Separation of seismic signal and ambient noise using deep neural network

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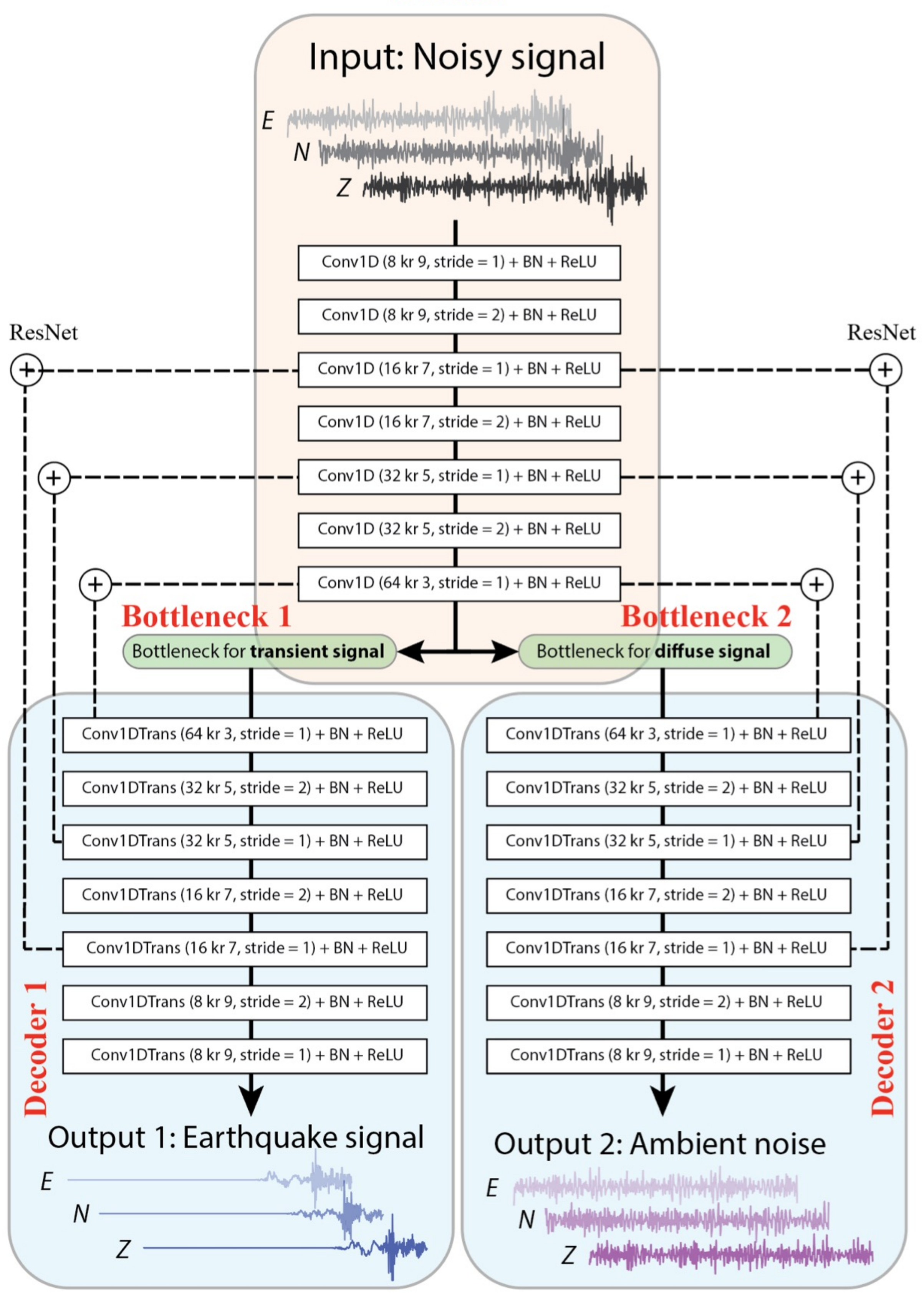
Summary

- We develop a machine learning method to separate the earthquake signal and noise signal in time domain.
- We systematically compare different network structures and find LSTM bottleneck outperforms others.
- We apply our network to continous seismic data and show improvement on the quality of both earthquake signals and ambient noise signals.

