3rd Quest Workshop
Introduction to Seismic Sources

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May 21, 2012 Slovakia

Plan for this morning

09:00-09:30 **Introduction**

09:30-09:50 ***Dionicio***: Multi-scale imaging of the MW 9.0 Tohoku earthquake combining back projection and kinematic modelling

09:50-10:10 ***Galvez***: A conceptual model for 2011 M9 Tohoku earthquake with an unstructured 3D spectral element method

10:10-10:30 ***Twardzik***: Determination of the robust source features of the Mw6.0 Parkfield earthquake

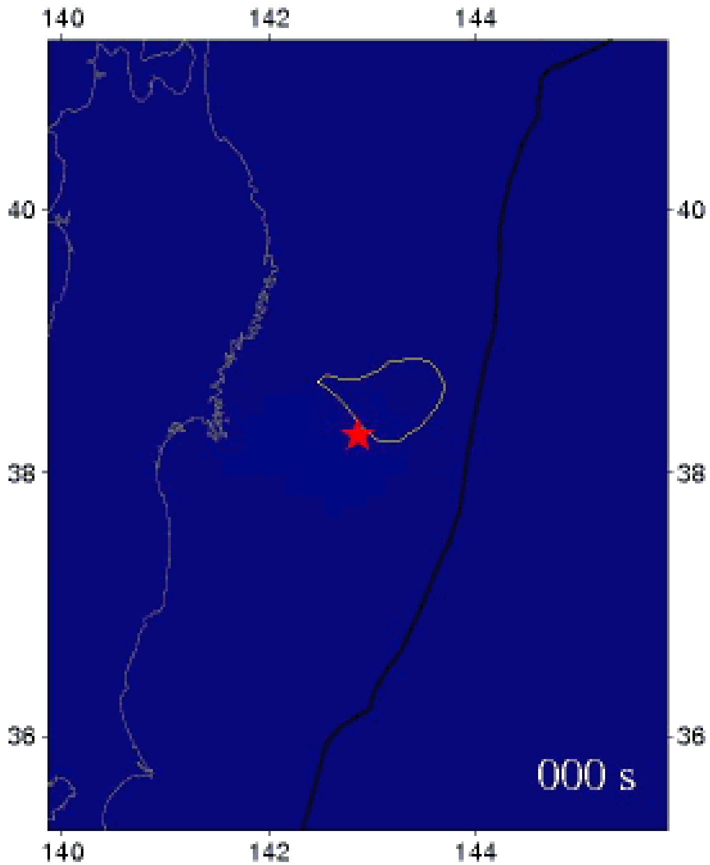
10:30 Coffee Break

11:00-11:20 ***Zecevic***: Source characteristics of a family of long period events recorded during an intrusive phase on Piton de la Fournace, La Reunion

11:20-11:40 ***Razanezhad***: Bayesian inference in linear mixed models for spatial distribution of fault slip

Understanding sources is key …

Large Earthquakes

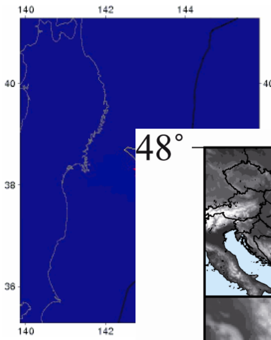


Courtesy of M. Ishii

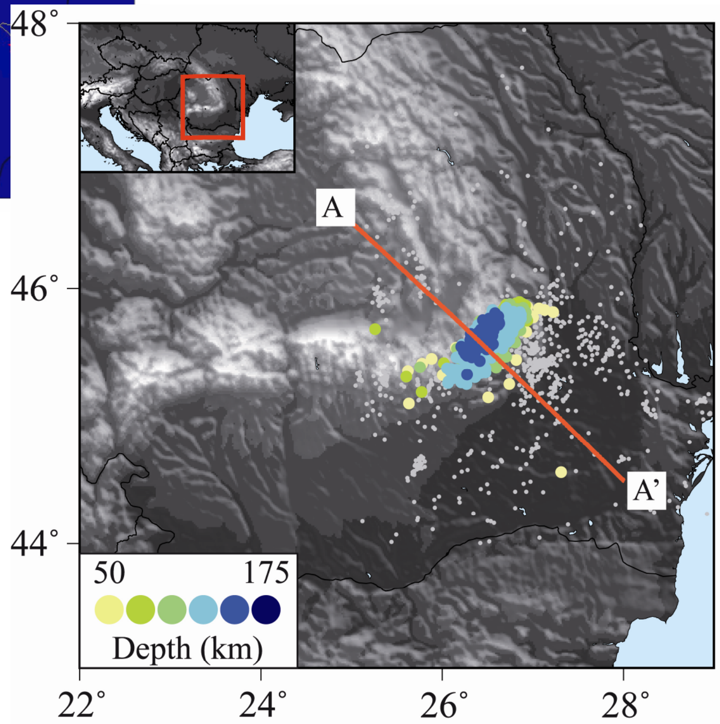
March 11, 2011 Tohoku-Oki, Japan Earthquake

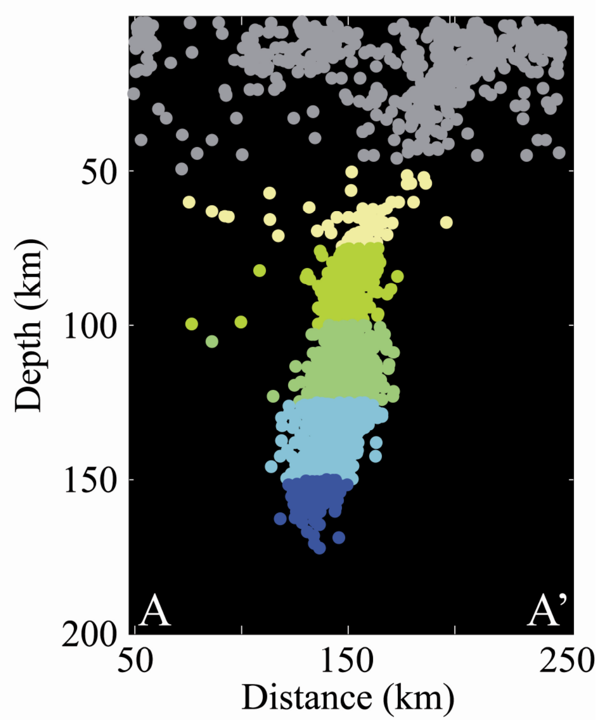
Understanding sources is key …

Deeper Earthquakes



Vrancea Earthquake Nest
Old subduction under slab-break?

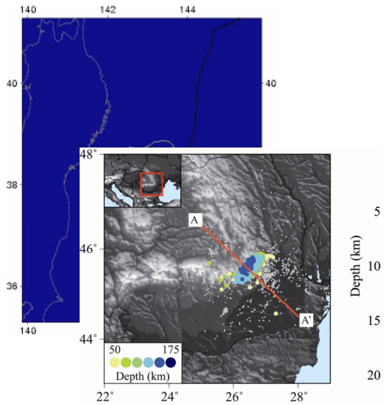




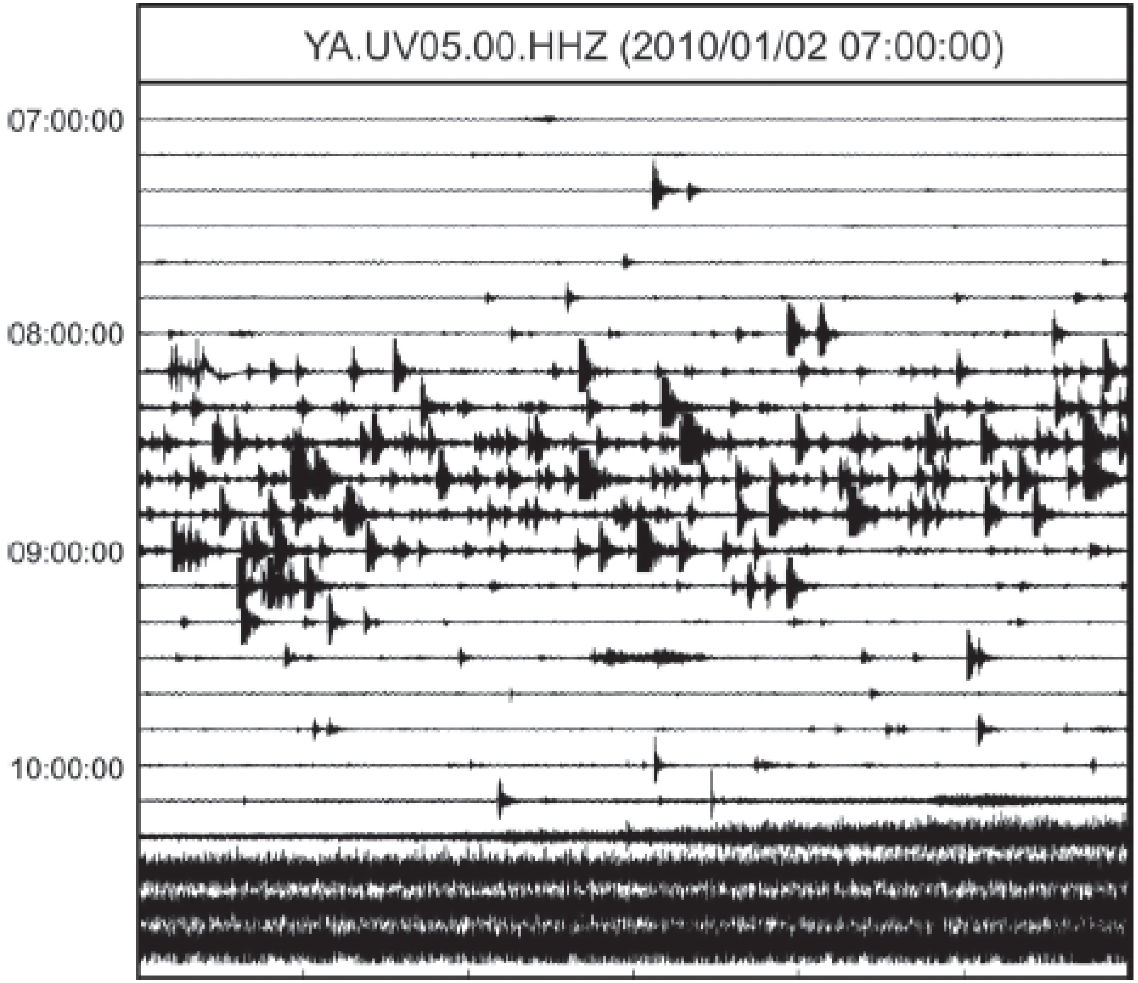
Prieto et al., 2012

Understanding sources is key …

Volcanic Sources



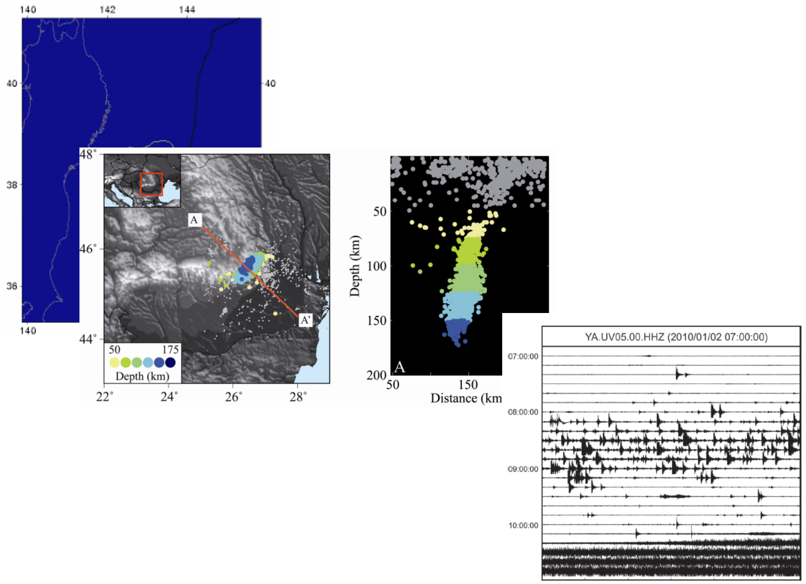
High frequency or long period volcanic seismicity
Piton de la Fournaise

