BEYOND PROSPECTIVITY MAPS: Multimodal Geospatial AI for Critical Mineral Systems and Geothermal Prospectivity Exploration

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Meaning of Life?

Are we Humans or Dancers?

Is AI a Dancer?

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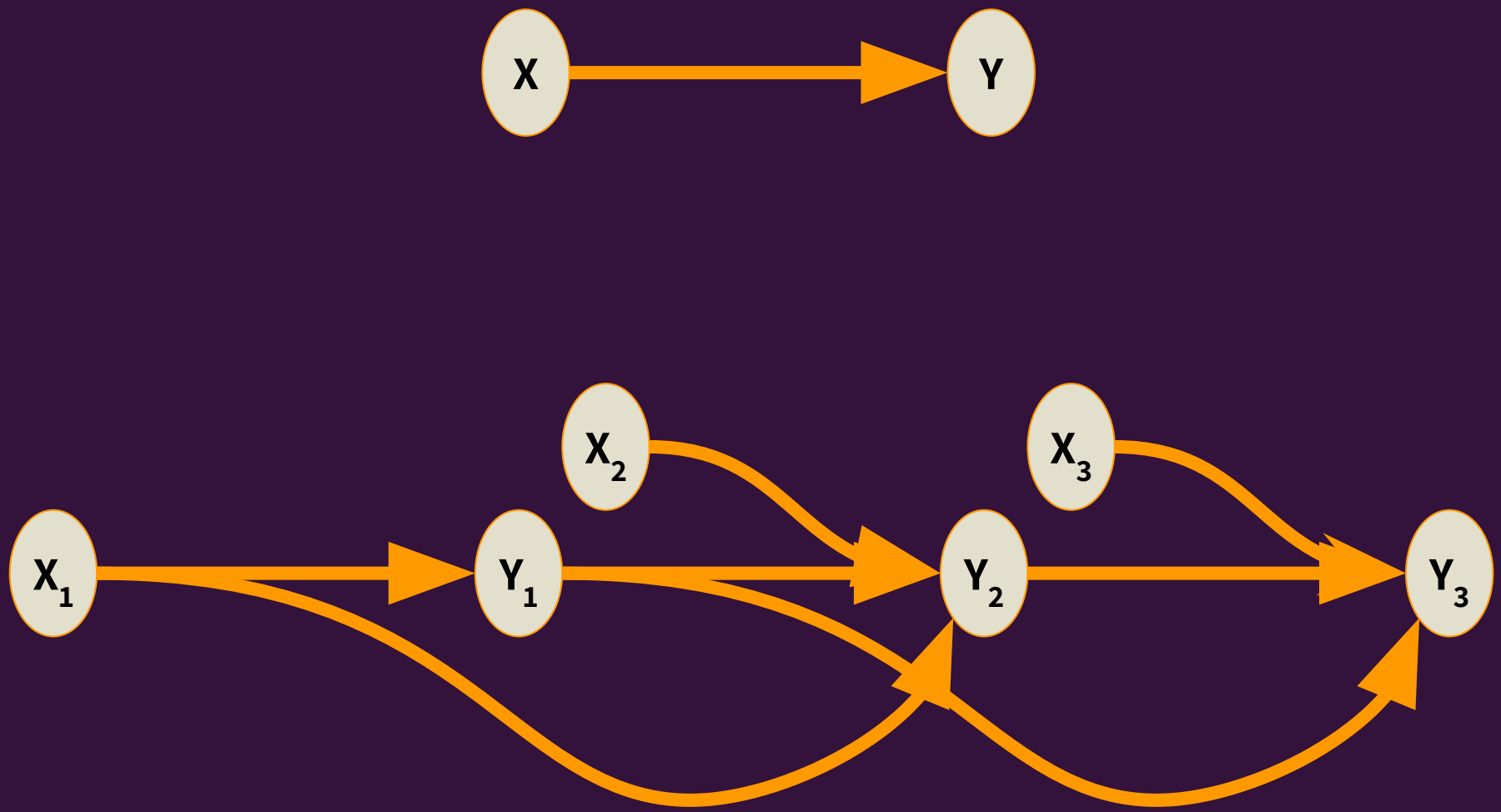
Geologic Reservoir Data Issues

- Gaps, Uncertainties, Errors & Inaccuracies
- Representativeness & Information Content
- Differences in spatiotemporal support scales of data & features/processes
- Heterogeneity (faults, facies, layers, synclinals, vents, volcanos, …)
- “Hidden” (latent) features/signatures

GeoML: Methods/Software for geospatial ML analyses

- Multi-step physics and geology aware ML algorithms
- Automated cross-validations and fine tuning
- Identifying the best approach for a given dataset/problem
- Geospatial benchmarks
- ML techniques (standardized APIs):
  - Nonnegative matrix/tensor factorization (NMFk/NTFk)
  - Support Vectors (SVM/SVR)
  - XGBoost/EvoTrees
  - Inverse Distance Weighted (IDW)
  - Spatial splines/Minimum curvature (Biggs FD and classical)
  - Kriging/Vecchia/Gaussian Process/Nearest Neighbour Gaussian Process
  - Kriging Convolutional Neural Networks (KCN)
  - Gaussian Markov Random Field (GMRF)
  - GNNs, MLPs, CNNs, LSTMs
  - Stochastic PDEs (SPDE)
  - Diffusion Model (DM)
  - Physics models (analytical/numerical)

Multi-step ML approach for geospatial analyses



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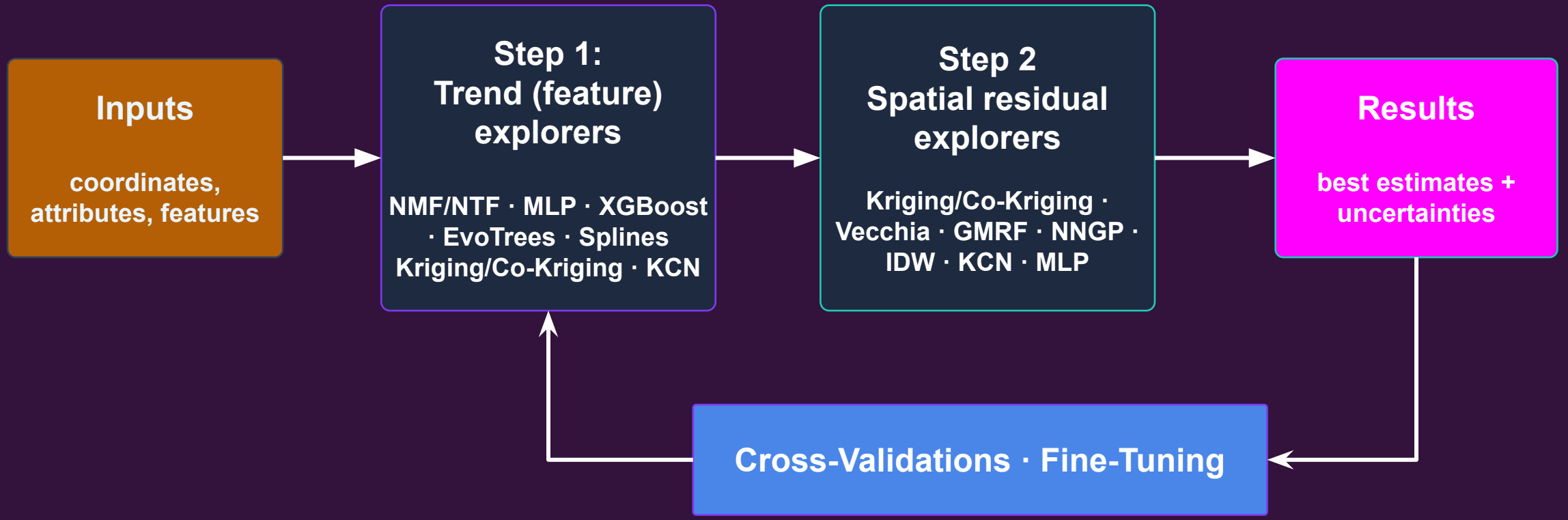
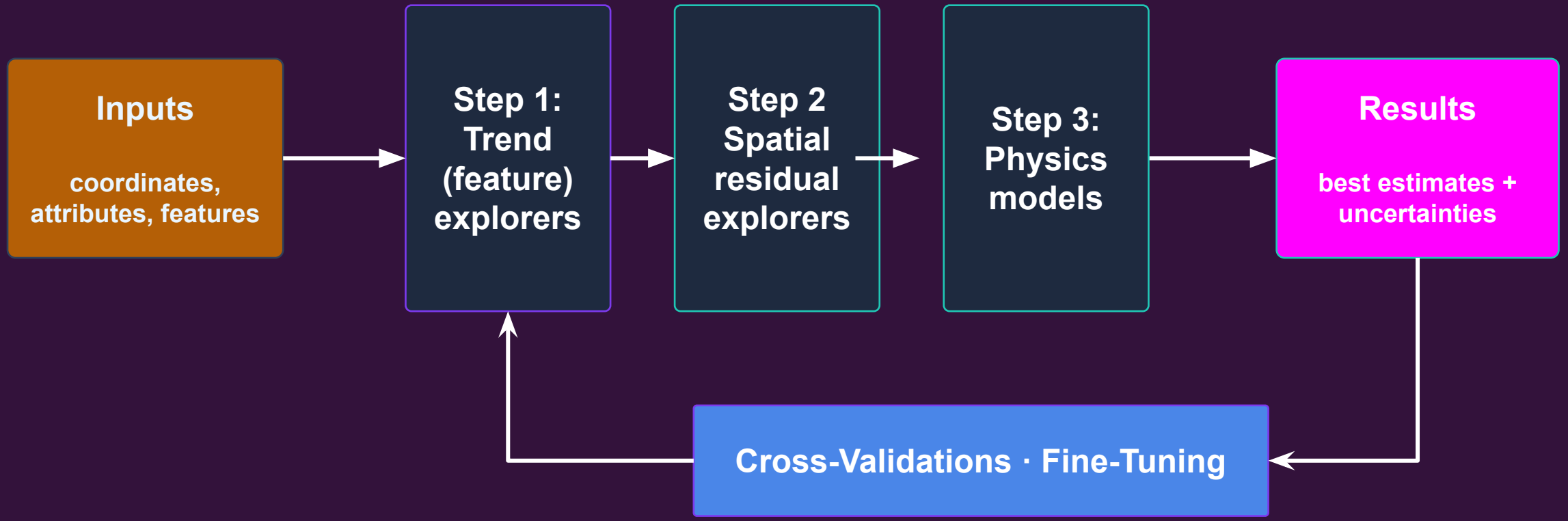
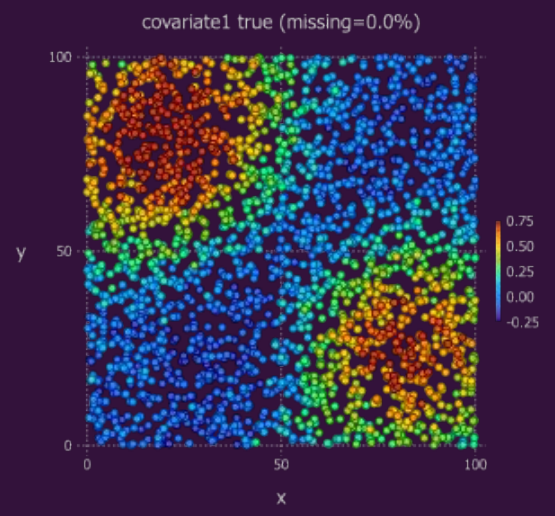
GeoML: Multi-step approach for geospatial analyses

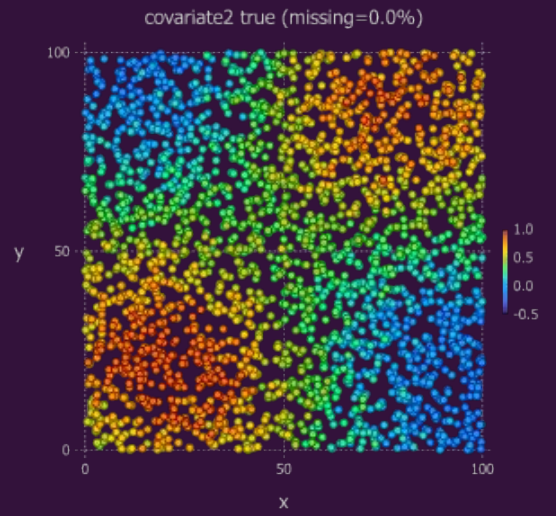


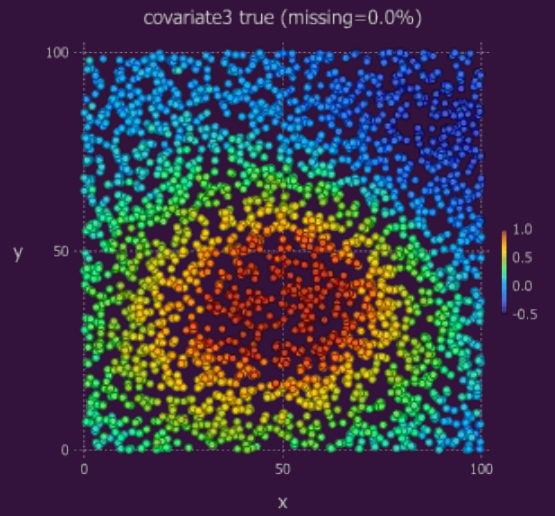
GeoML: Multi-step approach for geospatial analyses

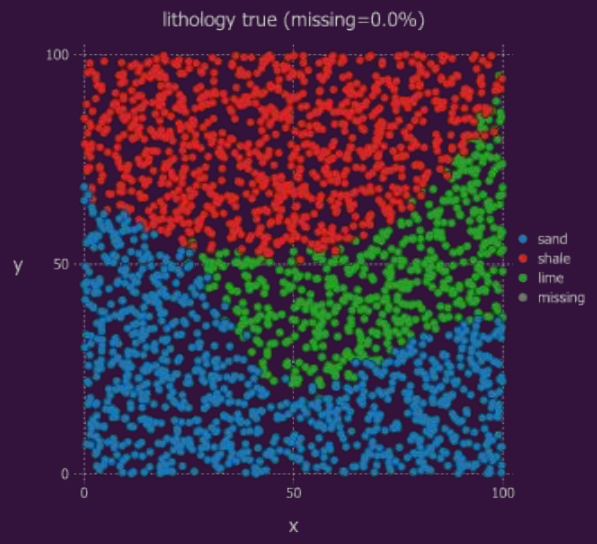


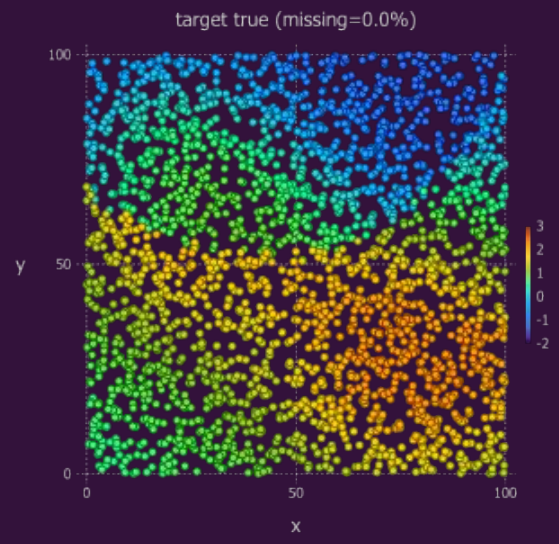
Geospatial problem











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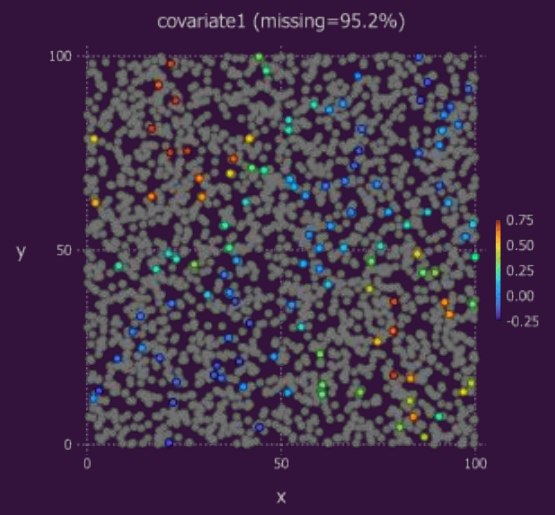
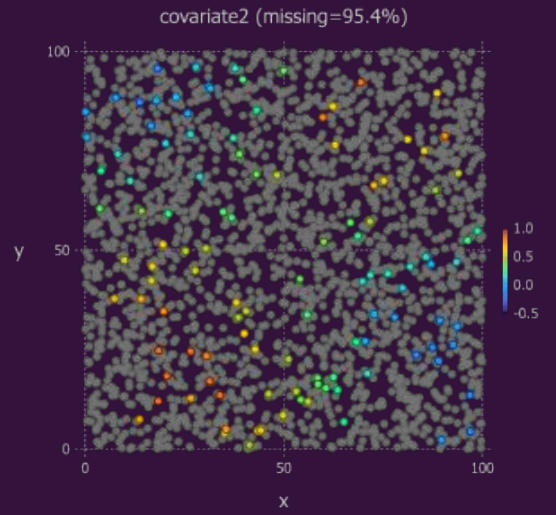
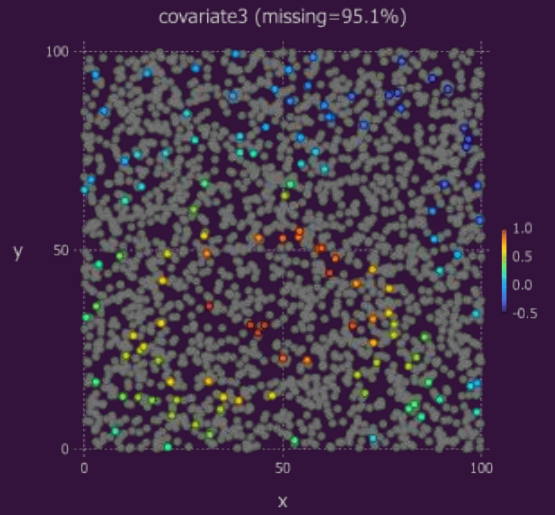
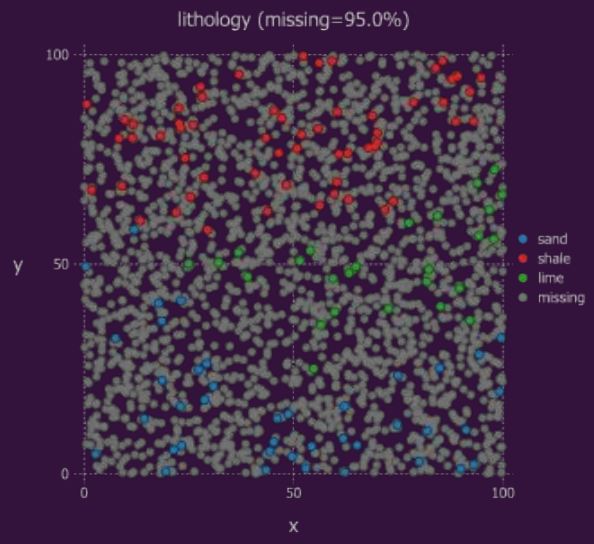
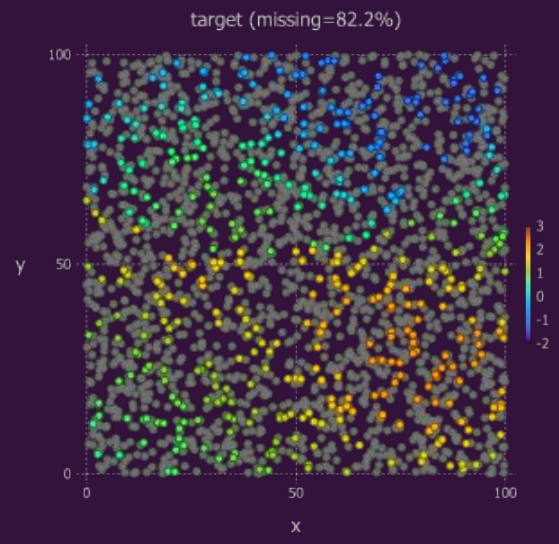
Geospatial problem (~95%)











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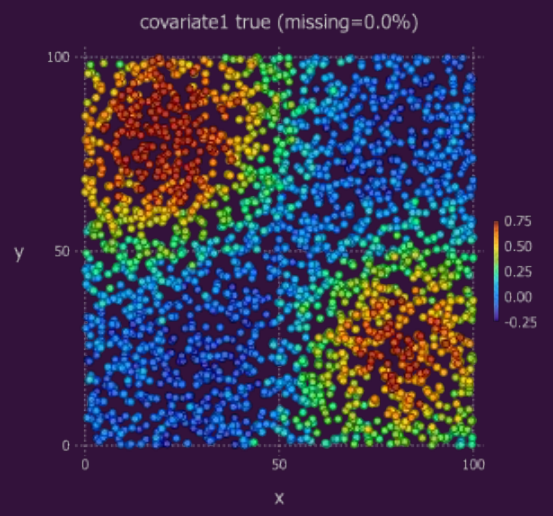
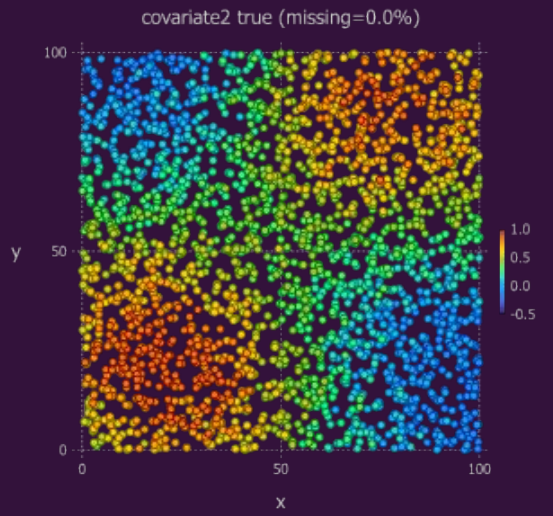
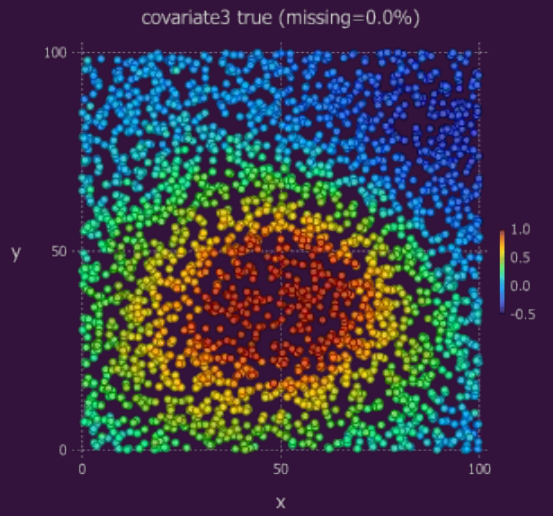
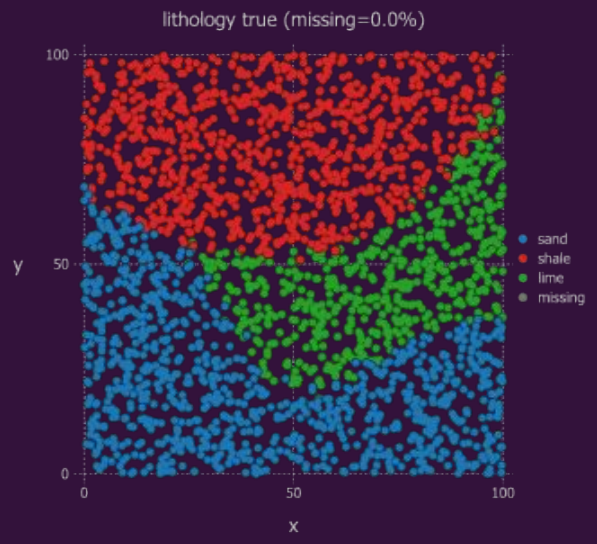
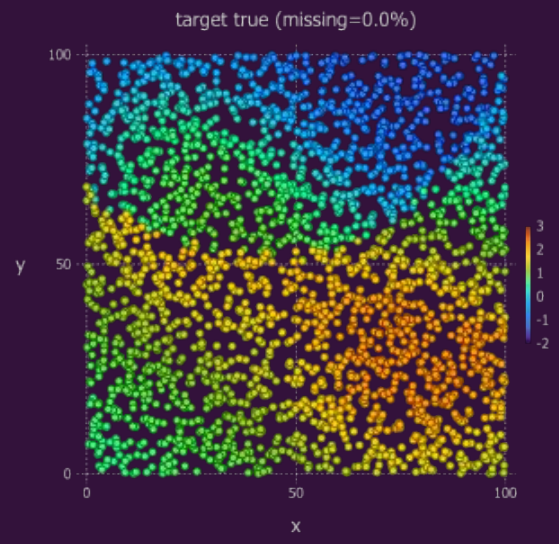
Geospatial problem (truth)











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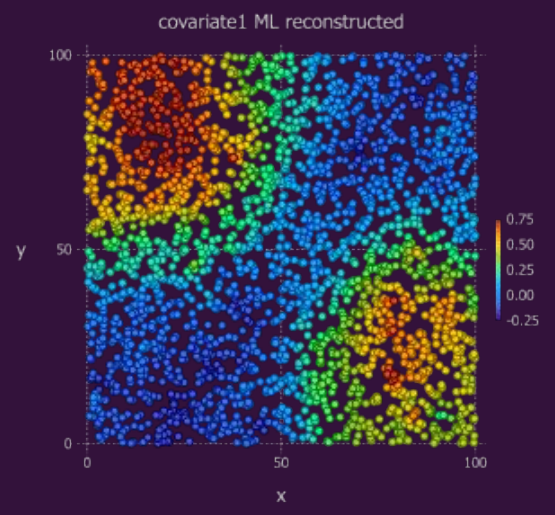

