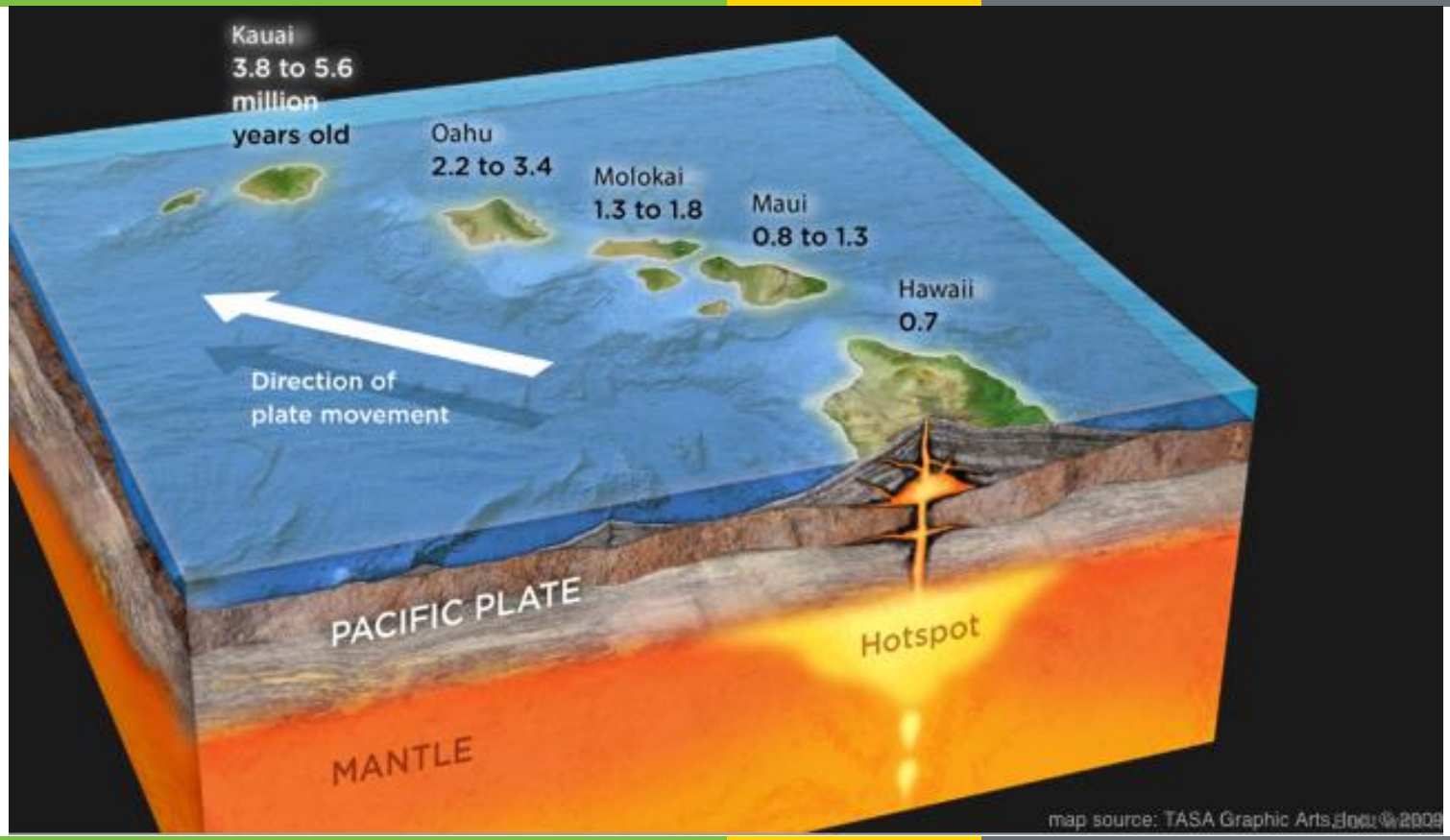


Play Fairway Analysis of Geothermal Potential across the State of Hawaii

May 11, 2015

Nicole Lautze

University of Hawaii (UH)

Track: Hydrothermal

Project Officer: Mark Ziegenbein

Total Project Funding: $386,369 (inc. 10% cost share)

