Project Title: Installation and Further Development of a Fully Automated Global Centroid Moment Tensor Code at the National Earthquake Information Center

External Grant Award Number: 05HQGR0003

Principal Investigator: Jarmila (Jascha) Polet
Institute of Crustal Studies
University of California
Santa Barbara, CA 91306
Tel.: (805) 893-2820
E-mail: polet@crustal.ucsb.edu

Key words: Source characteristics, Real-time earthquake information

Investigations Undertaken

We made significant improvements to the autoCMT software, which computes fully automated global Centroid Moment Tensors, at the National Earthquake Information Center. These improvements have resulted in a more efficient, more reliable and faster system to deliver completely automatic CMT solutions for worldwide large earthquakes.

The previously implemented systems at the NEIC either do not run fully automatically, do not determine a centroid time or location and/or are less suited for great earthquakes, because of their reliance on relatively short period body waves, in contrast to the very long period surface waves used by the autoCMT. Thus the autoCMT system fulfills an important need and, based on its unique strengths, is complementary to existing methods at the NEIC. The long period nature of the seismic waveform data the system uses as its input has the additional advantage that the method is relatively insensitive to the effects of timing errors, mislocation, and lateral heterogeneity. The autoCMT determines reliable moment magnitude estimates and mechanisms, and performs particularly well for events greater than 7.0. It is especially notable that this fully automatic method performs equally well as its human reviewed counterparts for most large events, even with its input minimum of less than 25 waveforms (see Figures 1 and 2).

Results

We have implemented the following improvements to the existing autoCMT software at the NEIC, where it has been running, fully automatically, over the past year. Further integration with routine NEIC operations and the Hydra system is currently proceeding.

Two main changes were made to the quality control of the input waveforms in the existing system (see Figure 3). A new module has been added that checks the quality of the incoming waveforms. The main purpose of this module is to remove data produced by malfunctioning sensors. Because the CMT inversion algorithm attempts to maximize the variance reduction of the waveforms by fitting them to synthetics, very low amplitude waveforms (produced, for example by broken sensors or dataloggers) will dominate the

inversion, resulting to an incorrect CMT solution. To remove this data from the input waveform list, a simple least squares fit is carried out after the variance of the waveforms has been computed. Extreme outliers are then removed from consideration. It is important to note that only extreme outliers are removed, since data that is simply noisy is now dealt with by a later processing step.

A second addition to the data quality control of the autoCMT system is represented by a secondary inversion. Originally a solution was sent out after one inversion was run. However, we now check the variance reduction of every waveform after this initial inversion is carried out (see Figure 3). Then, badly fit channels are removed prior to a secondary inversion. If sufficient channels remain and the overall variance reduction is increased by this second inversion, its solution is preferred and sent out by E-mail. We have chosen to define a "badly fit" channel by choosing only channels that showed a variance reduction of at least 2% after the preliminary inversion. This choice was made to balance the desire for a high overall variance reduction with the need for a good azimuthal coverage. Therefore, as long as the variance reduction of the channel shows at least some indication of the presence of a true signal, and not just noise, we choose to keep it on the input channel list.

Access to the waveform data at the NEIC is in the process of switching over to a new system. We have adapted the software to be able to work with this new system and have carried out tests and comparisons with the current data retrieval system. Feedback on the performance of the new system and bug reports were provided to NEIC personnel.

To facilitate and improve the dissemination of the source parameters determined by the autoCMT system, a mail server has been set up at the NEIC. A website can be used to subscribe or unsubscribe to a mailing list or to access an archive of previous inversion results.

In addition to these important improvements to the performance of the system in terms of data access and quality control, we have also started to investigate ways to improve the quality assessment of the CMT solutions. To help in the development of reliability assessment routines, and to carry out an evaluation of the importance of the different starting parameters on the CMT solutions, we have started the process of generating a catalog of moment tensor solutions for all events larger than M=7.5 since 1990 (see Figure 4), which will include a full error analysis using bootstrapping.

To estimate realistic inversion errors, 200 inversions are carried out with stations resampled with replacement from the original waveform input list. The histograms and focal mechanisms for the example events in Figure 5 and 6 show the distribution of the source parameters from these 200 CMT solutions. We plan to investigate the effectiveness of this bootstrapping method in a real-time setting and compare its results with those of the more time-efficient jack-knifing method. Our final goal is to produce meaningful error parameters for near real-time CMT solutions, which will be of help in the decision making process after the occurrence of a large event.

