European Geosciences Union General Assembly 2020

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Nikita Afonin[1], Elena Kozlovskaya[1,2]

Development of events detector for monitoring of cryoseisms in upper soils

[1] Oulu Mining School, University of Oulu, Finland
[2] Geological Survey of Finland, Espoo

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Introduction

This work is part of the project: IMPACT OF EXTREME WEATHER EVENTS IN THE ARCTIC ON TECHNOLOGICAL SYSTEMS, CRITICAL FACILITIES AND URBAN ENVIRONMENT

Principal investigator (PI): Elena Kozlovskaya
Professor of Applied Geophysics, Oulu Mining School, Faculty of Technology, University of Oulu and Geological Survey of Finland

Co-leader: Docent Esa Muurinen, Environmental and Chemical Engineering (ECE) research unit of the Faculty of Technology,

SITE OF RESEARCH:
(1) Oulu Mining School (OMS), Faculty of Technology, University of Oulu
(2) Environmental and Chemical Engineering (ECE) Research Unit of the Faculty of Technology, University of Oulu, Finland

HOW EXTREME WEATHER EVENTS ARE DEFINED?

- **EXTREME WEATHER EVENTS** have been defined as discrete episodes of extreme weather or unusual climate conditions, often associated with deleterious impacts on technological and natural systems and society.

- **EXTREME WEATHER EVENTS** can occur on a wide range of timescales from minutes to seasons or longer and on a wide range of spatial scales from a few kilometers to the size of continents.

- **IT IS IMPORTANT THAT** the timescales of occurence of extreme weather events are comparable with the life time of technological systems, urban environment infrastructures and critical facilities like mines, nuclear power plants etc.

Mining Tailings as an example of critical facilities :

Currently, there are about 3,500 tailings dams worldwide

Overtopping due to extreme precipitation was the reason for Talvivaara accident (THL 2012)

Mining taling facilities: the second case study

Another example of extreme weather changes is unusual and abrupt decreasing of air temperature, which may be the cause of cryoseisms.

Cryoseisms are earth vibrations produced by non-tectonic cracking of frozen material at the Earth's surface.

Ice quakes

Related to the ice rifting on the surface of water, such as lakes or glaciers

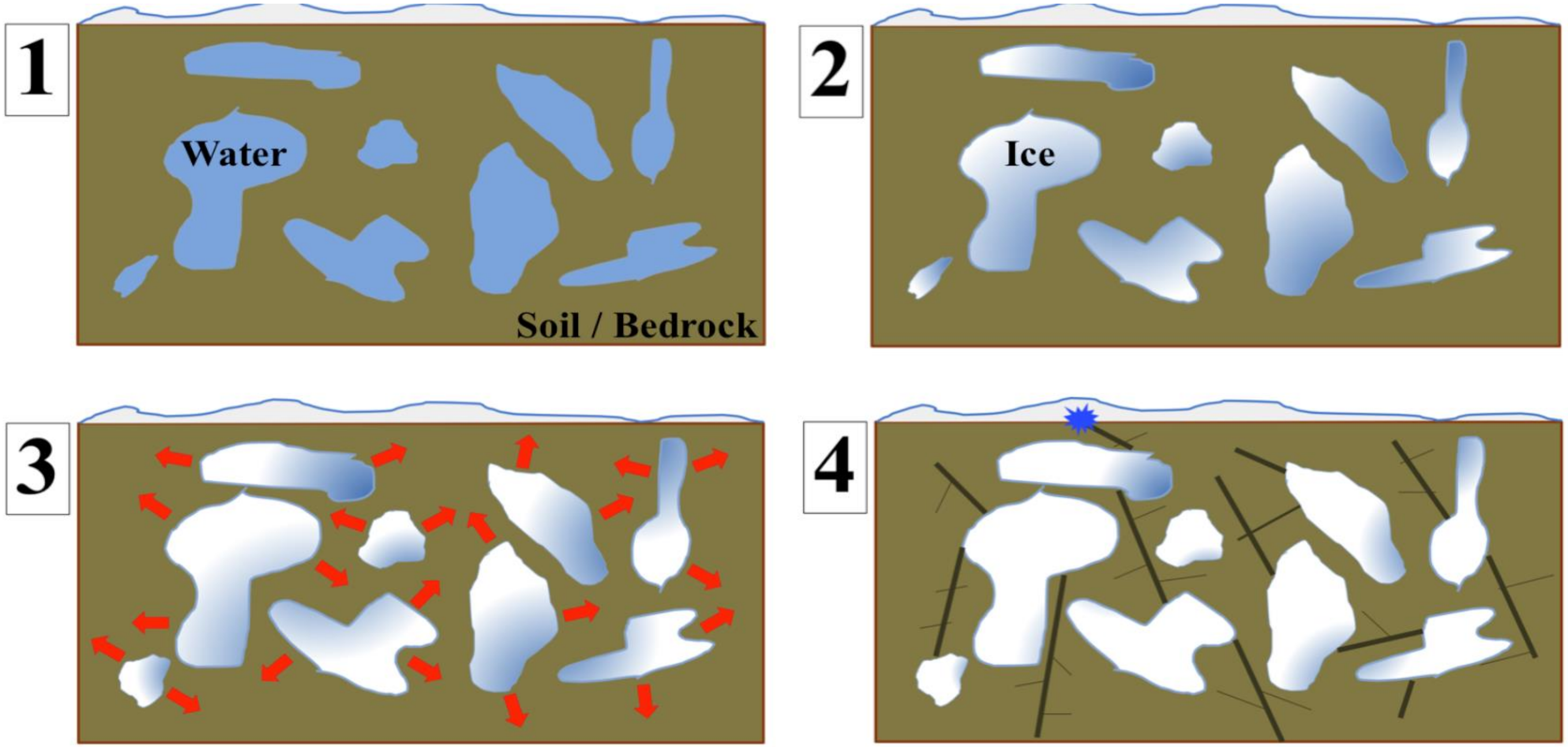
(Neave and Savage, 1970; Burke, 2004; Walter et al.,2008)

frost quakes

Associated with fracturing of saturated rock or soil on a landmass

(Lacroix, 1980; Nikonov, 2010)

Frost quake formation (Battaglia and Changnon, 2017)