Relevance/Impact of Research

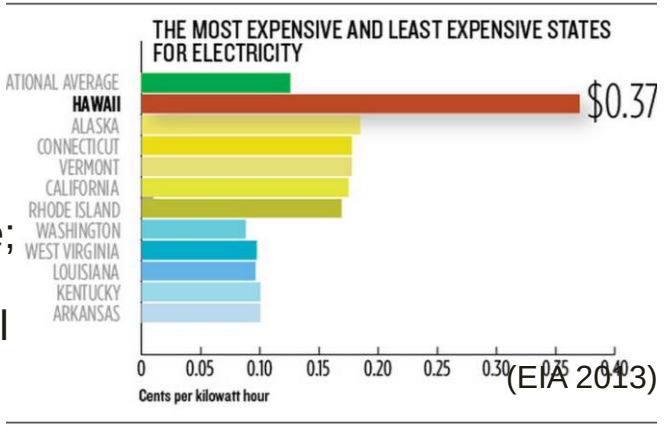
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Objectives:

- ***Identify***, ***obtain***, and ***compile*** existing geothermal relevant data across the State of Hawaii;
- ***Rank*** each dataset in terms of its ability to indicate subsurface ***Heat***, ***Fluid***, and ***Permeability;***.
- Develop ***broadly applicable geostatistical method*** to produce statewide Play Fairway map(s).

Impact / Innovation:

- Hawaii has unique geologic setting;
- Hawaii pays **≥ *twice*** as much for electricity as any other state;
- Last statewide geothermal assessment (1983) found potential resource on ***all*** islands but little exploration since;



(EIA 2013)

- ***Step forward:*** compilation of data currently among disparate sources; incorporate ***CURRENT*** techniques and information; data integration in a probability model/map of state; ID path ahead.

Alignment with GTO goals:

* *~20% of Hawaii's land is federally owned; Fed agencies paid $350M to HECO in 2014* *

- Lower risk of development & exploration
- Lower electricity costs to 6c / kWh by 2020
- Develop undiscovered resources

Scientific/Technical Approach

Technical Approach:

(1) Identify, obtain, and compile geothermal relevant data into GIS project

(2) Weight each dataset in terms of relevance to 3 desiderata: Heat (H); Fluid (F); Perm. (P)

(3) Apply geostatistical modeling to:

- map out estimates for joint probability of H, F, P across the whole state
- identify high priority areas for collecting new data
- be generally applicable to other settings

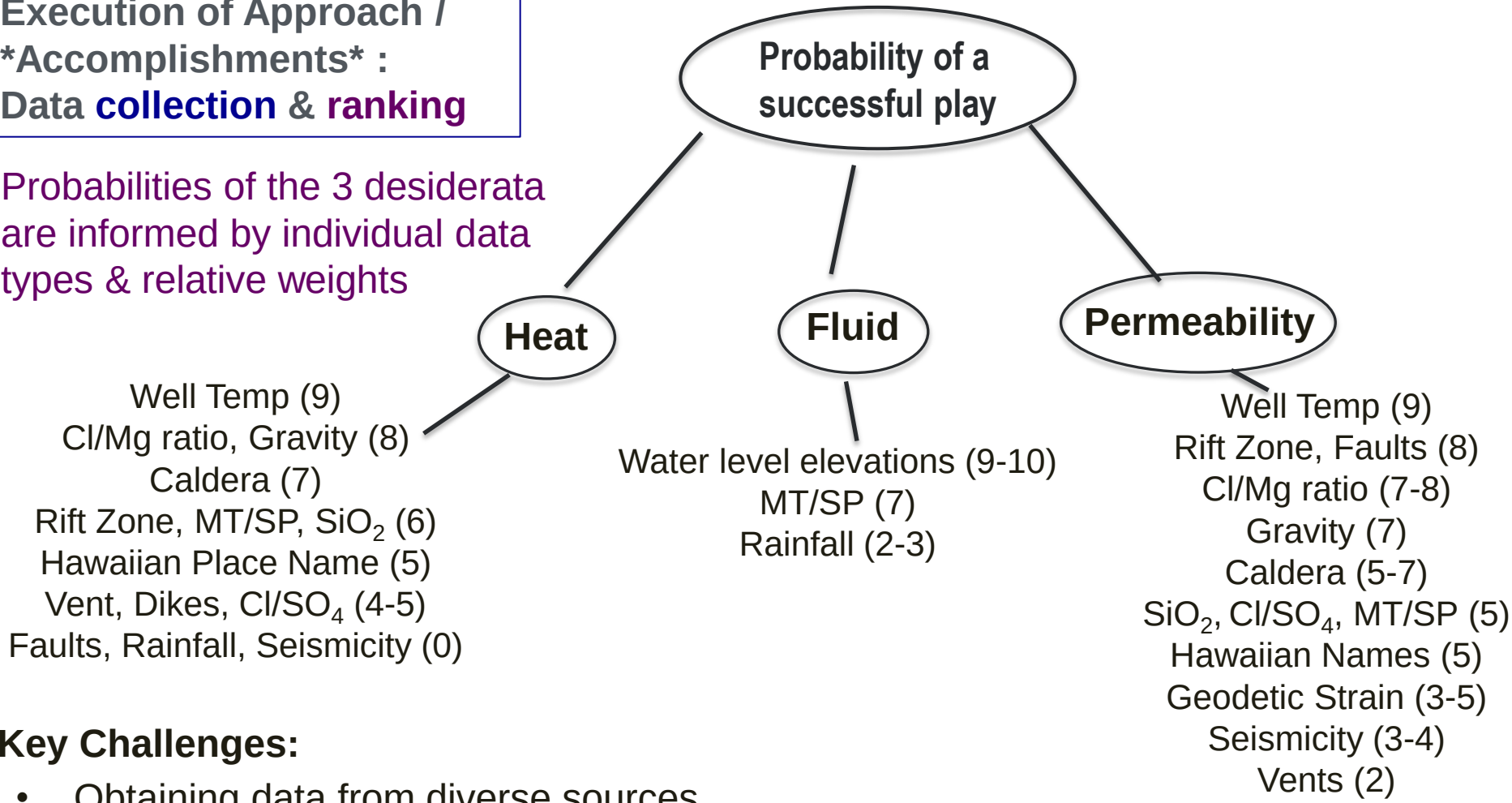
Technical Highlights:

