How the network density and geometric distribution affect kinematic source inversion models

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Youbing Zhang[1], Luis Dalguer[1], Seok Goo Song[1], John Clinton[1]
[1]Swiss Seismological Service, ETH Zurich, Switzerland. youbing.zhang@sed.ethz.ch

SED
Schweizerischer Erdbebendienst
Swiss Seismological Service

Motivation

One of the principal goals of earthquake seismology is to map the spatial and temporal evolution of source parameters from large earthquakes in detail. Finite-fault earthquake source inversions have grown into a standard analysis tool for studying the kinematics of earthquake ruptures by inverting seismic and/or geodetic data.

Previous source inversion results for the even same natural earthquake are non-unique, and it is difficult to calculate estimation uncertainty in source inversion without reference true solution.

Beresnev (2003) point out that the kinematic slip inversion solution depends on the array geometry. The azimuthal distribution and position of stations to the direction of rupture propagation are discussed, and how the network influences earthquake source inversion is debated and studied in severval literatures (e.g. Idia 1990, Sarao et.al. 1998, Jakka et.al. 2010).

Spontaneous dynamic rupture modeling, which incorporates conservation laws of continuum mechanics and constitutive behavior of rocks under frictional sliding, is capable of producing physically self-consistent kinematic descriptions of earthquake faulting and its associated seismic wave propagation, resulting in synthetic ground motions on the surface. Therefore, testing kinematic source inversion techniques by inverting these synthetic ground motions obtained from dynamic rupture simulations is a rigorous way of evaluating the suitability of different source inversion techniques for exploring the physics of the real earthquake source.

Objectives

* How many seismograms (stations) do we need to obtain a reliable earthquake source image via kinematic source inversion?
* How the network density and geometric distribution affect kinematic source inversion results?

Numerical test I. single station

Target dynamic rupture model

Mw 6.6, pure strike-slip, buried at 2 km depth (Dalguer and Mai 2011).

Fault dimensions: 36*18 km (strike & dip respectively)

Source inversion framework

Regularized Yoffe function (Tinti et. al. 2005) used as slip velocity function

Non-linear kinematic source inversion code (Monelli and Mai 2008) used, CompSyn package (Spudich and Xu, 2002) used to calculate Green's function, Evolutionary Algorithm (Beyer 2001) used to search optimal source parameters.

Grid size: 2*2 km

Velocity waveforms (< 1Hz) fit & model misfit calculated.

Minimize $\|Gm - d\|^2 + a^2 * \|Lm\|^2$, Tikhonov regularization (smoothing slip)

100 generations investigated.

~ 2,000,000 models searched totally in each case.

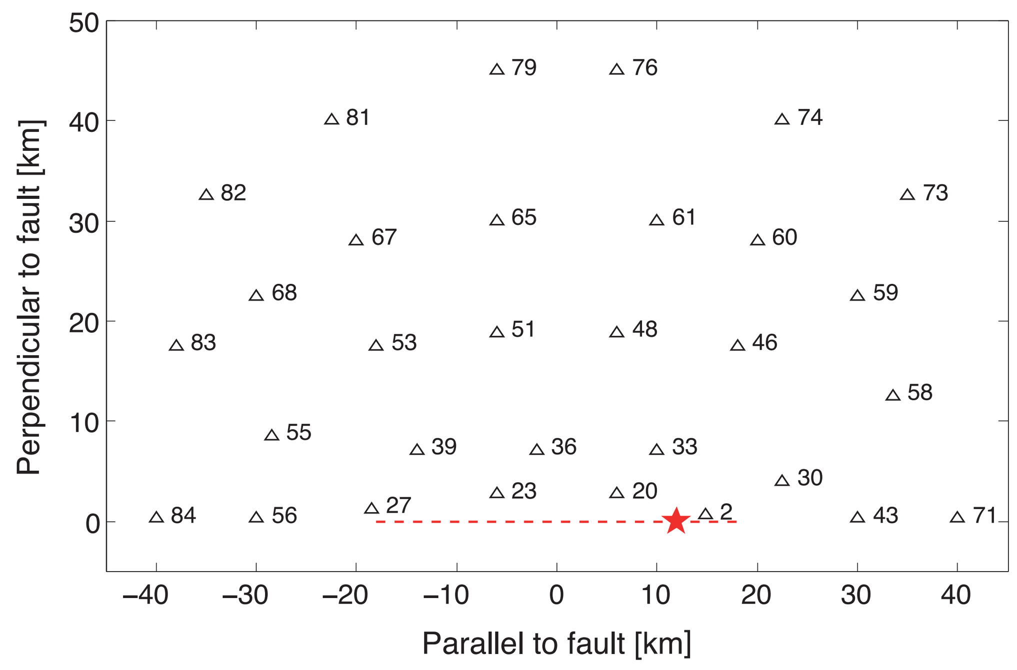

Fig 1. Selected 31 single station distribution, red dashed line indicates the fault mapping on the surface and red star indicates the epicenter location

