

Giant earthquakes and strong ground motions in South America

Nelson E. Pulido H.

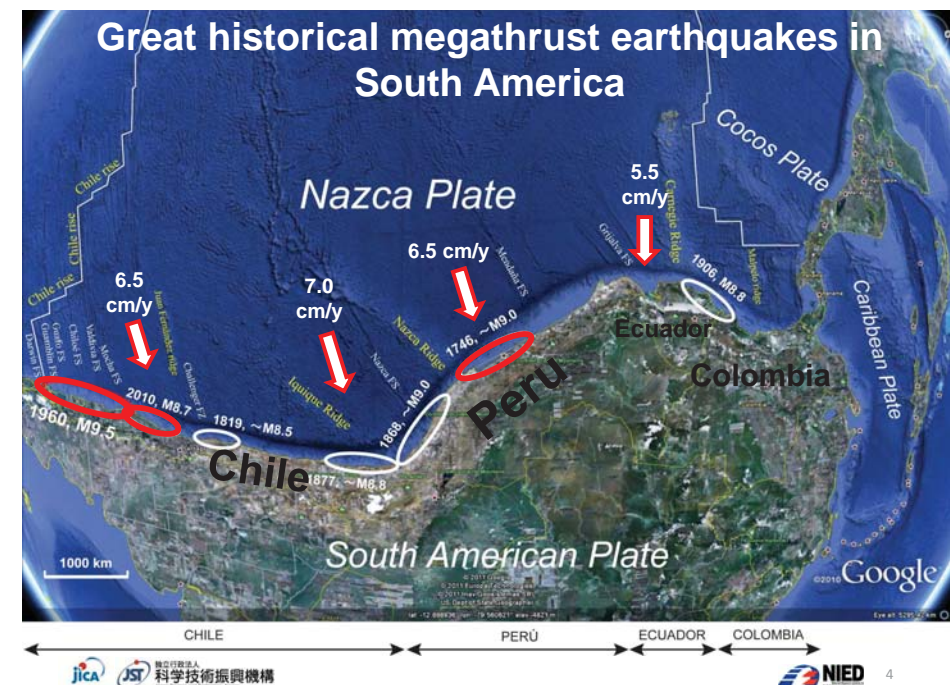
Collaborators: Yuji Yagi (U. Tsukuba), Mohamed Chlieh (U. Nice-Sophia, France), Hernando Tavera (IGP, Perú), Zenón Aguilar (UNI, Perú), Shoichi Nakai, Toru Sekiguchi, Diana Calderón, Fumio Yamazaki (U. Chiba), Hugo Perfettini (U. Joseph Fourier, France), Naoki Nishimura (U. Tsukuba), and Hiroyuki Kumagai (NIED)

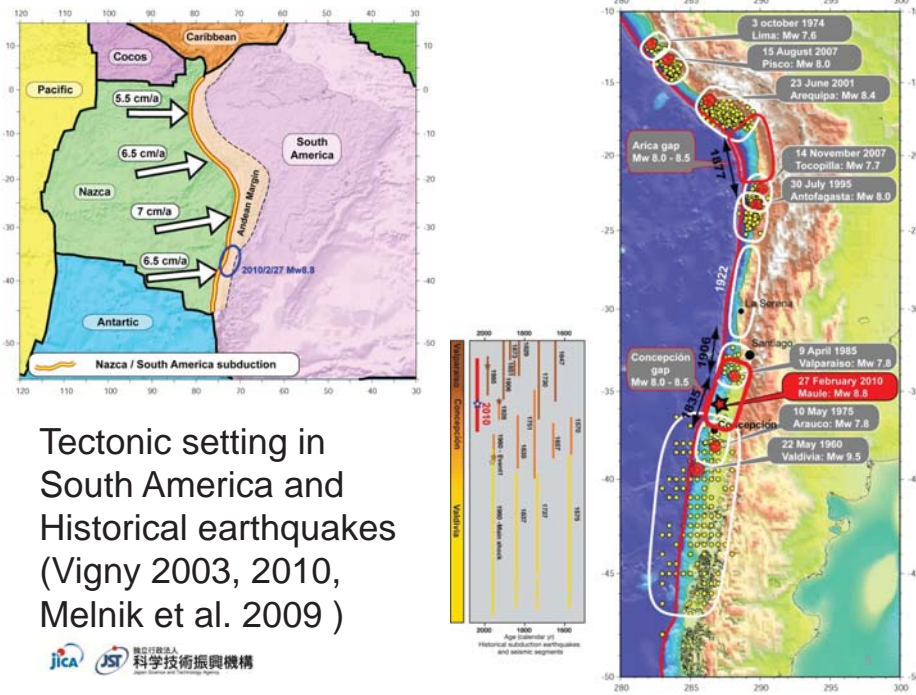
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Tectonic setting in South America and Historical earthquakes (Vigny 2003, 2010, Melnik et al. 2009)

