Local seismic events in area of Poland based on data from PASSEQ 2006-2008 experiment

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METHOD I: STA / LTA & grid search approach

Detection of seismic signals

A detection goal was to analyze continues time series (seismic record) and provide list of moments where possible signal (seismic wave) was recorded. Main python function was prepared to return a list of signal detections for a given file name (already prepared one-hour, one station, one component miniseed file).

The analysis is done in three steps: data loading, filtration and detection of signal. Data was filtered with zero-phase bandpass Butterworth filter (from 4.0Hz to 9.5Hz). After filtration mean value of trace was removed and amplitude has been normalized to constant value (the same value for all stations). An example of filtration of broadband trace is shown in Figure 2. A detector has to adapt to current conditions (eg. noise level). The simplest way to create such a detector is calculating two moving averages over signal with different windows: short and long. Most of seismic detectors use relation between short term average (STA) and long term average (LTA).

In this paper Carl Johnson's STA/LTA detection algorithm was used. This algorithm calculates four moving averages and takes two parameters:

$$\mathbf{eta} = \mathbf{star} - (\mathit{ratio} * \mathbf{ltar}) - \mathrm{abs}(\mathbf{sta} - \mathbf{lta}) - \mathit{quiet} \qquad (1)$$

where: **eta** - detector response - value over 0 means detection, **sta** - short term moving average of signal, **lta** - long term moving average of signal, **star** - short term moving average of absolute value of signal and **lta** difference, **ltar** - long term moving average of **star**, *ratio* and *quiet* - sensitivity parameters.

Short term average had 4 seconds window and long term average had 32 seconds window. Both *ratio* and *quiet* parameters had value 2. Example result is shown in Figure 2.

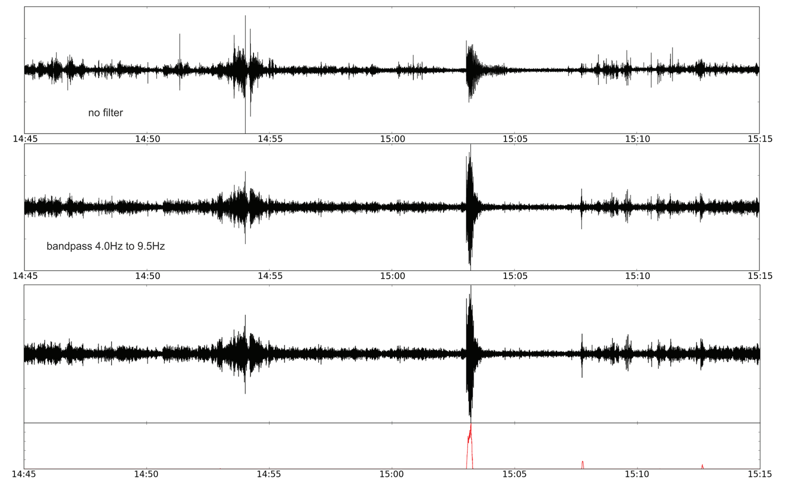

Fig. 2. Example of 30 minute recording with local event for station PA64. First trace shows unfiltered data, second trace shows filtered data (bandpass from 4.0Hz to 9.5Hz) and third shows filtered data with calculated Carl Johnson's STA/LTA detection.

Analysis of coinciding detections

A detector responses to seismic waves but also responses to noise. Additional analysis of detection signals is required to recognize local seismic events. Analysis were done one day at the time. A list of detections from all stations for that day was taken. For every grid cell (0.05 by 0.05 arc degrees) number of operating stations in 150 km radius was calculated. If there was at least 15 working stations traveltime between analyzed grid cell and all stations in radius was calculated using 1-D reference iasp91 model [Kennett and Engdahl, 1991] (Figure 3.4). All detections were moved back in time by calculated traveltime (different times for different stations!). Then a number of stations in radius with detection signals for every second of analyzed day was calculated. Detections were considered with 3 second tolerance. When number of stations giving detection exceeded 50% of total stations in radius event was noted. Examples of grid search result are shown on figures 4 and 5 - for previously known and new local event. Event localization was calculated as an weighted average of grid search results. Figure 3 shows accuracy of event localization calculated for previously known events.

