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Сибирское отделение Российской Академии наук

Digitization of Soviet Era Peaceful Nuclear Explosion Seismograms From Regional Stations

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T2.5-P4

Abstract

The crustal structure of Eastern Siberia is poorly known due to its inaccessibility and the sparseness of seismic stations and larger earthquakes. Peaceful Nuclear Explosions (PNEs), detonated by the former Soviet Union are seismologically significant because they are Ground Truth events, wherein the depth and geographic coordinates of energy release (the detonation) are precisely known. The PNEs are therefore excellent data sources for crustal studies. Analog seismograms from regional stations for PNEs in eastern Siberia were collected and scanned to create a seismogram database. This database currently contains 27 PNEs, that when incorporated together, provides data coverage better than what is possible using only earthquakes. The scanned seismograms were hand digitized using the computer program WaveTrack. Digitizing PNEs allows modern processing techniques to be applied to each seismogram and provides the opportunity to enhance studies that were previously done using analog techniques. Digital data manipulation allows further analysis of crustal, velocity, and attenuation models.

History and Importance of PNEs

Throughout the late 20th century, the former USSR detonated 122 Peaceful Nuclear Explosions (PNEs) within its territory for economic and scientific purposes. The associated point-source energy release produced seismic waves which were recorded throughout the former Soviet Union and globally.

Studying PNEs allows analysis of locations where natural earthquakes are uncommon, especially in cratonic regions. The unique PNE dataset provides information on subsurface crustal and upper mantle structure. The geologic emplacement settings of the Soviet PNEs are highly varied and contain many settings not represented in the formal nuclear test sites. This allows the observation of phenomena or signal variance unique to those settings.

PNE Dataset

Data collection was concentrated in Eastern Russia. The original photopaper seismograms were acquired through the course of collaborative efforts between Michigan State University (MSU), The Geophysical Survey, Russian Academy of Sciences, and their affiliated Baikal, Yakutsk, Far East, and Kamchatka regional seismic networks. Seismograms were scanned either on-site or at MSU. Currently 27 PNEs are represented in this dataset with ~650 seismic records (Fig 1). The events were recorded on three components on both short- and long-period instruments. Initially we have digitized all the short-period components (Fig 2). Data coverage extends across numerous geologic settings, such as the Siberian Craton, Verhoyansk fold and thrust belt, and the Baikal Rift Zone.