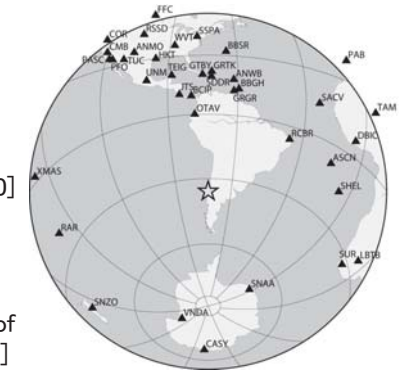
Rupture process of the 2010/2/27 Maule earthquake, Chile [Mw=8.7]

Data

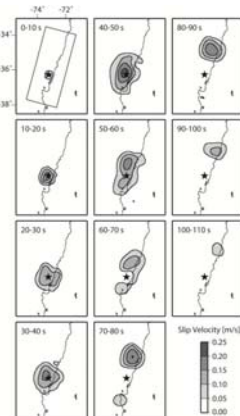
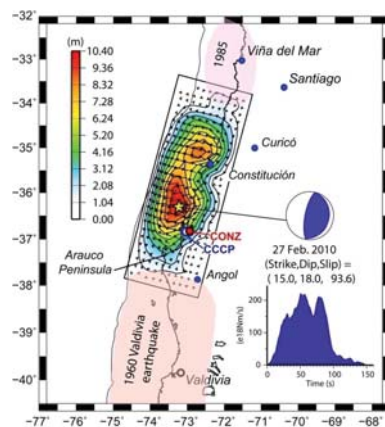
- P waveforms (38 stations)
- Anti-alias, Butterworth lowpass filter
- Subfault size: 18x18km²
- Velocity model Bohm et al. [2002]
- Geodetic data (28 sites) Farias et al. [2010]
- Strong motion record at Concepción

Method

- ABIC inversion including estimation errors of Green's functions, Yagi and Fukuhata [2011]
- Elastic dislocation model Okada [1992]

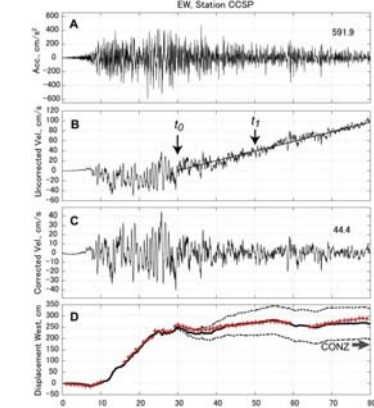
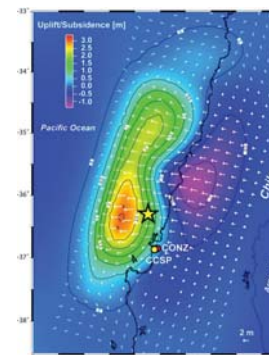


Rupture process of the 2010/2/27 Maule earthquake, Chile [Mw=8.7]



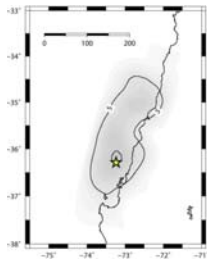
Rupture velocity 2.8km/s

Estimation of the permanent displacement at Concepción from a strong motion record and comparison with a 1Hz-GPS record



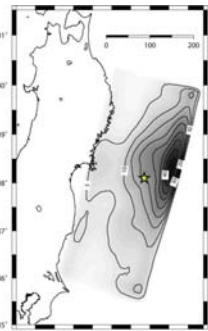
+ 1Hz-cGPS [CONZ] — Strong motion Concepción [CCSP]

