Limburg seismic campaigns
Intermediate report

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Summary

The ultimate goal of the E-TEST project is to facilitate the design and construction of a gravitational wave detector, also known as the Einstein Telescope, in the Euregio Meuse-Rhine region. Ground motions and seismic vibrations in the subsurface affect the accuracy and sensitivity of the detector. It is therefore crucial to characterize the sources that cause vibrations and to quantify the amplitude and frequency content of the ambient seismic field. Earthquakes, mining and quarry blasts, wind turbines, trains tracks, highways, industrial plants, and other natural and human-made sources all generate seismic vibrations.

A series of seismic acquisition campaigns are planned to measure these seismic vibrations, and to investigate the amplitude distribution, attenuation, and frequency content. Additionally, these data are leveraged to image the subsurface and gain insight to the geological structure and its complexity. In this intermediate report we describe our ongoing effort related to the above topics and provide an initial glimpse into some of the data we have collected.

Background

The first territorial challenge of E-TEST (**E**instein **T**elescope **E**uregio Meuse-Rhine **S**ite & **T**echnology) lies both in the size of the Einstein Telescope (ET), spanning roughly a triangle of 10 km long sides in the area between The Netherlands, Belgium and Germany at a depth of roughly 300 meters below the surface (see Figure 1. One of the main activities of E-TEST, is to model the geological conditions that will host the infrastructure of the underground observatory in the EMR region.

The Department of R&D Seismology and Acoustics (RDSA) of the Royal Dutch Meteorological Institute (KNMI) has a network of seismometers in Limburg to monitor natural seismicity. Tectonic earthquakes in Limburg occur in and near the Roeldalslenk, which is bounded by the Feldbiss and Peelrand fault. The seismic noise, relevant for the ET, can be determined with the seismometers, both at the surface of the earth and at depth.

An important constraint for locating the ET is the local seismic noise: ambient vibrations that more-or-less continuously shake the earth. This noise is strongly varying as function of location and depth. At the drilled holes, the seismic noise can be directly measured at the earth's surface and at depth, to find attenuation with depth. Existing seismic instruments in the region also provide local seismic noise recordings. This suffices to characterize the low-frequency component of the noise, which is primarily generated at the oceans. However, there are several other sources that generate seismic vibrations at higher frequencies. Notorious sources for example, are highways and wind turbines. An estimation of the strength of these sources is needed, together with seismic parameters of the near surface, to model the attenuation of the seismic waves away from the prominent sources. Several dense array seismic acquisition campaigns are planned to continuously record the ambient seismic noise over a period of roughly one month at the time (see Figure 1). The recordings of the seismic noise at many locations allows us to quantify the amplitude

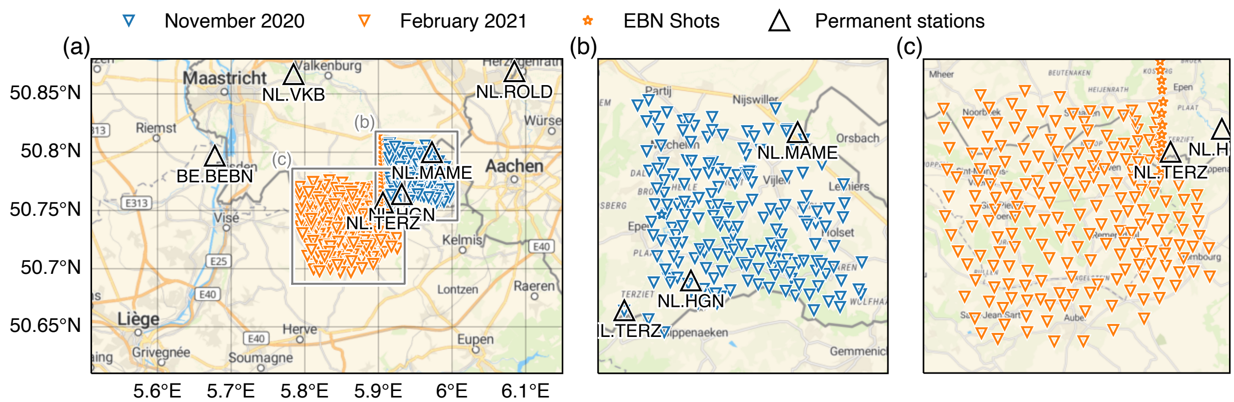

Figure 1: (a) Overview map of the target area in the Euregio Meuse-Rhine region and the locations of the seismic campaigns. (b) Zoom in on the November 2020 seismic campaign. (c) Zoom in on the planned February 2021 seismic campaign. Star symbols indicate shot (small explosive charges) locations conducted by EBN for the purpose of geothermal studies. This deployment is planned to leverage the signals radiated by these shots to image the subsurface in addition to monitoring the ambient noise.

distribution, attenuation, and frequency content of the noise field. Additionally, these data are leveraged to image the subsurface and gain insight to the geological structure and its complexity.