- Team of 15 individuals (7 PI/co-Is, 1 Masters, 1 senior thesis student, 6 employees)
- Weekly team meetings
- Data from multiple state agencies and > 40 published references are compiled

Scientific/Technical Approach

Execution of Approach / *Accomplishments* : Data collection & ranking

Probabilities of the 3 desiderata are informed by individual data types & relative weights



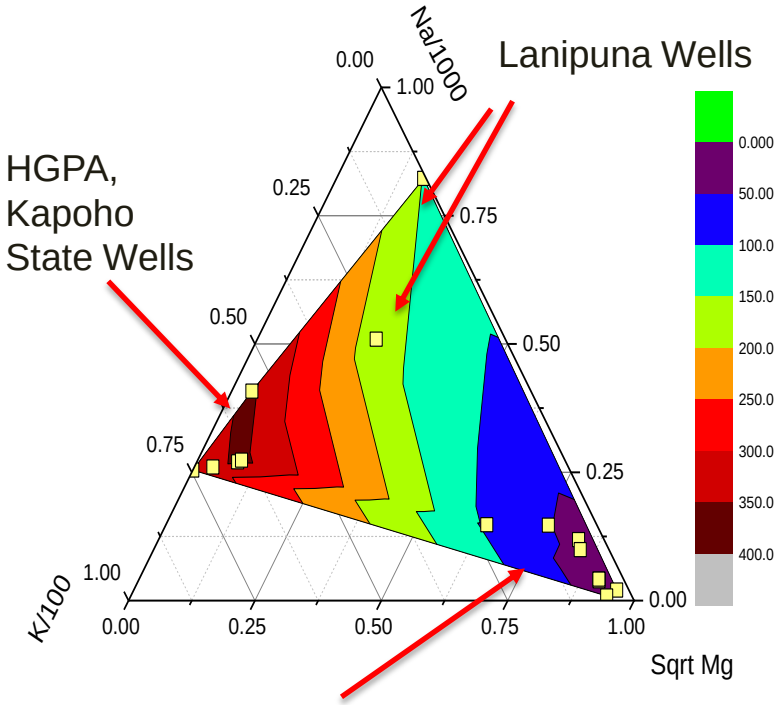
Key Challenges:

- Obtaining data from diverse sources
- To develop model that incorporates disparate data types, pertaining to different resource qualities, with variable quantities and spatial relevance.

