REGIONAL SEISMIC EVENT DISCRIMINATION IN SIBERIA

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ABSTRACT

In July and August of 1987, three Peaceful Nuclear Explosions (PNEs) were detonated in the northern Baikal Rift. These PNEs, each near m_b 5.0, were recorded at teleseismic distances and are listed in global seismic bulletins. Broadband and short-period sensors were being digitized at Chinese Digital Seismic Network (CDSN) station HIA during that summer (at event-station distances of about 1450 km). As HIA will become an International Monitoring System (IMS) primary array, these PNEs provide an excellent opportunity to test and calibrate regional, short-period discriminants in preparation for future test-ban monitoring. Hence, we retrieved HIA records of the explosions from the IRIS Data Management Center (DMC) along with about 400 additional presumed earthquakes from central Siberia, eastern Mongolia, and northeastern China. Binning event origin times into time-of-day histograms indicates uniform event distribution throughout the 24-hour day. We therefore concluded that the event catalogs (PDE and REB) used for data retrieval were not contaminated with industrial explosions.

We tested short-period discriminants by measuring root-mean-square (RMS) amplitudes of P_n, P_g, S_n, and L_g phases and then formed amplitude ratios using several frequency band measurements between 1 and 6 Hz. For most events, event-station distances are between 400 and 1600 km from HIA, with P_n being the first arrival. P_g and S_n are generally difficult to identify as distinct arrivals. L_g is the strongest secondary arrival. After correcting ratios for distance effect, the P_n/L_g ratios at frequencies above 3 Hz separate the explosions from the earthquakes. The P_n/L_g cross-spectral ratios (P_n above 3 Hz and L_g near 1 Hz) also separate the explosions from the earthquakes. Although it does not separate the explosions and earthquakes quite as well as the P_n/L_g ratios, the L_g spectral ratio appears to be a potentially useful discriminant, just as it has been recognized as a useful regional discriminant in the western United States. Of course more explosions will need to be measured before firmer conclusions can be reached regarding the L_g spectral ratio in Siberia.

Key Words: discrimination, seismic sources, regional seismology

OBJECTIVE

Over the past several years seismic verification research has emphasized the analysis of seismograms recorded at regional distances (between about 200 and 2000 km). The primary objective of this research has been to lower magnitude levels at which events can be detected, located, and identified. Our efforts have been directed at regional event identification in Asia. To date we have primarily relied on known nuclear tests from a few test sites to build data sets of nuclear explosion seismograms. There are, however, a few Soviet Peaceful Nuclear Explosion (PNE) seismograms that were digitally recorded at regional distances by the Chinese Digital Seismic Network (CDSN) during the late 1980's, and these records present additional opportunities to test discriminants.

In this paper, we examine regional broadband digital data recorded at CDSN station HIA in northeast China. Three PNEs detonated in Siberia were recorded at HIA during the summer of 1987 at event-station distances of about 1450 km. Many regional earthquakes have been recorded at HIA from throughout northeast China, Mongolia, and Siberia. As HIA is scheduled to become an International Monitoring System (IMS) array, our primary objective here is to test short-period regional body wave discriminants in Siberia as we have done elsewhere in Asia (Hartse et al., 1997).

RESEARCH ACCOMPLISHED

We obtained all waveforms for this study from the IRIS Data Management Center (DMC). All data were recorded at CDSN station HIA between the years 1987 and 1999 (Figure 1). From the 1980s until late 1994, HIA BH (20 sps) and SH (40 sps) components were operated in a triggered mode. In more recent years, SH and BH data have been acquired continuously. All events presented here fall within a box bounded from 44º to 70º north latitude and from 102º to 140º east longitude (Figure 1).

We obtained most of our data based on origin times reported in USGS PDE, pIDC REB, and SSB (Gao and Richards, 1994) event catalogs. The PNE event information from 1987 is listed in PDE and ISC catalogs, and we obtained additional information in Table 1 from Sultanov et al. (1999). In total, we assembled waveforms of about 400 earthquakes ranging in magnitude (m_b) from near 2.5 to near 6.5. The August 1987 Neva 2 explosion (Table 1) triggered the SH components at HIA with the P_n arrival, and it triggered the BH components at HIA with the L_g and surface wave arrivals. All three Neva 2 explosion records are shown in Figure 2 with a bandpass filter from 0.75 to 6 Hz applied. These waveforms are dominated by a strong L_g arrival. P_n is somewhat impulsive, but weak when considering these events are all near m_b 5.0 in size. P_g and S_n phases are generally poorly developed for earthquakes from Siberia and the explosions share these same characteristics.

To test for the presence of mining explosions within our presumed earthquake data set, we binned the numbers of events occurring within 4 sub-regions by hour of day (Figure 3). If significant numbers of mining explosions were present, we expected to see more events during daylight hours than during hours of darkness. Daylight hours in Siberia fall between about 0 hours and 14 hours GMT. We see no increase in event origin times during these hours. Hence, we conclude that our earthquake data set is not significantly contaminated by mining explosions. The large number of events occurring between hour 16 and 17 on the Stanovoy histogram is related to two m_b 5.5 earthquakes that occurred within one minute of each other on March 21, 1999, followed by several aftershocks.

