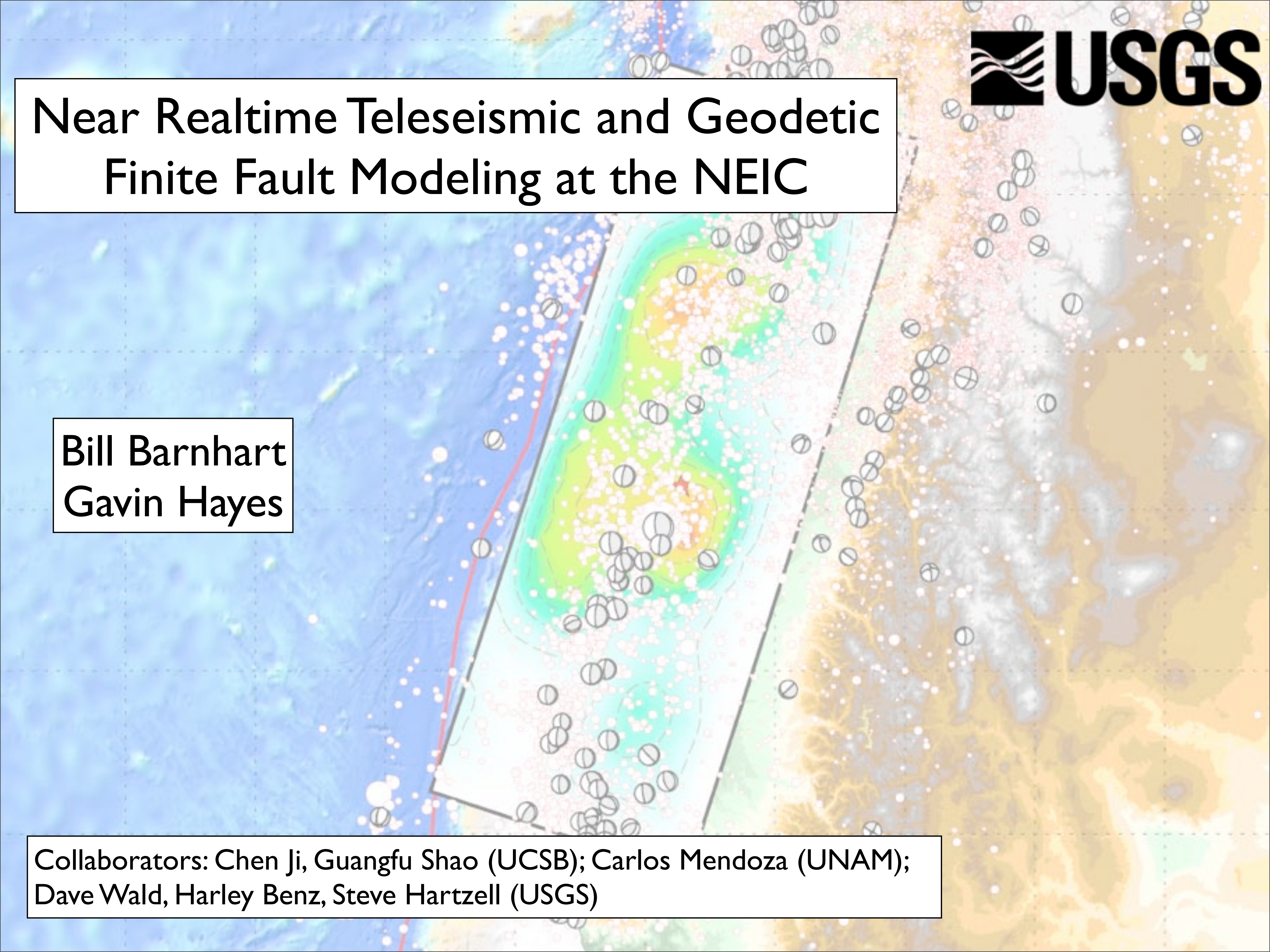
Near Realtime Teleseismic and Geodetic Finite Fault Modeling at the NEIC

Bill Barnhart
Gavin Hayes

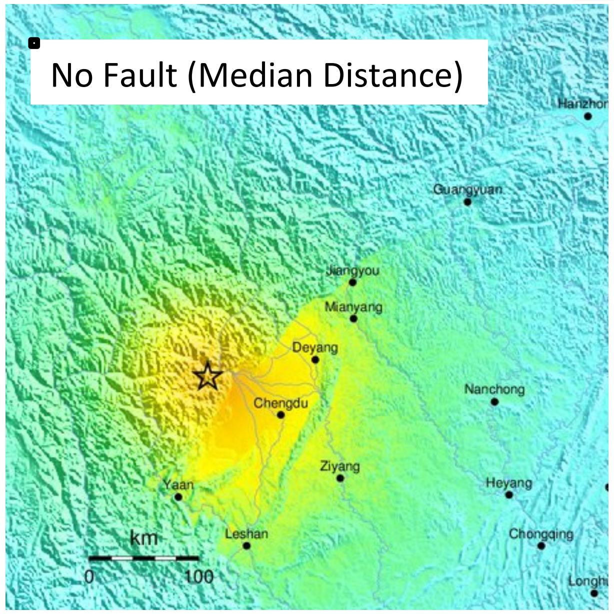


Collaborators: Chen Ji, Guangfu Shao (UCSB); Carlos Mendoza (UNAM); Dave Wald, Harley Benz, Steve Hartzell (USGS)

NEIC Realtime Response

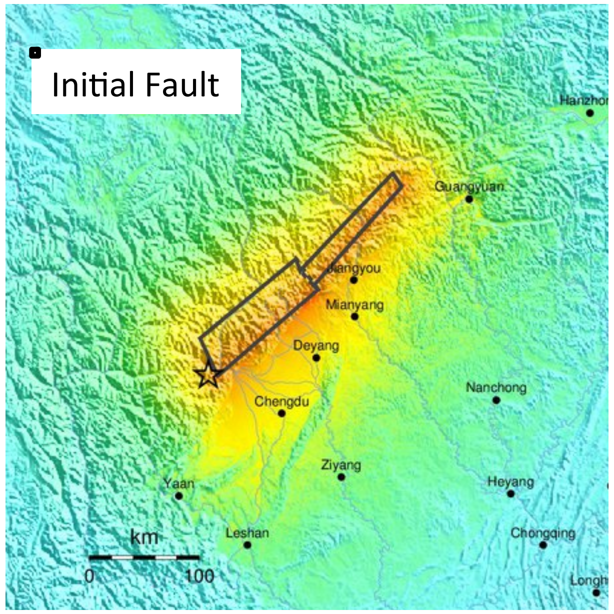
Location
Magnitude
Mechanism
- PAGER
- ShakeMap
- Press Releases

< 60 minutes



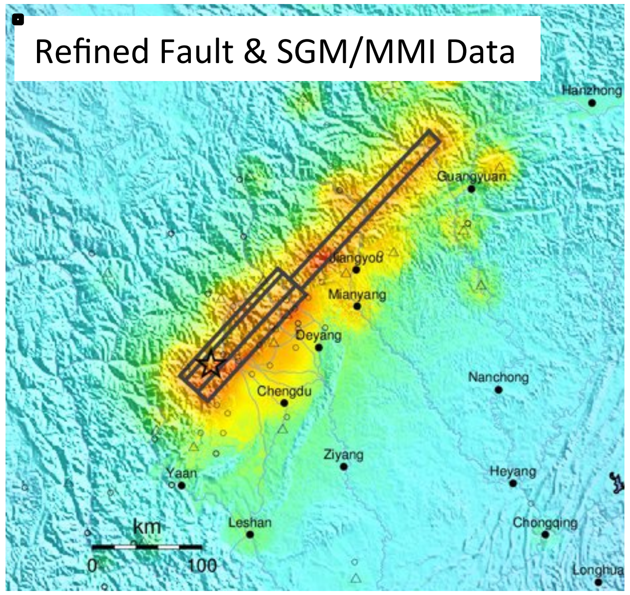
Fast Finite Fault Model
- Revised Products

60-95 minutes



Revised FFM
Geodetic Observations
- Revised Products
- Uncertainty Analysis
- Research Products

2-3 hours
Days-Months



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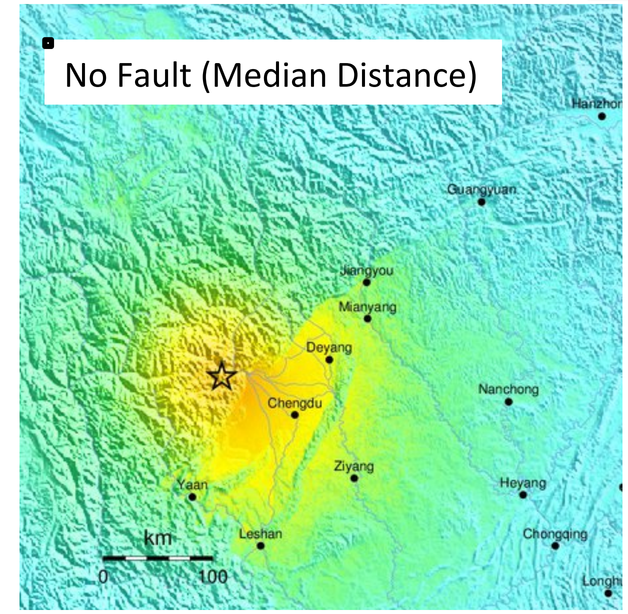

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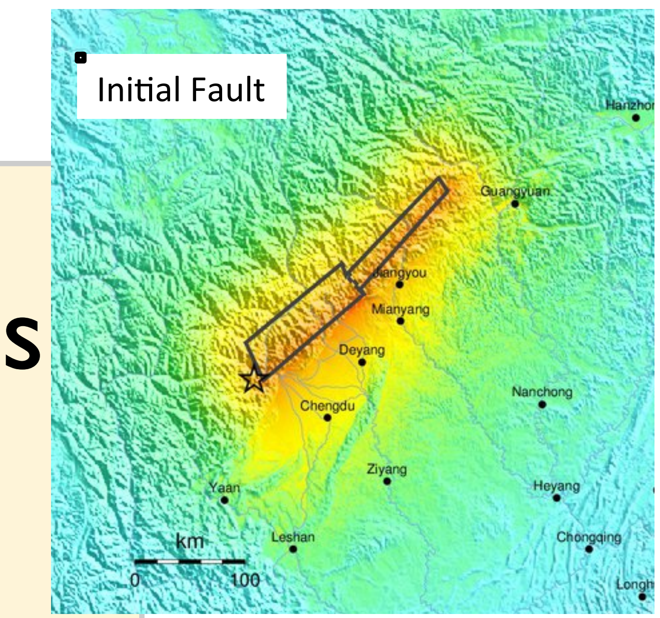

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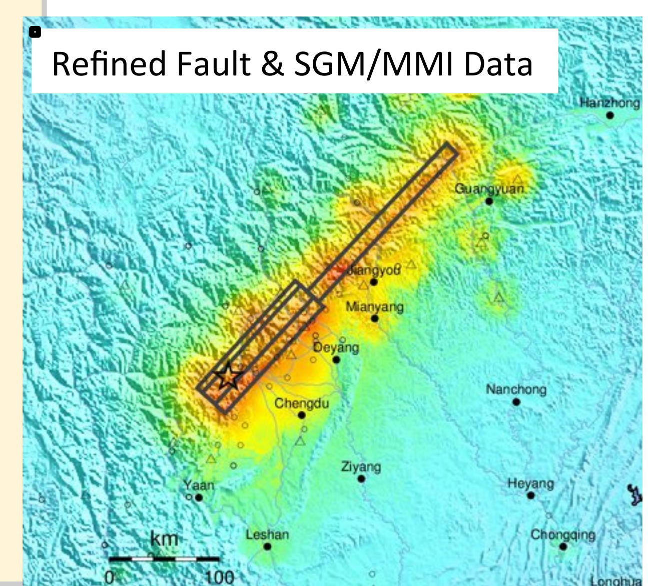
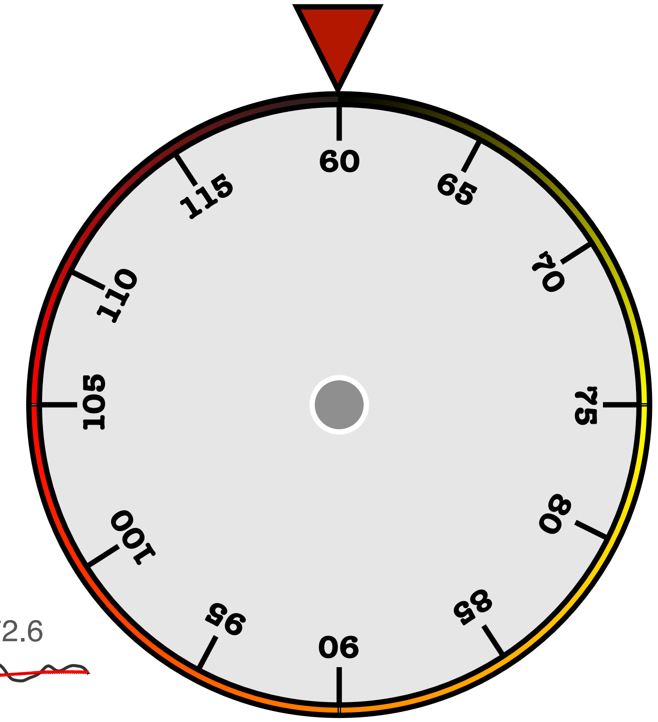
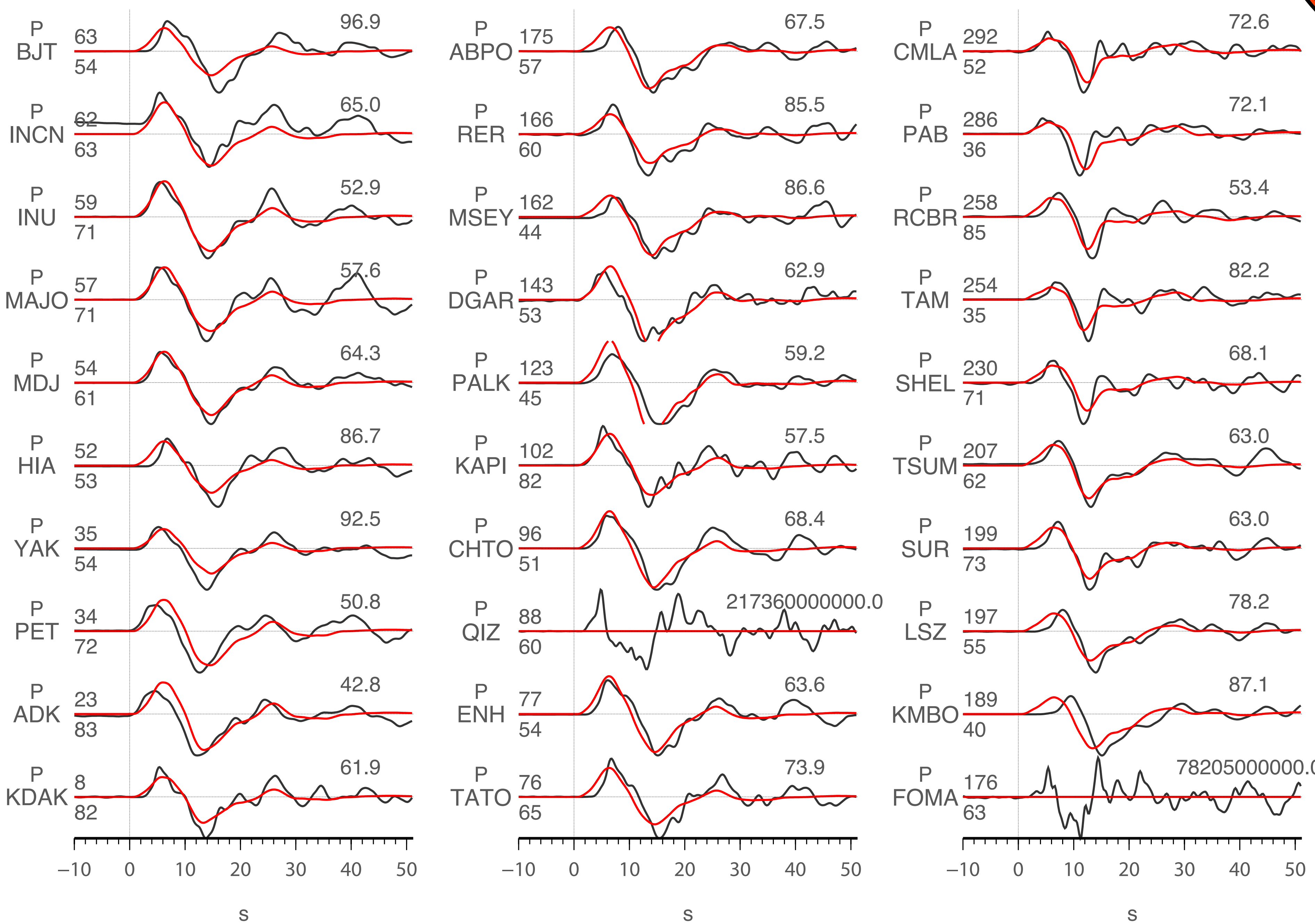


FFM Trigger (W-phase)

- After completion of W-phase, surface waves at ~90 degrees
- Uses best-fitting CMT nodal planes
- Omits waveforms flagged by W-phase noise criteria



