Efficient Cross-Correlation Modelling for Noise Source Inversion

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1 Introduction

We present a new method for the **computation of high-frequency ambient noise correlations on the global scale**. This is based on (1) **pre-computed wavefields** that enable the rapid calculation of noise correlations for any arbitrary noise source distribution, and (2) **spatially variable grids** that drastically reduce storage requirements. Furthermore, we forward model cross-correlations using **ocean bottom pressure maps** by Ardhuin et al. (2011) as input noise source distribution (see Figure 1) and compare them to cross-correlations of observed data. The **noise source distribution is described by the power spectral density**.

With our approach **no assumptions about Green's function retrieval or the noise source distribution** have to be made. This work is highly applicable to recently developed methods for full waveform ambient noise inversion (Sager et al., 2017) where more precise knowledge of the noise source distribution is needed. Additionally, cross-correlations could be a new observable of the ocean state in the present and past ocean (e.g. Aster et al, 2010).

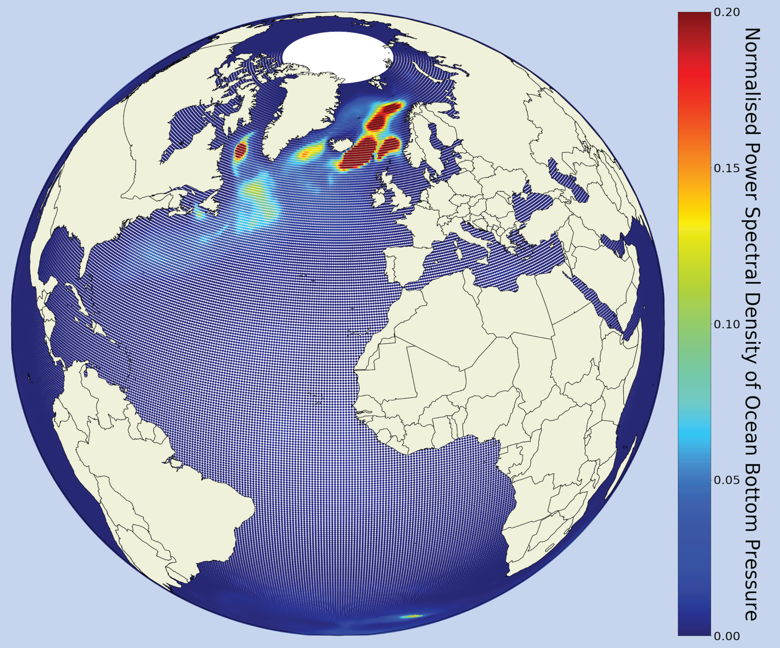

Figure 1: Normalised Power Spectral Density of Ocean Bottom Pressure by Ardhuin et al. (2011).

2 Spatially Variable Grid

To decrease the computational cost of the forward model we implement a **spatially variable grid**. This is able to account for the **heterogeneous noise source distribution** of ocean-generated microseisms. Areas of strong noise sources have a dense grid to resolve the structure well whereas regions with weak noise sources have a sparser grid. Since we are focusing on ocean-generated noise sources we remove all grid points on land. We compute the **Voronoi cell surface areas** to give a corresponding weight to each grid point, i.e. noise source. Figure 2 shows an example of Voronoi cells. The same grid with the source distribution used to automatically set up the grid is visualised in Figure 4.