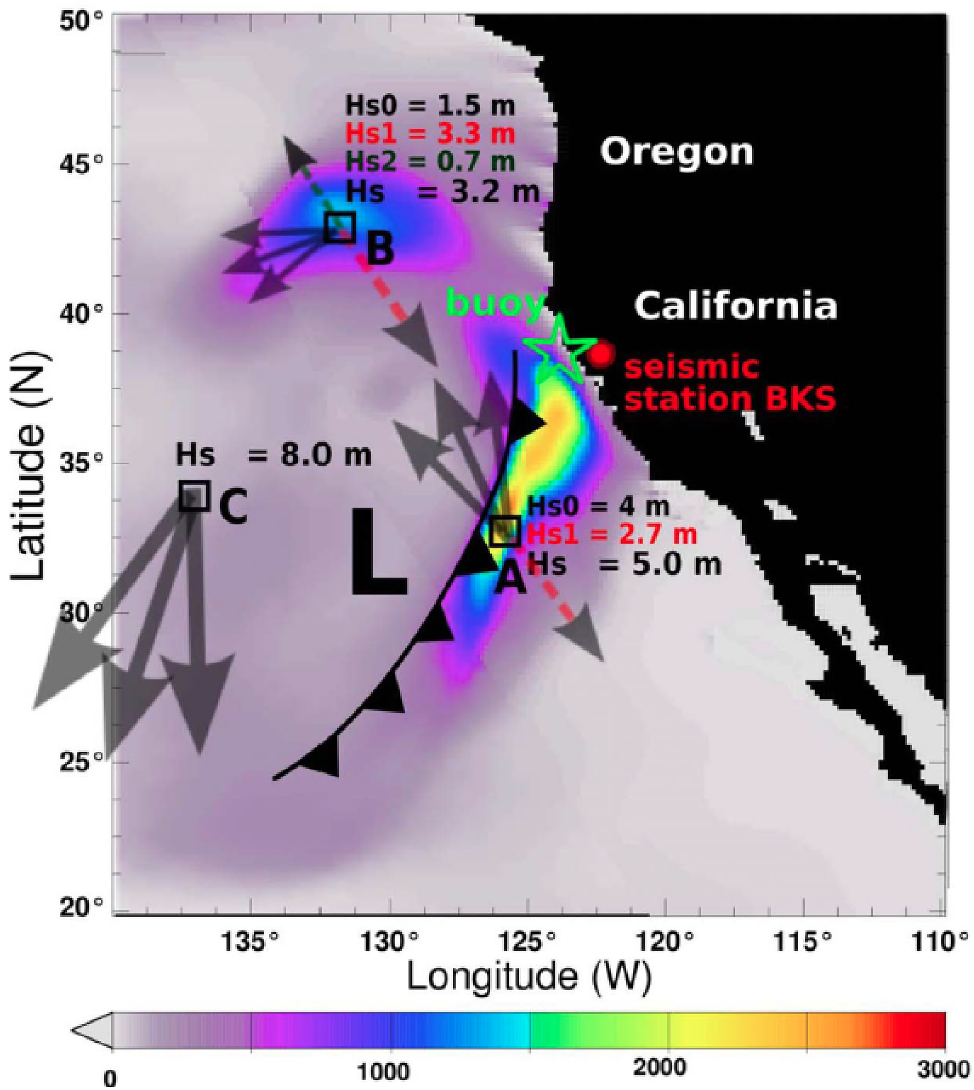


Brenguier et al., 2012

Understanding sources is key …

Even “noise” sources



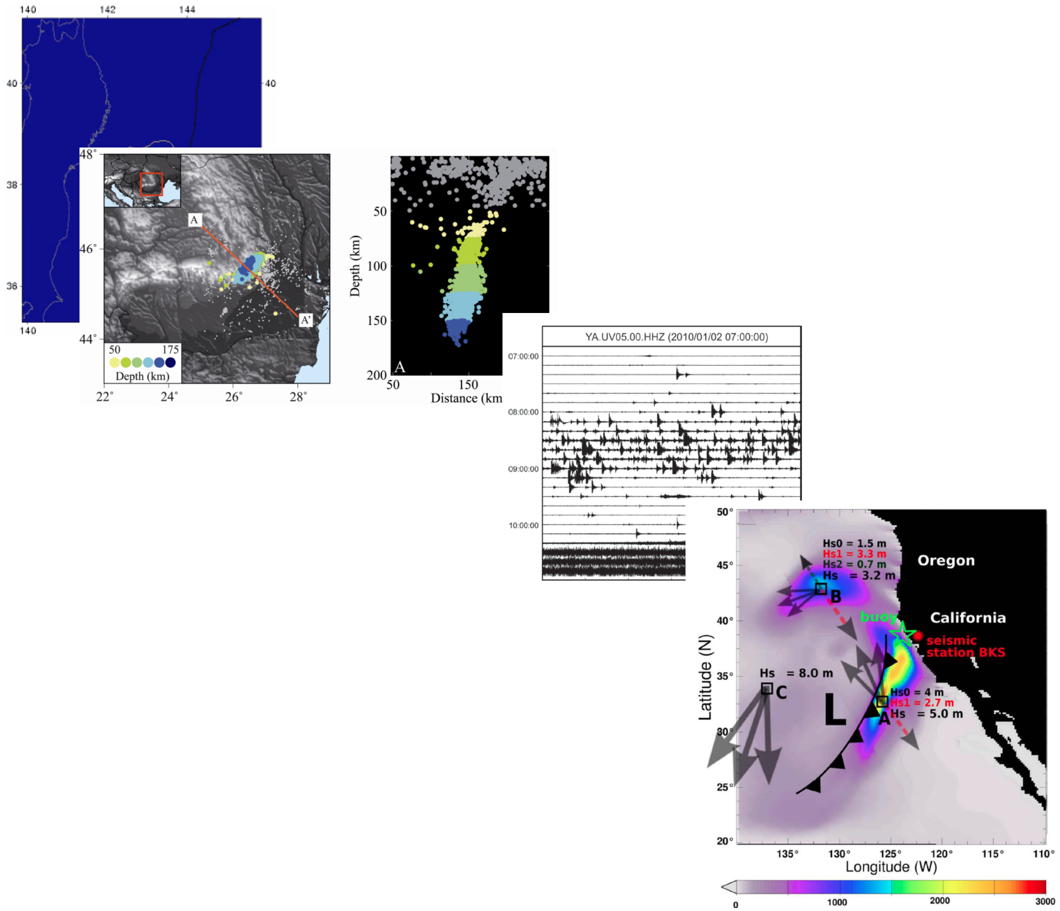


Ambient Seismic Noise

Associated sources and locations

Arhuin et al., 2011

Understanding sources is key …



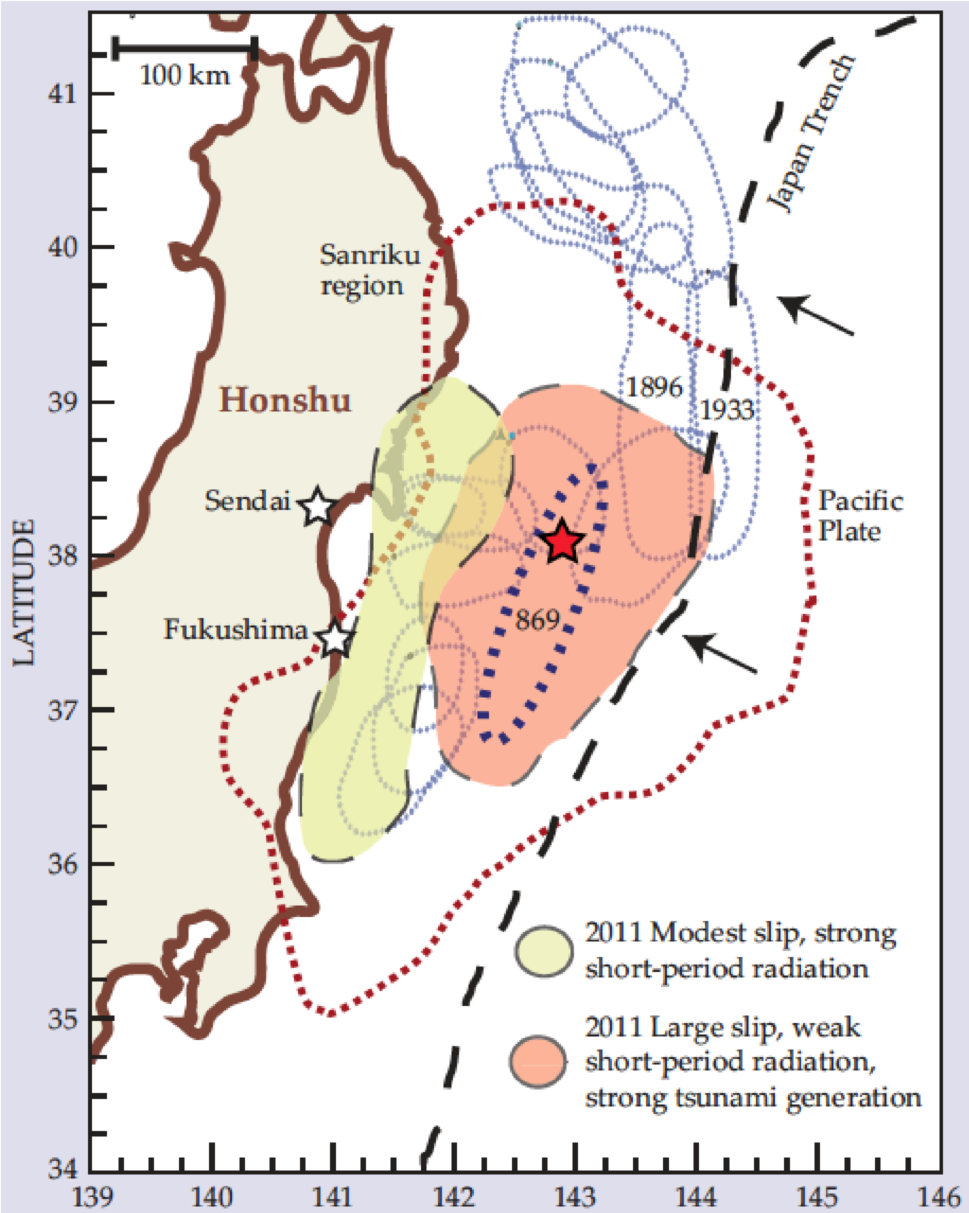
On all cases

-Want to know location, source time functions, directivity, focal mechanisms, etc.

