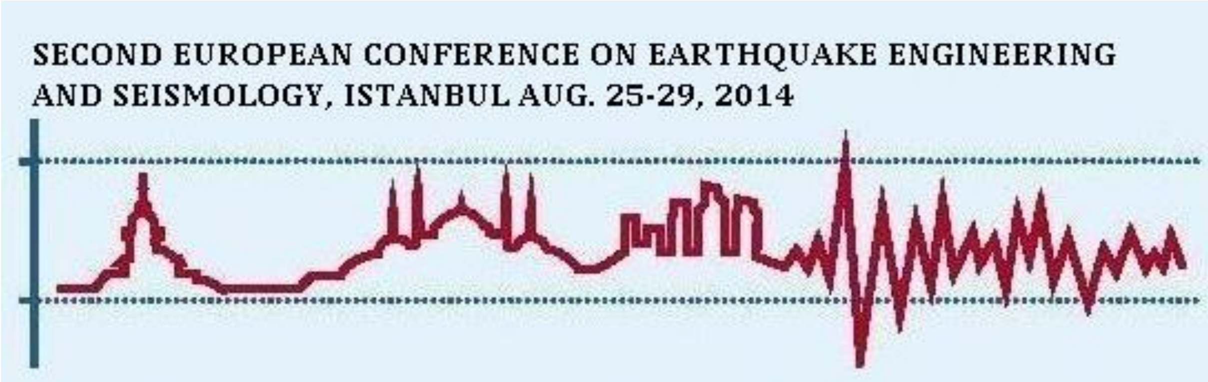

THE ALTERNATIVE APPROACH FOR SEISMIC MONITORING DATA IDENTIFICATION EXCLUDING "MASTER" EVENTS

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ABSTRACT

The problem of monitoring of different types of seismic events is one of the key in the modern ecology. The peculiarity of this kind of monitoring is that it is mobile seismic groups, which should be based in the proposed area of occurrence of events.

Using a new approach (not by location) by classification and subsequent exclusion of "master" events from all datasets will be discussed. Seismic events database and identification criteria creation for the East-European Platform (EEP) have the great importance and are innovative ones. It will be demonstrated usability of this algorithm by MSA "Mikhnevo" seismic monitoring data which based on quantitative parameters of signal, which accelerates target search.

INTRODUCTION

The main task of this work is to create an algorithm that based on a database of typical waveforms which would allow quick processing and identification of the events, recorded by the small-aperture seismic antenna MSA "Mikhnevo". MSA "Mikhnevo" established for the purpose of seismic monitoring in the central part of the East European Platform (EEP) in 2004, 80 km south from Moscow [Sanina et al., 2008, 2009; Sanina et al., 2011] (Fig. 1). A similar antenna achieves the task of identifying weak events with magnitudes of 3.5 and lower. An MSA advantage is the ability to reduce the noise influence and accordingly increases the amplitude of the useful signal. All registration points are equipped with sensors type SM3-KV with a sampling rate 200 Hz. The signals are transmitted by wire to a single point of registration. Converting signals are 24-bit ADC.

