An Integrated Machine Learning Framework for Fault Imaging from Event Detection, Phase Arrivals, and Source Plane Construction Using Raw Continuous Waveform Data.

Daniel Lizama, Hongkyu Yoon, , Jennifer L. Harding: Sandia National Laboratories, New Mexico, US

SAND2024-10020C

Science-informed Machine Learning to Accelerate Real Time (SMART) Decisions in Subsurface Applications

Motivation: We develop an integrated deep learning (DL) models approach for fast and accurate identification of microseismic (MS) source locations for MS data observed from geologic CO2 storage project at the Illinois Decatur Basin Project (IBDP)[1] (Fig. 1).

IBDP Site: Geophones recording array for continuous passive MS signals before, during, and after CO2 injection in deep reservoir formation. We analyze MS activity over a short time period (Feb. 27 - Mar. 12, 2012) with a total of 612 located events in the catalog. We use three channel time-series data from the lowest geophone.

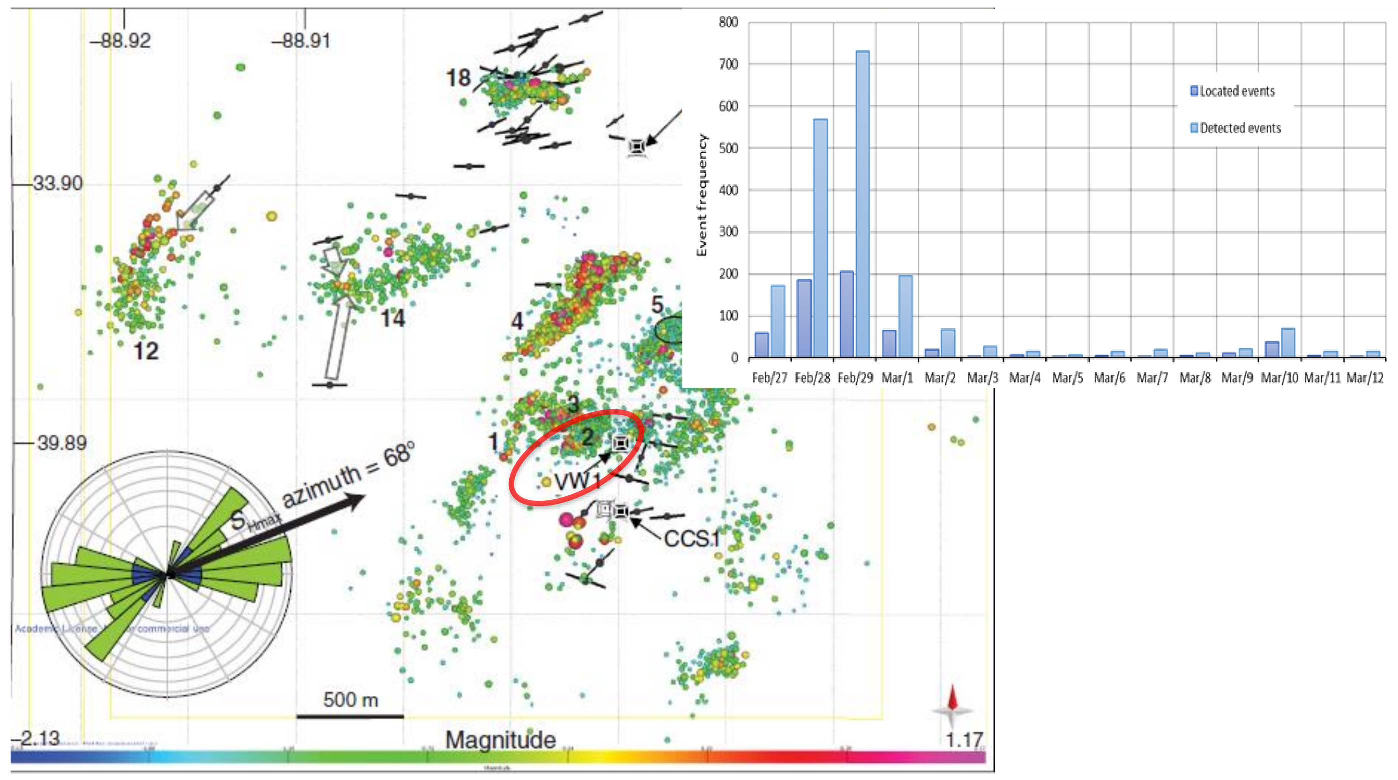

Figure 1. IBDP site events and Cluster #2 overview. [2]

Event Detection (Figure 2)

- CNN model with time-frequency feature extraction capability for fast and accurate MS event detection.
- Obtain new accurate MS event detections for reservoir analysis.

