Using Regional Moment Tensors to Constrain the Kinematics and Stress Evolution During the 2010-2012 Canterbury, New Zealand, Earthquake Sequence

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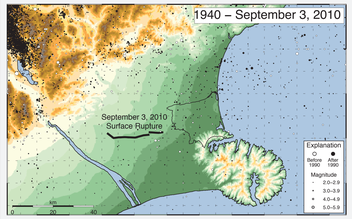
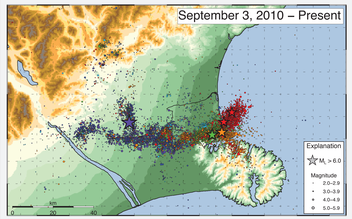
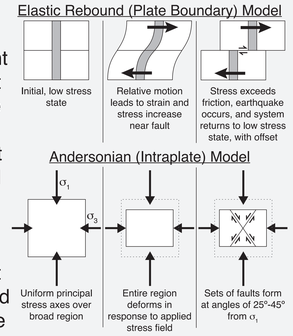
Introduction

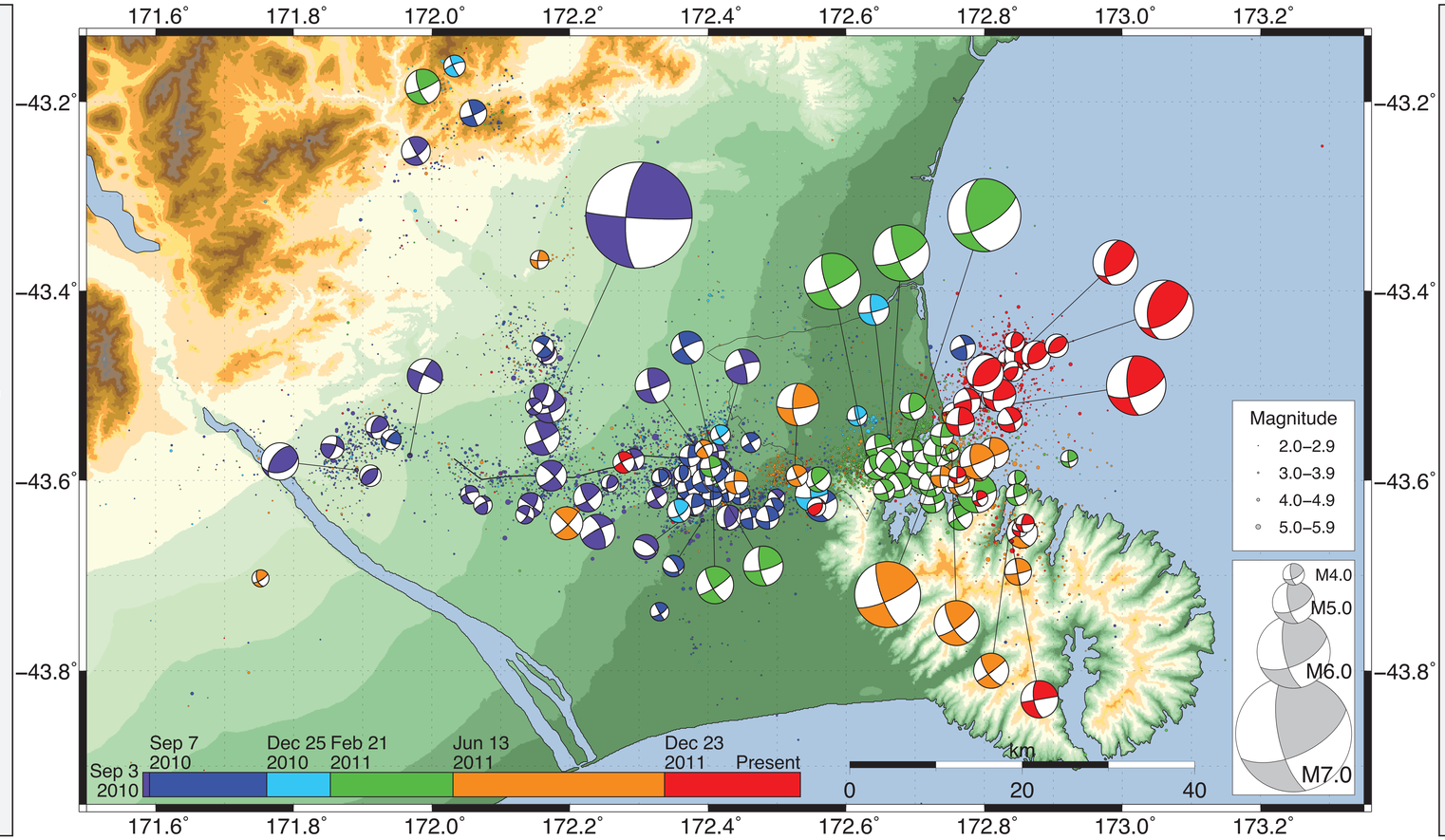




Prior to 2010, there were no earthquakes larger than ~M4.5 or active tectonic structures visible in the Canterbury Plains. On September 3, 2010, a M7.0 earthquake ruptured west of Christchurch, generating a 30 km E-W surface rupture with up to 5 meters of right lateral offset. Over 10,000 aftershocks have been recorded, including four ~M6.0 events near Christchurch.

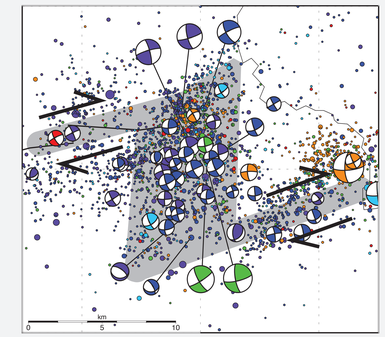