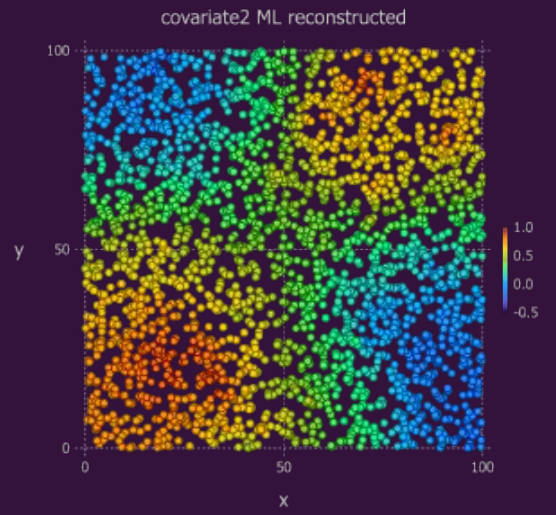

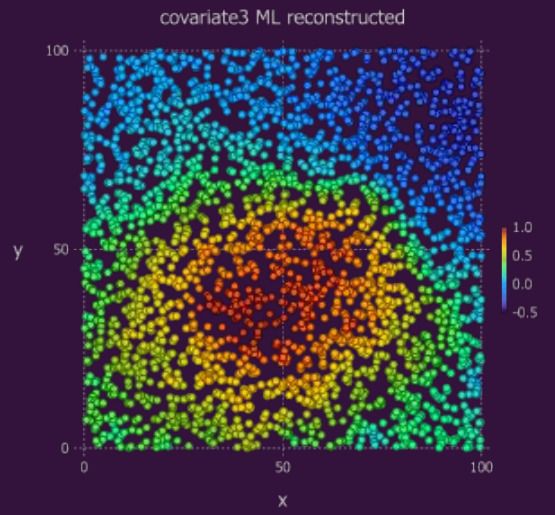

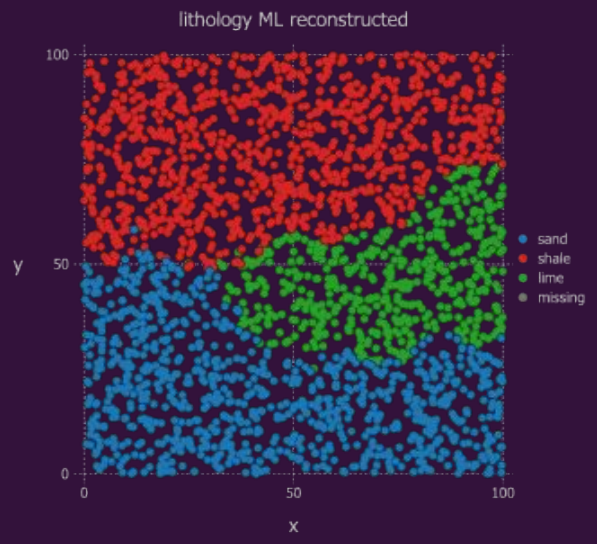

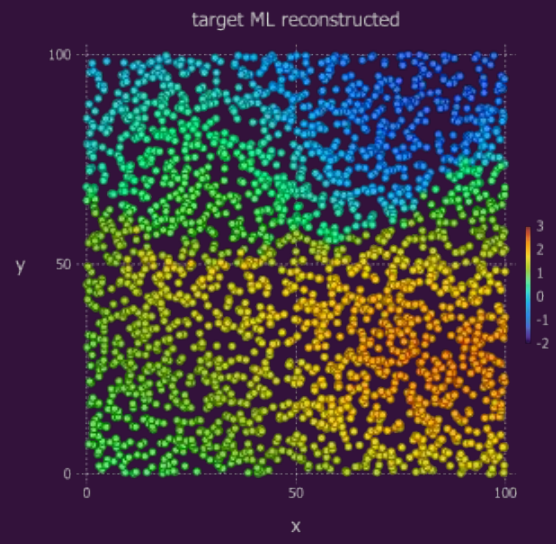

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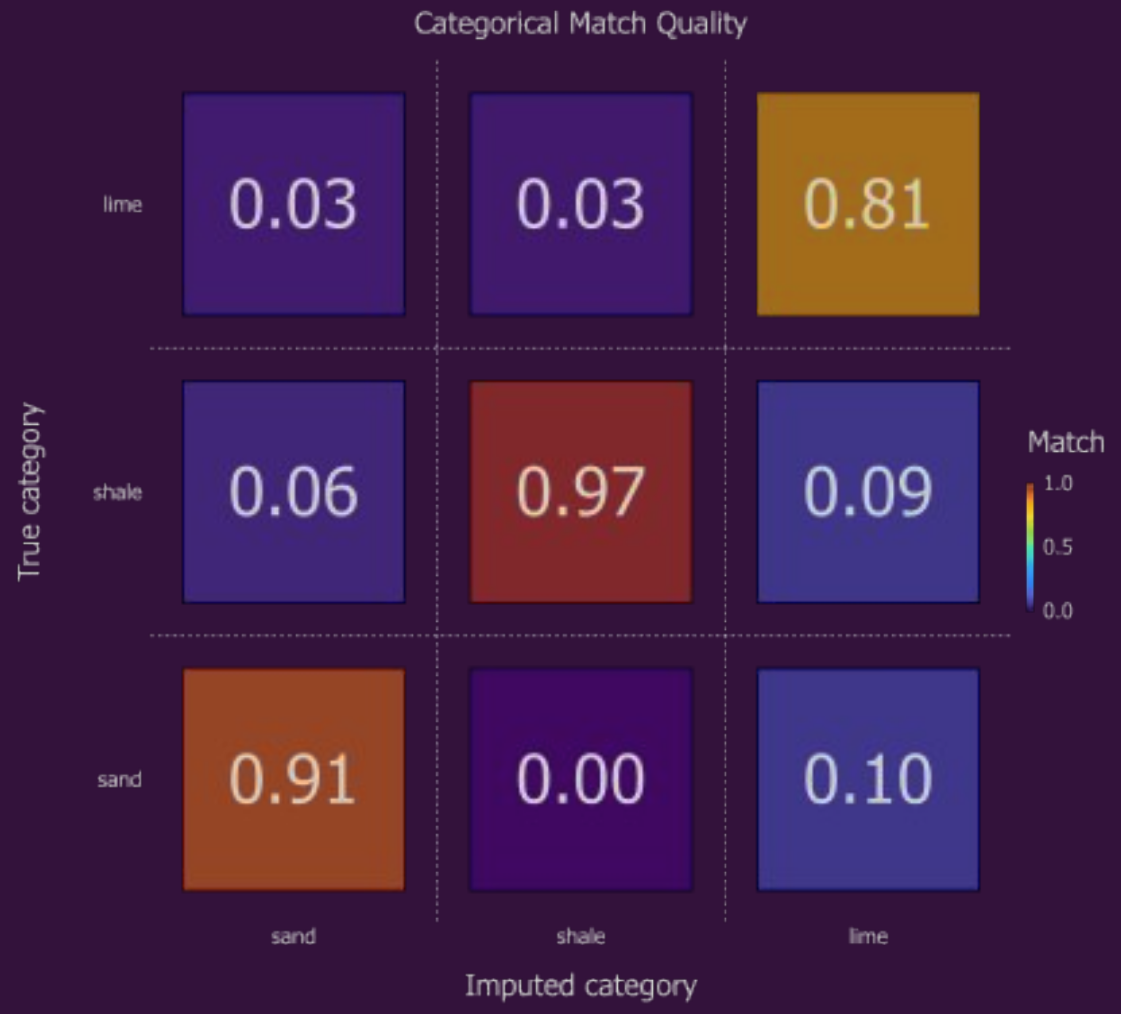

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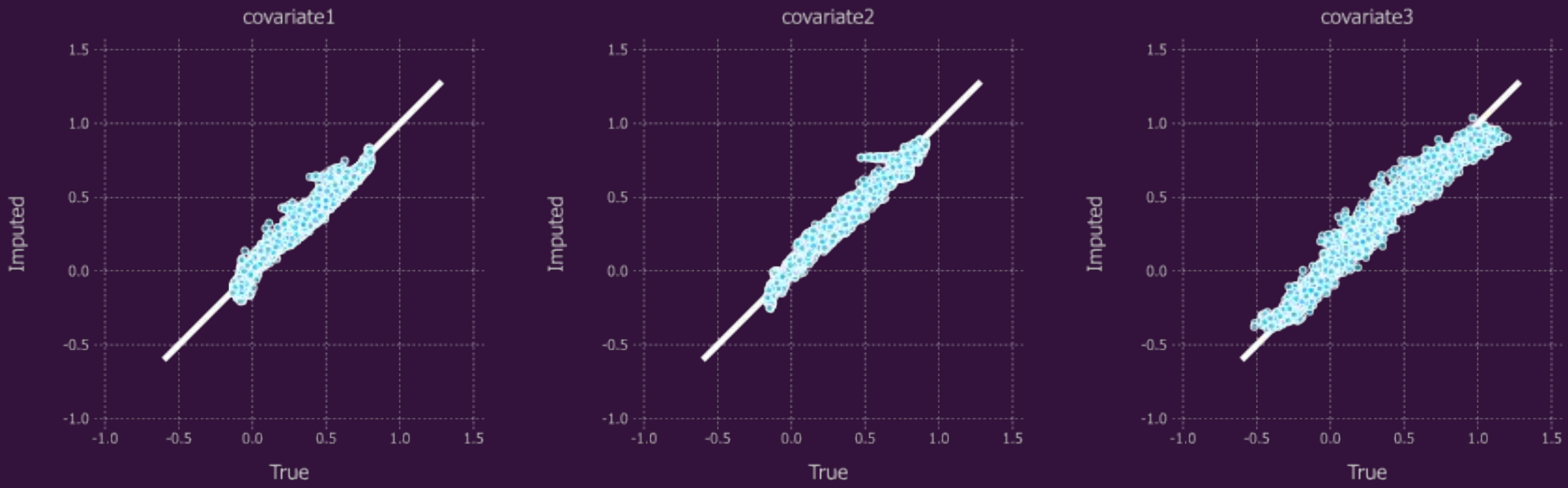
Geospatial problem



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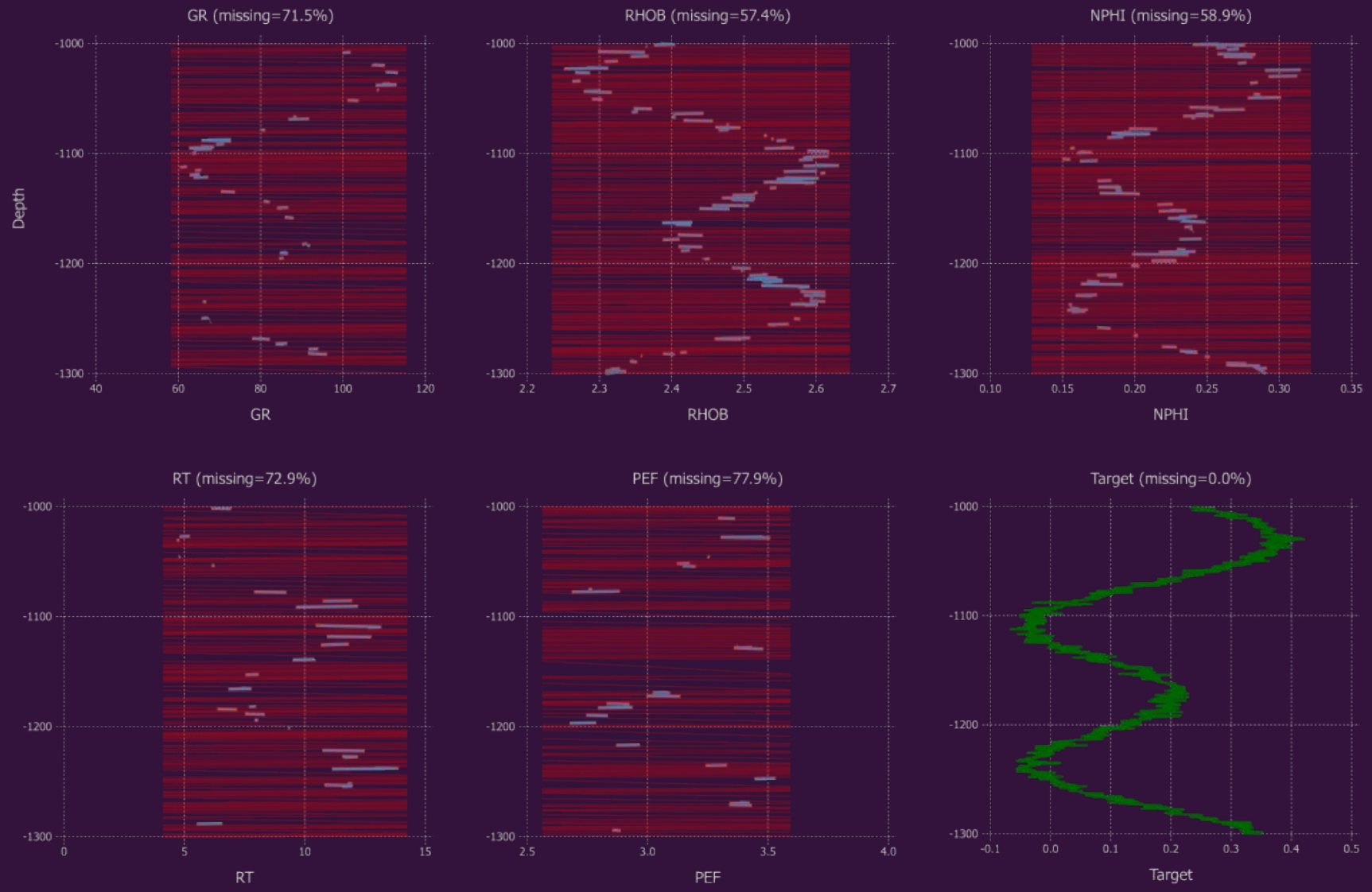
Well-log demo problem



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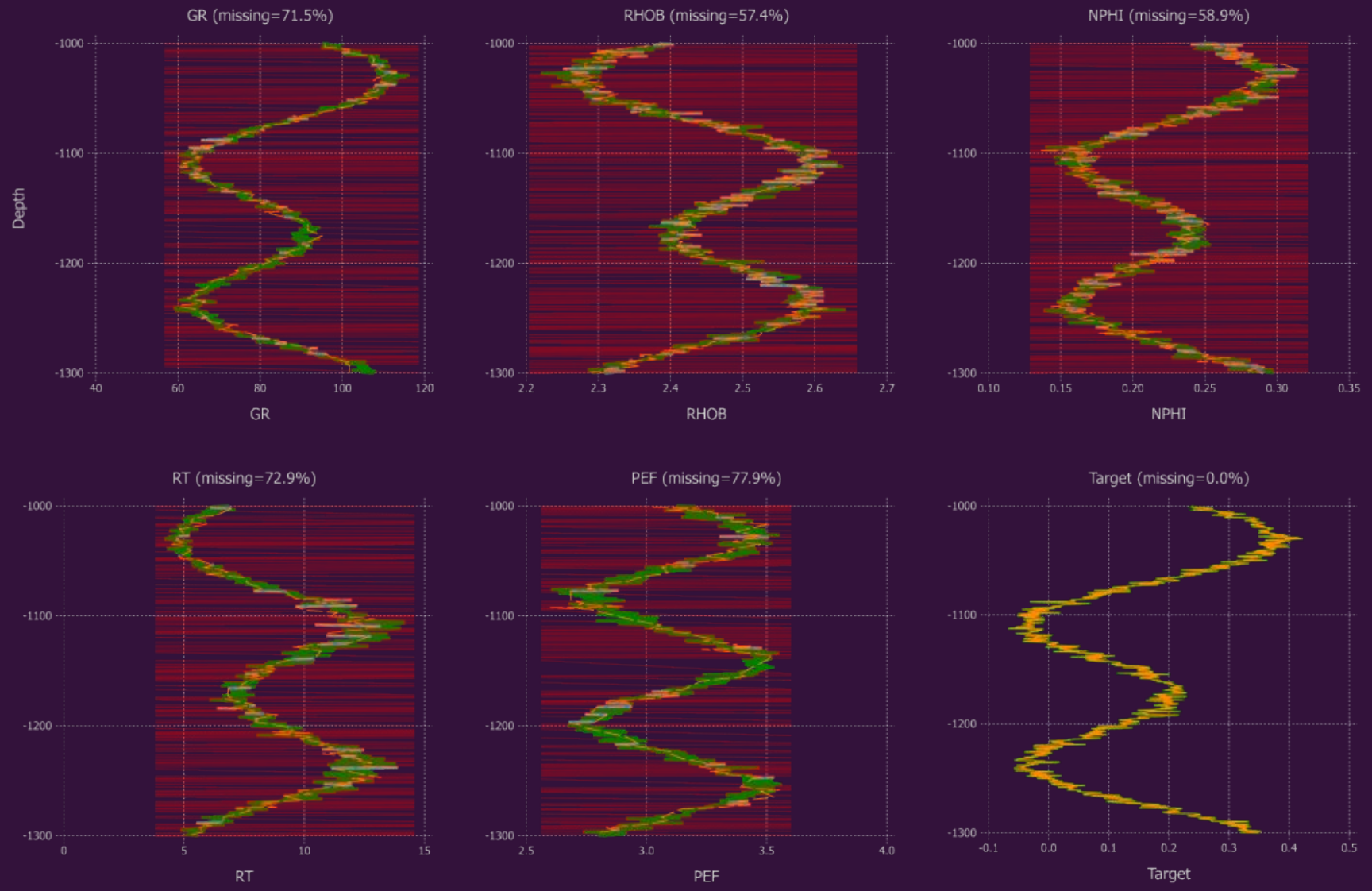

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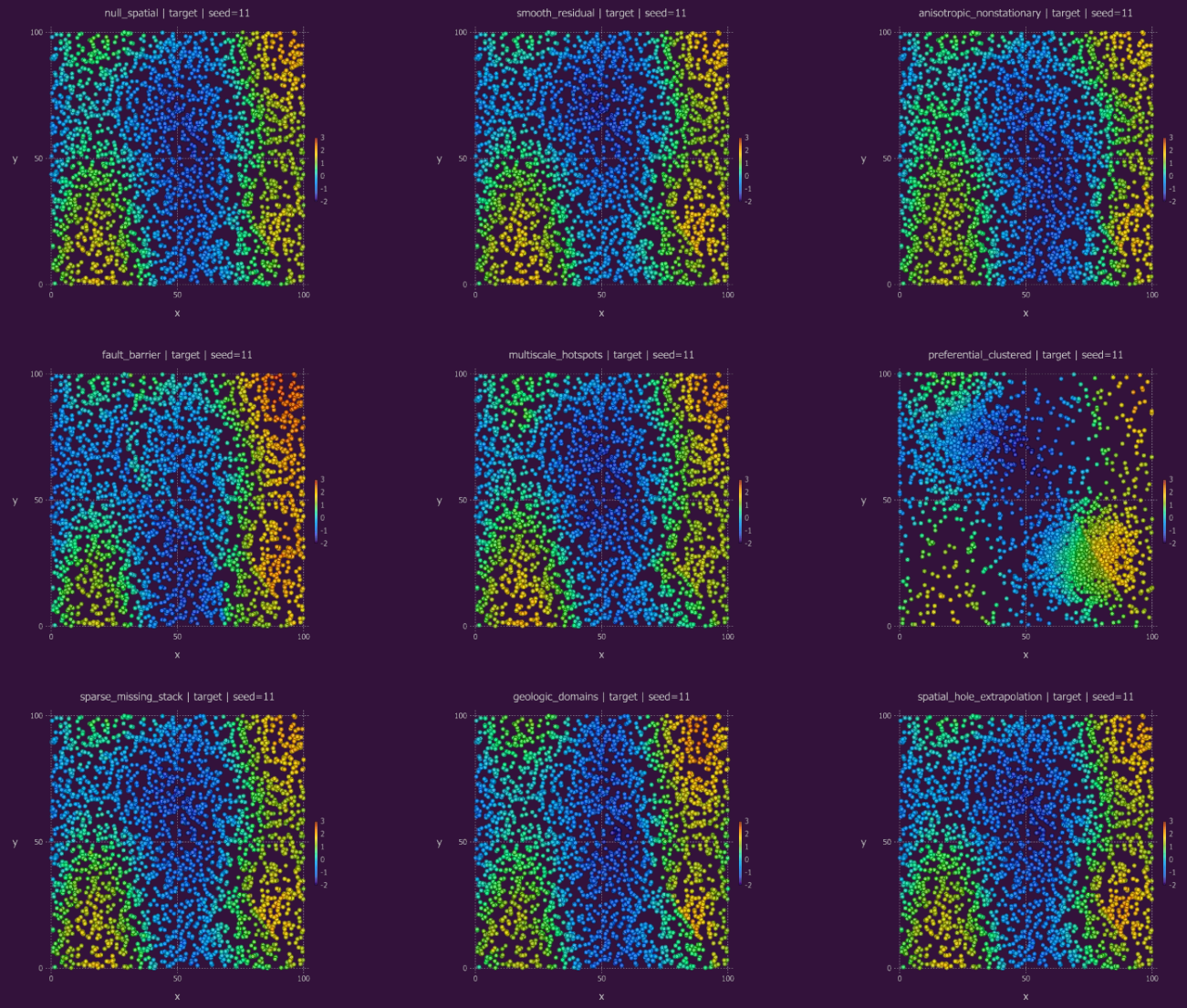
Realistic geo data benchmarks



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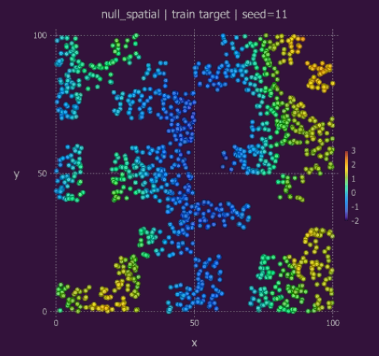

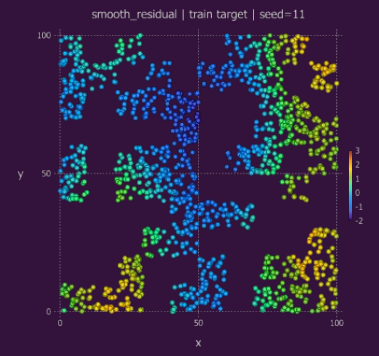

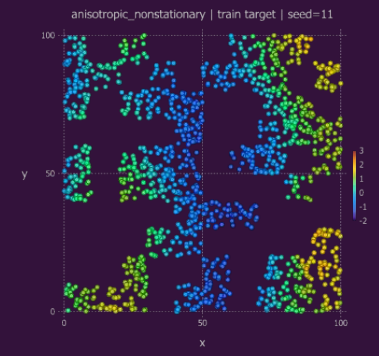

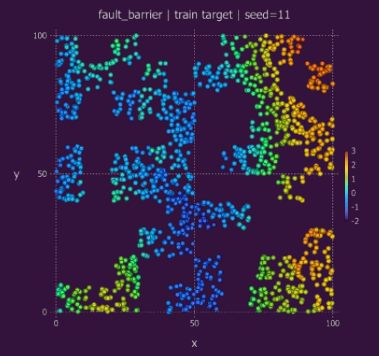

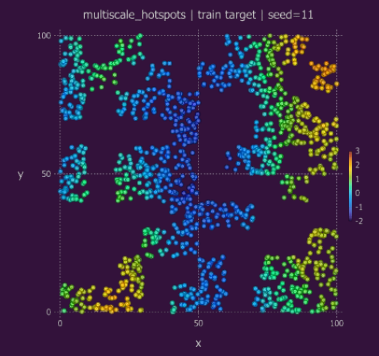

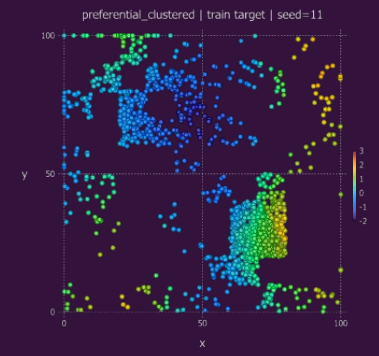

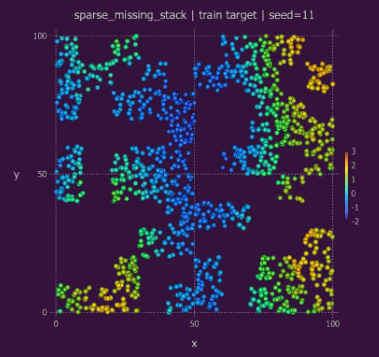

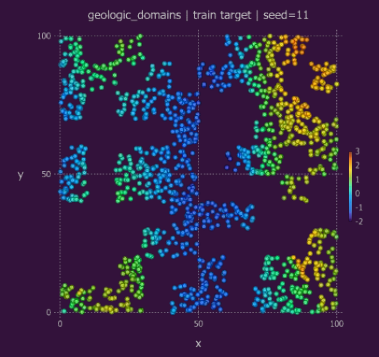

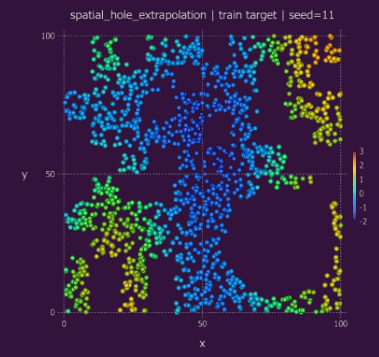

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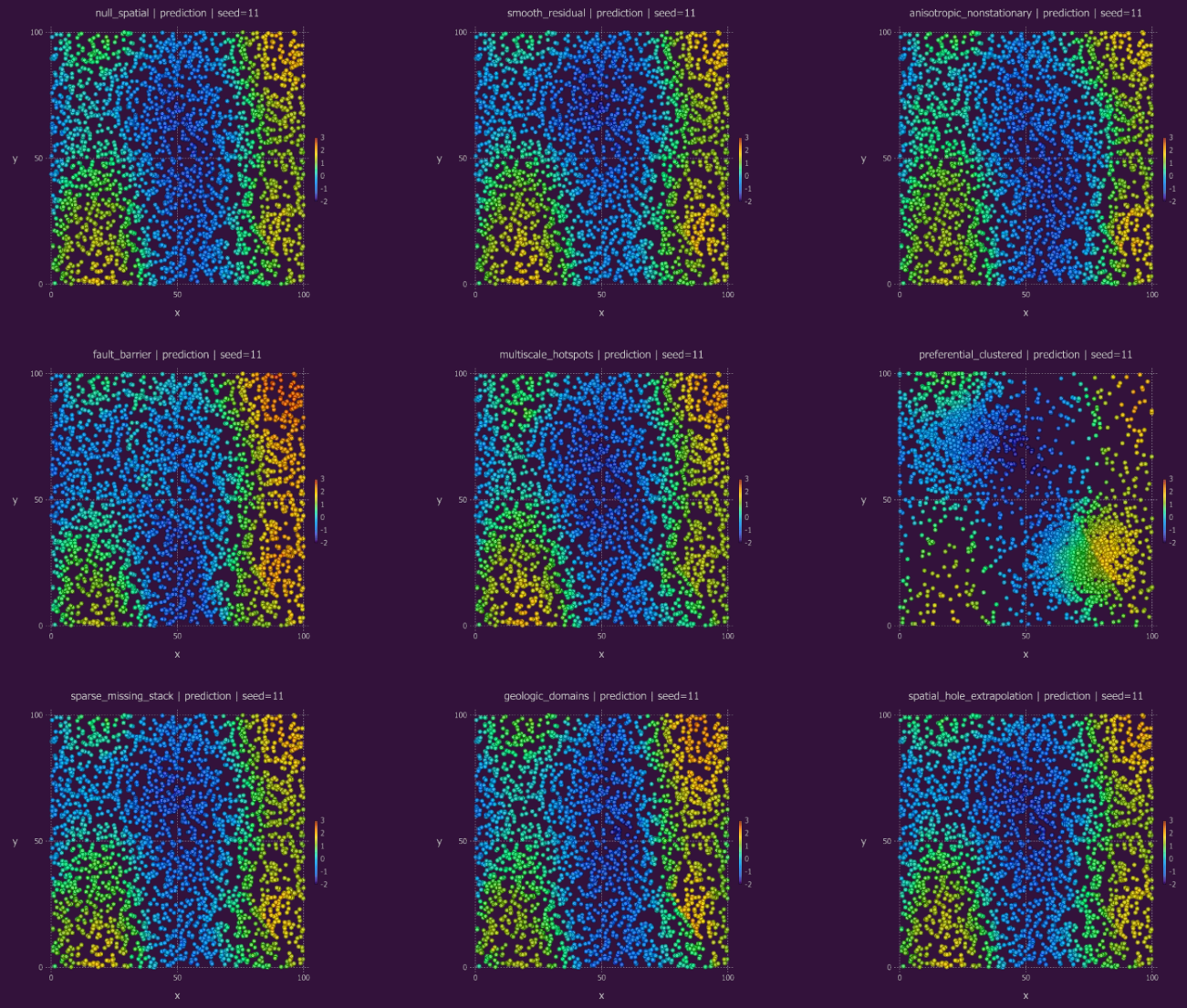
Realistic geo data benchmarks



