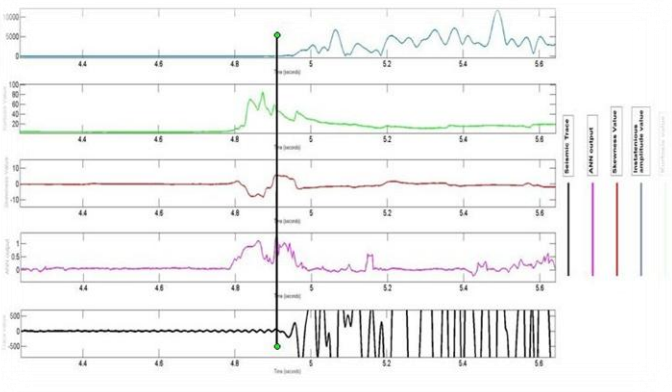
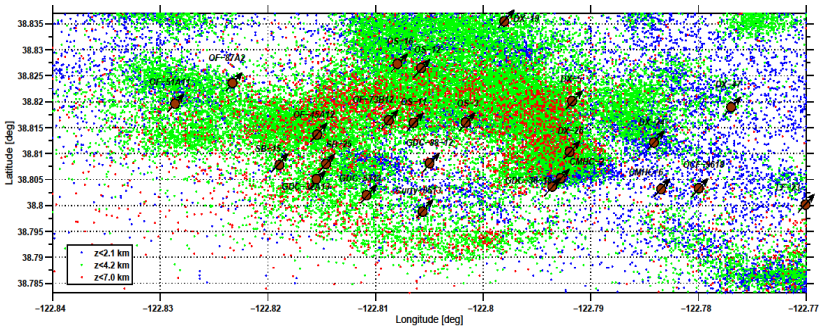
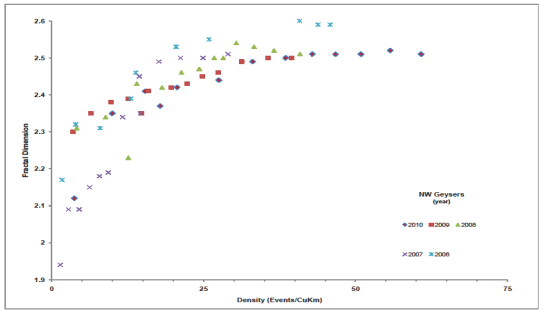
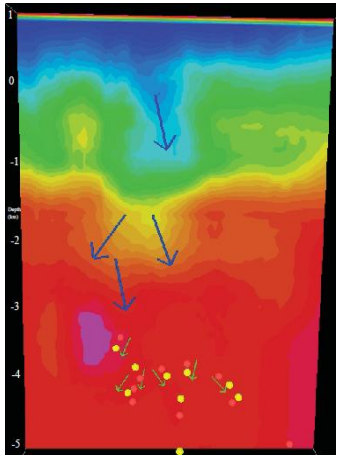
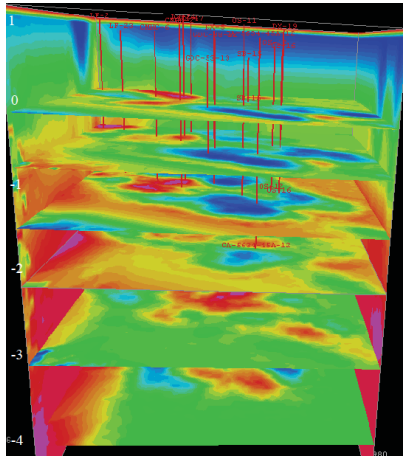










Characterizing Fractures in the Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy

June, 2011

Fred Aminzadeh

University of Southern California

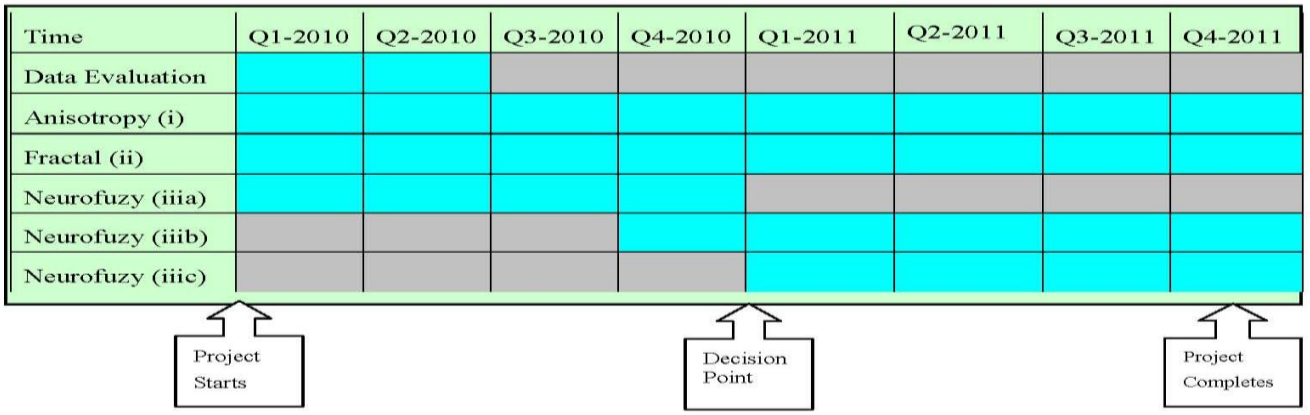
DOE Grant DE-FOA-0000075-23

Project Timeline and Budget

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Characterizing Fractures in the Geysers Geothermal Field by Micro-seismic Data, Using Soft Computing, Fractals, and Shear Wave Anisotropy

Original Project Time line



Revised Project Time line: All time lines are shifted 6 months due to delays in the project funding and ability to hire a post doc.

Original Budget

DOE Funding	$1,500K
Matching and Other External Funding	
USC	$200K
LBNL	$150K
Calpine	$300K
Total	$2,150K

Budget Variance and % spending- The project is expected to be completed on budget. The expenditure is roughly proportionate to the project time line.

