



Improved Location Estimates for Teleseismic Earthquakes using Surface Waves

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Abstract

Current earthquake-location capabilities provide no better than 25-km precision in remote areas, which is insufficient for many tectonic investigations. Differential body-wave relocation schemes offer limited improvements, particularly in the oceans where P waves are often poorly observed. Surface waves, with their slow horizontal propagation speeds and high signal strength even at teleseismic distances, contain information on earthquake location that can improve epicenter determinations. Earlier work by other authors has demonstrated the possibility of precise relative location by cross-correlation of Rayleigh waves for pairs of earthquakes with the same focal mechanism and depth, and Cleveland and Ammon (2013) have recently demonstrated success with this approach for multiple events with similar mechanisms and a double-difference relocation method. We extend earlier approaches to improve relative locations for earthquakes with arbitrary focal mechanisms. We correct inter-event cross-correlation functions of Love and Rayleigh surface-wave signals for differences in focal mechanisms and depths before calculating cross-correlation delay times and relative locations. Experiments on full synthetic seismograms indicate that the algorithm results in improved locations in the presence of realistic uncertainties in earthquake focal depths and mechanisms. We present results from the synthetic experiments and applications to real data, using earthquakes from the Global CMT catalog representing different tectonic environments. The application of source corrections works better in certain tectonic regions than others. We investigate the cause of this regional variability and explore modified procedures to accommodate changes in different earthquake populations. With these regional adaptations we are able to improve upon the precision of earthquake relocations that use no source corrections.

Introduction

Surface waves are both the largest and the slowest-propagating signals recorded on a seismogram. Arrival-time differences for different earthquakes with relatively small inter-event distances give information about the relative location of those earthquakes. A demonstration of the effectiveness of surface-wave relocation can be seen in **Figure 1**. Here, earthquake locations and mechanisms are plotted before (top) and after (bottom) surface wave relocation. The focusing of earthquakes on linear features is consistent with the pattern of seismicity anticipated from plate tectonics. These earthquakes, in the Eltanin Fracture Zone in the southern Pacific Ocean, are well-suited to this method since they are predominantly strike-slip and normal-faulting earthquakes. The type of earthquake source is very important to this type of relocation technique, since some earthquake geometries generate phase shifts in the recorded seismograms that can mimic a location shift. The corrections required to account for arbitrary earthquake geometries in the application of the surface-wave relocation is the focus of the remainder of this poster.

