ML Augmented Prediction for Labor Exploitation Detection

Stanford Data Science x Human Trafficking Data Lab Stanford University

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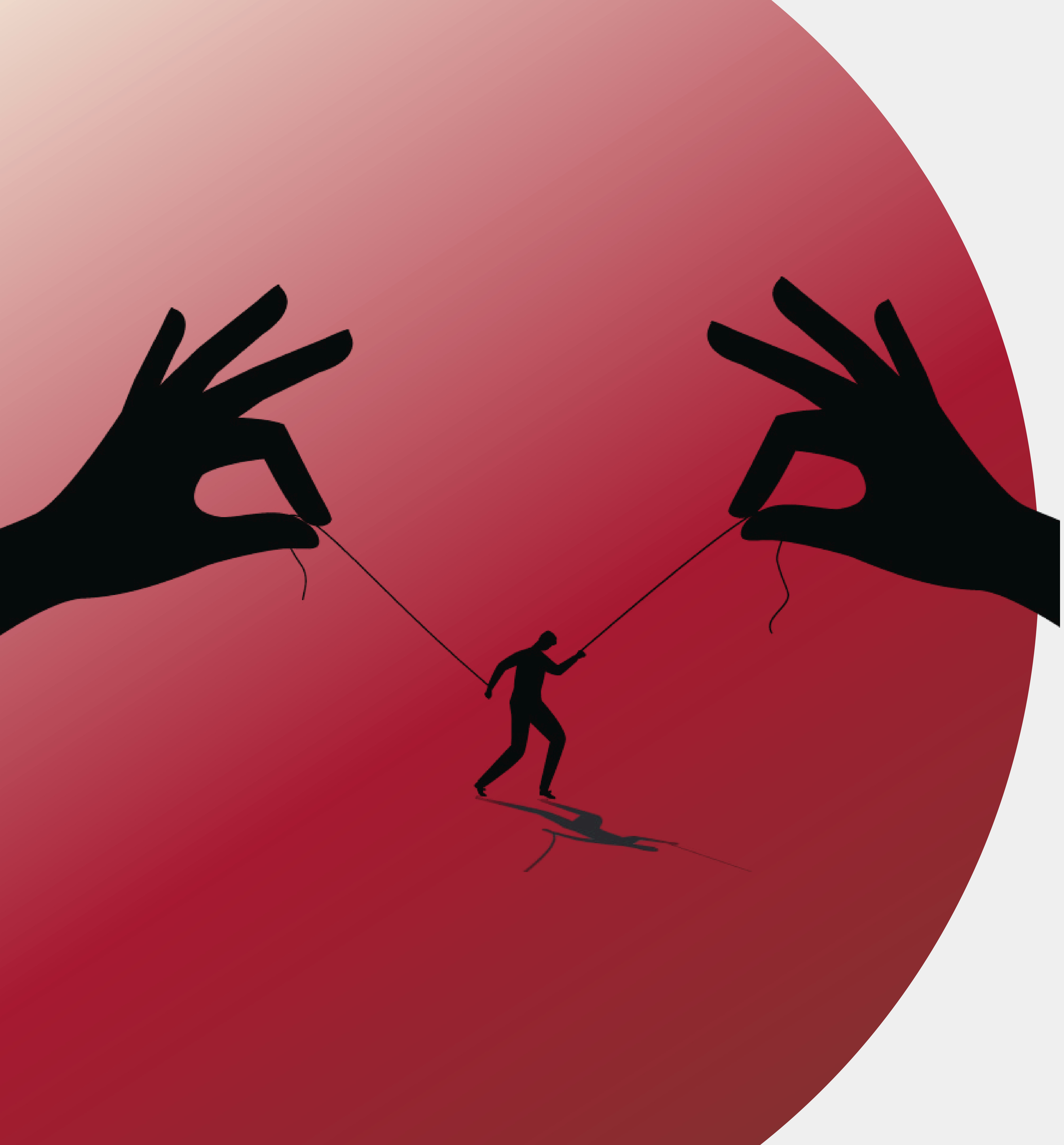
Background

Modern Slavery. Brazil. Charcoal. Our Goal.



Modern Slavery

- **50 million** exploited annually.
- Victims **trapped** by threats and coercion.
- **Data gaps** hinder effective policy.
- Global efforts **lack data-driven impact**.

HTDL’s Brazil Focus

Over 1 million trapped in modern slavery.

Strong collaboration with Brazil's Federal Labor Prosecution Office.

Robust data from record-keeping and transparency laws.

HTDL's Charcoal Focus

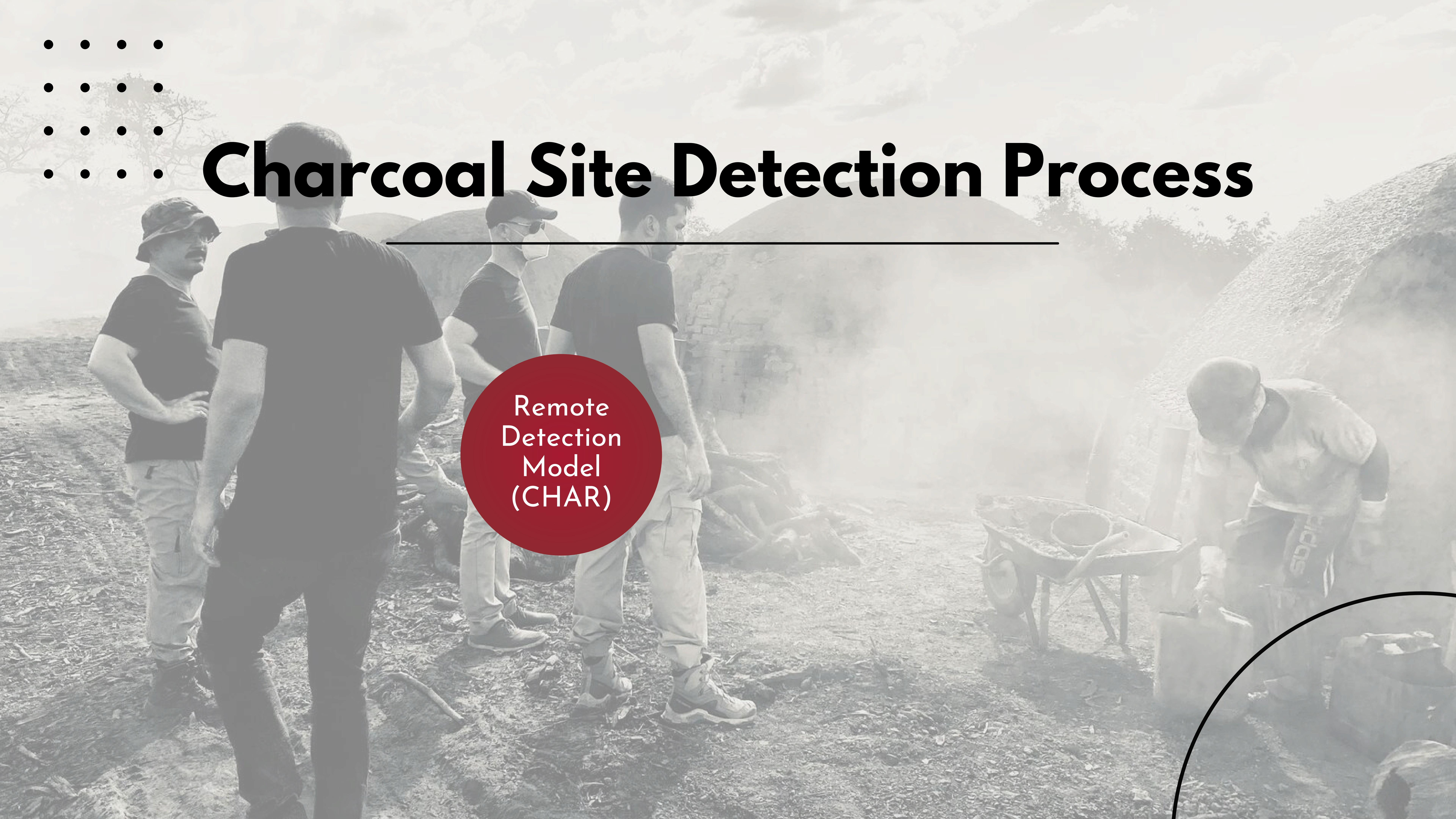
Why Charcoal?