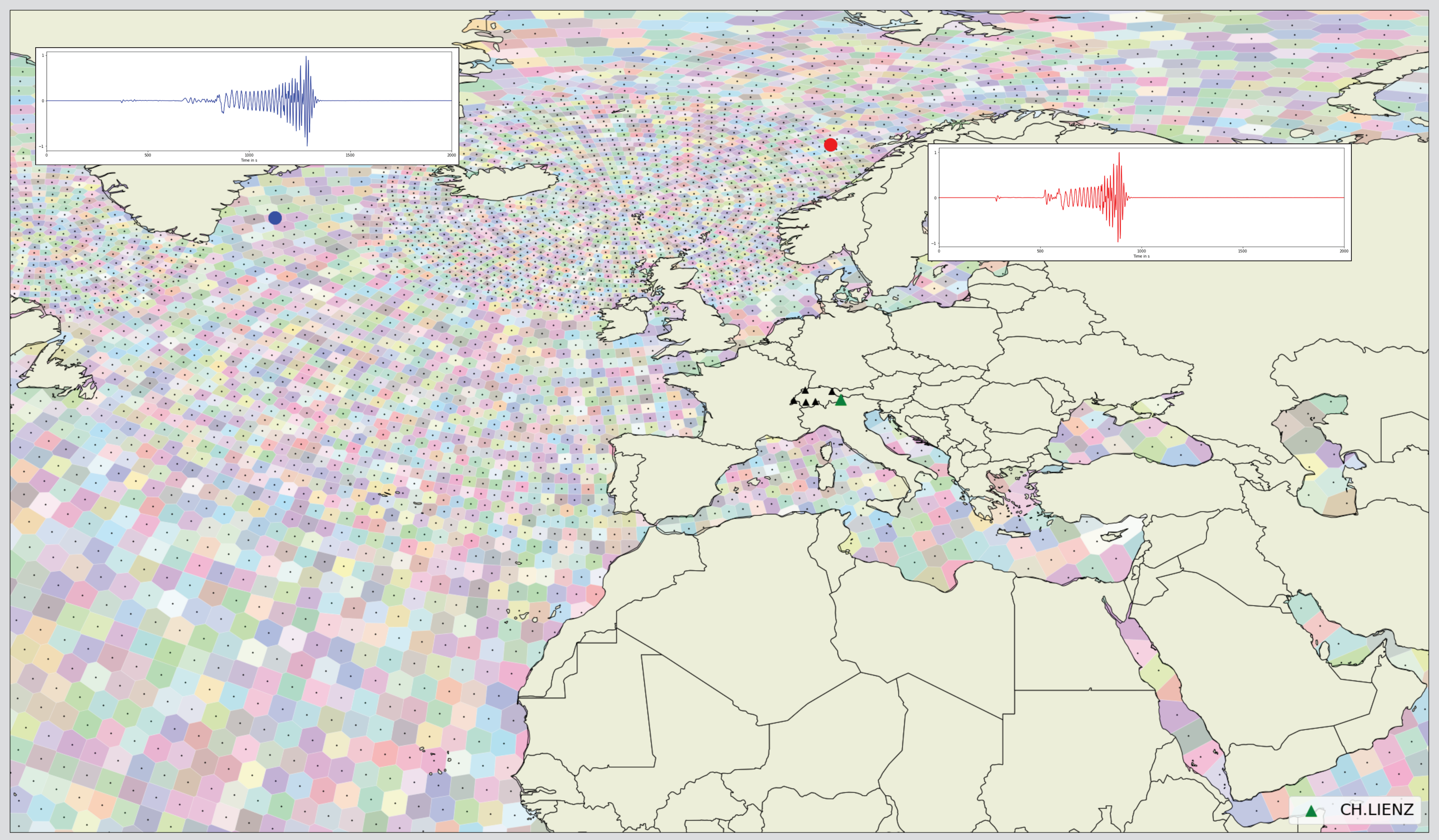

Figure 2: Example Green's functions for two grid points (blue and red dot) with the receiver CH.LIENZ as source. Voronoi cells for the automatically set up spatially variable grid from Figure 4 are visualised.

3 Pre-computed Wavefields

To forward model cross-correlations on a global scale we use the following equation (e.g. Ermert et al, 2017):

$$C_{ij}(x_1, x_2, \tau) = \int_{\delta\otimes} [G_{mj}(\xi, x_2, t) * G_{ni}(\xi, x_1, -t) * S_{nm}(\xi, t)](\tau) d\xi$$

Here, C_{ij} is the correlation wavefield between two receivers i and j at positions x_1 and x_2. G_{mj} and G_{ni} are the velocity Green's functions and S_{nm} the location-dependent noise source power spectral density. Performing purely noise source inversion without updates to the Earth structure allows us to **pre-compute the Green's functions using the wave propagation solver Axisem** (Nissen-Meyer et al., 2014). We extract the necessary seismograms for a given noise source distribution and stations with Instaseis (van Driel et al., 2015) by assuming reciprocity of the source-receiver pair. Green's functions for two example grid points with the receiver as source can be seen in Figure 2. Figure 3 shows **synthetic cross-correlations for a homogeneous noise source distribution in the ocean**.

