# SDSU Module

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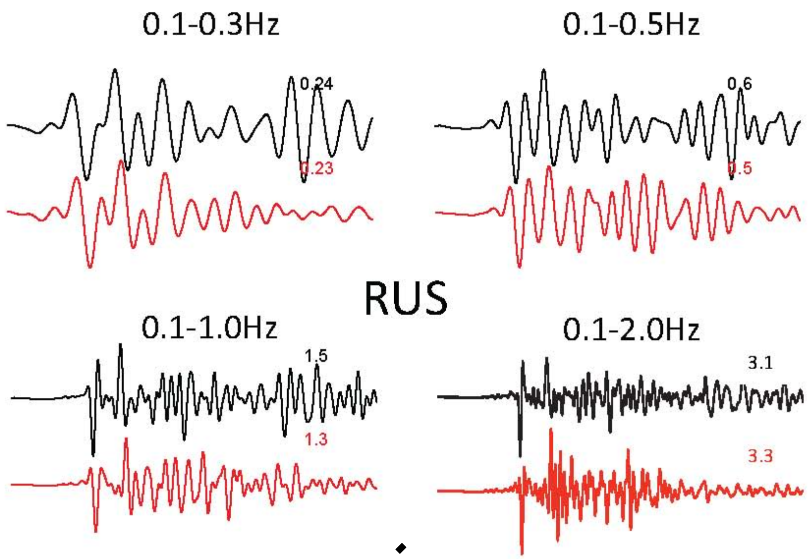
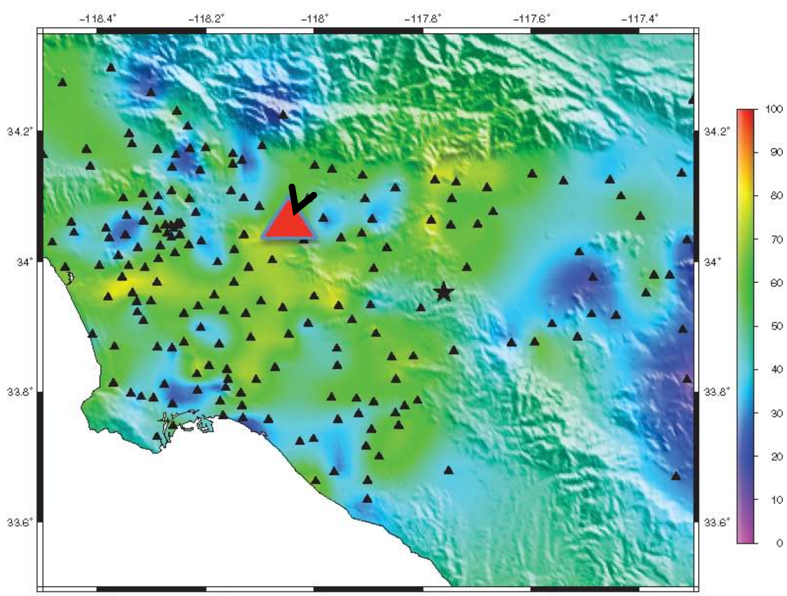
# Accuracy of Deterministic Long-period Ground Motion Prediction




Comparison of recorded data (black traces) and synthetics (red traces) for station RUS



Average goodness-of-fit (perfect fit = 100) at 0.1-0.5 Hz for synthetics relative to data.

# Ground Motion Prediction

- Low-frequency ground motion prediction (<1-2 Hz) reasonably accurate
- But what about high-frequency signals > 1-2Hz?

# High-frequency ground motion Modeling

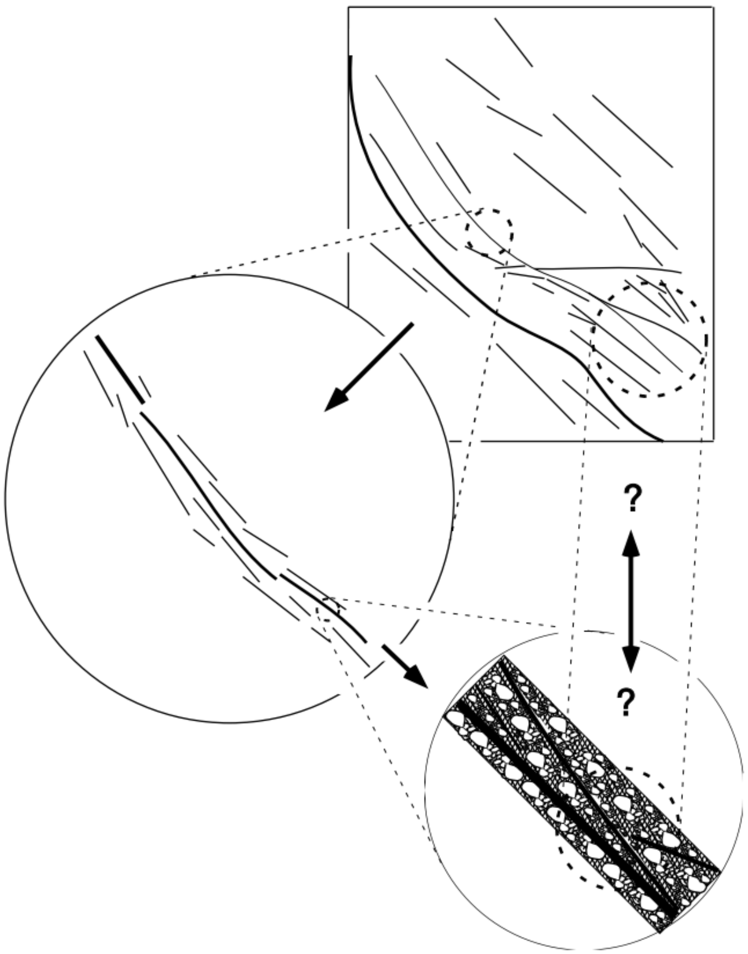
- Requires small-scale complexity

➢ Source

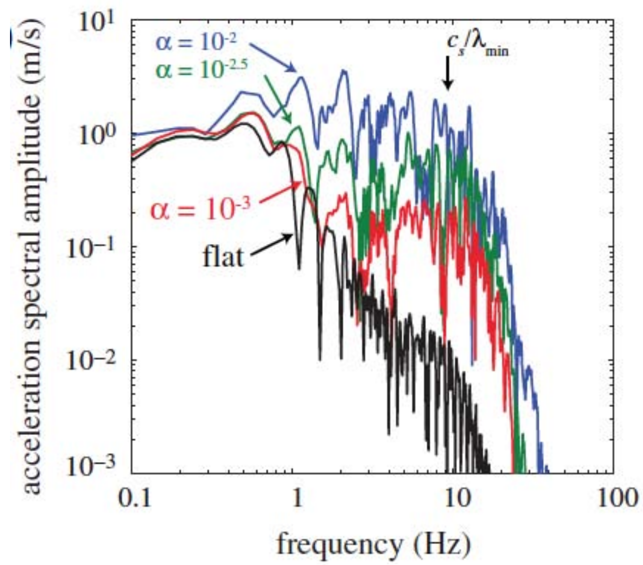
➢ Media

# Source Complexity: Rough Faults

- Roughness is observed at all scales



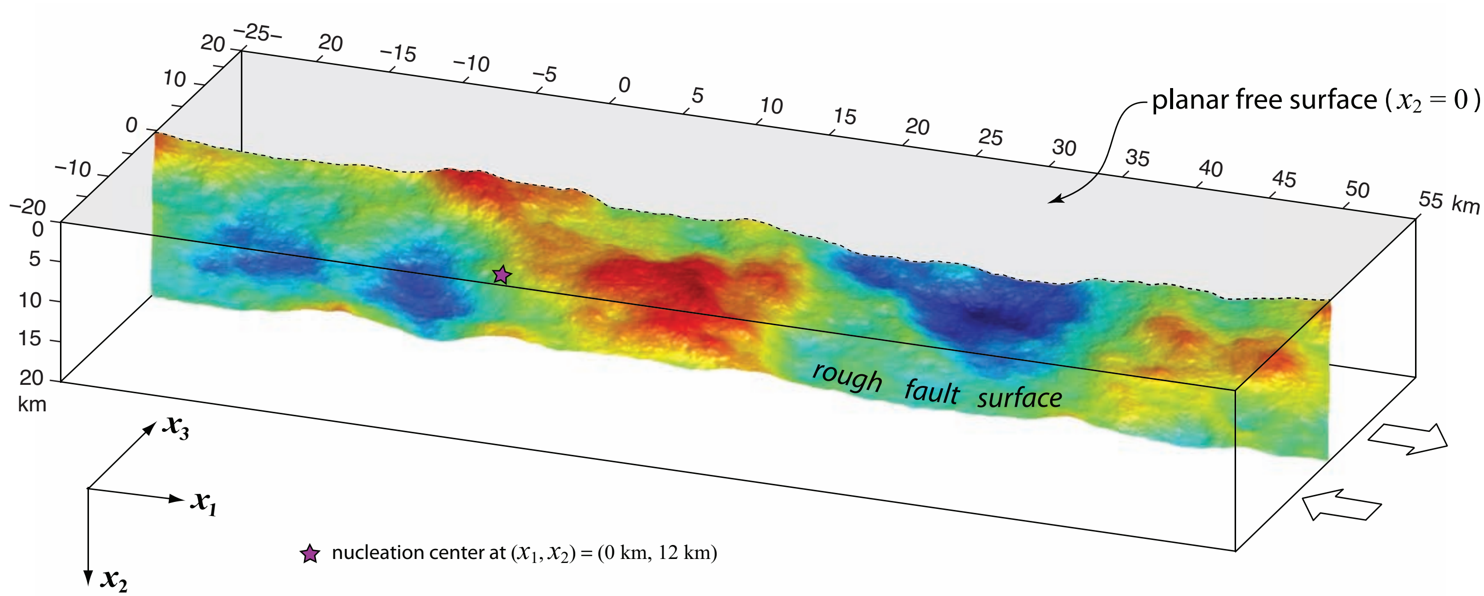

(Ben-Zion, 2003)




(Dunham, 2011)

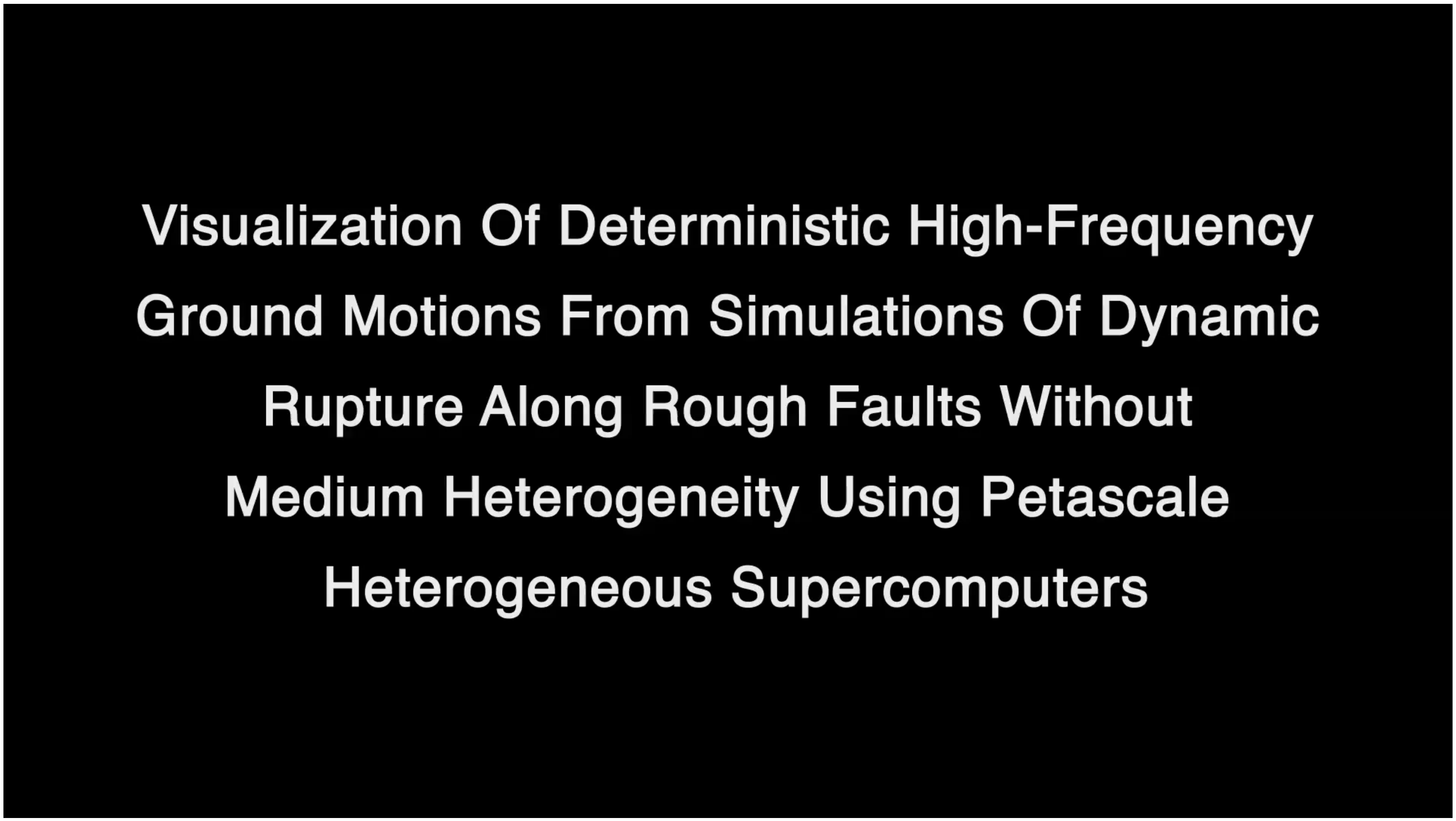
# Rough Faults

- Rough fault topography: subfaults follow self-similar fractal distribution for wavelengths from 80 m to length of fault

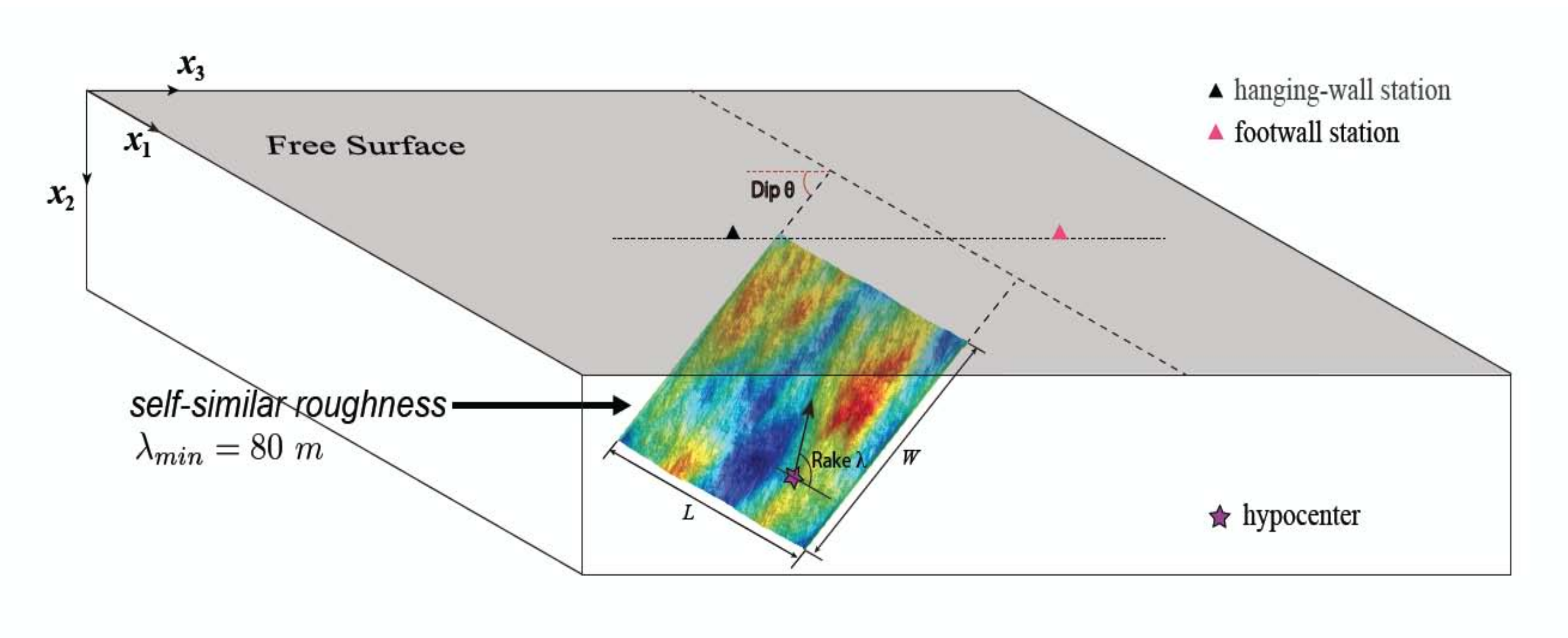



(Shi and Day, 2013)

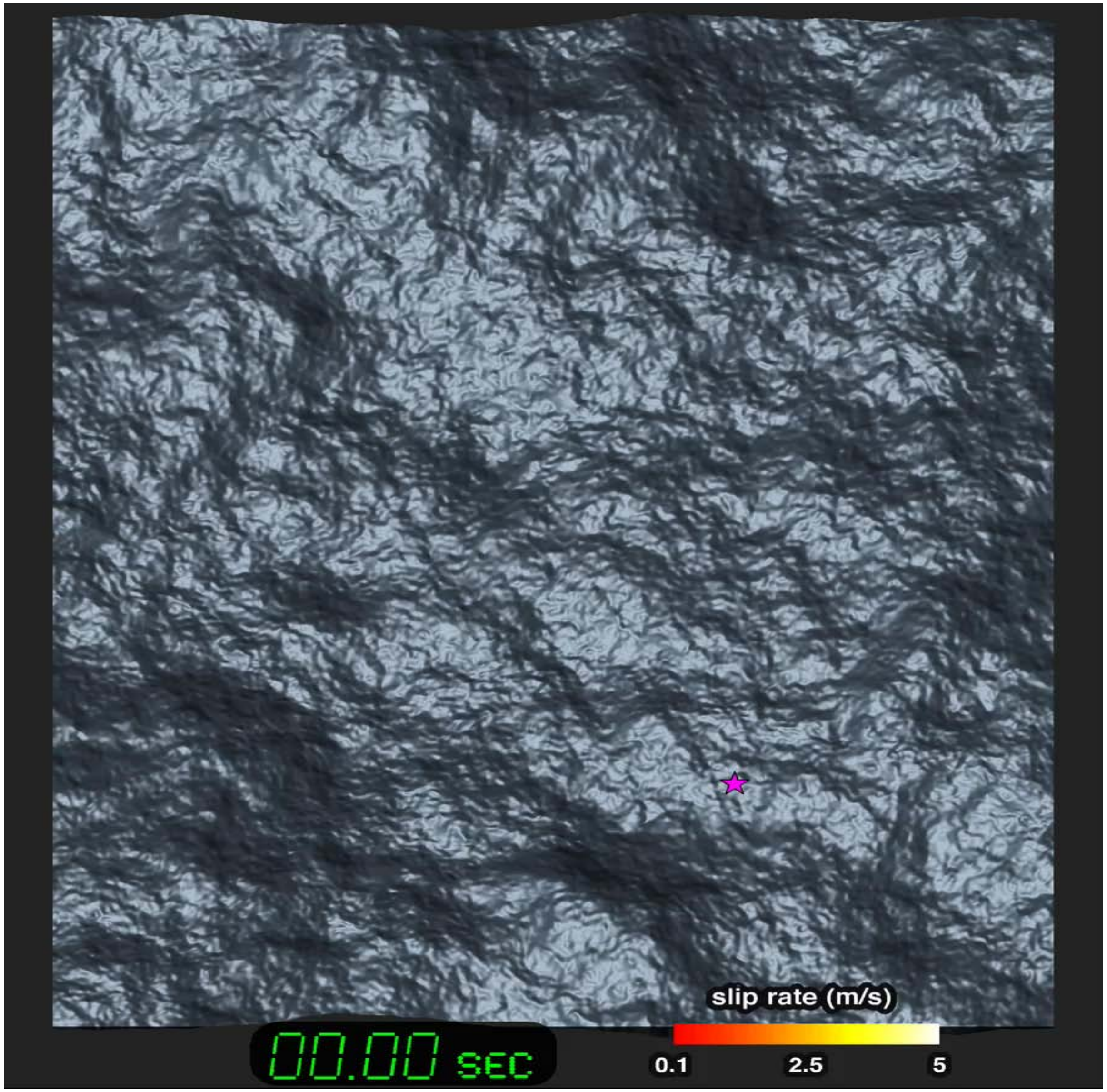
# Rough Fault Radiation



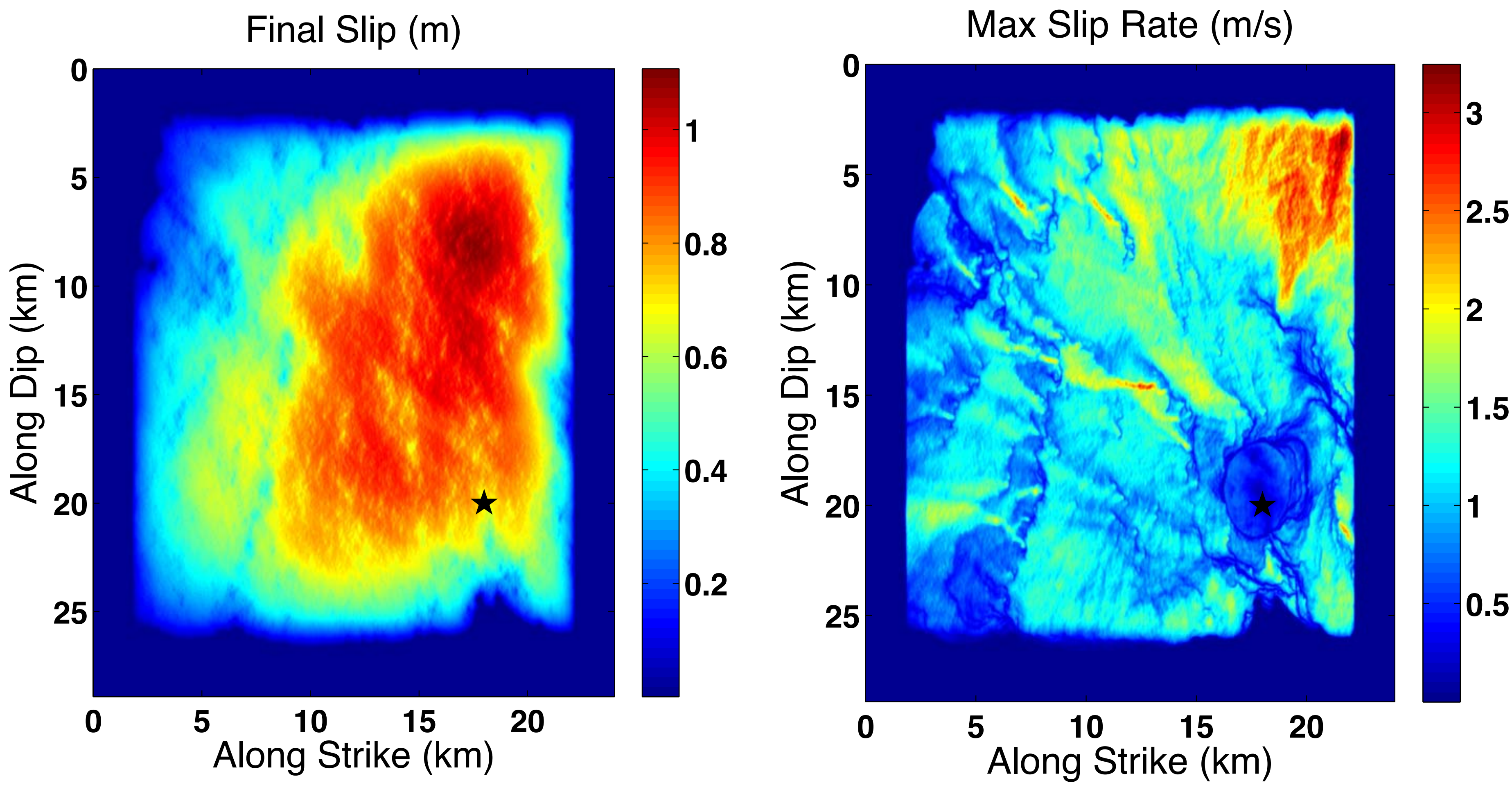
# Northridge Mw 6.7 1994 Earthquake



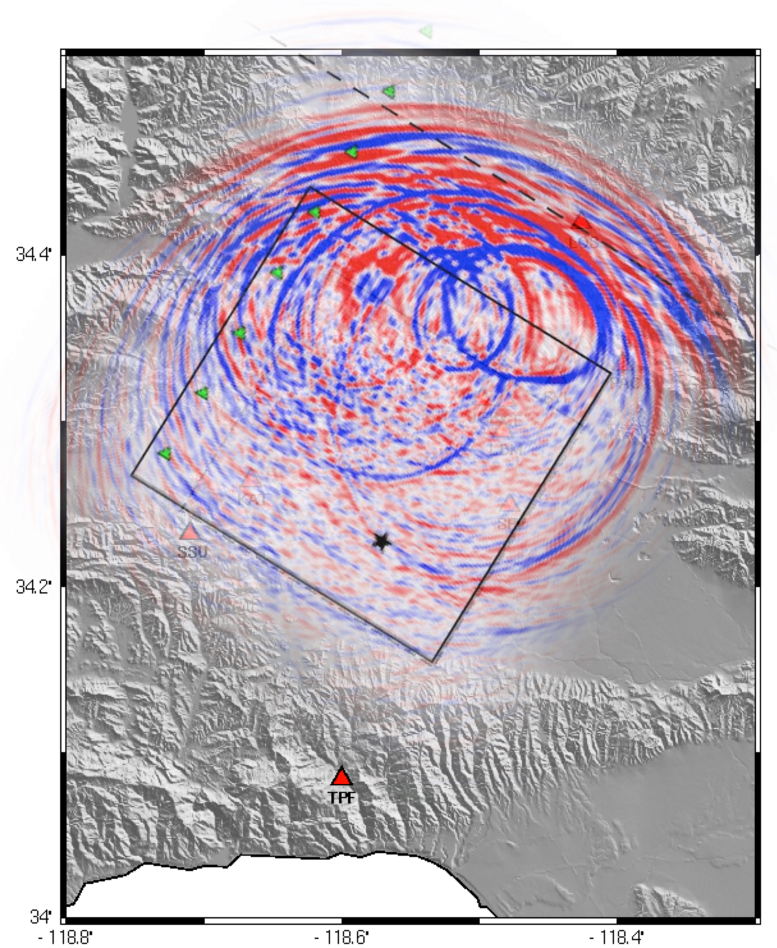
# 0-10Hz Northridge Rough Fault Rupture



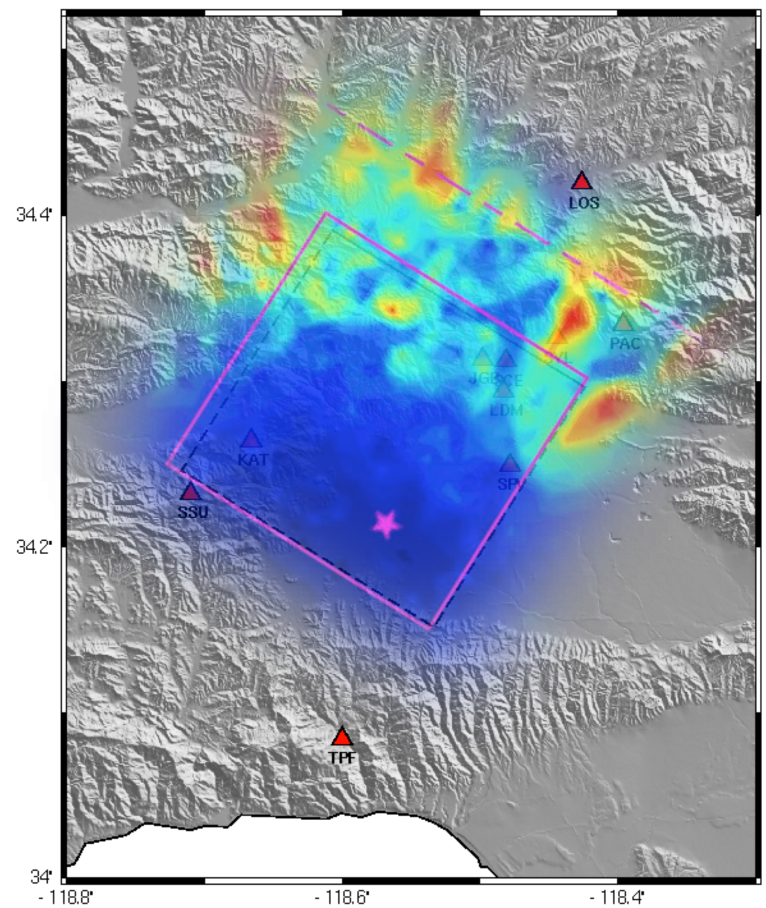
# 0-10Hz Northridge Rough Fault Rupture



# 0-10Hz Northridge Rough Fault Rupture



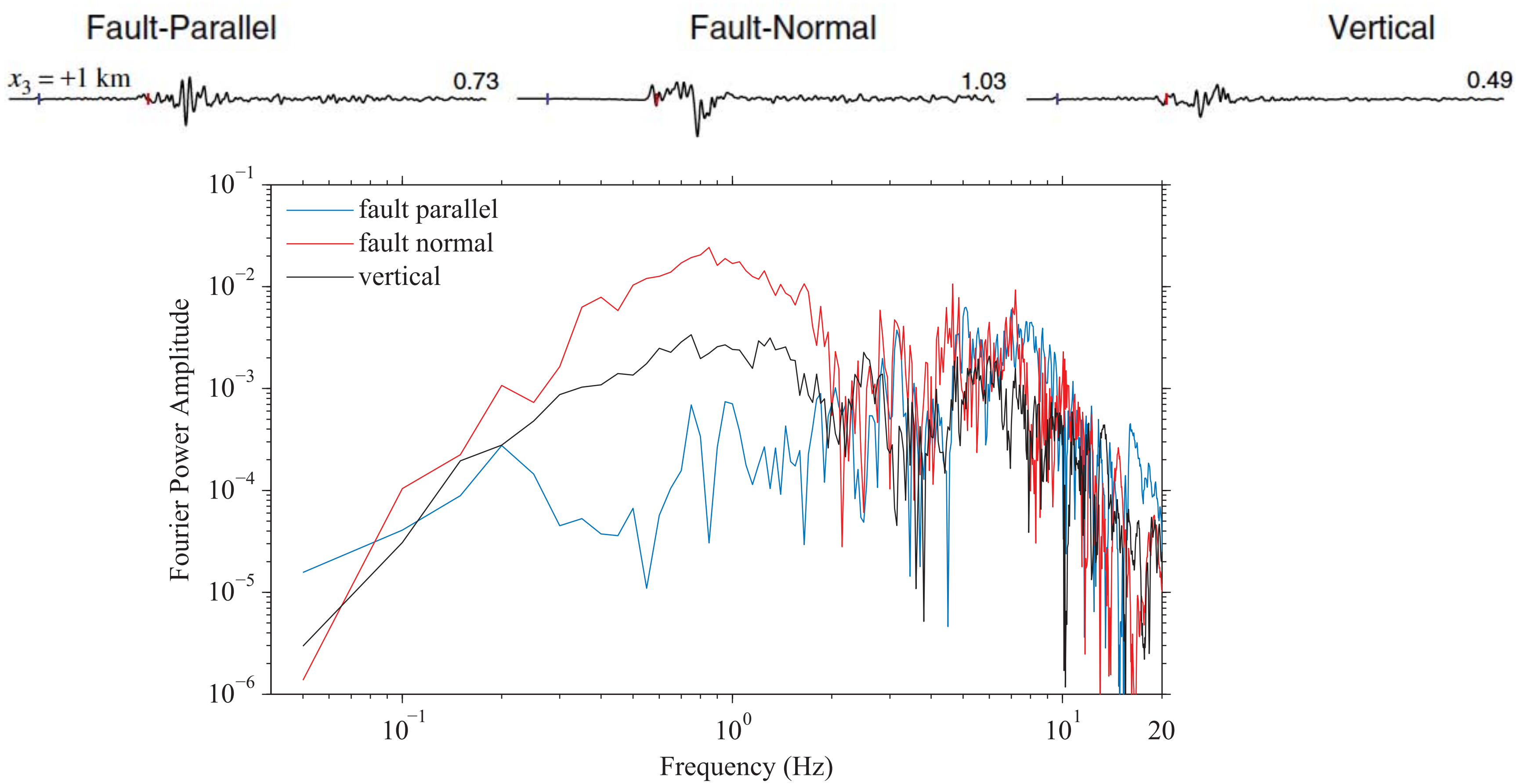

Snapshot of Acceleration




Strike-parallel PGA

# Realistic Power Spectra

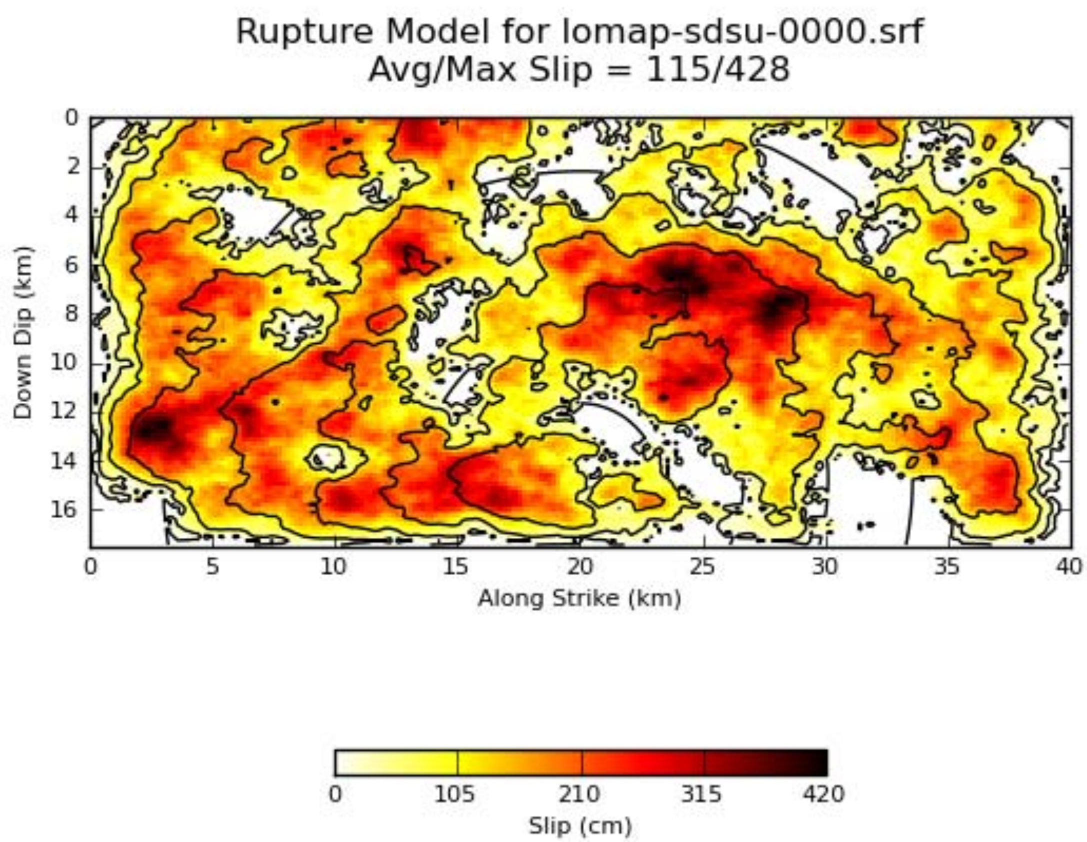
- Near-flat power spectra up to ~10 Hz

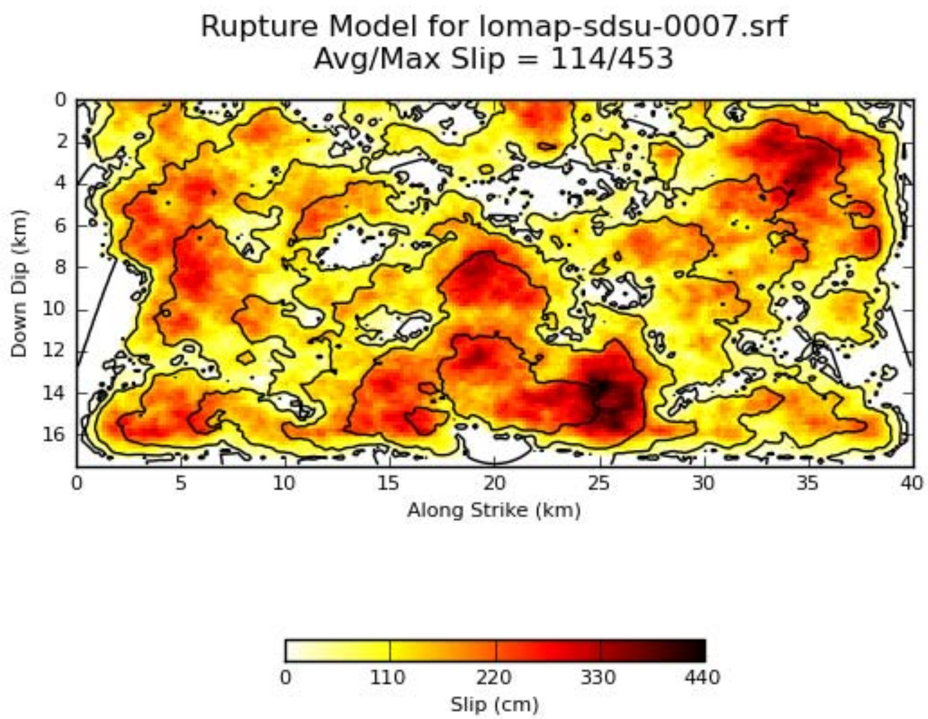


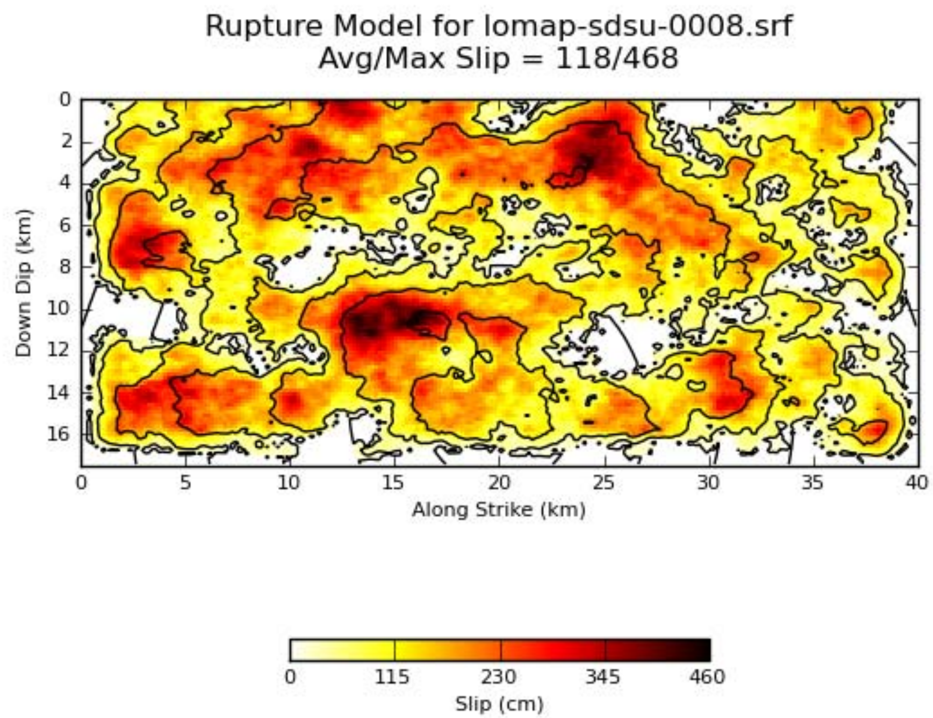

(Shi and Day, 2013)