- Labor-Intensive Production Process
- Exploitation Risk
- Environmental and Economic Factors
- Detection Challenges
- Satellite Tracking

Charcoal Site Detection Process

Satellite Imagery → Remote Detection Model (CHAR) → Human Post-Processing → Task Force Inspection

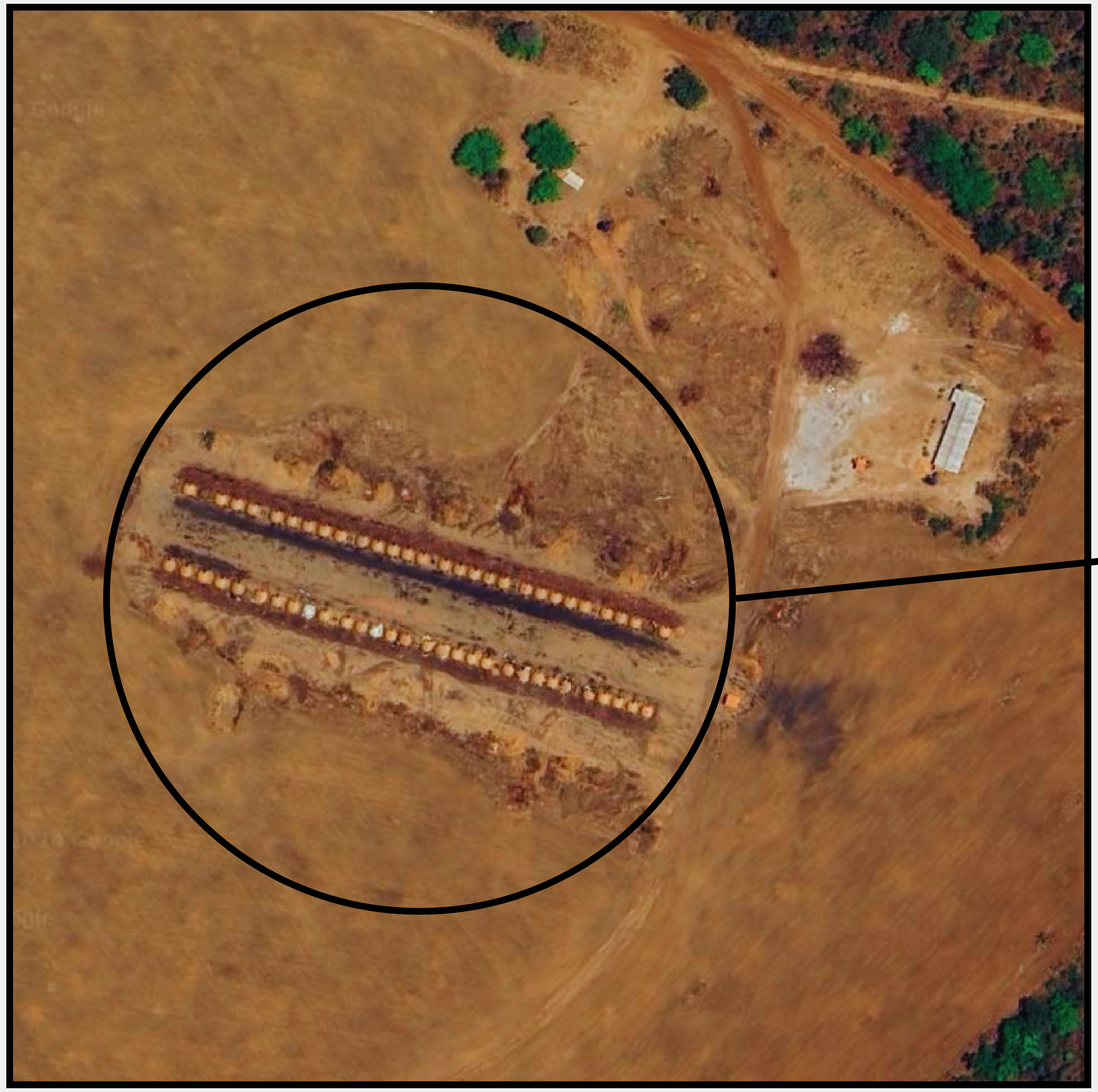
Charcoal Site Detection Process



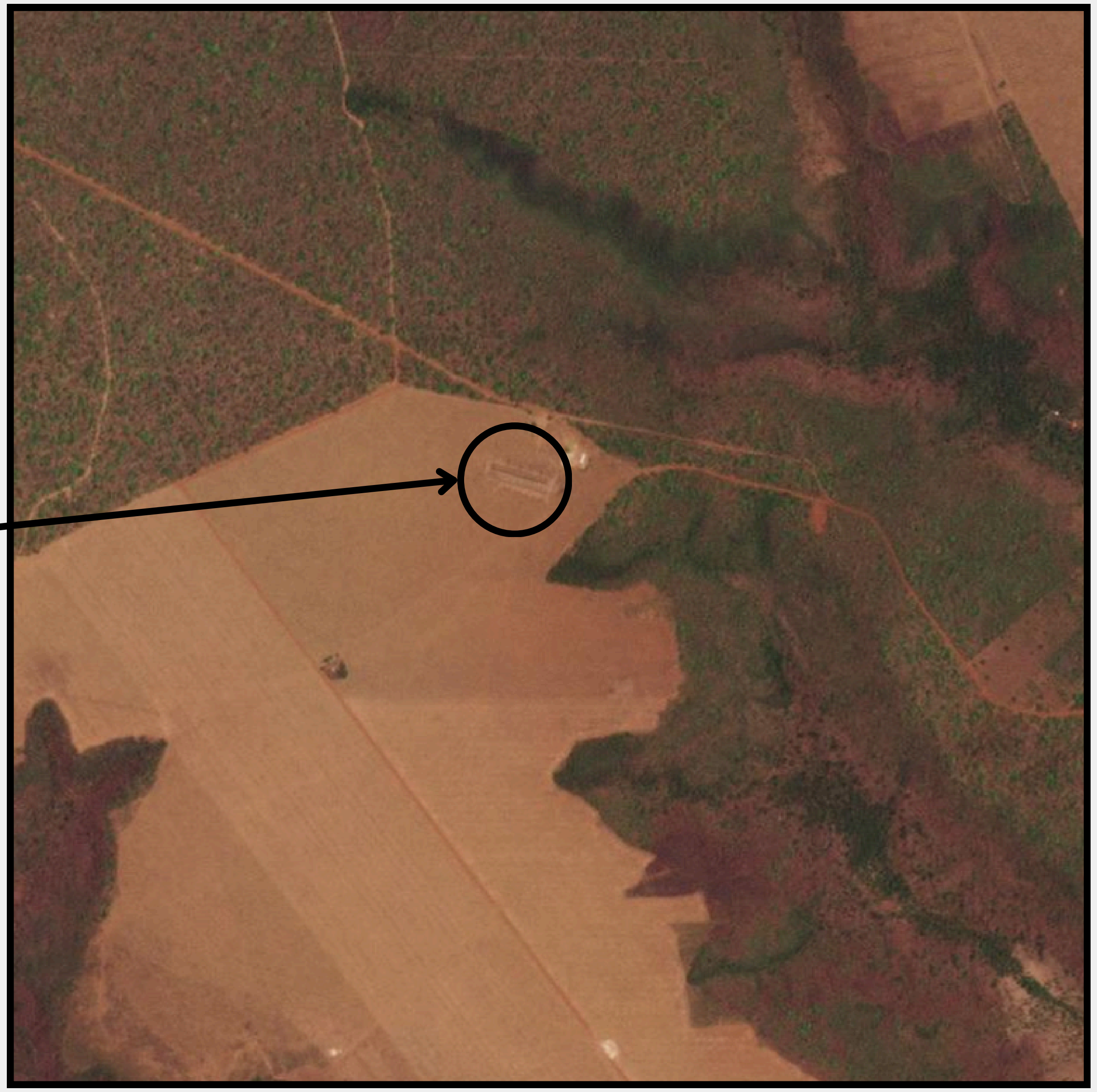
Remote Detection Model (CHAR)

What We Seek

What We Seek



High Resolution Image



Training Image

Charcoal Site Detection Process

- Satellite Imagery
- Remote Detection Model (CHAR)
- ML Model with Geospatial Covariates
- Task Force Inspection

Our Goal

Elevate the human post-processing.

Develop ML Models

Explore Geospatial Data

Analyze Feature Importance

Expand Training Data

Feature Engineering

GeoPandas Pipeline. Distance. Density.

Charcoal Site Data

5278 Sites

Flagged by the CHAR model from satellite images of Maranhão. Threshold of 0.9.

478 True Sites

Manually labelled and confirmed as charcoal sites.

Model Score

Model score from CHAR is included.