Relevance/Impact of Research

Challenges we address	Project Impact	Innovative Aspects
Efficient Use of MEQ Data	Auto-picker	Soft Computing
Triggered vs induced seis.	Fracture Mapping	Fractal Dimensions
Hot dry rock fracture regime	Monitoring Fluid/Temp	Dynamic Velocity field
Fracture Direction / Type	Correlating fracture & V_{anz}	Azimuthal Velocity/SWS

Contribution to Geothermal Technologies Program

Better use of MEQ data and its analysis will help better understanding of the fracture system and how it is changing with time as a results of injection and production

Scientific and Technical Approach

ANN autopicker

- Enhance picking efficiency
- Quicker approach with better results.
- Able to generate picks where conventional autopickers fail.

Fractal Analysis

- Find the correct fractal dimension of seismicity distribution
- Map the fractal structure of the fracture network from MEQ data
- Correlate “b” values with fractal dimension
- Investigate the triggered versus the induced seismicity

Velocity Modeling

- Correlation of movement of microseismic events with the velocity anomaly and migratory fracture network in a hot dry rock system

Anisotropy mapping

- Azimuthal polarization verified from three stations and consistency from multiple events at any station, confirming SWS due to fractures

Accomplishments, Results and Progress*

Accomplishments

- Developed a new neural networks first arrival auto-picker for MEQ data and validated its superior performance against other picking programs.
- Confirmed the induced (as opposed to triggered) nature of seismicity at the Geyser field from the b values and the fractal dimensions of the MEQ there.
- Based on the raw velocity fields generated by our project partners at LBNL, developed a smooth velocity field by Kriging and analyzed the changes in velocities with time to establish the impact of high temperature fluid movement in the rocks on the velocity field.

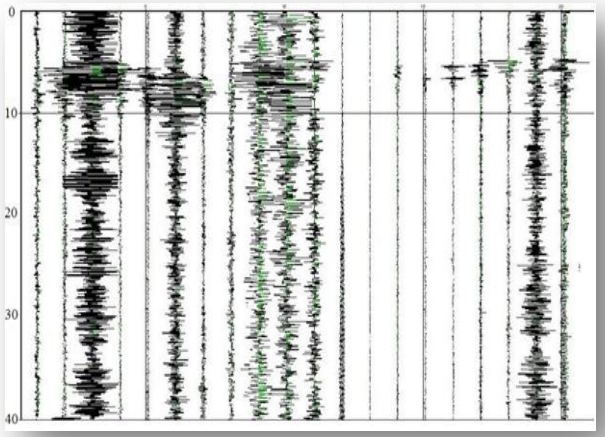
Challenges

- Ability to perform data transfer, formatting and software engineering across different platforms: Matlab, Zmap, OpendTect and SGeMS
- MEQ data quality and consistency of velocity estimates using seismic events of different size.

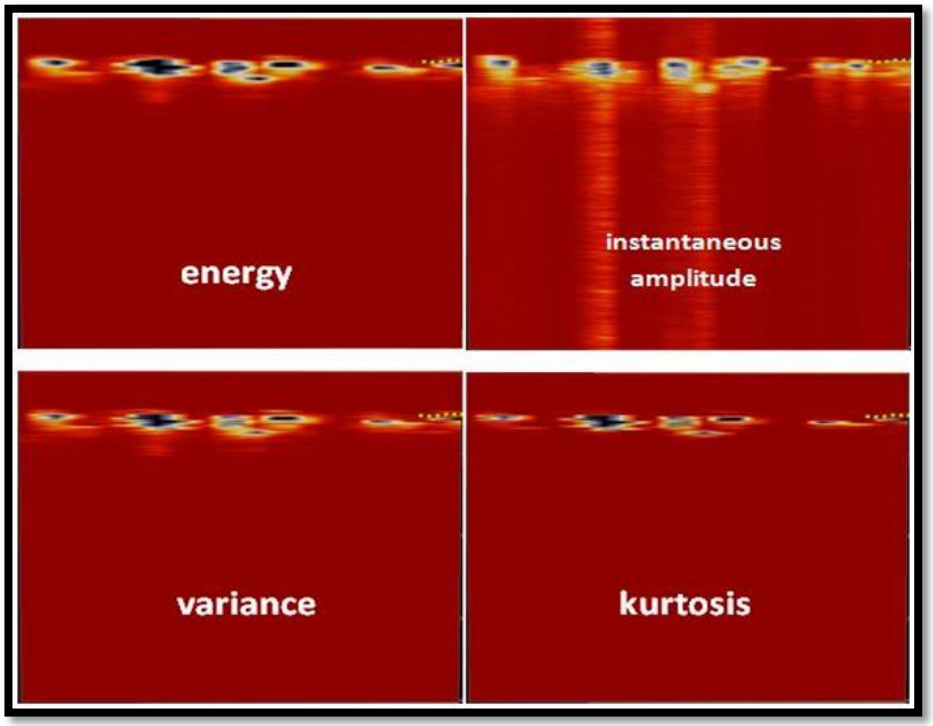
*Due to the delayed funding majority of the accomplishment during this reporting period (May 2010 to May 2011) is the same as the accomplishments to date

ANN Autopicker Design process

Select vertical component from 3-C data → Apply band-pass filter to remove noise if possible → Define attributes to be used as ANN node inputs → Make manual picks to train the network → Select some locations in the seismograms as "non-arrivals" for training → Run autopicker and generate "arrival maps" → Read the maps to define arrivals based on threshold → Compare arrivals with other autopickers

