



## KRYCÍ LIST – VÝSTUPY

<b>Název výstupu</b>	Upravený SW pro detekci a lokalizaci seismických jevů
<b>Výzkumný program</b>	VP2 - Indukovaná seismická a tektonická napětí
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# Upravený SW pro detekci a lokalizaci seismických jevů

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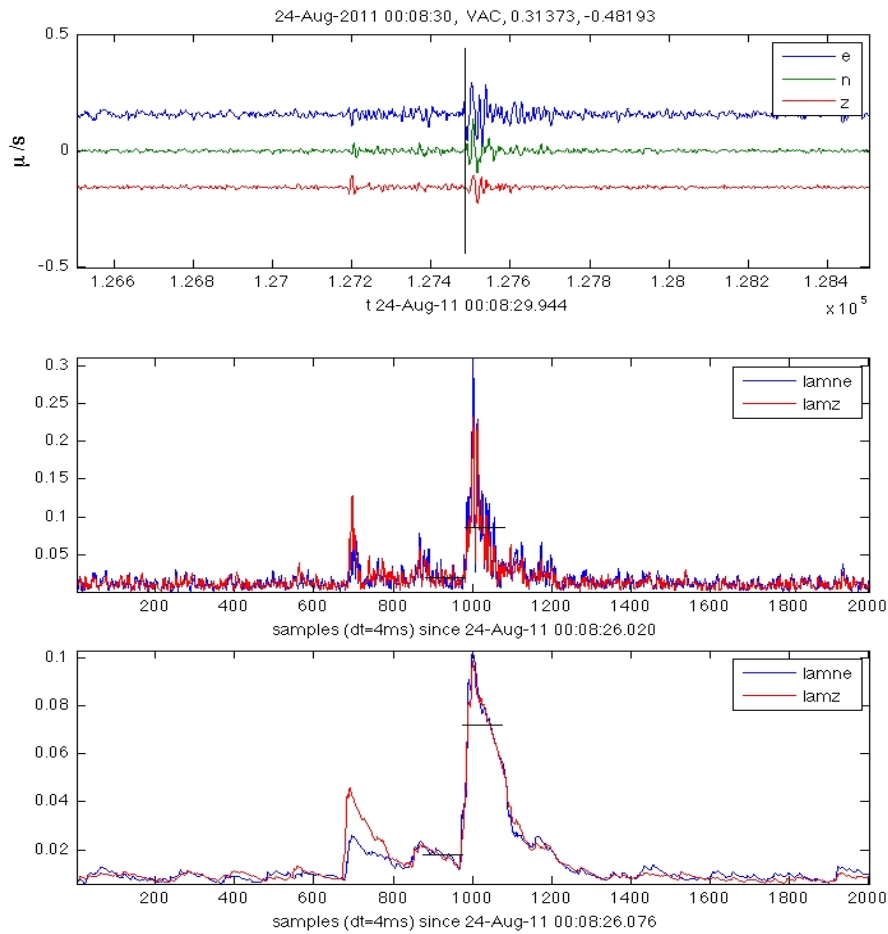
## Úvod

Za účelem rutinního automatického zpracování dat seismického monitorování na síti GRSN byl využit systém PEPIN (Polarization-based Earthquake Picker for Networks), který je po několik let úspěšně nasazen na seismické síti WEBNET v západních Čechách. Charakter seismické aktivity v oblasti těchto sítí se ale podstatně odlišuje. Zatímco západočeská oblast je seismicky nejaktivnějším územím Česka s množstvím malých přirozených zemětřesení, na Litoměřicku není dokumentována dosud žádná přirozená seismická aktivita. Tato zpráva popisující Výstup Upravený SW pro detekci a lokalizaci seismických jevů se tak nejprve zabývá popisem SW balíku Pepin v implementaci pro síť WEBNET a dále pak úpravami provedenými pro nasazení na síti GRSN.

