Earthquake Detection with Deep Learning

BY KAELYNN ROSE

APRIL 28, 2021

Goals

- Build Convolutional Neural Network (CNN) and Long-Short Term Memory (LSTM) models to predict earthquake class, magnitude, p-wave and s-wave arrival times

- Deploy best classification model to an AWS Lambda function to predict whether a signal is an earthquake in real-time

Use Case

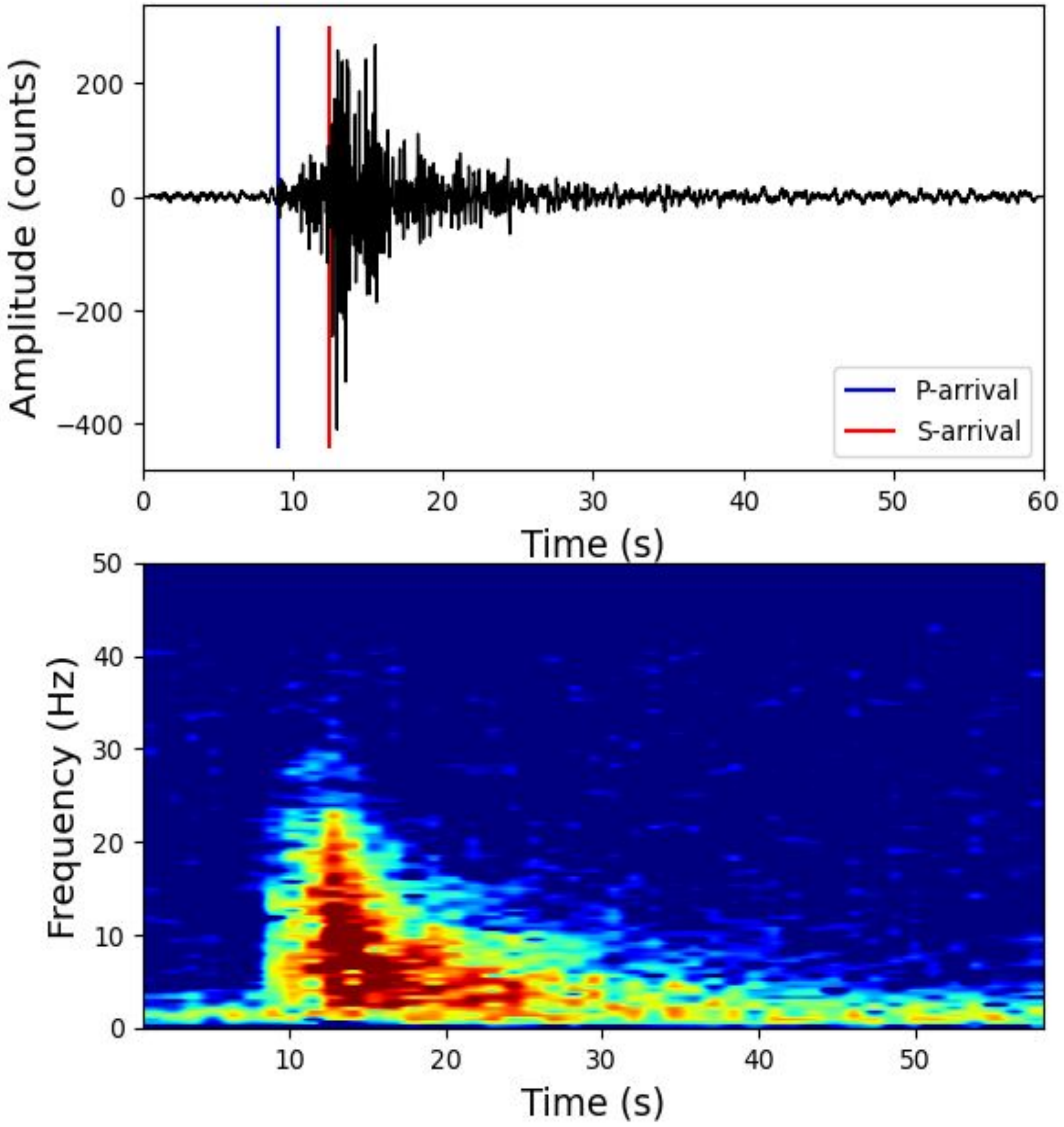
- Potential for faster or more reliable earthquake detection, as current methods typically depend on non-learning algorithms

Data

100,000 global seismic signals from the STanford EArthquake Dataset (STEAD), plus metadata

- 34 features
- ~40% noise signals
- ~60% earthquake signals
- Each signal is 60 seconds

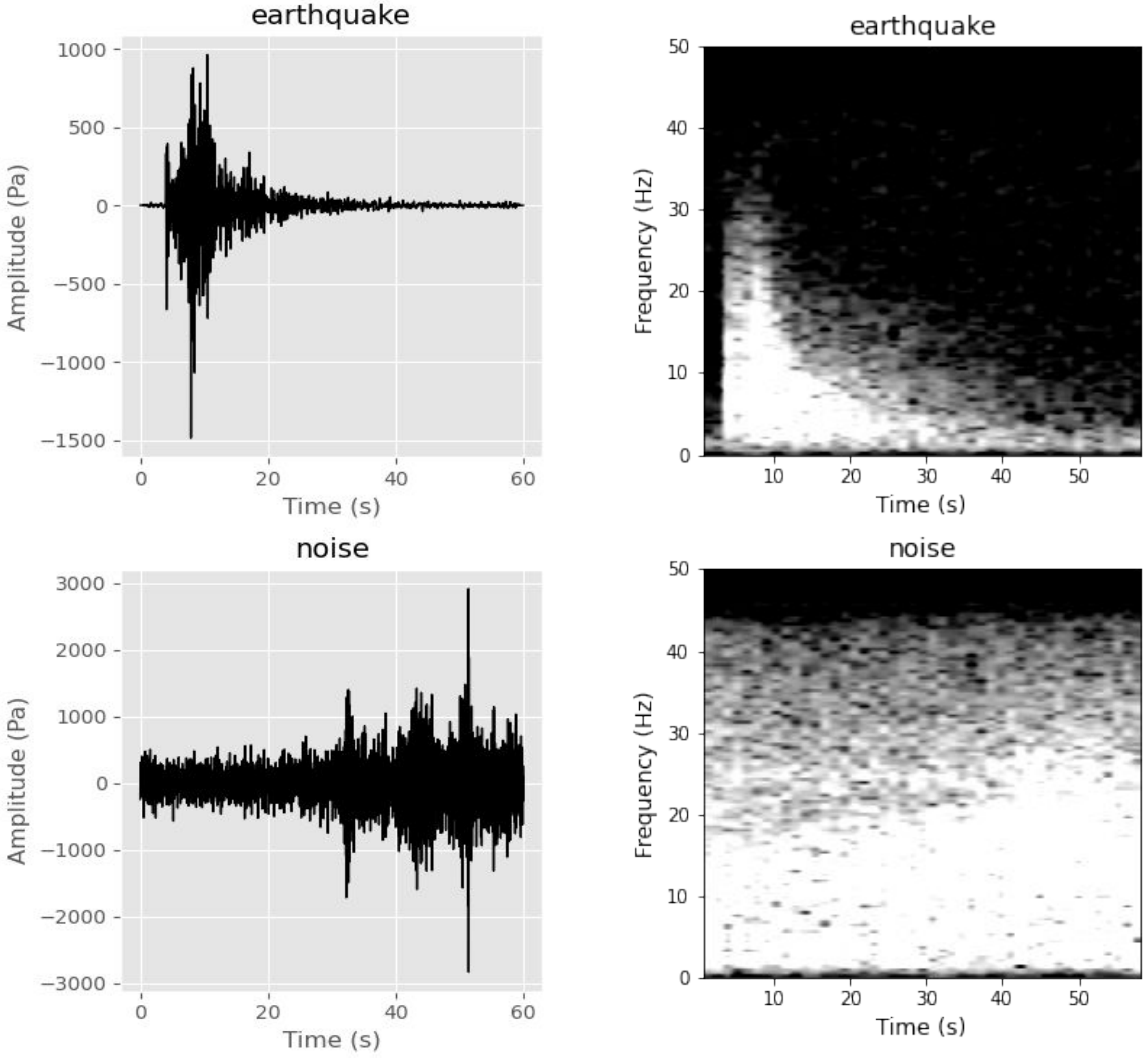
Example Earthquake Waveform & Spectrogram



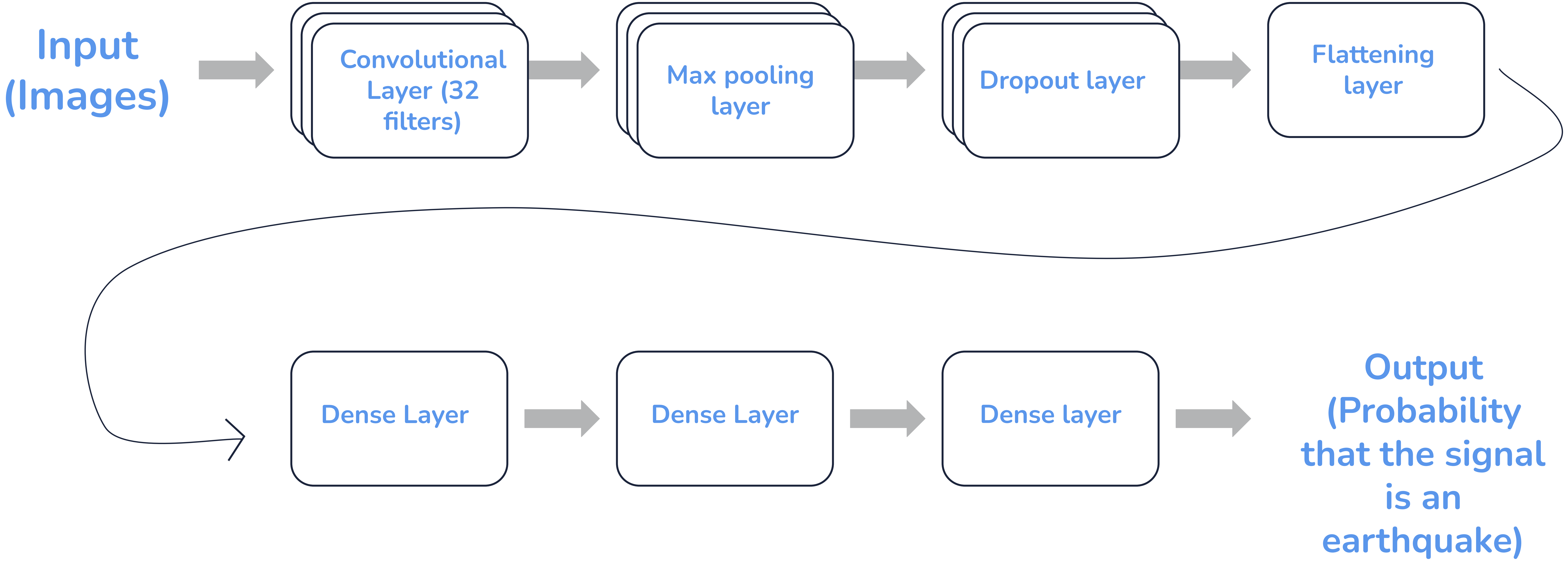
Methods: CNN

- Models trained/tested on spectrograms or waveform figures depending on target
- Used classification CNN model for predicting earthquakes, regression CNN for other targets, each with one convolutional layer

Example Waveforms & Spectrograms



Classification CNN Architecture



Input (Images)

Convolutional Layer (32 filters)

Max pooling layer

Dropout layer

Flattening layer

Dense Layer

Dense Layer

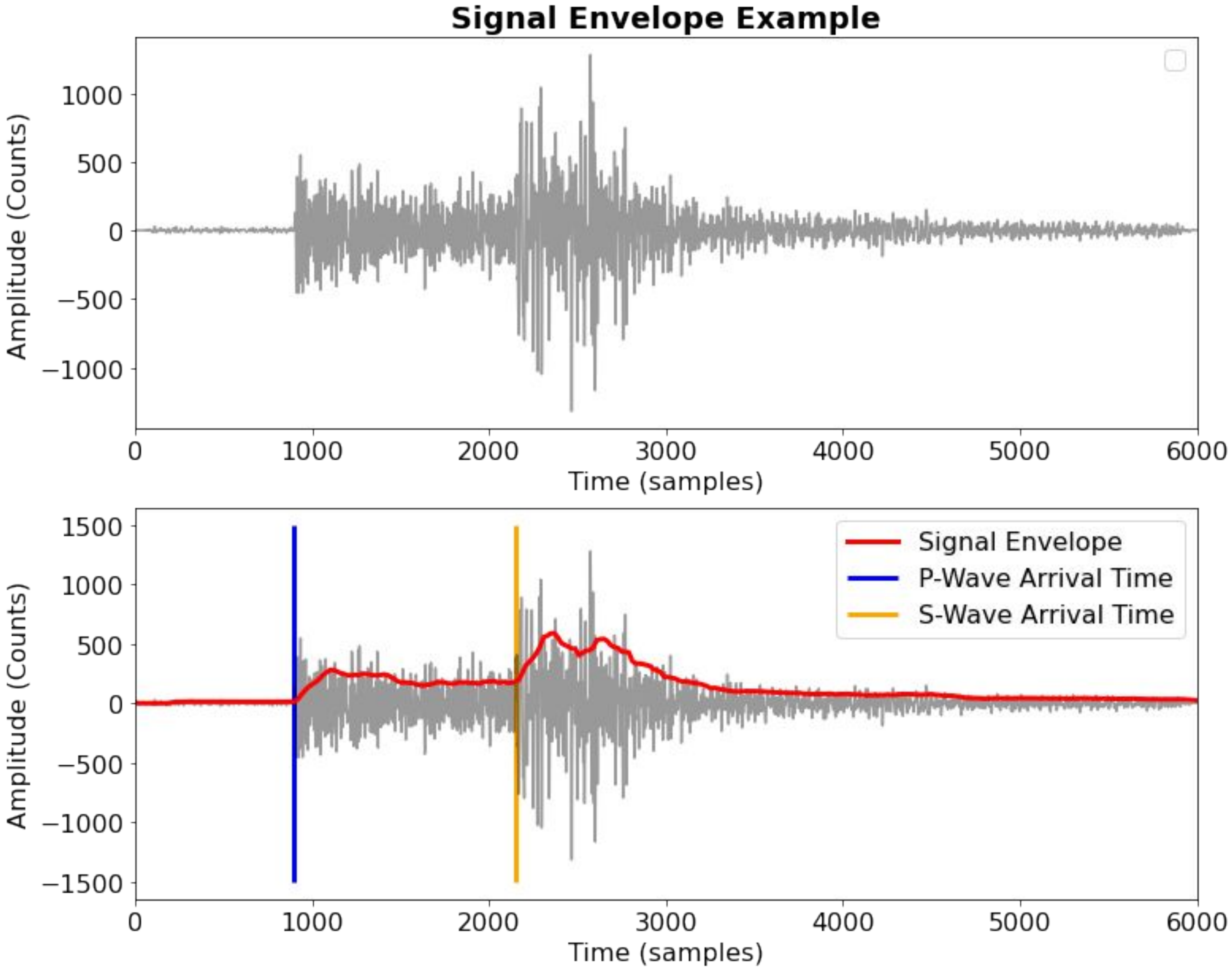
Dense layer

Output (Probability that the signal is an earthquake)

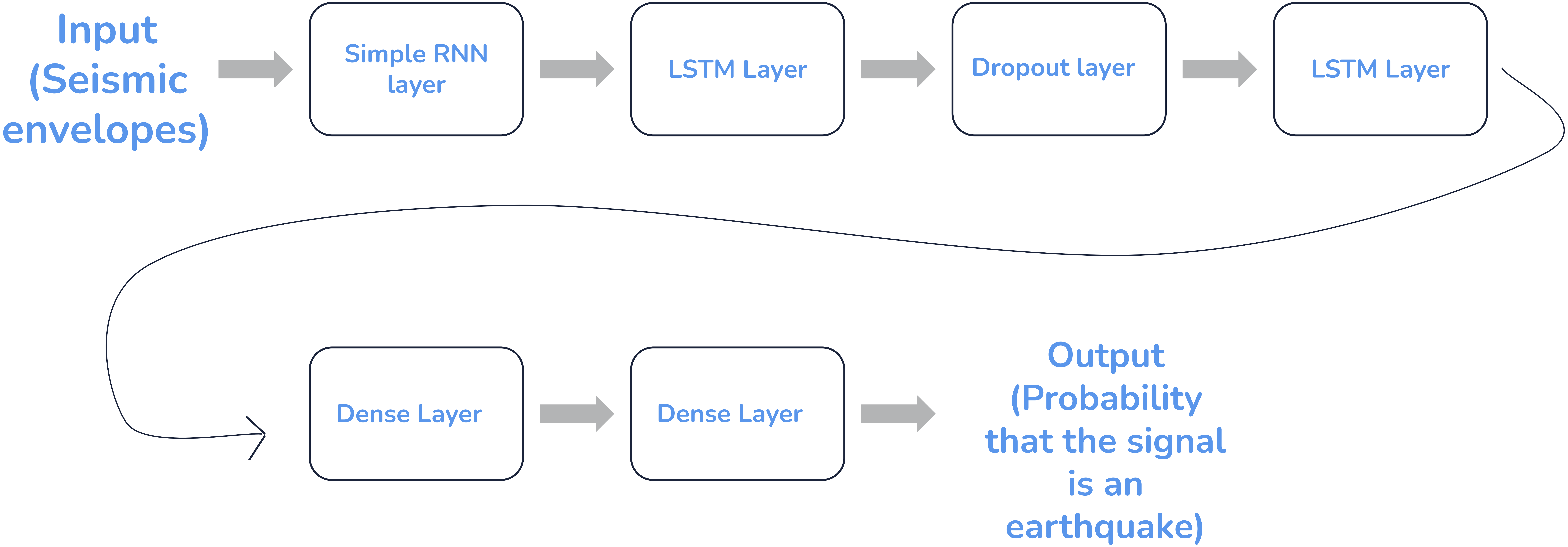
Methods: LSTM

- Built an LSTM model to use the time-series signal data, to see if I could remove the need to generate images as needed for the CNN

- Models trained/tested on seismic envelopes (time-series), each with 2 LSTM layers



Classification LSTM Architecture



Input (Seismic envelopes)

