The Vertical Component of Low Magnitude Earthquakes, Why Do We Care?

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Abstract

Up to now, almost all of the ground motion modeling and hazard assessment for induced seismicity in Groningen, the Netherlands, has been focused on the horizontal components of earthquake waves. Including the vertical component in site response studies is hardly being done for low magnitude earthquakes. Since the top part of the soils in the Netherlands is practically always unconsolidated, the elastic waves generated by deeper (~3000m) seated earthquakes will be subject to transformation when arriving in these layers. Recordings over a range of depth levels in a borehole show most of the amplification in the upper 50 meters of the sedimentary cover. We observe not only a strong amplification from shear waves on the horizontal components, but also from longitudinal waves on the vertical component. Furthermore, the seismic velocities show a large lateral heterogeneity. A better understanding of the vertical component of low magnitude earthquakes (to date, max M=3.6 in Groningen) aims to support the design of re-enforcement measures for buildings in areas affected by induced seismicity. This study focuses on longitudinal wave amplification in a sedimentary basin setting.Generally, the vertical component of ground motion is less than the horizontal, but the longitudinal waves are concentrated in a high frequency band which can cause damage to buildings with vertical periods in this range. Furthermore, interference between the longitudinal and shear waves might contribute to extra damage on structures. In Groningen, a dense borehole network is continuously recording seismic activity. From 19 seismic events with a minimum of magnitude two, transfer functions are retrieved between geophones at 50m depth and accelerometers at the surface, for 70 borehole sites. Peak frequencies and amplitudes derived from the transfer functions, do show significant variability across the region. Highest longitudinal wave amplification is measured in the center of the field, which is also the epicenter of most seismic activity. We investigate if the variations in amplification can be linked to the local geology. Additionally, the possibility and consequences of interference between the shear and longitudinal waves are presented.

The vertical motion of low magnitude earthquakes, why do we care?

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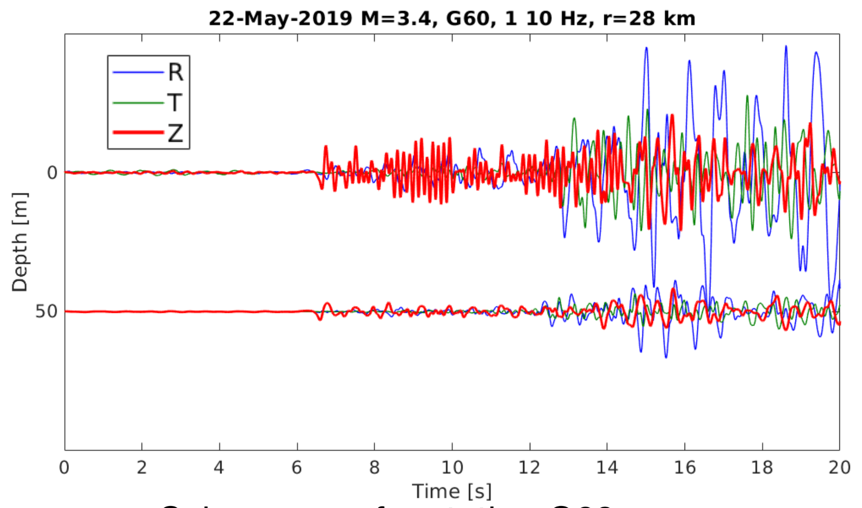
BACKGROUND

- In the Netherlands, including the vertical motion in site response studies is hardly being done since its impact on low magnitude earthquakes is considered as very low (max M=3.6).
- Since the conventional rule is a 2/3 contribution of vertical ground motion compared to horizontal[1], vertical motions by earthquakes are mostly not included in building design because of the assumption that structures are stronger in the direction of gravitational acceleration.
- In the Groningen region, we observe that the seismic waves are transformed in the soft, unconsolidated sedimentary sequence, leading to amplification for both S-[2,3] and P-waves.
- We focus on P-wave amplification in the frequency range 1 to 10 Hz, corresponding to the natural frequency of resonance of Dutch buildings [4].

