Temporary seismic network on drifting ice in the North Barents Sea

Andrey Jakovlev (1, 2), Sergey Kovalev (3), Evgeniy Shimanchuk (3), Egor Shimanchuk (3), Aleksey Nubom (3)

1. IPGG SB RAS, Geophysics, Novosibirsk, Russian Federation (jakovlevav@ipgg.sbras.ru)
2. Novosibirsk State University, Novosibirsk, Russian Federation
3. Arctic and Antarctic Research Institute, Sankt-Petersburg, Russian Federation

EGU2020-6385
EGU General Assembly 2020

Seismic investigations in Arctic region

- During the last decades, due to political and economic reasons the Arctic region has become a priority target for several countries. There are several international and national multidisciplinary programs that accumulate and analyze the scientific data on the Arctic. However, these studies face with many difficulties due to the harsh climatic conditions and high expenses.

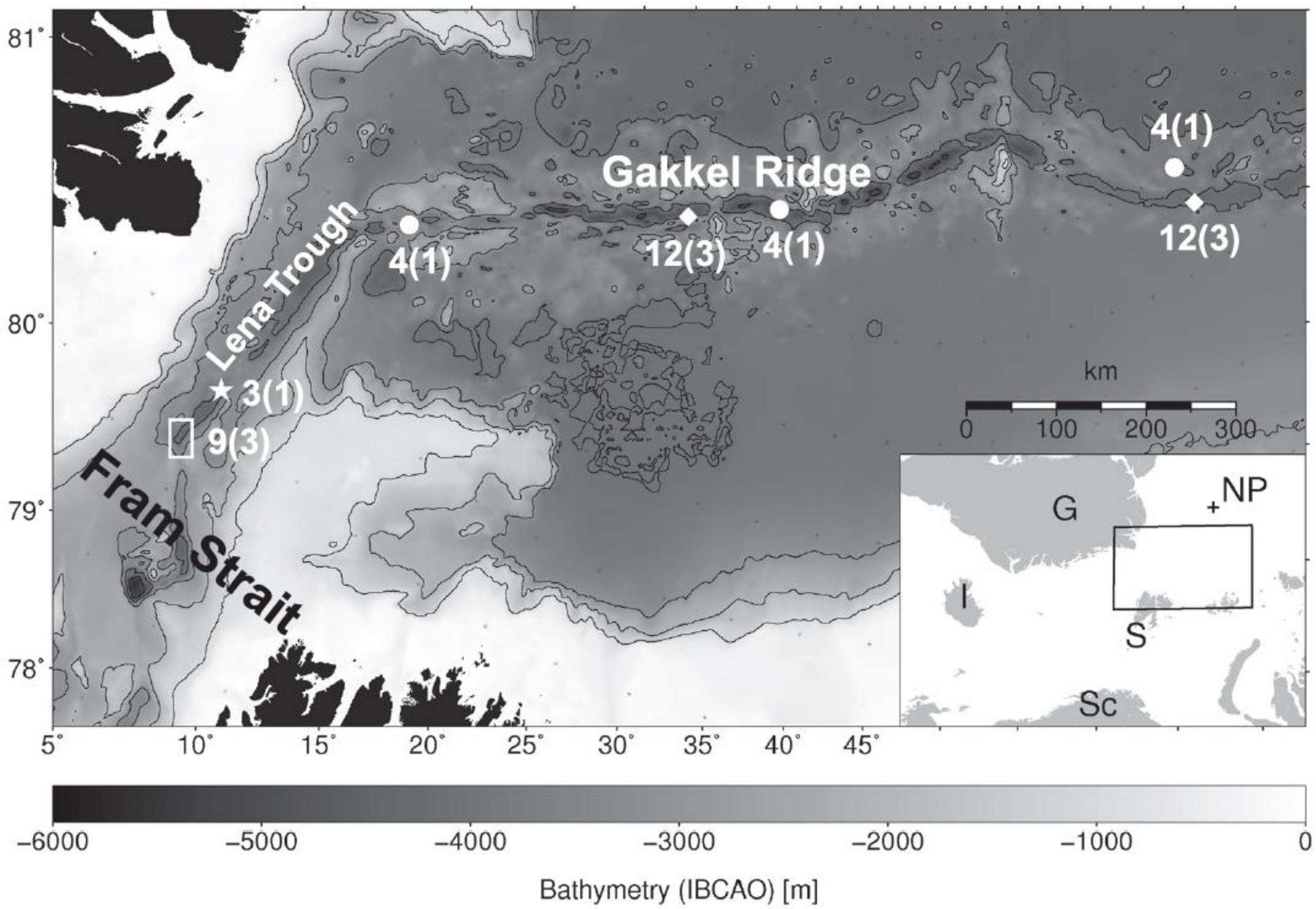
- One of the important topics is the distribution of seismicity. Based on the global seismic networks, most of the presently detected earthquakes are localized along the Gakkel Ridge; the other areas of the Arctic appear to be aseismic. However, the actual distribution can be different, because the remote stations are able to record only strong events, whereas the moderate and weak seismicity may remain unidentified due to lack of regional networks.

Photo by A. Jakovlev

- Detailed studies of the crustal structures and background seismicity require deployment of dense networks of seismic stations, which is extremely difficult in the Arctic conditions. For example, deploying bottom seismometers in the Arctic Ocean is risky because of the unpredictable behavior of the ice flows. Installing stations on islands does not provide sufficient coverage to illuminate most parts of the Arctic region.

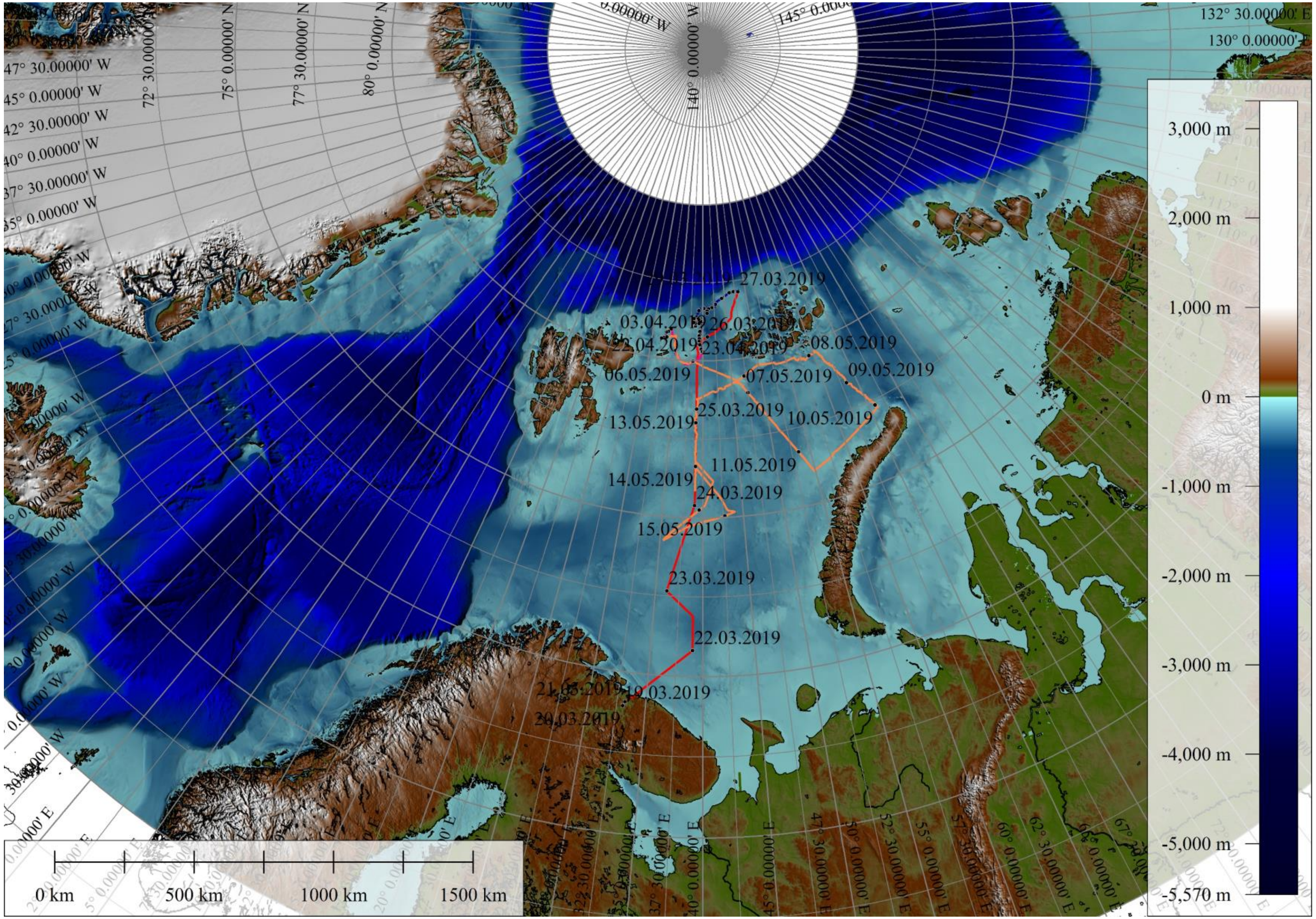
Previous seismic experiments on floating ice floes

One of the possible ways to investigate the offshore Arctic areas is installing seismic networks on ice floes. The first experiences of such installations were performed by the Alfred Wegener Institute (AWI) Bremerhaven (Schlindwein et al. 2007; Laderach and Schlindwein, 2011). They have shown that such floating networks are capable to detect the seismic signal from local and regional earthquakes.



