Ambient seismic noise tomography at Valhall, a 3D S-wave model of the subsurface

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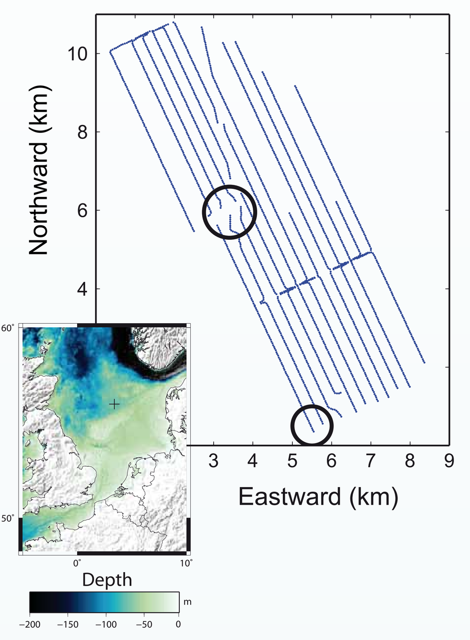
1 The Valhall LoFS network

The ambient noise surface wave tomography (ANSWT) has proved efficient at regional and continental scales and mostly onshore. Most of the studies focus on the secondary microseism frequency band (3-10s).

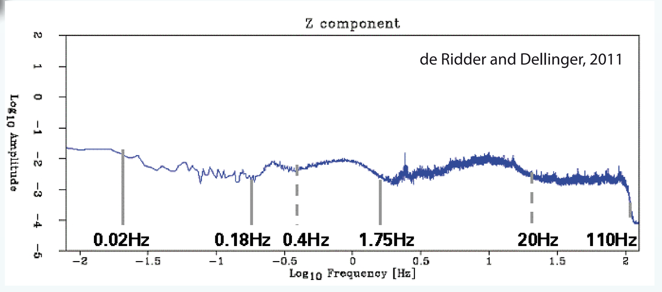
Is it possible to apply ANSWT at higher frequency (~1s) in marine exploration geophysics context?

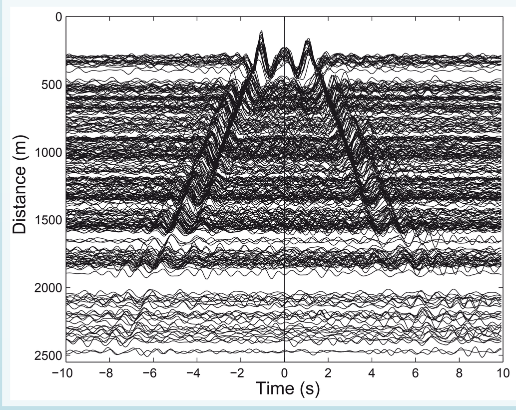
We used 6.5 hours of continuous passive data from the Valhall Life of Field Seismic network recorded on 2320 4C sensors to assess this question.

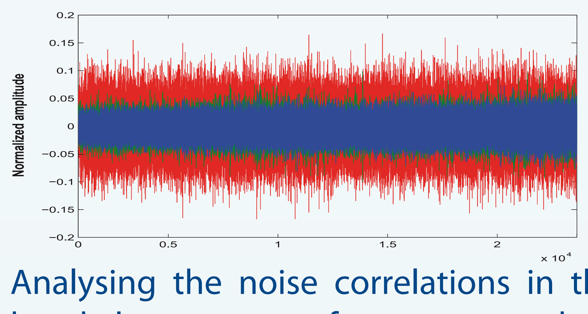


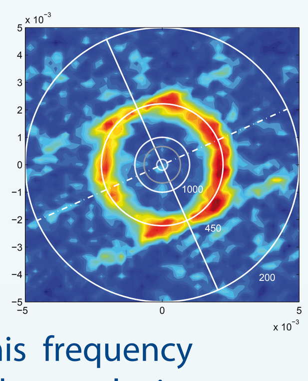
2 The seismic noise characteristics at Valhall

The ambient noise background consists of Scholte waves, which propagate with only a limited depth of penetration below the subsurface. Although the noise is broadband, it only has the necessary statistical properties required for interferometry (diffusivity) over a frequency range of about 0.18 to 1.75 Hz (0.4 to 1.75 Hz in our case). At such low frequencies, however, Scholte waves do penetrate the top few hundred meters of the subsurface.







