Probabilistic Prediction of Rupture Length, Slip and Seismic Ground Motions for au Ongoing Rupture

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EEW Bad News

- Near source area for M 6.5 is has a diameter of about 30 km
- Even with perfect technology, warning times will be, at most, several seconds
- There will be ten M 6.5’s for the occurrence of every M 7.5

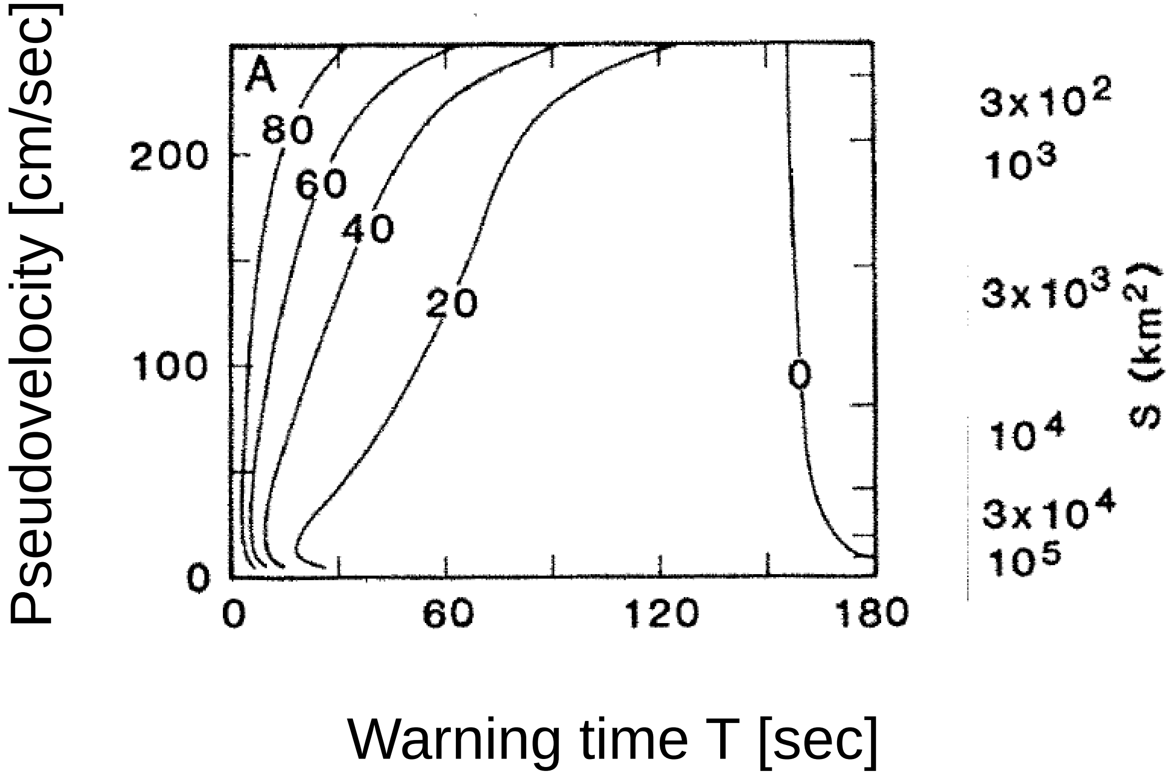
EEW Good News

- Near source area of a M 7.5 + earthquake will be 5 to 20 times larger than for a M 6.5
- Many heavily shaken areas can get significant warning times in a M 7.5 +

