Database from a Seismic Network to Monitor the 2018 Enhanced Geothermal System Stimulation in Espoo/Helsinki, Finland

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INTRODUCTION

In June and July 2018 St1 Deep Heat Oy (ST1DH) performed hydraulic stimulation between 6 km and 7 km depth beneath the Aalto University campus in Otaniemi, Espoo, Finland, to establish an Enhanced Geothermal System (EGS) doublet for district heating. The Institute of Seismology from University of Helsinki (ISUH) monitored the stimulation stage using a network of surface seismic stations and geophones.

In this work, we study the 6 km deep induced seismicity in the first stimulation stage. Focus will be on Elfvik array (EV-array). We also compare the borehole station ELFV located nearby (Figure 1).

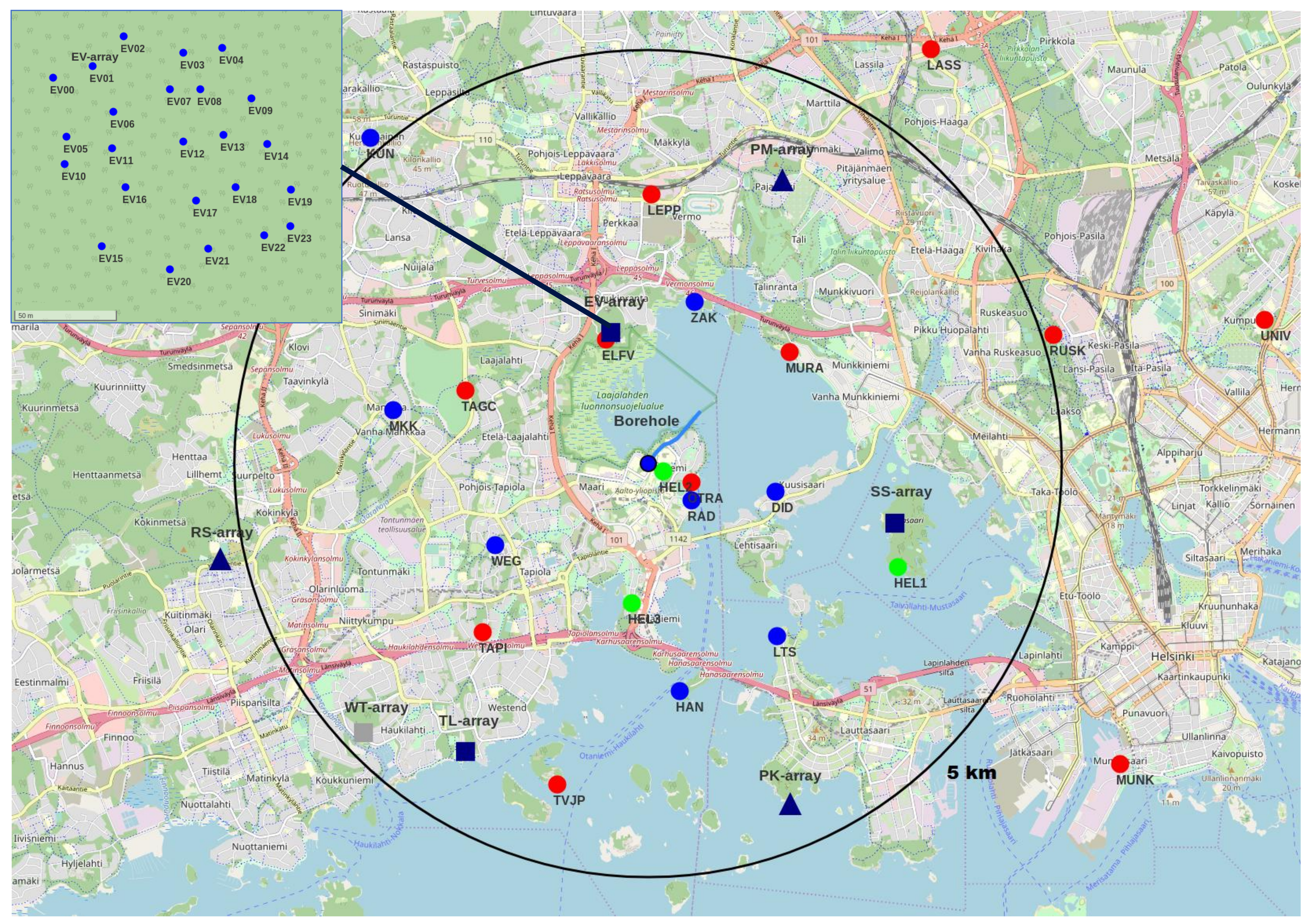

Figure 1. Map of EGS site with surrounding monitoring network. Circle marks 5 km radius. Top left is a close up of EV-array located ~200 m from ELFV borehole station installed at depth of 260 m.

MONITORING NETWORKS

ISUH operates 7 semi-permanent seismic station network Helsinki and Espoo area within 10 km of the EGS well; all recording at 250 Hz. ISUH also installed a temporary ~100 station network to monitor the stimulation and post-stimulation stage. This network consisted of three-component 4.5 Hz PE-6/B-geophones connected to DATA-CUBE3 digitizers recording at 400 Hz. The geophones were organized in 3 large arrays consisting of ~25 stations, 3 small 4-station arrays, and 8 single stations. ISUH was also granted access to data from 12 borehole seismometers registering at 800 Hz installed by ST1DH at depths between 238 m and 1620 m. Station networks and close up of 24 cube EV-array in vicinity of the EGS site are shown on Figure 1.