Network architecture



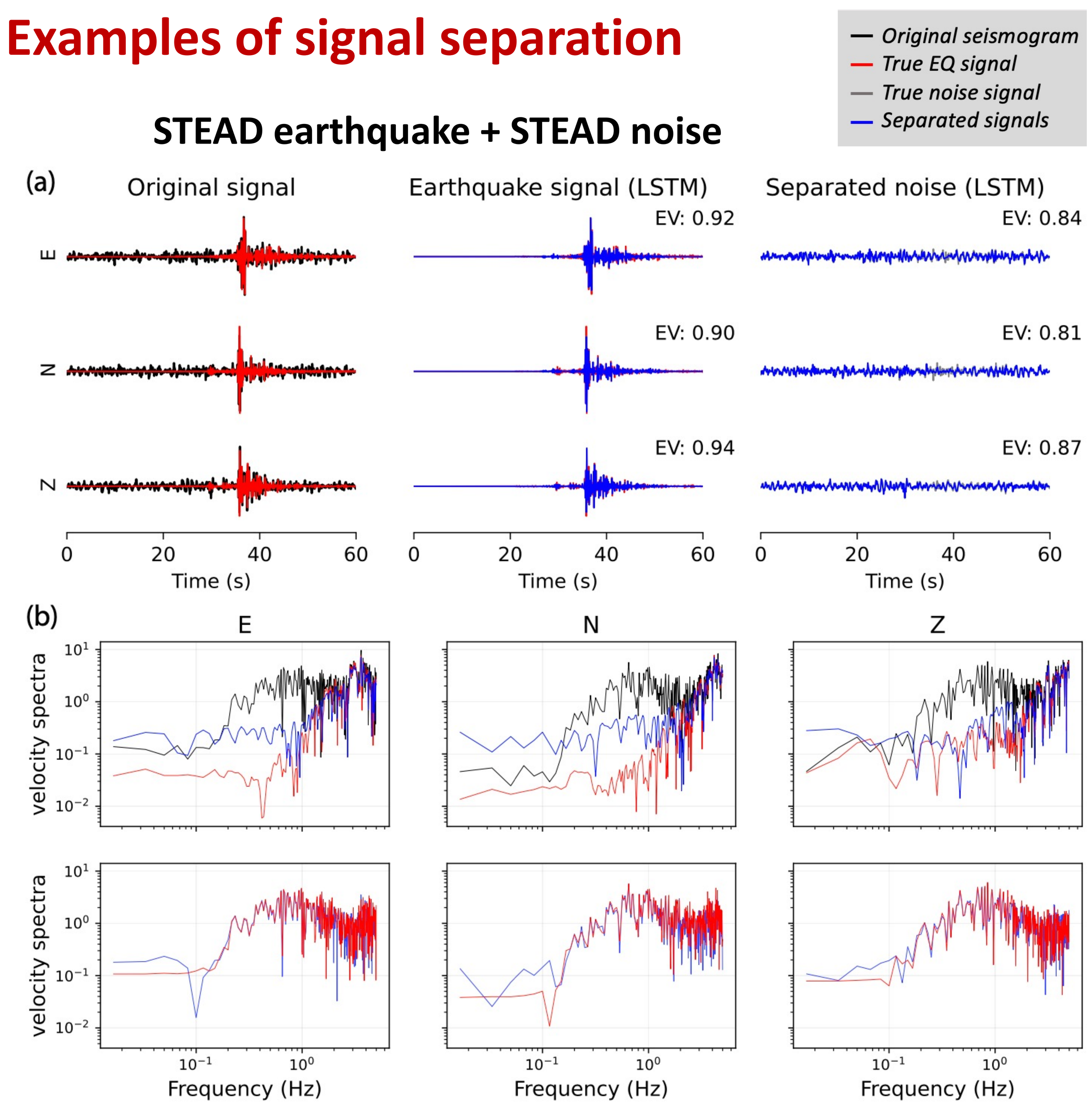
"x kr y, stride=z" refers to x kernels with y features and stride of z

