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Author: Mariusz Majdanski, Artur Marciniak, Bartosz Owoc, Wojciech Dobiński, Tomasz Wawrzyniak, Marzena Osuch, Adam Nawrot, Michał Glazer

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Geophysical imaging of permafrost in the SW Svalbard – the result of two high arctic expeditions to Spitsbergen

Mariusz Majdanski[1], Artur Marciniak[1], Bartosz Owoc[1], Wojciech Dobiński[2], Tomasz Wawrzyniak[1], Marzena Osuch[1], Adam Nawrot[1], and Michał Glazer[2]
[1]Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland (mmajd@igf.edu.pl)
[2]Department of Earth Sciences, University of Silesia, Sosnowiec, Poland

The Arctic regions are the place of the fastest observed climate change. One of the indicators of such evolution are changes occurring in the glaciers and the subsurface in the permafrost. The active layer of the permafrost as the shallowest one is well measured by multiple geophysical techniques and in-situ measurements.

Two high arctic expeditions have been organized to use seismic methods to recognize the shape of the permafrost in two seasons: with the unfrozen ground (October 2017) and frozen ground (April 2018). Two seismic profiles have been designed to visualize the shape of permafrost between the sea coast and the slope of the mountain, and at the front of a retreating glacier. For measurements, a stand-alone seismic stations has been used with accelerated weight drop with in-house modifications and timing system. Seismic profiles were acquired in a time-lapse manner and were supported with GPR and ERT measurements, and continuous temperature monitoring in shallow boreholes.

Joint interpretation of seismic and auxiliary data using Multichannel analysis of surface waves, First arrival travel-time tomography and Reflection imaging show clear seasonal changes affecting the active layer where P-wave velocities are changing from 3500 to 5200 m/s. This confirms the laboratory measurements showing doubling the seismic velocity of water-filled high-porosity rocks when frozen. The same laboratory study shows significant (>10%) increase of velocity in frozen low porosity rocks, that should be easily visible in seismic.

In the reflection seismic processing, the most critical part was a detailed front mute to eliminate refracted arrivals spoiling wide-angle near-surface reflections. Those long offset refractions were however used to estimate near-surface velocities further used in reflection processing. In the reflection seismic image, a horizontal reflection was traced at the depth of 120 m at the sea coast deepening to the depth of 300 m near the mountain.

Additionally, an optimal set of seismic parameters has been established, clearly showing a significantly higher signal to noise ratio in case of frozen ground conditions even with the snow cover. Moreover, logistics in the frozen conditions are much easier and a lack of surface waves recorded in the snow buried geophones makes the seismic processing simpler.

Acknowledgements

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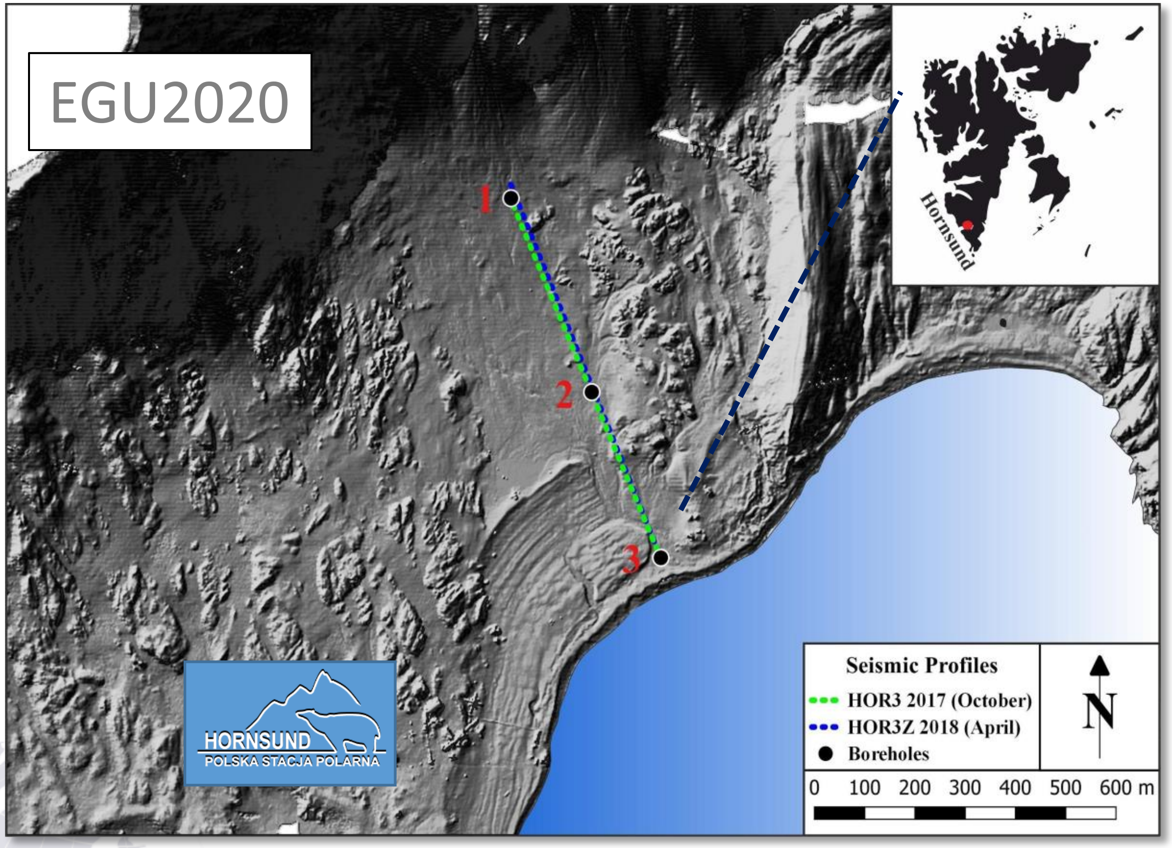
Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland

