Details on data processing for *Alvizuri et al.* (2018)

Celso Alvizuri

May 9, 2018

Overview

This file is part of a ScholarWorks collection (*Alvizuri*, 2017) that supplements a manuscript (*Alvizuri et al.*, 2018). The purpose of this file is to document details associated with retrieving seismograms, processing them, and selecting them for moment tensor inversions.

Processing waveforms

1. **Obtaining waveforms.** Most of the waveforms used in *Alvizuri et al.* (2018) are available at the IRIS Data Management Center and can be obtained using standard computer programs (see `pysep` below).

   Some waveforms associated with events in or near the Nevada Test Site were obtained from a CD whose contents are now (as of 2018) available at the IRIS DMC (*Walter et al.*, 2006). At this time, the waveforms and metadata have not been converted into seed format and are **not** available through standard tools.

   Here are the files within the top directory of *Walter et al.* (2006):

   ```
   Flori-ucrl.pdf       westernus.etype        westernus.remark
   README.txt           westernus.event        westernus.search_link
   responses            westernus.evids        westernus.sensor
   UCRL-MI-222502.pdf   westernus.explosion    westernus.site
   waveforms            westernus.instrument   westernus.sitechan
   westernus.arrival    westernus_isc.arrival  westernus.springer_explosion
   westernus.assoc      westernus_isc.assoc    westernus.wfdisc
   WESTERNUS.dmp        westernus_isc.site     westernus.wftag
   westernus.dmp.log    westernus.origin       WestUS-ver3-ucrl.pdf
   ```

   The two subdirectories are `responses` and `waveforms`.

2. **Reading waveforms.** For events in the Nevada Test Site, we have created the `llnl_client` to facilitate reading waveforms, station metadata, and event origin tables. This client is publicly available here:

   `https://github.com/krischer/llnl_db_client`

3. **Processing waveforms.** We use a set of scripts built upon ObsPy (*Beyreuther et al.*, 2010; *Krischer et al.*, 2015) and the `llnl_client` to:

   (a) fetch waveforms from either IRIS DMC or from the local database of *Walter et al.* (2006),

   (b) associate the waveforms with event data such as origin time and hypocenter,

   (c) deconvolve the instrument response, and

   (d) write sac (*Goldstein et al.*, 2003) files for use in our moment tensor inversions.

   These scripts are available within the package `pysep`, which is publicly available here:

   `https://github.com/uafseismo/pysep`

Custom treatment for LLNL waveforms

The waveforms in the LLNL database of *Walter et al.* (2006) are from events in the 1980s and 1990s and require special treatment. Here we outline several factors that we encountered while performing the inversions in *Alvizuri et al.* (2018).

1. **Amplitude correction factors.** We found that the LLNL waveforms required a scaling factor that depended on the channel. We estimated the scaling factors by performing moment tensor inversions with IRIS-only stations and then determining an order-of-magnitude scale factor for a particular channel. Making matters more challenging, a single station could have different sensors (and channels) and therefore different scale factors.

   Our amplitude correction factors can be found within the `pysep` package, utility `util_write_cap.py`, function `amp_rescale_llnl`. These are also listed below

   ```
   scale_factor_LH = -1.0e-2
   scale_factor_BB = -1.0e-9
   scale_factor_HF = 1.0e-9
   scale_factor_VB = 1.0e-9
   scale_factor_EH = 1.0e-9
   scale_factor_HH = 1.0e-9
   scale_factor_BH = 1.0e-9
   scale_factor_SH = 1.0e-9
   scale_factor_HG = 1.0e-5
   scale_factor_XX = -1.0e-9
   ```

2. **Phase correction factors.** Some channels required flipping the sign of the waveforms; from the list above:

   ```
   scale_factor_LH = -1.0e-2
   scale_factor_BB = -1.0e-9
   scale_factor_XX = -1.0e-9
   ```

   We inferred this by performing moment tensor inversions with IRIS-only stations and then identifying anomalous waveform mismatch and time shifts at LLNL stations. In some cases, the waveform mismatch and anomalous time shifts would mostly go away with a flip in the sign of the data. These correction factors were very challenging to isolate.

3. **Selection of waveforms for each station.** Some stations exhibit multiple networks, location codes, and channels. For example for PFO there are

   ```
   PFO.CI..BH
   PFO.II.00.BH
   PFO.II.10.BH
   PFO.LL.00.BH
   PFO.TS..BH
   PFO.TS..LH
   ```

   We only need one set of three-component waveforms per station, so we reviewed the full set and then picked one. Where choice of networks was needed, we prioritized II, followed by CI, TS, LL.