- We apply the encoder-decoder architecture (shown above) for this sequence-to-sequence regression problem.
- The bottleneck block is a key component for the encoder-decoder architecture. In this study, different choices of the bottleneck block for the feature-extraction of time-series are tested, including:
  - **None** (no specified block for the bottleneck)
  - **Linear** (fully-connected linear layer)
  - **LSTM** (Long-Short Term Memory block)
  - **attention** (dot-product self-attention mechanism)
  - **Transformer** (1-layer transformer encoder layer)

Datasets

- Our dataset consists of two parts:
  1. **Earthquake signal**: 144,000 earthquake waveforms (SNR > 10^4) from STEAD dataset (https://github.com/smousavi05/STEAD)
  2. **Ambient noise signal**: 100,000 noise waveforms from STEAD + 44,000 regional noise waveforms from IU.POHA (https://www.fdsn.org/station_book/IU/POHA/poha.html)
- Earthquake and noise waveforms are randomly combined to form the datasets with SNR (power ratio of signal and noise) varying from 10^{-2} to 10^4 (Randomly scaling + shifting).

Examples of signal separation

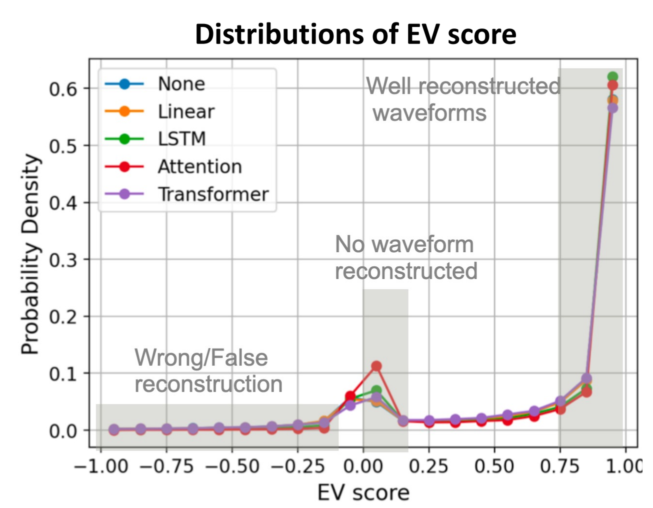


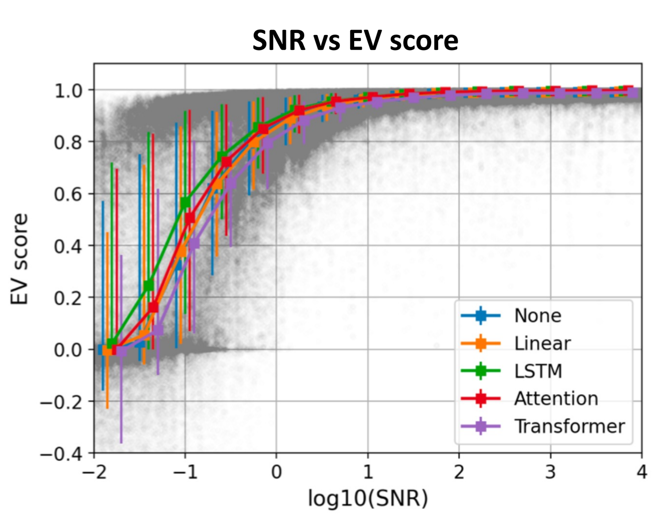
- Earthquake and ambient noise signals can be well separated, even when overlapped in the frequency domain.

Comparison between models

- We use the Explained Variance (EV) score to quantify the performance of trained models

