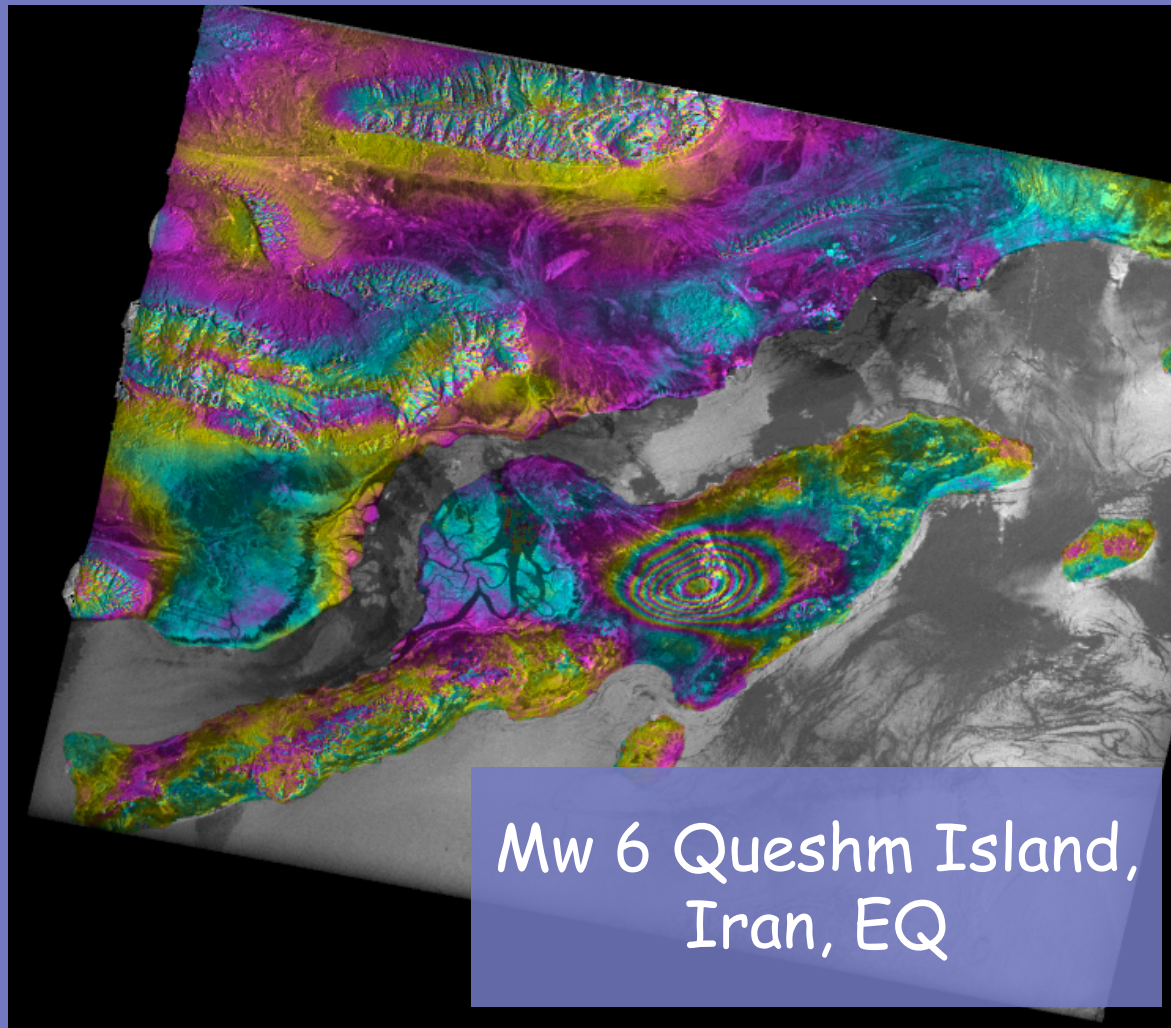


Generating Green's Functions with Pylith



Outline

- Overview/Motivation
 - When/where use FE models?
- Workflow
 - From data to mesh to Green's functions to model
- Examples
 - Bam & Qeshm Island earthquakes, Iran



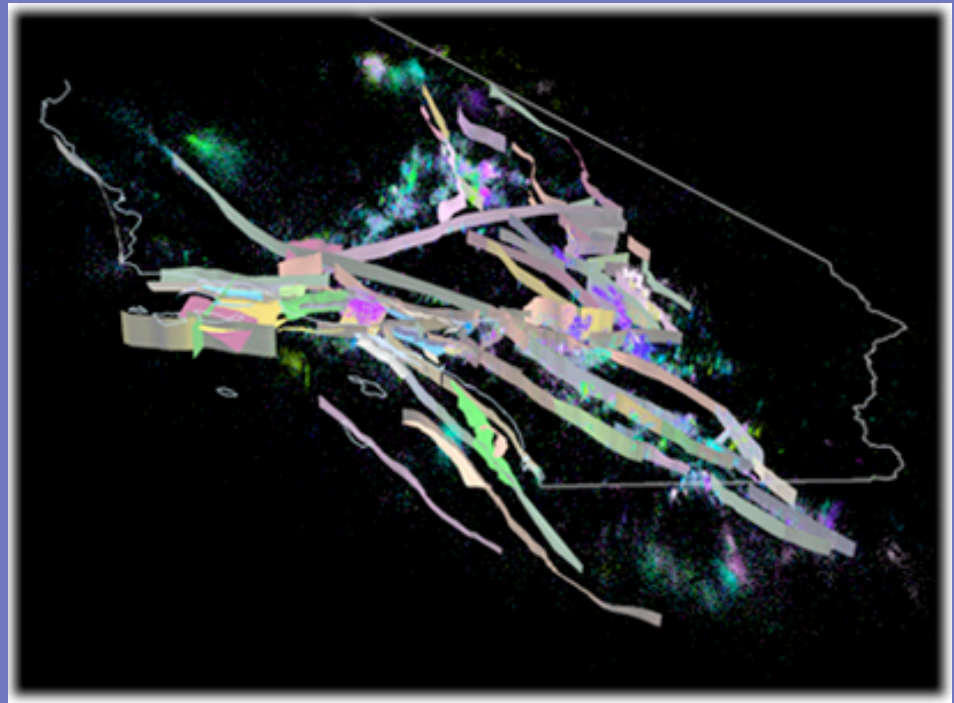
Astronaut photography
<http://eol.jsc.nasa.gov/>

Effects of Crustal Structure

- Vertical layering (2D)
 - Tends to move apparent source up or down (~10% effect)
- Horizontal contrasts (3D)
 - Map into slip features, inferred geometry
 - Fialko (2006) finds 2-2.5x contrasts in So. Cal
- Goal: For generic settings, what is inversion sensitivity?
 - Generate synthetic data using cross-fault contrast
 - Find best-fit solution in elastic half space
 - Assess bias: Inferred fault dip

Choosing Model Complexity

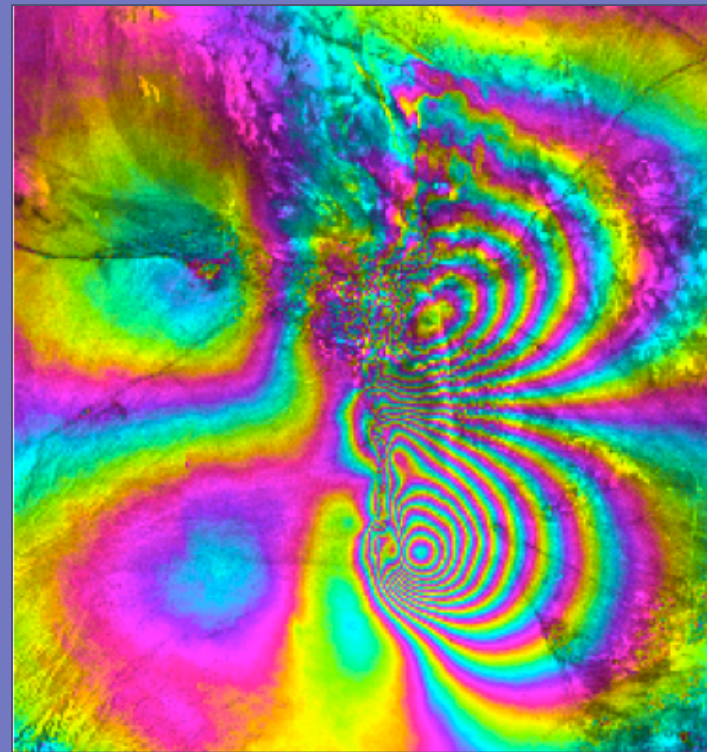
- Case 1
 - Lots of info
 - Seismicity
 - Velocity/rigidity structure
 - Mapped faults
 - Atmospheric water vapor content
 - Computationally expensive....



Community fault model
So. Cal

Choosing Model Complexity

- Case 2:
 - Sparse information
 - Mainly teleseismic EQ locations
 - No continuous GPS
 - Sporadic remote sensing



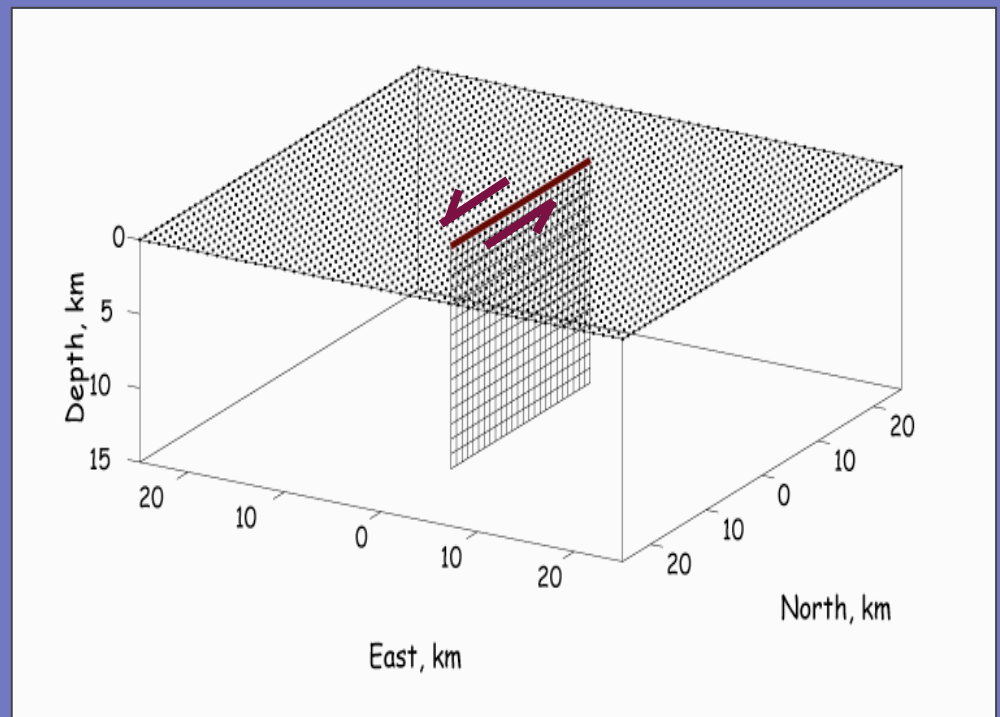
Bam EQ, courtesy E. Fielding

Choosing Model Complexity

- Case 1:
 - How do we use all this information?
 - When do we have to include all info?
 - When does it make sense to simplify?
- Case 2
 - What bias do we introduce by using inadequate models?
 - How should we present this error?
 - Which problems can we still address?

