LA-UR-23-31068

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Title:	GeoThermalCloud: A Machine Learning Tool for Discovery, Exploration, and Development of Hidden Geothermal Resources
Author(s):	Frash, Luke Philip Ahmmed, Bulbul
Intended for:	Demonstration video to advertise LANL's GeoThermalCloud tool for hidden geothermal resource discovery.
Issued:	2023-09-27

GeoThermalCloud Demo Video

A Machine Learning Tool for Discovery, Exploration, and Development of Hidden Geothermal Resources

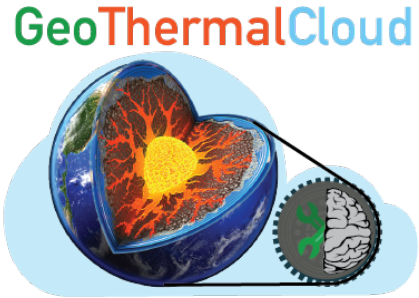
Abstract:

In this 25 minute presentation, we showcase our open source "GeoThermalCloud" tool for identifying hidden geothermal resources using a publicly available dataset for southwestern New Mexico. The presenters include Bulbul Ahmmed and Luke Frash. All of the visuals use source material from LA-UR approved publications and this work falls under the Earth Sciences DUSA. The code shown in this video is already released with LANL approval in open source format on GitHub and DockerHub. The audio in this video includes only material on the topics of geothermal energy and machine learning applied to geothermal energy. The primary machine learning method used is LANL's Non-negative Matrix Factorization "NMFk" method. Modeling work also mentions LANL's Geothermal Design Tool "GeoDT" which is another approved open source code that has been released by LANL. This work was performed for DOE Geothermal Technologies Office (DE-EE-3.1.8.1). The host for the released video is intended to be YouTube or a suitable perpetual data repository such as GDR.

GeoThermalCloud

A Machine Learning Tool for Discovery, Exploration, and Development of Hidden Geothermal Resources

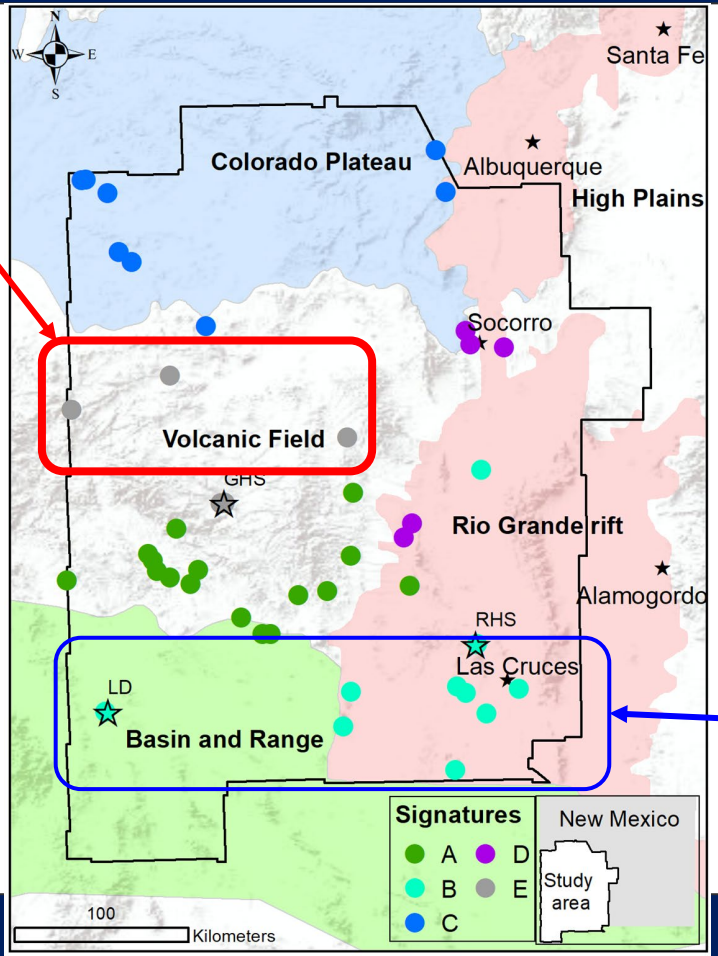
Luke Frash and Bulbul Ahmmed, EES, Los Alamos National Laboratory



U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
GEOTHERMAL TECHNOLOGIES OFFICE

