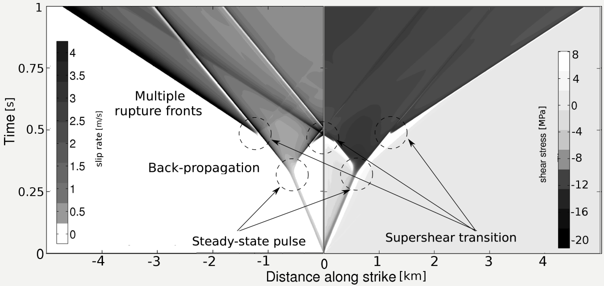
Complexity of Dynamic Rupture and Source Properties of Rupture Pulses in Plastic Media

ECGS Workshop 2012



Complex dynamic rupture pattern with multiple rupture fronts and multiple rupture styles

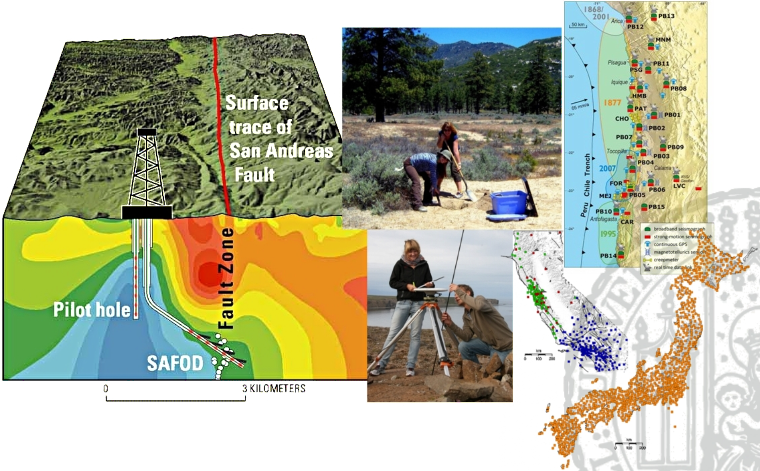
A.-A. Gabriel, LMU Munich
J.-P. Ampuero, Caltech
L. A. Dalguer, ETH Zurich
P. M. Mai, KAUST

Overview.

1. **Dynamic rupture styles.**
2. **Source properties of rupture pulses in the presence of off-fault plasticity.**
3. **Interpretation of observations.**

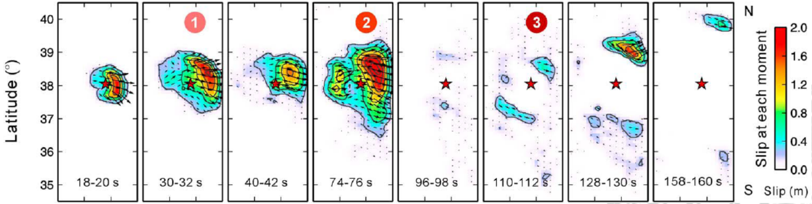
Complex source dynamics in observation.

- Increasingly dense instrumentation ⇒ **Gain of near-source data.**



Complex source dynamics in observation.

- Increasingly dense instrumentation ⇒ **Gain of near-source data.**
- Resolve complex source dynamics, for example: **Re-activation of slip**



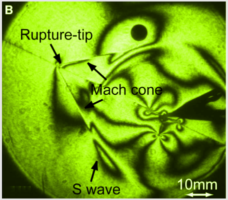
Lee & Wang (2011) - Tohoku (Japan) 2011, from combined local ground motion, teleseismics, GPS & multiple time window parametrization of slip rate. (see also Yao et al.,2011)

Complex source dynamics in laboratory earthquakes.

