Research report

For the short-term visit to ERI, September – October 2019

Laura Ermert

Host: Prof. Kiwamu Nishida

1) Summary

The aim of the short-term research stay at ERI was to interpret models of the sources of primary microseism generated by high ocean wave events in the Sea of Japan. These models were to be obtained by optimizing the distributed ambien noise source spectra to fit observed cross-correlations of the ambient seismic noise. The resulting maps of ocean ambient noise source spectra should improve our understanding of primary microseism generation.

Due to various technical difficulties, the inversions had not been conducted prior to visiting ERI, as was originally planned. Thus, the time of the short-term visit was utilized for the construction of a crustal model to be used in preparation for the inversion. By comparing the results from numerical wave propagation simulations of three earthquakes originating in the Sea of Japan with recordings of the earthquakes at stations of F-net [1], we chose one out of three crustal models that is most suitable for simulating seismic waveforms in the period range of interest. After the visit to ERI, this model was used for simulations to generate a database of Green's functions between surface sources (applicable to the ambient seismic noise) in the Sea of Japan region and 72 F-net seismic station locations. Although work on the final inversion for primary microseism sources is still ongoing, this was a very important step for the project. This research benefited from many discussions with Prof. Nishida and other colleagues at ERI as well as feedback at the Academia Sinica, Taipei, that we visited during the short-term stay.

2) Modeling ambient noise cross-correlations

Studies of the ambient seismic noise usually rely on observations of cross-correlations of continuous recordings at seismic stations, because this enables us to extract the waves propagating coherently along the inter-station path. The cross-correlations can be numerically modelled by superposing sources in a variety of source locations, e.g. all over the Sea of Japan [2, 3]. To perform this numerical modelling task, the impulse response of the medium between source and receiver must be quantified. In this project, we aimed to construct a cross-correlation model using impulse responses that represent our best state of knowledge of the crustal structure in the Japan Sea region at periods longer than 10 seconds.

Since numerical wave propagation modelling is a computationally intensive task, it is advantageous to build a database of impulse responses between any source location and seismic receivers, and to use it to simulate ambient noise cross-correlations by repeatedly reading impulse responses from disk and combining them with spectra of ambient seismic sources.