Seismic acquisition campaigns and observations

During the first campaign deployment in November 2020, via a collaboration of Nikhef, KNMI, and Antea Group, we deployed, and successfully retrieved 200 sensors (some pictures from the field in Figure 6). Sensor locations are presented in Figure 1b. We are currently processing the data. To verify the quality of the temporary deployment sensors we placed a sensor next to the KNMI permanent seismic station NL.TERZ in Terziet. Figure 2 shows two days of data comparison between the high quality permanent seismometer (black) and the temporary geophone sensor (orange). It is evident that anthropogenic activity is high during daytime. Vibrations from local activity near the station can register differently on the different sensors due to differences in the instrument response and sensitivity.

On November 11, EBN set off several shots (small explosive charges) in roughly 10 meter deep boreholes, just at the top of the Carboniferous rock. Figure 3 shows the signals that were recorded by a nearby sensor. Signal duration and shape is comparable between the shots due to the similar propagation path and the amplitude of the signal is in correlation to the size of the charge. The shots were detected by many other sensors as far as few kilometers.

On January 14, 2021 at 18:06:24.3 UTC, magnitude 2.9 earthquake occurred near Monschau, Germany. Signals from the earthquake were recorded by the KNMI seismological network (see Figure 4. In addition, temporarily deployed sensors around Mamelis and Wittem during our wind turbine monitoring campaign also recorded the earthquake's signals (see Figure 5). The onset of the P-waves is clearly visible around 18:06:30 UTC.

In February 2021, another campaign is planned. Planned sensor locations are indicated in Figure 1c. During this campaign, EBN are planning to set off charges along a line spanning from Terziet to Gulpen. As in the previous campaign, we intend to leverage these ground-truth events (events for which the location, origin time, and source parameters are known) to retrieve propagation velocities and attenuation parameters.

Future plans

We are currently working to make the data available through the KNMI web services so they are available to anyone interested. Data processing is expected to continue over the next months with focus on characterizing the sources, the amplitude and attenuation, the frequency content, and imaging the subsurface.

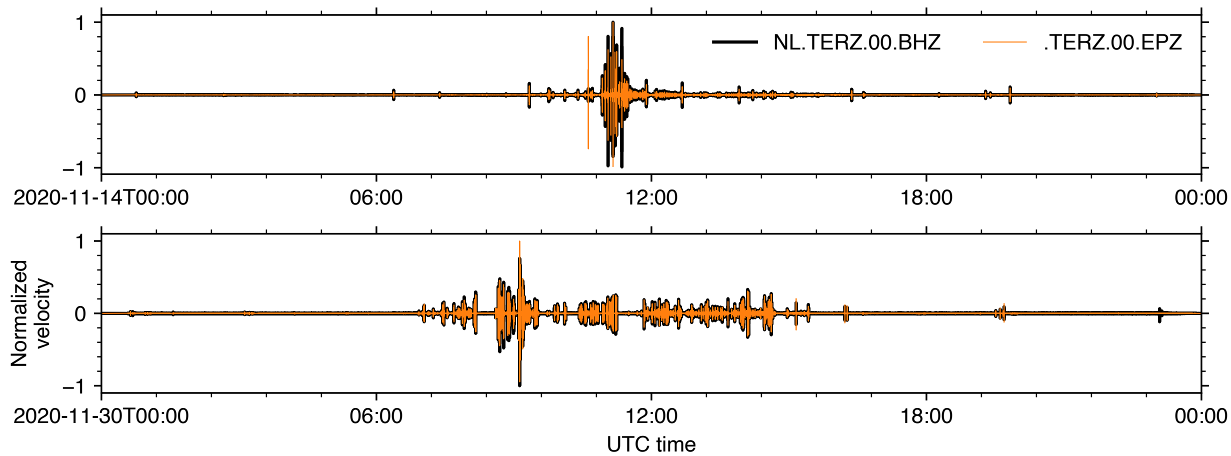

Figure 2: Two days of data comparison between the high quality permanent seismometer (black) and the temporary geophone sensor (orange).