Phase-pick (Figure 3)

- Integrate a PhaseNet [4] model optimized for MS events phase picking.
- Obtain high precision MS waveform phase arrival time information.

Source Location (Figure 5-7)

- CNN architecture with multiple input modality feature extraction capabilities for high fidelity MS event source location identification.
- Implement trained model on field data to identify discrete fractures.

Data Augmentation (Figure 4)

- Train a multi-channel WGAN-GP [3] model to emulate field MS waveform characteristics for a given event source locations.
- Generate new waveform for a variety of locations in the region

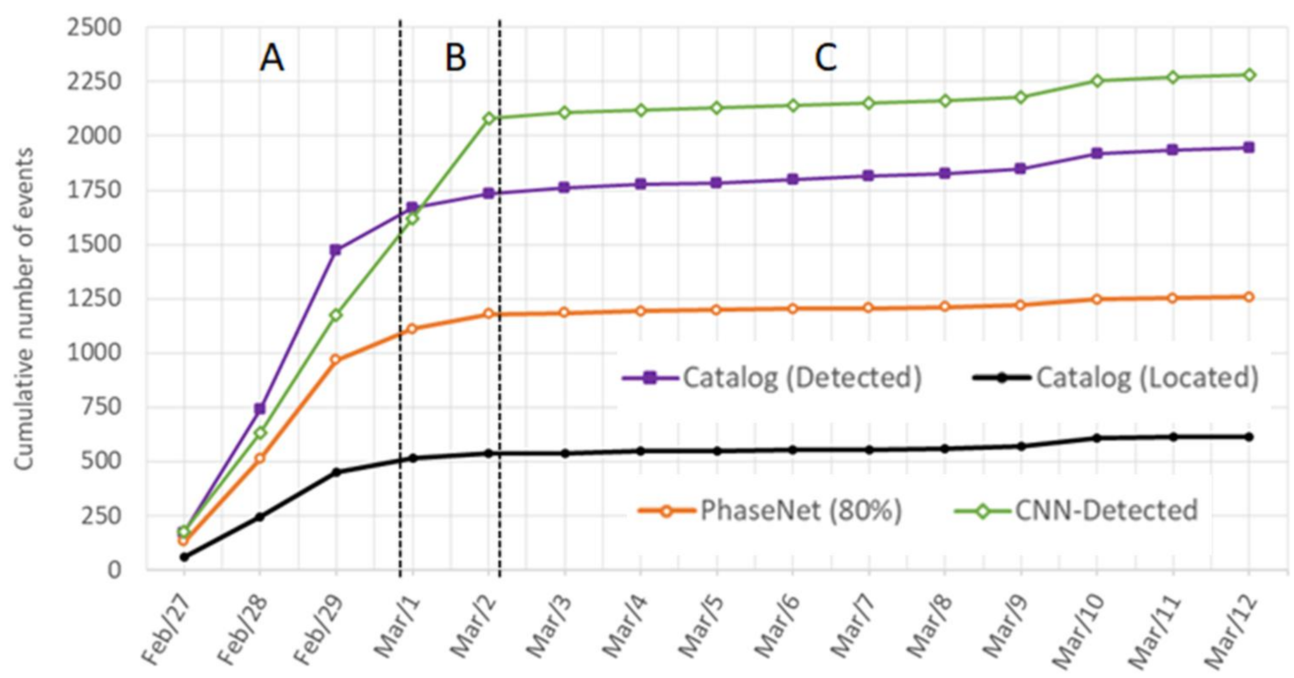

Figure 2. Cumulative detection of MS events for traditional and DL algorithms. Our DL Models achieve better precision.