# GFs, Rupture Model

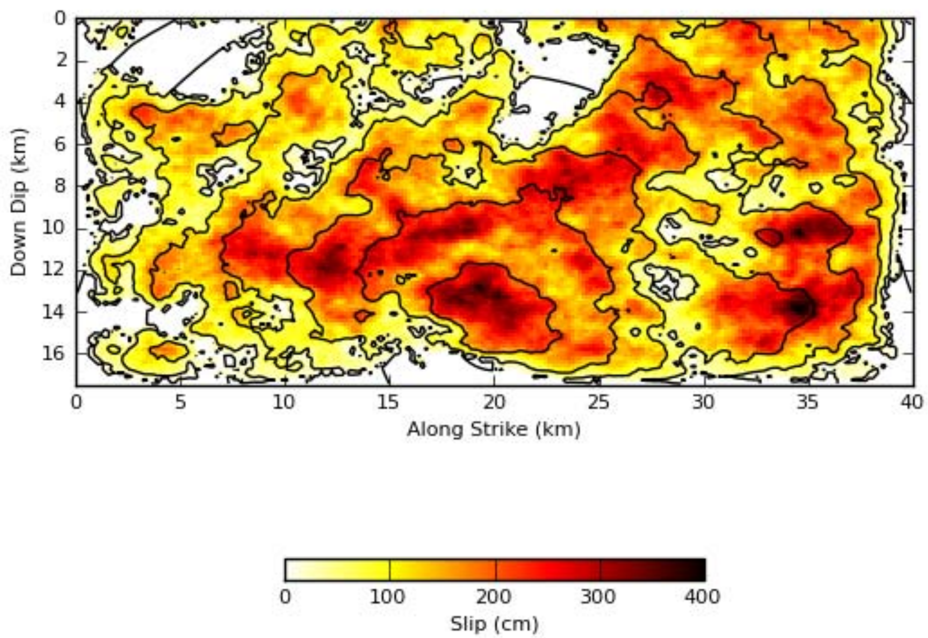
- SDSU module uses URS kinematic rupture generator



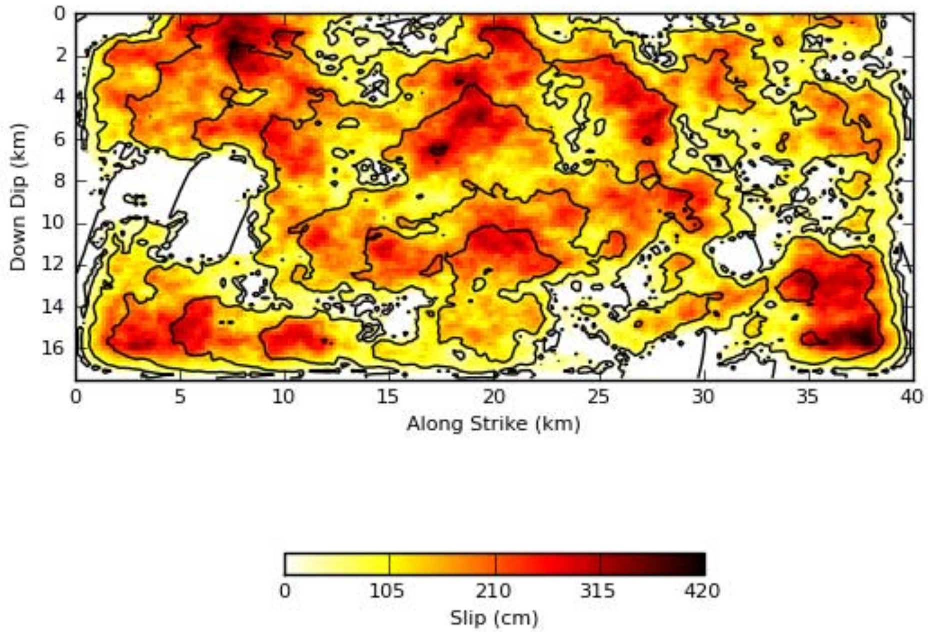

Rupture Model for lomap-sdsu-0007.srf
Avg/Max Slip = 114/453
Down Dip (km)
Along Strike (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
0
110
220
330
440
Slip (cm)

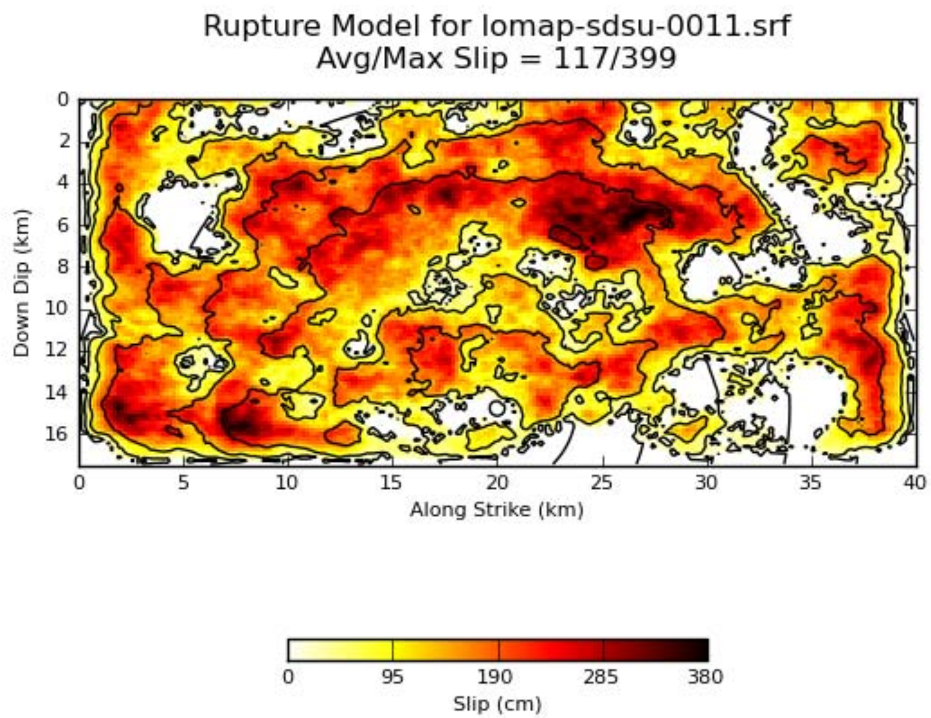

Rupture Model for lomap-sdsu-0008.srf
Avg/Max Slip = 118/468
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
115
230
345
460
Slip (cm)

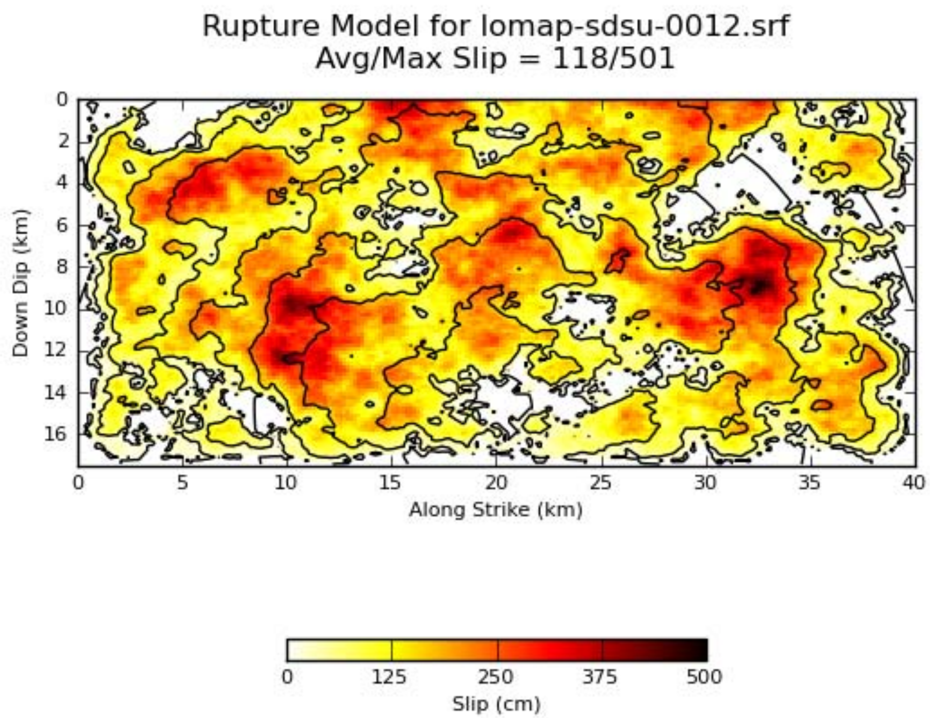
Rupture Model for lomap-sdsu-0009.srf
Avg/Max Slip = 115/410

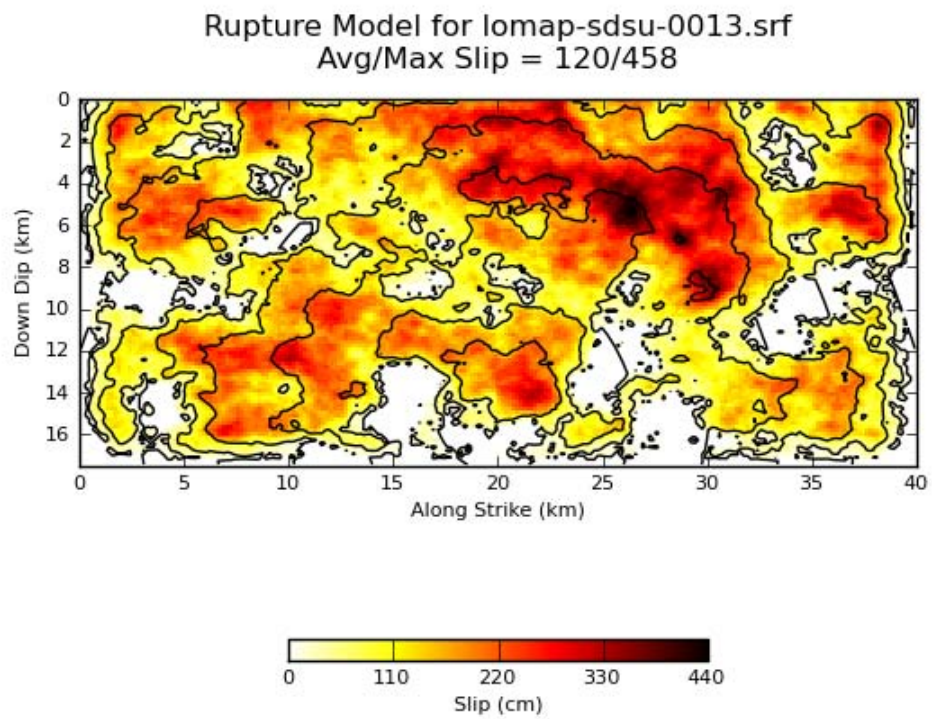


Rupture Model for lomap-sdsu-0010.srf
Avg/Max Slip = 117/427

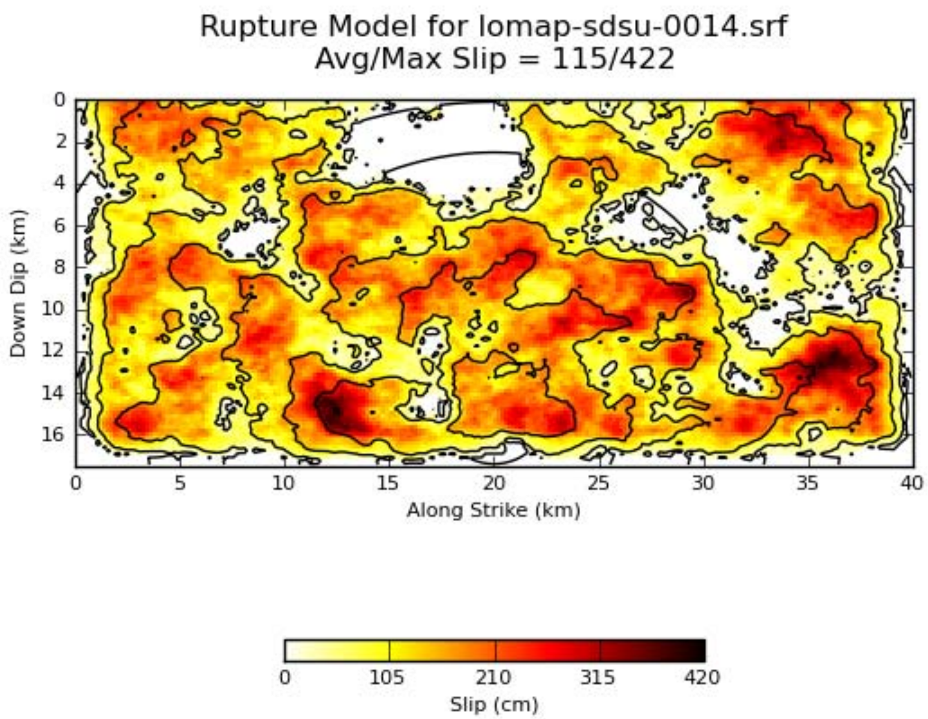


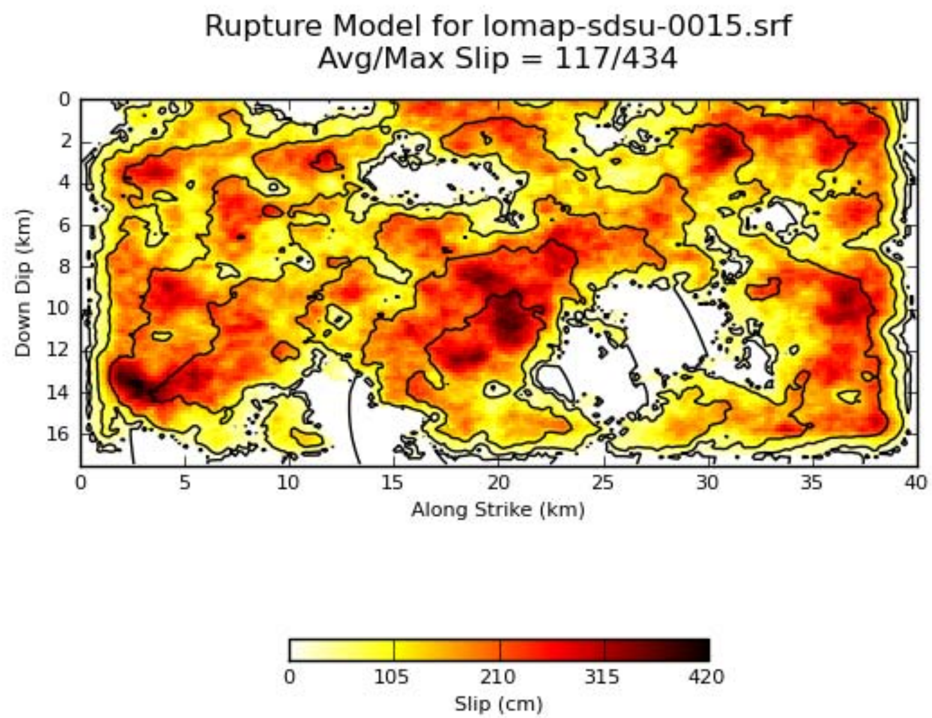

Rupture Model for lomap-sdsu-0011.srf
Avg/Max Slip = 117/399
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
95
190
285
380
Slip (cm)

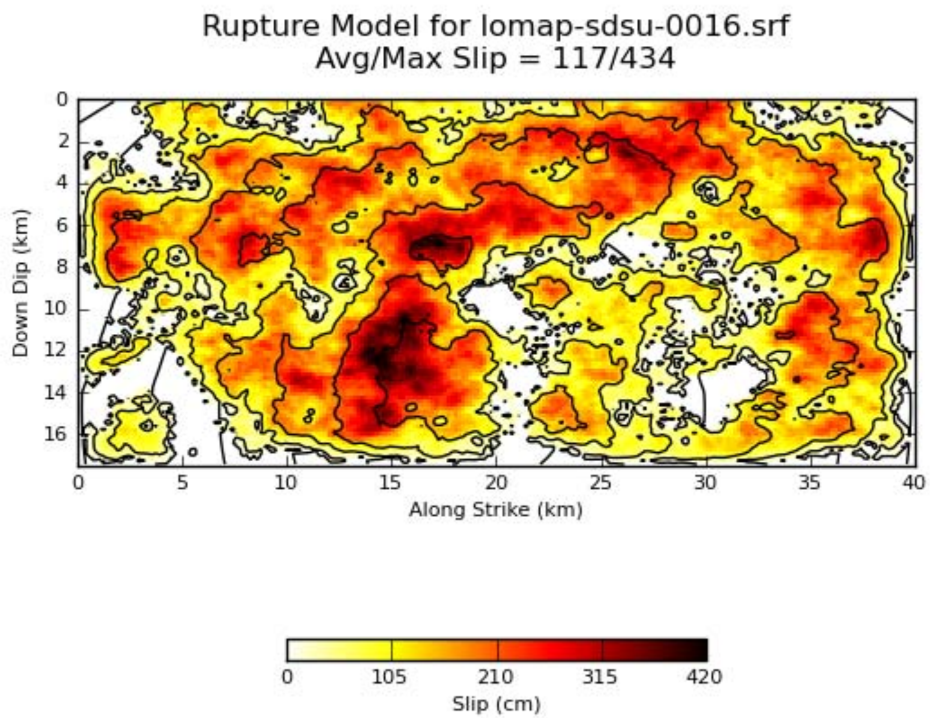

Rupture Model for lomap-sdsu-0012.srf
Avg/Max Slip = 118/501
Down Dip (km)
Along Strike (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
0
125
250
375
500
Slip (cm)



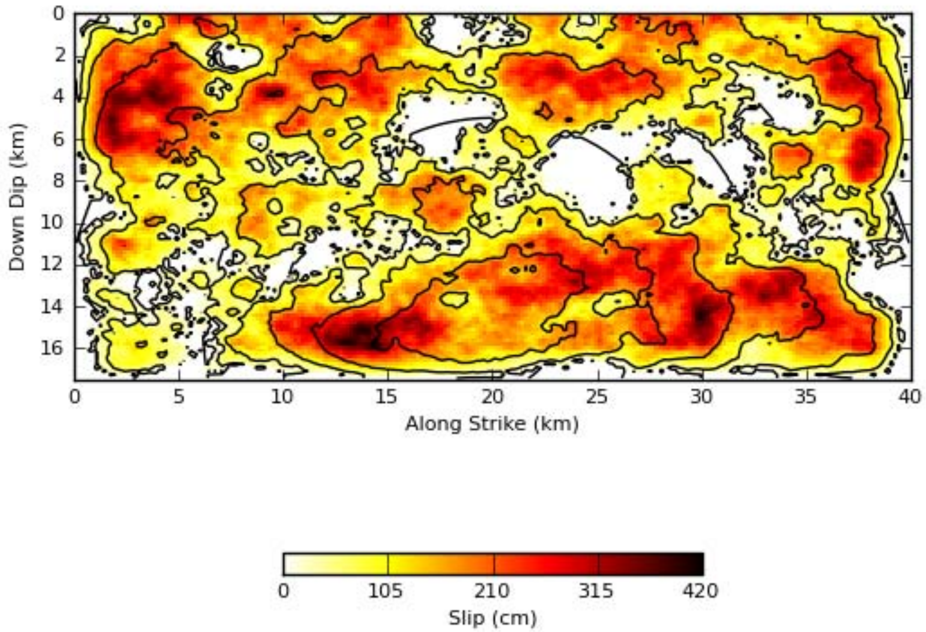
Rupture Model for lomap-sdsu-0013.srf
Avg/Max Slip = 120/458
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
110
220
330
440
Slip (cm)


Rupture Model for lomap-sdsu-0014.srf
Avg/Max Slip = 115/422
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
105
210
315
420
Slip (cm)

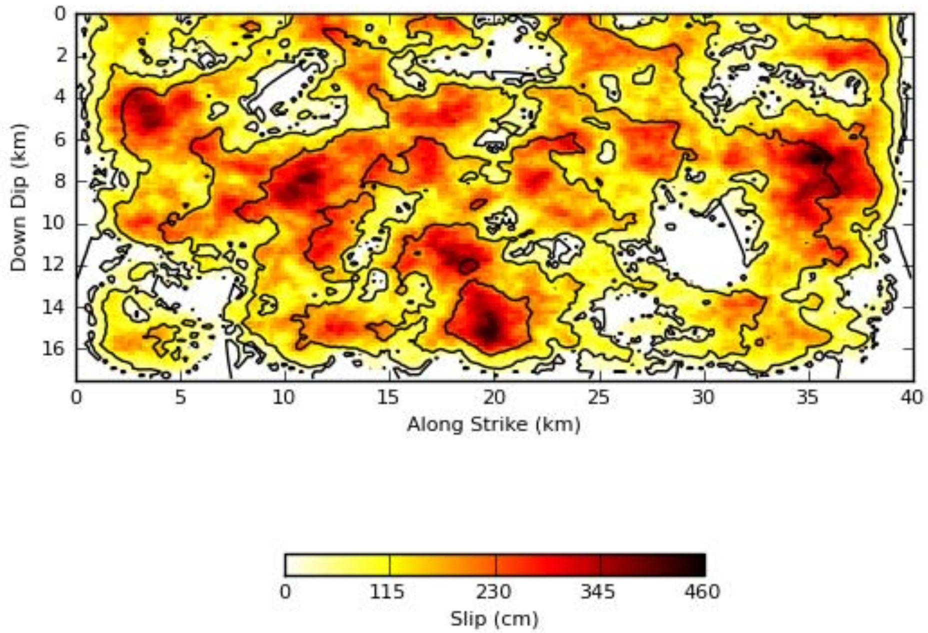

Rupture Model for lomap-sdsu-0015.srf
Avg/Max Slip = 117/434
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
105
210
315
420
Slip (cm)


Rupture Model for lomap-sdsu-0016.srf
Avg/Max Slip = 117/434
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
105
210
315
420
Slip (cm)

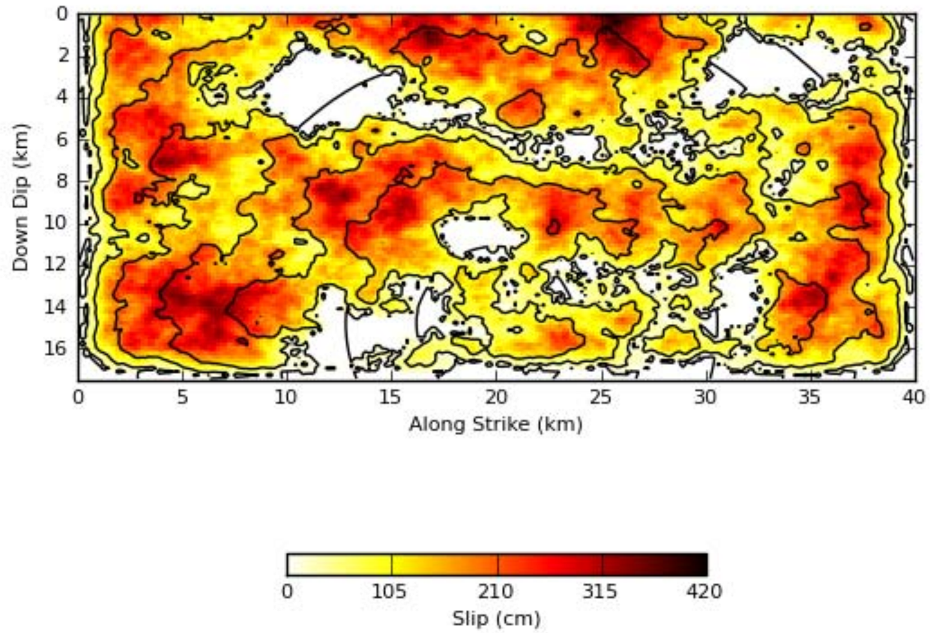
Rupture Model for lomap-sdsu-0017.srf
Avg/Max Slip = 116/425

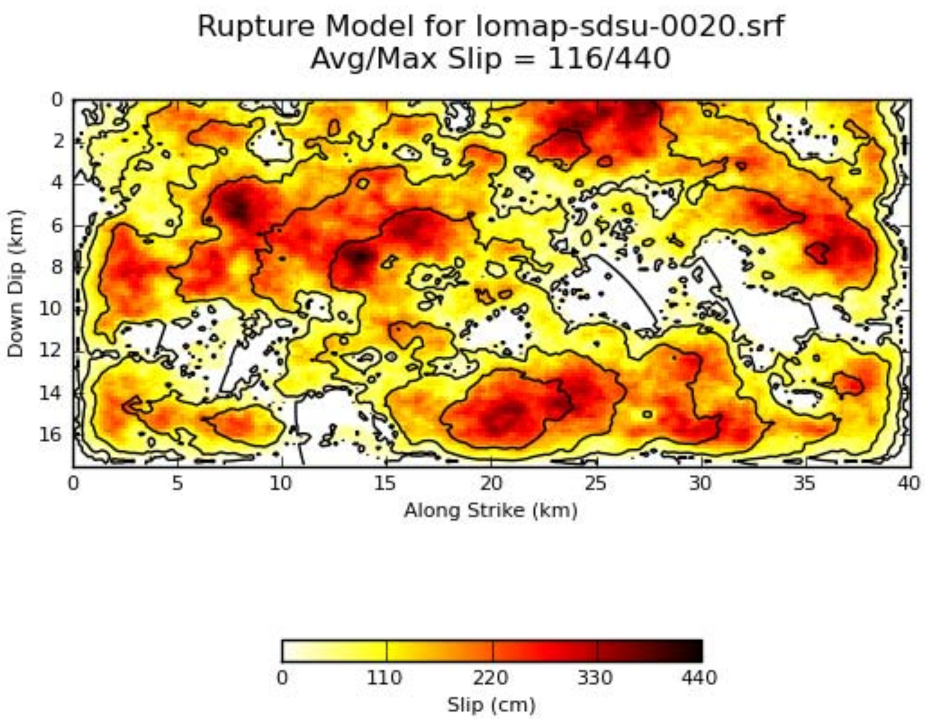


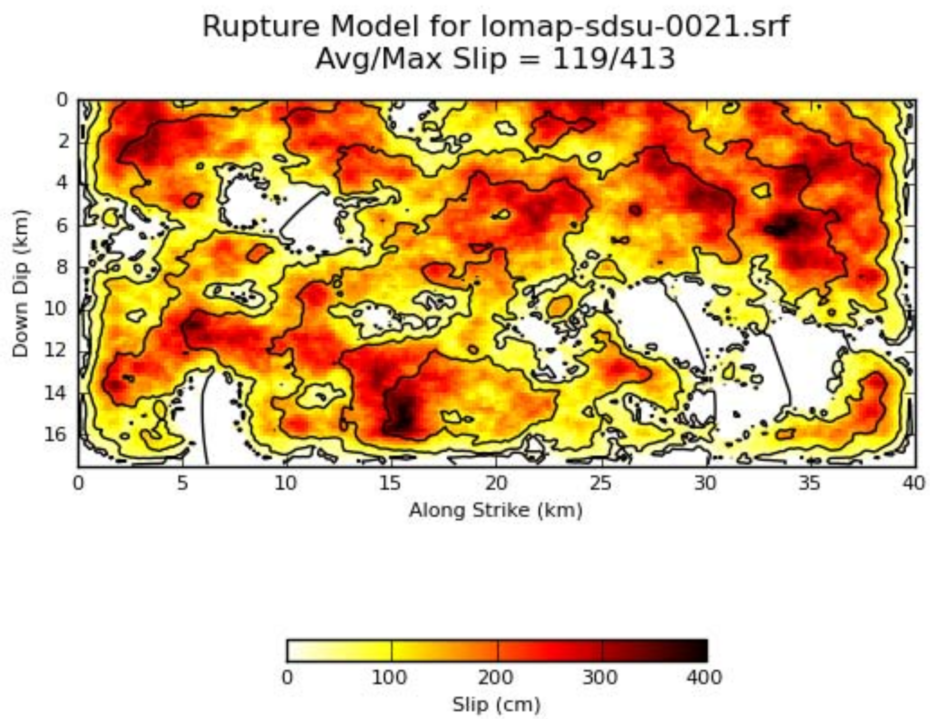
Rupture Model for lomap-sdsu-0018.srf
Avg/Max Slip = 116/460



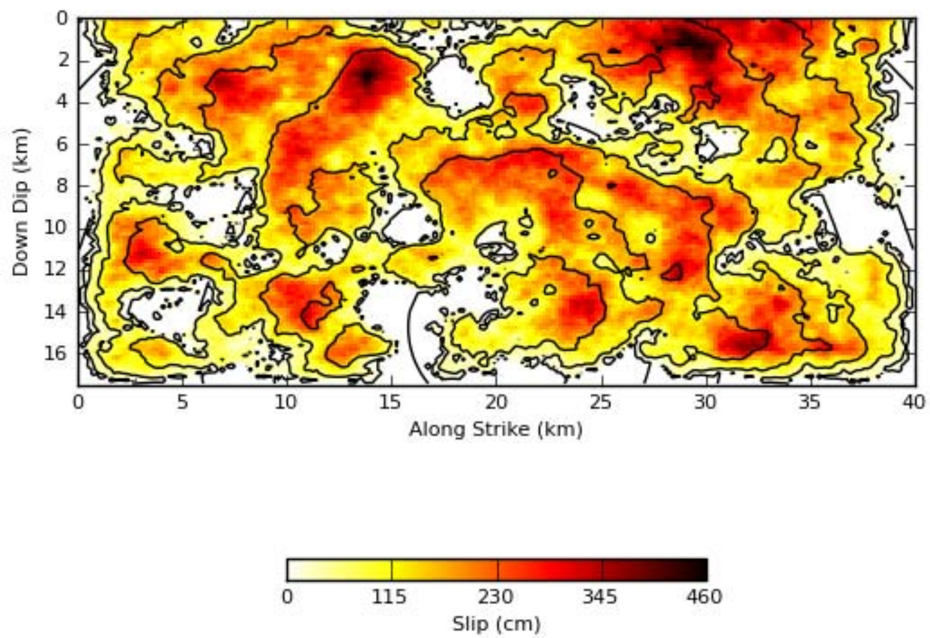
Rupture Model for lomap-sdsu-0019.srf
Avg/Max Slip = 117/424



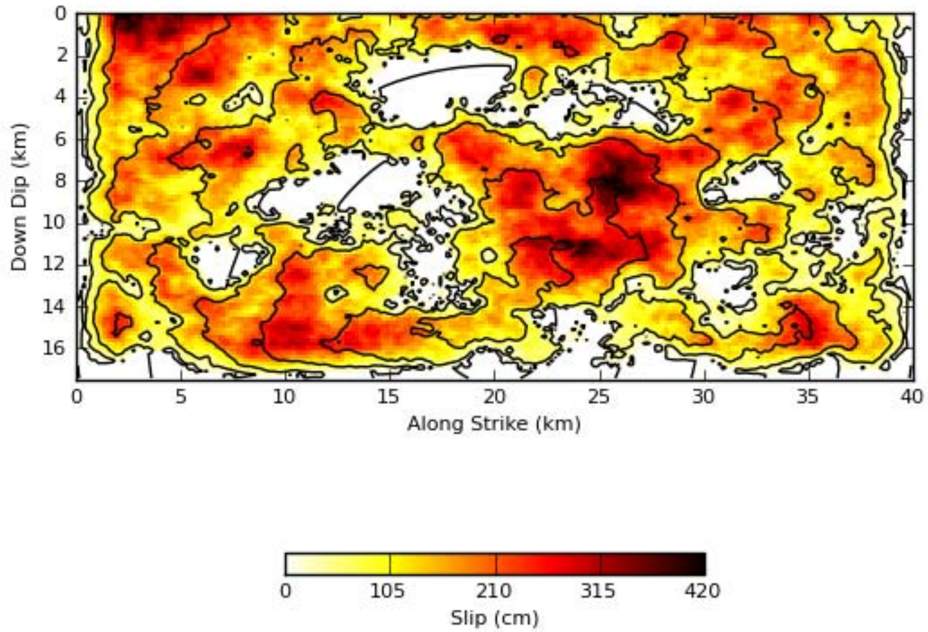

Rupture Model for lomap-sdsu-0020.srf
Avg/Max Slip = 116/440
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
110
220
330
440
Slip (cm)

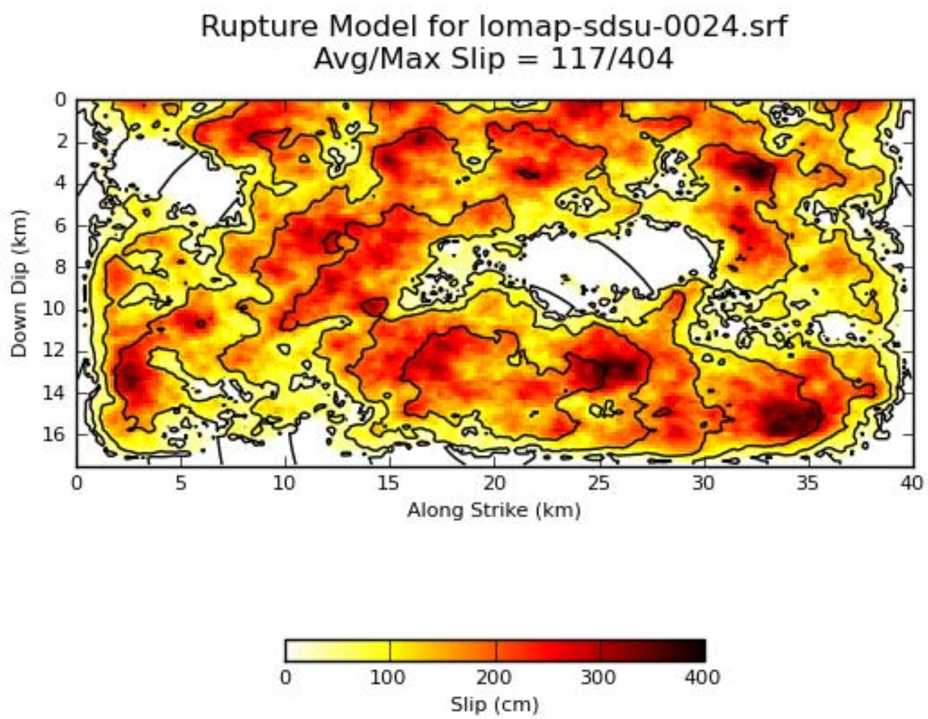

Rupture Model for lomap-sdsu-0021.srf
Avg/Max Slip = 119/413
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
100
200
300
400
Slip (cm)