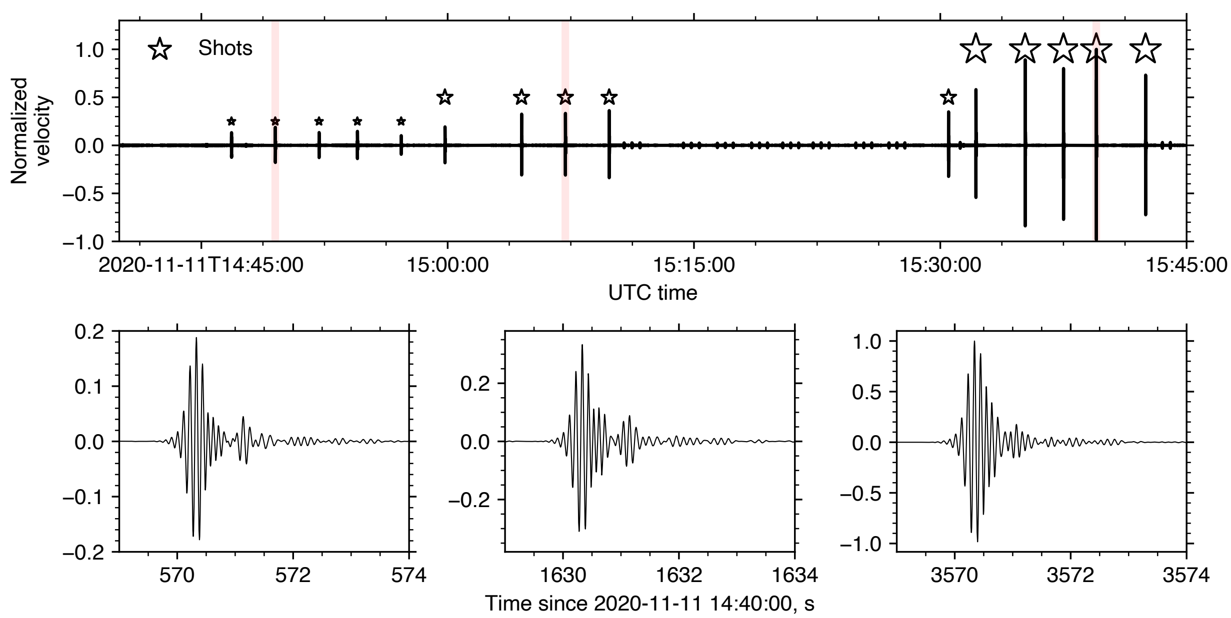

Figure 3: Shots detected by a near by sensor. Top frame shows impulsive signals on a continuous recording. The star symbols indicate time of shot and the size of the symbol indicates the size of the explosive charge ranging from 220 gr to 880 gr. The bottom frames zoom in on three shots indicated by a vertical red line in the top frame. Signal duration and shape is comparable due to the similar propagation path and the amplitude correlates with the size of the charge.