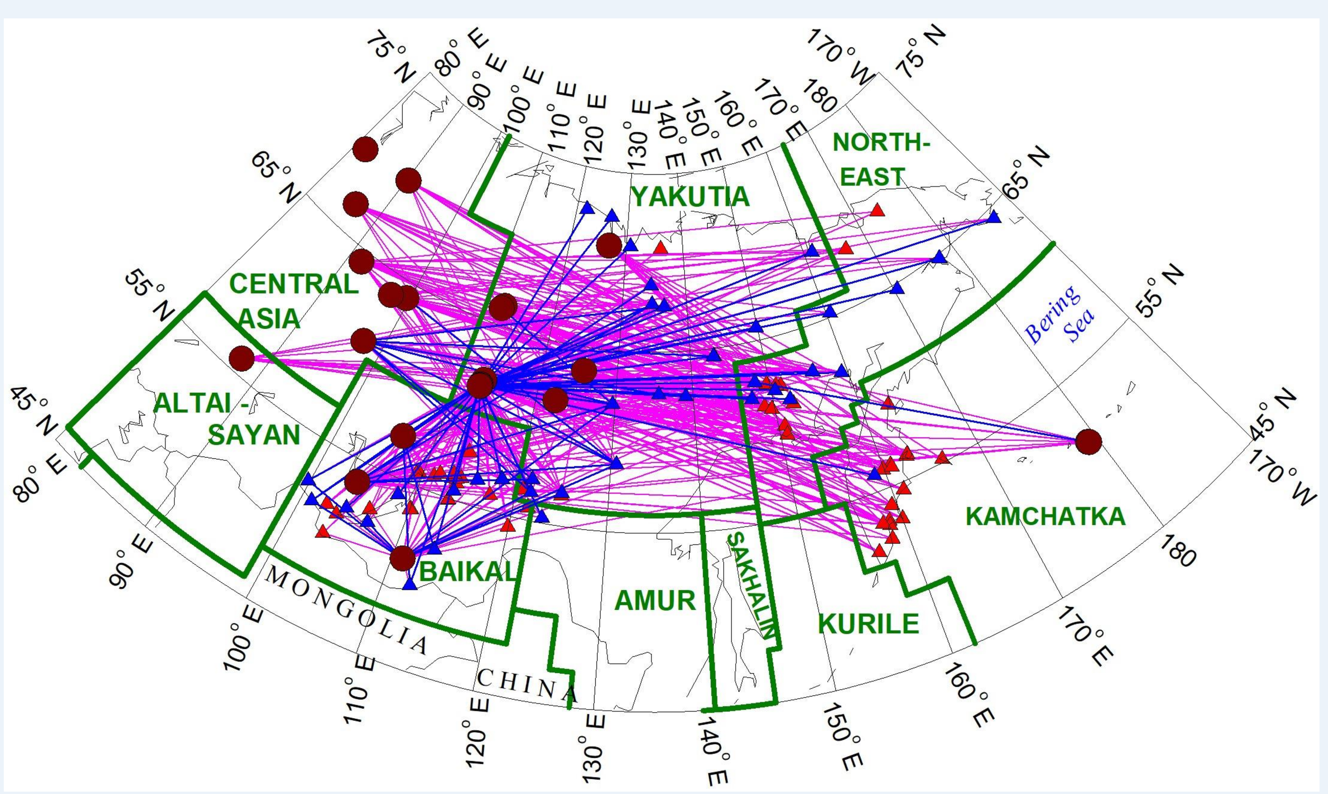

Figure 1. Raypaths between PNEs (brown circles) and stations (triangles) in Eastern Russia. Michigan State University (MSU) has approximately 650 seismic records. Digitized raypaths are shown in blue with its corresponding station and ones that still need to be digitized are shown in pink.

Seismogram Digitization

The analog records utilized here were recorded with photopaper and a light beam that traced the incoming data. Using WaveTrack, a Russian software program developed at the Institute of Petroleum Geology and Geophysics in Novosibirsk, the digitization of these records are made possible. Each peak and trough of every seismogram are hand-picked to recreate the digitized waveform. Digitized seismogram files take into account component amplification and time corrections. Files are converted to SAC and MSEED binary for analysis. Approximately 10% of MSU's current seismogram database has been digitized.

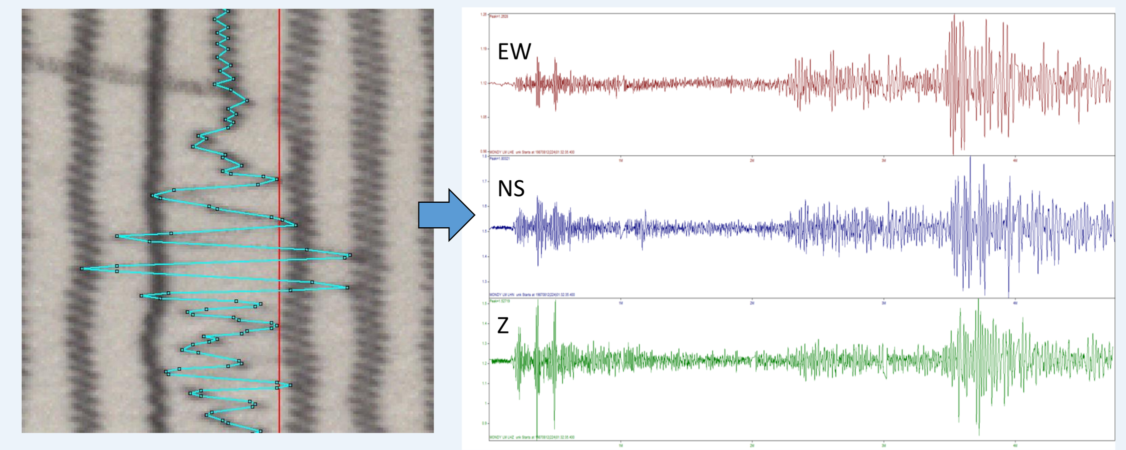

Figure 2. PNE Neva 2-3 at station Mondy was digitized using WaveTrack shown by the light blue overlay trace and red reference grid (left) and converted into SAC and MSEED formats (right).

