What Is Machine Learning Teaching Us? Explainable AI for Seismic Models

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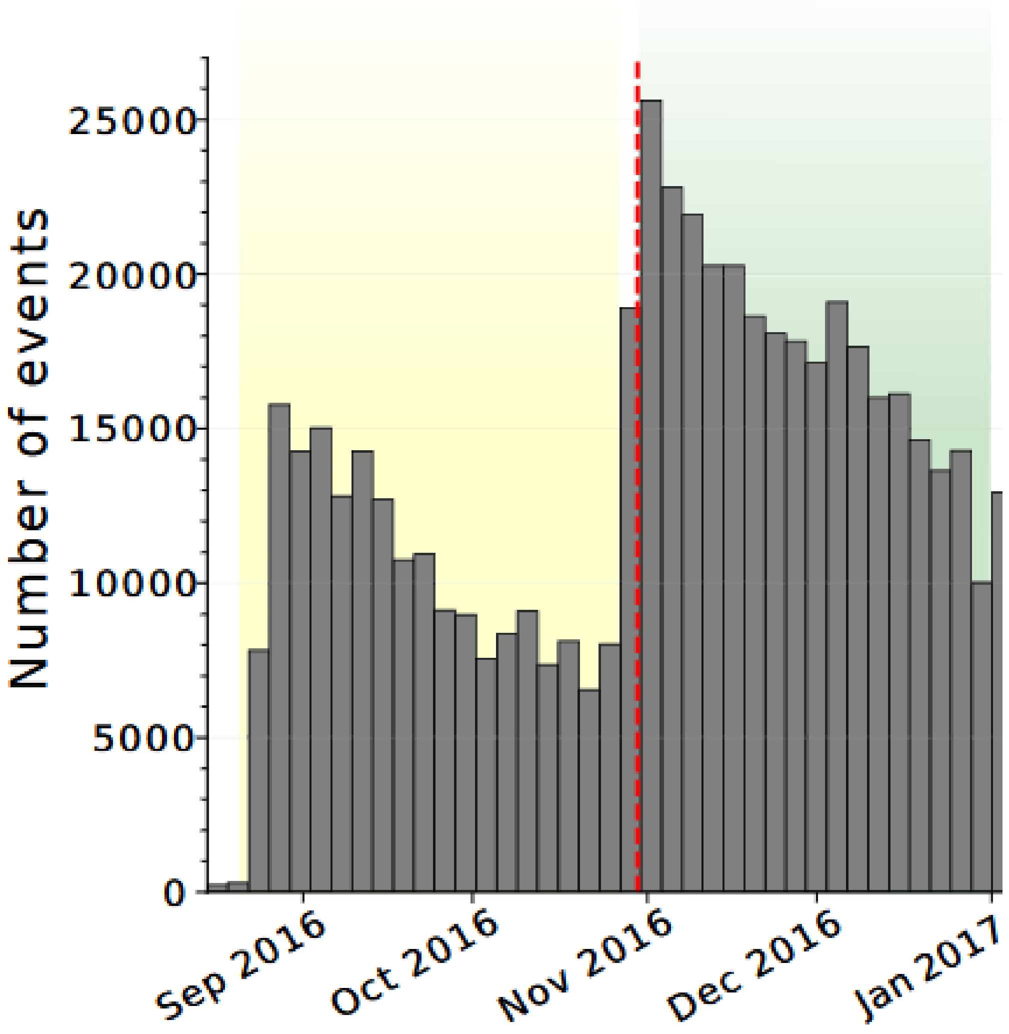
First experiment:

CNN Explainability for the classification of Foreshocks and Aftershocks

What are Aftershocks and Foreshocks?

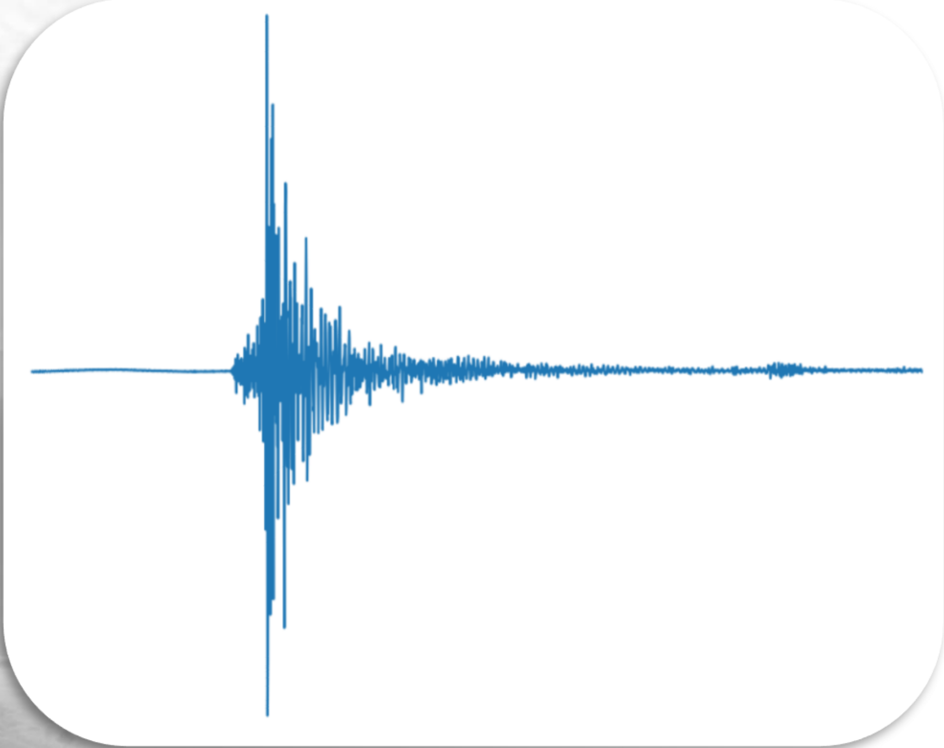
- **Foreshocks**: Smaller earthquakes occurring before a mainshock, often signaling stress build-up along a fault.
- **Aftershocks**: Smaller earthquakes following the mainshock, caused by the crust adjusting to new stress levels
- Both are critical stages in the seismic cycle, reflecting fault behaviour and stress redistribution

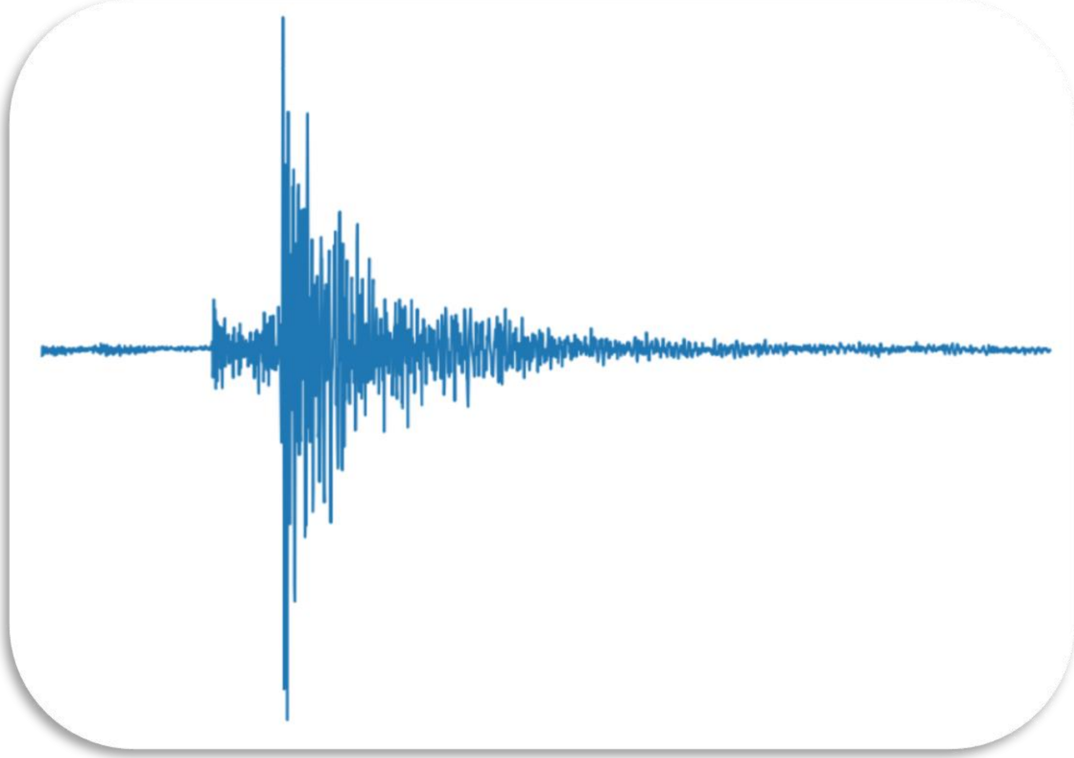


Why is classifying them important?

1. **Early Warning**: Identifying foreshocks can aid in predicting mainshocks, potentially saving lives.
2. **Risk Management**: Understanding aftershocks helps assess ongoing seismic risks
3. **Fault Dynamics**: Classifying these events provides insights into stress evolution during the seismic cycle

Shown here are two waveforms from the Norcia dataset, recorded during the M6.5 earthquake in Norcia, PG (Italy). One represents a foreshock, while the other is an aftershock of the same event.