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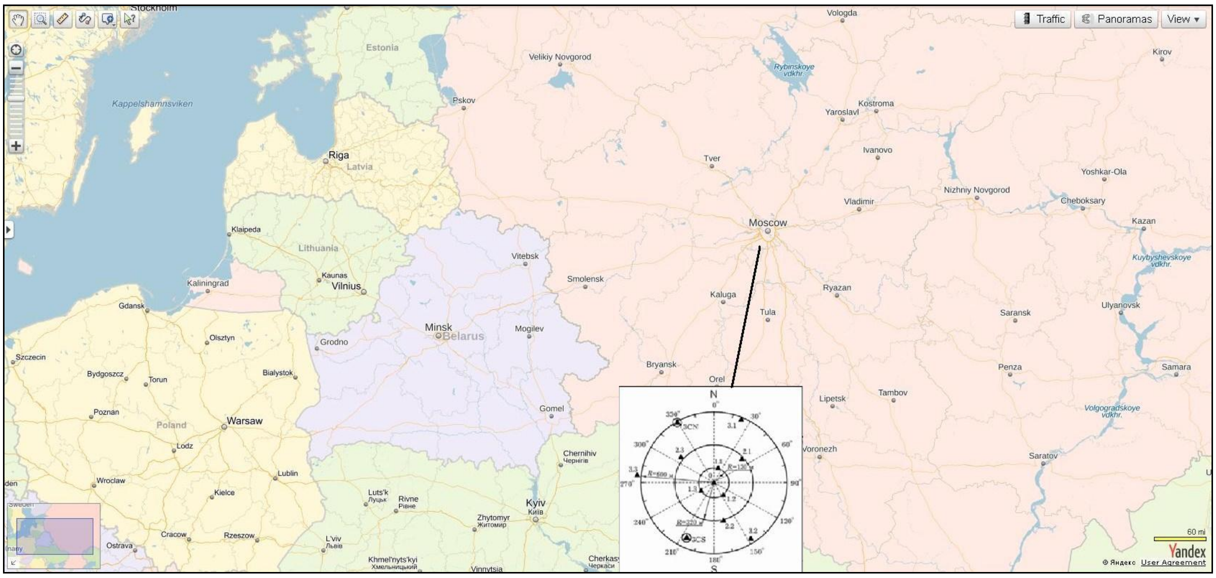

Figure. 1. MSA “Mikhnevo” location and arrangement

The territory of the Central Region of the European part of Russia lies entirely on the East European platform. For decades, major seismic stations that monitor in the Central region of Russia were seismic station "Moscow" and "Obninsk", recorded generally earthquakes at regional and teleseismic distances. Working in this region MSA "Mikhnevo" together with mobile seismic complexes of Institute of Geosphere Dynamics was aimed to solving local problems of seismic and environmental safety of quarry blasts. The results of these observations were published in several papers [Adushkin, 1996; Spivak et al., 1998; Adushkin et al, 2000; Kishkina et al., 2002] and have been used in the development of seismic safety requirements during mass explosions in quarries.

Annually MSA "Mikhnevo" record more than 600 quarry blasts, and the number of registered events manmade growing. Partly, this fact is connected with the increase of economic development speed on EEP territory. MSA "Mikhnevo" is also capable detect signals from other different types of sources.

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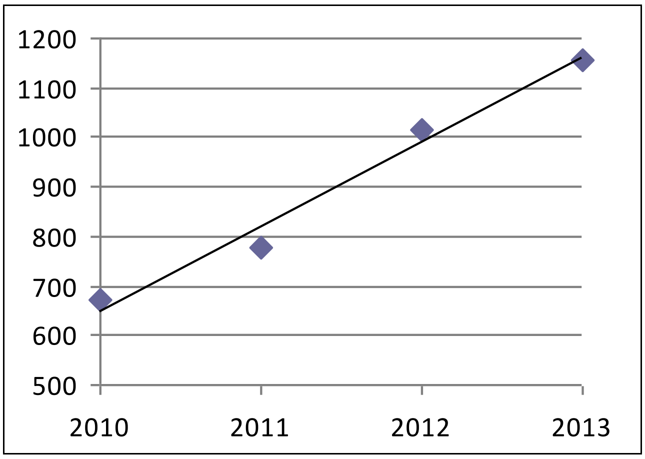


Figure. 2. Number of registered quarry blasts at MSA "Mikhnevo" from 2010 to 2013 year

Based on previous experience it is known that there are several classes of events: an earthquake, quarry blast, man-made clutter (pump operation, the machine running, etc.) and the unknown pulse. Data review also allowed to observe the different seismic events: for example, landslides and rock bursts. Due to the fact that all recorded man-made explosions only about 50 quarries’ locations are confidently identified and don’t change year in year out, it was decided to create 50 classes. Each class contains a set of "master" events in accordance with the geographic coordinates of the seismic source. This allows operating initial information about the source intensity and time in the source.

It is necessary to select signals from a variety of sources on the continuous array of recorded data and as a result to introduce bulletin of recorded events. Consider the example of the events selection algorithm using typical waveforms for known quarries explosions. The main procedures in the algorithm are:

- Preparing the database "master" events
- Frequency filtering
- STA / LTA detector
- F-K analysis and "beamforming"
- Cross-correlation for the source geographical coordinates determining

PREPARING THE DATABASE "MASTER" EVENTS

Annual catalog, generated by MSA "Mikhnevo", mostly consists of the marks as class "quarry explosion" in the frequency band 0.5-15 Hz. At first we should select the most typical waveforms for explosions at every career - the creation of a database "master" events.

