Data Mining Microseismicity using PageRank

Project Number (FWP0193)

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Presented by Dennise Templeton

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Presentation Outline

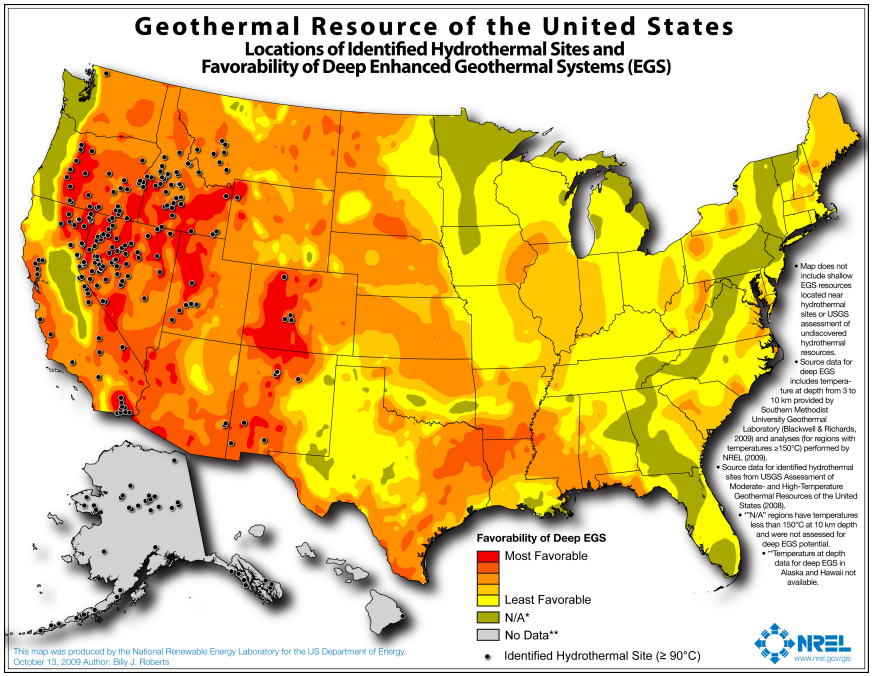
- Technical Status
  - Motivation: Geothermal systems, EGS and microseismicity
  - This study
    - Characterizing microseismicity
    - Analysis workflow: PageRank and MicroBayesloc
    - Application to Newberry Data
- Accomplishments to date
- Lessons learned
- Synergy Opportunities
- Summary

- Acknowledge **AltaRock Energy Inc** for providing the data

Technical Status

Motivation

- Geothermal Energy
  - Renewable power around the clock
  - Emits little or no greenhouse gases
- Not always easily accessible
- Enhanced Geothermal Systems (EGS)
  - Hydroshearing to allow heat extraction in locations devoid of naturally occurring hydrothermal systems



Western US has over 517,800 MW of EGS capacity (~1/2 US electric generating capacity from all sources) (USGS)

Technical Status

Motivation

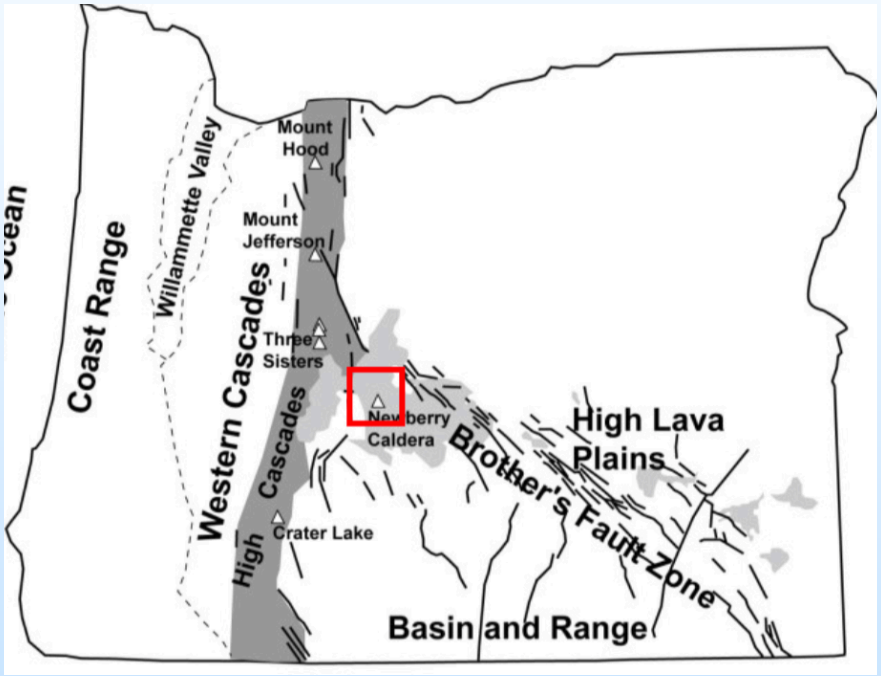
- Microseismic events related to hydroshearing in an EGS play a key role in understanding how these systems work.

- Find an effective/efficient method to characterize these events
    - > Aid in the relocation
    - > Development of the technology

Technical Status

In this study…

- Reanalyzed microseismic data from 2012/2014 hydroshearing events at the Newberry EGS site



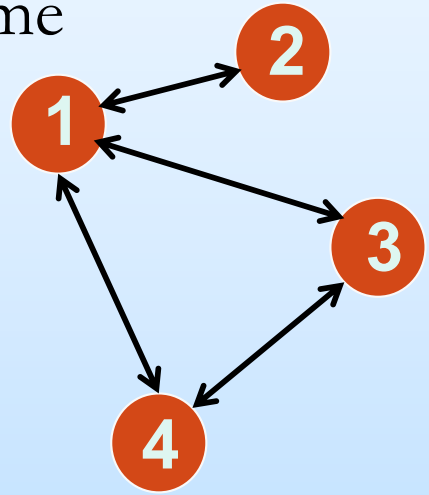
Mark-Moser *et al*. (2016)

- Deschutes National Forest, south of Bend, Oregon
- Phase 1 site for the DOE's FORGE program (Not selected for Phase 2)
- AltaRock Energy and Davenport Newberry
  - > Test EGS technology

