Resolving the Geometry of Global Subduction Zone Interfaces a priori - Working Towards Improved Earthquake Source Modeling

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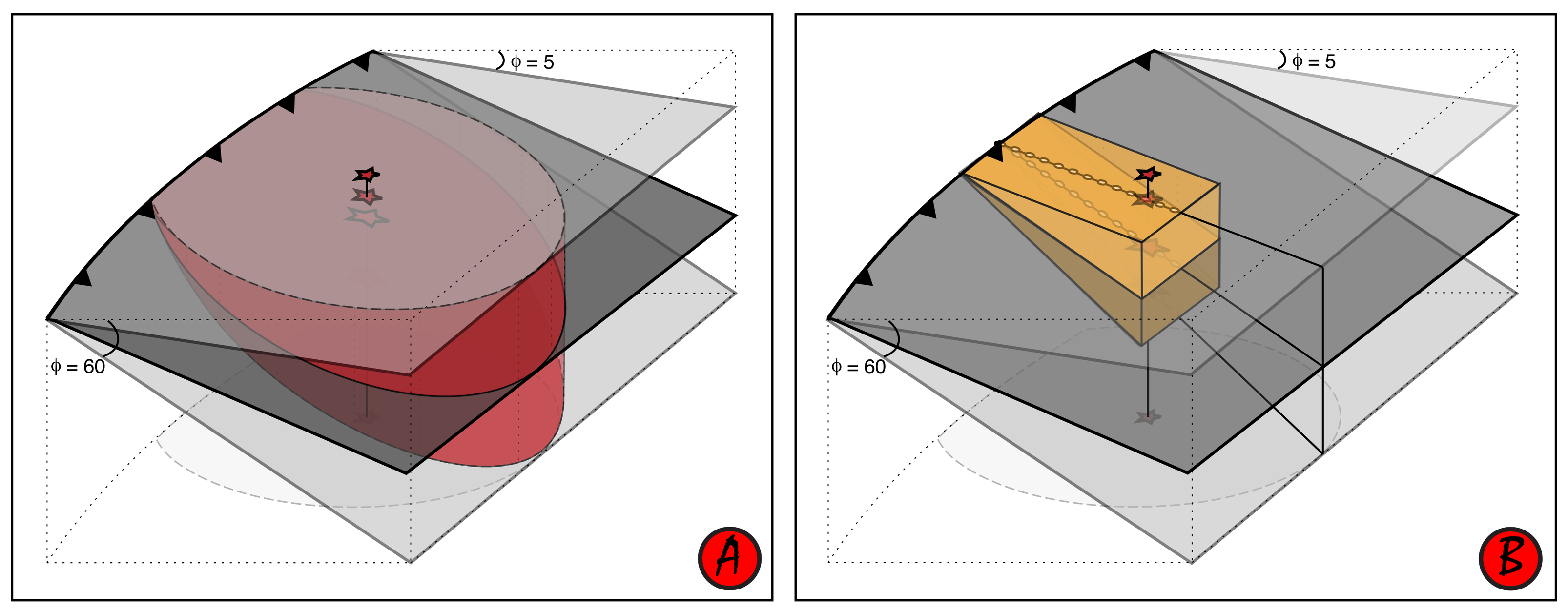
USGS science for a changing world

1 INTRODUCTION

Many earthquake source inversions in use today require knowledge of the geometry of the fault on which the earthquake occurred. Our knowledge of this surface is often uncertain, however (particularly in the immediate aftermath of an earthquake), and as a result fault geometry misinterpretation can map into significant error in the final temporal and spatial slip patterns of these inversions.

Here we attempt to improve the quality of fast finite-fault inversion results by combining, *a priori*, several independent and complementary data sets (historic earthquakes, CMTs, global plate boundaries, bathymetry, active seismic surveys) to more accurately constrain the geometry of the seismic rupture plane of subducting slabs. We construct probability density functions about each data point based on formal assumptions of their depth uncertainty and use these constraints to solve for the 'most likely' fault plane, exploring fits with both planar and polynomial geometries. This new approach allows us to rapidly determine more accurate initial fault plane geometries for source inversions of future earthquakes. We use these geometries to explore the effect on finite fault model slip distributions, and show that the model changes can have a significant affect on the assumed seismic hazard above source regions of major subduction zone earthquakes.

