Multi-Physics Imaging and AI-Assisted Interpretation:
Imaging Subsurface Reservoirs for Hydrogen, Geothermal, and Critical Minerals:

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Geologic Reservoir Data Issues

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

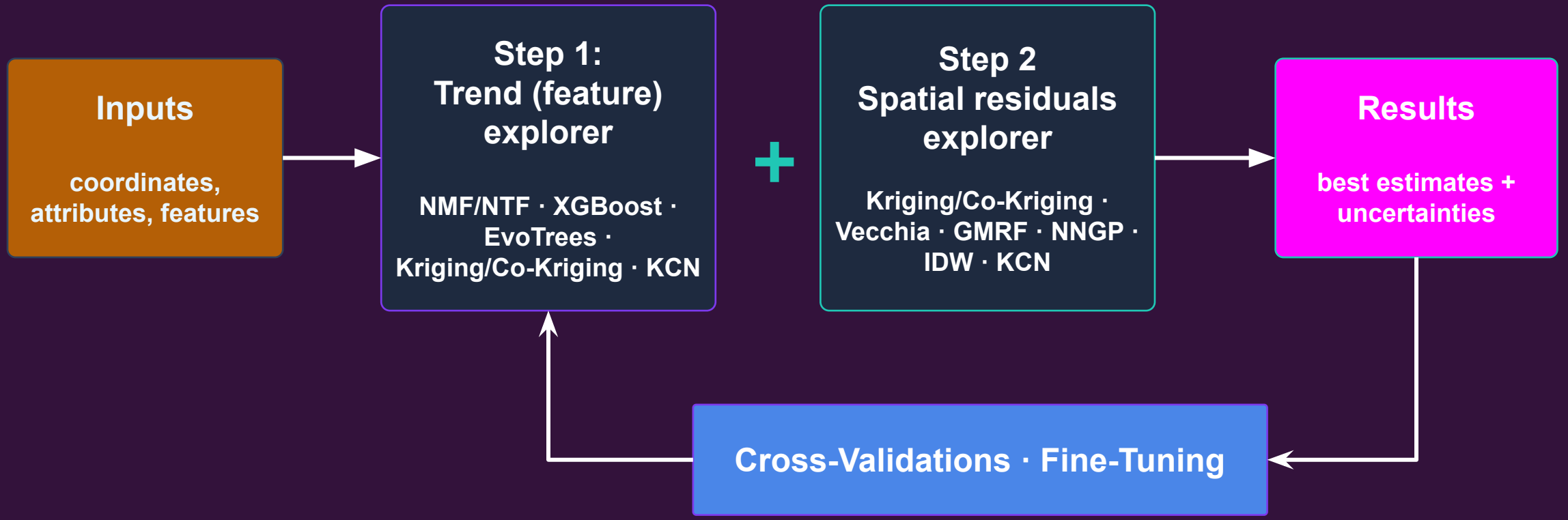
Physics/Geologic Models vs. ML Models

- Frequently, physics/geologic models are:
  - challenging to build
  - computationally and labor intensive
  - challaning to assimilate all the available data
- Frequently, ML models are:
  - black box
  - difficult to interpret
  - lack of robustness and trustworthiness
- ML model embedding the physics and geology bridge the gap

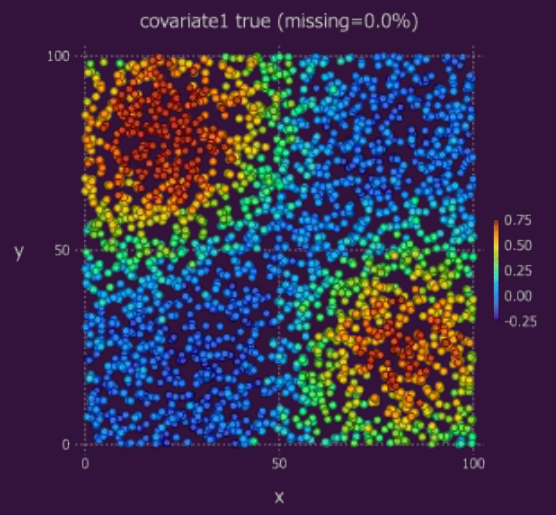
GeoML: ML geospatial analyses

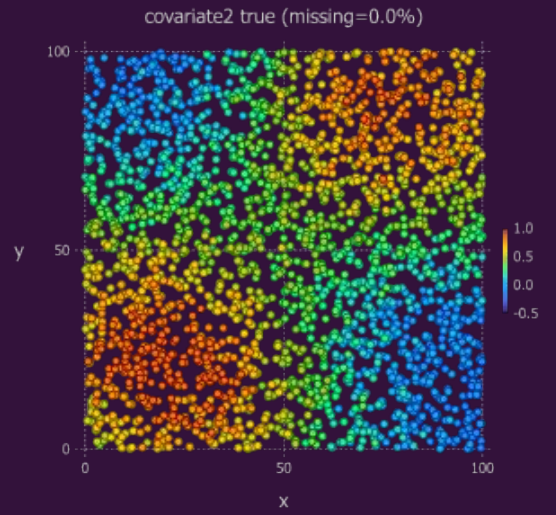
- Multi-step algorithm merging ML techniques
- Executing automated cross-validations and fine tuning
- Identifying the best approach for a given dataset/problem
- Available techniques:
  - Nonnegative matrix/tensor factorization (NMFk/NTFk)
  - Support Vectors (SVM/SVR)
  - XGBoost/EvoTrees
  - Kriging/Vecchia/Gaussian Process (GP)
  - Inverse Distance Weighted (IDW)
  - Spatial splines/Minimum curvature (Biggs FD and classical)
  - Kriging Convolutional Neural Networks (KCN)
  - Nearest Neighbour Gaussian Process (NNGP)
  - Gaussian Markov Random Field (GMRF)
  - Stochastic PDEs (SPDE)

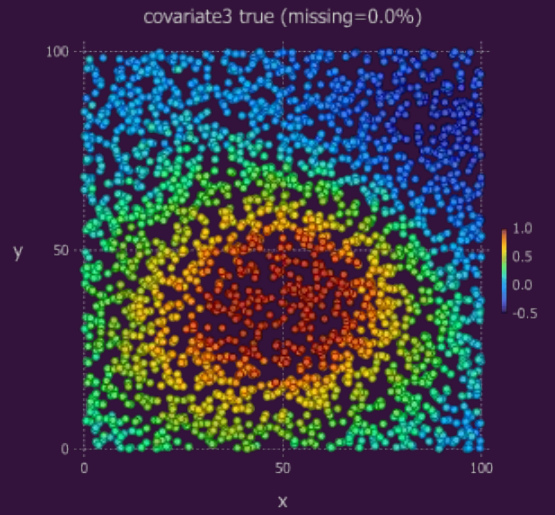
GeoML: Multi-step approach for geospatial analyses

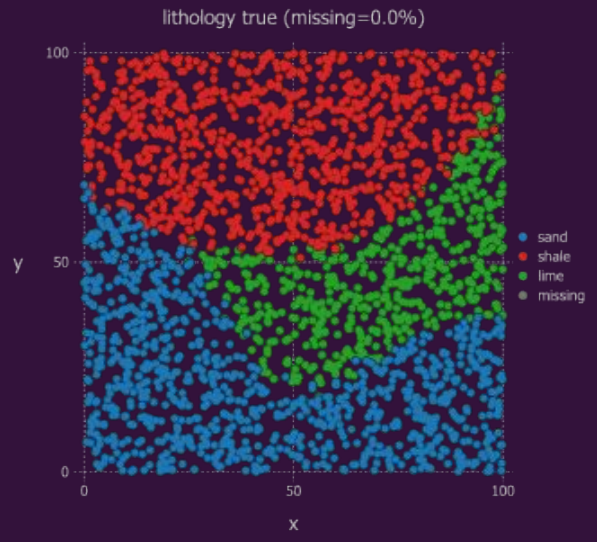


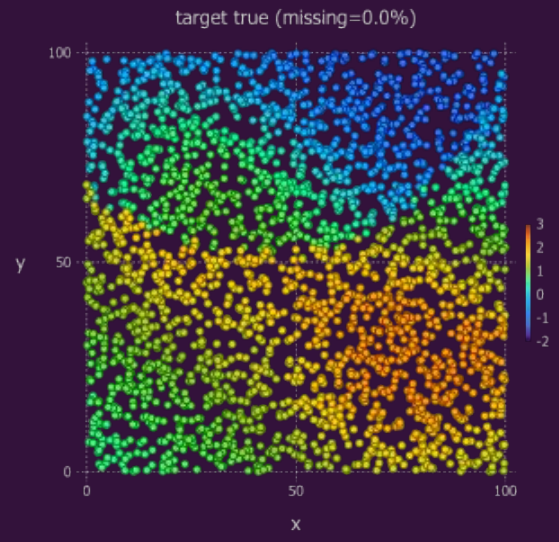
Geospatial demo problem











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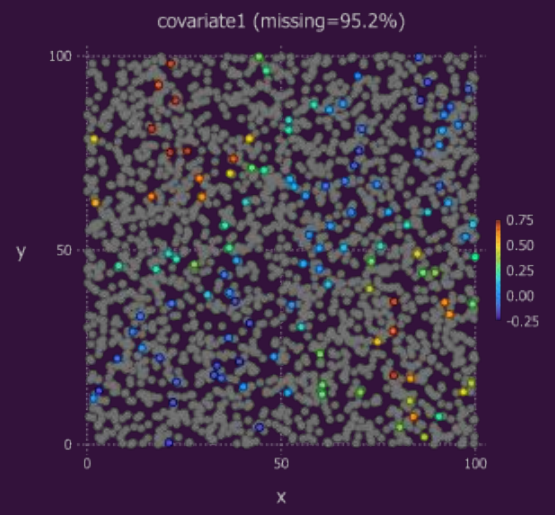

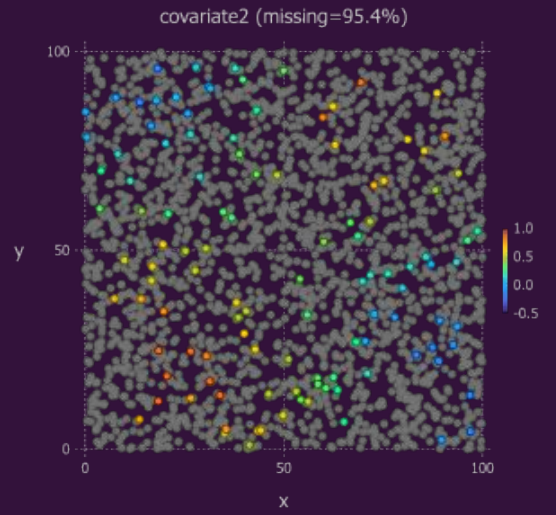

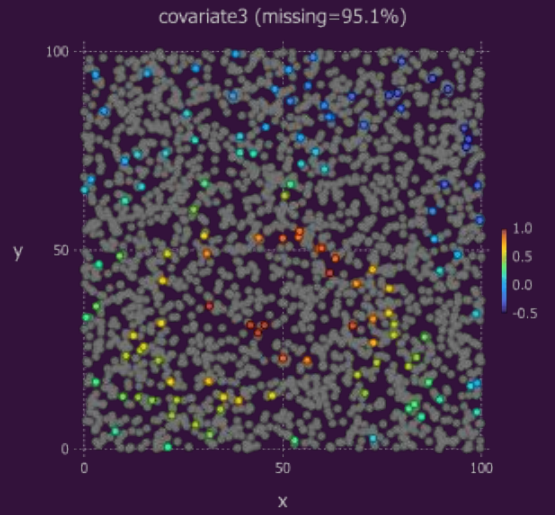

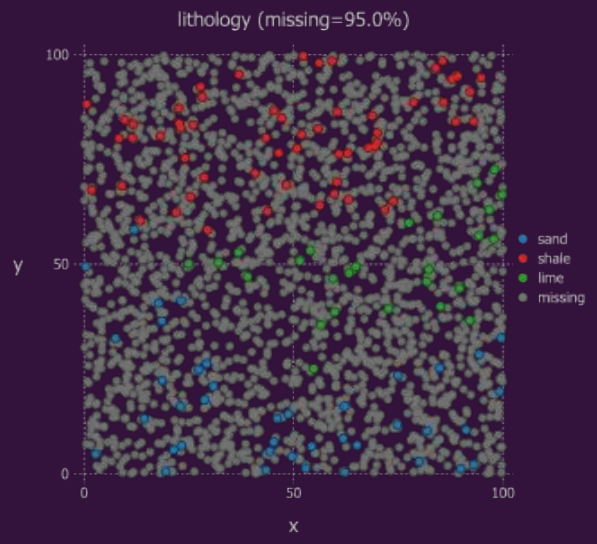

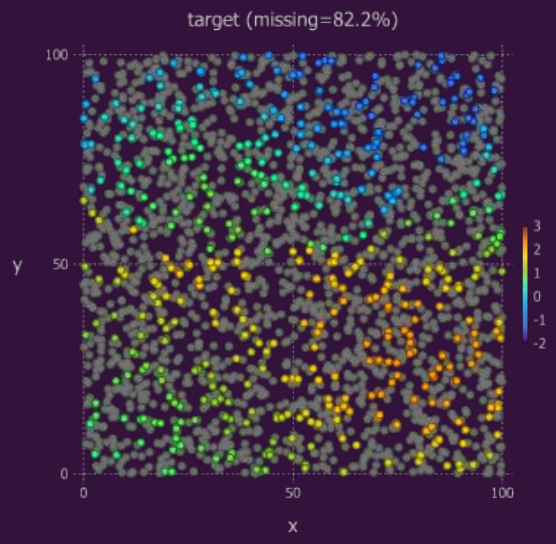

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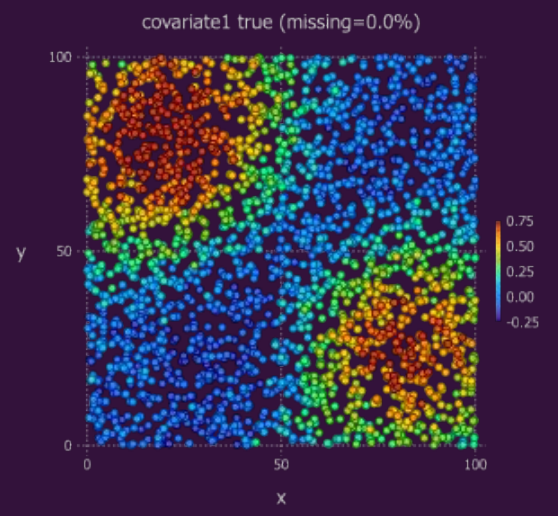
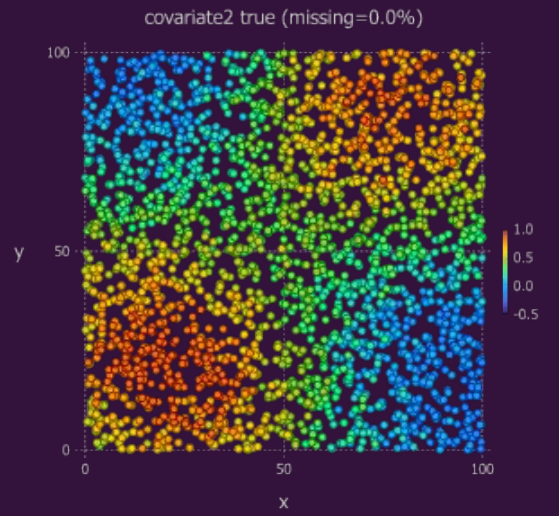
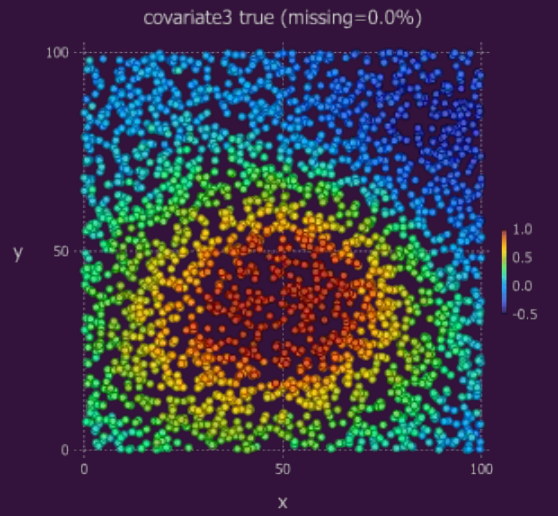
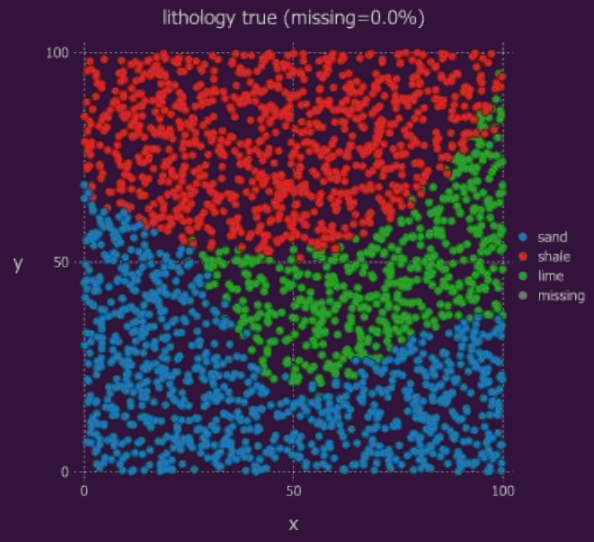
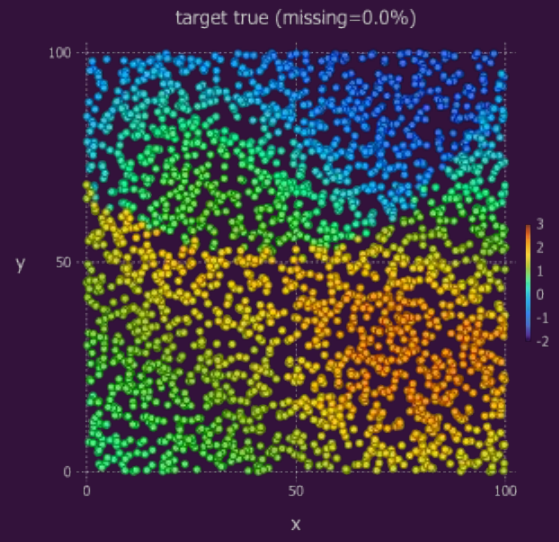
Geospatial demo problem (truth)











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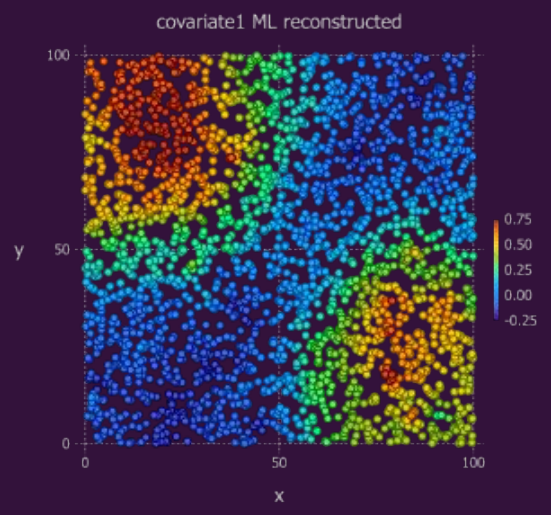

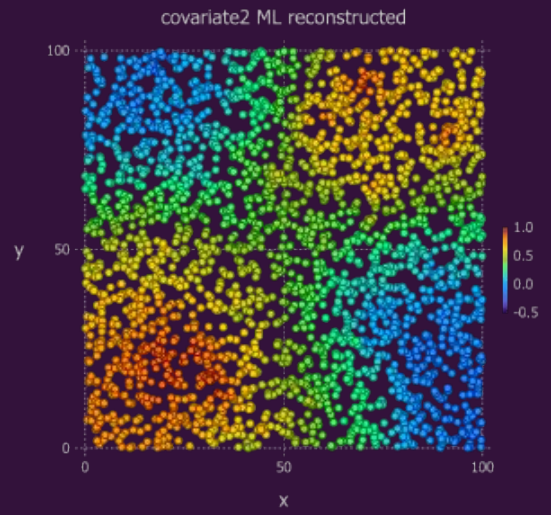

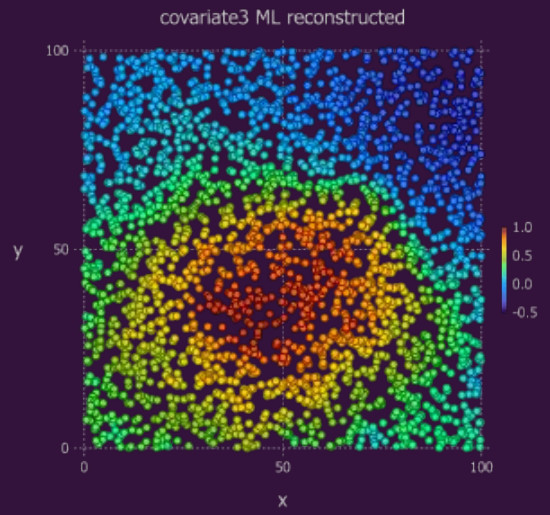

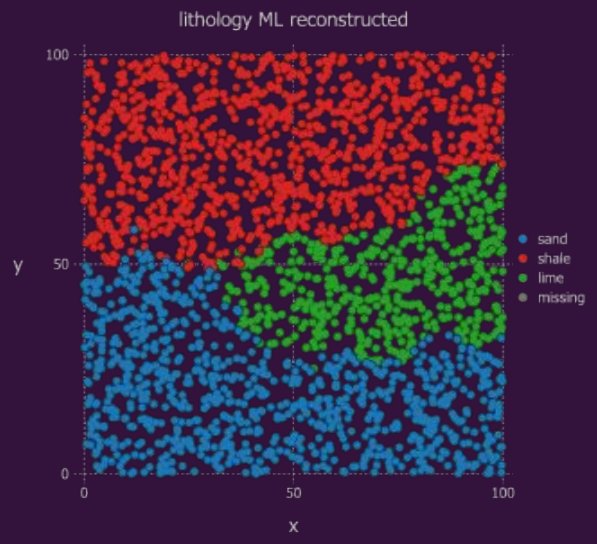

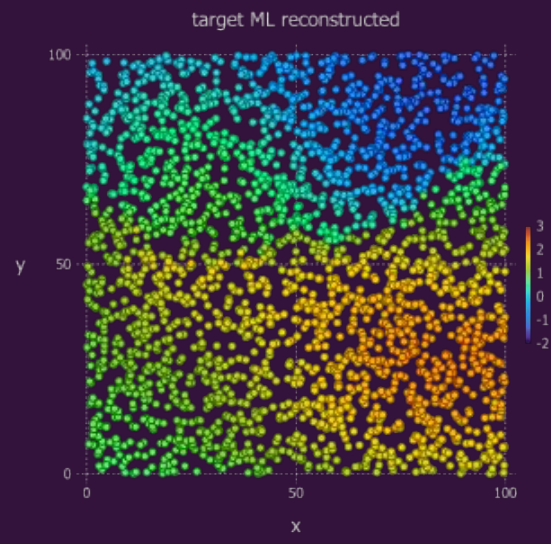

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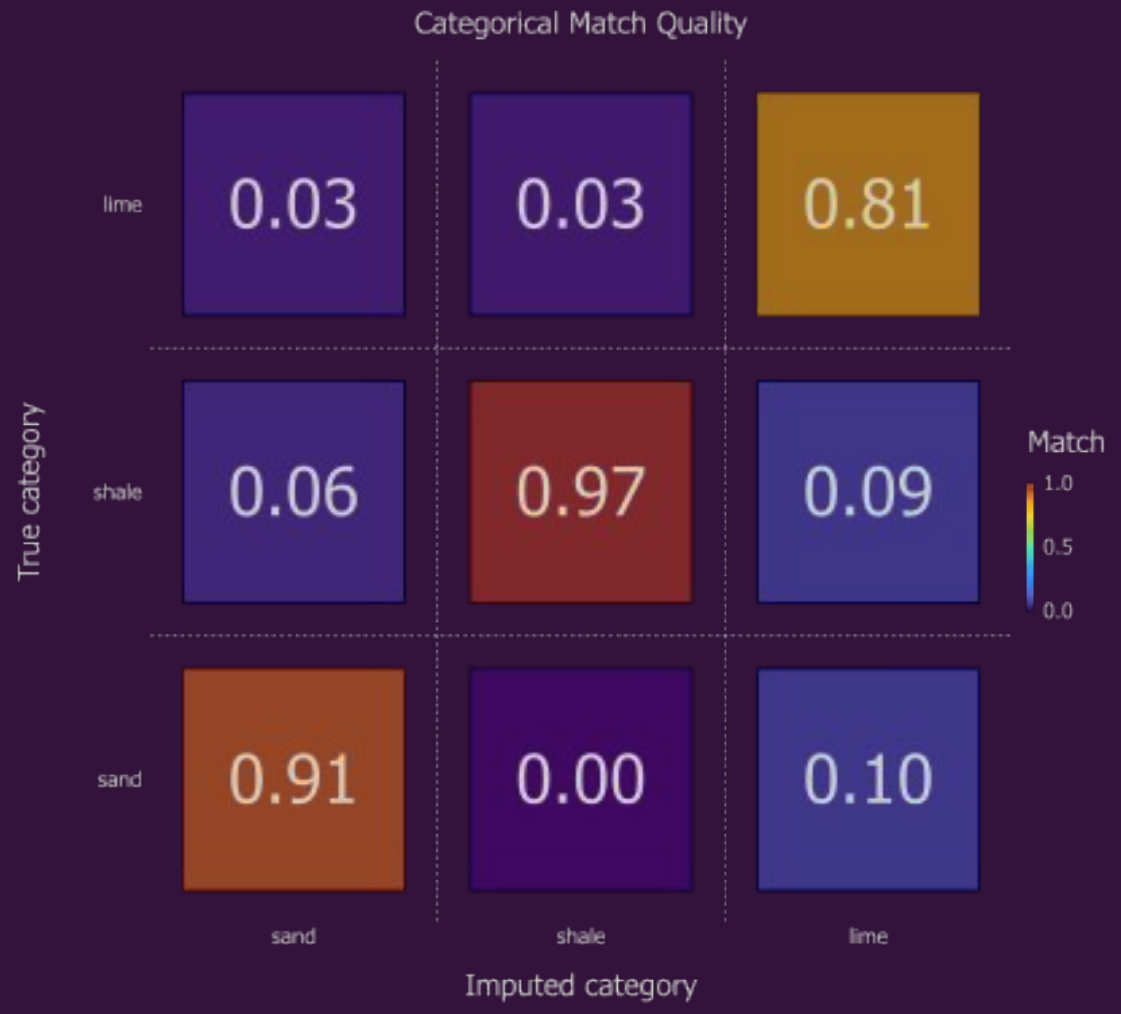

