

20 Years of Terrestrial Research in the Siberian Arctic

The History of the LENA Expeditions




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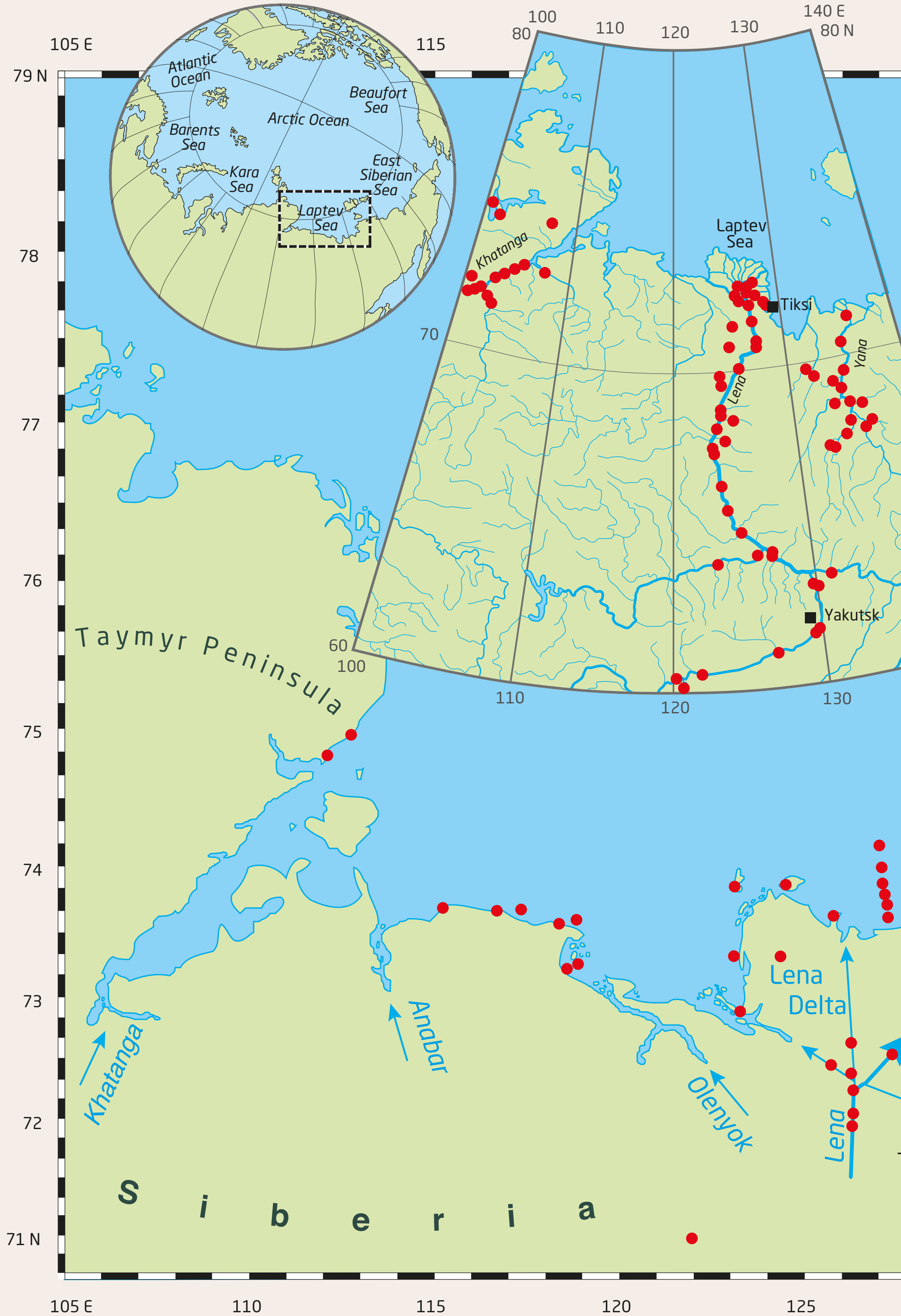

Atlantic Ocean
Barents Sea
Arctic Ocean
Beaufort Sea
Kara Sea
East Siberian Sea
Laptev Sea
Khatanga
Laptev Sea
Tiksi
Lena
Yana
Yakutsk
Taymyr Peninsula
Lena Delta
Khatanga
Anabar
Olenyok
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Siberia
105 E
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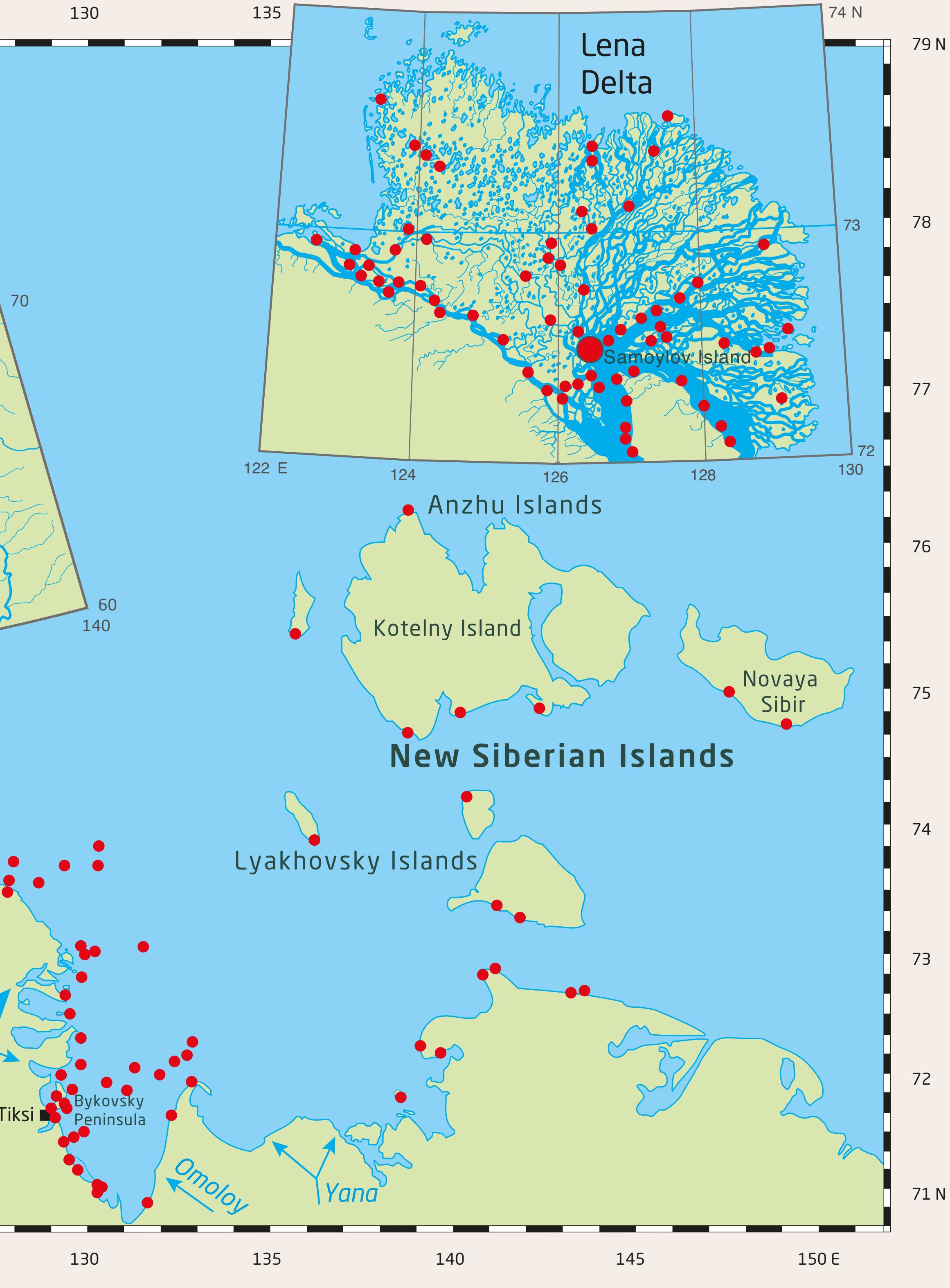

130
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Samoylov Island
72
122 E
124
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128
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Anzhu Islands
76
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140
Kotelny Island
Novaya
Sibir
75
New Siberian Islands
Lyakhovsky Islands
74
73
72
Bykovsky
Peninsula
Tiksi
Omoloy
Yana
71 N
130
135
140
145
150 E

Contents

(Photo: P. Verzone)

Introduction and Background to Terrestrial Expeditions in Siberia

The success of the Russian-German cooperation over the last two decades is based on the friendship of the involved people, who all know about the uniqueness of the Russian Arctic. Our retrospection allows new visions for the future.

It started with the perestroika in Russia and the unification in Germany. Both are historical steps for the beginning of the long-term Russian-German cooperation in polar research in Siberia. The foundation of the new Potsdam Research Unit of the Alfred Wegener Institute for Polar and Marine Research (short AWI Potsdam) in the year 1992 was another important step for joint research in the polar regions. AWI Potsdam, which integrated the former East German Antarctic Research, concentrated their research on paleoclimate studies, using lake sediments in Antarctica and the Arctic as archives and, investigations, related to the formation and transformation of permafrost landscapes mainly in Siberia, always building on the long partnership and experience of former East German

Figure 1: Expedition to Georg Forster Station, Schirmacher Oasis, Antarctica 1991/92.

and Soviet scientists. A first expedition to the Schirmacher Oasis and the East German Antarctic Georg Forster Station brought former East German and one West German scientists together as early as the summer of 1991/1992, where they formed a team for paleoclimate studies. (Figure 1). Based on the long-time cooperation of Soviet and East German scientists in joint logistics and research in Antarctica, several expeditions to Antarctic oases were realized in the following years, led by Sergey Verkulich from the Arctic and Antarctic Research Institute (AARI) in St. Petersburg and Martin Melles from AWI Potsdam.

In 1992, several members of AWI Potsdam participated in the International Conference on Cryopedology in Pushchino, Russia. Based on the experience of Christine Siegert, a cryolithologist who had worked for over 20 years in the Melnikov Permafrost Institute in Yakutsk (MPI) before joining AWI Potsdam, they began to plan joint research projects and expeditions to Siberia (Figure 2).

As a result, an expedition to the Lama Lake, close to the city of Norilsk in Siberia, took place with scientists from the Moscow State University. Together, the researchers successfully took several meter long lake sediment cores for paleoclimate reconstruction.

Figure 2: Conference on Cryopedology in Pushchino 1992 with Nikolai Romanovskii, Eva-Maria Pfeiffer, Hans-W. Hubberten, Christine Siegert and others of the first years of Russian-German cooperation.

As part of the cooperation between AWI and AARI, mainly in logistic operations in Antarctica, a fruitful cooperation was initiated with Dmitry Yu. Bolshiyanov, a leading scientist of the Geography Department of AARI.

In 1993, a first joint reconnaissance expedition was carried out to the Taymyr Peninsula, which was the base for the funding of the Research Project "Taymyr" by the German Ministry of Research and Education (BMBF) from 1994 to 1997. Members from AARI, Moscow State University, and Pushchino, together with German Groups from AWI, Universität Hamburg (UHH), and the Institute of Polar Ecology in Kiel, realized several successful expeditions to the Taymyr Peninsula and Severnaya Zemlya.

GEOMAR in Kiel has undertaken major initiatives in marine Arctic research under the lead of Jörn Thiede. In 1993, with the help of funding from the German BMBF, Heidemarie Kassens (GEOMAR), Sergei Priamikov (AARI) and Hans-W. Hubberten and Rüdiger Stein (AWI) organized a first Russian-German workshop in St. Petersburg. It brought together scientists from several German and Russian institutions (Figure 3). This workshop was the beginning of the successful German-Russian cooperation in polar and marine research with a focus on the

Figure 3: Organizers of the first Laptev Sea Workshop in St. Petersburg 1993. from left: Rüdiger Stein, Hans-W. Hubberten, Helga Henschel and Heidemarie Kassens.

Siberian Laptev Sea and its hinterland. A first larger research project, the System Laptev Sea Project, was coordinated by Jörn Thiede and Heidemarie Kassens. It concentrated mainly on the transpolar drift system from the Laptev Sea, to the Fram Strait and the North Atlantic. Almost every year, the famous “Transdrift” expeditions brought Russian and German students and scientists together. One subproject of the System Laptev Sea project, realized mainly by AWI in Potsdam and several Russian institutions, concentrated on the material transport via the Lena, Yana, Olenyok, and Anabar rivers flowing to the Laptev Sea. Volker Rachold from AWI and scientists from Moscow State University organized expeditions with smaller riverboats in three summers.

After the end of the Taymyr and the Laptev Sea Projects, a new Russian-German project was funded by the BMBF. It linked the marine research groups from GEOMAR, AWI, AARI, and other institutions with the terrestrial groups from Universität Hamburg, AWI Potsdam, Melnikov Permafrost Institute Yakutsk (MPI), AARI, and others. Jörn Thiede from GEOMAR coordinated this project, called Laptev Sea 2000. As part of this project, Volker Rachold (AWI), Mikhail N. Grigoriev (MPI), Eva-Maria Pfeiffer (UHH) and Dmitry Yu. Bolshiyanov (AARI) initiated the first Lena Expedition. Its major objectives were to study the permafrost system on Samoylov Island in the Lena Delta, as well as paleoclimate studies at the Ice Complex of Mamontovy Khayata on the Bykovsky Peninsula, and coastal dynamic studies using small riverboats in the Lena River Delta.

Since these days in 1998, interdisciplinary Lena expeditions have been organized every year, mainly under the responsibility of AARI, AWI, MPI, and UHH, to understand the complex system of permafrost landscapes in Russia. These expeditions would not have been possible without the excellent logistic support of the Hydrobase Tiksi and its director Dmitry Melnichenko, as well as of the local logistics company Arktika GeoCentre. Another main local partner has always been the Lena Delta Reserve (LDR), not least because large parts of the working area of the Lena Expeditions belong to its territories and LDR scientists under director Alexander Gukov have participated in the expeditions. Throughout the years, the Samoylov Research Station (RS Samoylov), which has been operated jointly by AWI and the LDR since 1998, has been the central starting point for various expeditions to the Lena River Delta.

In the following years, more and more equipment has been installed for the long-term measurement of budgets of energy, water, and trace gas fluxes. Studies on paleo-environmental changes were carried out on representative sites of the Lena River Delta and the New Siberian Islands, where lake sediments and long sequences of the Ice Complex were sampled.

Coastal dynamic studies developed into another major topic, and expeditions with small vessels went to the coast around the Lena Delta and westward to Taymyr Peninsula, as well as to the east of the Lena Delta, using a hydrographic vessel to reach different islands of the New Siberian Islands and the coast of the Dmitry Laptev Strait. A highlight of the coastal dynamic studies was the COAST drilling campaign, which was coordinated by Volker Rachold and Mikhail N. Grigoriev in 2005 and financially supported by the BMBF Laptev Sea 2000 project. After the BMBF-funding period of the Laptev Sea synthesis project ended in 2006, the Lena expeditions continued to be supported by German and Russian institutional money as well as other, smaller projects funded by the German DFG or the Russian RFBR.

Figure 4: Research in the Laptev Sea region. Russian-German workshop organized by OSL and AWI at AARI in 2010.

The terrestrial expeditions were linked to the marine expeditions in the Laptev Sea at all times, through the bilateral agreement between the Russian and German science ministries on German-Russian cooperation in marine and polar research, discussed year for year at the respective bilateral meetings. A focal point of this cooperation was the AARI, where all expeditions were coordinated, and permissions were obtained. Several workshops on the System Laptev Sea in St. Petersburg or Kiel stimulated the collaboration between scientists and students of both countries (Figure 4).

With the foundation of the Russian-German Otto Schmidt Laboratory for Polar and Marine Research (OSL) in the AARI in St. Petersburg in 2000, and mainly the initiation of a fellowship program under this project, one of the most important platforms for the cooperation was established. Coordinated by its co-directors Heidemarie Kassens and Leonid Timokhov (followed by Irina Fedorova and now Vasili Povazhnyy), the OSL became the home and meeting place for the Russian-German cooperation in polar and marine science.

Another important initiative was the consolidation of the master program MSc Polar and Marine Science, POMOR, at St. Petersburg State University (coordinated by Georgy Cherkashov) and the Universität Hamburg (coordinated by Eva-Maria Pfeiffer). It allowed the graduate education in the field of polar research in close collaboration with different German Universities (Bremen, Kiel, Potsdam, Rostock). POMOR master students obtain a double degree from both universities, St. Petersburg and Hamburg.

The Lena Expeditions continued to focus on permafrost and terrestrial systems and received major funding through the BMBF-Project “CARBOPERM” for the years 2013 to 2015. Coordinated by Eva-Maria Pfeiffer, UHH, and Hans-W. Hubberten, AWI Potsdam, new permafrost research topics could be initiated and allowed the continuation of the terrestrial Lena Expeditions.

The funding of European projects like INTERACT and the EU FP7 project PAGE 21, which was funded from 2011 to 2015 and coordinated by Hans-W. Hubberten, AWI Potsdam, opened the terrestrial research for other international groups from, for example, Sweden, Denmark, and Switzerland. Funding by

BMBF currently allows the permafrost carbon research in the Delta through the KoPf-Project, which is coordinated by Eva-Maria Pfeiffer, UHH, and ensures the continuation of the Lena Expeditions even after 20 years.

New possibilities opened for the Lena Expeditions with the visit of Prime Minister Vladimir V. Putin on Samoylov on 23 August 2010. The construction of a new Arctic research station on Samoylov Island as a consequence of this visit changed the familiar atmosphere on Samoylov to a high-tech research station. The station is now operated by station staff year-round. The Trofimuk Institute of Petroleum-Gas Geology and Geophysics of the Siberian Branch of the Russian Academy of Sciences (IPGG SB RAS) has served as operator of this new Research Station "Samoylov Island" since 2012. With Fyodor Sellyakhov, the station has a very experienced and highly responsible station leader who, together with his technical staff, perfectly organizes the daily life and work of the scientists on the station.

Compared to the small, old, seasonal station, the year-round availability of the new station and its technical and technological equipment and support changed the organization and the planning of the expedition work on and around Samoylov in favour of more scientific possibilities. During the last years, scientists from IPGG SB RAS and its partner institutions started field work on and around Samoylov Island during annual expeditions and made a large contribution to permafrost studies in the Lena Delta using a multidisciplinary approach including geophysical methods, remote sensing, soil science, geology, and botany.

With the involvement of a large group of scientists from Novosibirsk and other Russian institutions, planning a cooperation is much more complex than in the first 15 years of the Lena Expeditions, but the new specializations and experience of these scientists will substantially strengthen the joint research.

An international scientific Arctic expedition projects lasting 20 years in a row is a unique case. The Lena Expedition is an extraordinary exception and a lucky example of Russian-German cooperation. We hope that the new Arctic Research Station Samoylov Island will be a convenient and reliable base for successful activities of the joint expedition for many years to come.

These successful expeditions and scientific cooperations during these 20 years were only possible because of the intensive support of institutions and individuals. The German Ministry of Education and Research (BMBF) and the Russian Ministry of Education and Science (MON) provided the main funding. Additional funding was obtained through the German Science Foundation (DFG), the Russian Foundation for Basic Research (RFBR), and other funding organizations. The expeditions could not have happened without the important logistical support provided by AARI and AWI.

The help provided by the Hydrobase and the Lena Delta Reserve in Tiksi and the support by local and regional authorities were essential for the realization of the field work. Thanks go not only to these institutions and their employees in different departments but also to many people at the station and in the field. The rangers on Samoylov, the cooks on the stations and in the numerous field camps, the captains and crews of the boats we used in the delta and at the coast, the drilling teams, drivers of the transport, the technicians and all the numerous helpers did a fantastic job under sometimes difficult conditions.

We wish to thank all institutions and persons who made 20 Years of Terrestrial Lena Expeditions possible with their support and personal engagement.

In addition, we thank all who contributed to the preparation, design, and production of this anniversary booklet, namely Claudia Pichler and Yves Nowak from the Communications and Media Relations Department of AWI, Inge Glinsmann from Glinsmann Design Agency, Sebastian Laboor from AWI for preparing maps and graphics, Robert Hanna for editing the English texts, Elena Tschertkowa-Paulenz and Elena Herbst for Russian translations, Matthew Fentem for German translations, and many other persons who very much helped to finish this book.

Hans-Wolfgang Hubberten, Dmitry Yu. Bolshiyanov, Mikhail N. Grigoriev,
Volker Rachold, Eva-Maria Pfeiffer

“Lotsman” working through sediment-laden river ice in the Khatanga Bay, August 1996.

1. On the Way to the Lena Expeditions 1993-1997

Lake Sediments on Taymyr and Severnaya Zemlya as a Climate Archive

In 1993, Moscow State University, the Arctic and Antarctic Research Institute in St. Petersburg, and AWI organized the first expedition to the Taymyr Peninsula. This joint field work in central Siberia was a pilot study to prepare for co-operative German-Russian research focussed on the environmental history of the late Quaternary in central northern Siberia.

This initial disciplinary focus attracted the interest of other research groups. Within a year, it expanded to become a multi-year campaign with a wide range of researchers from more than a dozen institutes and universities.

The resulting field studies on the Taymyr Peninsula and Severnaya Zemlya added process studies of the ecology, climate, and geography of the region to the paleoenvironmental core of the initial pilot project. The campaign extended along a 1400 km transect from the southern Putoran Plateau in the northern taiga zone, across the Taymyr Peninsula, and north to the Severnaya Zemlya archipelago in the High Arctic tundra zone.

As such, the periglacial region encompassed forest, tree-line, tundra, and polar desert ecotones in an area where questions of glacial history in the late Quater-

Figure 1: The expedition team, the mobile drilling equipment, supplies and samples were transported from Khatanga to field sites using dependable Antonov AN-2 aircraft equipped with skis.

nary were unresolved. In addition to questions on the extent and timing of ice sheet coverage in Central Siberia, these campaigns focused on reconstructing the shifts between West Siberian marine and East Siberian continental climates, and on the effects of these climatic shifts on vegetation zones and water and energy fluxes between the land and atmosphere.

Expeditionary teams accessed their field sites through Norilsk and Khatanga, where they worked together with the Taimyrski Zapovednik (nature reserve) and flew to field sites by MI8 helicopter and Antonov AN2 fixed-wing aircraft. These were the years of Perestroika and the first years of German-Russian co-operation. The logistical challenges associated with any expedition were intensified by the former, but the engagement and enthusiasm of the expedition participants signified the latter from the very beginning.

From 1993 onward, the size of the expeditionary teams grew, and the active field season expanded from summer field camp, floating drill platform, and small boat efforts to include lake sampling and other studies of the lake ice in April and May. Records of these expeditions, which took place from 1993 to 1997, include lists of the participants and the samples collected and are available in a series of volumes in the expedition reports on Polar and Marine research (volumes 148, 175, 211, 237, 242, 298, and 324).

Figure 2: The drilling camp established for 6 days at the deepest point of Lake Taymyr in April 1995 consisted of a Russian kitchen & dormitory tent and a few smaller "bedroom" tents.

During these expeditions, the driving question of the regional paleo-environmental history led to drilling activities on a number of water bodies. Lake sediments were recovered from Lama Lake, Lake Labaz, Lake Levinson-Lessing, Taymyr Lake, Portnyagino Lake, Changeable Lake and Fjord Lake (Figure 3). Sediment cores ranged from tens of centimetres in length to a core with a total length of 22.4 m from Levinson-Lessing Lake in 1995.

An example of the type of insights that these sediment records yielded: The lake sediment pollen record from Lama Lake resulted in reconstructions of the air temperature and precipitation for the region over the past 12300 years, thus demonstrating how tundra and steppe biome have responded to a changing climate following the end of the last glaciation.

Figure 3: A map of Severnaya Zemlya and the Taymyr Peninsula showing sites where in-depth joint Russian-German work took place, including lake sediment sampling, in the period 1993-1997.

Figure 4: To permit drilling of lake sediments in inclement weather, a tent was erected around the drilling tripod, shown here on Levinson-Lessing Lake.
Figure 5: 1995 expedition team member T. Ebel, A. Zielke and P. Overduin relax after arriving at Taymyr Lake.

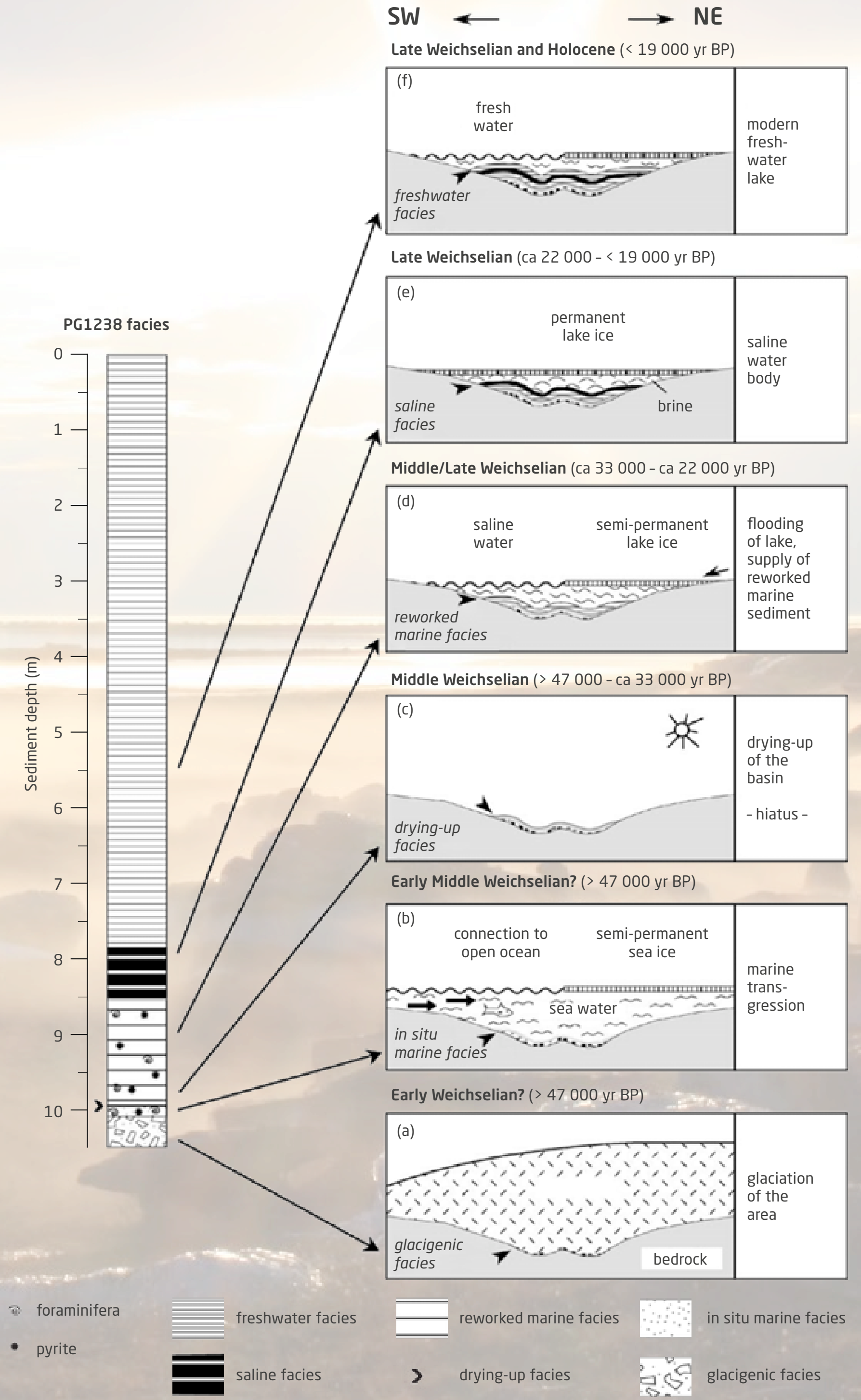


Figure 6: The sediment core from Changeable Lake on Severnaya Zemlya is shown (left) along with the reconstructed environmental history (at right; figure adapted from Raab et al., 2003).

Lake sediments from Severnaya Zemlya allowed us to extend our analysis of the development of recent environmental conditions further northward and further back in time to include the dynamics of the ice caps that left their records in Changeable Lake, showing the transition from ice-covered land mass to freshwater lake, with intervening marine stages (Figure 6).

By proving that there was no ice cap during the last glacial maximum, the results obtained from sediments of Changeable Lake were important findings for the reconstruction of the eastern extent of the Eurasian Ice Cap during the last glaciation and an essential contribution to the success of the ESF Eurasian Ice Sheets project.

The legacy of these initial lake sediment studies included the establishment of the ongoing Research Station Samoylov Island and the associated Lena Delta and Laptev Sea studies. Other projects are also the heritage of this cooperation, including the Lake El'gygytgyn drilling project (https://www.awi.de/forschung/geowissenschaften/geophysik/schwerpunkte/seen-als-klimaarchive/elgygytgyn-see.html) and the current PLOT project (http://www.geologie.uni-koeln.de/2037.html).

Pier Paul Overduin, Dmitry Yu. Bolshiyanov, Martin Melles

Figure 7: A musk ox stands in silhouette against the midnigt sun. The Taymyr musk oxen are descendants of a herd reintroduced from North America in 1975.

First Energy, Water, and Flux Studies of Tundra Soils – Labaz and Levinson-Lessing Lake, Taymyr Peninsula

First field studies on modern soil processes started in the Labaz Lake and the Levinson-Lessing Lake area during the Russian-German Expeditions TAYMYR 1994, 1995, and 1996. Their objective was to characterize the organic matter quality of permafrost-affected soils and to contribute to the reconstruction of the paleoenvironmental conditions of Middle Siberia.

The diversity of so-called Gelisols (a synonym for Cryosols for permafrost-affected soils) could show by 11 different soil-plant-patterned ground units of the wet subarctic sedges-moss-tundra in the Taymyr lowland including six different Gelisols types in the regions of Labaz Lake and at the Levinson-Lessing Lake (Figure 1).

Additional geobotanical studies with a special focus on lichens showed the richness of the arctic flora and the diversity of the Taymyr Peninsula landscape.

Figure 1: Permafrost-affected landscape of the Levinson-Lessing Lake region with the typical so called Taymyr polygons, Taymyr Peninsula, 1995. (Photo: E.-M. Pfeiffer)

The thermal and hydrologic regimes of the ground were studied in 1994 and 1995. The seasonal fluxes of water and heat in the active layer from spring thaw to fall were also quantified. Using Time Domain Reflectometry (TDR), the content of liquid water was measured in frozen and unfrozen soils and was found to be present in frozen soil at temperatures down to -12°C. This also enables microbial life and the production of greenhouse gas emissions.

First CH_4 emission rates (41-171 mg $CH_4 * m^{-2} * d^{-1}$) from the wet tundra of the Taymyr lowland have been determined via first closed chamber measurements. Further publications for the Labaz Lage region include the quality of soil carbon based on different soil C fractions and first estimations of the mean carbon stocks in the active layer (14.5 kg C m^{-3}) and the upper soil meter (30.7 kg C m^{-3}). These first Russian-German soil related investigations on the Taymyr Peninsula were the basis for the ongoing permafrost research in the Lena River Delta and the Kolyma-Indigirka Lowland in 2000 and following years.

Eva-Maria Pfeiffer, Julia Boike, Mikhail P. Zhurbenko, Dmitry Yu. Bolshiyanov

Figure 2: A typical polygonal ice wedge in tundra soils – classified as Typic Glacistels - which is characterized by glacic (ice-rich) layers and high organic material accumulation under very wet and cold conditions. (Photo: E.-M. Pfeiffer)

Exploring Permafrost Sequences in the Taymyr Lowland (1994-1996)

The available data suggested that inland ice masses did not cover the central Taymyr Lowland during the late Pleistocene, and that permafrost landscapes formed. Following the context of our sub-project, we investigated the cryogenic composition of permafrost sequences in the region. In combination with absolute dating, paleontological, sedimentological, and geochemical methods, these sequences were to help clarify the development of the region's paleoclimate. We focused on two areas: The northern shore of Lake Labaz and Cape Sabler on the northern shore of Lake Taymyr. The selected survey area on Lake Labaz, with elevations varying between 40 m and 115 m above sea level, offered favourable conditions for exploring recent geocryological and relief-formation processes in the typical tundra. Numerous outcrops of permafrost sequences were available for complex paleogeographical-geocryological investigation on the slopes, which were clearly separated and bore the marks of thermo-erosion. Moreover, we

Figure 1: Our camp at Lake Labaz, 1995. Remnants of the ice cover can be seen on the lake, as well as perennial firn fields on the eastern shore.

hoped to find evidence of the location of the edge of the last inland ice sheet on the northern shore of Lake Labaz. Given the morphological characteristics of thermokarst depressions, which we observed with aerial photography, we surmised that dead-ice remnants of this ancient ice cover might well be found preserved in the permafrost.

We reached our survey area on Lake Labaz after a stop in St Petersburg, a charter flight from St Petersburg to Khatanga, and a helicopter flight for the final leg of our journey, in mid-July of both years. Each time, we found remnants of ice on the surface of the massive Lake Labaz (with a diameter of 30 km) and numerous smaller neighbouring lakes, but rising temperatures and stiffening winds gradually eroded these remnants in a matter of days. The steep slopes were often still covered with snow, and residual firn even survived until the next summer in some nival niches. The higher, flat areas were already covered by typical tundra vegetation, however, and we found lush meadows on the uppermost south-facing slopes – not to mention hordes of mosquitoes.

We were able to set up camp on a broad, relatively level terrace, next to the Tolton-Pastakh-Yuryakh River's delta-shaped inlet into Lake Labaz. We gathered drinking water from the river. In this small delta, the annual ice movements had formed a wall of coarse sediment. It enclosed a small pool of calm, slightly warmer water. When the weather allowed, we often swam in it. On the second day, after setting up our tents for sleeping and cooking and preparing the boat, we suddenly had guests – Dolgan and Nganasan families, who fish on and live at the lake during the summer, had come with their boats to meet us. Our friendly contact with them paid off: In addition to the interesting things we learned about their way of life, they provided us with fresh fish, which they caught in great quantities, but which, in those complicated times, we couldn't purchase as we had in the past. They had ample supplies of frozen fish and reindeer meat in a huge icehouse on the lakeshore, and one family even let us use their small but lovely sauna from time to time. Regarding our work, they gave us valuable tips for fresh outcrops of ground ice and other interesting sights. To pay back the favour, we gave them the remainder of our provisions and fuel stores at the end of each season. In the second year, we also brought several duffel bags full of clothing that had been collected at the AWI.

During the summer weeks of both years, we examined numerous shoreline outcrops and collected samples for various subsequent lab tests, which provided the basis for creating a schematic cross-section of the permafrost sequences. We also used a small, Russian-made, transportable, and motor-powered auger, which allowed us to collect core samples of frozen sediments and ground ice to a depth of seven meters. Our highly experienced Russian partners drilled a total of 20 shallow boreholes, which enabled us to characterize the geocryological conditions at several sites.

At the same time, thanks to their accumulation in the permafrost, sedimentary sequences with polygonal ice wedges served as our most important paleoclimate archive. They often contain pollen and the fossilised remains of plants, diatoms, and woolly mammoth bones, all of which have been preserved by the “deep freeze”. Using these resources, together with data on the isotope composition of the ground ice and dating methods, we were able to successfully reconstruct the basic features of the region’s climatic and environmental development during the Late Quaternary. In this regard, the fieldwork on Cape Sabler in 1996 and the results of subsequent laboratory tests conducted on samples of permafrost sediments and the ice wedges they contained proved to be especially interesting.

Figure 2: The drilling brigade in action. Note the beekeeper’s hats, which were used to help fend off the droves of mosquitoes.
Figure 3: Core sample of permafrost soil, with the characteristic ice lenses.
Figure 4: After slope slumping, the upper section of the buried glacial ice could be seen under a thin seasonal active layer.

Tests run on the plant remains in the sediments provided the first-ever indisputable proof that the region had been home to steppe vegetation during the last glacial period. Today, similar relics of steppe landscapes can only be found in certain regions of Yakutia and Chukotka, which are notable for their extremely cold Continental climate.

In 1994, we didn't observe any massive bodies of stratified ice that could have been considered relics of the last inland ice sheet. But in the summer of 1995, following heavy precipitation, a large escarpment collapsed near our camp, finally revealing the first evidence of buried glacial ice in the region. We were so thrilled by our find that the whole group celebrated with a round of whisky on chunks of glacial ice.

At the end of the second season, unforeseen economic developments granted us additional time for fieldwork and allowed for some fascinating findings. In August 1995, the Russian government massively devalued the ruble, which meant the financial assets (cash!) set aside for our trip home suddenly weren't enough. As a result, Dima Bolshiyanov, who was responsible for organising the entire expedition, had to fly to St. Petersburg to pick up additional financial resources from the ARRI. Since heavy autumnal rains had already set in on the tundra, our unexpected extension wasn't particularly comfortable, especially because our provisions were running low. It also gave us the chance to investigate a second, more extensive outcrop of glacial ice. A group of Dolgans reported that they had spotted large bodies of ice on the lakeshore after major landslides. A few of us immediately jumped into the fisher boat (which was faster than ours) to check it out. Directly on the shore, near the fishers' icehouse, we could see massive bodies of ice with tell-tale structures of glacial ice. In the adjacent valley, beneath a wide, flat depression and a thin seasonal active layer, a broad swath of soil had slid away, uncovering additional glacial ice. This outcrop provided us with definitive proof that tongues of the inland ice had once extended to the northern shore of Lake Labaz. These findings were then used to reconstruct the distribution of inland ice in Siberia.

Christine Siegert, Alexander Yu. Dereviagin

Carbon in Arctic Desert Soils of Severnaya Zemlya

As part of the Russian-German Cooperation "The Expedition Taymyr 1995", a pilot-expedition to Severnaya Zemlya Archipelago took the first measurements of carbon in permafrost soils on the territory of the High Russian Arctic in 1995. The objective of this pre-expedition was to explore the conditions for future investigations on Severnaya Zemlya Archipelago (lake sampling, glacier coring, soil microbial studies, and others).

A team of German, Japanese, and Russian scientists (see Figure 1) started at the Russian-German field base, situated on the shore of Levinson-Lessing Lake, where, incidentally, the Japanese team had just won two evenings of song competitions between the nations. After visiting Lake Taymyr, Levinson-Lessing Lake, and Cape Cheluskin on the Taymyr Peninsula, the international team flew to the Severnaya Zemlya Archipelago (see Figure 2) and worked on the field base "Prima Station" on the Bolshevik Island, which was transformed into an AARI Hydro-Meteorological Observatory in 2014. The international team

Figure 1: Severnaya Zemlya pilot-expedition team of 1995. Left to right: T. Yamanouchi, G. Guggenberger, O. Watanabe, H. Kanda, S. Takanashi, Russian Colleague, M. Zhurbenko, D. Bolshiyanov, E.-M. Pfeiffer, M. Bölter. (Photo: H.-W. Hubberten)
Figure 2: Using a Russian helicopter technique to fly from the Taymyr Peninsula to Severnaya Zemlya Archipelago in 1995.

of 1995 visited different sites via helicopter and took various soil and plant samples on the islands October Revolution, Komsomolets, and Bolshevik. The German and Japanese scientists saw a vast, unforgettable, and huge world of the Siberian Arctic and decided to continue joint research of this unique high polar region of Russia. While Japanese-Russian investigations could not be enhanced, the Russian-German cooperation blossomed, and new permafrost expeditions were carried out on Taymyr Peninsula, Putorana Plateau, and Severnaya Zemlya Archipelago in the following years. In 1998, the interdisciplinary Russian-German permafrost research was continued in the Lena River Delta and its hinterland. As an outcome of this pilot study, between 1999 and 2001 a 724 m long ice core was drilled on Akademii Nauk Ice Cap on Severnaya Zemlya by a Russian-German team.

