Moment tensors of waste-water disposal induced seismicity in southern Kansas

Amandine Amemoutou[1], Patricia Martínez-Garzón[1], Grzegorz Kwiatek[1,2], Justin Rubinstein[3], Marco Bohnhoff [1, 2]

1 GFZ Potsdam, Section 4.2 'Geomechanics and Scientific Drilling', Germany; **2** Freie Universität Berlin, Germany;
3 US Geological Survey, California; contact : amandine@gfz-potsdam.de

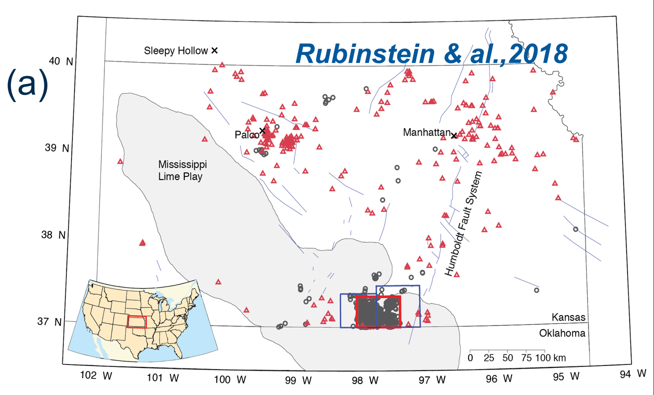
Helmholtz Centre Potsdam
GFZ German Research Centre for Geosciences

Introduction

During the last ten years the seismicity has dramatically increased in southern Kansas and Oklahoma in the US (**Ref.1, 2**). This includes four M>5 earthquakes caused by the reactivation of previously unknown critically stressed and thus hazardous faults in the basement. We investigate seismic recordings of relocated events with local Magnitude M_L 1.9 - 5.2 using a regional seismic network deployed in southern Kansas since 2014. Here we present first results of focal mechanisms (FM) obtained using a subset of 100 events.

1. Area & Data

The study area is located in the Sedgwick basin. The Arbuckle Group where the wastewater is injected lies on the Precambrian basement where earthquakes occur. The station network covers an area of ~40 km N-S and 55 km E-W (**Ref.2**). This USGS network is composed of 5 accelerometers and 14 broadbands. Most of the broadbands have also collocated accelerometer.