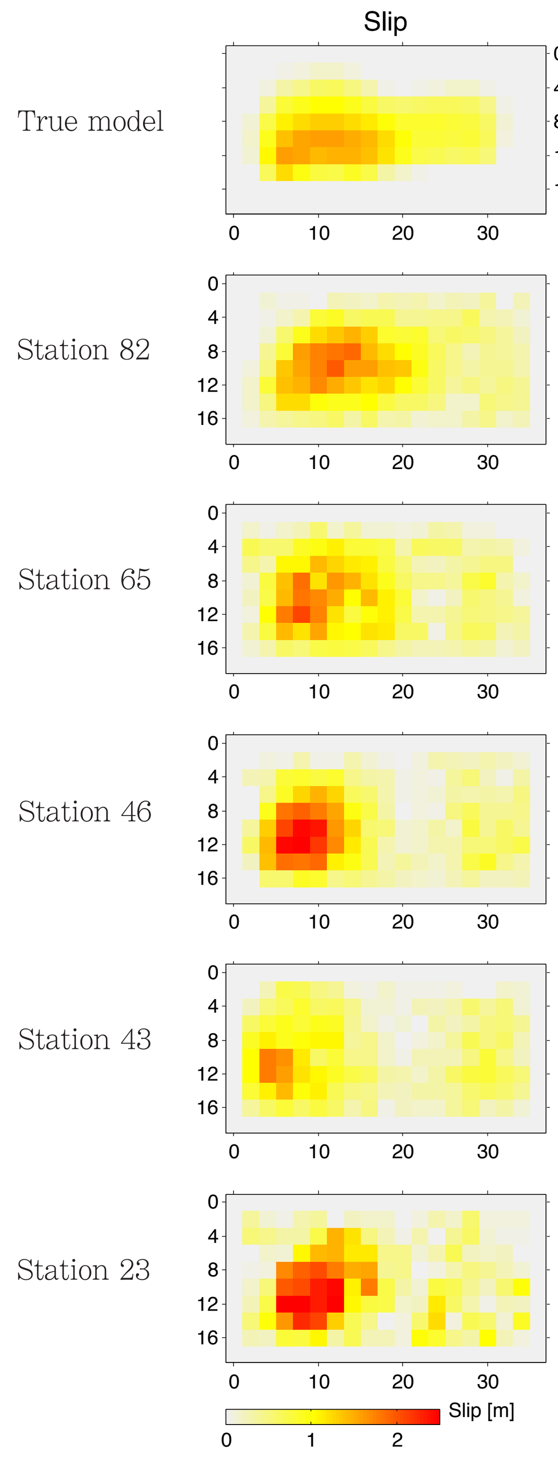

Fig 2. Comparison of estimated slip from selected station inversion with true finite slip

