TOMOGRAPHIC MAPPING OF REGIONAL WAVE Q IN EASTERN EURASIA

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ABSTRACT

In the past several months of research we have achieved the following: (a) nearly fully automated the processing of Fourier spectra of regional waves, including Lg, Pn and Pg on SUN workstations; (b) have collected a large set of new regional wave spectra from eastern Eurasia, which include about 1,000 Lg spectra from recent moderate seismic events (to year 2004), and hundreds of spectra of Pn and Pg; (c) have largely completed the implementation of the two-step procedure of tomographic regional wave Q inversion, which we proposed in January 2003. In the first step of the procedure, path-variable Q are measured using the most reliable, two-station methods. Since this method requires pairs of two recording stations to be aligned with the seismic sources, fewer Q measurements can be obtained in this step, leading to a low-resolution tomographic Q map. In the second step of the procedure, an event-based method that simultaneously measures source spectrum and path-variable Q is used. Using the low-resolution Q map, we can obtain an *a priori* knowledge on path-averaged Q for multiple stations that record a single event. This *a priori* knowledge can be used to remove the trade-off between source spectral level and path averaged Q, which may otherwise cause an uncertainty in both Q and source measurements. We estimate that for Lg Q inversion in eastern Eurasia, less than 10% of the total 2,500 spectra can be used in the first step, whereas all spectra can be used in the second step. The tomographic Q map obtained at the end of the second step will have a high resolution. We are currently in the process of completing the Lg Q map in eastern Eurasia.

OBJECTIVE

The objective of this research is to map lateral variations of regional wave Q in eastern Eurasia using data from various sources, including the Incorporated Research Institutions for Seismology Data Management Center (IRIS DMC) and other data centers. The regional waves to be used include Lg, Pg, Pn, Sn and long-period Rayleigh waves. The target is to develop regionalized Q models that have lateral resolutions as high as the data and methods permit. For some waves such as Lg and Pg, the resulting Q model will be in the form of a tomographic Q map; for other waves such as Sn, the resulting Q models may be region-specific, dividing eastern Eurasia into several (or more) subregions. The resulting Q models can be used for (a) estimating seismic source spectra, source energy radiation and seismic moments, (b) inferring source spectral scaling, stress drops and apparent stresses; (c) inferring fundamental properties of the crust and upper mantle such as their temperature fields, and (d) evaluating the magnitude threshold of seismic events that can be recorded and studied using any set of seismic stations.

Because the Q models are of such fundamental and practical importance for scientific research and earthquake hazard mitigation, and because the new Chinese National Digital Seismic Network (CNDSN) has a large number of stations providing data to Chinese seismologists, the Lamont-Doherty Earth Observatory (LDEO) established a mutually beneficial collaboration with the Data Management Center of the Chinese National Digital Seismic Network (DMC/CNDSN) to generate high-quality Q models. An LDEO seismologist (Jiakang Xie) installs software on the DMC/CNDSN computers and trains the local personnel to collect and process regional wave spectra. Eventually the large number of regional wave spectra collected at the IRIS DMC by LDEO, and at DMC/CNDSN by Chinese seismologists, will be merged and the seismologists from both LDEO and China will jointly invert these spectra to obtain Q models and source spectral scaling using high-frequency regional waves and long-period Rayleigh waves from eastern Eurasia.