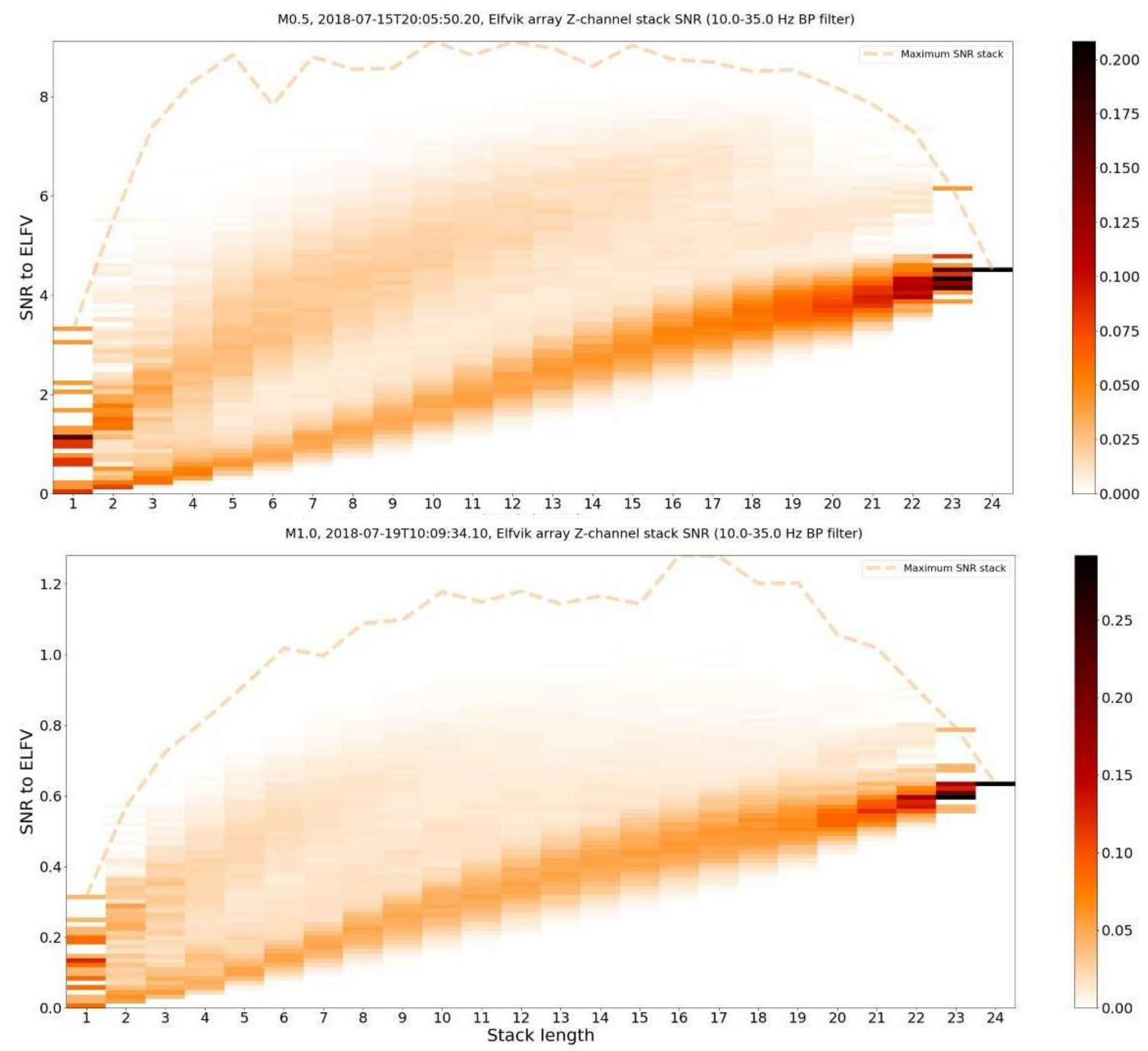

Figure 2. SNR of two events registered at EV-array compared to ELFV as a function of stack size using 12650 stack samples per size. Top: Low noise "optimal case" on Sunday midnight, bottom: An event on Wednesday midday. Dashed line represents maximum SNR stack.

ELFVIK

The EV-array was installed 1.7 kilometers North of the EGS site on bedrock, which serves as an excellent medium for high frequency propagation. The array was located near ELFV borehole station, installed by ST1DH to 260 m depth, enabling comparison of surface and borehole data. However, the array was also located ca. 250 meters from two major highways leading to highly variable noise levels based on time of day and weekday impacting detection thresholds (Figure 2).

SOURCE MECHANISMS

Manually picked borehole and surface station data from 13 selected events were used to estimate source mechanisms. The majority of solutions indicate reverse faulting (Figure 3). The shown solutions are lower hemisphere projection. The implied stress direction is consistent with the general compressional stress regime in the area (NW – SE in Fennoscandia; rotated towards EW in southern Finland).