Before making any measurements we corrected each seismogram for instrument response into units of displacement in meters. After manually picking each regional phase arrival, we bandpass filter, cut appropriate data windows, and measure the RMS amplitude (in the Log_{10} domain) for Pn, Pg, Sn, Lg, and pre-phase noise. We made time-domain phase amplitude measurements in several one-octave filter bands from 0.5-1 Hz up to 6-8 Hz. More details of our amplitude measurements are given in Hartse et al. (1997).

We tested several regional short-period discriminants. by forming amplitude ratios, removing the ratio-distance trend, and then plotting the corrected amplitude ratios versus magnitude. Before forming any amplitude ratio we test each phase amplitude to confirm that it exceeds pre-phase noise by at least a factor of 1.2. Figure 4, an L_g spectral ratio, shows the ratio-distance trend at the top and the discrimination plot on the bottom.

The L_g spectral ratio has long been identified as a viable discriminant for the western United States (Bennett and Murphy, 1986; Taylor et al., 1988). However, Hartse et al. (1997) found that the L_g spectral ratio did not separate Kazakh test site explosions from regional earthquakes recorded at station WMQ. For Siberia, and with a limited explosion data set, we find that the L_g spectral ratio separates the regional earthquake and explosion populations recorded at HIA. This result is more similar to results from the western United States than to other regions of Asia.

Figure 5 shows P_n/L_g ratios that also separate the explosions from the earthquakes. These ratios seem to work well in all regions of Asia where L_g is present (Hartse et al., 1997; Taylor et al., 2000), including Siberia. The dominant presence of L_g on the regional seismograms from Siberia help make these P_n/L_g discriminants and the L_g spectral ratio discriminant especially attractive because L_g can be observed over long distances at low magnitude levels. Figure 6 helps show why the P_n/L_g ratio works well in Siberia. The explosion records (red) filtered at 4-8 Hz have P_n and L_g amplitudes that are about equal, while the earthquake records (green and yellow) are dominated by L_g energy in all bands.

The P_n spectral ratio (top, Figure 7) does not separate the event populations as well as the L_g spectral ratio or the P_n/L_g ratios, but the explosions are near the top of the earthquake population. Hence, the P_n spectral ratio appears to perform in Siberia about as well as it has been observed to perform elsewhere in Asia (Hartse et al., 1997). The P_n/S_n ratios also apparently perform quite well in Siberia (bottom, Figure 7). However, S_n for small Siberian events is often in the P-coda noise and can not be measured.

CONCLUSIONS AND RECOMMENDATIONS

From this preliminary examination of discrimination performance in Siberia, we believe the outlook for successful regional event identification is quite promising. The regional P/S discriminants perform well, just as they do elsewhere in Asia. The exceptional strength of L_g recorded at distances of over 1000 km and for events smaller than m_b 4, will allow more and smaller events to be evaluated compared to the more tectonically active regions of Asia where S-wave attenuation is stronger.

We did not anticipate the good discrimination performance of the L_g spectral ratio. Perhaps the separation of the Neva 2 PNEs from regional earthquakes using the L_g spectral ratio is in some way related to the depth of burial for each PNE (between about 800 and 1500 m). The performance of this discriminant in Siberia should be studied more closely, because, if it can be documented as reliable, the exceptional propagation of L_g will allow for the L_g spectral ratio to be applied to many small events at distances of 1000 km or more.

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Table 1. Neva 2 PNE Information

Name	*Date (ymd)*	*Time (hr:mn:sc)*	*Lat ($^o N$)*	*Lon ($^o E$)*	*Depth (m)*	*Material*	*Yield (ktons)*	*m_b (ISC)*
Neva 2-1	19870707	00:00:00.0	61.50	112.85	1502	limestone	15 (13)	5.1
Neva 2-2	19870724	02:00:00.0	61.45	112.80	1515	limestone	15 (13)	5.1
Neva 2-3	19870812	01:30:00.5	61.45	112.80	815	salt	3.2	5.0

Information in this table is from Sultanov et al. (1999). Yields are from official reports and yields in parentheses are estimates from other sources.