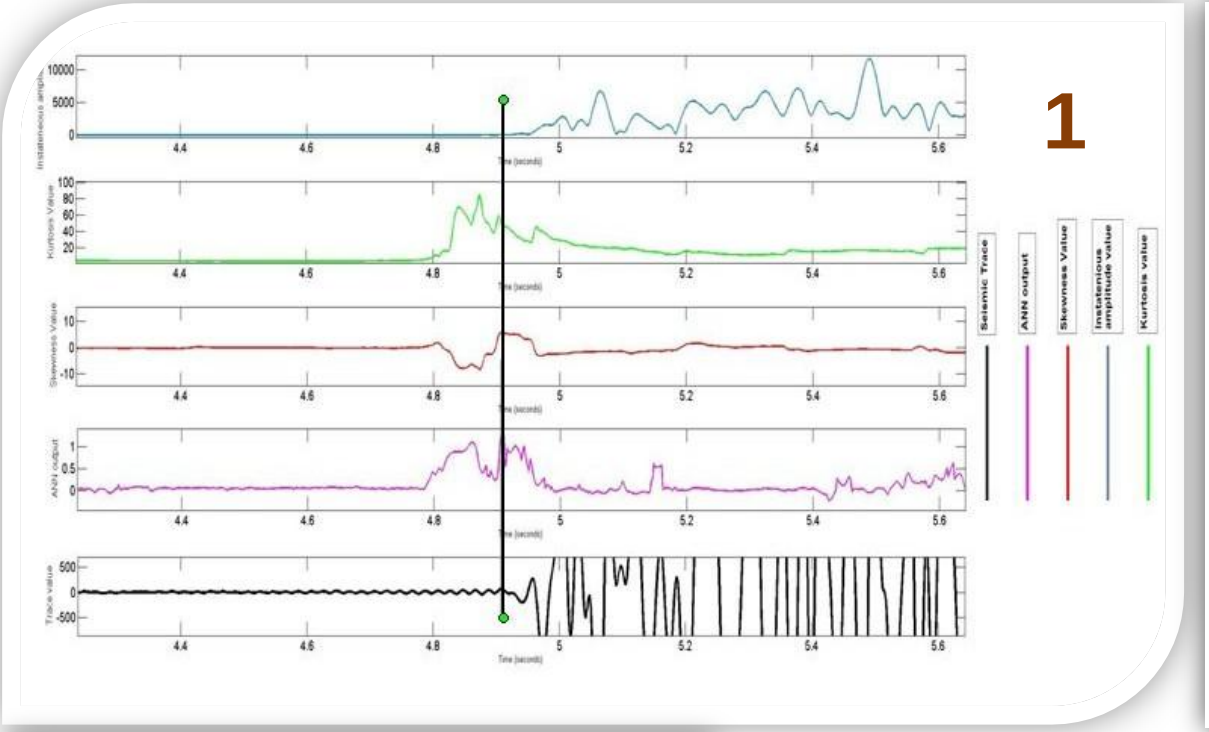


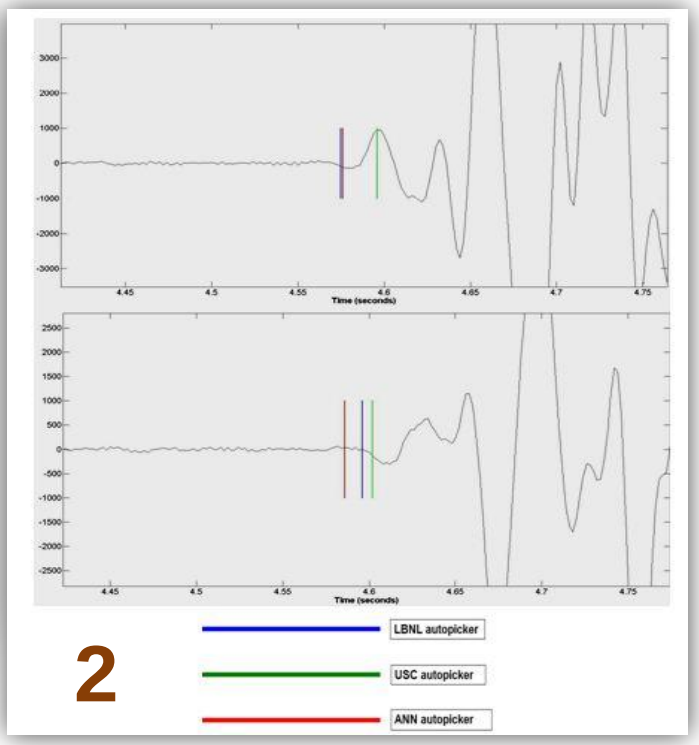
Processed data file for ANN design



Sample attributes as input to the ANN

ANN Autopicker Results





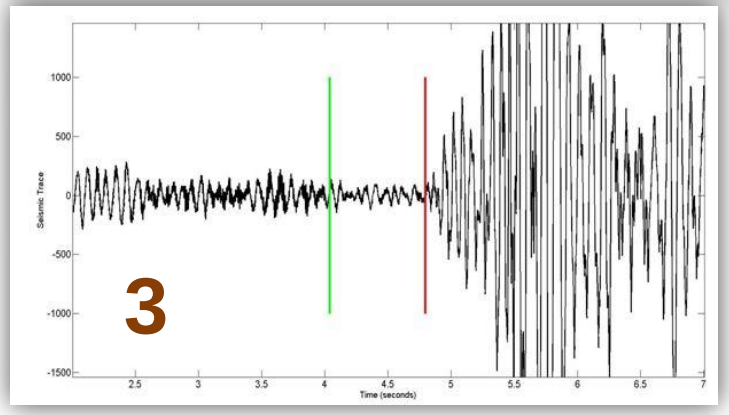
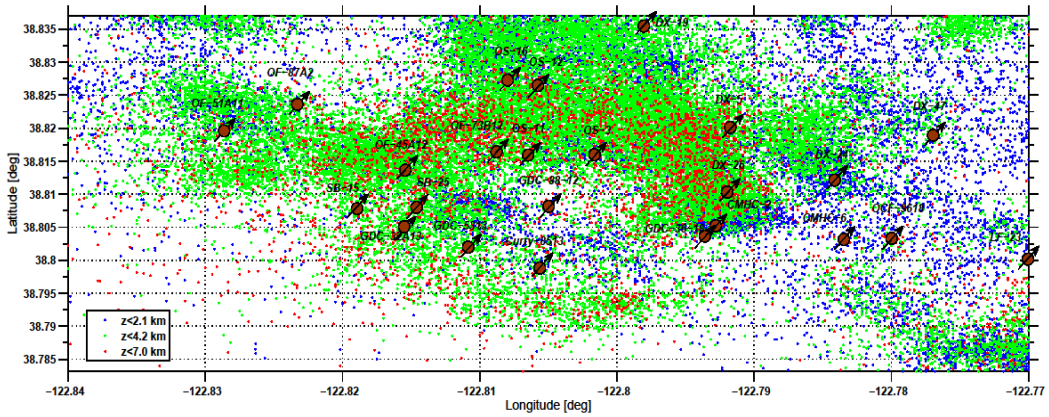