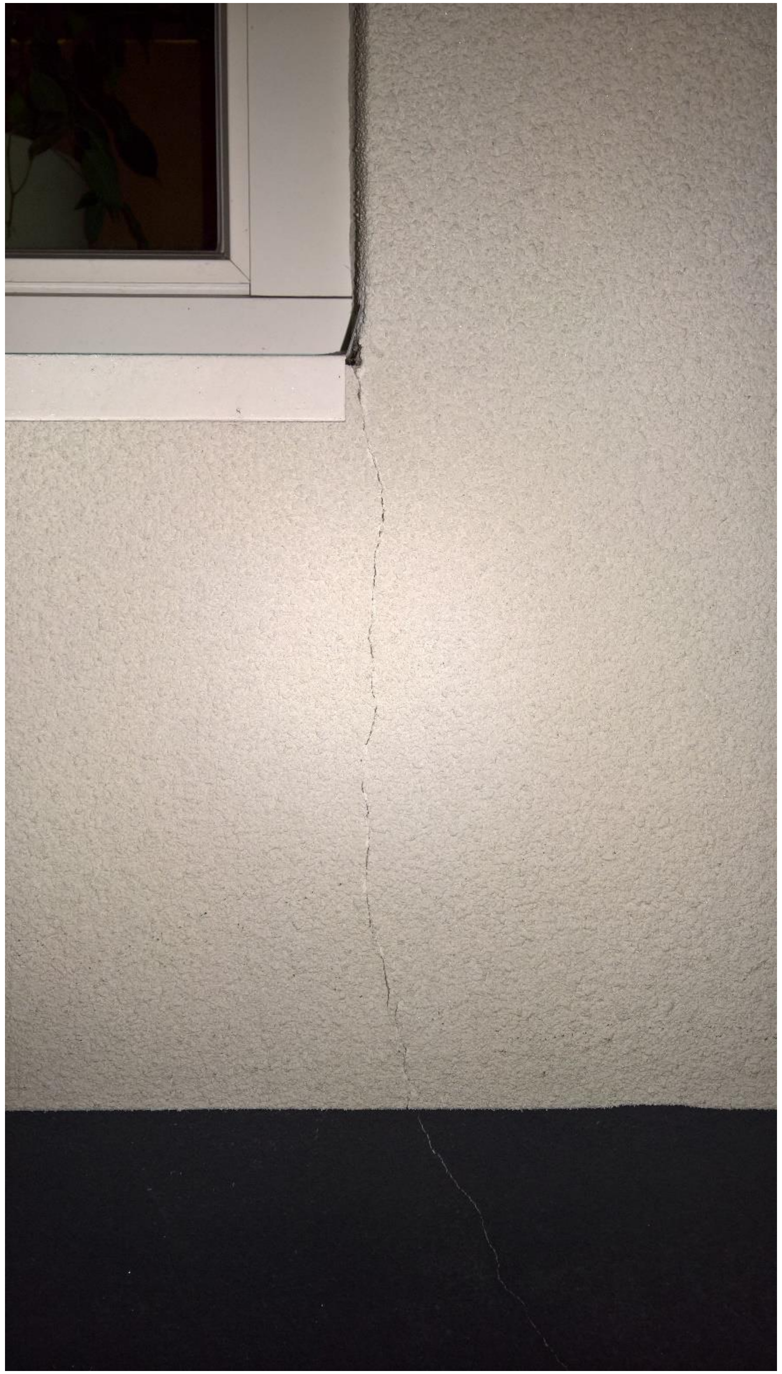


1 Water saturates the soil near surface;

2 Freezing of water in the subsurface;

3 Expanding of the ice, when temperature continue decrease;

4 Stress drop, which can create noise or ground shaking



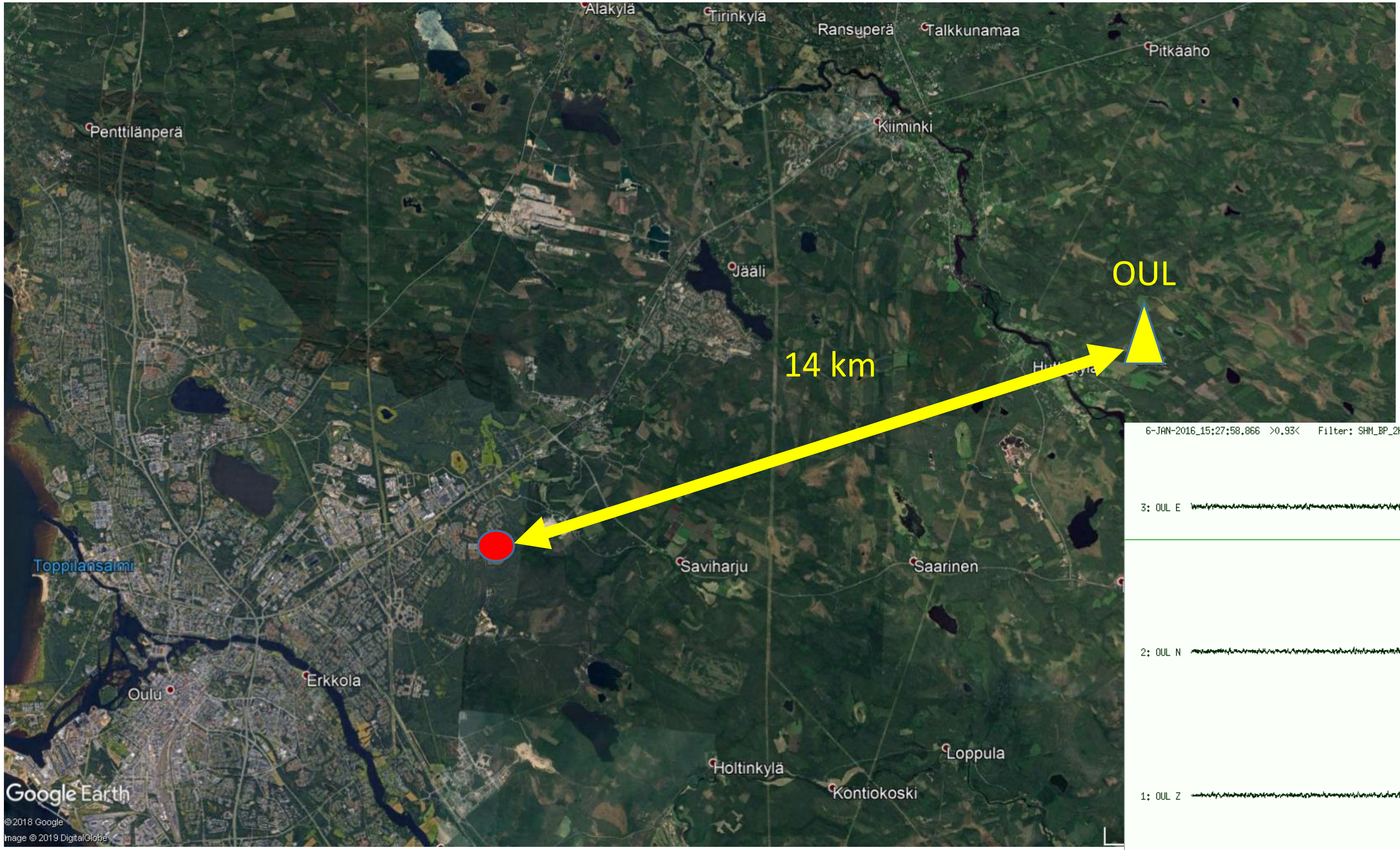
An extreme weather event occurred during the winter of 2015 - 2016 on 6.01.2015. (Kaleva, 15.01.2016, Iltalehti, 18.01.2016) in the Talvikangas district of Oulu.

