FINAL TECHNICAL REPORT
Award Number G10AP00048

"Validation and Refining of Velocity Models and Rapid Source Estimation"

Project Period Start/End Date: March 1, 2010 – February 28, 2012

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Abstract

Generally, P-wave arrival times have been used to locate regional earthquakes because they can be calibrated from explosions. In contrast, the travel times of surface waves dependent on source excitation. Thus, the source parameters and depth must be determined independently and surface wave path delays need to be known. These delays can be estimated from previous earthquakes using the Cut-And-Paste (CAP) technique, Ambient Seismic Noise (ASN), and from 3D models. Taking the Chino Hills event as an example, we show consistency of path corrections for (>10s) Love and Rayleigh waves to within about 1 sec obtained from these methods. We then use the phase delay maps to determine centroid locations of 157 Southern California moderate-sized (Mw>3.5) earthquakes. It appears that these methods are capable of locating the main zone of rupture within a few (~3) km accuracy and a possible real time inversion system discussed with the waveform inversion from only 5 stations azimuthally distributed. We also address the timing accuracy required to determine non-double-couple source parameters which trades-off with location.

For large events, we have static data to help locate and define the slip-dislocations. We generate such solutions for the 2010 El Mayor-Cucapah event. Here, we synthesize the earthquake data using modern methods in seismology, tectonic geodesy, remote-sensing (Global Positioning Systems (GPS), Interferometric Synthetic Aperture Radar (InSAR), sub-pixel correlation of optical satellite images and Synthetic Aperture Radar (SAR).

Results

1. Surface Wave Path Corrections and Source Inversions in Southern California

Ying Tan, Alex Song, Shengji Wei, and Don Helmberger
(*Published: BSSA, Vol. 100, No. 6, 2891-2904, December 2010*)

Abstract

The Cut-and-Paste (CAP) methodology for recovering source parameters has proven useful in many regions. The method uses a library of 1D Green's functions which are broken into segments and matched to observations where adjustable timing shifts and path corrections are found along with the source parameters. If these path corrections are known, we can use the same method but recover both mechanism and location, a procedure we call CAPloc. Here, we use 160 events with known locations to develop maps of Rayleigh and Love wave delays for Southern California using the TriNet array. We assume a 15 km thick seismogenic layer which is uniform in depth but can vary laterally in 10 km grids and use tomography to define the velocity variation which is up to 15%. Synthetics generated from 2D cross-sections connecting source and station pairs indicates that 1D synthetics are sufficient in modeling but simply shifted in time for most paths. This simplification allows source inversion for both mechanisms and locations to be easily obtained by grid-search. We test the usefulness of two station inversions involving PAS and GSC which have waveform data since 1960 against the full-array with considerable success when the events are bracketed.

2. Locating earthquakes with surface waves and centroid moment tensor estimation

Shengji Wei, Zhongwen Zhan, Ying Tan, Sidao Ni, and Don Helmberger
(*Published: JGR, Vol. 117, B04309, doi:10.1029/2011JB008501, 2012*)

Abstract

Traditionally, P-wave arrival times have been used to locate regional earthquakes. In contrast, the travel times of surface waves dependent on source excitation and the source parameters and depth must be determined independently. Thus, surface wave path delays need to be known before such data can be used for location. These delays can be estimated from previous earthquakes using the Cut-And-Paste (CAP) technique, Ambient Seismic Noise (ASN) tomography, and from 3D models. Taking the Chino Hills event as an example, we show consistency of path corrections for (>10s) Love and Rayleigh waves to within about 1 sec obtained from these methods. We then use these empirically derived delay maps to determine centroid locations of 138 Southern California moderate-sized ($3.5>M_w>5.7$) earthquakes using surface waves alone. It appears that these methods are capable of locating the main zone of rupture within a few (~3) km accuracy relative to Southern California Seismic Network locations with 5 stations that are well distributed in azimuth. We also address the timing accuracy required to resolve non-double-couple source parameters which trades-off with location with less than a km error required for a 10% Compensated Linear Vector Dipole resolution.

3. Superficial simplicity of the 2010 El Mayor-Cucapah earthquake of Baja California, Mexico

Shengji Wei, Eric Fielding, Sebastien Leprince, Anthony Sladen, Jean-Philippe Avouac, Don Helmberger, Egill Hauksson, Risheng Chu, Mark Simons, Kenneth Hudnut, Thomas Herring, and Richard Briggs
(*Nature Geoscience, 2011, doi:10.1038/ngeo1213*)

Abstract

The geometry of faults is known to affect the initiation, propagation and arrest of seismic ruptures. Geometric complexities might be the main reason why earthquakes, while being shear-faulting instabilities, sometimes generate seismic radiation patterns significantly different from the double-couple pattern expected for a planar elastic shear-dislocation. The Mw7.2 2010 El Mayor-Cucapah earthquake is such an earthquake. Here, we use geodetic, remote-sensing and seismological data to determine the faults geometry and the slip history during that earthquake. We find that it formed a 120 km straight fault trace cutting through the Cucapah mountain range and across the Colorado River Delta. At depth, the faults system consists of two N130ºE striking segments with opposite dip angles connected by a jog with a N5ºW striking normal segment. The earthquake initiated as a moderate normal event at this jog, and 15s later ruptured bilaterally the two main segments with dominantly strike-slip motion. Owing to the complexity of the fault geometry, our source model explains well the seismic waves generated by the earthquake, including the large non-double-couple component of its moment tensor. This study demonstrates the benefits of combining geodetic, remote-sensing and seismological data to investigate earthquake dynamics and its relation to faults geometry.

References

Li, Dunzhu and Don V. Helmberger (2011). Generation of earthquake sources using 2D staggered grid finite-difference method, *JGR* (in preparation).

Luo, Yan, Y. Tan, S. Wei, D. Helmberger, Z. Zhan, S. Ni, E. Hauksson, and Yong Chen (2010). Source Mechanism and Rupture Directivity of the M_w 4.6 May 18, 2009 Inglewood, California Earthquake, *BSSA*, Short Note, **100** (6), 3269-3277, doi:10.1785/0120100087.

Tan, Ying, Teh-Ru Alex Song, Shengji Wei, and Don Helmberger (2010). Surface Wave Path Corrections and Source Inversions in Southern California, *Bull. Seismol. Soc. Am.,* **100** (6), 2891-2904, doi:10.1785/0120090063.

Tan, Ying and D. V. Helmberger (2010). Rupture Directivity Characteristics of the 2003 Big Bear Sequence, *Bull. Seismol. Soc. Am*., **100**, No. 3, 1089-1106, doi: 10.1785/0120090074.

Wei, Shengji, Z. Zhan, D. V. Helmberger, Y. Tan, and S. Ni (2011). Rapid Regional Centroid Solutions, *Bull. Seismol. Soc. Am.* submitted.

Zhan, Zhongwen, S. Wei, S. Ni, and Don Helmberger (2011). Earthquake Centroid Locations Using Calibration from Ambient Seismic Noise, Short Note, *BSSA*, **101**, No. 3, 1438-1445, doi:10.1785/0120100118.