2010 Maule (Chile) [Mw 8.7]



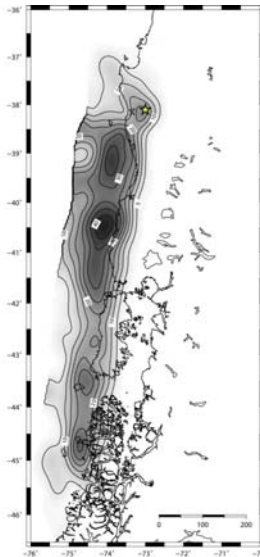
Pulido et al. EPS, 2011

2011 Tohoku-oki [Mw 9.0]



Suzuki et al. 2011

1960 Valdivia (Chile) [Mw 9.5]

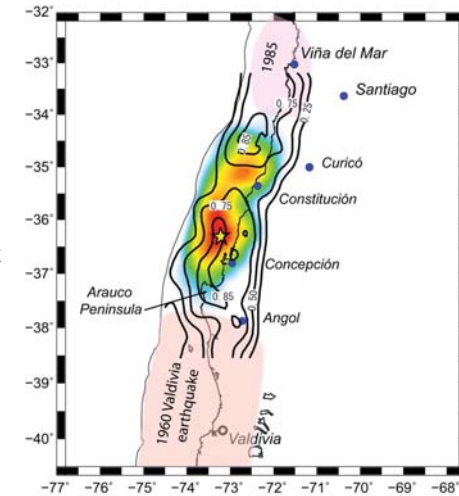


Moreno et al. 2009

Comparison of slip models of megathrust earthquakes

Maule Earthquake coseismic slip and plate coupling

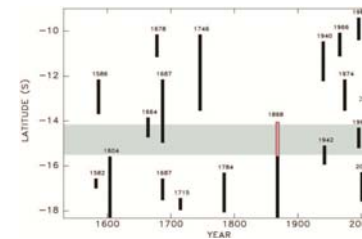
Contour lines correspond to plate coupling, Moreno et al. [2010]



Contents

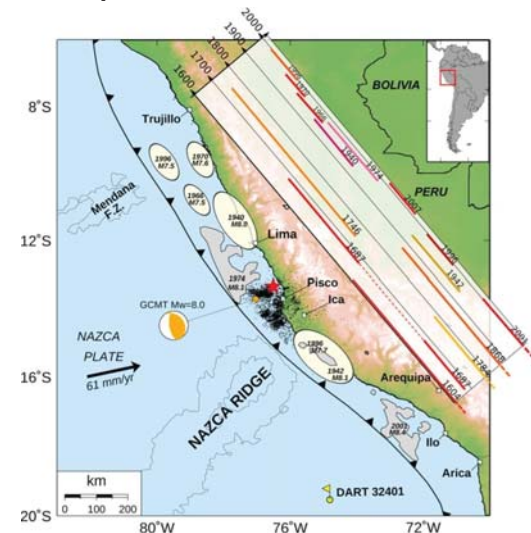
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Historical earthquakes in Peru



Adapted from Okal et al (2006)

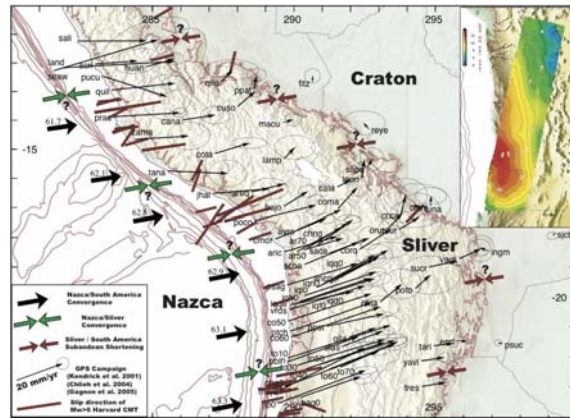
- 1940 05 24 Huacho, M8.2
- 1942 08 24 San Juan, M8.0
- 1966 10 17 Barranca, M8.1
- 1974 10 03 Lima, M8.1
- 1996 02 21 Chimbote, M7.5
- 2001 06 23 Atico, M8.4
- 2007 08 15 Pisco, M8.0



Sladen et al. (2010)

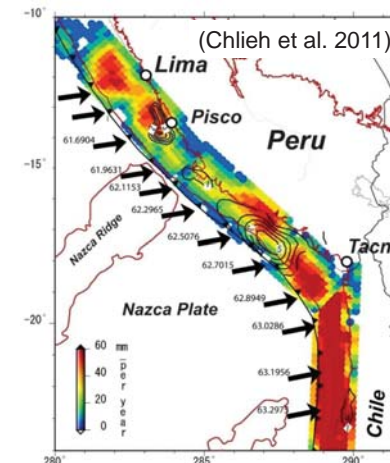
GPS campaigns in Peru-Northern Chile

- 87 surveyed sites (1993-2003) from Lat. 11°S to Lat. 24°S.
- Including measurements from ocean bottom GPS off-shore Lima