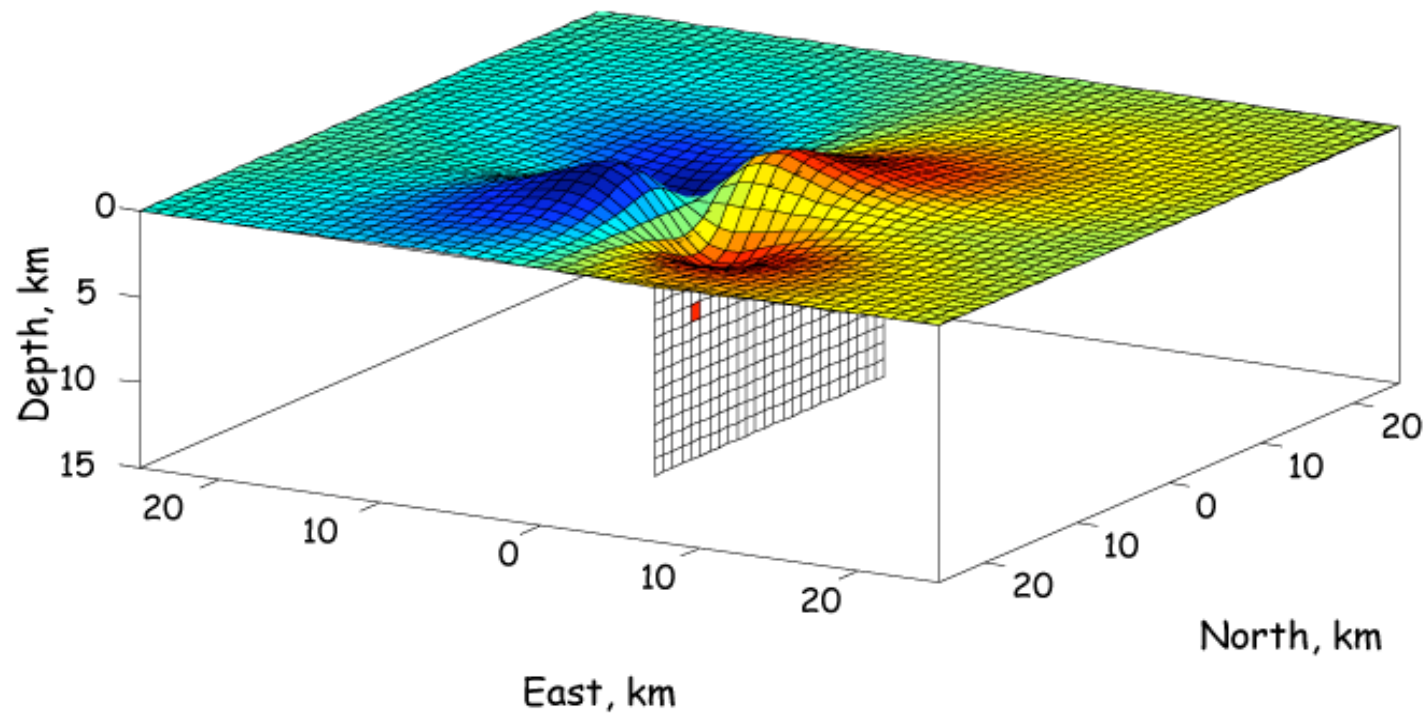
FE Workflow

- Step 1: Matlab
 - Define data/fault geometry
 - Define crustal structure
 - Subdivide fault
 - One patch at a time, build Cubit, Pylith input files



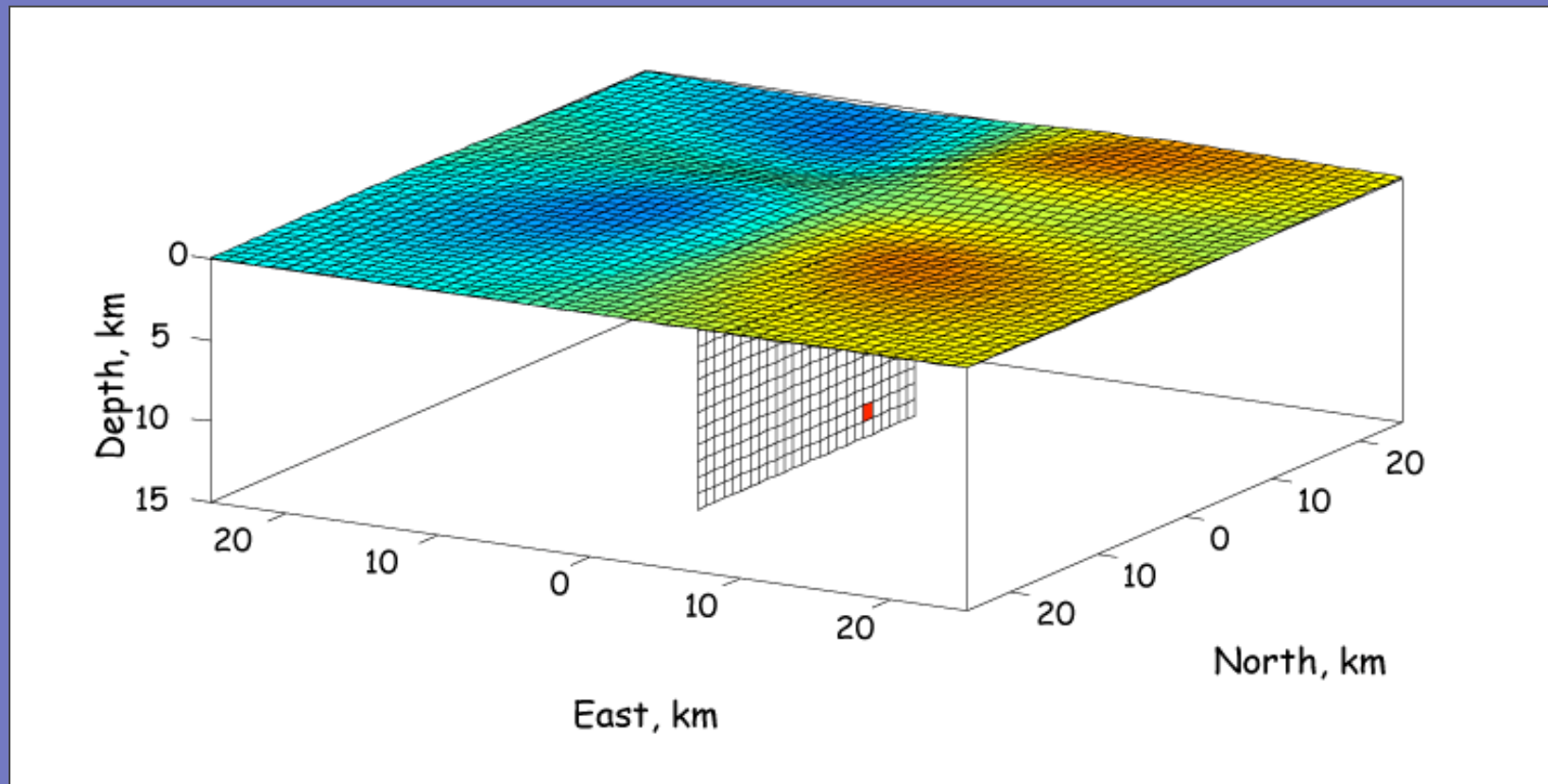
Vertical, strike-slip fault,
divided into patches

