DETECTING LOW FREQUENCY EARTHQUAKES IN CASCADIA WITH DEEP LEARNING

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Slow slip

- Fast earthquakes have durations of fractions of a second to a few minutes
- Slow earthquakes have durations of days, weeks, months, and even years





Nonvolcanic tremor

 Slow slip events have a weak seismic signature known as tectonic tremor



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Nonvolcanic tremor



Tremor and LFEs

- Tremor is made up of constituent lowfrequency earthquakes (LFEs)
- LFEs are **low** amplitude and depleted in highfrequency content relative to traditional earthquakes of the same magnitude







Tremor is an unusual seismic signal....

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24 hours

...that can be explained as a superposition of small earthquakes.



Cascadia seismicity

- We adopted the approach of Zhu and Beroza [2019] and trained a network to identify earthquakes and make phase picks
- It works really well for regular earthquakes!



Cascadia seismicity

- We adopted the approach of Zhu and Beroza [2019] and trained a network to identify earthquakes and make phase picks
- It works really well for regular earthquakes
- Using those same pickers to detect for low-frequency earthquakes does not work very well...





Cascadia seismicity

• Can we use the same deep learning approach we applied to regular earthquakes to detect LFEs?







ML for LFEs

- We use the P and S-picks from LFE catalogs assembled via template matching to train our network
- Inputs are 3C waveforms; outputs are Gaussians centered on arrivals
- It's difficult to impossible to see LFEs in the training data
- Given the low-frequency nature we add an additional target of 0.4 s



Performance metrics









Model evaluation using ROC

- ROC Curve: Plots true positive rate (TPR) vs. false positive rate (FPR) by varying decision thresholds.
- AUC (Area Under Curve) ranges from 0.5 (random guessing) to 1.0 (perfect model).
- Higher AUC = better model performance.





Model validation steps



P-wave model

S-wave model



Model validation steps



P-wave model

S-wave model





Arrival misfits







LFE data mining

- Early data mining results are promising
- There are high daily detection counts across the network during times of known SSEs
- There are also many events between known SSEs these could be real





The way forward

- Deep learning can successfully identify LFEs in continuous seismic data despite their low-amplitude nature
- It is capable of identifying known and new LFEs
- Still working on validating detections but ML is a promising tool for identification and characterization of LFEs in massive datasets



Ongoing challenges

- Useful, but we're still far from ML derived LFE catalogs
- S-waves alone aren't enough
- Probably need a specially trained associator that can untangle overlapping LFEs (to the extent possible)
- Want to know more? Lin, J.-T., Thomas, A., Bachelot, L., Toomey, D., Searcy, J., & Melgar, D. (2024). Detection of Hidden Low-Frequency Earthquakes in Southern Vancouver Island with Deep Learning. Seismica, 2(4). https://doi.org/ 10.26443/seismica.v2i4.1134

