SEISMIC CHARACTERIZATION OF NORTHEAST ASIA

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ABSTRACT

Our project of seismic characterization of northeast Asia continues on a multi-faceted approach concentrating on eastern Russia. The field work aspects of the project are addressing additional seismic station installations and calibration of existing digital stations. Seismic station deployments include permanent and temporary stations deployed in Chukotka, temporary stations deployed in the vicinity of Yakutsk, one aftershock study station for the April 19 2006, M_w 7.6 Koryak Highlands earthquake, and a planned 5 station temporary deployment in the Stanovoi Range in southern Yakutia. We also are planning permanent station deployments in the Amur region. As the existing digital stations include a diverse set of instruments and recorders, many with poorly defined characteristics and no established calibration procedure, we are obtaining empirical calibrations for remote unknown stations. The empirical calibrations are obtained by co-locating a calibrated reference station at each remote station and conducting a comparative analysis of both stations' recordings.

Our Siberia database enhancements for this past year include: (1) addition of about 8000 new events primarily from the Yakutsk and Magadan networks and mostly from between the years 1995 and 2005, (2) addition of about 11,000 mining explosions from between the years 1979 and 1997, (3) reconciliation of seismic instrument names noted within the database, and (4) general quality control efforts primarily targeting unmerged, multi-author origins and resolution of duplicated arrival information.

Using our arrival time data set we have been exploring the viability of differential Pn travel-time tomography across eastern Siberia. To date, we have observed the expected results of higher velocities under the Siberian platform, with generally lower velocities under the tectonically active regions in the central and eastern portions of our study area.

We have also continued our studies of the Russian K-class (Energy) system and the relationship between K-class and magnitude scales. Because K-class and magnitude are determined independently, we have calculated region specific orthogonal regressions between K-class and m_b and M_S. The relationships vary somewhat from network to network but major differences are noted for the Sakhalin, Kamchatka, and Kuril networks where local computational methodologies were used to account for perceived differences in attenuation.

In order to discriminate industrial explosions from earthquakes that were recorded during the latter portion of the analog period (1985-2000), we have examined amplitude ratios calculated from data reported in regional seismic bulletins. The best results are obtained using an average of ratios from several stations with correct event discrimination as high as 90 %.

OBJECTIVES

The main objective of our current research is to improve the overall seismic characterization of northeastern Asia. To accomplish this we seek to develop a complete seismicity database and use this database to discriminate industrial explosions, develop velocity models, and understand the relationship between the sizes and locations of events.

RESEARCH ACCOMPLISHED

The Russian K-class System and its Relation to Magnitudes

The size of local and regional earthquakes in the former Soviet Union (FSU) has been given by the energy class (K-class) system since the late 1950s. The nature, origin, and methodology of this system is poorly known to western seismologists studying Soviet and Russian seismological data, and yet of great interest to those conducting detailed research on the seismicity of the FSU. As the primary means of quantifying the size of small events in the FSU, understanding the K-class system is critical in the analysis of FSU seismological data. K-class data are also often used as the basis for magnitude values given in international catalogs. When the annual *Zemletrayseniya v SSSR* ("Earthquakes in the USSR") began to be compiled in 1962, almost all of the regional networks estimated K for their part of the catalog using the method of Rautian (1958); now, energy class is calculated for almost all of the regional earthquakes in the Former Soviet Union (Figure 1). The relationship between K-class and magnitude has also been a great interest of seismologists working with data from the FSU. To examine the empirical relationship between magnitude and K-class, we tabulated M_b and M_S magnitudes as reported by the International Seismological Centre (ISC), and K-class values reported in *Zemletryaseniya v SSSR* and its successor publication, *Zemletryaseniya Severnoi Evrazii* for each of the seismic regions for 1970-1997. Because K-class and magnitude are both independent variables with their own uncertainties, one can not simply calculate a regression holding one as the dependent variable. We thus calculated an orthogonal regression (see Figure 2 for an example) which minimizes the sum of the squares of the distance to the regression line. It should be noted that K-class is calculated, and calibrated, for events generally smaller than K = 10 – 11 ($m_b \sim 4$), while teleseismic magnitudes are calculated for larger events. For smaller events of m_b (or M_S) around 4, magnitude is often calculated with very few stations, or using stations with potentially weak arrivals, thus increasing the uncertainty and scatter.

All regressions were standardized to the form

$$\text{Magnitude} = c + s\,(K - 14)$$

This formulation eliminates having sign variations on c and makes comparisons clearer in the range for which K-class and magnitude are both calculated ($9 \leq K \leq 14$).