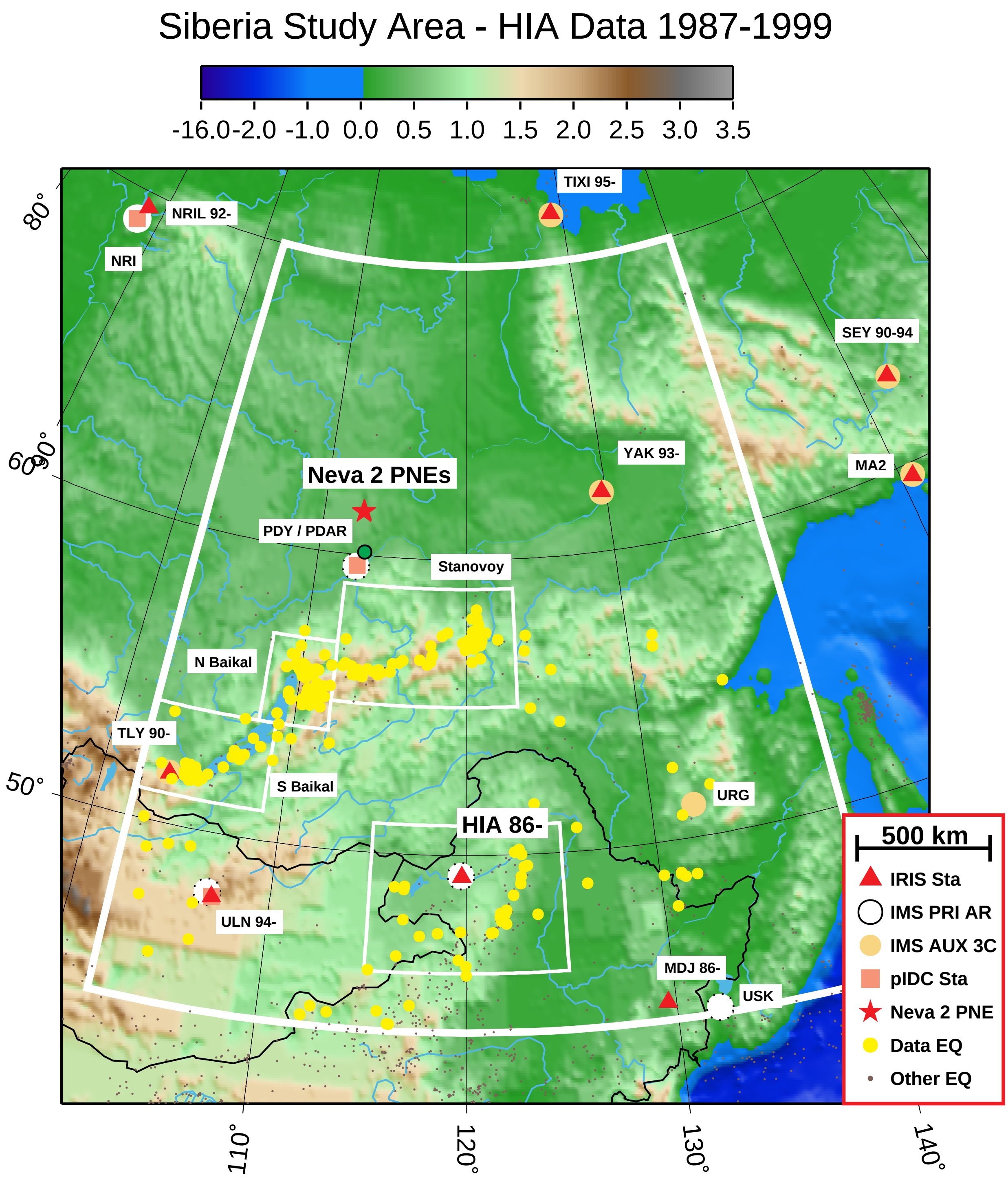


Figure 1. Study area map showing station HIA, other regional stations, and locations of events used in this study. The green circle near PDY represents the earthquake in our data set that is nearest to the "Neva 2" PNE locations. HIA recorded all three "Neva" PNEs detonated during the summer of 1987. The small white boxes outline sub-regions that we examined for evidence of mine-related seismicity. See Figure 3 for more details.