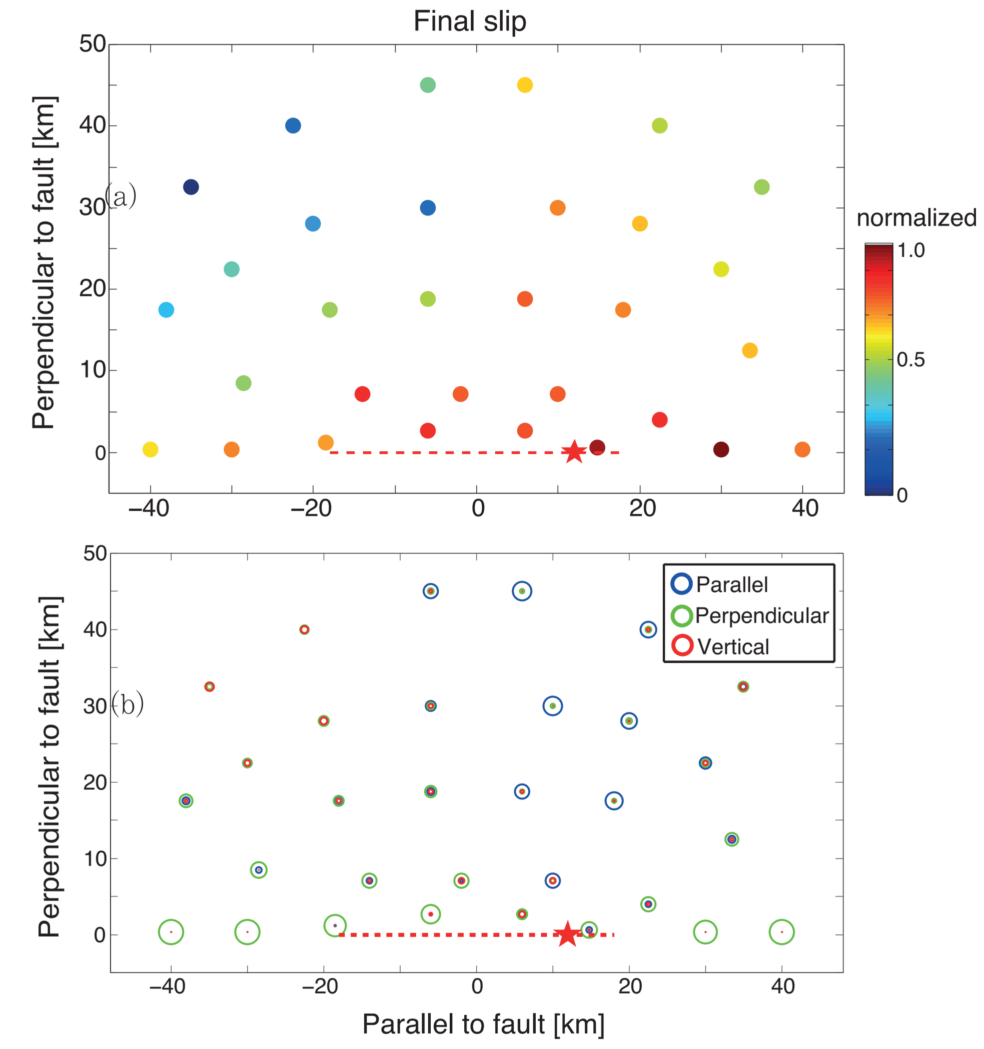

Fig 3. (a) Comparison of normalized final slip, including the area above mean slip of both estimated and target model, small value indicates smaller error; (b) Comparison of three components normalized peak velocity amplitude, large circle indicates one component is dominant

We did single station tests using the selected 31 stations (Fig 1), and the estimated source slip is shown as Fig 2. According to Fig 3, the stations located at nodal plane of radiation pattern and very close to fault are coincide with small slip fitting error and relatively small peak amplitude disparity among three components velocity waveforms.