Month

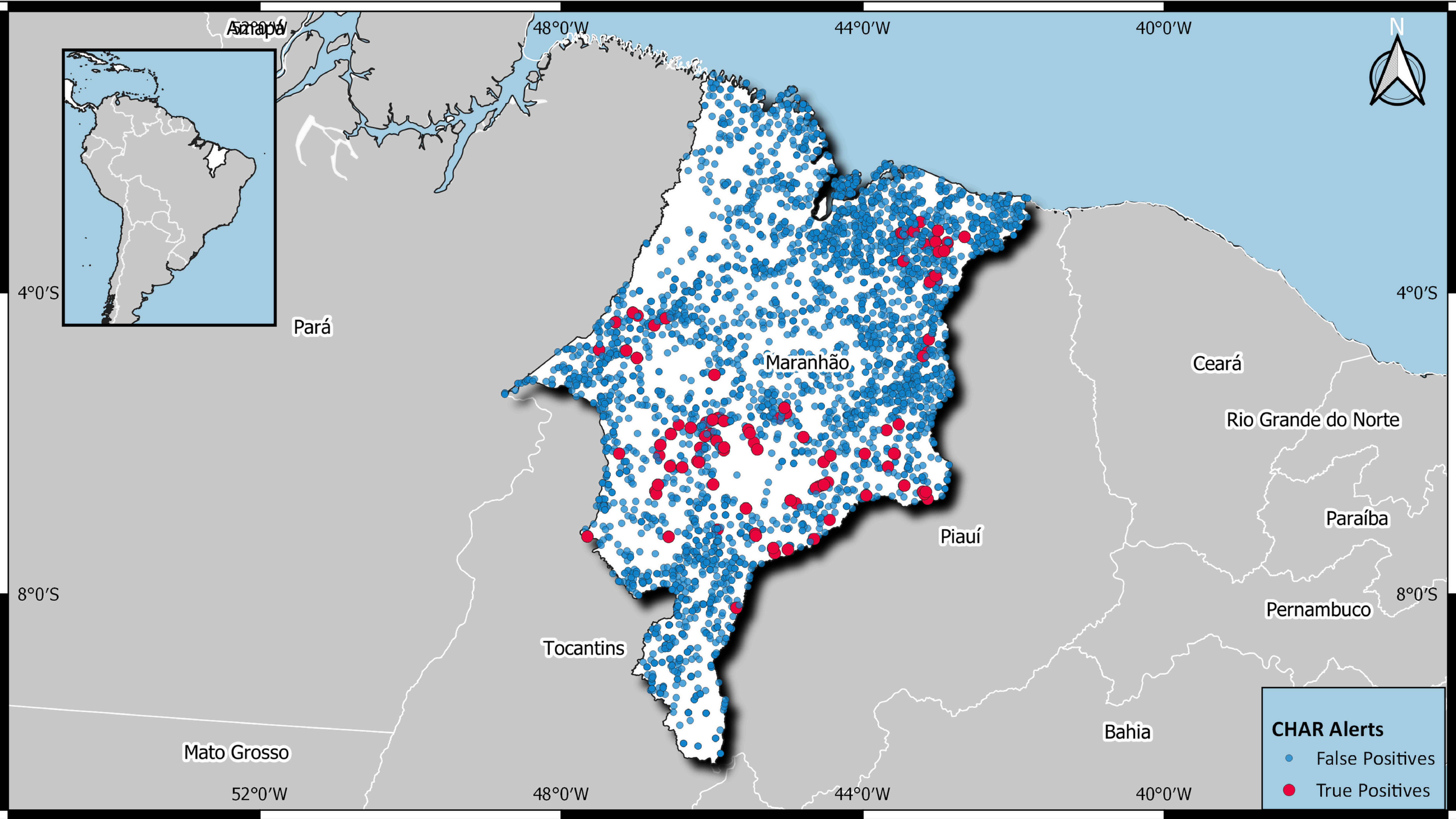
Images from 7/23 to 3/24.

Geometry

Includes precise location of the flagged site.

Tiling

Satellite imagery grouped by unique tile ID.



Amapá
52°0′W
48°0′W
44°0′W
40°0′W
N
4°0′S
4°0′S
Pará
Maranhão
Ceará
Rio Grande do Norte
Paraíba
Piauí
8°0′S
8°0′S
Pernambuco
Tocantins
Bahia
Mato Grosso
52°0′W
48°0′W
44°0′W
40°0′W
CHAR Alerts
False Positives
True Positives

Model Intuition

Roads

Charcoal needs to be transported to steel mills.

Deforestation

Charcoal is made from cutting down trees.

Villages

Charcoal sites may want to be far away from villages to avoid detection.

Other Sites

Expect some clustering of charcoal sites.

Feature Construction

1

Data Source

EDA and thinking to determine relevant data which may have signal.

2

Appropriate Metric

Determine which metric to construct. Shortest distance to, feature count within a radius, within municipality, etc.

3

GeoPandas

Create pipeline to query database and construct features to be fed into the model.

Feature Construction

1

Data Source

EDA and thinking to determine relevant data which may have signal.

- **SmartLab:**
  - Contains survey data of every municipality in Brazil. Includes data like literacy rate, poverty rate, number of workers rescued, and so on.
- **Geographic Features:**
  - Geometries (locations) of roads, lakes, towns, indigenous lands, deforestation permits.
- **MapBiomas Alerts:**
  - Geometries of deforestation alerts that are updated every two weeks by the Brazilian government.

Feature Construction

2

Appropriate Metric

Determine which metric to construct. Shortest distance to, feature count within a radius, within municipality, etc.

- It makes sense to ask how many charcoal sites might be within 10 km of a charcoal site.

- It makes sense to ask how many lakes are within 10 km of a charcoal site and how close a charcoal site is since the number and distance of lakes may have a bearing on whether to setup a charcoal site or not.

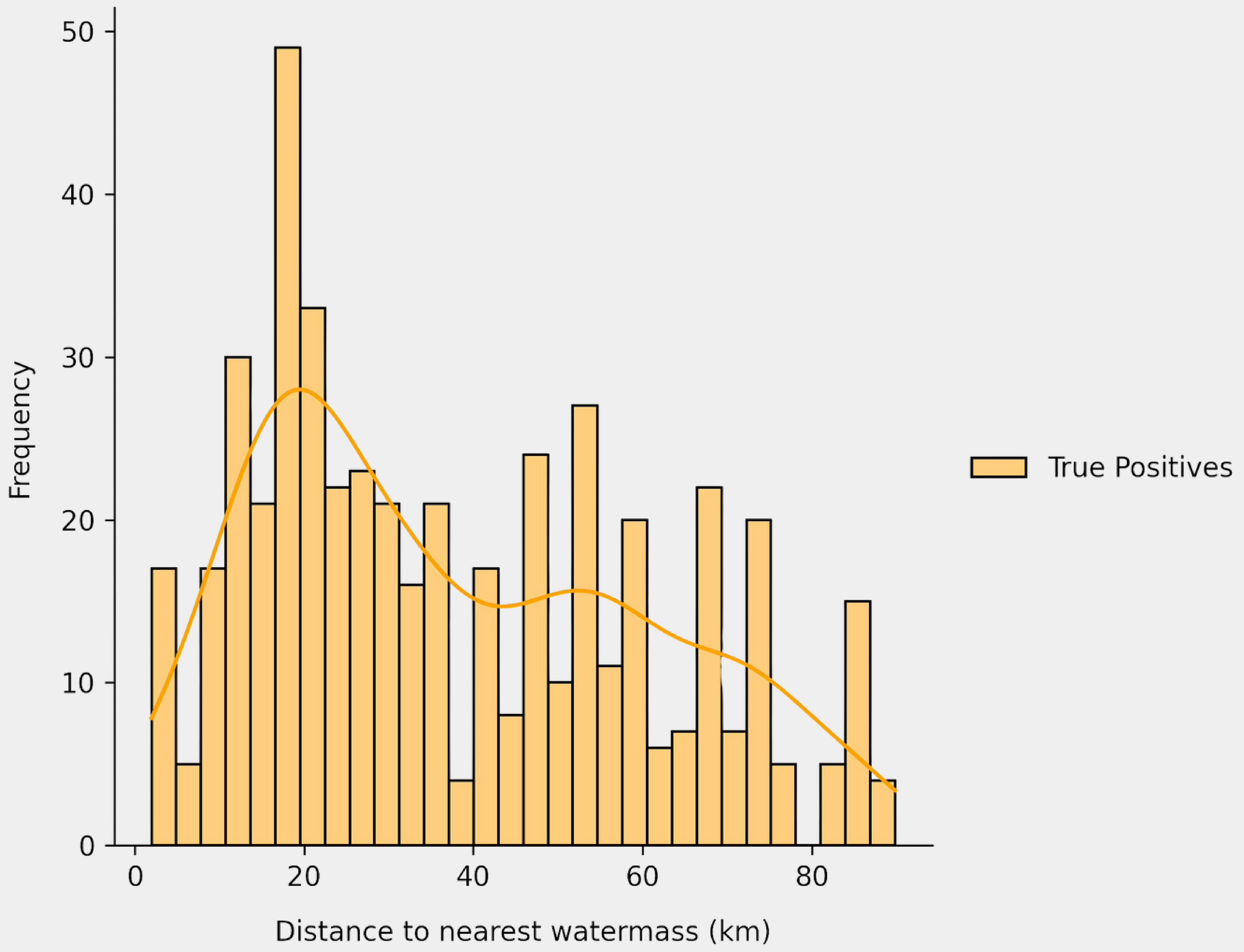
3

GeoPandas

Create pipeline to query database and construct features to be fed into the model.