Simple RNN layer

LSTM Layer

Dropout layer

LSTM Layer

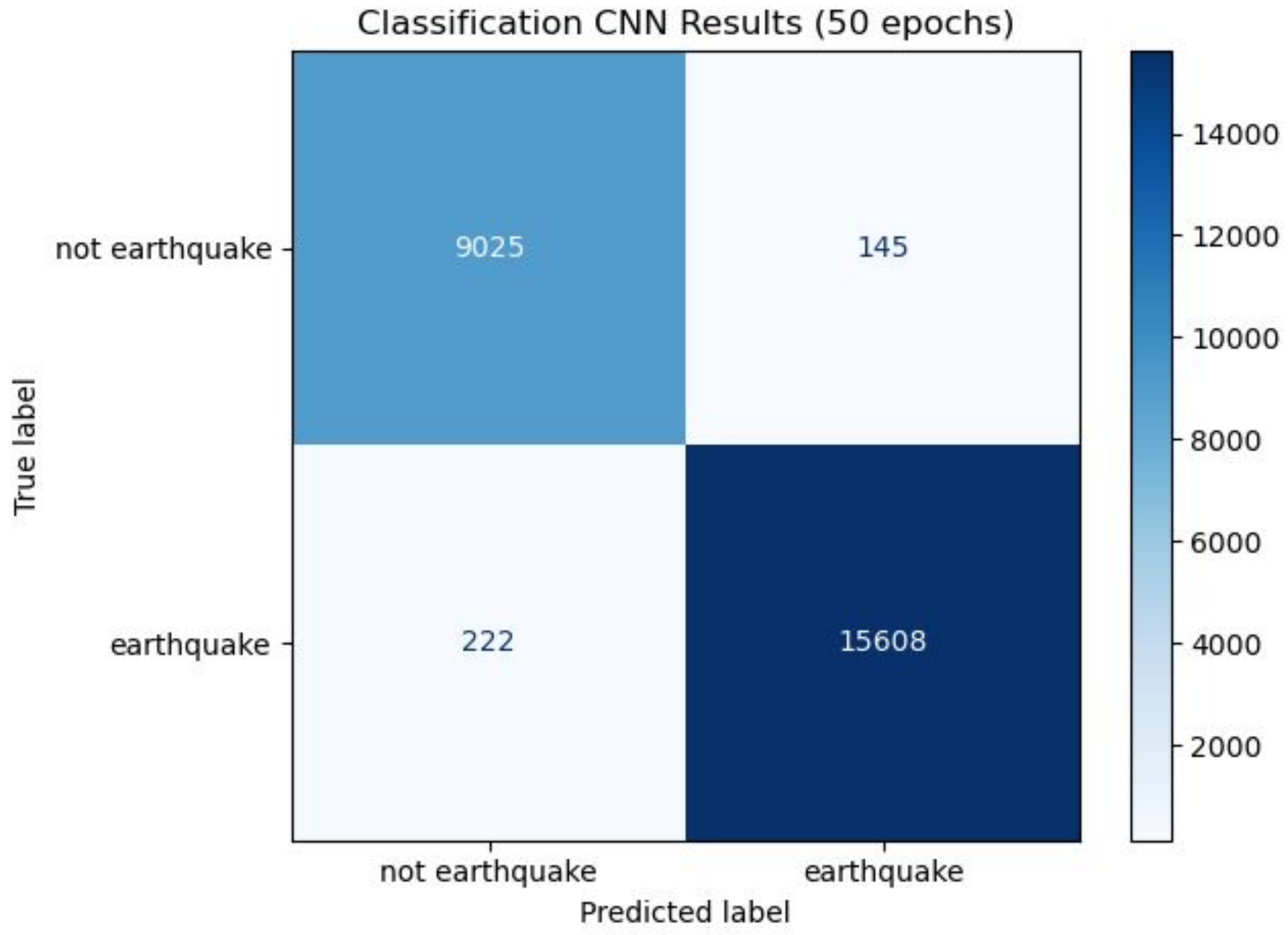
Dense Layer

Dense Layer

Output (Probability that the signal is an earthquake)

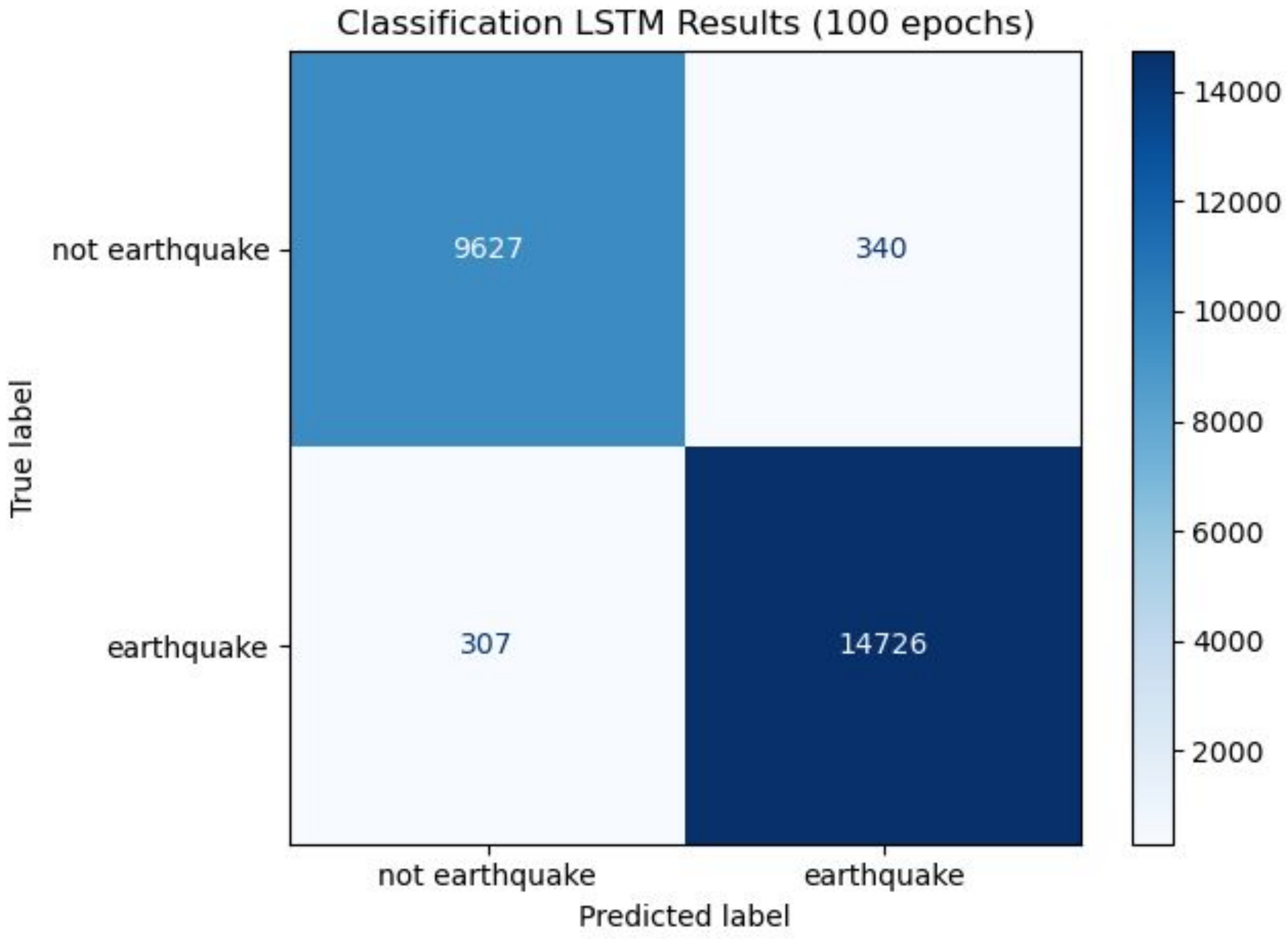
Results: Classifying Signals as ‘Earthquake’ or ‘noise’

CNN



Accuracy: 0.98532
Precision: 0.99080
Recall: 0.98598

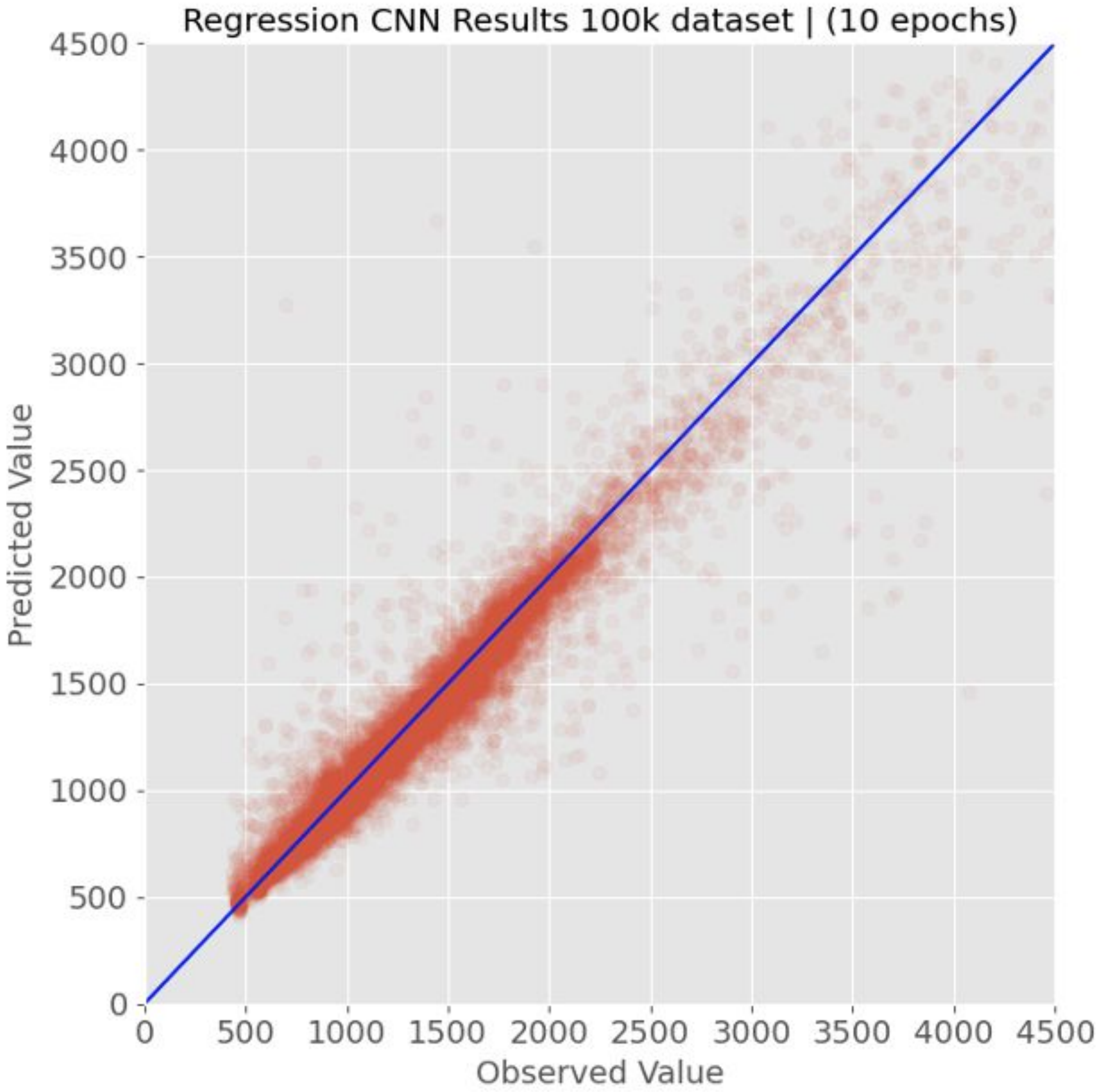
LSTM



Accuracy: 0.97412
Precision: 0.97743
Recall: 0.97958

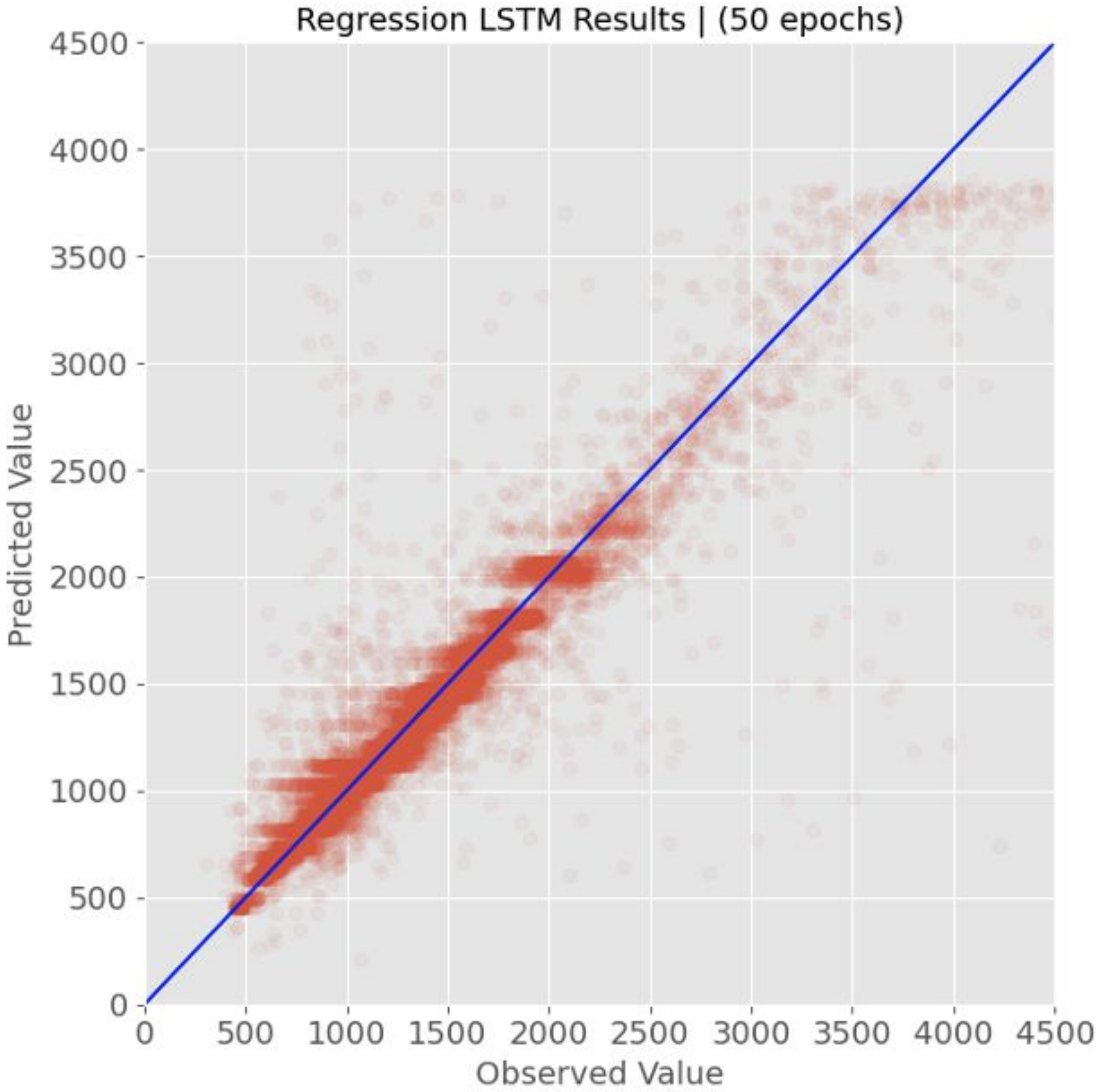
Results: S-Wave Arrival Time Prediction

CNN



MSE: 25648.9

LSTM



MSE: 42508.6

CNN vs. LSTM Comparison

	Classifier (Accuracy)	Magnitude (MSE)	P-Wave (MSE)	S-Wave (MSE)	Pre-Processing Time
Baseline	0.52164	0.95674	30772.7	366620.9	
Best CNN model	0.98532	0.15895	1216.2	25648.9	0.00761 s
Best LSTM model	0.97412	0.38736	3212.2	42508.5	0.05056 s

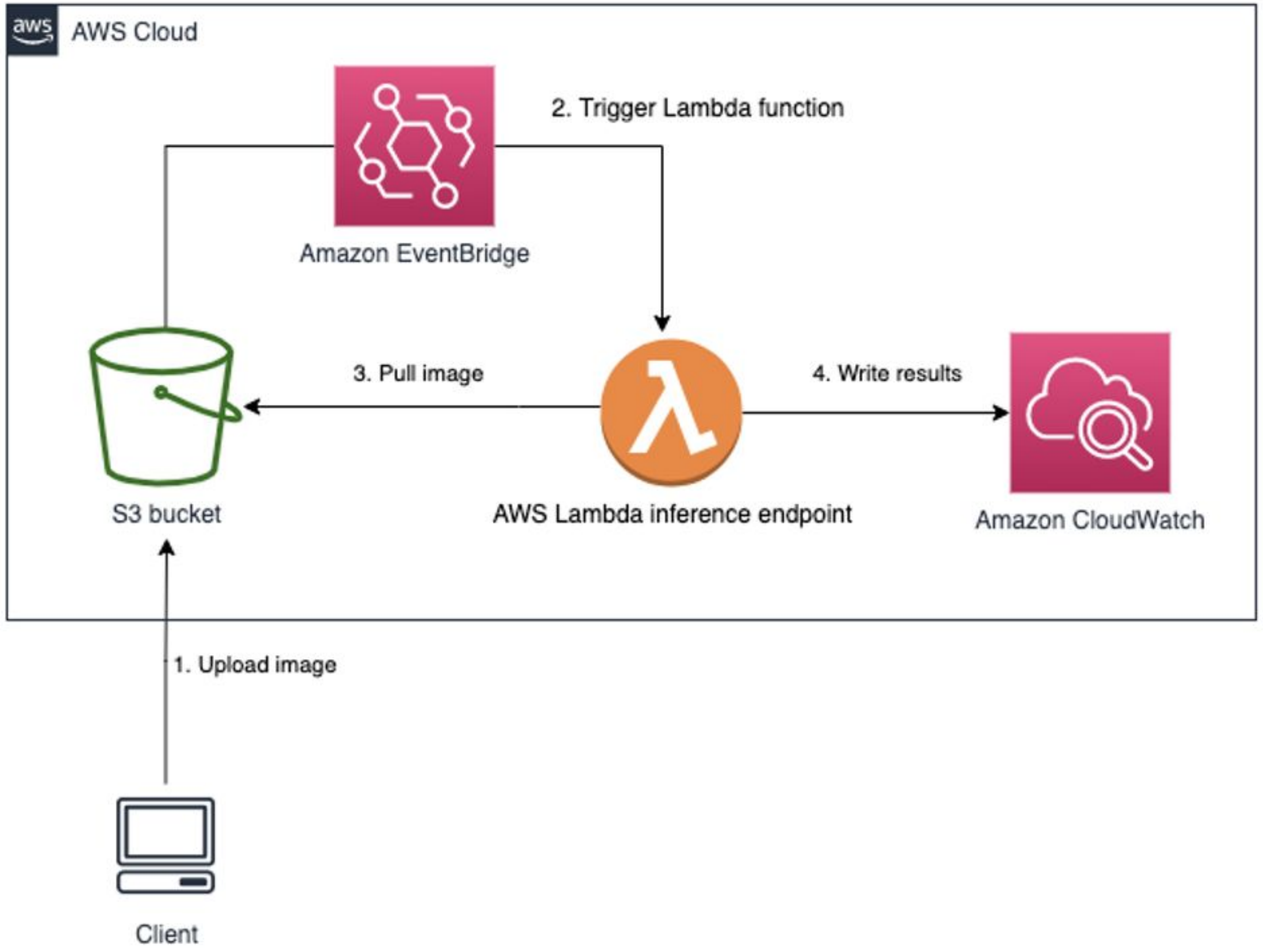
Deploying the Best Model

Model deployment method:

1.Containerized model using Docker

2.Created s3 bucket to store images

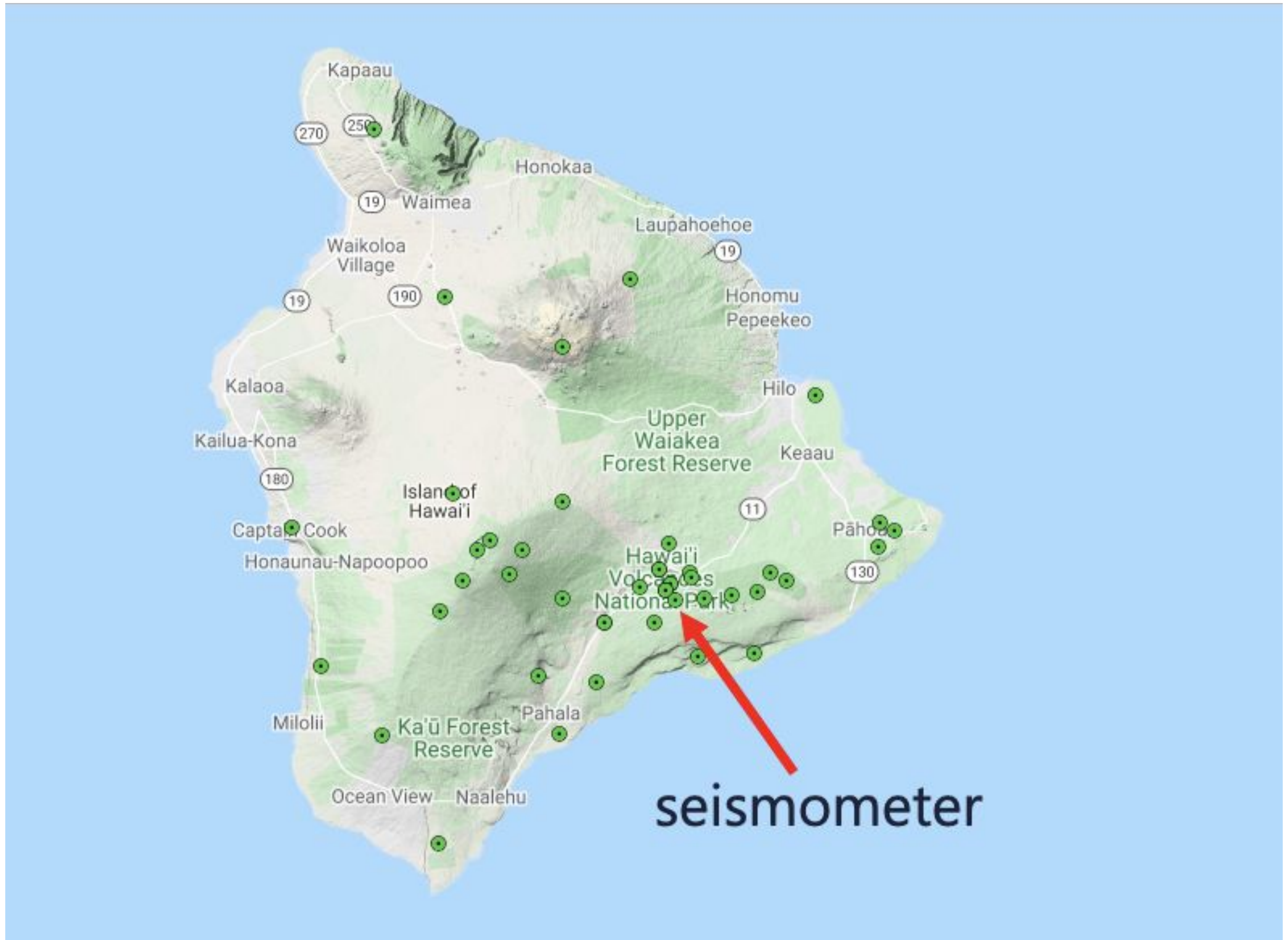
3. Deploy Docker image as AWS Lambda function



Real-Time Prediction

To make predictions in real time:

- Built a pipeline to stream live data from a seismometer on Kilauea, Hawaii because the volcano produces a lot of earthquakes
- Create an image every ~15 seconds, send to S3 bucket
- S3 bucket triggers the Lambda function, runs the model and predicts image class
- Compare model predictions to USGS public website



seismometer

Real-Time Prediction

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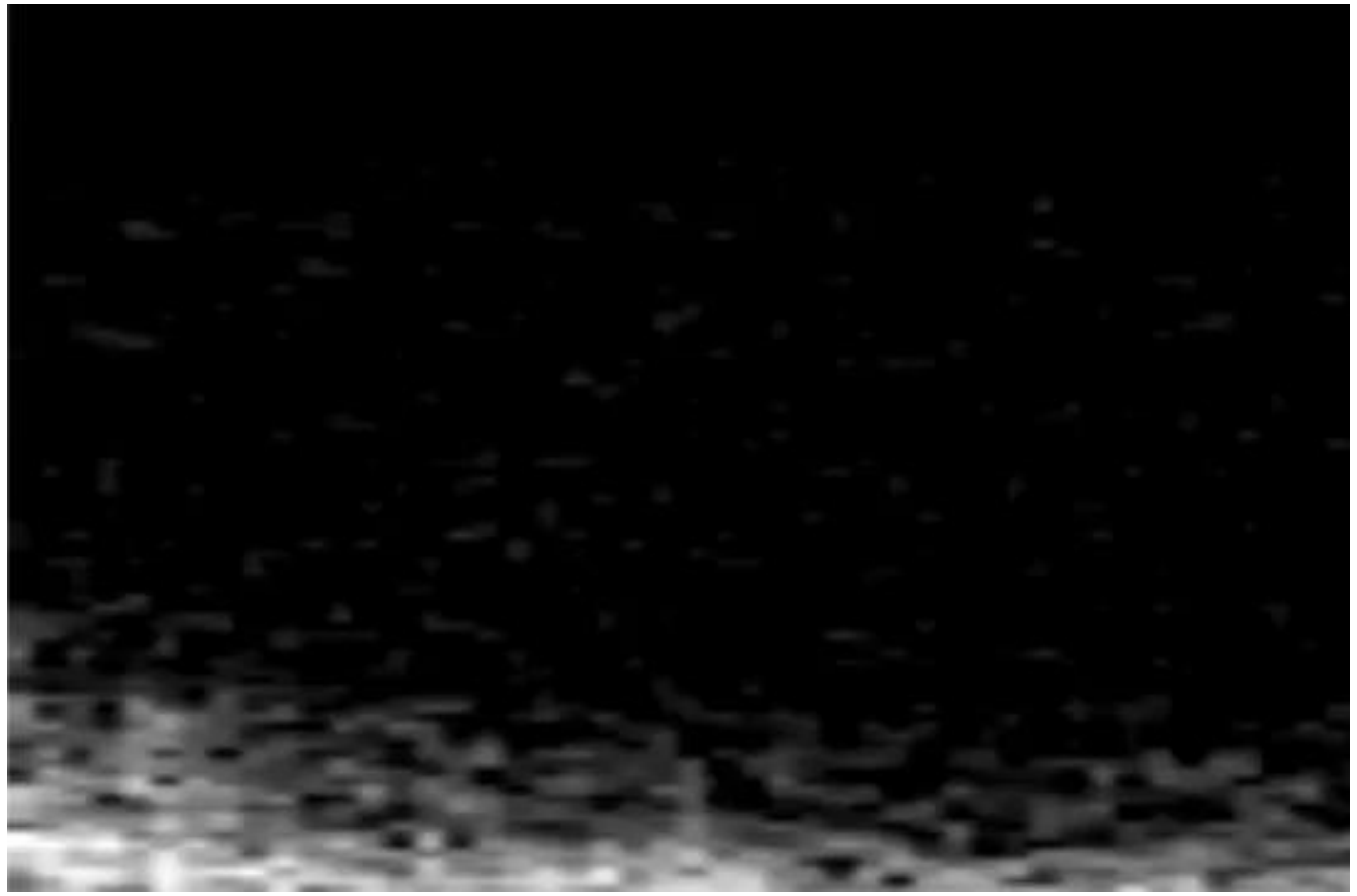
- S3 bucket triggers the Lambda function, runs the model and predicts image class
- Compare model predictions to USGS public website

Network: HV | Station: AHUD | Channel: EHZ



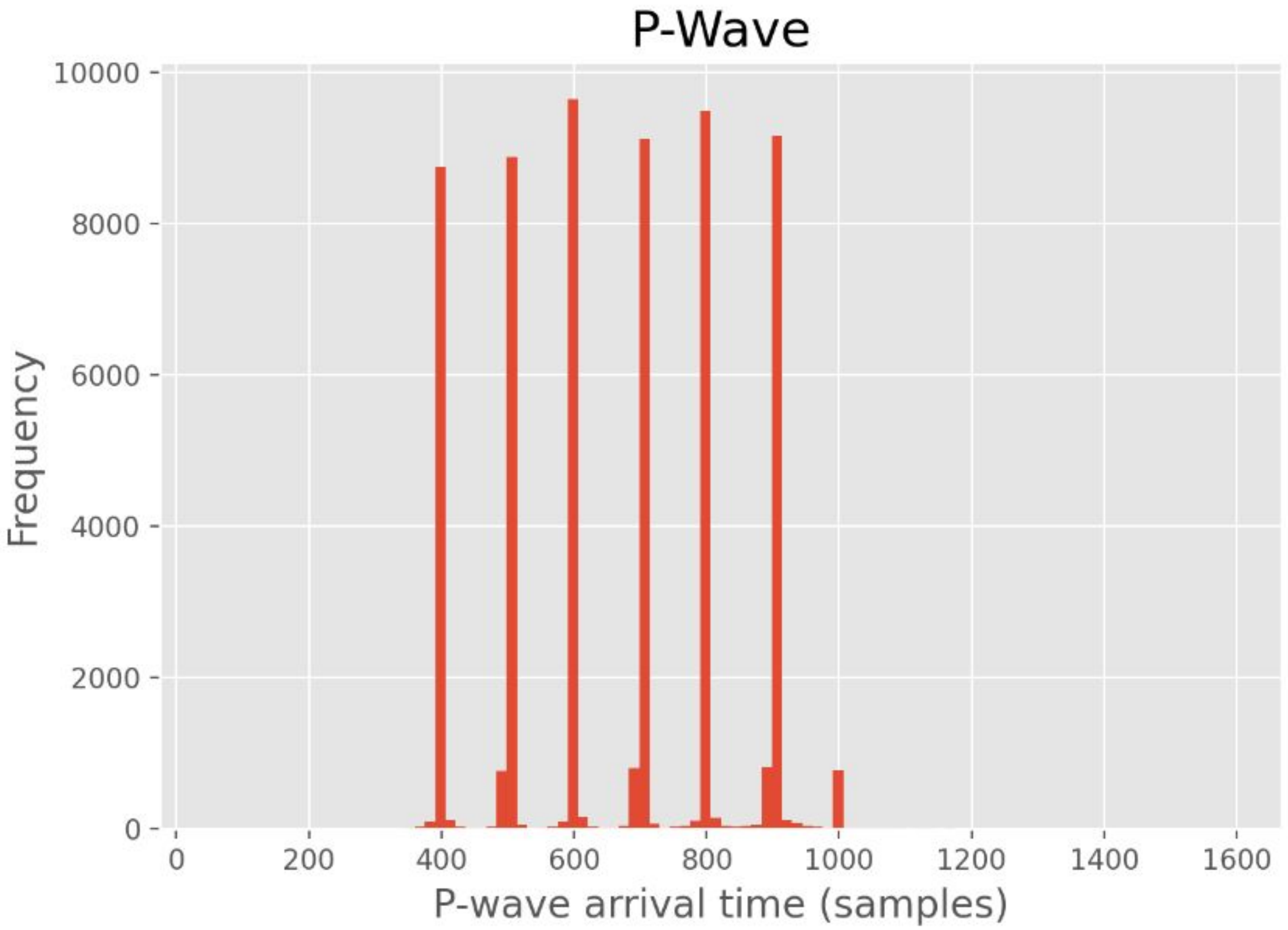
AWS Lambda Demo

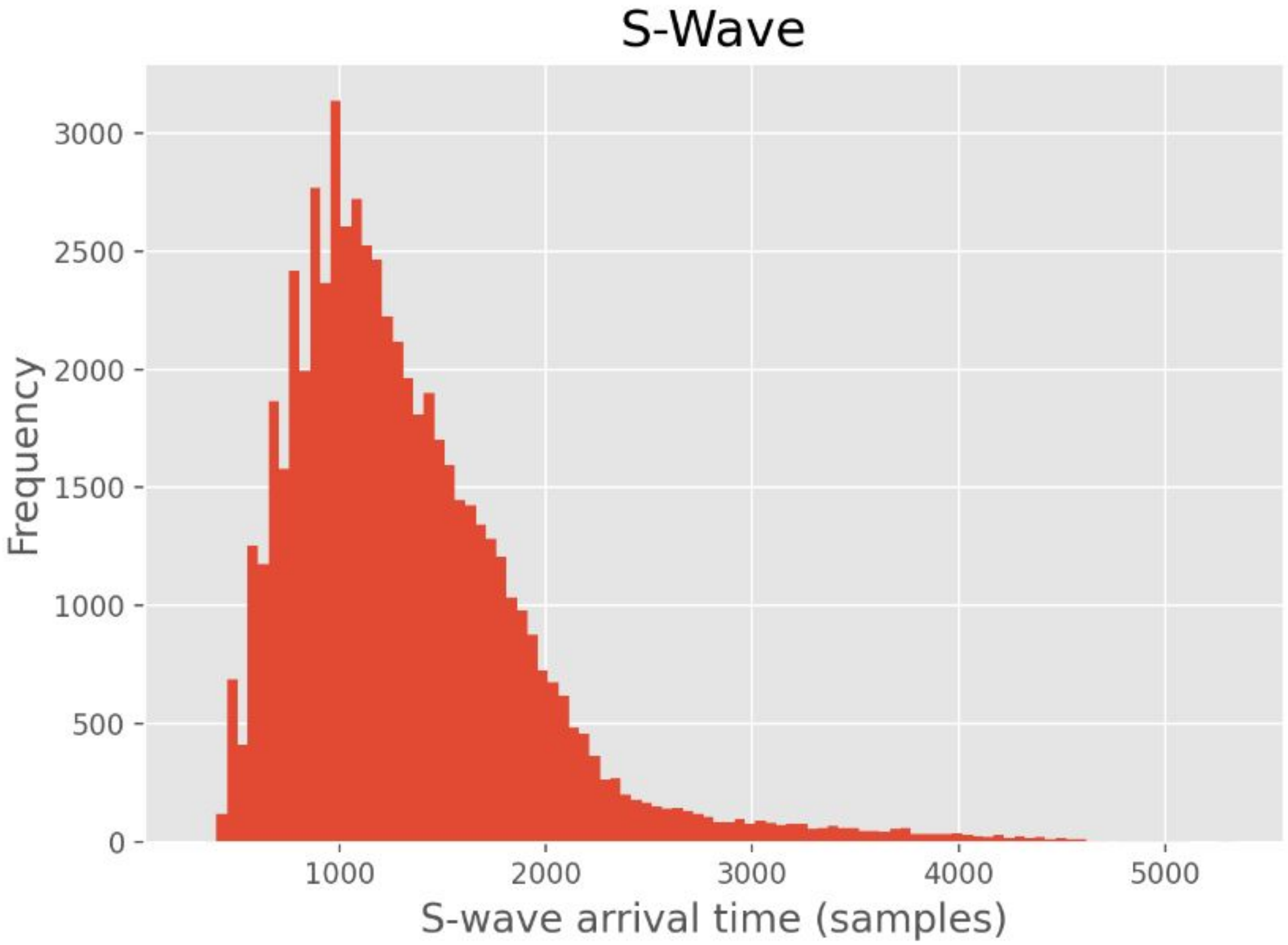
Thanks!

Any questions?

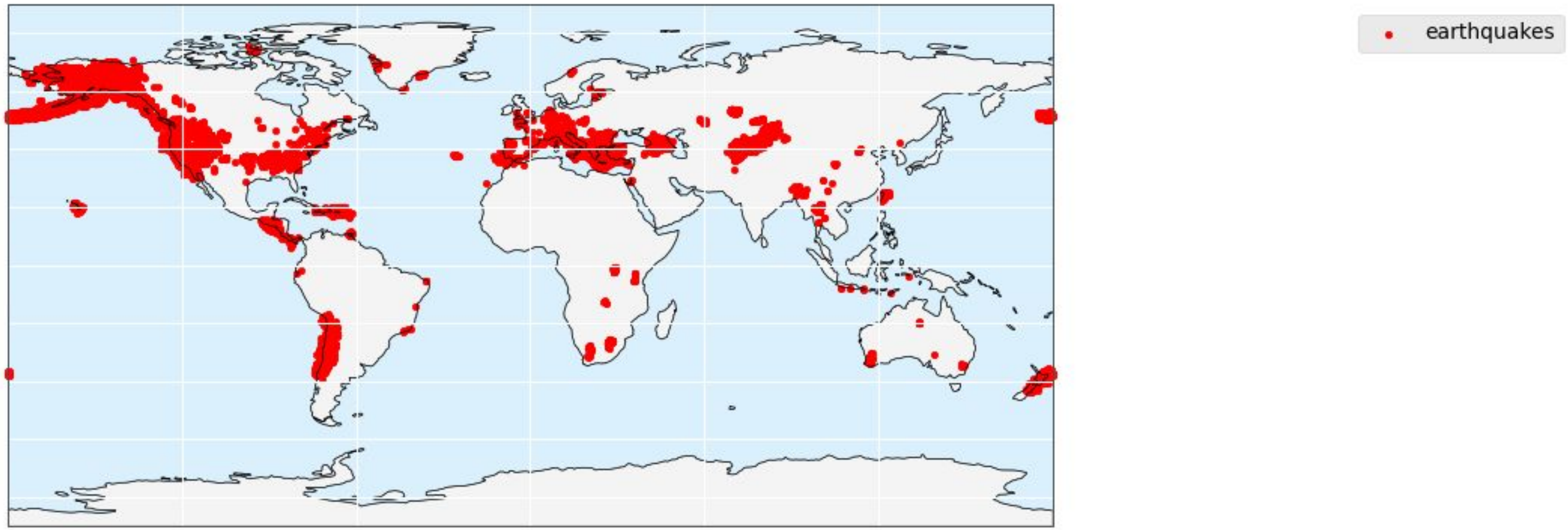
Appendices

More EDA


P-Wave
Frequency
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
1200
1400
1600
P-wave arrival time (samples)

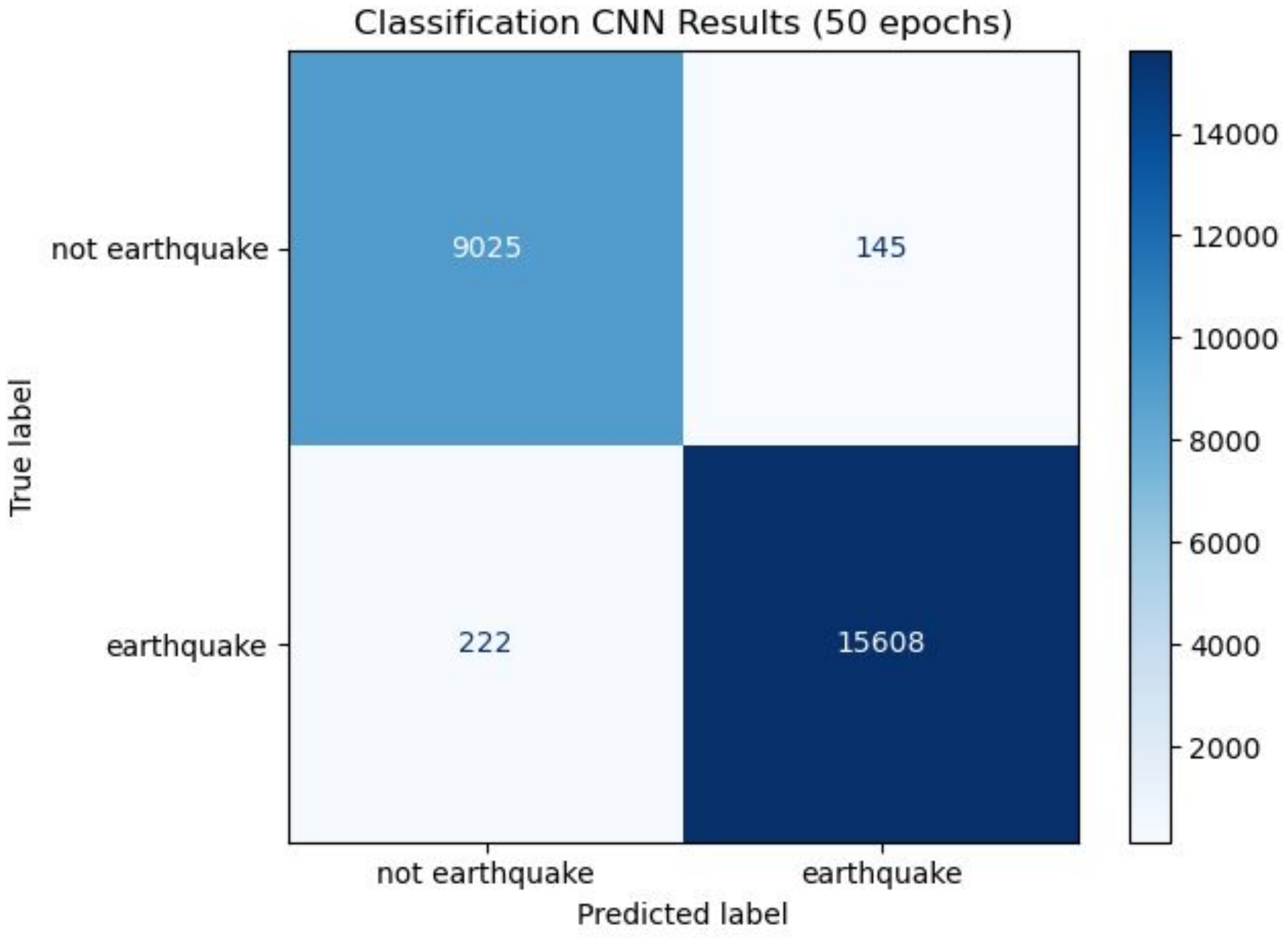

S-Wave
Frequency
3000
2500
2000
1500
1000
500
0
1000
2000
3000
4000
5000
S-wave arrival time (samples)