P & S wave radiation pattern should be considered

Numerical test II. multi-station

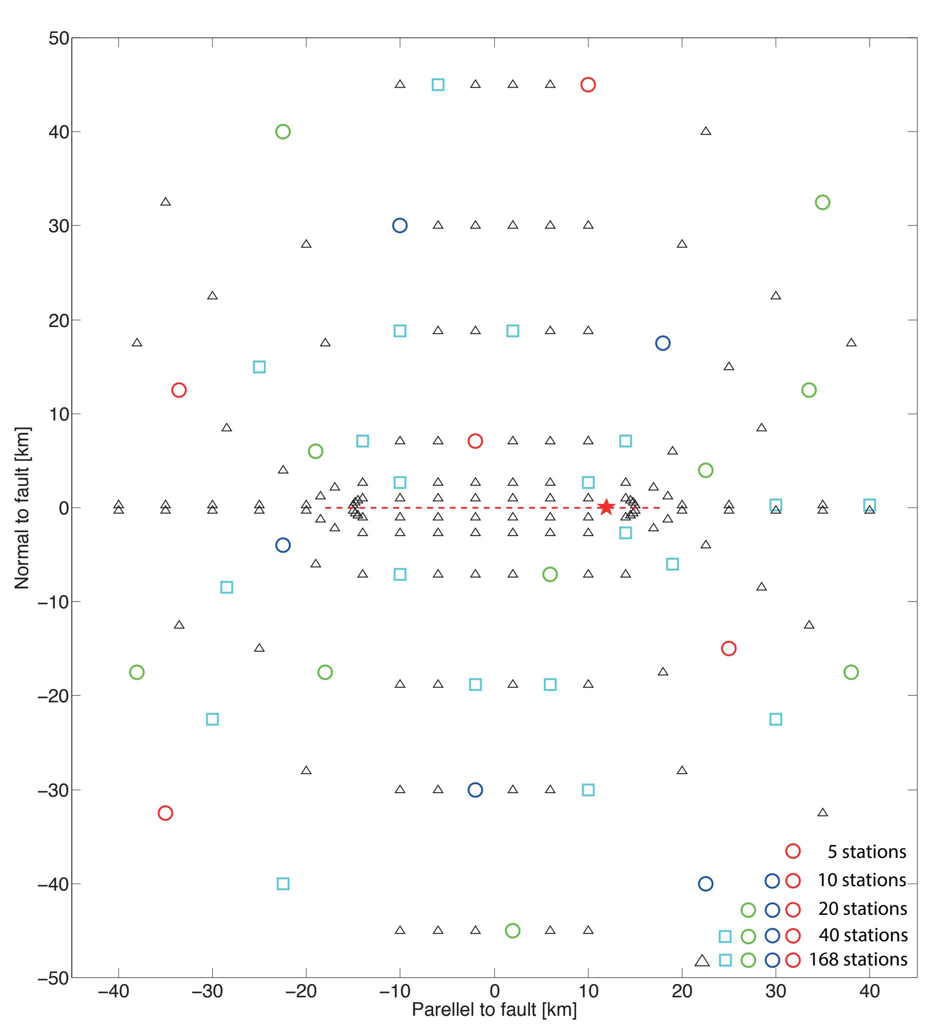

Fig 4. Five well spaced multi-station combinations (5, 10, 20, 40, 168)

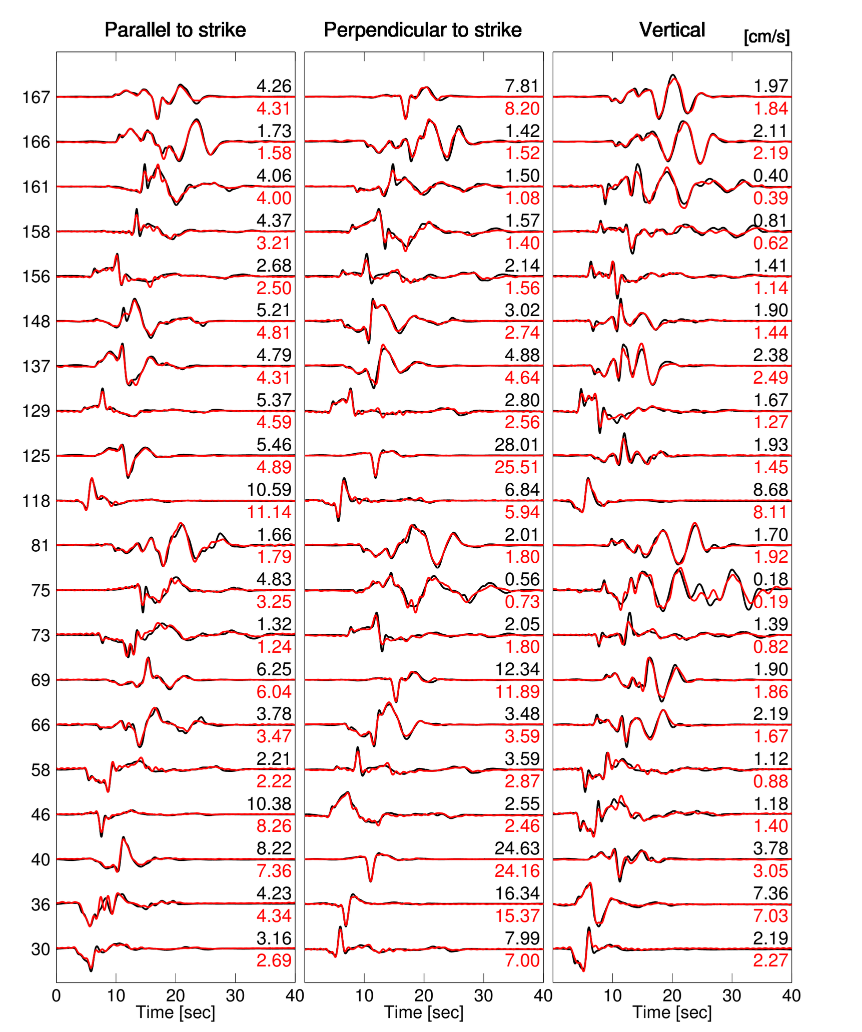

Fig 5. Comparison of velocity waveforms generated by dynamic model (black) and best estimated model using 20 stations (red) at low frequency (< 1Hz)

