Earthquake Catalog Building aided by AI

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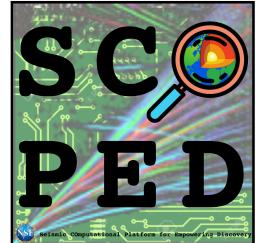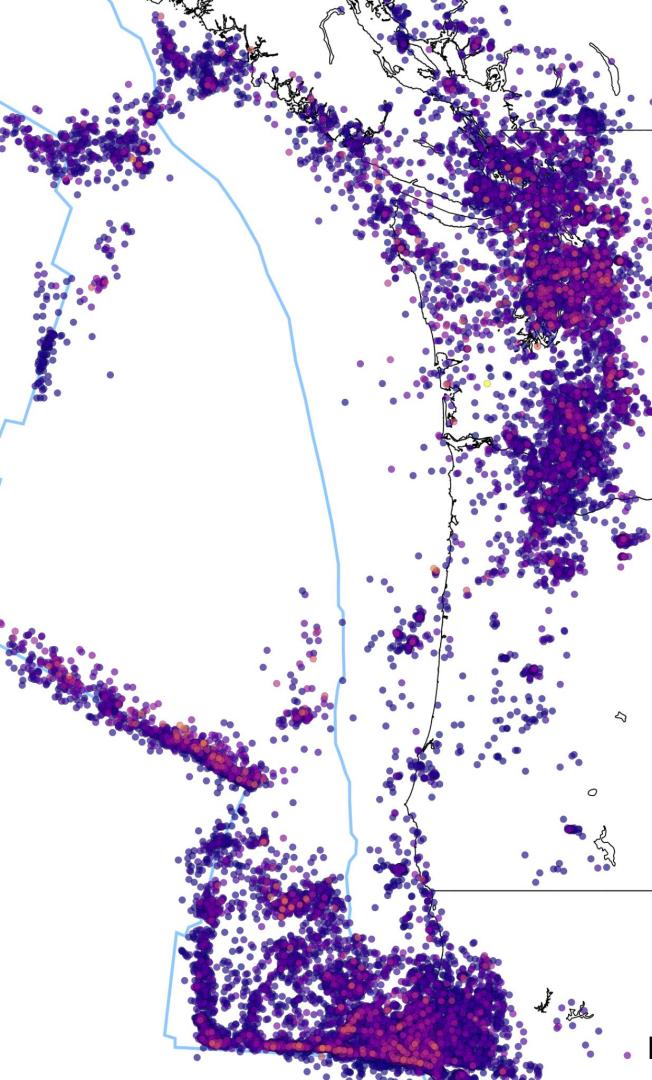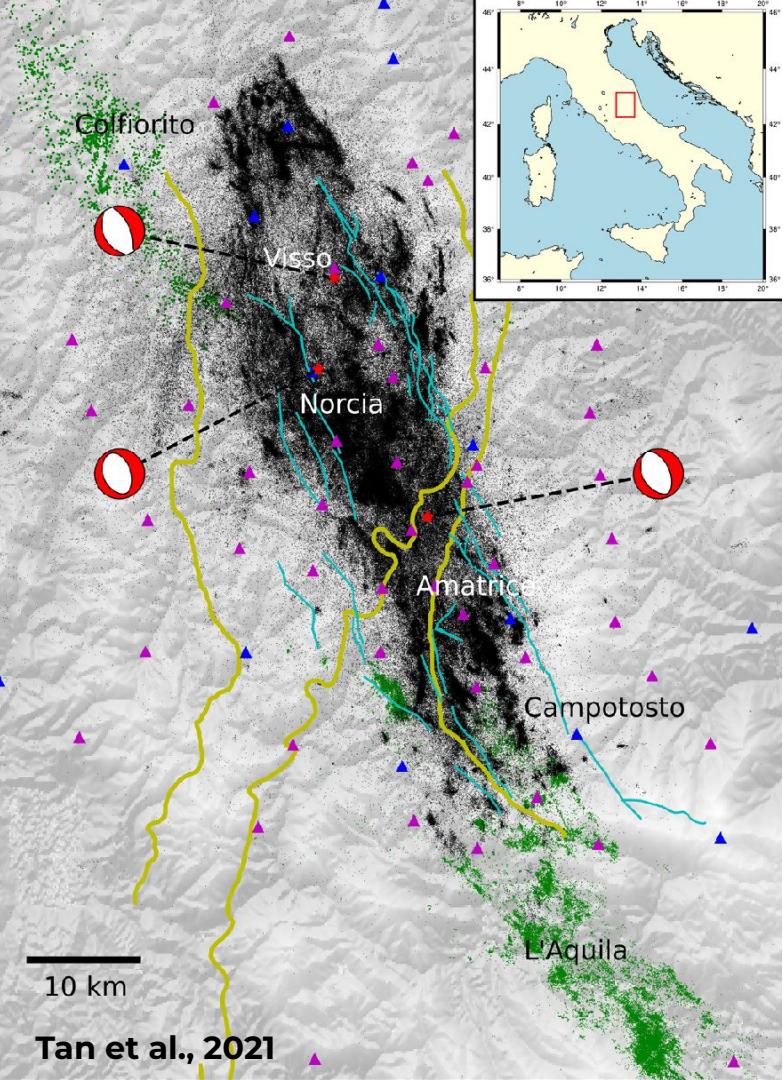
Discovering *earthquakes* and *active faults* in remote, noisy environments

Bito, Denolle, et al (in prep)

Tan et al., 2021

***Tracing fault networks* to <u>understand</u> the complex <u>earthquake sequences</u>**

~ 1M earthquakes in 1 year

Park et al, 2022

Kansas
Oklahoma

Figure 3

Figure 2

(a)

(b)

0°
45°
30
20
10
0
90°
135°
180°

10 km
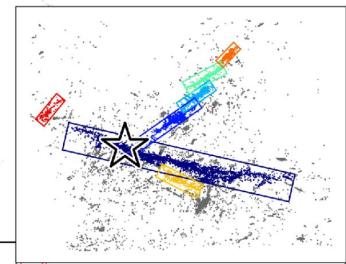
Tan et al., 20

20 km
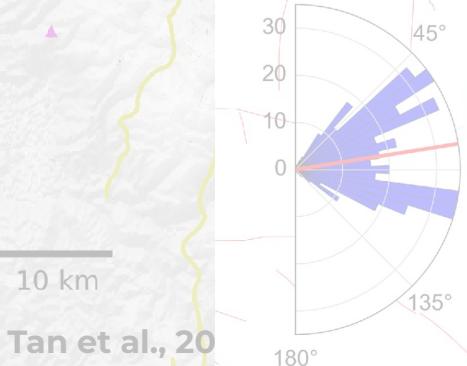
Unearthing potential for M5+ intraplate earthquakes activated by anthropogenic activities

