Nonlinear Inversion of Dynamic Rupture Parameters

Kim Olsen

Sophie Peyrat

Siobhan Corish

Smolenice Castle

SPICE

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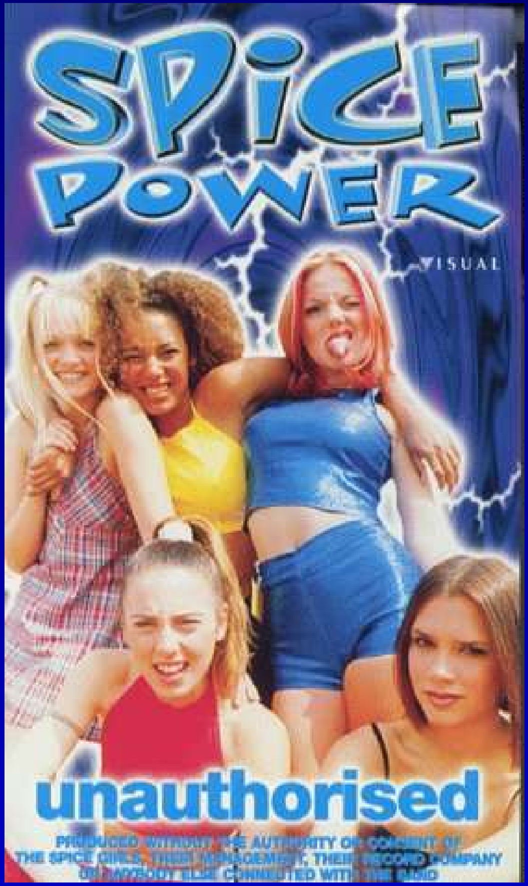
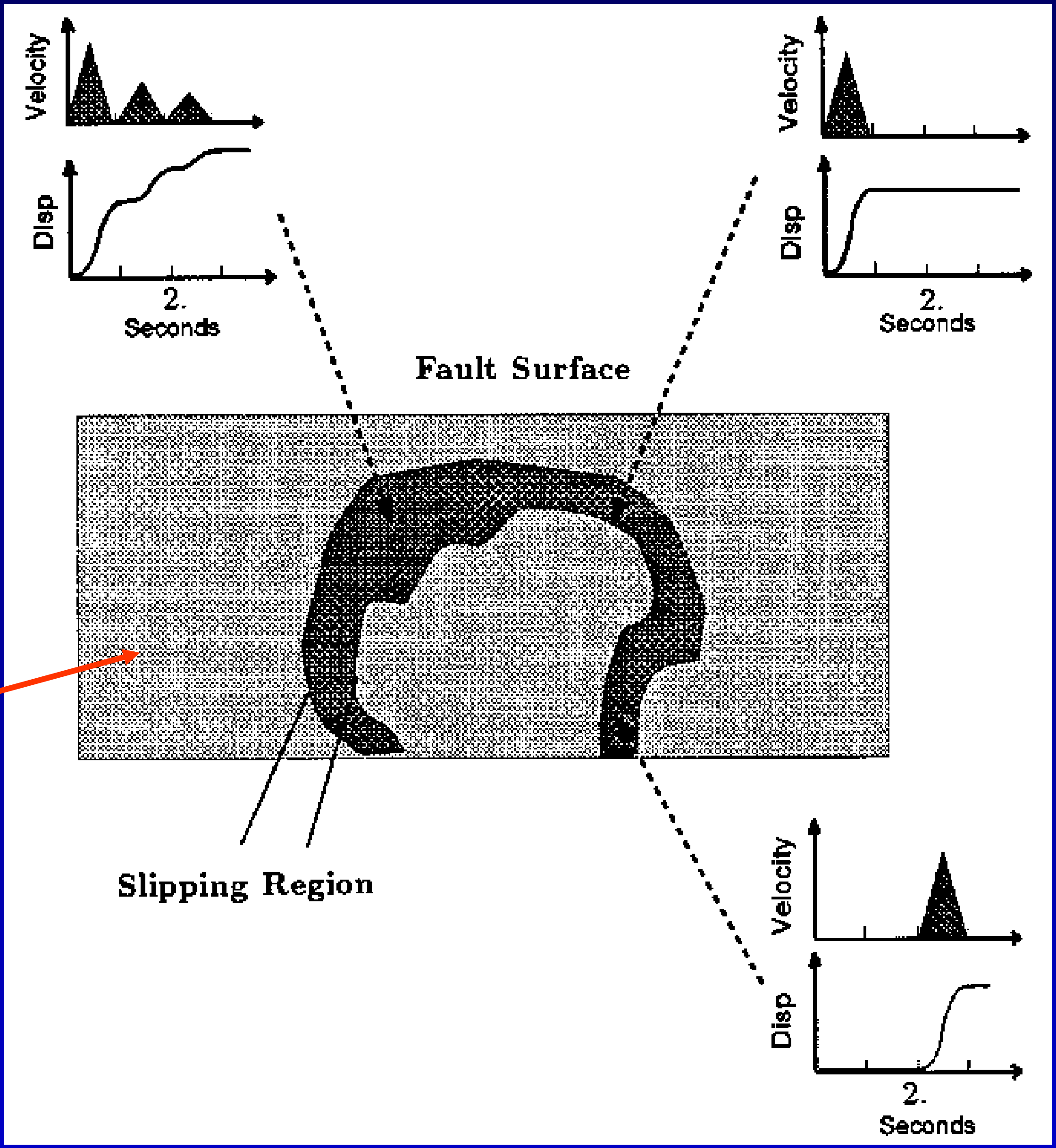
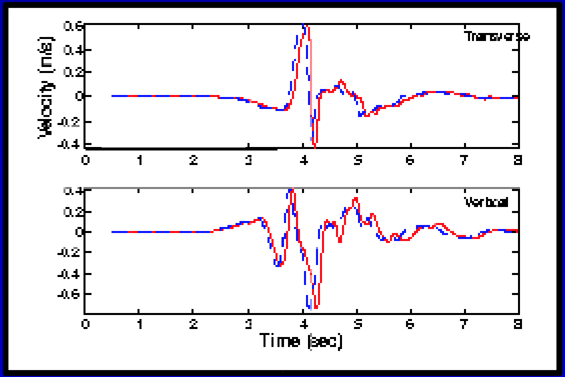


Previously on *Earthquake Source Analysis:*

Kinematic Inversion





However:

There are some limitations of *kinematic* slip inversion

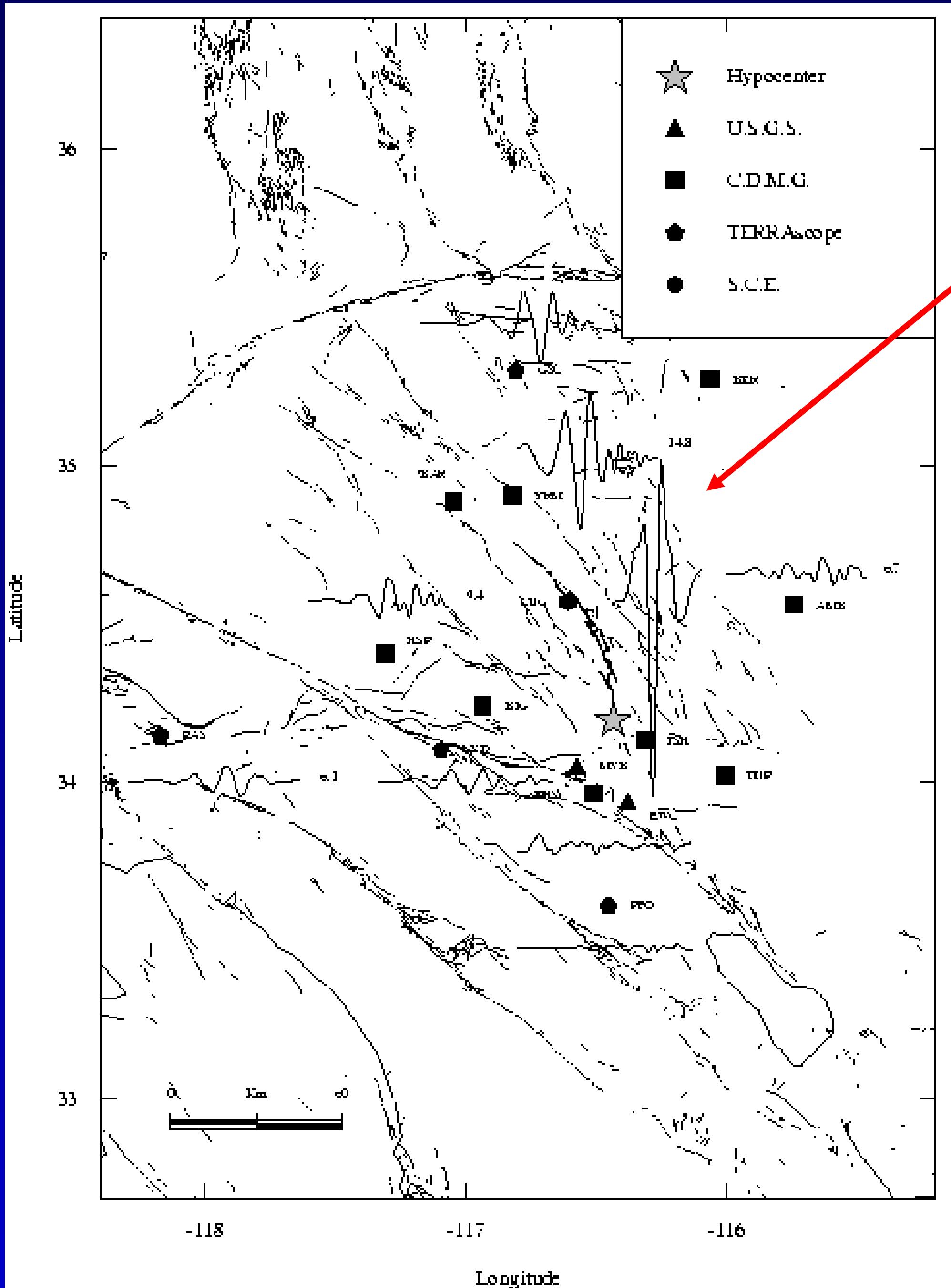
- ✓ Constrained rupture velocity
- ✓ Pre-determined source time functions
- ✓ *No direct* information about stress changes, friction

Reason to move toward

- ✓ *Dynamic* Rupture Inversion

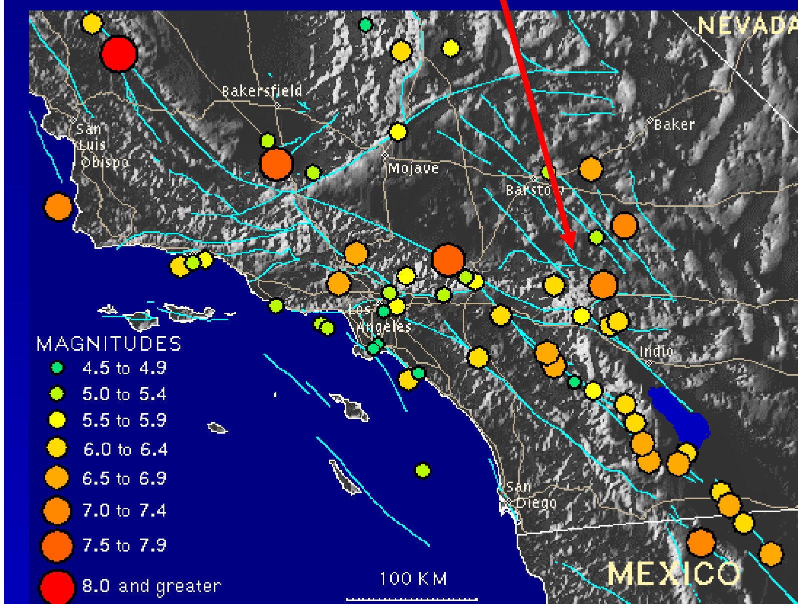
Critical Question:

Are radiated waves sensitive to variation in dynamic rupture parameters??