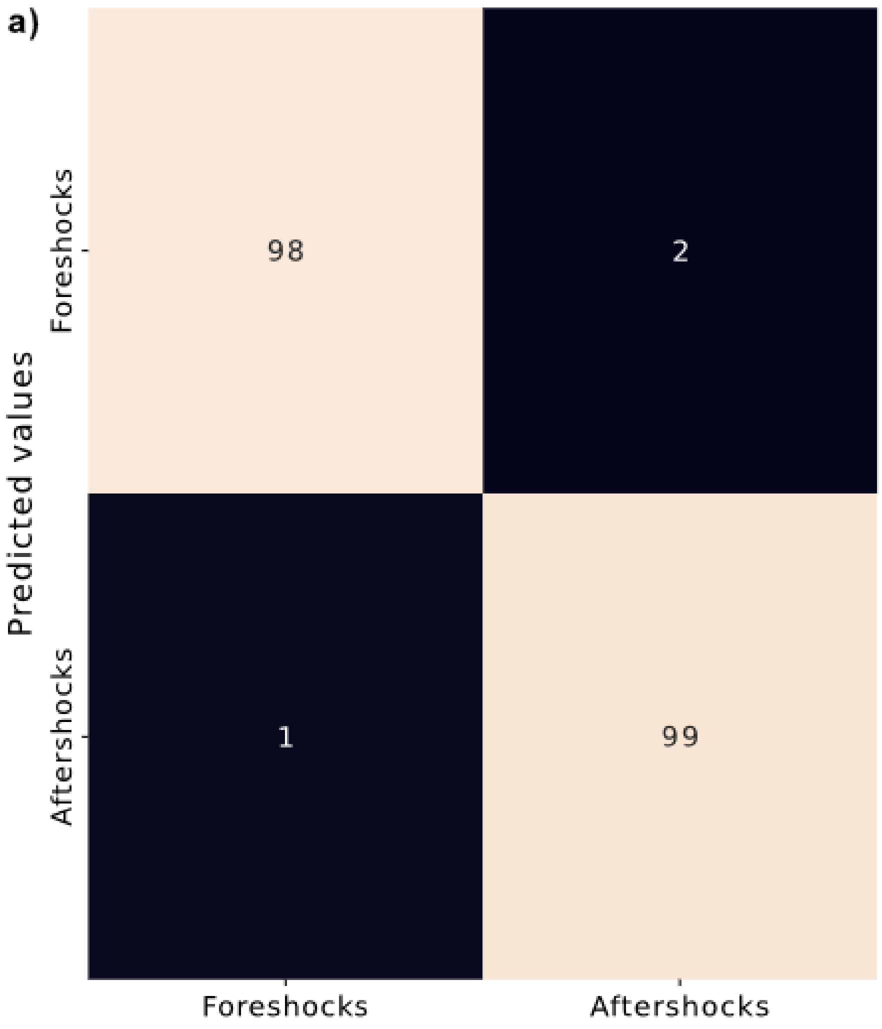
Can you spot the differences?

In their work, *Probing the evolution of fault properties during the seismic cycle with deep learning,* Laura Laurenti, Gabriele Paoletti, et al. demonstrated that DL models accurately distinguish seismic waves recorded before and after a mainshock.

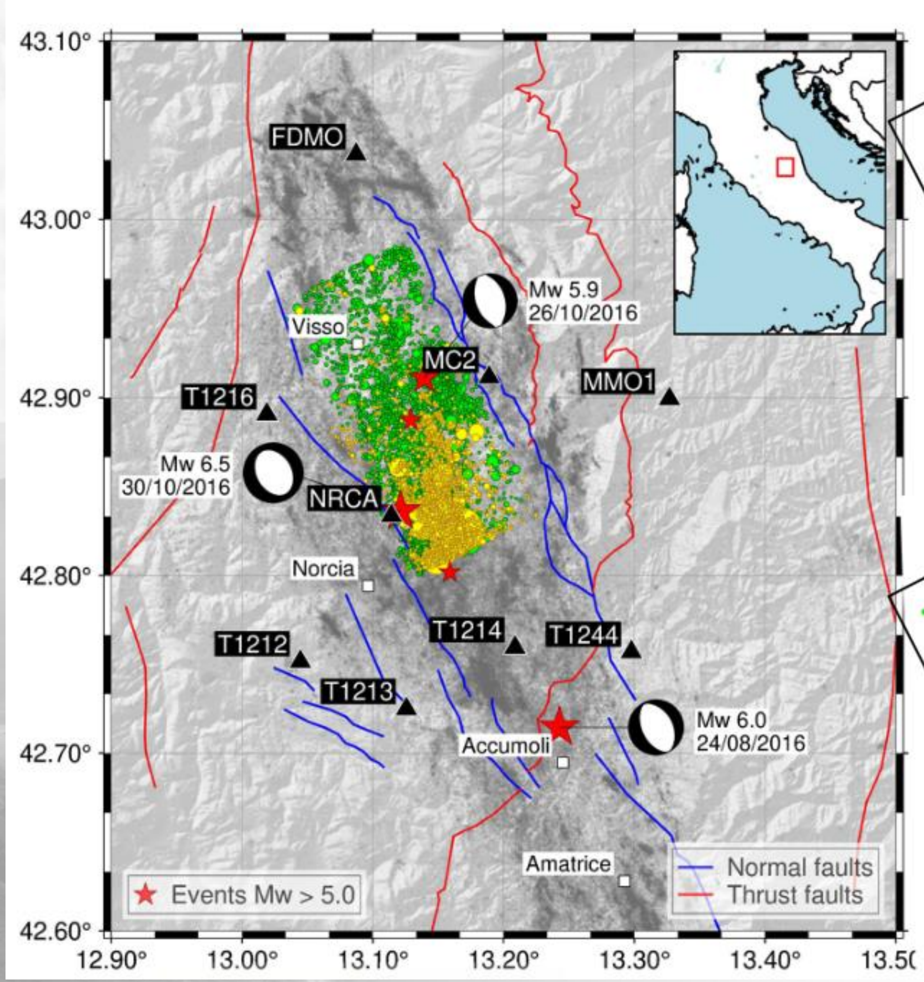
But what are these DL models really learning?

Can they teach us something useful?

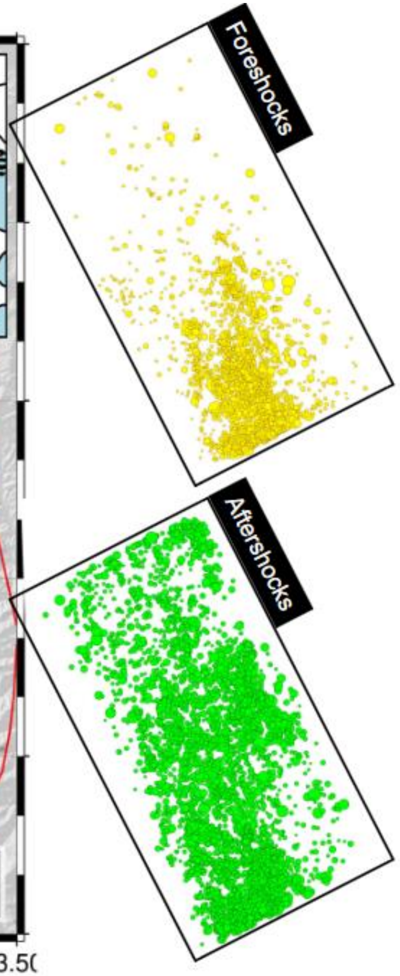
In our project we aim to build a new DL model to replicate the task from the paper and then use SHAP for model explainability.
This allow us to better understand which features drive the model's predictions.



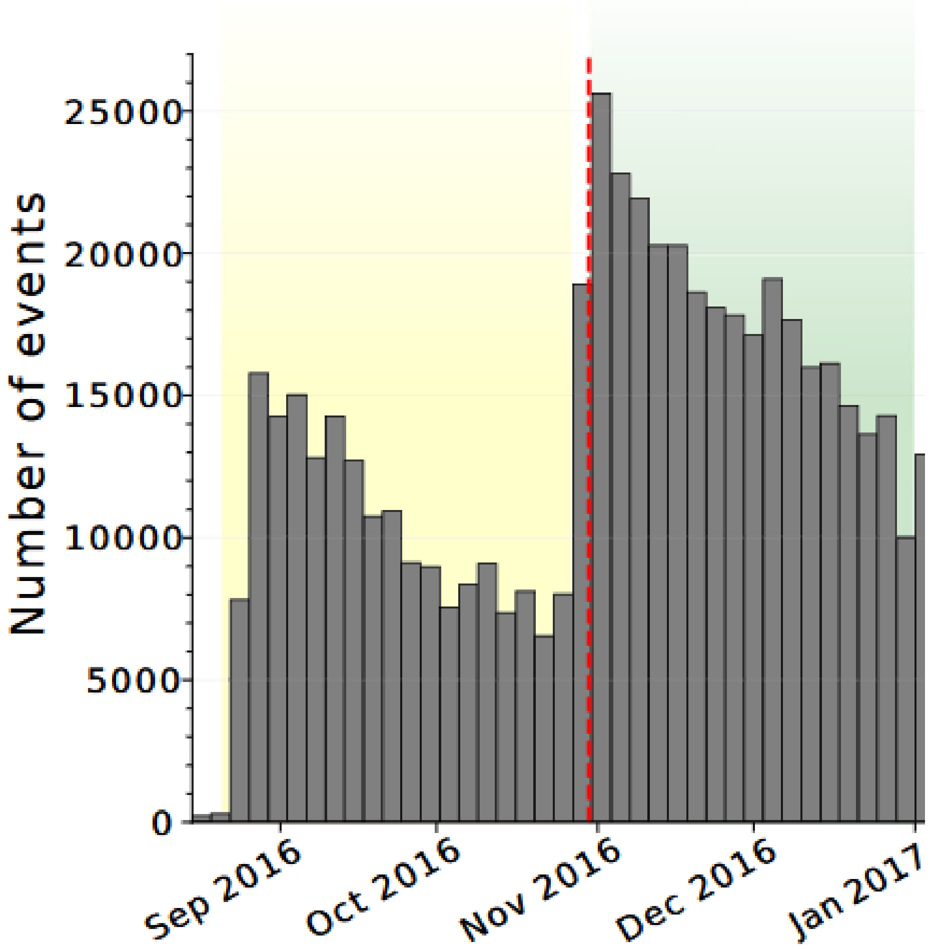
Dataset



43.10°
43.00°
42.90°
42.80°
42.70°
42.60°
12.90°
13.00°
13.10°
13.20°
13.30°
13.40°
FDMO
Mw 5.9
26/10/2016
Visso
MC2
MMO1
T1216
Mw 6.5
30/10/2016
NRCA
Norcia
T1212
T1214
T1244
T1213
Mw 6.0
24/08/2016
Accumoli
Amatrice
Events Mw > 5.0
Normal faults
Thrust faults