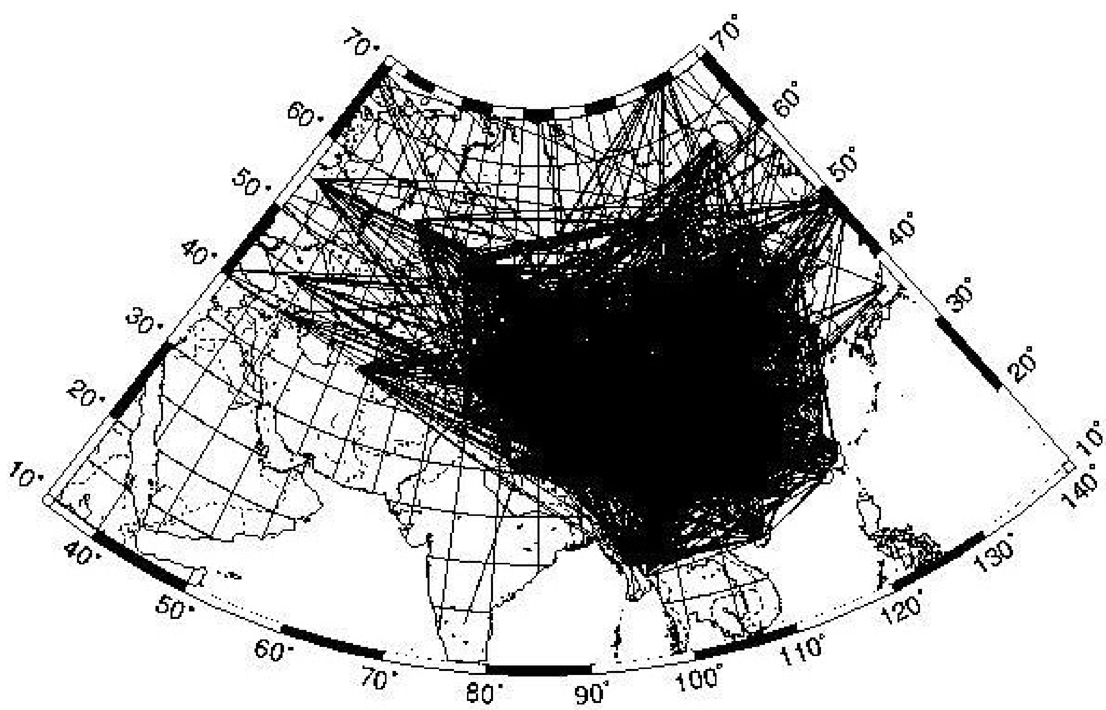

Figure 1. Path-coverage for eastern Eurasia currently available for tomographic inversions of Lg Q_0 and η. So far, Lg spectra have been collected over more than 3,000 paths, from numerous events and stations. Lg spectra over most (about 70%) paths have been collected by LDEO from the Incorporated Research Institutes for Seismology Data Management Center (IRIS DMC). The rest (about 30%) spectra have been collected by the Data Management Center of the Chinese National Seismic Network (DMC/CNDSN). This figure was produced by the DMC/CNDSN.