More EDA

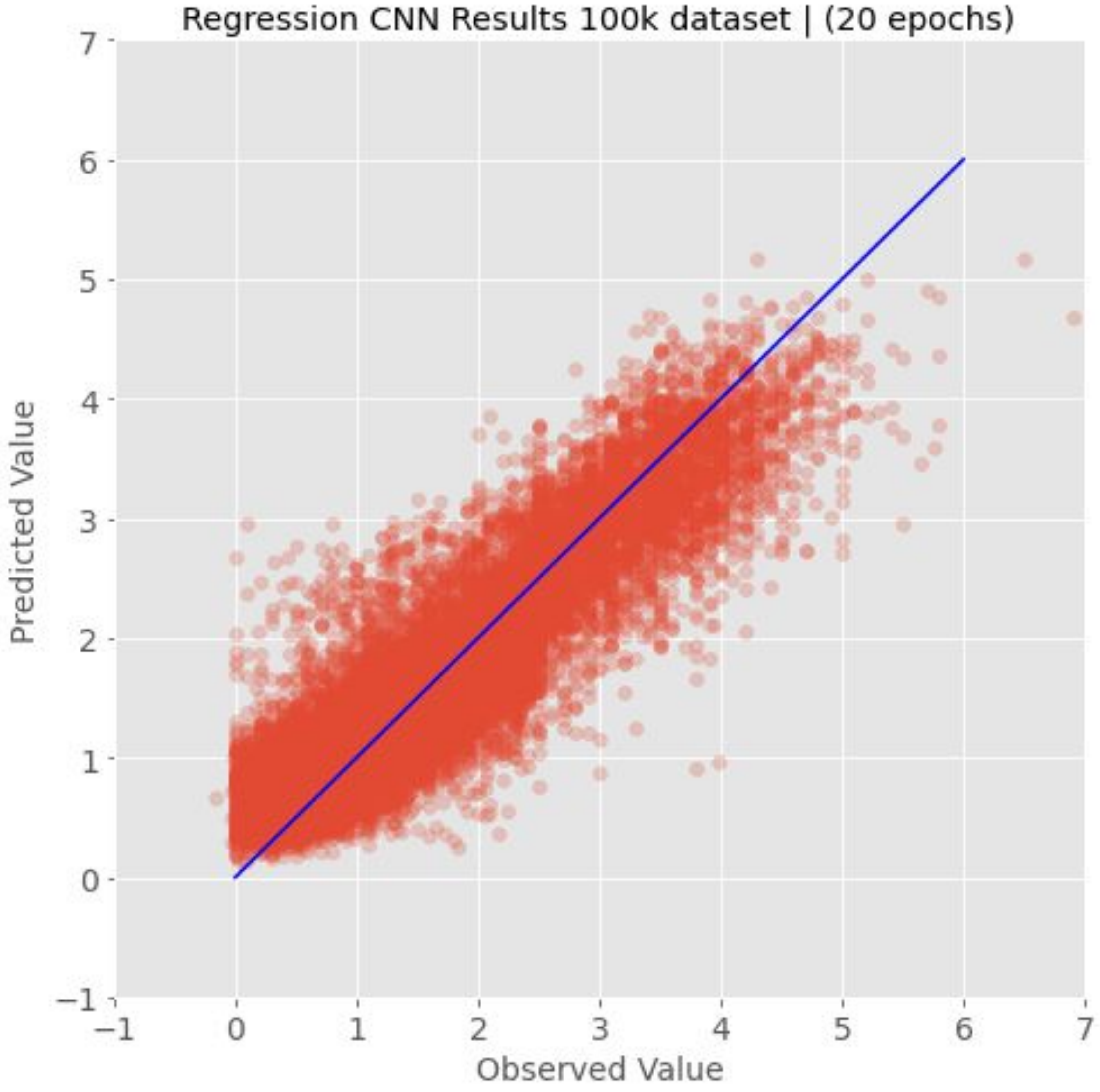


CNN Results

Class Prediction

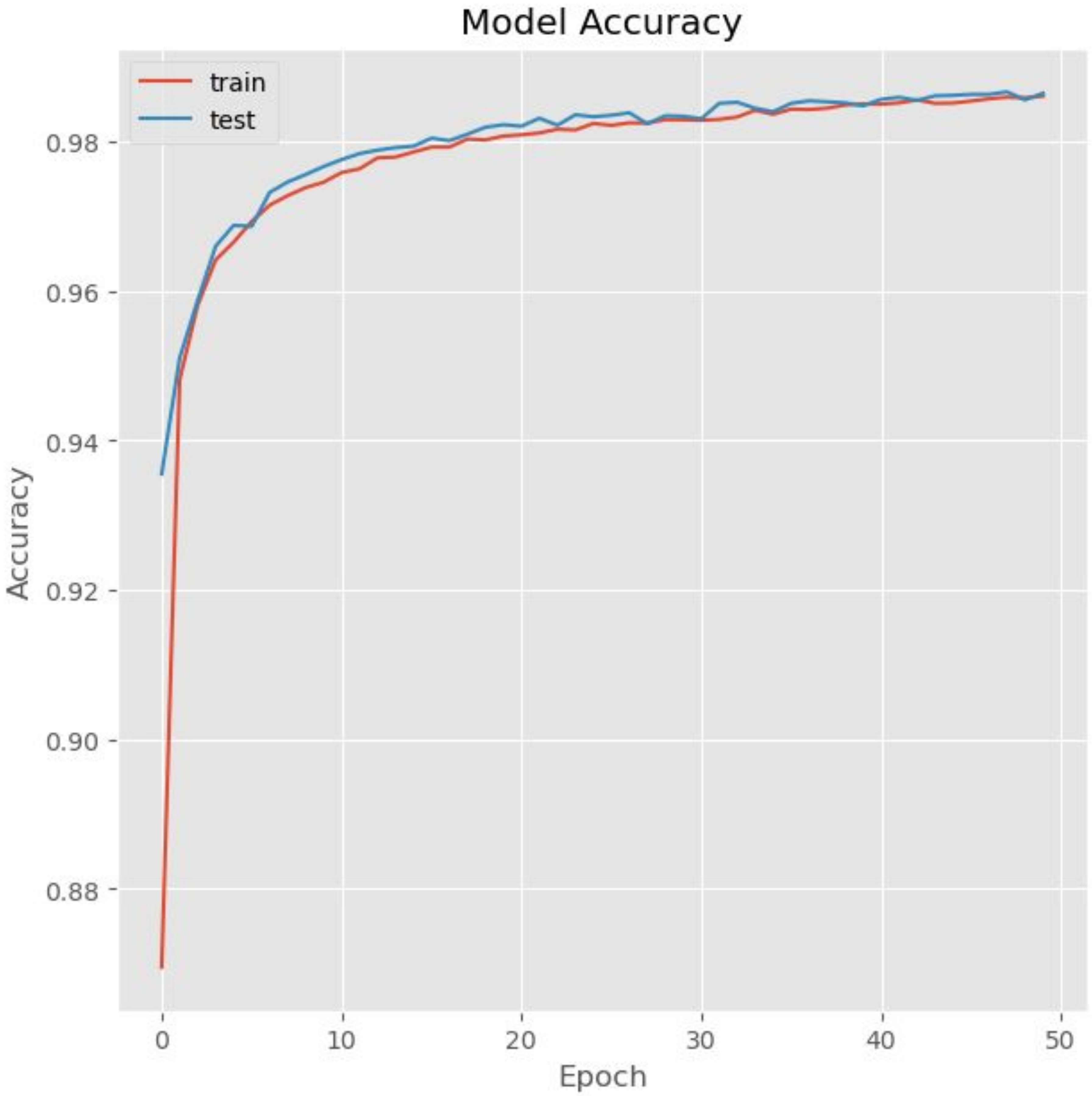


Magnitude Prediction

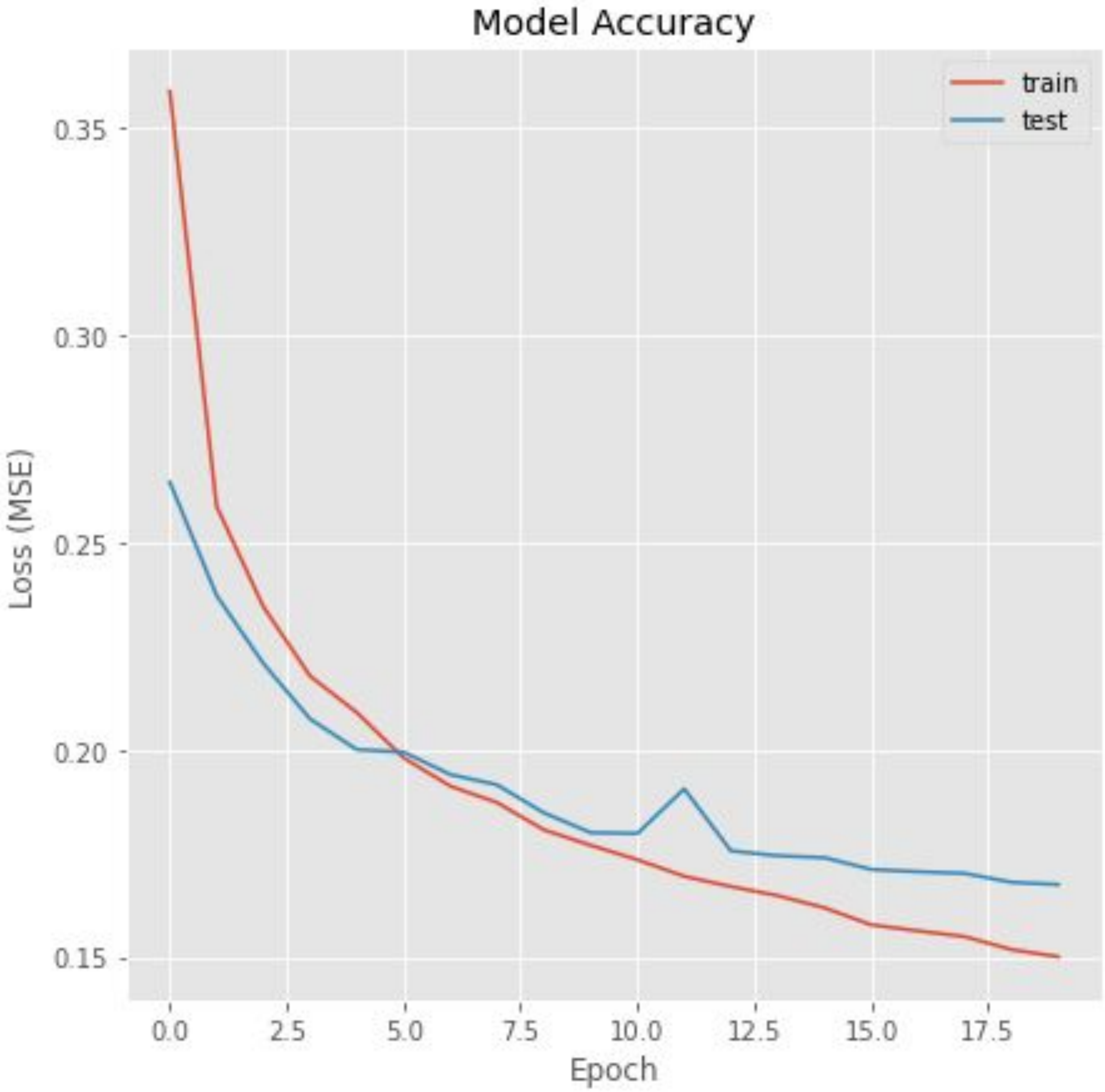


CNN Results

Class Prediction

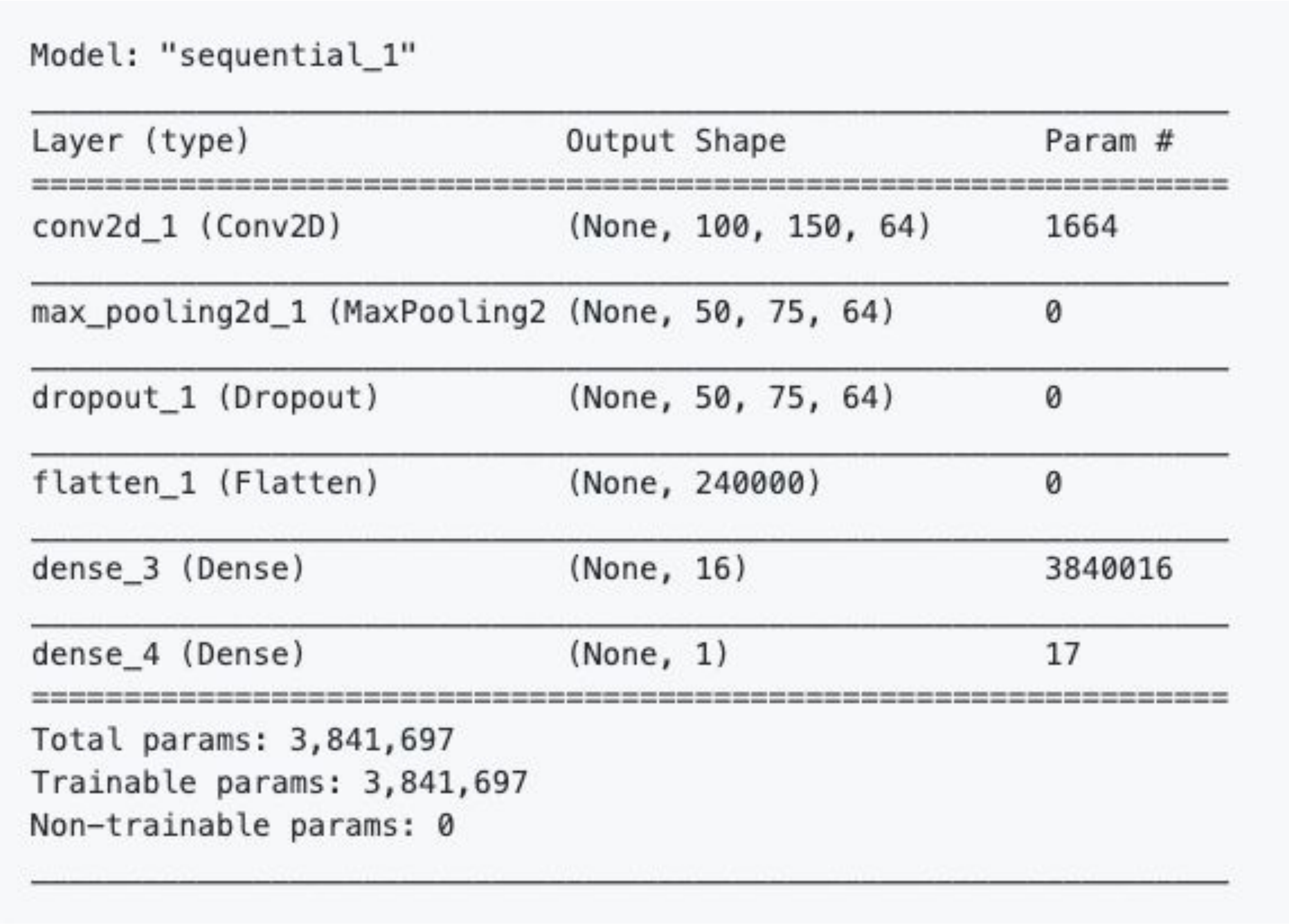


Magnitude Prediction



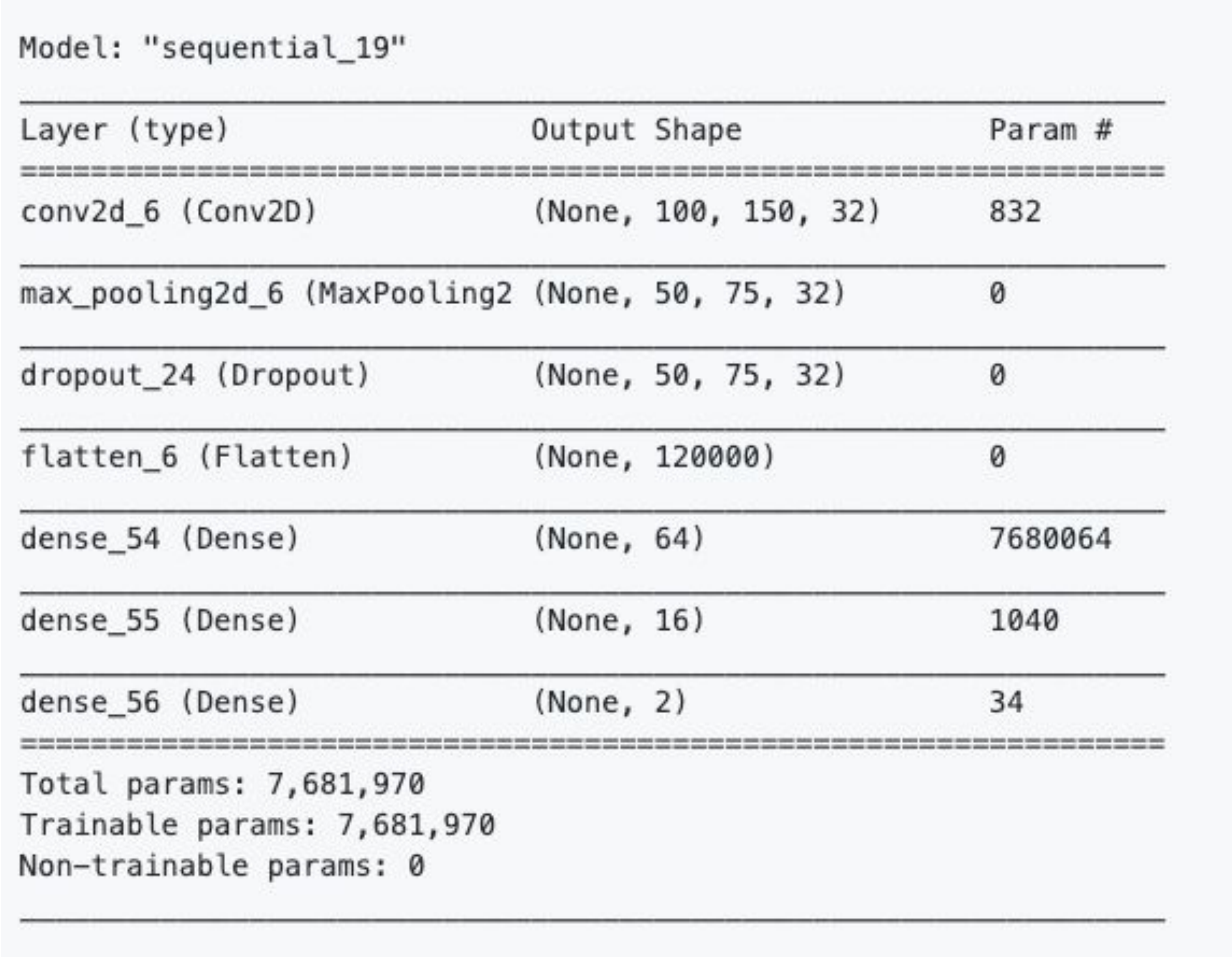
CNN Results

Class Prediction



```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 100, 150, 64)      1664
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 50, 75, 64)        0
_________________________________________________________________
dropout_1 (Dropout)          (None, 50, 75, 64)        0
_________________________________________________________________
flatten_1 (Flatten)          (None, 240000)            0
_________________________________________________________________
dense_3 (Dense)              (None, 16)                3840016
_________________________________________________________________
dense_4 (Dense)              (None, 1)                 17
=================================================================
Total params: 3,841,697
Trainable params: 3,841,697
Non-trainable params: 0
_________________________________________________________________
```