Okada-based Green's functions



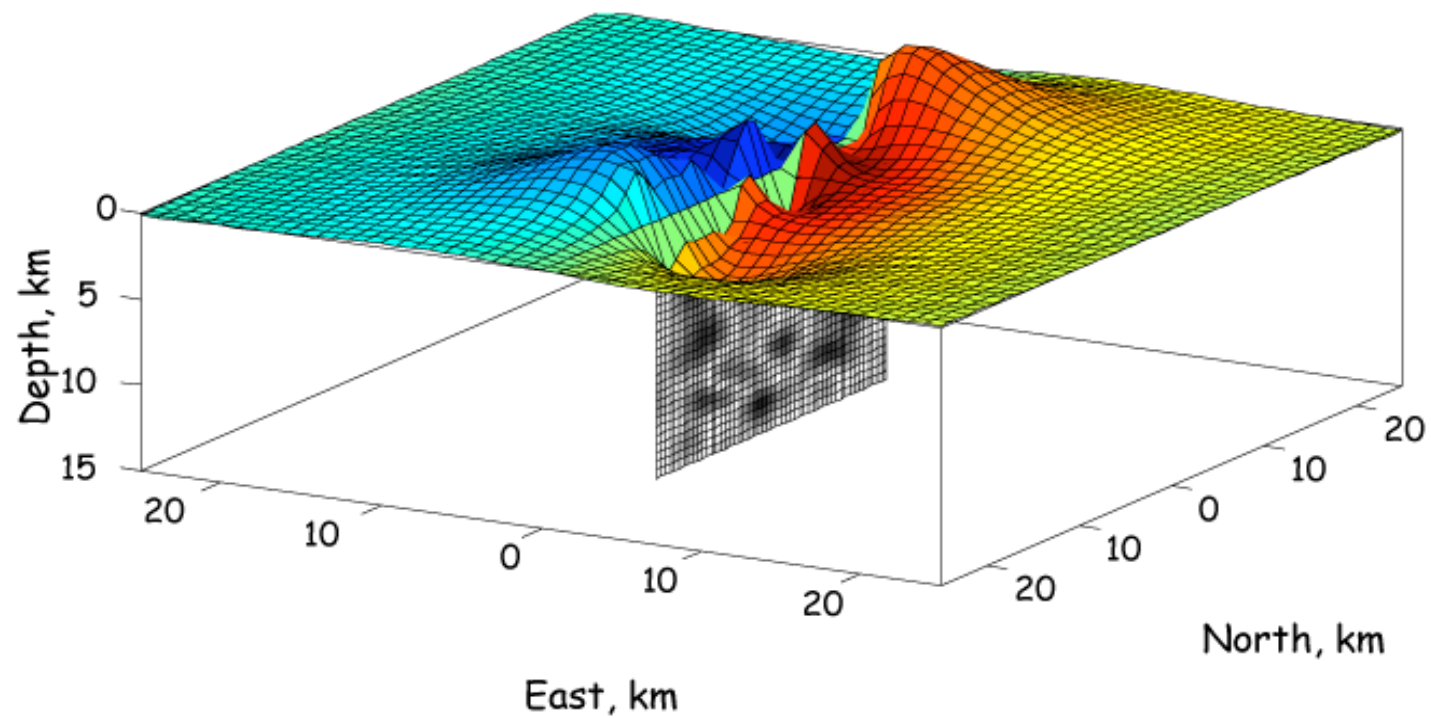
Slip on shallow fault patch

Okada-based Green's functions



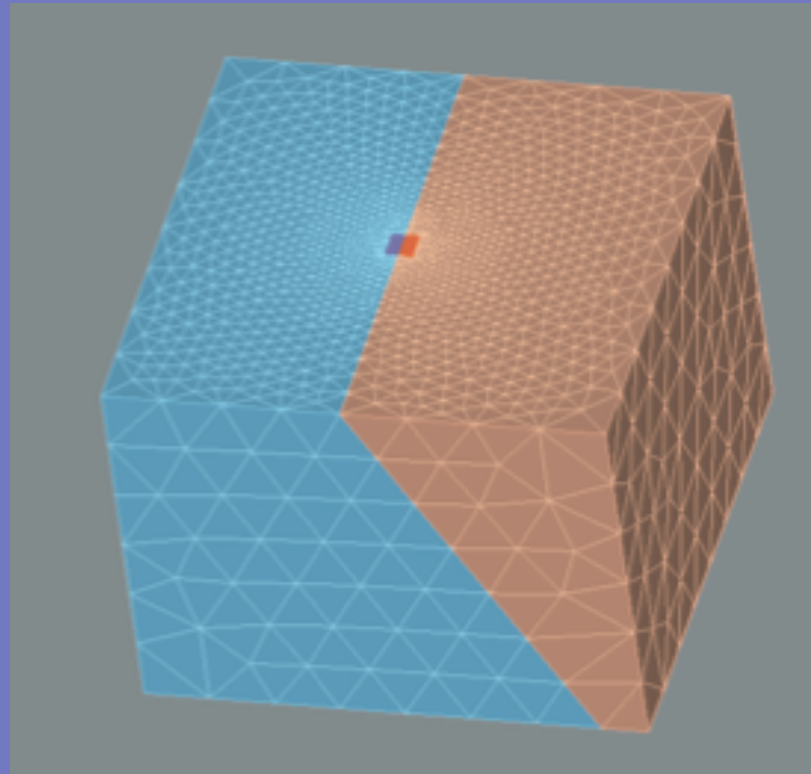
Slip on deep fault patch

Inversion



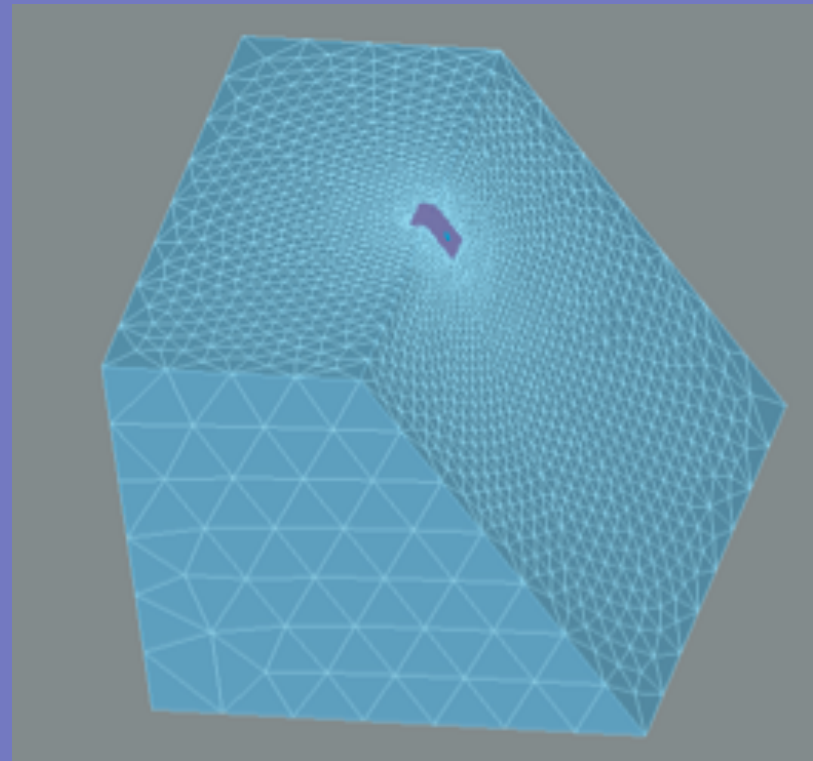
FE Workflow

- Step 2: Cubit
 - Build mesh
- Step 3: Pylith
 - Generate Green's functions
- Step 4: Matlab
 - Assemble all patches, perform inversion



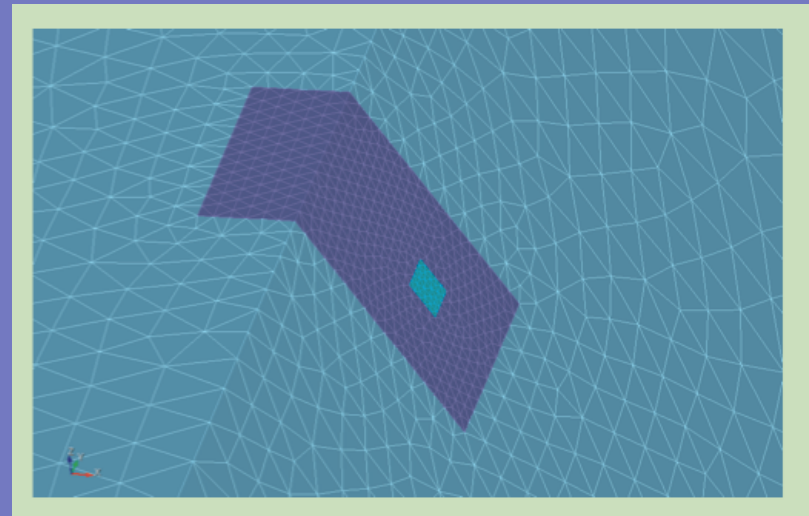
FE Workflow

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FE Workflow

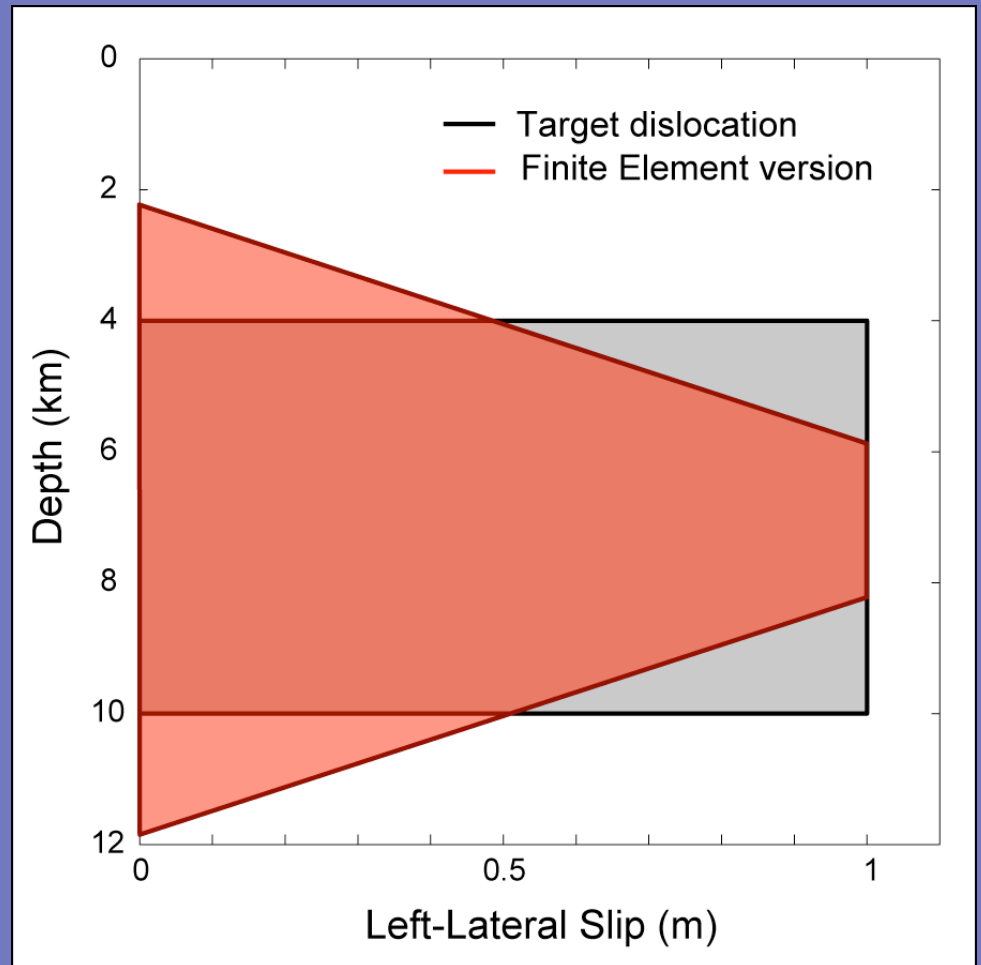
- Step 2: Cubit
 - Build mesh
- Step 3: Pylith
 - Generate Green's functions
- Step 4: Matlab
 - Assemble all patches, perform inversion



Mesh quality/density?

