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# Waveform and Dispersion Modeling Using DPRK Regional Seismograms Recorded by the High Sensitivity Seismic Network of Japan

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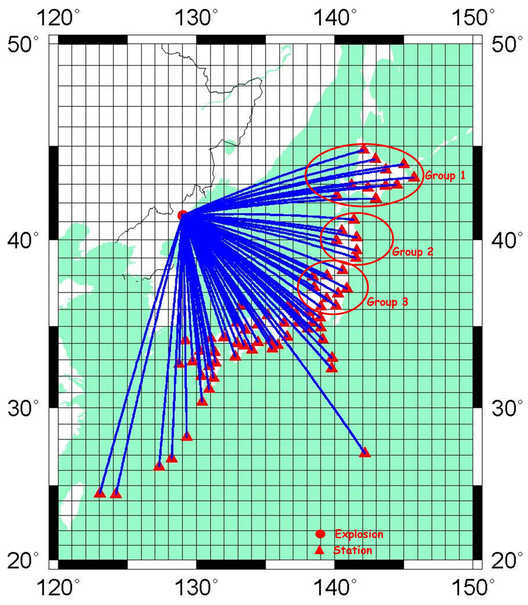
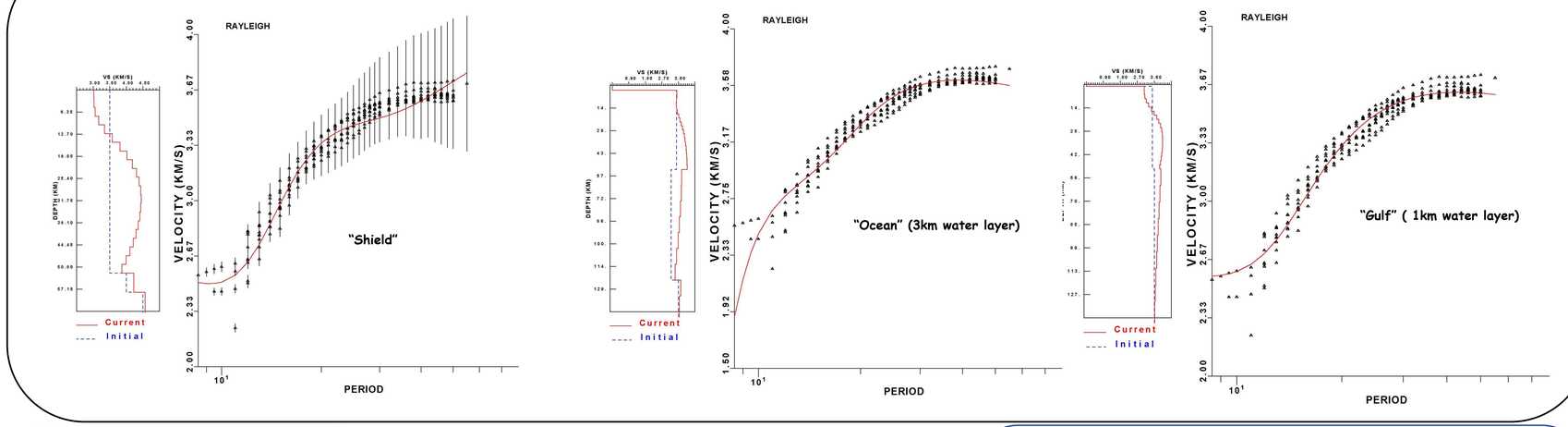
T2.3-P030