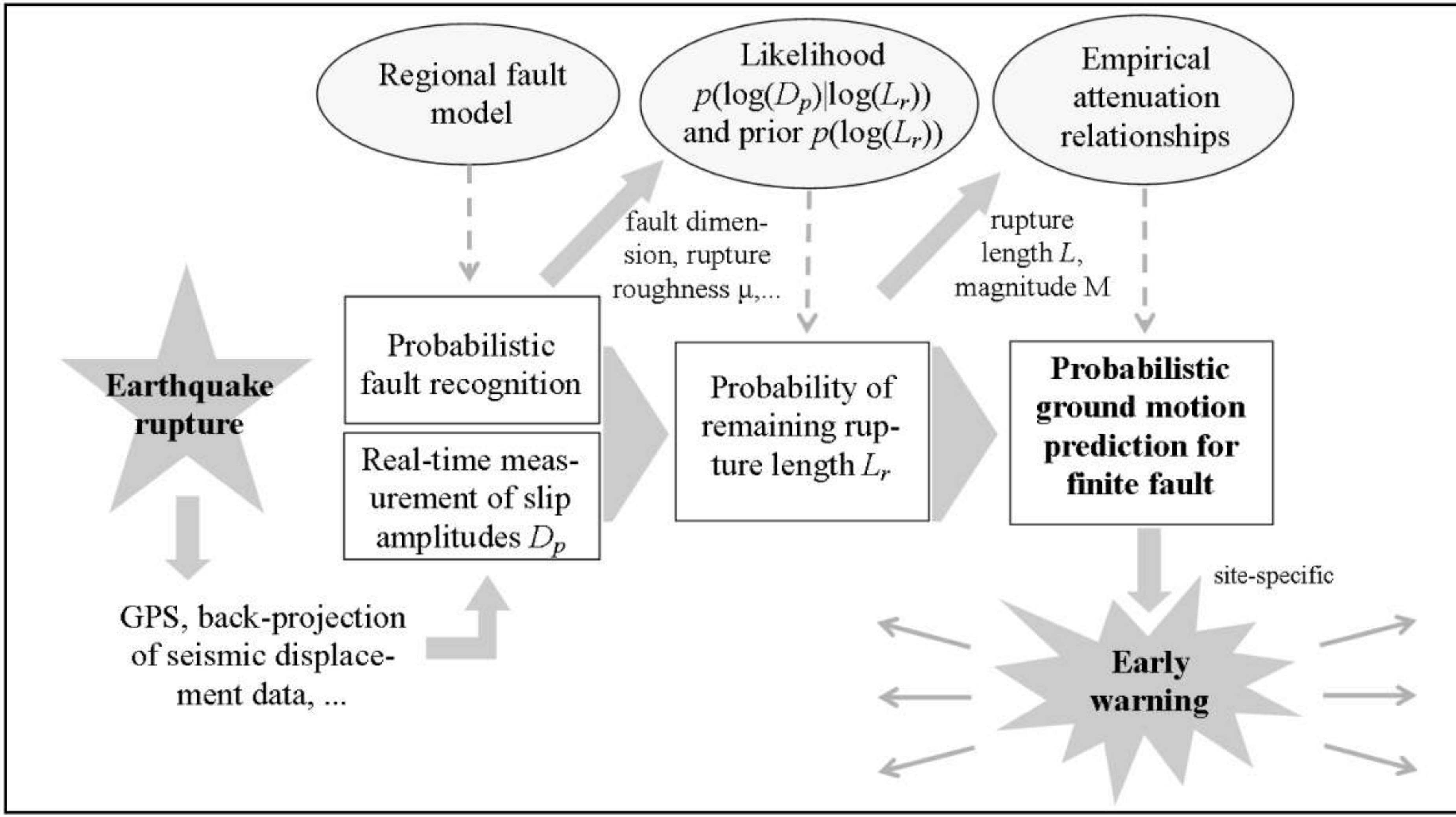
EEW for a Long Rupture

- Should warn some areas that rupture is headed towards them and strong shaking is possible
- Real-time analysis of a finite rupture is challenging
- Few events to practice on
- If we fail on a large event it may be the only chance in a generation

Percent of area receiving warning time T or greater (log $N^*=6.89-M_w$)



