Ambient seismic noise tomography of the Outre-Forêt region (Alsace, France) from the EstOF dense temporary seismic array

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Traditional seismic imaging relies on body or surface waves generated by impulsive sources of natural (local to teleseismic earthquakes) or manmade (explosions, vibrator trucks) origins. After different processing, analysis and inversion schemes, they allow us to extend our knowledge of the internal structure of the Earth at different scales. Uneven distribution of sources in time and space is usually the main parameter that limits the resolution of these tomographic images. For passive imaging, earthquakes distribution is an unavoidable problem and precludes the use of such technique in low seismicity regions. Artificial sources allow defining more suitable geometries, but are often synonymous with high costs and can be practically difficult to implement in hard to reach or restricted areas.

Underdevelopment approaches based on the use of ambient seismic noise can partly overcome such limitations. Indeed, the basic principle of such techniques is that the cross-correlation of long time series of seismic noise recorded at two stations converges towards the Green function between them. In other words, each seismic station virtually becomes a seismic source recorded by all the other stations of the network. Thus, the resolution of the resulting tomographic images is mostly governed by the geometry and the density of the network. Several studies performed at different scales and in different contexts have demonstrated the effectiveness of this new approach (Shapiro & Campillo, 2004; Shapiro et al., 2005; Lin et al, 2013.). Since no seismic source (natural or artificial) is needed, ambient seismic noise correlation can be applied in various environments and at a reasonable cost.

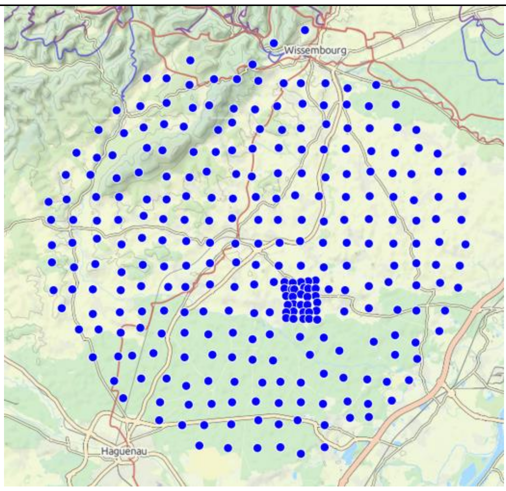

Figure 1 : Map of the 288 stations deployed for one month during the EstOf experiment in Northern Alsace (France). The diameter of the disc is ~25km. Station spacing is ~1.5 km except within the inner array centered on the Rittershoffen site where it is ~400m.

The aim of this study is to analysis the potential of this technique to probe the first five kilometers of the crust in the context of deep geothermal reservoir exploration. In contrast to Calo et al. (2013) or Lehujeur et al. (2015) who tried to apply this technique to sparse networks of permanent seismic stations, we rely here on a much denser array deployed during the EstOF (temporary seismological Experience in Outre-Forêt) project. It consisted in a disc of 288 seismic stations operated for one month in September 2014 and located in the Outre-Fôret region (Alsace – France) around the Soultz-Sous-Forêts and Rittershoffen deep geothermal sites. This network has been deployed in 2 days thanks to the use of Zland© nodes which package a 10Hz vertical geophone, a digitizer, a GPS and a battery in a single small box.