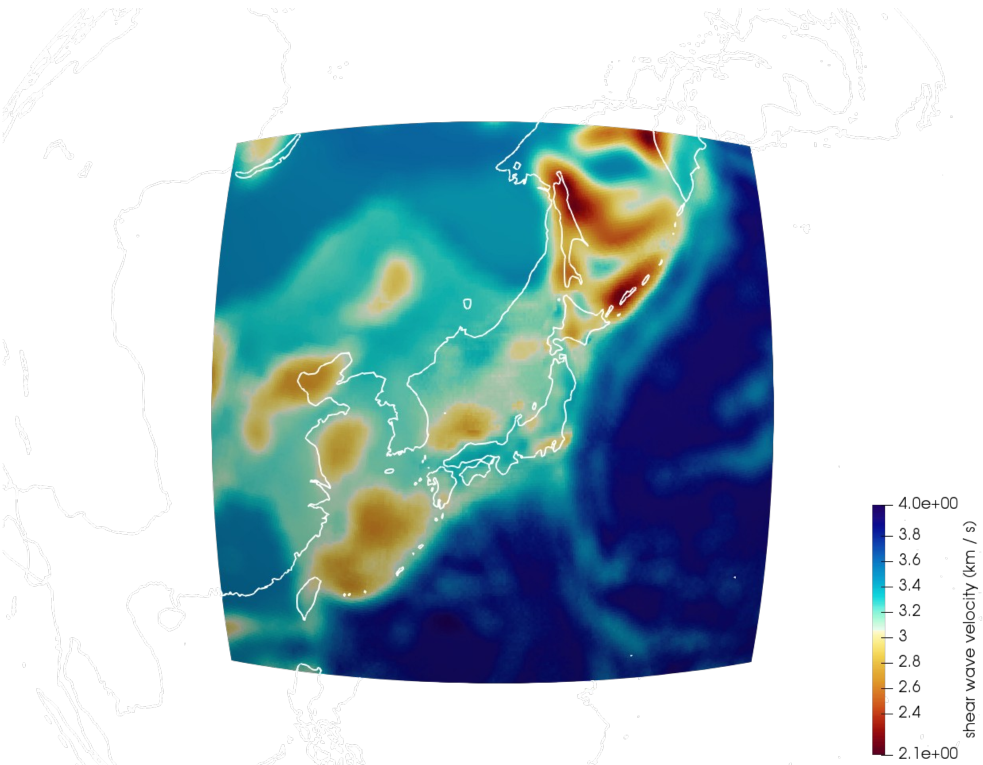

Figure 1: Surface of the mesh of the combined crustal model, colored by shear wave velocity.

3) Work conducted at ERI: Crustal model building and simulation of shallow earthquakes

Ambient noise cross-correlations are usually dominated by seismic surface waves, particularly in the presence of strong nearby sources, such as is the case for high ocean wave heights in the Sea of Japan. Therefore, an Earth model including detailed crustal structure is required for obtaining the source-receiver impulse responses, so that the representation of ambient noise cross-correlations is approximately realistic. The Japan Integrated Velocity Structure Model [4] provides a detailed structure of the shallow structure of the Japanese Islands. However, the present study is targeting longer-period seismic surface waves at ten periods and more, so that a less detailed model of the crust is sufficient and computationally more economical to simulate for several tens of sources. Thus, we considered several models of the Sea of Japan region:

- a full-waveform tomography model obtained using earthquake recordings up to 18 seconds period [5]
- an ambient-noise tomography model based on Rayleigh surface waves [6]
- an ambient-noise tomography model based on Rayleigh and Love surface waves [7]
- the widely used global crustal model Crust1.0 [8]

Since neither of the models [6] and [7] cover the entire modelling region, we merged them into one combined model using spherical Gaussian smoothing at the model boundaries, and added Crust1.0 wherever neither of them provided coverage. Model [7] took precedence over [6] and model [6] took precedence over [8].