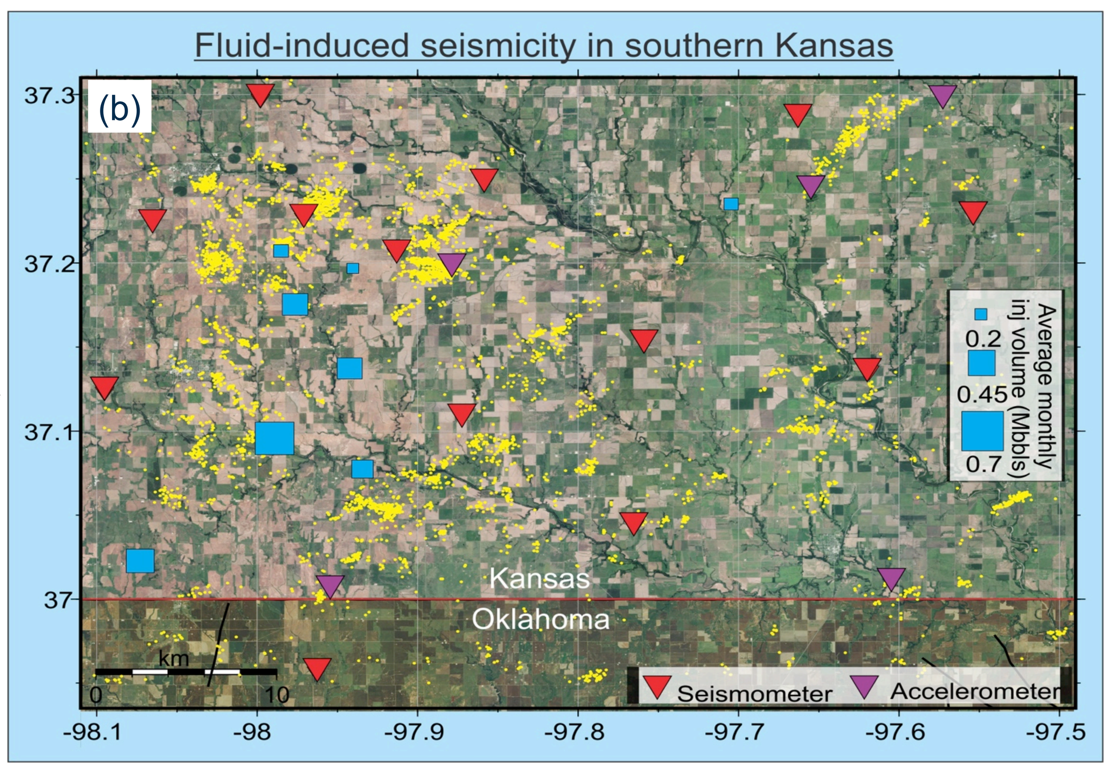


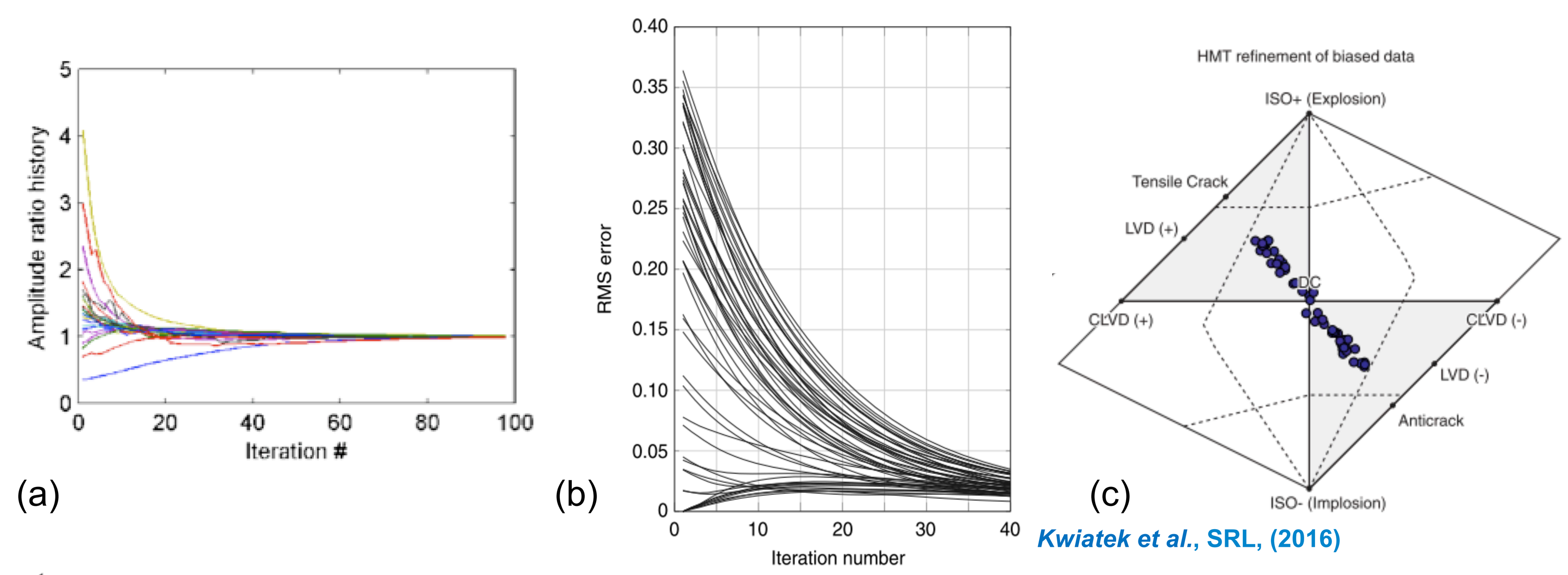
Figure 1: (a) All documented earthquakes in Kansas (1867-2016). The red square shows the study area. (b) Seismicity map of the study area with 5269 relocated earthquakes recorded by the USGS seismicity network from March 2014 to December 2016. Seismometers, accelerometers and injection wells are represented as red triangles, magenta triangles and blue squares, respectively.

2.1 Method - Data processing

We selected a subset of 100 events as test dataset. We calculated integrals of the first P-wave ground-displacement pulses to estimate the seismic moments and manually picked the polarities after applying a Butterworth bandpass filter between 5 and 20 Hz.

