The 2nd Japan-Pery Workshop on Enhancement of Earthquake and Tsunami Disaster Mitigation Technology, March 9, 2011

Scenario Earthquakes for Central and Southern Peru, and Strong Motion Simulation of the 2007 Pisco earthquake

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Contents

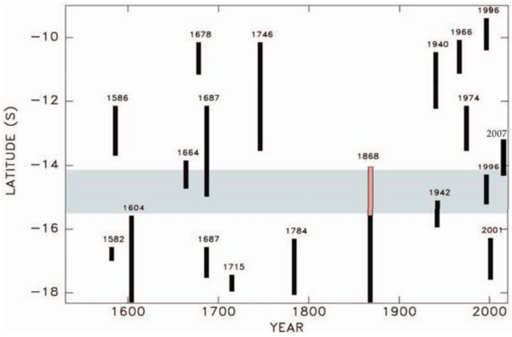
Deterministic vs Probabilistic seismic hazard assessment

•Seismic hazard estimation in earthquake prone regions has been traditionally addressed using a probabilistic approach.

•However when a detailed study of the hazard posed from specific seismic sources for a particular site is required, the deterministic approach is more adequate.

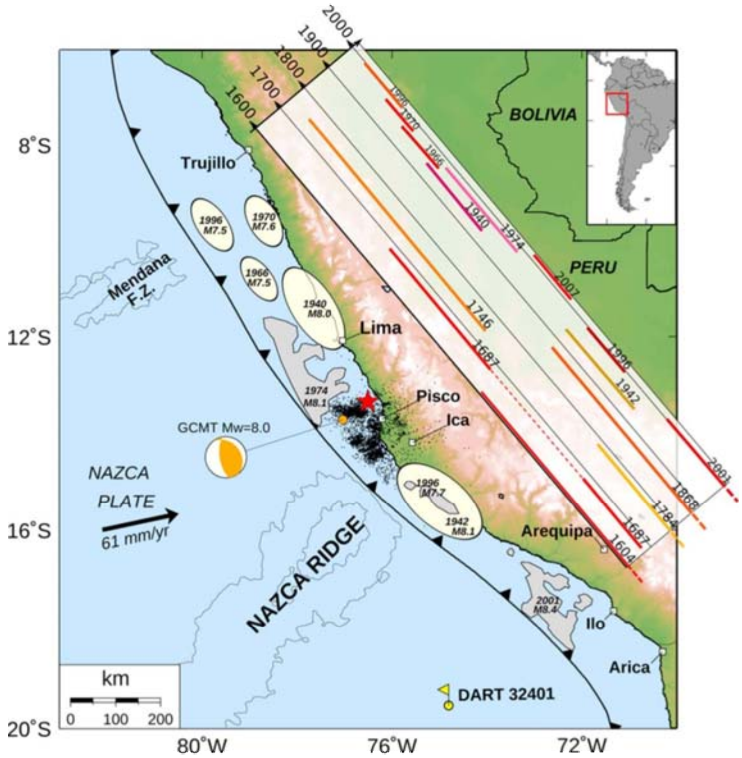
•In this study we follow the deterministic approach as we want to investigate the possible effects of the most likely damaging earthquakes that could affect central and southern Peru.

Historical earthquakes in Peru



Adapted from Okal et al (2006)

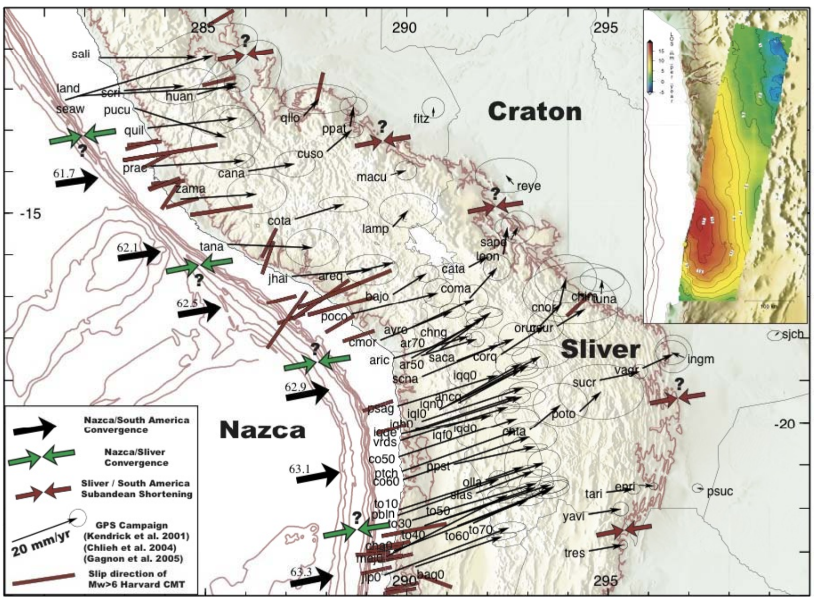
1940 05 24 Huacho, M8.2
1942 08 24 San Juan, M8.0
1966 10 17 Barranca, M8.1
1974 10 03 Lima, M8.1
1996 02 21 Chimbote, M7.5
2001 06 23 Atico, M8.4
2007 08 15 Pisco, M8.0



Sladen et al. (2010)

GPS campaigns in Peru-Northern Chile

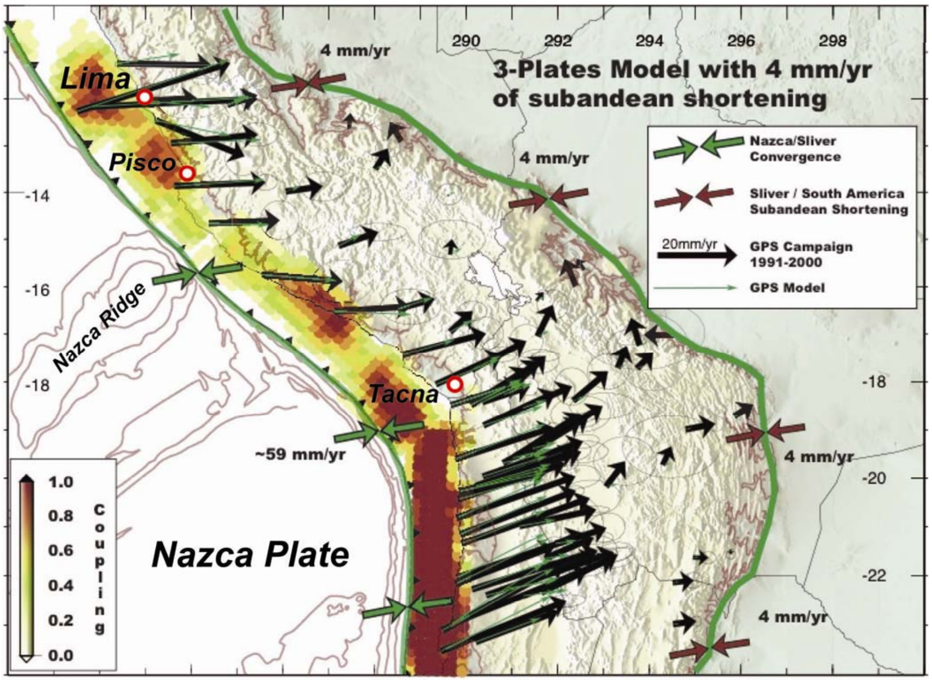
- 87 surveyed sites (1993-2003) from Lat. 11ºS to Lat. 24ºS.



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

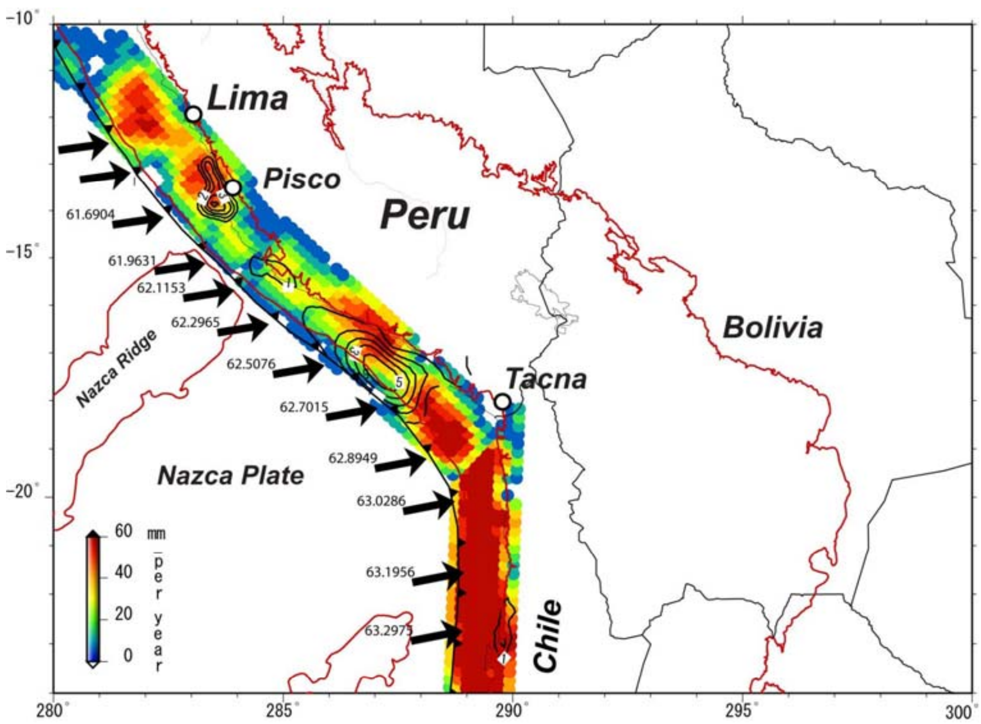
Interseismic coupling model for Peru and Northern Chile

- 3 plates model
- Includes sub-andean shortening od 4 mm/y
- Fore-arc convergence 59 mm/y
- Nazca/South America convergence 63 mm/y



Chlieh et al. 2010

Slip deficit rate for Peru and Northern Chile

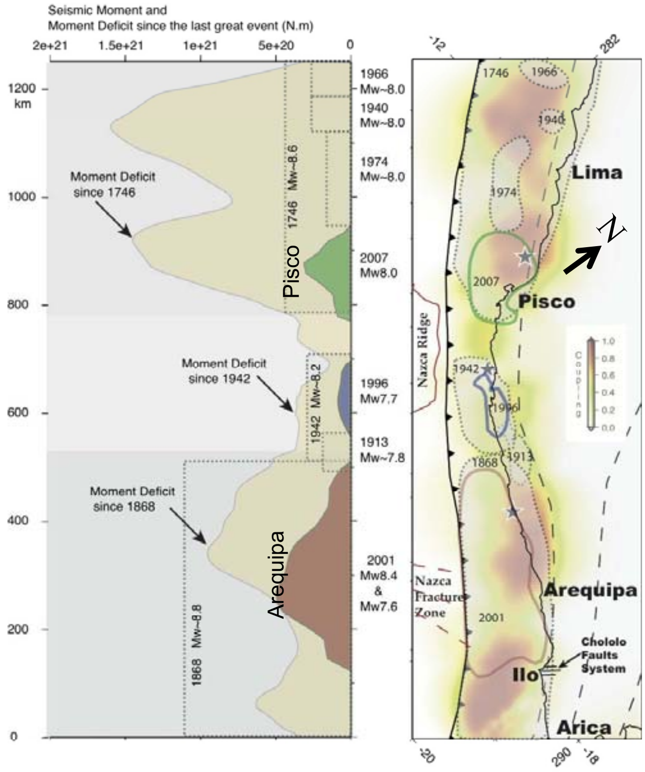


Chlieh personal communication

Moment deficit in Central and Southern Peru

- The Pisco-Lima segment could generate an earthquake of Mw 8.8
- The Nazca ridge segment could generate an earthquake of Mw 8.2
- The Arequipa segment could generate an earthquake of Mw 8.5

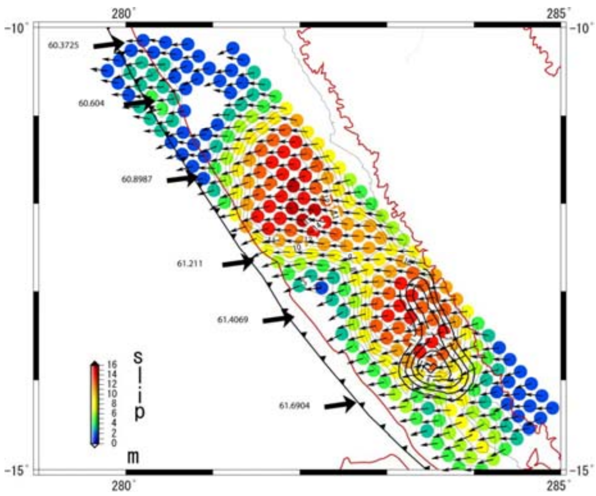
Chlieh et al. 2010

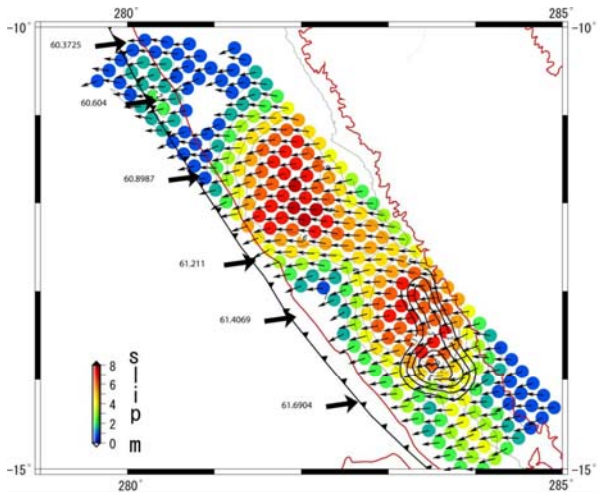


Scenario earthquakes for Central Peru

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

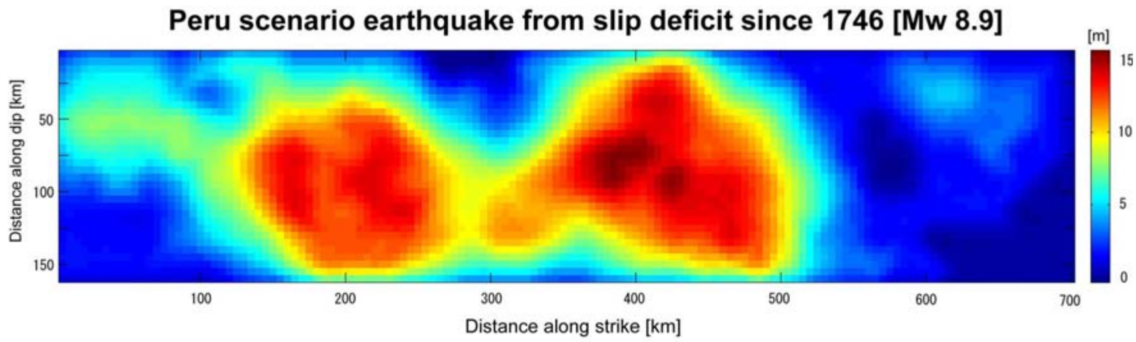
- Slip deficit since 1746 (265 years)
- Maximum slip is 8 m
- Magnitude Mw~8.7, correcting by the 20 century earthquake sequence

