Constraints on source properties of low-frequency earthquakes (LFEs) in Parkfield and Cascadia

Amanda M. Thomas

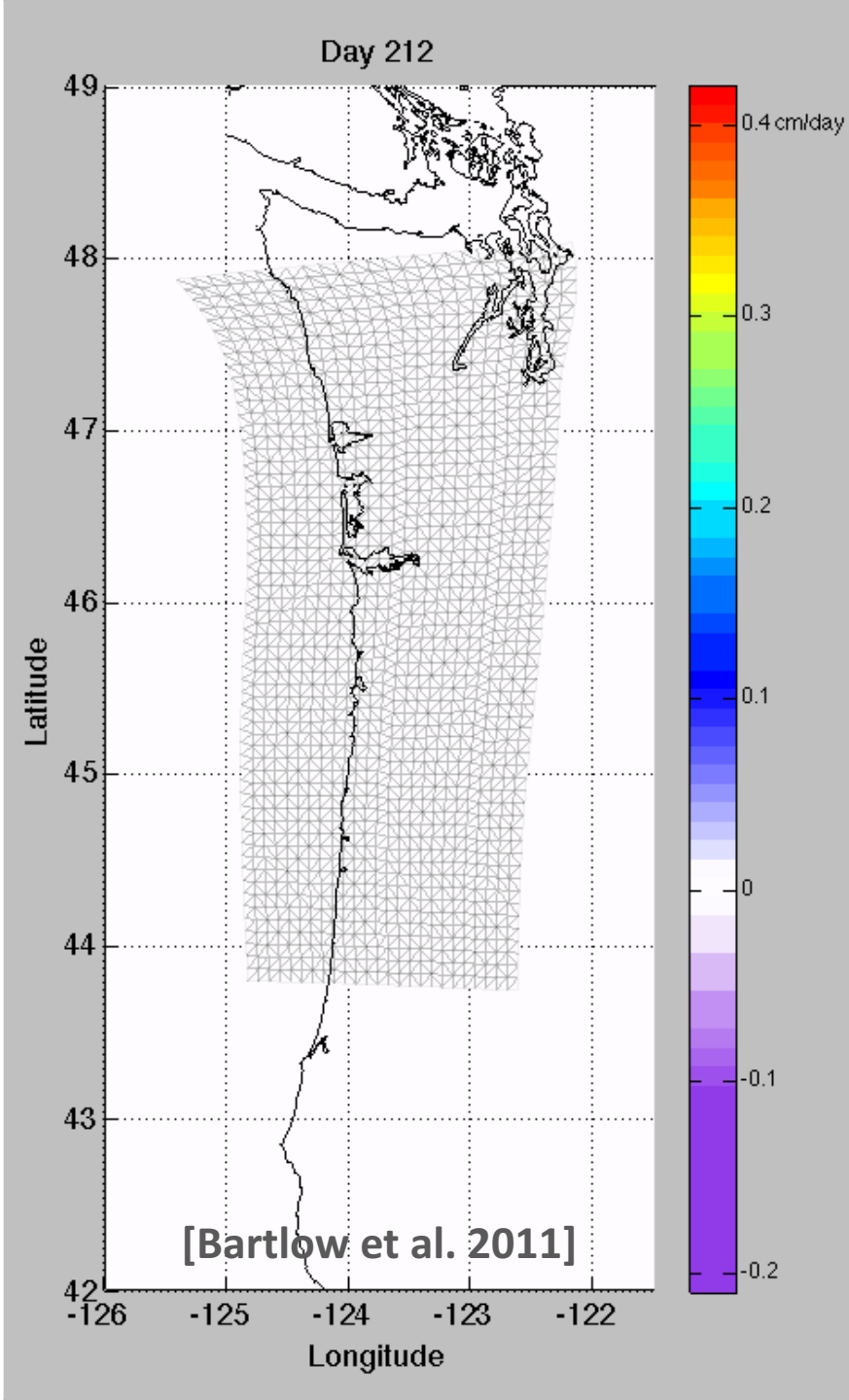
SCEC, 9/13/2016

PRINCETON UBC

Slow vs. fast earthquakes

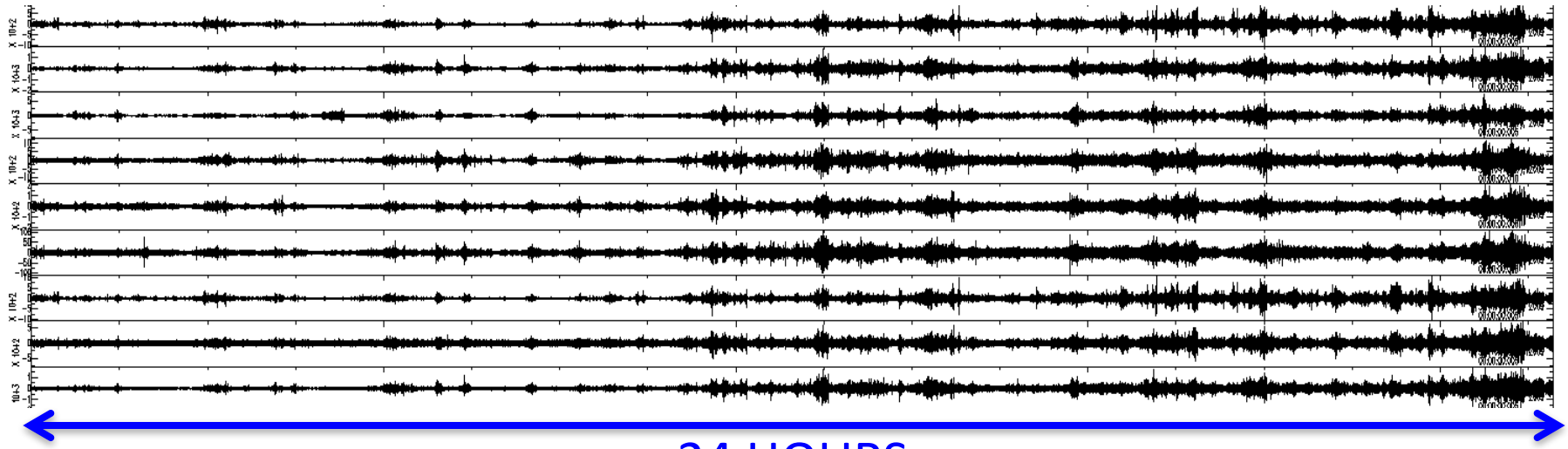
Fast earthquakes have durations of fractions of a second to a few minutes.

Slow earthquakes have durations of fractions days, weeks, months and even years.



Tremor and low-frequency earthquakes

Tremor is an unusual seismic signal….



Tremor and low-frequency earthquakes

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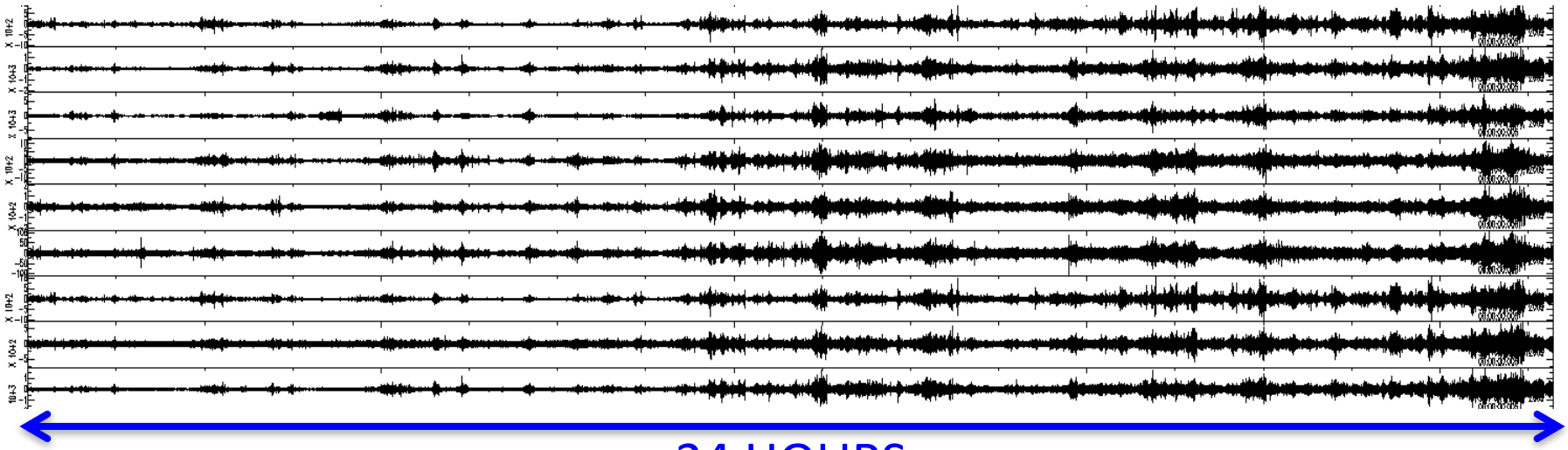
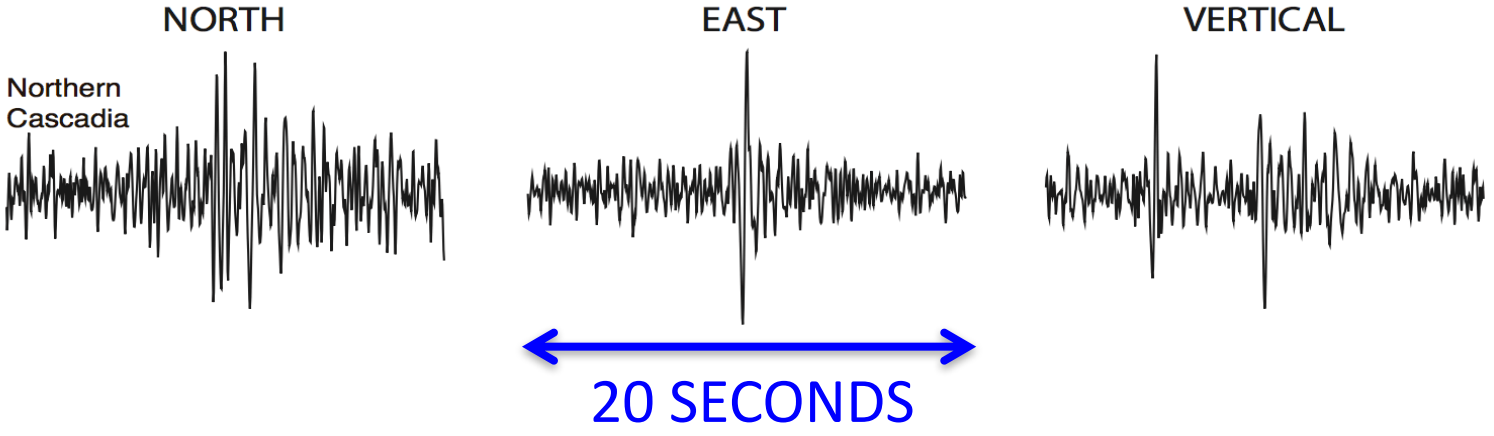


24 HOURS

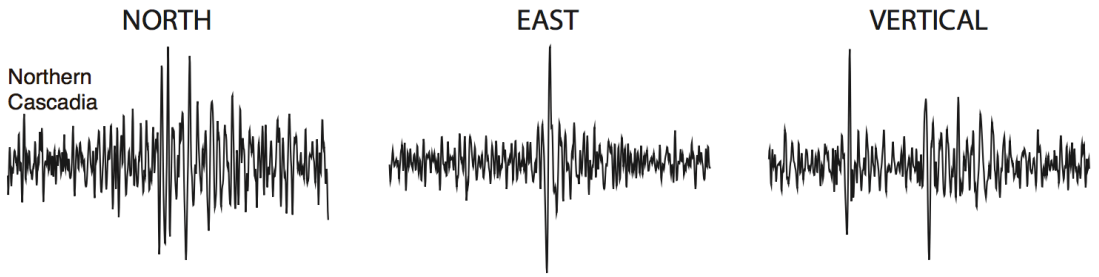
…that can be explained as a superposition of small earthquakes.

