CAN WE MONITOR SHALLOW GROUNDWATER USING AMBIENT SEISMIC NOISE?

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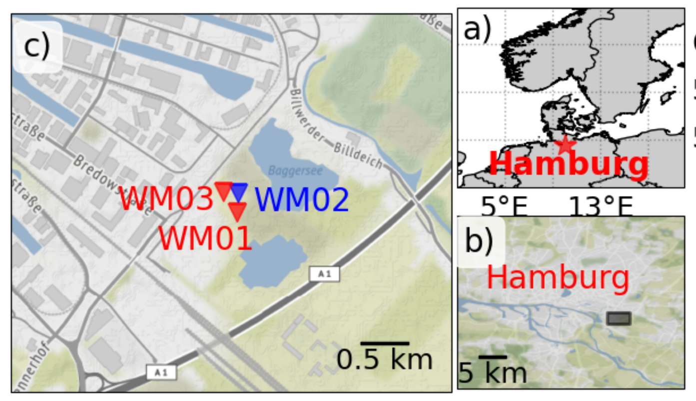
CLUSTER OF EXCELLENCE CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

MOTIVATION



Shallow soil is affected by environmental influences like temperature, rainfall or drought, which in turn changes the seismic velocity in the subsurface.

To monitor velocity changes in the subsurface continuously, Seismic Interferometry is used.

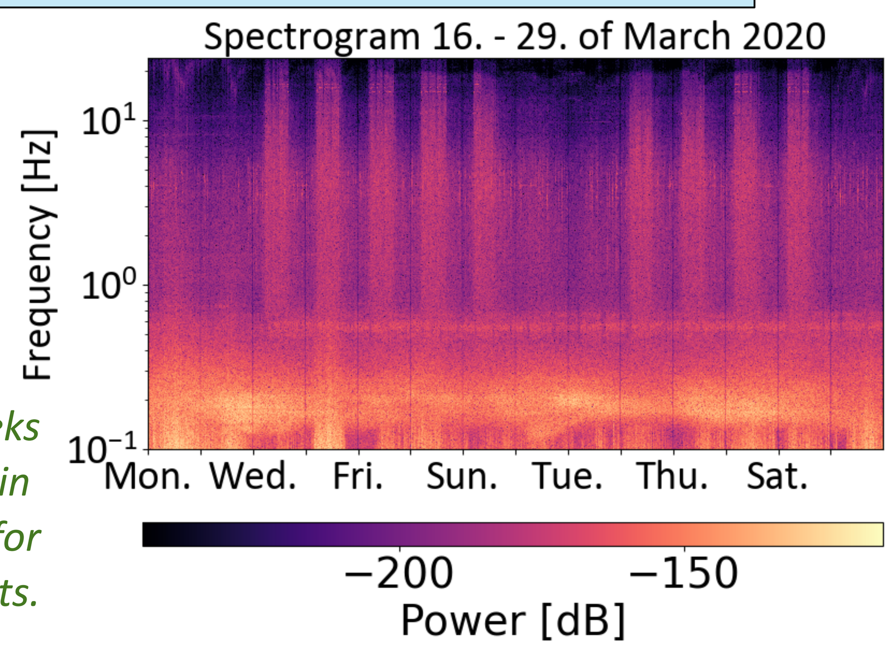
Study site in the urban area (c) in the east of Hamburg (a and b), equipped with three 3-component broadband seismometers (triangles) and soil sensors at station WM02 in several depths (blue).

At this study site, the groundwater level is regulated via drainage channels, making it stable.

URBAN SEISMIC NOISE FIELD

Urban activity produces strong signals > 1 Hz.

