The 2nd International Workshop on Earthquake Early Warning
April 21-22, 2009, Kyoto (Japan)

Up-dates on EEW Testing (of the τ_c-P_d Algorithm) and Finite Fault Research at Caltech

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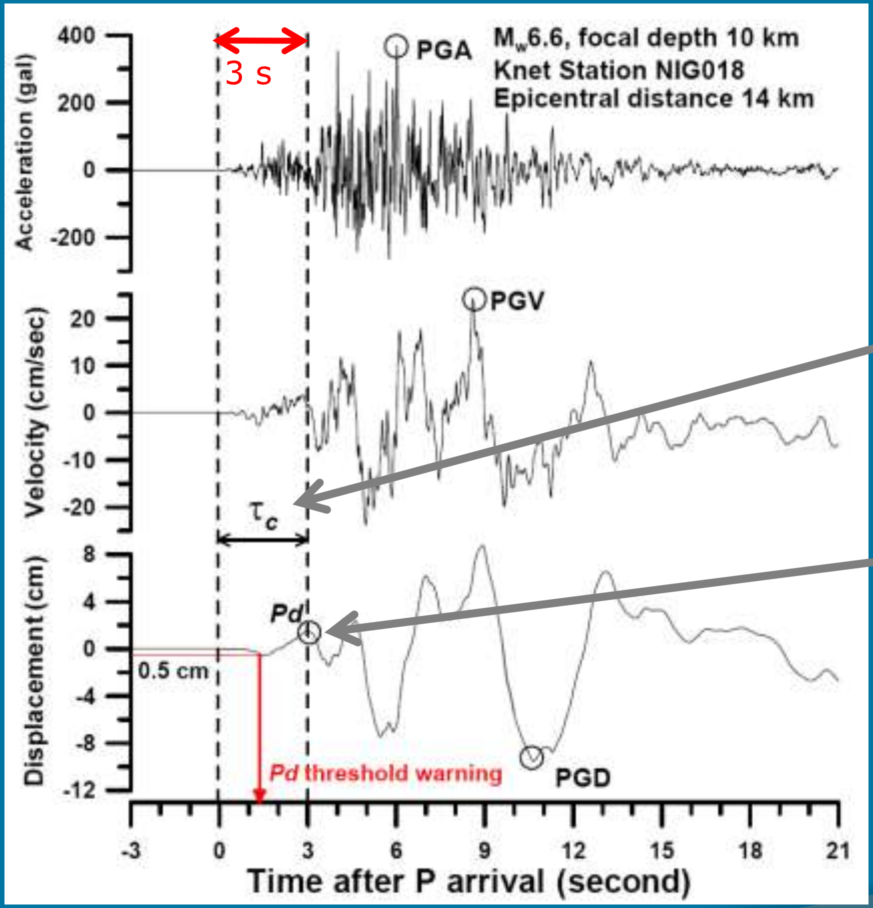
Time	Step/Event	CISN Channels	Observation	Solution/Action
2006-2008	**Implementation and initial testing** of the τ_c-P_d algorithm at Caltech	CI, AZ southern CA **172** HH channels		



The τ_c-P_d algorithm

1. Period parameter τ_c
   $\tau_c \rightarrow$ magnitude M_w

2. High-pass filtered displ. amplitude P_d
   $P_d \rightarrow$ **peak ground vel. (PGV)**

Wu and Kanamori, 2008

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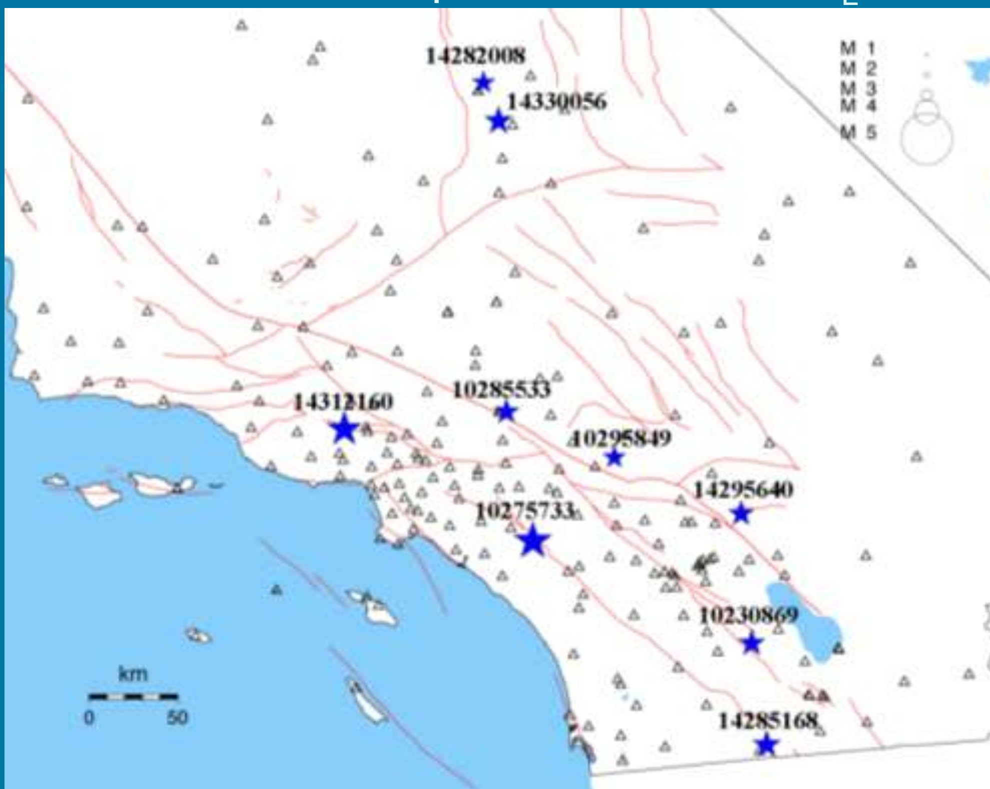
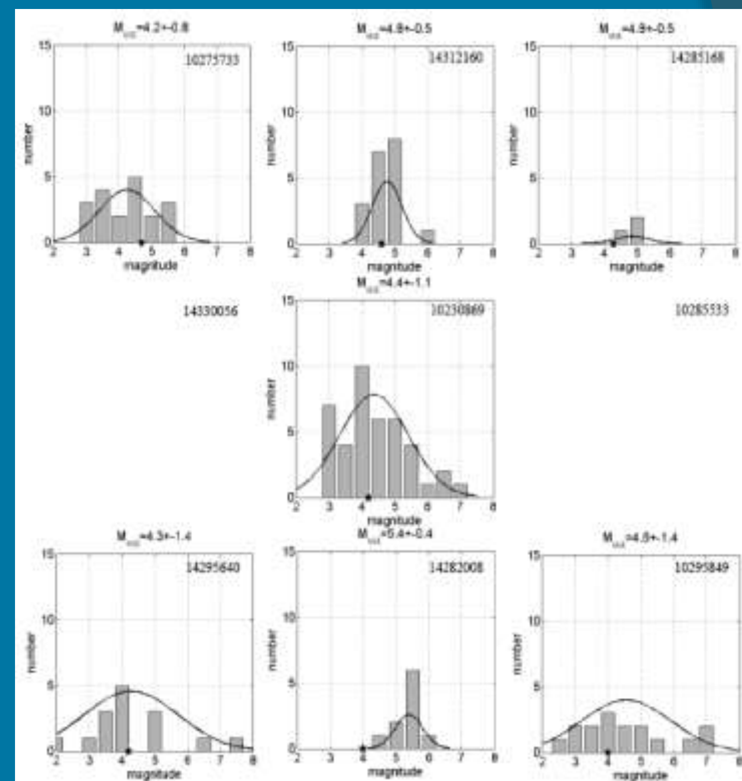
2007-2008	**Implementation and initial testing** of the τ_c-P_d algorithm at Caltech	CI, AZ southern CA **172** HH channels	Many **false triggers** **Scattering in M estimates** for small earthquakes	