The autoCMT solutions also have a valuable use as a near real-time starting point for full finite fault rupture inversions and strong ground motion predictions of great earthquakes. To this aim, further integration with Dr. Chen Ji's software at the NEIC has been started.

Non-technical Summary

We have implemented significant improvements to the autoCMT software at the National Earthquake Information Center. This system provides completely automatic, near real-time, source mechanisms and moment magnitudes for worldwide large earthquakes, performing particularly well for events greater than magnitude 7.0. Data quality control has significantly improved, providing more reliable source characterizations. We have also started to investigate techniques to improve the quality assessment of the inversion results and, as a by-product, produce a catalog of CMT solutions for all large earthquakes since 1990 with complete error analysis.

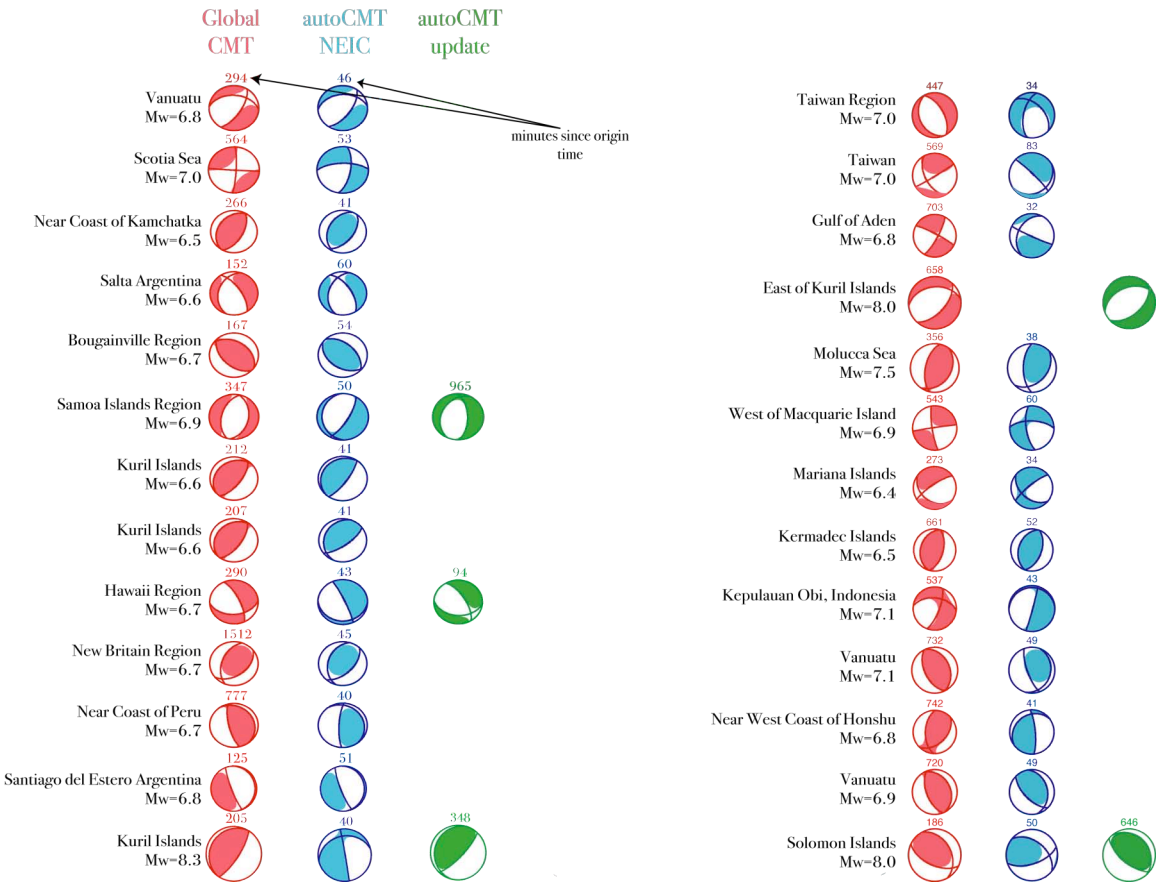

Figure 1: Comparison between (from left to right) mechanisms from Global CMT group, autoCMT and manually re-run autoCMT for events greater than Mw6.5 in the past 7 months. Numbers above mechanisms indicate when the solution was available, in minutes after origin time.