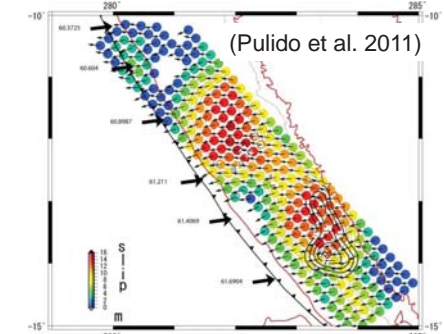
Kendrick et al. (2001), Chlieh et al. (2004), Gagnon et al. (2005)

Slip deficit rate for Peru and Northern Chile and scenario earthquake for Central Peru



$$C(x) \cdot v_o$$

- Slip deficit since 1746 (265 years)
- Maximum slip is 15 m
- Magnitude Mw~8.9, neglecting the 20 century earthquake sequence

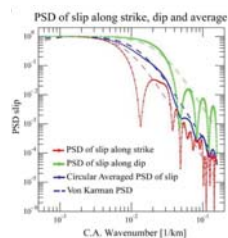


$$S(x) = C(x) \cdot v_o \cdot t$$

S(x): slip, t : elapsed time

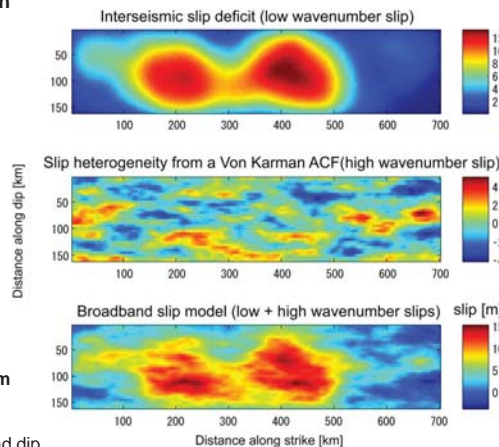
Construction of broadband wavenumber slip (Pulido et al. 2011)

PSD of geodetic scenario slip, and Von Karman PSD function

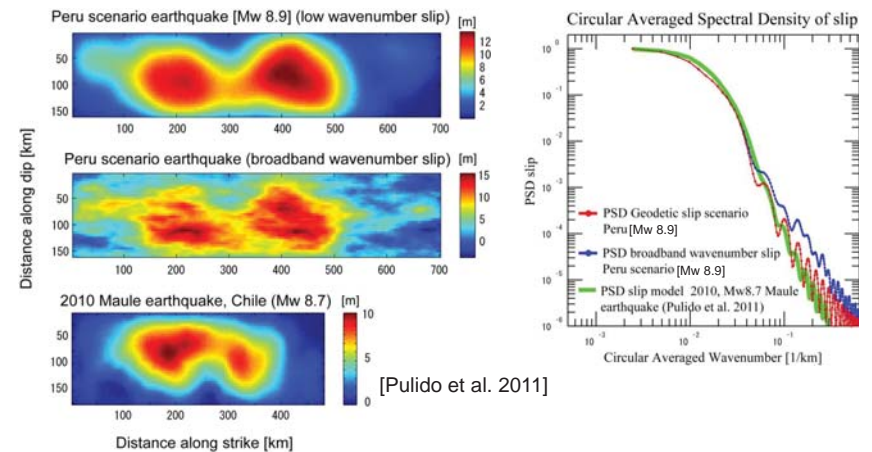


$$P(k_s, k_d) = \frac{k_s k_d}{[1 + a_s^2 k_s^2 + a_d^2 k_d^2]^{H+1}}$$

- Correlation length along strike: $a_s = 110$ km
- Correlation length along dip: $a_d = 40$ km
- Hurst exponent: $H=1.0$
- k_s and k_d are wavenumbers along strike and dip



Comparison of PSD of scenario slip and PSD of Maule earthquake slip (Pulido et al. 2011)

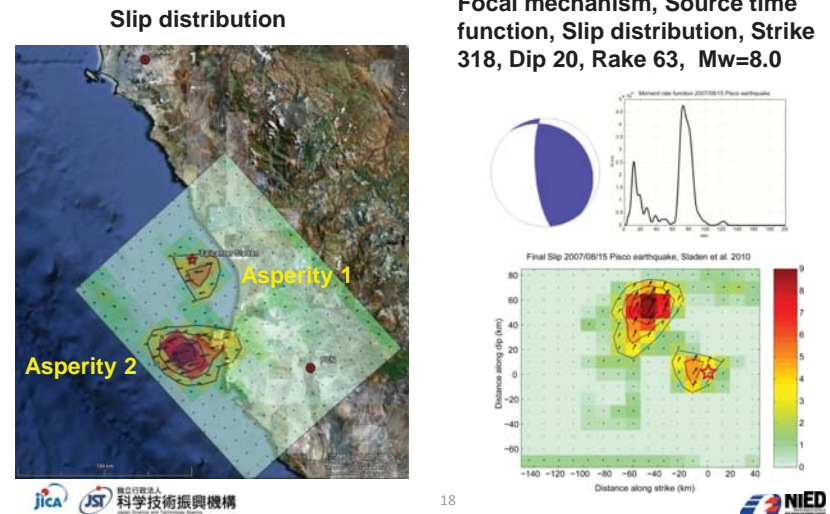


[Pulido et al. 2011]

