Rayleigh Wave Group Velocity Maps of The Netherlands From Ambient Seismic Noise

Tedi Yudistira, Hanneke Paulssen, Jeannot Trampert

Faculty of Geosciences – Department of Earth Sciences - Utrecht University, Budapestlaan 4, 3584 CD Utrecht, The Netherlands.
Contact: tedi@geo.uu.nl

A. Introduction

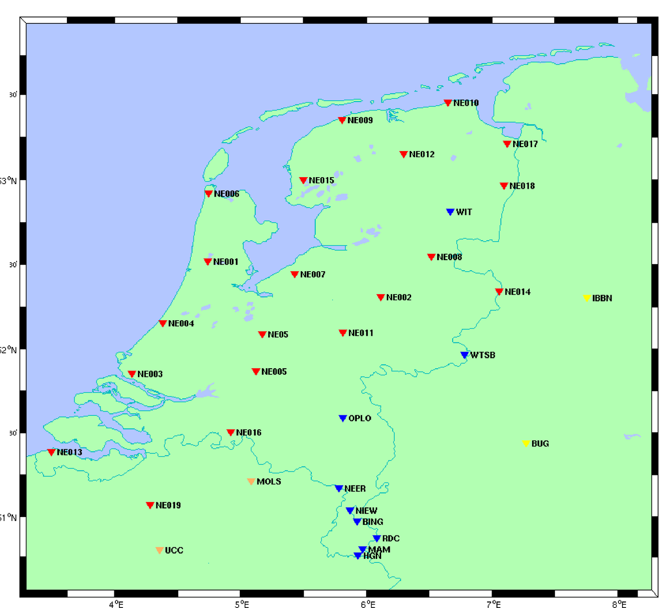
While the sediment and the uppermost crustal structures beneath The Netherlands are relatively well known from seismic reflection and borehole data, the deeper crustal and upper mantle structures are not much investigated. Using a new temporary deployment of broadband seismometers in The Netherlands we aim to investigate the crustal structure and upper part of the mantle using an integrated surface wave analysis.

The current focus is to determine Rayleigh wave group velocities based on cross-correlations of ambient seismic noise data.

C. Data and Data Analysis

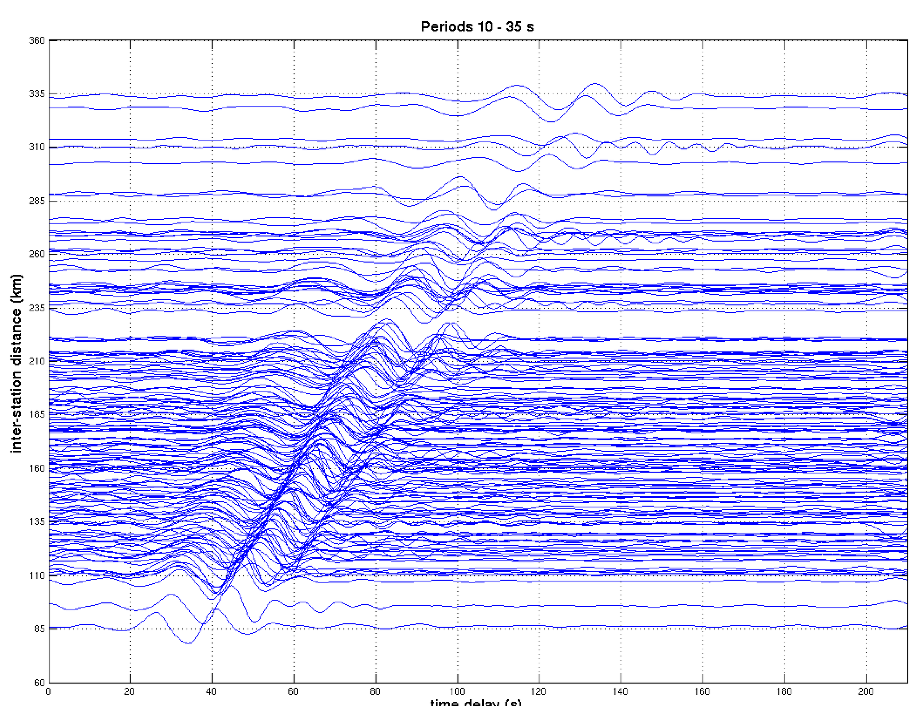
Data are from the NARS*-Netherlands project, a temporary deployment of 20 broadband seismometers in The Netherlands (red). To cover the entire area of The Netherlands we also used data from 9 permanent KNMI stations (blue), 2 German stations (GRSN, yellow) and 2 Belgium stations (BSN, brown).