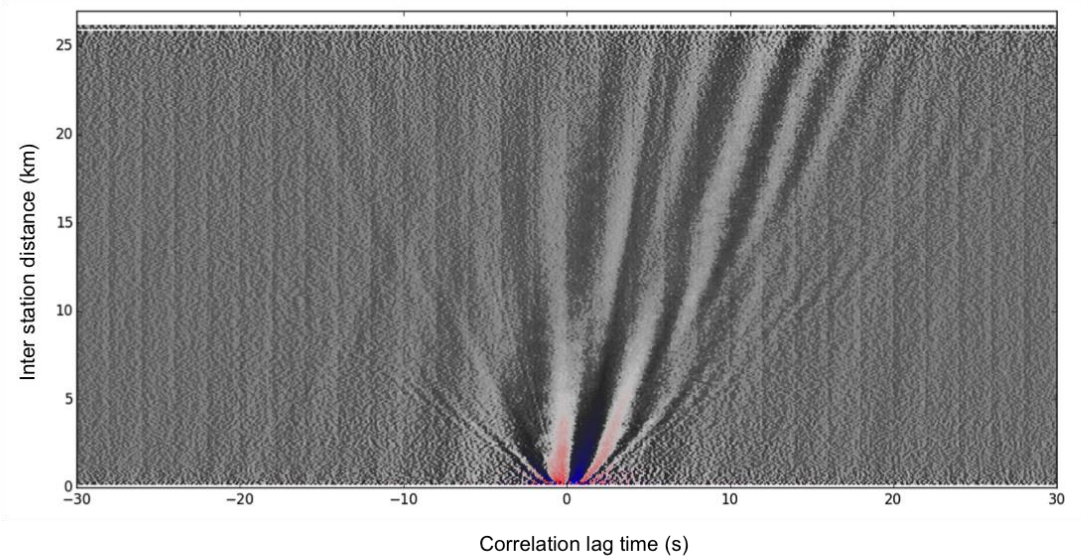

Figure 2 : Cross-correlation functions between all stations pairs of the EstOf network filtrered between 0.2 and 1Hz, ordered as a function of inter station distance and stacked in 150m distance bins

This one month experiment results in ~1.5 Tb of continuous data and more than 40 000 cross correlations between all combinations of stations pairs. The recovered empirical Green functions exhibit clear surfaces waves in the 0.2 – 1Hz frequency band (Fig. 2). We use the dispersive character of these Rayleigh waves to produce group and phase velocity maps at different periods. For every station pair separated by more than one wavelength, group velocity dispersion curves for the fundamental and first overtone modes have been extracted using a classical frequency-time analysis. A regionalization of these measurements based on a linear inversion allows the reconstruction of group velocity maps at different periods (Fig. 3a). To produce phase velocity maps (Fig. 3b) we apply an eikonal approach (Lin et al. 2013), which eliminates the inversion step by directly estimating local gradient of the interpolated phase travel times. This approach can only be applied to sufficiently dense arrays like the EstOf network. These tomographic images highlight structures that are well correlated with the regional geology. The Rhine fault, which separates the crystalline Vosges massif to the West from the sedimentary graben to the East, is well marked by a strong lateral contrast in phase and group velocities at all periods. Coherent patterns are also observed within the graben such as an elongated SSW-NNE higher velocity body observed at 1s period and that may correspond to a known horst structure situated just east of the Soultz-sous-Forêts geothermal power plant.

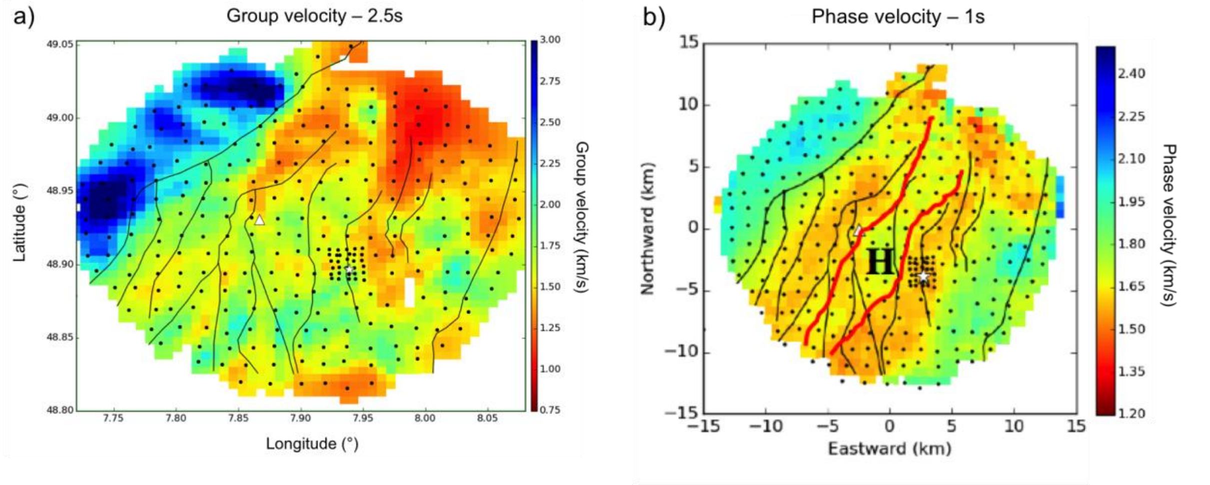

Figure 3: Examples of tomographic images of Rayleigh wave group (a) and phase (b) velocities at 2.5, resp. 1s, periods deduced from the analysis of the cross-correlation functions between the EstOF stations (dots). Black lines represent major regional faults extracted from Baillieux (2014) and red lines represent the boundaries of a known horst situated between the Soultz-sous-Forêts and Rittershoffen sites (white triangles).

References

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