We carried on the multi-station tests, and five well-spaced station combinations used (Fig. 4). Fig 5 compared the velocity waveforms generated by dynamic model and best searched model using 20 stations at low frequency, and waveforms by other models are all quite close to observed ones. And we compared the estimated kinematic source parameters of five multi-station combinations, the location of asperity is same to the true model for all the five station combinations, but the estimated subfaults with large peak slip velocity are not exactly the same as true model among the five models.

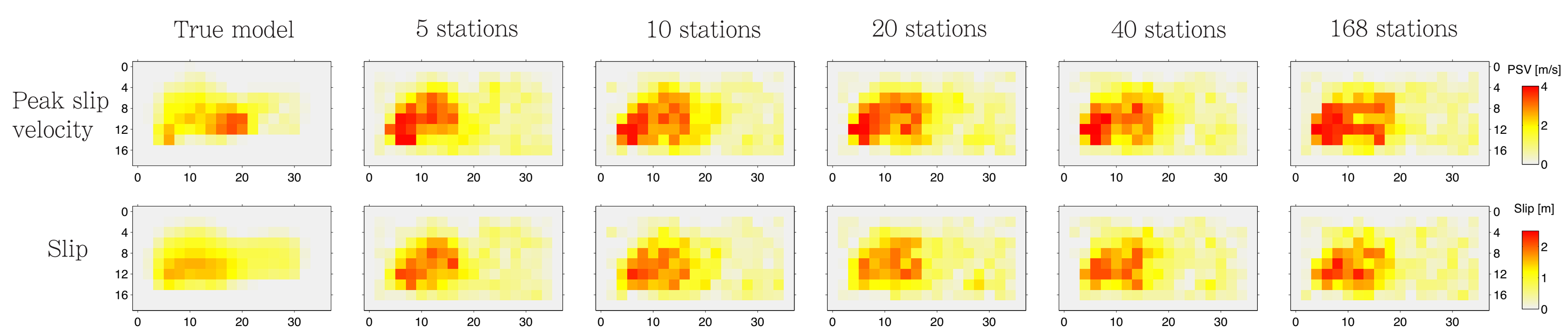

Fig 6. Comparison of PSV and slip between true model and five estimated models via multi-station combination test.