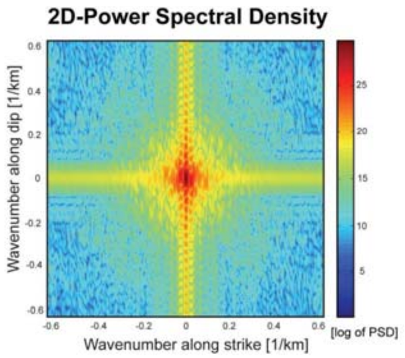


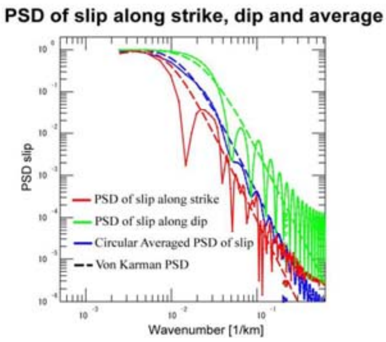


Chlieh personal communication

Power spectral density of scenario slip [Mw 8.9]





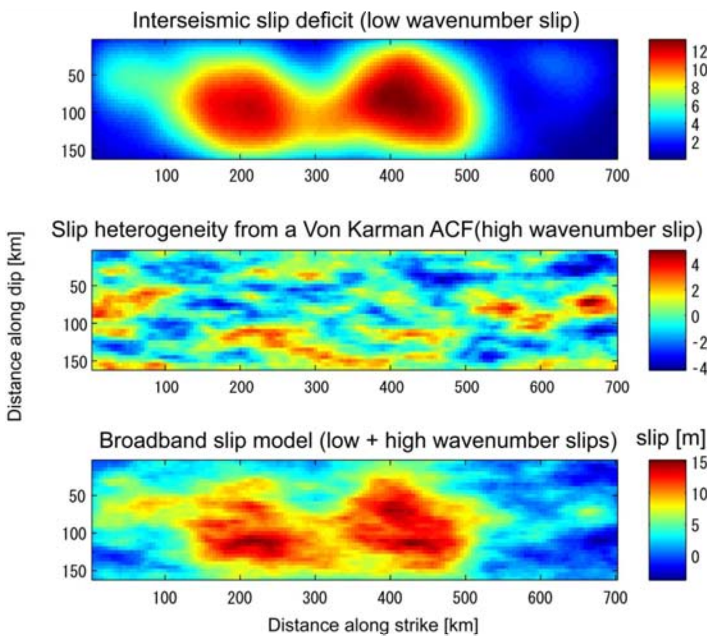


Parameters Von Karman PSD of slip

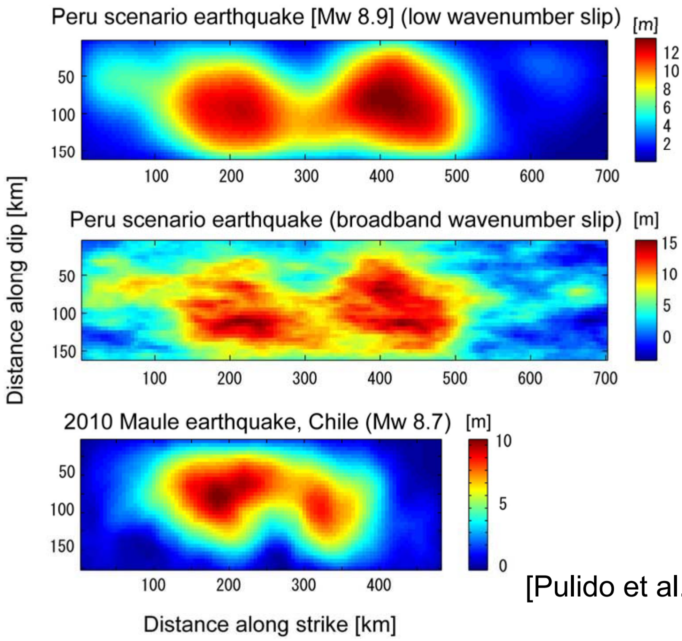
$$P(k_s, k_d) = \frac{k_s k_d}{[1 + a_s^2 k_s^2 + a_d^2 k_d^2]^{H+1}}$$

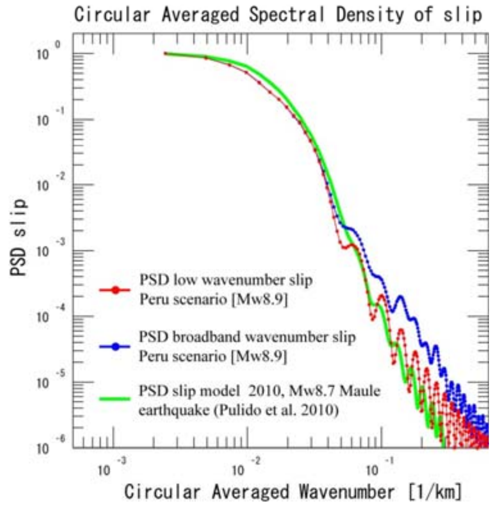
- Correlation length along strike: **a_s = 110 km**
- Correlation length along dip: **a_d = 40 km**
- Hurst exponent: **H=1.0**
- **k_s** and **k_d** are wavenumbers along strike and dip

Construction of broadband wavenumber slip



Comparison of low and broadband wavenumber slips

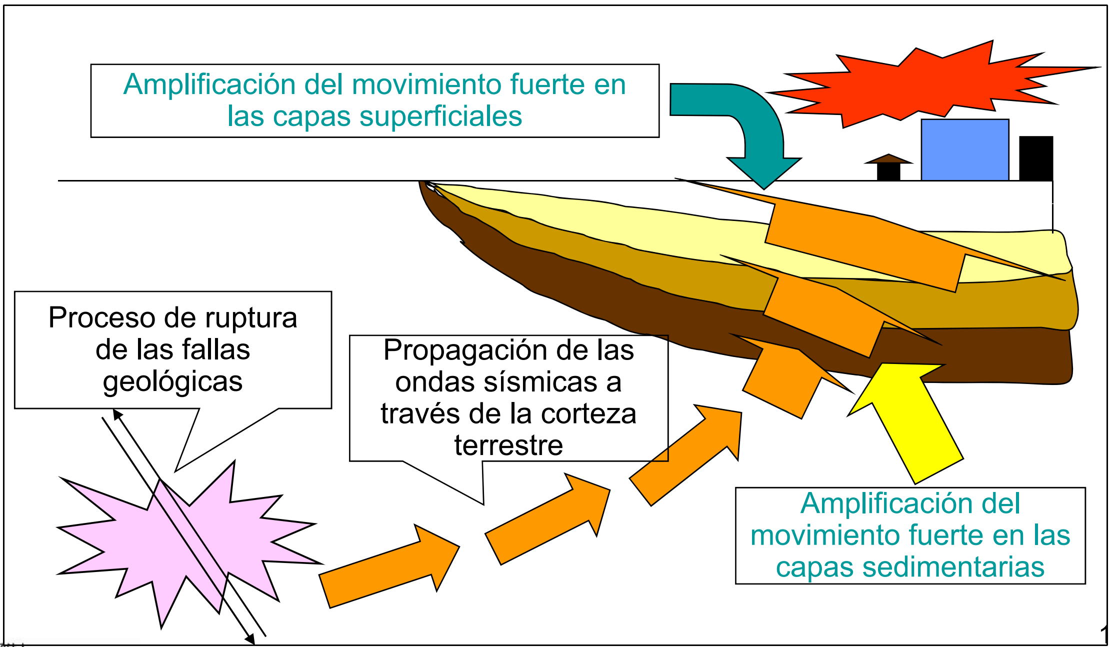




[Pulido et al. 2010]

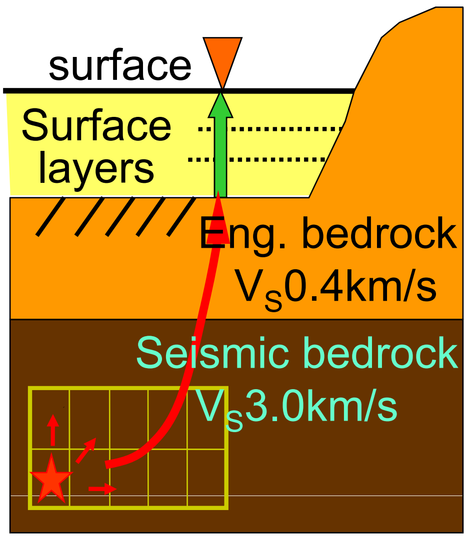
Strong Motion Simulation Methodology (estimation of the deterministic seismic hazard)

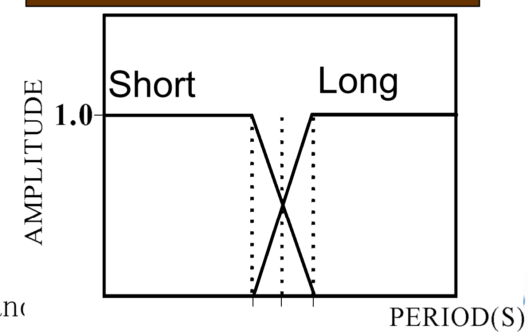
Simulation of the strong ground motion (deterministic seismic hazard estimation) [Aoi et al. 2003, Pulido et al. 2004]



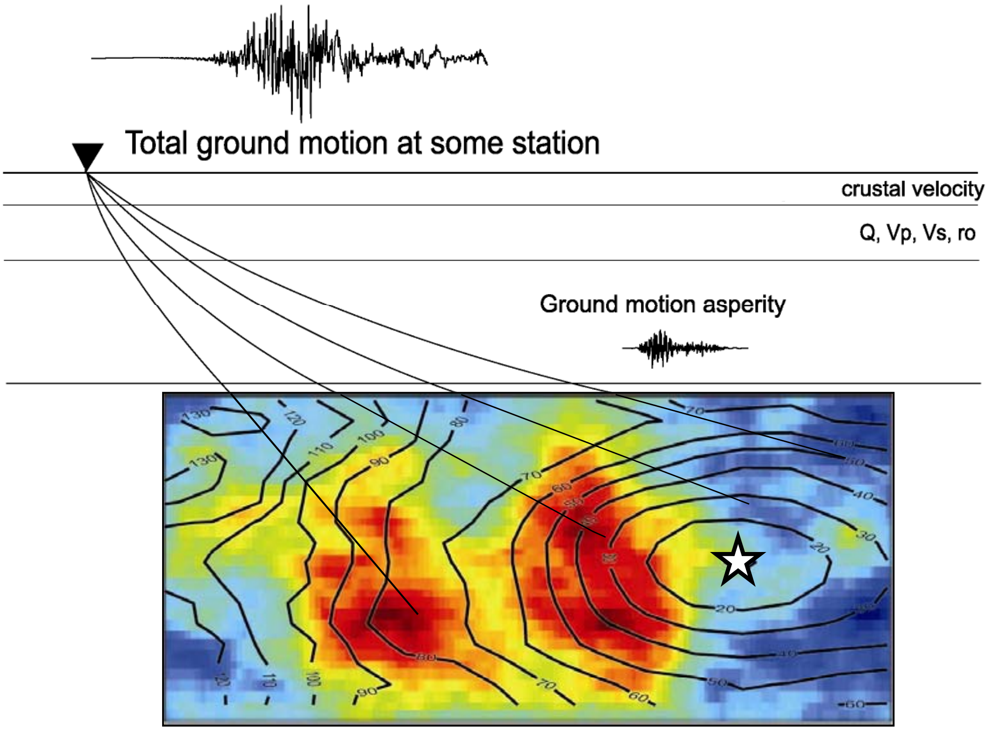
Ground Motion Simulation Methodology

- Low frequency (f<1Hz): Based on a fault rupture model, as well as wave propagation in a velocity structure model 1D, 2D or 3D (Bouchon 1981, Pitarka et al.1998, Aoi et al. 2004, Pulido and Kubo 2004).
- High Frequency (f>1Hz): Strong motion simulation based on kinematic or dynamic model of fault rupture, incorporating a stochastic component (Kamae et al. 1998, Pulido and Kubo 2004, Pulido and Dalguer 2009).

