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Candidate methods for the implementation of OSI Resonance Seismometry

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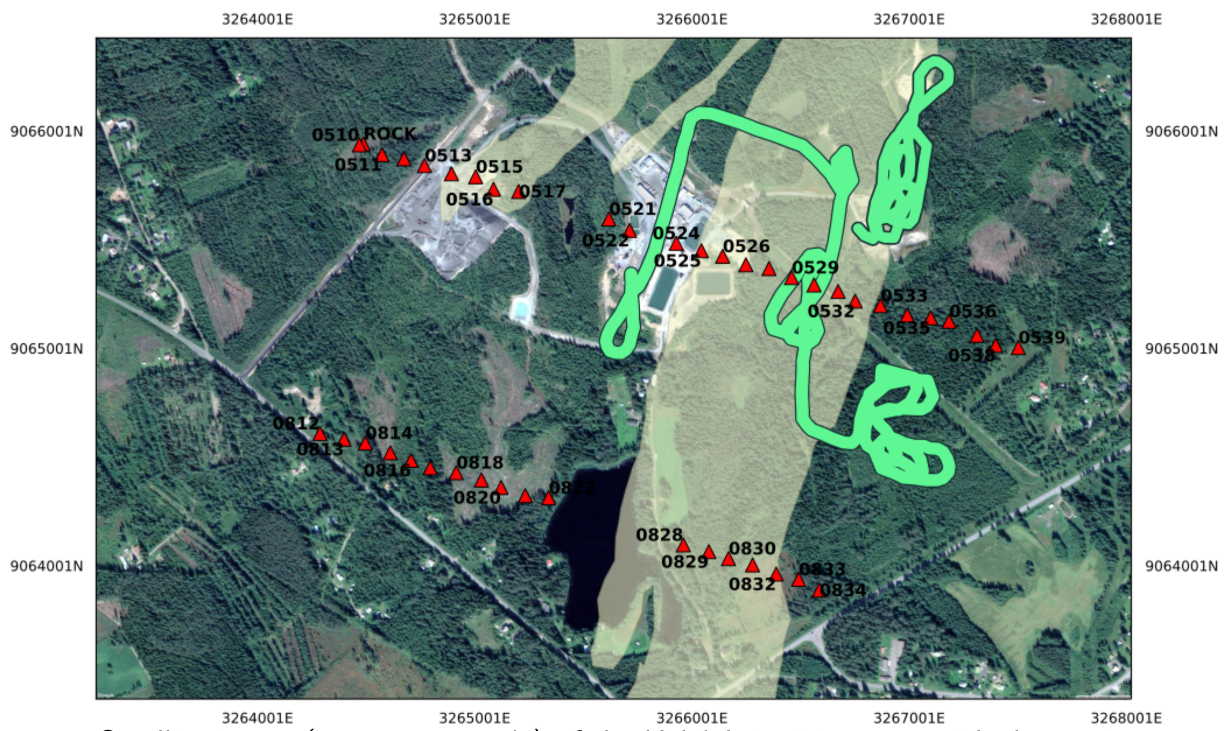
Introduction

The company Sonicona GbR was contracted by the CTBTO to explore processing methods applied to seismic measurement data for the development of OSI resonance seismometry capabilities. The general motivation of this study is to analyse the capability to detect any cavity or rubble zone caused by a possible nuclear explosion applying passive seismic methods. The theoretical background is that any underground disturbance (e.g. by rubble zone or cavity) changes the wavefield of seismic body waves regardless if the seismic waves are generated by anthropogenic or natural sources. Generally, the change of the wavefield depends strongly on dimension, shape and depth of the rubble zone/cavity and the geological situation (heterogeneities, faults, etc.) in the surrounding area.



Satellite image (src.:maps.google) of the Kylylahti mining area with the station setup. Green: Position of the tunnel system. The entry ramp is located near station 0522. Light Yellow: Outokumpu Cu-Co-Zn ore belt.