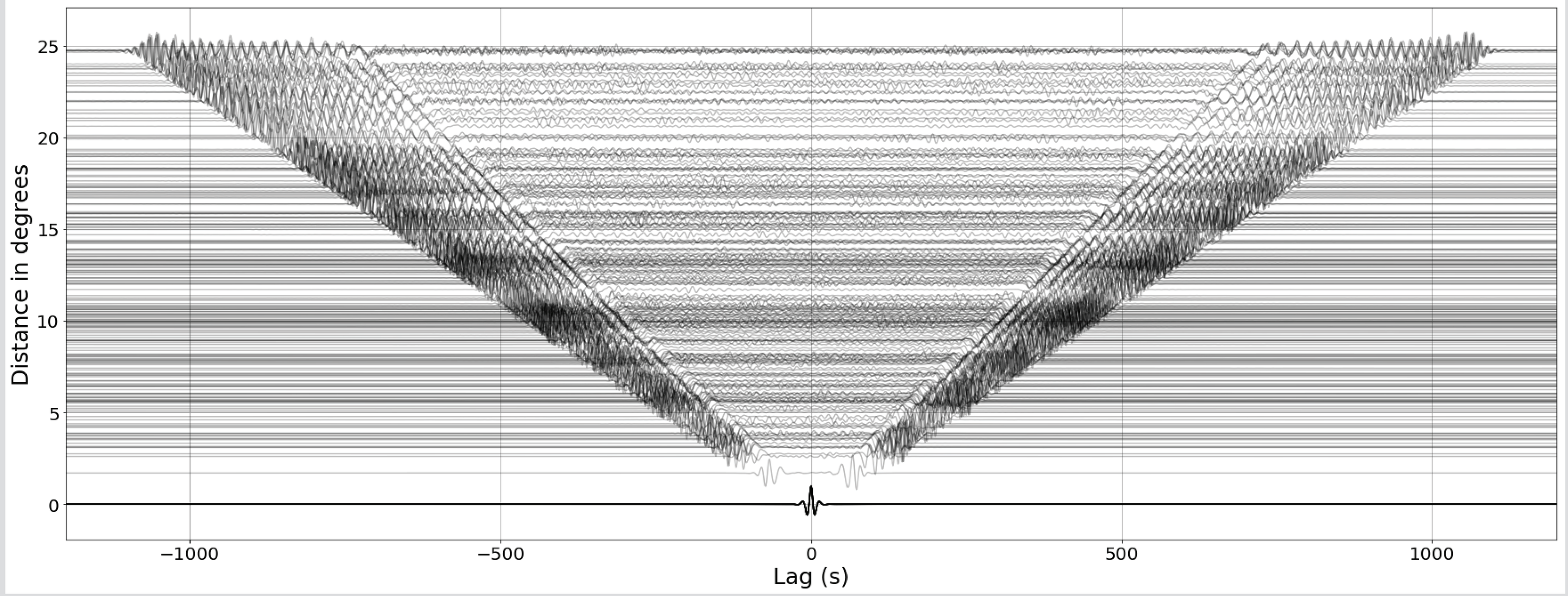

Figure 3: Synthetic cross-correlations for a homogeneous noise source distribution in the ocean.

4 Ocean Surface Pressure Maps

With the above explained tool we are able to **easily compute cross-correlations for a given noise source distribution**. Since the ocean-generated noise depends on the ocean state we are able to use **ocean bottom pressure maps** from Ardhuin et al. (2011) as input distribution. The spatially variable grid is able to **adapt automatically to the input data** by adding dense grids in areas above a given threshold value. One such automatically generated grid can be seen in Figure 4 where the colourscale has been capped at the threshold value. The cross-correlations computed with this grid and noise source distribution can then be compared to observed data.