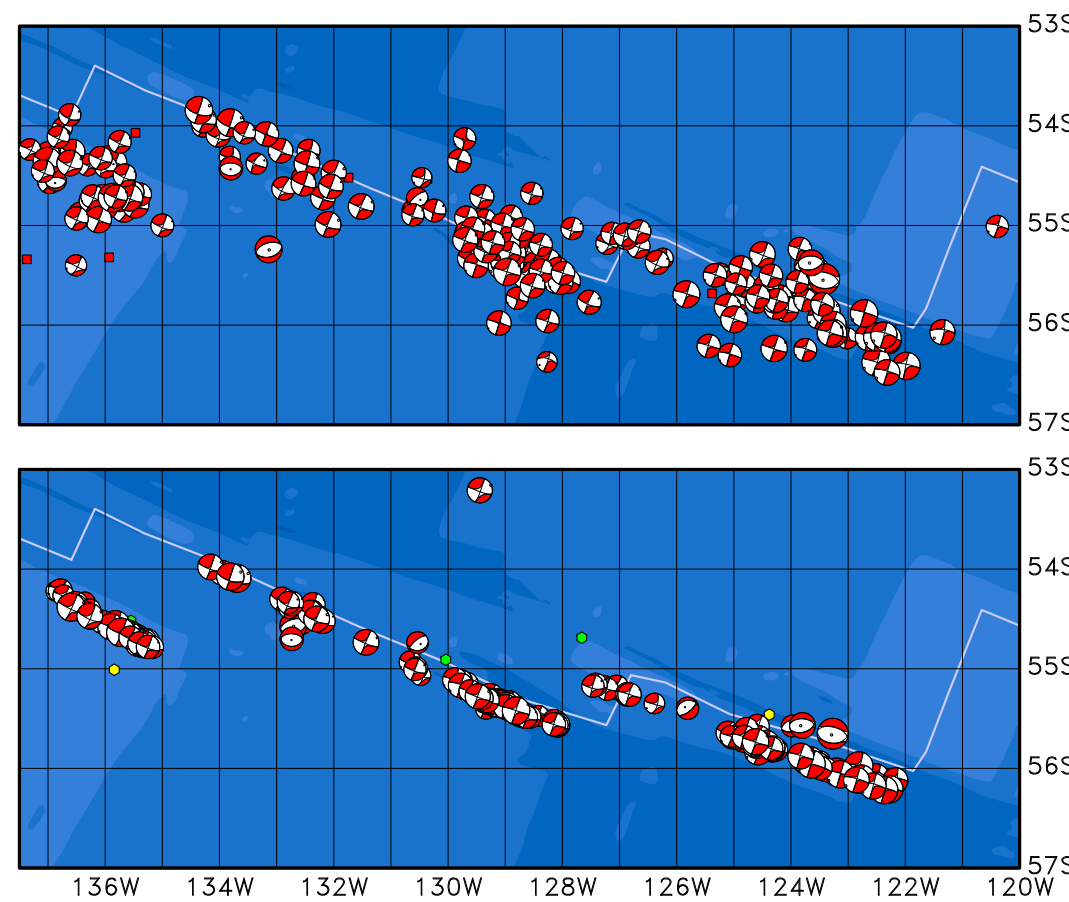


Figure 1: Eltanin Fracture Zone relocations. Significant location improvement when comparing before (top) and after (bottom) surface wave relocations. The gray lines are plate boundaries which, as can be seen by the relocated earthquakes, are not entirely correct.

Theory

We measure time-lag of the cross-correlation between the recorded waveforms of two events within a prescribed inter-event distance. If the effect of the receiver is removed, each waveform can be expressed as a convolution of the effects of the path of propagation (Green Function) and the effects of the source. In the frequency domain, this is a product of those two terms, as shown in **Equations 1 and 2**. The cross-correlation of these two waveforms