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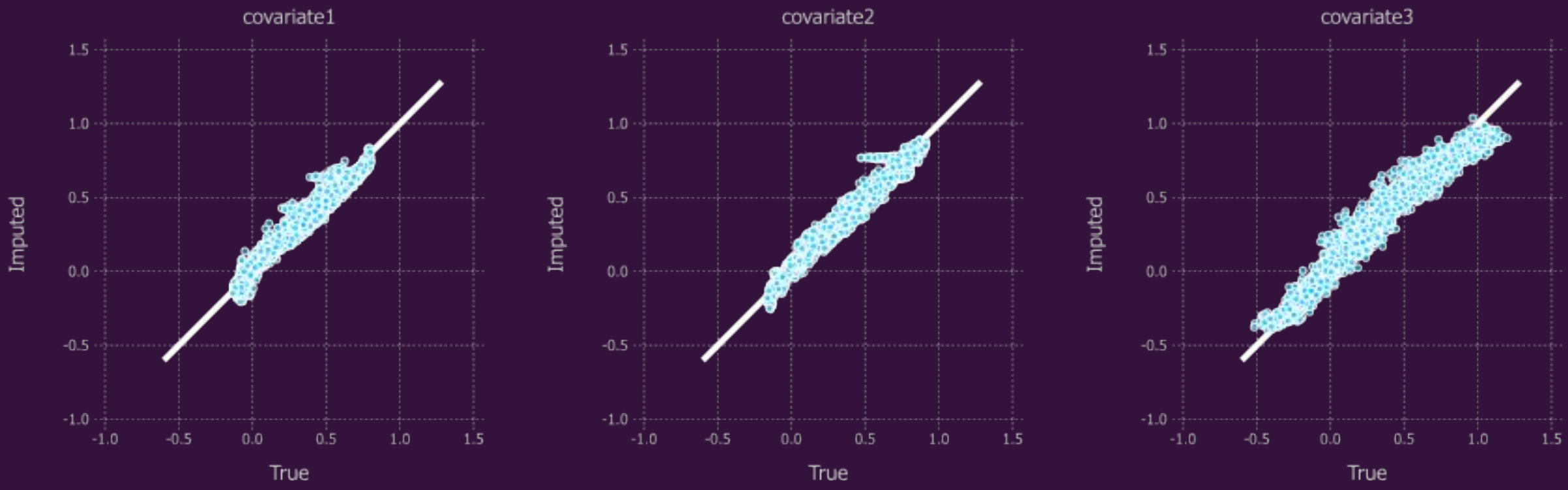

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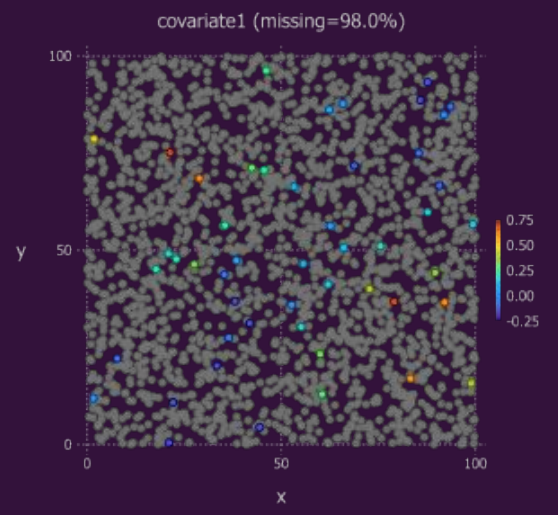

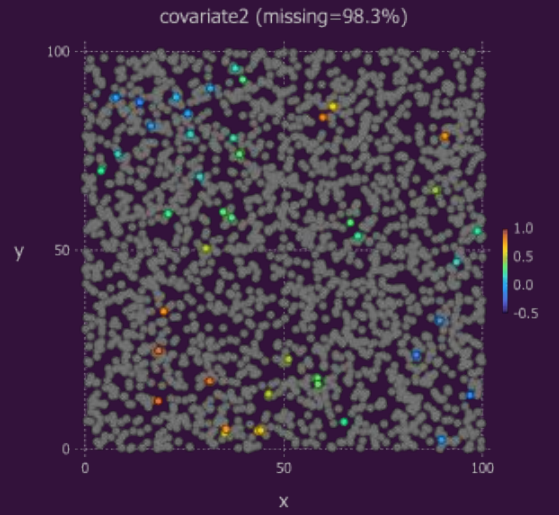

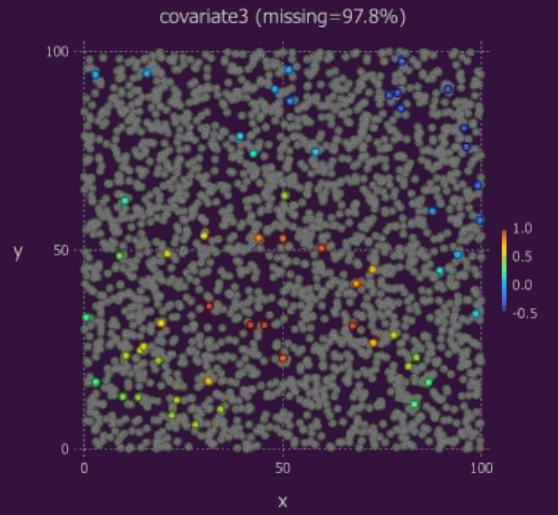

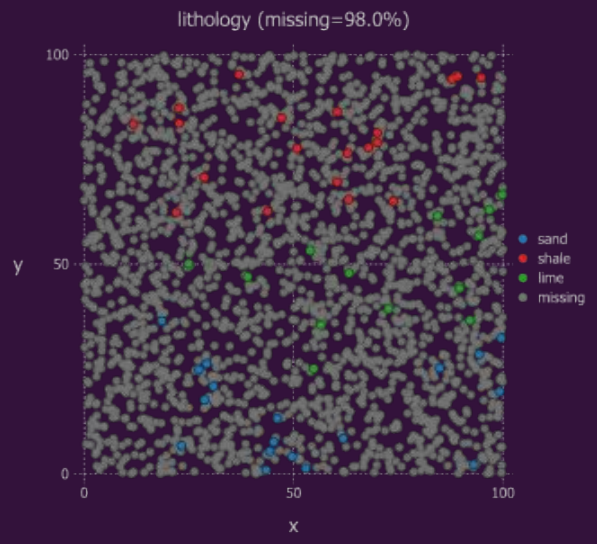

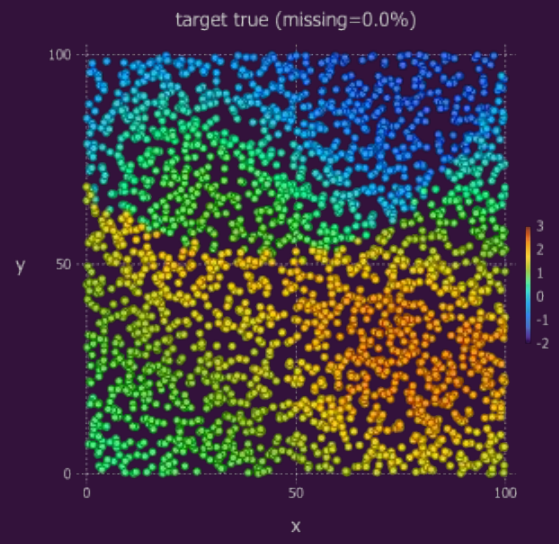

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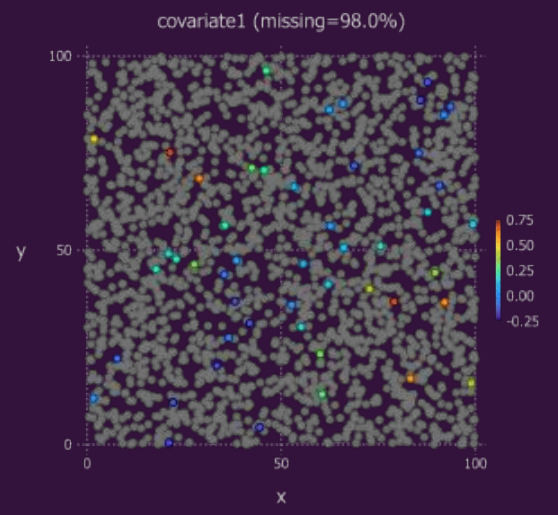

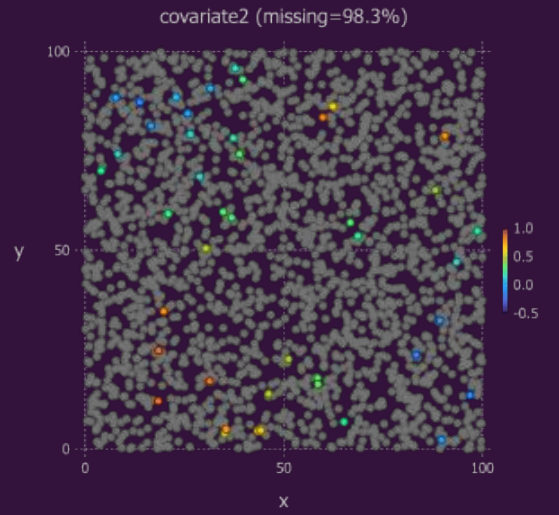

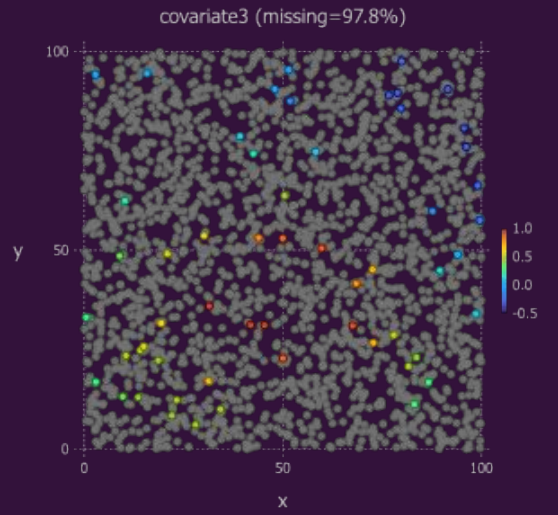

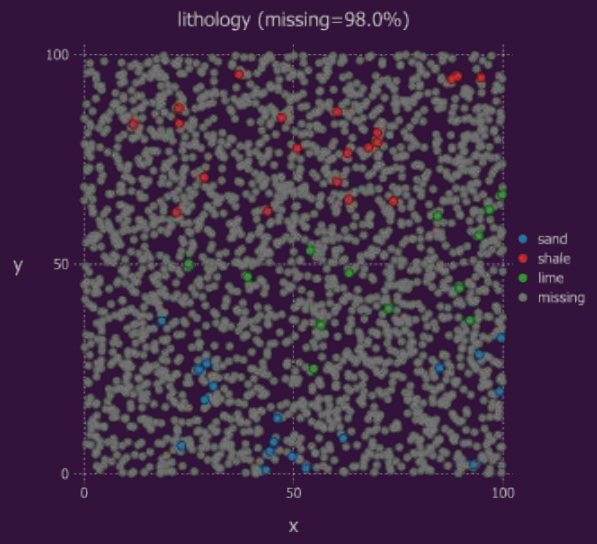

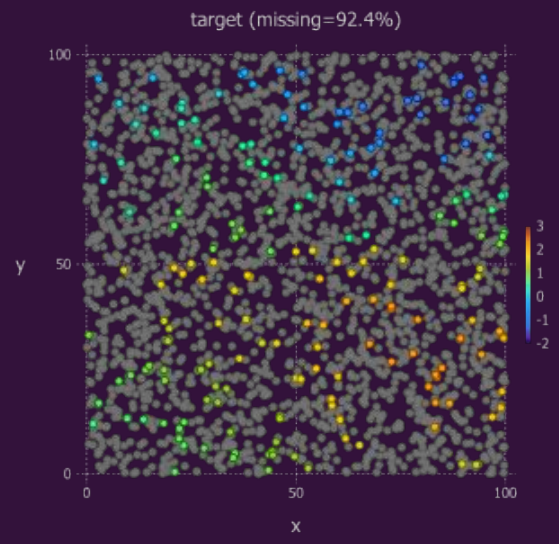

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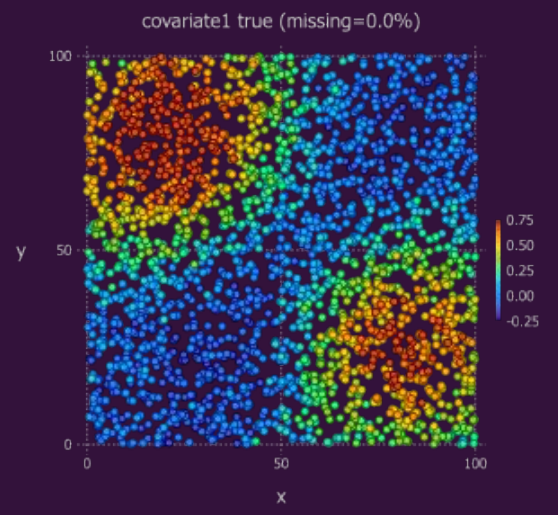

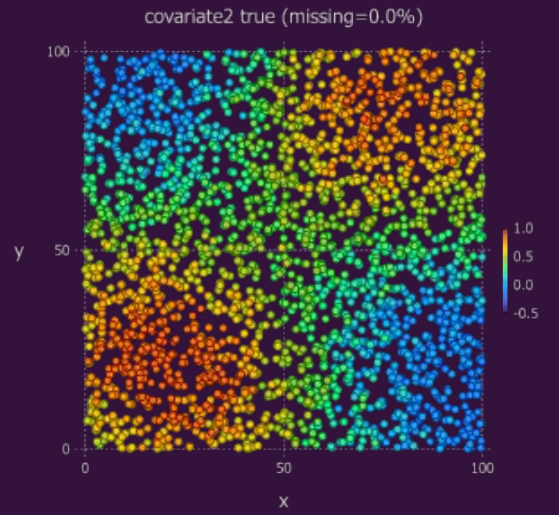

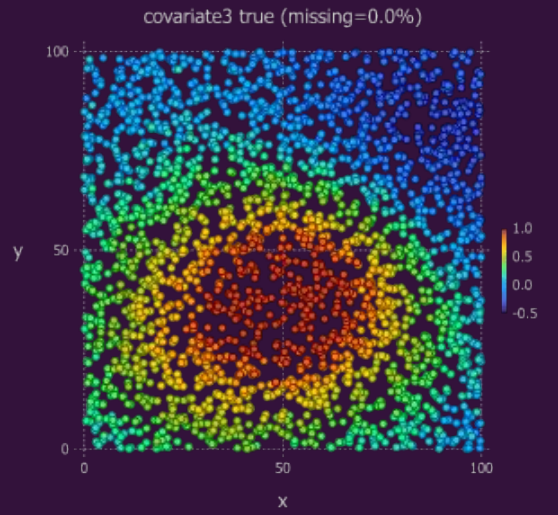

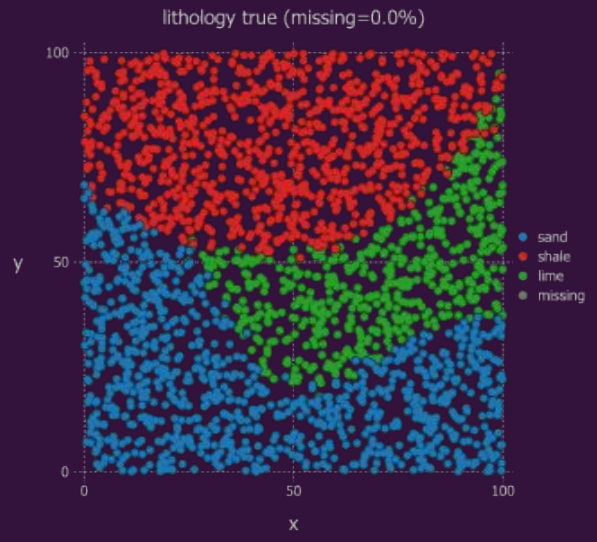

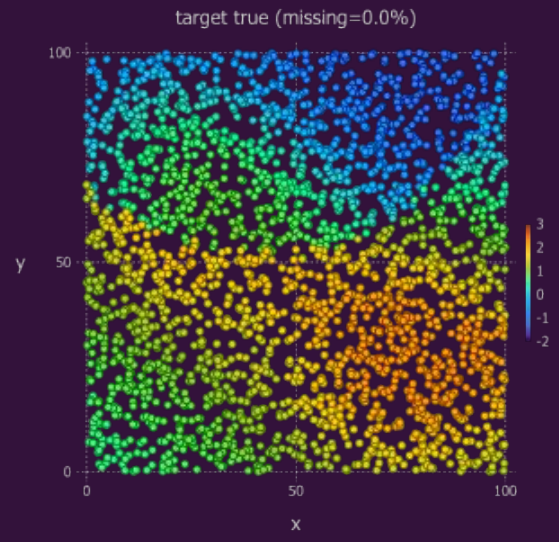

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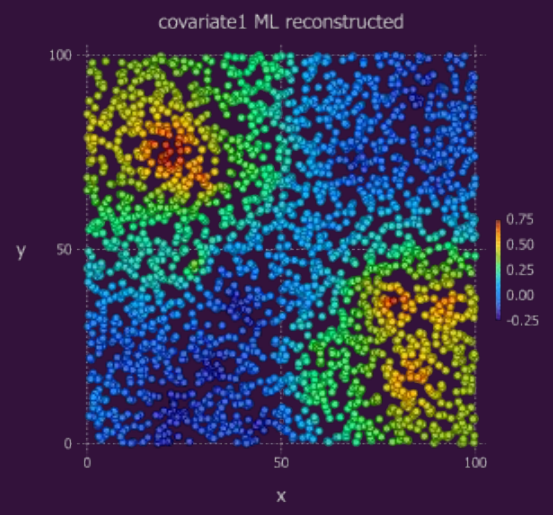

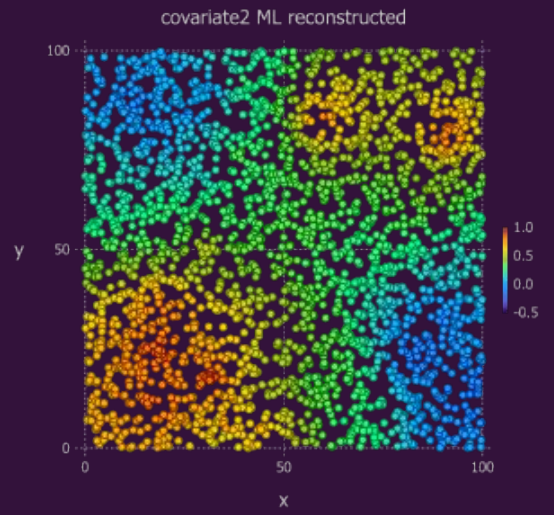

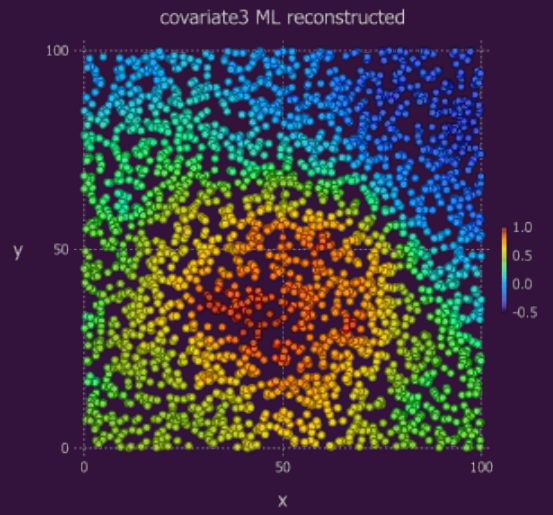

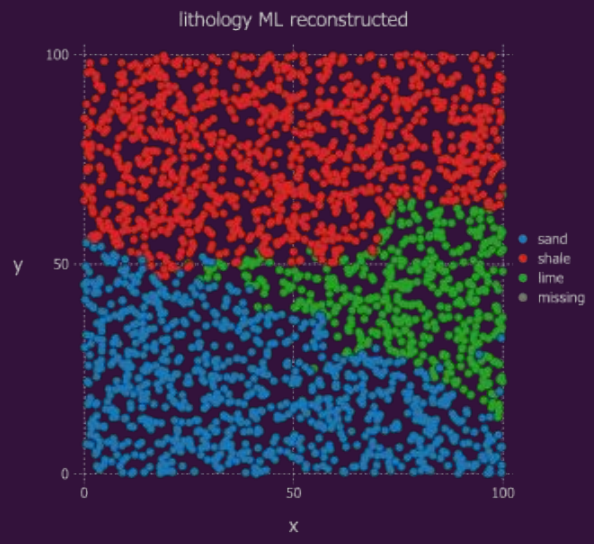

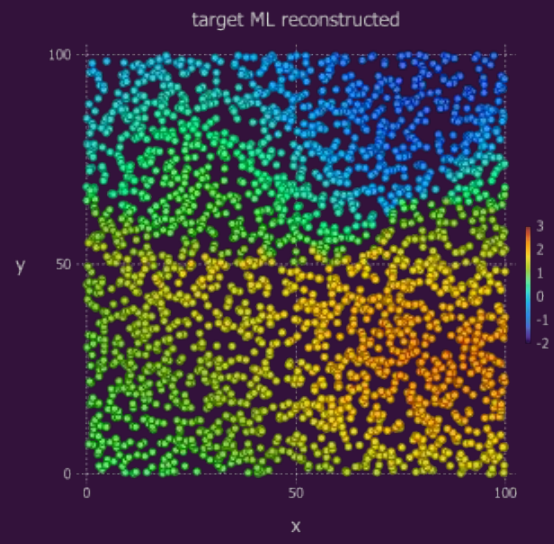

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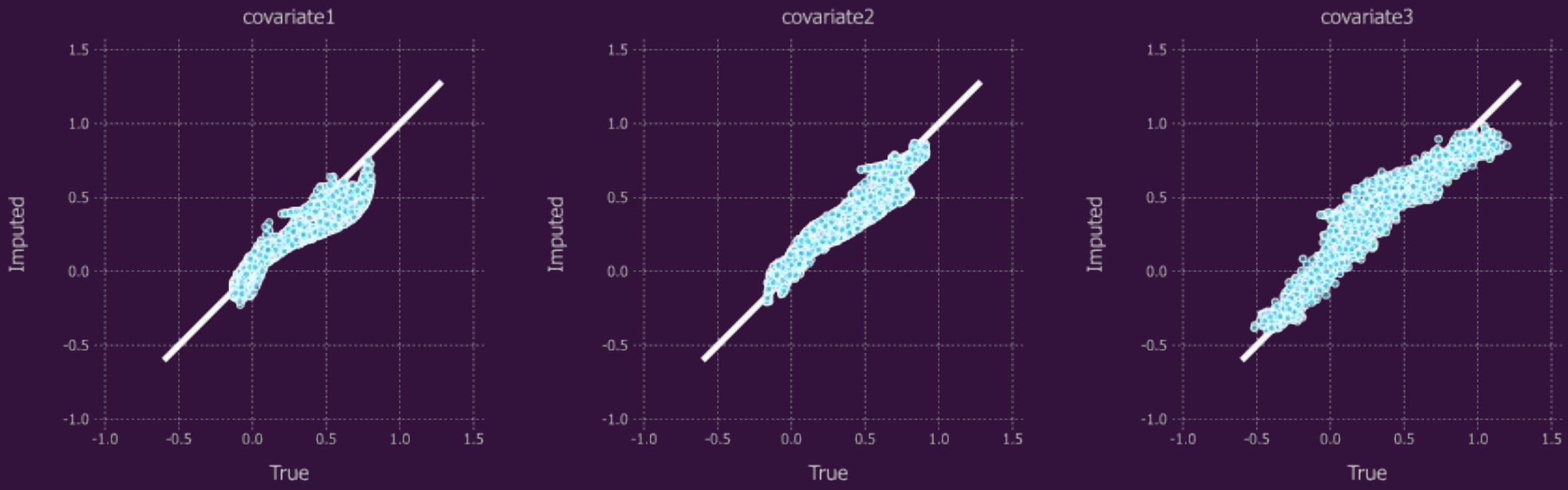