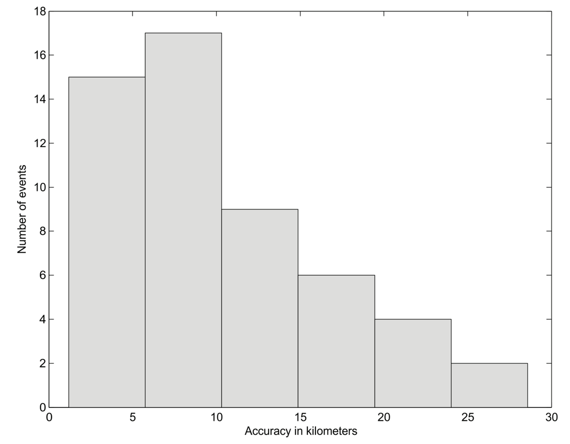

Fig. 3. Histogram of event location accuracy (difference between bulletin and grid search location). Total of 53 Lubin events were analyzed from August 1st 2006 to October 31st 2006.

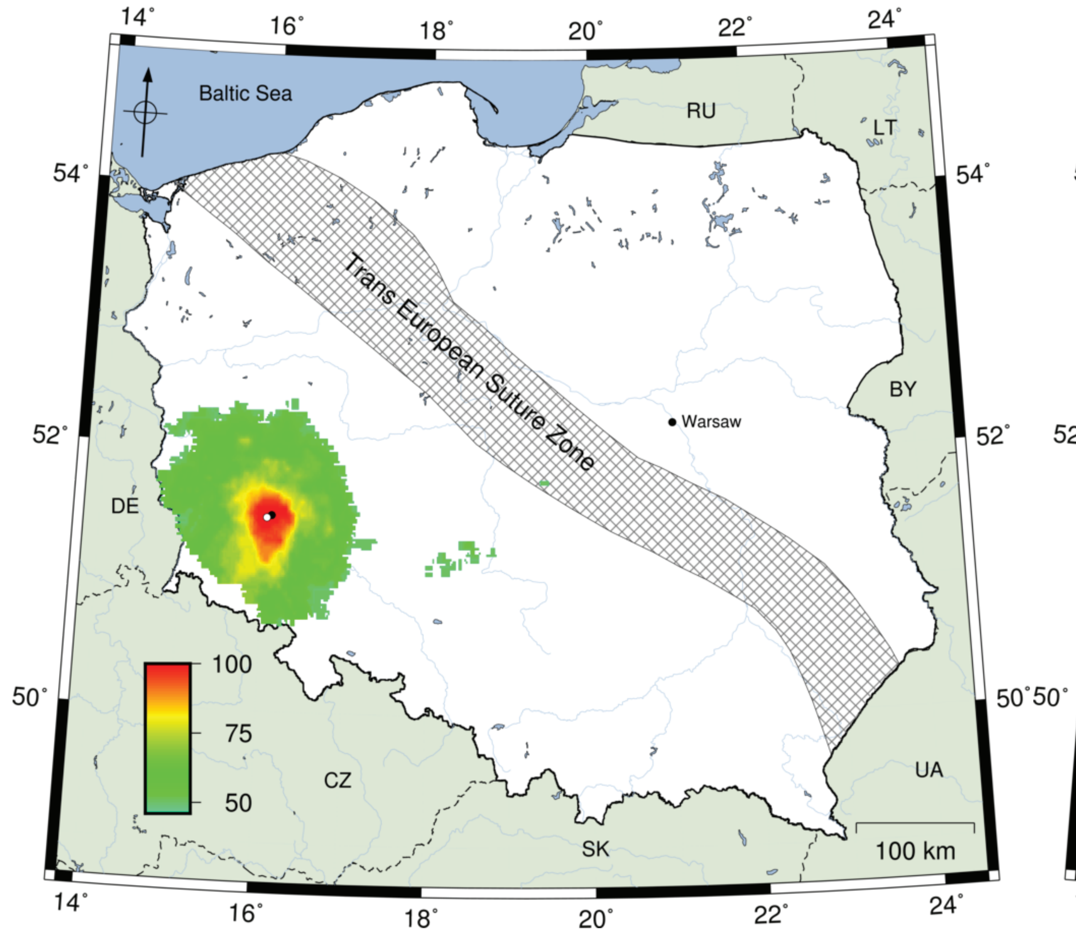

Fig. 4. Grid search example: a probability map of the grid search for analyzed M3.5 event from Lubin. Color represents percent of stations in 150 km radius that recorded signal at the same time. Black dot shows event epicenter from Local Bulletin (IGF P.A.S.) and white dot shows calculated epicenter.

