Supervised Deep Learning Models to Improve the Yellowstone Seismic Catalog

Supervised deep learning is becoming a standard method of detecting and processing earthquakes as it can quickly and reliably generate analyst-quality arrival time picks. This method is ideal for areas of abundant seismicity that often have events occurring close together in time, such as Yellowstone National Park. In Yellowstone, the presence of hydrothermal fluids and magma related to the volcanic system leads to ~50% of the seismicity occurring in swarms. Standard processing workflows often capture only a subset of the events during periods of high seismicity and struggle to detect smaller magnitude (<M2) events. We anticipate that increasing the size of the Yellowstone earthquake catalog will allow for detailed analysis of swarm migration, improved tomographic imaging, fine-scale mapping of fault architectures, and more. Additionally, an improved automated system will aid in producing rapid and accurate earthquake products in situations of unrest, thus increasing prepardness for emergency situations.

Using a supervised deep learning approach, we produce an improved catalog of phase arrival times and P-wave first motions for the Yellowstone region. To the best of our knowledge, similar studies for other regions train their models using only three-component data. Since many of our observations in Yellowstone are made on single-channel seismometers, we develop a method to detect phase arrivals using only the vertical component. We also use data augmentation to enhance the success of our models in periods of dense seismic activity. Additionally, we use MultiSwag to approximate P-pick uncertainty and compare it to analyst assigned pick-quality. We demonstrate our new methodology by applying it to a seismic swarm occurring in the Norris Geyser Basin from September 2013 into June 2014. This period includes an M_w 4.8 event, the largest Yellowstone earthquake in over 35 years.

We have applied our deep learning pipeline to continuous seismic data from 26 stations (17 three-component and 9 single-channel) operating over 25 March 2014 to 03 April 2014. Initial results show 630 new, locatable events, representing a ~2.5x increase from the UUSS catalog. Figure 1 demonstrates that our method is capable of detecting the phase-arrivals of small Yellowstone events occurring close together in time. Only 5 of the events shown meet our association and location requirements, suggesting our total event count is conservative. The recall of our automated system is 79%, while that of the standard automated system (AQMS) used by the UUSS is 63%. Though our system missed 49 UUSS catalog events, 44 of these were manually created by seismic analysts post hoc, and correspond to small or overlapping events. The accuracy of the P-wave first motions is ~95% when considering up and down labels. Initial results suggest that our new automated system substantially improves the processing of this swarm relative to the conventional UUSS approach.

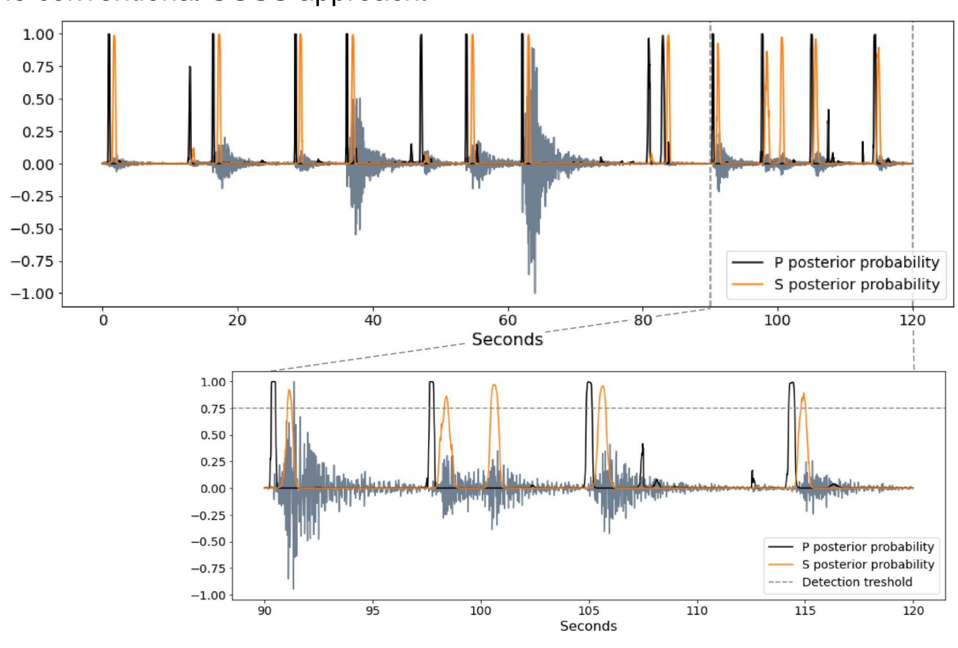

Figure 1. Two minutes of continuous, normalized seismic data (gray) from station WY.YNR.HHZ, starting at UTC 13:30:51.50 on 03/30. P-phase (black) and S-phase (yellow) detection probabilities greater than 0.75 are passed to the next processing step. There are no UUSS catalog events during this time.