ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

750
2021

Berichte
zur Polar- und Meeresforschung
Reports on Polar and Marine Research

Focus Siberian Permafrost – Terrestrial Cryosphere and Climate Change

International Online Symposium
Institute of Soil Science, Universität Hamburg
24 – 25 March 2021

Edited by

E.M. Pfeiffer, O. Vybornova, L. Kutzbach, I. Fedorova,
C. Knoblauch, L. Tsibizov & C. Beer

HELMHOLTZ

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Am Handelshafen 12
27570 Bremerhaven
Germany

www.awi.de
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The Reports on Polar and Marine Research contain presentations and results of research activities in polar regions and in the seas either carried out by the AWI or with its support.

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Titel: Der Yedoma-Eiskomplex, Nordkap der Insel Muostakh in der Buor-Khaya-Bucht, Laptewsee (Foto: Mikhail N. Grigoriev)

Cover: Yedoma Ice-Complex, northern cape of Muostakh Island in Buor-Khaya Gulf, Laptev Sea (Photo: Mikhail N. Grigoriev)

International Online Symposium

Focus Siberian Permafrost – Terrestrial Cryosphere and Climate Change

Institute of Soil Science – Universität Hamburg
March 24 – 25, 2021
Hamburg, Germany

Editorial board
Pfeiffer EM, Vybornova O, Kutzbach L, Fedorova I, Knoblauch C, Tsibizov L & Beer C

Please cite or link this publication using the identifiers

http://hdl.handle.net/10013/epic.cb5f4f81-0195-4df0-b1bf-2315dda14177 and https://doi.org/10.48433/BzPM_0750_2021

ISSN 1866-3192

Focus Siberian Permafrost – Terrestrial

Cryosphere and Climate Change

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Institute of Soil Science, Universität Hamburg

24 – 25 March 2021

Edited by

E.M. Pfeiffer, O. Vybornova, L. Kutzbach, I. Fedorova,

C. Knoblauch, L. Tsibizov & C. Beer

Welcome to International Online Symposium

Focus Siberian Permafrost - Terrestrial Cryosphere and Climate Change

March 24 to 25, 2021

The largest global permafrost areas are located in Siberia. These areas store vast amounts of organic carbon, which is mostly locked up in the frozen ground. As a consequence of the observed accelerated arctic warming, permafrost soils and sediments start to thaw, and microorganisms decompose the sequestered organic matter to carbon dioxide and methane. The rising release of these greenhouse gases may further amplify global warming. The aim of this international symposium is to improve the knowledge of important processes in cold regions – with focus on the Siberian permafrost landscapes, which are still poorly investigated. The symposium will bring together modelling and observing permafrost scientists and contribute to our understanding of the consequences of climatic and environmental changes in the high Arctic.

The symposium was primarily planned for spring 2020, but the Pandemic situation changed our whole life, and so also our scientific permafrost exchange had to be shifted to 2021 and realized as an online meeting. We are happy about the support by the Center of Earth System Science and Sustainability (CEN) and the cluster of excellence Climate, Climatic Change, and Society (CliCCS), both at the Universität Hamburg. Furthermore, the German Society of Polar Research (DGP), the German Research Foundation (DFG) and the Ministry of Education and Research (BMBF) foster our permafrost research.

The proceedings at hand comprise all actualized abstracts which have been submitted to the online symposium, and cover a broad variety of research from microbial processes to soil-vegetation-interaction in different permafrost-affected landscapes to the complex impact of climate change in Siberia. The BMBF funded German-Russian-project “Carbon in Permafrost” (KoPf) is included in this symposium and will provide a major contribution to answer open questions of permafrost research. “Focus Siberian Permafrost” will discuss broader topics like carbon transformation and greenhouse gas release, aggregation and degradation of permafrost landscapes, past cold ecosystem dynamics, recent biogeochemical dynamics in frozen ground and future changes on permafrost ecosystems.

Enjoy reading the abstracts of the oral and poster presentations and relish the exchange with all participating scientist and permafrost-interested people. We are sure that the symposium “Focus Siberian Permafrost” will support a better understanding of the carbon dynamics in the Siberian permafrost region, thereby improving our knowledge on the global carbon cycle as well as current and future greenhouse gas fluxes from changing permafrost landscapes in Russia. We are looking forward to the panel discussion “Importance of permafrost ecosystems for future climate” and wish you all an inspiring dialogue on Siberian permafrost research.

Eva-Maria Pfeiffer & all colleagues of the KoPf steering committee

Hamburg, March 2021

International Online Symposium „Focus Siberian Permafrost“, 24 – 25 March, 2021

	Wednesday, 24th March	Thursday, 25th March
08:30 – 09:00	**Waiting room**	**Waiting room**
08:45 – 09:00		
09:00 – 09:15	Official Opening Pfeiffer, Graener, Overbeck, Fretzdorff	**Panel discussion** ***‚Importance of permafrost Ecosystems for future climate‘***
09:15 – 09:30		
09:30 – 09:45	Beer	
09:45 – 10:00	Abakumov	
10:00 – 10:15	Kutzbach	Yurkevich
10:15 – 10:30	Bolshianov	Zdorovennova
10:30 – 10:45	Liebner	Tsibizova
10:45 – 11:00	Zimov	Kaverin
11:00 – 11:15	**Break**	**Break**
11:15 – 11:30		
11:30 – 11:45	Shibistova	Juhls
11:45 – 12:00	Laschinskiy	Tsibisov
12:00 – 12:15	Shevtsova	Zdorovennov
12:15 – 12:30	Brovkin	Faguet
12:30 – 12:45	Stepanenko	Kut
12:45 – 13:00	Grosse	Veremeeva
13:00 – 13:15	Sabrekov	Runge
13:15 – 13:30	**Lunch**	**Lunch**
13:30 – 13:45		
13:45 – 14:00		
14:00 – 14:15	Fedorova	Zaplavnova
14:15 – 14:30	Evgrafova	Dietze
14:30 – 14:45	Prokushkin	Rivkina
14:45 – 15:00	Poliakov	Eliseev
15:00 – 15:15	Porada	Georgievski
15:15 – 15:30	Habeck	Pravkin
15:30 – 15:45	Fiencke	**Break**
15:45 – 16:00	van Delden	
16:00 – 16:15	**Break**	Jongejans
16:15 – 16:30		Lehmann
16:30 – 16:45	Mangelsdorf	Vybornova
16:45 – 17:00	Jongejans	Morgenstern
17:00 – 17:15	de Vrese	**Poster Session**
17:15 – 17:30	Heim	
17:30 – 17:45	Buchwal	
17:45 – 18:00	Heslop	
18:00 – 18:15	Knoblauch	**Public talk – Permafrost for everyone Martin Heimann, Jena**
18:15 – 18:30	Walz	
18:30 – 18:45	Strauss	
18:45 – 19:00	Ramm	Closing session Beer