A first characterization and analysis of the organic matter in different Gelisols (12 sites) of the Severnaya Zemlya Archipelago with its High Arctic landscapes (see Figure 3) demonstrated low organic carbon content (0,1 – 1,3% C_{org}) in the upper 20 cm of apex positions of the patterned ground (unsorted circles and stripes). In the depressions of the patterned ground, however, higher organic

Figure 3: High arctic landscape of Bolshevik Island and blue flowering forgot-me-not *(Eritrichium villosus),* Severnaya Zemlya 1995. (Photo: E.-M. Pfeiffer)

carbon content with values between 1,6 and 7,1 % C_{org} in the upper 20 cm soil depth was found. Due to the moisture regime of the soil and the presence of vegetation only in sheltered relief positions, the arctic desert soils of Severnaya Zemlya Archipelago were weakly developed and functioned as weak carbon sinks. The main soil formation processes in these polar deserts are the enrichment of soil organic matter and the translocation of iron oxides due to water influence, as well as cryoturbation and the formation of patterned ground (see Figure 4).

Additional soil-vegetation complexes (see Figure 5) have been described as arctic tundra with *Dryas octopetala, Salix polaris* and *Cassiope tetragona* as dominant tundra species. Lichens like *Acarospora putoranica* and *Sticta arctica* were the dominating plants of the marginal arctic meadows. The lichen *Teloshistes contortuplicatus* was determined as a new species for this High Arctic region of the Severnaya Zemlya Archipelago.

Eva-Maria Pfeiffer, Mikhail P. Zhurbenko, Dimitry Yu. Bolshiyanov

Figure 4: Patterned ground formation and an example of a permafrost-affected soil *(Psammentic Aquiturbel)* on Bolshevik Island, Severnaya Zemlya, 1995. (Photo: E.-M. Pfeiffer)
Figure 5: Diversity and composition of lichens on sandstones (with a typical *Protosysrozem*) of Bolshevik Island, Severnaya Zemlya, 1995. (Photo: E.-M. Pfeiffer)

Figure 1: Map showing the sampling locations during the three river expeditions.

Hydrology, Geochemistry, and Sediment Transport of the Siberian Rivers – The SYSTEM LAPTEV SEA Project 1994-1997

The studies of the Siberian rivers formed an integral part of SYSTEM LAPTEV SEA, a Russian-German project that the German Ministry of Education and Research and the Russian Ministry of Research and Technology have funded since 1994. The overall objectives of the project were to understand the modern features of the Arctic transpolar ice drift system and its variations throughout the geological past. Today, sea ice transports much of the sediment that enters the central Arctic Ocean. This material mainly stems from the broad Siberian shelves where it becomes embedded in the Arctic sea ice. The Laptev Sea region is considered the primary source area of this sediment-laden sea ice.

The SYSTEM LAPTEV SEA project consortium focused on the study of mineralogical and geochemical parameters that can be applied to reconstruct and thus un-

derstand the mechanisms of modern and ancient sediment transport via sea ice. As part of the project, our team focused on the characterization of the sediments transported by the Siberian rivers (see Table 1). Other project teams studied the sediment-laden sea ice, marine surface sediments on the shelf and in the central Arctic Ocean, and sediment cores concerning variations over the geological past.

The sampling program included water, bottom sediments, and suspended load to qualify the recent material supply from the continent. Samples were collected at numerous stations along the main rivers and their tributaries (see Figure 1).

The scientific analyses included (a) the quantitative assessment of the water and sediment discharge based on hydrological data and sediment load and (b) the characterization of the bottom sediments and suspended material based on mineralogical and geochemical data. Several parameters were tested to characterize the material transported by each river and to distinguish material transported by different rivers. The results showed that the composition of the river sediments reflects the geology of the drainage area of each river. A specific

Figure 2: "Prof. Makkaveev" landing on a sandbank in the Lena River, July 1995.

heavy mineral composition characterizes the bottom sediments of each river. This composition can be used to circumscribe specific heavy mineral provinces on the Siberian shelves. Heavy minerals, however, are mainly transported in the bottom load. Analyses of the suspended load are more suitable to understand the long-range transport. In this respect, the clay-mineral composition was successfully applied to map provinces associated with specific rivers. The geochemical characteristics of the suspended load are the most powerful tools to fingerprint the material from the rivers to the shelves and further into the Arctic Ocean. The composition of the Rare Earth Elements (REE) and the isotopic composition of Sr and Os, both of which are closely linked to the composition of the rocks in the drainage areas, could be used in particular to fingerprint the fluvial sediments on the shelves and in sediment cores of the central Arctic Ocean. The three expeditions resulted in 10 publications in peer-reviewed journals.

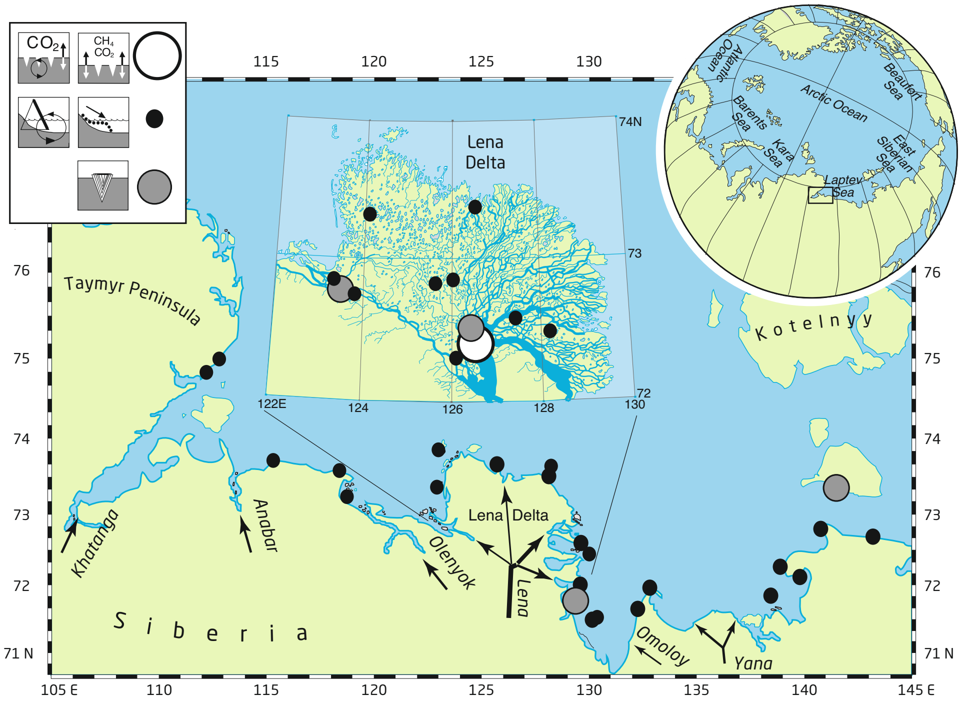
Volker Rachold

	Lena 1994	**Lena/Yana 1995**	**Khatanga 1996**
Rivers	Lena River and Lena Delta and tributaries	Lena River and Lena Delta, Yana, Omoloy and Olenyok and tributaries	Khatanga and tributaries
Dates	July 5 to August 3	June 26 to September 7	July 14 to August 20
Ships	"Prof. Makkaveev"	"Prof. Makkaveev", "Eisberg" and "Sarya 9"	"Lotsman"
Participants	Andrey M. Alabyan, Jörg Hermel, Vyacheslav N. Korotaev, Volker Rachold and Alexander A. Zaitsev	Andrey M. Alabyan, Erich Hoops, Vyacheslav N. Korotaev, Volker Rachold and Alexander A. Zaitsev	Erich Hoops, Irina J. Kirtsidely, Volker Rachold and Alexander W. Ufimzev
Organizers	AWI Potsdam and Moscow State University, Geographical Faculty	AWI Potsdam and Moscow State University, Geographical Faculty	AWI Potsdam and Arctic and Antarctic Research Institute (AARI)

Table 1: From 1994 to 1996, three ship-based expeditions were organized to the main rivers that flow into the Laptev Sea.

Arga lakes (RapidEye_2010-07-06) are located on a sandy plain and have broad, shallow shelf areas (<2 m water depth) and deep central basins. Lake Nikolay (partly ice covered) has several basins (17 m water depth at maximum) and is 8 km in length and width at maximum.

2. The Beginning of the Lena Expeditions 1998-2002



Initiation of the Research Project Lena Delta: Science Strategy, Cooperation, and Logistics

The funding for both the SYSTEM LAPTEV SEA and the TAYMYR projects came to an end in 1996. It became clear that the marine and terrestrial studies should be merged in a future project. Under the leadership of Heidemarie Kassens (GEOMAR) and Hans-Wolfgang Hubberten (AWI), the project collaborators developed a concept for this new Russian-German project called SYSTEM LAPTEV SEA 2000. It was based on the results of the SYSTEM LAPTEV SEA and the TAYMYR projects but also addressed completely new scientific problems. The following subjects were identified:

A. Seasonal variability of modern fluxes in permafrost areas
- Balance of greenhouse gases (carbon dioxide and methane) and process studies of the methane balance
- Water and energy flux in permafrost soils
- Microbial communities and carbon dioxide flux in permafrost soils

Figure 1: Location map of Lena 1998-2001 expeditions.

B. Environmental reactions of the terrestrial-marine system of the Siberian Arctic during the last 100 years
- Marine environmental reactions and material balance
- Atmospheric input of radionuclides
- Sensibility of marine Arctic ecosystems

C. Land-ocean interactions and the influence on the sediment budget of the Lena Delta
- Environmental and climatic history of the Lena Delta
- Particle transport in the delta-shelf system

D. Terrestrial system: short- and medium-term climatic trends in the Siberian Arctic
- Terrestrial climatic signals in ice-rich permafrost deposits

E. Marine system: long-term climatic trends in the Siberian Arctic
- Causes and consequences of short- and medium-term climatic trends in permafrost regions
- Acoustic signatures of submarine permafrost

Heidemarie Kassens organized a SYSTEM LAPTEV SEA workshop in November 1997, hosted by Martin Antonow at Freiberg University. It was a milestone with regard to the design of the scientific program. The workshop brought together the Russian and German collaborators from both the SYSTEM LAPTEV SEA and TAYMYR projects. The concept of the SYSTEM LAPTEV SEA 2000 project included numerous terrestrial and marine expeditions. They were also discussed at the workshop. It was agreed that GEOMAR would organize the marine TRANSDRIFT expeditions in cooperation with the AARI and that the AWI-Potsdam would organize the terrestrial LENA expeditions in close co-operation with the AARI, the Melnikov Permafrost Institut Yakutsk (MPI), and the Lena Delta Reserve (LDR).

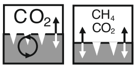
While the logistical framework for the marine expeditions could be based on the experience gained during previous TRANSDRIFT expeditions, much of the logistical requirements for the terrestrial LENA expeditions had to be developed from scratch. Dmitry Bolshiyanov's group at the AARI could handle general issues, such as research permissions, customs operations, and flight logistics. For the on-site logistics, however, new partnerships and logistical conditions had to

be acquired. To prepare the ground, Martin Antonow and Volker Rachold travelled to Yakutsk in April 1998 to meet with Mikhail N. Grigoriev. The agenda of the trip included several meetings in Yakutsk and Tiksi to discuss the on-site and transport logistics in the Lena Delta and to negotiate contracts. Unfortunately, the group got stuck in Batagay at the Yana River due to bad weather conditions. The necessary arrangements could still be made: The partnerships with the Tiksi Hydrobase (Dmitry Melnichenko) and the LDR (at that time Alexander Gukov), established during this first year of LENA expeditions in 1998, proved to be extremely fruitful and are still functioning today, 20 years later.

During the same meeting, the participants made the important decision to use the Samoylov Station in the central Lena Delta as the base for the permafrost studies instead of the existing Lena Nordenskiold Station. Mikhail N. Grigoriev and Volker Rachold made this decision because the Nordenskiold Station is located in a mountainous tundra zone rather than the wet polygonal tundra region, which is typical for the Lena River Delta. Studying the wet tundra of the Lena Delta would have involved crossing the biggest channel of the Lena Delta (Bykovsky Channel) with small boats, which is only possible during good weather conditions. Samoylov Island, therefore, became the basis for Russian-German permafrost research for both logistical and scientific reasons.

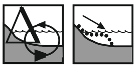
Figure 2: The 1998 Samoylov team.
Figure 3: The 1998 Lena Delta team.

The first expedition (LENA 1998) with about 30 participants was able to start a few months after the logistical groundwork had been laid, under the leadership of Mikhail N. Grigoriev and Volker Rachold. The expedition addressed the terrestrial research objectives of the project SYSTEM LAPTEV SEA 2000 with a focus on permafrost. They were studied by three teams:



Team Samoylov
Seasonal variability of modern fluxes in permafrost-affected soils

- Balance of greenhouse gases (carbon dioxide and methane) and process studies of the methane balance
- Water and energy flux in permafrost soils
- Microbial communities and carbon dioxide flux in permafrost soils



Team Lena Delta
Land-ocean interactions and the influence on the sediment budget of the Lena Delta

- Environmental and climatic history of the Lena Delta
- Particle transport in the delta-shelf system

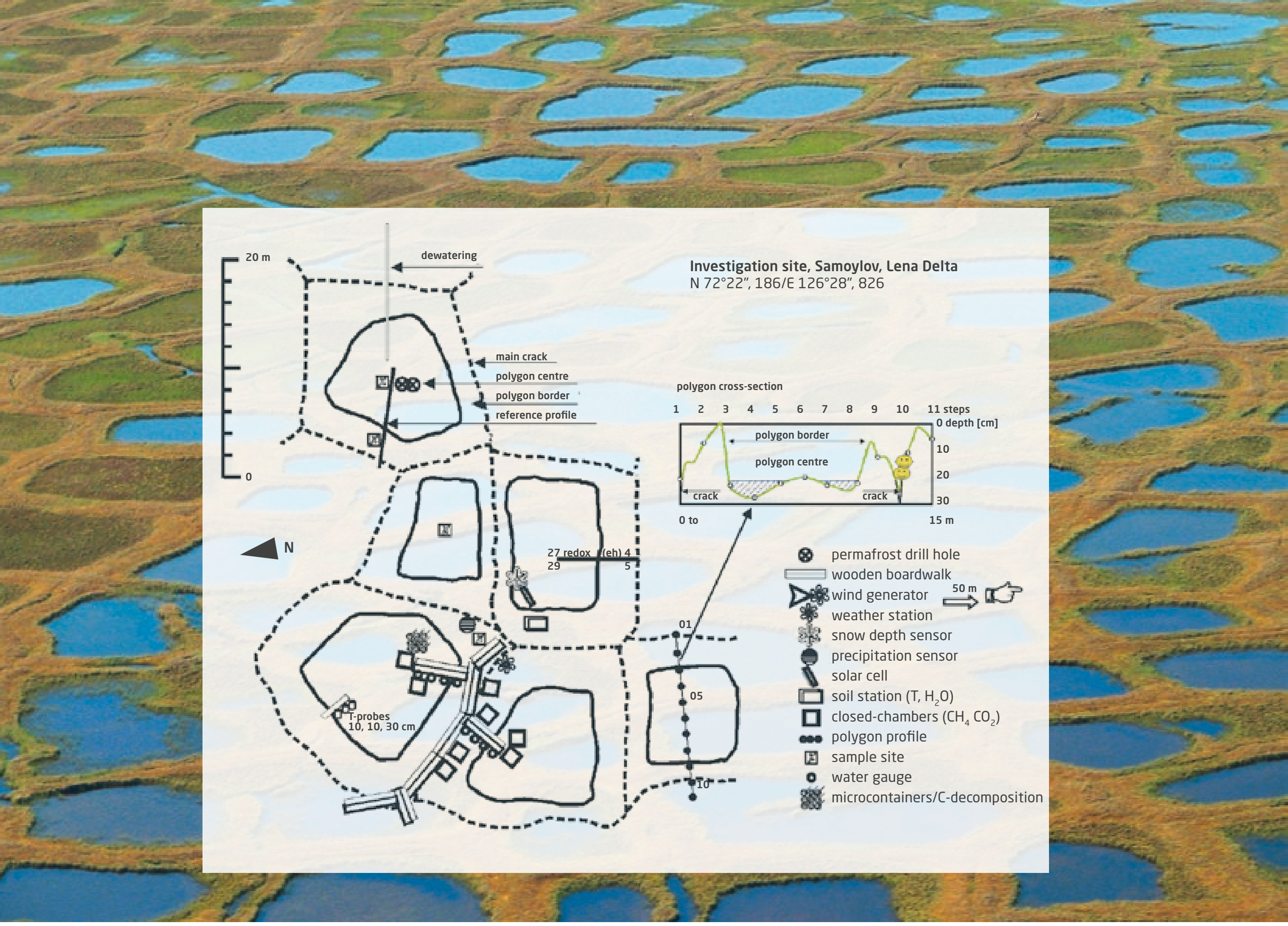
Team Permafrost
Terrestrial system: short- and medium-term climatic trends in the Siberian Arctic

- Terrestrial climatic signals in ice-rich permafrost deposits

The subsequent expeditions were organized in a similar way, although the composition and field of work of some of the teams changed.

Volker Rachold, Martin Antonow, Mikhail N. Grigoriev, Dmitry Yu. Bolshiyanov, Eva-Maria Pfeiffer

Figure 4: The 1999 Permafrost team.



The First Years of Soil and Climate-Related Permafrost Research on Samoylov Island and Surroundings (Investigations 1998 - 2001)

Multi-disciplinary permafrost research began on Samoylov Island in 1998, based on the results of previous investigations (Pushchino Conferences 1992 & 1994, The LAPTEV SEA 2000, The Expedition TAYMYR 1994-1997). It was the starting point for many open research questions about climate-relevant processes in permafrost-affected soils, the actual sedimentation conditions, the environmental history of the Lena Delta, and other topics related to the ice-rich permafrost.

In the years 1998 to 2001, the Russian and German scientists (up to 15 people in the most frequented summer time) shared a small kitchen to eat and talk and a workroom for preparing samples (microscopy, describing, drying samples, etc.).

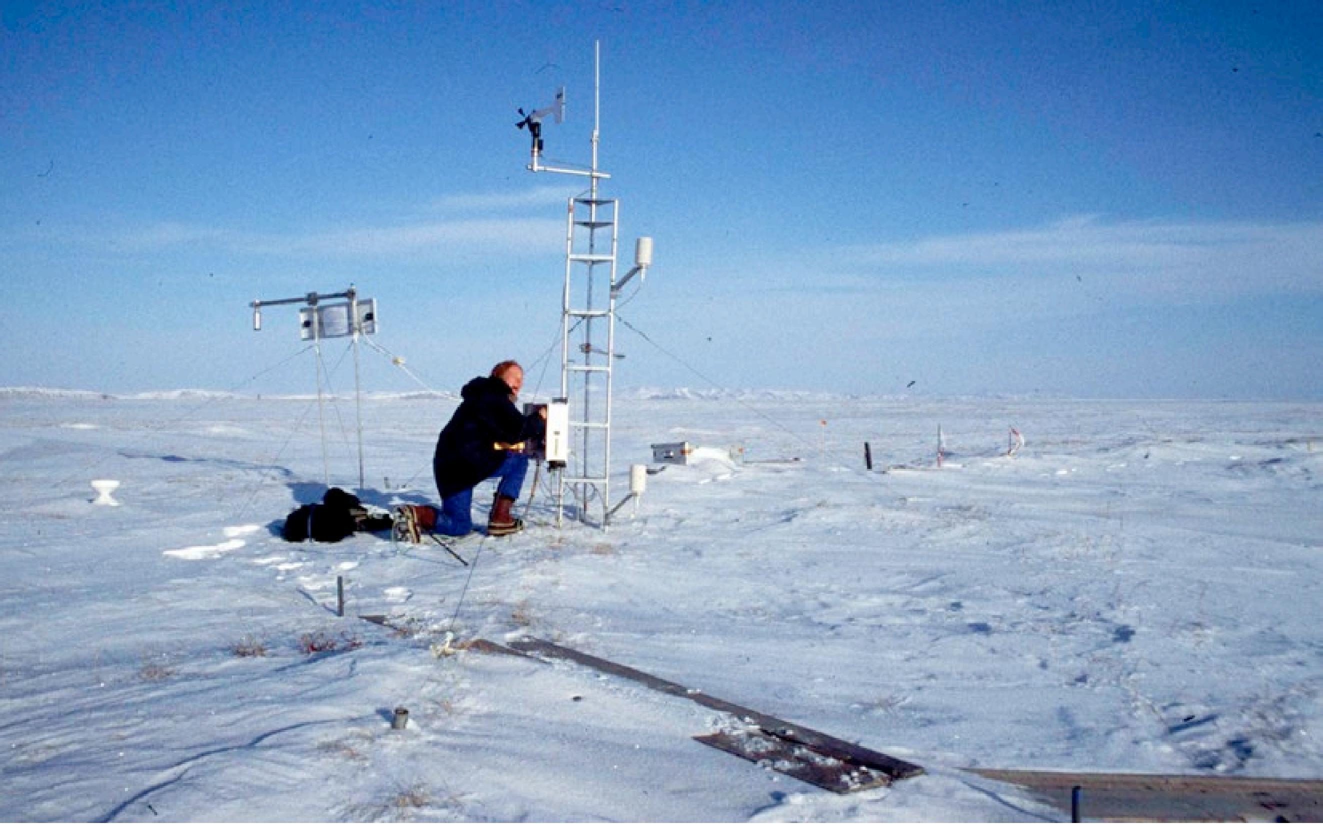
Figure 1: Scheme of the installed instruments of the weather and soil station on the polygonal tundra of Samoylov Island in 2001. (Sketch: G. Stoof, Photo: Konstanze Piel)

One room was used as a first GC lab for trace gas determination and soil microbial lab studies, another room was used as a dorm for three people. All other participants lived in small tents and, once a week, enjoyed the Banya (sauna hut) next to a freshwater lake. A cook of the Lena Delta Reserve (LRD) took care of the expedition members. Good food means good mood for hard-working scientists. Many Germans learned new things about preparing fish, meat, and bread. The whole group was responsible for maintaining the quality of fresh food like apples, lemons and cabbages. They were kept in a special food store and in the lednik (a storage place in the frozen ground), which had to be checked every week because there were no other cooling possibilities.

In case of problems with their highly technical equipment, the participants learned to improvise quickly. In most situations, the AWI engineer Günter Stoof, a.k.a. the "Hausmeister", could soon help with simple and practical solutions – the working program of the expeditions rarely had to be changed due to technical problems.

Despite the long and arduous working days in the field, starting at 8 am until 6 pm or later, the Russian and German participants never missed a chance for an exchange about their work and future plans. And if the participants were not too tired, they enjoyed singing together in the evenings with "piwo and compott " (stewed fruit with little alcohol – lecker, lecker). During these hours, the scientist called Samoylov their "dream island" (Trauminsel) of the Delta, which is how work colleagues became friends forever!

In the first years on Samoylov, research on modern processes concentrated on the characterization of carbon properties of soils and the functions of these properties for energy, water, and trace gas fluxes. The climate observation site on Samoylov Island has been recording important weather, soil, and permafrost parameters for almost 20 years. The first automated weather- and soil-monitoring station was set up during the summer expedition in 1998. The sensors and detectors of this first soil-related station allowed for measurements of air temperature, humidity, wind speed, radiation, precipitation, snow high, soil temperature, soil bulk electrical conductivity, soil volumetric water content, and heat fluxes from soil (see Figure 1). Automated observations are challenging for climate sensors and energy supplies due to the extreme climate conditions, with minimum winter air temperatures below -45°C, wind speeds up to 16 m/sec, and



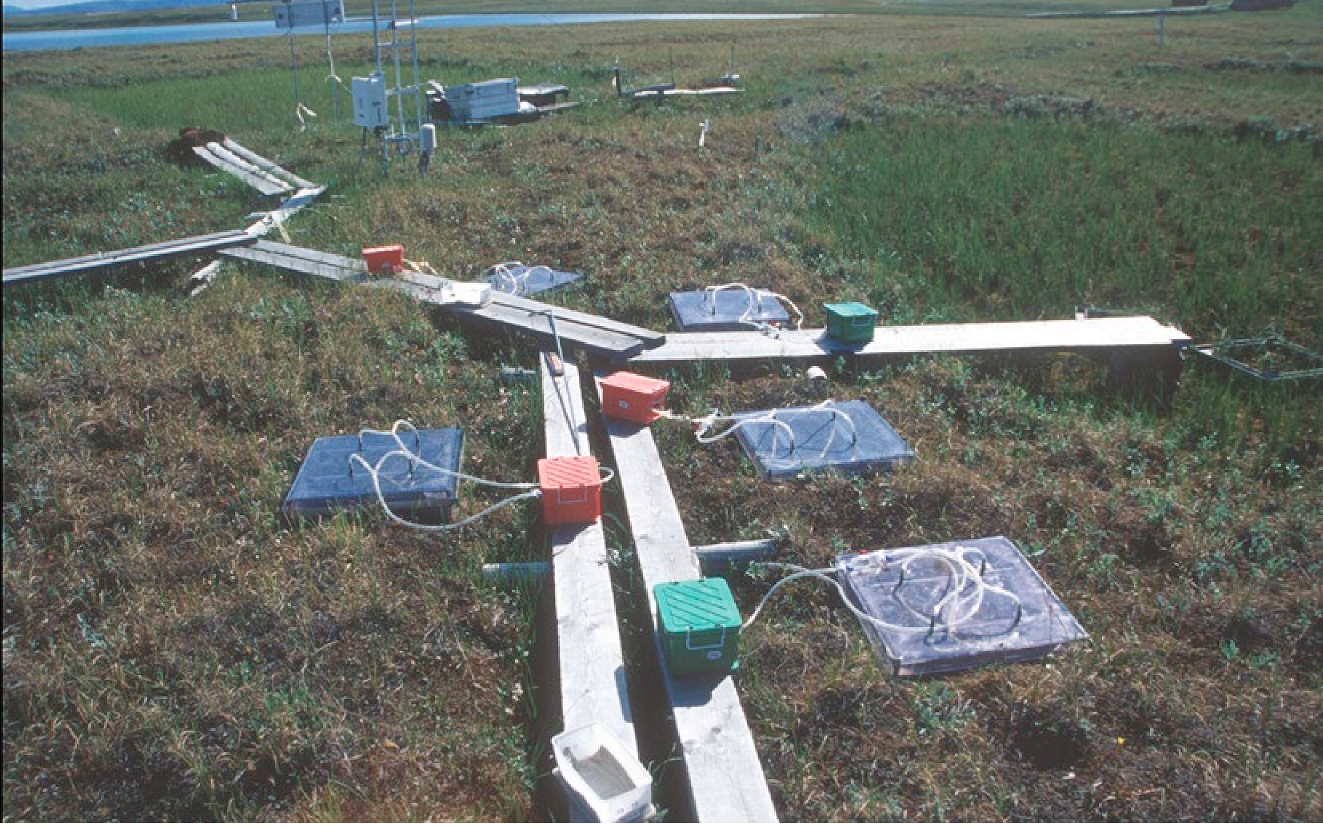
prolonged winter darkness. These Arctic conditions can cause equipment to fail or break down in unfamiliar ways.

The first automated weather station ran successfully on battery power and solar panel (Figure 2) over the winter 1998-1999 and the observations were thus continued.

Originally only planned for a 3-year-project, this station was checked in 2001 and replaced with a new station in August 2002. This station has been maintained up until now, thus providing a long-term dataset. The data are widely used (i.) to quantify responses to drivers of ecosystem change, (ii.) to understand complex ecosystem processes that occur over prolonged periods, and (iii.) to parameterize and validate earth system and land cover models.

This long-term observational site on Samoylov serves as a platform for collaborative studies promoting multidisciplinary research. Samoylov Island has become a reference site for several international programs like CALM (Circumpolar Active Layer Monitoring Network), FLUXNET (network coordinating regional and global analysis of observations from micrometeorological tower sites), and others.

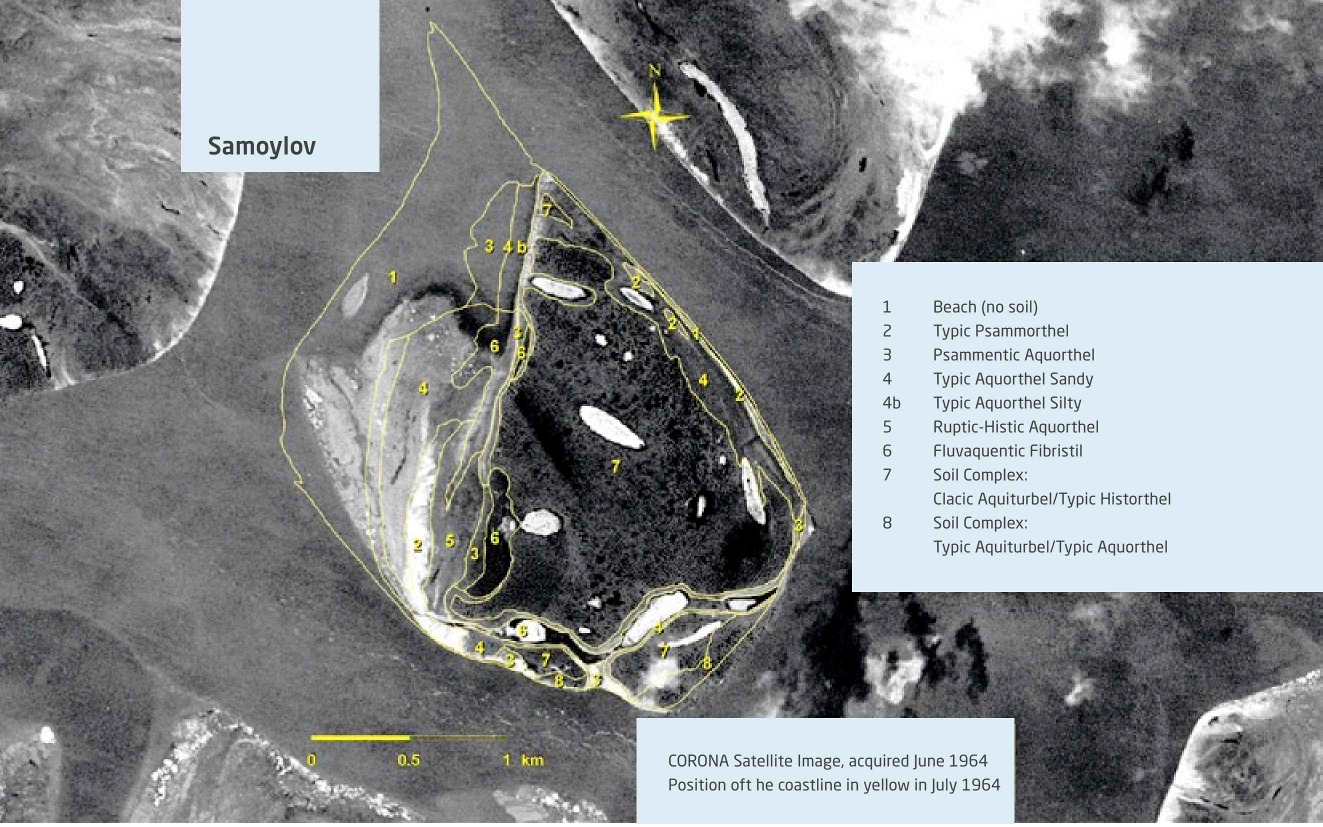
Figure 2: The first automated weather and soil monitoring station in the polygonal tundra of the first terrace on Samoylov Island, set up August 1998, successfully produced the first data over the winter 1998-1999. (Photo: W. Müller-Lupp)



The investigation of soil carbon turnover and trace gas fluxes on Samoylov Island also started in the year 1998. Data of closed chamber measurements (Figure 3) showed a strong variability of the released methane from wet polygonal tundra soils, with low rates of <10 mg CH_4 d^{-1} m^{-2} from the border sites of the polygons and high values between 70-80 mg CH_4 d^{-1} m^{-2} from the polygon centres. The CH_4 flux variability in the polygons was caused by soil hydrology (depth distribution of oxic and anoxic soil conditions), substrate availability for CH_4-producing Achaea, and the consumption rates of CH_4 by methane-oxidizing bacteria in the upper aerated soil surface horizons. The first in-situ investigations of microbial processes started in 2000 and focused on CH_4 production in soils and CH_4 and CO_2 concentrations in ice wedges from different locations in the Lena River Delta.

The first microbial nitrogen-cycle studies started in our field-lab on Samoylov Island in 1999 and were based on former studies of the Russian "Beringia" expedition. Using surface soil samples, the coexistence of nitrite-oxidizing bacteria *Nitrobacter* and *Nitrospira* was demonstrated by microbial-morphological and immunological methods applied to enrichment cultures from soil materials

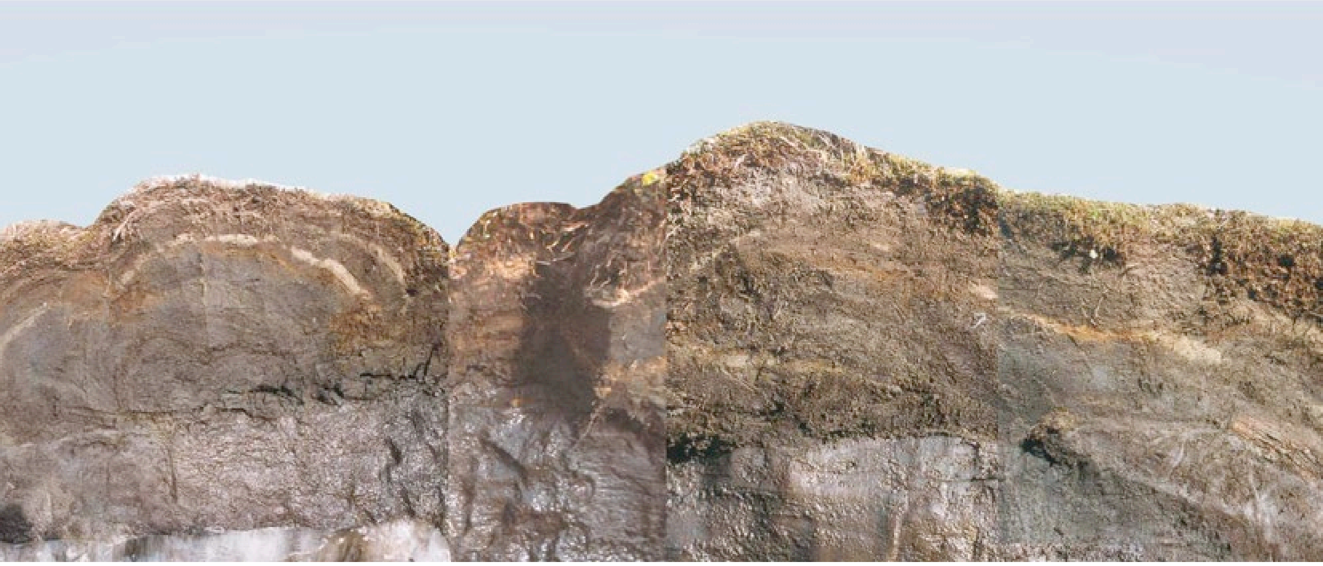
Figure 3: Closed chamber systems for measuring methane fluxes from the wet polygonal tundra on Samoylov Island in 2001. (Photo:E.-M. Pfeiffer)



derived from the rim of low-centred polygons. In the active layer and deeper sediments aged at about 40.000 years, the nitrifying activity was higher at 28 °C in comparison to 17 °C, whereas in more ancient deposits (0.6-3 million of years) the bacteria preferred a lower temperature at 17 °C. In soil samples taken from the active layer of a transect from the polygon rim to the centre in 2001, a novel chemolithoautotrophic nitrite-oxidizing bacteria species, proposed as 'Candidatus Nitrotoga arctica', could be enriched at low temperatures up to 17 °C.

A first soil map of Samoylov (see Figure 4) could be generated based on the Russian and US Soil Classification systems. It shows the diversity of the permafrost-affected soils on Samoylov Island. The first terrace above the floodplains in the eastern part of Samoylov is covered rather homogeneously by the soil complex of *Glacic Aquiturbel* and *Typic Historthels* (nearly 70% of the island area). A representative soil cross-section shows the heterogeneity of the permafrost-affected soils of the low-centered polygons on Samoylov Island (Figure 5). This soil heterogeneity explains the high variability of C turnover rates and trace gas fluxes.

Figure 4: First soil map of Samoylov Island, based on a CORONA satellite image of 1964 and showing the diversity of permafrost-affected soils. (Pfeiffer et al. 2001)



To obtain additional data from the carbon pools in deeper permafrost sediments, first permafrost drilling started on the islands of Samoylov, Kurungnakh, and Sardakh during the Lena Expedition 2001.

The soil-related research generated basic data sets for further investigations of energy and water budgets, carbon sinks (stocks, sequestration, turnover) and sources (C-fluxes, trace gas emissions) in the arctic wet tundra ecosystems of the Lena Delta. These long-term studies of climate, soil, and ecology are needed to provide key insights into changes in the environment, climate, and biodiversity. This is especially critical in Arctic areas, where the station density of observational sites is under-represented, and year-round measurements are difficult. Maintaining high-quality data is only possible through regular maintenance, calibration, and site visits to these remote sites.

Eva-Maria Pfeiffer, Julia Boike, Günter Stoof, Lars Kutzbach, Mikhail N. Grigoriev, Irina A. Yakshina, Anna N. Kurchatova, Dmitry Yu. Bolshiyanov

Figure 5: Cross-section of a low-centred polygon showing the different Gelisols and the heterogeneity of cryoturbated soils. (Photo: L. Kutzbach)

Bykovsky Peninsula: The First Land Expedition with a Focus on Paleoclimate

Russian-German joint expeditions have journeyed to Northern Siberia since 1993, bringing together numerous scientists from both countries. The purpose of these expeditions has been to study the current and past environmental conditions in the Arctic. In 1998, the substantial research project "System Laptev-Sea 2000" started. The "Lena Delta 1998" expedition took place within the framework of this project in July and August 1998. Our research group was to study the traces of past landscape, environmental, and climatic developments in Siberian permafrost.

Permanently frozen ground (permafrost) has existed in Siberia for hundreds of thousands of years. Extreme winter cold means that the ground cannot thaw completely in summer. Permafrost thickness gradually increases as sediment ac-

Figure 1: The thermokarst hill named Kuno, still intact on the shores of the Laptev Sea.

cumulates. These conditions remained constant for a long time, and the ground in Siberia froze to a depth of several hundred meters. The remains of plants and animals, which characterize past landscapes, also froze and were thus conserved. In addition to these "bioindicators", the composition of the stable oxygen and hydrogen isotopes in the ground ice serves as an important climate signal. At the same time as sediments were being deposited, wedges of ground ice formed inside of them. These wedges develop because of thin annual layers of atmospheric precipitation that freeze in fissures. Fissures form in winter and penetrate deep into the permafrost. The analysis of the isotopic composition of ice wedge samples from horizontal profiles allows the reconstruction of the winter temperatures in past epochs.

In March 1998, many of us started our work at the Potsdam Research Unit of the Alfred Wegener Institute. By the end of March, we were already deep in expedition preparations. In April, we purchased necessary equipment, and by May, we packed everything in containers in Bremerhaven and sent it to Russia. Our Russian partners in St. Petersburg continued to work on the organization of the expedition. In July, we finally found ourselves in an aeroplane flying over the Siberian tundra. We stood at the windows for hours, looking down at the unique permafrost landscapes. Our young participants could not completely grasp the fact that their lives as researchers had begun. This sense of awe continues to baffle many expedition participants to this day.

Our expedition destination was the coast of the Bykovsky Peninsula southeast of the Lena Delta. Our most important research object was a famous kilometre-long outcrop of very ice-rich permafrost, the "Ice Complex" on the east coast. The selected territory reminded us a little of Easter Island. Frozen sediment columns, several meters in height, often stand out between thawed ice wedges. These columns exhibit long, narrow or thick, broad "heads" that reminded us of the Easter Island statues. We named one of them "Kuno" in honour of Viktor Kunitsky, our experienced colleague from the Permafrost Institute in Yakutsk. Kuno was a particularly nice specimen of thermokarst hill or "Baydzherakh" in Russian. He stood firmly in the mud on his slender legs and proudly stretched his head towards the Arctic sun. This hill was particularly suitable for fieldwork because frozen deposits lay undisturbed here at a depth of nearly

10 m. An investigation later determined that these deposits covered 20,000 years. We probably hacked and drilled at Kuno for too long because he lost his head after two days. There was a loud noise, and Kuno was rendered completely headless. Fortunately, his once proud head rolled towards the sea, where nobody was working.