2 DATA SELECTION AND FILTERING



A: All well-constrained thrust mechanisms from the gCMT catalog within 200km of the reference location, deeper than the equivalent depth of a plane dipping 5°, and shallower than the equivalent depth of a plane dipping 60°, are retained.

B: Using the remaining mechanisms, the average CMT strike is calculated. This angle is assumed to represent the approximate subduction interface strike. From the reference location, we project back to the nearest point on the trench with this angle to establish the starting point of our reference profile. Using this trench location and angle, we construct the reference profile. All events greater than 100 km distance from this profile, in a direction perpendicular to that profile, are removed.

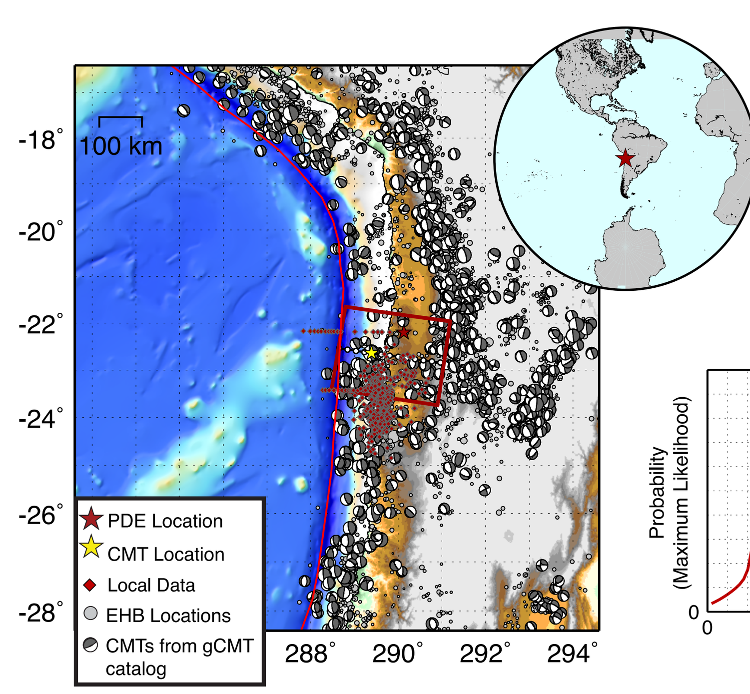
The remaining region of events is shaded in orange. For those events selected, we construct Normal Distribution Probability Density Functions about their reported depth, whose variance is based on reported depth error. All events are also weighted by magnitude.

The dip of the subduction zone is computed in a direction perpendicular to the average strike of selected events by fitting an inclined plane (and/or polynomial, if warranted by the data) through these PDFs.

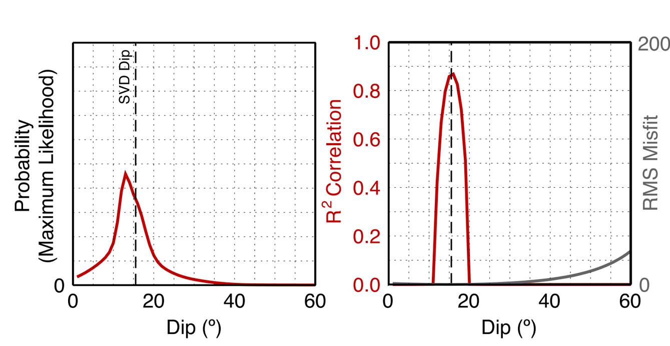
3 SUBDUCTION ZONE INTERFACE GEOMETRY ANALYSIS (SIGA) EXAMPLE - ANTOFAGASTA, N. CHILE, 2007/11/14