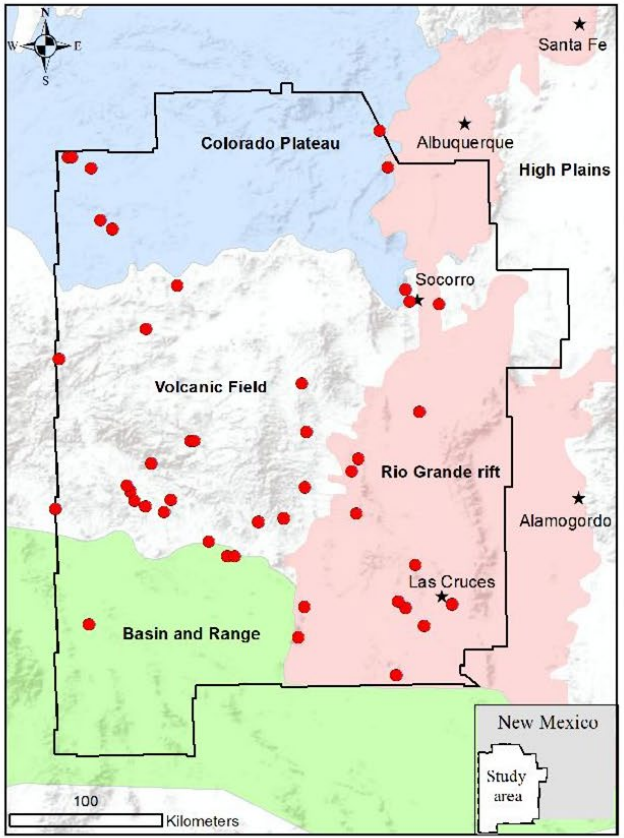
Demo: Hidden Geothermal Resources in New Mexico

New discovery of highly prospective region



Highly prospective region, which is consistent with previous studies

SWNM Geothermal Exploration



SWNM Dataset

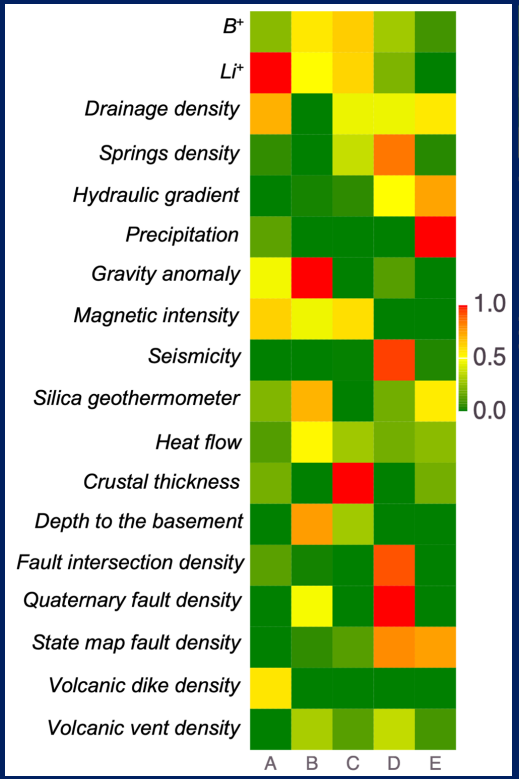
$X = 44 \times 18$

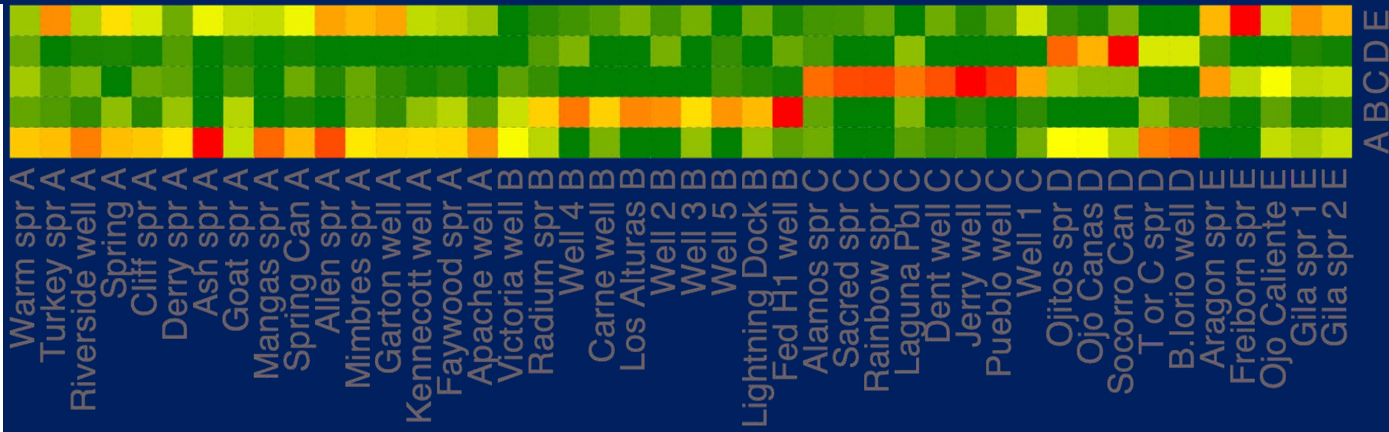
- B^+ concentration
- Li^+ concentration
- Drainage density
- Springs density
- Hydraulic gradient
- Precipitation
- Gravity anomaly
- Magnetic intensity
- Seismicity
- Silica geothermometer
- Heat flow
- Crustal thickness
- Depth to the basement
- Fault intersection density
- Quaternary fault density
- State map fault density
- Volcanic dike density
- Volcanic vent density