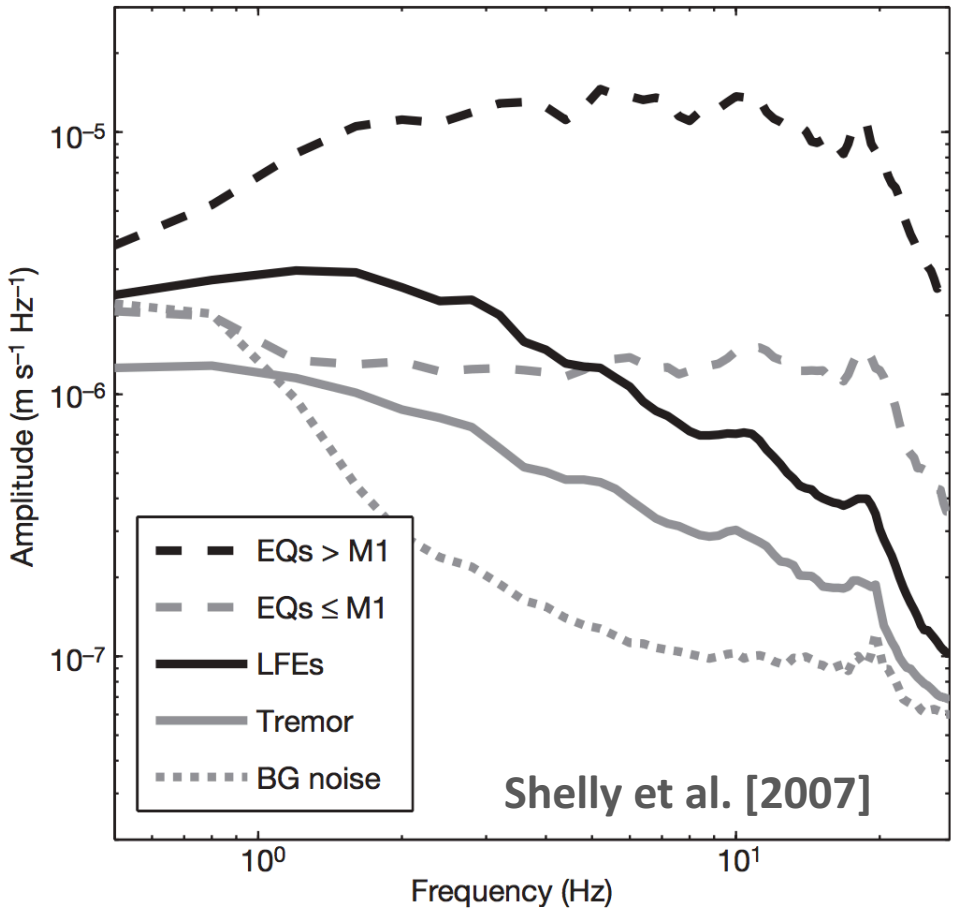


Low-frequency earthquakes

Properties of LFEs:

1) Depleted in high frequency content relative to traditional earthquakes of similar magnitude
2) Reflect slip on asperities that rupture repeatedly in response to surrounding slow slip
3) Never get large





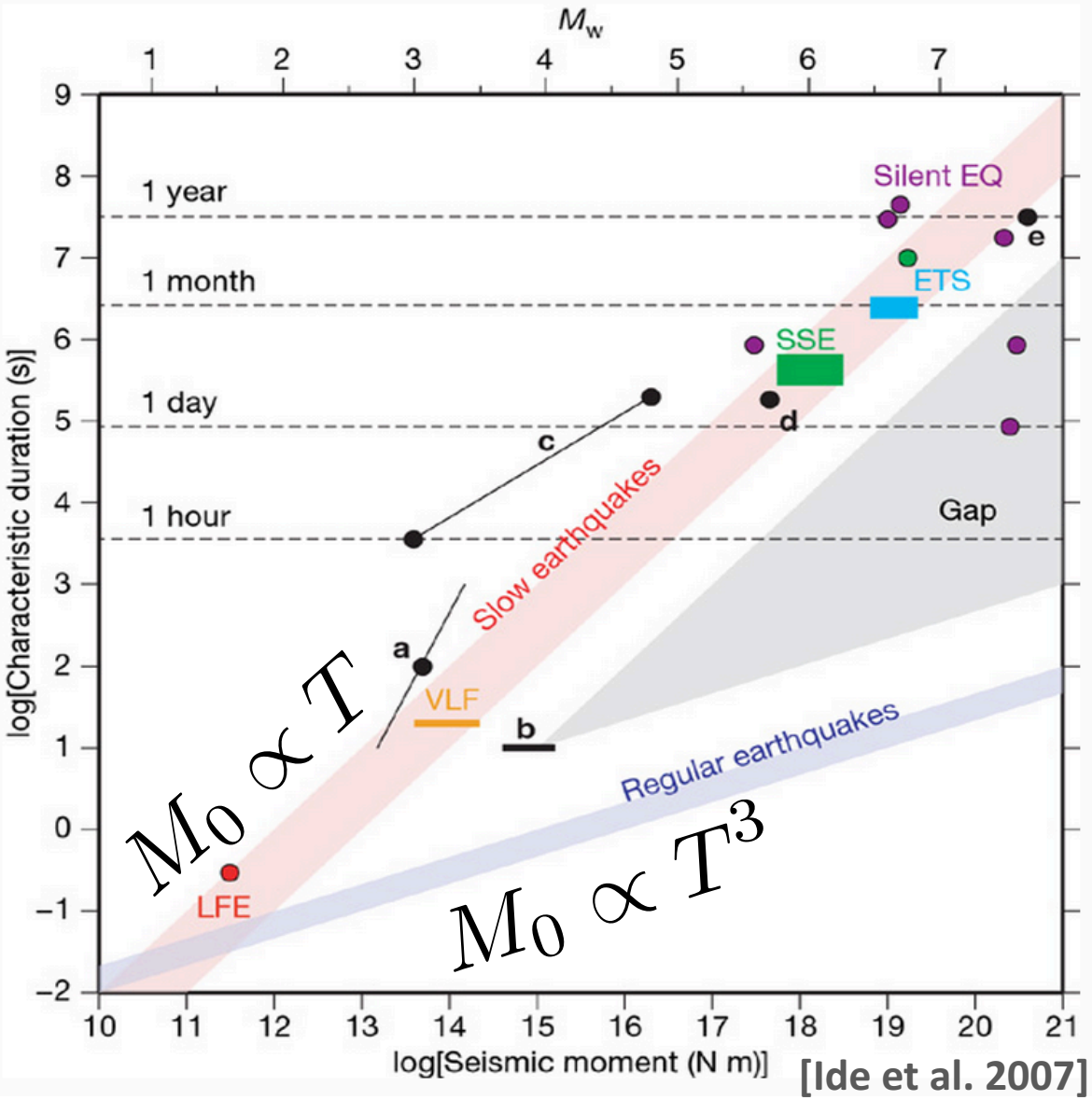
Moment-duration scaling

Seismic moment is a measure of earthquake size (similar to magnitude)

Moment — Area

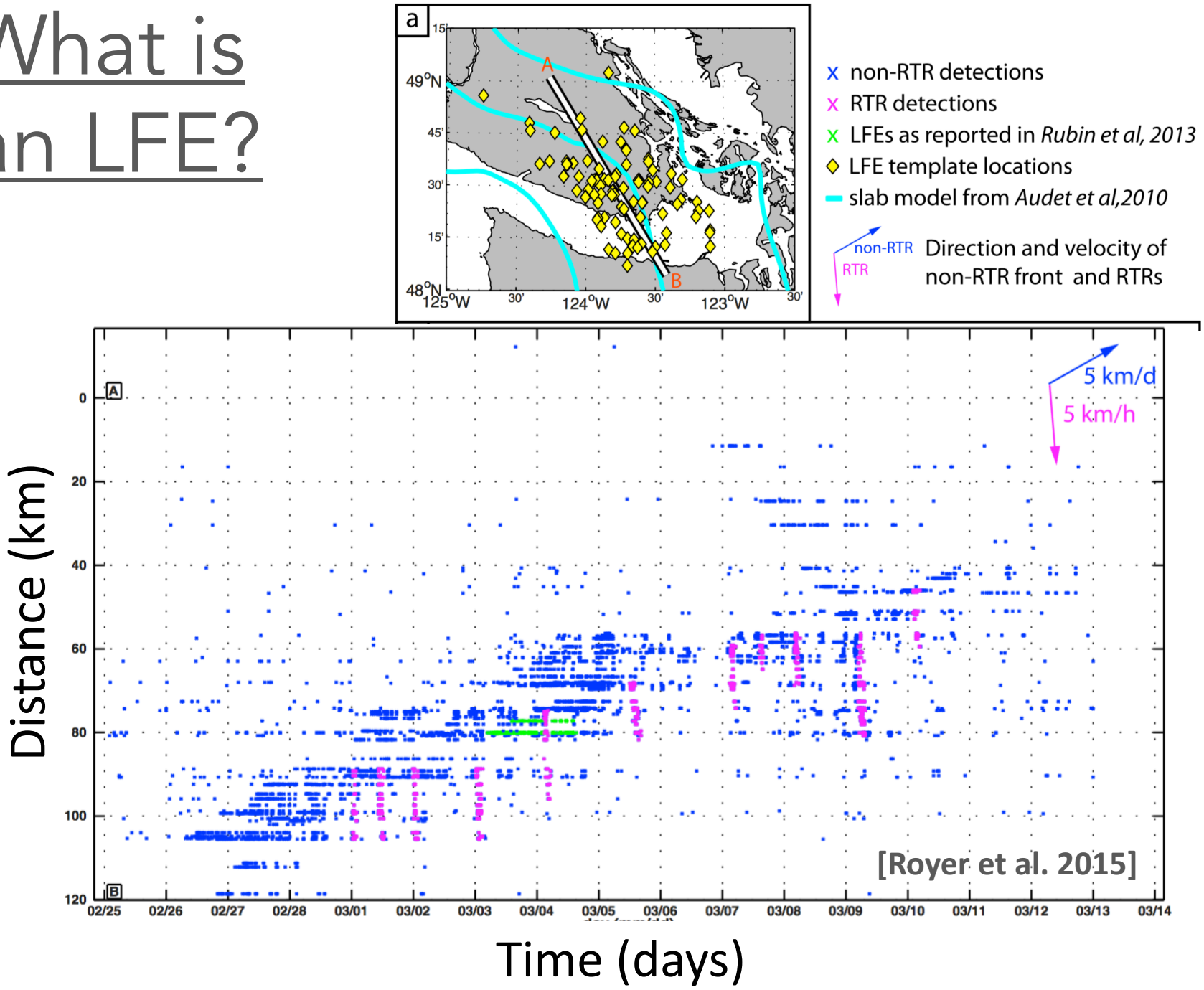
$$M_0 = \mu A d$$

Rigidity — Displacement



[Ide et al. 2007]

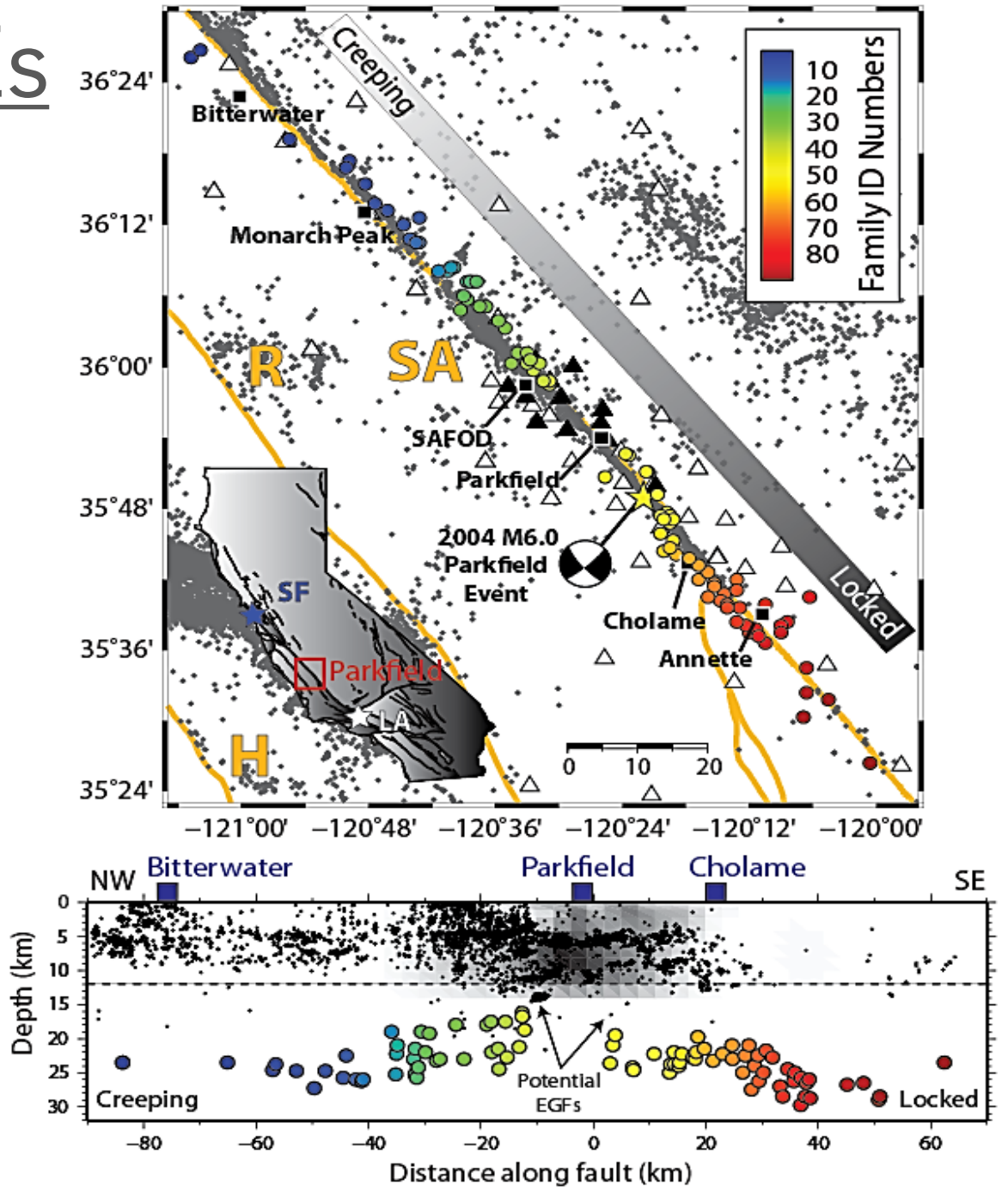
What is an LFE?



What is an LFE?