Colfiorito
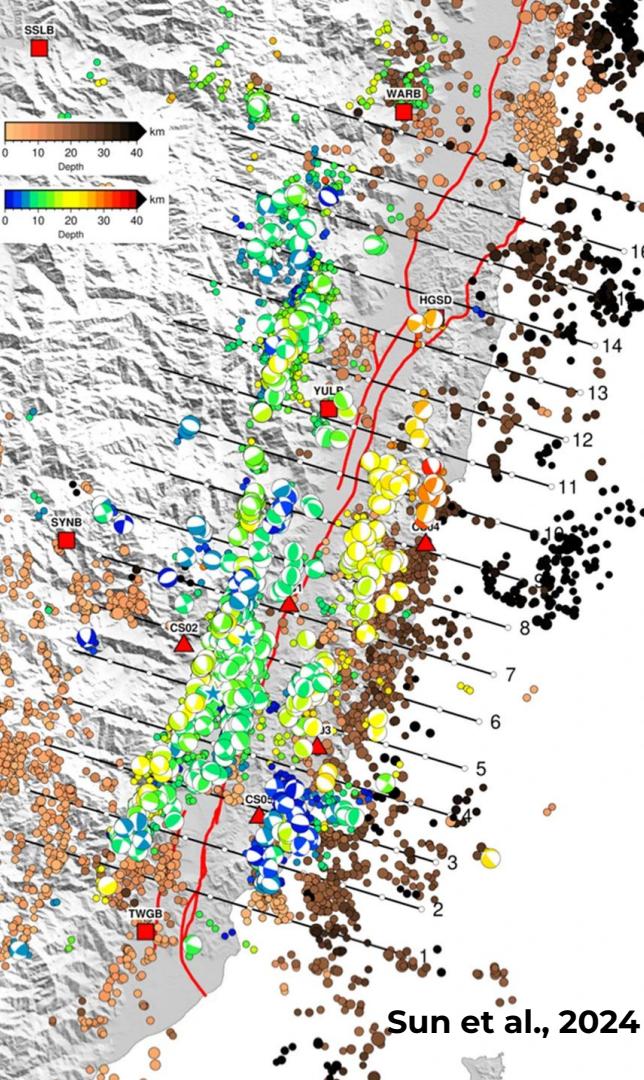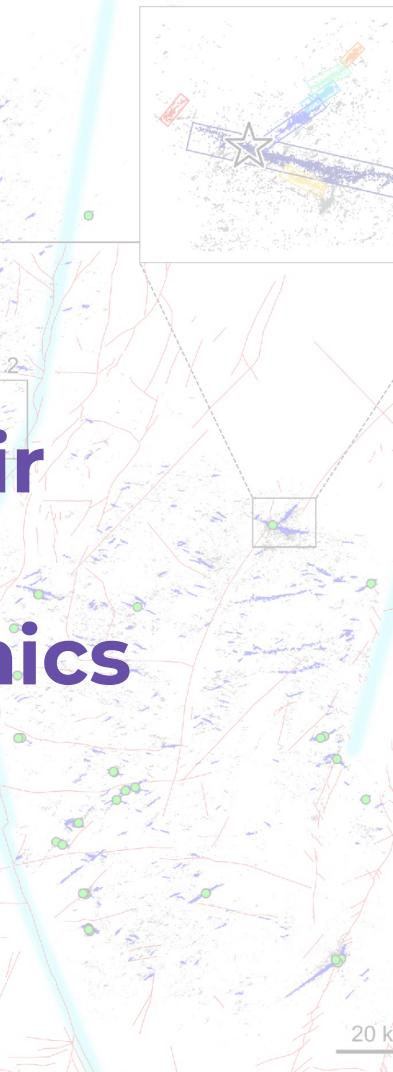
Explaining the mechanisms of complex fault systems and their role in plate boundary dynamics

Park et al, 2022

Tan et al., 20

Sun et al., 2024

Machine Learning for building earthquake catalogs
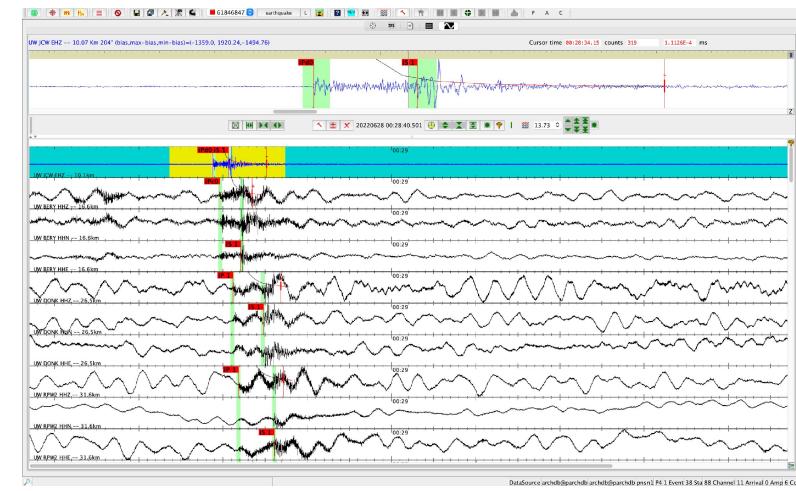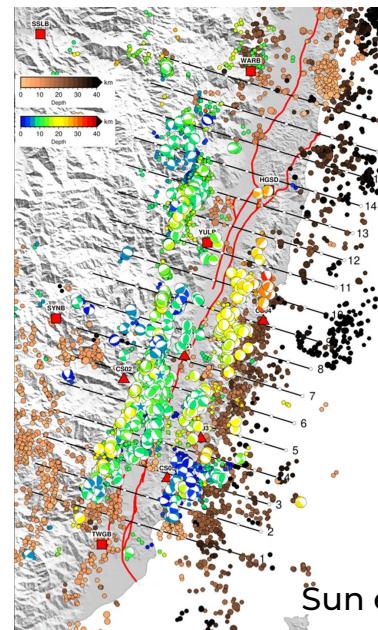
Data Preparation	Event Discrimination	Phase Picking	Phase Association	Location & *Relocation*	Magnitude (Md, Ml, Mw)	Focal Mechanism