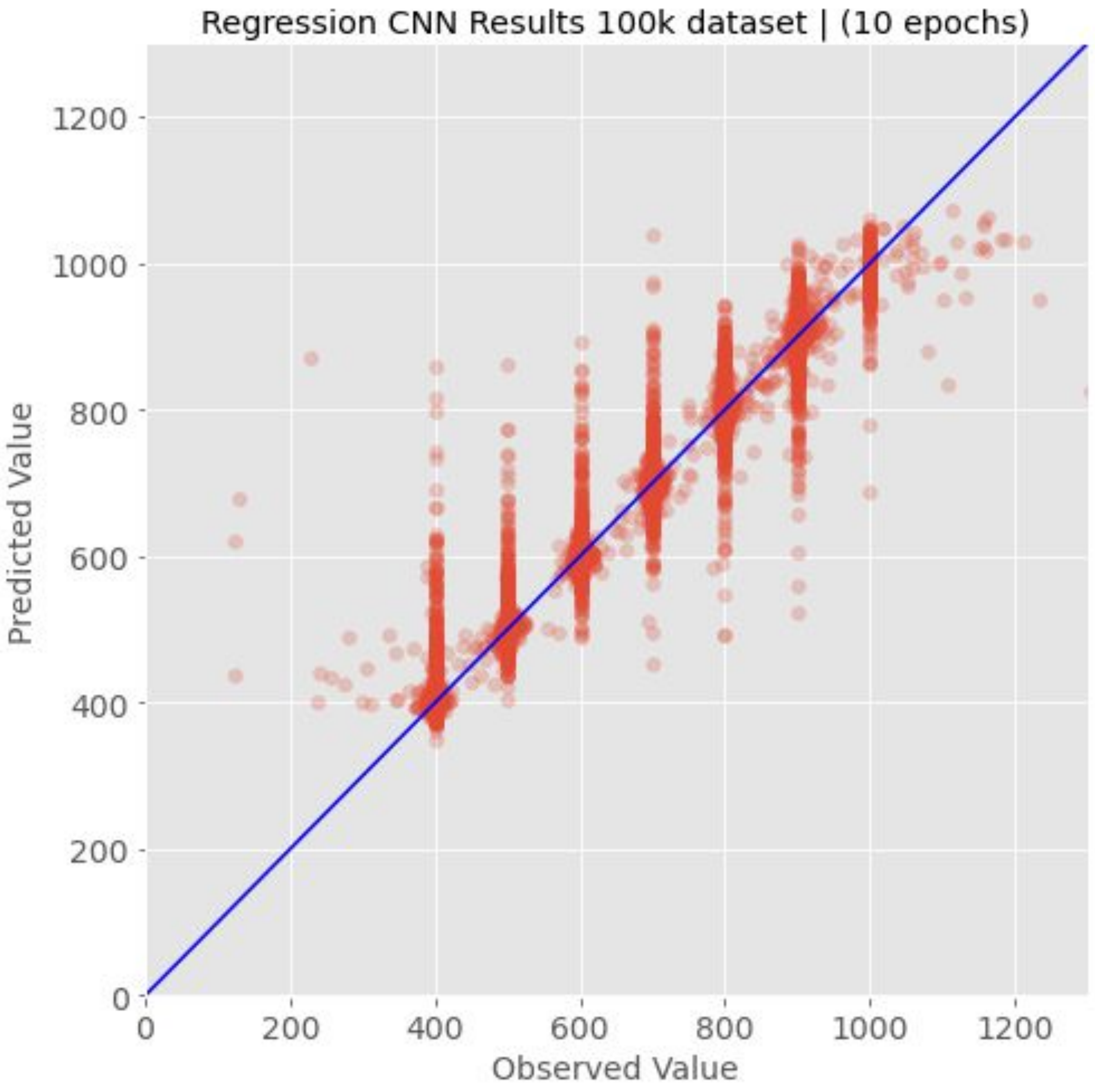
Magnitude Prediction



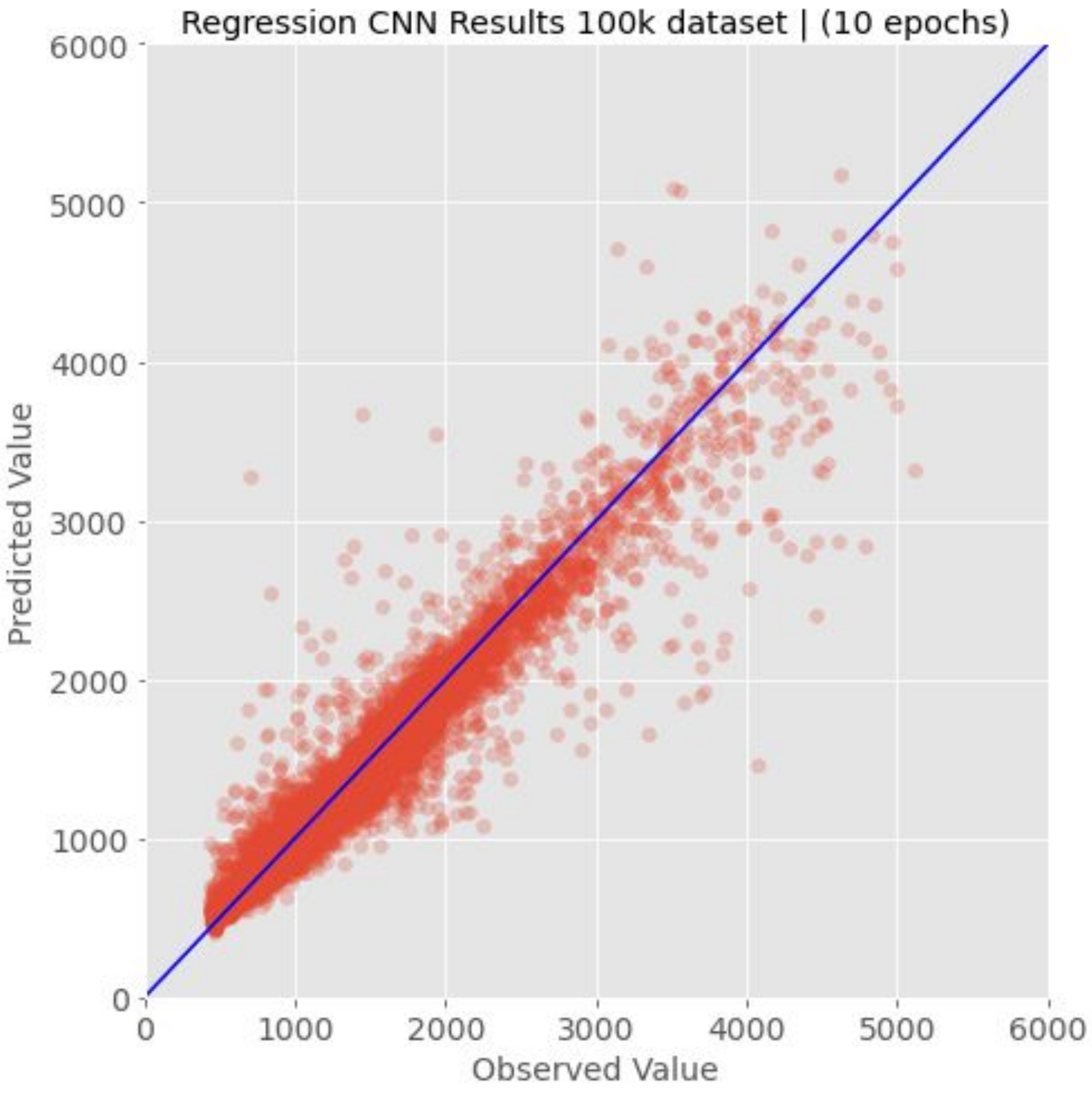
```
Model: "sequential_19"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_6 (Conv2D)            (None, 100, 150, 32)      832
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 50, 75, 32)        0
_________________________________________________________________
dropout_24 (Dropout)         (None, 50, 75, 32)        0
_________________________________________________________________
flatten_6 (Flatten)          (None, 120000)            0
_________________________________________________________________
dense_54 (Dense)             (None, 64)                7680064
_________________________________________________________________
dense_55 (Dense)             (None, 16)                1040
_________________________________________________________________
dense_56 (Dense)             (None, 2)                 34
=================================================================
Total params: 7,681,970
Trainable params: 7,681,970
Non-trainable params: 0
_________________________________________________________________
```