- Rupture style classification based on

⇒ **Rupture speed.**

Sub- & Supershear



Xia, Rosakis, Kanamori (2004)

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⇒ Rupture speed, **healing properties.**

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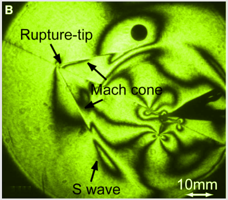

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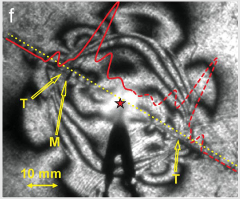
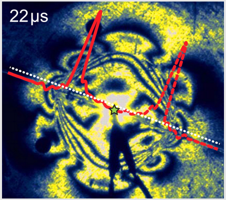
Crack



Lu,Lapusta,Rosakis (2007)

Pulse



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⇒ Constrained by constitutive model, nucleation, background stress

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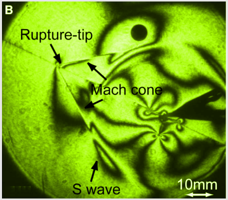

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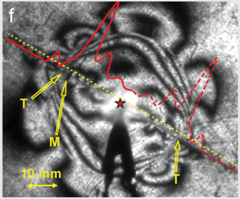

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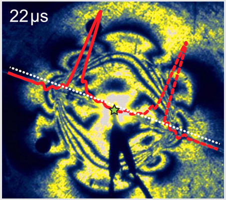

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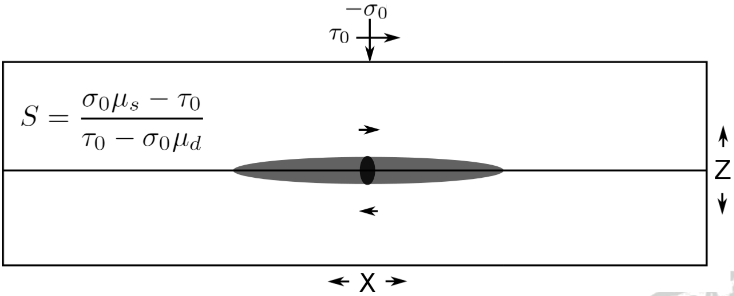
⇒ Constrained by constitutive model, nucleation, background stress.

Some open questions.

- Temporal evolution of rupture? Dominant rupture style? Self-similar growth? How do ruptures initiate and stop?
- Distribution of slip, stress drop, and high frequency radiation across the fault plane? Preferred hypocenter location, preferred propagation direction?
- Which physics on which scale dominate the rupture process? How do micro-, meso-, and macro-scale effects affect rupture?
- Physical limits of extreme ground motion?

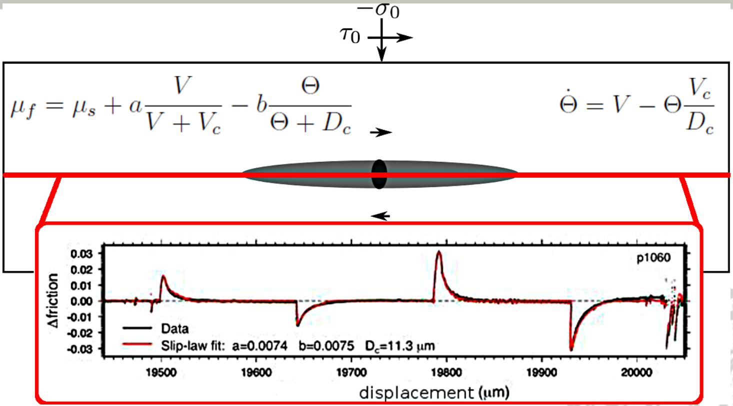
SCEC Shakeout scenario involving a magnitude 7.8 earthquake along the southernmost San Andreas fault.

Model complex source dynamics.