Scientific/Technical Approach

Execution of Approach: Water Well Chemistry

Puna Wells Ternary Diagram With Temperature Contours (0 to 400 deg. C)



Pahoa, Airstrip, Kapoho, Keauohana 1, Alison, Kapoho Test, Malama Ki, GTW3 Wells

- Assemble HI water chemistry database from all available sources (Boards of Water Suppy, Dept Health, Department of Land and Natural Resource, USGS)
- Apply geochemical indicators:
  - Cl/Mg ratio,
  - Silicate and Cation Geothermometers
  - Sulfate/Cl ratio
  - Mixing Analysis
- Identify wells with potential heat alteration as positive indicators in comprehensive Play Fairway Analysis
- Continuously update database for project and through mission of Hawaii Groundwater and Geothermal Resources Center (HGGRC)
- Make data and findings accessible through HGGRC & DOE Geothermal Repository

Scientific/Technical Approach

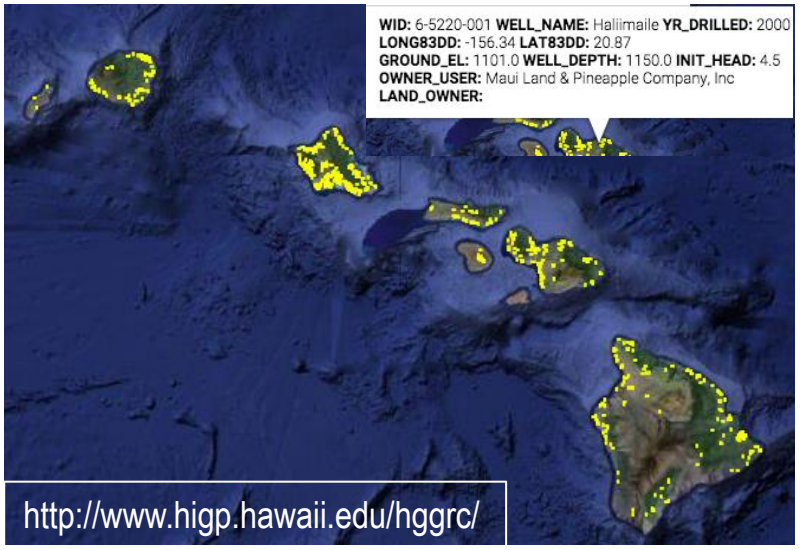
Execution of Approach: Water Well Chemistry

Issues:

- Hawaii's geothermal resources are "blind"; few deep wells outside of Puna;
- No detailed geothermometers for Hawaii; Iceland studies (e.g. Arnorrson et al.) provide best surrogate;
- Fluid indicators of heat may originate some distance from well; flow paths also not well established.
- Much well chemistry data is dated; prior test methods may have reduced analytical accuracy.

Take Away:

- Compiled groundwater data will facilitate current and future investigation;
- Understanding aquifer capture zones and hydraulic pathways will assist with interpretation of geochemical data.

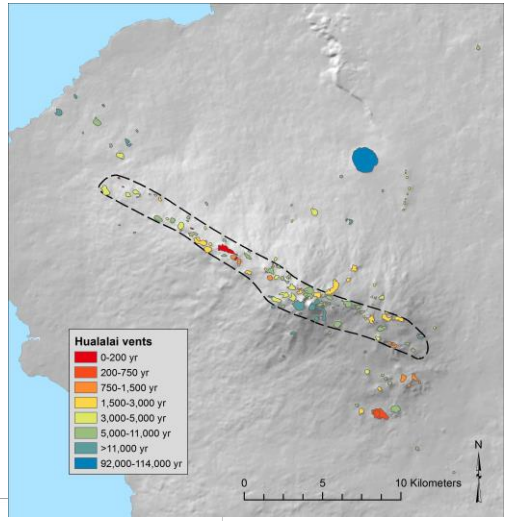


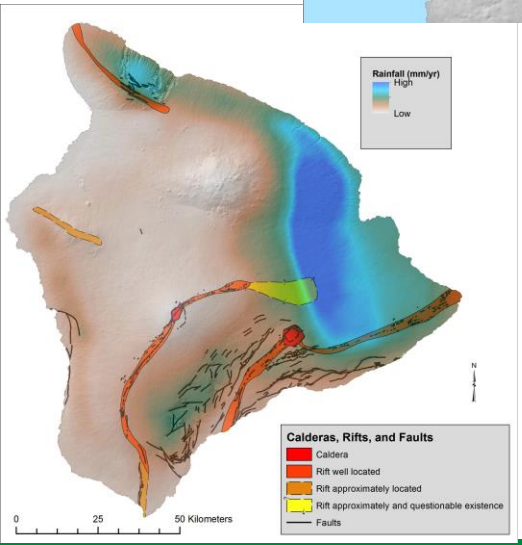
Map of Hawaii showing location of water wells in yellow.