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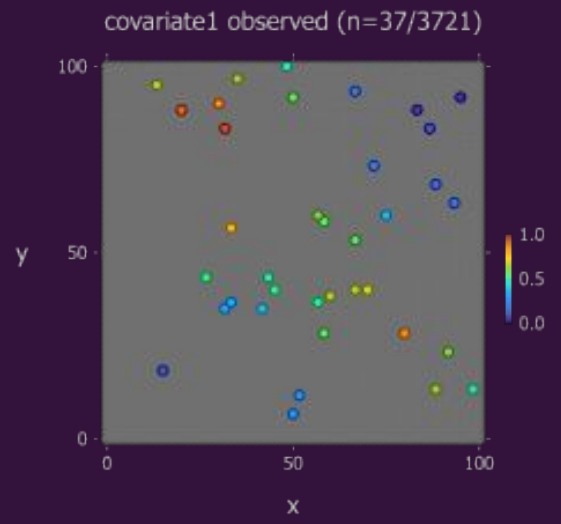
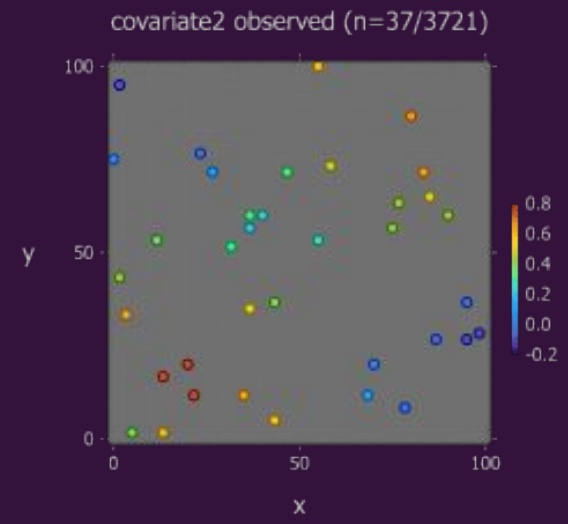
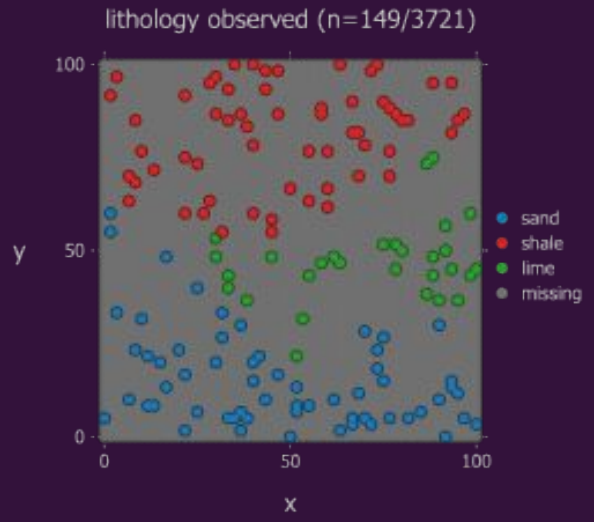
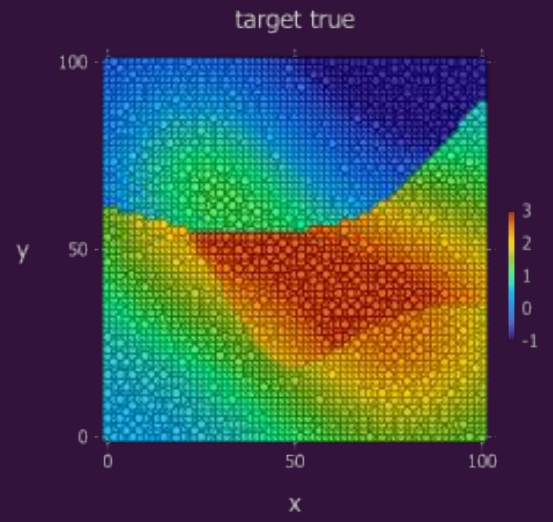
Geospatial demo problem (grid)









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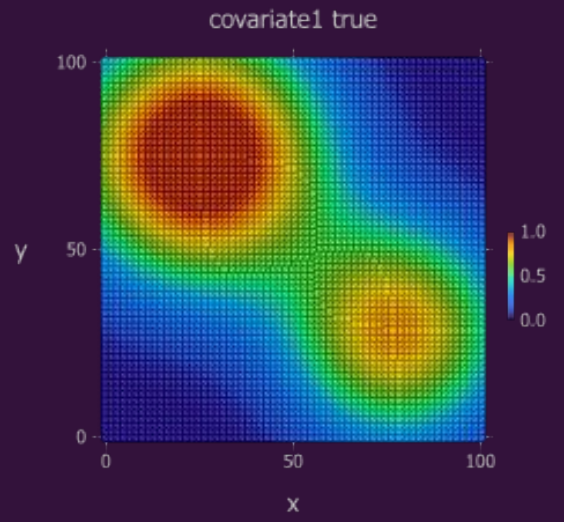

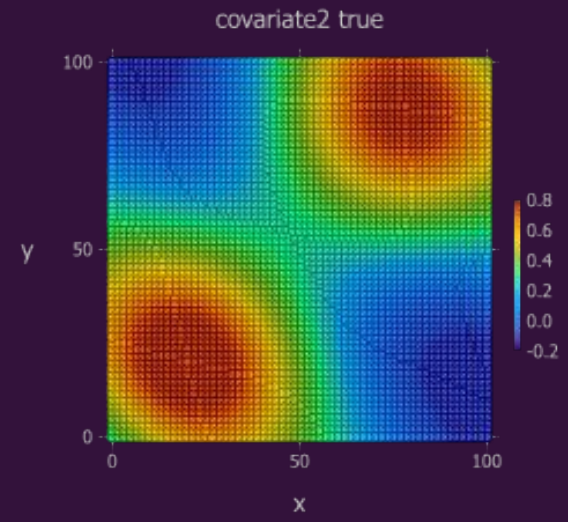

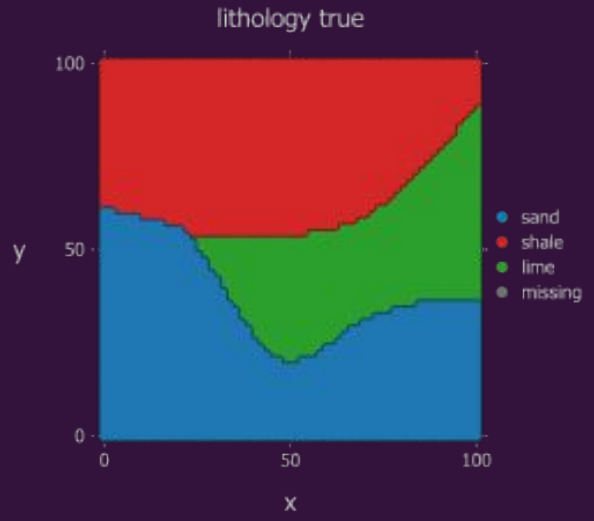

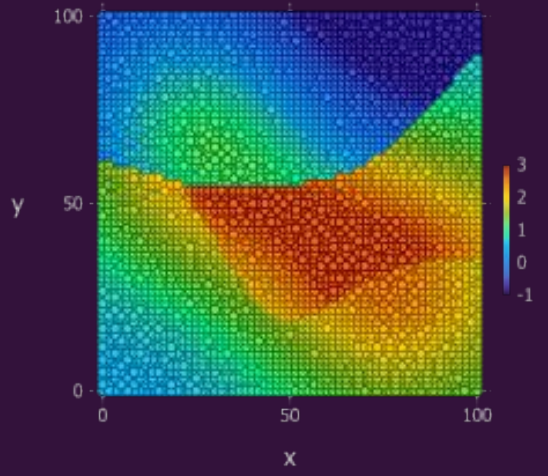

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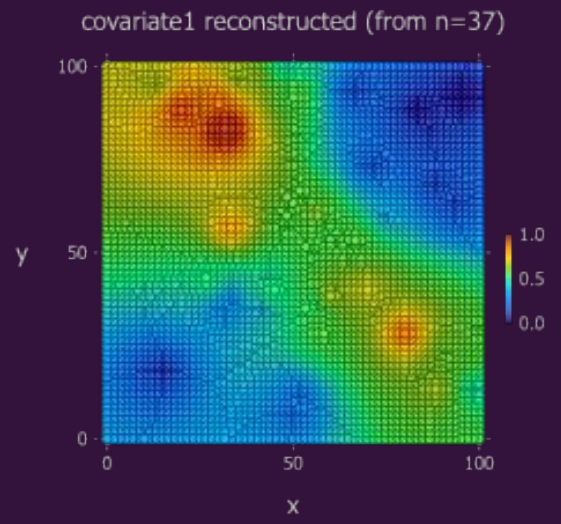

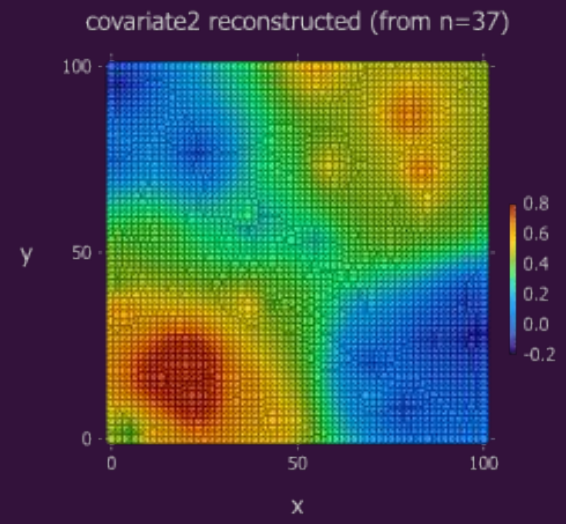

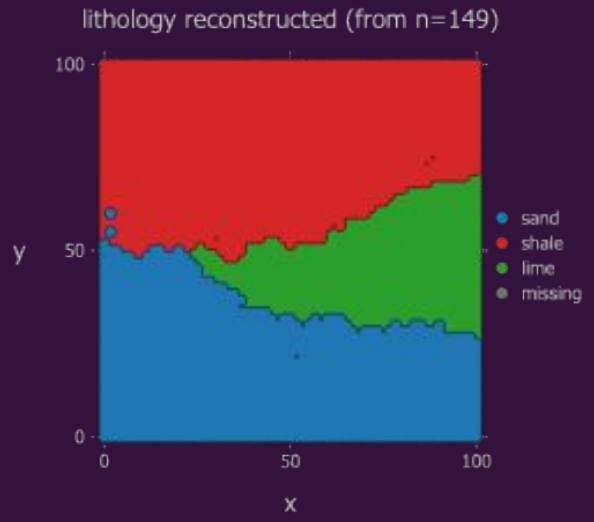

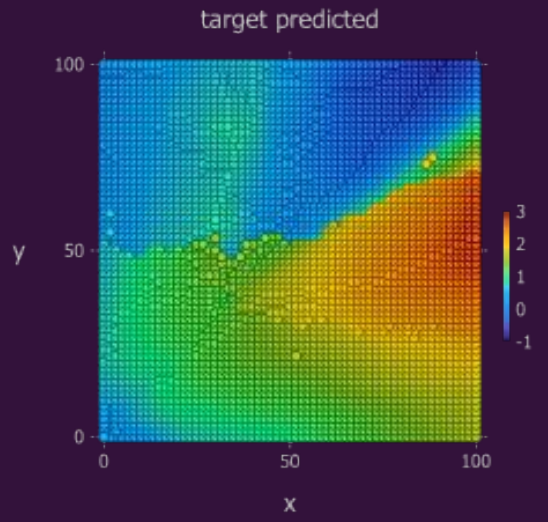

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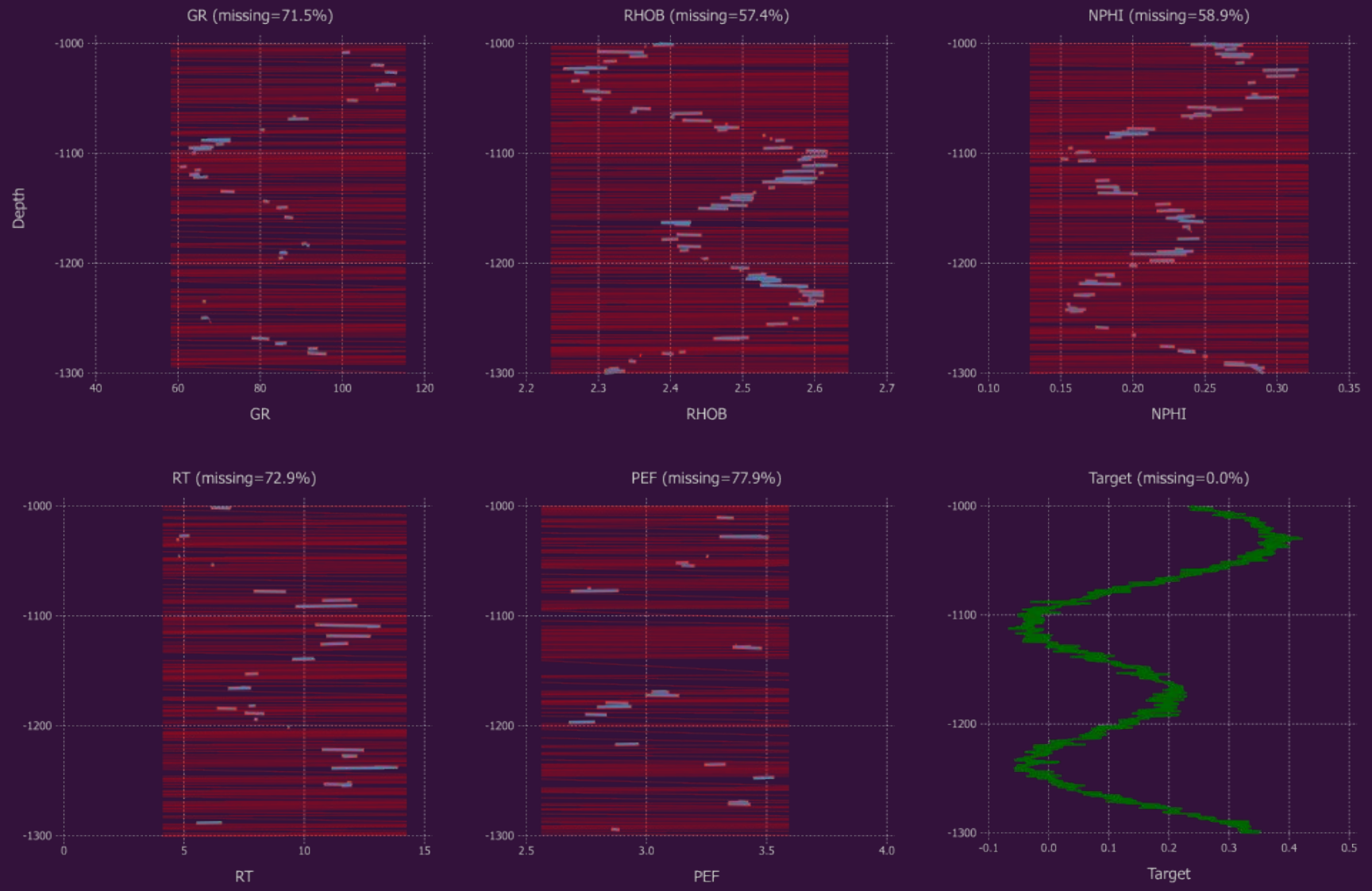
Well-log demo problem



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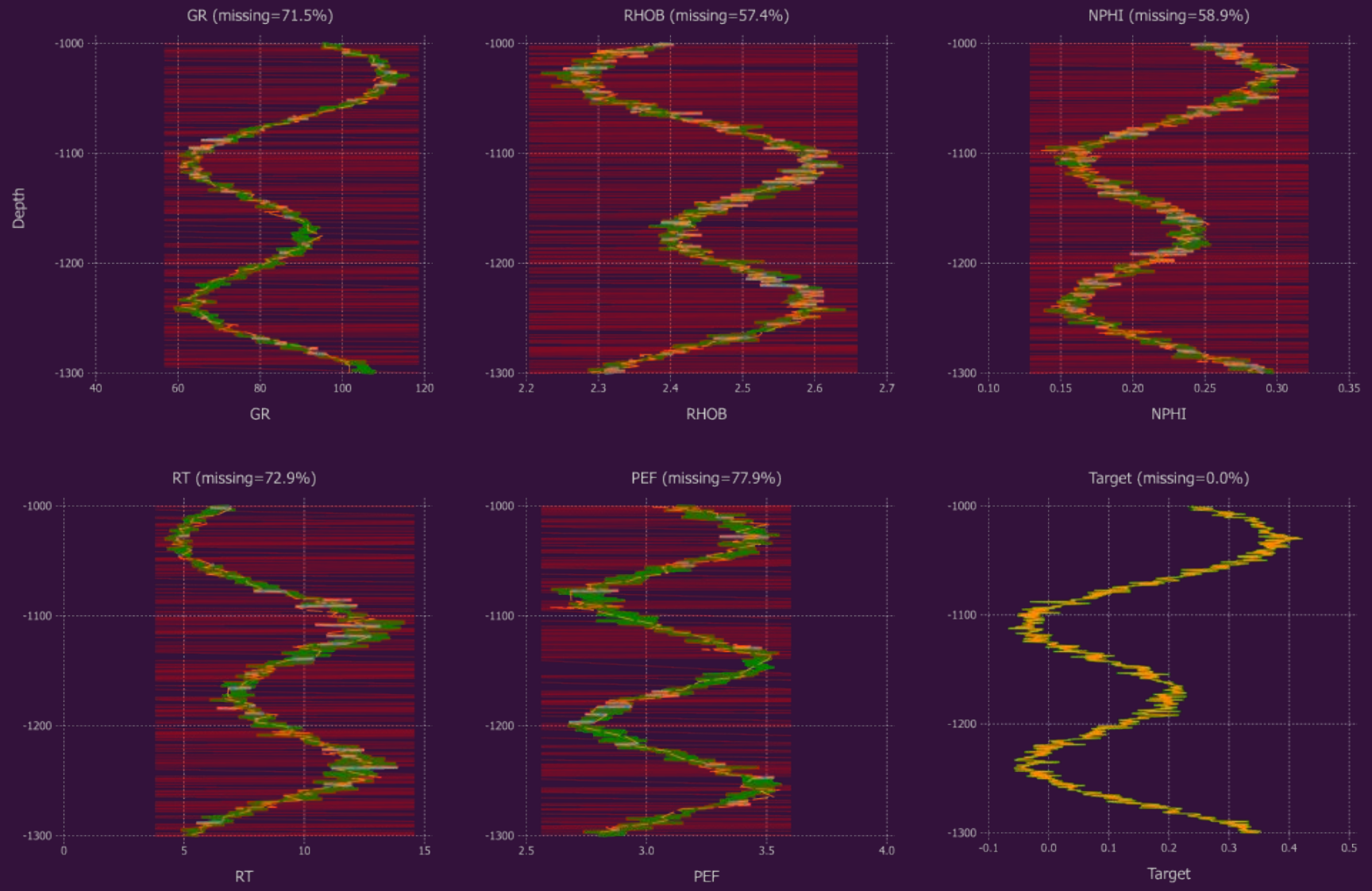
Well-log demo problem



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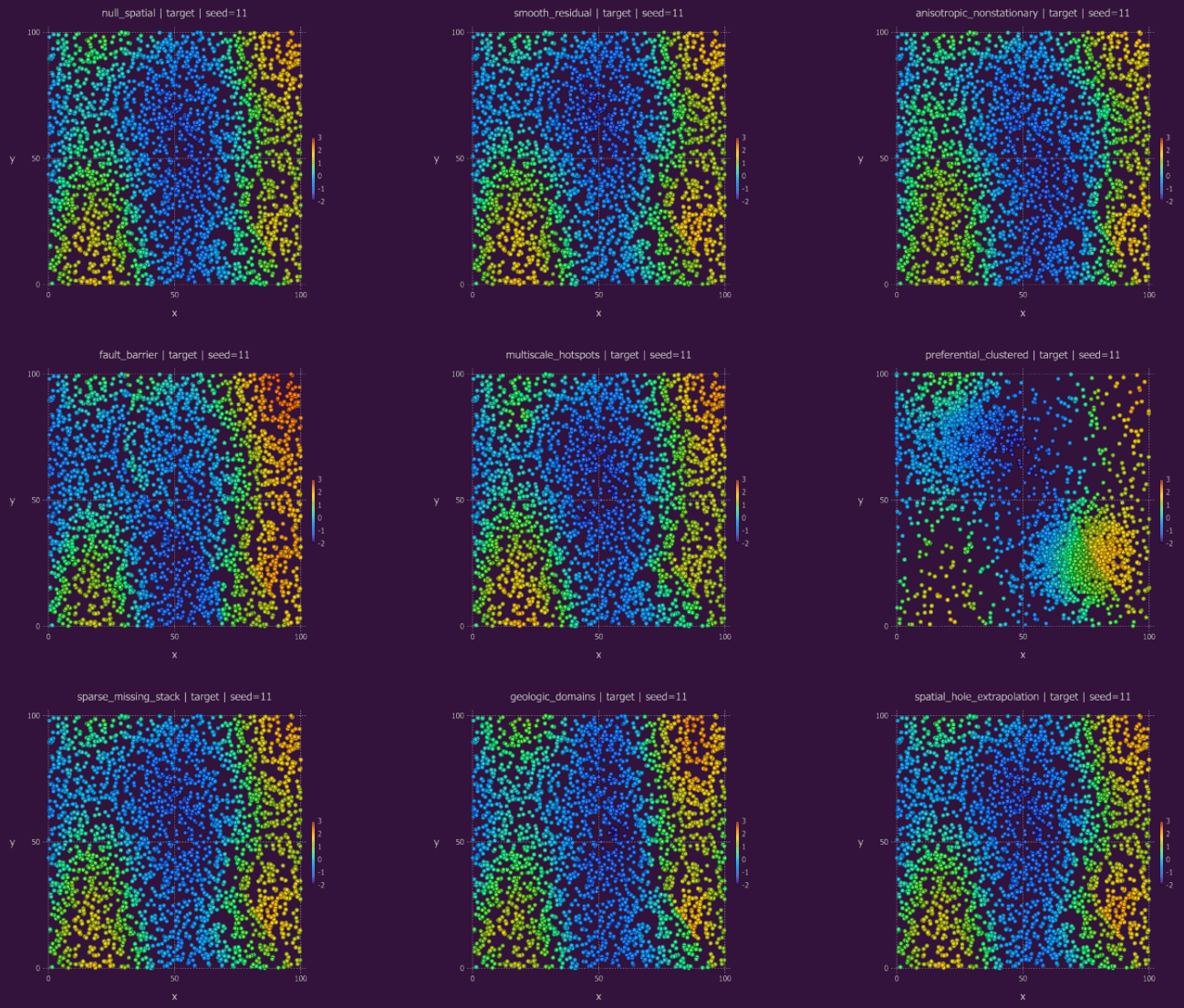
More realistic geo data masking



