Single Layer Recurrent Neural Network for Detection of Local Swarm-like Earthquakes - the Application

J. Doubravová and J. Horálek

Institute of Geophysics, Dpt. of Seismology

CzechGeo Workshop, 4.12.2019

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

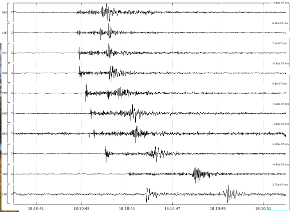
MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Supported project:
Acronym: CzechGeo/EPOS-Sci *Registration number:* CZ.02.1.01/0.0/0.0/16_013/0001800

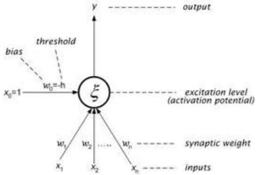
Outline

Motivation

- continual data produced by dense seismic networks must be reduced
- detection of seismic events should:
  - minimize false detections
  - detect also weak events
- neural networks can extract useful information and generalize to unseen examples, forward problem is solved fast

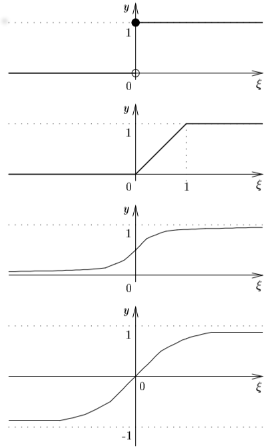


Artificial neuron



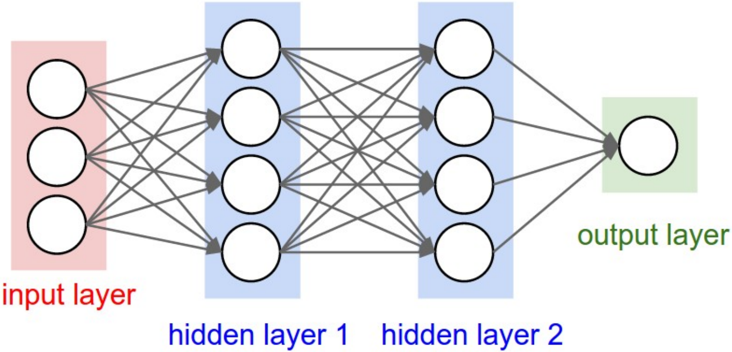
- n real inputs x = dendrites, bias $x_0 = 1$
- weights w = synaptic weights, bias $w_0 = -h$ threshold
- activation potential $\xi = \sum_{i=0}^{n} w_i x_i$
- activation function

$$y = \sigma(\xi) = \begin{cases} 1, & \xi \geq 0 \\ 0, & \xi < 0 \end{cases}$$



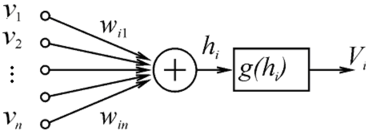
Artificial neural network

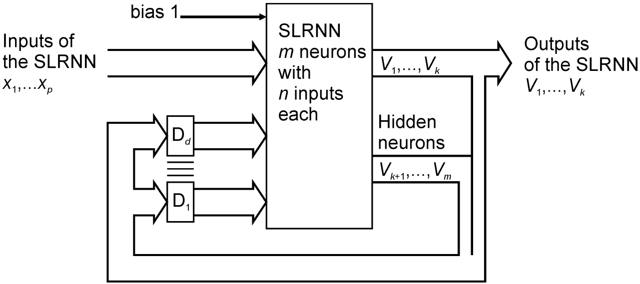
- neurons interconnected into networks to solve complex problems
- typical tasks: classification, pattern recognition, regression



SLRNN - architecture

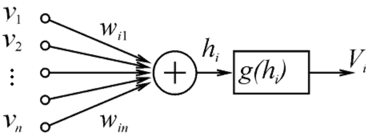
- outputs fed back as inputs = recurrence, memory
- variable delay $D_1..D_d$