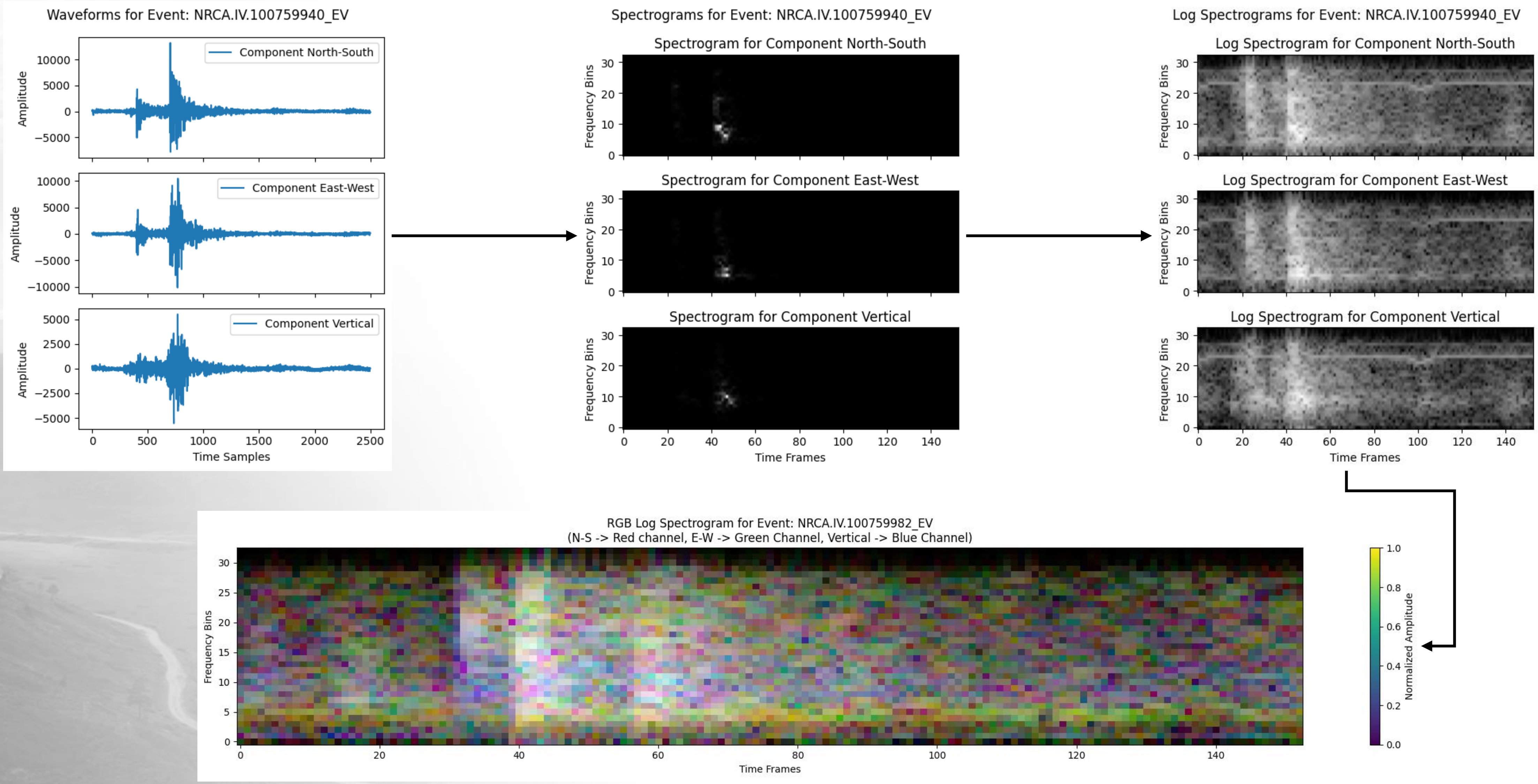


Foreshocks
Aftershocks



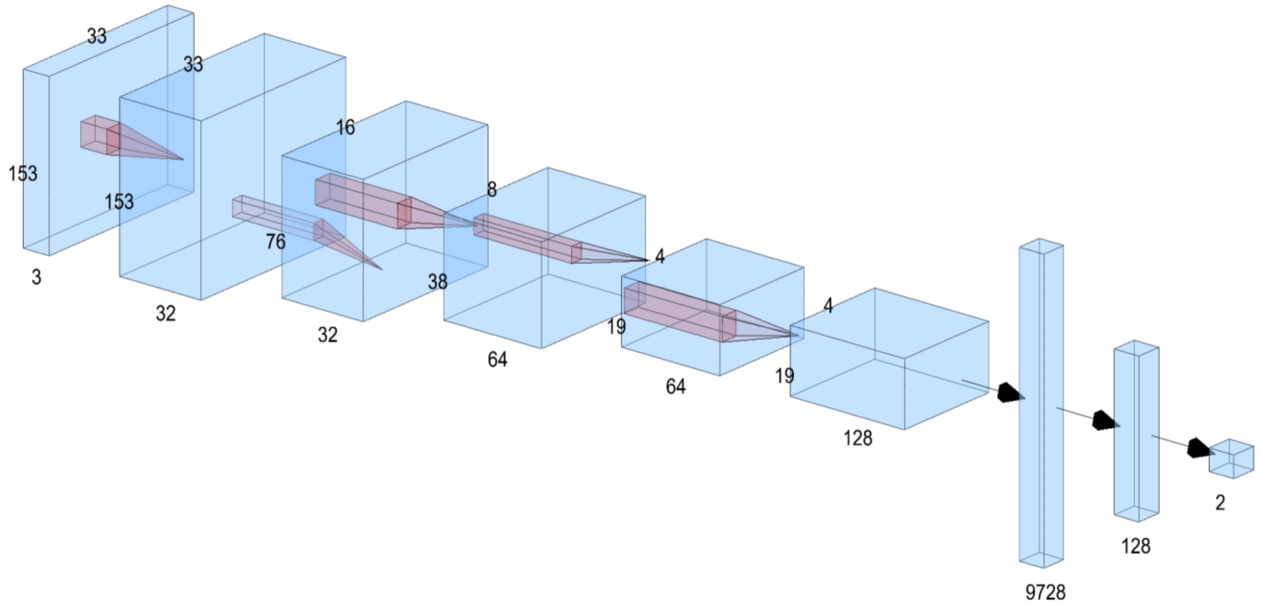
Number of events
0
5000
10000
15000
20000
25000
Sep 2016
Oct 2016
Nov 2016
Dec 2016
Jan 2017

Data Preprocessing



Model Architecture

The model is a 7-layer convolutional neural network (CNN). It takes a 3-channel log spectrogram as input and processes it through three convolutional layers with batch normalization and max pooling. The output is a tuple with the raw probabilities for the event being a foreshock or aftershock, without SoftMax applied.

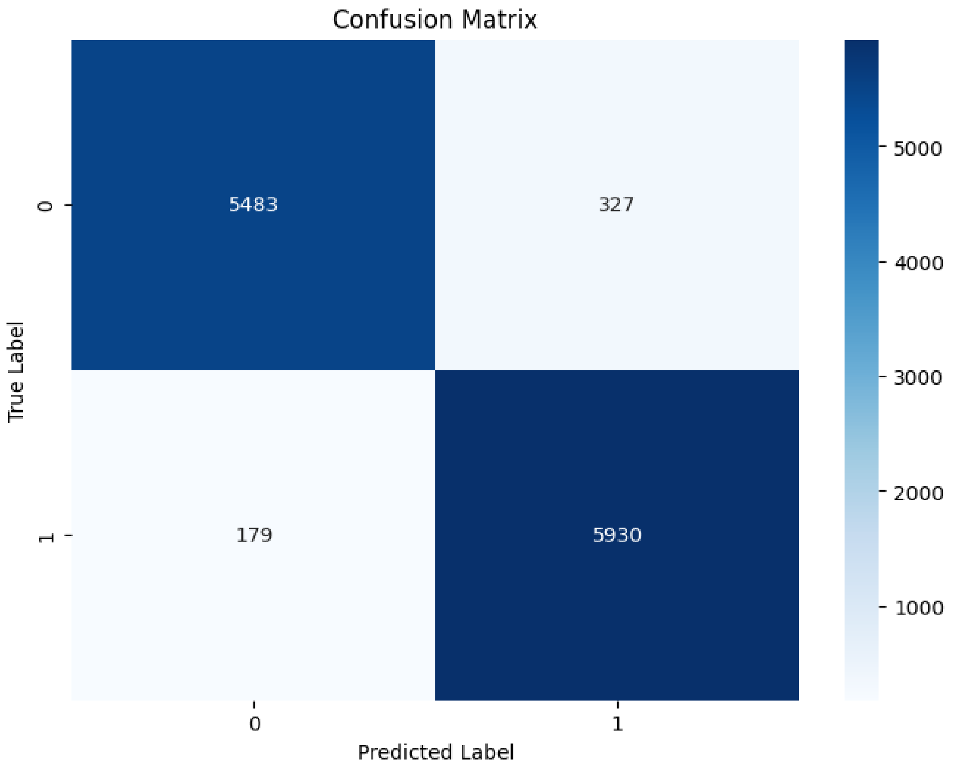


Model Evaluation

The model demonstrates excellent performance with 95.75% **accuracy**.
It maintains a **high precision** (94.77%) and **recall** (97.07%), resulting in a balanced **F1 score** of 95.91%.

The confusion matrix shows minimal misclassifications, highlighting its reliability.

It **slightly underperforms** compared to the model presented in the paper, which achieved **>98% accuracy**.