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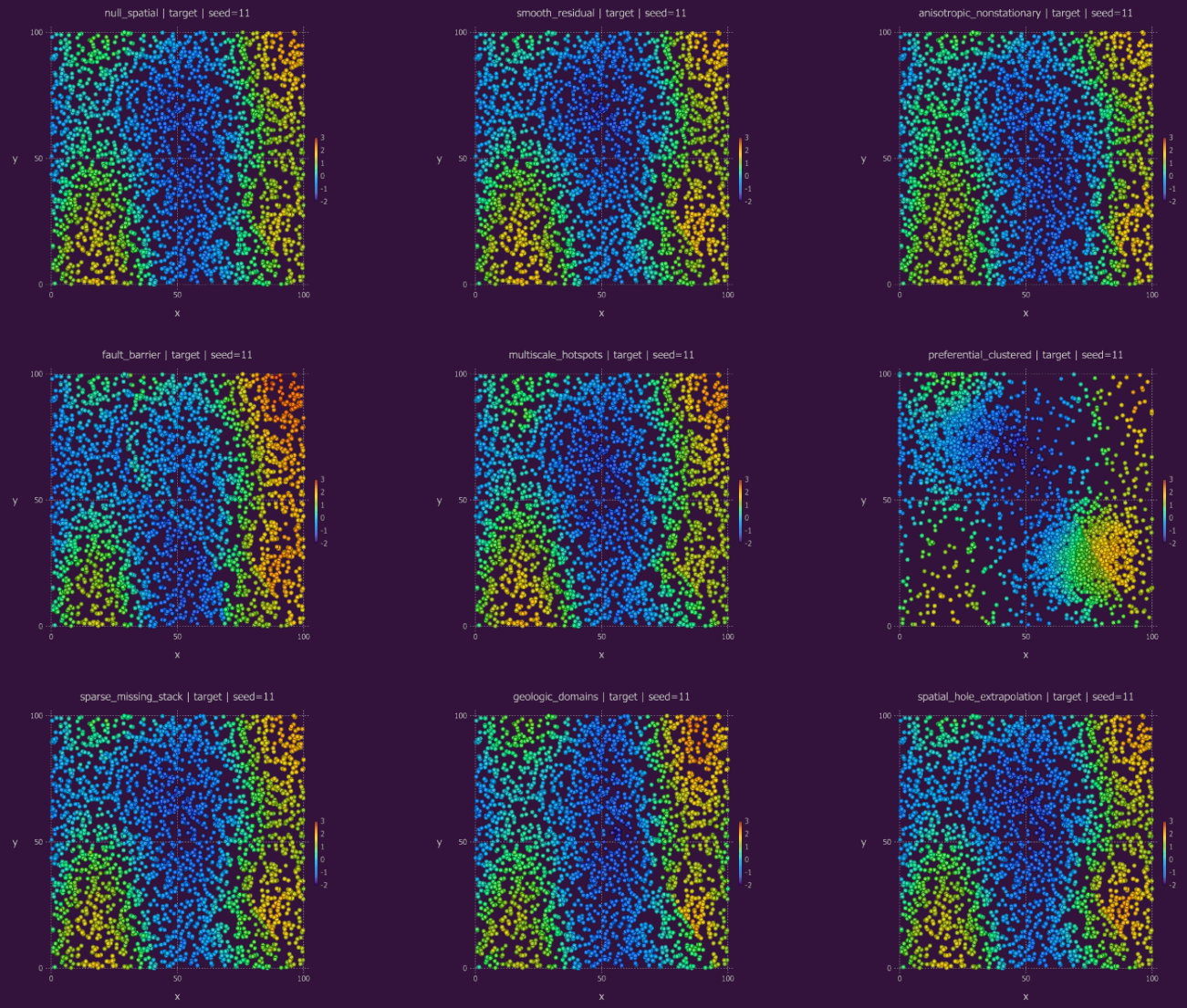

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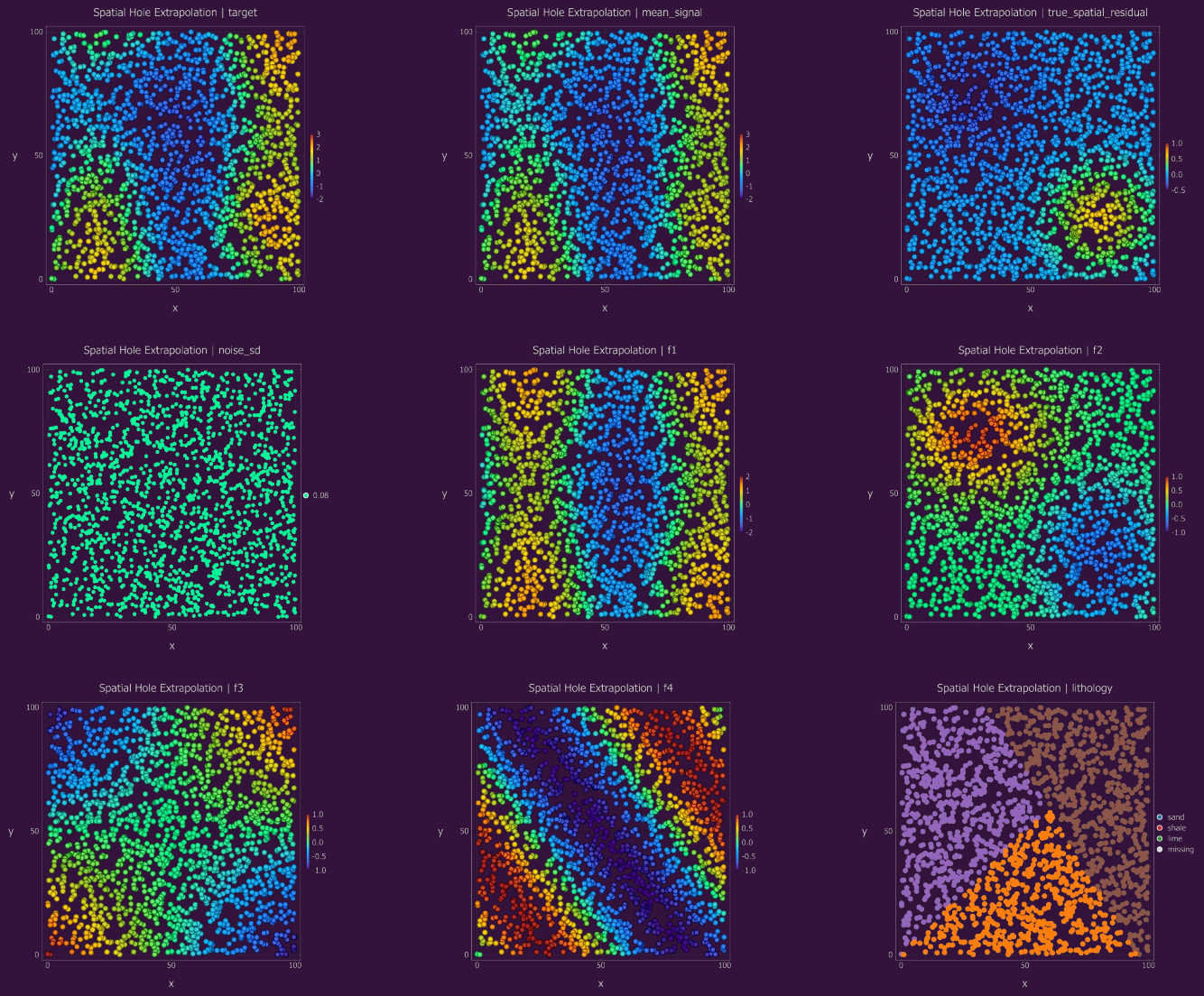
Big data gap imputation



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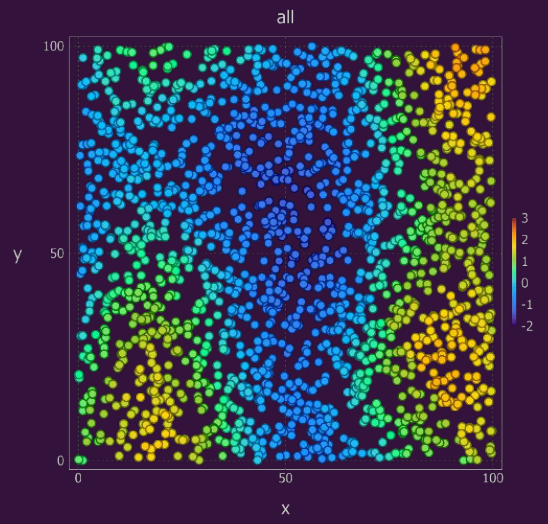

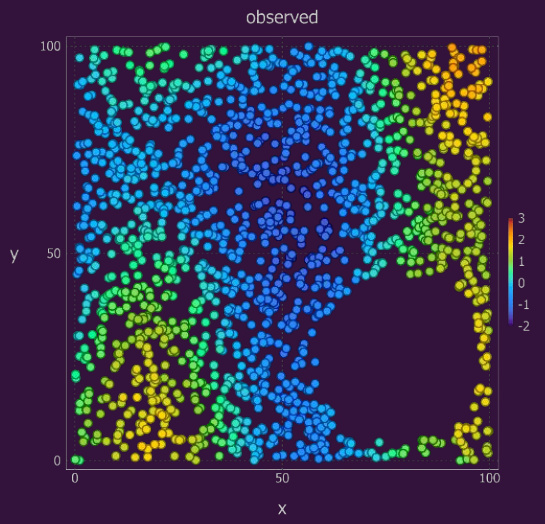

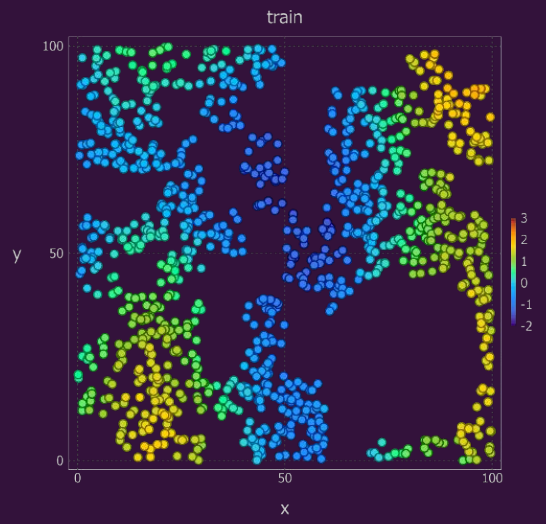

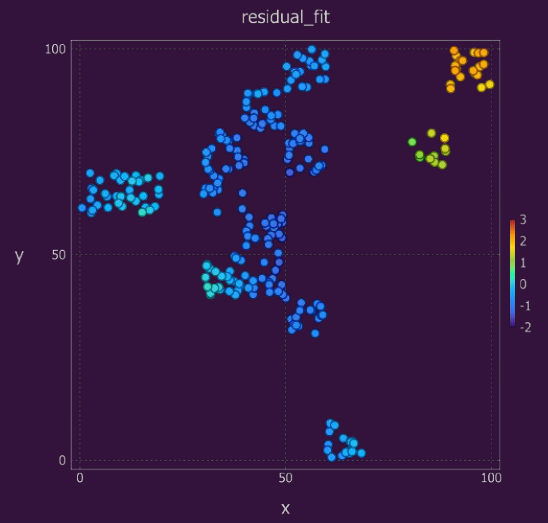

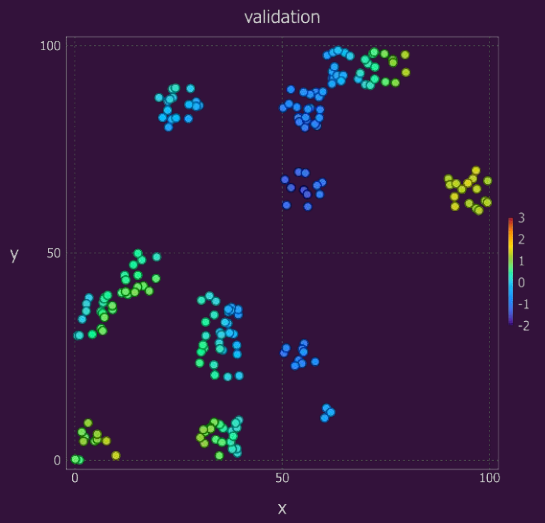

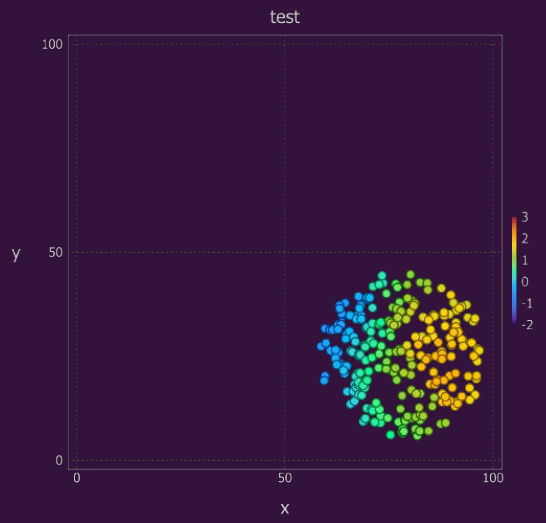

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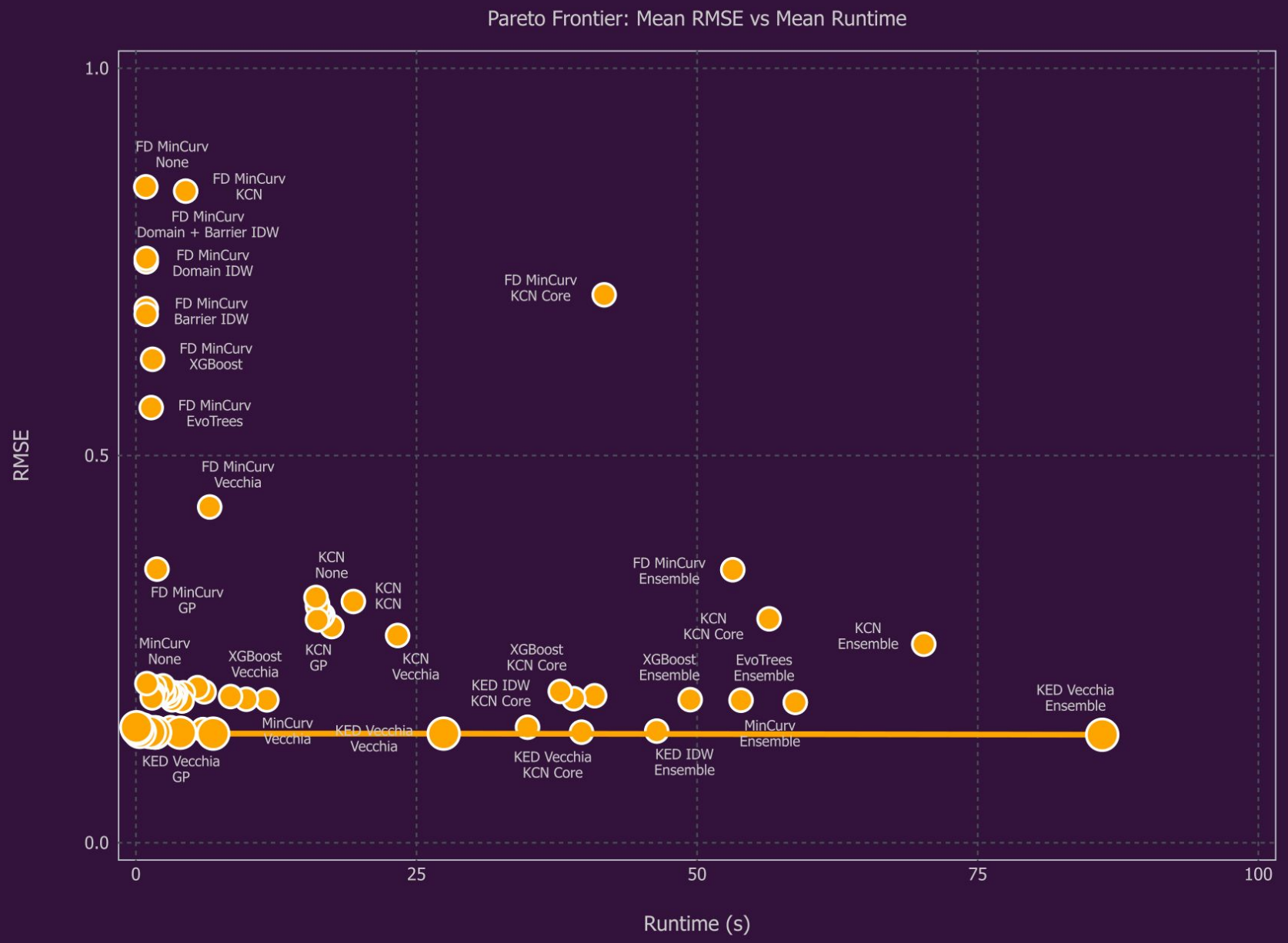
Performance



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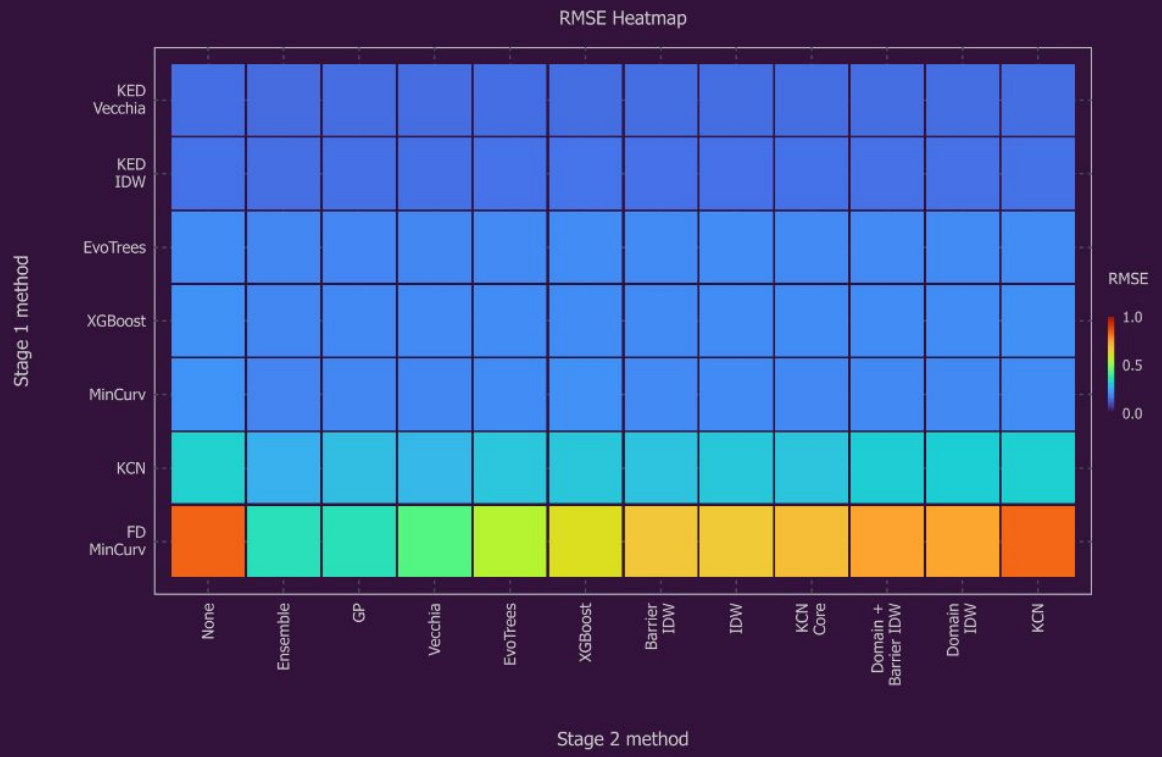