2007: 9 local earthquakes with $4.0 \leq M_L \leq 4.8$





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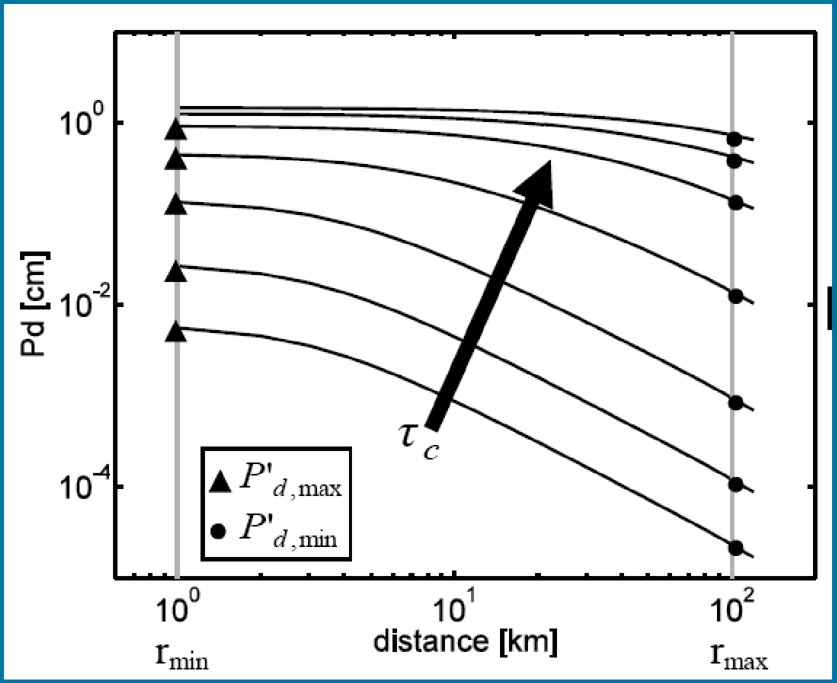
Attenuation relations



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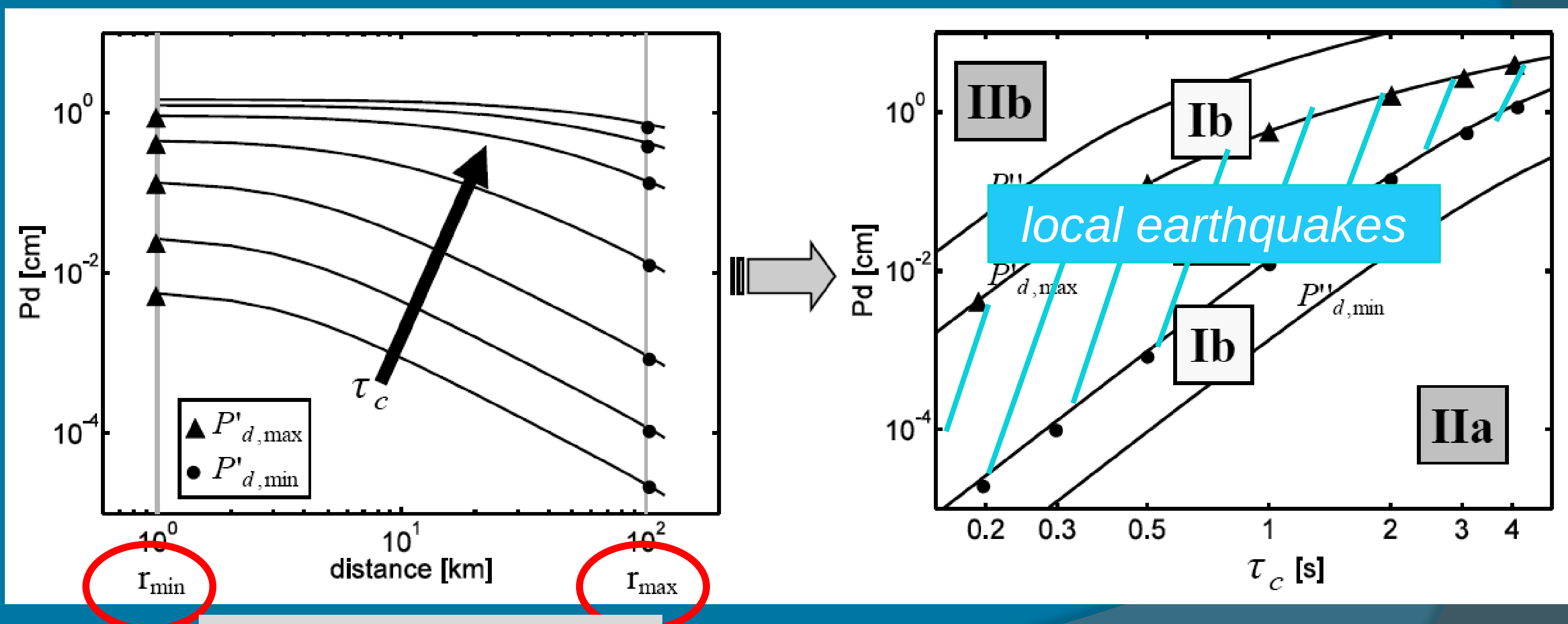
Attenuation relations

τ_c-P_d trigger criterion



Limit distance range!