Body Waves, Turkey EQ 10/23/2011



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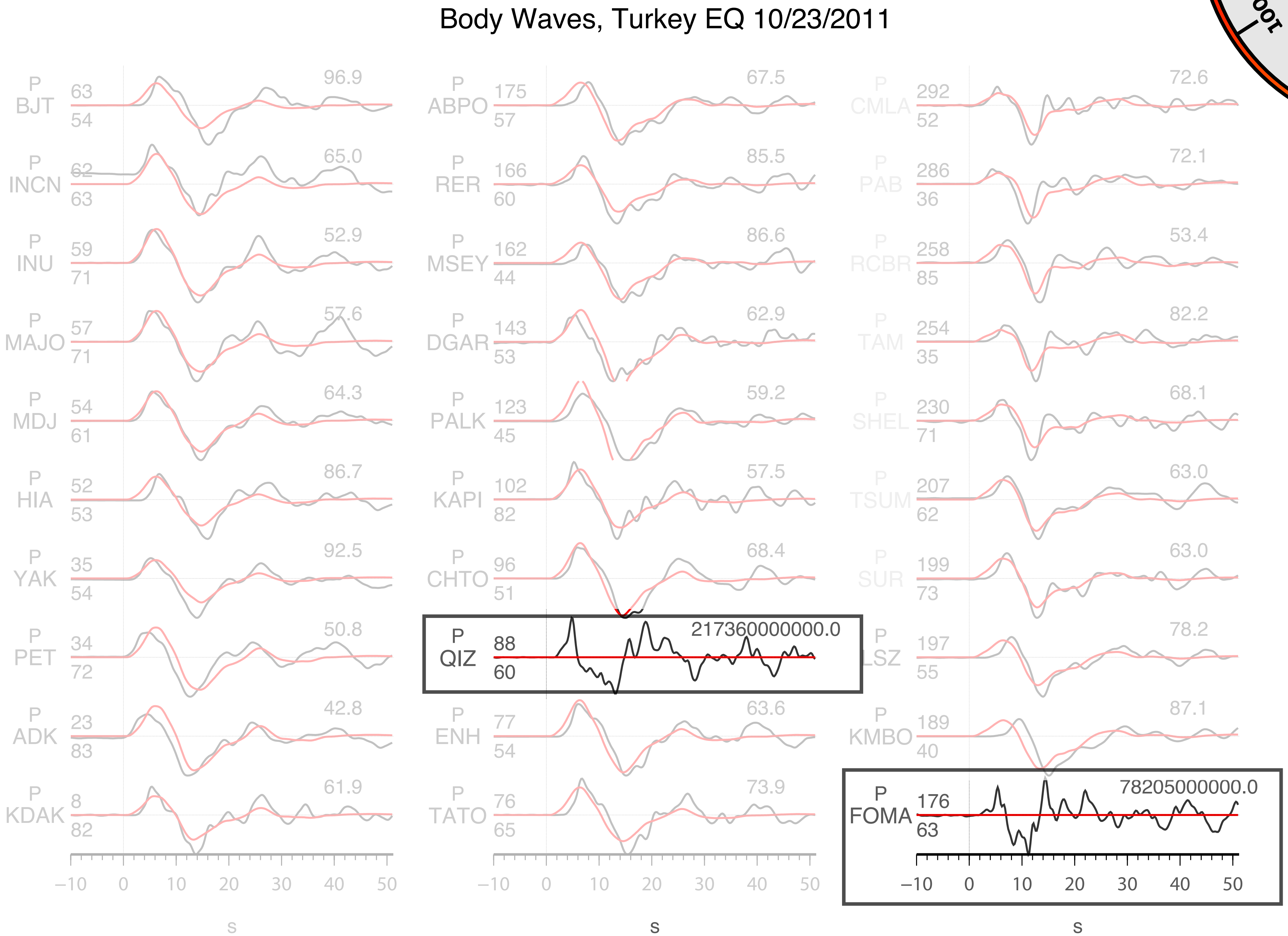
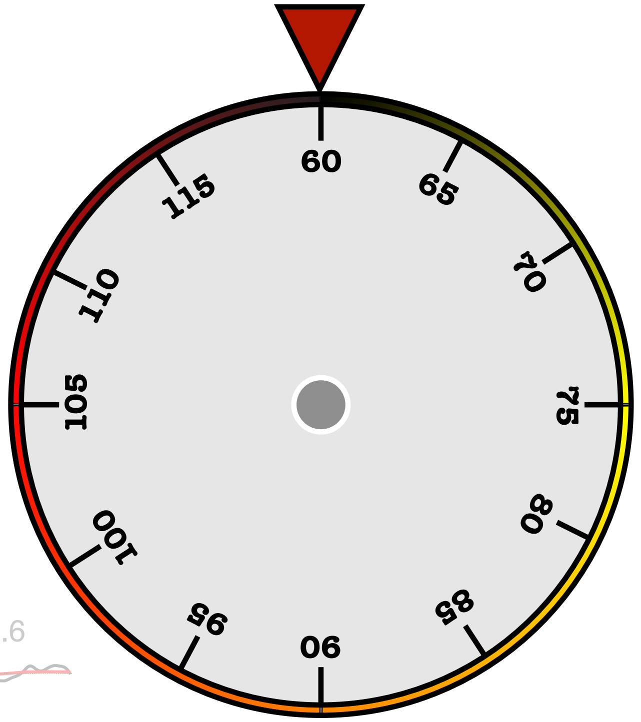
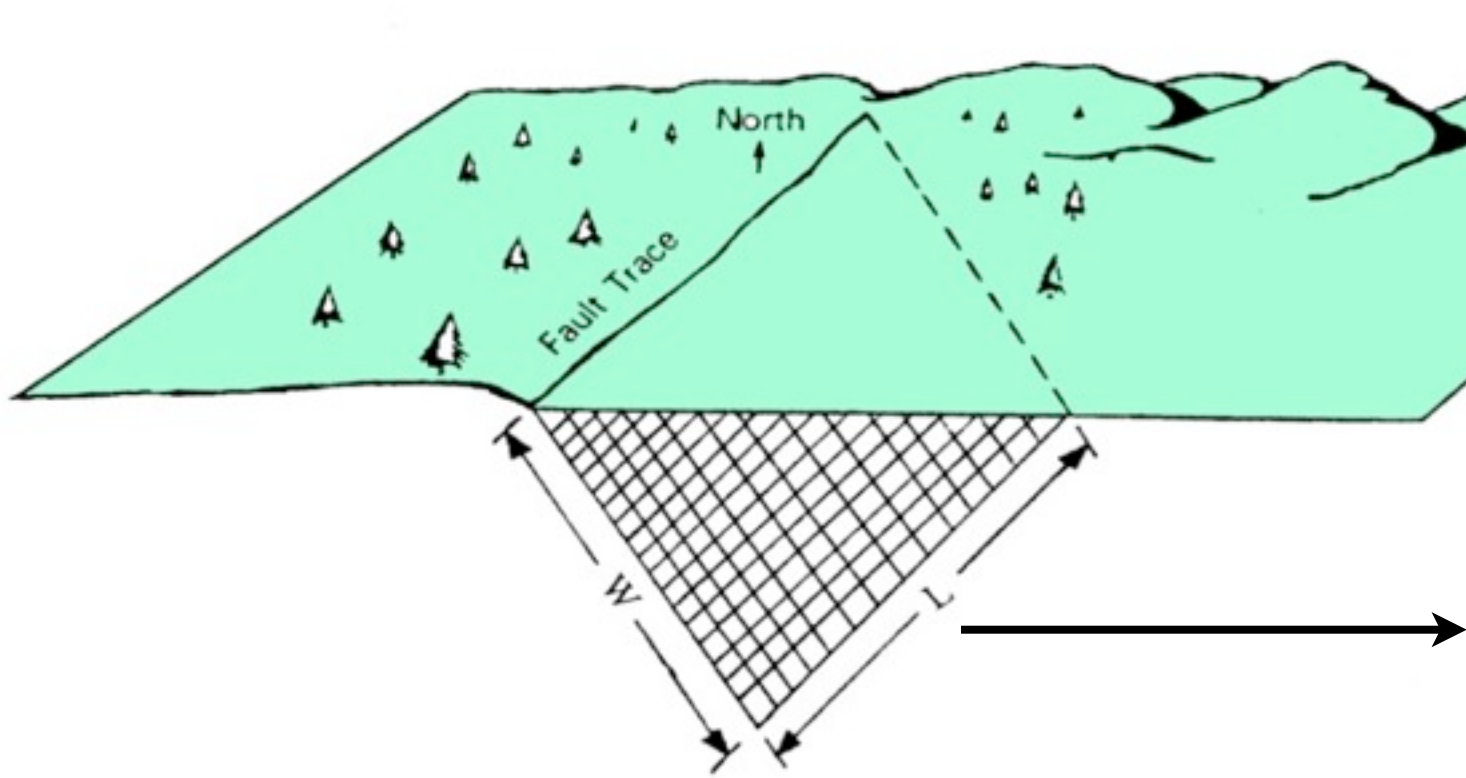
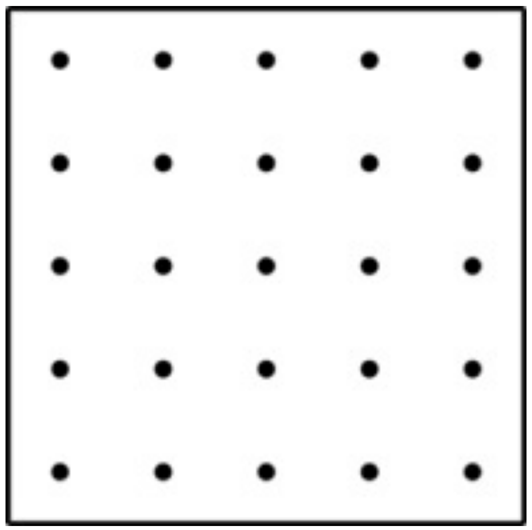




FFM Inversion 1



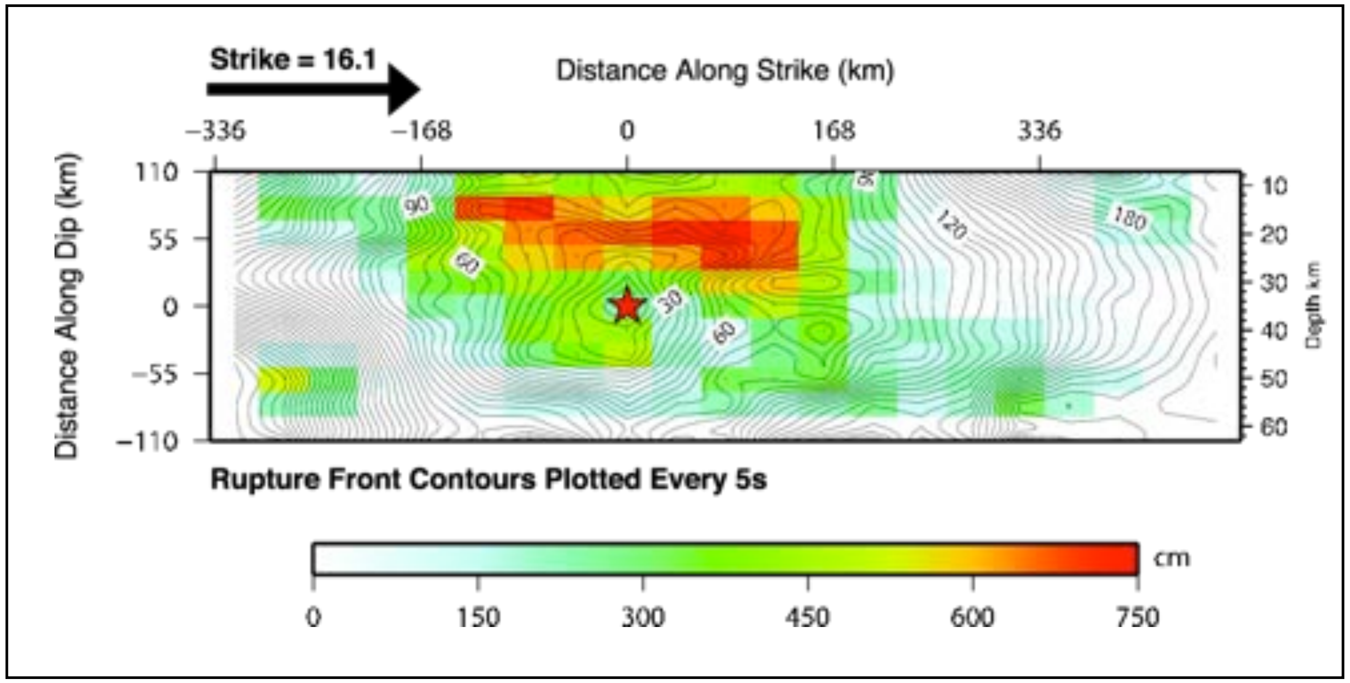


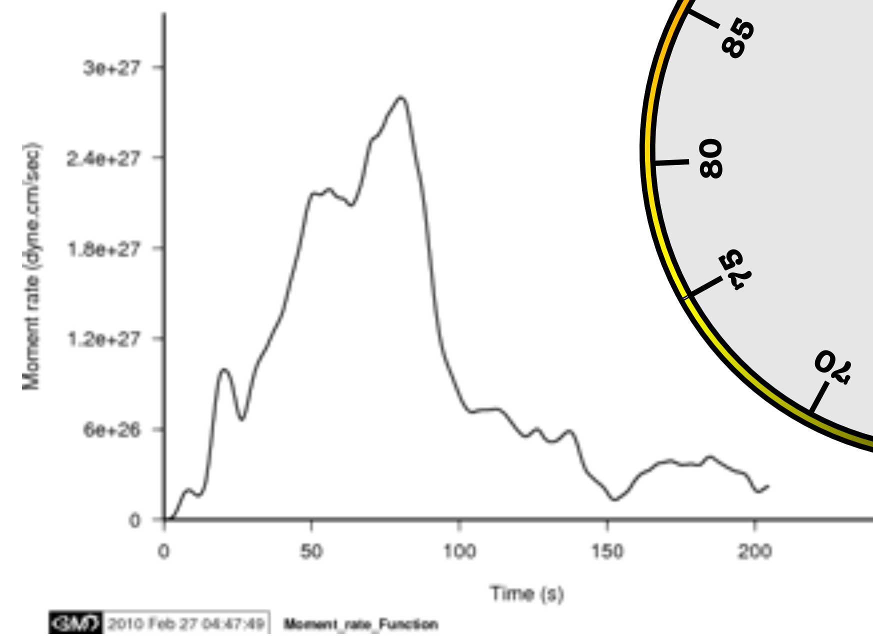
At each sub-fault, solve for:

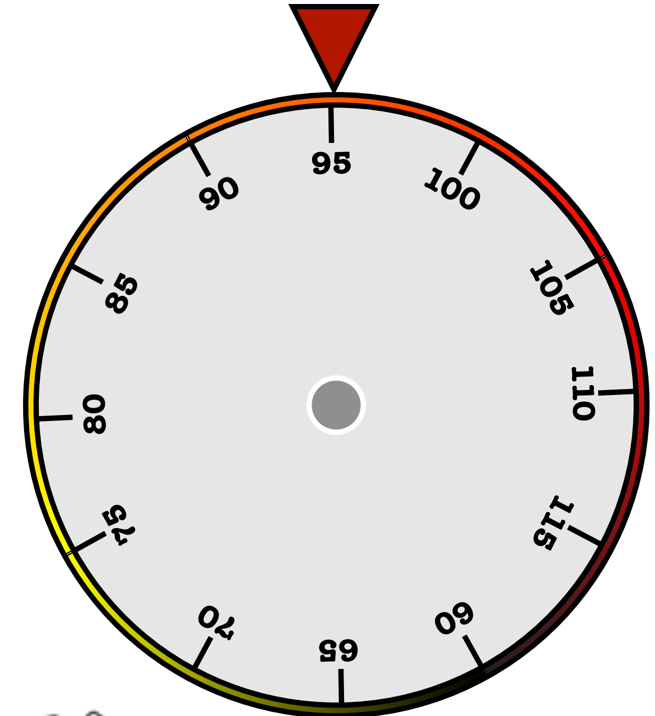
- Slip Magnitude
  - moment constrained
- Slip Direction (rake)
  - CMT or input assumption constrained
- Rupture Initiation (e.g. Rupture velocity)
  - input assumption constrained
- Rupture Duration
  - moment constrained

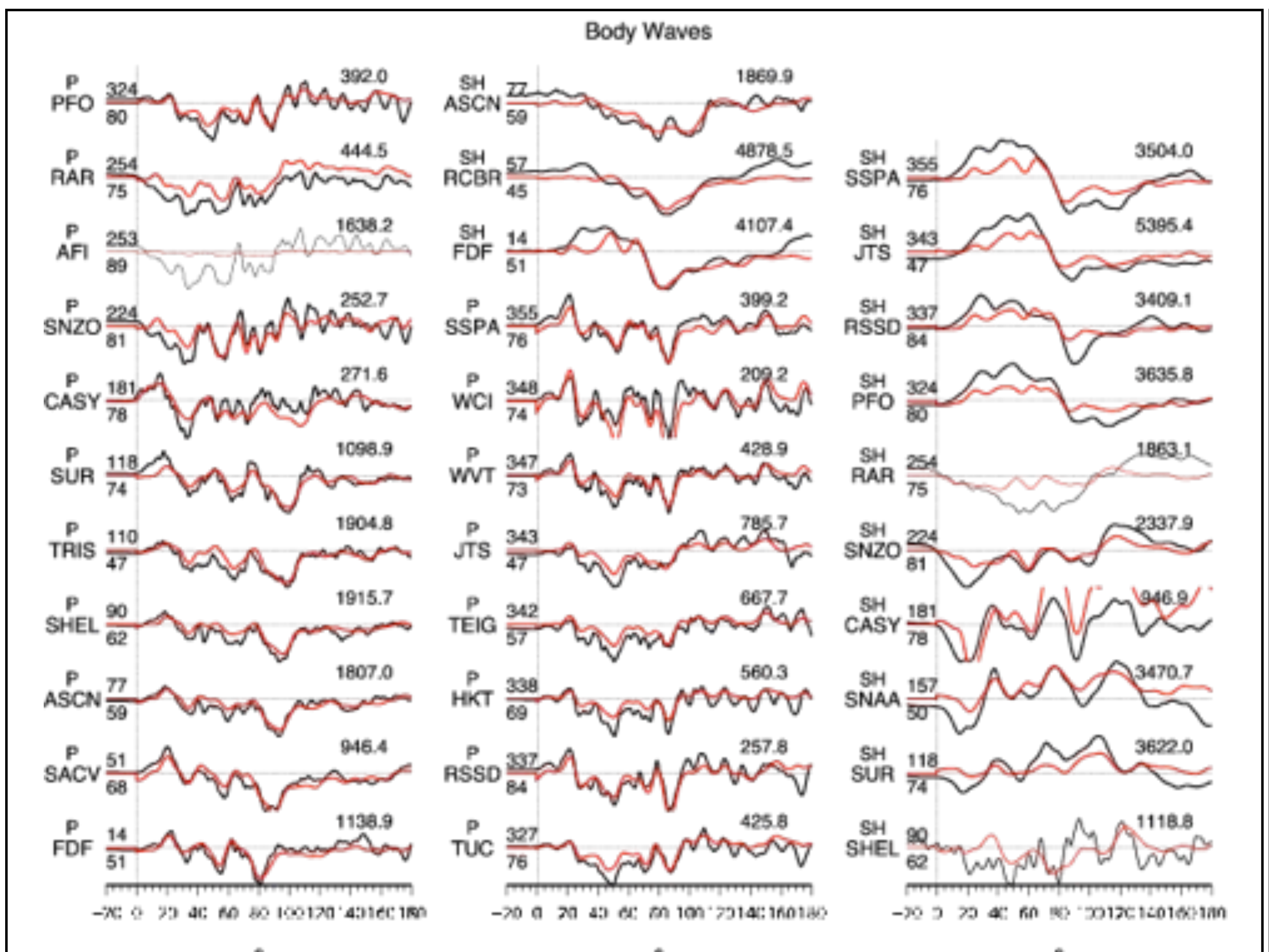
Figure & inversion approach courtesy of Chen Ji

