SEISMIC AND GEOPHYSICAL CHARACTERIZATION OF NORTHERN ASIA
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ABSTRACT

We are beginning a major research effort consisting of a combination of seismic field deployments, historical seismic data retrieval, and seismic data analysis to calibrate northern Asia for Nuclear Explosion Monitoring purposes. This project is a cooperative effort between Michigan State University (MSU), Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and several seismic networks in Russia, Mongolia, and Japan. The geographic scope of this project covers, Russia from the Urals to the Bering Strait and from the Arctic Ocean to the North Korean border. We are expanding our unique and previously unobtainable historical datasets on earthquakes and nuclear and industrial explosions. Combining these historic datasets with data from approximately 50 existing Russian and MSU/Russian and Japanese/Russian digital seismic stations, new deployments, and geologic information, we will dramatically increase ground-truth (GT) data and our understanding of the seismicity, velocity structure, explosion discrimination, and wave propagation characteristics in northern Asia. Our work will further improve location and detection and discrimination capabilities and data on crustal and upper mantle structure, wave propagation, and natural seismic source characteristics of northern Asia.
OBJECTIVES

Research is being undertaken to characterize seismicity and geophysical parameters of northern Asia. This project is a continuation of our long-running eastern Russia project with an expanded geographic area (Mackey, 2008; Mackey et al., 2007, 2006). This project is cooperative between Michigan State University, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and several institutes and organizations in Russia, Mongolia, and Japan.

RESEARCH DIRECTIONS

Seismic Networks, Digital Stations, and Deployments

We plan to continue our active field program, deploying and operating both broadband and short-period digital stations in eastern Russia. Our existing short-period network will continue operation in roughly the current configuration (Figure 1). Network changes will focus primarily on improvement of the broadband stations and their distribution in the Baikal and Yakutsk regions, as well as joint work with the main office of the Geophysical Survey, Russian Academy of Sciences in Obninsk (GSRAS) as discussed below. MSU has additional cooperative work with the seismic networks in Yuzhno Sakhalinsk, Yakutsk, and Petropavlovsk-Kamchatski in Russia, as well as with Ulaanbaatar, Mongolia. MSU also has a cooperative agreement with the University of Hokkaido (HKU), Japan, for research and data exchange, using their stations operating in eastern Russia.

Three MSU broadband stations are currently operating in the Baikal network (Figure 1). We plan to upgrade the seismic recorders for these stations because the initially purchased recorders are obsolete and are no longer possible to repair. We will purchase three Geotech Instruments SMART-24 recorders to pair with the existing Geotech Instruments KS-2000 seismometers already deployed.

We also plan to upgrade the short-period station at Vitim in the Yakutsk network to a broadband seismometer and recorder. Vitim is only a few kilometers from the non-operational Peledui station and array; lies within the Siberian Platform, which historically has been under-instrumented relative to seismically active areas; and is an important location for improving the ray path coverage in Eurasia. If political or logistical issues prevent a deployment at Vitim, an alternate site will be chosen (one possibility is Lensk).

We plan several options for temporary seismic deployments. MSU and the Magadan network (MAGN) maintain four portable digital stations in Magadan, operable by generator, solar panels, or batteries. We maintain these stations so that they can be deployed rapidly for earthquake aftershock studies to acquire GT data if the opportunity arises; equipment can also be transported to other networks if needed. Second, we will deploy temporary stations to record industrial explosions for discrimination, velocity profile, or GT studies, depending on opportunities or needs of the project. For temporary deployments, we are not restricted to the summer. MSU and MAGN maintain three snowmobiles, sleds, and associated equipment, and both MSU and MAGN are experienced at winter deployment operations in remote areas of eastern Russia.

MSU, jointly with GSRAS, and the Yakutsk Affiliate of the Geophysical Survey, RAS, are planning a 2010 or 2011 field expedition and temporary network deployment in the remote eastern Stanovoi Range of southern Yakutia (see Figure 1). Most of this highly seismically active region has never been instrumented, and no permanent stations operate within several hundred kilometers. In 2006, MSU deployed the first seismic stations in this area. In this current study, we plan to deploy to the east of the 2006 study and hope to acquire GT events, with some events also recorded by regional stations. Together with field observations, this may help delineate unknown active faults in the region. Second, this deployment will be cooperative with, and partially supported by, GSRAS, with whom MSU recently ratified an agreement.

