Global Surface Wave Tomography Using Seismic Hum

Kiwamu Nishida,[1]* Jean-Paul Montagner,[1,2] Hitoshi Kawakatsu[1]

Earth's background free oscillations, or seismic "hum" (*1*–*3*), are excited continuously and persistently by the ocean and atmosphere. Cross-correlation (CC) analysis of hum signals shows a clear global propagation of background Rayleigh waves, which opens the possibility for global surface wave tomography without referring to earthquakes.

One technique known as ambient noise tomography (*4*) cross-correlates random surface waves (Love and Rayleigh waves) with periods of around 10 s excited by ocean swells. Here, we show that the randomness of the sources of both the hum and ambient noise allows this technique to be applied for hum at much longer periods, 100 to 400 s, to explore the mantle to depths of 500 km.

We analyzed continuous records for 1986 to 2003 observed at 54 stations of the International Federation of Digital Seismographic Networks (FDSN). The record section of the CC functions between two stations as a function of their separation distance should indicate clear Rayleigh wave propagation (*5*), and the CC function should exhibit Green's-function-like signals at a station when a point source of excitation exists at the other station (*6*). This is the case in our data (Fig. 1A). The symmetry of the functions for positive and negative time lags is an indication of the randomness of the hum sources.

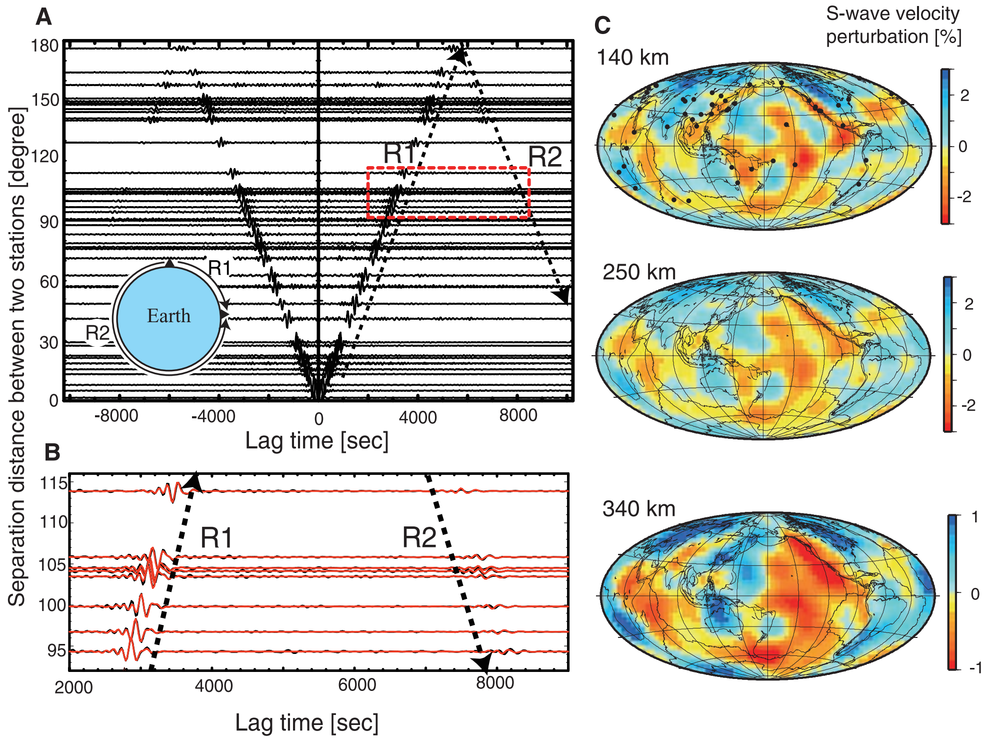

Fig. 1. (**A**) Observed CC functions plotted against separation distance between a pair of stations. They show R1 (Rayleigh wave traveling along the minor great circle arc) arrivals and R2 (traveling along the major great circle arc) arrivals. Positive lag time is defined as time advance of the second seismogram. (Inset) Schematic figure of R1 and R2. (**B**) Comparison of observed (black) and synthetic (red) CC functions shown for an enlarged view of the red-dotted box in (A). (**C**) *S*-wave velocity structure at depths from 140 to 340 km. We also show station location used in this study by circles.

Following (*5*), we calculated synthetic CC functions for a global one-dimensional (1D) model [the Preliminary Reference Earth Model (PREM) (*7*)] (Fig. 1B), and these generally agree with the observations except for a small discrepancy, which we attribute to lateral heterogeneity of Earth not to source heterogeneity (*8*).

We measured the phase differences between the observed and synthetic CC functions of 906 R1 and 777 R2 Rayleigh waves at six central periods: 376, 323, 275, 233, 172, and 121 s. We isolated the R1 and R2 wave packets along their group velocity curves by using 2000-s time windows with the central time predicted from the group velocity. These data were inverted to obtain isotropic phase-velocity maps of the Rayleigh waves with 5° by 5° grid points at each central period (*8*, *9*).

The phase-velocity maps were inverted to obtain a 3D *S*-wave velocity model (Fig. 1C) that includes a correction for the crustal contribution (*8*). The model at 140 km shows the typical low-velocity anomalies beneath plate boundaries and high-velocity anomalies beneath old continental cratons in Asia, North and South America, and Australia. Our model compares well with other global tomographic models created with use of earthquakes (*8*). A good agreement is obtained at all depths of the upper mantle, including the transition zone, which demonstrates that robust deep 3D structure of Earth can be recovered from seismic hum.

Our tomographic approach could conceivably be used in planetary exploration for investigating the deep internal structures of Mars or other bodies. Martian atmospheric disturbances might excite background long-period Rayleigh waves (*2*, *10*, *11*), which might then be used to retrieve Green's-function-like signals between stations of a small Martian seismic network (*8*).

References and Notes

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Materials and Methods
Figs. S1 to S4
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[1]Earthquake Research Institute (ERI), The University of Tokyo, 1-1-1, Yayoi, Bunkyo-ku, Tokyo, Japan. [2]Institut de Physique du Globe de Paris, Case 89, 75005 Paris, France.

*To whom correspondence should be addressed. E-mail: knishida@eri.u-tokyo.ac.jp