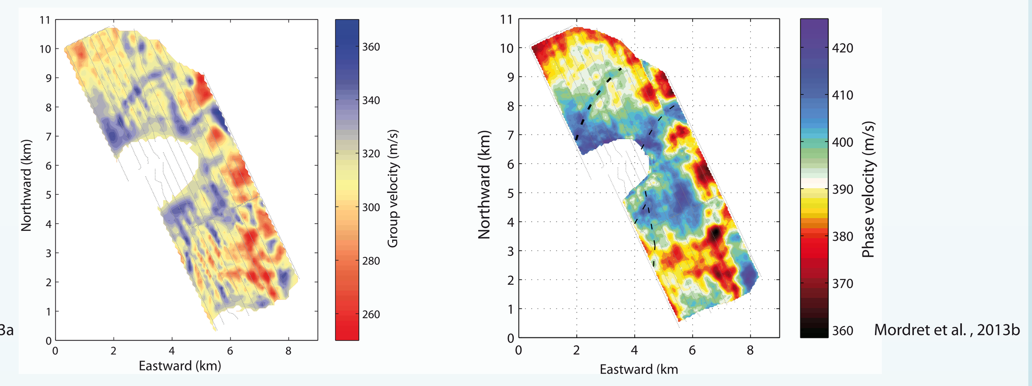


Analysing the noise correlations in this frequency band allows us to perform group and phase velocity tomographies to create a 3D S-wave velocity model of the first hundred meters of the seafloor

3 Surface-wave tomography

Traditional surface-wave tomography are performed in 3 steps:

1) Extraction of the dispersion curves from the waveform (performed by FTAN, Levshin et al. ,1989)
2) Construction of (group and/or phase) velocity maps for each frequency using regionalisation (Barmin et al, 2001) or Eikonal tomography (Lin et al., 2009)
3) Inverting the local dispersion curves from 2) at depth with 1D inversion and gathering them to create a pseudo 3D model



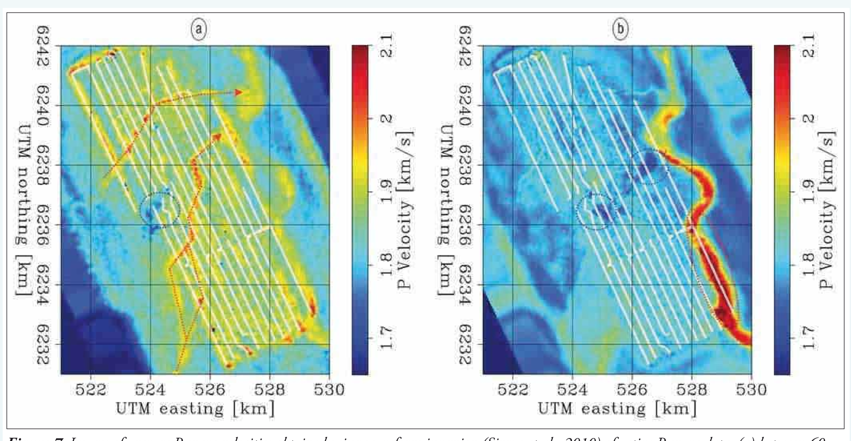
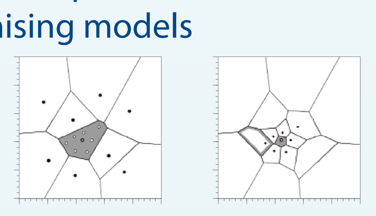


Figure 7. Images of average P-wave velocities obtained using waveform inversion (Sirgue et al., 2010) of active P-wave data: (a) between 60 and 105 m depth, (b) between 150 and 195 m depth. Dotted red lines indicate channel features; dotted blue lines indicate two distinct low-velocity zones.