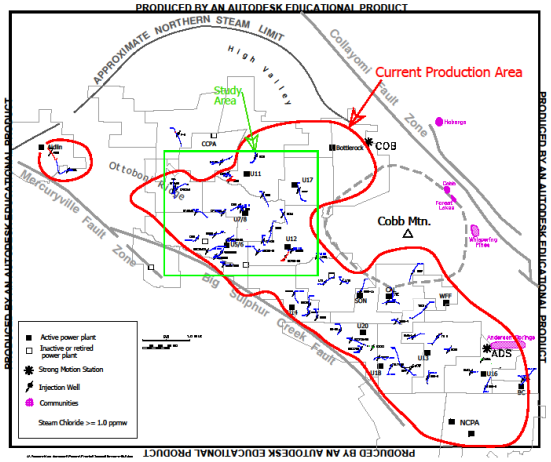
Fig. 1: Sample trace with ANN output and few attribute values used at input nodes**.**

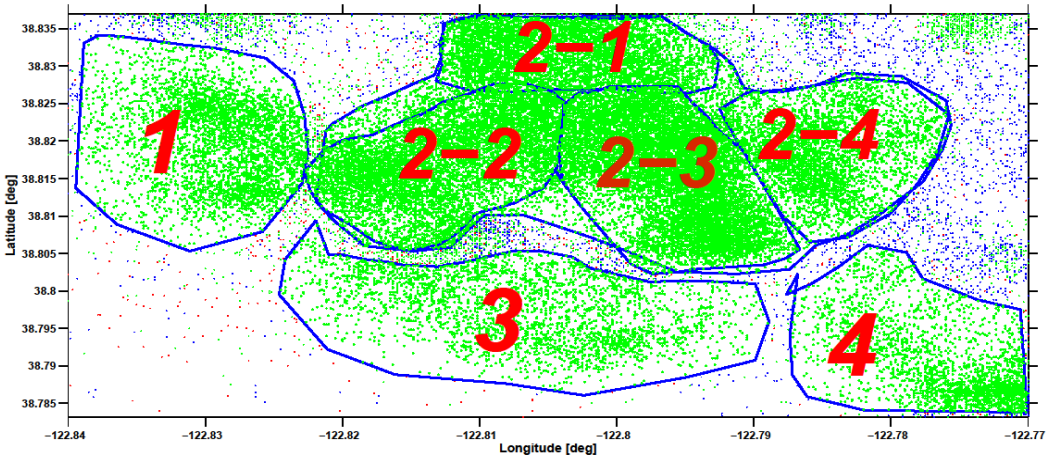
Fig. 2: Sample seismic traces ANN output compared with other autopickers.

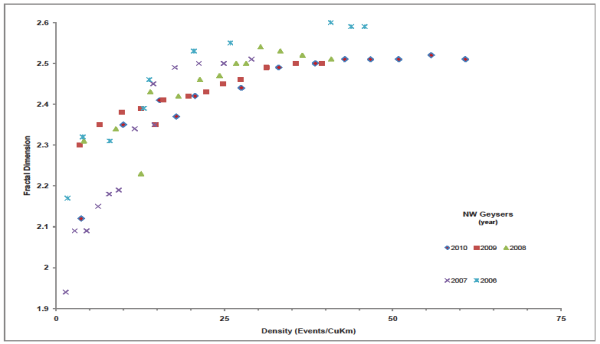
Fig. 3: ANN autopicker pick where other autopickers failed.

