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Combing empirical matched field processing at IMS station SPITS and convolutional neural networks for calving event detection in Svalbard

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We combine the empirical matched field (EMF) method and machine learning using Convolutional Neural Networks (CNNs) for calving event detection at the IMS station SPITS and GSN station KBS on the Arctic Archipelago of Svalbard. EMF detection with seismic arrays seeks to identify all signals similar to a single template generated by seismic events in a confined target region. In contrast to master event cross-correlation detectors, the detection statistic is not the waveform similarity, but the array beam power obtained using empirical phase delays (steering parameters) between the array stations. Unlike common delay-and-sum beamforming, the steering parameters do not need to represent a plane wave and are directly computed from the template signal without assuming a particular apparent velocity and back-azimuth. As for all detectors, the false alarms rate depends strongly on the beam power threshold setting and therefore needs appropriate tuning or alternatively post-processing. Here, we combine the EMF detector using a low detection threshold with a post-detection classification step. The classifier uses spectrograms of single-station three-component records and state-of-the-art CNNs pre-trained for image recognition. Spectrograms of three-component seismic data are hereby combined as RGB images. We apply the methodology to detect calving events at tidewater glaciers in the Kongsfjord region in Northwestern Svalbard. The EMF detector uses data of the SPITS array, at about 100 km distance to the glaciers, while the CNN classifier processes data from the single three-component station KBS at 15 km distance using time windows where the event is expected according to the EMF detection. The EMF detector combines templates for the P and for the S wave onsets of a confirmed, large calving event. The CNN spectrogram classifier is trained using classes of confirmed calving signals from four different glaciers in the Kongsfjord region, seismic noise examples, and regional tectonic seismic events. By splitting the data into training and test data set, the CNN classifier yields a recognition rate of 89% on average. This is encouragingly high given the complex nature of calving signals and their visually similar waveforms. Subsequently, we process continuous data of 6 months in 2016 using the EMF-CNN method to produce a time series of glacier calving. About 90% of the confirmed calving signals used for the CNN training are detected by EMF processing, and around 80% are assigned to the correct glacier after CNN classification. Such calving time series allow us to estimate and monitor ice loss at tidewater glaciers which in turn can help to better understand the impact of climate change in Polar regions. Combining the superior detection capability of (less common) seismic arrays at a larger source distance with a

powerful machine learning classifier at single three-component stations closer to the source, is a promising approach not only for environmental monitoring, but also for event detection and classification in a CTBTO verification context.