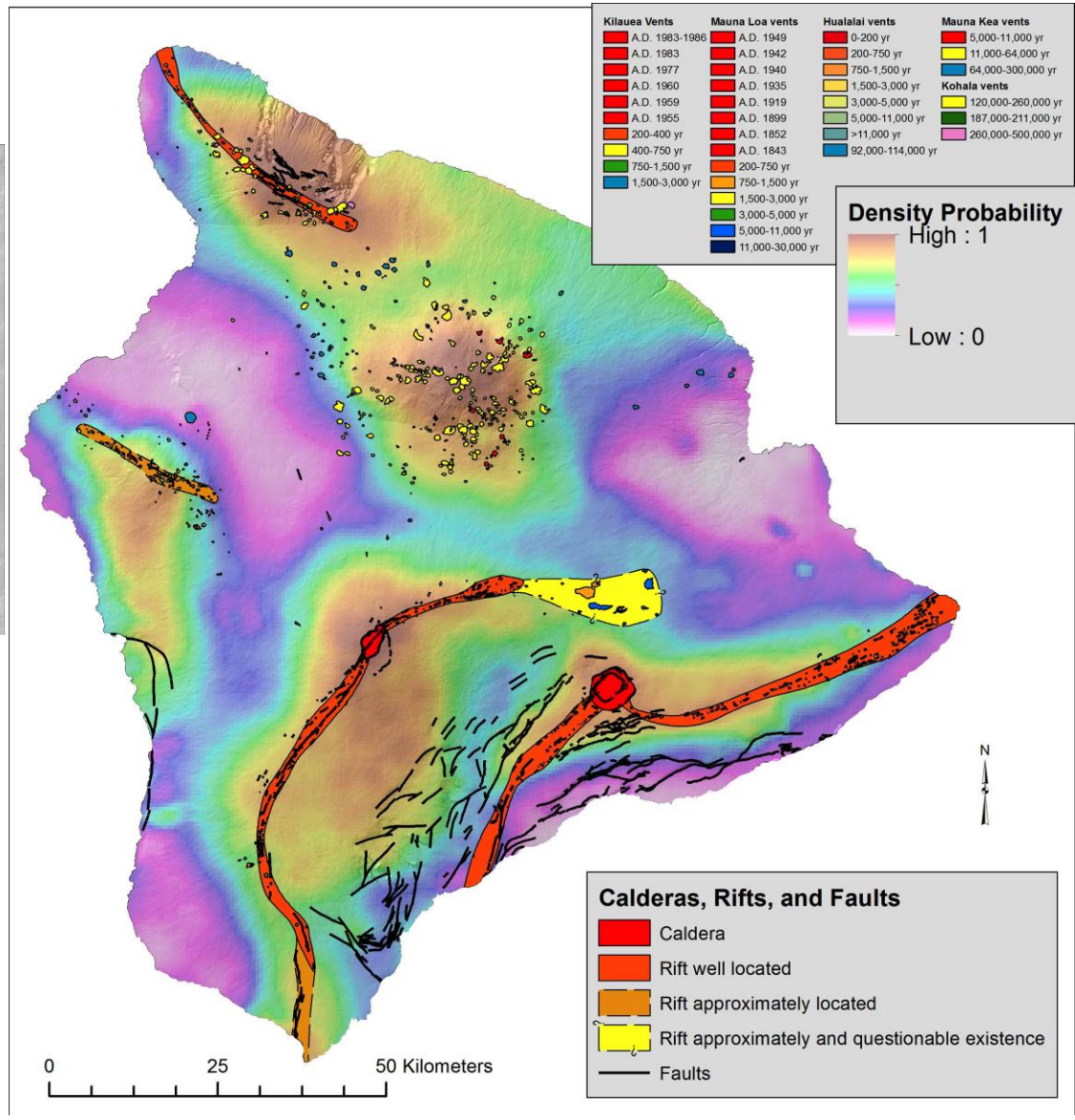
Scientific/Technical Approach

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

Execution of Approach: GIS Database







Execution of Approach: Geostatistical Modeling

Each scaled and processed data type a_i is weighted and combined with other data using a generalized linear model with logistic inverse-link function. For example, the probability of heat at location *x* is given by the map,