MSU and Japanese researchers from HKU have also recently signed a cooperative agreement for mutual program support and data exchange. HKU, in conjunction with GSRAS, operates eight broadband stations in eastern Russia, primarily in the Amur region (Figure 1), which are of great interest to this project. Some of the MSU-supported stations are located in areas of interest to HKU (deep mantle structure around the Sea of Okhotsk). As there is no scientific conflict between the respective HKU and MSU studies, each can benefit from data exchange. Waveforms obtained will be analyzed in conjunction with other northern Asia broadband stations included in this project.
Database Improvements

First, we will expand our historic database to include the Altai-Sayan network. MSU has in hard copy (in Materiali po Seismichnosti Sibiri) the full seismic catalog of the Altai-Sayan network for 1970–1993, with the hypocentral parameters of tens of thousands of events and the complete bulletin (all analyzed phases, their time picks, 3-component amplitudes, station magnitudes, and first motions) for the same time period for earthquakes larger than magnitude ~3.0 (tens of thousands of arrival times). It is necessary to hand enter data into a computer-readable format by student workers at MSU as character recognition software is not sufficient. It will also be necessary to develop a table of all seismic station parameters for the Altai-Sayan Network. Experience shows that this can be a difficult task as stations were often moved and changes not documented; parameters for temporary stations were often not recorded.

As MSU acquires data from northern Asia, LANL’s primary objective will be to ensure that the information (both historic and new) is parsed, merged, organized, and quality controlled for inclusion in the MSU/LANL database so it will be useful for model derivation and other geophysical characterizations of this region.

In collaborating with MSU, LANL has developed codes that improve our ability to manage incoming data. As LANL receives bulletins, we will evaluate the incoming formats and apply the appropriate parser to create flat file database tables. We will then load newly parsed flat files into temporary database space to conduct quality-control processes. Quality control efforts rely heavily on automated processes developed and described by Stead et al. (2006). After quality control, we will merge new tables with existing tables. As a result of the long-standing cooperation between LANL and MSU, this work will be performed more efficiently than during prior collaborations. However, we must emphasize that this effort is far more complicated than is routine parsing and loading of standard global bulletins, such as the ISC or EDR. The northern Asia data originate from disparate regional seismic networks with limited funding and computing capability. Often, formats change abruptly, stations are renamed (or moved) without warning, channel naming conventions vary between networks, and many other unanticipated situations occur.

Figure 1. Digital seismic stations currently operating in eastern Russia that are part of this proposed research. Upward triangles—Red, MSU broadband stations; Dark Blue, MSU short-period stations; Light Blue, Russian short-period stations available to MSU; Pink, 2008 broadband deployments. Black triangles are IRIS stations or other digital stations for which data are available internationally. Downward triangles are Japanese broadband stations.
Waveform Collection

LANL will continue to collect digital waveforms from northern Asia as MSU provides them. As with bulletin information, these waves originate within several networks, each with somewhat different recording practices. From experience, we know the waves can have header problems, such as incorrect time stamps and/or sample rates. LANL has codes in place that check for such situations, and we will use reported pick times within the database to confirm that final wfdisc lines hold correct start time information.

Ground Truth Studies—Extension and Improvement of GT Criteria

To further improve the database, LANL will evaluate events for both location and event GT. Event type GT (explosion or earthquake) will allow for expanded discrimination studies in northern Asia, and calibration efforts that rely on earthquake populations, such as coda-magnitude efforts, will avoid explosion contamination of datasets. This work will be supplemented by source association and characterization studies conducted by MSU (below).

For newly acquired northeastern Asia bulletin data, we will scan the data for events near known mining sites for GT2–3 events. The GT levels for mines can usually be set based on the size of mine. We then scan for events that have the specific station distribution and phases to already pass the Bondár criteria. Using the distance ranges outlined, we will relocate the new events with subsets of the arrivals, matching locations to the GT criteria.

Eastern Russia bulletin data do not typically lend themselves to the Bondár criteria, given their use of S phases and the distance distribution of the defining phases that typically cross the 2.5 deg boundary from local GT into the near-regional range. If arrivals are limited to P phases within 2.5 deg, few events have the azimuthal coverage necessary to define GT5. Figure 2 shows the distance distribution of P phases in our current bulletin. Sufficient distance coverage is attained at distances under about 8 deg, with most arrivals within about 4 deg and crossing into the local distance range of 2.5 deg. In addition, there are high-quality Pg phases available beyond the Pg/Pn crossover that are not accepted in the Bondár criteria.

![Distance distribution of P phases](image)

Figure 2. Travel times for P phases from previous Siberia/northern Asia catalogs. Note the preponderance of arrivals at less than 8 deg and the density of arrivals crossing into the local (0–2.5 deg) distance range.