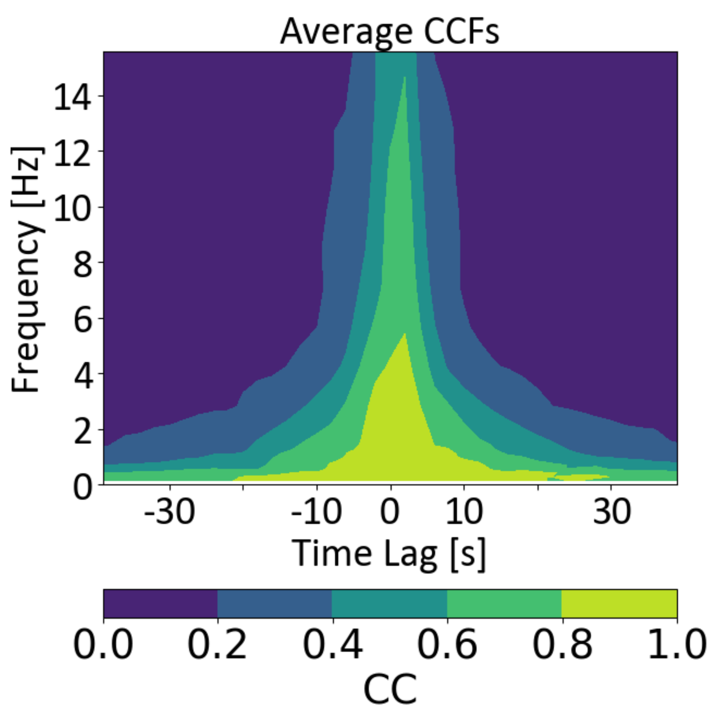
Noise with frequencies < 1 Hz is produced by oceanic and meteorological noise sources.



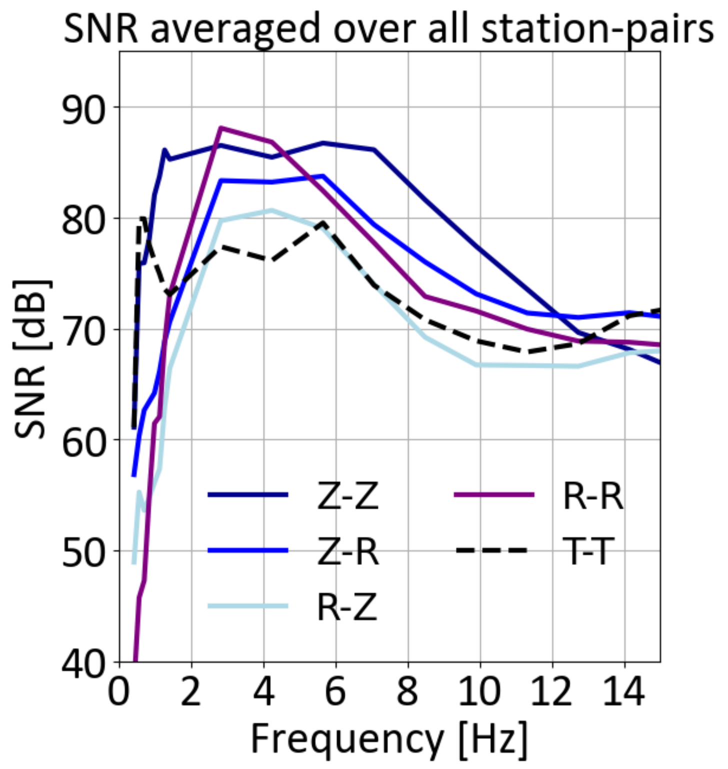
Spectrogram for two weeks showing a decrease in noise for high frequencies for weekends and nights.

WHICH FREQUENCIES ARE STABLE?

The Cross Correlation Functions (CCF) are calculated for all 3 station and 9 channel pairs in Vertical(**Z**)-**R**adial-**T**ransverse-components. To perform Seismic Interferometry, a stable noise field (= high **W**ave-**F**orm-**C**oherency(WFC)) with high signal-to-noise ratio (SNR) is needed.



WFC averaged over station and component pairs.



SNR for direct Rayleigh (solid) and Love (dashed) wave components.

The CCFs are suficiently stable for direct waves up to around 11 Hz. The stability is further increased by stacking 4 days of CCFs. To ensure a high SNR for the CCFs, direct waves are included and frequencies from **1 to 6 Hz** used.