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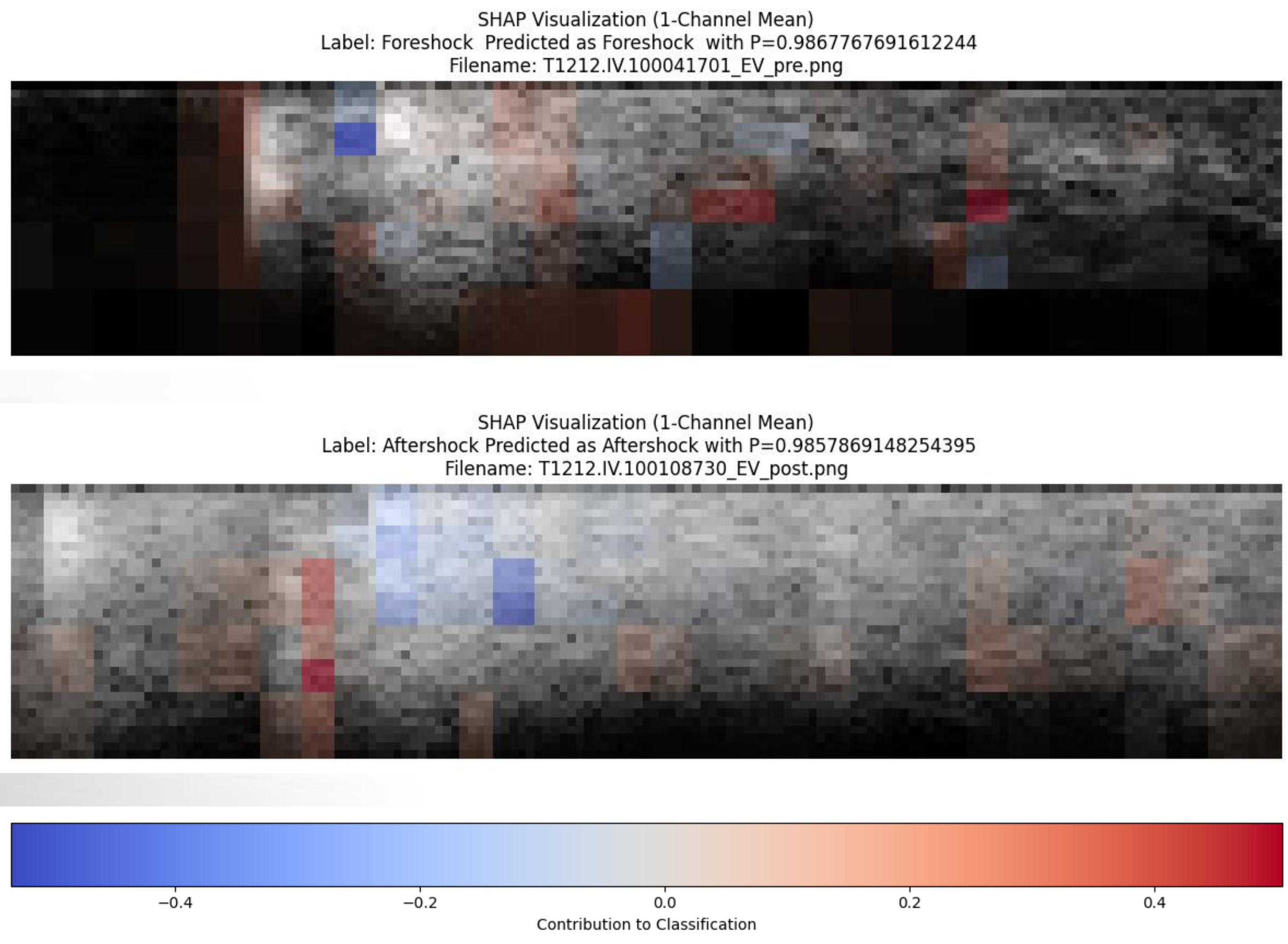
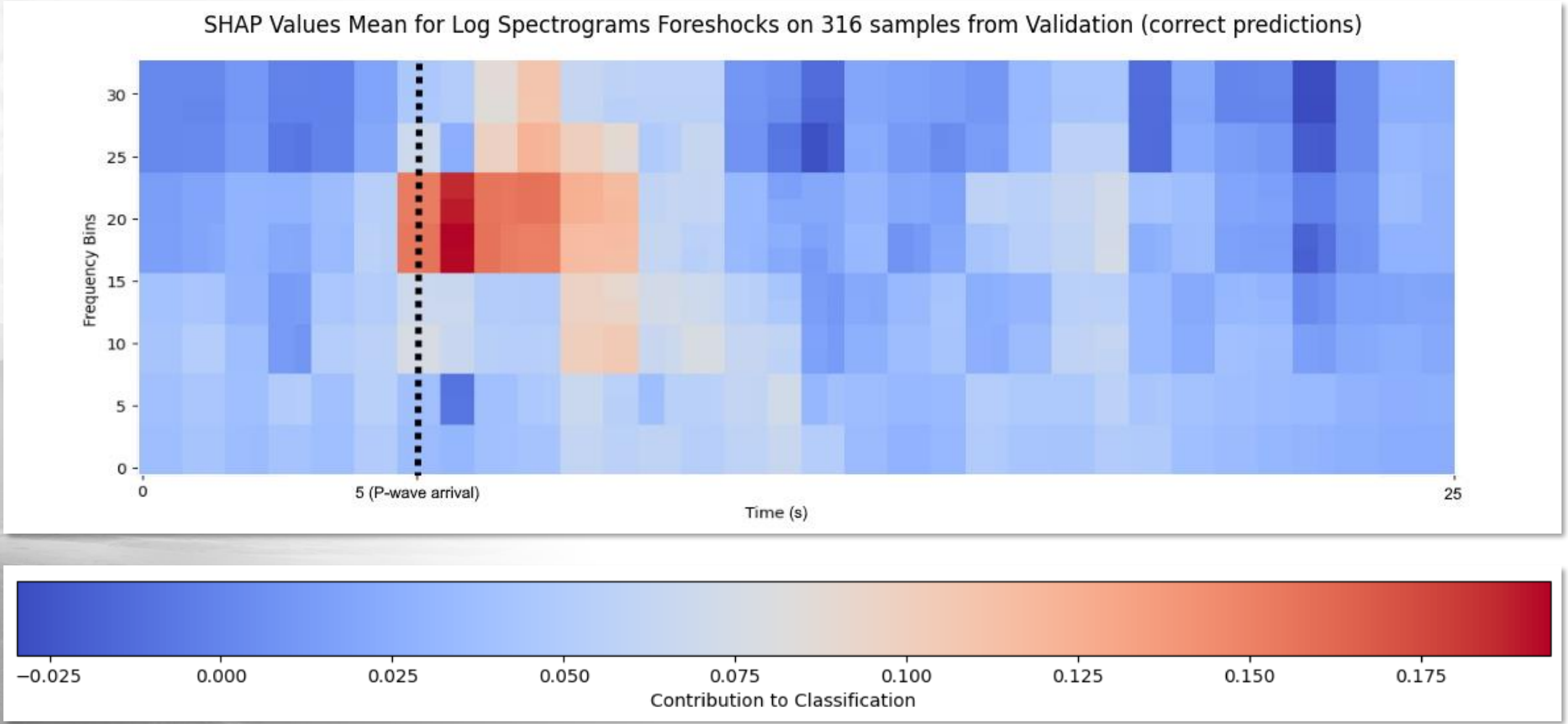
Test Accuracy: 0.9575
    Precision: 0.9477
       Recall: 0.9707
     F1 Score: 0.9591
```

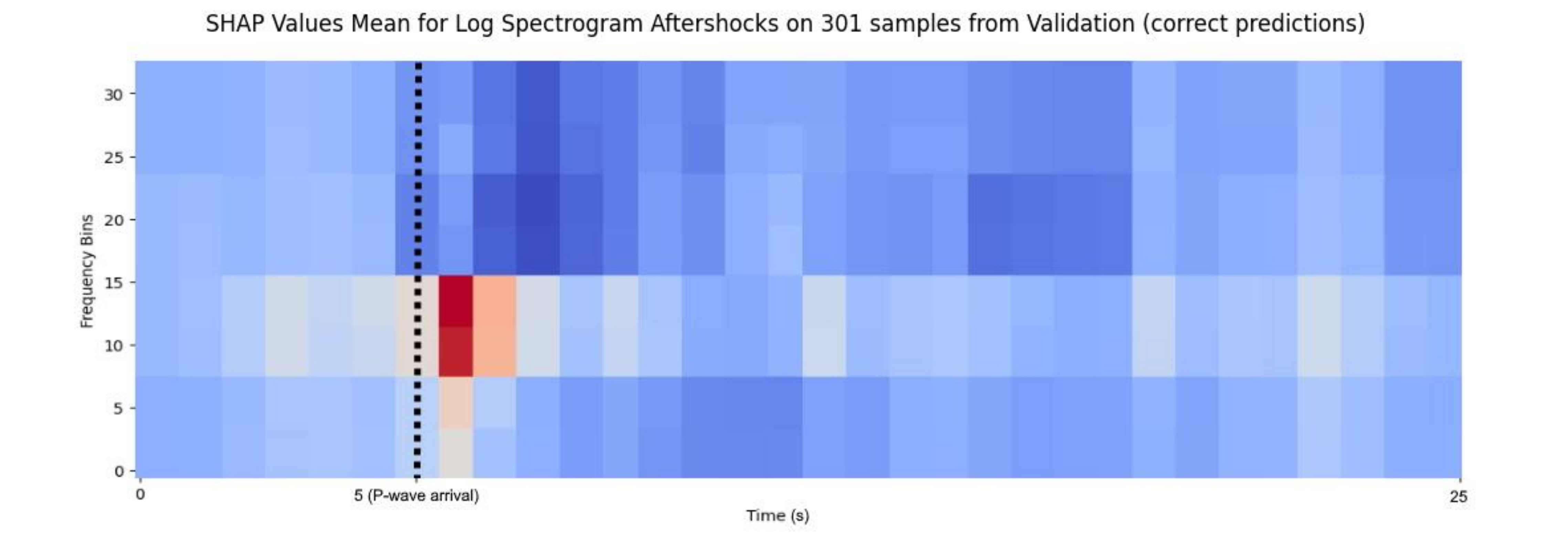
SHAP Example

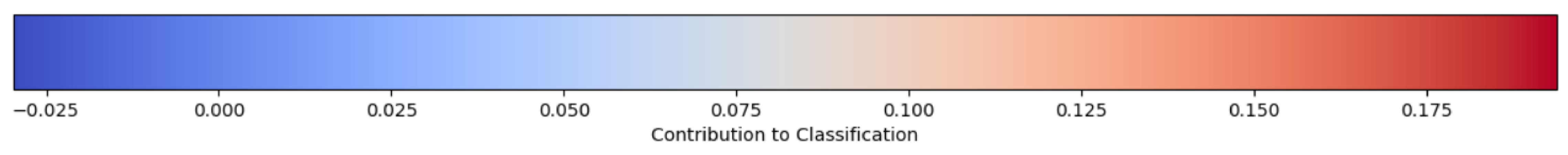


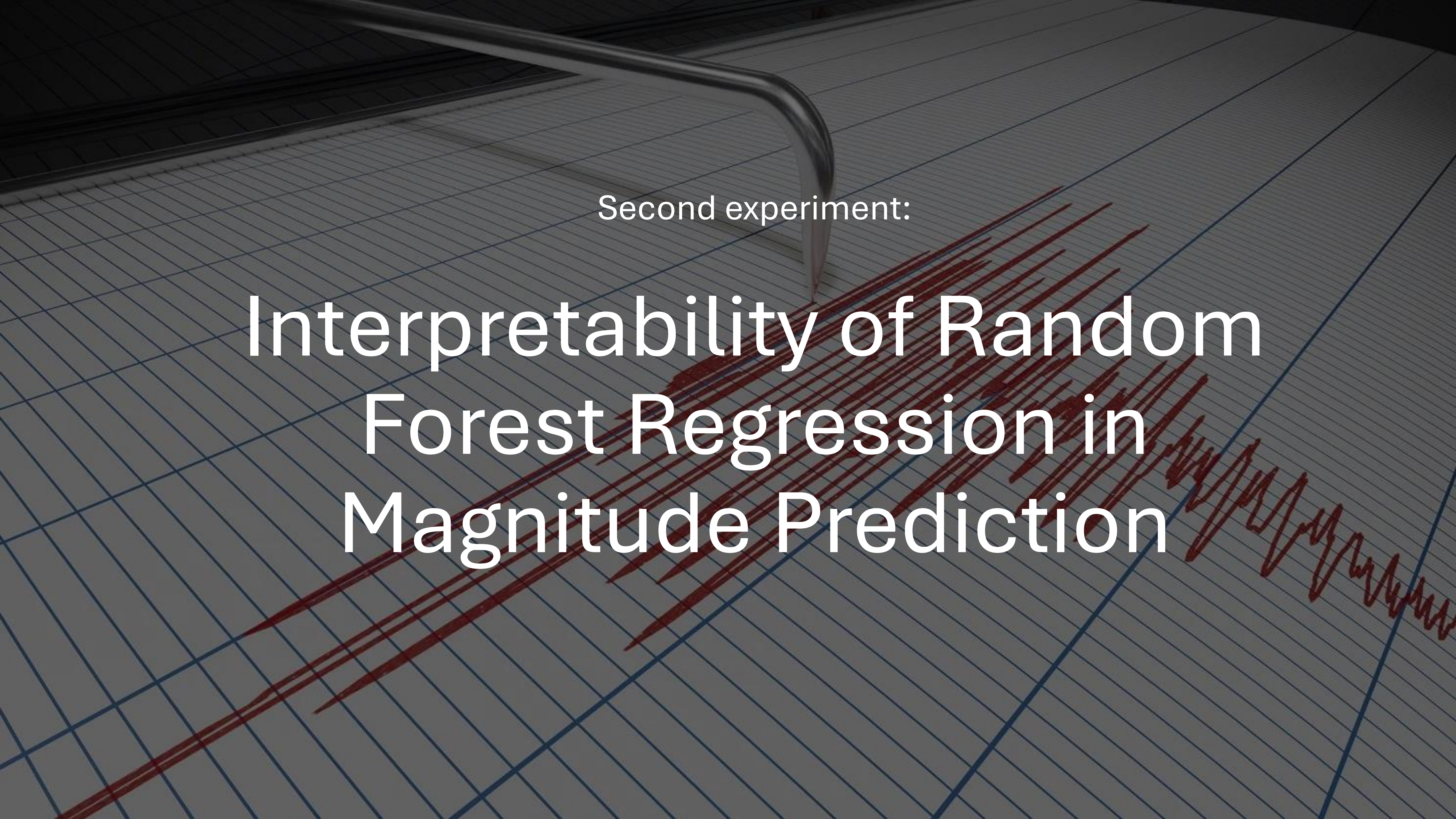