$$\Pr(H|\vec{x}) = \left[1 + \exp\left(-w_{0H} - \sum_{i=1}^{n} w_{iH} a_i(\vec{x})\right)\right]^{-1}.$$

The probability of a resource at a given location is the joint probability of the three main desiderata, which, in the independence approximation useful for point-wise processing of large areas, is equal to the product map:

$$\Pr(H, F, P|\vec{x}) \approx \Pr(H|\vec{x}) \Pr(F|\vec{x}) \Pr(P|\vec{x}).$$

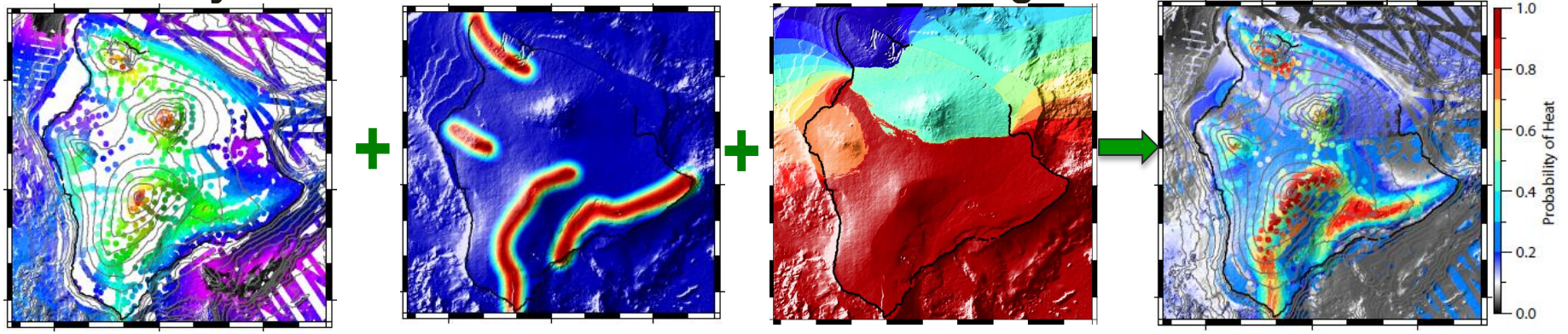
To indicate prospects where more information about fluid, say, would be helpful, we generate a partial product map in areas where fluid data are absent or ambiguous, and similarly for the other two partial products,

$$\Pr(H|\vec{x}) \Pr(P|\vec{x}).$$

Scientific/Technical Approach

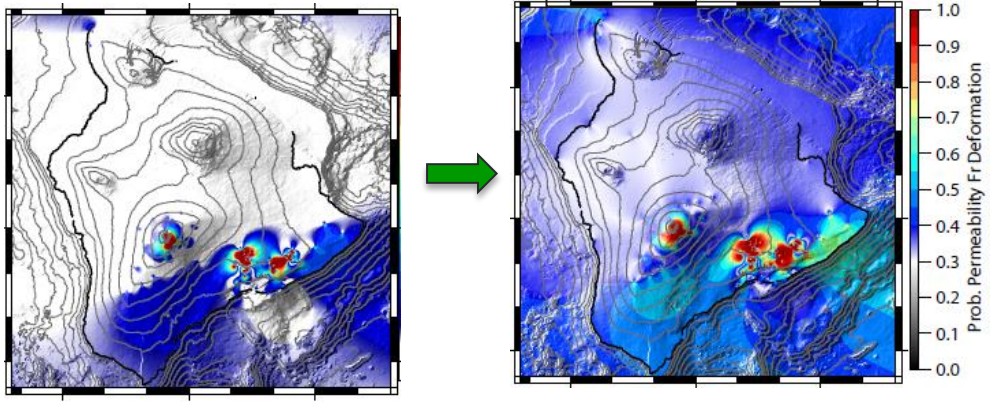
Execution of Approach: Geostatistical Modeling

