LLNL-CONF-767221

LAWRENCE LIVERMORE NATIONAL LABORATORY

Microseismic Correlation and Cluster Analysis of DOE EGS Collab Data

D. Templeton, J. Morris, M. Schoenball, T. Wood, M. Robertson, P. Cook, P. Dobson, C. Ulrich, J. Ajo-Franklin, T. Kneafsey, P. Petrov, P. Schwering, D. Blankenship, H. Knox, L. Huang

February 1, 2019

43rd Workshop on Geothermal Reservoir Engineering
Stanford, CA, United States
February 11, 2019 through February 13, 2019

PROCEEDINGS, 44th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 11-13, 2019
SGP-TR-214

Microseismic Correlation and Cluster Analysis of DOE EGS Collab Data

Dennise Templeton[1], Joseph Morris[1], Martin Schoenball[2], Todd Wood[2], Michelle Robertson[2], Paul Cook[2], Patrick Dobson[2], Craig Ulrich[2], Jonathan Ajo-Franklin[2], Timothy Kneafsey[2], Paul Schwering[3], Doug Blankenship[3], Hunter Knox[3], and the EGS Collab Team

[1]Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550, USA

[2]Lawrence Berkeley National Laboratory, One Cyclotron Rd., Berkeley, CA 94720, USA

[3]Sandia National Laboratories, 1515 Eubank SE, Albuquerque, NM 87123, USA

templeton4@llnl.gov

Keywords: EGS, Collab, microseismicity, mesoscale experiment

ABSTRACT

Enhanced geothermal systems (EGS) can enrich the US energy portfolio by increasing the amount of renewable baseload power available to the electrical grid. To advance EGS technological readiness, meso-scale field studies were funded by the Geothermal Technologies Office (GTO) to validate subsurface reservoir models using observed geophysical data, borehole characterization data, and fluid flow information. The EGS Collab initiative is putting this collaborative multi-Laboratory and multi-university experiment into practice at the Sanford Underground Research Facility (SURF), formerly the Homestake Mine, in South Dakota. At the first site, established approximately 1.5 kilometers beneath the ground surface, 18 3-component accelerometers, four 3-component geophones, and two strings of 12-sensor hydrophones were deployed in 6 observation wells and in shallow boreholes near the drift to monitor fluid movement from the injection borehole to the production borehole.

Here we present results using data from the microseismic monitoring network to correlate and cluster microseismic events occurring before, during and after fluid injection stimulation tests between May - July 2018. Using microearthquakes identified using traditional short-term-average / long-term-average (STA/LTA) techniques, we correlate the known microseismicity with one another to characterize the similarity of seismic events within the fracture network. A comprehensive examination of the locations of these clustered events with complementary fracture information can inform us as to the character of the microearthquakes with respect to the developing and existing fracture network.

1. INTRODUCTION

The overall EGS Collab initiative aims to address critical barriers to enhanced geothermal system (EGS) advancement by providing an opportunity for reservoir model prediction and validation, using a wide variety of observation types from geophysical to biological, at an underground meso-scale field site located within the Sanford Underground Research Facility (SURF) in South Dakota (for more information see Kneafsey et al. (2019)). For this study, we specifically investigate the 4D evolution of the character of the microseismic events observed within the test reservoir, located approximately 1.5 kilometers below the ground surface.

Using microearthquake seismic data and event catalogs, we correlate and cluster known microseismicity identified using the subsurface seismic network to characterize the similarity of events within the developing reservoir. The similarity, or lack thereof, may be used to infer the evolution and nature of the fracture network. Comparing the location and timing of the clustered and unclustered events through time with complementary fracture information can shed light as to the character of the microearthquakes with respect to the fracture network.

2. MICROSEISMIC NETWORK AND INITIAL DATA PROCESSING

The passive microseismic monitoring network for Experiment 1 consists of 18 3-component piezoelectric PCB 356B18 accelerometers, two strings of 12-sensor HTI-96-Min hydrophones, and four 3-component geophones. The accelerometers and hydrophones were installed within six observation wells surrounding the injection and production wells while the geophones, which have generally yielded no usable data, are located in a series of short borings drilled off the drift. Two separate seismic recording systems recorded continuous seismic sensor signal data: a 96-channel OYO GeoRes recorder sampling at 4 kHz and a 64-channel Data Translation VibBox system sampling at 100 kHz. All sensors recorded data on the GeoRes system. Only the hydrophones and 12 accelerometers were recorded on the VibBox system and are used in this study.

Using this data, Schoenball et al. (2019) applied a coincidence short-time-average / long-time-average (STA/LTA) trigger algorithm to the continuous data to identify individual seismic events occurring at the Collab Experiment 1 site. The microseismic event P-phase arrival times were determined using an Akaike Information Criterion (AIC) picker (Chen and Holland, 2016). A subset of picks, those occurring during an active stimulation or flow test, were manually reviewed, refined, and expanded to include S-wave picks. These pick times along with a preliminary velocity model (constant V_p of 5900 m/s and a V_p/V_s ratio of 1.78) were input into a modified version of the Hypoinverse program (Klein, 2014) to determine event locations.