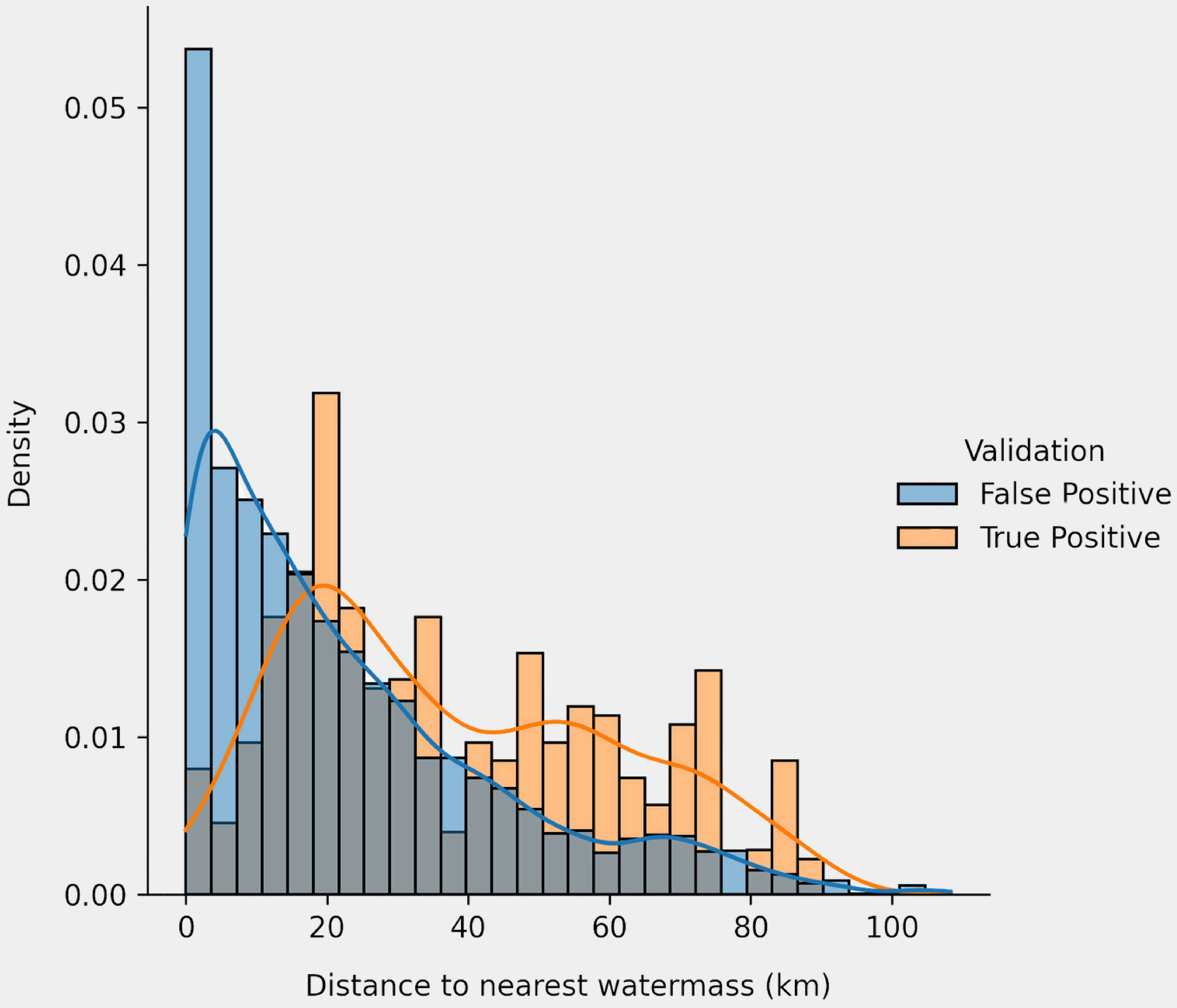
Initial Results

In general, data aligns with expectations. Watermass is proxying for other features



Initial Results

Discernment between FP and TP sites exists. Suggests there is signal here for the model to pick up on.



Full Feature Construction

38 Total

14 Distance Variables
Shortest straightline distance to feature

3 Density Variables
Feature count within 10 km radius

12 Landcover Categories
Forest plantation, savannah formation, etc.

9 Survey Variables
From SmartLab data on poverty, literacy rate, rescued workers, etc.

Machine Learning Model

Architectures. Analytics. Performance.

Implementation

- Grouping and Stratification
- Model Architectures
- Hyperparameter Tuning and Result Analysis

Data Handling

1

Grouping

Group datapoints by location to prevent train/test knowledge leakage.

2

Stratification

Balance by label to ensure sufficient training points and consistent evaluation.

3

Splitting

1/6 Holdout set, remaining 5/6 broken into 5-fold cross validation.