Gravity + Rift Zones + Volcano Age → Heat



$$\Pr(H|\vec{x}) = \left[1 + \exp\left(-w_{0H} - \sum_{i=1}^{n} w_{iH} a_i(\vec{x})\right)\right]^{-1}$$

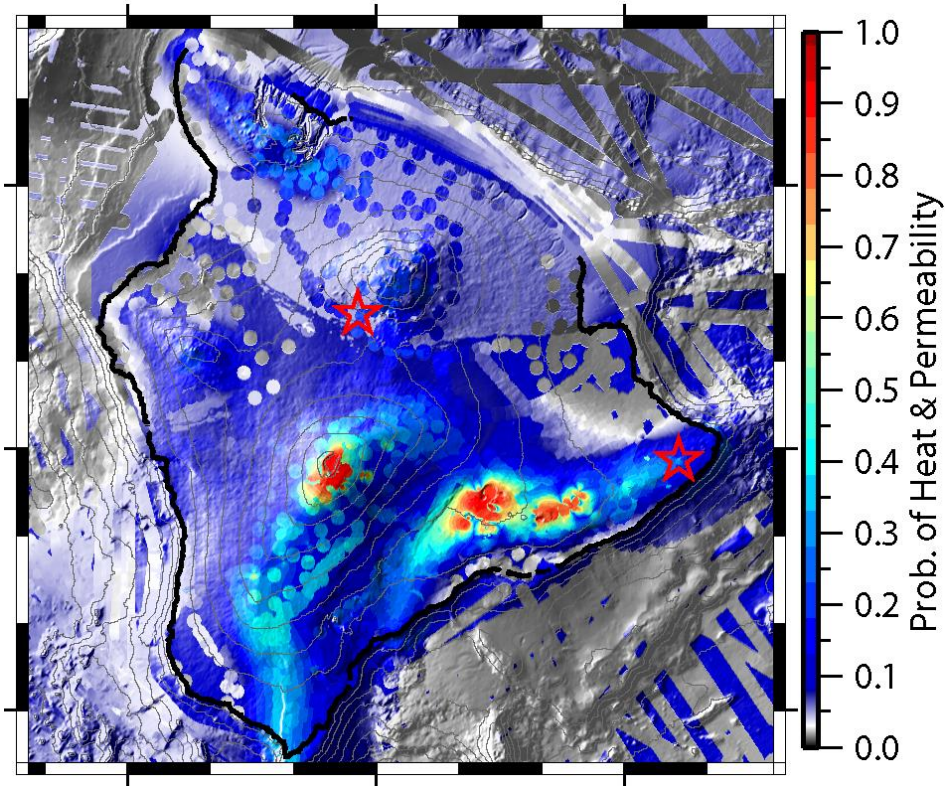
Geodetic Strain Rates → Permeability



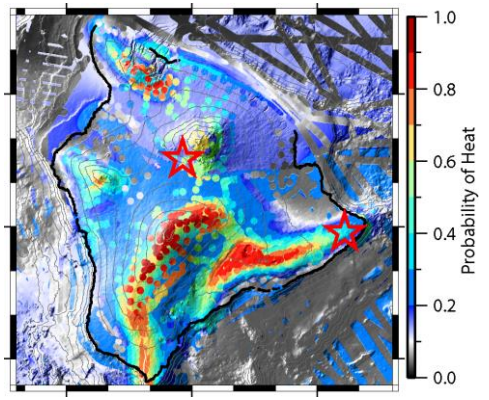
Execution of Approach: Geostatistical Modeling