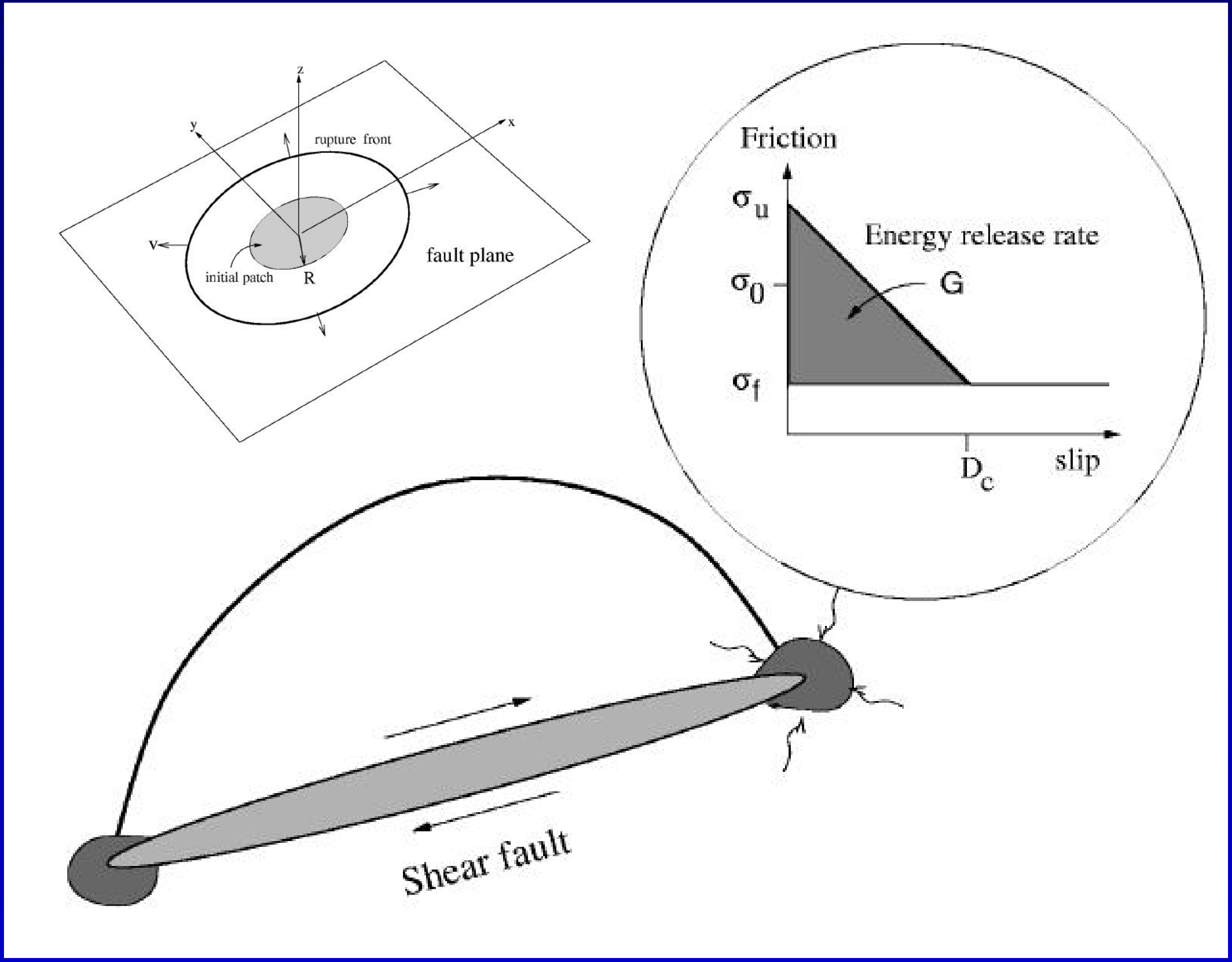
Well-recorded event

Test case:
1992 M 7.3 Landers

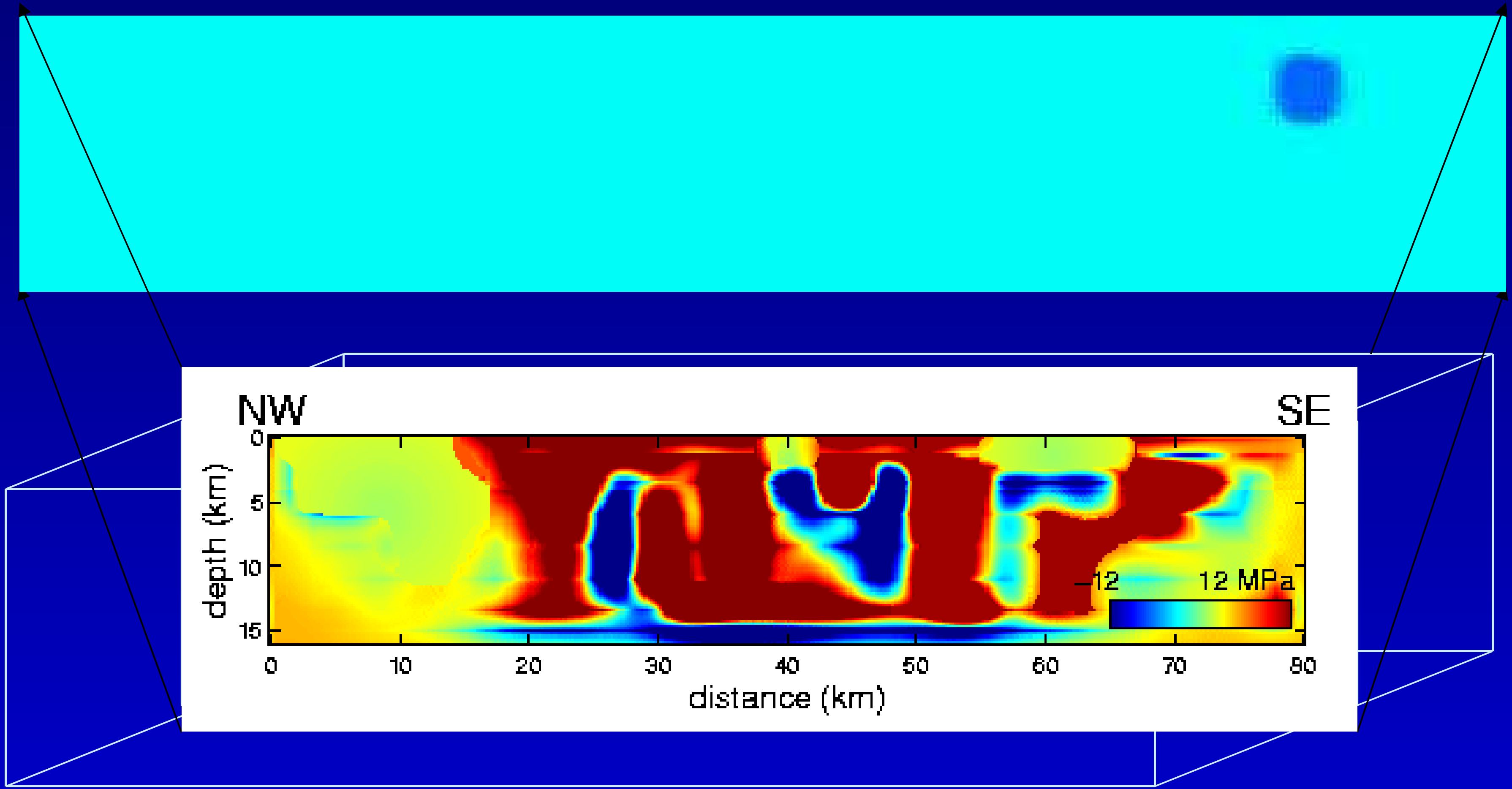


Landers: Classic Vertical Strike-Slip Event

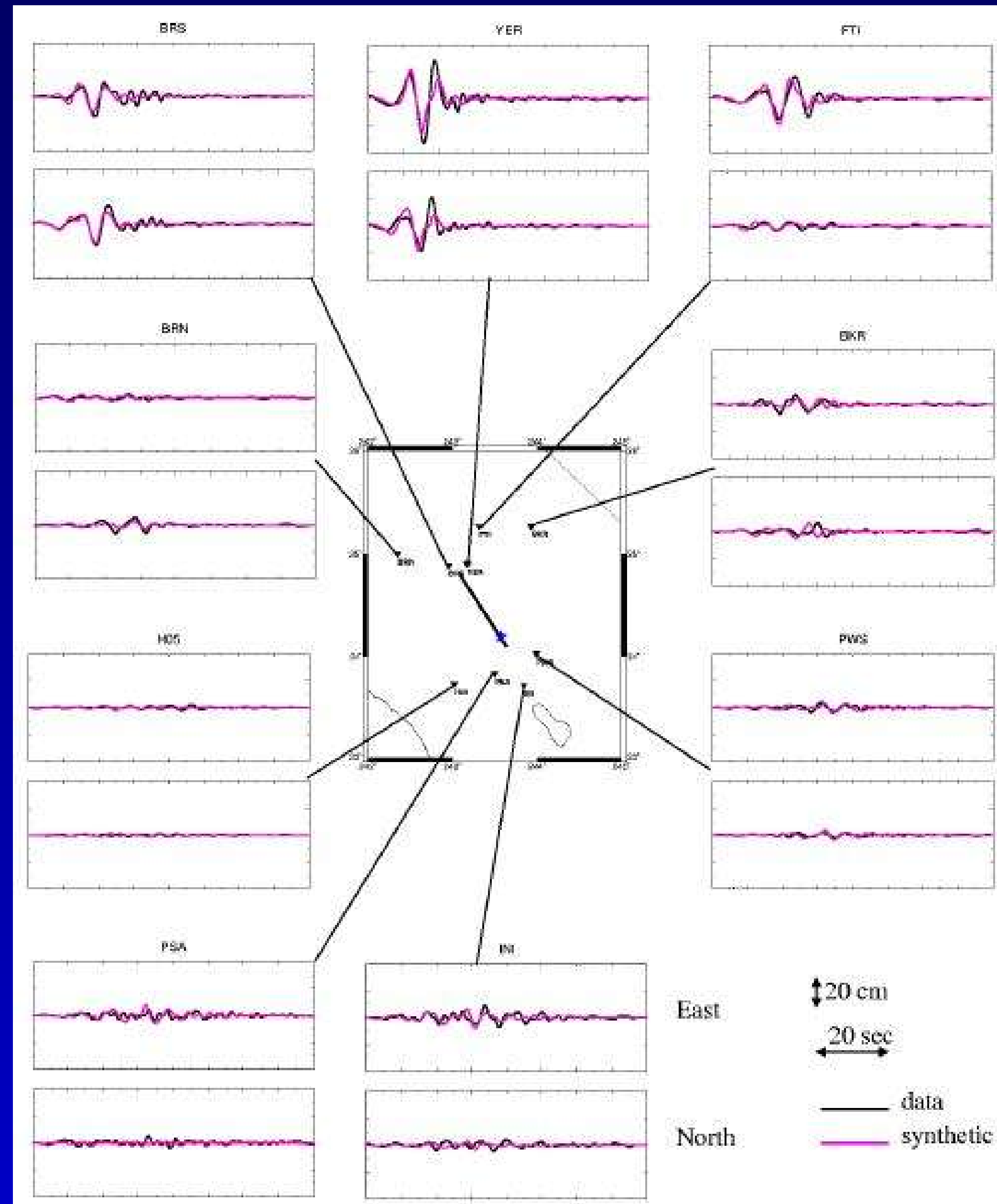
Slip-weakening Rupture Model



Dynamic Rupture From Trial-and-Error Finite-Difference Modeling

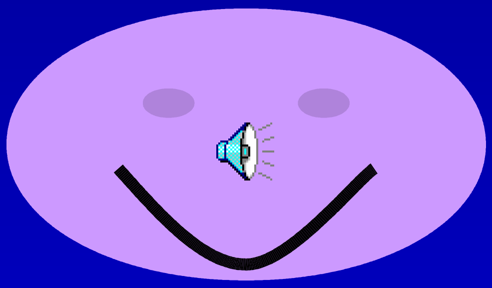


Inverted (Trial-and-Error) Dynamic Radiation Versus Data



YES!

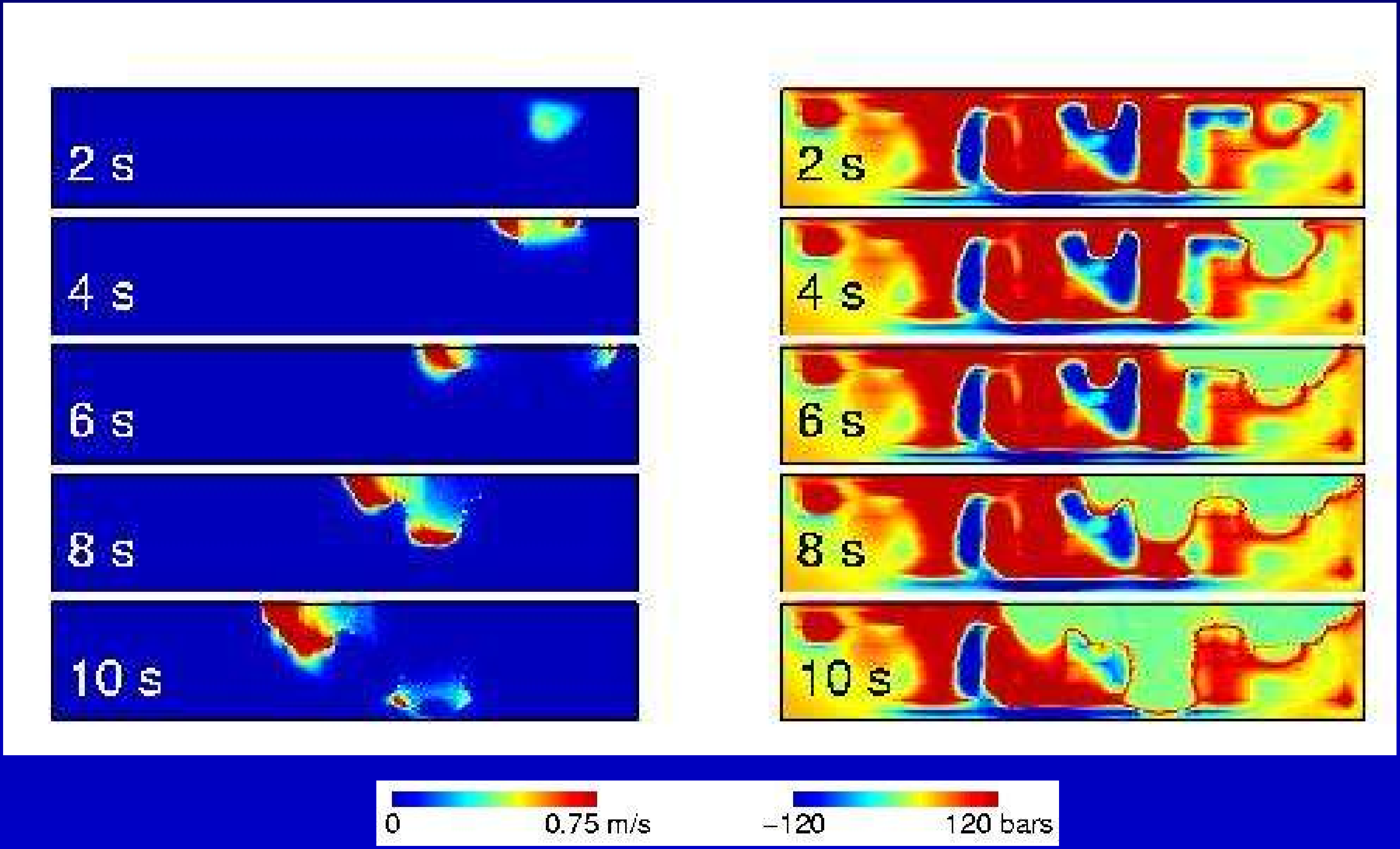
Radiated waves are sensitive to variation in dynamic rupture parameters (friction, stress drop)!



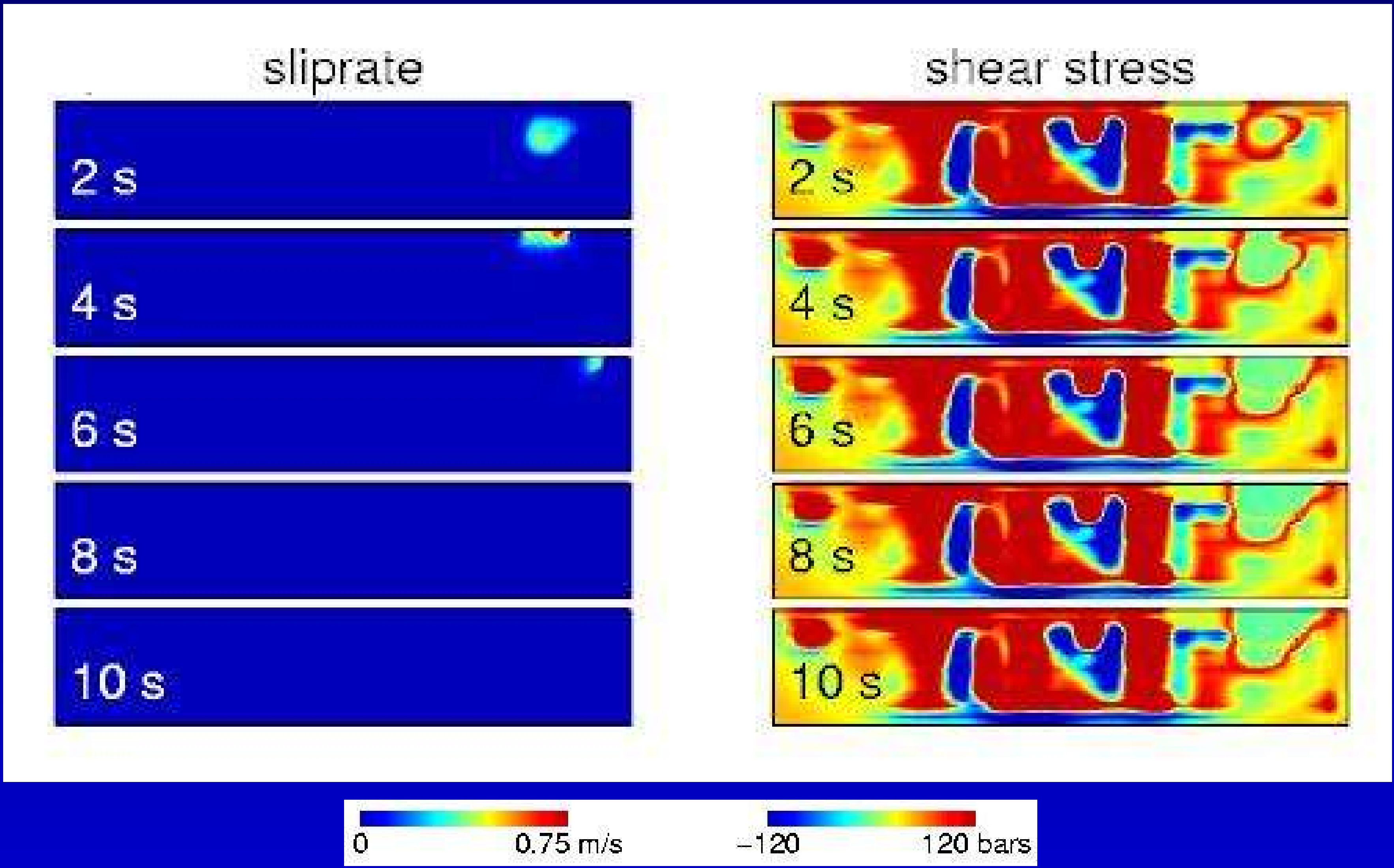
How is rupture propagation affected by realistic variation of dynamic parameters?