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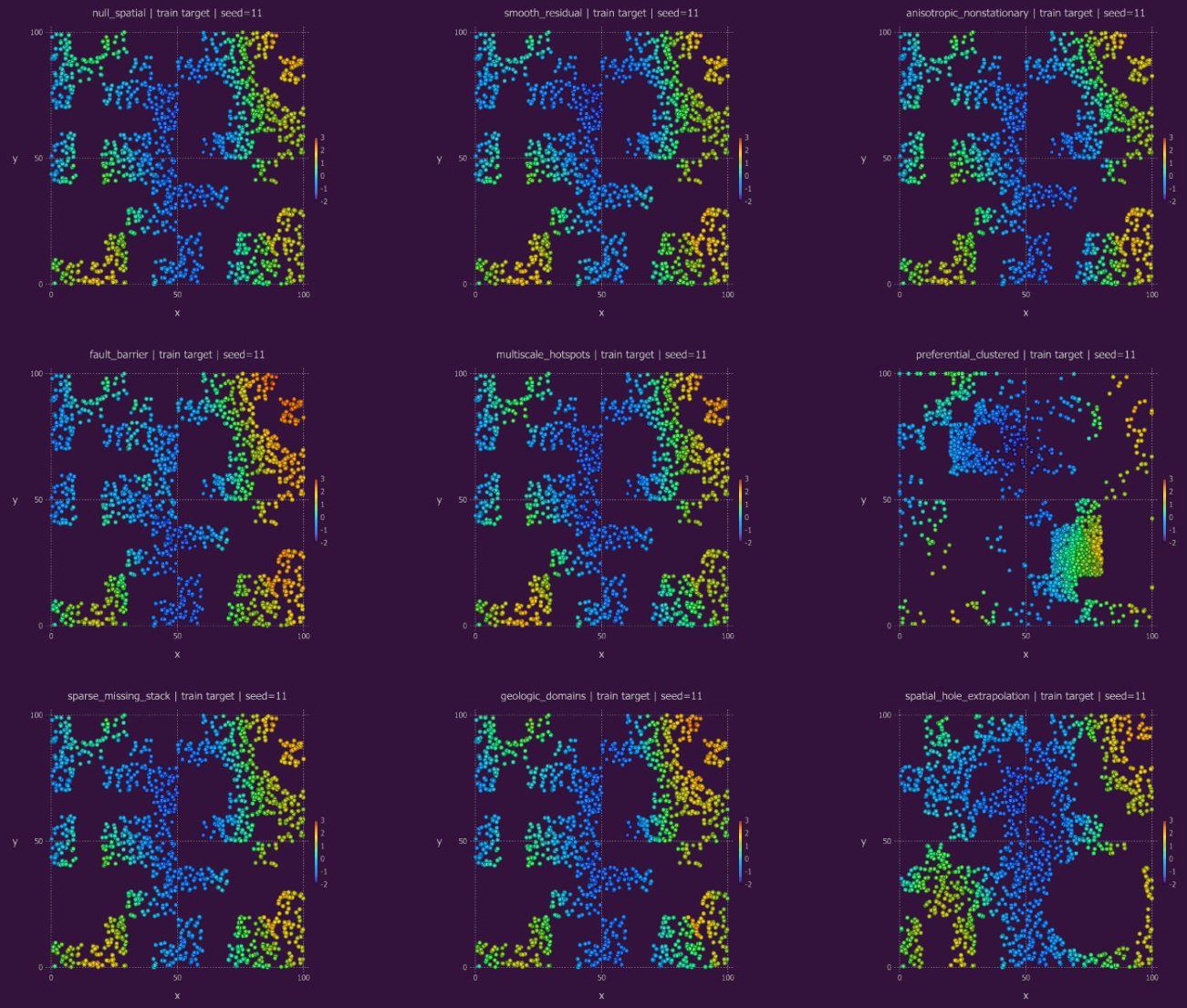
More realistic geo data masking



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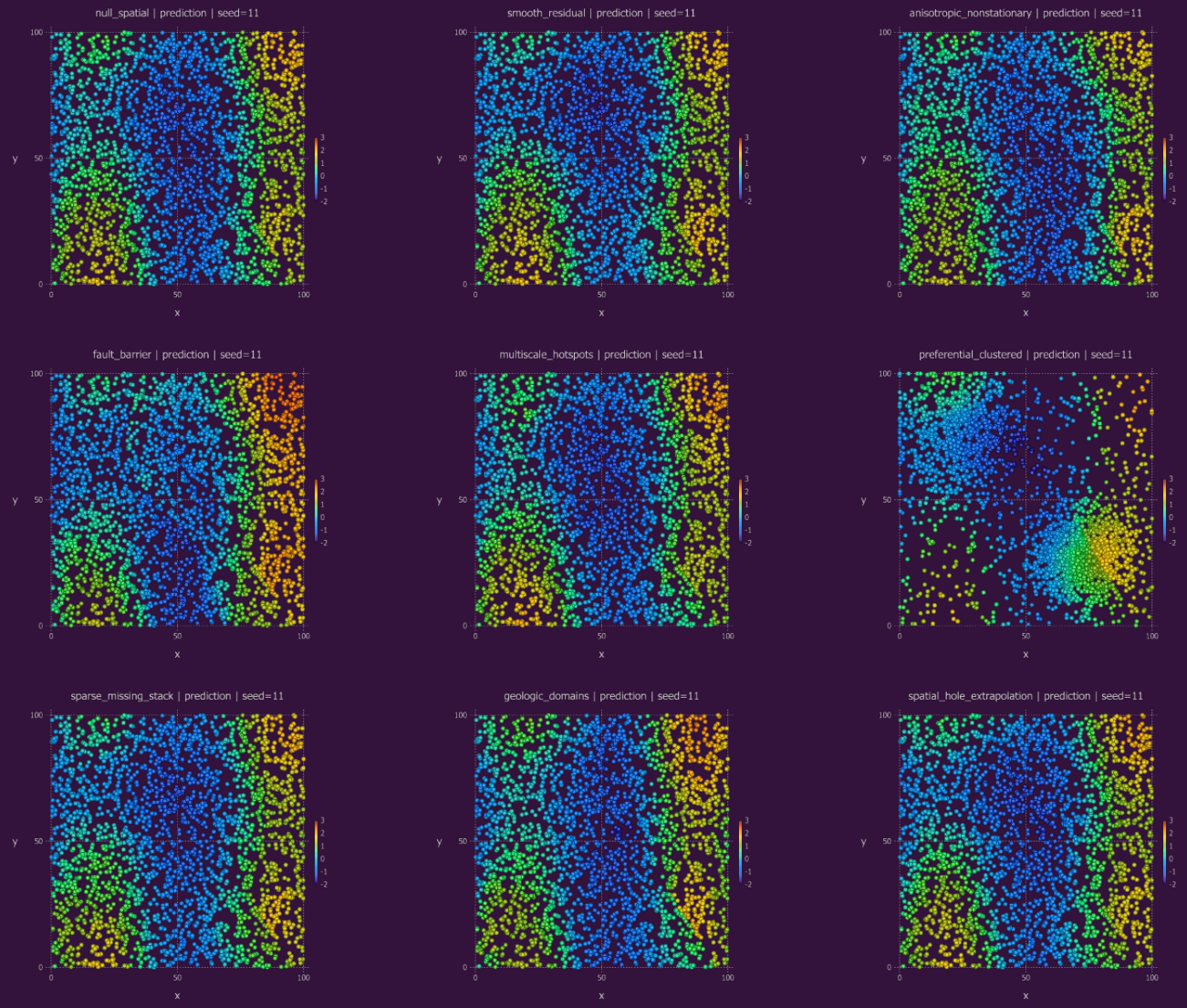
More realistic geo data masking



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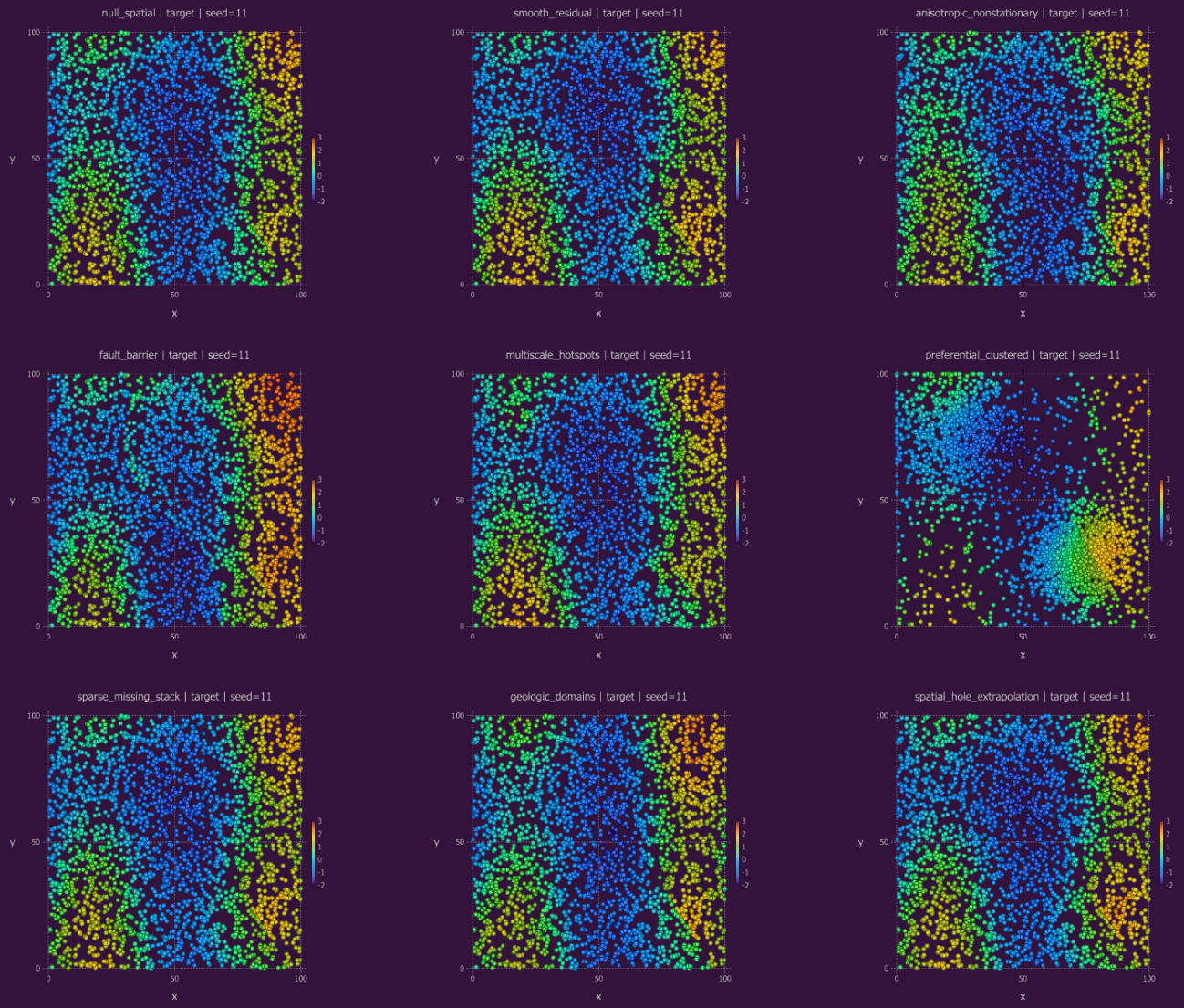
More realistic geo data masking



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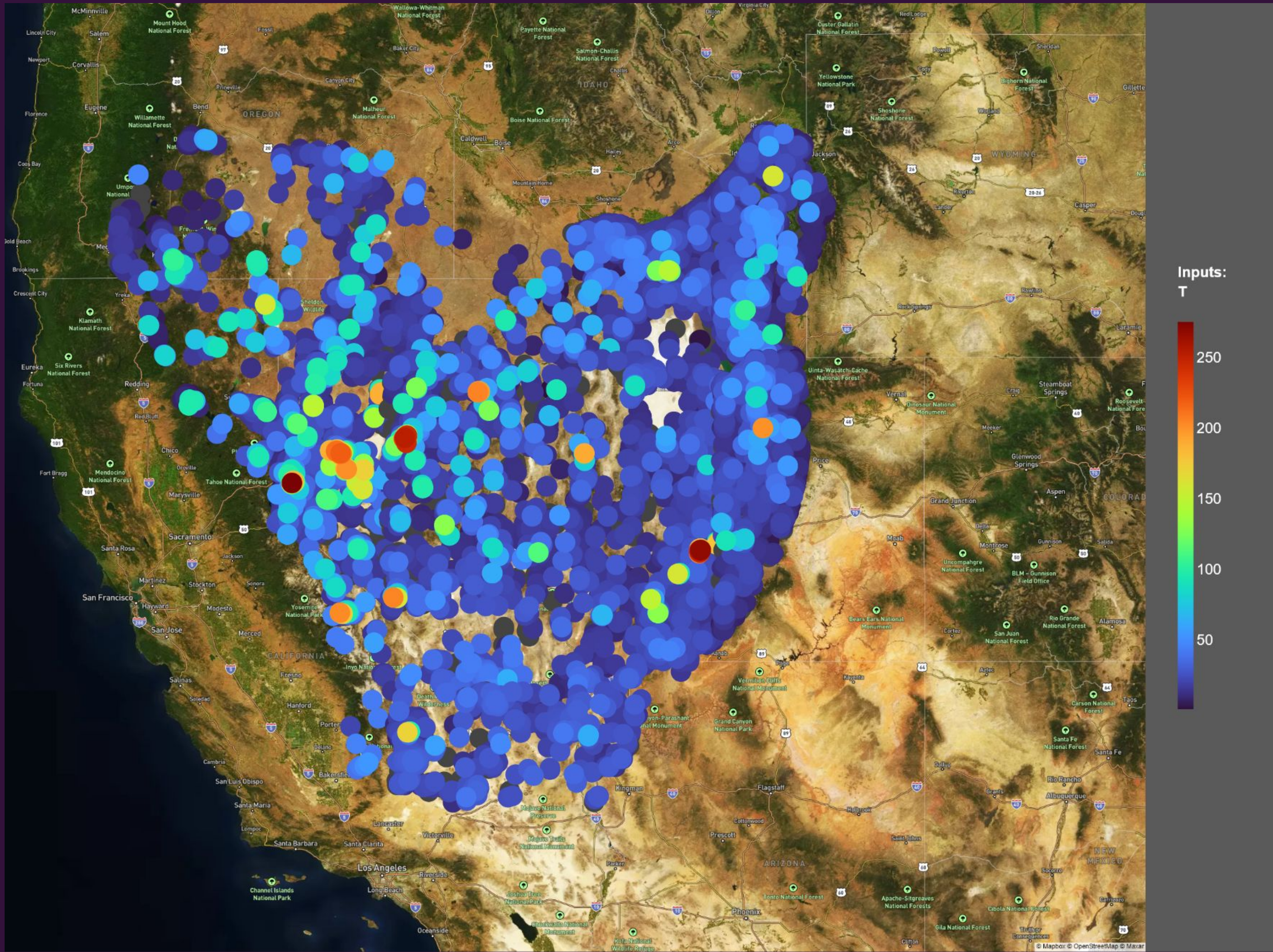
Great Basin Datasets

- Geology
- Geochemistry
- Geophysics (including GeoDAWN)

- 126 data attributes in total



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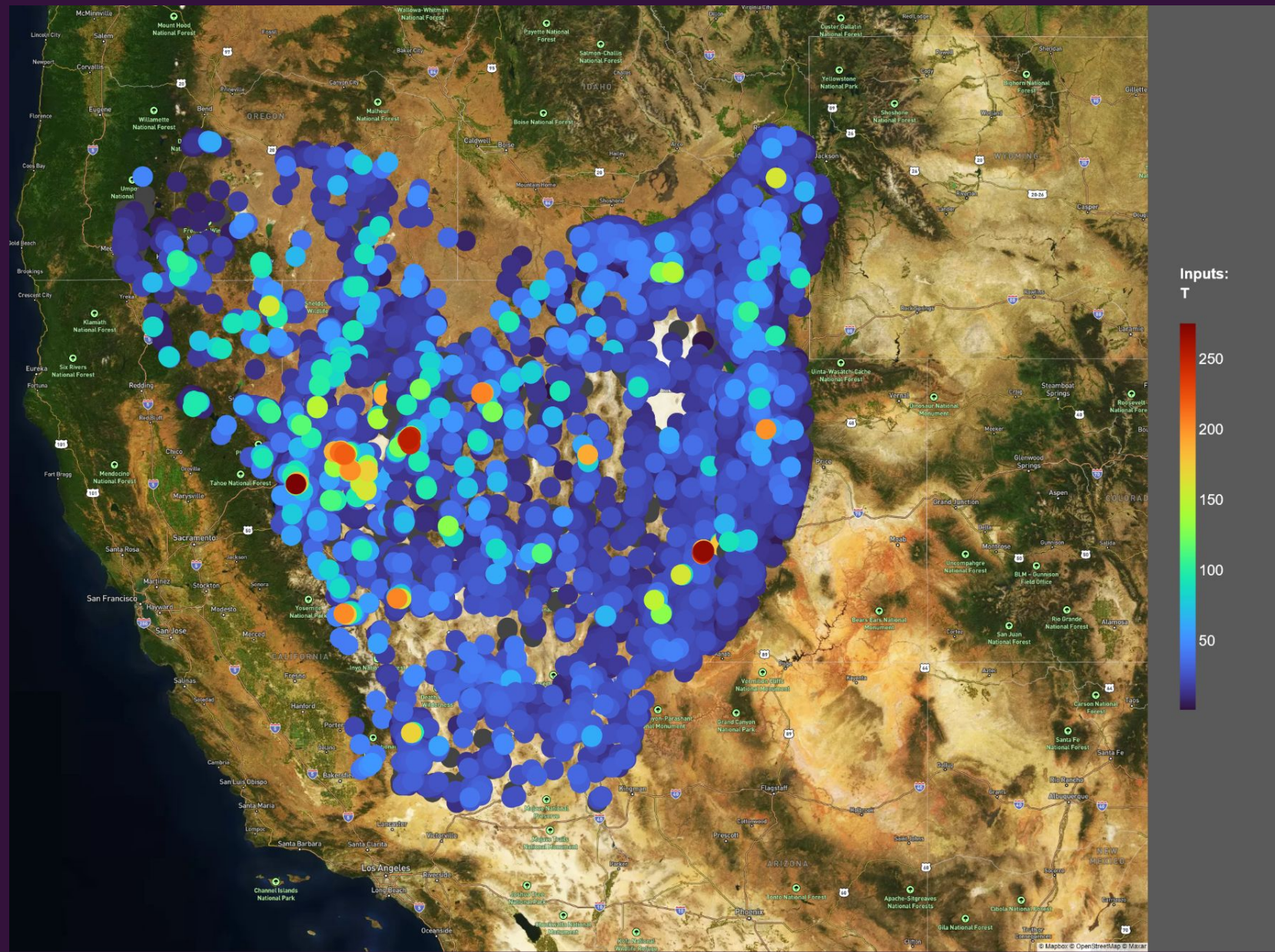
Great Basin Datasets (126 attributes in total)

- 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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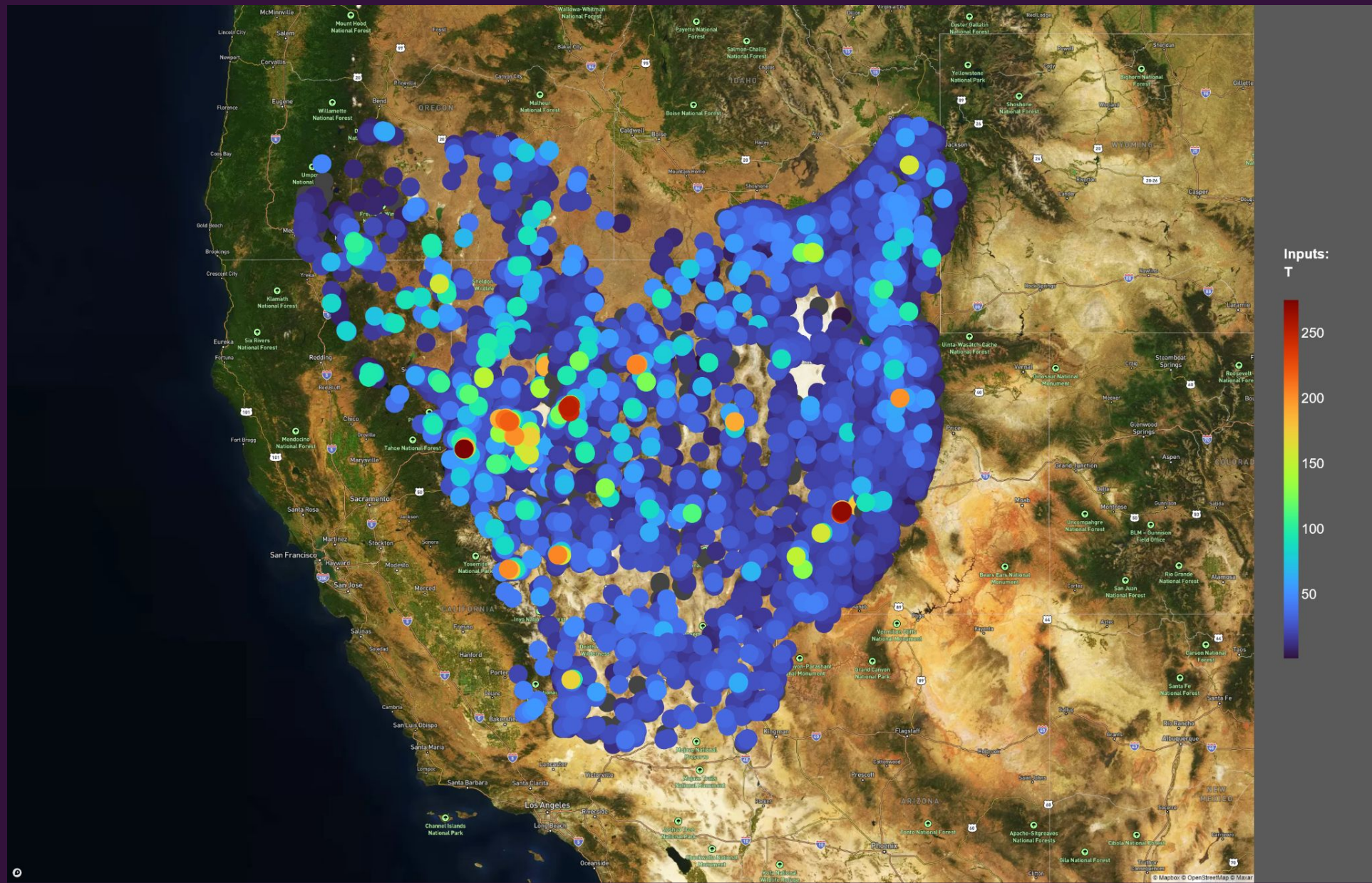
Temperature [C]



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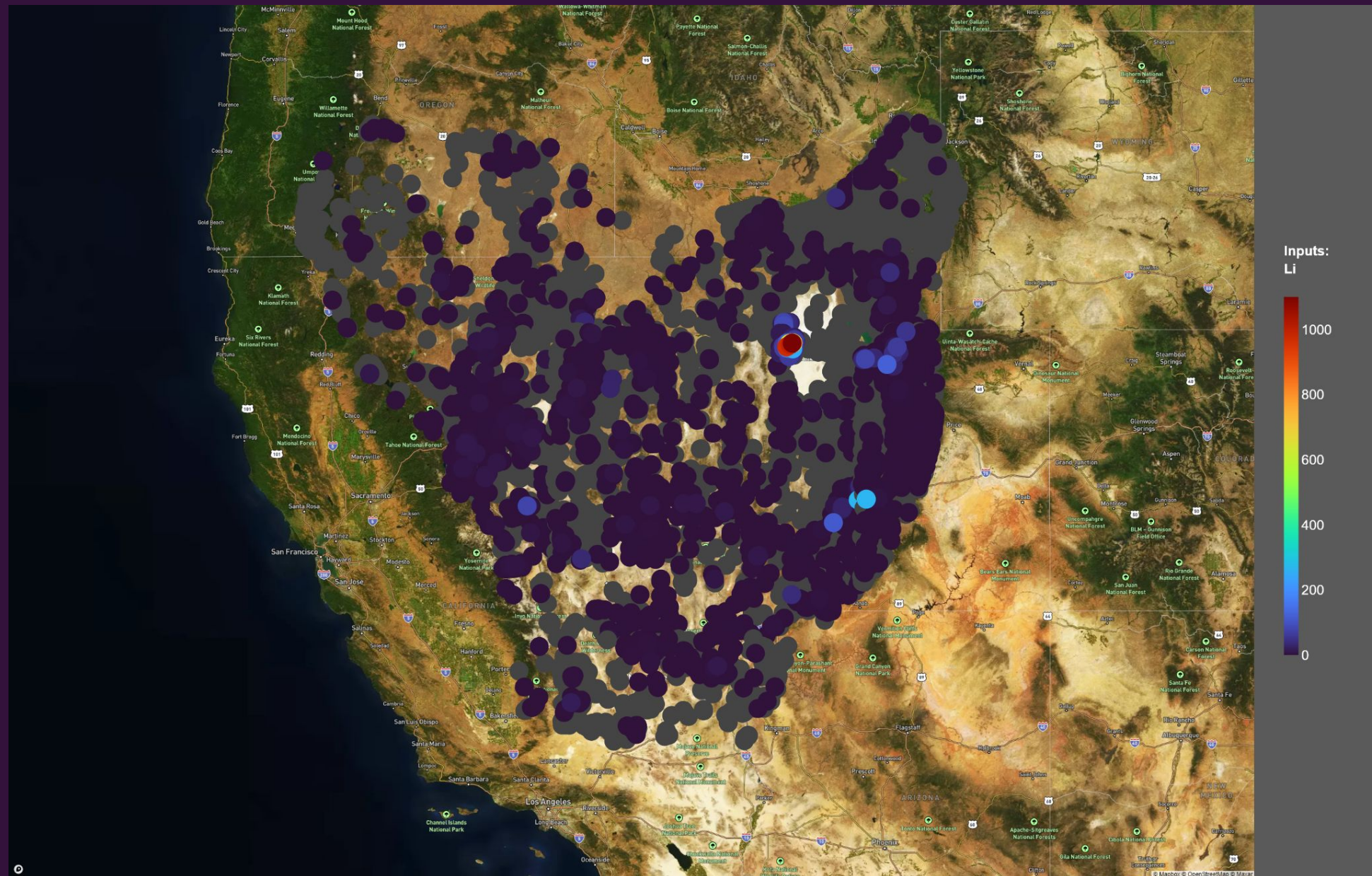
Lithium [ppb]