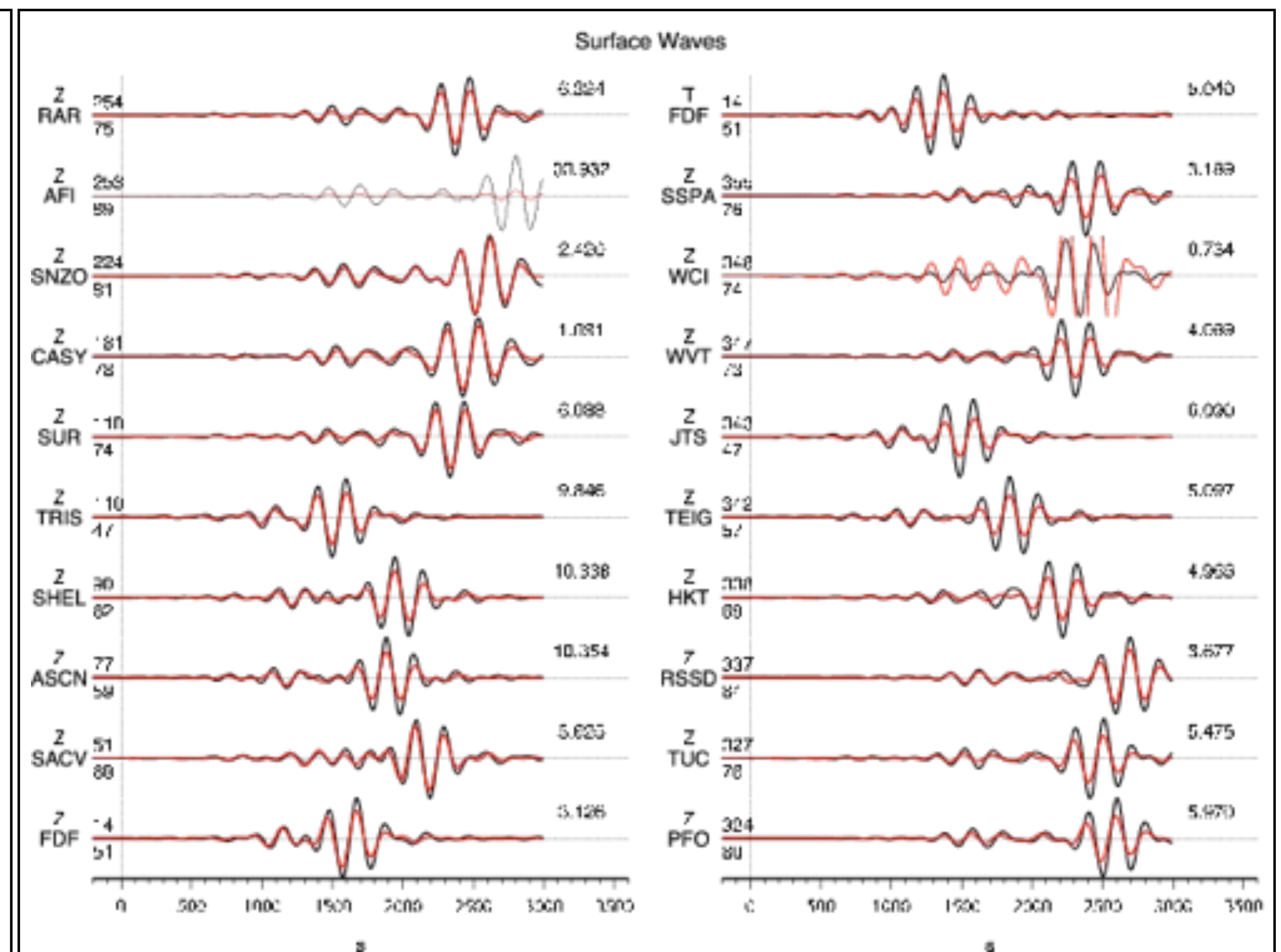
FFM Inversion 1: Solution (Maule)



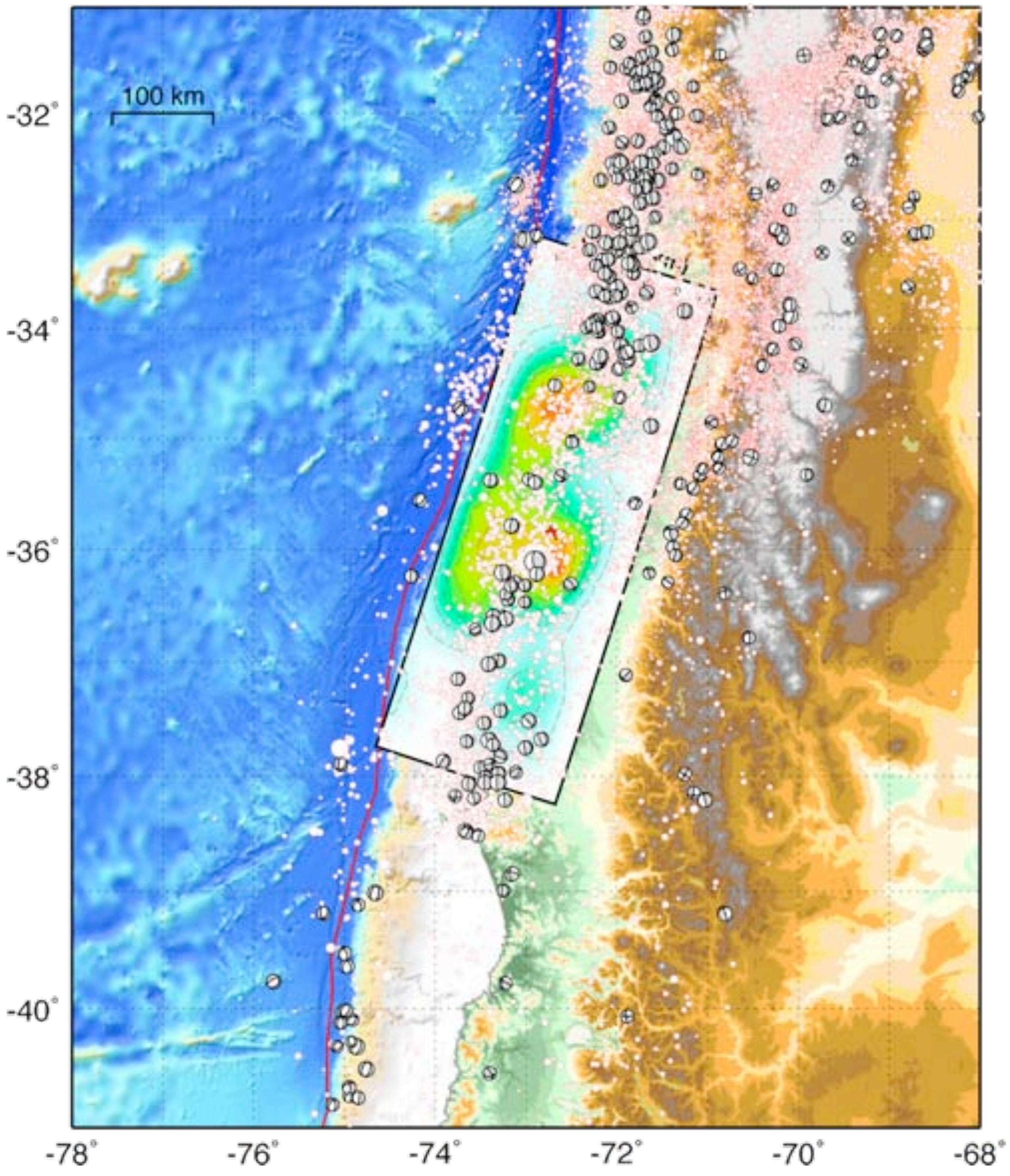


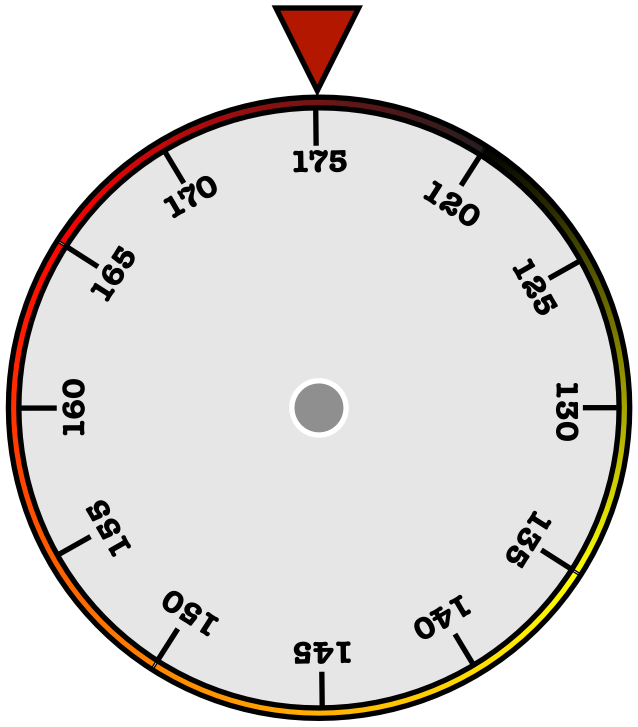






FFM Inversion 2: Revised Solution (Maule)





Explore:

- Waveform fits, onsets
- Assumed fault geometry
- Rupture velocity
- Slip & rake constraints
- Data sensitivities

Teleseismic RT FFM Uncertainty

1) Timing - misfit between data & synthetics
   Use analyst picks
   Shift with X-correlation/calibration event

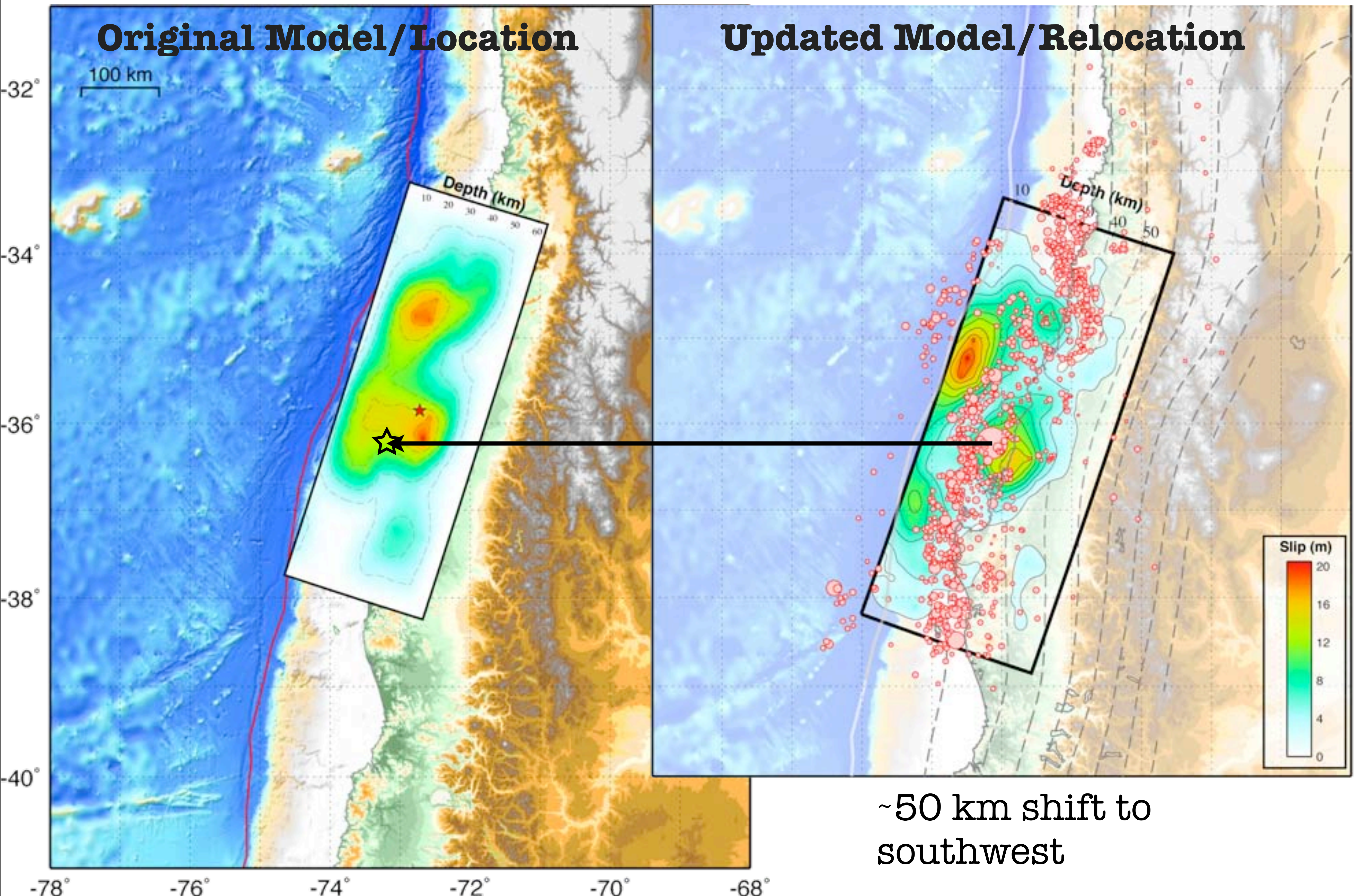
2) Fault Geometry
   Fix to known structure (e.g. Slab 1.0, Geodetic location)

3) EQ Mislocation
   Rapid relocations necessary *

4) Incorrect Assumptions (e.g., Vr, time, rupture direction)
   Difficult to handle rapidly

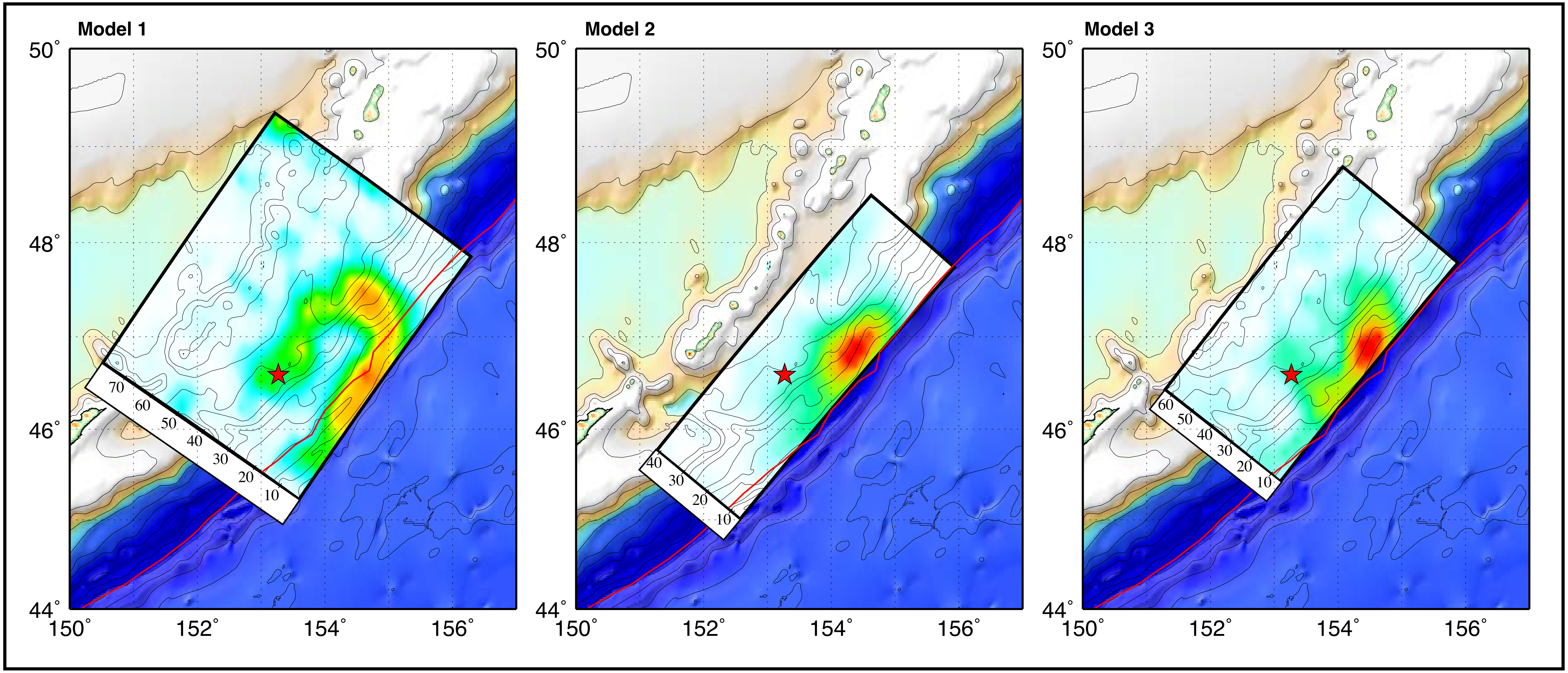
5) Green's Functions, Velocity Model, etc
   Difficult to handle rapidly