Overview of the Arctic Ocean with the locations of the seismic arrays with orientation map (inset at lower right corner) of the study area. Circles: AMORE 2001 deployment; diamonds: AGAVE 2007; rectangle: LENA 2008; star: LENA 2009. White numbers show the respective number of stations and arrays in brackets. Abbreviations in orientation map: G = Greenland, I = Iceland,
NP = North Pole, S = Svalbard, Sc = Scandinavia. IBCAO 2 bathymetry (Jakobsson *et al.* 2008) with contour lines (1,000 m spacing).
(Figure from Laderach and Schlindwine, 2011)

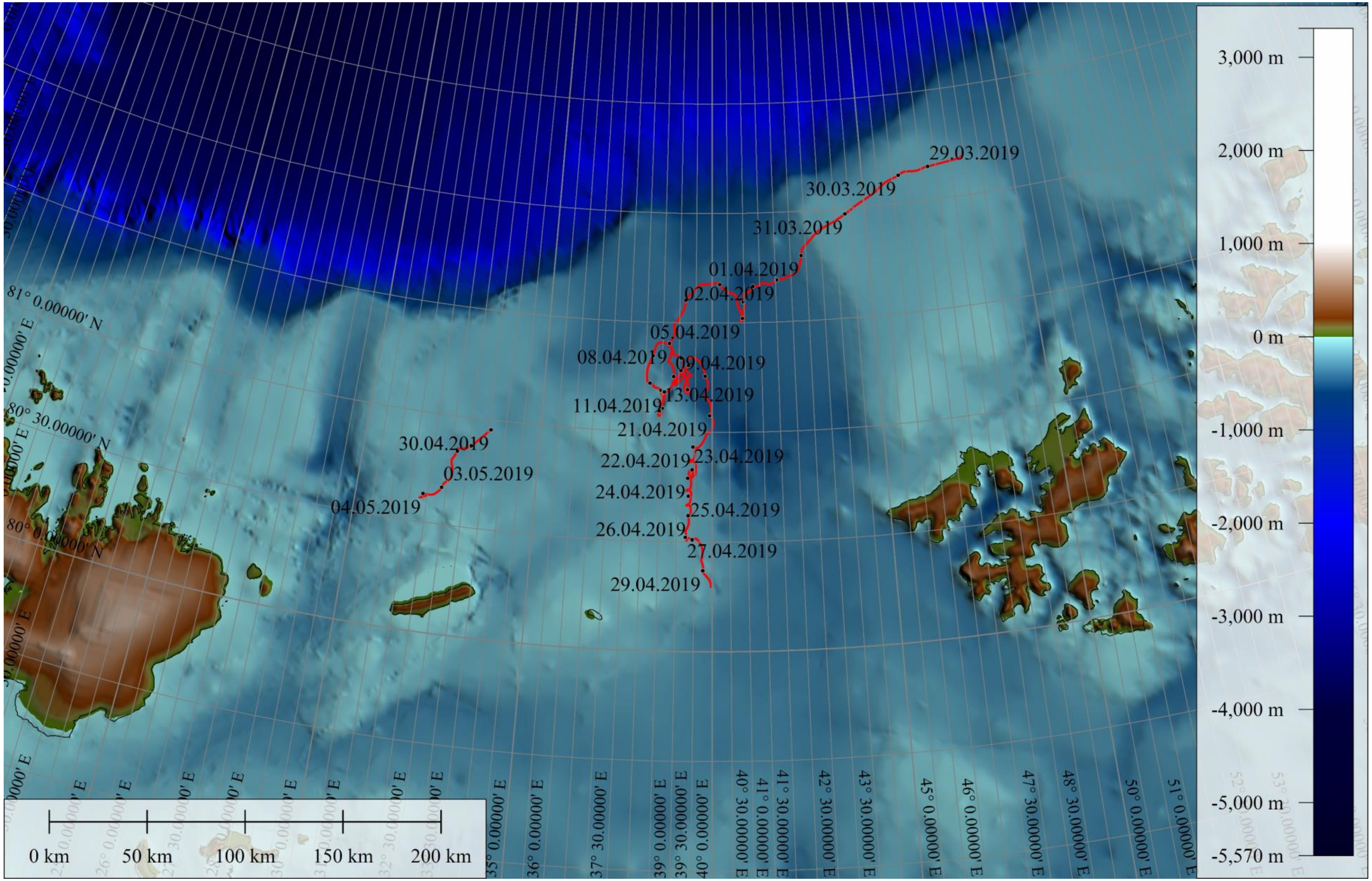
“TransArctica 2019” Expedition



Track of the EV “Akademik Tryoshnikov” during “TransArctica 2019” expedition. Bathymetry (Ryan et al., 2009) is shown according to the scale.

From March to May 2019, a seasonal scientific expedition on the Expedition Vessel “Akademic Tryoshnikov” (EV “Akademik Tryoshnikov”) operated by the Federal State Budgetary Institution "Arctic and Antarctic Research Institute" (AARI) that belongs to Russian Federal Service for Hydrometeorology and Environmental Monitoring (Rosgidromet) were conducted in the framework of the first stage of the “TransArctica 2019” program. The scientific program of the expedition included multidisciplinary investigations with collaboration of many institutions from Russia and Europe.