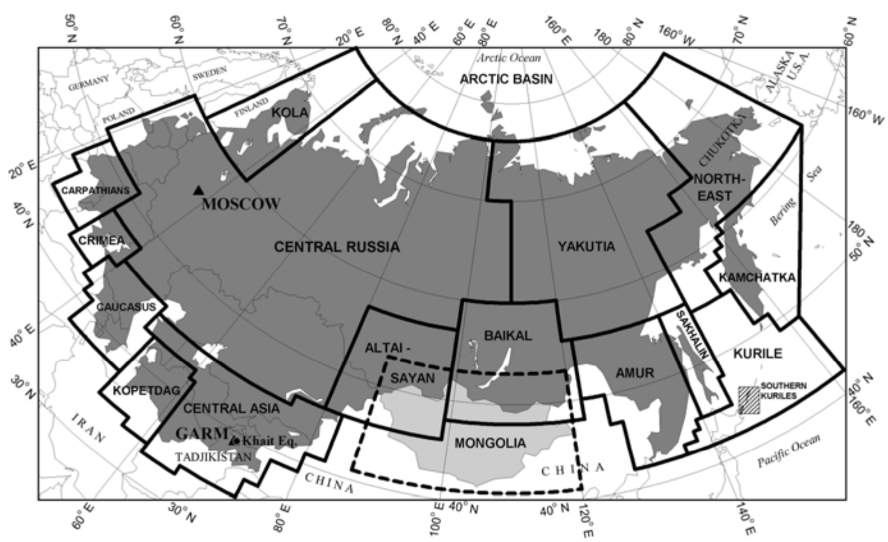

Figure 1. Index map showing boundaries between regional networks in the Former Soviet Union. Individual regressions between K-class and magnitude were calculated for each region.

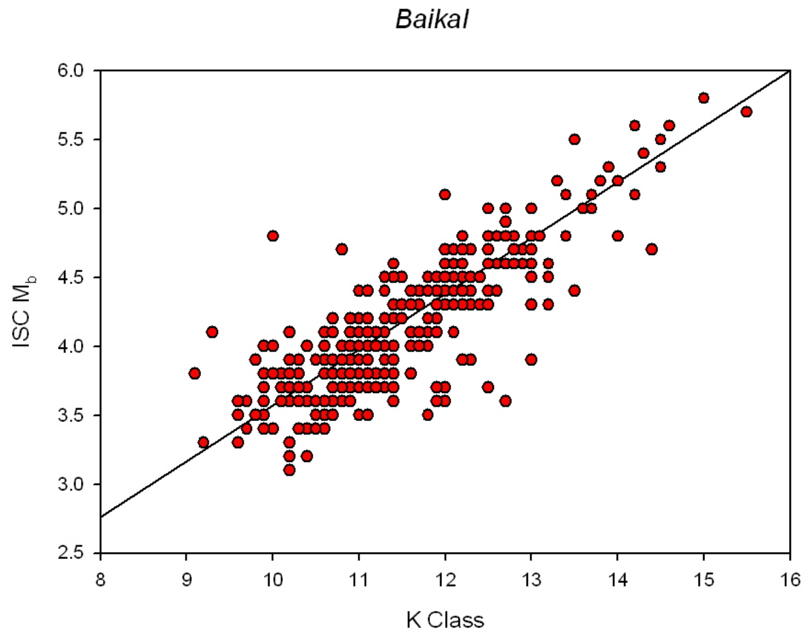

Figure 2. Sample orthogonal regression between K-class and ISC magnitude (m_b).

The m_b regressions (Table I) are generally similar, close to 5.41 + 0.43 (K – 14), in the K-class range of interest ($9 \leq K \leq 14$) except for Crimea, Sakhalin, Kuril, and Kamchatka (Figure 3). Crimea, Sakhalin, and Kamchatka have higher c and s values than the other regions, while Kuril has a similar slope, but higher c. As noted above, the three Far Eastern regions use a different formulation for K, and are therefore expected to be different from the rest of the FSU; the difference for the Crimea may reflect a smaller number of data points. It is interesting that the Kuril regression differs from both Sakhalin (which administers the Kuril network) and Kamchatka (which is tectonically similar).

The intercepts (c) for the Sakhalin m_b relationship and Central Asia regressions are close to those calculated by Solov'ev and Solov'eva (1967; 6.59 + 0.55 (K_S – 14)), and Bune et al. (1960; 5.48 + 0.55 (K – 14)), respectively; however, the slopes differ by more than 0.1 in both cases.