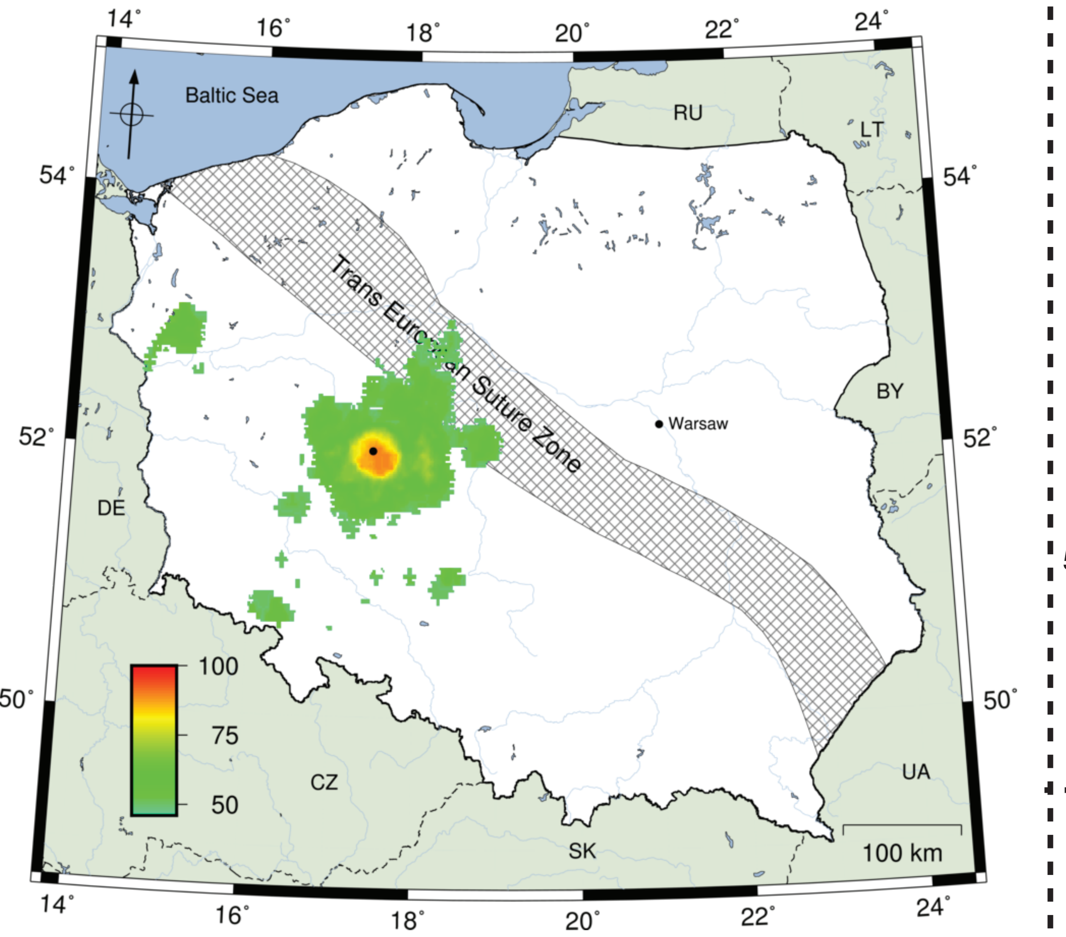

Fig. 5. A grid probability map of Jarocin event, May 6th, 2007. Black dot shows calculated coordinates of epicenter.