“TransArctica 2019” Expedition

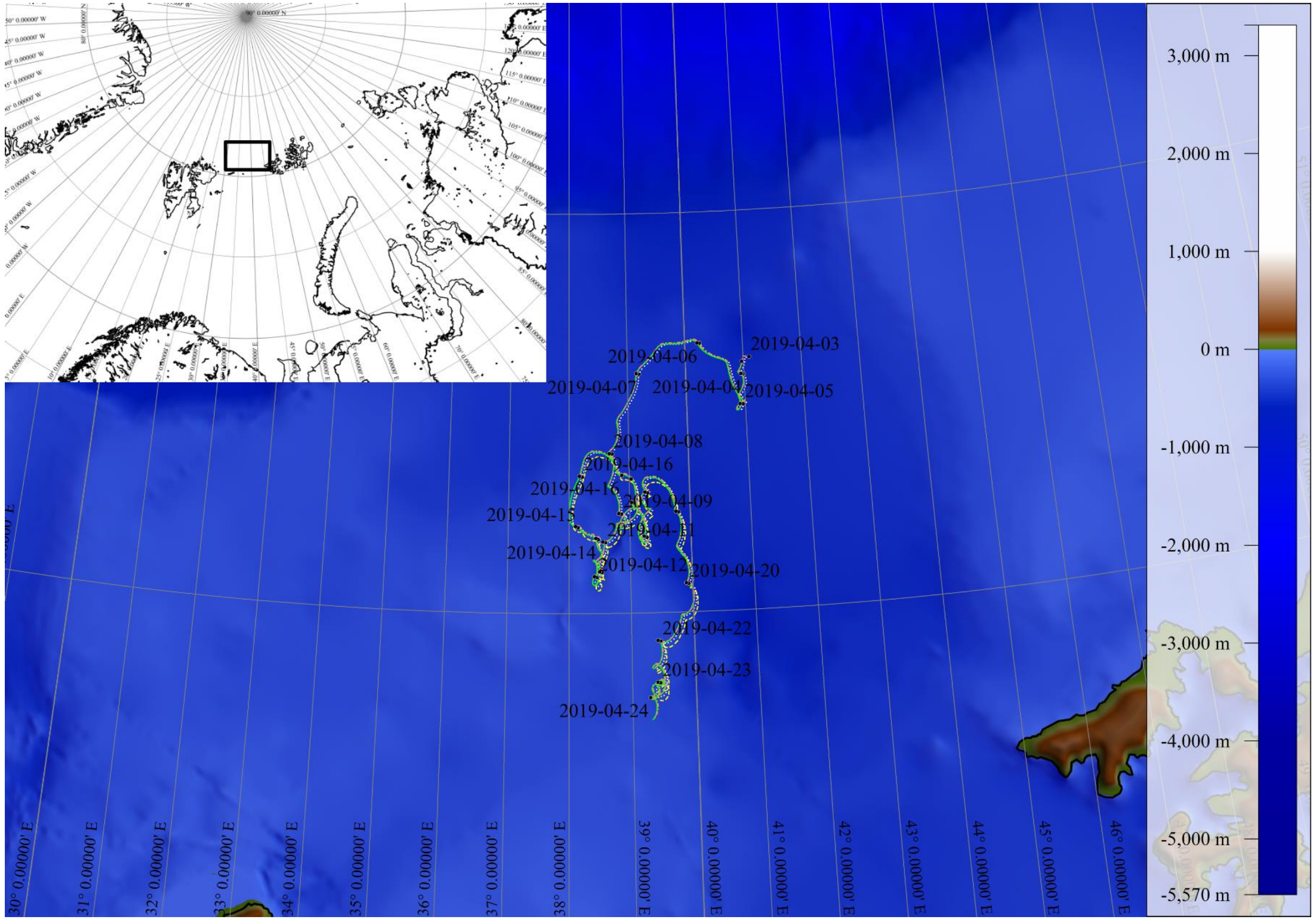


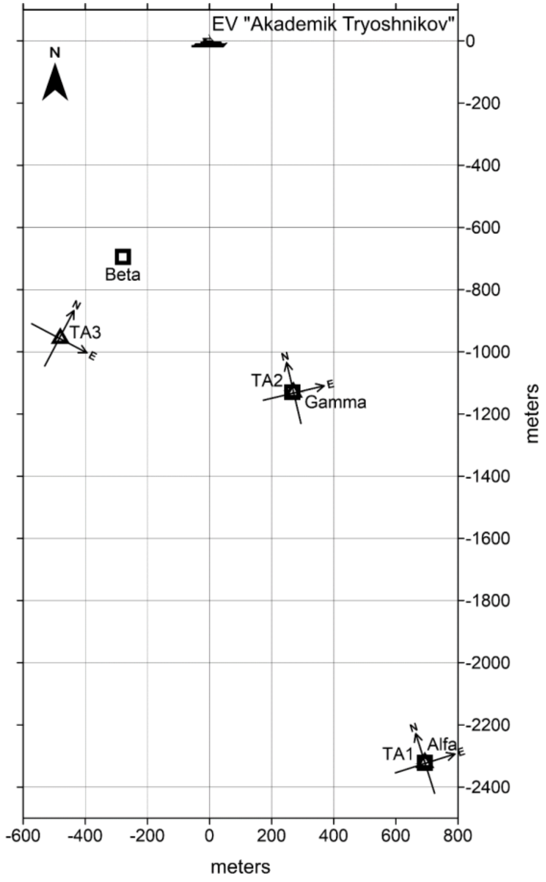
Tracks of the the EV “Akademik Tryoshnikov” during passive drift. Bathymetry (Ryan et al., 2009) is shown according to the scale.

Seismic Experiment

In the framework of the seismological experiments six temporary seismic stations at four different locations were installed on a drifted ice floe in the North Barents Sea. The stations were installed in the April 2019 on the ice floe near the EV “Akademik Tryoshnikov” that were “frizzed” in the ice floes and drifted together with them. Four stations (TA2, TA3, Beta and Gamma) were installed at 3 different locations on 3rd of April and the last two stations (TA1 and Alfa) were installed at one location on 10th of April. Stations TA1, TA2, Alfa and Gamma were picked up on 23rd of April and stations TA3 and Beta on 24th of April.

Left. Map with trajectory of the stations drift. Bathymetry (Ryan et al., 2009) is shown according to the scale. Location of the region where experiment was conducted is shown in the inset.
Right. Scheme of the stations position relative to the vessel at 12:00UTC on April 10th, 2019 are shown. Arrows indicates orientations of the North and East components of the seismic sensors at TA1, TA2 and TA3 stations.





Instrument description

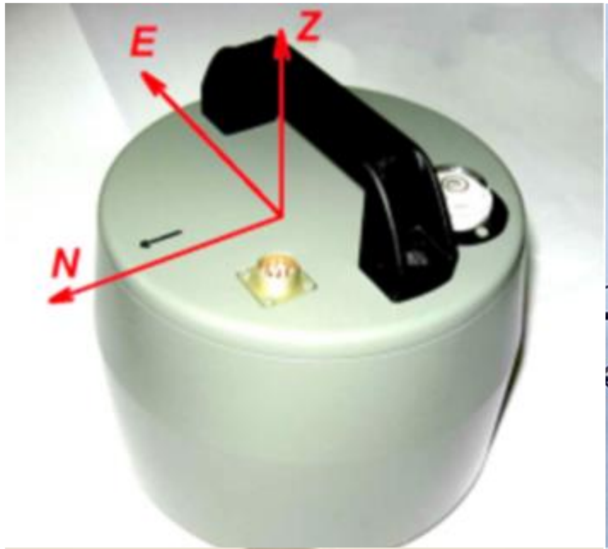
Two different instrument configurations were used in the seismic experiment. Three stations were deployed by IPGG (TA1, TA2, TA3) and another three stations by AARI (Alfa, Beta, Gamma). The IPGG stations were composed of the Guralp CMG-6T (30 sec) sensor and the DataCube^3 ext logger. A Breakout Box (BoB) which decreases the amplitude of the signal by 10 times is used to connect the sensor and logger. Sample rate were set to 200 Hz, gain of the logger is set to 2, three components were recorded (north, east and vertical). The north component of the IPGG sensors was oriented toward position of the vessel GPS antenna. Current GPS coordinates were recorded every 30 minutes. The block of 8 batteries “Baken VC1” connected in series was used as power source. Each battery has voltage of 2.6 V and capacity of 350 A*h.

Photo by A. Jakovlev

Photo by A. Jakovlev

Instrument description

The AARI stations were composed of CME-4311-LT sensor and Baykal-8 logger, both Russia designed instruments. In addition, the inclinometers IN-D3a-360 were installed at stations Beta and Gamma. Sample rate for the seismometers were set to 100 Hz. At stations Beta and Gamma five component were recorded (north, east, vertical and two orthogonal inclination components). The north component of the AARI seismometers and X-component of the inclinometers were oriented toward North at the installation time. The recorded data were saved to the internal memory of the logger and telemetrically transmitted to the vessel via radio channel and with the use of one repeater antenna deployed on a halfway. The 12 V accumulator was used as power source for this instrument configuration.

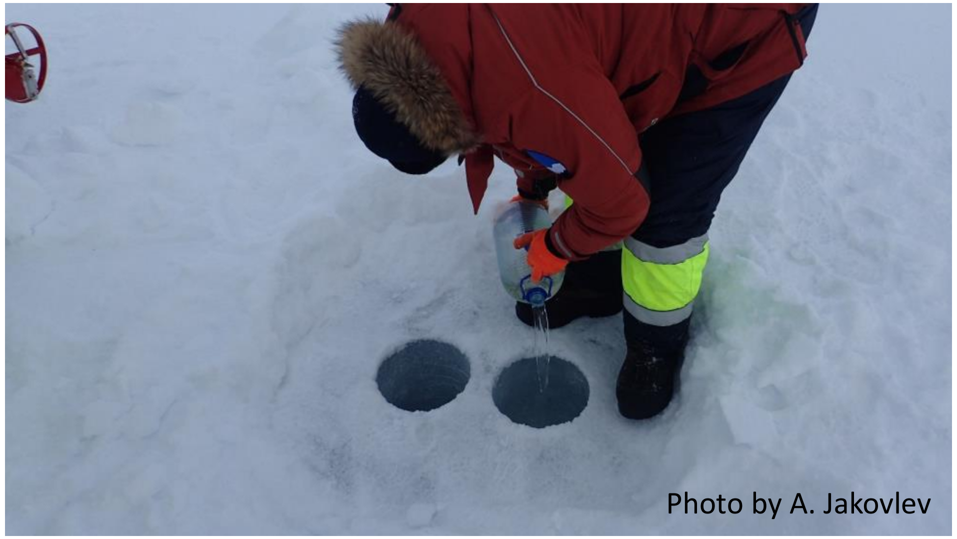


Instrument description

Station name	Sensor	Logger type	Registered Channels	Sample rate	Gain
TA1	Velocimeter Guralp CMG-6T (30 sec)	DataCube^3 ext with BoB (10:1)	North, East, vertical	200 Hz	2
TA2	Velocimeter Guralp CMG-6T (30 sec)	DataCube^3 ext with BoB (10:1)	North, East, vertical	200 Hz	2
TA3	Velocimeter Guralp CMG-6T (30 sec)	DataCube^3 ext with BoB (10:1)	North, East, vertical	200 Hz	2
Alfa	Velocimeter CME-4311-LT	Baykal-8	North, East, vertical	100 Hz	1
Beta	Velocimeter CME-4311-LT and inclinometer IN-D3a-360	Baykal-8	North, East, vertical, X,Y	100 Hz	1
Gamma	Velocimeter CME-4311-LT and inclinometer IN-D3a-360	Baykal-8	North, East, vertical, X,Y	100 Hz	1

Table 1. Instruments description

Stations deployment



Basement preparation: A hole of 20 cm in diameters and ~30 cm depth were drilled in the ice. First we try to use a fresh water to produce a flat ice base, but after several hours the holes were filled by salt water. Therefore, a wooden basement was hammered into the hole and frizzed in.

Stations deployment


Photo by A. Jakovlev


Photo by A. Jakovlev


Photo by S. Nickolaev


Photo by A. Jakovlev


Photo by A. Jakovlev

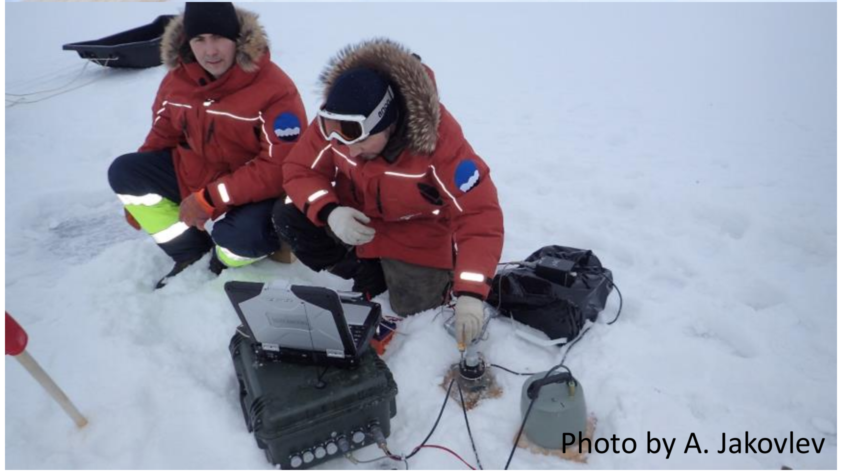


Photo by A. Jakovlev

Sensor installation and connection of the cables.