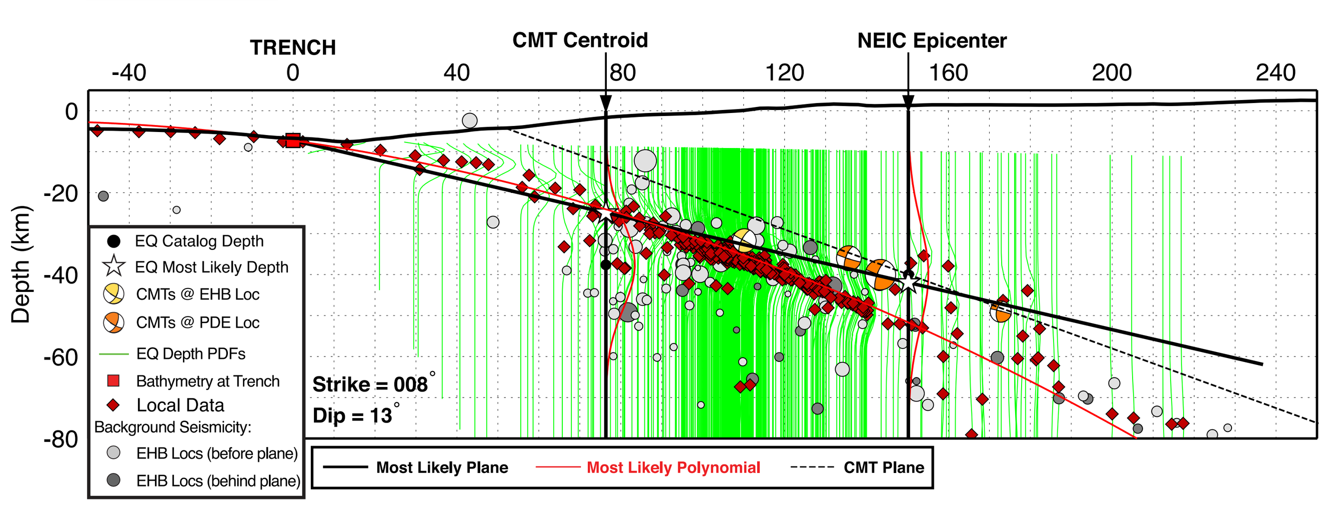
Most likely depth: Planar interface = 41.9km, polynomial = 50.5km

Local data from Husen et al. (1995), Salleres & Ronero (2005), Patzwahl et al. (1999).