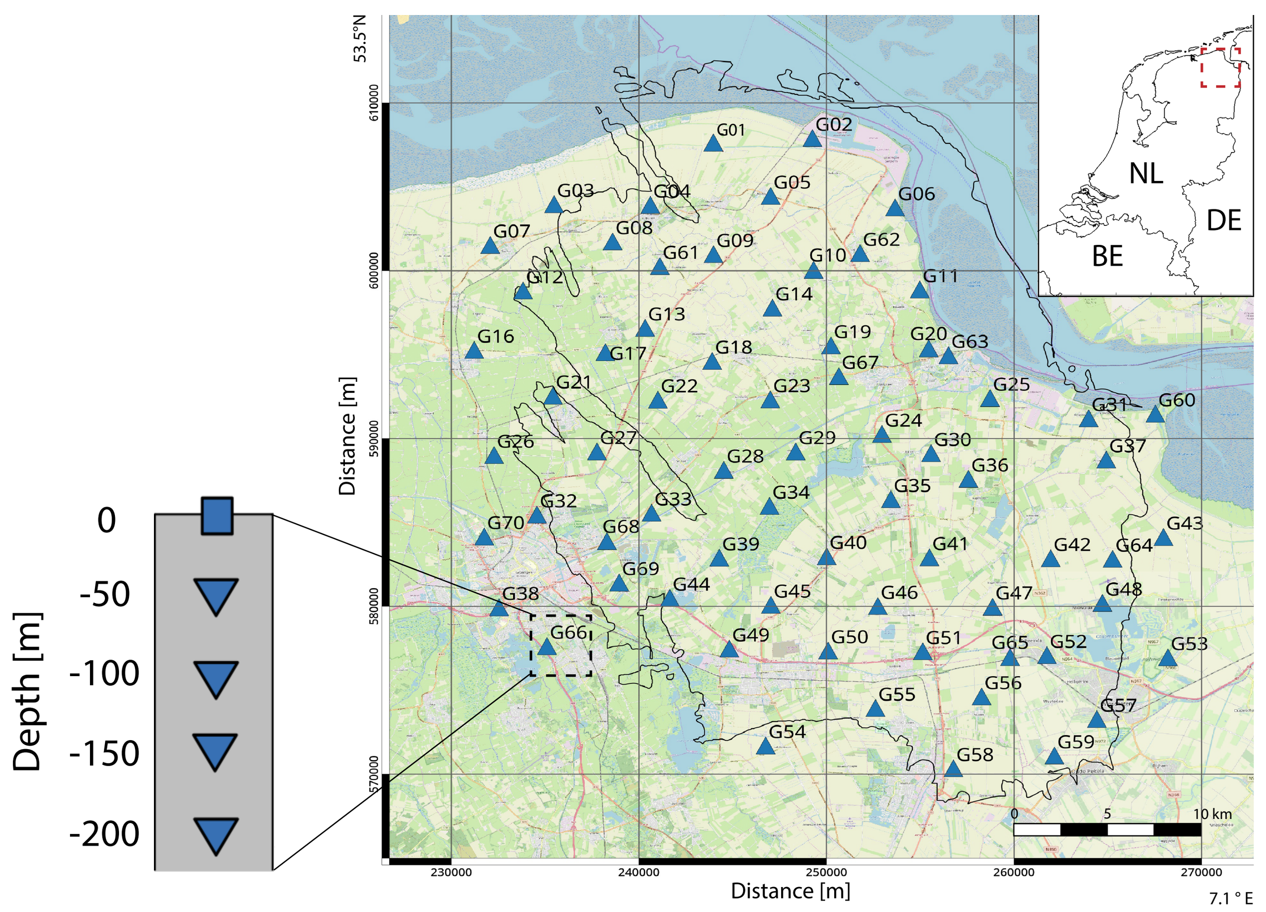
HYPOTHESIS

Local P-wave amplification in soft soils is relevant to be included in seismic hazard assessment