141 station pairs were manually selected from all of the possible pairs based on the signal-to-noise ratio of the CCFs. We obtained good quality CCFs for inter-station distances of more than 75 km constructed from noise time series longer than three months. The causal and acausal parts of the CCFs are not similar, due to the inhomogeneous distribution of the noise sources. We selected the strongest and cleanest part of the CCFs rather than use the average CCF.



(*) NARS : Network of Autonomously Recording Seismographs

CCFs as a function of inter-station distance



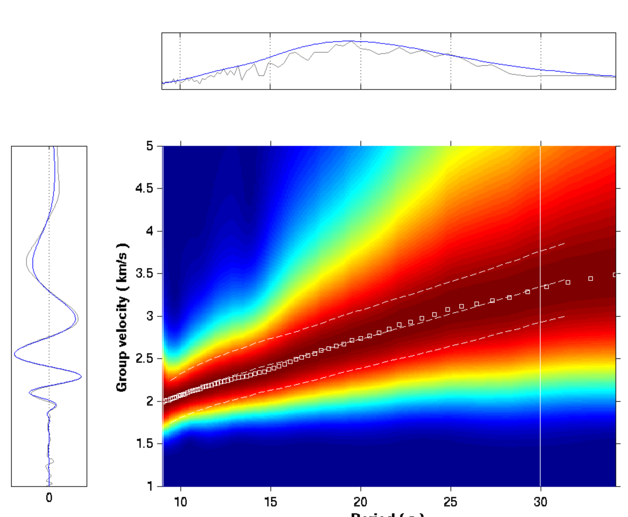
Vertical component CCFs of 141 station pairs, filtered between 10 and 35 s. For every inter-station distance dispersive waves can be identified, indication the average characteristics of the group velocity in the study area.

At the selection stage of the strongest CCFs, we found that the dominant noise sources are associated with microseismic activity of the North Sea.

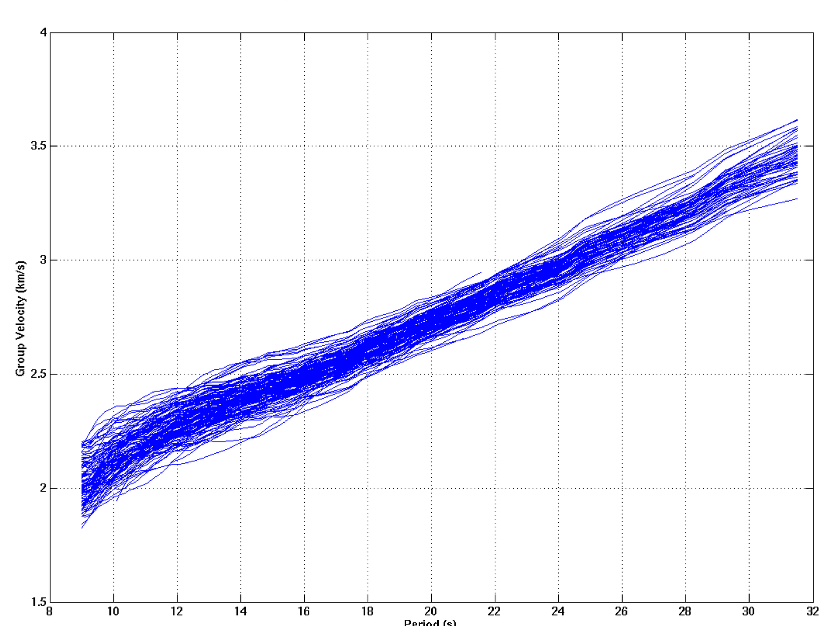
An example of FTAN

The FT-map bellow corresponds to the station pair NE003-NE008 with an inter-station distance of 180 km and constructed from 400 days worth of data

The white squares represent the automatically selected group velocity curve, and the white dashed-line is the group velocity reference. Blue lines on the CCFs and amplitude spectrum panels are filtered and gray lines are unfiltered.



Group velocity curves



The overlay of 141 individual Rayleigh wave group velocity curves. The period range is 10 – 30 seconds. These group velocity curves were used to create Rayleigh wave group velocity maps.