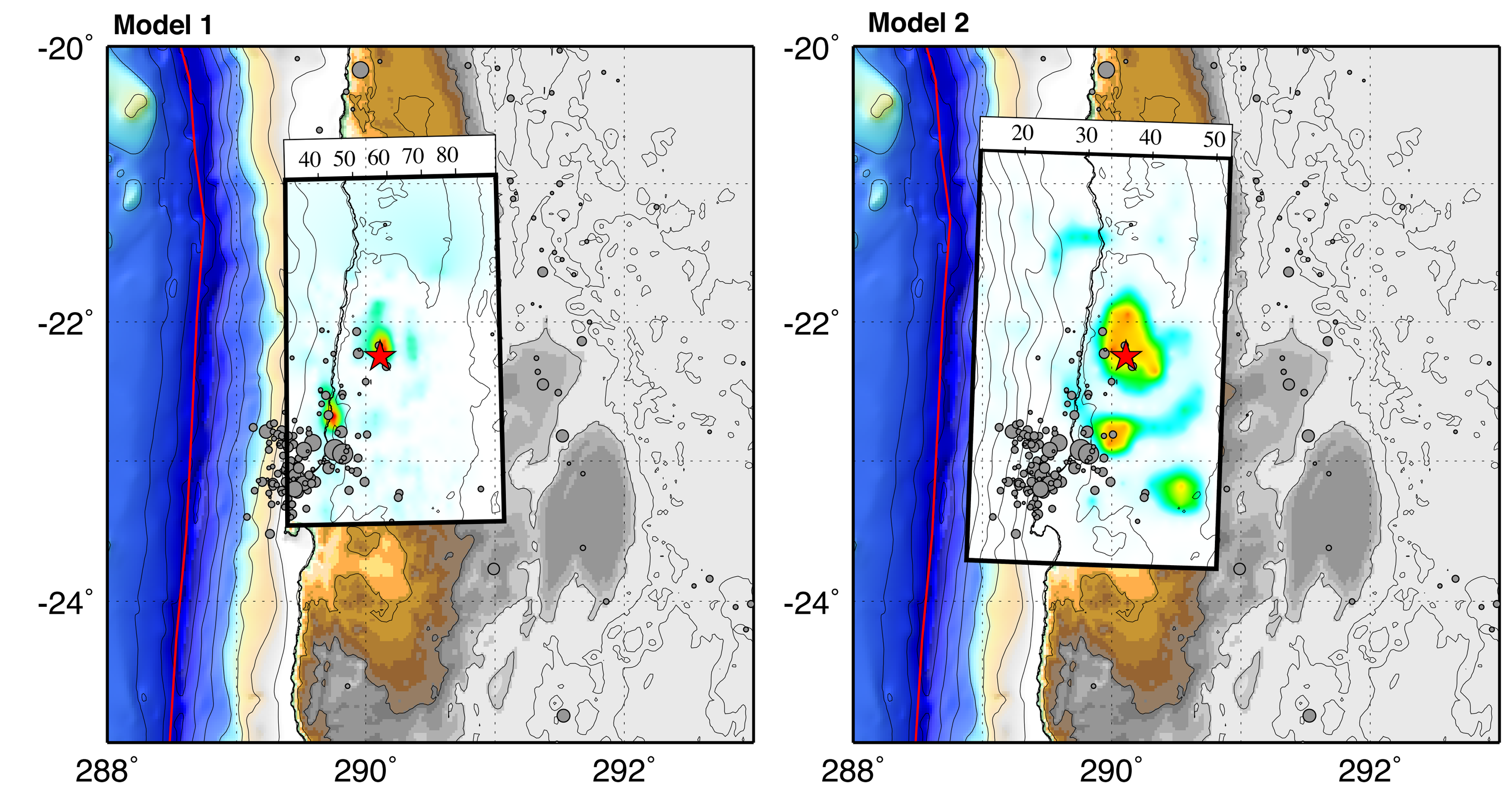


Interface geometry (lower panel) is calculated using the selected events and their respective PDFs. Selected events are shown by mechanisms from the gCMT catalog; yellow at EHB locations, and orange at NEIC PDE locations. Background seismicity is shown with gray circles; these events are either too small to have CMT solutions, or did not match the filtering criteria.





4 EARTHQUAKE SOURCE INVERSIONS - ANTOFAGASTA



Model 1: Finite Fault Inversion using gCMT plane through NEIC hypocenter.

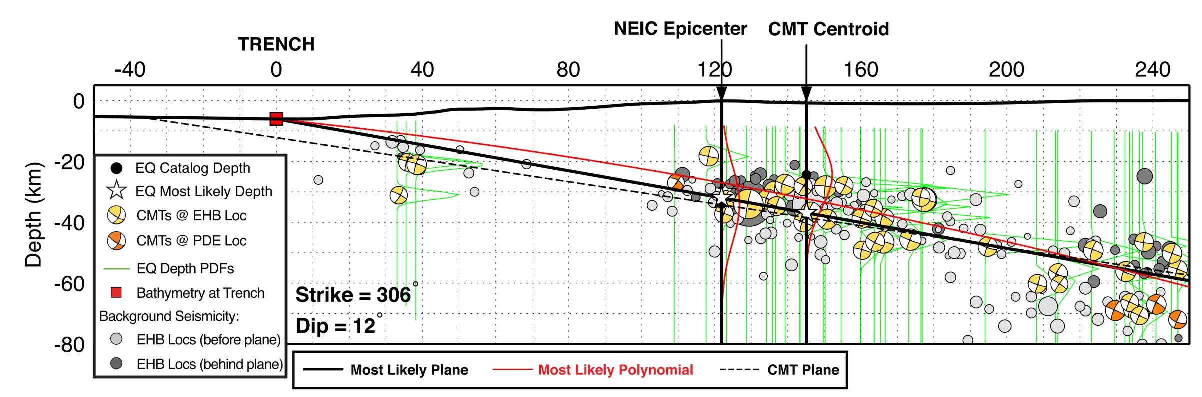
Model 2: Inversion using revised SIGA plane and depth.