Seismogram for station G60

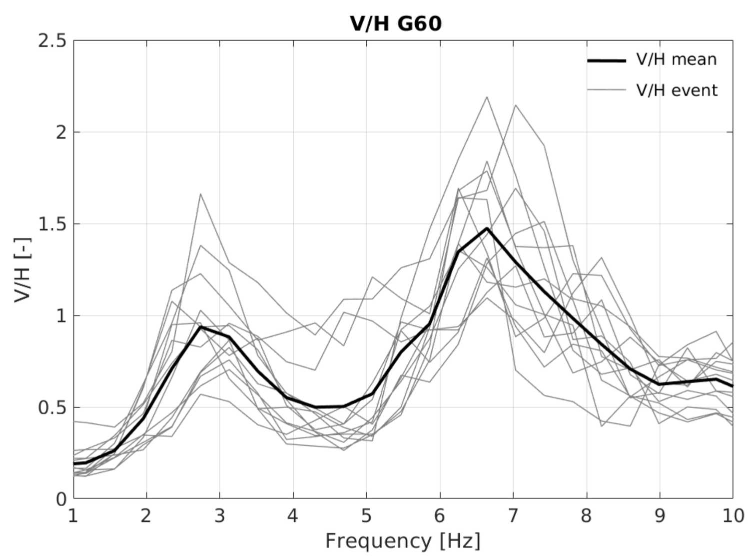
THE GRONINGEN NETWORK



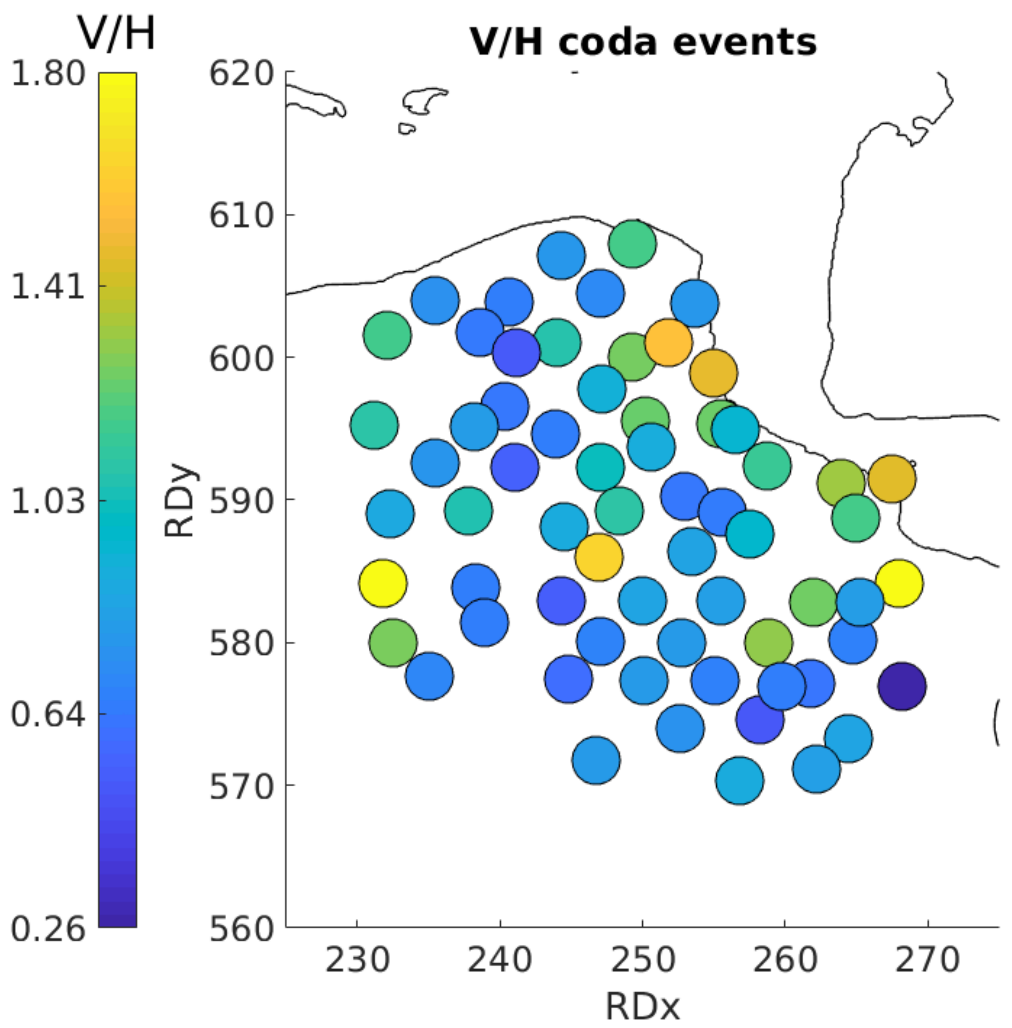
V/H EVENT CODAS

$$V/H = \frac{\sqrt{PSD_Z}}{\sqrt{PSD_E + PSD_N}}$$

PSD = power spectrum density
Z = vertical component
E = east component
N = north component