Model Architectures

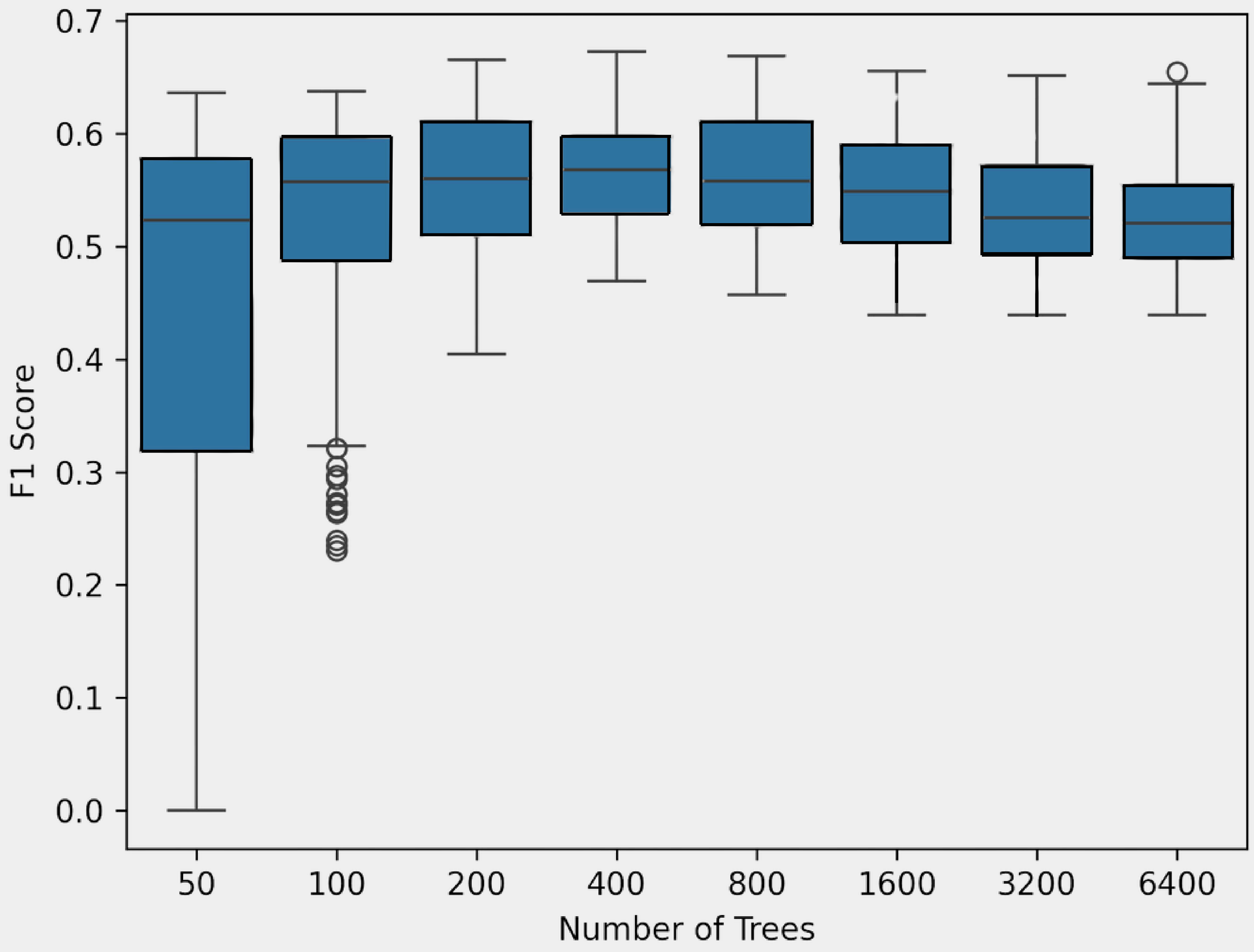
Tree-based models

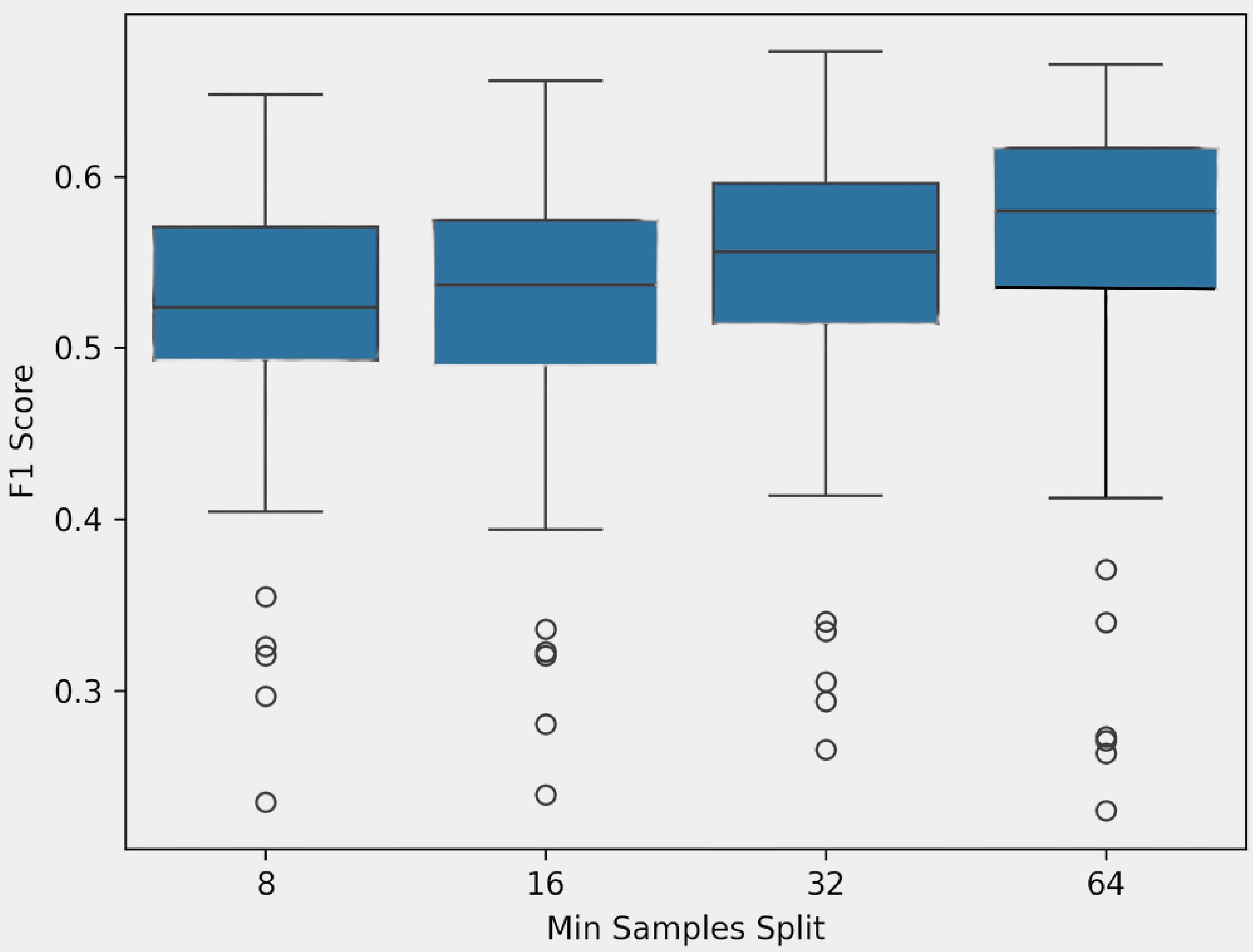
Gradient Boosting, Random Forest

Transformer-based models

TabPFN

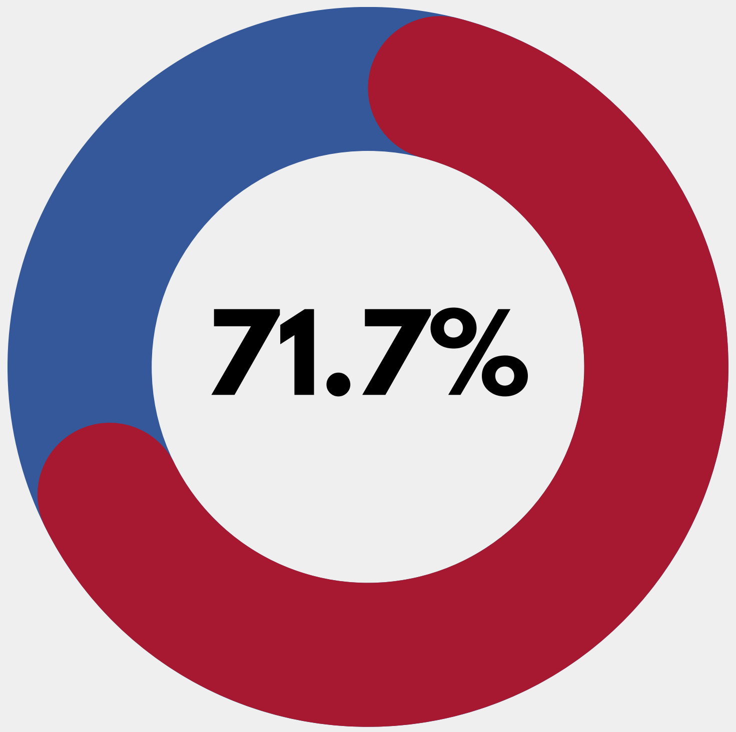
Hyperparameter Tuning



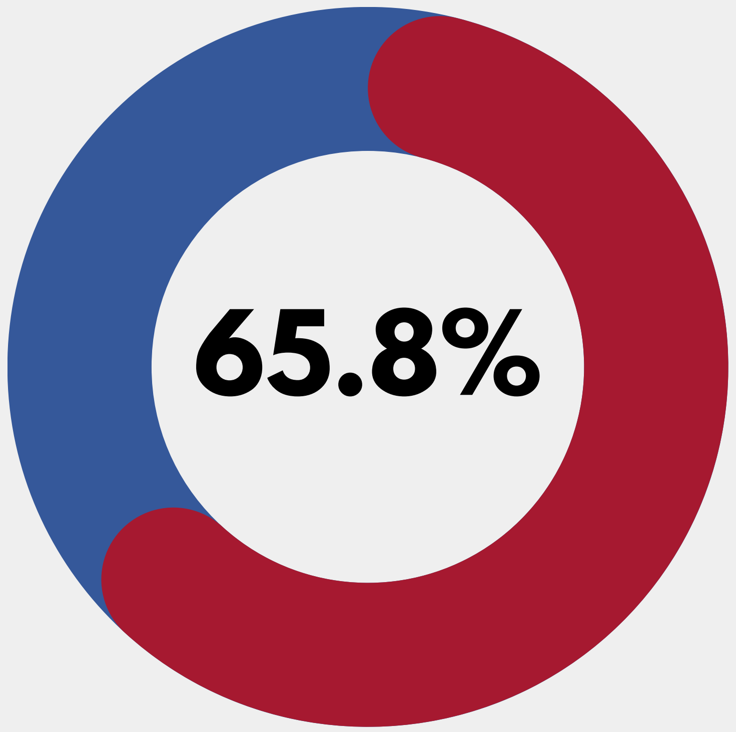


Model Performance

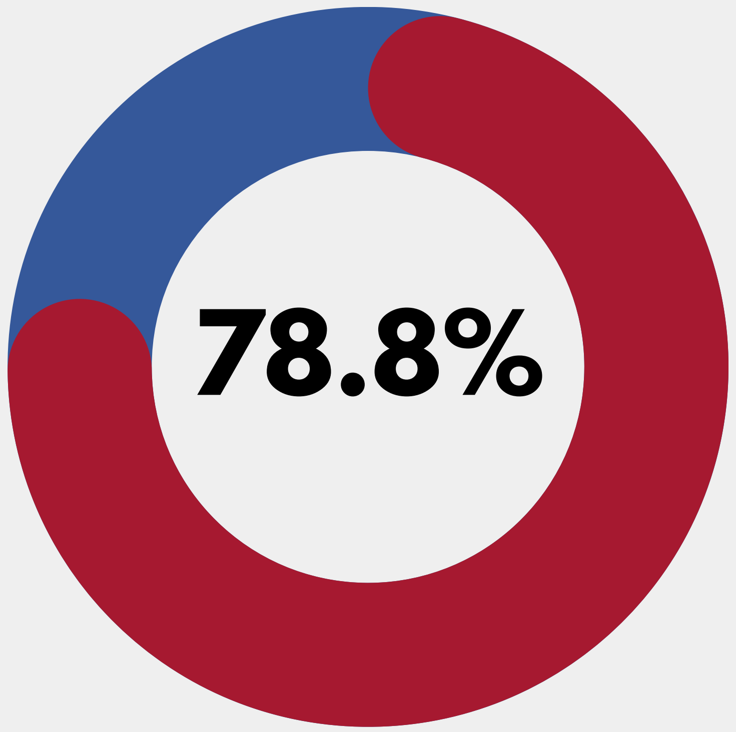
On validation set, at threshold 0.25.



