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Improving real-time passive seismic monitoring with AI-based phase pick quality control

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Summary

Near real-time passive seismic monitoring is increasingly relied upon to support risk management, regulatory compliance, and operational decision-making in both induced and natural seismicity settings. Neural-network-based automatic detectors have significantly improved sensitivity and coverage; however, a large fraction of automatically generated events still require manual review to correct phase picks and remove false positives, limiting catalog timeliness and consistency. This work describes an AI-based phase pick classifier that learns array-specific analyst behavior and filters low quality or misplaced automatic picks prior to final location and magnitude estimation, enabling a higher proportion of automatic events to reach manual-quality standards while reducing manual workload.

Theory & Method

Initial picking and locations of seismicity are facilitated by a convolutional neural network trained on a diverse dataset of P and S observations to convert raw waveform data into phase pseudo-probability time series. These probability traces are beamformed in space and time to identify candidate hypocenters, from which phase picks are extracted by aligning high network probability with travel-time predictions; this first stage is tuned for high recall, intentionally gathering a generous set of candidate picks to avoid missing real arrivals. A second-stage phase pick classifier, implemented as a gradient-boosted trees model trained on a per-array basis, uses features describing pick characteristics, waveform context, and event geometry to estimate the probability that a given automatic pick would be retained during manual processing, and removes low-probability picks before final event location, magnitude calculation, and catalog integration.

To evaluate and control the quality of resulting catalogs, a separate quality model framework is

employed that learns statistical patterns from an existing, array-specific manually processed earthquake catalog. The quality model summarizes how well each event's parameters (such as location, magnitude, and network geometry indicators) fit the established manual catalog as a single quality rating, which can then be thresholded to identify events whose quality is greater than or equal to typical manual results and to benchmark automatic processing performance.

Results & Conclusions

The integrated workflow is evaluated on two large, seismically active arrays in North America, each with more than 50 stations, over ten thousand cataloged events, and a magnitude of completeness near M0.0, representative of high-sensitivity monitoring scenarios. Incorporating the phase pick classifier on top of the neural-network and beamforming system yields substantial improvements in automatic event quality, including typical gains on the order of 25–28% in location accuracy, 50–57% in magnitude estimation, 23–56% reduction in false positive count, and 22–46% in catalog quality rating, while increasing the proportion of automatic events meeting or exceeding manual quality to approximately 75%.

Figure 1 summarizes these comparison results for "Array A" and "Array B", showing epicentral distance and magnitude differences between automatic and manual solutions, as well as histograms of quality-model ratings and the corresponding fraction of high-quality automatic events. The spatial patterns of seismicity, displayed in Figure 2, show tighter clustering for automatic locations, reduced location bias near array edges, and, in many cases, event distributions that visually appear more consistent than those from manual catalogs, indicating that a well-tuned AI workflow can match or surpass human performance while enabling lower-latency, more consistent seismicity products.