-These sources are used for tomographic imaging.

-Have information about the behavior and physics of faults and rupture, stress in the crust, coupling oceans, atmosphere-lithosphere, etc.

New observations about large thrust earthquakes



March 11, 2011
Tohoku-Oki, Japan Earthquake

Frequency-dependent source properties?

Lay and Kanamori, 2011 (Physics Today)

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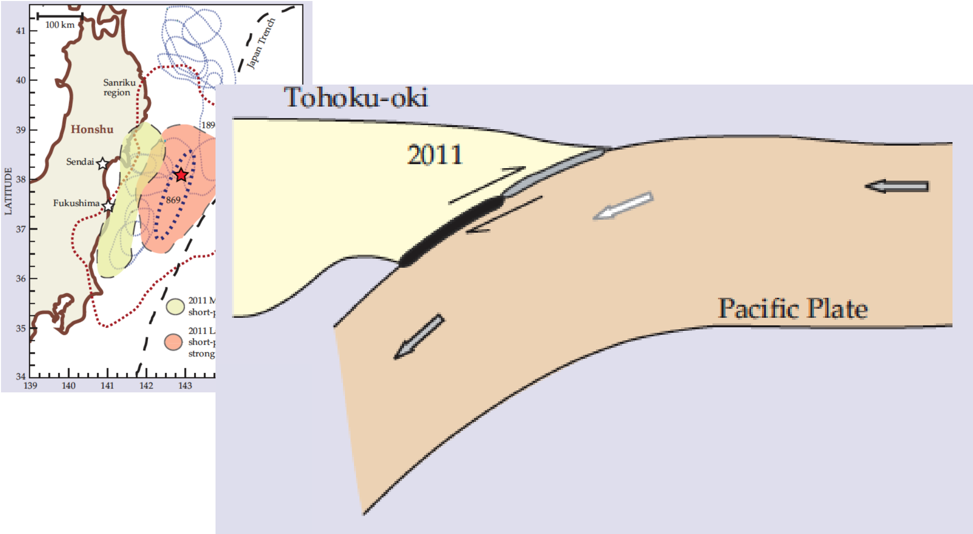
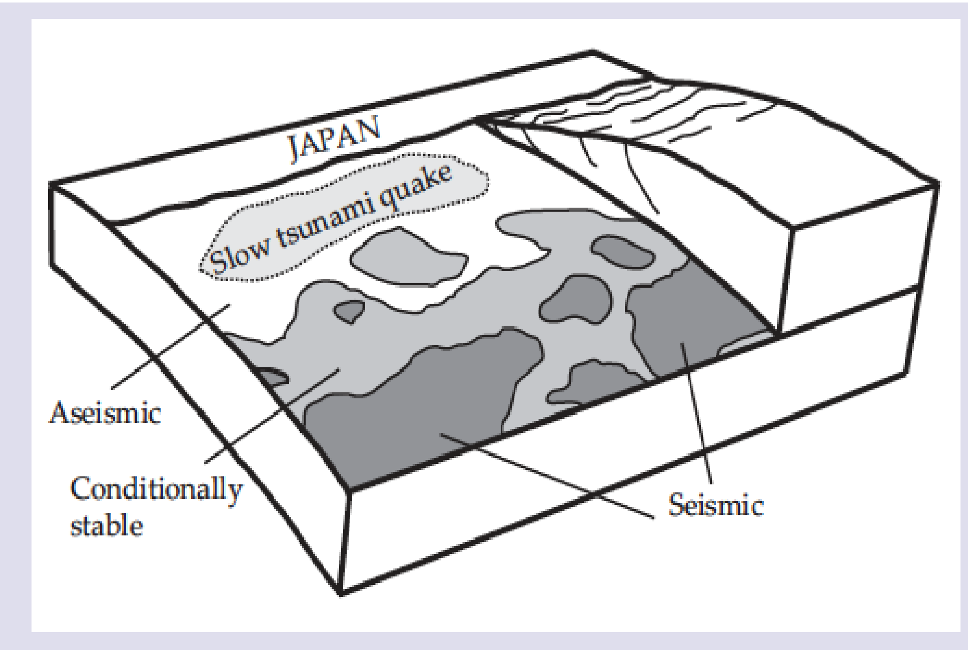


March 11, 2011 Mw9.0
Tohoku-Oki, Japan Earthquake

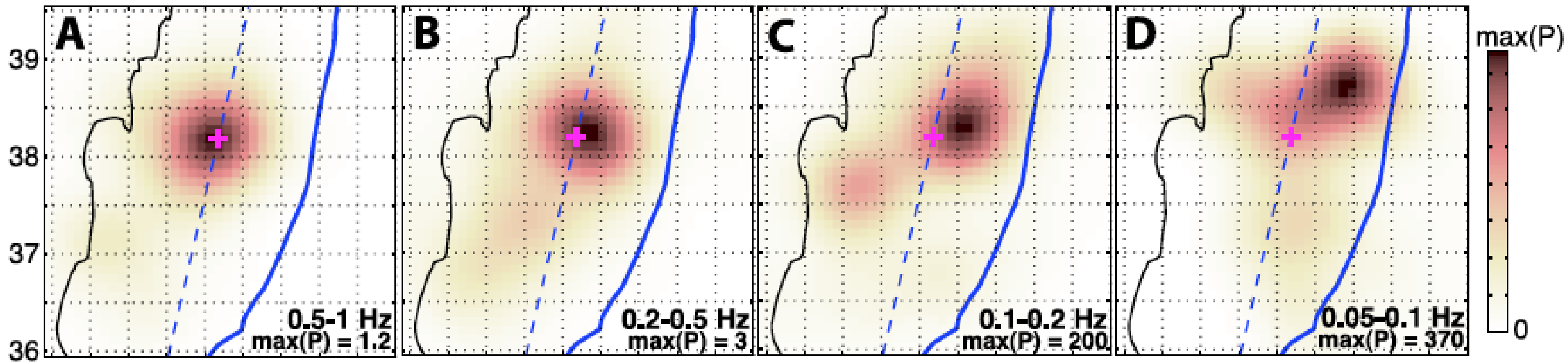
Frequency-dependent source properties



Frictional complexity as a function of depth along the thrust?

Lay and Kanamori, 2011 (Physics Today)

New observations - Backprojection

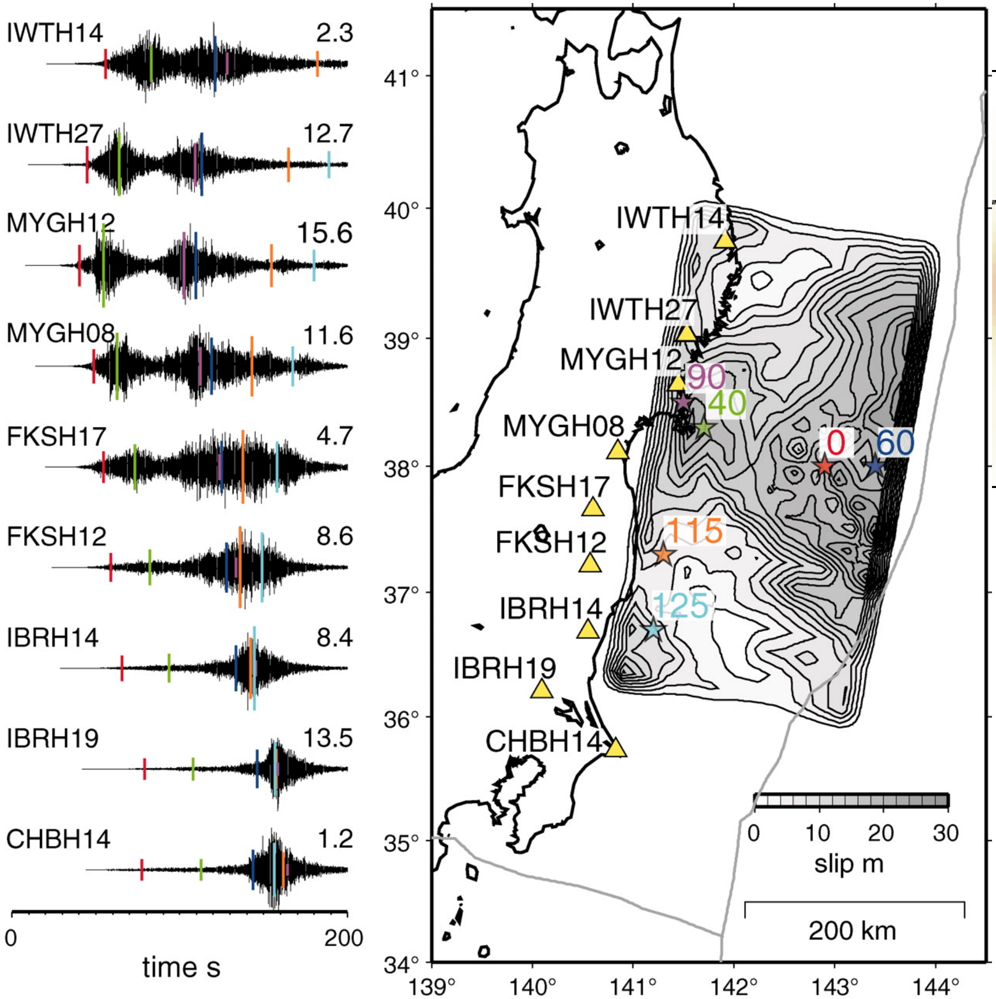


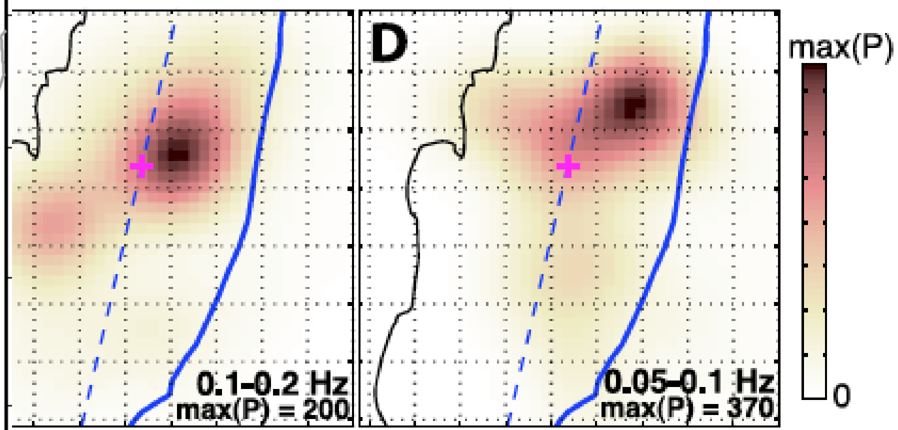
Is there any bias in the location of energy radiation?
Can pP or other depth phases improve our imaging?