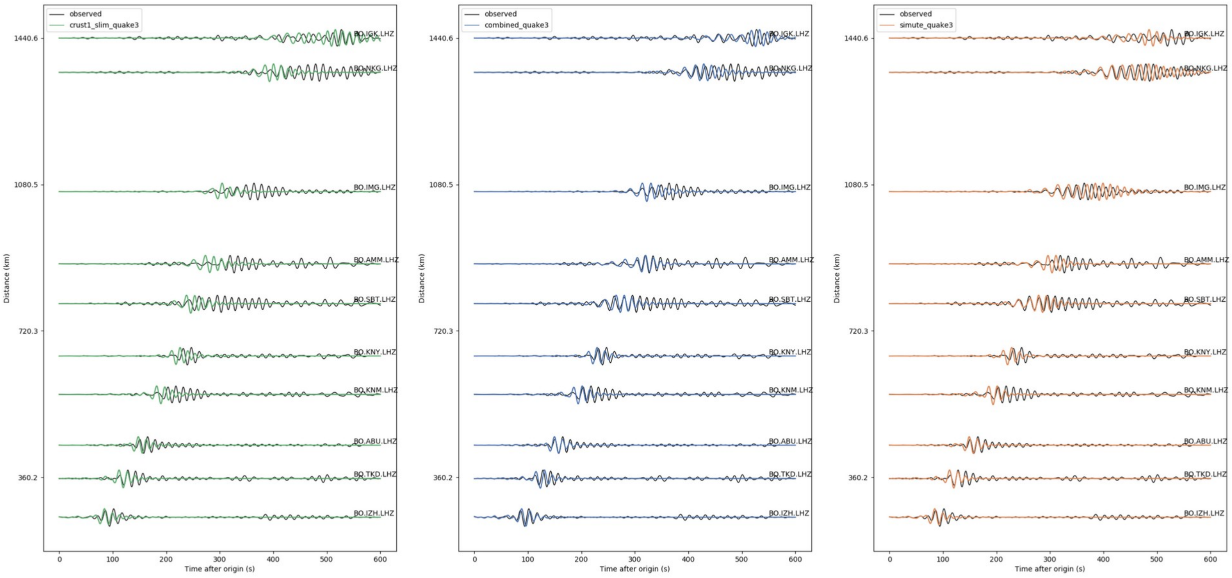

Figure 2: Comparison of observed (black) and modelled (green, blue, yellow) waveforms from shallow event in the Sea of Japan region. Left: CRUST1.0, center: Combined ambient-noise tomographie models + Crust1.0, right: full waveform inversion model. Only a subset of stations is shown for better visibility.

Ambient seismic sources are generally not known in detail, and there are some open questions regarding the modelling of cross-correlations, such as the influence of spatially correlated sources. Thus, it was more practical to investigate the predictive power of the structural models using earthquakes. Here, shallow earthquakes in the Sea of Japan region were chosen, because ambient sources are assumed to be at the Earth's surface and because the propagation from the Sea of Japan to F-net stations is the most relevant for this project, which is focused on the Sea of Japan (compared to propagation from the Pacific). Three earthquakes were chosen, recordings and moment tensors were obtained from NIED. Simulations of the earthquakes, using NIED moment tensors, were performed using Specfem3D globe, in regional mode, for three models

- the full-waveform tomography model [5]
- a combined model, composed of two ambient-noise tomographies and Crust1.0 [6, 7, 8]
- Crust1.0 alone

A sketch of the mesh of the combined model is shown in Figure 1. Computations were run on the ARCHER UK National Supercomputer. We compared the resulting waveforms to data by filtering in the relevant frequency range with a zero-phase Chebysheff filter, and by measuring the L2 norm of the waveforms itself and the envelope of the waveforms. After comparing the different measures for all the obtained waveforms, the combined model showed the lowest misfit. In particular, the CRUST1.0 model as implemented in Specfem did not produce sufficiently long surface wave trains, whereas the low velocity anomalies in the shallow regions of both the full-waveform and the combined ambient noise models partially reproduced them. The combined model overall had a better fit of the phases. An exemplary comparison of data and synthetics is shown in Figure 2. It illustrates that none of the models works perfectly, and this needs to be kept in mind for future inversions.

4) Work conducted after ERI visit

Equipped with the chosen model, we created simulations generating impulse responses between F-net station locations and surface source locations on a dense grid in the model domain by using reciprocity, i.e. choosing the F-net station locations as source locations and the noise source grid locations as receivers in the simulation. Simulations were again run on the ARCHER UK National Supercomputer. Simulations of 1200 seconds duration were created to allow the slowest surface waves to propagate out of the domain of interest. After simulation, the surface seismograms were filtered and decimated and stored in the format applicable to use with the "noisi" cross-correlation simulation and inversion tool [9]. In contrast to previous studies by various authors [e.g. 10, 11], three components of each source were simulated to offer the possibility to conduct cross-correlation modeling and inversion with vertical, horizontal or oblique noise sources. Additionally, three components of the receivers were also recorded, allowing us to model nine (six independent) components of the cross-correlation. Figure 3 shows an illustration of the wavefields originating from a vertical source at three F-net station locations, with three recorded components each (E=East, N=North and Z=vertical).

