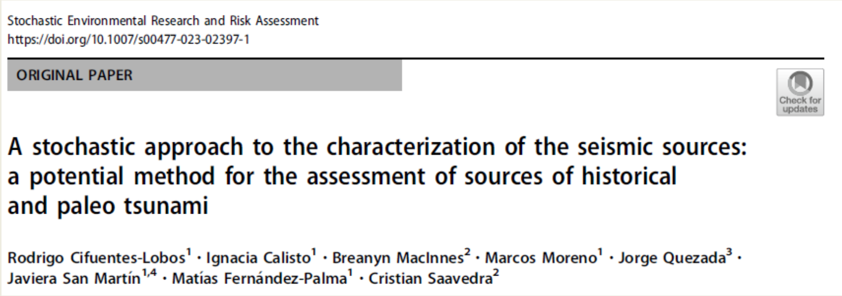
The 869 Jogan and the 2011 Tohoku-oki earthquake tsunamis

Show affiliations

Sugawara, D. ; Imamura, F. ; Goto, K. ; Matsumoto, H. ; Minoura, K.

Satake and Atwater, 2007 Annual reviews
Philibosian and Meltzner, 2020 Quaternary Science Reviews
Becerra et al., 2016

Discussion: Reconstructing a seismic segment



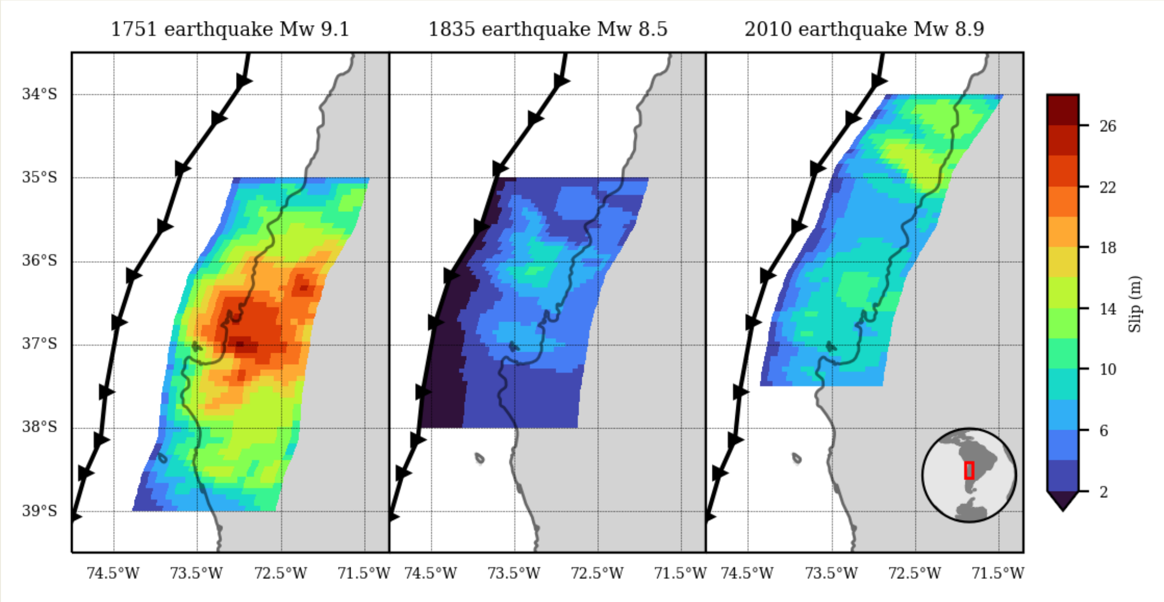
Stochastic Environmental Research and Risk Assessment
https://doi.org/10.1007/s00477-023-02397-1