Stations deployment

Photoplan of the ice camp.
11.04.2019.

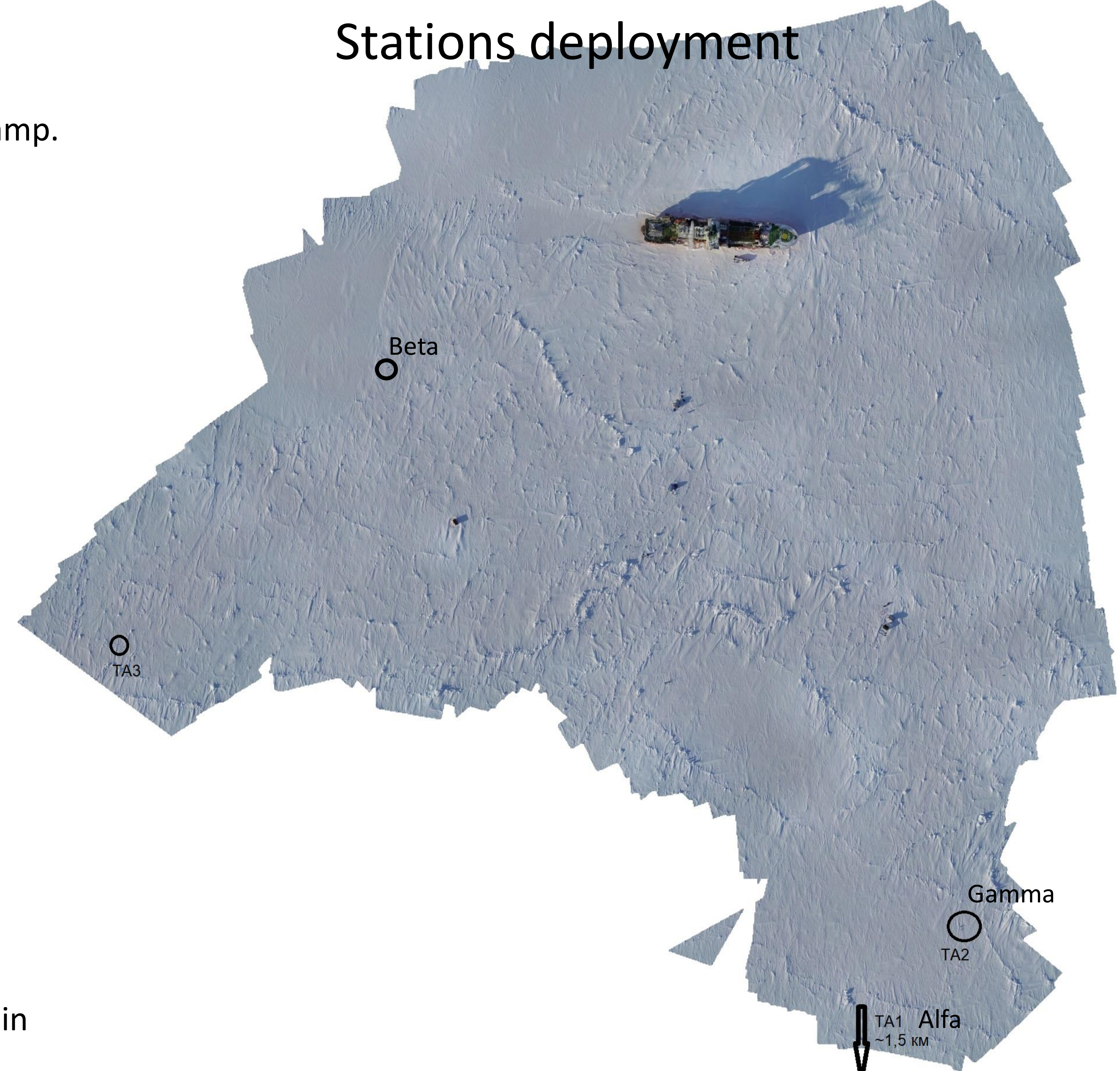
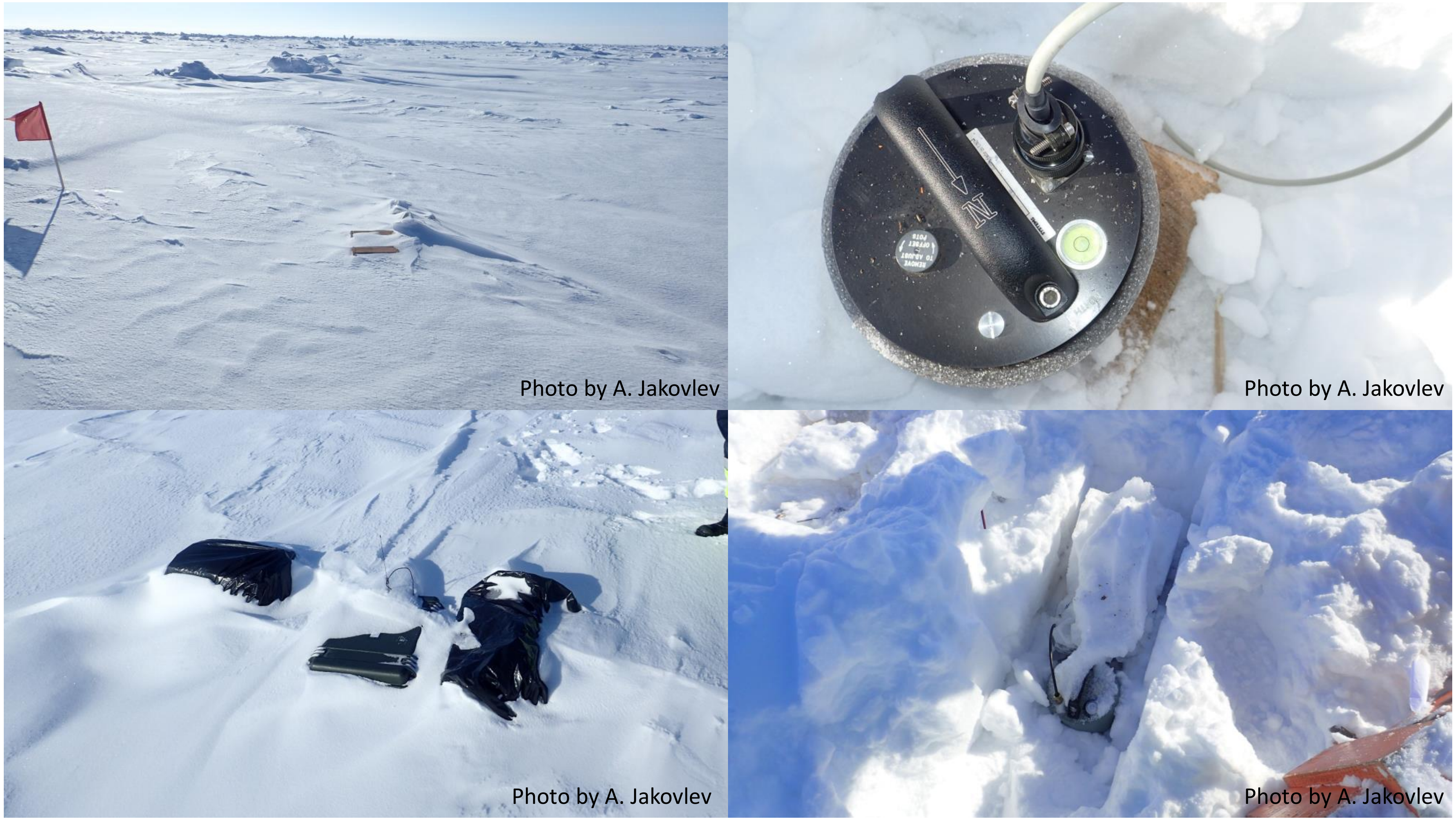


Photo by Andrey Paramzin

Seismic experiment

Photo of the ice field on 23rd of April. At this day stations TA1, Alfa, Gamma were removed.