"Master" – is a 1-minute recording of actual data (120 000 samples), which includes the yet known recorded useful signal on a definite day and time, which is taken as a reference, and can could be an etalon for comparison later. It contains the same number of channels as the real data, and subjected to filtering by channel within the ranges. "Master" is a matrix of size m × n, where m - the number of columns consisting of one record per channel unfiltered and filtered seven (i.e.m = 16 × 7 = 112 columns), n - number of samples (1 minute ÷ 0,005 (second per count) = 12000 counts). Of importance, the "master" will be universal for any day. Such "masters" should be several in a single class, because bursts, produced at the same quarry, can have differences in the waveforms. Initially, during the preparation of "master" events it was taken 10 minute interval. An advantage of 10 minute interval is that after filtering it can be avoided "artifacts" on the ends of the segment. Another advantage is that the known signal is in the middle of the segment, and therefore the processing of the standard algorithm STA / LTA (where STA - short time average for the first 5 seconds, and the LTA – long time average for the first 20 seconds), the signal cannot be omitted from for zero-start recording. Then from the middle of the 10-minute interval, filtered in several bands, we cut one-minute matrix containing all the necessary information for the algorithm.

To simplify working with the archive, it was decided to create a folder «Master» with subfolders from "01" to "50" (Fig. 4 a) in accordance with the classes.