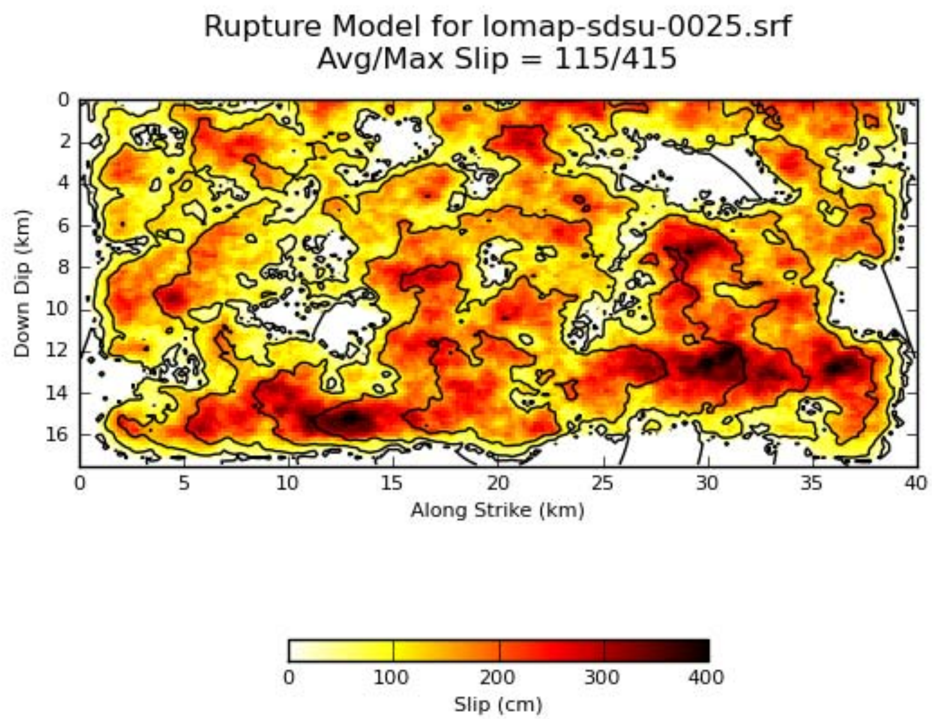
Rupture Model for lomap-sdsu-0022.srf
Avg/Max Slip = 118/462



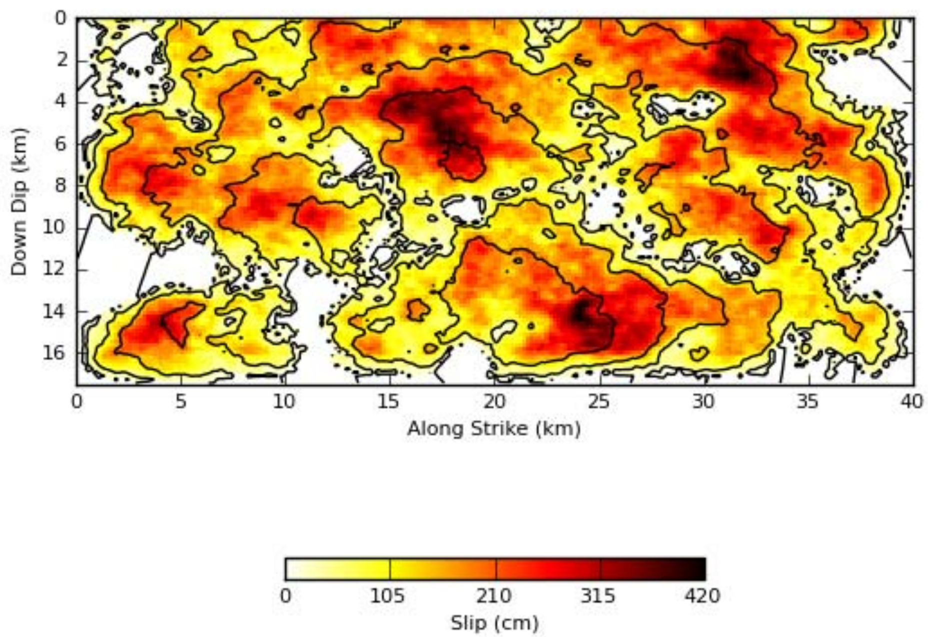
Rupture Model for lomap-sdsu-0023.srf
Avg/Max Slip = 117/434

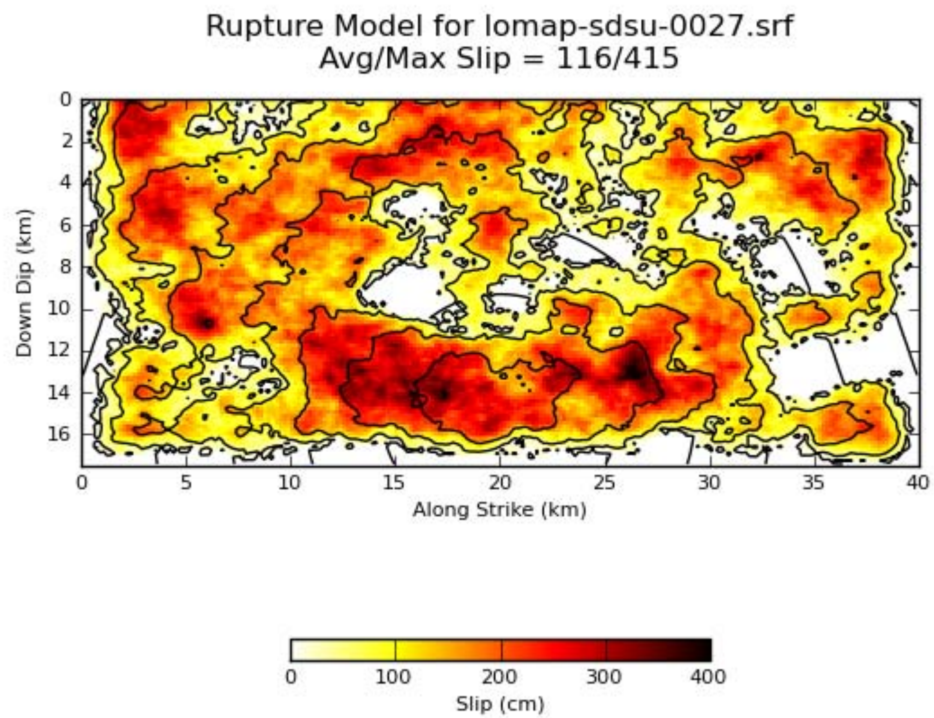


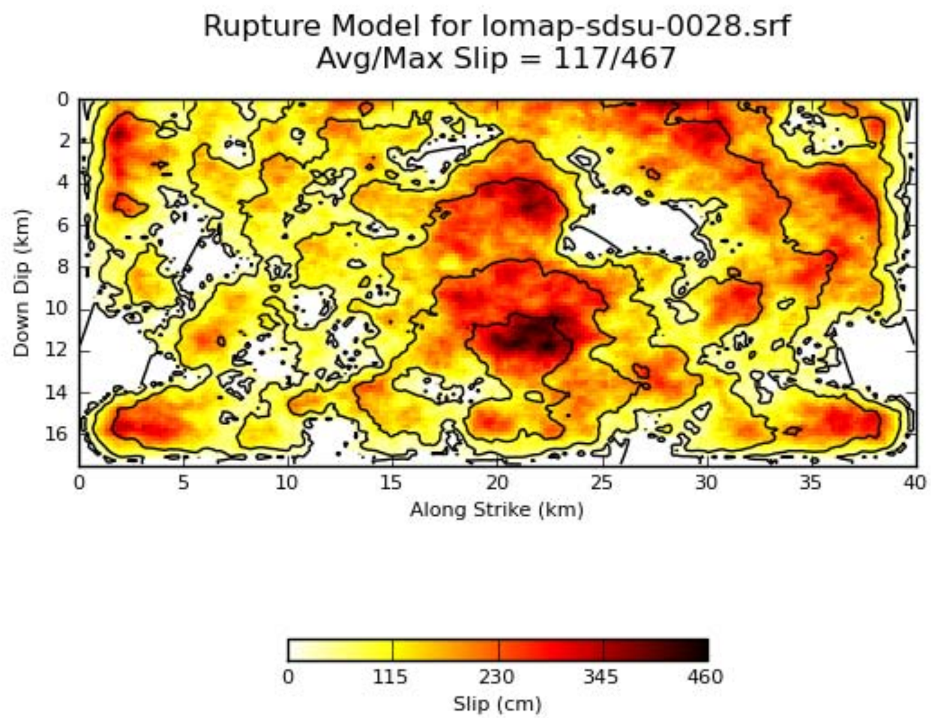

Rupture Model for lomap-sdsu-0024.srf
Avg/Max Slip = 117/404
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
100
200
300
400
Slip (cm)


Rupture Model for lomap-sdsu-0025.srf
Avg/Max Slip = 115/415
Down Dip (km)
Along Strike (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
0
100
200
300
400
Slip (cm)

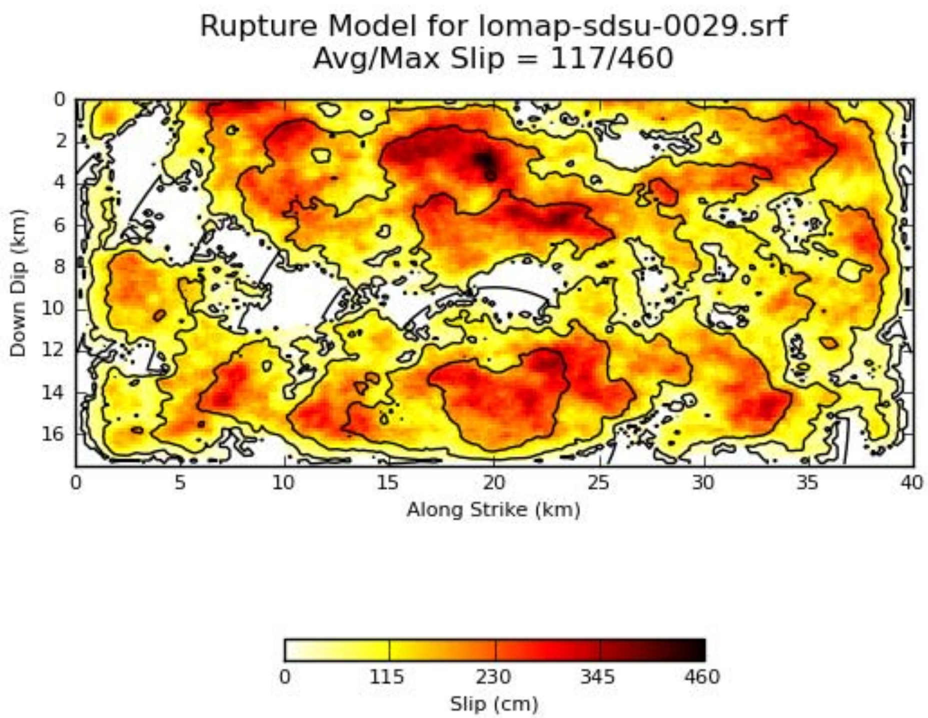
Rupture Model for lomap-sdsu-0026.srf
Avg/Max Slip = 117/436

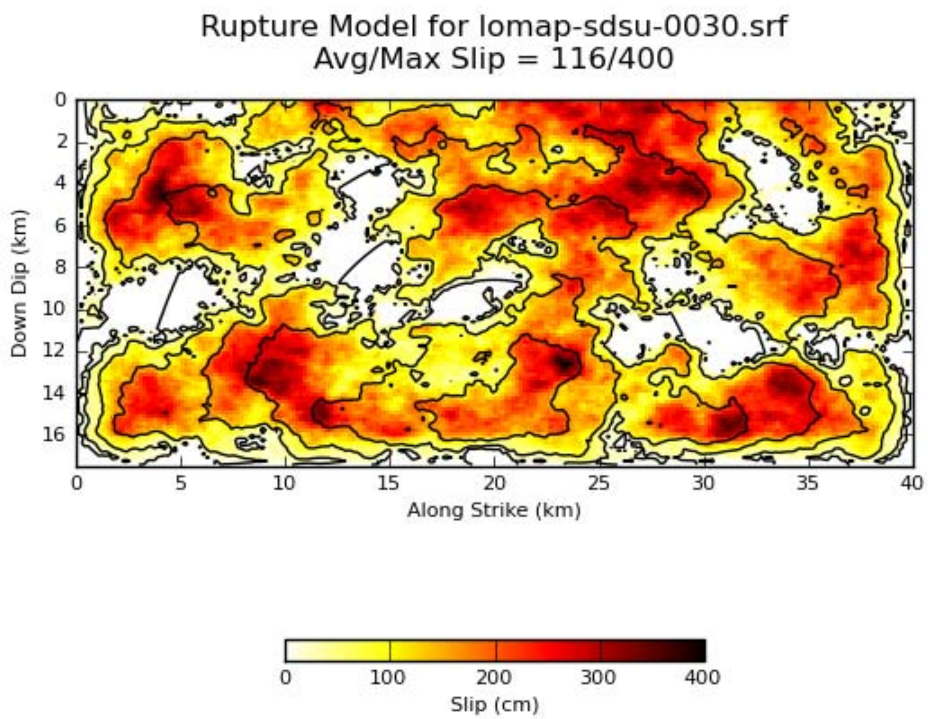



Rupture Model for lomap-sdsu-0027.srf
Avg/Max Slip = 116/415
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
100
200
300
400
Slip (cm)

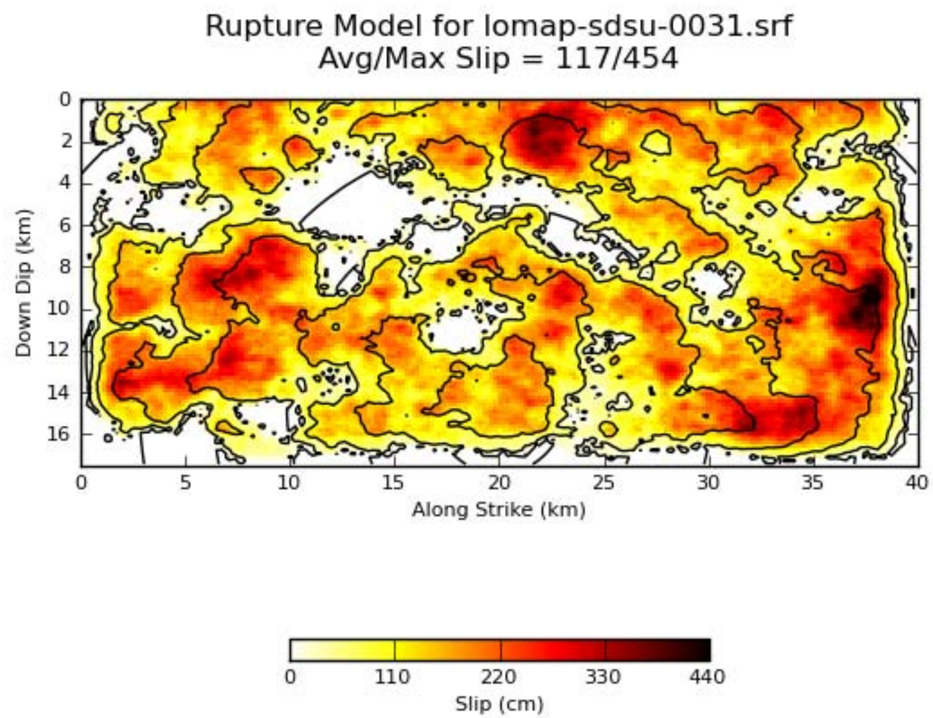


Rupture Model for lomap-sdsu-0028.srf
Avg/Max Slip = 117/467
Down Dip (km)
Along Strike (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
0
115
230
345
460
Slip (cm)

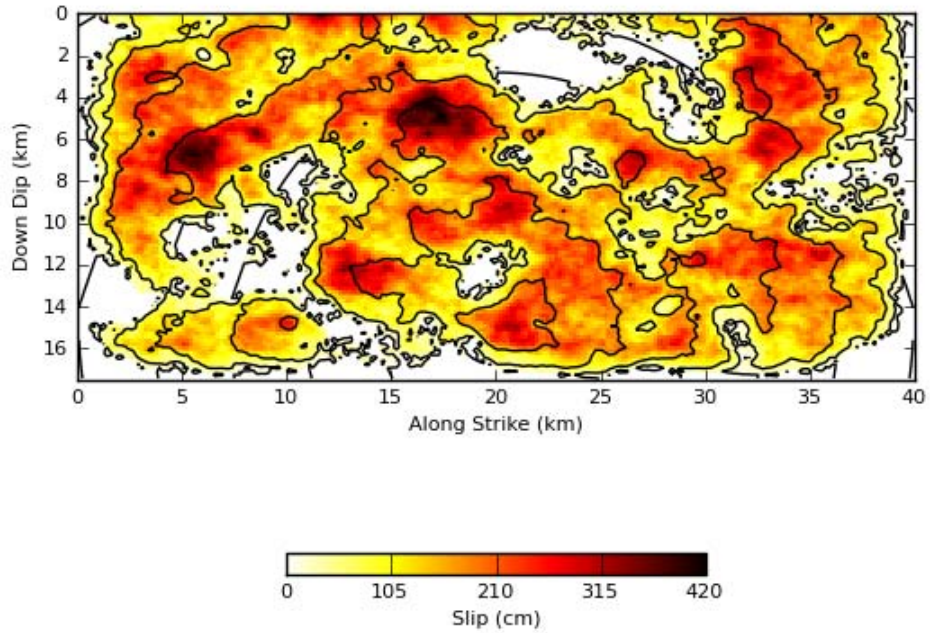

Rupture Model for lomap-sdsu-0029.srf
Avg/Max Slip = 117/460
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
115
230
345
460
Slip (cm)

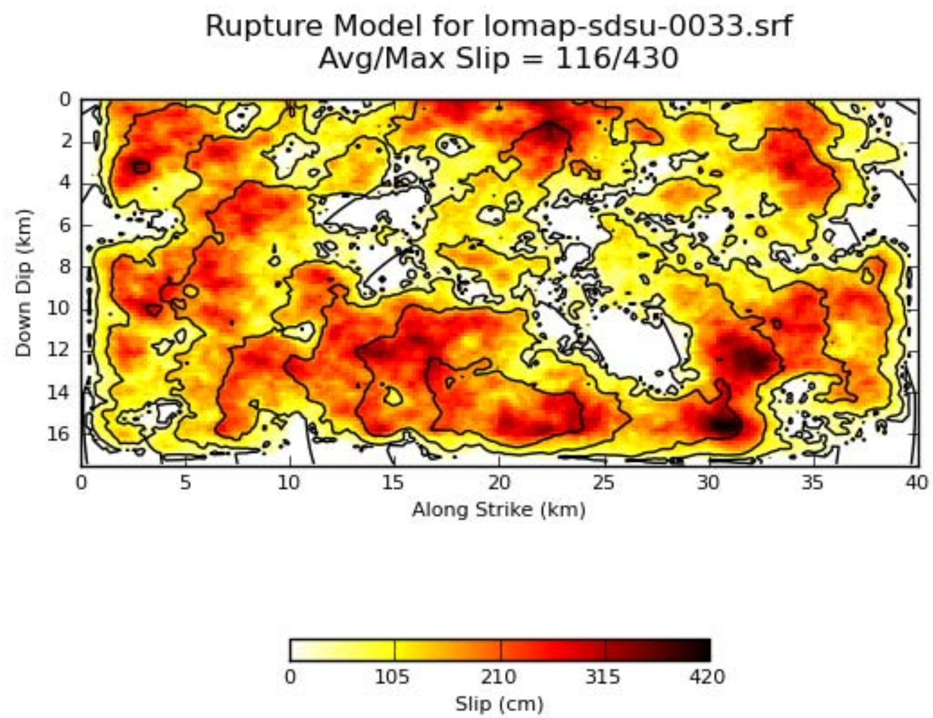


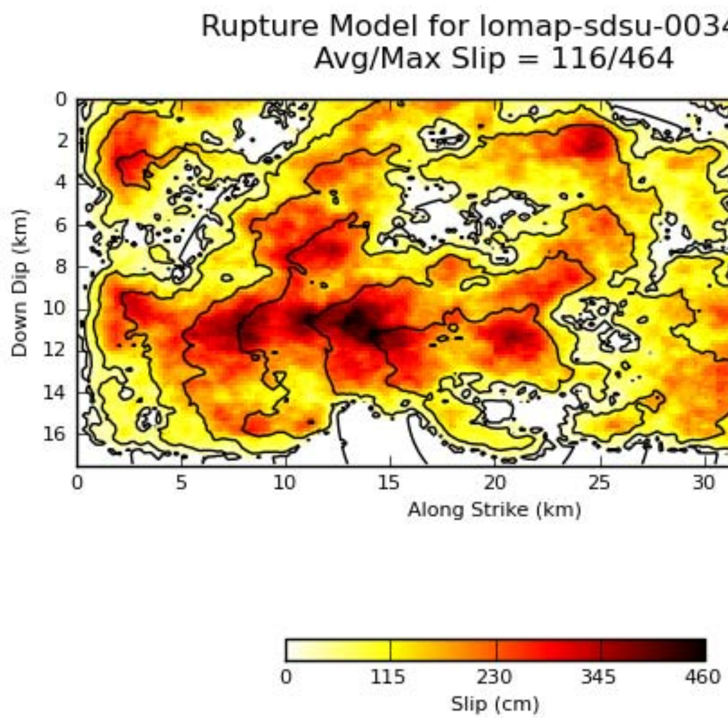
Rupture Model for lomap-sdsu-0030.srf
Avg/Max Slip = 116/400
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
100
200
300
400
Slip (cm)


Rupture Model for lomap-sdsu-0031.srf
Avg/Max Slip = 117/454
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
110
220
330
440
Slip (cm)

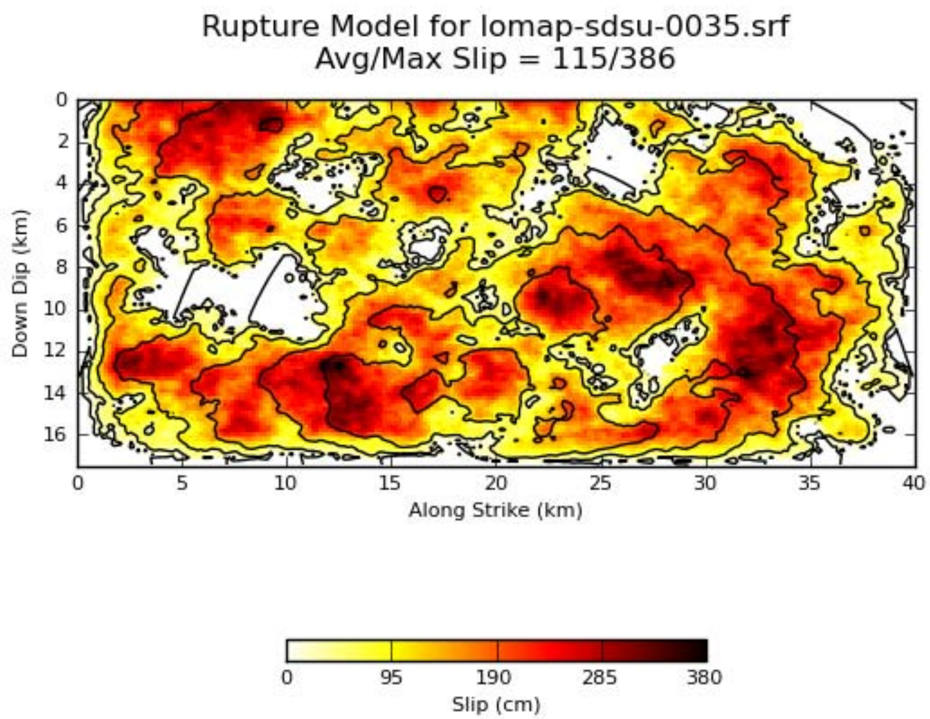
## Rupture Model for lomap-sdsu-0032.srf
## Avg/Max Slip = 117/427



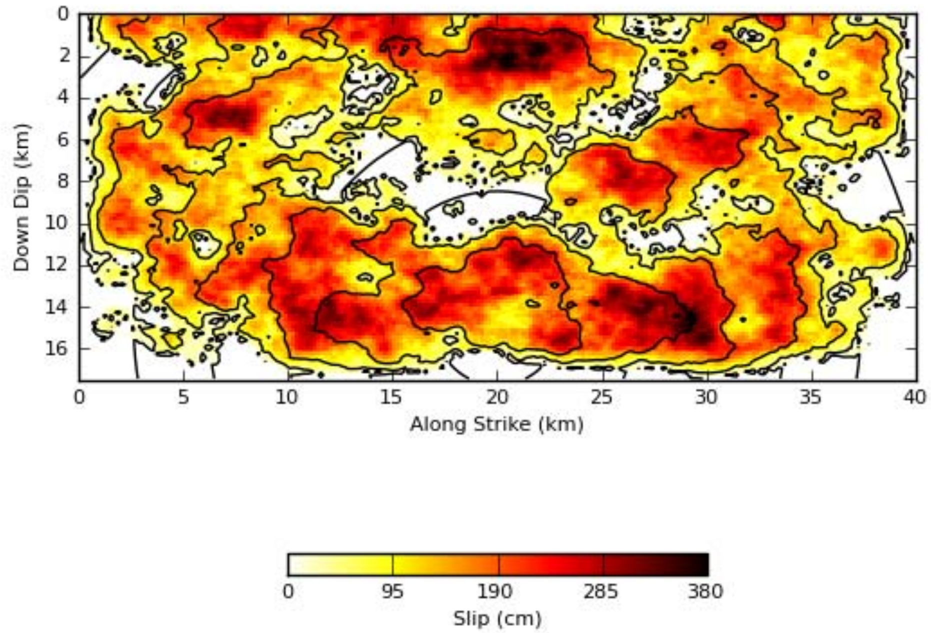

Rupture Model for lomap-sdsu-0033.srf
Avg/Max Slip = 116/430
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
105
210
315
420
Slip (cm)



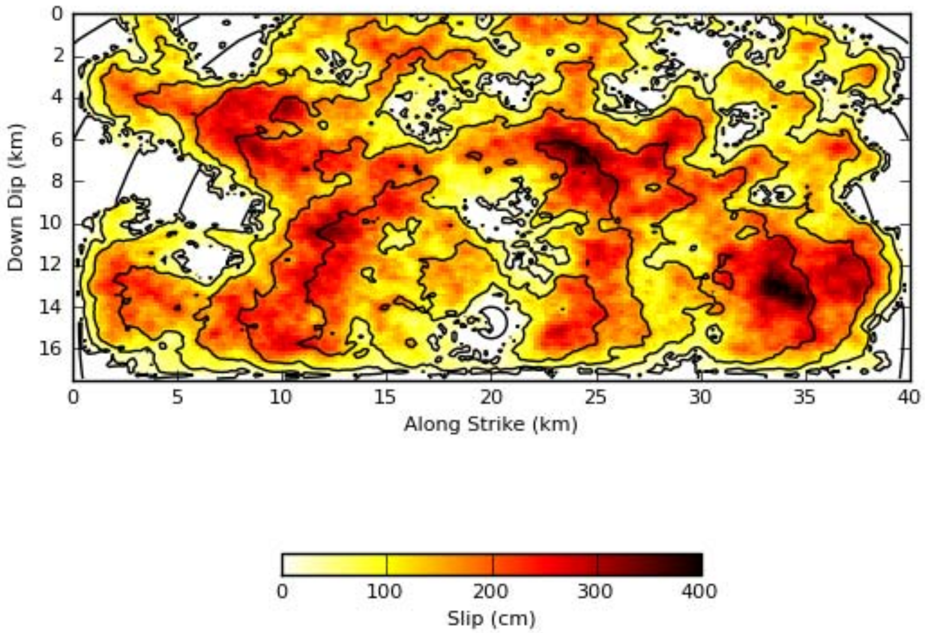
Rupture Model for lomap-sdsu-0034.srf
Avg/Max Slip = 116/464
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
115
230
345
460
Slip (cm)

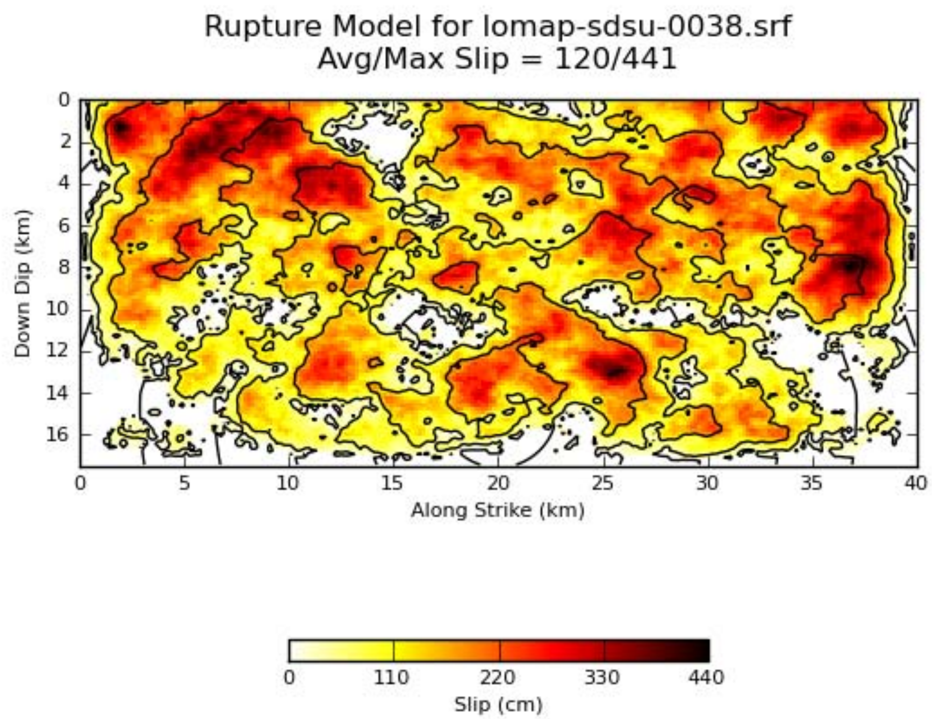

Rupture Model for lomap-sdsu-0035.srf
Avg/Max Slip = 115/386
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
95
190
285
380
Slip (cm)

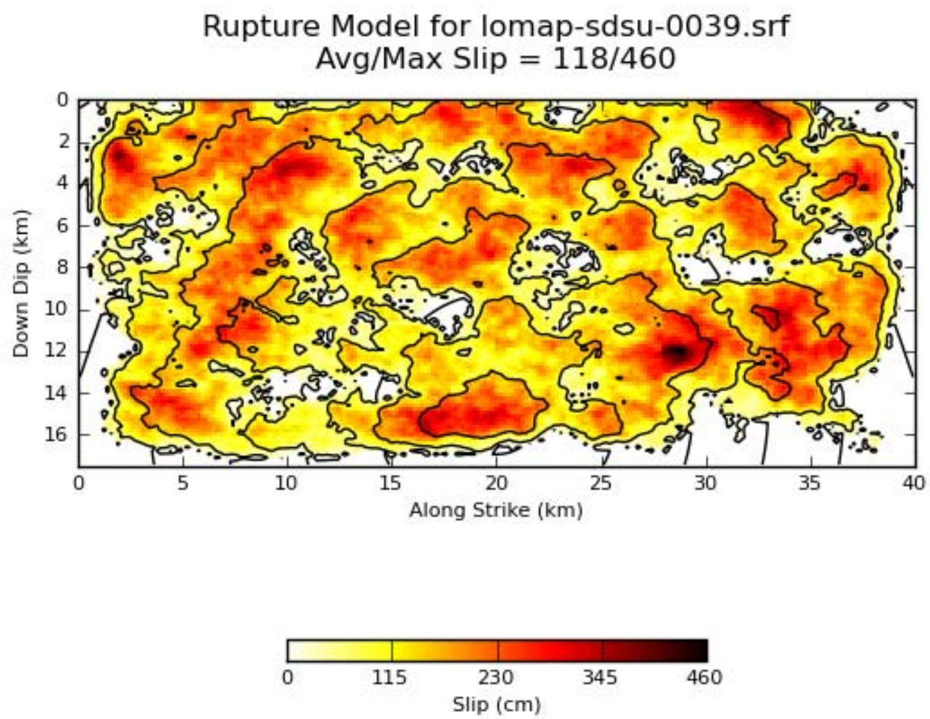
Rupture Model for lomap-sdsu-0036.srf
Avg/Max Slip = 117/398

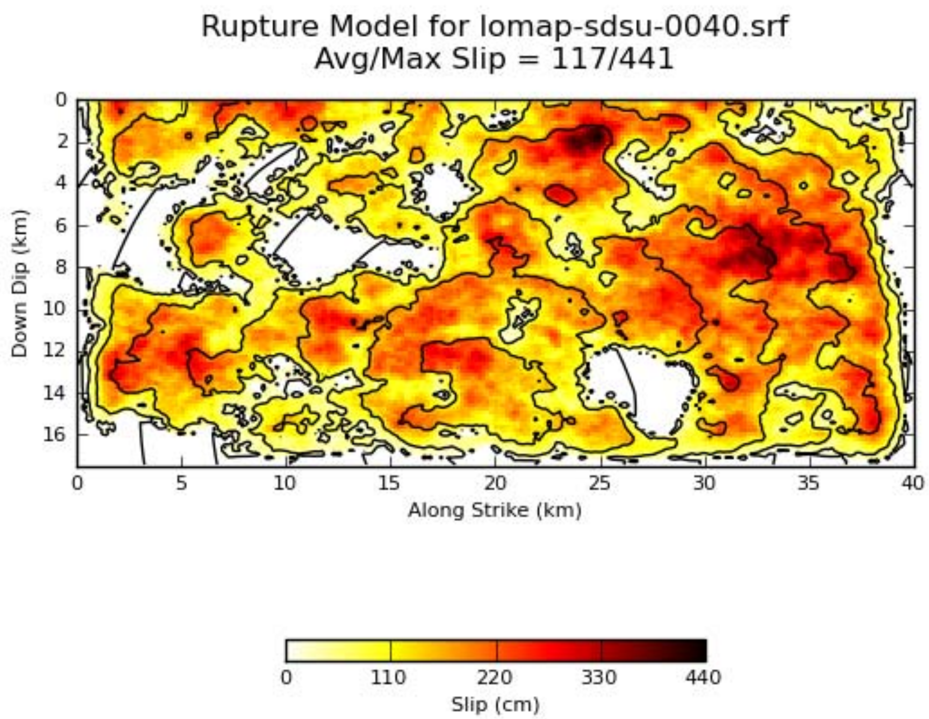


Rupture Model for lomap-sdsu-0037.srf
Avg/Max Slip = 114/419

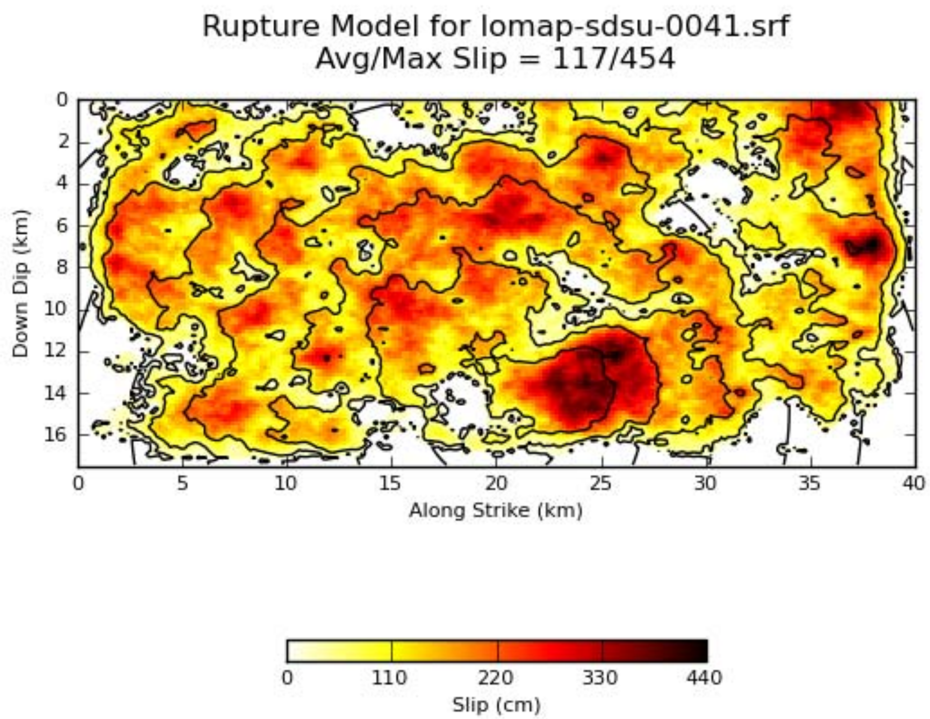


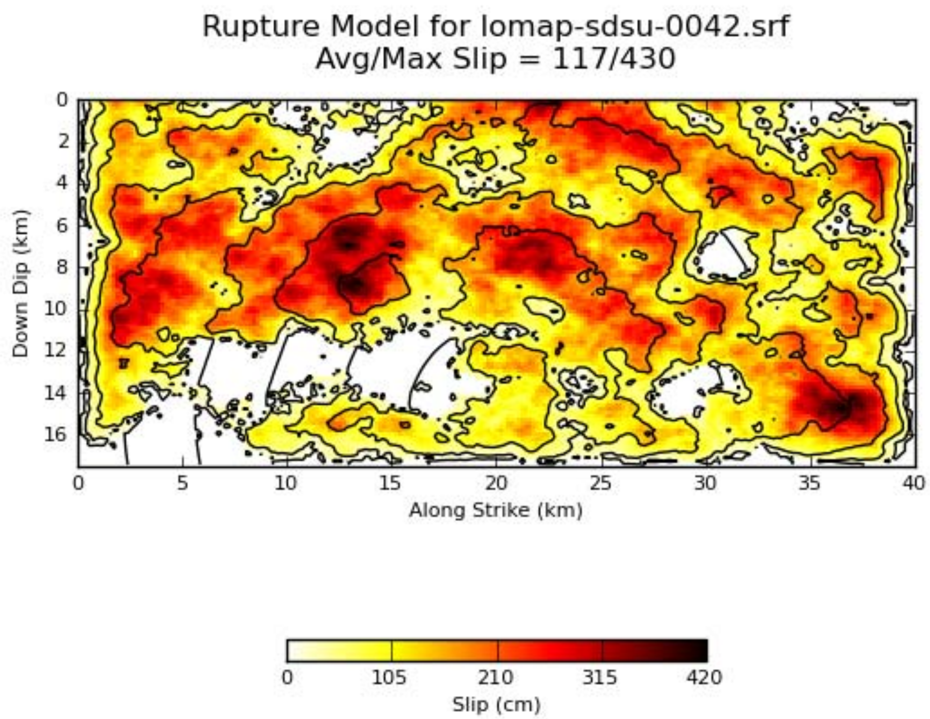

Rupture Model for lomap-sdsu-0038.srf
Avg/Max Slip = 120/441
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
110
220
330
440
Slip (cm)