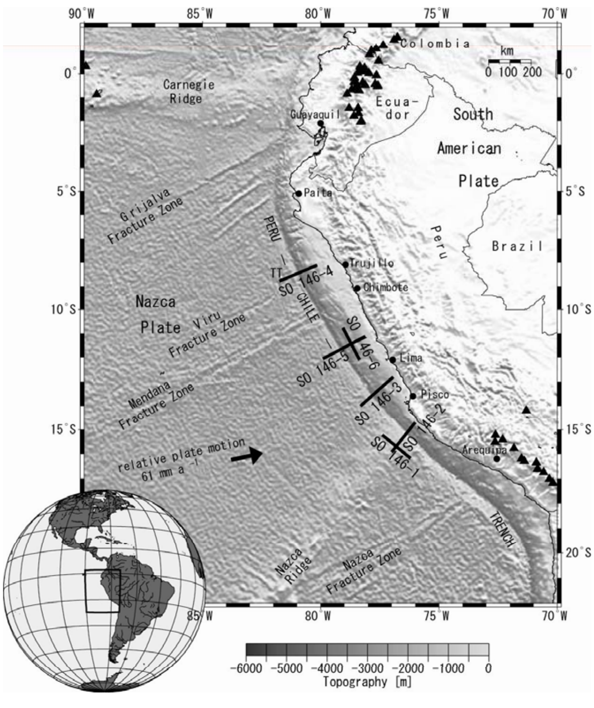


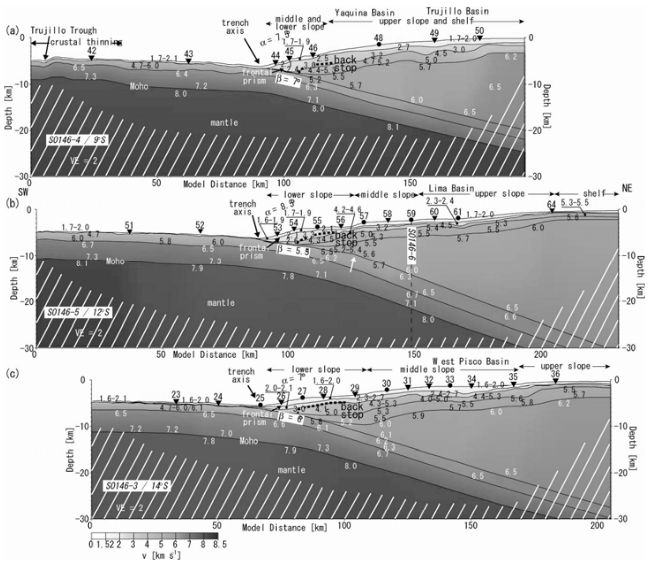


Source model scenario earthquake



Velocity model and Geometry of the Nazca Plate

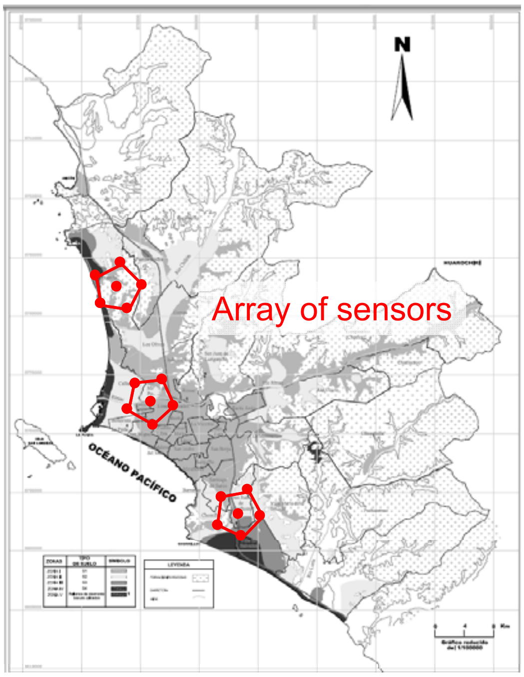


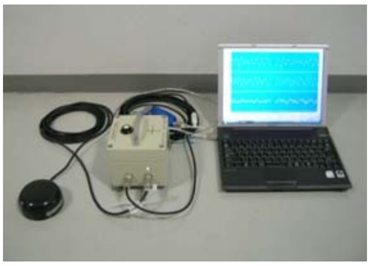


Krabbenhoft et al. (2004)

Array Measurement of Microtremors and temporal seismic observation

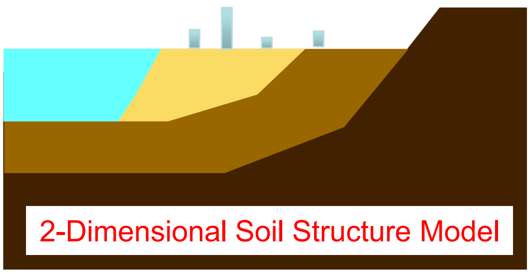
- Array measurements of microtremors and temporal seismic observations are conducted in several locations in order to estimate 1D, 2D or 3D soil profiles in Lima.

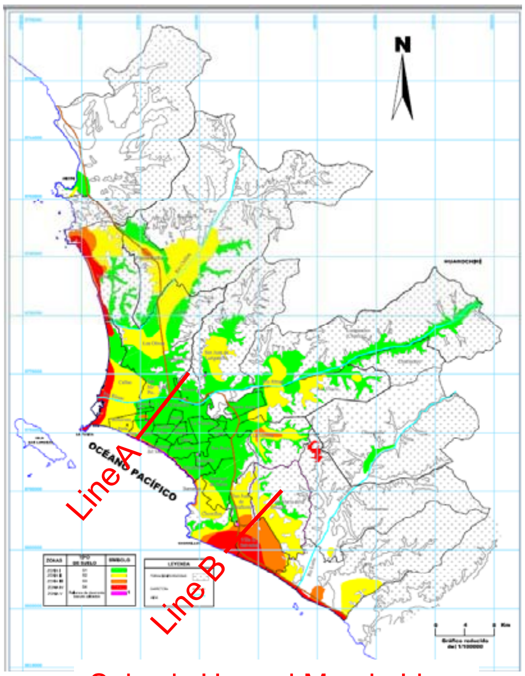




Seismic Microzoning

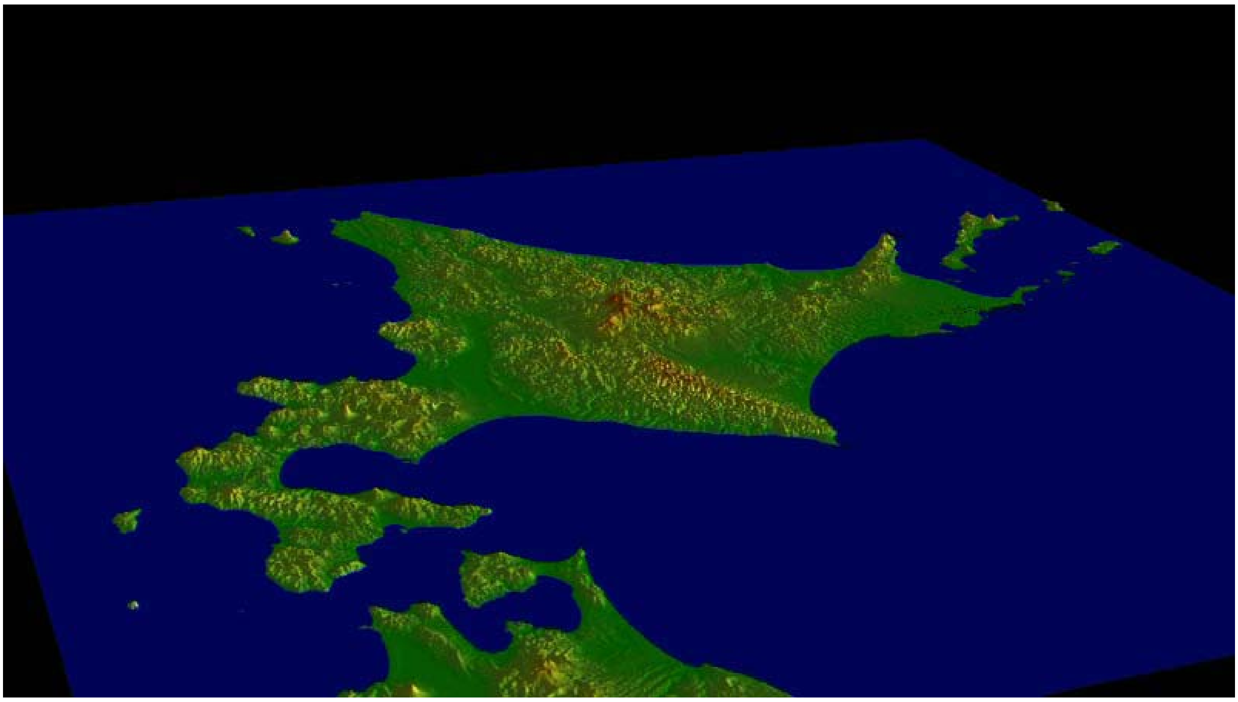
- Seismic Micro Zoning will be improved based on various in-depth surveys.
- 2 or 3-Dimensional soil structure model will be constructed.





Seismic Hazard Map in Lima (CISMID)

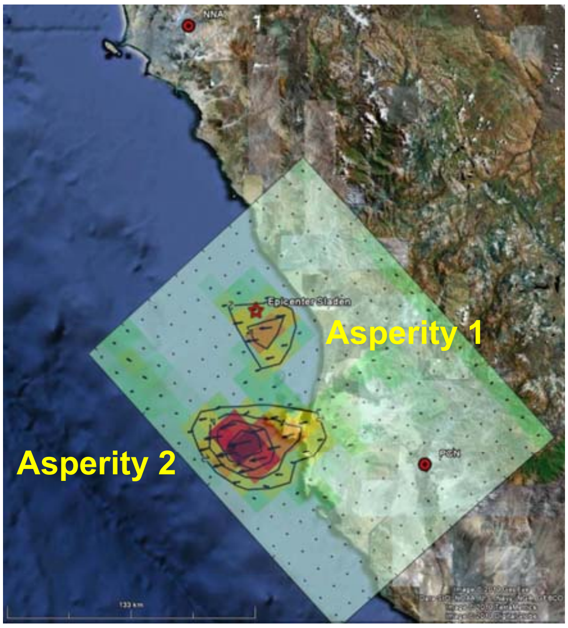
Animation Strong Motion simulation



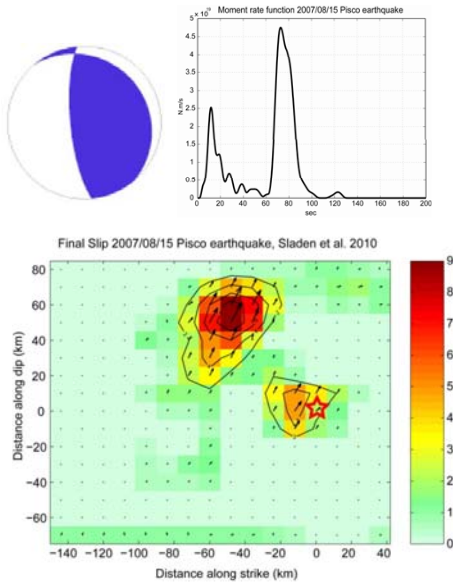
Fault rupture process and strong motion simulation of the 15 August 2007, Pisco earthquake

Source Model 2007 Pisco earthquake Sladen et al (2010)

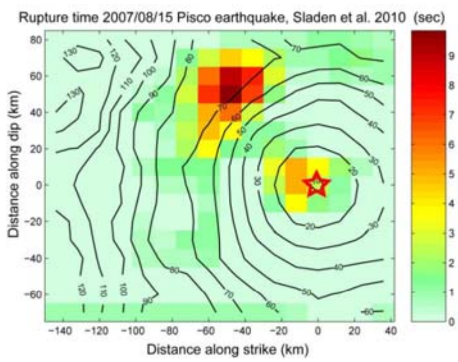
Slip distribution

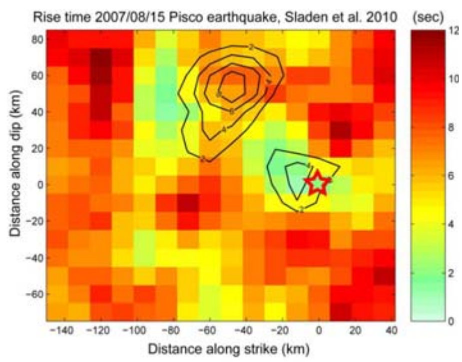


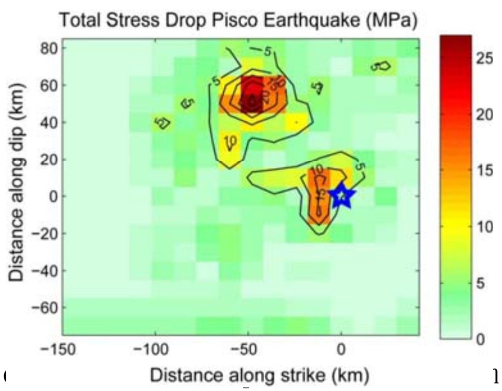
Focal mechanism, Source time function, Slip distribution, Strike 318, Dip 20, Rake 63, Mw=8.0