Location	Boron	Gravity	Magnet	Dikes	Drain	Fault	Qfault	Seism	NMFlt	Springs	Vents	Lithium	Precip	Silica	Δh	Qheat	Crust	Bsmt
Alamos Spring	-0.2	-203.3	136.2	0.431	7.4	0.000	0.00	0.004	16.2	0.010	0.003	-3.1	264.8	16.5	5.6	4.6	38.7	1439
Allen Springs	-3.2	-189.3	184.6	3.625	17.3	0.000	0.01	0.002	15.6	0.003	0.001	-4.0	514.5	24.0	13.9	4.4	32.5	51
Apache Tejo Warm Springs well	-1.8	-181.2	15.0	3.807	17.3	0.001	0.03	0.001	0.7	0.003	0.000	-8.6	326.3	52.0	4.7	4.6	30.7	24
Aragon Springs	1.5	-229.1	-317.7	0.010	19.0	0.000	0.00	0.000	41.1	0.005	0.003	-7.5	387.0	56.5	4.0	4.5	38.8	1486
Ash Spring	-2.7	-193.2	66.6	4.914	17.0	0.000	0.00	0.002	9.3	0.003	0.000	-5.0	492.0	29.3	4.1	4.4	32.2	-92
B. Iorio 1 well	-2.1	-196.5	-48.2	1.936	18.8	0.057	21.02	0.000	9.1	0.003	0.003	-2.6	260.4	59.4	0.9	4.0	30.9	-188
Cliff Warm Spring	-2.5	-199.1	-47.1	1.290	22.8	0.001	2.58	0.002	11.0	0.002	0.001	-6.9	364.2	64.2	1.8	4.2	33.1	-191
Dent windmill well	-2.1	-230.8	89.3	0.000	13.4	0.000	0.00	0.000	0.0	0.005	0.000	-7.3	341.7	19.7	2.4	4.7	43.5	865
Derry Warm Springs	-1.5	-161.6	197.0	0.659	18.3	0.007	9.16	0.000	15.9	0.002	0.000	-7.5	276.1	37.4	3.0	4.6	30.0	-120
Faywood Hot Springs	-2.6	-172.1	-49.8	0.939	16.6	0.002	2.81	0.000	1.9	0.003	0.000	-4.8	346.4	67.2	4.2	5.5	30.0	619
Federal H 1 well	-0.4	-132.0	35.0	0.000	5.8	0.004	20.31	0.001	7.2	0.000	0.015	-5.0	253.8	78.7	2.7	4.9	27.3	2906
Freiborn Canyon Spring	-2.5	-225.0	-242.0	0.401	13.1	0.000	0.00	0.001	19.8	0.001	0.004	-12.6	538.6	49.8	13.0	4.6	38.4	1138
Garton well	-3.2	-196.8	35.6	0.150	18.0	0.000	0.00	0.000	28.9	0.002	0.001	-5.0	489.9	70.0	4.3	3.9	30.9	-266
Gila Hot Springs 1	-1.9	-221.6	-149.3	0.127	24.2	0.000	0.00	0.001	25.5	0.003	0.003	-7.8	422.6	69.9	6.6	4.4	34.0	413
Gila Hot Springs 2	-1.8	-222.9	-138.8	0.112	24.7	0.000	0.00	0.001	23.7	0.003	0.003	-6.7	425.9	70.8	3.2	4.6	33.9	519
Goat Camp Spring	-2.1	-159.2	-29.7	0.751	10.0	0.001	2.22	0.007	10.6	0.002	0.001	-8.0	344.0	68.9	5.8	4.4	32.4	19
Jerry well	-0.8	-219.6	172.4	0.111	15.5	0.000	0.00	0.000	6.3	0.004	0.005	-7.9	243.9	13.4	1.0	4.4	42.3	1190
Kennecott Warm Springs well	-2.4	-178.3	-69.9	1.422	17.8	0.002	1.76	0.000	1.1	0.003	0.000	-6.9	355.0	66.1	4.3	5.0	30.0	409
Laguna Pueblo	0.4	-204.2	62.5	0.406	8.6	0.004	4.58	0.006	14.6	0.018	0.005	-3.3	259.7	42.9	2.6	4.4	37.2	1506
Lightning Dock	-1.0	-168.0	-168.1	0.086	4.6	0.008	8.40	0.002	4.3	0.000	0.000	-3.9	291.5	107.3	0.8	5.0	29.8	1800
Los Alturas Estates	-1.5	-141.4	-127.5	0.004	7.6	0.003	0.05	0.002	6.6	0.001	0.000	-12.7	265.3	71.9	2.2	6.3	27.4	4321
