6 Technical Reports / Papers Published

6.1 Seismological research related to geophysical processes in the European Arctic (project GEOPROC)

A cooperative project between institutes in Norway and Russia focused during the time interval 2014 – 2016 on improving the existing knowledge of geophysical processes in the European Arctic. The principle project partners were NORSAR and the Institute of Environmental Problems of the North, Ural Branch of the Russian Academy of Sciences (RAS) (since April 2016: Federal Center for Integrated Arctic Research, RAS), Russia. Additional partners contributing to the project came from the Kola Branch of the Geophysical Survey (KRSC), RAS, as well as the Centre for Earth Evolution and Dynamics (CEED) and the Glacial Seismology Group, both from the Department of Geosciences, University of Oslo. The project was financed from the Norwegian side by a grant from the Research Council of Norway (Grant Number 233973) and from the Russian side by a grant from the Russian Foundation for Basic Research (Grant Number 14-05-93080).

6.1.1 A short description of the project

The last years have shown an increased interest in possibilities for gas and oil exploitation in the Barents Sea and the whole European Arctic. At the same time, seismic studies have shown that this region has the potential for large earthquakes. Today's seismic monitoring of the European Arctic suffers from patchy seismic networks and limited exchange of raw data and parametric analysis results between the institutes in Norway and Russia.

During the project, a new, most complete seismic bulletin has been compiled for the European Arctic north of latitude 70°. This bulletin covers the time-period since 1990 and utilizes all available seismic observations from the project partners and many national and international sources. This new seismic bulletin will be published and made open for further research. A copy will be also provided to the International Seismological Centre (ISC) in Thatcham, UK.

A new database of heat-flow observations in the Barents Sea and the European Arctic has been compiled based on published papers, but not always easily accessible sources in Russian and international literature. This database is now open for further analysis and interpretation.

Results of the joint project have been presented at national and international conferences and workshops. Some project results are already published as articles in scientific journals or in proceeding volumes, and a list of articles, which utilize project results and have been published or are under revision, are referenced at the end of this section. At least two additional publications are in preparation, which will present the newly compiled seismic bulletin and the heat-flow database.

At the end of the project, a joint document was compiled with the title “Recommendations for Future Norwegian – Russian Geophysical Cooperation in the European Arctic”. This content of this document is presented in the following.

6.1.2 Recommendation for Future Norwegian – Russian Geophysical Cooperation in the European Arctic

The largest part of the European Arctic consists of the Barents Sea and the Archipelagos Svalbard and Franz-Josef-Land and is under governance by either Norway or Russia. Due to the effect of the observed climate change in the cryosphere and the increasing interest from the Norwegian and Russian industry and policymakers in potential exploitation of geo-resources in the Arctic, the need for a better understanding of the natural processes on the Earth's surface and in the Earth's crust in this Polar region has also increased in Norway as well as in Russia.

6.1.2.1 Seismology

In 2008, a magnitude 6 earthquake occurred in Storfjorden, Svalbard Archipelago, on a previously unmapped fault. The latest larger earthquake in the Storfjorden area with a magnitude of 5.1 occurred 29 March 2016. This time of the year is high season for winter tourism on Spitsbergen and besides the local inhabitants many visitors experienced this event as quite alarming (see also Svalbardposten from 1 April 2016).

These earthquake magnitudes are significantly larger than those known from the areas of gas and oil production in the North Sea. Mapping of potential active faults in the Arctic and estimating the seismic hazard is necessary before any start of hydrocarbon exploitation in the region.

Many studies in Scandinavia have shown that large earthquakes occurred directly after the last ice age (up to magnitude 8) due to isostatic rebound of the Earth's lithosphere and mantle. One can expect that the earthquake activity will change in areas, where large masses of ice may melt away in the near future (e.g., Greenland, Alaska, Antarctica, but also Svalbard (Nordaustlandet) and Novaya Zemlya). This potential danger needs to be evaluated and monitored.