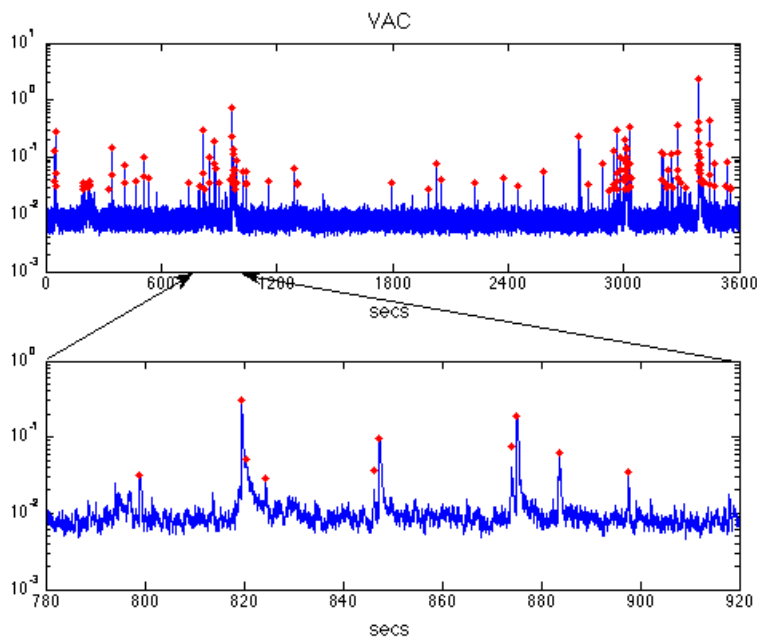
Pepin se, stejně jako většina automatických systémů pro zpracování dat seismického monitorování, skládá ze dvou modulů – pickeru pro odečet seismických fází a asociátoru seismických fází, který zároveň určuje odhad polohy hypocentra seismických jevů. Spolupráce těchto dvou modulů je v různých systémech řešena odlišně. Integrace asociátoru do pickeru umožňuje průběžnou kontrolu a případné vylepšení zjištěných časů příchodu s pomocí průběžné lokalizace nalezených jevů. Nevýhodou tohoto postupu, který byl implementován v předchůdcích systémech PEPIN (Fischer, 2003), je určitá neobjektivita měření časů příchodu, jejichž výběr může být ovlivněn průběžnou lokalizací. Pro potlačení tohoto efektu byl proto PEPIN navržen s oddělenými a nezávislými moduly pickeru a asociátoru. Picker je nastaven s vysokou citlivostí tak, aby poskytoval dostatečný výběr fází, z nichž si asociátor vybere vhodné kombinace fází.

## PEPIN Detector & Picker

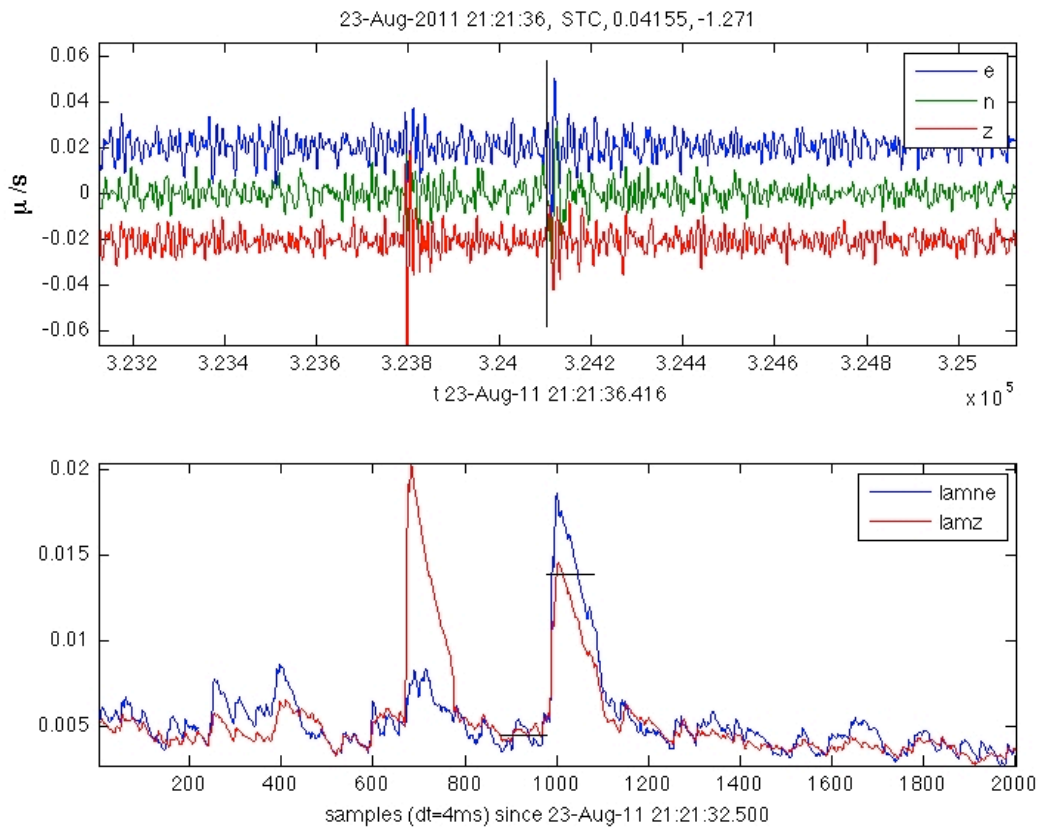
The task of detector is to identify seismic phases and determine their arrival time and amplitude. A characteristic function CF based on the polarization properties of the seismic waves which amplifies the signal correlated among components is used in the Pepin's detector. To this purpose the maximum eigenvalue of the signal covariance matrix of selected components is computed in a running window. The horizontal and vertical eigenvalue is obtained this way from which comparison the wave type (S or P) can be estimated. The implementation of the Pepin's detector employs the fact that local earthquakes have striking S-phase whose amplitude prevails the P-wave amplitude. Fig. 1 shows the three-component seismogram of small earthquake and the wave number series in the horizontal and vertical plane before and after low-pass filtering. For each local maximum of the wavenumber series (Fig. 2), its time and amplitude are recorded. After identifying the phases their onset is found using a modified STA/LTA algorithm in the window preceding the phase maximum. The procedure is illustrated in Fig. 3 showing the seismogram and wavenumber series of a very small earthquake. Based on empirical tests two succeeding intervals of similar length were found optimum for arrival time picking; the onset is identified at the maximum of the ratio of the ATA/BTA (After time average / Before time average) levels.