4. **Comparison with *Ford et al.* (2009).** The 32 events in *Ford et al.* (2009) were reexamined in *Alvizuri et al.* (2018). *Ford et al.* (2009) showed waveform fits for three events:

   - Little Skull Mountain earthquake (Figure 2)
   - HOYA explosion (Figure 3)
   - DIVIDER explosion (Figure 8)

   Their DIVIDER waveforms show stations from ELK, MNV, and KNB. However, we do not see usable waveforms from these stations in the LLNL database. For example, DIVIDER occurred on 1992-09-23; its day of year is 1992267. The command `grep 1992267 westernus.wfdisc` will return a list of waveform files that are available for this event. The subset for ELK, KNB, and MNV are:

```
grep 1992267 westernus.wfdisc

ELK    vbe        717260539.99806 36353372    42812  1992267   717262139.99819
200001 124.9999900        1.000000          1.000000 guralp - t4 u ./waveforms
ELK_vbe_36353372_unk.w                     0       -1 05/29/2003       ELK
vbn        717260539.99806 36353373    42813  1992267   717262139.99819
200001 124.9999900        1.000000          1.000000 guralp - t4 u ./waveforms
ELK_vbn_36353373_unk.w                     0       -1 05/29/2003       ELK
vbz        717260539.99806 36353374    42814  1992267   717262139.99819
200001 124.9999900        1.000000          1.000000 guralp - t4 u ./waveforms
ELK_vbz_36353374_unk.w                     0       -1 05/29/2003

KNB    vbe        717260220.28501 10340573    42836  1992267   717263102.48524
360276 124.9999900        1.000000          1.000000 LNN15  - t4 u ./waveforms
KNB_vbe_10340573_unk.w                     0       -1 08/07/2002       KNB
vbn        717260220.28501 10340574    42837  1992267   717263102.48524
360276 124.9999900        1.000000          1.000000 LNN15  - t4 u ./waveforms
KNB_vbn_10340574_unk.w                     0       -1 08/07/2002       KNB
vbz        717260220.28501 10340575    42838  1992267   717263102.48524
360276 124.9999900        1.000000          1.000000 LNN15  - t4 u ./waveforms
KNB_vbz_10340575_unk.w                     0       -1 08/07/2002

MNV    vbe        717260139.99298 10340576    42880  1992267   717262940.00120
350002 124.9999900        1.000000          1.000000 LNN15  - t4 u ./waveforms
MNV_vbe_10340576_unk.w                     0       -1 08/07/2002       MNV
vbn        717260139.99298 10340577    42881  1992267   717262940.00120
350002 124.9999900        1.000000          1.000000 LNN15  - t4 u ./waveforms
MNV_vbn_10340577_unk.w                     0       -1 08/07/2002       MNV
vbz        717260139.99298 10340578    42882  1992267   717262940.00120
350002 124.9999900        1.000000          1.000000 LNN15  - t4 u ./waveforms
MNV_vbz_10340578_unk.w                     0       -1 08/07/2002
```

   Though waveforms for these stations are available, they have gaps and do not show any signal that we can use.