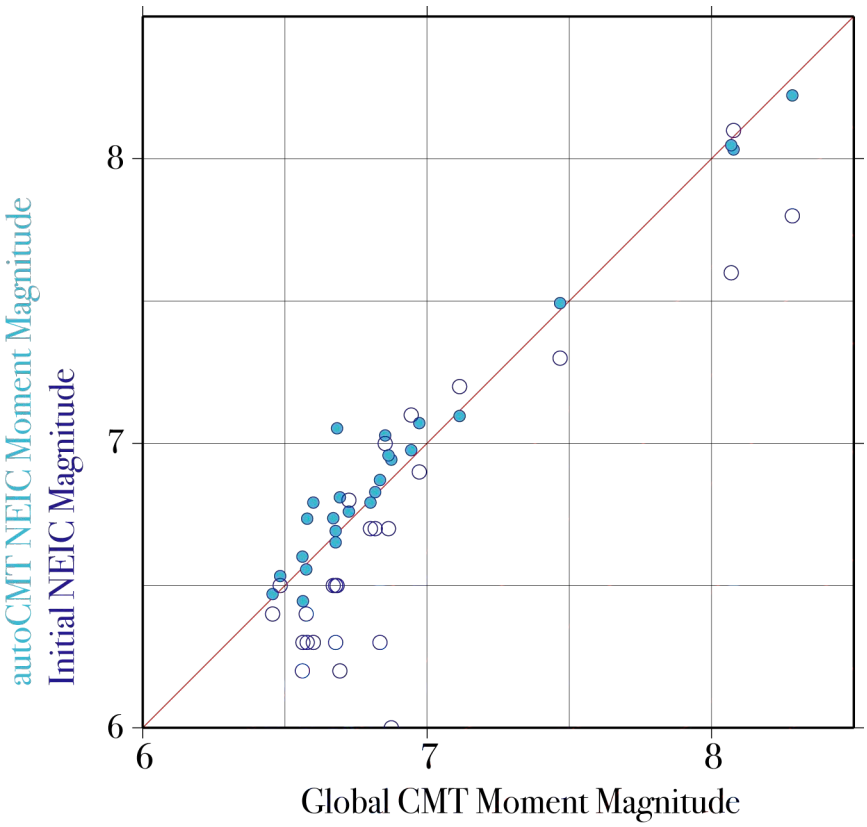

Figure 2: Comparison between autoCMT magnitudes (blue closed circles), initial NEIC magnitudes (open blue circles) and Global CMT magnitudes.