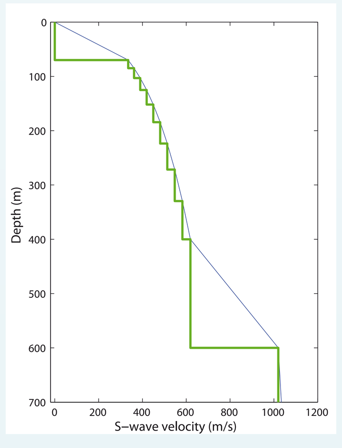
de Ridder and Dellinger, 2011

4 Depth inversion with NA

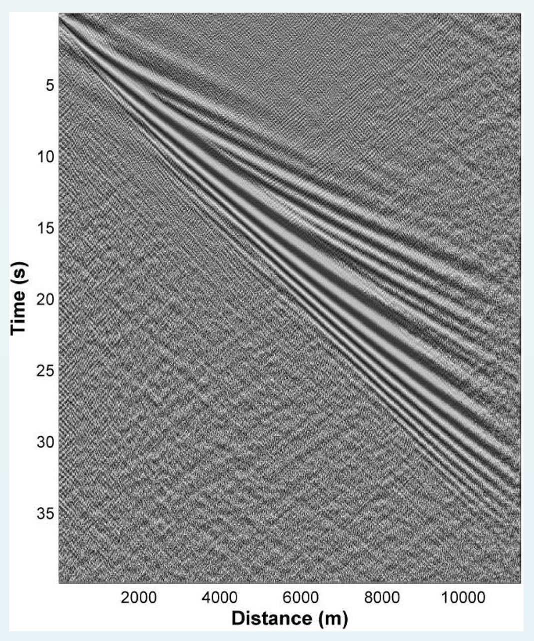
The neighbourhood algorithm principles:
- Random sampling of the entire model space
- Resampling around the most promising models but keeping the previous ones
- iterations



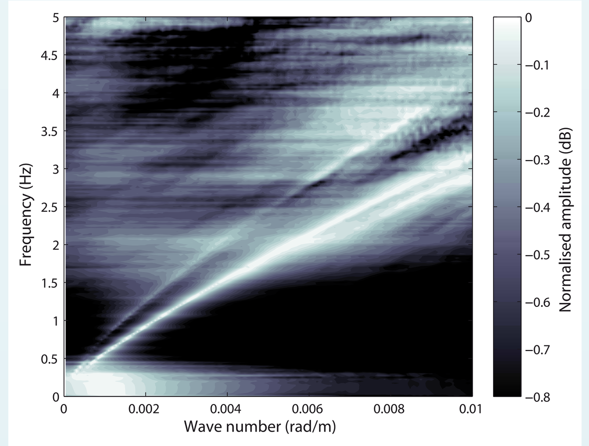
Parametrization:
- Compacting sediment => power law velocity profile: $V_s(d) = V_0((d+1)^\alpha-(d0+1)^\alpha+1)$ Wathelet et al., 2004
- High velocity layer (V_n~800 m/s) at 600 m depth