Rapid temperature decrease and thin snow cover resulted in rapid freezing of underground water, which, in turn, resulted in bedrock rupture at a shallow depth and visible damage to road surfaces and the basements and walls of buildings.

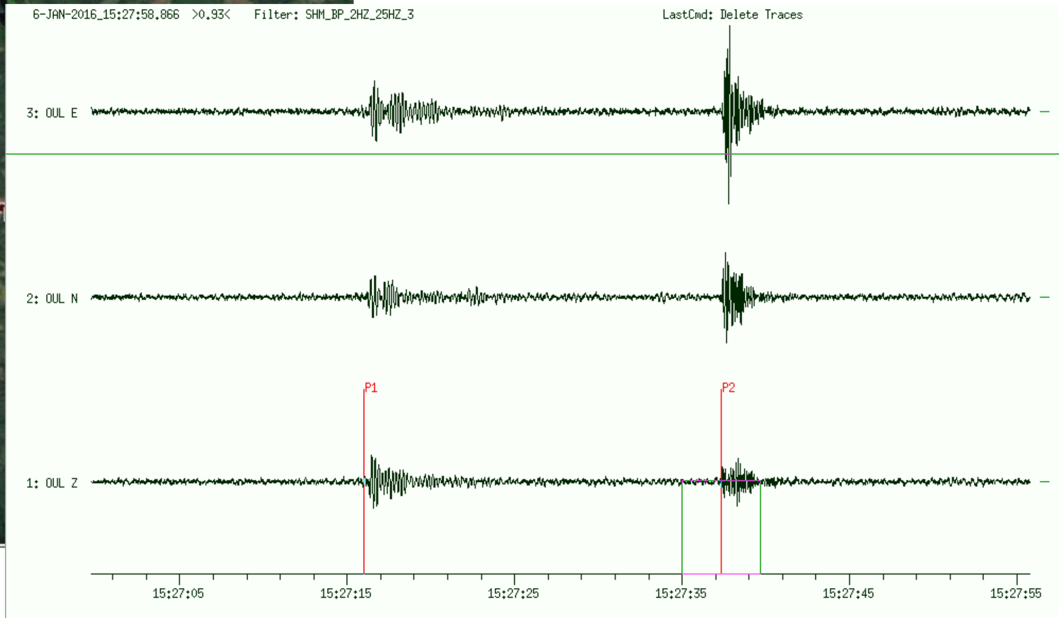
(Photo: Jarkko Okkonen)

Talvikangas: the first test site
(Urban facility)

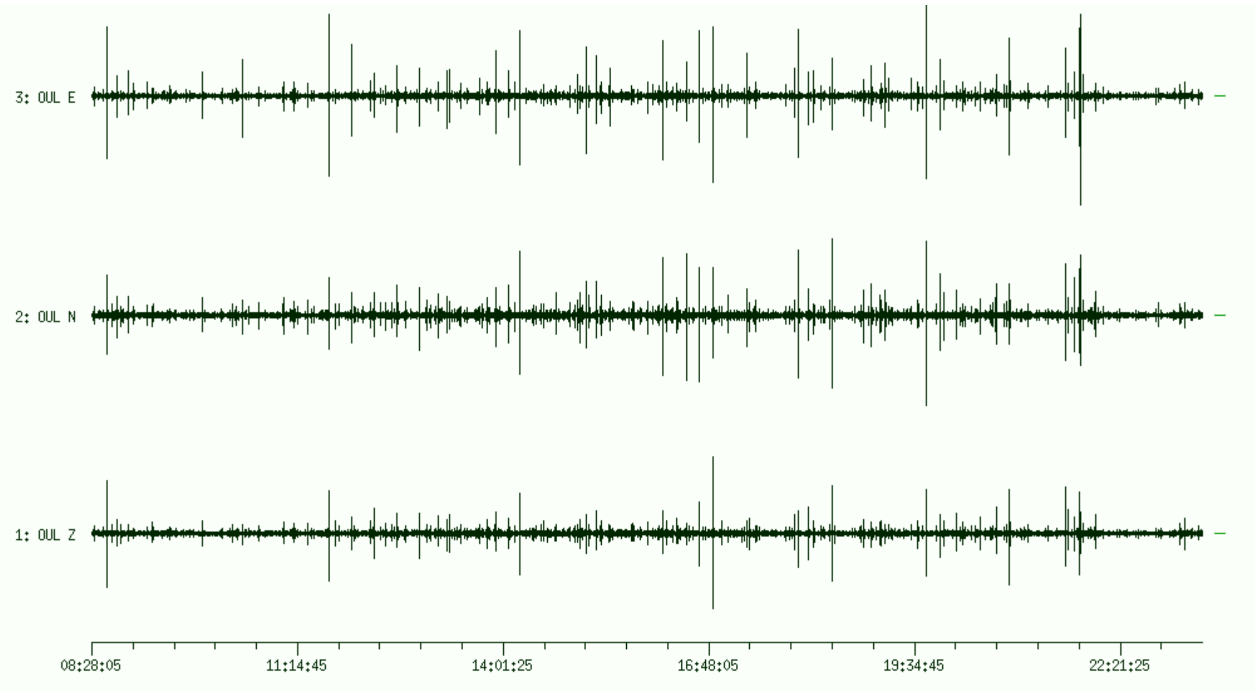
The earthqake caused by soil freezing originated near Oulu in Talvikangas 06.01.2016 and take effect of cracks on roads and walls of buildings.



