

International Symposium on Earthquake & Tsunami Disaster Reduction – Learning from the Great East Japan Earthquake –  
March 14–15, 2012, Sendai, Japan

## Giant earthquakes and strong ground motions in South America

Nelson E. Pulido H.

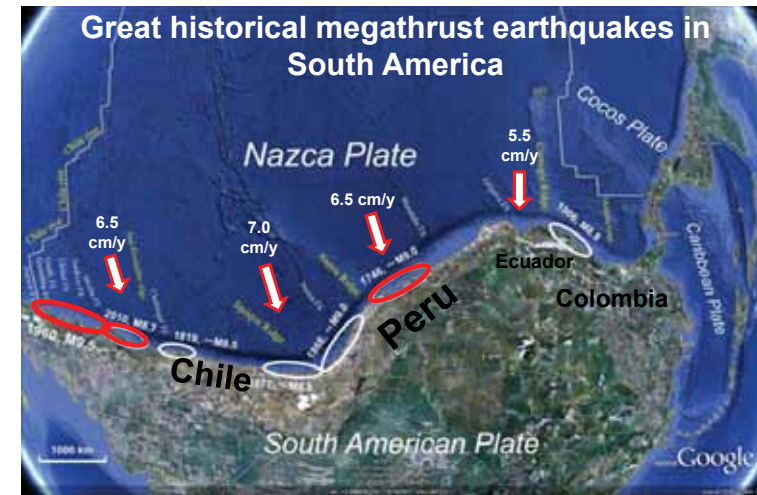
Collaborators: Yuji Yagi (U. Tsukuba), Mohamed Chlieh (U. Nice-Sophia, France), Hernando Tavera (IGP, Perú), Zenón Aguilar (UNI, Perú), Shoichi Nakai, Toru Sekiguchi, Diana Calderón, Fumio Yamazaki (U. Chiba), Hugo Perfettini (U. Joseph Fourier, France), Naoki Nishimura (U. Tsukuba), and Hiroyuki Kumagai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

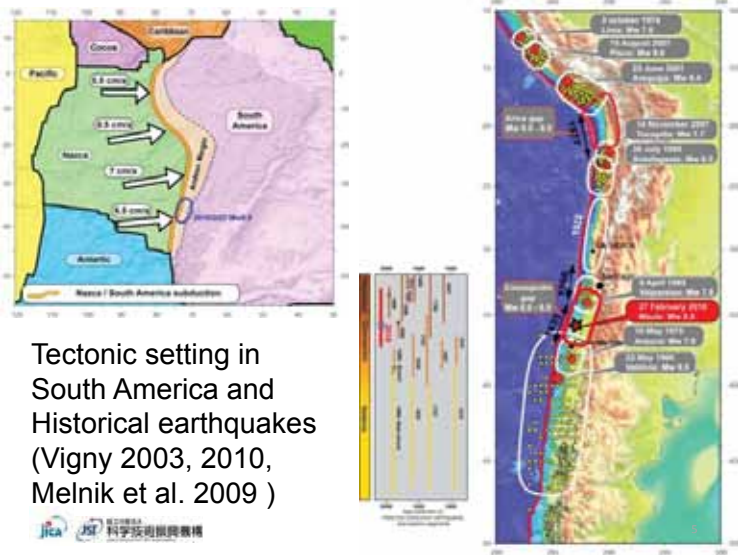
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- Historical Mega-earthquakes of South America and the source model of the 2010/2/27 Maule earthquake, Chile (Mw 8.7).
- Earthquake scenarios for Central Andes (Peru).
- Strong ground motion simulation of the 2007/8/15 Pisco earthquake, Peru.
- Site effects characteristics and strong ground motions during the 2010 Maule earthquake.
- Preliminary results strong motion simulation for the Central Andes, Lima scenario earthquake.