PROPERTY	**EARTHQUAKES**	**LFEs**
DURATION (M=1)	~0.01 s	
b-VALUE	1	
MOMENT-DURATION SCALING	$M \sim D^3$	
SELF SIMILARITY	YES	

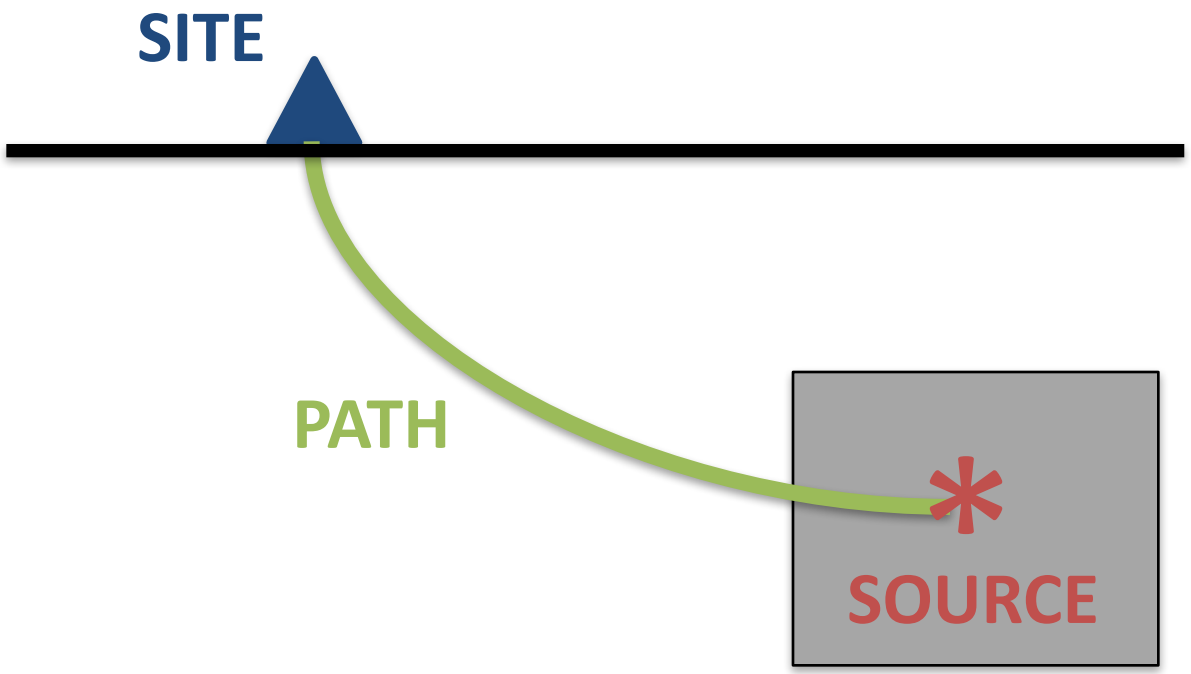
Parkfield LFEs



Source seismology

RECORDED GROUND MOTION **SOURCE** **PATH** **SITE**

$$u(t) = s(t) * g(t) * i(t)$$



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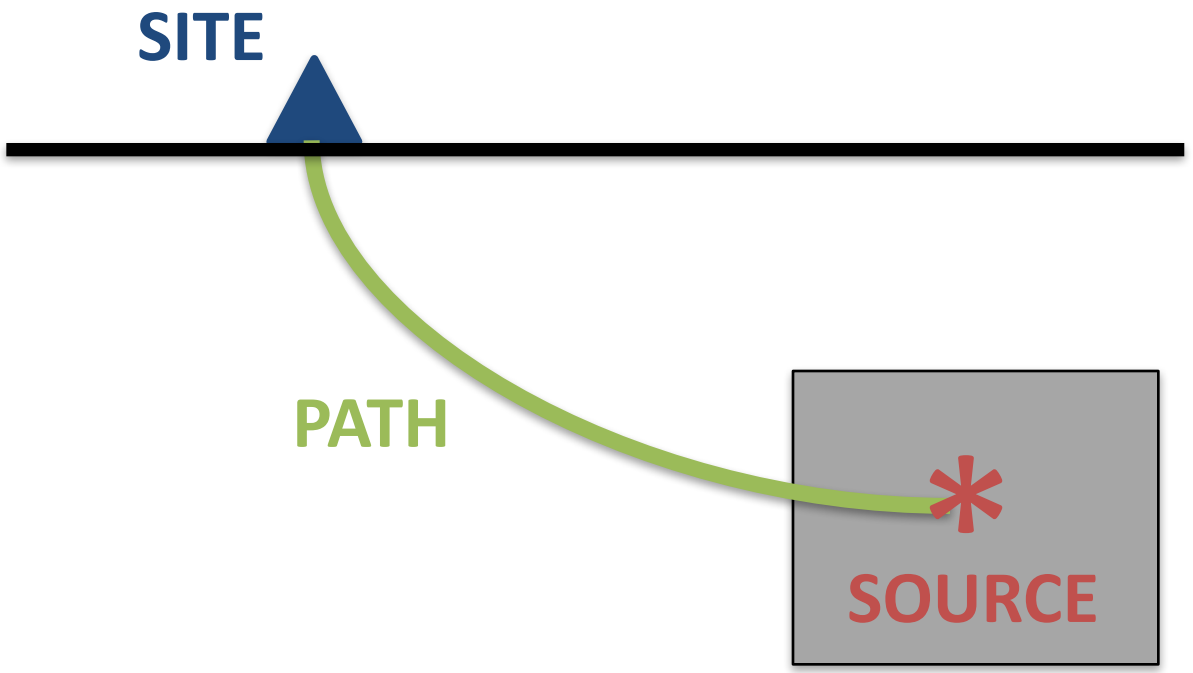


Source seismology

TARGET EVENT GROUND MOTION

SOURCE PATH SITE

$$u = s(t) * g(t) * i(t)$$

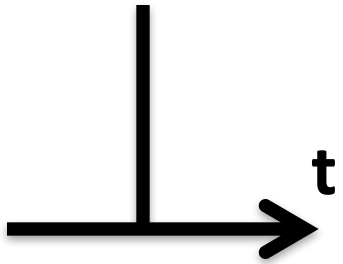
eGF GROUND MOTION

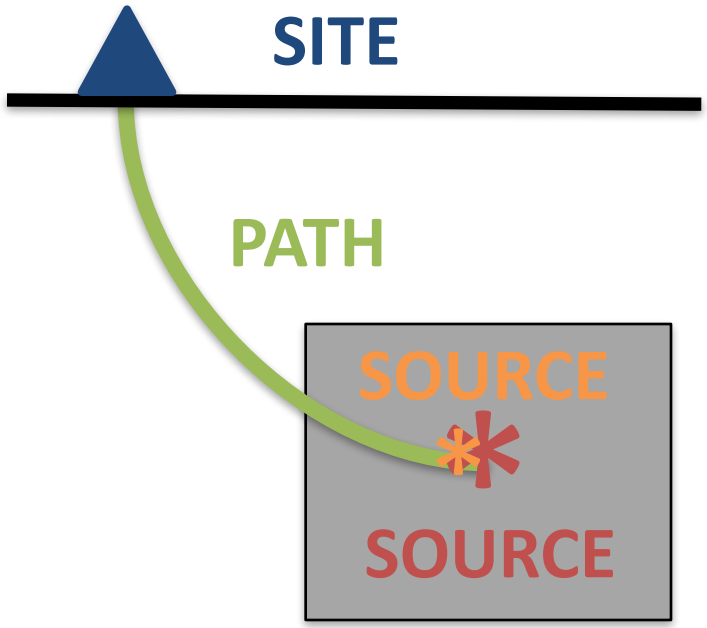
SOURCE PATH SITE

$$u = s(t) * g(t) * i(t)$$

If the eGF source duration is short relative to the the target event then...

$$s(t) \approx$$

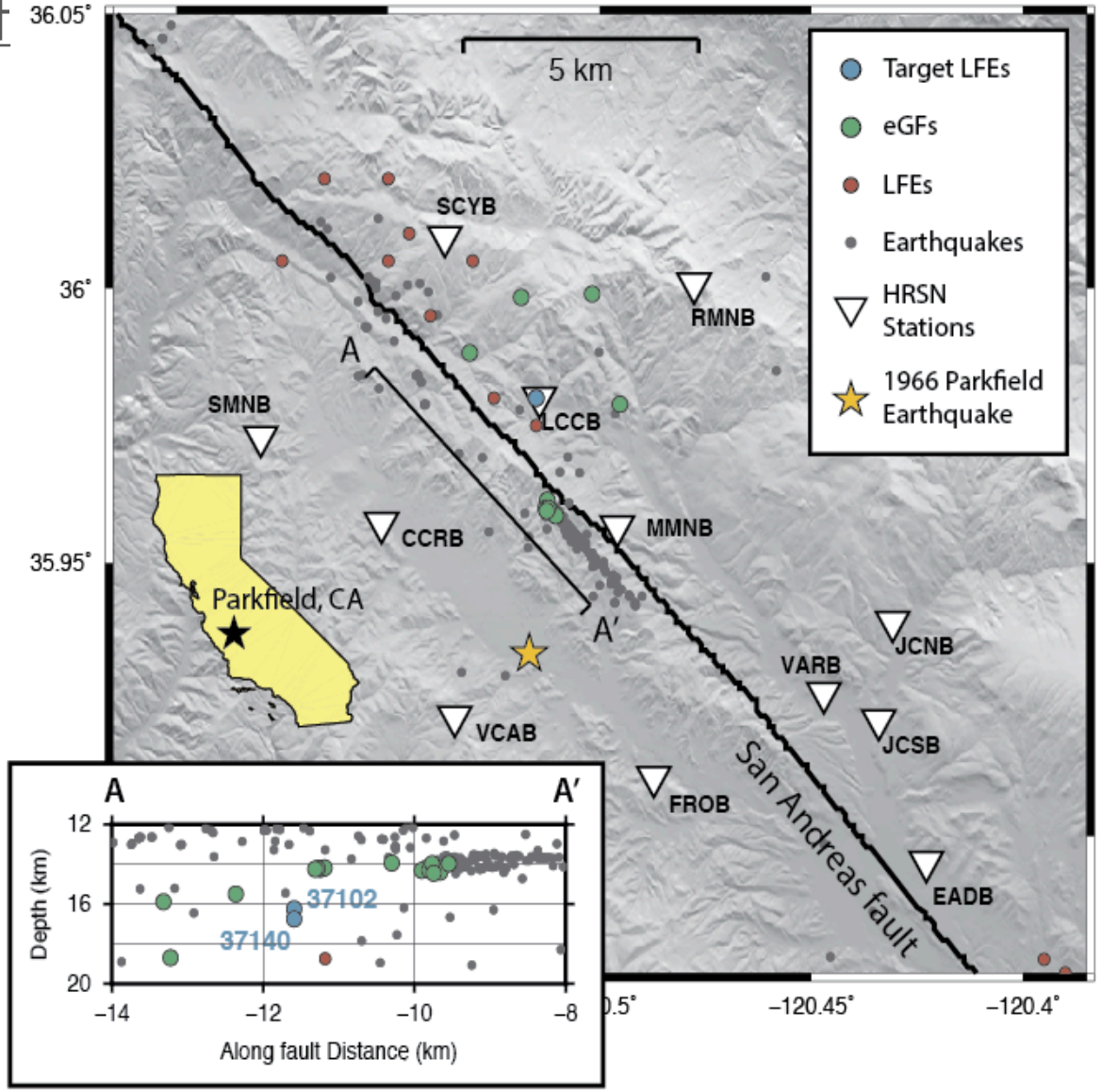




eGf analysis applied to LFEs

Requirements for eGf analysis:

1) The earthquakes are "close"
2) They have the same focal mechanism
3) Their durations are substantially different (i.e. the eGf doesn't contain a strong signature of its own source complexity)



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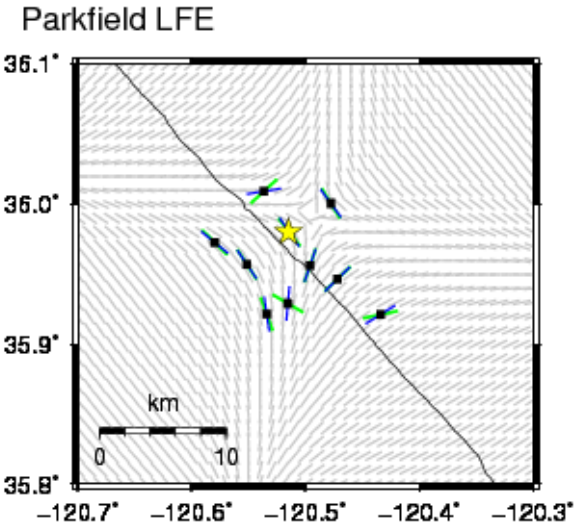