The elastic rebound model that applies near plate boundaries may not represent the seismogenic process that occurs in low-strain intraplate settings. Instead, intraplate earthquake kinematics reflect the orientation of the regional stress field. Preexisting structures in near-optimal orientations for slip will preferentially rupture. It is not clear how stress is discharged or recharged following a large intraplate rupture.

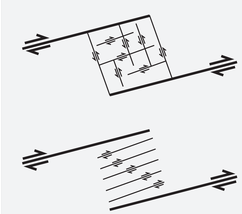




Stepover

East of the surface rupture, the dominant right lateral structure takes a 5-10 km dextral (releasing) step, apparent in the seismicity as a polygon of intense and sustained aftershock activity. Only two small normal faulting events were recorded within the stepover; all other focal mechanisms were strike slip. Epicenter locations are not precise enough to determine the internal structure of the stepover, but two possible scenarios are shown below.





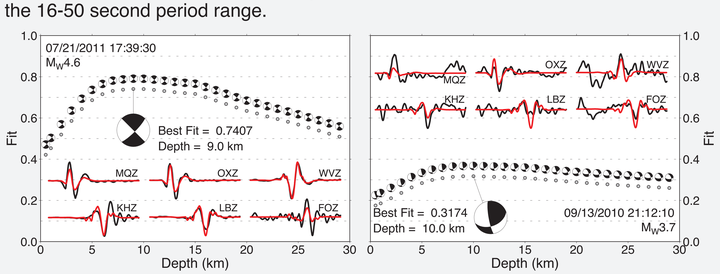
Network of conjugate faults (connected by extension fractures?) after Sibson, 1986