Seismicity at The Geyser



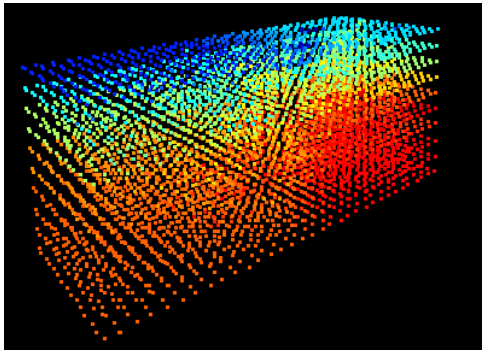


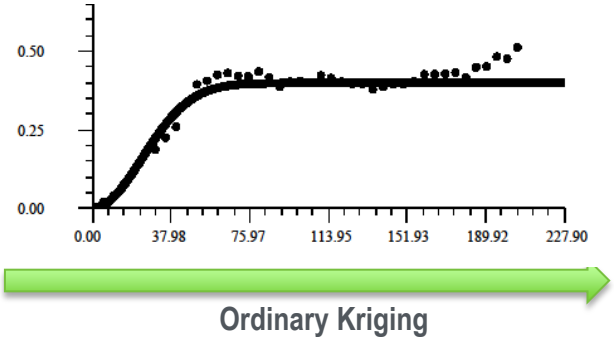


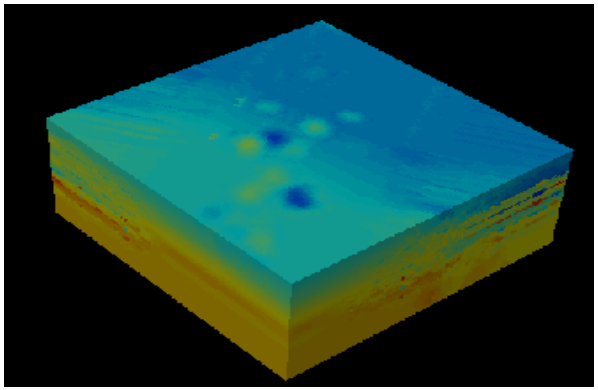


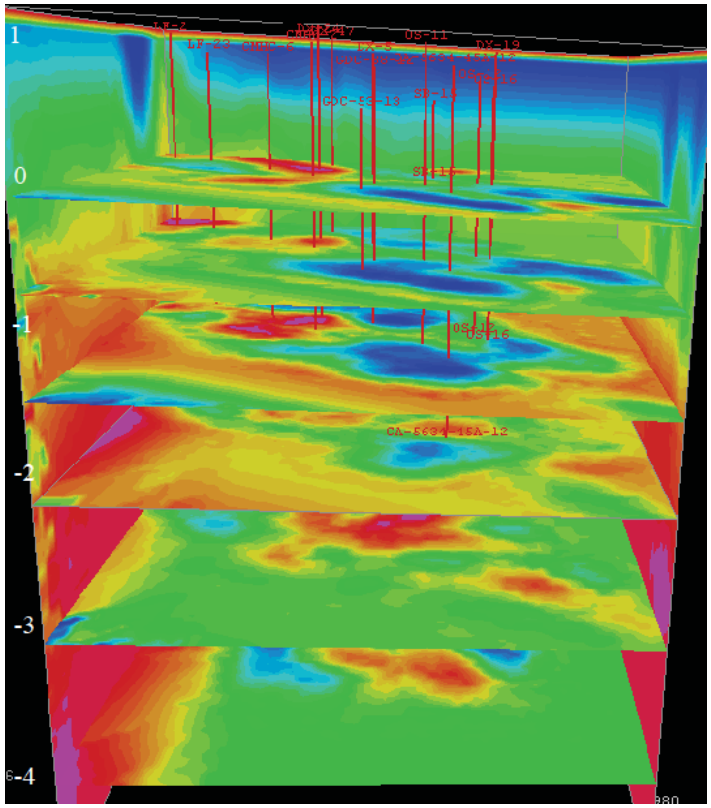
fractal dimension of 2.5

Velocity Modeling



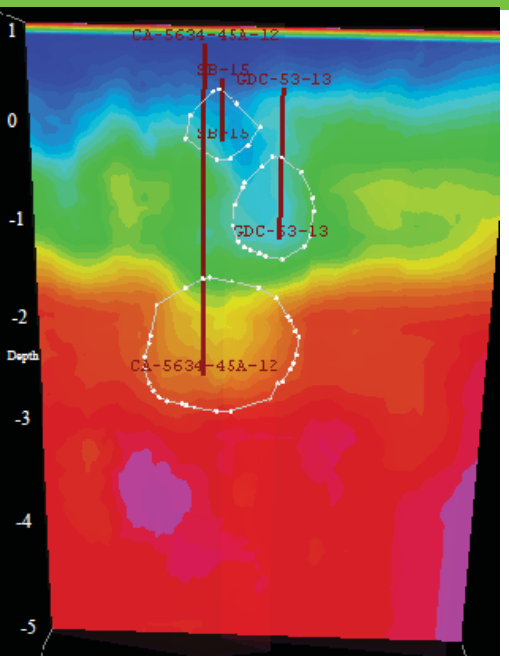


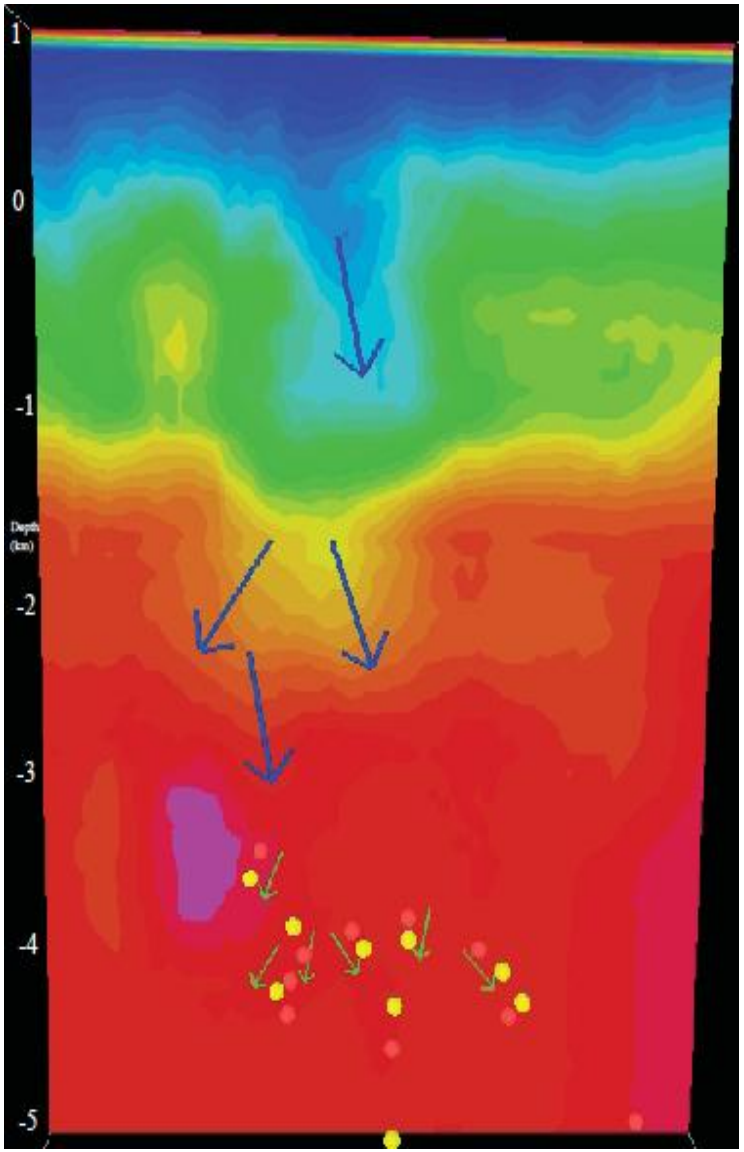


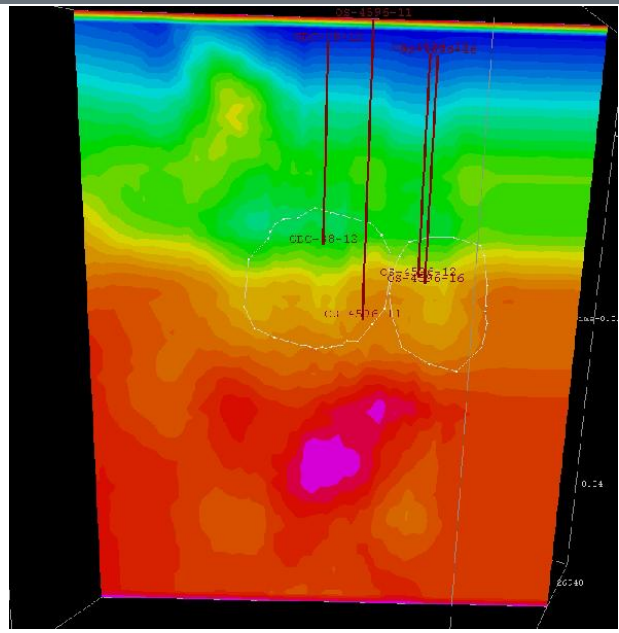


The velocity anomalies are correlated with injection locations where denser fracture network or more permeable regions are created.

Velocity Modeling







The evolution of fracture network in broad area of high temperature zone

presence and movement of microseismic events may be correlated with the migratory fracture network in a hot dry rock system, and may indicate fracture connectivity.

Project Management/Coordination

- Project management activities or approaches,
  - Upon the project funding (with about 4 month delay from the original project proposal, received approval from the university to advertise for a post doc position.
  - After several job posting and contacting faculty in different universities was not able to hire a qualified post docs
  - Different measures were taken to complete the project (hiring additional graduate students, part time faculty and getting additional help form our project partners (LBNL)
  - Established weekly meetings and technical exchange with our partners
  - Coordinated our work with the industry and academia through our monthly distinguished lecture program, followed by discussions with the project team.
- Variance from original project plans
  - We expect to have a shift of two quarters (6 months) for much of our deliverables.
  - With the corrective measure (item 3 above) we expect to deliver all the deliverables within the original budget.

Data Sharing

- This project does not generate any new MEQ or well data. It uses the data collected by LBNL and Calpine funded by other DOE grants or independently collected data.
- We have shared our results through publications (at GRC and AGU meetings) with the general public.