Obr. 1. Záznam slabého zemětřesení (nahore), maximální vlastní číslo v horizontální a vertikální rovině (uprostřed) a po nízkofrekvenční filtraci (dole). Za zmínku stojí nízká horizontální polarizace P vlny, ve srovnání s S vlnou.



Obr. 2. Časová řada maximálního vlastního čísla s vyznačenými lokálními maximy.



Obr. 3. Reading the S-phase onset; the horizontal bars show the BTA and ATA levels.

### PEPIN Associator and Locator

Phase association aims at choosing the suitable phase arrival times to a single event. This, apparently easy task for a human analyst, becomes a tricky problem for a computer algorithm. The point is that the criteria used by human analyst as the phase amplitudes, durations, waveform shape and periods are rather difficult to implement in the computer code. To overcome this drawback, Pepin associator employs various kinematic criteria related to the seismic network geometry to pick the correct phases and form a seismic event.

The associator works with phase times and amplitudes (Fig. 4) and finds the consistent combination of arrival times using the criterion of the maximum permitted time difference between S-phases at stations and the maximum event depth that constrains the maximum S-P time. All stations are of equal weight in this process. The following processing steps are worth mentioning

- Giving each phase the weight of being P or S phase based on the ratio of the horizontal and vertical polarization eigenvalues
- Phases of all stations are joined to a single series; events are defined as phase groups with time differences of consecutive S-phases lower than the maximum permitted S-time difference

