Uncertainty in kinematic rupture models from variation in source time function and Earth structure

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Motivation

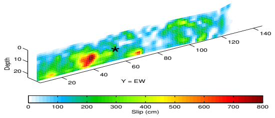
Significant variability in the rupture models : difficult to assess their reliability

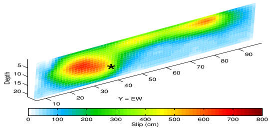
⇒ Necessity to quantitatively assess the uncertainty

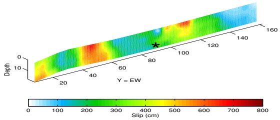
What are the major source of uncertainty:

- Choices in the parametrization
- Algorithm (MTW, STW)
- Data selection

1999 Izmit rupture models



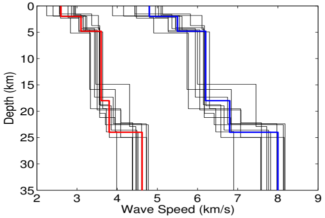




Objective

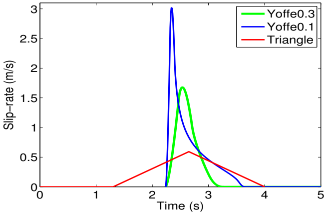
- To infer the kinematic source parameters in terms of PDFs
- To analyze the uncertainty related to the choice of the **source time function** and the variability in **Earth structure**

Crustal structure variability



Variation of 4% for the seismic velocities (Mooney, 1998)

Source time function



Triangle: commonly used

Yoffe: dynamically consistent

Bayesian inference

Map the **solution space** in terms of **posterior density functions**

$$\overbrace{\pi(\theta|d)}^{\text{posterior probability}} = k \overbrace{f(d|\theta)}^{\text{Likelihood}} \overbrace{\pi(\theta)}^{\text{Prior}} \qquad (1)$$

- **Prior :** uniform distribution
- **Gaussian Likelihood**

$$f(d|\theta) = cexp[-\underbrace{\frac{1}{2}(g(\theta)-d)^T C_D{}^{-1}(g(\theta)-d)}_{S(\theta)}] \qquad (2)$$

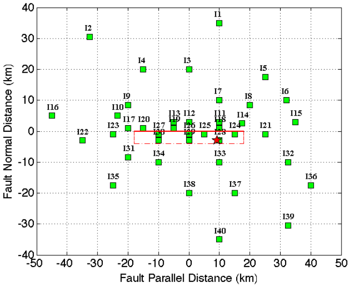
Empirical formulation (Monelli et al., 2009)

$$f(d|\theta) = cexp[-\frac{S(\theta)-S(\theta_{best})}{S(\theta_{best})}.100] \qquad (3)$$

Data

Synthetic data set in context of Source Inversion Validation

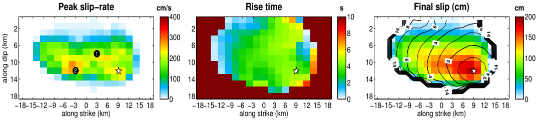
- **Reference model** : generated from a spontaneous dynamic rupture calculation
- **Inversion**: three-component velocity waveforms at 40 sites; frequency range up to 1Hz



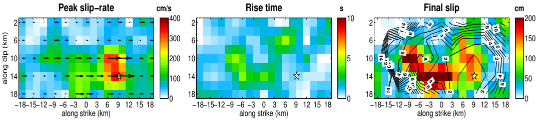
Rupture model from Optimization

- Capture the high slip/slip-rate patch around the hypocenter
- Extension of the patches changes between source models
- Rupture propagates faster for the isosceles triangle than for the regularized Yoffe
- Prediction of these models fits the data well with variance reduction of 94%