- We have also provided copies of these publications to the “DOE Geothermal Data Repository”. We intend to provide them with the copies of all the developed software and reports (with maps, numerical data, seismic attribute volumes, and images) we generate under this project.

Collaborations

Project Team

USC

Fred Aminzadeh (PI), Mo Sahimi (Petroleum Engineering), Charles Sammis (Earth Sciences)

LBNL

Ernie Majer, Leon Thomsen, Larry Hutchings and Katie Boyle

Calpine

Mark Walters, Joseph Beall, Alfonso Pingol and Julio Garcia

Collaboration was enhanced through frequent regularly scheduled conference calls with the team members. In addition, through USC Center for Geothermal Studies (CGS) monthly distinguished lecture series, further communication and knowledge sharing both within the project team and the outside researchers was accomplished.

Jobs

Two full time and one part time graduate students were hired to work on this project.

Future Directions

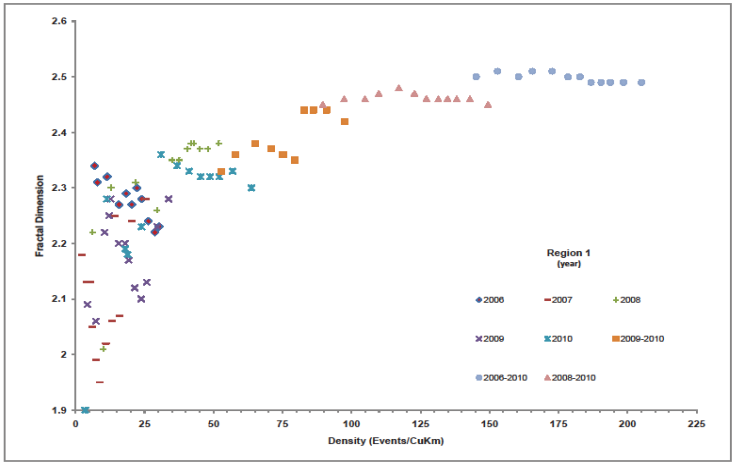
- We intend to deploy our auto-picker at LBNL and provide a copy of our software to the “DOE Geothermal Data Repository”
- A new auto-picker will be developed and tested to include several new set of seismic attributes and add fuzzy logic concept to our ANN.
- Perform additional work on the changes of velocity field with time through integrating well log data to develop a more accurate base velocity field to better quantify changes in time and correlate them to fluid injection and steam production.
- Map the porosity field based on the velocity field (both P waves and shear waves) and the log data using neuro-fuzzy approach.
- Confirm shear wave splitting phenomena with more elaborate analysis of seismic traces and establish its relationship with the anisotropy and how it relates to the fracture network.
- Develop a method to create an anisotropic version of tomoDD.
- Planned milestones are the same as those in the original work plan (slide 2).