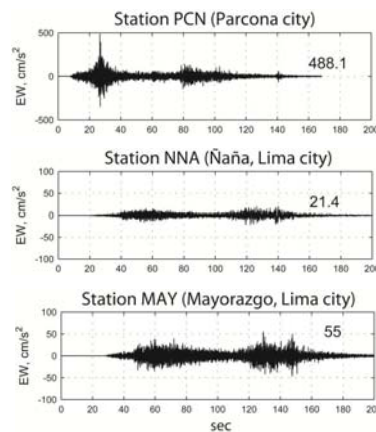
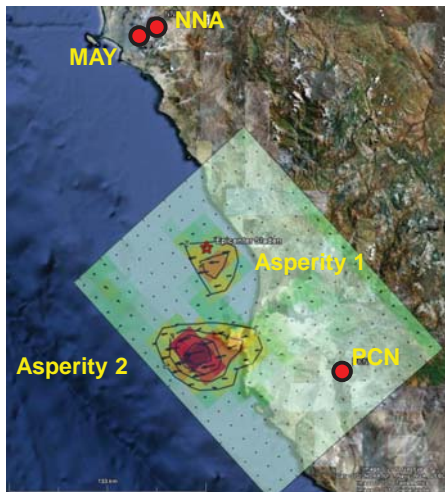
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Source model of the 2007/8/15 Pisco, Peru earthquake [Mw=8.0] (Sladen et al 2010)

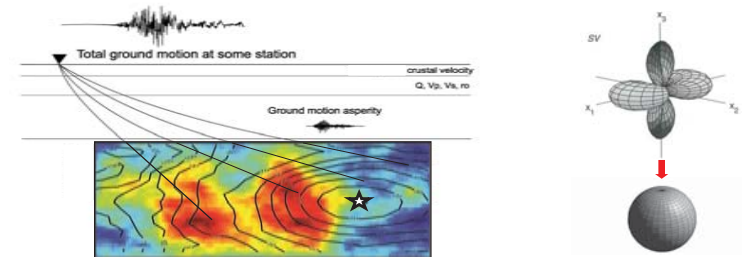


Strong motion records Pisco earthquake (IGP)



Strong motion recordings during the 2007 Pisco earthquake (IGP)

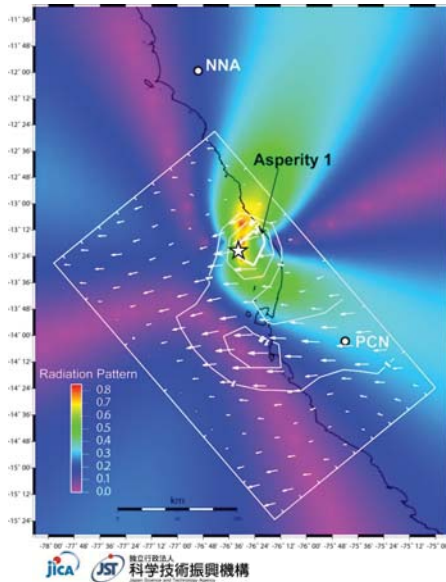
Strong motion simulation method [Pulido et al. 2004, 2007, 2012]