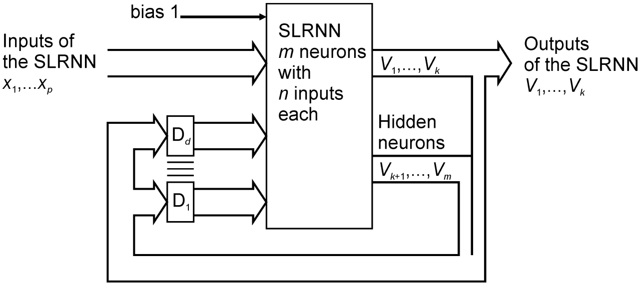




SLRNN - architecture

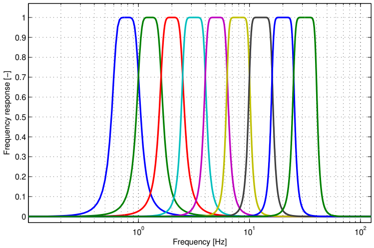
- 8 neurons, 18 inputs, 3 outputs (**event**, P, S)
- delays 1, 2, 4, and 8 samples - 4x8=32 feedbacks

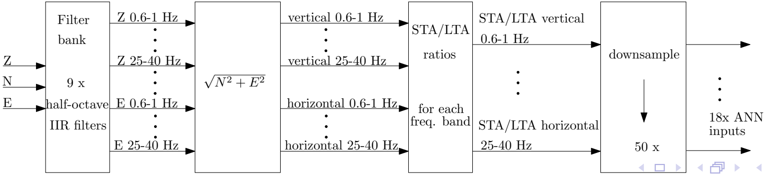




SLRNN - data preprocessing

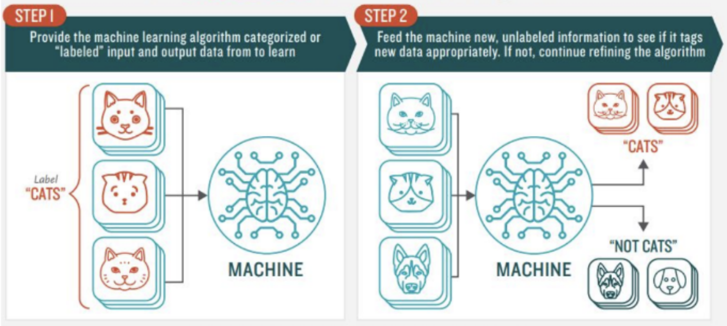
- STA/LTA in 9 narrow-band filtered velocity records
- decimation to 0.2 s



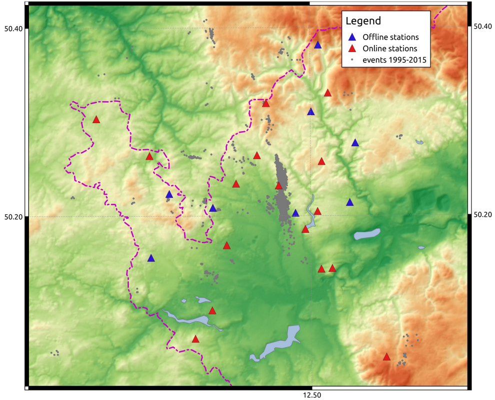


Training

- supervised learning: searching w_{ij} to fit required outputs for training set
- seismic swarm 2008 (events) and calm year 2010 (disturbances) WEBNET (West Bohemia)



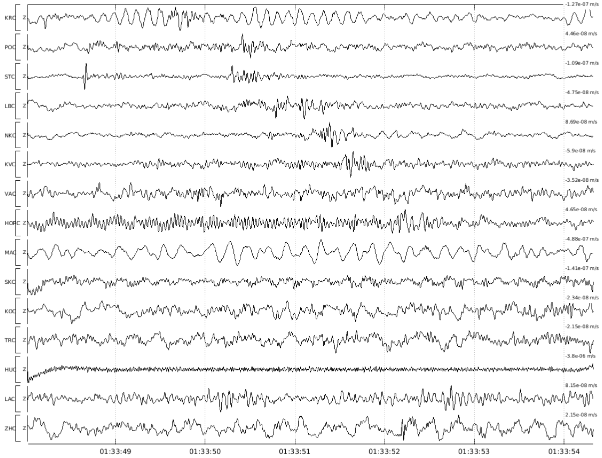
WEBNET



- West Bohemia/Vogtland
- seismic swarms, CO2 emanations
- 24 stations at present
- 16 stations online
- 250Hz, 3C velocity records