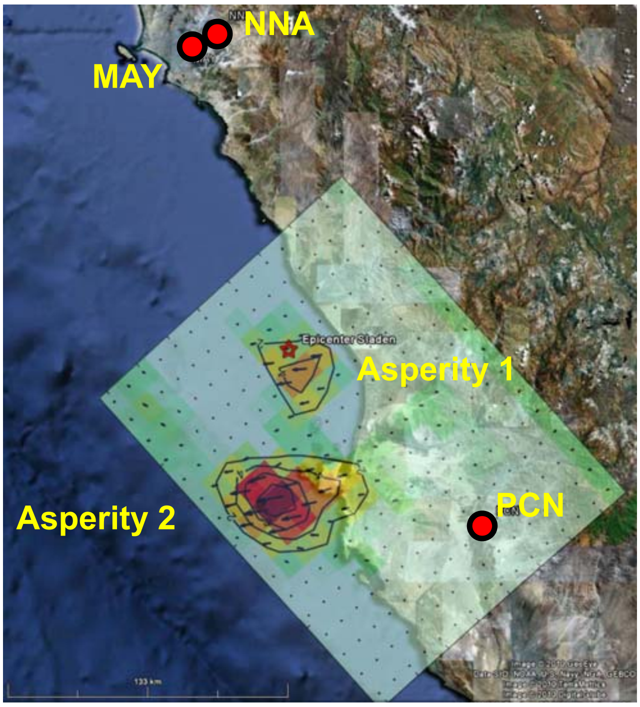
Rupture process, rise time and stress drop Pisco earthquake



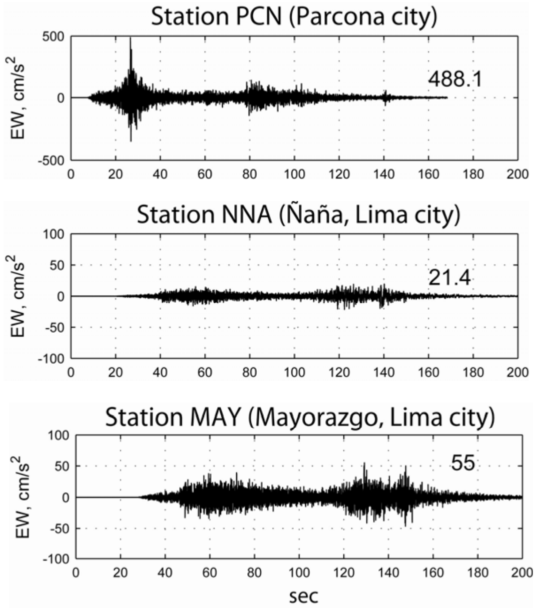




Observed Strong Motion Pisco earthquake



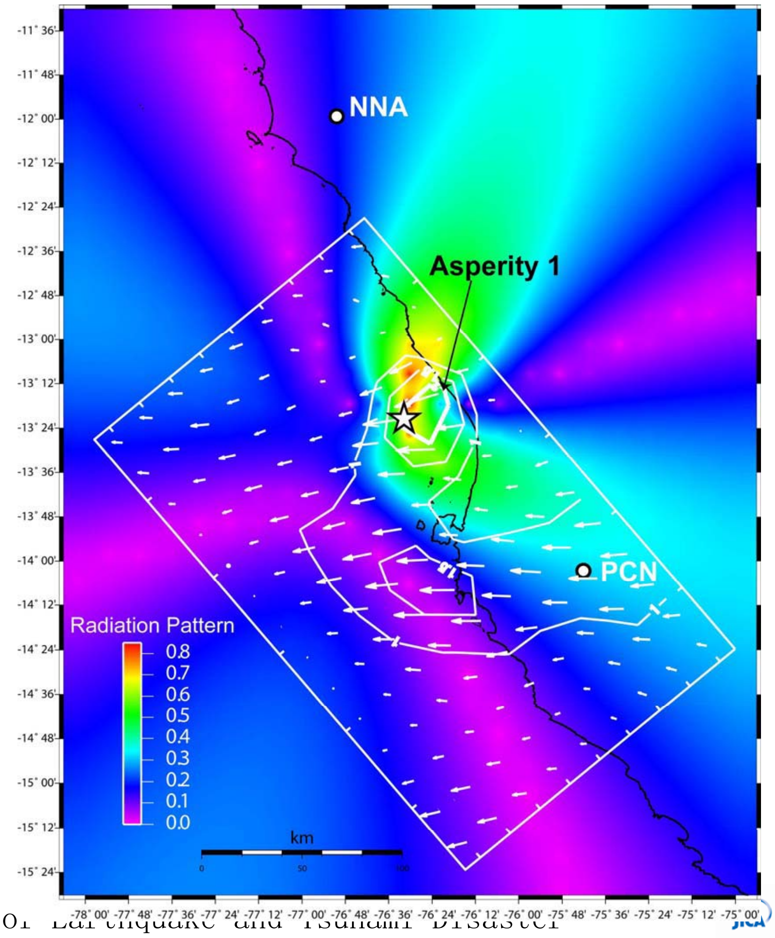
Source Process of the 2007 Pisco earthquake (Sladen et. al. 2010).



Strong motion recordings during the 2007 Pisco earthquake (IGP)

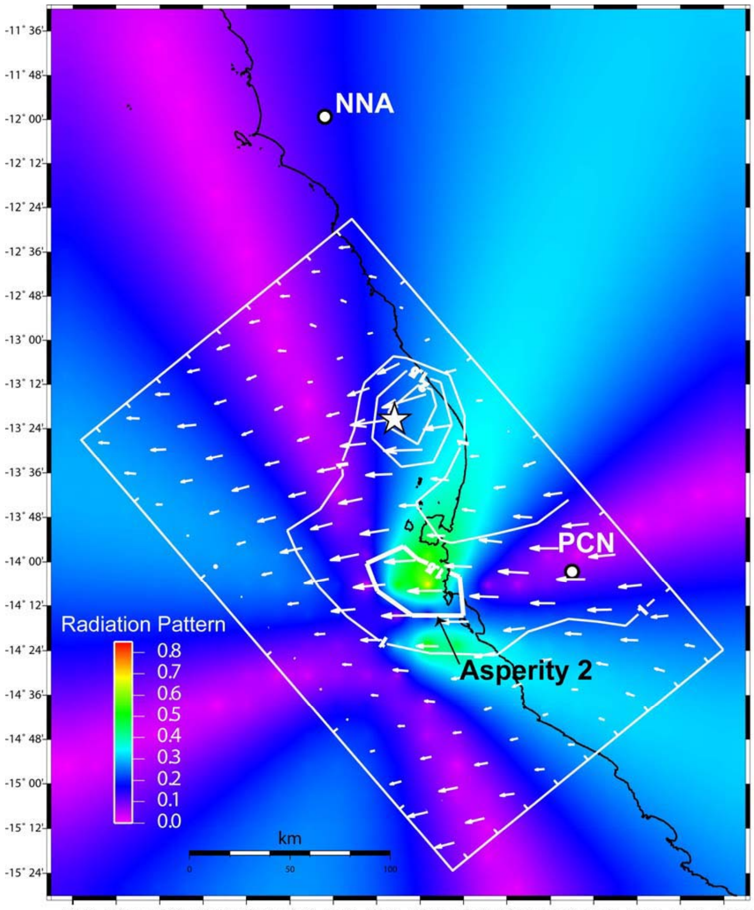
Radiation Pattern SH waves from asperity 1

- Cada punto en el plano de una falla irradia cantidades distintas de energía en diferentes direcciones (la forma como lo hace se denomina *patrón de radiación*



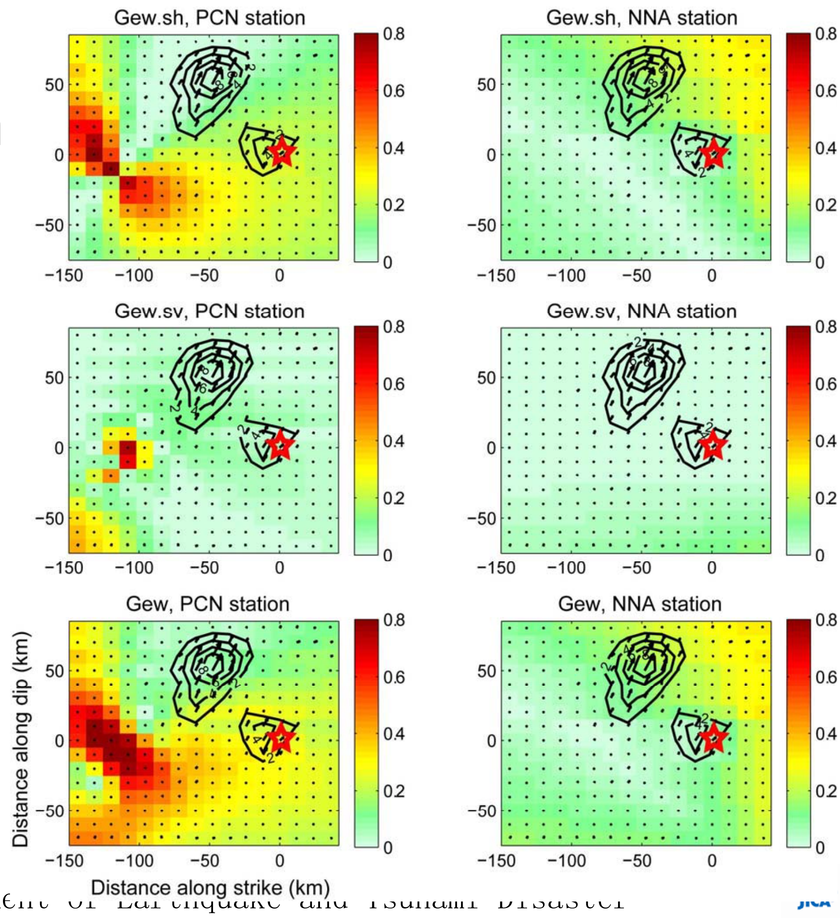
Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru

Radiation Pattern SH waves from asperity 2



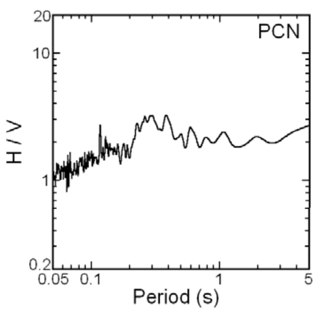
Radiation pattern as seen from PCN and NNA stations

Slip model 2007 Pisco earthquake (Sladen et. al. 2010).

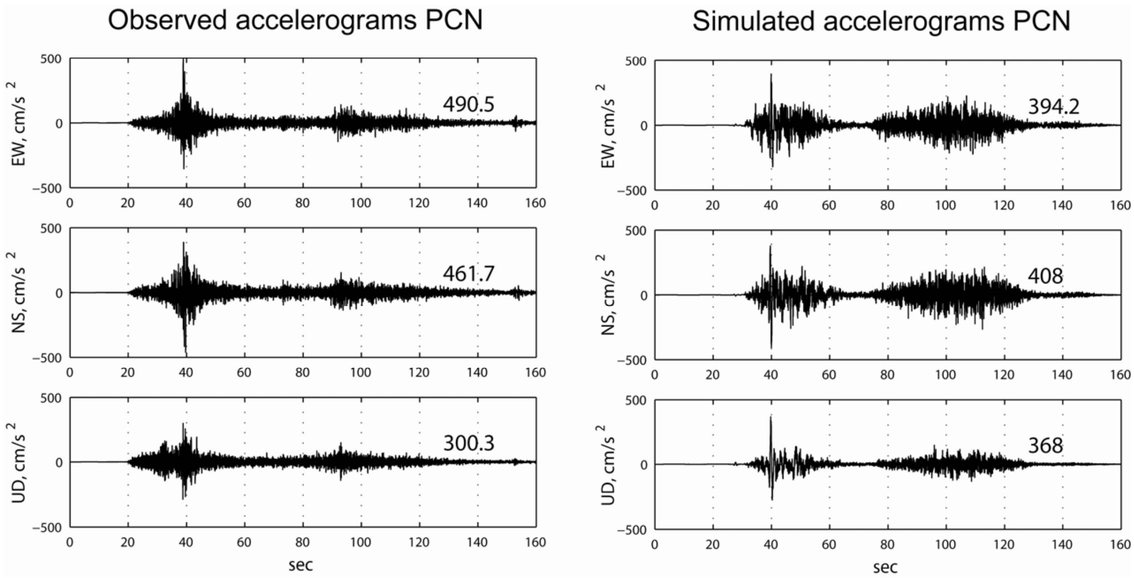


Strong Motion Simulation of the 15 August 2007, Pisco earthquake

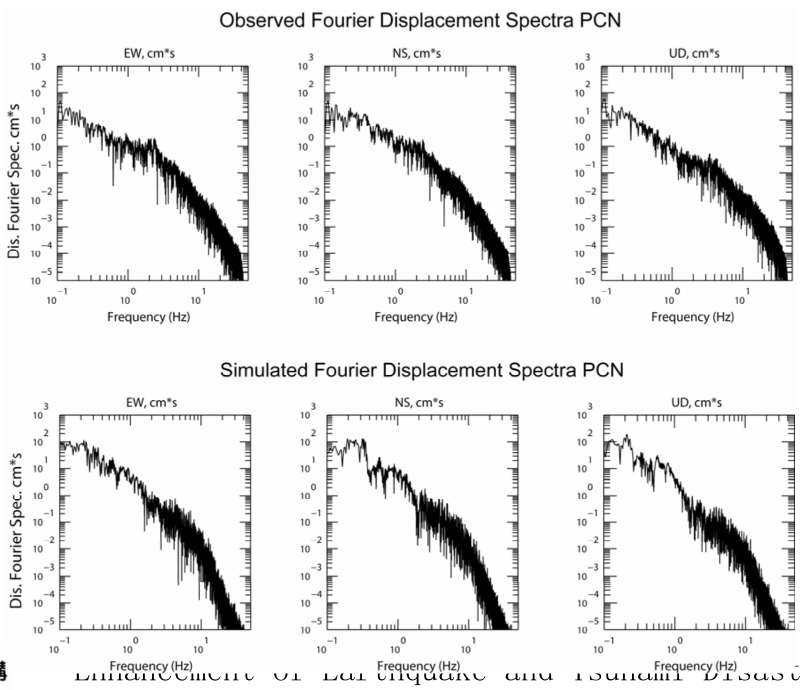
Microtremors measurements at Parcona city in 3/2010