Böse et al., 2009b

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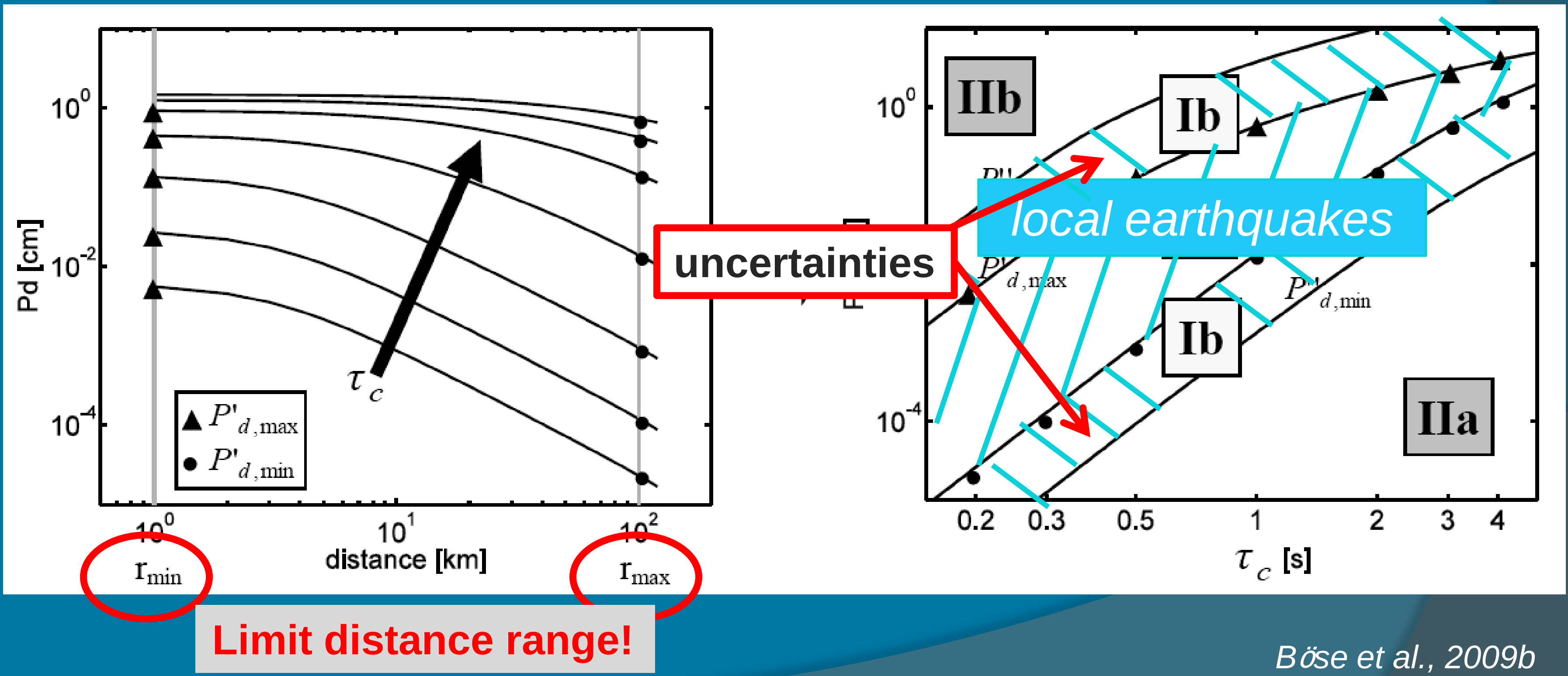
τ_c-P_d trigger criterion



Böse et al., 2009b

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Attenuation relations

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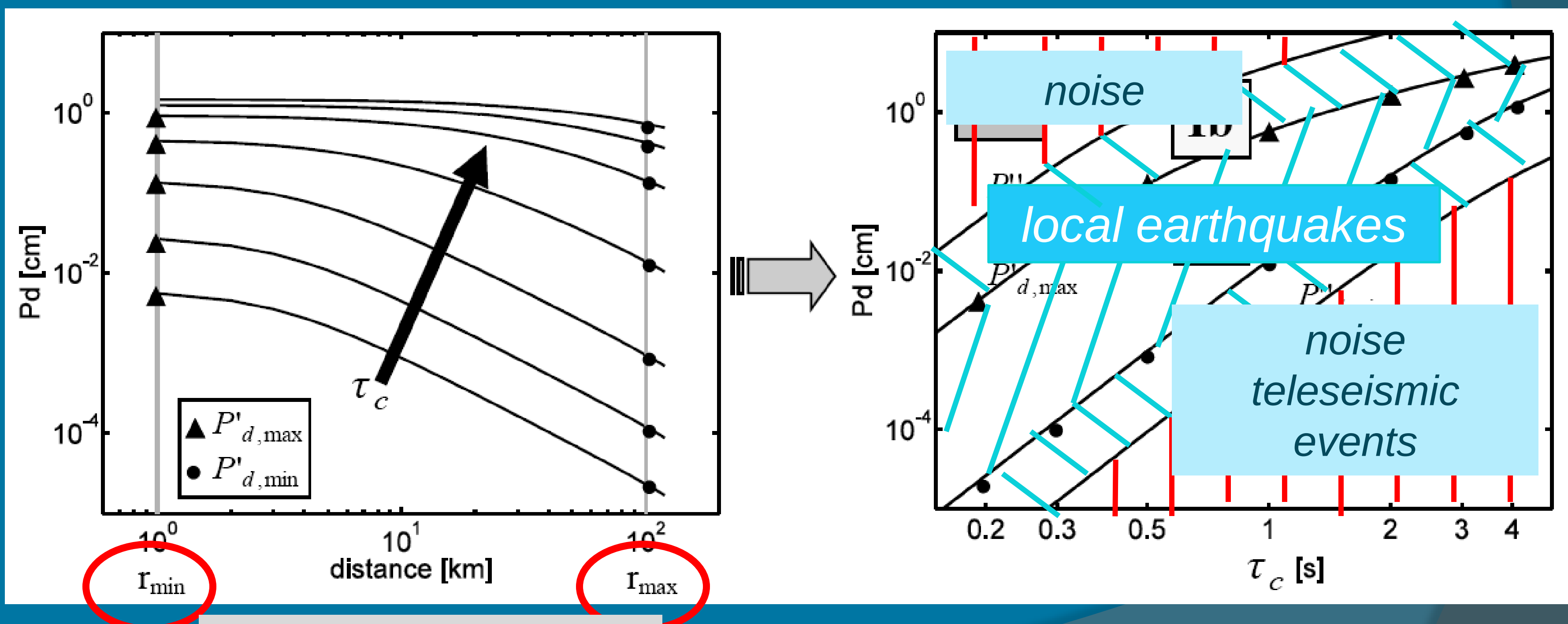