Data received at seismic network

Precise Earthquake Catalog

PNSN - Jiggle

Sun et al., 2024

Machine Learning for building earthquake catalogs
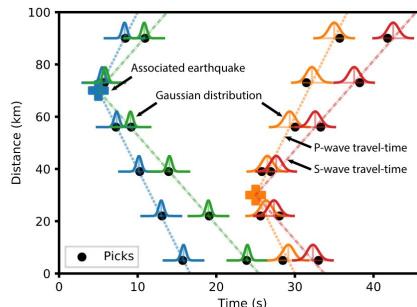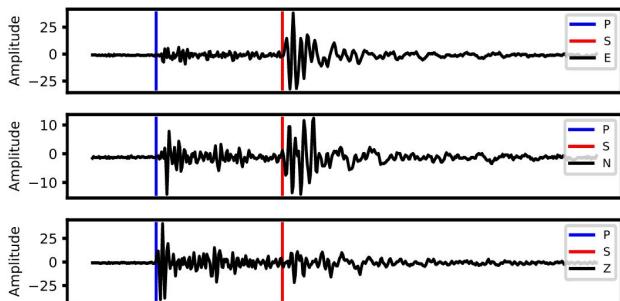
| Data Preparation | Event Discrimination | Phase Picking | Phase Association | Location & *Relocation* | Magnitude (Md, Ml, Mw) | Focal Mechanism |

- GPD (Ross et al., 2018)
- PhaseNet (Zhu et al., 2018)
- EqTransformer (Mousavi et al., 2020)
- PhaseNO (Sun et al., 2022)
- ELEP (Yuan et al., 2023)
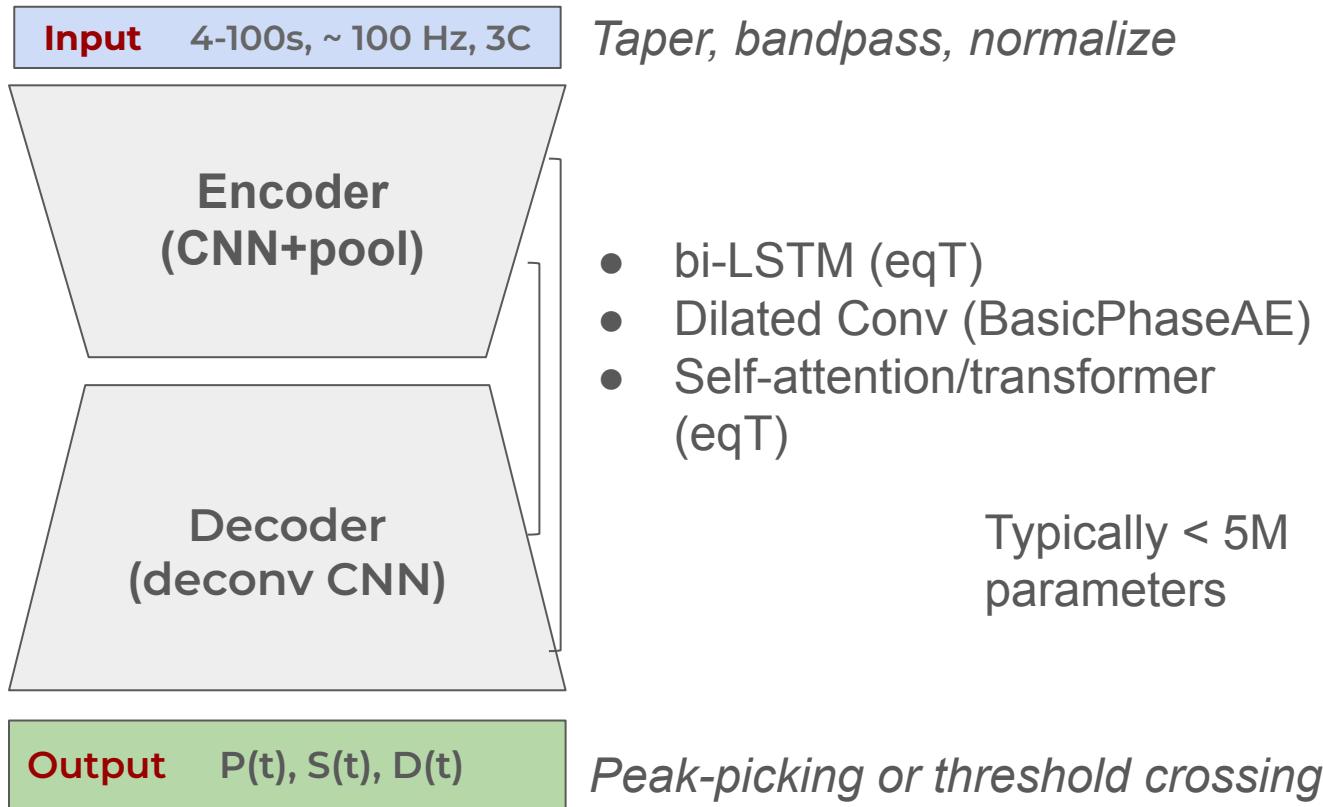
- PhaseLink (Ross et al., 2019)
- GaMMA (Zhu et al, 2021)
- Neuma (Ross et al., 2023)
- PyOcto (Münchmeyer, 2023)
- GENIE (McBreatry&Beroza, 2023)

Workflows

- easyQuake (Walter et al., 2021)
- SeisBench (Woollam et al., 2022)
- QuakeFlow (Zhu et al., 2022)
- Loc-Flow (Zhang et al., 2022)
- QuakeScope (Ni et al, *in prep*)

Model Architectures - Many U-Nets

Input	4-100s, ~ 100 Hz, 3C

Taper, bandpass, normalize

Encoder (CNN+pool)

Decoder (deconv CNN)

- bi-LSTM (eqT)
- Dilated Conv (BasicPhaseAE)
- Self-attention/transformer (eqT)

Typically < 5M parameters

Output	P(t), S(t), D(t)