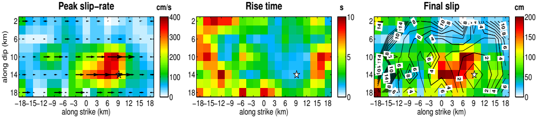
Reference



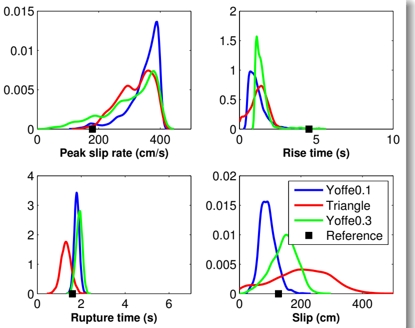
Triangle

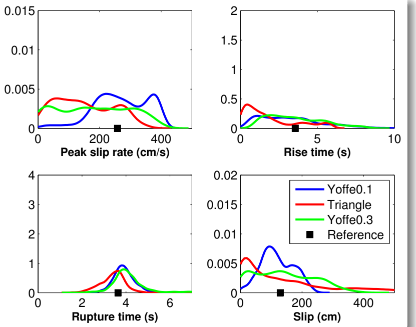


Regulaized Yoffe



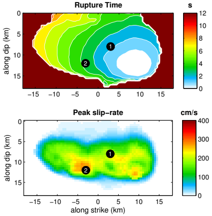
Posterior PDFs

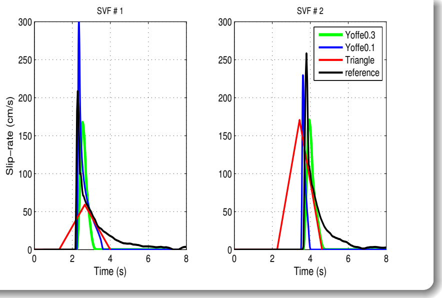




- Characteristics of the uncertainty vary from point to point
- Accuracy of source parameters decreases with increasing distance from the hypocenter
- Rupture times for triangle STF: artificially earlier leading in overestimating the rupture speed

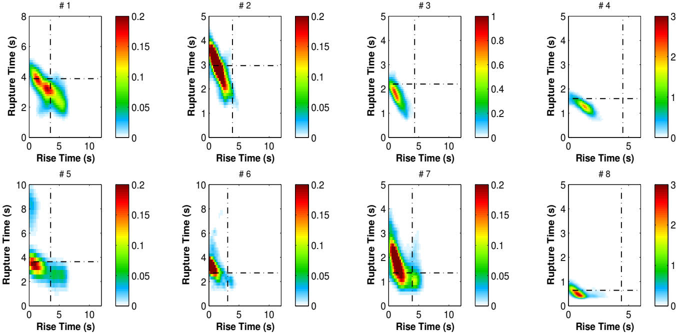
Slip-rate function





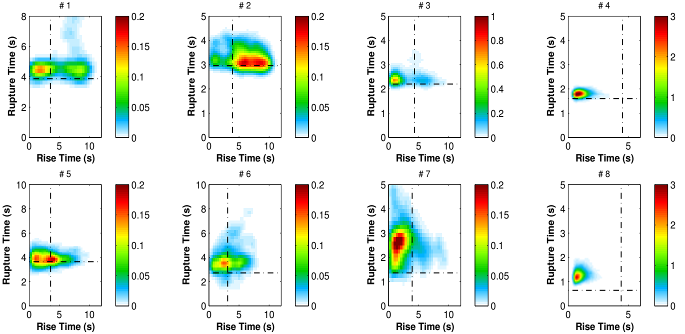
- Ground motion: most sensitive to the **time of the peak slip-rate** (Goto and Sawada (2010), Oglesby and Mai (2012))

2D Marginal for Triangle STF



- Rupture time and rise time are **negatively correlated** for a triangle source time function
- Constraining the rupture time for a triangle source time function, the data also constrain the rise time

2D Marginal for regularized Yoffe STF



- Rupture time and rise time are **negatively correlated** for a triangle source time function
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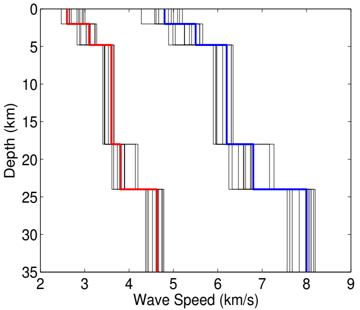
Conclusion 1

- The use of an isosceles triangle as source-time function biases the result of finite fault source inversions. It accelerates the rupture to propagate faster
- The use of an isosceles triangle generates an artificial linear correlation between parameters that does not exist for the Yoffe source-time functions

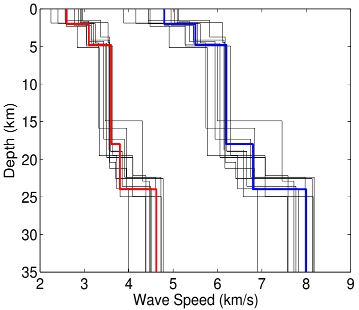
Crustal structure

Impact of including variability in the 1D crustal structure

Wave speed only

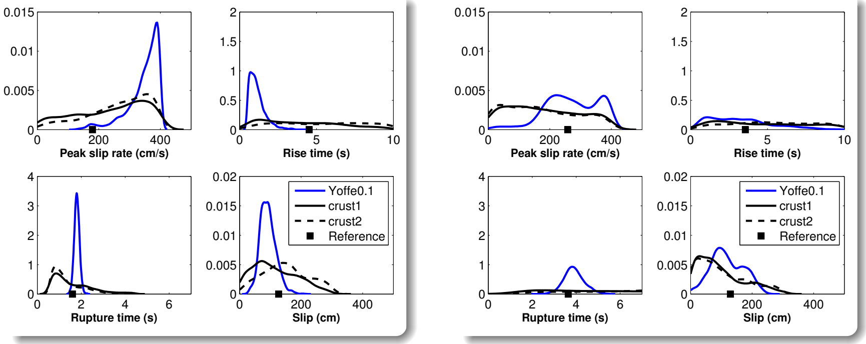


Wave speed and layer depth



Random samples of V_P and V_S drawn from a normal distribution with variance based on Mooney (1998)