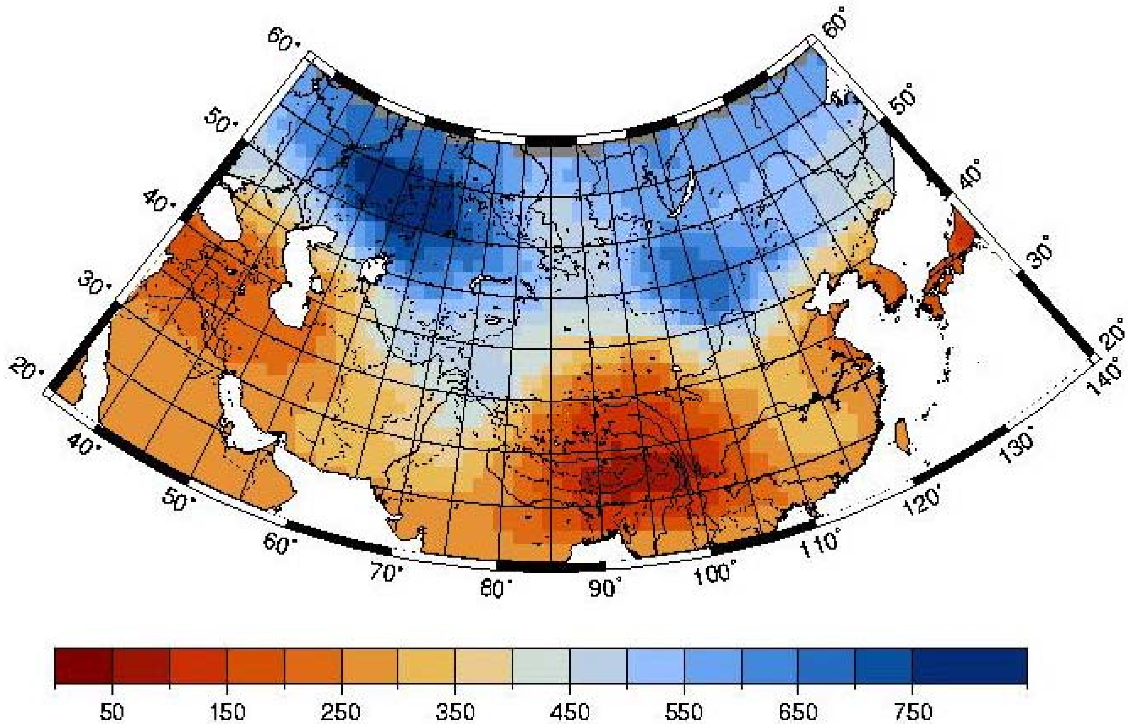

Figure 2. A low-resolution tomographic Lg Q_0 map in eastern Eurasia obtained in a "pilot" inversion, in which only about 100 path-variable Lg Q_0 measurements are input into the tomographic algorithm. Only long-wavelength features for the central portion are retrieved in this map. We anticipate that a total of more than 3,000 Lg Q measurements (Figure 1) will soon be input into our two-stage inversion algorithm to obtain a final tomographic Lg Q_0 model.

We plan to develop regionalized Q models using the Lg waves first (within the next few months). We will then develop Q models for Pg, Pn, Sn and Rayleigh waves, in the second and third phases of this research.

RESEARCH ACCOMPLISHED

This is a multi-year research project that only started several months ago. In the following sections, we summarize the research conducted so far.

Implementation of a two-stage tomographic Q inversion method

In January, 2003, we proposed to invert for a tomographic Q model using a two-stage procedure. The procedure is designed to maximize the resolution of tomographic Q inversions while avoiding bias resulting from the parameter trade-off between source spectra and path Q. The latter trade-off is often difficult to remove unless a priori knowledge exits prior to the Q measurements (Xie, 1998). We illustrate this procedure using the map showing paths that are currently available for a tomographic Lg Q inversion in eastern Eurasia (Figure 1). The map contains over 3,000 paths over which Lg spectra are processed. We anticipate that Lg Q over a significant number of inter-station paths (more than 300) can be measured with the two-station method (e.g., Xie, 2002). Lg Q_0 and η (Lg Q at 1 Hz and its power-law frequency dependence) values measured using the two-station method are reliable since they are not subject to the trade-off between source and path parameters. In the first stage of the tomographic inversion, the Q_0 and η values along these 300 or more paths will be used to derive a long-wavelength Q map. This map is of lower spatial resolution but is reliable in the sense that it is not affected by the source-path parameter trade-off.

In the second stage we shall measure path-variable Q for all of the 3,000+ paths using an event-based algorithm that simultaneously determines the source seismic moment (M_0), corner frequency (f_c) and path-variable Lg Q_0 and η values, using *a priori* knowledge of path-averaged Q_0 and η (Xie, 1998). Such *a priori* knowledge is obtained using the results from the first stage using the following procedure: for each event with multiple-station Lg recordings, we ray-trace the respective paths through the low-resolution Q_0 and η maps obtained in the first stage, and predict path-averaged Q_0 and η values. These path-averaged Q_0 and η values are then used as *a priori* knowledge to constrain the simultaneous determination of the source M_0, f_c and path-variable Lg Q_0 and η values. Applying this procedure to all events, Lg Q_0 and η values along all the 3,000+ paths can be measured free of the parameter trade-off between source spectra and path Q. At the end of the second stage, the resulting Q_0 and η for all of the 3000+ paths will be input to a new tomographic inversion of Q_0 and η maps, which will be of much higher spatial resolution than the first maps derived using only the 300+ inter-station paths in the first stage.

We have implemented virtually the entire two-stage algorithm on SUN workstations. Figure 2 shows a low-resolution Lg Q_0 model obtained by a "pilot" application of the algorithm. For this model, only about 100 path-variable Lg Q_0 measurements are used as against the anticipated 3,000+ paths. We are currently in the final stages of completing the measurement of Lg Q values along these 3,000+ paths.

