Investigating Seismic Source Discrimination at Local and Near-Regional Distances in the United Kingdom using P/S Amplitude Ratios and a Convolutional Neural Network

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INTRODUCTION AND MAIN RESULTS

Many classical seismic source discriminants (e.g., m_b:M_s, moment tensor analysis and depth criteria) cannot be used to discriminate between smaller magnitude events usually only detected at local to near-regional distances. However, the *P/S* amplitude ratio method has recently had mixed success at these distances. We test this method by applying it to the UK. *P/S* ratios are successful in discriminating between earthquakes and explosions in our UK dataset, particularly at high frequencies (>8Hz). We also apply a machine learning model previously trained in France to discriminate between sources, obtaining an accuracy >95% in our UK dataset. By combining *P/S* ratios with the machine learning predictions we form a multi-variate discriminant which further identifies anomalous events.

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Merrett et al.

P2.1-161

Introduction

Discriminating smaller magnitude explosions from earthquakes poses a challenge. These events generate complex high-frequency waveforms strongly affected by local geology. Signals are only detected at local to near-regional distances (<400km) and have low Signal-to-Noise Ratio (SNR). Source discriminants used in the context of CTBT monitoring, such as m_b:M_s, moment tensor analysis and depth criteria, are often not applicable in this context.

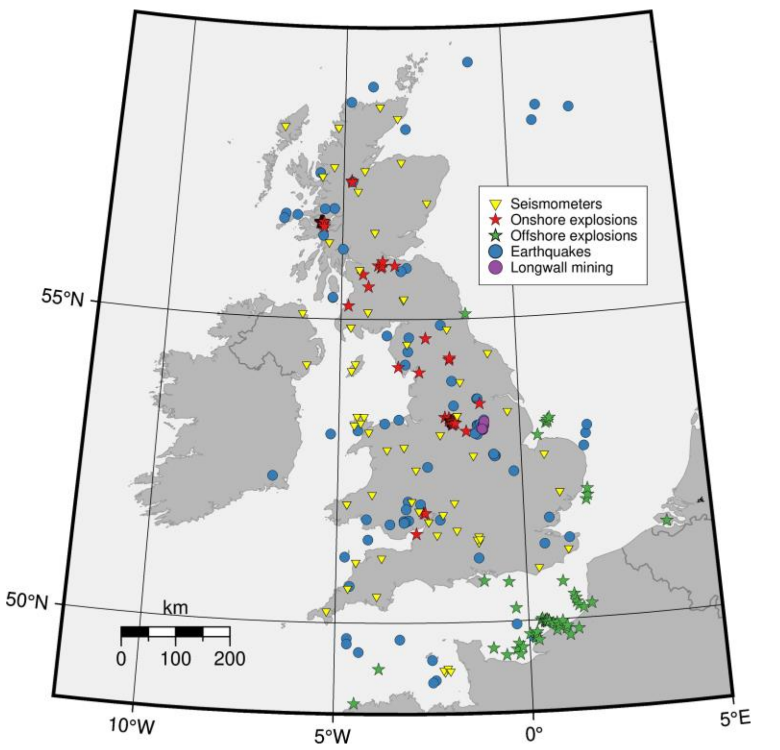
The *P/S* amplitude ratio method has recently been applied to discriminate small magnitude events at local to near-regional distances (<400km), with mixed success (Grannell et al., 2018; Pyle & Walter, 2019).

Machine learning models have been able to learn features from raw seismic data to discriminate between small magnitude explosions and earthquakes. However, the generalization of these models to new regions is variable (Maguire et al., 2024).

The UK is an attractive region to test *P/S* ratios and a previously trained machine learning model for discrimination. Catalogues of smaller magnitude explosions and earthquakes are available, with most events only detected at local to near-regional distances (<400km).

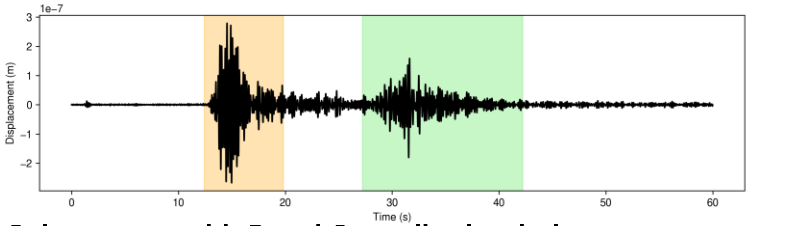
Dataset

Our dataset consists of presumed earthquakes, assumed mine and quarry blasts, offshore explosions and non-explosive mining induced events. These 217 events were detected by the British Geological Survey from 2014 to 2016 and have magnitudes M_L 0.61 – 4.48.



Seismic events in our UK dataset

Methods



Seismogram with *P* and *S* amplitude windows

P/S ratios

Root-Mean-Square (RMS) amplitudes of *P*- and *S*-waves are measured in specific time windows on raw waveforms in multiple passbands from 1 to 28Hz. The *P* window begins 1s before the manual pick, whereas the *S* window begins at a theoretical arrival time calculated using the LOWNET velocity model (Galloway, 2024)**.** For a given station, we use the mean of the squares of components with SNR greater than 2.0 for *P*, and 1.5 for *S.* We do not perform any corrections for propagation or site effects. Instead, we use at least six stations to calculate the average *P/S* ratio across the networks.