Sessions
Process dynamics in heterogeneous permafrost landscapes under climate change
Permafrost changes under environment and climate pressure
Biogeochemical dynamics in permafrost landscapes
Past and recent permafrost ecosystem dynamics
Transfer of permafrost knowledge for science community and society
Poster session

Program of the International Symposium

"Focus Siberian Permafrost – Terrestrial Cryosphere and Climate Change"

24 – 25 March 2021

organized by Institute of Soil Science, Universität Hamburg

Online Conference

Join us via link:

https://uni-hamburg.zoom.us/j/96918527793?pwd=VklJL2VZWUNhWUhPQzNlNlZLTmk2dz09

or via Zoom Client

Meeting-ID: 969 1852 7793

Passcode: 82788852

Day 1: Wednesday, 24 March 2021

(all timeslots are given in Germany local time)

08:30 – 09:00	Check-in the meeting (Waiting room)
09:00 – 09:30	**Official opening of the Symposium** *Welcome greetings and Introduction by* *Prof. Dr. Eva-Maria Pfeiffer / Prof. Dr. Christian Beer (UHH)* *Prof. Dr. Heinrich Graener (MIN UHH)* *Dr. Norbert Overbeck (BMBF)* *Dr. Susanne Fretzdorff (PTJ)*
09:30 – 11:00	**Session I: "Process dynamics in heterogeneous permafrost landscapes under climate change"** *Session chair: Christian Beer, Dmitry Bolshiyanov*
09:30 – 09:45	*Christian Beer, N. Zimov, J. Olofsson, P. Porada, S. Zimov* Protection of permafrost soils from thawing by increasing herbivore density

09:45 – 10:00	*Evgeny Abakumov, V. Polyakov, E. Morgun* Pedodiversity and soil taxonomy of abandoned agricultural ecosystems of central Yamal
10:00 – 10:15	*Lars Kutzbach, N. Rößger, T. Sachs, C. Wille, J. Boike, I. Fedorova, M.N. Grigoriev, E.-M. Pfeiffer* Methane flux dynamics across temporal scales at polygonal tundra of the Siberian Lena River Delta
10:15 – 10:30	*Dmitry Bolshiyanov, J. Boike, S. Pravkin* Permafrost rate of the Siberian Arctic
10:30 – 10:45	*Susanne Liebner, S. Yang, J. Kallmeyer, C. Knoblauch, J. Strauss, M. Jenrich, M. Angelopoulos, P.P. Overduin, E. Damm, I. Bussmann, M.N. Grigoriev, E. Rivkina, B.K. Biskaborn, D. Wagner, G. Grosse* Microbial controls on the fate of methane along a thermokarst lake to lagoon transition
10:45 – 11:00	*Sergey Zimov, O. Anisimov* Methane emission in the Russian permafrost zone
11:00 – 11:30	**Break** (private discussions in Break-out rooms)
11:30 – 13:15	**Session II: "Permafrost changes under environment and climate pressure"** *Session chair: Zoé Rehder, Victor Stepanenko*
11:30 – 11:45	*Olga Shibistova, J. Boy, G. Guggenberger, D. Boy, M. Aguirre Morales, R. Godoy* Biota as driver of mineral weathering and soil formation in maritime Antarctica
11:45 – 12:00	*Nikolay Laschinskiy, E. Talovskaya* Combination of ice and wind erosion in Lena Delta landscape desertification (Eastern Siberia)
12:00 – 12:15	*Iiulia Shevtsova, U. Herzschuh, B. Heim, L.A. Pestryakova, S. Kruse* Recent dynamics of total above-ground biomass (AGB) and future tree AGB in central Chukotka
12:15 – 12:30	*Victor Brovkin* Permafrost carbon in Earth System Models: Progress and challenges
12:30 – 12:45	*Victor Stepanenko, A.I. Medvedev, V.Y. Bogomolov, A.V. Debolskiy, E.D. Drozdov, E.A. Marchuk, V.N. Lykosov* Representing cold-climate hydrological processes in the INM RAS-MSU land surface model
12:45 – 13:00	*Guido Grosse, I. Nitze, A. Runge, M. Fuchs, T. Henning, S. Barth, B. Heim, F. Günther, J. Boike, M. Grigoriev* Remote sensing of permafrost landscape change in the Lena Delta Region using multispectral timeseries and spatially very high resolution change detection

13:00 – 13:15	*Aleksandr Sabrekov, I. Terentieva, I. Filippov, M. Glagolev, Y. Litti* Origin of methane seeping in West Siberian middle taiga river floodplains
13:15 – 14:00	**Lunch** (private discussions in Break-out rooms)
14:00 – 16:00	**<u>Session III: "Biogeochemical dynamics in permafrost landscapes"</u>** *Session chair: Claudia Fiencke, Vyacheslav Poliakov*
14:00 – 14:15	*Irina Fedorova, E. Shestakova, A. Pashovkina, A. Chetverova, G. Nigamatzyanova, R. Zdorovennov, G. Zdorovennova, N. Alekseeva, V. Dimitriev* Recent biogeochemical dynamics in Arctic lakes ecosystems
14:15 – 14:30	*Svetlana Evgrafova, V. Kadutskii, V. Polyakov, E. Abakumov, O. Novikov, G. Guggenberger, D. Wagner* Field-based incubation experiment in tundra: Buried soil organic matter decomposition
14:30 – 14:45	*Anatoly Prokushkin, A. Steinhof* Tracing the permafrost carbon release using radiocarbon dating of dissolved and particulate organic carbon in the Yenisei River and its major tributaries
14:45 – 15:00	*Vyacheslav Poliakov, E. Abakumov* Stabilization of organic matter from the Ice Complex, Lena River Delta, Russia
15:00 – 15:15	*Philipp Porada, C. Beer* Impact of mosses and lichens on future carbon emissions from permafrost soils
15:15 – 15:30	*Joachim O. Habeck, M. Ulrich* Animal husbandry in permafrost regions of Siberia and northern Mongolia: How permafrost has shaped the ecological conditions for pastoral forms of land use, and how the latter interact with permafrost dynamics
15:30 – 15:45	*Claudia Fiencke, T. Sanders, N. Zell, E.-M. Pfeiffer* Microbial transformation and availability of dissolved nitrogen in the active layer of cryosols
15:45 – 16:00	*Lona van Delden, M. Marushchak, C. Voigt, G. Grosse, A. Faguet, N. Lashchinskiy, J. Kerttula, C. Biasi* Towards the first circumarctic N_2O budget – Extrapolating to the landscape scale
16:00 – 16:30	**Break** (private discussions in Break-out rooms)