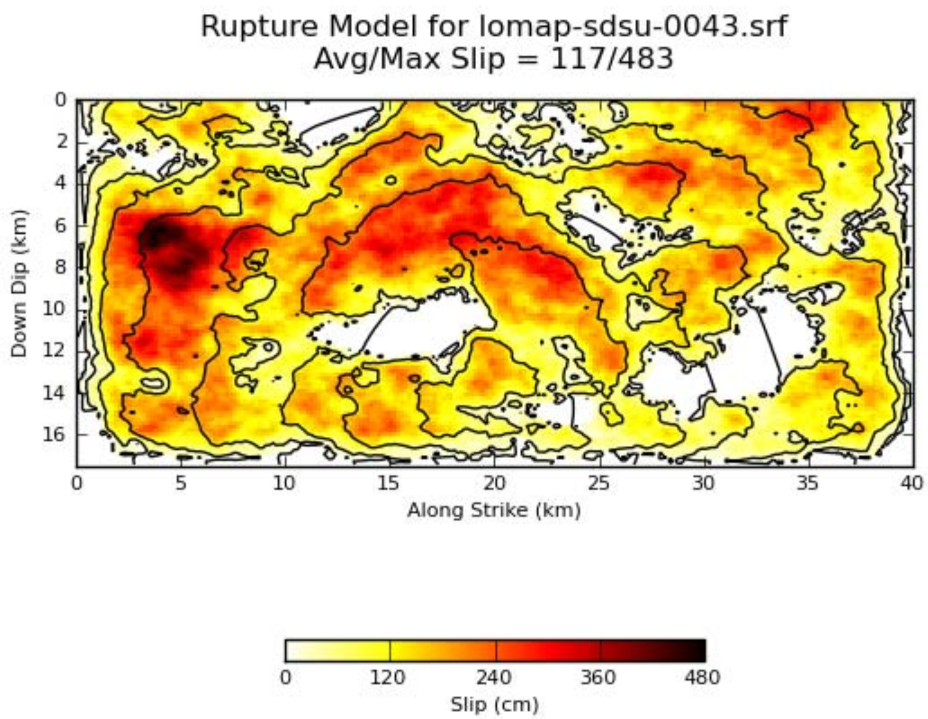

Rupture Model for lomap-sdsu-0039.srf
Avg/Max Slip = 118/460
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
115
230
345
460
Slip (cm)



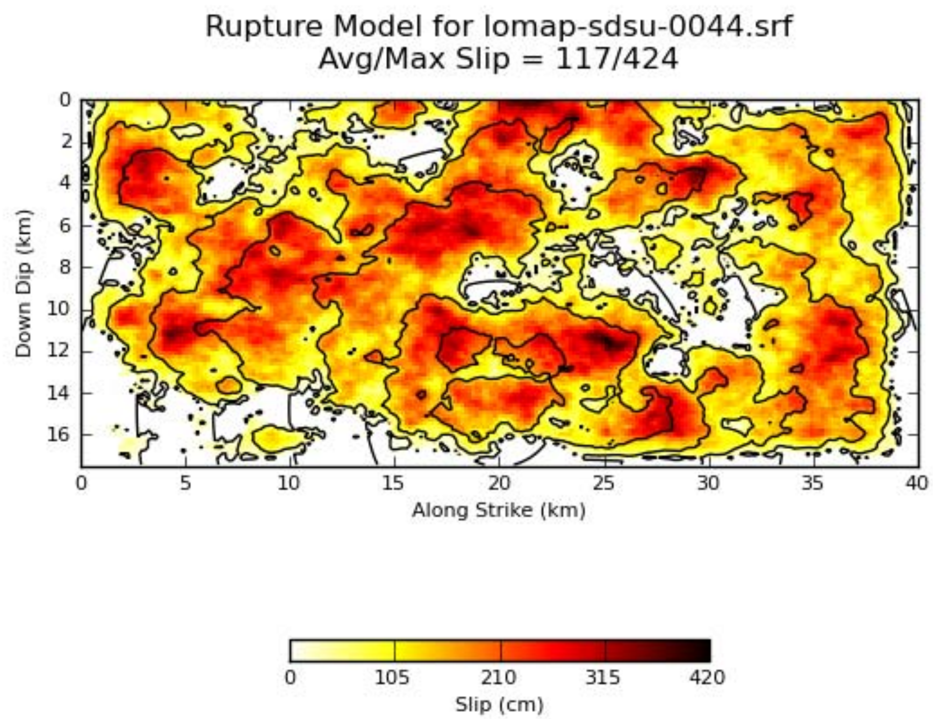
Rupture Model for lomap-sdsu-0040.srf
Avg/Max Slip = 117/441
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
110
220
330
440
Slip (cm)

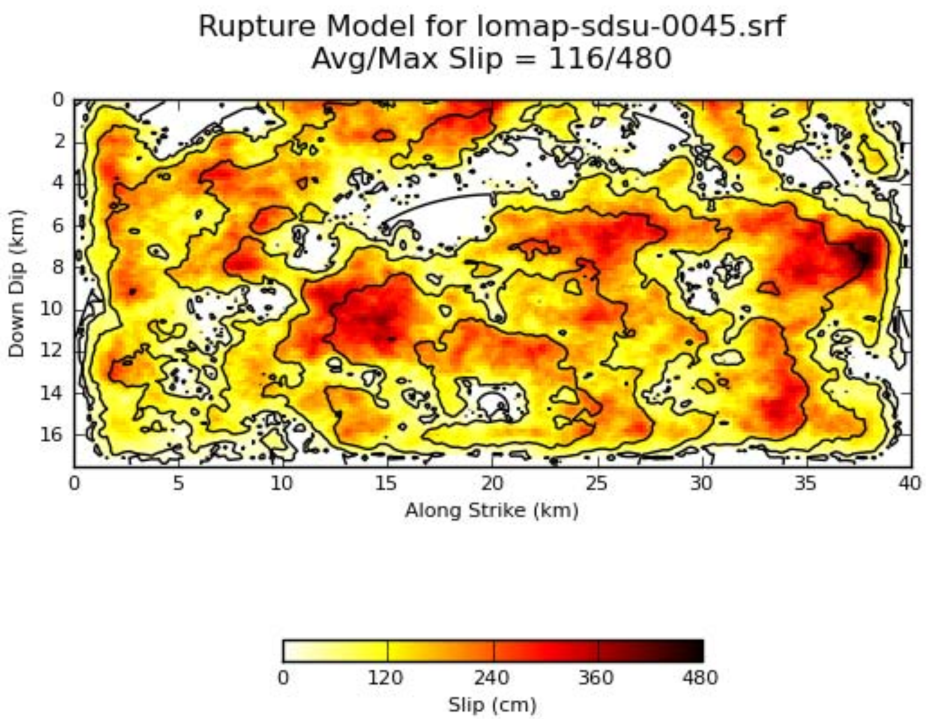

Rupture Model for lomap-sdsu-0041.srf
Avg/Max Slip = 117/454
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
Slip (cm)
0
110
220
330
440


Rupture Model for lomap-sdsu-0042.srf
Avg/Max Slip = 117/430
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
105
210
315
420
Slip (cm)



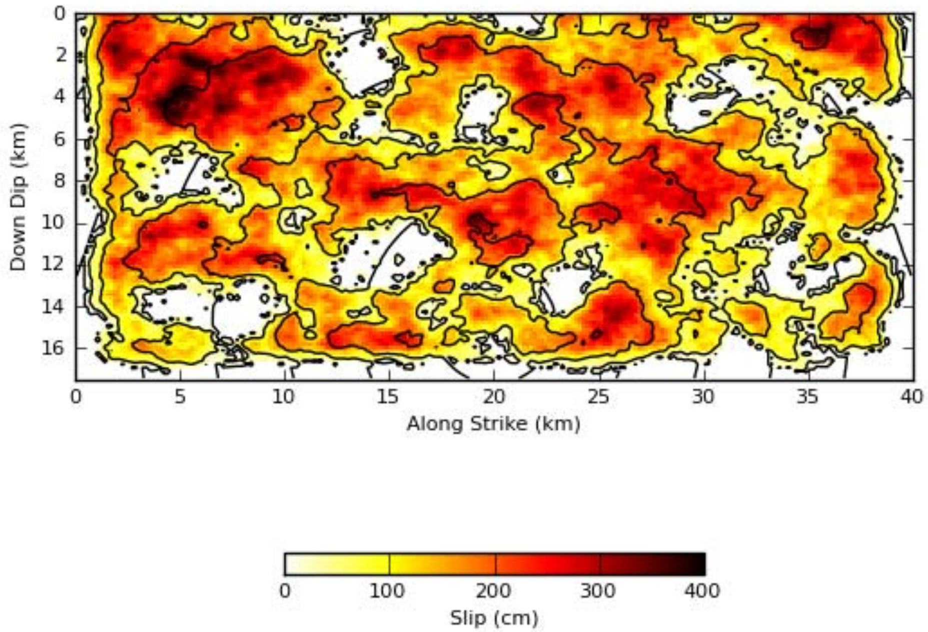
Rupture Model for lomap-sdsu-0043.srf
Avg/Max Slip = 117/483
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
120
240
360
480
Slip (cm)

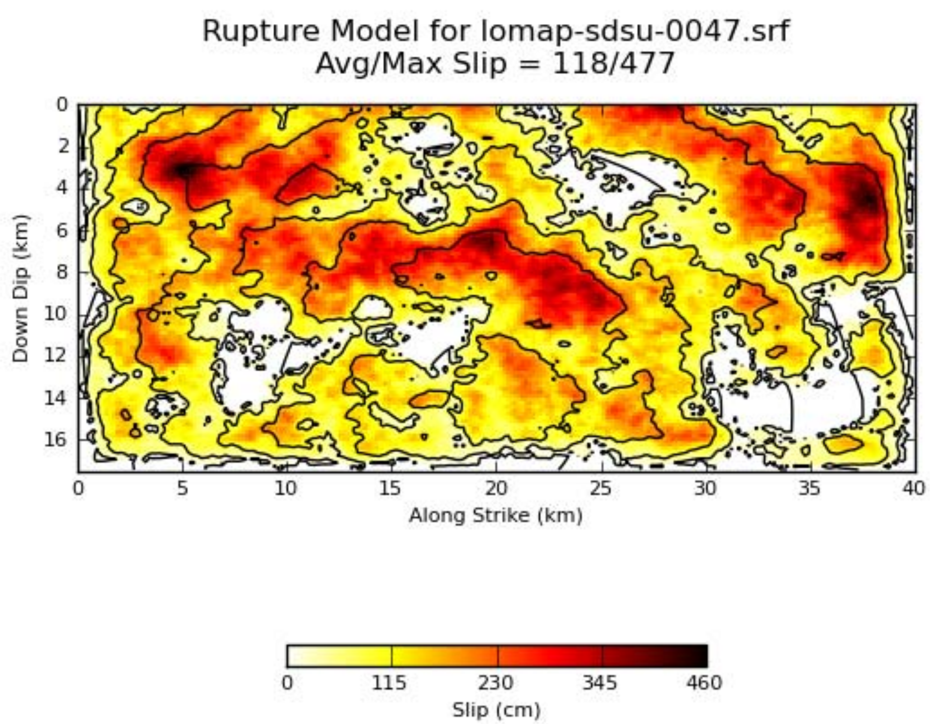

Rupture Model for lomap-sdsu-0044.srf
Avg/Max Slip = 117/424
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
105
210
315
420
Slip (cm)

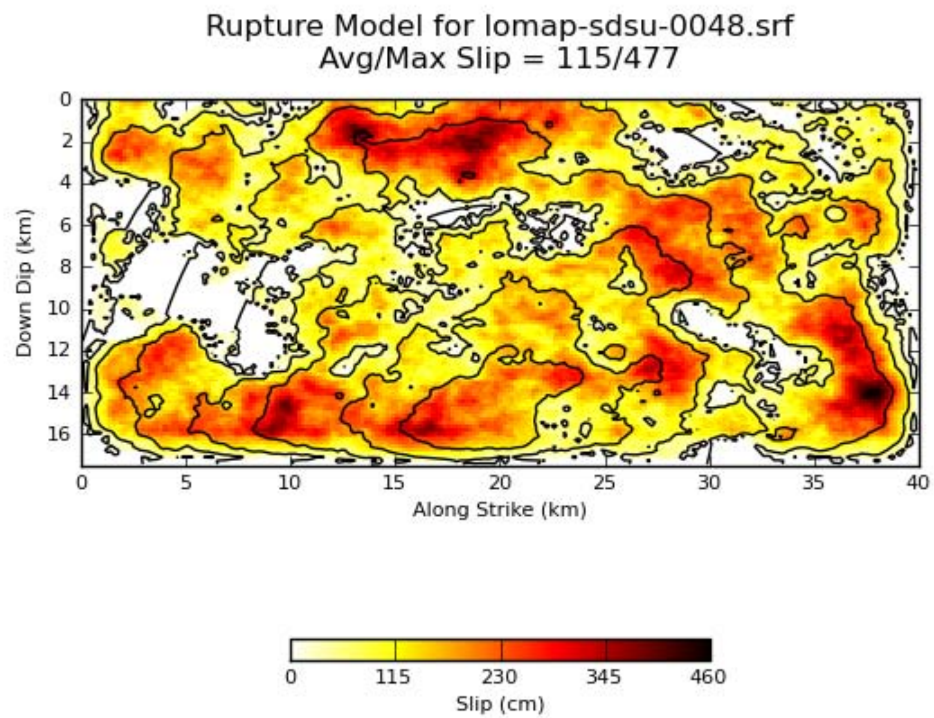


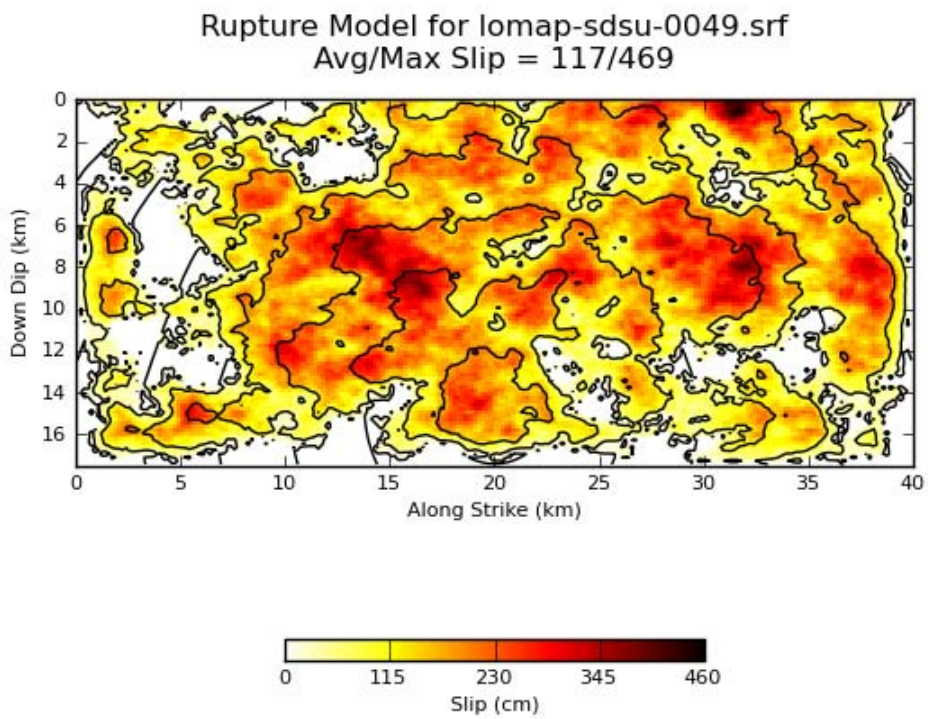
Rupture Model for lomap-sdsu-0045.srf
Avg/Max Slip = 116/480
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
120
240
360
480
Slip (cm)

Rupture Model for lomap-sdsu-0046.srf
Avg/Max Slip = 118/404




Rupture Model for lomap-sdsu-0047.srf
Avg/Max Slip = 118/477
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
115
230
345
460
Slip (cm)


Rupture Model for lomap-sdsu-0048.srf
Avg/Max Slip = 115/477
Down Dip (km)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
35
40
Along Strike (km)
0
115
230
345
460
Slip (cm)


Rupture Model for lomap-sdsu-0049.srf
Avg/Max Slip = 117/469
Down Dip (km)
0
2
4
6
8
10
12
14
16
Along Strike (km)
0
5
10
15
20
25
30
35
40
0
115
230
345
460
Slip (cm)

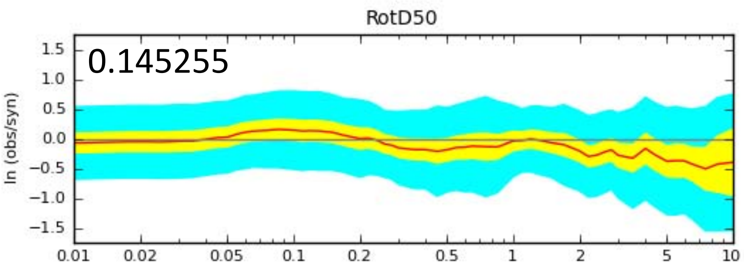
# Ensembles of Source Realizations

- Introduces uncertainty in estimates
- Median of realizations comparable to data
- Vary rupture history (slip, rupture speed, …)

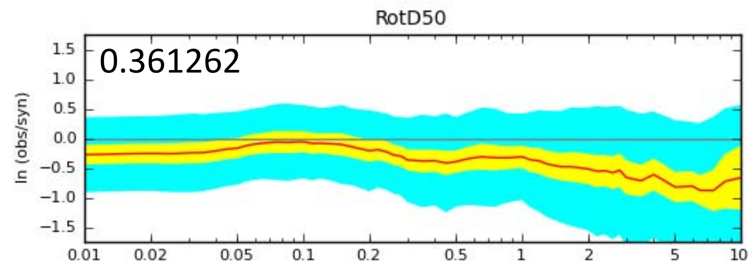
# Landers

| Simulation | Average Bias |
|---|---|
| 10000040 | 0.145255 |
| 10000020 | 0.184751 |
| 10000043 | 0.194791 |
| 10000008 | 0.200322 |
| 10000016 | 0.205302 |
| 10000048 | 0.205685 |
| 10000013 | 0.206232 |
| 10000002 | 0.210312 |
| 10000012 | 0.213936 |
| 10000034 | 0.214638 |
| 10000031 | 0.216000 |
| 10000019 | 0.217733 |
| 10000018 | 0.218331 |
| 10000049 | 0.219801 |
| 10000014 | 0.220046 |
| 10000047 | 0.220104 |
| 10000004 | 0.222954 |
| 10000010 | 0.223977 |
| 10000011 | 0.227900 |
| 10000033 | 0.228365 |
| 10000003 | 0.232264 |
| 10000017 | 0.233471 |
| 10000022 | 0.238922 |
| 10000023 | 0.239782 |
| 10000027 | 0.241769 |
| 10000009 | 0.251068 |
| 10000042 | 0.263262 |
| 10000044 | 0.263435 |
| 10000030 | 0.268027 |
| 10000036 | 0.269801 |
| 10000028 | 0.271416 |
| 10000021 | 0.273601 |
| 10000001 | 0.274374 |
| 10000041 | 0.278330 |
| 10000006 | 0.286065 |
| 10000024 | 0.290665 |
| 10000046 | 0.293202 |
| 10000045 | 0.294136 |
| 10000007 | 0.296948 |
| 10000037 | 0.298380 |
| 10000039 | 0.306187 |
| 10000025 | 0.307114 |
| 10000000 | 0.325274 |
| 10000038 | 0.327012 |
| 10000035 | 0.335134 |
| 10000029 | 0.354691 |
| 10000015 | 0.355555 |
| 10000005 | 0.356290 |
| 10000032 | 0.356825 |
| 10000026 | 0.361262 |

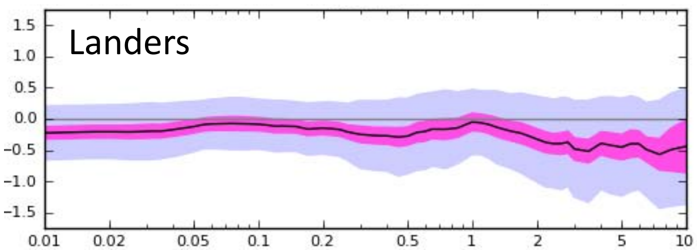
## Smallest |GOF| Landers

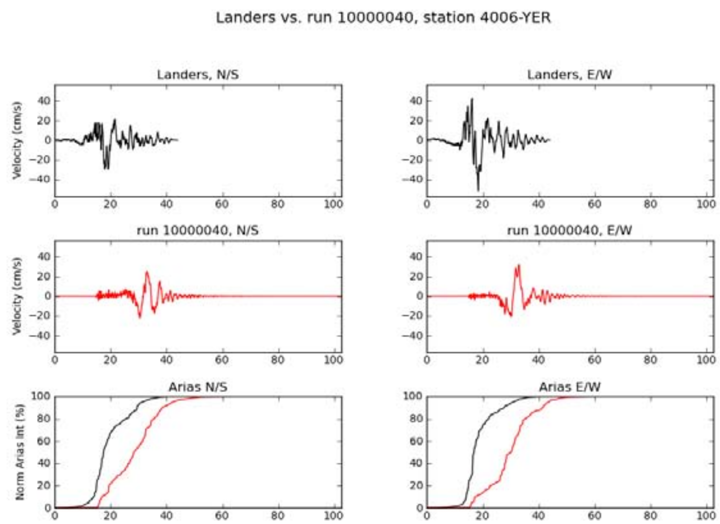


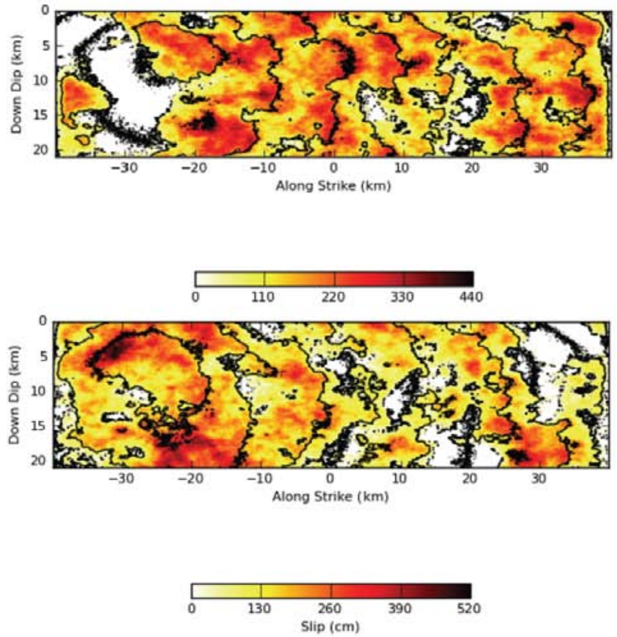

## Largest |GOF| Landers

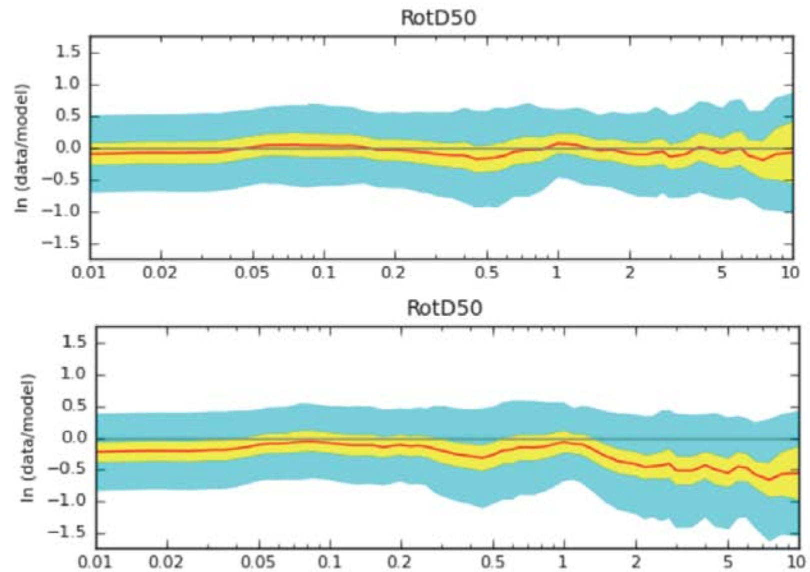


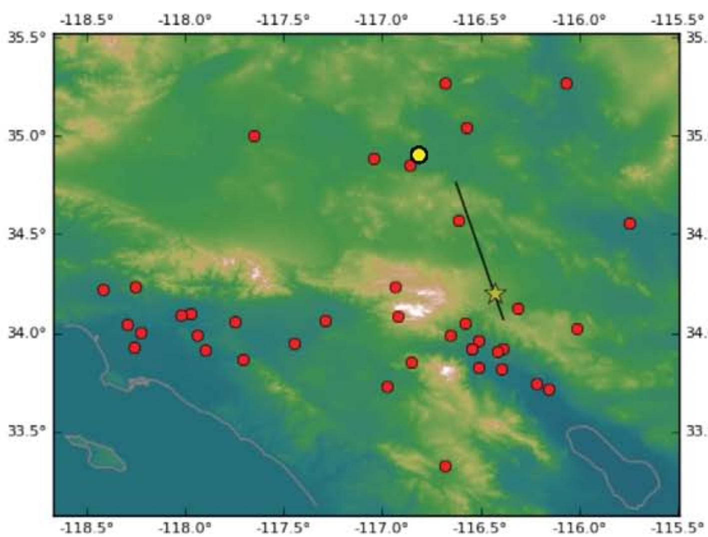

## Ensemble Average

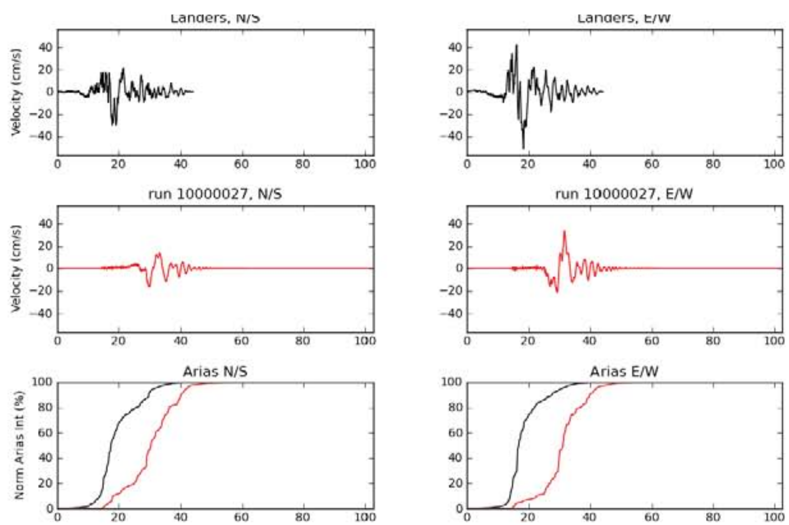


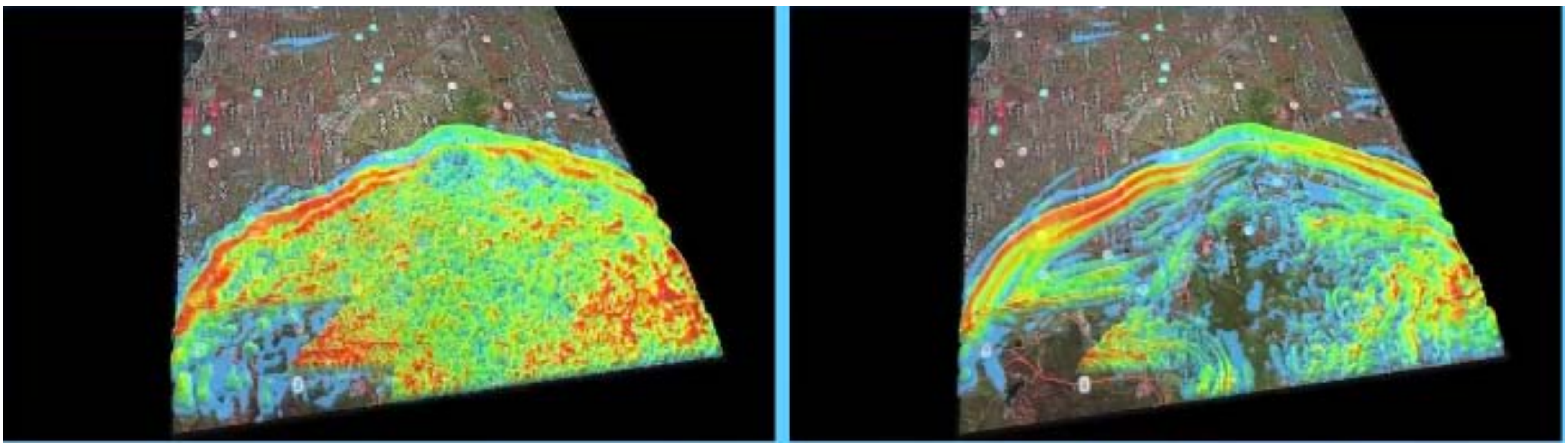

Down Dip (km)
Along Strike (km)
Slip (cm)


RotD50
ln (data/model)
RotD50
ln (data/model)



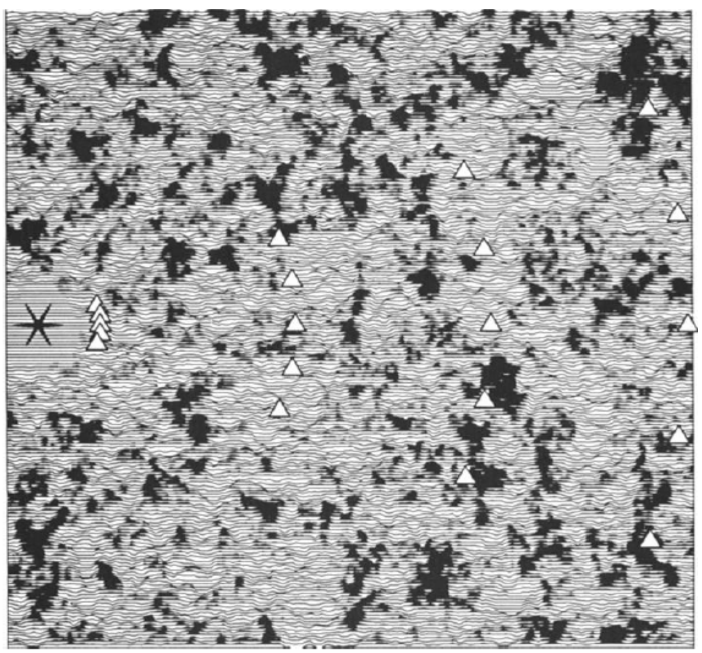

Landers, N/S
Landers, E/W
Velocity (cm/s)
run 10000027, N/S
run 10000027, E/W
Velocity (cm/s)
Arias N/S
Arias E/W
Norm Arias Int (%)

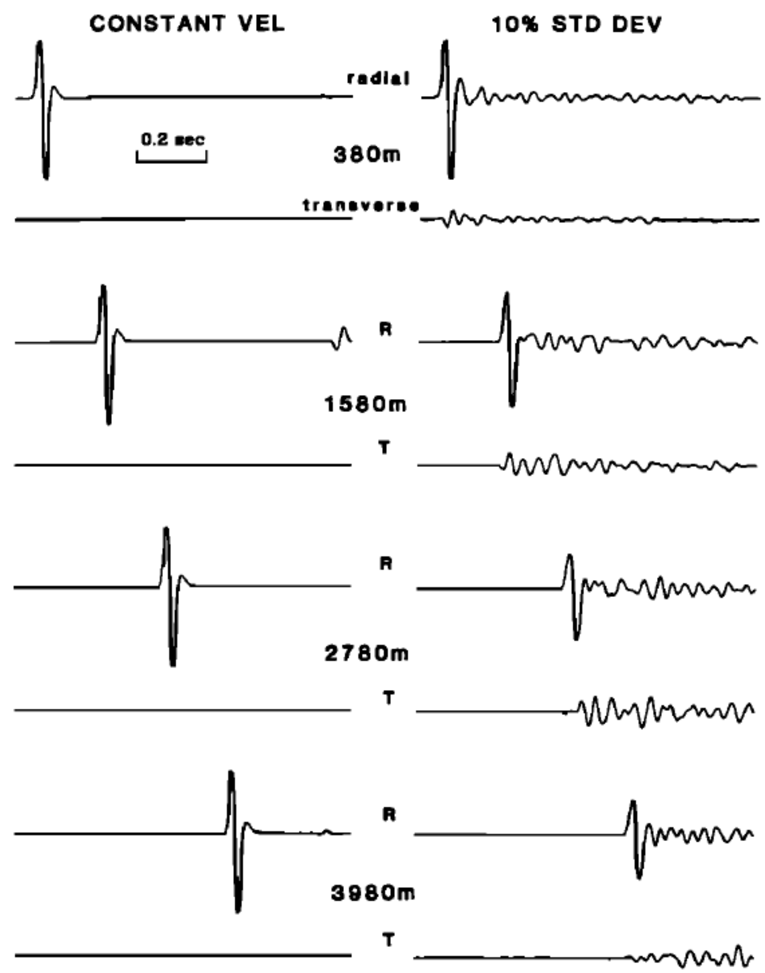
# Media Complexity



# Small-scale Media Heterogeneity

- Scattering in earth's crust is known to effect seismic ground motion





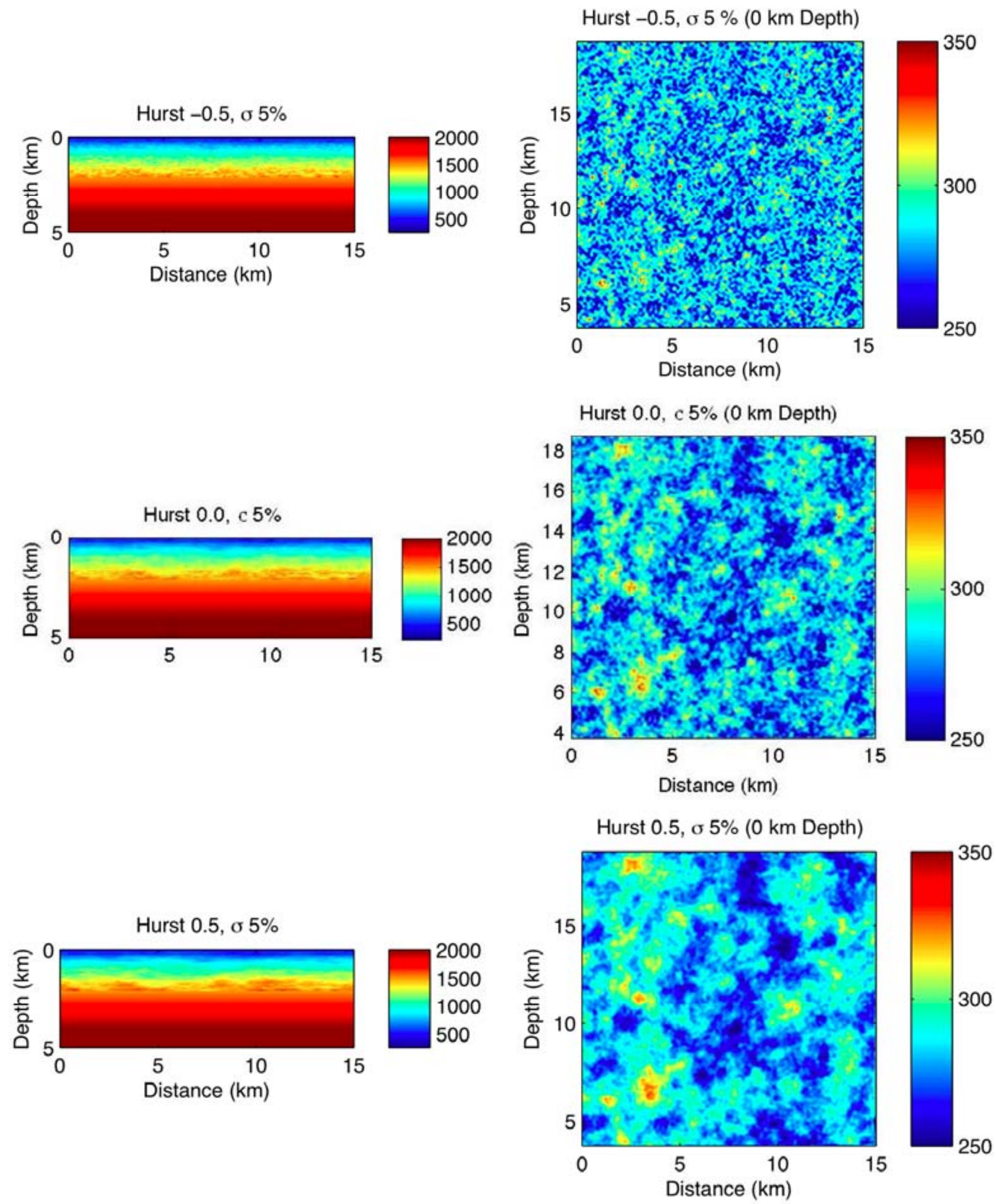

(Frankel and Clayton, 1986)