2.2 Method – HybridMT & moment tensor inversion

HybridMT (HMT) uses the first P-wave amplitudes of the vertical component to compute seismic moment tensor (MT) inversion in time domain for local to regional networks. The MTs are refined for seismic events forming a spatial cluster by assessing and correcting for poorly known path and site effects**.** Figure 2 shows an example of synthetics dataset from **Ref.3**.



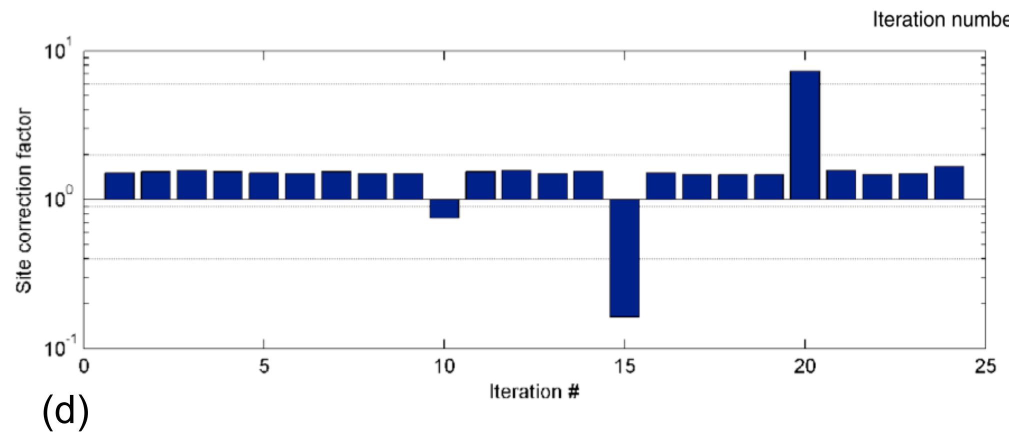


Figure 2: Subfigures are from **Ref.3**: (a) Evolution of amplitude ratio with iteration. (b) Changes in rms errors of MT solutions with iteration number. (c) Result of hybrid moment tensor (HMT) technique refinement of MTs from synthetic data with intentionally biased amplitudes; (d) Evolution of the site effect correction factor with iteration number

2.3 Method - Synthetic test and implementation of 3-component inversion

We extended the HybridMT methodology by including polarities from horizontal components, thus including 3 times more data. The methodology was tested on synthetic datasets based on the shear-tensile source model (**Ref.5**). We generated synthetic input data for the 3 components based on fault parameters determined in **Ref.2** . The resulting HybridMT faults parameters (Tab.1) are comparable to **Ref.2** . The 3-component and vertical component inversion give similar focal mechanisms (Fig. 3). This proves that the implementation of the horizontal components works correctly.

Strike/Dip/Rake (Ref.2)	Strike/Dip/Rake HybridMT
(Ev.1) 249 / 43 / -85	248.99 / 43 / -84.99
(Ev.2) 204 / 68 / 140	204 / 68 / 140
(Ev.3) 243 / 85 / 168	238 / 77,99 / 178

Table 1: Comparison between fault parameters from **Ref.2** (left) and HybridMT synthetic results (right) using a 3-component inversion for earthquakes of M_L 4.6 (Ev.1), 3.5 (Ev.2) and 2.6 (Ev.3).

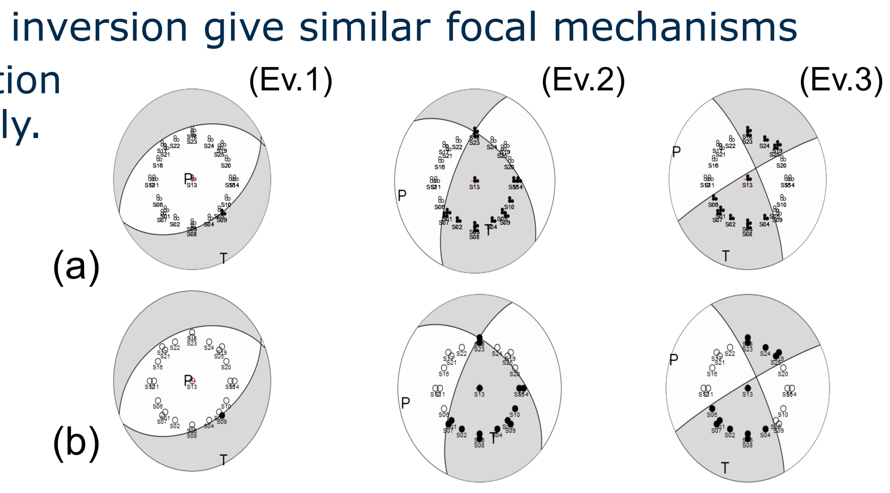


Figure 3: Comparison of synthetic focal mechanisms after (a) inversion using 3-components and (b) inversion with vertical component only. The numbers are listed in Table 1.