3. CORRELATION AND CLUSTER ANALYSIS

For this study we exclusively use the twelve 3-component accelerometer data recorded on the VibBox recording system and events identified in the microseismic event catalog from Schoenball et al. (2019) to perform the correlation analysis. To quantify the effects of the template length and bandpass filter when performing the correlation analysis, we first conduct two parameter studies.

The first parameter study investigated the effect of the template length. To begin, we determined that event durations (e.g., the time duration of the microseismic events between the first P-wave phase until the amplitude of the wave train returns back to the background noise level) for most of the smaller events are no more than approximately 0.020 sec (Figure 1), and that event durations for most of the larger events are typically no greater than approximately 0.050 sec. Therefore, each of the event templates were cut from 0.005 sec prior to the origin time to 0.020 sec, 0.030 sec, 0.040 sec, and 0.050 sec after the origin time. For this template length study, we keep the bandpass filter constant at 5 kHz – 10 kHz.

The second parameter study investigated the effect of the bandpass filter on the results. We determined that although some of the larger events did indeed have energy up to 40 kHz, a significant percentage of the smaller events only had energy between 5 kHz – 15 kHz (Figure 1). Therefore, for the filter study, we kept a constant template length (0.005 sec prior to the origin time and 0.020 sec after the origin time) and performed the correlations using three different bandpass filters: 1) 5 kHz – 10 kHz, 2) 5 kHz – 15 kHz, and 3) 10 kHz – 15 kHz.

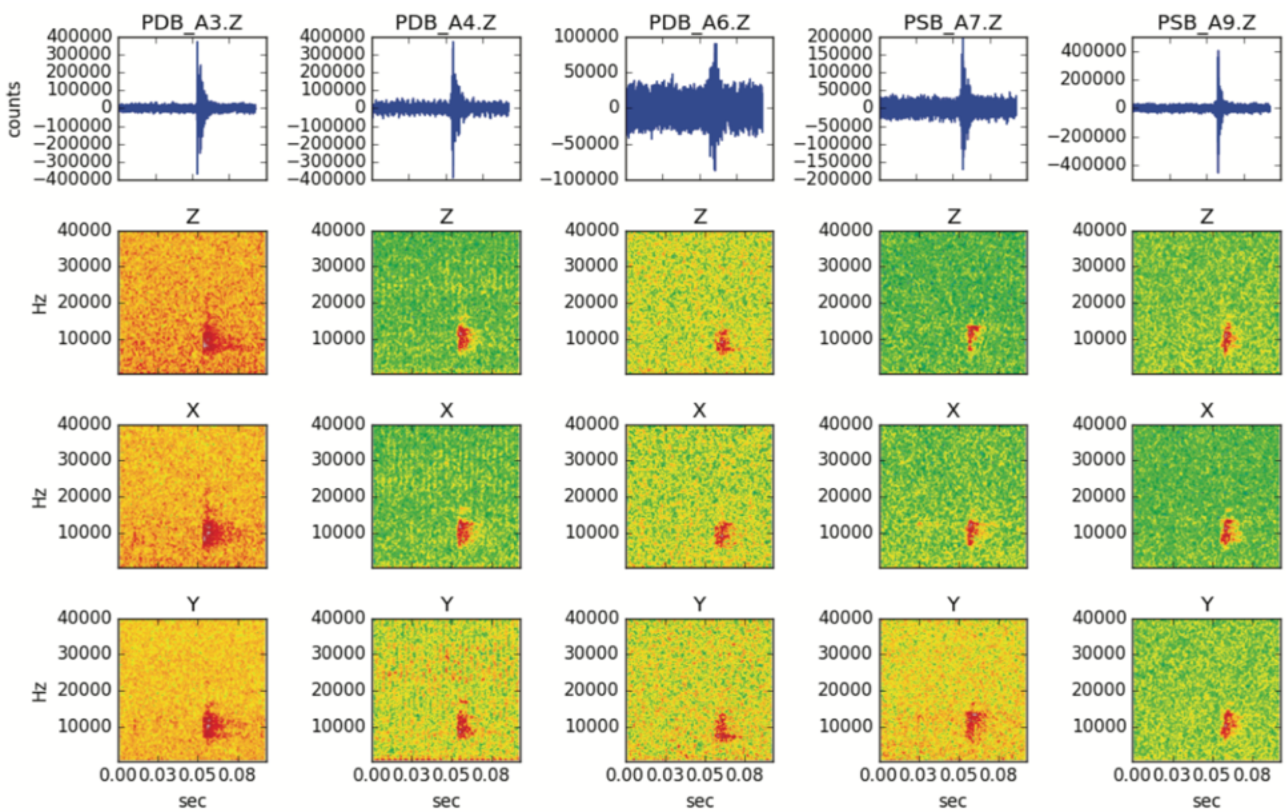

Figure 1: Event 2018/05/23 16:10:04.735990 showing the frequency content and duration of a smaller event. The first row shows the vertical component waveform as seen in the time domain at 5 stations. The second, third and fourth rows show the spectrograms for the vertical and two horizontal components between 500 Hz – 40 kHz.