## Abstract

In this study, we analyze long-period (5-60s) surface waves recorded from all DPRK nuclear explosions by the stations of the High Sensitivity Seismic Network of Japan (HSSNJ). The purpose of this study is to understand the influence of the Sea of Japan (SOJ) on surface waves and the effect of multi-path due to the three-dimensional structure, as these effects can influence the estimation of the source parameters. Rayleigh-wave dispersion curves were processed after removing the instrument response and rotating the horizontal traces. We inverted the dispersion curves using a fixed water layer on the top. The HSSNJ stations cover an azimuthal range from 65° to about 195° over the distance range from 670 to 1465 km, and therefore grouped them separately to invert for the propagation models. Models are shown for three groups of the path models. We used the shield, gulf, ocean, gulf, and shield model in succession to represent a propagation path to generate synthetic Green's functions to compare with the observation. We find that the oceanic water layer and Q structure in the models play significant roles in characterizing the Rayleigh waves. The final goal of this study is to use these surface waves, including the P waves, for investigating the RDP (reduced displacement potential) time function, $\Psi_\infty$, and depths of individual explosions, by implementing the waveform equalization method (WEM, T2.3-O2, SnT2019).




## Group 1 shear-wave velocity structure (left) from dispersion curves (right)




## Theory

Spectral displacement(U) for a laterally varying medium, for a single mode at a distance, r, and buried at a depth, z, from a source of depth, h, is:

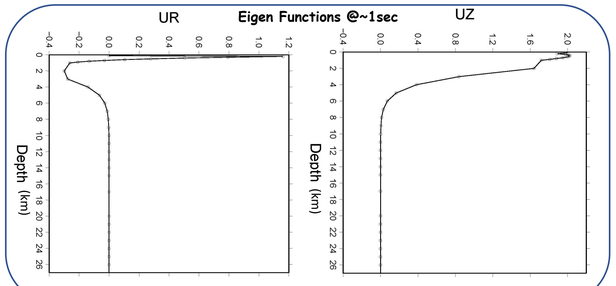
$$U(\omega,r,\varphi,z) = e^{-\left(\frac{i\pi}{4}\right)} \cdot e^{-i\omega\left(\int_L \frac{dr}{C(r)}\right)} \cdot \frac{1}{(2\pi k_r)^{1/2}} \cdot \frac{\varepsilon V_r(\omega,z)}{(2CUI_o)_r^{1/2}} \cdot \frac{W_s(\omega,h)}{(2CUI_o)_s^{1/2}}$$

ω = angular frequency,
k = wave number,
C = phase velocity,
U = group velocity, and
$I_0$ = energy integral.

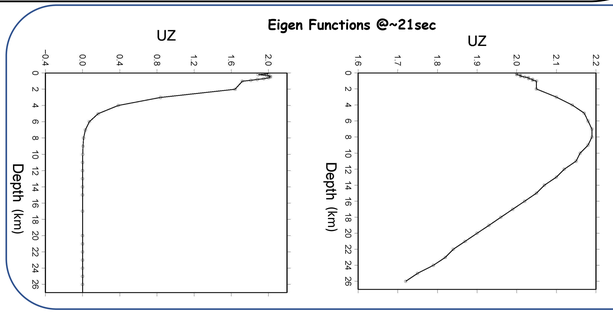
ε = either a real or imaginary number (component dependent)
V(ω, z) = eigenfunction sampled at receiver
W(ω, h) = source controlled factor

The subscripts, s, and, r, represent evaluations of the quantities at the source and receiver, respectively (Herrmann: SLU EAS CPS; Keilis-Borok et al. 1989).