6.1.2.2 Cryosphere

A strong interaction has been observed globally between climate change and changes in the cryosphere. In particular, the stability of the large ice masses in the Polar Regions is of special interest due to their influence on mean sea-level height and the global ecosystem. During the last decade, an increasing number of seismologists have started to study icequakes, which are the result of dynamic processes in the Earth's glaciers and ice sheets (ice flow and surge or calving events). More investigations are needed in cooperation with glaciologists to better understand how these observations are linked to the dynamic behavior of glaciers and whether particular types of seismic signals can be associated with particular types of glacier activity. At a few sites, seismic observations in the Polar Regions are going back several decades and can now be used for a retrospective, long-term analysis of individual glacier dynamics.

A significant hazard for human activities (ship traffic, hydrocarbon exploitation) in the off-shore areas of the European Arctic are icebergs. The sources of icebergs are calving tidal glaciers or ice caps in the Svalbard and Franz-Josef-Land Archipelagos, and on the islands of Novaya Zemlya and Greenland. Calving is also a major contributor to glacier-mass loss and mean sea-level rise. Glacier calving events radiate elastic waves into the Earth, in the water and the atmosphere and can therefore be recorded on seismometers. Recent seismic studies on Svalbard did not only show the capability of monitoring calving activity at different glaciers in the region, but also allowed for the first time to determine the

amount of frontal ice loss at a single glacier directly from seismic data, producing a record whose temporal resolution and length opens a treasure chest for glaciologists to better understand glacier dynamics in a changing climate. More case studies at different glaciers are needed to produce more of such records in the European Arctic. Recently, it was shown that apart from seismic stations, infrasound sensors can also be used to monitor calving of tidal glaciers. More research is needed to investigate how infrasound signals from calving events can be integrated into monitoring systems and jointly analyzed with seismic data.

6.1.2.3 Geotectonics

During the last years, a large component of climate research has focused on historical climate scenarios, using them as models for today's observed climate change. Past climates cannot be understood without knowing past geology and the geographic distribution of land and sea (tectonic plate geometry), which has a large influence on water circulation and thereby heat transport in the oceans. The key for understanding these processes is a better knowledge of today's tectonics, the structure of the crust and plate dynamics in and around the Arctic, which can only be investigated by geophysics and geology.

Best possible knowledge of tectonic history and the current structure of the crust and uppermost mantle is also a key to the discovery of off-shore potential hydrocarbon reservoirs.

The geotectonic situation in the Arctic is unique with a concentration of slow to ultra-slow spreading mid-ocean ridges. In the northernmost part of the Atlantic Ocean, the region is relatively easily accessible and large interest exists for all types of interdisciplinary studies between geophysics, geology, volcanology, geochemistry, and oceanography to investigate a diversity of phenomena related to the building of new crust and the structure and history of continental margins.

In the largely inaccessible Arctic Ocean, the ultra-slow spreading Gakkel Ridge constitutes the end-member in the slow spreading rate scale. Therefore, its study is crucial to our comprehension of the formation and evolution of the oceanic lithosphere and its seismicity pattern seems to be a key to inferring processes and properties of crustal accretion and their relation to dynamics of the Earth's mantle.

6.1.2.4 International Cooperation

Because of the nature of the necessary research described above, the logistic challenges related to Polar Research, and the need to optimize the usage of financial resources, a strong international cooperation is needed: collected data and research results have to be exchanged on a regular basis because they are relevant for all research groups active in the region; many problems can only be investigated by a joint analysis of all available data. Due to the Norwegian and Russian interests in the European Arctic, a close cooperation between Russian and Norwegian scientists and research institutions is essential and should be a natural first choice. This cooperation should of course not be understood as exclusive; all other nations active with research in the European Artic should be invited to join, in particular, since many research topics are not only of regional but also of global interest. As an example, one can mention that high quality observations of globally distributed seismic sources are still relatively rare in the Polar Regions and the network of stations is rather sparse. To acquire new knowledge about the structure of the Earth's interior such kind of data are very valuable and will be particularly sought after.