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

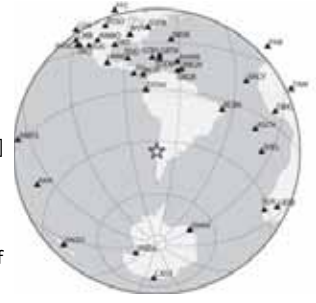
## Rupture process of the 2010/2/27 Maule earthquake, Chile [Mw=8.7]

### Data

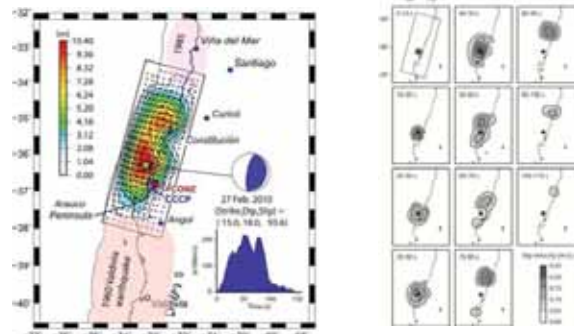
- P waveforms (38 stations)
- Anti-alias, Butterworth lowpass filter
- Subfault size: 18x18km<sup>2</sup>
- Velocity model Bohm et al. [2002]
- Geodetic data (28 sites) Farias et al. [2010]
- Strong motion record at Concepción

### Method

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

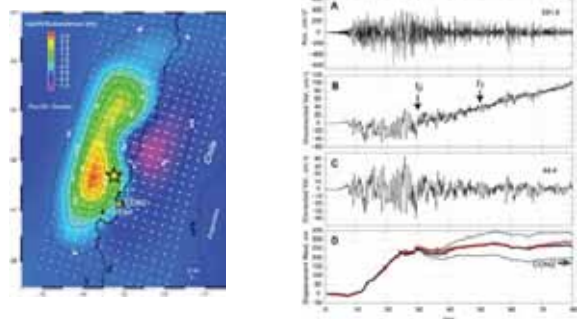


## Rupture process of the 2010/2/27 Maule earthquake, Chile [Mw=8.7]



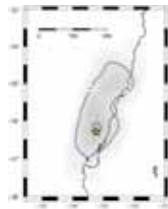
Rupture velocity 2.8km/s

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



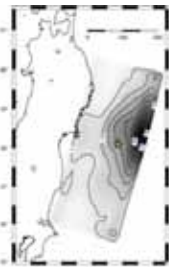
+ 1Hz-cGPS [CONZ] - Strong motion Concepción [CCSP]

2010 Maule (Chile) [Mw 8.7]



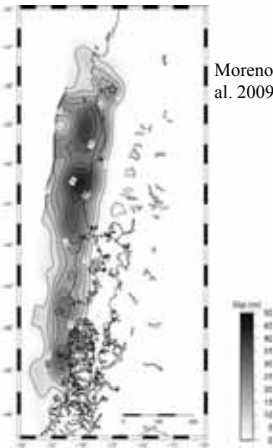
Pulido et al. EPS, 2011

2011 Tohoku-oki [Mw 9.0]



Suzuki et al. 2011

1960 Valdivia (Chile) [Mw 9.5]

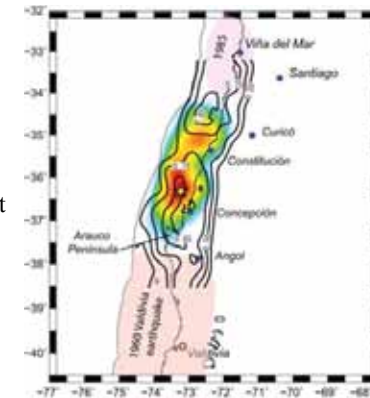


Moreno et al. 2009

Comparison of slip models of megathrust earthquakes

## Maule Earthquake coseismic slip and plate coupling

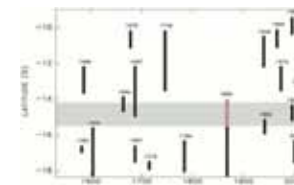
Contour lines correspond to plate coupling, Moreno et al. [2010]