Mangas Springs	-2.6	-201.0	-227.1	3.503	20.2	0.000	0.91	0.002	11.5	0.002	0.000	-4.5	393.5	53.6	0.3	4.2	32.4	-178
Mimbres Hot Springs	-2.3	-200.6	43.4	0.670	15.4	0.002	1.13	0.000	19.0	0.004	0.000	-3.8	445.9	68.3	9.1	4.9	31.0	50
Ojitos Springs	-1.6	-202.1	-7.5	1.342	19.6	0.044	19.74	0.037	31.0	0.020	0.005	-4.5	257.5	57.6	7.2	4.5	33.0	-255
Ojo Caliente	-2.6	-226.5	-168.4	0.000	20.5	0.000	0.00	0.000	8.3	0.004	0.000	-2.9	333.6	48.4	3.5	5.5	33.8	2415
Ojo De las Canas	-1.7	-188.5	-85.8	0.839	22.3	0.036	12.55	0.036	28.0	0.013	0.003	-6.0	270.5	14.2	4.0	4.5	31.8	101
Pueblo windmill well	-1.2	-228.8	315.9	0.029	15.2	0.000	0.00	0.000	6.1	0.004	0.003	-12.0	265.8	18.3	2.9	4.3	42.5	1027
Radium Hot Springs	-0.8	-151.4	-7.8	0.010	8.8	0.013	11.40	0.003	10.6	0.001	0.000	-5.3	264.2	63.6	0.3	5.4	28.2	1191
Rainbow Spring	-1.7	-227.1	-48.5	0.000	11.0	0.000	0.00	0.001	0.0	0.006	0.000	-7.0	307.8	21.7	3.3	4.7	43.9	755
Riverside Store well	-1.3	-196.1	-102.9	1.562	22.6	0.000	2.50	0.002	11.7	0.002	0.001	-2.4	356.1	60.8	0.9	4.3	32.9	-165
Sacred Spring	-1.8	-228.4	-80.4	0.000	10.9	0.000	0.00	0.001	0.0	0.006	0.000	-7.0	298.4	21.2	1.3	4.6	43.9	742
Socorro Canyon	-1.8	-204.7	-136.5	1.203	21.1	0.051	28.88	0.034	33.8	0.020	0.005	-6.7	284.1	44.6	11.1	5.0	32.6	-229
Spring	-4.1	-183.5	334.5	0.218	20.1	0.011	1.81	0.000	20.1	0.001	0.006	-6.8	361.9	117.2	5.1	3.8	31.5	-104
Spring Canyon Warm Spring	-2.1	-194.2	117.3	2.293	21.9	0.000	1.50	0.002	12.7	0.002	0.000	-8.3	361.7	51.6	5.8	4.2	32.6	-57
Truth or Consequences spring	-1.1	-168.2	-54.3	2.175	18.4	0.064	20.51	0.000	10.3	0.003	0.002	-3.3	265.9	55.3	0.6	4.3	31.0	304
Turkey Creek Spring	-3.2	-196.4	54.8	0.984	19.2	0.001	3.69	0.002	28.1	0.002	0.002	-3.7	493.4	81.3	5.8	4.4	33.6	56
Victoria Land and Cattle Co. well	-1.8	-165.9	-65.4	0.478	6.4	0.003	0.06	0.001	0.9	0.001	0.000	-2.9	253.0	43.0	1.9	4.1	30.7	2014
Warm Springs	-2.1	-193.3	113.5	0.220	19.0	0.029	2.63	0.000	16.5	0.004	0.003	-2.5	314.6	56.0	5.4	4.3	32.7	1252
Well 1	-1.4	-230.7	-31.3	1.190	15.7	0.000	0.75	0.001	22.1	0.004	0.002	-6.6	345.4	49.0	1.7	4.4	40.0	1961
Well 2	-1.2	-162.5	0.8	0.000	4.5	0.008	24.24	0.003	11.8	0.000	0.006	-10.1	279.5	70.5	1.7	4.8	27.8	2993
Well 3	-2.5	-140.0	31.7	0.839	2.1	0.001	2.11	0.001	5.0	0.001	0.000	-7.3	369.0	51.0	4.1	4.3	28.0	3073
Well 4	-1.3	-161.7	-56.1	0.000	3.4	0.008	28.49	0.003	10.6	0.000	0.006	-10.0	274.3	94.0	1.9	4.7	27.7	3373
Well 5	-1.9	-167.2	-29.9	0.000	2.5	0.008	15.48	0.002	3.1	0.000	0.005	-6.8	243.8	47.0	0.3	4.0	27.4	5460
Well south of Carne	-2.4	-156.7	-129.6	0.457	4.3	0.000	2.11	0.002	6.0	0.001	0.000	-6.8	269.7	87.1	1.4	4.5	28.4	2761