Heaton, 1985

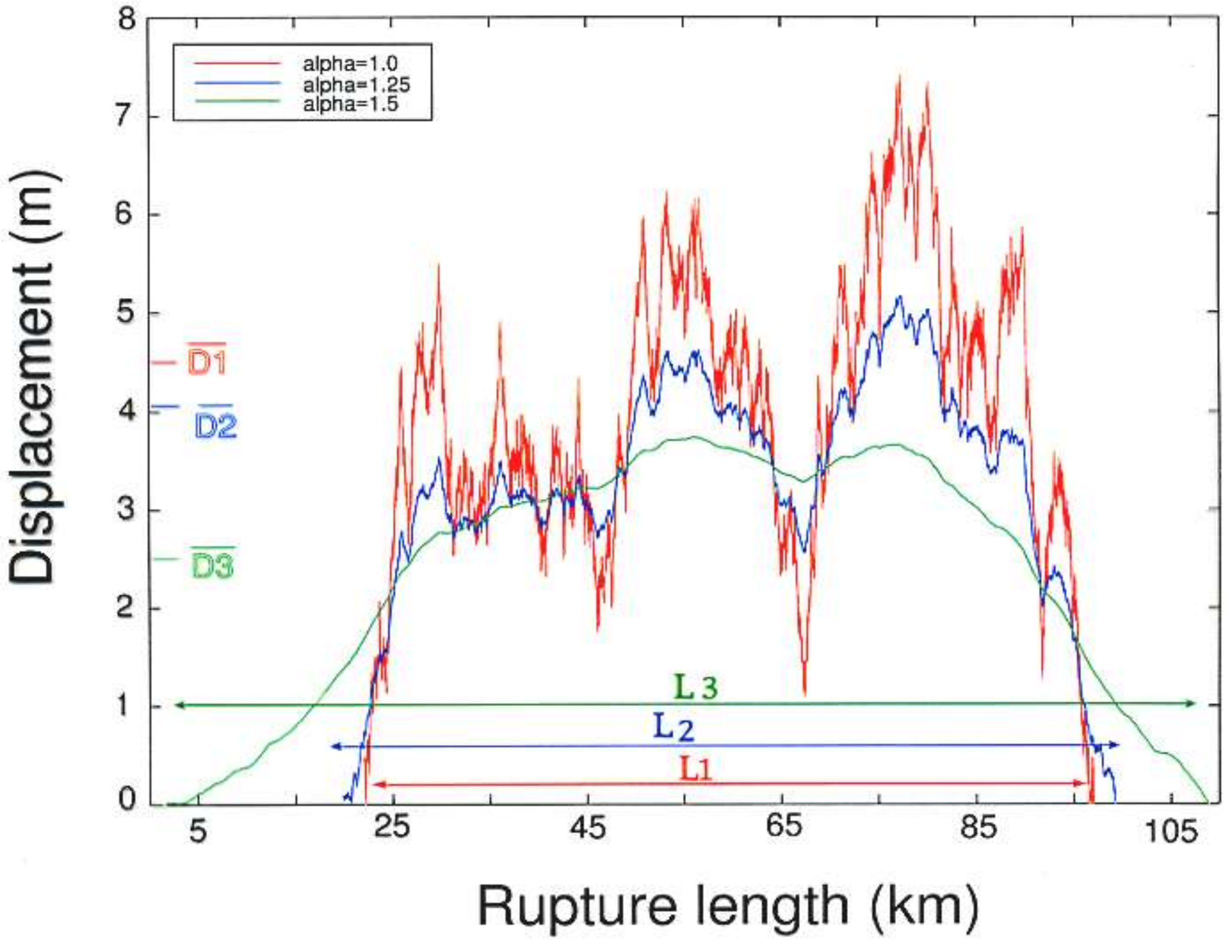


Regional fault model
Likelihood $p(\log(D_p)|\log(L_r))$ and prior $p(\log(L_r))$
Empirical attenuation relationships
fault dimension, rupture roughness μ,...
rupture length L, magnitude M
Earthquake rupture
Probabilistic fault recognition
Real-time measurement of slip amplitudes D_p
Probability of remaining rupture length L_r
Probabilistic ground motion prediction for finite fault
GPS, back-projection of seismic displacement data, ...
site-specific
Early warning

Example of the Shake-Out Scenario

- So easy to know what happens next because we created it
- Let’ s assume that at any point in time that we know 1) the causative fault, 2) the current rupture length, and 3) the current slip of an ongoing rupture (GPS?)
- What is the likelihood of different rupture lengths and magnitudes?