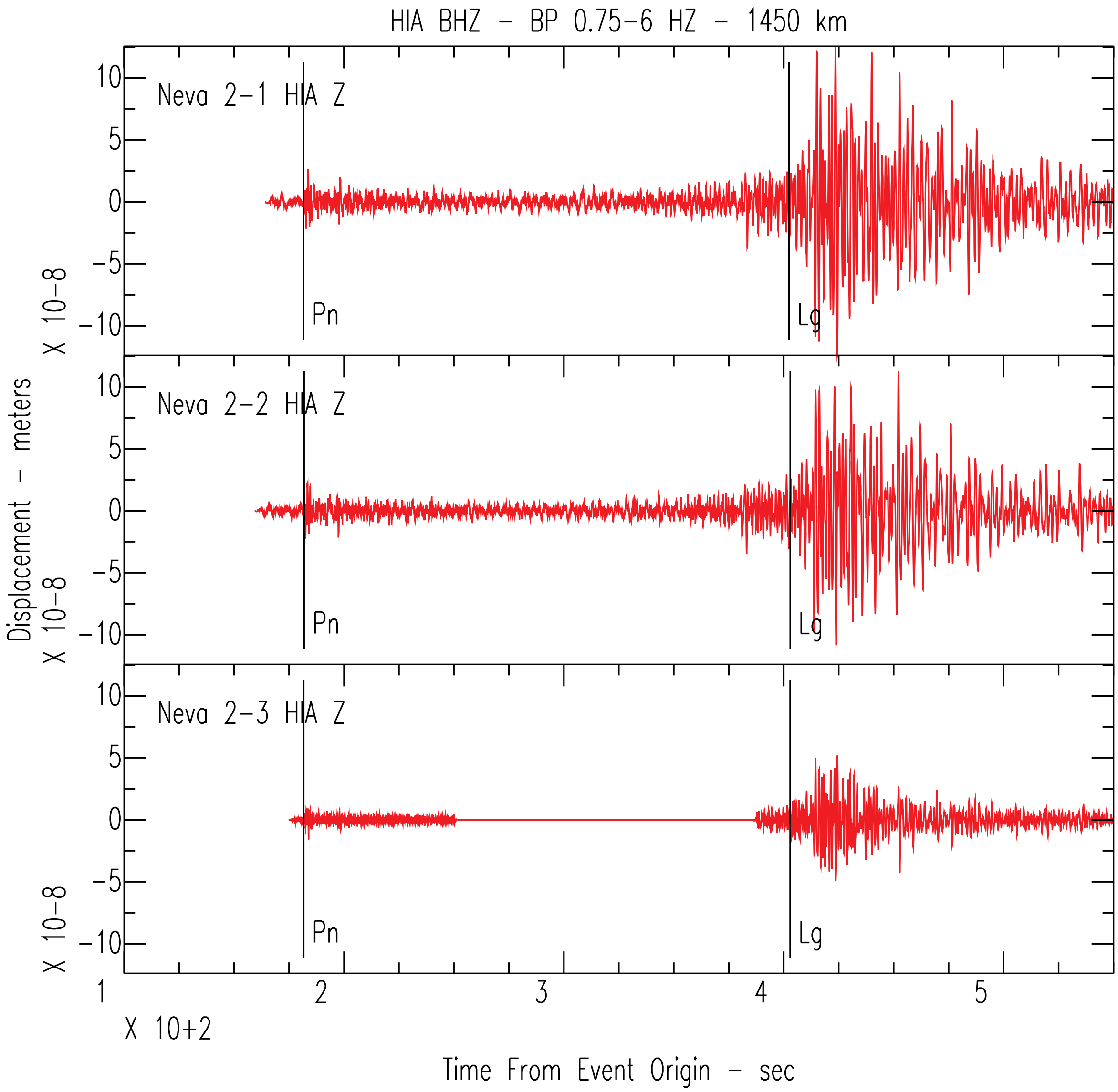


Figure 2. The "Neva 2" PNE records from station HIA bandpass filtered between 0.75 and 6 Hz. Only the P_n and L_g phases from the Neva 2-3 explosion triggered the event detector at HIA. Regional waveforms of Siberian seismic events generally have moderately weak P_n, weak to missing P_g and S_n, and a strong L_g. All three PNEs have m_b (ISC) values near 5.0. Table 1 presents more information on each explosion.