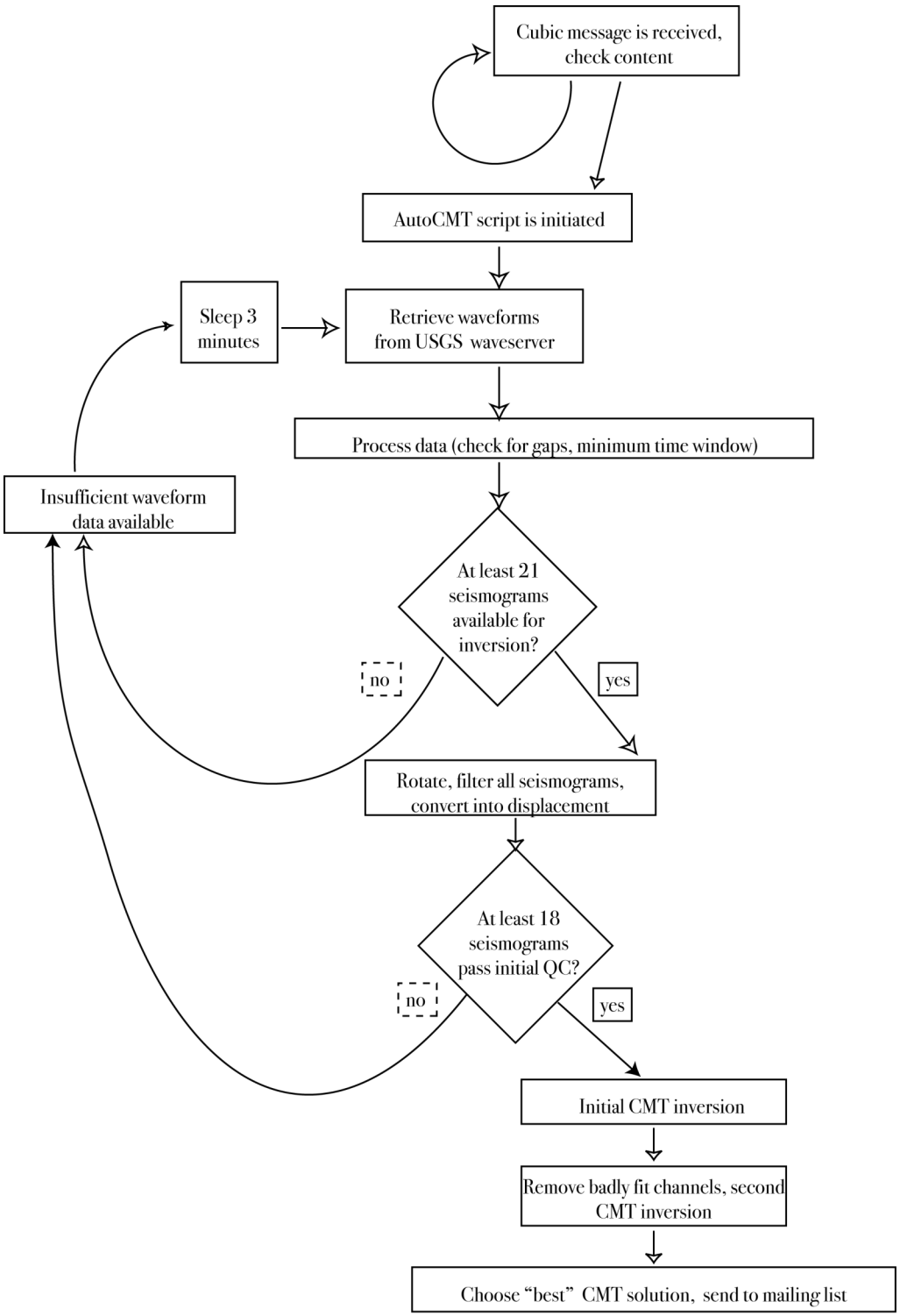

Figure 3: Simple flowchart of the autoCMT system. The main modifications were the addition of data quality control modules.

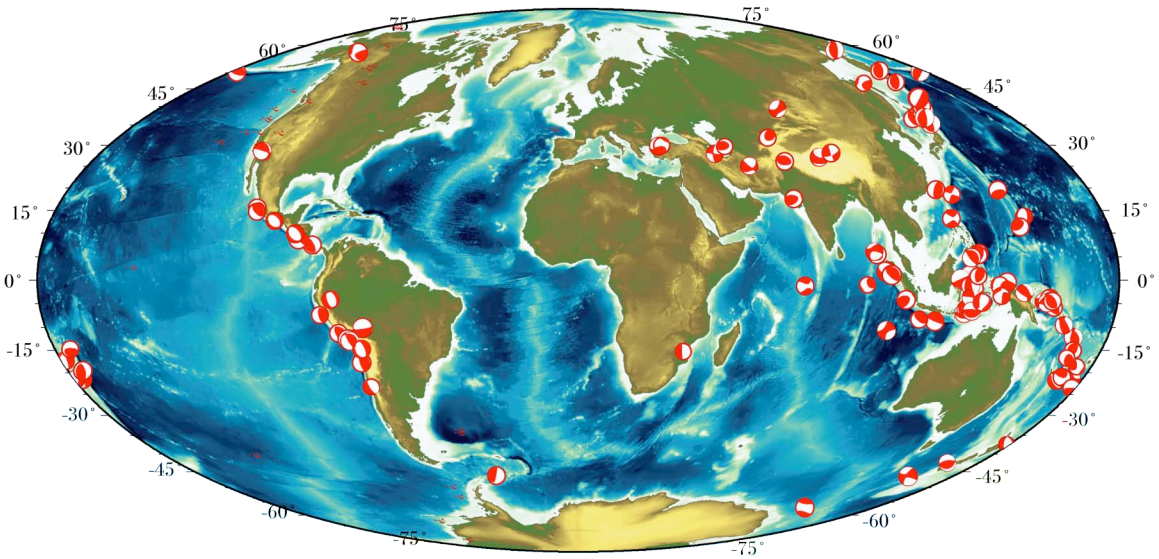

Figure 4: World map showing the CMT solutions for the catalog of events greater than magnitude 7.5 since 1990.