is (again in the frequency domain) the complex conjugate of waveform A multiplied by waveform B, as in **Equation 3**.

$$u^A(\omega) = G^A(\omega)S^A(\omega) \quad (1)$$

$$u^B(\omega) = G^B(\omega)S^B(\omega) \quad (2)$$

$$S(\omega) = R(\omega) + iJ(\omega) \quad (3)$$

$$\begin{aligned} C^{AB}(\omega) &= G^A G^{B*} S^{A*} S^B \\ &= G^A G^{B*} \cdot [R^A R^B - J^A J^B + i(R^A J^B - J^A R^B)] \end{aligned} \quad (4)$$

$$C_{corr}^{AB}(\omega) = \frac{C^{AB}(\omega)}{S^{A*} S^B} \quad (5)$$

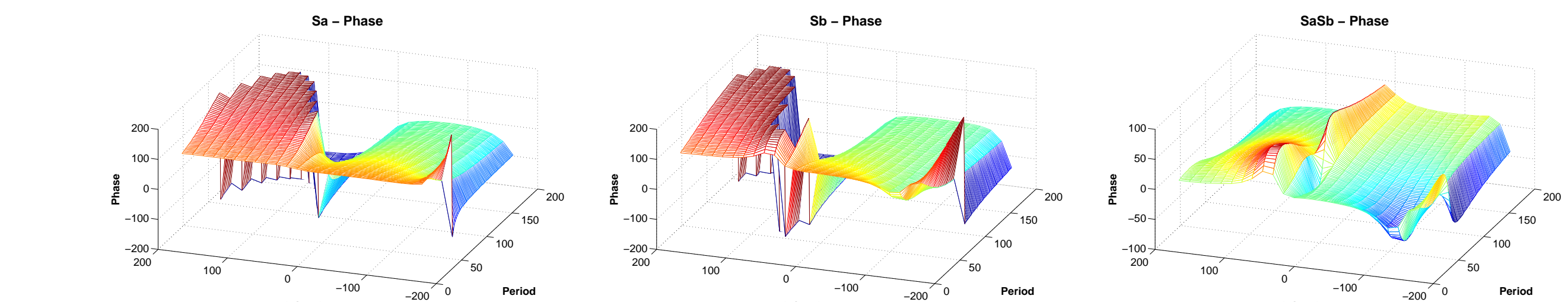


Figure 2: Phase of two reverse-faulting earthquakes with a vertical dip-slip component and slightly rotated relative strikes: Strike/Dip/Rake = 189/20/94 (left) 228/17/124 (middle). The combined phase vs. frequency and azimuth