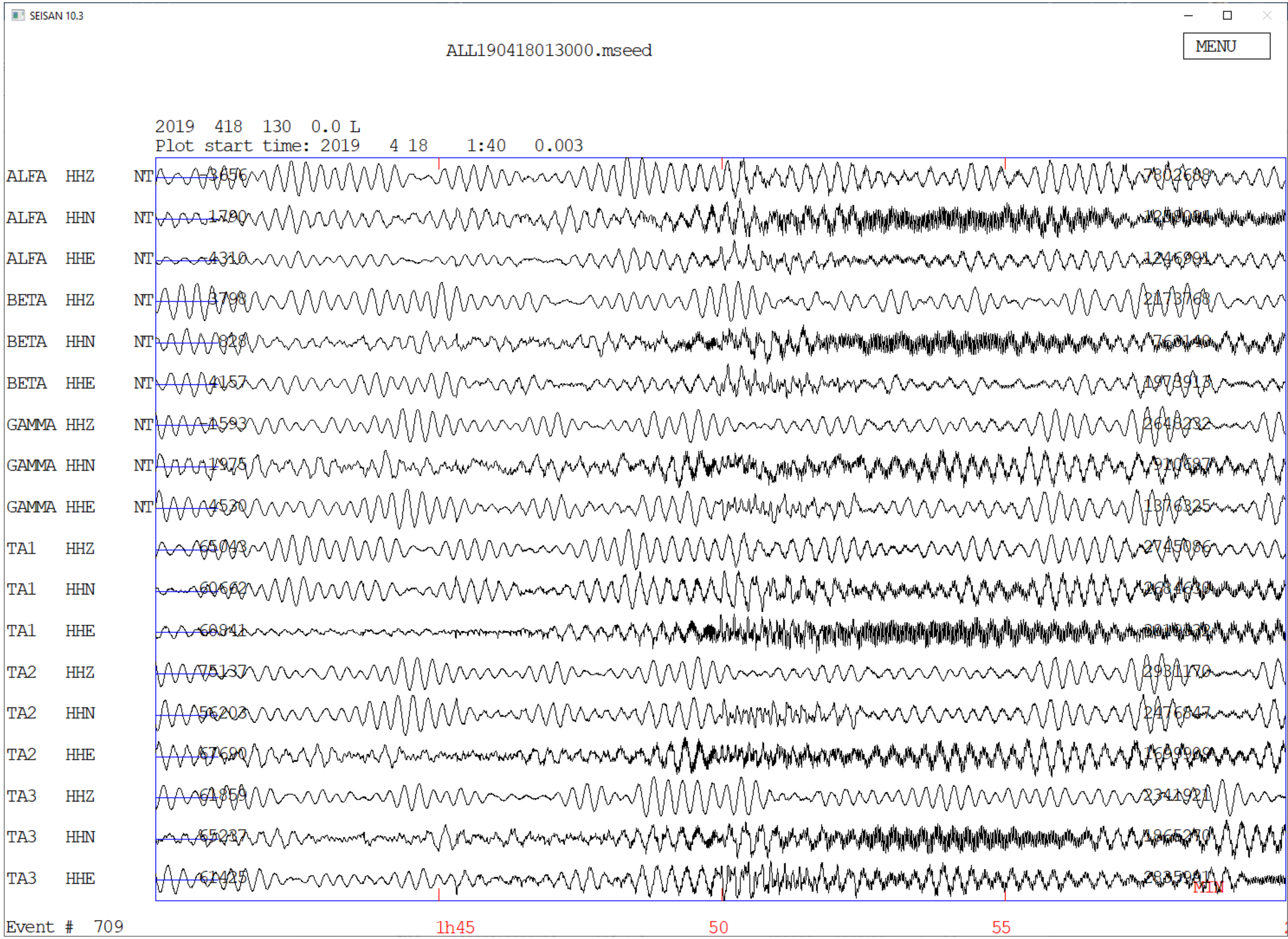
Seismic experiment



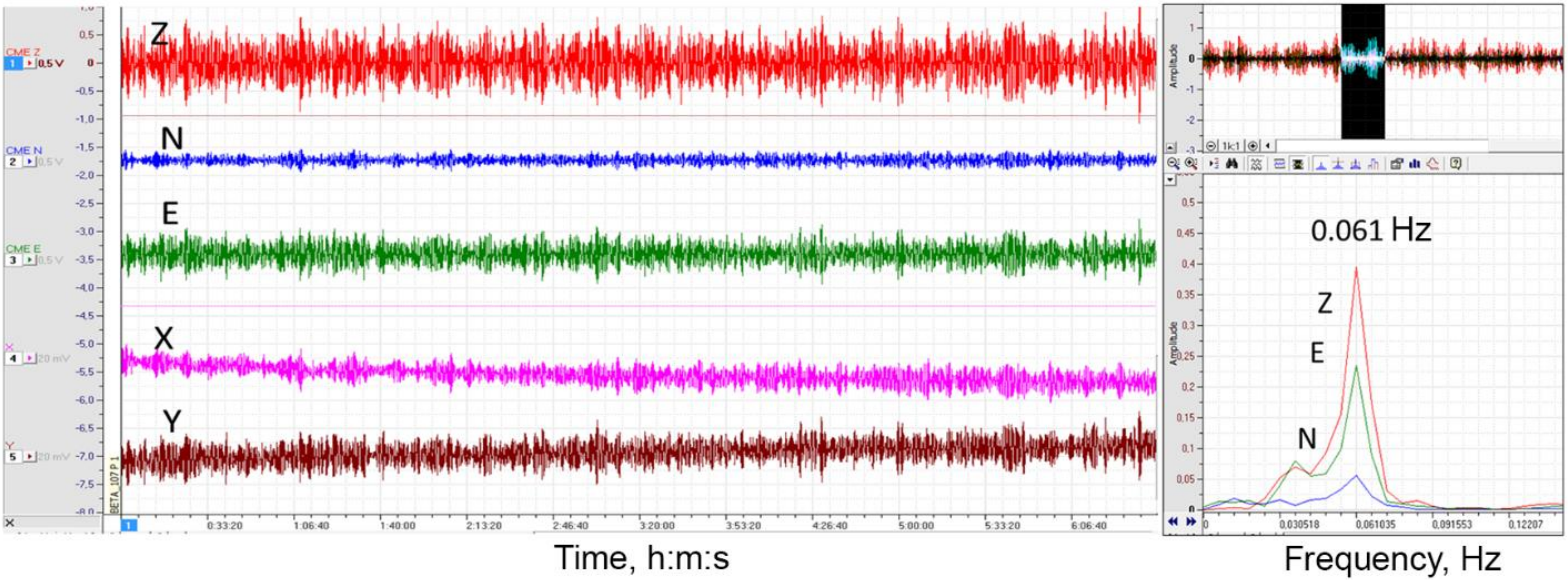
Stations at the last day of operation period (24.04.2019).

Examples of recorded data

After analysis of the recoded data, the several types of the seismic signal generated by processes in the ice were observed.
Background signal from bending-gravitational waves with periods from 1 to 10 sec was observed with strong gusts of wind and with crack formation.
Swell waves with periods from 17 to 30 sec were observed permanently during the whole period of network operation.
SAISAN software is used for data visualization (Havskov and Ottemoller, 1999).



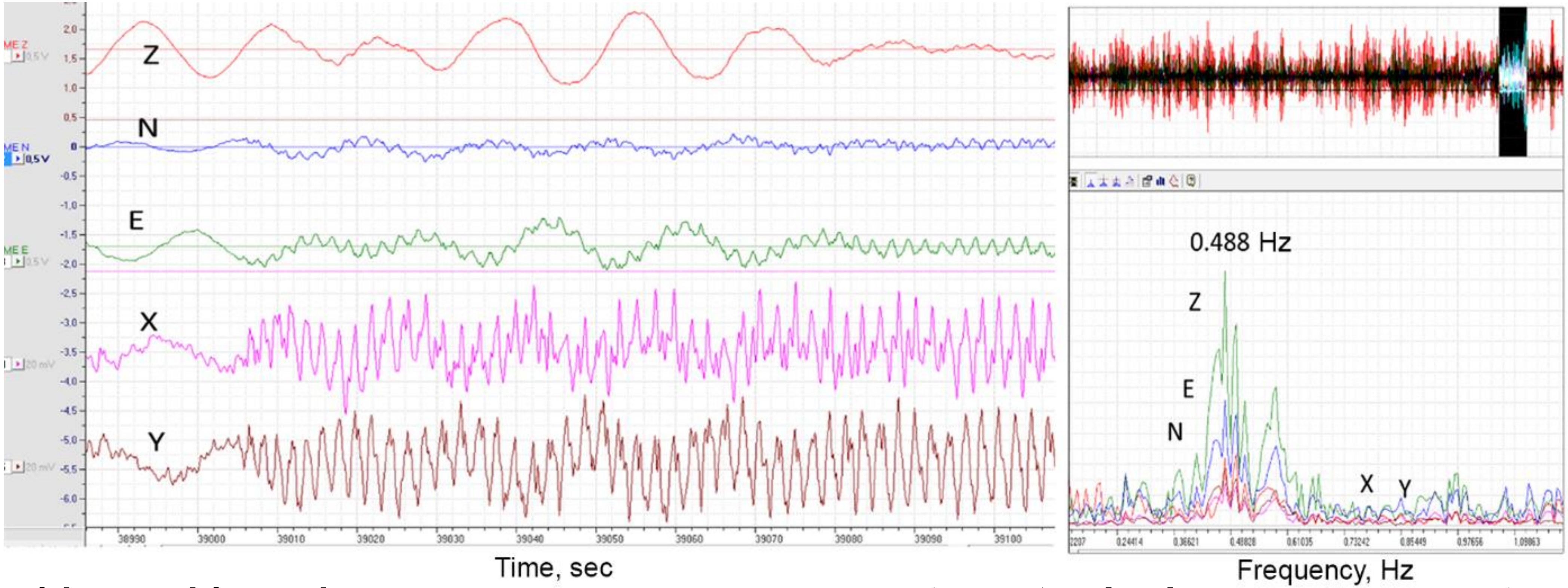
Examples of recorded data



Example of the swell waves record, April 18th 2019. Original records from a three-component seismometer CME-4311 (Z, N, E) and inclinometers IN-D3a-360 (X, Y). The amplitude spectrum of the record of a three-component seismometer Z, N, E. Window length 20 minutes. The maximum amplitude on the vertical component at period of 14–18 sec reached 18 mm. Station Beta, April, 17 2019.