Peak-picking or threshold crossing

Pure U-nets
(PhaseNet, BasicPhaseAE, ARRU)
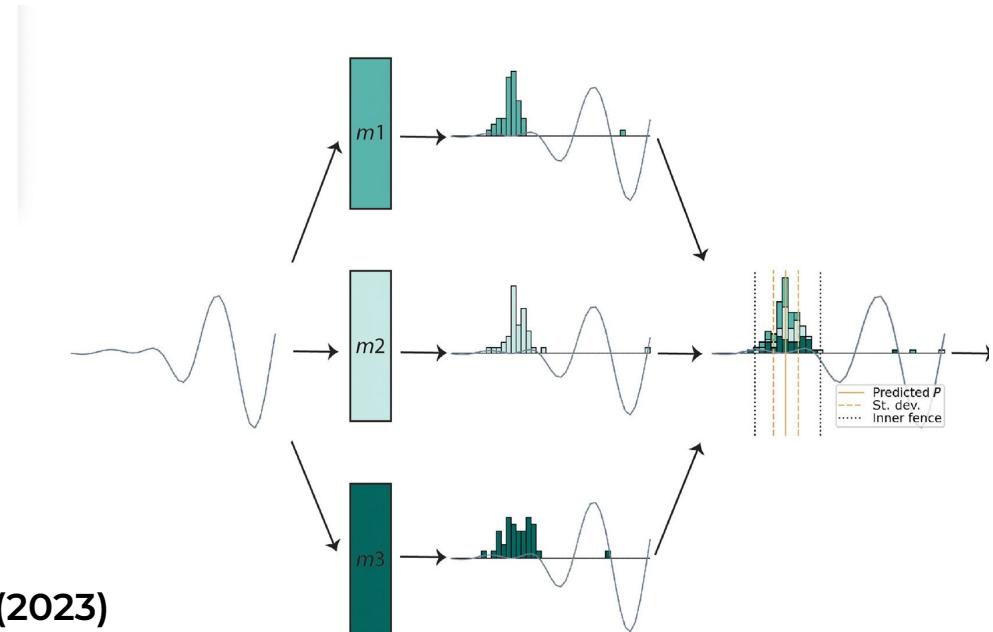
Hybrid CNN-RNN-Attention
(EqT)

Ultra-light CNN
(GPD, PickNet)
great for IoT
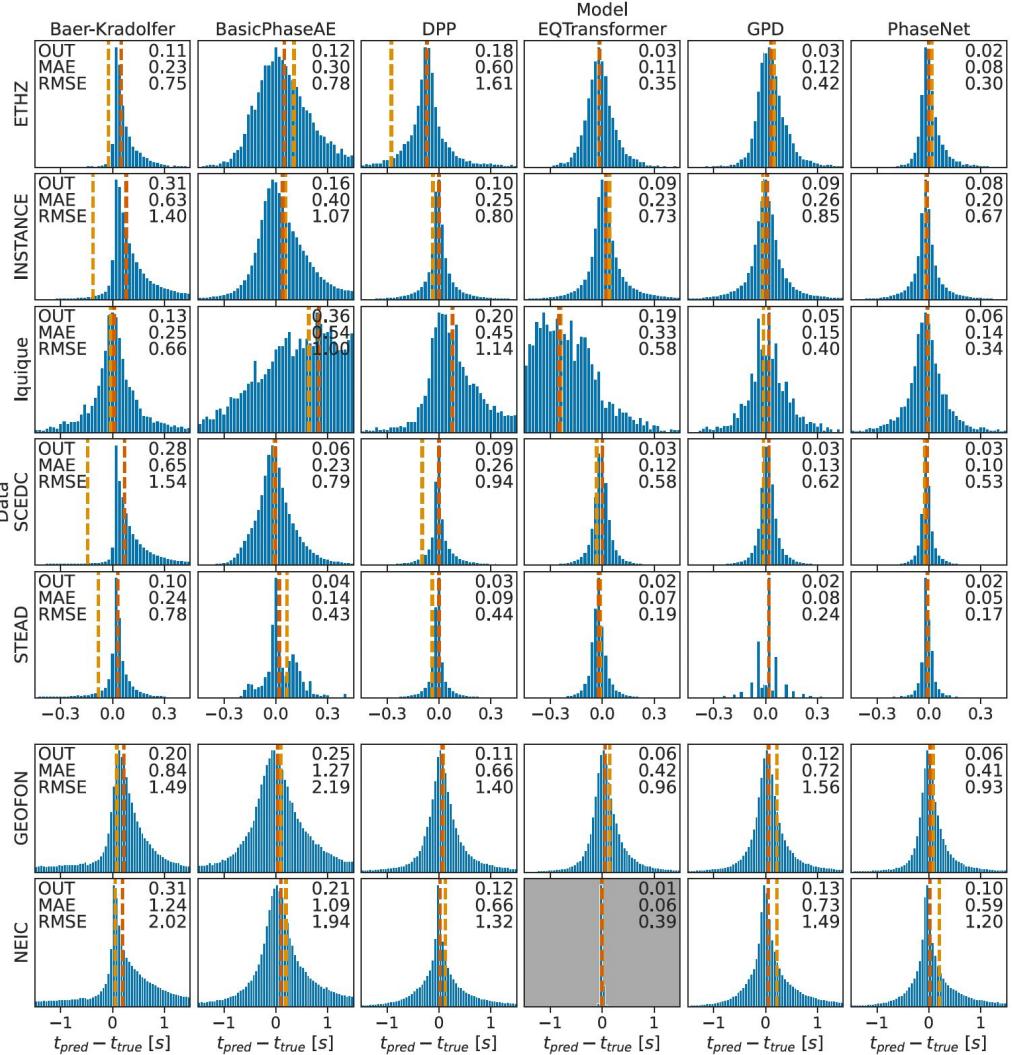
Domain-specific
Add hydrophone channel as input (PickBlue)

# What is the uncertainty of picks?

- Uncertainties from seismic analyst are typically not included in the training.
- Most labeling assumes a fixed gaussian/triangle uncertainty