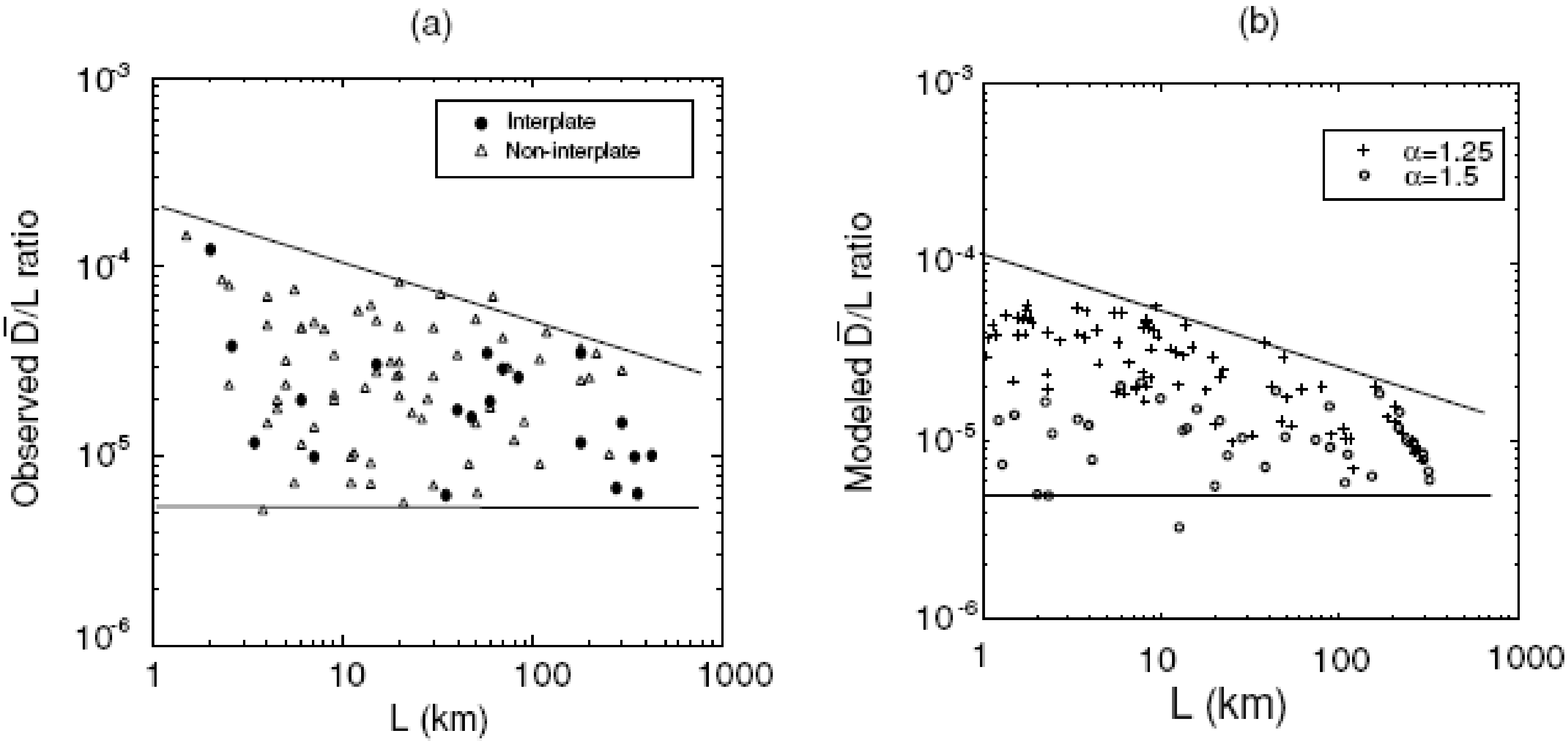
Given equal surface areas, islands with rougher topography have higher average elevations



$$\tilde{D}(k) \sim k^{-\alpha}\text{ , where } k \equiv \text{ wavenumber}$$

From J. Liu and T. Heaton

Observed vs. Simulated slip/length

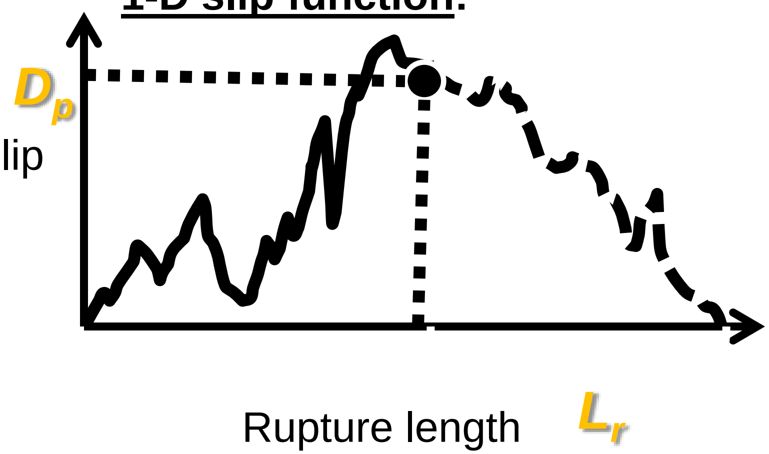


Liu-Zheng and Heaton

Early Warning for Large Earthquakes (Research)

Large earthquakes (M>7.0) are rare, but they affect **much larger areas** with damaging ground shaking and provide **longer warning times** !

1-D slip function:



D_p **: present slip amplitude**

L_r **: remaining rupture length**

A probabilistic approach (Bayesian):

$$p\left(\log(L_r)|\log(D_p)\right) = \frac{p\left(\log(D_p)|\log(L_r)\right)p\left(\log(L_r)\right)}{p\left(\log(D_p)\right)}$$

"Probability of L_r for a given D_p"

How far will the rupture propagate ?