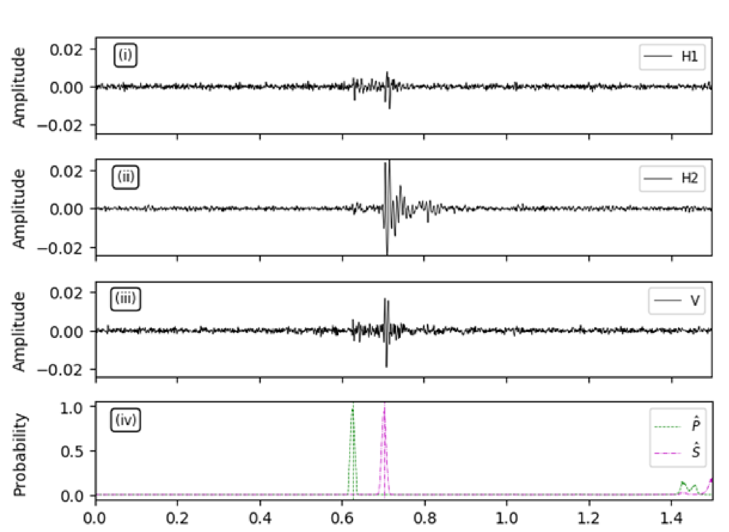

Figure 3. PhaseNet phase picking sample.

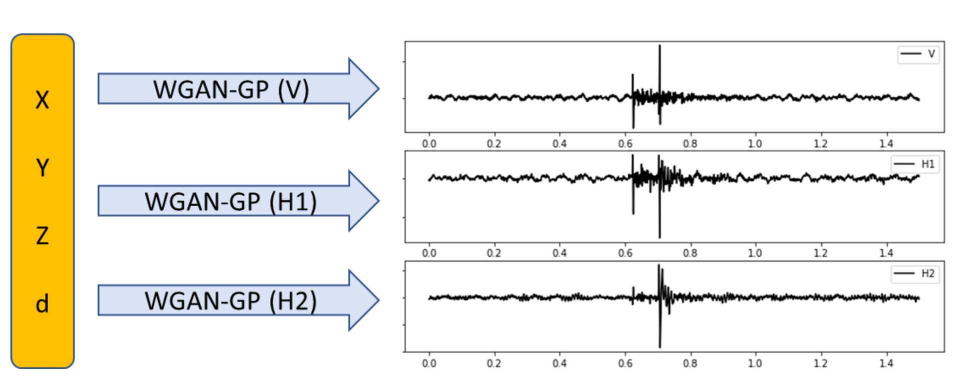

Figure 4. Seismogram generative model using multiple Wasserstein generative adversarial network with gradient penalty (WGAN-GP). Waveform modulations and phase arrivals assimilate field data well.