Parallel series of right lateral earthquakes, forming "bookshelf" pattern

Regional Moment Tensor Estimation

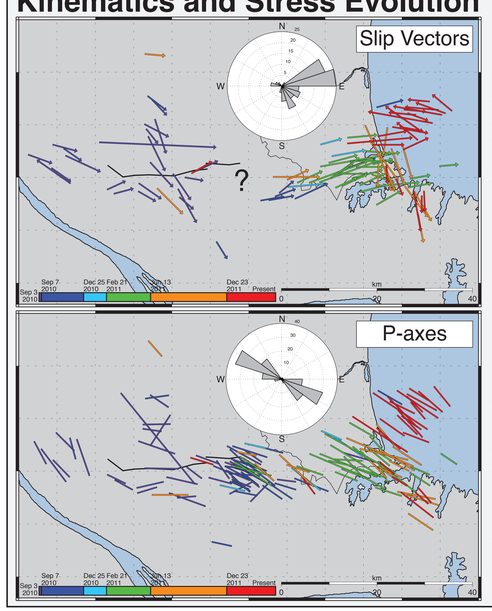
To characterize the kinematics during the Canterbury sequence, we calculated double couple focal mechanisms and moment magnitudes for 146 events larger than M_W3.8 from September 2010 to July 2012 (see large map).

We performed a grid search over strike, dip, rake, and source depth to find the double couple producing synthetic waveforms that best fit seismograms observed at regional stations on South Island, New Zealand (method of Herrmann et al., 2011). These waveforms were dominated by fundamental mode surface waves, filtered in the 16-50 second period range.



At each depth, a fit parameter is computed for each set of strike, dip, and rake. The highest overall fit parameter corresponds to the best double couple source and source depth. Examples of good and poor waveform fits are shown, not to scale (transverse component). Full moment tensor inversions of several events were dominantly double couples.

Kinematics and Stress Evolution



Slip Vectors

Slip vectors for right lateral earthquakes are defined as the direction the north side slipped, and for left lateral events as the direction the west side slipped. We did not interpret slip directions for events within the stepover (see box at right).

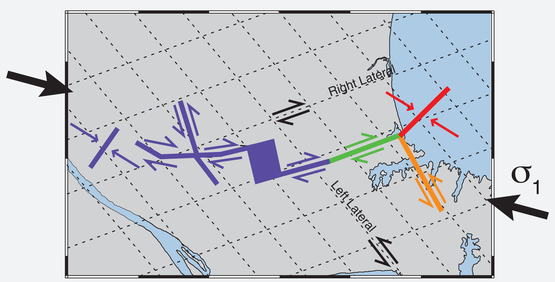
The Canterbury sequence is comprised of two major segments with E-ENE right lateral slip, at least two left lateral branches emerging to the NNW from the surface rupture and SSE onto Banks Peninsula, and reverse segments with ESE slip that bracket the sequence.

Earthquake Pressure Axes

Despite having varying slip directions and occurring on multiple discrete fault segments, nearly all of the moment tensors have sub-horizontal P-axes trending ESE. Aftershocks following the large ruptures in the sequence exhibit no P-axis rotations, contrasting with the behavior near plate boundaries, where aftershocks following large earthquake ruptures have observable P-axis rotations up to 20°.

Conclusions

The earthquakes in the Canterbury sequence ruptured in response to the regional, South Island, New Zealand stress field. The stress field inferred from strike slip earthquakes in this study (σ_1 oriented at ~115°, σ_3 at ~25°) is consistent with previous geological and geophysical stress indicators. Right lateral strike slip earthquakes dominate the moment release, suggesting the subsurface contains sufficient near-vertical E-ENE structures that are preferentially reactivated.



The dashed lines show orientations of optimal fault planes in a stress field with σ_1 as shown. The strike slip segments are compatible with this stress field, and the reverse faulting segments reflect compressive slip in the same stress field. This stress field does not change significantly over time.

References

Herrmann, R.B., Benz, H., and Ammon, C.J., 2011. Monitoring the earthquake source process in North America. Bulletin of the Seismological Society of America 101, 2609-2625.

Sibson, R.H., 1986. Rupture interaction with fault jogs. In Earthquake Source Mechanics, ed. S. Das, J. Boatwright, and C.H. Scholz, 157-167. American Geophysical Union Monograph 37 (Maurice Ewing Series 6). Washington, D.C: American Geophysical Union.