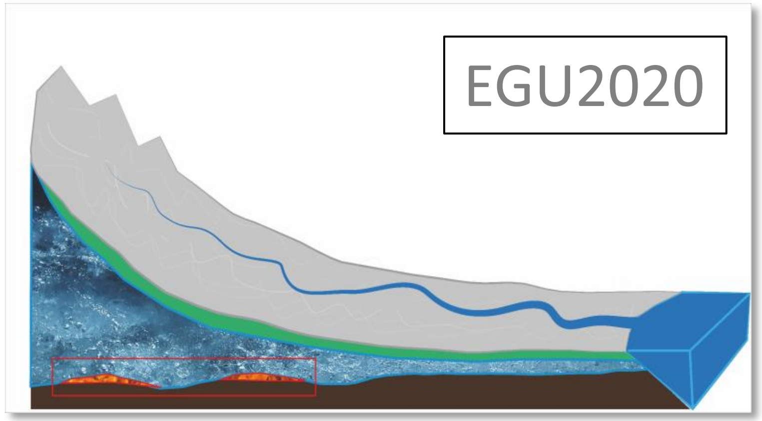
Department of Earth Sciences, University of Silesia, Sosnowiec, Poland

UNIVERSITY OF SILESIA IN KATOWICE

Institute of Geophysics Polish Academy of Sciences

Study area – Hornsund, Spitsbergen





Questions:
Can seismic image the shape of permafrost?
What is the optimal acquisition for that?
Which seismic methods are suitable for this task?

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Fieldwork – Two Arctic Campaigns

2017 October

- 3 Seismic lines
- Parameters testing

2018 April

- 2 Seismic lines
- 6 Boreholes up to 20 meters with thermal monitoring
- GPR data on each profile with time-lapse measurements

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Seismic data acquisition & processing

Acquisition:

PEG-40 accelerated weight drop – in-house modification

GPS based timing system (by IG PAS)

60 Stand alone DATA-CUBE stations

with 4.5Hz geophones (1C & 3C)

Shot spacing – 2 m in 2017 and 2.5 m in 2018

+ 20 m extra offsets on both sides

Receiver spacing – 2 m in 2017 and 5 m in 2018

Pre-processing:

Repeated sources (4-5 times) – manual QC (removed first strike)

Manual front mute (!)