Strong motion simulation at PCN, using Sladen et al. [2010] source model and methodology of Pulido et al. [2004]



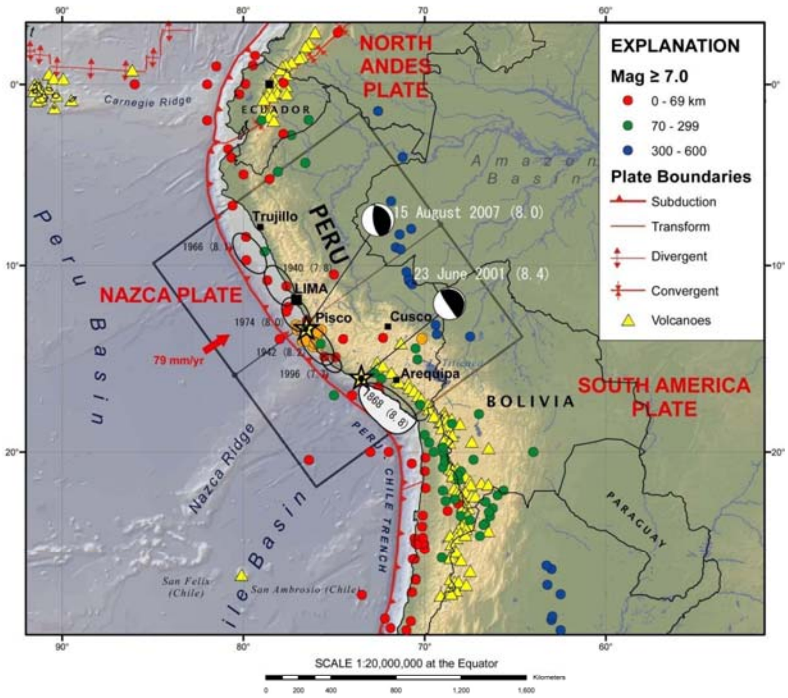
Strong motion simulation at PCN, using Sladen et al. [2010] source model and methodology of Pulido et al. [2004]



Conclusions

- We estimated two earthquake scenarios for Central and Southern Peru to be used for the estimation of strong motion.
- Our results show that the Lima segment has accumulated enough slip to be able to generate an earthquake as large as Mw 8.9 and the Arequipa segment an earthquake of Mw 8.5.
- Our results for the strong motion simulation of the 15/08/2007 Pisco earthquake, show that source parameters have a great influence on the near-source observed ground motions.

Muchas gracias por su cordial atención

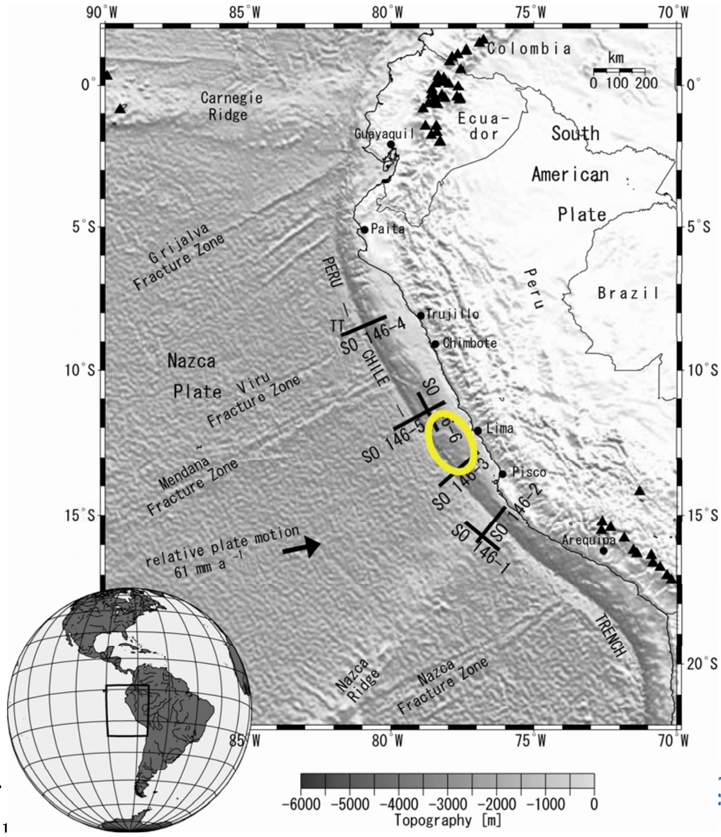


Objectives of the SM/GT group (seismic source)

- Elaboration of several scenario earthquakes from the subduction of the Nazca plate that could likely affect Lima, to be used for the seismic hazard estimation.
- Broadband strong ground motion simulation from the different scenario earthquakes in Lima, based on a 2D and 3D velocity model and scenario earthquakes (deterministic seismic hazard estimation).
- Validation/Improvement of the source and structure velocity models by simulation of observed strong motions of past subduction earthquakes in Peru.

Earthquake Scenarios for Lima [Intermediate class event]

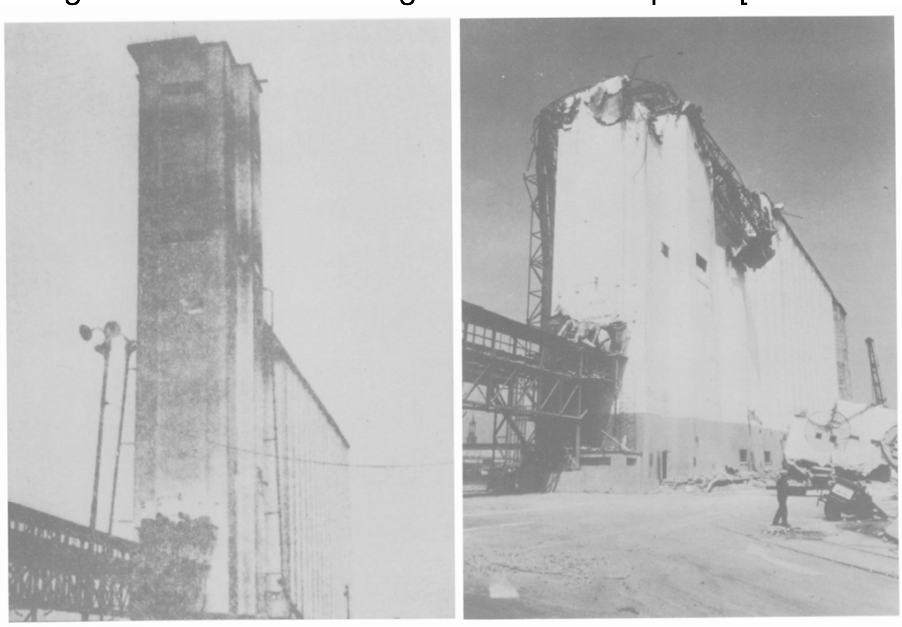
- A representative example for such an event is the October 3/1974 Mw8.0 earthquake which occurred 80 km west of Lima at a depth of 10 km.



Earthquake Scenarios for Lima [Intermediate class event]

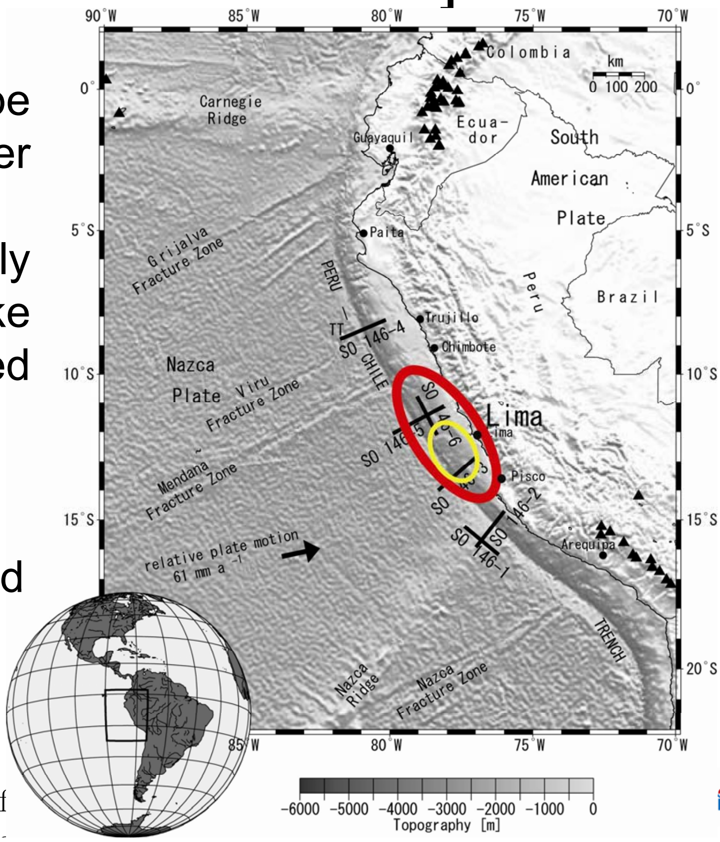
The Lima 1974 earthquake produced a moderate damage to Lima mainly in districts with soft sediments such as La Molina and Callao.

Damaged silo in Callao during the 1974 earthquake [Husid 1977]



Earthquake Scenarios for Lima [Worse scenario event]

- A mega-subduction type event, like the 28 October 1746 earthquake.
- This event is reportedly the worst earthquake Lima has experienced since its foundation.
- Source area of at least 350 km (Dorbath et al. 1990), based on compiled intensity reports.

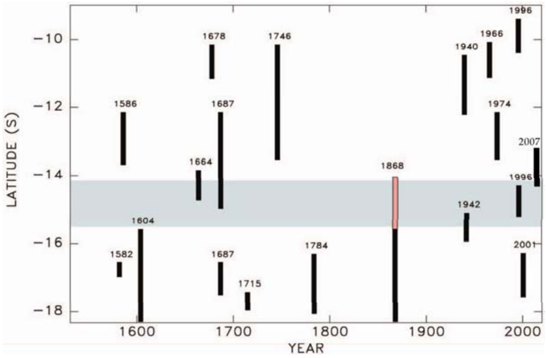


Earthquake Scenarios for Lima [Worse scenario event]

- Moment magnitude of the 1746 earthquake is ~8.8, based on reports of a tsunami runup height of 24m observed in Callao (Swenson and Beck 1996).

Illustration of El Callao in the XVI century (John Oliby 1671)

Historical earthquakes in Peru



Adapted from Okal et al (2006)

1940 05 24 Huacho, M8.2
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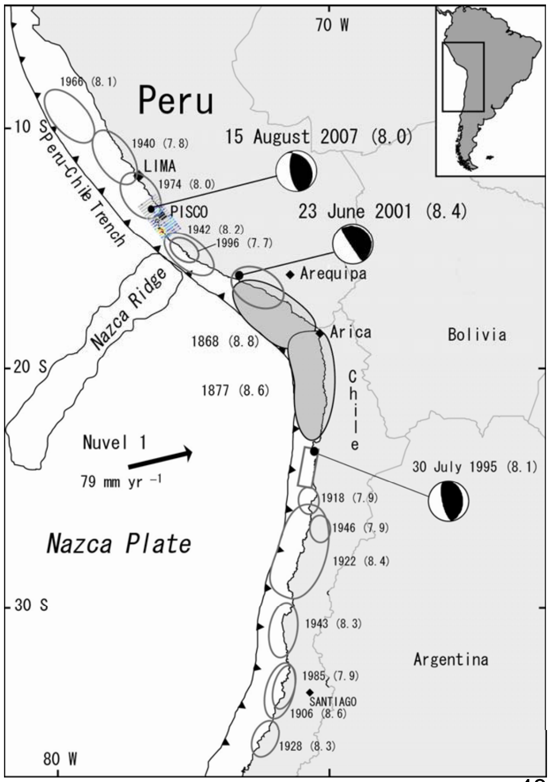
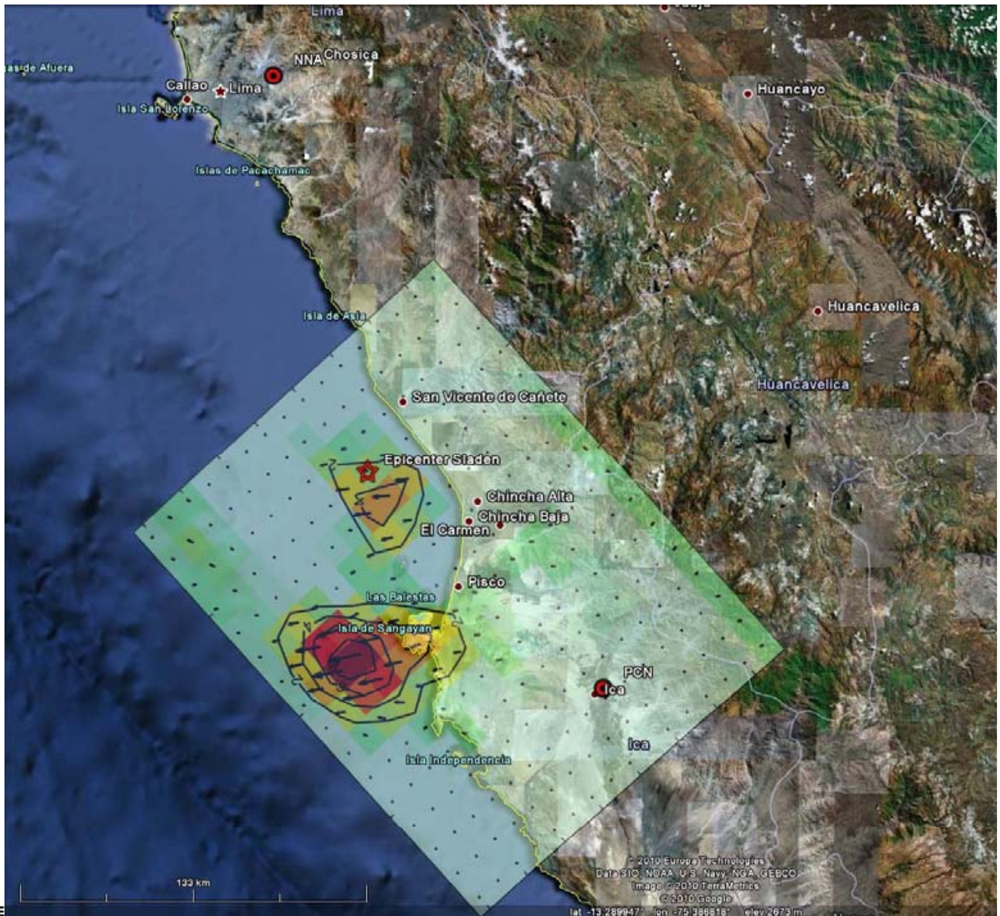
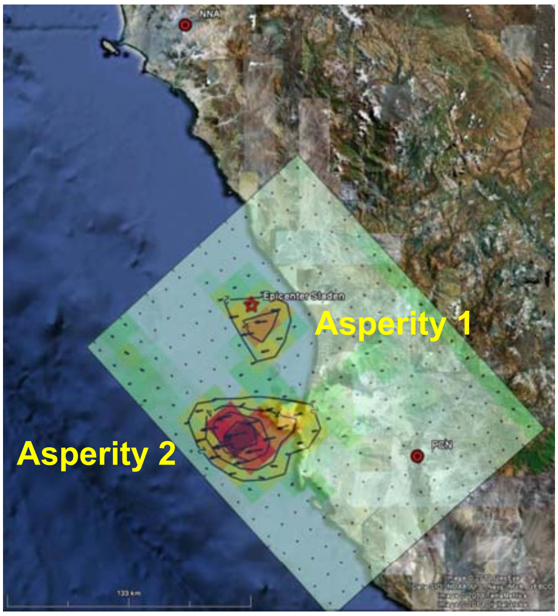