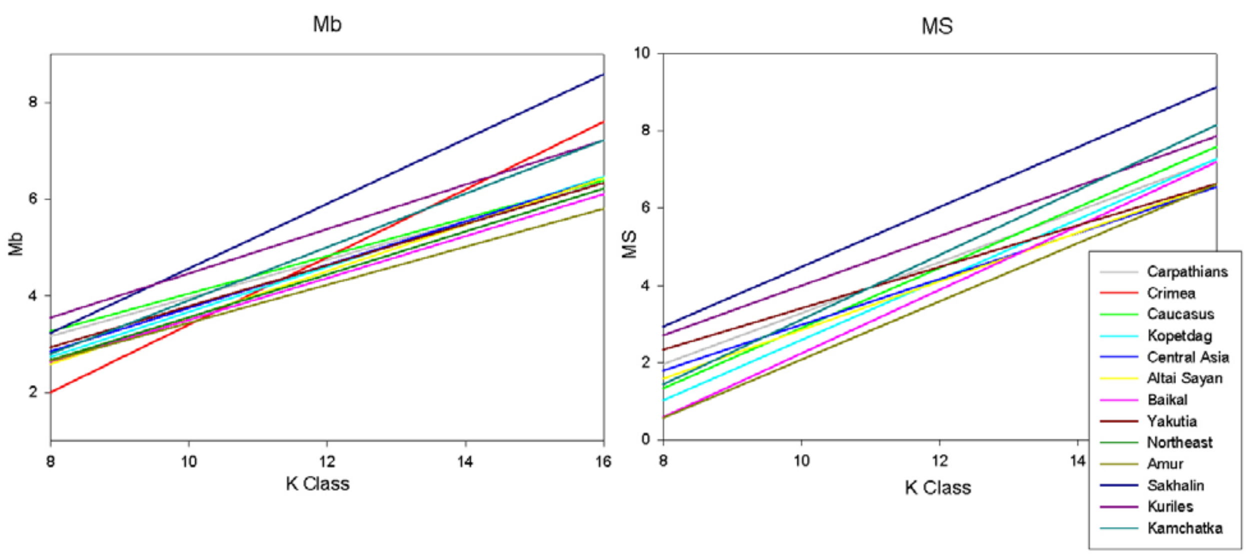

Figure 3. Comparisons of orthogonal regressions between K-class and a) m_b and b) M_S for various regions of the FSU.

The M_S regressions are more variable (Table 1; Figure 3), reflecting the fact that the methodology and frequencies used for calculating m_b and K are more similar than those for determining M_S. Slopes for the M_S values fall into three general groups; those near 0.8 (Caucasus, Turkmenistan, Baikal, Amur, Sakhalin, and Kamchatka), those near 0.6 (Carpathians, Central Asia, Altai-Sayan, Kuril), and those near 0.5 (Yakutia). The Carpathians are based on very limited data. The c values are generally near 5.5 except for the three Far Eastern regions ($c > 6.4$), and the Caucasus and the Crimea ($c \sim 6.0$). In general, however, most of the curves are fairly close to each other in the $10 \leq K \leq 14$ range. Sakhalin has an abnormally high intercept (as it did for m_b).

We present here our preferred results, but note, however, that both c and s can vary considerably depending on different regression methodology and algorithms, data sets used, cut-off magnitudes and K-classes, and to what degree the data are cleaned. Variations in c of 0.5 and in s of 0.1 are easy to obtain.

K-class is calculated from, and calibrated to, short-period instruments. Therefore like m_b, K-class saturates; because of the similarity in the frequency response of FSU and western short- period seismometers, this probably occurs at about the same level ($K \approx 16$-17).

Because of the standard of using magnitude in the west, many regional events in western catalogs are reported with magnitude calculated from K-class using a locally derived regression. Examples include the data for the Crimea and Chukotka (although the Chukotka relationship is particularly abnormal) in the *New Catalog of Strong Earthquakes in the USSR* (Kondorskaya and Shebalin, 1977), the digital SSR catalog distributed by the US Geological Survey, and the Kamchatka data in the International Seismological Centre catalog. However, this is not always explicitly stated, causing confusion as to what the primary measurement was and how it was derived.

Table 1. Regressions between K Class and ISC Magnitude

Region	m_b	M_S
Carpathians	5.5382 + 0.3966 (K-14)	5.9198 + 0.6613 (K-14)
Crimea	6.2001 + 0.6992 (K-14)	Insufficient Data
Caucasus	5.6014 + 0.3910 (K-14)	6.0221 + 0.7818 (K-14)
Kopetdag	5.5332 + 0.4673 (K-14)	5.7114 + 0.7811 (K-14)
Central Asia	5.5332 + 0.4490 (K-14)	5.3636 + 0.5943 (K-14)
Altai - Sayan	5.4650 + 0.4823 (K-14)	5.3686 + 0.6327 (K-14)
Baikal	5.2298 + 0.4337 (K-14)	5.5397 + 0.8276 (K-14)
Yakutia	5.4871 + 0.4270 (K-14)	5.5524 + 0.5387 (K-14)
Northeast	5.3288 + 0.4452 (K-14)	Insufficient Data
Amur	5.0080 + 0.3943 (K-14)	5.1003 + 0.7547 (K-14)
Sakhalin	7.2456 + 0.6688 (K_S-14)	7.5682 + 0.7727 (K_S-14)
Kuril*	6.2958 + 0.4602 (K_S-14)	6.5628 + 0.6422 (K_S-14)
Kamchatka	6.1060 + 0.5518 (K_F-14)	6.4744 + 0.8380 (K_F-14)