Let's look at changes in the stress drop…

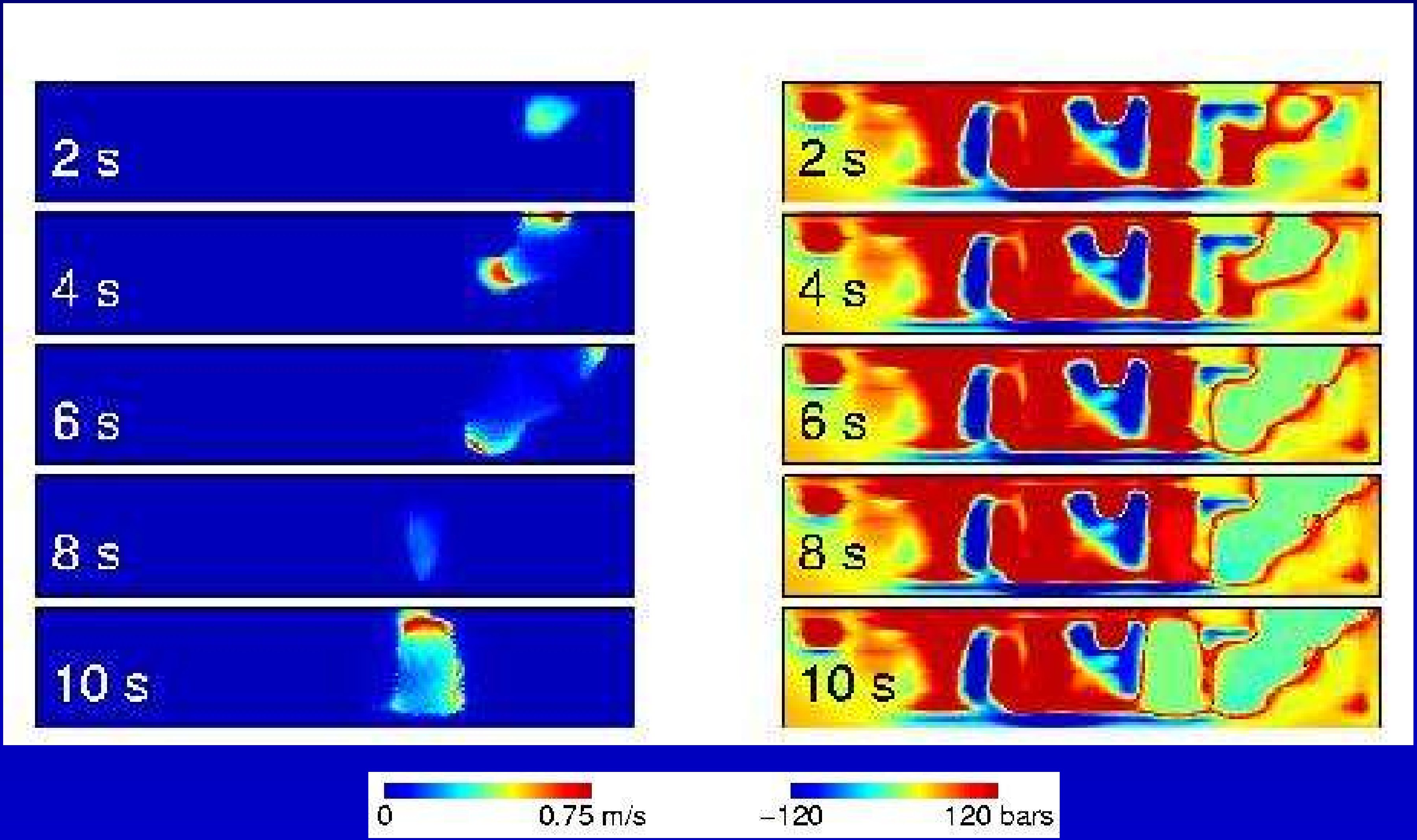
Stress Field (a)



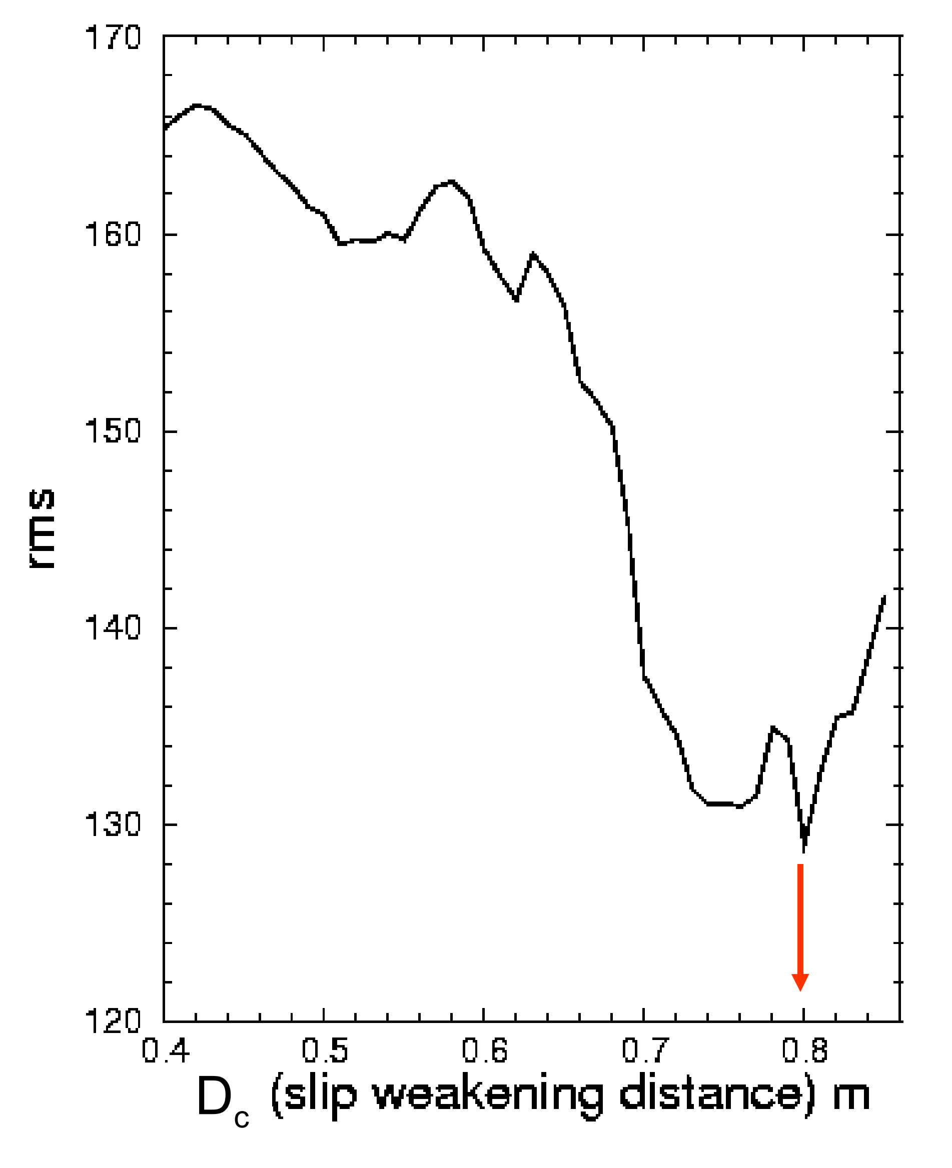
Stress Field (b)



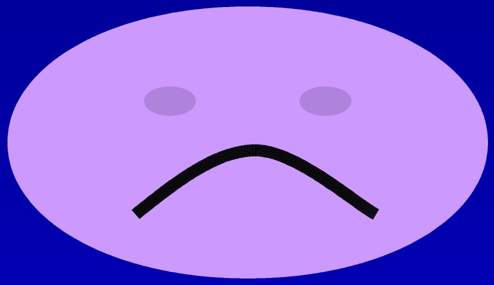
Stress Field (c)



Landers Misfit for Various Constant D_c Values



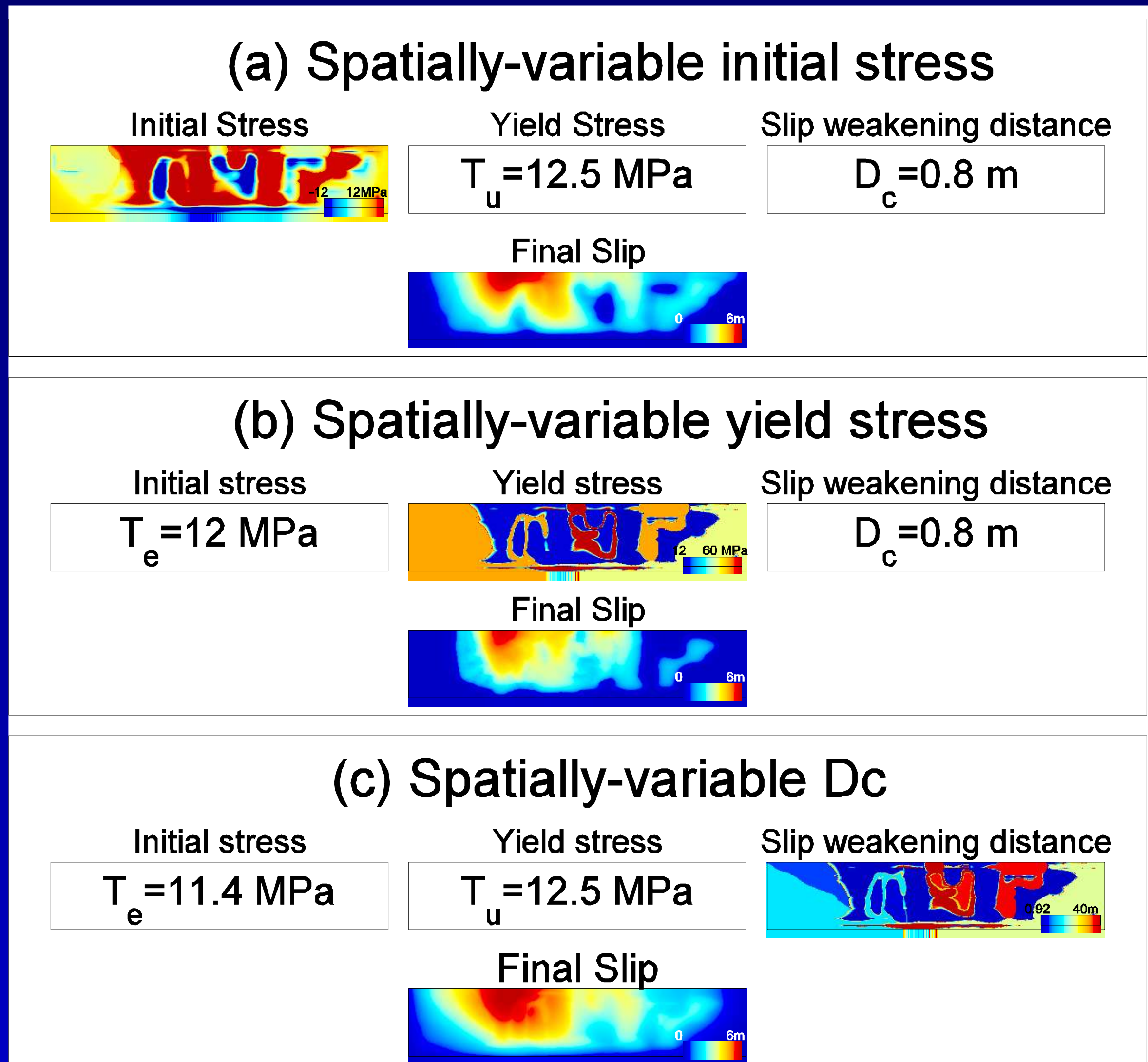
Very *nonlinear* dynamic rupture



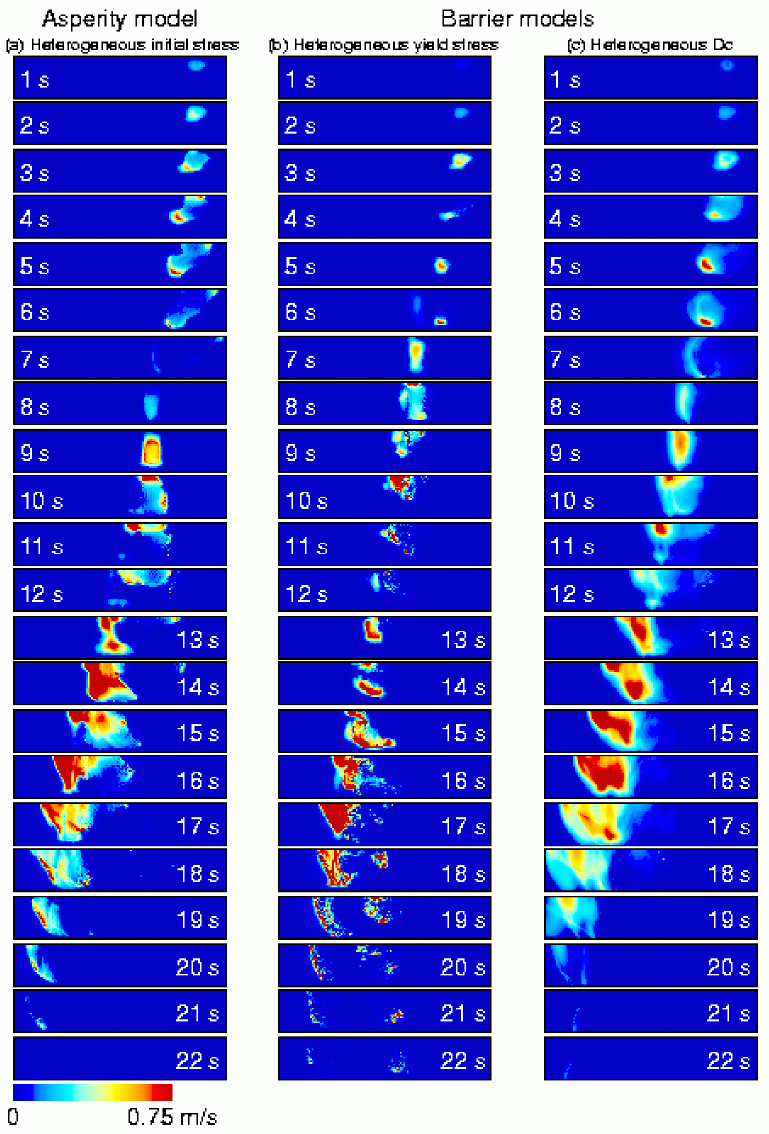
Friction - Strength – Stress

Possible to Estimate Separately ?