CNN Results

P-Wave Prediction

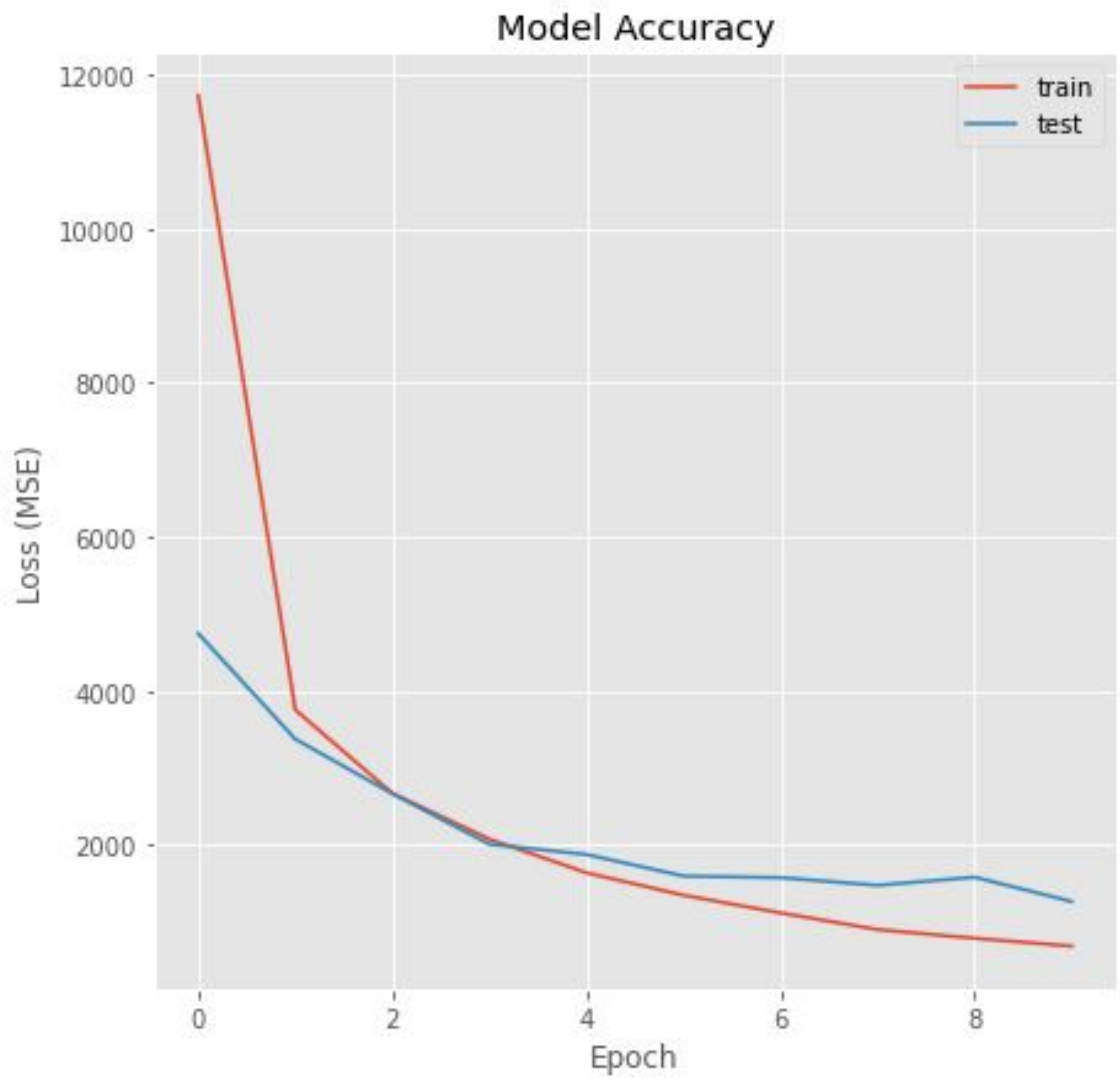


S-Wave Prediction

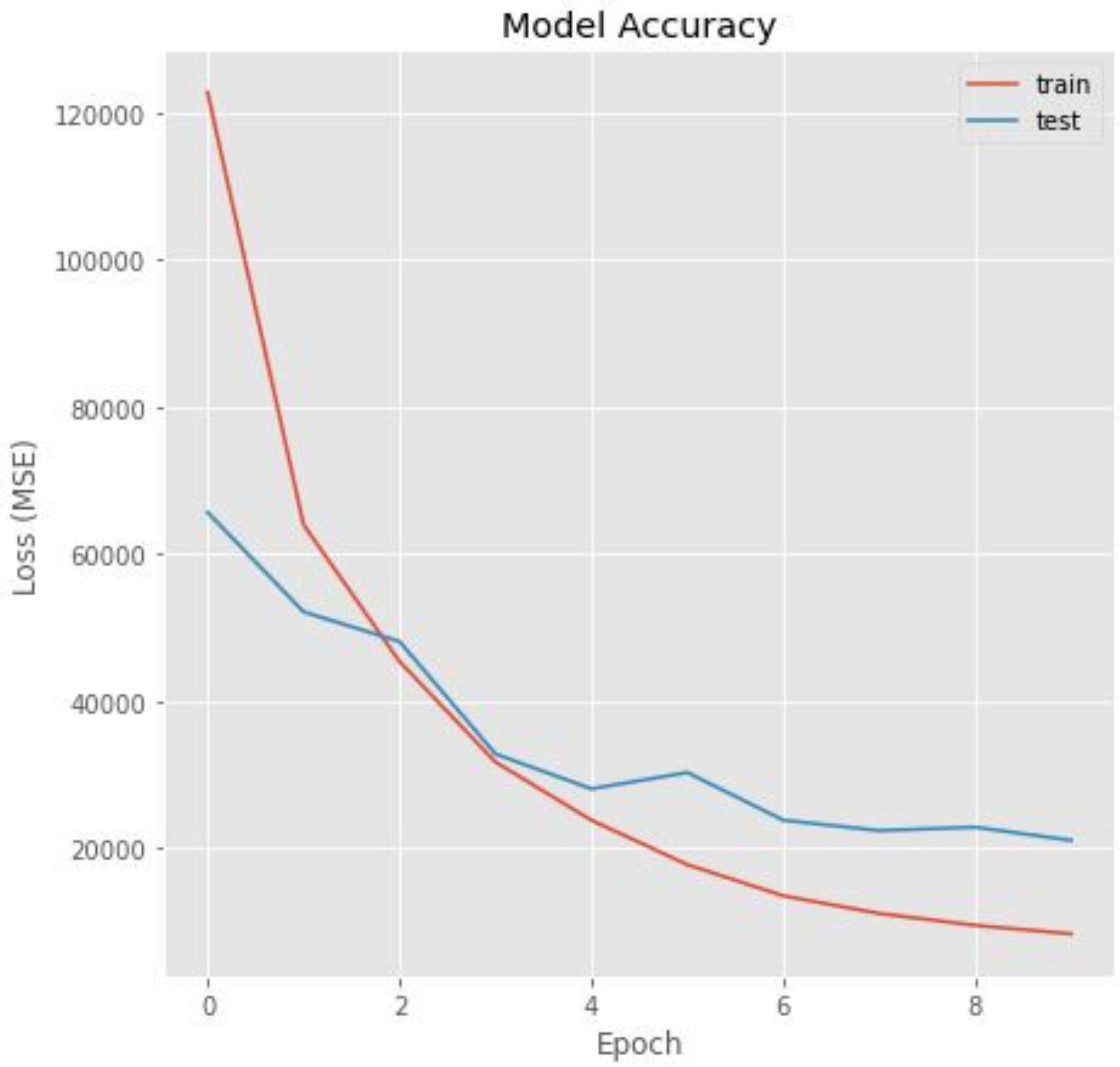


CNN Results

P-Wave Prediction



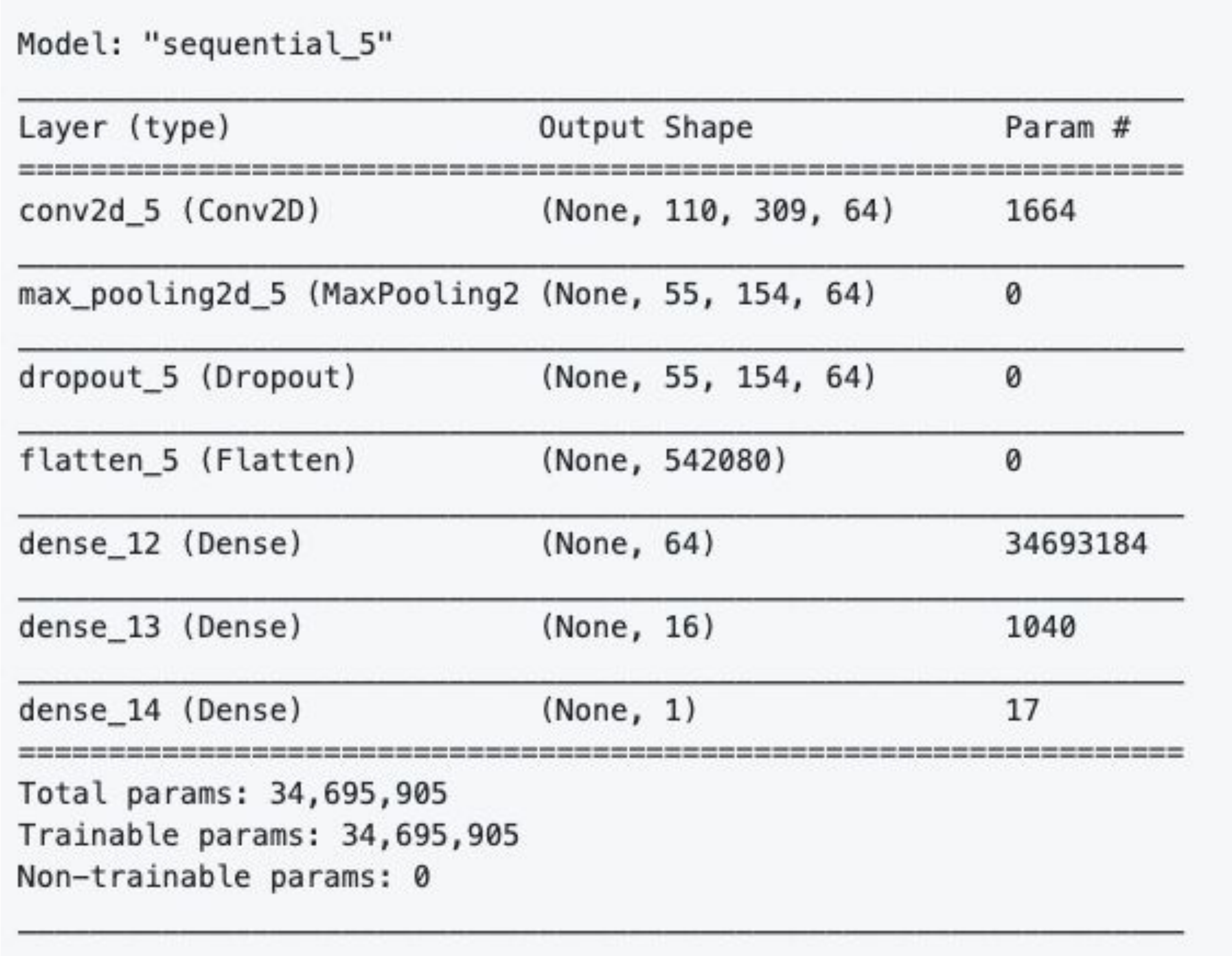
S-Wave Prediction



CNN Results

P-Wave Prediction

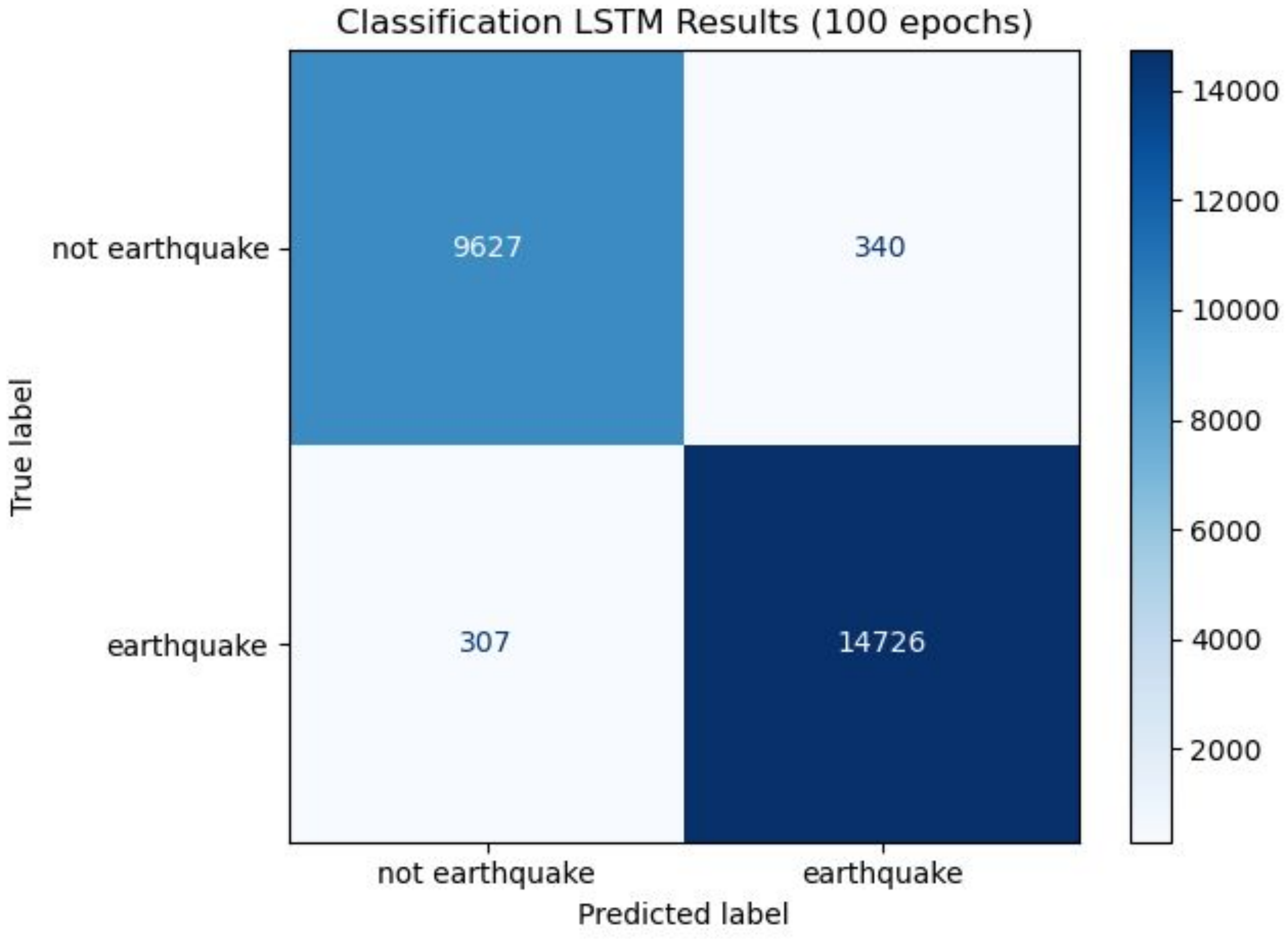
S-Wave Prediction



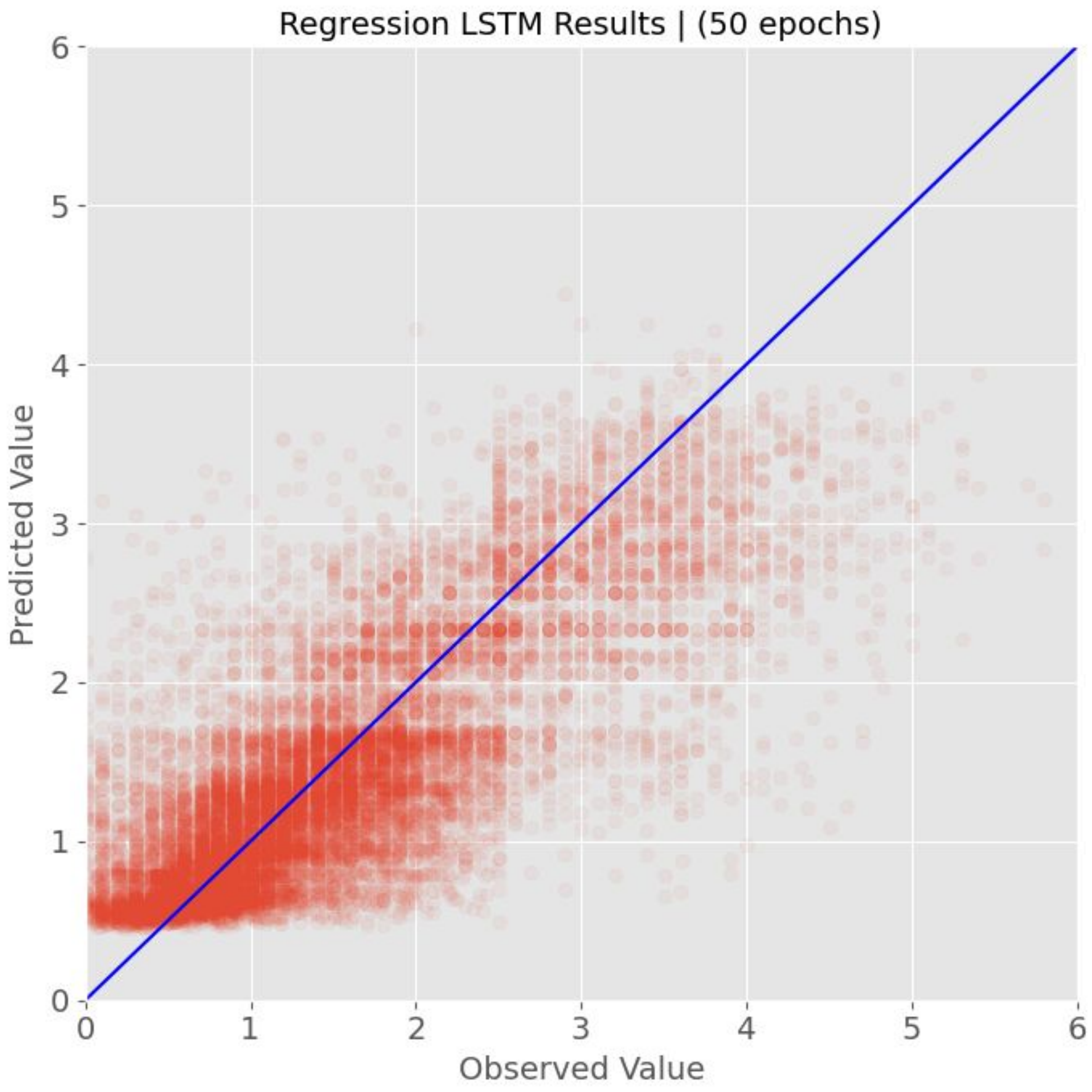
```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_5 (Conv2D)            (None, 110, 309, 64)      1664
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 55, 154, 64)       0
_________________________________________________________________
dropout_5 (Dropout)          (None, 55, 154, 64)       0
_________________________________________________________________
flatten_5 (Flatten)          (None, 542080)            0
_________________________________________________________________
dense_12 (Dense)             (None, 64)                34693184
_________________________________________________________________
dense_13 (Dense)             (None, 16)                1040
_________________________________________________________________
dense_14 (Dense)             (None, 1)                 17
=================================================================
Total params: 34,695,905
Trainable params: 34,695,905
Non-trainable params: 0
_________________________________________________________________
```