SWNM Geothermal Signatures

W ***H***



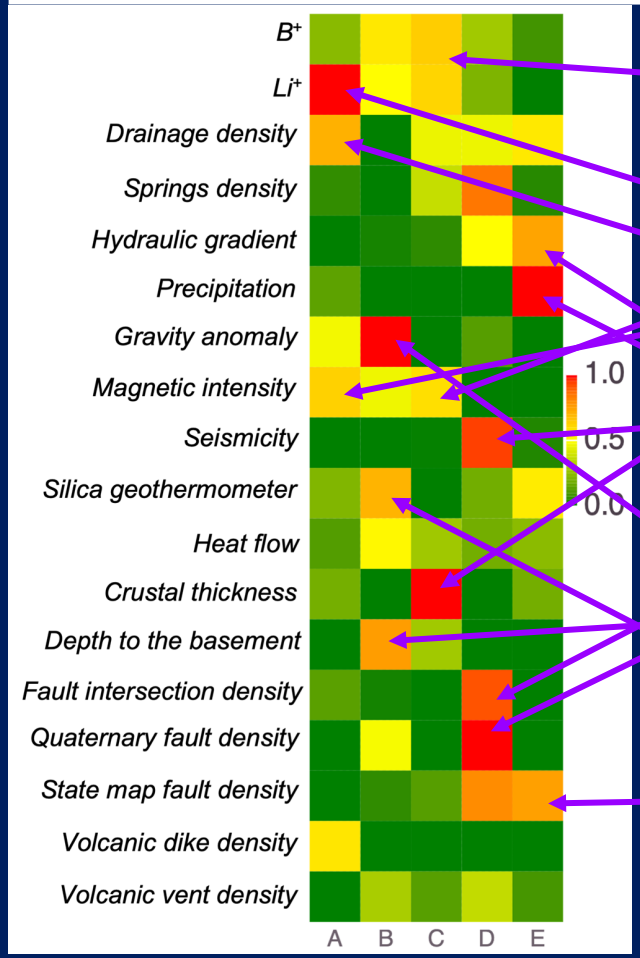


$$X = W \times H$$

W: attribute matrix

H: location matrix

SWNM Signature Interpretation



Signature A:
- Li^+ concentration
- Drainage density
- Magnetic intensity
- Volcanic dike density
- Gravity anomaly

Signature B:
- Gravity anomaly
- Depth to the basement
- Silica geothermometer
- B^+ and Li^+ concentrations
- Magnetic intensity
- Quaternary fault density
- Heat flow