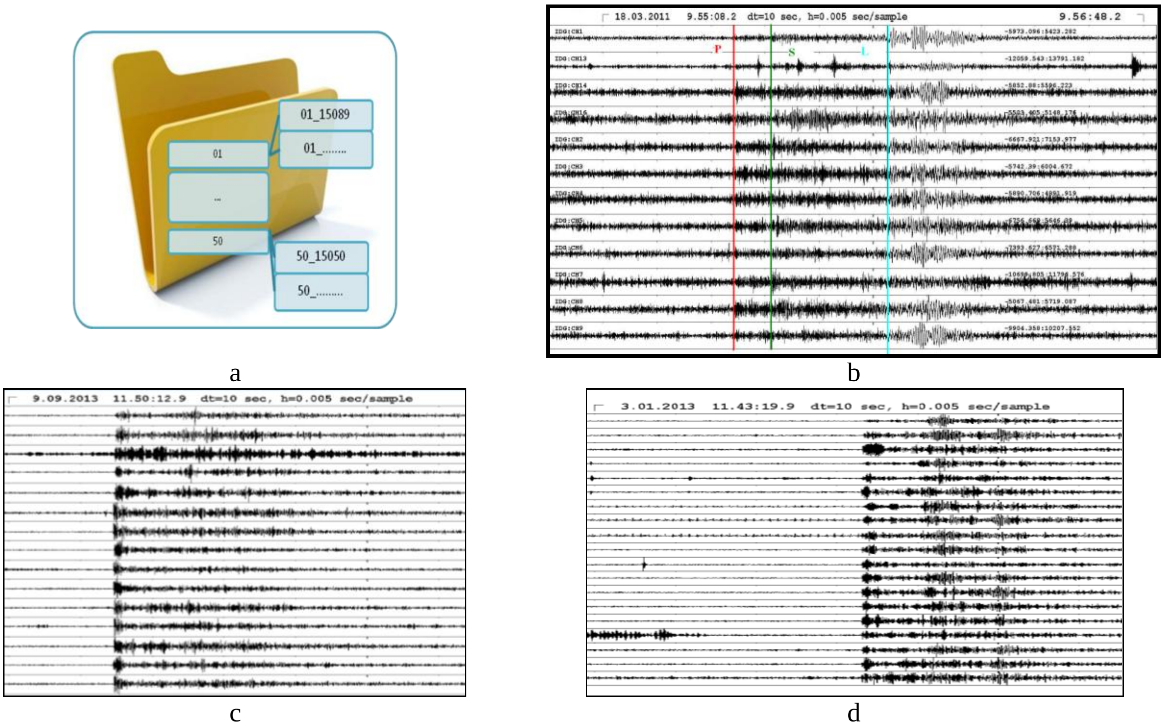


Figure. 3. a - Schematic representation of the folder «Master», containing subfolders by class of "01" to "50», b - Typical filtered signal from quarry blast in Kovrov 18.03.2011 (0,5-15 Hz), 09:55 UTC (lines mean picked waves onsets: red - P, green - S, blue - surface L); c – Typical filtered signal from quarry blast in “Demidovsky” 09.09.2013 (0,5-15 Hz), 11:50 UTC; d - Typical filtered signal from quarry blast in “Novogurovsky” 03.01.2013 (0,5-15 Hz), 11:43 UTC

The reason for using the "master" of the events as a tool for searching similar repetitive events, so-called "twins", closely related to the idea that the signals coming from one of the epicentral area are related to the same point of excitation and come from one and the same type of source. This idea is reflected in the work «Twin Earthquakes» by Charles Davison (The Journal of Geology Vol. 35, No. 6 (Aug. - Sep., 1927), pp. 507-526 Published by: The University of Chicago Press).

FREQUENCY FILTERING OF THE SEISMIC MONITORING MSA "MIKHNEVO"

To the data for each channel it should be applied Butterworth filter 3rd order in different frequency bands (Hz): 0.5-2; 1-5; 4-8, 6-10; 9-12; 10-16; 12-20 (Fig. 2). Bandwidth must overlap each other to avoid loss of the desired signal at the ends of filtration segment.

The amplitude-frequency characteristic $G(\omega)$ of the Butterworth filter of n^{th} order can be obtained from the transfer function $H(s)$ in formula (1):

$$G^2(\omega)=|H(j\omega)|^2=G_0^2/(1+(\omega/\omega_c))^{2n}, \qquad (1)$$

where n – is the order of the filter, ω_c - the cutoff frequency (the frequency at which the amplitude is 3 dB), G_0 - gain constant component (gain at zero frequency).

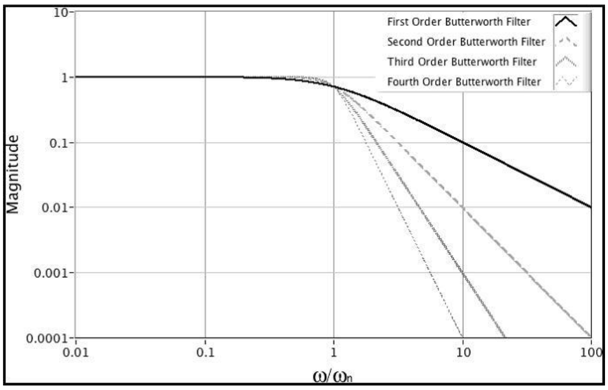
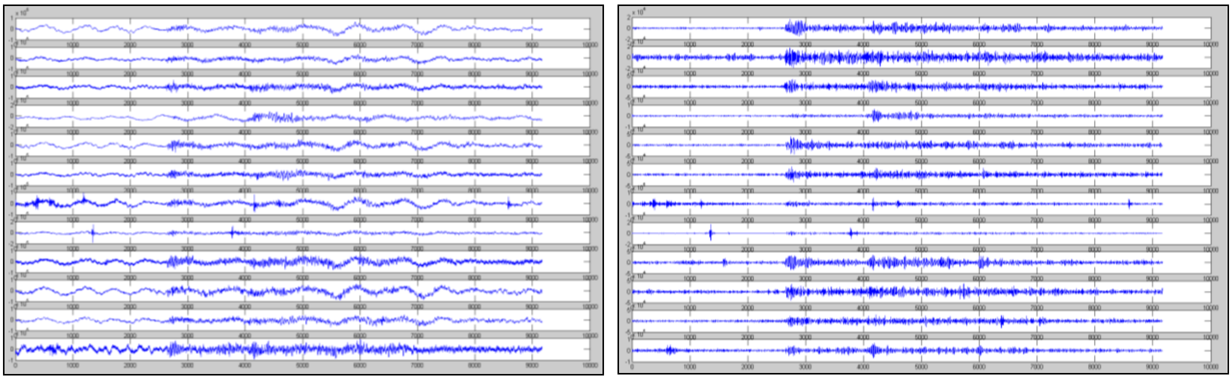