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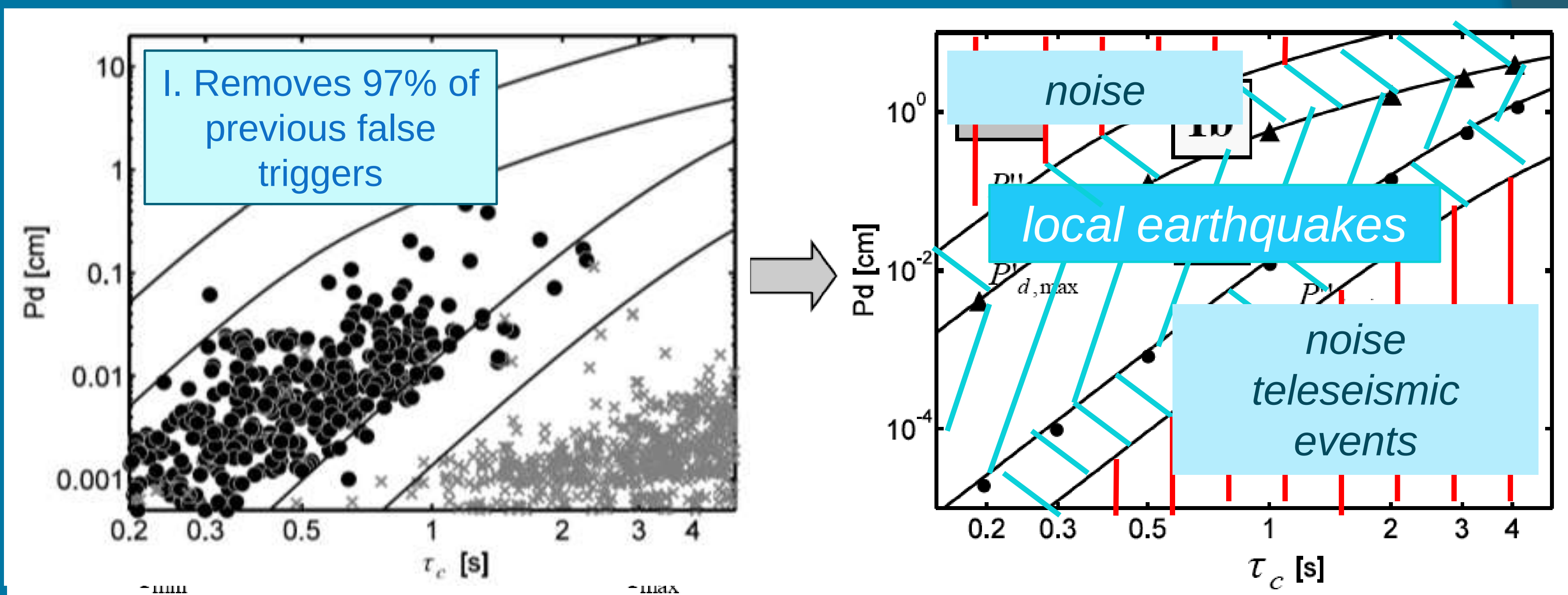
τ_c-P_d trigger criterion



Böse et al., 2009b

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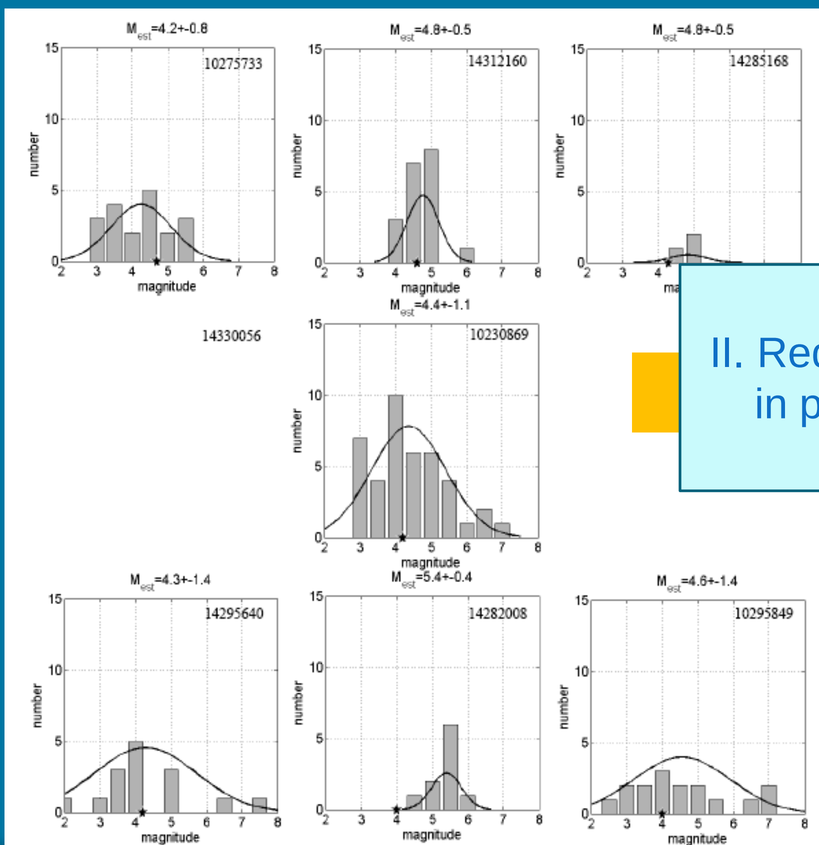
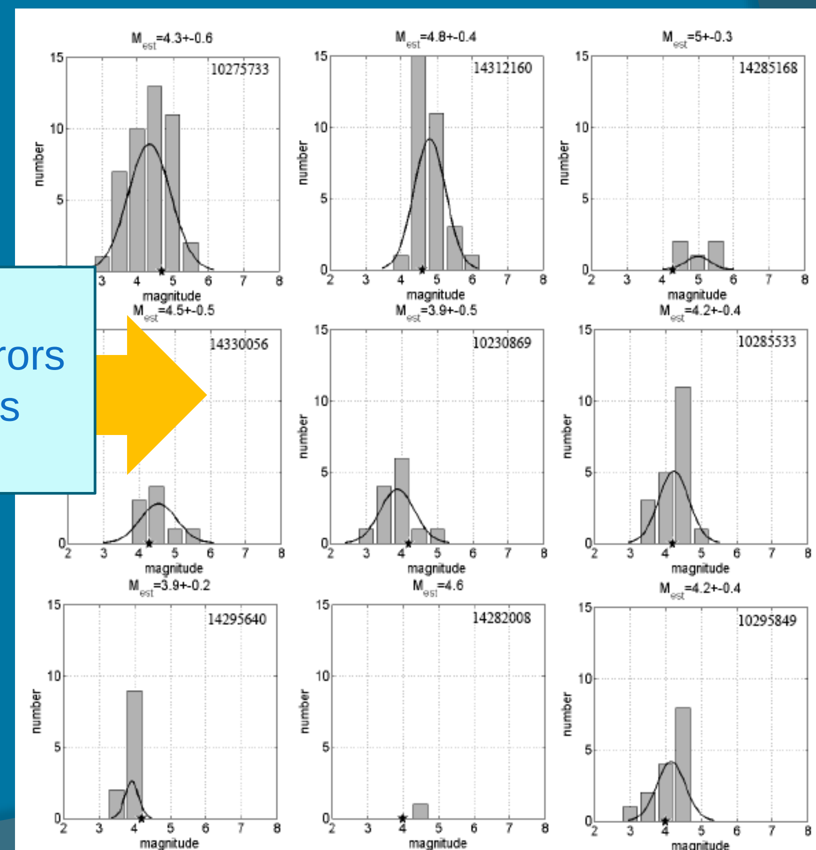
previous