Yao et al., 2011

Frequency dependent energy radiation observed using backprojection imaging (Meng,Koper,Ishii,Dionicio, etc)

New observations - Backprojection



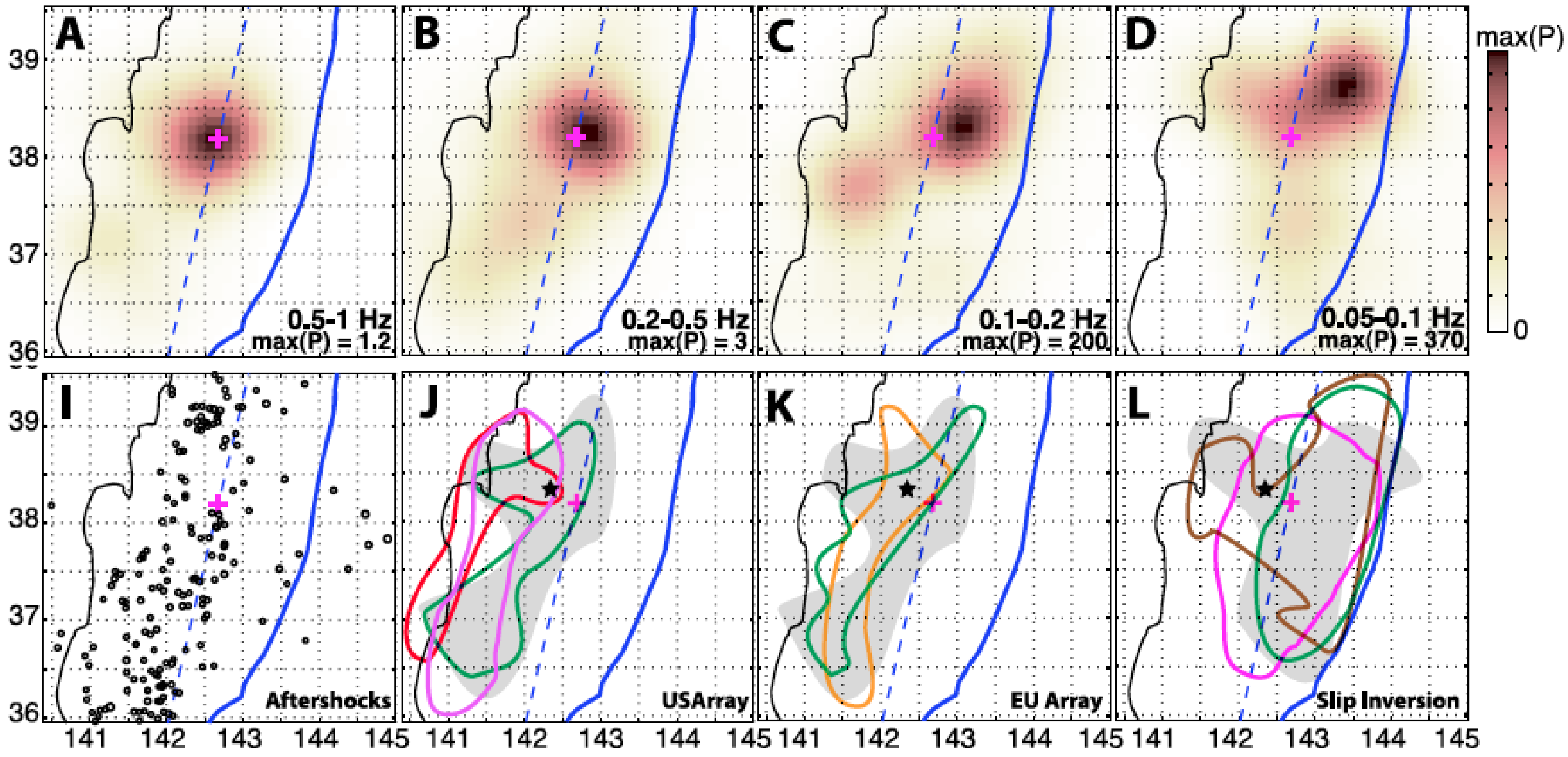


10-Hz high pass filtered strong motion records.

Ide et al., 2011

Frequency dependent energy radiation observed using backprojection imaging (Meng,Koper,Ishii,Dionicio, etc.)

New observations – Kinematic Source inversion

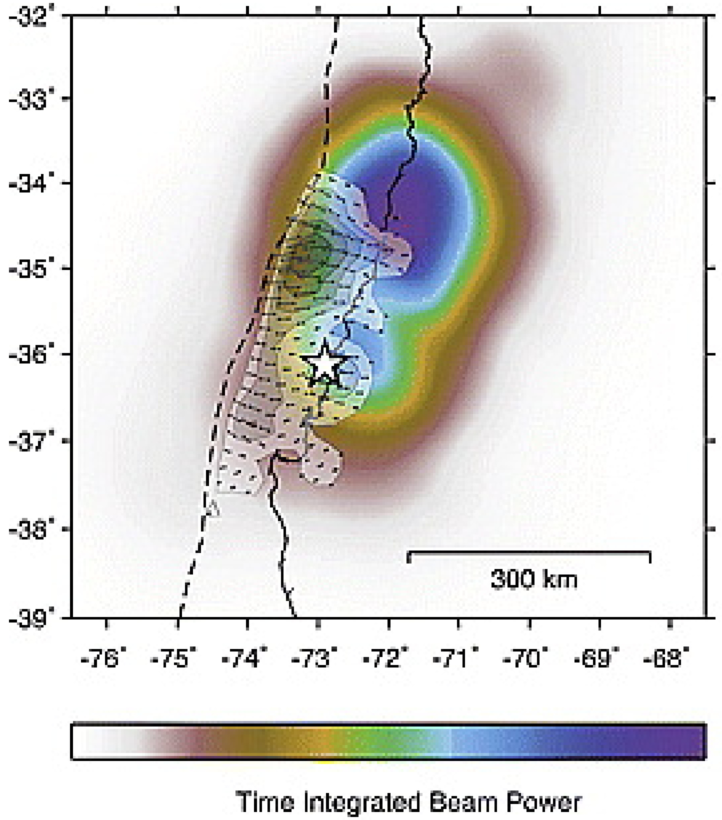


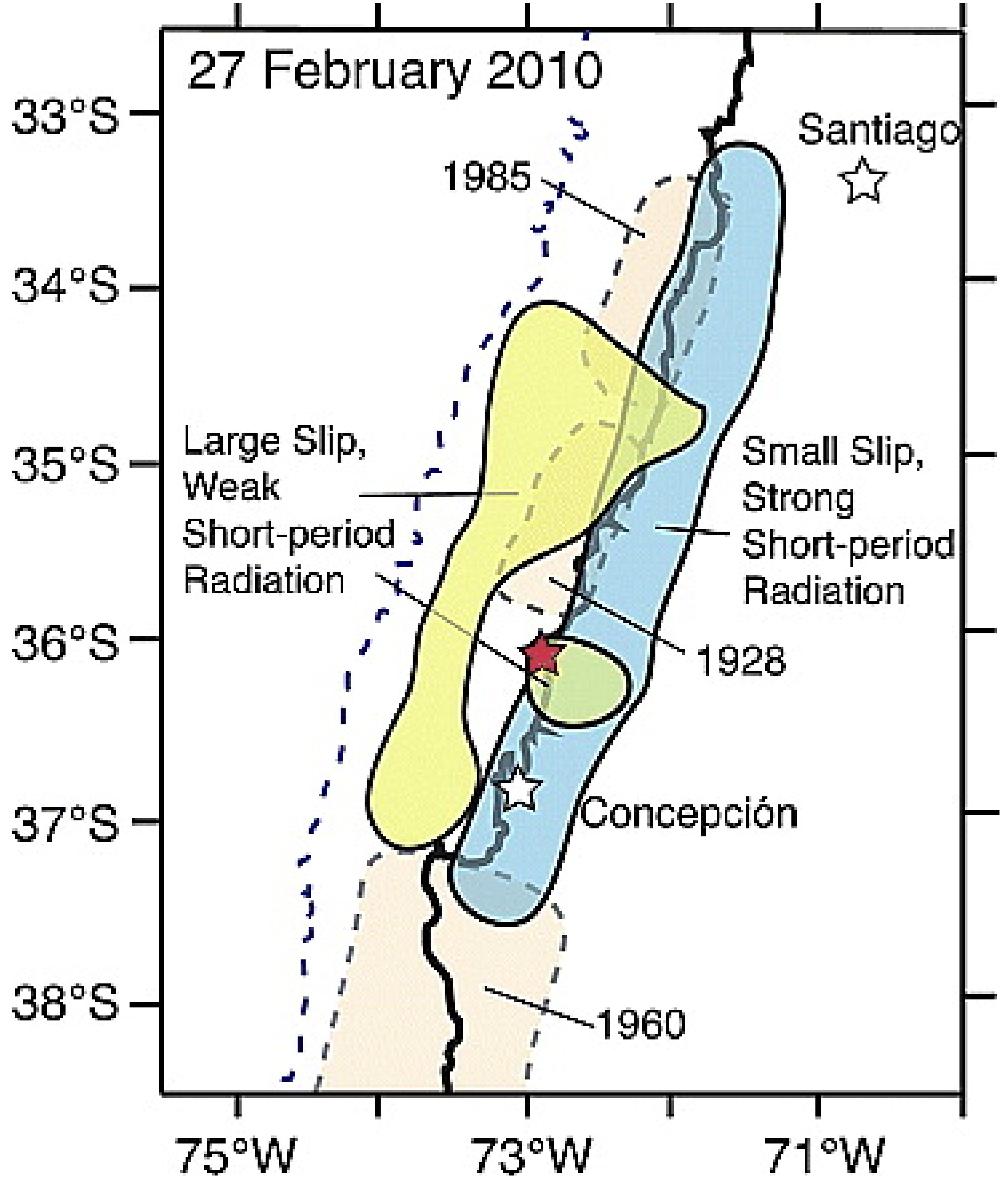
Yao et al., 2011

High frequencies deep using backprojection
Shallower high-slip regions from finite slip inversions