By the end of July, the weather had become increasingly unfriendly, windy and rainy with temperatures around 8°C. We slogged through the gales to the ice wall with its sticky mudflows. Our goal was to collect as many samples as possible to study the entire sequence of the deposits and the recent history of the Arctic. We quickly looked like we had taken a mud-bath because we did: Despite our climbing shoes, we fell over a lot. Whether it was raining or the sun was shining, the steep coast was thawing all summer long. As a consequence, material constantly broke off and slid down the slope. We heard a continual crash of dislodged material falling onto the ice. As soon as enough mud had accumulated, an avalanche would slide down to the beach, sometimes carrying one of us with it.

Figure 2: Ascent to the headless Kuno and the wall of the Ice Complex.

The challenging conditions could not disrupt the good mood in our group. Everyone worked together with great enthusiasm. Our research on the Bykovsky Peninsula in 1998 was only the beginning. The following year, we went to Bol'shoy Lyakhovsky Island, 400 km to the east. We have returned here four times to supplement the results. Later expeditions travelled several times to the Lena Delta, to the western coast of the Laptev Sea, and further east to Kolyma, always with the aim to study and reconstruct late Pleistocene and Holocene environmental history in all of its diversity. The expeditions of the first years resulted in about 30 peer-reviewed publications in international journals, as well as a whole series of diploma and doctoral theses. One thing is for sure: Once you have experienced research up in the Arctic, it is not easy to walk away from it. A vast number of unanswered scientific questions remains. Clarifying these questions together with Russian colleagues is truly unique.

Lutz Schirrmeister, Guido Grosse, Viktor V. Kunitsky, Christine Siegert, Hanno Meyer

Figure 3: Part of the Ice Complex ice wall with ice wedges and sediment.

The 1998-2002 Ship-Based Expeditions for Coastal Erosion and Geomorphological Studies with Dunay, Neptun, Sofron Danilov, and Pavel Bashmakov

The research activities to address the environmental and climatic history of the Lena Delta, the particle transport in the Lena Delta shelf system, and the quantification of coastal erosion and associated sediment and organic carbon transport to the Laptev Sea also included a comprehensive sampling program. Figure 1 shows an overview of the stations that were visited, studied, and sampled during five expeditions from 1998 to 2002. Different research vessels and other ships were used to reach these often extremely remote locations (Table 1). The expedition crew used the ships as a base and ferried to the coast with small boats. All ships were chartered from the Tiksi Hydrobase.

The small coaster "Dunay" (Figure 2) was used for the work within and around the Lena Delta (1998, 1999). In 2000 and 2001 a similar vessel "Neptun"

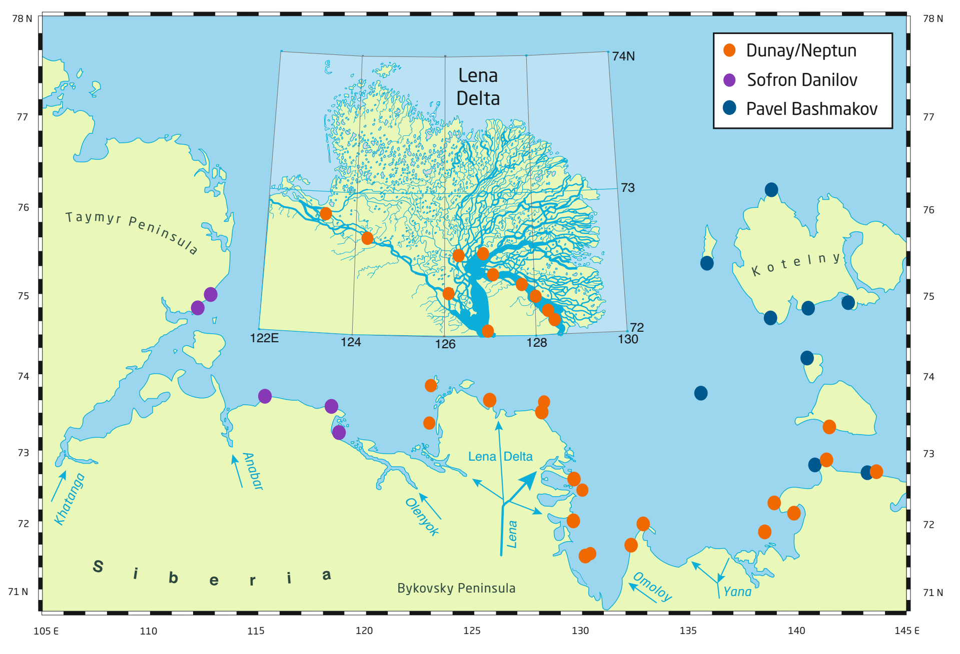


Figure 1: Stations visited during the ship-based expeditions 1998-2002.

Year	Ship	Working area	Field studies
1998	Dunay	Lena Delta channels	Deployment of current meters, CDT (conductivity, depth, temperature) measurements, sediment sampling (for sedimentology, mineralogy, geochemistry, and optically stimulated luminescence)
1999	Dunay	Eastern and central Lena Delta front	Bathymetrical measurements (shoreface profiles), shallow seismic, sediment sampling (for sedimentology, mineralogy, and geochemistry)
2000	Sofron Danilov	Western Laptev Sea	Bathymetrical measurements (shoreface profiles), shallow seismic, sediment sampling (for sedimentology, mineralogy and geochemistry), surveying, and mapping of the coastline
2001	Dunay	Western Lena Delta front and offshore islands	Bathymetrical measurements (shoreface profiles), shallow seismic, sediment sampling (for sedimentology, mineralogy, and geochemistry), surveying, and mapping of the coastline
2002	Pavel Bashmakov	Eastern Laptev Sea and New Siberian Islands	Bathymetrical measurements (shoreface profiles), shallow seismic, sediment sampling (for sedimentology, mineralogy, and geochemistry), surveying, and mapping of the coastline

Figure 2: Coaster "Dunay".
Table 1: Overview of the ship-based expeditions for coastal and geomorphological studies.



(Figure 3) was used for hydrological and geomorphological studies in the Lena Delta. These small vessels were also used for transportation of several expedition groups to their specific study areas. In other years, larger vessels were applied to reach more remote stations along the Laptev Sea coast. In the year 2000, the tugboat "Sofron Danilov" (Figure 4) was used to study and sample a number of coastal stations in the western Laptev Sea and in 2002, the research vessel "Pavel Bashmakov" (Figure 5) was chartered to visit the eastern Laptev Sea, including the New Siberian Island. Table 1 provides an overview of the work program of the five expeditions, including the working area and field studies.

In addition to serving as the base for the coastal workgroup, the ships were also used as the coordination centre for the whole expedition as well as for logistical purposes. The other expedition teams, who were working in different places of the Lena Delta or Laptev Sea region at the same time, could be contacted via satellite telephones. Other teams were also often transported to their working areas by ship.

Volker Rachold, Waldemar Schneider, Mikhail N. Grigoriev, Hans-Wolfgang Hubberten, Felix E. Are, Dmitry Yu. Bolshiyanov

Figure 3: River Vessel „Neptun". Figure 4: Tugboat "Sofron Danilov". Figure 5: Research Vessel "Pavel Bashmakov".

Lake Studies on Arga:
History and Formation of the Lena Delta

A modern river delta has been protruding into the eastern portion of the Lena Delta since the Early Holocene. In contrast, the northwestern part of the Lena Delta – also known as Arga-Muora-Sise Island – is characterized by numerous disconnected lakes and the absence of major river branches. The lakes are several hundred meters wide and long. In their centre areas, they show unusual deep hollows, surrounded by very shallow sandy shelves. What is the origin of this conspicuous lake morphology, and why are many of these lakes so elongated and have such a pronounced orientation?

With this question in mind, we decided to conduct winter and summer field work on Arga Island. In 1998 and 1999, we combined geophysical surveys with shallow sediment drilling to clarify the origin of these extraordinary lake environments. A numerical model completed our interpretation.

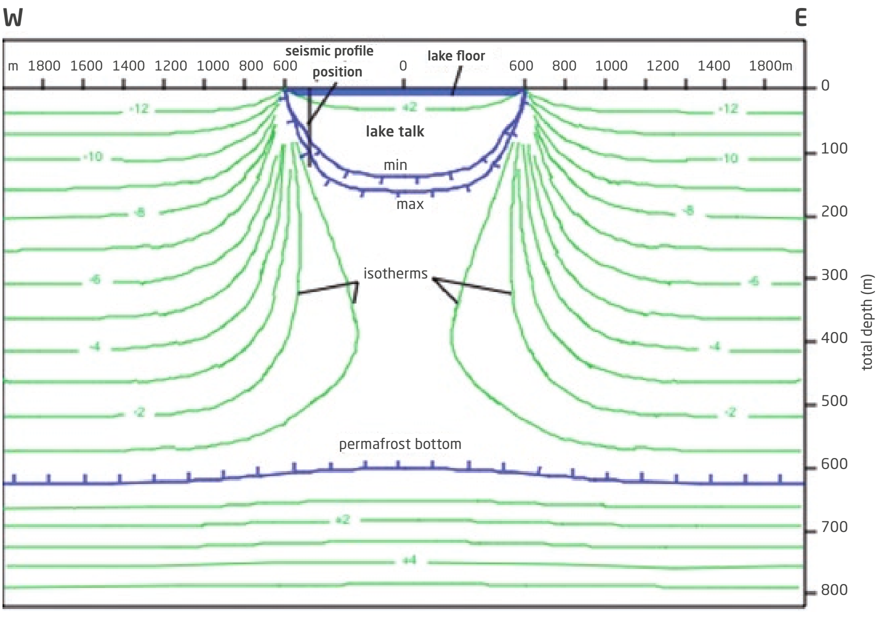
We focused on determining the age and genesis of Lake Nikolay, the largest and most prominent amongst the Arga lakes. We believed it might hold representative clues about the history of Arga Island. One objective of this study was to resolve the scientific controversy about whether these lakes are of glacial or periglacial origin, in other words, to shed light on the history of Arga Island during the Late Quaternary.

Figure 1: Arga lakes (RapidEye_2010-07-06) are located on a sandy plain and have broad, shallow shelf areas (<2 m water depth) and deep central basins. Lake Nikolay (partly ice covered) has several basins (17 m water depth at maximum) and is 8 km in length and width at maximum.

Shallow seismic profiles across the basin, complimentary ground penetrating radar (GPR) profiles of frozen shallow margins, and a set of sediment cores taken from one of Lake Nikolay's deep central basins provided evidence for the lake's evolution since the early Holocene. The uppermost meters of the second sandy terrace of the Lena River delta, where Lake Nikolay is located, accumulated at the end of the late Pleistocene (14,500 to 10,900 yr BP) and are representative of the environment prior to lake formation. Sediment properties suggest a fluvial environment with riverbed sediment layering. After an initial wetland stage, a lake basin formation was established in the sandy environment due to thermokarst subsidence at 7000 ^{14}C yr BP. According to pollen analyses, the onset of extensive thermokarst coincides with the regional Holocene climatic optimum.

Seismic profiles revealed that thick zones of unfrozen deposits (termed "talik") exist under the deep central lake basins, and that permafrost surrounds them. A mathematical model of talik growth and expansion underneath the lake confirmed this interpretation. Based on our findings, neither geological nor geophysical results support the hypothesis that the area's morphology is of glacial origin. This has been deduced from remote sensing techniques of other authors. Instead, gradual river channel migration from west to east left behind a sandy plain, in which abandoned river ponds turned into thermokarst basins. Thermokarst lakes sometimes merged to create a twin lake morphology such as the large Lake Nikolay.

Figure 2: Ground-penetrating radar from the winter ice imaged the bathymetry and sediment geometry in the lakes.
Figure 3: Sediment coring helped to verify geophysical reflectors from the sub-ground and provided material for the reconstruction of past environmental stages in the area.



Research of Arga Island was continued in 2001, 2005, and 2009 with further drilling and exposure studies. Results from all studies were incorporated into several PhD and Master's theses.

It might be worth mentioning that junior researchers, i.e. doctoral students, were at the narrow end of an upside-down field party pyramid in the early days of our Lena Delta research. Many senior researchers were present then, and there was much laughter with each other. In the meantime, things have changed, and there are many junior researchers including student assistants at the wide bottom end of a staff pyramid in the field. Nowadays there are only a few senior researchers at the top end in the field, which might show the progress in regional knowledge and in the skills required to prepare and conduct fieldwork. It might also demonstrate the young researchers' advance in technical skills, but also an improved automated routine.

Georg Schwamborn, Mikhail N. Grigoriev, Volker Rachold, Vladimir E. Tumskoy, Lutz Schirrmeister, Guido Grosse

Figure 4: Numerical modelling backed up the interpretation of deep thaw lake expansion (thermokarst) in sandy terrain left behind from a former fluvial stage of the Lena River.

Microbial Carbon Turnover in the Active Layer and in Permafrost

Introduction

Only a few decades ago, permafrost was considered 'sterile', and the mobilization of permafrost carbon and associated climate feedbacks were of no concern. Today, this situation has reversed. The Lena Delta has been central to numerous studies on the microbial carbon turnover since 1998. The production and consumption of the potent greenhouse gas methane are of particular interest. Microbiological studies conducted in the Lena Delta discovered a large amount of methane-consuming and methane-producing microorganisms. They were identified to be active at temperatures spanning the (sub)zero range up to more than 30 °C. These microorganisms are highly adapted to the harsh conditions of either regular or permanent freeze. Activities and cell numbers of microorganisms in permafrost-affected soils of the Lena Delta are in general very similar to those of less extreme regions. Microbial communities of deep, permanently frozen sediments also serve as an imprint of past environmental changes and determine the boundary conditions for future responses to permafrost thaw. The diverse conditions of micro-relief, hydrology, and vegetation inherent to the Arctic polygonal tundra landscape display multiple factors controlling microbial methane production and consumption. For example, vascular plants such as *Carex* sp. but also mosses provide food and oxygen to the microorganisms, while standing water in polygonal depressions favours peat formation and the turnover of carbon in the absence of oxygen. Fieldwork in the remote northern tundra means little sleep, a lot of work, relentless mosquito attacks, and pulling heavy equipment and samples through muddy soil. The compensation for these struggles: Unforgettable moments with cherished colleagues. The following anecdotes paint a picture of two benchmarking activities for microbial ecology in the Siberian Lena Delta.

A Methanogen travels from Samoylov Island to Space

Fieldwork in summer 2002 (Figure 1 left) kicked off the unusual career of a microbe with extraordinary capabilities. The new methanogenic culture *Methanosarcina soligelidi* was finally published in 2013, 11 years after the first methane producing samples were taken at the northern tip of Samoylov Island. Now, it serves as model organism for potential life on Mars. Long-time exposure to a regular freeze-thaw cycle caused this active-layer methanogen to evolve into an extremely stress tolerant microorganism. It is resistant to desiccation and can survive at extremely high levels of radiation and salinity. Given its special features, *Ms. soligelidi* was a passenger of the exposure platform "EXPOSE-R2". This platform was fixed to the Russian Zvezda module of the International Space Station (ISS) (Figure 1 middle and right) and exposed to Mars-like CO_2-concentrations (95%) and radiation for 18 months.

Methane-Consuming Bacteria Living with Mosses: An Example of Improvised Research

Working in remote areas always requires flexibility, especially if things don't turn out as planned.

Which is exactly what happened in July 2009, when the required equipment got stuck in various unknown Russian airports – and the scientific collaborator was stuck because of visa problems.

Since other colleagues could also not start field measurements, we took many long walks across the island together. They resulted in many new ideas for joint fieldwork, mainly based on the equipment that was available at the station.
We used the spare time to develop and discuss novel hypotheses and to plan new experiments, field measurements, and sample collections to confirm these new hypotheses.

The results of the adapted field work showed for the first time a close interaction between typical mosses of the Arctic polygonal tundra *(Scorpidium scorpi-*

Figure 1: Soil sampling on Samoylov Island (Photo: Günther Stoof), the ISS and the "EXPOSE-R2 Exposure Platform" of the Russian Zvezda ISS module (Source: DLR).

oides, Meesia triquetra) and methane-consuming bacteria living below the water table of the numerous ponds on Samoylov Island (Figure 2).

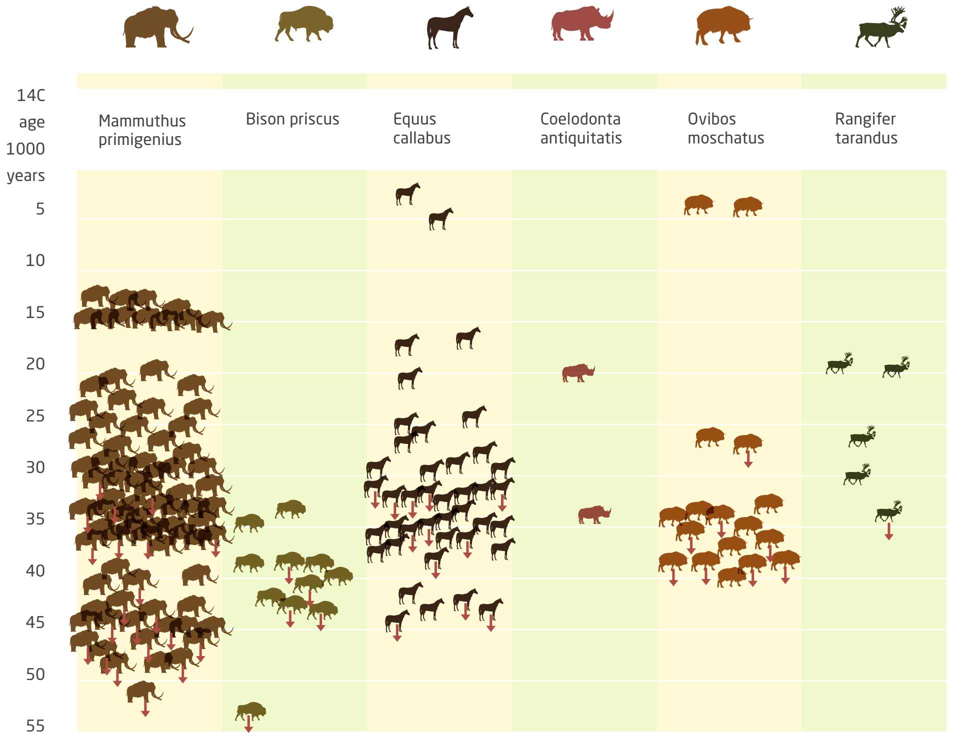
Methane-consuming bacteria were able to use the oxygen produced by the moss via photosynthesis to oxidize almost all of the methane formed in the oxygen-free, water-saturated pond bed.

Although the anoxic pond bottom soil was CH_4-saturated, the ponds could consequently even become a sink for atmospheric methane, which was a result that had previously never been reported for any water-saturated soil. The consumption of methane via this association between plants and microbes is responsible for a large fraction of the carbon fixed by the mosses.

The extensive research on the microbial turnover of organic matter in the permafrost landscapes of the Lena Delta and its regulation by environmental parameters and biological interaction plays an important role in pioneering the field of microbial ecology in permafrost environments. Right from the start, it has brought together scientists from Russia (Krasnoyarsk), Germany (Hamburg, Potsdam, Cologne, Munich), and Switzerland (Zurich). It has contributed substantially to a better understanding of greenhouse gas production and turnover in the Siberian permafrost under a changing climate.

Susanne Liebner, Christian Knoblauch, Eva-Maria Pfeiffer, Svetlana Yu. Evgrafova, Dirk Wagner

Figure 2: Sampling aquatic brown moss on Samoylov Island (left) and an underwater picture of the brown moss *Scorpidium scorpioides* (right). These mosses live in symbiosis with methane-oxidizing bacteria by providing oxygen and in turn gaining CO_2.



Fieldwork for Reconstructing the Paleo-Environment

The remains of the plants themselves are important key witnesses of warmer summers with lush plant cover in the late Pleistocene Siberian tundra-steppe. But so are the remains of numerous large mammals of the mammoth fauna. In addition to the woolly mammoths *(Mammuthus primigenius)*, horses *(Equus caballus)*, woolly rhinos *(Coelodonta antiquitatis)*, reindeer *(Rangifer tarandus)*, antelopes *(Saiga tatarica)*, steppe bison *(Bison priscus)*, muskoxen *(Ovibos moschatus)*, and hares *(Lepus)* were also found. These herbivores range widely in size. Collectively, they must have consumed a considerable amount of food. Our investigations showed the simultaneous presence of predators such as lions *(Panthera leo spelea)*, wolves *(Canis lupus)*, and foxes *(Vulpes vulpes)*, also suggests a large number of prey animals. One can conclude from the presence

Figure 1: Radiocarbon dating of fossil remains of the main mammoth fauna representatives, collected during the joint German-Russian expedition in 1998 on the Bykovsky Peninsula. Downward arrows indicate the minimum age.

of these animals that the summers were warm and dry when they inhabited this place. Since this assemblage of wildlife no longer exists here, some crucial factors must have changed. Today, a species-poorer mammal community lives here, and it is dominated by small- and medium-sized animals such as reindeer, rabbits, lemmings, wolves, and foxes. Polar bears also occasionally migrate from the pack ice to the islands of the Laptev Sea.

Numerous finds of bones and tusks are evidence of the faunal richness that once existed here. They are continuously being exposed from the frozen ground during the melting season on coasts and rivers, and sometimes include remains of skin and coat. The very first polar travellers in these areas reported amazing finds: They appreciated the ivory of the mammoth tusks in particular. Even today, these treasures, highly valued by artisans and collectors, are a lucrative source of income for the modern Yakut and Russian "ivory hunters" in the harsh North. Our mammal specialist, palaeontologist Tatyana Kuznetsova from Moscow, identified and catalogued several hundred individual finds, from a horse's rib to a mammoth scapula, during our 2002 expedition in the New Siberian Islands archipelago alone.

Figure 2: Tatayana Kuznetsova cleans the first collection of mammal bones (Bykovsky 1998).

From 1998 to 2007, our Russian colleagues from Moscow studied numerous finds of mammoth bones that were preserved in permafrost. As a result, geographic terms based on mammoth names are frequent on the Bykovsky Peninsula. A complete mammoth skeleton was recovered on the Bykovsky Peninsula as early as 1799. It was recovered and examined by the Russian botanist Mikhael Adams in 1806 and now resides at the Zoological Museum in St. Petersburg. In 1998, an extensive bone collection was assembled, and the first guided tours

Figure 3: Igor Syromyatnikov with a mammoth thigh bone (Bykovsky Peninsula, 1998).

were organized. Bones of two different mammoth species were found, as well as many bones of horses, reindeer, Nordic antelope, buffalo, polar lions, and hares. The preparation of the bone collections was a major event at the end of each expedition. Of course, not all the finds could be taken to Moscow. Larger pieces of bone were required to determine the age of the animals that once trotted through the tundra-steppe – from the scapula, thigh, or pelvis, for example. Viktor Kunitsky kindly demonstrated the art of chainsaw bone cutting: Put on protective goggles and gloves, place the bone on a block of wood, and cut it. All the expedition members stood in a circle and took an active part in this paleontological closing ceremony.

Cape Anisii, the northern tip of Kotel'ny Island, was the northernmost point of our 2002 expedition by ship through the New Siberian Islands. We found our northernmost bone here. A mighty mammoth thigh protruded vertically out of the ground, not far from a thermokarst hill. The lower part of this bone was still frozen, while gnaw marks were visible at the top, probably evidence of hungry polar foxes. There were a few more single bones in the surrounding area. These mammoth bones show that herds reached 76° northern latitude in the Ice Age – and found food.

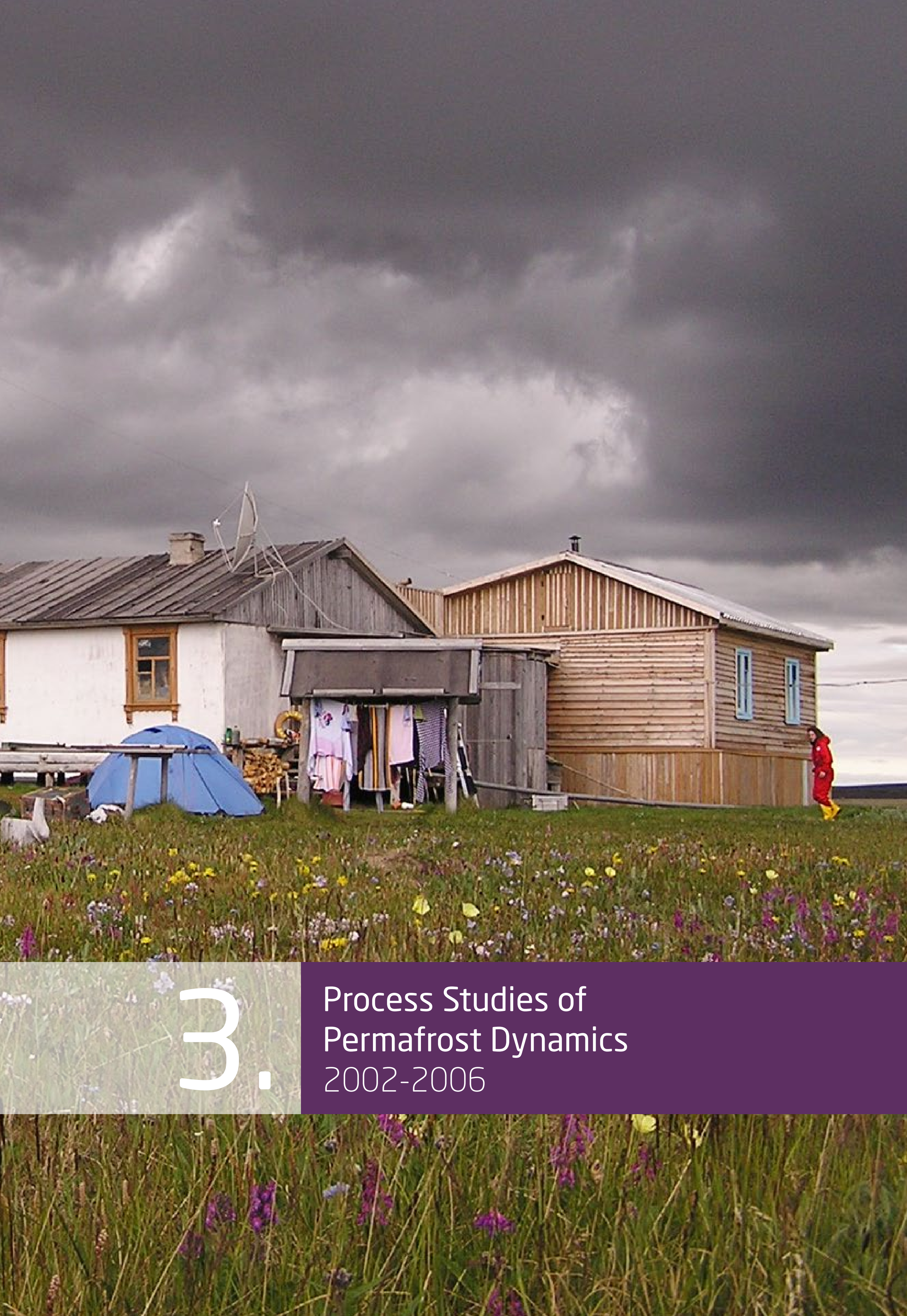
A few days later, we worked on a coastal strip called Oyogossky Yar near the mouth of the Kondrateeva River. Russian researchers had worked here many years ago and had reported excellent outcrops. The Yakutian name Oyogossky Yar means something like "steep bank on which the foal was eaten", apparently a reminder of an historic emergency barbecue. A steep cliff runs along the Dmitry Laptev Strait for several kilometres. It is up to forty meters high in some places and appears to be composed almost entirely of ice. It became clear why early Siberian polar explorers in the 19th century, still guided by the first hypotheses of the great ice ages and inland icing of northern and central Europe, thought they saw buried glaciers in these ice walls. It turned out, however, that they were not glacial remnants, but gigantic ice wedges, several tens of meters long and up to six meters wide. Black, brown, and gray lumps of frozen soil look out of the ice wall, which gleamed in the sunlight and was furrowed by streams of meltwater. We saw a protruding mammalian bone, exposed by the summer heat. It was muddy and impassable directly in front of the ice wall, but fossil treasure awaited us here and a few meters further down the beach. Everyone worked to carry 369

individual pieces of bone, from a small horse tooth to a mammoth shoulder blade, down to the landing site. Thousands of fossils from the late Pleistocene mammoth fauna were collected in the Laptev Sea region between 1998 and 2007. The results were used in numerous publications, including dozens of international publications and several theses that reported the results of examining spores and pollen, plant macrofossils, ostracods, shell-bearing amoebae, diatoms, chironomids, fossil beetles, and daphnia under the microscope.

Lutz Schirrmeister, Tatyana V. Kuznetsova, Andrei A. Andreev, Frank Kienast, Dmitry Yu. Bolshiyanov

Figure 4: Tatyana Kuznetsova with a frozen mammoth tusk (Oyogossky Yar, 2007).

Samoylov Station showing the main building on the left and the new extension on the right. Tents were used for expedition participants in summer. (Photo: G. Stoof)



3. Process Studies of Permafrost Dynamics

2002-2006

Subsea Permafrost Drilling During the COAST 2005 Expedition

As a result of their exposure during the Last Glacial Maximum, large areas of the Arctic shelves are thought to be almost entirely underlain by subsea permafrost from the coastline down to a water depth of about 100 meters. This subsea permafrost is known to contain gas hydrates, a solid phase composed of water and gases that formed under low temperature and high-pressure conditions. Large volumes of methane can be stored within or below the subsea permafrost in the form of gas hydrate. The existence of permafrost sustains the stability of this gas hydrate zone. Degradation of subsea permafrost and the consequent destabilization of gas hydrates could significantly, if not dramatically, increase the flux of methane, a potent greenhouse gas, to the atmosphere.

In April 2005, the coastal and offshore drilling program COAST took place in the western Laptev Sea. Its main objectives were to understand the transition from onshore to offshore permafrost and the influence of saline seawater on the evolution of subsea permafrost after inundation. The coastal area can be used as a natural laboratory because onshore permafrost is constantly transformed into subsea permafrost due to coastal erosion. The time since the inundation de-

Figure 1: Field camp of the COAST 2005 Expedition on the sea ice in the western Laptev Sea.

pends on the distance from the modern shoreline. This period can be quantified with known coastal erosion rates.

Figure 1 shows the field camp on the sea ice. Two mobile accommodations, laboratory containers, and the drill rig were transported over the sea ice from Tiksi on sledges, pulled by two caterpillars. The expedition crew arrived by helicopter. This remote location was selected despite the complex and costly logistics because warm and less saline river water has little influence on this part of the Laptev Sea. In addition, the coastal onshore region at this location had been intensively studied. Sediments were known to be generally ice-rich permafrost deposits of the Siberian Ice Complex and models suggested that continuous ice-bearing permafrost with a thickness of 400-600 meters could be expected in the coastal offshore zone.

Five boreholes were drilled and cored along a transect running perpendicular to the coastline. The transect extended from onshore to 12 kilometres offshore, where the water depth reached 6 meters. A dry drilling technique and a casing prevented seawater infiltration. The field studies included geocryological core descriptions, borehole temperatures, and pore water/ice salinities. Figure 2 shows a drill core sample of ice-rich subsea permafrost deposits, figure 3 the

Figure 2: Drill core sample showing ice-rich subsea permafrost.

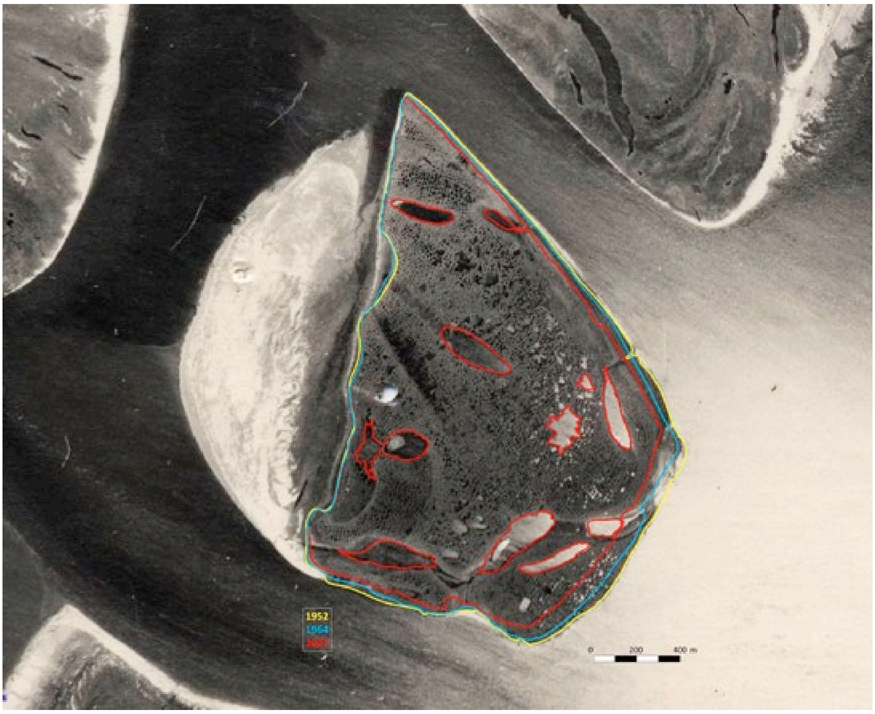
drilling operations, and figure 4 the pore water squeezer that was used to separate the pore water/ice. Further laboratory analyses included oxygen and hydrogen isotope concentrations of the pore ice and infrared-optical stimulated luminescence (IR-OSL) age determinations of sediment from the deepest borehole.

In 2005, subsea permafrost was still poorly understood, due mainly to the lack of direct observations. The results of the COAST expedition provided some important insights but also revealed some unexpected findings. All offshore cores contained frozen sediments, and the phase boundary elevation decreased with increasing distance from the shore. Based on the typical cryogenic structures and the isotope values of the pore ice, the frozen sediments could be identified as the inundated Siberian Ice Complex. Using recent coastal erosion rates, it could be shown that the upper surface of the frozen sediments may reach 35 m below sea level after only 2500 years of inundation. A surprising result was that the borehole located furthest away from the coast encountered almost completely unfrozen and ice-free sediments below a depth of 64.7 m below sea level. This finding was in contrast to the models, predicting 400-600 meters thick continuous permafrost in this area.

Overall, the results of the expedition suggested that submarine permafrost may be warmer and less widespread than expected before, in particular for the Laptev Sea shelf, most of which has been inundated for over 6000 years.

Volker Rachold, Mikhail N. Grigoriev, Dmitry Yu. Bolshiyanov, Waldemar Schneider

Figure 3: Operating the drill rig.
Figure 4: Pore water (ice) sampling in the field.



The Early Samoylov Station and Its Extension in 2005

In 1998, the first of now 20 expeditions left for the Lena Delta, one of the largest deltas (32.000 km$^{2)}$ in the Arctic region. This expedition, called Expedition LENA 1998, brought together about 30 Russian and German scientists, students, and technicians from different study fields. For the first time, the Samoylov Station was the logistical base for the beginning of long-term investigations on the permafrost formation and decay, the production and emission of greenhouse gases (CH_4, CO_2, H_2O), as well as the thermal and hydrologic conditions in the active layer.

Samoylov Island (72°22'N, 126°28'E) is a representative island in the active and youngest part (8,000-9,000 yr) of the Lena Delta. It covers an area of about 1,200 ha and has an elevation of 2 to 14 m above sea level (Figure 1). The western coast of the island is characterized by modern accumulation processes of fluvial and aeolian sedimentation. Three floodplains with differing flood-

Figure 1: Samoylov Island and land lost through coastal erosion in the years 1952, 1964, and 2007. (Photo: G. Stoof)

ing frequency and vegetation coverage can be distinguished. The texture of accumulated sediments is dominated by fine to medium sand. In contrast, the eastern coast of Samoylov Island is dominated by erosion processes that form an abrasional coast. This part is composed of middle Holocene deposits, which cover about 70 % of the total area of the island.

The former small research station Samoylov of the Lena Delta Reserve (LDR) had been developed into an ideal location for coastal and terrestrial polar research. The station can be reached from Tiksi (which has an airport and connects to Moscow, St. Petersburg, and Yakutsk) by helicopter in about 45 minutes or by ship in about 12 hours.

The station was built as one large wooden main house on wooden piles installed in the permafrost, its outer walls covered with plaster. A washhouse, a sauna, three small wooden stores, and one big freezing storage in the frozen ground (Russian = lednik) complete the station ensemble (Figure 2), which fits very well in the polygonal tundra landscape of the Lena Delta.

Figure 2: Research station „Samoylov": Main building and stores, view from southwest (helicopter picture 2001).

The total area is about 190 m², about 120 m² of which can be used for expedition work.

The western part is used by the local station leader of the Lena Delta Reserve (LRD). The available rooms include a kitchen (10.7 m²), a sleeping room, and two laboratories for scientific work. A 6 KVA diesel generator (Honda ECT 6D) supplies sufficient energy for the general equipment of the station and the scientific instruments (GC, computers, etc.).

While drinking water had to be carried from the nearby freshwater lake with a mobile water tank in the first three years, a pumping system now transports water to the station. The adjacent sauna is also used as a bathroom. A toilet hut is about 50 m away from the station.

The universal lab has a size of about 15 m² and is equipped with two working benches with a total length of 6.5 m. The second laboratory is about 12 m² and equipped with a gas chromatograph (Chrompack CP-9003; FID, WLD) and a hydrogen generator (Domnick Hunter UHP-20H) for trace gas analyses (Figure 3).

A new annex building was constructed in 2005 at a 90° angle with the existing structure (see pages 66-67). It is connected to the old station through the anteroom. The new building features an additional 68 m² of space of, which was split into three sleeping rooms and one large living room. Special attention was paid to the insulation of the annex to enable research activities in the Lena Delta during the winter season. The extended station provides space for eight scientists during winter and up to 16 people in summer by using additional tents.

Figure 3: Laboratory for trace gas analyses (e.g. equipped with a gas chromatograph and a hydrogen generator) and sample preparation for microbiological and pedological analyses. (Photo: D. Wagner)
Figure 4: The construction of the new German-Russian Samoylov Station organized by the AWI and the Lena Delta Reserve. In the background: The old Samoylov Station. (Photo: G.Stoof)

The long-term experimental plots – including the automatic climate and soil stations – are easily reached by two-minute walk from the main station. The measurement plots have been producing good-quality climatic and soil-related temperature data since 1998. Half-automatic trace gas measurements were added some years later.

In 2002, the long-term studies on carbon dynamics were supplemented by a micrometeorological eddy covariance measurement system, which was designed to continuously determine the turbulent fluxes of carbon dioxide, methane, momentum, heat, and water in the atmospheric boundary layer. The elaborate measurement system was applied for the first time during the LENA 2002

Figure 5: Land loss near the station area on Samoylov Island by coastal erosion in the years 2003 to 2016. Seen is the old Station and the southern part of the new Station. (Photo: G. Stoof)

expeditions in the Lena Delta, in northern Siberia. The flux measurements were conducted in parallel with the monitoring of standard meteorological and soil physical data during the vegetation period. The obtained data sets allowed the coupling of the energy and water budget of permafrost landscapes with the carbon exchange processes between permafrost soils, tundra vegetation, and the atmosphere. Such studies were necessary for the validation and improvement of process models that assess the impact of environmental and climatic change on arctic ecosystems.