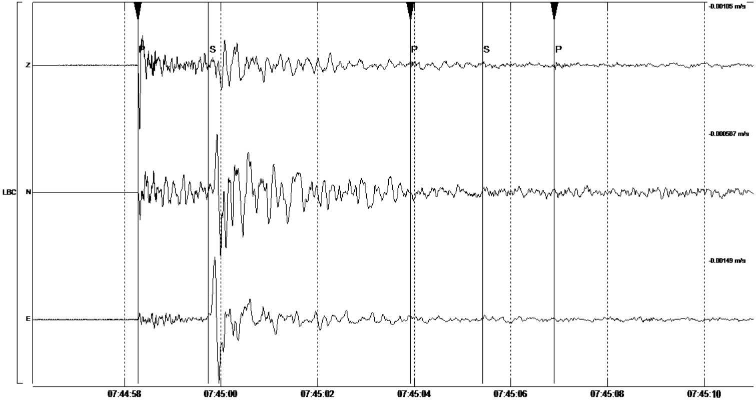
False detections ?

- tested on swarm 2011, single station detection
- many false detections
- many events => small events without manual reading



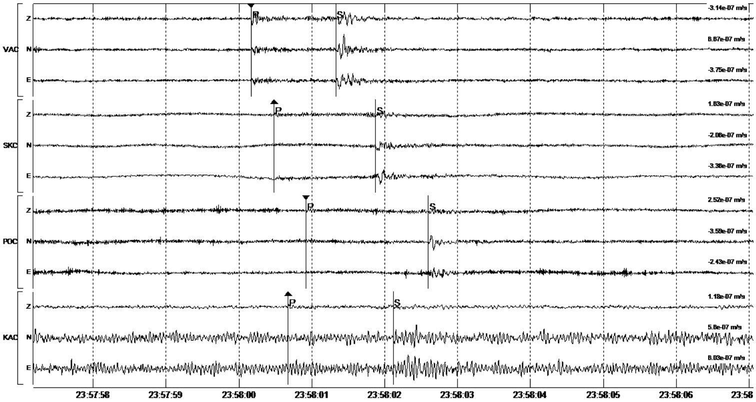
Undetected events

Ev. $M_L = 2.3$ and $M_L = 2.2$ in coda of $M_L = 3.8$



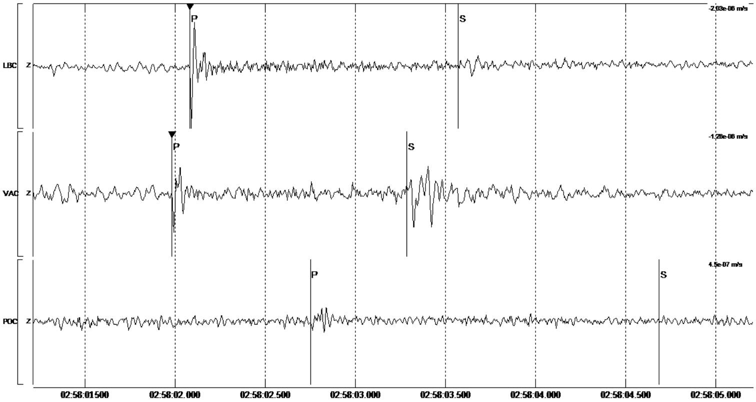
Undetected events

$M_L = -0.3$ noisy record on KAC



Undetected events

weak amplitudes on POC $M_L = 0.2$

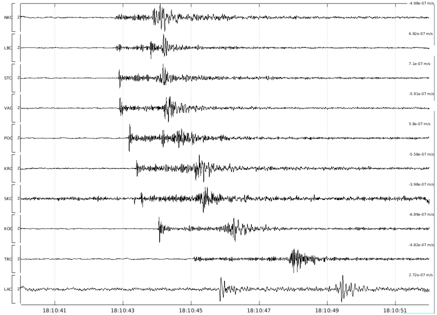


How to solve it?