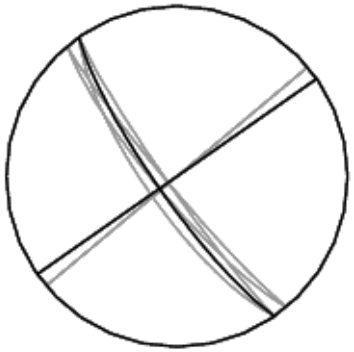

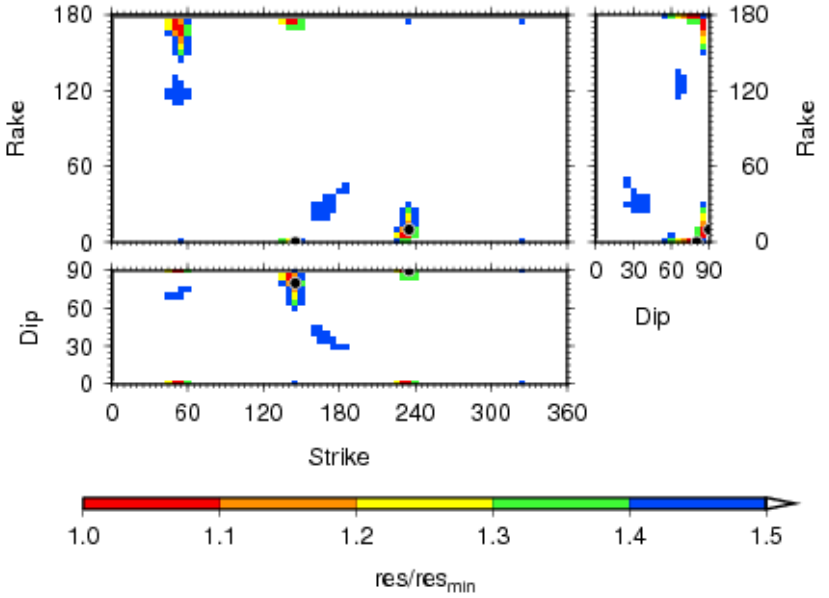

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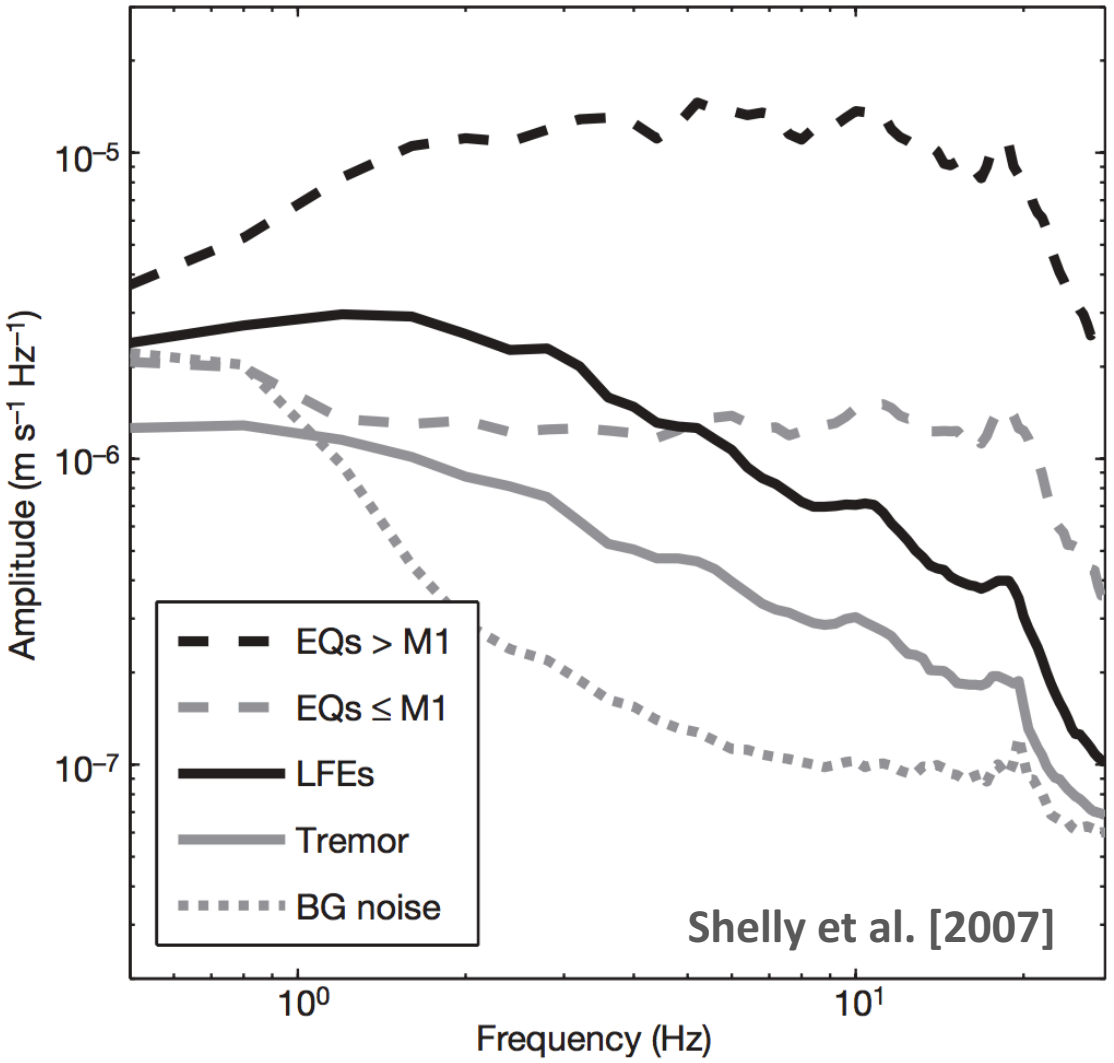
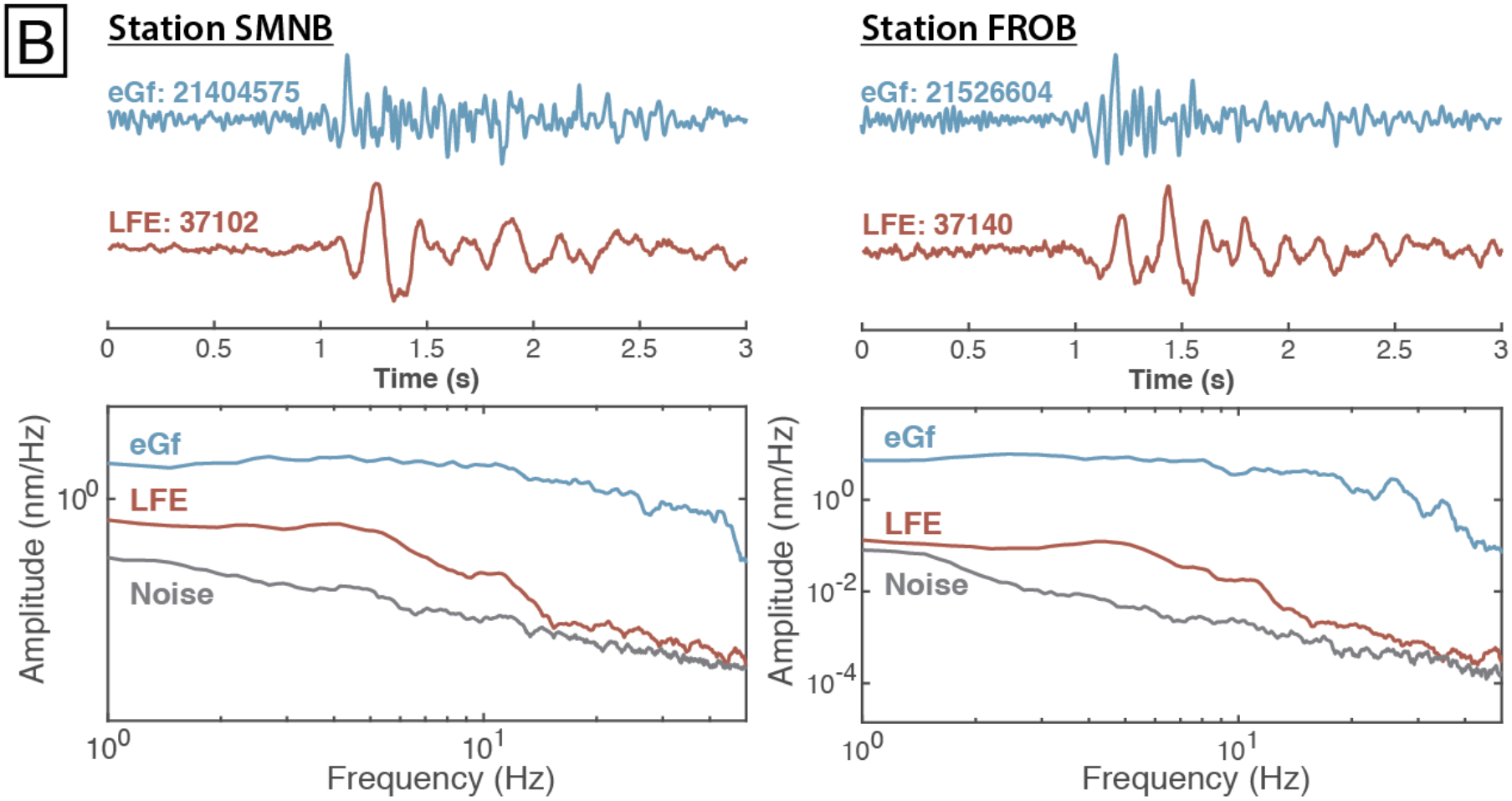
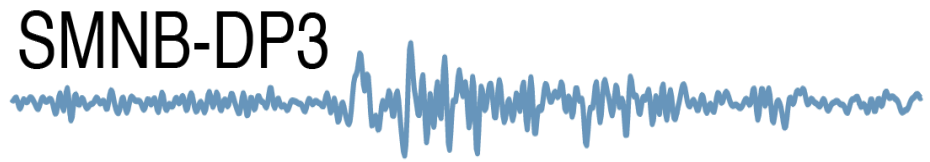


Waveforms and spectra



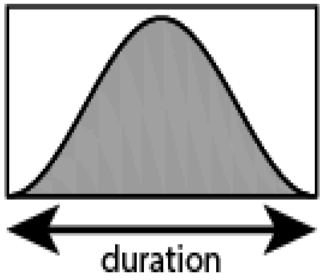
Modified eGf analysis

PATH + SITE

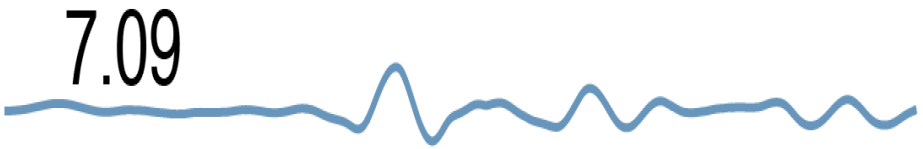


SOURCE

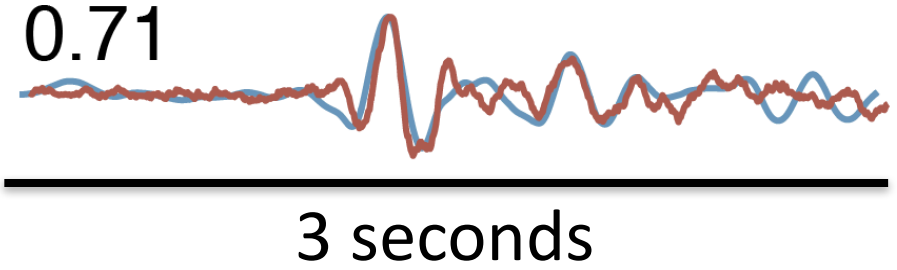
Example Hann window source-time function



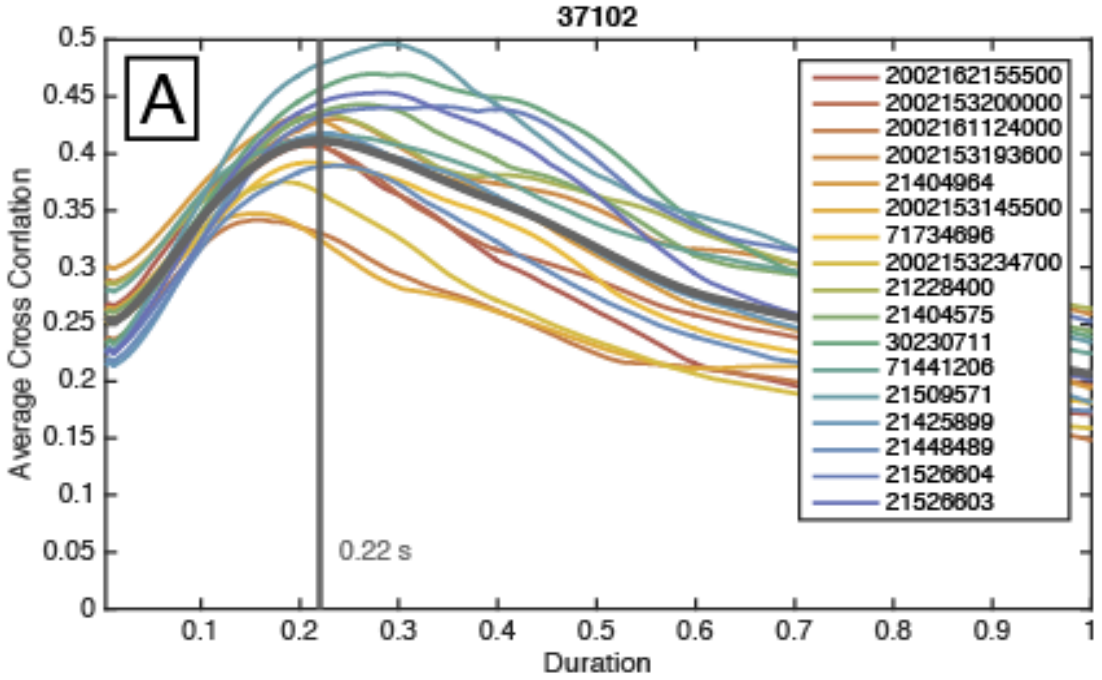
SYNTHETIC

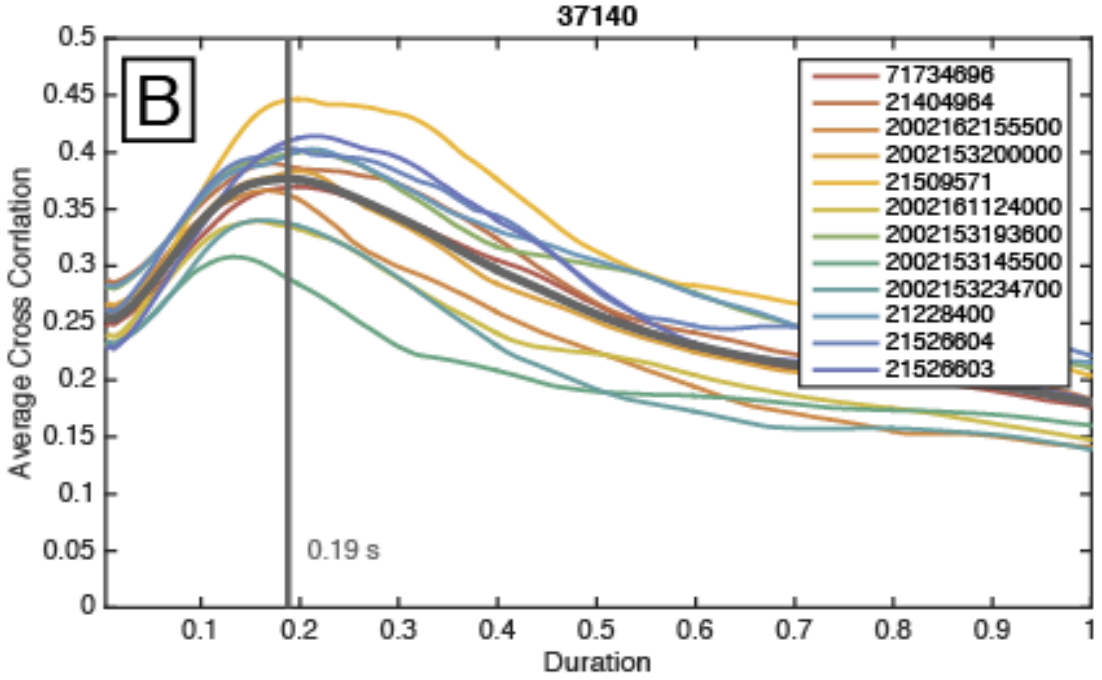


COMPARISON



LFE duration





Duration=~0.2 s

What is an LFE?