Examples of recorded data

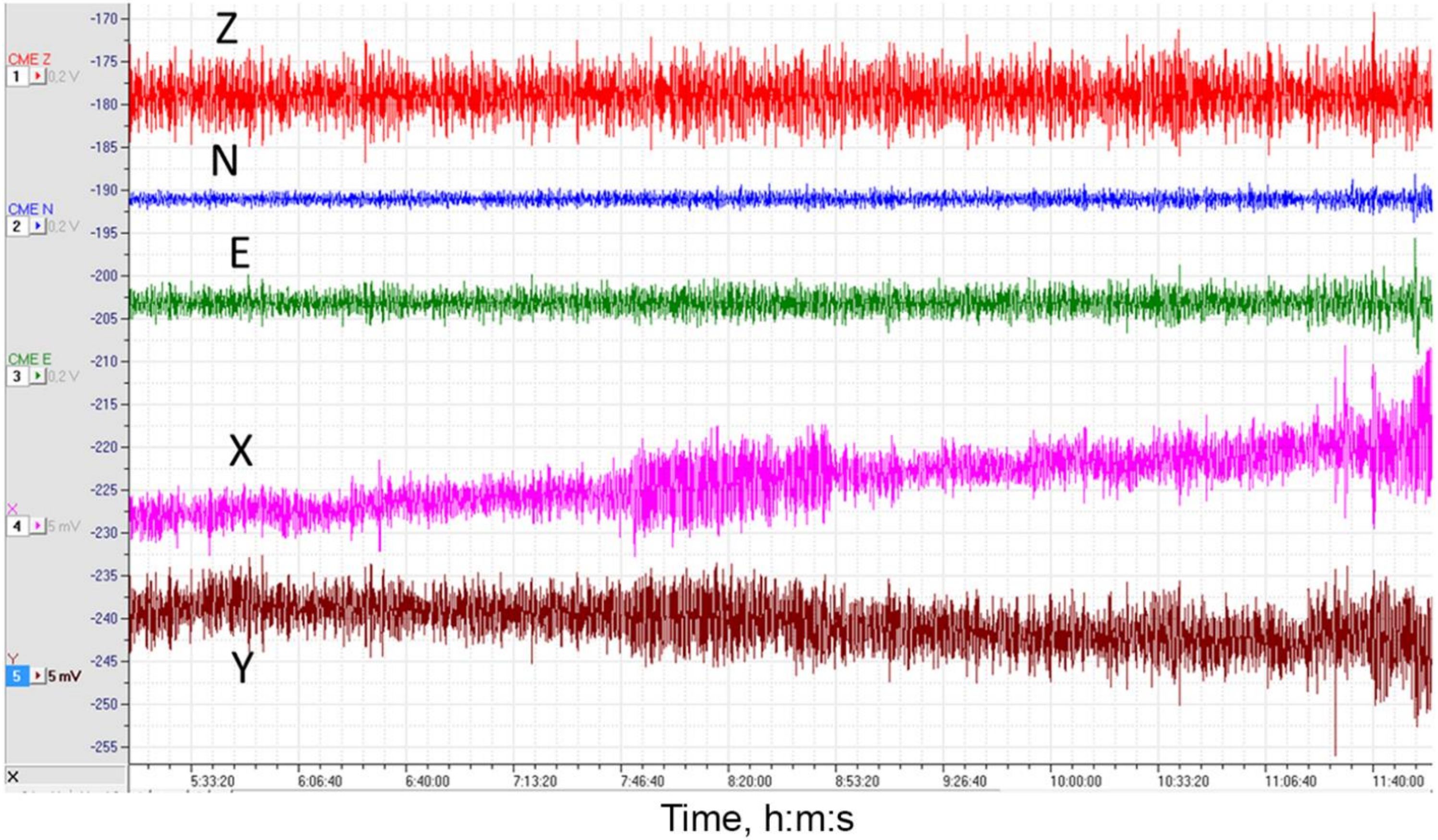
Continuous mechanical vibrations (self-oscillations) with a period of up to 2-3 sec. This process was observed in the ice cover by all stations at a base of up to 2 km. That kind of information in real time and at a great distance was obtained for the first time. The considered example for the first time indicates the possibility of studying the processes of deformation mechanics and faults of drifting ice cover in real time. Note that this process was recorded at different points with various intensities and it is not yet clear why. We assume that this could be due to an inhomogeneous structure of the ice field, the peculiarities of the propagation of registered waves, etc.



A fragment of the record from a three-component seismometer CME-4311 (Z, N, E) and inclinometer IN-D3a-360 (X, Y) and its amplitude spectrum. The window length is 15 minutes. The peaks in the spectrum are observed at 0.4 – 0.6 Hz. Station Beta, April, 17 2019.

Examples of recorded data

Special attention is paid to the initial monitoring data during the period of cracks formation and fracture of the ice cover. Figure shows the records for the 6-hour period when a wide spectrum of wave processes was recorded both before the formation of cracks and after breaking the ice field. Throughout the entire process, a gradual tilt of the ice surface was noted. Data on this process continues to be processed with considering data from meteorology, oceanology and satellite images.



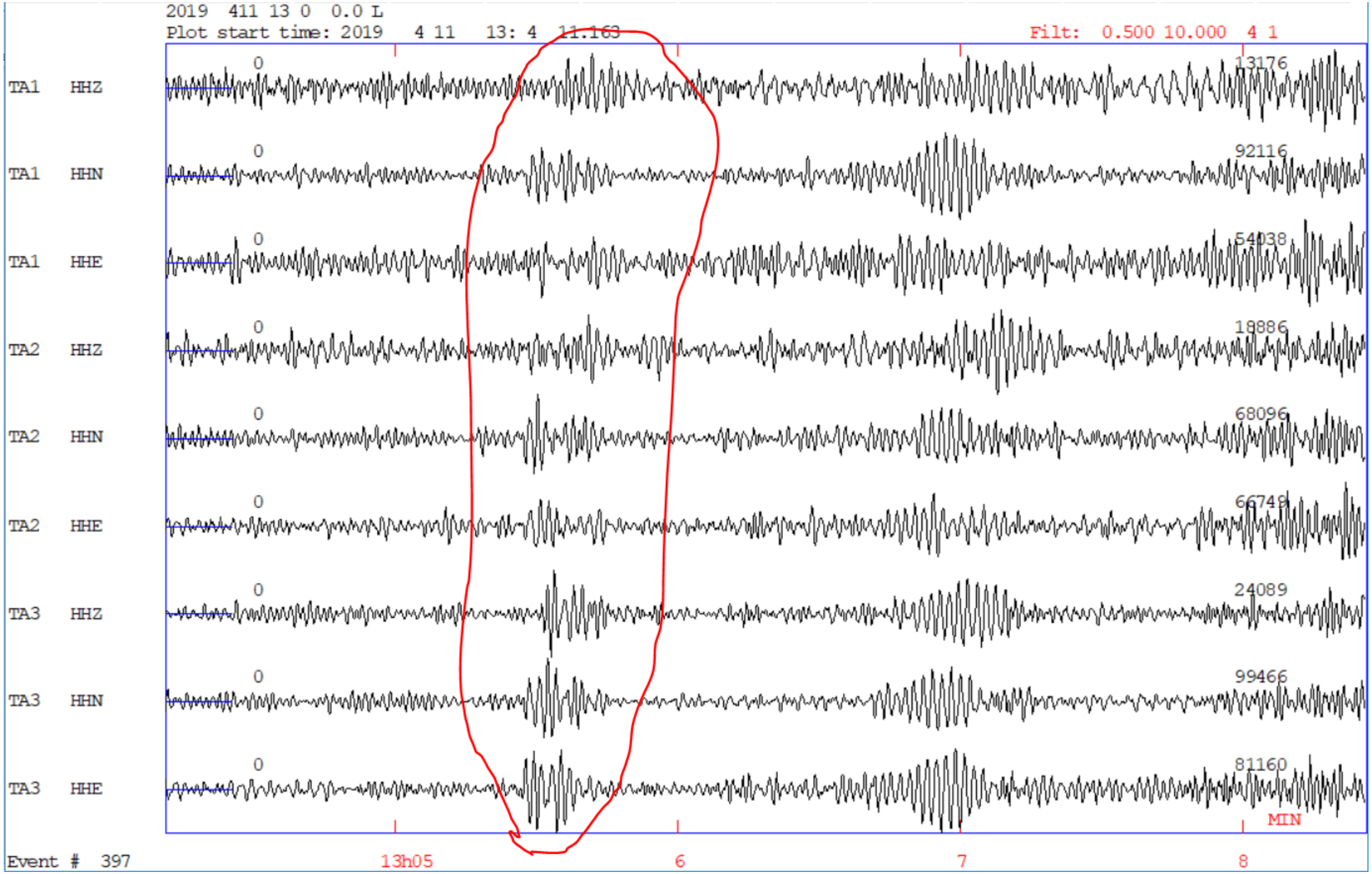
Record of the swell waves during the ice shear movements and formation of cracks in the ice field. Data from a three-component seismometer CME-4311 (Z, N, E) and inclinometer IN-D3a-360 (X, Y). The scale on X and Y components is increased by 2.5 times for comparison. The duration of the process is 6 hours. Station Beta, April, 12 2019.

Ice monitoring results

- In the most cases there are no direct correlations of processes within the ice floes and local hydrometeorological condition.
- During the process of ice cover, fracturing an increased value of the ice horizontal movement were observed.
- Analysis of the seismic signal from ice events has shown that stick-slip events preceded origin of the ice fractures.
- Information about periodicity of the stick-slip events and duration of the self-oscillation processes could be used for short-term forecast of the ice cover disruption.