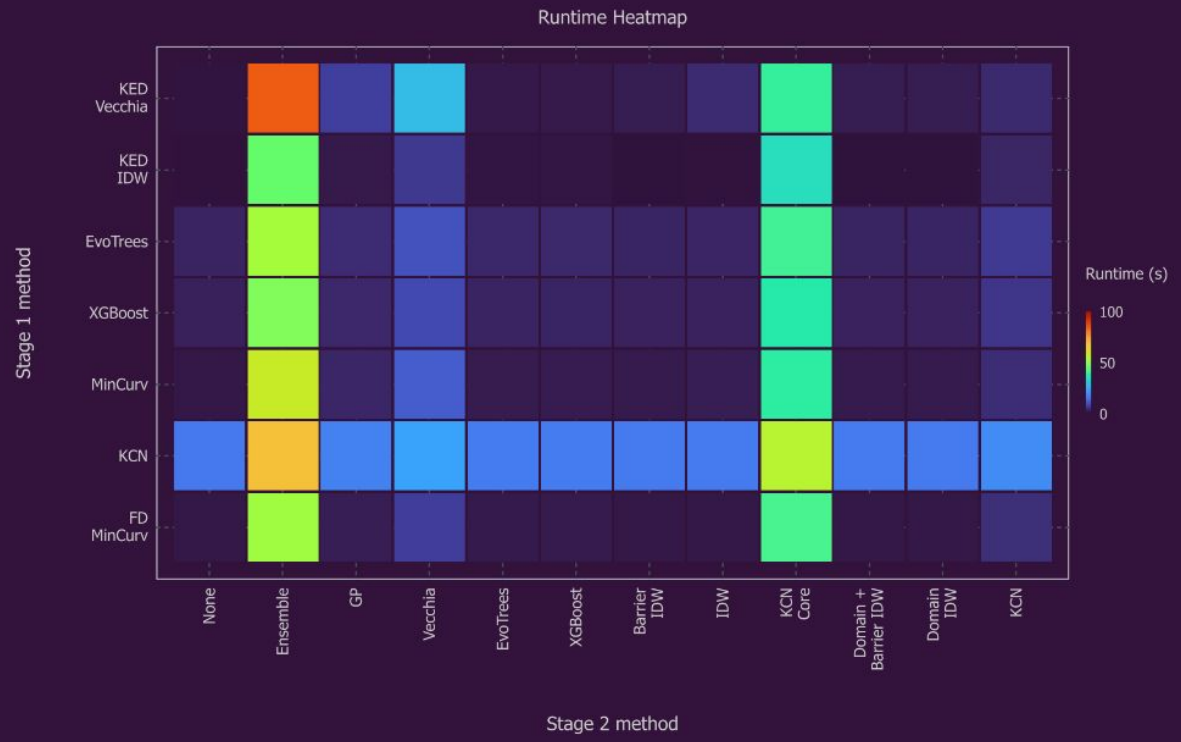

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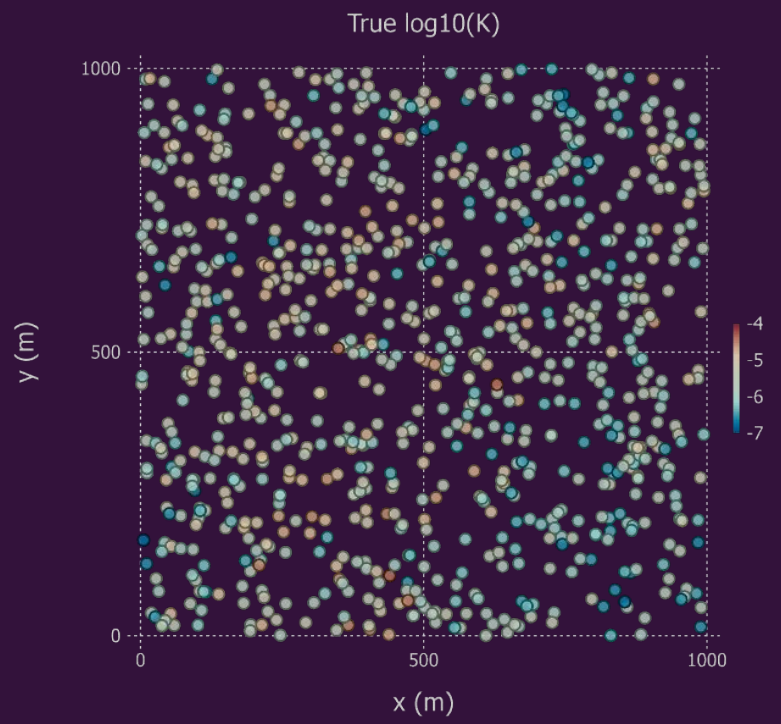
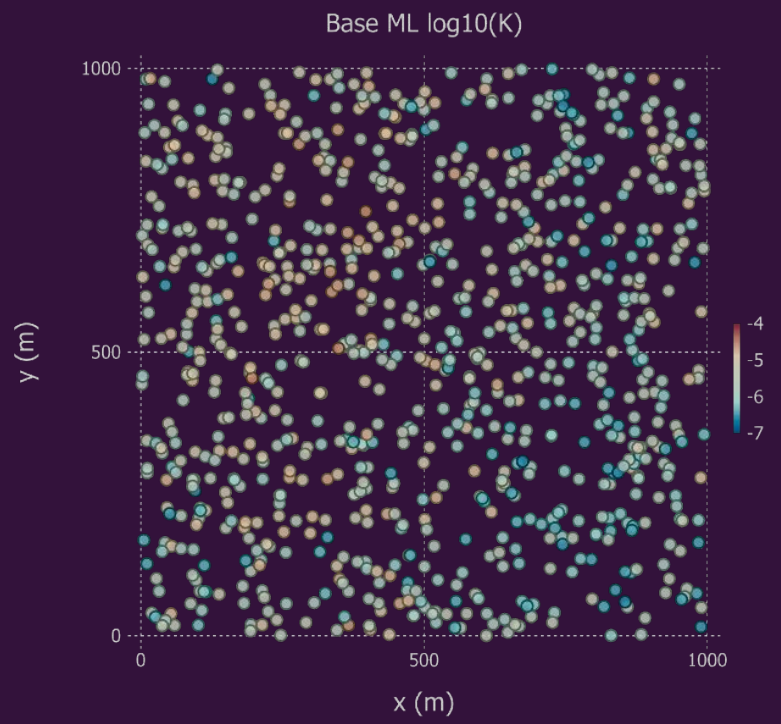
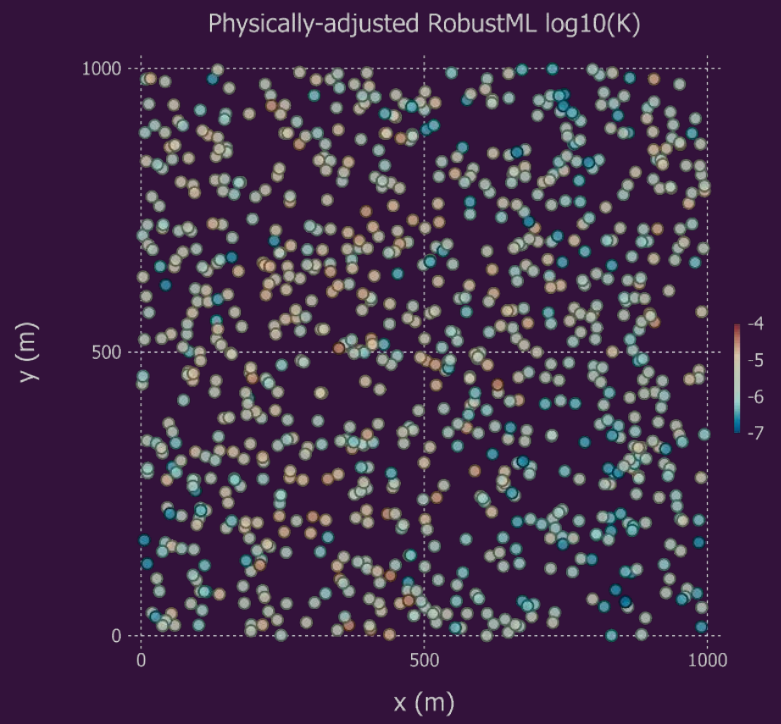
Physics layer (pumping tests)







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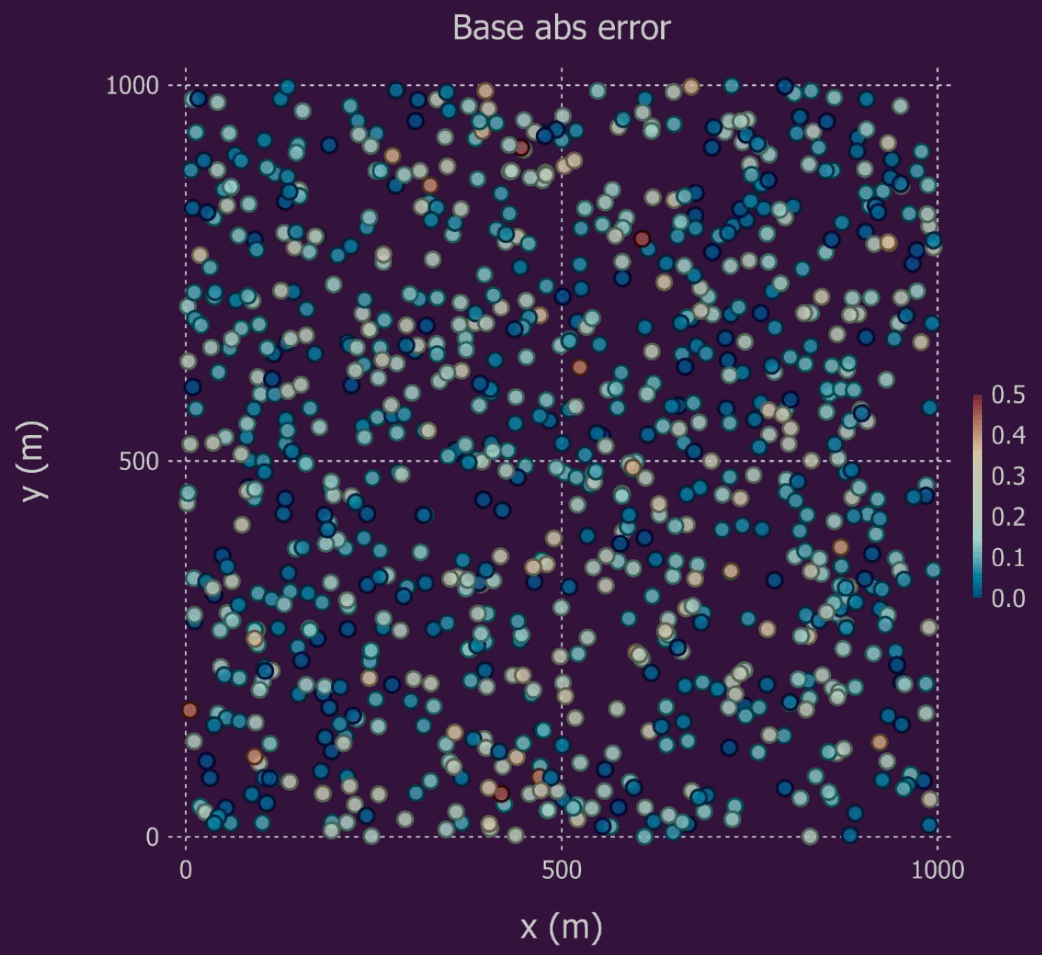

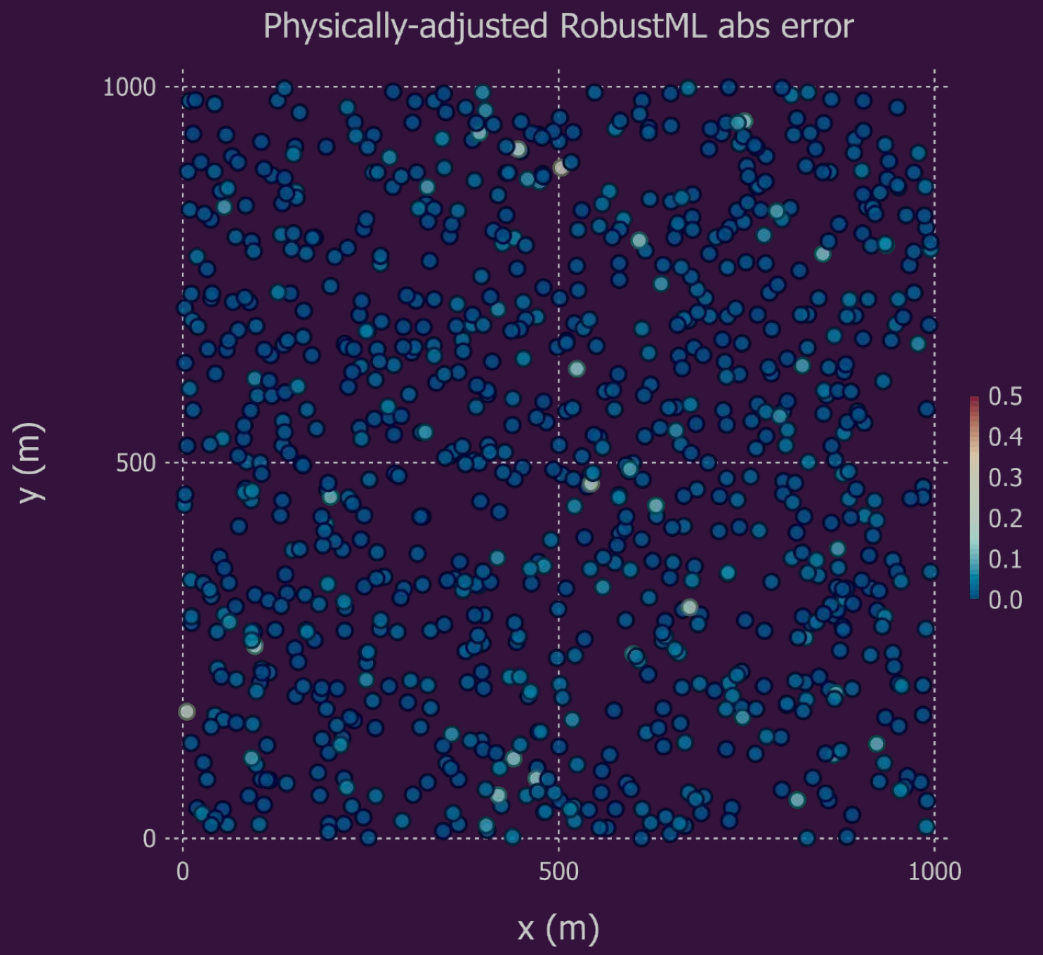

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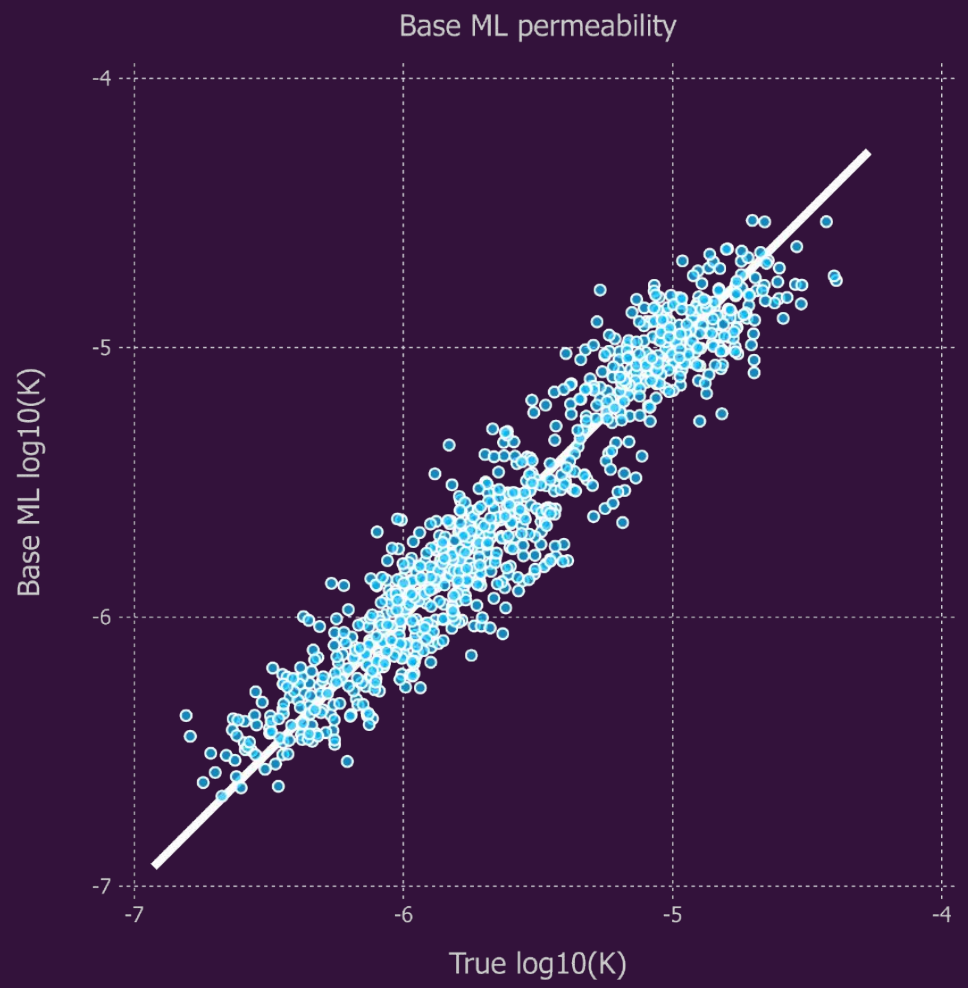

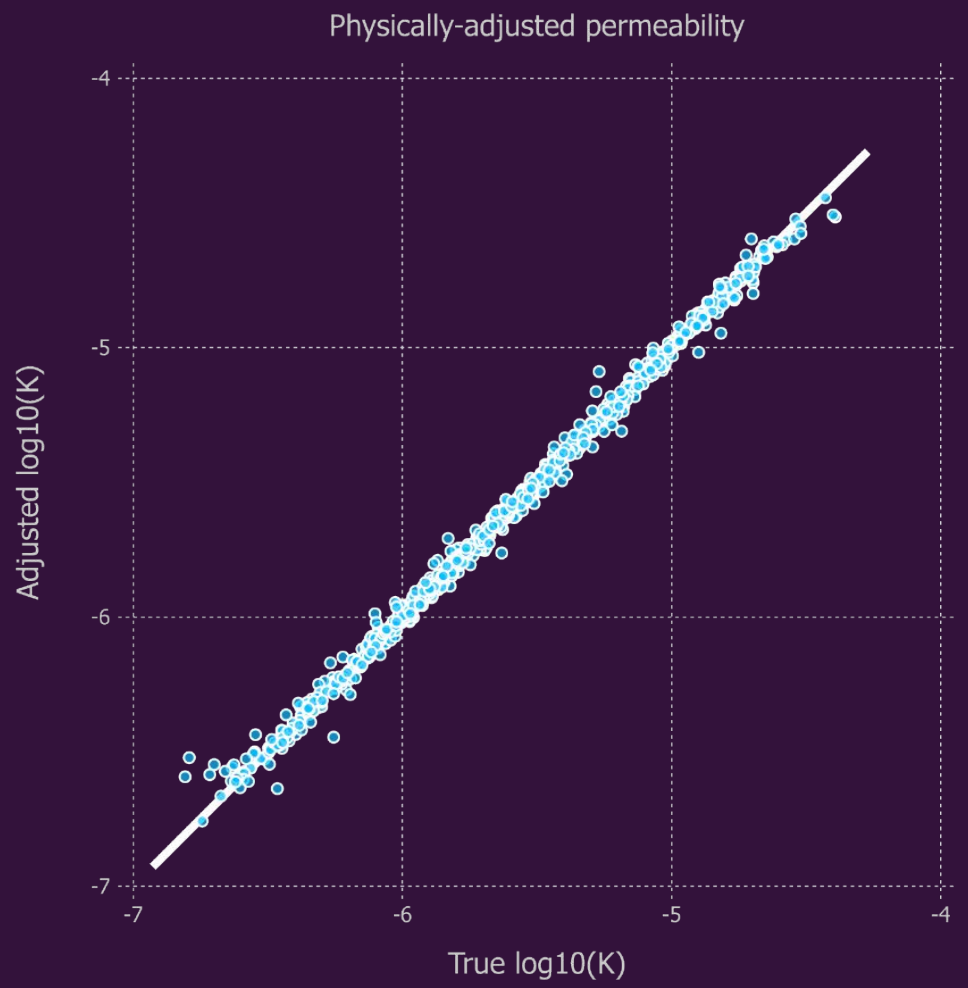

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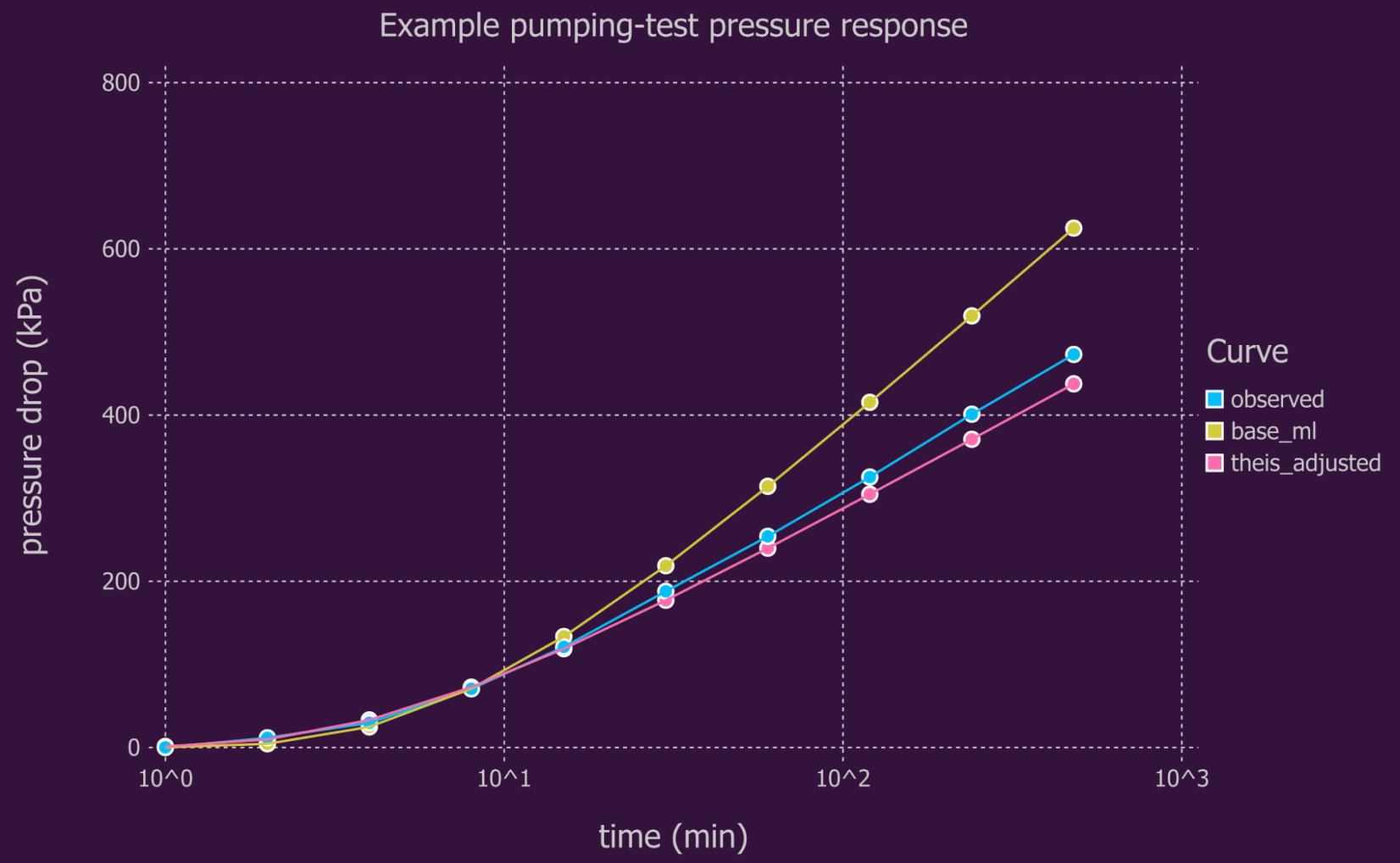

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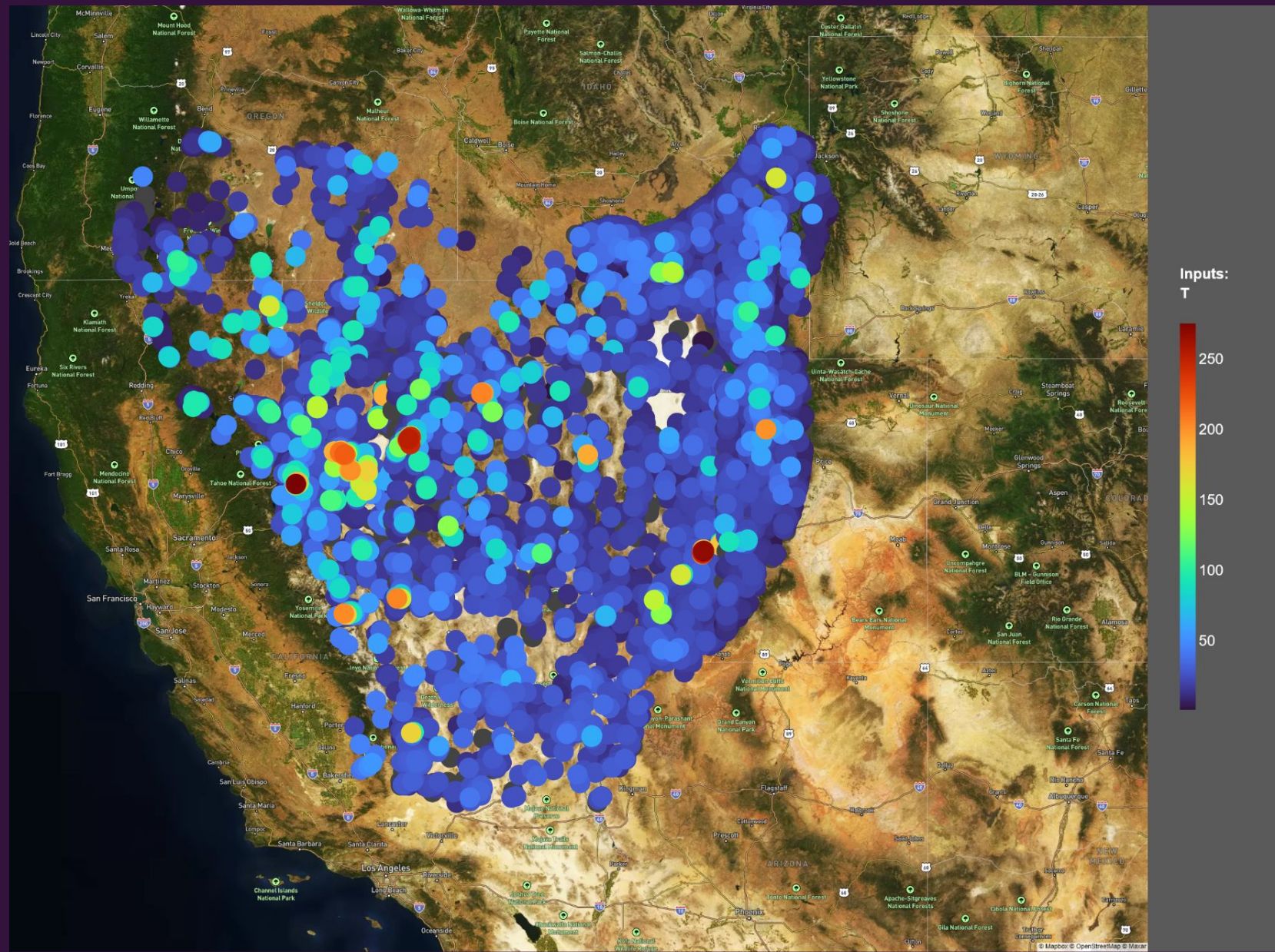
Great Basin Datasets

- Geology
- Geochemistry
- Geophysics (including GeoDAWN)