Convolutional Neural Network (CNN)

We apply a CNN previously trained with earthquakes, and explosion seismograms from France (Hourcade et al., 2022) to our dataset. The model is trained with single-station three-component spectrograms, and averages predictions over multiple stations for each event.

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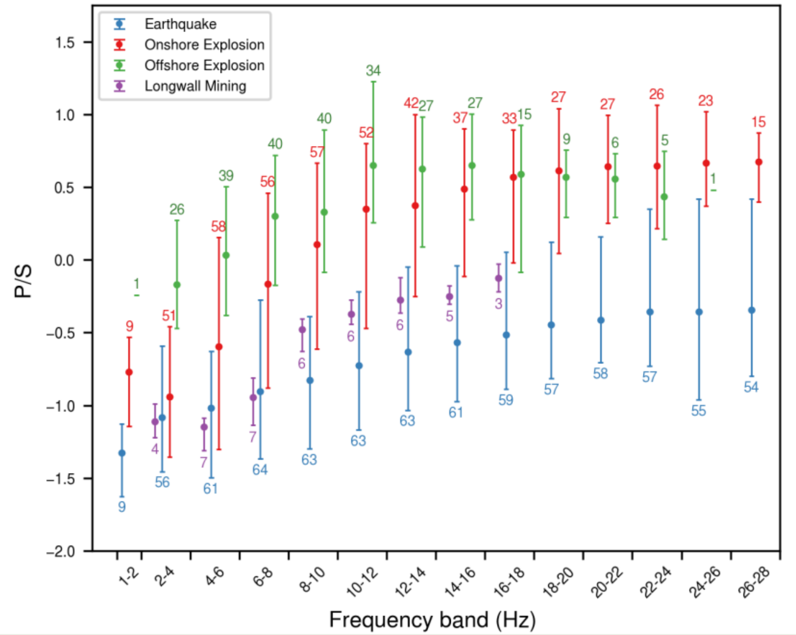
P/S ratio results

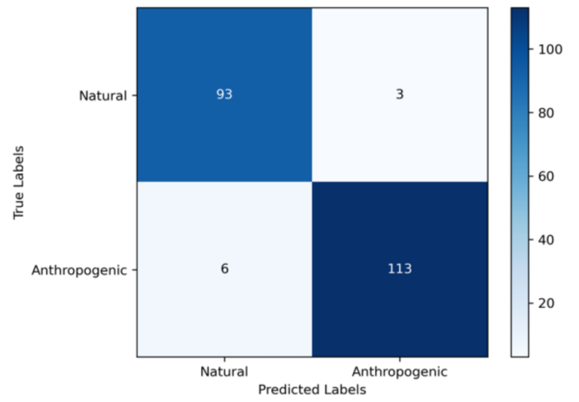
The average *P/S* ratios of explosions are higher than other seismic events in every frequency band we investigate. Above 8Hz the two source-types are well separated. In the 20-22Hz passband, the two source-types are completely separated. In some frequency bands onshore explosions have lower *P/S* ratios than offshore explosions, which could be explained by ripple-fired blasting mechanisms at quarries.

Log_{10}*(P/S)* ratios in each frequency band



CNN results

The CNN has an accuracy of 95.8% when applied to our UK dataset, compared to 98.5% in the original application in France (Hourcade et al., 2022).

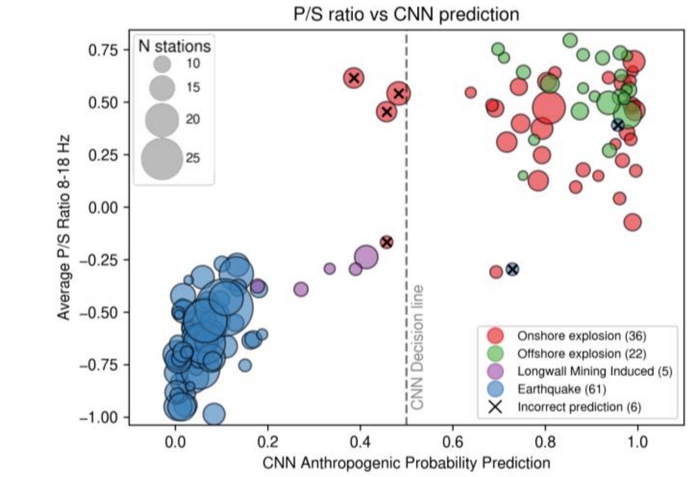


Confusion matrix evaluating the performance of the CNN on our UK dataset

Multi-variate discrimination

We combine the average *P/S* ratios in multiple passbands (8-18Hz) with the prediction probabilities from the CNN to form a multi-variate discriminant. The results suggest that the CNN incorporates *P/S* ratios into its prediction, which could help us to understand what part of the seismogram the model uses.

We can use the multi-variate discriminant to identify incorrectly labelled events and investigate anomalous events, such as seismicity induced by Longwall mining activity.



Multi-variate discrimination using *P/S* and the CNN

Conclusions

P/S ratios work as a source discriminant at local to near-regional distance (<400km) in the UK. A CNN event classifier trained in France generalizes well to the UK, with accuracy >95%. Forming a multi-variate discriminant allows us to better characterise anomalous seismic events and improve discrimination accuracy.

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