5 Average velocity model

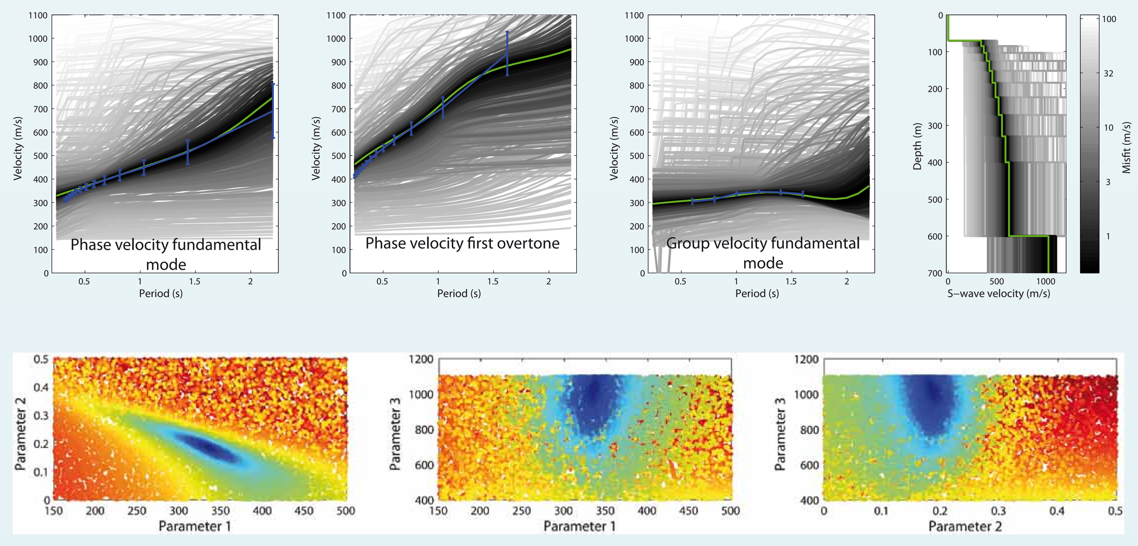


- Averaging of the correlations in 10 m inter-station distance bins
- F-K analysis (the binning allows a better resolution in wave-number direction)
- Picking of the dispersion curves (fundamental mode and first overtone)