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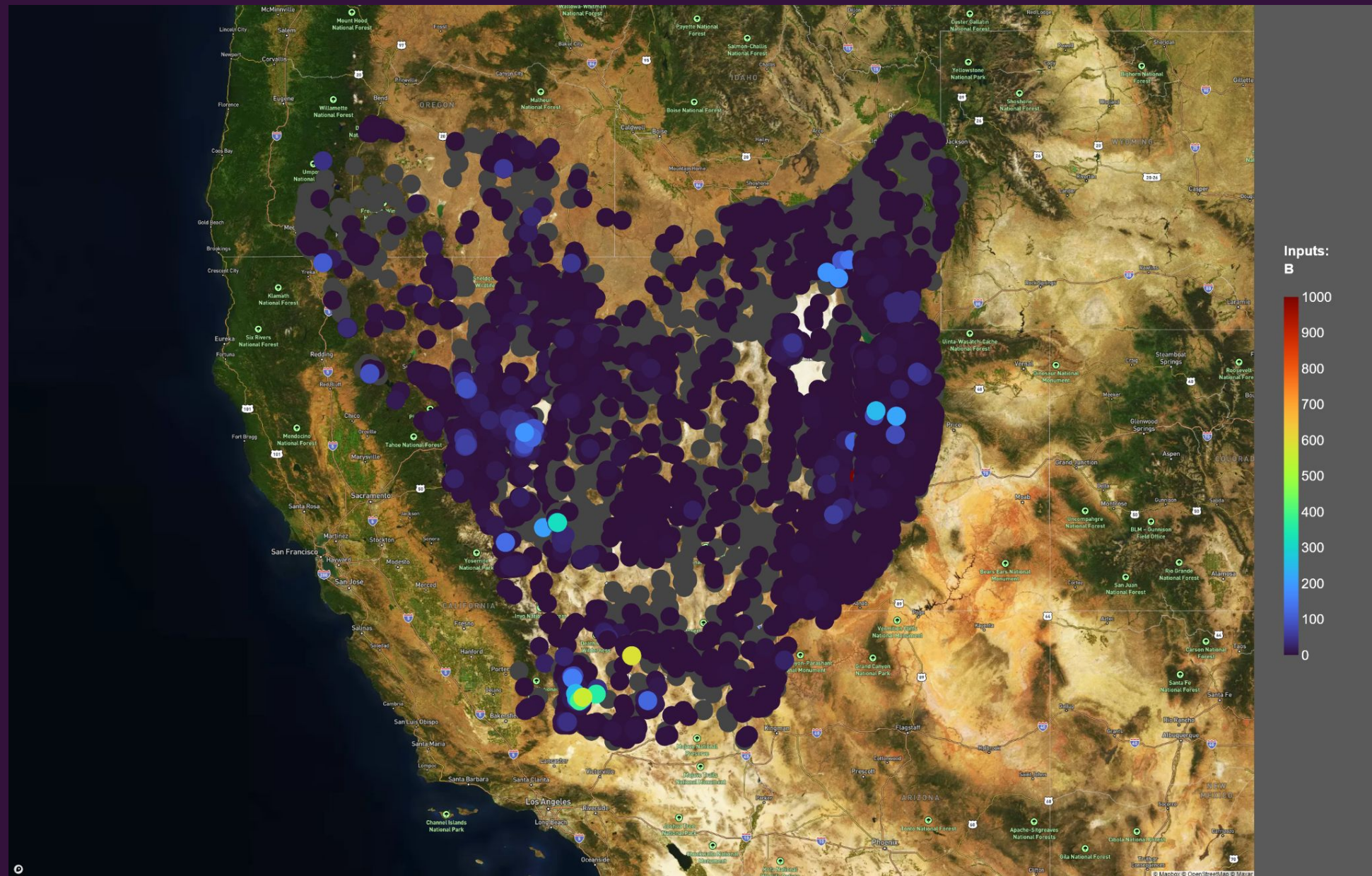
Boron [ppb]



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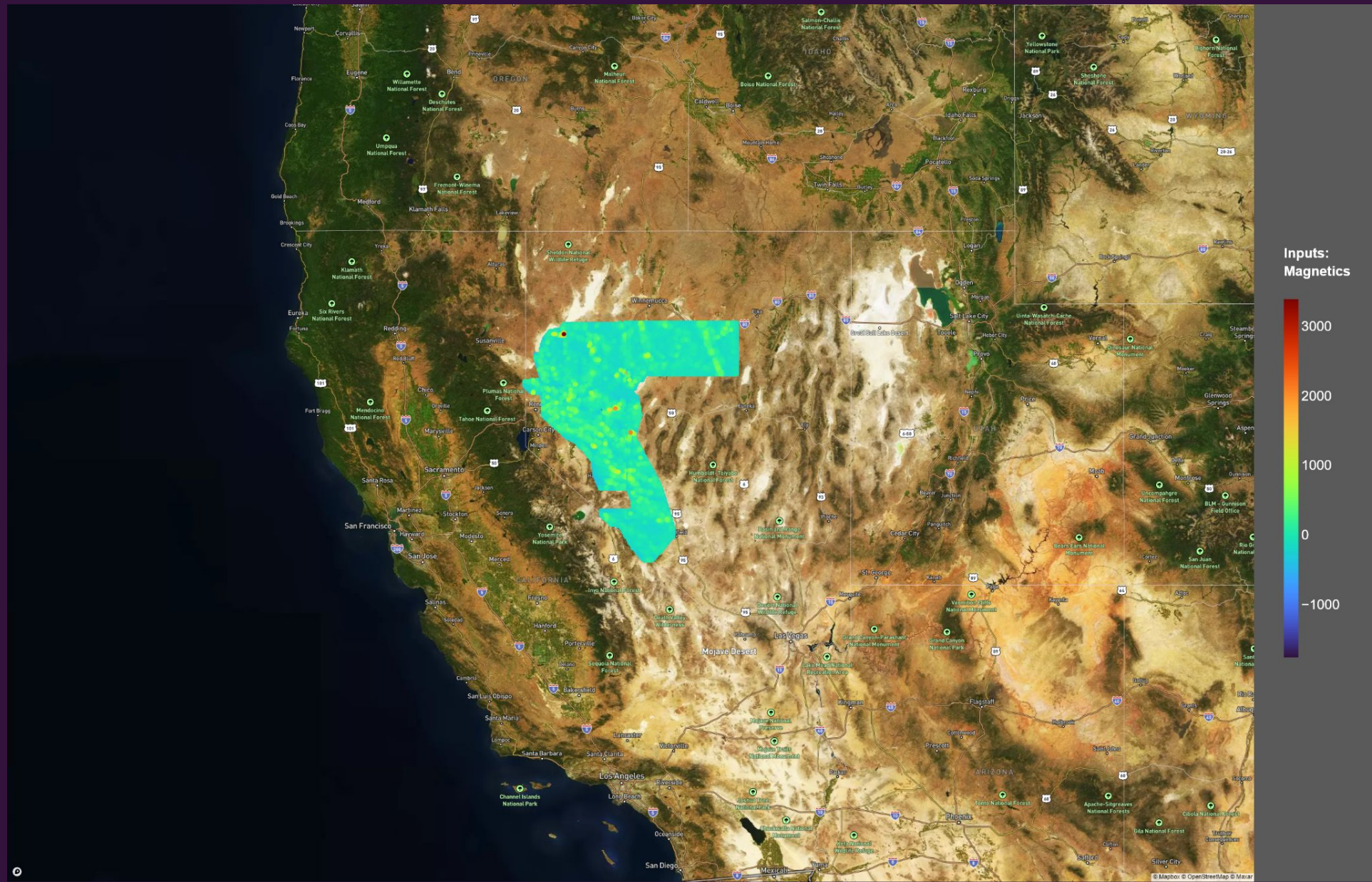
GeoDAWN: Magnetics



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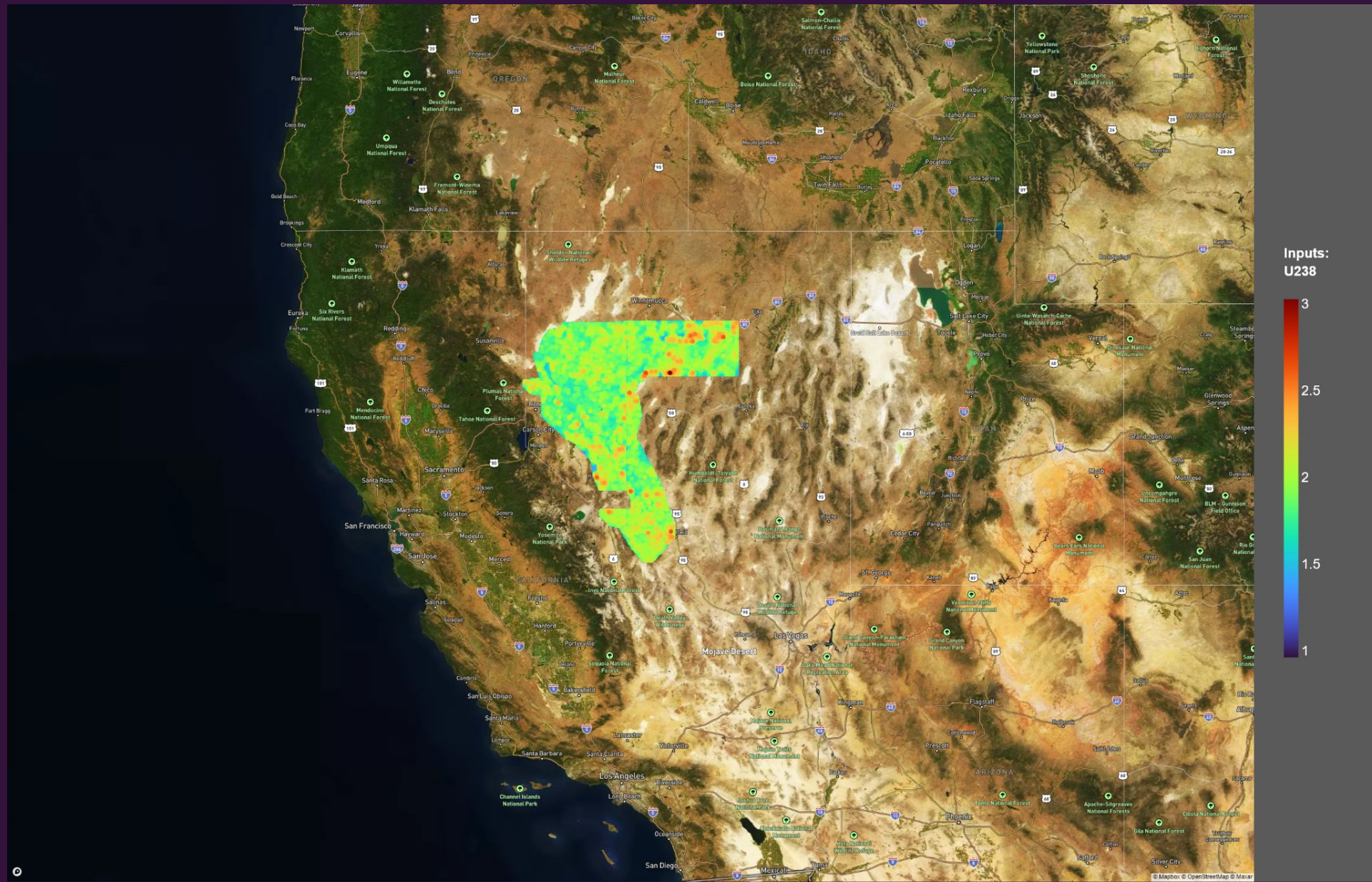
GeoDAWN: Uranium-238



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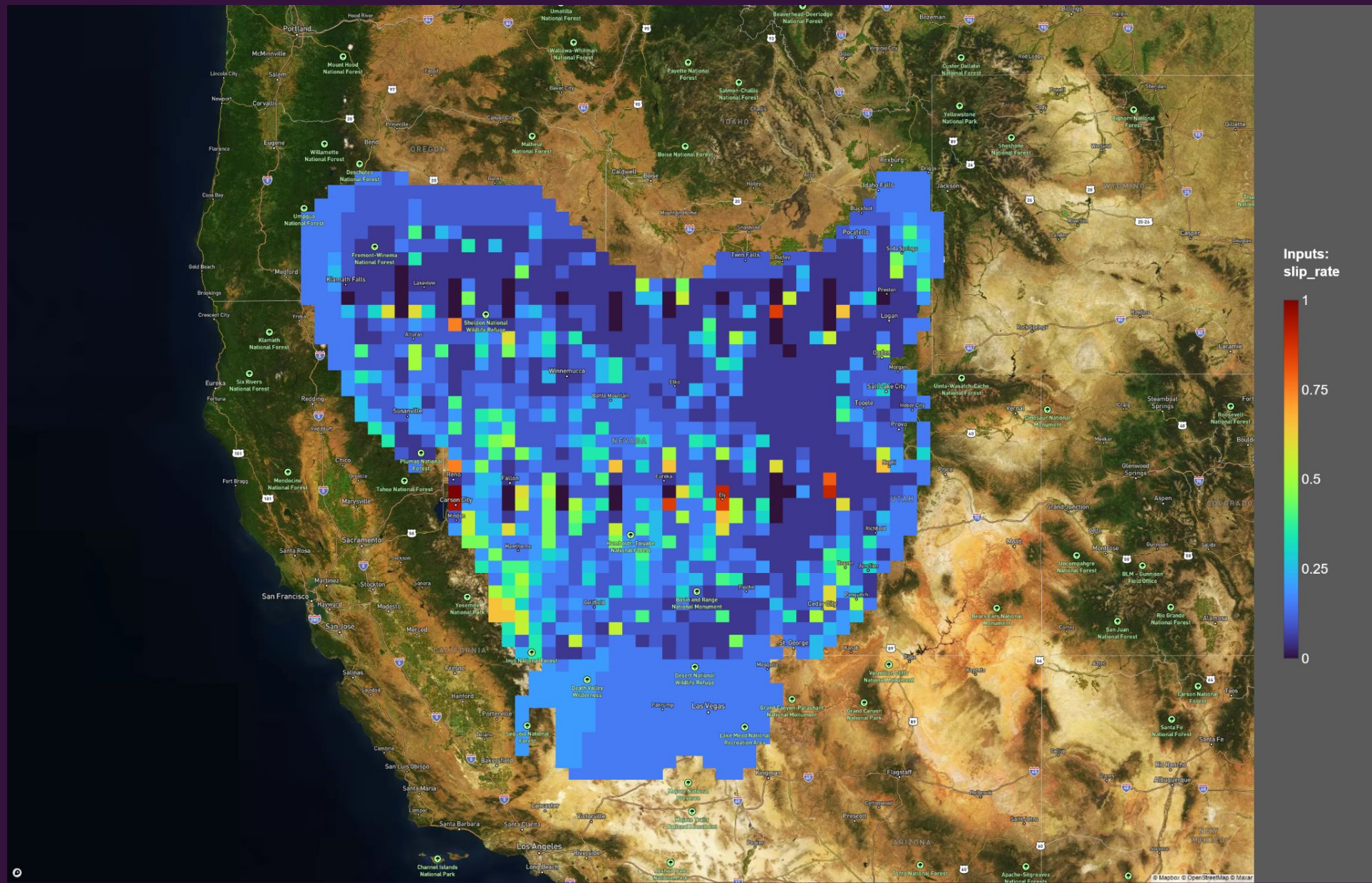
Fault Densities: Slip rate



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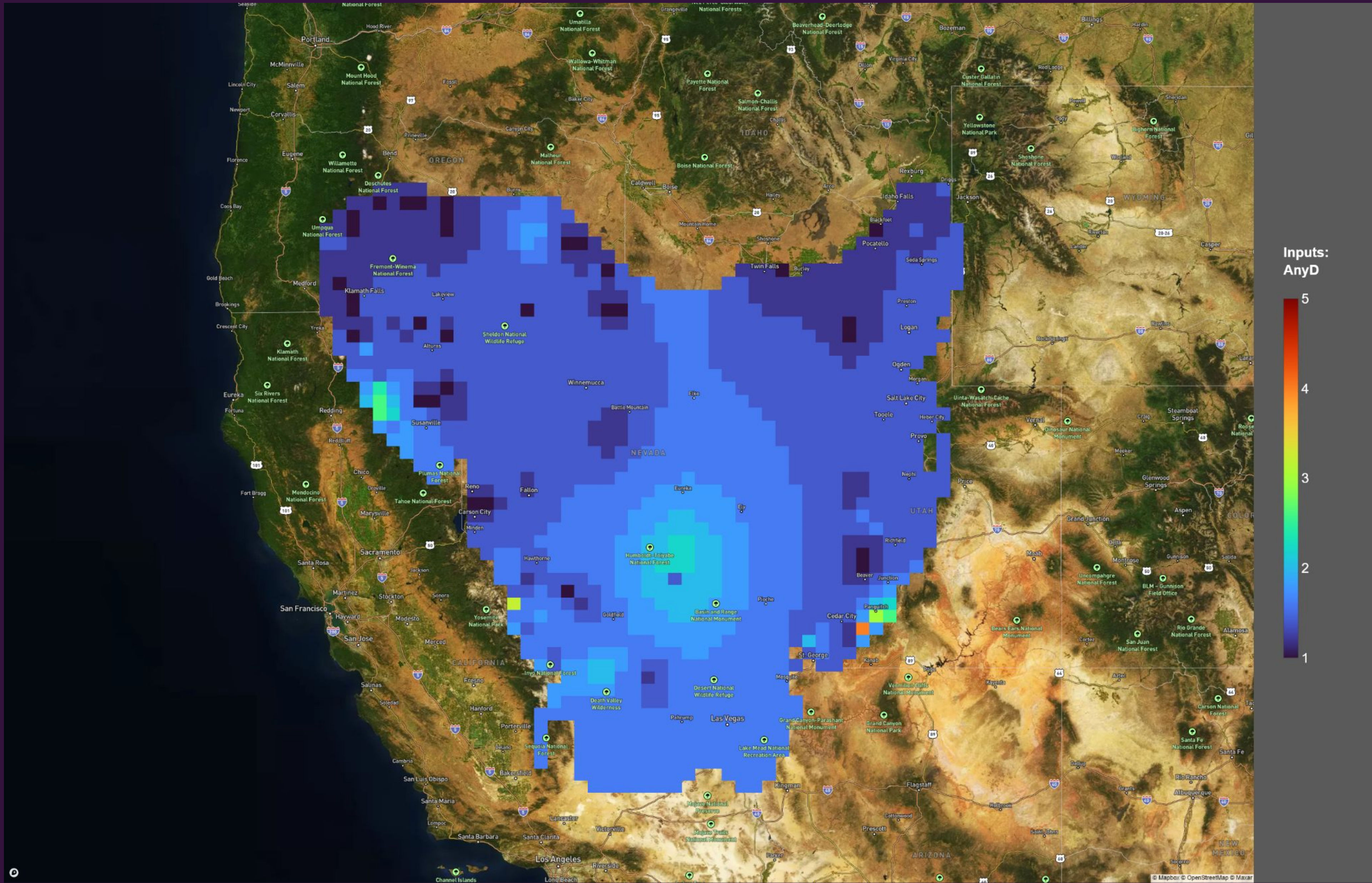
Quaternary Vent Densities



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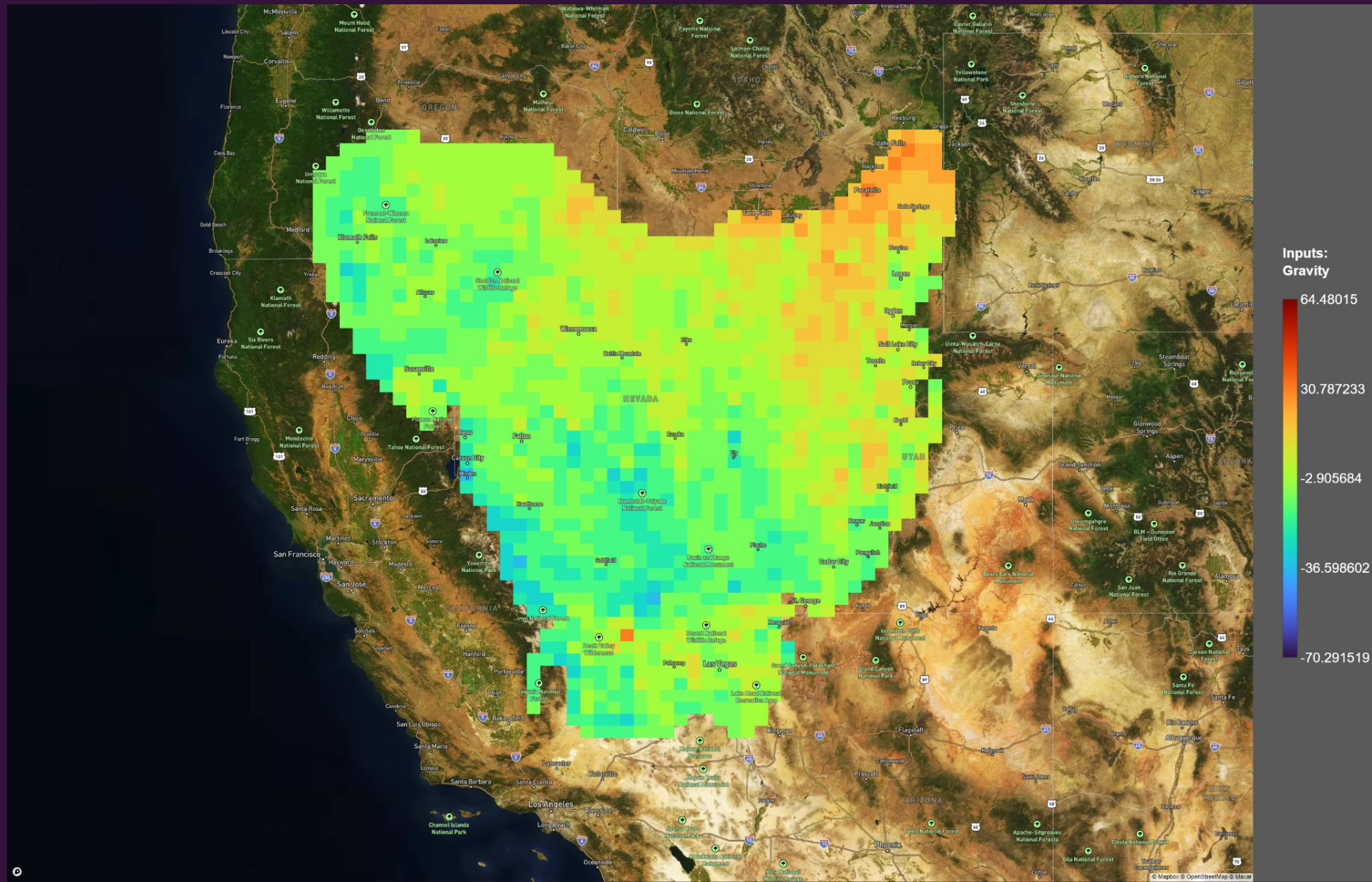
Gravity