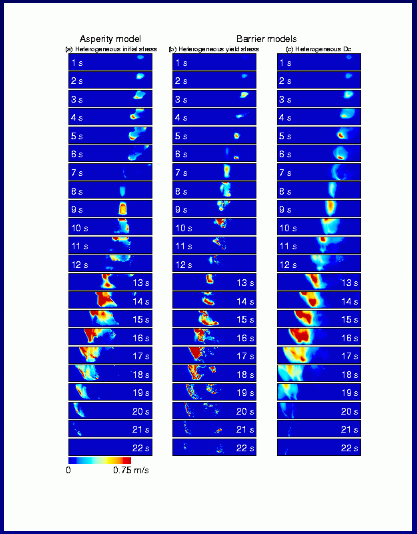
Three Equivalent Dynamic Rupture Models

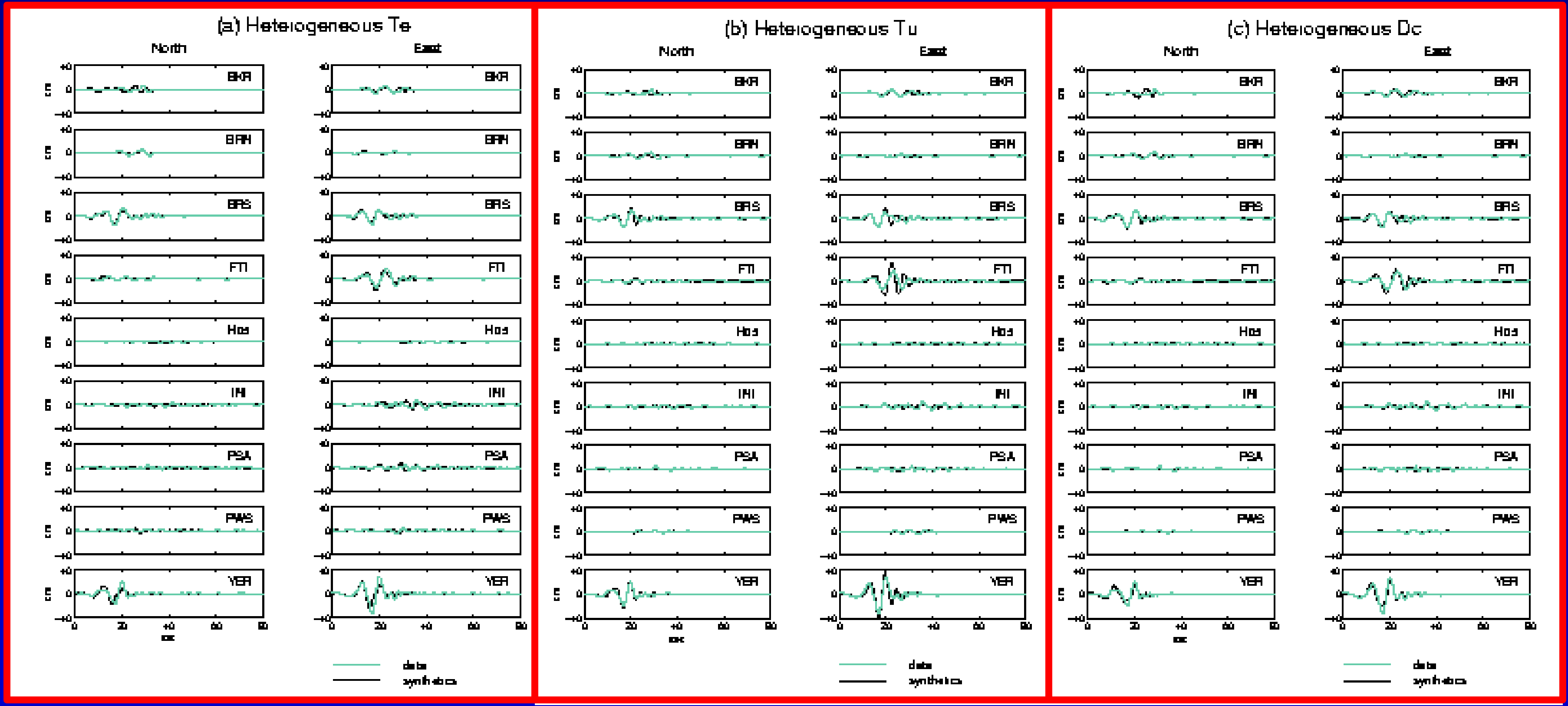


Comparison of Dynamic Rupture Propagation



Accelerograms Versus Synthetic Ground Motion From Inversion of Dynamic Rupture





Trial-and-error Inversion not successful in estimating Te, Tu, and Dc

Can we devise a more successful systematic inversion method instead, that avoids the tedious trial-and-error modeling?

Problem

- ✓ *Data alone does not determine the model uniquely, and no or an infinite number of models satisfy the data.*

Approach

- ✓ *Characterize the ensemble of data-fitting models in an optimal way*

Question:

How can a search for new models be best guided by all previous models for which the forward problem has been solved (and hence the data misfit value evaluated)

?

Tools:

Nonlinear Derivative-free (Direct Search) Inversion Methods:

- ✓ Monte Carlo techniques
- ✓ Simulated annealing/genetic algorithms

…expensive, subjective tuning parameters

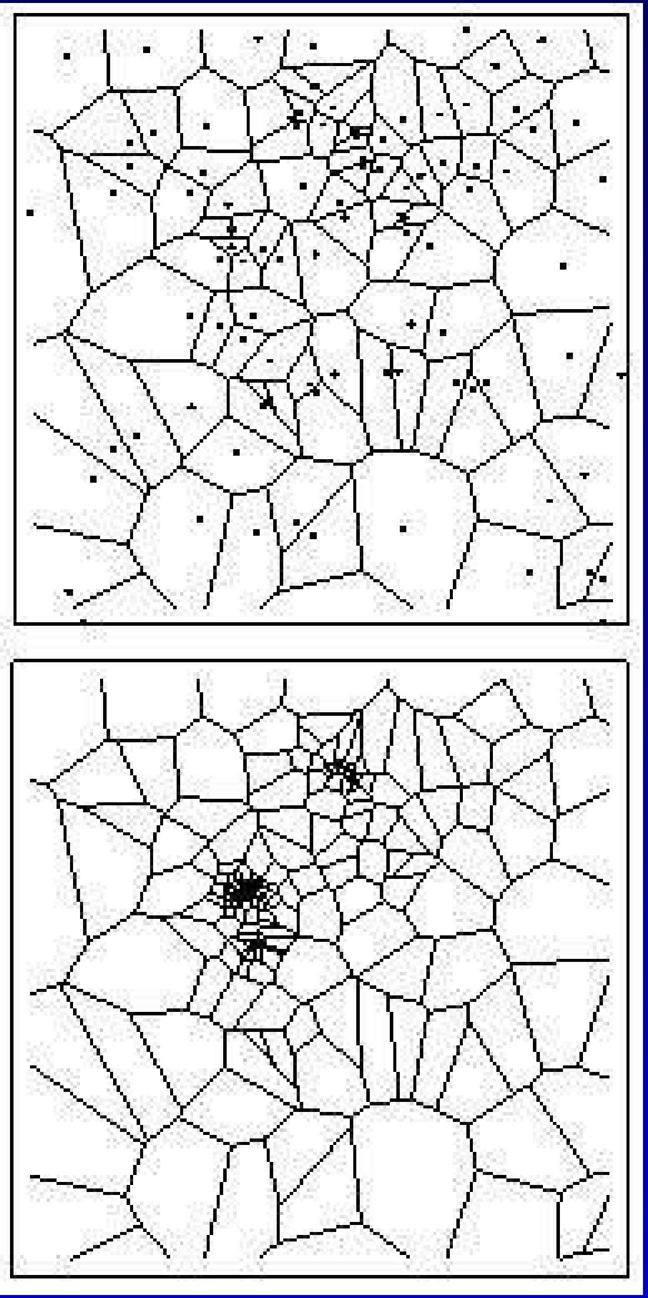
Voronoi cells:

- Nearest neighbor regions about previous samples

- Size inversely proportional to sample density

- No spatial scale length, directionality imposed

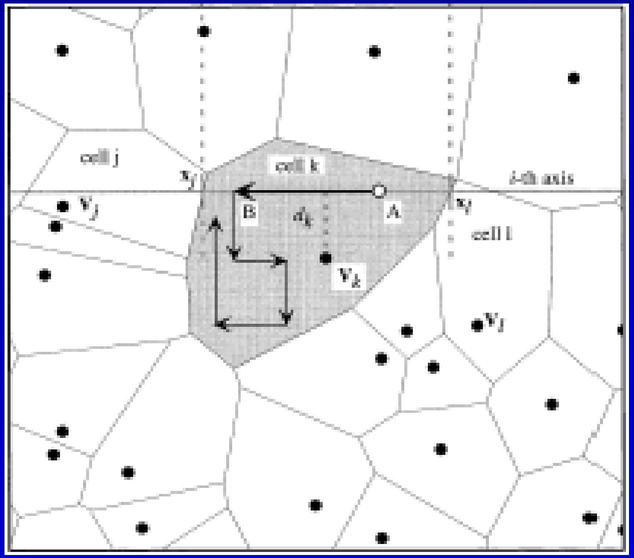
- *Misfit constant within each cell*



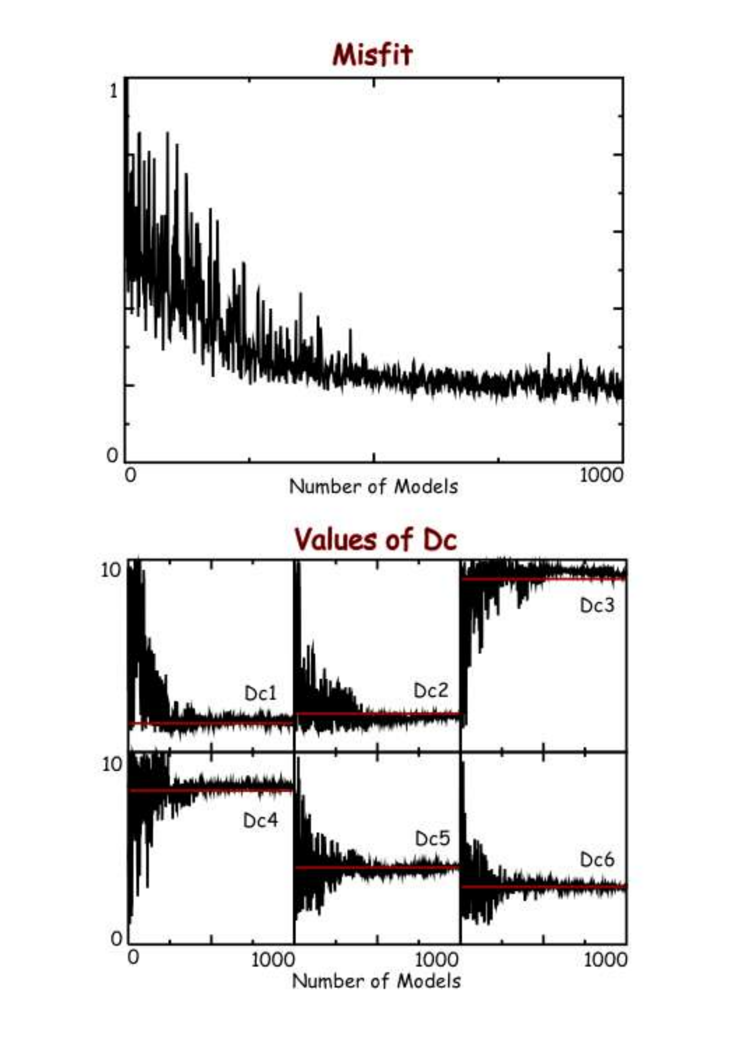
A Neighborhood Algorithm

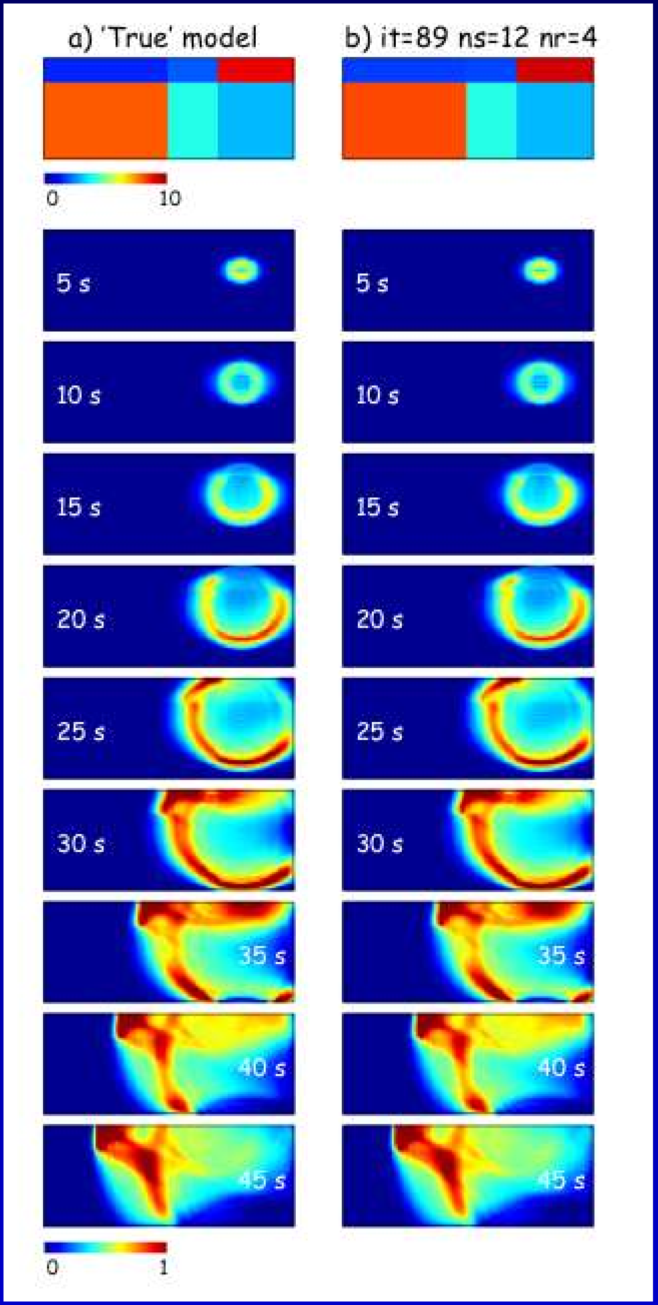
At each iteration:

Calculate the misfit function for ns models by a uniform random walk in the most recently updated Voronoi cells and determine nr models with lowest misfit