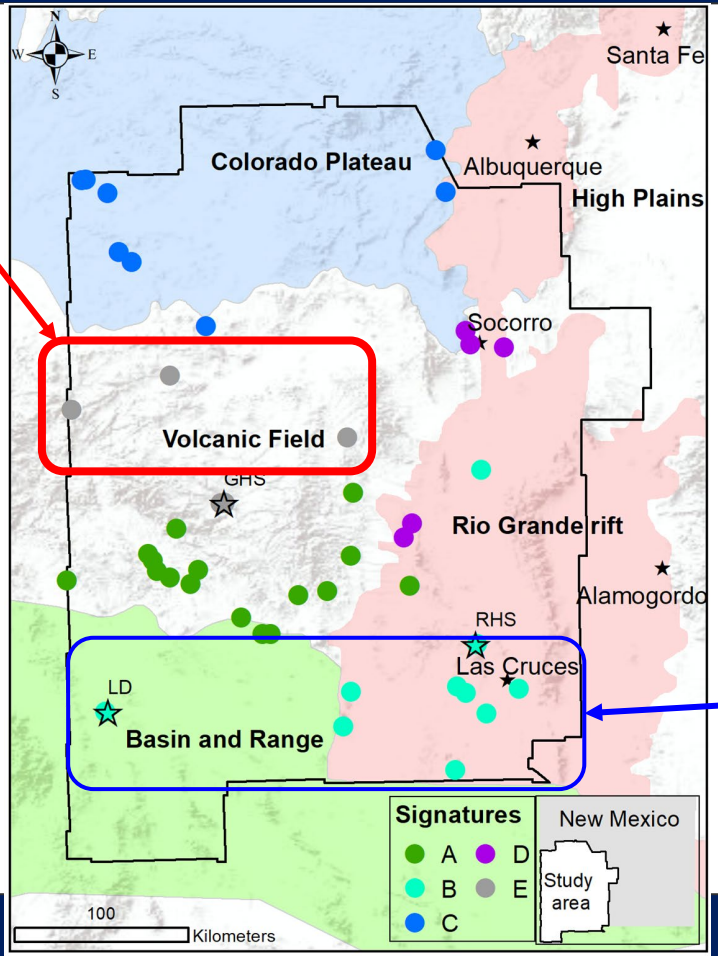
Signature C:
- Crustal thickness
- Magnetic intensity
- B^+ and Li^+ concentrations
- Drainage density

Signature D:
- Quaternary fault density
- Fault intersection density
- Seismicity
- State map fault density
- Spring density
- Hydraulic gradient
- Drainage density

Signature E:
- Precipitation
- Hydraulic gradient
- State map fault density
- Drainage density
- Silica geothermometer

Demo: Hidden Geothermal Resources in New Mexico

New discovery of highly prospective region



Highly prospective region, which is consistent with previous studies

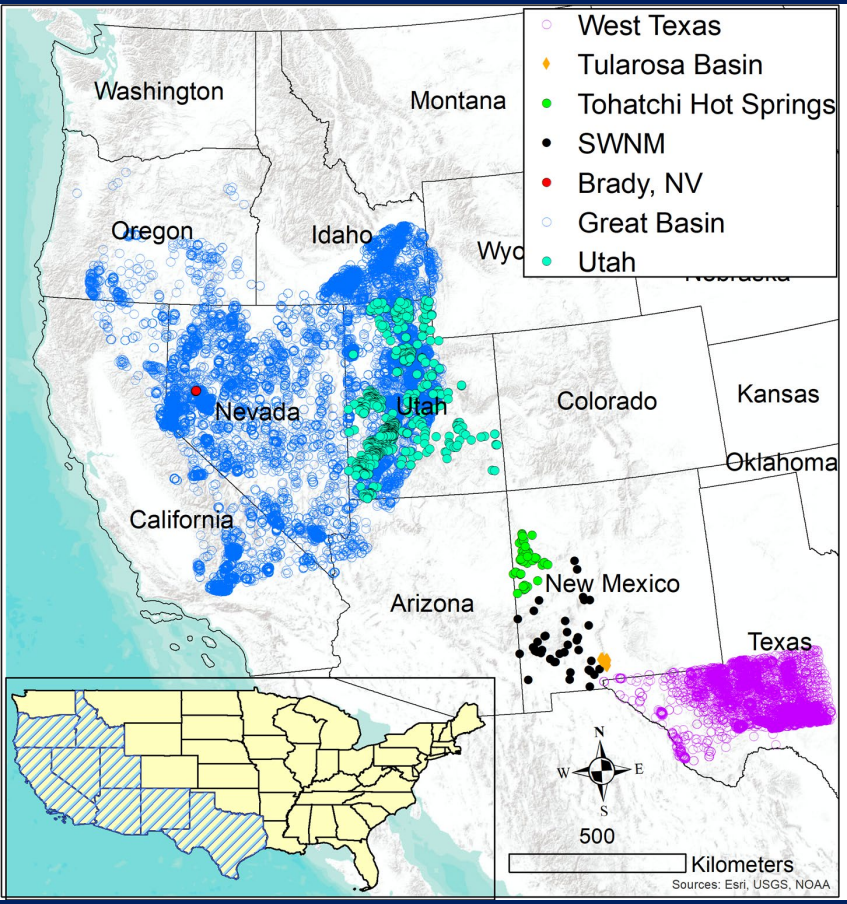
GeoThermalCloud Advantages:

- **Open-source:** An open-source cloud-based machine learning framework for geothermal resources exploration.
- **Resource discovery:** This tool can identify new unknown or hidden geothermal prospects using large datasets and non-obvious relationships.
- **Reduces preprocessing effort:** Automatically categorizes dataset inputs and identifies prospectivity (a.k.a., ‘signatures’).
- **Data valuation:** Help identify high-value data that could be relatively cheap to obtain and find low-value data that does little to inform prospectivity.
- **Diverse datasets:** Inputs can be field data and model data spanning across dimensional scales and data types (e.g., chemistry, fault maps, and modeled power production).
- **Handles sparse / missing dataset:** Missing some data here and there? Not a problem.