Comparison w/Okada

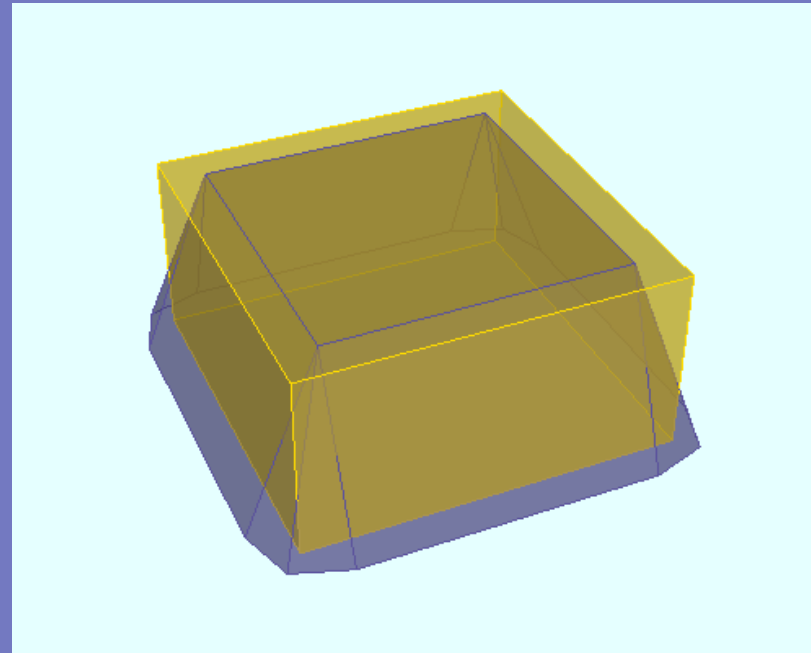
- Discrete fault patches
 - Readily available (Okada, Poly3D)
 - Easy to visualize
 - Historical: compare with previous work
- Node, points
 - More natural comparison once Pylith Green's functions mode



Comparison w/Okada

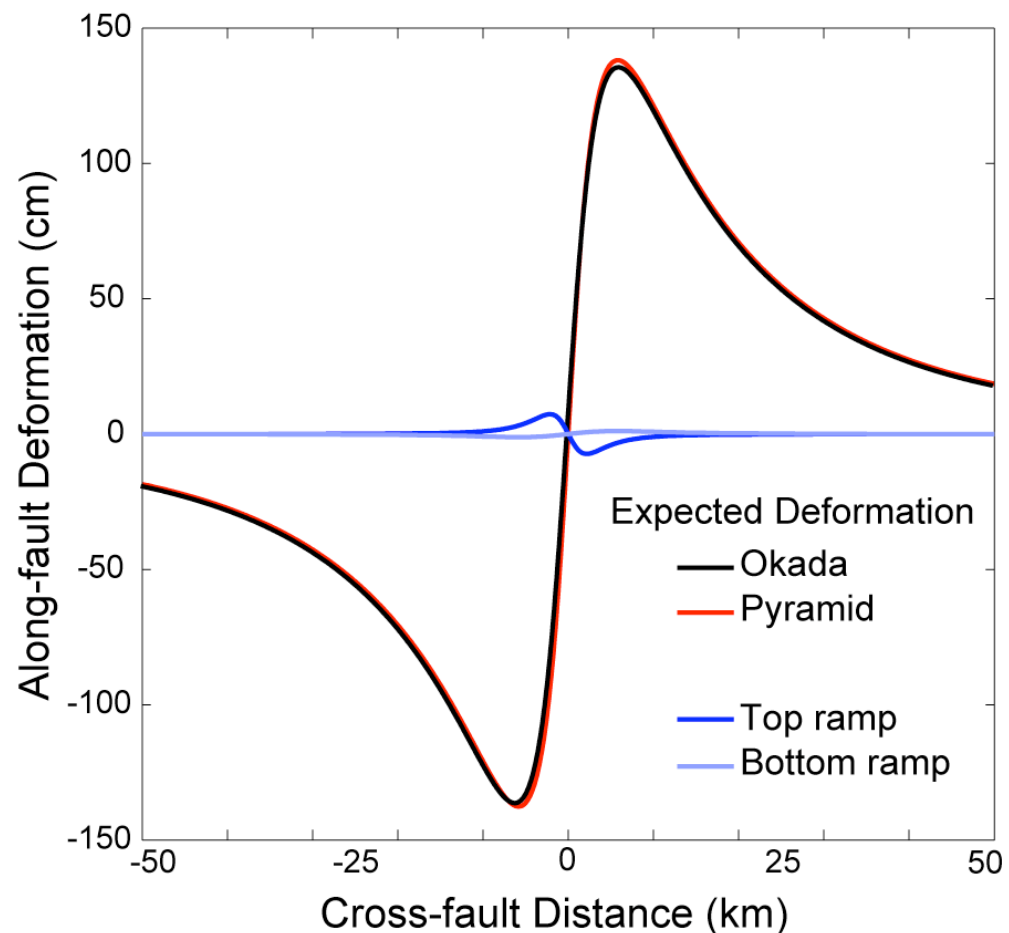
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3D version



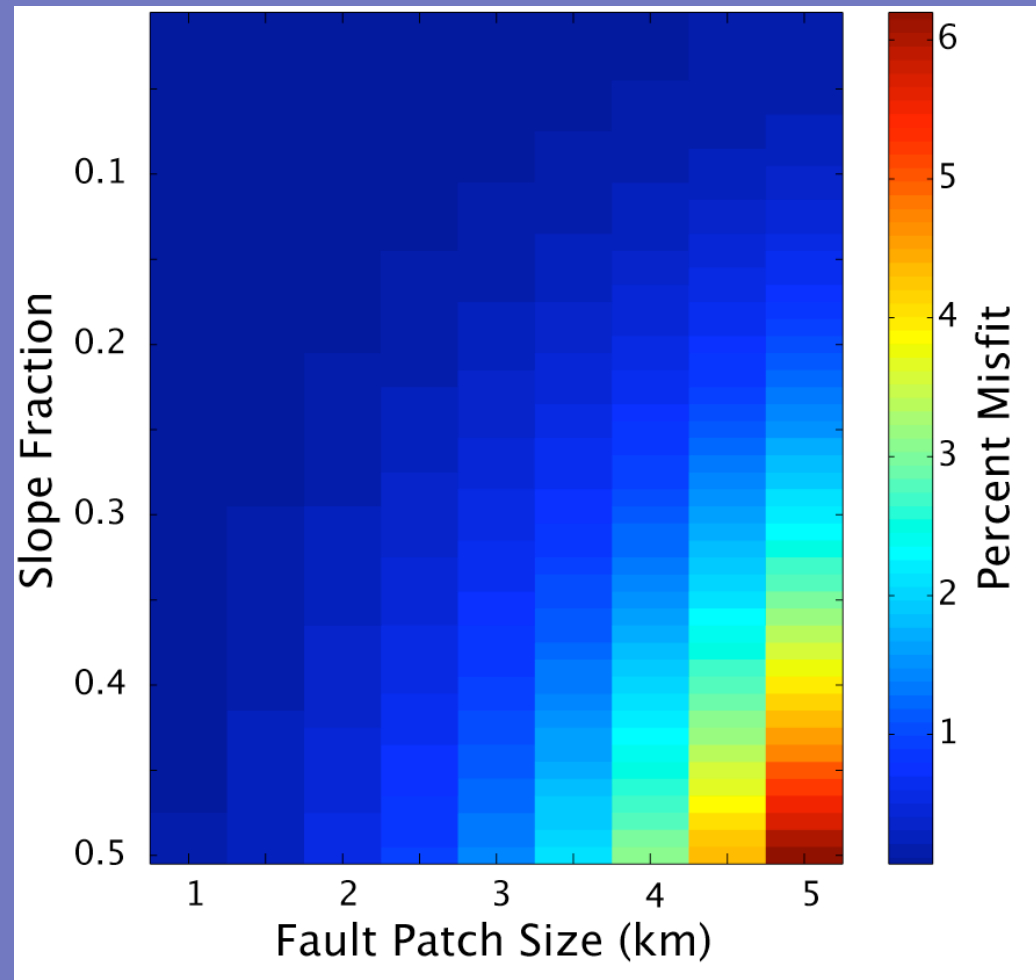
Comparison w/Okada

- More misfit from shallower ramp
- Can fit almost exactly with different fault patch