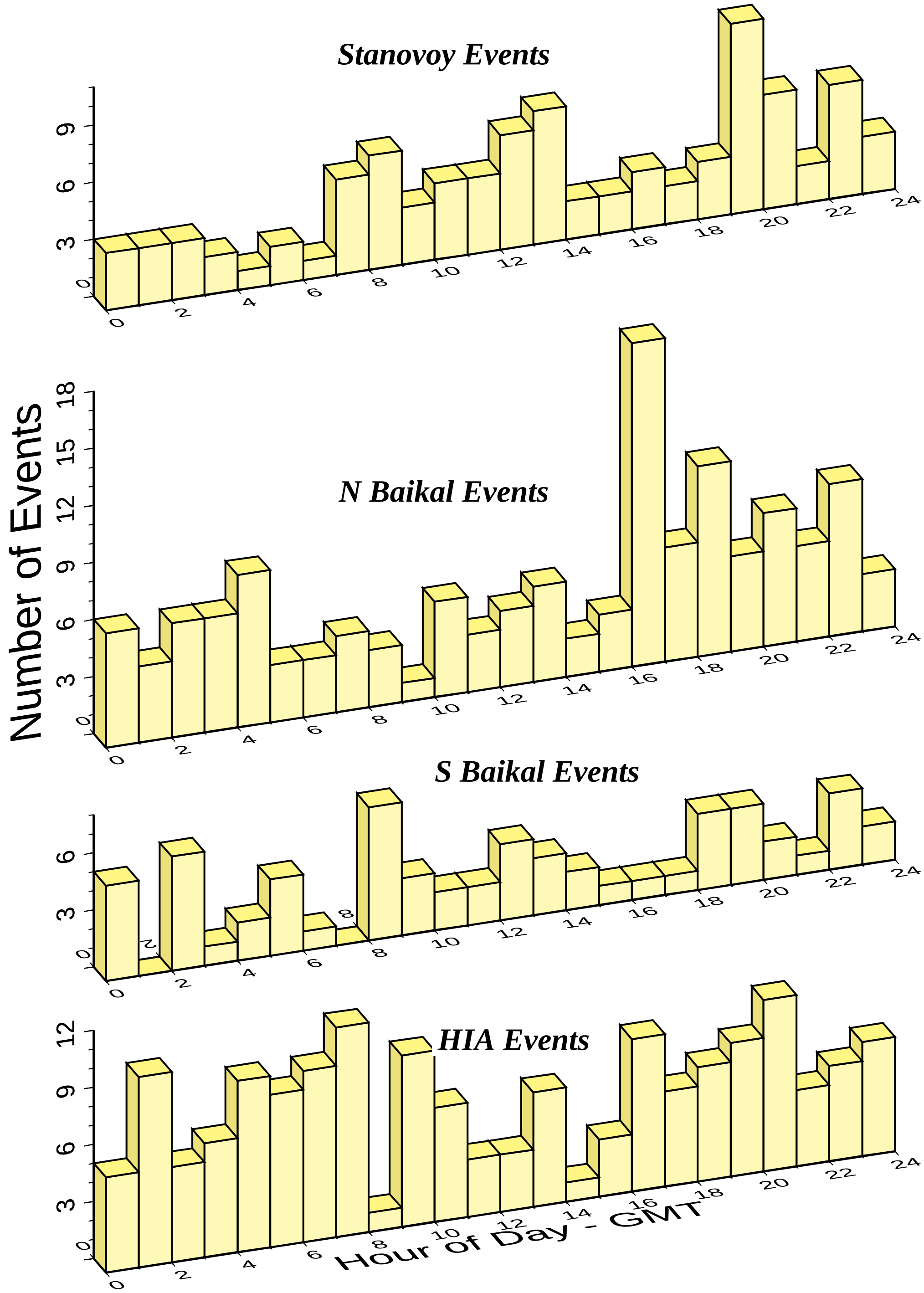


Figure 3. Number of events versus hour of day histograms for the presumed earthquakes that we analyzed in this study. Each sub-region outlined in white and labeled in Figure 1 corresponds to each histogram shown here. Daylight hours should be between 0 and 14 GMT. We see no evidence of increased seismicity during daylight hours in any of these subregions, and, hence, conclude that our data are not significantly contaminated by mining explosions. The large number of events occurring between hour 16 and 17 on the Stanovoy histogram is related to two m_b 5.5 earthquakes that occurred within one minute of each other on March 21, 1999, followed by several aftershocks.