# Media Complexity

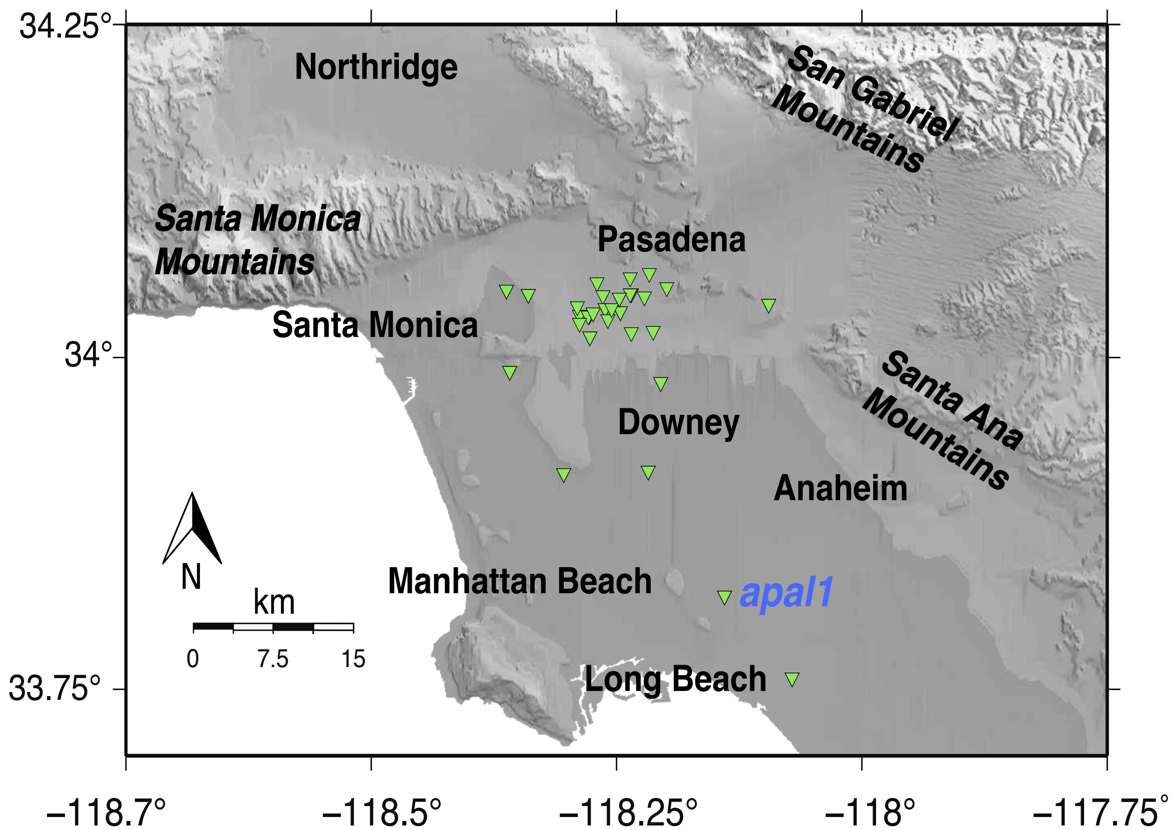
In 3D, a fractal distribution has a high wave-number decay of the power spectrum P(k) as:

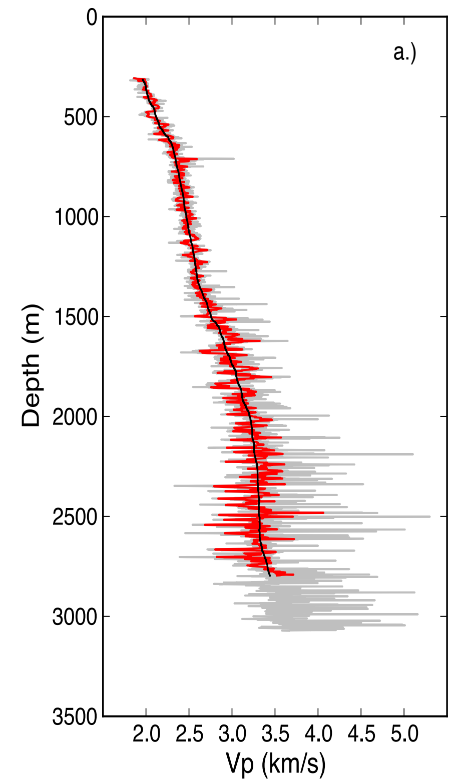
$$P(k) = P_0\left(1+\left(k/k_{corner}\right)^2\right)^{-(1.5+H)}$$

where $H$ is the Hurst number, $k_{corner}$ is a wave number below which the spectrum is approximately constant



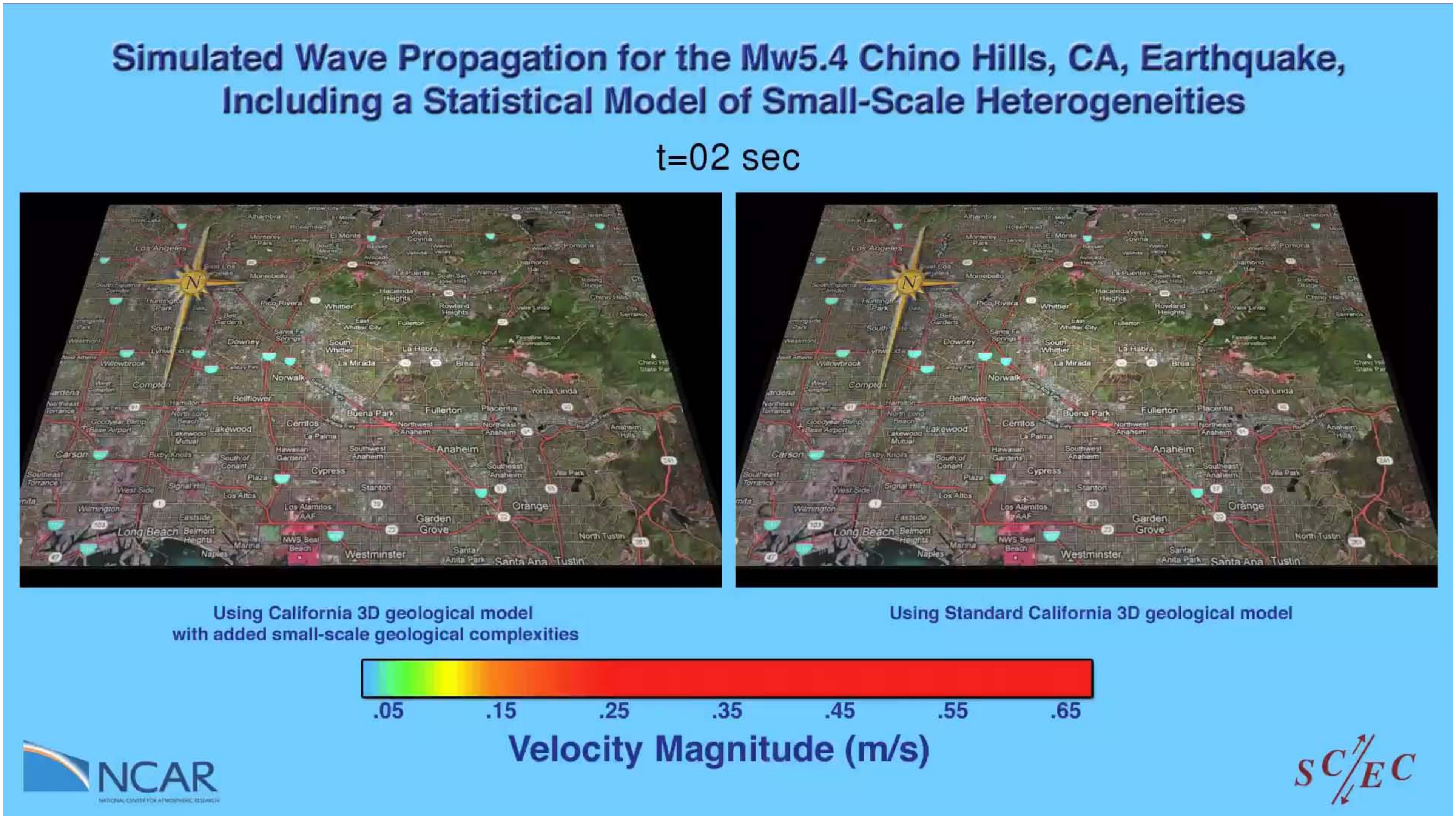
# Small-scale Heterogeneities, CVM, Q Tests




Analysis of
38 Sonic logs
from LA
basin

# Illustration of Scattering Effects



Visualization Of Deterministic High-Frequency Ground Motions From Simulations Of Dynamic Rupture Along Rough Faults With And Without Medium Heterogeneity Using Petascale Heterogeneous Supercomputers

# Scattering on BBP

- Deterministic calculation of small-scale scattering computationally expensive, hours on largest supercomputers
- Instead, we approximate high-frequency scattering by analytical expressions

# Multiple S-S Scattering

$$E(\vec{r}, t) = \frac{\delta(t - \frac{r}{v})e^{-\eta v t}}{4\pi v r^2} + \sum_{n=1}^{2} E_n(\vec{r}, t) + \left(\int_{-\infty}^{+\infty} \frac{e^{i\Omega}}{2\pi} d\Omega \right.$$
$$\left. \times \int_0^{\infty} \frac{(\frac{\eta_s}{k})^3 \times [\tan^{-1}(\frac{k}{\eta + i\Omega/v})]^4 \times \sin(kr)}{2\pi^2 v r[1 - \frac{\eta_s}{k}\tan^{-1}(\frac{k}{\eta + i\Omega/v})]} dk \right), \quad (1)$$

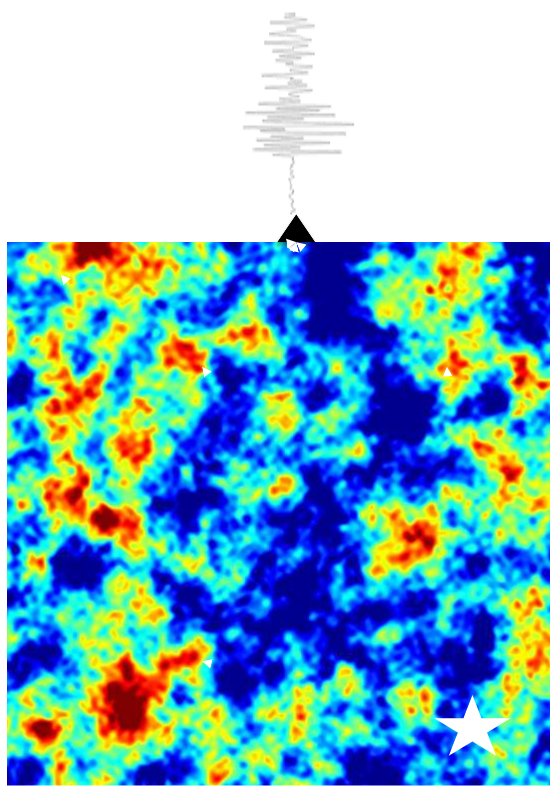
Zeng et al., 1991, 1993

# Scattering/attenuation Parameters

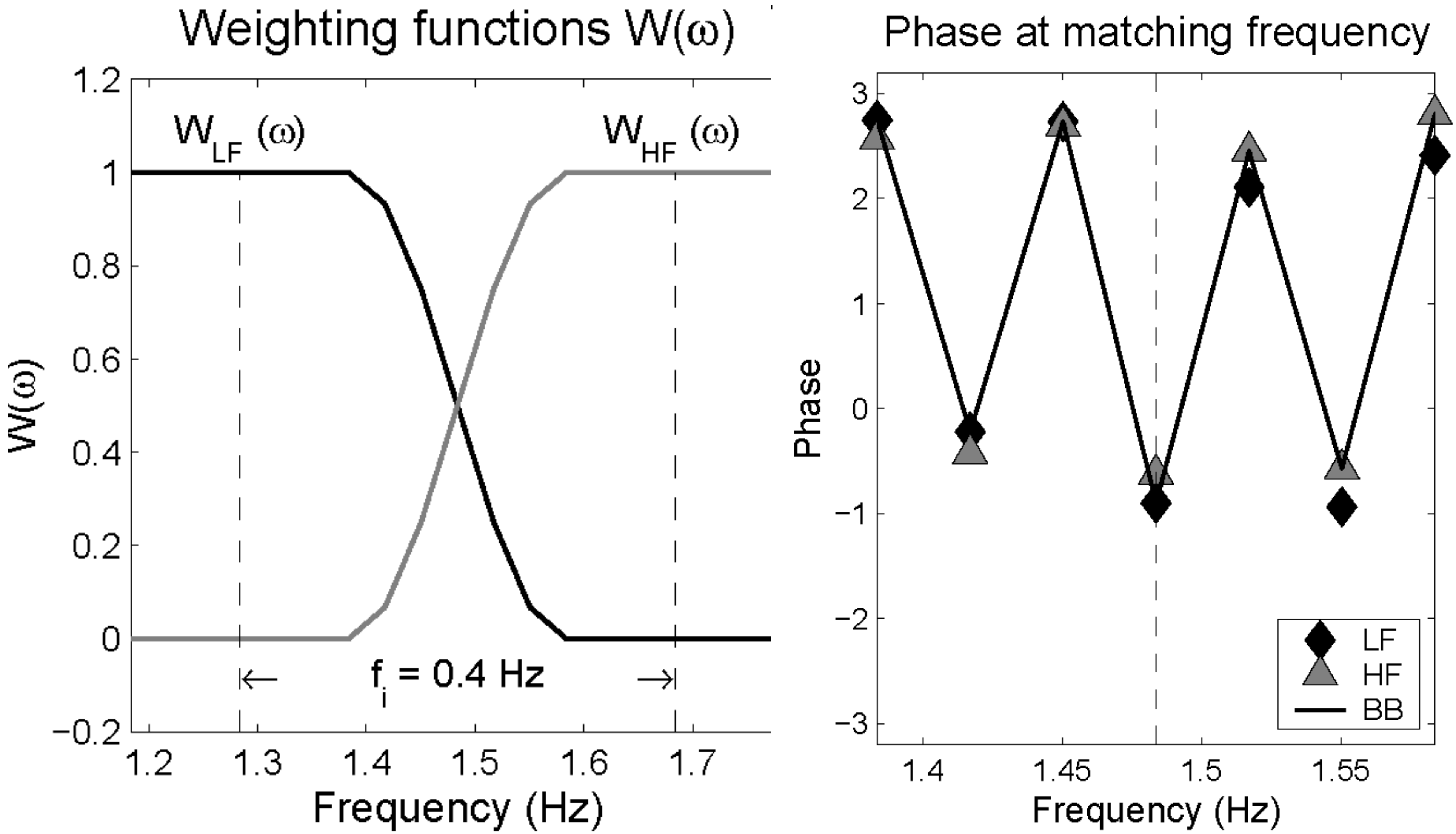
- $\eta=\eta_s+\eta_i$
- $L_e=1/(\eta_s+\eta_i)$ extinction distance (primary S-wave energy decreased to 1/e)
- $1/Q_s=\eta_s/k$
- $1/Q_i=\eta_i/k$

# BBtoolbox V1.5

- Hybrid broadband seismograms are calculated from low-frequency deterministic synthetics and high-frequency scatterograms



Assumes that the high-frequency component of recorded seismic signals can be modeled as the scattering contribution from random media



Weighting functions W(ω)
W_LF (ω)
W_HF (ω)
W(ω)
f_i = 0.4 Hz
Frequency (Hz)
Phase at matching frequency
Phase
LF
HF
BB
Frequency (Hz)

# BBtoolbox

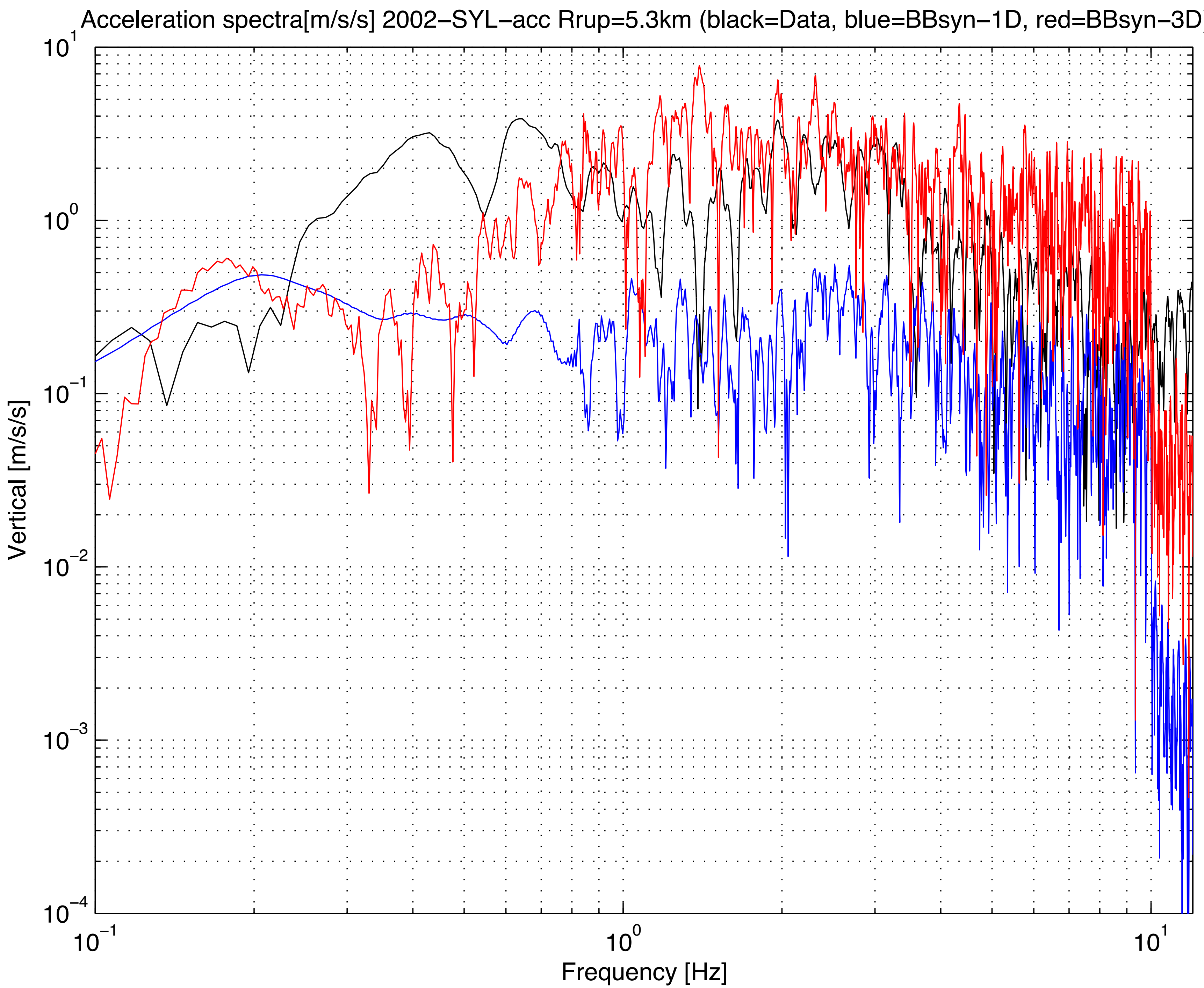
Mai, P.M., W. Imperatori and K.B. Olsen (2010). Hybrid broadband ground-motion simulations: combining long-period deterministic synthetics with high-frequency multiple S-to-S backscattering, Bull. Seis. Soc. Am. 100, 5A, 2124-2142, doi: 10.1785/0120080194.

Mena, B., P.M. Mai, K.B. Olsen, M.D. Purvance, and J.N. Brune (2010). Hybrid broadband ground-motion simulation using scattering Green's functions: application to large-magnitude events, *Bull. Seis. Soc. Am.* **100**, 5A, 213-2122, doi: 10.1785/0120080318.

Olsen, K.B., and R. Takedatsu (2014). The SDSU Broadband Ground Motion Generation Module BBtoolbox Version 1.5, Seis. Res. Lett., revised.

# Mai et al. (2010) LF-HF Merging

- HFs scaled to LFs within a user-chosen (small) bandwidth (usually 1Hz)
- Rationale behind methods includes desire to minimize mismatch at merging frequency
- However, the accuracy of this technique depends critically on the LFs
- When 1D GFs are used, this method is not sufficiently accurate


Acceleration spectra[m/s/s] 2002−SYL−acc Rrup=5.3km (black=Data, blue=BBsyn−1D, red=BBsyn−3D)
Vertical [m/s/s]
Frequency [Hz]
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-1}$
$10^{0}$
$10^{1}$

# V1.5 Merging Technique

- 'Anchoring' the HFs to an estimate of the acceleration amplitude spectrum at 1Hz:
- $A_i(f) = C_{ij}\, S_i(f)\, G_{ij}(f)\, P(f)$, where
- $C_{ij}=F_s\, Rp_{ij}/[4\pi\rho_i\beta_i^3]$ (radiation scale factor)
- $S_i=m_i(M_o/N](2\pi f)^2[1+F(f/f_{ci})^2]^{-1}$ (source radiation term)

- $m_i=d_i\mu_i A_T/M_o$ (average subfault moment)
- $F=M_o/[N\ strfac\ dl^3]$ (subfault scaling factor)
- $F_{ci}=c_o V_{Ri}/[\alpha_T\pi dl]$ (subfault corner frequency)
- $G_{ij}(f)=I_i(f)*\exp(-\pi\, f^{1-fdec}\, \Sigma t_{ijk}/q_k)*/r_{ij}$ (path term)
- $q_k=afac+bfac*V_s$
- $P(f)=\exp(-\pi\kappa f)$

Modified from Graves and Pitarka (2010)

# Region-specific (Input) Parameters

- a + b * $V_s$ (scaling of HF only)
- $Q_o f^n$
- kappa
- strfac

- From srf file: $M_w$, nsub, subfault areas, strike, dip, hypocenter location

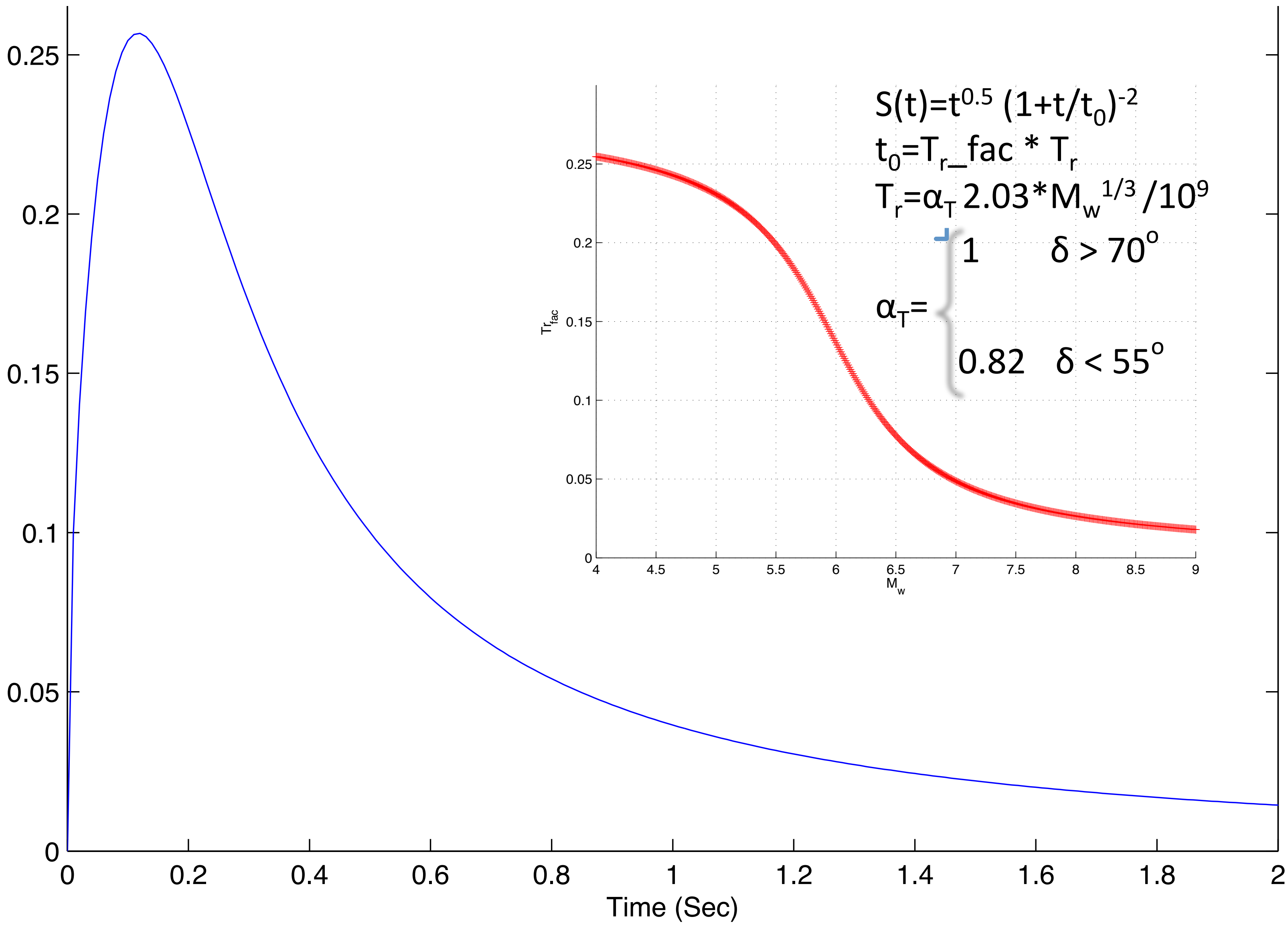
# Fixed Parameters

- Scattering Coefficient (uniform 0.005 – 0.05)
- Absorption Coefficient (0.03)
- Number of Scattering Wavelets (1500)
- Number of Points in Coda Envelope (500)
- Seed Number (3000)

# Scenario-specific (calculated) Parameters

- Tr_fac (determines rise time, calculated from moment)

# HF Source-time Function Scaling

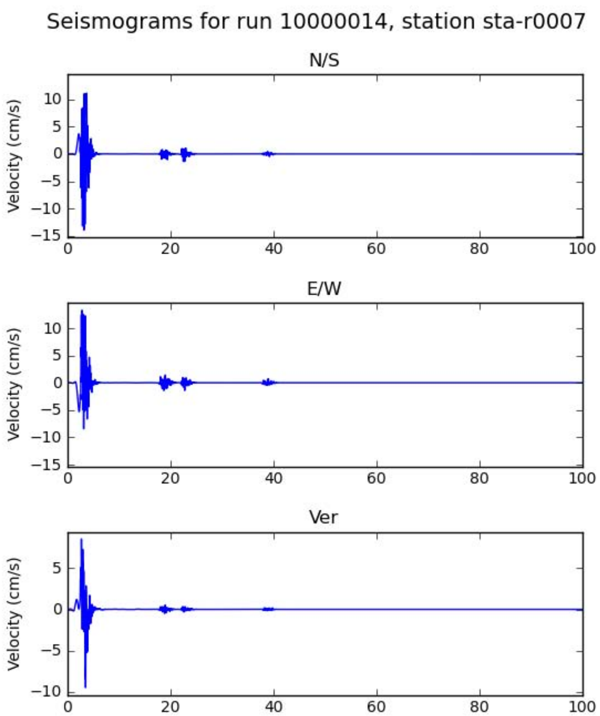


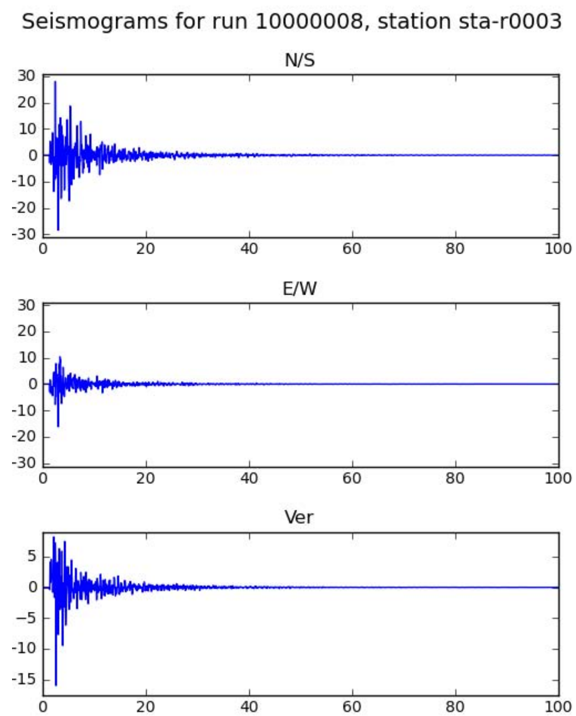
# Region-specific (variable) Parameters:

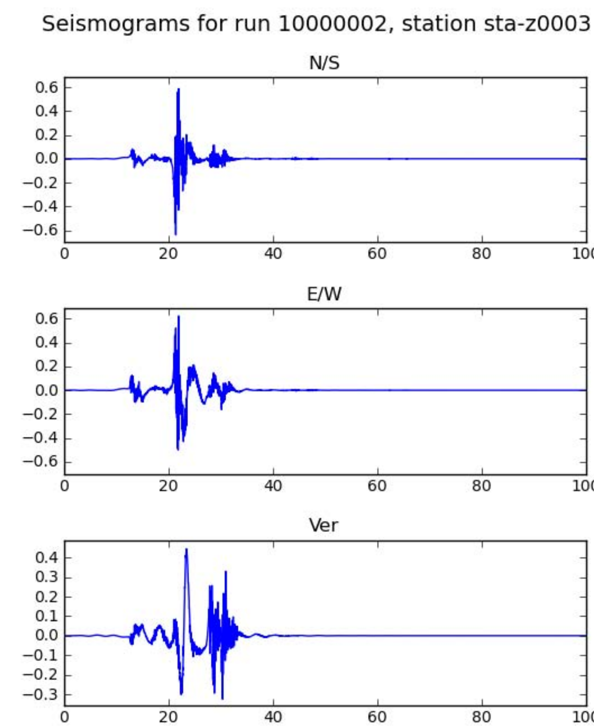
| Parameters | |
|---|---|
| a + b * Vs (HF scaling only) | 41 + 34 * Vs |
| $Q_o f^n$ | 150 $f^{0.8}$ |
| kappa | 0.04 |
| strfac | 50 bars |

# Synthetic Seismograms

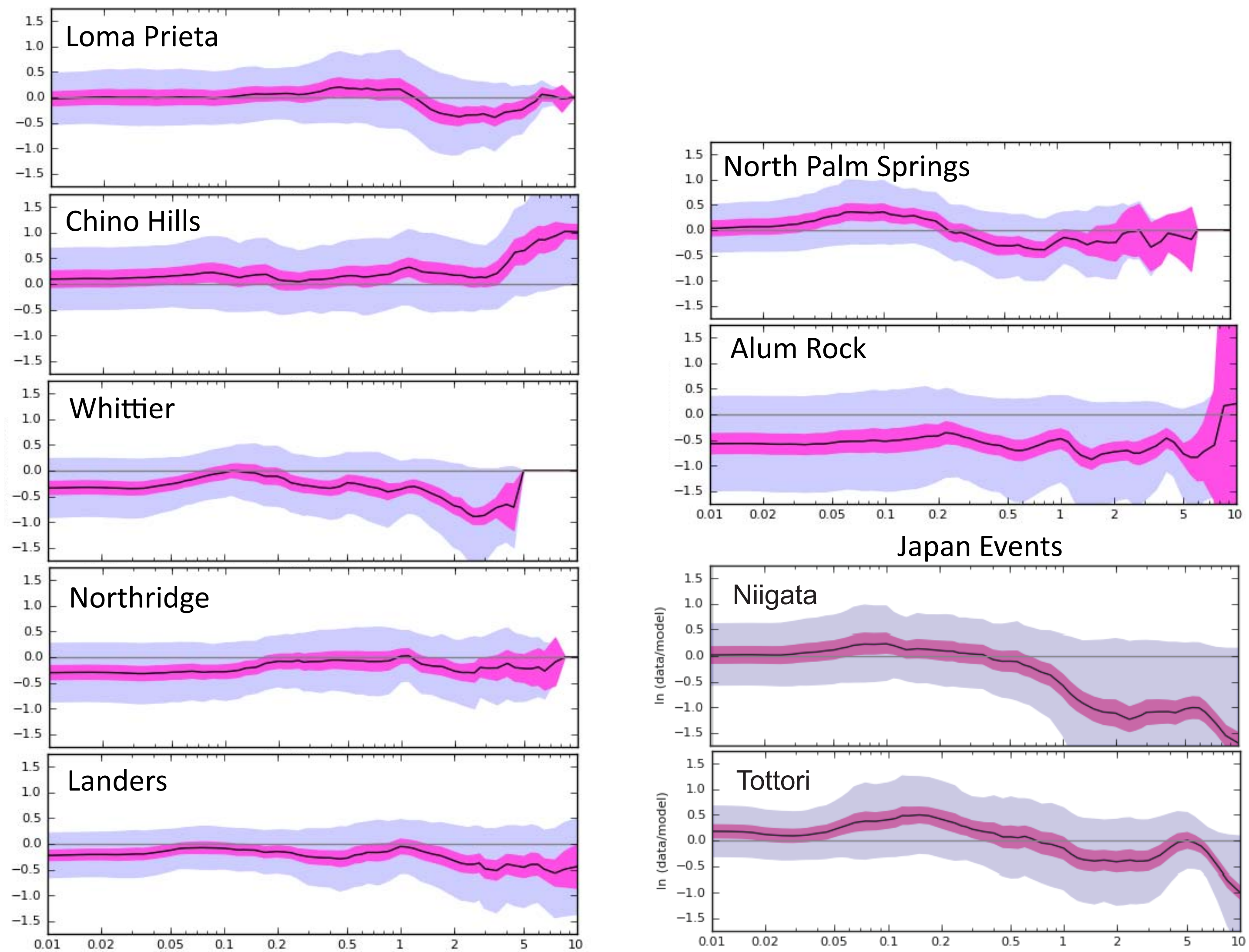
Duration, other features depend on specific HF method!