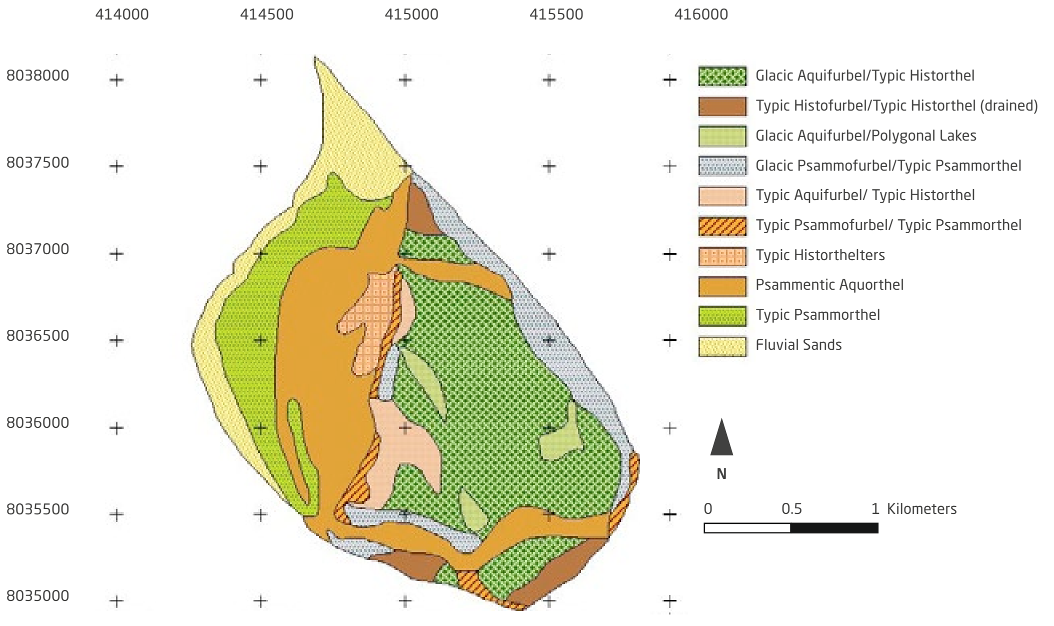
Furthermore, a broad spectrum of research was performed on Samoylov Island and its surrounding, which can be reached by using rubber boats or a small river boat. Over the last 20 years, Russian and German expedition participants have used the Samoylov Station for hydrobiological investigations in the Lena Delta, studies on recent cryogenesis, observations of the tundra's energy and water budget across multiple spatial and temporal scales, and geomorphological studies in the Lena River Delta, as well as late Quaternary research.

Due to the Lena River eroding the shoreline of Samoylov Island (see Figure 5) especially during ice break-up, the cliff edge came as close as 10 m, and the stability and remaining lifespan of the station were increasingly endangered. As a result, AWI, together with the Lena Delta Reserve, decided to construct a new station at a higher position of the island.

In summer 2010, an agreement had been signed by both parties, and the construction material was transported to the island. The construction of the new station started by putting wooden piles into the frozen ground. The construction work continued into the summer of 2011, but it had to be stopped in the same year: The space was needed for the construction of the new Samoylov Station thanks to the initiative of Russia's president, Vladimir Putin (see Figure 4).

With the inauguration of the new Samoylov Station and the first expedition work in spring 2013, the old Samoylov station ended up as a bilateral research station between Russia and Germany. Since then, it is only used as an annex and for the station leader of the Lena Delta Reserve.

Hans-Wolfgang Hubberten, Julia Boike, Eva-Maria Pfeiffer, Günter Stoof, Alexander Yu. Gukov



Installation of the Samoylov Observatory – Permafrost-Affected Soils and Greenhouse Gases (Investigations 2002-2006)

Rapid changes in the Arctic of Northeast Siberia with its sensitive permafrost-affected soils, their unique tundra ecosystems, and their ice-rich landscapes animated the Russian-German permafrost scientists to act. They established modern measurement instrumentation on Samoylov Island to investigate all major components of the carbon cycle, with a focus on the greenhouse gas budget.

Progress on permafrost-affected soil studies

A new automatic soil and meteorology measurement station was installed on Samoylov Island in August 2002 to overcome several technical problems with the first station from 1998. Based on the detailed knowledge (gained from

Figure 1: Distribution of permafrost-affected soils (Gelisols) on Samoylov Island. Map based on soil survey during the LENA 2001 expedition (according to Pfeiffer et al. 2002).

expeditions in 1998-2001) about the morphology, properties, and distribution of soils (see Figure 1), a site for the new soil station was identified, and the soil scientists and technicians of the expedition team set up the new station in an interdisciplinary effort (see Figure 2). The sensors of the station allowed the measurement of variables like air temperature, air humidity, wind speed, radiation and precipitation, snow high, soil temperature, soil volumetric water content, and soil heat fluxes.

A thaw depth monitoring program was started in 2002 in the direct vicinity of the new station (see Figure 3). Within an area of 28 m x 18 m, a grid of 150 measurement points was marked in intervals of 2 m x 2 m and mapped with a laser tachymeter. The seasonal development of thaw depths has been regularly measured at the 150 points during all expeditions from 2002 until now.

Figure 2: Installation of the new soil and meteorology station: Using an ice corer for the installation of sensors in the ice-wedge of the polygon.

In combination with the micrometeorological land-atmosphere flux measurements, the automatic soil and meteorology station (see below) allows the analysis of the coupling of the water and energy budget of permafrost-affected landscapes with the carbon exchange (e.g. CO_2, CH_4) between Gelisols, tundra vegetation, and the near-surface atmospheric boundary layer. Soil-related data is important for the evaluation of the question if the polygonal tundra of the Siberian permafrost-affected lowlands has turned from a sink to a source of carbon. To do this properly, the long-term soil and meteorology station on Samoylov Island needs our further technical support to investigate the changing carbon budget and the spatial variability of trace gas fluxes on a larger scale. The recorded data is necessary to evaluate the impact of the ongoing warming on the Siberian Arctic, and to provide sensible advice to our society in a changing world.

Figure 3: Measuring thaw depths with a permafrost rod (steel stick) in September 2003. (Photo: U. Zimmermann)

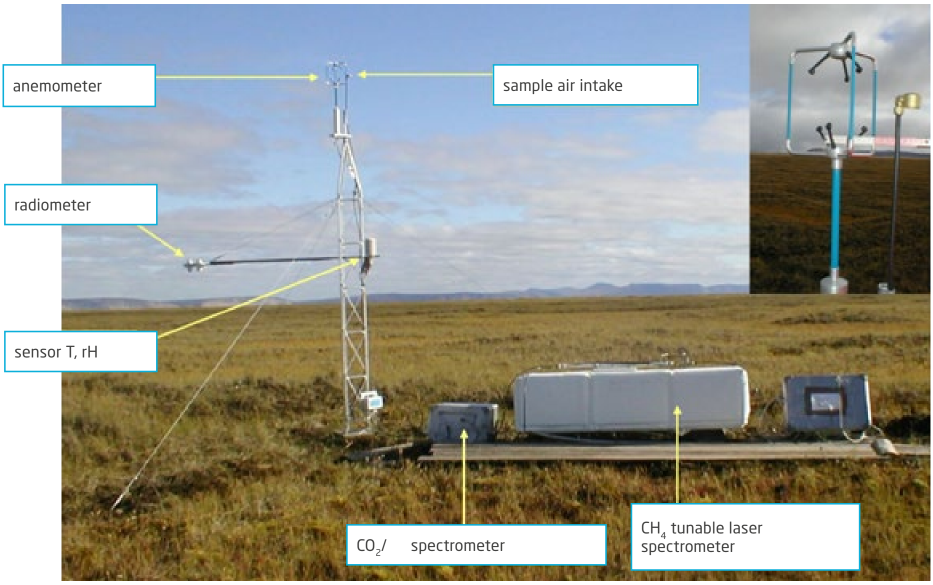


Figure 4: The eddy covariance team in June 2002 on Samoylov Island – harsh weather conditions, but the team is happy that the delicate instruments and generator fuel reached the island.
Figure 5: The eddy covariance system included a three-axis sonic anemometer (at the top of the tower and in detail in the figure inset), an infrared CO_2/H_2O analyzer, a CH_4 analyzer based on tunable laser infrared spectroscopy, and the power supply.

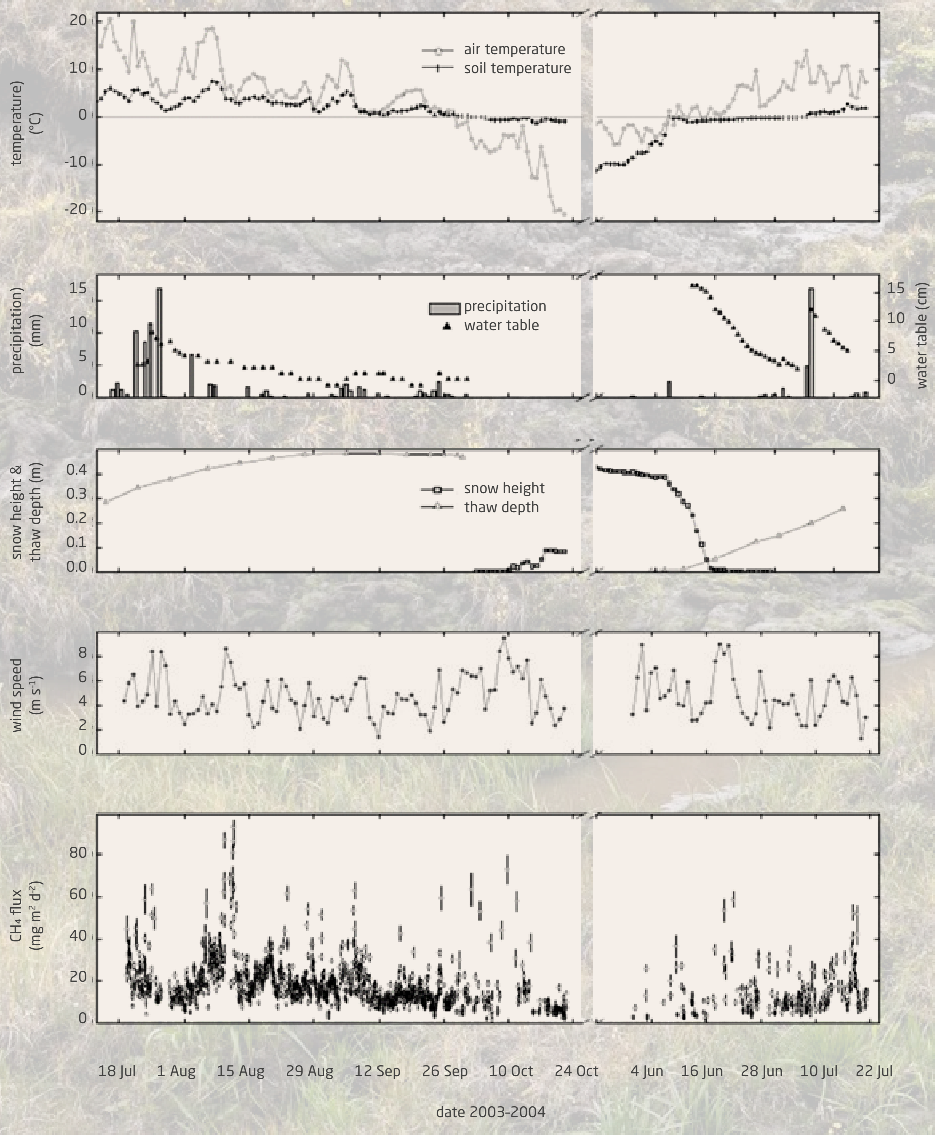


Figure 6: Data recorded by the eddy covariance system including CH_4 emissions rates for July-October 2003 and June-July 2004 (Wille et al. 2008). (Background photo: P. Verzone)

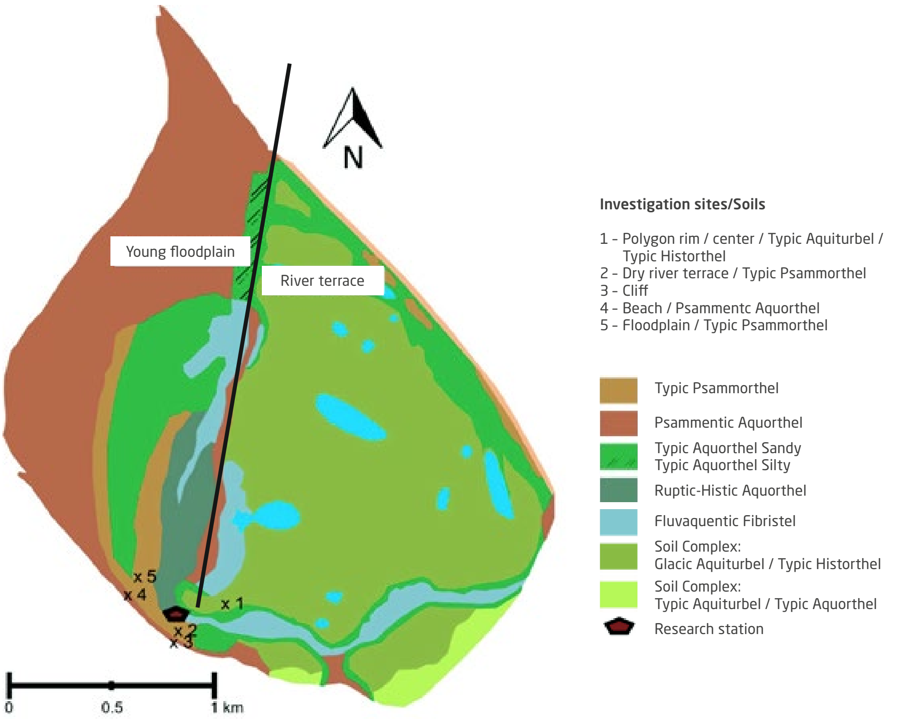
Eddy covariance methodology for studies on greenhouse gases emissions on Samoylov Island

The microbial process studies and simple closed chamber measurements from the years 1998-2001 delivered interesting initial results about the complex carbon cycle of polygonal tundra. For a better quantification of the temporal variability of CH_4 and CO_2 budgets, however, the greenhouse gas studies were brought to a new quality in 2002 by establishing a micrometeorological eddy covariance flux measurement system on Samoylov Island (see Figure 4). The eddy covariance methodology allows the determination of gas fluxes at a high temporal resolution, integrated on the landscape scale, and without disturbance of the soil-vegetation ecosystems under study. The main components of the eddy covariance system are shown in Figure 5. The first generation of an eddy covariance system was installed in June 2002 in the centre of the polygonal tundra on the first river terrace part of Samoylov Island.

After solving various time-consuming and patience-demanding technical problems, starting with the generator and ending with the tunable diode laser, the expedition group was finally able to establish the eddy covariance technique on Samoylov Island which could be successfully operated during many follow-up expeditions. This state-of-the-art measurement system produced long-term flux data, which allowed the first evaluation of sink and source strengths of CO_2 and methane of the polygonal tundra of the Lena River Delta (see Figure 6). The continuation of this unique data set on carbon fluxes in Russia is essential for the international Earth System Science (see pages 177–179).

Important conclusions from the analysis of the CO_2 and CH_4 fluxes are: (1.) The North Siberian polygonal tundra is still a robust CO_2 and carbon sink in most years. (2.) Hot summers can, however, reduce the summer CO_2-uptake so much that the tundra is shifted to an annual carbon source. (3.) The CH_4-fluxes are comparatively low and not significant for the carbon balance, but large enough to cancel out the climate-cooling radiative forcing due to the annual CO_2-uptake – even in years that are normal in terms of temperature.

Lars Kutzbach, Christian Wille, Torsten Sachs, David Holl, Günter Stoof, Julia Boike, Mikhail N. Grigoriev, Eva-Maria Pfeiffer



Microbial Nitrogen Turnover in the Active Layer and Deeper Permafrost Sediments of the Lena River Delta

Field studies on Samoylov in 2004 and 2005 showed that the nitrogen cycle in permafrost soils depends mainly on soil moisture and structure. Variation in nitrogen conversions, therefore, exists on small spatial scales. Ammonium accumulated in the polygon centre soils under moist, anaerobic, and methane-containing conditions, while only low concentrations of nitrite and nitrate were measured. These data correlate with low cell numbers and low activities of ammonia-oxidizing microbial communities. In contrast, in the dryer aerobic polygon rim, high

Figure 1: Soil map of the Samoylov Island with locations of investigated sites (Sanders et al., 2010). The black line indicates the separation of the island into the less N-limited soils *(Typic Psammorthel, Psammentic Aquorthel, Typic Aquorthel Sandy* and *Silty)* of the young floodplain and the dry river terrace in the western part of the island, and the more N-limited soils of the polygonal tundra, especially the Typic Historthel on the wet river terrace in the eastern part of the island.
Figure 2: Site and soil profile of the soils of the river terrace (a: Site 1, b: Site 2 in Figure 1) and young floodplain (c: Site 4, d: Site 5 in Figure 1) (Sanders et al., 2010). a: *Typic Aquiturbel* of polygon rim and *Typic Historthel* of polygon centre, b: *Typic Psammorthel* near the old station, c: *Psammentic Aquorthel* on the beach, d: *Typic Psammorthel* on the floodplain.


O
Ajj
Bjjg1
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a
Oi
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C1
A
Bw
b
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Cg1
Cg2
c
A
Ab/C
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C1
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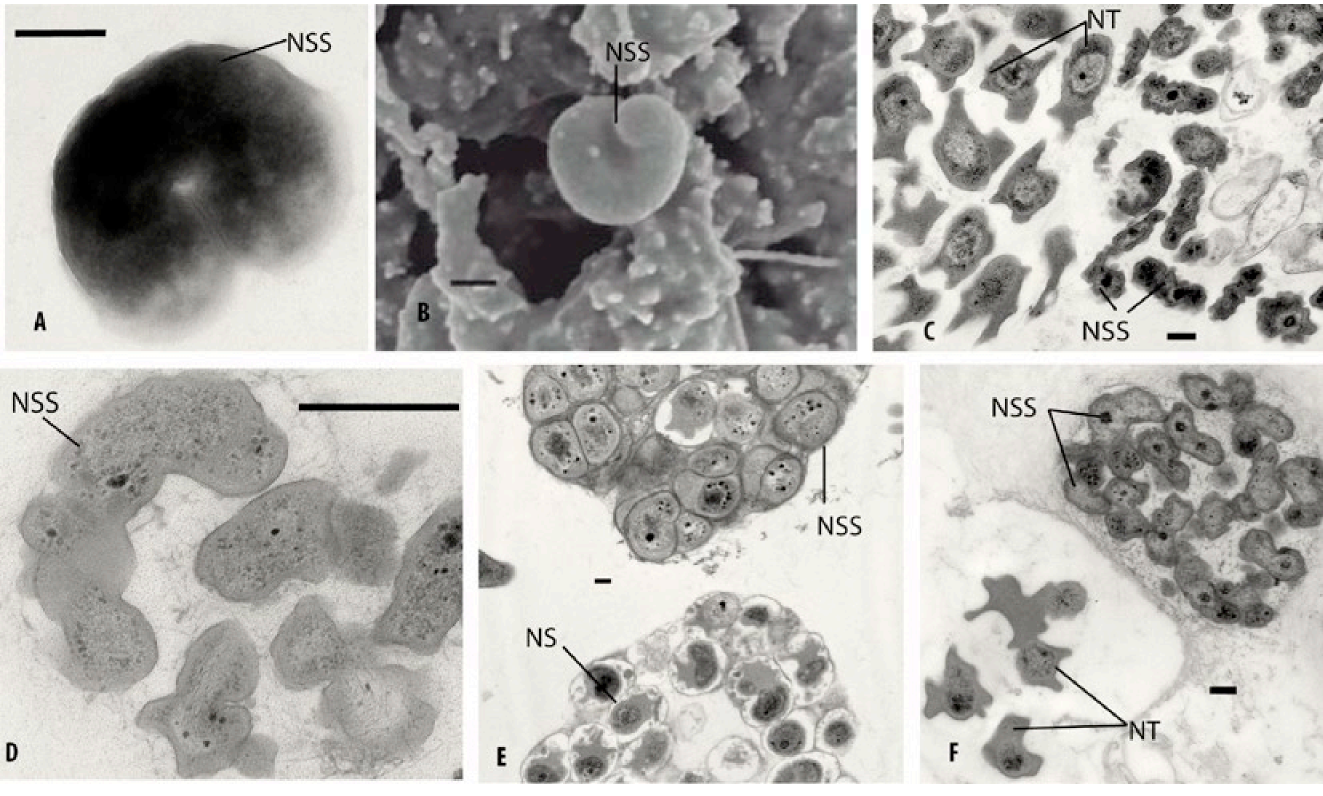
C2
Ab3
d

levels of nitrate and low concentrations of inhibitory methane correlated with high cell numbers and high activities of ammonia-oxidizing bacteria.

Investigations into nitrogen cycles during the summer expedition in 2008 were expanded beyond the polygonal tundra to include soils of the dryer river terraces, erosional cliffs, and young floodplains. The dissolved nitrogen concentration depends on the amount of organic matter, the air and soil temperature, and the vegetation cover. Ammonium was detectable only in organic-rich soils at the beginning of the vegetation period (up to 10 µg g^{-1} dry weight (dw)). Nitrite was only enriched on relatively cold days with soil temperatures below 5 °C (up to 2.3 µg g^{-1} dw). At the end of the vegetation period, nitrate enrichment was limited to soils without vegetation (up to 90 µg g^{-1} dw). Relatively high nitrification capacities were found in the dry and sandy soils of the floodplain and the dryer river terrace. In the polygonal tundra, nitrification capacity was only detectable in the mineral horizon of the polygon rim.

In summary, these results showed that permafrost-affected soils are not generally nitrogen-limited, low in inorganic nitrogen, and low in an abundance of nitrogen-cycling organisms. Instead, there are variations in nitrogen-limitation on small spatial scales. Overall, soils of the young floodplain and the polygon rims of the river terrace were less nitrogen-limited than soils of the polygon centres (Figure 1, 2). The less N-limited soils were characterized by less soil moisture; narrower C/N, higher pH-values. These soils showed N-mineralization and nitrification activity. Ammonium, therefore, decreases during the vegetation period and nitrate accumulates especially in vegetation-free soils (Figure 2c). Furthermore, the results showed that soils, relief, and microtopography play a critical role in controlling the microbial community composition of nitrogen cycling ammonia oxidizers, which was dominated by bacteria of the genus *Nitrosospira* and not by archaea (Figure 3).

Based on these research results on nitrogen cycling and the understanding that there is a widespread degradation of permafrost, the release of inorganic nitrogen was studied at different, additional sites in arctic East Siberia in 2012. Models for the polygon ridge on Samoylov Island estimated the highest increase of active-layer thickness compared to the eastern sides of the Indigirka lowland and the Kolyma Delta until 2100. Compared to the other sites, the total carbon, nitrogen, and ammonium contents were higher in the permafrost than in the



active layer on Samoylov Island, but not nitrate. This DIN storage in the permafrost can result in substantial liberation of N at the polygon rim of (22 ± 4) N mg year^{-1} m^{-2} and (8 ± 3) N mg year^{-1} m^{-2} at the polygon centre, but the flux is small compared to the overall ecosystem N budget.

Claudia Fiencke, Tina Sanders, Fabian Beermann, Elena E. Lebedeva, Eva-Maria Pfeiffer

Figure 3: Electron microscope pictures of enrichment cultures of ammonia and nitrite-oxidizing bacteria from soils from Samoylov Island.
1. A: Negative stain image, B: Scanning electron microscope (SEM) image, C–F: Transmission electron microscopy (TEM) images with *Nitrospira*-like, *Nitrosospira*-like and *Nitrotoga*-like cells. Bars=0.2 µm, NS: *Nitrospira*, NSS: *Nitrosospira*, NT: *Nitrotoga*. (Photos: T. Sanders)

Geocryological and Paleoenvironmental Studies on the Coasts of the Laptev Sea

During the 2002 LENA expedition, the ice-going research vessel "Pavel Bashmakov" took researchers along the coasts of the New Siberian Islands and the adjacent mainland. As part of this Russian-German cooperative effort, twelve sites were surveyed from 14 August until 2 September 2002, most of them for the first time.

The Russian and German scientists aboard intended to gain new insights into the developmental history of the New Siberian Islands. The work program focused on paleoenvironment and coastal dynamics.

Part of the team was engaged in the study and sampling of permafrost profiles at various sites for following laboratory analyses. The results of this research

Figure 1: Landing on New Siberia Island.

will help us to reconstruct paleoenvironmental development. All participants collected fossil bones in the riparian zone near the outcrops. These findings allowed our Russian palaeontologist Tatyana Kuznetsova, a specialist in large mammals, to determine the species composition of mammal fauna specific to the Ice Age and its evolution over time. The variety of geologic structures at the studied sites allowed us to examine permafrost sequences of different structure and age. We found something new at every landing. What follows is a detailed description of one such landing.

We landed on the island of New Siberia on 21 August. The research vessel had to anchor several kilometers off the coast because the ship's draft did not allow a closer approach. The swell was moderate; it would take us about an hour to reach the shore with our landing craft. It became clear that the shallow slope of the seafloor would not allow us to approach the shore closely in our boat. At this point we were fifty meters from the island, surrounded by ice floes stranded

Figure 2: The research vessel "Pavel Bashmakov" in drift ice.

around us in the shallow water. After a quick consultation, we decided to wade to shore. All of us fifteen researchers, wearing waders, jumped into the water and carried our equipment and tools through the waves to land, leaving the pilot of the landing craft to return to the main ship. Inevitably, some boots filled with ice-cold water. Once on land we quickly built a campfire made of driftwood to dry our wet feet and boots, and to warm ourselves. Then we split into small groups to accomplish our various tasks: Coastal surveying, sampling the sediment profiles and anything contained in the sediments, and collecting fossilized remains of animals and plants. We stayed in constant radio contact with the crew of the main ship to be informed about the latest weather conditions. The weather deteriorated. It became foggy and a fine drizzle set in. Nevertheless, we managed to sample a large profile on the coastal cliff from top to bottom. Standing in frigid mud, we took sediment samples, noted sampling positions, described the sediments and ice structures, rejoiced over small organic remains that might be datable, and gradually slipped further and further down the mud to the beach.

Figure 3: Marine sediments with drop-stones at beach level.
Figure 4: Preparation for ground ice sampling from a presumably buried remnant of glacier ice.

A few hundred meters to the west we found obvious marine deposits in the cliff at altitudes up to 3 meters above sea level. In the clayey sediments containing small shell remnants, we discovered a large rock, a so-called drop-stone. Drop-stones were once transported by an iceberg and fell into the water when the iceberg melted. These had penetrated deeply into the soft seabed. We found more and can now assume that these deposits were created in times of high iceberg activity. Ultimately, the existence of marine sediment higher than the existing waterline means that either the sea level has dropped since the sediments were deposited or the land has been raised. We believe the latter explanation is more likely because the New Siberian Islands lie in a very tectonically active region near the boundary between the Eurasian and the North American plates.

Suddenly, a bright red signal flare captured our attention, fired into the air and now slowly sinking into the sea. It was the agreed-upon signal indicating that we must immediately terminate our work and return to the landing site. We knew why we were being summoned: We had noticed the increasing onshore wind and the light spray blowing over the waves. We could already see the landing craft approaching the coast on the way back to the meeting point. The fog was now thicker, and the onshore wind pushed the water up the beach. An easy entry into the landing craft was out of the question. We all managed to clamber gratefully into the landing craft after several attempts, and an ice-cold, foggy, wave-tossed ride of over one hour began. We completely lost our sense of direction as the bone-chilling spray broke over us, over and over again. We peered into the distance, trying to make out our mother ship. Suddenly, the massive shape of the "Pavel Bashmakov" emerged in the fog ahead. The visibility was less than twenty meters. We were warmly welcomed back to the ship with vodka and a sauna preheated to 120 °C, a pleasant ending to this exciting and successful day. The 2002 ship expedition was primarily intended as an exploration tour. Nevertheless, results from the sample series taken at the landing sites were included in several publications and theses, and our explorations served as a basis for further expeditions to this region.

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Long-Term Observations of the Pelagic Fauna in Lakes and Ponds in the Lena Delta

The Lena River Delta is the territory of the tundra with a huge number of large and small channels and lakes: Permanent and temporary water reservoirs of various origins. Various and poorly studied free-swimming invertebrates inhabit all of these reservoirs in high numbers, primarily crustaceans and rotifers. In spite of their relatively small size, these representatives of aquatic fauna play an important role in the flows of matter and energy in tundra ecosystems. They are an important part of the food chains in water bodies and a food resource for many predatory invertebrates, juvenile fish, and waterfowl.

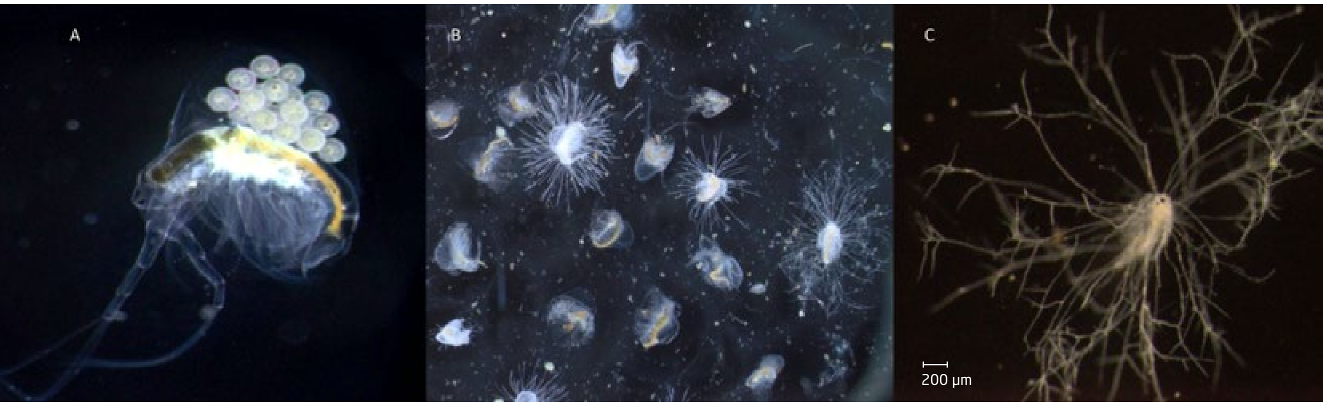
Figure 1: Our hydrobiological edge at the old station (left) and the microscope room in the laboratory of the new scientific station "Samoylov Island" (right).

Our research of the water ecosystems in the Lena River Delta started in 1987 in the north part of the delta on the Sagastyr Island and south of the delta on the Tit-Ary Island. Annual observations of pelagic fauna have been conducted on Samoylov Island since 2000. At that time, the expedition "Lena-Delta" was based at the old station belonging to the Ust-Lensky nature reserve. We all worked in two small rooms, allotted to the laboratory. For many years, our two MBS-10 binoculars and numerous bottles with samples stood in the corner of one of these rooms. This was our hydrobiological laboratory, where we spent most of our working time processing zooplankton samples (Figure 1).

In the end, we found about 120 species of plankton organisms during the 18 years (2000 - 2017) of our monitoring investigations of the different waters on Samoylov Island. More than 20 of them are new species for the fauna of north Yakutia. Some were first noted for the Palearctic region and were previously known only from Alaska and northern Canada. This confirms the common origin and relatedness of the fauna of these Arctic regions.

Increased runoff and higher seasonal fluctuations in water levels in large Arctic rivers due to climate warming have been recorded in recent decades. In these conditions, the Lena River can exert a broad influence on the floodplain reservoirs of its vast catchment basin, contributing to the active resettlement of the fauna from northern temperate latitudes. This contributes to changes in the distribution area of a number of species and affects biodiversity, both at local and regional levels. In years with extremely high spring tides, the expansion of species not typical for the area was catastrophic.

A mass invasion of certain species, for example, *Holopedium gibberum* Zaddach, 1855 (Figure 2), can cause a rapid restructuring of the lake biocoenosis and disturb the ecological balance in it, resulting in parasitic epizootic among water invertebrates. Despite the annual river water influence, however, tundra reservoirs are relatively resistant to the introduction of new species. Organisms from temperate latitudes have difficulty adapting to low water temperatures, food competition from native fauna, and the pressure of predators. Most of the invader species die after the first winter, but those that manage to survive gradually spread into nearby tundra water bodies.



Within the framework of Russian-German expeditions to the Lena River Delta, special attention was also paid to the research of modern freshwater ostracods on Samoylov Island. These small crustaceans are numerous in the bottom biocenoses of tundra lakes and ponds. Shells of these invertebrates can remain in the sediments for a long time and are used for paleoclimatic reconstructions. With the opening of the modern scientific station "Samoylov Island", different seasons of the year revealed new opportunities for field and experimental research. Modern Olympus microscopes with digital cameras now allow a more detailed taxonomic analysis of different groups of organisms. Some of them can exist and reproduce in the polar night, under an ice thickness of about 2 m. The abundance of winter zooplankton in some lakes is comparable to the summer number of plankton organisms in them. Other invertebrates freeze into ice or sediment in completely freezing shallow ponds, retaining their viability for 8-10 months, then immediately pass into an active state with the appearance of free water. All living creatures strive to make full use of the short polar summer to produce a new generation that can survive the next severe arctic winter.
The fruitful cooperation with the German scientists led by Julia Boike (AWI,

Figure 2: Female *Holopedium gibberum* with eggs in the brood chamber (A), general view of the population infected with a parasitic fungus (B), a dead individual (C).

Potsdam) allows us to obtain information on variations in different parameters of the aquatic environment throughout the year. This is very important for the analysis of biological processes in water ecosystems.

Despite the comfortable living and working conditions at the new station, it is always pleasant to gather in a cozy old wooden house in the evenings. To share a table and remember how everything began (Figure 3). How many different interesting people and events might the walls of this house remember? It was a lovely time. Thank you very much to everybody for all these wonderful expeditions, for your help, and many years of successful cooperation.

Ekaterina N. Abramova, Irina I. Vishnyakova, Grigory A. Soloviev, Anna A. Abramova

Figure 3: Sitting together at the kitchen table of the old Samoylov Station (from left: Fyodor Sellyakhov, station leader of the new station; Molo (Günter) Stoof, "Hausmeister" old station; Ekaterina Abramova). (Photo: H.-W. Hubberten)

Lunch break in front of an ice wedge on Muostakh Island 2012. (Photo: V. Kochan, RBB)

4. Implementation of New Research Topics 2007-2012

Arctic Coastal Dynamics

Permafrost coasts in the East Siberian Arctic are susceptible to a variety of changing environmental drivers. All of them point towards increasing coastal erosion rates and mass fluxes of sediment and carbon to the shallow arctic shelf seas. Unconsolidated, permafrost-bonded sediments comprise 65% of the coastline around the Arctic Ocean. Along 25 % of the 7500 km-long coastline in the Laptev Sea region, steep cliffs delimit marshy coastal tundra lowlands that are composed of syngenetic continental late Pleistocene permafrost sequences of the Ice Complex. The vast spatial distribution of extremely ice-rich permafrost is a particular geological feature of coasts in the eastern sector of the Russian Arctic, where coastlines are retreating at a mean rate of -1.9 m a^{-1}. Sediment release from the coasts to the Laptev Sea is at least on the same order of magnitude as the amount of riverine input, which underlines the importance of coastal erosion processes and the need for an improved quantification.

Figure 1: Yedoma Ice Complex, 30 m high coastal cliff at Cape Mamontov Klyk. (Photo: H.-W. Hubberten, 2008)

The currently observed and rapid changes to the sea ice regime and summer air temperature have the potential to severely change coastal dynamics in the region, which already expresses in accelerated coastal erosion. Given the cold ground temperatures in the region, coastal erosion is currently the most important geomorphic process capable of mobilizing deep carbon pools. The Arctic Coastal Dynamics project (ACD) of the International Arctic Science Committee tackled the challenge of creating an initial estimate of carbon release from coasts to circumpolar marine ecosystems. In this context, a major aim of a series of almost 20 joint Russian-German expeditions to the coasts of the western, central, and eastern Laptev Sea region has been organized to establish an inventory of erosive coastline segments and coastal erosion rate monitoring efforts. A particular emphasis was also put on mapping subaerial shoreface profiles during ship-based expeditions to the western Laptev Sea aboard the RV "Sofron Danilov" in 2000, and along the Dmitry Laptev Strait and around the New Siberian Islands aboard the RV "Pavel Bashmakov" in 2002. Using the large ships

Figure 2: M. N. Grigoriev and H.-W. Hubberten measuring coastal erosion at Dmitry Laptev Strait (2002).

as a base, coasts were visited with small boats to study coastal erosion rates in a detailed manner.

Coastal retreat monitoring is typically conducted via observations of coastline positions at different times, using either repeat on-site measurements or remote sensing data. Because of the remoteness and range of the study region, in-situ observations were mostly limited to key investigation areas, for which the field campaigns mentioned above had accomplished topographic reconnaissance of the terrain. These included particularly areas around Cape Mamontov Klyk, Cape Terpyai Tumus, barrier islands west of the Lena Delta, Bykovsky Peninsula, and Muostakh Island. Substantial efforts have been made to capture the spatial variability of coastal regimes and to compile long-term base datasets. In 2011, a year of very early sea ice retreat in spring, the expedition plans came to a sudden stop when a nosy polar bear hampered ongoing field works at Cape Mamontov Klyk. The expedition team of seven Russian and German scientists quickly adapted their plans and switched to Muostakh Island to intensify research on subsea permafrost degradation processes and coastal erosion dynamics at this important location for studying land-ocean interactions in the Arctic.

Long-term stationary monitoring of coastal erosion in the Laptev Sea is generally conducted only in two locations: Mamontovy Khayata on the Bykovsky Peninsula and on Muostakh Island. Based on these unique time series, Muostakh Island is famous for very high erosion rates: The northern end of the island, for example,

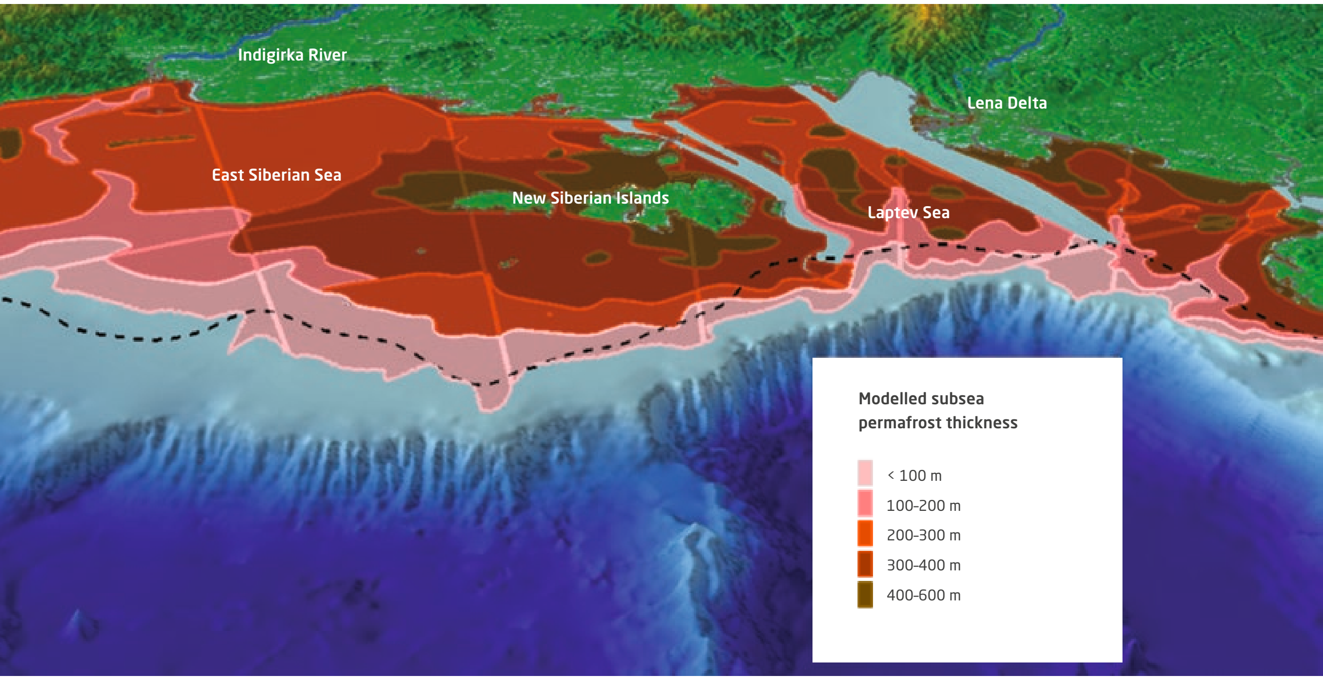
Figure 3: Overnight stay during side expedition to the northern cape of the Buor Khaya Peninsula. (Photo: F. Günther, 2010)
Figure 4: Disembarking close to the northern cape of the Buor Khaya Peninsula. (Photo: F. Günther, 2010)


retreated by about 39 m between repeat field surveys in 2011 and 2012. Several regional scale studies took advantage of the archives of historical satellite and aerial imagery, collected over the region from the 1950's to the 1960's, and compared coastline position changes with modern high-resolution satellite data. The findings showed that recent erosion rates were almost twice as rapid as the long-term mean rates across the whole mainland coast of the Laptev Sea and on Muostakh Island.