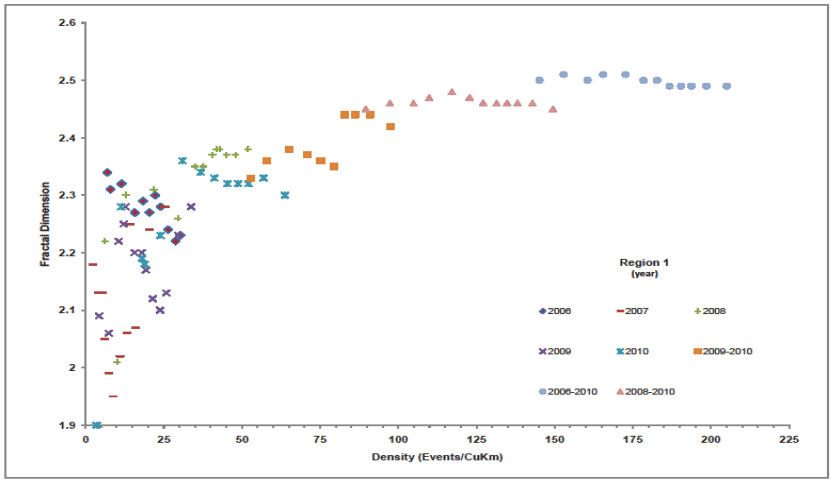
Summary

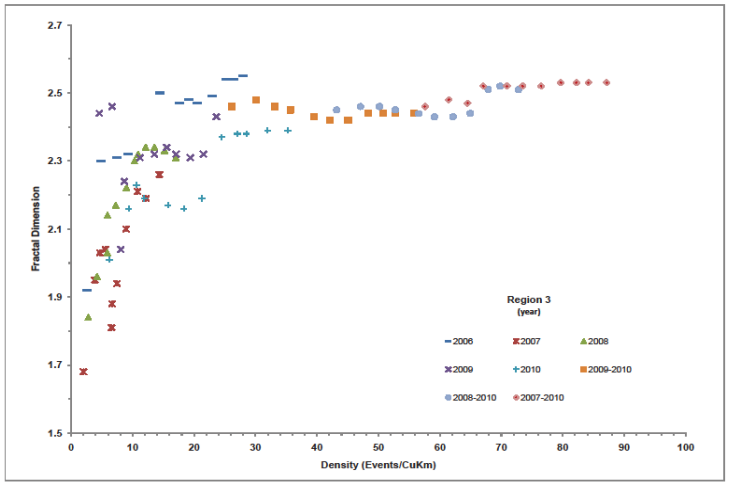
- ANN Auto-picking is viable and a superior alternative to other picking methods,
- Fractal dimension indicates majority of seismicity is induced,
- Changes in the velocity field in time can be correlated to injection and production. It is possible to use this as a monitoring tool
- Shear wave splitting and velocity anisotropy can give us information on fracture network, direction and type.

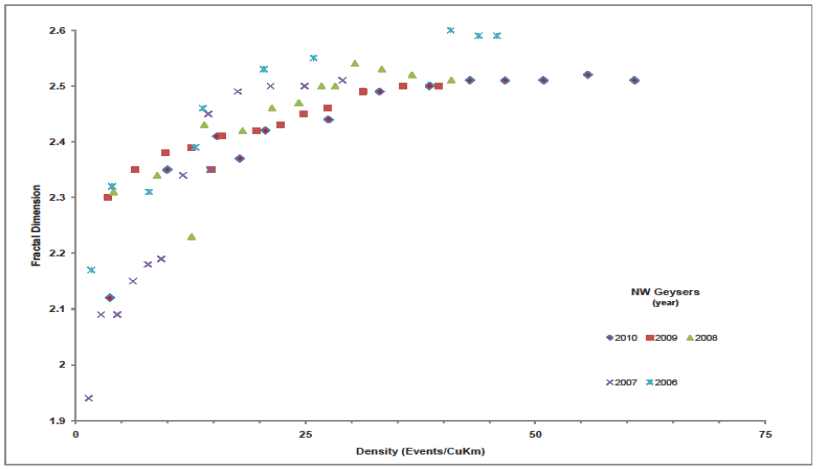
	FY2010	FY2011
Target/Milestone	ANN autopicker	Neuro-Fuzzy autopicker
Results	Implemented. Working on improvements	Work in progress
Target/Milestone	Fractal & b value analysis	Integrated evaluation
Results	Induced nature of events verified.	Map the fractal structure of fracture network
Target/Milestone		Anisotropy mapping
Results		Under implementation using shear wave splitting
Work area		Time lapse velocity tomography
Results		Correlation of change in velocity with fracture network