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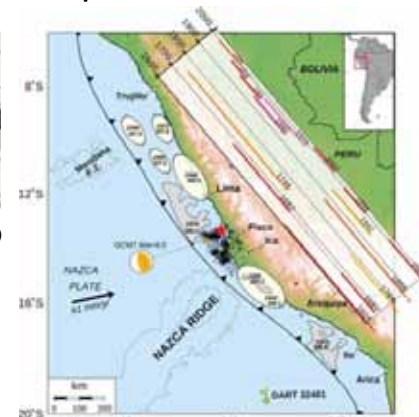
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## Historical earthquakes in Peru



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)

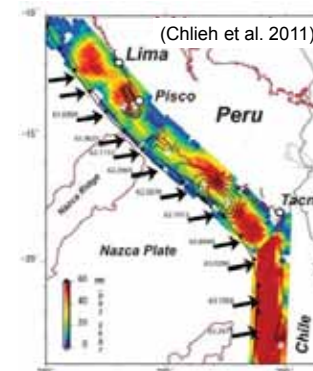
## GPS campaigns in Peru-Northern Chile

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



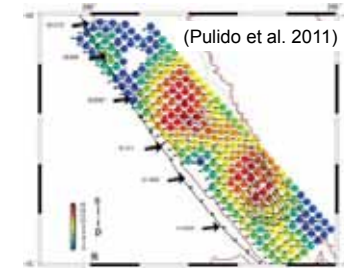
Kendrick et al. (2001), Chlieh et al. (2004), Gagnon et al. (2005)

## 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  $M_w \sim 8.9$ , neglecting the 20 century earthquake sequence

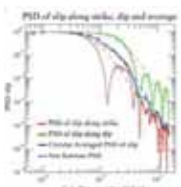


$S(x) = C(x) \cdot v_o \cdot t$

$S(x)$ : slip,  $t$ : elapsed time

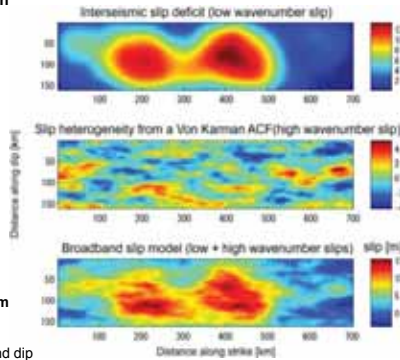
## Construction of broadband wavenumber slip (Pulido et al. 2011)

PSD of geodetic scenario slip, and Von Karman PSD function

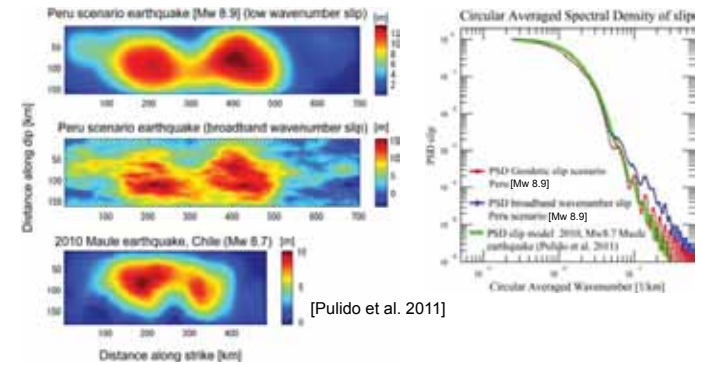


$$P(k_s, k_d) = \frac{k_s k_d}{[1 + a_s^2 k_s^2 + a_d^2 k_d^2]^{H+1}}$$

- 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)



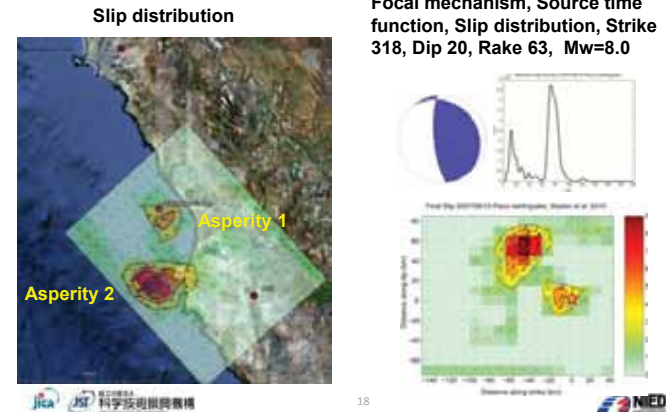
[Pulido et al. 2011]



