What kinematic parameters are resolvable in finite fault inversions?

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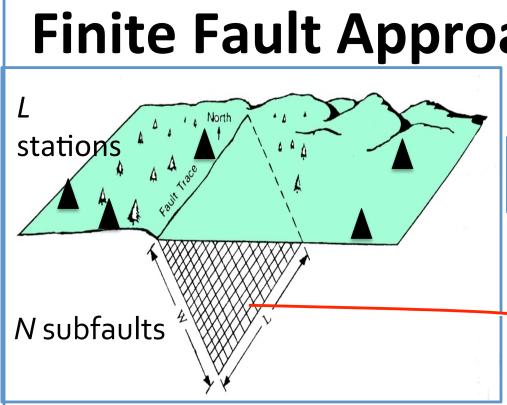
Introduction

- Detailed mapping of spatial and temporal slip distributions of large earthquakes is one of the principal goals of seismology
- Disparities between different rupture and inversion models to finite fault source studies might be caused by:
    - Differences in data distribution
    - Model parameterization
    - Green's function calculation
    - Inversion algorithm
- Considering the general uncertainties in Green's function calculation and fault geometry approximation, and considering the limited spatial data coverage for most earthquakes, none of the inverted source models can fully resolve all the rupture details
- Using the Source Inversion Validation (SIV) BlindTest 1 exercise, investigate uncertainties of earthquake finite-fault inversions based upon strong motion

So, what can we actually resolve about the rupture process?

Finite Fault Approach



$$Y^{i}_{jk}(t,t',\vec{x}) = \sum_{p} G^{i}_{jk}(\vec{x}_p,\vec{x},t) * \delta(t-\Delta t^{p}_{jk}-t')$$

Each subfault = series of point sources

Representation Theorem:

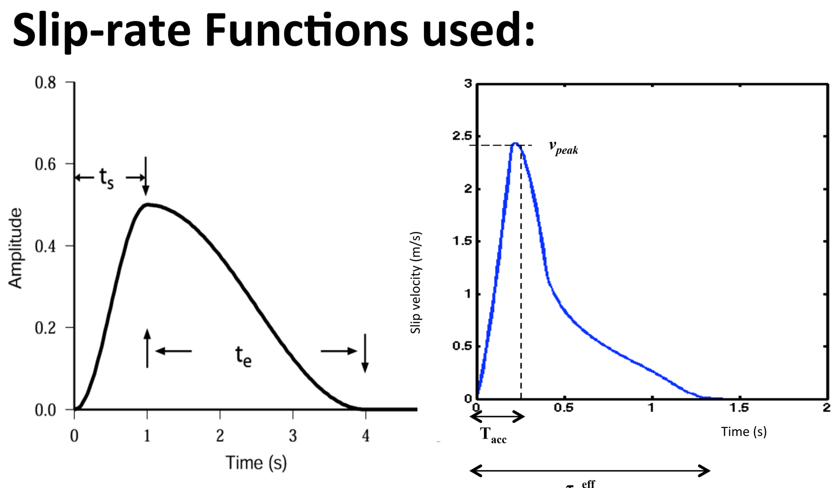
$$u(t,\vec{x}) = \int_{-\infty}^{\infty} d\tau \iint_{\Sigma} [u_i(\xi,\tau)] c_{ijpq} \partial G_{np}(\vec{x},t-\tau;\xi,0)/\partial \xi_q \, d\Sigma$$

Numerical Approximation:

$$u(t,\vec{x}) \approx \sum_{j=1}^{n}\sum_{k=1}^{m} D_{jk}[\cos(\lambda_{jk}) Y^{1}_{jk}(t,t',\vec{x}) + \sin(\lambda_{jk}) Y^{2}_{jk}(t,t',x)] * \dot{S}_{jk}(t)$$

D_{jk}	Slip amplitude
λ_{jk}	Rake angle
$\dot{S}_{jk}(t)$	Slip rate function
t'	Rupture initiation time
$Y^{i}_{jk}(t,t',\vec{x})$	Subfault Green's functions

Slip-rate Functions used:



Asymmetric cosine function **Modified Yoffe function**

Source Inversion Validation

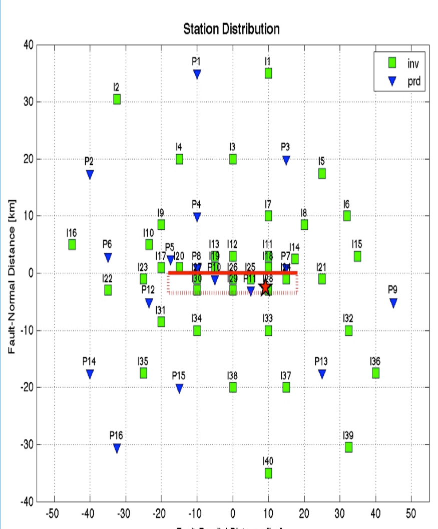


Figure: Receiver geometry for inversion exercise. Red line is the surface projection of the fault plane.

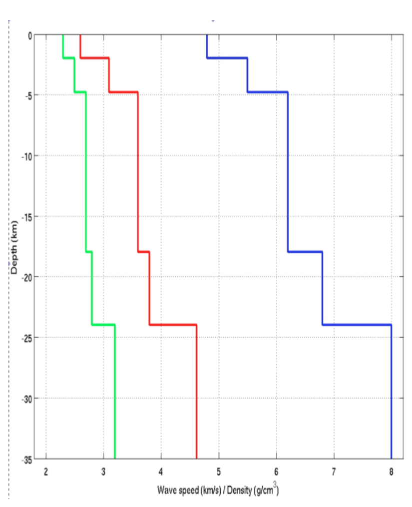


Figure: Velocity-density structure (green), s-wave velocity (red), p-wave velocity (blue).

- A crack-like spontaneous dynamic rupture embedded in a layered isotropic velocity-density structure
- Synthetic ground motions data at 40 stations are provided (~2.5 Hz)
- Inversion computed on a purely strike-slip fault striking at 90° and dipping at 80° with rupture initiating at a depth of 14 km