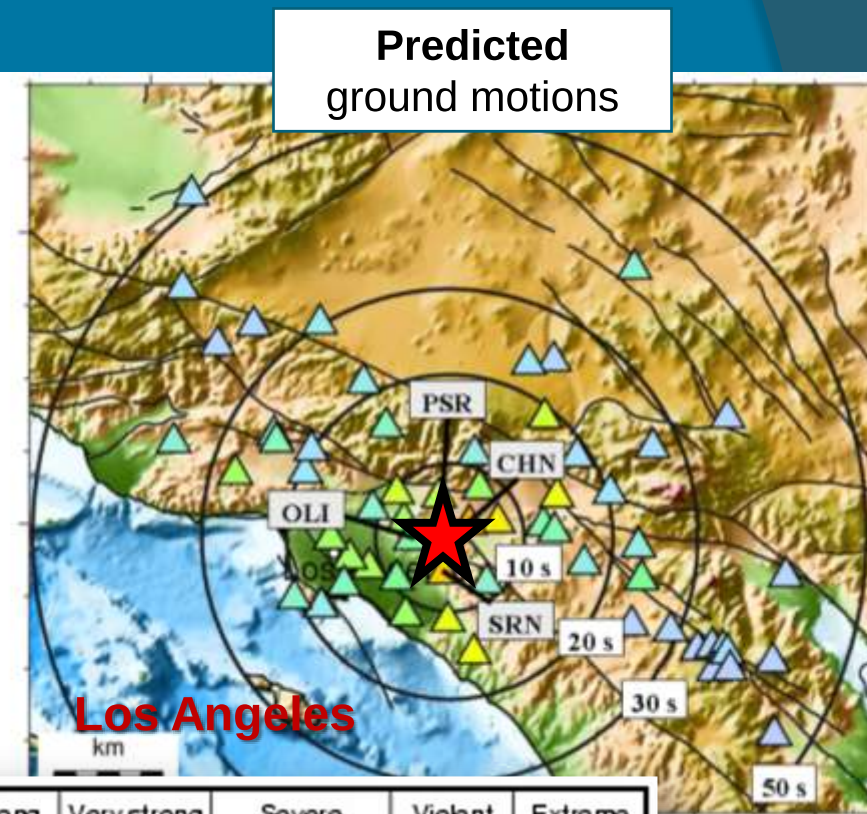


II. Reduced errors in predictions

with τ_c-P_d trigger criterion



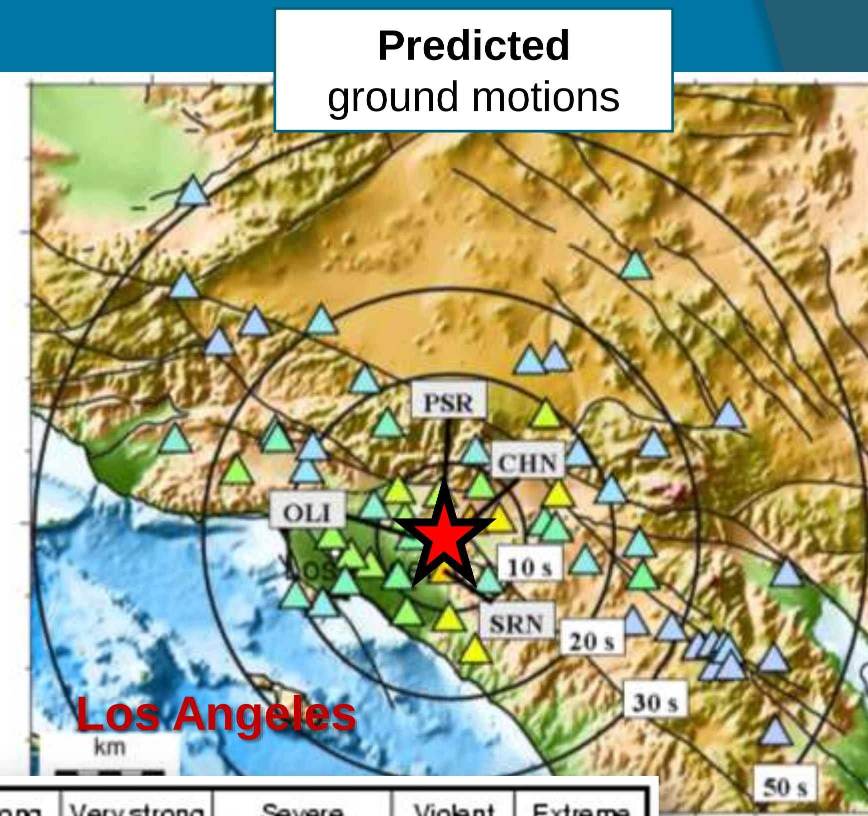
Time	Step/Event	CISN Channels	Observation	Solution/Action
July 29, 2008	**Chino Hills M_w5.4**		**Good performance**: **60 triggered** CISN stations Estimates: **M_w4.4-6.5** (median: M_w5.6) First report: **10 seconds after O.T.** (M_w6.1)	



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Böse et al., 2009a

Time	Step/Event	CISN Channels	Observation	Solution/Action
July 29, 2008	**Chino Hills M_w5.4**		**Good performance** τ_c /P_d are **site-dependent**	



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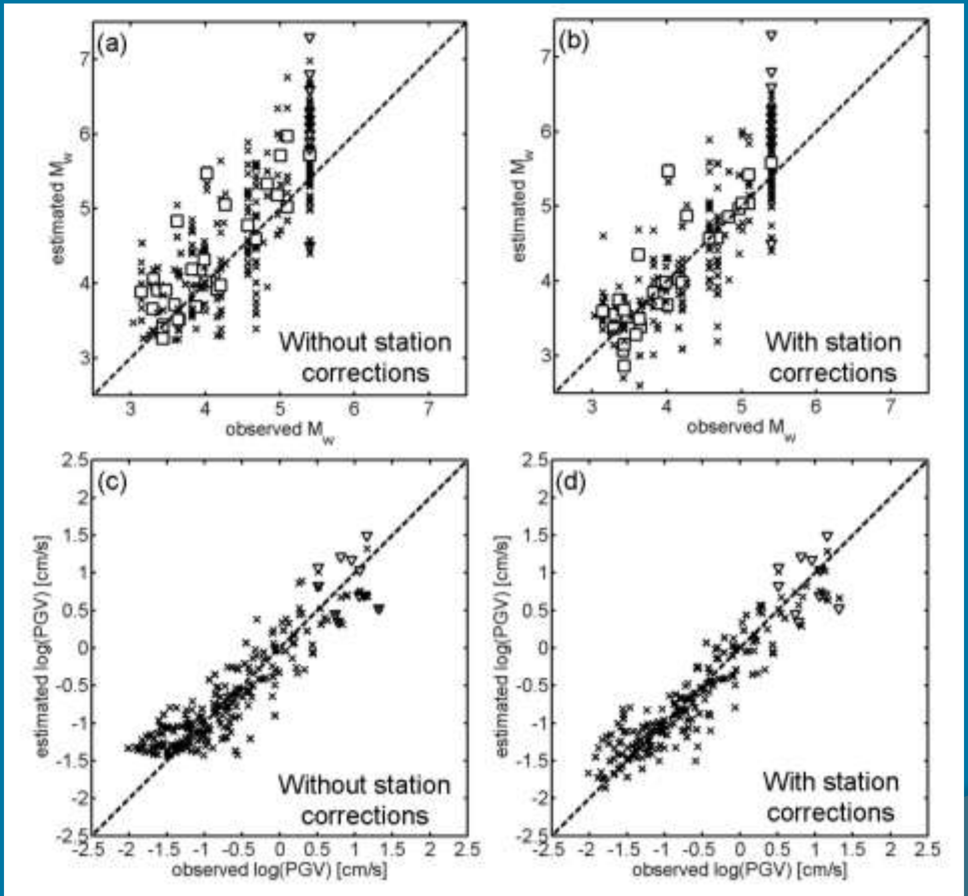
Böse et al., 2009a