Abstract

PASSEQ (Passive Seismic Experiment in the Trans - European Suture Zone) international passive seismic experiment was conducted in the years 2006 - 2008. 17 scientific institutions from 10 countries participated in the project. The main objective of the project was to identify the deep structure of the lithosphere in the Trans-European Suture Zone (TESZ) and gain knowledge of tectonic processes taking place in Central Europe. Trans-European Suture Zone is a contact zone of eastern and western Europe. The eastern boundary of the TESZ is Teisseyre'a – Tornquist Zone (TTZ), which delimits the two tectonic units: East European Platform and Paleozoic Platform of Western and Central Europe. The purpose of the seismic experiment PASSEQ 2006-2008 was to determine the construction of the earth's crust and upper mantle in the TTZ. Moreover there was made diagnosis of seismic records from stations PASSEQ to identify the local seismicity in the area covered by the project. PASSEQ covered a strip of about 400 km wide and 1200 km long, starting in Germany through the Czech Republic, Poland until Lithuania. Project used 196 recording equipment in combination with 147 short-period and 49 broadband seismometers. Seismic data sampling frequency varied and was 20, 50, 100 and 125 Hz. Stations were installed on predetermined seismic profiles. The distance between the stations was usually about 60 km, while on the central profile longest distance between stations was approximately 20 km. The seismic network included the national seismological observatories: Polish, German, Czech, Slovak, Lithuanian and Belarusian. Local seismic analysis was performed simultaneously using two methods STA/LTA trigger with grid search and Recurrent Neural Network (analysis of 3 components). The study focused on Polish territory, with stations located within its borders and a few from the area of Lithuania to better determine the analysis area of the Gulf of Gdansk and southern Baltic Sea.

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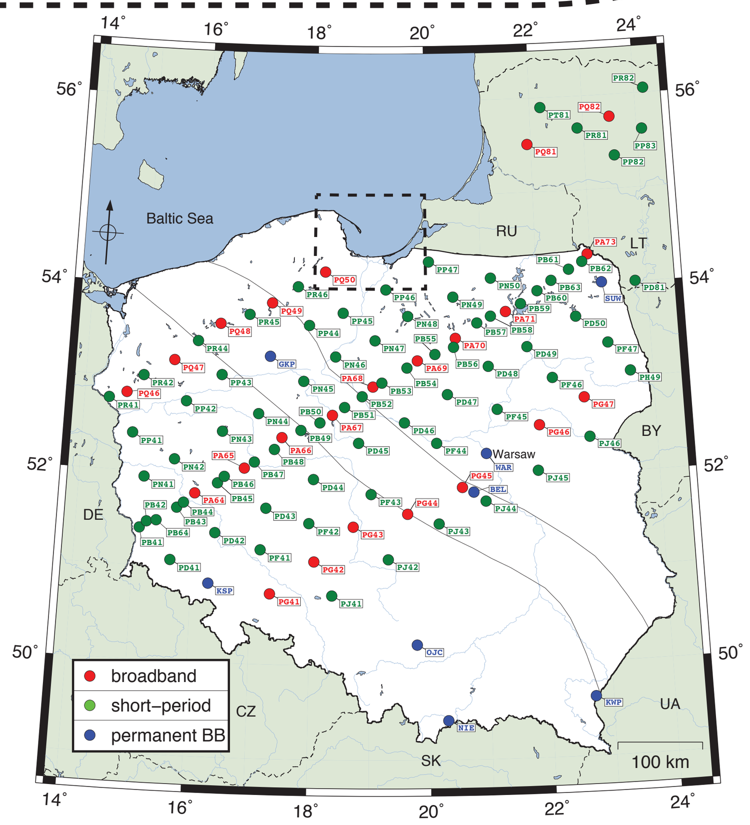

Fig. 1 PASSEQ seismic stations from which data were analyzed in terms of local seismicity in area of Poland.