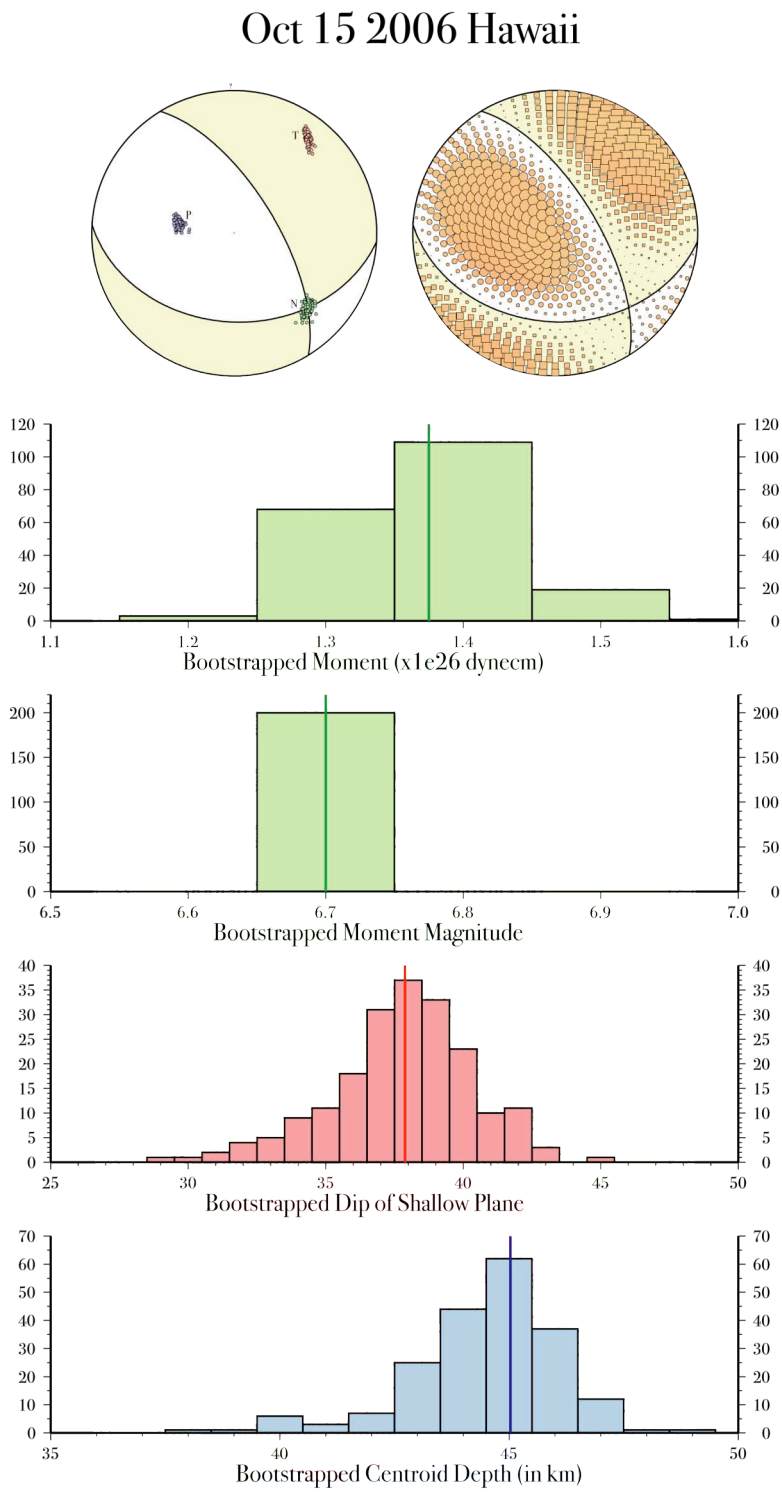

Figure 5: Example of a well constrained CMT solution. Final "best" CMT solution parameters are indicated by solid lines and fault planes in mechanisms. Axes shown in focal mechanism plot and moment, moment magnitude, dip and depth shown in histograms are those of 200 bootstrapped inversion results. Symbols inside focal mechanism show P wave radiation values (by size) and their standard deviation (by colors, darker colors indicating large values).