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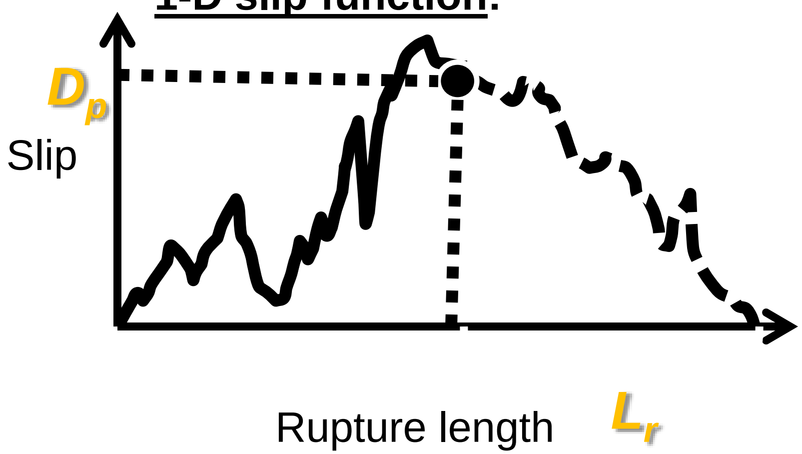
1-D slip function:



D_p **: present slip amplitude**

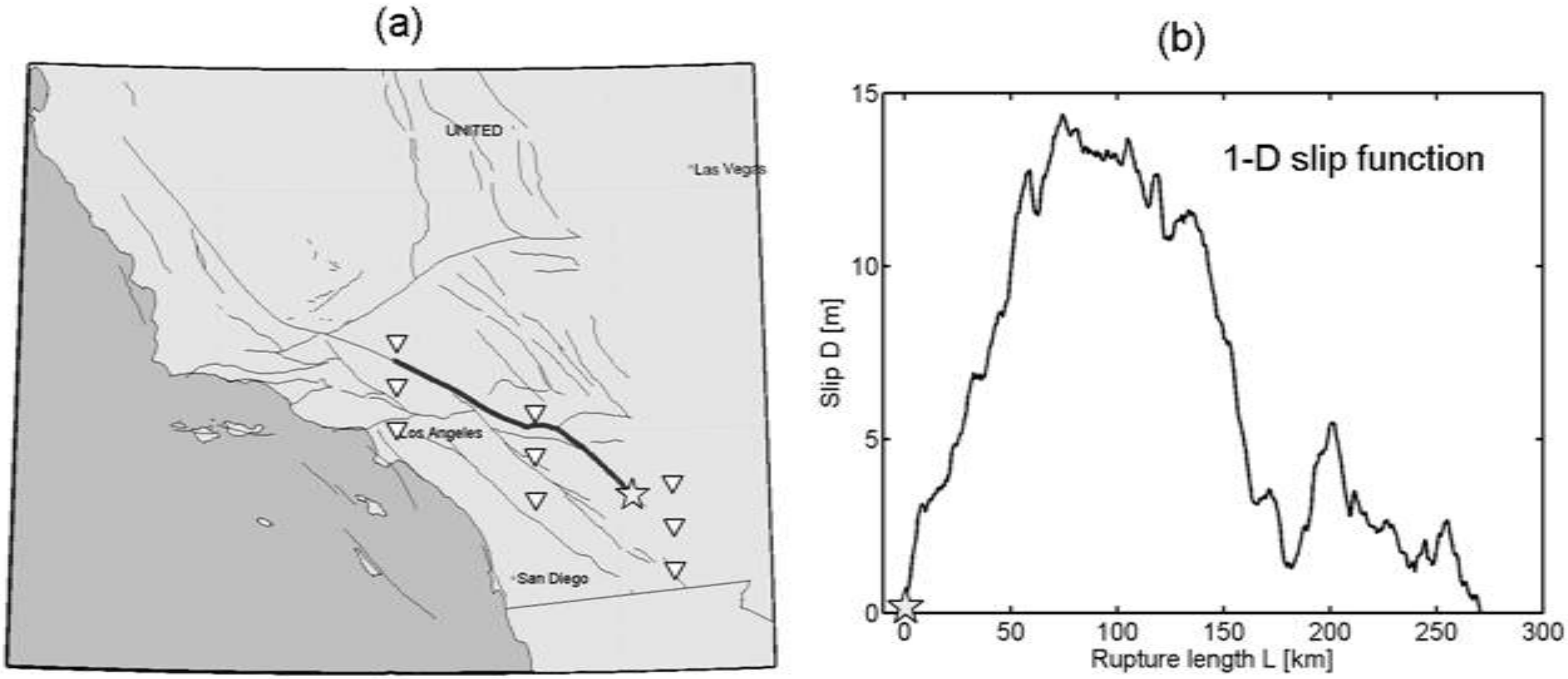
L_r **: remaining rupture length**

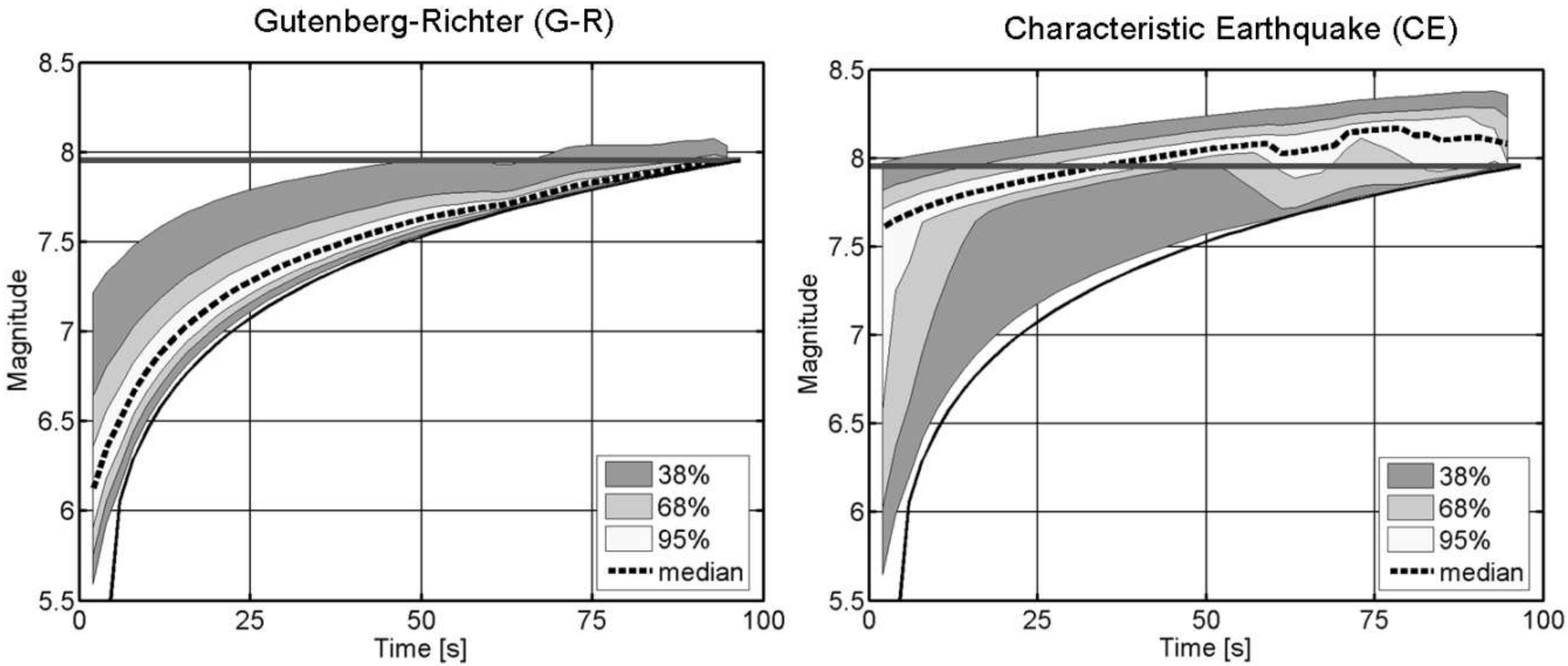
RESULT:

- The ***a priori* probability (AP)** for the occurrence of earthquakes of different magnitudes is extremely important.
- The AP depends on the **characteristics of the underlying fault** (slip heterogeneity on generic/mature faults)