Digitization Challenges

High Amplitude: Stations close to PNE detonation site have higher amplitudes. Since records have all three components on one sheet, higher amplitude signals can blend between components or they might go over the edge of the paper (Fig 3). Amplitudes may be clipped and become inaccurate.

Resolution of scanned images and High Frequency Signal: Scan resolution of analog images plays an important part in the digitization process. The higher the scan resolution the more accurate the digitization. Optimal resolutions are at least 600 dpi to achieve a good digitization. Lower resolution images, like 200 or 220 dpi, cause high inaccuracies for trace selection, especially with a record containing high frequency signals. Compounded with underexposure of the photopaper, the light beam travels so fast across the photopaper causing it to have little contact with the paper resulting in signals appearing faint (Fig 4). This causes problems with following the seismic signal.

Minute Marks: Soviet analog records have a data break every minute. This break lasts a second or two where no data is collected creating an issue where there is a physical data disruption while digitizing. Environmental conditions at the station produce another issue for minute marks as it causes the rotating drum to turn at different speeds creating varying lengths between each minute. Variations between minutes can be up to a few seconds (Fig 5). WaveTrack allows us to adjust each minute so an accurate time can be kept for each digitized record.

Curvilinear Seismogram: A few PNEs were recorded with ink pen and paper using a curvilinear pen. This pen generates a curved line which causes a shifted time scale as a function of amplitude. Using Photoshop's 'Shear' tool can correct this issue.

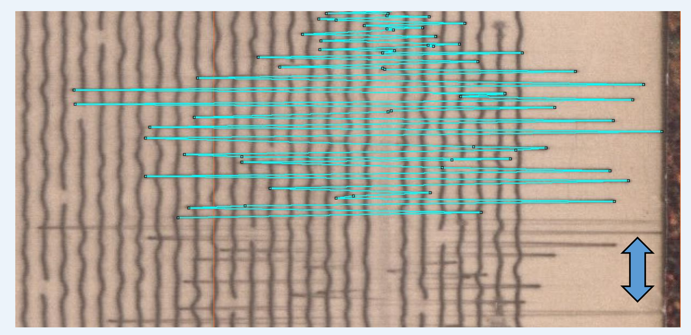

Figure 3. High amplitude seismograms can cause the signal to go off the paper (see arrows above) which cause clipped amplitudes while digitizing.

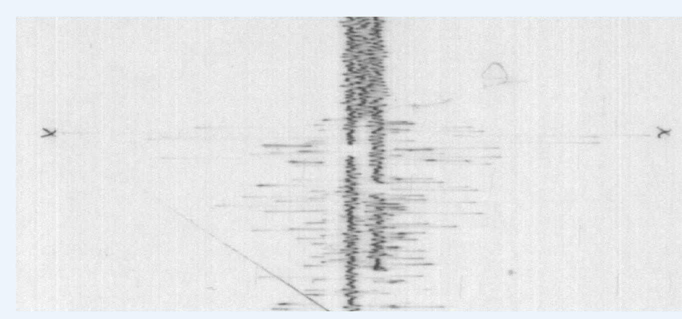

Figure 4. High frequency seismic signals cause faint traces on a photographic paper due to a light beam traveling fast across the paper.