Average SHAP on Foreshocks



Average SHAP on Aftershocks



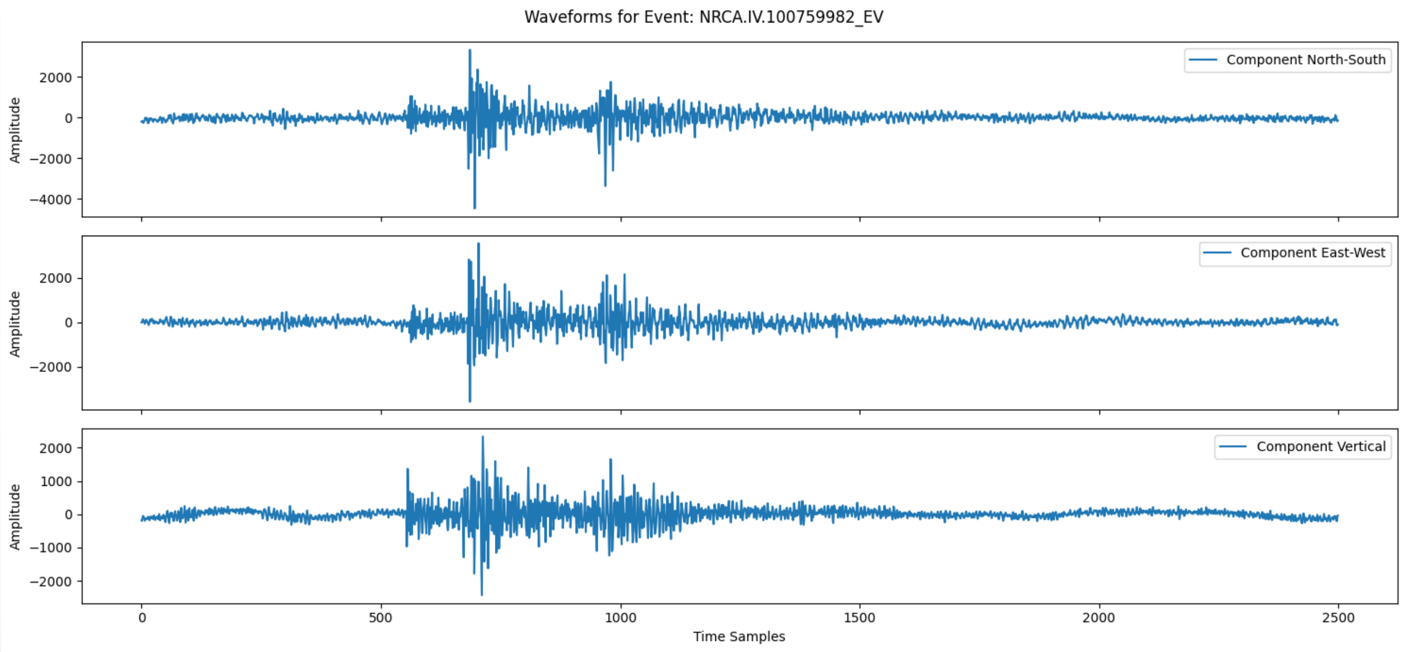




Second experiment:

Interpretability of Random Forest Regression in Magnitude Prediction

Data Preprocessing



Extracted Features (for each channel) + **Metadata**

Extracted feature example: *f{feature_number}_c{channel_number}_{feature_name}*