Record of the main shock



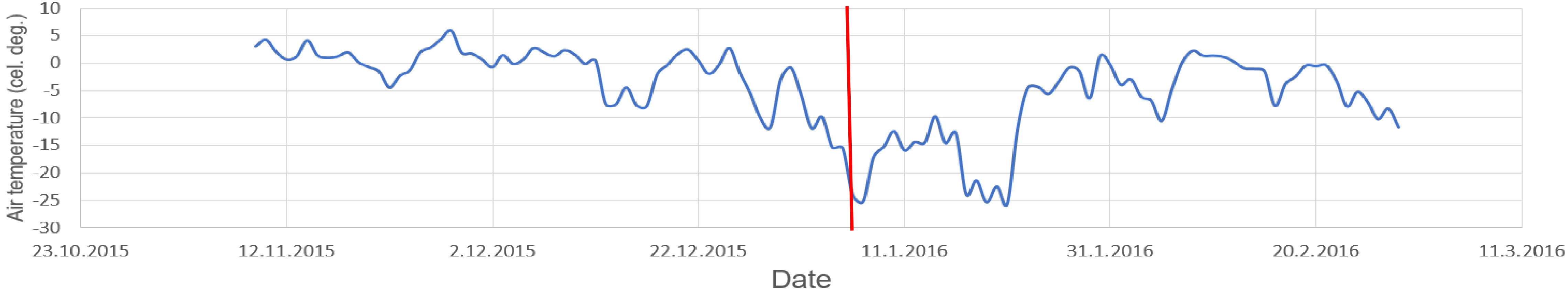
In the same day, seismic station ”Oulu” recorded huge number of impulses during the day.



Short-duration events recorded by OUL seismic station during one day 6.01.2016

In the same day, air temperature decreased to the minimum

06.01.2016



Motivation for development of detector

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1. Studying of processes in upper soils, caused by cryoseisms, connected with necessity of analysis of huge amount of data, recorded by seismic station, which require a lot of time for routine processing by visual inspection;

Usually in winter time the seismic station “Oulu” recorded about ***3000 impulses per day***, part of which may be cryoseisms.

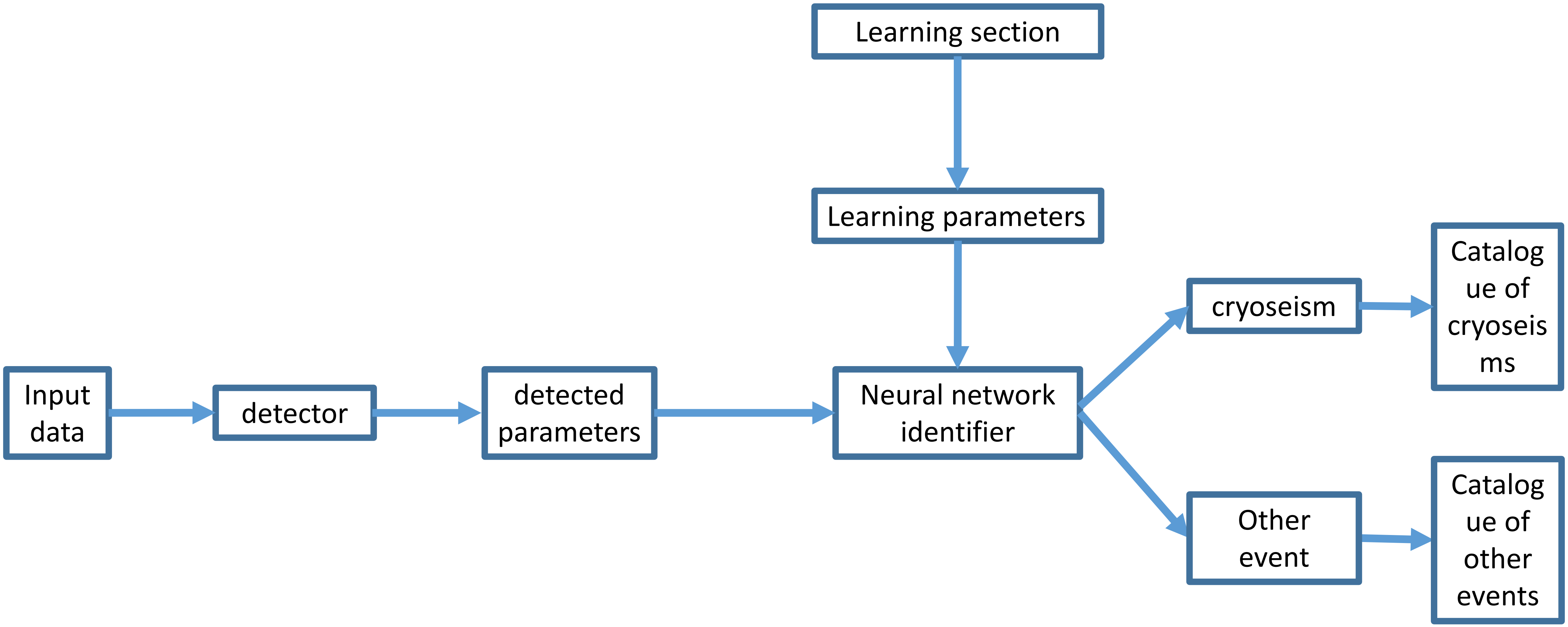
2. Necessity of separation cryosesims from other seismic events or noise.

Some characteristics of seismic records, which used in visual inspection of seismic records, such as envelopes in time domain, may be the same for different types of seismic events. That is why, deeper analysis of each recorded impulses is necessary. In case of visual inspection this work require a lot of time.

3. Developed detector is universal and allows idetifying not only cryosesms but also other types of seismic events.

Identifyed type of events depends only on learning section, which may consists on any types of events.