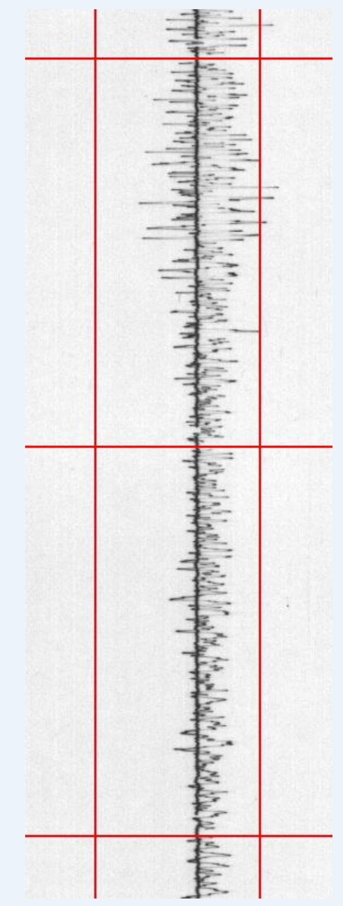

Figure 5. Example of varying minute mark lengths in a PNE seismogram. To keep accurate timing while digitizing we manually adjust each minute line on the red reference grid.

Quality of Digitizations

Numerous stations where these PNE records were collected currently operate as IRIS GSN digital stations. A test was designed to compare an analog seismogram that was hand digitized with a digital station at the same location. Using a SKM seismometer (black line) and an IRIS STS-1 seismometer (red line) at Yuzhno Sakhalinsk (YSS) we compared the frequency recovery of both records from 10^{-5}–10^{9} Hz. Recovery of the waveform was accurate up to 8 Hz on the vertical and up to 5 Hz on both horizontal components. This early comparison study is a qualitative look on frequency recovery of digitized seismograms. Currently we are looking for a more quantitative way to evaluate the signal recovery.

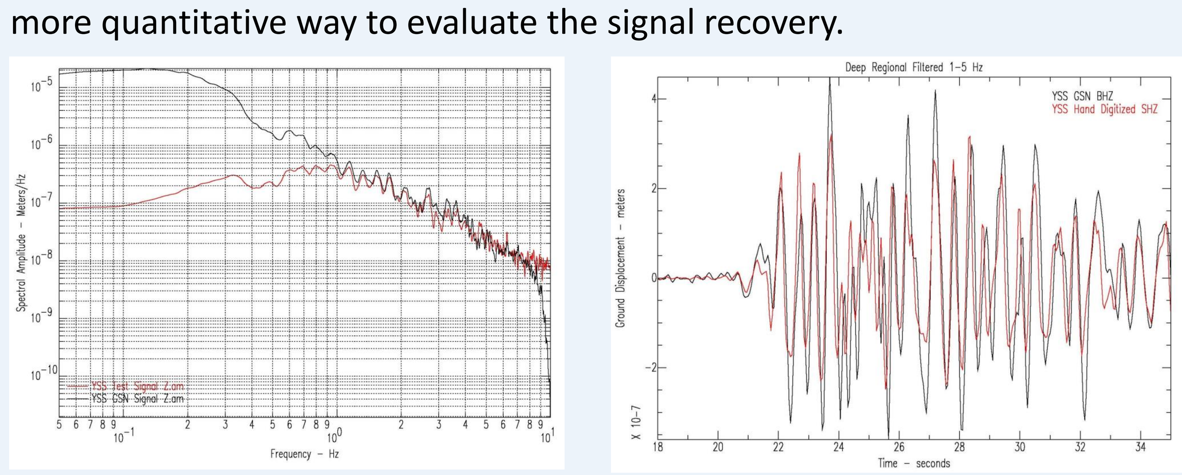

Figure 6. Comparison of frequency response (left) and 1-5 Hz filtered waveforms (right) between digital seismometer (black) and digitized analog record (red).

Recreating Response Curves

Utilizing a more quantitative approach for a digitization's frequency response requires recreating a station's response curve. Annual station booklets from seismic networks recorded instrument and galvanometer parameters such as seismometer period (Ts), seismometer damping ratio (Ds), galvanometer period (Tg), galvanometer damping ratio (Dg), coupling factor (σ^2), and magnification factor (Vo). A best fit model was used to back calculate the poles and zeros for a station.