- 126 data attributes in total



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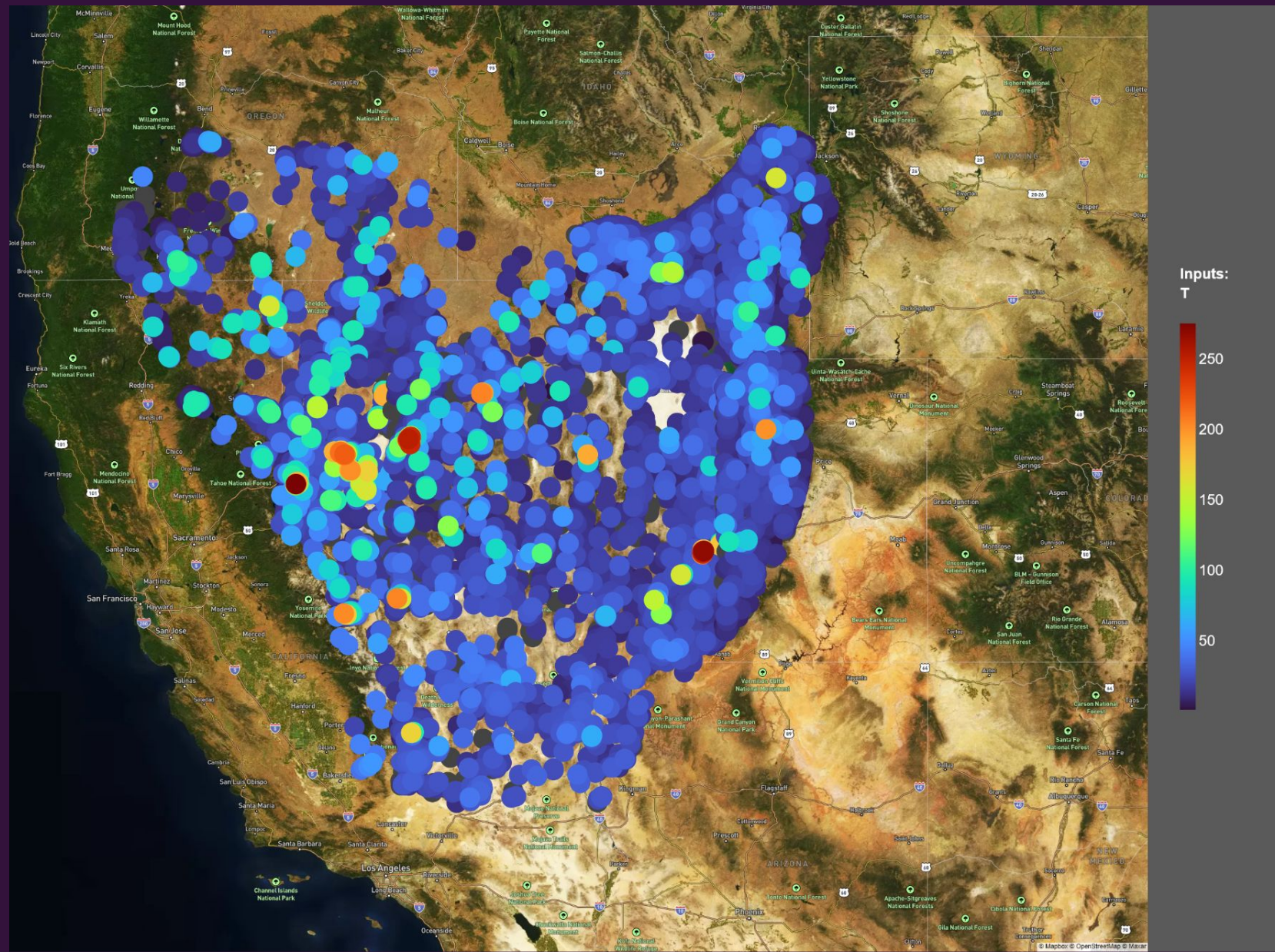
Great Basin Datasets (126 attributes in total)

- Magnetics
- Radiometry
- Gravity
- Li, Mg, Na, Fe, HCO3, SiO2, Ba, F, SO4, K, B, Ca, Cl, As, …
- Heat flow
- Favorable Geothermal Structural Settings (INGENIOUS project)
- Quaternary Faults
- Well & Spring Chemistry
- Principal Aquifers



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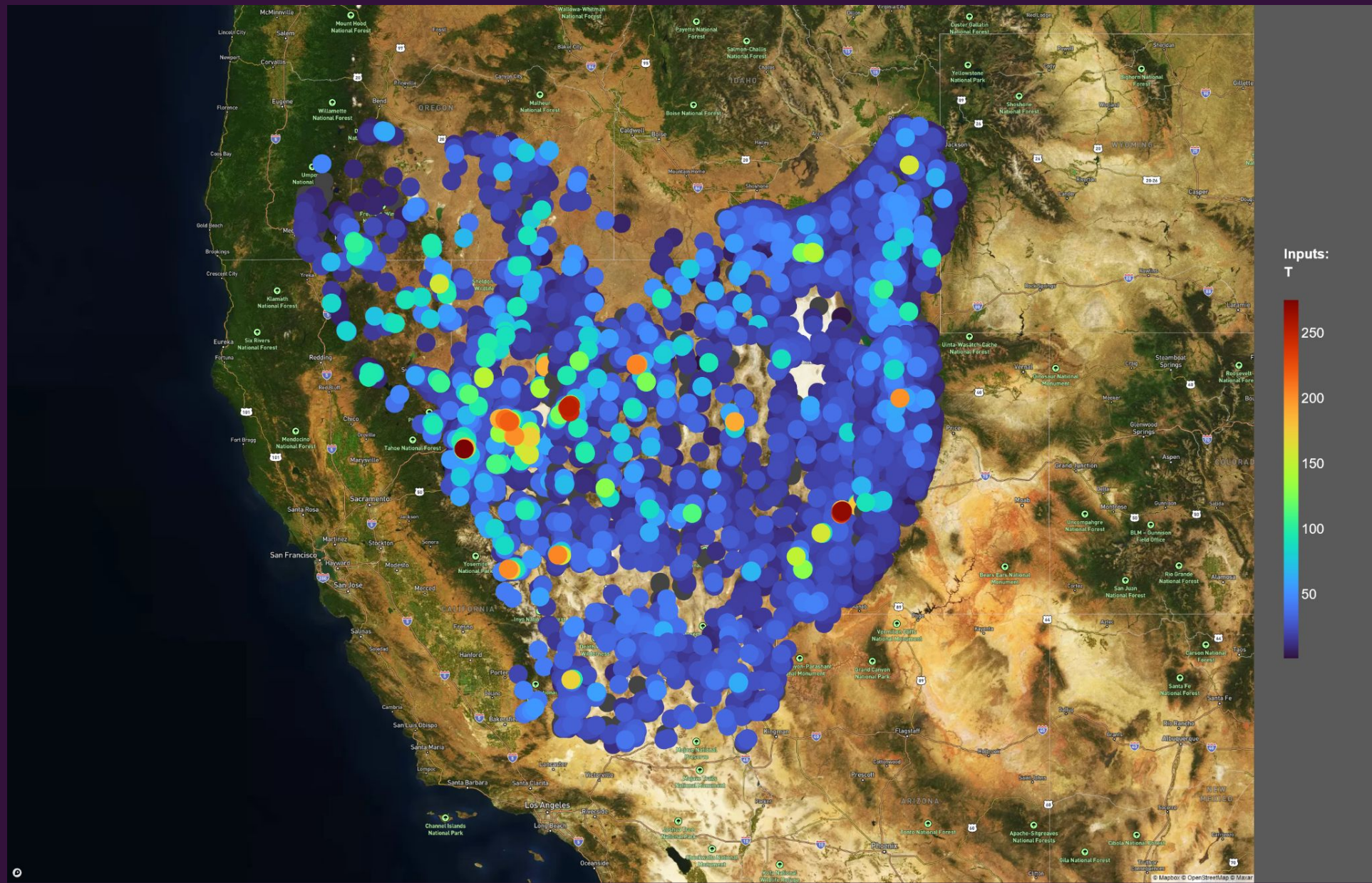
Temperature [C]



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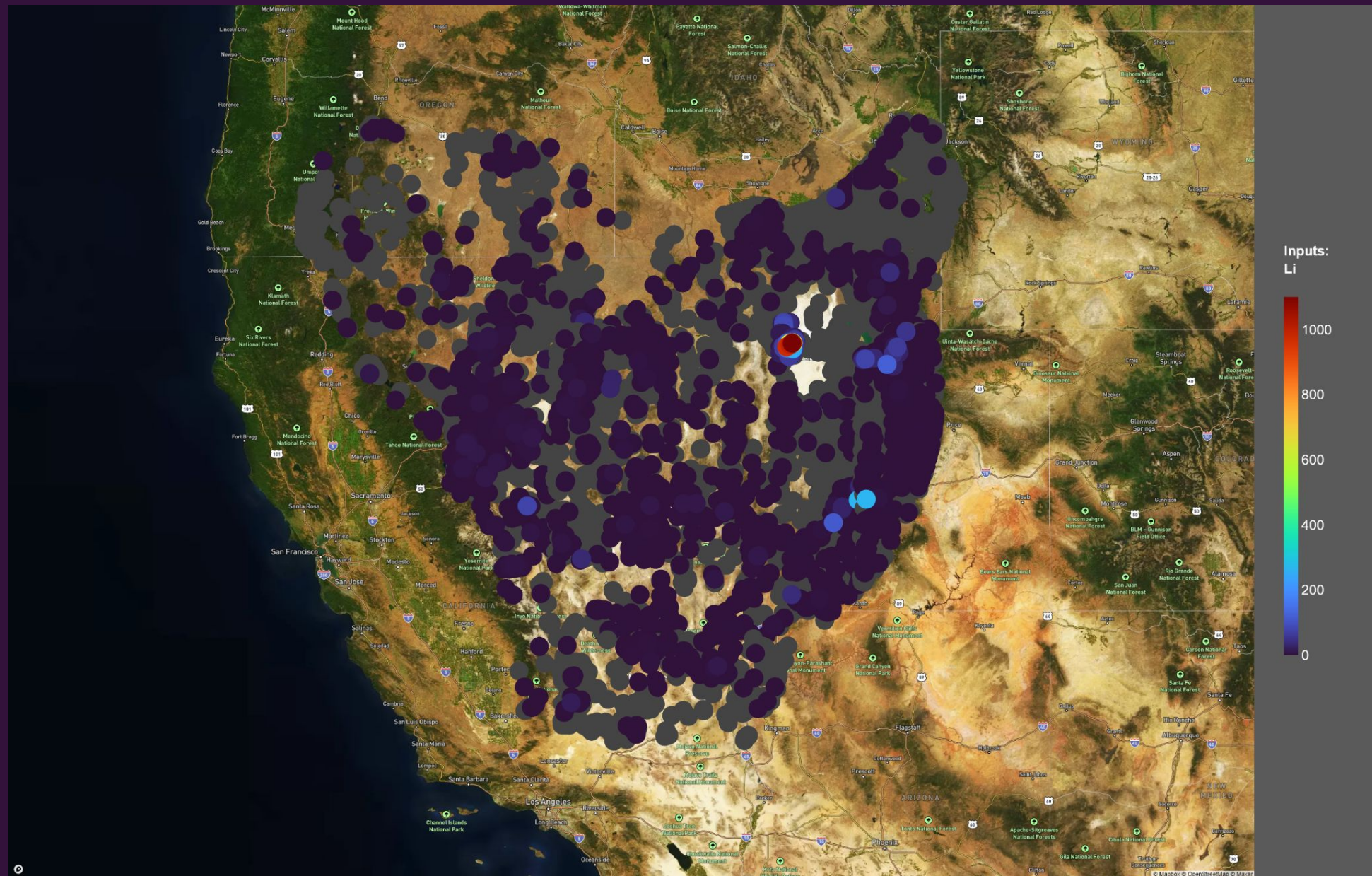
Lithium [ppb]



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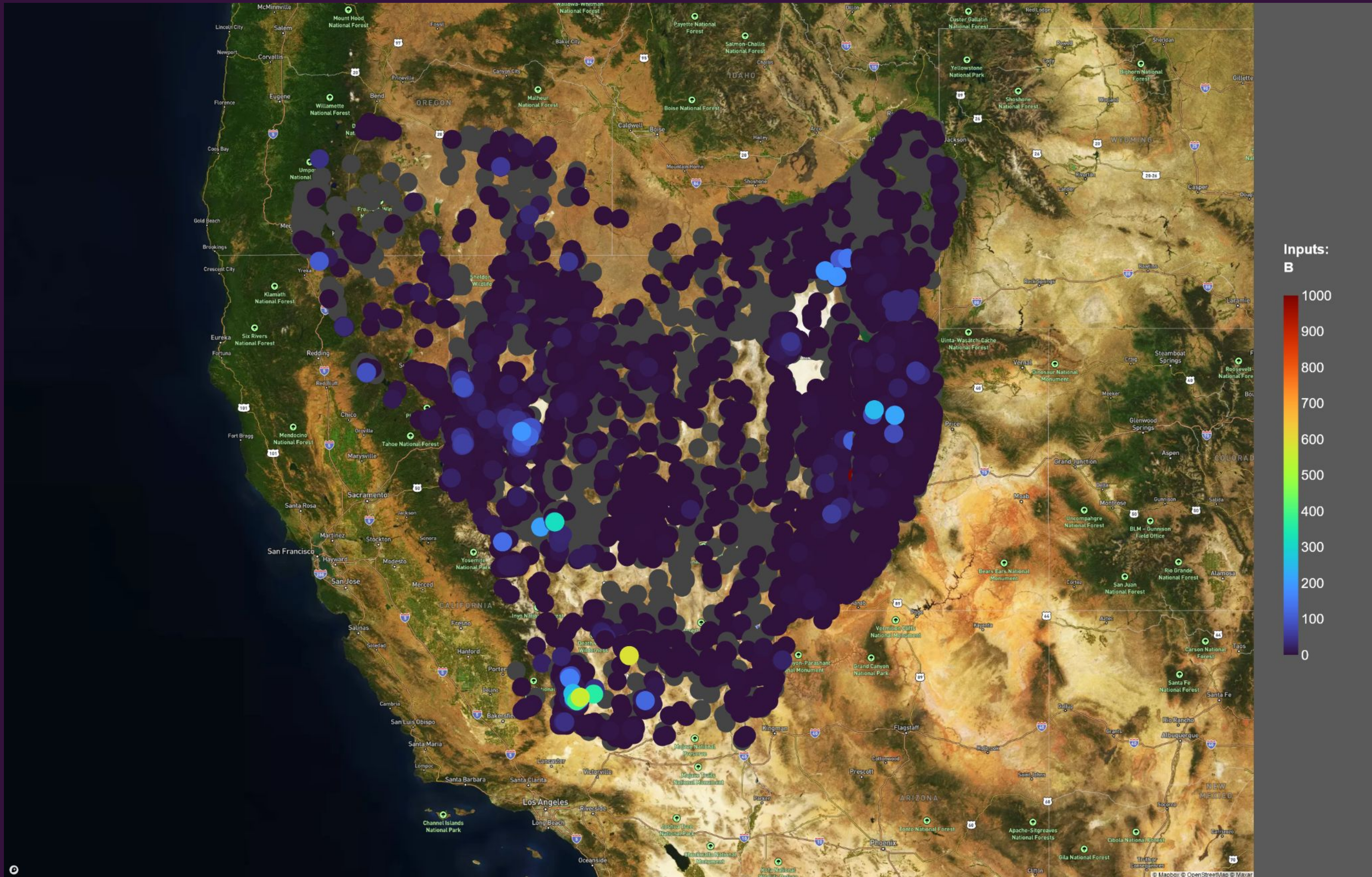
Boron [ppb]



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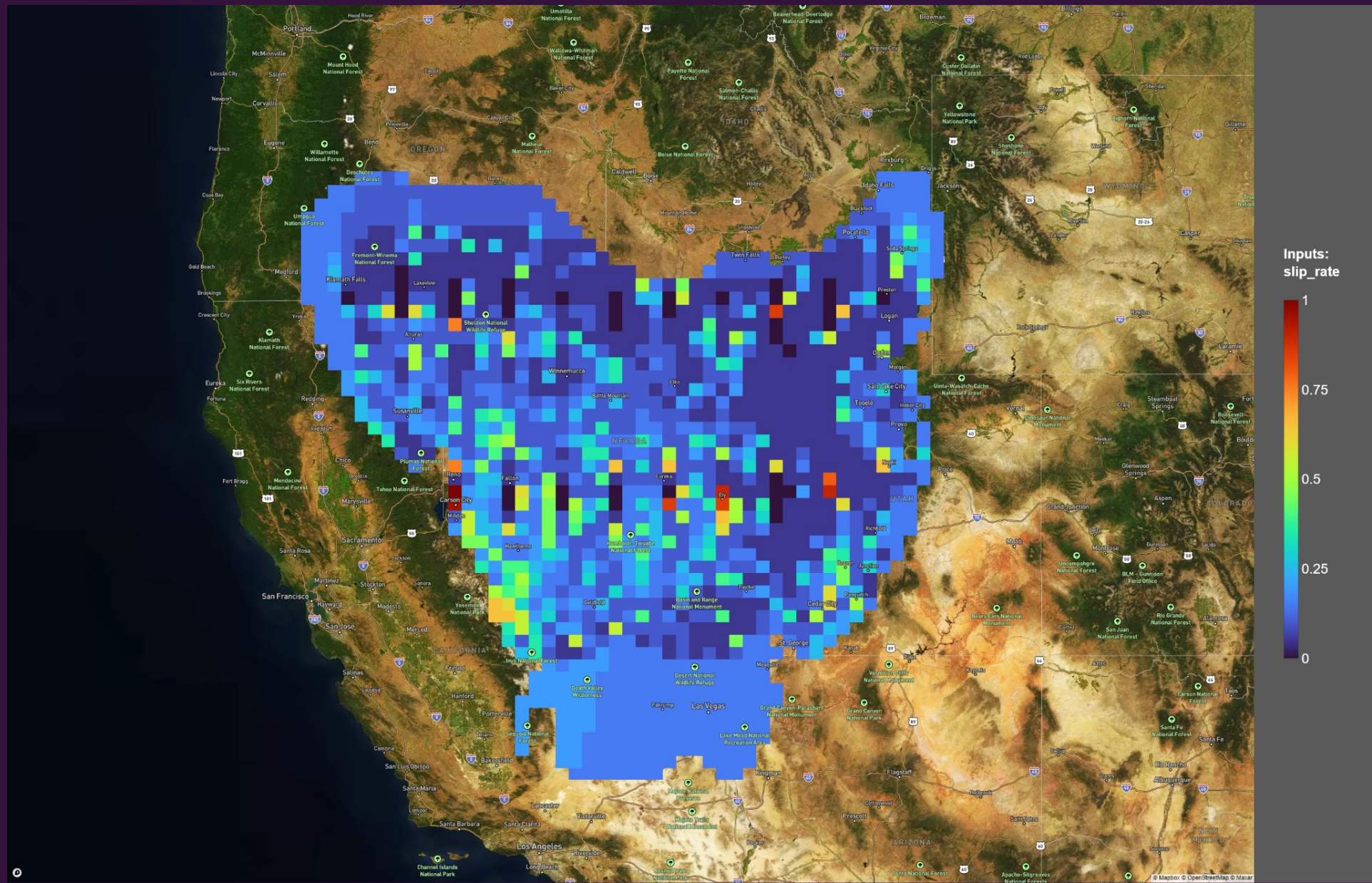
Fault Densities: Slip rate



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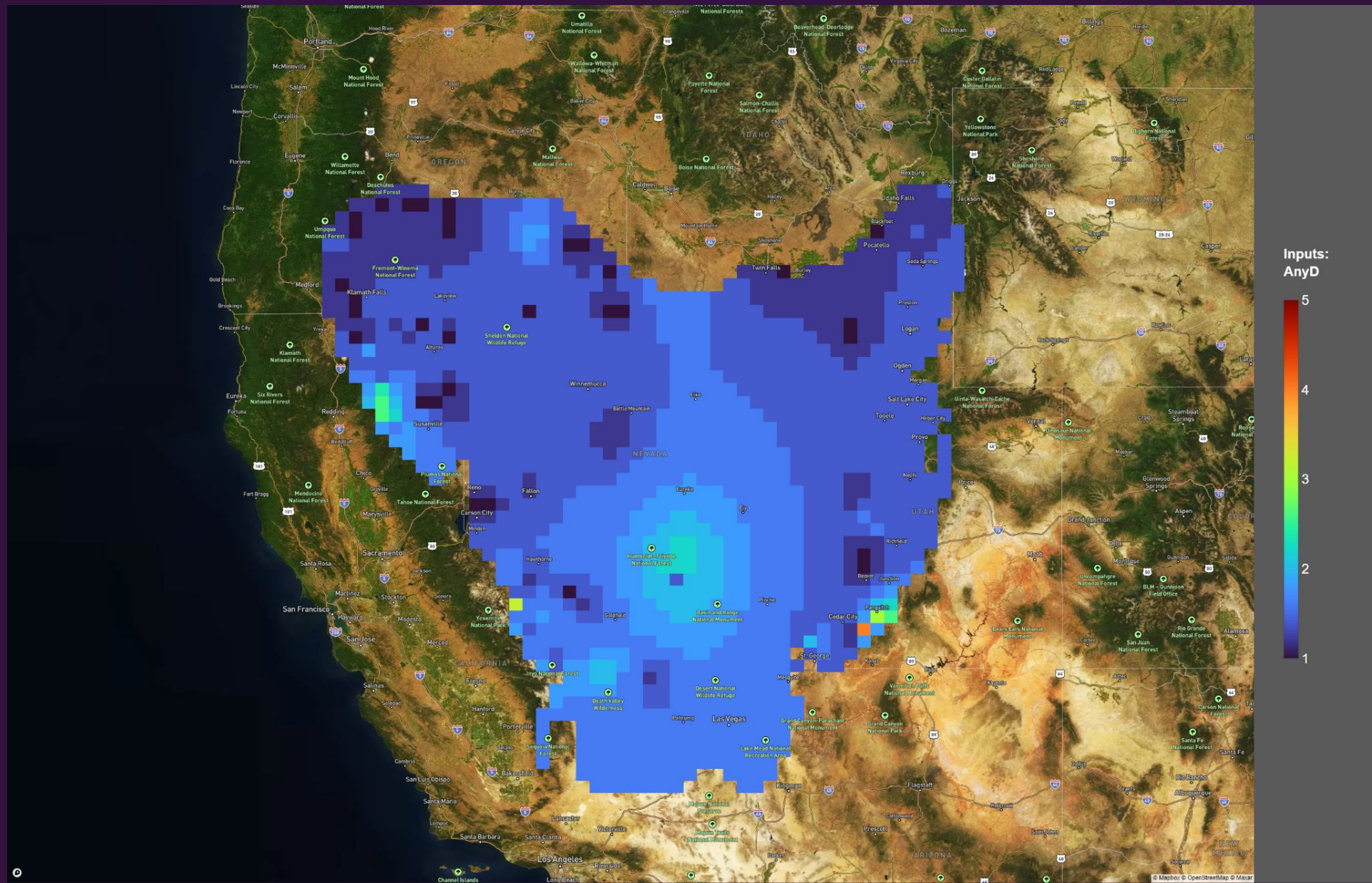
Quaternary Vent Densities



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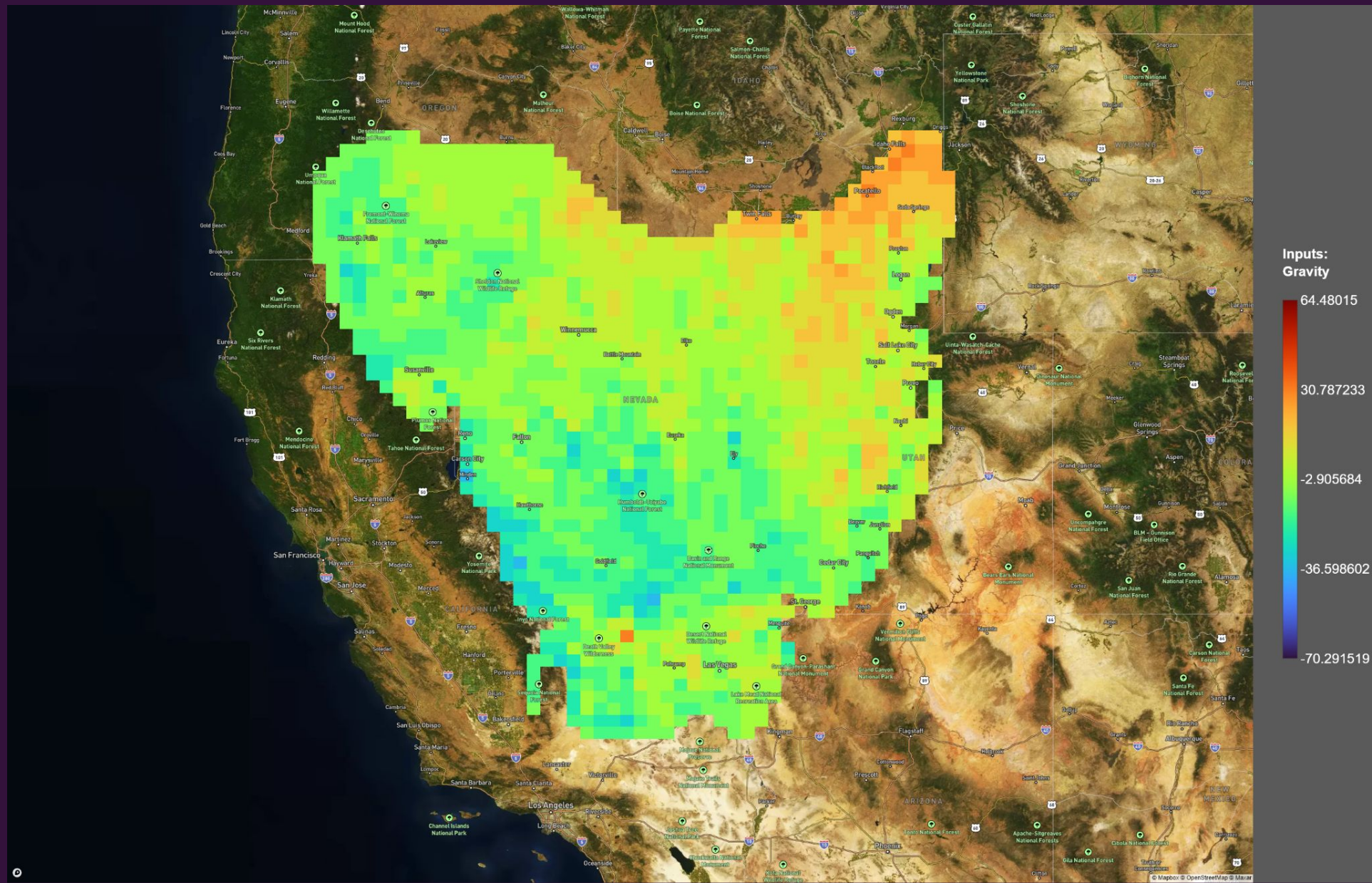
Gravity