Technical Status

In this study…

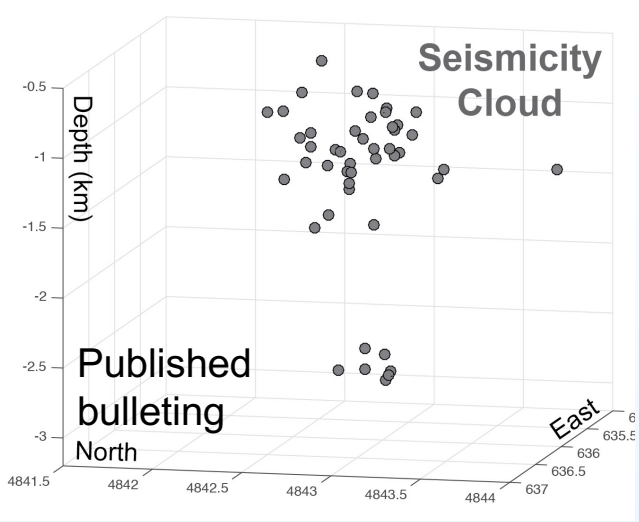
- Reanalyzed microseismic data from 2012/2014 hydroshearing events at the Newberry EGS site
- Apply a data mining method: PageRank, Google's original search algorithm based on webpage links (Page and Brin, 1999) to analyze how events are linked in space and time
- Changes in microseismic signals → changes in the state of stress/pore pressure
- Aid in the relocation of the events
  - Understand the properties of the EGS.



Analysis Workflow

1

Cross-correlate

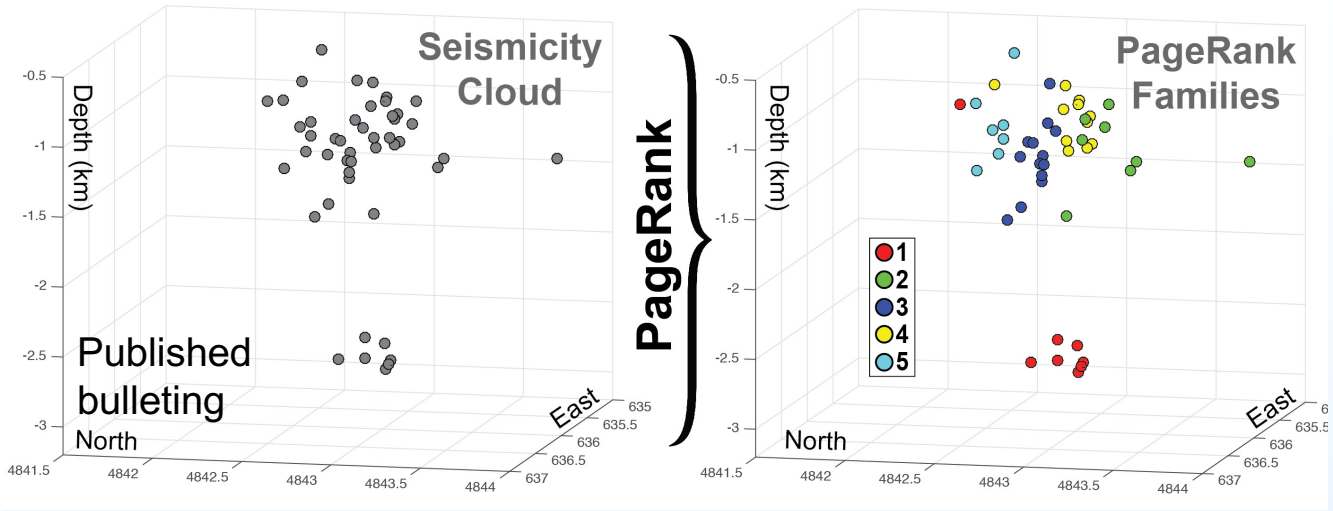


- Cross correlate each event with all others
  - CC > initial threshold

Analysis Workflow

PageRank

2



- Compute PageRank to identify PageRank families

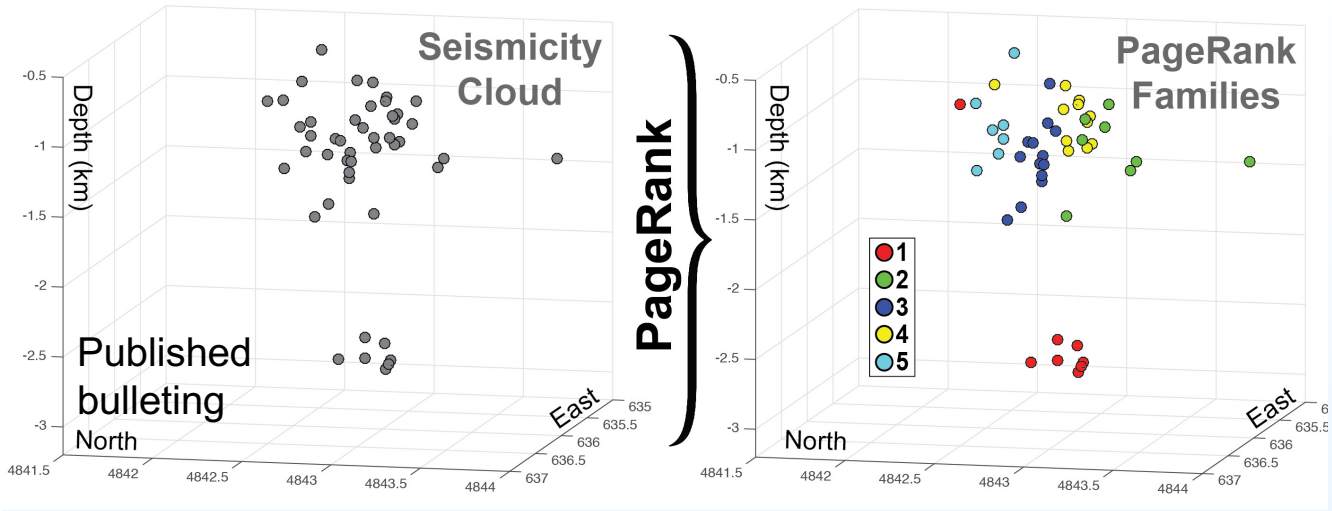
$$\mathbf{p}_k = \mathbf{A}\mathbf{p}_{k-1}$$

- Show statistically how events relate to each other
- Matrix **A** contains cross-correlation information from previous step