Slip patch located near the hypocenter moves 20 km shallower in revised model.

Such results become significant for any subsequent models that rely on the depth and distribution of slip:
-Ground shaking estimates (leading to rapid response decisions)
-Tsunami modeling & predictions

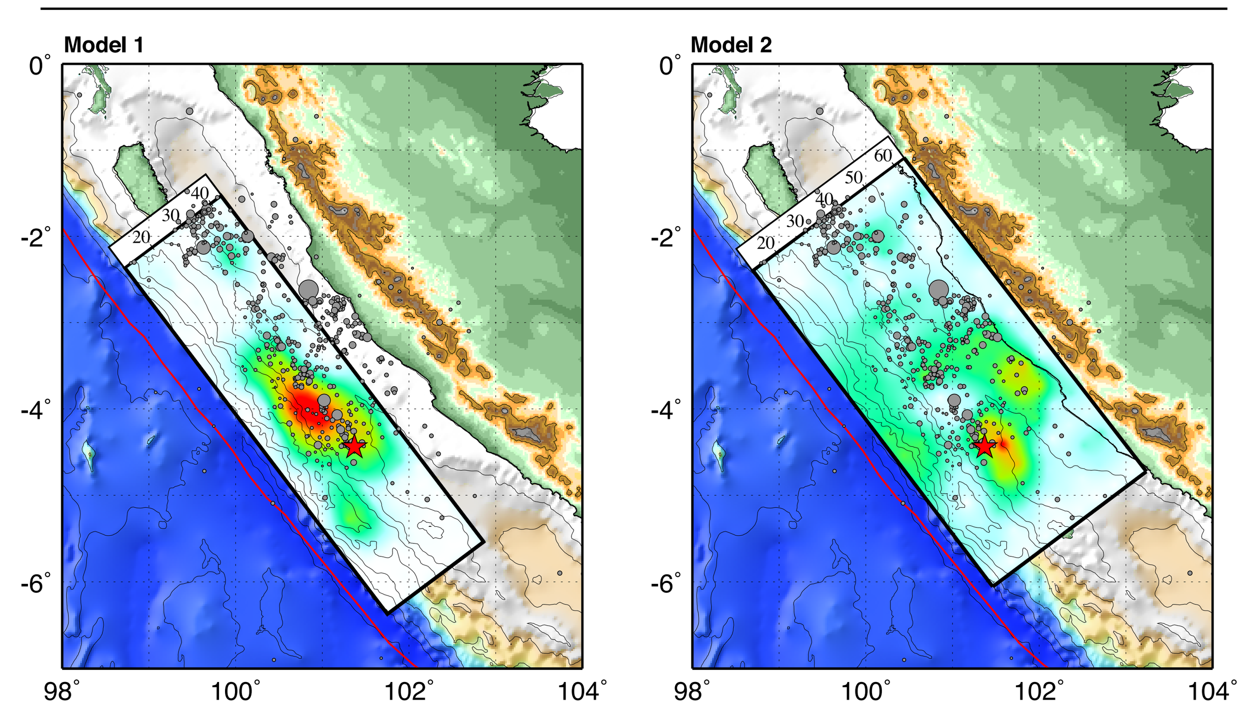
Red star = Event hypocenter
Gray circles = 3 months of aftershocks

5 EARTHQUAKE SOURCE INVERSIONS - S. SUMATRA, 2007/09/12, 11AM



Most likely depth: Planar interface = 32.0km. Polynomial interface = 26.7km.