Arctic coastline recession rates are highly variable both spatially and temporally. An analysis of waves and storms revealed that they serve as the largest forcing factors for arctic coastal erosion. In this context, continued sea ice decline will not only lead to warmer sea water and a further increase of the steric component of sea level rise but ultimately to an enhanced wave action which could lead to further acceleration of coastal erosion rates. Our long-term coastal research efforts covered a wide range of key study sites and different coastal types. They resulted in conceptions and insights about prevailing coastal erosion processes and magnitudes that not only provide valuable process understanding for other arctic regions with similar geological conditions but may also be used for regional environmental planning and infrastructure development processes.

Frank Günther, Mikhail N. Grigoriev, Pier Paul Overduin, Hugues Lantuit, Hans-Wolfgang Hubberten

Figure 5: The 21 m high northeast-facing cliff of Muostakh Island. (Photo: M. N. Grigoriev, 2012)



Field Work and Numerical Modelling for Subsea Permafrost and Gas Hydrates

Subsea permafrost is earth material that lies beneath the ocean with a temperature of below 0 °C for at least two consecutive years. In contrast to terrestrial permafrost, its upper temperature is controlled by interactions of the sediment surface with the marine water column rather than land-atmosphere exchanges. Arctic subsea permafrost is usually relict terrestrial permafrost that was inundated following the last glaciation when sea level was around 125 m lower, and hundreds of kilometres of the actual shelf were exposed to the extremely cold air resulting in the formation of hundreds of m thick permafrost. At the end of the last glacial with sea level rise, the permafrost was flooded by seawater and

Figure 1: A view southward from the Arctic Ocean towards the East Siberian and Laptev shelf seas. Topography and Bathymetry are shown, overlaid by regions of modelled subsea permafrost thickness based on modelling by Romanovskii et al. (2005). The black dashed line shows the subsea permafrost extent given by the International Permafrost Association's map of permafrost distribution for this region.

is currently degrading under the influence of the overlying shelf sea. More than 80% of potential subsea permafrost is found beneath the East Siberian shelf, where observational data is scarce.

The idea to investigate the composition and degradation of subsea permafrost fascinated the scientists of the early cooperation of AWI and Russian experts. Prompted mainly by the active involvement of Prof. Nikolai N. Romanovskii from Moscow State University, a fruitful collaboration began which resulted in numerous highly ranked publications (Figure 4). Nikolai spent several weeks as a guest scientist in Potsdam almost every summer in the 1990s, often accompanied by students or collaborators from Moscow. Day by day, constructive discussions led to the development of new ideas and concepts about the evolution, stability, and degradation of subsea permafrost. These ideas and insights were subsequently quantified and tested by numerical modelling. Nikolai enjoyed the relaxed academic life in Potsdam by going running from the guest house on the Telegrafenberg through Babelsberg Park and by swimming in the Havel River. He always arrived at the institute full of energy and new ideas.

Modelling has shown that subsea permafrost degrades from above and below, via heat transfer and probably also salt diffusion. Modelling predicts that permafrost has persisted on the Siberian shelves for at least the past 400,000 years (Figure 1).

After publishing several papers on the stability and degradation of subsea permafrost, the focus of joint work shifted to the question of the existence of methane in the form of gas hydrates in or below the subsea permafrost. This question became the next topic of the joint modelling experiments. Circum-arctic subsea permafrost is a reservoir and confining layer for greenhouse gases, whether dissolved, free, or in hydrate form. A large amount of gas potentially contained and retained by subsea permafrost means that warming permafrost beneath the ocean might release substantial amounts of greenhouse gas to the atmosphere over a short climatic time. The zone in which gas hydrates are stable is associated with cold subsea permafrost, so that aggradation of subsea permafrost means an increase in the possible reservoir of gas hydrates.

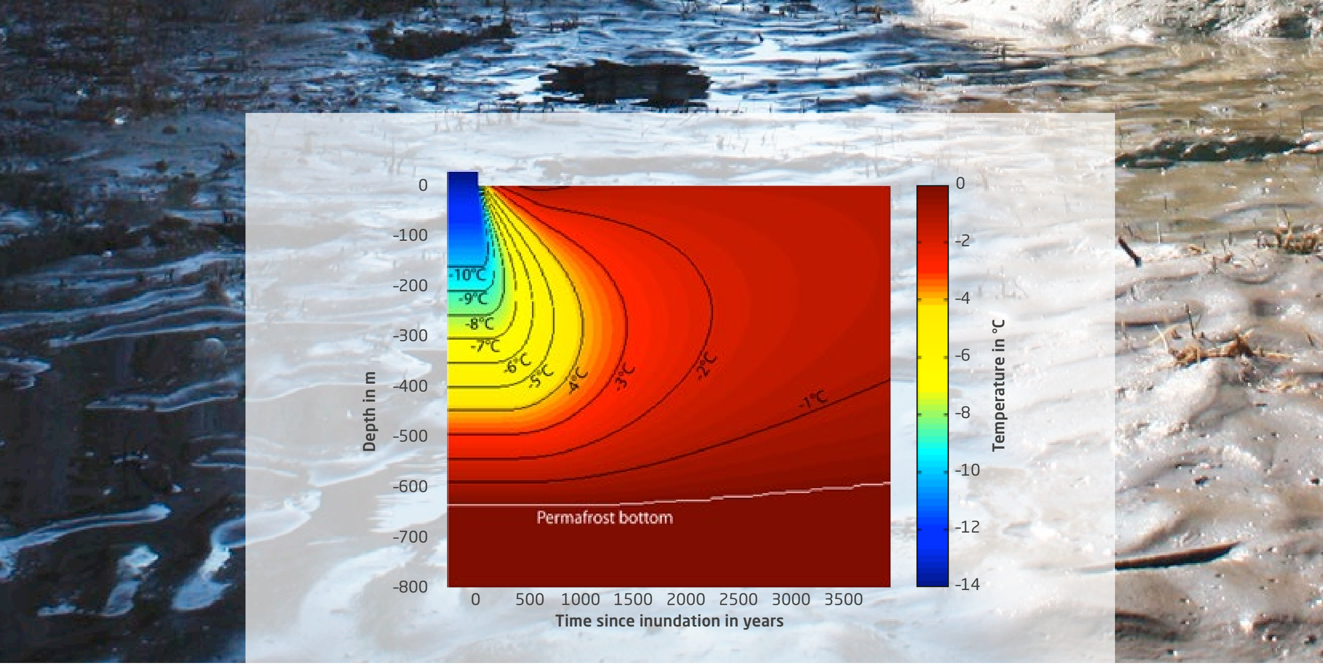
German-Russian efforts to improve our understanding of the transition of permafrost from terrestrial to subsea, for example during coastline retreat or as a result

of marine transgression, and of permafrost distribution on the Siberian shelf, led to the conception, planning, and execution of the COAST 2005 drilling campaign, as well as subsequent and ongoing drilling expeditions (Figure 2).

The existence of subsea permafrost in shallow waters could be proven with a series of boreholes. This confirmed the results obtained in the 1950s and 1960s by N. F. Grigoriev, the father of the co-author Mikhail N. Grigoriev. Temperature measurements showed the rapid warming that accompanies inundation of the land, which is corroborated by modelling heat flux in the sediment (Figure 4). The sediment cores yielded a reconstruction of the paleo-environment dating back to before the last glaciation.

Challenges with permits prevented offshore drilling for many years, but alternatives were found, including sampling and geophysical work close to shore. Near-shore work included measurements of benthic temperature and salinity regimes in the central Laptev Sea and geophysical methods for the detection of frozen sediment (seismic and geoelectric) from 2008 onwards. Much work was devoted to methods of detection, including testing improved geoelectric devices and the development of a passive seismic sensor to measure the thickness of the unfrozen sediment layer overlying frozen permafrost, which was tested around the northern end of Muostakh Island in 2013 and thereafter.

Figure 2: Drilling rig on the sea ice on the western side of the Buor Khaya Peninsula in 2012. Drilling reached 52 m below the sea floor at this location. The sediment core recovered showed that thawing permafrost some 25 m below the sea floor was releasing methane as it thawed.
Figure 3: Nikolai N. Romanovskii together with Hans-W. Hubberten and IPA President Hugh French in Nikolai's flat in Pushchino.

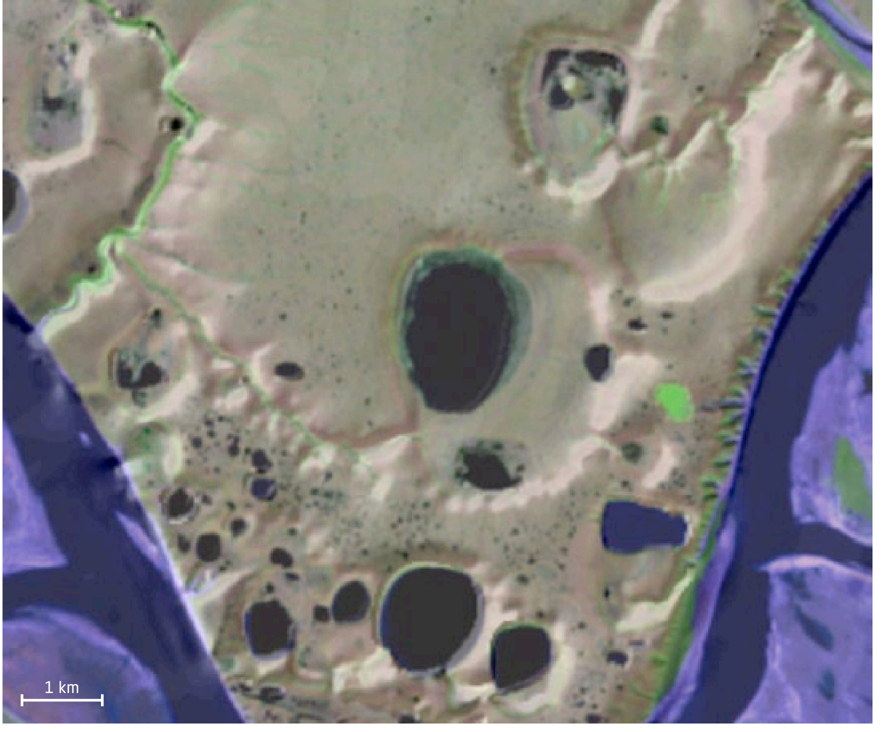


Further research is required, in particular on the relevance of subsea permafrost to modern observations of methane emissions from the seabed of the Siberian shelf seas. Parts of the Lena Delta, the pro-deltaic region, and the central Laptev Sea have been shown to be super-saturated with respect to methane. Observations of high methane content in the water column of the Laptev Sea and within the Lena Delta suggest deep and continuous sources and pathways that may or may not be limited by permafrost. Joint Russian-German coring in 2012 in the central Laptev Sea showed methane being released from permafrost but in amounts small enough that it was consumed by bacteria as quickly as it was released.

Together with the Melnikov Permafrost Institute, Yakutsk and the Trofimuk Institute of Petroleum-Gas Geology and Geophysics, Novosibirsk, permafrost at the coast and on the shelf remains a central study object of German-Russian cooperation, endorsed by the ministerial committee for bilateral Scientific-Technical Cooperation. Under the current changing climate in the Arctic, this component of the climate system needs to be better understood.

Hans-Wolfgang Hubberten, Pier Paul Overduin, Sebastian Wetterich, Mikhail N. Grigoriev

Figure 4: Warming of permafrost following inundation is demonstrated through numerical modelling. Using sediment and permafrost characteristics from sediment cores recovered from the COAST 2005 expedition, we can test such models against observation and better understand the function of subsea permafrost as a control on greenhouse gas release (Figure supplied by Fabian Kneier, 2018). (Background photo: T. Sachs)



Permafrost Degradation, Thermokarst and Thermal Erosion – Fieldwork on Kurungnakh Island

In summer 2008, intensive investigations of permafrost degradation on Kurungnakh Island started with a group of six young researchers. The diploma and PhD students from Hamburg and Potsdam set up a field camp at the narrow sandy eastern shore of the island, in front of the impressive Ice Complex cliff at the outlet of a steep thermo-erosional valley. They chose the campsite to be close to their study objects – large thermokarst basins that incised deeply into the ice-rich permafrost of Kurungnakh Island. But why would anyone choose a study site that's half an hour boat ride away, instead of staying in the cosy Samoylov station? They did not want to escape the controlling eyes of the very sceptic senior technicians residing on the station, nor miss the experience of that extra romantic arctic adventurous life -- but the permafrost on Kurungnakh Island is completely different to the permafrost on Samoylov Island. While Samoylov Island belongs to the modern active delta with Holocene permafrost deposits, Kurungnakh Island is a remnant of an accumulation plain that formed during the Late Pleistocene and features Ice Complex deposits on top of fluvial sands of the paleo-Lena river. Ice Complex deposits are very ice-rich permafrost deposits

Figure 1: Relief of Kurungnakh Island with characteristic landforms of permafrost degradation: Thermokarst lakes and basins and thermo-erosional valleys (Landsat-7 ETM+, RGB 4-5-3, over DEM shaded relief).

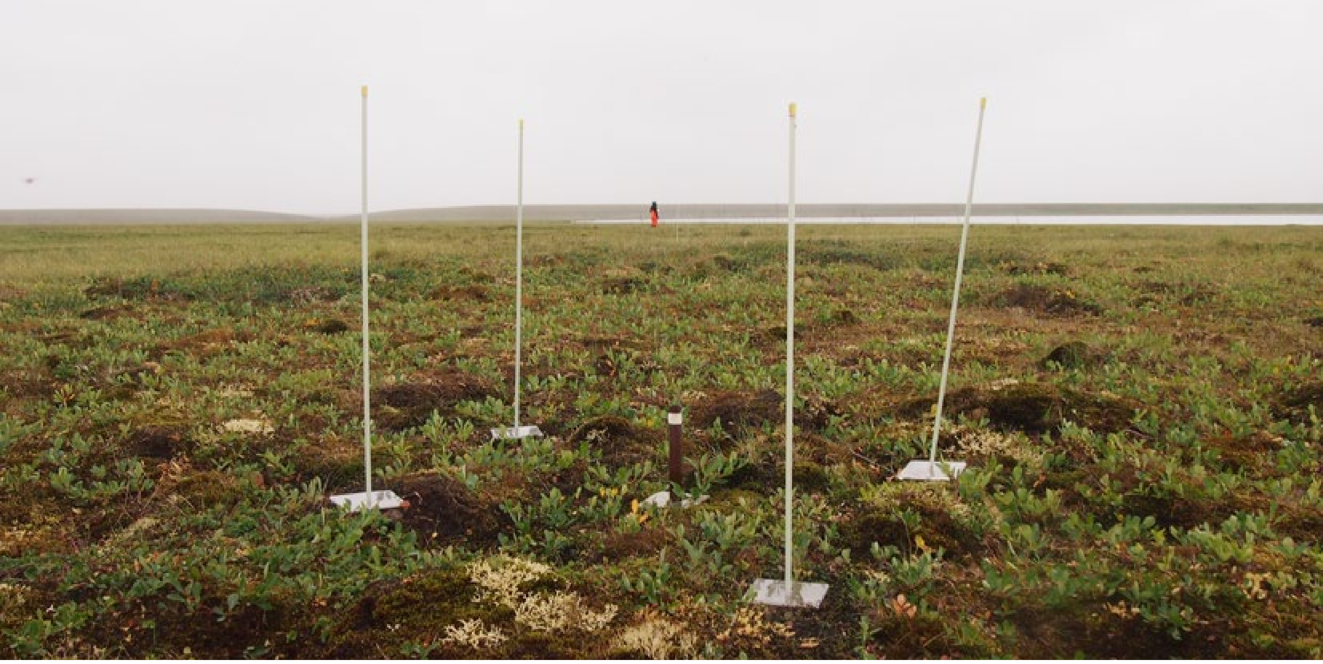
up to tens of meters thick. They are widespread in the Arctic and raised a lot of attention because they are vulnerable to thaw under climatic warming. Degradation processes have affected these Pleistocene deposits throughout the Holocene. Rapid permafrost thaw underneath ponding water (thermokarst) has created thermokarst lakes; when these lakes drain, the remaining thermokarst basins can be several kilometres wide and up to twenty meters deep. Rapid permafrost thaw by running water (thermal erosion) has created gullies, valleys, and valley networks that also incise deeply into the island. All these landforms play an important role for the landscape's hydrology, energy budget, and carbon cycle. The question is: How will they develop in the future?

The six young researchers started to investigate the morphometry and the evolution of exemplary thermokarst lakes and basins in high detail on Kurungnakh Island. Carrying equipment back and forth to conduct extensive geodetic and bathymetric surveys of an entire, three-kilometre wide thermokarst depression and three lakes within it was worth it: Ultimately, the efforts resulted in valuable geodatasets that could be combined with in-situ measurements of radiation, active layer thickness, vegetation communities, and sedimentological samples. The researchers were especially happy about the support from Russian researchers, who crossed over from Samoylov to see if the group was alright and to

Figure 2: Tacheometric surveys include two different tasks: Operating the instrument and running across the tundra with a reflector mirror. While the latter provides a little warmth, the operator's fingers are almost freezing off.

share their supply of fresh meat, and fish -- a welcome variation to the meals in the camp. The visitors also found overlapping scientific interest and engaged in joint sampling and measurements. Back home in the institutes, the researchers combined the field data with analyses of satellite imagery and Digital Elevation Models (DEM) to transfer the detailed knowledge of the investigated field site to larger regions and derive a process understanding on the landscape scale. They found, for example, that only one-third of Kurungnakh Island provides the conditions for a future formation of thermokarst and thermo-erosional landforms because thermokarst and thermal erosion have already degraded a large area during the Holocene. Newly developing landforms will not be able to grow to such large sizes as the existing Holocene thermokarst landforms. They simply do not have enough space to develop extensively. The existing landforms vary in their activity: Some thermokarst lakes and thermo-erosional valleys are expanding and actively erode the Ice Complex deposits, many have been stable over the last decades, and some lakes have shrunk or drained, thereby enabling permafrost to reestablish. This variation of erosion activity is also reflected in different hydrogeochemical compositions of the waters in thermokarst lakes and streams in thermo-erosional valleys: Water samples from eroding sites have higher concentrations of dissolved organic carbon than those from stable sites. The camp inhabitants received an impressive demonstration of thermal erosion when a pulse of very turbid dark (= rich of organic sediments) water suddenly rushed past the camp through the adjacent thermo-erosional valley and flushed

Figure 3: Outlet of a thermo-erosional valley into the Lena River a) during and b) after a flood pulse from ice-rich permafrost.



a considerable portion of the camp “beach” into the Lena river. This pulse lasted just for a few minutes; then the stream changed back to a trickling streamlet with almost clear water. It turned out that a portion of ice-rich permafrost in the upper valley part functioned as a dam for stream water running down the valley so that the water ponded. At a certain point, the ponded water thawed the damming ice-rich permafrost and the water flushed down the valley, thereby eroding the valley further.

Five years later, fresh young researchers continued along the marked path and deepened the investigations of different kinds of permafrost degradation in the Ice Complex. Uniform permafrost degradation occurs due to the ubiquitous melt of the ground ice. It is invisible to an observer because it does not necessarily lead to an apparent landscape disturbance, such as thermokarst or thermal erosion. Such isotropic degradation, however, can be detected by repeated measurements of the surface elevation. To take these measurements, multiple reference rods were installed on Kurungnakh Island in 2013-2014. The rods are at approximately one meter below the seasonal thaw depth and, therefore, provide a fixed levelling point. We intermittently measured the distance between the ground surface and the top of the rod to detect the elevation changes. The reference rods are distributed quite far away from each other, so measuring them all by foot can be a demanding task. The most recent measurements show that the Ice Complex subsided by an average of 9 cm during the last four years.

Figure 4: Reference rods to measure surface elevation changes. The rods are fixed in the permafrost; the discs move up and down when the tundra surface changes its elevation.

More rapid degradation of permafrost can have hazardous impacts on infrastructure in the Arctic which can be well observed at the impressive riverbank cliffs of Kurungnakh. Researchers investigated how rapidly this cliff is eroding by using a unique remote sensing time series between 2015 and 2017 of synthetic aperture radar (SAR) from the German TerraSAR-X satellite. The researchers set up a simple measurement field on the cliff top of the Kurungnakh coast to validate the remote sensing analyses. The study revealed that the cliff top is retreating at a constant speed throughout the whole season and that precipitation, next to air temperature, had an important impact on the erosion. Hydrochemical analyses showed that the meltwater streams running from this eroding cliff have a much higher content of total dissolved solids, higher concentrations of mineral components, and are much more turbid compared to waters from thermo-erosional valleys and thermokarst lakes. The summer water discharge of these Ice Complex streams is, however, negligible compared to the discharge of the Lena branch, into which the streams flow. The meltwater streams, therefore, hardly affect the composition of the Lena branch on its way to the Arctic Ocean.

The permafrost expertise of the Russian and German colleagues, who have been working on Kurungnakh Island over the past ten years, has been complemented by geophysical measurements since the beginning of the research activities of the IPGG in the Lena Delta. These measurements give valuable insights into

Figure 5: Measurement of cliff erosion on Kurungnakh Island: The measurement setup was photographed every four hours by a time-lapse camera; the measurements were compared to satellite observations and revealed erosion throughout the whole season.

subsurface structures and provide valuable information for the process understanding of thermokarst and thermal erosion of ice-rich permafrost (see pages 171–173).

The results derived from fieldwork on Kurungnakh Island are not only important for a better understanding of ice-rich permafrost in the Arctic. They also served as “ground truth analogues” for the investigation of permafrost degradation on our neighbouring planet Mars. A large thermokarst basin formed in the Ice Complex deposits on Kurungnakh Island, for example, was investigated as a terrestrial analogue for scalloped depressions in Martian volatile-rich mantle deposits. Results from field studies, insolation modelling, and geomorphometric analyses suggest lateral thermokarst development and lake migration in a northern direction on Kurungnakh. This conclusion is evident due to steeper slope angles of the south-facing slopes. Insolation and surface temperatures are crucial factors which directly influence thermokarst slope stability and steepness.
By direct analogy, the development of a climatically-controlled lateral scalloped depression was postulated on Mars that was primarily forced on steep pole-facing slopes in equator-ward direction.

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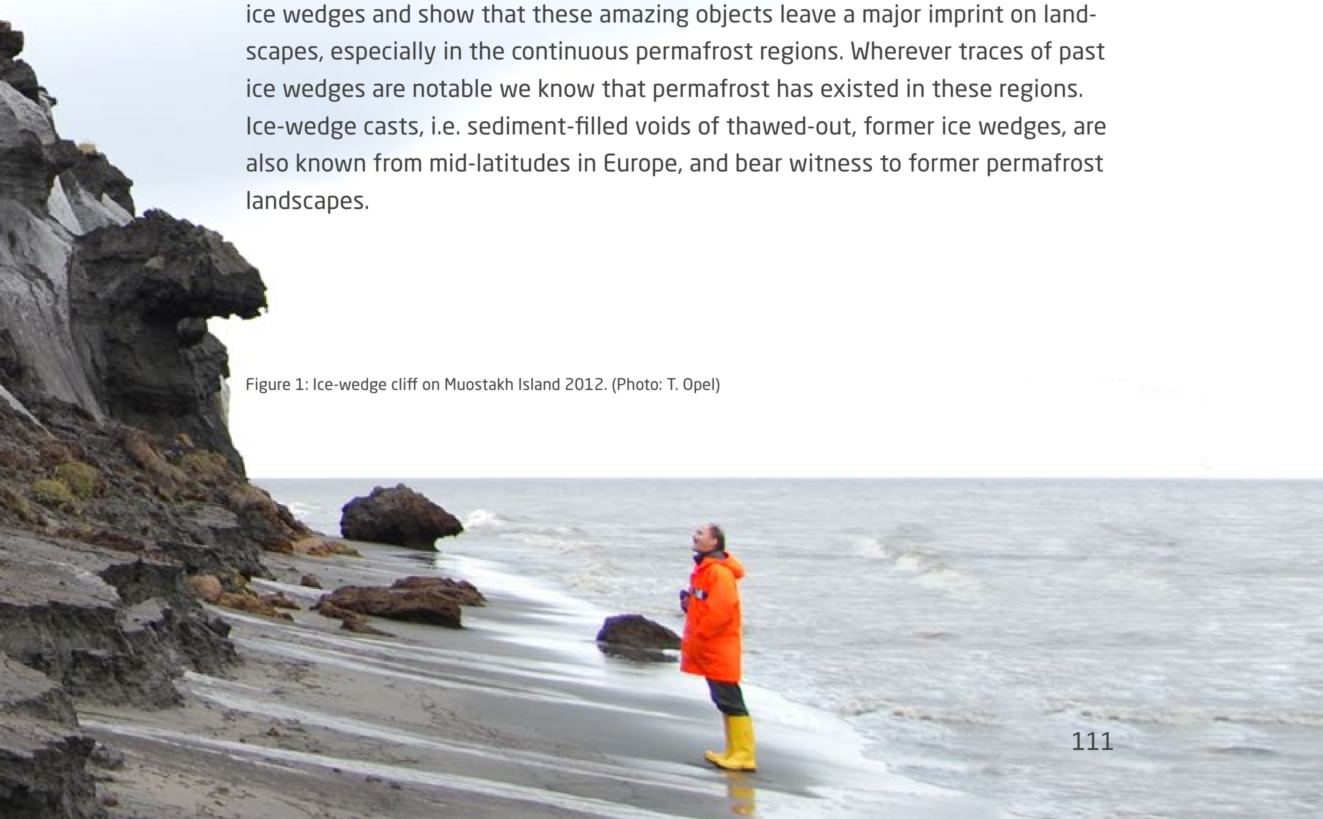
Figure 6: Radiation measurements on the slopes of a thermokarst basin on Kurungnakh Island. The results were also used for analogue studies of thermokarst on Mars.

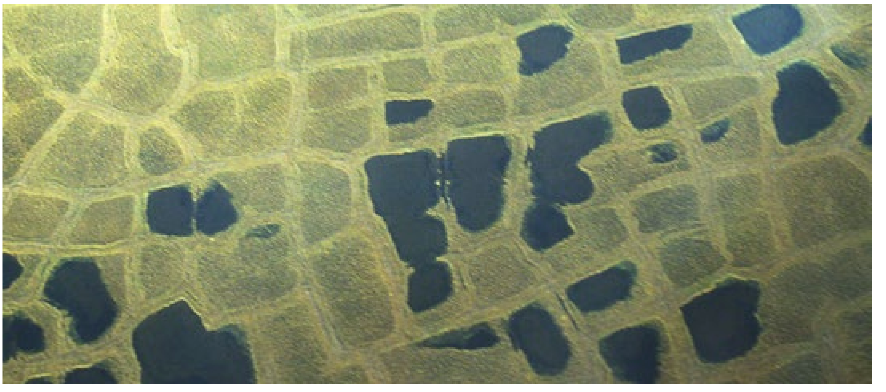
With the Chainsaw to Climate Modelling – Ice Wedges as a Winter Climate Archive

Ice wedges are prevalent and characteristic features of permafrost landscapes. As the name suggests, they are often wedge-shaped, and visible at coastal or riverine cliffs as huge, impressive ice blocks. They are mostly 2-3 m wide (reaching up to 6 m) and propagate several, sometimes tens of meters, into the ground, narrowing downwards. They are formed by frost-cracking processes: The cooling during winter periods causes the frozen ground to shrink and a frost crack to open, which is subsequently filled by snow and snowmelt water during spring. The very negative soil temperatures of sometimes -10°C and below lead to immediate freezing of this meltwater, which in turn induces the formation of an ice vein. This process is repeated year by year, and an ice wedge is formed – it is therefore composed of many single vertical ice veinlets, each containing a chemical signature of the preceding winter snow.

Permafrost, i.e. frozen ground with distinctly negative temperatures, is required to form ice wedges. In turn, ice wedges are diagnostic permafrost phenomena. Wherever ice wedges exist, the landscape is structured into vast polygonal patterns of extraordinary beauty. Viewed from a helicopter or an aeroplane, they might resemble city maps. These polygonal patterns indicate the position of the ice wedges and show that these amazing objects leave a major imprint on landscapes, especially in the continuous permafrost regions. Wherever traces of past ice wedges are notable we know that permafrost has existed in these regions. Ice-wedge casts, i.e. sediment-filled voids of thawed-out, former ice wedges, are also known from mid-latitudes in Europe, and bear witness to former permafrost landscapes.

Figure 1: Ice-wedge cliff on Muostakh Island 2012. (Photo: T. Opel)





Ice wedges have been studied in numerous expeditions with an AWI lead or participation and in close Russian-German cooperation since the mid-1990s: It started in 1996 at Cape Sabler at Labaz Lake and continued in 1998 on Bykovsky Peninsula and in 1999 on Bol'shoy Lyakhovsky Island. Since this early phase, ice wedges have become a key research object, especially for paleoclimate studies and hydrological investigations. They have also been linked to the understanding of the processes involved in ice-wedge genesis, i.e. the timing of the frost cracking, the ice-vein formation in spring, and the preservation of a climate signal within ground ice.

Ice-wedge studies are always embedded in the research dedicated to the host sediment sequences in permafrost. Ice-wedge studies are often connected to permafrost aggradation areas and are most impressively visible in the so-called Ice Complex deposits. Standing in front of a 25-30 m high, steep cliff of greyish ice that has been formed by many single ice veinlets over tens of thousands of years, is a magical moment of understanding the Arctic a bit better. Standing in front of these walls of almost pure ice, it is easy to understand that scientists first believed glaciers must have been responsible for building them.

In the early years, the researchers extracted hundreds of ice wedge samples using ice screws. Over time it became clear that frozen material could be sampled better in its original state using chainsaws and more sophisticated drills. A closed cold chain was established using freezers in field camps and Styrofoam boxes for transport. This enabled the precise sampling of the frozen wedge ice in a cold laboratory in Germany, the extraction of enclosed organic matter, and

Figure 2: Ice wedge polygons in the western Lena Delta. (Photo: H. Meyer)


thus the direct Radiocarbon dating of a given frozen piece of ice. Dated organic remains in ice wedges comprised about 30.000-year-old, greenish leaves with chlorophyll still visible even after such long time. They also included less fresh-looking plant remains and numerous lemming droppings, which allowed for the precise age determination of the respective ice veins or wedges – a precondition for constructing time series needed for climate reconstruction.

Over the years it became obvious that ice wedges, as snowmelt forms them, have a direct connection to the atmosphere and are, therefore, excellent recorders of past climate conditions, specifically of the winter season. To use ice wedges as climate archives in more than a millennial-scale resolution, however, quite a few Radiocarbon dates were needed. Moreover, a bit of luck was necessary to identify three key study sites that allowed for a precise up to sub-centennial scale 14C-dated Holocene and late Pleistocene winter climate reconstruction: One in Barrow, Alaska, one in the Lena Delta, and a third at the Siberian Oyogos Yar coast. Understanding winter temperature change is of particular importance because the current Arctic warming is most substantial in winter.

Ice wedges can specifically capture the winter season. For the Lena Delta, they show natural, gradual warming towards a recent maximum over the past 7.000 years, as shown in a well-known publication. This contrasts with long-term Holocene summer cooling seen in many other Arctic proxies (i.e. in pollen) but confirms what paleoclimate model simulations predicted.

Hanno Meyer, Thomas Opel, Alexander Yu. Dereviagin

Figure 3: Sampling of a Pleistocene ice wedge on Bykovsky Peninsula 1998 with ice screws. (Photo: H. Meyer)
Figure 4: Ice-wedge sampling with a chainsaw. (Photo: L. Schirrmeister)

Past and Present Treeline and Lake Changes in Northern Siberia in Response to Warming

The climate in northern Siberia has warmed strongly in recent years. As a result, boreal forests are expected to extend into the north. This would cause the loss of the unique tundra ecosystems that presently cover only a narrow band north of the taiga and south of the Siberian Arctic coast.

An expansion of boreal forests would also cause changes in chemical characteristics and biological composition of lakes. Our knowledge of treeline transition in the course of global warming in northern Siberia is, however, currently based almost exclusively on simulations using global vegetation models. In contrast to all other circum-Arctic regions, the larch (*Larix* sp.), a deciduous conifer, forms the tree line in Siberia. The reliability of most ecological models in this region is therefore questionable. Larches have a very long generation cycle. The time delay with which they respond to temperature increases is still unknown. This means we also do not know how long the recent warming effect on ecological change will last into the future.

Our team of Russian and German (palaeo)ecologists has been conducting research at the taiga-tundra transition zone in northern Siberia for more than

Figure 1: The expedition groups often hike several kilometres through tundra and taiga to reach the areas where they want to conduct vegetation surveys and sampling. (Photo: S. Kruse)


a decade, to investigate the population dynamics of larches in response to warming and the ecological consequence for northern lake systems. Our research included fieldwork in several areas of the Siberian treeline along an west-east transect including the southern Taymyr peninsula (in 2011 and 2013), the Anabar region (in 2007), the lower Lena River region (in 2009), the Omoloy River region (2014), the lower Kolyma River region (2008, 2012), and central Chukotka (2016). Sites that span transects from boreal forest to the tundra region were of special interest. The sites were reached by helicopter to minimize effects from the river and human impact on vegetation and lakes.

Fieldwork was comprised of vegetation analyses, including vegetation plot analyses, measuring thousands of individual trees, and collecting tree cores for dendrochronological analysis. We also investigated lakes with (palaeo-) limnological methods, by measuring lake parameters, sampling lake water, zoobenthos, and phytoplankton, and collecting lake sediment cores. Fieldwork means living in tents for weeks in a harsh environment. The days were full of hard work and fascinating moments, such as unloading more than a ton of field equipment from a helicopter hovering a meter above the peaty ground or the brown bears that regularly visited our field camps in Chukotka.

Our field investigations of plants, diatoms, chironomids (non-biting midges), and water fleas (Cladocera), among others, indicated that terrestrial and aquatic ecosystems in the tundra differ strongly from forest sites. Lake sediments represent archives of past environmental change and can provide information on past relationships between ecosystem development and climate.

Figure 2: Sediment cores from arctic lakes are natural archives in which bioindicators have been preserved. Their analysis allows the reconstruction of the regional vegetation history and how environmental conditions changed over time. (Photo: E. Zakharov)
Figure 3: Larches can grow in the form of Krummholz during times when environmental conditions are unfavourable, as shown here at the southern Taimyr peninsula in northern Siberia. (Photo: S. Kruse)

We investigated microfossils such as pollen, diatoms, and ancient DNA in our "Joint German-Russian Laboratory for the Investigation of the Environmental Dynamics in the Terrestrial Arctic (Biological Monitoring–BioM)". Our results indicated that vegetation (maybe driven by climate change) is likely to be a more important driver of lake changes than direct climate change.

We also found that the treeline was located several hundred kilometres further north on the Taymyr peninsula during the mid-Holocene despite the climate being of similar warmth to today. We hypothesize that this mismatch between present treeline position and climate is a result of the abrupt warming in the recent past causing a vegetation-climate non-equilibrium.

Our investigations of larch population dynamics indicated that larch forests densify in the open forest areas but only slowly extend their range into the north. To get a better mechanistic understanding of the larch population processes, we set up a vegetation model that simulates the life cycle of millions of trees and their interactions in response to climate.

The simulations indicated that the slow response in the north is likely due to a lack of recruitment caused by limited seed dispersal ability and low seed quality. Although the treeline will expand only slowly to the north, this process will last for hundreds of years even in the unlikely case that warming stops soon.

This will likely result in an irreversible loss of unique Arctic biodiversity. Even more, the expansion of forests will result in further warming due to the feedbacks between vegetation and climate originating from changes in surface reflectance.

A combination of field-based (palaeo)ecological studies with remote sensing investigations and vegetation modelling in future will help to better predict future forest changes in northern Siberia and its relevance for biodiversity and climate at local, regional, and global scale.

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Organic Matter Matters – Quantifying the Amount of Carbon in Northern Siberia

The Lena River Delta is underlain by permafrost. Thus, it is highly vulnerable to climate warming and may degrade in different ways, by shoreline erosion (figure 1), land surface subsidence, deepening of the seasonal thawing front, and development of rapid thaw features such as lakes, gullies and landslides.

Permafrost thaw could cause a strong feedback with global implications, because high amounts of organic matter are stored in sediments and soils of the Lena River Delta. This organic matter, consisting of ancient dead plant and animal remnants, was freeze-locked for millennia due to the permanently frozen ground. In this way, it was kept away from the active carbon cycle. Now, thawing permafrost sets this organic matter free for mobilization and microbial activity. Thus, it is available in the active carbon cycle again where microbial decomposition processes result in the production of the greenhouse gases carbon dioxide and methane, which accelerate atmospheric warming. This, in turn, induces more permafrost thaw and carbon release – a feedback cycle that becomes stronger and stronger. Better understanding of how much and how fast carbon is vulnerable

Figure 1: Sediment layers rich in organic carbon including peat blocks sticking out of a Yedoma cliff on Sobo-Sise Island, Lena Delta, in 2014. (Photo: M. Fuchs)

to thaw and mobilization is therefore a critical need to predict the consequences of permafrost thaw in the Arctic. Our research in the joint Lena expeditions therefore put a spotlight on understanding the characteristics, origins, distribution, amount and vulnerability of carbon in the North Siberian Arctic.

Until the late 90's it was assumed that cold Arctic climate, causing low vegetation productivity, only allows a small input of organic matter into the Arctic soils. A low soil carbon pools was therefore assumed for this region. With increasing understanding that permafrost soils actually may feature characteristics such as low temperatures and water logging that slow or prevent organic matter degradation, and processes the enhance carbon burial, such as cryoturbation and long-term sedimentation under periglacial environmental conditions, this view changed in the late 2000's. Within the framework of the Lena Expeditions and based on numerous field surveys we were able to establish new insights into deep permafrost carbon storage in North Siberia. We sampled organic carbon in ancient permafrost sediments deeper than 50 metre, in the periodically unfrozen top layer, in summer and winter, in ice wedges and even in methane bubbles trapped in lake and ocean ice (figure 3). We found impressive witnesses of the last ice ages mega fauna, like mammoth tusks and skulls, woolly rhino bones and even the hair of a mammoth fur. One of the challenges during summer fieldwork for sampling organic carbon is to keep the carbon frozen to avoid decomposition after sampling. This sometimes results in a situation like bringing a freezer in a helicopter and run a freezer on permafrost.

Figure 2: Landing with an MI-8 helicopter in a remote site in the Lena Delta and starting a multi-week expedition to decipher the Delta's organic carbon characteristic. (Photo: J. Strauss, 2014)

Using the unique opportunities of the Lena expeditions and analysing the samples in our laboratories we were able to revise calculations specifically for the Lena Delta area (and contributed important datasets for circumarctic permafrost zone soil carbon estimates). We now know that freezing of organic matter over a period of thousands of years stored and freeze-locked large amounts of carbon in the Lena River Delta, 240,000,000,000 kg down to 1 m depth. In other words, this huge carbon inventory in the first meter of the Lena Delta equals the amount 29 million times the mass of the huge MI-8 helicopter (see figure 2) often used to bring us to the remote places where we want to study carbon and other interesting topics in the Lena River Delta.

However, even beyond the upper meter of soil abundant organic matter is preserved today but vulnerable to thaw in a future warming Arctic.