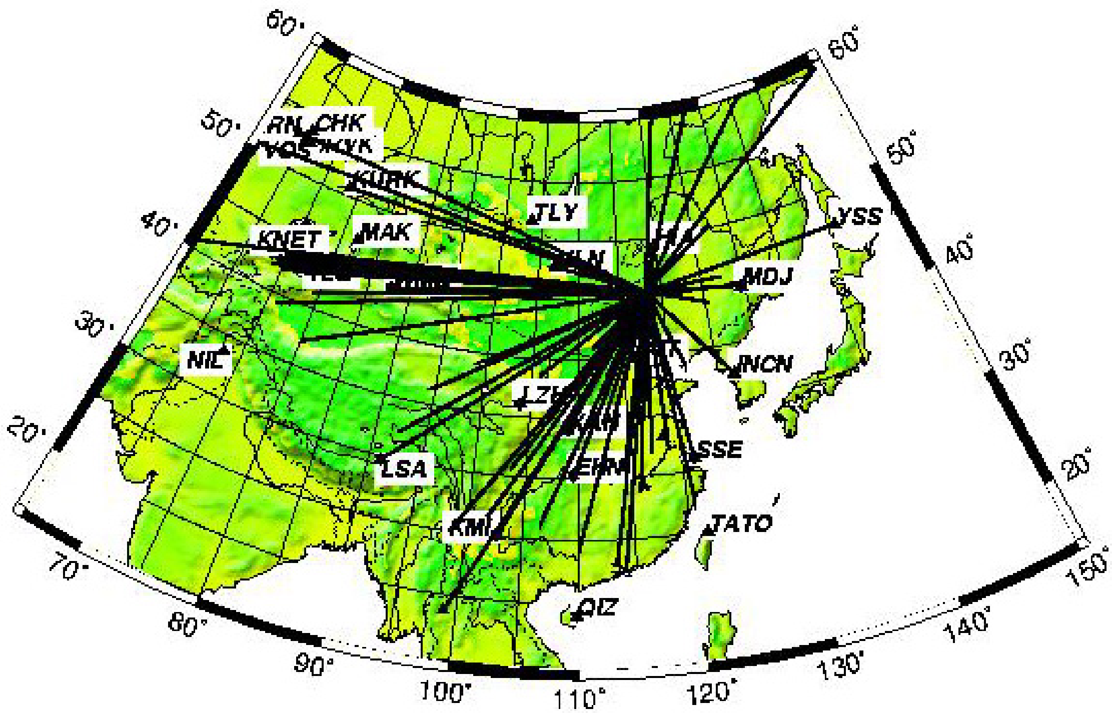

Figure 3. Paths over which regional waves from the March 24, 2004, Inner Mongolia earthquake (M_W = 5.4, 01:53:49.3 UT) were recorded. The paths connect the source to more than 60 recording stations belonging to the Global Seismic Network (GSN), and various national networks in eastern Eurasia. This figure is generated using software package GMT. Courtesy of the Data Management Center of the Chinese National Digital Seismic Network.

