# Seismic Interferometry at the TIMO2-network, Germany

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***Abstract*—Using seismic interferometry, we analyze the seismic noise wavefield around the city of Landau, Germany. The cross-correlation functions (CCFs) are investigated with respect to signals which might contain information on the underground and its temporal variations. The used data set comes from the TIMO2-project (TIMO: Deep Structure of the Central Upper Rhine Graben). Since the summer of 2009, seismic stations have been installed especially to detect induced seismicity in the region of Landau. The obtained CCFs are dominated by signals with frequencies between 0.4 and 0.8 Hz which are strongly asymmetric. We will present the results of the ongoing work to characterize and identify the source(s) of these signals.**

## I. Data set, TIMO2-project

We analyze seismic broadband data of the TIMO2 project (TIMO: Deep Structure of the Central Upper Rhine Graben) with seismic stations located in the area of the city of Landau in the Palatinate in southwestern Germany (figure 1).
The ground motion velocity recordings from July 2009 until September 2012 of ten three-component stations of the TIMO2 project are investigated. The maximum interstation distance of these ten stations is about 16.2 km (TMO20-TMO57), the minimum interstation distance is about 1.8 km (TMO50-TMO53). The instruments are broadband as well as short-period sensors and are a part of the KArlsruhe BroadBand Array (KABBA). TIMO2 is the second project phase of TIMO and started in July 2009. Within TIMO2 we study not only the lower lithosphere and the upper mantle but also the microseismicity in the surroundings of geothermal power plants in Landau and Insheim using passive seismic monitoring techniques. TIMO2 is a cooperation with the State Geological Survey of Rhineland-Palatinate, and it contributes to the project MAGS (Microseismic Activity of Geothermal Systems) which is financed by the Federal Ministry for the Environment and coordinated by the BGR (Federal Institute for Geosciences and Natural Resources), Hannover.

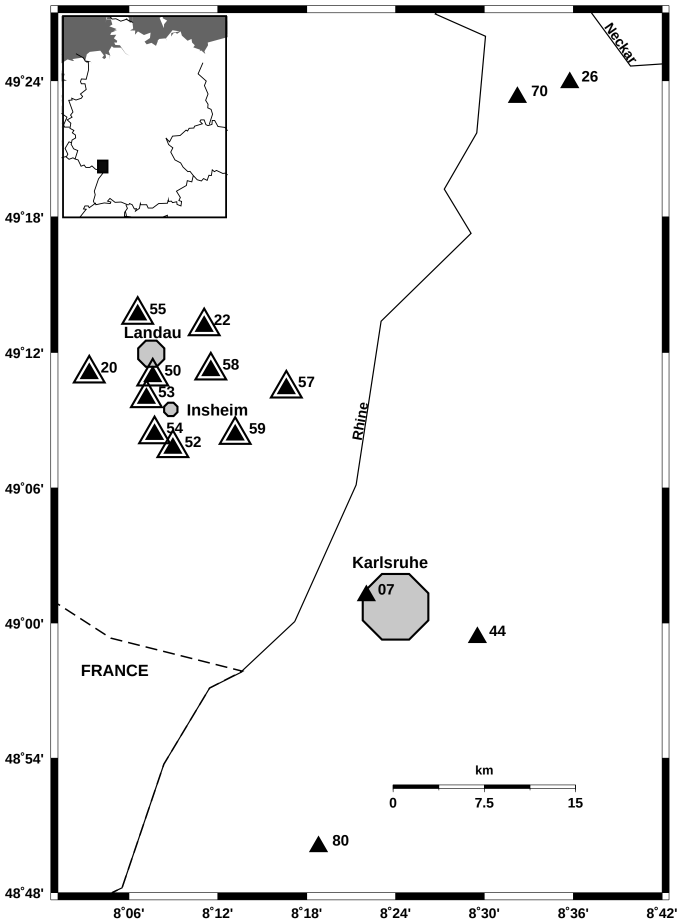


Fig. 1. TIMO2-network of the KIT around Landau. The triangles indicate seismic stations. The framed triangles mark the ten stations that are used for this study.

## II. Data processing

The processing scheme of the data is divided into three main steps: the preprocessing, the calculation of the cross-correlation functions (CCFs) with short time windows (20 minutes) and the subsequent normalization of the CCFs [Groos et al. (2012)].
As the waveform data of all TIMO2-stations are stored in files on a daily basis at the KABBA data center, the preprocessing is applied to one-day long time series. At first, the mean value and the linear trend are removed from the data. Afterwards, a zerophase 0.01 Hz high-pass filter is applied to the time series. Then, the instrument response is removed. Possible low frequency artefacts caused by the removal of the instrument response are eliminated by applying a zerophase 0.1 Hz high-pass filter. In a last step of the preprocessing, the sampling rate is set to 100 Hz.
For the calculation of the linear CCFs in the frequency-domain, the one-day long time series are segmented into 20-minutes long time windows with an overlap of 200 seconds. Then, the 20-minutes long segments of the time series are

cross-correlated for every pair of stations. Afterwards, every CCF is normalized in the frequency domain by spectral whitening after [Brenguier et al. (2008)]. Finally the CCFs are stacked.