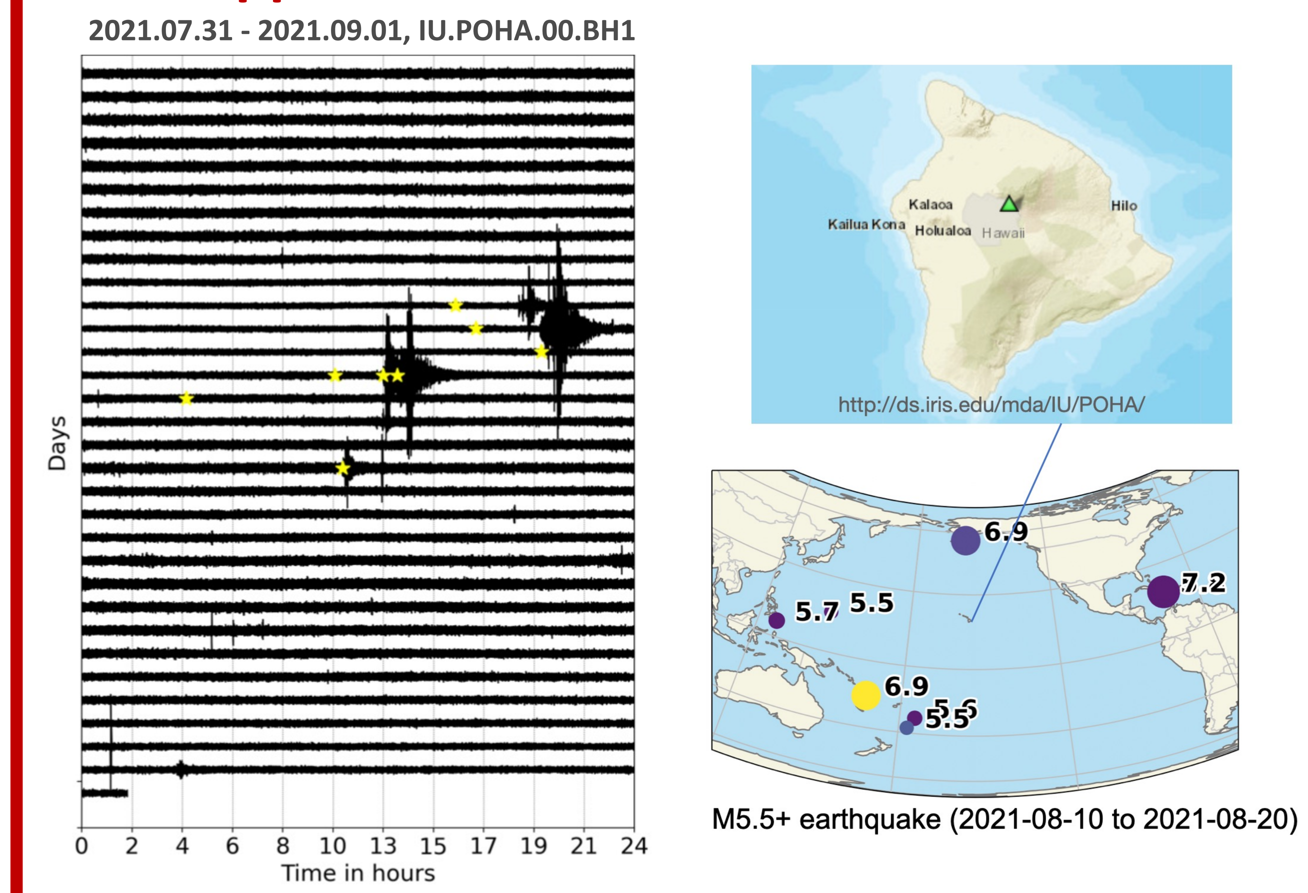
$$explained\_variance(y,\hat{y}) = 1 - \frac{Var\{y-\hat{y}\}}{Var\{y\}}$$