Time	Step/Event	CISN Channels	Observation	Solution/Action
July 29, 2008	Chino Hills M_w5.4		Good performance τ_c /P_d are **site-dependent**	**Station corrections**



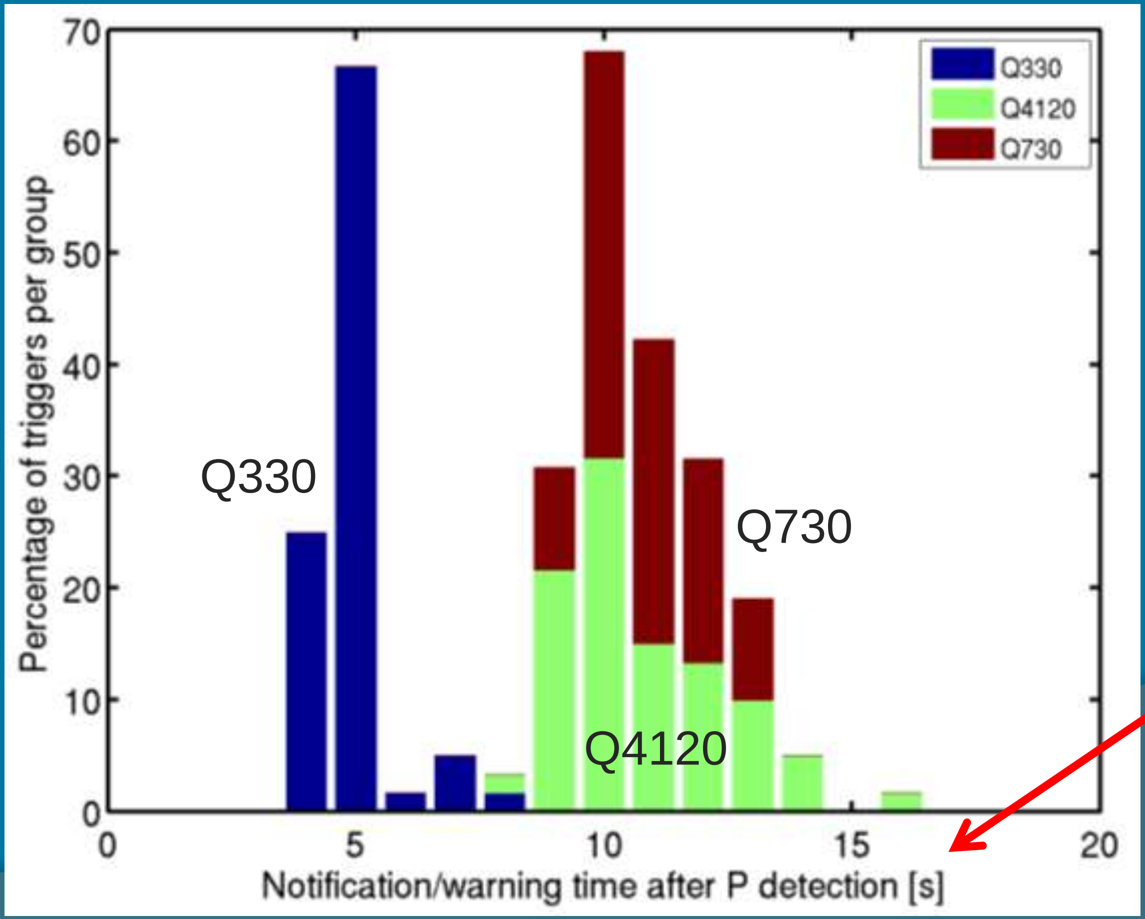
With station corrections:

M_w: ±0.5*
MMI: ±0.7*

* standard deviation

Böse et al., 2009a

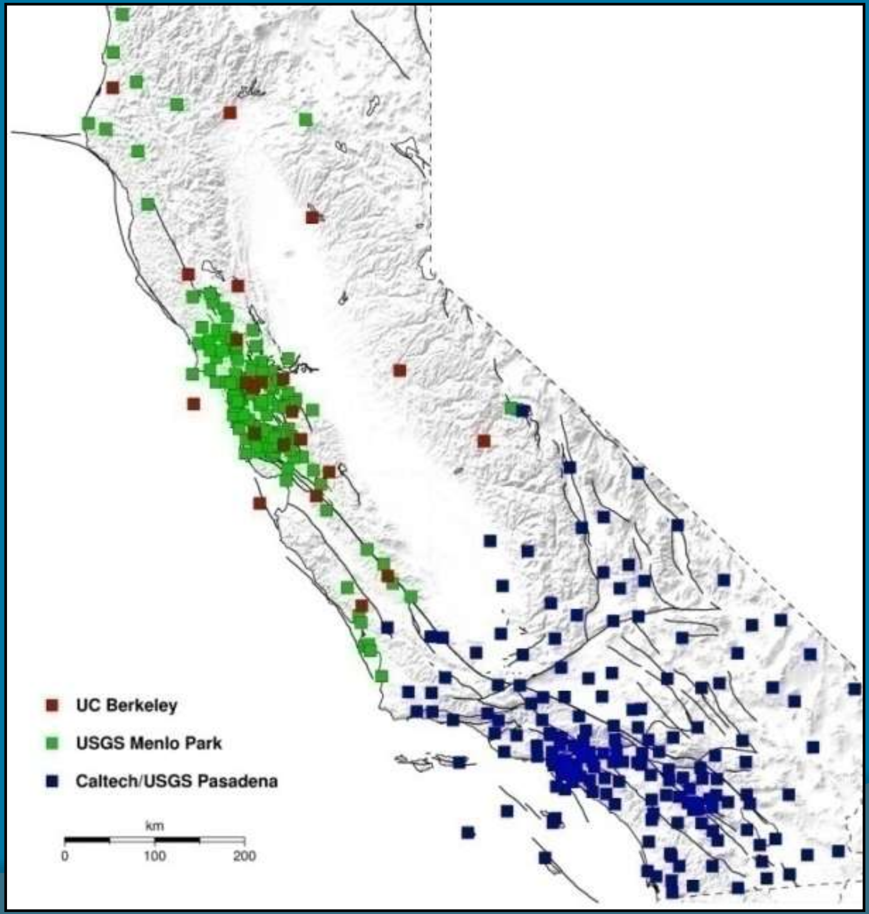
Time	Step/Event	CISN Channels	Observation	Solution/Action
July 29, 2008	Chino Hills M_w5.4		**Good performance** τ_c / P_d are **site-dependent** **Data latencies** …depend on **data logger** …are **variable with time**	→ Poster by K. Solanki Process **native Q330 wave packets**



CI network

Includes
- **data transmission**
- **algorithm (3 s)**
- **processing**

Time	Step/Event	CISN Channels	Observation	Solution/Action
2008-2009	**State-wide implementation, including strong motion sensors**	CI, AZ BK, NC, NP state-wide **221** HH channels **364** HN channels at 382 locations	**Similar results for HH and HN channels**	



California Integrated Seismic Network (CISN)

R. Allen

Time	Step/Event	CISN Channels	Observation	Solution/Action
2008-2009	**State-wide implementation, including strong motion sensors**	CI, AZ BK, NC, NP state-wide **221** HH channels **364** HN channels at 382 locations	**Similar results for HH and HN channels** more **false triggers at HN**	**in progress**

CESMD, 2009

Time	Step/Event	CISN Channels	Observation	Solution/Action
Since Nov. 2008	Deployment of **SLATE field processors** and on-site processing software			**in progress**

The Kinemetrics Slate Field Processor:

- rugged, low-power, embedded Linux computer
- ARM instruction-set CPU (400 MHz Intel PXA255 Xscale)
- 256MB SDRAM
- compact or SD Flash for persistent storage
- power consumption: 0.4W (idle) to 0.9W (both Ethernet ports active)
- operational temperatures: -20 to +60 Celsius.