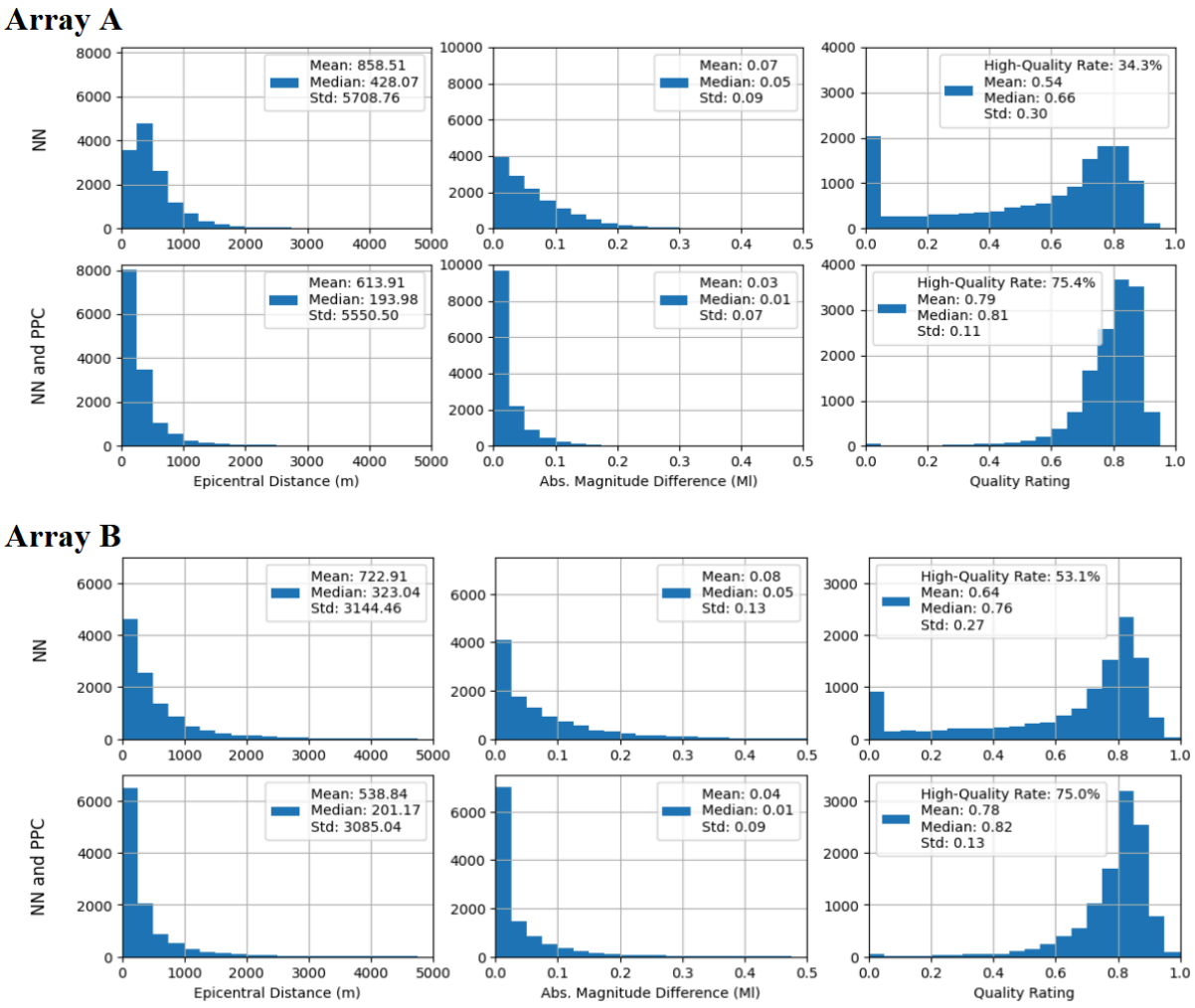


Figure 1. For Array A and Array B, display compares automatically generated events before applying PPC (top row, NN) and after applying PPC (bottom row, NN and PPC). Epicentral (XY) distance and absolute magnitude (Ml) difference are displayed in the left and middle columns respectively, which compare matching automatically generated and manually processed events. A histogram of quality rating values for each catalog is shown on the right column, and an estimate of the percentage of high quality automatic events is displayed in corresponding legend

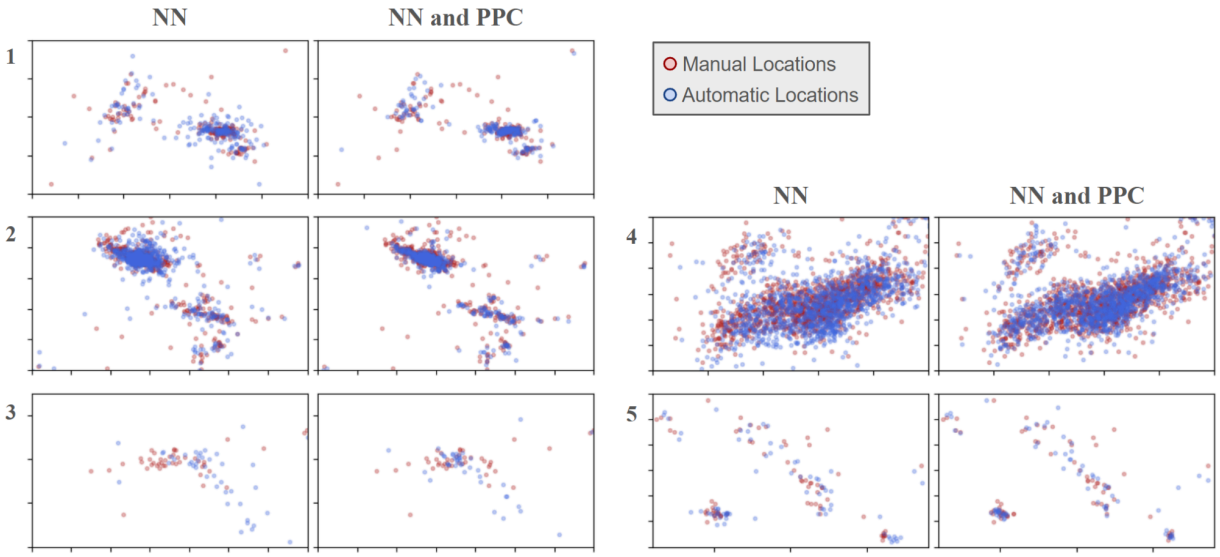


Figure 1. Earthquake locations (easting, northing) obtained from manual processing (red) and AI-automatic processing (blue). Compares neural network only (NN) and neural network with the application of phase pick classification (NN and PPC) across 5 various regions within Array A and Array B.

Novel Information

A key contribution of this work is the explicit use of human-in-the-loop information—manual pick retention and rejection decisions—to train an array-specific phase pick classifier that captures local analyst practices and noise conditions, rather than relying solely on globally trained neural networks. The combination of a high-recall neural-network detector, beamforming-based location, an independent quality model, and a per-array phase pick classifier forms a hierarchical AI architecture that not only improves event locations and magnitudes, but also directly reduces manual review effort and catalog latency in dense, high-activity monitoring environments. This framework provides a scalable path toward fully automated, high-confidence seismic catalogs that support modern regulatory, operational, and risk-mitigation demands.