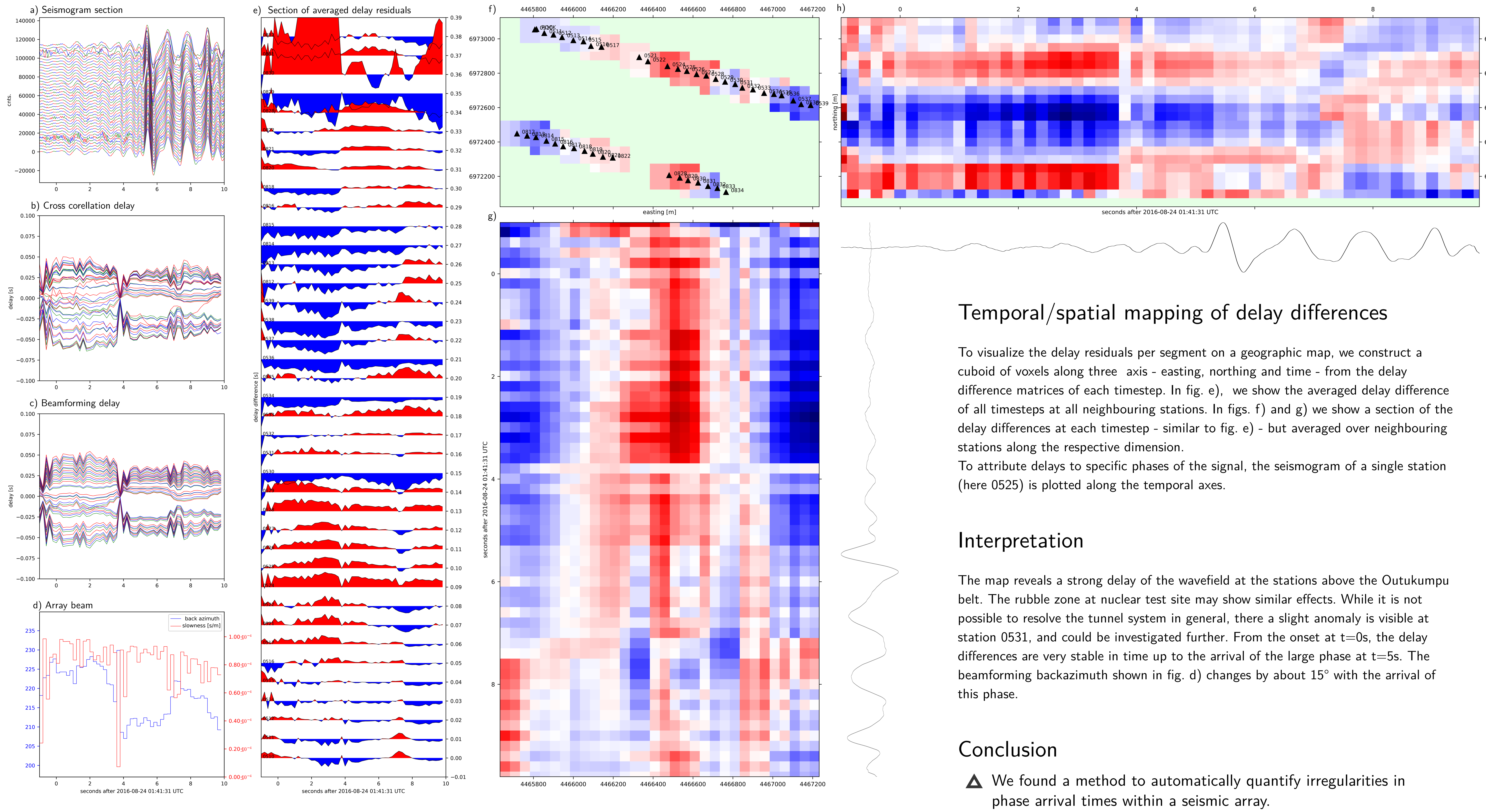
The Kylylahti experiment

To analyse the capability of passive seismic methods for cavity detection a dataset from a OSI experiment performed at the Kylylahti mining area, Finland, in 2016 was provided by the contracting authority. The experiment was performed there as the tunnel system and therefore the geometrical properties of the 'cavities' are well known.

From 16.08. to 14.09.2016 in the framework of the COGITO-MIN project (Lindblom 2016), 45 of the 3-component LE3D/1s seismometers of the PTS/OSI mini-array equipment were set up along two profiles crossing the Outokumpu belt. All data was recorded with a sampling rate of 500 Hz and high gain. Alongside numerous regional and teleseismic events numerous local active seismic experiments form the COGITO-MIN project were recorded. Beeing located on an active mining area, the signals are often contaminated by high anthropogenic noise levels, especially during the day.

Deviations in seismic wave fields

To reveal subsurface anomalies, we developed a method which is based on small variations of the seismic wavefield between the stations in the experimental area. We use the very homogeneous wavefield of strong regional events. Here, we show data for the M6.1 Italy event on 24.08.2016. Note the homogeneity of the seismograms in fig. a).
In our earlier work, we concentrated on the interpretation of small changes in amplitude between stations. Now, we examine differences in arrival time of different phases to map the subsurface.



Method

Because of higher noise levels on the horizontal traces, we only use the Z components. The set of seismogram is split up in segments of 0.2 seconds (denoted by color in fig. a). For each segment t_i, the following three operations are performed:

A cross correlation with a window length of 3 seconds around t_i yields a matrix D_{CC} of delays between each station pair for the segment. The average delay for each station in shown in fig b).

Based on the delays D_{CC}, we estimate a slowness vector via beamforming for the current segment t_i (shown in fig. d). Using this slowness, we estimate a theoretical delay matrix D_{beam}. The resulting average delay at each station is shown in fig c).

Finally, we compute the residual delay D_{CC}-D_{beam}. From the resulting matrix, we plot averages for each station in fig. e). These delays are not explained by the assumption of a planar wavefront, and may indicate subsurface anomalies.

Temporal/spatial mapping of delay differences

To visualize the delay residuals per segment on a geographic map, we construct a cuboid of voxels along three axis - easting, northing and time - from the delay difference matrices of each timestep. In fig. e), we show the averaged delay difference of all timesteps at all neighbouring stations. In figs. f) and g) we show a section of the delay differences at each timestep - similar to fig. e) - but averaged over neighbouring stations along the respective dimension.
To attribute delays to specific phases of the signal, the seismogram of a single station (here 0525) is plotted along the temporal axes.

Interpretation

The map reveals a strong delay of the wavefield at the stations above the Outukumpu belt. The rubble zone at nuclear test site may show similar effects. While it is not possible to resolve the tunnel system in general, there a slight anomaly is visible at station 0531, and could be investigated further. From the onset at t=0s, the delay differences are very stable in time up to the arrival of the large phase at t=5s. The beamforming backazimuth shown in fig. d) changes by about 15° with the arrival of this phase.

Conclusion

- We found a method to automatically quantify irregularities in phase arrival times within a seismic array.
- These irregularities can be mapped and correlated to known subsurface anomalies.
- Using a passive method, we rely on the occurrence of strong regional and teleseismic events.

Outlook

For further refinement this method should be testet at other known anomaly sites with more homegeneous station distributions. Less noise could allow for the usage of more local events, which could widen the frequency range to shorter periods.

Another possibility is the inclusion of horizontal component data to measure variations of the polarization of the seismic wave within the array. This may reveal a focusing effect of seismic ray paths above a low velocity anomaly.