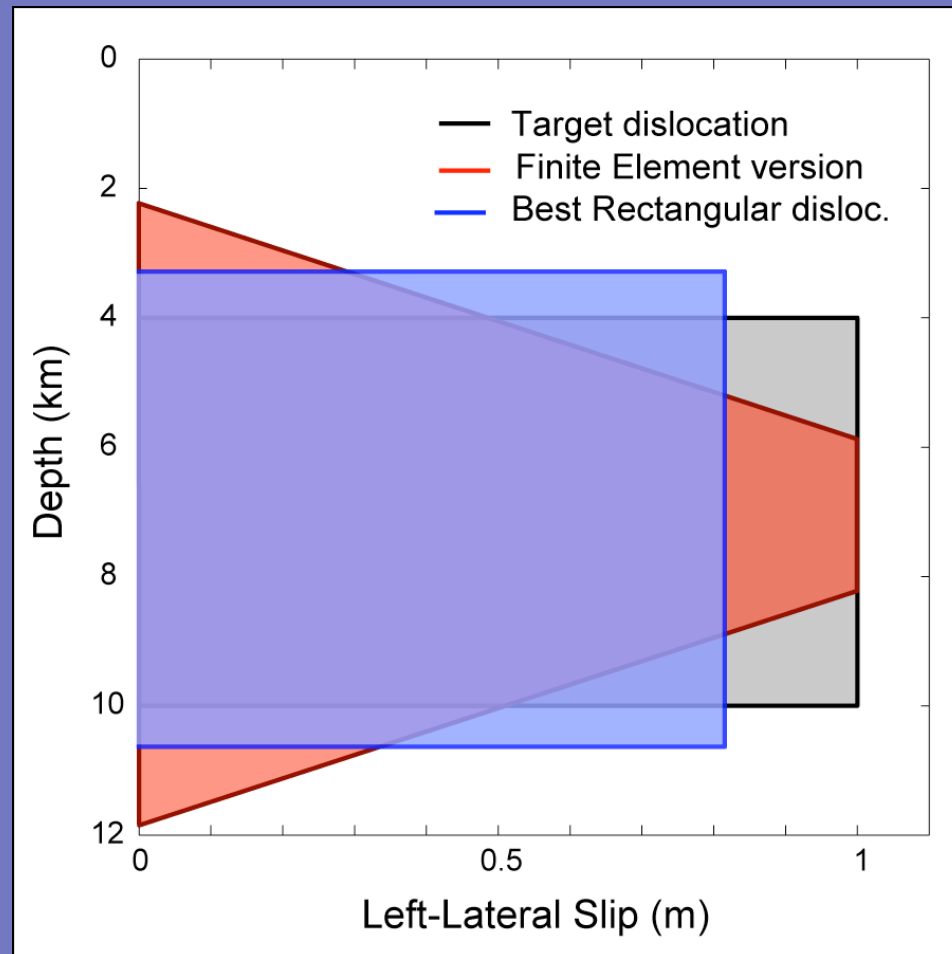
Comparison w/Okada

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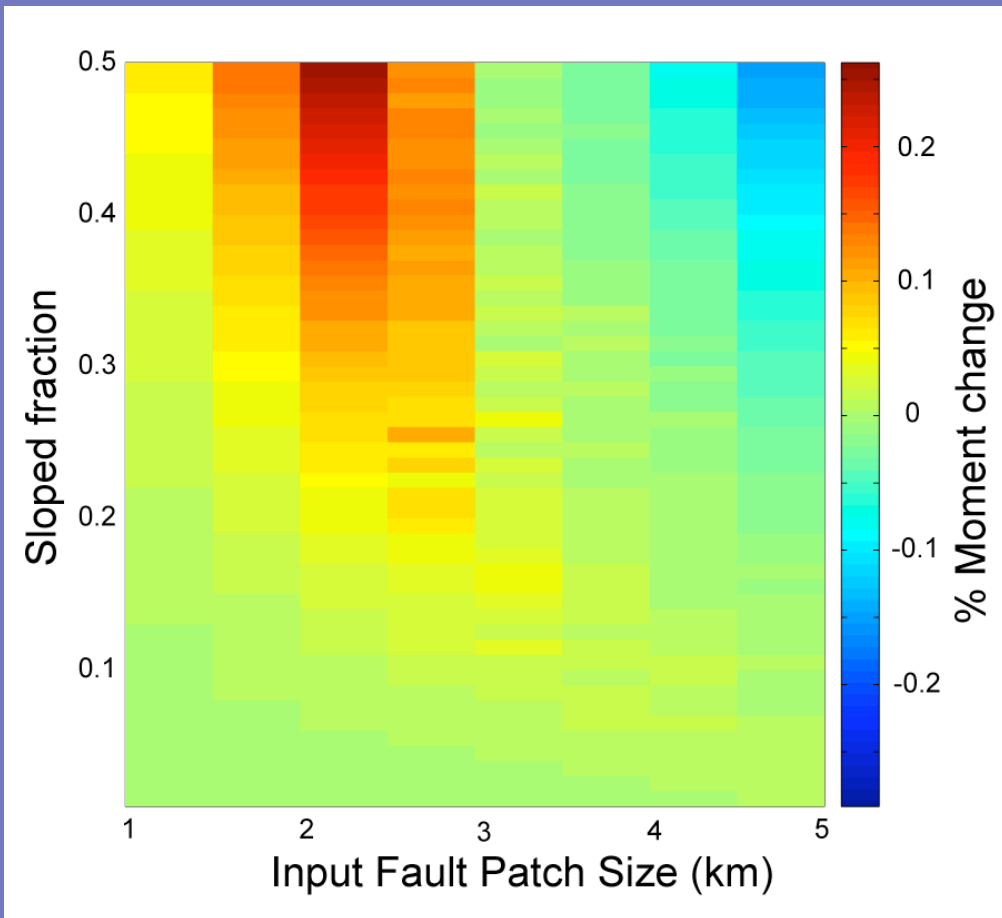
Comparison w/Okada

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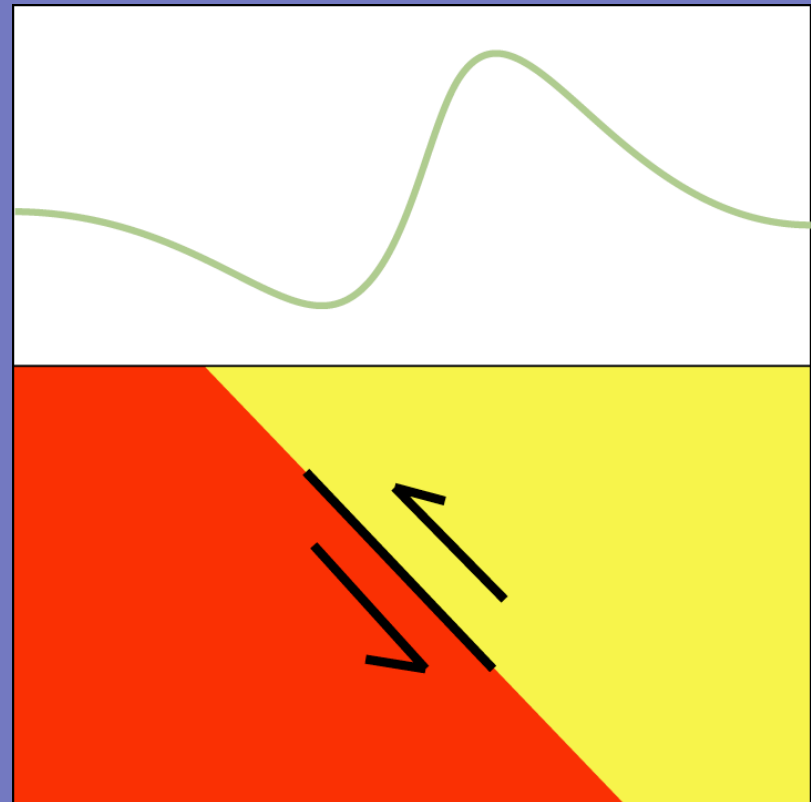
Comparison w/Okada

- More triangular -> wider patch w/ less slip
- Moments/centroid almost identical