- we have high number of false detections / or very weak events - too much events to process
- few undetected events - really unacceptable
- => WE MUST USE **COINCIDENCE** IN THE NETWORK

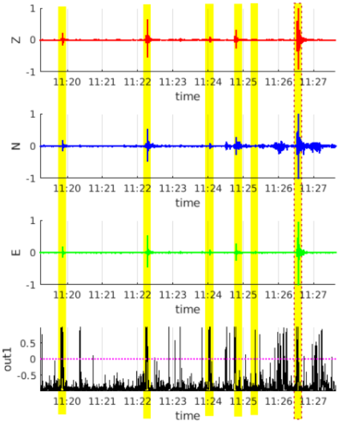
Coincidence

- when a human processes waveforms, he takes into account all the stations at once
- let the machine see detection outputs of the stations at once
- for each detection we look for sufficient number of detections on other stations in certain time window



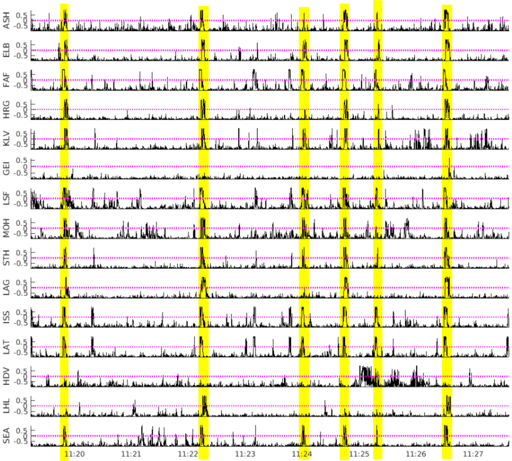
Coincidence

- single-station detection during the swarm - seismogram/detection output
- dashed line marks event in catalogue with $M_L = 0.9$
- yellow stripes mark events after coincidence

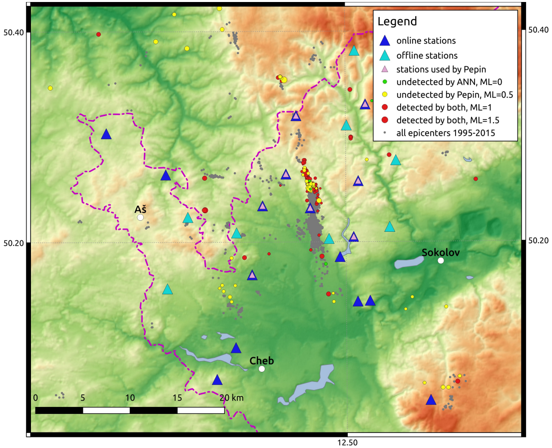


Coincidence

- outputs for whole network
- 15 stations, 6 stations-coincidence required
- yellow stripes mark events after coincidence



Webnet



- even there is a good detection and location provided by PEPIN, there are some limitations
- especially events outside the NK focal zone could be missing
- example -10/18-11/18 processed manually to the lowest possible magnitudes, background seismicity