The scheme of detection and identification of cryoseisms



Procedure of detection in frequency-time domain

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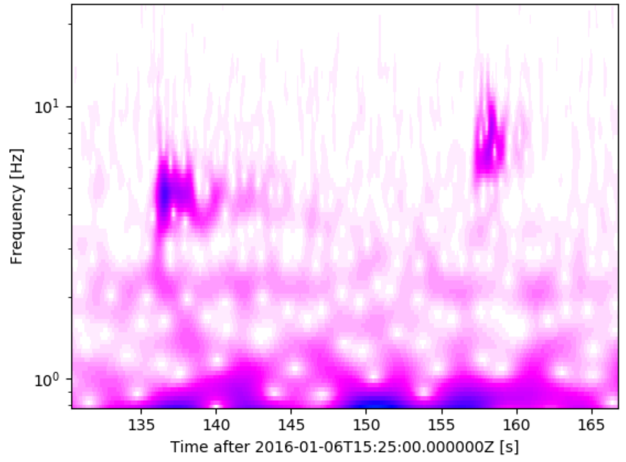
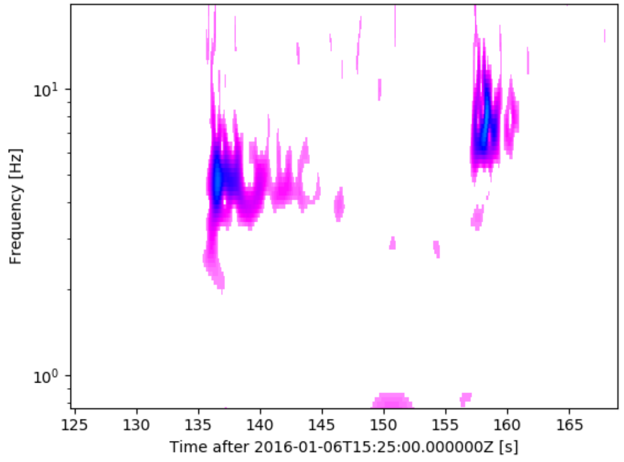
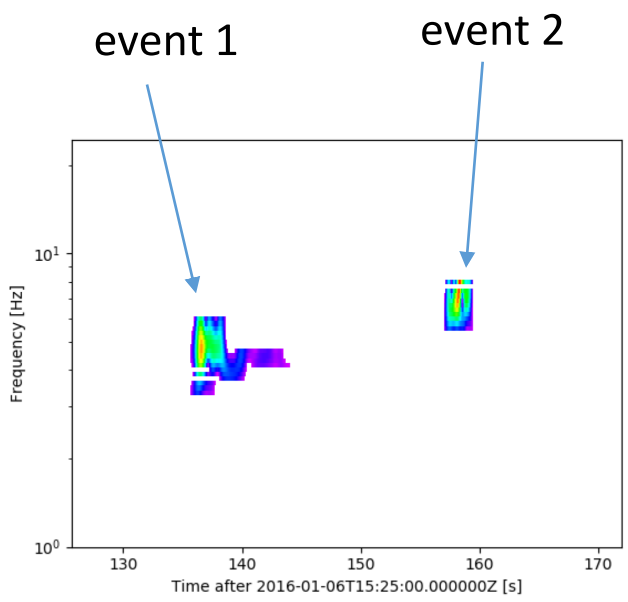
The main shock recorded by seismic station ”Oulu” 6.01.2016 in frequency-time domain