Synthetics - Simulated Subduction Zone

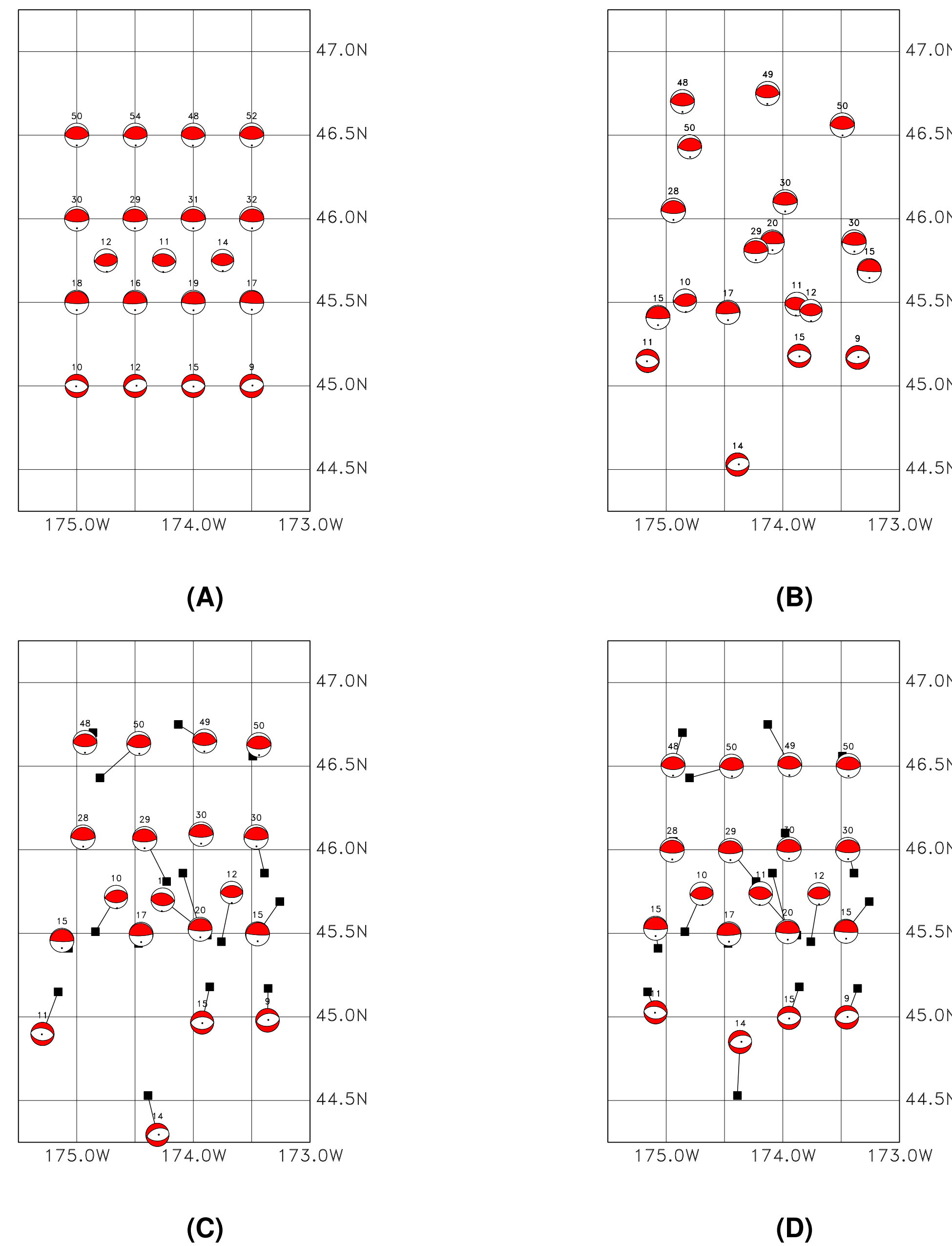


Figure 3: We conducted a synthetic experiment, simulating a subduction zone, dipping from south to north, with outer-rise normal-faulting events, upper-plate thrust-faulting events and interplate megathrust events. (A) True locations of 19 earthquakes used in a synthetic experiment. (B) Initial locations assumed when making source corrections and relocation calculations. (C) Surface wave relocations without any source corrections. (D) Surface wave relocations with source corrections made for each event.