Examples of recorded data

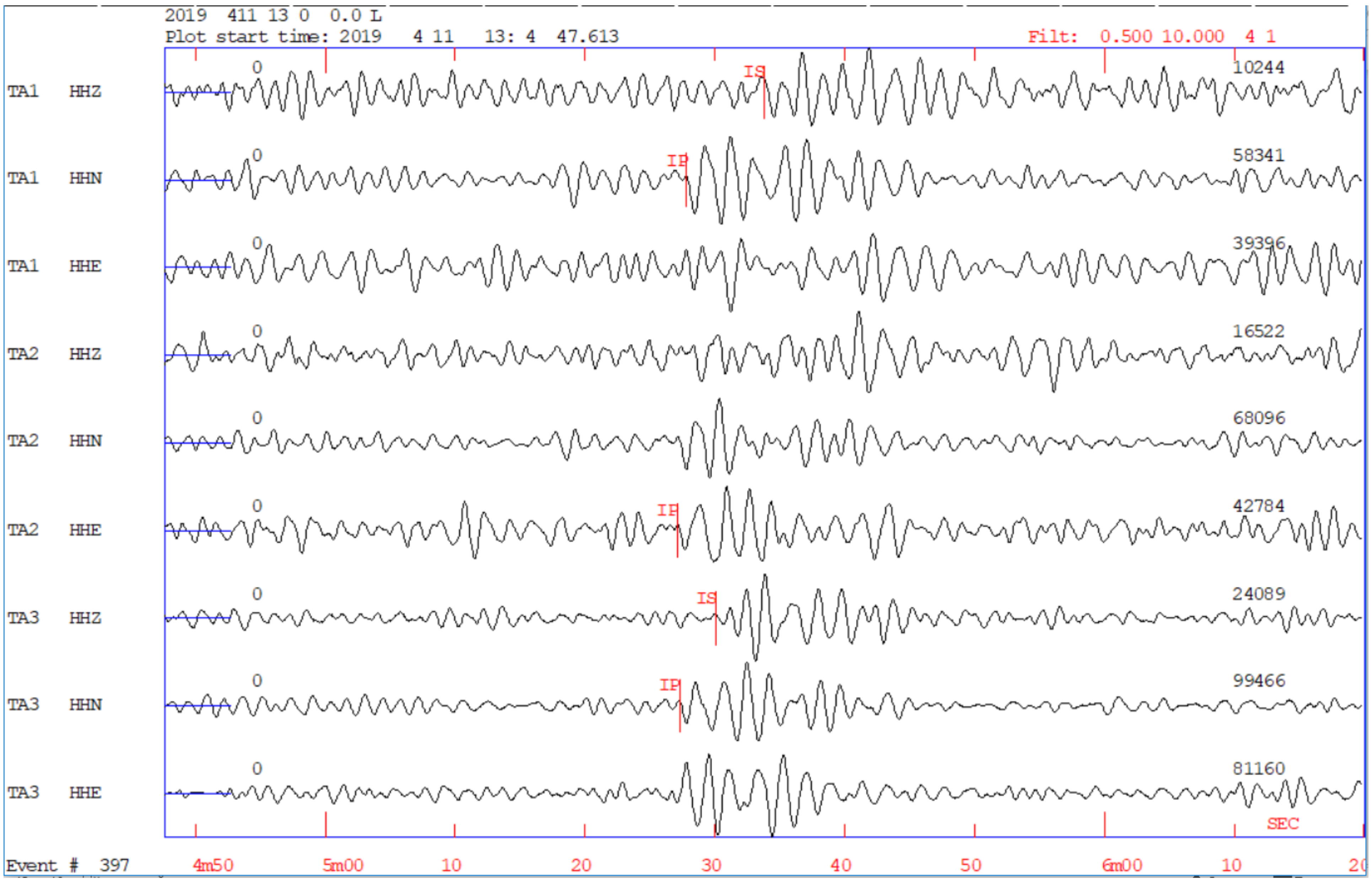
Example of the icequake. SAISAN software is used for data visualization (Havskov and Ottemoller, 1999).



Note: Signal observed on vertical and horizontal components.

Examples of recorded data

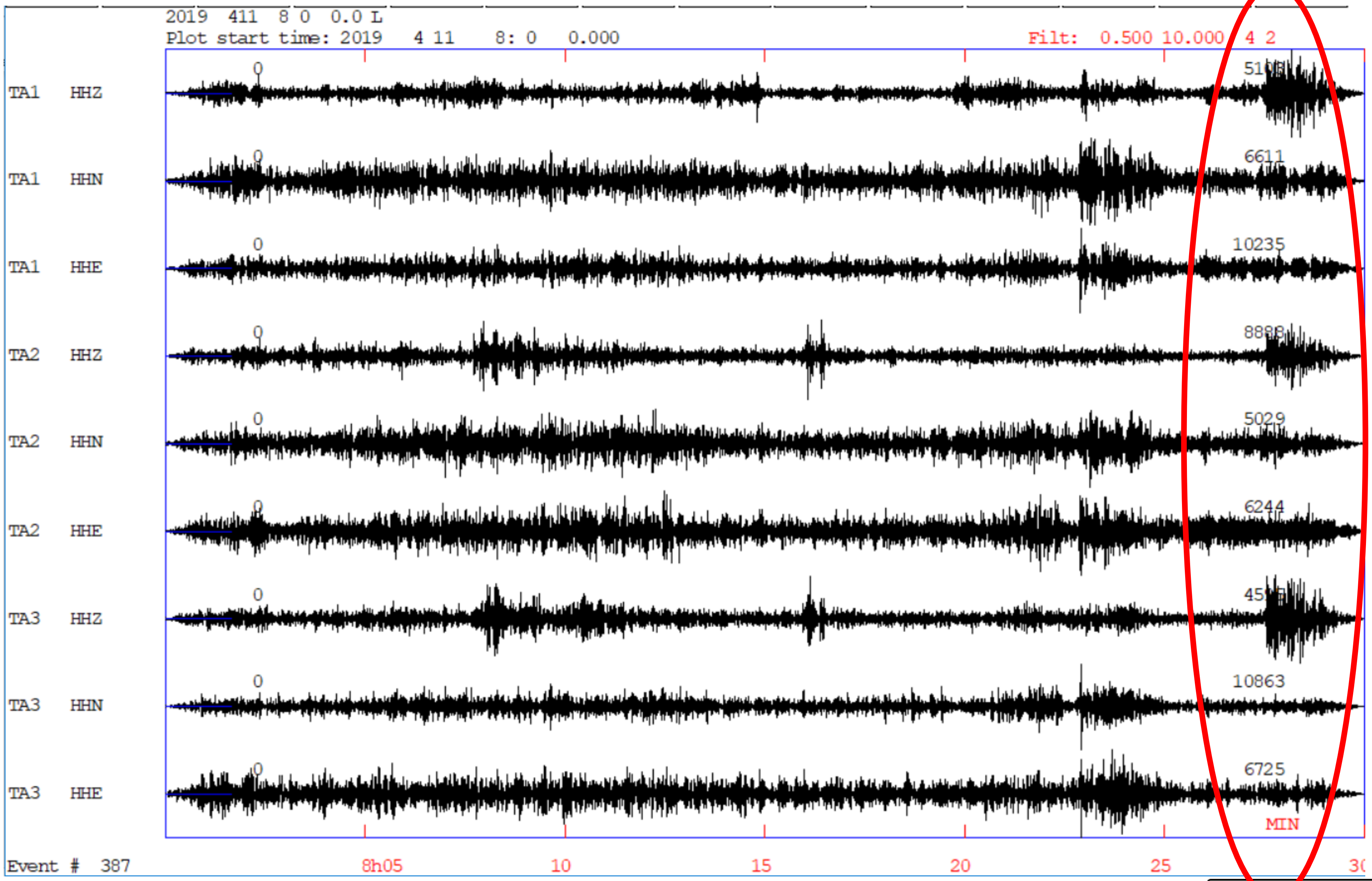
Example of the icequake. SAISAN software is used for data visualization (Havskov and Ottemoller, 1999).



Note: Signal observed on vertical and horizontal components.