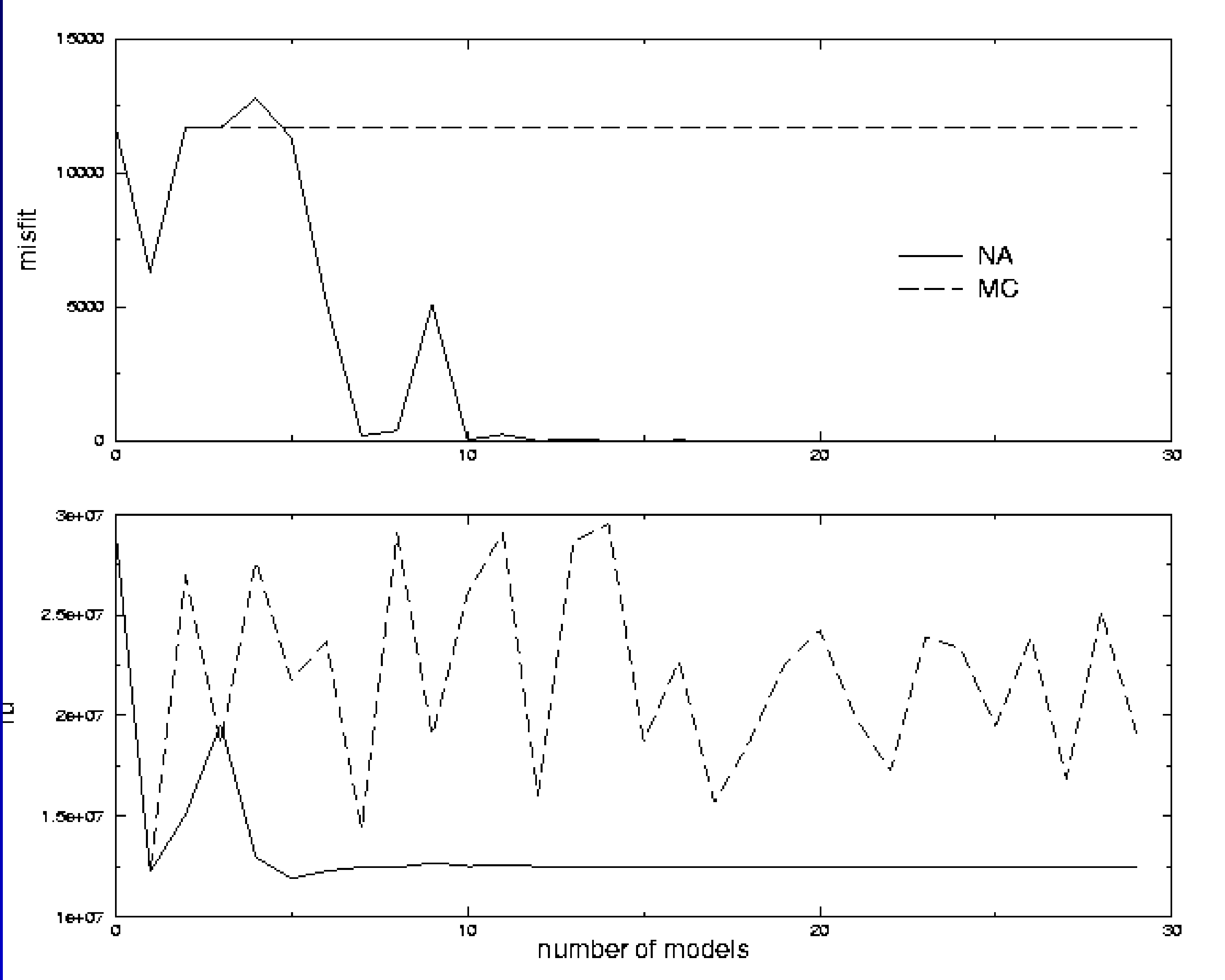


6 parameters

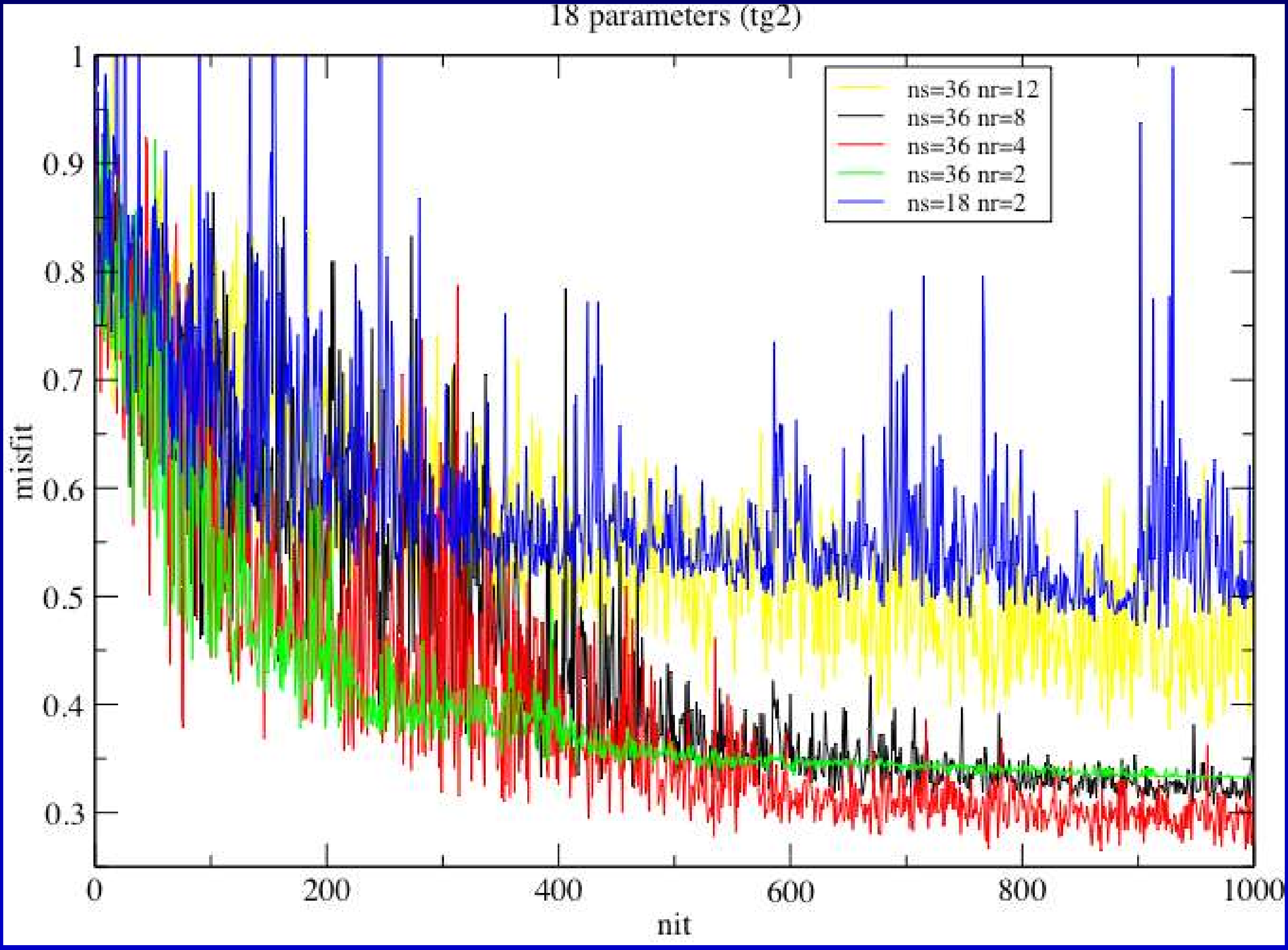




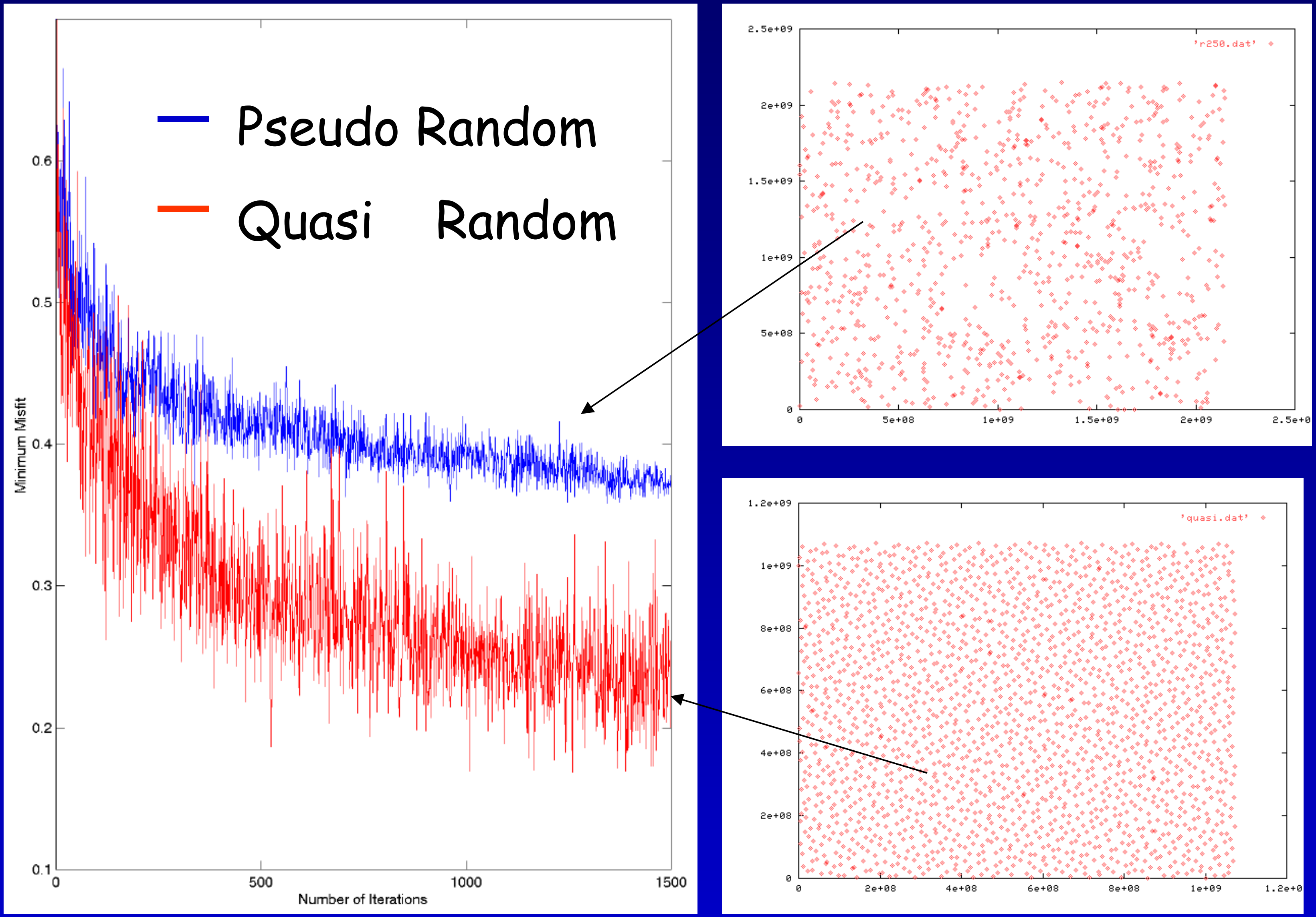
Neighborhood Algorithm (NA) Versus Monte Carlo (MC)



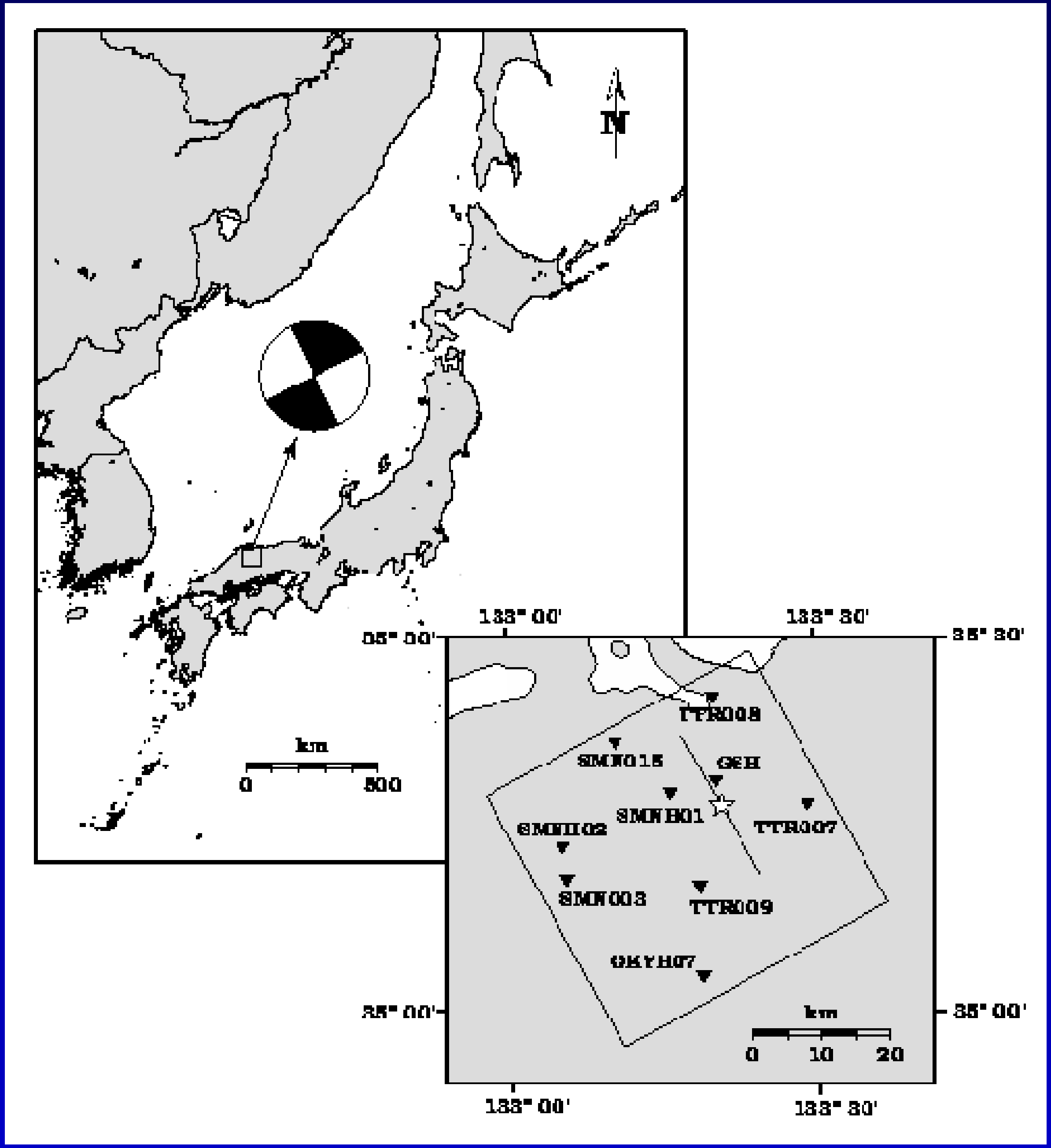
Control Parameters (ns and nr)