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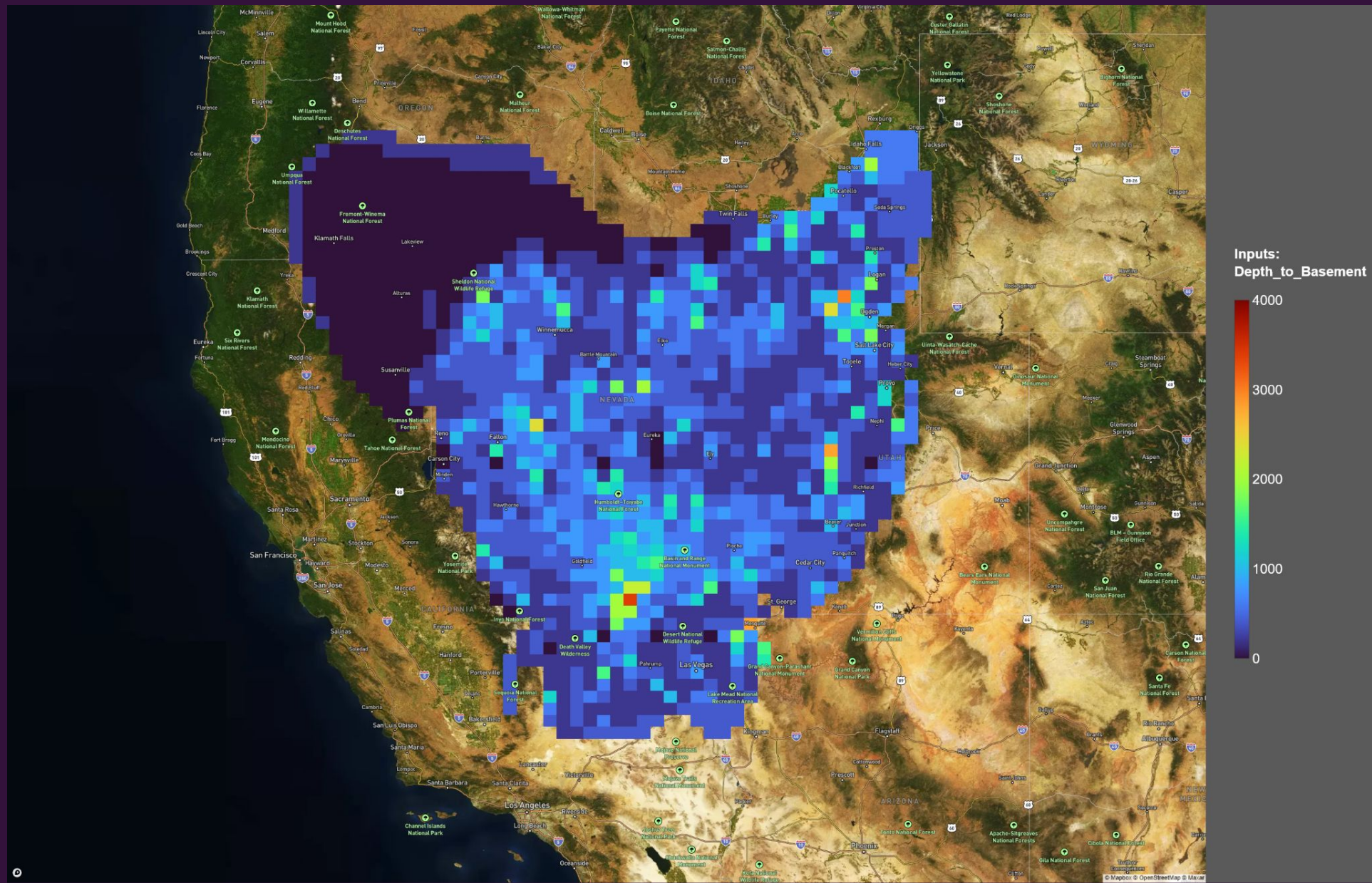
Depth to Basement



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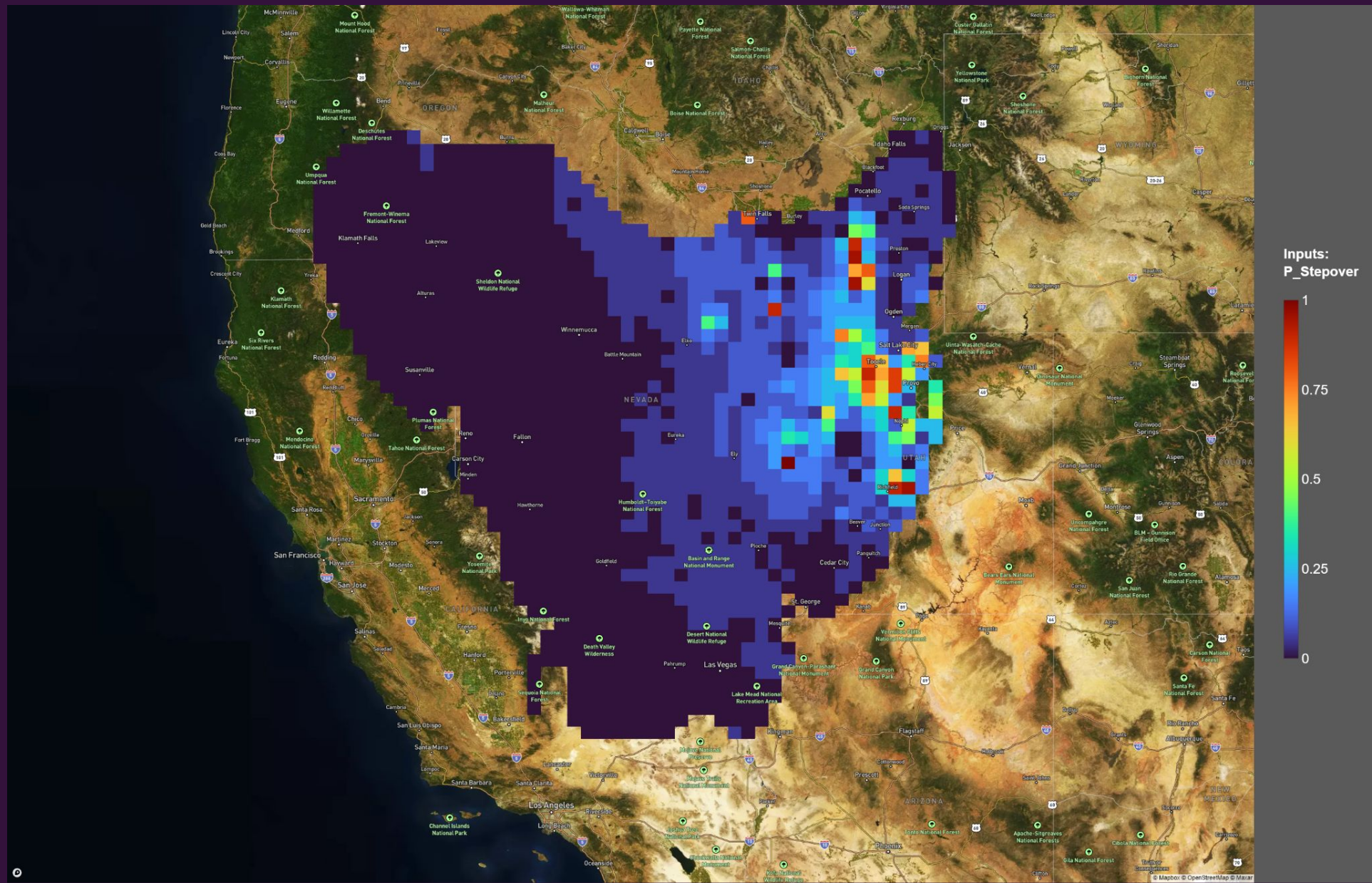
Fault Structure Densities: Stepover



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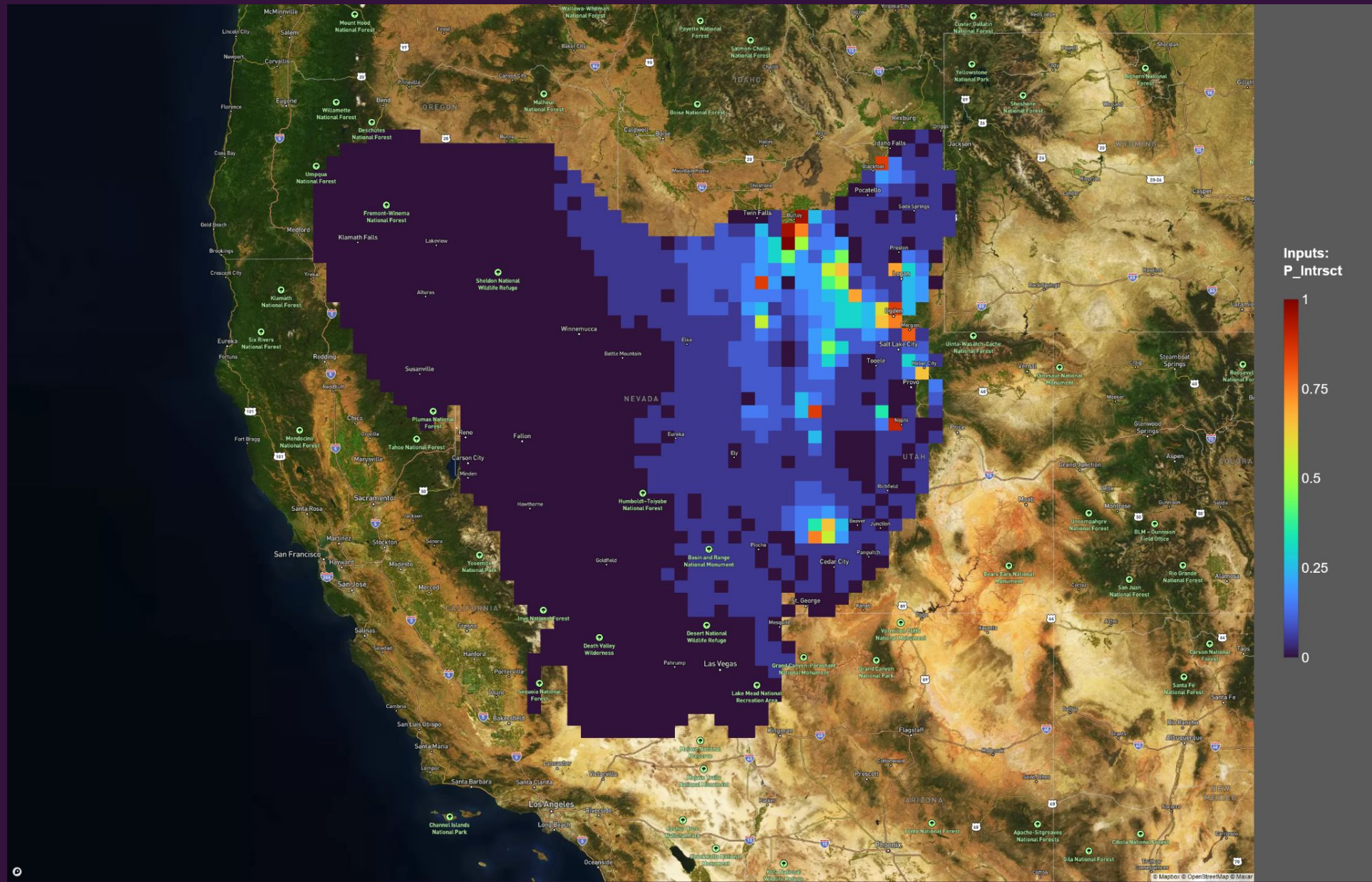
Fault Structure Densities: Intersections



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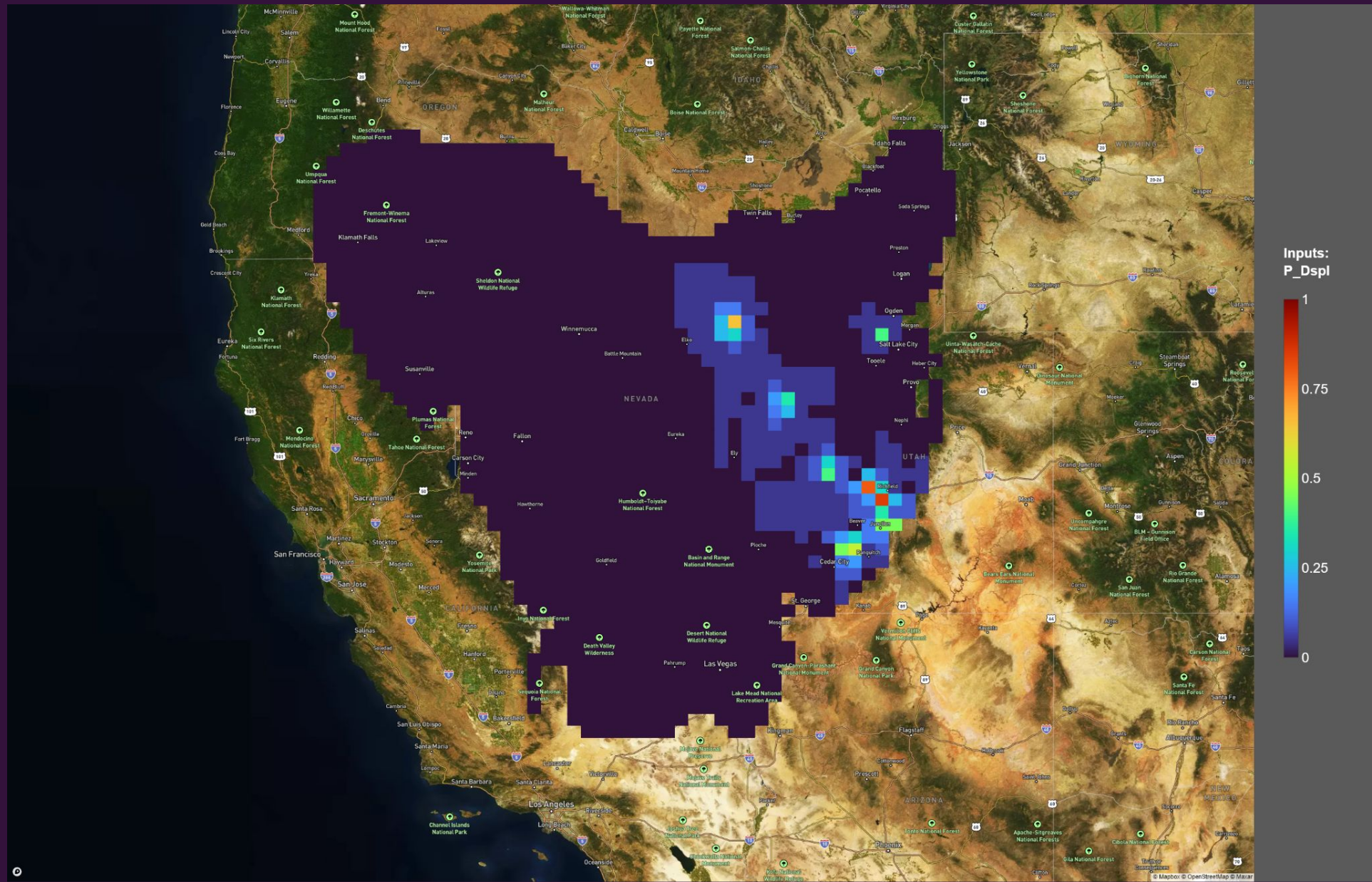
Fault Structure Densities: Displacements



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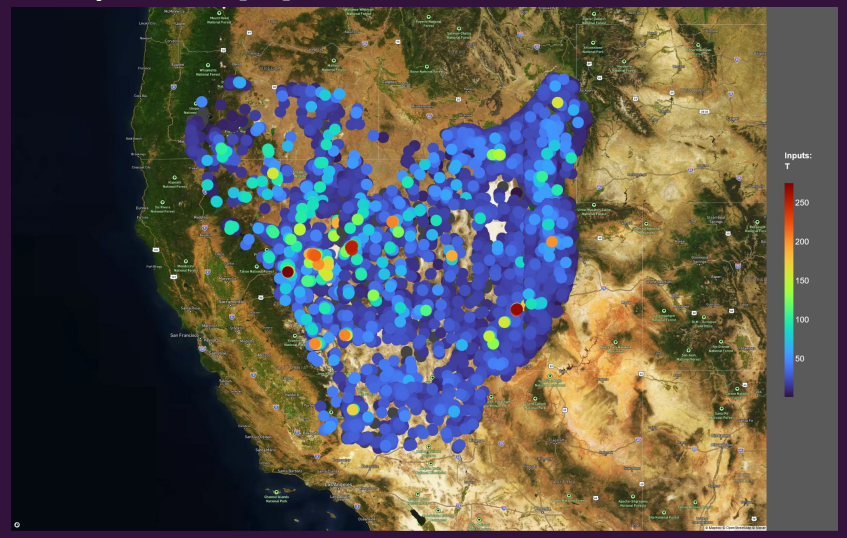
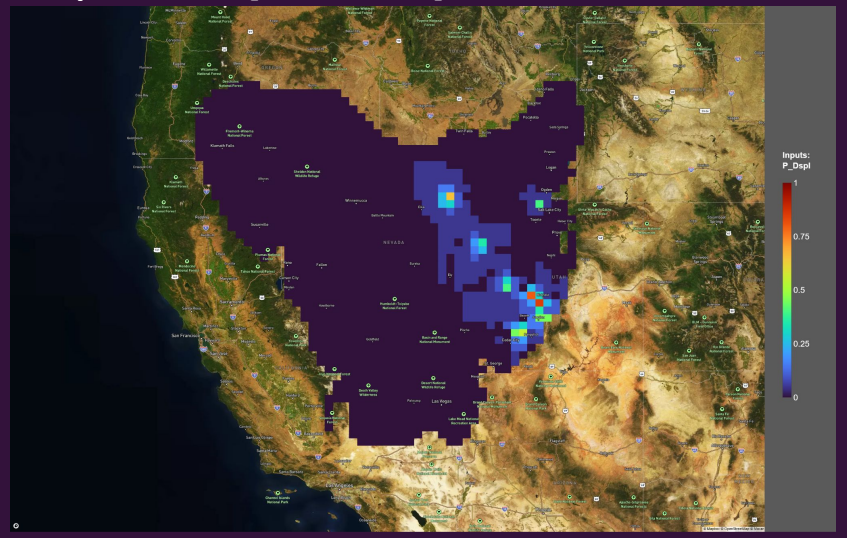
Finding a Needle in a Haystack

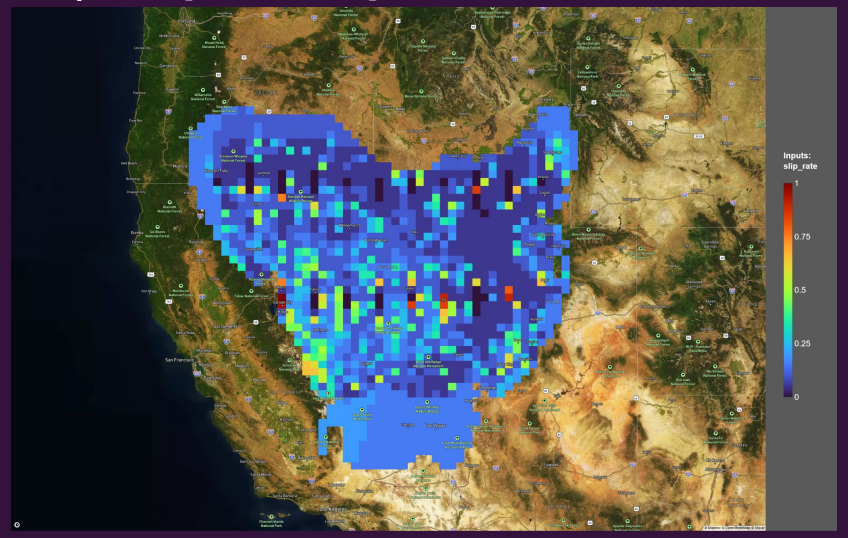
Temperature [°C]



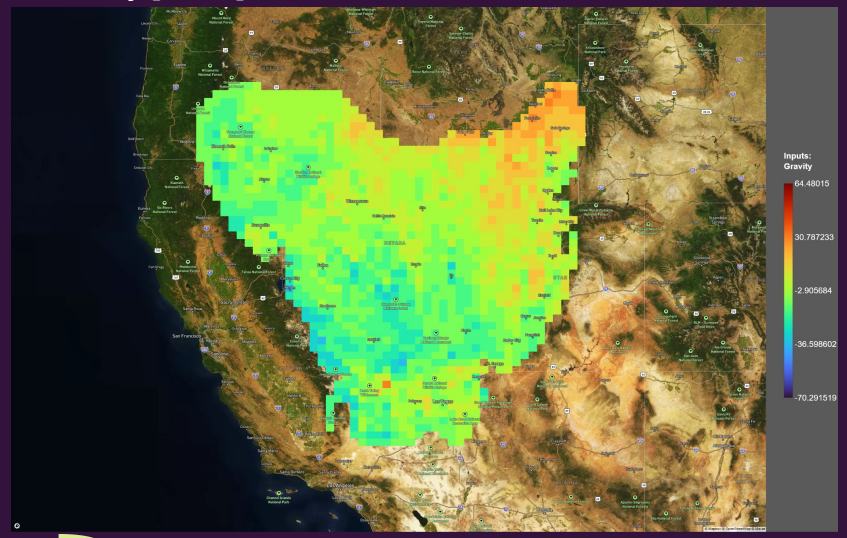
Displacement [normalized]



Slep Rate [normalized]

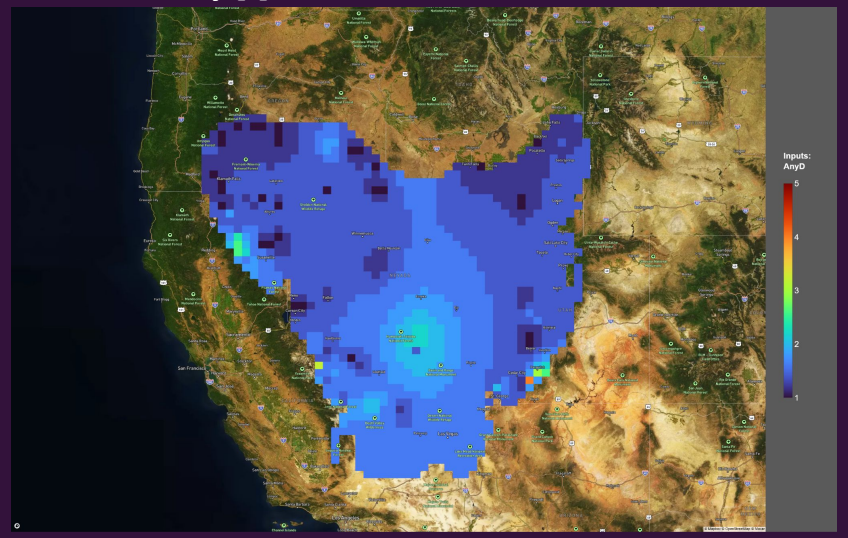


Gravity [m/s^2]



Magnetics [nT]

Vent Density [-]



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Hidden Feature Extraction

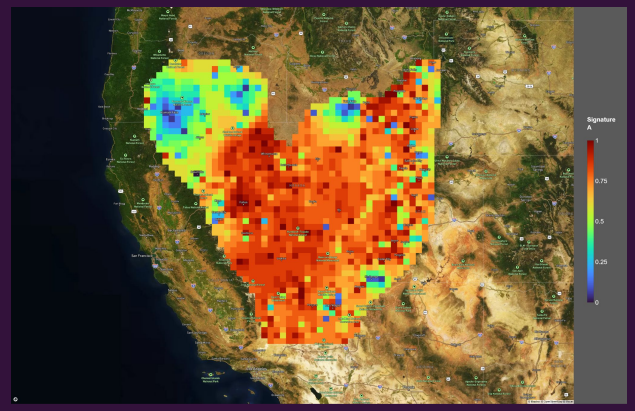
- Helps analyze and synthesize challenging geo data
- Discovers hidden (latent) geologic features representing and impacting geologic conditions
- Supports estimation of reservoir prospectivity and productivity potential
- Forms a core part of our physics-informed AI/ML methods and tools

Signatures

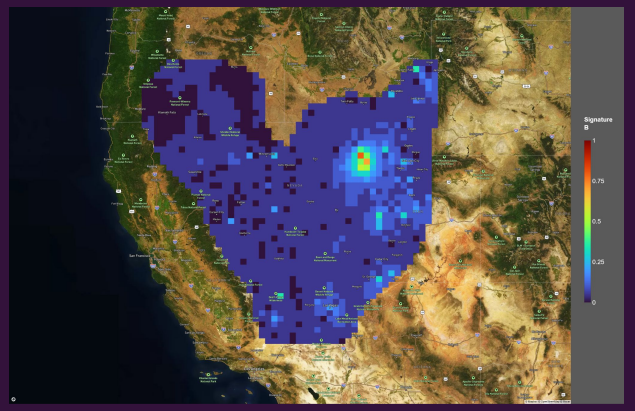
- 126 data attributes synthesized into 8 hidden (latent) signatures
- Each signature captures the essence of the data
- Each signature is associated with one or more data attributes
- Associations guide the understanding of the geologic conditions