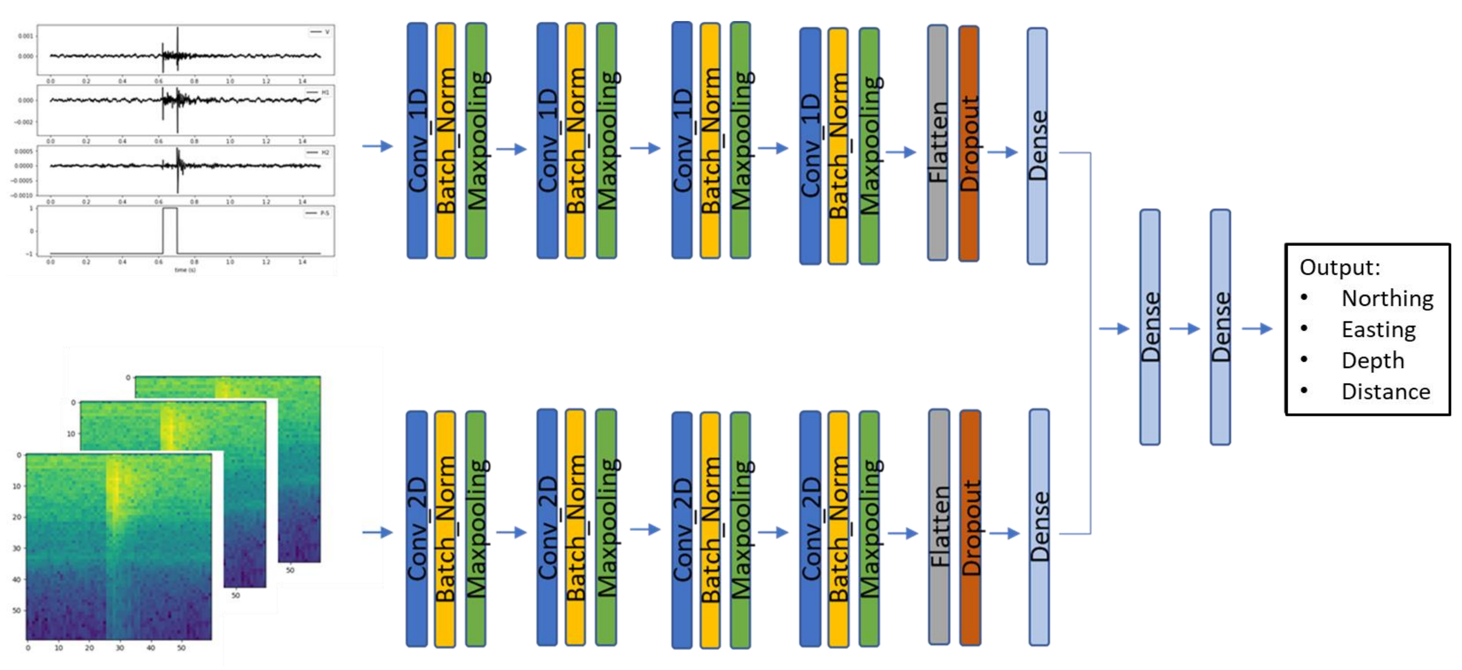

Figure 5. Multi-head CNN (MHCNN) architecture for microseismic source location with separate feature extraction pipelines and their input modality.

Conclusions

- We combined WGAN-GP and PhaseNet to produce quality P & S phase arrivals for event samples. Data augmentation boosts MHCNN task optimization.
- Our integrated DL model approach achieves rapid and accurate source location and fault fracture identification.
- Source location of new detections proposes an extension of the main fault moving deeper in the reservoir.