16:30 – 19:00	**Session III: "Biogeochemical dynamics in permafrost landscapes"**
	Session chair: Christian Knoblauch, Loeka Jongejans
16:30 – 16:45	*Kai Mangelsdorf, J.G. Stapel, L. Schirrmeister, J. Walz, C. Knoblauch* Assessment of the Substrate Potential of Terrestrial Permafrost Deposits from NE Siberia for microbial Greenhouse Gas Production
16:45 – 17:00	*Loeka Jongejans, S. Liebner, C. Knoblauch, G. Grosse, J. Strauss* CO_2 and CH_4 production in in-situ thawed Yedoma sediments in the Yukechi alas, Yakutia
17:00 – 17:15	*Philipp de Vrese, V. Brovkin* The high latitudes' response to temperature overshoot scenarios
17:15 – 17:30	*Birgit Heim, S. Lisovski, I. Shevtsova, S. Kruse, N. Bornemann, M. Langer, J. Boike, A. Morgenstern, U. Herzschuh, S. Evgrafova, E. Abramova, C. Rixen* ‚Seeing' vegetation green-up after snowmelt using MODIS satellite time series in the Lena Delta, Siberia
17:30 – 17:45	*Agata Buchwal, G. Rachlewicz, B. Heim* Dendrochronological records from tundra shrubs in the vicinity of Samoylov island
17:45 – 18:00	*Joanne K. Heslop, S. Liebner, K.M. Walter Anthony, M. Winkel, R.G.M. Spencer, D.C. Podgorski, P. Zito, R. Neumann* MicroModel: Microscale controls on greenhouse gas production from thawing permafrost
18:00 – 18:15	*Christian Knoblauch, C. Beer, A. Schütt, L. Sauerland, S. Liebner, E. Abakumov, J. Rethemeyer, E.-M. Pfeiffer* Carbon dioxide and methane release following abrupt thaw of Pleistocene permafrost deposits in arctic Siberia
18:15 – 18:30	*Josefine Walz, F. Gehrmann, E.A.S. Andersen, E. Dorrepaal* Year-round CO_2 flux partitioning from snow-covered Arctic heath ecosystems
18:30 – 18:45	*Jens Strauss, P.J. Mann, M. Bedington, M. Fuchs, G. Grosse, C. Haugk, G. Mollenhauer, B. Juhls, O. Ogneva, P. Overduin, J. Palmtag, L. Polimene, R. Torres* Assessing the dynamic interface between land and ocean in the Arctic: results from the joint BMBF-NERC project Changing Arctic organic Carbon cycle in the cOastal Ocean Near-shore (CACOON)
18:45 – 19:00	*Elisabeth Ramm, C. Liu, X. Wang, H. Yue, W. Zhang, Y. Pan, B. Hu, M. Schloter, S. Gschwendtner, C.W. Mueller, H. Rennenberg, M. Dannenmann* Current research on Eurasian permafrost in northeast China: The DFG-NSFC NIFROCLIM project
19:00 –	**Check-out the meeting (End of Day 1)**

Day 2: Thursday, 25 March 2021

(all timeslots are given in Germany local time)

08:30 – 09:00	Check-in the meeting (Waiting room)
09:00 – 10:00	**Panel discussion ‚Importance of permafrost ecosystems for future climate‘** *Session chair: Lars Kutzbach, Mikhail Grigoriev* Contributions by all participants are welcome
10:00 – 11:00	**Session III: “Biogeochemical dynamics in permafrost landscapes”** *Session chair: Bennett Juhls, Dmitry Kaverin*
10:00 – 10:15	*Nataliya Yurkevich, A. Karotziia* Water ecosystems of the Siberian tundra: Geochemical and geomorphological features (Samoylov and Kurungnakh islands, Lena Delta)
10:15 – 10:30	*Galina Zdorovennova, I. Fedorova, A. Shadrina, T. Efremova, R. Zdorovennov, N. Palshin* Dissolved oxygen in ice-covered lakes
10:30 – 10:45	*Ekaterina Tsibizova, N. Yurkevich, T. Fedorova* Chemical composition of water and bottom sediments in thermokarst lakes on Kurungnakh island, Lena Delta
10:45 – 11:00	*Dmitry Kaverin, A.V. Pastukhov, M. Marushchak, C. Biasi* Impact of microclimatic and landscape changes on the temperature regime and thaw depth under a field experiment in the Bolshezemelskaya tundra
11:00 – 11:30	**Break** (private discussions in Break-out rooms)
11:30 – 13:15	**Session II: “Permafrost changes under environment and climate pressure”** *Session chair: Alexandra Runge, Alexey Faguet*
11:30 – 11:45	*Bennett Juhls, C.A. Stedmon, A. Morgenstern, H. Meyer, B. Heim, J. Hölemann, V. Povazhniy, Paul P. Overduin* Seasonality in Lena River biogeochemistry and dissolved organic matter