- DL model uncertainties can be estimated using **Dropout** in inference.
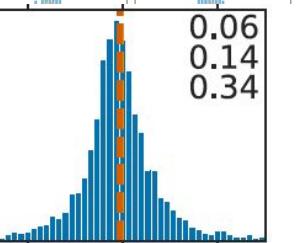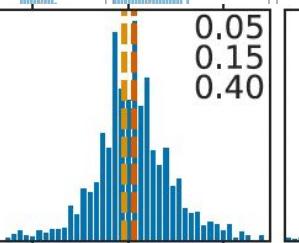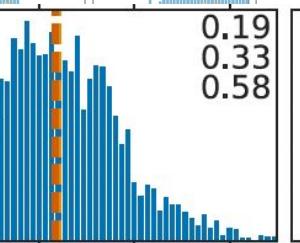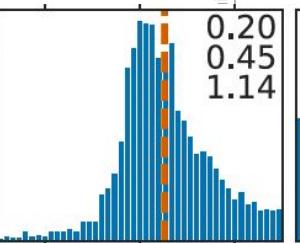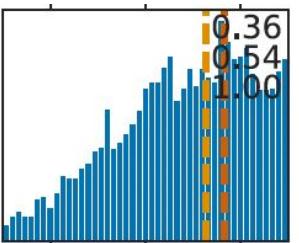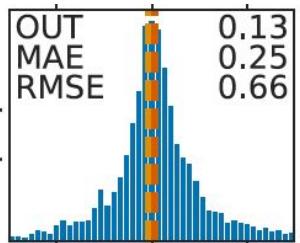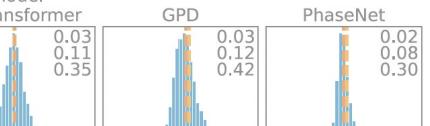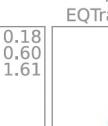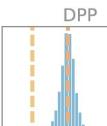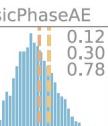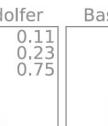
Armstrong et al. (2023)

DL Picker's performance

Munchmeyer et al. (2022)

DL Picker's performance

Munchmeyer et al. (2022)

DL Picker's performance

Munchmeyer et al. (2022)
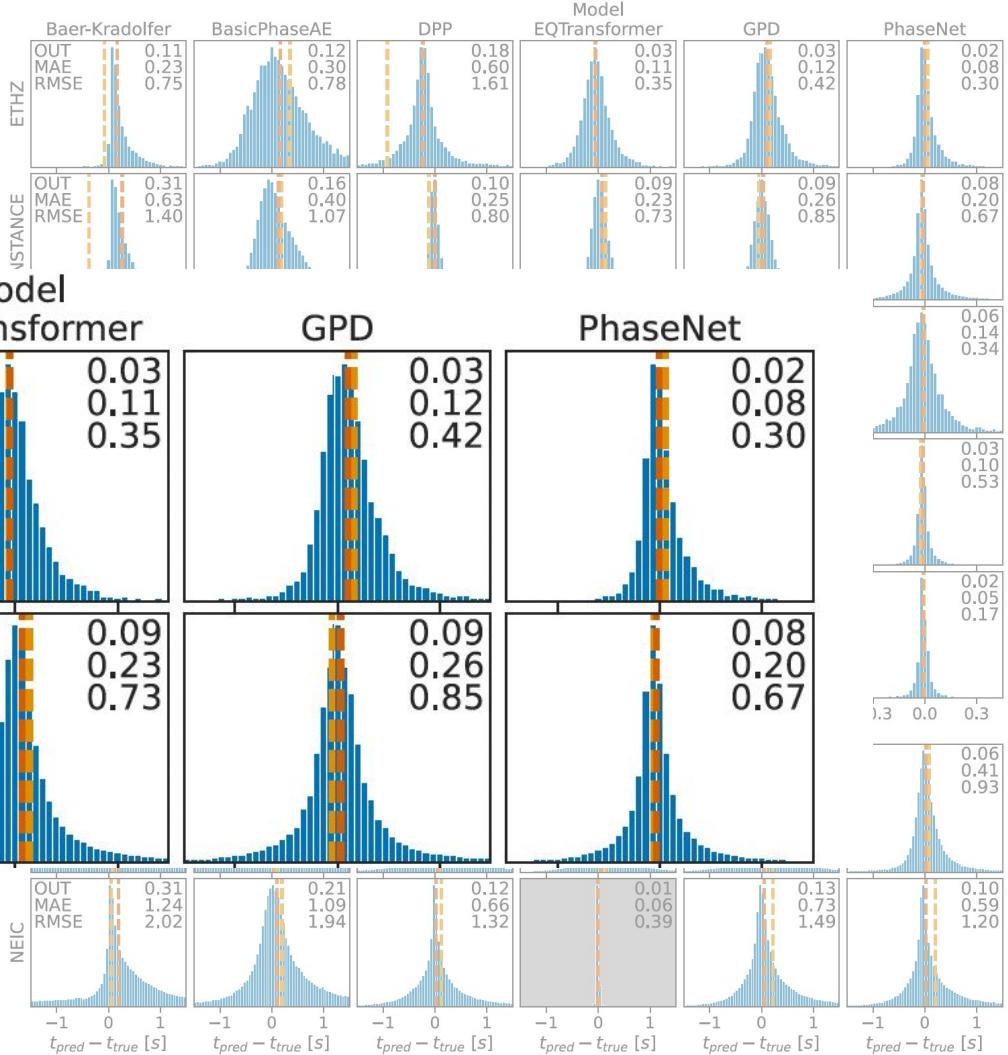
Ensembling over datasets and model architecture: ELEP (Congong Yuan & Yiyu Ni)