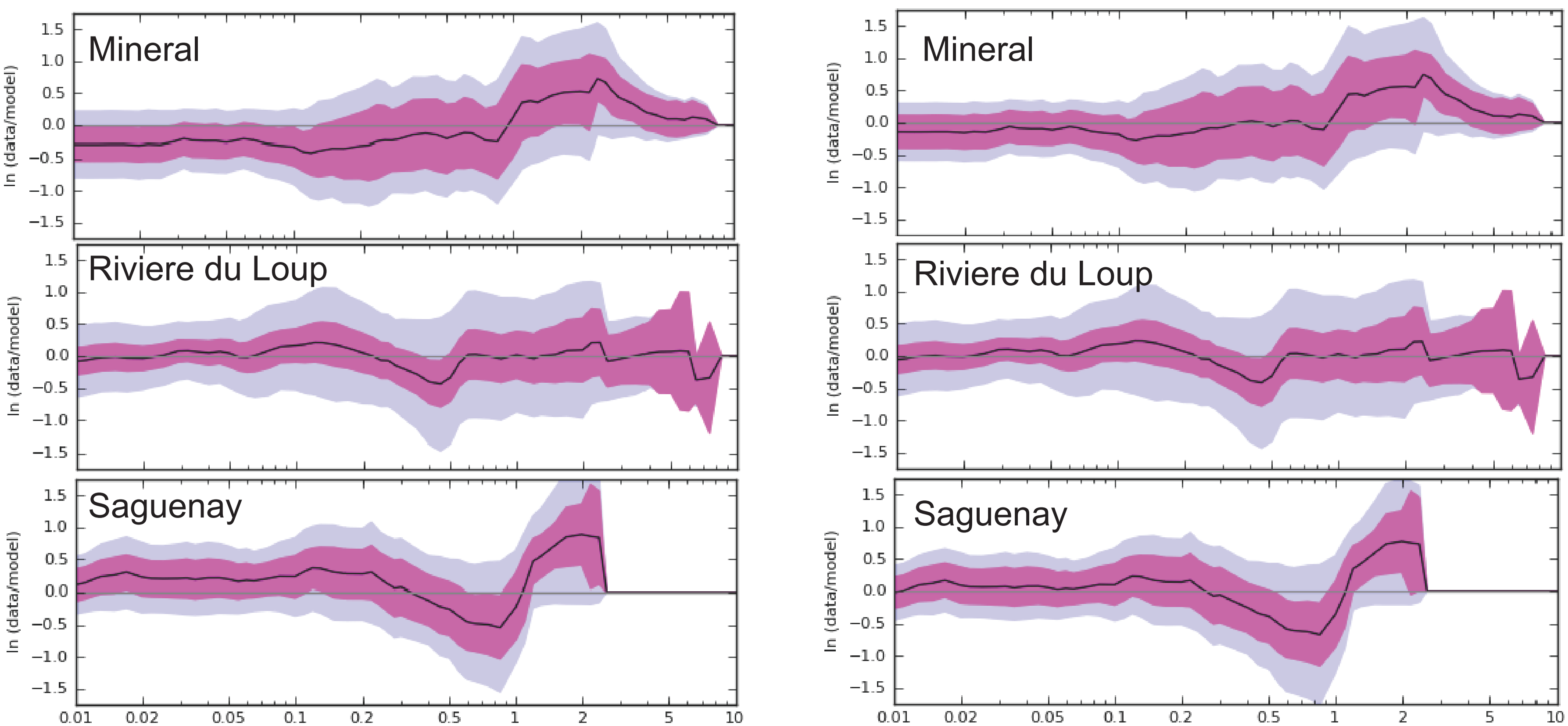



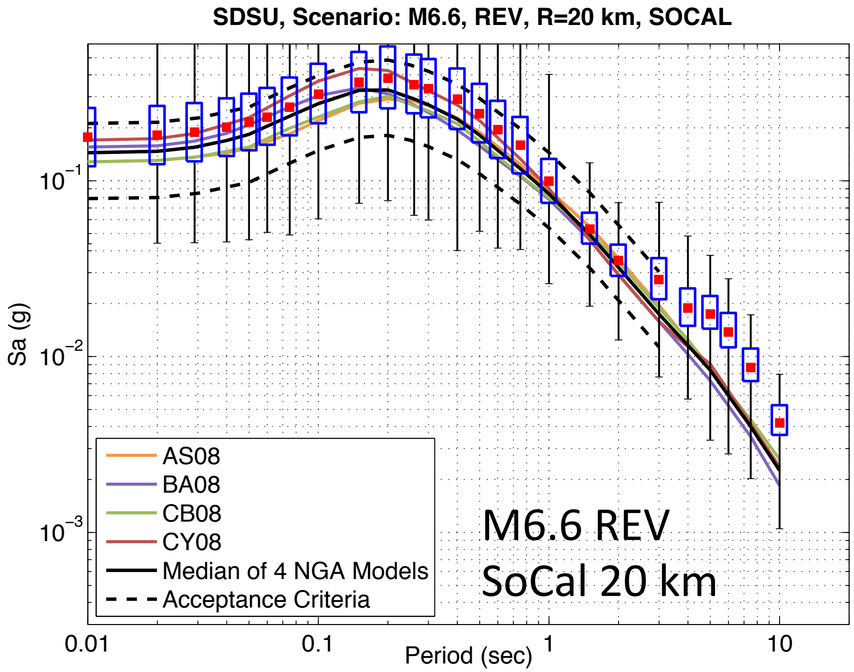



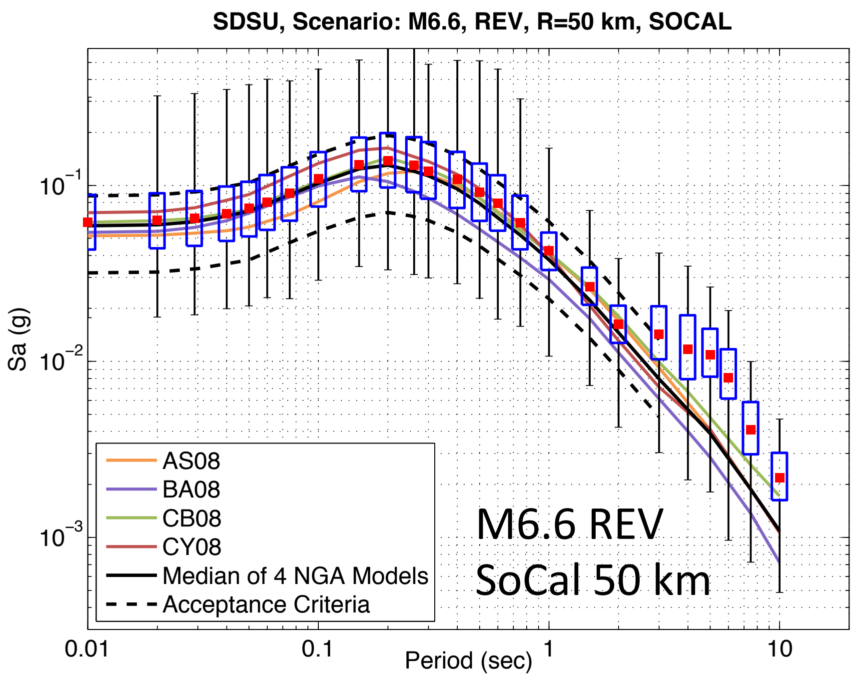
# Ensemble Averages

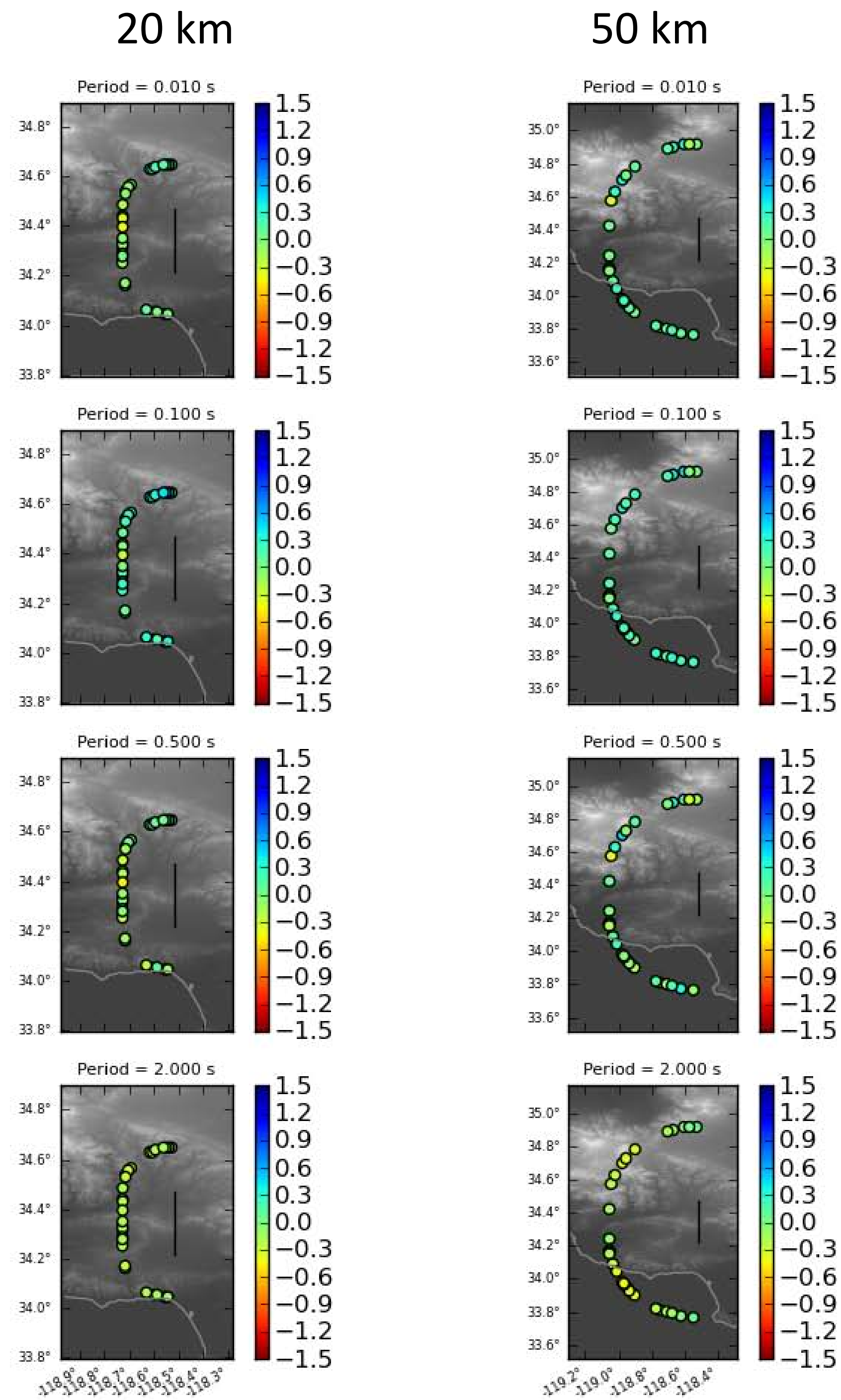


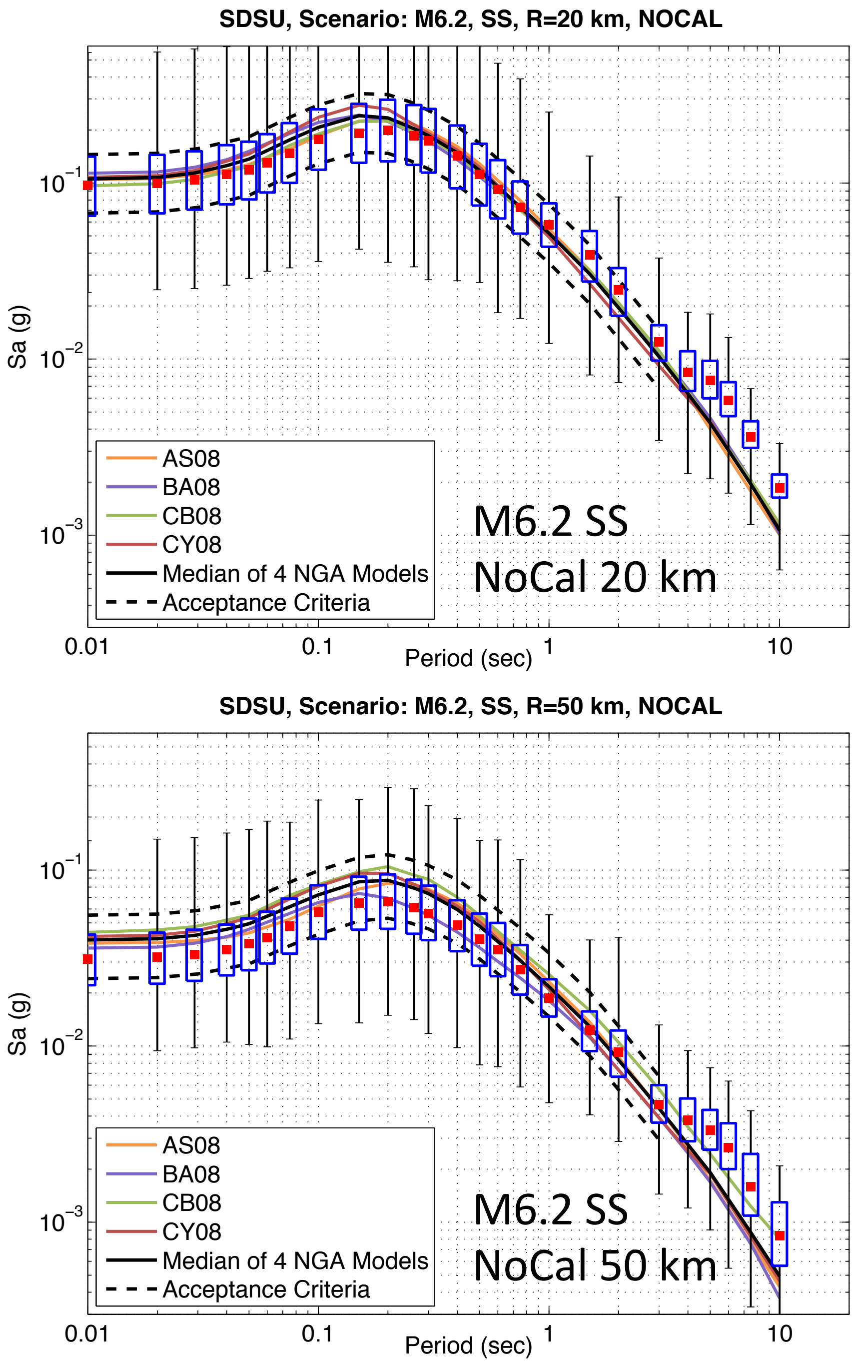
# Ensemble Averages

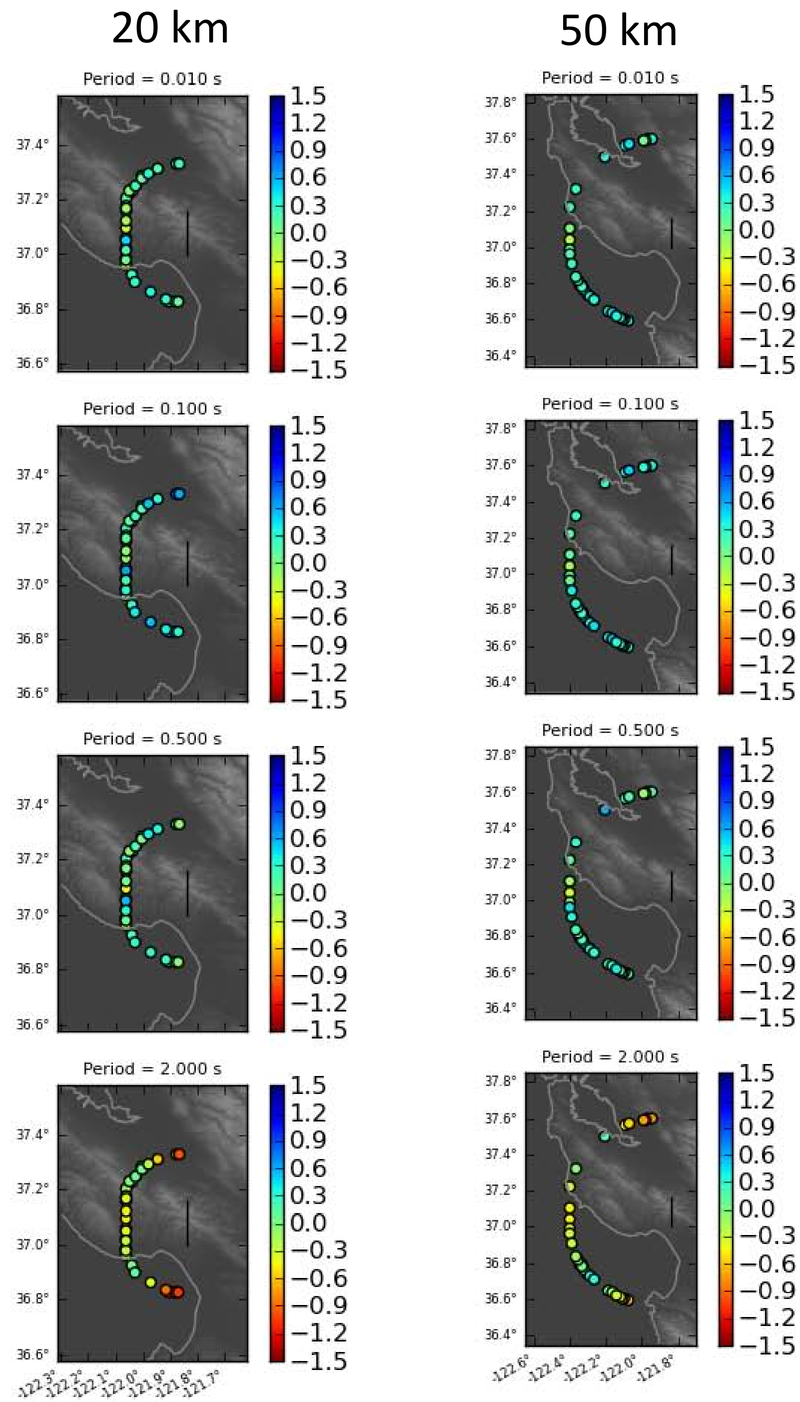



SDSU, Scenario: M6.6, REV, R=20 km, SOCAL
Sa (g)
Period (sec)
AS08
BA08
CB08
CY08
Median of 4 NGA Models
Acceptance Criteria
M6.6 REV
SoCal 20 km


SDSU, Scenario: M6.6, REV, R=50 km, SOCAL
Sa (g)
Period (sec)
AS08
BA08
CB08
CY08
Median of 4 NGA Models
Acceptance Criteria
M6.6 REV
SoCal 50 km


20 km
50 km
Period = 0.010 s
Period = 0.100 s
Period = 0.500 s
Period = 2.000 s


SDSU, Scenario: M6.2, SS, R=20 km, NOCAL
Sa (g)
Period (sec)
AS08
BA08
CB08
CY08
Median of 4 NGA Models
Acceptance Criteria
M6.2 SS
NoCal 20 km
SDSU, Scenario: M6.2, SS, R=50 km, NOCAL
M6.2 SS
NoCal 50 km


20 km
50 km
Period = 0.010 s
Period = 0.100 s
Period = 0.500 s
Period = 2.000 s

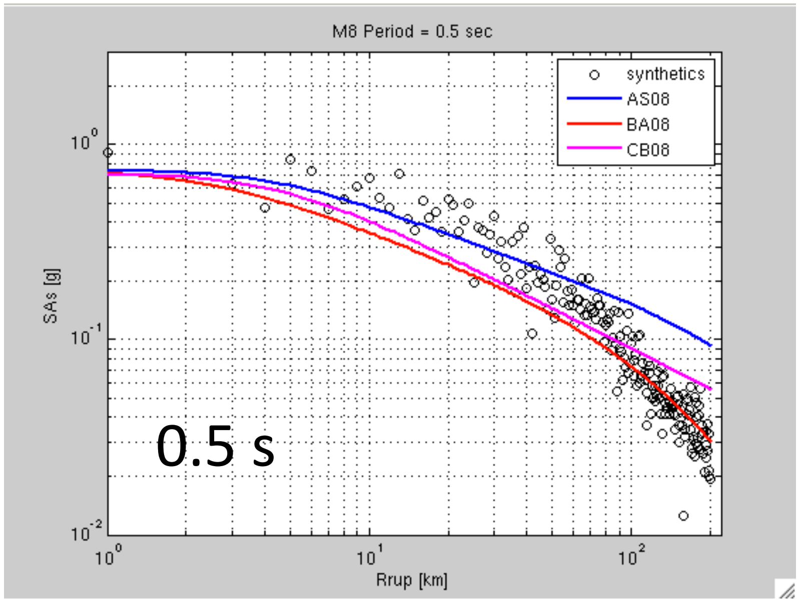
# Part A Validation Summary

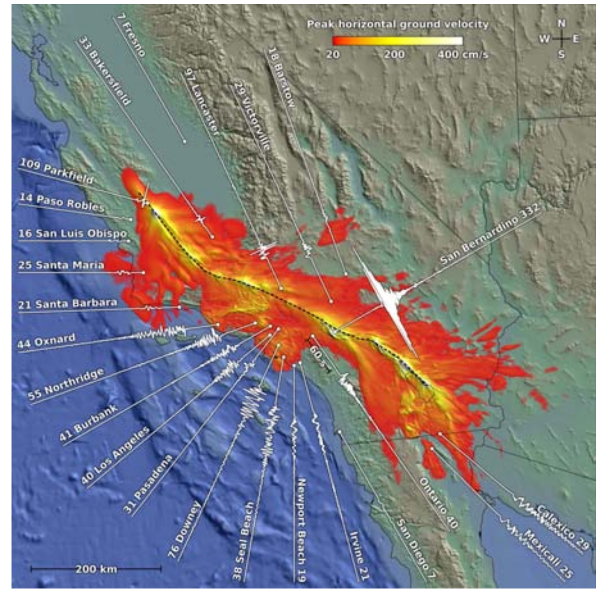
| | Event (Mw, Mech.) | SDSU 0.01-0.1s | | SDSU 0.1-1s | | SDSU 1-3s | | SDSU >3s | |
|---|---|---|---|---|---|---|---|---|---|
| Rrup=[0-5] km | Chino Hills (5.39, ROBL) | | | | | | | | |
| | Alum Rock (5.45, SS) | -0.65 | 0.65 | -0.78 | 0.78 | -1.32 | 1.32 | -1.05 | 1.05 |
| | Whittier Narrows (5.89, REV) | | | | | | | | |
| | North Palm Springs (6.12, ROBL) | 0.36 | 0.36 | 0.22 | 0.32 | -0.51 | 0.51 | -0.95 | 0.95 |
| | Tottori (6.59, SS) | -0.40 | 0.40 | 0.40 | 0.51 | -0.13 | 0.21 | -0.31 | 0.31 |
| | Niigata (6.65, REV) | | | | | | | | |
| | Northridge (6.73, REV) | | | | | | | | |
| | Loma Prieta (6.94, ROBL) | 0.19 | 0.33 | 0.29 | 0.37 | -0.12 | 0.53 | -0.39 | 0.39 |
| | Landers (7.22, SS) | 0.92 | 0.92 | 0.45 | 0.45 | 0.53 | 0.53 | 0.44 | 0.44 |
| | Riviere-du-Loup (4.6 REV) | | | | | | | | |
| | Mineral (5.68 REV) | | | | | | | | |
| | Saguenay (5.81 REV) | | | | | | | | |
| | **Average CA** | 0.20 | 0.48 | 0.13 | 0.44 | -0.28 | 0.66 | -0.24 | 0.54 |
| | **Average CENA** | | | | | | | | |
| | **Average ALL** | 0.11 | 0.47 | 0.16 | 0.45 | -0.26 | 0.60 | -0.25 | 0.49 |
| Rrup=]5-20] km | Chino Hills (5.39, ROBL) | 0.17 | 0.28 | 0.29 | 0.38 | 0.65 | 0.65 | 0.84 | 0.84 |
| | Alum Rock (5.45, SS) | -0.13 | 0.25 | -0.03 | 0.38 | -0.27 | 0.60 | -0.17 | 0.68 |
| | Whittier Narrows (5.89, REV) | -0.28 | 0.43 | -0.16 | 0.40 | -0.54 | 0.55 | -1.01 | 1.01 |
| | North Palm Springs (6.12, ROBL) | -0.11 | 0.33 | -0.17 | 0.41 | -0.30 | 0.65 | -0.05 | 0.24 |
| | Tottori (6.59, SS) | -0.29 | 0.32 | 0.08 | 0.38 | -0.01 | 0.49 | 0.04 | 0.44 |
| | Niigata (6.65, REV) | -0.15 | 0.52 | -0.01 | 0.44 | -0.53 | 0.81 | -0.55 | 0.68 |
| | Northridge (6.73, REV) | -0.06 | 0.37 | 0.16 | 0.42 | -0.14 | 0.35 | -0.10 | 0.32 |
| | Loma Prieta (6.94, ROBL) | 0.18 | 0.35 | 0.20 | 0.39 | -0.32 | 0.40 | -0.25 | 0.28 |
| | Landers (7.22, SS) | -0.29 | 0.66 | -0.02 | 0.54 | -0.36 | 0.51 | -0.85 | 0.85 |
| | Riviere-du-Loup (4.6 REV) | -0.02 | 0.35 | 0.13 | 1.17 | 0.57 | 1.02 | 1.20 | 1.20 |
| | Mineral (5.68 REV) | -0.66 | 0.66 | -0.68 | 0.68 | -0.23 | 0.23 | -0.25 | 0.25 |
| | Saguenay (5.81 REV) | | | | | | | | |
| | **Average CA** | -0.06 | 0.37 | 0.05 | 0.41 | -0.21 | 0.48 | -0.07 | 0.51 |
| | **Average CENA** | -0.24 | 0.45 | -0.14 | 1.01 | 0.25 | 0.71 | 0.84 | 0.96 |
| | **Average ALL** | -0.09 | 0.38 | 0.04 | 0.43 | -0.19 | 0.52 | -0.10 | 0.53 |
| Rrup=]20-70] km | Chino Hills (5.39, ROBL) | 0.01 | 0.47 | -0.02 | 0.50 | 0.10 | 0.47 | 0.55 | 0.63 |
| | Alum Rock (5.45, SS) | -0.72 | 0.80 | -0.70 | 0.79 | -0.81 | 0.86 | -0.55 | 0.58 |
| | Whittier Narrows (5.89, REV) | -0.27 | 0.43 | -0.25 | 0.51 | -0.51 | 0.61 | -0.49 | 0.49 |
| | North Palm Springs (6.12, ROBL) | 0.30 | 0.52 | -0.01 | 0.50 | -0.15 | 0.42 | -0.43 | 0.43 |
| | Tottori (6.59, SS) | 0.29 | 0.44 | -0.02 | 0.59 | -0.62 | 0.70 | -0.44 | 0.57 |
| | Niigata (6.65, REV) | 0.04 | 0.43 | -0.10 | 0.55 | -0.95 | 1.07 | -1.09 | 1.13 |
| | Northridge (6.73, REV) | -0.54 | 0.55 | -0.37 | 0.46 | -0.22 | 0.53 | -0.33 | 0.80 |
| | Loma Prieta (6.94, ROBL) | -0.33 | 0.43 | -0.18 | 0.42 | -0.45 | 0.57 | -0.18 | 0.36 |
| | Landers (7.22, SS) | -0.27 | 0.35 | -0.27 | 0.44 | -0.55 | 0.64 | -0.73 | 0.75 |
| | Riviere-du-Loup (4.6 REV) | 0.09 | 0.47 | -0.08 | 0.60 | -0.10 | 0.63 | -0.25 | 0.30 |
| | Mineral (5.68 REV) | -0.16 | 0.31 | -1.18 | 1.19 | -0.05 | 1.00 | -0.07 | 0.10 |
| | Saguenay (5.81 REV) | 0.25 | 0.35 | -1.33 | 1.33 | -1.98 | 1.98 | | |
| | **Average CA** | -0.25 | 0.50 | -0.26 | 0.52 | -0.38 | 0.59 | -0.35 | 0.62 |
| | **Average CENA** | 0.08 | 0.44 | -0.34 | 0.75 | -0.11 | 0.69 | -0.23 | 0.28 |
| | **Average ALL** | -0.15 | 0.49 | -0.23 | 0.55 | -0.45 | 0.66 | -0.54 | 0.72 |

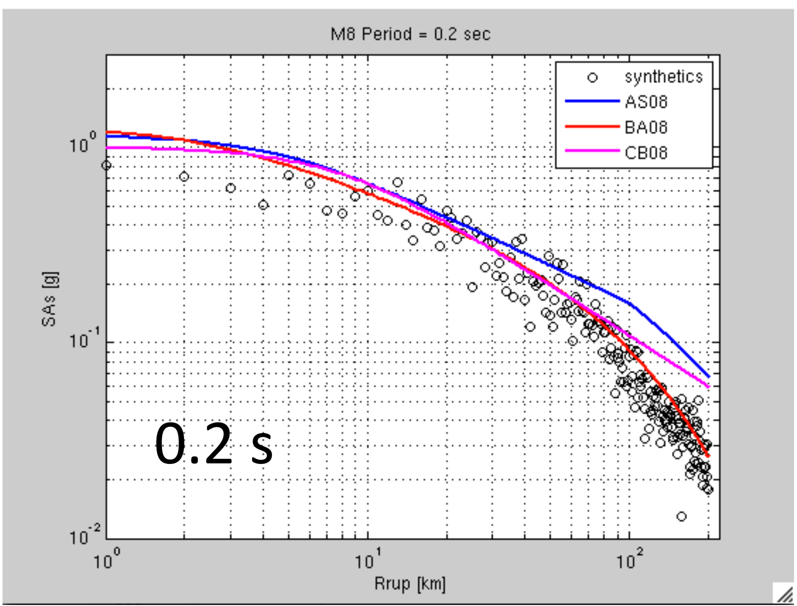
# Part A Validation Summary

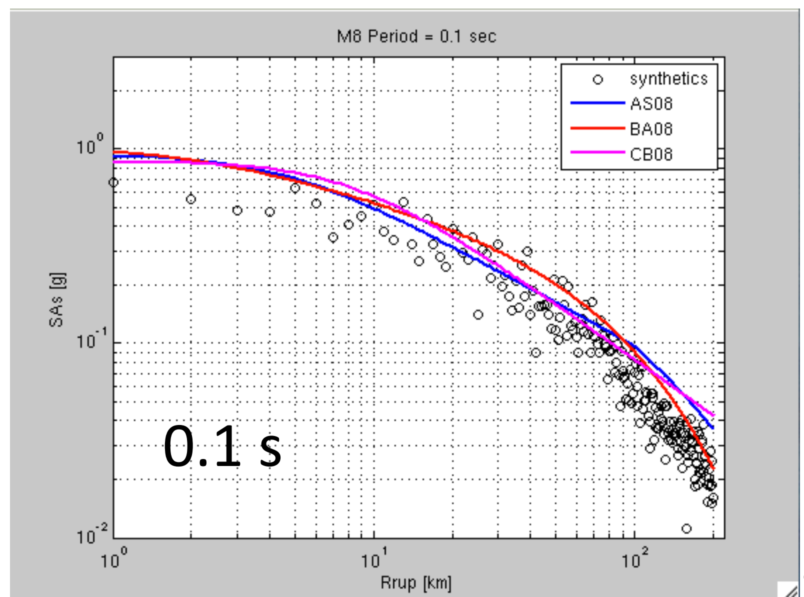
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rrup=]70-300] km | Chino Hills (5.39, ROBL) | **0.31** | 0.55 | **0.31** | 0.60 | **0.19** | **0.73** | 0.58 | **0.91** |
| | Alum Rock (5.45, SS) | -0.54 | **0.80** | **-0.48** | **0.77** | **-0.85** | **0.86** | **-0.86** | **0.86** |
| | Whittier Narrows (5.89, REV) | | | | | | | | |
| | North Palm Springs (6.12, ROBL) | **-0.23** | **0.26** | **-0.46** | **0.50** | **0.23** | **0.36** | | |
| | Tottori (6.59, SS) | **0.36** | 0.51 | 0.51 | 0.67 | **-0.32** | 0.70 | **-0.31** | 0.58 |
| | Niigata (6.65, REV) | **0.22** | 0.62 | **0.02** | 0.63 | **-1.33** | **1.36** | **-1.49** | **1.50** |
| | Northridge (6.73, REV) | **-0.05** | **0.28** | **0.19** | **0.49** | **-0.32** | 0.56 | **-0.31** | **0.31** |
| | Loma Prieta (6.94, ROBL) | 0.54 | 0.54 | **0.74** | **0.77** | 0.51 | **0.92** | **0.03** | 0.62 |
| | Landers (7.22, SS) | **-0.08** | **0.21** | **-0.14** | **0.35** | **0.03** | **0.39** | **0.03** | **0.47** |
| | Riviere-du-Loup (4.6 REV) | **-0.07** | **0.38** | **0.04** | 0.63 | **0.24** | **1.00** | 0.58 | 0.58 |
| | Mineral (5.68 REV) | **-0.03** | **0.38** | **0.31** | 0.51 | **0.79** | **0.81** | **0.20** | **0.28** |
| | Saguenay (5.81 REV) | **0.03** | **0.38** | **0.10** | **0.49** | **0.50** | 0.62 | **-0.13** | **0.13** |
| | **Average CA** | **-0.01** | **0.48** | **0.01** | 0.57 | **-0.06** | 0.65 | **0.00** | 0.69 |
| | **Average CENA** | **-0.01** | **0.38** | **0.15** | 0.53 | 0.58 | **0.77** | **0.18** | **0.27** |
| | **Average ALL** | **0.08** | **0.49** | **0.12** | 0.59 | **-0.22** | **0.80** | -0.52 | **0.86** |
| Mechanism | Reverse (REV) | **-0.11** | **0.45** | **-0.11** | 0.54 | **-0.42** | **0.76** | **-0.80** | **0.95** |
| | Reverse-Oblique (ROBL) | **0.10** | **0.45** | **0.07** | **0.49** | **-0.05** | 0.56 | **0.16** | 0.54 |
| | Strike-Slip (SS) | **-0.18** | **0.49** | **-0.16** | 0.57 | **-0.45** | 0.66 | **-0.40** | 0.61 |
| | Normal (NM) | | | | | | | | |
| Total | **Average CA** | **-0.15** | **0.47** | **-0.13** | **0.50** | **-0.26** | 0.58 | **-0.20** | 0.60 |
| | **Average CENA** | **0.01** | **0.41** | **-0.08** | 0.66 | **0.28** | **0.74** | **0.09** | **0.33** |
| | **Average ALL** | **-0.07** | **0.46** | **-0.08** | 0.53 | **-0.33** | 0.67 | **-0.44** | **0.72** |

# Self Assessment Supporting Information for >$M_w$7.3: M8 Generally Agrees with GMPEs

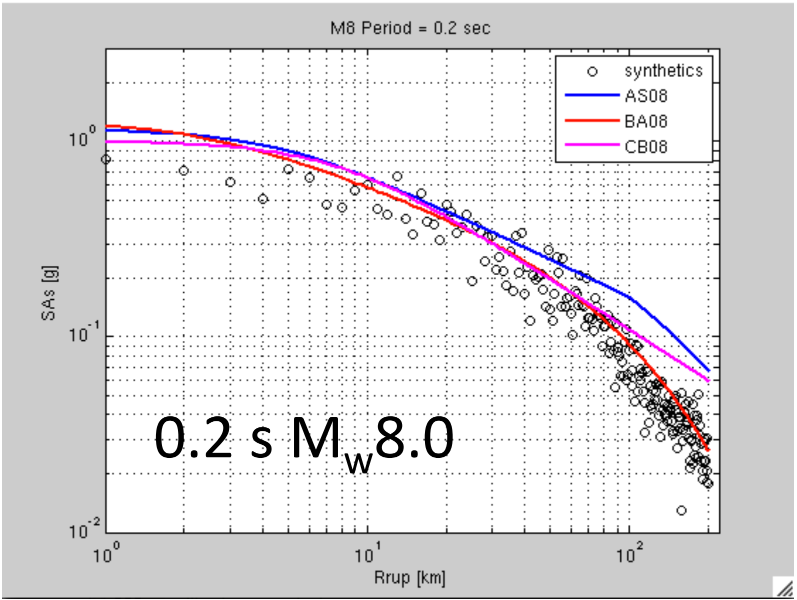


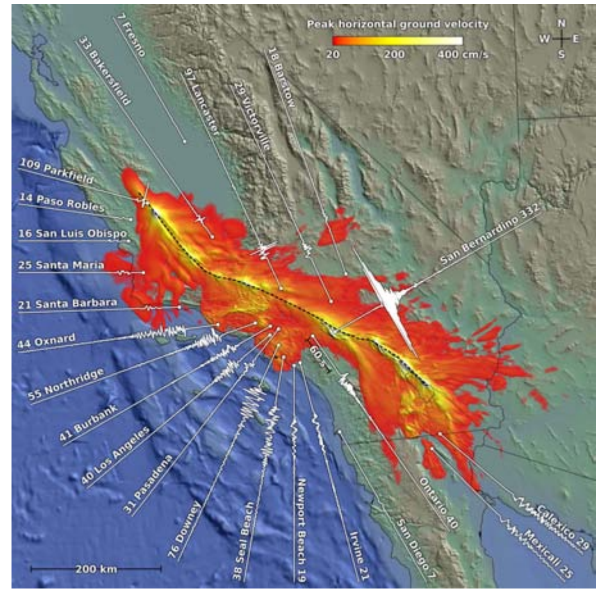



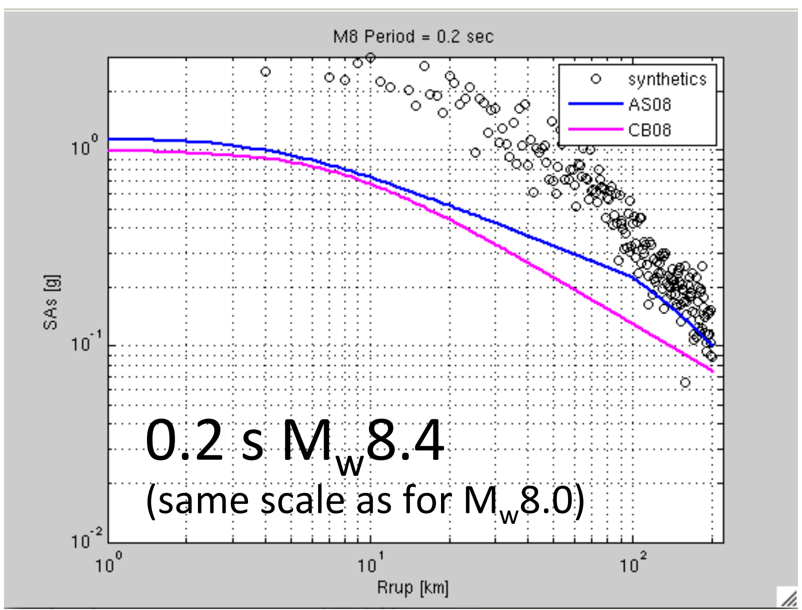



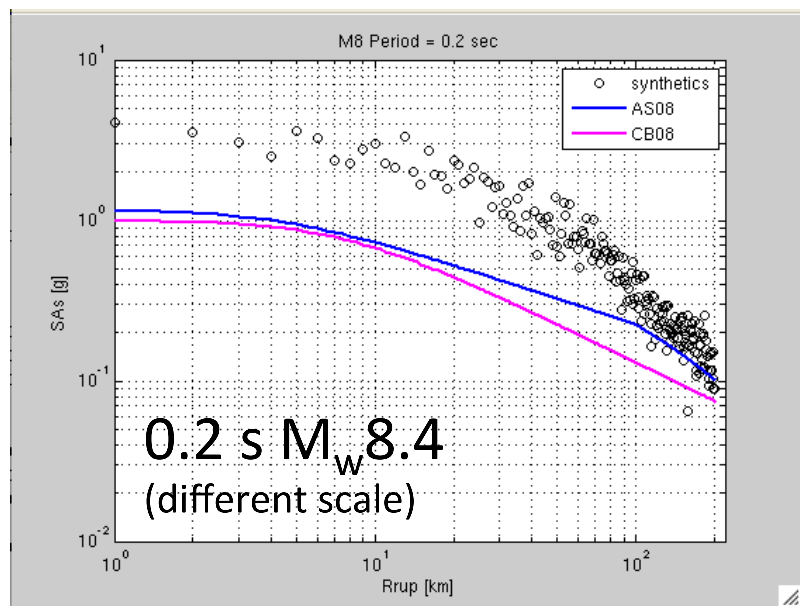



# Potential Issues for $M_w$>8.0



# Self Assessment – Expected Performance

## SDSU Module ('Bbtoolbox')

| | Magnitude | PSA period range: [0.01-0.1] s | ]0.1-1] s | ]1-3] s | > 3s* |
|---|---|---|---|---|---|
| Rrup=[0-20] km | 5-6 | Expected to work | Expected to work | Expected to work | Expected to work |
| | 6-7 | Expected to work | Expected to work | Expected to work | Expected to work |
| | 7-8 | Expected to work | Expected to work | Expected to work | Expected to work |
| | >8 | Not sure / potential issues | Not sure / potential issues | Not sure / potential issues | Not sure / potential issues |
| Rrup=]20-70] km | 5-6 | Expected to work | Expected to work | Expected to work | Expected to work |
| | 6-7 | Expected to work | Expected to work | Expected to work | Expected to work |
| | 7-8 | Expected to work | Expected to work | Expected to work | Expected to work |
| | >8 | Not sure / potential issues | Not sure / potential issues | Not sure / potential issues | Not sure / potential issues |
| Rrup=]70-200] km | 5-6 | Expected to work | Expected to work | Expected to work | Expected to work |
| | 6-7 | Expected to work | Expected to work | Expected to work | Expected to work |
| | 7-8 | Expected to work | Expected to work | Expected to work | Expected to work |
| | >8 | Not sure / potential issues | Not sure / potential issues | Not sure / potential issues | Not sure / potential issues |
| Mechanism | Reverse (REV) | Expected to work | Expected to work | Expected to work | Expected to work |
| | Reverse-Oblique (ROBL) | Expected to work | Expected to work | Expected to work | Expected to work |
| | Strike-Slip (SS) | Expected to work | Expected to work | Expected to work | Expected to work |
| | Normal (NM) | Expected to work | Expected to work | Expected to work | Expected to work |

**Expected Performance Level**

- Expected to work
- Not sure / potential issues
- Definite issues

* dependent on rupture generator

# Computer Exercises

- Running BBtoolbox

# Computer Exercises

1) Northridge SRC file, SoCal velocity structure, 5 stations within 40 km of fault (Epicentral distance is limited so that Green's functions are computed for less time.) This fault has top of rupture at 5.0 km. Choose 5 stations that are distributed at various distances from fault and various azimuths (Figure 1).
   - Students will compute 3-component time histories, Fourier amplitude spectrum (FAS), and response spectrum.
   - Plot the 3-components of ground motion at each site using the data.
   - At the same scale as part b, plot the 3-components of synthetic ground motion.
   - Compute the FAS for each component of the data and plot on log-log scale.
   - Compute the FAS for each component of the synthetic and plot on log-log scale.
   - Compare response spectrum from synthetic with that from GMPE (overlay two plots).
   - For students own homework, run a different realization of the kinematic model and compare with the results from parts c and d.