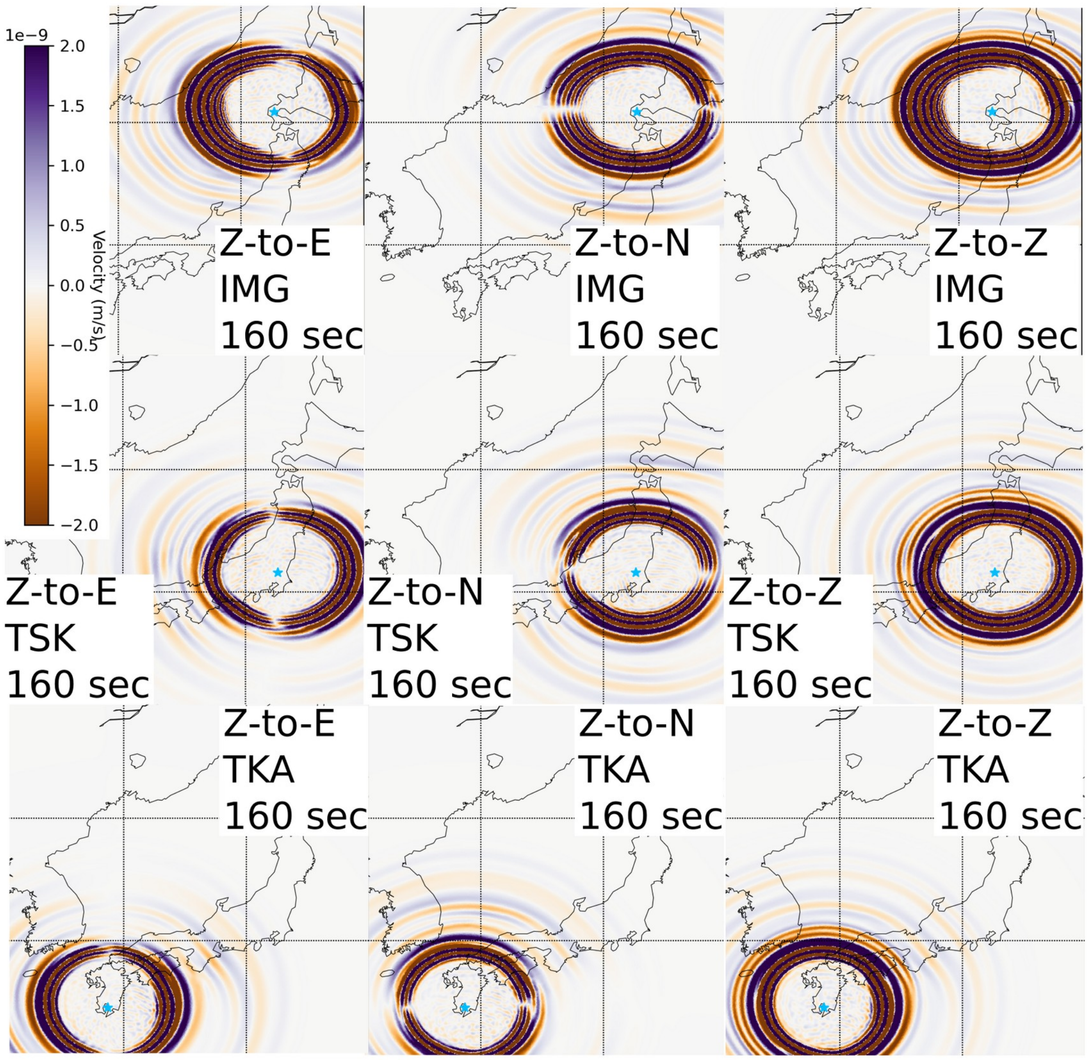

Figure 3: Snapshots of the wavefields excited by vertical sources at three F-net station locations (top row: IMG, center row: TSK, bottom row: TKA). Blue stars denote station locations. For this illustration, the wavefields were filtered to remove periods shorter than 10 seconds, because the target of this study are primary microseisms which have periods longer than 10 seconds. The color scale is clipped at 2 nm / s for better visibility.

5. Outlook

Work is ongoing in utilizing the waveform database that was created in order to simulate ambient noise cross-correlations, and in order to perform inversion for the sources of primary microseisms in the Sea of Japan. As first step, synthetic inversions are performed, i.e. inversions where a known target model is used to create a test dataset, and an inversion starting from a homogeneous model is run with the goal to recover the known target model. These are useful both to test the technical feasibility of the inversion, which is currently being run at the Texas Advanced Computing Center, and to determine the strategy for inverting data and the anticipated resolution.

6. References:

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