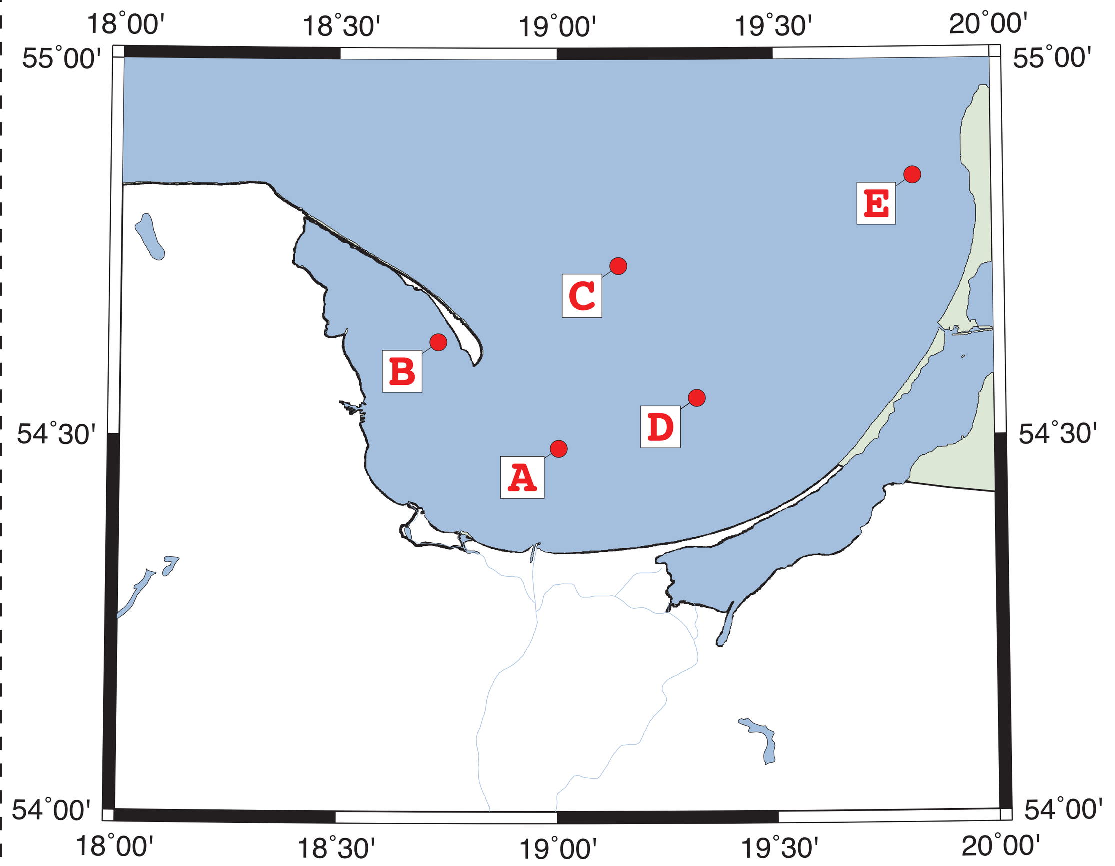

Fig. 11 Map of localization of local events form southern Baltic Sea. Area shown on this map is noted on Fig. 1 by thick dashed line.

Results

Local seismic events were studied using two different approaches. STA/LTA detected four events while Neural Network detected six events. Four events were detected by both methods with similar estimation of origin time and localization. Table 1 summarizes detected events for both methods. Detected events are shown on maps on Fig. 5 (event F, black dot) and Fig. 11.

Event	*STA/LTA method*	*Neural Network method*
A M_L=2.3		2007-06-14 00:10:10 UTC 54.48°N, 18.99°E, Z=10KM
B M_L=3.0	2007-03-20 23:08:51 UTC 54.60°N, 18.75°E	2007-03-20 23:08:51 UTC 54.62°N, 18.73°E, Z=4km
C M_L=3.2	2007-05-02 07:08:23 UTC 54.69°N, 19.17°E	2007-05-02 07:08:23 UTC 54.72°N, 19.14°E, Z=10km
D M_L=??	2006-09-12 15:12:14 UTC 54.55°N, 19.32°E	2006-09-12 15:12:14 UTC no location
E M_L=2.6		2007-05-22 16:29:30 UTC 54.85°N, 19.82°E, Z=12km
F M_L=2.8	2007-05-06 07:32:30 UTC 52.02°N, 17.48°E	2007-05-06 07:32:31 UTC 52.01°N, 17.50°E, Z=4km

Tab. 1 Details of 6 local events detected using both methods. Events A-E are shown on map on Fig. 11. Event F was located in Central Poland and its localization is shown on map on Fig. 5 (black dot).