   By comparison, for HOYA (1991-09-14; 1991257), there are many channels (notably `bb` and `hf`) available for KNB and MNV:

```
grep 1991257 westernus.wfdisc
```

```
KNB    bbe        684874680.40600 10340377    42823  1991257   684875400.36600
18000  25.0000000         1.000000         1.000000 spreng - t4 u ./waveforms
KNB_bbe_10340377_unk.w                    0       -1 08/07/2002       KNB
bbn        684874680.40600 10340378    42824  1991257   684875400.36600
18000  25.0000000         1.000000         1.000000 spreng - t4 u ./waveforms
KNB_bbn_10340378_unk.w                    0       -1 08/07/2002       KNB
bbz        684874680.40600 10340379    42827  1991257   684875400.36600
18000  25.0000000         1.000000         1.000000 spreng - t4 u ./waveforms
KNB_bbz_10340379_unk.w                    0       -1 08/07/2002       KNB
hfe        684874680.40600 10340380    42833  1991257   684875400.39806
90000 124.9999900         1.000000         1.000000 gs-13  - t4 u ./waveforms
KNB_hfe_10340380_unk.w                    0       -1 08/07/2002       KNB
hfn        684874680.40600 10340381    42834  1991257   684875400.39806
90000 124.9999900         1.000000         1.000000 gs-13  - t4 u ./waveforms
KNB_hfn_10340381_unk.w                    0       -1 08/07/2002       KNB
hfz

MNV    bbe        684874680.40600 10340389    42871  1991257   684875400.36600
18000  25.0000000         1.000000         1.000000 spreng - t4 u ./waveforms
MNV_bbe_10340389_unk.w                    0       -1 08/07/2002       MNV
bbn        684874680.40600 10340390    42872  1991257   684875400.36600
18000  25.0000000         1.000000         1.000000 spreng - t4 u ./waveforms
MNV_bbn_10340390_unk.w                    0       -1 08/07/2002       MNV
bbz        684874680.40600 10340391    42873  1991257   684875400.36600
18000  25.0000000         1.000000         1.000000 spreng - t4 u ./waveforms
MNV_bbz_10340391_unk.w                    0       -1 08/07/2002       MNV
hfe        684874680.40600 10340392    42877  1991257   684875400.39006
89999 124.9999900         1.000000         1.000000 gs-13  - t4 u ./waveforms
MNV_hfe_10340392_unk.w                    0       -1 08/07/2002       MNV
hfn        684874680.40600 10340393    42878  1991257   684875400.39006
89999 124.9999900         1.000000         1.000000 gs-13  - t4 u ./waveforms
MNV_hfn_10340393_unk.w                    0       -1 08/07/2002       MNV
hfz        684874680.40600 10340394    42879  1991257   684875400.39006
89999 124.9999900         1.000000         1.000000 gs-13  - t4 u ./waveforms
MNV_hfz_10340394_unk.w                    0       -1 08/07/2002
```

5. **P onset times.** Picked P onset times in recorded seismograms may be useful within the moment tensor inversions. Our moment tensor inversions will align the synthetics with the data in the following order of priority:

   (a) use P arrival time from CAP input weight file

   (b) use P arrival time from header of recorded seismogram

   (c) use P arrival time based on 1D model, obtained from user-specified Green's functions used in the moment tensor inversion

   Some LLNL waveform files have P onset times included in their headers; therefore our moment tensor code will factor this in when applying time shifts to the synthetic seismograms.

References

Alvizuri, C. (2017), Moment tensor catalog results for nuclear explosions, volcanic events, and earthquakes, ScholarWorks@UA at `http://hdl.handle.net/11122/8007` (last accessed 2018-05-09): descriptor file, text files of catalogs, and composite figures of waveform fits, uncertainty results, and time shifts.

Alvizuri, C., V. Silwal, L. Krischer, and C. Tape (2018), Estimation of full moment tensors, including uncertainties, for nuclear explosions, volcanic events, and earthquakes, *J. Geophys. Res. Solid Earth* (in press), doi:10.1029/2017JB015325.

Beyreuther, M., R. Barsch, L. Krischer, T. Megies, Y. Behr, and J. Wassermann (2010), ObsPy: A Python toolbox for seismology, *Seismol. Res. Lett.*, *81*(3), 530–533, doi:10.1785/gssrl.81.3.530.

Ford, S. R., D. S. Dreger, and W. R. Walter (2009), Identifying isotropic events using a regional moment tensor inversion, *J. Geophys. Res.*, *114*, B01306, doi:10.1029/2008JB005743.

Goldstein, P., D. Dodge, M. Firpo, and L. Minner (2003), SAC2000: Signal processing and analysis tools for seismologists and engineers, in *International Handbook of Earthquake and Engineering Seismology*, *International Geophysics Series*, vol. 81B, edited by W. H. K. Lee, H. Kanamori, P. C. Jennings, and C. Kisslinger, pp. 1613–1614, Academic Press.

Krischer, L., T. Mengies, R. Barsch, M. Beyreuther, T. Lecocq, C. Caudron, and J. Wassermann (2015), ObsPy: a bridge for seismology into the scientific Python ecosystem, *Computational Science & Discovery*, *8*(1), 014003, doi:10.1088/1749-4699/8/1/014003.

Walter, W. R., K. D. Smith, J. L. O'Boyle, T. F. Hauk, F. Ryall, S. D. Ruppert, S. C. Myers, R. Abbot, and D. A. Dodge (2006), An assembled western United States dataset for regional seismic analysis, ISSO 9660 CD, LLNL release UCRL-MI-222502, available via download request at `https://ds.iris.edu/mda/18-001`.