Numerical test III. optimal station

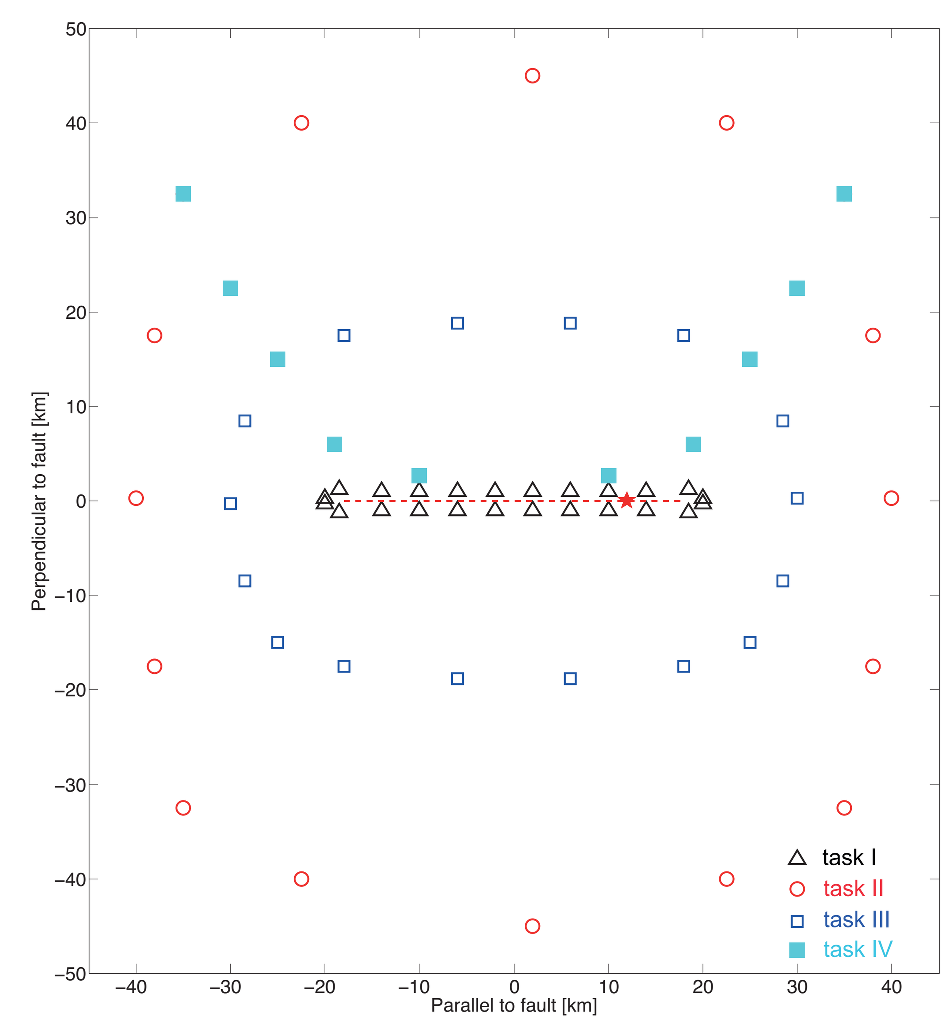

Fig 7. Four optimal multi-station combinations

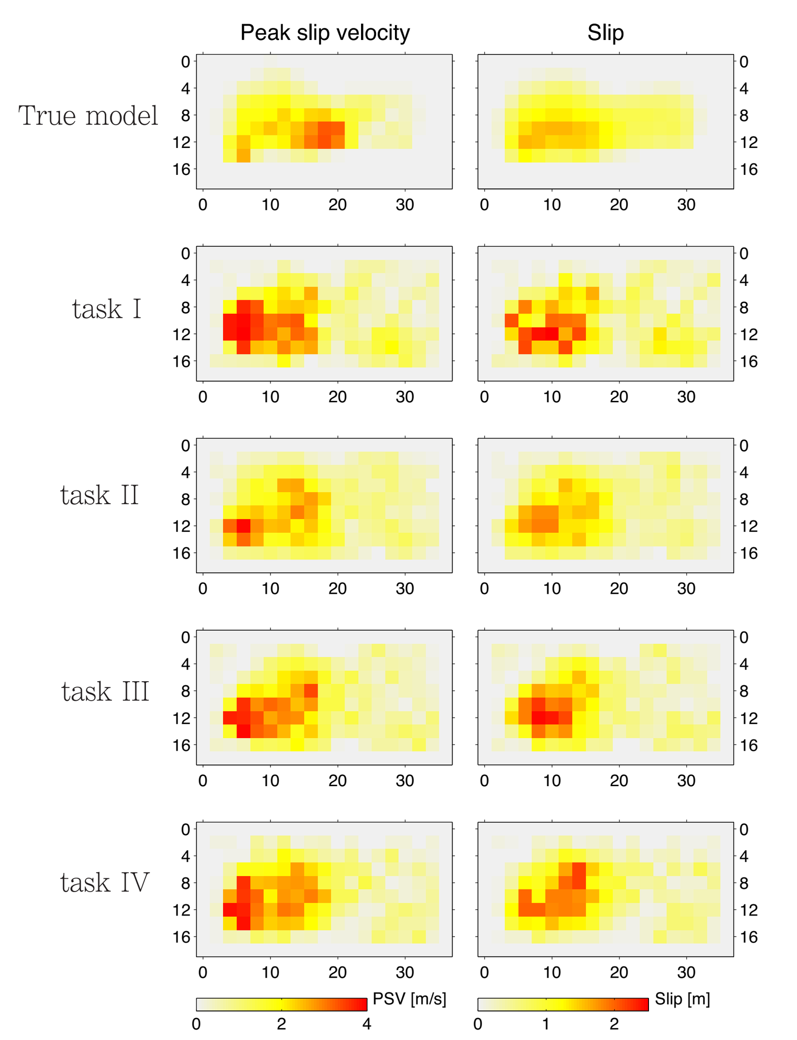

Fig 8. Comparison of PSV and slip between true model and four estimated models via optimal station tests

Four designed optimal station combination (e.g. Iida 1990) in Fig 7. were tested, and we want to investigate whether the circle distributed stations could improve the source inversion results. As shown in Fig 8 9 & 10, the stations extremely close to fault could fit the waveforms well but have relatively large slip error. The stations with uniform azimuthal distribution around a rupturing fault and certain epicentral distance could not give the best both source image and small waveform fitting at the same time.