LSTM Results

Class Prediction

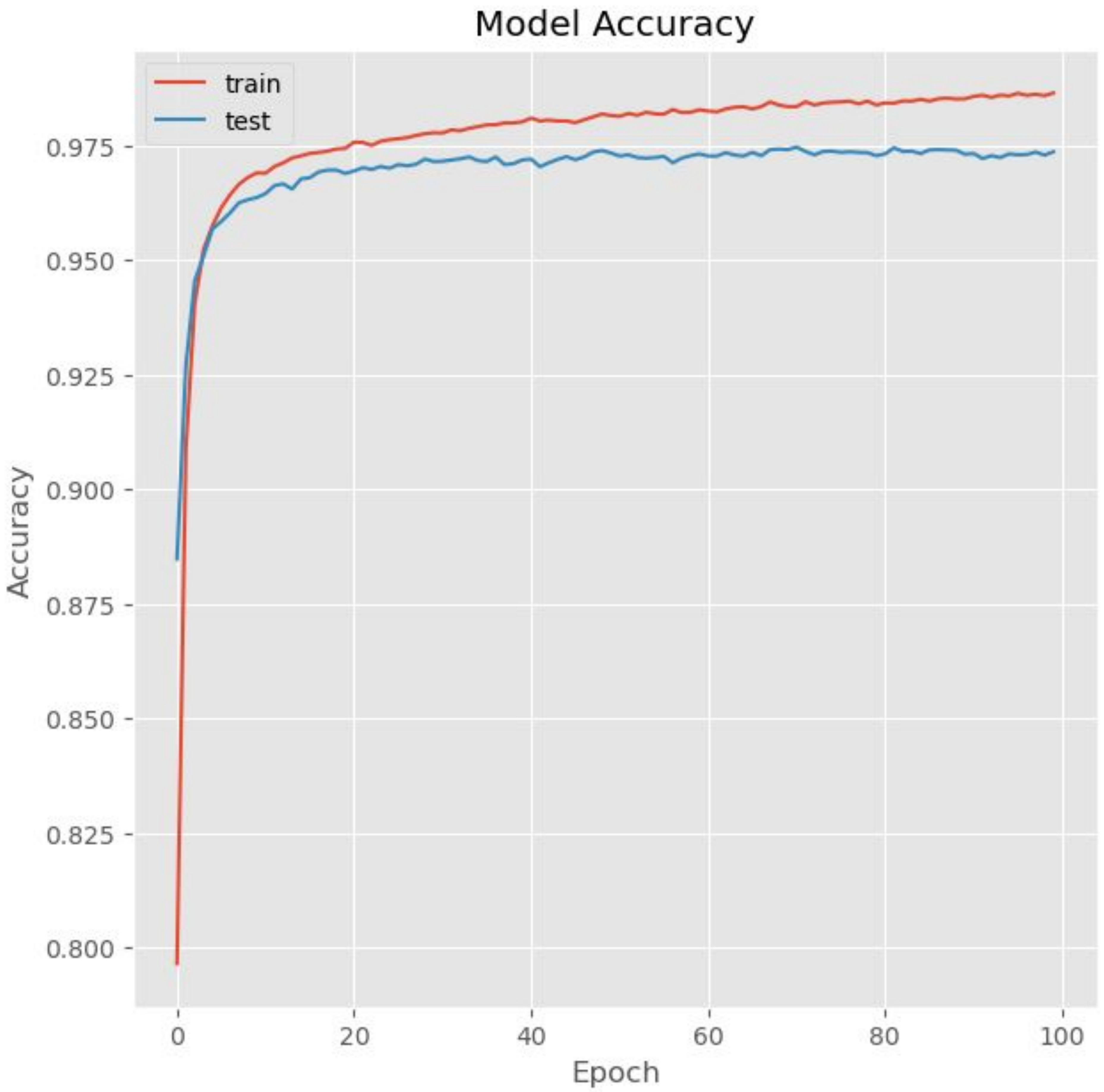


Magnitude Prediction

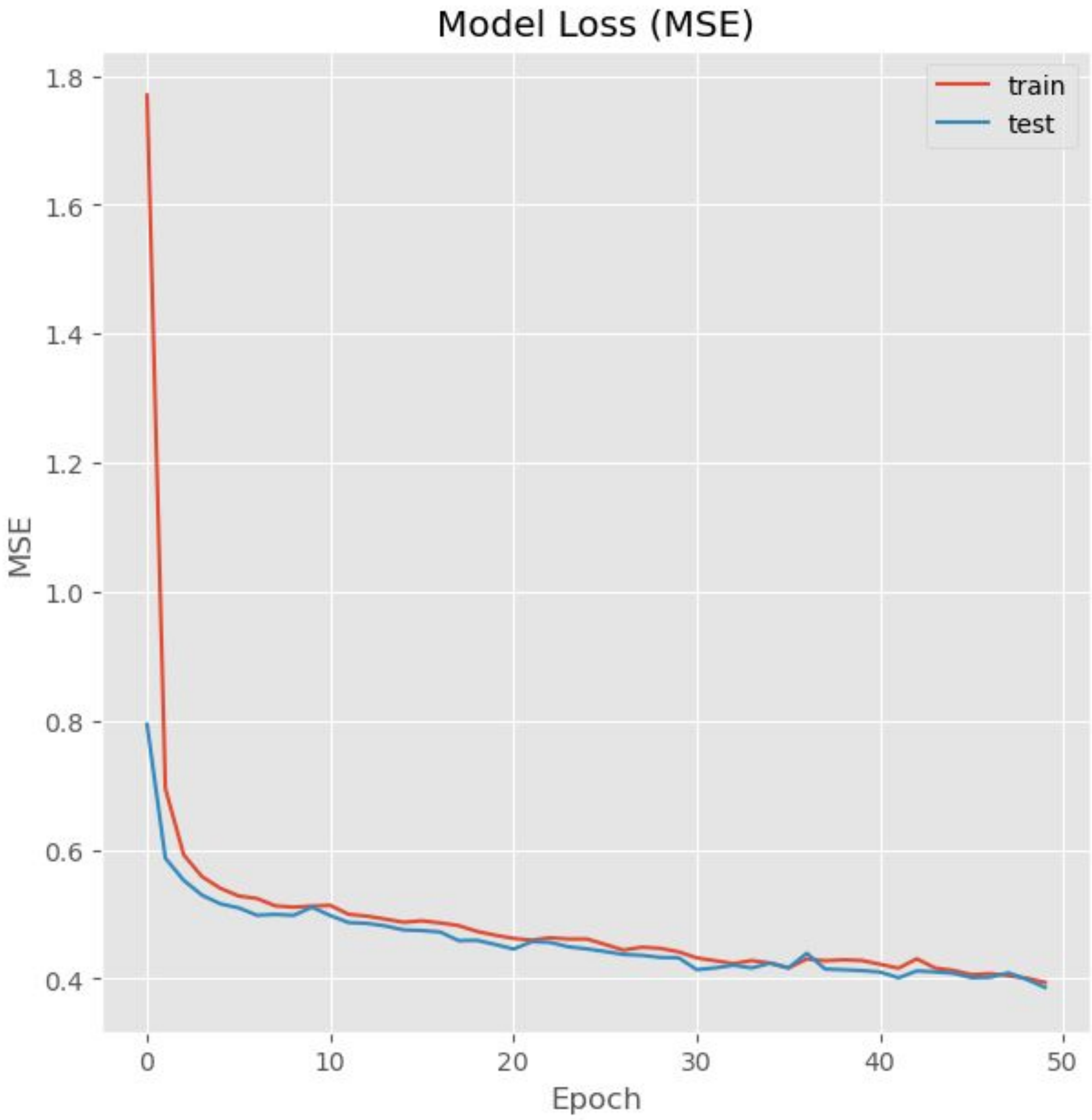


LSTM Results

Class Prediction

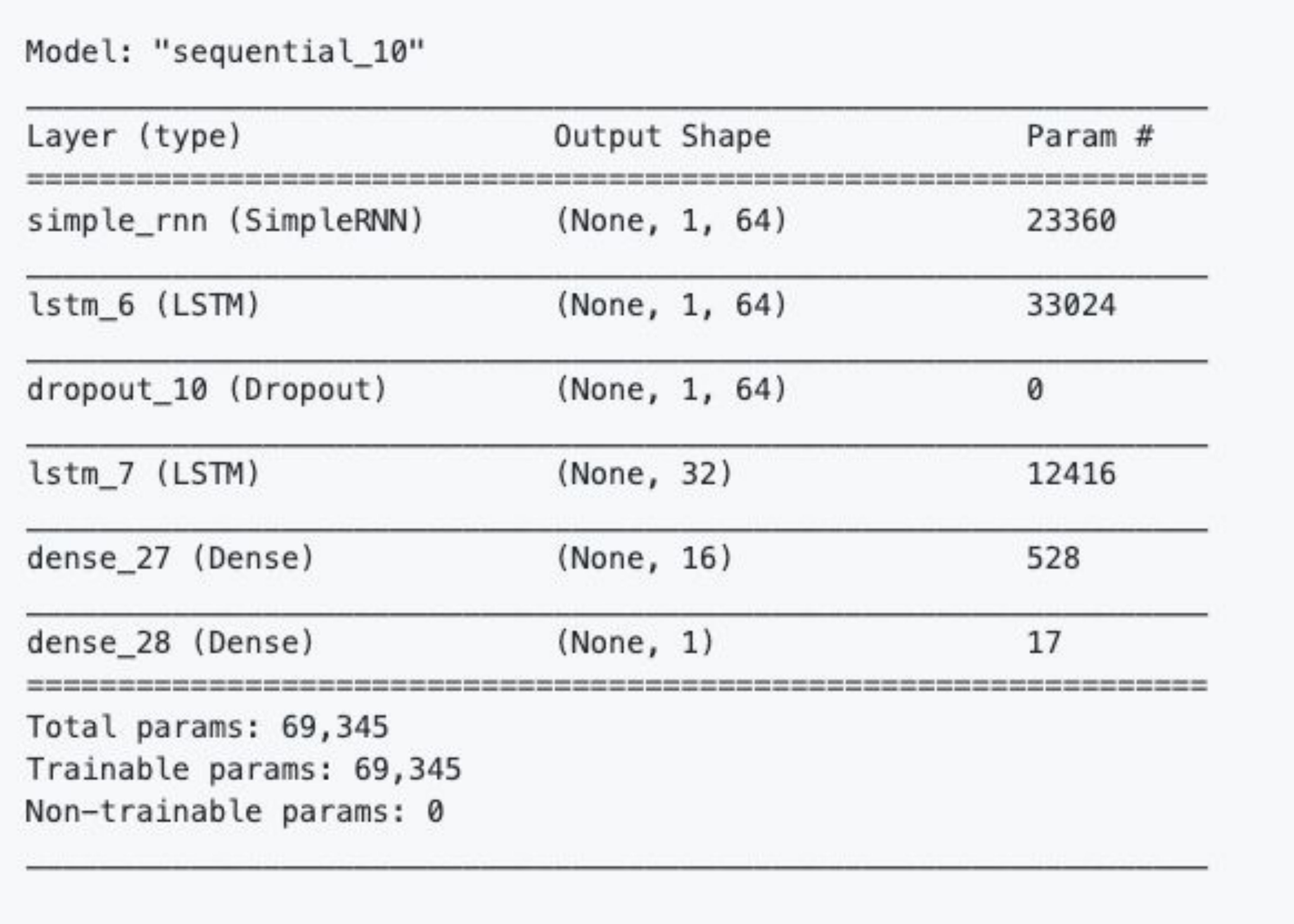


Magnitude Prediction



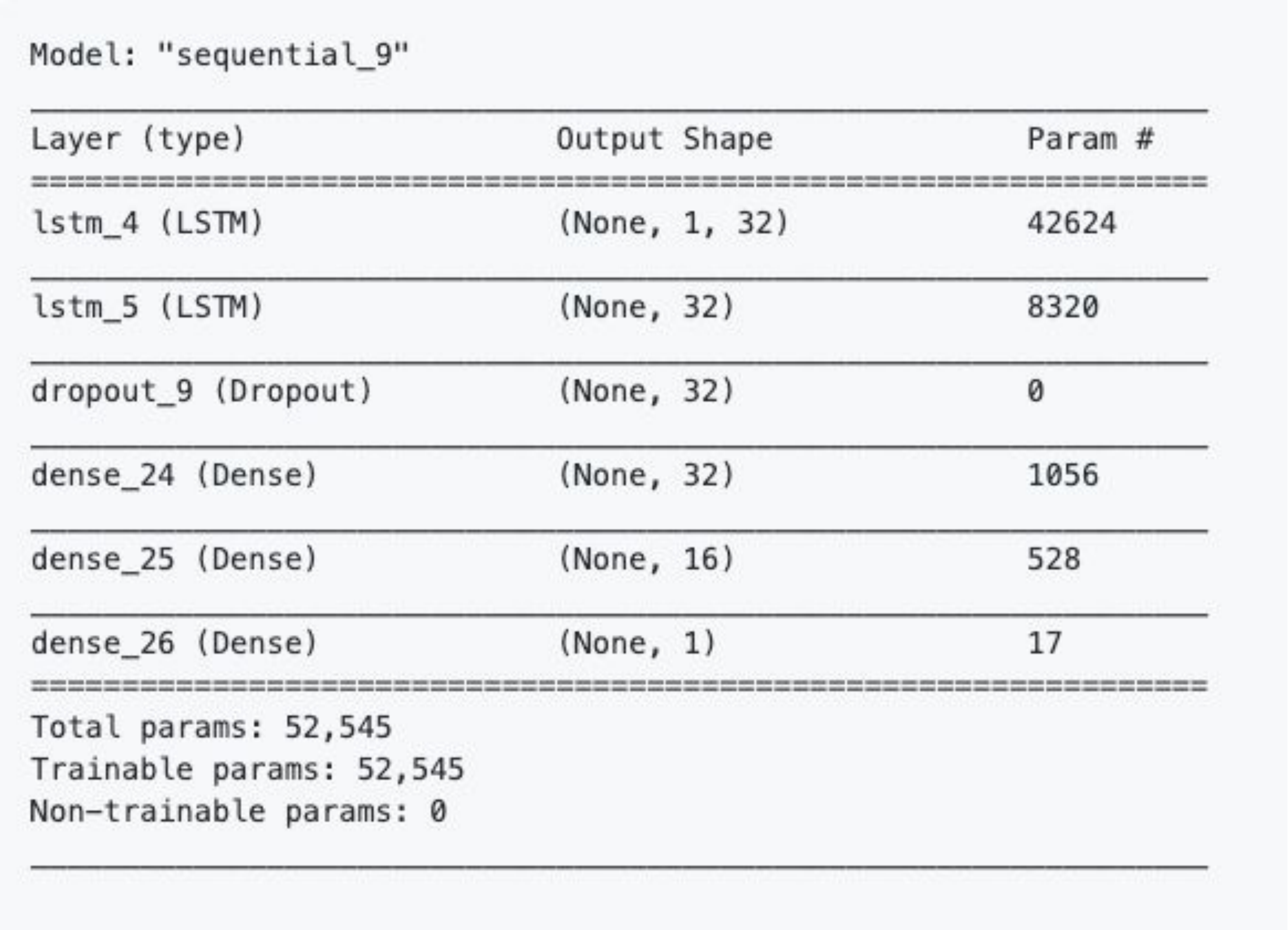
LSTM Results

Class Prediction



```
Model: "sequential_10"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
simple_rnn (SimpleRNN)       (None, 1, 64)             23360
_________________________________________________________________
lstm_6 (LSTM)                (None, 1, 64)             33024
_________________________________________________________________
dropout_10 (Dropout)         (None, 1, 64)             0
_________________________________________________________________
lstm_7 (LSTM)                (None, 32)                12416
_________________________________________________________________
dense_27 (Dense)             (None, 16)                528
_________________________________________________________________
dense_28 (Dense)             (None, 1)                 17
=================================================================
Total params: 69,345
Trainable params: 69,345
Non-trainable params: 0
_________________________________________________________________
```

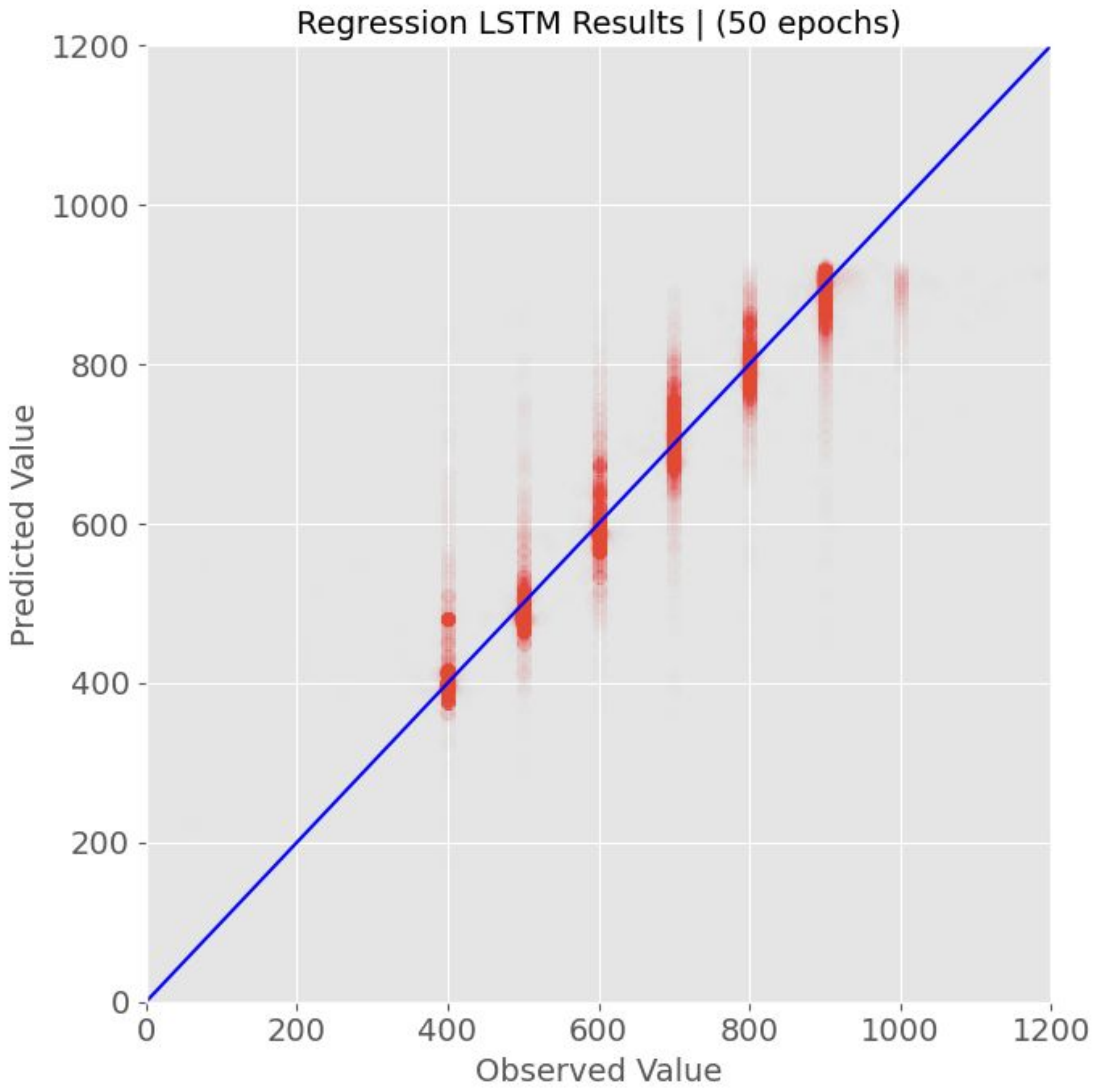
Magnitude Prediction



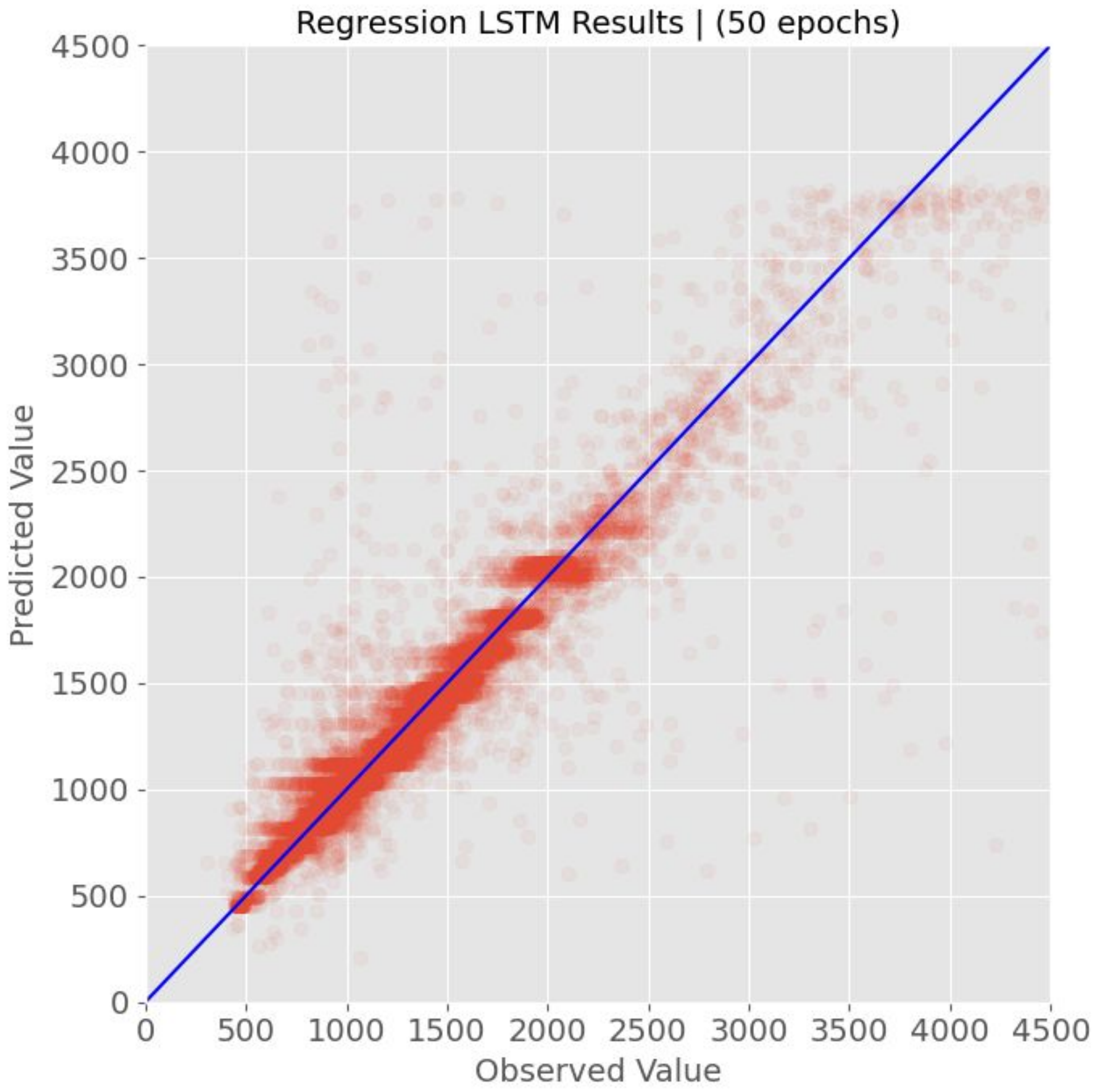
```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
lstm_4 (LSTM)                (None, 1, 32)             42624
_________________________________________________________________
lstm_5 (LSTM)                (None, 32)                8320
_________________________________________________________________
dropout_9 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_24 (Dense)             (None, 32)                1056
_________________________________________________________________
dense_25 (Dense)             (None, 16)                528
_________________________________________________________________
dense_26 (Dense)             (None, 1)                 17
=================================================================
Total params: 52,545
Trainable params: 52,545
Non-trainable params: 0
_________________________________________________________________
```