$$\Pr(H, P \mid \vec{x}) = \Pr(H \mid \vec{x}) \Pr(P \mid \vec{x})$$

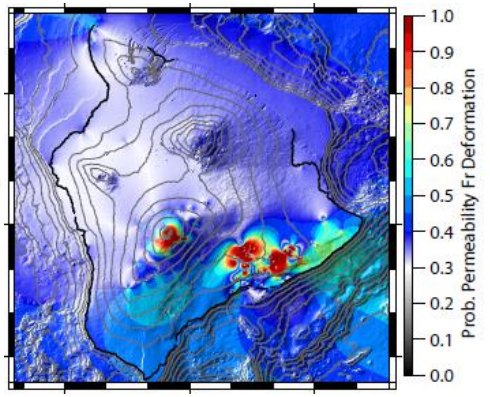
Heat & Permeability



Heat



Permeability



Accomplishments, Results and Progress

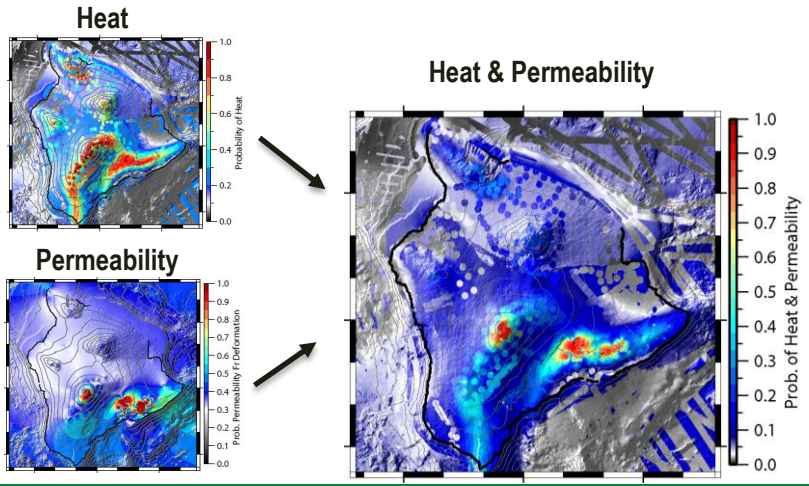
Technical Accomplishments:

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
1. Search for data	1. Data identified and obtained*	12-31-15 ***Q1***
2. Compile data	2. Data compiled (GIS; Matlab)	3-30-15 ***Q2***
3. Initial modeling	3. Data ranked; modeling initiated	in progress ***Q3***

Cost and Performance Variances:

none

Data Demonstrating Accomplishments:



Special recognition ~ *Press!*

January 2015

Creation and launch of website announcing UH's new Hawaii Groundwater and Geothermal Resources Center (HGGRC)

***Related Press**:*

"How hot is your Hawaii? New Geothermal Resources Center" – ThinkTech Hawaii (a television show interview with Nicole Lautze and Jay Fidell)

"UH website makes groundwater research public" – Ka Leo O Hawaii (news article)

"Hawaii: Groundwater and geothermal data compiled for first time" – International Association of Hydrogeologists

"New database a tool in groundwater, geothermal discussions" – West Hawaii Today (news article)

"Hawai'i groundwater and geothermal data compiled for first time" – University of Hawaii at Manoa (press and news release)

Hawaii Public Radio (an affiliate of NPR) interviewed Nicole Lautze regarding launch of HGGRC.

March 2015

Geothermal Exploration Permit application to conduct MT surveys on Hualalai volcano goes before Dept of Land and Natural Resources Board.

***Related Press**:*

"Hualalai geothermal study planned" – Big Island Video News (news article); West Hawaii Today (news article); KITV (news article and video); Hawaii News Now (news article); The Republic (news article); Geothermal Resources Council (blog entry) Civil Beat (news article)

October 2014

"Aia lā i 'o Pele i Hawai'i: There is Pele in Hawai'I Is Geothermal Energy Appropriate for Hawai'i?" (Geothermal Cafe Summary) – Hawaiian Islands Science via Academia.edu

Future Directions

Next steps:

- Incorporate all datasets in model
- Expand model to entire state
- Refine model and test new statistical method(s)

Milestone or Go/No-Go	Status & Expected Completion Date
4. Review Results, Refine Model	July 2015
5. Develop Final Model(s)	September 2015
6. Identify and Rank Plays for Phase 2	October 2015

Comment on preliminary thoughts regarding Phase 2.

Summary

- Time is ripe for updated geothermal resource assessment in Hawaii.

- Hawaii's Play Fairway project meets GTO's goals to:
  - lower cost of exploration and development **by identifying highest probability resource areas;**
  - lower the cost of electricity **in the state that pays the most for it;**
  - accelerate development of undiscovered resources **as recent findings suggest resources may exist in previously unrecognized area(s).**

- To date, project is on target:
  - Data are obtained and compiled, initial modeling commenced;
  - Current focus is expansion and refinement of model;
  - Successful meeting of all project objectives anticipated at Phase 1 conclusion.

Thank you!