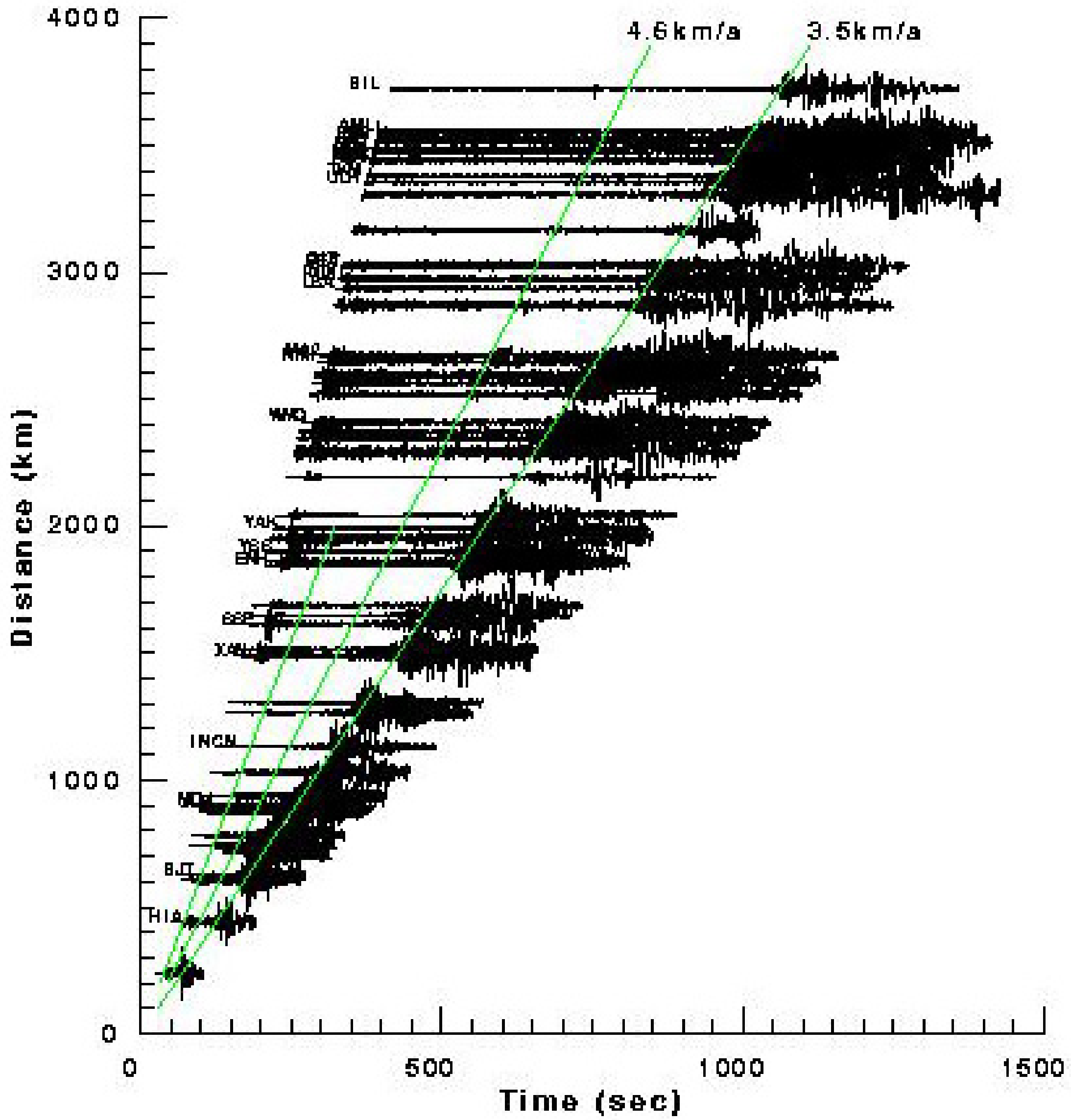

Figure 4. Record section showing over 60 seismograms from the March 24, 2004 (M_W= 5.4) earthquake in Inner Mongolia (Figure 3). The seismograms are collected from stations of the Global Seismic Network (GSN), and various national networks in continental Eurasia. Straight lines indicate arrivals with typical regional wave group velocities (e.g., 4.6 and 3.5 km/s for Sn and Lg, respectively). Courtesy of the Data Management Center of the Chinese National Digital Seismic Network.

Data processing

In the past several months, we have retrieved and processed regional wave spectra from various stations, including IRIS, GSN, Kyrgyzstan, Kazakhstan and Chinese Digital Seismic Network stations. A substantial computer programming effort was carried out for processing Pn and Pg spectra, and for automating much of the regional wave processing (we did not fully automate the processing because we wished to use certain steps for manual quality controls, and for precise phase picking). These data processing and programming efforts were carried out simultaneously on SUN workstations at LDEO and DMC/CNDSN.

The collection of Lg spectra is much ahead of other phases because we have collected over 1,500 sets of Lg spectra in past work prior to this project. In the past several months, marking the beginning phase of this project, we wrapped up the Lg spectra collection from earthquakes as recent as 2004, and started to collect Pn and Pg spectra. In this time period at LDEO we have retrieved over 2,500 Lg, Pg and Pn spectra from the IRIS DMC. At the DMC/CNDSN, our Chinese colleagues have processed a similar quantity of spectra. Figure 3 shows paths from a recent event in Inner Mongolia that provided Lg, Pg and Pn spectra. Figure 4 shows the record section. Data accumulation rate is very high in Eastern Eurasia owing to the high seismicity and increasingly large number of broad-band stations. As mentioned above, we will soon complete tomographic maps of Lg Q_0 and η. Maps of Q_0 and η developed using other regional waves will be obtained in the later phases of this research.

CONCLUSIONS AND RECOMMENDATION

We have been collecting a large number of regional wave spectra from Eastern Eurasia. Multiple-source data that are archived at the IRIS DMC are collected at LDEO, while data archived at the DMC/CNSDN are collected by colleagues in China using LDEO software. We are currently completing Lg Q_0 and η measurements over more than 3,000 paths. These measurements will be input to the two-stage method that we proposed in 2003 for generating high-quality tomographic Lg Q maps. The final inversion will soon be jointly conducted by LDEO and DMC/CNDSN.

We have collected over 1,000 Pg spectra so far, and several hundred Pn spectra. We shall continue collecting Pn, Pg and Sn spectra in the next year so that regionalized Q models can be derived in a later phase of this research, probably in the next year.

REFERENCES

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