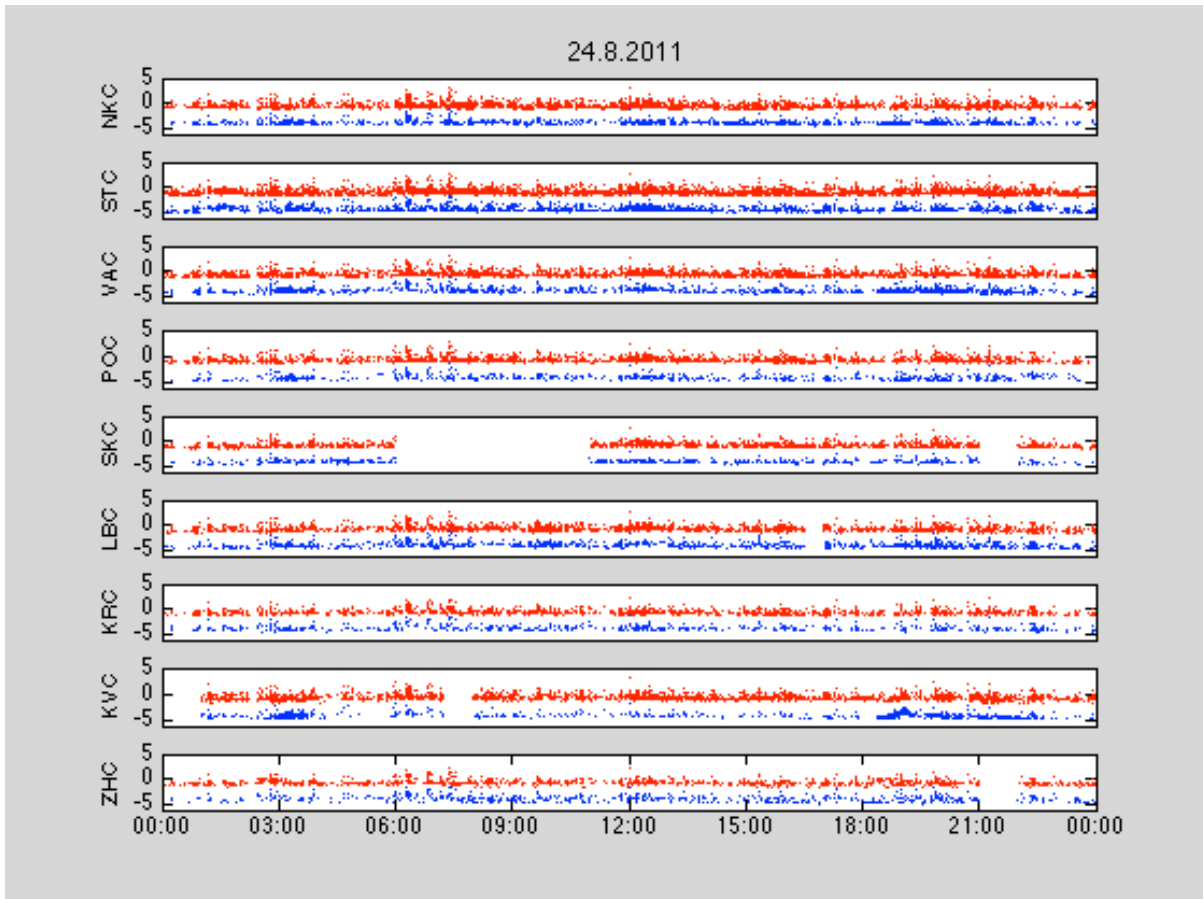


Fig. 4. P (blue) and S (red) detections for 24 hours during a seismic swarm at the WEBNET stations. P log amplitudes are shifted from S log amplitudes by -5 for clarity

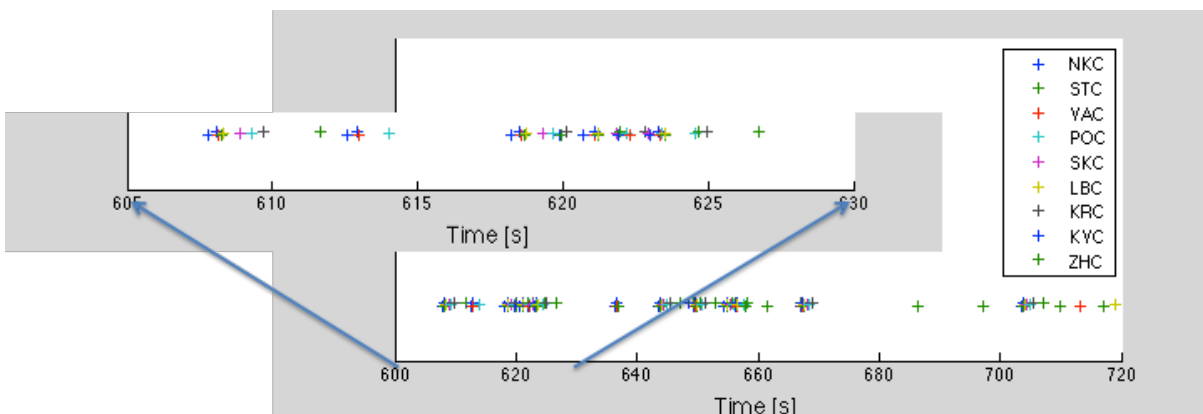


Fig. 5 Jointed time series of S phases for all stations

- Because the above-defined phase groups may contain more S-phases per station, time consistency measures are applied to choose the most suitable S-phase for each station
- P-phases are searched prior to each valid S-phase in a time window derived from the network aperture. Wadati diagram is applied to find the most suitable P-phase in the case multiple possible P-phases exist and also to exclude possible outlier

Preliminary locations of detected earthquake hypocenters are obtained using homogeneous velocity model by the simplex inversion method. Fig. 6 shows locations provided in semi-real time on the Webnet homepage.