Example of a V/H ratio for seismometer G60

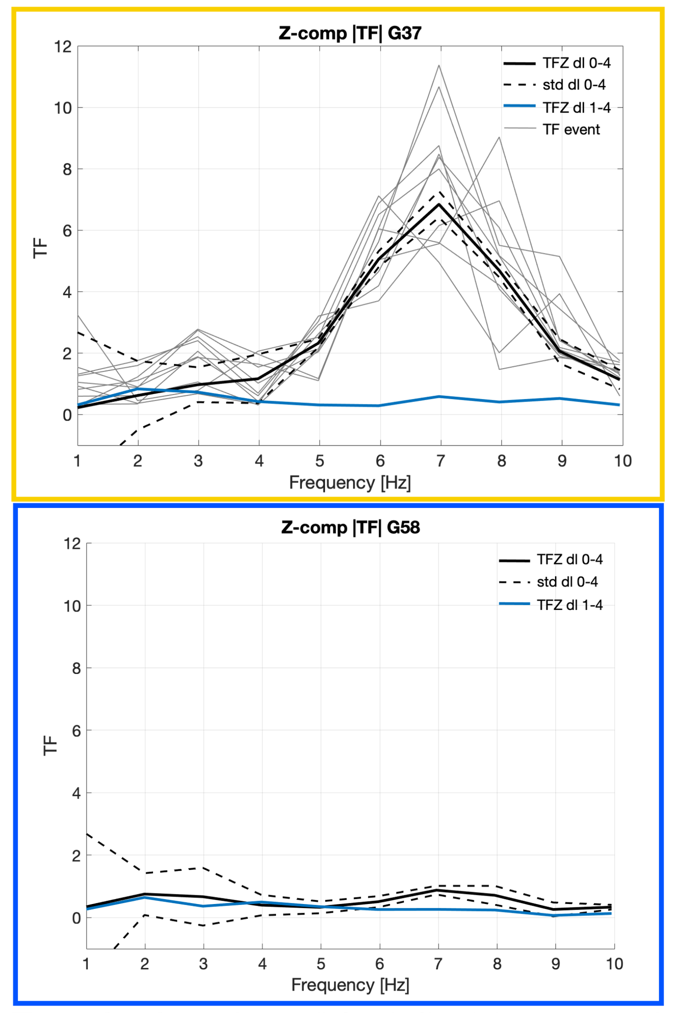


V/H ratios measured at the surface for all sites

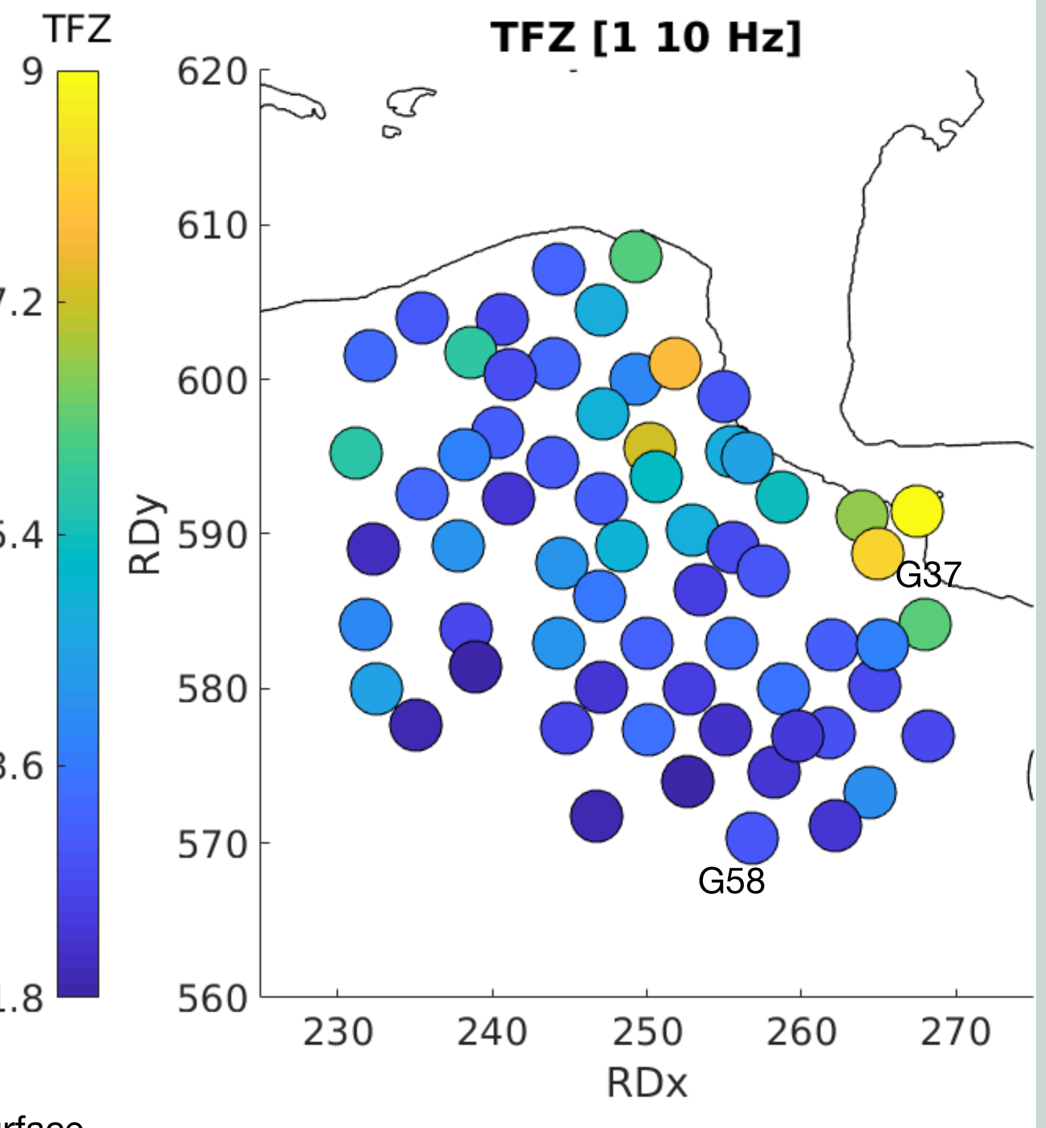
TRANSFER FUNCTIONS

$$TF_{m,n}(f) = \frac{u_m}{u_n}$$

u = up- and downward wave amplitudes
m = layer of interest
n = reference horizon



Transfer functions (black line) between the surface and 200m depth seismometer and between 50m and 200m (blue line) for sites G58 & G60