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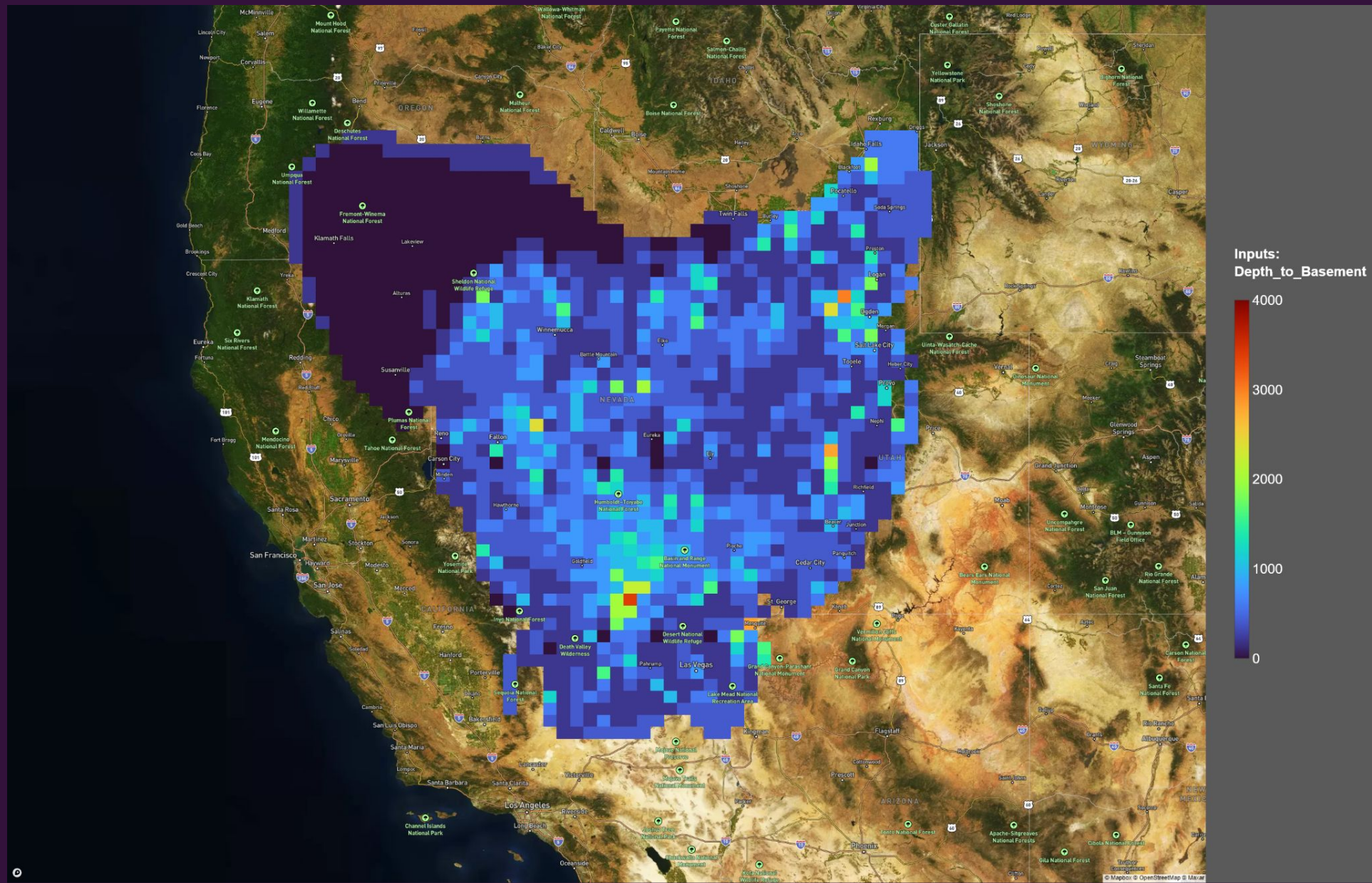
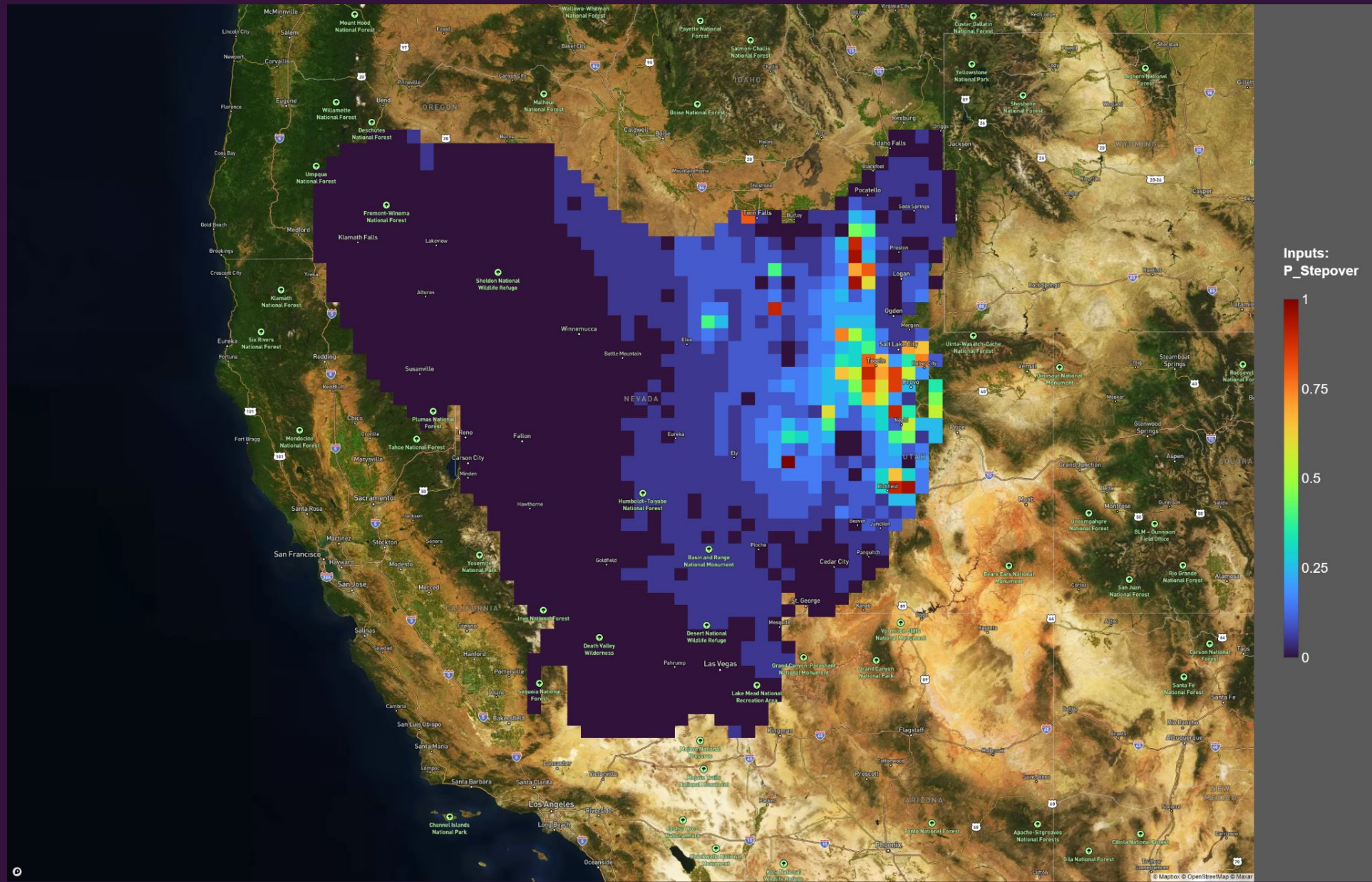
Depth to Basement



Fault Structure Densities: Stepover



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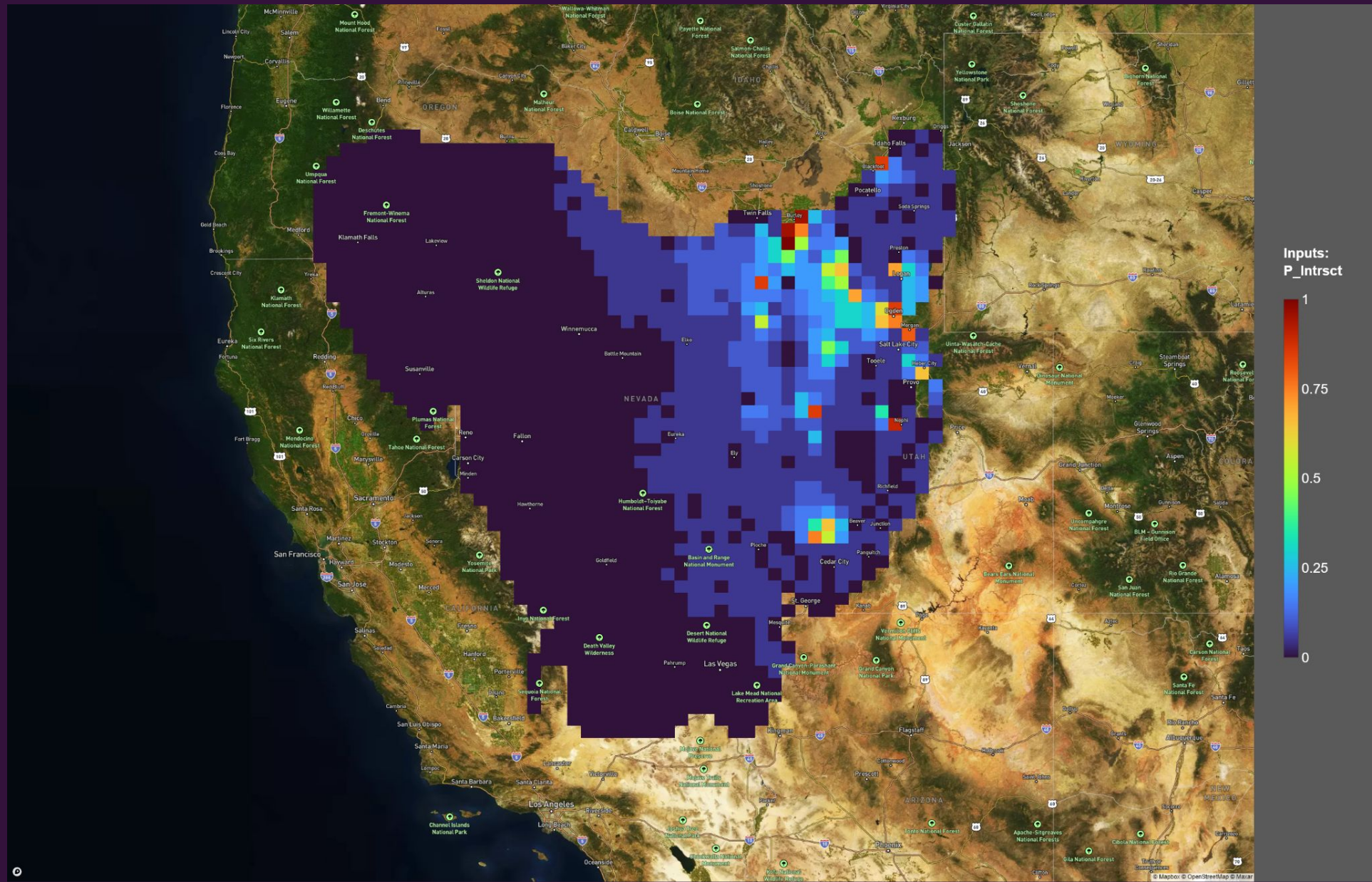
Fault Structure Densities: Intersections



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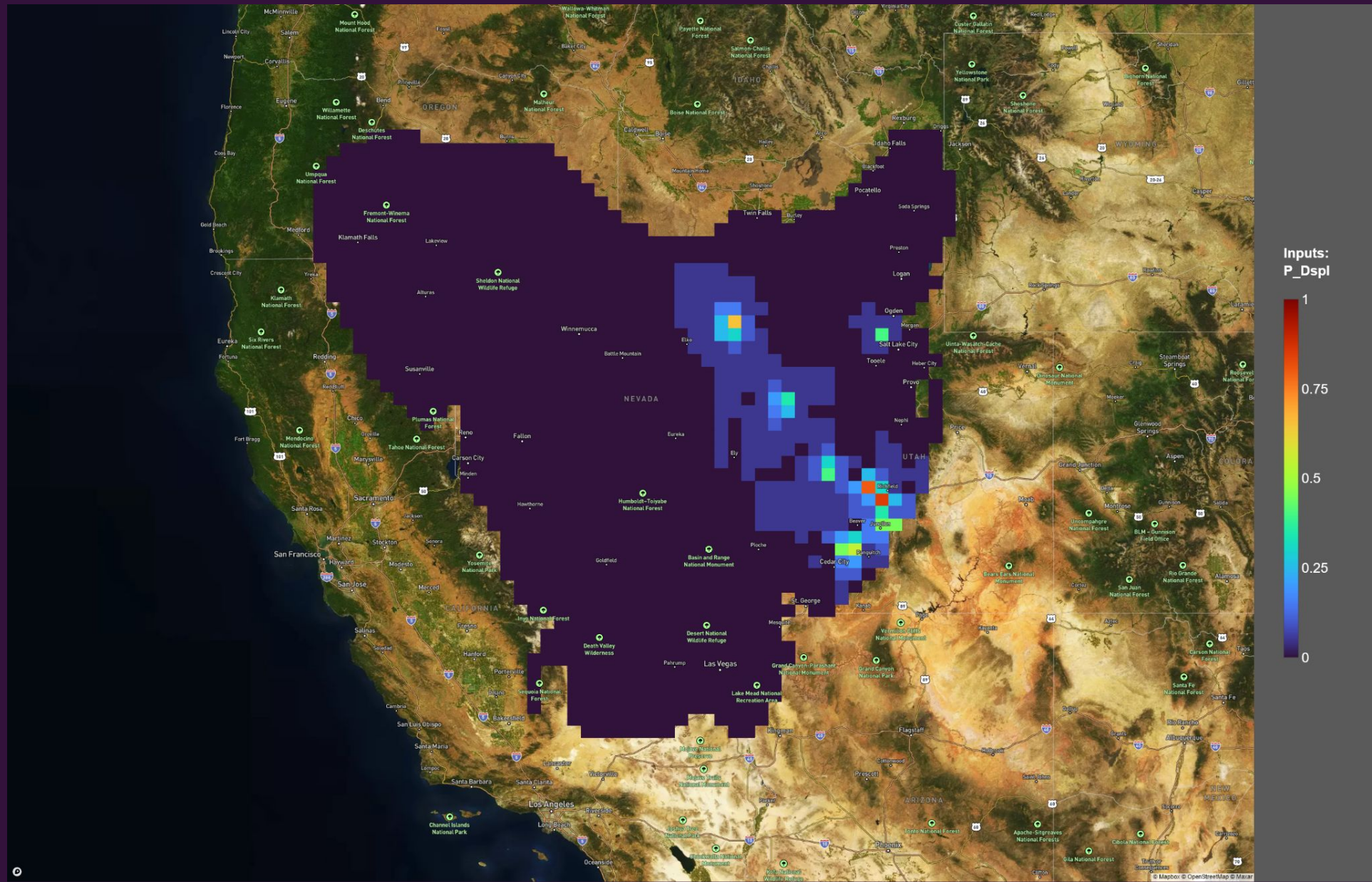
Fault Structure Densities: Displacements



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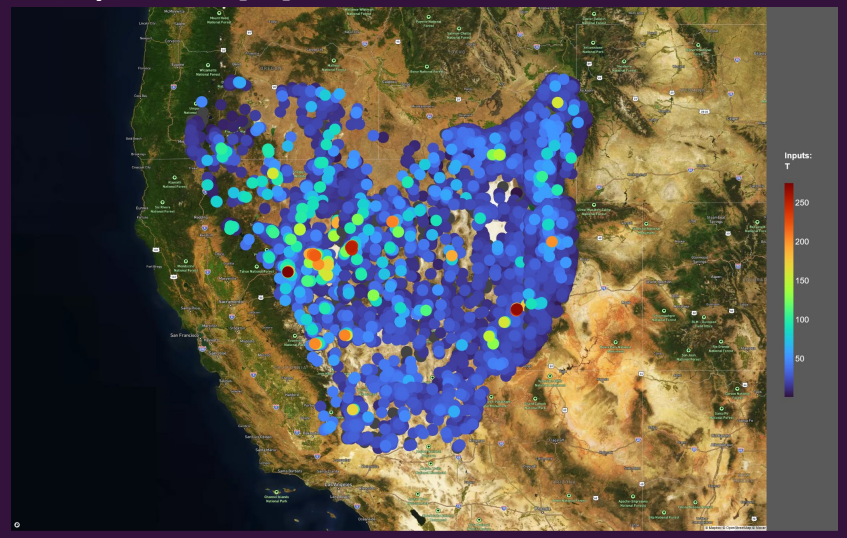
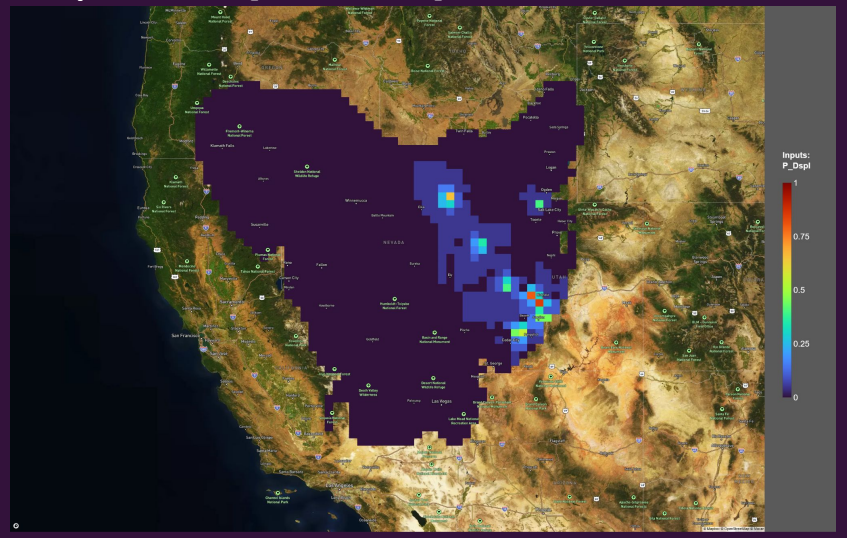
Finding a Needle in a Haystack

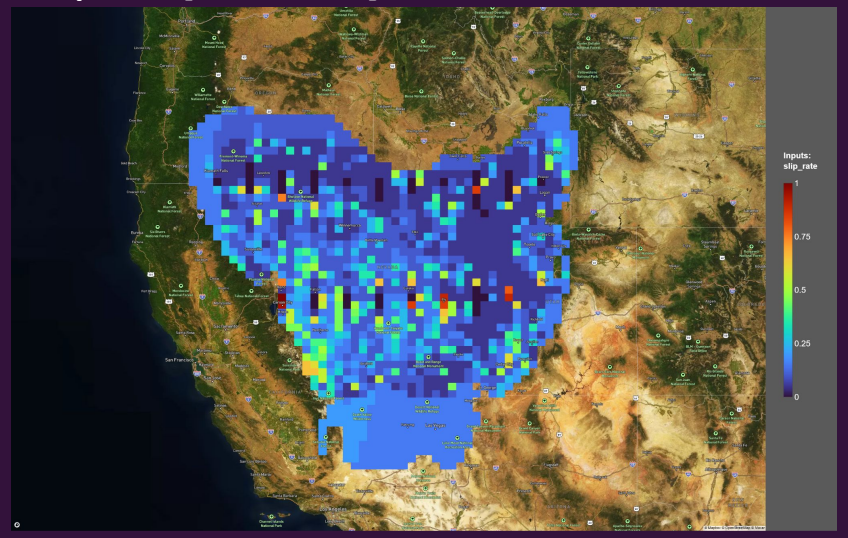
Temperature [°C]



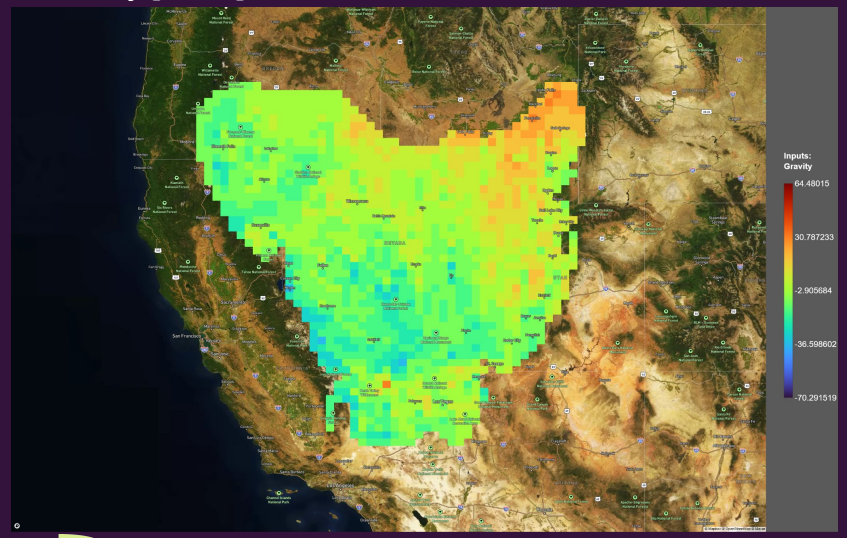
Displacement [normalized]



Slep Rate [normalized]

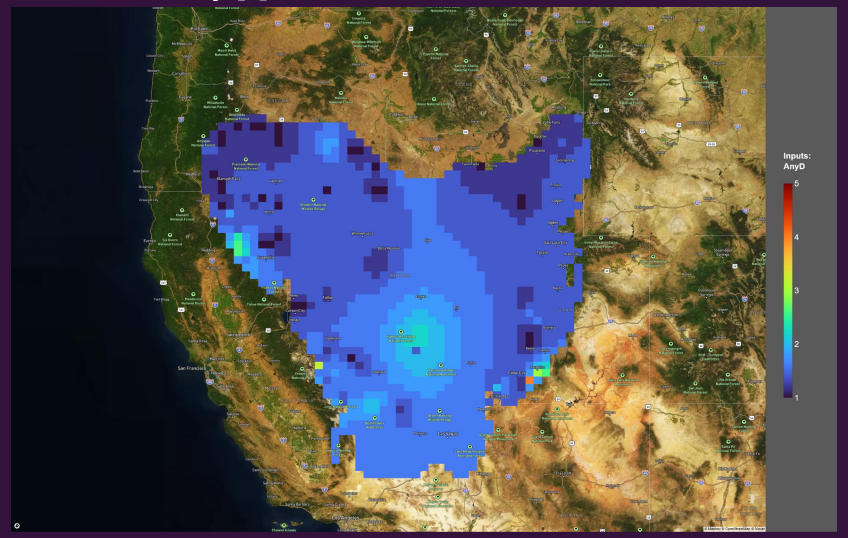


Gravity [m/s^2]



Magnetics [nT]

Vent Density [-]



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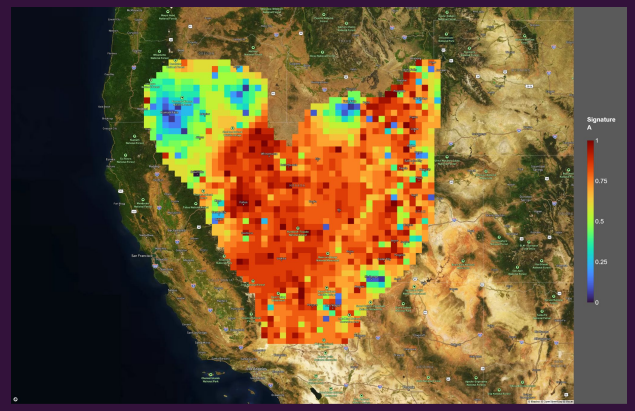
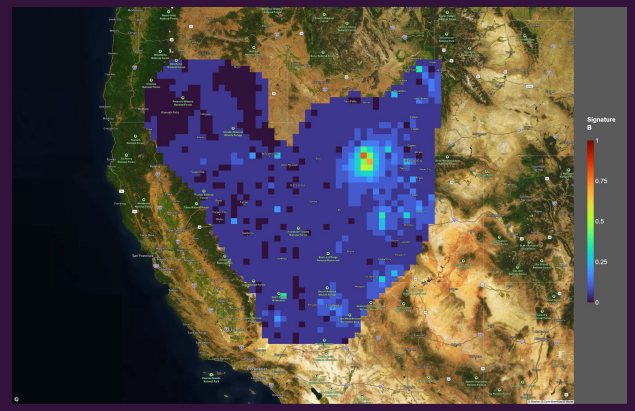
Signatures