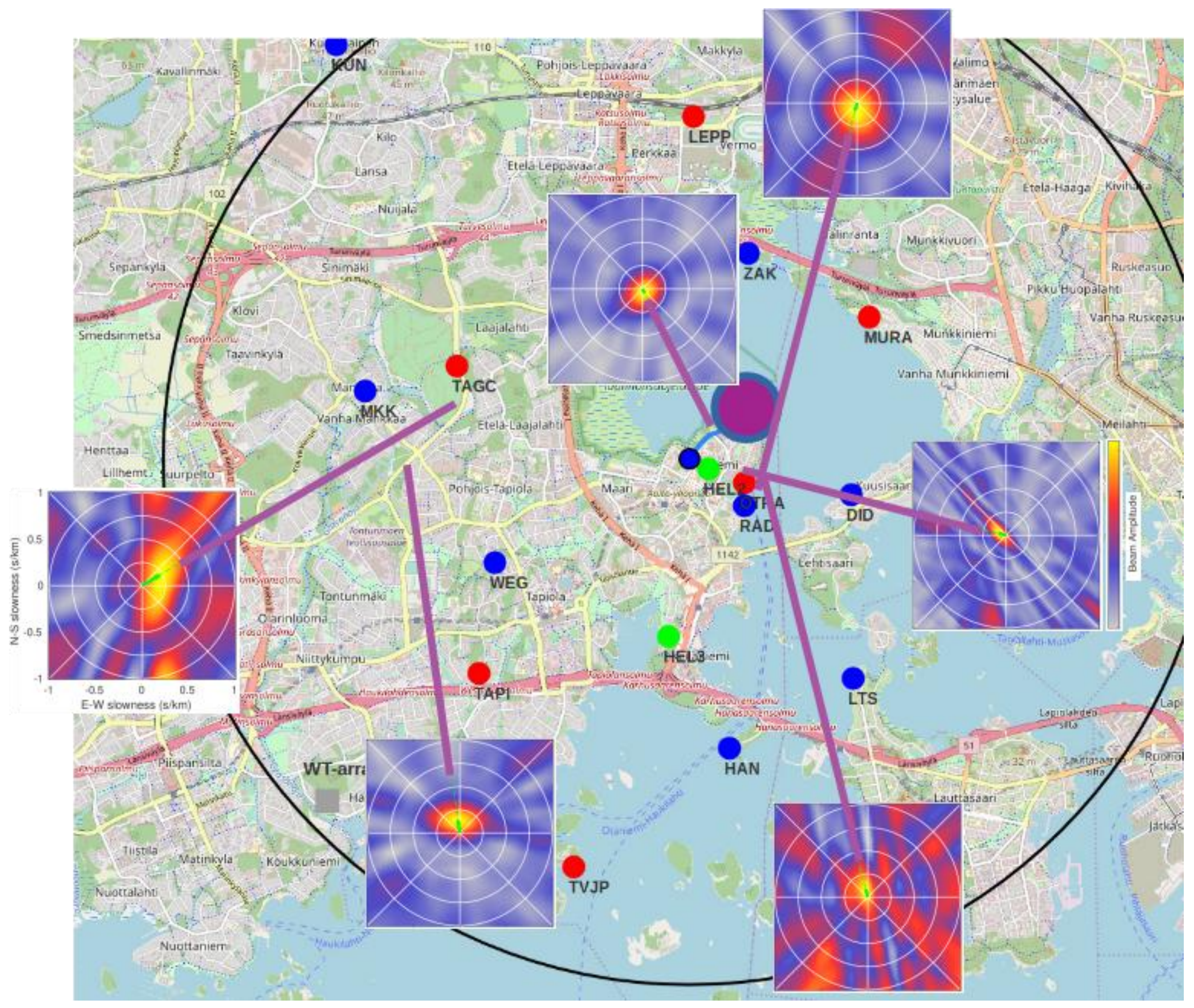

Figure 4. Preliminary beamforming. Arrays South & West show non-direct pathway characteristics.