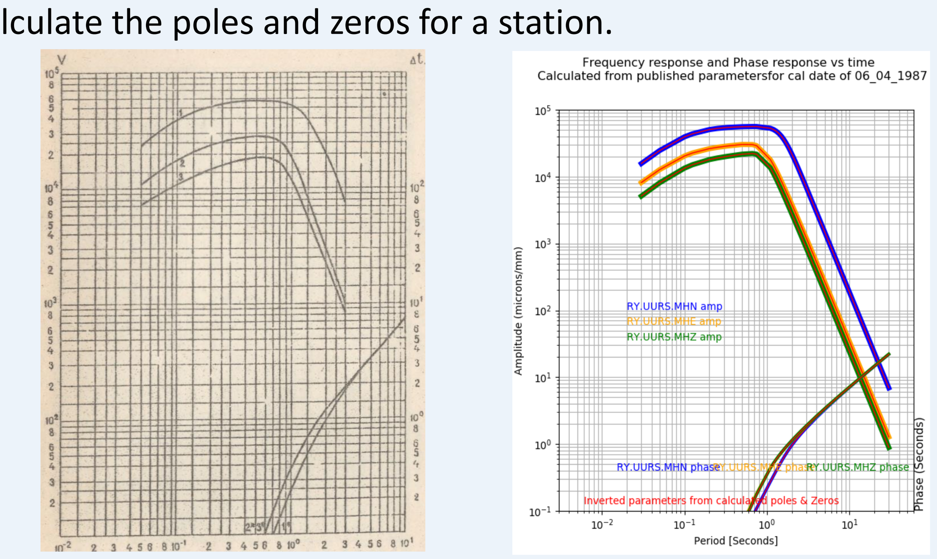

Figure 7. Replicated response curve produced from station parameters for Ust'Urkyma (UURS). Left is the original, right is the new curve generated from station and galvanometer parameters from annual station booklets. Thin red lines in the right show the back calculated poles and zeros.

Seismogram Analysis

Earthquake and nuclear explosion seismograms are usually distinguishable from one another. Generally earthquakes have large Lg phases relative with smaller Pn and Pg phases, while nuclear explosions have large Pn and small Lg phases. Discrimination between earthquakes and nuclear explosions are thus established by amplitude ratios between the two crustal phases, Pg and Lg. Filtered waveforms at different frequencies yield different amplitude heights. Using specific phase ratio discriminants, generally earthquakes plot separate from nuclear explosions (Fig 9). However that is not the case with one PNE, Meteorite 5 (green stars).

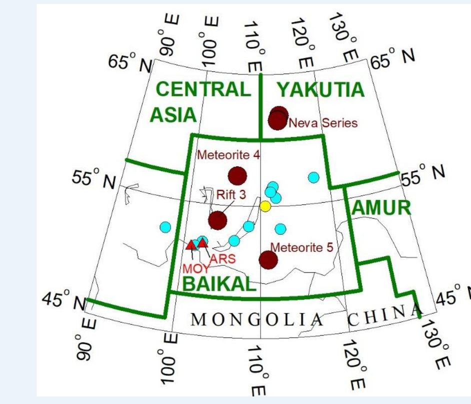

Figure 8. PNEs (brown), earthquakes (blue/yellow) and stations (triangles) in Baikal network.