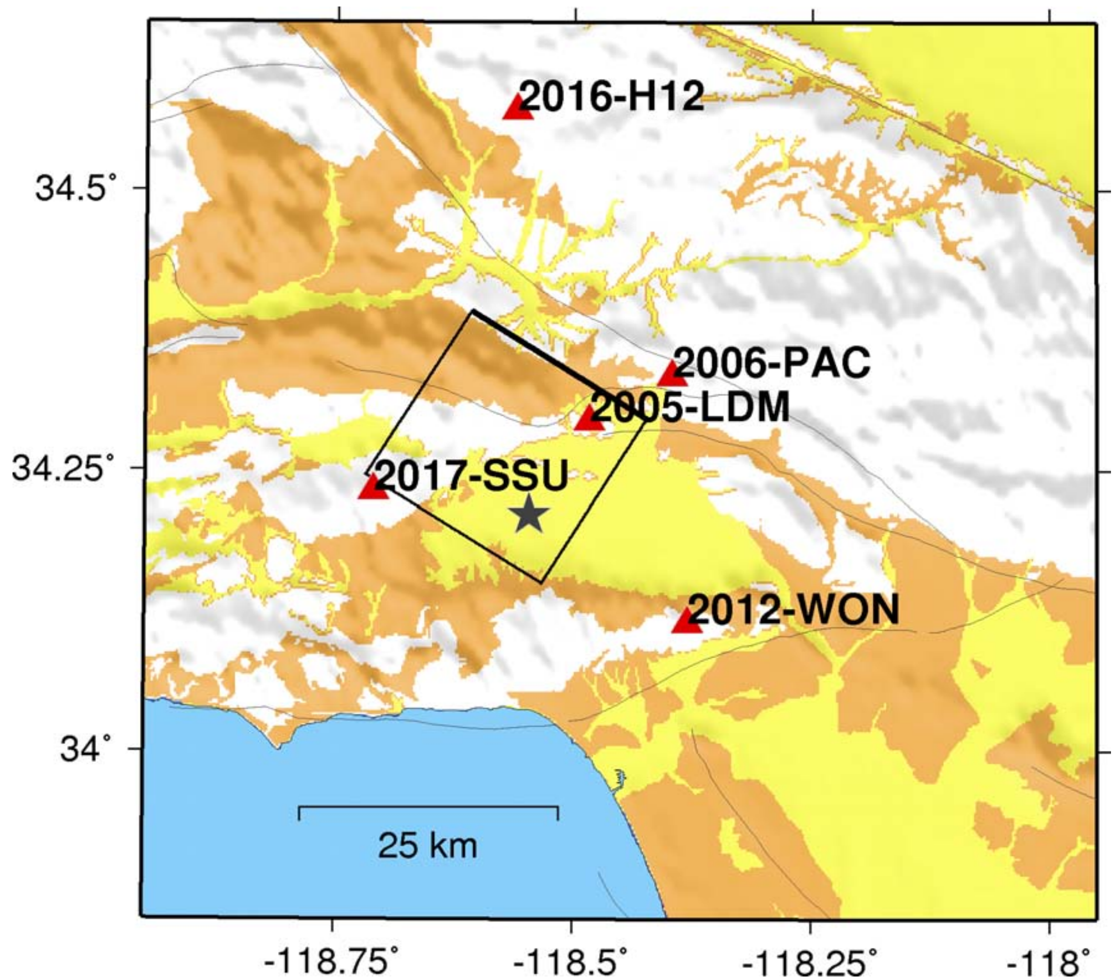
# Computer Exercises

2) Northridge, but SRC file will have fault coming to the surface, SoCal velocity structure, 5 stations within 40 km of fault. The dip here should be same as that for Ex. 1. However, this fault has top of rupture at 0.0 km. Students can see the difference of surface vs buried rupture.
   - Students to compute 3 component time histories, FAS, and response spectrum at the same 5 stations chosen in Exercise 1.
   - Compare response spectrum from synthetic with that from GMPE (overlay two plots).
   - Compare ground motions between surface rupture (Ex. 1) and buried rupture. Plot synthetics from this exercise (Ex. 2) and those from Ex. 1 on the same plot. Use SAC.

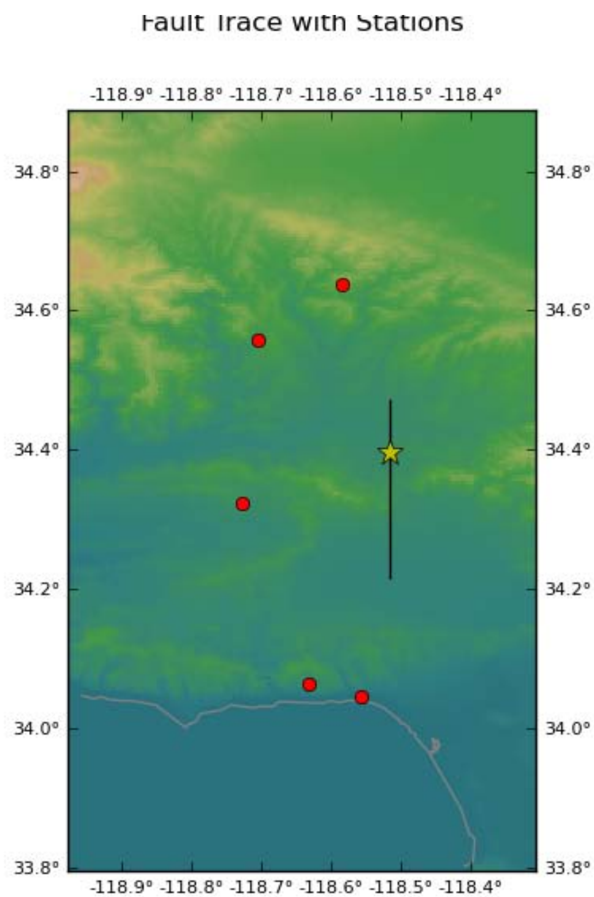
# Computer Exercises

3) Strike slip, M 6.6, SoCal velocity structure, surface rupture, 5 stations. All stations are located 20 km from the fault. Hypocenter is random.
   - Compute 3-component time histories, FAS, and response spectrum for each station.
   - Compare response spectrum from synthetic with that from GMPE (overlay two plots).
   - If you have time, repeat parts a and b with a different realization.

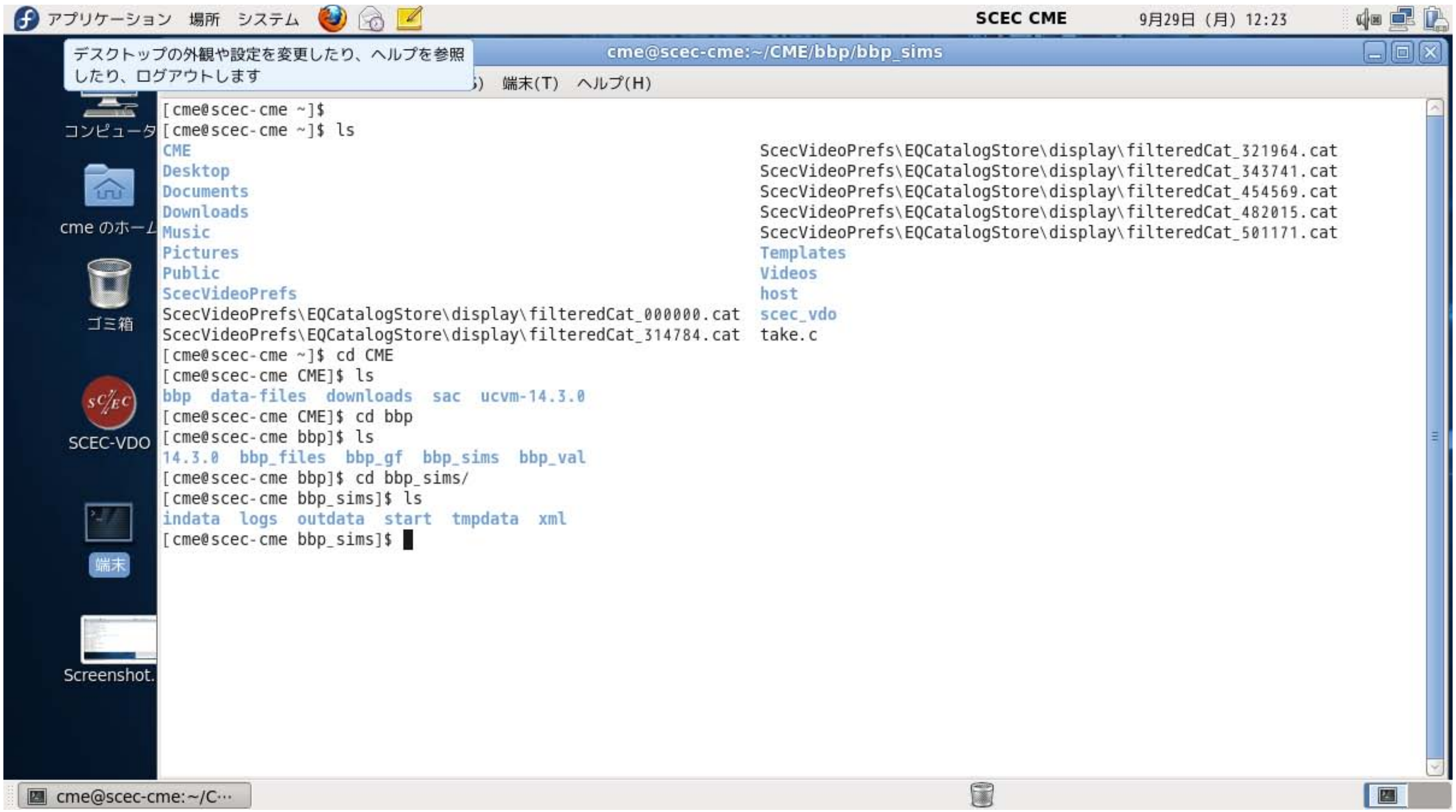
# 5 Station Locations



# Station Locations

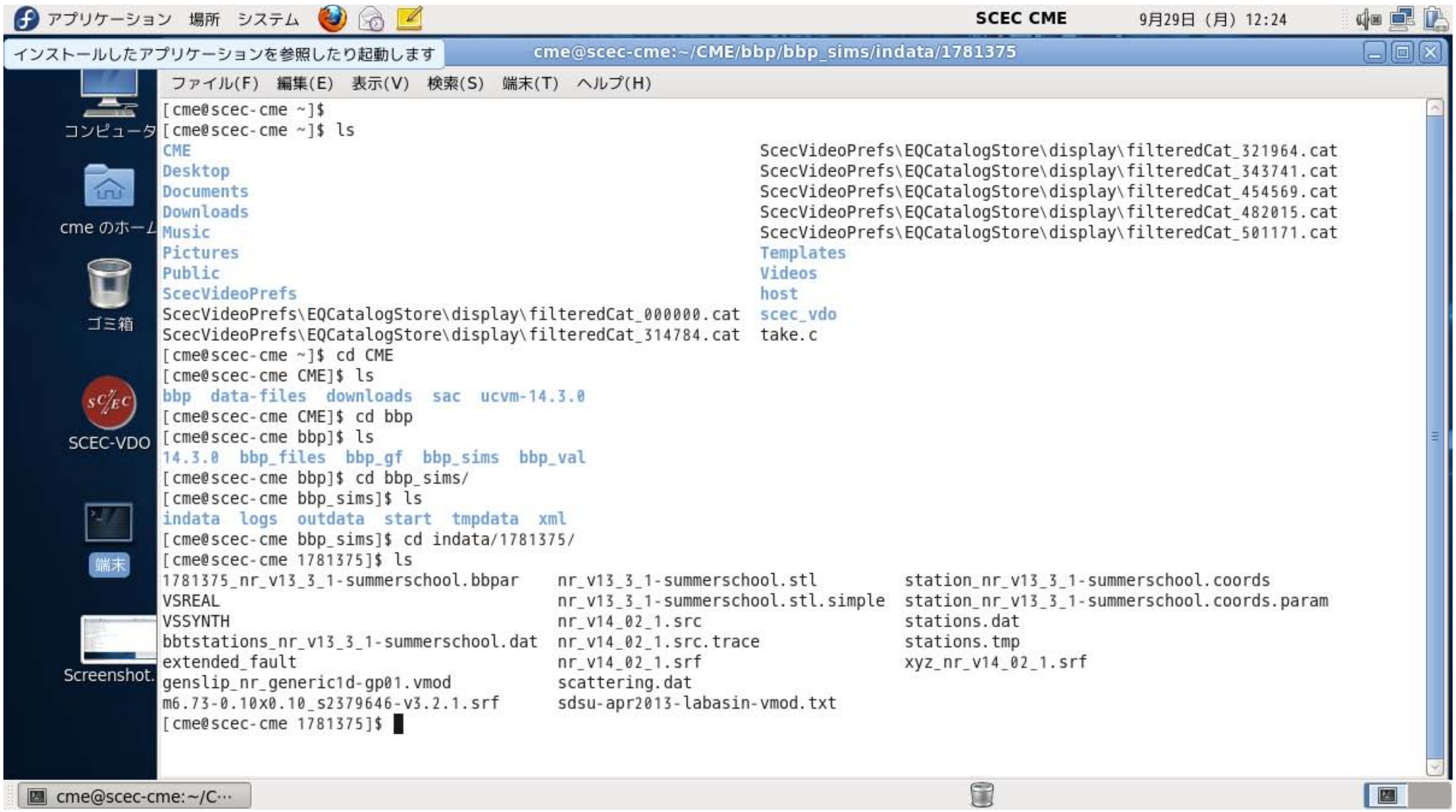


# BB simulations
# /home/cme/CME/bbp/bbp_sims



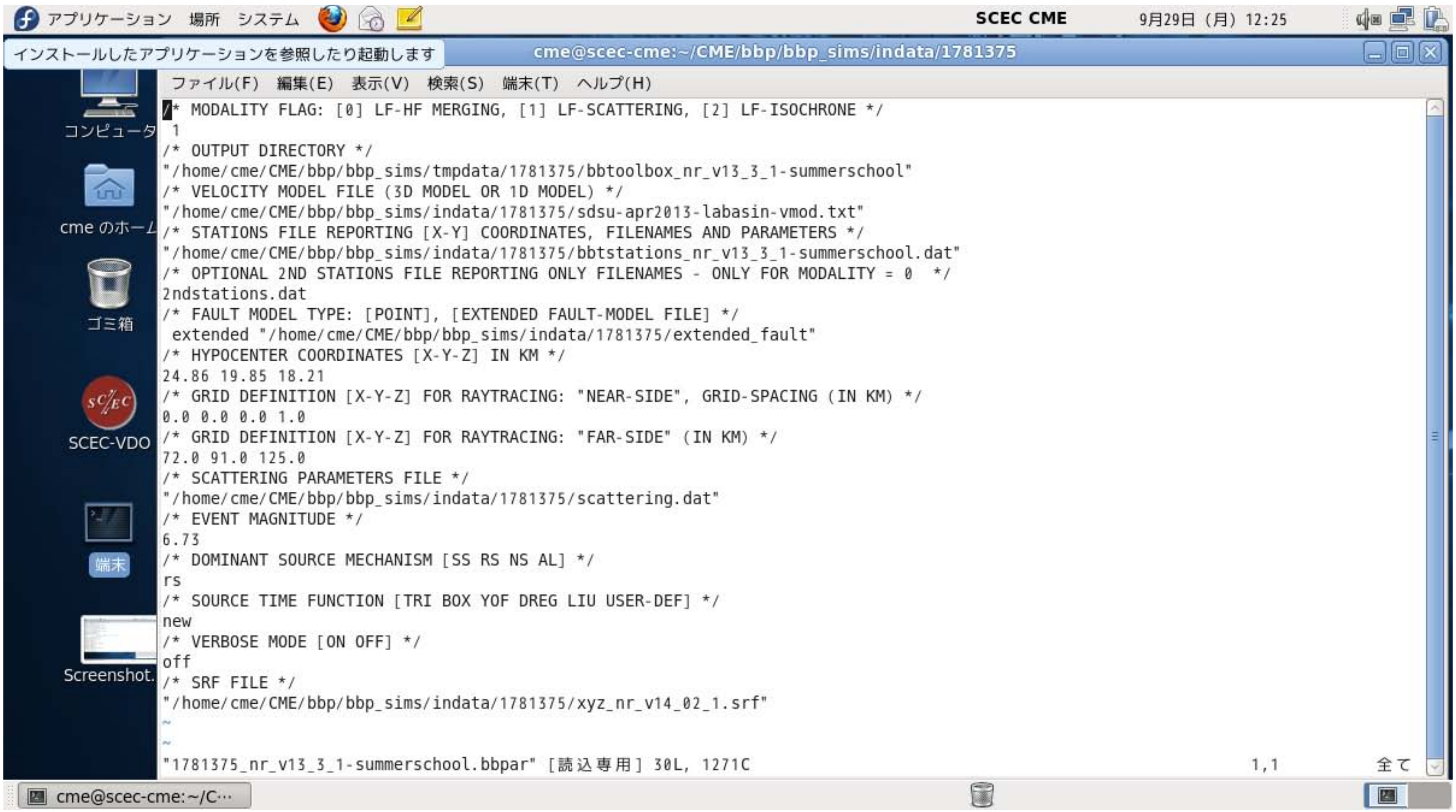

BB simulations are created under bbp_sims

# input files
# /home/cme/CME/bbp/bbp_sims/indata/



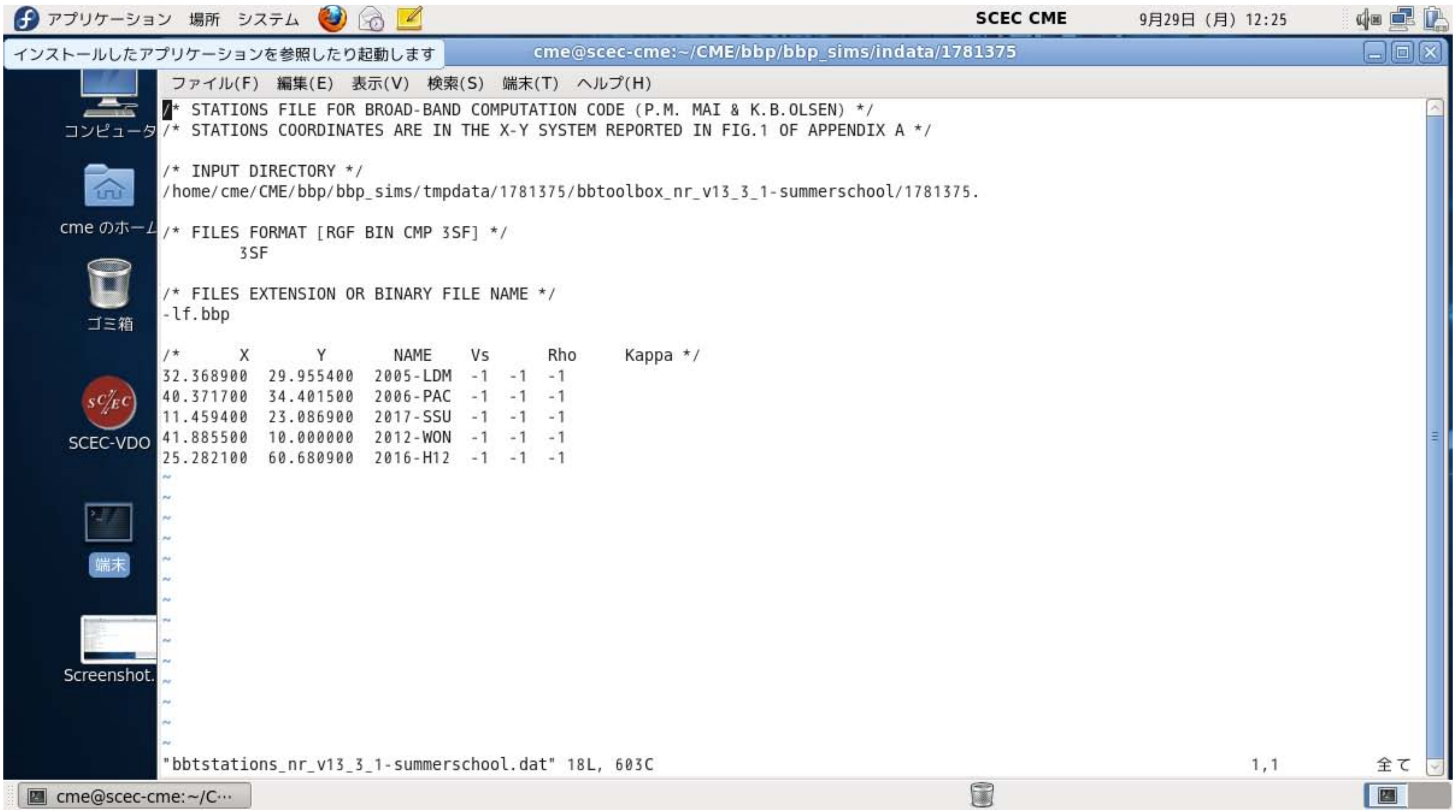

Input files for BBtoolbox code are created under bbp_sims/indata/

# input files: *_nr_v13_3_1-summerschool.bbpar
# /home/cme/CME/bbp/bbp_sims/indata/



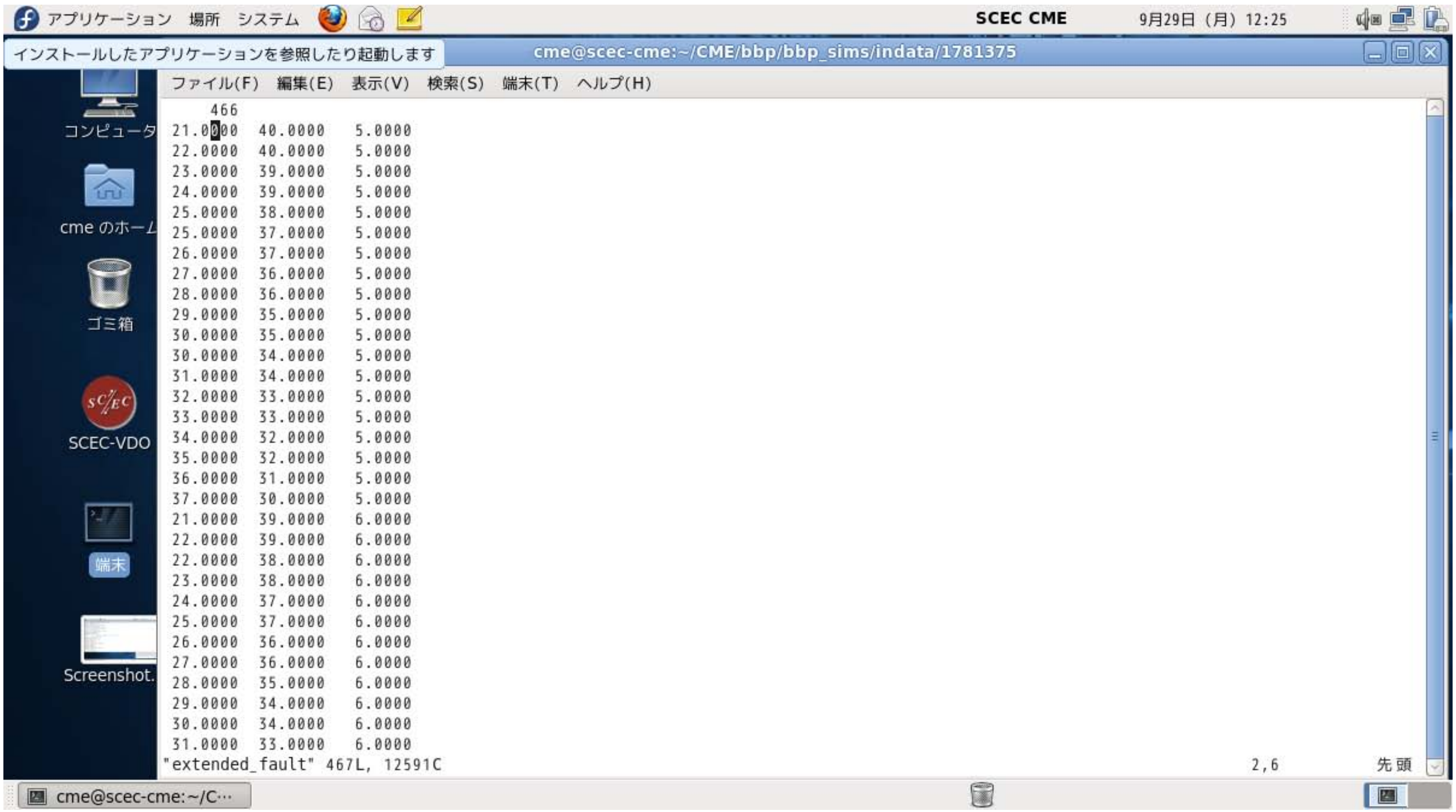

*.bbpar file:

input files: bbtstations_nr_v14_4_1-summerschool.dat
/home/cme/CME/bbp/bbp_sims/indata/



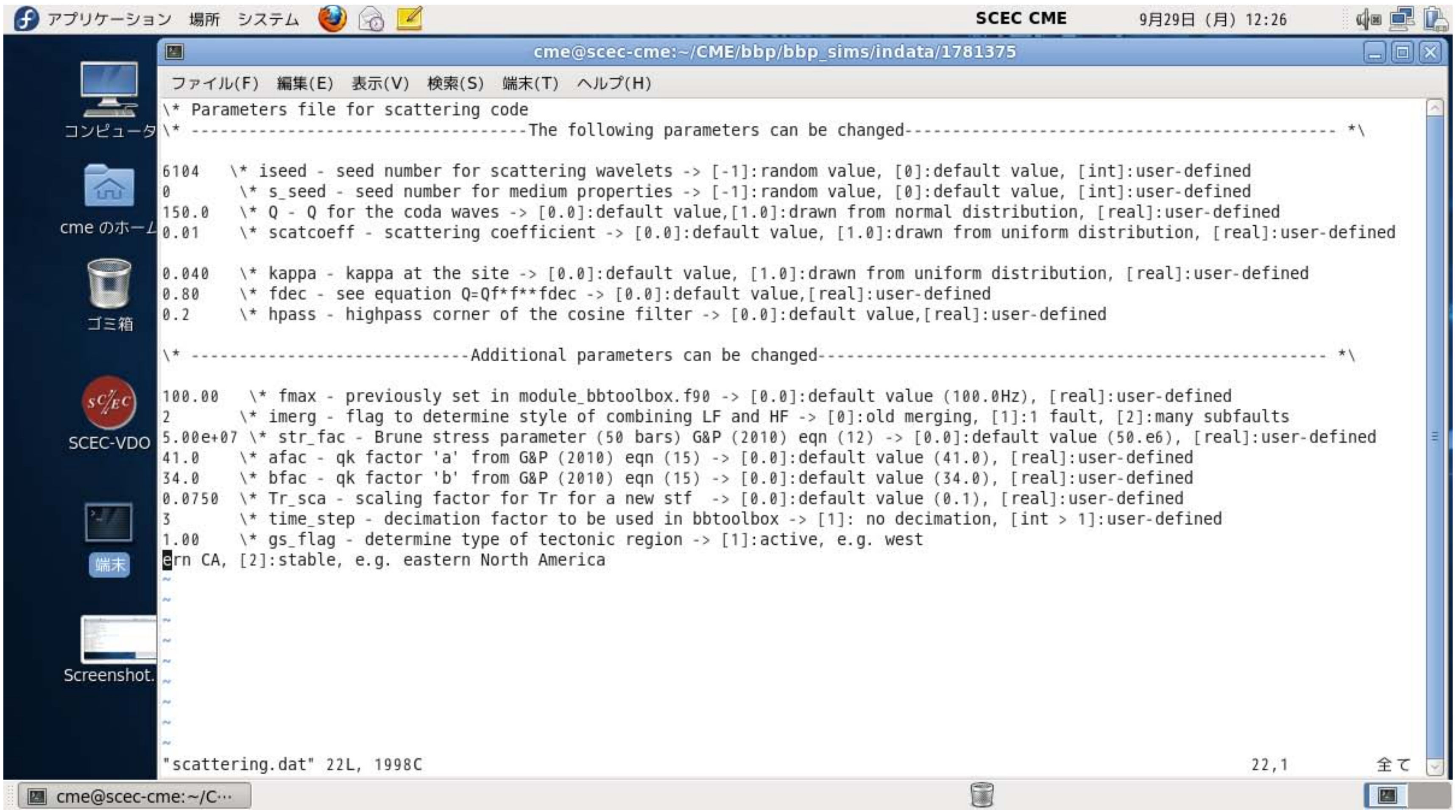

station file:

# input files: extended_fault /home/cme/CME/bbp/bbp_sims/indata/




extended fault file:

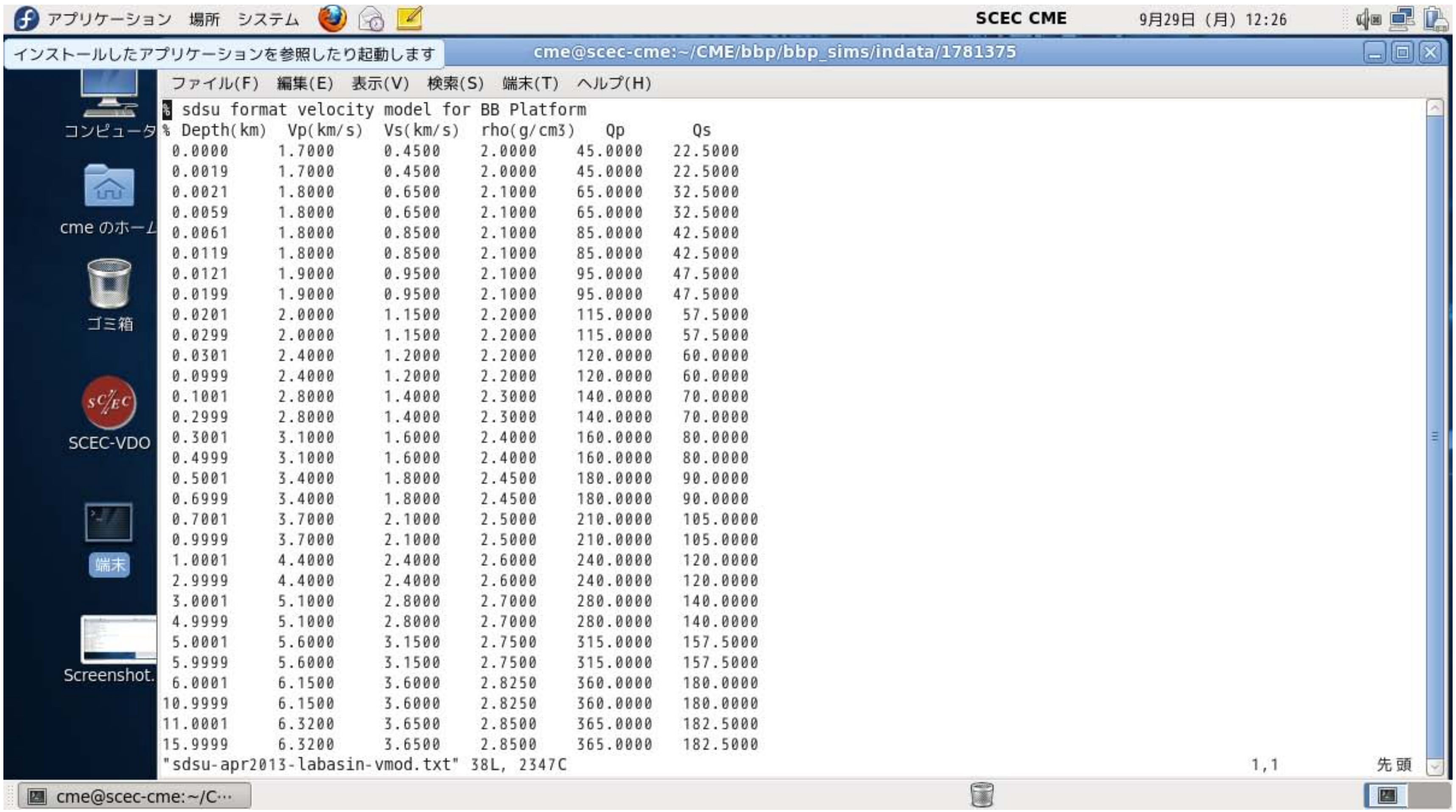
# input files: scattering.dat
# /home/cme/CME/bbp/bbp_sims/indata/



```
\* Parameters file for scattering code
\* ----------------------------------The following parameters can be changed-------------------------------------------- *\

6104    \* iseed - seed number for scattering wavelets -> [-1]:random value, [0]:default value, [int]:user-defined
0        \* s_seed - seed number for medium properties -> [-1]:random value, [0]:default value, [int]:user-defined
150.0    \* Q - Q for the coda waves -> [0.0]:default value,[1.0]:drawn from normal distribution, [real]:user-defined
0.01     \* scatcoeff - scattering coefficient -> [0.0]:default value, [1.0]:drawn from uniform distribution, [real]:user-defined

0.040    \* kappa - kappa at the site -> [0.0]:default value, [1.0]:drawn from uniform distribution, [real]:user-defined
0.80     \* fdec - see equation Q=Qf*f**fdec -> [0.0]:default value,[real]:user-defined
0.2      \* hpass - highpass corner of the cosine filter -> [0.0]:default value,[real]:user-defined

\* ----------------------------Additional parameters can be changed---------------------------------------------------- *\

100.00    \* fmax - previously set in module_bbtoolbox.f90 -> [0.0]:default value (100.0Hz), [real]:user-defined
2        \* imerg - flag to determine style of combining LF and HF -> [0]:old merging, [1]:1 fault, [2]:many subfaults
5.00e+07 \* str_fac - Brune stress parameter (50 bars) G&P (2010) eqn (12) -> [0.0]:default value (50.e6), [real]:user-defined
41.0     \* afac - qk factor 'a' from G&P (2010) eqn (15) -> [0.0]:default value (41.0), [real]:user-defined
34.0     \* bfac - qk factor 'b' from G&P (2010) eqn (15) -> [0.0]:default value (34.0), [real]:user-defined
0.0750   \* Tr_sca - scaling factor for Tr for a new stf  -> [0.0]:default value (0.1), [real]:user-defined
3        \* time_step - decimation factor to be used in bbtoolbox -> [1]: no decimation, [int > 1]:user-defined
1.00     \* gs_flag - determine type of tectonic region -> [1]:active, e.g. west
ern CA, [2]:stable, e.g. eastern North America
```

scattering.dat file:

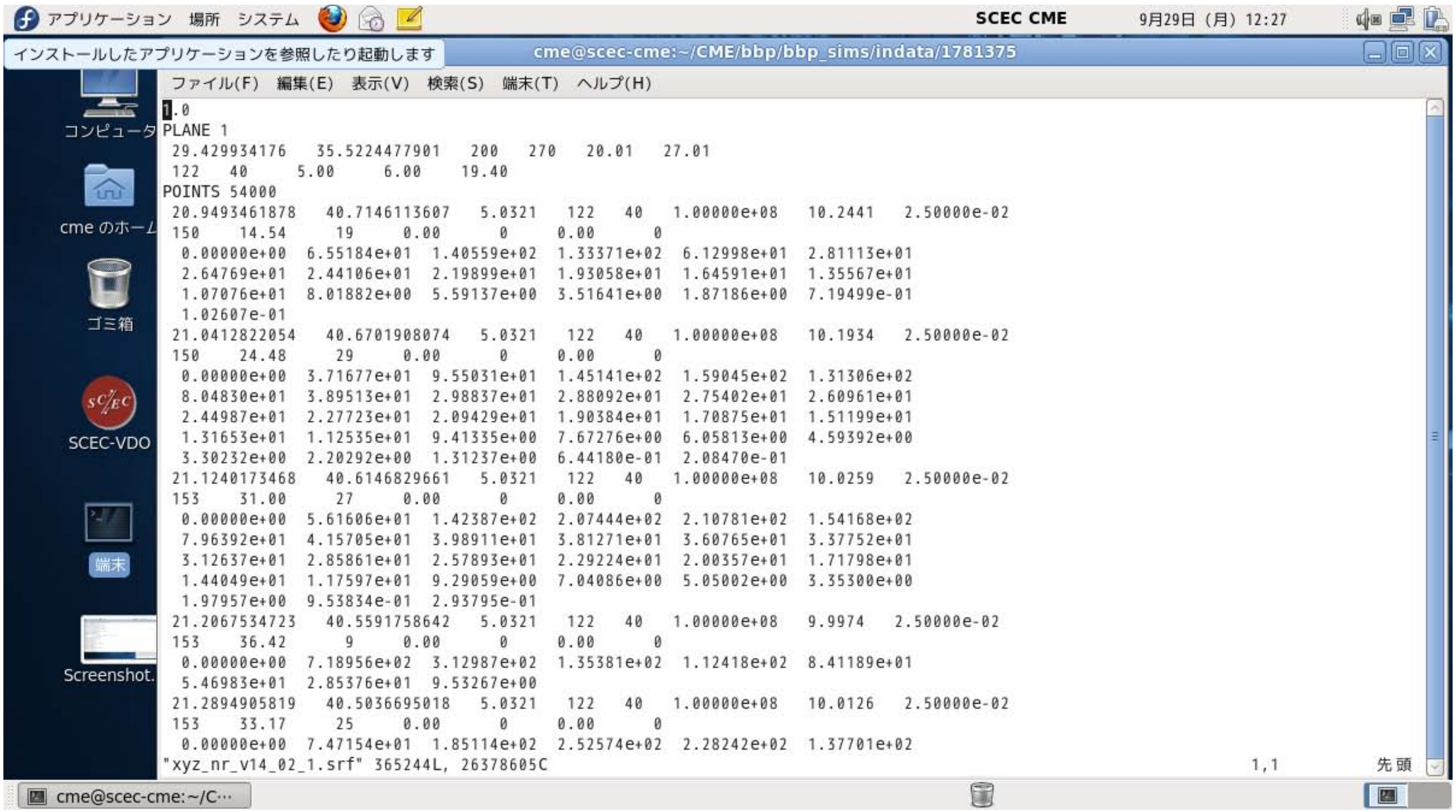
# input files: sdsu-apr2013-labasin-vmod.txt
# /home/cme/CME/bbp/bbp_sims/indata/




```
% sdsu format velocity model for BB Platform
% Depth(km)  Vp(km/s)  Vs(km/s)  rho(g/cm3)  Qp        Qs
 0.0000      1.7000    0.4500    2.0000      45.0000   22.5000
 0.0019      1.7000    0.4500    2.0000      45.0000   22.5000
 0.0021      1.8000    0.6500    2.1000      65.0000   32.5000
 0.0059      1.8000    0.6500    2.1000      65.0000   32.5000
 0.0061      1.8000    0.8500    2.1000      85.0000   42.5000
 0.0119      1.8000    0.8500    2.1000      85.0000   42.5000
 0.0121      1.9000    0.9500    2.1000      95.0000   47.5000
 0.0199      1.9000    0.9500    2.1000      95.0000   47.5000
 0.0201      2.0000    1.1500    2.2000      115.0000  57.5000
 0.0299      2.0000    1.1500    2.2000      115.0000  57.5000
 0.0301      2.4000    1.2000    2.2000      120.0000  60.0000
 0.0999      2.4000    1.2000    2.2000      120.0000  60.0000
 0.1001      2.8000    1.4000    2.3000      140.0000  70.0000
 0.2999      2.8000    1.4000    2.3000      140.0000  70.0000
 0.3001      3.1000    1.6000    2.4000      160.0000  80.0000
 0.4999      3.1000    1.6000    2.4000      160.0000  80.0000
 0.5001      3.4000    1.8000    2.4500      180.0000  90.0000
 0.6999      3.4000    1.8000    2.4500      180.0000  90.0000
 0.7001      3.7000    2.1000    2.5000      210.0000  105.0000
 0.9999      3.7000    2.1000    2.5000      210.0000  105.0000
 1.0001      4.4000    2.4000    2.6000      240.0000  120.0000
 2.9999      4.4000    2.4000    2.6000      240.0000  120.0000
 3.0001      5.1000    2.8000    2.7000      280.0000  140.0000
 4.9999      5.1000    2.8000    2.7000      280.0000  140.0000
 5.0001      5.6000    3.1500    2.7500      315.0000  157.5000
 5.9999      5.6000    3.1500    2.7500      315.0000  157.5000
 6.0001      6.1500    3.6000    2.8250      360.0000  180.0000
10.9999      6.1500    3.6000    2.8250      360.0000  180.0000
11.0001      6.3200    3.6500    2.8500      365.0000  182.5000
15.9999      6.3200    3.6500    2.8500      365.0000  182.5000
"sdsu-apr2013-labasin-vmod.txt" 38L, 2347C                      1,1      先頭
```

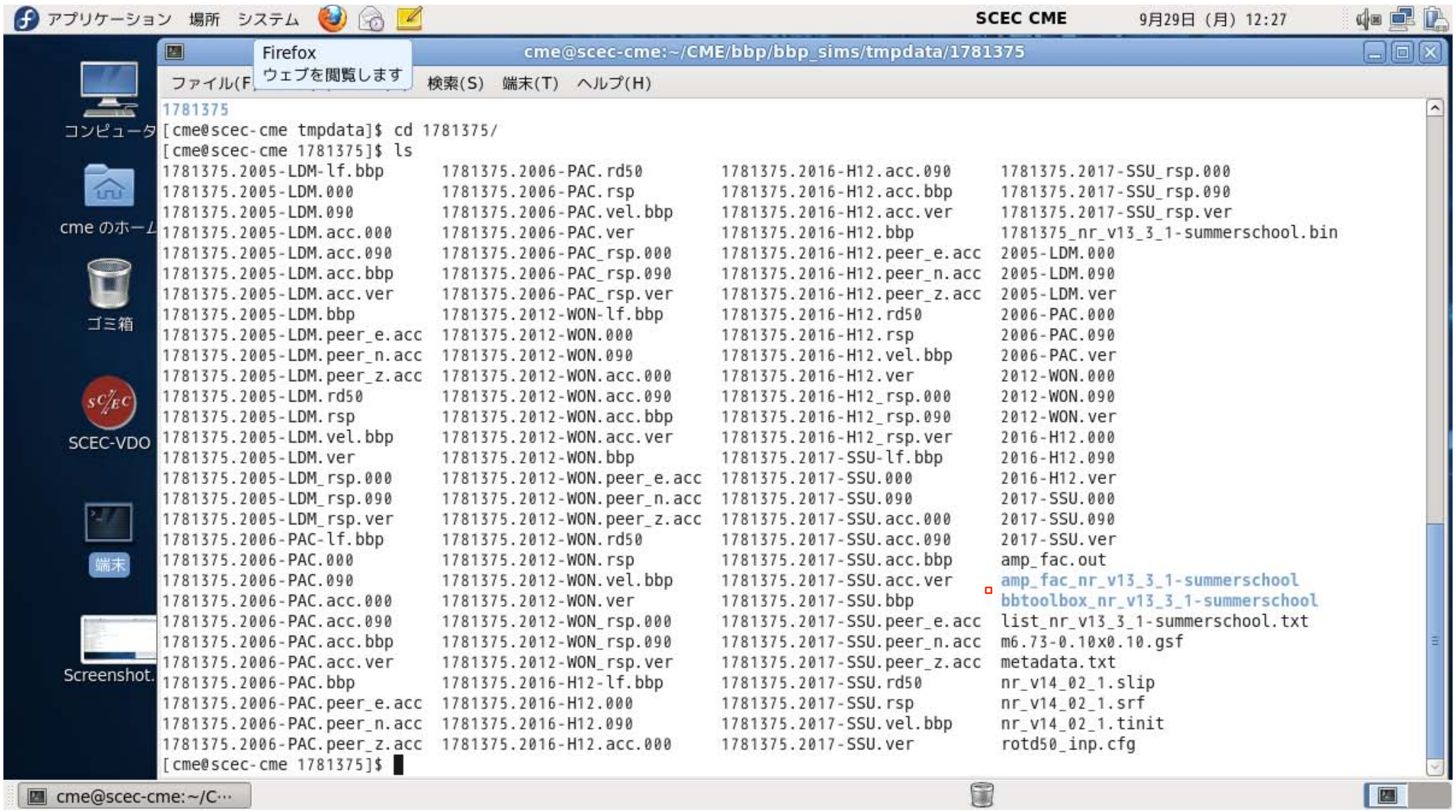
velocity model file:

# input files: xyz_nr_v14_02_1.srf
# /home/cme/CME/bbp/bbp_sims/indata/



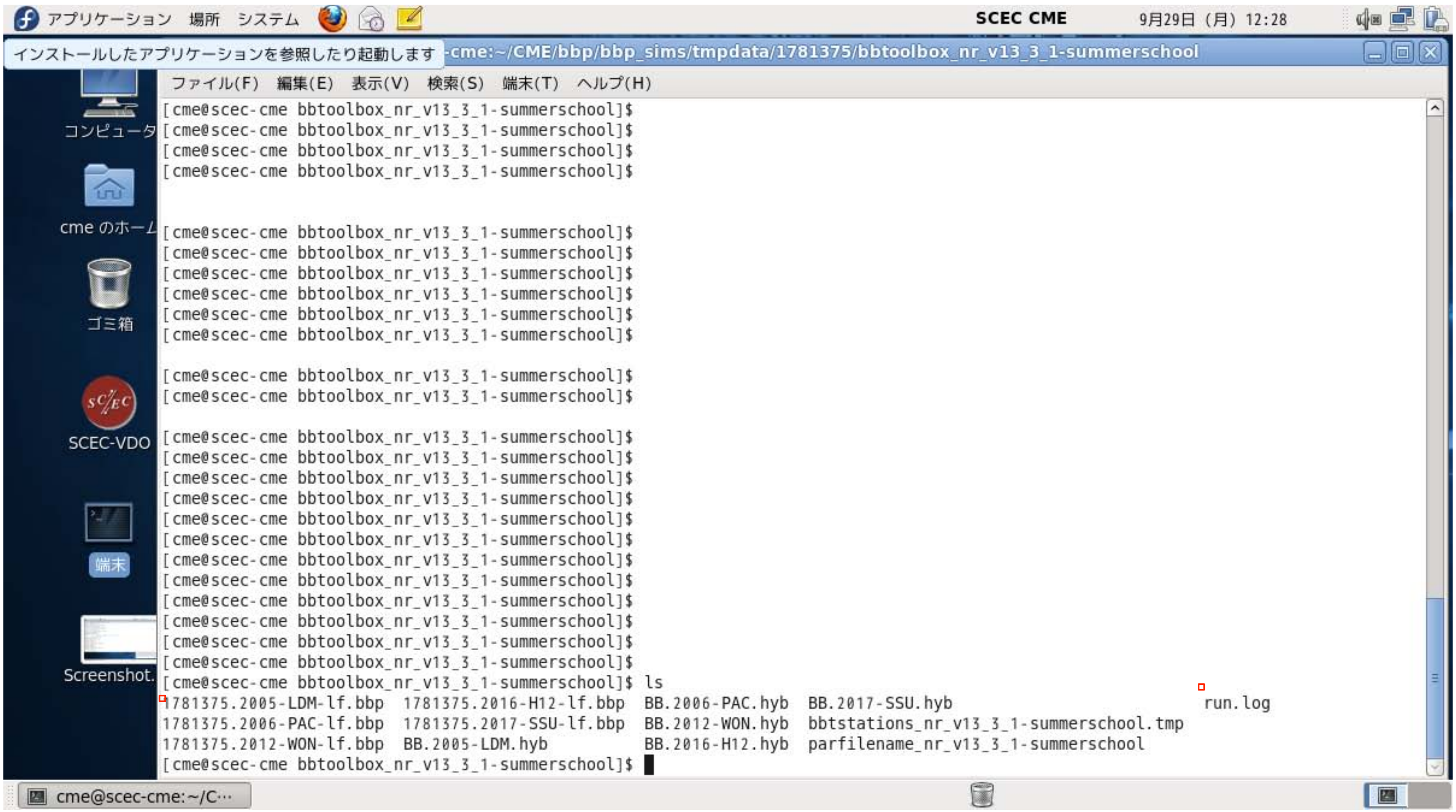

srf file:

# tmp files
# /home/cme/CME/bbp/bbp_sims/tmpdata/



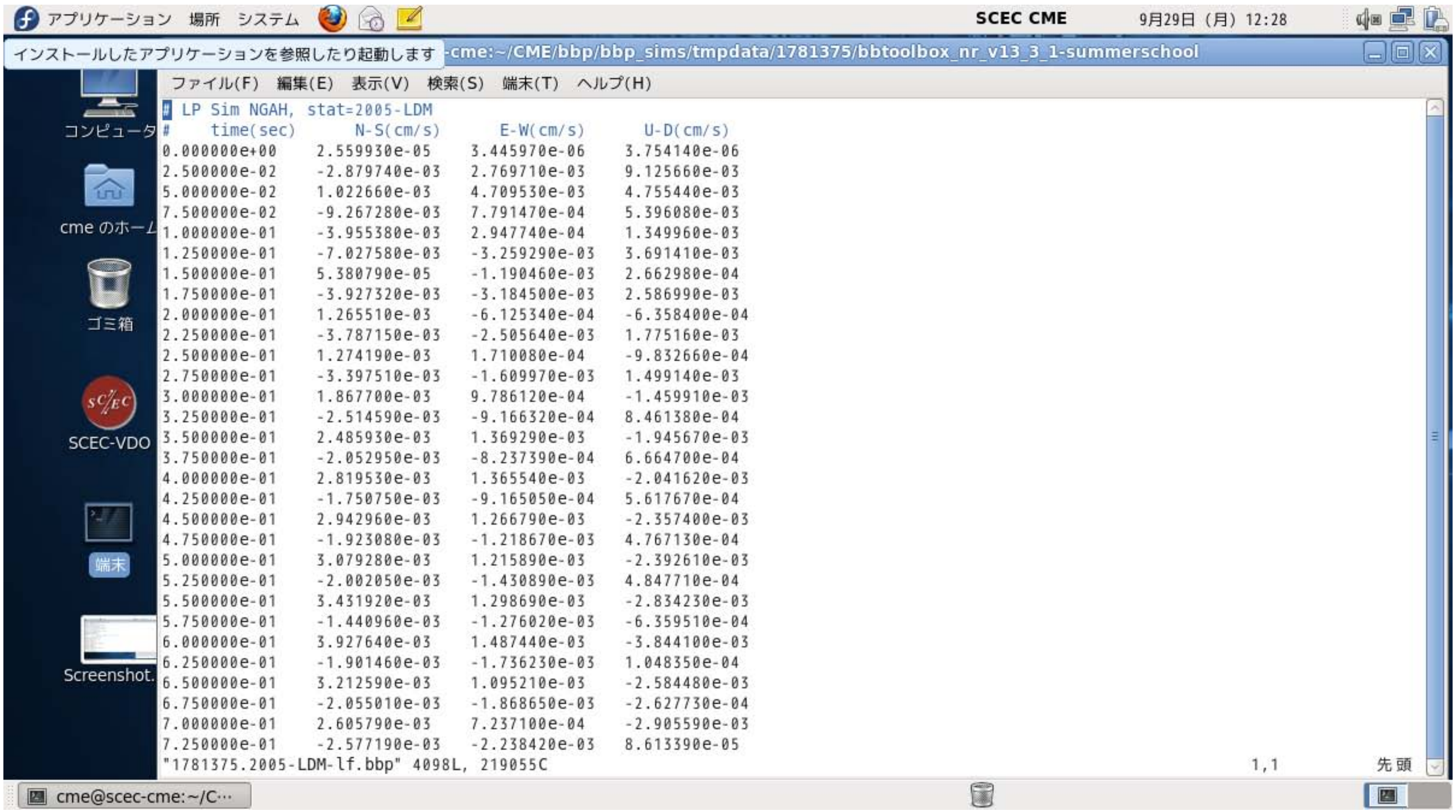

LFs are saved under tmpdata.bbtoolbox_nr_v13_3_1-summerschool:

# tmp files: LFs (*-lf.bbp) /home/cme/CME/bbp/bbp_sims/tmpdata/1781375/ bbtoolbox_nr_v14_4_1-summerschool/



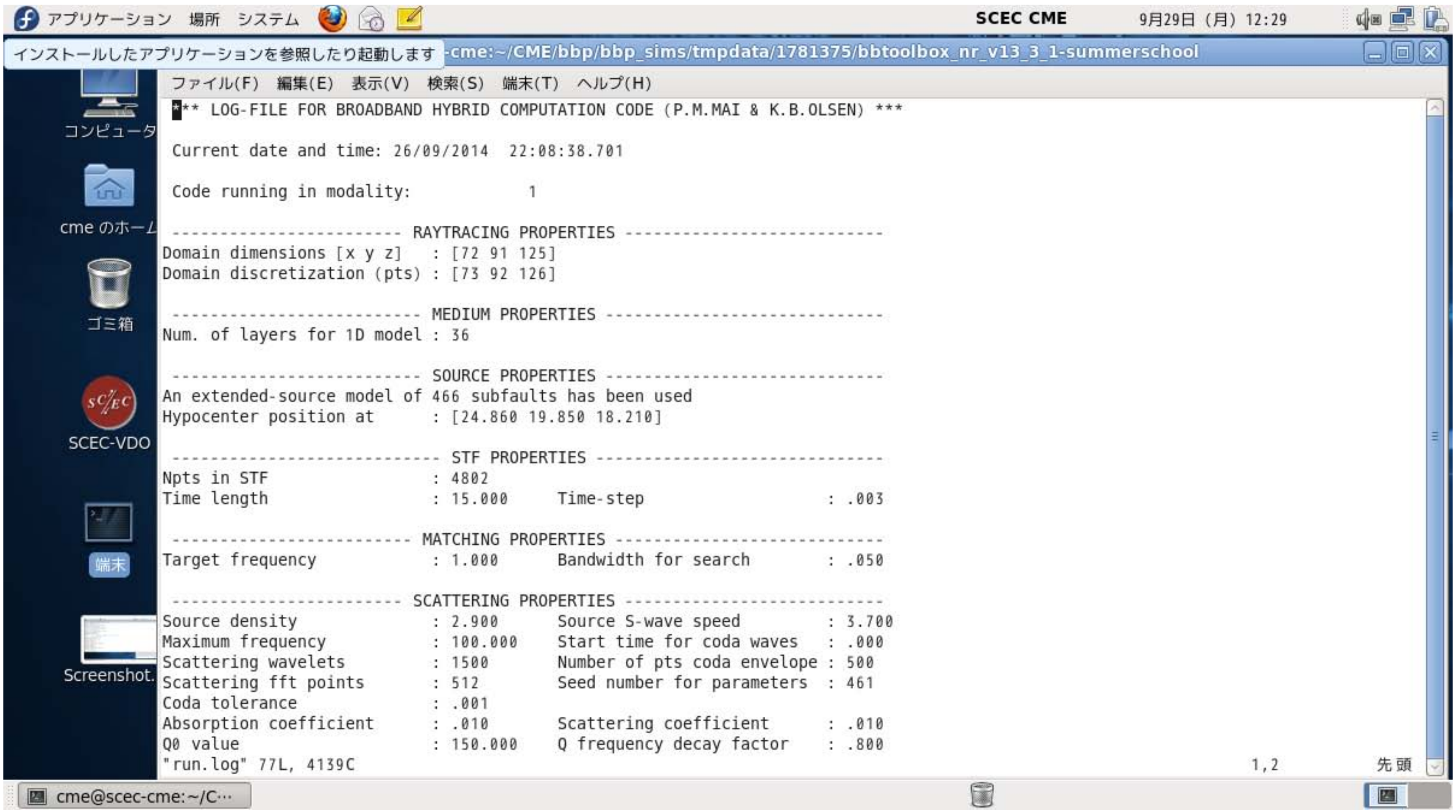

LFs are saved under tmpdata.bbtoolbox_nr_v13_3_1-summerschool/*-lf.bbp:

# tmp files: LFs (*-lf.bbp)
# /home/cme/CME/bbp/bbp_sims/tmpdata/1781375/
# bbtoolbox_nr_v14_4_1-summerschool/



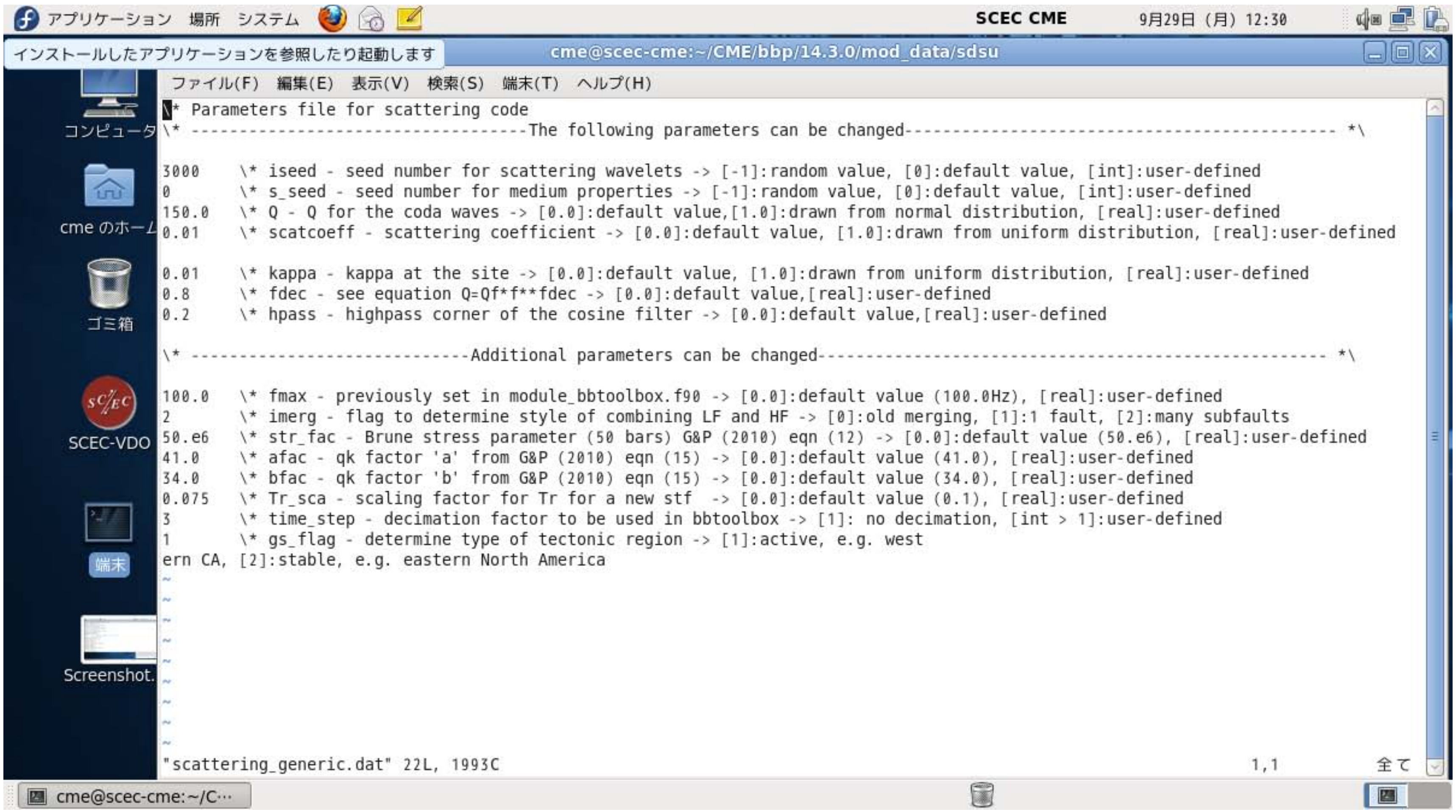

an example of LFs :

# tmp files: run.log /home/cme/CME/bbp/bbp_sims/tmpdata/1781375/ bbtoolbox_nr_v14_4_1-summerschool/



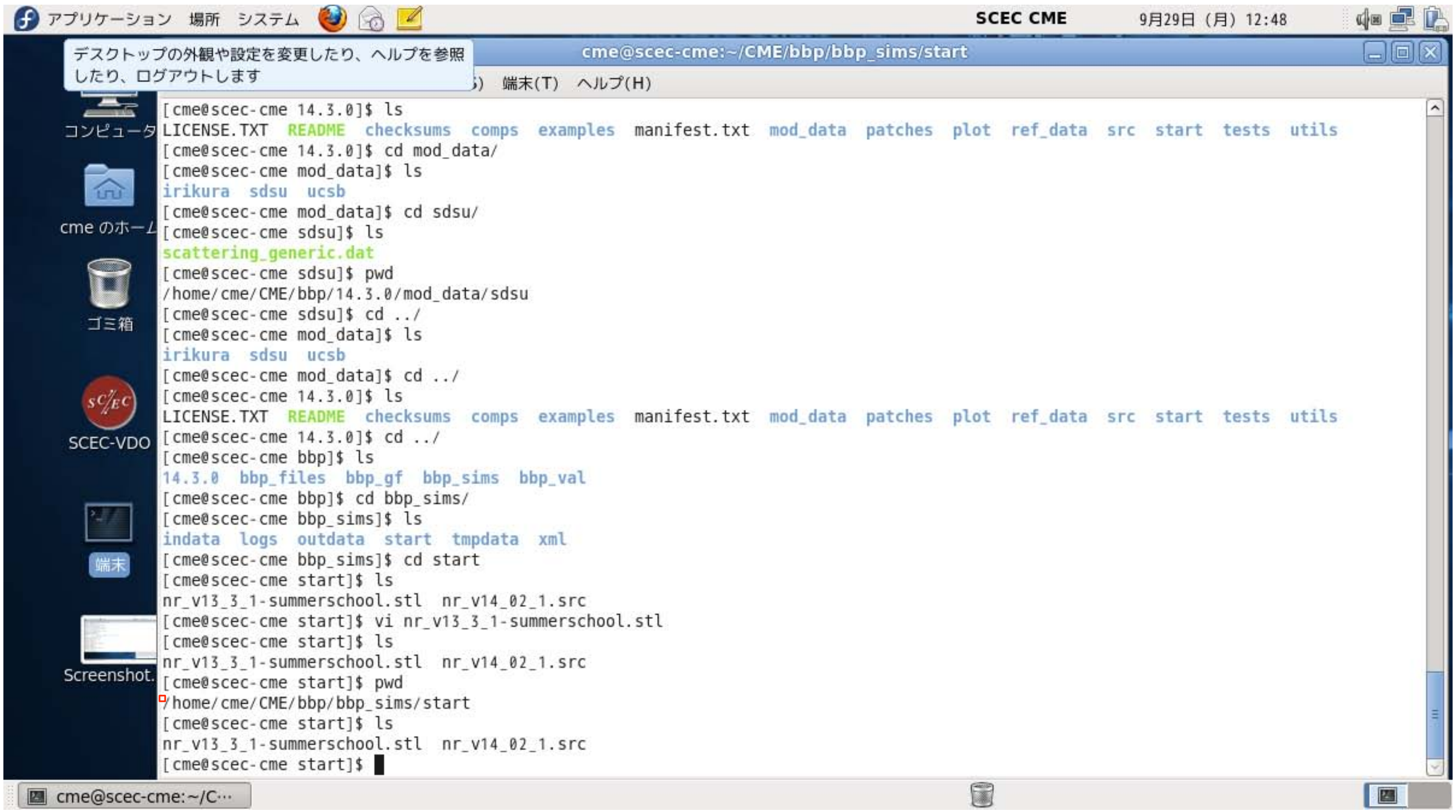

run.log are saved under tmpdata.bbtoolbox_nr_v13_3_1-summerschool:

# scattering_generic.dat
# /home/cme/CME/bbp/14.3.0/mod_data/sdsu/




users can change parameters in scattering_generic.dat:

# src and station files
# /home/cme/CME/bbp/bbp_sims/start




users can save own src file and station file (*.stl) in the start directory:
add/extract stations from the *.stl file.

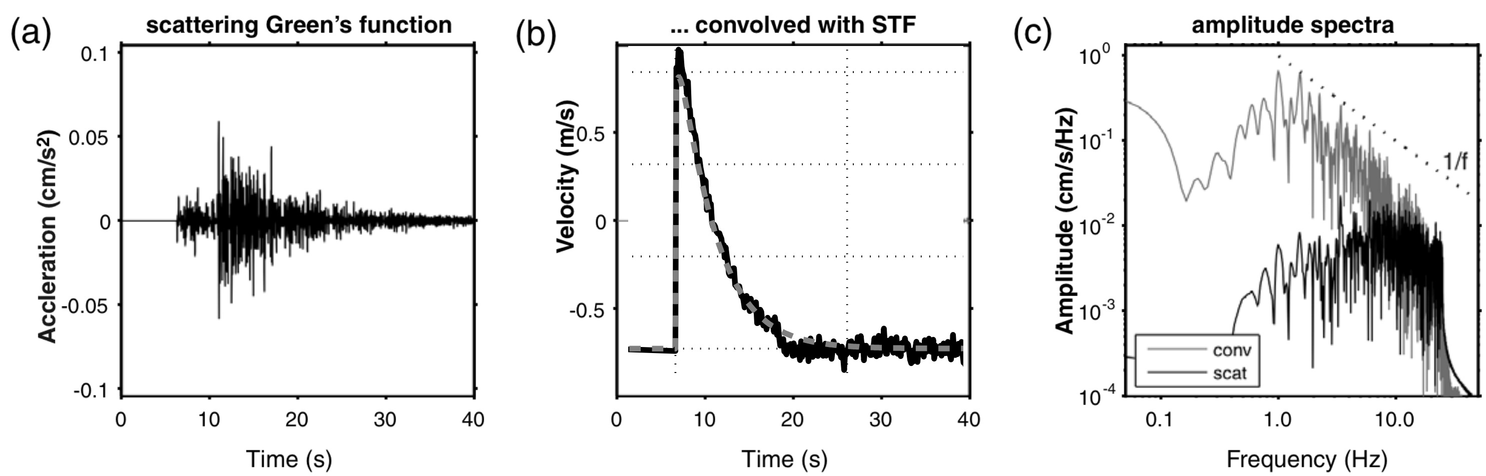
```
[cme@scec-cme comps]$ python run_bbp.py
Welcome to the SCEC Broadband Platform.
Please select the modules you want to run.
Do you want to perform a validation run (y/n)? n

Please select a velocity model (number or name are ok):

(1) LABasin
? 1
Choose a Method to use in a Broadband forward simulation:
(1) GP (Graves & Pitarka)
(2) UCSB
(3) SDSU
(4) EXSIM
(5) CSM
(6) Irikura
? 3
Do you want to run a rupture generator (y/n)? y
Do you want to
(1) select a source description in /home/cme/CME/bbp/bbp_sims/start
(2) enter a path of a source description file
? 2
Enter path and filename of source description: /home/cme/CME/bbp/bbp_val/NR/gp/nr_v14_02_1.src

Do you want to
(1) select a BBP station list in /home/cme/CME/bbp/bbp_sims/start
(2) enter a path of a BBP station list file
? 2
Enter path and filename of BBP station list: /home/cme/CME/data-files/nr_v13_3_1-summerschool.stl
Do you want to run the site response module (y/n)? n
Do you want to plot velocity seismograms (y/n)? y
Do you want to plot acceleration seismograms (y/n)? y
 Running Genslip
```

# Site-Specific Scattering Functions

➢Scattering Green's functions computed for each component of motion based on Zeng et al. (1991, 1993) and P and S arrivals from 3D ray tracing (Hole, 1992) convolved with a dynamically-consistent source-time function, generating 1/f spectral decay

➢Site-scattering parameters (scattering and attenuation coefficient, site kappa, intrinsic attenuation) are taken from the literature and are partly based on the site-specific velocity structure.

➢Assuming scattering operators and moment release originate throughout the fault, but starts at the hypocenter




➢Hybrid broadband seismograms are calculated from low-frequency and high-frequency synthetics in the frequency domain using a simultaneous amplitude and phase matching algorithm (Mai and Beroza, 2003)

## No Bias From Depth to Top of Fault

| Event | Depth | \|GOF\| |
|---|---|---|
| • Landers (ss) | 0.00 | 0.15-0.36 |
| • Tottori (ss) | 0.10 | 0.18-0.27 |
| • Niigata (rev) | 1.09 | 0.38-0.46 |
| • LOMAP (robl) | 3.85 | 0.13-0.35 |
| • N P Springs (robl) | 4.00 | 0.20-0.32 |
| • Northridge (rev) | 5.00 | 0.11-0.32 |
| • Whittier (rev) | 12.00 | 0.19-0.29 |
| | | |
| • M6.6ss | 0.00 | best GMPE |
| • M6.6rv | 3.00 | good |
| • M6.2ss | 4.00 | as good |

## Mechanism

**|GOF|**

| | <0.1s | 0.1-1s | 1-3s | >3s |
|---|---|---|---|---|
| Rev | 0.57 | 0.61 | 0.76 | 1.00 |
| ROBL | 0.60 | 0.63 | 0.67 | 0.48 |
| SS | 0.48 | 0.60 | 0.68 | 0.70 |
| NM | ------------------------- | | | |
| Av-CA | 0.57 | 0.61 | 0.61 | 0.66 |
| Av-All | 0.55 | 0.61 | 0.71 | 0.79 |

# Mechanism, Overall Bias

0.01-0.1s 0.1-1s 1-3s >3s

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mechanism | Reverse (REV) | 0.47 | 0.32 | 0.27 | 0.35 | 0.48 | | 0.82 | 0.34 | 0.32 | 0.35 | 0.37 | | 0.51 | 0.35 | 0.55 | 0.64 | 0.52 | | 0.76 | 0.28 | 0.88 | 0.93 | 0.59 | |
| | Reverse-Oblique (ROBL) | 0.30 | 0.40 | 0.26 | 0.28 | 0.28 | | 0.57 | 0.31 | 0.25 | 0.28 | 0.26 | | 0.54 | 0.34 | 0.29 | 0.31 | 0.26 | | 0.45 | 0.51 | 0.35 | 0.35 | 0.37 | |
| | Strike-Slip (SS) | 0.47 | 0.35 | 0.38 | 0.43 | 0.38 | | 0.33 | 0.43 | 0.46 | 0.43 | 0.38 | | 0.37 | 0.42 | 0.54 | 0.65 | 0.45 | | 0.41 | 0.37 | 0.50 | 0.55 | 0.30 | |
| | Normal (NM) | | | | | | | | | | | | | | | | | | | | | | | | |
| Total | **Average CA** | 0.34 | 0.27 | 0.33 | 0.31 | 0.36 | | 0.58 | 0.28 | 0.35 | 0.32 | 0.32 | | 0.49 | 0.35 | 0.40 | 0.42 | 0.36 | | 0.48 | 0.35 | 0.40 | 0.40 | 0.33 | |
| | **Average CENA** | 1.47 | 0.38 | 0.50 | 0.25 | 1.27 | | 2.19 | 0.52 | 0.57 | 0.34 | 0.76 | | 1.90 | 0.57 | 0.76 | 0.46 | 0.43 | | 0.48 | 0.77 | 0.23 | 0.22 | 0.47 | |
| | **Average ALL** | 0.33 | 0.29 | 0.27 | 0.32 | 0.35 | | 0.63 | 0.27 | 0.34 | 0.33 | 0.31 | | 0.47 | 0.34 | 0.47 | 0.55 | 0.42 | | 0.42 | 0.36 | 0.58 | 0.62 | 0.38 | |

# Summary

- Plan B scenarios
  - All within specified tolerances
  - Strike-slip scenarios at or slightly below median
  - Reverse scenarios at or slightly above median
  - No significant dependence on velocity model

- Plan A scenarios
  - |Bias| generally < 0.2
  - Time histories look reasonable
  - No significant distance bias, (two) Plan A near-fault (1-3 km) OK
  - No known issues with mechanism, depth to top of fault
  - General overprediction at LFs (as do the GMPEs…)

- Projection to lower and higher magnitudes
  - $5 < M_w < 5.9$ expected to work with modified input parameter
  - $5.9 < M_w < 8$ expected to work as is
  - $M_w > 8$ not sure/potential issues – no saturation of synthetics

- Known Issues:
  - Raytracer domain size (no show stopper)