6.1.2.5 Norwegian – Russian Cooperation in Seismology

Already during the last years of the Soviet Union, NORSAR researchers came in contact with seismologists working at the Kola Regional Seismological Centre (KRSC) of the Kola Branch of the Russian Academy of Sciences in Apatity. In the framework of a joint project, a seismic array was installed on the Kola Peninsula close to Apatity in autumn 1992. This joint project with KRSC became the base for more than 25 years of successful cooperation in exchanging data, improving the monitoring capabilities and classifying seismic events in the European Arctic, but mostly concentrating on the western part of the Barents Sea and Svalbard.

At the beginning of the 2010s, the contact between NORSAR and Russian colleagues was further strengthened by starting a new cooperation with the Federal Center for Integrated Arctic Research of the Ural Branch of the Russian Academy of Sciences in Arkhangelsk. Within the NORRUSS program of the Research Council of Norway, a joint Norwegian-Russian project (GEOPROC) between these three institutes and the University of Oslo to compile a joint seismic bulletin for the European Arctic was funded for the years 2014 – 2016. Figure 6.1.1 shows a map of all seismic events compiled in this new seismic event catalogue and Figure 6.1.2 shows today's network of seismic stations in the region.

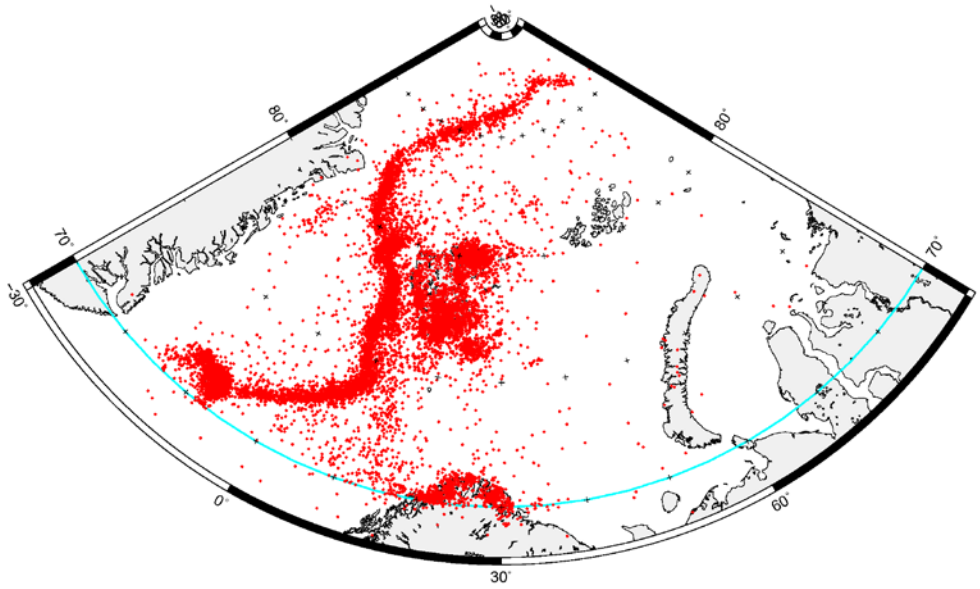

Fig. 6.1.1 The map shows all seismic events for the years 1990 – 2016 in the European Arctic as compiled in a new catalogue based on sources from Norwegian, Russian and international data centers within the frame of the joint Norwegian-Russian NORRUSS project GEOPROC.

The now finishing GEOPROC project has shown that due to the distribution of land and sea in the European Arctic any seismological or infrasonic monitoring needs a close cooperation between Norwegian and Russian institutions. Only a regular, near-real-time exchange of the recorded data and parameters of observed seismic events can guarantee a future high-quality seismic bulletin, which is needed for all types of seismic hazard analysis and understanding of the physical processes in the Earth's crust and on its surface. In addition, it is necessary to exchange and coordinate ideas about any future new monitoring stations in the European Arctic and to have platforms available for meetings and exchanging research results.