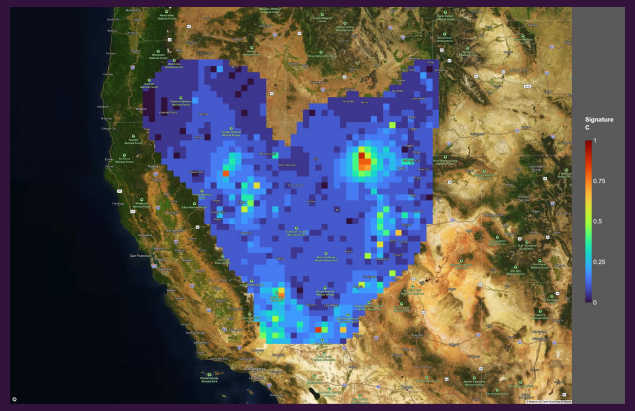
C14/Basement Depth



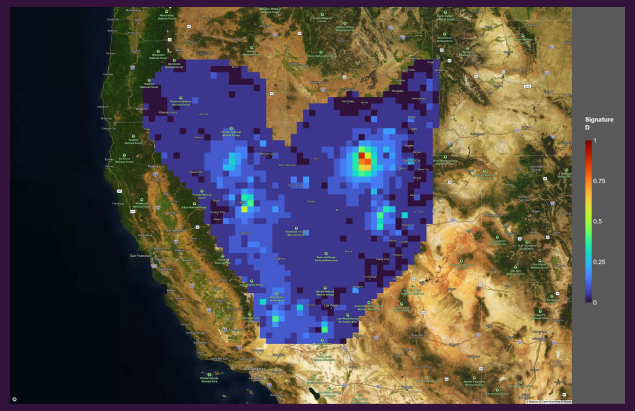
Radon



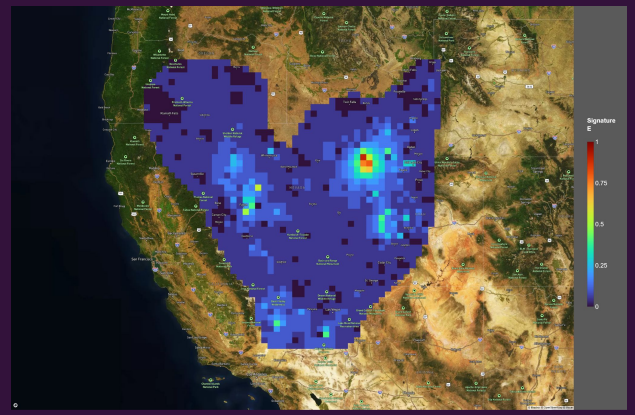
TDS/Conductivity



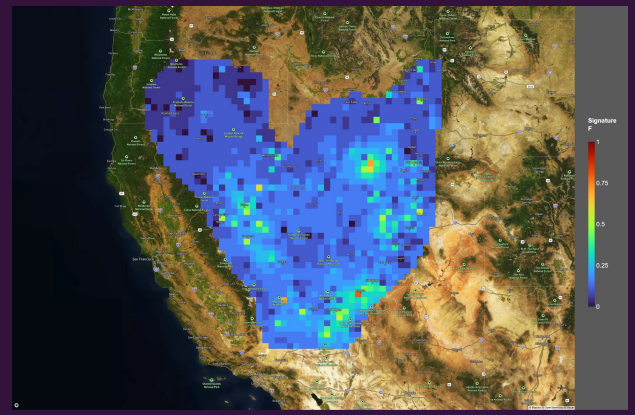
Technetium-99



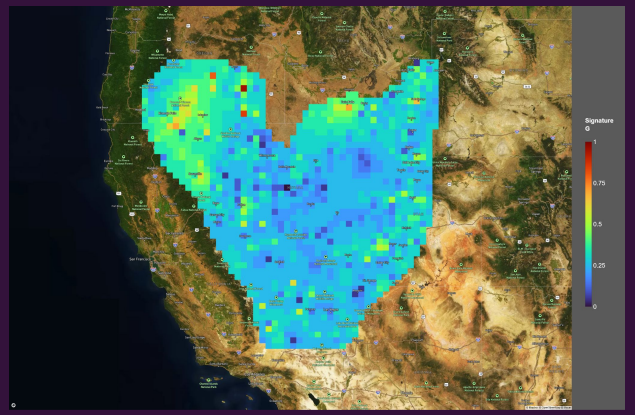
Li/Cl



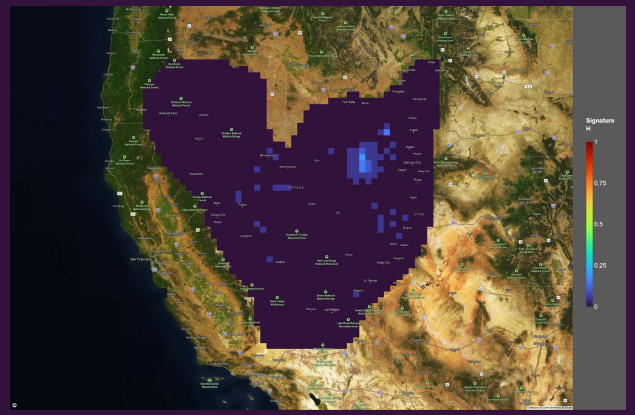
Carbonate hardness



T/B/Stepover Faults

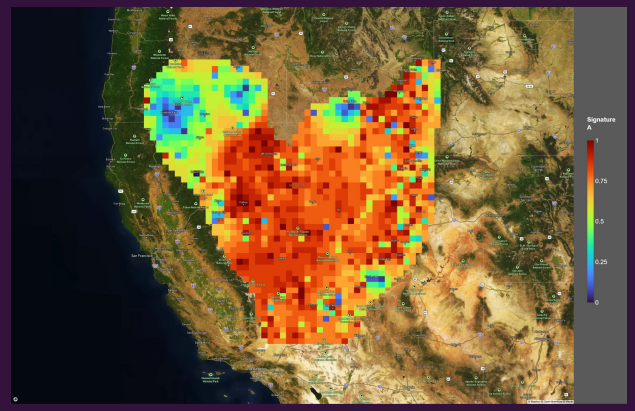


Na/Ca/Mg

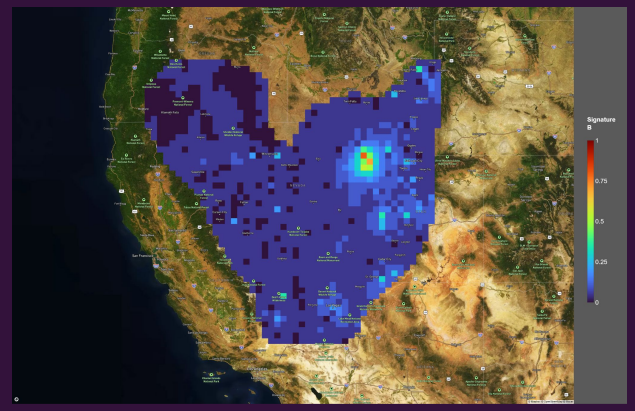


Signatures

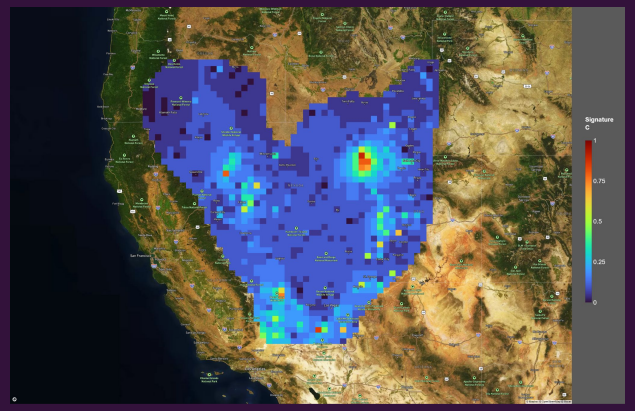
C14/Basement Depth



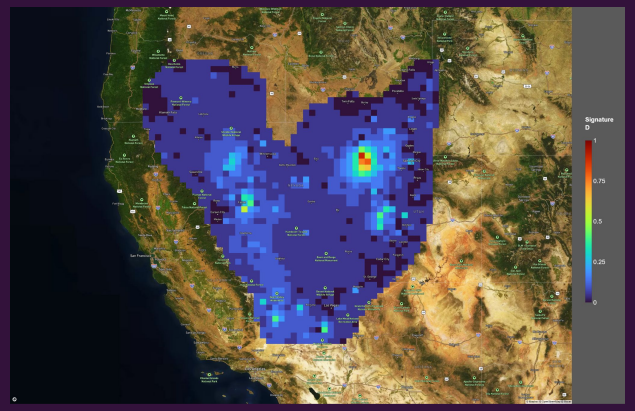
Radon



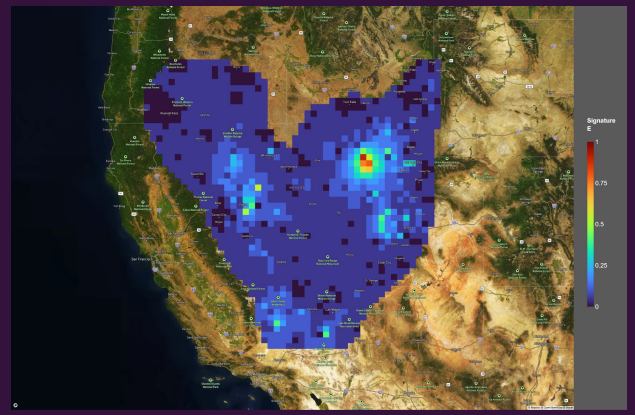
TDS/Conductivity



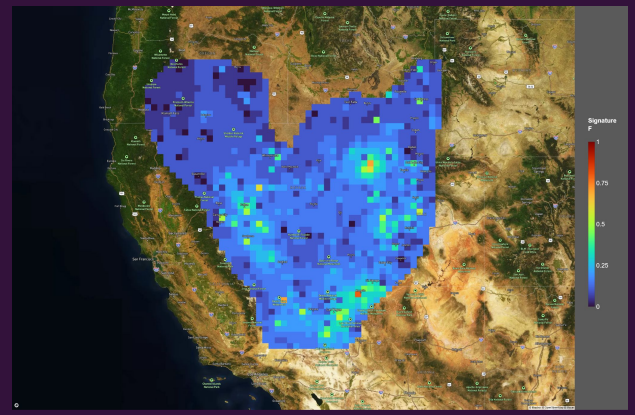
Technetium-99



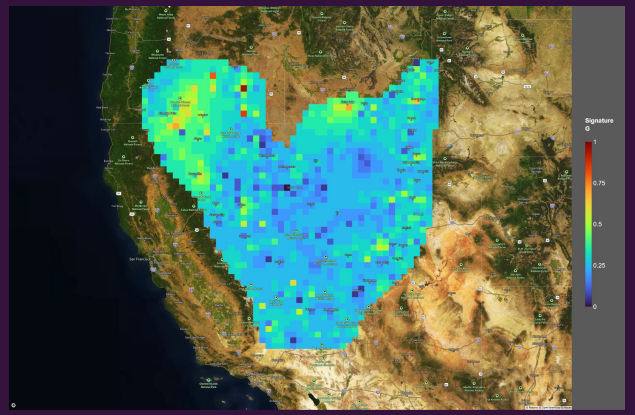
Li/Cl



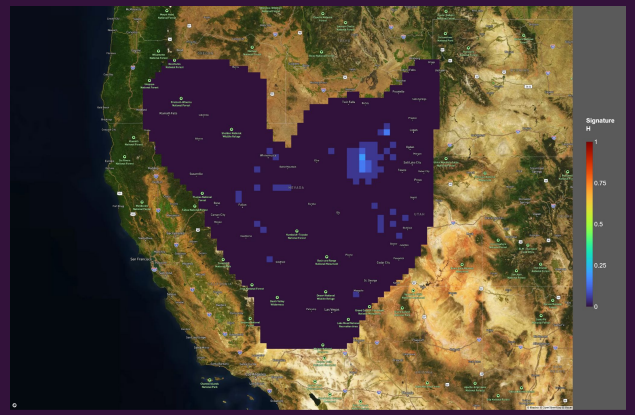
Carbonate hardness



T/B/Stepover Faults

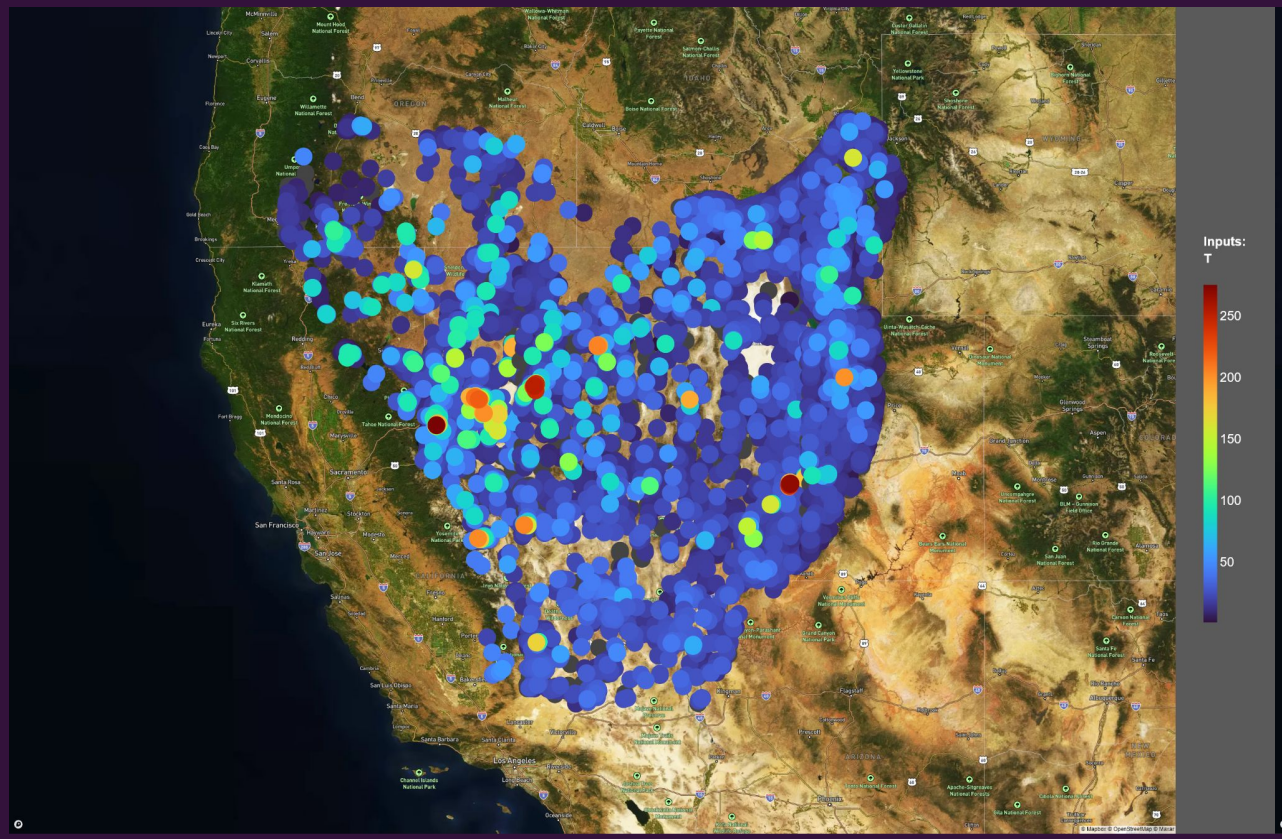


Na/Ca/Mg

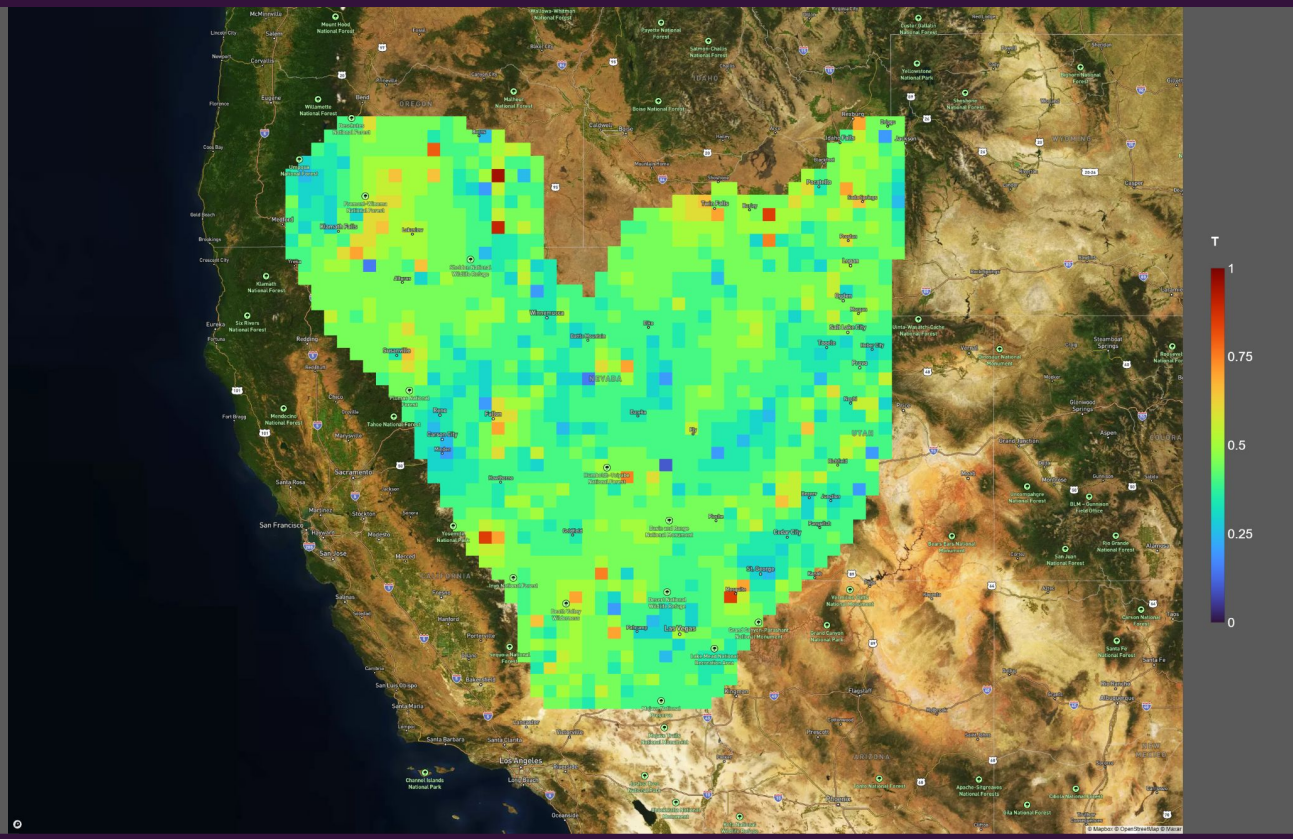


Geothermal Temperature: Data vs Prospectivity

Temperature [°C]



Geothermal Prospectivity [normalized]



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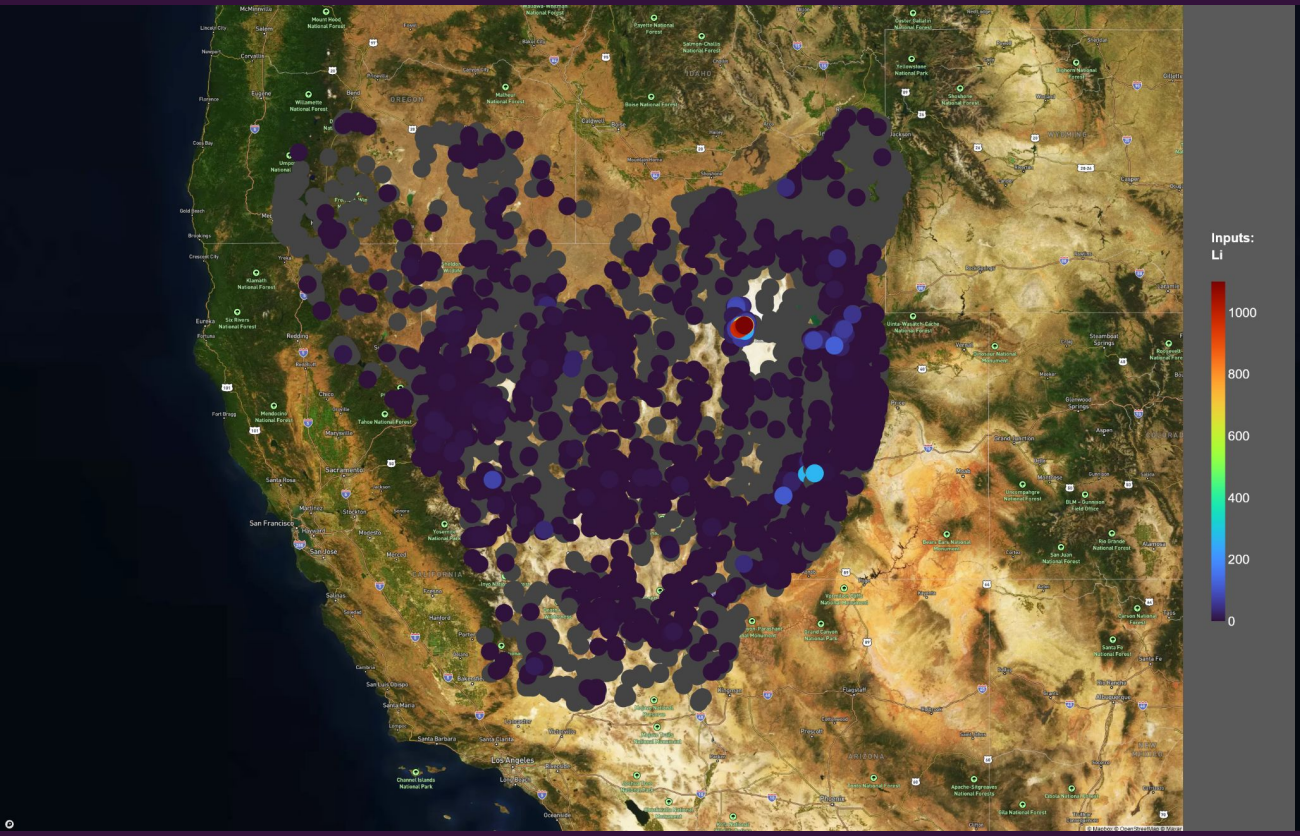
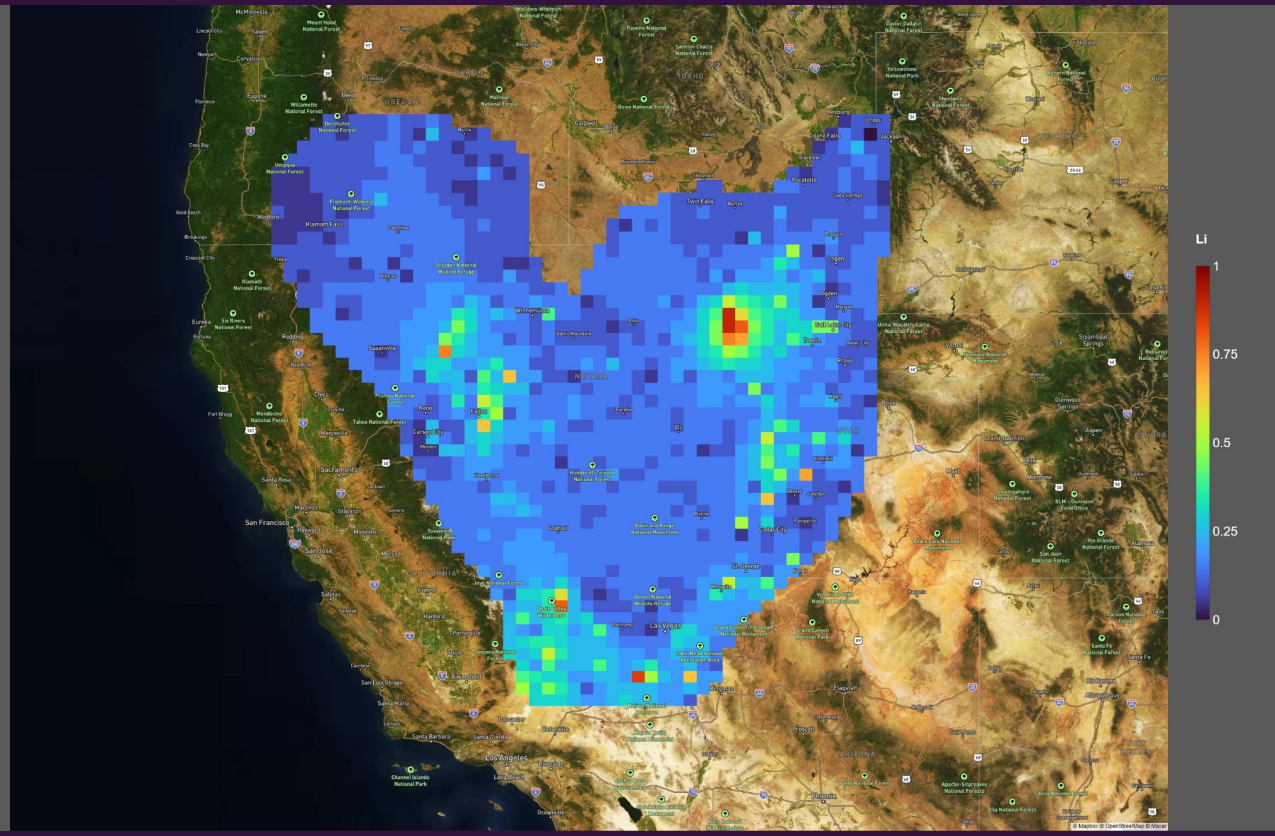
Lithium: Data vs Prospectivity

Lithium Groundwater Concentrations [ppb]

