Near Realtime Teleseismic and Geodetic Finite Fault Modeling at the NEIC

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NEIC Realtime Response

- Location
- Magnitude
- Mechanism
  - PAGER
  - ShakeMap
  - Press Releases

Fast Finite Fault Model
- Revised Products

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

- No Fault (Median Distance)
- Initial Fault
- Refined Fault & SGM/MMI Data

- < 60 minutes
- 60-95 minutes
- 2-3 hours
- Days-Months
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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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Body Waves, Turkey EQ 10/23/2011
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
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
• Model 1: Quick FFM. CMT Dip = 15°, initial PDE Depth = 39km.
• Model 2: Adjusted FFM (days after event), made to fit trench geometry (Chen Ji).
• Model 3: Slab1.0 Dip = 18°, 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
Recent Examples

July 2013 NZ (OT +3days)

August 2013 NZ (OT +1day)

Inversions: 20s-5min

2013 Khash, Iran (Mw7.7)

Displ. (cm)

2cm

2cm

5cm

Depth (km)

Along-Strike Length (km)
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

Parkfield Earthquake

Time: ~1 min-30 mins

Barnhart & Lohman 2010
Assessing Uncertainty (Geodesy)

Best-Fit Model

Synthetic Datasets + Noise

- Fault Geometry
- Fault Geometry
- Fault Geometry

Ensemble Behavior

Devlin et al. 2011

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
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 telesismic 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.
Maule GPS