Kinematic Source Inversion

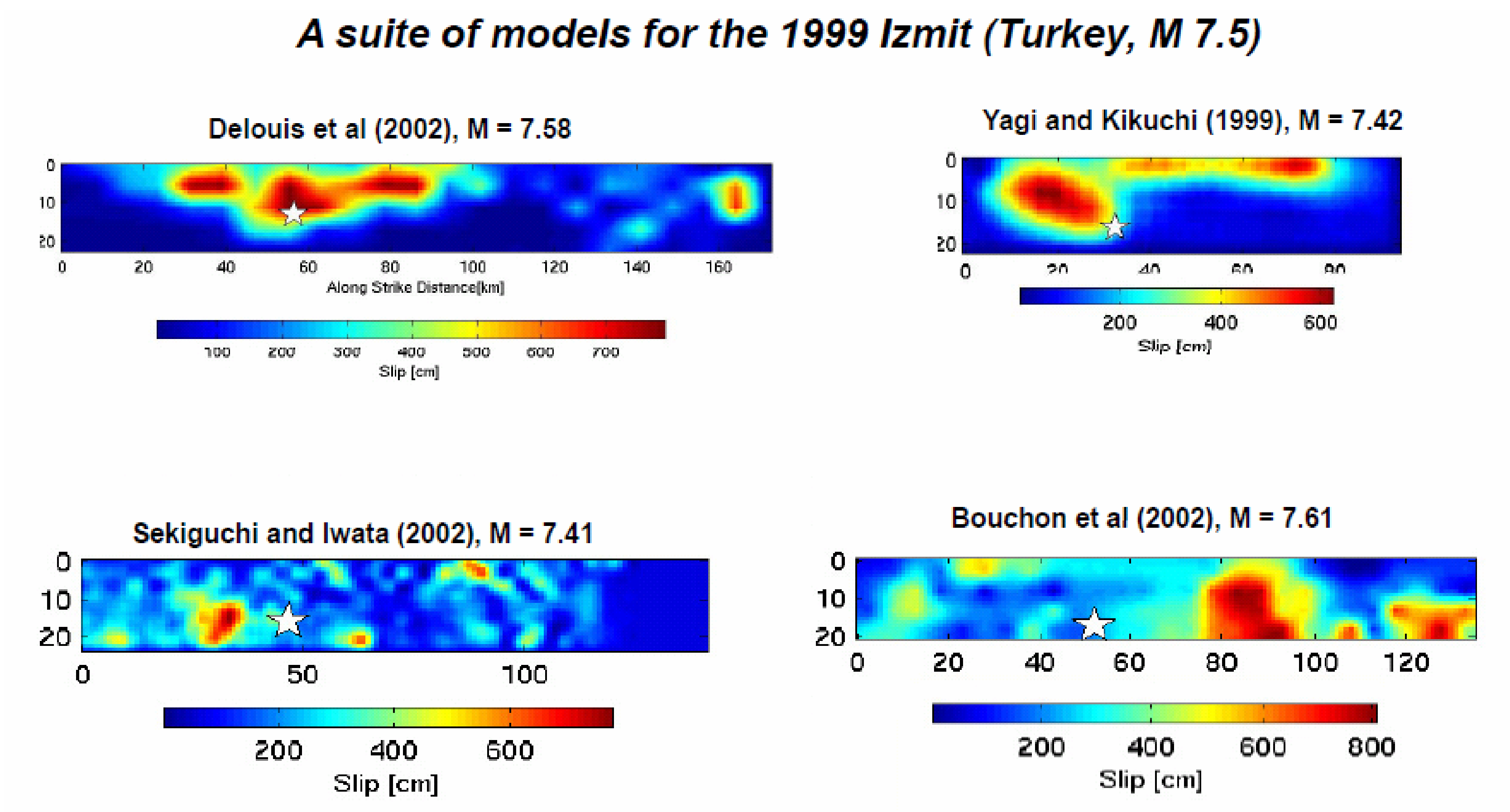
Koper et al., 2012





February 27, 2010 Mw8.8
Maule, Chile Earthquake

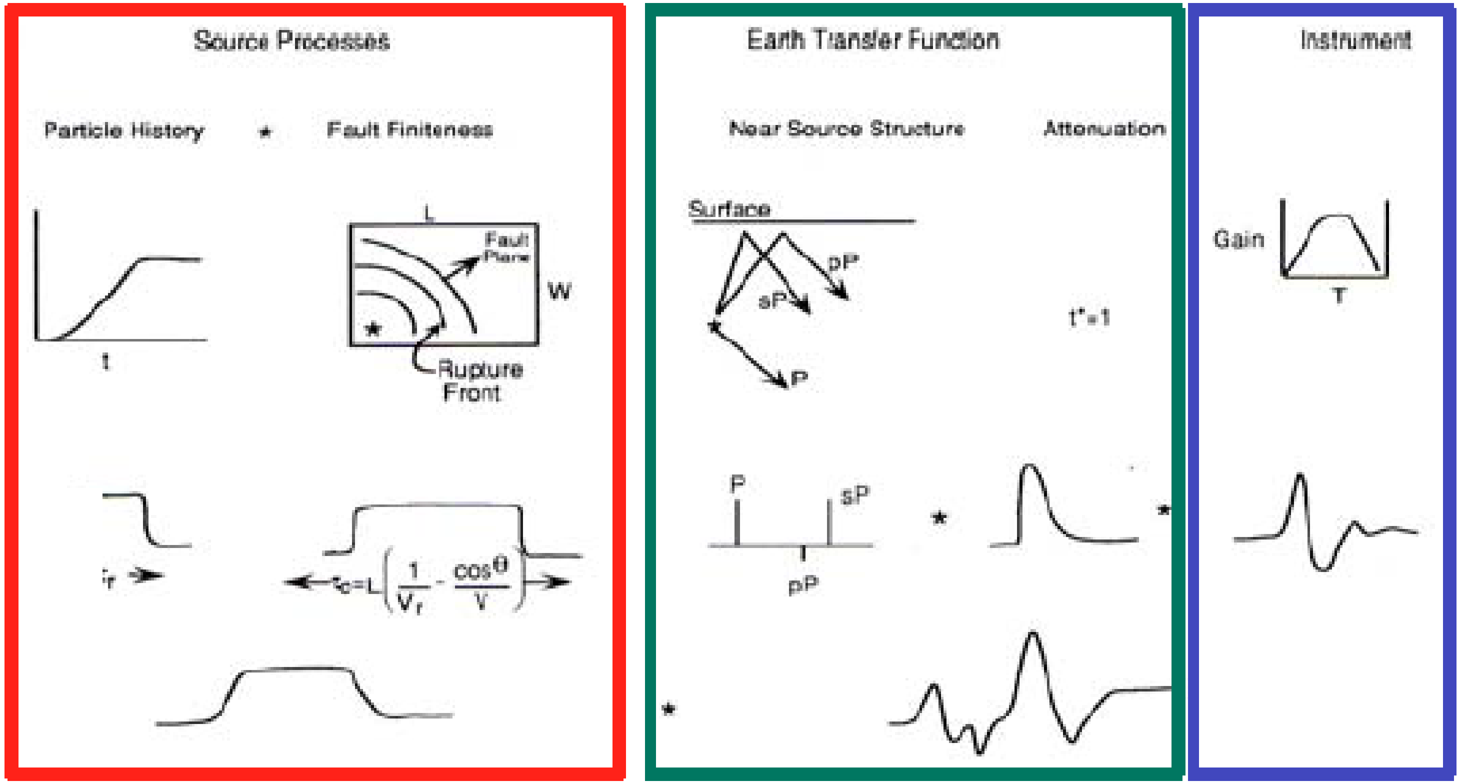
Kinematic Slip Inversions



Which features are robust. What are the uncertainties?
We will hear about this today.

Kinematic Slip Inversions

$$u_k(t) = s(t) * g_k(t) * i_k(t)$$



Martin Mai., Quest 2011

Which features are robust. What are the uncertainties?
We will hear about this today.

Earthquake source inversion is a hard problem

We want to … quantify the uncertainties in source inversions
distinguish robust features from artifacts

Data is band-limited
Recorded on the surface only
Non-uniqueness

Uncertainty in Green's function
Uncertainty in fault geometry, hypocenter.

Martin Mai., Quest 2011

Which features are robust. What are the uncertainties?
We will hear about this today.

Physically based earthquake rupture

Can we explain these observations using a physical model?

"earthquake featured a diversity of rupture styles, comprising distinct stages of fast and slow rupture intermingled with high-frequency radiation"
Galvez et al., 2011

Physically based earthquake rupture

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"earthquake featured a diversity of rupture styles, comprising distinct stages of fast and slow rupture intermingled with high-frequency radiation"
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Today:
Dynamic Rupture

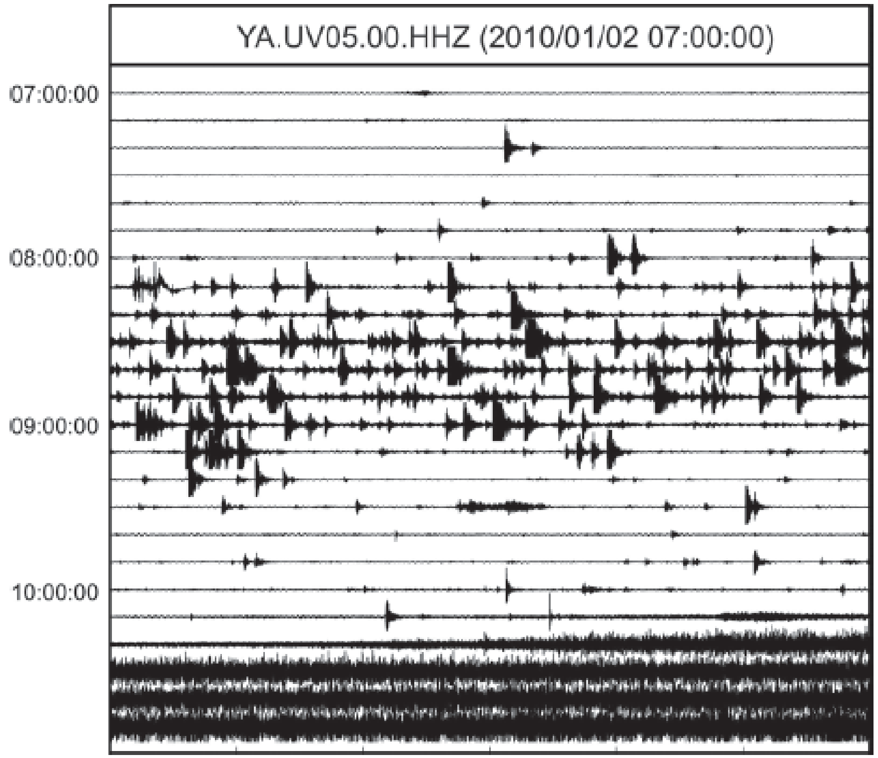
Reproduce the observed complexity?
Slow slip, brittle asperities
Spatial variations of physical properties of faults

Long Period and/or high frequency seismicity

Relation to eruption, state of stress of the upper crust, magma movement?