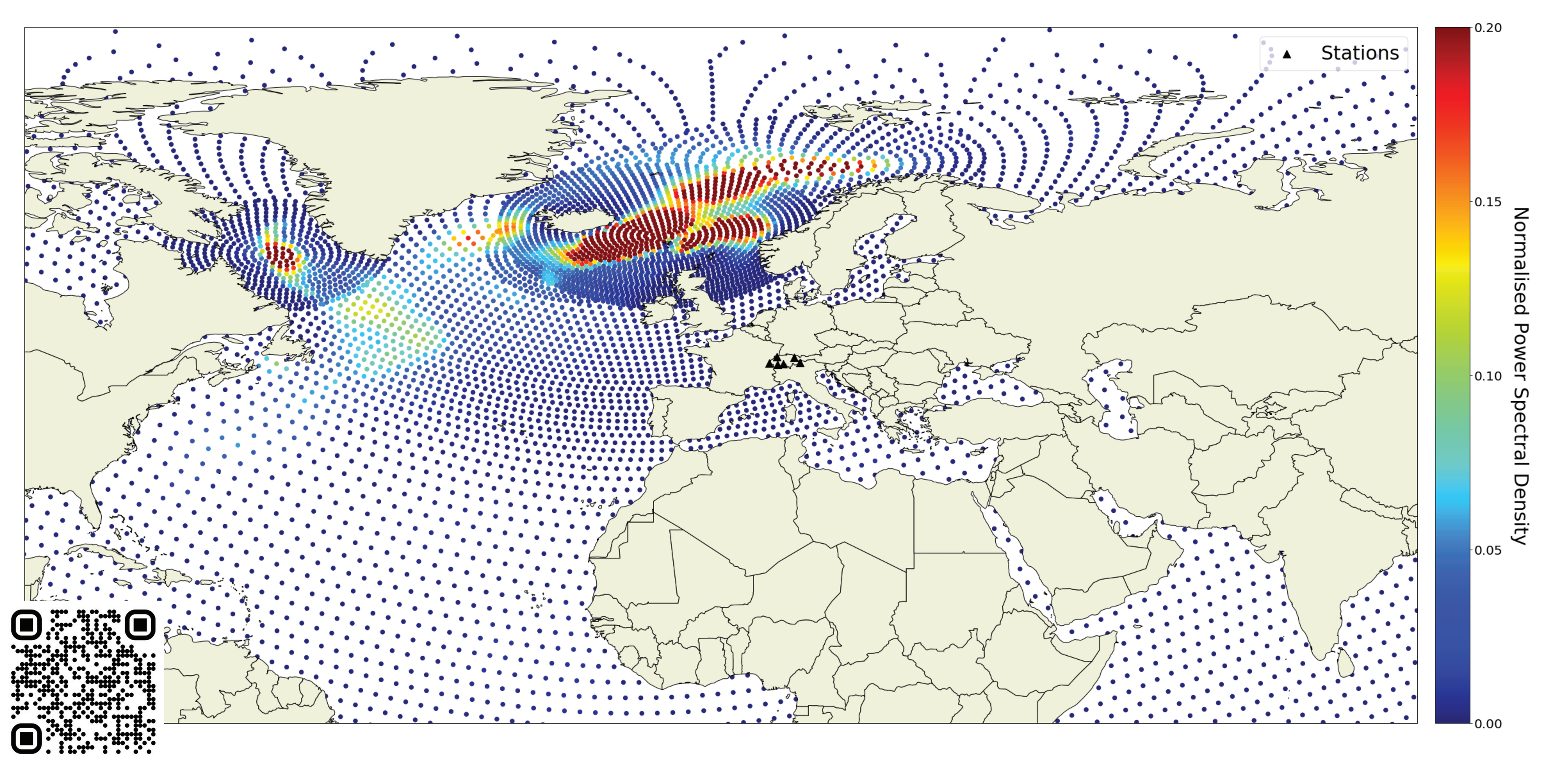

Figure 4: Automatically generated spatially variable grid with the ocean bottom pressure map as seen in Figure 1 from Ardhuin et al (2011) as input. Six stations in Switzerland are shown.

5 Comparison to Data

We choose 6 stations in Switzerland (see Figure 2 and Figure 4) and compute the **synthetic cross-correlations for the noise source distribution** shown in Figure 4, **a homogeneous distribution,** as well as the **observed cross-correlations for all station pairs.** We use data from the 3 hour time window for which the pressure map was created. All cross-correlations were filtered using a Hann window function with a central frequency of 0.1 Hz. By comparing the synthetics of the pressure map based distribution and homogeneous distribution with the observed correlations we see that the former shows much stronger similarities. Thus, it is a better starting model for future inversions.