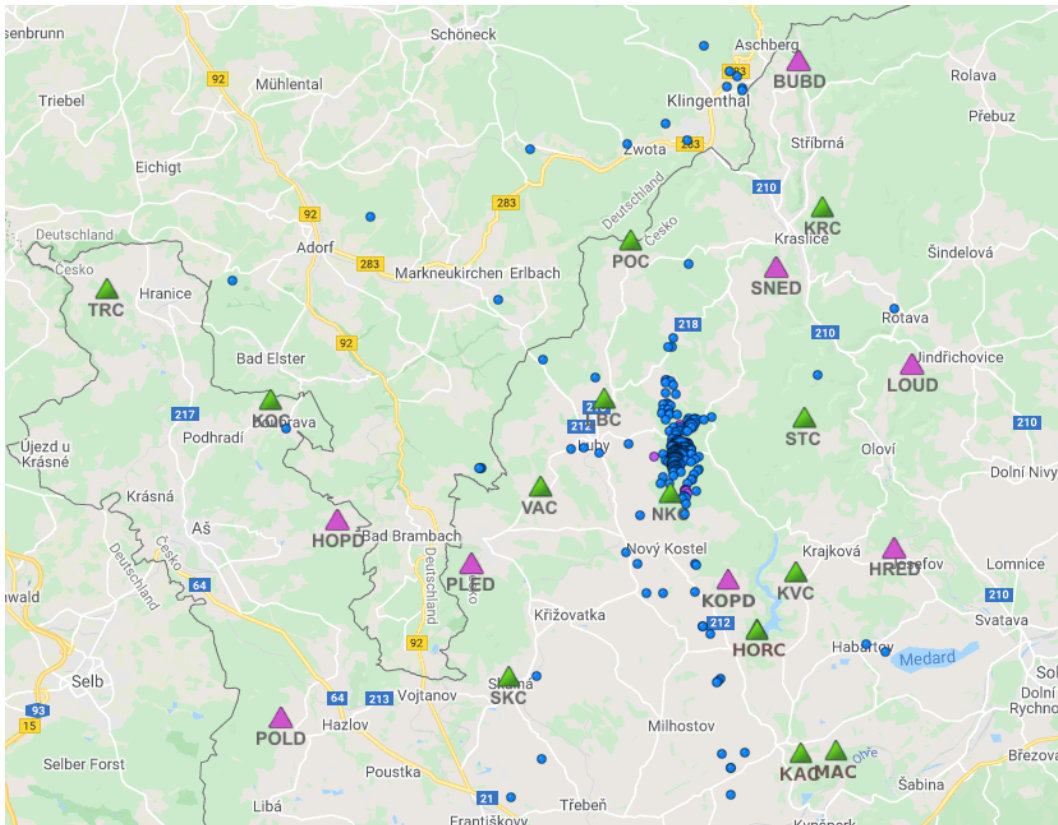


Fig. 6. Map of the WEBNET with epicenters of seismic activity within for one-year period April 2019 – May 2020 obtained by the PEPIN picker and locator.

## Review of the Pepin parameters

The parameters for detection and association include the following.

### Detector and picker

- corner frequencies of the filter for seismogram (4, 30 Hz)
- frequency of the low-pass filter for the characteristic function (10 Hz)
- daily maximum of detections per station (5000)
- ratio of ATA/BTA (2)
- minimum time difference between S-phases (0.8 s)

### Associator and locator

- the maximum  $t_S - t_P$  difference for identifying possible P-phases (3 s)
- maximum hypocenter depth (15 km)
- minimum apparent velocity (14 km/s)
- tolerance  $ss\_fact$  of the S-phase time difference for identifying events (1.5)
- P-wave velocity and  $V_p/V_s$  ratio for location (5.9 km/s, 1.7)
- maximum residuum for plotting residuals (0.12 s)

## PEPIN implementation at GRSN

To apply Pepin on the Litoměřice GRSN several different area characteristics have to be considered. The main point is the deficit of existing seismic activity which would allow for testing the performance of detection. On top of that, no industrial seismicity occurs within the network's



aperture as no quarry is in operation there. Accordingly, it was not possible to test the setting of detection and association parameters for the local activity.

To this purpose the Pepin functionality was adapted so that also industrial seismicity is detected. This includes quarry blasts and regional induced seismicity. While quarry blasts seismograms show only weak S-phases, regional seismograms are missing impulsive onsets and show large  $t_S-t_P$  time differences. The following modification were introduced.

1. To increase the detection sensitivity to this type of activity a new operation mode of the associator was introduced in which all detections are considered as P-waves. Hence no S-waves for defining event are required which allows for a better detection of quarry blasts; this is controlled by the onlyP parameter
2. The tolerance  $ss\_fact$  was increased to 5, the maximum  $t_S-t_P$  increased to 30 s, the maximum hypocenter depth to 70 km

To detect both quarry blasts missing S-phases and possible local microearthquakes, the Pepin associator is executed twice: first using the onlyP option set to 1 and second set to 0. The detection results are finally joined.

Pepin run is scheduled daily at 5:00 a.m. using a batch Matlab script `runPepinDaily.m`, which prepares marker files and trimmed waveform event sections to be further checked manually using the Snuffler Python code.