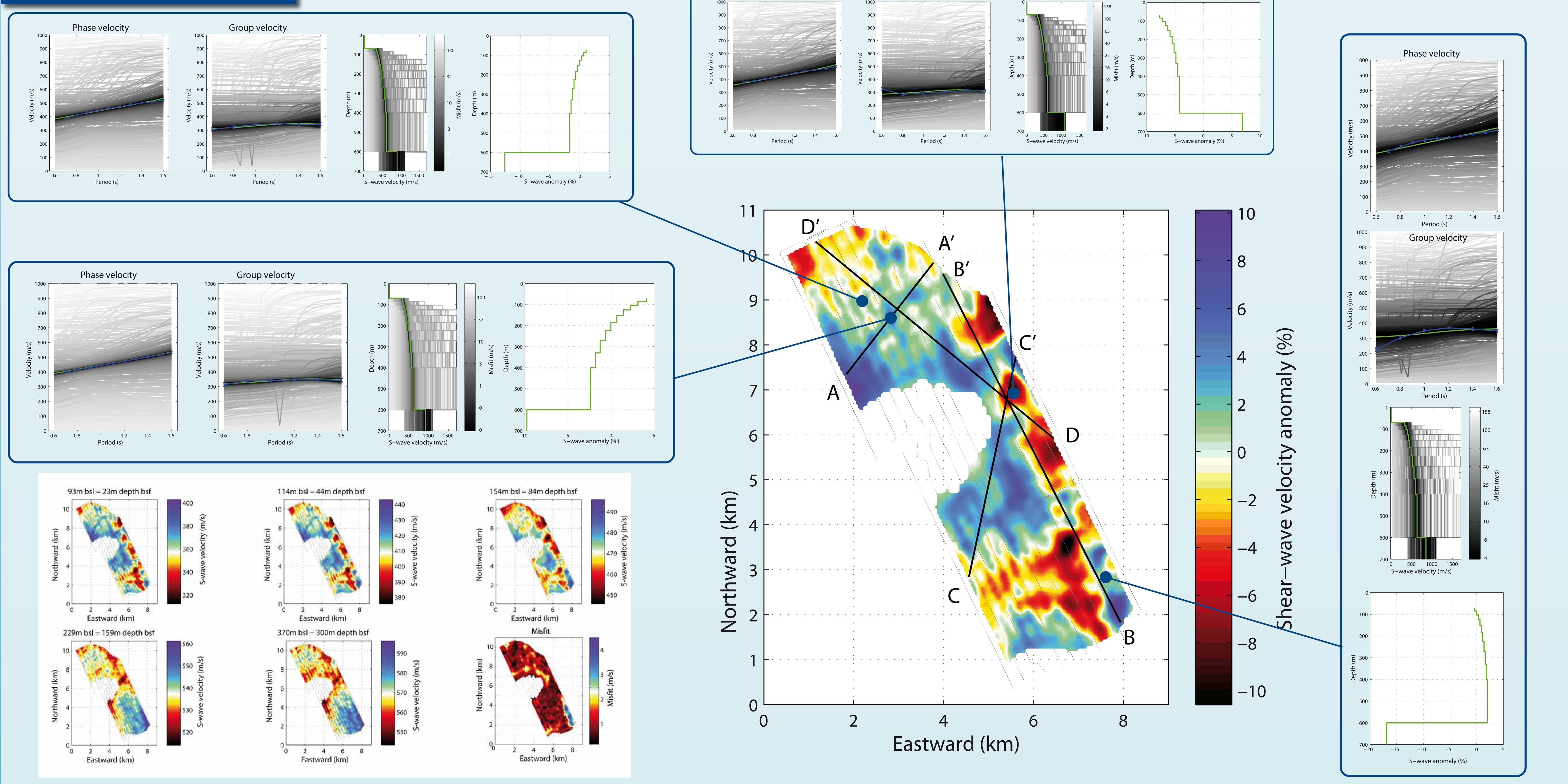


Best model:

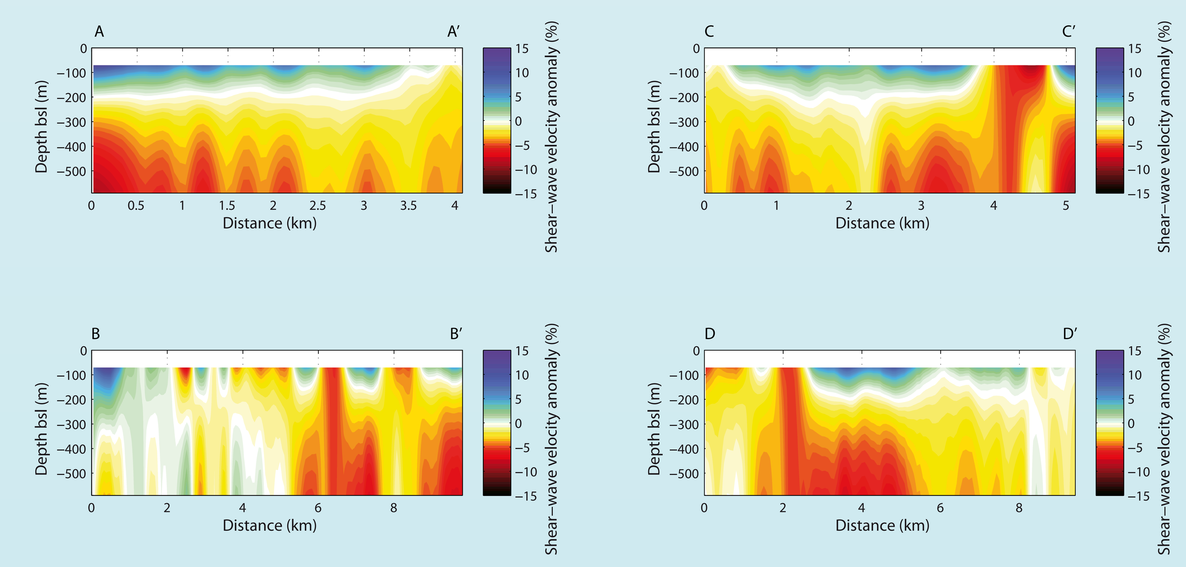
- V_0 = 334.8 m/s
- α = 0.187
- V_n = 1020 m/s