Forecasting Tool?

Volcanic seismicity at Piton de la Fournaise



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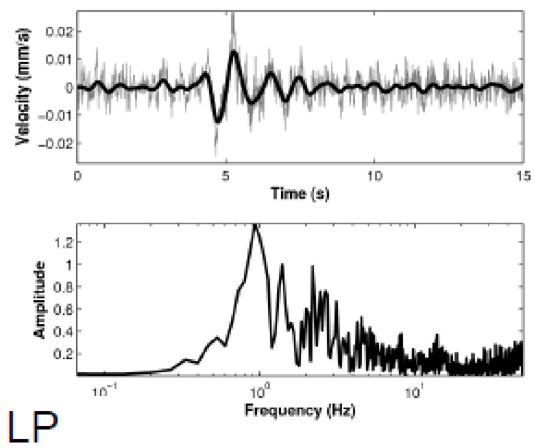
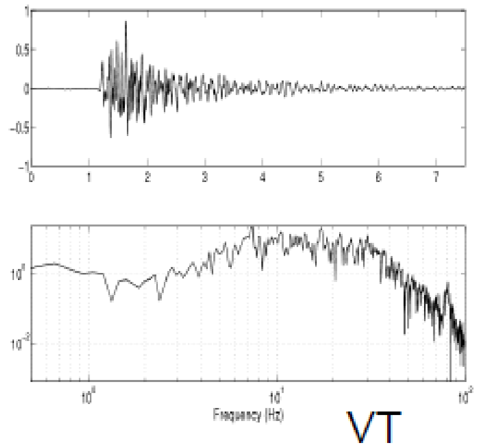
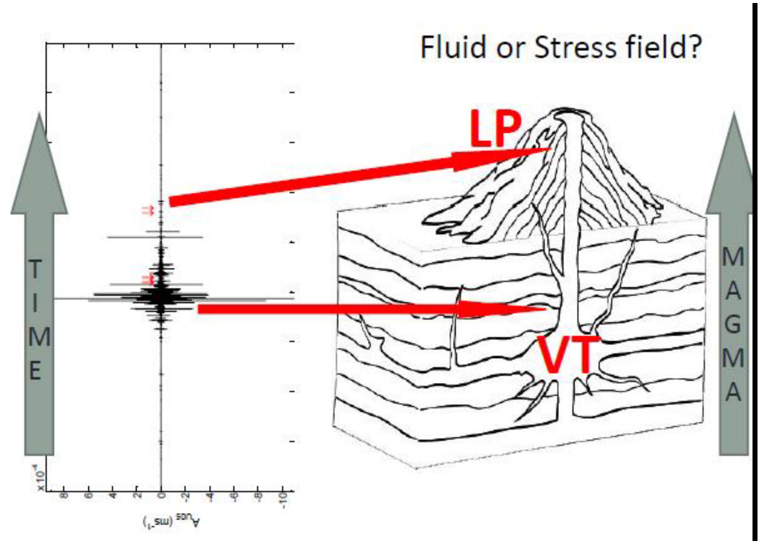






If we have time, some of the things I do …

Deep and Intermediate Depth Earthquakes

- Depth > 50 – 60 km
- 25% of global earthquake catalogs
- Mechanism is not well constrained

Occur at temperatures and pressures above the point where ordinary fractures ought to occur.

Intermediate Depth Earthquakes

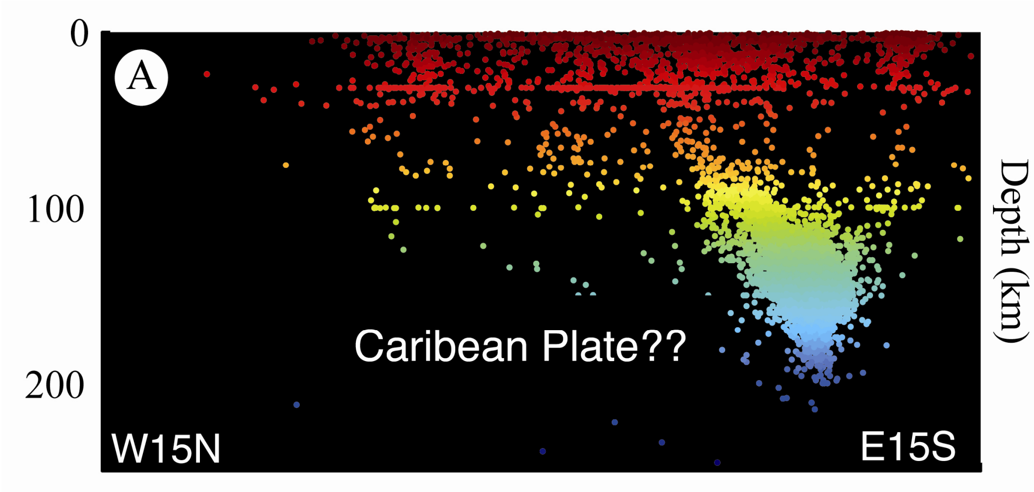
Deep and Intermediate Depth Earthquakes

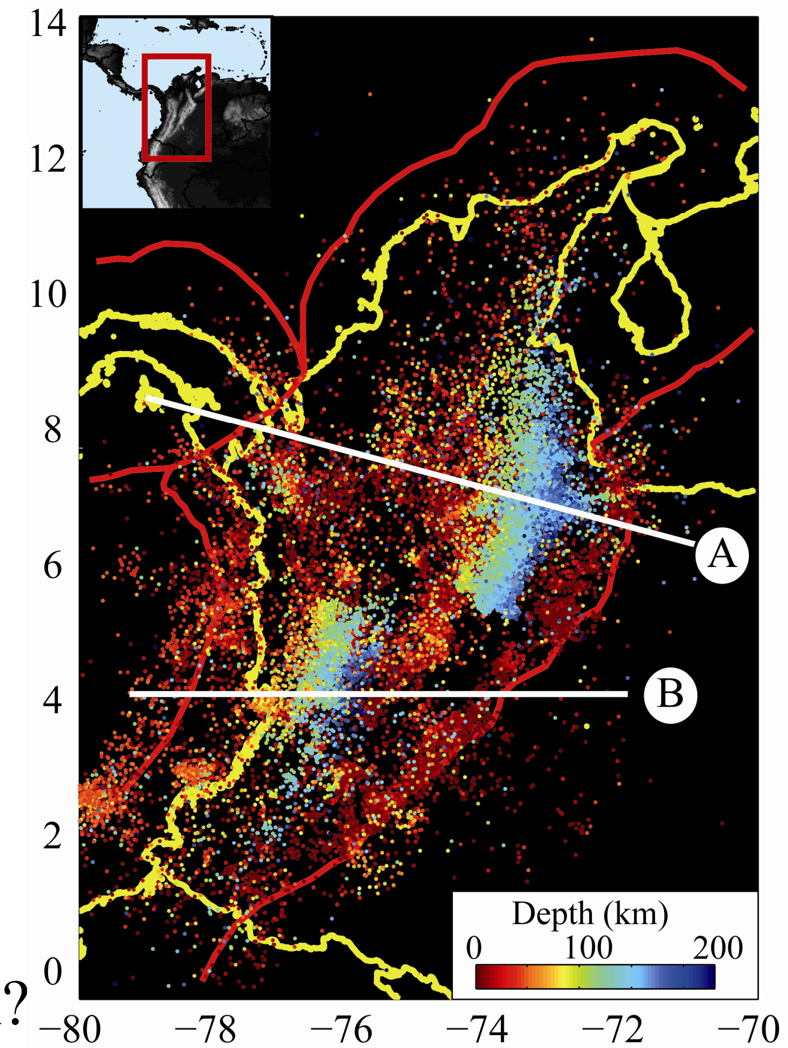
- Depth > 50 – 60 km
- 25% of global earthquake catalogs
- Mechanism is not well constrained

Proposed Mechanisms

- Dehydration embrittlement
- Thermal Shear runaway instability
- Phase transformations
- ….