To perform the event clustering, we take the calculated correlation values and link pairs of events that have cross correlation coefficients greater than 0.5. Group clusters are formed by combining linked pairs. For example, if event A and B are linked above the threshold value, and if B and C are linked above the threshold value, then A, B, and C are considered one cluster irrespective of the correlation between A and C.

4. RESULTS AND CONCLUSIONS

Our correlation parameter study showed that longer time windows produced lower cross correlation values using the same data and bandpass filter. This could be an indication that most of the events are of shorter duration, between 0.02 – 0.03 sec, and that longer time windows only include more background noise data. In essence, beyond these duration values we would be correlating a greater percentage of post-event background noise signals rather than event signals in the templates.

The bandpass filter parameter study showed that slightly more events were identified as having cross correlation values above our threshold limit using the 5 kHz – 10 kHz bandpass filter than using filters that included energy up to 15 kHz. The difference would perhaps suggest that there is typically slightly more energy below 10 kHz than above 10 kHz for smaller events. We could expect that the higher frequency event energies attenuate more rapidly above 10 kHz. Additionally, the effect of scattering on small heterogeneities could play a role since this phenomena is more pronounced at higher frequencies.

Our initial microseismic event cluster analysis linked pairs of events above the cross correlation threshold level of 0.5. The results showed that for templates cut 0.005 sec prior to the origin time to 0.020 sec after the origin time (the shortest template duration included in our study), and bandpass filtered between 5 kHz – 10 kHz, there are 176 events that are included in a cluster, or approximately 26% of catalog events, and 55 separate clusters. For reference there were 676 total events in the catalog. Each cluster contained between 2 – 38 events and the 3 largest clusters occurred on June 25, 2018.

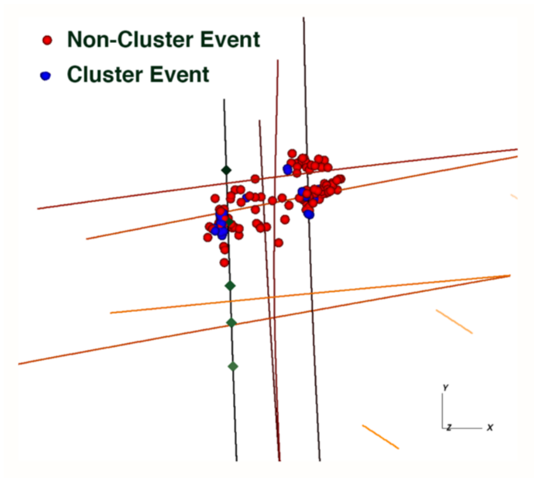

Figure 2: Map view of seismic events that occurred in June 2018. Events that were part of a cluster are in blue. Events that were not linked to other events above 0.5 cross correlation coefficient are plotted in red.

5. ACKNOWLEDGEMENTS

This material was based upon work supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Office of Technology Development, Geothermal Technologies Office, under Award Number DE-AC52-07NA27344 with LLNL, and Award Number DE-AC02-05CH11231 with LBNL. The United States Government retains, and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The research supporting this work took place in part at the Sanford Underground Research Facility in Lead, South Dakota. The assistance of the Sanford Underground Research Facility and its personnel in providing physical access and general logistical and technical support is acknowledged. This is document LLNL-CONF-767221.

REFERENCES

Chen, C., and Holland, A. A.: PhasePApy: A Robust Pure Python Package for Automatic Identification of Seismic Phases. *Seismological Research Letters*, **87**, (2016), 1384–1396.

Klein, F. W.: User's Guide to HYPOINVERSE-2000, a Fortran Program to Solve for Earthquake Locations and Magnitude, U. S. Geological Survey, Open File Report 02-171, revised June 2014.

Kneafsey, T. J., Blankenship, D., Knox, H. A., Johnson, T. C., Ajo-Franklin, J., Schwering, P. C., Dobson, P., Morris, J., White, M. D., Fu, P., Podgorney, R., Roggenthen, W., Doe, T. Mattson, E., Ghassemi, A., Valladao, C., and the EGS Collab Team: EGS Collab Project: Status and Progress, *Proceedings,* 44th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2019).

Schoenball, M., Ajo-Franklin, J., Blankenship, D., Cook, P., Dobson, P., Guglielmi, Y., Fu, P., Kneafsey, T., Knox, H., Petrov, P., Robertson, M., Schwering, P., Templeton, D., Ulrich, C., Wood, T., and the EGS Collab Team: Microseismic Monitoring of Meso-

Scale Stimulations for the DOE EGS Collab Project at the Sanford Underground Research Facility, *Proceedings,* 44th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2019).