Multistep velocity analysis

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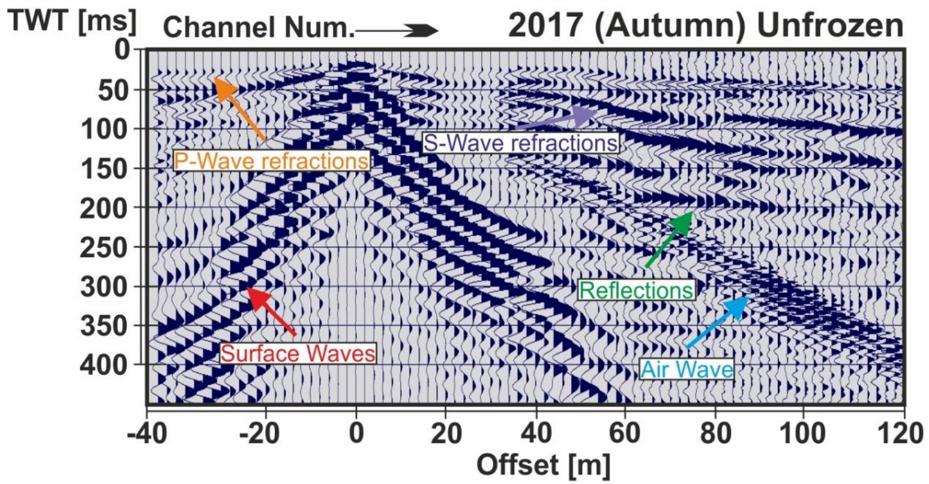
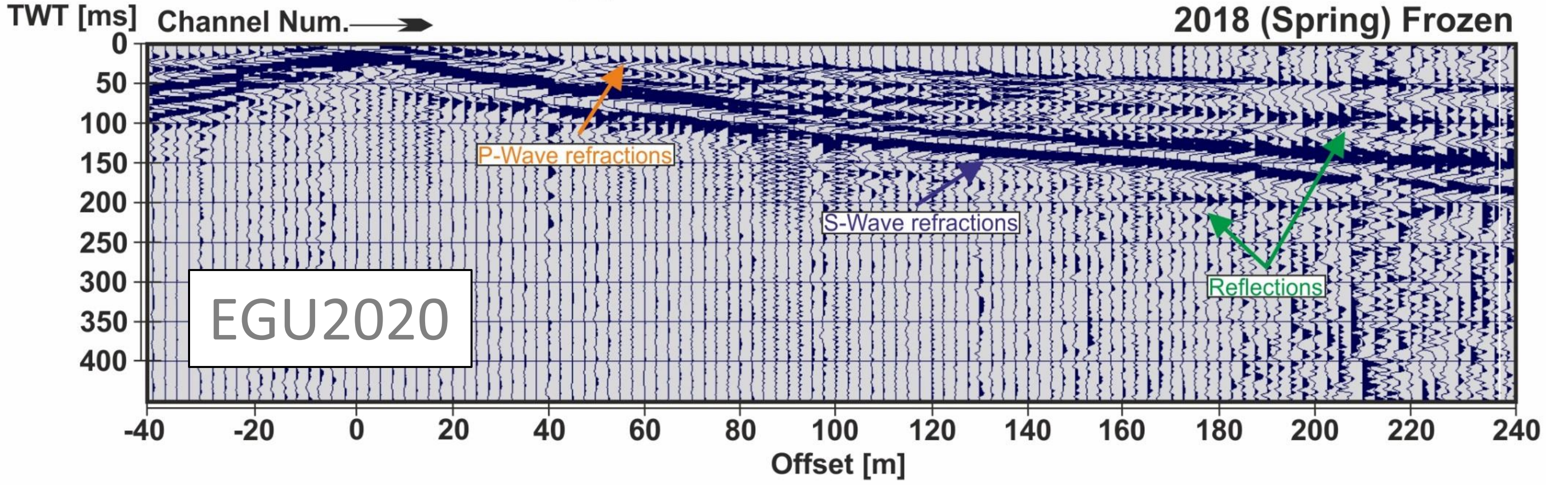
Seasonal variability of seismic wavefield