Analysis Workflow

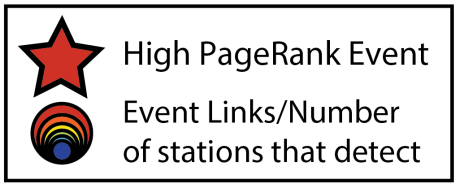
PageRank

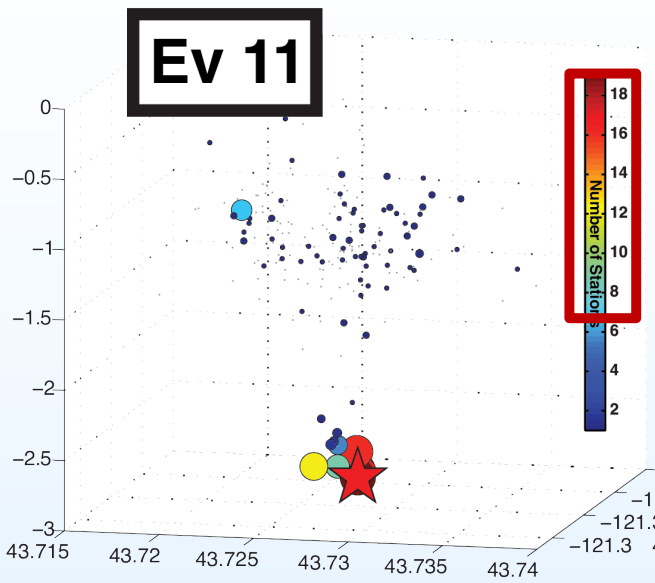
2

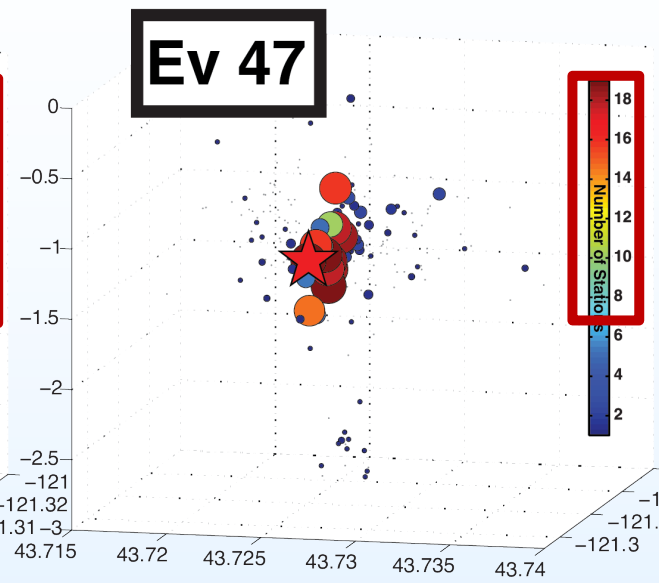


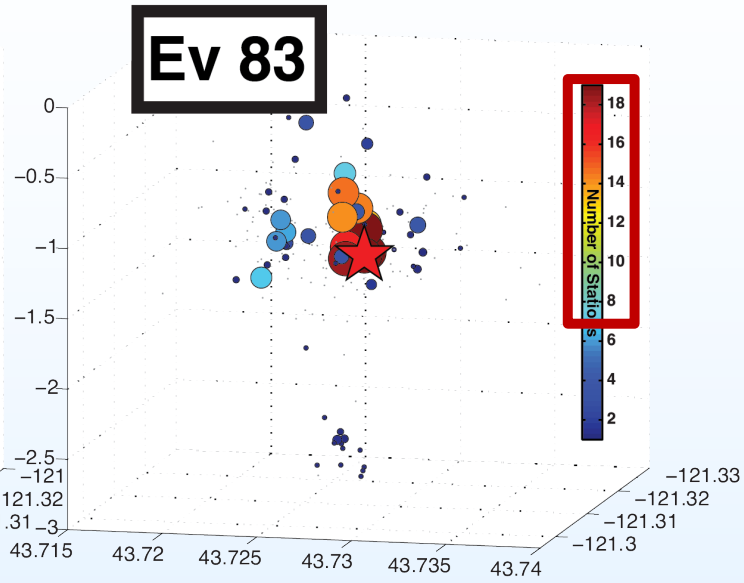
- Compute PageRank to identify PageRank families
- Compute <u>differential travel times</u> between events within each family taking advantage of both direct and indirectly linked events