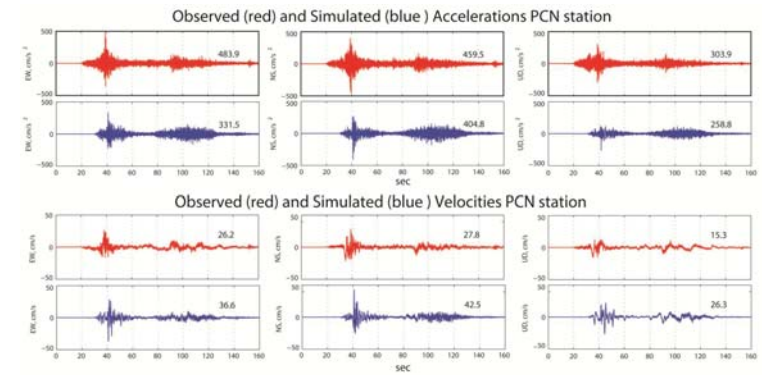
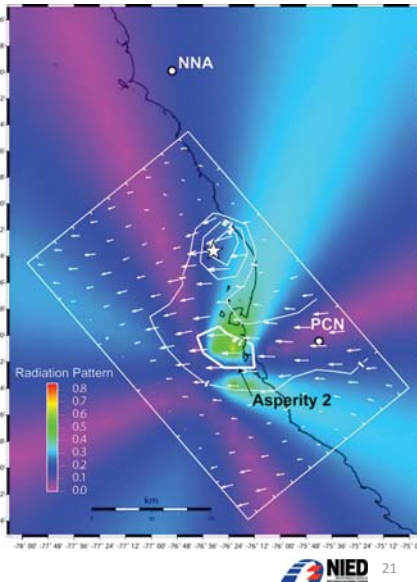
$$A_{ij}(f) = \frac{R_{p_{ij}}(\theta, \phi, f) M_0 S(f, \Delta\sigma_i) G(f) e^{-\pi f R_{ij} / Q(f)\beta} P(f, f_{\max})}{4\pi\rho\beta^3 R_{ij}}$$

Acceleration Fourier Spectra at the i subfault and j station

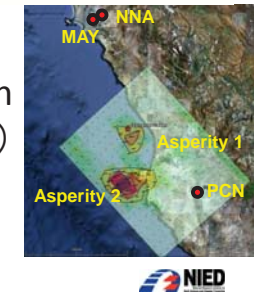
Radiation pattern from asperity 1 (SH waves)



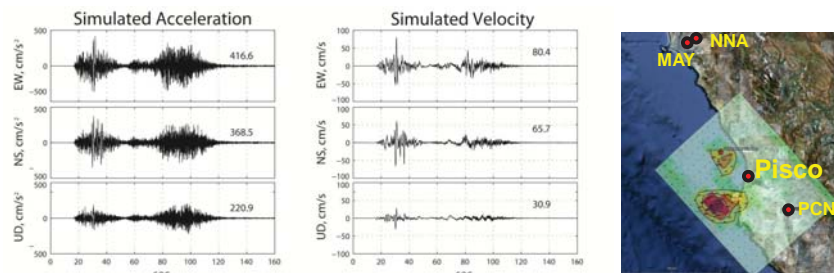
Radiation pattern from asperity 2 (SH waves)



Observed and simulated strong motion simulation at PCN (Pulido et al. 2011) (data from IGP)



Strong motion simulation at Pisco city from the Pisco earthquake ($V_s = 150\text{m/s}$)



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Field survey of the 2010 Maule earthquake

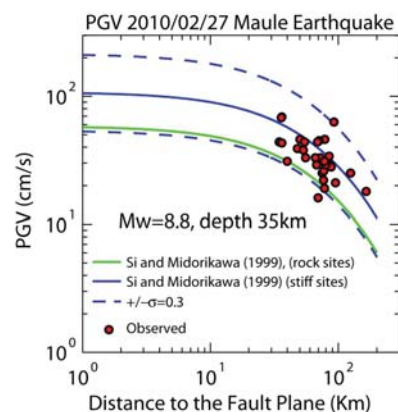
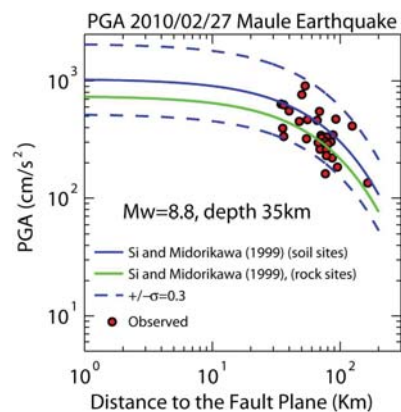
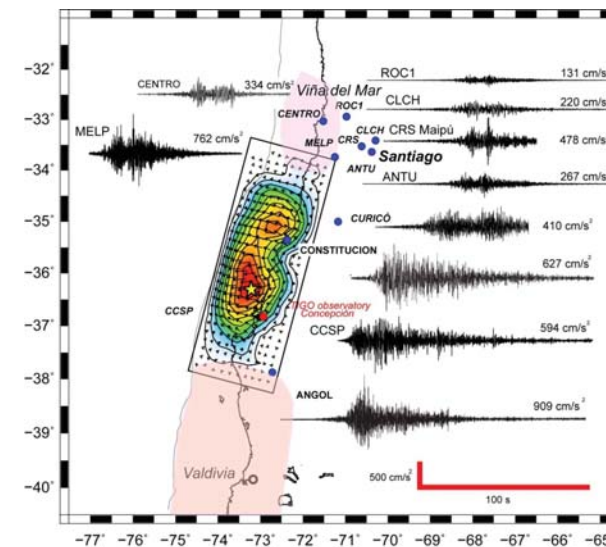