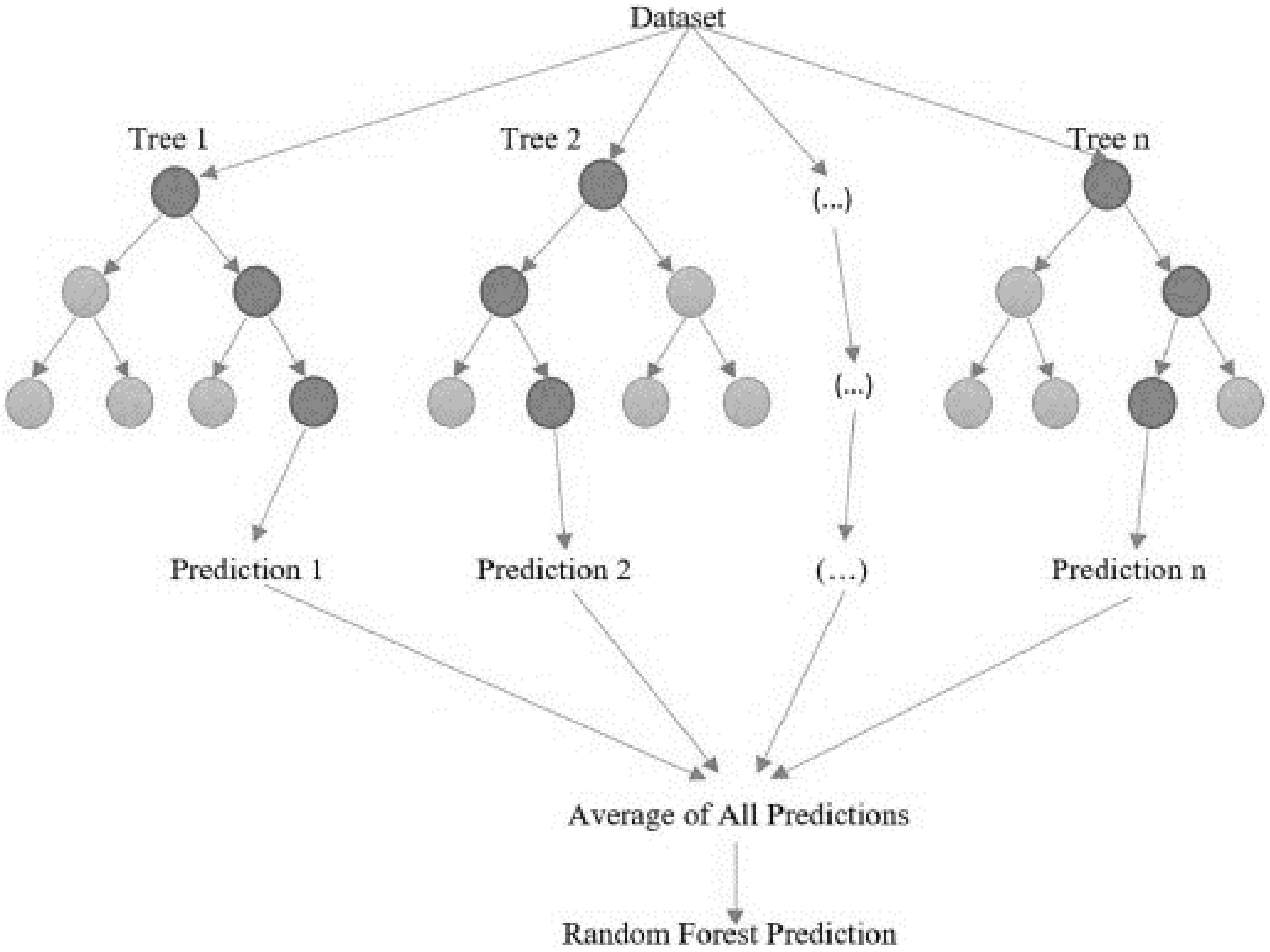
Number of peaks in the first channel -> f16_c0_num_peaks

Model

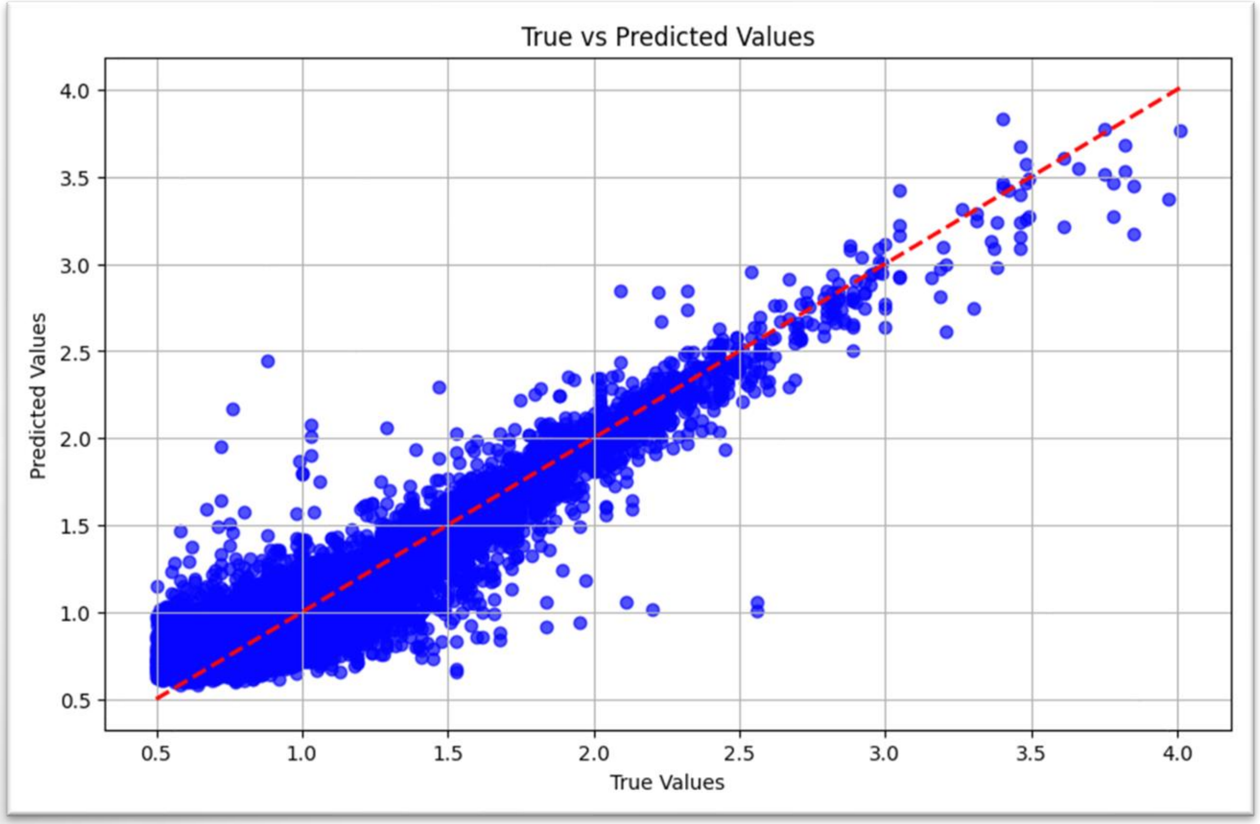
Random Forest Regressor

- Number of trees: 100
- Criterion: Squared Error
- Max Depth: None

(Default parameters from scikit learn)

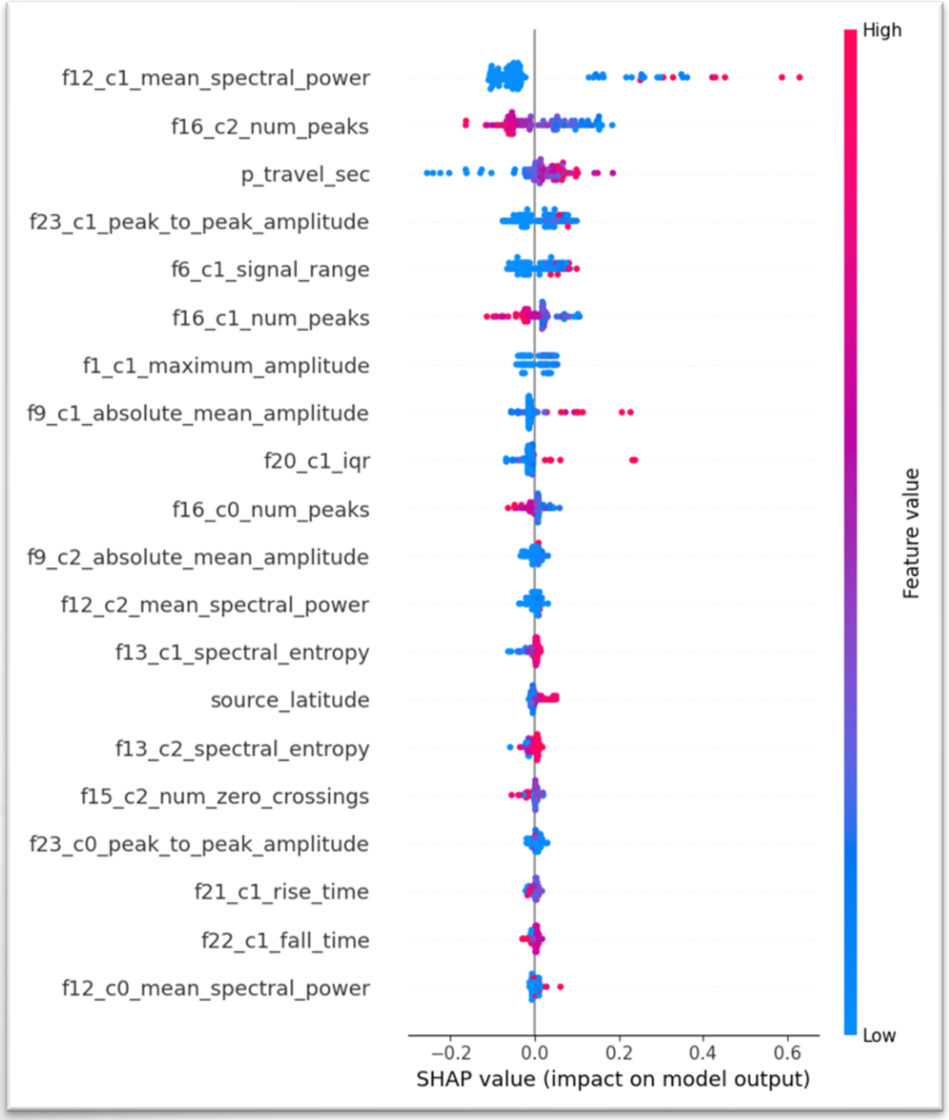


Model Evaluation

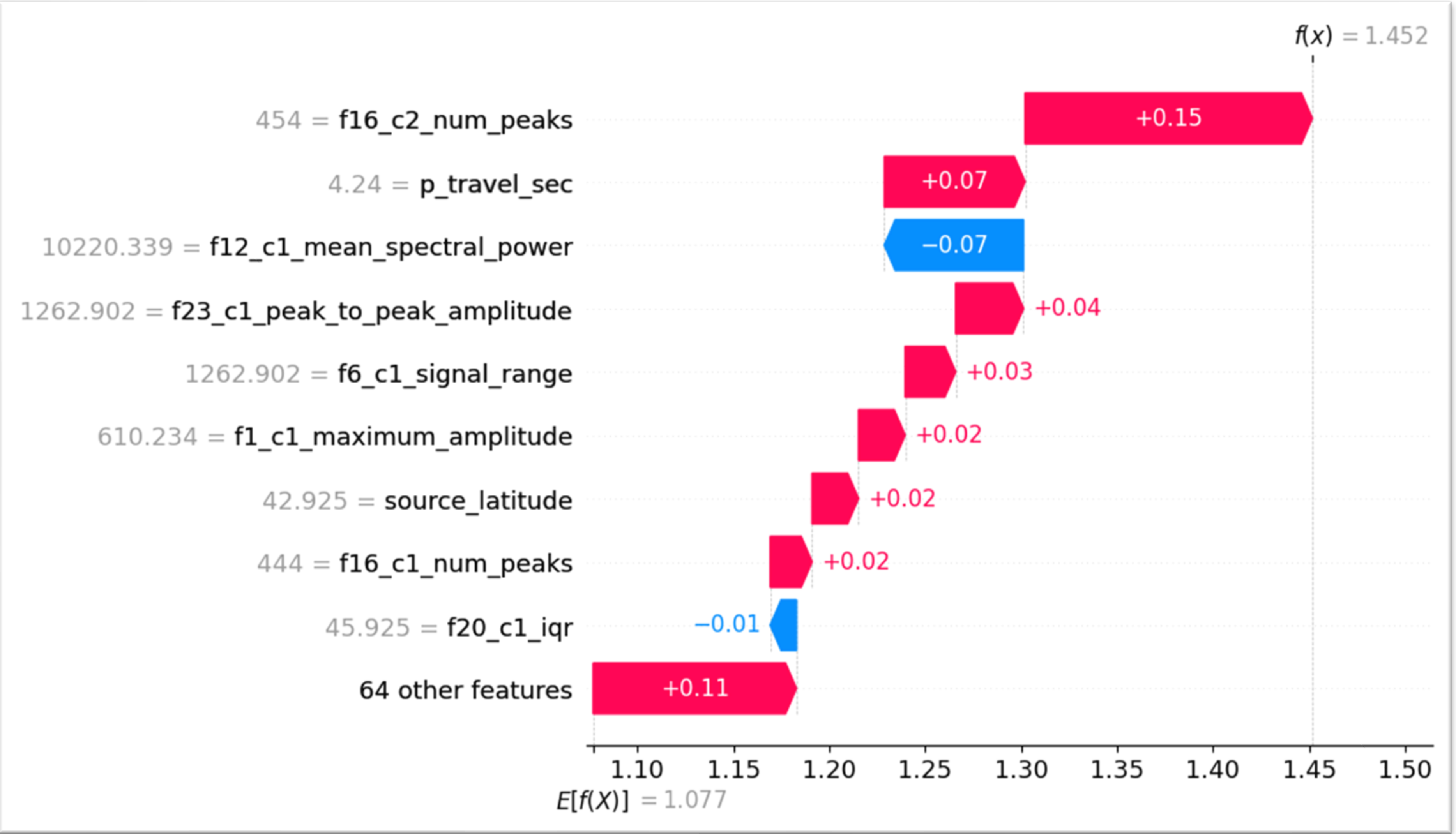