Conclusions & Outlook

- The 3-component implementation is validated by synthetic tests.
- The seismicity expands to the edge of the network.
- The use of accelerometers is possible. The number of available polarities is increased, and therefore also the number of moment tensors.
- In general, focal mechanisms seem to coincide with the regional faulting regime.

As a next step, we will use the whole dataset applying the HMT technique and study the stress field.

3. Temporal migration

Over two years of recorded earthquakes we observe a temporal migration of the seismicity towards the edge of the network (Fig. 4).

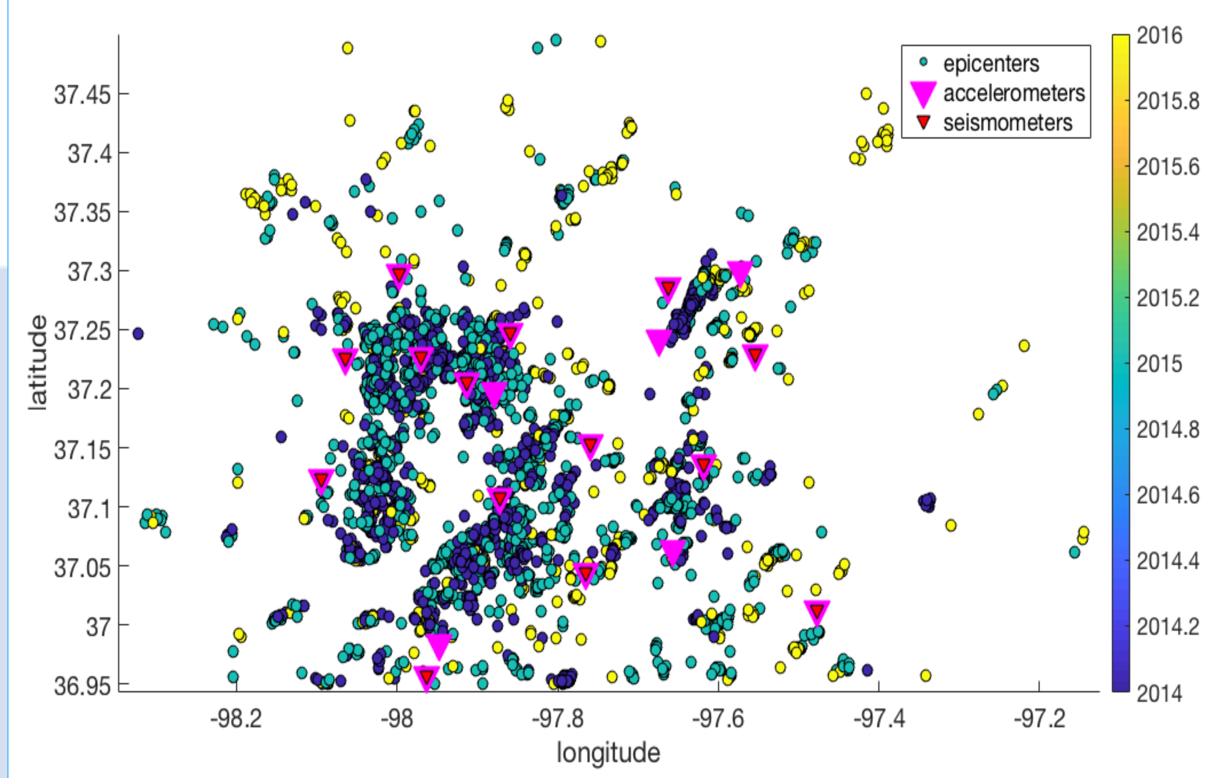


Figure 4: Seismicity map of the 5269 relocated earthquakes (colored with time) recorded by the USGS seismic network.. Seismometers and accelerometers are represented by red and magenta triangles, respectively.

4. Necessity of accelerometers

Using only seismometers is not sufficient. Additional accelerometers increases the number of picked polarities of the test dataset by 26%. The use of accelerometers is feasible due to comparability of velocity (Fig. 6) and displacement signals.

