# Text Supplement for ScholarWorks@UA collection "Seismic moment tensor catalog for Uturuncu volcano, Bolivia"

Celso Alvizuri

December 7, 2015

**Attribution:** If you use these files, please cite Alvizuri & Tape (2015) and this ScholarWorks entry.

### Description of files

The files here are part of the PhD thesis work by Celso Alvizuri. This supplement will be cited in Alvizuri & Tape (2015).

A seismic moment tensor catalog of 63 events was generated using first-motion polarities, body waves and surface waves. The best solution ($M_0$) was obtained through a grid-search in the moment tensor space using the 'cut-and-paste' (CAP) approach of Zhu & Helmberger (1996); Zhu & Ben-Zion (2013). Figures are listed in Section 1. The waveform fits for the 63 events in the catalog are shown in Figure A1. The waveform misfit on the source-type plot for these events are shown in Figure B1.

A second seismic moment tensor catalog for the same 63 events was generated using body waves and surface waves but without first-motion polarities. This second set of figures is listed in Section 1.

## 1 Inversions using first-motion polarities

### Figure A1: Waveform fits (Catalog events) [`utuhalf_P01_V10_R01_S10_waveform_fits.pdf`]

Waveform fits for 63 moment tensor inversions for which waveform misfit is plotted on the source-type plot. (Figure B). Black are observed waveforms; red are synthetic waveforms computed using a frequency-wavenumber method (Zhu & Rivera, 2002) that assumes a (1D) layered model. We use a homogeneous halfspace model `utuhalf`. The waveforms are fit separately within five time windows: P wave vertical component (PV), P wave radial component (PR), Rayleigh wave vertical component (SurfV), Rayleigh wave horizontal component (SurfR), and Love wave transverse component (SurfT). At far left in each row is the station name, source-station distance in km, and station azimuth in degrees. Below each pair of waveforms are four numbers: the cross-correlation time shift between data and synthetics, the cross-correlation value, the percent of the misfit function represented by the waveform pair, and the amplitude ratio between waveforms, $\ln(A_{\mathrm{obs}}/A_{\mathrm{syn}})$, where $A$ is the max value of the waveform within the time window.

The beachball represents the best solution $M_0$ (i.e., the global minimum of the misfit function). The beachball is plotted as a lower-hemisphere projection (standard seismological convention) of the moment tensor. The surrounding black dots denote the azimuthal location of the stations used, and the red crosses denote the lower hemisphere piercing points of the ray paths to the stations.

Here is a description of the four header lines:

1. `Event 20100516063454464 Model and Depth utuhalf_004`
   The event ID is derived from the origin time of 2010-05-16 06:34:54.464.

The halfspace model used is `utuhalf`, and the event depth is 4 km.

2. `FM 150 76 -75 Mw 2.80 ISO -10 CLVD 10 rms 1.790e-07 VR 22.1`
   The orientation of the moment tensor solution $M_0$ is strike 150°, dip 76°, rake −75°. The estimated magnitude is $M_w$ 2.8. The ISOtropic coordinate is $\delta = -10°$ and the CLVD coordinate is $\gamma = 10°$. The waveform difference between data and synthetics is $1.790 \times 10^{-7}$, and the variance reduction is $VR = 22.1\%$.

3. `Filter periods (seconds): Body:0.10--0.50. Surf:2.00--4.00`
   The body waves were filtered 0.10–0.50 s, the surface waves were filtered 2.00–4.00 s.

4. `# norm L1 # Pwin 1.5 Swin 60 # N 11 Np 22 Ns 33`
   An L1 norm was used for the misfit function. The (reference) P-window is 1.5 s long, the surface wave window is 60 s long, there are 11 stations with at least one waveform, 22 is the number of P windows used, and 33 is the number of surface wave windows used.

The numbers below each station are

1. source–station epicentral distance, km
2. station azimuth, in degrees
3. sign of the observed first-motion polarity, which is either 1 (up or compression) or −1 (down or dilatation). The number in parentheses is the predicted amplitude, which ranges between $\pm\sqrt{2}$; numbers close to zero indicate that the station is near a nodal surface of the radiation pattern for the assumed mechanism.

The four numbers below each pair of waveforms are

1. the cross-correlation time shift $\Delta T = T_{\text{obs}} - T_{\text{syn}}$ required for matching the synthetics $s(t)$ with the data $u(t)$ (a positive time-shift means that the synthetics arrive earlier than the data)
2. the maximum cross-correlation percentage between $u(t)$ and $s(t - \Delta T)$
3. the percentage of the total misfit
4. the amplitude ratio $\ln(A_{\text{obs}}/A_{\text{syn}})$ in each time window

### **Figure B1: Summary misfit plots for all 63 events** [`utuhalf_P01_V10_R01_S10_misfit.pdf`]

Alvizuri & Tape (2015), Figure 6, caption:
Full moment tensor misfit summary for the example event. For details, see Section 3. (a) Map of source location (red star) and stations used in the inversion for this event. The station is colored blue if the observed first-motion polarity on the vertical component is up (compression) and white if it is down (dilatation). (b) Contour plot of the polarity misfit on the lune. Not to be confused with the waveform misfit, the polarity misfit $n(M)$ (Eq. 5) for a moment tensor $M$ is the number of stations where the observed first-motion polarity differs from the polarity predicted from $M$. The polarity misfit $n(\mathbf{\Lambda})$ (Eq. 6) at a point $\mathbf{\Lambda}$ on the lune is then the minimum of $n(M)$ for moment tensors $M$ having source type $\mathbf{\Lambda}$. At each point $\mathbf{\Lambda}$ in the region where $n(\mathbf{\Lambda}) = 0$