11:45 – 12:00	*Leonid Tsibizov, V. Olenchenko, V. Potapov, A. Faguet, K. Bazhin, D. Auynov, E. Esin* Geophysical studies of permafrost on Samoylov and Kurungnakh islands, Lena Delta
12:00 – 12:15	*Roman Zdorovennov, G. Zdorovennova, A. Guzeva, S. Evgrafova, S. Golosov, I. Zverev, I. Fedorova* Thermal regime and hydrodynamics of Arctic lakes and rivers
12:15 – 12:30	*Alexey Faguet, A. Kartoziia, N. Lashchinskiy* Permafrost evolution in Lena Delta as seen on 2016-2019 drone survey data. An overview.
12:30 – 12:45	*Anna Kut, V. Spektor, B. Woronko* Micromorphology of Quartz grains in sediments of Abalakh plate, Central Yakutia
12:45 – 13:00	*Alexandra Veremeeva, I. Nitze, F. Günther, G. Grosse, E. Rivkina* Thermokarst lake area increase trend and its geomorphic and climatic drivers in the Kolyma lowland yedoma region, NE Siberia
13:00 – 13:15	*Alexandra Runge, G. Grosse* A comprehensive remote sensing-based assessment of annual retrogressive thaw slump dynamics across North Siberia for 1999-2020
13:15 – 14:00	**Lunch** (private discussions in Break-out rooms)
14:00 – 15:30	**<u>Session IV: "Past and recent permafrost ecosystem dynamics"</u>**
	Session chair: Anne Morgenstern, Alexey Eliseev
14:00 – 14:15	*Anna Zaplavnova, V. Potapov* Upper part of the geoelectrical section from the Lena River Delta using MTS data
14:15 – 14:30	*Elisabeth Dietze, R. Glückler, S. Kruse, K. Mangelsdorf, A. Andreev, L.A. Pestryakova, U. Herzschuh* The role of forest fires in Eastern Siberia – Feedbacks between fire, climate, vegetation, permafrost and humans across space and time
14:30 – 14:45	*Elizaveta Rivkina, T. Vishnivetskaya* Biogeochemical processes in permafrost
14:45 – 15:00	*Alexey V. Eliseev, V.V. Malakhova* Uncertainty in temperature and sea level datasets for the Pleistocene glacial cycles: Implications for thermal state of the subsea sediments
15:00 – 15:15	*Goran Georgievski, P. De Vrese, S. Hagemann, V. Brovkin* Evaluating historical simulations of MPI-ESM for key permafrost-relevant climatic variables in high northern latitudes
15:15 – 15:30	*Sergei Pravkin, D. Bolshiyanov, A. Aksenov* The first river terrace and the Ice Complex of the Lena Delta: Common origin and evolution

15:30 – 16:00 **Break** (private discussions in Break-out rooms)

16:00 – 17:00 **Session V: "Transfer of permafrost knowledge for science community and society"**

Session chair: Eva-Maria Pfeiffer, Irina Fedorova

16:00 – 16:15 *Loeka Jongejans*
Communicating Arctic Science

16:15 – 16:30 *Rainer Lehmann*
How to bring the Polar regions and Permafrost into the classrooms

16:30 – 16:45 *Olga Vybornova, N. Kakhro, H. Kassens, I. Fedorova, C. Beer, E.-M. Pfeiffer*
Russian-German Higher Education cooperation on Permafrost Science: two research-driven Master Programs between universities Saint-Petersburg and Hamburg

16:45 – 17:00 *Anne Morgenstern*
Russian-German cooperation – driver for international advances in permafrost and Arctic research

17:00 – 18:00 **Session VI: Poster session**

Session chair: Olga Vybornova, Paul Overduin

Evgeny Abakumov
The role of vascular plants in stabilization of organic matter in soils of maritime Antarctica, north-west part of Antarctic Peninsula region

Natalia Alekseeva, I. Fedorova, S. Romanov, A. Chetverova
Variability of carbonate system components in Arctic water ecosystem

Sara E Anthony, C. Rosinger, J. Rethemeyer
Controls of organic matter degradability in thawing Holocene permafrost deposits in the Lena Delta, Russia

Annett Bartsch, ESA DUE GlobPermafrost team, ESA CCI+ Permafrost team
Siberian change revealed by satellite - Data collections of ESA DUE GlobPermafrost and ESA CCI+ Permafrost

Lutz Beckebanze, B.R.K. Runkle, J. Walz, C. Wille, D. Holl, M. Helbig, I. Fedorova, J. Boike, T. Sachs, L. Kutzbach
Low impact of lateral carbon export on net ecosystem carbon balance of a polygonal tundra catchment

Mariya Chernysheva, I. Fedorova
Geochemistry of bottom sediments of Yamal anthropogenically impacted lakes exposed

Damir Gadylyaev, J. Nitzbon, S. Schlüter, J. M. Köhne, G. Grosse, J. Boike
Applying Computed Tomography (CT) scanning for segmentation of permafrost constituents in drill cores

David Holl, C. Wille, T. Sachs, J. Boike, M. Grigoriev, I. Federova, E.-M. Pfeiffer, L. Kutzbach
Inter-annual variability of CO_2 fluxes on Samoylov Island

Marina Kashkevich, O. Galanina, N. Voropay, T. Parshina, I. Fedorova
Geoecological studies of the Tunkinskaya depression (Buryatia, Russia)

Melanie Kern, X. Rodriguez-Lloveras, C. Beer
A novel approach to process-oriented cryoturbation modelling

Johanna Kerttula, H. Siljanen, M.E. Marushchak, C. Voigt, J. Ronkainen, C. Biasi
Microbial community related to observed high N_2O emissions from thawing Yedoma permafrost

Sebastian Laboor, S. Muster, B. Heim, A. Haas, A. Walter, J. Matthes, I. Nitze, A. Bartsch, G. Grosse
The Arctic Permafrost Geospatial Center – a portal for high-quality open access scientific data related to permafrost in the Arctic

Maija Marushchak, J. Kerttula, K. Diakova, A. Faguet, J. Gil, G. Grosse, C. Knoblauch, N. Lashchinskiy, M. Nykamb, P.K. Martikainen, A. Morgenstern, J. Ronkainen, H. Siljanen, L. Van Delden, C. Voigt, N. Zimov, S. Zimov, C. Biasi
Thawed Yedoma permafrost as a neglected N_2O source

Olga Ogneva, G. Mollenhauer, H. Grotheer, M. Fuchs, J. Palmtag, T. Sanders, P. Mann, J. Strauss
The permafrost thaw fingerprint: the Isotopic composition of Particulate Organic Carbon From Lena River to Laptev sea