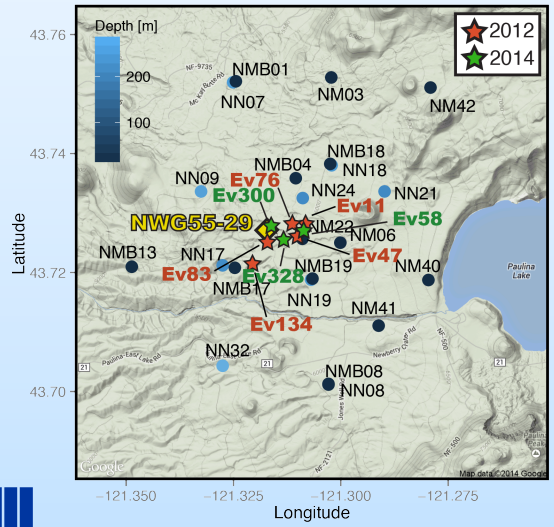
PageRank Families 2012

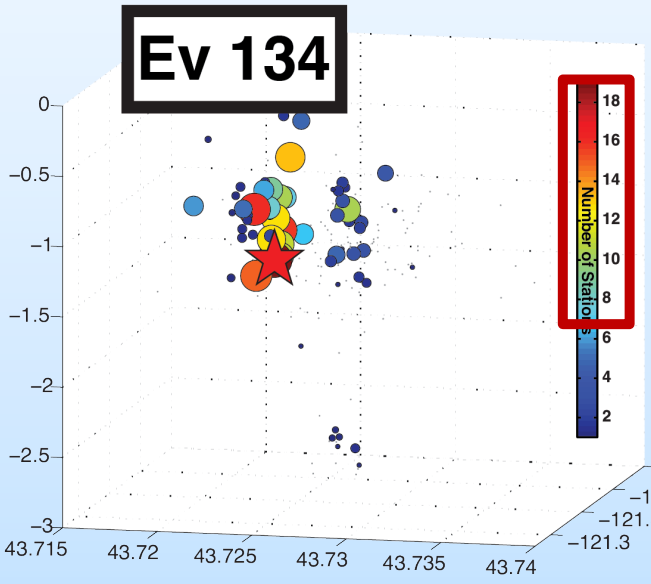


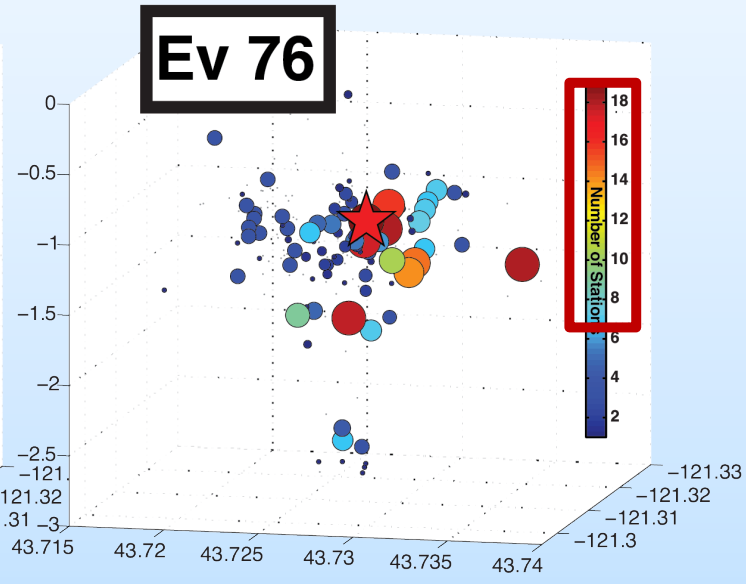










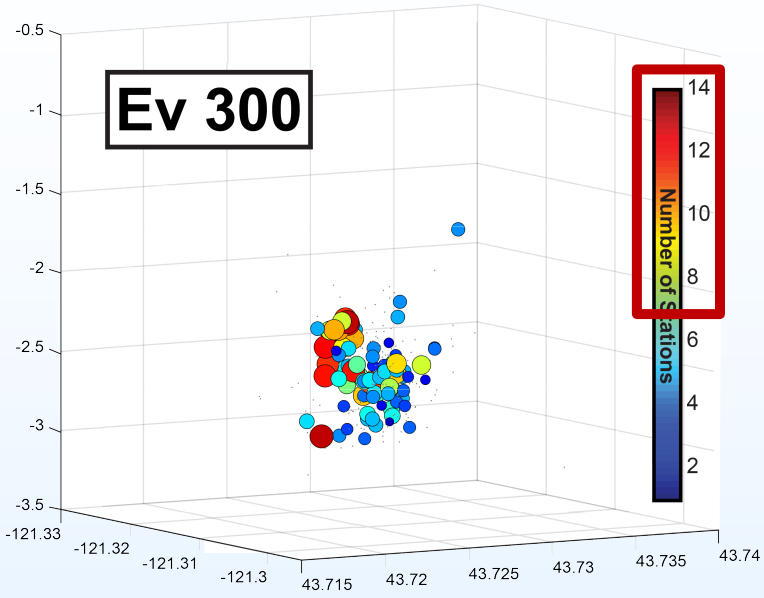


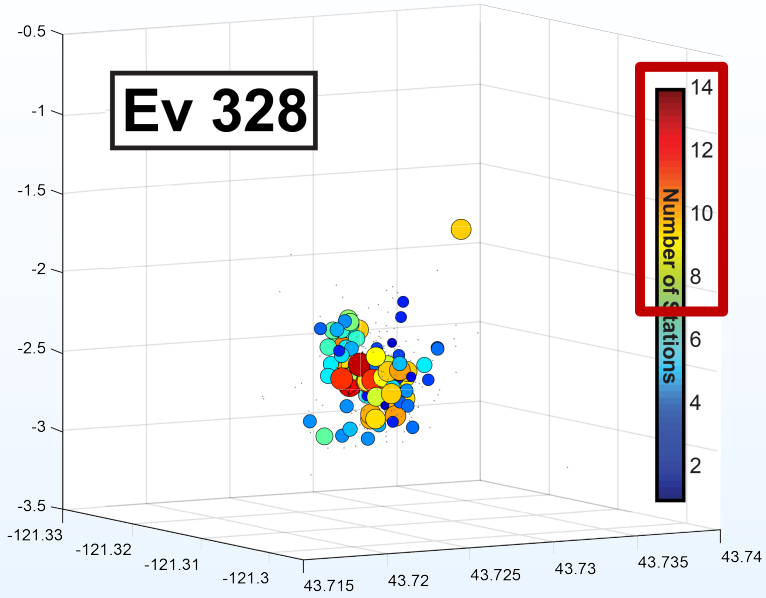
PageRank Families 2014

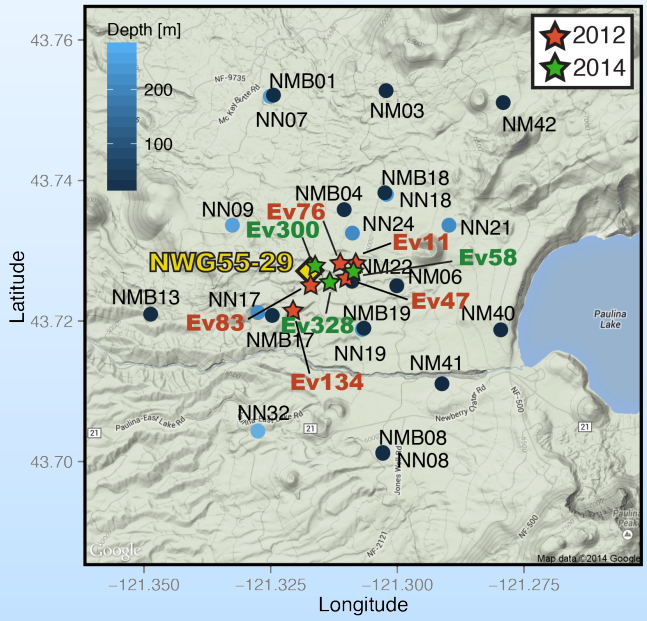
High PageRank Event

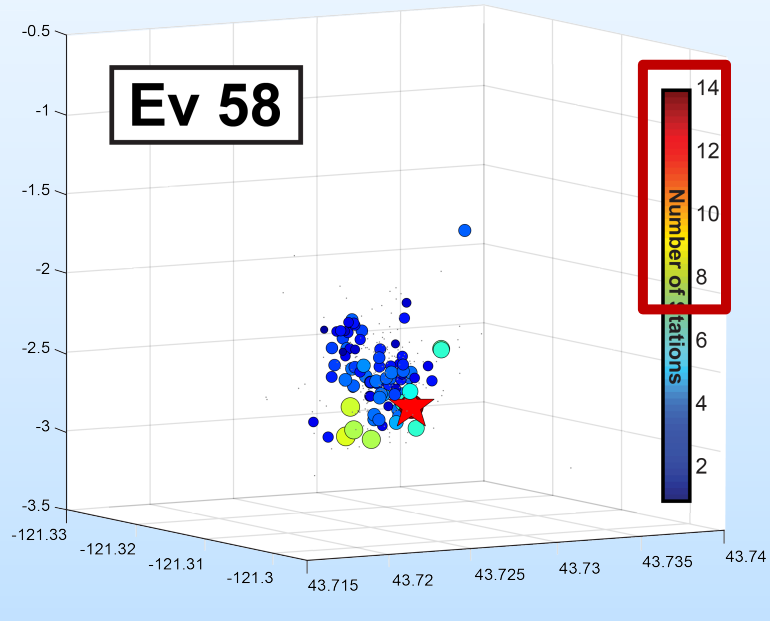
Event Links/Number of stations that detect