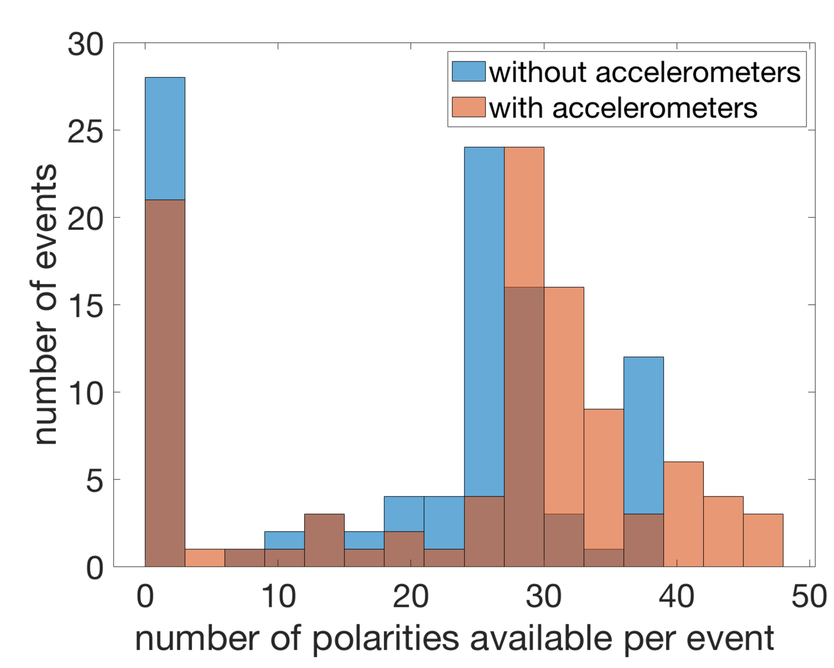


Figure 5: Number of manual picked polarities in the test dataset.

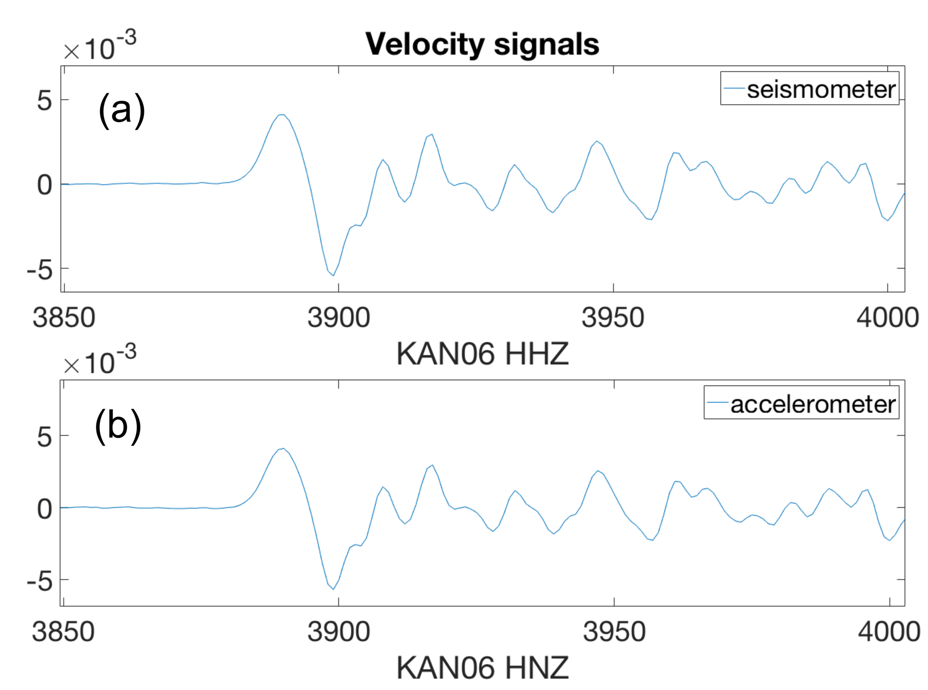


Figure 6: Comparison of the velocity signal between (a) a seismometer and (b) its collocated accelerometer. Polarity and size of the first pulse are similar.