6 3D S-wave velocity model



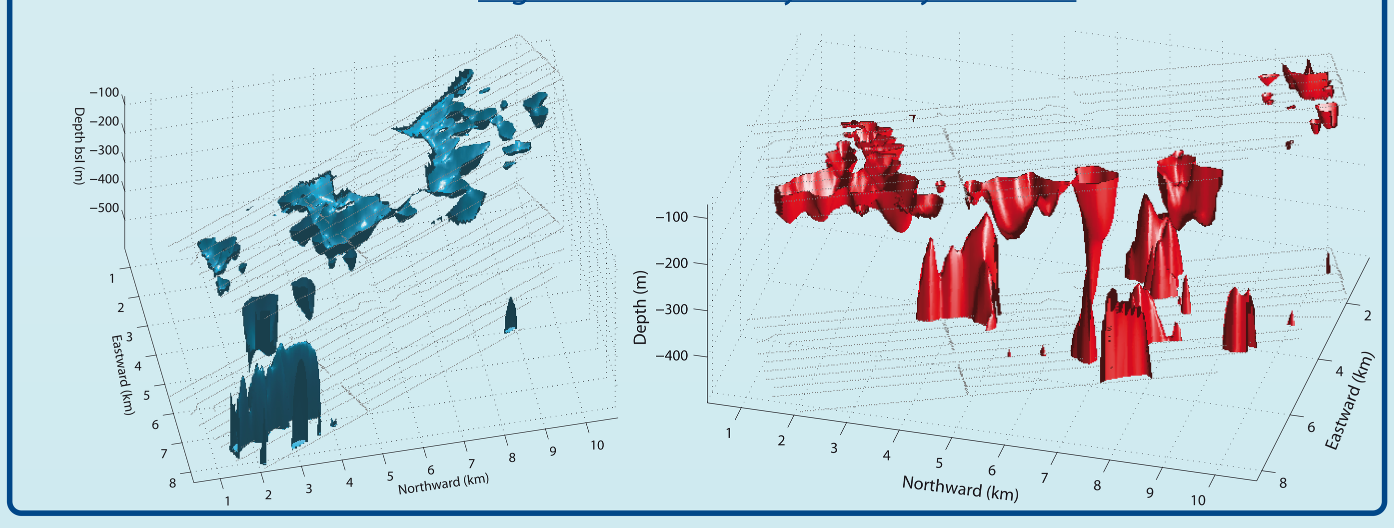
7 3D structures



Several 3D structures can be mapped thanks to this depth inversion:

1) A high-velocity shallow paleo-channel
2) A large shallow high velocity anomaly which could be attributed to compressive stress in the subsidence bowl
3) A chimney-like low-velocity anomaly which is related to gaz leaking from the reservoir
4) A deep low-velocity anomaly, mirror of 2), which could be the top of the stretched rock-column caused by the reservoir depletion

High and low velocity anomaly contours



Conclusion

We computed a 3D S-wave model of the Valhall field overburden using 6.5 hours of continuous records from 2320 4C OBC sensors. Some particular 3D structures in relation with reservoir depletion or gaz infiltration have been highlighted. We used a simple power law parametrization. However, some areas exhibit poor misfit showing that this simple parametrization is not sufficient to explain the data. The production of an hybrid model with a more complex parametrization in these zones is under consideration.

Main References

Mordret, A., M. Landes, N. M. Shapiro, S. Singh, P. Roux, and O. Barkved, 2013. Studying seabed above the Valhall oil field with Ambient Noise Surface Wave Tomography: GJI.
Mordret, A., N. M. Shapiro, S. Singh, P. Roux, and O. I. Barkved, 2013. Helmholtz Tomography of ambient noise surface wave data to estimate Scholte wave phase velocity at Valhall Life of the Field, Geophysics