F1 Score

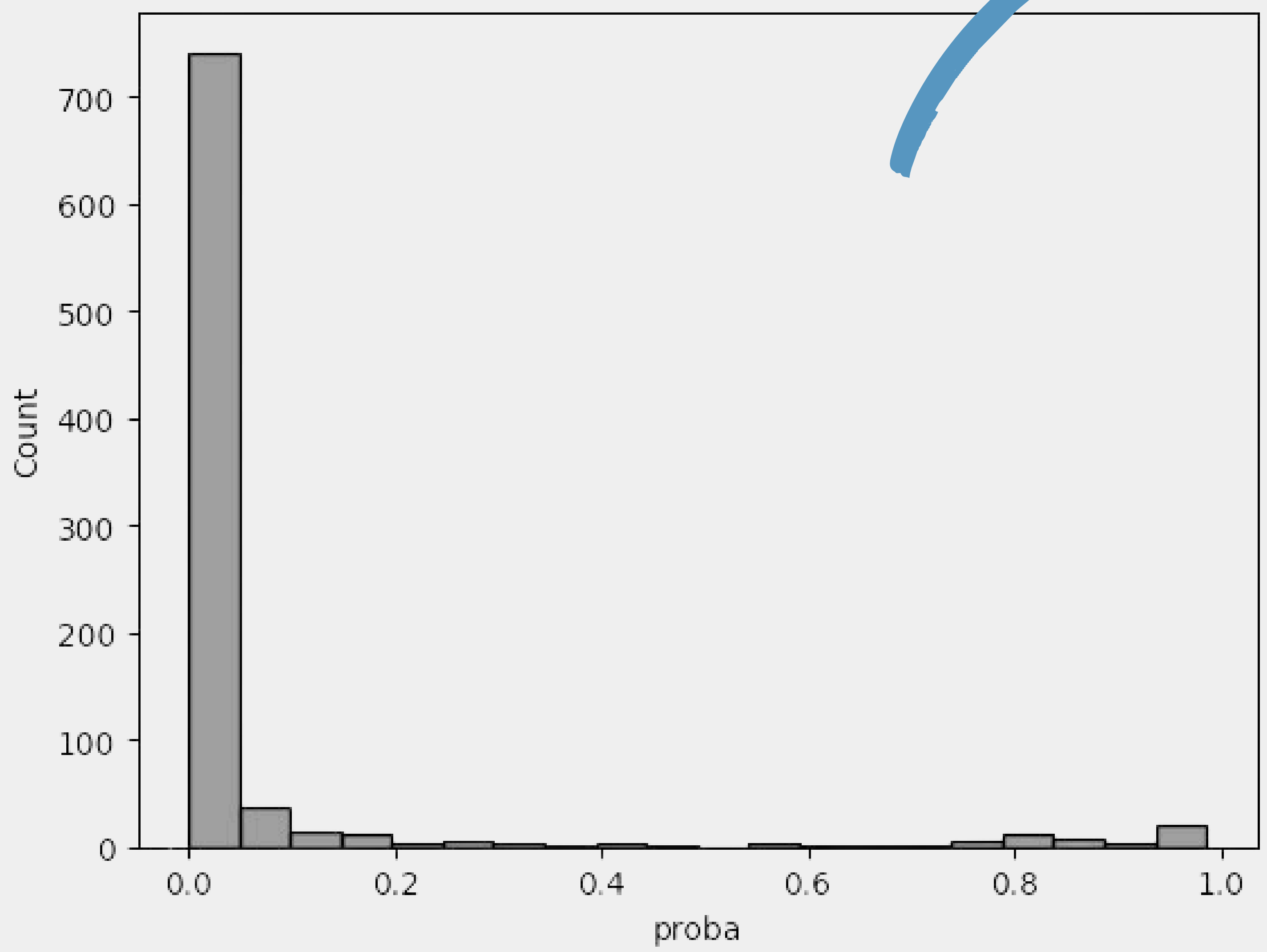


Precision

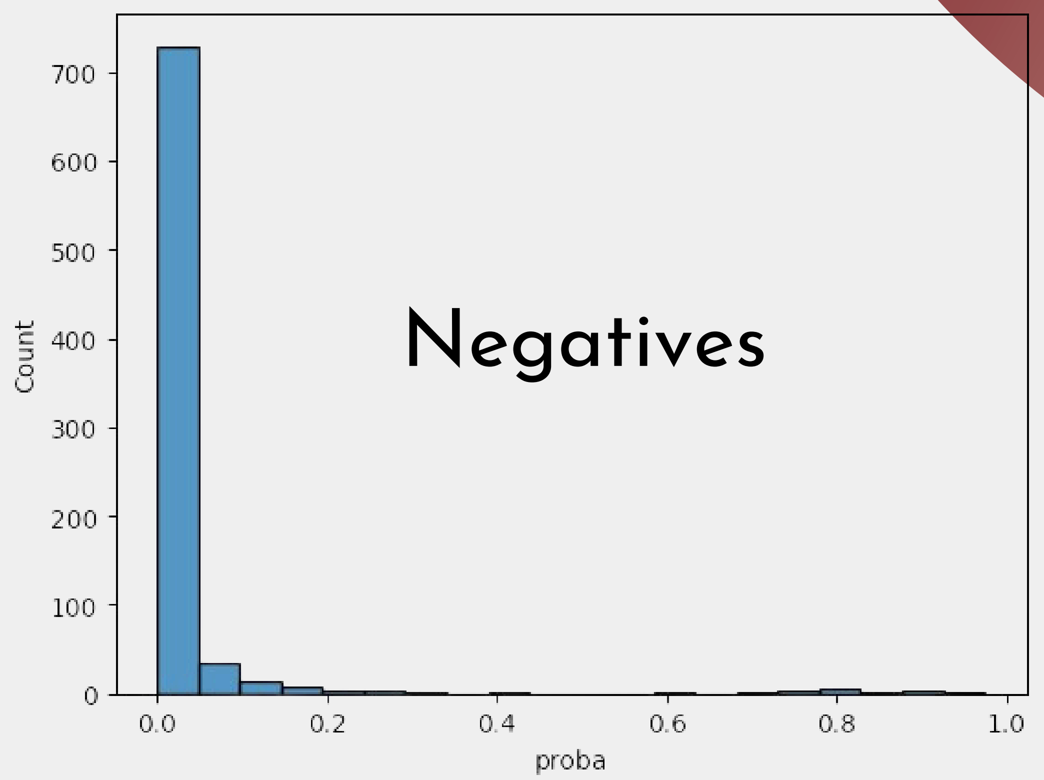


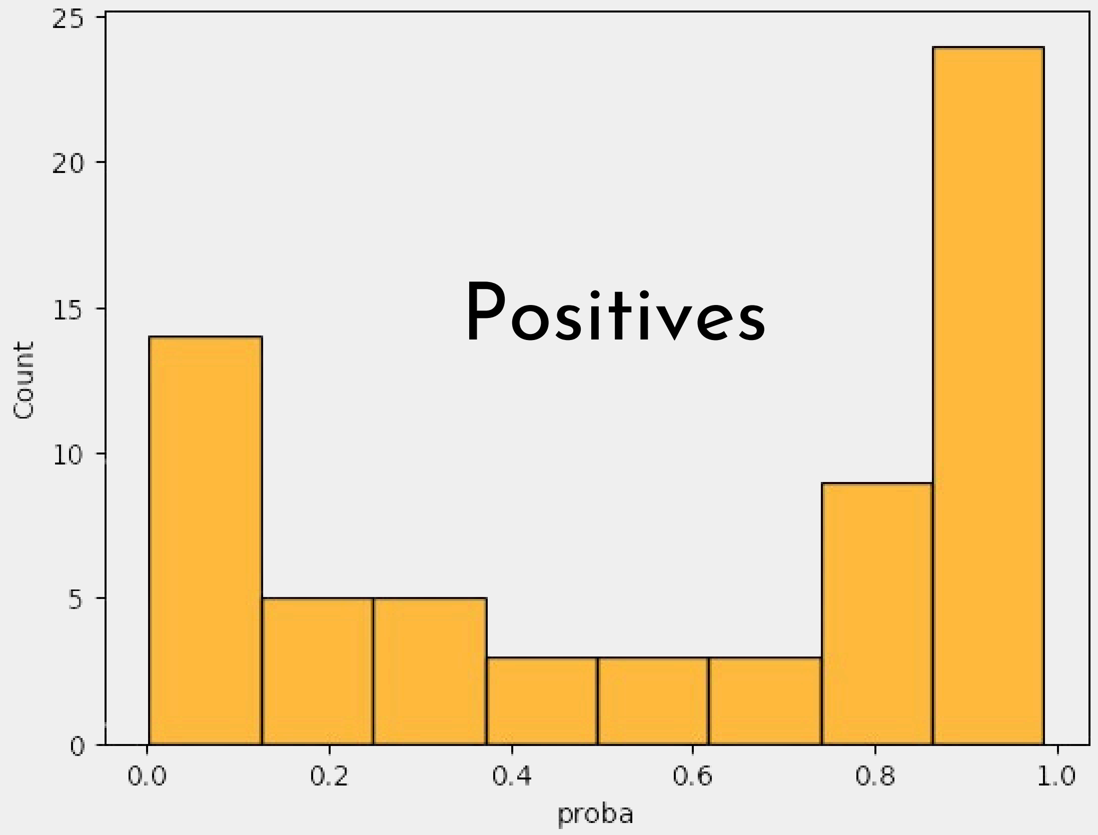
Recall