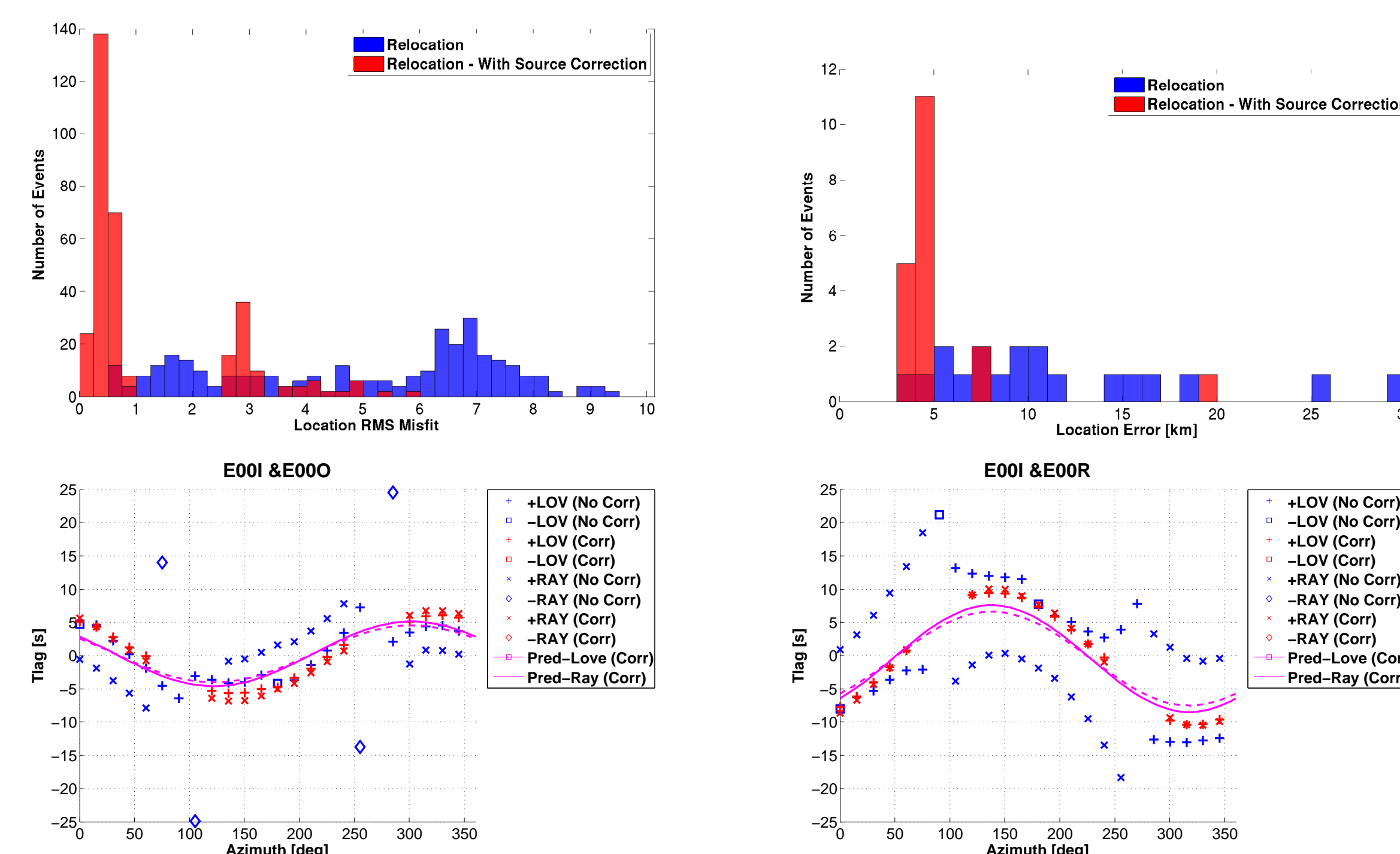


Figure 4: (A) Distribution of location error of the 19 synthetic events with (red) and without (blue) source corrections. (B) Distribution of RMS misfit values for fits to the time-lag resulting from cross-correlating event pairs. (C) & (D) Examples of two inter-event pair cross-correlation measurements. (C) is between two interplate events with different dips and (D) is between an interplate event and an upper-plate thrust-faulting event.

Real Data - Blanco Transform Fault Zone

After demonstrating the validity of our technique, using source corrections and synthetic waveforms, we apply it to real data. While our relocation technique performs well in a real subduction zone, it does not work as well as relocations without source corrections in ridge-transform tectonic settings. We believe this discrepancy has several causes. First, ridge-transform systems are the ideal case for the original surface-wave relocation scheme because the M_{xz} and M_{yz} components of the moment tensors of typical ridge-transform earthquakes are relatively small. Second, for these same earthquakes depths tend to be shallow and the M_{xz} and M_{yz} moment-tensor components are the least well-constrained for global solutions of source mechanisms in these settings.

To reduce the influence of these uncertainties in our source-corrected relocation technique, we apply a modified source correction where we set M_{xz} and M_{yz} equal to zero in the calculation of the corrections. We expect these terms to be small, comparable to their calculated inversion errors. However, by retaining some information about the source, we can correct the source amplitudes at least enough to have the correct polarity, which means that when we calculate differential travel times from our cross-correlations we only need to search for positive-valued maxima, which is an improvement from source-uncorrected relocations.