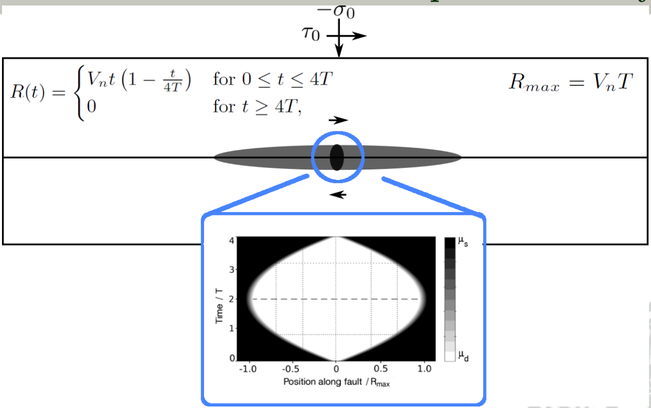
- Homogeneous visco-elasto-plastic material, prescribed linear fault, **mode II** loading (⇒ **relative fault strength** "S": initial strenth/nominal stress drop).

Model complex source dynamics.



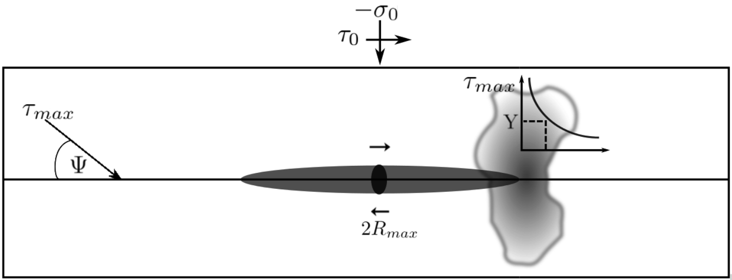
- **Severe velocity-weakening friction**
  Ampuero&Ben-Zion (2008)

Model complex source dynamics.



- Self-healing time-weakening nucleation ($\Rightarrow$ **max. half-width** "R_{max}")

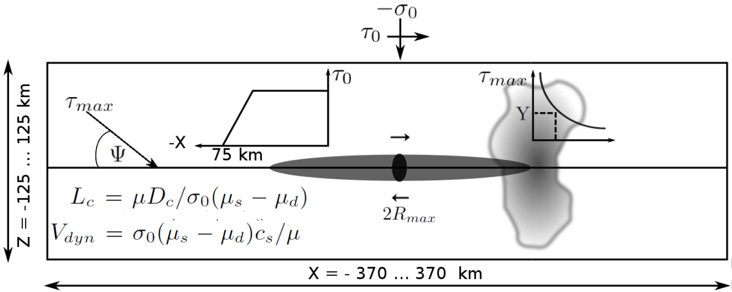
Model complex source dynamics.



$$\mathrm{CF} = \frac{(\mu_s + S\mu_d) / \sin(\phi)}{(1+S)\sin(2\Psi) + (\mu_s + S\mu_d)\cos(2\Psi)}$$

- **Off-fault plasticity** mimicked by Coulomb yield criterion
  Andrews (2005)

Model complex source dynamics.

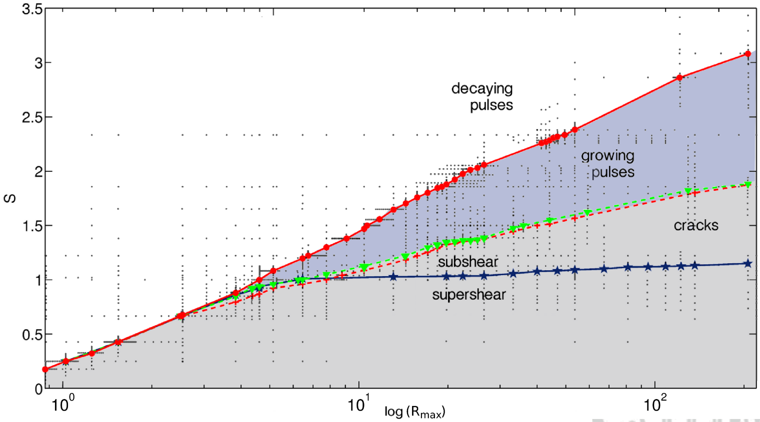


$V_{dyn} \approx 1$ m/s and $L_c \approx 100$ m if $D_c \approx 0.1$ m

- Scaling by **characteristic friction parameters and strength drop**

Dynamic rupture styles.