Model Analytics



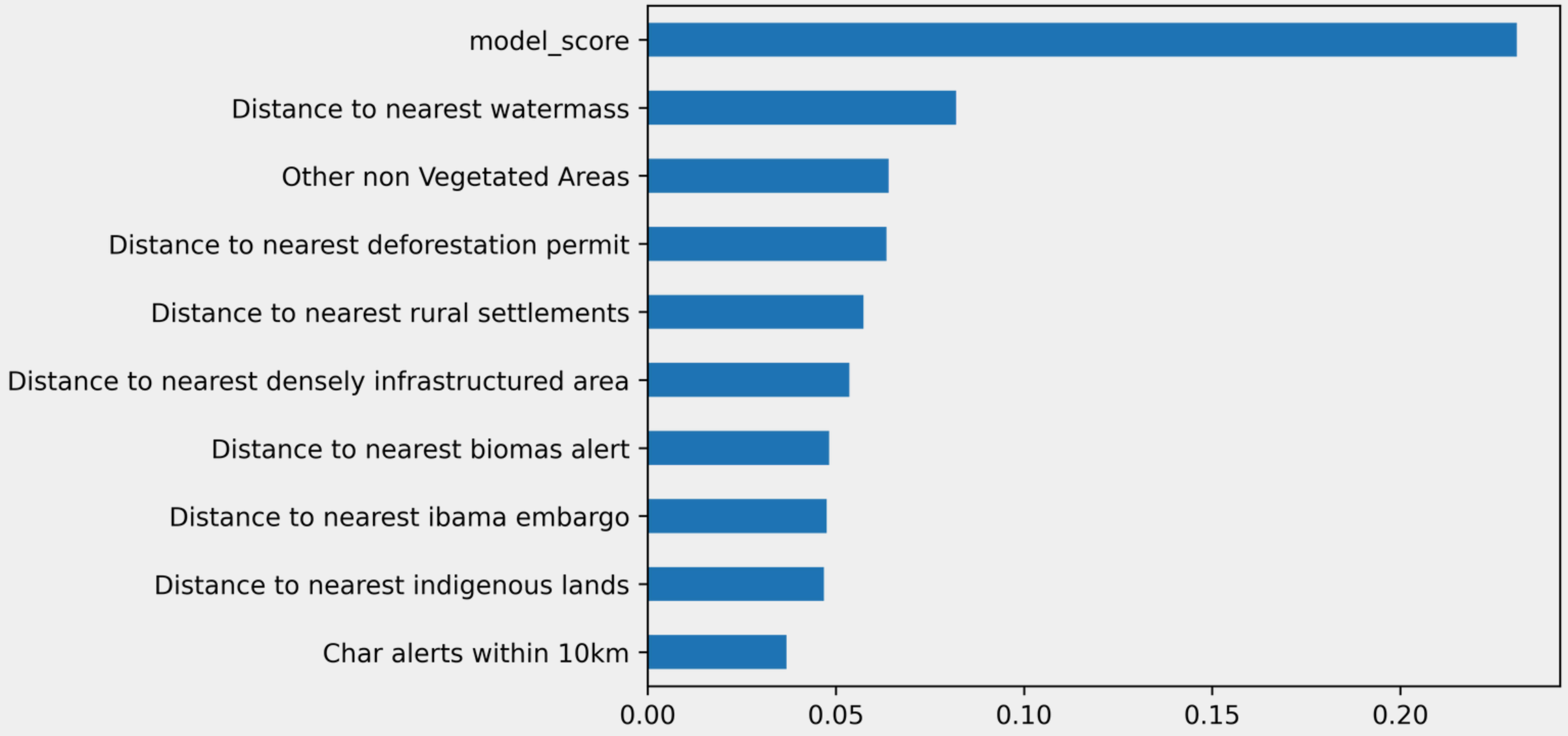
Ground Truth



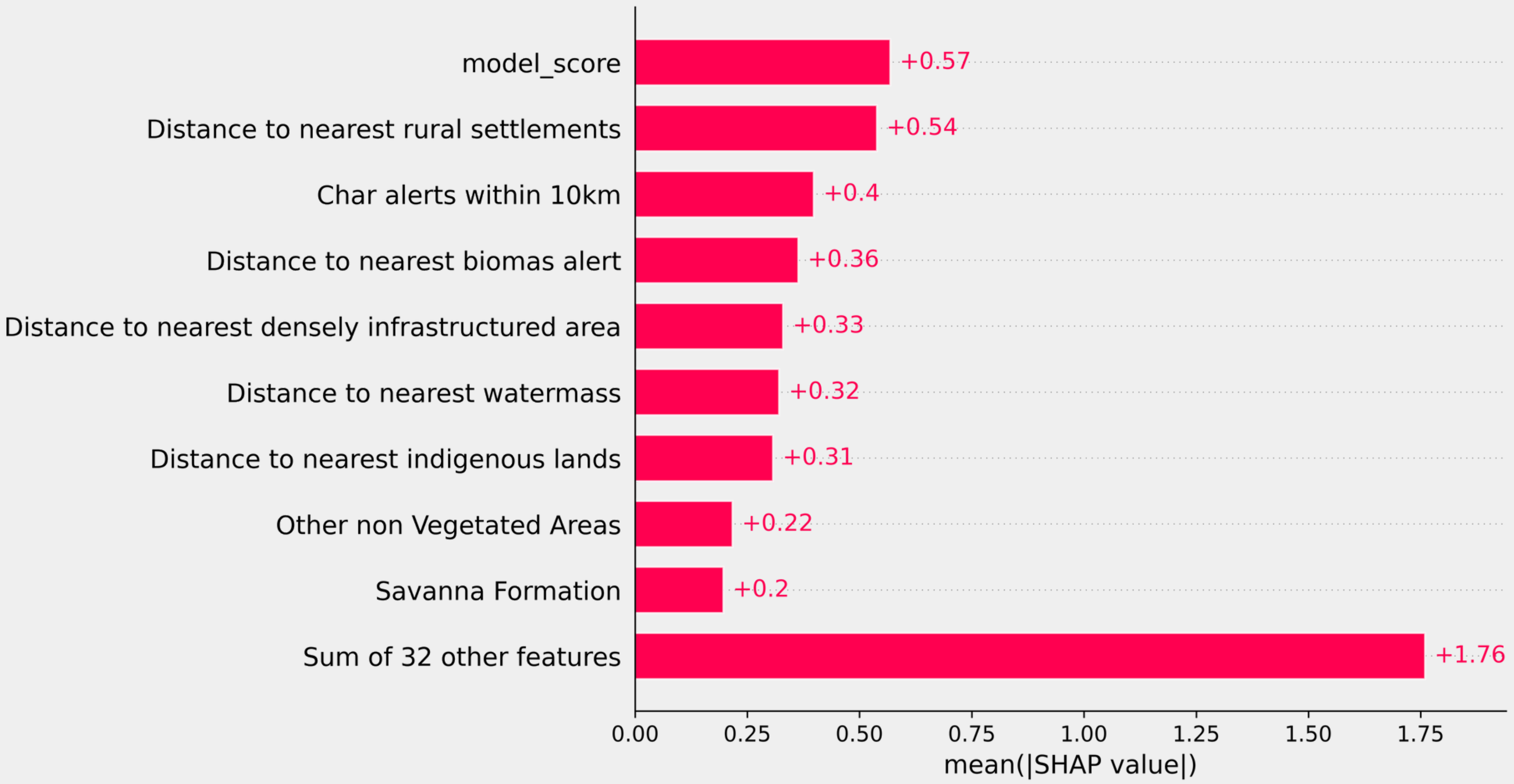


Feature Importance

Built-in Gradient Boost (top 10)