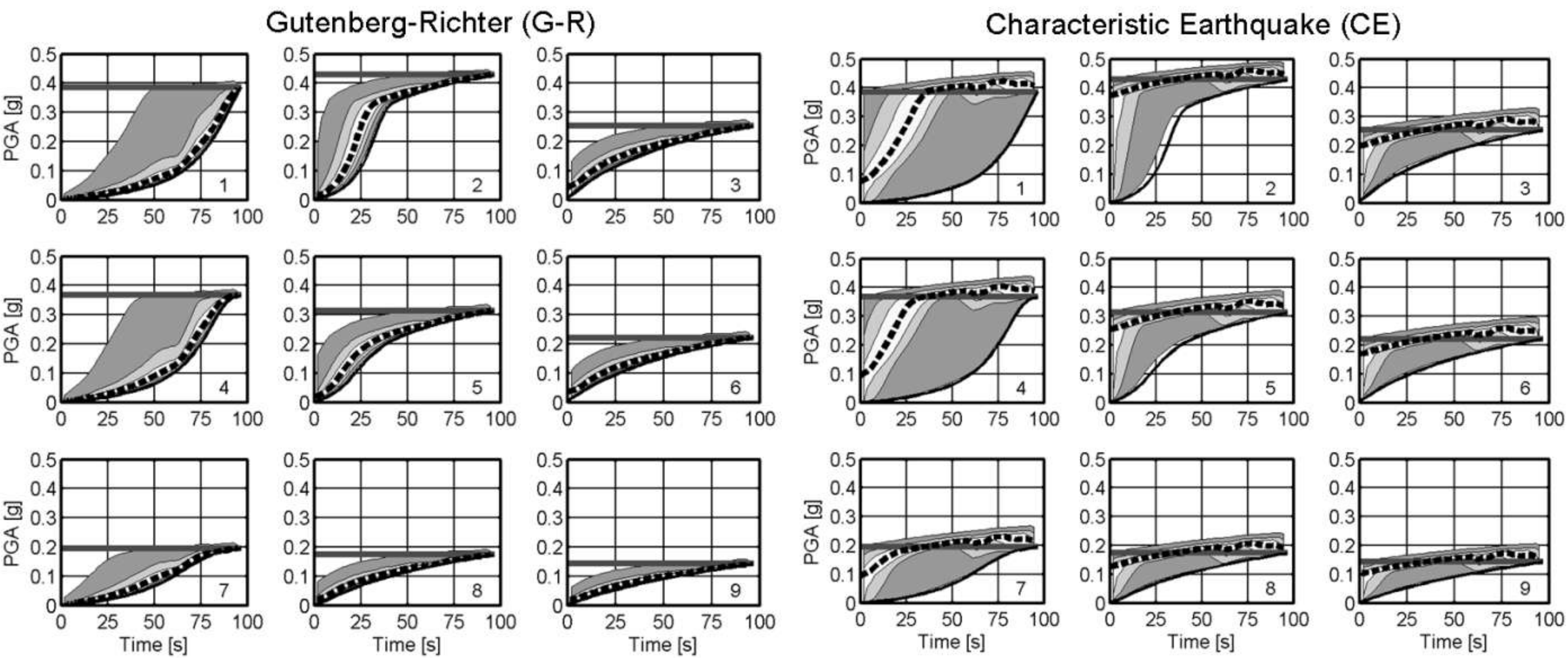
EEW for large earthquakes requires a rapid recognition of the rupturing fault !

→ *Presentation by Tom Heaton*


(a)
UNITED
Las Vegas
Los Angeles
San Diego
(b)
1-D slip function
Slip D [m]
Rupture length L [km]
0
5
10
15
0
50
100
150
200
250
300



Gutenberg-Richter (G-R)
Magnitude
Time [s]
8.5
8
7.5
7
6.5
6
5.5
0
25
50
75
100
38%
68%
95%
median
Characteristic Earthquake (CE)
Magnitude
Time [s]
8.5
8
7.5
7
6.5
6
5.5
0
25
50
75
100
38%
68%
95%
median



Gutenberg-Richter (G-R)
Characteristic Earthquake (CE)
PGA [g]
Time [s]
0
0.1
0.2
0.3
0.4
0.5
0
25
50
75
100
1
2
3
4
5
6
7
8
9