Mean Absolute Error (MAE): 0.1052
Mean Squared Error (MSE): 0.0212
Root Mean Squared Error (RMSE): 0.1457
R^2 Score: 0.8834

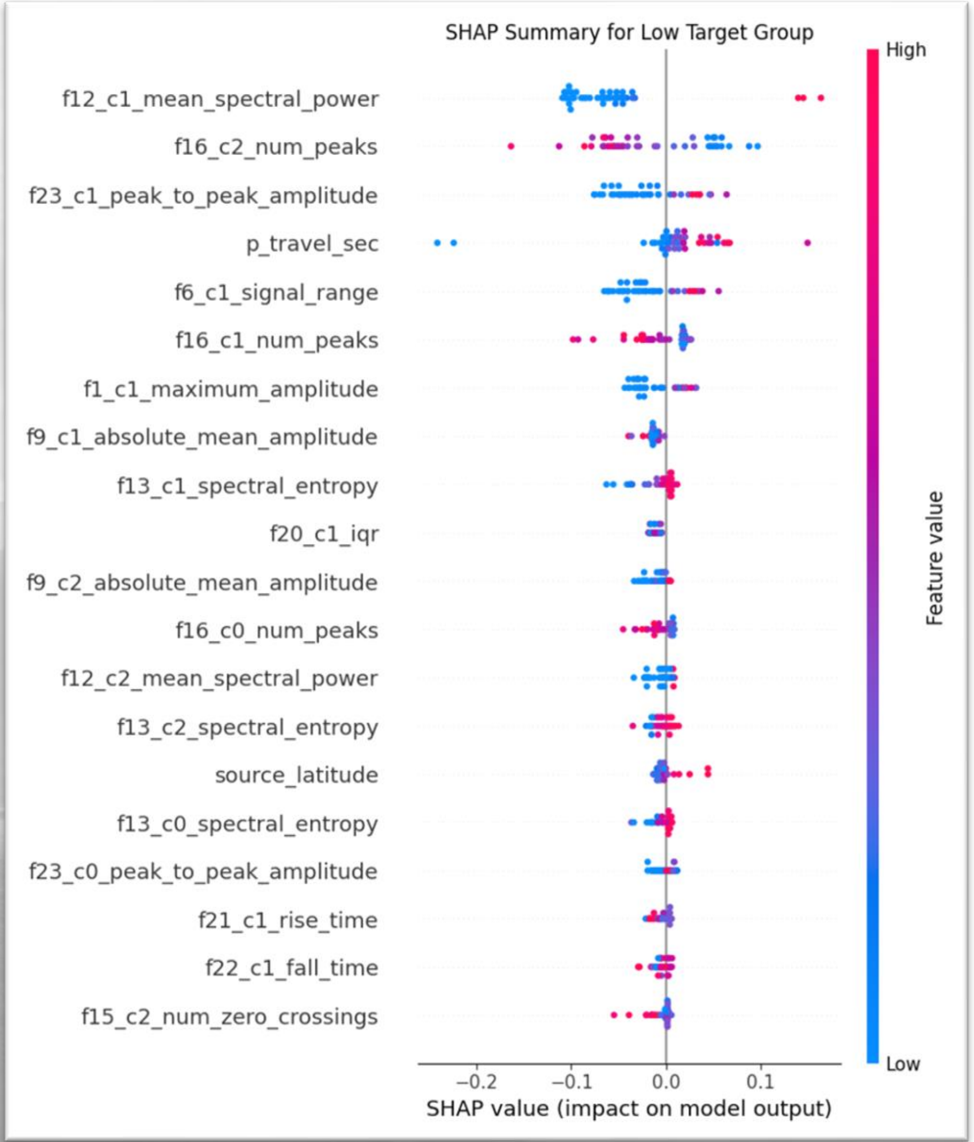
SHAP Results (Summary Plot)

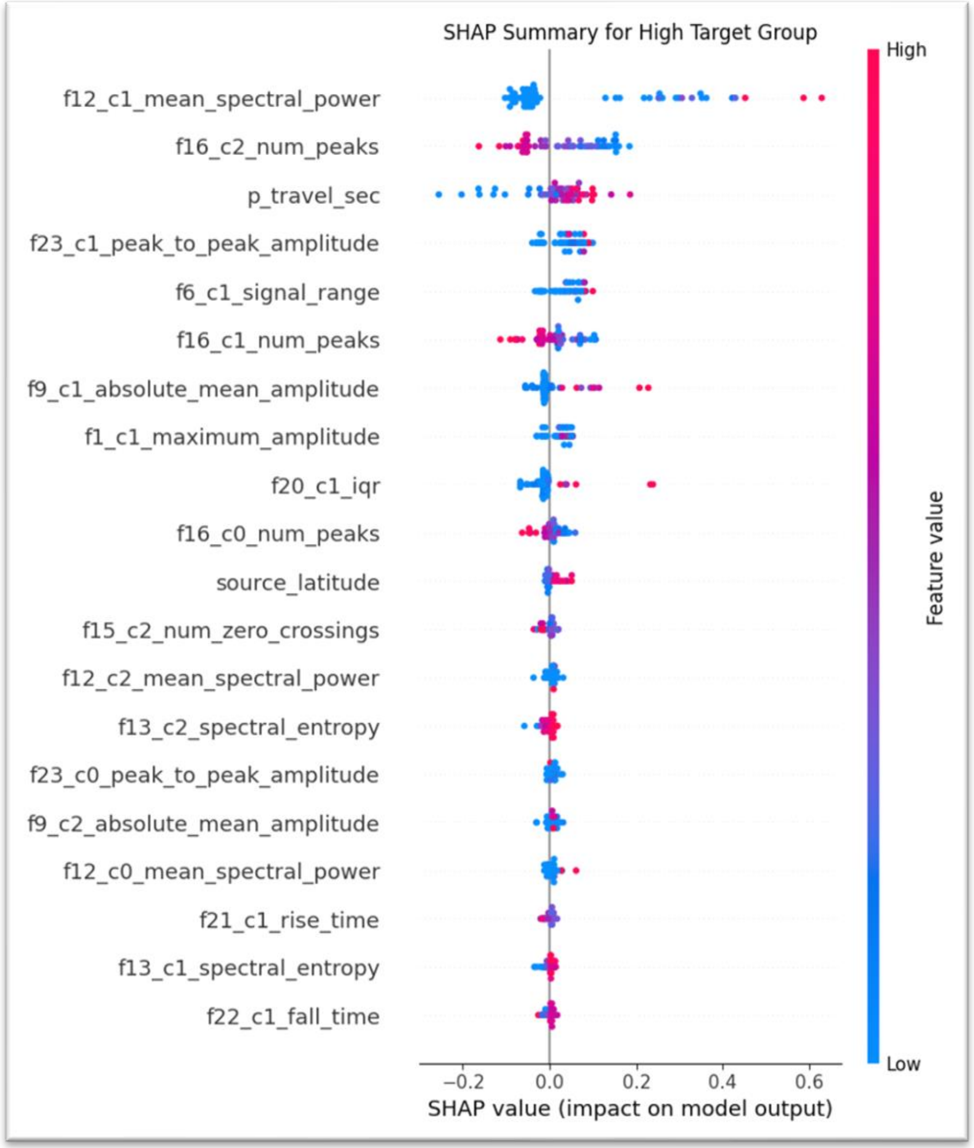


Explaining Individual Predictions

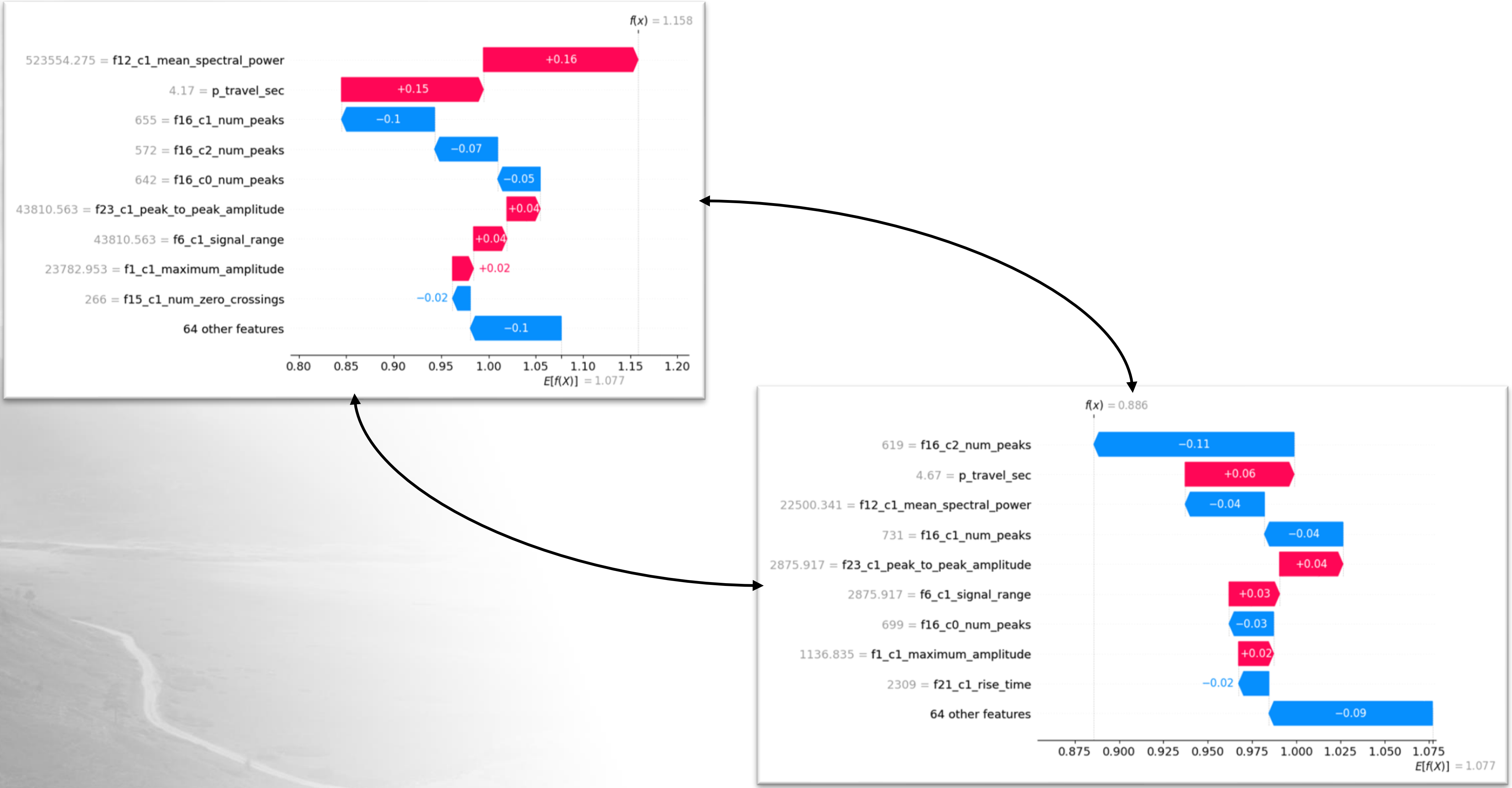


Group-Specific Interpretation