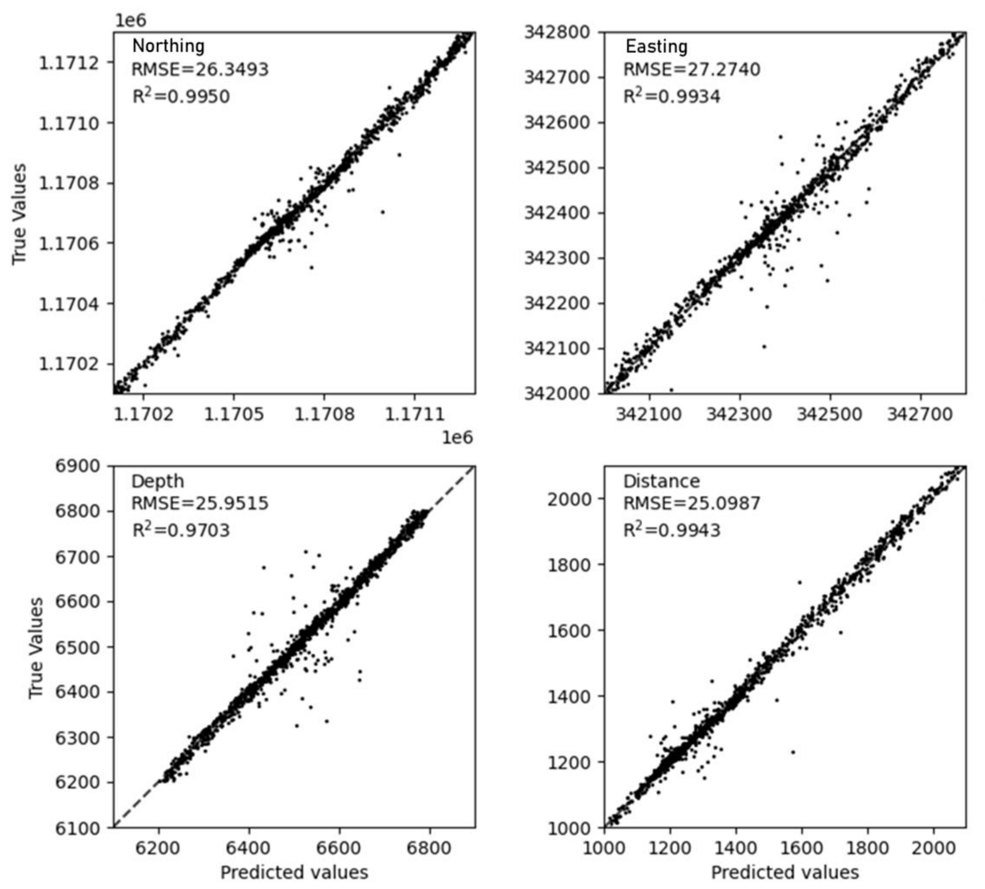

Figure 6. MHCNN model performance of source location coordinates for 1,211 samples. Predictions accuracy increased, highly coinciding with true values after augmentation.

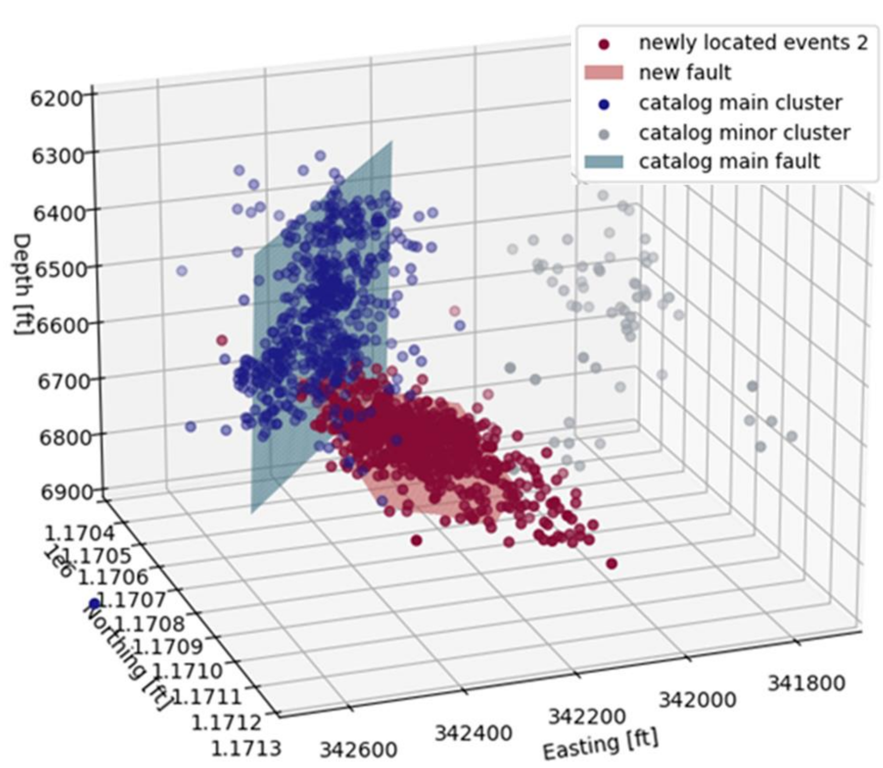

Figure 7. IBDP discrete fracture projection of the original catalog and new detections. Our models estimate both fault planes connecting at the lowermost section.

References

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3. Spurio Mancini, A., Piras, D., Ferreira, A. M. G., Hobson, M. P., and Joachimi, B.: Accelerating Bayesian microseismic event location with deep learning, Solid Earth, 12, 1683–1705, https://doi.org/10.5194/se-12-1683-2021, 2021.
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Acknowledgments:
U.S. DOE, Office of Fossil Energy and Carbon Management, Fossil Energy Research and Development Program (DE-FE0031685, project title: Identification of Faults Susceptible to Induced Seismicity)U.S. DOE, Office of Fossil Energy and Carbon Management, Science-informed Machine Learning to Accelerate Real Time (SMART) Decisions in Subsurface Applications.
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