YUAN et al.: BETTER TOGETHER: ENSEMBLE LEARNING FOR EARTHQUAKE DETECTION AND PHASE PICKING

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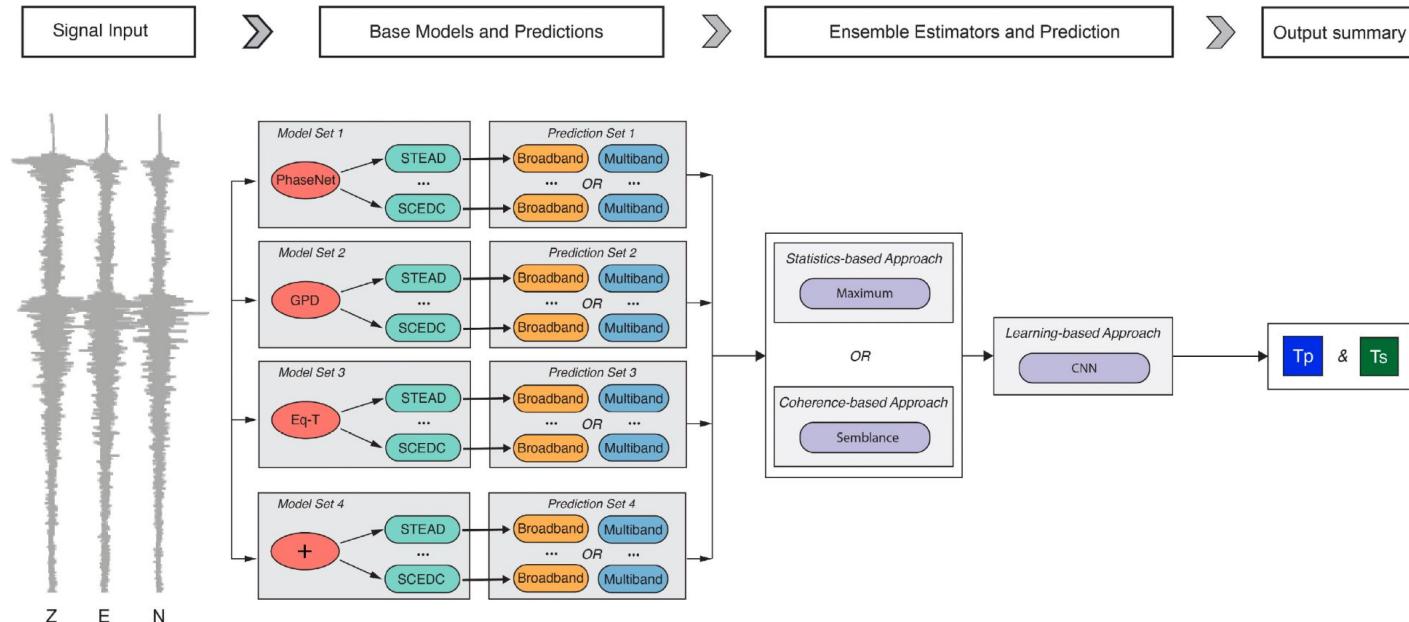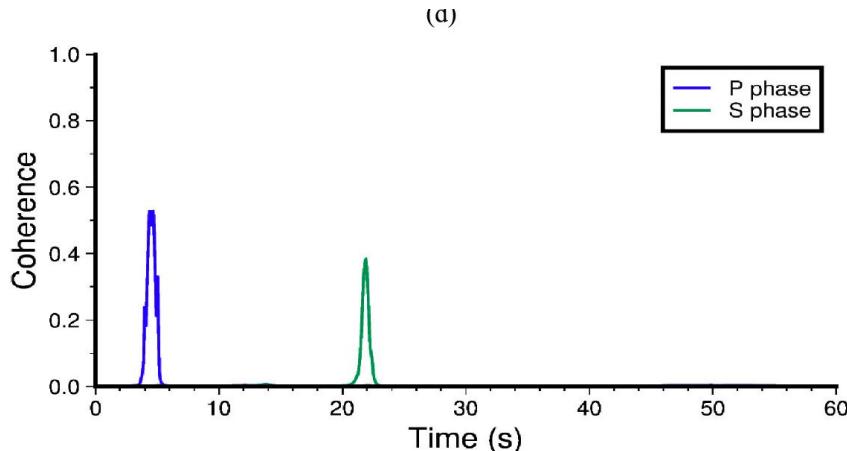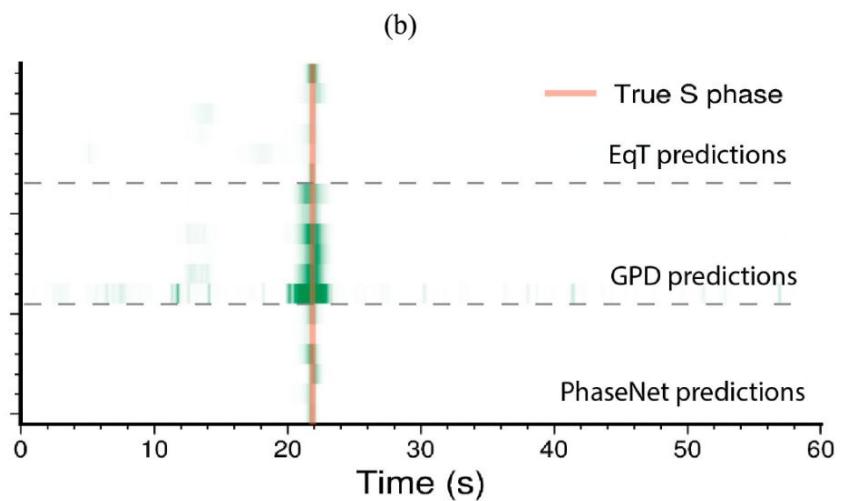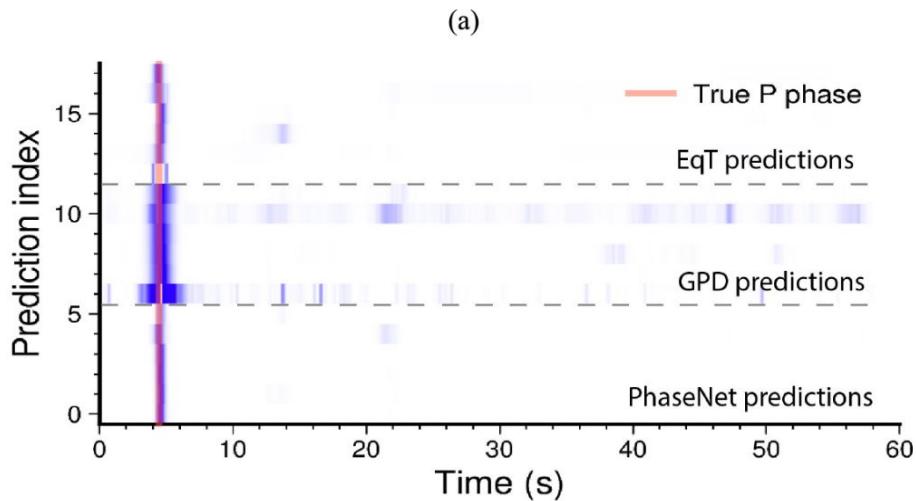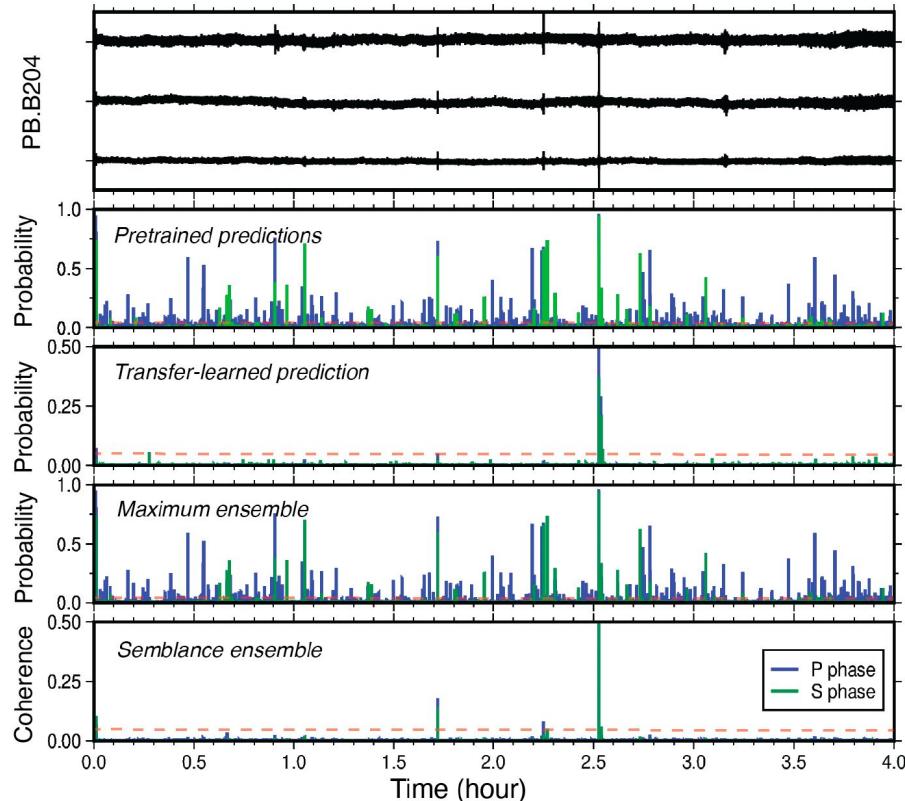
Fig. 1.   Ensemble estimation-based framework for earthquake detection and phase picking. The main components include base predictions at BB or multiple-frequency bands (e.g., filtered data) and ensemble estimation by either statistics-, coherence-, or a learning-based approach. Note that only EqT-based pretrained models are tested.
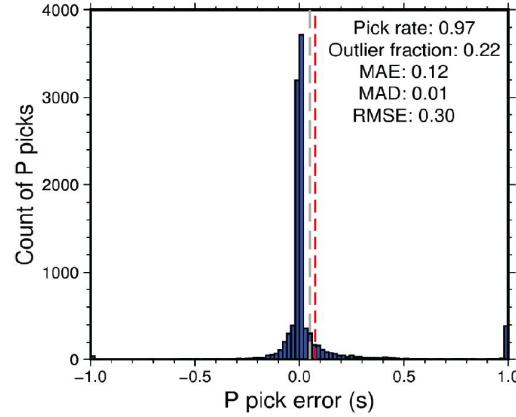
**Yuan et al. (2023)**