Webnet

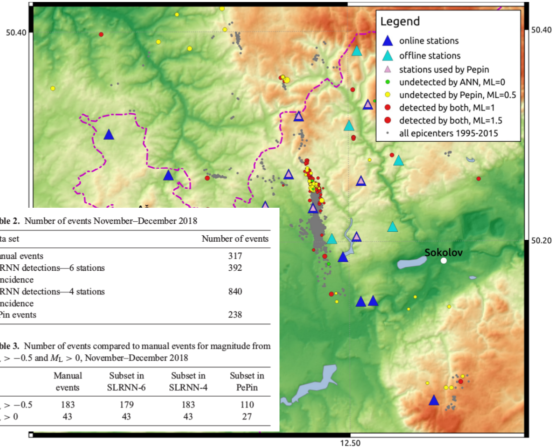


Table 2. Number of events November–December 2018

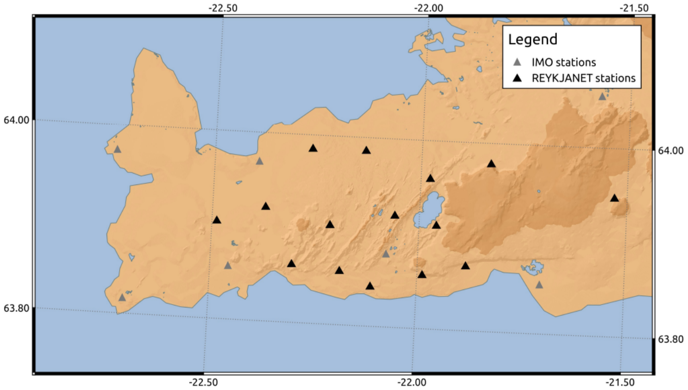
Data set	Number of events
Manual events	317
SLRNN detections—6 stations coincidence	392
SLRNN detections—4 stations coincidence	840
PePin events	238

Table 3. Number of events compared to manual events for magnitude from $M_L > -0.5$ and $M_L > 0$, November–December 2018

	Manual events	Subset in SLRNN-6	Subset in SLRNN-4	Subset in PePin
$M_L > -0.5$	183	179	183	110
$M_L > 0$	43	43	43	27

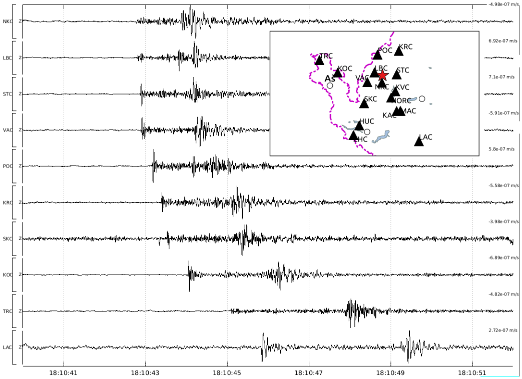
- 6-station coincidence is sufficient for completeness magnitude $M_c = 0$
- 4-station coincidence found all manual events downt to $M_L = -0.5$
- but the number of false events is much higher (20% vs. 60%)

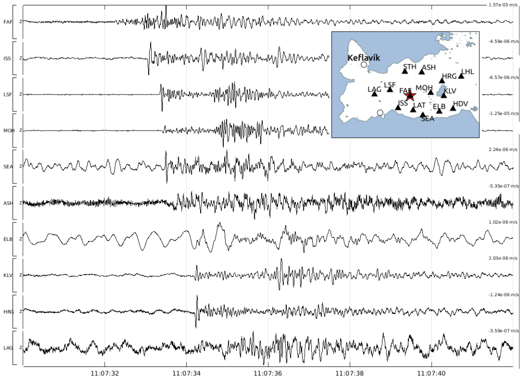
Reykjanet network



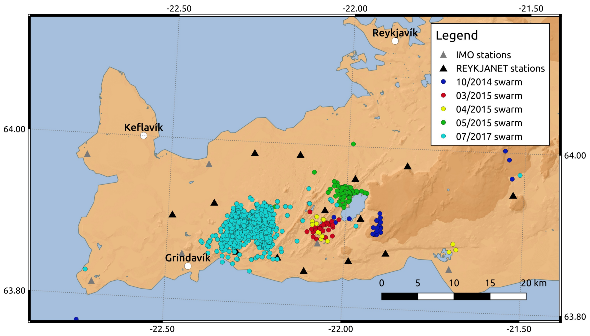
- south-west Iceland, Reykjanes peninsula
- 15 off-line stations
- size of the network, number of stations, earthquake swarm activity - similar to WB