Seasonal Velocity Variation

[m/s]	2017	2018
Vp	3500	5200
Vs	1300	2300
Rayleigh	360	----



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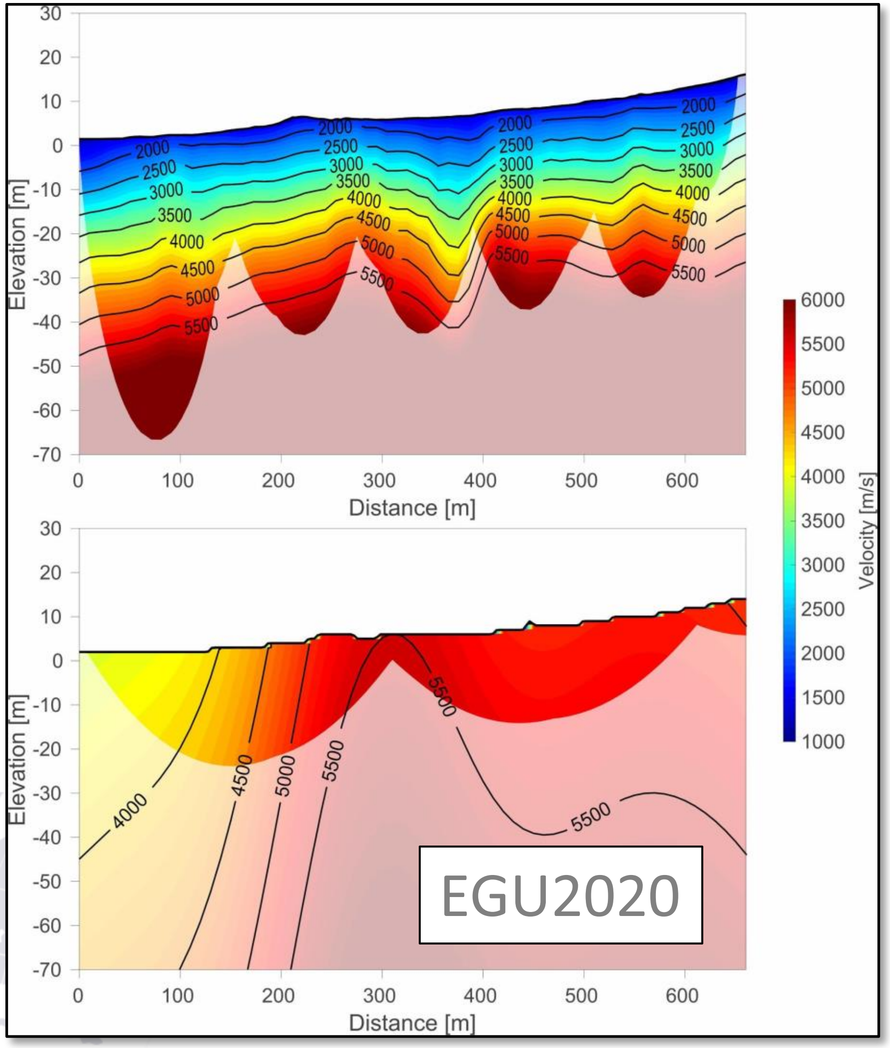
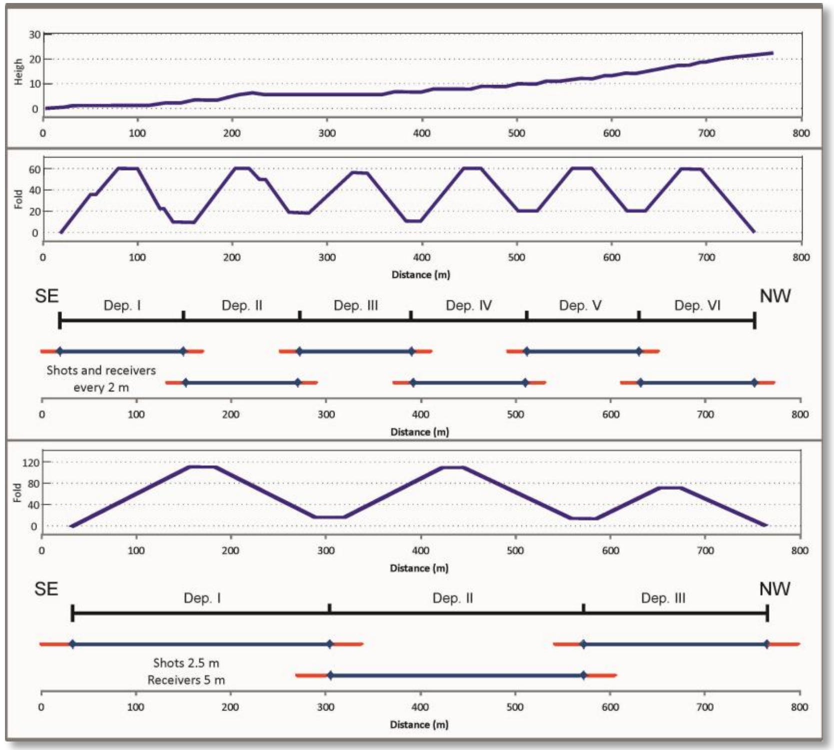
First breaks tomography



2017

2018



Schematic acquisition geometry
Walking deployments with extra offset shots

Significant seasonal difference in near-surface Vp values

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Conclusions

- Geophysical (seismic) imaging of the permafrost is possible and precise
- Active layer maximal thickness and its spatial variability is significantly larger than previously expected
- Seismic measurements during the winter period (frozen ground)
    - results in higher data quality,
    - are easier to process and
    - much simpler to acquire in the field

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