* see text for calculation methodology

Explosion Discrimination

Contamination of the seismicity catalog from mining and industrial explosions continues to be a problem for both historic seismicity as well as current events. Using historic analog data we have completed the first amplitude based study to address discrimination of individual events. We extracted 484 events from the seismicity database of which 237 are local nighttime occurring earthquakes and 247 are known daytime explosions. Events were extracted in two regions, Magadan – Northern Yakutia, and Southern Yakutia (Figure 4). For each event, all available Pg and Sg amplitudes were added to the database to construct ratios. For approximately 100 events, additional amplitudes were read directly from the original seismograms in the archives of the Yakutsk and Magadan seismic networks. All earthquake and explosion data utilized here were recorded on photo paper and using only short period instruments. Although we were unable to conduct any frequency analysis due to the analog nature of the records and the lack of such information in the bulletins, the response of the seismometers restricts recorded signals to higher frequencies (1-5 Hz), which other studies indicate are generally better for explosion discrimination. Events extracted cover the

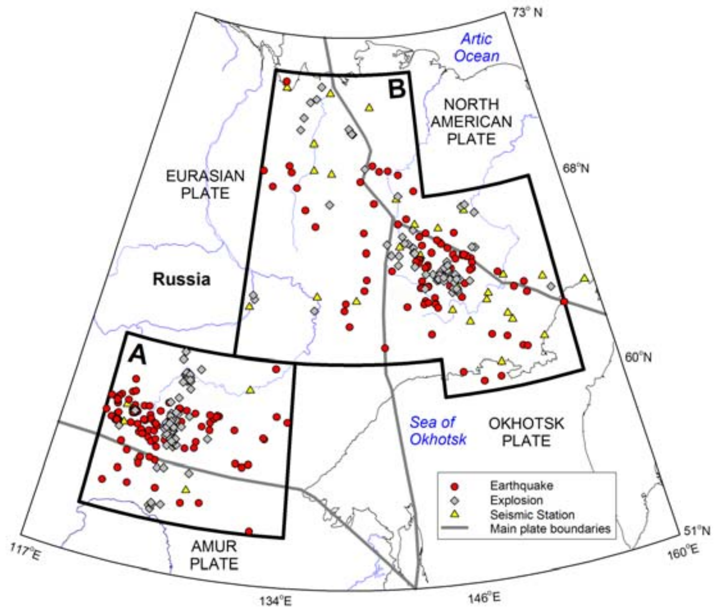

Figure 4. Study regions where Pg/Sg explosion discrimination studies were undertaken showing earthquakes, explosions, and seismic stations used. A. Southern Yakutia region. B. Magadan – Northern Yakutia region.