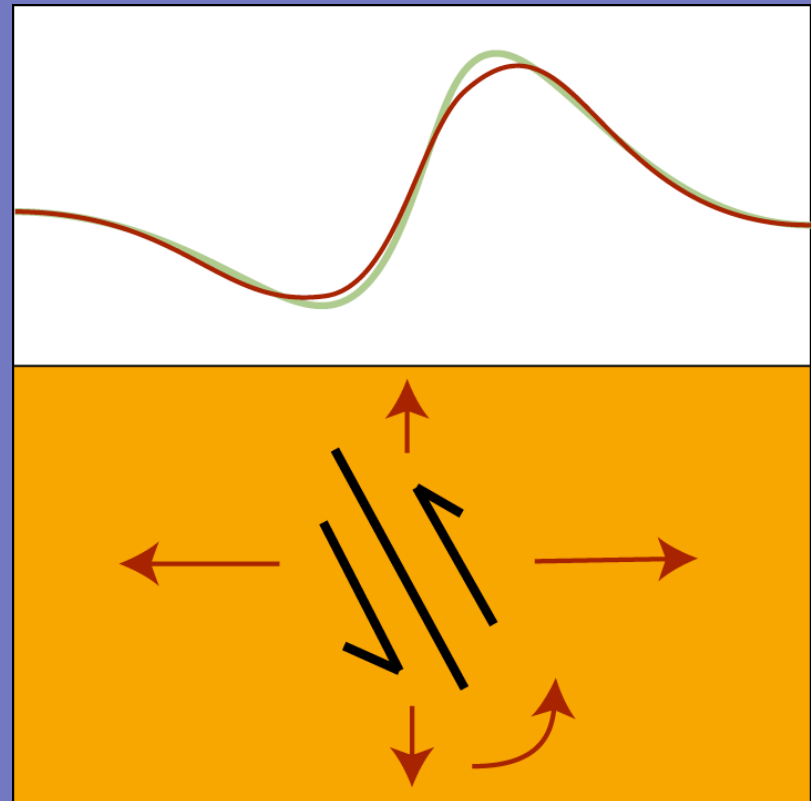
Examples: Sensitivity Tests

1. Generate synthetic data using cross-fault contrast (slow)
2. Invert using half space (fast)
3. Assess potential bias



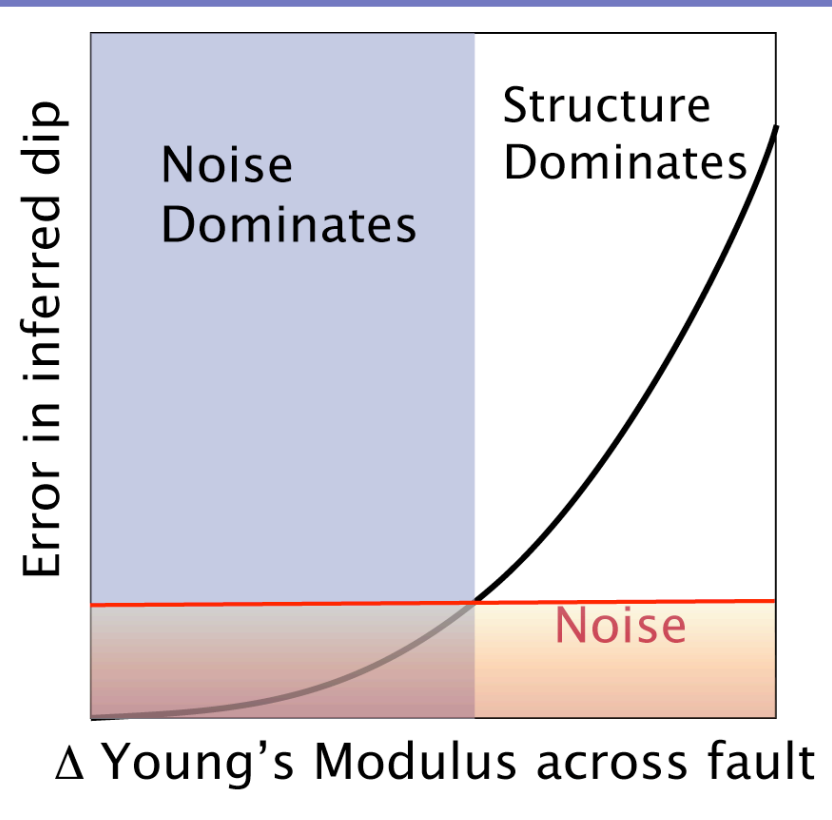
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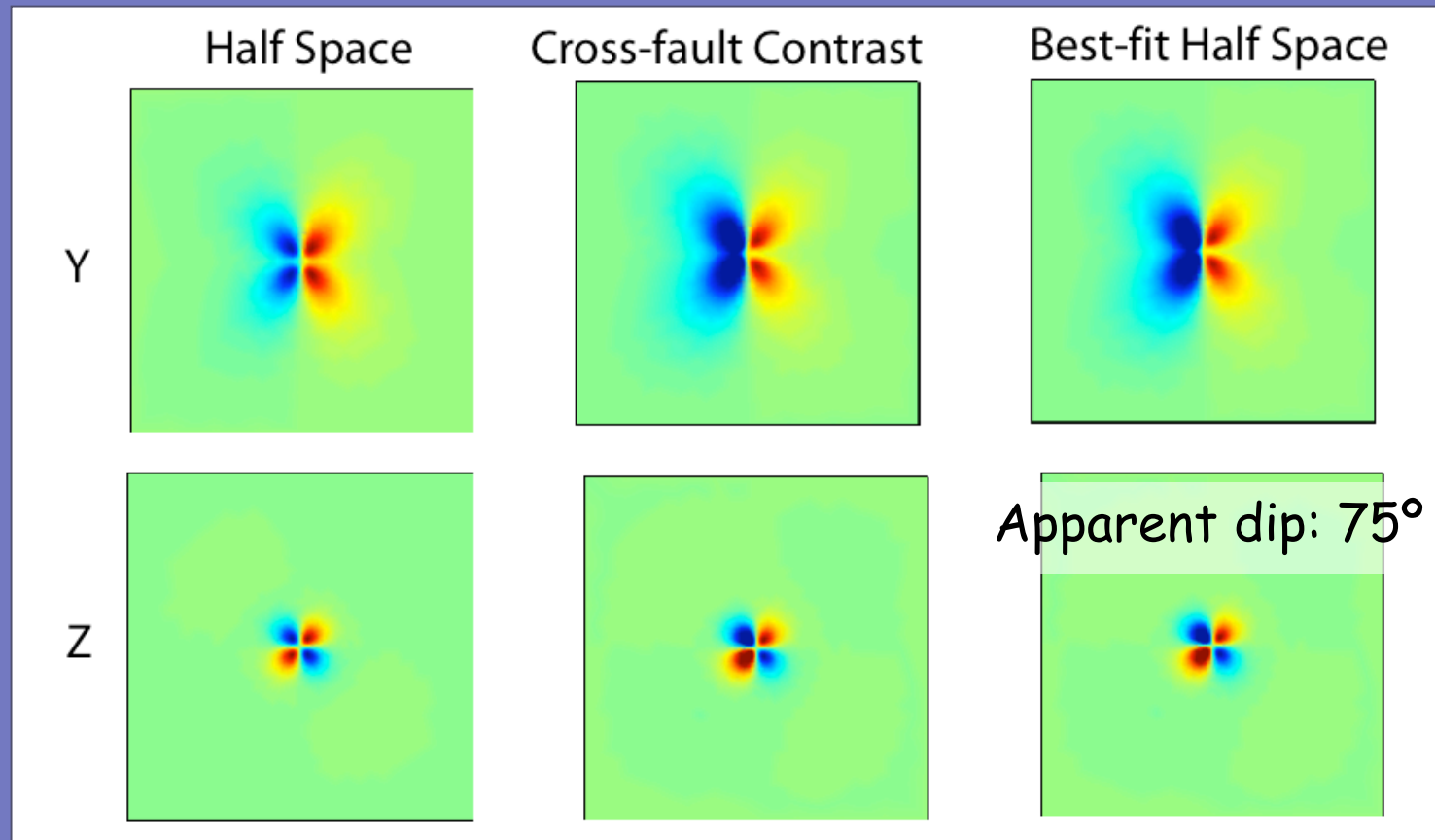
Examples: Sensitivity Tests

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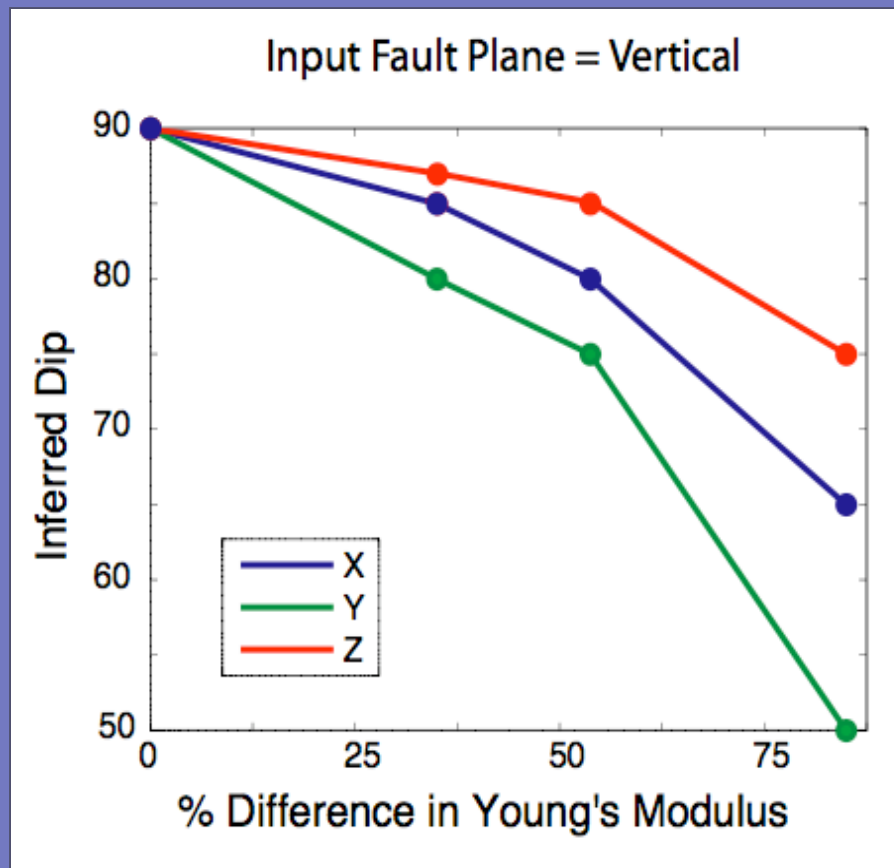


Vertical Fault Deformation Patterns

Can't fit asymmetric pattern with vertical fault

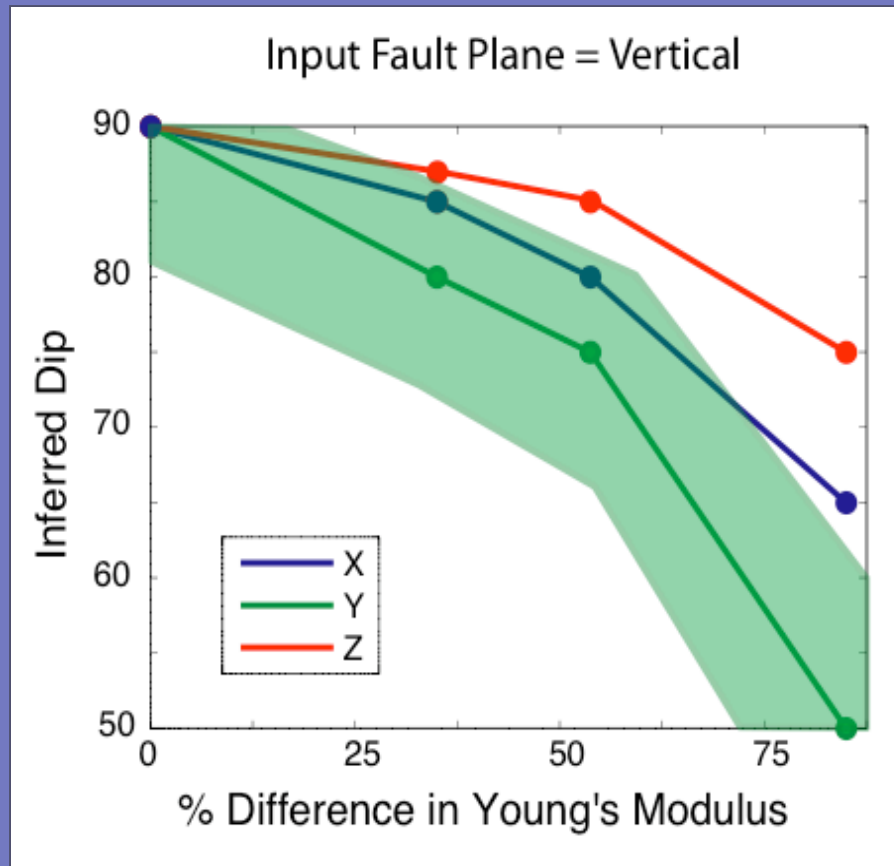


Cross-Fault Contrast Results



- Retrieve input geometry when contrast=0
- Up to 20 degree error for reasonable values
- Sensitivity depends on noise RMS, viewing geometry