Event Mislocation



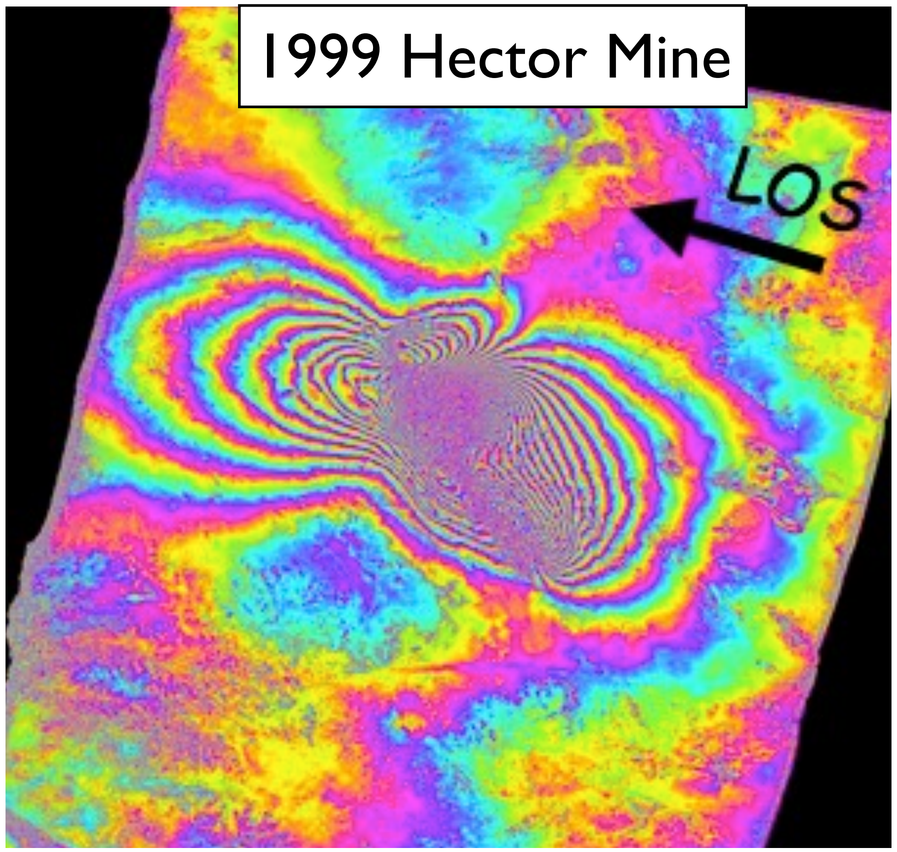
~50 km shift to southwest

FFMs & Slab1.0: Model error



- Model 1: Quick FFM. CMT Dip = 15º, initial PDE Depth = 39km.
- Model 2: Adjusted FFM (days after event), made to fit trench geometry (Chen Ji).
- Model 3: Slab1.0 Dip = 18º, Depth = 30km.

Geodetic Source Inversions



Data Sources:

- GPS (continuous, high rate)
- InSAR
- Optical Imagery
- LiDAR

Invert For:

- Location/Depth
- Orientation
- Fault Dimensions
- Slip Distribution

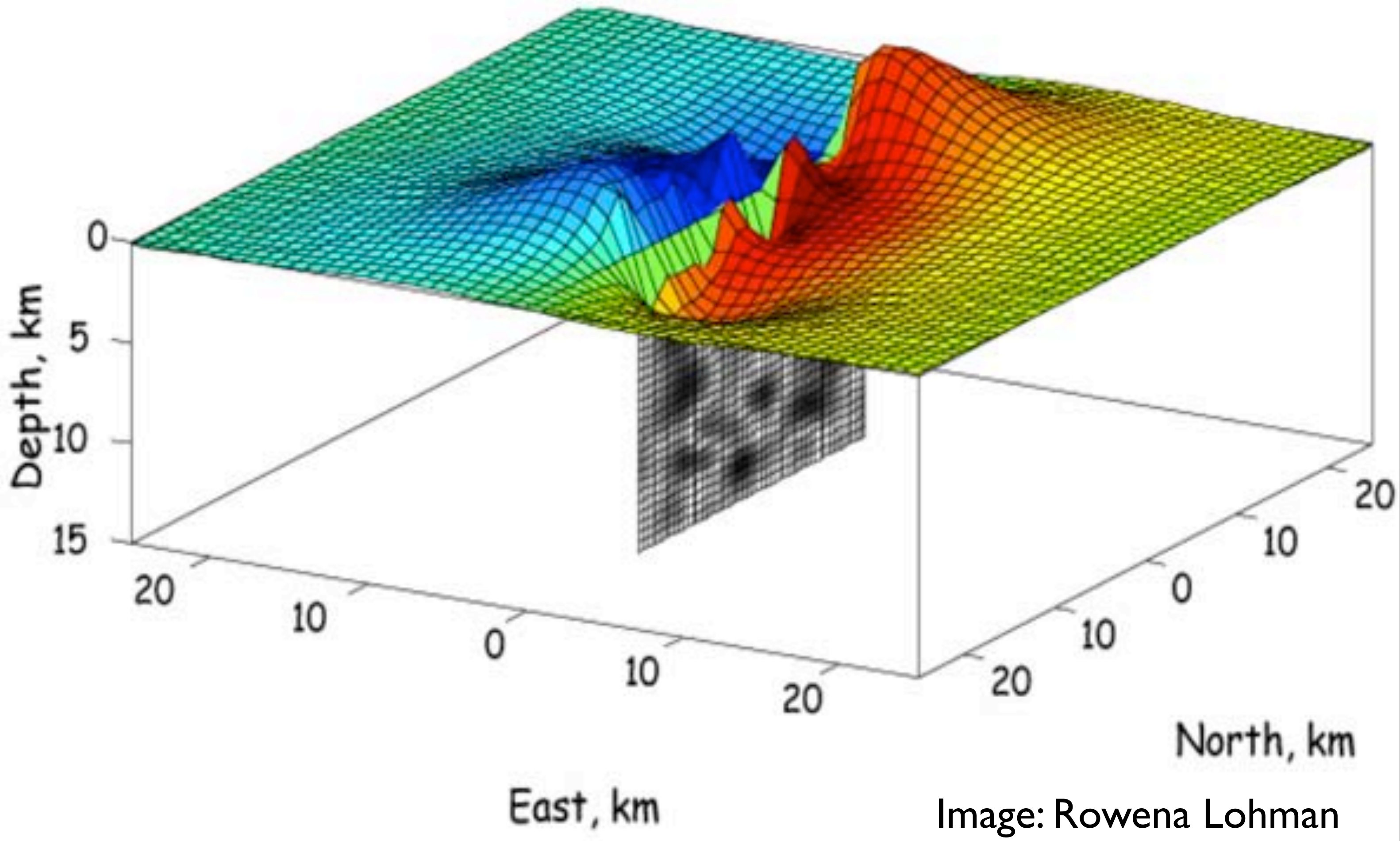


Image: Rowena Lohman

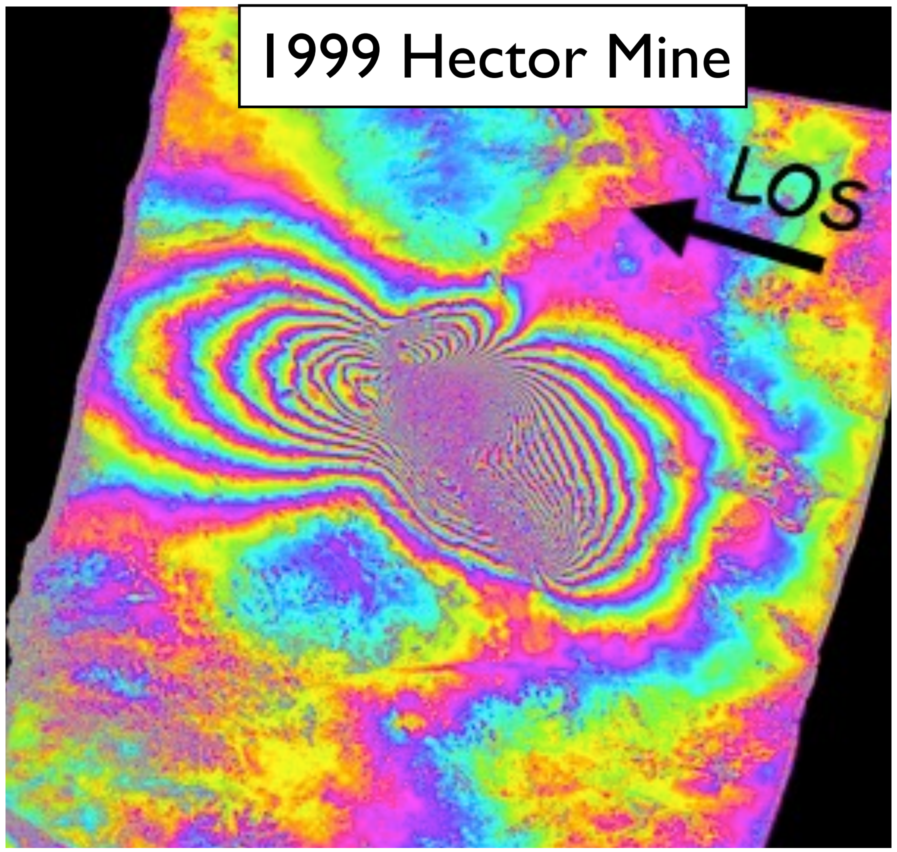
Geodetic Source Inversions

Advantages:

- Centroid location and rupture dimensions
- Slip and faulting complexity
- Expands magnitude range of EQs
- Inversions are fast
- Uniform GFs (w/ analytical answer)

Disadvantages:

- Time latency
- Spatial coverage
- Contamination with aseismic
- Simplified GFs



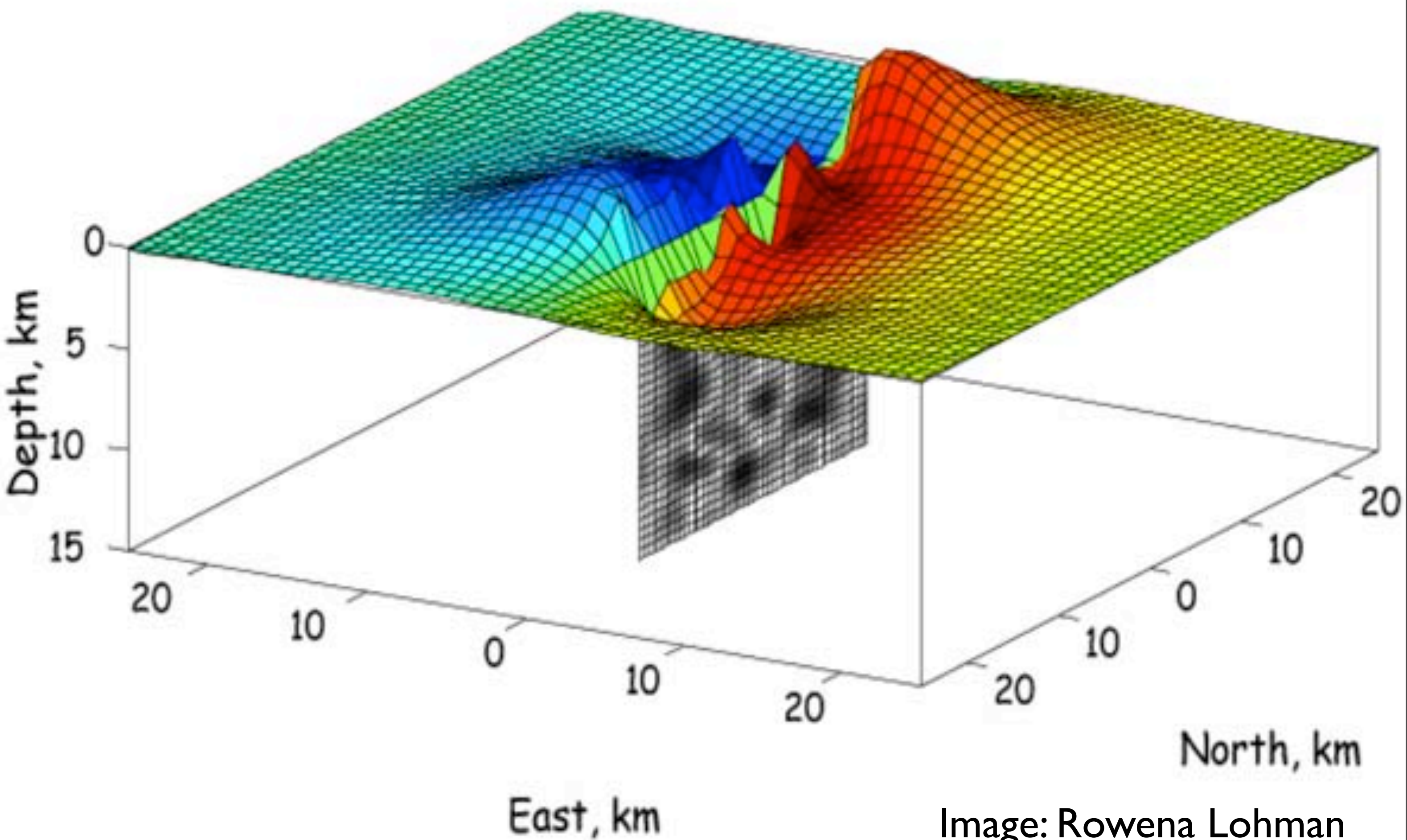
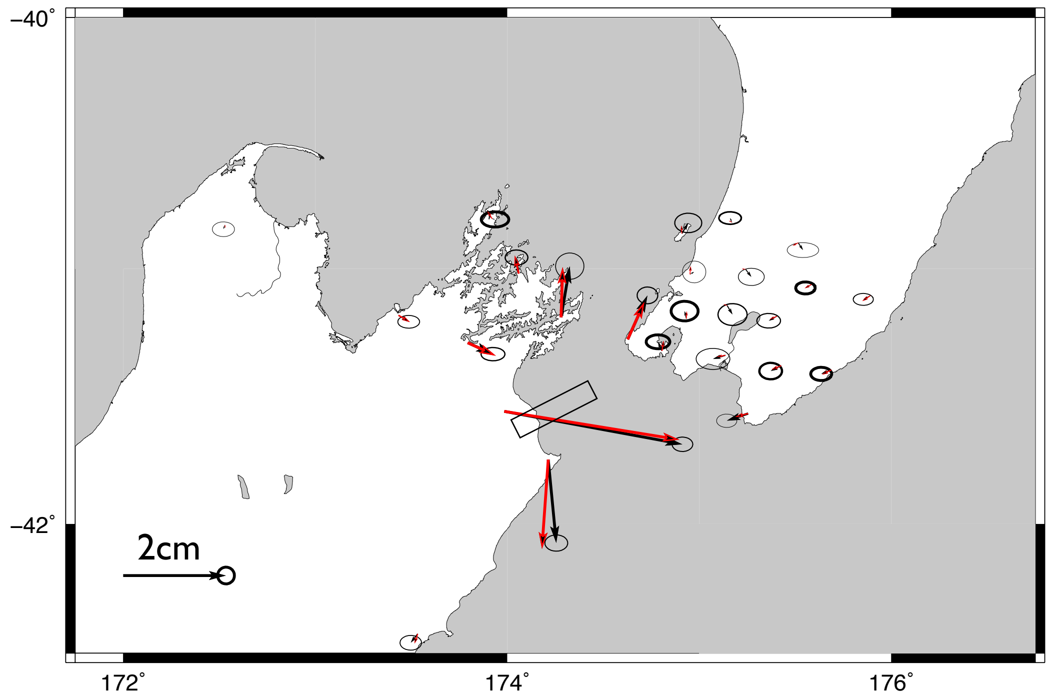