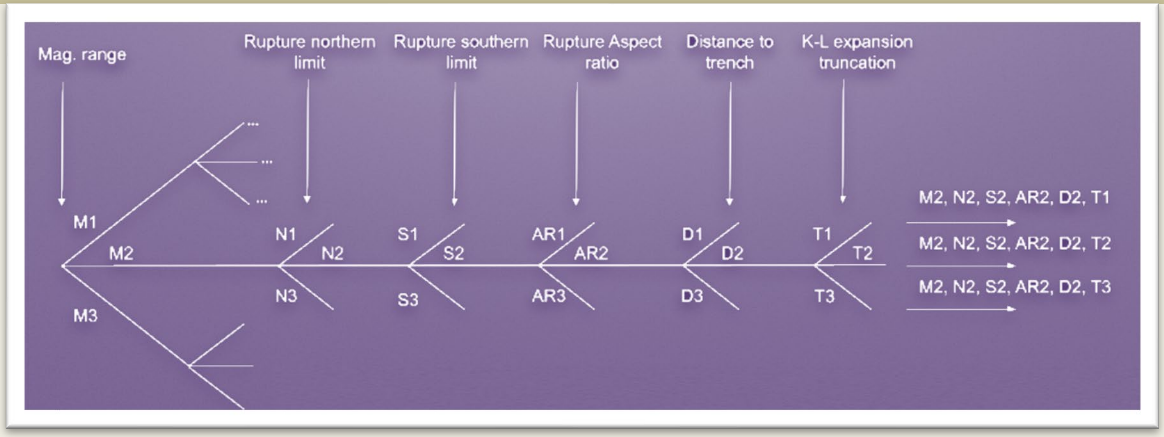
ORIGINAL PAPER

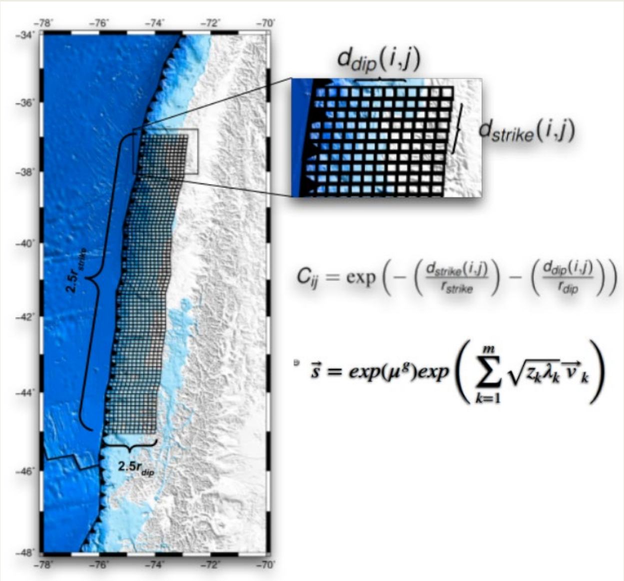
Check for updates

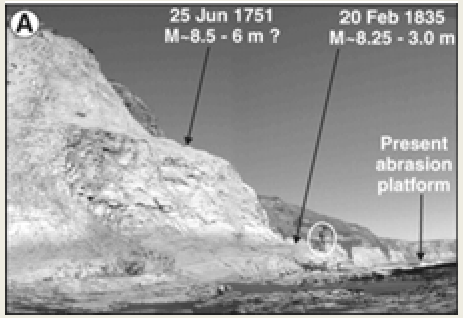
A stochastic approach to the characterization of the seismic sources: a potential method for the assessment of sources of historical and paleo tsunami

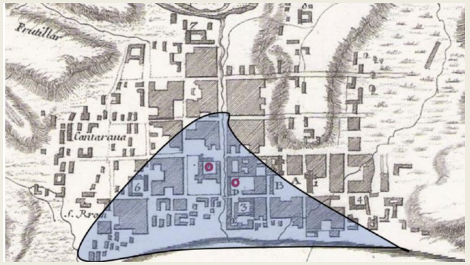
Rodrigo Cifuentes-Lobos[1] · Ignacia Calisto[1] · Breanyn MacInnes[2] · Marcos Moreno[1] · Jorge Quezada[3] · Javiera San Martín[1,4] · Matías Fernández-Palma[1] · Cristian Saavedra[2]











San Martin et al., 2023
Cifuentes et al., 2023
Melnick et al., 2006

Some Questions

- How does the slab geometry control the rupture distribution?
- What is the role of the velocity on the rupture?
- How the structural factors govern the spatial distribution of a seismic rupture?
- How, and under what earthquake characteristics, a seismic barrier is exceeded?
- How is the seismic cycle, super-cycle, superimposed cycles, etc., for each segment?
- Which areas from the same seismic segment tend to break in the majority of earthquakes, and which areas are unlikely to break?

Some Conclusions

- A deeper knowledge is needed to understand the rupture process.
- The slip distribution of different earthquakes on the same seismic segment would show some features about how the segment itself is controlled.
- It is necessary to have more data to reconstruct past tsunamigenic earthquakes.
- In a seismic gap not the entire segment would rupture.
- Homogeneous models can be used for a rapid calculation, although more accurate models are preferred.