Figure. 4. Butterworth filter 3rd order [ipso.usu.edu]



a b

Figure. 5. Filtration work result: raw data from 12 channels "Novogurovsky" master (a) and filtered 0.5-2.0 Hz (b)

STA / LTA DETECTOR

Firstly the standard algorithm *STA / LTA* is applied separately to each channel for automatic signal detection (Fig. 6). Presence of a signal is characterized by excess of the threshold of 3.5, so characteristic of excess noise. SNR (signal to noise ratio) is calculated as the ratio of accumulated "energy" stored in a short window to that in a long (*STA / LTA*). Results of this detector is shown on the figure 6.

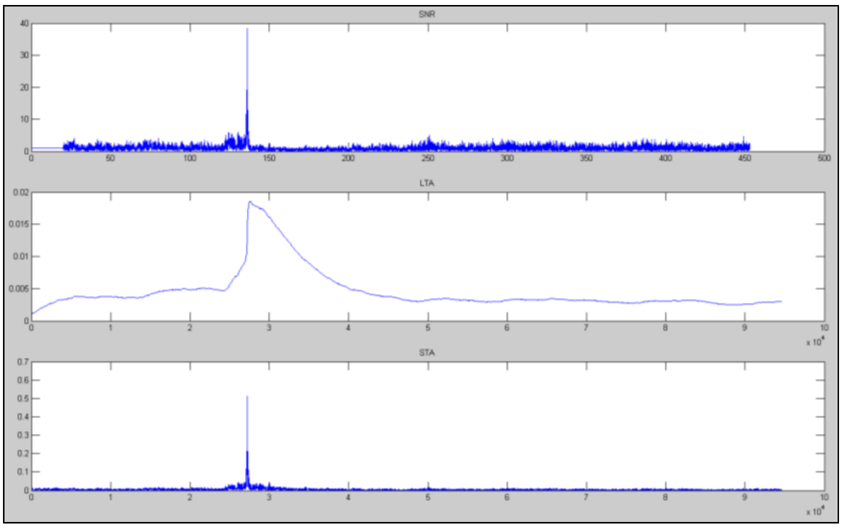


Figure. 6. *SNR*, *LTA*, *STA* sums for "Novogurovsky" master and raw data 18.09.2013

_F-K_ ANALYSIS AND "BEAMFORMING"

F-K analysis – is a method for calculating the energy distributed between different areas and slowness (Fig. 7). This method uses the summation of the signal tracks recorded seismic data, recorded by components of the seismic group subject to the time delay, depending on the *U* - the waveform, *A* – azimuth, and the signal receiver location. The method target is to bring all signals to the same phase and receiving the maximum amplitude of the summarized signal for estimating slowness and direction for seismic waves arrival in the 10 seconds window. Since originally the parameters *A* and *U* are unknown, there it is performed meshing in an area to estimate the total signal power at each point of the plane.

Signal received at the base point seismic array with horizontal velocity V_s and the direction *A*, denoted as $S(t)$. Signal $X_n(t)$, recorded by n[th] seismometer with the vector location R_n is calculated by the formula (2):

$$X_n(t)=S(t-U_0 * R_n), \qquad (2)$$

$$\text{where } U_0=(\cos(A),\cos(A))/V_s \qquad (3).$$

The total output signal is calculated by the formula (4):

$$Y(t)=(1/N)\sum_{n=1}^{N} X_n(t+U_0 * R_n), \qquad (4)$$

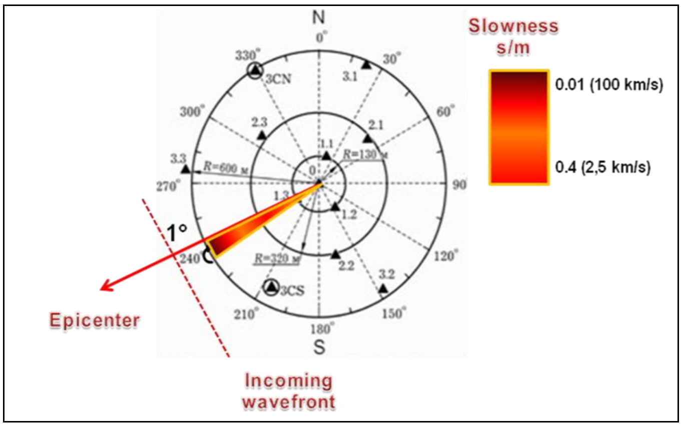


Figure. 7. Configuring MSA "Mikhnevo" and calculated parameters in the "cells" in the subject of wave propagation from the source (partition of the plane comes in increments of 1 ° for the last round of sensors)