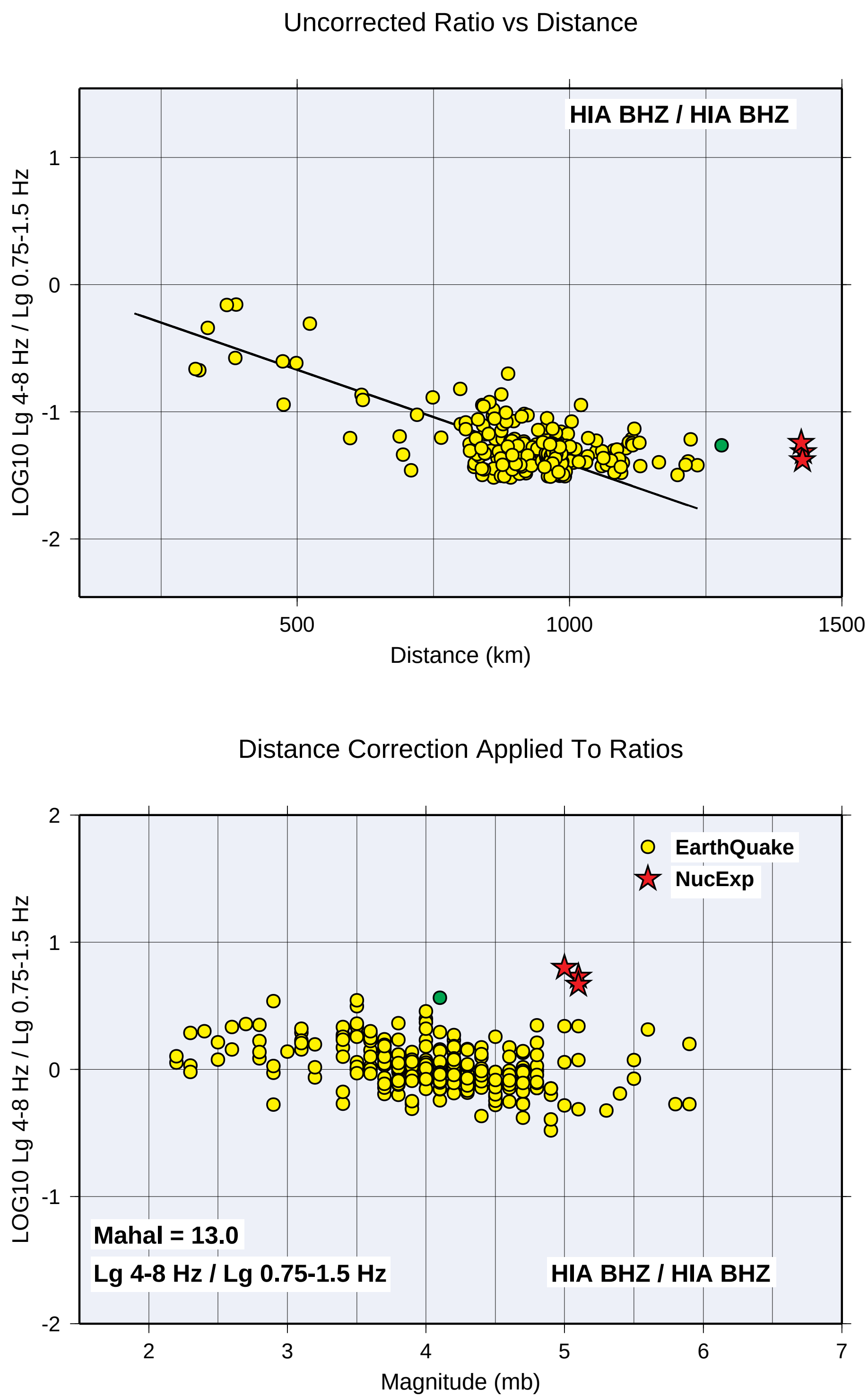
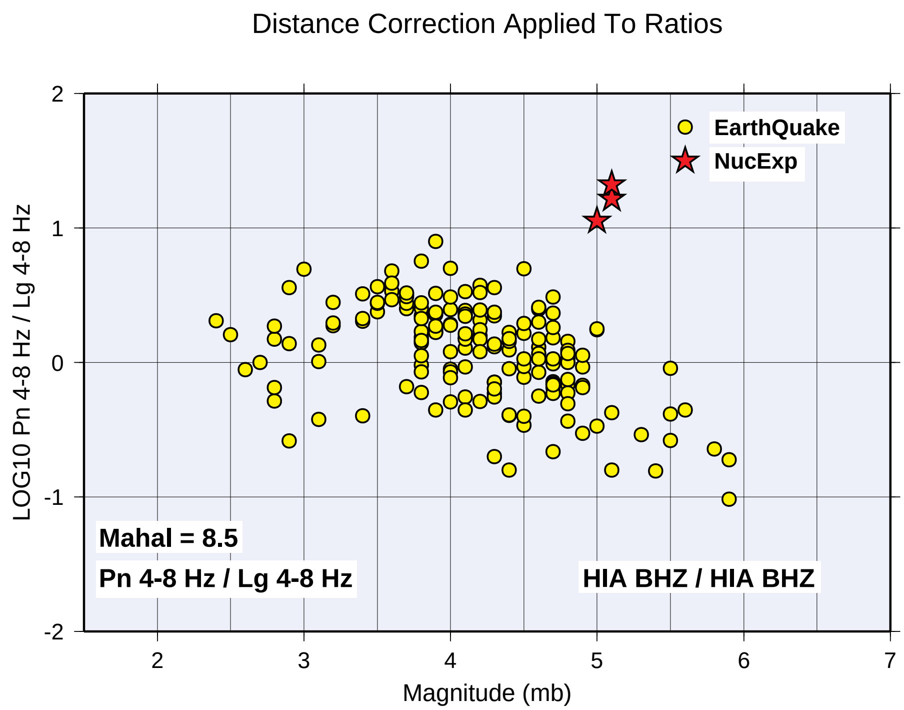


Figure 4. L_g spectral ratio discriminant for Siberian events. The top shows the ratio-distance trend of the earthquake population and the bottom is the distance-corrected ratio versus magnitude discrimination plot. The green dot represents the earthquake that occurred nearest the PNE locations. This discriminant separates the PNEs from the earthquakes, which we had not previously observed with regional events from near the Lop Nor and Kazakh test sites.