- Speed, healing properties, stability and complexity under varying relative strength of the fault and nucleation size.



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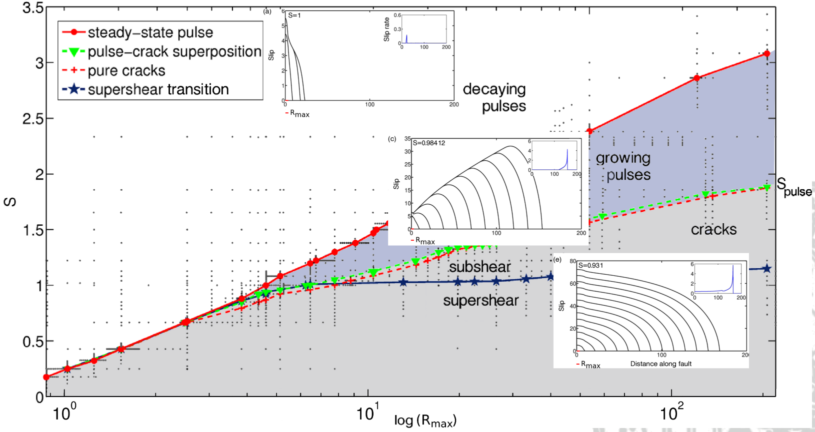
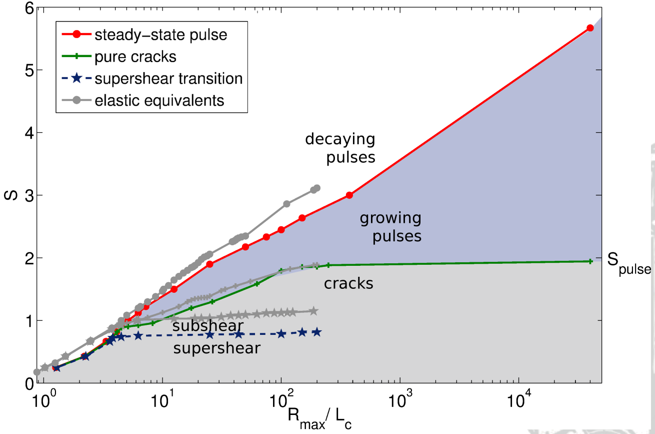


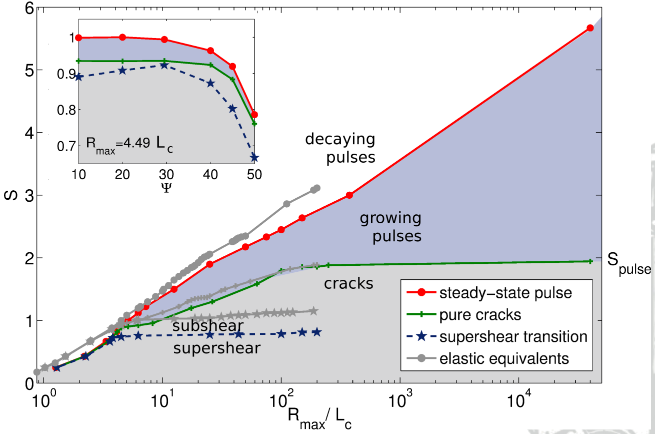
Dynamic rupture styles.