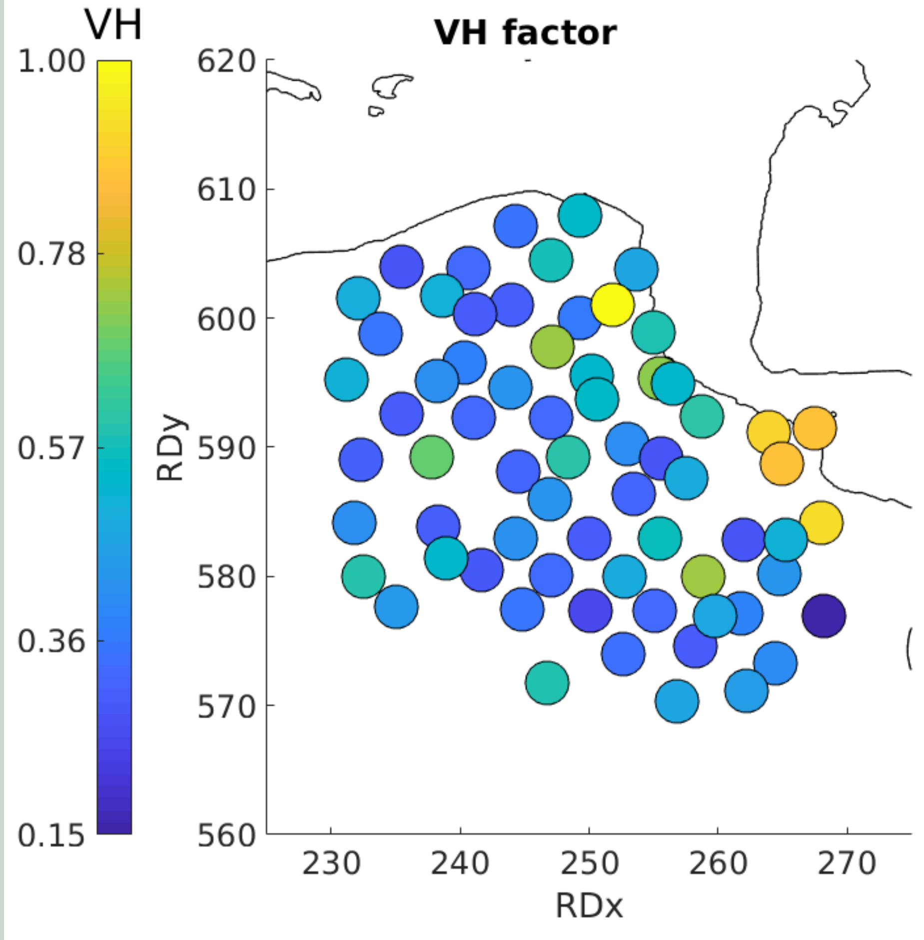
Peak amplitude of transfer functions between surface and 200m for all sites