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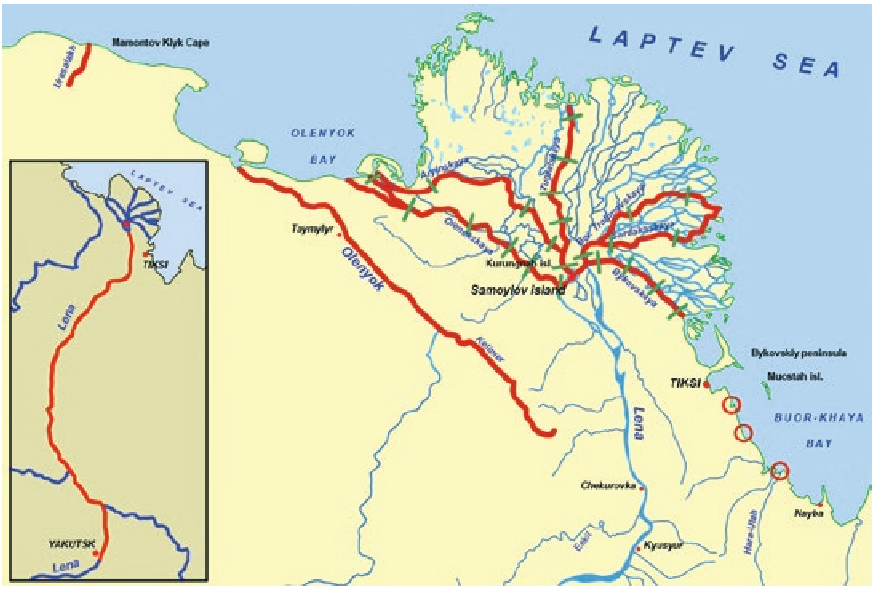
Figure 3: Sampling for methane in ice on Bykovsky Peninsula. (Photo: H. Zimmermann, 2017)



Expeditions with Rubber Boats and Small River Vessels – Hydrology and Geomorphology of the Lena Delta

This Russian-German project aimed to investigate the geological and geomorphological composition of the Lena River Delta and to study hydrological processes within. For all of its stages, small vessels were used for river expeditions along the Delta's main channels. The small vessels were provided to the expeditions by the Hydrobase in Tiksi.

During the first years of the Project, the small vessels were the "Dunay" and the "Neptune". In the more recent times, the expedition members have actively used the vessel "Merzlotoved " of the Melnikov Permafrost Institute in Yakutsk and the navigation ship "P-405". These ships are important platforms for either long routes through the Delta or to transfer field groups and other investigations.

Figure 1: Map of the Lena Delta and the expedition routes on the rivers.
Figure 2: The great Lena River.

In 2005, hydrological measurements were done along all Olenyokskaya Channel using the “Neptune” vessel. These investigations provided data about water flow and sediment load transformation along this channel, from the beginning of the Delta to the bar of Olenyokskaya Channel.

Several small research groups have conducted hydrological and geomorphological studies along the channels and other rivers of the Laptev Sea coastal zone by boat. Two explorers have passed the Sardakhskaya, Tumatskaya, Bykovskaya Arynskaya, and Osokhtokh channels during different periods of the project.

In 2006, two researchers used a rubber boat to study the Urasalakh, a river that travels through the Pronchishchev Mountain Ridge. The river Kelimeer, the Olenyok River tributary with a Low Olenyok River, was visited in 2008, and sediments of the Olenyok River Delta were dated for the first time.

A big junction of channels branching near Sardakh Island was investigated during two seasons in 2001 and 2002. Water flow and sediment load were measured in four hydrometrical ranges of the Sardakhskaya and Trofimovskaya channels.

These measurements were compared with hydrometrical characteristics of these channels measured in 70th of XX century by hydrologists of Tiksi observatory. This comparison shows that the water flow and sediment load continue to deviate in the south-eastern direction, moving from the Trofimovskaya channel to the branches of Bykovskaya and Sardakhskaya.

Geomorphological investigations along these channels provided a reason for this redistribution of water flow. On the one hand, tectonic uplifting has caused a warp of the Earth's surface in the western part of the Delta. This warp forces water to flow in a south-eastern direction. On the other hand, bulkheads of the Ice Complex in the south-eastern part of the Delta were destroyed some centuries ago, and the waterway to the east opened followed the inclination of the Earth's surface.

The Bykovskaya Channel is the youngest branch of the Delta. It is only 1500-2000 years old. The geological composition and the geomorphology of the Delta were investigated with boats and other vessels. As a result of this research, a geomorphological map of the Lena River Delta could be constructed, and the Holocene evolution of the Delta has now been understood.

The consequence of this evolution in the moving of filling estuaries from the west to the east during sea level fluctuations and the disappearance of Ice Com-

Figure 3: Shoreline testing area on Alkhan Island at the northern border of the Delta.

plex remnants due to abrasion and erosion processes. Ancient parts of the first terrace are situated in the western part of the Delta, and the youngest islands are in the eastern part of the Delta.

The unique geological composition of the Lena River Delta means that islands of the first terrace consist of organic and mineral sediments of different ages, but they make up a single surface of the first terrace. Such geological and geomorphological features indicate that a sea level fluctuation is a major reason for Delta formation, today and in the past.

Boat trips along the Kelieemer and Olenyok rivers with visits to the Olenyok River Delta show that the latter is analogous to the Lena River Delta and sea level fluctuations are very important for the formation of the Olenyok River Mouth. Following the Tumatskaya and Osokhtokh channels north of the Lena River Delta resulted in the organization of a testing area on Alkhan Island for northern coastal dynamics.

During all boat trips, the investigation of lakes is continued in the Delta and on the coastal zone of the Laptev Sea. There morphological, hydrological and hydrochemical regime, as well as sediments of lakes, are being investigated. Complex investigations into Sevastian Lake, situated near the Tiksi meteorological station, helped to understand the climate history of this area over the last millennia. A pilot investigation to study the sea level fluctuation in the Buor-Khaya Bay lagoons started in 2017.

From 2014-2017, the Lena River valley was studied from Yakutsk to the Delta to investigate processes that were previously recognized in the Delta. The river reacts to sea level changes along the valley up to thousand kilometres from the sea. This marine influence is documented in the river terraces. These investigations were carried out on board the vessel “Merzlotoved” during cargo operations from Yakutsk to Samoylov Station and by boat trips along the Lena River valley.

Overall, the boat and vessel travel supplied a rich data set about the composition and history of the Lena River Delta and the coastal zone of the Laptev Sea. The book “Origination and Evolution of the Lena River Delta” is dedicated to all these paleoenvironmental questions for the Delta and Laptev Sea Region.

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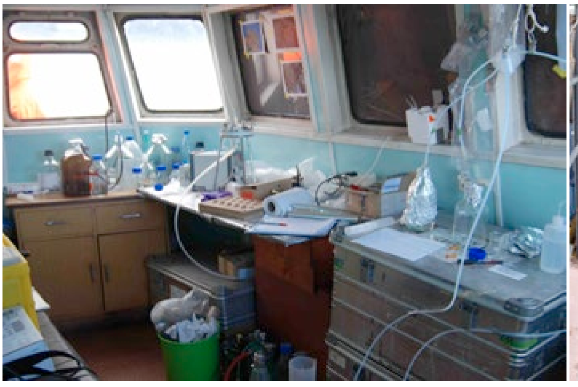
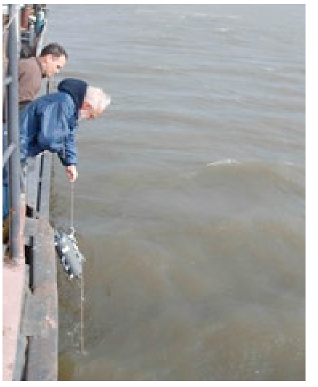
Mobilization and Deposition of Carbon in the Lena River System

The great Russian Arctic rivers transport vast amounts of dissolved and particulate organic matter, including nutrients, to the Arctic Ocean. The organic matter is mainly derived from the soils and permafrost deposits in the drainage basins of the rivers. Thawing and progressive warming in the region, therefore, have a probable impact on the organic matter. Due to degradation, changes in the composition and age of the organic matter are expected to occur after thawing, upon mobilization, and during transport in the rivers. The type of soils, as well as the local hydrological conditions, further determine the organic matter characteristics.

In the summers of 2009 and 2010, we set out on expeditions to sample the different branches of the Lena River Delta. We aimed to trace the fluxes of dissolved and particulate organic matter from their sources in the local deposits to their ultimate deposition in sediments of the Arctic Ocean. We also wanted to

Figure 1: River vessel Puteyski 405 on the beach of Samoylov Island. (Photo: G. Mollenhauer)





monitor the carbon loss due to degradation. During the first expedition in 2009, we sampled water and sediments from the main branches of the Delta: The Bykovskaya, the Trofimovskaya and Sardakhskaya, and the Olenyokskaya channels. For this purpose, we chartered the river craft “Puteyski 405” (Figure 1). We, being a group of six Germans and one Russian scientist, loaded several boxes with laboratory equipment and embarked in Tiksi. Our first task was to set up a makeshift laboratory in one of the two cabins of the ship (Figure 2).

The first leg of our river cruise brought us to Samoylov Island in the early hours of the morning. We had to wake the scientific leader of the station and were received with a warm welcome in the cosy kitchen. Over the next 10 days, we travelled through the delta, occupied over 30 stations at sites in the main branches of the Lena delta, took water and sediment samples with simple hand-operated equipment (Figure 3), and filtered hundreds of litres of water. When we weren’t able to return to Samoylov at night, we camped on one of the isolated and strikingly beautiful islands of the delta.

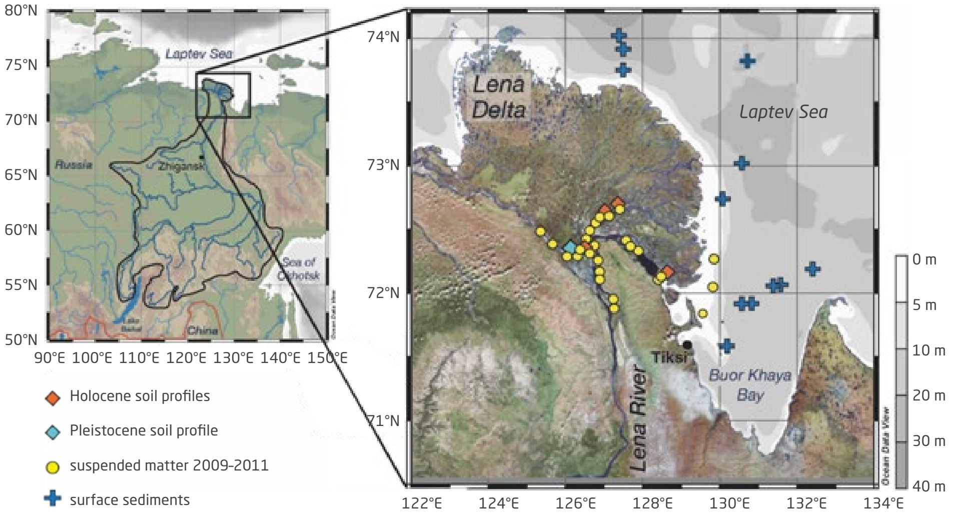
During our expedition, we experienced life on board a Russian river vessel and the hospitality of the crew. We often had to use gestures to bridge language barriers and enjoyed the regional cuisine, which usually involved reindeer stews (Figure 4). After leaving the delta, we ventured across Buor Khaya Bay, which can be quite dangerous in adverse weather conditions.

Figure 2: Makeshift laboratory for water sample processing onboard river vessel Puteyski 405: Filtration devices, sample containers, and record keeping equipment. (Photo: G. Mollenhauer)
Figure 3: Water sampling of Lena River water from the ship, using a hand-held Niskin bottle. (Photo: G. Mollenhauer)

One of the highlights of the expedition included an overnight stay on Muostakh Island, where our Russian colleague Mikhail (Misha) Grigoriev conducted his regular measurements of coastal erosion. We were free to explore the island for a few hours and then gathered on the beach, where we had set up our camp (Figure 5). Misha lit a campfire and taught us how to use the bark of birch trees that can often be found in the debris on the beaches to ignite the first flames. We made tea on the fire, and Misha produced a small bottle of cognac from his pocket. It was turning August 23rd, the first snowflakes of the year were gently falling, and we were toasting to our friend's birthday.

To build on our experiences of 2009, we repeated the expedition in the summer of 2010. This time, the team was bigger and sub-divided into two groups. Each group took turns in using either the river vessel Puteyski 405 to re-occupy the stations sampled in 2009 or the coastal vessel "TB-0012" to sample water and sediments in Buor Khaya Bay. While the latter was more suitable to cope with the choppy wave regime in the Bay, neither ship was designed to conduct scientific sampling campaigns. Two young female PhD students from Germany carried out the water and sediment sampling with the support of an apprentice technician. Again, only hand-operated sampling devices were available, and we were able to collect a sample set comparable to 2009. This time, our sampling campaign was complemented by hydrological measurements carried out by a team from Saint Petersburg. The crew of the coastal vessel also got creative and was able to retrieve some short sediment cores by jamming a metal tube into the shallow water of the Bay – much like harpooning a large mammal.

Figure 4: Pantry of Puteyski 405 with the German science party enjoying lunch cooked by the crew on board. (Photo: G. Mollenhauer)
Figure 5: Camp on the beach of Muostakh Island. (Photo: G. Mollenhauer)



We were finally successful in chartering a small research vessel from Murmansk in the late summer of 2013. The ship was used for a dedicated sampling campaign by several groups. Water and sediment samples were obtained along several transects off the major branches of the Lena River Delta (see pages 142-147). Overall, with creativity and by using simple sampling strategies, we now have a comprehensive sample set at our disposal to study the composition and age of dissolved and particulate organic matter discharged through the Lena River Delta – from source to sink (Figure 6). These samples have been evaluated in two PhD theses and two Master theses. They are currently being investigated as the subject of a Bachelor thesis. Our valuable samples are also the basis of an international research project starting in summer 2018.

We found that particulate and dissolved organic matter in the Lena River Delta reflects the composition of the local deposits. Samples could be differentiated according to their source. This highlights the importance of local input to the total organic matter load of the river.

Gesine Mollenhauer, Maria Winterfeld, Boris P. Koch, Irina V. Fedorova

Figure 6: Map of sampling locations from the combined expeditions in 2009, 2010, and 2013. Surface sediment samples were recovered in 2013.

Holocene Lakes Around the Lena Delta

Palaeolimnological studies of lakes around the Lena Delta were undertaken during the Lena expeditions in 1998, 1999, 2009, 2010, and 2017 (Figure 1). Since 2003, these studies also included various lake systems all over eastern Siberia. The limnogeological work was funded by the Russian-German partner institutions and by several third-party grants under the umbrella of the SibLake programme.

The study area extends far into the forested hinterland of Yakutia, the Verkhoyansk Mountains, and as far as Kamchatka at the Pacific Ocean. Our research seeks to provide broad spatial coverage to capture the spatial-temporal dimension of palaeoenvironmental changes in Siberia. In this sense, it is comparable to the weather forecast, which is based on a wide network of meteorological sta-

Figure 1: Palaeolimnological study sites in the northern Lena River region: Lake Nikolay (1998/1999), nameless lakes referred to as Tik sites (2009), lakes Kyutyunda and El'gene Kyuelle (2010), lakes Golzovoye and Northern Polar Fox near the town of Tiksi (2017).
Figure 2: Field camp and tripod raft for sediment coring at Lake Kyutyunda. (Photo: B. Diekmann)

tions. We are particularly interested in the period since the last ice age and the Holocene. This time span includes the natural climate variability of approximately the last 50,000 years until the current era of human-made climate change.

The research approach in the field is devoted to the recovery of lacustrine sediment records. In order to infer the palaeolimnological changes, the samples are subsequently analysed in the laboratory using radiocarbon dating as well as sedimentological, geochemical, and micropalaeontological methods.

As an example of how adventurous limnogeological fieldwork in the Arctic periglacial wilderness can be, we highlight the experiences in a late summer season during a sub-campaign of the Russian-German expedition "Lena 2010".

September 3, 2010: A final flight over the sprawling tundra of northeastern Siberia. We finally spot the first houses on the horizon. We land and unload almost two tons of expedition equipment from the packed helicopter – one last time. We're back home in Tiksi, the polar outpost of Russian civilization at the Arctic Ocean. Behind us lie three weeks of field work, carried out on two lakes in the hinterland of the Lena Delta.

The first voyage took us 300 km south of Tiksi to Lake Kyutyunda (3 x 3 km, 5 m water depth), situated in the forest-tundra. Swarms of mosquitoes and biting flies greeted us, though the first night frosts soon replaced them as autumn approached. We set up our camp on a soft beach made up of reworked peat debris (Figure 2). We enjoyed unforgettable sunsets at midnight, which announced the fading of the 24-hour polar days. The fieldwork had been quite successful: We retrieved several up to 8 m long sediment cores, which would later document the Holocene history of the lake's development and Siberian climate over the last 11,000 years.

Ten days later, the helicopter picked us up again and dropped us off at Lake El'gene Kyuele, some 200 km to the north. Here we were faced with the harsh sides of the tundra. The days were mostly rainy and windy, the nights were wet and cold, and became noticeably longer. Walking on the soft, lumpy, and damp underground became a permanent challenge which our chilly rubber boots narrated with continuous smacking sounds. Such conditions, however, could in no way curb our enthusiasm for the upcoming field work at this exciting study site.

The lake is located in a 20 m deep and 3 x 5 km wide alas depression, which is widely occupied by silted-up areas (Figure 3). Today, the lake has an area of 3 x 3.5 km and is limited to the western part of the basin. Spectacular bluffs of the Pleistocene Ice Complex (Yedoma) with mighty ice wedges often border the lake's edges. The Yedoma formation shows signs of thermal erosion with typical retrogressive thaw slumps and remnants of frozen loess-like sediment pillars between lost ice wedges, thus forming a characteristic "egg-carton landscape".

A steep ridge up to three meters high borders the eastern shore of the lake. The ridge merges into an old lakeside terrace, where we set up camp. Young peat deposits cover the terrace. Fossil subaquatic sediments lie underneath it, with abundant wood remains and fossil logs from warmer times of the early Holocene. Our fieldwork started with a bathymetric survey of the lake. It revealed quite an uneven underwater relief, with numerous irregular subaquatic holes that reached a depth of 10 m.

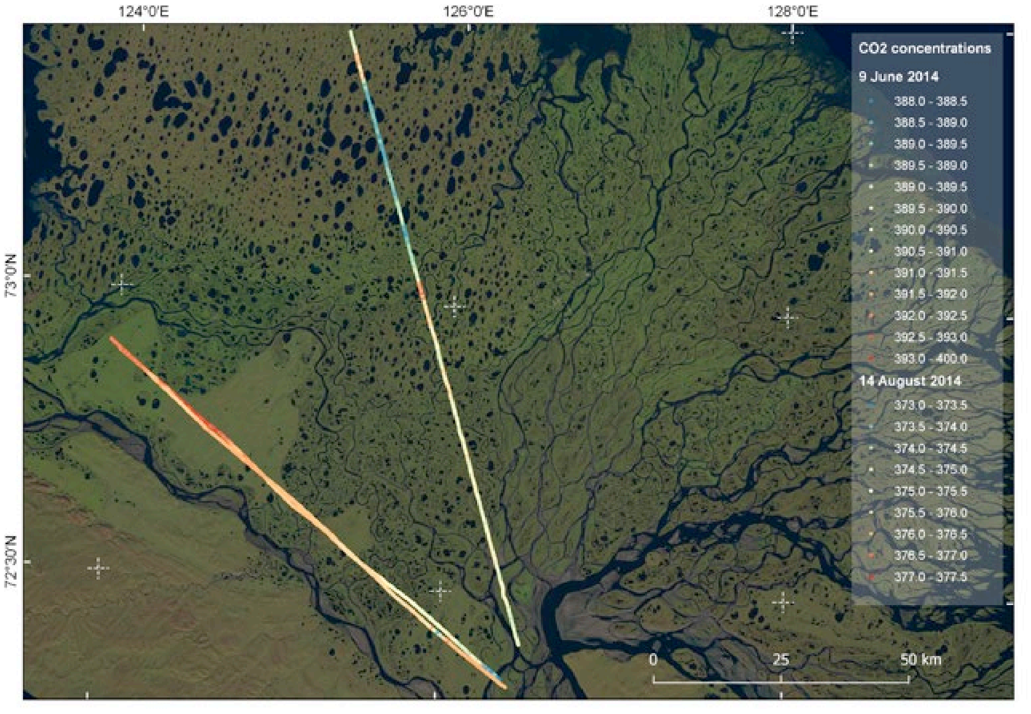
Sediment cores up to five meters long were recovered from different water depths at four representative sites across the lake (Figure 4). We also took

Figure 3: Northward view across the thermokarst setting of Lake El'gene Kyuele. The left lake margin shows small deltas resulting from sediment redeposition by onshore thaw slumps. (Photo: B. Diekmann)

samples from fossil lake sediments, peats of the old lakeside terrace, Yedoma sediment, and ground ice. Later studies on the sediment records showed that climate-related thermokarst subsidence and lake level changes mainly controlled the lake history, as well as shore erosion and migration during the Holocene.

Bernhard Diekmann, Boris Biskaborn, Luidmila A. Pestryakova, Dmitry A. Subetto, Dmitry Yu. Bolshiyanov, Ulrike Herzschuh, Georg Schwamborn, Volker Rachold

Figure 4: Part of a sediment core section from Lake El'gene Kyuele, showing light event layers of sediment redeposition from shore erosion, embedded in dark, organic-rich lake gyttya. (Photo: D. Subetto)



Complex Logistical Operations – Airborne Energy and Greenhouse Gas Flux Observations by Helipod

Some of the most pressing questions concerning climate feedback processes in the warming Arctic are: How much of the greenhouse gases (GHG) carbon dioxide (CO_2) and methane (CH_4) are currently being released from Arctic permafrost areas? Is the observed warming already causing changes in the energy and GHG dynamics? Locally, the exchange of heat and GHG between permafrost and atmosphere can be monitored with the so-called eddy covariance method (see pages 76–81), which provides continuous observations and, if funded and maintained for the long-term (i.e. decades), enables the detection of such potential

Figure 1: Map of flight lines in June (towards NW) and August (towards NNW) in 2014, colour-coded according to CO_2 concentrations.

changes and trends amidst inter-annual variability. These types of observations are still rare in the Arctic, however, and logistical constraints, among others, usually limit site selection. As a consequence, these observations cover only small areas, and it is not always clear if they are truly representative of the wider region of interest.

The same method, however, can also be deployed from aircraft, helicopter-towed sensor systems, and unmanned aerial vehicles (drones). Airborne measurements can overcome the spatial limitations of ground-based observation by covering distances of hundreds of kilometres in a few hours – as a drawback, however, they only provide snapshots in time. Combining both approaches has great potential for developing a comprehensive, regional-scale understanding of the actual contribution of permafrost ecosystems to the atmospheric greenhouse gas burden.

The first airborne measurements of heat and greenhouse gas fluxes in the Lena River Delta

In 2012, a helicopter-towed instrument package called “Helipod” was deployed from Samoylov Island to prove the feasibility of airborne measurements for quantifying heat and greenhouse gas fluxes across the entire Lena River Delta. Owned by the Technische Universität Braunschweig, Helipod is 5 m long, weighs about 350 kg, and was at first carried from its “hangar” (a tent behind the research station) to the helicopter landing place by hand – a favourite activity for everyone involved. Thankfully, it was later reduced to lifting Helipod onto a trailer pulled by a motorized all-terrain vehicle or “Quad”. Helipod was then attached to a Russian MI-8 helicopter with a 30 m rope and towed across the delta at an airspeed of 40 m s^{-1}. It provided high-resolution meteorological measurements of small-scale turbulent fluctuations of wind, temperature, humidity, CO_2, and CH_4, as well as the infrared surface temperature. Each meteorological variable was measured with two complementary sensors, one with a short response time but low absolute accuracy, the other with a longer response time but high accuracy and long-term stability. A complementary filter combined the two data sets.

Two flights scheduled in 2012 were filmed by a camera team of the Berlin-Brandenburg public television (“Geheimnisse im Eis der Erde”; rbb) as part

Figure 2: Helipod just before take-off for the first science flight in 2012.
Figure 3: Helipod passing the Samoylov flux tower.

of a 45 minute documentary of the LENA-2012 expedition. Because helicopter availability was comparable to a lottery win, only one flight was conducted during excellent measurement conditions above the Yedoma Ice Complex (third terrace of the Lena River Delta), in a northwest direction along the Olenekskaya Channel. The second flight – under less favourable conditions – covered the second terrace towards the Arga-Muora Island north-northwest of Samoylov. Flight patterns included a wind calibration square after take-off, vertical profiles at the beginning and end of each transect to determine the boundary layer height, and long (100-130 km) low altitude transects for flux measurements. While only the Helipod "hangar" tent was blown away by the MI-8 rotor downwash during the first take-off, a mishap during the second take-off resulted in displacement and bending of Helipod's GPS antenna array. Fortunately, it could be corrected during data post-processing.

The 2014 intensive airborne campaign

After the promising test run in 2012, major investments were made to integrate a fast CH_4-sensor into the Helipod, and an intensive campaign was planned for 2014. Starting in April to cover the winter background, flights followed the same

Figure 4: Helipod above the polygonal tundra of the Lena River Delta.

transects as in 2012, from Samoylov towards the coast. They were extended with an additional flight above the first terrace towards the northeast of the delta. During snowmelt and river breakup, a second campaign was conducted in May and June to cover heat and greenhouse gas flux dynamics during the transition from winter to summer. A final set of flights took place in August during the peak of the growing season and close to the maximum thaw depth of the active layer.

Preliminary results

Post-processing of Helipod raw data turned out to be much more complicated than anticipated. Virtually all Helipod-experts at the TU Braunschweig have left for other positions or retired, and the outdated data acquisition and processing system itself requires in-depth analysis. First results indicate that the post-processing software of the GPS attitude determination system, in particular, must be adapted to the unfavourable geometric GPS satellite constellation at high latitudes, as inevitable constellation changes during the flights resulted in discontinuities in all position and attitude variables. Several proposals are currently pending to hire a dedicated person for the adaptations as well as for applying enhanced algorithms to improve the derived wind vector, which is the basic requirement for flux calculations. Cospectral analysis currently still shows a correlation of wind components and motion state variables.

It should be noted that GHG concentration data along the flight tracks, as shown in figure 1, already demonstrate significant spatial as well as intra-seasonal variability: Concentrations typically vary by up to 5 ppm (parts per million) during any given flight. The difference of the overall concentration level of about 15 ppm between flights at the beginning of the growing season and near its peak shows the effect of two months of tundra photosynthesis.

Torsten Sachs, Eric Larmanou, Katrin Kohnert, Andrei Serafimovich

Lena Expeditions: Integration of New German Research Groups

The preceding major research programs and the development of Russian-German cooperation provided an important momentum for the time span without large-scale funding that now followed. The pioneering Russian-German research activities attracted German research groups from disciplines such as coastal research, biology, organic chemistry, and remote sensing, and they expressed interest in working in the region and being involved in the research program. In summer 2008, an expedition aimed to provide coastal ecosystems researchers with access to the region, as part of the Helmholtz Research Programme PACES -

Figure 1: Group photo in front of the Samoylov Station (August 2008). From left to right:
1st row, sitting: Günter (Molo) Stoof (AWI Potsdam), Tina Sanders (Universität Hamburg), Karen Wiltshire (AWI Helgoland), Conrad Kopsch (AWI Potsdam), Sergey Volkov (Ranger, Lena Delta Reserve), Niko Bornemann (AWI Potsdam), Moritz Langer (AWI Potsdam).
2nd row, sitting: Karsten Reise (AWI Sylt), Irina Fedorova (Uni St. Petersburg), standing: Pyotr Ivlev, Hans-Wolfgang Hubberten (AWI Potsdam), Maren Grüber (AWI Potsdam), Roland Doerffer (Coastal Research, HZG);
3rd row: Ingeborg Bussmann (AWI Helgoland), Dirk Mengedoth (AWI Logistik), Mikhail Grigoriev (Melnikov Permafrost Institute, Yakutsk), Waldemar Schneider (AWI Potsdam), Susanne Liebner (ETH Zürich, DAAD), Svetlana Evgrafova (Sukachev Institute of Forest, IL, Krasnoyarsk), Paul Overduin (AWI Potsdam).

Polar Regions and Coasts in the changing Earth System. The expedition brought coastal perspectives of the North Sea and the Baltic Sea into the Lena River Delta, to the Research Station Samoylov Island (Figure 1), and to the central and western Laptev Sea regions, by ship (the Orlan, of the Lena Delta Reserve), and helicopter. Roland Doerffer (Coastal Research, Helmholtz-Zentrum Geesthacht, HZG) prepared a documentary film on the science and the scientists working in the region.

The reconnaissance expedition resulted in the conceptualization of the function of the Lena Delta as a biofilter, and a series of working hypotheses in various scientific fields sparked interest in further work. Participants organized a joint ship expedition to the central Lena Delta and the coastal waters of the Buor Khaya Gulf in the following summer (2009). Mikhail N. Grigoriev, now Vice Director of the Melnikov Permafrost Institute, Yakutsk, led the expedition. The expedition

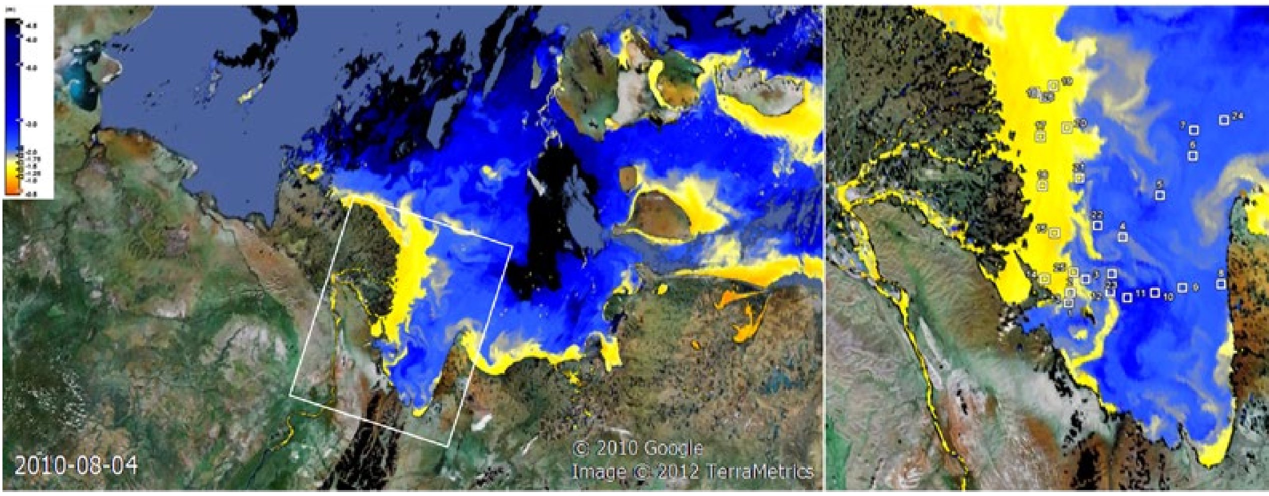
team sampled marine, riverine, and terrestrial surface sediments, coastal and Lena River water, and material from ice- and organic-rich coastal cliffs (Figures 2a-c).

The late summer sampling time window in 2009 was extended by several weeks with a further expedition in 2010 and involved hydrologists from the St. Petersburg State University, led by Irina Fedorova (Figure 3). The teams sampled sediment and water on a regular basis and installed biochemical degradation experiments to monitor changes in the concentration, character, and stability of organic matter in rivers and thermokarst lakes.

Figure 2a: Sampling Buor Khaya Gulf and the Lena River in August 2009.
Figure 2b: View on camp on Muostakh Island in August 2009.
Figure 2c: 2-week experiment on optical degradation of organics in the Lena River water on board the ship (August 2009).

In order to understand the transition from coastal to marine systems better, the ship expedition in 2010 (Figure 4) also sampled water and sediments in marine-influenced waters, thus extending the sampling campaigns of 2008 and 2009 further offshore into regions less affected by terrestrial coastal waters. The expedition data from 2008 to 2010 provided powerful support for the validation of satellite products that estimate water composition based on ocean colour. They showed that the large amounts of organic carbon of the surface waters led to an overestimation of the satellite chlorophyll concentration by more than one magnitude. Other disciplines also benefited from the efforts and established small vessel research in shallow shelf waters.

Figure 3: The Russian-German hydrologists (Antonina Chetverova (St. Petersburg State University), Irina Fedorova (St. Petersburg State University, Otto Schmidt Laboratory), Ruth Flerus (AWI)) during their regular sampling of thermokarst lakes on Samoylov Island and of the Lena River in the summer of 2010.



The period from 2007 to 2012 introduced new German researchers and research groups, expanded the spectrum of research goals in the Lena River Delta and the Laptev Sea coastal waters, and earned Russian recognition of the importance of the accomplished and pursued science in the region.

Birgit Heim, Hans-Wolfgang Hubberten, Pier Paul Overduin, Irina V. Fedorova

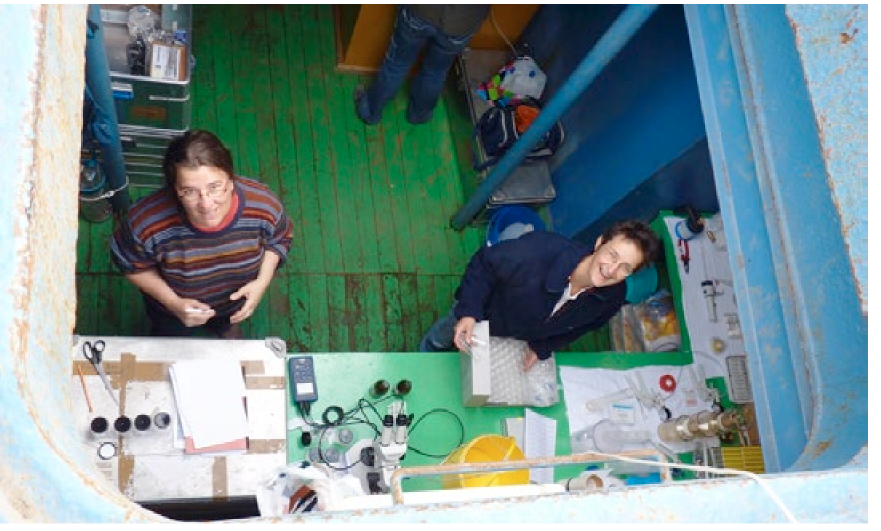
Figure 4: Laptev Sea region and the Lena River Delta (left) and the stations of the Lena 2010 ship expedition (29.06.-07.08.2010) in the Buor-Khaya Gulf (right). The colour scale shows the first attenuation depth (Z90) derived from a MERIS Ocean Color satellite acquisition on 04.08.2010. Clouds are masked in dark gray and black. The background land surface is a Google EarthTM Land Mosaic (© 2012 Google, Image © 2012 TerraMetrics).

A Decade of Coastal Research in the Lena Delta

A better understanding of coastal systems in the Siberian Arctic is essential because the region is very sensitive to environmental changes. Fluctuations in river discharge and water temperature influence the temperatures of air, sea water, and permafrost in the Lena Delta. All these changes can be expected to transform Arctic shelf ecosystems. In our coastal research, we examine processes at the land-sea transition, from fluvial mass transfer, hydrography, and water chemistry to coastal geomorphology and subsea permafrost.

Since 2008, several expeditions with smaller ships have been conducted in the region. The Laptev Sea shelf is broad and shallow, and the local availability of adequate vessels is a limiting factor for coastal research. Marine ships with large

Figure 1: Disembarking from the "Orlan" in 2008. (Photo: C. Kopsch)



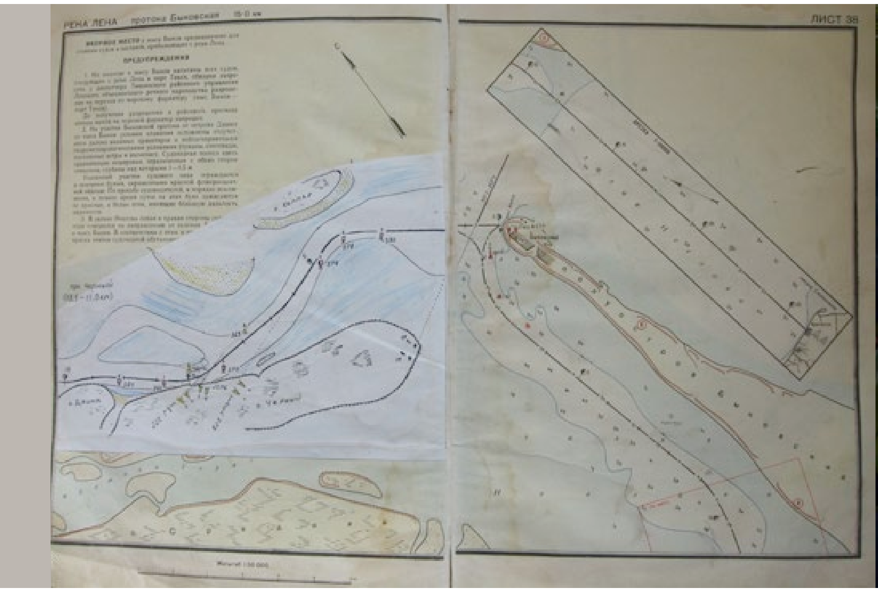
draft cannot reach shallow coastal areas, while river vessels with small draft cannot be used on the open sea. Reaching the shore for work on land is a challenge with either vessel type. Small boats are used to transfer between larger vessels and the shore. River vessels are either anchored on sandbars or beached, meaning that transfer is via ladder or plank. In any case, disembarking can be a rather wet affair (Figure 1).

Almost none of the vessels used were dedicated research vessels. Thus, all equipment for sampling and sample processing had to be taken aboard. Most of our devices (such as water sampler and sediment corer) were of the hand-held variety. Space on board the vessels was limited, and we quickly learned to improvise to convert available workbenches and other small spaces to "miniature laboratories" (Figure 2).

Navigation was a challenge in the early years. Access to nautical charts was restricted, and detailed cruise plans had to be developed on site using the crew's expertise and hand-corrected river charts (Figure 3). Later, it became possible to acquire charts in advance (Figure 4). In recent years, navigation with hand-held GPS systems became more accepted.

Most of the cruises with the river vessels Orlan and Puteyski 405 were carried out as a series of day trips. We either returned to the research station Samoylov

Figure 2: Working in the bunt of the "TB 0012". (Photo: M. Löder)

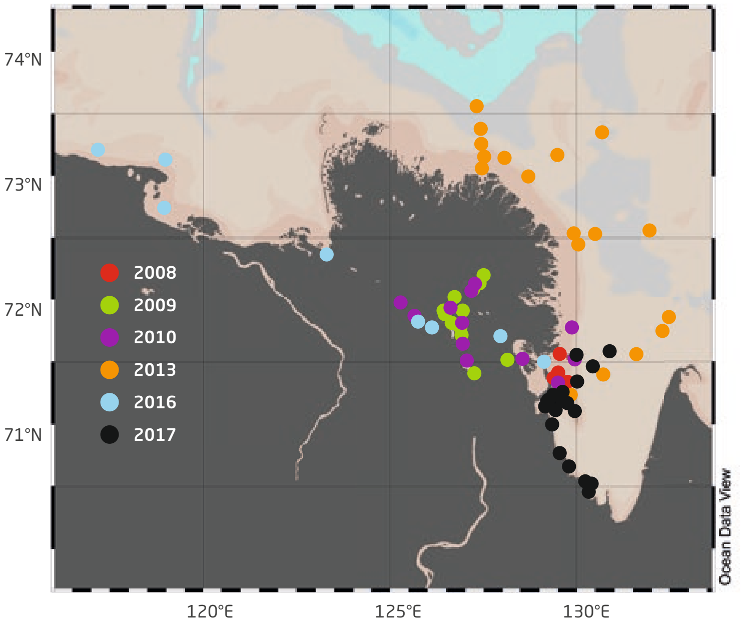


Island each evening or pitched tents on shore. Working times were very flexible. We occasionally withdrew to our tents due to poor weather but embarked again at 4 a.m. because the weather had improved enough to permit shipboard research. The highly dynamic sediment system of the Lena Delta resulted in special surprises like the boat suddenly hitting a sandbar that had shifted. Such abrupt stops made laboratory work, such as water filtration and pouring, quite ambitious.

The larger vessels such as TB-0012 and Nicole (15 m) offered small cabins on board and enabled meals together with the crew. Science and life aboard the research vessel Dalnie Zelentsy were well-structured, with several laboratories, cabins, and a big mess room. The small glass-fibre reinforced cabin cruiser Nicole, of Venetian provenance, has been used annually since 2016. Under calm conditions, the Nicole is fast and makes it easy to reach remote field locations.

