20 Joint Seismic and Geodetic Analysis of the 2009 Padang, Sumatra Intraslab Earthquake

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20.1 Introduction

The $M_w$ 7.6 Padang earthquake occurred on 30 September 2009 offshore of central Sumatra (Figure 2.42). Seismicity in the Sumatra region is driven by the oblique subduction of the Indian and Australian plates beneath the Burma forearc block and Sunda plate at the Sunda trench. The Sunda megathrust has been extremely active ever since the 2004 $M_w$ 9.2 Sumatra-Andaman earthquake, with additional megathrust earthquakes in 2005, 2007, and 2010. The last remaining section of the Sunda megathrust without a modern great earthquake is the Siberut segment, which lies offshore of Padang. Thus, it is especially important to understand the fault mechanism of the 2009 Padang earthquake in order to assess how it affects the stress levels on the Siberut segment of the megathrust.

The Padang earthquake is an unusual event because it likely ruptured the subducting Australian plate. The Engdahl relocated earthquake catalog locates the earthquake at 78 km depth, ~250 km from the Sunda trench, where the Hayes et al. (2009) Sunda slab model places the interface at ~69 km depth. The Padang earthquake rupture mechanism is also consistent with an intraslab event. The strike is approximately perpendicular to the trench with significant left-lateral strike-slip motion. Possible candidates for the rupture plane could be subducted paleo transform faults, fractures, or ridges. We attempt to resolve the fault plane using regional broadband seismic data, GPS data, and aftershock locations.

20.2 Data and Processing

There are 7 three-component broadband stations located within 750 km of the epicenter, with useable data available on IRIS, operated by the GEOFON network, the Malaysian National Seismic Network, and the Singapore National Network. For our finite fault inversions, both the displacement waveform data and the Greens functions are bandpass filtered between 0.01 to 0.3 Hz. The maximum waveform amplitude for each component varies from about 0.5 to 1.5 cm at this frequency range. We also include data from 18 three-component permanent GPS stations, located within 380 km of the epicenter, from the SuGAr and ENS-INSU regional networks (Figure 2.42).

![Figure 2.41: Left: Slip models for the east-west nodal plane using GPS, seismic, and joint data. Right: Slip models for the north-south nodal plane. The hypocenter is marked with a star and the arrows indicate the variable inverted rake direction.](image)

20.3 Inversion Method

The Green’s functions for our finite fault inversions are calculated using a 1D frequency-wavenumber integration method (Saikia, 1994). Our starting earth model consists of the Lange et al. (2010) velocity structure, PREM densities, and typical crustal attenuation values. To invert for finite fault slip, we use a least-squares inversion method that employs simultaneous smoothing and damping (e.g. Kaverina et al., 2002). We initially invert the GPS data for fault geometry, using a uniform slip model. Nodal plane (NP) 1 has a strike of 80° and dip of 57°, and NP2 has a strike of 190° and dip of 60°. Our optimal strike and dip values are very similar to the GCMT moment tensor solution geometry, and we allow variable rake in the finite fault inversions. Our fault plane extends 100 km along strike by 75 km downdip, divided into 5 x 5 km patches. The hypocenter is located in the central
position along strike and 3 patches downdip to prevent slip from propagating through the plate interface.

20.4 Inversion Results

The initial seismic finite fault inversion for both nodal plane geometries does a fairly good job of fitting the waveform amplitudes and polarities. However, all of the synthetics have significant phase shifts on the order of 10 seconds that cause the variance reductions to be negative. The highest variance reductions for each NP geometry are achieved using the Lange model with a uniform 10% increase in velocities across all depths. NP1 has a variance reduction (VR) of 56% and NP2 has a VR of 54%. For both inversions, there are two high slip regions, one near the hypocenter and the other ∼40 km downdip (Figure 2.41).

The NP1 GPS-only inversion also has two high slip regions, although the deeper slip extends further east than the seismic-only inversion and has a VR of 79%. The NP2 GPS-only inversion has one focused high slip region, south of the hypocenter, with a VR of 80%. The NP2 model has higher peak slip values than the NP1 model, but the total moment is ∼20% lower.

The joint inversions both have one high slip region. The east-west NP1 slip distribution is broader and extends 45 km downdip of the hypocenter, with a 40 x 55 km high slip region. The north-south NP2 slip distribution has a more focused depth range, and the high-slip region is constrained to 40 x 25 km. The seismic and GPS data are very compatible, and the joint variance reductions are within 95% of their individual inversion values.

20.5 Discussion

Our joint inversions of the Padang earthquake, using both regional seismic waveform and geodetic data, have shown that the two nodal planes have equivalent variance reductions and the total moment differs by only ∼10%, equal to $M_w$ 7.7 events. The north-south plane has a more focused slip distribution than the east-west plane. However, the NEIC aftershock sequence better aligns with the strike and depth range of the east-west plane (Figure 2.42). Therefore our preferred fault model is slip on the east-west nodal plane, primarily southwest of the hypocenter.

20.6 Acknowledgments

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20.7 References


Lange et al., The fine structure of the subducted investigator fracture zone in Western Sumatra as seen by local seismicity, EPSL, 298, 47-56, 2010.