References & acknowledgments

ObsPy A Python Framework for Seismology

python

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METHOD II: 3D RTRN DETECTION

The structure of the Real Time Recurrent Network (RTRN) applied for seismic detection

Structure of the RTRN and learning method was developed by Wiliams and Zipser (1989) and then applied for seismic event detection by Wiszniowski et. al (2014) for detection of small natural with magnitude 0.4 to 2.5 in mountains south Poland. This is the simplest recurrent artificial neural network that operates in discrete time. Output signals from the neurons in the network are fed to the input with a one step delay. The i th artificial neuron (Fig. 6) at a moment t has an output value

$$V_i(t) = g\left(\sum_{j=0}^{n-1} w_{ij} v_j(t)\right) \qquad (2)$$

where w_{ij} are weight coefficients between inputs and the output of the neuron, $v_j(t)$ are input values:

$$V_j(t) = \begin{cases} V_j(t-1) & j = 0,\ldots,n_r-1 & \text{recurrent neurons} \\ x_i(t) & j = n_r+1,\ldots,n-1 & \text{inputs of RTRN} \\ 1 & j = n_r & \text{constant value 1} \end{cases} \qquad (3)$$

$V_j(t)$ is an output value and g(.) is an activation function, or a transfer function, n_r is the number of recurrent neurons.

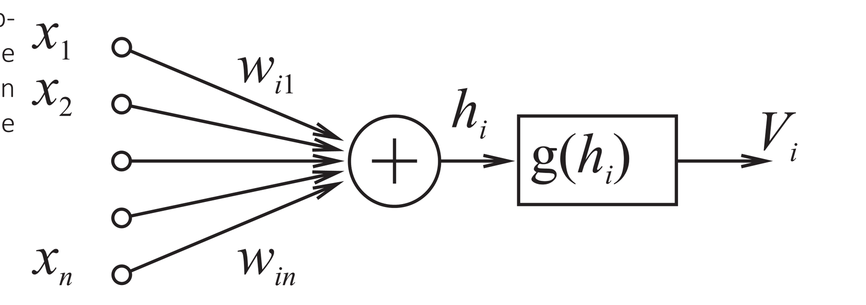


Fig. 6. Single neuron composed of: n inputs, from v_1 to v_n, weight coefficients from w_{i1} to w_{in}, adder with output $h_i = \Sigma w_{ij} v_j$, activation function g(.) and output $V_i = g(h_i)$.