Strong Motion, Geotechnical explorations
 Nelson Pulido (NIED)
 Toru Sekiguchi (Chiba University)
 Gaku Shoji (Tsukuba University)
 Jorge Alva (UNI)
 Fernando Lázares (CISMID)



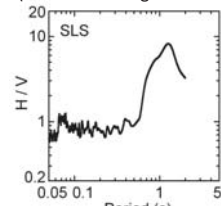
Shoji Pulido Alva Lázares Sekiguchi

Observed strong motion during the 2010 Maule earthquake

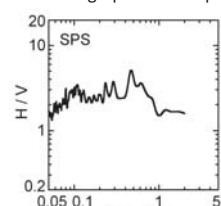


Microtremors Measurements at Concepción city

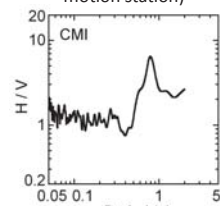
Edificio Salas 1343 (Near the damaged building)



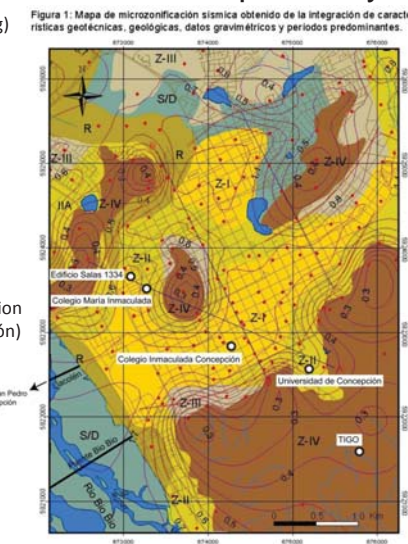
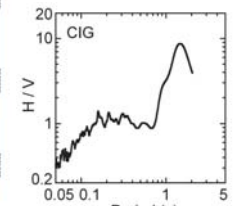
Colegio San Pedro (Near the CCCP strong motion accelerograph at Concepción)



Colegio María Inmaculada (Near a temporal strong motion station)



Colegio Inmaculada Concepción (Near an analog strong motion station)

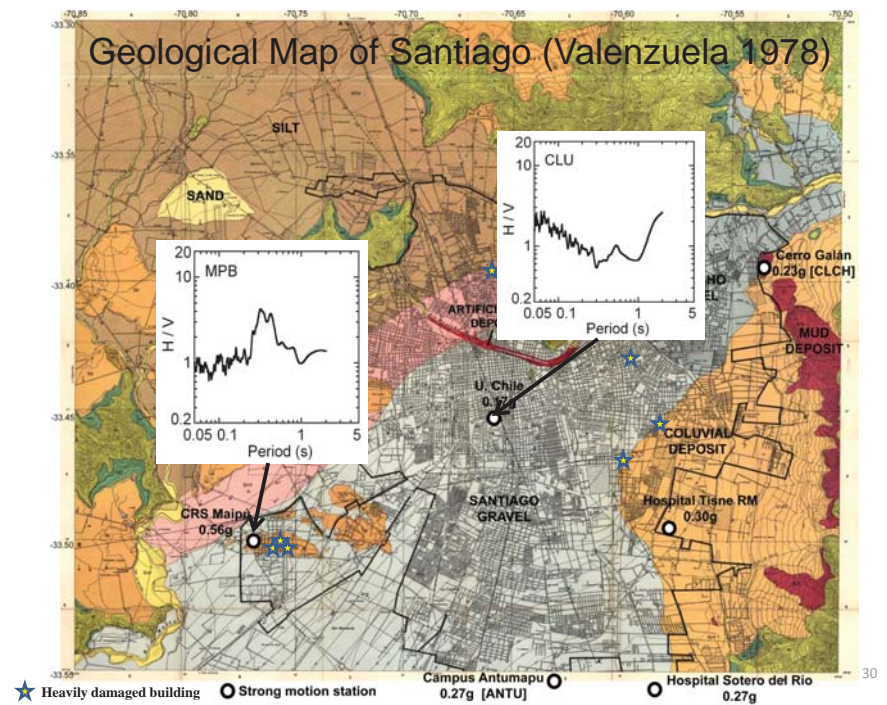


Microzonation map (Ramírez and Villalobos 2009)



Salas 1343 building
Heavily damaged building at Concepción city during the 2010 Maule earthquake

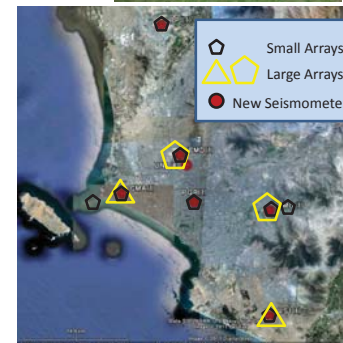
The soil surrounding the damaged building exhibit a large deformation suggesting a building rocking around its long axis.