Nature of Random Model Generation



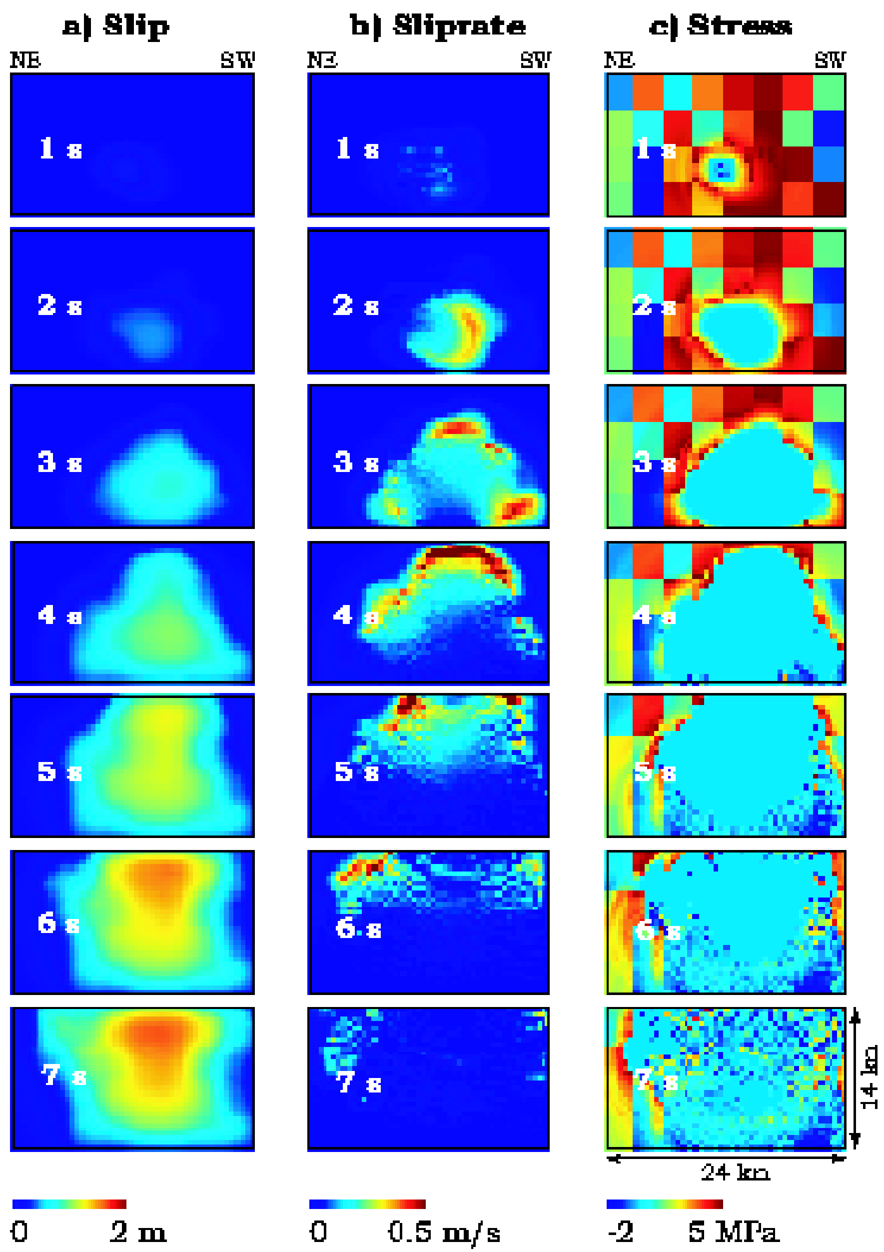
Dynamic Inversion Results For 2000 M6.6 Tottori (32 Parameters)



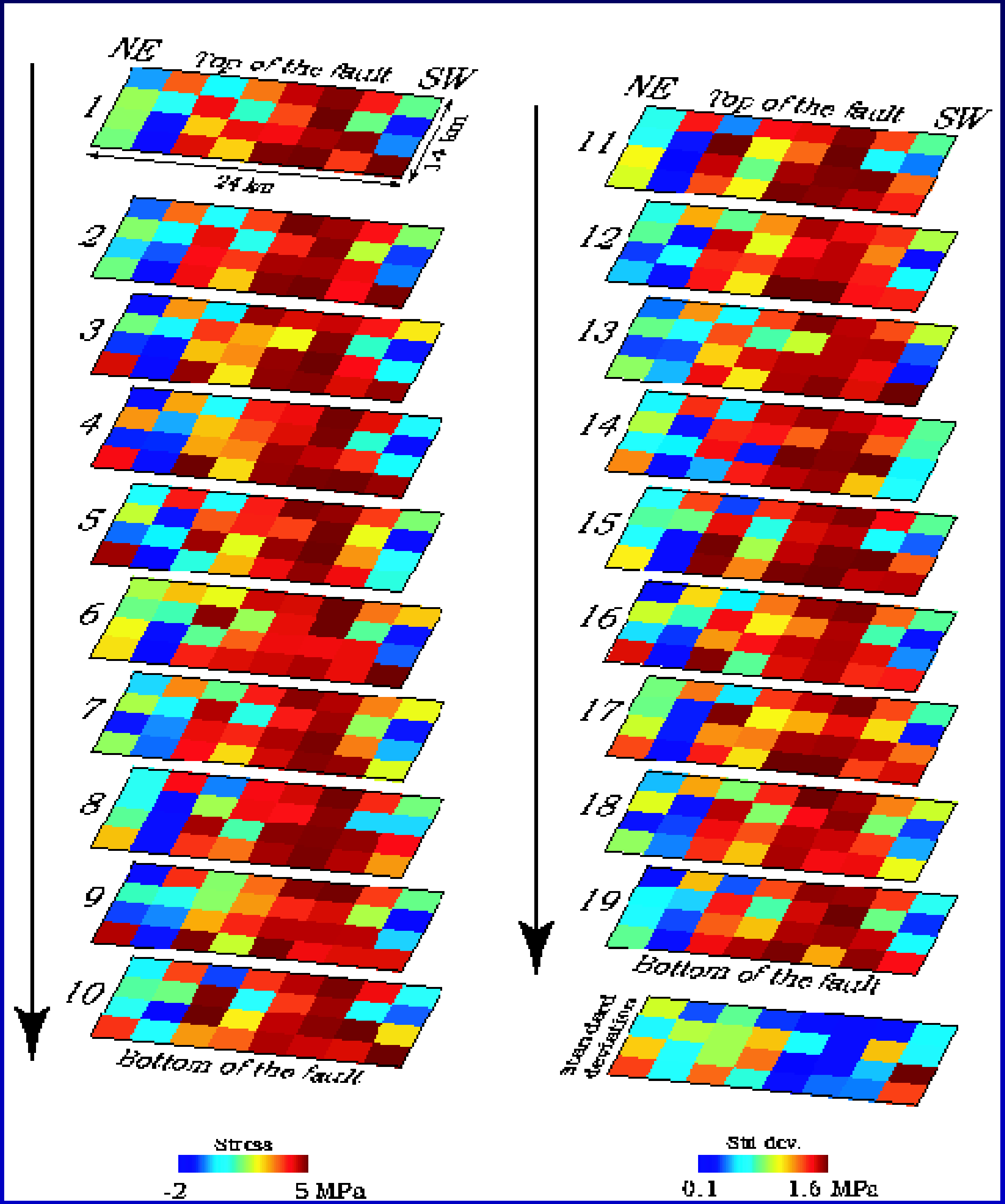
Te Only!

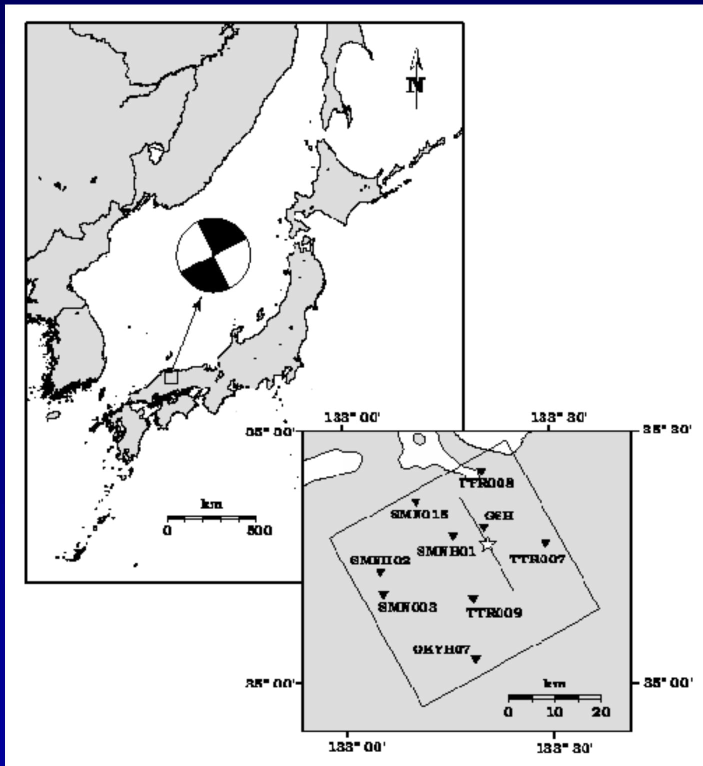
Numerical Parameters

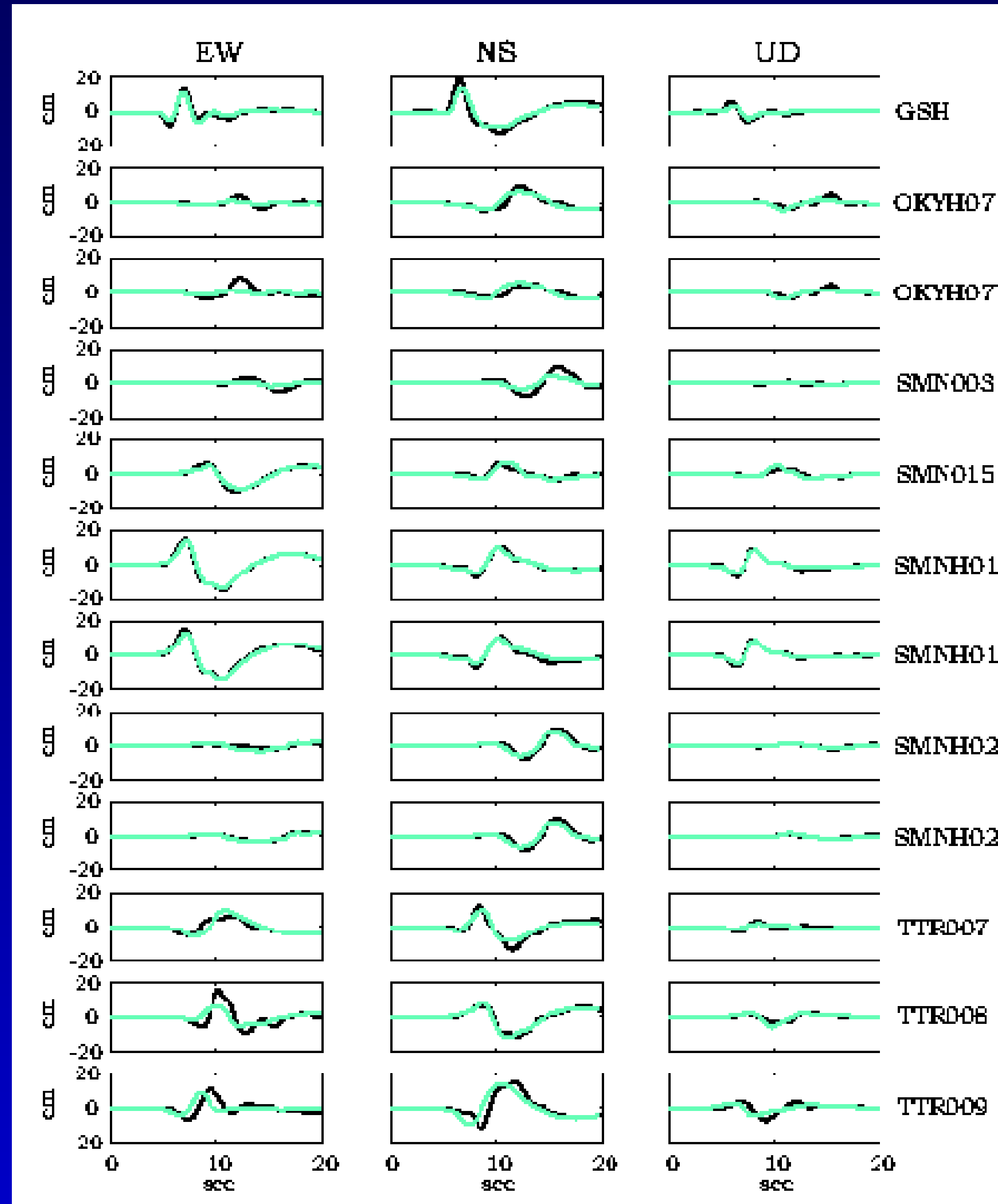
dx	500m	Fault width	14 km
dt	0.025s	Fault length	24 km
T_u	5 MPa	No of grid points	~1 million
f_{max}	0.5 Hz	D_c	28 cm
# iterations	1,500	# inversion parameters	32
# models/it	40	# ‘best’ models	

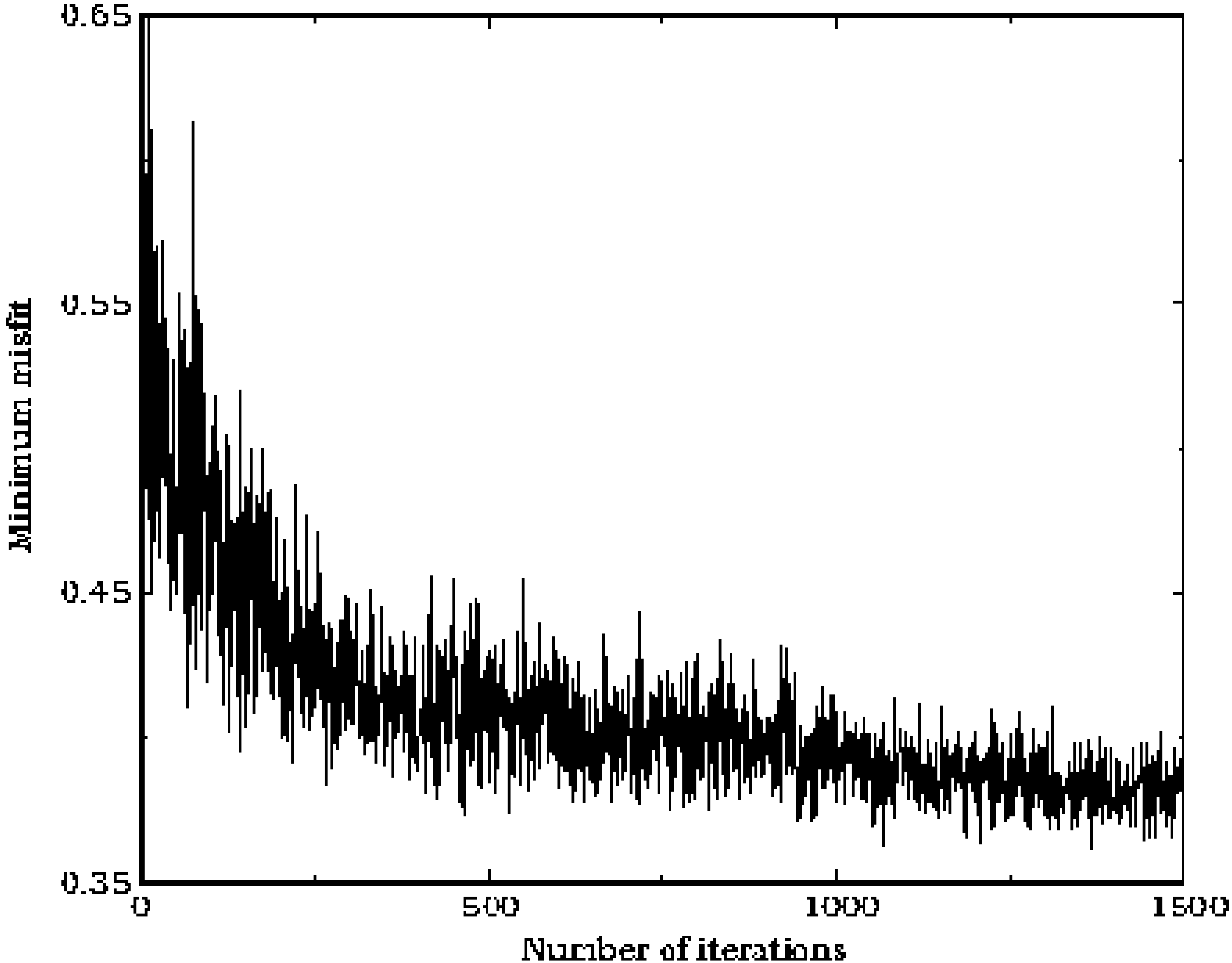

a) Slip
b) Sliprate
c) Stress
NE
SW
1 s
2 s
3 s
4 s
5 s
6 s
7 s
14 km
24 km
0
2 m
0
0.5 m/s
-2
5 MPa