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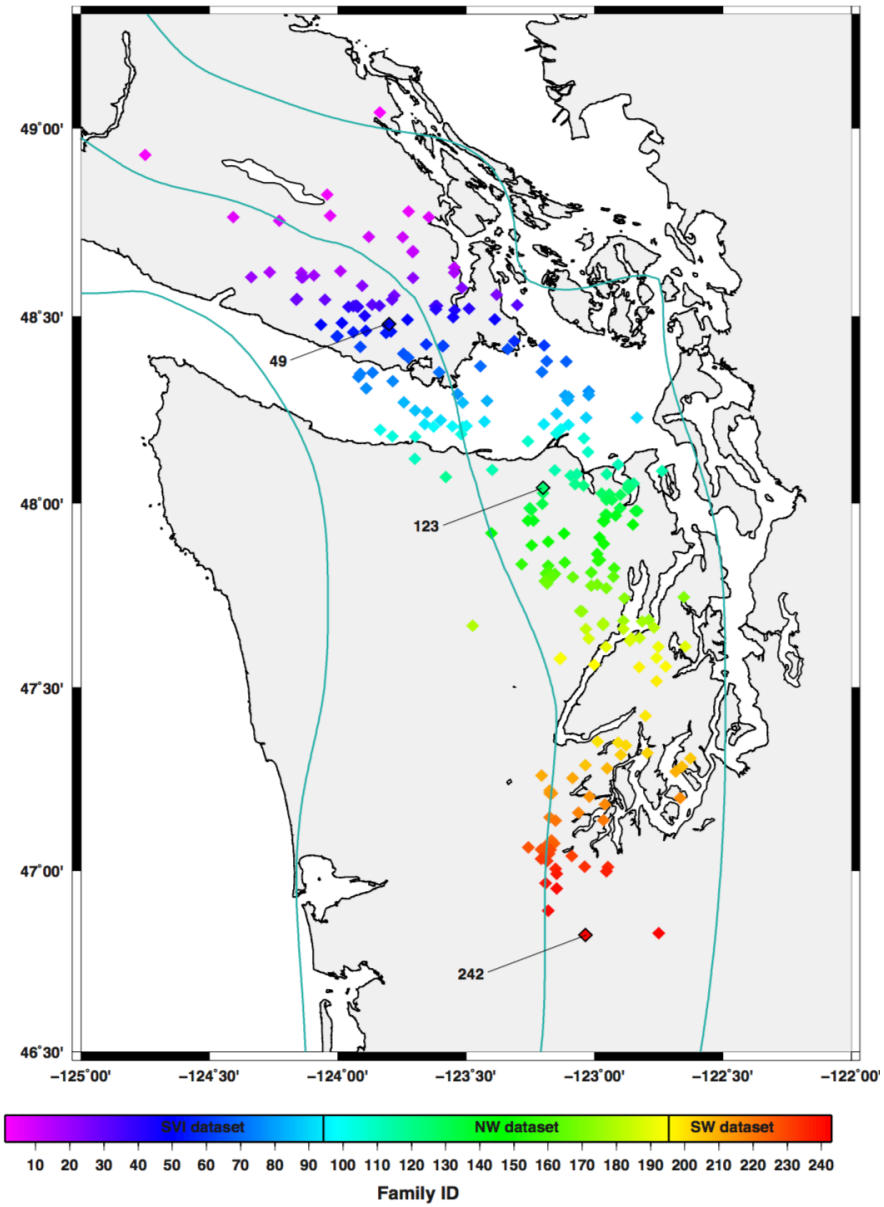
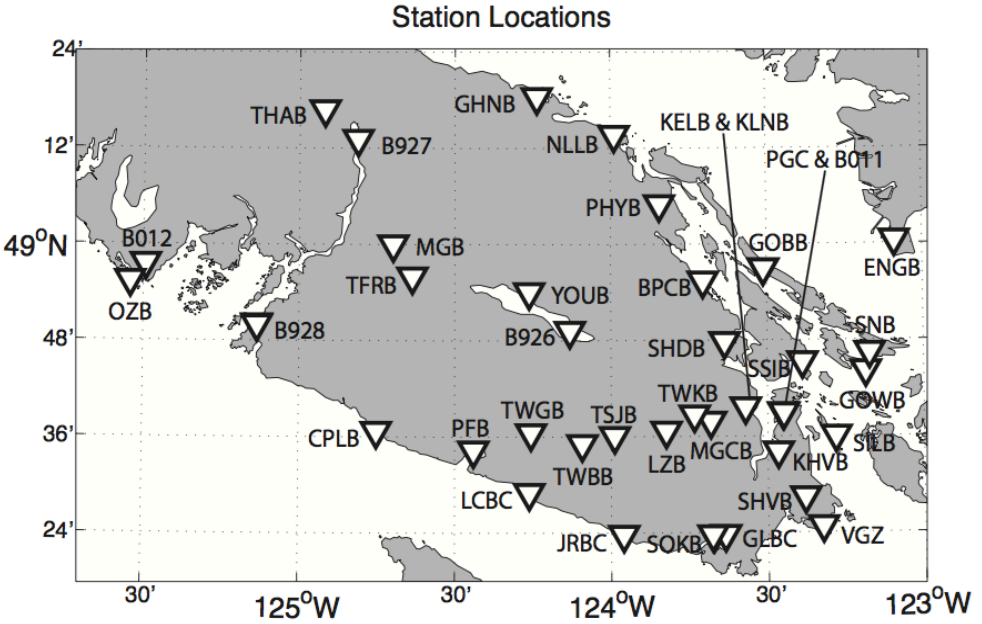
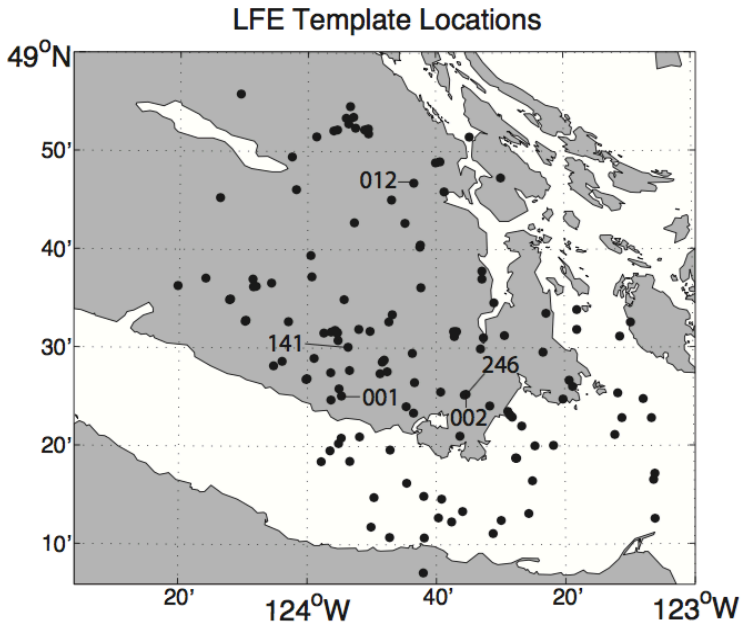
DURATION (M=1)	~0.01 s	~0.2 s
b-VALUE	1	
MOMENT-DURATION SCALING	$M \sim D^3$	
SELF SIMILARITY	YES	

Cascadia LFEs







Estimating moment

RECORDED GROUND MOTION

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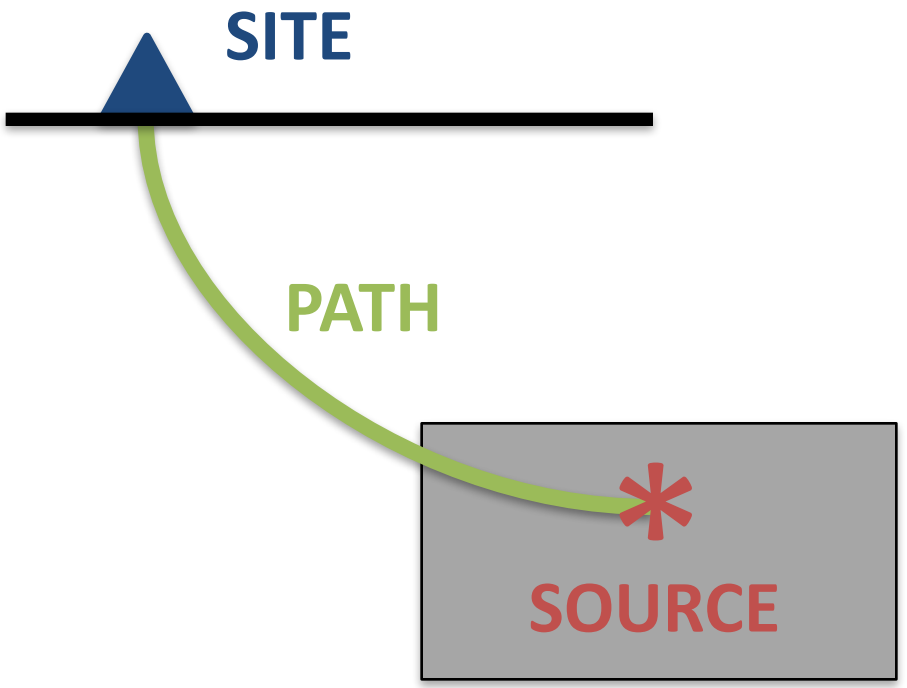


Estimating moment

Displacement u at position x as a function of time t

Intrinsic attenuation

Source radiation pattern

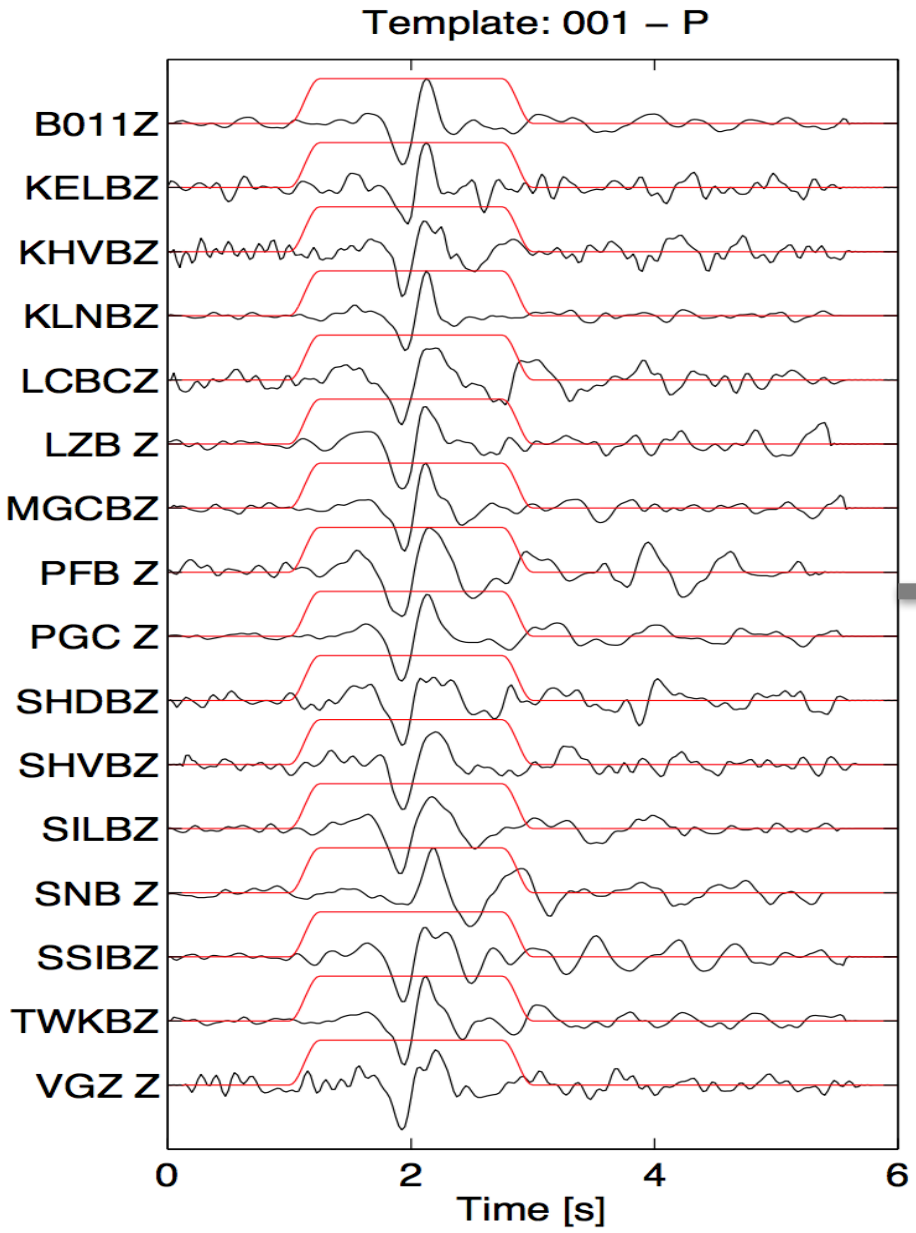
$$u_i(\mathbf{x},t) = A(\mathbf{x},\mathbf{x}')\,E(\mathbf{x},\mathbf{x}')\,F_{ij}(\mathbf{x},\mathbf{x}')\,R_j(\mathbf{x},\mathbf{x}')\,\dot{M}_0(t-\tau(\mathbf{x},\mathbf{x}')),$$

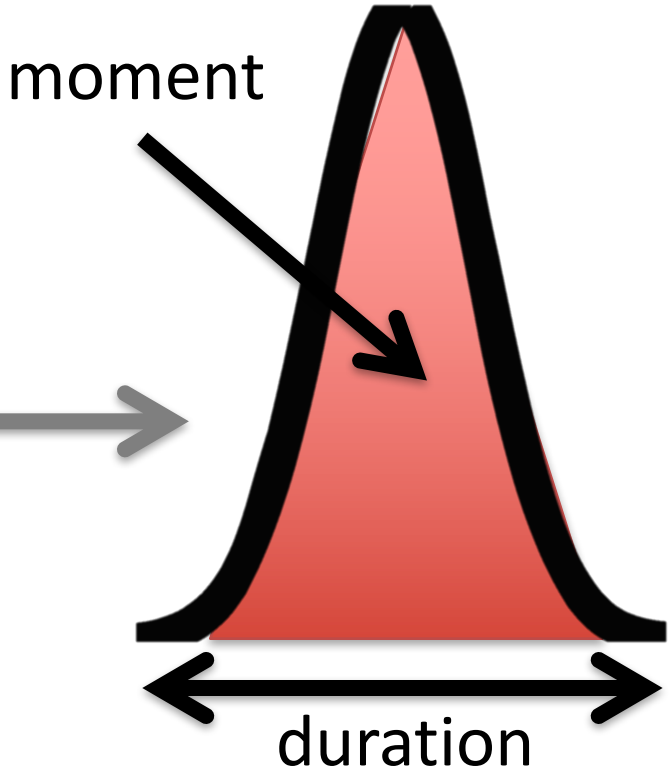
Material properties, transmission coefficients, and geometric spreading.