It was this motley collection of infrastructure which, over the past ten years of coastal research collaboration, thankfully made it possible for us to obtain important baseline information and crucial data for a large region of the Lena Delta and adjacent coastal waters.

Figure 3: River chart in 2009. (Photo: G. Kattner)



In 2008, the Orlan, with A. Gukov as PI, sampled in the Lena around the Samoylov Island research station. On the way back to Tiksi, additional water and sediment samples were collected to validate satellite data. In 2009, the Puteyski 405, with I. Fedorova and G. Kattner as PIs, was used to sample the Lena Delta once again, with a special focus on the chemical composition of dissolved and particulate organic matter.

In 2010, we were able to charter two vessels with two scientific parties. The Puteyski 405 worked in the Lena River and the TB 0012 in the Lena Delta (Figure 6). Rough waters thwarted an attempt to exchange equipment and groups offshore of the delta. Thus, both ships returned to the bay sheltered by the Bykovsky Peninsula. The research in 2010 focused on the composition and distribution of phytoplankton within the Delta, as well as the spreading of methane with the river plume.

In 2013, the RV Dalnie Zelentsy was used in cooperation with our colleagues from the Murmansk Marine Biological Institute (Figure 7). The expedition start was delayed due to a late flight from Murmansk to Tiksi. An even lengthier delay awaited us, however: Ice in the Vilkitsky Strait slowed the research vessel travel-

Figure 4: Bridge on the “TB102” with captain and officer. (Photo: I. Bussmann)
Figure 5: Map of the study area.


ТБ-0012


DALNIE ZELENTSY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ling from Murmansk to Tiksi. Thanks to the prodigious efforts of our German and Russian logistics departments, we at least managed to get six days of ship time. We were able to reach the northern part of the Delta with the Dalnie Zelentsy and obtained new insights into the distribution and dilution of coloured dissolved organic matter, phytoplankton, and methane, as well as the influence of submarine groundwater.

In 2016, the Nicole was chartered for a long voyage from Tiksi westwards through the Lena Delta. A refuelling stop at the Samoylov Island research station made it possible to reach the western Laptev Sea through the Olenyoskaya Channel. At the most western extent of the trip, we made landfall at the site of the 2005 COAST expedition to visit the borehole site. The Nicole proved a storm-worthy platform for oceanographic and subsea permafrost studies, including the validation of data for ocean color satellite missions and studies of subsea permafrost and methane distribution.

Several scientifically uncharted locations along the southwestern shoreline of Buor Khaya Bay were investigated with the Nicole in August 2017 (Figure 8). During the trip, we obtained GPS elevation data and collected material for radiocarbon dating. We wanted to establish the potential of the field sites as paleo-environmental archives for the reconstruction of Holocene sea level and wave energy.

Exceptional Russian-German scientific collaboration under exceptional conditions with exceptional logistics have resulted in ten years of exceptional scientific endeavours in an exceptional environment. We look forward to the next ten years of collaboration.

Ingeborg Bussmann, Dmitry Yu. Bolshiyanov, Irina V. Fedorova, Mikhail N. Grigoriev, Alexander Yu. Gukov, Gerhard Kattner, Alexandra Kraberg, Denis V. Moiseev, Pier Paul Overduin, Lasse Sander, Karen H. Wiltshire

Figure 6: "TB 0012" in 2008 near Bykovsky Peninsula. (Photo: I. Bussmann)
Figure 7: RV „Dalnie Zelentsy" in the port of Tiksi. (Photo: A. Kraberg)
Figure 8: "Nicole". (Photo: P. Overduin)

5. New Horizons for Lena Expeditions – The New Research Station Samoylov Island

(Photo: P. Verzone)

Prime Minister V. V. Putin Visits Samoylov Island (P-Day)

Sometimes there are these unforgettable days when something really unique happens. One of these days was 23 August 2010, when Russian Prime Minister at that time, Vladimir Putin, visited the Russian-German polar research station "Samoylov". This day, internally called P-Day and, coincidentally, also Mikhail 'Misha' Grigoriev's birthday, was a very special event that only lasted a few hours, but changed life on this small island drastically.

It all started a couple of weeks earlier when rumours came up that Prime Minister Vladimir Putin would visit the Russian North and might also come to the Lena Delta. When helicopter and boat activities in the delta increased, and a temporary camp was constructed on one of the small islands opposite Kurungnakh Island, just a few kilometres from Samoylov Island, things started to get more real. Putin's personal staff visited us and invited us to prepare a "scientific" presentation at said camp. We answered that real science could only be shown on Samoylov Island, and proposed that the Prime Minister should come and see our four km², which was agreed on after a couple of further visits from security and personal advisors.

Figure 1: Welcoming Prime Minister Vladimir Putin on Samoylov Island.


Tension rose with every day the event drew closer and then, suddenly, P-Day began. It started with first one MI-8 helicopter spitting out journalists and security, then a second one, a third, and a fourth, and all of a sudden the number of people on the island had increased from about twenty to more than a hundred. Strange people populated the island, some boasting machine guns, others taking pictures, shooting videos, or interviewing scientists. Then a fifth helicopter, a larger, white MI-8 appeared, and we knew it was him. The helicopter landed, and the Prime Minister was received by the expedition's "natschalniks" (leaders). They guided Putin through a prepared scientific parcours to inform him about the scientific work of the Russian and German colleagues dedicated to Siberian permafrost. Putin visited the field experiments related to micrometeorology, greenhouse gas flux studies, and the palaeoclimate research of the Alfred Wegener Institute in Potsdam, the Universities of Hamburg and Cologne, the Arctic and Antarctic Research Institute in St. Petersburg, the Permafrost Institute in Yakutsk, Moscow State University, and the Institute of Forest Research, Krasnoyarsk.

While explaining our work and regional peculiarities, we came extremely close to him. We even had the chance to drill into the permafrost together with Vladimir Putin, one of the most powerful persons on this planet, to show him that the ground is frozen just a few decimetres below his feet. During the drilling, he smilingly asked if we knew his rate for one working hour. He would undoubtedly have been an expensive drilling assistant. It was our impression that he enjoyed himself and his stay, and he was open-minded and certainly much more personal than on TV. He spoke excellent German and even corrected his translator when the latter made a small mistake.

Figure 2: Svetlana Evgrafova explains the importance of microbial activity in permafrost to Putin.
Figure 3: Drilling into the permafrost with Putin. (H. Meyer, A. Dereviagin)

He then visited the station, two cosy but simple wooden huts. Here, a one-hour round-table discussion between the Prime Minister and the members of the expedition took place and was filmed for Russian television. Putin discussed the current situation and the future of joint Polar Research in Northern Russia with Russian and German scientists and students. As part of this discussion, Misha received a watch as a birthday present. Prime Minister Putin emphasized that we were doing extremely important work, but casually added that we were living like "clochards" or tramps and than he said he would sign a contract to build a new scientific research station on the island. A short visit, on this one peculiar day, changed the fate of our small island.

Looking back now, in 2018, we can gratefully say that he kept his promise: the construction work started in 2011, and the new, modern, blue-white-red station was finished in 2013 and hosted the first expedition team in April the same year. This impressive research station is operated year-round by a fantastic team under the guidance of Fyodor Sellyakhov and offers many opportunities, such as a new laboratory complex, transport vehicles, and drill equipment, but also electricity, WiFi, and a hot shower 24 hours a day, enabling field work even during the harshest Siberian winter.
Bol'shoye spasibo, Vladimir Vladimirovich!

Hanno Meyer, Thomas Opel, Alexander Yu. Dereviagin, Svetlana Yu. Evgrafova, Waldemar Schneider, Alexander S. Makarov, Mikhail N. Grigoriev

Figure 4: Round-table discussion with Putin and expedition participants.
Figure 5: Group picture of Russian Prime minister Vladimir Putin with the participants of the expedition „Lena Delta. 2010" in front of the Russian-German Research station „Samoylov".
(All photos: T: Opel)

The New Research Station Samoylov Island: Construction, Opening Ceremony, Facilities, and Operation

The scientific Research Station “Samoylov Island” was built in 2011 and 2012 by decree of the Government of Russian Federation to boost Arctic environment studies. The Trofimuk Institute of Petroleum-Gas Geology and Geophysics of the Siberian Branch of the Russian Academy of Sciences (IPGG SB RAS) has been serving as an operator of the station since 2012.

Construction

The construction of a new station on the island began in the summer of 2011, immediately after the preliminary engineering and geological survey, which always precedes any construction. First, large ships delivered a great number of building materials and modules from Arkhangelsk to the port of Tiksi. The cargo also included expeditionary transport, including boats, a cargo bus, a drilling tractor, and much more. All of this was then transported to the island on river barges, through the shallow canals of the Lena Delta.

Figure 1: The New Research Station Samoylov Island.

About 100 workers arrived on Samoylov Island, where they first built a temporary dwelling house. Soon after, a lot of special construction equipment appeared. After that, the workers began to install hundreds of steel pipe piles to a depth of 15 m into the ground and filled them with concrete. In 2012, the building frameworks were ready. Multiplane complex work began on the premises. In the same year, the Russian government decided to transfer the new station to the IPGG SB RAS in Novosibirsk.

First field work

The first research expedition on the new station was held in spring and summer 2013. Everything at the station was excellent. We felt very comfortable, almost like a holiday resort. With the only difference that temperatures here were Arctic. Technical staff of the station and the station chief Fyodor Sellyakhov were outdoing themselves for the expedition. The station started its work.

Opening

The official opening ceremony of the station took place on 23 September 2013. We invited President Vladimir Putin to take part in this ceremony because he was the main initiator of the new station, but his administration responded that, unfortunately, the President was very busy during this period, but he sent us his best wishes. We learned that the President chaired the Arctic conference in Salekhard on this day. Some of those invited were not able to attend because they also needed to be in Salekhard, including the head of the Republic of Yakutia,

Figure 2: Delivery of cargo to the Samoylov Island by barges, July 2011. (Photo: G. Stoof)
Figure 3: Piles for buildings of the new station, July 2011. (Photo: V. Mikheev)

chairman of the Siberian Branch of RAS, and others. Many other guests came to the opening ceremony, however. The guests flew to Tiksi via Yakutsk, then by helicopter to the station. The guests were given a tour to field sites and around the station. Welcome speeches, ribbon cutting, symbolic key transfer, gifts -- all this was very beautiful and symbolic.

The opening was attended by Yakutia government officials, leaders of the Siberian and Far East branch of RAS, administration of the Alfred Wegener Institute from Germany, directors of institutes and academicians of RAS, leading Russian and German scientists involved in the Lena expeditions, the Consul General of Germany in Novosibirsk, CEO of Spetstroy Rossii Co., and reporters from news agencies, including the TV channel Rossija. A small scientific conference informed the guests about the tasks and prospects of the new station, followed by a gala dinner.

The guests received a lot of positive emotions and learned much about the Lena expedition activities in the Arctic and the prospects for future work of the new research station. The station was officially opened, and the guests left us to continue our job in the Arctic. Three flags, Russian, German, and Yakutian, were always present at the station entrance and in the conference hall.

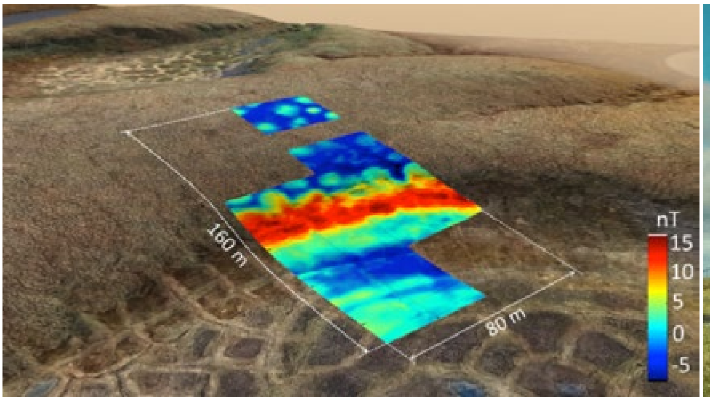
Figure 4: The first field team of the Lena 2013 expedition at the new station, April 2013. (Photo: M. Grigoriev)
Figure 5: Opening Ceremony. Cutting the ribbon of the new Samoylov Station: Academician Prof. Mikhail Epov (Director Trofimuk Institute of Petroleum-Gas Geology and Geophysics, Siberian Branch, Russian Academy of Sciences in Novosibirsk, left), Prof. Mikhail Grigoriev (Deputy Director, Melnikov Permafrost Institute, Siberian Branch, Russian Academy of Sciences in Yakutsk, center), and Dmitri Glushko (Vice-president of the Republic Sakha (Yakutia) from Yakutsk, right). (Photo: H.-W. Hubberten)

Operation

The station has been operating in a full-year regime since 2013. It is equipped with a set of modern scientific instruments and tools which are required in different fields of research (bio- and geochemistry, geophysics, climatic studies, hydrology, etc.). In terms of accommodation, the station provides a world-class level of comfort.

The Siberian Branch of the Russian Academy of Sciences (SB RAS), together with the Far East Branch of RAS, the Arctic and Antarctic Research Institute of Russian meteorological service (AARI), the North-East Federal University, the Alfred Wegener Institute of Polar and Marine Research (AWI), and a number of other partners, have developed a joint Arctic research program "Integrated Studies of the State and Evolution of Siberian Arctic Environment". Every year researchers from IPGG SB RAS, Melnikov Permafrost Institute SB RAS, AARI, AWI, and other Russian and foreign scientific and educational organizations perform a large volume of scientific work in Lena Delta as a part of a joint expedition. The research program addresses both national scientific research problems stated before Russian organizations and international programs and is aimed towards the study of global changes that occur during Arctic (Lena Delta, Laptev Sea zone) evolution.

Figure 6: Co-chairmen of the conference, devoted to the opening of the station. From left to right: Vice President of the Sakha Republic (Yakutia) Dmitry Glushko, Deputy Chairman of the Siberian Branch of the Russian Academy of Sciences and Director of IPGG SB RAS academician Mikhail Epov, Consul General of Germany in Novosibirsk Neithardt Höfer-Vissing, Chairman of the Far-East Branch of the Russian Academy of Sciences academician Valentin Sergienko, 23 September 2013. (Photo: H.-W. Hubberten)
Figure 7: Maximal spring tide at the new Samoylov Station, 1 June 2012. (Photo: M. Grigoriev)



The main objectives of the project are:

1. Acquire data on the developmental history of the Laptev Sea region during the Pleistocene and the Holocene (sea level fluctuations, paleoclimate, icings, permafrost evolution, palaeogeography);
2. Evaluate the input of the Arctic tundra to the global greenhouse gas emissions (methane, carbon dioxide) and determine the intensity and origin of gas emission to the atmosphere for different landscape conditions;
3. Evaluate the volume of solid material and carbon that is being transported to the Laptev Sea by rivers in the course of riverbank erosion, as well as the organic carbon volume (carbon cycle in the atmosphere and hydrosphere);
4. Study the interaction of natural processes in the region and their reaction to modern climatic fluctuations.

Over the last years, scientists from IPGG SB RAS have enhanced permafrost studies in the Lena Delta significantly with a set of geophysical methods such as aerial imaging magnetic measurements, electrical resistivity tomography electromagnetic imaging, thermal monitoring, etc.

The annual expedition to Samoylov Island, performed by a joint field party from the Institute of Petroleum Geology and Geophysics and Novosibirsk State University is a good example of the interdisciplinary approach of sophisticated Arctic research. This expedition combined modern geophysics and rich experience of Novosibirsk geologists, paleontologists and paleomagnetologists, botanists, and

Figure 8: Anomalous magnetic field mapped on the textured digital elevation model (left); Unmanned aerial vehicle (UAV) with aerial imagery equipment takes off (left).

soil scientists to permafrost research in Lena Delta. A number of interesting objects, common for Arctic region, were studied: Thermokarst lakes, alases (drained basins of thermokarst lakes), pingos, lake and channel taliks, erosional valleys, yedoma sediments, degrading subsea permafrost, and many others.

Together with colleagues from other countries (Germany, Finland, Canada, USA, Japan, Sweden, and others), we work on data processing and interpretation as well as publication. Scientists from Novosibirsk raise the quality of Arctic research to a new level with their fruitful work. This is especially important in this country, where permafrost covers the major part of the surface. It is safe to say that this direction of studies will be dominating the next 50 years.

Conclusion

It is a unique case when an international scientific Arctic Expedition project lasts 20 consecutive years. The Lena Expedition "Lena" is an extraordinary exception. We hope that the new Arctic station on Samoylov Island will be a convenient and reliable base for successful activities of the joint expedition for many years to come.

Mikhail N. Grigoriev, Hans-Wolfgang Hubberten, Igor N. Yeltsov, Anne Morgenstern

Figure 9: Meeting of AWI representatives and the director of IPGG SB RAS Igor N. Yeltsov on Samoylov in August 2017 to plan future cooperation and expeditions. From left: Karsten Wurr, AWI administrative director, Waldemar Schneider, AWI logistics, Guido Grosse, head of AWI section Permafrost Research, Hans-W. Hubberten, AWI, Igor N. Yeltsov.

Samoylov in International Programs and Networks – FLUXNET, GTN-P, INTERACT

Samoylov has evolved into an important and internationally recognized research site for terrestrial polar research over the past twenty years. The operation of long-term monitoring sites and field experiments on Samoylov Island has created results and datasets that are of high relevance to the international scientific community: They are unique in several aspects. For standard parameters that are measured circum-arctic or globally, the Samoylov site delivers valuable regional coverage of the East-Siberian Arctic, where monitoring sites are much scarcer than in other parts of the world. Other important data result from the long-term cooperation of the Russian-German research teams, from their fields of expertise, and their in-depth knowledge of the permafrost landscapes and processes in this area. The results and datasets have been published in the scientific literature and made publicly available in open-access databases such as PANGAEA (data publisher for Earth & Environmental Science, member of the World Data System (WDS) of the International Council for Science (ICSU), https://www.pangaea.de). Other international research teams have used these results as input for site comparison, modelling, syntheses, and more. The results and datasets have also contributed to large multilateral research projects such as the EU FP7 project PAGE21 or the Permafrost project of the European Space Agency (ESA) Data User Element (DUE) program. To facilitate broad distribution and use, some of the long-term monitoring results from Samoylov Island, which are globally important key variables and continuously measured over long time scales according to international standards, are being fed into databases run by international networks and programs:

The results of the long-term eddy covariance measurements of land-atmosphere exchange fluxes of momentum, energy, water, carbon dioxide, and methane (see pages 76–81) have been fed into the global network FLUXNET (Site ID: Ru-Sam). This network links measurement sites of carbon dioxide and water vapour exchange using the eddy covariance method routinely on all continents (http://fluxnet.fluxdata.org/).

The Global Terrestrial Network for Permafrost (GTN-P, https://gtnp.arcticportal.org/) compiles two permafrost key variables as Essential Climate Variables (ECVs)

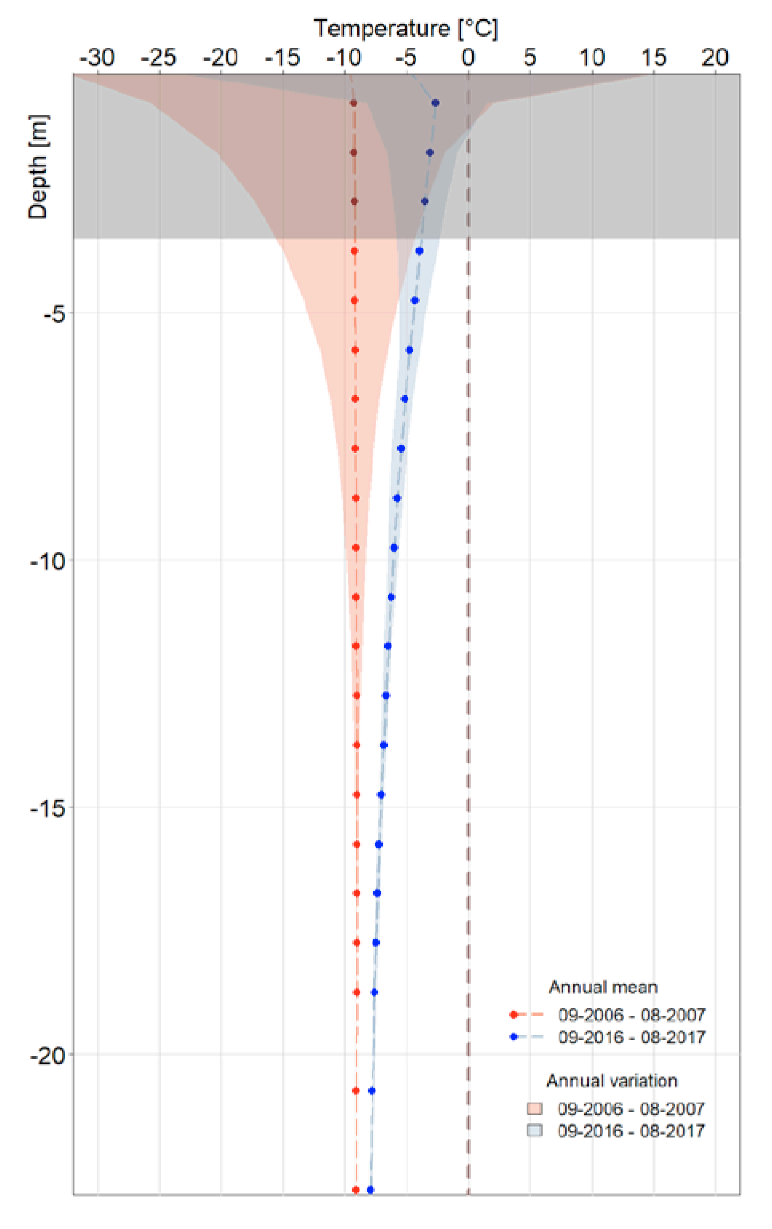


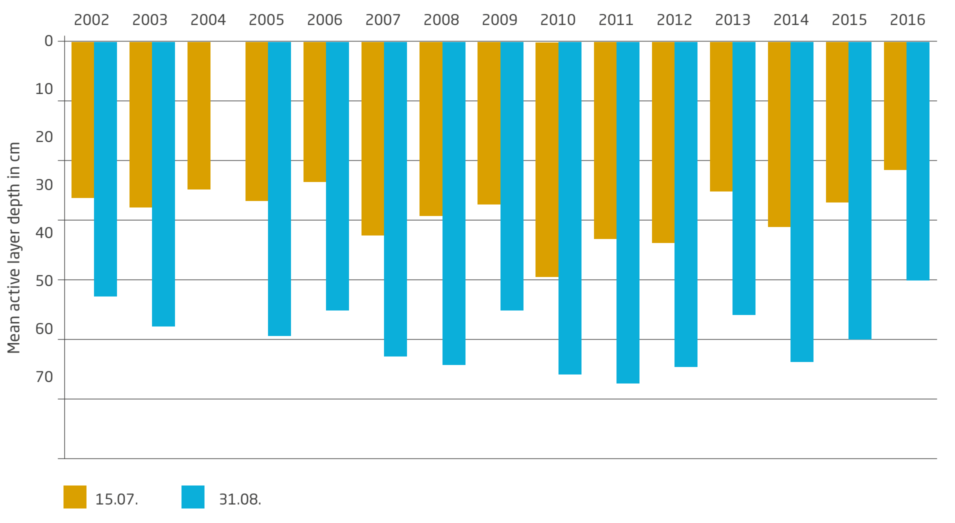
Figure 1: Permafrost temperatures recorded in the 26 m deep borehole on Samoylov Island show permafrost warming between 2006/07 and 2016/17 (after Boike et al. ESSD, in review).

established by the Global Climate Observing System (GCOS) and the Global Terrestrial Observing Network (GTOS). The first key variable is the Thermal State of Permafrost (TSP), which is permafrost temperature, monitored long-term by an extensive borehole network throughout the permafrost region. The second is the Active Layer Thickness (ALT), which is the annual thaw depth of permafrost, measured according to the standards of the Circumpolar Active Layer Monitoring (CALM). Samoylov has delivered monitoring data to both, TSP and CALM.

A 26 m deep borehole was drilled on Samoylov Island in 2006 and equipped with a temperature chain with 24 temperature sensors that have been continuously recording permafrost temperature throughout the whole depth profile (Figure 1). In addition to this Samoylov borehole, several other permafrost boreholes were drilled in the Laptev Sea region as part of the LENA Expeditions. Permafrost temperatures measured in these boreholes have been uploaded to the TSP database. Continuous ALT measurements on Samoylov Island already started in 2002, when a CALM grid was established (see pages 76–81).

The EU-funded infrastructure project INTERACT – International Network for Terrestrial Research and Monitoring in the Arctic (https://eu-interact.org/) is a

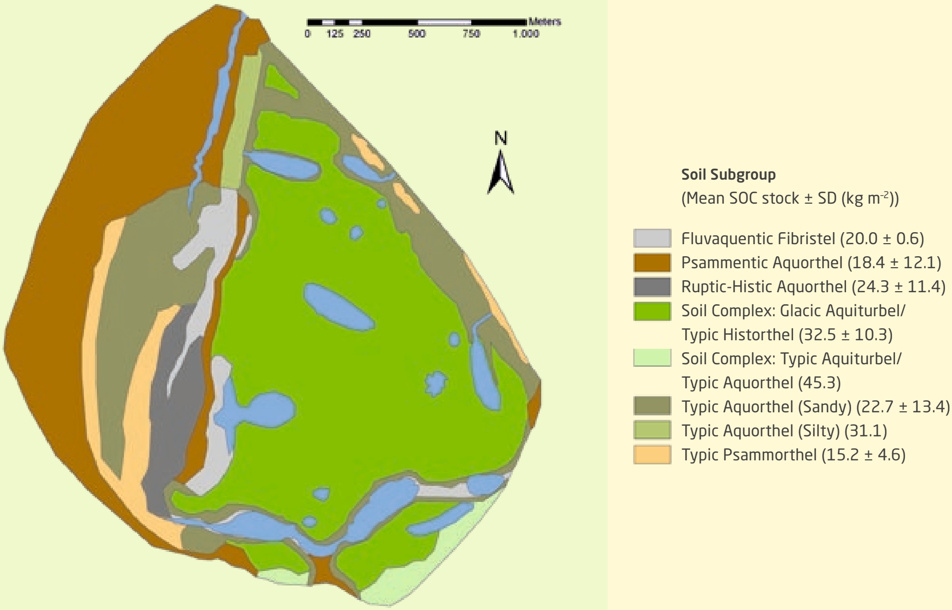
Figure 2: Metal pipe of the Samoylov borehole for access of the borehole instrumentation.



circumarctic network of currently 82 terrestrial field bases, including Samoylov. It does not focus on the compilation and distribution of specific datasets, but is multidisciplinary and aims at capacity building for research and monitoring in the European Arctic and beyond. It offers access to numerous research stations via its Transnational Access program. In addition to the aforementioned data availability from Samoylov, the possibility to use the research station as a scientific and logistical base for fieldwork in the Lena Delta and the Laptev Sea region has attracted other external researchers besides the Russian-German research teams to conduct fieldwork on and around Samoylov. The INTERACT Transnational Access program has supported access to Samolylov for such international research teams since 2013. INTERACT's joint fieldwork with the Russian-German LENA-Expedition members has been very fruitful and led to joint publications and continuing cooperation.

Anne Morgenstern, Mikhail N. Grigoriev, Dmitry Yu. Bolshiyanov, Julia Boike, Lars Kutzbach

Figure 3: Mean active layer thaw depth at the end of season measured at 150 points at the CALM grid (Boike et al. ESSD, in review).



Short Overview of the Russian-German Permafrost Projects CARBOPERM and KoPf

The terrestrial permafrost research cooperation between Russia and Germany was initiated about 25 years ago, during the Pushchino Conference in 1992. Here German experts for soil and polar regions met Russian cryogeologists – and were thrilled by the fantastic permafrost research expertise in Russia. Since then, a multidisciplinary and continuous exchange between Russia and Germany has been growing – pushed mainly by AWI Potsdam and its partners at several universities in Germany.

Figure 1: Mean carbon stocks in the diverse permafrost-affected soils (down to 1 m depth) of Samoylov Island as database for interdisciplinary work in permafrost (Zubrzycki et al. 2013).

It took nearly 20 years to enable the first permafrost project with Russian-German funding: CARBOPERM (BMBF/MON funding 2013-2016) was a joint research effort on the formation, turnover, and release of carbon in Siberian permafrost landscapes. It aimed to enhance the understanding of how permafrost-affected landscapes will respond to global warming, and how this response will influence the local, regional, and global trace gas balances.

Continuously low temperatures in the permafrost had prevented organic carbon decomposition, which had caused permafrost-affected soils to accumulate large pools of organic carbon (OC). According to recent estimates, these soils once contained 1670 Pg of OC or about 2.5-times the amount of carbon in the global vegetation. The carbon stocks of Samoylov Island are given as an example in Figure 1.

Rising Arctic temperatures resulted in increased permafrost thaw, which led to a mobilization of formerly frozen OC. The degradation of the newly available OC caused an increased formation of the greenhouse gases methane and carbon dioxide. The rising concentrations of trace gases in the atmosphere due to permafrost thaw thereby form positive feedback to climate warming. Permafrost scientists from Russia and Germany worked together at different key sites in the Siberian Arctic, such as the Bolshoy Lykahovsky Island at the Dmitry Laptev Strait, the Lena River Delta, and the Kolyma lowlands close to Cherskii.

CARBOPERM strengthened permafrost research in underrepresented areas of Siberia, which are hardly accessible to international researchers. The obtained results improved the understanding of the future development of the sensitive and economically relevant arctic permafrost regions.

The current permafrost project KoPf (BMBF funding 2017-2020), which is coordinated by the University of Hamburg, the Alfred Wegener Institute for Polar and Marine Research Potsdam, the Arctic and Antarctic Research Institute (AARI) in St. Petersburg, and the Permafrost Institute Yakutsk (PYI), is improving the process understanding of the effects of a changing climate on permafrost carbon with field observations, remote sensing, and numerical simulations.

The terrestrial permafrost research is once more conducted in a very close Russian-German cooperation, with a focus on Siberia. In KoPf, current Earth System Models are improved with regard to permafrost-related processes. These models are subsequently applied to different warming scenarios to investigate when the current Arctic carbon sink will turn into a future carbon source. Further objectives are the determination of the long-term degradability of permafrost organic carbon and its contribution to greenhouse gas fluxes based on biogeochemical and microbial process studies of organic carbon decomposability and carbon dioxide and methane production.

The project works across local, regional, and continental scales, and quantifies the contributions of land cover change, their ecosystems, and the changes in permafrost soil carbon characteristics in response to greenhouse gas dynamics. The obtained data is being used for further model validation. KoPf combines new methods of microbiology, biogeochemistry, ecology, micrometeorology, remote sensing, and numerical modelling to study changes over the period 1850-2100.

The resulting model-based projections for thawing permafrost and feedbacks to the climate system are essential for designing appropriate mitigation and adaptation strategies.

Furthermore, KoPf supports the education of young researchers in the field of permafrost and strengthens the bilateral network between Russia and Germany with collaborations between 14 German and 12 Russian institutions on current permafrost topics.

Both projects CARBOPERM and KoPf are the basis for the ongoing and future research projects at the Research Station Samoylov, which will continue to be in close collaboration of the Russian and German friends of the permafrost.

Eva-Maria Pfeiffer, Hans-Wolfgang Hubberten, Mikhail N. Grigoriev, Dmitry Yu. Bolshiyanov, Sebastian Zubrzycki, Ulrike Herzschuh, Guido Grosse

Application of Remote Sensing in the Laptev Sea Region

Active and passive satellite and airborne remote sensing provides tools to observe and quantify dynamics of terrestrial and marine environments for the remote regions of Northern Siberia. The diversity of techniques and observation targets results in a wide range of applications, increasingly in combination with field measurements or modelling. Remote sensing has been used as part of Russian-German collaborations in the Lena Delta region to characterize sea ice and ocean colour, land cover and its changes, the abundance of thermokarst and thermo-erosion, greenhouse gas fluxes, coastal erosion, permafrost thaw-subsidence, and changes in Arctic lakes and lake ice.

Sea ice, ocean surface, and coastline

Optical and radar satellite data show that the shallow Siberian Arctic shelves are an important source area of ice-rafted sediments and play an important role for uptake, redistribution, and dispersal of sediments, nutrients, and pollutants. Entrainment into sea ice takes place primarily by suspension-freezing in frazil ice in shallow waters. The Transpolar Drift moves particle-laden sea ice over the central basin towards the Fram Strait where it exits the Arctic Ocean and melts.

Russian-German research collaborations investigated the ice retreat in summer and its influence on the production, thickness, and dynamics of ice in the Laptev Sea. A combination of airborne surveys and optical, thermal, and radar imagery were used to quantify ice production and the impact on local hydrography in the Laptev Sea. Interannual variability and trends in fast ice and pack ice cover were also investigated in this way. Information about sea ice motion that was obtained from passive microwave satellites shows a significant increase in drift speed and sea ice area export. An increase in ice export has a thinning effect on the ice cover, a precondition for an early ice retreat during summer months. Moreover, ice dynamics in winter also accelerate the decay of fast ice. Understanding the sea ice dynamics in the Laptev Sea is therefore crucial to project the fate of Arctic sea ice.

During the few months in the summer season without sea ice, remote sensing allows observations of the changing hydrography and turbidity of the Laptev

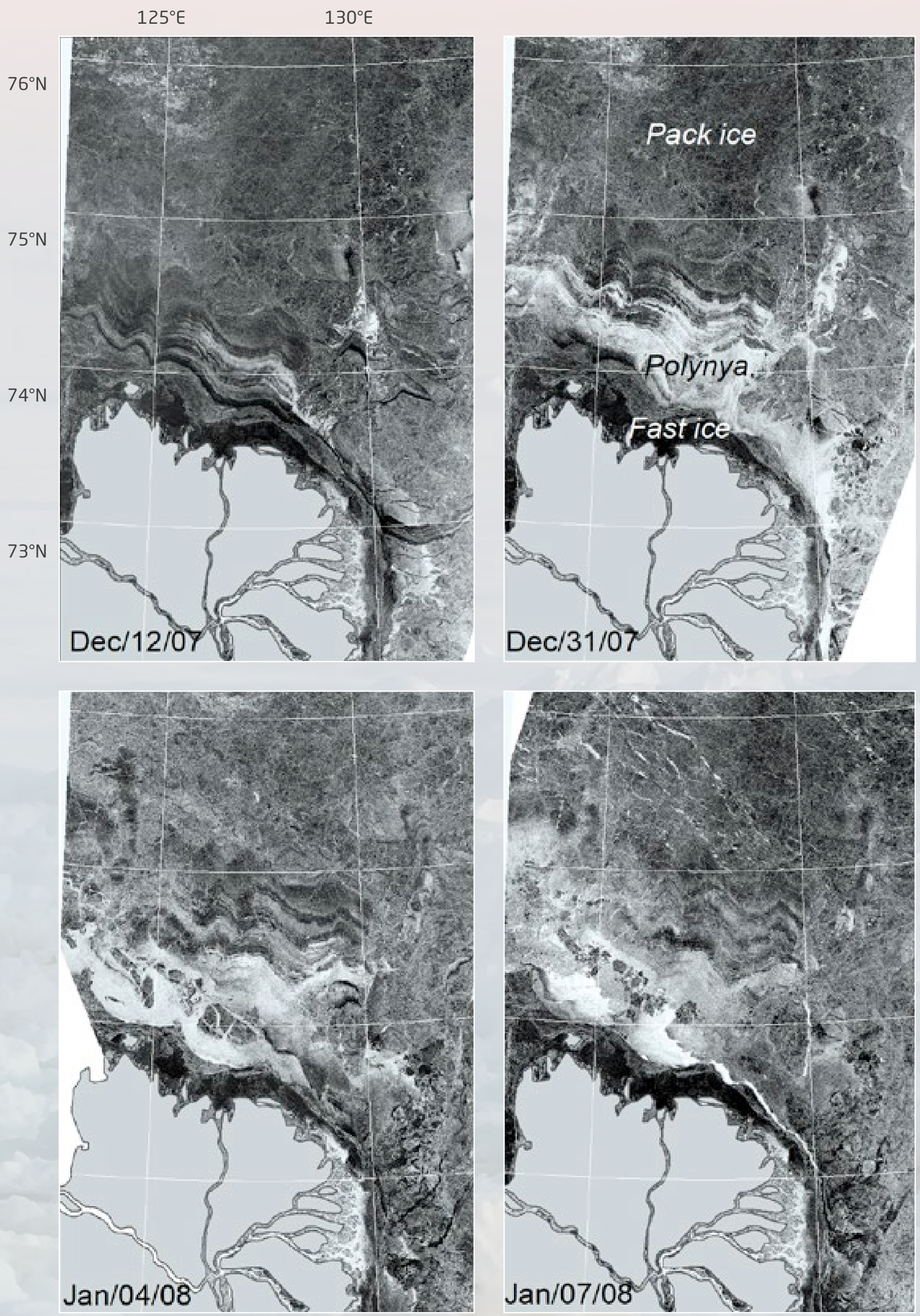


Figure 1: Sea ice dynamics observed with ENVISAT SAR for winter 2007/2008, north of the Lena Delta.
(Background photo: S. Hendricks)

Sea. Here, organic matter input from larger rivers and coastal erosion is the highest in the Arctic. The high organic carbon content in surface waters is the reason for a more than tenfold overestimation of satellite chlorophyll standard products. Current work on new algorithms adapted to Laptev Sea conditions enables the derivation of reasonable concentrations of chlorophyll and coloured dissolved organic matter absorption.

In the Laptev Sea region, flooding and the erosion of permafrost coasts transforms terrestrial landscapes into marine environments. Remote sensing using high-resolution satellite and historical aerial imagery provided accurate measurements of the retreat of permafrost coastlines.

Land surface state and changes

Various land cover classifications were produced for the Lena Delta region. Landsat data has been extensively used to map rapid permafrost thaw landforms, such as thermokarst lakes and basins, as well as thermo-erosional gullies. In many regions, such landforms characterize more than 50 % of the landscape. Modern (2002–2013) high-resolution imagery with a resolution of 5 m and better was used to create an inventory of small ponds throughout the Lena Delta. As a result, the total of the delta's known water surface area increased from 13% to 20%.

Ground-based field spectral surveys of land surfaces and vegetation using field spectrometers helped to differentiate vegetation types and enhanced the classification of multispectral satellite data. During the International Polar Year (2007-2008), new data from several satellite missions became available for the Lena Delta region. For Kurungnakh Island in the central Lena Delta, a detailed ALOS-PRISM digital elevation model allowed the mapping of the Yedoma relief that was affected by thermokarst as well as the identification of ice-rich permafrost areas that might be subjected to future thermokarst.

In parallel, land cover types were classified using multispectral ALOS-AVNIR data to characterize moisture regimes and vegetation coverage and composition. Highly automated data processing methods using all multispectral Landsat data from 1999-2014 now provide detailed insights into the dynamic nature of the Lena Delta, including riverbank erosion, sandbank migration, changes in vegetation, wetting and drying of land surfaces, and thermokarst lake changes.

An unmanned aerial vehicle survey conducted by the Novosibirsk Institute for Petroleum Geology and Geophysics in 2016 resulted in a very high-resolution optical image mosaic and digital elevation models for Samoylov Island and portions of Kurungnakh Island. Based on this data, detailed maps of vegetation communities and geomorphology now provide a better understanding of linkages between the geomorphology and the vegetation of the polygonal tundra.

An upscaling of the methane emissions from different land cover classes suggested that the Lena Delta emits about 0.03 Tg of methane per year. Helicopter-borne surveys of methane fluxes conducted in 2014 link broad-scale greenhouse gas patterns with detailed data from an eddy covariance tower on Samoylov Island.