- Plastic energy dissipation does not alter the nature of the transitions between rupture styles
- **Transitional S values depend on Ψ**

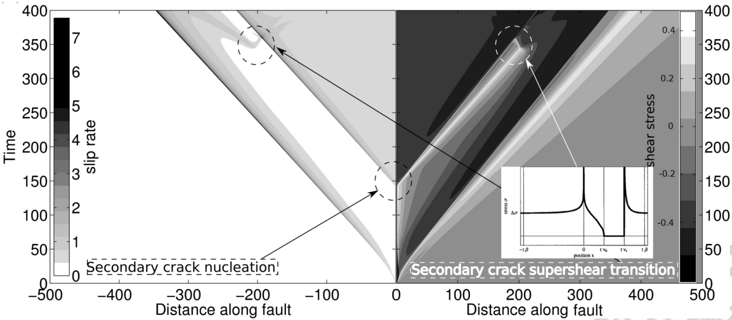


Dynamic rupture styles.

- Plastic energy dissipation does not alter the nature of the transitions between rupture styles
- **Critical nucleation sizes scale with total energy dissipation**



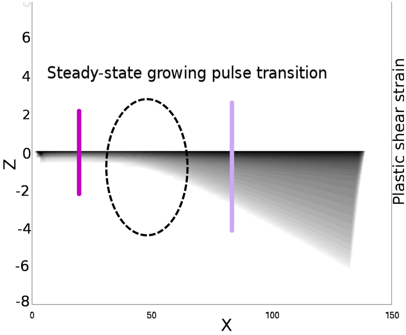
Pulse-Crack Transition.

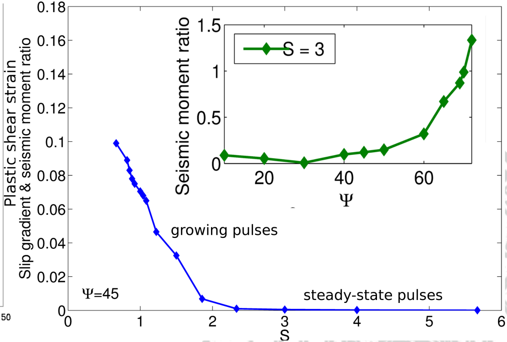


- Growing pulses lead to **re-activation** of slip due to gradual stress build up at the hypocenter
- Earthquakes may show multiple complex rupture patterns depending on fault stress, nucleation, friction, (and heterogeneities).

Interaction of growing pulses with off-fault plasticity.

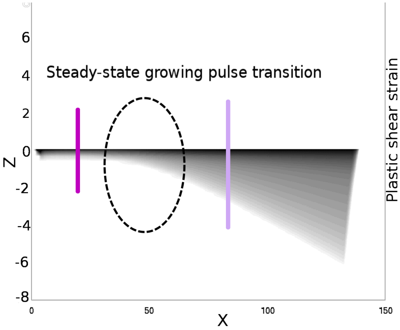
- Plasticity induces steady-state pulses at high S
- The relative plastic moment becomes dominant at large Ψ

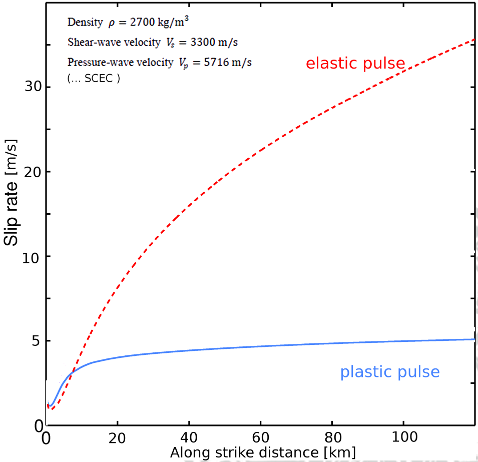




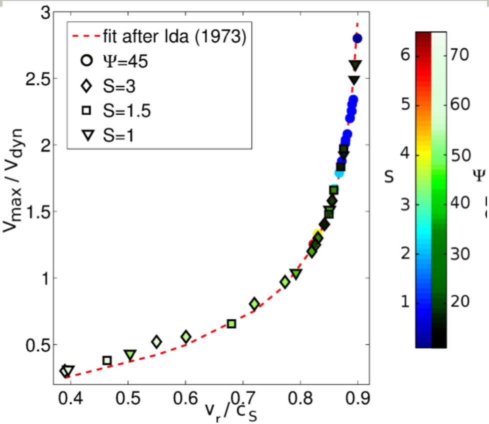
Interaction of growing pulses with off-fault plasticity.