Free surface amplification

Source-time function

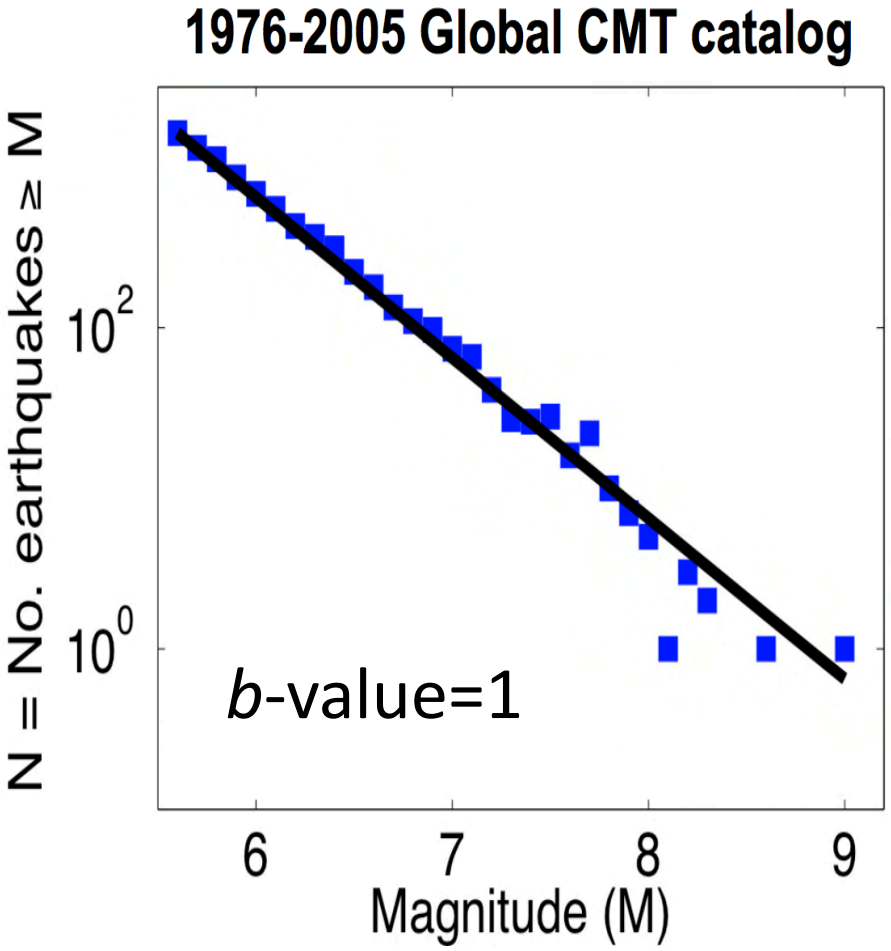
Waveforms


Template: 001 – P
B011Z
KELBZ
KHVBZ
KLNBZ
LCBCZ
LZB Z
MGCBZ
PFB Z
PGC Z
SHDBZ
SHVBZ
SILBZ
SNB Z
SSIBZ
TWKBZ
VGZ Z
0
2
4
6
Time [s]


moment
duration

b-values

Fast earthquakes



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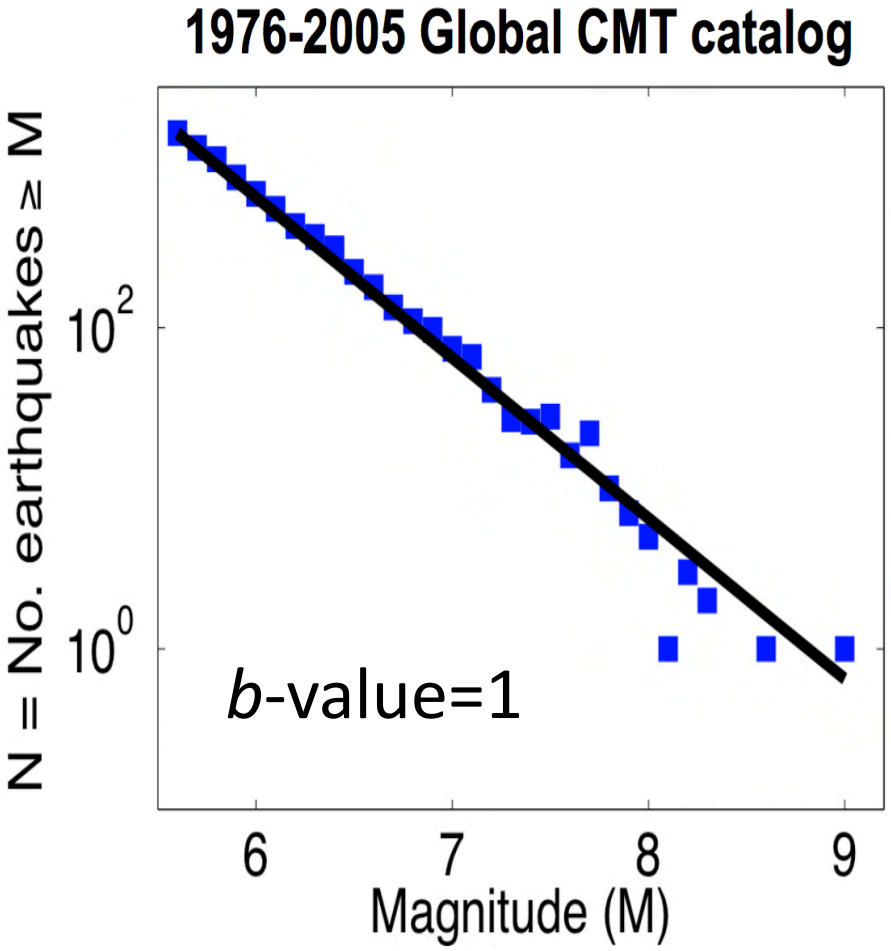
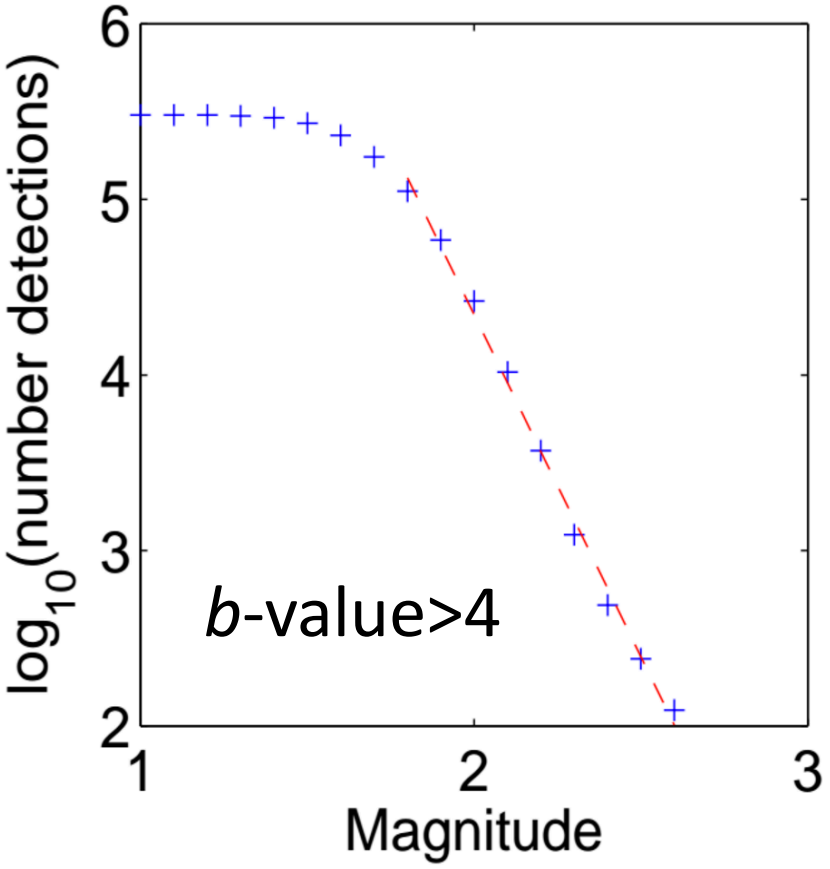


LFEs



What is an LFE?

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b-VALUE	1	4+
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SELF SIMILARITY	YES	

Moment-duration scaling

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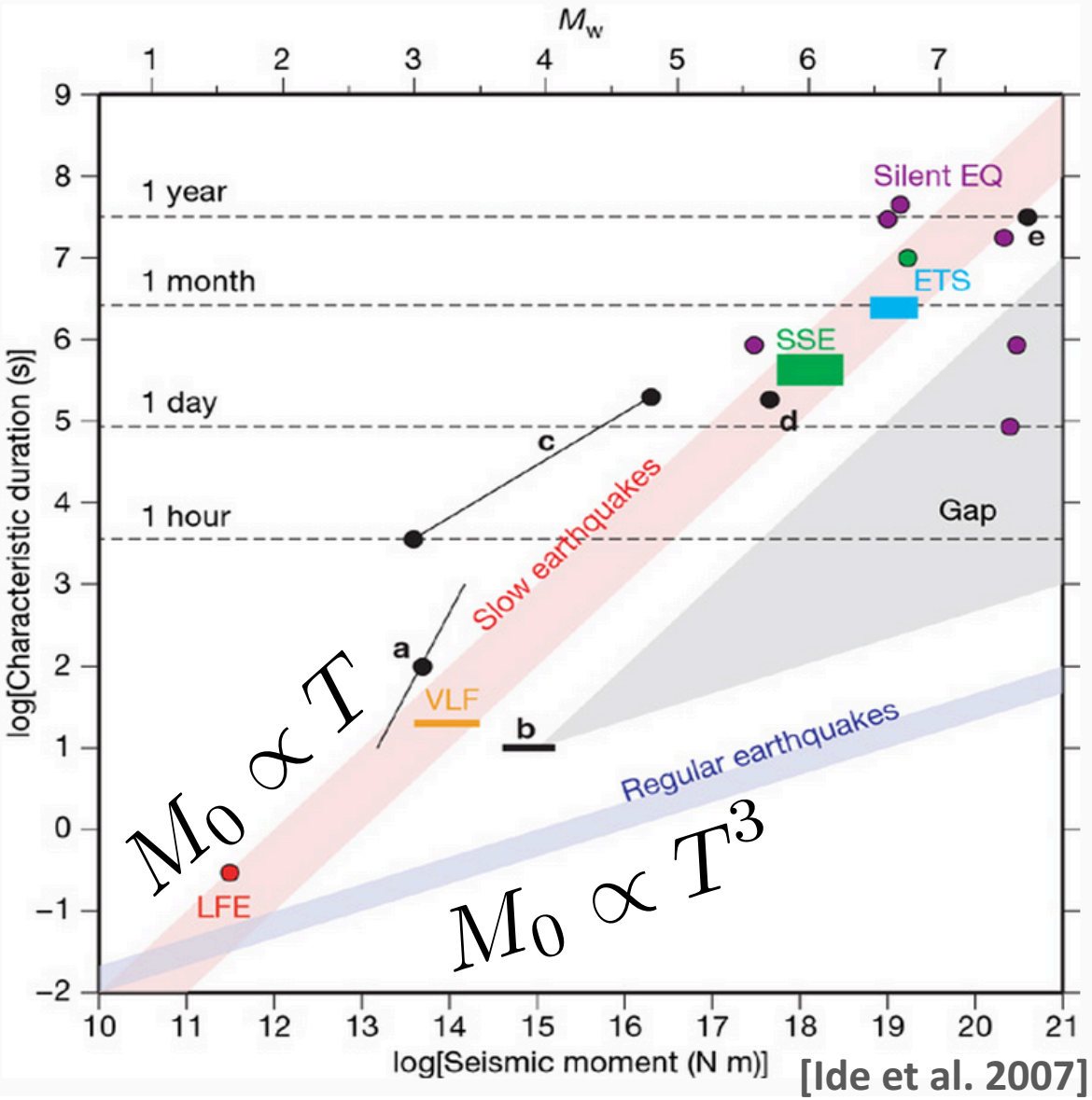


[Ide et al. 2007]