LSTM Results

P-Wave Prediction

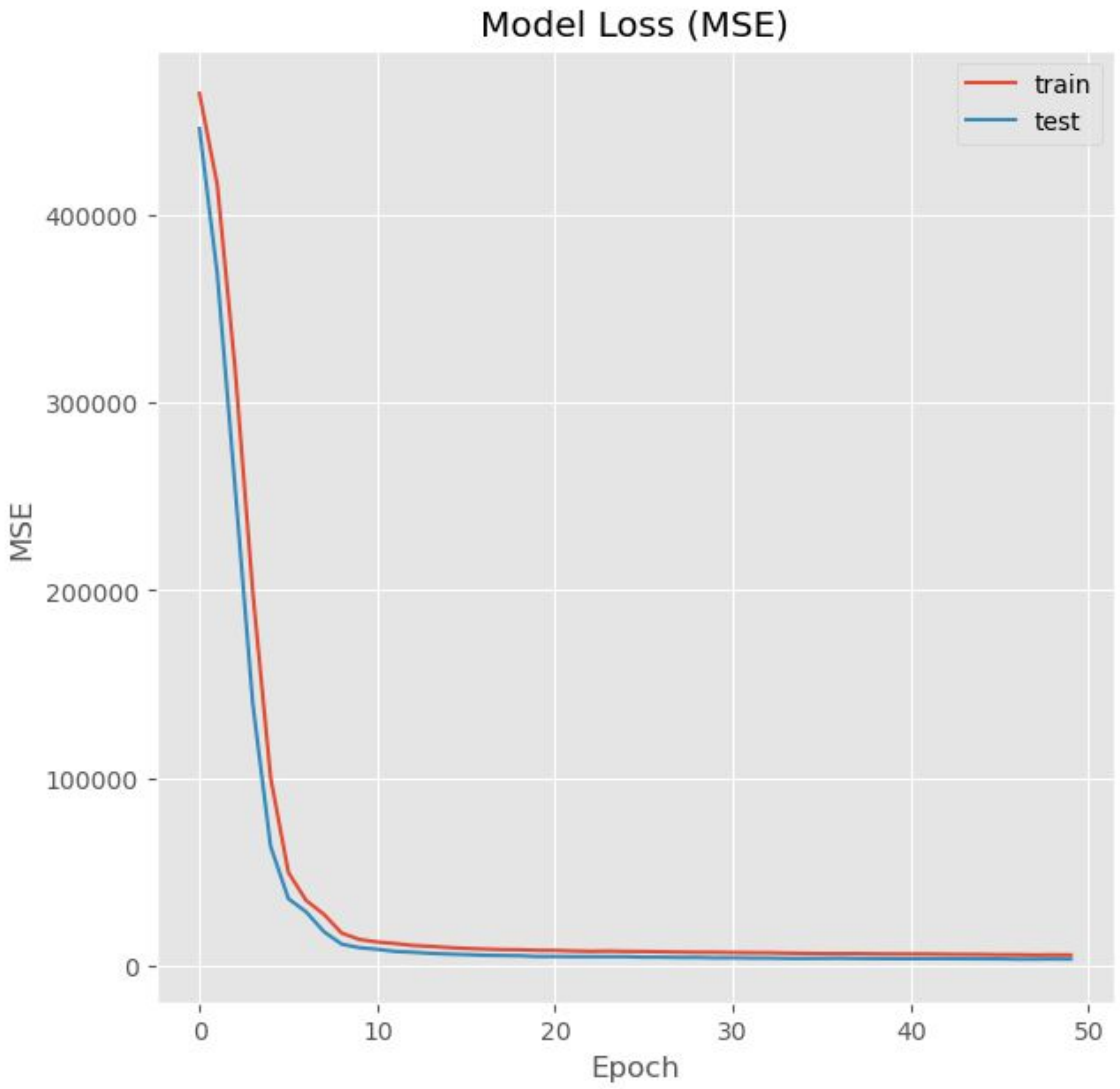


S-Wave Prediction

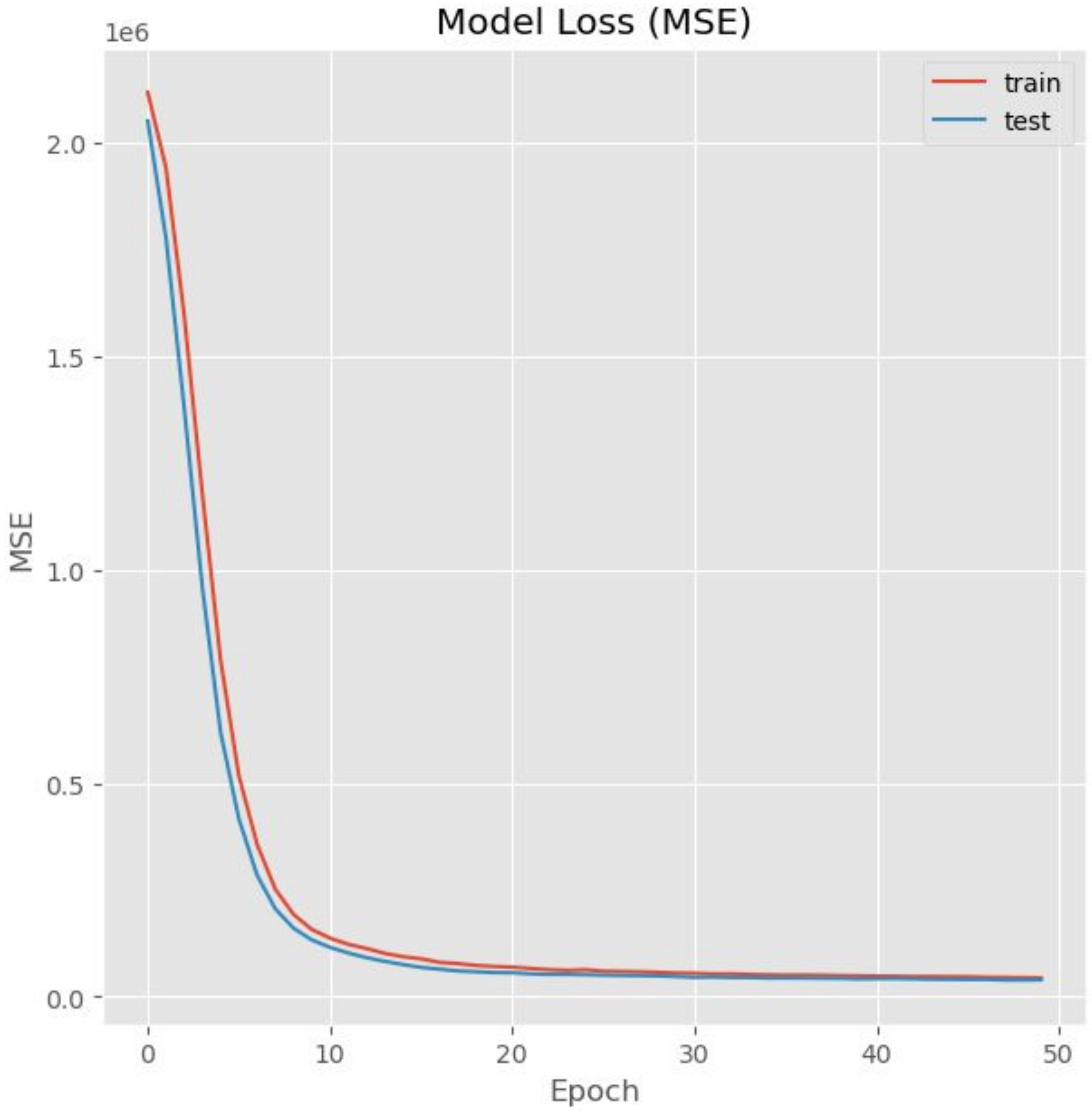


LSTM Results

P-Wave Prediction



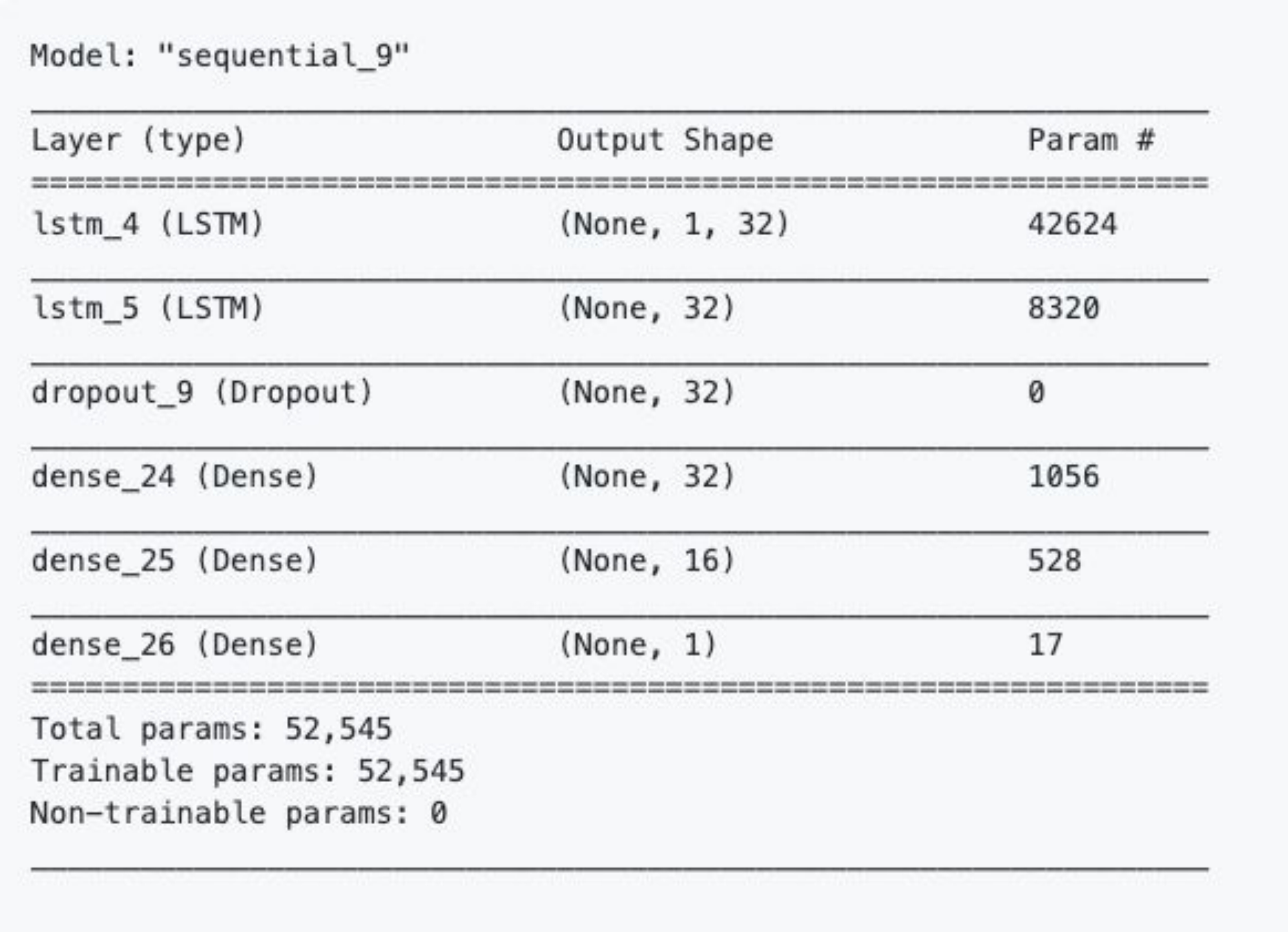
S-Wave Prediction



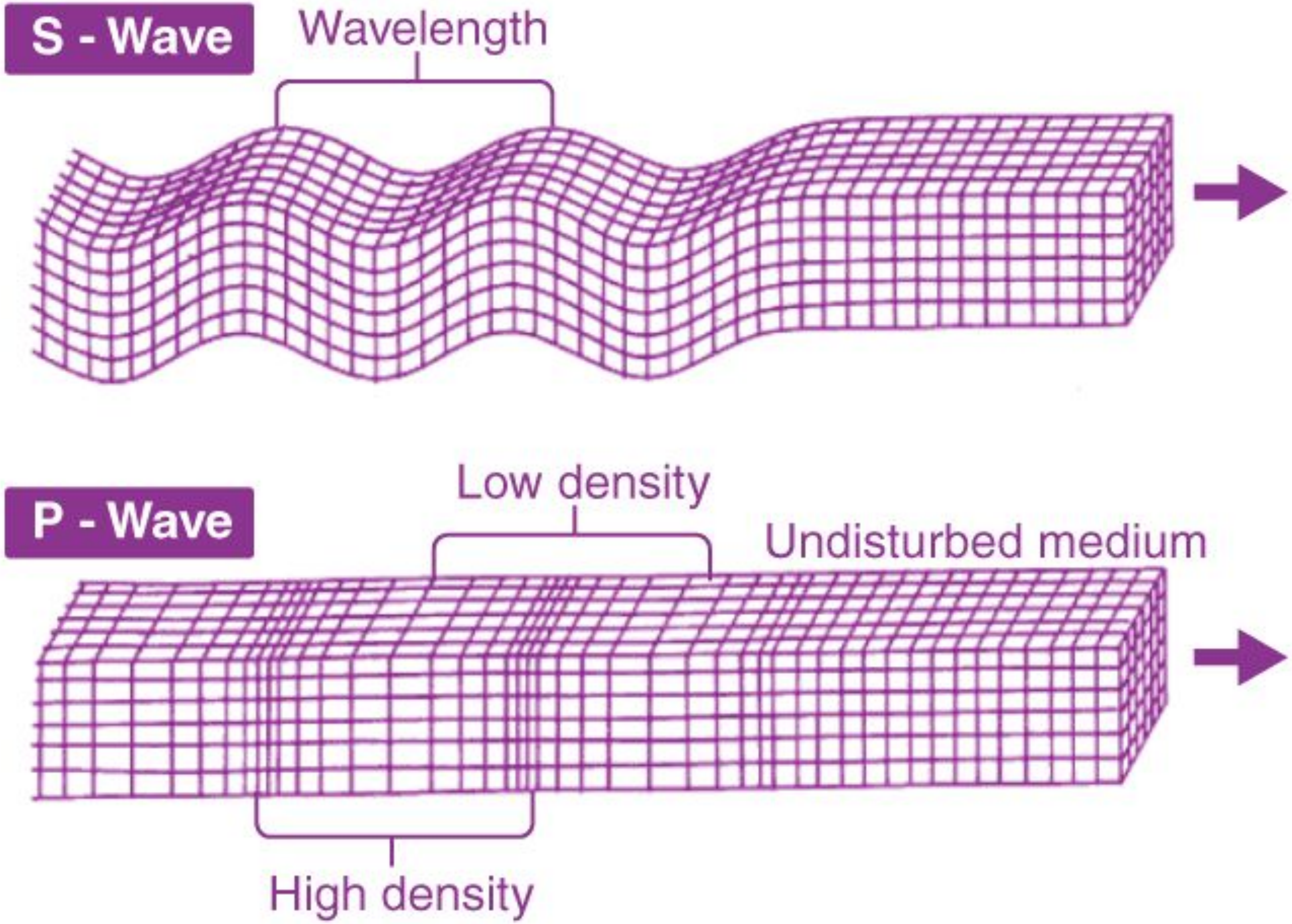
LSTM Results

P-Wave Prediction

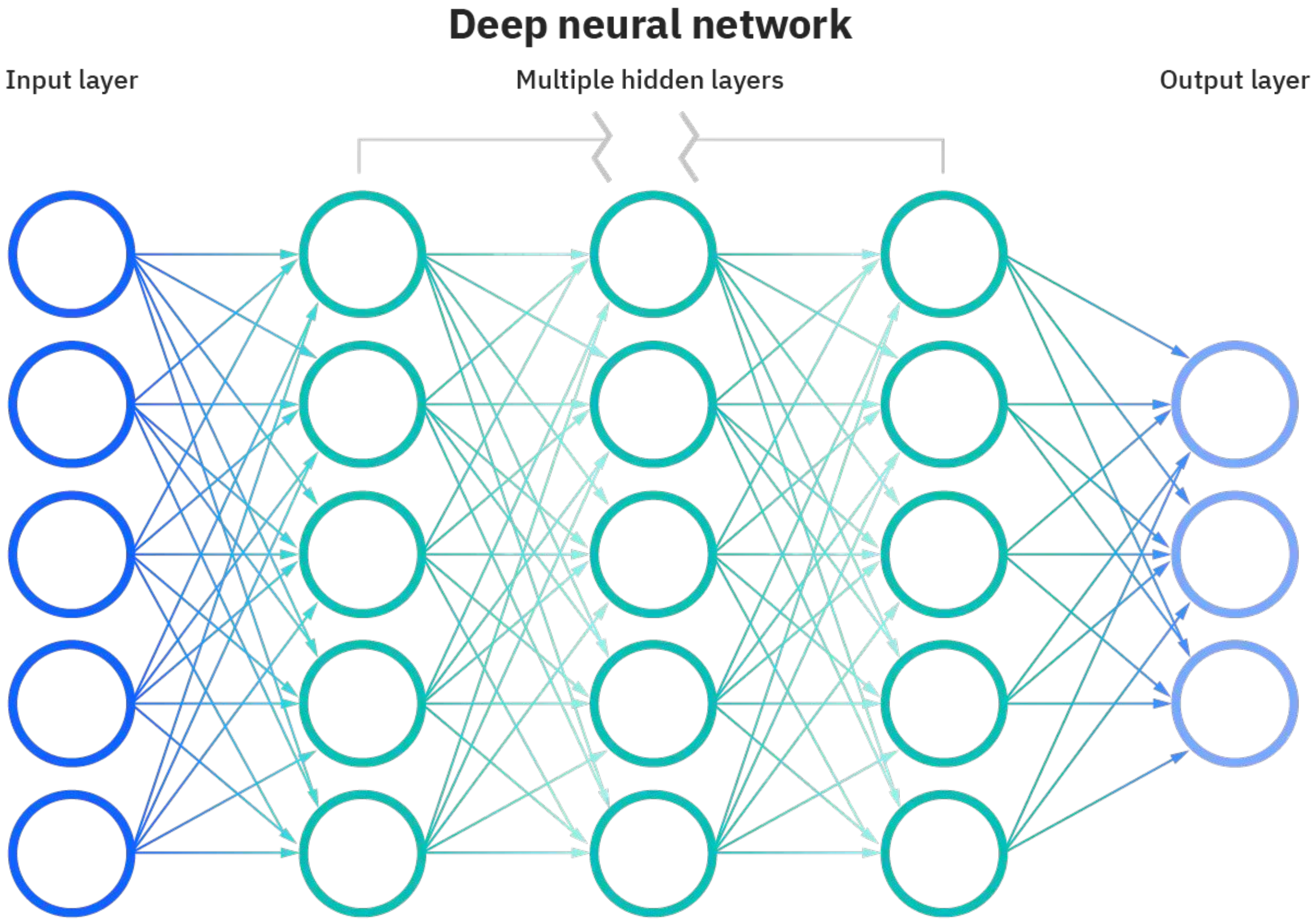
S-Wave Prediction



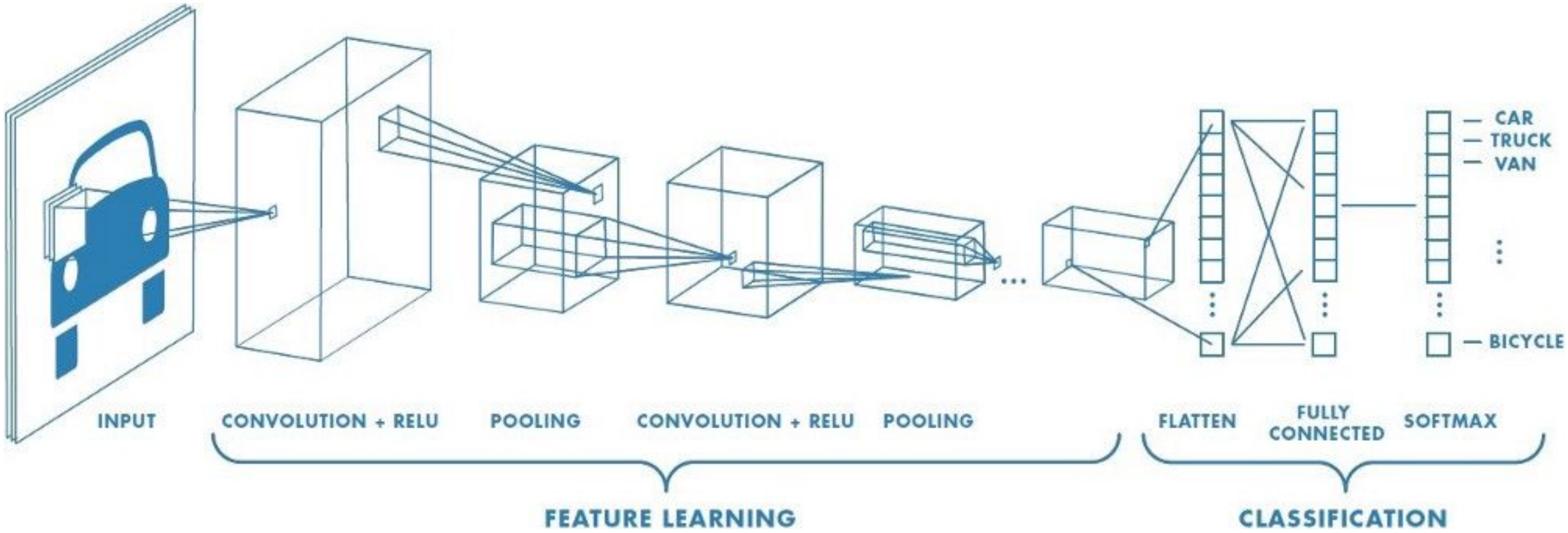
```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
lstm_4 (LSTM)                (None, 1, 32)             42624
_________________________________________________________________
lstm_5 (LSTM)                (None, 32)                8320
_________________________________________________________________
dropout_9 (Dropout)          (None, 32)                0
_________________________________________________________________
dense_24 (Dense)             (None, 32)                1056
_________________________________________________________________
dense_25 (Dense)             (None, 16)                528
_________________________________________________________________
dense_26 (Dense)             (None, 1)                 17
=================================================================
Total params: 52,545
Trainable params: 52,545
Non-trainable params: 0
_________________________________________________________________
```


S - Wave
Wavelength
P - Wave
Low density
Undisturbed medium
High density

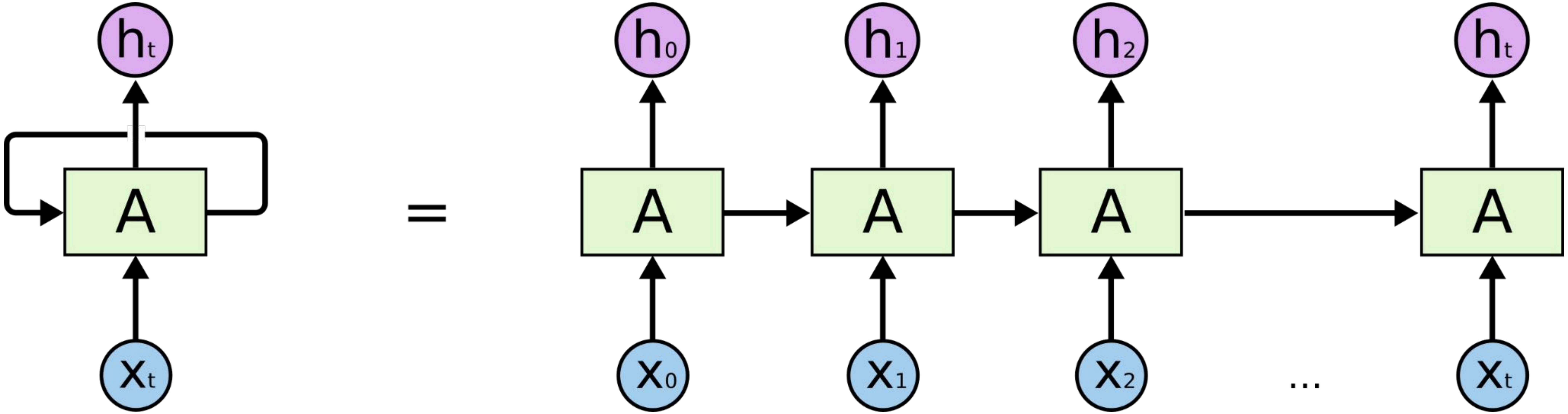
Neural Networks



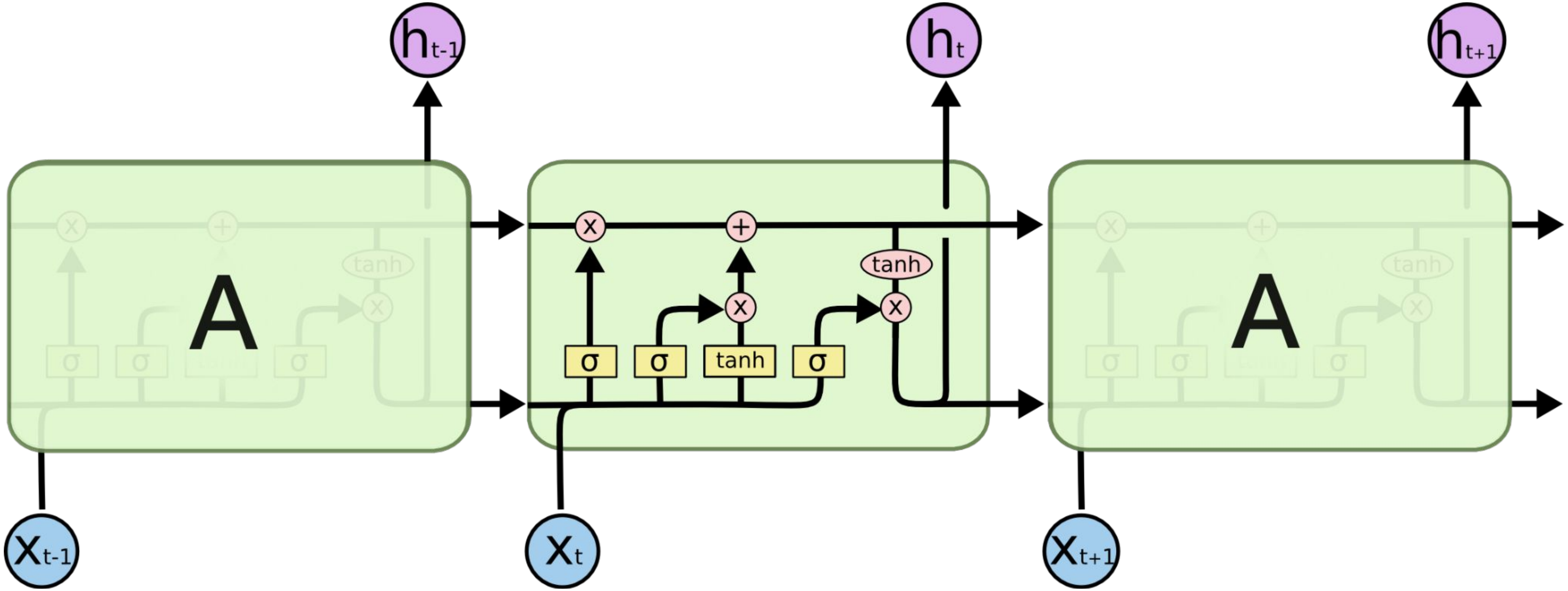
Convolutional Neural Networks



Recurrent Neural Networks



LSTMs



h
t-1
h
t
h
t+1
A
x
+
tanh
σ
σ
tanh
σ
A
X
t-1
X
t
X
t+1