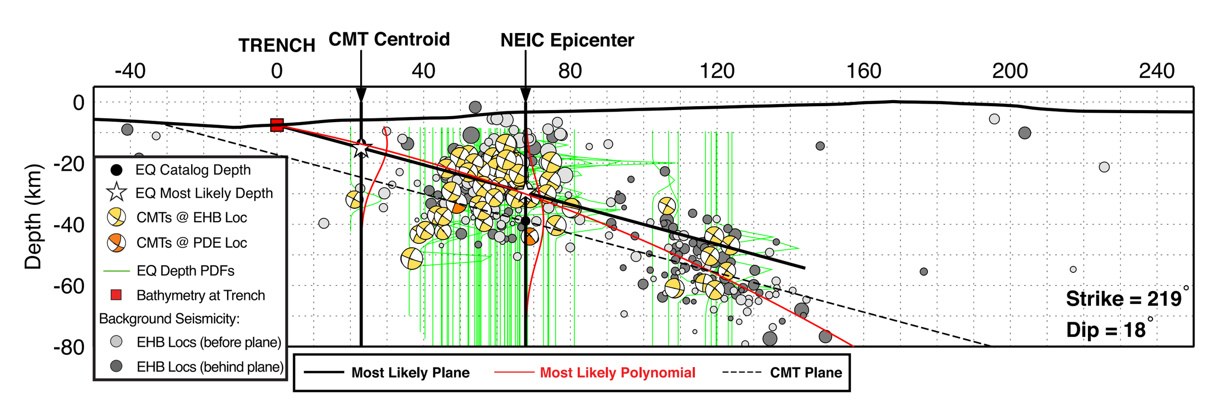
gCMT Dip = 8.5°, NEIC PDE initial depth = 34.0km.



Model 1: Finite Fault Inversion using gCMT plane through NEIC hypocenter.

Model 2: Inversion using revised SIGA plane and depth.

6 EARTHQUAKE SOURCE INVERSIONS - KURIL ISLANDS, 2006/11/15



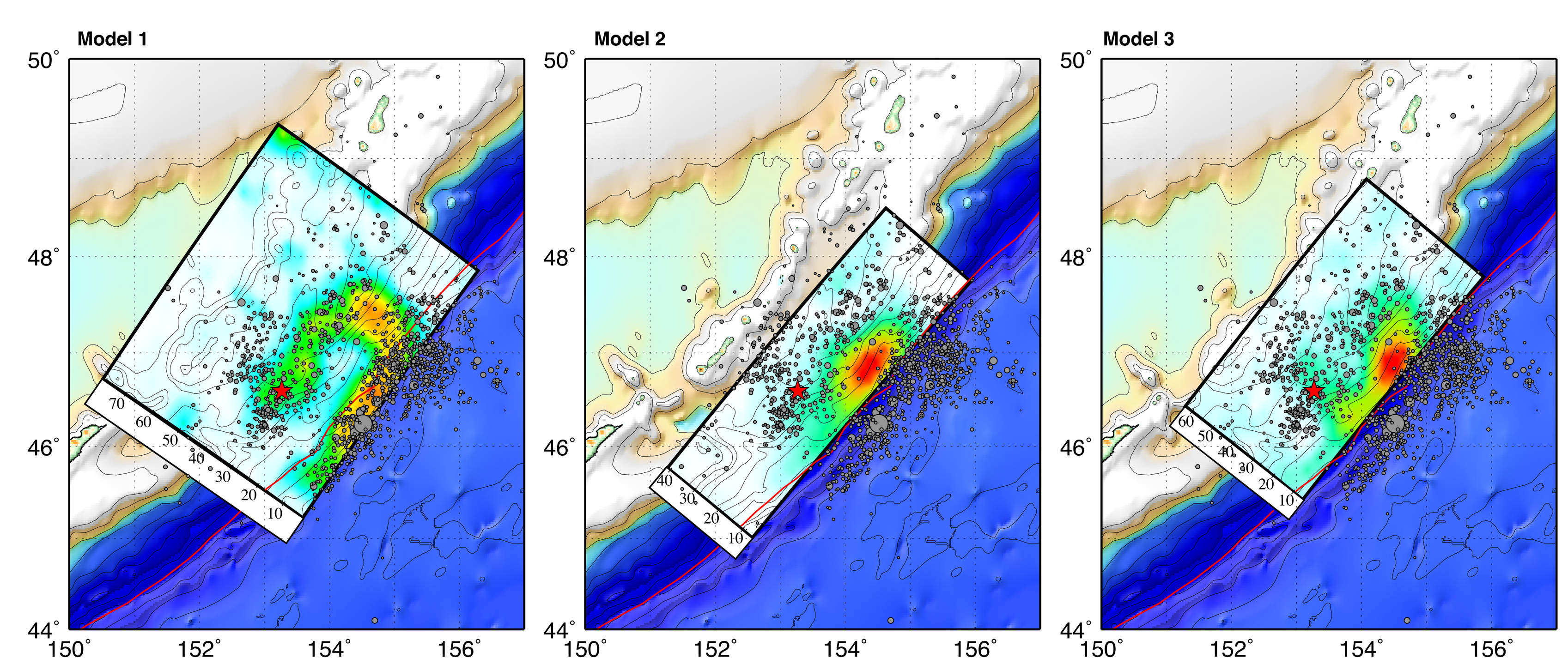
Most likely depth: Planar interface = 29.5km. Polynomial interface = 29.0km.