Tectonics and the Bucaramanga Nest





Bucaramanga Nest

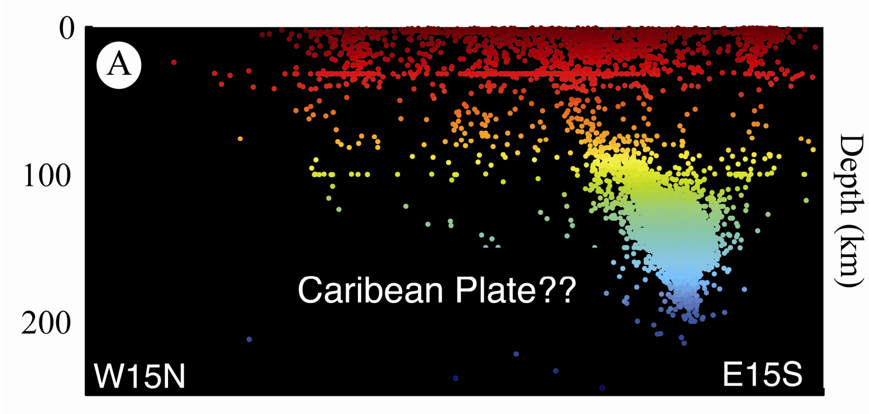
Depths 145 – 165 km

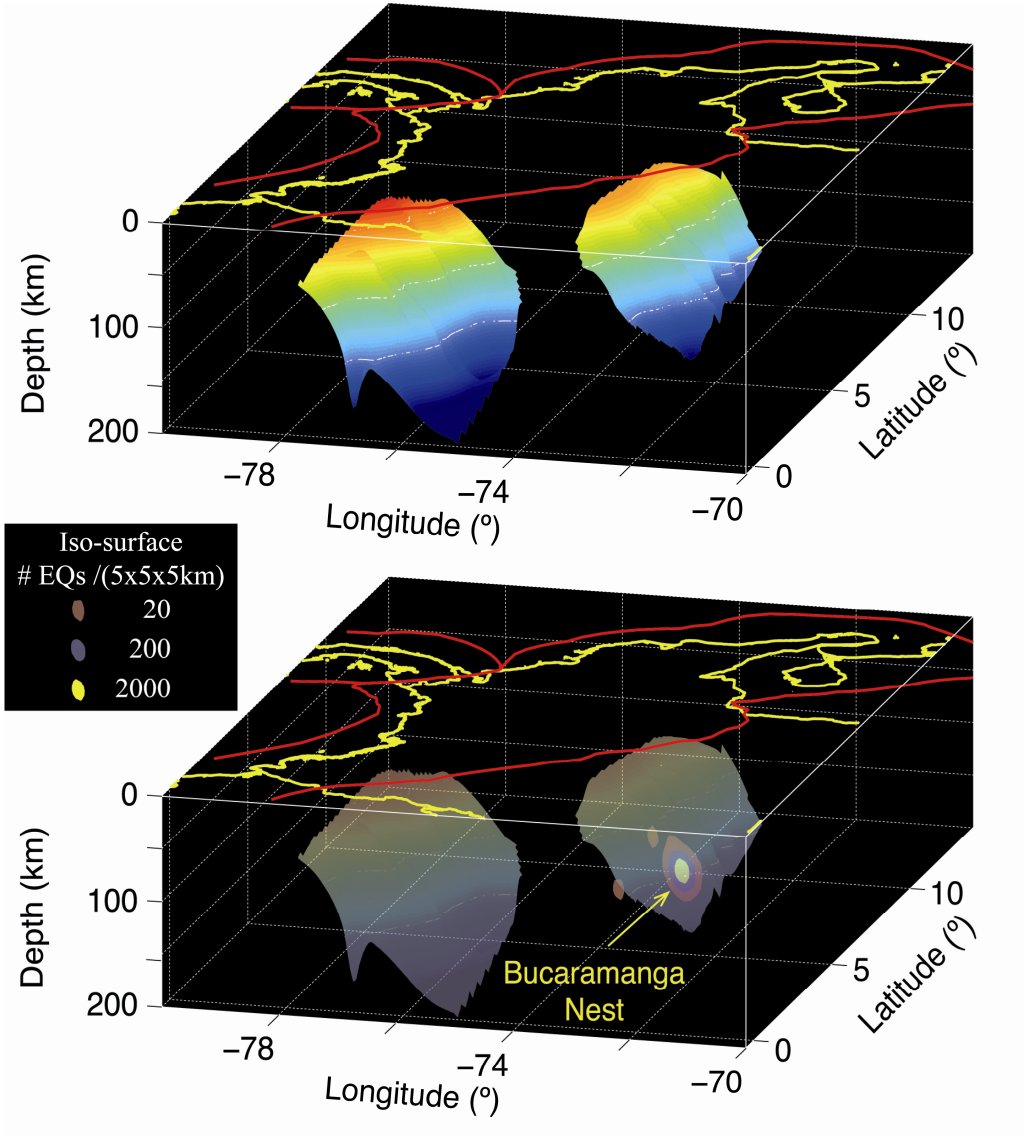
Caribbean subduction? Slab Collision?

Most concentrated nest in the world

Prieto et al, 2012, submitted

The Bucaramanga Nest – a Natural Laboratory





Clear isolation of nest

More than 2.000 earthquakes on a 5x5x5 km volume.

Bucaramanga Nest

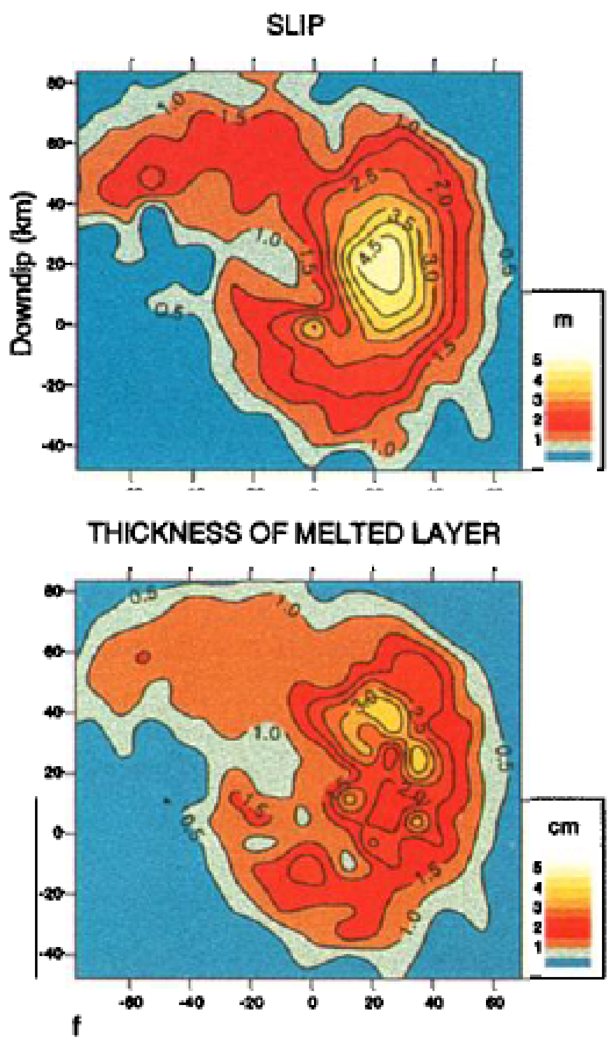
Depths 145 – 165 km

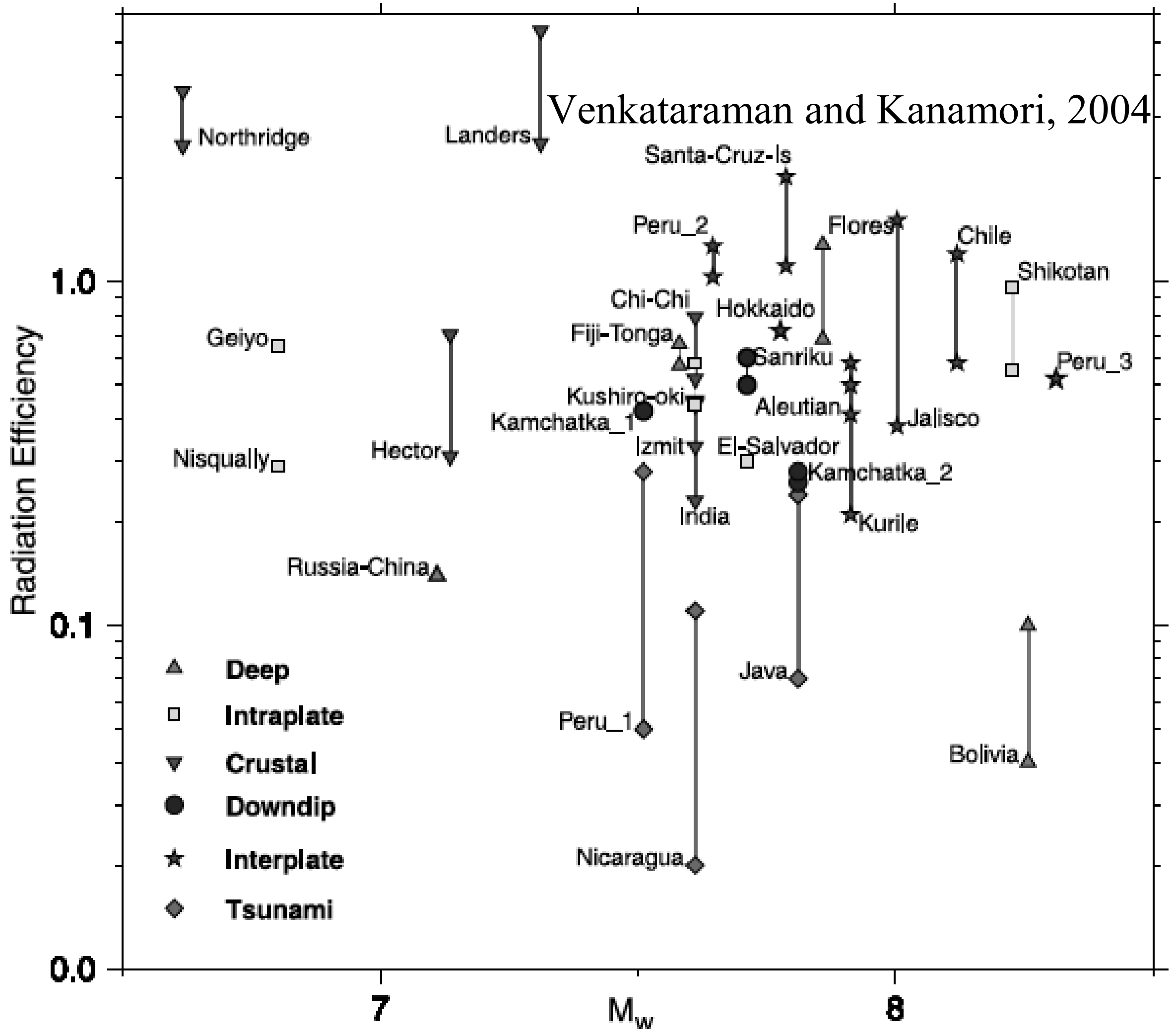
Caribbean Plate?

Most concentrated nest

Prieto et al, 2012, submitted

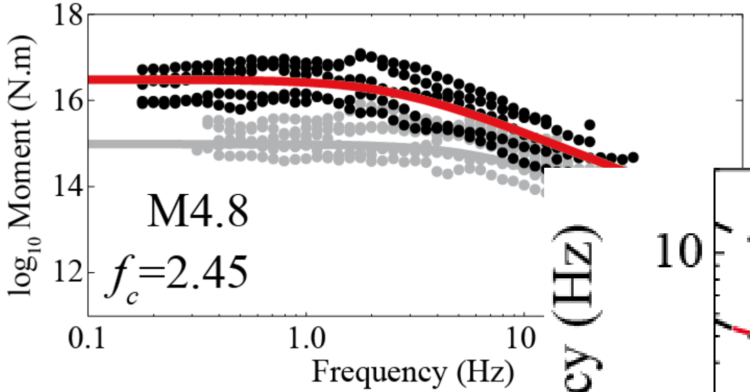
Frictional Melting at depth?