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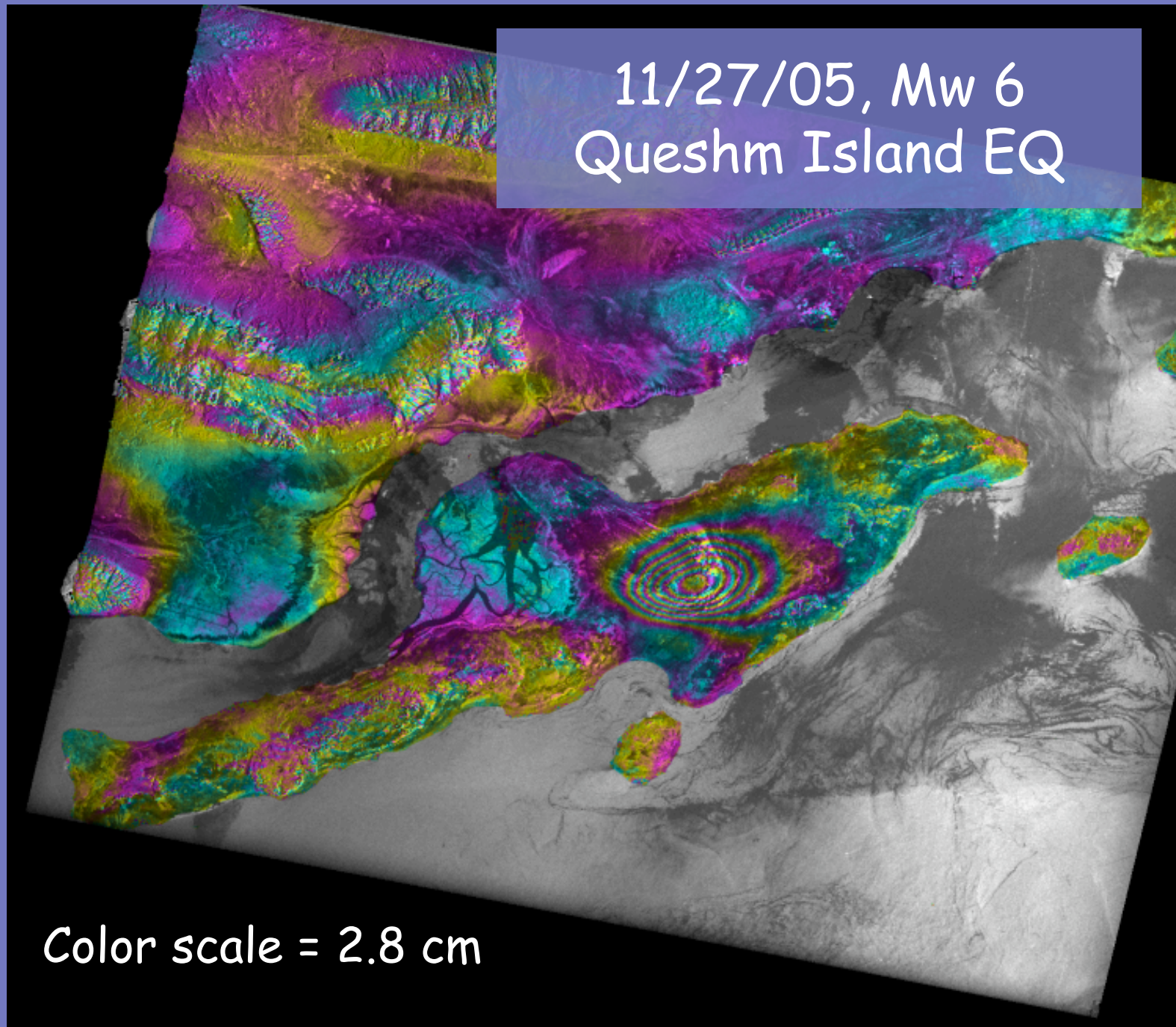
11/27/05, Mw 6 Qeshm Island EQ