- Each ref event/family define different volume of original cloud





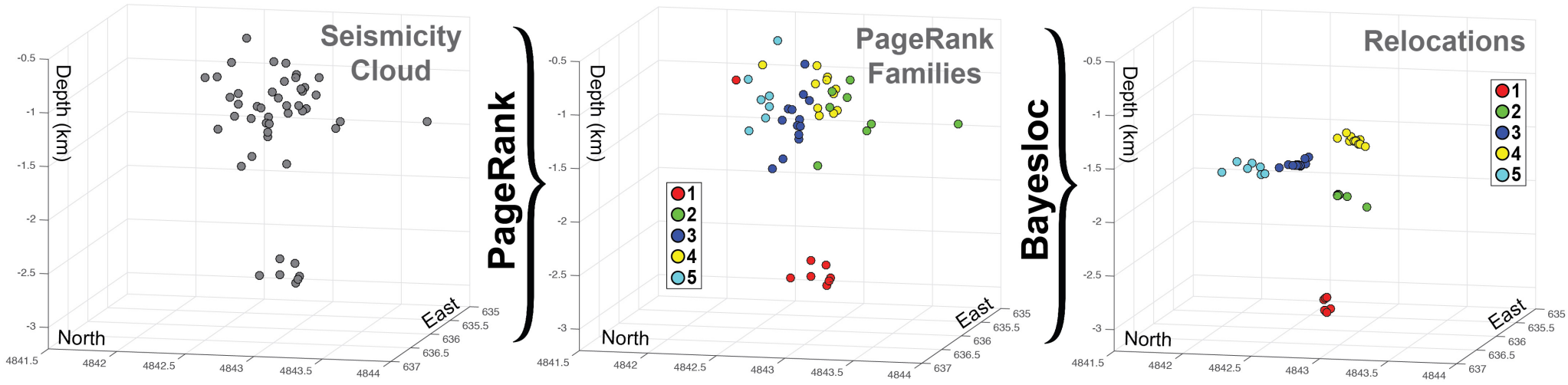




Analysis Workflow

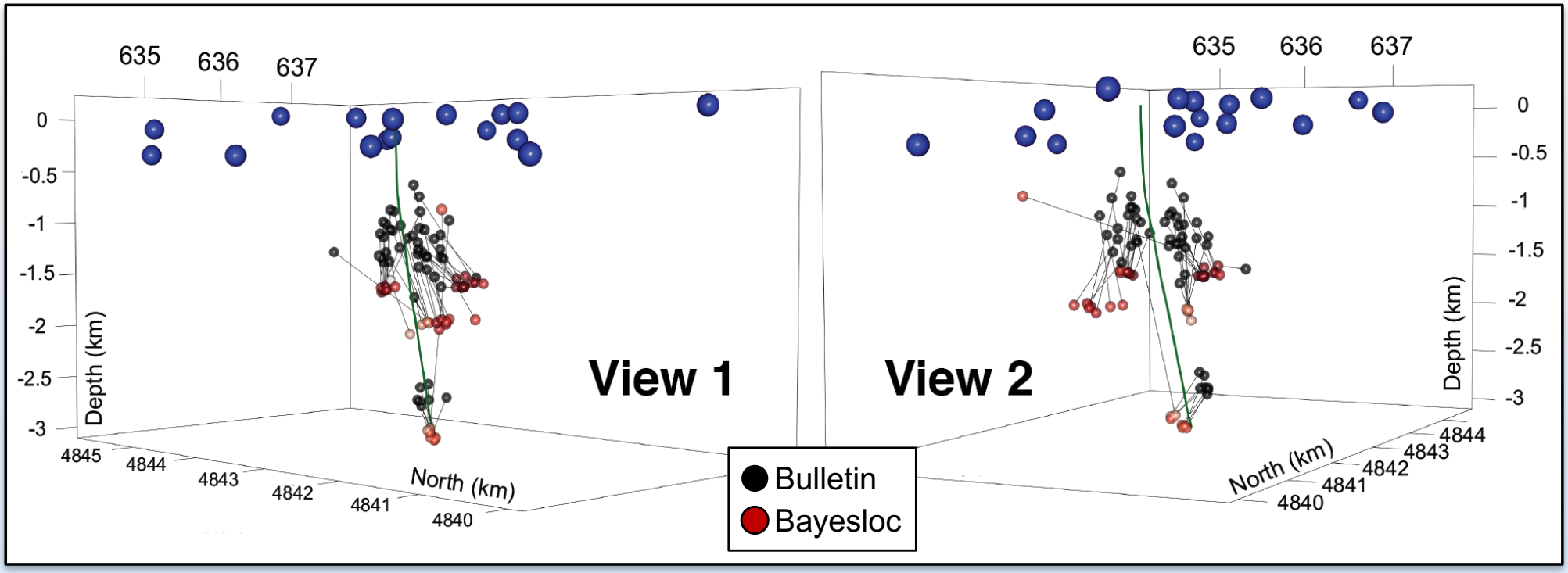
Relocate

3



- Relocate clusters, Bayesloc (Myers *et al.* [2007])
  - Inverts joint probability while simultaneously solving event location, travel time corrections, phase information, pick precision
  - Velocity model is a linear gradient with station correction to account near-surface low velocity
  - Markov Chain Monte Carlo (MCMC) to sample the models.
  - Differential travel times from CC of PageRank families and absolute picks at once, unlike hypoDD