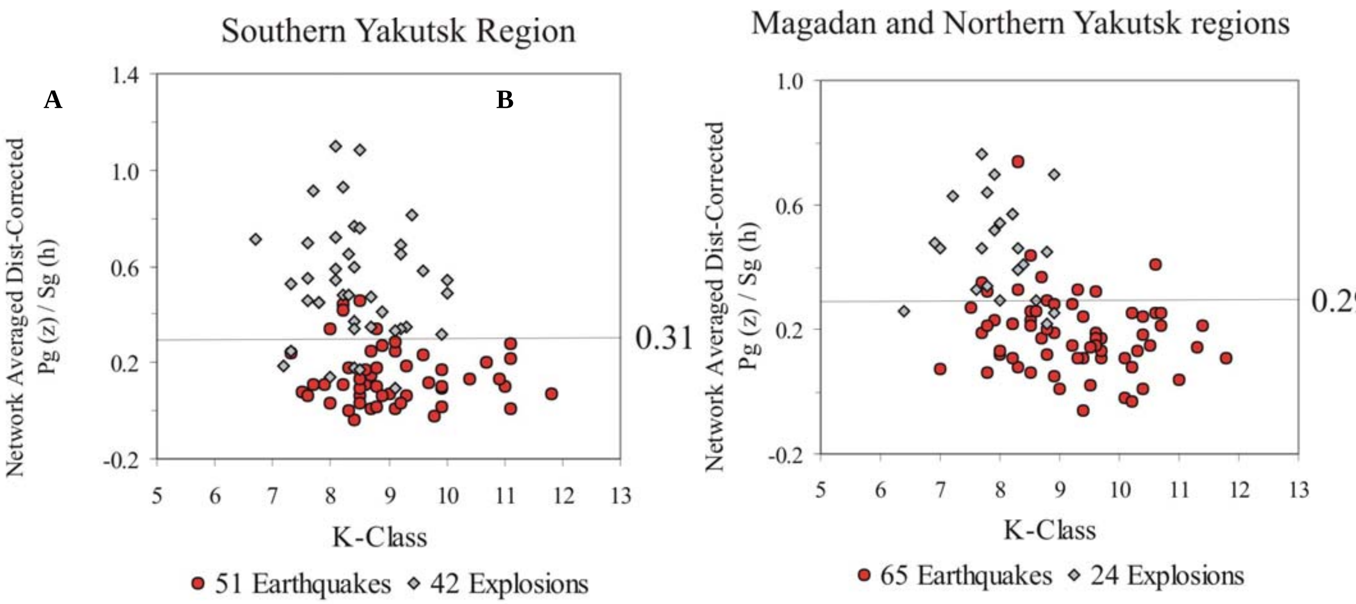

Figure 5. Network averaged-distance corrected Pg_z/Sg_h ratio discrimination plots for the Southern Yakutia (A) and Magadan – Northern Yakutia (B) regions. With this discrimination plot, critical values of 0.31 and 0.29 respectively correctly separate 87% of the events.

time interval 1985-2000, with a magnitude range of 1.5 to 4.9 for earthquakes and 1.4 to 3.9 for explosions. For each region we calculated 5 different Pg/Sg ratios,varying by components (Pg_z/Sg_z, Pg_h/Sg_h, Pg_h/Sg_z, Pg_z/Sg_h, and full vector Pg/Sg), and evaluated the discrimination effectiveness of these ratios against event size, event distance, with and without distance corrections applied, and ratios averaged over the network for individual events. Only events where a minimum of three stations had ratios were used to calculate network averages. Figure 5 (A and B) illustrate the discrimination plot using the Pg_z/Sg_h ratio with distance correction applied and network averages for the Southern Yakutia and Northern Yakutia - Magadan regions, respectively. For each discrimination plot constructed, the best value that distinguishes earthquakes from explosions (critical value) was calculated. The relative number of earthquakes and explosions was normalized in this calculation. For the Pg_z/Sg_h ratio, 86 to 87% of the events are correctly classified using the best critical values for both study regions using the network averaged ratios (Figure 6, A and B). Although some other ratios perform slightly better, the Pg_z/Sg_h ratio is the most practical to use in evaluation of existing data sets as it is these amplitudes most often recorded in the historic event bulletins.

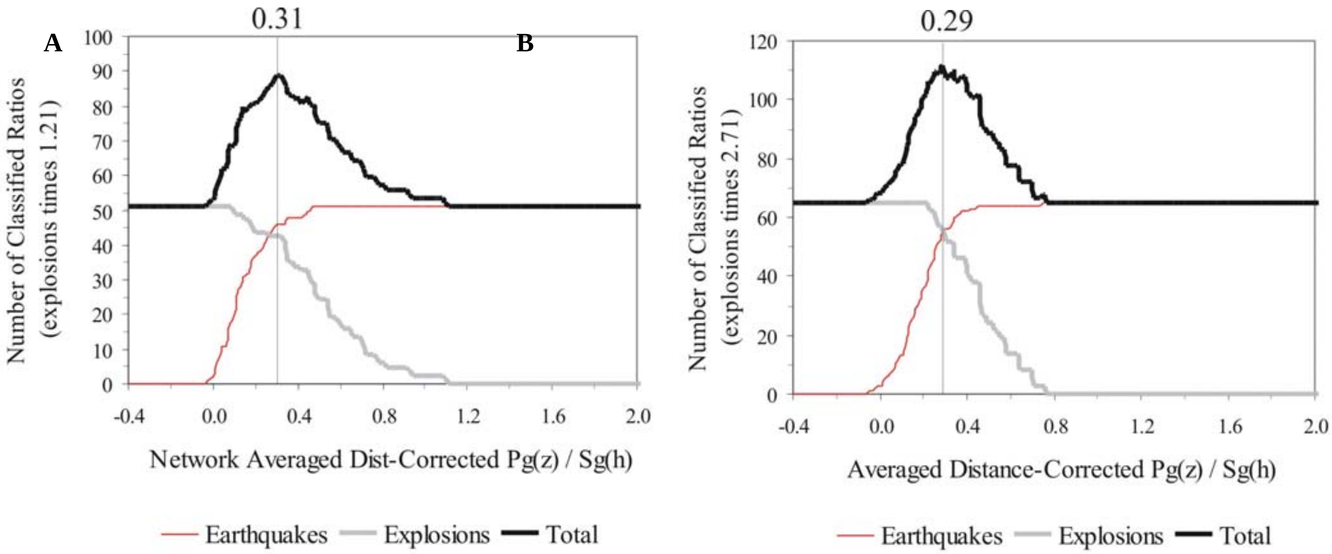

Figure 6. Network averaged-distance corrected Pg_z/Sg_h ratio critical value determination for the Southern Yakutia (A) and Magadan – Northern Yakutia (B) regions (see Figure 5).