Juri Palmtag, P.J. Mann, M. Cara, M. Bedington, M. Fuchs, G. Grosse, G. Mollenhauer, B. Juhls, O. Ogneva, P. Overduin, L. Polimene, R. Torres, J. Strauss
Seasonal methane and carbon dioxide emissions upon the coastal region of the Kolyma river

Aleksandr Pastukhov, V. Kovaleva, D. Kaverin, C. Knoblauch
Microbial communities in Permafrost-affected peatlands in the South of the East-European Cryolithozone

Eva-Maria Pfeiffer, C. Beer, D. Bolshiyanov, I. Fedorova, M. Grigoriev, G. Grosse
KOPF Synthesis – carbon in terrestrial permafrost landscapes of the Siberian Arctic under a changing climate

Evgeny Abakumov, V. Polyakov
The role of microparticles of organic carbon in degradation of ice cover of polar regions of the earths and in the process of soil-like bodies formation

Zoé Rehder, T. Kleinen, L. Kutzbach, V. Stepanenko, V. Brovkin
New model MeEP gives insights on the impact of methane emissions from ponds on the local methane budget in the Lena River Delta

Tina Sanders, M. Fuchs, K. Dähnke
Fate and transport of nitrogen in soils, sediment and water of the Lena Delta, Northeast Siberia

Irina Terentieva, I. Filippov, A. Sabrekov, M. Glagolev
Mapping West Siberian seeps and floodplains using convolutional neural networks

Yana Tikhonravova
Isotopic composition within heterogeneous ice wedge

Stiig Wilkenskjeld, F. Miesner, P. Overduin, M. Puglini, V. Brovkin
The Fate of Subsea Permafrost under Future Climate Warming

Sizhong Yang, S. Liebner, J. Walz, C. Knoblauch, T. Bornemann, A. Probst, D. Wagner, Mike S.M. Jetten, M. in 't Zandt
Effects of a long-term warming scenario on microbial community structure and functional potential of permafrost-affected soil

17:00 – 17:30 Short poster presentations (1 min/poster)

17:30 – 18:00 Break-out rooms parallel poster discussions (separate room pro poster)

18:00 – 18:45 **Public talk – Permafrost for everyone**
Martin Heimann, M. Goeckede, S. Zimov, N. Zimov, Brovkin
In search of greenhouse gas emissions from permafrost in northeast Siberia

18:45 – 19:00 **Official Closing of the Symposium**

Prof. Dr. Christian Beer (UHH)

Contents

PEDODIVERSITY AND SOIL TAXONOMY OF ABANDONED AGRICULTURAL ECOSYSTEMS OF CENTRAL YAMAL

Evgeny Abakumov[1], Vyacheslav Polyakov[1], Evgenya Morgun[2]

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The soils of the Russian Arctic and the cryolitozone are considered as a hidden food resource (basket) of the Russian Federation and all of Eurasia. Arctic warming would contribute to the expansion of agricultural practice into the northern ecosystems. Nowadays, a program of re-involvement of fallow lands in agricultural use is underway in the Russian Federation. Numerous abandoned agricultural landscapes are located in cryogenic ecosystems in the central and south part of Yamalo-Nenets autonomous regions. In the Soviet period, agriculture was quite intensive and widespread in remote regions of North-West Siberia. Soils of abandoned agricultural lands as well as soils of current agricultural fields were investigated in terms of morphology, taxonomy and nutrient state. About 25 soil profiles, located in former arable lands in the vicinity of the cities of Salekhard and Labynangy (tundra) as well as Nadym, Stary Nadym and Novy Urengoy (forest-tundra), were surveyed and analysed. Soils of forest tundra zone are presented, normally, by Gleezems and Entic Podzols with an abandoned arable humus horizon. Over 30 years of the soils being in the fallow state, the arable layer is well preserved, even in terms of thickness. At the same time, levels of nutrients and total organic carbon content remain on one level, comparable with what was fixed in 1990-1991. Soils of former greenhouses are presented by a thick layer of humus and nutrient-enriched materials. Anthropogenically transformed Podzols of forest tundra demonstrate humus layers with thicknesses of about 20-40 cm, in some cases soils have a second organic horizon, resulting from rotational plowing. Abandoned Agrosoils demonstrate agrogenic morphological features and evident fingerprints of the application of mineral amendments in the recent past. Nowadays, soils that are involved to agricultural practices are mainly used for potato and vegetable production. Current agriculture is strongly localized in vicinities of cities and settlements, while previously, in Soviet times, it was spread over wide areas.

Acknowledgements

This work was supported by the Russian Foundation of Fundamental researches, project No 19-416-890002.

THE ROLE OF MICROPARTICLES OF ORGANIC CARBON IN DEGRADATION OF ICE COVER OF POLAR REGIONS OF THE EARTHS AND IN THE PROCESS OF SOIL-LIKE BODIES FORMATION

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Rapid glaciers retreatment in polar and mountain regions of the Earth results not only from the direct effect of the climate changes, but, at the same time, from the global transfer of microparticles. An accumulation of these microparticles on the glaciers surface result in changing of albedo values and ice-sheets degradation. The cryoconites play a specific role in glaciers degradation, these formations are presented by specific organic soil-like bodies. They present self-deepening dark colored formations and aggregations in the surface part of the glacier. Inside the ice layer, they become aggregates and form a space-developed web of organo-mental material, which finally result in the intensification of the deglaciation. In this context, this report is aimed at the complex investigation of this process with use of numerous instrumental and molecular methods. Humic acids, isolated from selected soils of paraglacial Antarctic and Arctic areas, were investigated in terms of molecular composition and resistance of decomposition. The degree of soils organic matter stabilization has been assessed with the use of modern instrumental methods (nuclear magnetic resonance spectroscopy (CP/MAS 13C-NMR). Analysis of the humic acids showed that aromatic compounds prevail in the organic matter formed in cryoconites, located on the glacier's surfaces. The predominance of aliphatic fragments is revealed in the soils of paraglacial and periglacial areas. This could be caused by sedimentation of fresh organic matter exhibiting a low decomposition stage due to the harsh climate and processes of hydrogenation in the humic acids, destruction of the C-C bonds and formation of chains with a high hydrogen content. These processes result in the formation of aliphatic fragments in the humic acids. In general, soils of the studied region are characterized by low stabilized soil organic matter which is indicated by low aromaticity of the HAs. The cryoconites contain more stabilized organic matter than soils.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research, project No 19-05-50107.