Input record in frequency-time domain

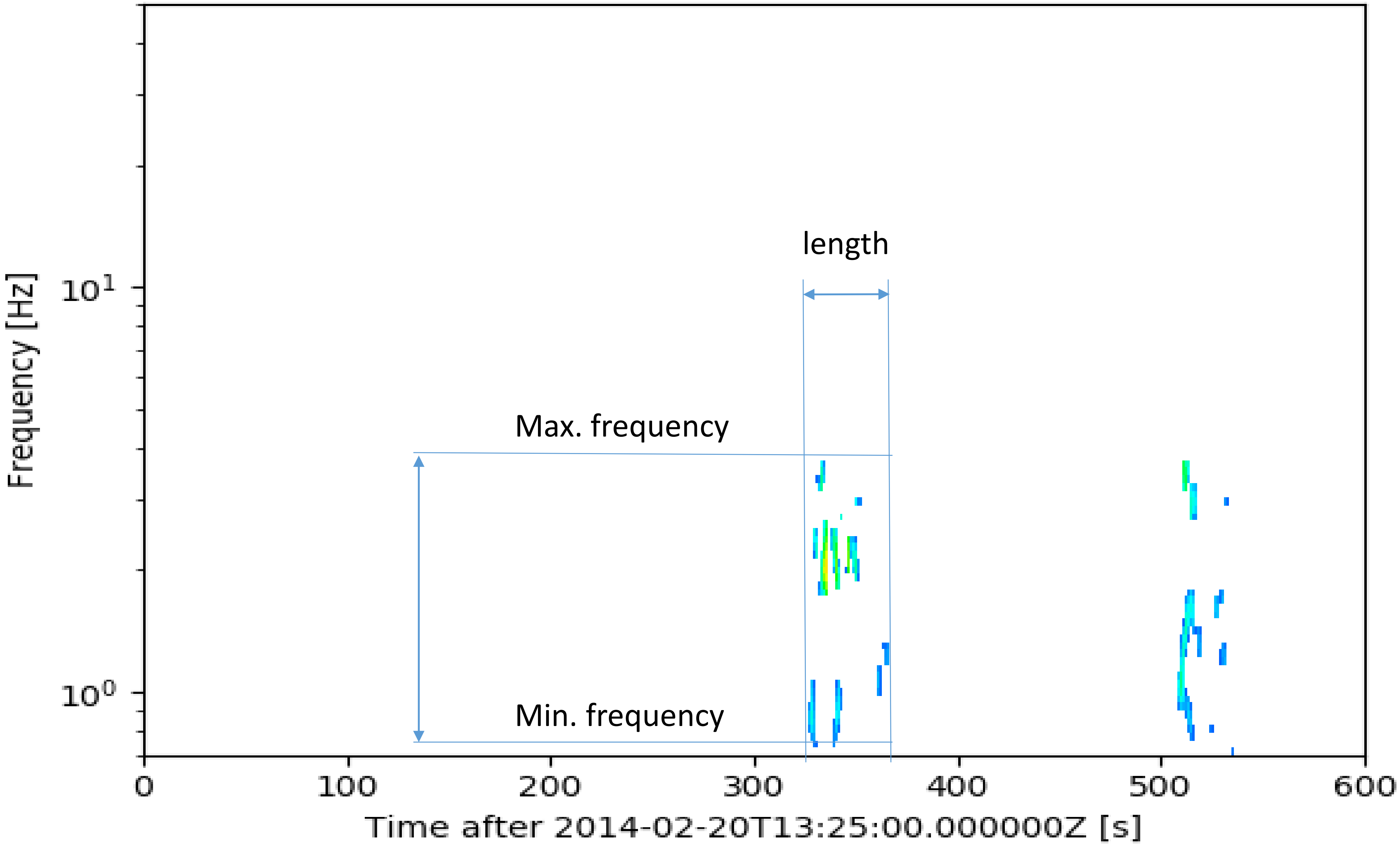


Seismic record in frequency-time domain after removing background noise

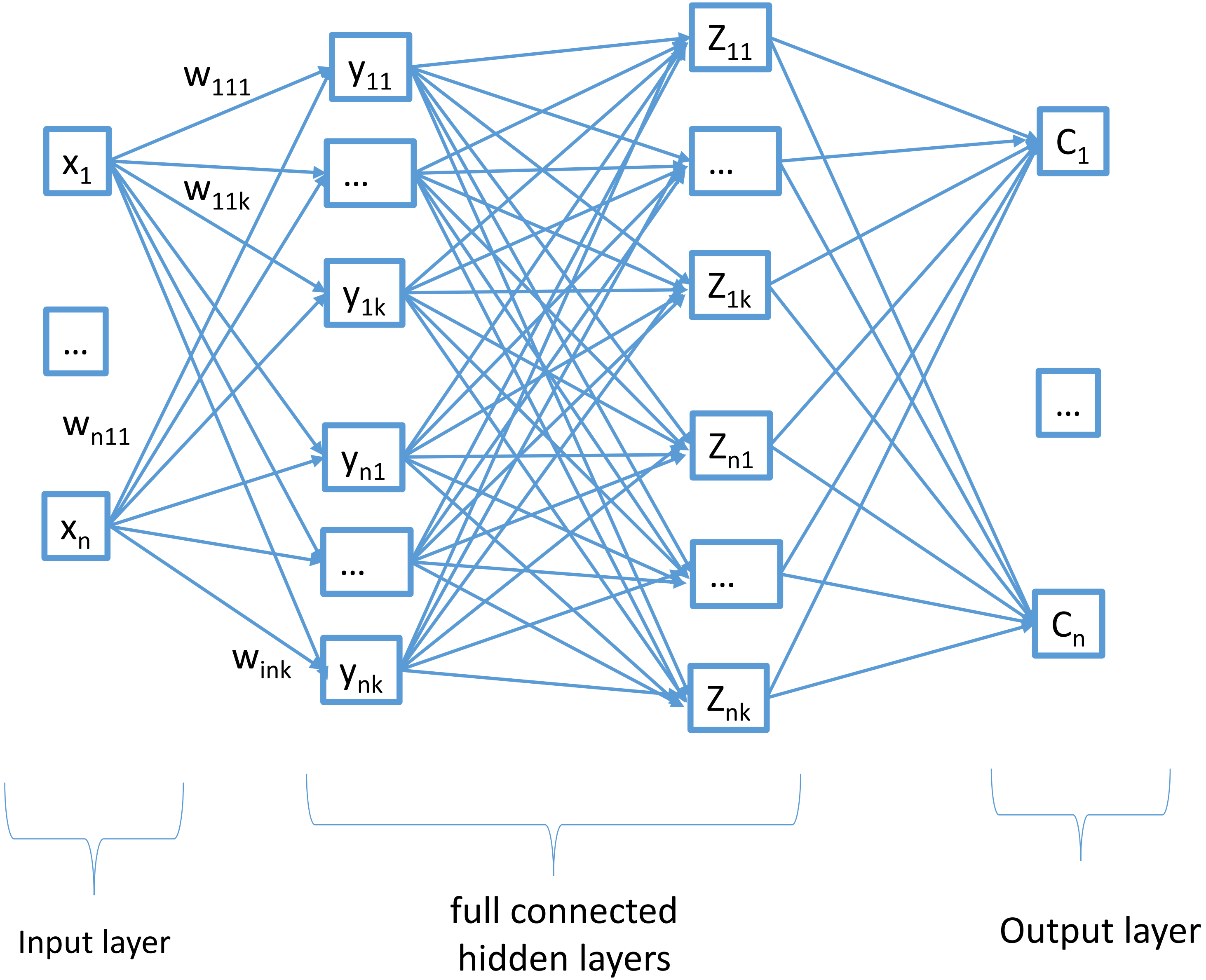


Seismic record in frequency-time domain after STA/LTA calculation

Some characteristics of records, used for identification



The scheme of the artificial neural network for identification



X_n – parameters of seismic record ;

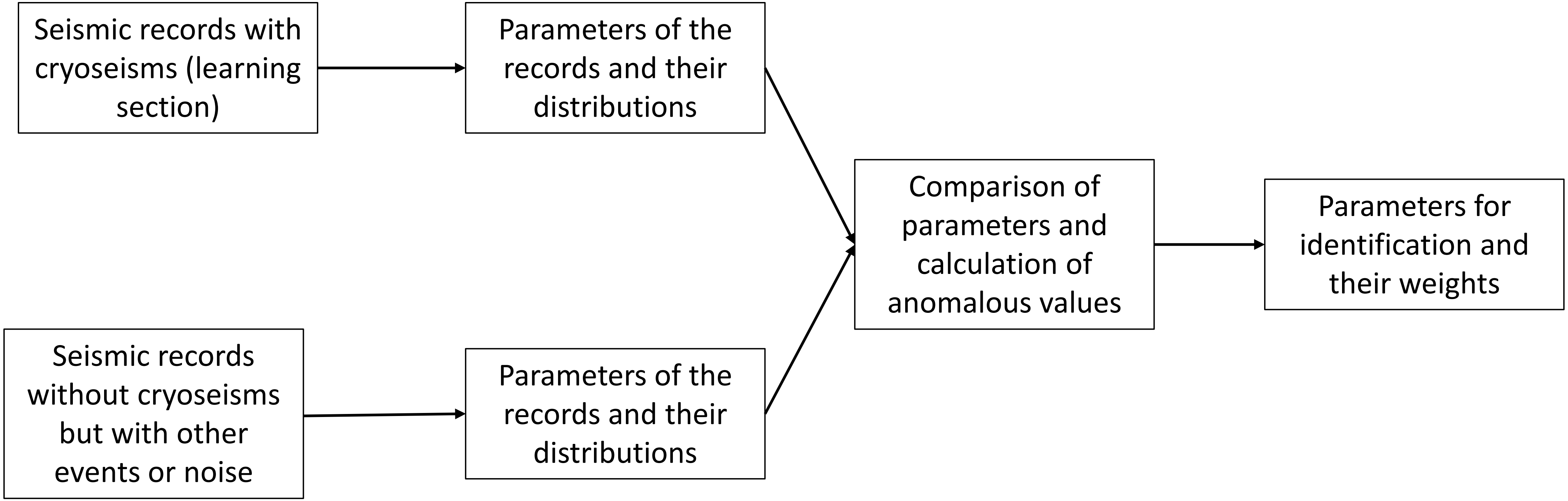
Y_{nk} , Z_{nk} – neurons of hidden layers;

W_{ink} – weights (i – layers number; n – input neuron; k – output neuron.