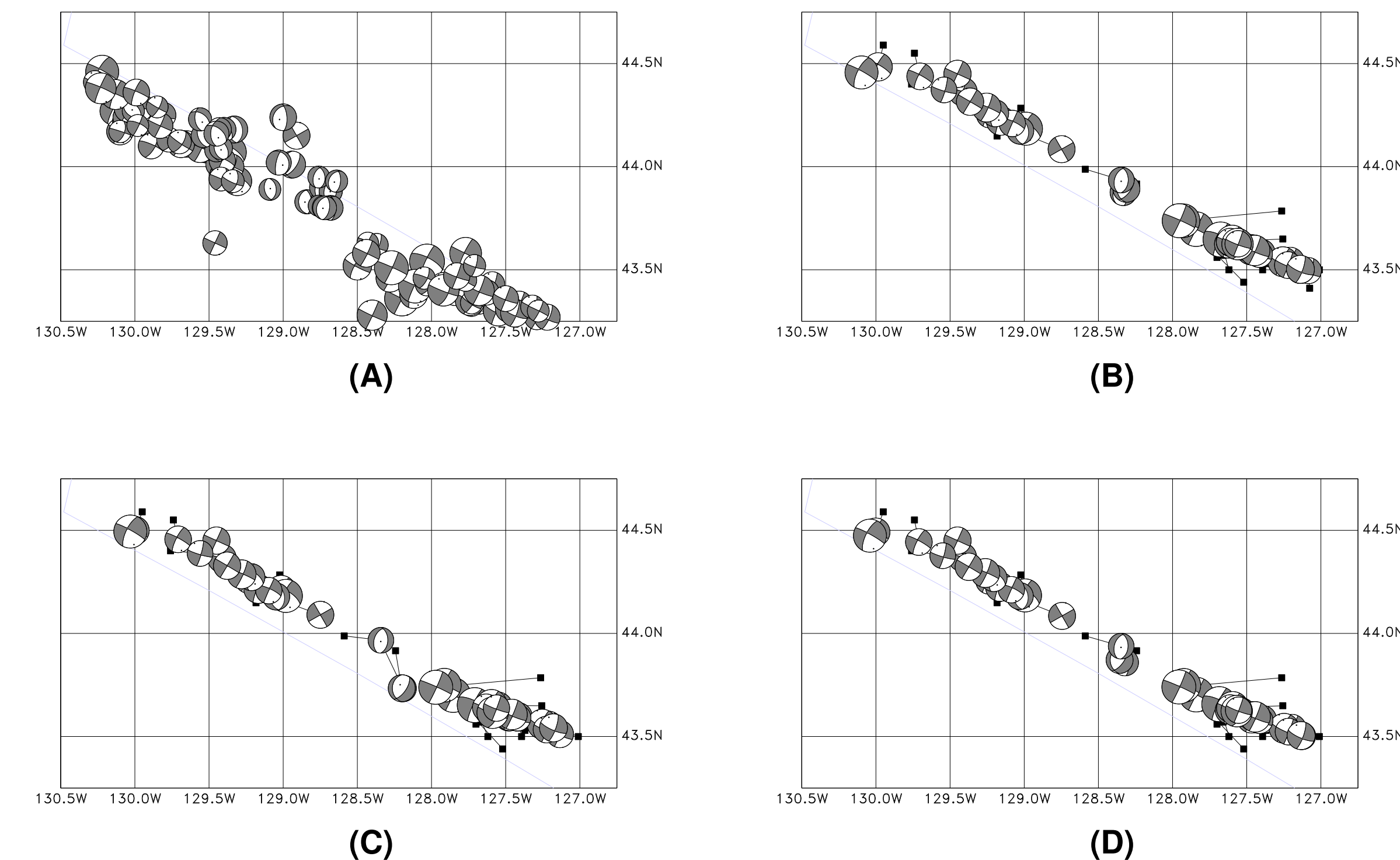


Figure 5: Relocations of real earthquakes in the Blanco Transform Fault Zone using both the full source-correction technique, and our modified source-correction technique. (A) Initial earthquake locations. (B) Relocations without any source corrections. (C) Relocations using the full source corrections. (D) Relocations using modified source corrections.

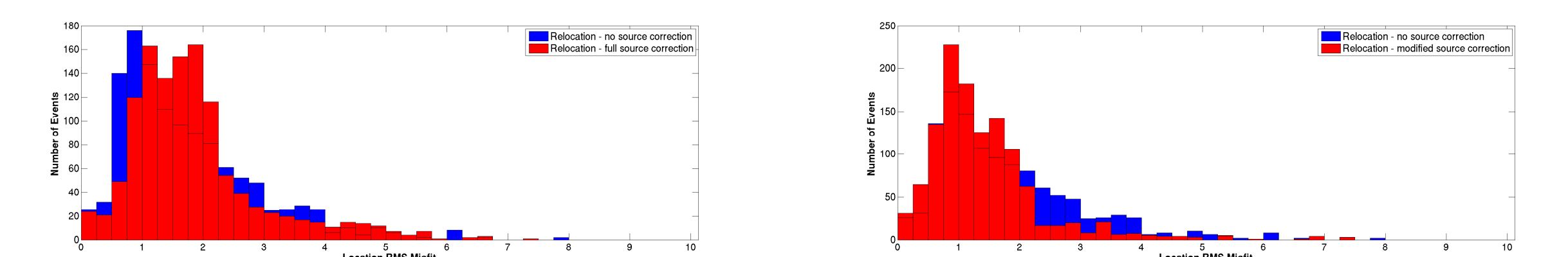


Figure 6: (Left) RMS-misfit histograms plotted against each other for relocations with (red) and without (blue) source correction. It appears the RMS misfits are larger for source-corrected relocations when all moment tensor components are used in the corrections. (Rights) RMS-misfit histograms plotted against each other for relocations with (red) and without (blue) source correction, but this time the source corrections are modified so that $M_{xz} = M_{yz} = 0$. The relocations using the modified source corrections now have misfits that are just as good, if not better, as relocations without source corrections.

Forthcoming Research

Building upon this work, we will explore parameters of explosion sources using their radiated surface wave signals. Specifically, we will investigate the presence and interaction of tectonic release in the context of seismic monitoring for underground nuclear explosions.

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