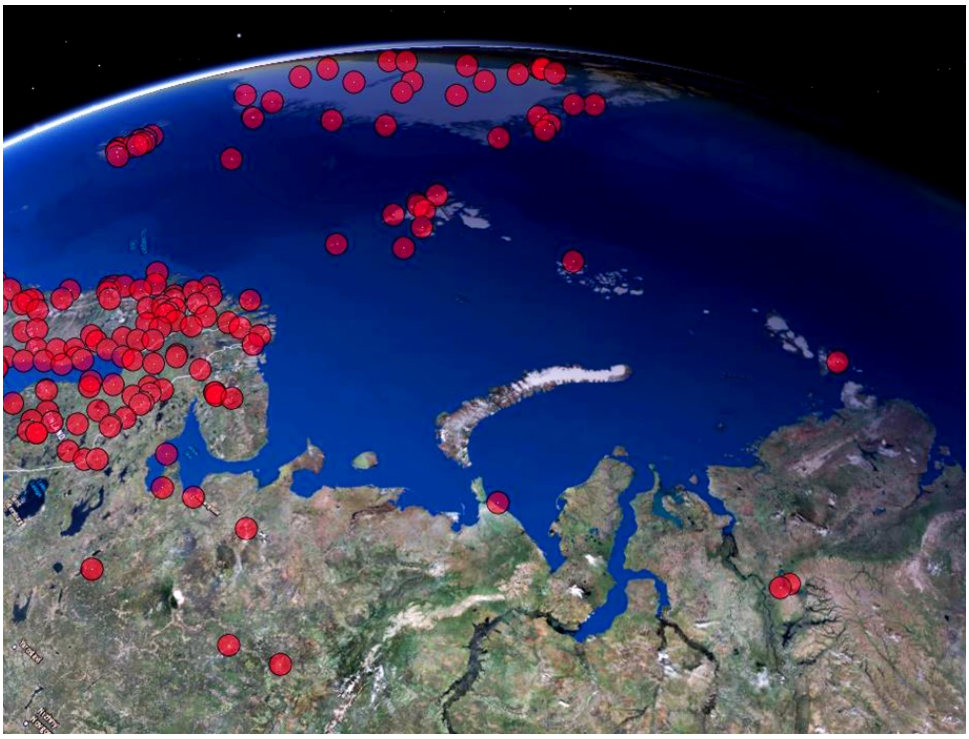

Fig. 6.1.2 The network of permanent seismic stations in operation in the European Arctic in 2016.

6.1.2.6 Enhancing Cryo-Seismological Research

In recent years, Norwegian and Russian seismologists initiated research activities that employ seismic and infrasound instrumentation to monitor and study glacier-dynamic activity, in particular calving, at individual tidewater glaciers on Svalbard (e.g., Kronebreen, Esmarkbreen, Nordenskjöldbreen). The recent GEOPROC project allowed for the first time to connect those researchers and to exchange expertise in cryo-seismological research. The collaboration needs to be intensified in order to improve existing and develop new glacier-monitoring strategies in the European Arctic and to initiate new cooperation involving also the Norwegian and Russian glaciological research community. Such cooperation could include joint field experiments, data exchange, and training courses.

6.1.2.7 Infrastructure Update

It is obvious that the huge gap (see Figure 6.1.2) of seismic stations in the Barents Sea and further to the east limits monitoring tectonic and glacier activities in the region. Therefore, each opportunity to increase the density of seismic stations has to be taken. It is also needed to increase the number of infrasound sensors in the region to collect the basic data for infrasound monitoring of cryosphere dynamics.

Such monitoring stations (seismic or infrasonic) have minimal environmental impact, can run autonomously, and do not need, under usual conditions, continuous access. This makes them the right tool to monitor sensitive, remote and largely inaccessible areas.

6.1.2.8 Targeted, Temporary Deployments

Due to the geographic distribution of sea and land, as well as the harsh climate, there are severe restrictions in the realization and improvement of permanent seismic networks in the European Arctic. However, specific topics of interest could be pursued by temporary deployments as, e.g., seismicity studies of the eastern Gakkel Ridge based on temporary stations/arrays on Severnaya Zemlya.

6.1.2.9 Norwegian – Russian Warning and Rescue Center

A future goal of all Norwegian – Russian geophysical cooperation could be to contribute to a joint Norwegian – Russian Warning and Rescue Center for the European Arctic. Such a Center could additionally work together with e.g., meteorologists and remote sensing (satellite) specialists and distribute information about actual threats (weather, icebergs, earthquakes, oil spills, …) in the polar regions.

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