THE ROLE OF VASCULAR PLANTS IN STABILIZATION OF ORGANIC MATTER IN SOILS OF MARITIME ANTARCTICA, NORTH-WEST PART OF ANTARCTIC PENINSULA REGION

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Soils of Antarctica are known as biogenic-abiogenic formations with low content of organic matter and related biogenic elements. The content of organic matter in soils of coastal and intercontinental territories normally is not higher than 1 %. Organic matter is characterized by very low enrichens of soil organic matter by nitrogen. At the same time, soils of maritime Antarctic show increased portions of organic carbon in the fine earth. Considering the fact that there is also an increased portion of the fine earth in soils of the maritime zone, one can conclude that the rate accumulation of organic matter here is essentially higher than in soils of the continental part. The aim of this research was to evaluate stocks, content and molecular compositions of organic matter, formed under two vascular plants, which are indigenous for the Antarctic Peninsula – *Deschampsia antarctica* and *Colobantus quitensis*. These two plants normally occupy former bird rookeries and other places of nesting (normally – elevated ridges and hills), enriched by biogenic elements. That is why initial enrichens of fine earth by organic carbon and nitrogen is higher in normal soils under the lichens and mosses. Moreover, the composition of individual precursors of humification in soils, formed under vascular plants, essentially differs from those under lichens and mosses. That is why organic matter stabilization rate is higher in soils under two higher plants, as mentioned above. The most important fact, which can affect the stabilization degree, is the amount of aromatic compounds of different structure and origin in case of soil formation under flowering plants. Thus, the current expansion of these Antarctic herbs caused by the factor of ornitohoria, within the inland territories, should result in increasing the areas, occupied by soils with high organic matter stabilization degree.

Acknowledgements

This work was partially supported by the Russian Foundation for Basic Research, projects No: 19-54-18003, 19-54-18003 and 19-05-50107.

VARIABILITY OF CARBONATE SYSTEM COMPONENTS IN ARCTIC WATER ECOSYSTEM

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During the winter and summer period, we carried out the hydrological and hydrochemical components of the water ecosystems of the Lena River Delta. The seasonal variations of the run-off and important hydrochemical parameters in branches and lakes are determined. In lakes on Samoylov Island and Lena River, channels measured the carbonate system components such as carbon dioxide, hydrocarbonates, pH and dissolved organic matter. The regularity range in the spreading of CO_2, hydrocarbonates, dissolved organic matter and nutrients are determined. The Carbon dioxide concentration in the channels ranges from 3 to 26 mg/ l, in the lakes it is 0.1 to 25 mg/l.

Annual variation of the carbon dioxide concentration at most lakes has a small amplitude and generally matches the annual variation hydrocarbons. The carbon dioxide amount in water bodies is not much different from the channels. The CO_2 concentration varies slightly from the surface to the depth. However, the increased dissolved gas concentration noted at the main channel (25 mg/l). The lakes are characterized by no trace of a change in the concentration of CO_2 with depth, but there are alkalizing and slightly acidified lakes with atypical concentration values. The absence of carbon dioxide in one of the lakes may also be explained by its eutrophication and insignificant amount of active nekton. An additional source of CO_2 in the other lake might be a research station located on its shore. The low concentration of free CO_2 in winter allows to predict an active absorption of atmospheric carbon dioxide during ice drift and floods in the delta.

Acknowledgements

This research was conducted within the framework of the expedition "LENA". The reported study was funded by RFBR, project number 19-34-50086 «Mobility» and by RFBR, project number 18-05-60291 «Adaptation of Arctic limnosystems under fast climate change». Hydrochemicals analyses water samples were done in Resource educational center “Chemistry” by Saint Petersburg State University and OSL of AARI, Saint Petersburg.

CONTROLS OF ORGANIC MATTER DEGRADABILITY IN THAWING HOLOCENE PERMAFROST DEPOSITS IN THE LENA DELTA, RUSSIA

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Organic matter (OM) in permafrost soils is at risk of increased microbial degradation as the climate warms. To assess lability of OM and susceptibility of organic carbon (OC) losses in a Holocene permafrost deposit, samples were collected along a 6-meter depth profile on Samoylov Island, in the Lena River Delta. A combination of ^{14}C dating, microbial lipid analysis, and microbial respiration experiments were conducted to determine the variations in lability. Apparent ^{14}C ages of bulk OC declined linearly in the active layer (approx. 0-80 cm) and the first approx. 100 cm of permafrost from 692 to 3988 yrs BP, while OM ages vary in 200-600 cm (approx. 3500 to 5800 yrs BP). Variations in the 200 to 600 cm range may be due to mixing and re-deposition of sediment originally deposited upstream.

Several soil variables showed a significant difference between the active layer (n=4) and permanently frozen soils (n=23). Total phospholipid fatty acid (PLFA) concentration, an indicator of viable microbial biomass, was significantly higher in the active layer than in the permafrost. Total neutral lipid fatty acid (NLFA) concentrations, an indicator of total microbial biomass (including Eukaryotic organisms and fungi) were significantly lower in the active layer compared to the permanently frozen soils. In addition, P_{wax}, an indicator of dominant plant type based on alkanes reveals significant differences between the active layer and permanently frozen soils.

Total PLFA and NLFA concentrations along the entire depth profile were significantly positively correlated to total organic carbon (TOC), total inorganic carbon (TIC), total nitrogen (TN) and total sulfur (TS). While total NLFAs were correlated with water content, total PLFAs were not, and total PLFAs were negatively correlated to ^{14}C age while total NLFAs were not. Total NLFAs were moderately correlated with total PLFAs. This suggests that the viable microbial community and more degraded OM is concentrated in the younger active layer while permafrost layers contain less degraded OM and potentially large amounts of easily degradable microbial detritus. This is also supported by the results of the respiration analysis, as respiration was strongly correlated to total NLFAs, but not correlated to total PLFAs. Microbial respiration rates are promoted by higher TOC/TN values and water contents, indicating that future climate conditions will play a strong role in carbon release from these soils.