LFE moment-duration scaling

Fast earthquakes

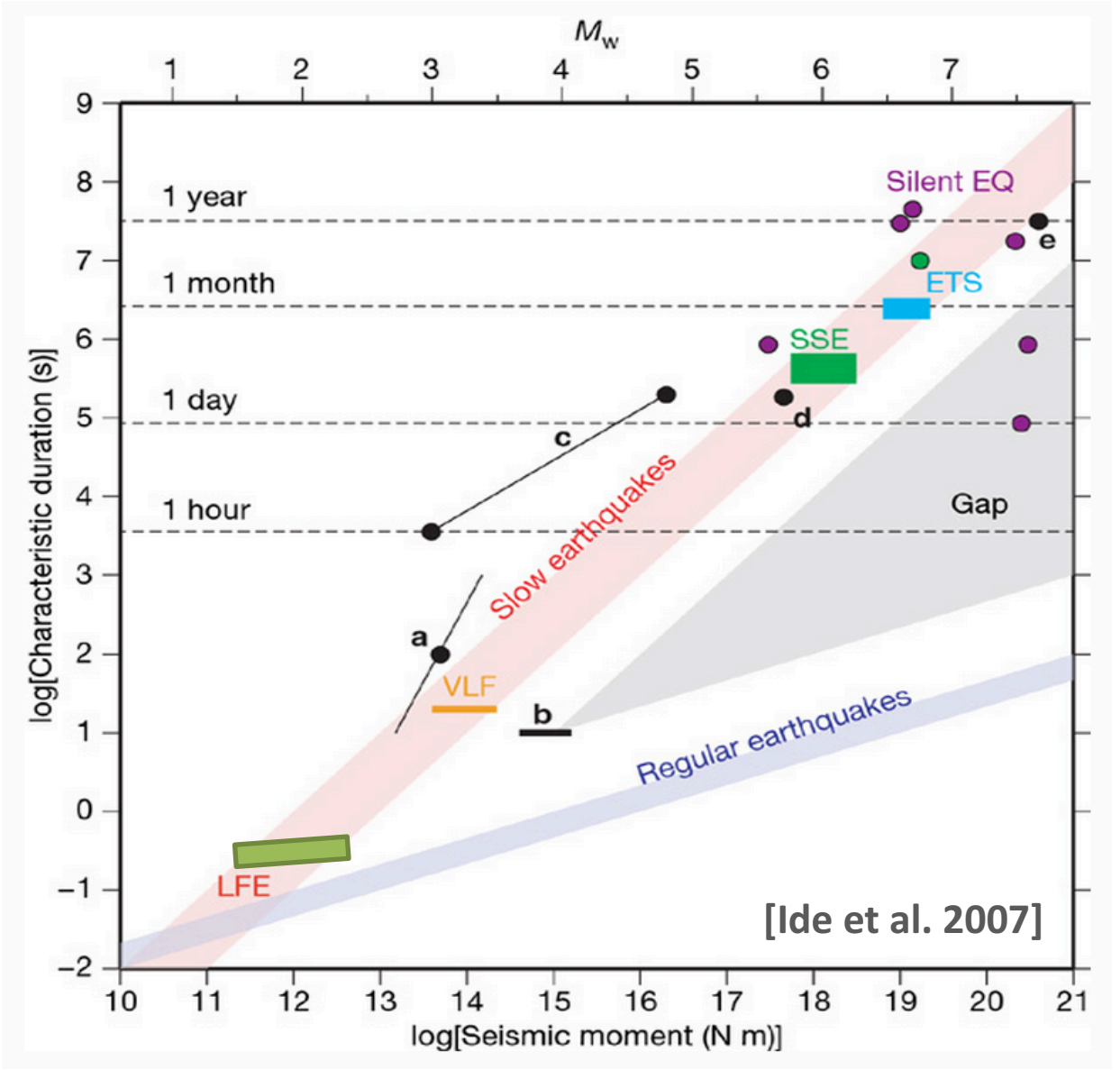
$M_0 \propto T^3$

Slow earthquakes

$M_0 \propto T$

LFEs

$M_0 \propto T^{10}$



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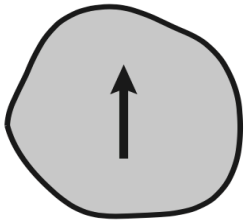
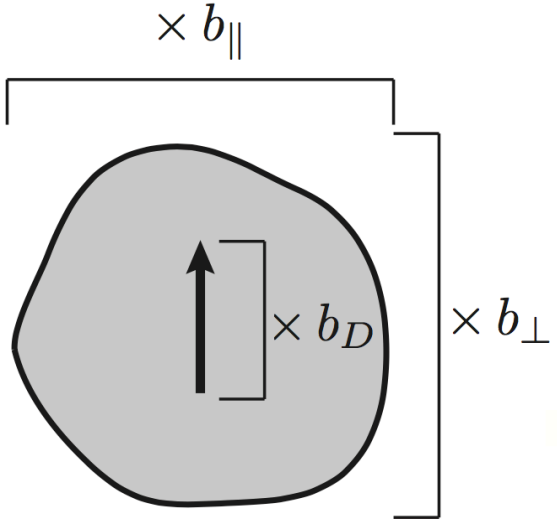
How are moment changes accommodated?

Small Moment



Large Moment



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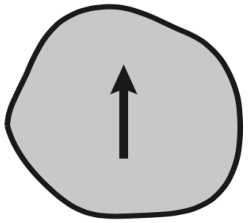

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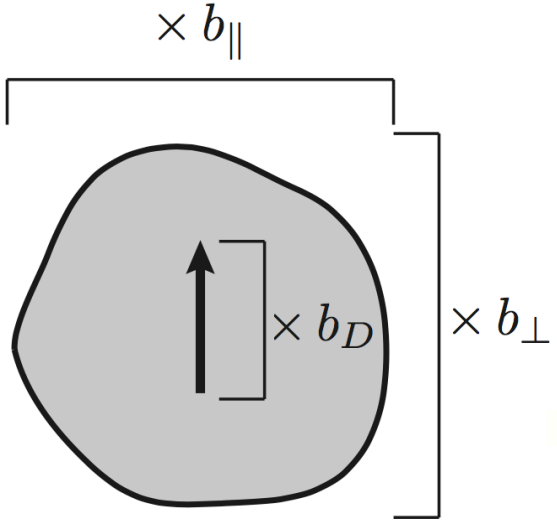

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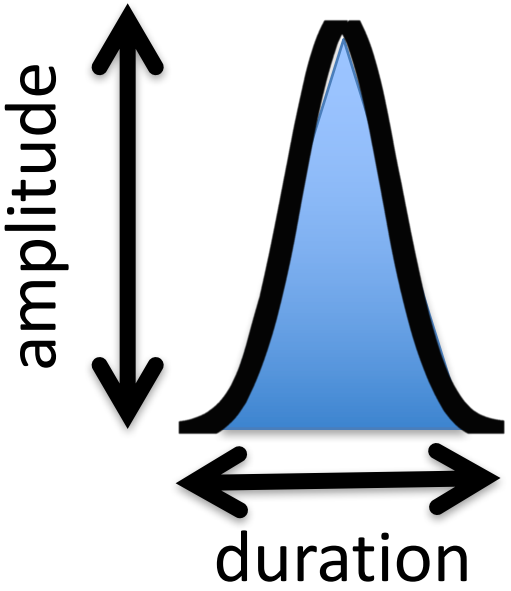

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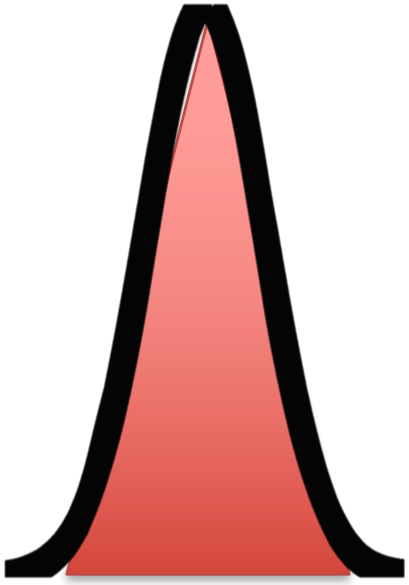
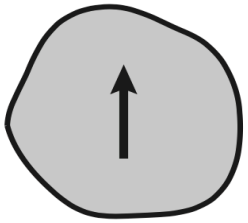


Observations:

1. Duration ratio: $b_{\|}$
2. Amplitude ratio: $b_{perp}b_D$

How are moment changes accommodated?

Small Moment



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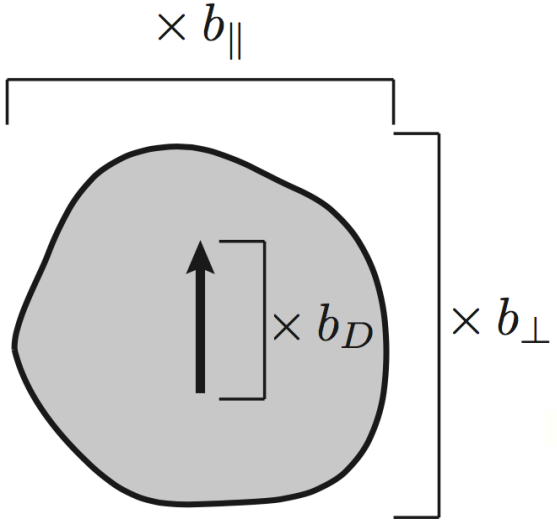

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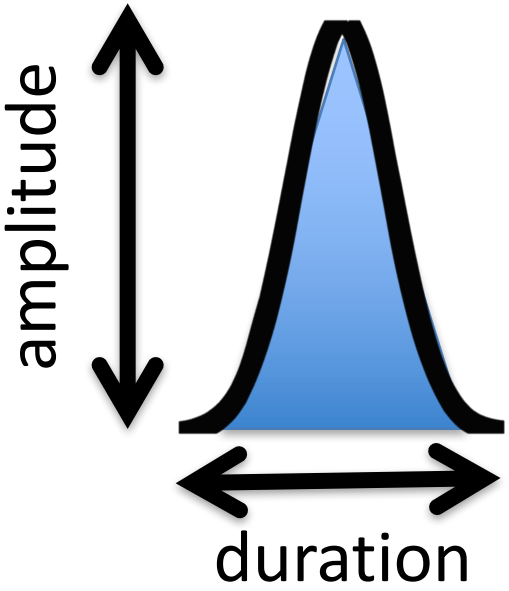

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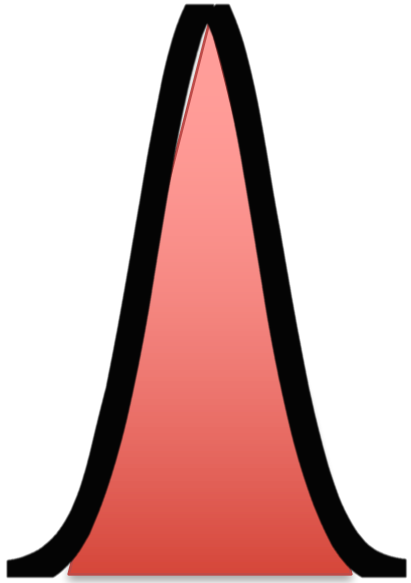
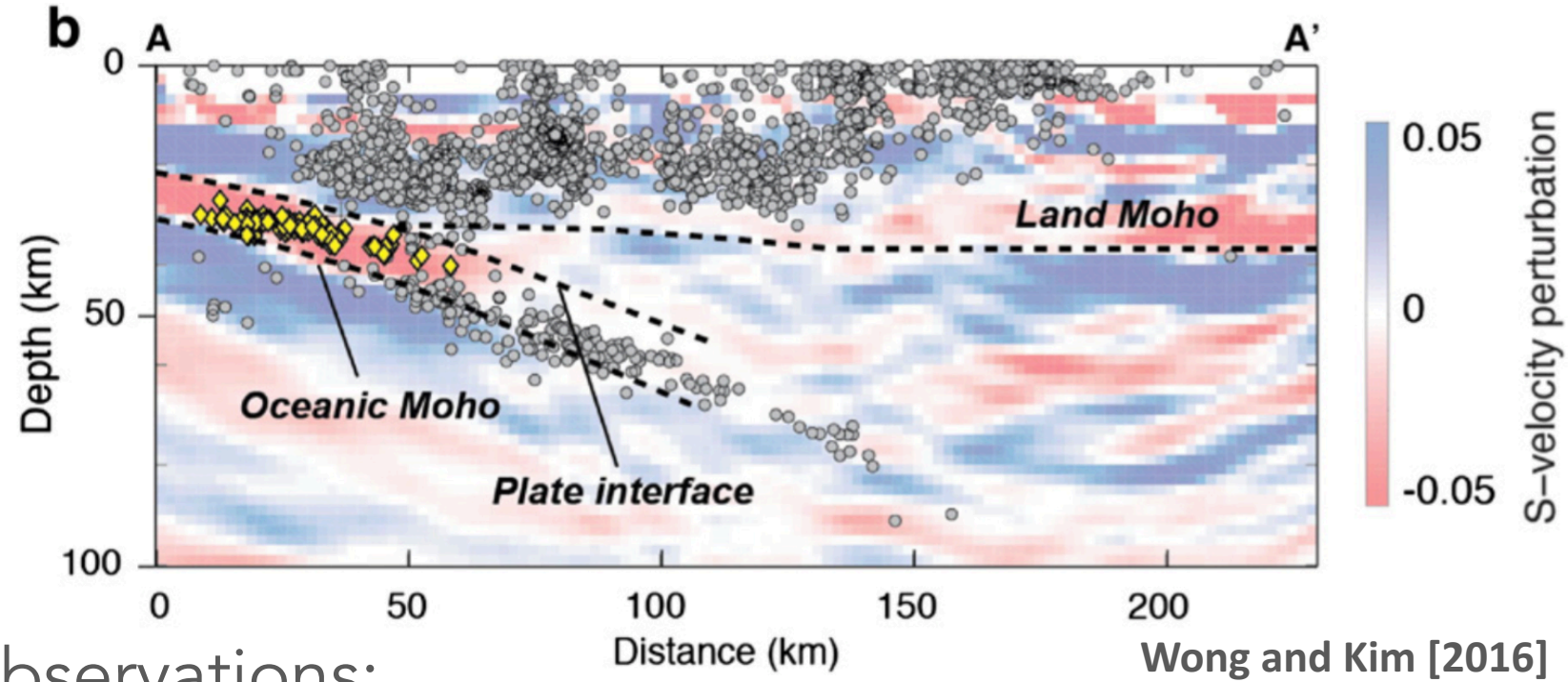


Observations:

1. Duration ratio: $b_{\|}$ (1.29)
2. Amplitude ratio: $b_{perp}b_D$ (9.49)

Near source attenuation?