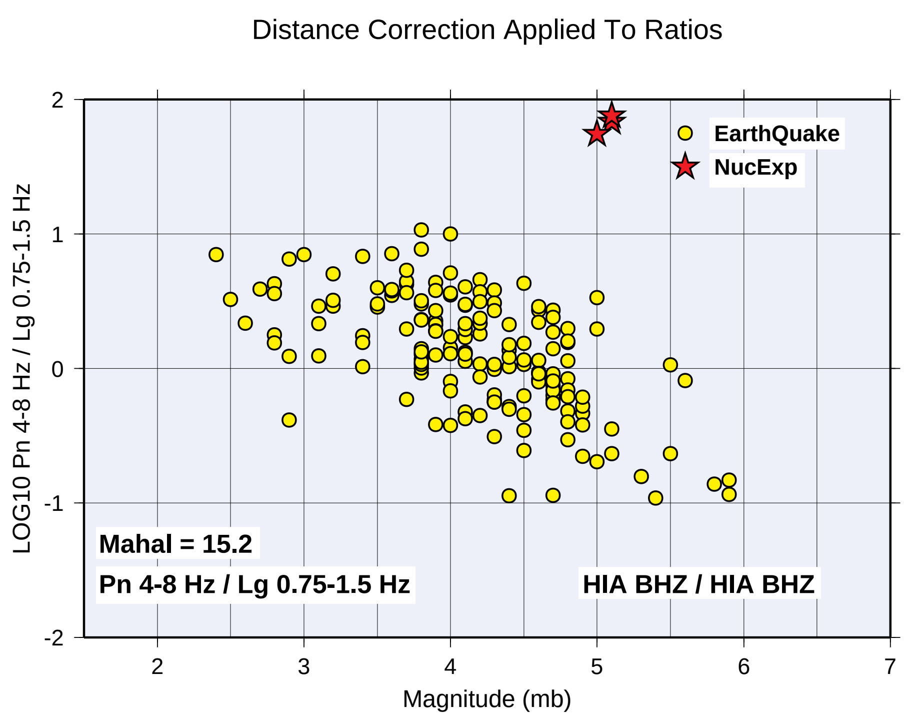


Figure 5. P_n/L_g ratio versus magnitude discriminants for Siberian events. The top shows the 4-8 Hz P_n/L_g ratio and the bottom shows that P_n(4-8 Hz)/L_g(0.75-1.5 Hz) ratio. Distance corrections have been applied. Both ratios separate the explosions from the earthquakes, as we have previously observed in other regions of Asia.

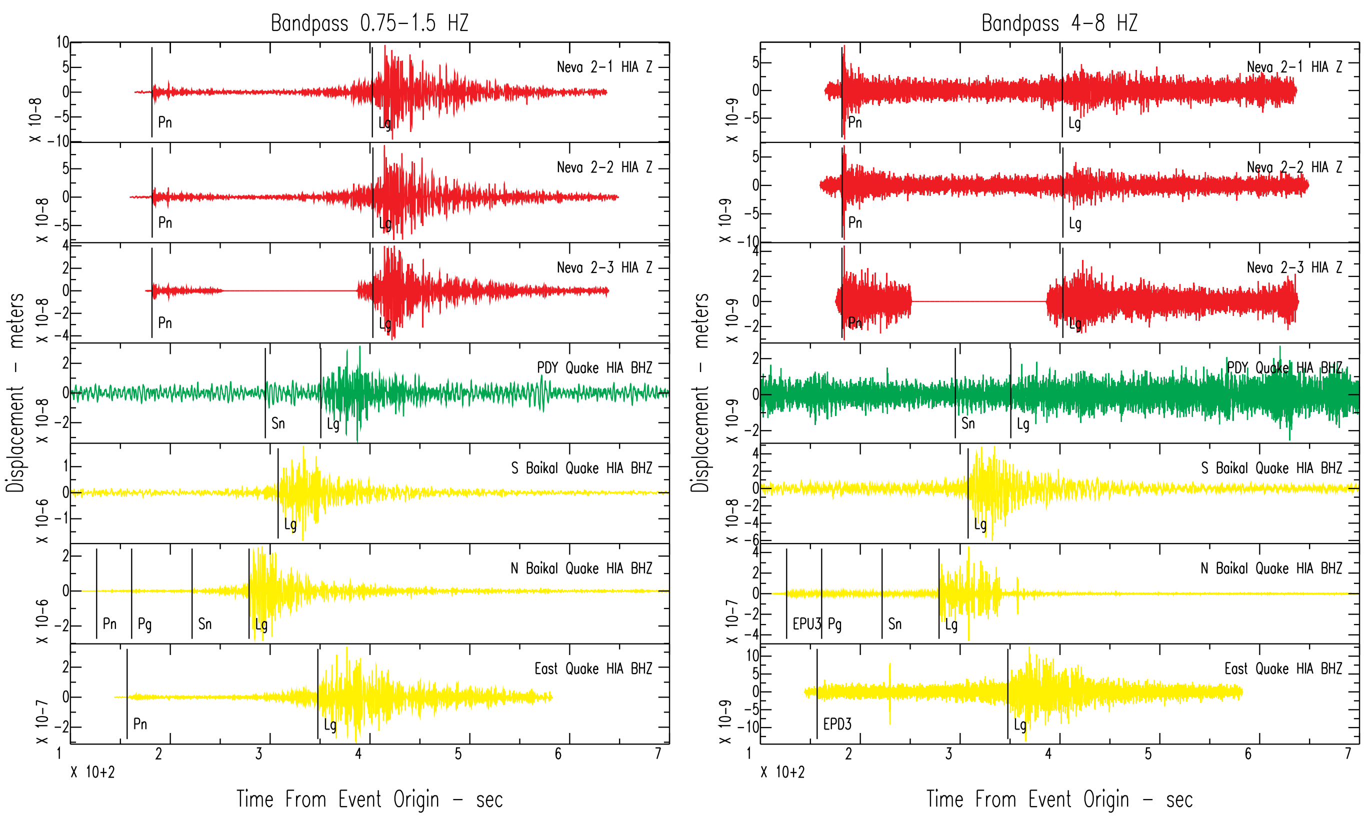
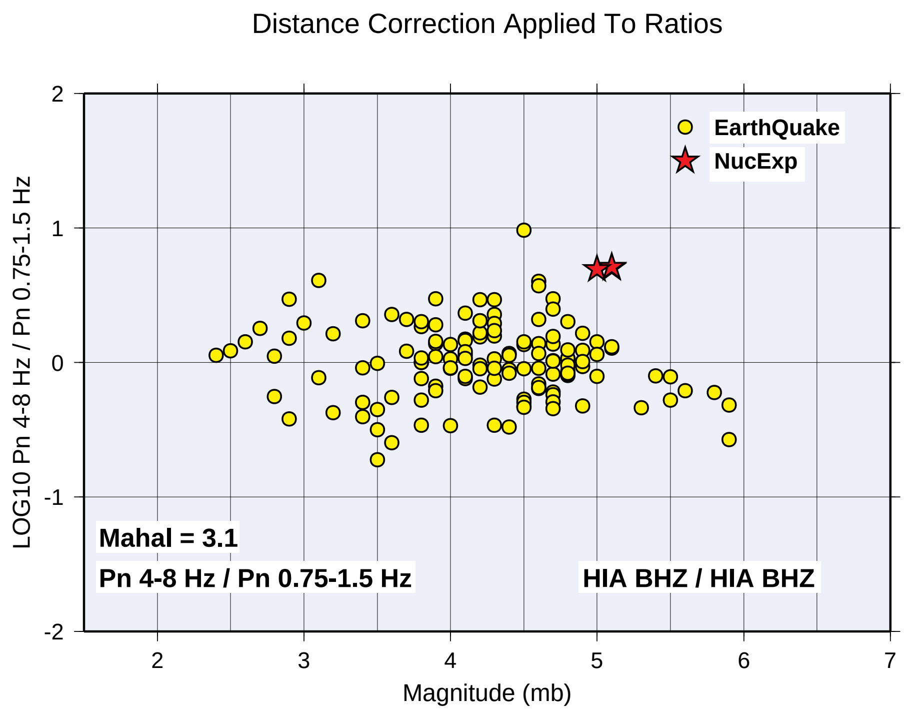