ABOVE-GROUND PHYTOMASS AND ITS NITROGEN CONTENT IN A THERMOKARST DEPRESSION IN THE LENA DELTA: PRELIMINARY RESULTS

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During a field campaign in August 2018, we investigated a thermokarst depression on Kurungnakh Island in the Lena Delta. This depression differs from many others and has a distinctive bright green colour that is visible even on low-resolution satellite images. As recently reported by Lashchinskiy with co-authors (2020), the depression originated from a shallow thermokarst lake drained not later than 40 years ago, and its vegetation is quite a contrast to the zonal tundra in terms of its structure and floristic composition. The bottom of the depression is extremely inhomogeneous and consists of baidjarakhs and flat low sites between them. Baidjarakhs occupy 56% of the depression area (A.A. Kartoziia, personal communication).

Our objective was to estimate the active soil layer, above-ground phytomass, and its N content in the area of the baidjarakhs. We determined the thickness of the active soil layer at 30 sites along a 35 m transect that included three baidjarakhs (n=15) and three flat low sites (n=15). The active soil layer was 44.7±1.71 cm (CV=15%) in the baidjarakhs and almost 30% less, 34.8±1.20 cm (CV=13%) in the flat low sites.

The vegetation of the baidjarakhs is quite different from the rest of the depression surface and is represented almost exclusively by one species of the *Gramineae* family, *Arctagrostis arundinacea*. Obviously, this plant species gives the bright green coloration in the spatial images. The stock of above-ground phytomass of three baidjarakhs was 260±22.2 g m^{-2} (n=12, CV=30%), and root mass was 208 g m^{-2} (n=3), giving a total of 468 g m^{-2}. The stock of living phytomass of typical shrubby moss-lichen tundra on the undegraded surface of the third flood terrace in the immediate vicinity of the depression was 521 g m^{-2} (n=3). However, due to the significantly higher nitrogen content in *Arctagrostis arundinacea* plants (1.95% in the above-ground part and 1.00% in the roots), compared to typical tundra vegetation (0.65%), the nitrogen content in phytomass of baidjarakhs exceeded by 2.1 times the nitrogen stock in plants of non-eroded terrace surface (7.2 g m^{-2} vs 3.4 g m^{-2}). Such a significant difference between the plant communities of typical tundra and *Arctagrostis arundinacea* in the content of nitrogen and, consequently, in the uptake of N by plants from soil convinces that the decomposition of SOM and probably N turnover in the soils of baidjarakhs is much faster.

The high values of above-ground plant mass (260 g m^{-2}) obtained on baidjarakhs covered with *Arctagrostis arundinacea* are quite comparable with the above-ground phytomass of meadow and true steppes, the average value of which is 246 g m^{-2} (Titlyanova et al., 2002). Such highly productive spots (existing thousands of years in tundra) allow to agree with the hypothesis that the spots served as pastures not only for modern herbivorous animals, but also for the Pleistocene megafauna (Lashchinskiy et al., 2020).

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SIBERIAN CHANGE REVEALED BY SATELLITE - DATA COLLECTIONS OF ESA DUE GLOBPERMAFROST AND ESA CCI+ PERMAFROST

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A Permafrost Information System (PerSys) based on satellite data has been set up as part of the ESA DUE GlobPermafrost project (2016-2019, www.globpermafrost.info). This includes a data catalogue as well as a WebGIS hosted by the Alfred-Wegener-Institute for Polar and Marine Research, both linked to the Pangaea repository for easy data access.

The thematic products available include InSAR-based land surface deformation maps, rock glacier velocity fields, spatially distributed permafrost model outputs, land surface properties (examples shown in Fig. 1) and changes, and ground-fast lake ice. Extended permafrost modelling (time series) is implemented in the new ESA CCI+ Permafrost project (2018-2021, http://cci.esa.int/Permafrost), which will provide the key for our understanding of the changes of surface features over time. Additional focus is on documentation of kinematics from rock glaciers in several mountain regions across the world supporting the IPA action group ‘kinematics as an essential climate variable’.

We will present the Permafrost Information System including the time series of ground temperatures and active layer thickness for the entire Arctic from the ESA CCI+ Permafrost project and results from the latest update (extension to 1997-2018). Ground temperature is calculated for 0, 1m, 2m, 5m, and 10 m depth and has been assessed based on a range of borehole data. A survey regarding data repositories containing relevant borehole data has been conducted. The records have been evaluated for the project purpose and harmonized.

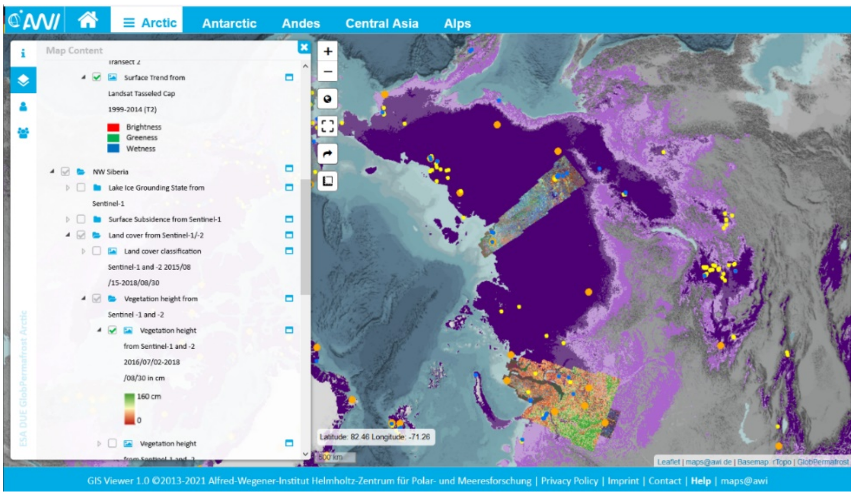

Fig. 1: View of WebGIS over Siberia – GlobPermafrost results. Background – permafrost extent (https://doi.pangaea.de/10.1594/PANGAEA.888600). Western Siberia – vegetation height (https://doi.pangaea.de/10.1594/PANGAEA.897045), eastern Siberia – transect of Landsat trends (https://doi.pangaea.de/10.1594/PANGAEA.884137)

LOW IMPACT OF LATERAL CARBON EXPORT ON NET ECOSYSTEM CARBON BALANCE OF A POLYGONAL TUNDRA CATCHMENT

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Permafrost soils contain a large quantity of soil organic carbon (SOC) potentially available for decomposition, and its permanence depends on the net ecosystem carbon balance (NECB), including both vertical and lateral fluxes. In most polygonal tundra landscapes, the CO_2 flux is known to be a sink on the annual scale, but less is known about the role of lateral carbon flows. To fill this gap, we present and contextualize lateral export rates from a polygonal tundra site in northern Siberia, Russia. Furthermore, we present the vertical carbon (C) fluxes of CO_2 and CH_4 from this study site. Thus, we derive the NECB in one growing season.