Signatures

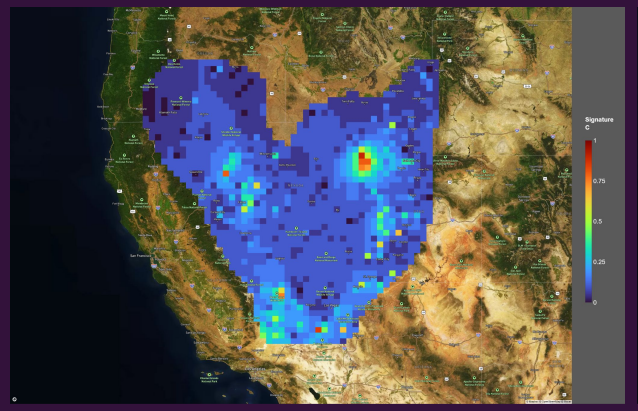
C14/Basement Depth



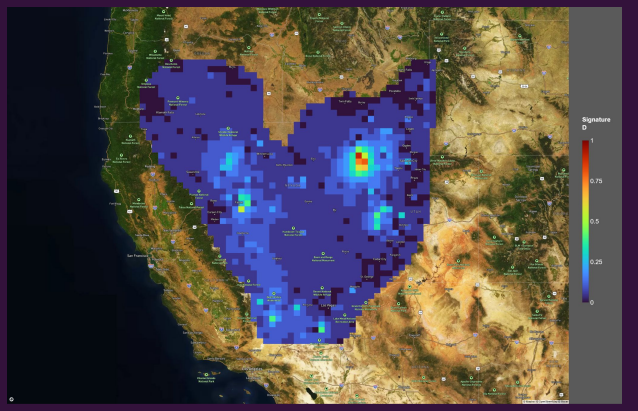
Radon



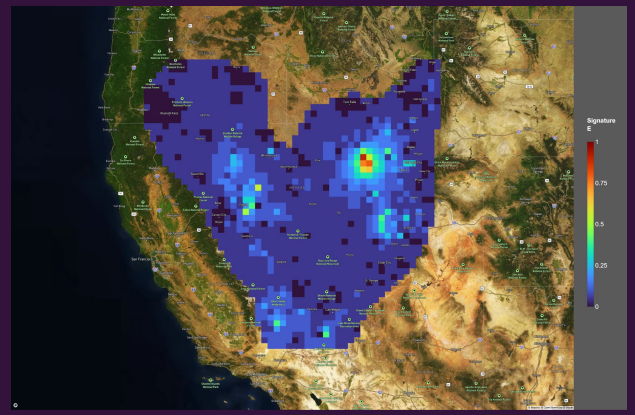
TDS/Conductivity



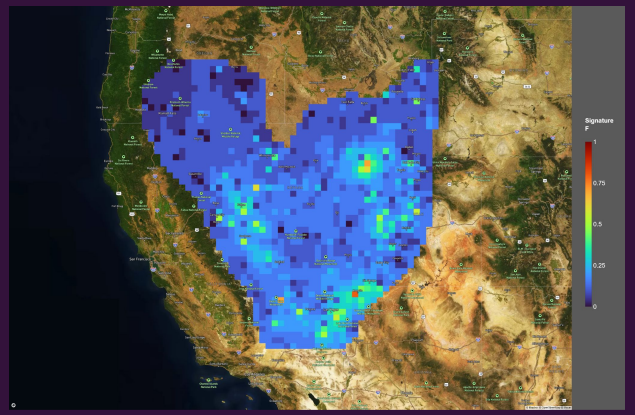
Technetium-99



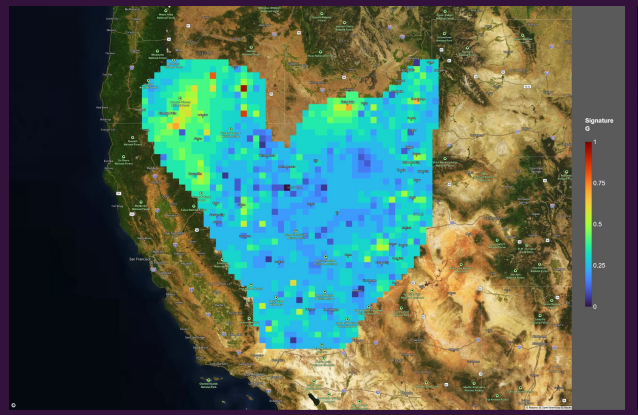
Li/Cl



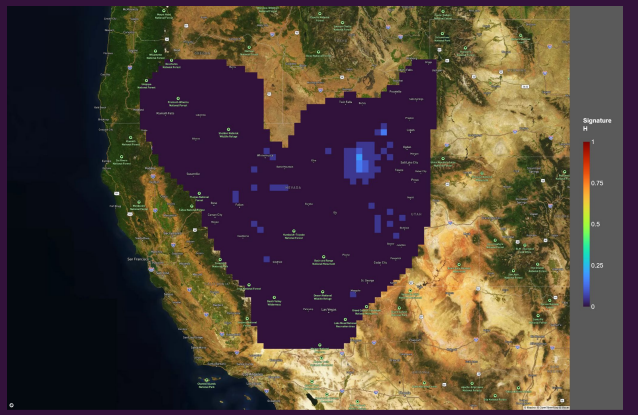
Carbonate hardness



T/B/Stepover Faults

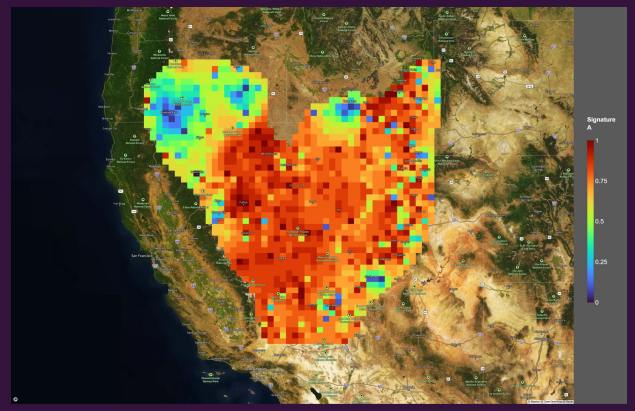


Na/Ca/Mg

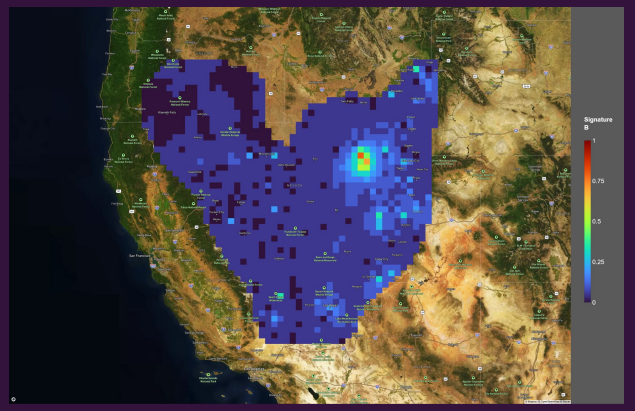


Signatures

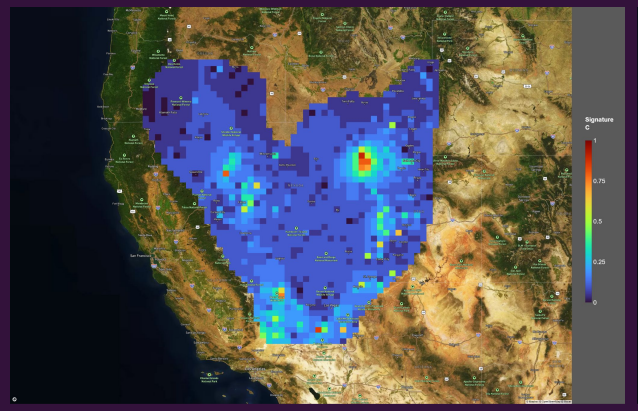
C14/Basement Depth



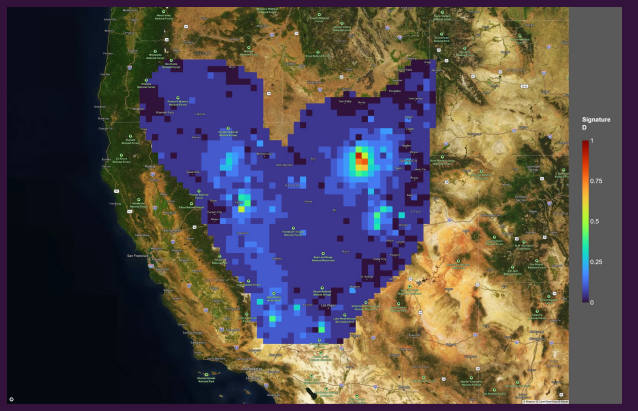
Radon



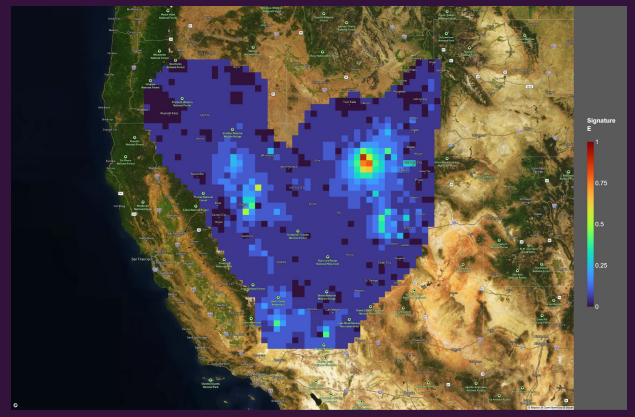
TDS/Conductivity



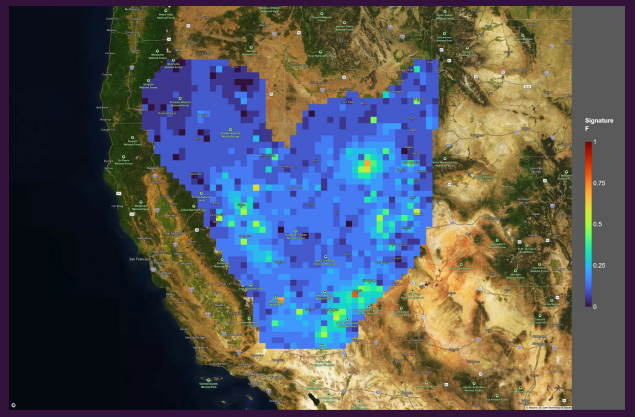
Technetium-99



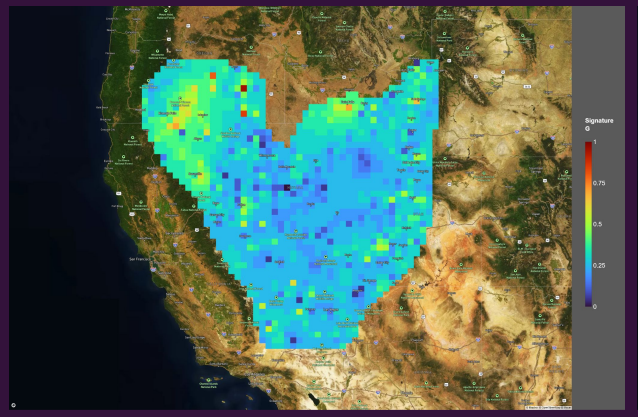
Li/Cl



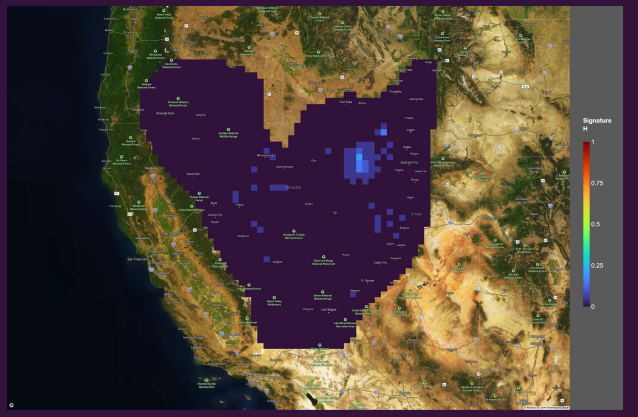
Carbonate hardness



T/B/Stepover Faults

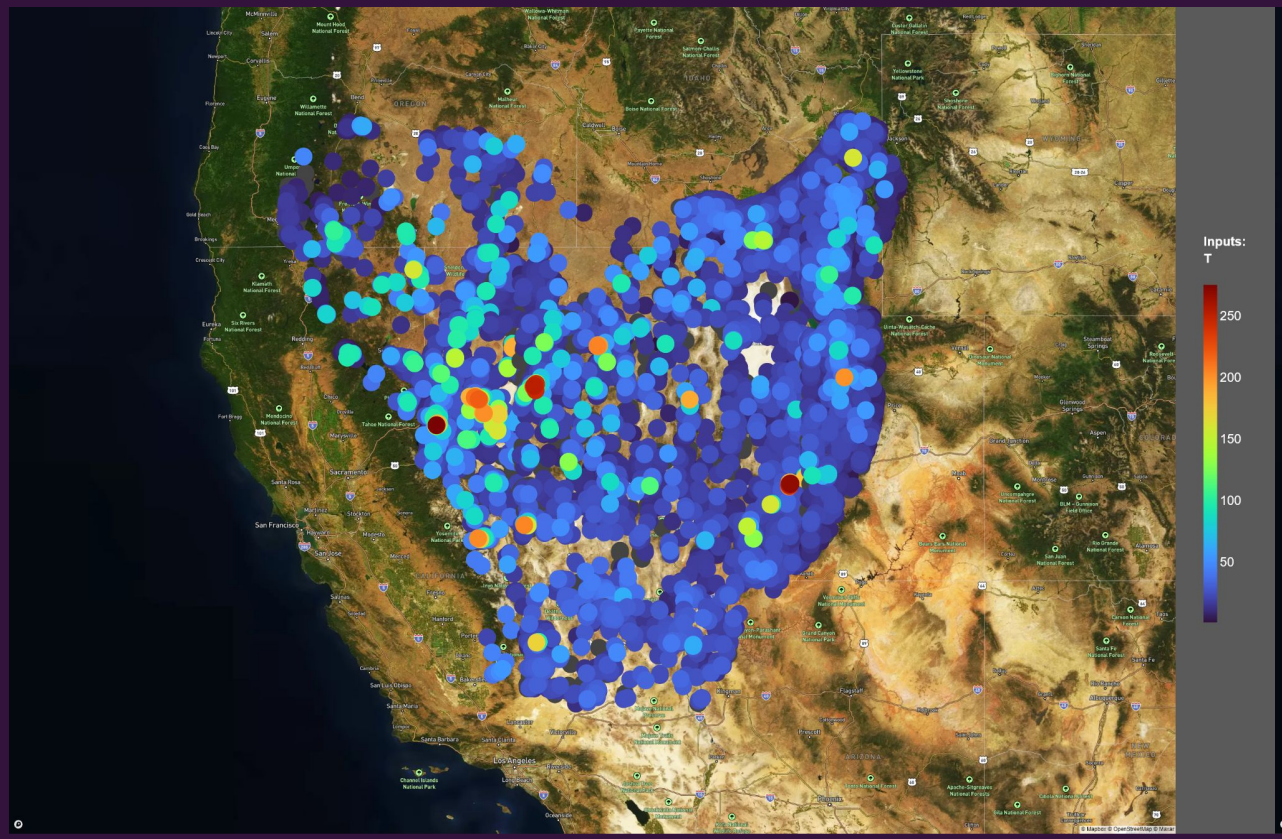


Na/Ca/Mg

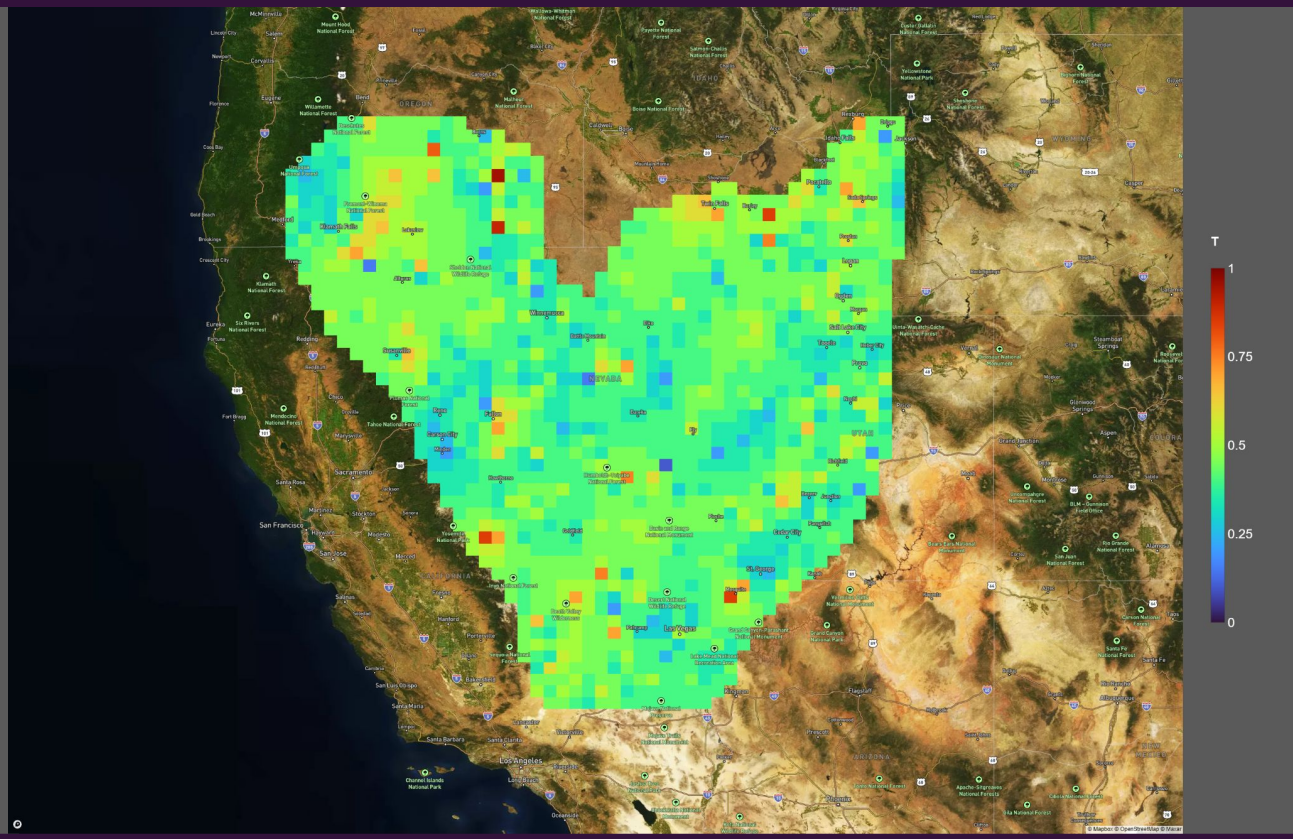


Geothermal Temperature: Data vs Prospectivity

Temperature [°C]

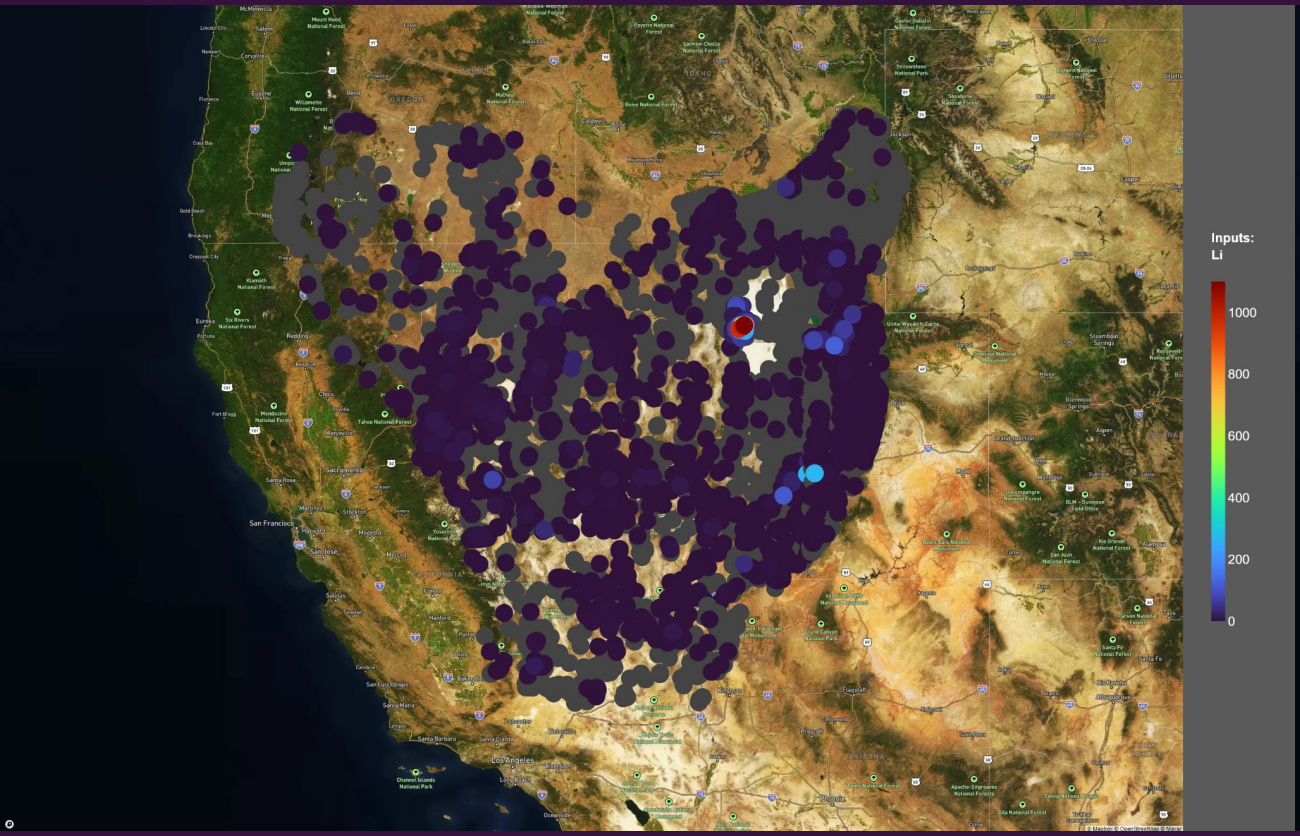


Geothermal Prospectivity [normalized]

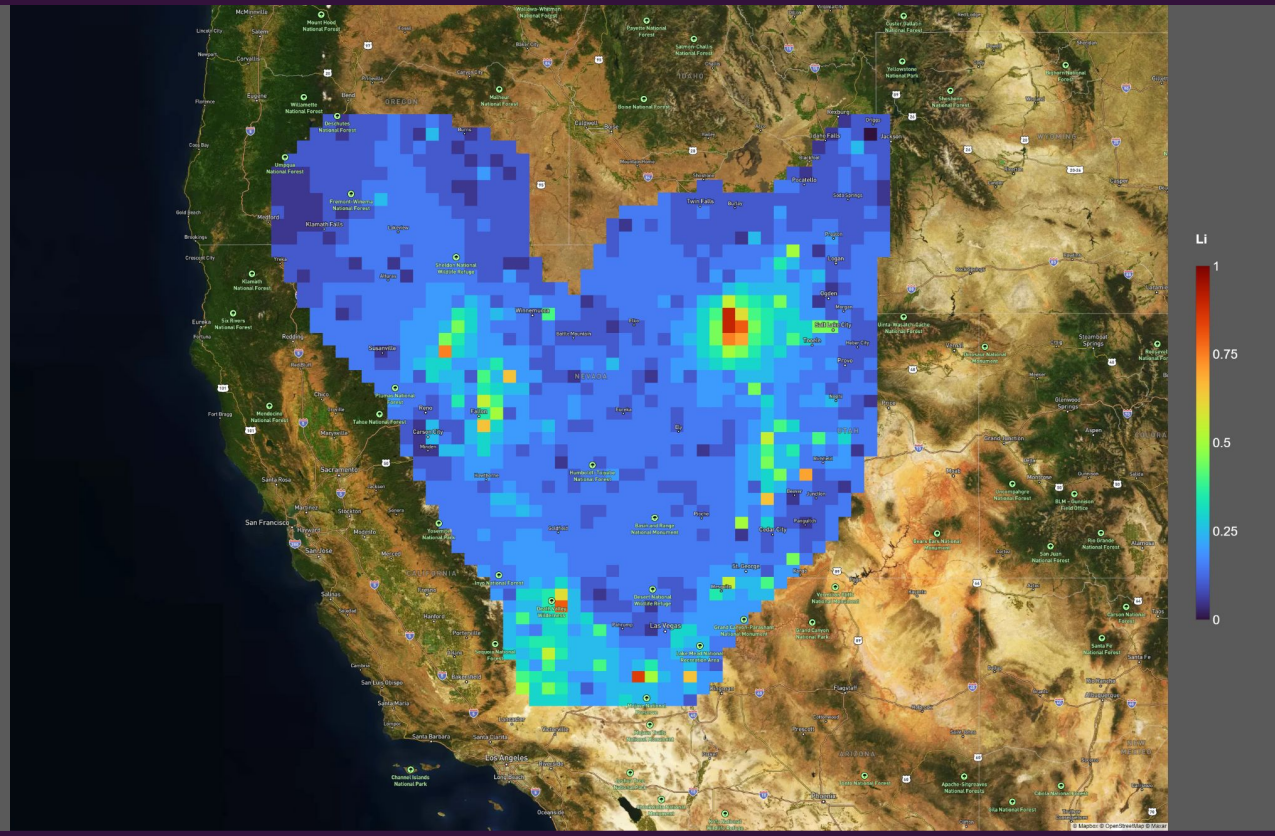


Lithium: Data vs Prospectivity

Lithium Groundwater Concentrations [ppb]