Figure 6. Explanation for the success of the P_n / L_g discriminants shown in Figure 5. The "Neva 2" PNE records bandpass filtered between 0.75 and 6 Hz (on left in red) have a slightly impulsive P_n arrival, but appear quite similar compared to the earthquakes (in green and yellow). However, in the 4- to 8-Hz band, the "Neva 2" records display P_n and L_g amplitudes that are about equal, while the earthquakes have L_g amplitudes that are much larger than their P_n amplitudes.



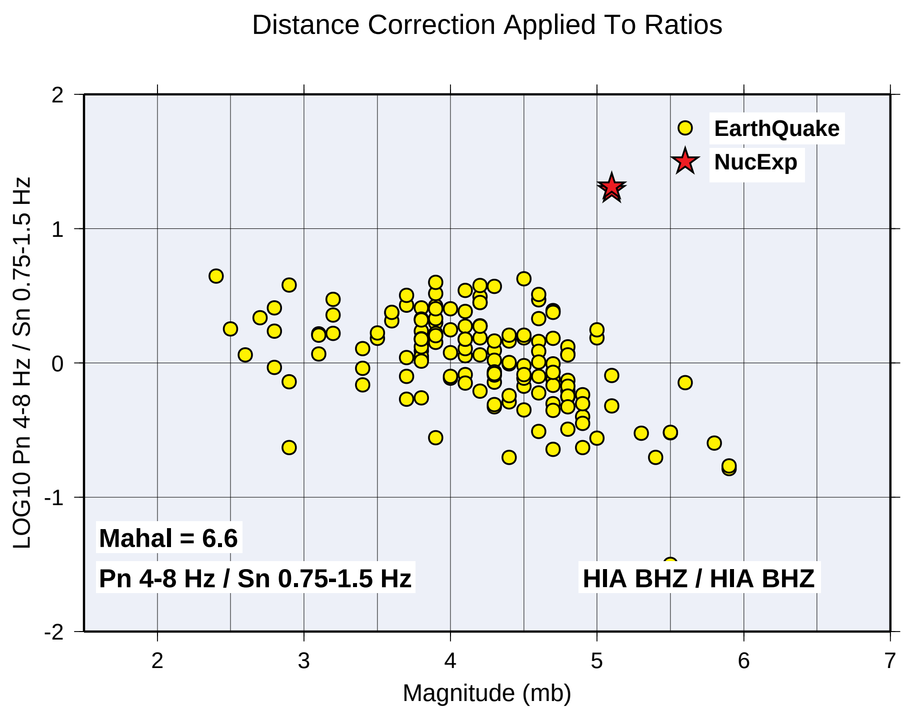


Figure 7. P_n spectral ratio and the P_n(4-8 Hz)/S_n(0.75-1.5 Hz) ratio versus magnitude. Distance corrections have been applied. Both ratios separate the explosions from the earthquakes, but not quite as well as ratios that use L_g. The primary drawback of these ratios is that P_n is often a weak phase, and S_n is a poorly developed phase in Siberia. Hence, signal-to-noise problems often eliminate many smaller regional events from consideration when applying these discriminants.