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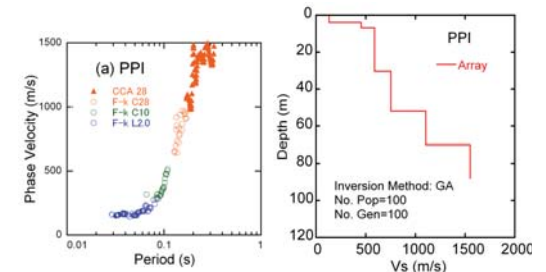
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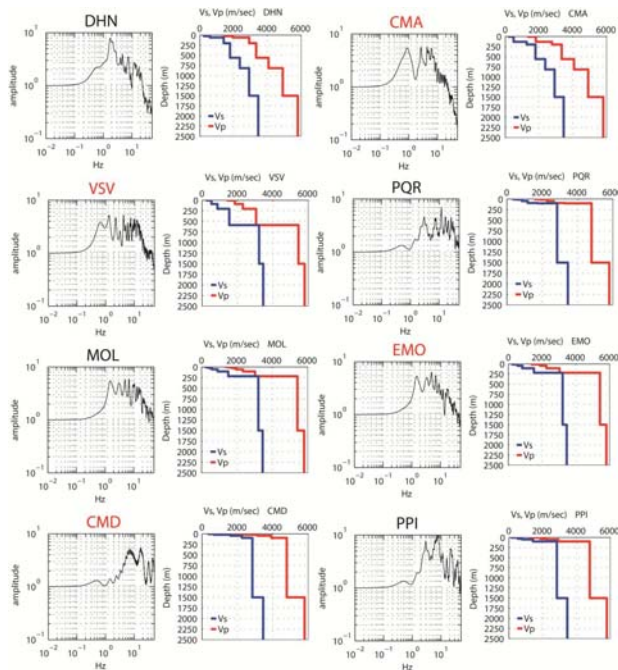
Array microtremors measurements in Lima, and installation of a strong motion network [SATREPS project]



Observation sites in Lima

Dispersion curve and estimated Vs profile

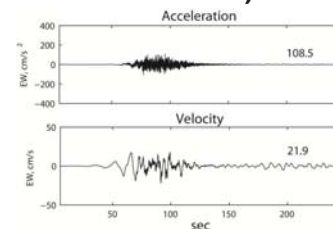




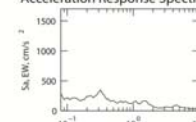
Velocity models obtained from microtremors arrays in Lima and their 1D transfer functions (Calderón et al. 2012)



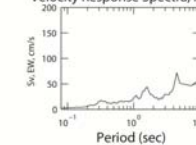
Simulated strong ground motion at Callao (seismic bedrock)



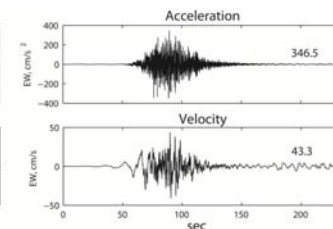
Acceleration Response Spectra, h=0.05



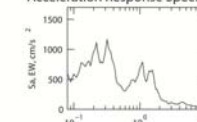
Velocity Response Spectra, h=0.05



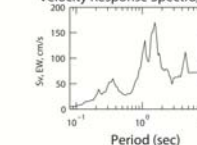
Simulated strong ground motion at Callao including site effect



Acceleration Response Spectra, h=0.05



Velocity Response Spectra, h=0.05



Conclusive remarks

- Our source model of the 2010/2/27 Maule earthquake, Chile (Mw 8.7), suggests a significant correlation between coseismic slip and plate coupling distribution.
- Our results based on geodetic and historical earthquakes data, indicate that an earthquake of magnitude Mw 8.9 is likely to occur in the Central Andes region (Peru).
- Observed and simulated strong ground motions of the 2007 Pisco earthquake, Peru, indicate a significant contribution from a complex source rupture process.
- We obtained preliminary results of the strong motion simulation in Lima for a scenario earthquake.