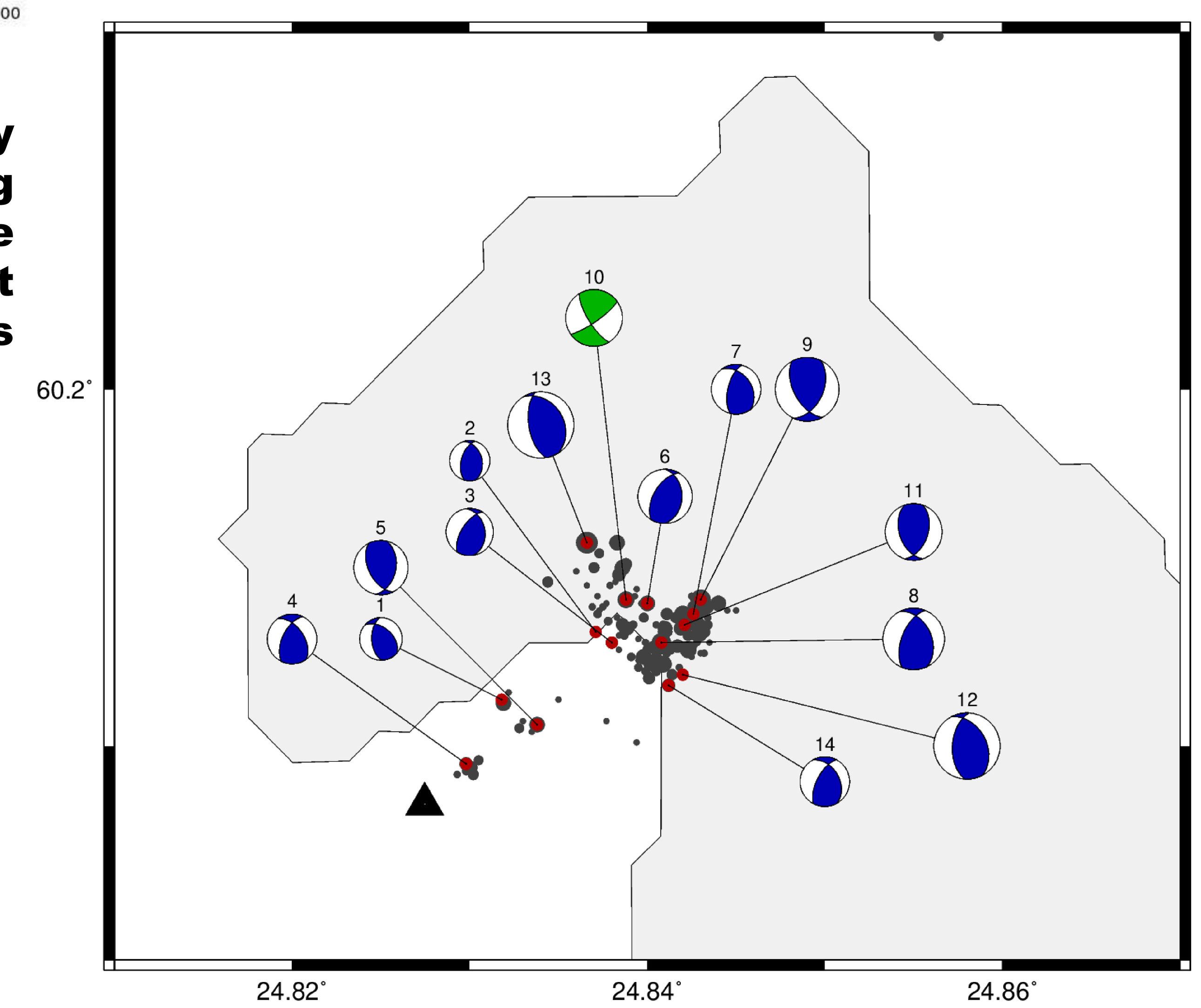

Figure 3. Source mechanisms of 14 selected events. Solutions indicate faulting mostly consistent with local near EW stress regime.

NOISE CORRELATIONS

Noise correlations between the 24 stations of the southern TL and the 4 stations of the northern PM arrays contain the signature of the direct P-wave that travels between the two sites (Figure 5). Propagating above the stimulated volume, we intend to research time-dependent variations in propagation properties that are potentially linked to changes in the subsurface associated with the stimulation.

BEAMFORMING

The six arrays allow estimates of local propagation parameters that can be used for locating events. Here we show P-wave beamforming results using vertical component data, 2 – 30 Hz. Our preliminary results from the six largest events indicate that azimuths obtained at the two arrays to the south-/west are less consistent with a "straight" propagation from the source region (Figure 4). More testing should also clarify the influence of topography (10 – 15 m elevation difference at some sites).