## III. The dominating 0.4 - 0.8 Hz signals

The acausal part of the CCFs of the 45 possible station combinations of the ten analyzed stations is dominated by signals with frequencies between 0.4 Hz and 0.8 Hz (figure 2). As the signals are identified predominantly in the acausal part of the CCFs it might be an indicator for a propagation of these signals in a roughly west-east-direction. Figure 2, where the CCFs are plotted against the interstation distance, also shows that there is no distinct moveout of the signals related to the interstation distance. Thus, the source of the signal is either placed at the inner part of the station network or the signal arrives from outside of the station network at a particular angle.

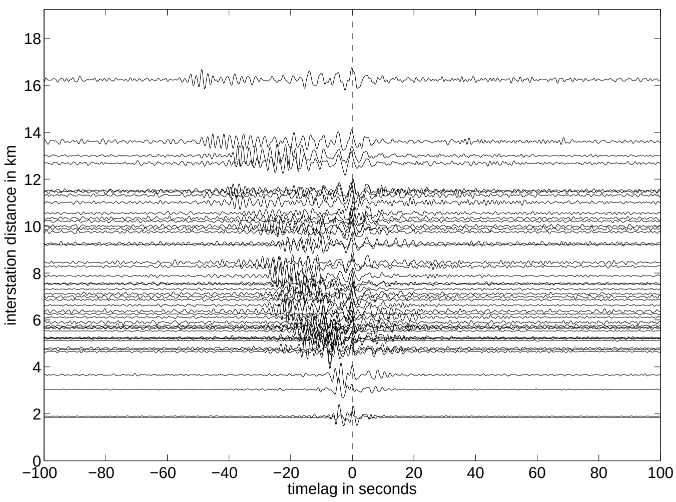


Fig. 2. 45 CCFs with a maximum timelag of $\pm 100$ seconds plotted as a function of the interstation distance. In the time period of 14 days from June, 27th 2011 to July, 10th 2011 the CCFs of the vertical component of the time series are calculated and then spectral whitened. After stacking (the number of stacks equals 1218), a band-pass filter from 0.2 - 0.8 Hz is applied to each CCF. The CCFs are strongly asymmetric with signals predominantly in the acausal part.

In addition, stacking the CCFs of one station pair of only one day already reveals these signals with frequencies above the ocean-generated microseismic noise and below 1 Hz (figure 3). Figure 3 shows the CCF of the stations TMO53 and TMO57, which are placed about 11.5 km apart from each other. In the acausal part of this CCF two signals can be identified: a faster one at timelag -15 seconds (*fs*) with a dominant frequency of $\sim$0.4 Hz and a slower one at timelag -40 seconds (*ss*) with a dominant frequency of $\sim$0.5 Hz. The apparent velocity of signal *ss* between TMO53 and TMO57 is about 300 m/s, between TMO20 and TMO57 it is about 330 m/s. Signal *fs* propagates with an apparent velocity of about 800 m/s between the stations TMO53 and TMO57.

The dominating 0.4 - 0.8 Hz signals also occur over long time periods of several months.

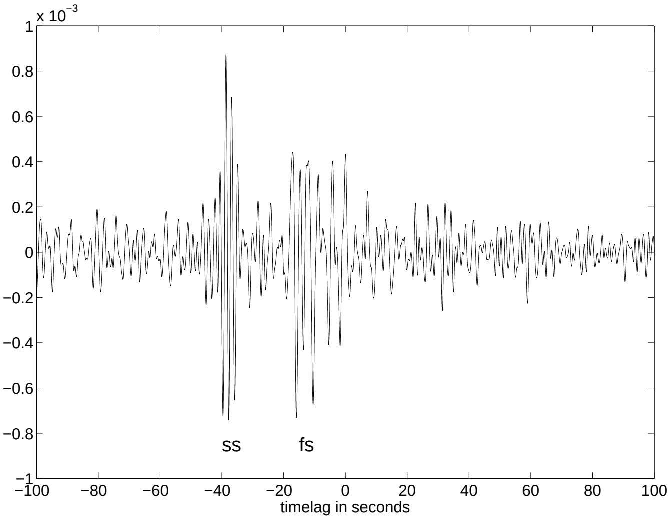


Fig. 3. Stacked CCF of the 20-minutes long time series segments of only one day (June, 27th 2011) of the vertical component of the stations TMO53 and TMO57 (interstation distance: about 11.5 km). The CCFs are spectral whitened. Afterwards, a band-pass filter from 0.2 - 0.8 Hz is applied to the CCFs. Finally, the CCFs are stacked (number of stacked CCFs = 87). In the acausal part of the CCF two signals can be identified: one faster propagating signal *fs* at timelag -15 seconds with a dominant frequency of about 0.4 Hz and one slower signal *ss* at timelag -40 seconds with a dominant frequency of about 0.5 Hz.

For a better understanding of these signals, we will locate their source(s) and then determine the type of source.
It is also planned to eliminate the asymmetric dominating 0.4 - 0.8 Hz signals to hopefully be able to identify symmetric signals in the CCFs. In a next step, this might provide informations on the underground.

## References

[Groos et al. (2012)] J. C. Groos, S. Bussat, and J. R. R. Ritter, 2012: Performance of different processing schemes in seismic noise cross-correlations. *Geophys. J. Int., vol. 188*, **498-512**.

[Brenguier et al. (2008)] F. Brenguier, N. M. Shapiro, M. Campillo, V. Ferrazzini, Z. Duputel, O. Coutant and A. Nercessian, 2008: Towards forecasting volcanic eruptions using seismic noise. Supplementary Information *Nature Geoscience 1*, **126-130**.