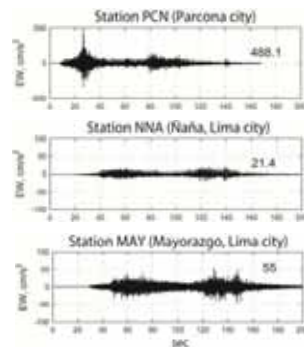
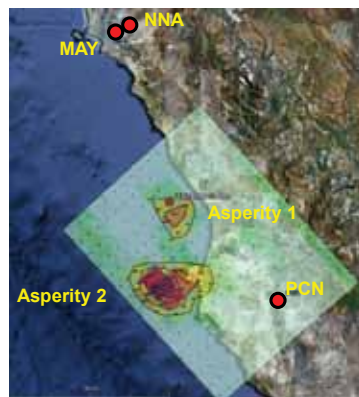
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# Source model of the 2007/8/15 Pisco, Peru earthquake [Mw=8.0] (Sladen et. al 2010)



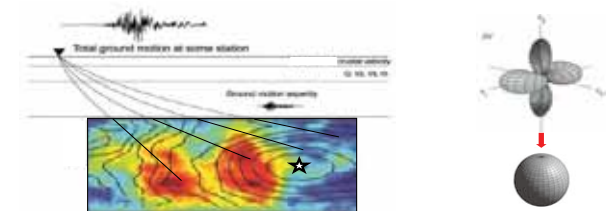
# Strong motion records Pisco earthquake (IGP)



Strong motion recordings during the 2007 Pisco earthquake (IGP)

Source Process of the 2007 Pisco earthquake (Sladen et. al. 2010).

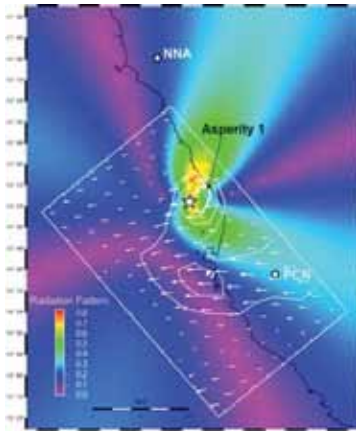
# Strong motion simulation method [Pulido et al. 2004, 2007, 2012]



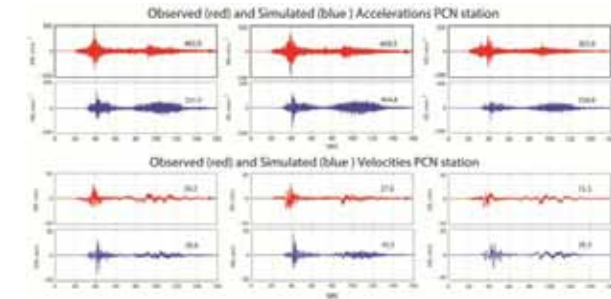
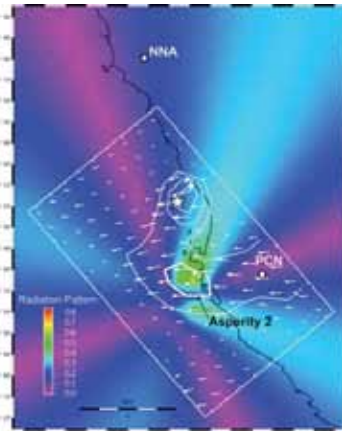
$$A_{ij}(f) = \frac{R_{pij}(\theta, \phi, f) M_0 S(f, \Delta\sigma_i) G(f) e^{-\pi R_{ij} / Q(f) \beta} P(f, f_{max})}{4\pi\phi^3 R_{ij}}$$