Overall, the network average Pg_h/Sg_h, Pg_z/Sg_h, and full vector Pg/Sg ratio appear to discriminate earthquakes best, with successful discrimination ranging from 86.4 to 91.7%, while the Pg_z/Sg_z and Pg_h/Sg_z, ratios are poorer with successful discrimination ranging from 78.5 to 81.3% (Table 2). The network averaged ratios always discriminate better than individual ratios. Surprisingly, we found that the inclusion of a distance correction had little effect on the ability of a ratio to discriminate, though this may be a result of small events at only local and near regional distances.

Table 2. Summary of successful discrimination percentages using different amplitude ratios and methods.

Discrimant	Raw Phase Ratio		Distance Corrected Ratio		Network Averaged Ratio		Net. Avg.-Dist. Corr. Ratio	
	S. Yak.	Mag.	S. Yak.	Mag.	S. Yak.	Mag.	S. Yak.	Mag.
Pg(h)/Sg(h)	71.3%	70.7%	71.0%	70.0%	89.1%	91.0%	89.1%	91.7%
Pg(z)/Sg(z)	65.4%	63.8%	66.6%	63.8%	78.5%	78.1%	80.1%	79.1%
Pg(h)/Sg(z)	69.4%	62.8%	69.4%	63.3%	81.3%	80.2%	80.6%	80.2%
Pg(z)/Sg(h)	68.0%	67.0%	68.6%	66.0%	86.8%	86.4%	86.8%	86.1%
Full Vector	71.2%	70.9%	71.6%	70.8%	87.9%	91.7%	89.1%	91.7%

Database Improvements

Over the past year we have been working quality-control issues and adding additional information to the MSU Siberia database. Most quality-control issues have involved combing origin information from (typically) two or three separate origins into single events. These situations occurred because network operators have sometimes reported the same event more than once, but from separate bulletins. A few hundred of these cases were resolved (from over 245,000 total events). We added approximately 8000 new events, including location, arrival time, and amplitude information, to the database. Most events were from the Magadan and Yakutsk networks covering the years 1995 to 2005.

We also added around 11,000 mining explosions to the database. Most of these explosion records were derived from individual station operator's notes. In the Russian Far East station operators often note approximate times (to within the nearest minute) when waves from an explosion at a known mine arrive at their station. Sometimes station operators call mining companies to confirm explosion times and locations. Hence, even though many of these mining events were never formally located, records of time and approximate source location were often available. These mining explosions are from the Magadan and Yakutsk networks. The MSU Siberia database now holds origin information for over 11,700 mining explosions.

Station Calibrations

One of the long term problems with the established digital stations in eastern Russia deals with station calibrations. The majority of digital stations operating in our field area combine various short period Russian sensors with either Russian or U.S. digitization systems. Accurate calibrations of the merged systems has been difficult due to this diverse set of seismometers and recorders, many with poorly defined characteristics and no established calibration procedure. We have therefore established an empirical calibration procedure for the remote, unknown stations. The empirical calibrations are obtained by co-locating a calibrated reference station (a Geotech Instruments KS-2000 broadband seismometer recorded on a Geotech Instruments Smart24 recorder) at each remote station over a sufficient time interval to record multiple local, regional, and teleseismic events (see Figure 7).

To begin this calibration process, we first located the Geotech system at station MA2 adjacent to the GSN STS1 seismometer, which has operated for over a decade. Using STS1 response information provided by the IRIS Data Management Center and response information from Geotech, we confirmed that we could successfully correct the KS-2000 raw records (ground velocity in digital counts) into displacement (in meters) and obtain a close match to the corrected STS-1 records. Figure 8 compares the corrected KS-2000 and STS1 records from a deep, eastern Afghanistan event (December 12, 2005, mb near 5.7, depth near 220 km). Both the broadband and short-period records match well. Thus we have now obtained a calibrated pole-zero file for the KS-2000 system.

With the transportable KS-2000 system calibrated, we have been moving the system to other Magadan network sites throughout winter, spring, and summer of 2006. We now have joint records at stations OCHR and SUUS (Russian SM3 seismometers). During instrument co-locations, OCHR recorded the large Koryak earthquake of April 20, 2006, (Mw 7.6, see Figure 7). Based on reported SM3 free period and damping constant values (Mackey et al., 2005) we designed a pole-zero file for the SM3, and then instrument-corrected the SM3 and KS-2000 event records into displacement (in meters). Figure 9 shows the quite close match between displacement records from a local earthquake (top) and from the Koryak earthquake (bottom). We applied a high pass filter to these records because the SM3 is a short-period sensor. We plan to refine our SM3 calibration at OCHR, and then continue efforts to include SUUS and other Magadan network stations where Russian recording systems are deployed.