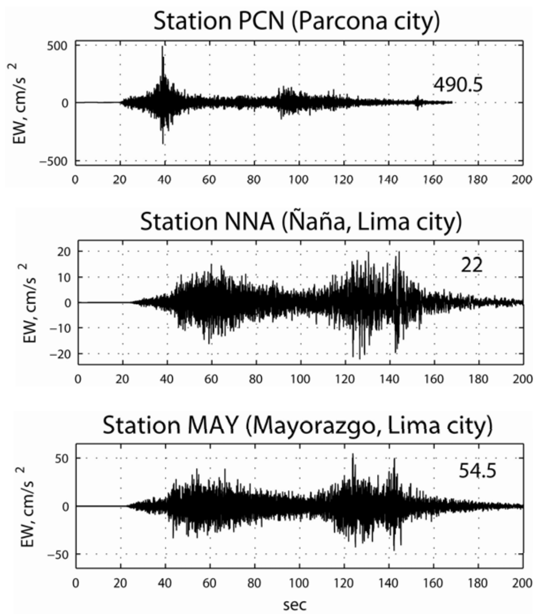
Adapted from Chlieh et al (2004)



Observed Strong Motion 2007 Pisco earthquake

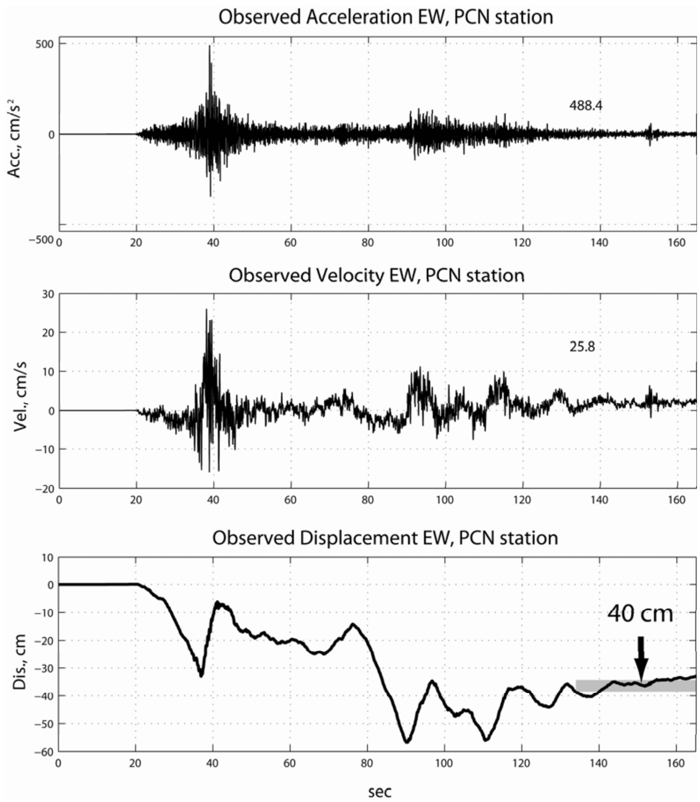


Source Process of the 2007 Pisco earthquake (Sladen et. al. 2010).

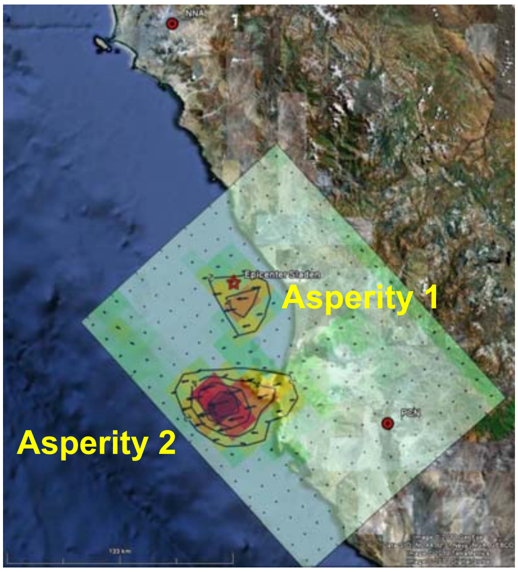


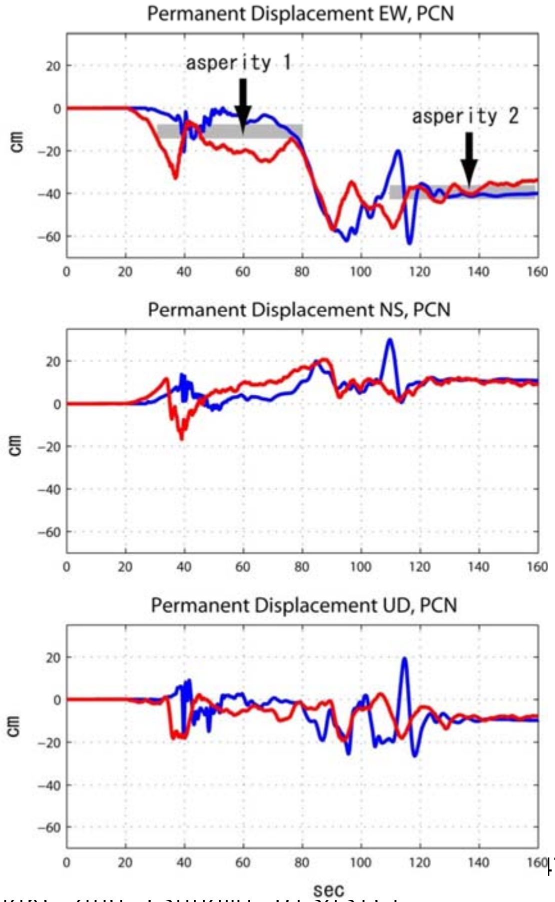
Strong motion recordings during the 2007 Pisco earthquake (IGP)

Calculation of permanent coseismic displacement during the Pisco earthquake at Parcona city from PCN strong motion station



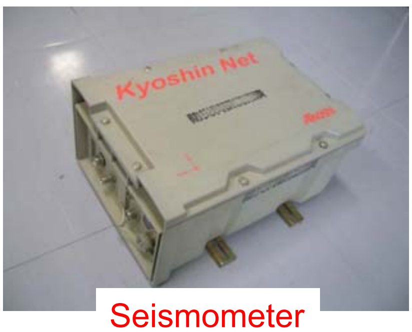
Simulation of permanent coseismic displacement during the Pisco earthquake at PCN station

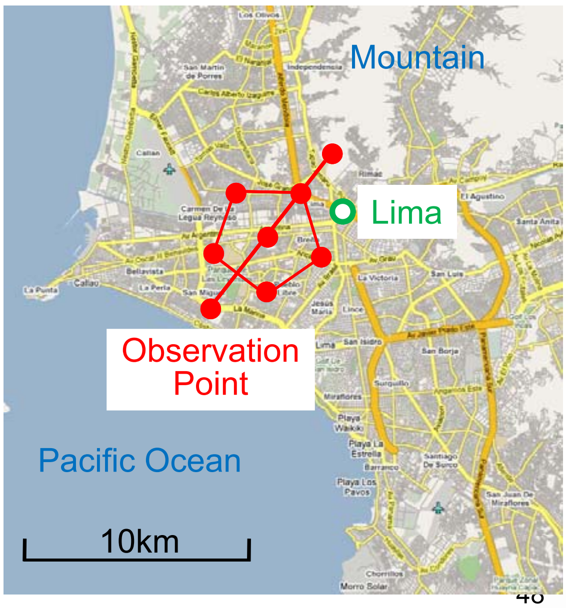




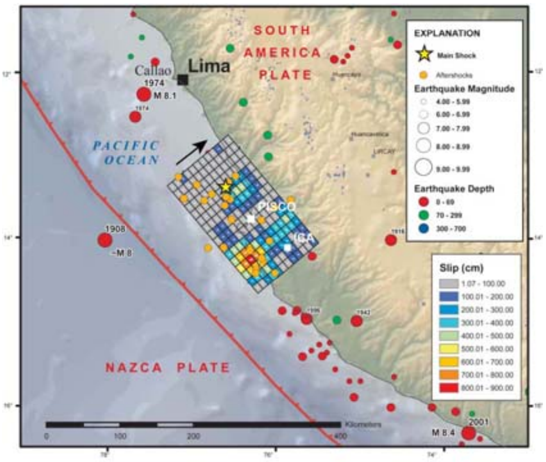
Seismic Observation

- Seismic observation is also carried out to examine the effect of surface soils by using the array of sensors in Lima city.

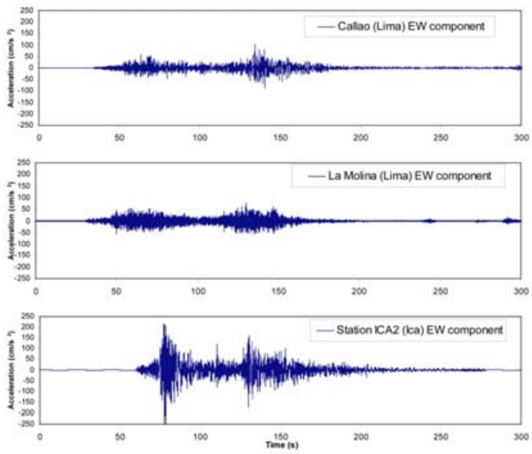




2007 Pisco earthquake Strong Motion

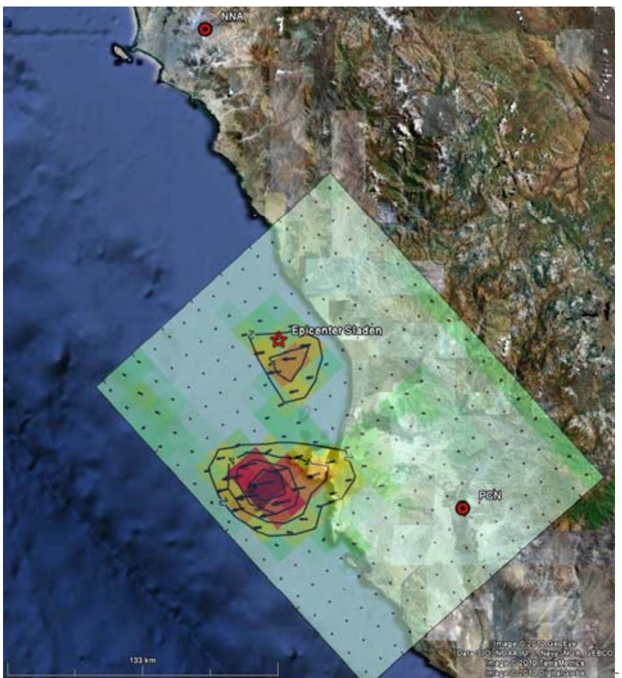


Source Process of the 2007 Pisco earthquake (Ji, 2007)