Event Relocations 2012

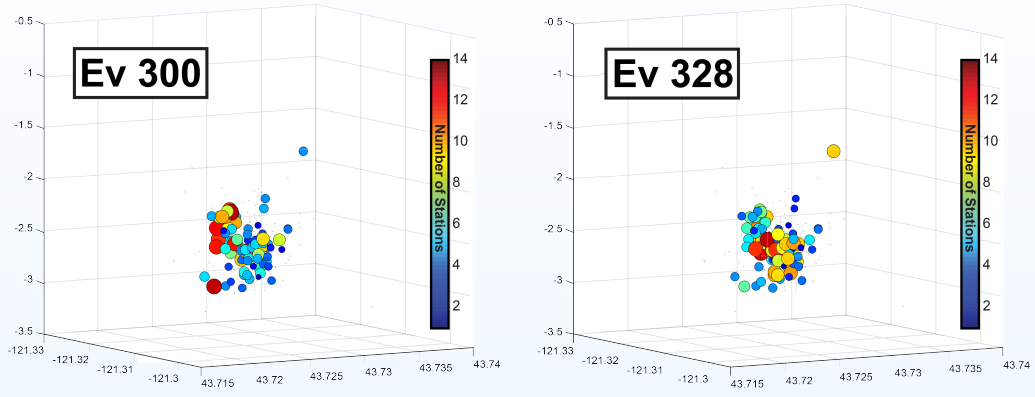


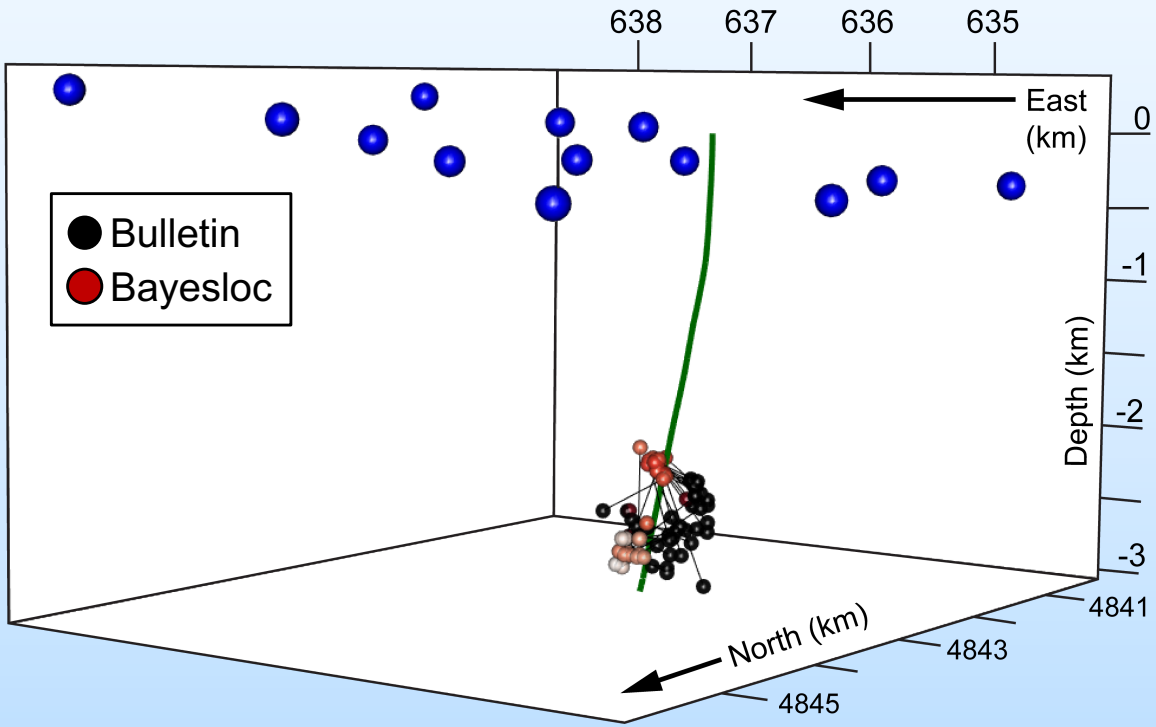
- MicroBayesloc relocated events: **3 distinct** depths
- Deep cluster: two smaller clusters
- Events within clusters are significantly closer together

Event Relocations 2014

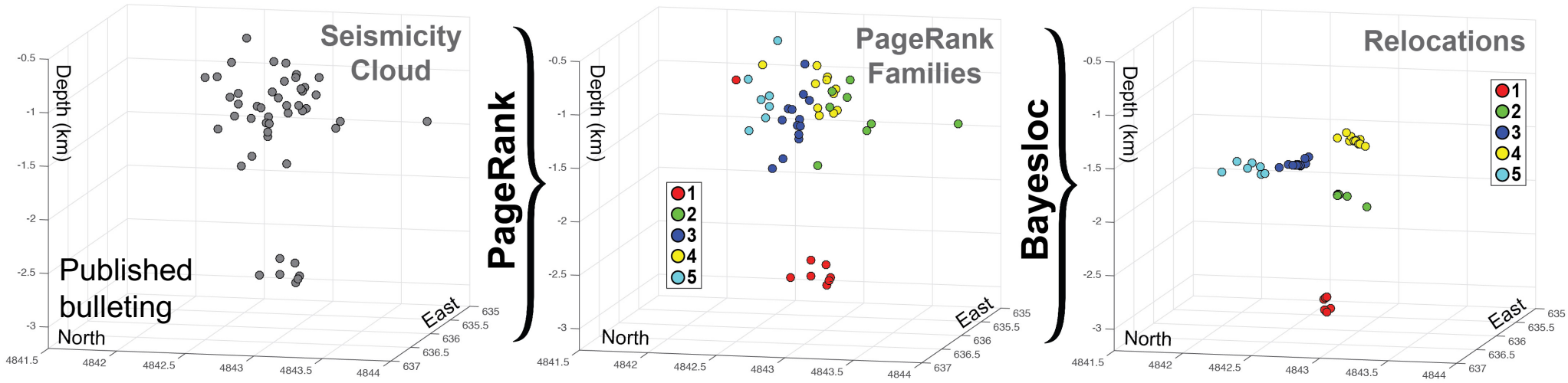
- Relocated two families so far: Family **Ev300** and **Ev328**