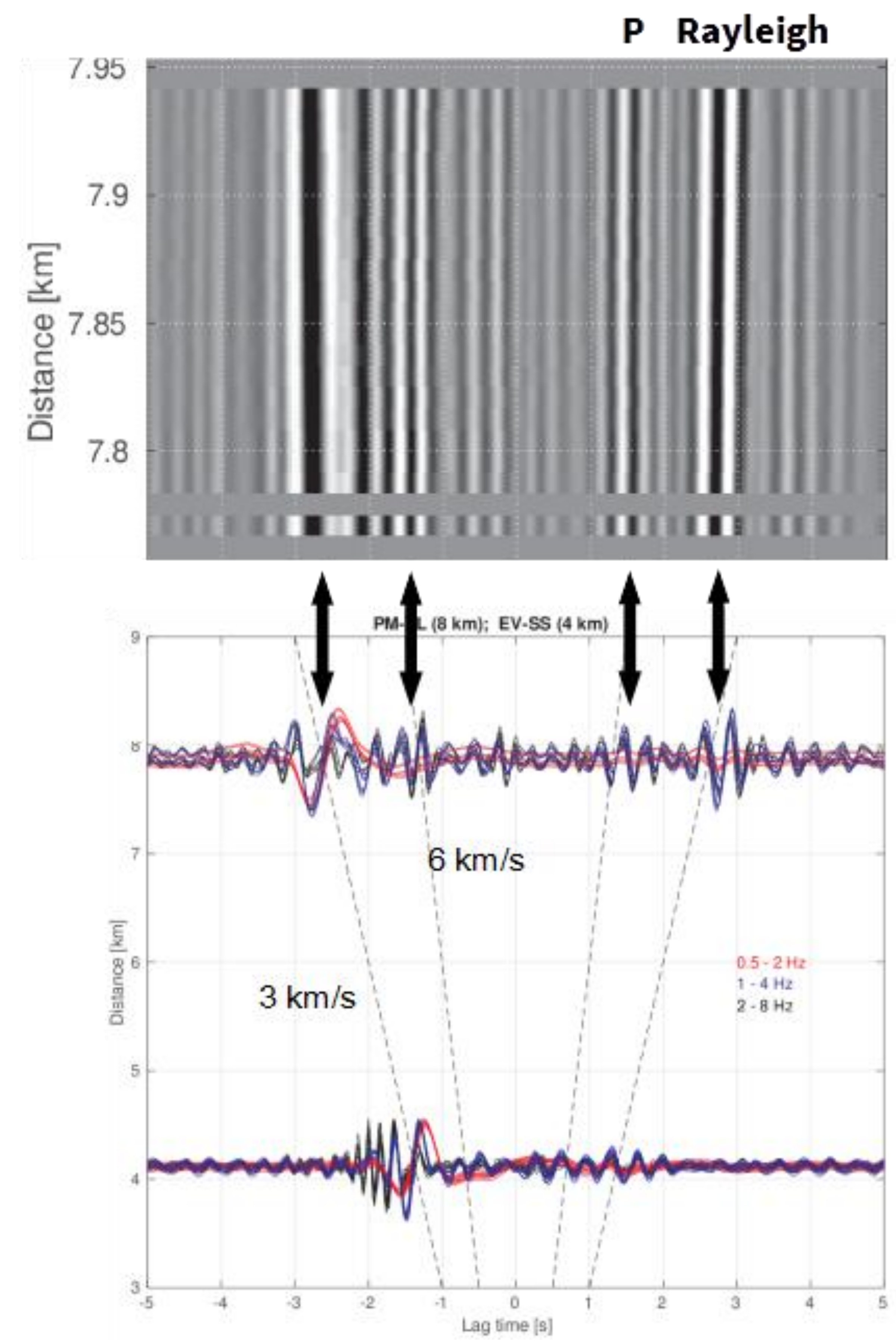

Figure 5. Double-beam between Pajamäki (PM-array, 4 Cubes) and Seurasaari (SS-array, 25 Cubes) arrays. Surface wave propagation displays high frequency dispersion probably due to shallow waterbody between the arrays (see map on Figure 1).