While individual models may be uncertain, the semblance/coherence of their prediction is robust.

Yuan et al. (2023)

Reduced false positives. As accurate as transfer learned models. No training required.
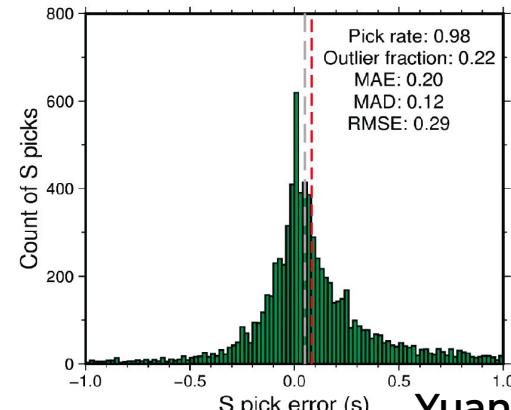
**OBS benchmark dataset**

Mt St Helens
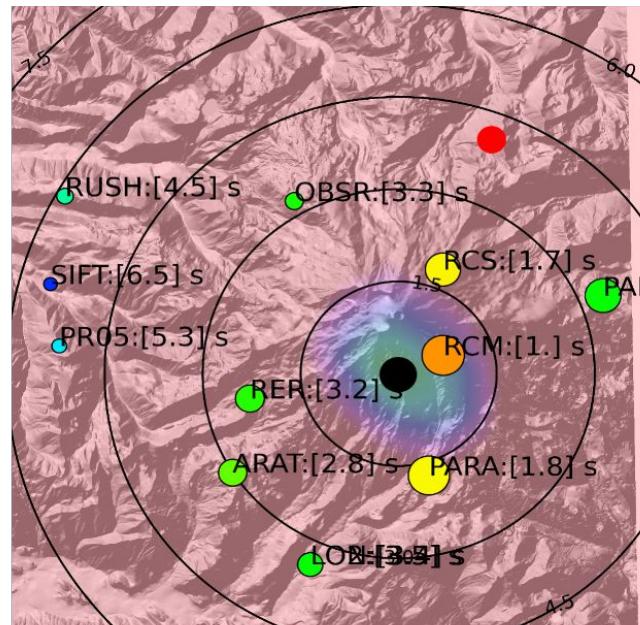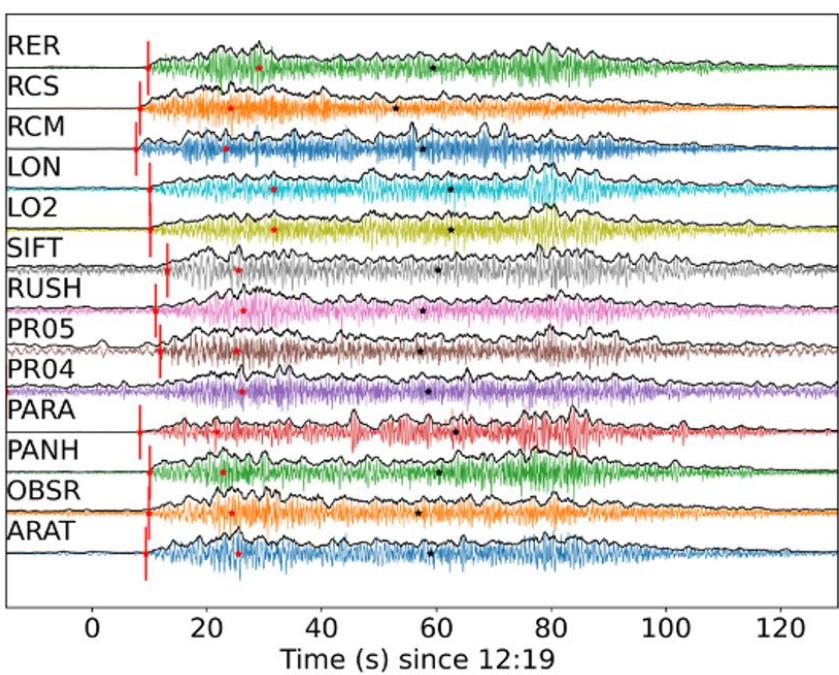
Yuan et al. (2023
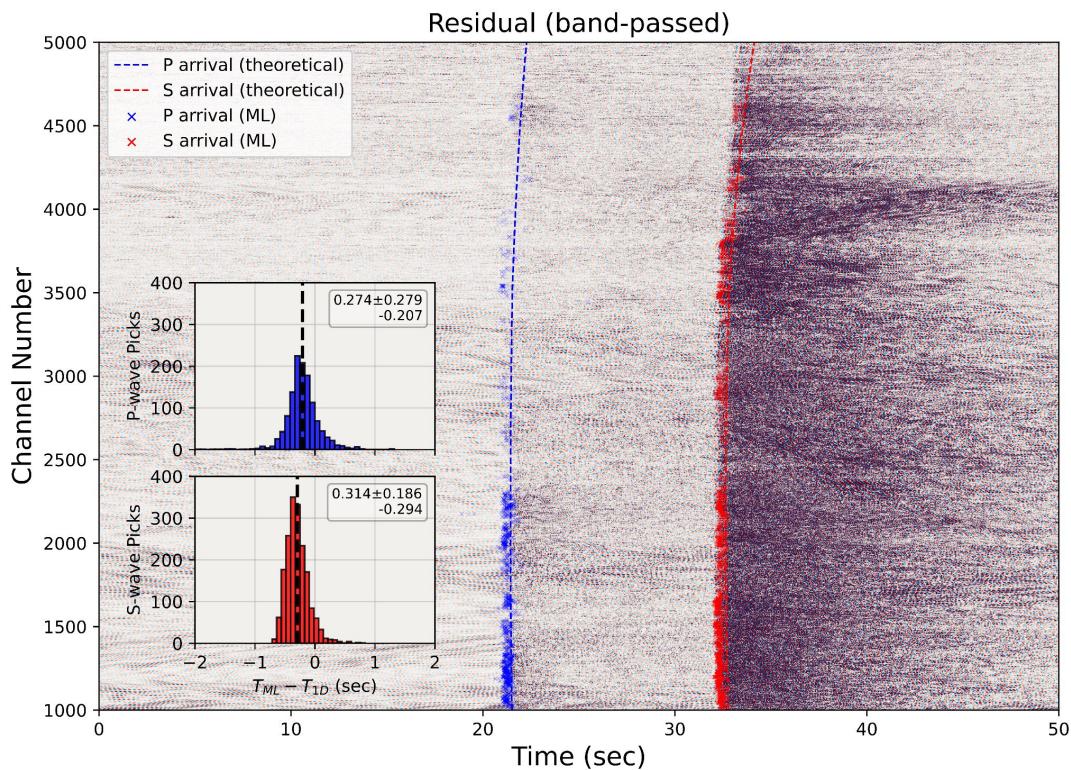
Ensemble deep learning generalizes to detected other types of seismic events
## *Avalanches at Mt Rainier*

Denolle et al. (in prep)
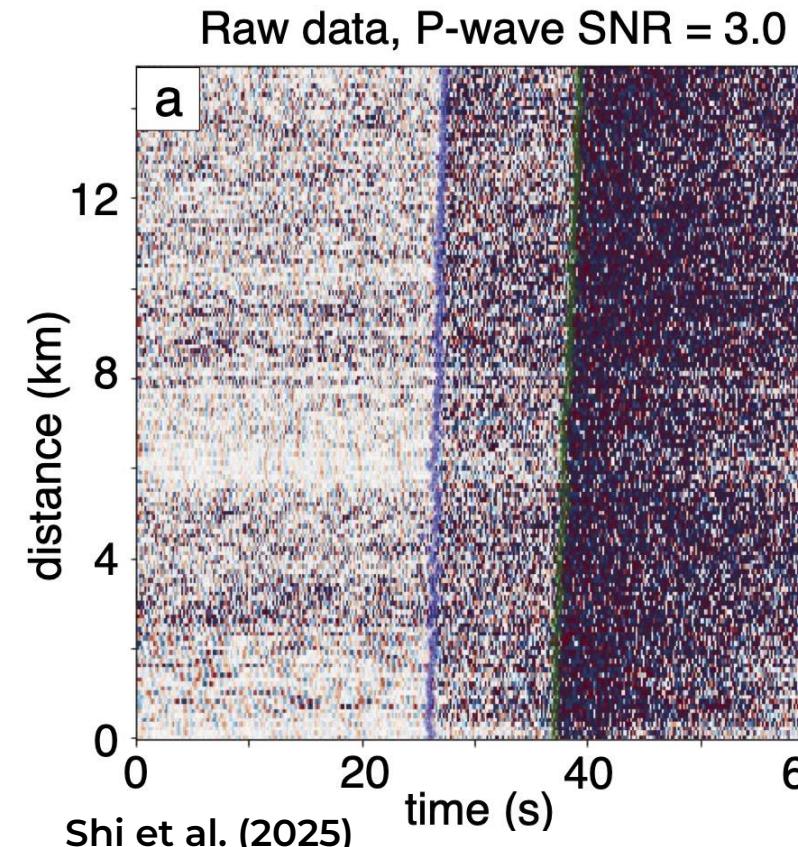
Ensemble deep learning generalizes to detected other types of seismic events
Detecting Earthquakes on DAS

Ni et al. (2024)

Shi et al. (2025)

Merci

github.com/Denolle-lab
github.com/niyiyu
github.com/seisscoped/quakescope
github.com/congcy/ELEP
https://cascadiaquakes.github.io/2025_ML_TSC/intro.html