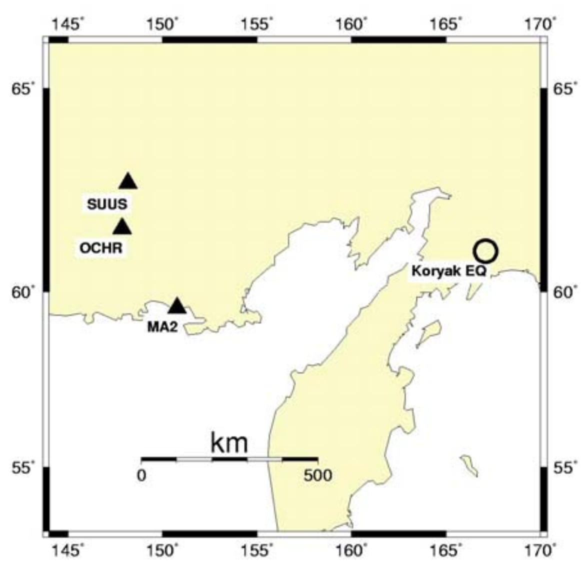

Figure 7. Locations of Magadan network stations discussed in text and location of April 20, 2006, Koryak earthquake (see text).

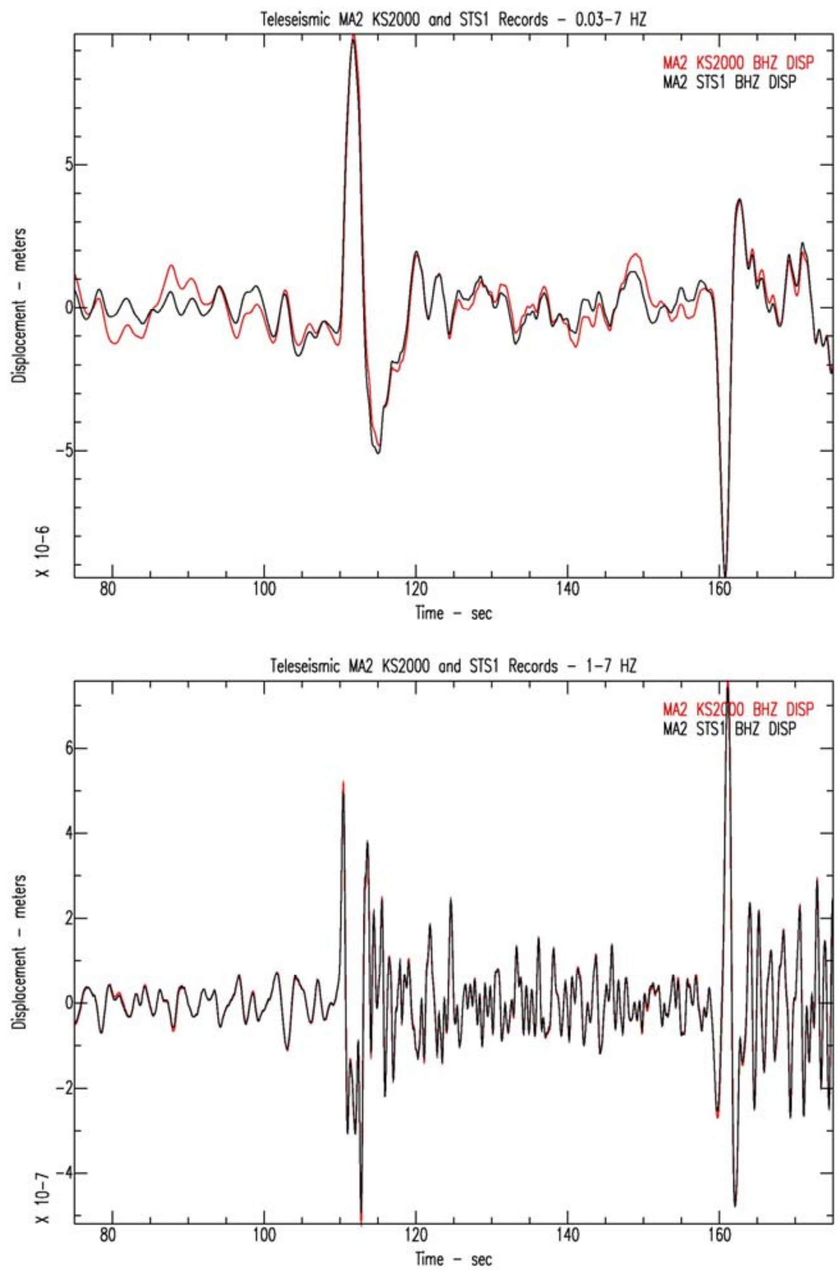

Figure 8. Station MA2 STS1 (black) and KS2000 (red) records corrected to displacement in meters. Top shows broadband records of a deep teleseism from eastern Afghanistan. Bottom shows a filtered short-period comparison.