Posterior PDFs



- Change in the resolution of the parameters : broadening of the posterior PDFs due to incorrect Earth structure
- PDFs for the two types of crustal model variability remain essentially unchanged
- Rupture time: shift in peak location (isochrone theory)

Conclusion 2

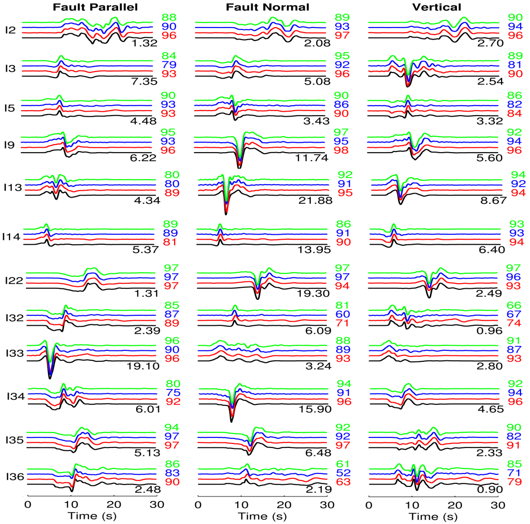
- Including the uncertainty in Earth structure broadens the PDFs of the source parameters with particular shifts in peaks location for the rupture time
- Rupture time is the parameter that is most strongly affected both by variations of the source time function and in the crustal structure.

Open Question

- What are the best ways to parametrize the temporal parameters?
- What others techniques could we use to incorporate the Earth structure uncertainty ?

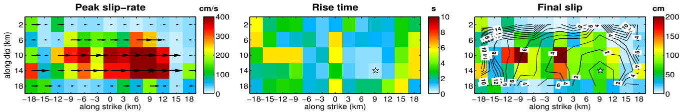
Thank You

Waveform fits

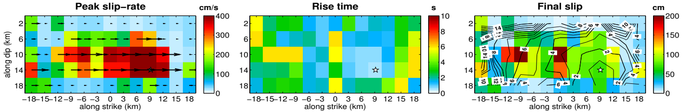


Estimates

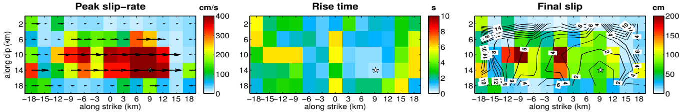
MAP



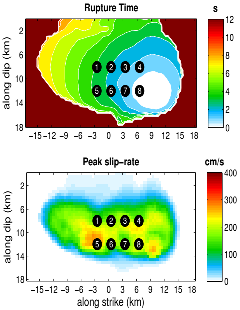
Median

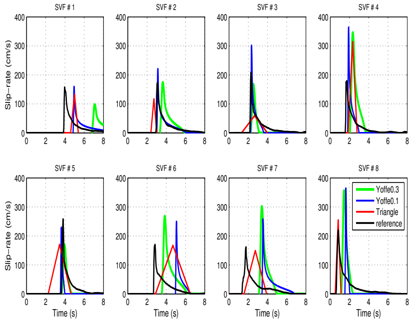


Mean



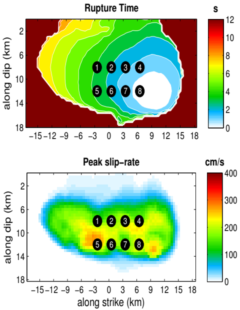
Slip-rate function

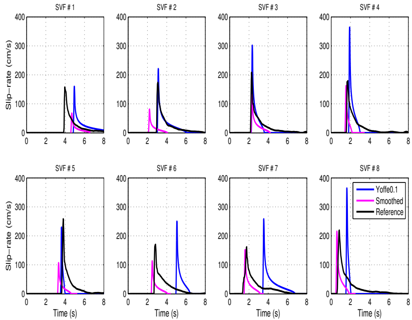




- The time of the peak doesn't coincide for all nodes
- trade-off between neighbouring patches
- non-uniqueness

Slip-rate function





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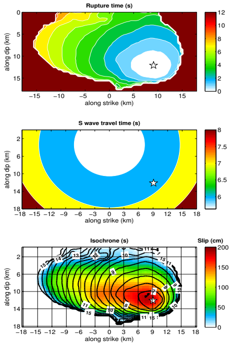
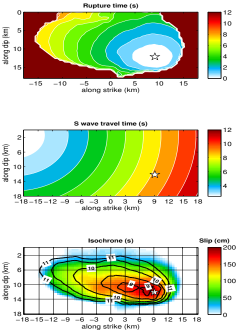
Isochrone

Around the hypocenter: large isochrone velocity or with abrupt change in isochrone velocity ⇒ Significant radiated seismic energy

Station3



Station9



Station32