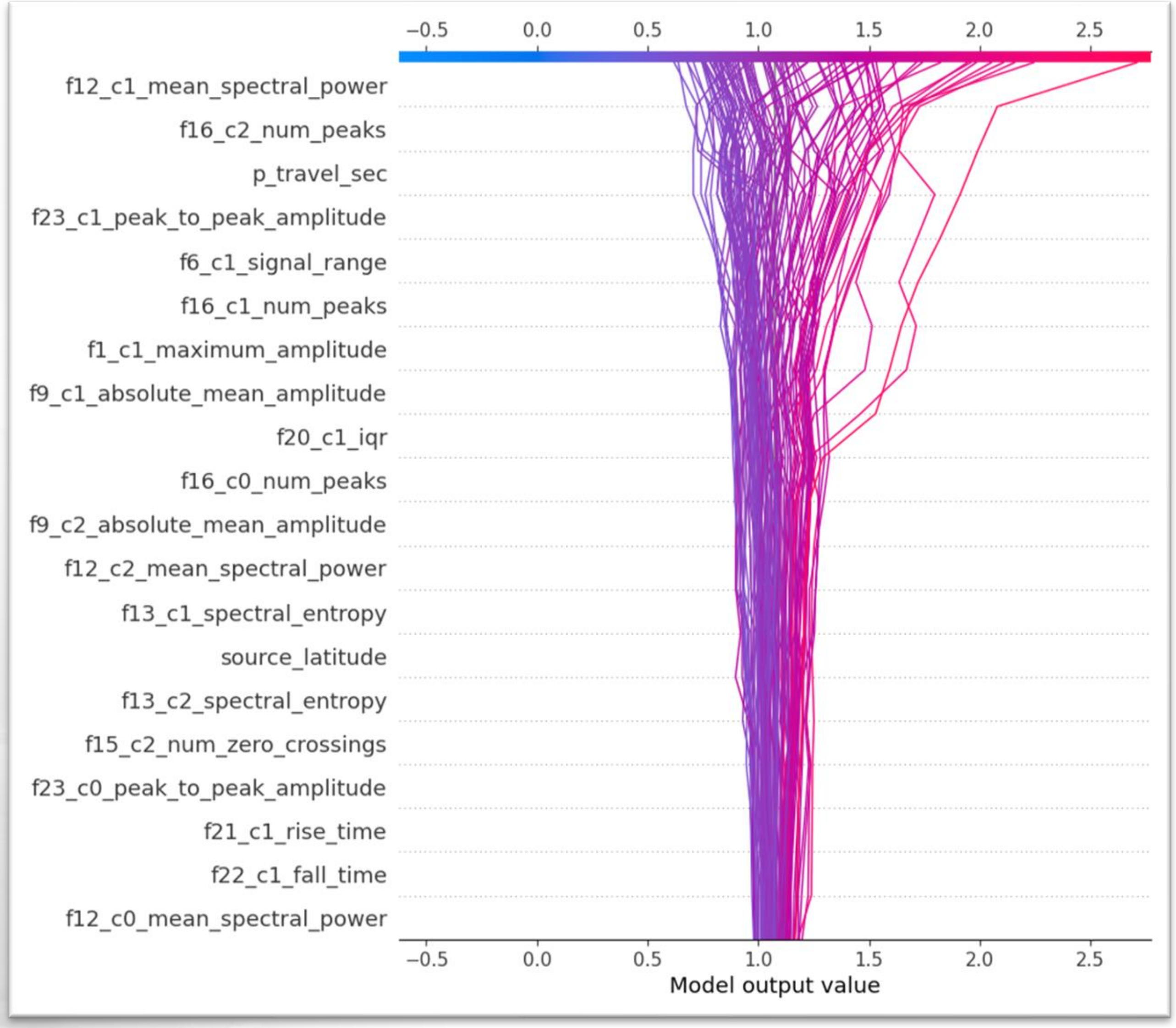




Contrastive Explanation

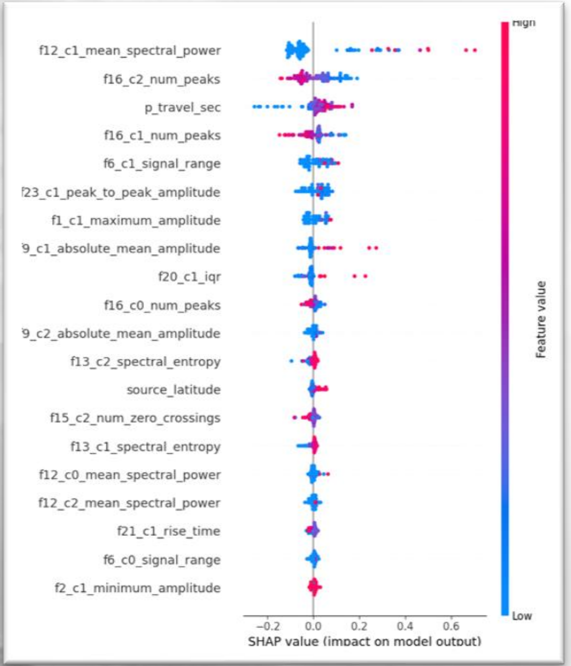


Anomaly Detection

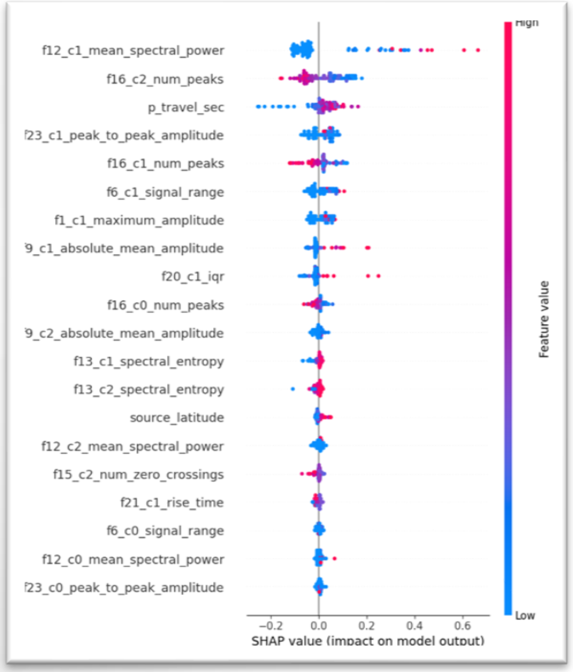


Explainability for Hyperparameter Tuning

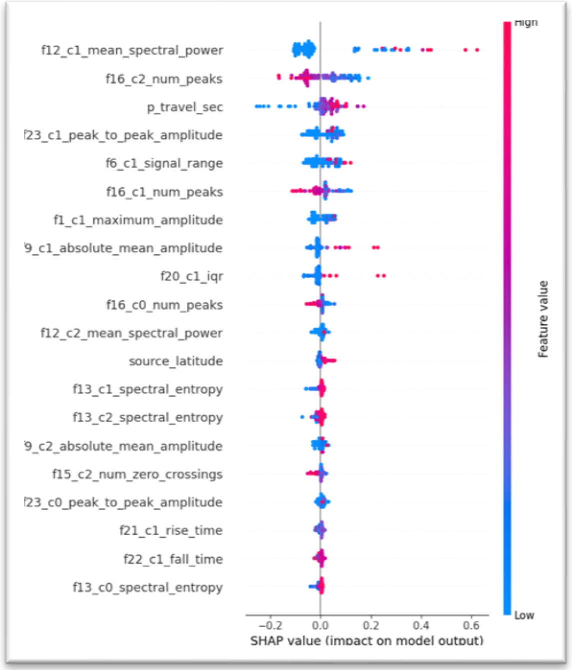
10 Trees



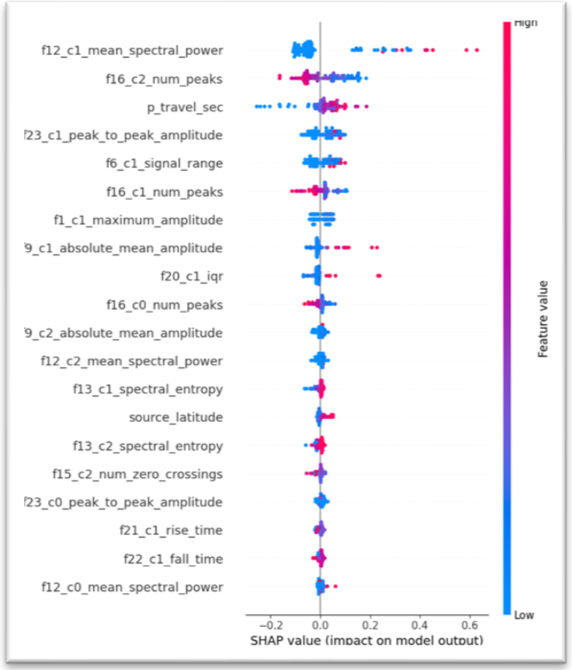
25 Trees



50 Trees



100 Trees




Thank you!