We plan additional analysis to extend the current GT criteria to better address the distinct arrival distribution of the northern Asia catalog. This will involve phase distance distribution, azimuthal distribution at various ranges, travel-time residuals, and comparison to mining events. We will also assess whether the dominantly reported Sg phase can be included in any new criteria we develop.

Event Ground Truth Studies—Mining Event Identification

For both existing and newly obtained northern Asia bulletin information, we propose to evaluate event type GT through an analysis of event size, event time of day, and event magnitude, following MacCarthy et al. (2008).

Using the northern Asia database, we will evaluate reported event times relative to local daytime hours and location, similar to analysis by Mackey et al. (2003). Mackey et al. (2003) confirmed contamination of the region’s seismicity catalogs using a grid analysis of event origin times in specific regions or cells. Many cells showed dominantly daytime and winter origin times, consistent with mining practices in the region.
Guided by our initial explosion contamination study, we will select waveforms from nearby stations, cross correlate the waves, and cluster events based on correlation coefficient size. Figure 3 shows the types of information that can be obtained by combining location and magnitude with cross-correlation information. This example shows the locations of over 100 events, with magnitude 2.25–3.25 and origin times during hour 7 or hour 13 GMT (1 pm and 7 pm local time). Even though the locations are scattered (mostly based on a single array), we know these events are from a particular mine because of waveform similarity.

Figure 3. Sample waveform correlation and time-of-day analysis from Kazakhstan, showing waves from a single mine where nearly all origin times are near hour 7 or hour 13 GMT and magnitudes are between 2.25 and 3.25. Red circles are the event locations, and green stars are reported approximate mine locations. Origin time and other parameters were reported by the Kazakh National Data Centre. We propose a similar study of small events for northern and eastern Asia.

For our proposed cross correlation efforts, we will use waveforms from waveform data archived at MSU, new data from Russian/MSU stations, and GSN stations obtained via the IRIS DMC. From experience in Kazakhstan, mining events must be within 300 to 400 km of a station to obtain signals above background noise. We will use available imagery to assign explosions to particular mines whenever possible.

Association of Seismicity to Active Faulting

In regions where mines and their associated explosions are not readily identifiable or available, GT criteria estimates can be tested by associating events with specific faults. Previous studies have shown that relocated teleseismic events can be closely associated with specific faults in the Magadan district (McLean et al., 2000). We propose to continue our previous studies, identifying active faults through a combination of remote sensing and field observations.

Most eastern Russian studies have focused on identifying faults that are presently or recently active by identifying seismically generated features (fault scarps, large landslides, etc.; e.g., Vazhenin, 1992, Imaev et al., 2000) with little attention paid to river offsets, geomorphology, and active seismicity. Most of the work has been conducted in the Magadan district and adjacent parts of the Sakha Republic (Yakutia). The northeastern Sakha Republic (Yakutia) and far northeastern Russia remain entirely unstudied.

The availability of such tools as Google Earth make topographic reconnaissance easy and allow for the identification of drainage offsets, realignment of river networks, areas of active uplift, and other geomorphological indicators. This, combined with the MSU eastern Russia seismic database, allow for the first time, the possibility of detailed
correlations between earthquakes epicenters and focal mechanisms and lineaments and geologic offsets observable in satellite imagery. As a result, active segments of faults can be identified.

To support GT studies, we plan to make a detailed study of satellite imagery to identify possible GT events by associating earthquakes with specific faults and to identify which faults are active in the present day. This study will incorporate both the Magadan district, where epicentral location accuracy and the level of geologic mapping is relatively high, as well as the northwest Chersky and Verkhoyansk Ranges, where both location accuracy and geologic mapping are poor but little information is available except immediately south of Tiksi; however, the region is seismically and tectonically active (Fujita et al., in press; Imaev et al., 2000). A by-product of this study will be the identification and location of mines which may be sources for explosions. Attention will also be paid to the southeast extension of the Ulakhan fault from the Seimchan basin to Kamchatka.

For events with aftershock sequences, relative event relocations may help identify the approximate strike of the fault rupture. The elongation of isoseismals in the strike of the fault plane has also been noted in the region.