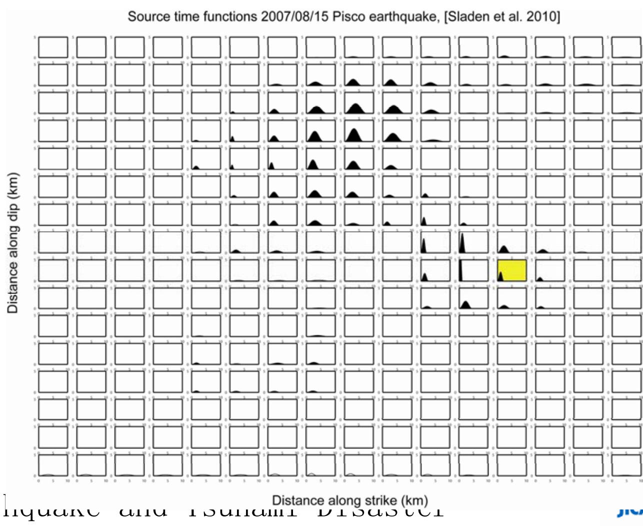


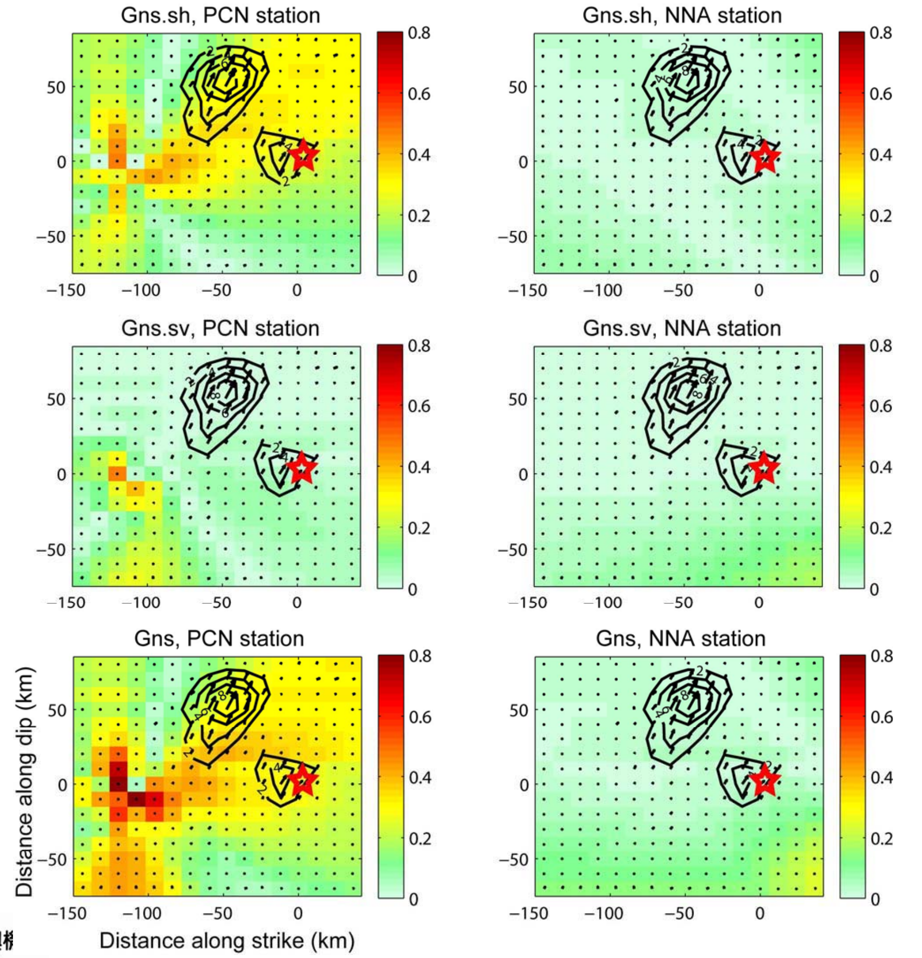
Strong motion recordings during the 2007 Pisco earthquake (CISMID)

Simulation of permanent coseismic displacement during the Pisco earthquake at PCN station

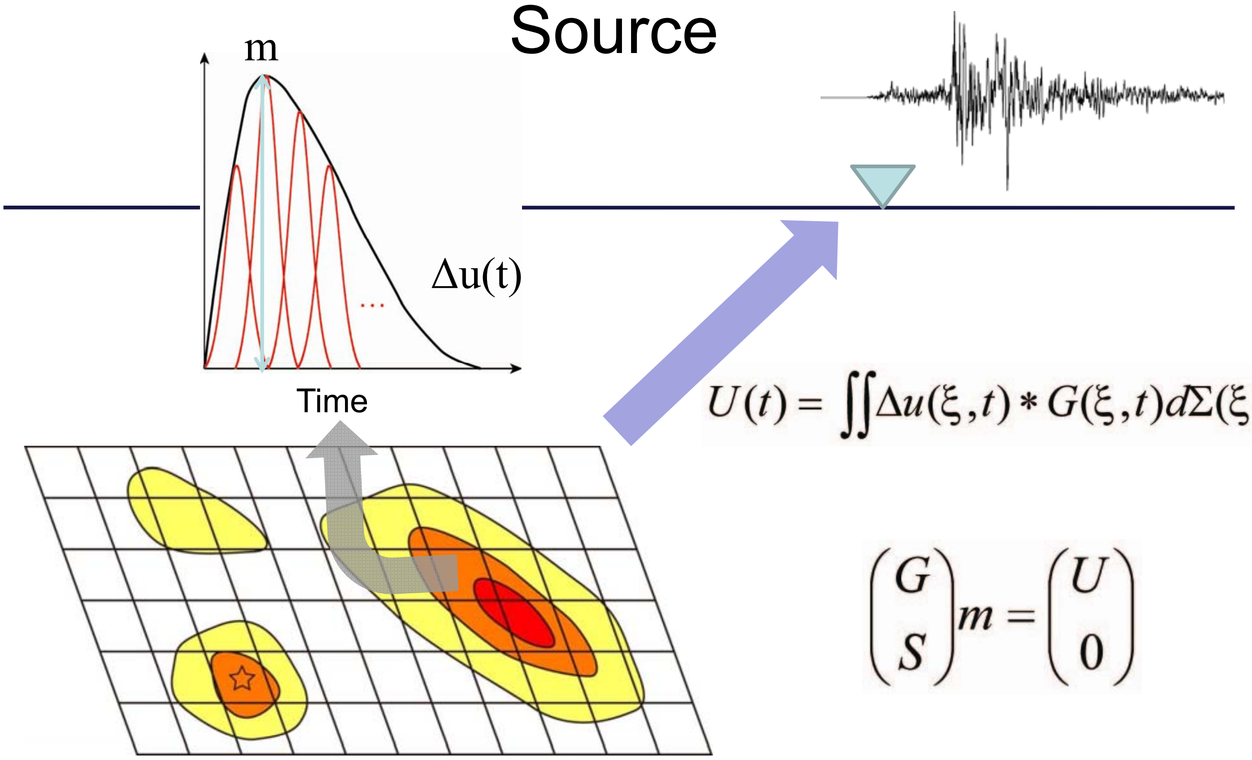


Distribution of slip velocity functions 2007 Pisco earthquake across the fault plane (Sladen et. al. 2010).





Estimation of Models for the Seismic Source

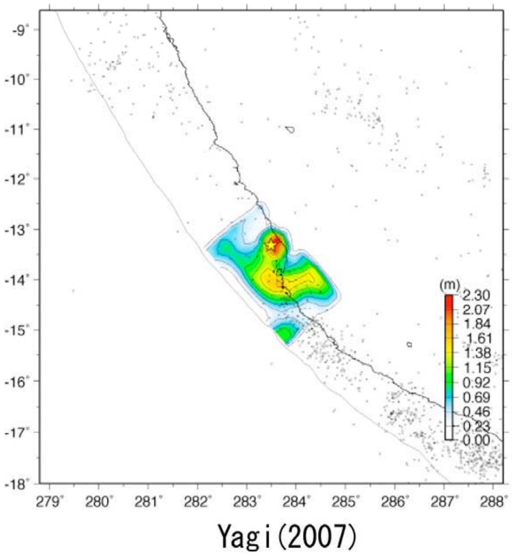


$$U(t) = \iint \Delta u(\xi,t) * G(\xi,t)\, d\Sigma(\xi)$$

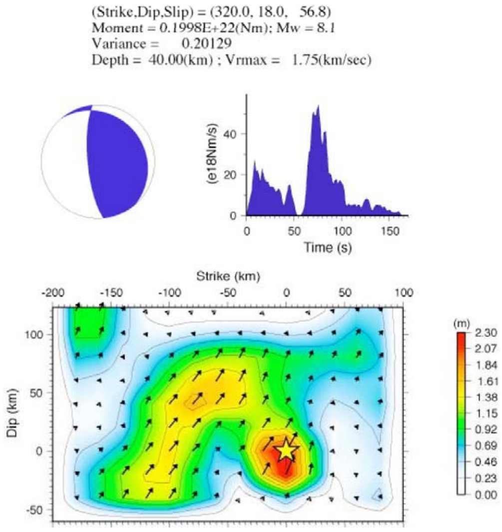
$$\begin{pmatrix} G \\ S \end{pmatrix} m = \begin{pmatrix} U \\ 0 \end{pmatrix}$$

Source Model 2007 Pisco earthquake Yagi (2007)

Slip distribution (map view)

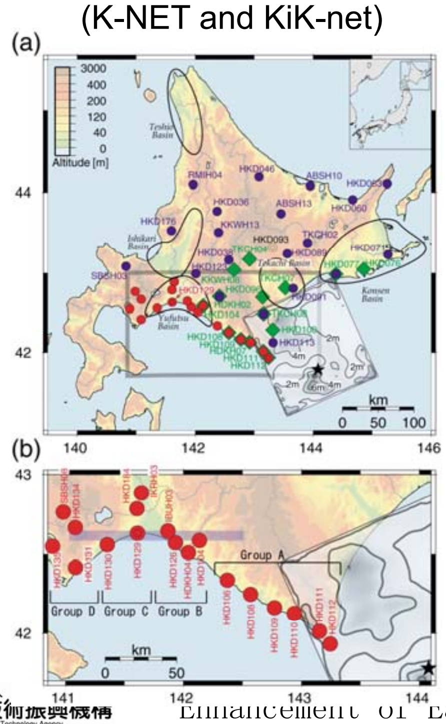


Focal mechanism, Source time function, Slip distribution (fault plane view)

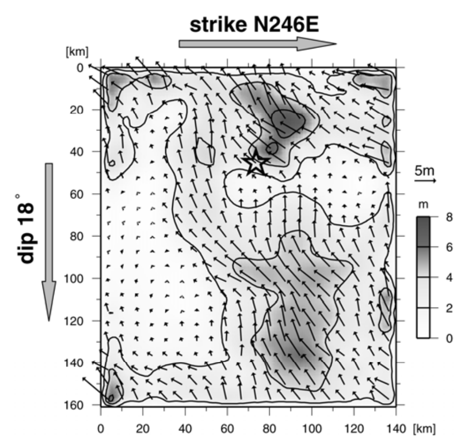


Source Model of the 2003 Tokachi-oki earthquake

Strong motion stations (K-NET and KiK-net)



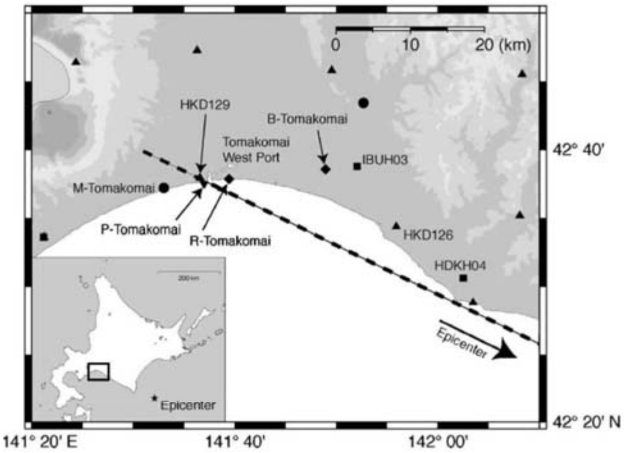
Slip distribution (fault plane view)



Honda et. al. (2004)

Damage to oil storage tanks during the 2003 Tokachi-oki earthquake

Hatayama (2008)

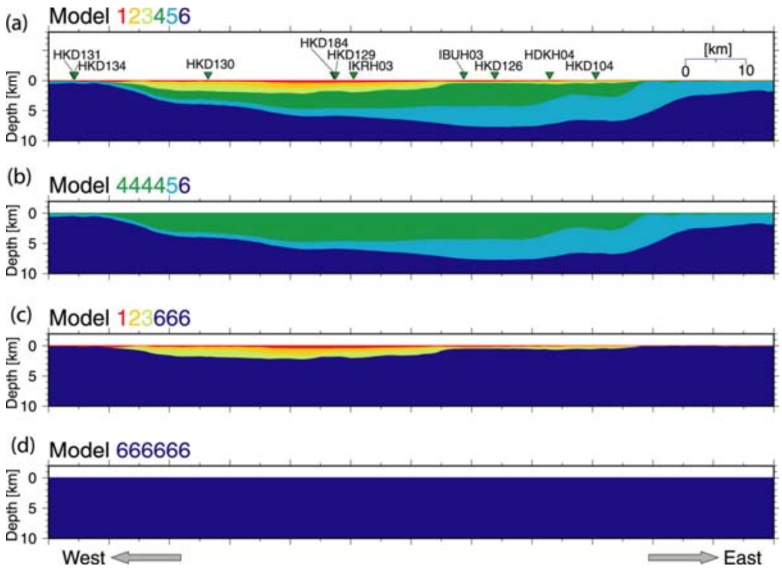


Oil storage tanks were located around 300 km from the epicenter. Long period ground motions (4-8s) caused severe damage to the tanks.