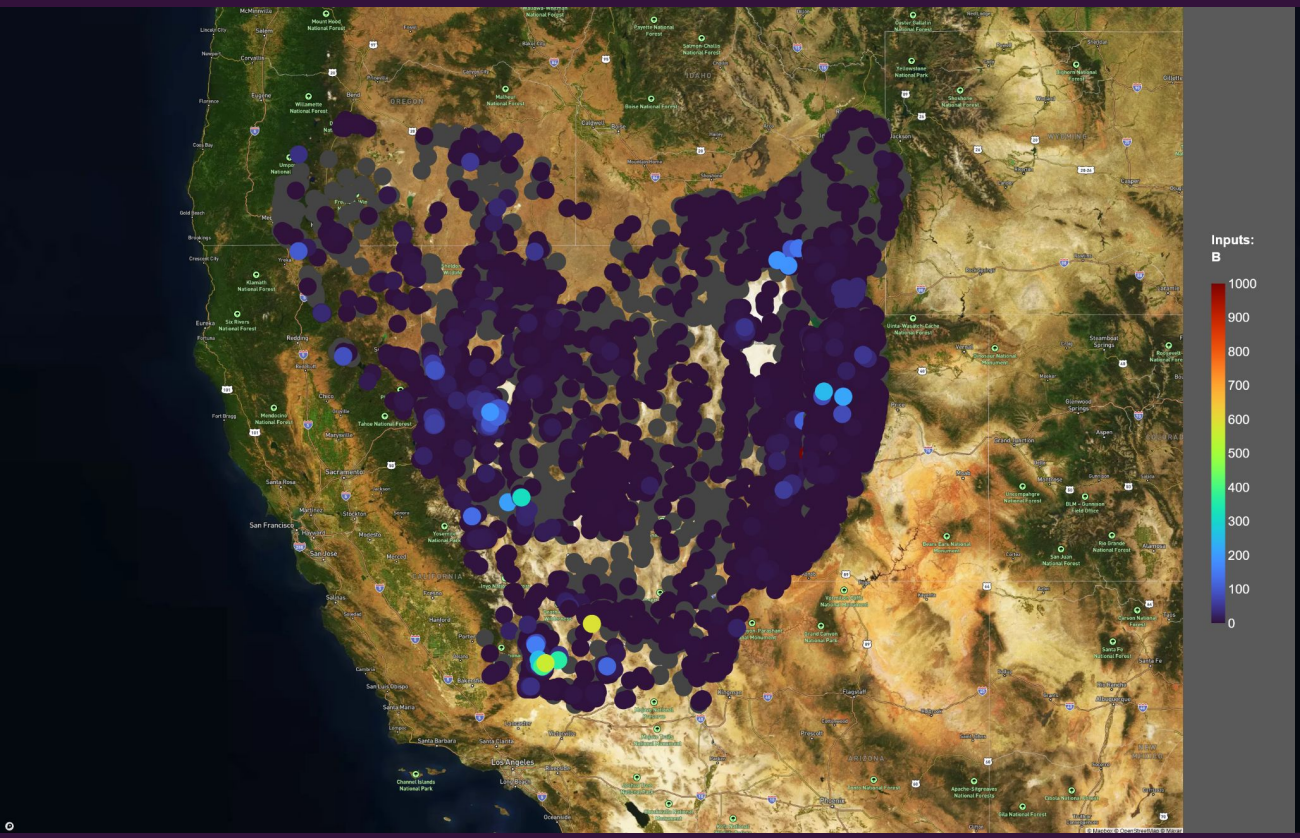


Lithium Prospectivity [normalized]

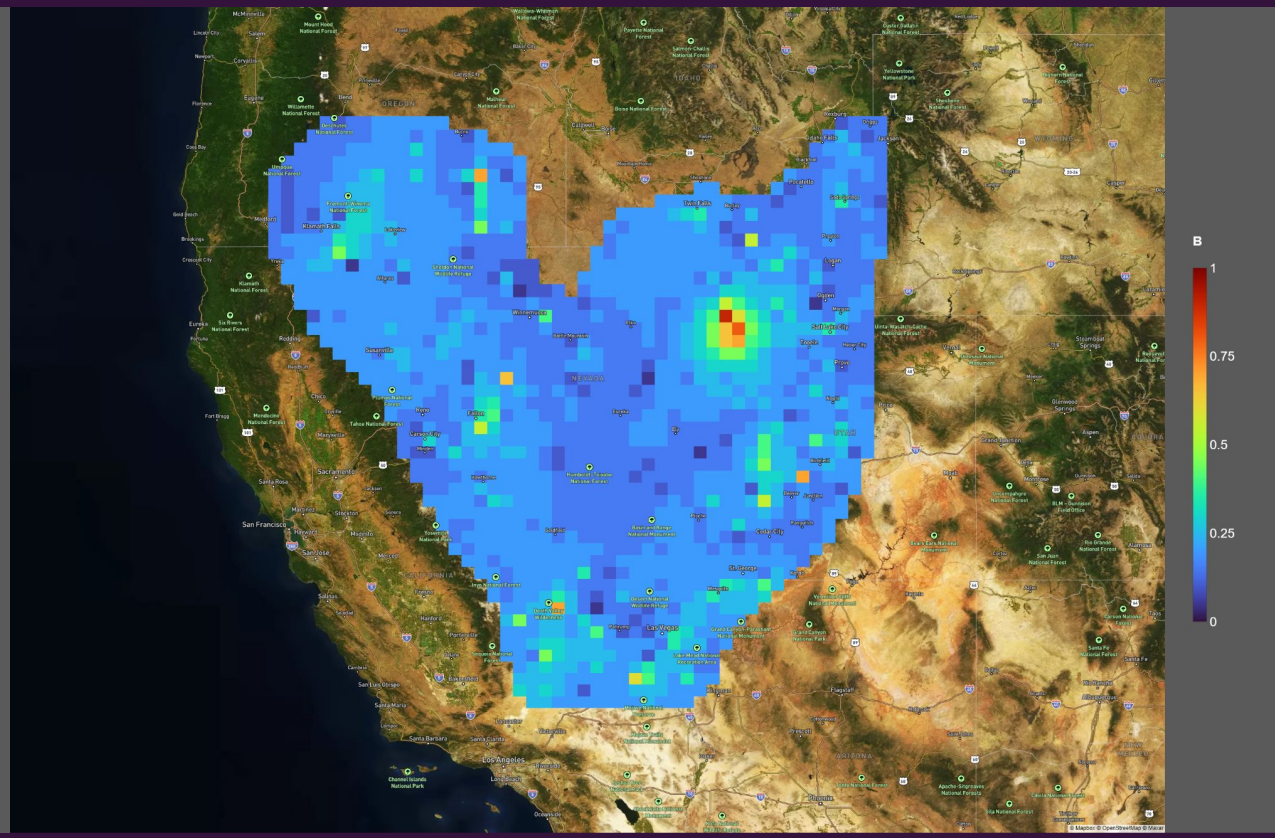


Boron: Data vs Prospectivity

Boron Groundwater Concentrations [ppb]



Boron Prospectivity [normalized]



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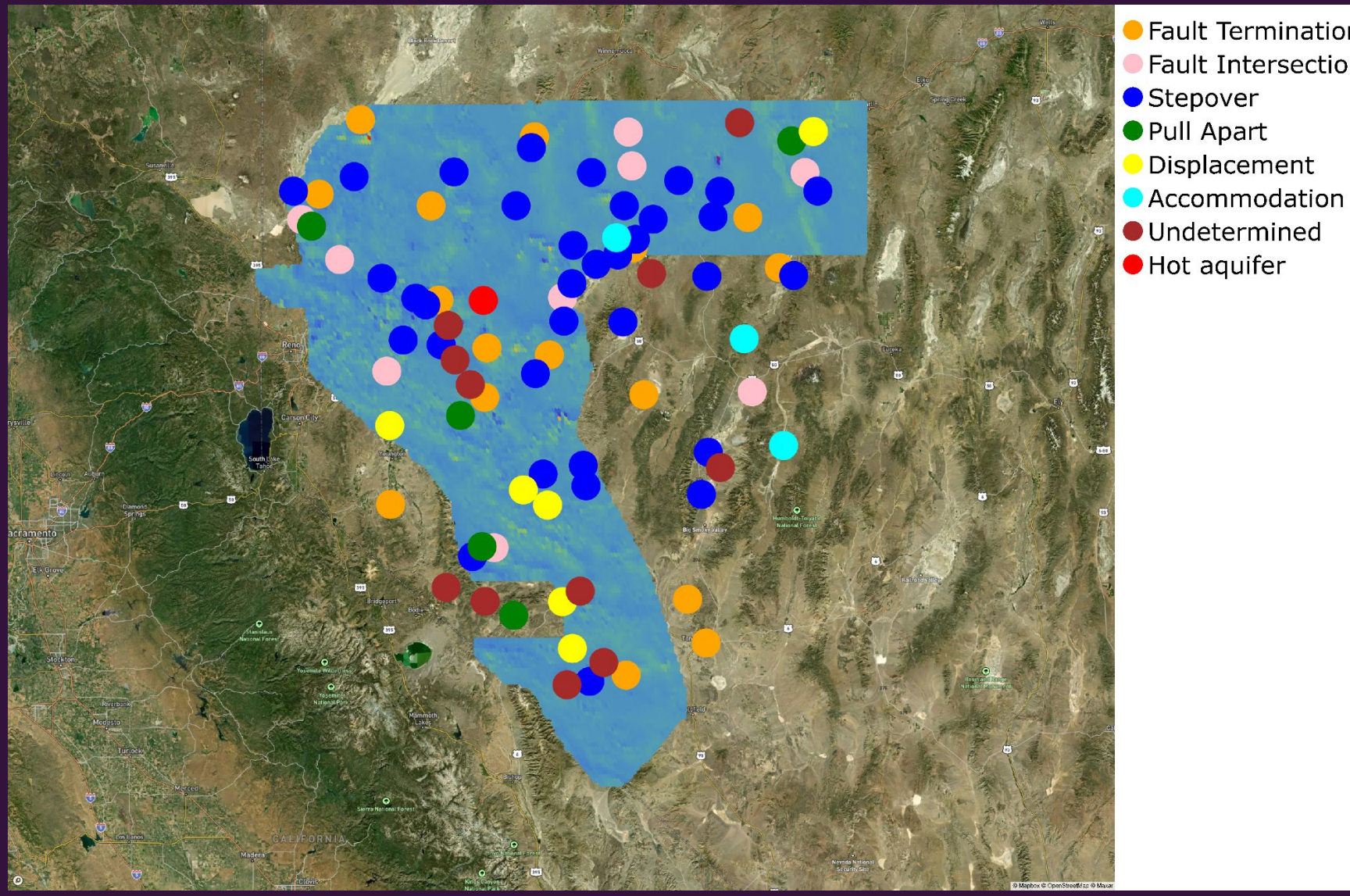
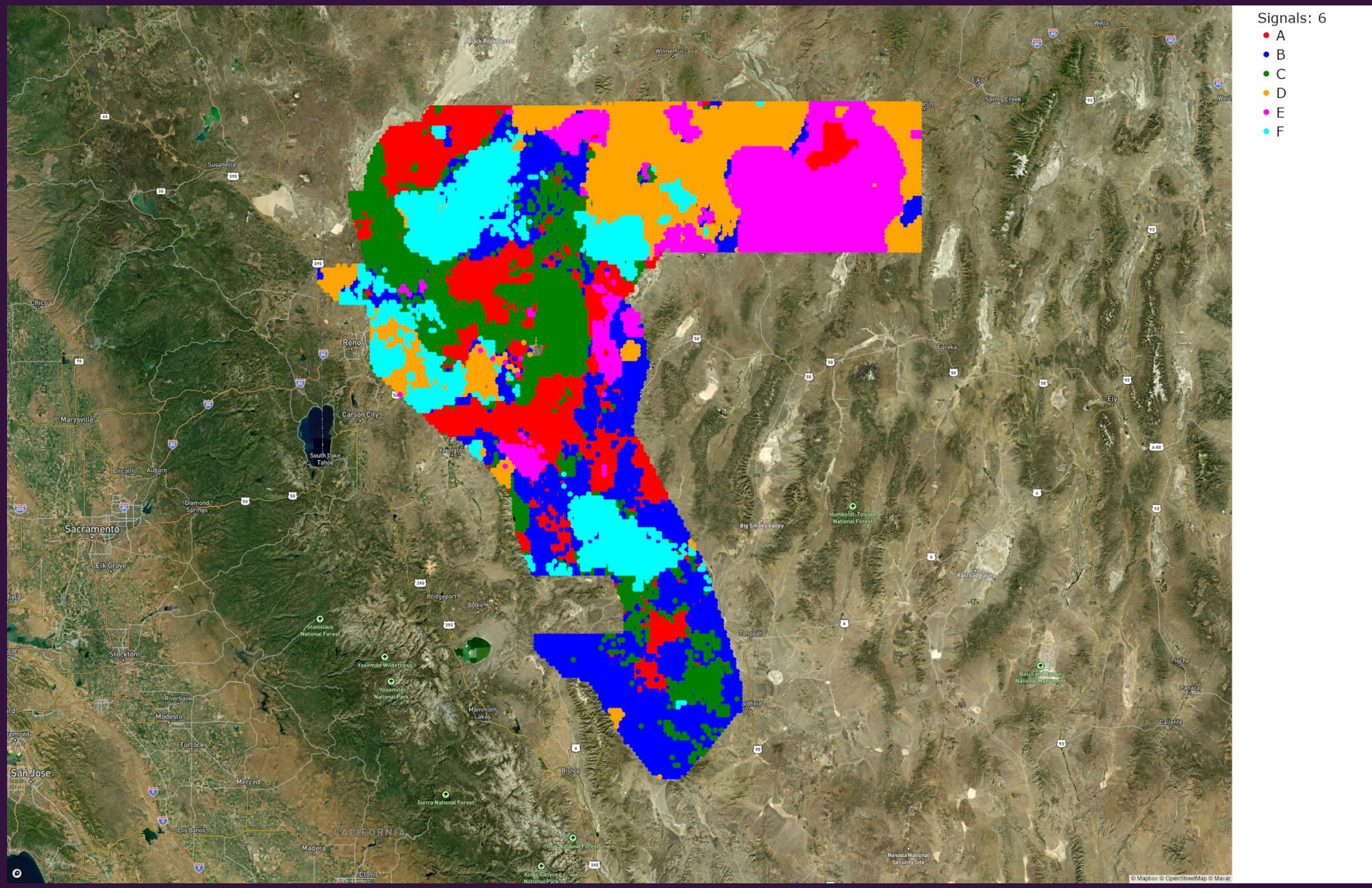
Geologic structures in the GeoDAWN region



GeoDAWN ML results:

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



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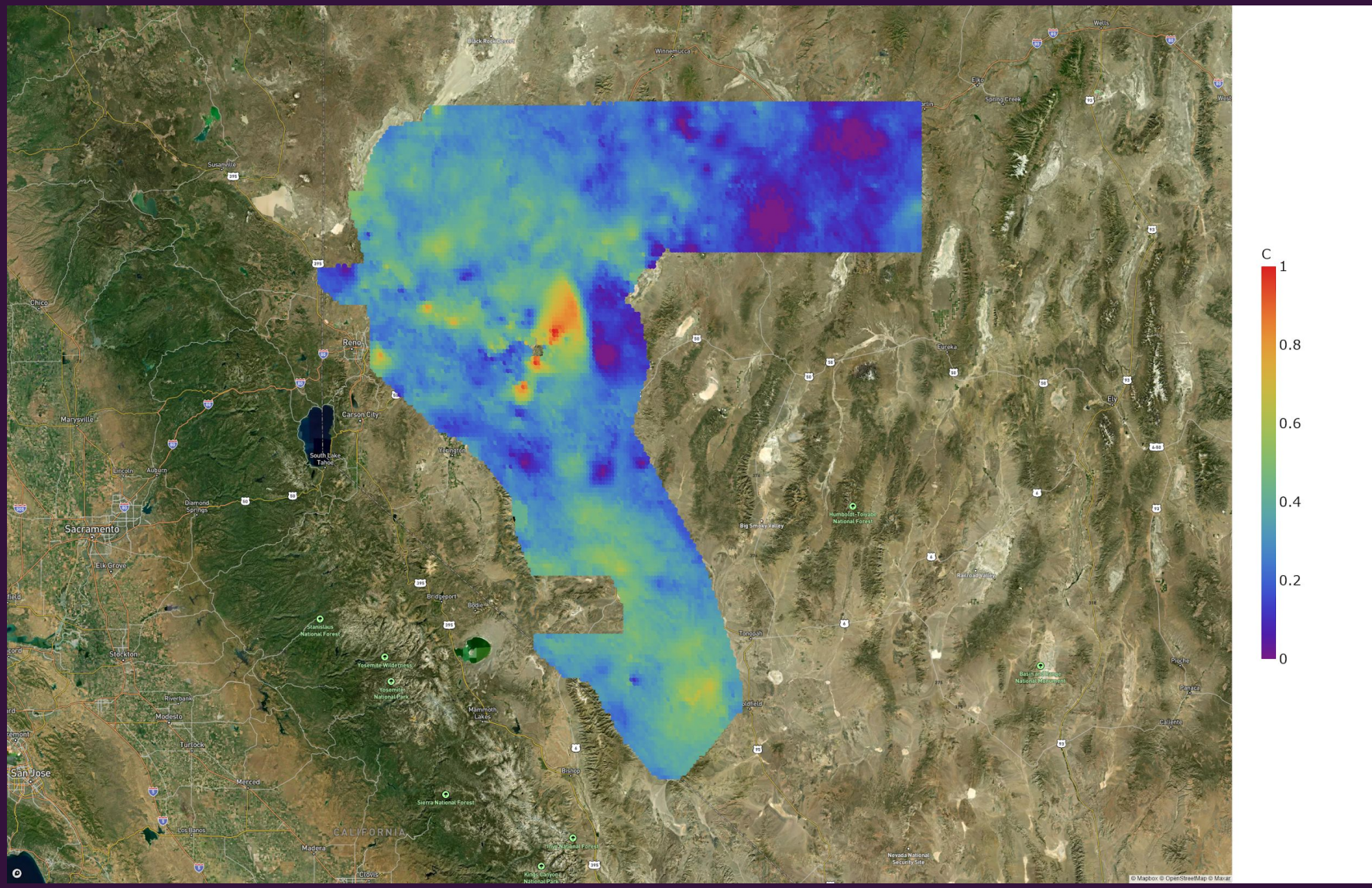
GeoDAWN ML results:

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

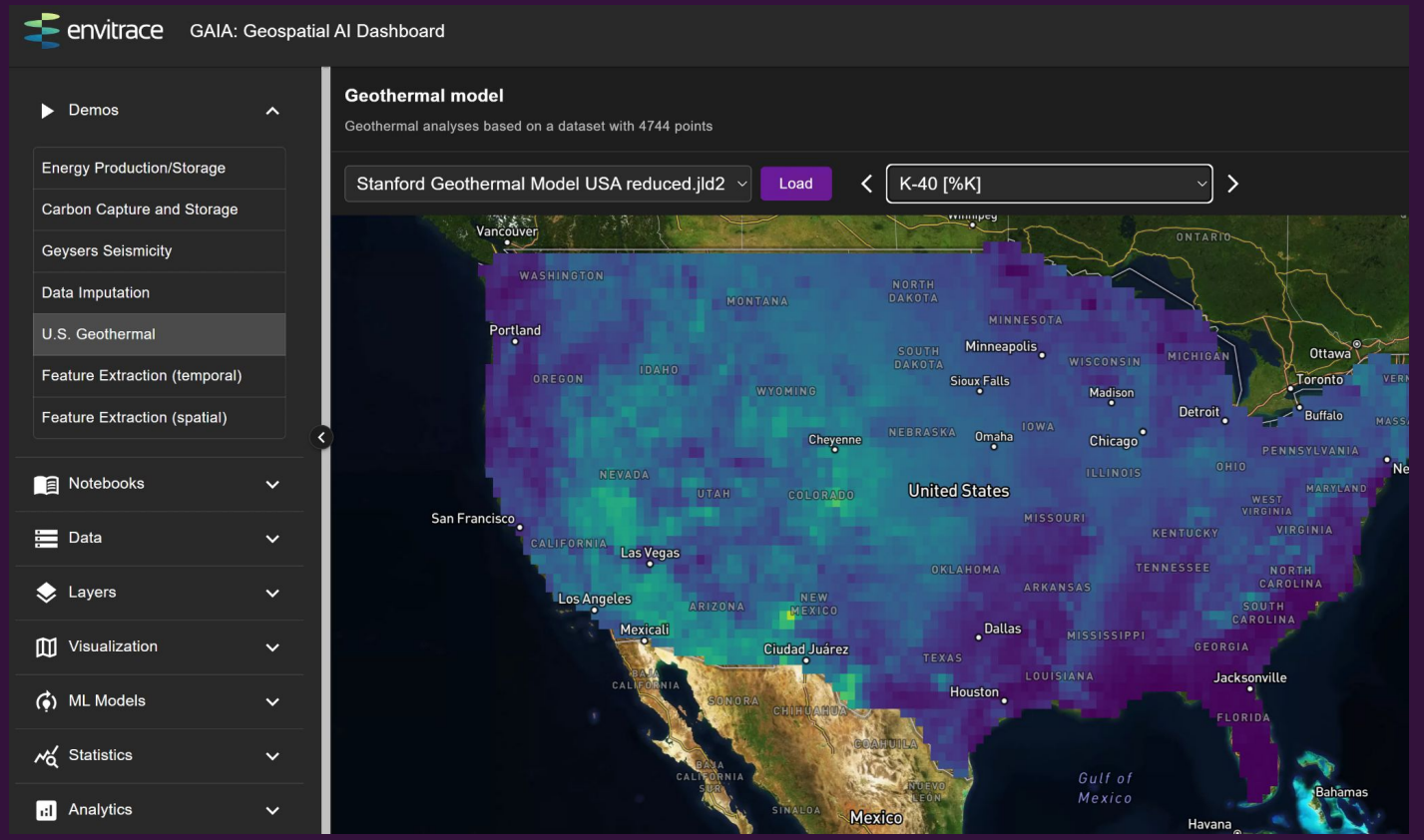


Our SaaS

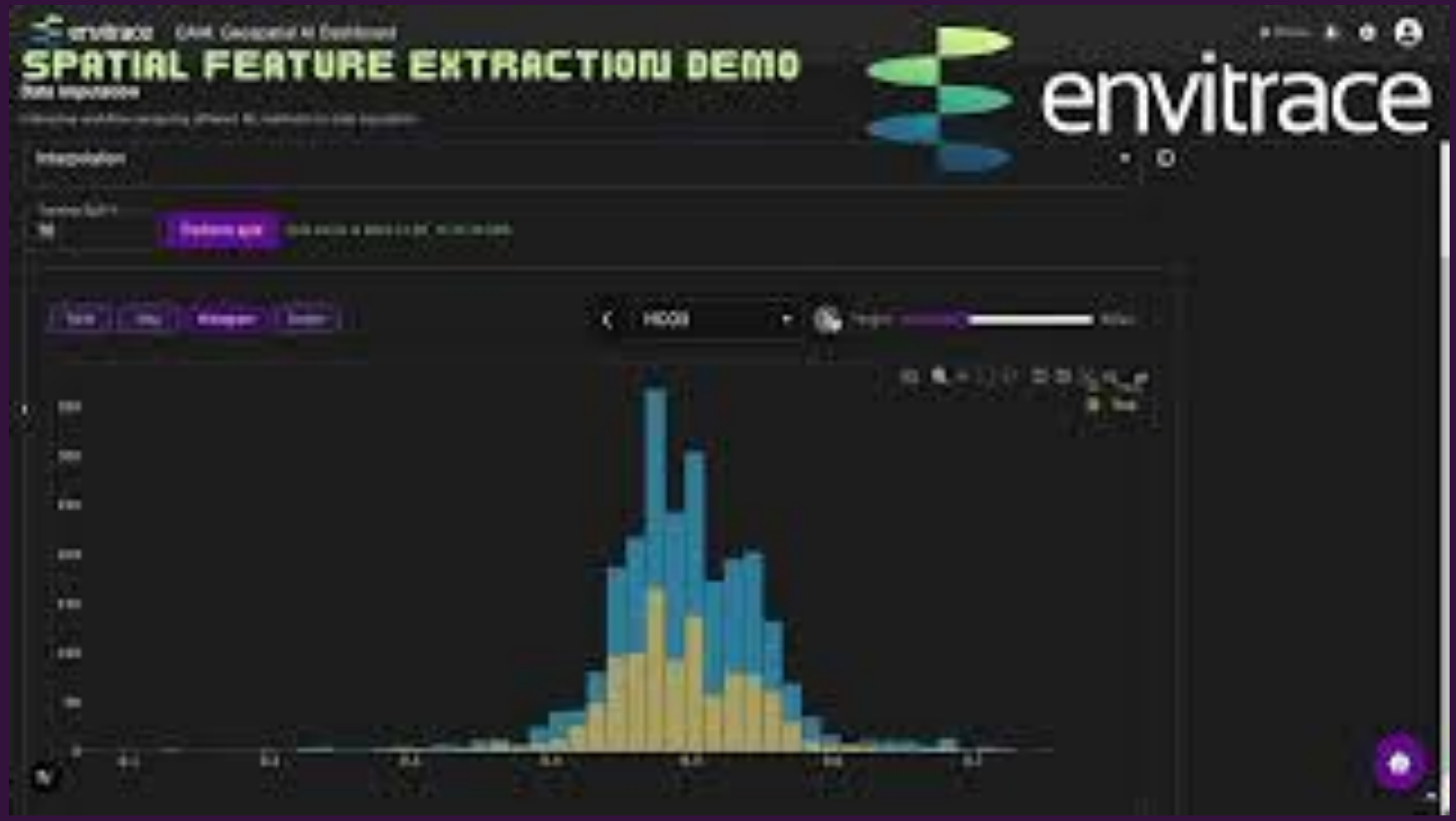
AI/ML cloud product for geo spatio-temporal analyses

- 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
- Extracts features
- Evaluates prospectivities
- SaaS dashboard: http://envitrace.com/saas

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Acknowledgement

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

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