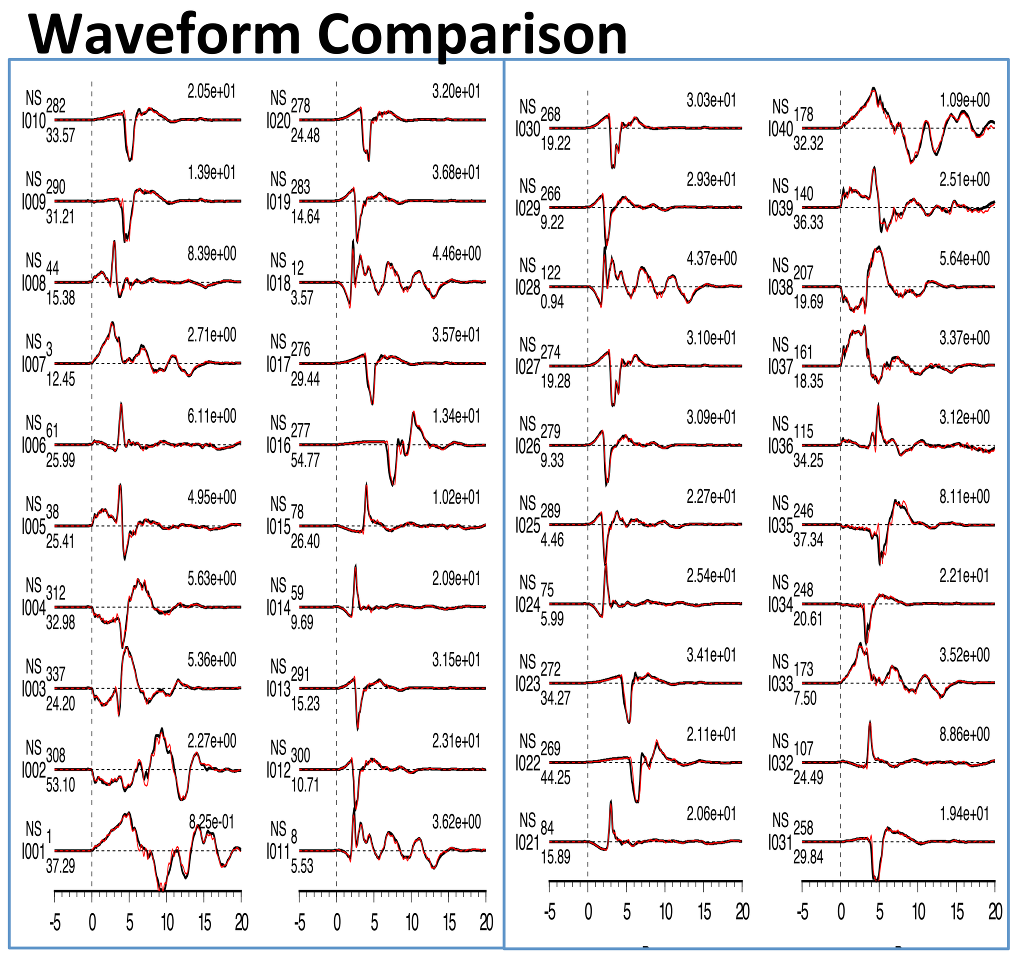
Tests Done in this Study

	Frequency Band (Hz)	Number of Stations	Subfault Dimensions (km)	Along-strike length (km)	Down-dip length (km)	Along-strike location of hypocenter (km)	Down-dip location of hypocenter (km)
1	[0, 1.56]	40	1.0 x 1.0	40	20	30	14
2	[0, 3.13]	40	1.0 x 1.0	40	20	30	14
3	[0, 3.13]	32	1.0 x 1.0	40	20	30	14
4	[0, 3.13]	40	1.5 x 1.0	37.5	20	30	14

- Rupture velocity can vary from 1.25 km/s to 3.75 km/s
- Inversions use a Simulated Annealing method and based on a weighted L1+L2 norm in the wavelet domain

Model Results:

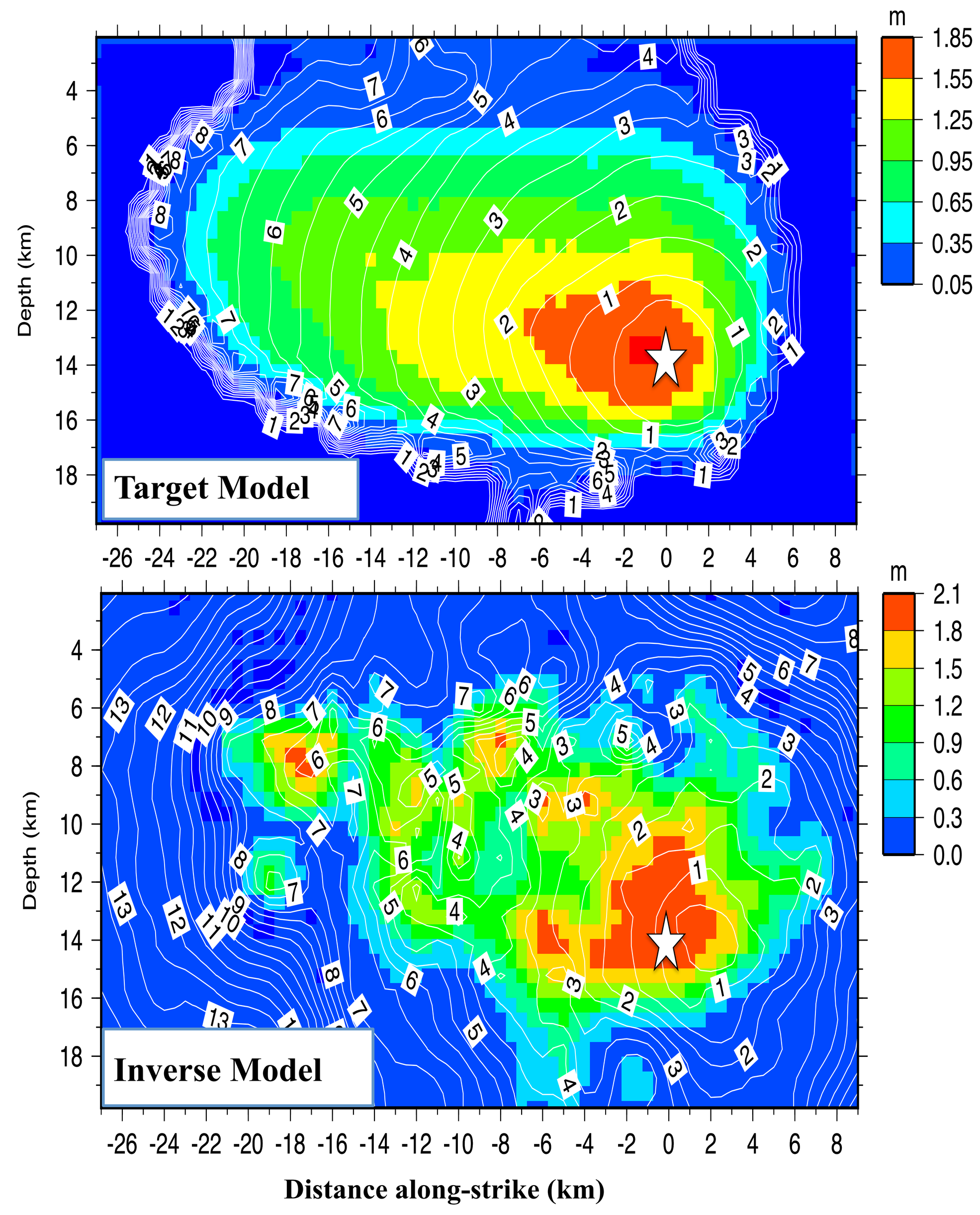
Waveform Comparison



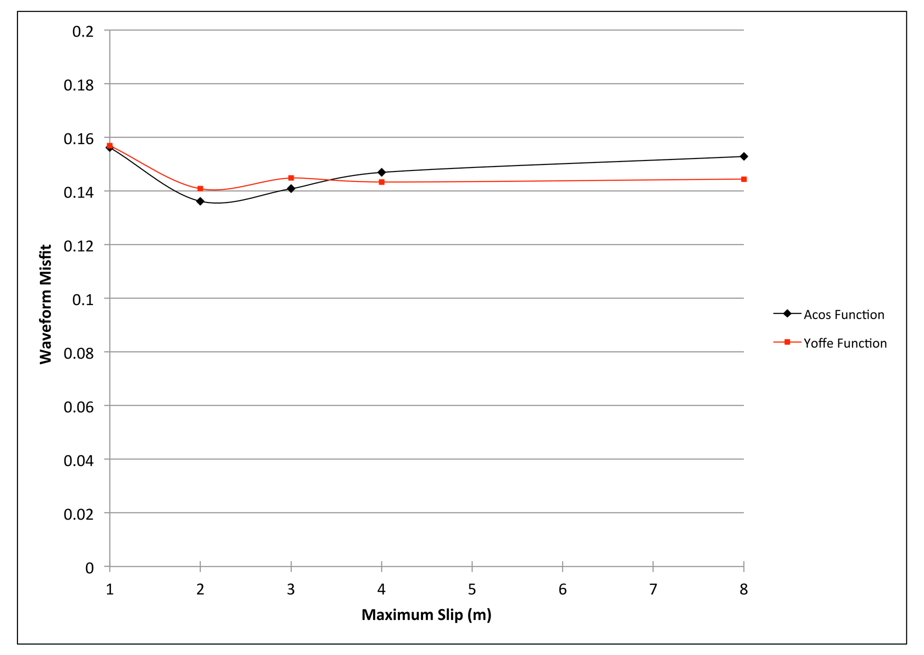
Target model (black) = forward model generating synthetic seismograms using a spontaneous dynamic rupture simulation with heterogeneous initial stress on the fault, and assumes a linear slip-weakening friction model