TreeSHAP



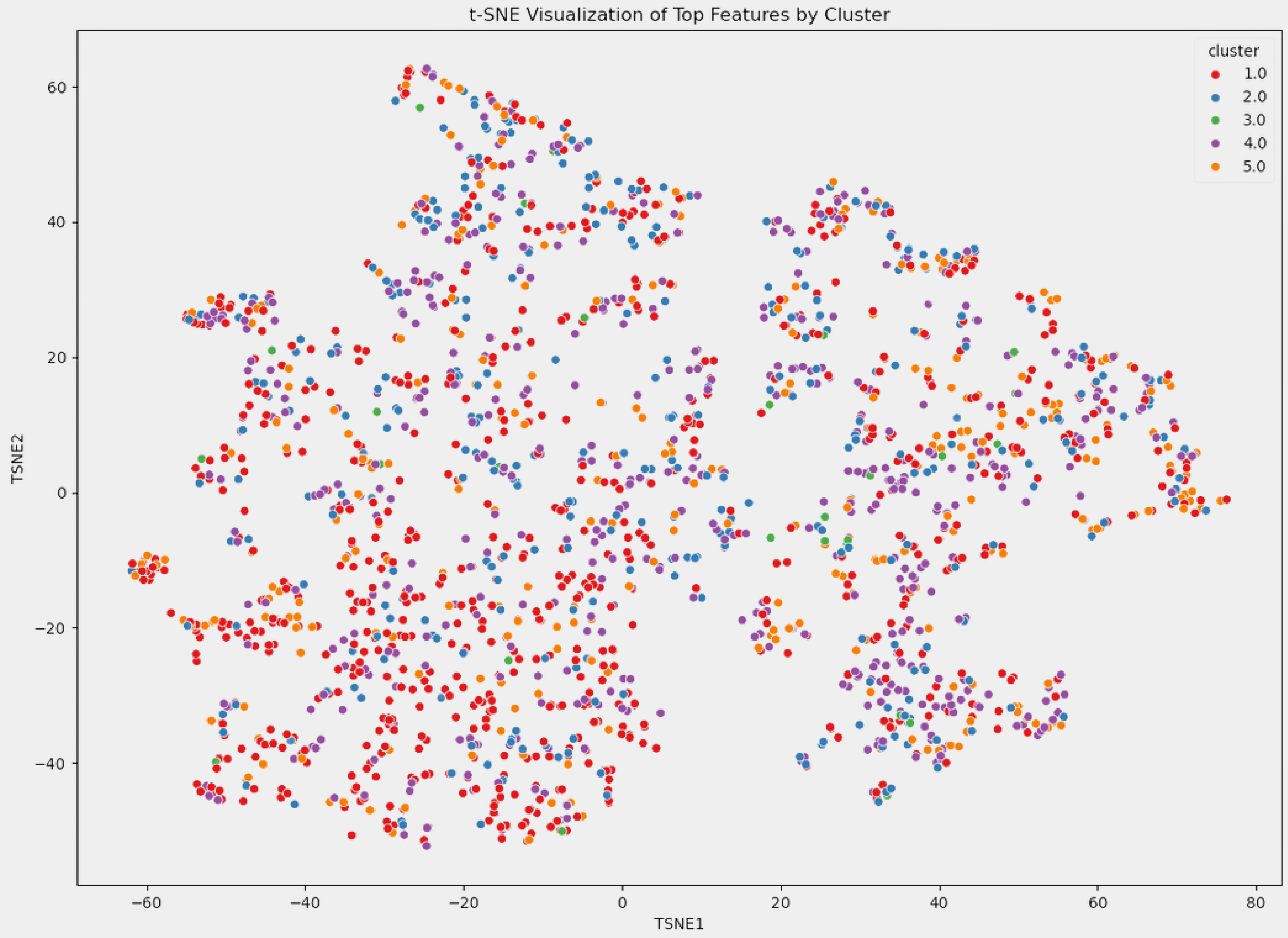
Cluster Analysis

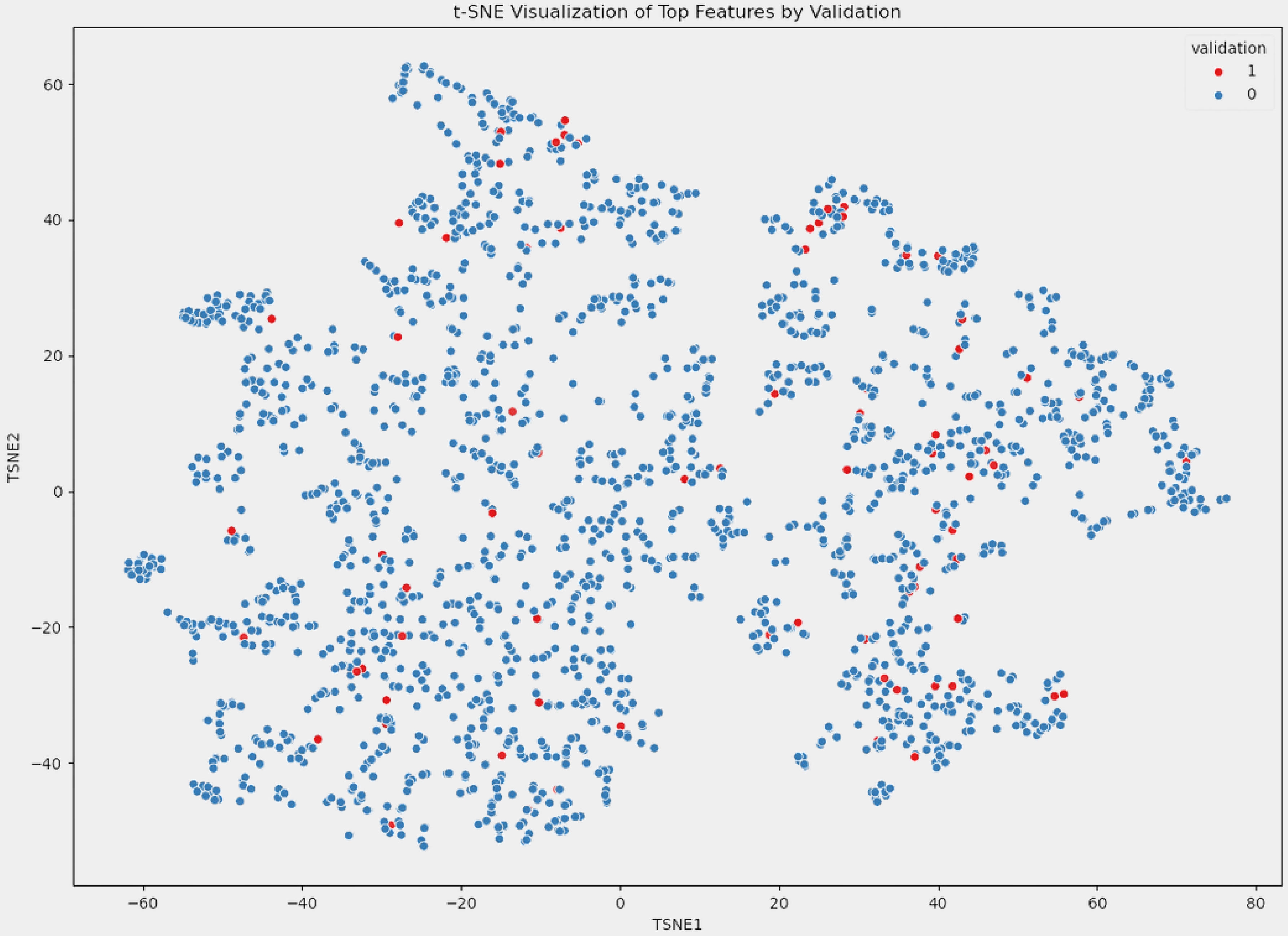
Geospatial. Full Feature.

Geospatial Cluster Analysis

- Total True Charcoal Sites: 86
- Unique Clusters Identified: 26
- Max Clustering Distance: 20 km
- Min Sites per Cluster: 2

Feature Cluster Analysis





Conclusion

Future Work. Acknowledgements.

Future Work

Image feature embeddings

Enrichen the information from the first stage of the model.

Improved time-series modeling

“Hotspot” feature, deforestation chronology

Feedback from fieldwork

Brazil FLPO task force deployment this August

Acknowledgements

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