5. Magnitude comparison & focal mechanisms

Figure 7 presents moment magnitudes determined by the full and double couple (DC) inversions for the test dataset. The DC inversion provides better constrained moment tensors. Focal mechanisms of Figure 8 suggest predominant strike-slip faulting system with predominant normal regime consistent with the structure delineated by the relocated seismicity. (**Ref.1**)

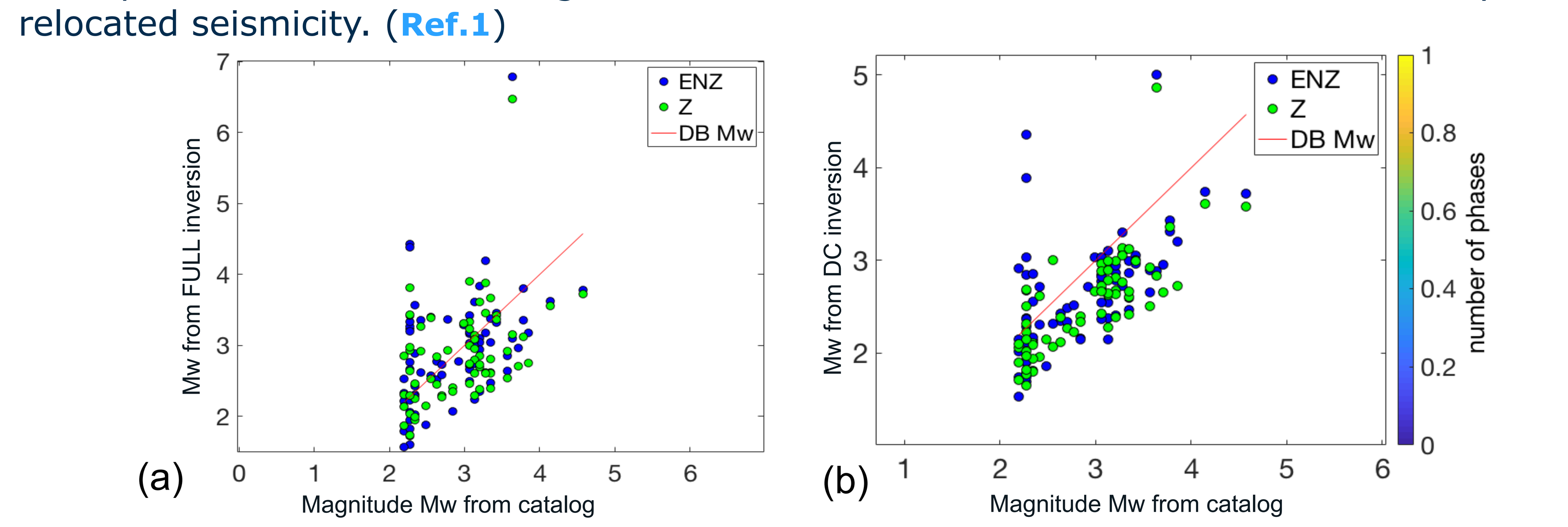


Figure 7: Comparison between the moment magnitude from (a) full inversion, (b) DC inversion and the converted M_L (to Mw) using the scaling from **Ref.4** .