- Off-fault plasticity limits peak slip rate and rupture velocity.





Relations between source parameters.



- Peak slip rate and rupture speed are related by (following Ida 1972):

$$V_{max} \approx 0.65 \frac{v_r}{\sqrt{1 - v_r/c_R}} \frac{(1-\nu)\sigma(\mu_s - \mu_d)}{\mu}$$

- Rupture speed slower than c_S resulting from self-similar energy dissipation
- Peak slip rate correlates with strength drop implying depth dependence
- Gradient of energy dissipation rate in dependence of (S, Ψ) would enable rupture speed prediction

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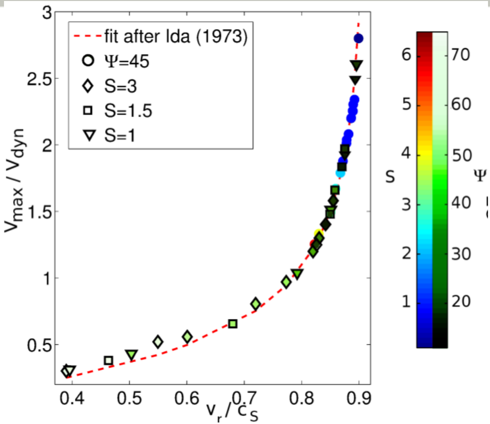

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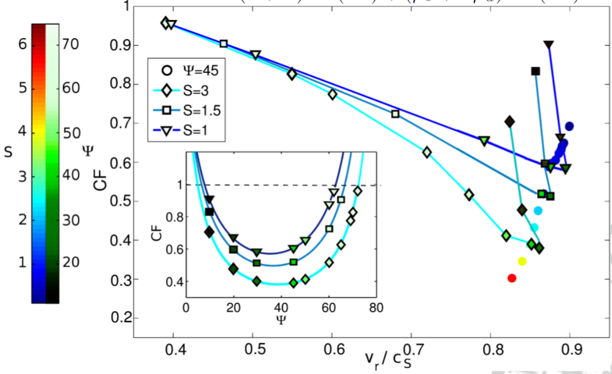
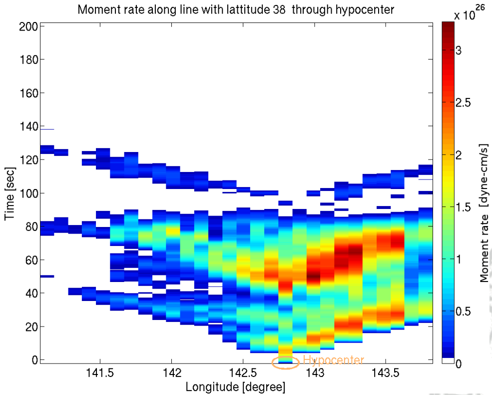


- CF is a good predictor of the combined effect of $\Psi > 30^\circ$ and S on rupture speeds for slow ruptures ($0.6c_S$) $\Rightarrow$ slower ruptures if the initial stress state is closer to failure

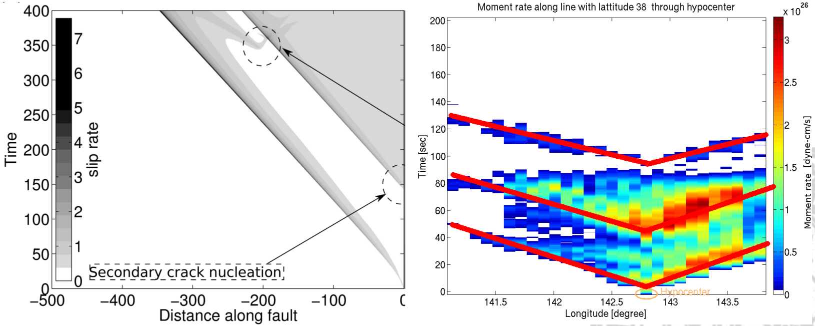
Re-activation of slip.