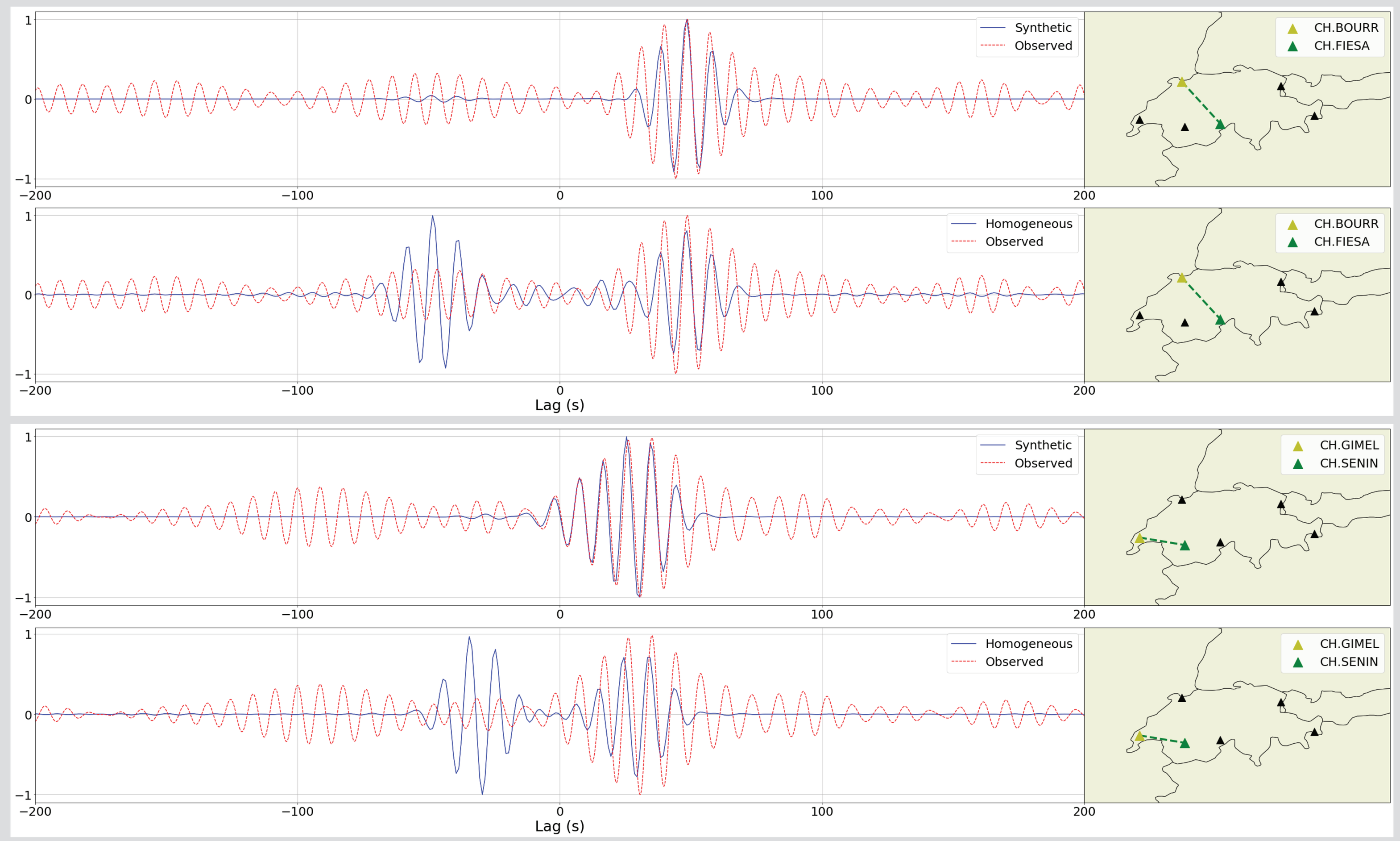

Figure 5: Observed and synthetic cross-correlations for the 3 hour time window of the noise source map in Figure 3 and a homogeneous distribution for two station pairs. The pressure map based synthetics show stronger similarities.

6 Conclusion

Our study shows that it is possible to **efficiently compute cross-correlations on a global scale** in the microseismic frequency range. For example, computing a cross-correlation set such as in Figure 3 for 27 stations, i.e. 351 station-pairs, with 3-D wave propagation through PREM, is feasible within a short time on a PC. By comparing it to real data we find a **better initial fit for the pressure map based distribution**. Overall, the ocean surface pressure maps are a **reasonable starting model for future ambient noise source inversions**. The next step is to use a bigger data set of European stations and perform a noise source inversion based on sensitivity kernels for the North Atlantic.

7 References

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