Evaluation of deep-neural-network-based seismic arrival-time picking method for S-net data

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The number of detectable earthquakes is increasing rapidly as seismograph networks expand. Off the Pacific coast of Tohoku Japan, seismograms recorded by a 150 cabled ocean bottom seismic stations (S-net) available from 2016 enable much clearer characterization of offshore seismicity. Many approaches to automatic phase picking methods have been proposed to improve seismic monitoring. In this study, we evaluate an arrival-time picking method based on a deep neural network, PhaseNet (Zhu and Beroza, 2019), to detect and locate more earthquakes offshore Tohoku. PhaseNet estimates P and S arrivals as probability distributions using three-component seismic waveforms. PhaseNet has already achieved good performance for the Northern California Earthquake Data Center Catalog using the model trained by the seismograms of the region as input.

To evaluate the performance of the deep-neural-network-based seismic arrival-time picking model, we compared the output of PhaseNet with manual picks for S-net data. We used 512 offshore earthquakes listed in the Japan Metrological Agency (JMA)'s catalogue which are detected by land stations and the manual picks for S-net performed by the analysts in Graduate School of Science, Tohoku University. Please note that in this comparison we have not re-trained PhaseNet model with S-net arrival data for the evaluation of the model. According to the application for 22 stations belonging to the S-net S1 cable during 22 months, PhaseNet detected P-picks within 0.1 second from the manual picks (hereafter we call this good P or S-picks) for about the half of input, and good S-picks for 24.7% of input. We note that the data of S-net located at the ocean bottom tends to have weaker first arrivals for P and S waves than do on land stations on which the model was trained.

To evaluate the performance with existing method, we compared the result of PhaseNet with the 'auto pick' function of the WIN system (Urabe and Tsukada, 1991). We found that the ratio of good P-picks is larger for PhaseNet (53.2%) than that for the WIN system (21.4%). For S-wave, PhaseNet also achieves a higher ratio (24.7%) than that for the WIN system (10.0%). We also compared the results with the automatic earthquake location system in operation at Tohoku University (Horiuchi et al., 2014; Nakayama et al., 2014). Please note the system is working for land stations and the comparison does not contains S-net data as input. For 695 waveform data recorded in January 2017, PhaseNet was able to detect 99.9% of the P-picks with high precision (81.4%) and recall rate (81.3%) that are two standard performance measures for deep learning models (Zhu and Beroza, 2019). In addition, the performance for S-wave is much better than existing methods (the Tohoku University's automatic earthquake location system and the WIN system could detect good S-picks for about 10 % of input, but the PhaseNet detected 54.8% of input).

These results suggest that even for S-net data, PhaseNet is an effective method to find accurate arrival times for both P and S waves, though the performance could be improved with a re-trained model. We expect that arrival-time picking methods based on deep neural networks will help reveal the distribution of small earthquakes in offshore Japan from continuous S-net waveform data.

Acknowledgements: We thank the staff of the National Research Institute for Earth Science and Disaster Resilience who deployed the S-net, maintained the network and opened the data to the public.

Keywords: S-net, Neural networks, Computational seismology, Seismic monitoring