GeoThermalCloud Disadvantages:

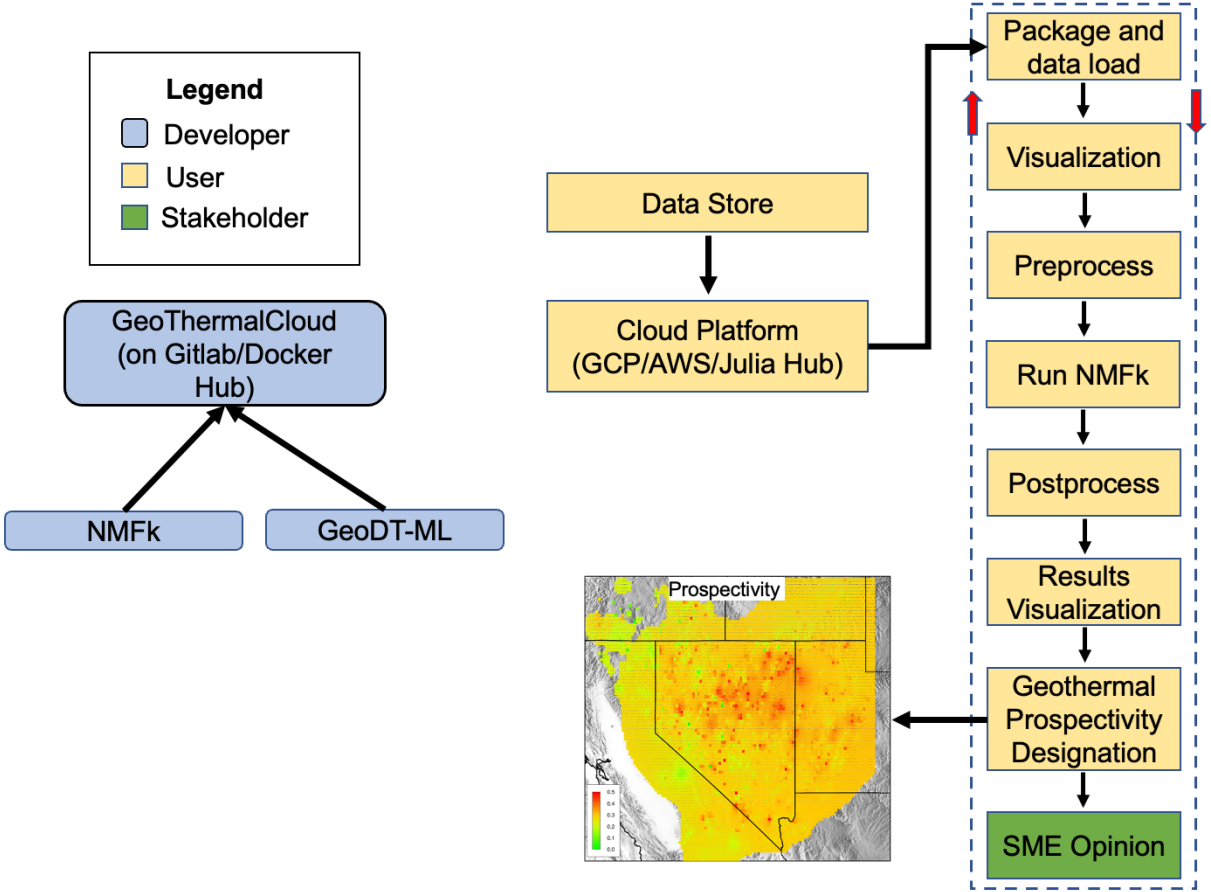
- **Interpretation:** Subject matter expertise is required to get the best interpretation of the results. Unfortunately, there is no way around this.
- **False negatives:** Just like any other method, GTC cannot identify resources that have no data to show they exist. A lack of a signature does not signify non-existence of a resource.
- **Adding new data:** The machine learning models should be rerun to accommodate new data to achieve the best results, which adds some computational time when applying GeoThermalCloud.
- **Indefinite answers:** Machine learning models such as GTC cannot provide “yes” or “no” answers for prospectivity.