Reykjanet network





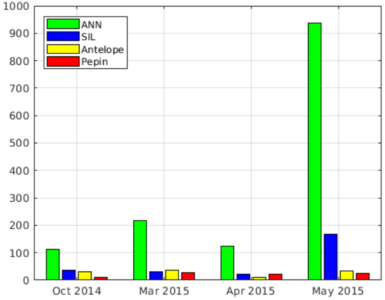
Data: 5 activities 2014-2017



- the best SLRNN network trained for WEBNET
- 10/2014 (2days, $M_{Lmax} = 2.8$)
- 3/2015 (1day, $M_{Lmax} = 2.2$)
- 4/2015 (3days, $M_{Lmax} = 1.6$)
- 5/2015 (2days, $M_{Lmax} = 3.5$)
- 7/2017 (3days, $M_{Lmax} = 3.9$)

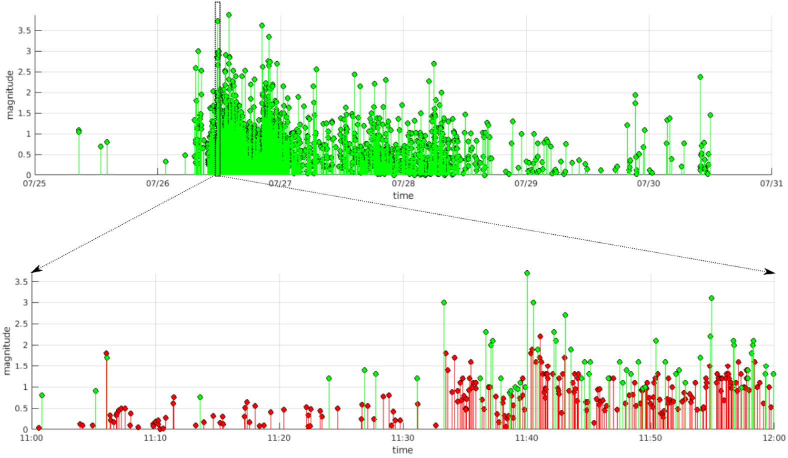
Number of events

- SIL - IMO catalog - manually revised automatic locations from Icelandic regional network
- Antelope - automatic catalog by Antelope from Reykjanet stations (B. Růžek)
- PePiN - automatic locations from PePiN (T. Fischer)
- ANN - detection (no location)



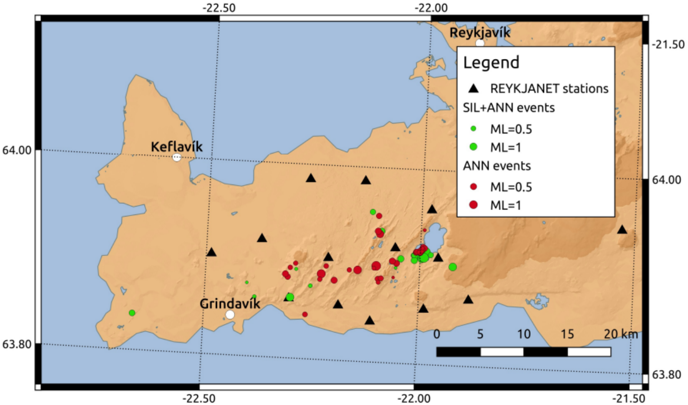
Swarm 2017

- $M_L > 0$
- 1 hr detail
- SIL (56) vs. manual (281)
- all detected by SLRNN



Background seismicity 6-12 June 2017

- 34 events in SIL catalog (green)
- 37 more by SLRNN (red)



Conclusion

- SLRNN detector is fast and effective
- the training dataset must be prepared with special care
- coincidence within a network solves undetected events and reduces reasonably number of false detections
- further processing will reveal weak events as they can't be successfully localized
- the neural network trained for West Bohemia works well for Reykjanet - good generalization