Image: Rowena Lohman

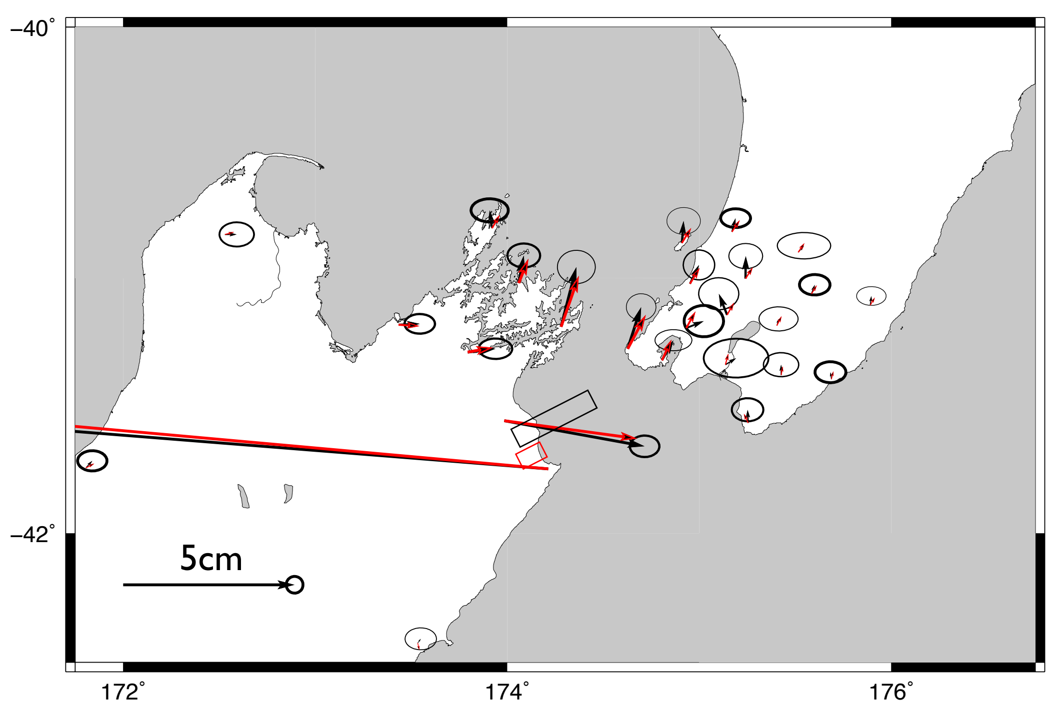
Recent Examples

Inversions: 20s-5min

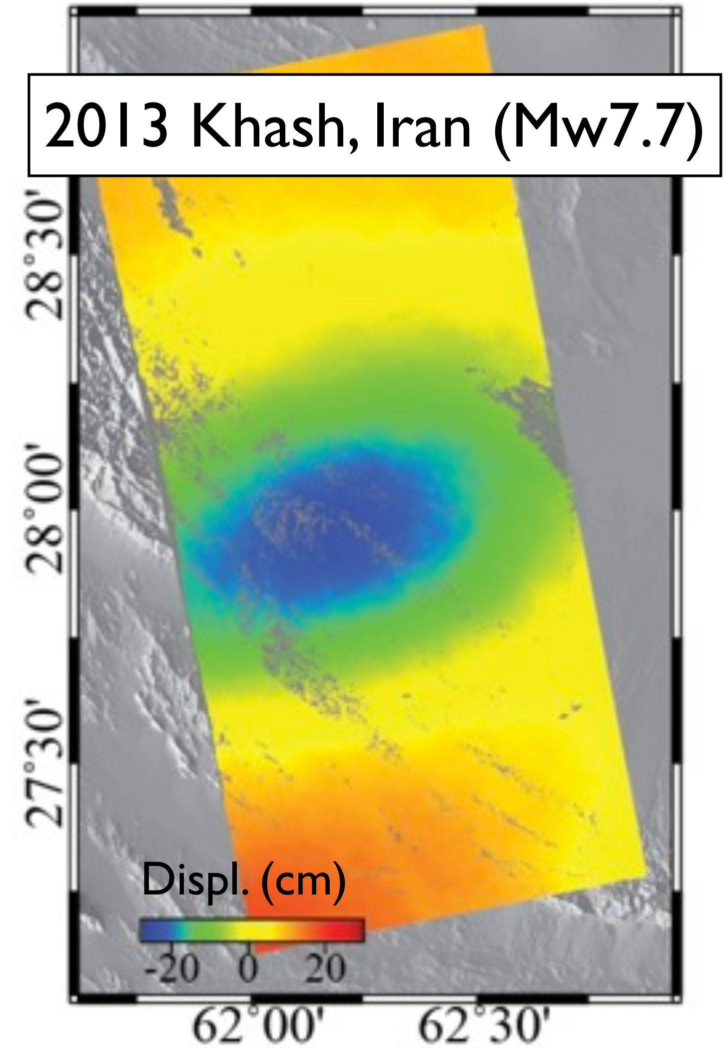
July 2013 NZ (OT +3days)

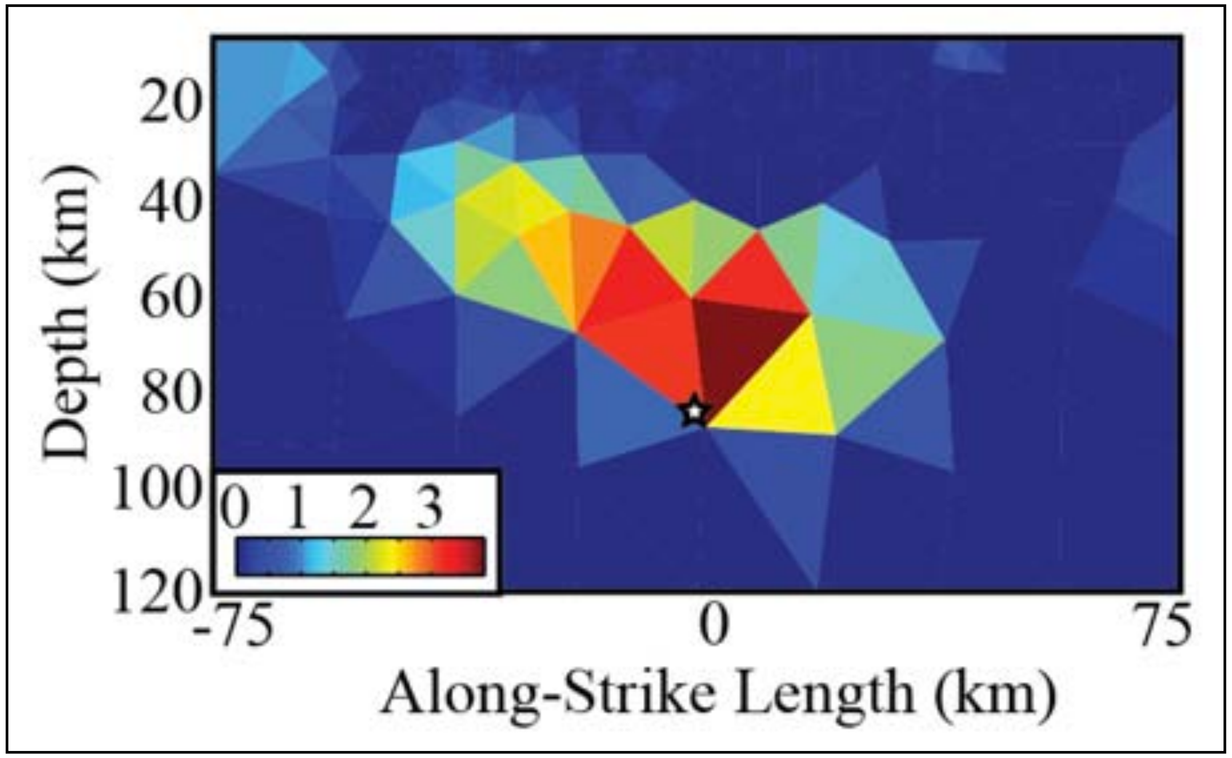


August 2013 NZ (OT +1day)



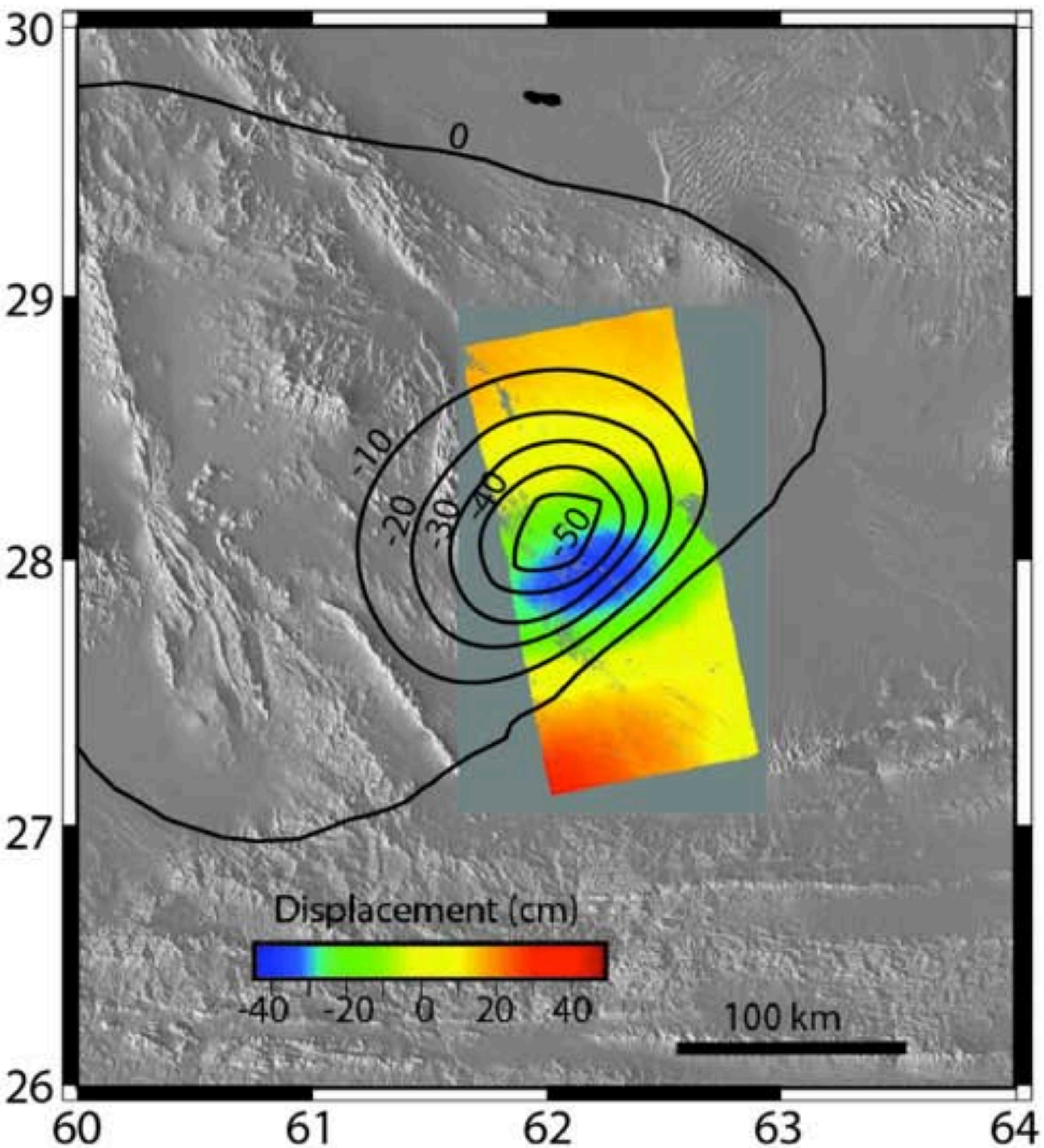
2013 Khash, Iran (Mw7.7)



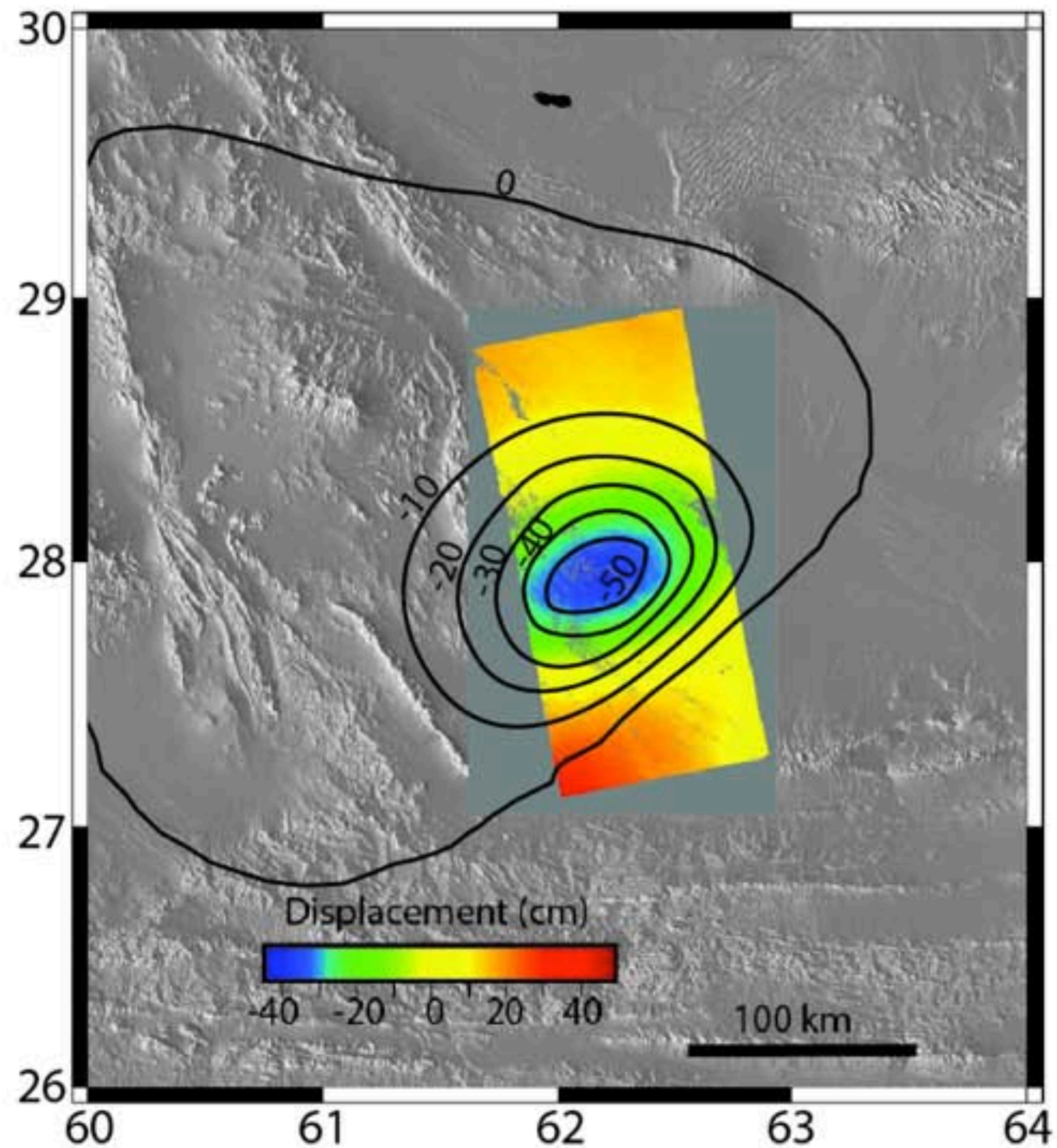


Reducing Location Uncertainty

Initial FFM (Z-displacements)