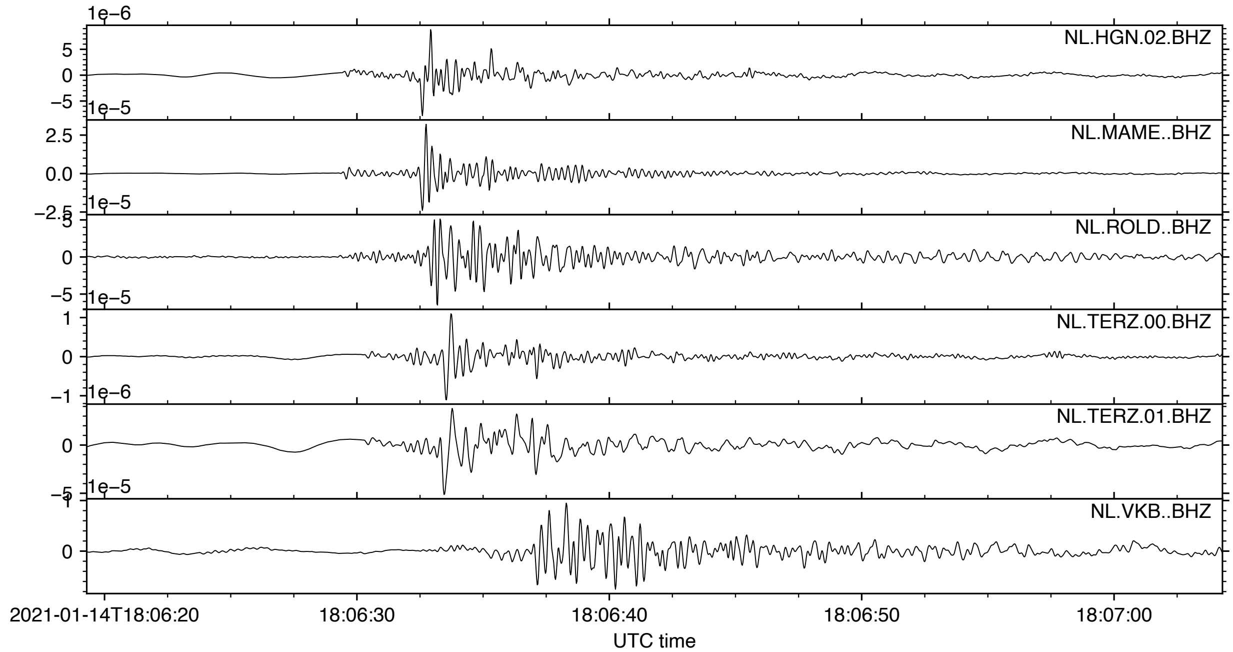

Figure 4: Signals from a magnitude 2.9 earthquake in Monschau, Germany on January 14, 2021 at 18:06:24.3 UTC, recorded by the KNMI seismological network.

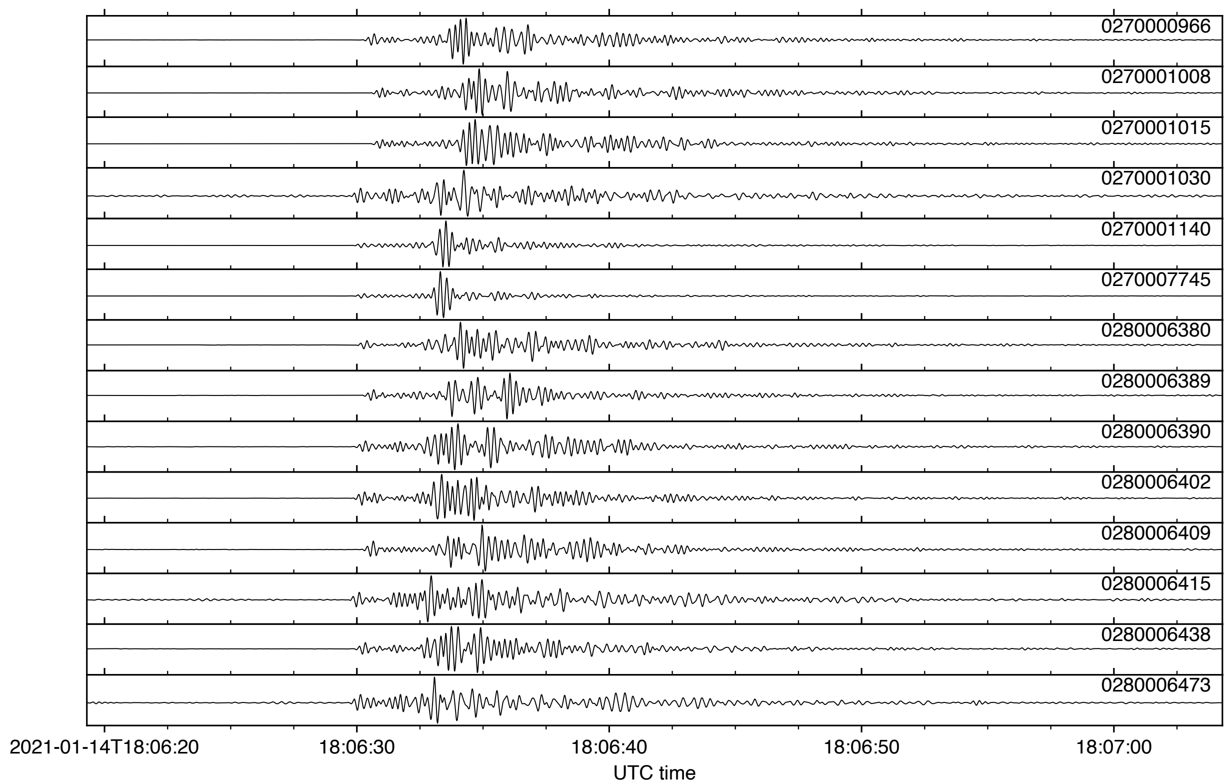

Figure 5: Signals from a magnitude 2.9 earthquake in Monschau, Germany on January 14, 2021 at 18:06:24.3 UTC, recorded by temporarily deployed sensors during out win turbine monitoring campaign.

Figure 6: Top-left: The geophone sensor used for the campaign deployments. Top-right: Geophone in the ground - very low profile. Second row: Vlaai and coffee for lunch. Third row: Frank taking the precise coordinates of a sensor. Bottom-left: Catching the last sun rays of the day. Bottom-right: Bjorn pointing at a sensor placed in the forest - Those are difficult to find after a month. (photos: Shahar Shani-Kadmiel)