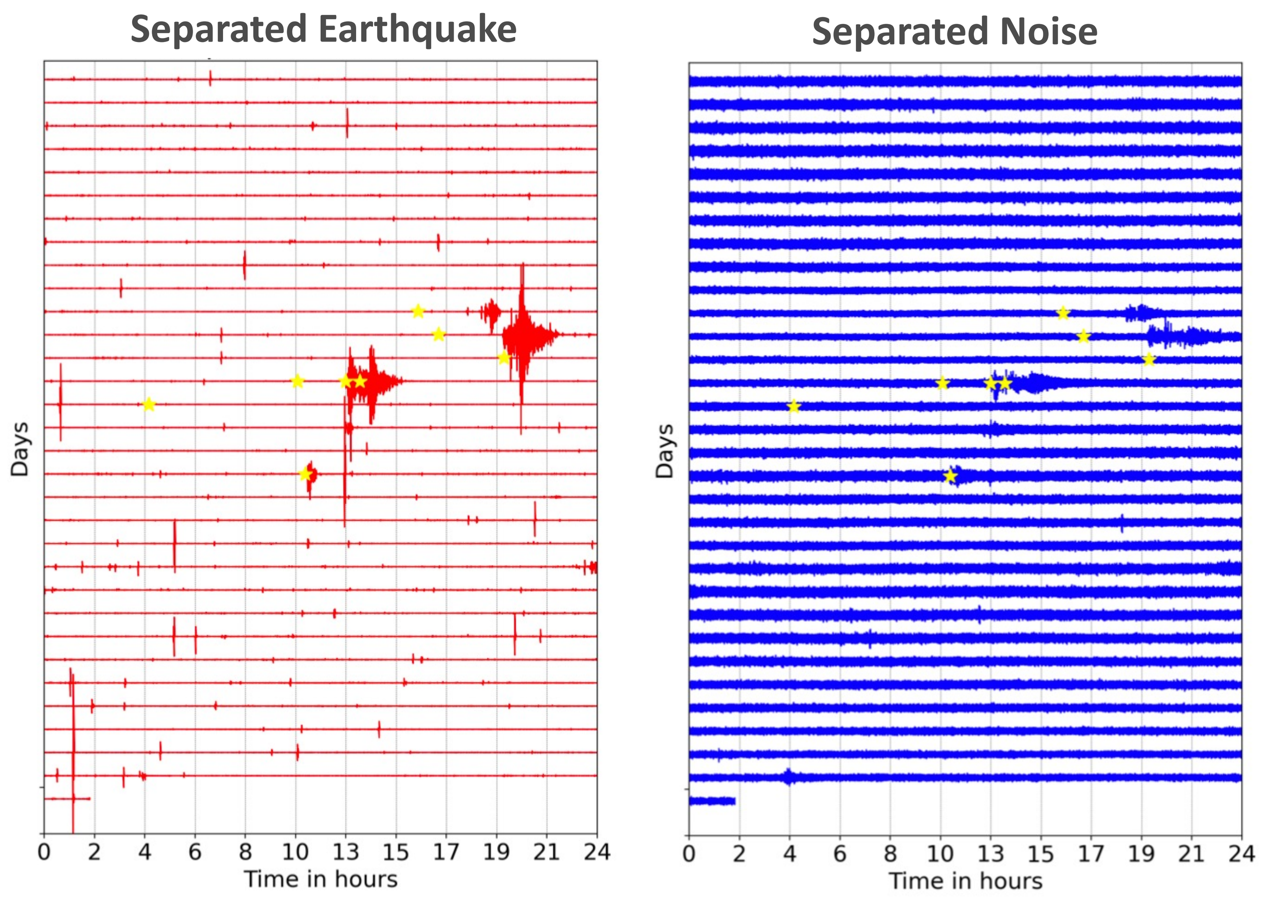




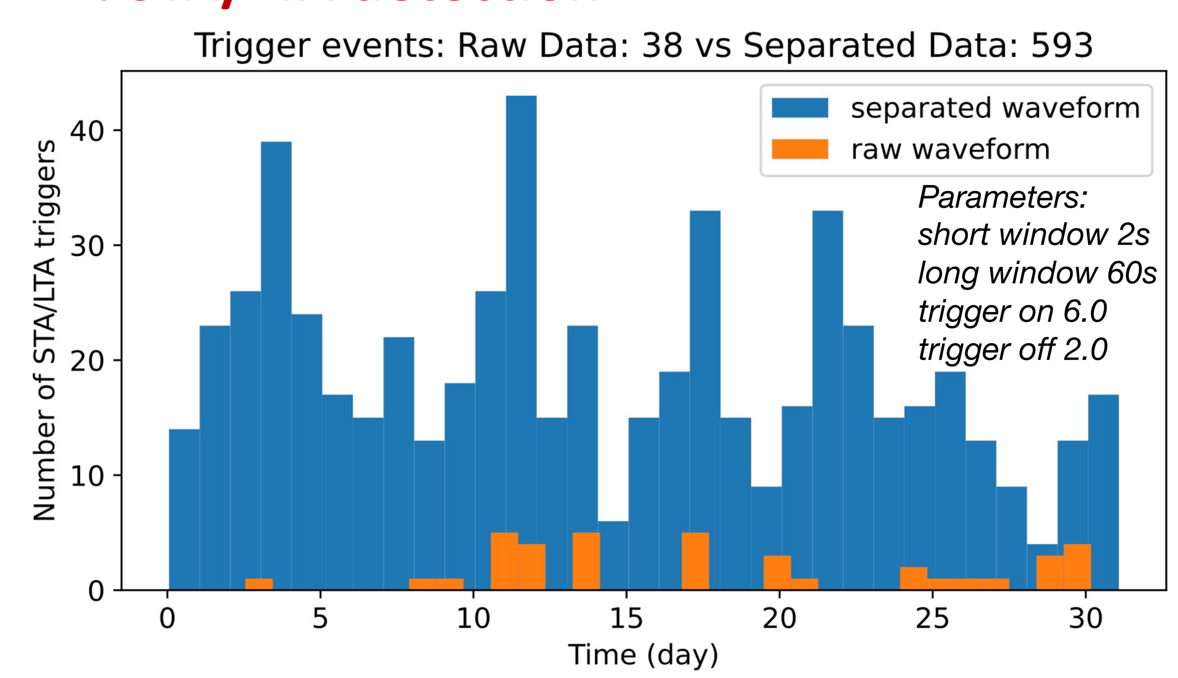
- In general, all models preform well to reconstruct both earthquake and ambient noise waveforms (> 50% well reconstructed)
- LSTM has best performance in reconstructing waveforms