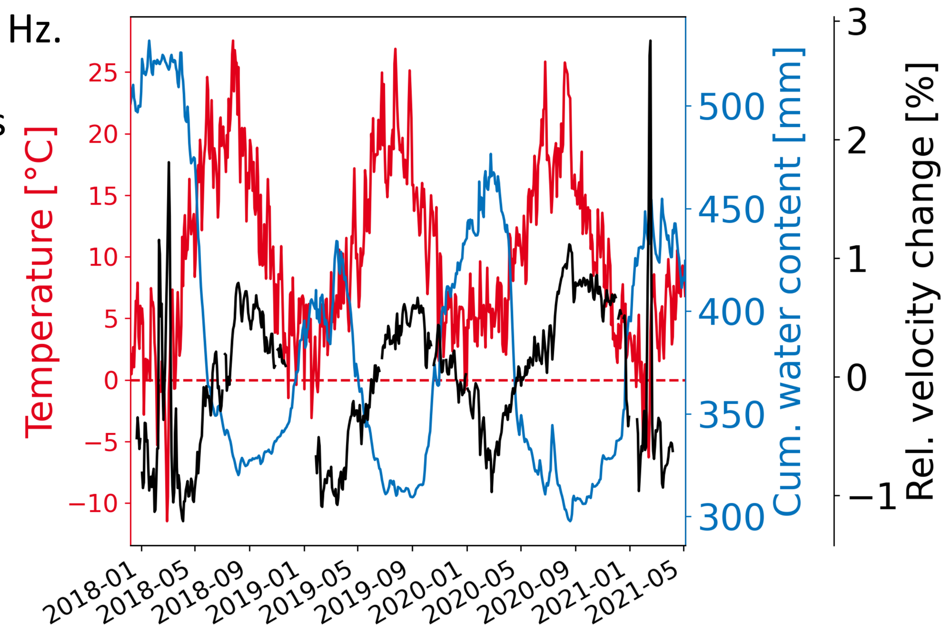
RELATIVE VELOCITY CHANGES

The Cross Correlation Functions are calculated for all 3 stations and 9 channel pairs in Vertical-Radial-Transverse-components. To perform Seismic Interferometry, a stable noise field with high signal-to-noise ratio and high waveform coherence is needed. This is the case for 1 - 6 Hz.

Relative seismic velocity changes are calculated using the Stretching Method.

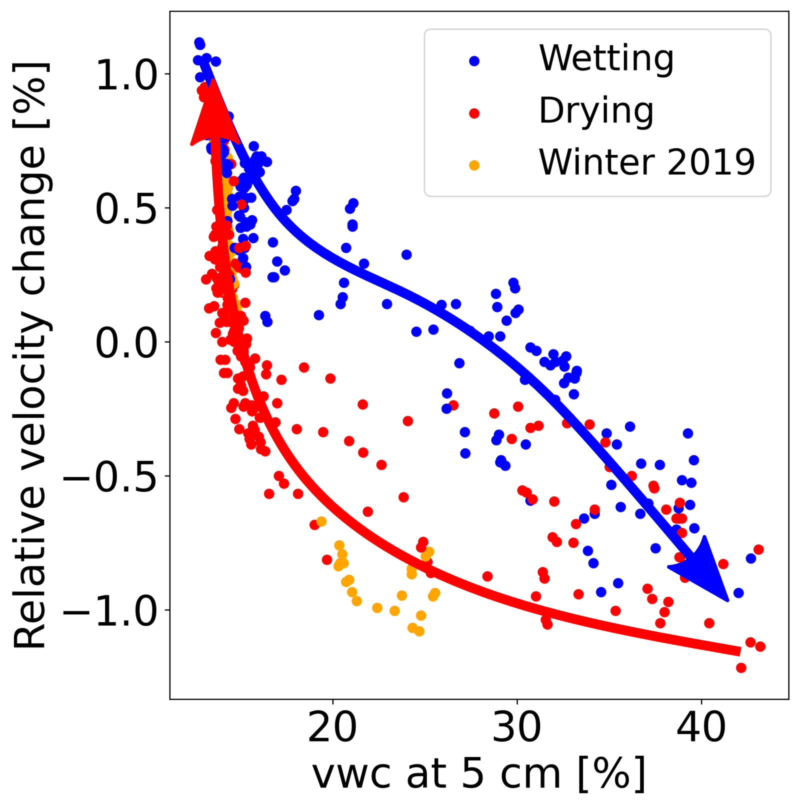
➜ **Seismic velocity change shows correlation with temperature and anticorrelation with water content.**

➜ **Freezing in winter increases velocity by up to 1.5 % (see Steinmann et al., 2021)**



Temperature at the surface and volumetric water content measured in 5 cm depth with relative velocity changes of surface waves.