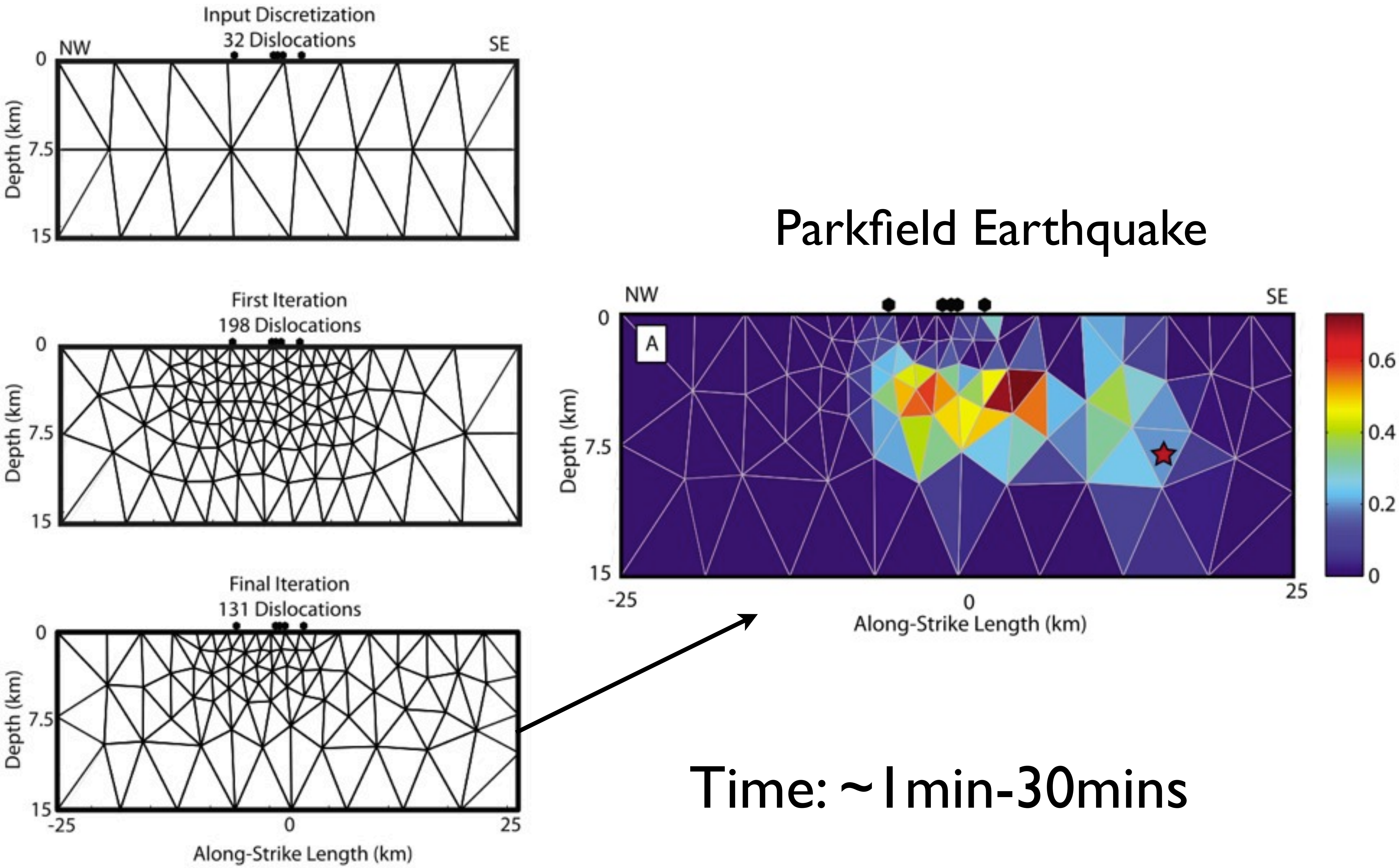


Revised FFM: Fixed to InSAR Derived Plane



Barnhart et al. *revised*
GFs: Bob Herrmann

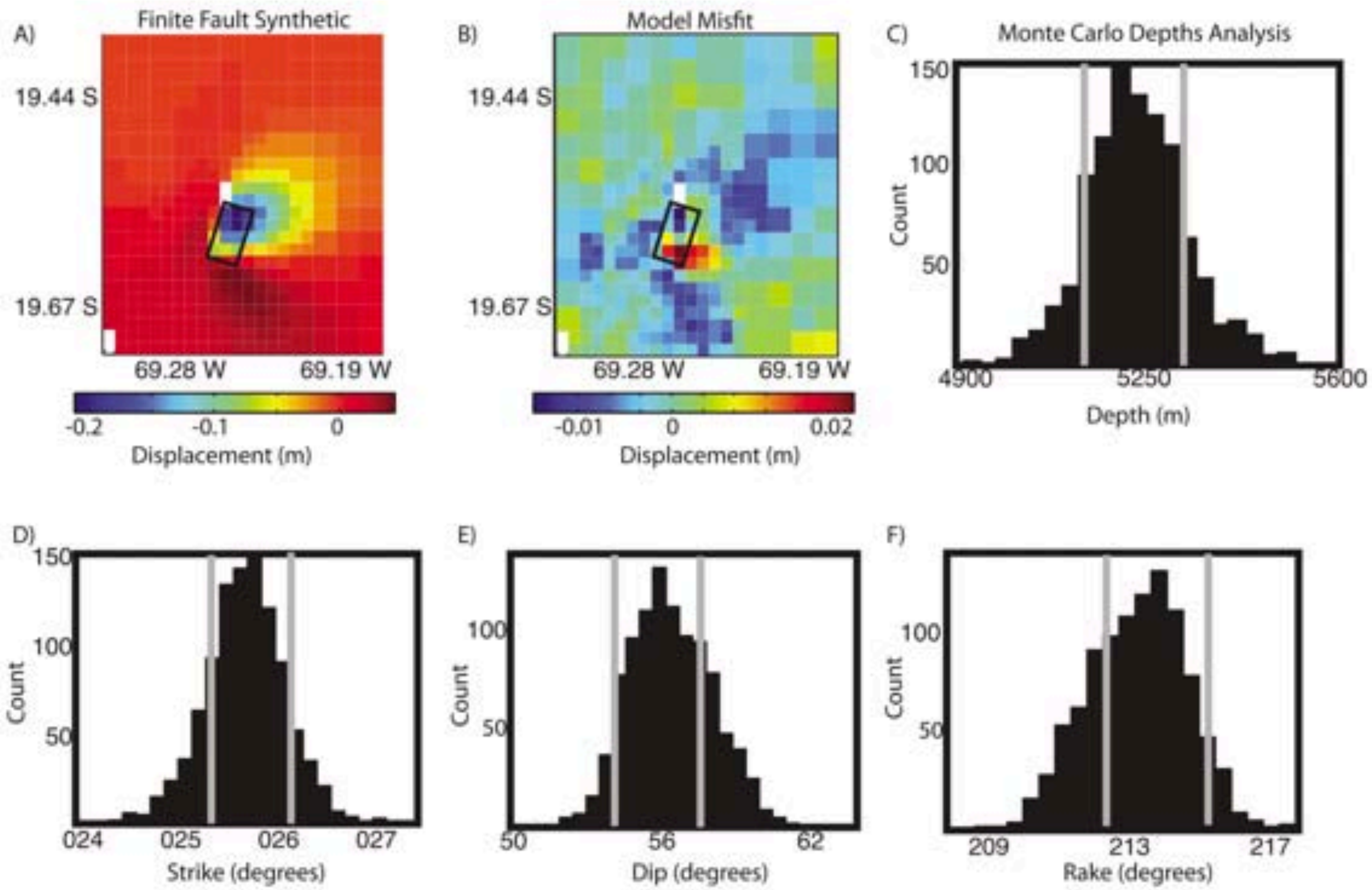
Model Resolution-Based Discretization



Time: ~1min-30mins

Barnhart & Lohman 2010

Assessing Uncertainty (Geodesy)



Devlin et al. 2011

Best-Fit Model

↓

Synthetic Datasets + Noise

Fault Geometry | Fault Geometry | Fault Geometry | Fault Geometry

↓

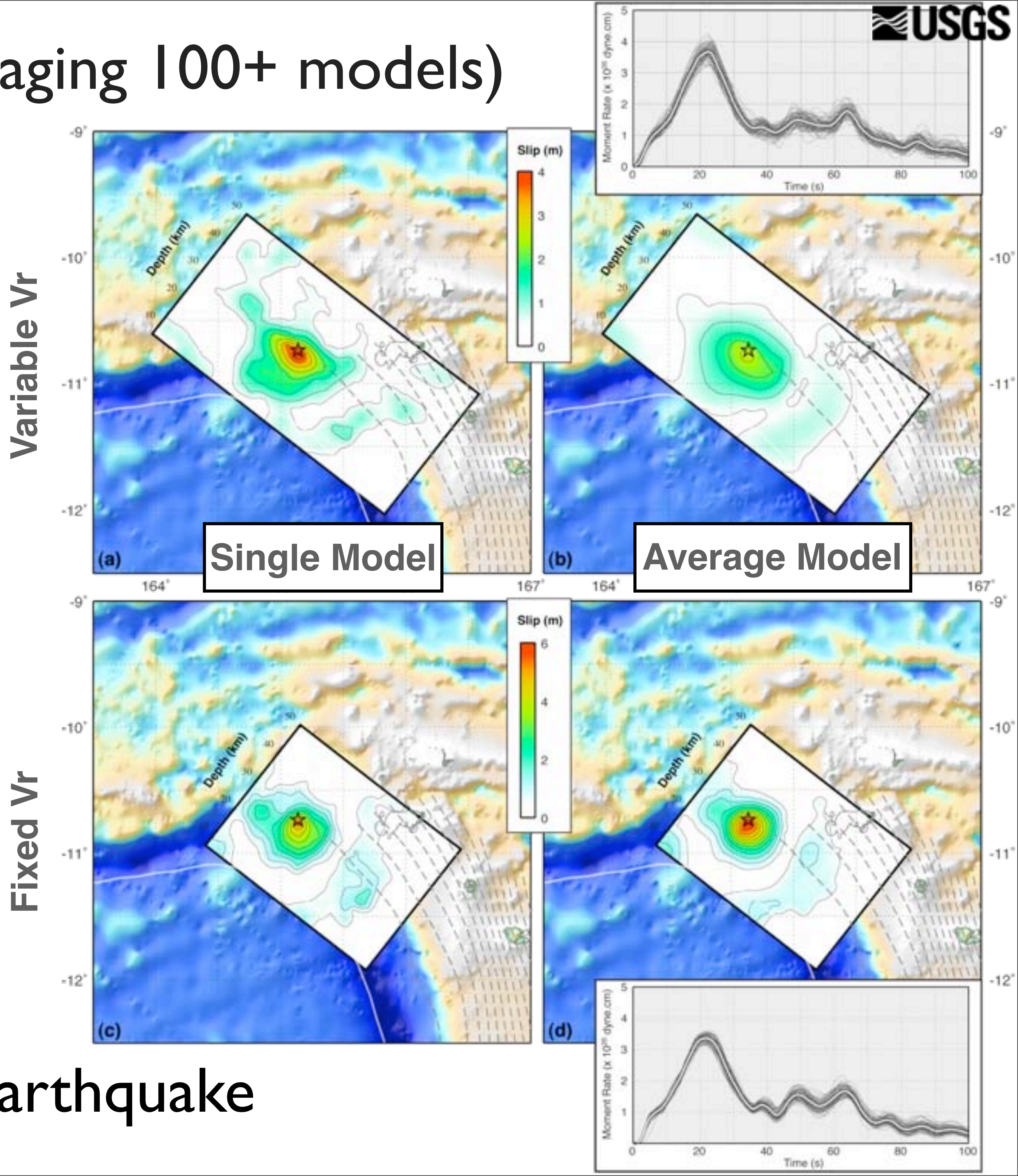
Ensemble Behavior

Time: 30min - 6hours

Bootstrapping (averaging 100+ models)

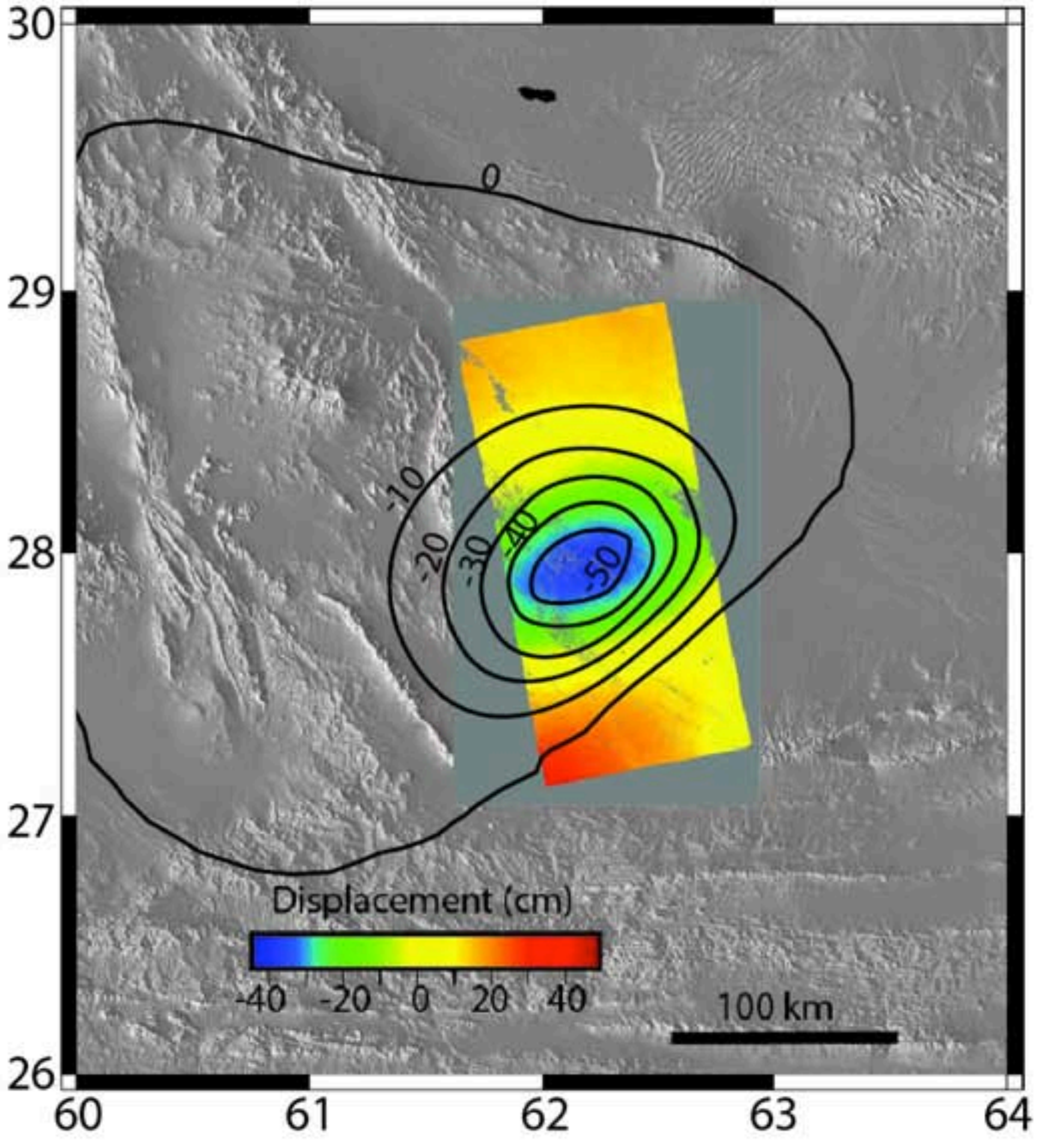
Gives an indication of model sensitivity with respect to data used in the inversion.

=> Consistency of slip given assumptions of inversion.



2013 Craig, AK Earthquake

2D Geodetic Green's Functions



Static offset from synthetic seismic GFs

GFs: Bob Herrmann

Take Aways

NEIC's goal to produce rapid, accurate source dimensions

- Necessary for ShakeMap, PAGER, etc.
- Models are revised for derivative products and research applications
- Hampered by location, time, 3D structure, model assumptions

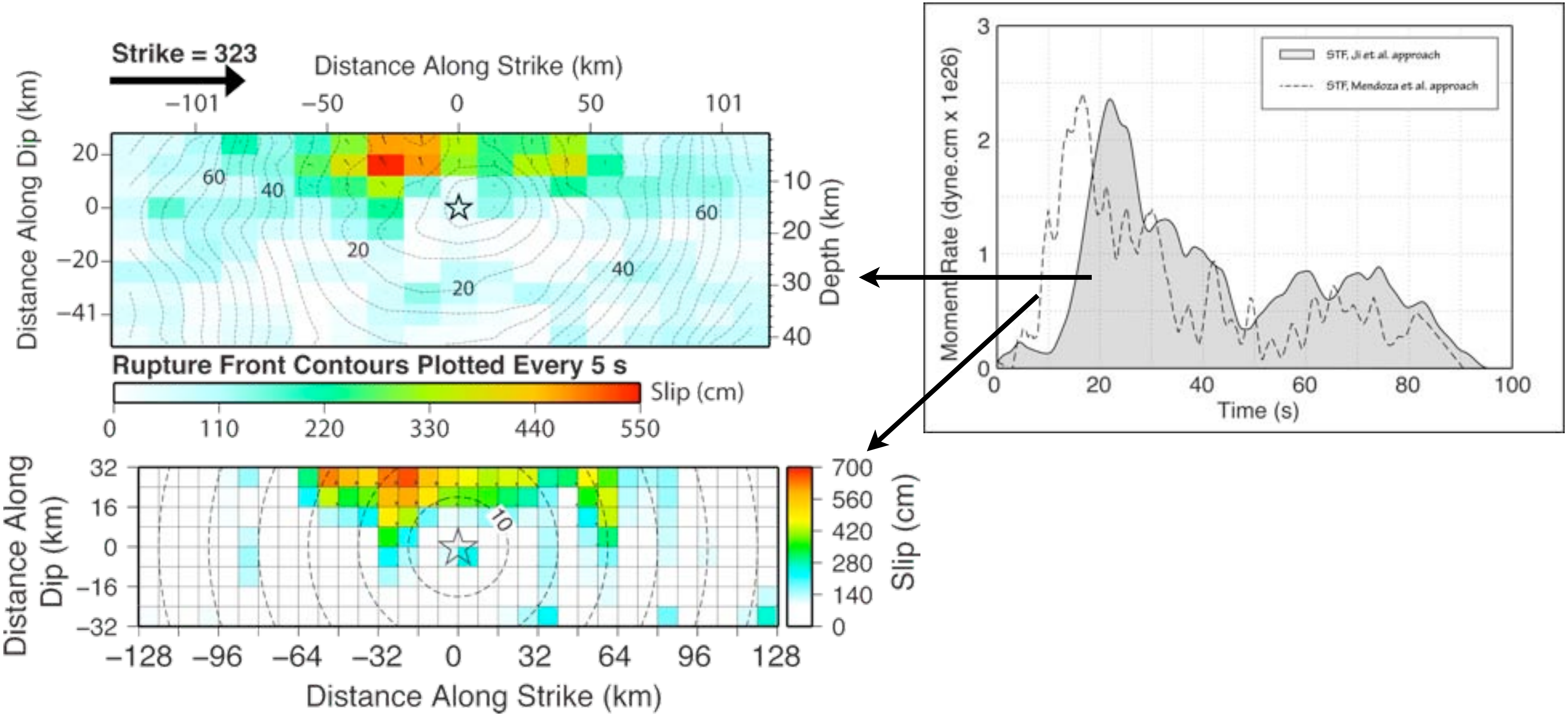
Geodetic Observations

- Currently using continuous GPS (2-5 day latency) and InSAR (weeks)
- Moving towards in-house real-time processing (seconds-minutes latency)
- Inversions w/ seismic-derived Green's functions

Future Work

- OpenMP - speed up Ji approach from ~40 mins to ~5-10mins
- Better, closer data
- Add SH to Mendoza P-wave inversion technique
- Test multiple GF databases (multiple constructed at the NEIC)
- Joint seismic-geodetic inversions

FFM Inversion 2



P-wave only analysis (lower plot) to obtain first-order slip characteristics soon after an earthquake occurs (**within ~10 mins of CMT solution**).