E. Conclusion and Outlook

We have obtained Rayleigh wave group velocity maps of The Netherlands for periods between 10 and 30 s, with a good agreement with gravity anomaly data. The shear wave velocity structure beneath The Netherlands will be determined by inversion of these group velocity maps. Furthermore, together with Love wave group velocity maps it will be possible to explore the anisotropic shear velocity structure.

Acknowledgements

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B. Basic Theory and Practical Measurement Technique

Seismic noise interferometry is increasingly used to study the subsurface structure, from very local to global scales. The method provides the observational Green's function between two points by cross-correlating long records of noise wavefields recorded at those points (Lobkis & Weaver 2001; Wapenaar 2004; Snieder 2004).

The empirical Green's function between two receivers at position x_A and x_B is given by the cross-correlation of two wavefields u_A and u_B recorded at station A and B, (Wapenaar, et. al., 2010):

$$(G_{BA}(t)+G_{BA}(-t))*S_N(t)=\langle u_B(t)*u_A(-t)\rangle$$

where $G_{BA}(t)$ and $G_{BA}(-t)$ are the Green's functions corresponding to the response at location B due to the an impulse source at location A and vice-versa $S_N(t)$ is the auto-correlation of the source signal.

We determine Rayleigh wave group velocity curves between station pairs based on the cross-correlation of daily seismic records. We use the following steps as described in detail by Bensen, et al. (2007) :

(1) Time domain 1bit normalization and spectral equalization; the aim of this step is to reduce the dominant effect of earthquakes and to equalize the signals spectrally.
(2) Cross-correlation of daily normalized records.
(3) Temporal stacking, this enhances coherent signals and suppresses incoherent ones.
(4) Dispersion curve measurement.

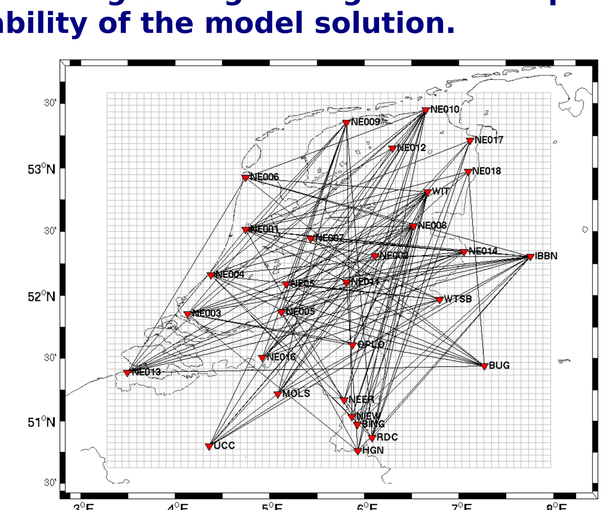
The group velocity is measured using a frequency time analysis (FTAN) (Dziewonski, et al., 1969) of the stacked cross-correlation function (CCF). To enhance the energy distribution of the fundamental mode in the frequency-time map (FT-map), time-variable filtering is applied using a reference group velocity curve. The reference group velocity is determined from the average of selected good quality group velocity curves.

D. Rayleigh Wave Group Velocity Inversion

We used a regularized least-squares inversion to create group velocity maps

$$\Delta \mathbf{m}=(\mathbf{A}^T\mathbf{W_d}\mathbf{A}+\lambda_0^2\mathbf{I}+\lambda_1^2\mathbf{L}^T\mathbf{L})^{-1}\mathbf{A}^T\mathbf{W_d}(\mathbf{d_{obs}}-\mathbf{A}\,\mathbf{m_0})$$