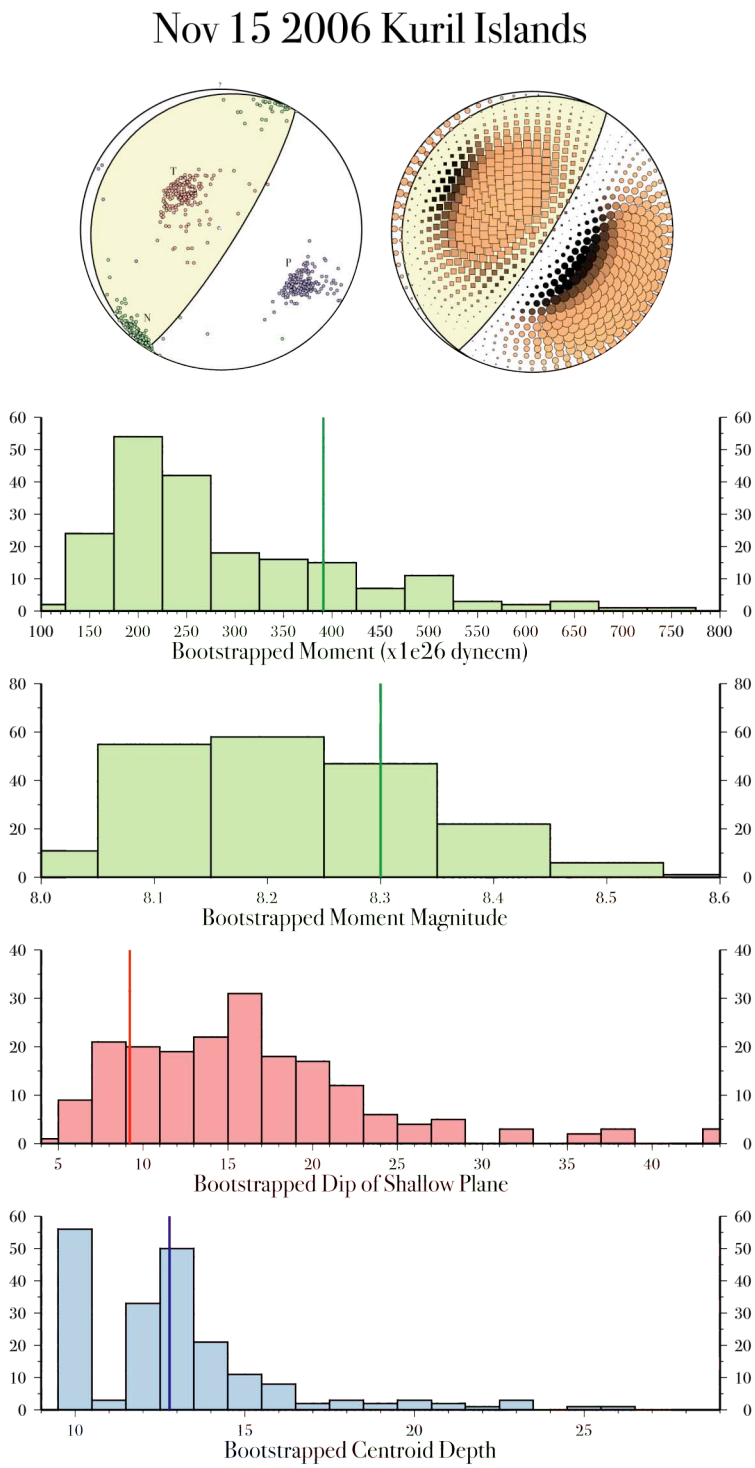

Figure 6: Example of a poorly constrained CMT solution. Final "best" CMT solution parameters are indicated by solid lines and fault planes in mechanisms. Axes shown in focal mechanism plot and moment, moment magnitude, dip and depth shown in histograms are those of 200 bootstrapped inversion results. Symbols inside focal mechanism show P wave radiation values (by size) and their standard deviation (by colors, darker colors indicating large values).