Tohoku-Oki (Japan) 2011 after Lee and Wang (2011)

Re-activation of slip.

- Dynamic rupture mechanisms help understanding complex source observations.



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Rupture speed and stress drop

- Correlations between low rupture speed and high stress drop

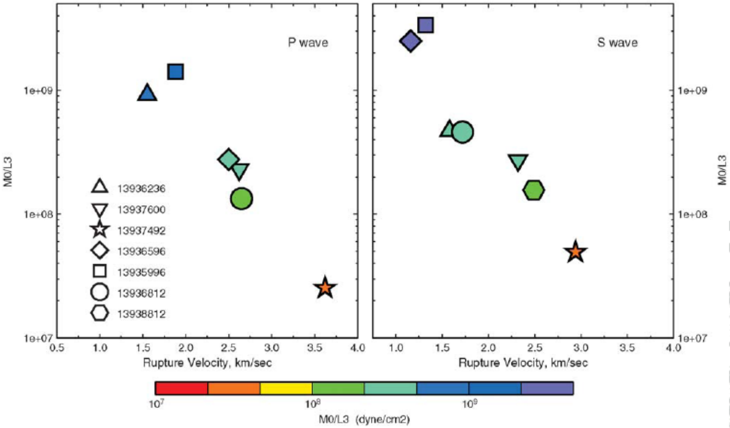
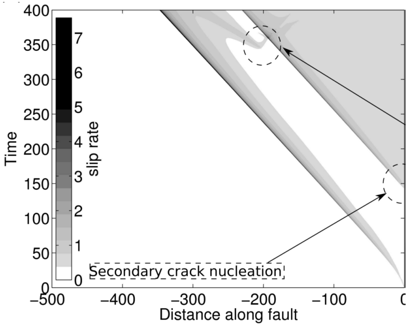


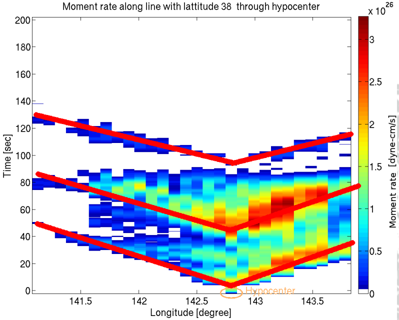
Figure 20. M_0/L^3 versus V_r from the studied events. The results from P wave are displayed on the left, and the S-wave results are on the right.

Big Bear 2003 sequence after Tan and Helmberger (2010)

Conclusions.

- Dynamic rupture mechanisms help understanding complex source observations.





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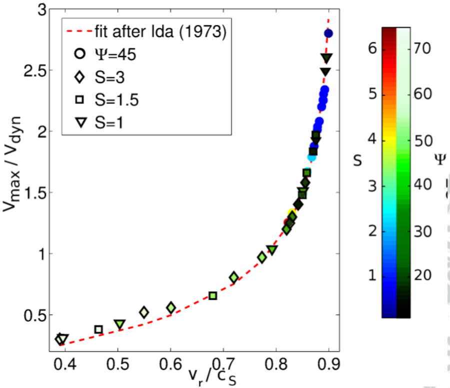

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- Relations between state of stress (S, Ψ) and source parameters may encapsulate a major effect of plastic deformation on near-field ground motion ⇒ e.g. to calibrate pseudo-dynamic source parametrizations or to constraint dynamic strength drop accounting for off-fault plasticity

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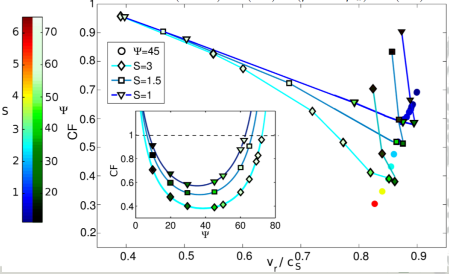

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Thank you!