Fig. 2 Ring fire in a crude oil tank (tank A photograph courtesy of Sapporo Fire Bureau)

Fig. 3 Open-top fire in a naphtha tank (tank B, photograph courtesy of Sapporo Fire Bureau)

Cross section of the underground velocity model at the Yufutsu basin



Full basin geological model

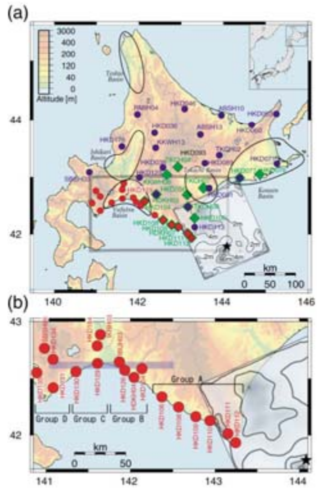
Overall basin model only

Sub-basin model only

Uniform model

Aoi et. al. (2008)

Observed and Simulated strong motions

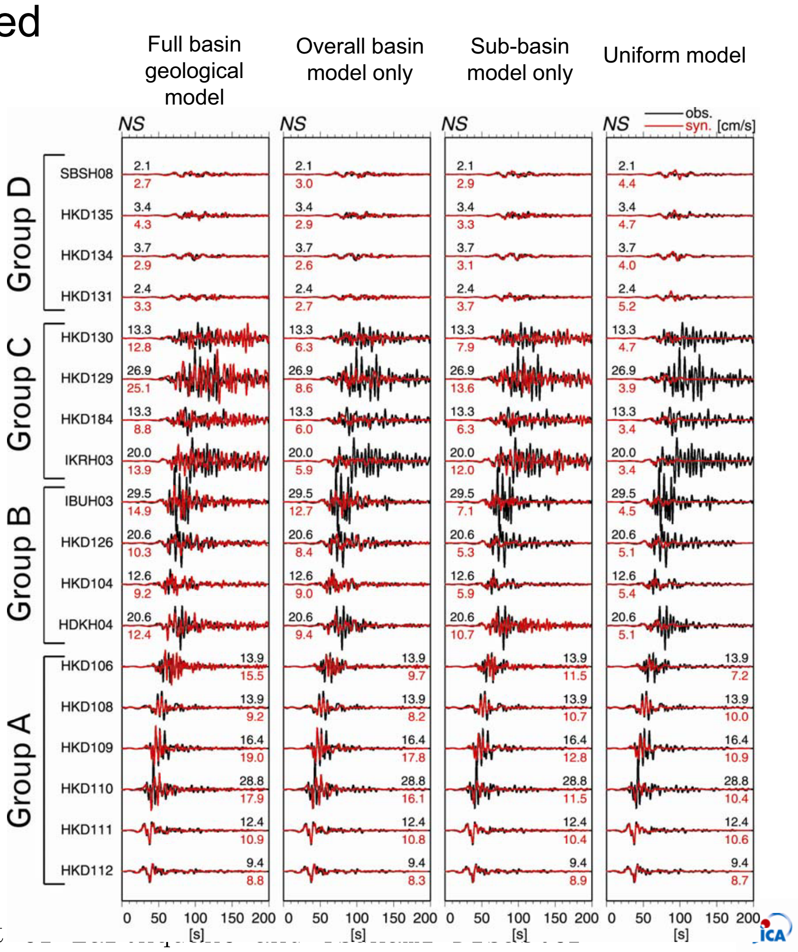


Rock sites western side of basin

Western part of Yufutsu basin

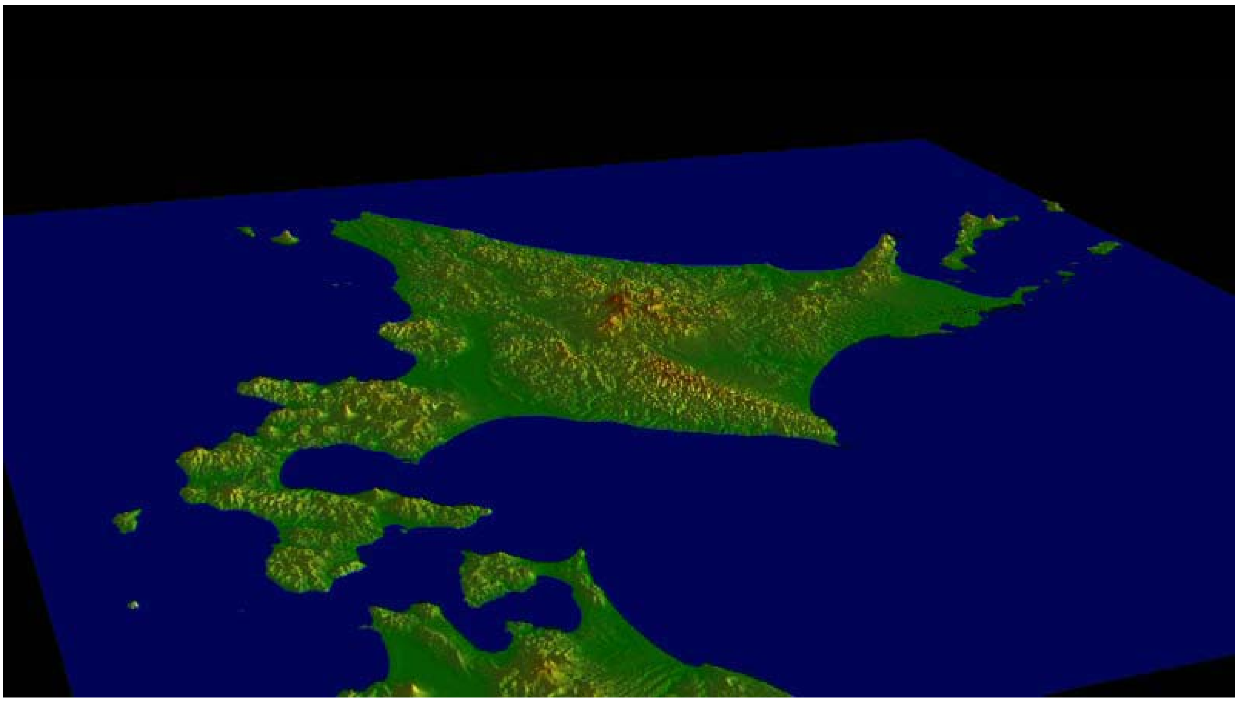
Eastern part of Yufutsu basin

Rock sites



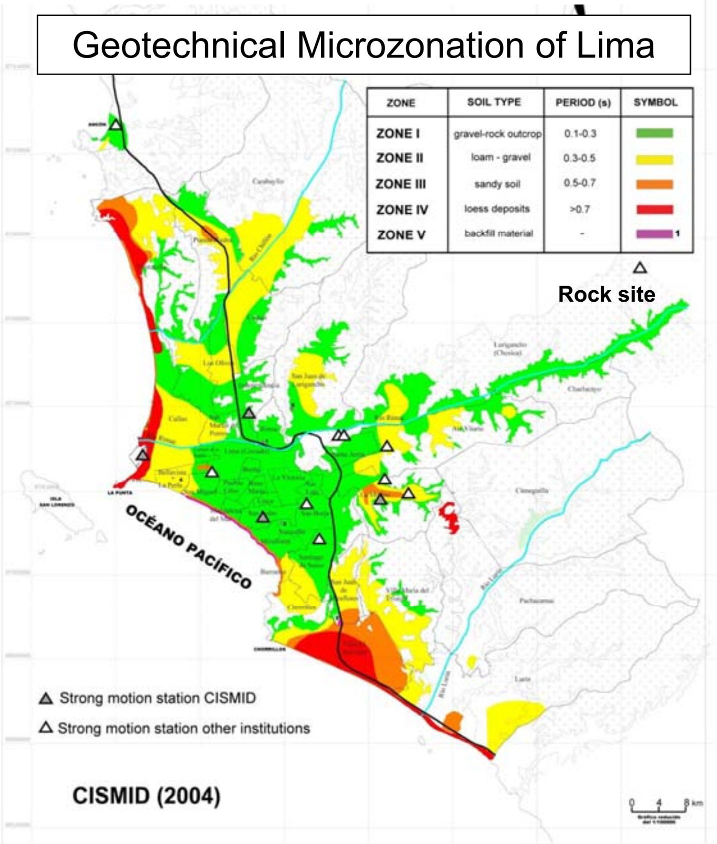
Aoi et. al. (2008)

Animation Strong Motion simulation



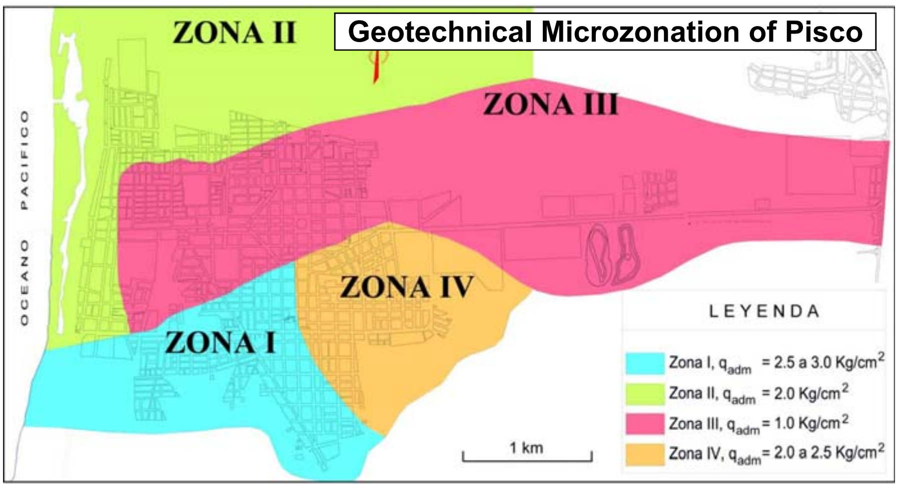
Strong Motion Simulation

- Broadband strong ground motion simulation from the different scenario earthquakes in Lima, up to an engineering bedrock condition, based on a 3D velocity model and using a hybrid approach (FDM for LF + Stochastic for HF).



Strong Motion Simulation (3)

- Broadband strong ground motion simulation from the different scenario earthquakes in Pisco up to an engineering bedrock.
- Deployment of a temporal network of accelerometers in Pisco, to study site effects, Q and source parameters of small earthquakes.

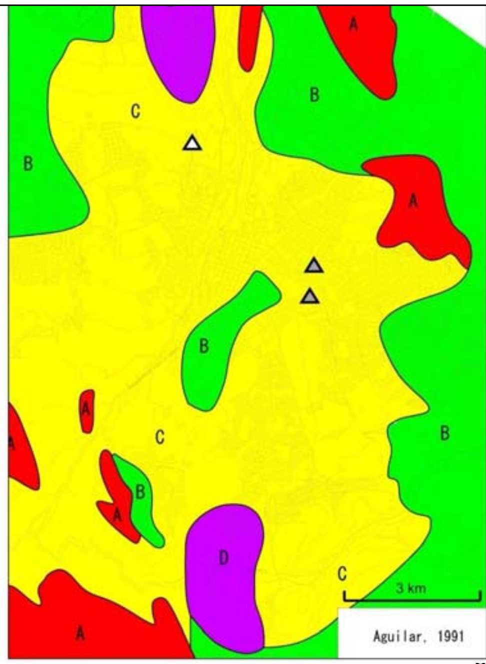


Parra et al. 1999

Strong Motion Simulation (2)

- Broadband strong ground motion simulation from the different scenario earthquakes in Arequipa up to an engineering bedrock.
- Deployment of a temporal network of accelerometers in Arequipa, to study site effects, Q and source parameters of small earthquakes.

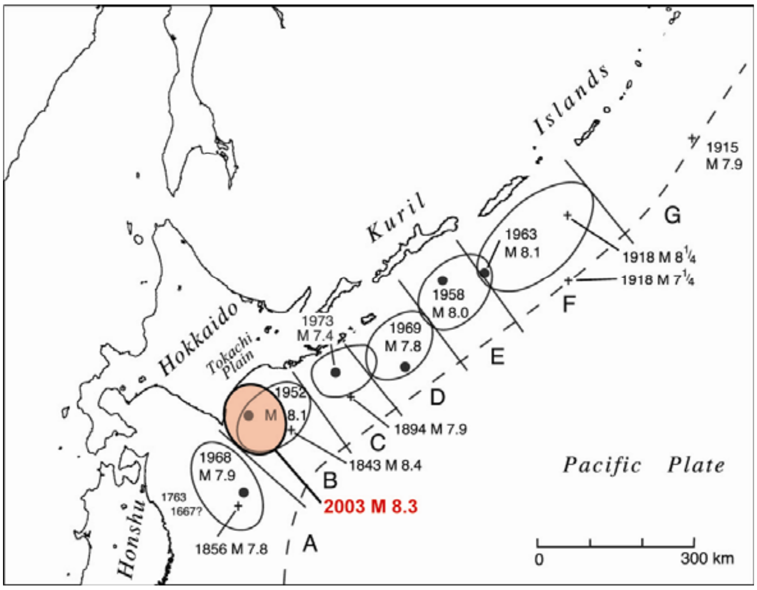
Geotechnical Microzonation of Arequipa



△ Strong motion station CISMID
△ Strong motion station IGP

ZONE	Soil type	Period (s)	Symbol
ZONE A	Igneous rocks	0.15 - 0.25	
ZONE B	mud flow	0.15 - 0.25	
ZONE C	gravel - sand - mud flow	0.30 - 0.45	
ZONE D	volcanic ash soil	0.30 - 0.45	

Strong Motion simulation of the 2003 Tokachi-oki earthquake Mw 8.3



Source regions of great interplate earthquakes along the northern Japan Trench and southern Kuril trench

Mapa de las Redes de Observación Sismológica a nivel nacional, administradas por el NIED