Acceleration Fourier Spectra at the *i* subfault and *j* station

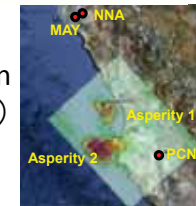
Radiation pattern from asperity 1 (SH waves)



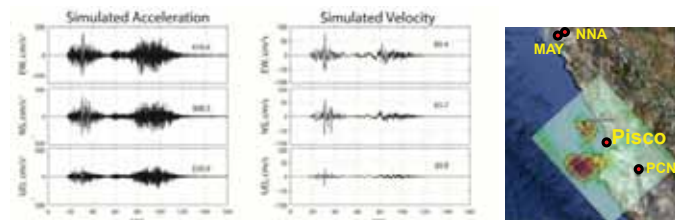
Radiation pattern from asperity 2 (SH waves)



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



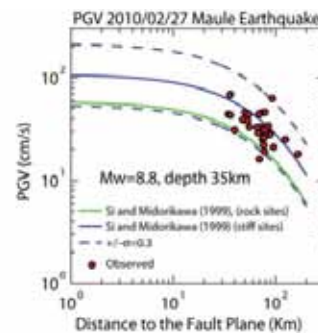
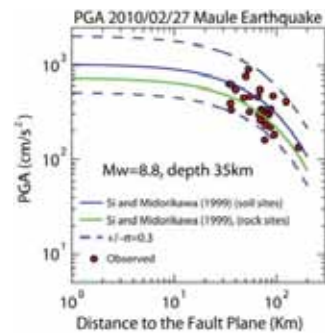
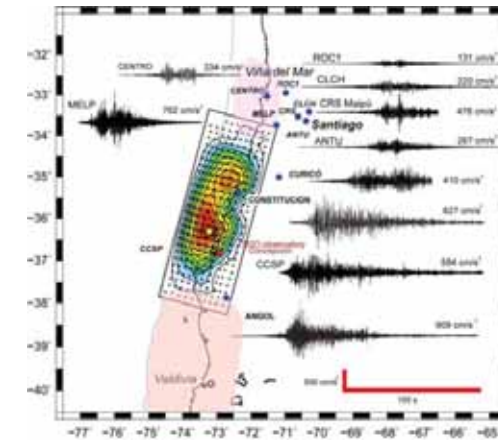
### Strong Motion, Geotechnical explorations

Nelson Pulido (NIED)  
Toru Sekiguchi (Chiba University)  
Gaku Shoji (Tsukuba University)  
Jorge Alva (UNI)  
Fernando Lázares (CISMID)



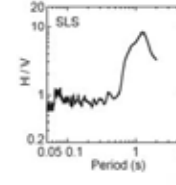
Shoji Pulido Alva Lázares Sekiguchi

## Observed strong motion during the 2010 Maule earthquake

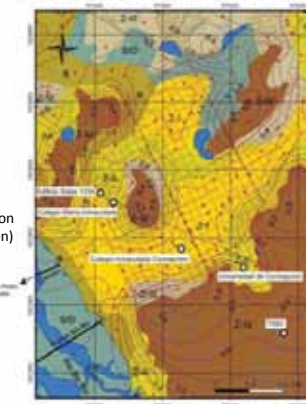
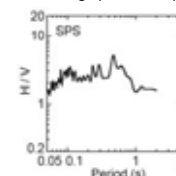


## Microtremors Measurements at Concepción city

Edificio Salas 1343  
(Near the damaged building)

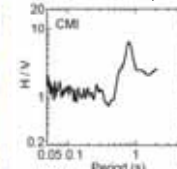


Colegio San Pedro  
(Near the CCCP strong motion accelerograph at Concepción)

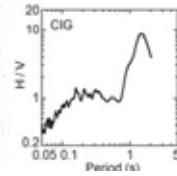


Microzonation map (Ramírez and Villalobos 2009)

Colegio María Inmaculada  
(Near a temporal strong motion station)



Colegio Inmaculada Concepción  
(Near an analogue strong motion station)