Ensemble of 'Best' Models

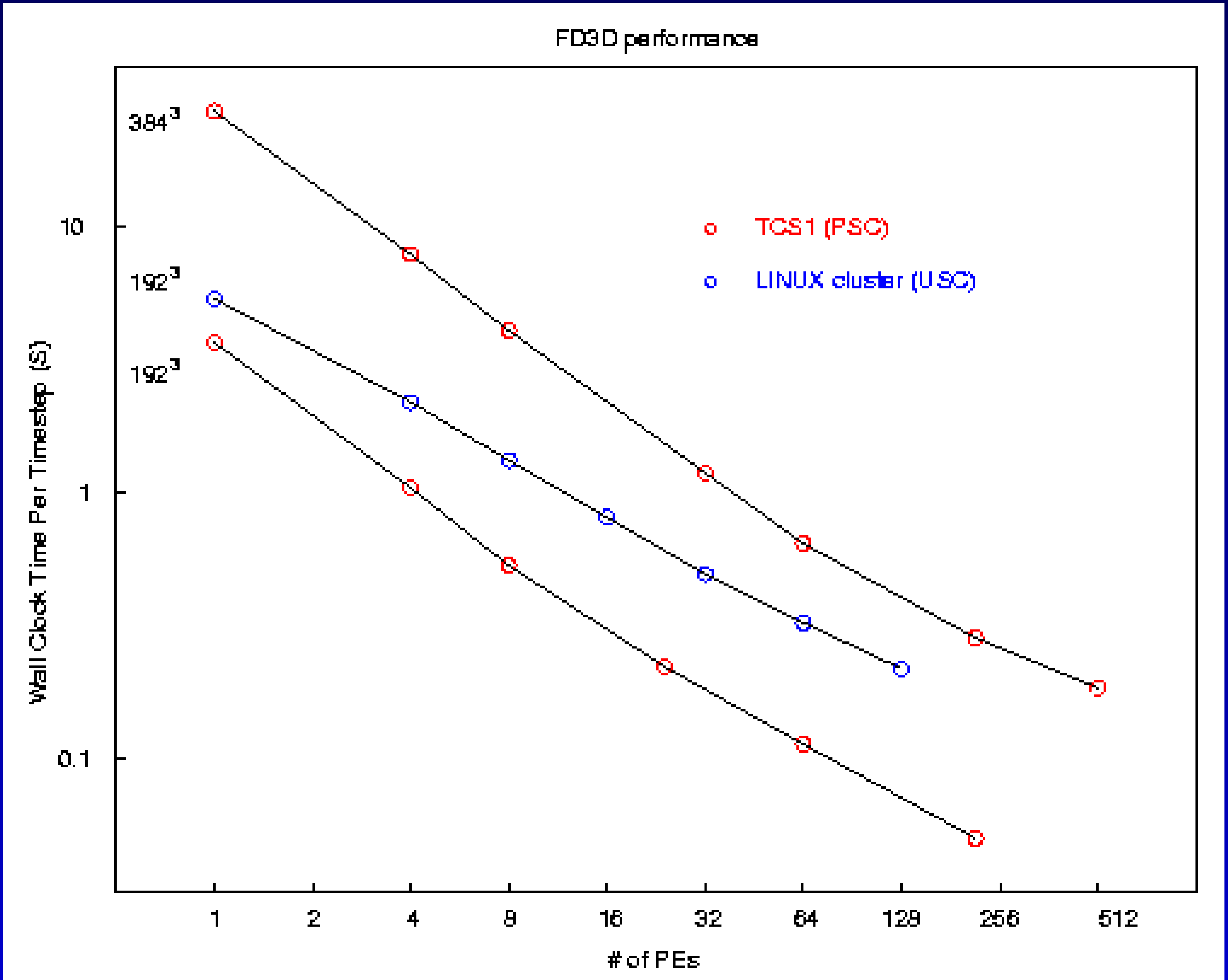



N
km
0
500
133° 00'
133° 30'
35° 30'
35° 00'
TTR008
SMN015
GSH
SMNH01
TTR007
SMNH02
SMN003
TTR009
OKYH07
km
0
10
20


EW
NS
UD
cm
20
0
-20
GSH
OKYH07
OKYH07b
SMN003
SMN015
SMNH01
SMNH01b
SMNH02
SMNH02b
TTR007
TTR008
TTR009
0
10
20
sec



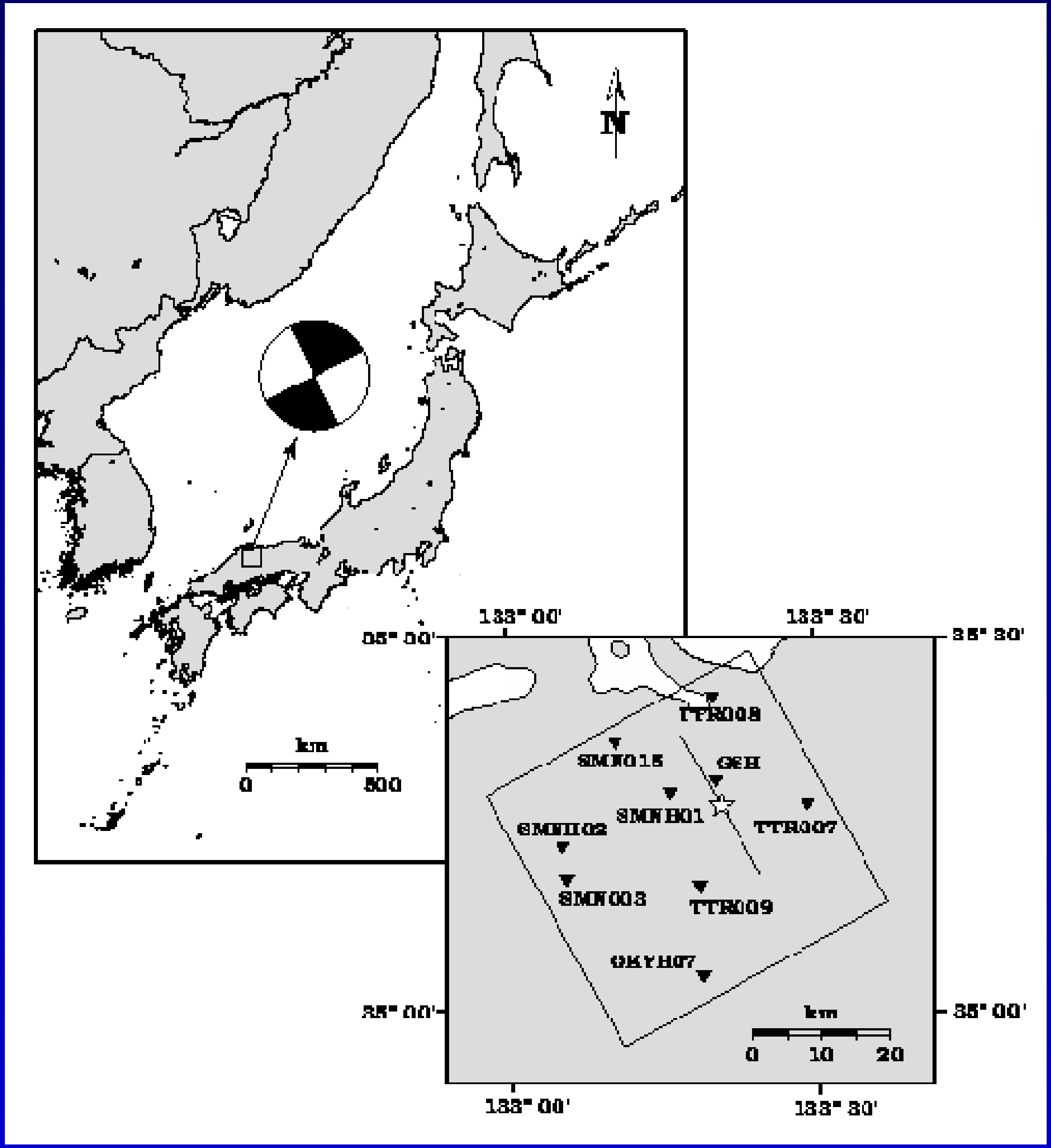
0.65
0.55
0.45
0.35
Minimum misfit
0
500
1000
1500
Number of iterations


FD3D performance
384^3
192^3
192^3
TCS1 (PSC)
LINUX cluster (USC)
Wall Clock Time Per Timestep (S)
10
1
0.1
1
2
4
8
16
32
64
128
256
512
# of PEs

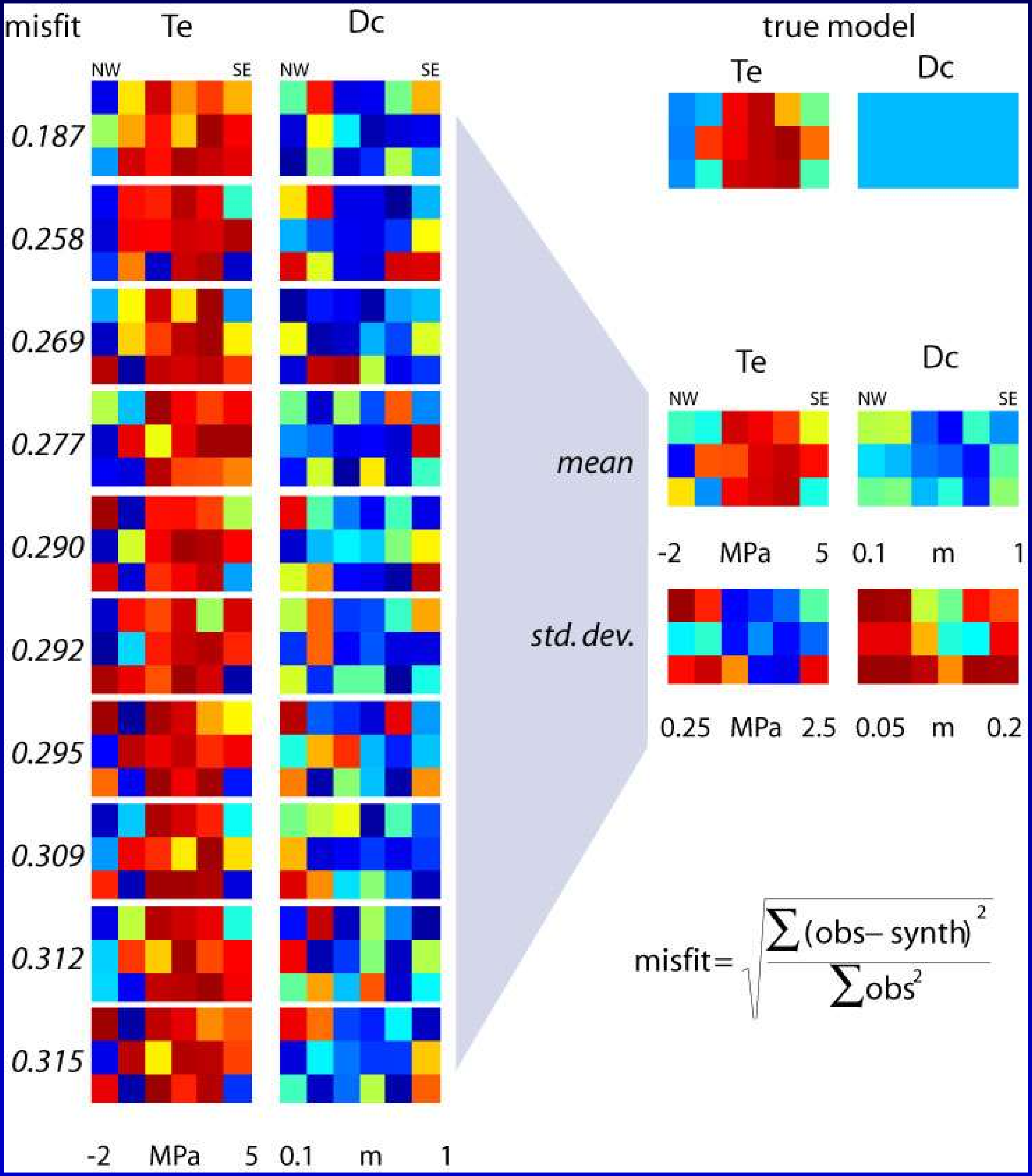
Conclusions

- ✓ Systematic Dynamic Inversion Works!
- ✓ Random Initial Models
- ✓ Only 2 Control Parameters
- ✓ Ensemble of 'Best' Models
- ✓ Computational Expensive