- Again, events within clusters are significantly closer together



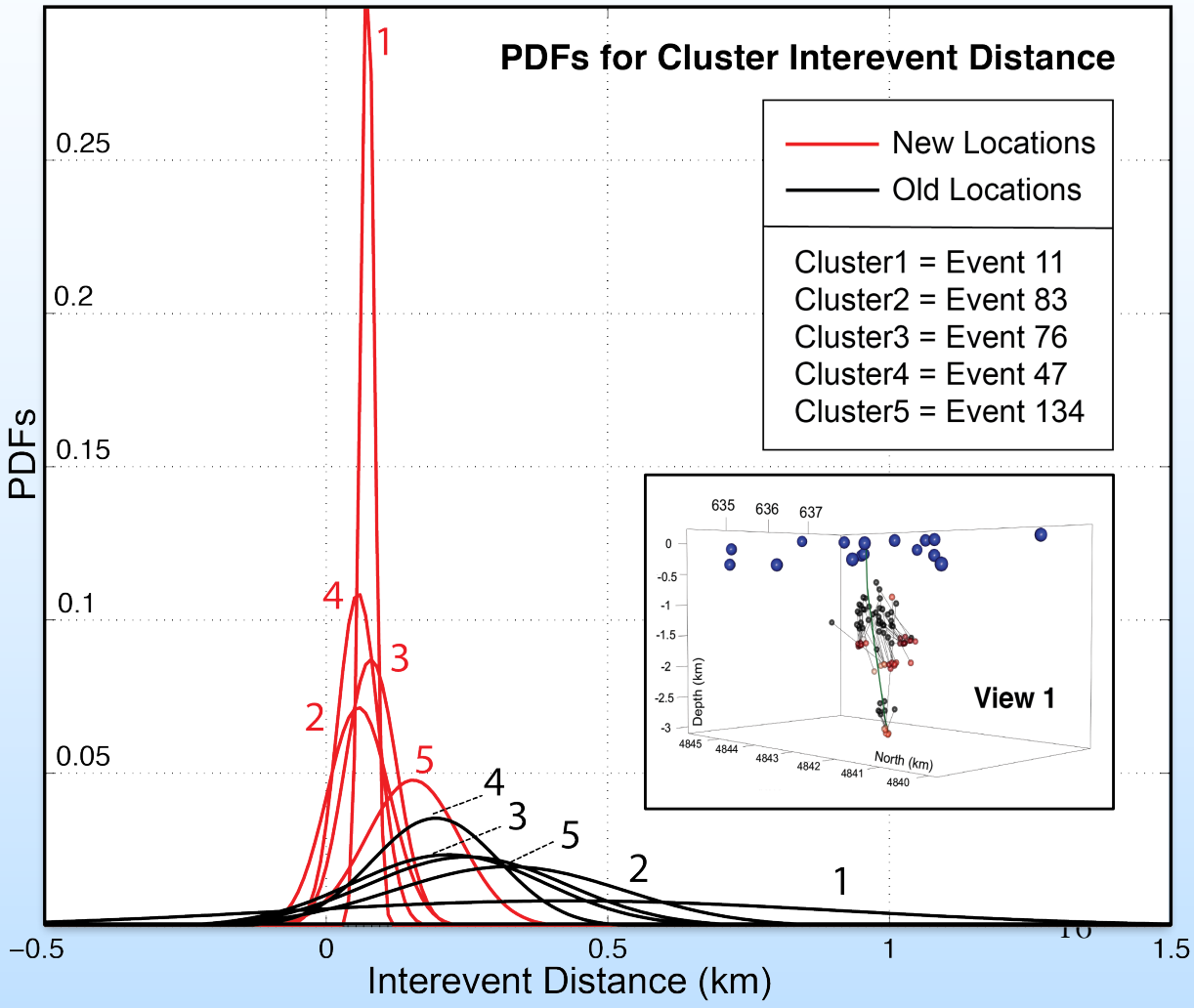


Analysis Workflow



Findings to Date

- PageRank successfully identifies clusters of events with similar physical characteristics
- Rock volume in which micro-earthquakes occurred – where micro-shearing can be inferred – is far smaller than previous studies suggest.
- Consistent with small increase in fluid extraction volume observed at Newberry after hydroshearing.



Accomplishments to Date

- MicroBayesloc
  - Development of Langevin-Hastings algorithm to improve computational efficiency of MCMC sampling when differential time data are used.
  - Development of portable Java version of Bayesloc code.

- Newberry Data Analysis
  - Implementation of PageRank algorithm to work with microseismic data in identifying data clusters with similar physical characteristics.
  - Calculation of differential travel times within clusters to aid in relocation of microseismic events.
  - Relocated events within clusters of reference PageRank (highly linked) events.

Lessons Learned

- PageRank successfully identifies events with similar location and physical characteristics
- Combined PageRank and MicroBayesloc analysis results in event locations that occupy a significantly smaller volume than previously thought
- Data quality checks and analysis of low signal-to-noise data inhibits automated processing (much of the analysis had to be done by a diligent post-doc)
- The data set's resistance to automated processing precluded the use of microseismic results to either validate geomechanical models or test whether the scattered wavefield evolved during microshearing.
- More time should be allowed for data quality assessment and analysis.
- Resolution of empirical Green's functions from waveform cross correlations between surface and borehole is insufficient to test whether the scattered seismic wavefield changes when fractures open.

Synergy Opportunities

- Results of Newberry reanalysis could be used to assess the effectiveness of hydroshearing injections.
  - Event relocations show that micro-seismicity is limited in spatial extent and the 2014 stimulation did not produce micro-seismicity to a great distance from the borehole.

- Relocated events could be used to test the hypothesis that microshearing changes the scattered wavefield (Seismic imaging of open fractures).

Project Summary

– Key Findings.

- Rock volume in which micro-earthquakes occurred during the Newberry 2012 and 2014 events– where micro-shearing can be inferred – is far smaller than previous studies suggest.

- Consistent with small increase in fluid extraction volume observed at Newberry after hydroshearing.

– Next Steps.

- Work with geomechanics experts to infer the change in state of stress resulting from 2012 and 2014 simulations.
- Use relocated events to determine whether the scattered wavefield changes as micro-shearing progresses.