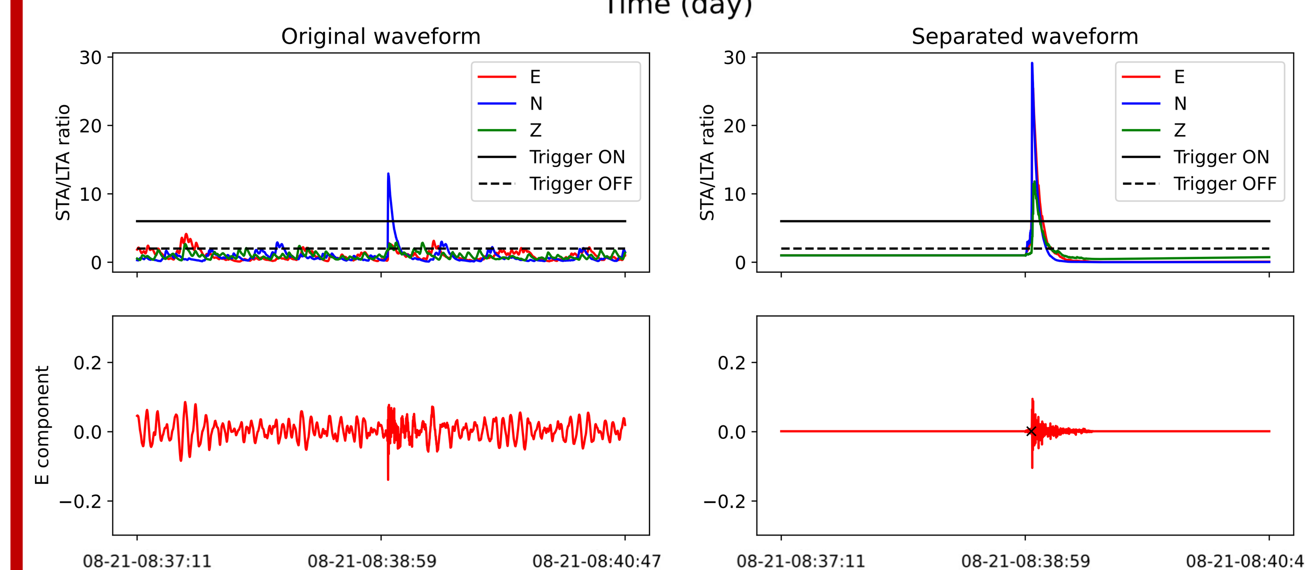
Application to continous seismic data





1. STA/LTA detection





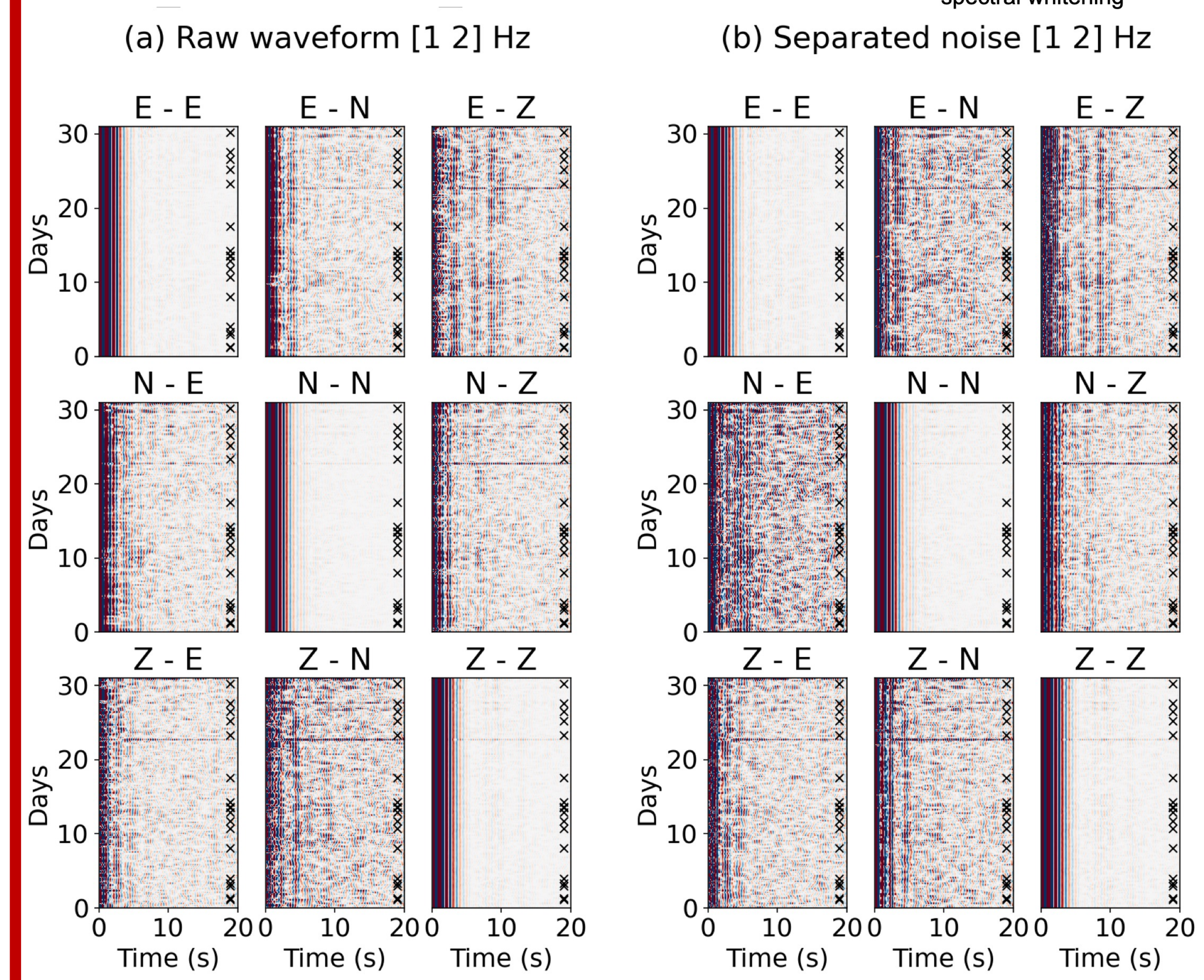
- Separated earthquake waveforms help to detect more events and allow better picking of arrival time