VH FACTORS & PGA

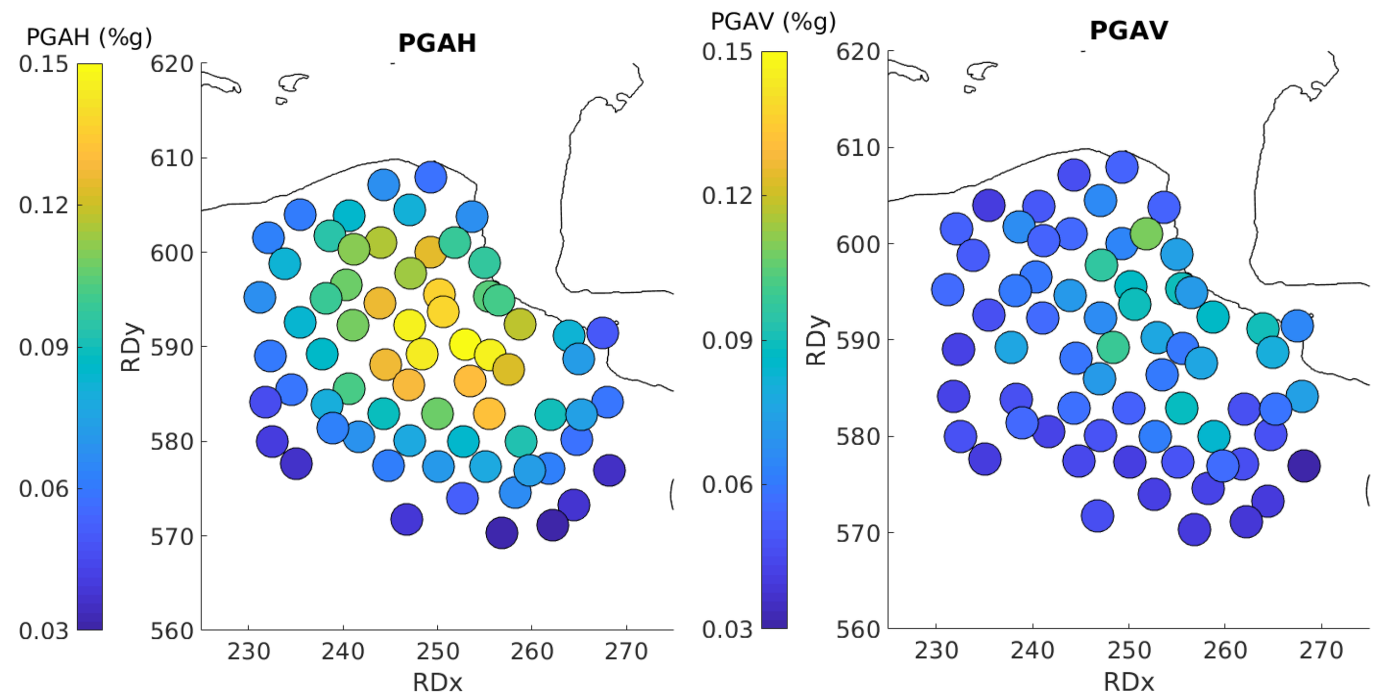
$$VHfactor = \frac{|Z_{max}|}{\left|\sqrt{E^2 + N^2}_{max}\right|}$$

$$PGAV = PGAH * VHfactor$$

Z = particle acceleration Z-comp
E = particle acceleration E-comp
N = particle acceleration N-comp
PGAH/V = peak ground acceleration horizontal/vertical



VH factors measured at the surface for all sites.