In other words, the signal at each of the sensors will increase to a wavefront arriving from the same direction at a certain velocity of propagation. In accordance with the slowness and time of wave arrival it can be calculated - origin time, the distance between the source and the record point MSA "Mikhnevo", azimuth and spatial coordinates. After analyzing the interpreter can also add extra information. New "summarized" data channel created by processing *F-K* analysis, called "beam". Results of calculation are recorded in a particular file.

CROSS-CORRELATION TO DETERMINE THE GEOGRAPHICAL COORDINATES HEARTH

An automatic processing by cross-correlation is proved to be an effective algorithm for signal identification. This algorithm is very modern, and was first used by Gibbons and Ringdal (2006), Schaff & Richards (2011), Bobrov and Kitov (2011), Bobrov and Kitov, 2011; Bobrov and Kitov and Zerbo (2012); Bobrov et al., (2012). Thus, the true signal, encoded on the record, will correlate only with the "master" event with which they share common source type and location.

For cross-correlation coefficient we use the following formula (5):

$$CC(t)=\frac{<\upsilon(t+t_0),\omega(t_0)>_{N,\Delta t}}{\sqrt{<\upsilon(t+t_0),\upsilon(t+t_0)>_{N,\Delta t}<\omega(t_0),\omega(t_0)>_{N,\Delta t}}}, \qquad (5)$$

Where $\upsilon(t+t_0)$ - waveform data source, $<\omega(t_0), \omega(t_0)>_{N,\Delta t}$ - the waveform of the "master" of the event. A vector $CC(t)$ will be called "summarized track" because it is the track calculated by summation all channels.

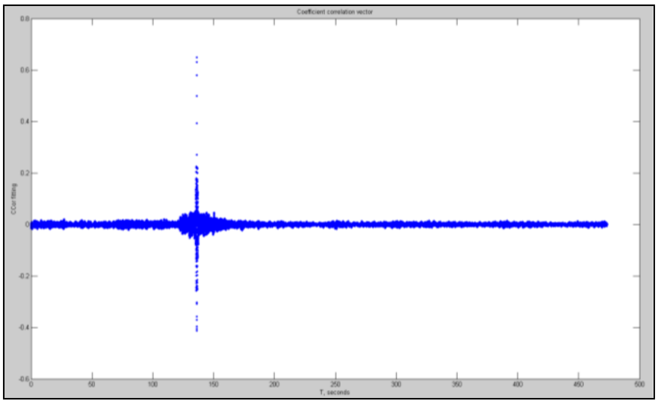


Figure. 8. A cross correlation vector for “Novogurovsky” master and raw data 18.09.2013

We will observe a peak with maximum amplitude only in the case of a wave arrival from the same source as that of the "master" of the event. Obviously, the correlation coefficient (*CC*) between noise and any known event gives a value near zero. For this reason, we consider only the values $|CC|>0.20$.

Thus, if the unknown event "coincides" with one of the known types of events recorded in the "master", it immediately occurs into the event catalog – a bulletin, and discarded from further analysis. If it does not look like any "master" event, it will be assigned to class "unknown event" and is subject to deeper analysis - standard procedure locations, i.e. determining the direction and distance to the source. Notably we conduct *F-K* analysis again. As a result, the operator-analyst will decide on the nature of seismic events in the source. The scheme of the decision rule is given below.

ACKNOWLEDGEMENTS

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CONCLUSIONS

A rapid and effective algorithm for processing of passive seismic monitoring data on small-aperture antenna "Mikhnevo" on the basis of cross-correlation, which allows more than one order reduce the magnitude threshold of registered events.

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