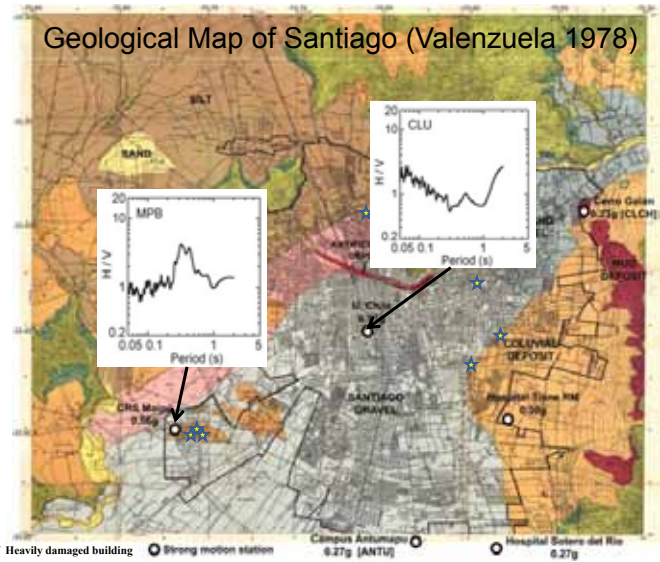






*Salas 1343 building*  
Heavily damaged building at Concepción city during the 2010 Maule earthquake

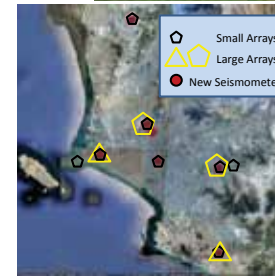
The soil surrounding the damaged building exhibit a large deformation suggesting a building rocking around its long axis.



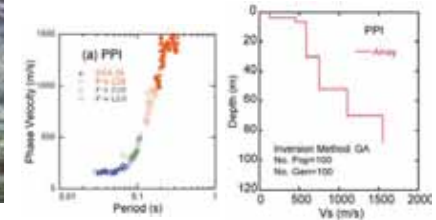
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## Array microtremors measurements in Lima, and installation of a strong motion network [SATREPS project]

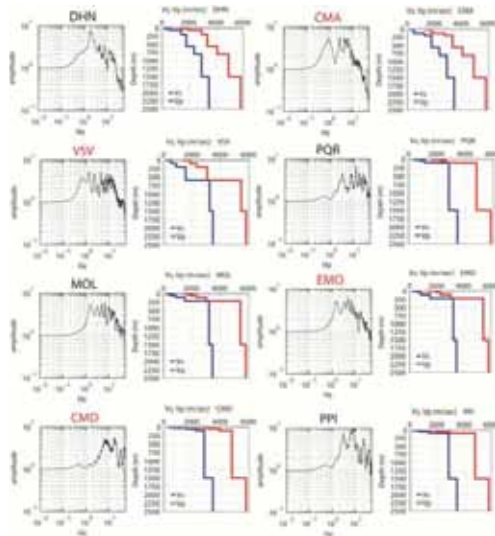


Dispersion curve and estimated  $V_s$  profile



Observation sites in Lima

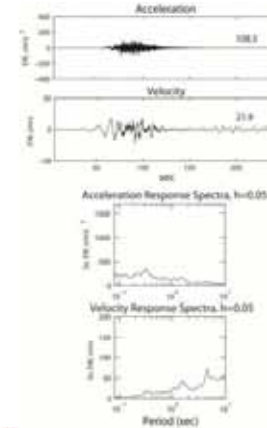




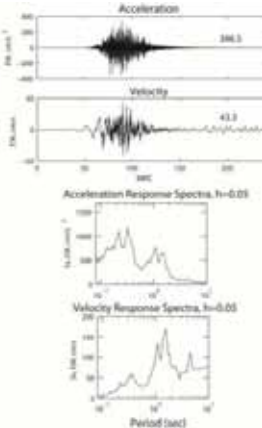
Velocity models obtained from microtremors arrays in Lima and their 1D transfer functions (Calderón et al. 2012)



Simulated strong ground motion at Callao (seismic bedrock)



Simulated strong ground motion at Callao including site effect



## 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.