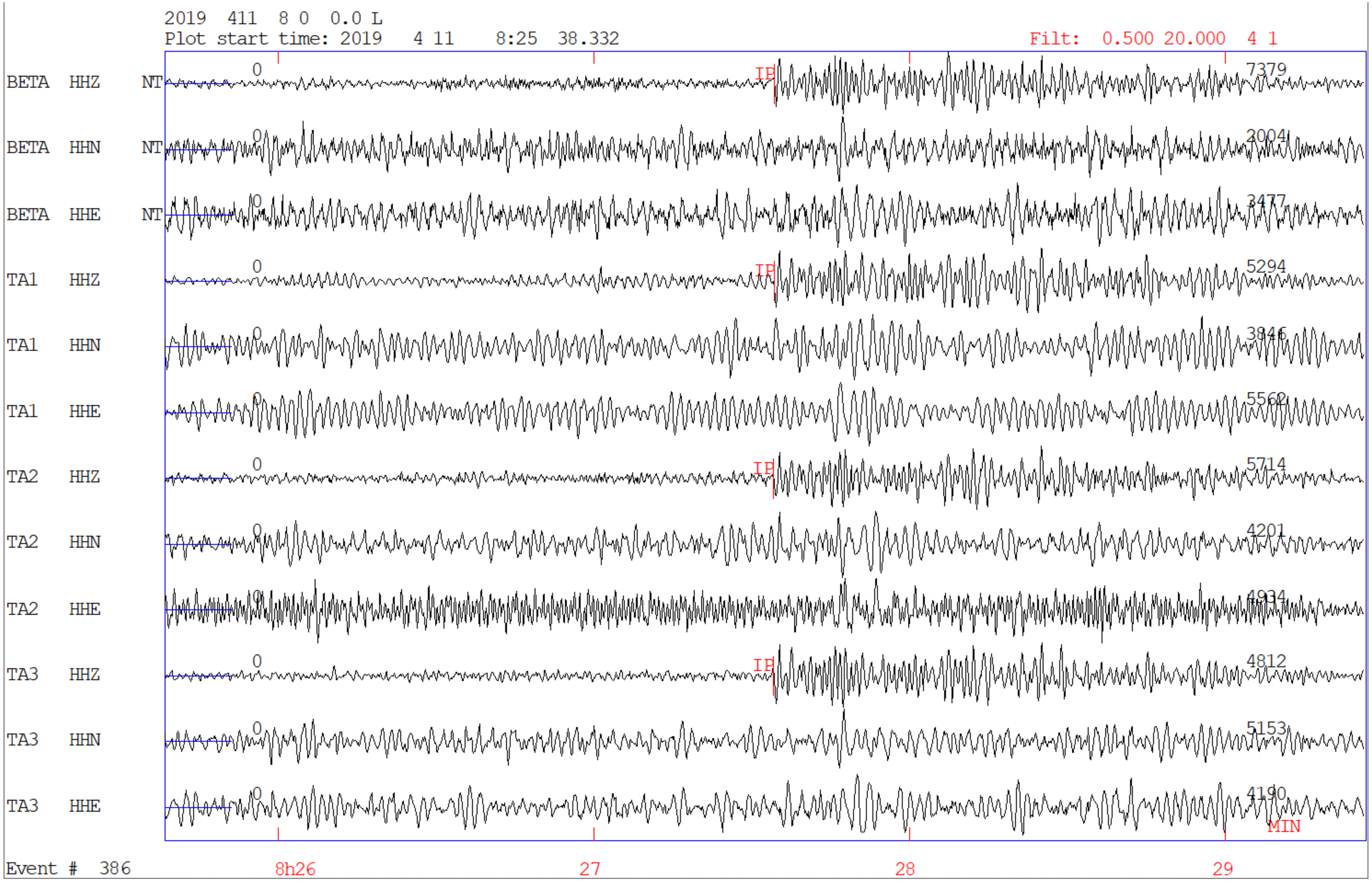
Examples of recorded data

As a result of the initial analysis of the seismograms several signals from remote and regional earthquakes were detected. For example, in Figure, we show a record of a remote event, that was identified in the ISC catalogue as an earthquake occurred at 08:18:23UTC on April, 11 2019 near the Japan (40.35°N, 143.35°E, 35 km depth, MS = 6.0). The frequency content of this record and the signal to noise ratio appears to be not principally different from those recorded at land stations. SAISAN software is used for data visualization (Havskov and Ottemoller, 1999).



Examples of recorded data

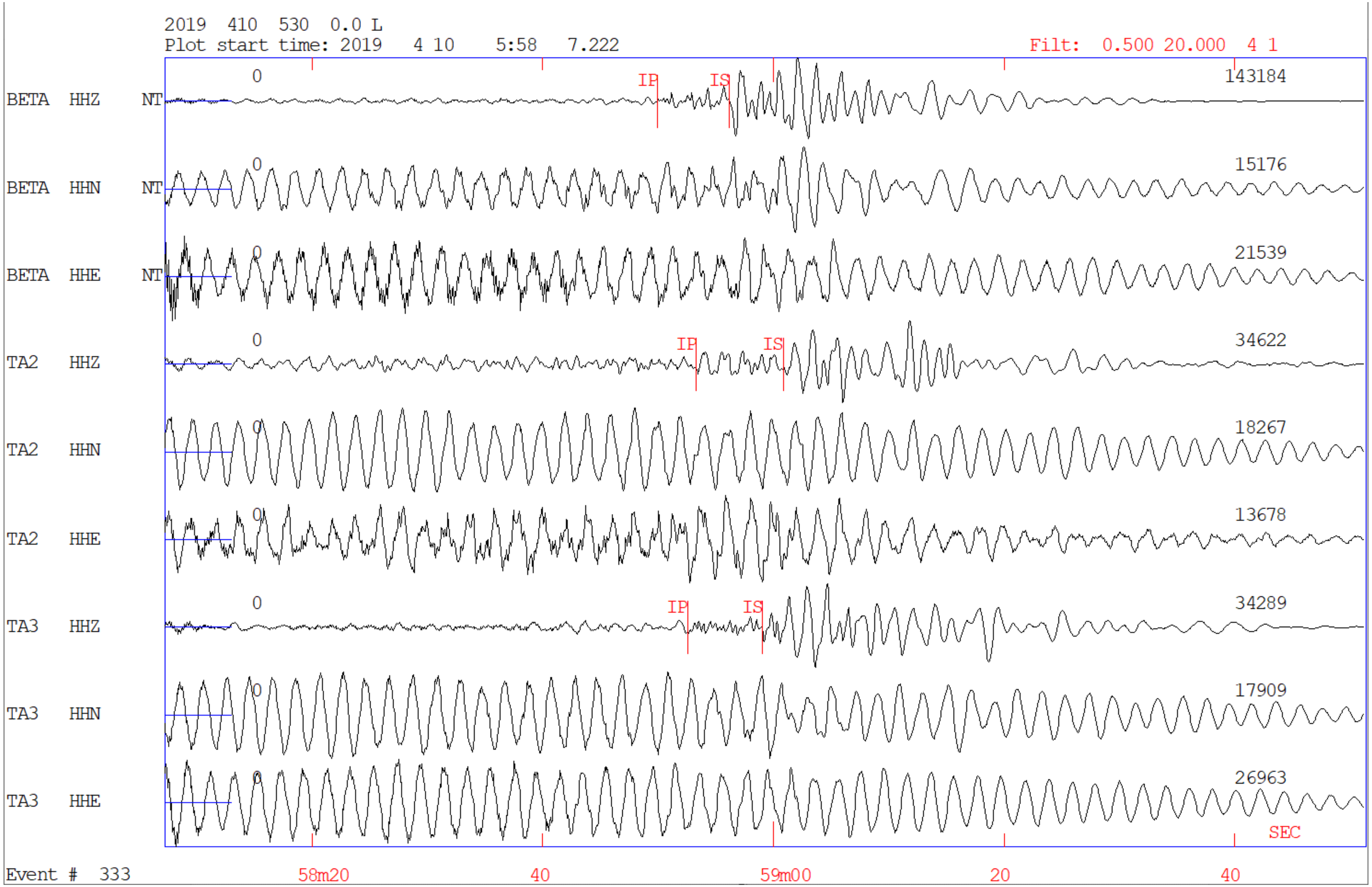
Remote earthquake (11.04.2019T08:18:23UTC, 40.35^{o}N 143.35^{o}E 35 km). SAISAN software is used for data visualization (Havskov and Ottemoller, 1999).



Note: Signal is observed only on vertical component!

Examples of recorded data

Figure shows an example of record from a regional earthquake that occurred approximately at 05:58UTC on April, 10 2019. We can clearly detect both primary P phase and the secondary phase, which is identified as a converted S-wave. Based on the difference between these two phases, we estimate that the distance to this earthquake is about 500 km. Due to the small aperture of the seismic network, the determination of the earthquake coordinates is impossible. SAISAN software is used for data visualization (Havskov and Ottemoller, 1999).



Results of the conducted experiment

- Deployment of seismic stations on the drifted ice floes could be used for registration of the local and remote seismicity.

- During the experiments were registered seismic signals from various processes within ice floes, as well as signals from several remote and local earthquakes.
-
- The experiment has shown that using floating networks can strongly enhance the detectability of seismicity with moderate and small magnitudes.

- To obtain information about seismic structure of the crust in Arctic region it is necessary to install seismic network that consist of tens stations and will operate for at least several months. Such a network will be able to register enough earthquakes and obtained data could be used to perform seismic tomography and to perform an analyze with use of other seismic methods.

Acknowledgements

The work of AJ from IPGG was supported by grant RNF 18-47-00095. The work was supported by the target scientific and technical program 5.1.5 of Rosgidromet. We thank to Novosibirsk state university for providing Guralp CMG-6T seismic sensors.

References

Havskov, J., Ottemoller, L., 1999. SeisAn Earthquake Analysis Software. Seismological Research Letters 70, 532–534. https://doi.org/10.1785/gssrl.70.5.532

Läderach, C., Schlindwein, V., 2011. Seismic Arrays on Drifting Ice Floes: Experiences from Four Deployments in the Arctic Ocean. Seismological Research Letters 82, 494–503. https://doi.org/10.1785/gssrl.82.4.494

Ryan, W.B.F., Carbotte, S.M., Coplan, J.O., O'Hara, S., Melkonian, A., Arko, R., Weissel, R.A., Ferrini, V., Goodwillie, A., Nitsche, F., Bonczkowski, J., Zemsky, R., 2009. Global Multi-Resolution Topography synthesis. Geochemistry, Geophysics, Geosystems 10. https://doi.org/10.1029/2008GC002332

Schlindwein, V., Müller, C., Jokat, W., 2007. Microseismicity of the ultraslow-spreading Gakkel ridge, Arctic Ocean: A pilot study. Geophys J Int 169, 100–112. https://doi.org/10.1111/j.1365-246X.2006.03308.x


Thank you for your attention!