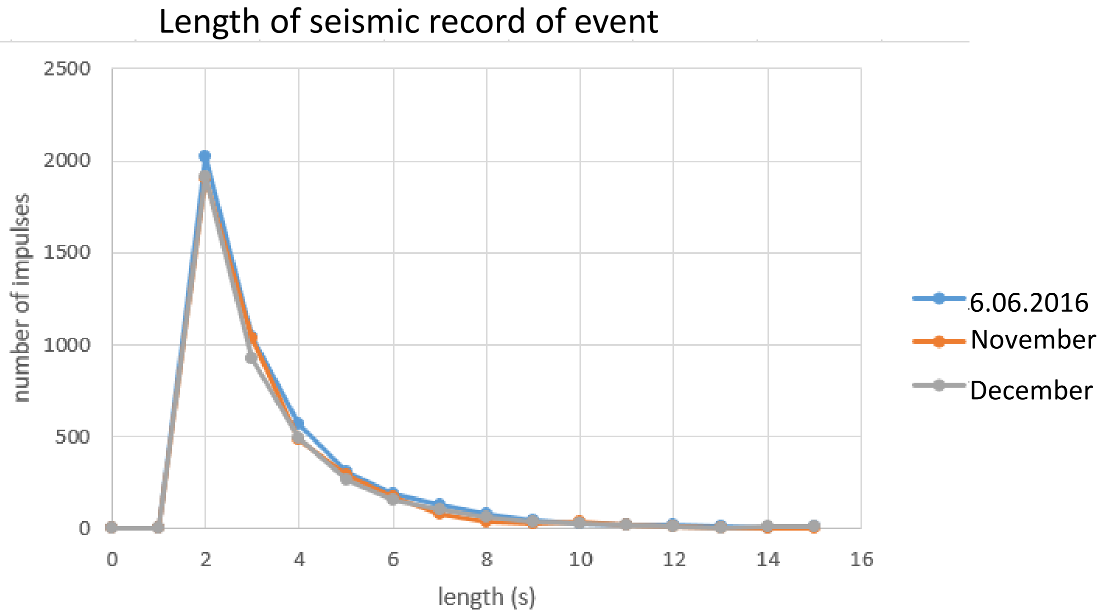
C = [C_1, C_2, …. C_n] – a vector, which corresponds to type of event.

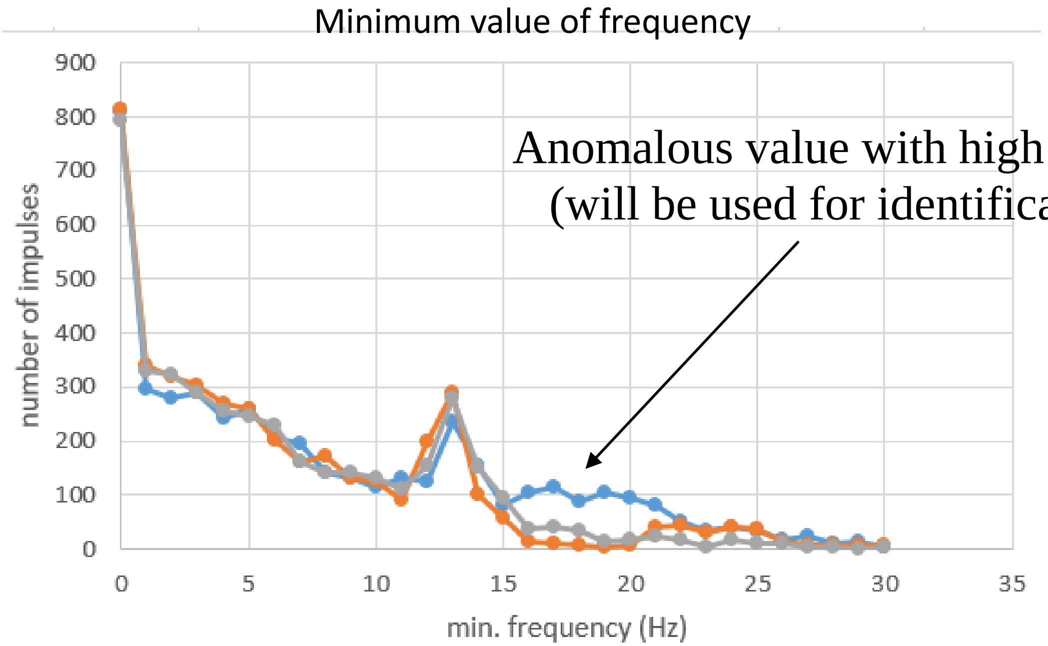
Learning process of artificial neural network

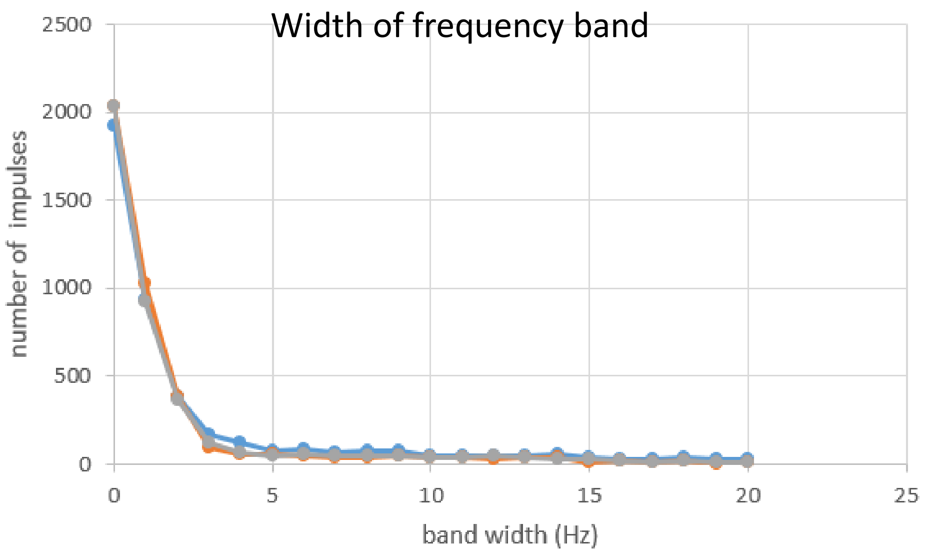
This process based on statistical analysis of parameters of seismic records, which include cryoseisms