gCMT Dip = 15°, NEIC PDE initial depth = 39.0km.

Model 1: Finite Fault Inversion using gCMT plane through NEIC hypocenter.

Model 2: Revised inversion from Chen Ji, adjusting plane to match trench geometry (hours-days after event).

Model 3: Inversion using revised SIGA plane and depth.



7 EARTHQUAKE SOURCE INVERSIONS - IMPLICATIONS

New interface models facilitate source inversions on planes more closely aligned with the true subduction thrust.

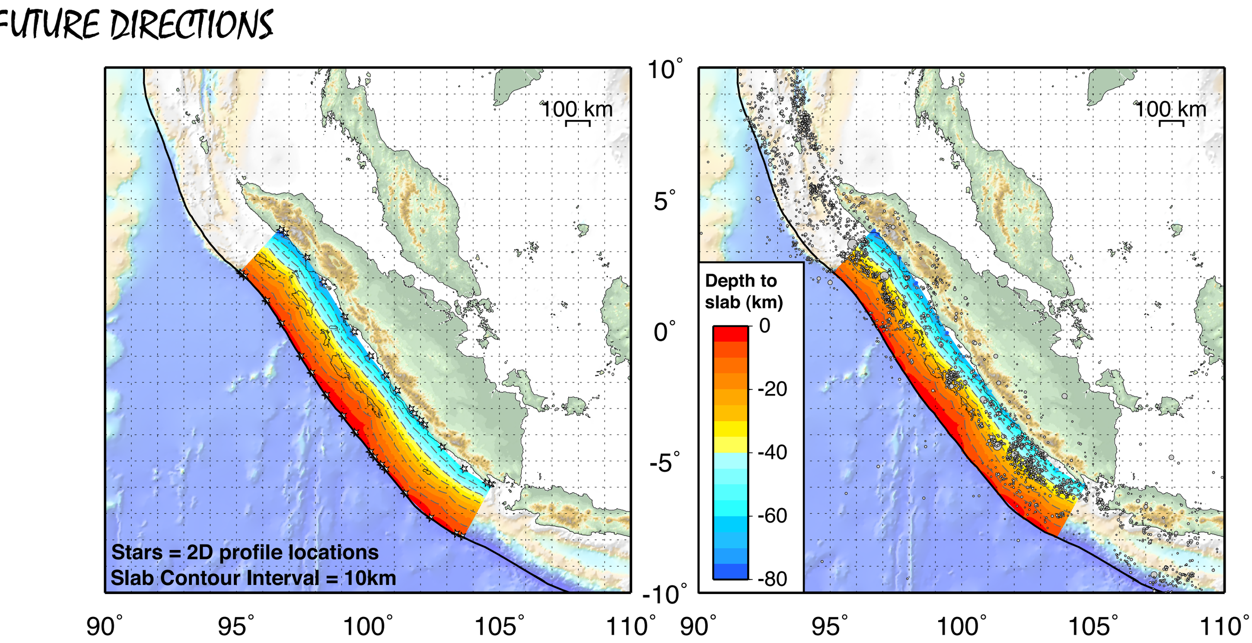
Inversions show significant spatial changes in slip distribution - particularly in depth if initial dip estimates differ.