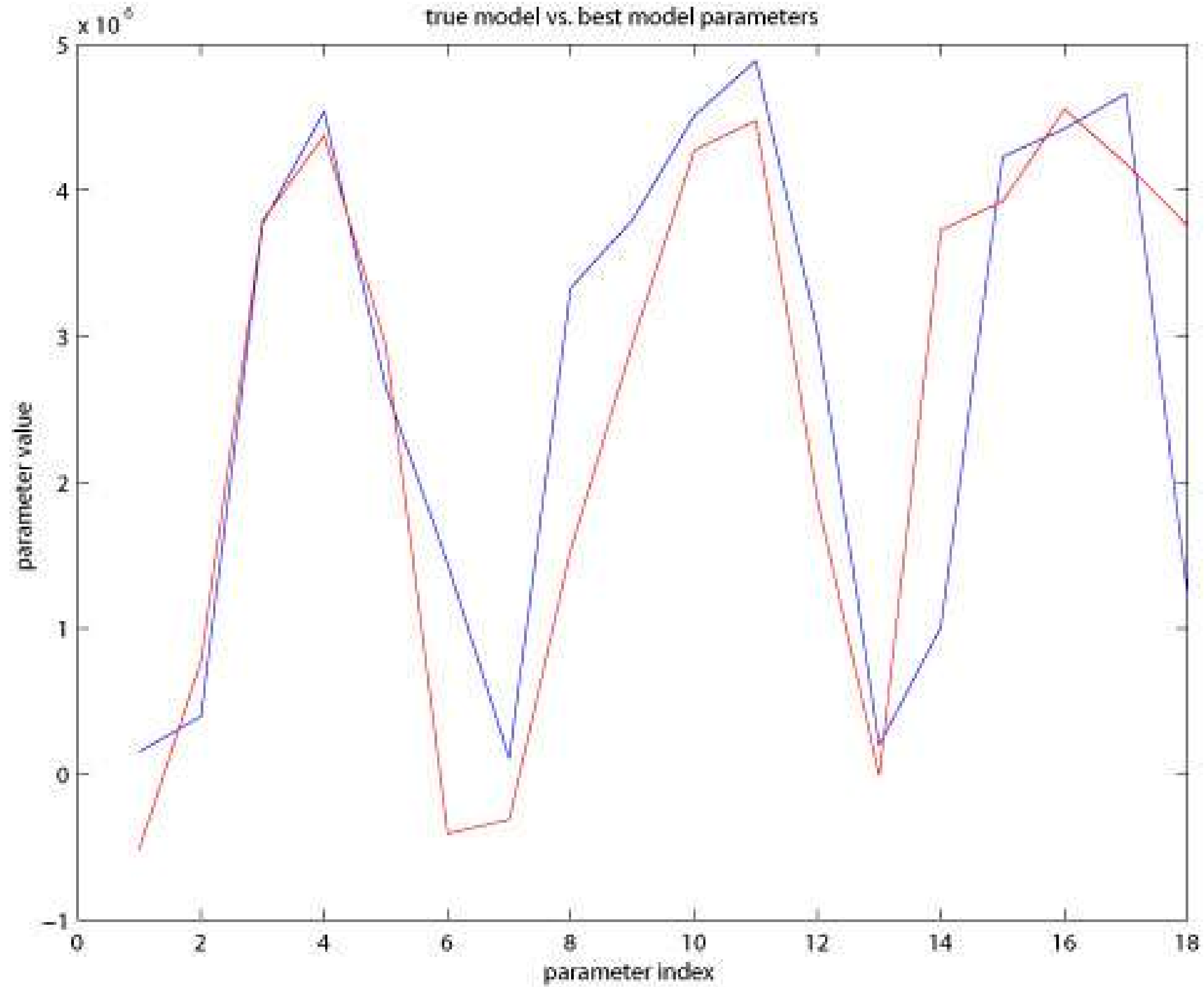
Simultaneous Inversion For Te and Dc for 'Tottori-like' Synthetic earthquake (18 + 18 Parameters)



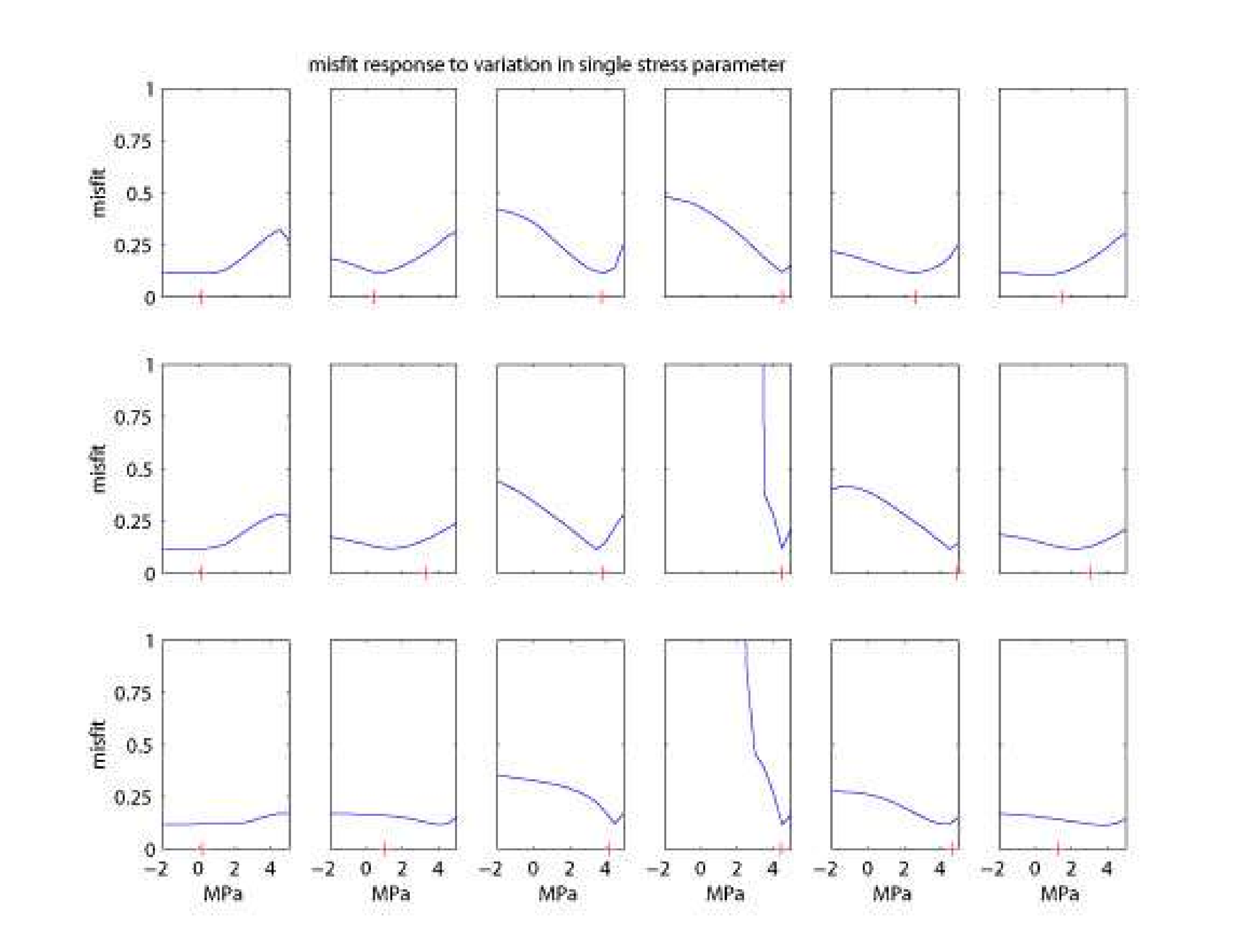
Simultaneous Inversion for Te and Dc



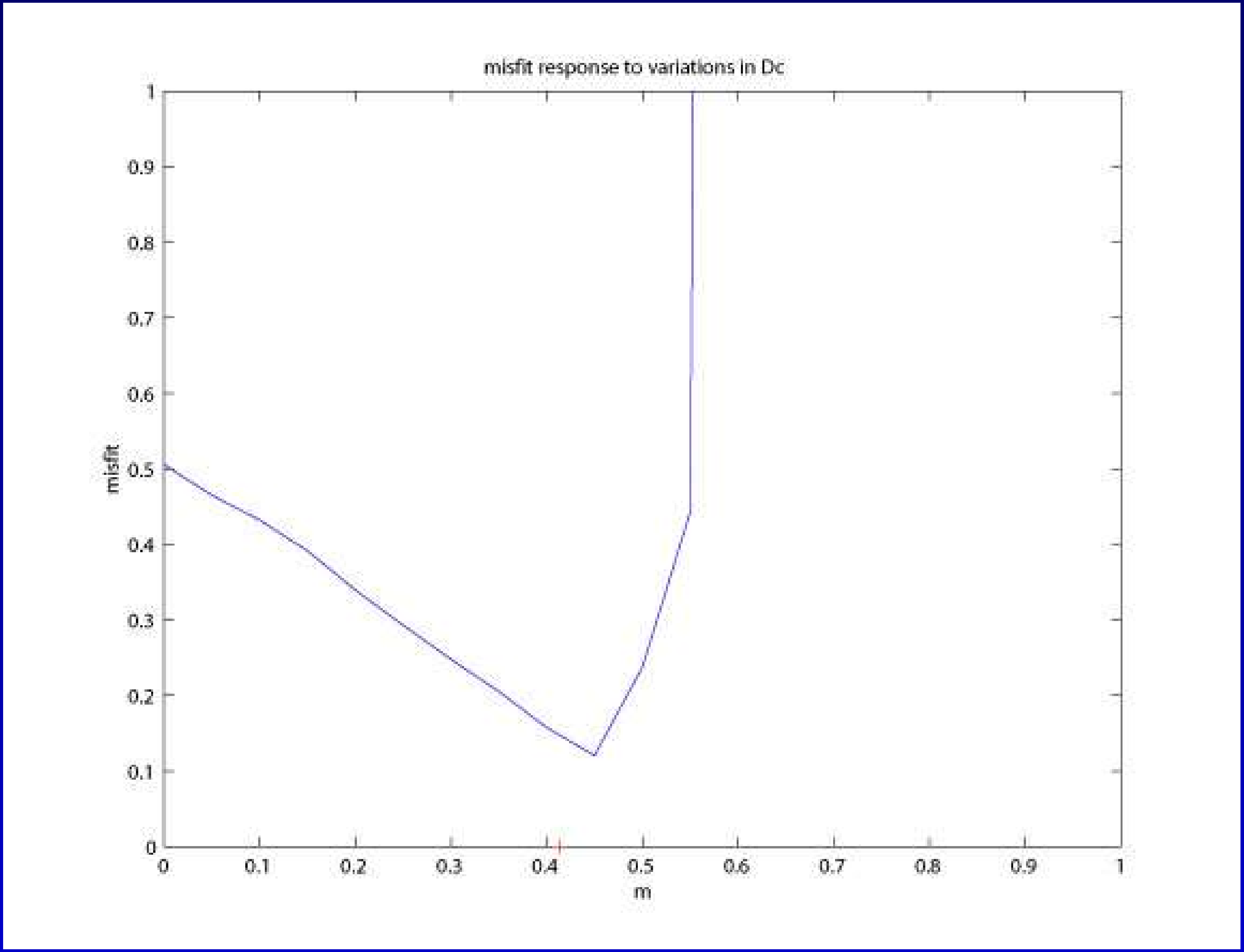
True Versus Minimum Misfit Model



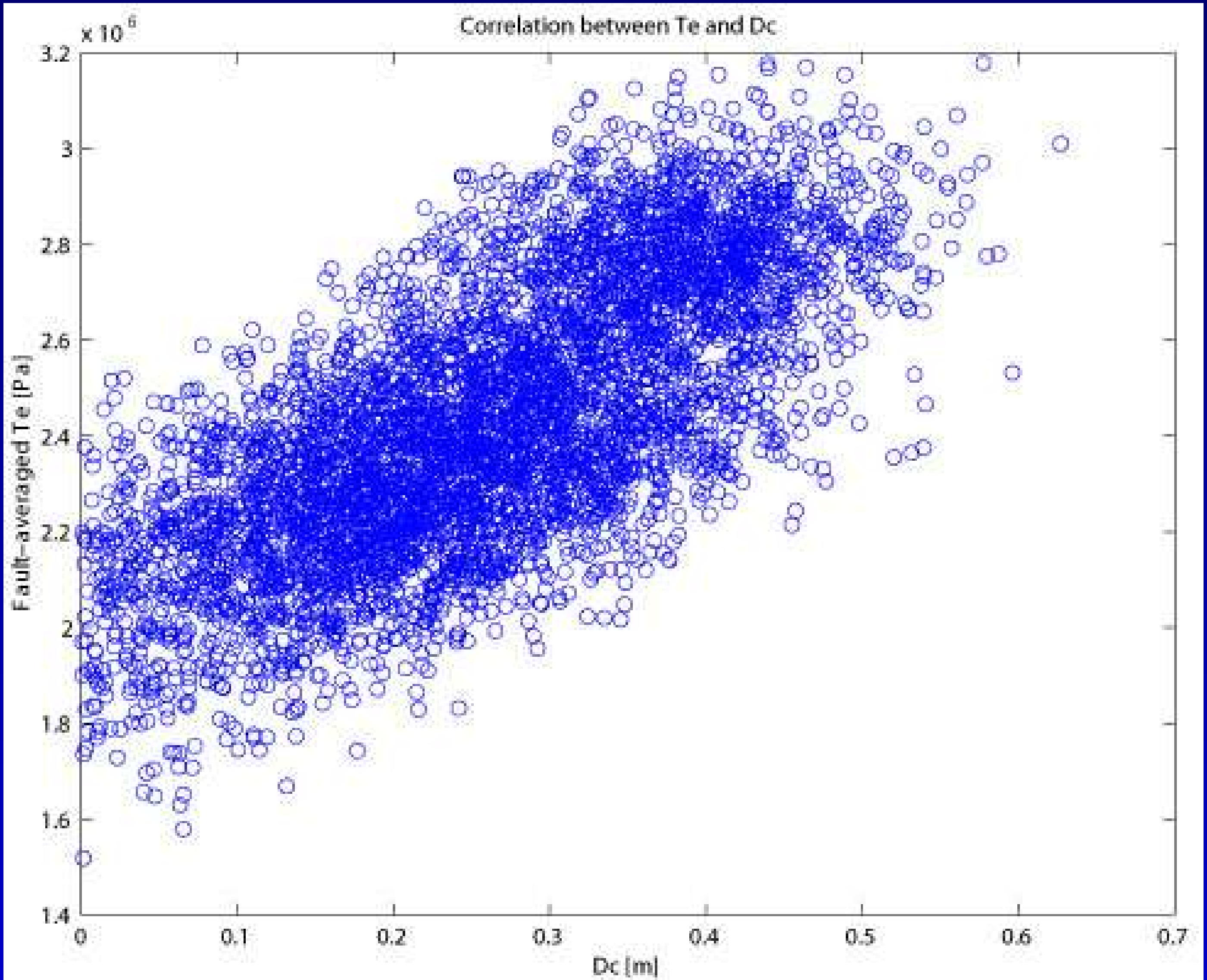
Misfit Response to Te Variation



Misfit Response to (Single) Dc Variation



Correlation Between Te and Dc



Conclusions

- ✓ Te and Dc correlated
- ✓ Only uniform Dc resolved (?)
- ✓ Only large slip areas resolved (?)

Future Work

- ✓ Requirement for Constraints
- ✓ Smoothing of Inversion Parameters
- ✓ Optimal Choices for nr, ns
- ✓ Inversion for $T_u/T_e/D_c$
- ✓ Combine With 1D Propagation
- ✓ Other Objective Functions

Websims

- Interface for rupture solution storage and download facility
- Facilitate comparisons of dynamic (and kinematic) rupture code results

http://scecdata.usc.edu/rdm

Site Capabilities:

- Storage and downloads of time histories
- Dynamic cross plots of sliprate/slip/stress time histories
- Dynamic cross plots of rupture time contours
- User selection of trace color, axis scales, contour intervals

Dynamic Contour Plots on the Web

MATLAB has a web server toolbox which allows the dynamic creation of plots using MATLAB which can then be automatically saved for display on the web

Websims for Waveforms

http://sceclib.sdsc.edu/TeraShake