Speeds up inversion by constraining the model space:
- Fixed rake
- Fixed rupture velocity
- Fixed moment

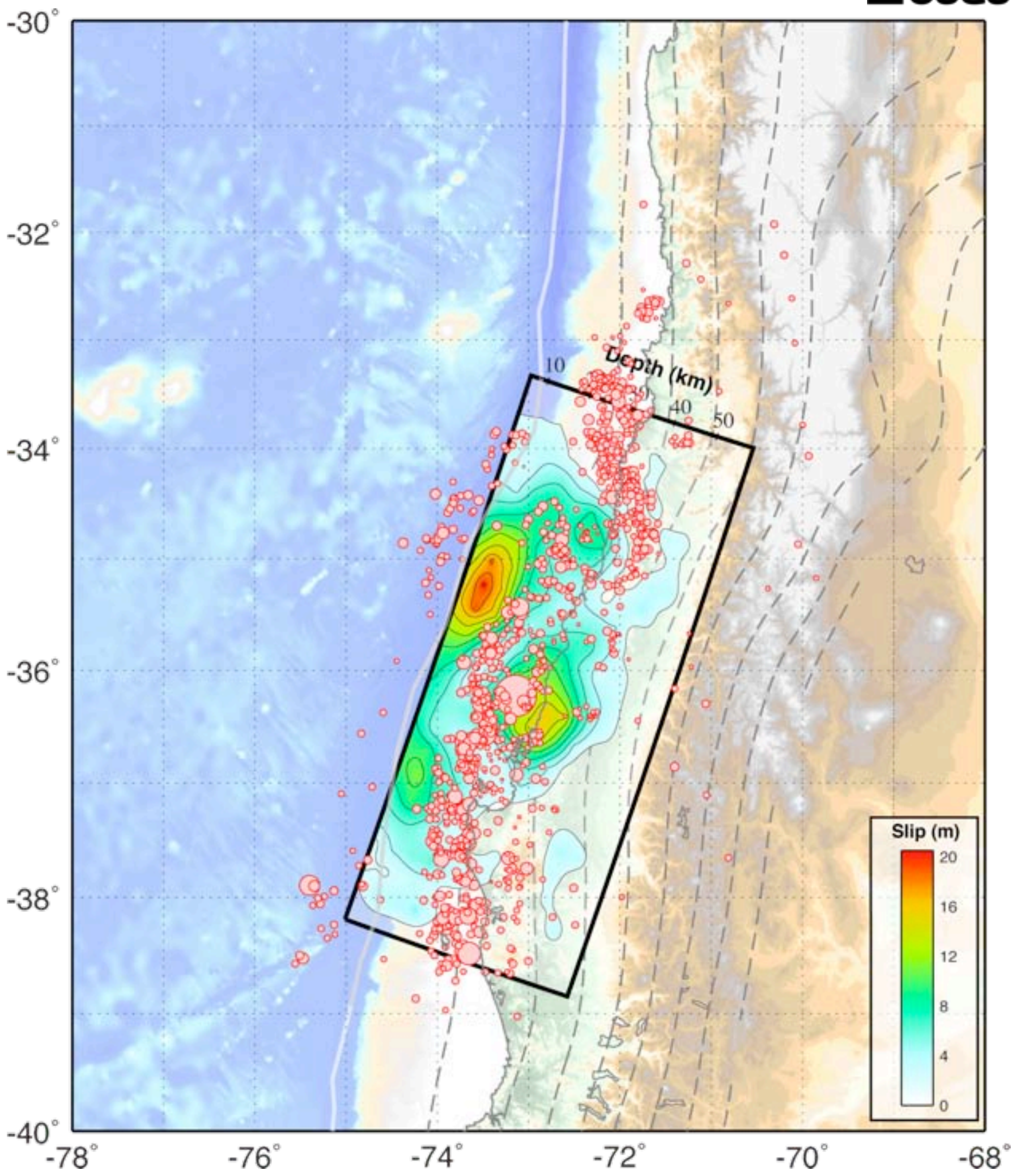
Maule FFM

Single-plane teleseismic FFM.

Fits seismic data extremely well (explains 88% of waveform data).

Aftershocks dominantly cluster in regions of lower or transitional slip.

Reasonable fits to horizontal & vertical GPS data.



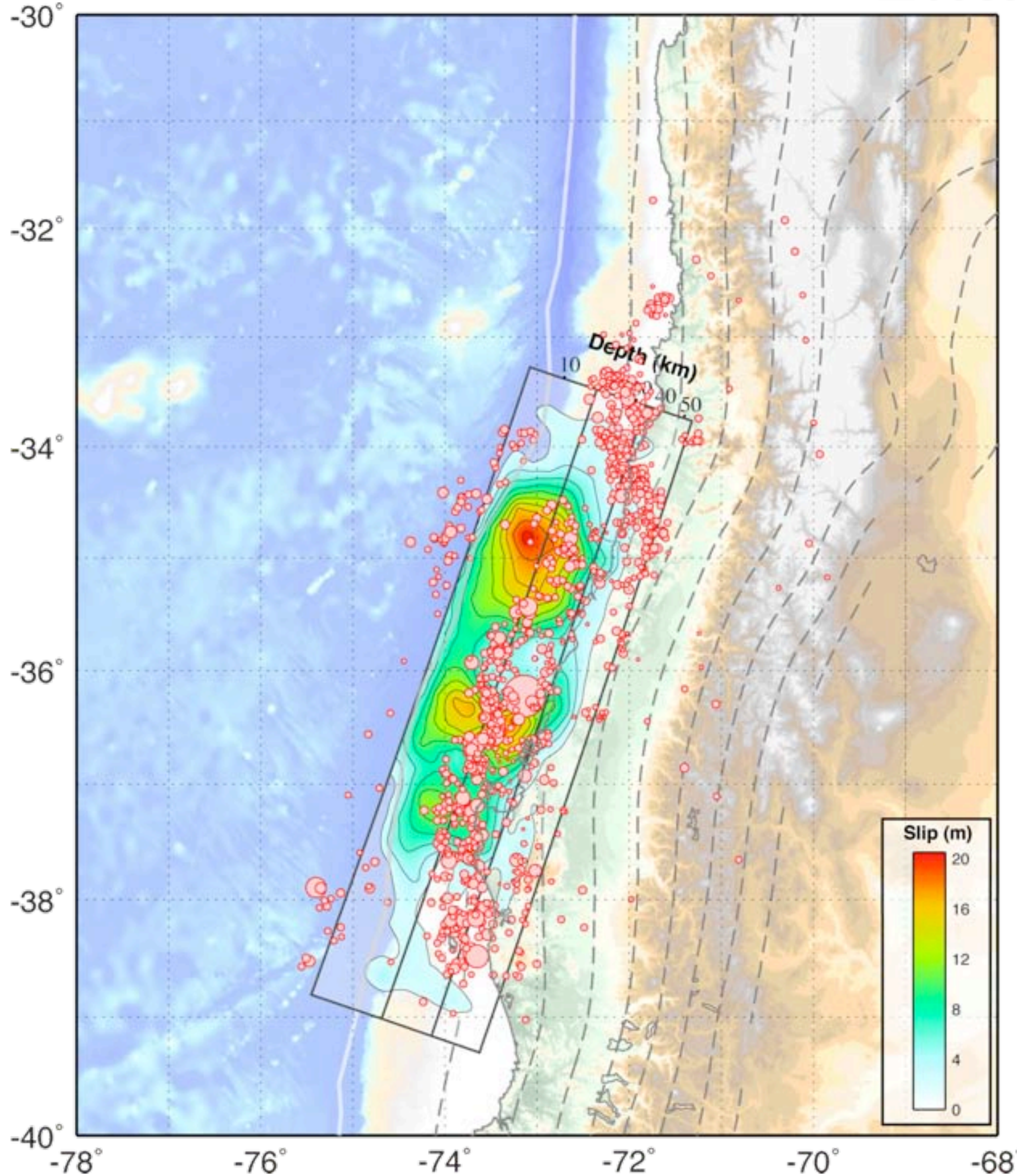
Maule FFM

Three-plane teleseismic FFM.

Fits seismic data extremely well (explains 89% of waveform data).

Better accounts for downdip changes in slab geometry.

Much better fits to horizontal GPS data.



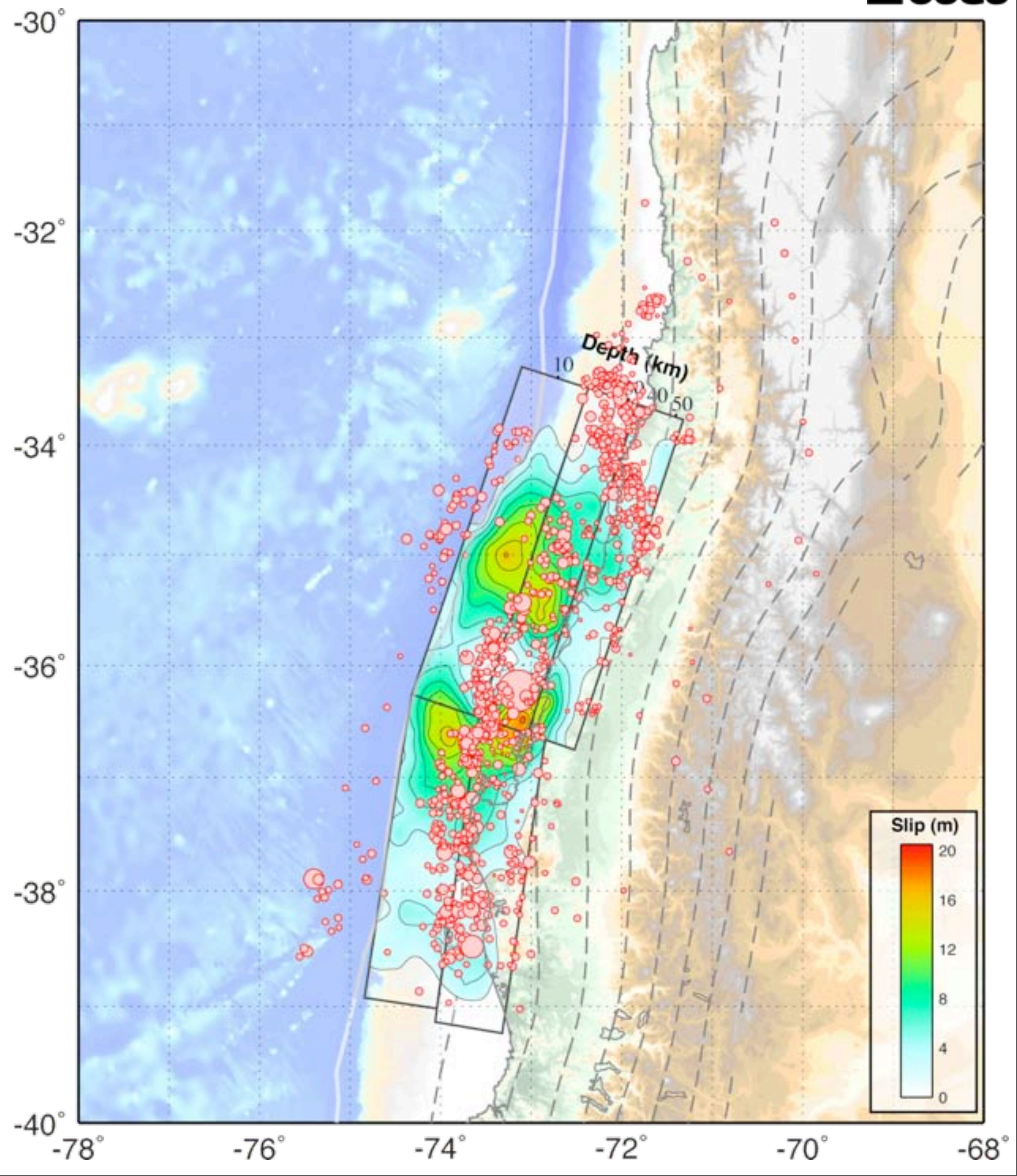
Maule FFM

Five-plane teleseismic FFM.

Fits seismic data extremely well (explains 90% of waveform data).

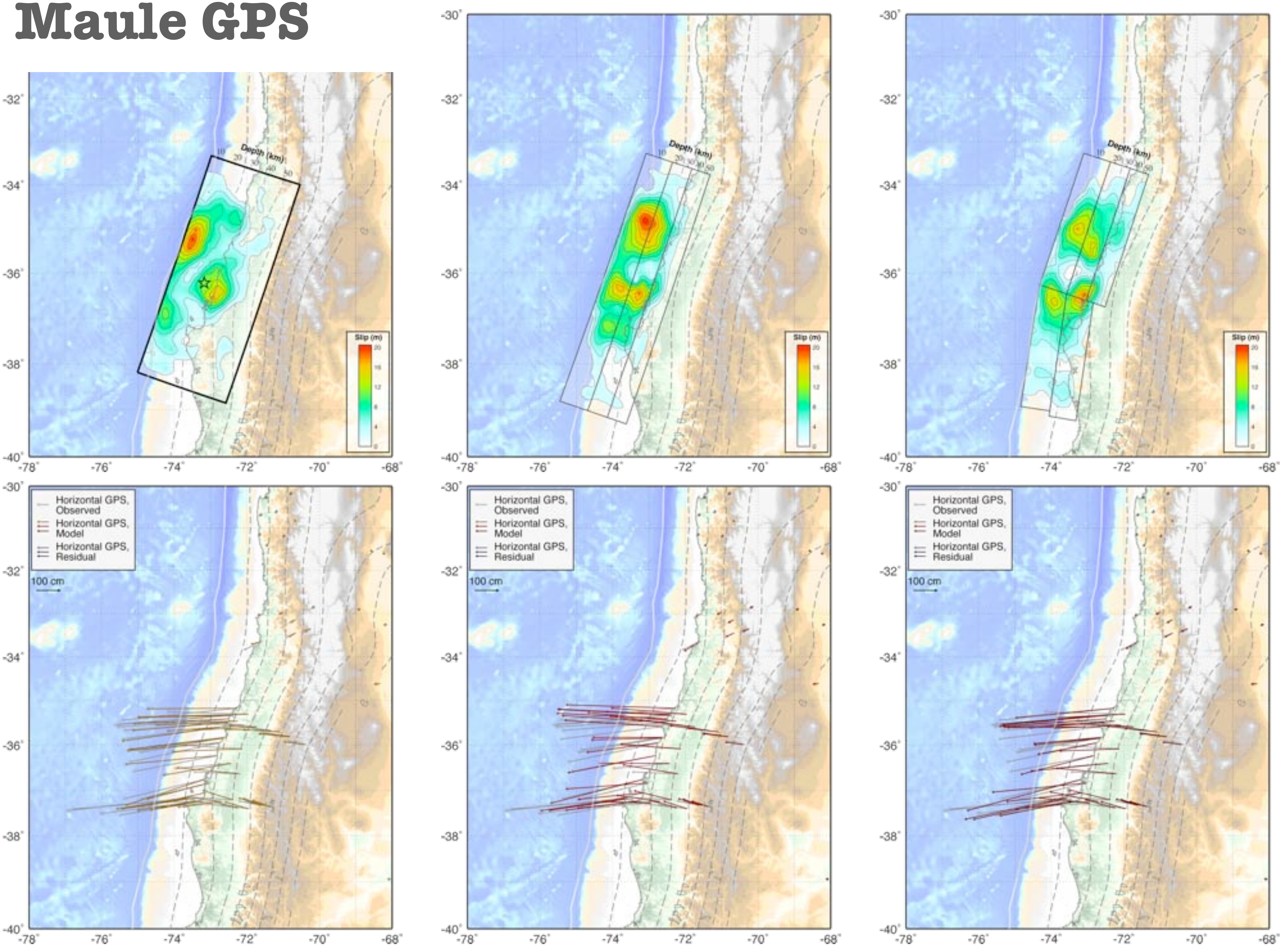
Better accounts for down-dip and along-strike changes in slab geometry.

Much better fits to horizontal & vertical GPS data.