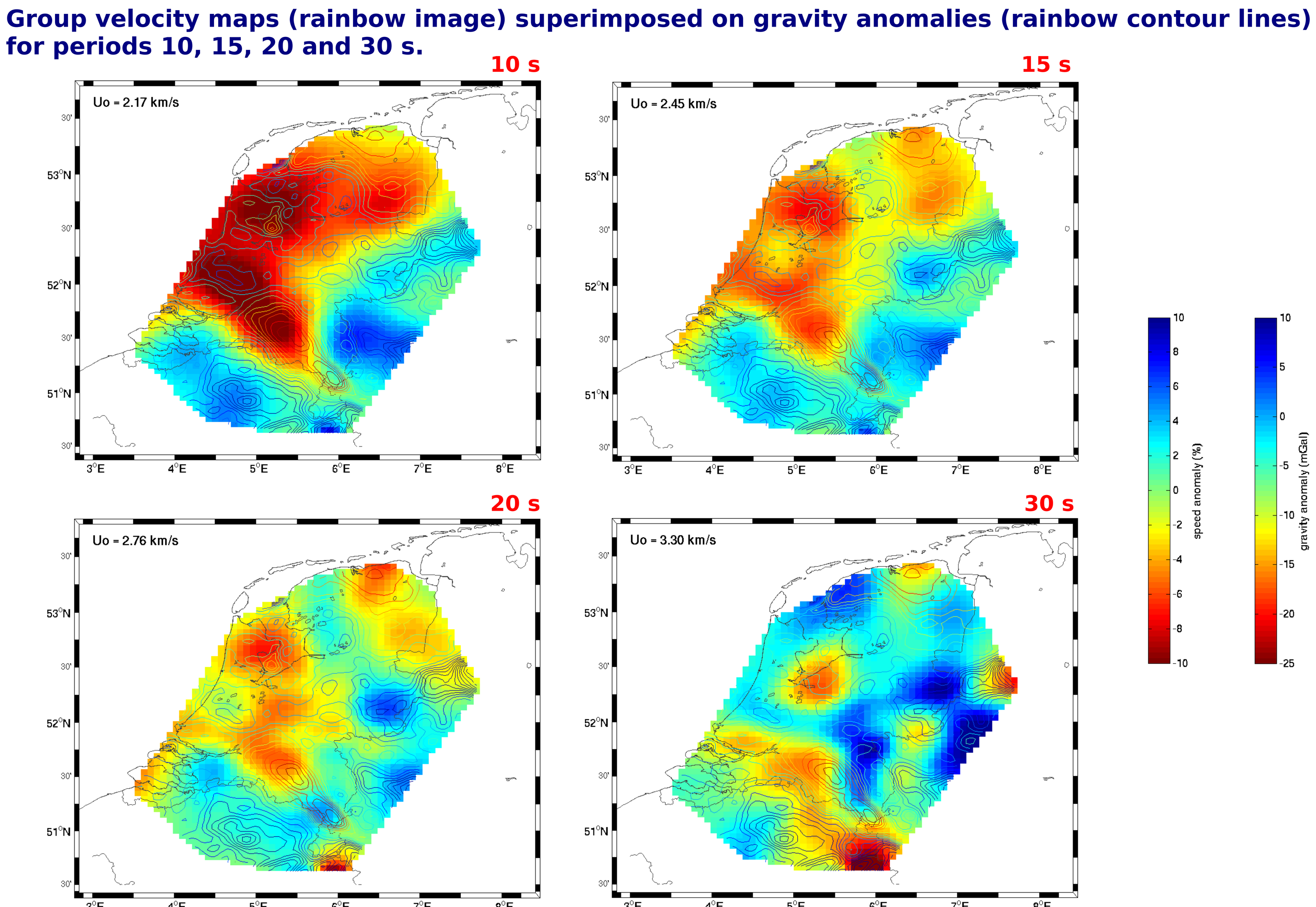
Where Δm is the model perturbation from a reference group velocity. A is the forward operator matrix, W_d the data weighting matrix, L the model smoothing matrix, λ_0 and λ_1 are norm-damping and smoothing strength. Regularization parameters were chosen based on criteria of the misfit value and stability of the model solution.



A block parameterization is used by dividing the area into 60 x 60 blocks. The same parameterization and regularization is used for all periods.

The ray-path coverage shown is for a period of 10 s.

Group velocity maps (rainbow image) superimposed on gravity anomalies (rainbow contour lines) for periods 10, 15, 20 and 30 s.



The group velocity maps at 10, 15, 20 and 30 s are most sensitive to upper, middle and lower crust and lower crust/uppermost mantle, respectively.

At 10 – 15 s low group velocities are found for the NW-SE trending West Netherlands Basin and Roer Valley Graben, the Zuiderzee Low in the NW, and the Lower Saxony Basin in the NE. These anomalies are most likely related to sedimentary layers. This probably also explains the agreement between the group velocity maps of 10 – 20 s with the pattern of gravity anomalies.

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