Fractal Structure **Supplemental Slide 1**



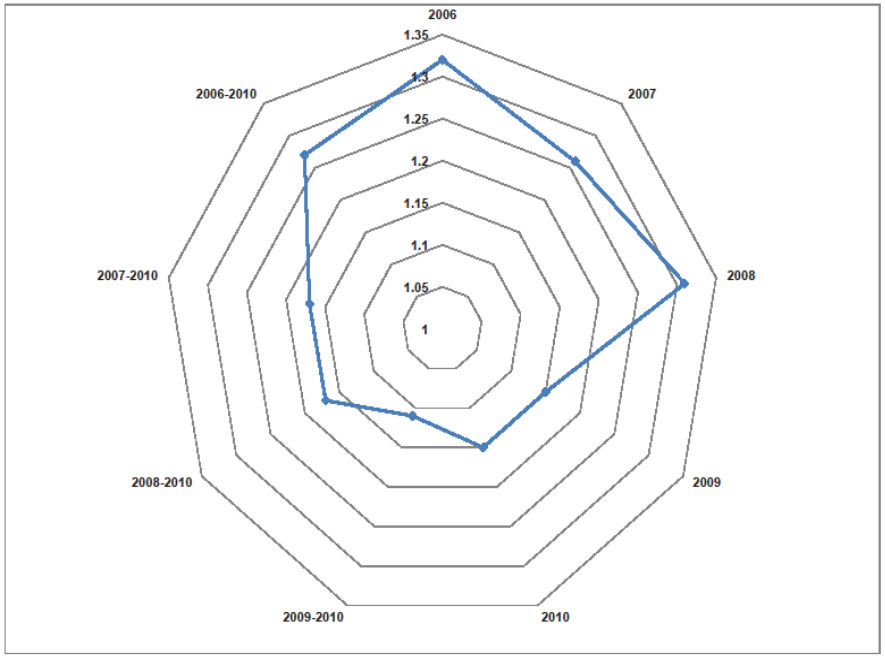




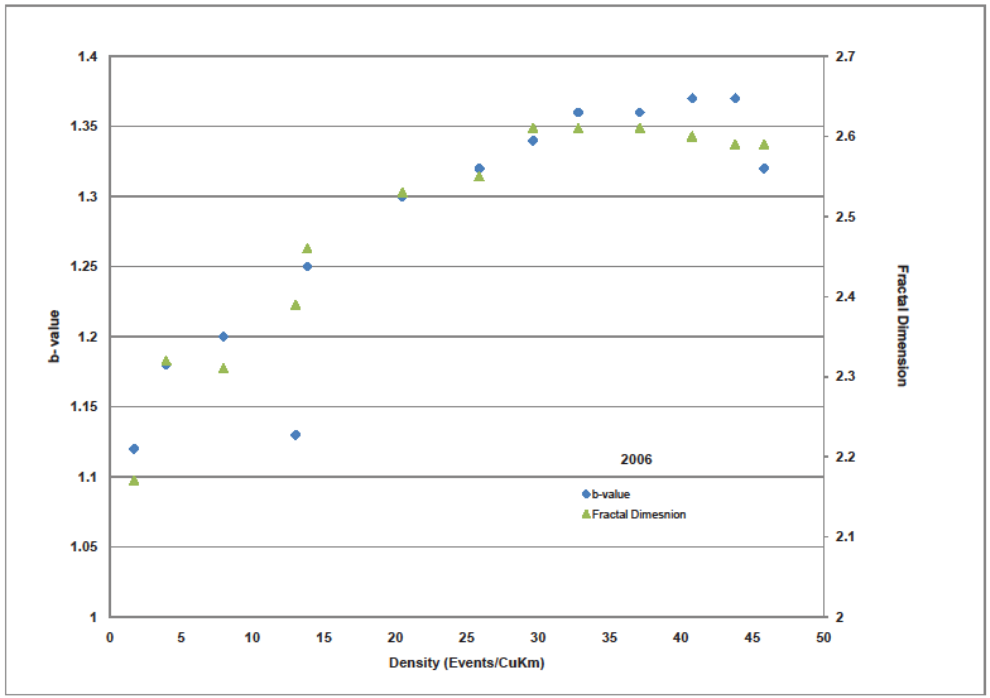


The seismicity distribution has the fractal dimension of 2.5 which is identical to the fractal dimension of nucleation and growth of fractures in random media.

b value Supplemental Slide 2



- Automatic b-value calculation does not work well
- The values are higher than 1.1
- Conclusion: events are induced and not tectonic.

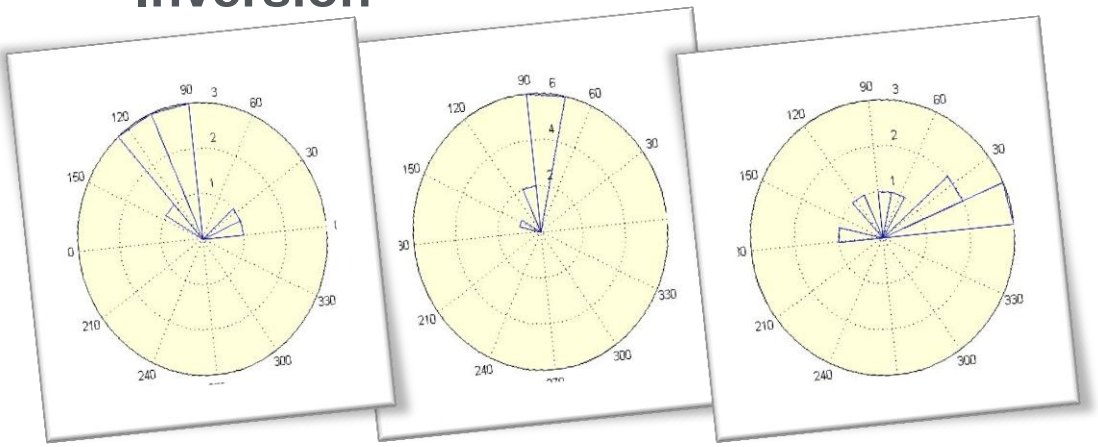


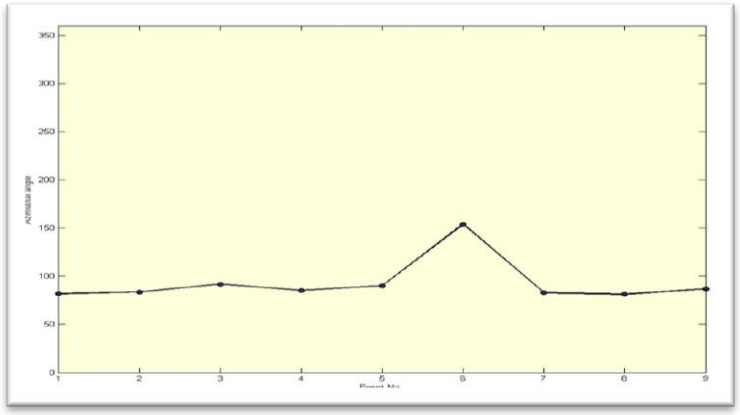
- There is a strong correlation between b-values and fractal dimension,
- Specific relationship or equation can not be assigned to this correlation.

Indication of Shear wave splitting:

STEPS:

- **Processing of data files and identification of “usable” samples.**
- **Identification of shear arrivals.**
- **Rotation to determine azimuthal polarizations and arrival time differentials.**
- **Inversion**





Preliminary Results showing azimuthal polarizations at three stations and consistency from multiple events for specific station verifying presence of SWS due to fractures