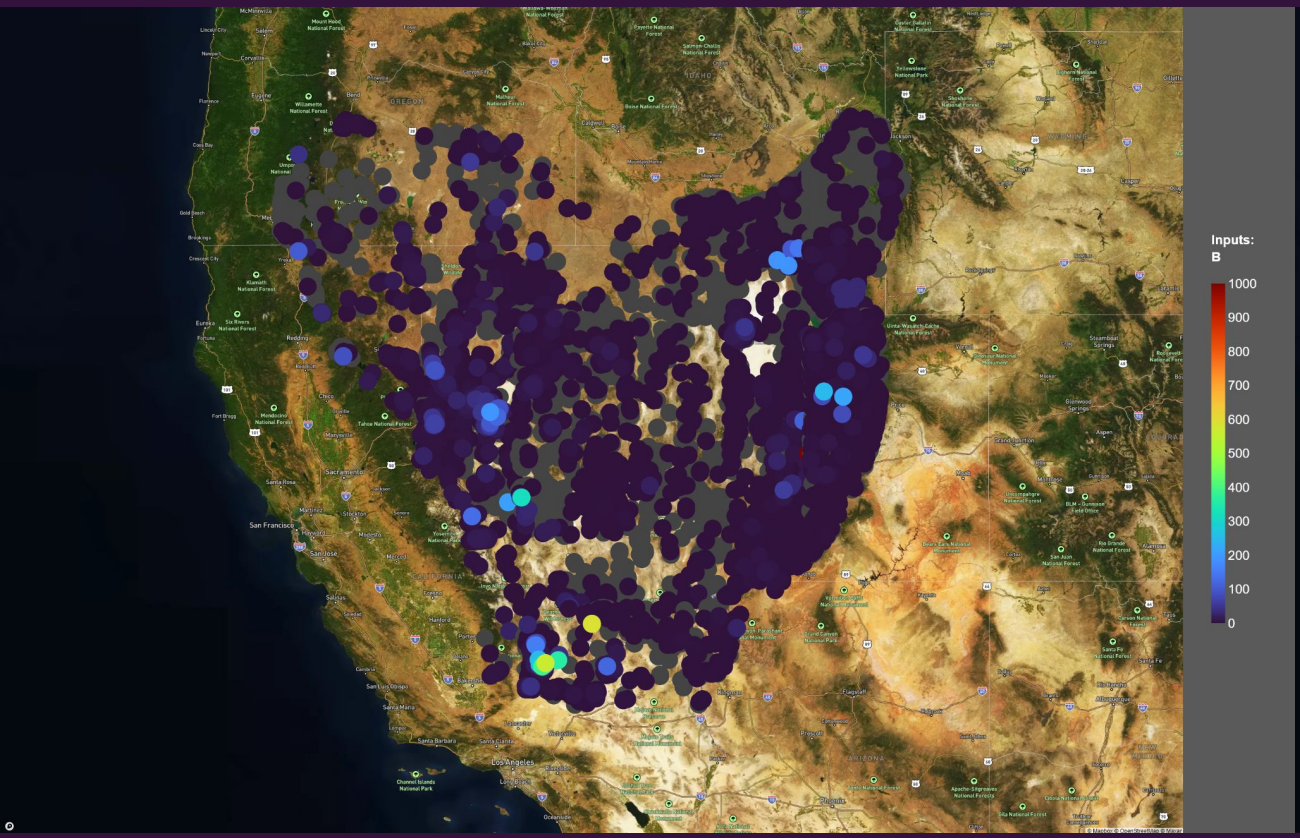


Lithium Prospectivity [normalized]

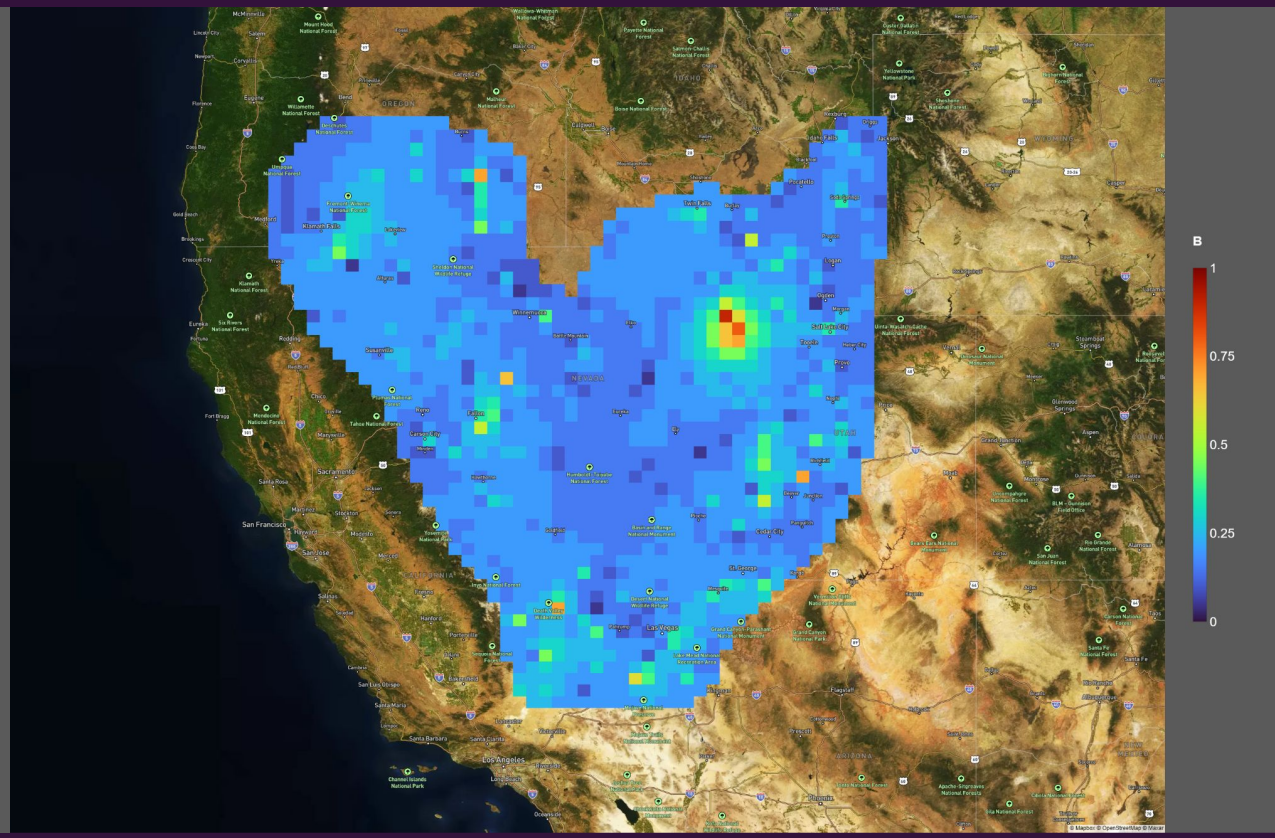


Boron: Data vs Prospectivity

Boron Groundwater Concentrations [ppb]



Boron Prospectivity [normalized]



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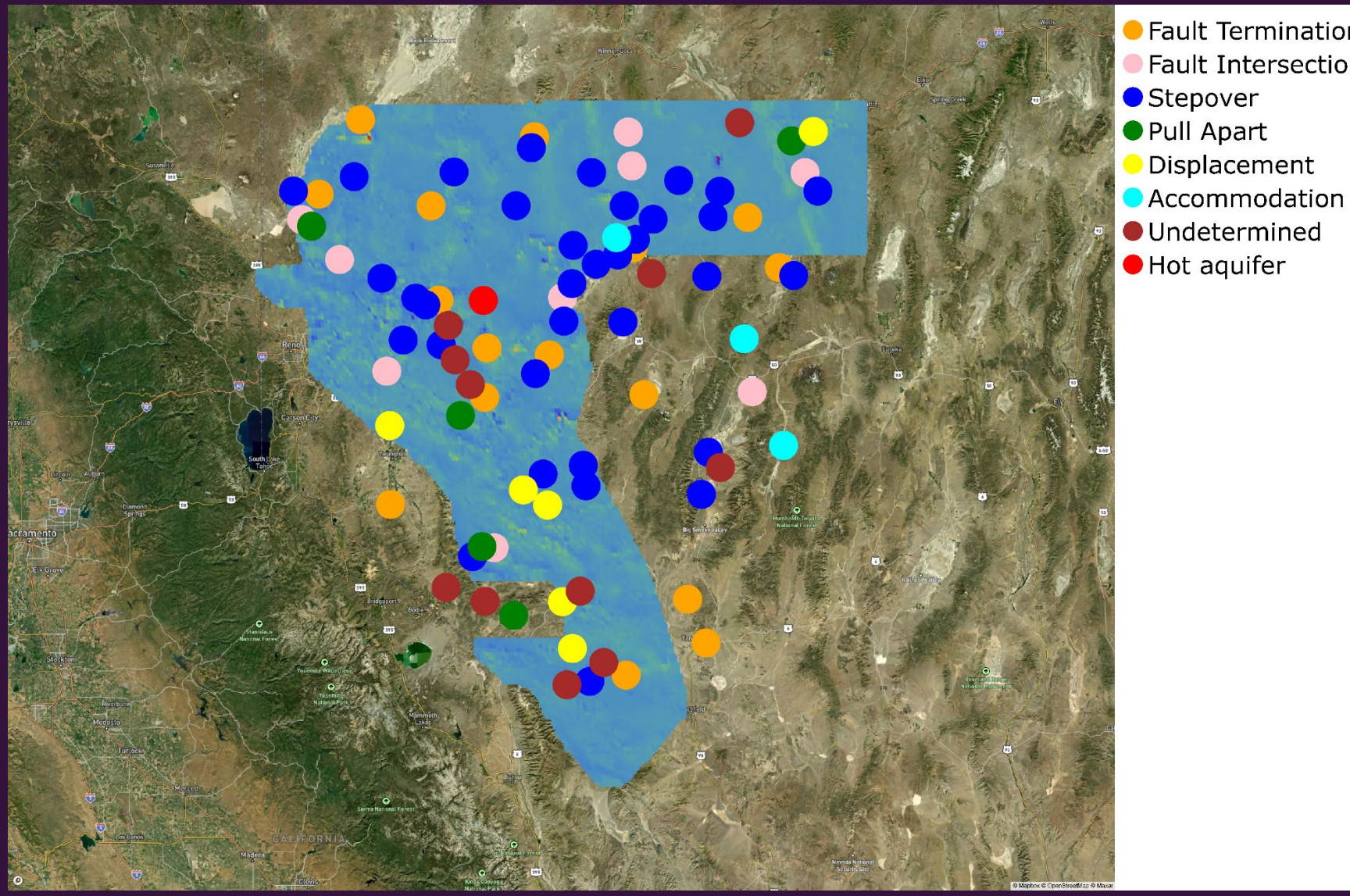
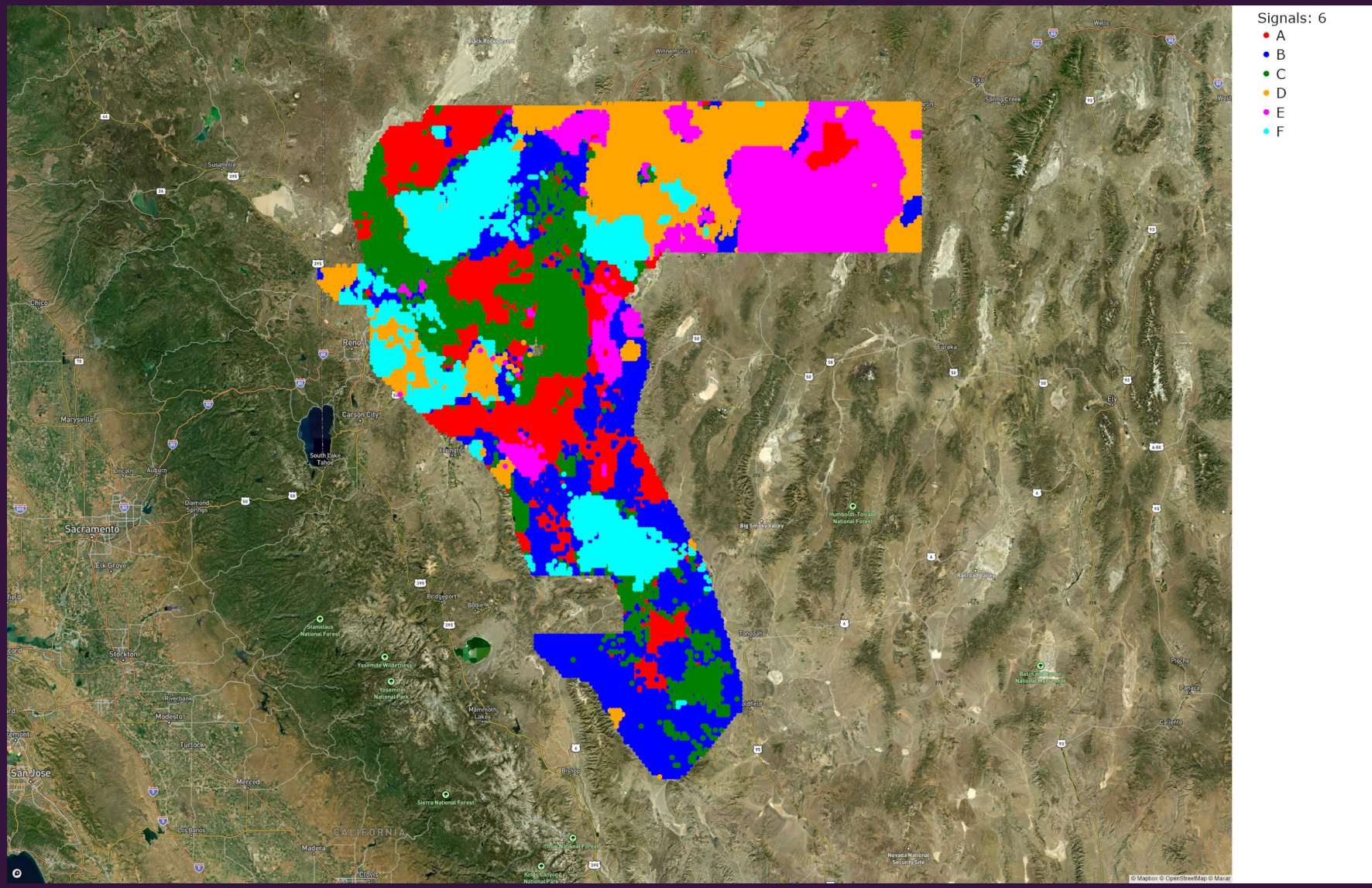
Geologic structures in the GeoDAWN region



GeoDAWN ML results:

- A: Pull apart / Fault Termination
- B: Displacement
- C: Stepover
- D: Fault Intersection / Undetermined
- E: Accomodation
- F: Fault Termination



GeoDAWN ML results:

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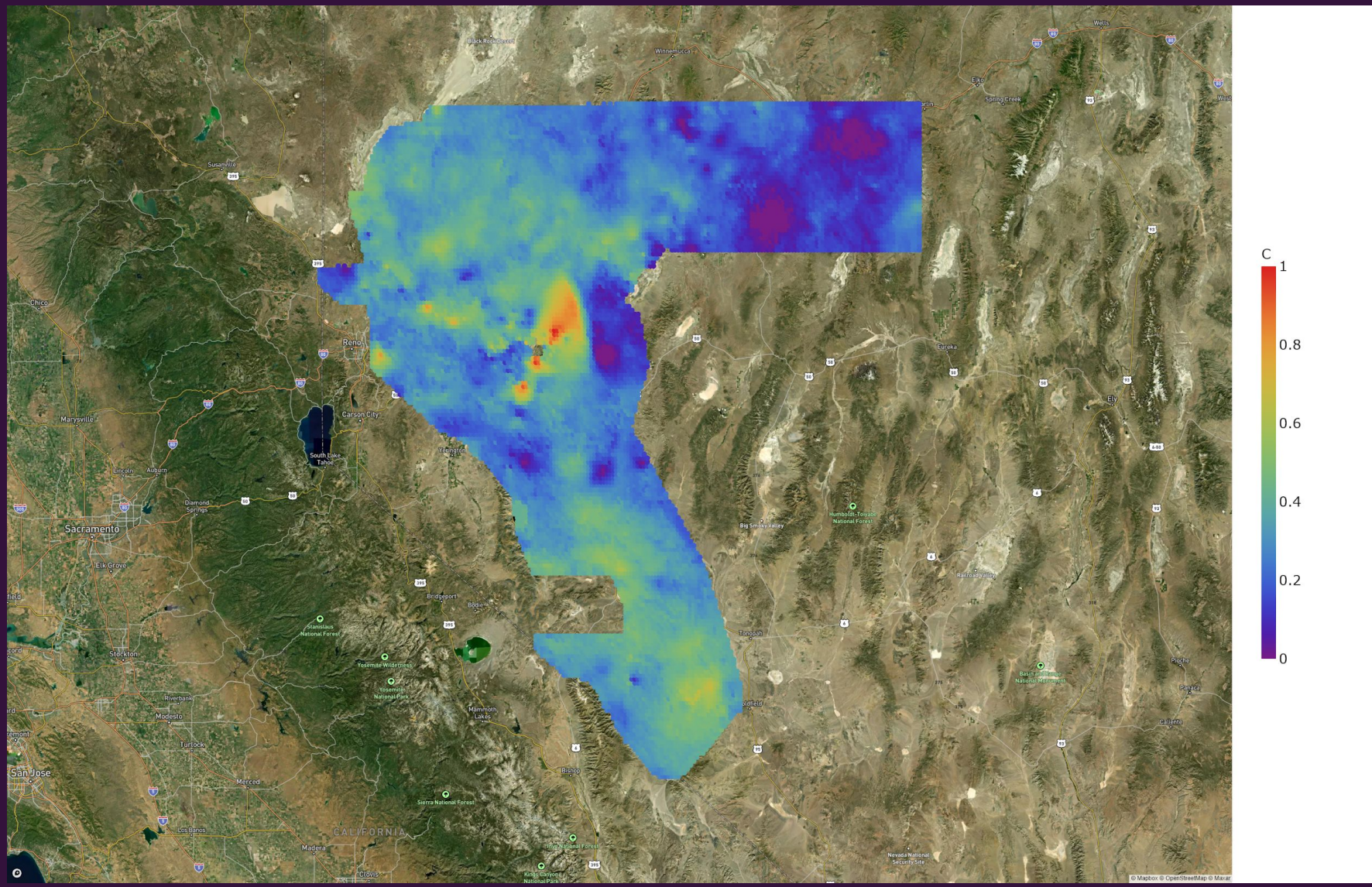

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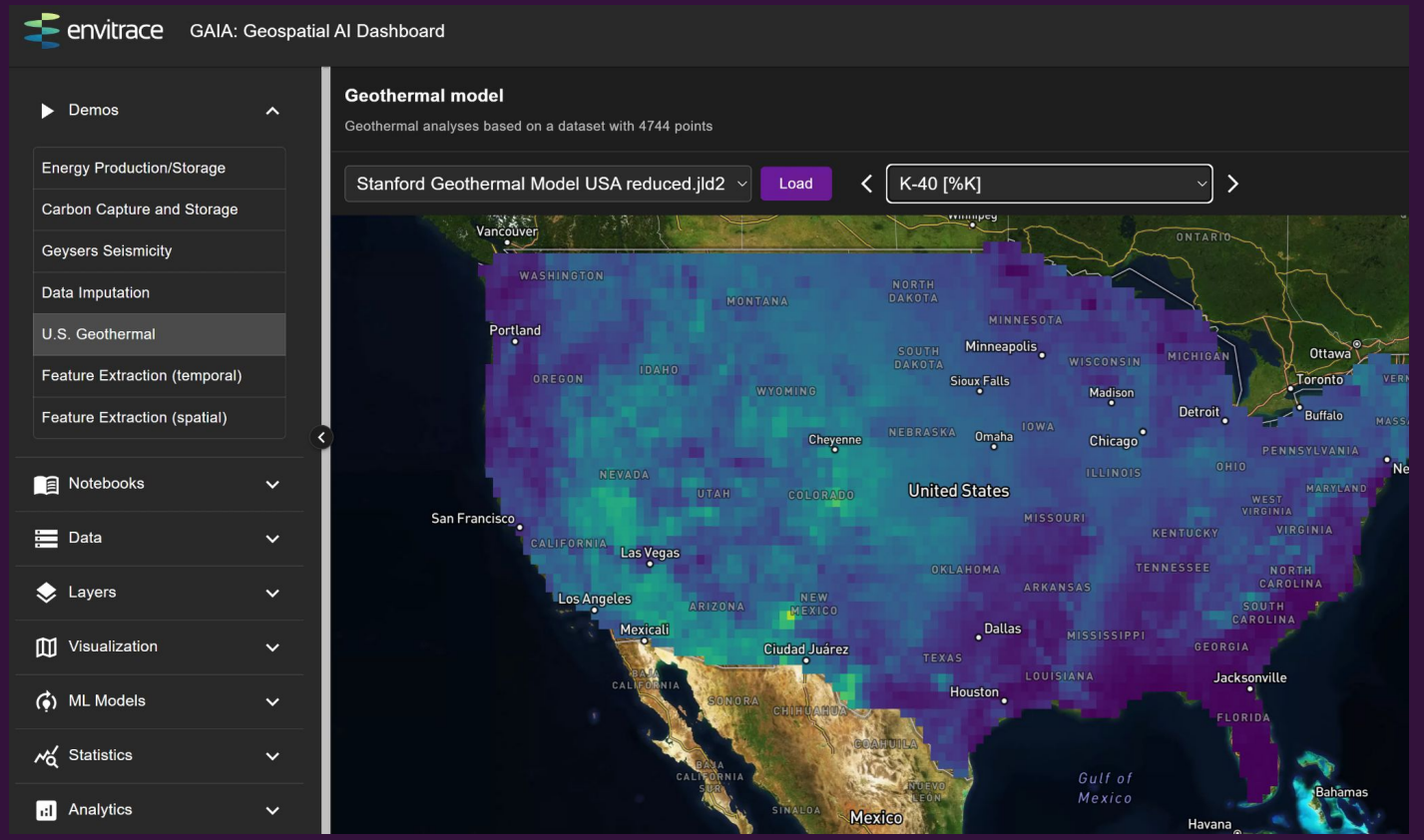
Our SaaS

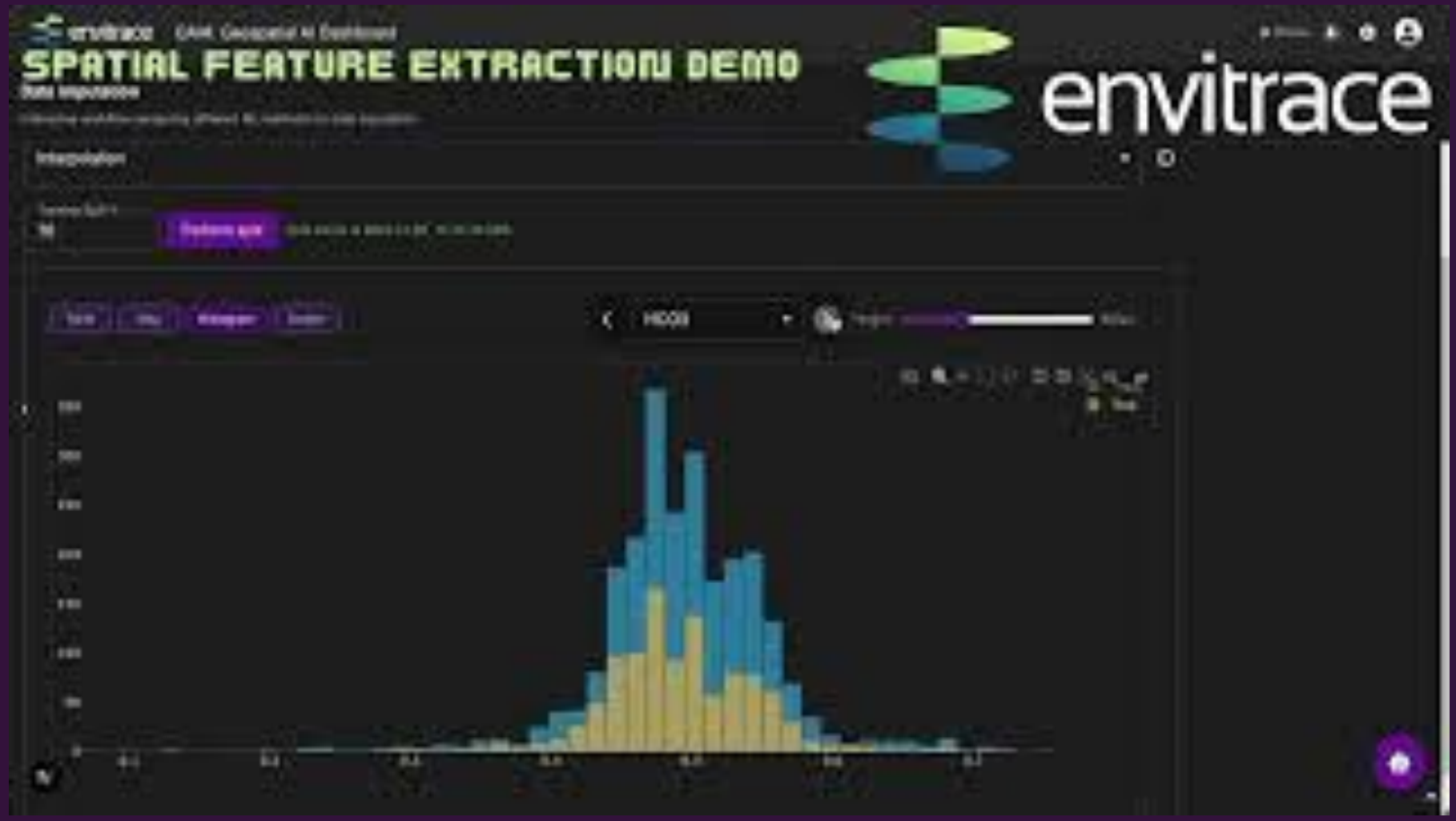
AI/ML cloud product for geo spatio-temporal analyses

- Public and proprietary data
- Various supervised, unsupervised, and physics-informed ML methods
- Accounting for physics and geology
- Accounting for data gaps and measurement errors
- Extraction of hidden geologic features
- Estimation of prospectivity and productivity

http://envitrace.com/saas



Spatial Feature Extraction



Conclusions

info@envitrace.com, http://envitrace.com

- Our AI workflows allow for efficient, fast and robust data assimilation
- Exploration of ML alternatives
- Benchmarking
- Extracts features
- Imputes data
- Evaluates prospectivities
- SaaS dashboard: http://envitrace.com/saas

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Acknowledgement

info@envitrace.com, http://envitrace.com

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