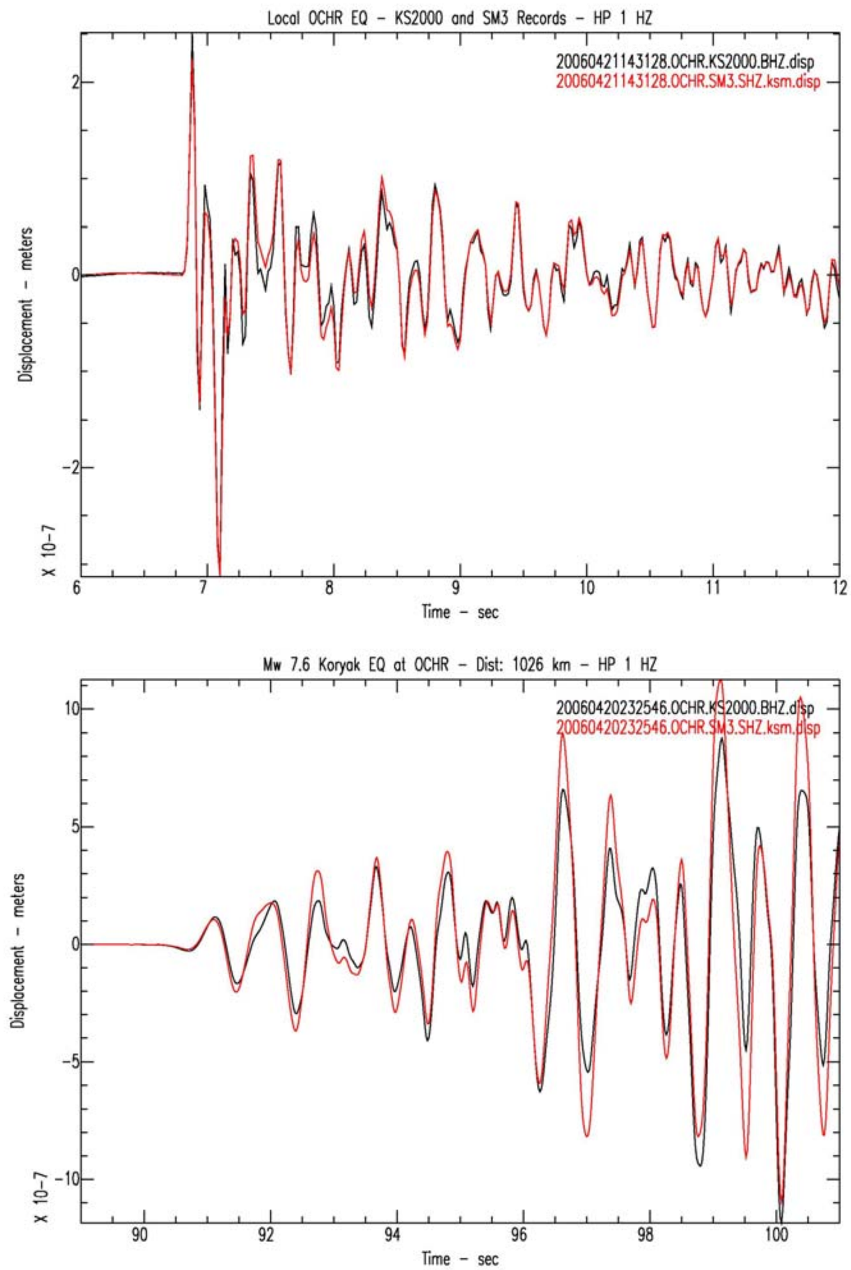

Figure 9. Instrument-corrected displacement records from OCHR. Top compares SM3 SHZ record (in red) to KS2000 BHZ record for a local earthquake. Bottom compares records from the large Koryak earthquake of April 20, 2006 (Mw 7.6). Records are high-pass filtered at 1 Hz.

Pn Tomography

Preliminary results of the use of differential Pn tomography (e.g., Phillips et al., 2005) as applied to the relocated eastern Russian catalog, a part of this study, are discussed in this volume in the paper by Steck et al. (2006, these Proceedings).

CONCLUSION(S) AND RECOMMENDATIONS

We continue to improve our seismicity characterization of northeast Russia with improvements in the seismicity database, discrimination of industrial explosions, station calibrations, and ongoing fieldwork.

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