**Source Characterization**

We propose to continue studies of focal mechanisms of the larger earthquakes in northeastern Russia to determine the nature, tectonics, and orientation of faults. This will help event GT studies by determining the nature of natural seismic sources as well as discriminating natural from mining sources by identifying aftershock sequences, strikes of active faults, and (in some cases) focal depth. Our compilations of focal mechanisms have indicated that there are many inconsistent and poorly constrained mechanisms. In collaboration with our colleagues in Yakutia, we plan to re-examine many of the larger pre-moment tensor events in Yakutia and the Magadan district as well as determine new mechanisms using regional first motions and waveform modeling. We have a substantial collection of World-Wide Standardized Seismographic Network (WWSSN) microform records as well as access to the WWSSN seismogram collection at Northwestern University. Depending on the quality of the available data, additional methods may be applied.

We also plan to expand our compilations of previously-determined focal mechanisms to include Sakhalin and the Laptev Sea, and to upgrade our compilations for the Amur region.

**Digitization of PNE Records**

Long-range refraction profiles were conducted in the Soviet Union from 1971 to 1988 to conduct deep seismic sounding (DSS), using peaceful nuclear explosions (PNEs) as sources (e.g., Benz et al., 1992). These profiles have been extensively analyzed, using the original profile data both in Russia (e.g., Belousov et al., 1991), and more recently reprocessed in the west (e.g., Morozov et al., 2005). These PNEs were recorded using instruments deployed along the profiles at distances of 100–200 km spacing. These PNE profiles have been used to study a wide range of seismological phenomena, including attenuation, lithospheric and upper mantle structure, and scattering (e.g., Egorkin et al., 1987). Given that most of the PNEs were detonated in stable, cratonic areas, while the regional networks were located in the seismically active periphery, study of the PNEs recorded at the regional network stations will add a great number of previously unutilized ray paths through the seismically more complex fold belts and accretionary zones, in particular, in eastern Russia and along the Russian border with China.

These PNEs were recorded at analog seismic stations operated by the regional networks, resulting in over 7,800 of seismograms (GSRAS, 2001) from the permanent Russian seismic stations. Only one systematic study has been conducted with these records, basically consisting of P- and S-phase time picks for calibrating Russian geophysical stations for Comprehensive Nuclear-Test-Ban Treaty (CTBT) monitoring. Although broad in scope, the study did not conduct any waveform analysis (GSRAS, 2001). Many seismograms were digitally scanned but are of poor quality and low resolution and thus of little use beyond picking some basic arrival times. The study did not address stations in the now former-Soviet republics besides Russia.

We are working with the seismology group at the Institute of Petroleum Geology and Geophysics (IPGG) in Novosibirsk to begin assembling, digitizing, and analyzing records from the regional networks of Russia. The current state this project is summarized in Mackey and Hartse (2009, these Proceedings). We will expand this study by collecting, digitizing, and analyzing additional seismograms from the various archives in Russia, focusing
initially in the Far East and along the border with Mongolia and northeast China, followed by other former-Soviet republics and Mongolia, as time allows.

**Surface Wave Studies**

We plan on using data from the Siberian deployments to make surface wave dispersion measurements of this region. Figure 4 shows an existing path map for 15-sec Rayleigh waves (Pasyanos, 2005). Coverage of the region south of 60°N is dense, but due to the lack of seismic sources and limited number of seismic stations, the area north of this latitude is sparsely covered. As a result, when we tomographically invert the region for group velocities (Figure 5), the velocities at this period correspond well with sediment thickness maps (Laske and Masters, 1997) south of 60°N (Figure 5); both the Song Liao Basin in China and the Sea of Okhotsk are well imaged as slow velocities. However, the slow velocities from large sediment deposits along the Lena River are not isolated but smeared out in the northern portion of the map. Also, slow velocities from the sediments in the Laptev Sea and East Siberian Sea (north of the Eurasian landmass) are smeared south.

![Figure 4. Ray path coverage currently available for 15-sec surface wave studies. Very few events and stations are available north of 60°N and in the Russian Far East. The existing MSU broadband stations and their waveforms from regional and near-teleseismic events over the past several years and through the course of this project will improve the ray path coverage in these sparse areas.](image)

Use of broadband stations throughout northern Asia (Figure 1) should improve coverage of this area considerably, particularly at short periods, allowing us to better image shallow structures like sedimentary basins. Similar improvements in coverage and resolution at intermediate and long periods will allow us to make advances in crustal thickness, upper-mantle velocity, and lithospheric thickness in this region.
Figure 5. Left, 15-sec Rayleigh wave group velocities resulting from tomographic inversion of available ray paths, as depicted in Figure 4. Right, comparison to the sediment thickness map (Laske and Masters, 1997) shows that virtually all anomalies north of 60° are smeared or unresolved. Most anomalies present are not currently resolvable using surface-wave studies due to insufficient ray path coverage at short periods.

REFERENCES