In order to understand spatial and temporal variations of summer surface temperatures of the wet polygonal tundra better, satellite-derived land surface temperature data from MODIS were compared with measurements from a ground-based thermal imaging system at the Samoylov site. The results led to recommendations to enhance satellite-derived surface temperature algorithms for tundra landscapes. Satellite-derived land surface temperature data were also

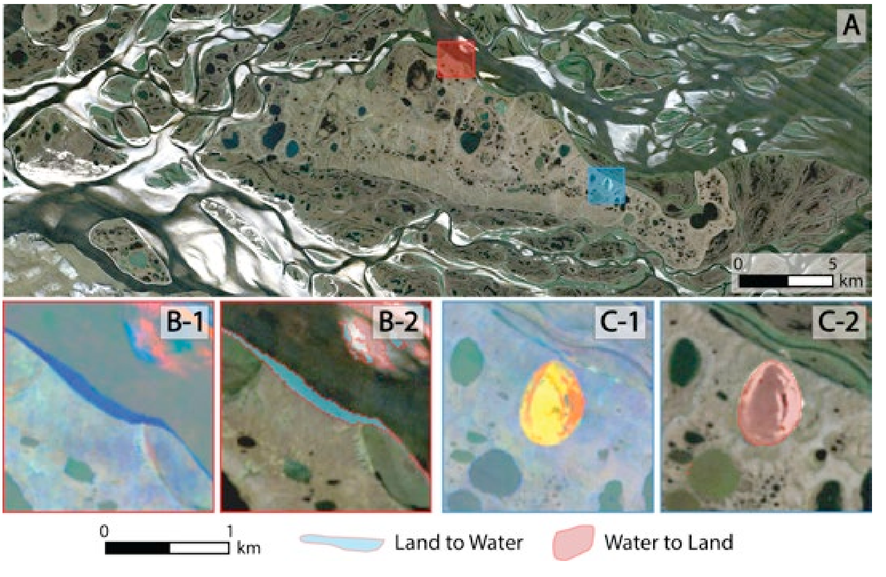
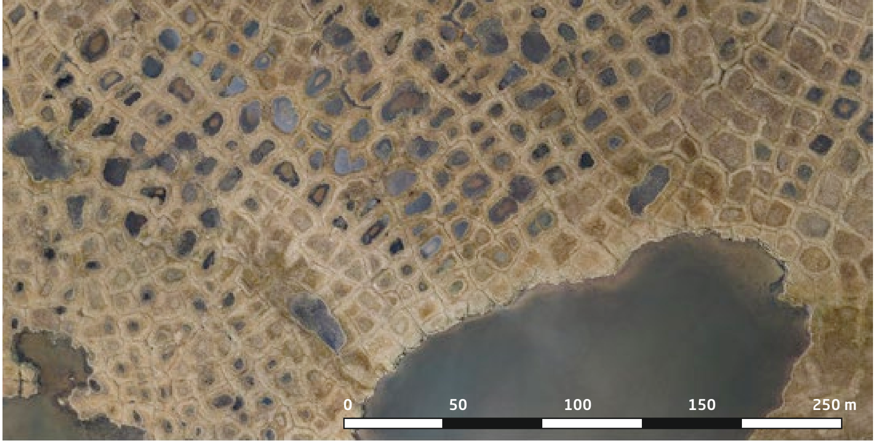


Figure 2: Landsat data (1999-2014) indicating strong shore erosion and lake drainage in the Lena Delta.



used in combination with snow water equivalent data to inform numerical models of permafrost temperature and active layer dynamics of the Lena River Delta.

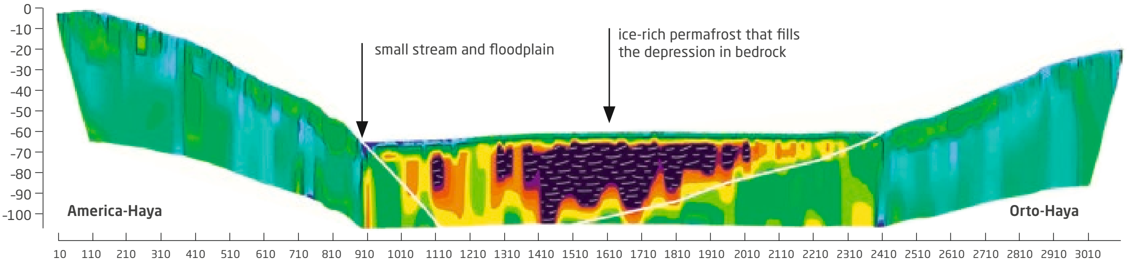
Cloud-penetrating active microwave remote sensing with Synthetic Aperture Radar (SAR) systems can overcome the observation limitations posed by frequent cloud cover in Arctic summers. In collaboration with the German Space Agency, an ongoing data collection of TerraSAR-X images of the Lena Delta region allowed the quantification of rapid shoreline erosion, the monitoring of lake ice regimes, and the assessment of retrogressive thaw slump dynamics with unprecedented accuracy. Differential SAR interferometry with TerraSAR-X and Sentinel-1 data was applied to quantify seasonal thaw-subsidence of Yedoma in the Lena Delta. Stereophotogrammetric observations of permafrost thaw-subsidence on Muostakh Island indicate a decrease in surface elevation by several meters between 1951 and 2013. Ground-based laser scanning has recently been used to study surface elevation changes. Repeated surveys indicate interesting interannual permafrost thaw-subsidence and frost heave dynamics.

Outlook

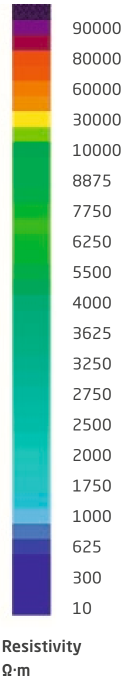
Remote sensing provides new and comprehensive insights into the state and dynamics of the Lena Delta and Laptev Sea region during recent decades. Remote sensing also plays an important role in planning field activities, scaling field measurements, parameterizing and evaluating models, and testing hypotheses about processes vulnerable to climate change. Ground truth data collected during field campaigns is a critical input for data analysis and interpretation for nearly all remote sensing studies, which highlights the importance of field access in these regions and the presence of a well-equipped research station in the Lena Delta as a logistical base.

Guido Grosse, Birgit Heim, Sofia Antonova, Julia Boike, Astrid Bracher, Alexey N. Fague, Frank Günther, Thomas Krumpen, Moritz Langer, Anne Morgenstern, Sina Muster, Ingmar Nitze, Torsten Sachs

Figure 3: High-resolution UAV image of ice wedge polygons on Samoylov Island.

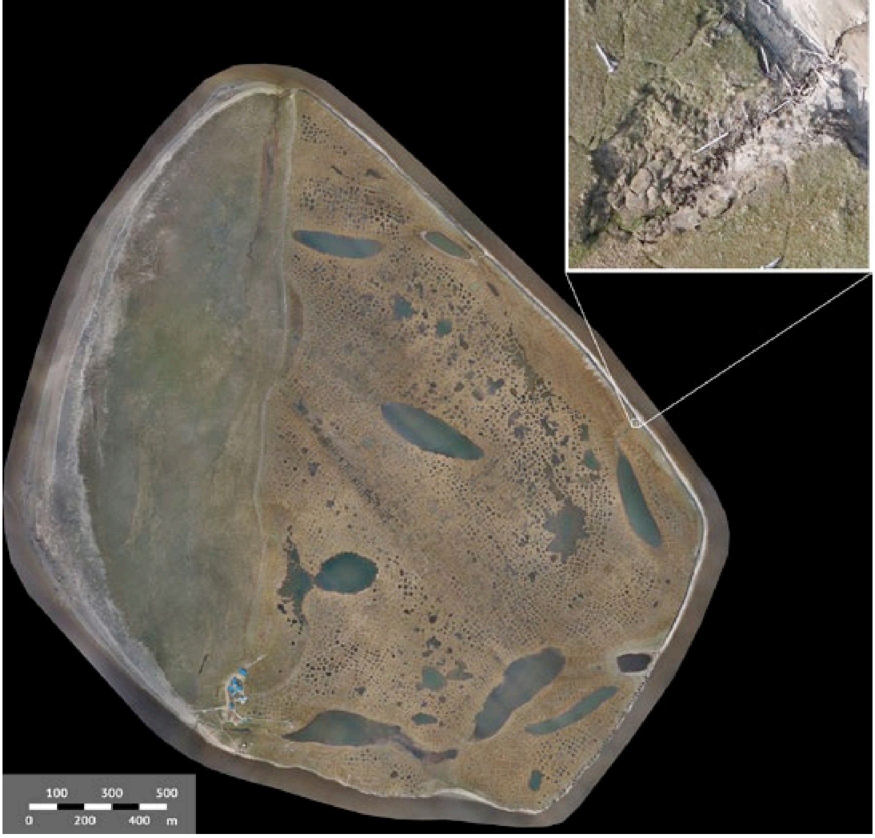


Multidisciplinary Studies on Samoylov and Kurungnakh: Geophysics, Remote Sensing, Geology, Botanical, and Soil Studies



In 2013, the new Samoylov station was placed under the supervision of the IPGG. Since 2014, the IPGG has been organizing an annual multidisciplinary expedition with scientists from various institutions of the Siberian Branch of the Russian Academy of Sciences. In 2014, this expedition consisted of only six people, five geophysicists and one geologist. The first expedition by the IPGG started with a good sign: As the helicopter landed on Samoylov Island and the group began to unload its cargo, one of the expedition members jumped out and ran to hug a girl, who was standing amidst the welcoming crowd. It turned out that they had known each other each other since university years here, in Novosibirsk. After graduation, she had moved to Germany to pursue a PhD at AWI. They had not seen each other for more than five years and were destined to meet again on a very remote piece of land, 2800 km from Novosibirsk and 5200 km from Potsdam. What were the chances? Since then, the expedition and our collaboration with international colleagues are regularly described as "a fortunate turn of events". IPGG worked hard to intensify its presence, and in 2017, the expedition grew to 16 people. Among them were scientists from the fields of geophysics, geology, paleomagnetics, geobotanics, and soil studies, as well as some students from Novosibirsk State University.

Figure 1: An electrical cross-section reconstructed from electrical resistivity tomography data acquired along the profile from mounts America-Haya to Orto-Haya maps bedrock (white line) overlaid by Quaternary sediments.

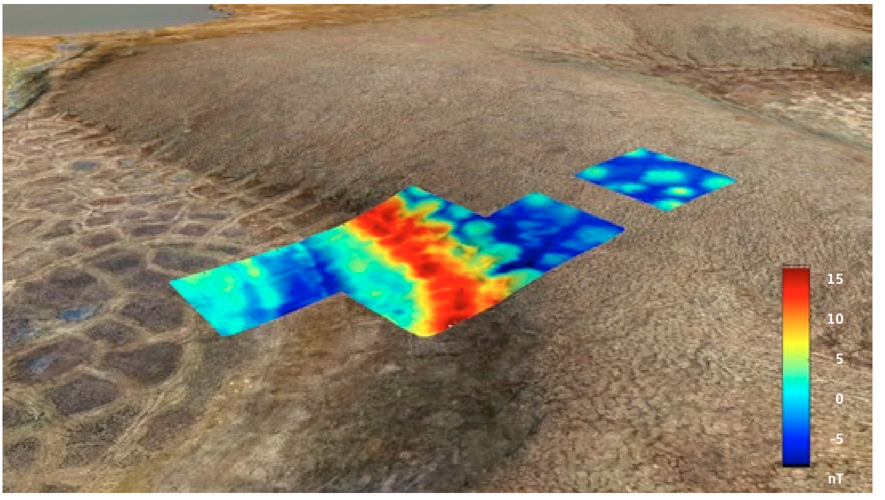


During the 4 years of its operation, this expedition managed to collect unique data on the permafrost structure via geophysical methods. We applied cutting-edge electrical methods (electrical resistivity tomography) and studied permafrost degradation under thermokarst lakes and residual taliks in alases. We probed permafrost table composed of thawing yedoma sediments under the Laptev Sea shelf.

We combined our data with data from our German colleagues and managed to create an electrical cross-section from the land surface to the marine deposits. This allowed us to trace permafrost degradation patterns in the "sea-to-land surface advancement" scenario. Another geophysical technique: A high precision magnetic survey helped us to map ice wedges that are covered by a layer of moss and soil.

In 2016, we successfully carried out a UAV-based study of Samoylov Island and the southern part of Kurungnakh Island. Results of the study are now presented by detailed orthophoto maps (0.05 m\pixel) and digital elevation models (0.25 m abs. height precision; 0.5 m horizontal grid step). These data open new possibilities for future studies in various fields of science.

Figure 2: An orthophotomap of Samoylov Island made from data acquired via UAV-based survey. A full resolution sample of the map can be seen in the upper right corner.



Botanical studies that we conducted in 2017 have already yielded fantastic results. Not only did we manage to create the most detailed botanical map of Samoylov Island, we also worked with geologists to develop a geobotanical classification of Samoylov and a region on Kurungnakh based on aerial imaging data. This new field "Geobotanics based on super-high resolution remote sensing data" promises new amazing discoveries in permafrost studies.
Geological data that we gathered in 2017 allow us to add new knowledge to the existing picture of Lena Delta Quaternary history. The paleomagnetic survey presents new facts about the ancient history of the delta and the continent in general.

We now plan to further expand the multidisciplinary approach: We aim to further integrate the different institutions of SB RAS in permafrost research. There is, however, another giant field that we are working on together: SB RAS, Alfred Wegener Institute, and other international scientific organizations have formed a multidisciplinary collaboration to conduct the next 20 years of Lena Expeditions with the Samoylov Research Station.

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Figure 3: Map of the anomalous magnetic field with a distinctly visible ice-wedges pattern. It is created from the high-precision magnetic survey data and visualized over the terrain model built from the UAV imaging results.

Deep Insights into the Past: Terrestrial Permafrost Drilling Campaigns

Permafrost thaw is associated with impacts on climate, land surface and coastal and river bank structures. Thermokarst and thermoerosion, for example, are thaw processes that lead to ground subsidence. Two main factors of surface subsidence vulnerability are the sedimentological composition, including ground ice content, and the temperature state of permafrost. This surface destabilization is getting relevant because of a potential positive feedback of deep thaw to the global climate system through the release of greenhouse gases trapped beneath or in the permafrost (see pages 68–70), as well as through the release of so far freeze-locked old carbon by microbial decomposition (see pages 117–119). With these facts in mind the overarching aims of our drilling campaigns were to retrieve deep (> 50m) frozen and unfrozen sediment cores including sediments, ice, and organic components. We analysed the cores for understanding the geology and cryostratigraphy of the Lena Delta and adjacent regions, the deep carbon characteristics and amounts, sediment thicknesses, permafrost conditions, as well as fluvial and deltaic environmental history of these regions (Figure 1). We used deep permafrost as a window into the past, which is needed to understand the conditions today, and to assess the changes in a warming future. Several scientific disciplines have been involved in the research based on these coring

Figure 1: Sites where we drilled deep into the permafrost and unfrozen deposits to get deep insights into the past. Included sites are Bols'hoy Lyakhovsky (Island (2014 N73.33, E141.32), Buor Khaya Peninsula (2012, N71.4203, E132.111), Bykovsky Peninsula (2017, N71.7452, E129.3022), Kurungnakh Island (2015, N72.2903, E126.1843), Mamontovy Klyk (2005, N73.60597, E117.17736), Samoylov Island (2005 and 2018, N72.3766, E126.4816), Sardakh Island (1998, 2009 N72.571544, E127.241499), and Turakh Island (2005, N72.9740, E123.7986). Map compiled by S. Laboor.

campaigns including geocryology, sedimentology, paleoecology, geophysics, and geochemistry. Deep drilling expeditions are mostly carried out during Arctic spring time, when the large and heavy drilling equipment can be easier transported over the frozen tundra and water bodies and when cores remain frozen while retrieved from the coring equipment. Field life and work under conditions of -20 °C, and a potential risk of snowstorms and polar bears, are challenging. However, good logistical preparation and longstanding experience for such work on both the Russian and German expedition organizers and leaders make such

Figure 2: Defying the harsh Arctic temperatures during a Russian-German spring drilling expedition in North Siberia: A small temporary settlement on sledges with a canteen, a generator sledge, two two-storey houses, and the drilling rig (from left to right).

expeditions possible. Within the very good logistical framework of the Lena expeditions, those field camps often resemble a small temporary settlement on sledges that may be able to relocate to new drilling adventures as needed based on scientific questions (Figure 2).

Another important piece of field logistics is of course the drilling device itself. The technical options within the Lena expedition framework are outstanding: Various types of drills are available to the joint expeditions to retrieve cores in different landscape settings, down to different depths, and in different ground materials. In most cases an URB2-4T drilling rig was used for permafrost (Figure 3), because it is suitable and well-tested for drilling deeper than 20 m into frozen sediments. Another often used system is the KMB drill for cores up to 20 m depth which is smaller but able to be transported with a helicopter like an MI-8 and an all-terrain vehicle (vezdekhod).

One of the deepest holes was drilled very recently on Samoylov Island in April 2018. In the future, this borehole will provide us with the unique opportunity for long-term deep permafrost temperature observations revealing the influence of Arctic warming to deep permafrost sediments, and will give us an idea for how long the permafrost-legacy of the last ice age will last.

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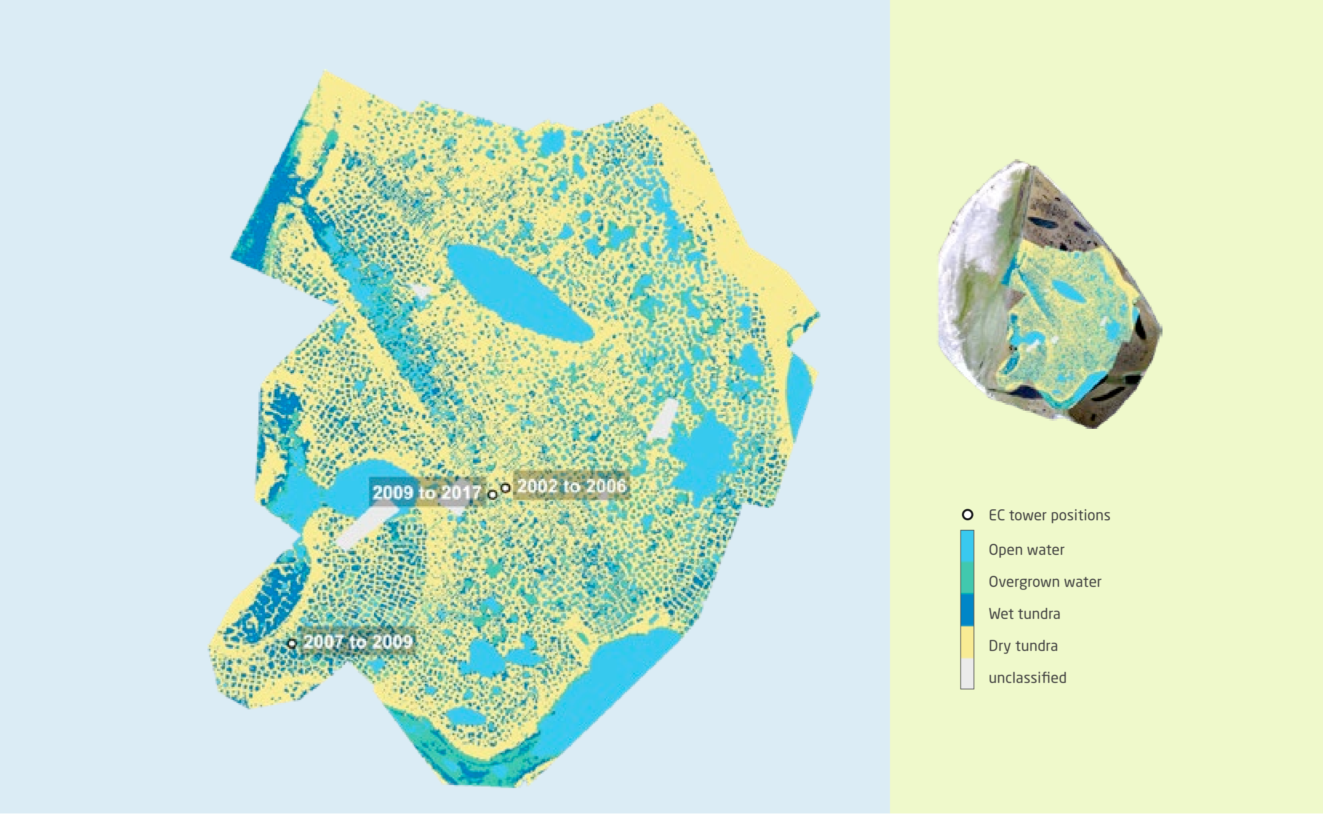
Figure 3: Drilling rig in action: Starting the URB2-4T drilling rig for deep drilling on Bykovsky Peninsula, April 2017. (Photo: J. Strauss)

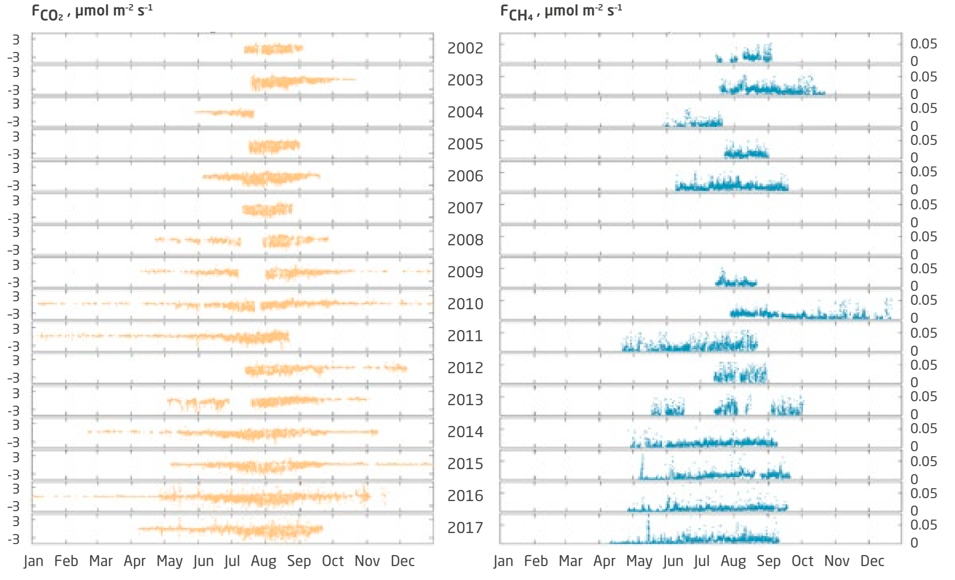


Long-Term Measurements of Land-Atmosphere Fluxes of Energy, Water, and Greenhouse Gases from 2002 until Today and Beyond

Fluxes of water vapour, carbon dioxide, and methane have been investigated with the eddy covariance (EC) technique since 2002. Changes in hydrological conditions, instrumentation, and available manpower, as well as changes in financial and logistical support, led to four different tower setups at three different locations on the island (see Figure 1). Frequent setup variations are, however, limited to the early years. The system has been installed at the same position in the centre of the island's river terrace since 2009. Although different tower structures have been used, the measurement height remained unchanged at 4.15 m.

The high resolution (20 Hz) gas concentration and 3D wind speed data recorded with the EC system yield, after processing, half-hourly gas flux time series that represent spatially integrated, landscape-scale exchange fluxes between the surface and the atmosphere. With respect to carbon dioxide and methane fluxes,

Figure 1: Surface class distribution and eddy covariance (EC) tower positions on the central river terrace of Samoylov Island.



these data can be used to estimate robust carbon (C) budgets, thereby enabling the quantification of the river terrace C-sink strength. These cumulative fluxes are especially valuable when they are available for multiple years because relationships to flux drivers and changing environmental conditions can be revealed. Efforts towards this goal are ongoing and two-fold. Fluxes can be modelled with in-situ measurements of ancillary soil and meteorological variables to gain process understanding, and with remote sensing data products to enable regional upscaling. Figure 2 gives an overview of the unique dataset of CO_2 and CH_4 fluxes measured by the EC system during 16 expeditions to the Lena River Delta from 2002 to 2017.

Close to the new 10 m research tower installed in 2016, a specially streamlined igloo-shaped field lab has been placed on a wooden platform in 2017 (Figure 3.). The igloo, tower, and boardwalk are financially supported by the infrastructure project ACROSS (Advanced Remote Sensing- Ground Truth Demo and Test Facilities). These facilities will enable the collection of ground-truth data covering environmental variables across different spatial and temporal scales and environmental compartments. The igloo can house high precision instruments under constant temperature conditions. The glass fibre construction was additionally

Figure 2: Greenhouse gas fluxes: CO_2 and CH_4 fluxes recorded from 2002 to 2017 by the eddy covariance flux station on Samoylov Island.

insulated from the inside, and the interior is climate-controlled through an additional heating/cooling system. The igloo is connected to the main power source of the Samoylov research station and will ensure continuous power all year round, even under extreme weather conditions.

The continuation of the long-term meteorological and land-atmosphere flux data series (fluxes of energy and H_2O, CO_2, and CH_4) is important for analyzing the intra- and inter-annual variability, as well as balancing the carbon, water, and heat fluxes between permafrost soils, vegetation, and the land surface. Data will be contributed to international databases, such as FLUXNET and PANGAEA. Similar to the long-term climate and soil observations (see pages 42–47), these data will be used to (i) quantify responses to drivers of ecosystem change, (ii) understand complex ecosystem processes that occur over prolonged periods, and (iii) parameterize and validate earth system and land cover models.

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Figure 3: The new climate-controlled observatory and 10 m tower on Samoylov (established in 2017). (Photo: P. Verzone)

Carbon Turnover of Thawing Permafrost in the Lena Delta

The ongoing climate warming has a strong impact on permafrost soils. The thawing of the surface layer deepens. Another consequence is the initiation of thermokarst, which is most intense in ice-rich permafrost such as the Ice-Complex deposits (Figure 1) that formed during the last glaciation.

Permafrost thaw causes the release of elevated amounts of carbon and the microbial decomposition of organic matter. It is still a matter of debate how fast the permafrost carbon is decomposed and produces the greenhouse gases CO_2 and CH_4, and how much of these gases are emitted to the atmosphere.

These important research questions were investigated during the Lena Delta expeditions from 2013 to 2017 as part of the Russian-German permafrost projects CARBOPERM (BMBF funding 2013-2016) and KoPf (BMBF funding 2017-2020). Together with their Russian project partners, scientists from the universities of

Figure 1: Pleistocene permafrost deposits of Kurungnakh Island in the Lena Delta. Left: Thermoerosion features at the thaw front of the Ice-Complex deposits (Picture taken July 2016). Right: Ice-Complex exposure with clearly visible ice wedges (light grey) surrounding the mineral permafrost material (dark brown). (Right photo: I. Preuss)

Hamburg and Cologne and the GFZ in Potsdam used the well-equipped laboratories on the Research Station Samoylov Island to determine CH_4 and CO_2 fluxes and the organic matter turnover (Figure 2), conducting both field and laboratory analysis.

The possibility for these measurements at the new RS Samoylov Island is unique for the Siberian Arctic, and the so far collected soil, plant, water, and gas samples contribute to answering the open research questions. Numerous international scientific publications based on Lena Delta research helped to better understand carbon turnover after thawing and the greenhouse gas emissions on long time scales (e.g. CO_2 and CH_4 until 2100).

The organic matter of permafrost soils is easily accessible for microorganisms and thus prone to rapid degradation. A comparison of organic carbon decomposition under oxic conditions, as found in well-drained upland soils, and anoxic conditions, typical in water-saturated soils, showed that much less organic matter from thawing permafrost of Kurungnakh and Samoylov might decompose in the absence of oxygen. Under anoxic conditions, however, the more potent greenhouse gas CH_4 is formed in an equal share with CO_2.

Because of the higher climate forcing of methane, more climate-relevant greenhouse gases are formed in anoxic, water-saturated soils. At the islands Samoylov and Kurungnakh analytical techniques are applied to sample CO_2 that was released from the permafrost directly in the field, for subsequent radiocarbon analyses in the laboratories at University Cologne.

This method allows the identification and quantification of the proportion of ancient carbon that is stored for millennia in the Pleistocene Yedoma deposits and now enters the active carbon cycle. The results show that up to 70% of the freeze-locked material may be released to the atmosphere upon thaw, and the decomposition can be stimulated by younger organic matter that is admixed during thaw and erosion.

Several scientific questions remain open, for example how permafrost thaw will affect CO_2 uptake by vegetation or how fast thawing organic matter might decompose under in situ conditions. These questions will be part of the future research at the Research Station Samoylov in close collaboration with Russian partners during the Russian-German permafrost project KoPf.

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Figure 2: Field and lab work in the Lena Delta. Page 182: Permafrost drilling on Kurungnakh. Page 183 upper foto: Greenhouse gas flux measurements from thawed permafrost in Kurungnackh. Bottom: Gas measuerements in the GC lab on he old Samoylov Station (Photo: C. Fiencke)

(Photo: P. Verzone)

6. Permafrost Cooperation in the Frame of Future Lena Expeditions

An Outlook

Future Polar Research Cooperation in the Lena Delta Region – An Outlook

Current Earth System Models developed to project future global environmental and climate change still have major weaknesses in the implementation of cryosphere dynamics and processes. Especially processes that characterize the vast permafrost regions of Earth from microbial to continental scales are poorly represented. They include permafrost formation and degradation, soil carbon cycle and vegetation dynamics, northern hydrology, and energy exchange between surface and atmosphere.

Permafrost regions are among the most vulnerable landscapes on the globe and are already affected by rapid warming and thawing, which results in subsidence, erosion, and changes in biogeochemical cycling, vegetation composition, and hydrological systems. Loss of permafrost will affect greenhouse gas concentration in the atmosphere. In addition, with enhanced accessibility, the Arctic permafrost regions will experience increased attention by economic and social development projects.

Over the last decades, the Lena Delta in North Siberia has been a key study region for Russian and international Cryospheric and Arctic ecosystem research. With longer time series of many parameters now available from intense field research and remote sensing, it is primed to be one of the most valuable research sites to understand long-term developments of the state of the high Arctic in a warming climate. Also, the Lena Delta is a particularly vulnerable fluvial ecosystem at the interface between land, ocean, and atmosphere that will be affected by coastal erosion, sea ice loss, permafrost thaw, sea level rise, changing river runoff, increasing water temperatures, and changes in biota.

The scientific push – also driven by concrete environmental policy needs – for a better understanding of the environmental processes and dynamics of a rapidly evolving Arctic resulted in many concerted international activities around the Arctic and will further increase. The Lena Delta, with its research stations such as on Samoylov Island, can remain a prime area for scientific discovery in the Siberian Arctic as well as an area to help constrain the large uncertainties associated with projecting the future state of the Arctic.

It is thus important to continue and nurture existing international Polar research programs in this region, which will also benefit the development of the Siberian North. The design and implementation of the new Polar Research Station Samoylov Island in 2013 was a major step in this direction. Operated under Russian authority, the new station has been a new home to the continuing Russian-German "Lena Expeditions", as well as to international Polar research under the INTERACT Framework of Arctic Research Stations, for several years now. The new station provides excellent infrastructure for cutting-edge research in a remote high Arctic permafrost region and will need to facilitate continued access for international researchers as is common for all Arctic and Antarctic Stations around the poles.

Continued scientific knowledge gaps that can be addressed in the Lena Delta region include the quantification of processes related to permafrost dynamics,

Figure 1: The Lena Delta research region is located in the heart of the Arctic permafrost domain.

both thaw and formation, and their impacts on soil carbon pools. Estimates of consequences of permafrost thaw on global climate still have substantial uncertainties, while recent studies point out their importance on a global level under different climate scenarios. To close these gaps, it is important to continue biogeochemical field and laboratory studies, atmospheric and meteorological studies, remote sensing analyses of landscape and coastal change caused by permafrost thaw, geophysical observations, and modelling of permafrost and carbon across spatial and temporal scales. Russian-German research in the Lena Delta and at the Research Station Samoylov already made important contributions towards this research on an internationally visible level.

The Russian-German research activities in the Lena Delta and its surroundings uniquely contributed to the reconstruction of climate and environmental history of permafrost-affected landscapes in North Siberia from the last 200.000 years. A complete survey of soils and sediments in both frozen and unfrozen parts of the subsurface, such as under lakes and rivers, and their role for the production of greenhouse gases is still pending.

By focusing on latitudinal transects from the boreal forest into the arctic tundra, ecosystem studies can address knowledge gaps about the rapid change of high latitude ecosystems over time and space. Biogeochemical studies of nitrogen and phosphorus cycles in permafrost regions will improve our understanding of the limitations of biota in cold-climate soils, how this may change in the warming Arctic, and how the Siberian region may contribute to global cycles that can affect faraway regions outside the Arctic.

The integration of results from different scientific disciplines will be the key for future research activities in the region. It will require even closer cooperation between partners from various institutions and their expertise in permafrost research, hydrology, climatology, botany, biology, microbiology, biogeochemistry, Quaternary geology, palaeontology, geophysics, remote sensing, and numerical modelling. Continued cutting-edge polar research in the remote North will also require the continuation of substantial amounts of technological development and logistical expertise.

Environmental observatories on Samoylov Island have been part of international networks for many years now, including the Global Terrestrial Network for Permafrost (GTN-P) or the global FluxNet Network of micrometeorological observations. The existing observatories on Samoylov Island deliver reliable data on permafrost temperatures, seasonal and annual natural carbon dioxide and methane fluxes, as well as energy balance of heterogeneous tundra landscapes. This research site has therefore been a very critical building block for international observation networks in the otherwise sparsely covered north of Siberia – the largest permafrost domain on Earth. The data generated at this observatory forms an important puzzle piece in global efforts to project the future state of the climate in Earth System Models.

The Russian-German permafrost research within the Lena Expeditions on Samoylov Island, in the Lena Delta, and in the surrounding regions over the last 20 years, is an excellent and highly visible example of international cooperation to foster a better understanding of our climate and environment. The generous support of this research over such a long time, by many individuals, institutions, and organizations up to the highest level, allowed the creation of a unique research oasis in the Arctic that has scientific work, discovery, and collaboration as its most valuable goals and should be extended into the future.

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The new climate-controlled observatory and 10 m tower on Samoylov (established in 2017). (Photo: P. Schreiber)

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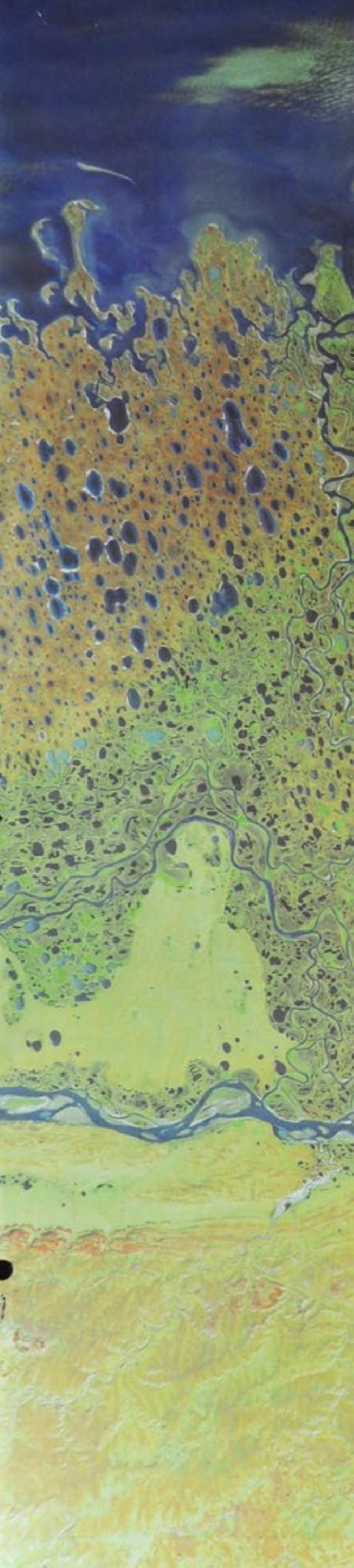

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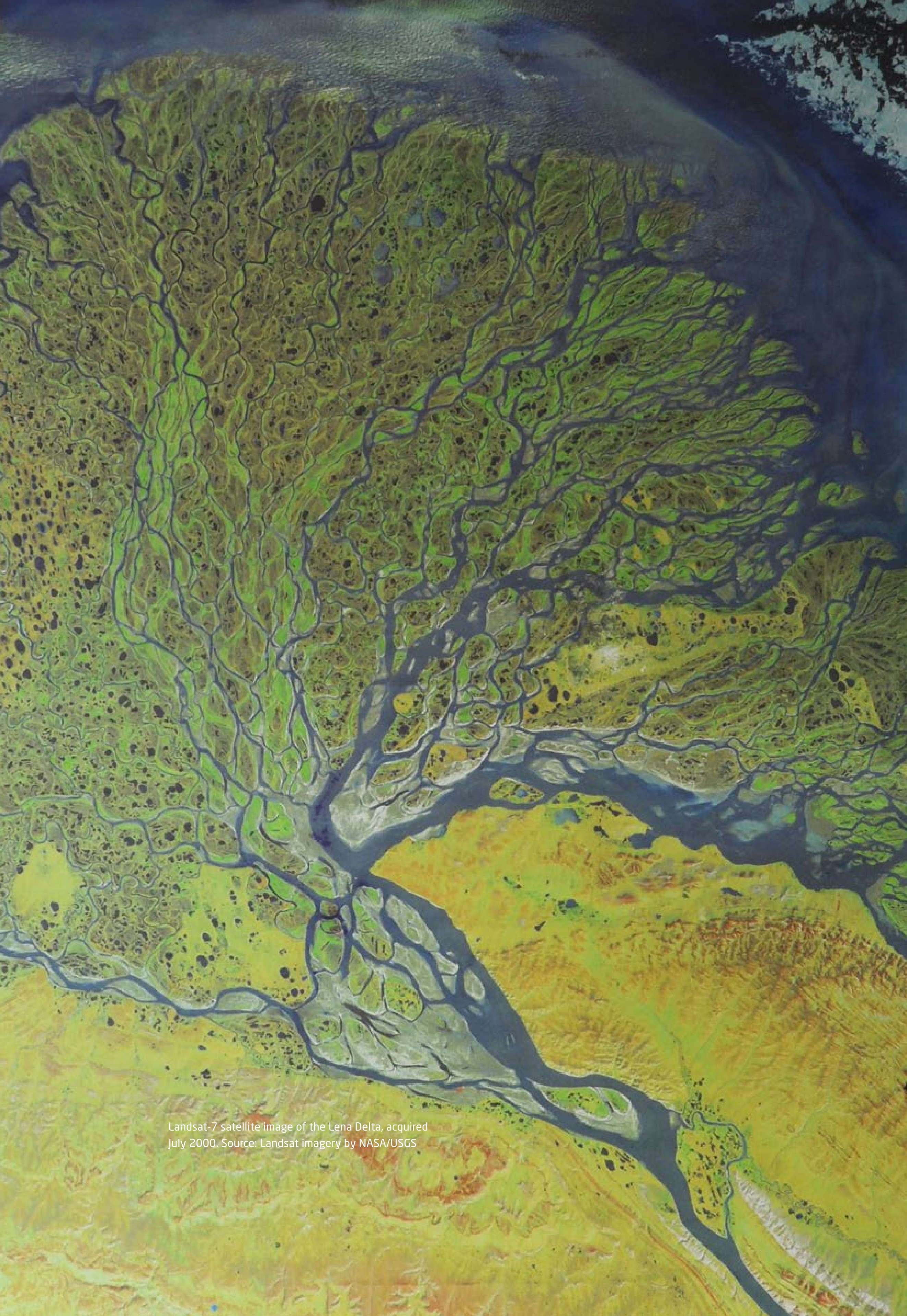
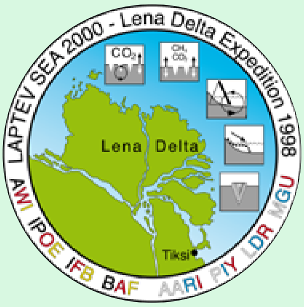


Landsat-7 satellite image of the Lena Delta, acquired July 2000. Source: Landsat imagery by NASA/USGS



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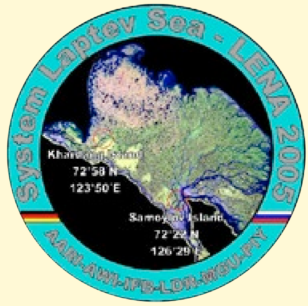

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