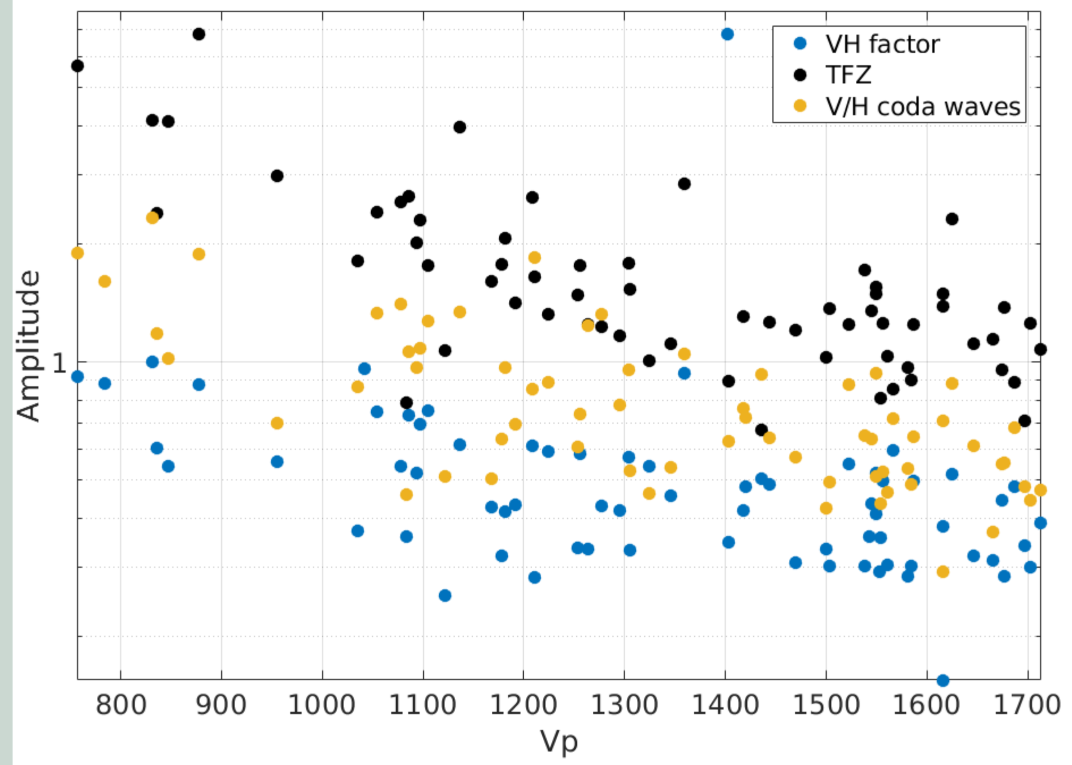


PGA values for horizontal and vertical ground motion as percentage of *g*.

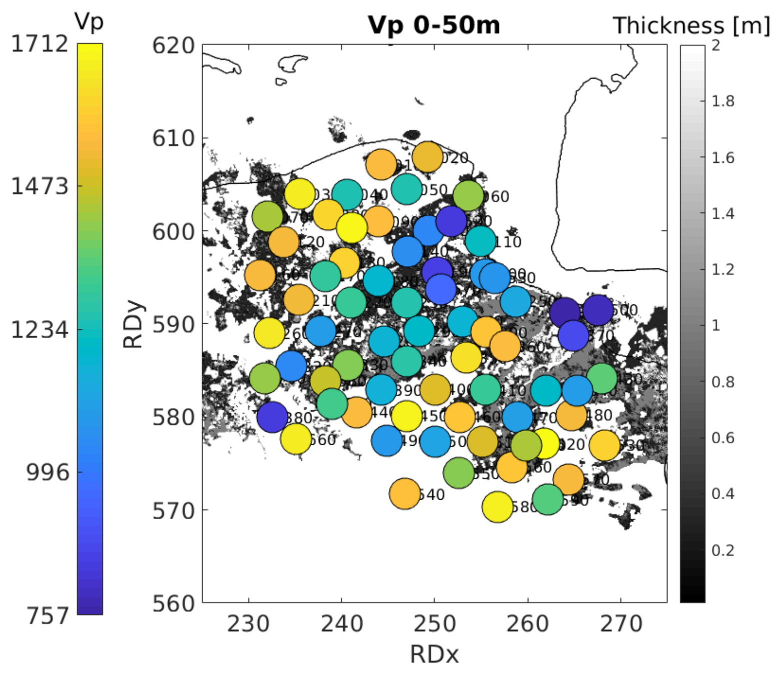
CONCLUSIONS

- From V/H from event codas we obtain a proxy for vertical amplification
- Peak ground accelerations for vertical ground motion are higher towards the east, compared to horizontal PGA
- V/H from event codas underestimate the amplification, as determined with transfer functions
- All three methods show high amplification in the upper 50 meter at identical sites, matching low P-wave velocities

LINK WITH P-WAVE VELOCITY



Correlation between P-wave velocity and the peak amplitude from the V/H codas and transfer functions for each site. The VH factor is not an actual amplitude measure but plotted to show a similar trend.



P-wave velocity (0-50m) for all sites plotted on thickness map of peat

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