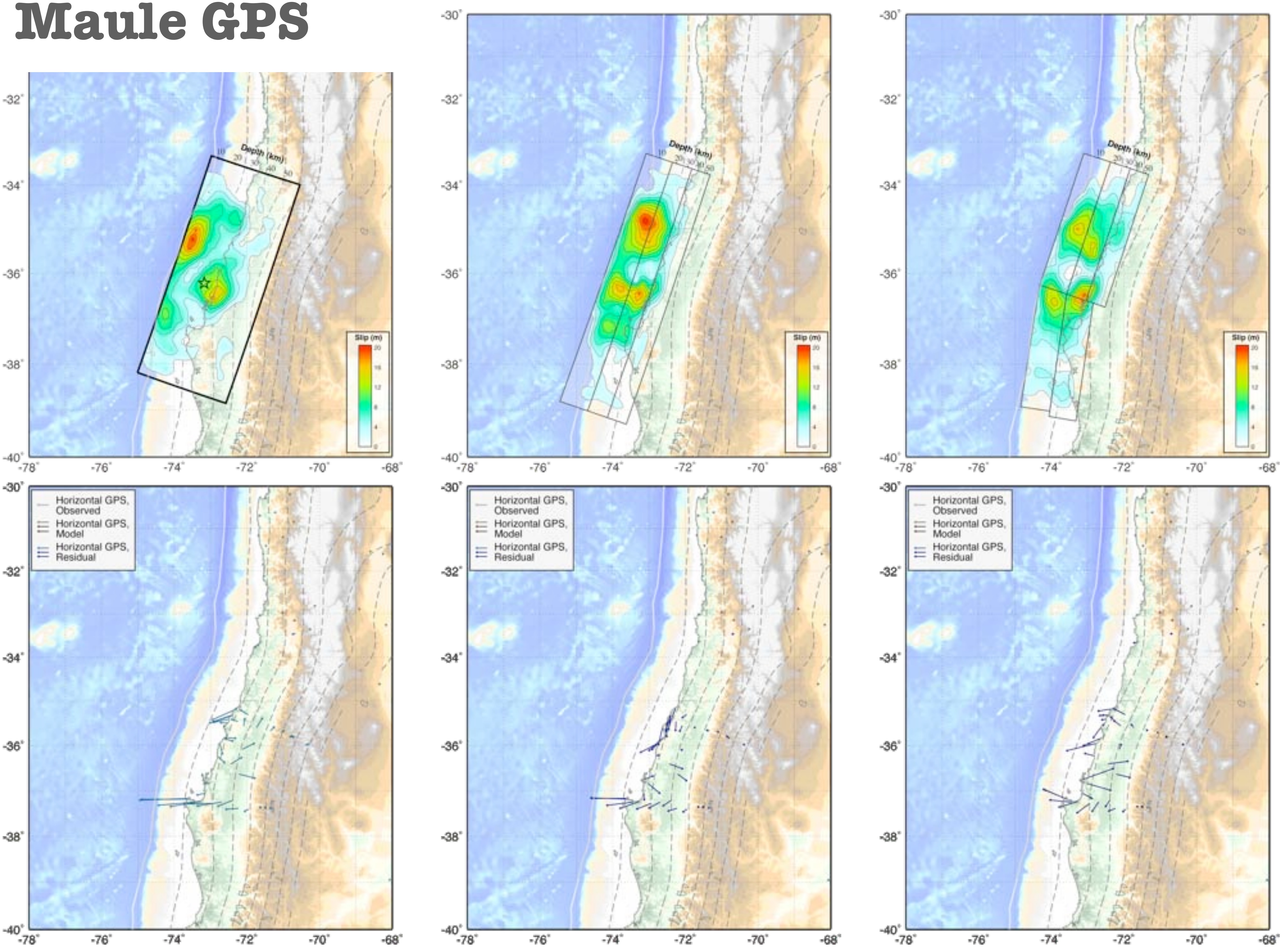
USGS

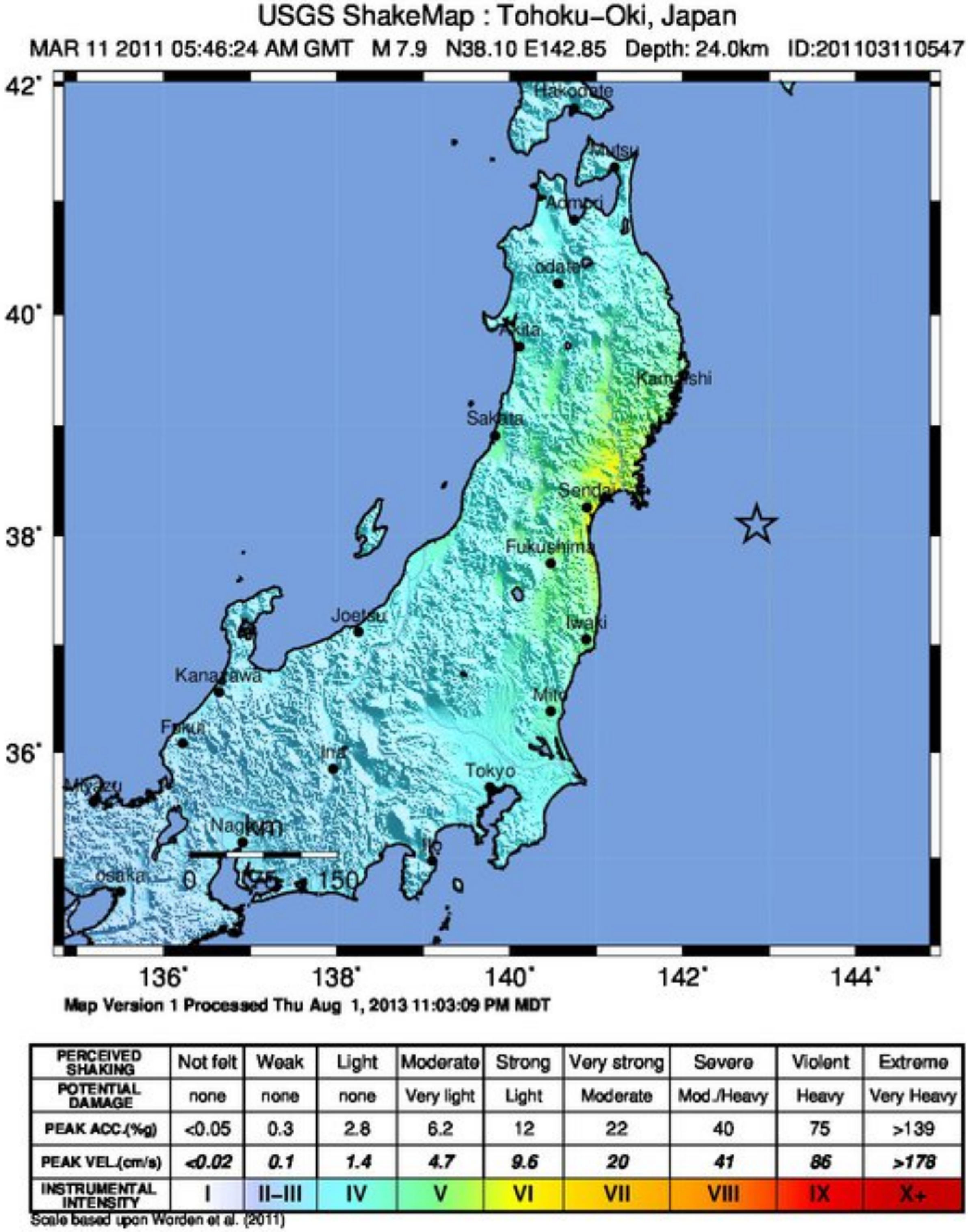
Maule GPS



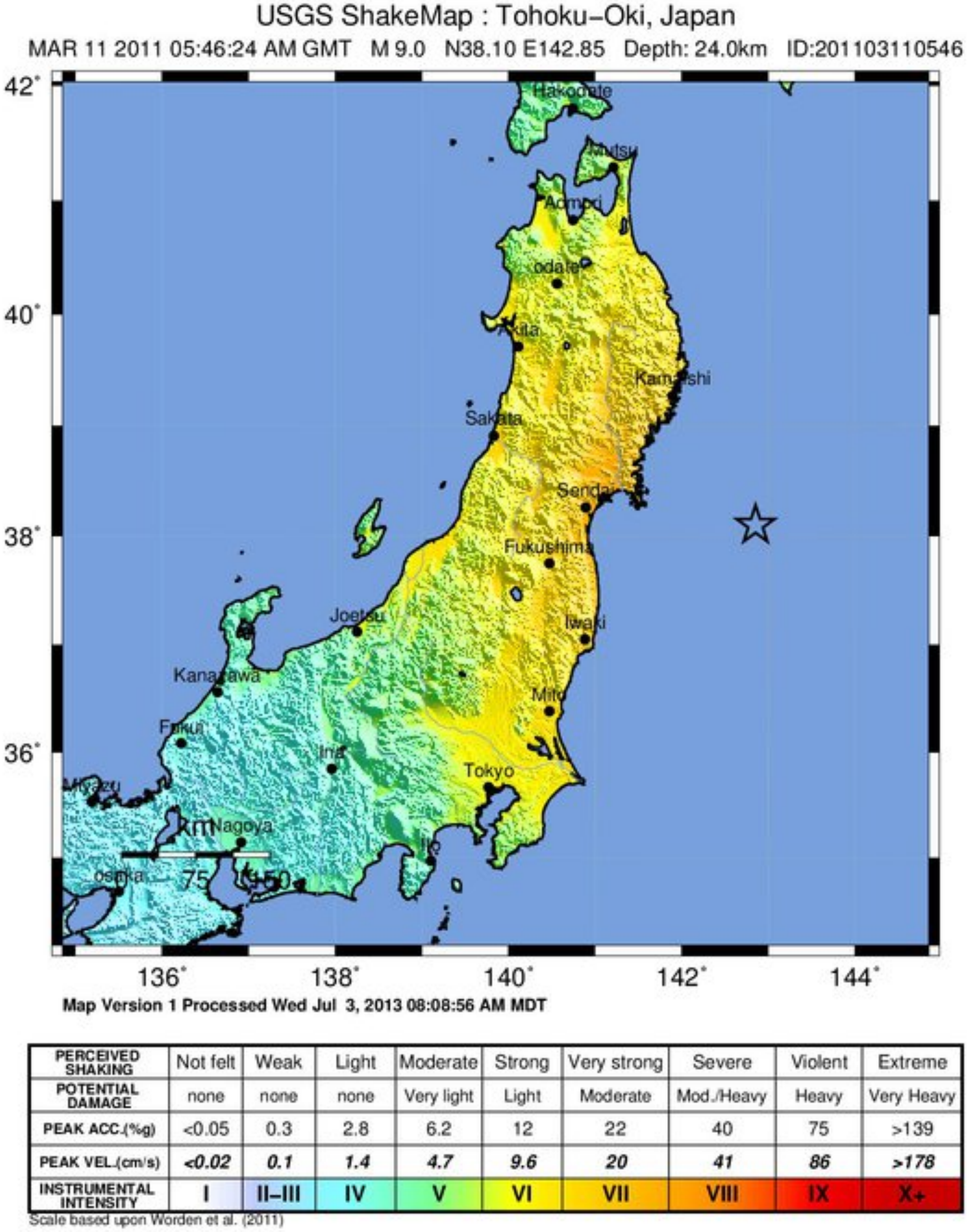
Depth (km)
Slip (m)
Horizontal GPS, Observed
Horizontal GPS, Model
Horizontal GPS, Residual
100 cm

Maule GPS

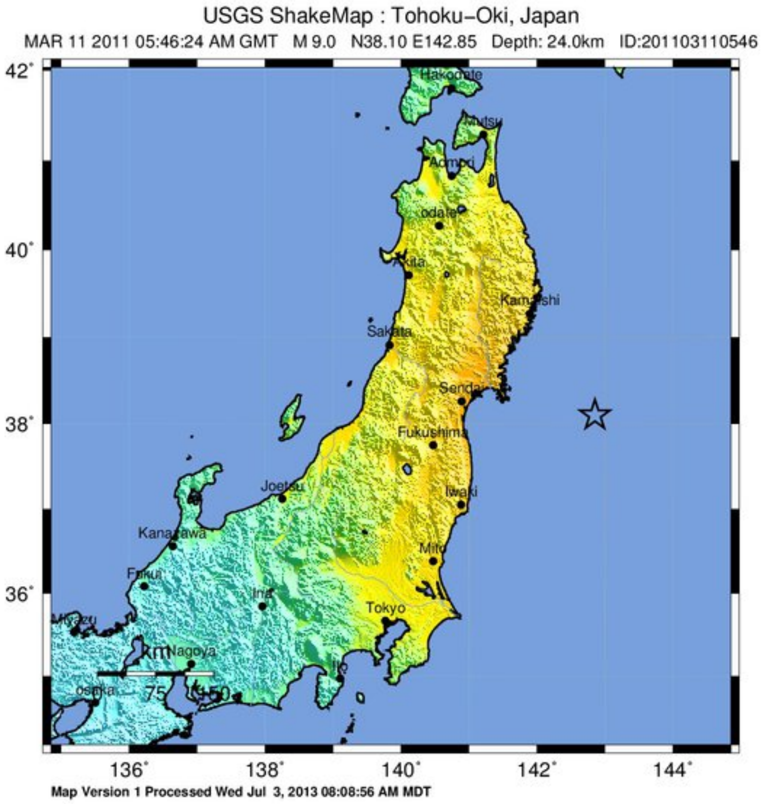

USGS
Depth (km)
10
20
30
40
50
Slip (m)
Horizontal GPS, Observed
Horizontal GPS, Model
Horizontal GPS, Residual
-30°
-32°
-34°
-36°
-38°
-40°
-78°
-76°
-74°
-72°
-70°
-68°



Magnitude 7.9 (Initial Release)

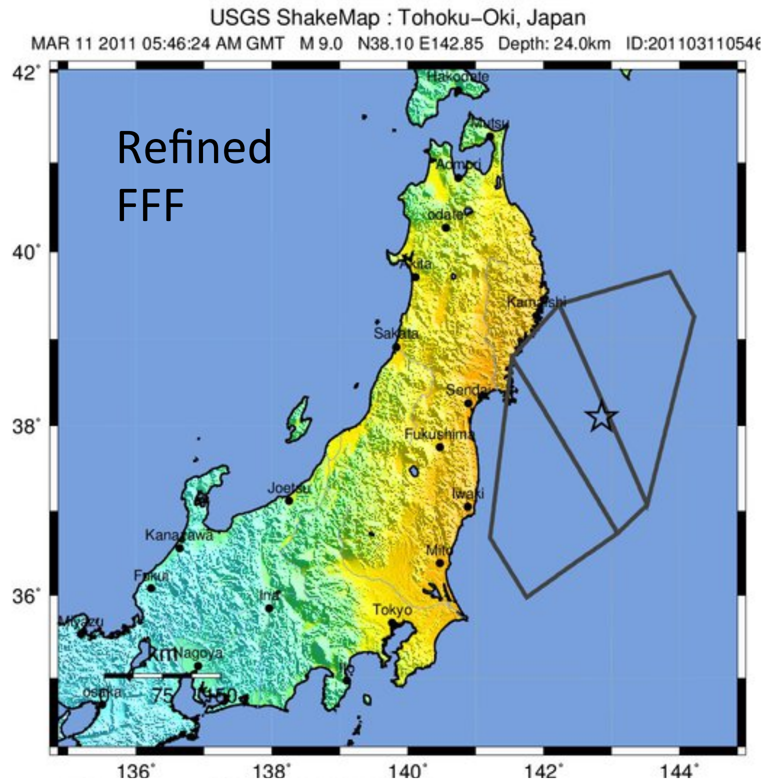


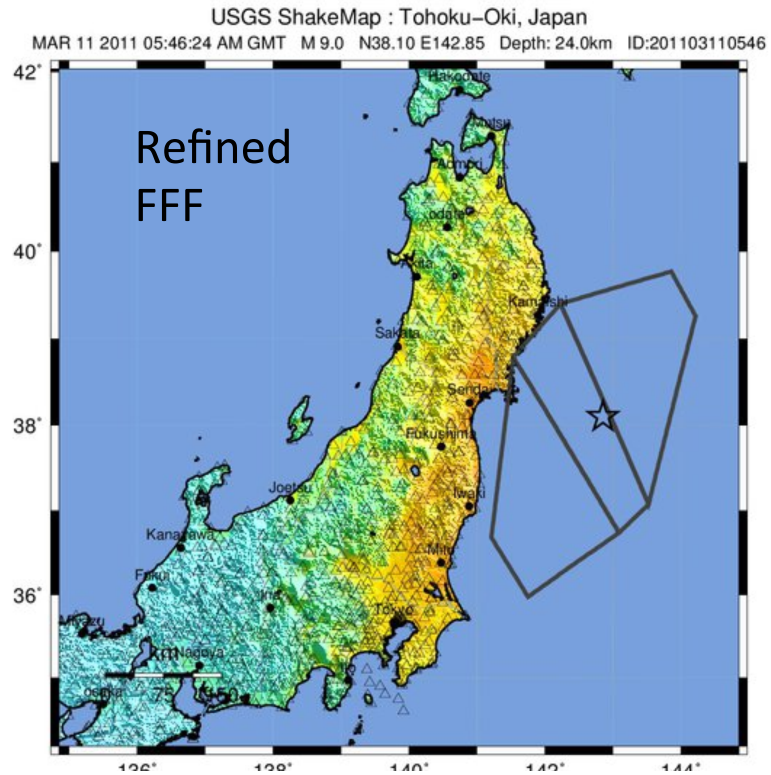
Magnitude 9.0 (M_ww at 20 min)

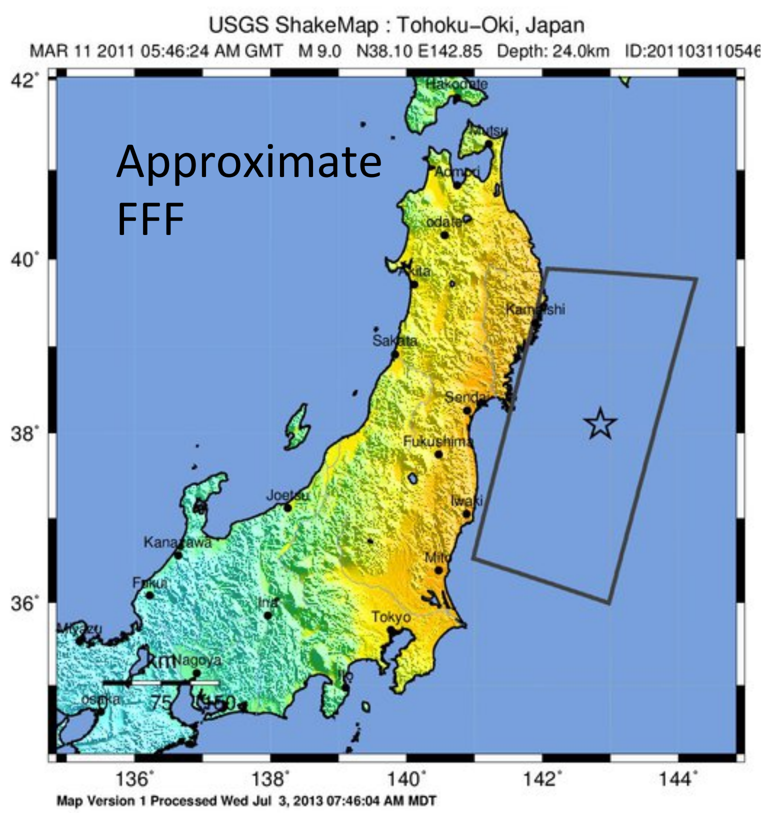


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2011)







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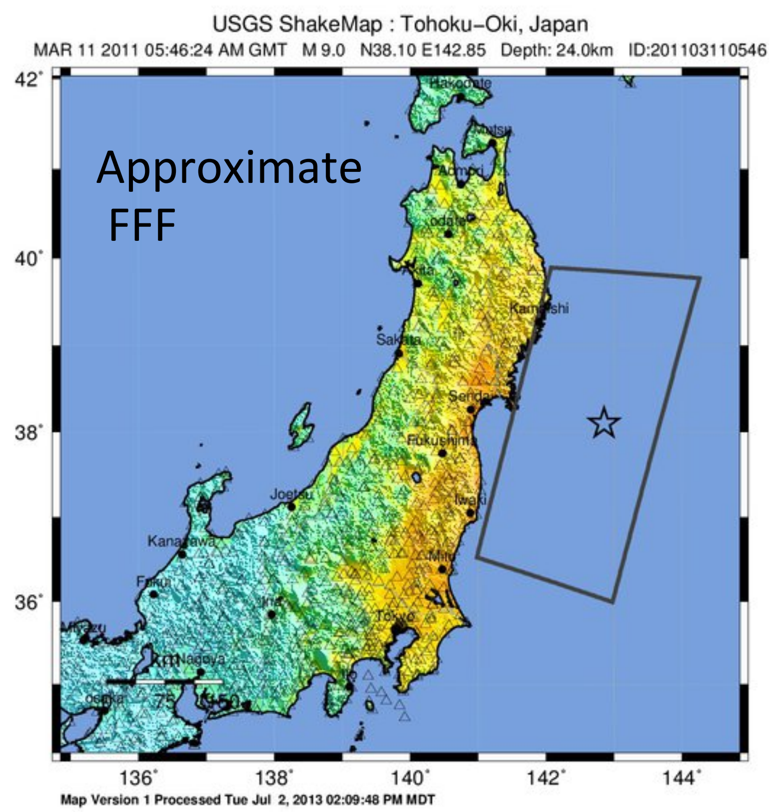

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