Astronaut photography
<http://eol.jsc.nasa.gov/>

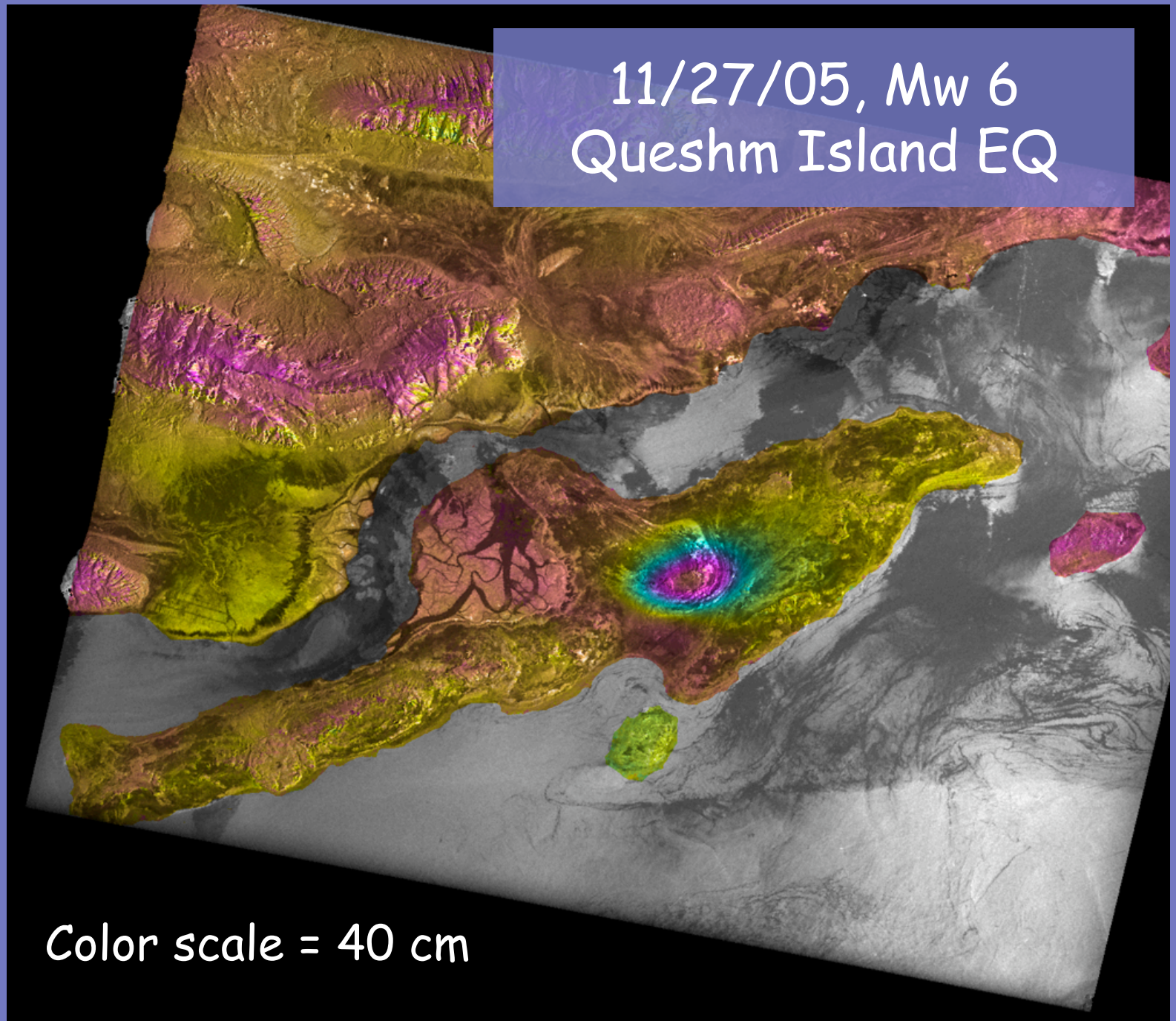
11/27/05, Mw 6
Queshm Island EQ

Color scale = 2.8 cm



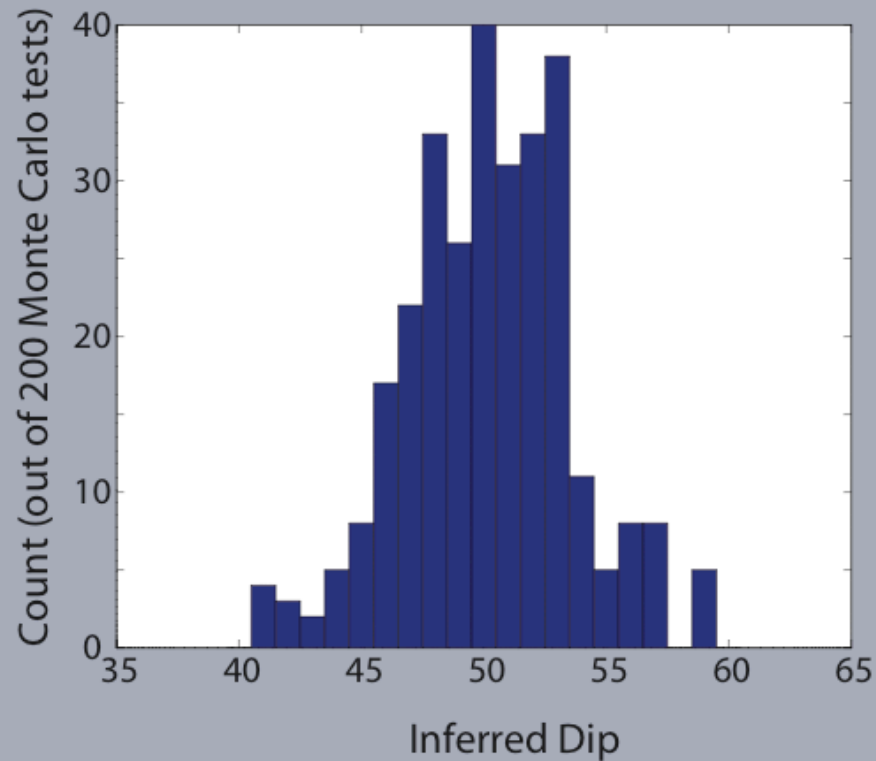
11/27/05, Mw 6
Queshm Island EQ

Color scale = 40 cm

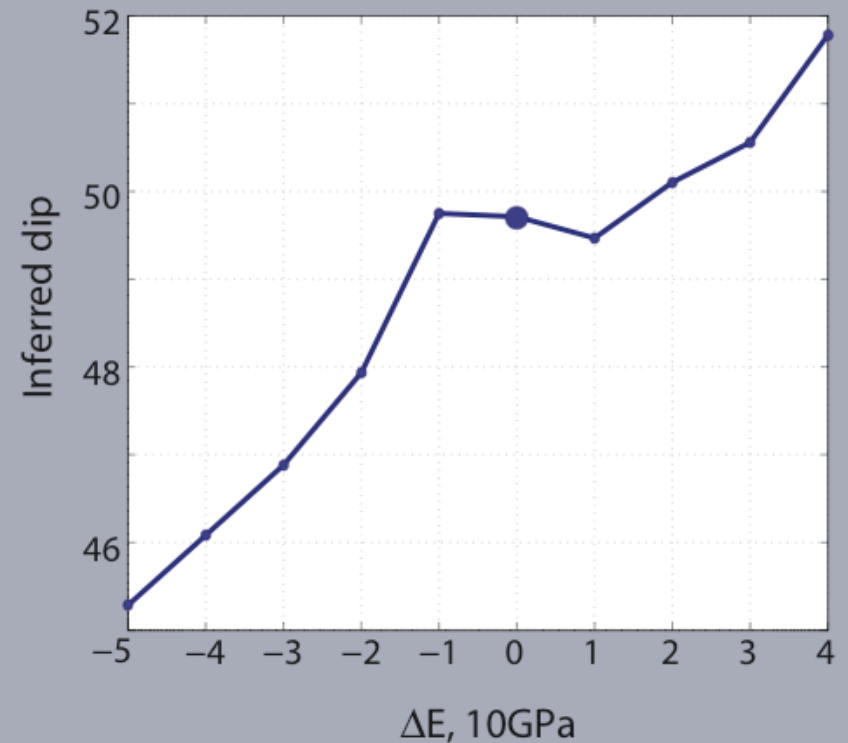


Assessing Potential Bias in Inferred Dip

Error from noise



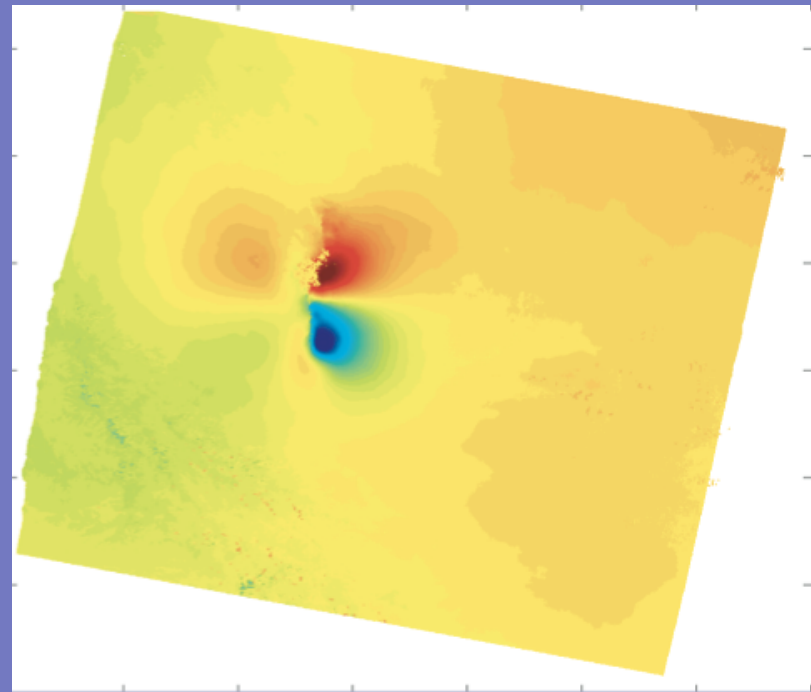
Error from structure



Atmospheric noise > Structure error

2003 Bam, Iran, Earthquake

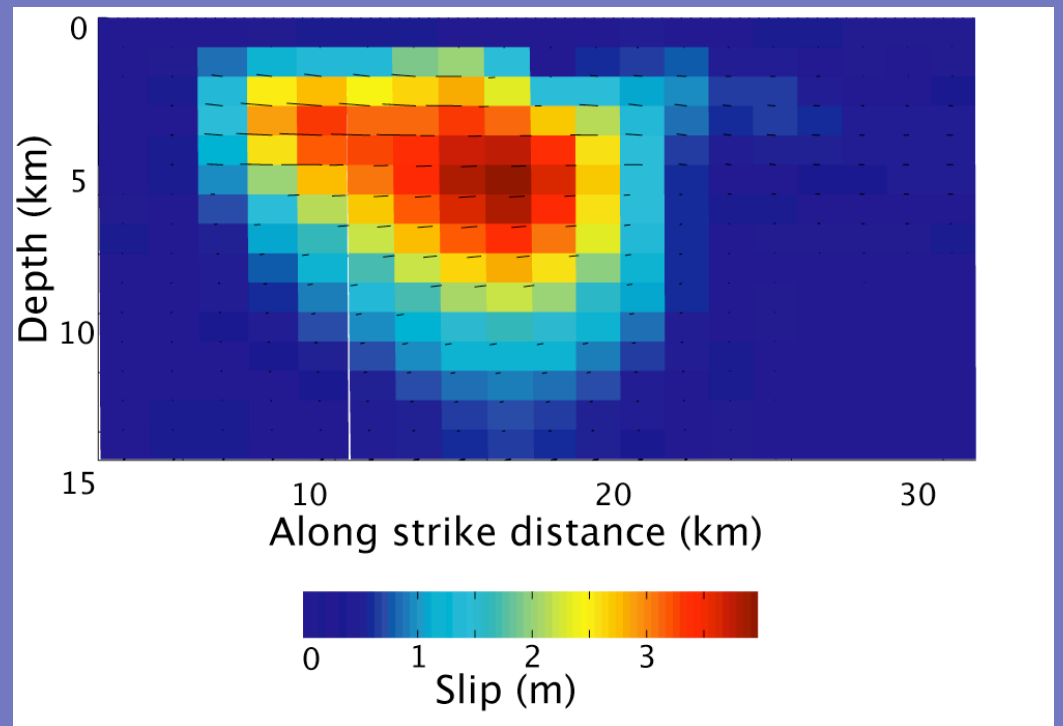
- > 40 cm line-of-sight deformation
- Not much structural/fault location info
- How well do inversions for fault dip perform?



Data courtesy Eric Fielding

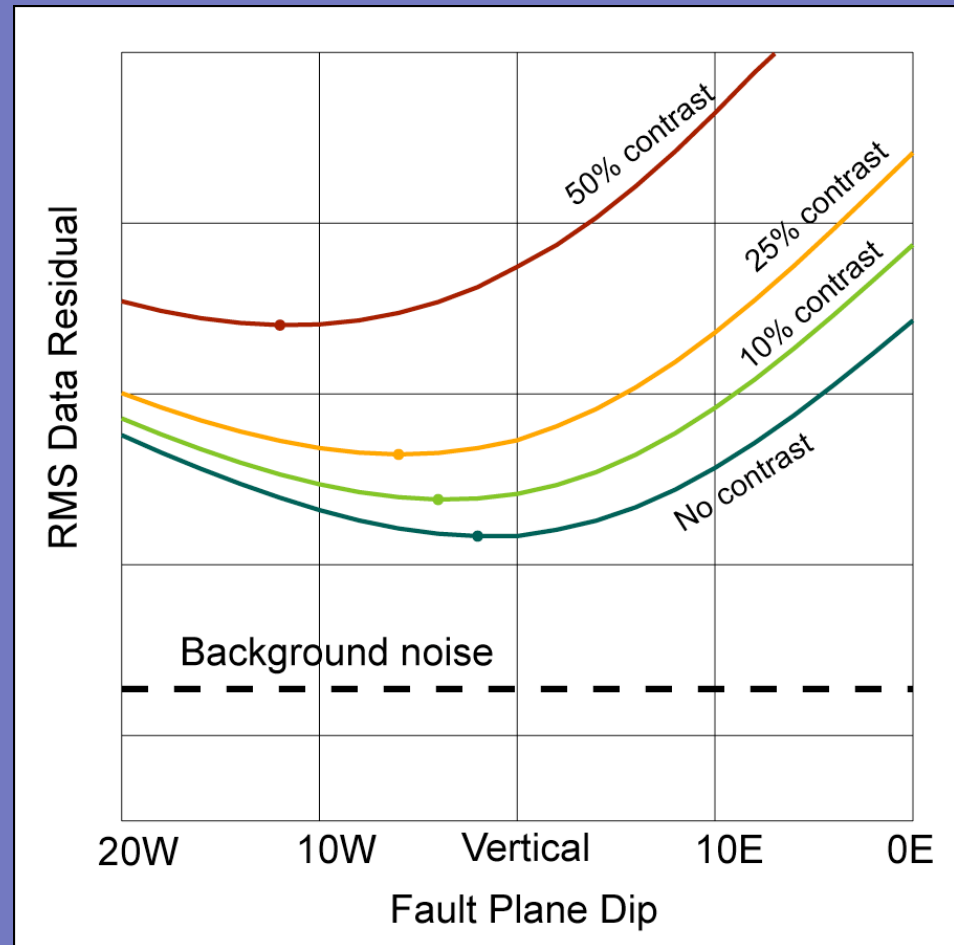
2003 Bam, Iran, Earthquake

- Pylith:
 - Generate Green's functions for distributed slip inversion
 - Repeat for various dip angles, cross-fault contrasts



2003 Bam, Iran, Earthquake

- Increased contrast = increased dip
- Best fit still no-contrast solution, near-vertical dip
- Geometrical irregularities = large residual
- Need more complicated geometry before can assess crustal contribution



Conclusions

- Sensitivity tests can largely be done with analytic inversions
- More time consuming FE modeling (especially inversions) can be avoided for many problems
 - Large atmospheric noise
 - Known fault plane geometry
- Patch by patch Green's function generation very time consuming
 - Can be a bit more efficient, use redundant dip/strike info
 - Internal Pylith Green's function producer very desirable