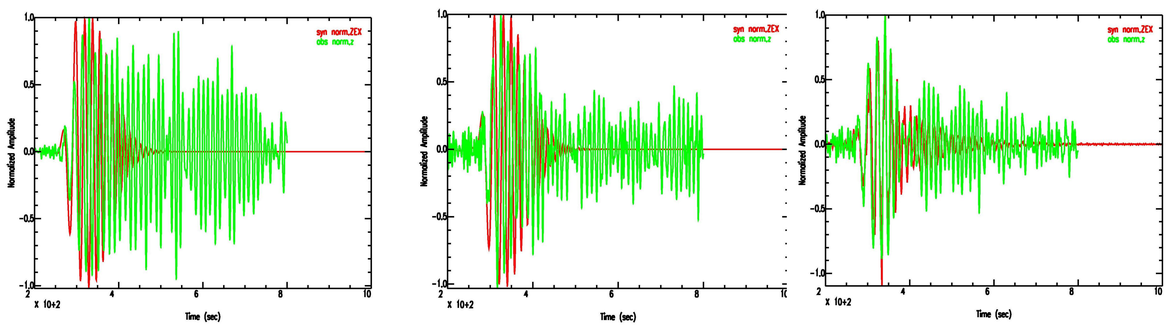
## Eigen Functions @~1sec




## Eigen Functions @~21sec




## Synthetic (red) and Observed (green) seismograms

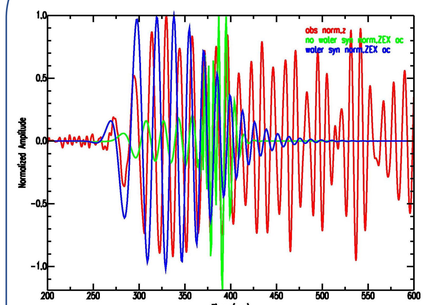



A station of Group 1. No time shift.

A station of Group 2: No time shift

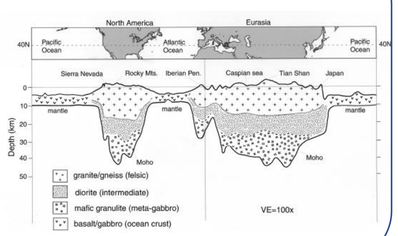
A station of Group 3. Synthetic (red) is shifted to the left just by 2 seconds. Green is observed data

## Effect of adding a water layer and allowing lateral velocity variations



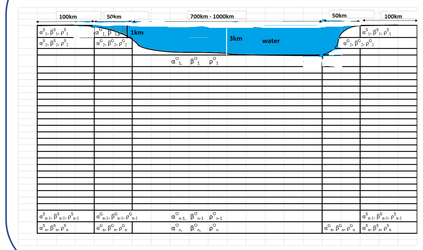

Model with a 3km water oceanic layer and lateral velocity variations (blue) explains observation (red) better than model without these (green)

## Ocean-Gulf-Shield-Gulf-Ocean-Gulf-Shield-Gulf-Ocean




Credit: http://gfzpublic.gfz-potsdam.de

## Our Model




### Observation:

- The character and arrival time of synthetic waveforms are very sensitive to the shear-wave velocity of deep layers
- When water layer is included, deep layers require small shear-wave velocities to fit the observed seismograms "wiggle-by-wiggle", especially for the oceanic and gulf paths
- Small shear-wave Q for the water layer and high P- and S- wave Q values ( 100 to 1000) were used for the solid layers to enhance the amplitude of the synthetics

### Conclusions:

- The first few cycles of the observed data could be modeled with less than 2 seconds time shift.
- Lateral structural variation in the Shield-Gulf-Ocean-Gulf-Shield structure models played a crucial role in the synthetic calculations.
- Model with a 3-km water oceanic layer and lateral velocity variations explains observation better than model without these.

### Future work:

- Compute synthetics for Love-waves
- Include source information in the synthetic computation

### References:

- Herrmann, R. B. (2013) Computer programs in seismology: An evolving tool for instruction and research, *Seism. Res. Lettr.* **84**, 1081-1088, doi:10.1785/0220110096
- Levshin, A. L. and A. z. Yanson (1971). Surface waves in vertically and radially inhomogeneous media (English translation by R. Herrmann)
- Keilis-Borok, V. I., A. L. Levshin, T. B. Yanovskaya, A. V. Lander, B. G. Bukchin, M. PBarmin, L. I. Ratnikova, and E. N. Its (1989). Seismic surface waves in a laterally inhomogeneous earth, Kluwer Academic Publishers, Dordrecht.

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