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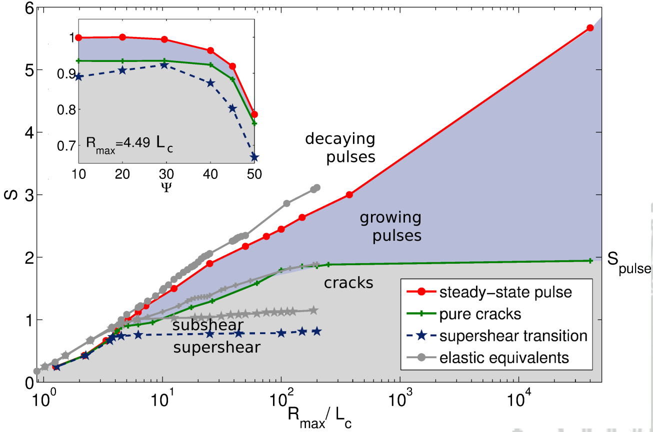
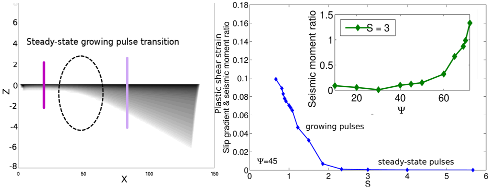


- $\Psi > 30^\circ$ **decreases transitional** S **values**

Stability and seismic moment.



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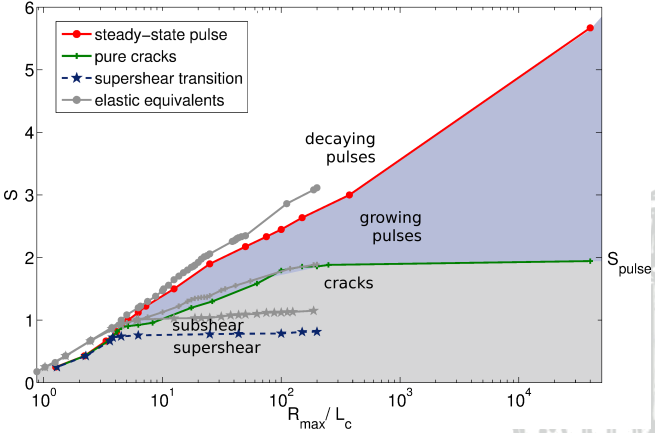

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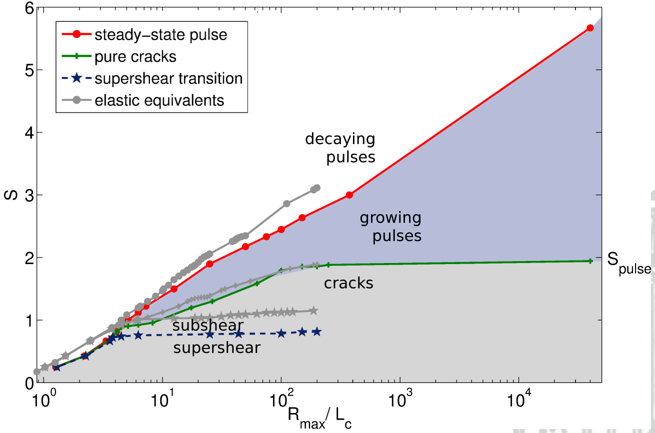

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