Inverse Model (red) = inverse kinematic model

Cumulative Slip Distribution

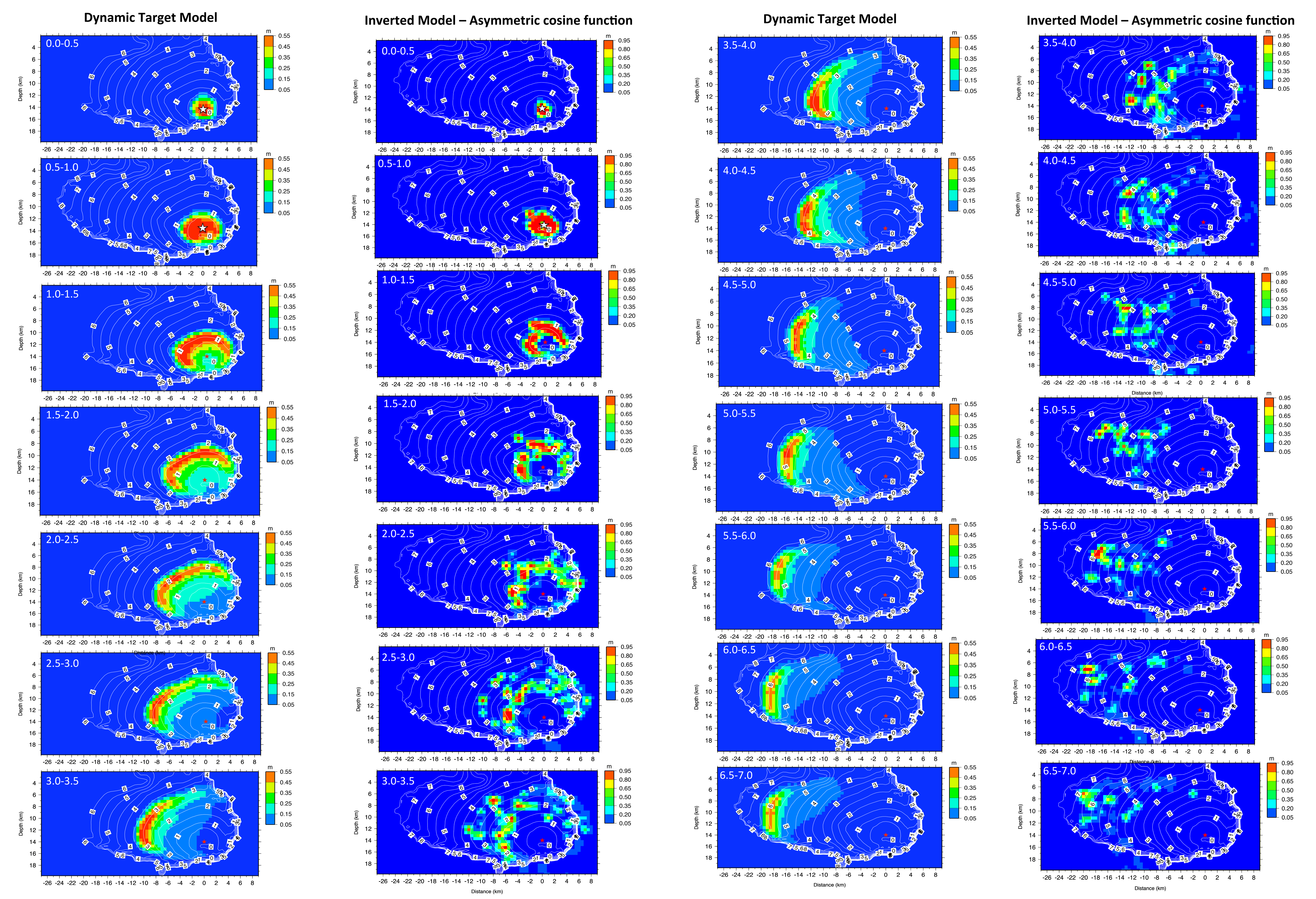


Maximum Allowable slip vs. Waveform Misfit

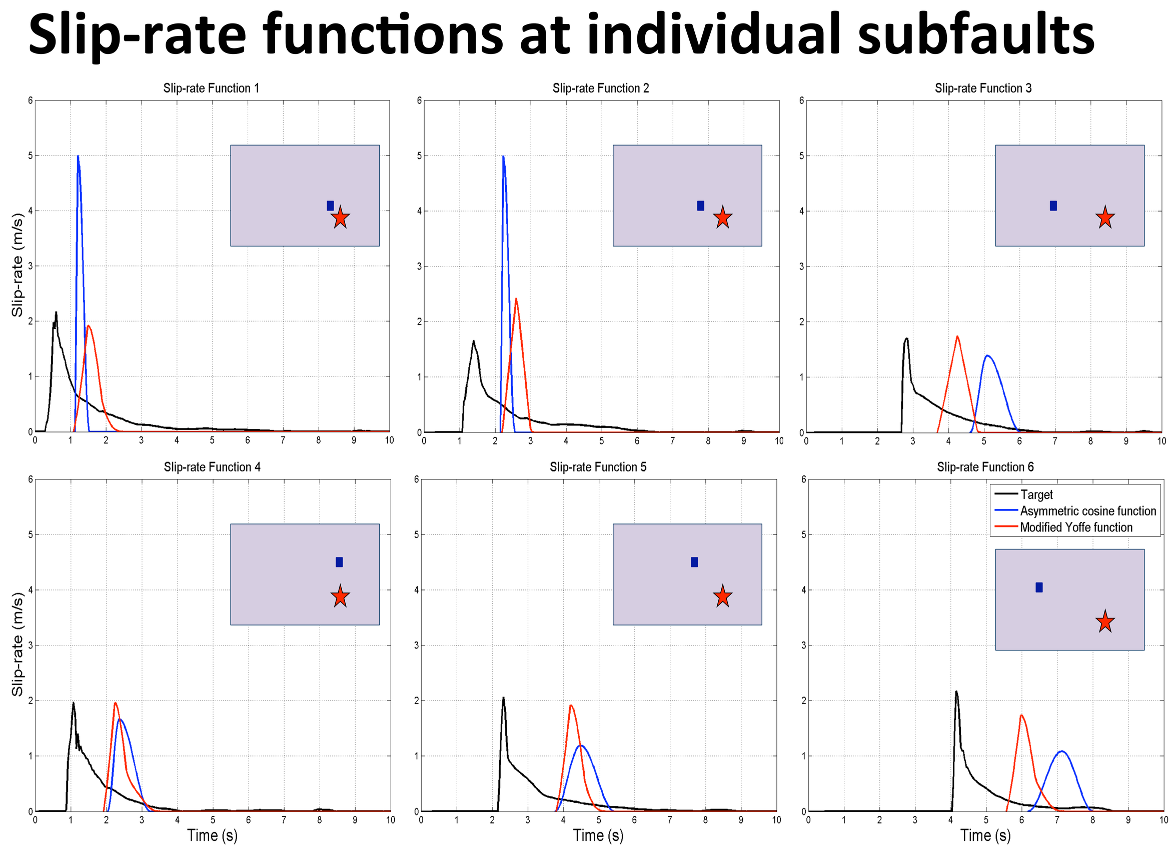


- Simulated annealing algorithm looks for the model that fits the data best inside a given model space.
- We notice that there is a weak but notable correlation between the misfit function value of the preferred model and the maximum slip allowed for each subfault.
- The lowest waveform misfit is obtained when the range of inverted slip is limited to [0,2] m, which is close to the range of slip in the target model.

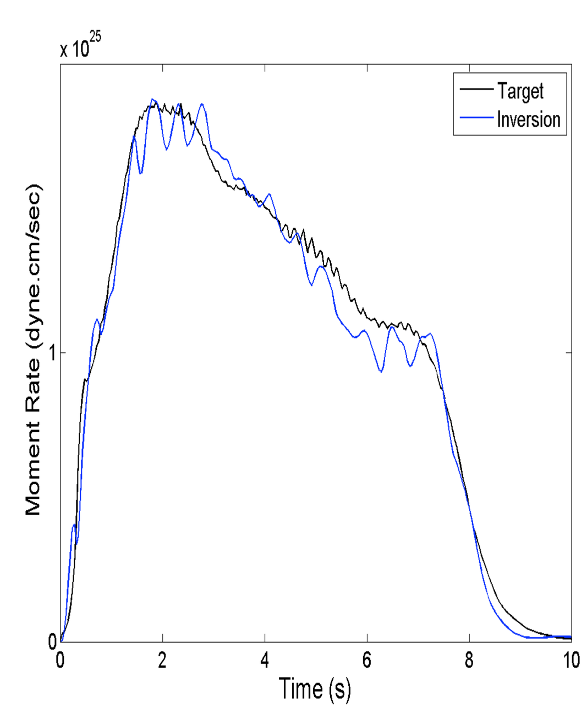
Snapshots of slip every 0.5-seconds



Slip-rate functions at individual subfaults



Cumulative Moment Rate Function



Conclusion

- By studying the SIV INV2 problem, we were able to:
    - Get a good fit to the surface strong motion observations
    - Recover general characteristics of rupture such as the total cumulative moment rate function
    - Resolve well the extent of rupture down-dip and along-strike
    - But, cannot constrain the spatio-temporal rupture characteristics in detail
- Our analysis reveals that:
    - Inconsistencies in rupture initiation between the dynamic simulation (target model) and kinematic inversion leads to error in the initial stage of our inverted result and also in the synthetic seismograms
    - The error in the synthetic seismograms then leads to errors in subsequent temporal windows