Time	Step/Event	CISN Channels	Observation	Solution/Action
April 2009	**Capability to "replay" off-line data** as real-time data streams			**in progress**

τ_c-P_d algorithm

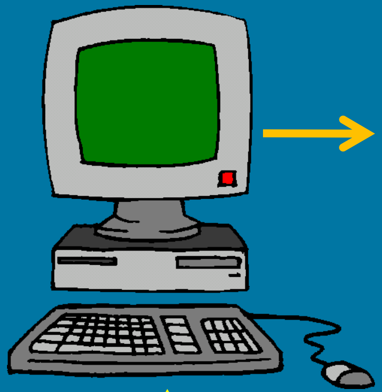
1. Real-time data
CISN

2. Off-line data (from database)

- Northridge, Landers, etc.
- earthquakes from other regions
- simulated waveform data
- noise

"Replay"

"real-time" data stream



M_w
PGV
MMI
…

To do:

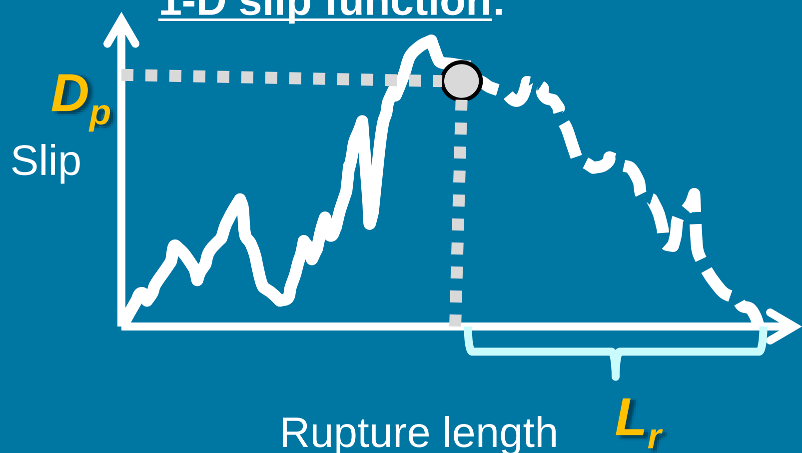
Optimize algorithm performance:
- evaluate **impact of changes in the code**
- quantify **uncertainties in M_w, PGV, MMI,…**
- reduce **false triggers**
- improve **station corrections**
- optimize **station distribution**

…

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 ?

Early Warning for Large Earthquakes (Research)

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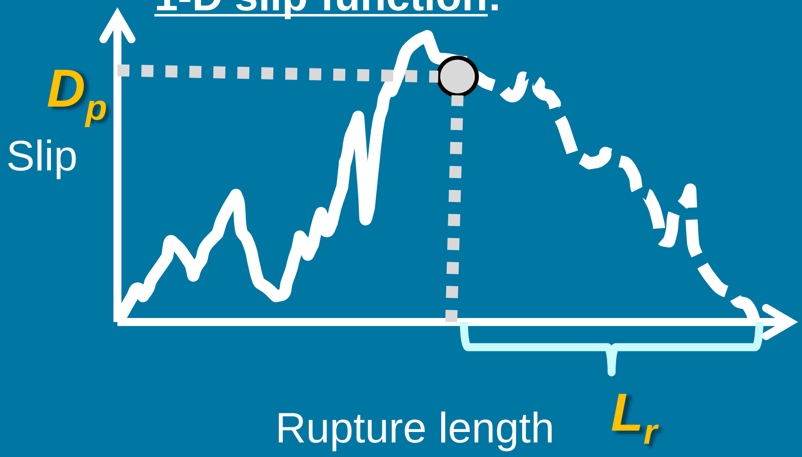
<u>**1-D slip function**</u>**:**



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<u>**RESULT:**</u>

- 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 !

$\longrightarrow$ *Presentation by Tom Heaton*

Time	Step/Event	CISN Channels	Observation	Solution/Action
July 2005	**First EEW workshop** at Caltech			
June 2006	**CISN as a test-bed for algorithm testing** (project by Caltech, UC Berkeley, USC/SCEC, USGS)			
2007-2008	**Implementation and initial testing** of the τ_c-P_d algorithm at Caltech	CI, AZ southern CA **172** HH channels	Many **false triggers** **Scattering in M estimates** for small earthquakes	**τ_c-P_d trigger criterion** install **testing server**
July 29, 2008	**Chino Hills M5.4**		**ogger** **time** **dent**	Process **native Q330 wave packets** Enhance **log-files** **Station corrections**
2008-2009	**State-wide implement ation, including stron motion sensors**	state-wide **221** HH channels **364** HN channels at 382 locations	**H HN** **peed** More **false triggers at HN**	**Optimization of source code** (compact instead of modular design) **Higher thresholds for HN/coupling with HH** (in progress)
Since Nov. 2008	Deployment of **SLATE field processors** and on-site processing software (in progress)			
April 2009	**Capability to "replay" off-line data** as real-time data stream • Northridge, Landers etc. • earthquakes from other regions • simulated waveform data /scenarios • noise records		**Objective**: **Enhance algorithm performance** - evaluate **impact of changes in the code** - assess **uncertainties**/reduce **false triggers** - improve **station corrections** - **optimize station distribution** EEW for **large earthquakes**	

THANK YOU !