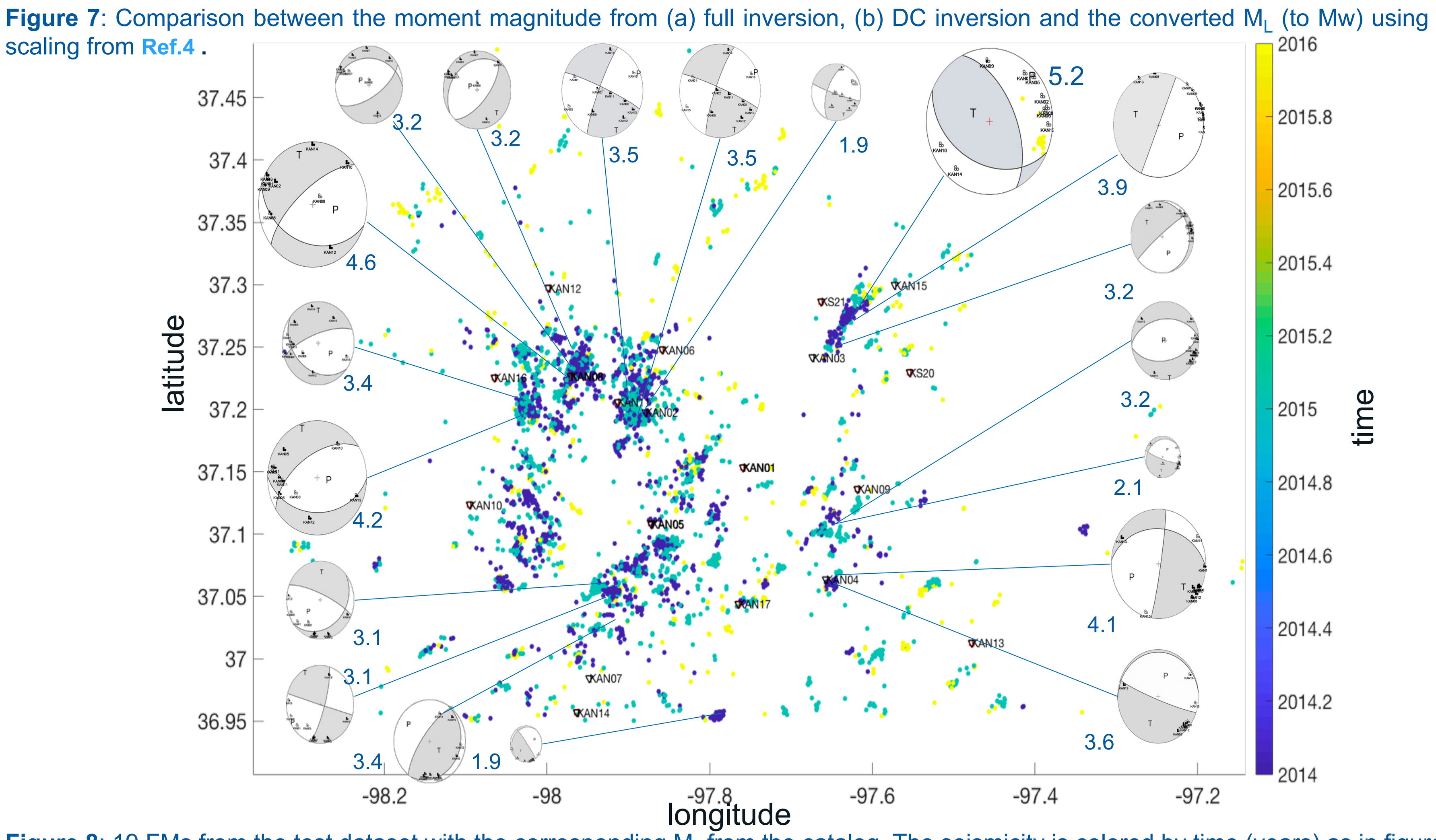


Figure 8: 19 FMs from the test dataset with the corresponding M_L from the catalog. The seismicity is colored by time (years) as in figure 4.

Acknowledgement

We acknowledge funding from the Helmholtz Association in the frame of the Young Investigators Group VH-NG-1232 (SAIDAN, www.saidan.org)

www.gfz-potsdam.de

References

1. W.L. Ellsworth, A.L. Llenos, A.F. McGarr, A.J. Michael, J.L. Rubinstein, C.S. Mueller, M.D. Petersen, E. Calais (2015) Increasing seismicity in the U.S. midcontinent : Implication for earthquake hazard, *The Leading Edge*, doi:10.1190/tle34060618.1

2. J. L. Rubinstein, W. L. Ellsworth, S. L. Dougherty. (2018) The 2013-2016 Induced Earthquakes in Harper and Sumner Counties, Southern Kansas, *Bulletin of the Seismological Society of America*, 108, pp. 674–689, April 2018, doi: 10.1785/0120170209

3. G. Kwiatek, P. Martínez-Garzón, M. Bohnhoff. (2016) HybridMT : A MATLAB/Shell Environment Package for Seismic Moment Tensor Inversion and Refinement, *Seismological Research Letters,* 87, pp. 964—976. doi: https://doi.org/10.1785/0220150251

4. D.T. Trugman,, S.L Dougherty, E.S Cochran, P.M. Shearer. (2017) Source Spectral Properties of Small to Moderate Earthquakes in Southern Kansas, *Journal of Geophysical Research : Solid Earth,* 122, pp. 8021–8034. https://doi.org/10.1002/2017JB014649, 2017

5. V. Vavrycuk. (2001) Inversion for parameters of tensile earthquakes, *Journal of Geophysical Research : Solid Earth*, 106, pp.16,339-16,335, https://doi.org/10.1029/2001JB000372

SAIDAN Seismology Research Project

HELMHOLTZ