(blue), there is therefore a moment tensor $M$ with source type $\mathbf{\Lambda}$ that has correct polarities, that is, polarities that match the observed polarities at all 11 stations. (c) Contour plot of the variance reduction $VR(\mathbf{\Lambda})$. The variance reduction $VR(\mathbf{\Lambda})$ at a point $\mathbf{\Lambda}$ is the maximum variance reduction $VR(M)$ for moment tensors $M$ that have source type $\mathbf{\Lambda}$ and that have correct polarities. (Compare Eq. 7, which is the analog of $VR(\mathbf{\Lambda})$ for misfit.) Large values (blue) of $VR$ represent better fit between observed and synthetic waveforms. Since $M$ is required to have correct polarities, the plot of $VR(\mathbf{\Lambda})$ is only defined on the region $n(\mathbf{\Lambda}) = 0$. The beachball plotted at each point $\mathbf{\Lambda}$ of this region is the moment tensor $M(\mathbf{\Lambda})$ that maximizes $VR(M)$ with $\mathbf{\Lambda}$ fixed. Of the beachballs $M(\mathbf{\Lambda})$, our desired solution $M_0$ (green box) is the one with largest $VR$. The gray arcs on the lune are the great circle arcs $\lambda_1 = 0$, $\lambda_2 = 0$, and $\lambda_3 = 0$ (white, green, and red in Figure 1). Selected eigenvalue triples (black dots) on the boundary of the lune are indicated, with the understanding that the triples need to be normalized. The positive isotropic source $(1, 1, 1)$ is at the top, the negative isotropic source $(-1, -1, -1)$ is at the bottom, and the double couple $(1, 0, -1)$, not shown, would be at the center of the lune. (d) The moment tensor $M_0$, the same as in (c) but plotted in a lower-hemisphere projection. For this event, all ray paths travel upward from the source to the stations, so the stations to the east, having upward (compressional) first motions, are plotted on the left of the beachball at the antipode of the ray path direction.

### Text file table for moment tensor catalog [`utuhalf_P01_V10_R01_S10_mecha.txt`]

Seismic moment tensor catalog of 63 events. Details can be found within the header lines, which also refer to Kanamori (1977); Silver & Jordan (1982); Tape & Tape (2012).

### Input text files used in the moment tensor inversion [`weights_utuhalf_P01_V10_R01_S10.zip`]

We provide a text file for each of the 63 events in this study. These files show which stations and which time windows were used (or not) in each moment tensor inversion. It also shows the first-motion polarity observations that were used.

## 2 Inversions without using first-motion polarities

### Figure A2: Waveform fits (Catalog events) [`utuhalf_P00_V10_R01_S10_waveform_fits.pdf`]

Same as in Figure A1 except polarities are not listed under each station label.

### Figure B2: Summary misfit plots for all 63 events [`utuhalf_P00_V10_R01_S10_misfit.pdf`]

Same as in Figure B1 except that since first-motion polarities are not used, there is no $n(\mathbf{\Lambda})$ plotted in (b). Beachballs with $VR < 0$ are considered least likely; we do not plot a beachball at $\mathbf{\Lambda}$ if $VR(\mathbf{\Lambda}) < 0$.

### Text file table for moment tensor catalog [`utuhalf_P00_V10_R01_S10_mecha.txt`]

### Input text files used in the moment tensor inversion [`weights_utuhalf_P00_V10_R01_S10.zip`]

## References

Alvizuri, C. & Tape, C., 2015. Full moment tensors for small events ($M_{\rm w} < 3$) at Uturuncu volcano, Bolivia, *Geophys. J. Int.* (in prep.).

Kanamori, H., 1977. The energy release in great earthquakes, *J. Geophys. Res.*, **82**, 2981–2987.

Silver, P. G. & Jordan, T. H., 1982. Optimal estimation of scalar seismic moment, *Geophys. J. R. Astron. Soc.*, **70**, 755–787.

Tape, W. & Tape, C., 2012. A geometric setting for moment tensors, *Geophys. J. Int.*, **190**, 476–498, doi:10.1111/j.1365-246X.2012.05491.x.

Zhu, L. & Ben-Zion, Y., 2013. Parameterization of general seismic potency and moment tensors for source inversion of seismic waveform data, *Geophys. J. Int.*, **194**, 839–843, doi:10.1093/gji/ggt137.

Zhu, L. & Helmberger, D., 1996. Advancement in source estimation techniques using broadband regional seismograms, *Bull. Seis. Soc. Am.*, **86**(5), 1634–1641.

Zhu, L. & Rivera, L. A., 2002. A note on the dynamic and static displacements from a point source in multilayered media, *Geophys. J. Int.*, **148**, 619–627, doi:10.1046/j.1365-246X.2002.01610.x.