2. Ambient noise cross-correlation

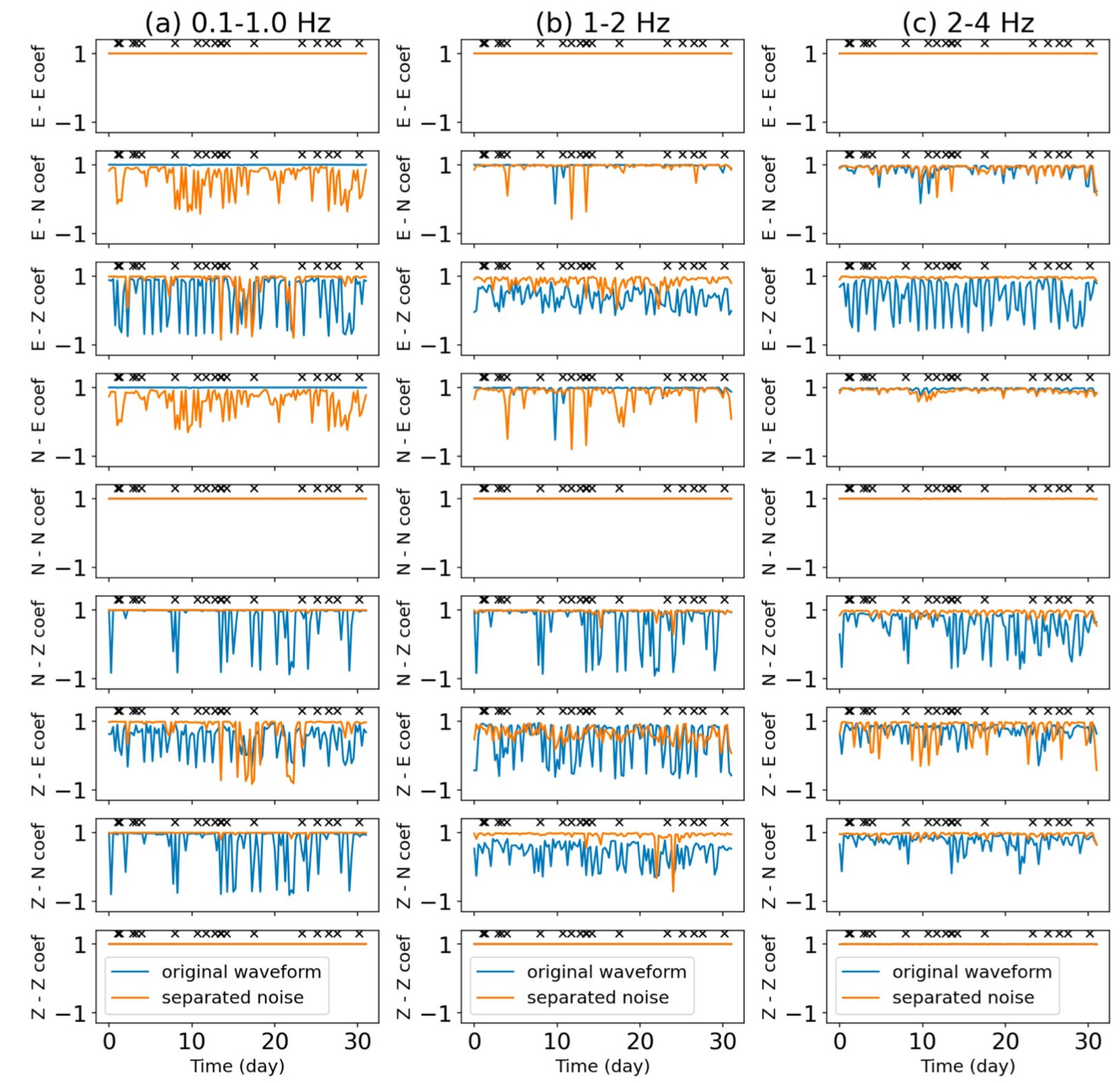
Cross-correlation functions of ambient noise between channels:

$$CCF_{ij}(t) = F^{-1}\left(\frac{\hat{a}_i\hat{a}_j^*}{|\hat{a}_i||\hat{a}_j|}\right)$$

(cross-correlation; spectral whitening)



CCF coherence (correlation with averaged CCF)



- Separated ambient noise waveforms show improvement in the coherence of CCFs.

Conclusion

- **The Encoder-Decoder network is shown to successfully separate the earthquake signal and noise signal directly in the time domain.**
- **LSTM block outperforms others in accurate separation of the signals from data with low SNR.**
- **Our network can greatly improve the quality of seismic data, and futher help in both earthquake and ambient noise seismology.**