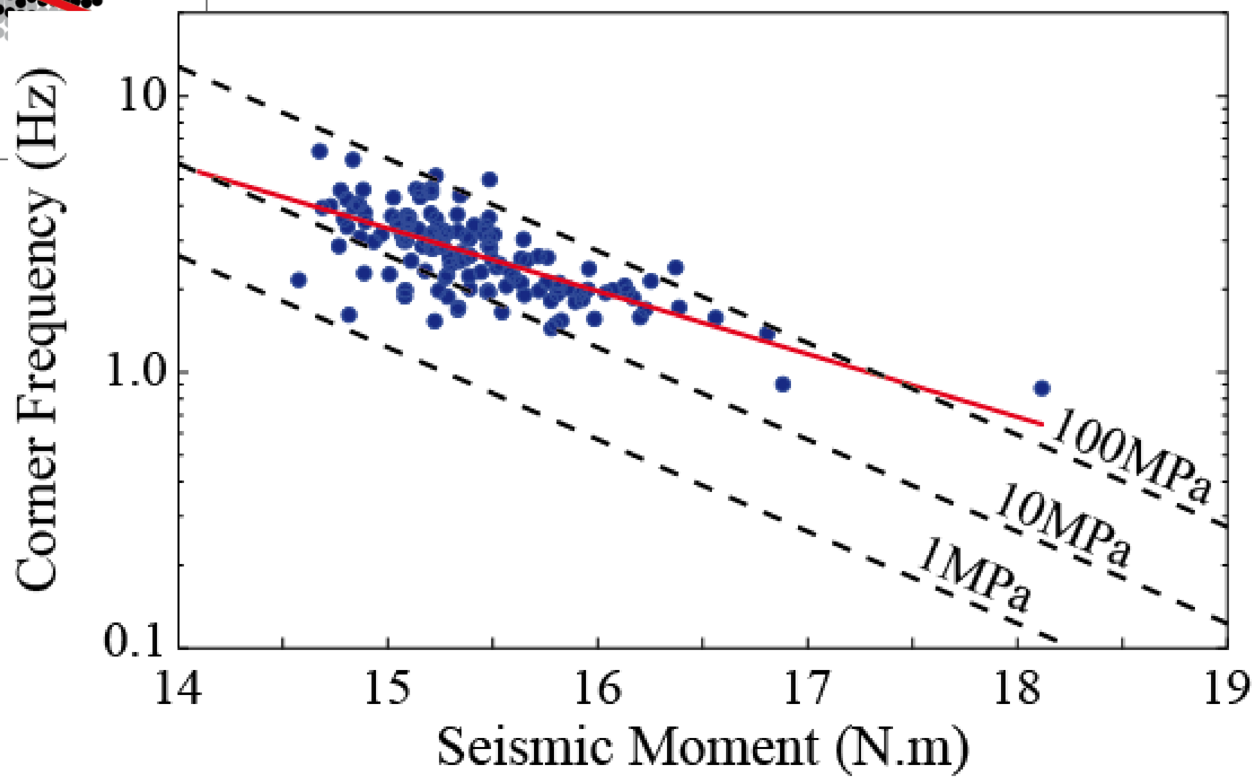




Kanamori et al. (1998) & Bouchon et al (1999) show evidence of small seismic efficiency and frictional melting for deep Bolivian earthquake.

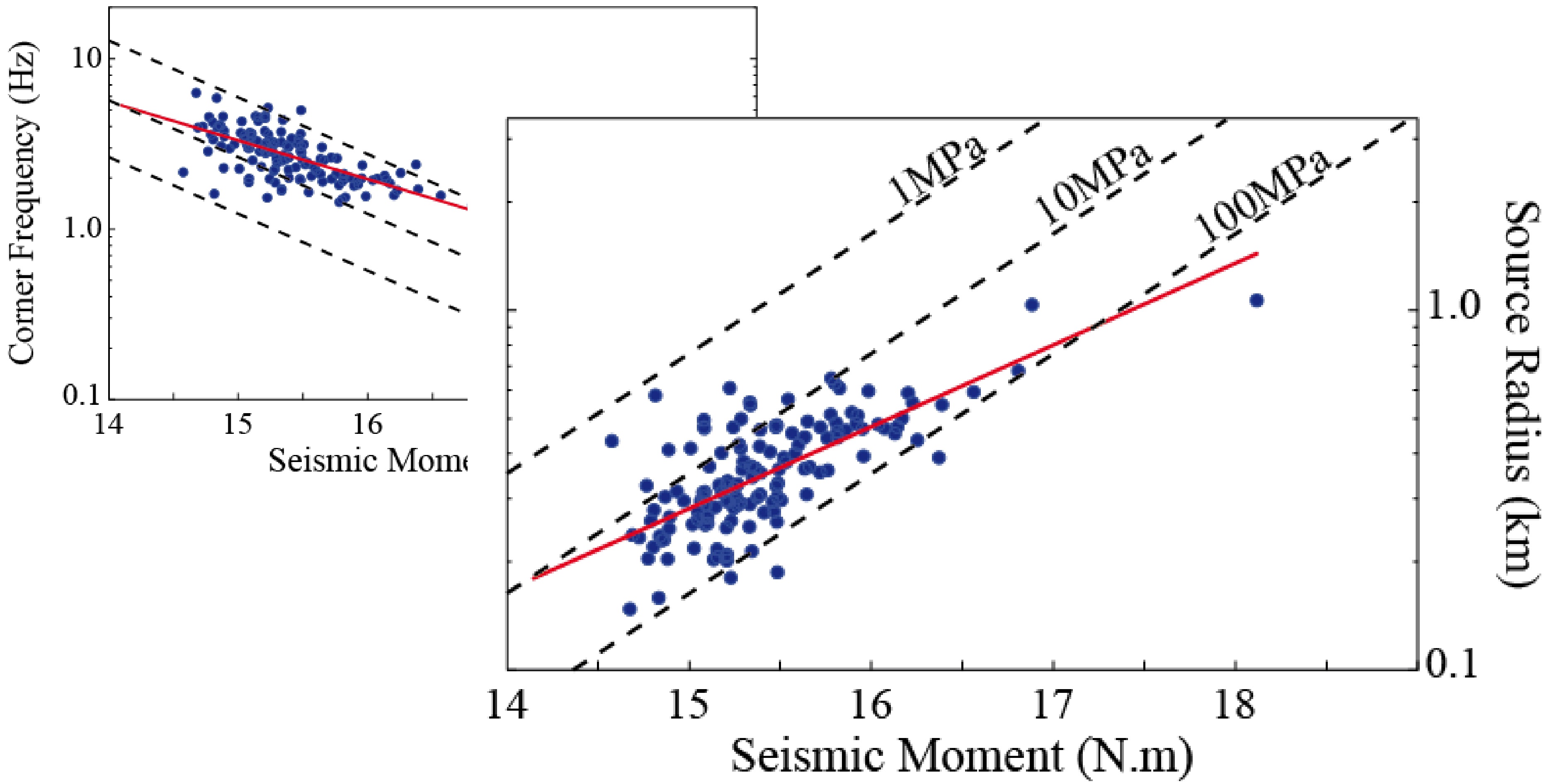
Corner frequencies and Source Radius





$$S(f) = \frac{M_0}{1+\left(\frac{f}{f_c}\right)^2}$$

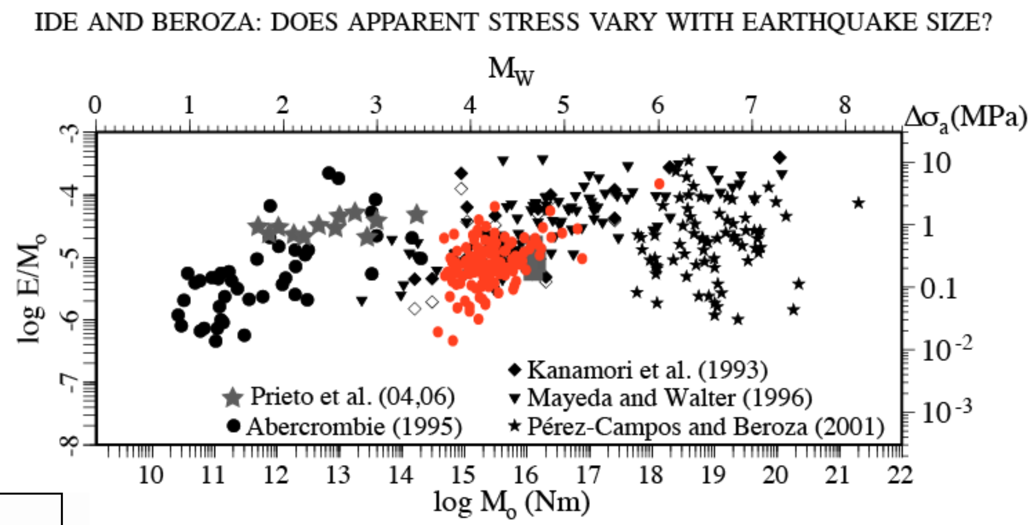
Corner frequencies and Source Radius

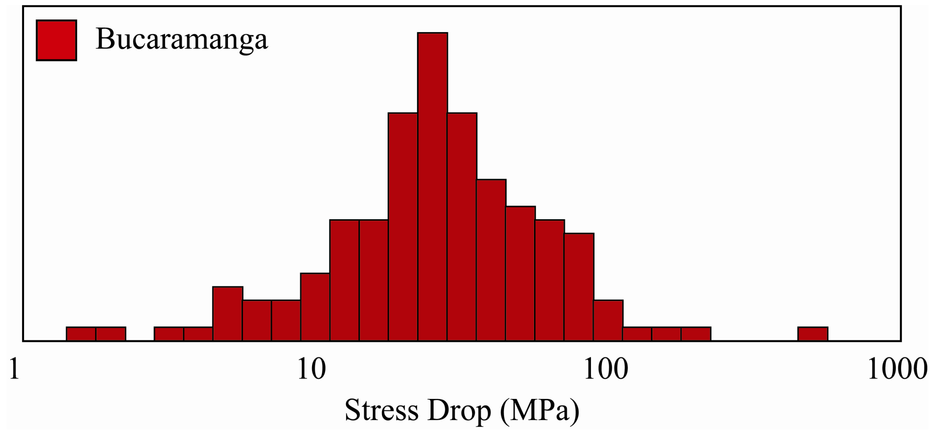


Small source area (1 km for a M5.7 earthquake)

Leads to very high Stress Drops

Radiation Efficiency





$$\eta \propto \frac{2\sigma_a}{\Delta\sigma} \approx 0.045$$

Relatively large stress drops, small apparent stress.

Suggests very small seismic efficiency (~0.045)

If we have time, some of the things I do …

Enjoy this session