HYSTERESIS EFFECT

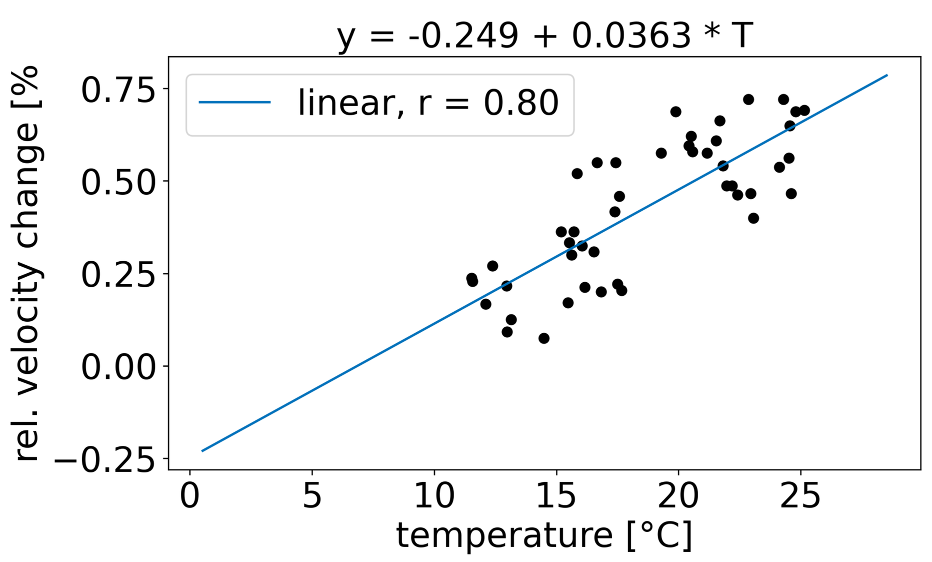


Volumetric water content (vwc) in 5 cm depth and relative seismic velocity changes show a hysteresis effect for drying and wetting periods. Laboratory studies found similar hystersis effect but with the branches in the opposite direction. Temperature effects are not accounted for.

➜ **There is a possible hystersis effect between very shallow volumetric water content and seismic velocity. However, this result could be explained by influence of temperature .**

Seismic velocity change vs. volumetric water content in 5 cm depth. Colors show wetting and drying period and some outliers which would belong to a wetting period in winter 2019.

RELATION TEMPERATURE & WATER CONTENT

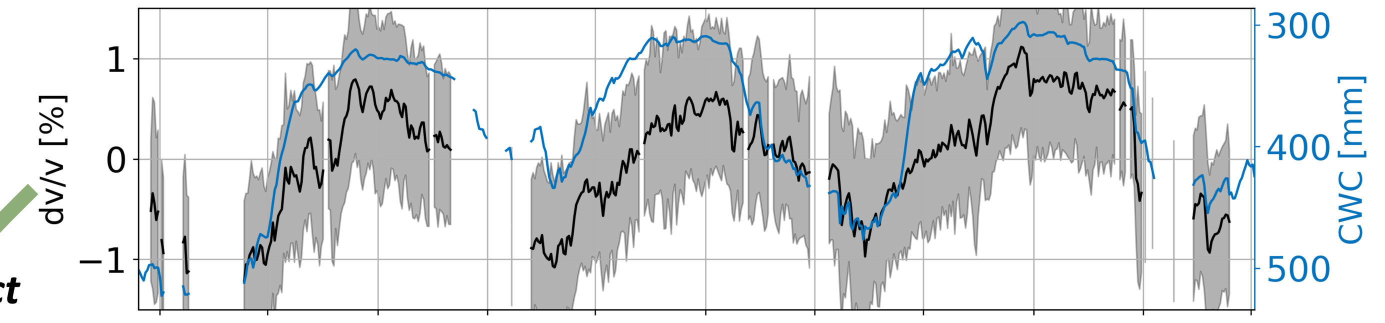


Temperature and seismic velocity show a positive correlation during a time period of nearly stable cumulative water content in upper 120 cm. The relation is approximated and quantified by a linear regression.

Seismic velocity change vs. temperature in 5 cm depth. Data is from summer until fall of 2018 when the cumulative water content was nearly stable.