GeoThermalCloud's Pedigree



- **Platform:** Based on the R&D 100 award winning SmartTensors toolset.
- **Tools:** SmartTensors use patented matrix/tensor factorization methods.
- **Applications:** GeoThermalCloud has been successfully employed on several large datasets (e.g., Great Basin, New Mexico, and FORGE) and on synthetic datasets from models (e.g., GeoDT).
- **Explainability:** It produces rational and explainable results.
- **Development status:** GeoThermalCloud is actively being developed at Los Alamos National Laboratory and Pacific Northwest National Laboratory.

GeoThermalCloud Workflow



GeoThermalCloud+GeoDT-ML Workflow

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Legend
- Developer
- User
- Stakeholder

GeoThermalCloud (on Gitlab/Docker Hub)

NMFk | GeoDT-ML

Data Store

Cloud Platform (GCP/AWS/Julia Hub)

Package and data load

Visualization

Preprocess

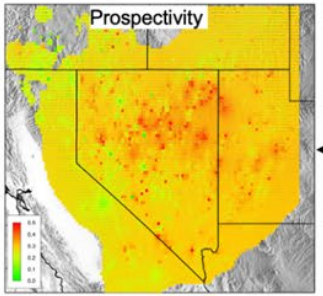
Run NMFk

Postprocess

Results Visualization

Geothermal Prospectivity Designation

SME Opinion



Load EGS Data

Visualization

Preprocess

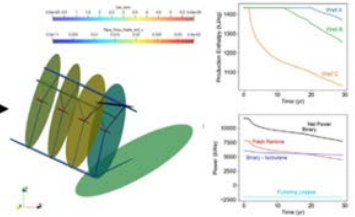
Run GeoDT-ML

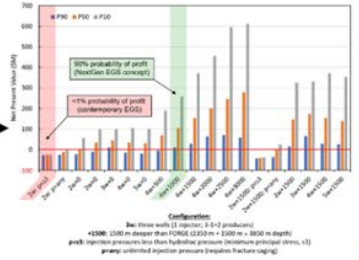
Postprocess

EGS Design Optimization

Technoeconomic analysis

EGS Prospectivity Designation





GeoThermalCloud

GeoDT-ML

Where you can get it

To get started using GTC, download from DockerHub:

docker pull bulbulahmmed/geothermalcloud-v1

For advanced users, install from GitHub:

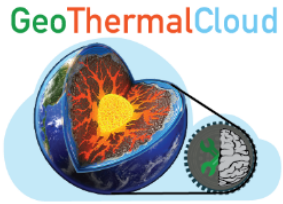
https://github.com/SmartTensors/GeoThermalCloud.jl

Thank you for your interest and enjoy!

Questions: ahmmedb@lanl.gov

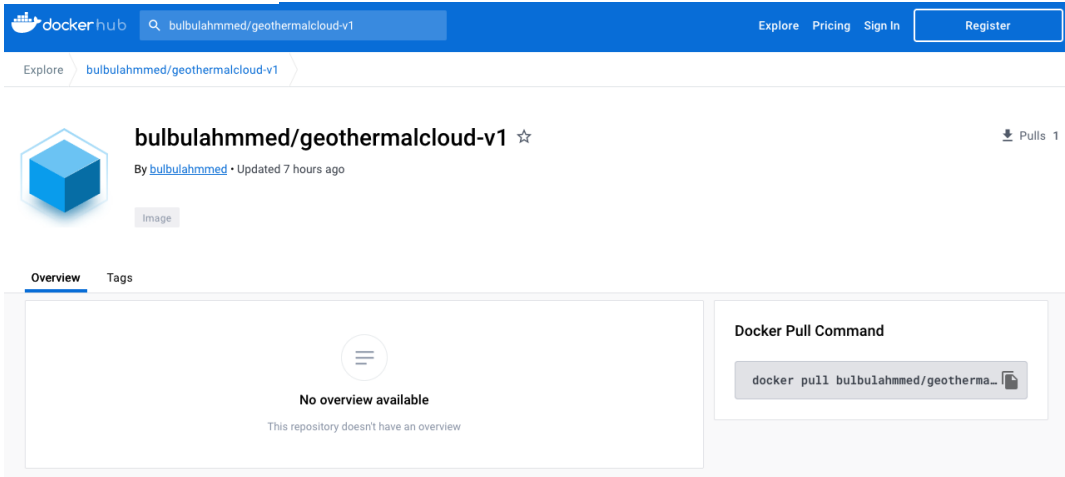
How to Use GeoThermalCloud?

GeoThermalCloud: A Machine Learning Framework for Geothermal Resources Exploration



https://github.com/SmartTensors/GeoThermalCloud.jl

It can be used on personal laptop, cloud platform, and supercomputer



docker pull bulbulahmmed/geothermalcloud-v1