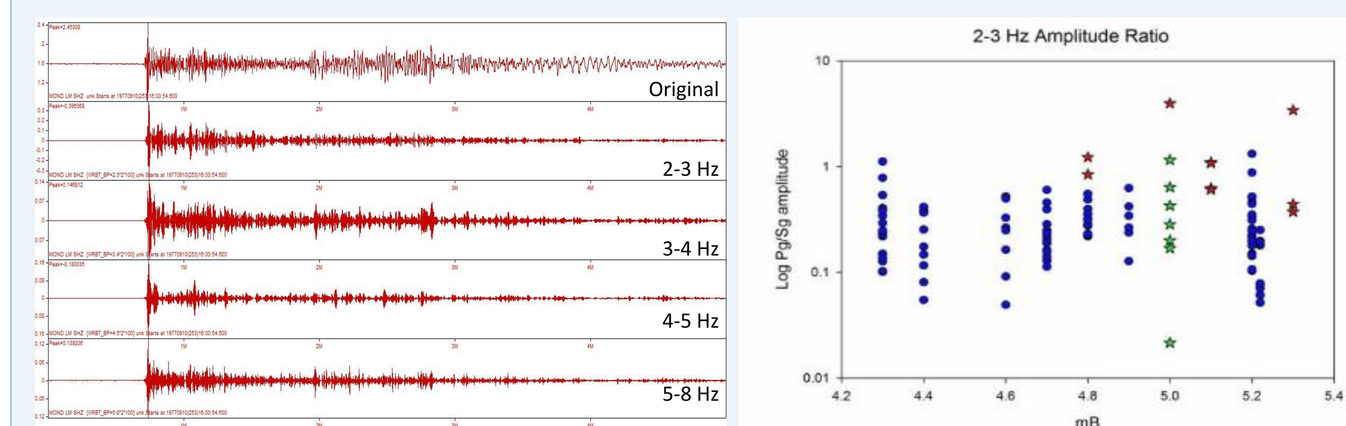

Figure 9. Filtered nuclear explosion (left) and a comparison of nuclear explosion and earthquake amplitude ratios (right). Circles are earthquakes and stars are nuclear explosions. PNE Meteorite 5 (green stars) appears earthquake-like appearance with low Pg/Sg ratios, and plots well within the earthquake distinction. All points are station ratios, not event averages. Data are not distance corrected.

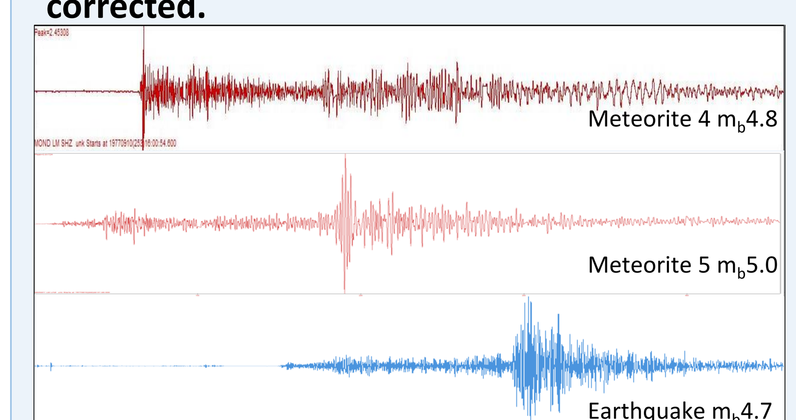

Figure 10. Digitized PNE seismograms (red) compared with a digital earthquake seismogram (blue) in the Baikal area. Meteorite 4 (top) is a typical PNE with large Pn and small Lg. Meteorite 5 (middle) however is earthquake-like with a large Lg and small P phase.

Other Digitization Methods

Digitizing with WaveTrack is time consuming. The search for an automated digitization program that produces the caliber of a hand digitized seismogram is still ongoing. Existing digitization programs all have difficulties. For example, Harvard's Digitseis is a semi-automatic digitization software package for analog seismic records. In our records, there are physical data breaks where no data collection occurs for a few seconds, however Digitiseis cannot accommodate this, resulting in an error within the program.

Conclusions

- Analog seismic records can be recovered digitally by hand digitizing each waveform. This allows modern processing techniques to be applied and enhance seismic studies.
- Reproduction of response and phase curves can be generated with station parameters from annual station booklets.

Collaborations continue between MSU and Institute of the Earth's Crust to further PNE analysis and digitization. Please visit the Dobrynina et al. poster presentation T1.2-P123 to see continued seismic analysis using PNE seismograms.

Acknowledgements

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PUTTING AN END TO NUCLEAR EXPLOSIONS