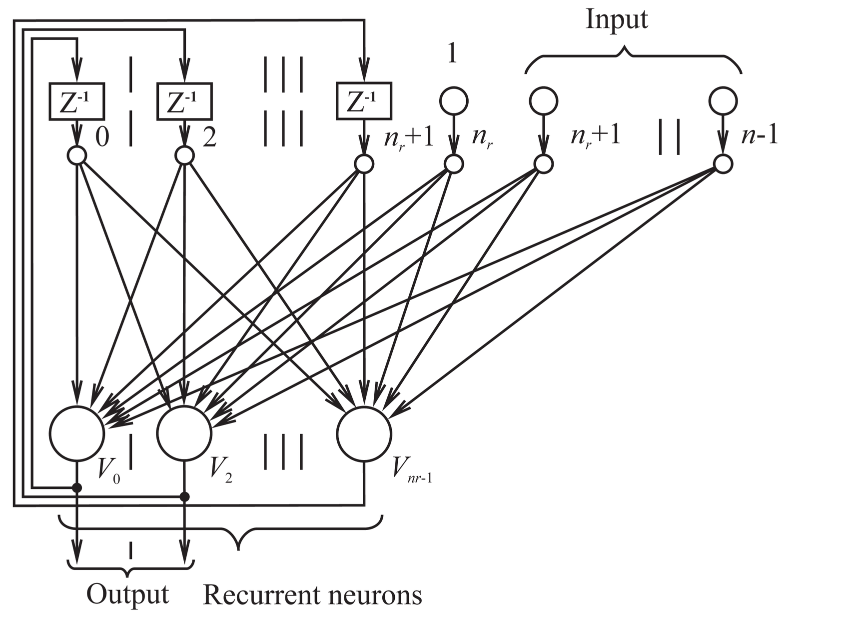


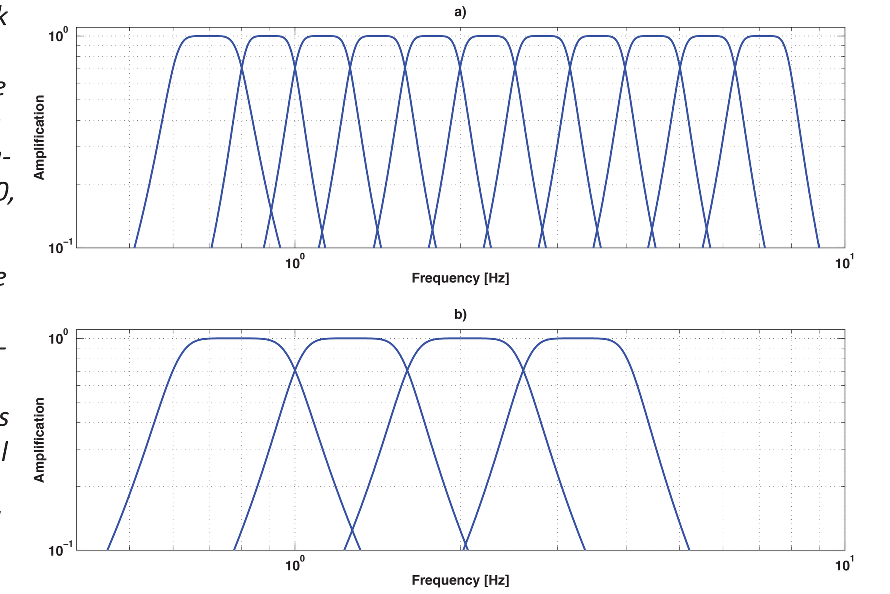
Fig. 7. Model of the RTRN network applied to the detection of small natural earthquakes in Poland. It contains nr recurrent neurons. Outputs of neurons V_0, V_1 and V_2 are outputs of the network. They corresponded to: detection of event (V_0), detection of phase P (V_1) onset and detection of phase S (V_2) onset. Inputs from n_r+1 to n-1 are inputs of the network, whereas input n_r has a constant value 1. [Z^{-1}] is a delay element with delay 1. The RTRN used for detection in PASSEQ consisted of 26 inputs and 16 recurrent neurons

Analyze data from PASSEQ experiment

Seismic signal in the PASSEQ was sampled 100, 50 and 20 sps. Therefore frequency band of seismic signal had to be reduced to 8 Hz. It reduced the capability of events discrimination. Therefore the RTRN used for PASSEQ analyzed 3D data. Is consisted of 26 inputs and 16 recurrent neurons and some input were moved in time. Input for the network was a filter bank of ratios of the short and long term averages (STA/LTA) of both vertical and horizontal component of the seismic signal. Figure 8 presents the frequency response of the FB.

Fig. 8. (a) The filter bank of the vertical and horizontal input signals of the RTRN. The FB consisted of 11 1/3 Octave Band Filters with narrow frequencies 0.6, 0.8, 1.0, 1.2, 1.6, 2.0, 2.5, 3.2, 4.0, 5.0, 6.3, 8.0 Hz

(b) The filter bank of the time shifted vertical input signals of the RTRN. The FB consisted of 11 1/5 Decade Band Filters with narrow frequencies 0.5, 1.0, 1.6, 2.5, 4.0 Hz. Signal from this FB was 10 sec time shifted to apply S wave signal for P wave detection.