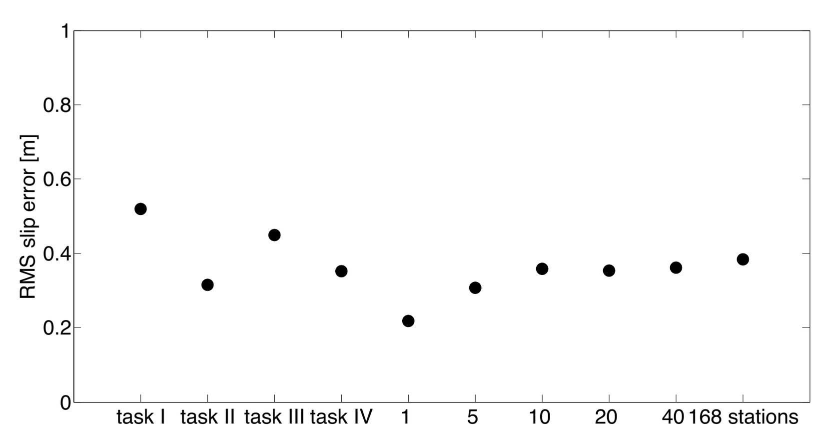

Fig 9. Root mean square slip error between true model and estimated models via all used multi-station tests (1 indicates estimated model using station 82 at single station test)

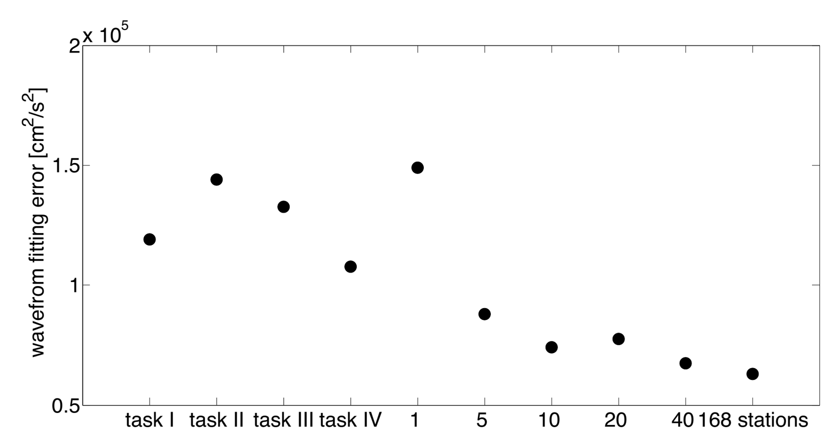

Fig 10. All 168 stations velocity waveforms fitting error between true model and estimated models via all used multi-station tests (1 means the same as Fig 9.)

Conclusion

* Inversion using stations that records waveform in which the amplitude of the three components are equally weighed produces the best source models. This suggests that radiation pattern play important role in the selection of stations.
* Stations located very near to the fault produces the worst source models.
* Once we could minimize the uncertainty from Green's function calculation, velocity structure, etc., then few number of stations appear sufficient to obtain a stable solution, consequently number of station is less important. Mayor priority has to be given to the azimuthal distribution (considering radiation pattern) and distance to the fault.

Outlook

Correlation of kinematic source parameters (e.g. slip, Vr, peak slip velcity) derived from dynamic rupture model are studied in many Literatures (e.g. Bizzarri 2012, Song and Dalguer 2013), and could be implemented to constrain the parameters for kinematic source inversion. It's called pseudo-dynamic source inversion

prior, data

$$\sigma_M(m) = k\rho_M(m)\cdot\rho_D(g(m))$$

$$\rho_M(m) = N(\mu, \Sigma)$$

$$\text{error} = \|Gm\text{-}d\|_2^2 + (M - M_0)^T\Sigma^{-1}(M - M_0)$$

data misfit, model misfit

Covariance matrix of kinematic source parameters (Song et.al. 2013)