Wong and Kim [2016]

Observations:

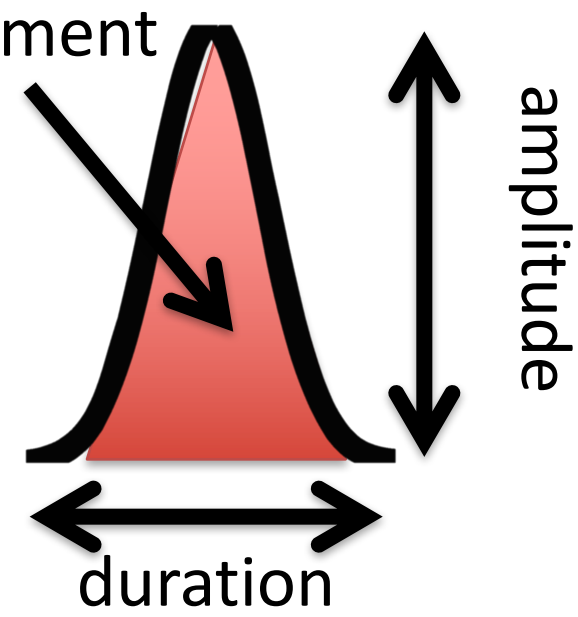
1) Intraslab EQs with overlapping and similar paths retain high frequency content
2) Intraslab EQs are more severely attenuated due to transit through a low-Q layer at the top of the oceanic crust [Yabe et al. 2014]

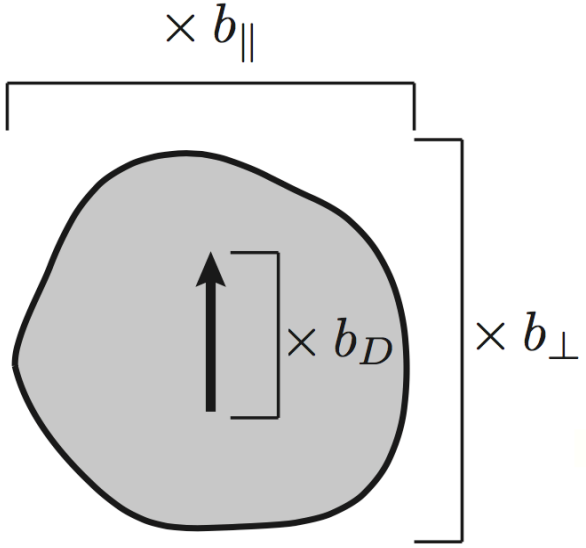
What is an LFE?

PROPERTY	**EARTHQUAKES**	**LFEs**
DURATION (M=1)	~0.01 s	~0.2 s/~0.5 s
b-VALUE	1	4+
MOMENT-DURATION SCALING	$M \sim D^3$	$M \sim D^{10}$
SELF SIMILARITY	YES	NO

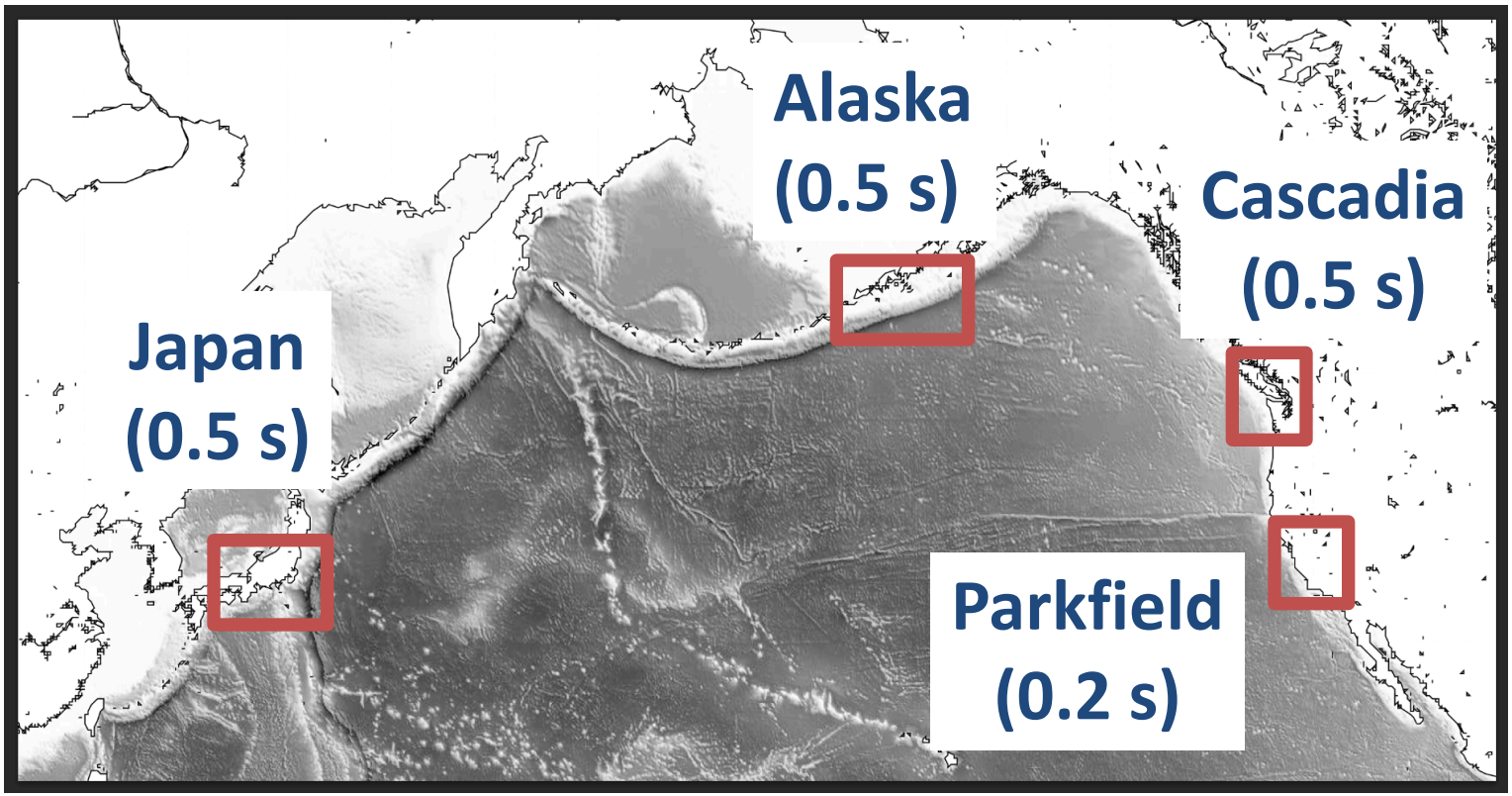
What is an LFE?

- LFE duration represents rupture duration, assuming constant rupture velocity this reflects a length scale
- Moment duration scaling suggests LFEs have nearly constant size
- LFEs are severely spatially confined
- Low effective stress limits the LFE stress drop, and can explain why LFEs never become large magnitude

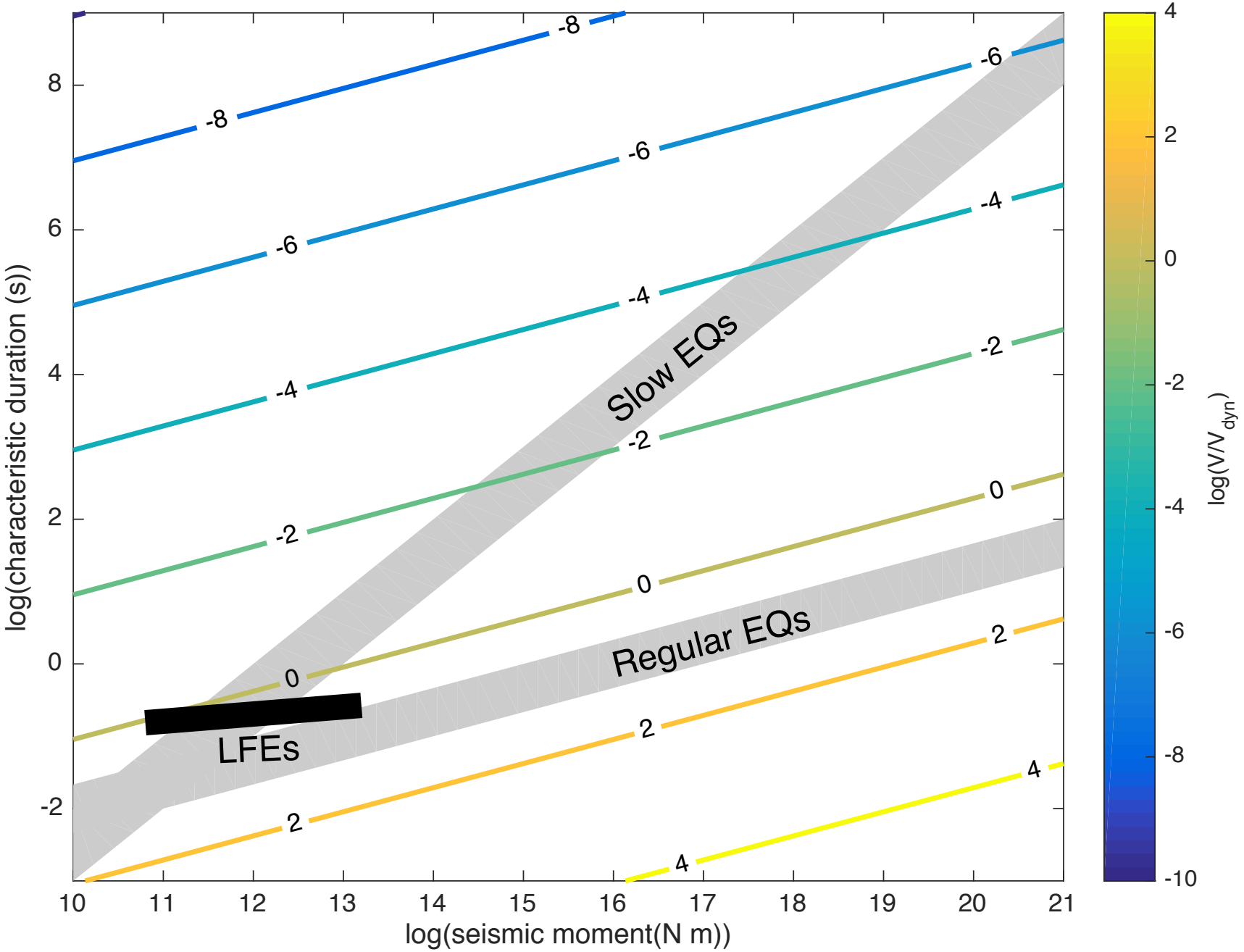




What is an LFE?



Constant patch size across 100s of kms along strike, 10s of kms along dip, and multiple subduction zones?


log(characteristic duration (s))
log(seismic moment(N m))
log(V/V_dyn)
Slow EQs
Regular EQs
LFEs
-8
-6
-4
-2
0
2
4
8
6
-10
10
11
12
13
14
15
16
17
18
19
20
21

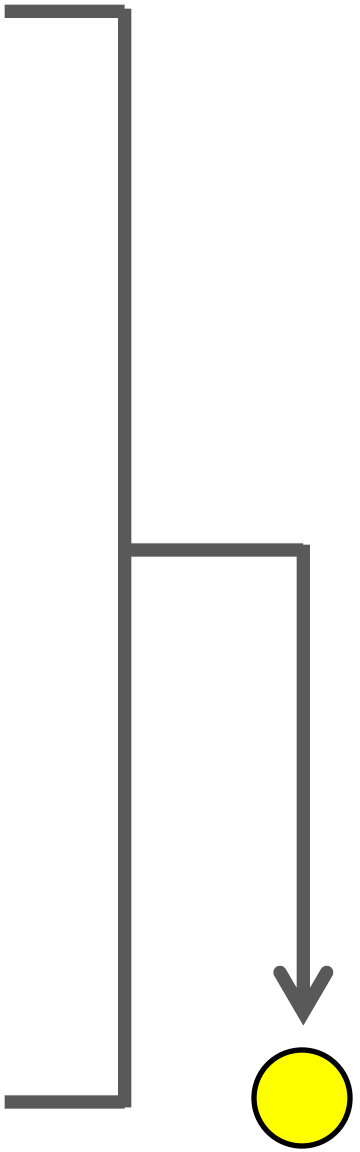
Speculometer

-- not very speculative

-- somewhat speculative

-- speculative

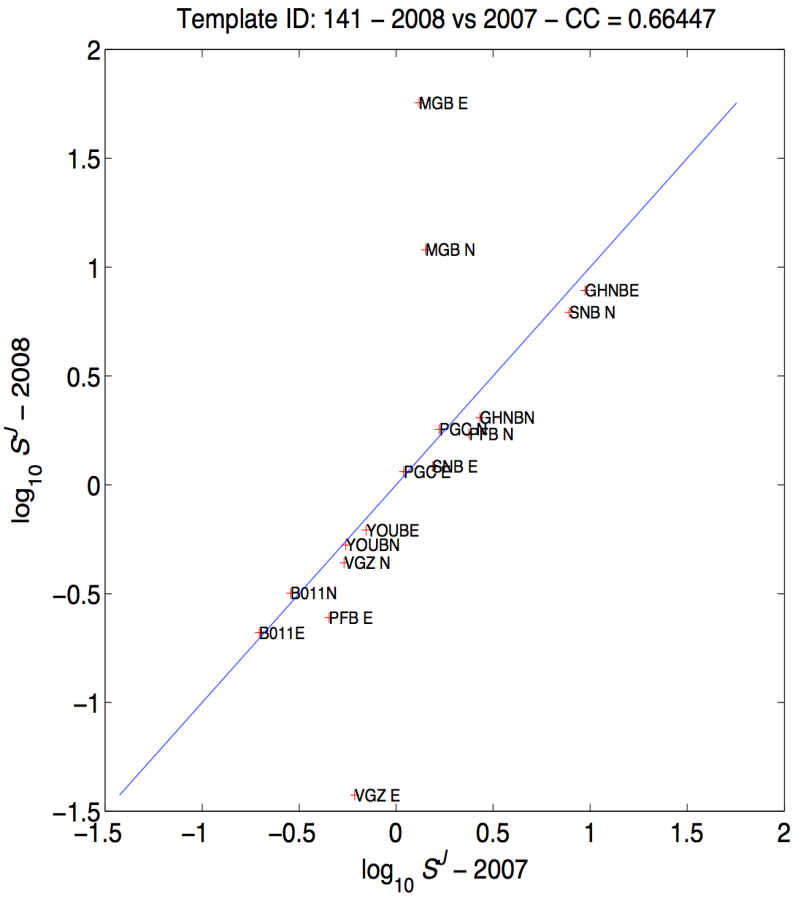
-- very speculative



Estimating moment (2)

- Correct for free surface and make corrections to attain moment estimate
- Still significant sources of error due to anisotropy, etc.
- Assume a multiplicative path term that relates the true moment to the measured moment

$$M_0 = \frac{\int \mathrm{d}t\, \acute{u}_j(\mathbf{x}, t)}{A(\mathbf{x}, \mathbf{x}')\, E(\mathbf{x}, \mathbf{x}')\, R_j(\mathbf{x}, \mathbf{x}')},$$

$$\log M_0^{IJ} = \log M_0^I + \log S^J.$$

$$\sum_J \log S^J = 0.$$