Example of training the RTRN - the expected output values

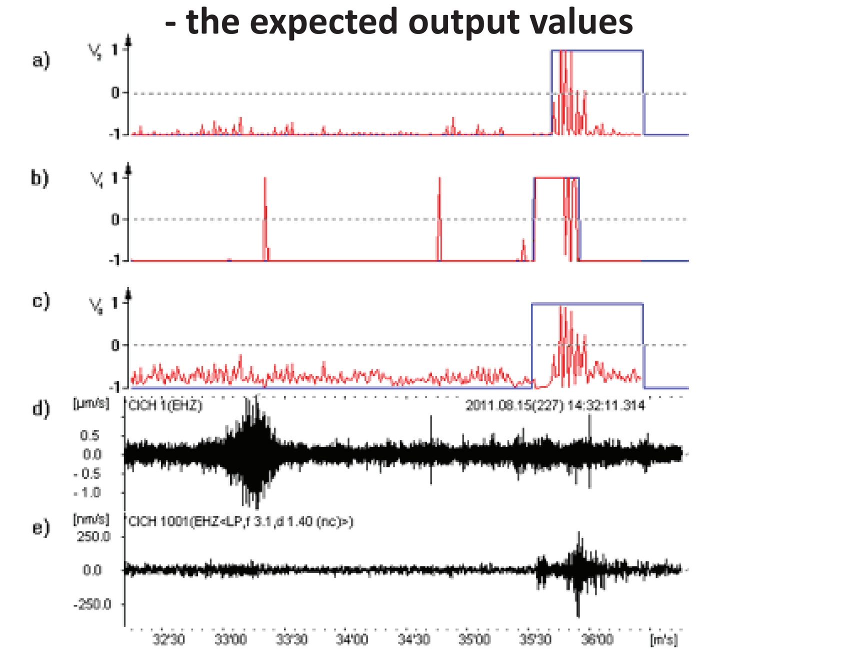


Fig. 10. Output signals of trained RTRN and corresponding seismic signals. Outputs are related to: (a) S wave, (b) P wave, (c) detection. Red lines are required outputs, whereas blue lines are real outputs. The Z component of short period seismic signal is presented as raw signal (d) and the filtered with 4 Hz low-pass filter signal (e).

Result of the RTRN detection of a local event from PASSEQ experiment

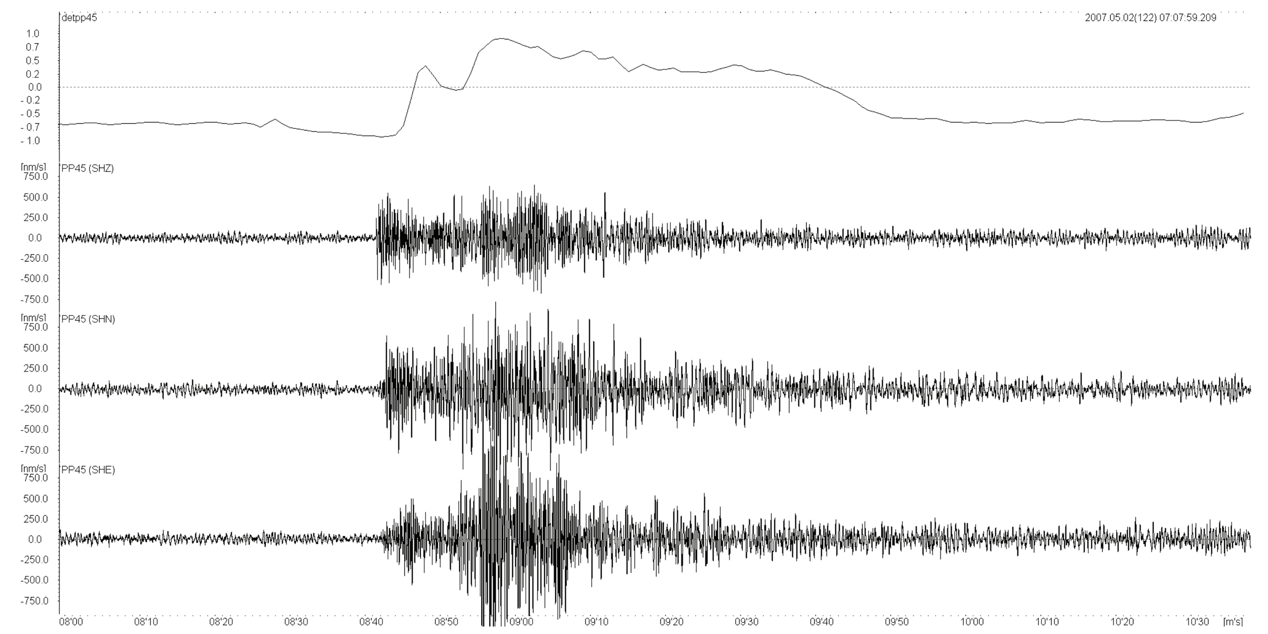


Fig. 9 Output of detection of the RTRN (detpp45) together with seismic signal of PASSEQ station PP45 for 2 nd May 2007 event. It is seen that both P and S waves are used for events detection.