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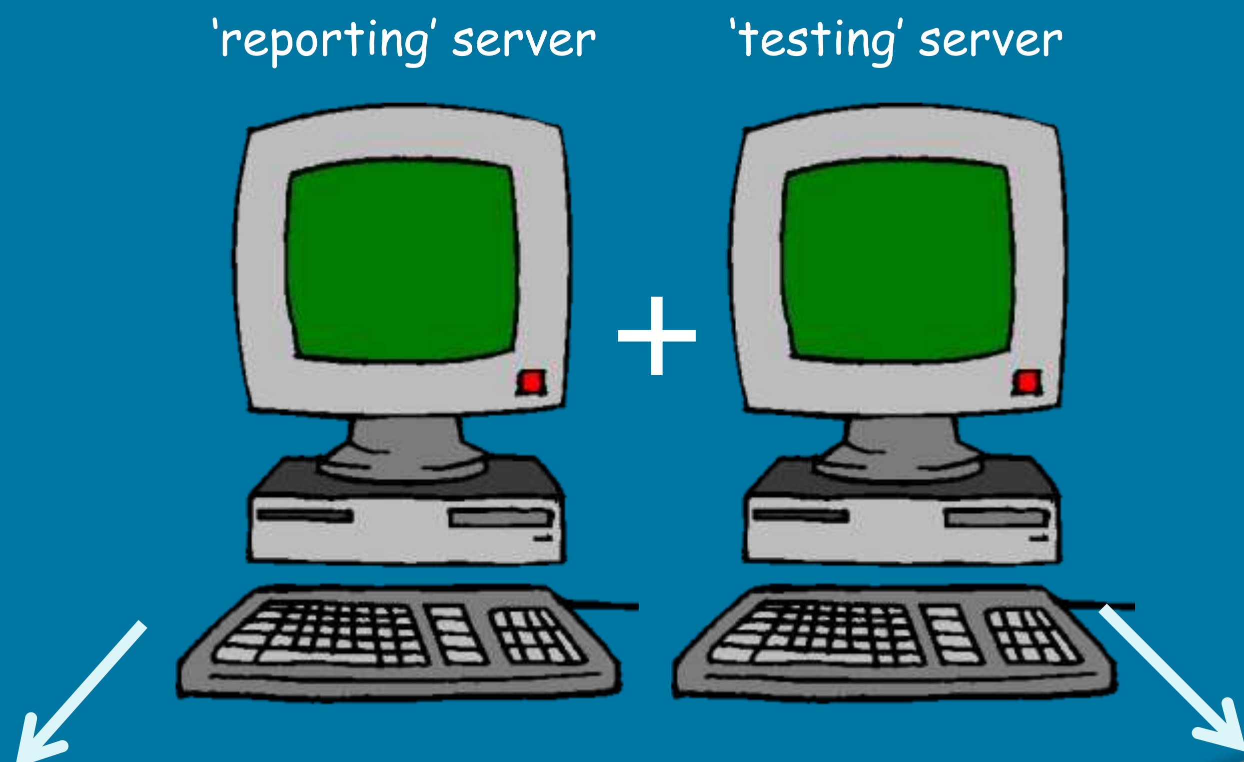

External evaluation of algorithm performance at SCEC

→ Poster by P. Maechling

Internal enhancement of algorithm performance at Caltech

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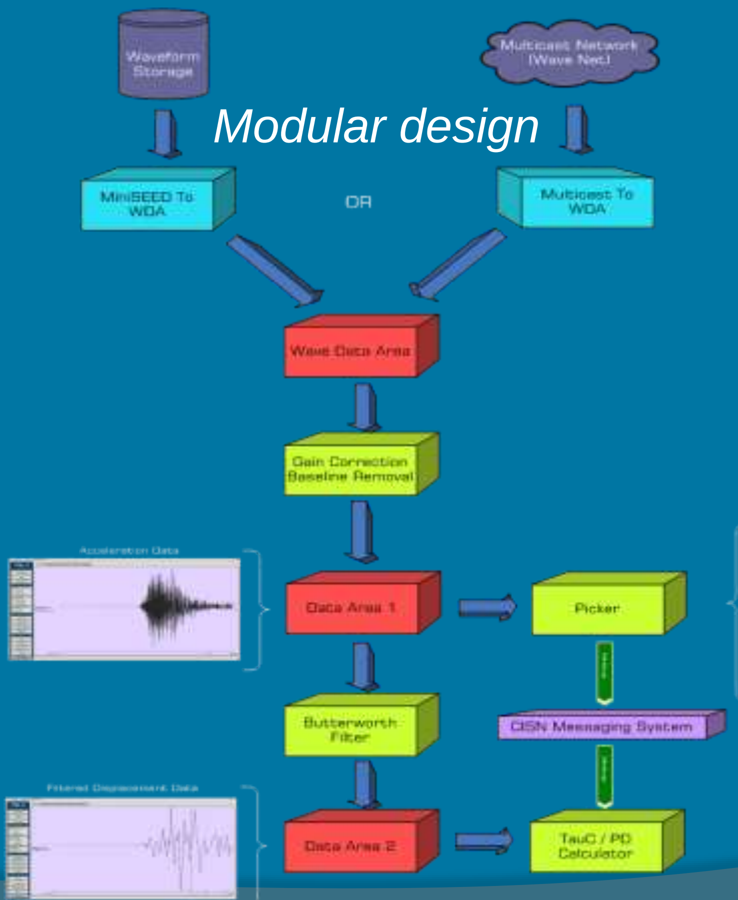

Solanki et al., 2007

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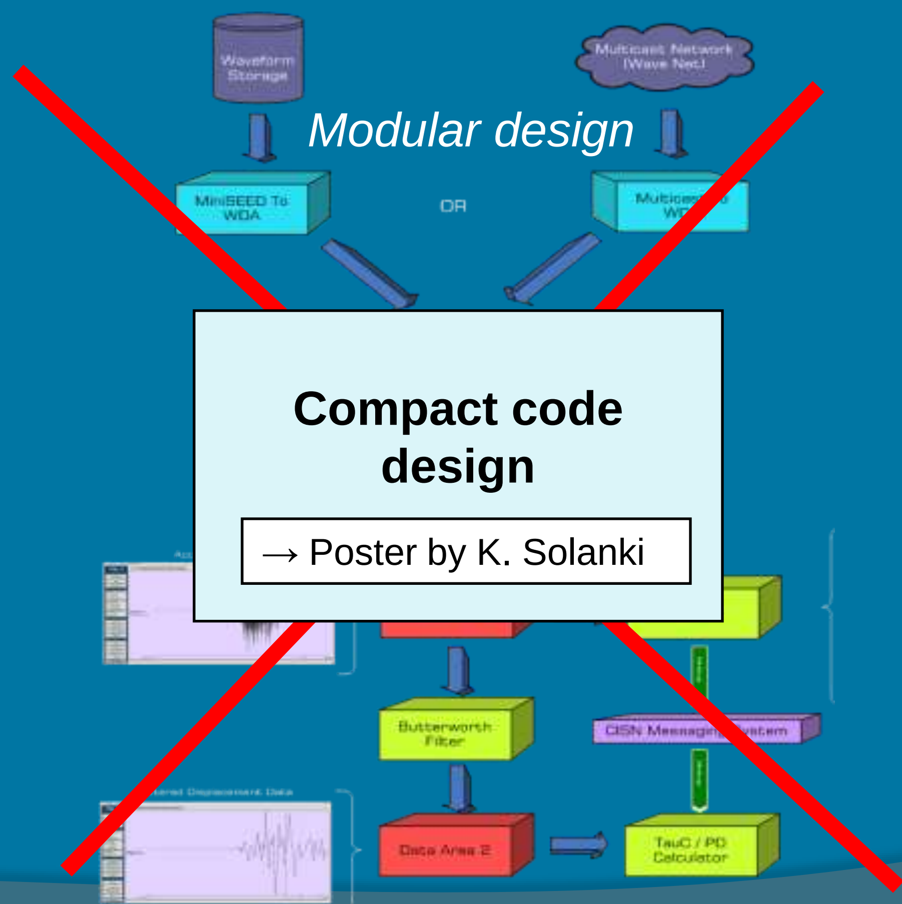

Compact code design

→ Poster by K. Solanki