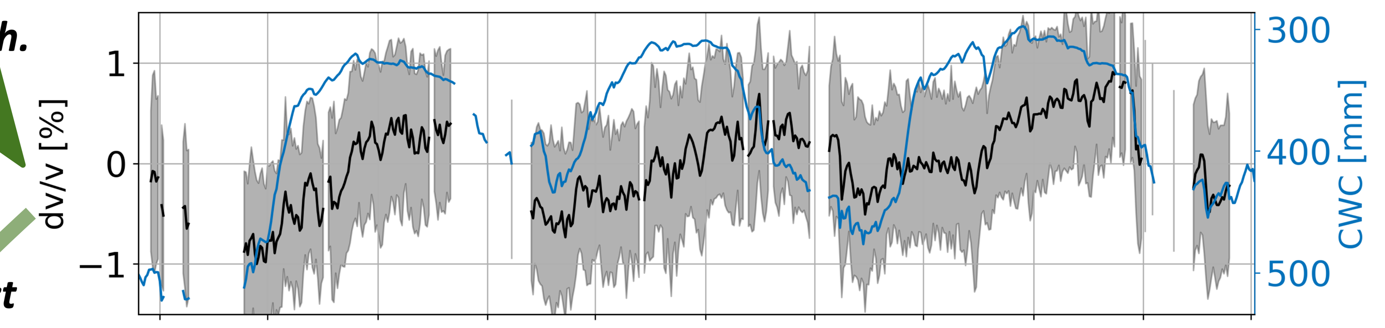
YES, WE CAN APPROXIMATE IT

The **goal of this study** is to track water content changes through changes in seismic velocity. Assuming seismic velocity is directly influenced by temperature and groundwater content, temperature effects are eliminated from seismic velocity changes using a linear regression. Freezing events are excluded since they alter the seismic velocity due to the stiff frozen layer.



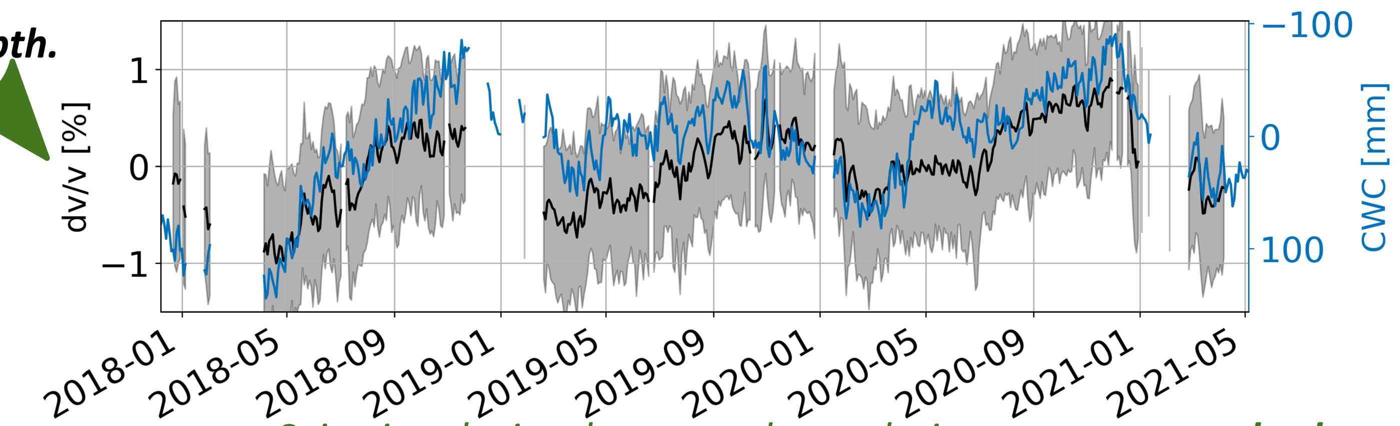
Determined seismic velocity change (dv/v) and its error (grey) and measured cumulative water content (CWC).

Substract regression dv/v and T. at 5 cm depth.



Seismic velocity change without temperature effects and measured cumulative water content.

Substract regression CWC and T. at 5 cm depth.



*Seismic velocity change and cumulative water content **both without temperature effects**.*

➜ **After removing temperature effects using a simple linear regression, the residual seismic velocity changes approximate the residual water content. Since temperature has to be eliminated from in-situ measurements of water content, there has to be an additional relation between temperature and water content.**

CONCLUSION & OUTLOOK

- Groundwater in shallow soil can be approximated by measuring relative seismic velocity changes and eliminating temperature effects.
- Seismic velocity in loose soil is not only directly related to temperature but there is a more complex relation including interaction of water and temperature.
- Potential to monitor climate induced changes in urban areas using (already installed) geophones and seismometers or new technologies like fiber-optic cables in Smart City infrastructure.

References

Steinmann, R., Hadziioannou, C., Larose, E. 2021. Effect of centimetric freezing of the near subsurface on Rayleigh and Love wave velocity in ambient seismic noise correlations. Geophys. J. Int. 224 (1), 626-636. DOI: 10.1093/gji/ggaa406

Richter, T., Sens-Schönfelder, C., Kind, R., Asch, G. 2014. Comprehensive observation and modeling of earthquake and temperature-related seismic velocity changes in northern Chile with passive image interferometry. J. Geophys. Res. Solid Earth 119. DOI: 10.1002/2013JB010695.

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Part of the **raw seismic data is available** under DOI: 10.5281/zenodo.3992631

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