Appendix

Benefit to the Program

- SubTER aims to assess the change in state of stress caused by fluid extraction and/or stimulation activities
- Improved micro seismic data analysis techniques greatly improve the accuracy of event locations and other source characteristics.
  - Improved assessment of rock volume where fracture occurs
  - Better assess the time progression of micro-seismicity and fracture
  - Identify events with similar focal mechanisms (fracture orientation)
  - Identify similar events through PageRank procedure

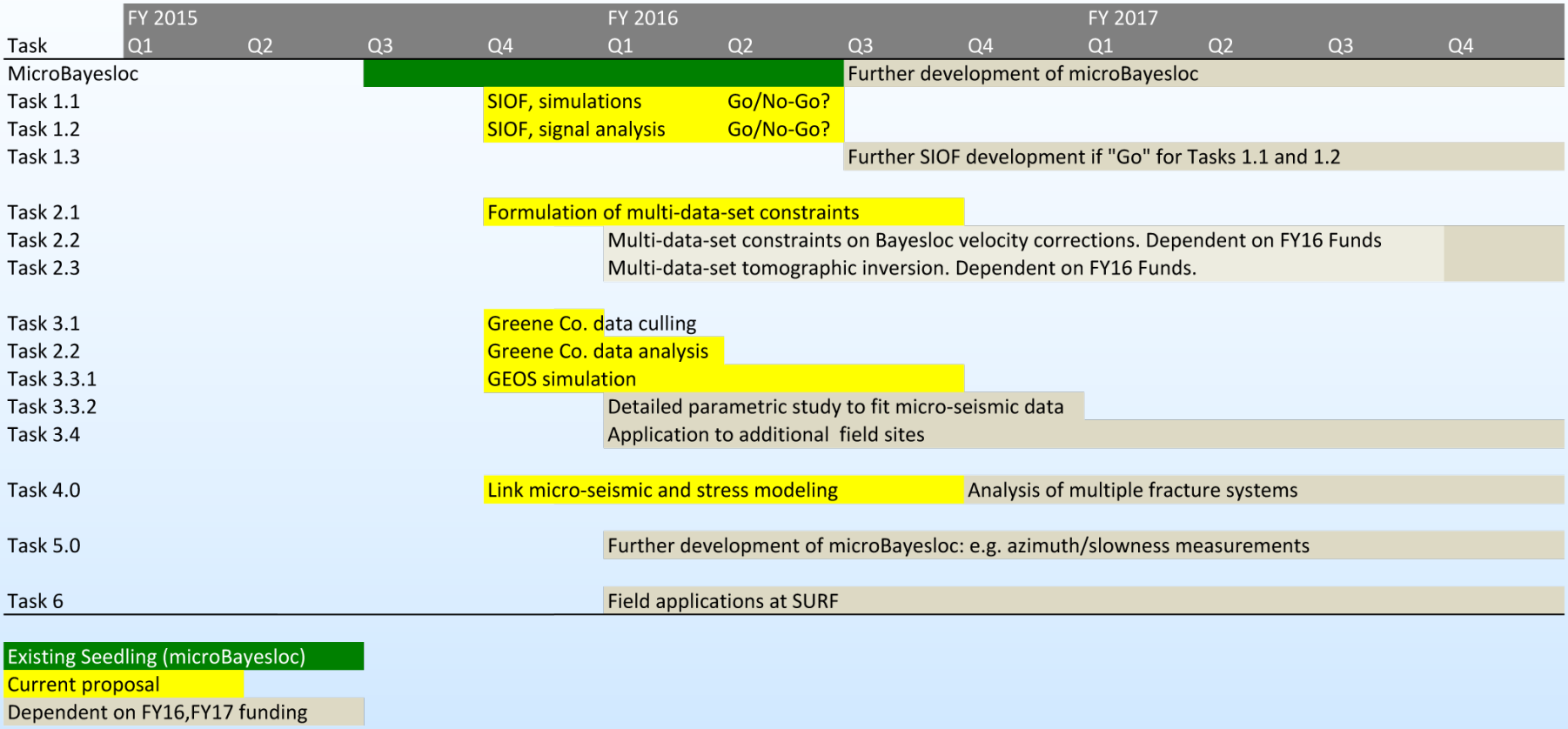
Project Overview
Goals and Objectives

- The LLNL SubTER project aims to use improved micro-seismic analysis to improve characterization of subsurface stress through direct observation
  - Geomechanical methods model the response of the subsurface to changes in state of stress
  - Micro-seismic analysis validates geomechanical predictions
  - Analysis of changes in the seismic wavefield before and after hydroshearing may be used to image the opening of fractures

Organization Chart

Name	Total FTE	SIOF % FTE	Multi-Data Tomography % FTE	Data Analysis (NETL % FTE	Big Data (NETL) % FTE	Muon (PNNL) % FTE	Bayesloc/Stress Modeling (LANL) % FTE	microBayesloc % FTE
AGUIAR, ANA	0.73			0.3			0.18	0.25
BARNO, JUSTIN	0.18	0.06						0.12
BULAEVSKAYA, VERA	0.08	0.08						
George Chaplin	0.02					0.02		
CHU, ALBERT L	0.01				0.01			
MAGANA-ZOOK, STEVEN	0.24				0.09			0.15
MATZEL, ERIC M	0.08	0.08				0.02		
MELLORS, ROBERT	0.07		0.02			0.04		
Morris Joe	0.05			0.05				
MYERS, STEPHEN	0.18	0.1	0.02	0.02	0.02		0.02	
PITARKA, ARBEN	0.08	0.08						
RUPPERT, STANLEY	0.01				0.01			
Scherman, Chris	0.25			0.25				
SIMMONS, NATHAN	0.04		0.04			0.02		
TEMPLETON, DENNISE	0.11			0.03			0.08	
Total	2.13							

Gantt Chart



Work plan is delayed by 1 quarter due to late arrival of funds

Bibliography

- Peer review publications
  - Aguiar, A.C., and S.C. Myers, 2017, Analysis of Newberry Oregon geothermal field seismicity. Bull. Seismic. Soc Am, In preparation.
- Presentations
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  - Aguiar, A.C., Datamining microseismicity using PageRank, Berkeley SeismoLab weekly seminar, February 2017.
  - Aguiar, A.C., and S.C. Myers, 2017, Microseismic event relocation based on PageRank linkage at the Newberry Volcano Geothermal Site, PROCEEDINGS, 42st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California.
  - Aguiar, A.C., and S.C. Myers, 2017, Microseismic event relocation based on PageRank linkage at the Newberry Volcano Geothermal Site, Seismological Society of America Annual Meeting, Denver, CO.
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  - Aguiar, A.C., and S.C. Myers, 2016, Characterizing Microseismicity at the Newberry Volcano Geothermal Site using PageRank, Seismological Society of America Annual Meeting, Reno, NV.
  - Aguiar, A.C., and S.C. Myers, 2016, PageRank as a Microseismicity Characterization Tool: An application to the Newberry Volcano Geothermal Site, Conference on Data Analysis (CoDA), Santa Fe, NM.
  - Aguiar, A.C., and S.C. Myers, 2016, Characterizing Microseismicity at the Newberry Volcano Geothermal Site using PageRank, PROCEEDINGS, 41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California.