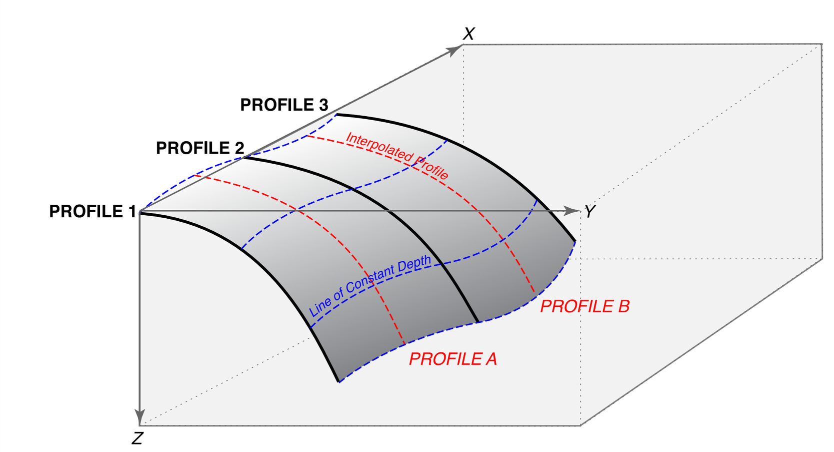
Such changes influence subsequent models that rely on the depth and distribution of slip (tsunami modeling, ground shaking estimates).

Comparisons of new models on SIGA interface (available *a priori*) with 'adjusted' FFMs (hours-days after the event) show high correlation - implying we can reach a more accurate model of slip distribution more quickly.

Issues:
Changes in dip across width of fault plane?
Changes in strike along length of rupture?

8 FUTURE DIRECTIONS





SLAB1.0 - A model of seismogenic subduction zone interfaces, merging 2D polynomial profiles (active & passive data), and segment boundaries to produce fault surfaces for each subduction zone.

These profiles/surfaces will be explicitly merged with current Finite Fault Modeling algorithms, allowing us to invert over a 'mesh' geometry rather than one or more planar interfaces.

9 CONCLUSIONS

This work presents a new approach for constraining the interface geometry in the shallow, seismogenic portion of subducting slabs using information from historic earthquake catalogs, sea floor trench locations, and probabilistic assessments of location uncertainties.

Planar geometries match data well for the shallow slab (to depths of ~60km).

New geometries become inputs to subsequent finite-fault models. These inversions show significant differences in the temporal and spatial patterns of slip when compared to rapid finite fault models produced using a best fitting CMT plane.

Future Enhancements Will Include:
-Further Incorporation of active seismic data (reflection surveys across the trench)
-Incorporating estimates of sediment thickness at the trench
-Routine analyses of subduction interfaces worldwide
-Inclusion of polynomial interfaces in finite fault inversions

Paper describing methodology, results & interpretations recently accepted at Geophysical Journal International:
Hayes & Wald, Developing framework to constrain the geometry of the seismic rupture plane on subduction interfaces a priori – a probabilistic approach, *Geophys. J. Int.*, *in press.*, accepted 10/28/2008.