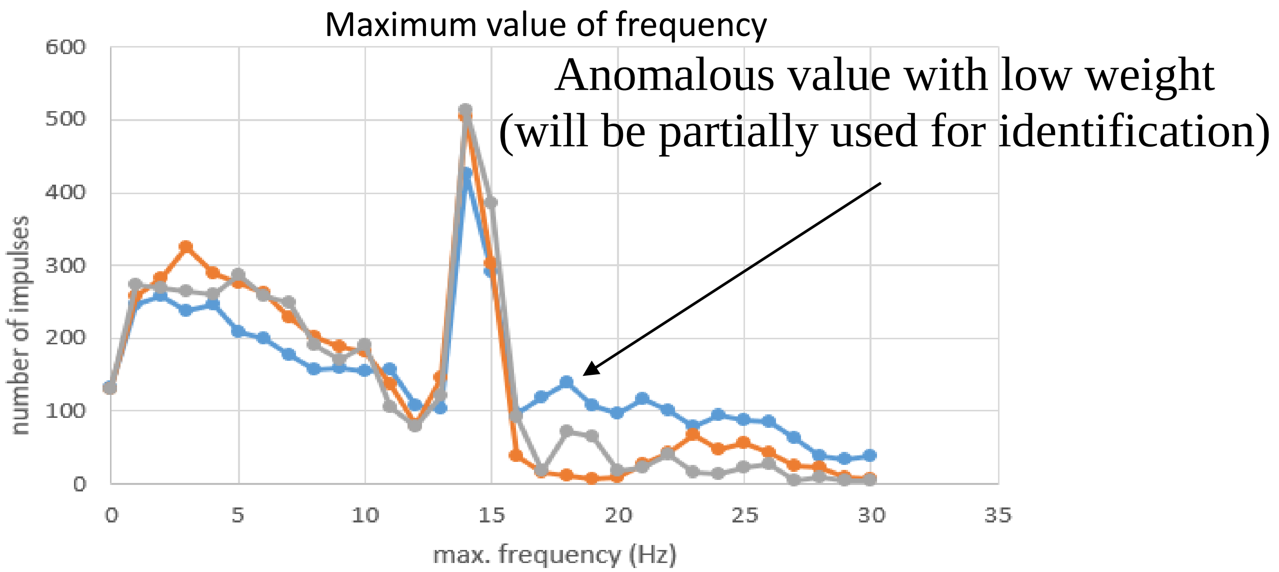


An example of data analysis during learning process of ANN



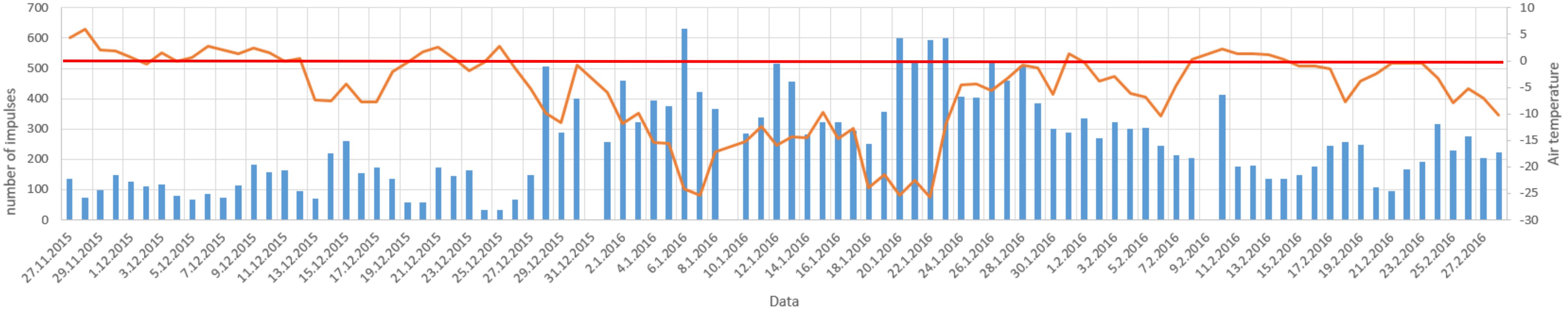




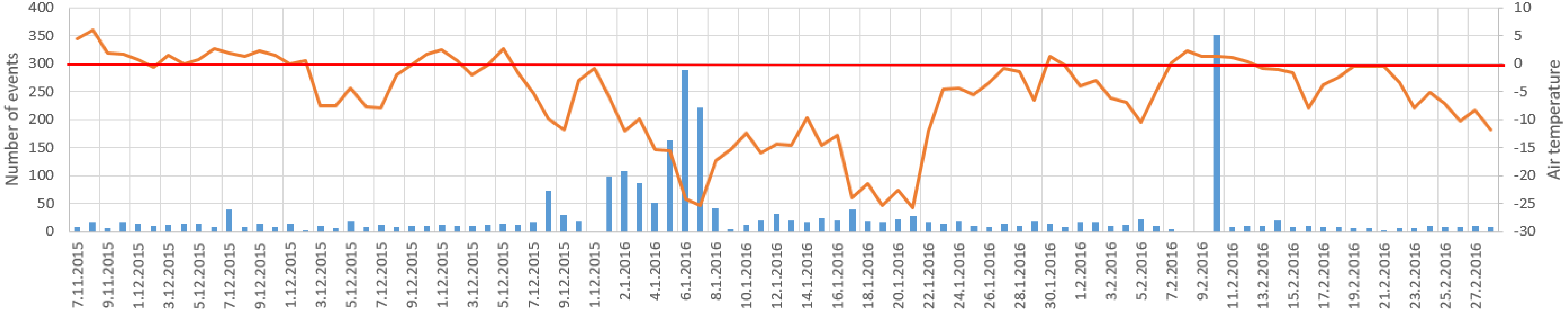


Test of the ANN with the data, recorded by seismic station ”Oulu”

Using only vertical component of records (3 parameters and relationships between them)



Using all components of records (9 parameters and relationships between them)



Conclusions

1. Using advanced algorithm of detection, based on analysis of seismic records in frequency-time domain, allows to find records of seismic events in widely frequency band simultaneously, which make data processing faster;
2. Simple artificial neural network is useful for identification of cryoseisms. Nevertheless it is necessary to improve this by using of more number of parameters and relationships between them.
3. Identified seismic events, probably are cryoseisms, because number of them per days have correlation with air temperature.
4. The most part of identified cryoseisms have frequencies between 15 and 20 Hz, which directly connected to sizes of sources of these events. High frequency character of identified events partically proove our proposal considering nature of events, because sizes of sources of cryoseisms may not be too large in upper soils.
5. Number of cryoseisms not strongly depends on air temperature, because of complex impact of air temperature and hygrogeological processes inside the soils.
6. Further development of ANN for identification of seismic events, allow to significantly increase possibilities for study not only cryoseisms, but also other seismic events.

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Thanks for your attention!