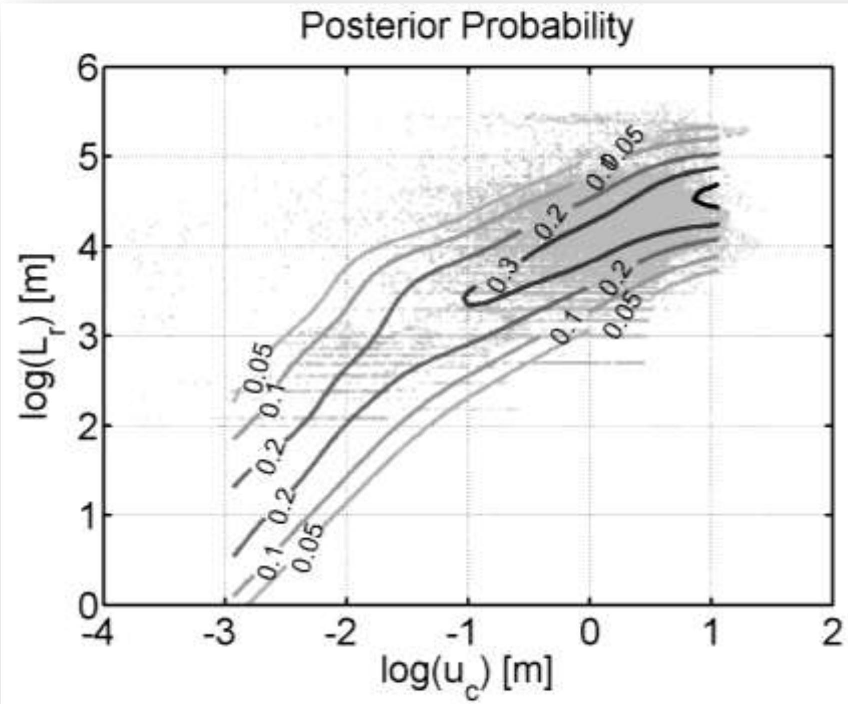
Conclusions

- Bayesian statistical framework allows integration of many types of information to produce most probable solution and error estimates
- Strategies to determine rupture dimension and slip look promising …GPS
- Identification of rupture on several key faults (e.g. San Andreas) may be a high priority

Real-time prediction of ultimate rupture

Böse and Heaton, in prep.

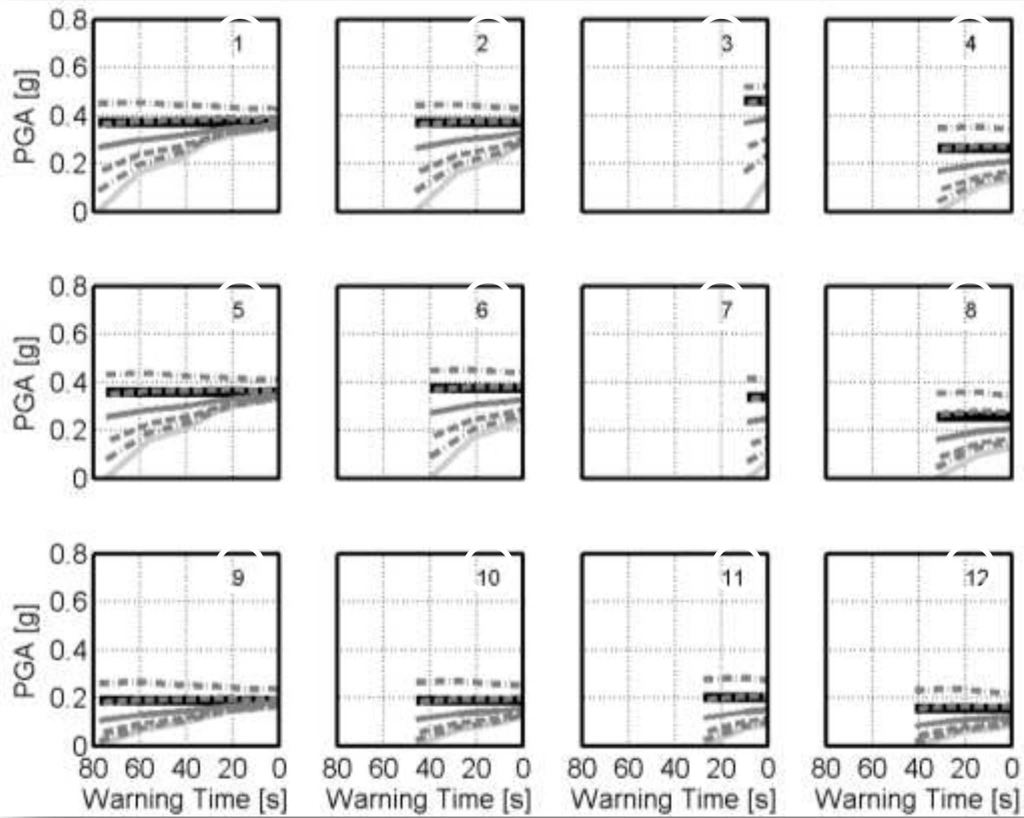
Remaining Rupture Length



slip

Is the rupture on the San Andreas fault?

Probabilistic Rupture Prediction → Probabilistic Ground



Böse and Heaton, in prep.

Strategy to Handle Long Ruptures

- Determine the rupture dimension by using high-frequencies to recognize which stations are near source
- Determine the approximate slip (and therefore instantaneous magnitude) by using low-frequencies and evolving knowledge of rupture dimension
- GPS