The results show cumulative lateral DIC and DOC fluxes of 0.25 – 0.28 and 0.05 – 0.06 g C m^{-2}, respectively, during the observation period (8 June – 8 September). The vertical fluxes of CO_2 and CH_4 accumulate to -19.0 ± 1.2 and 1.1 ± 0.02 g C m^{-2}, respectively. The lateral carbon export thus represents 1.6 – 1.8% of the net ecosystem exchange (NEE). However, the relationship between lateral and vertical fluxes changed over the observation period. At the beginning of the growing season (early June), the lateral carbon flux outpaces the vertical CO_2 flux, causing the polygonal tundra landscape to be a carbon source at this time of the year. With ongoing growing season, the vertical CO_2 flux dominates the NECB.

We conclude that lateral carbon fluxes can have a considerable influence on the NECB on short time scales (days), especially during the early growing season. However, their impact decreases on seasonal time scales. Therefore, the vertical carbon flux can be seen as a good approximation for the NECB of this study site on the time scale of months.

PROTECTION OF PERMAFROST SOILS FROM THAWING BY INCREASING HERBIVORE DENSITY

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Climate change will cause a substantial future greenhouse gas release from warming and thawing permafrost-affected soils to the atmosphere enabling a positive feedback mechanism. Increasing the population density of big herbivores in northern high-latitude ecosystems will increase snow density and hence decrease the insulation strength of snow during winter. Consequently, theoretically 80% of current permafrost-affected soils (< 10m) are projected to remain until 2100 even when assuming a strong warming using the Representative Concentration Pathway 8.5. Importantly, permafrost temperature is estimated to remain below -4°C on average after increasing herbivore population density. Such ecosystem management practices would be therefore theoretically an important additional climate change mitigation strategy. Our results also highlight the importance of new field experiments and observations, and the integration of fauna dynamics into complex Earth System models, in order to reliably project future ecosystem functions and the climate.

PERMAFROST RATE OF THE SIBERIAN ARCTIC

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Conclusions about tendencies of climate or permafrost rates are possible on the basis of long series observations only. Such long permafrost observations in the Arctic are rare and continuing in some places. The rate of active layer thickness measurements on Samoylov Island (Lena River Delta) consists of 18 years (2002-2019). The same measurements in the lower Kolyma River region are being conducted since 1997 (Veremeeva, 2017). Measurements of active layer thickness on Bolshevik Island (Cape Baranov, Severnaya Zemlya Archipelago) started in 2016 only. Obvious tendency to the growth of active layer thickness shows the short Bolshevik Island rate. But if to think of rates from Lena River and Kolyma River regions, there is now tendency to permafrost getting warmer in the Arctic. There are fluctuations of active layer thickness with the period of 7-10 years. The warmest summer in Siberian Arctic was in 2020. Next summer will be much colder, and the tendency to thicker active layer will change to the opposite trend, as it was at some times during the period of observations.

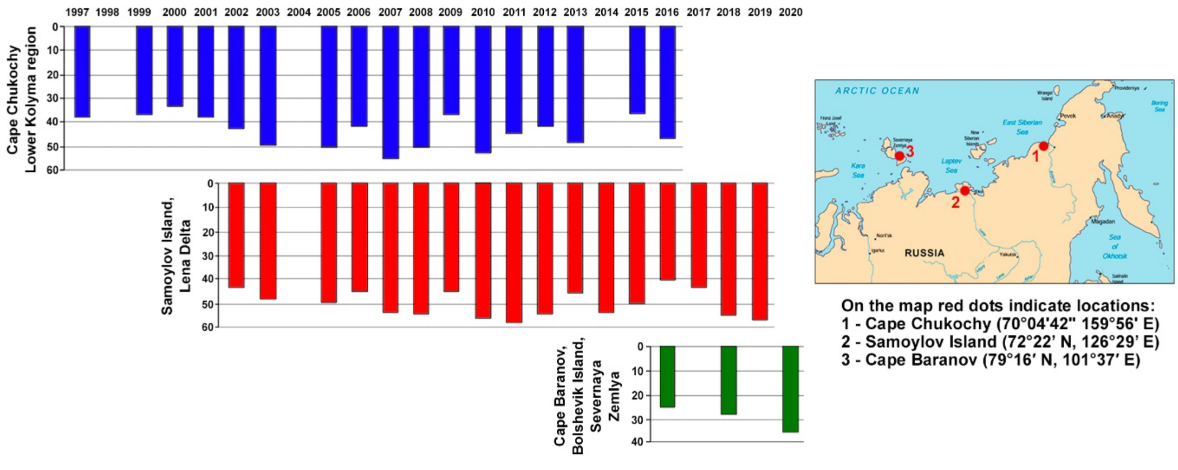

Fig. 1. Dynamics of active layer thickness in the Kolyma lowland (cape Chukochy), Lena River Delta (Samoylov Island) and Bolshevik Island (Severnaya Zemlya Archipelago).

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PERMAFROST CARBON IN EARTH SYSTEM MODELS: PROGRESS AND CHALLENGES

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Response of organic carbon stored in permafrost to ongoing climate change is a main uncertainty in future climate-carbon projections. Will the Arctic turn from a weak sink into a strong source of carbon? How abruptly could permafrost CO_2 and CH_4 fluxes change in the near future? Earth System Models (ESMs) participating in the current Coupled Model Intercomparison Project, CMIP6, do not include permafrost carbon, with the only exception of the NCAR model, which, however, does not account for an important process of vegetation dynamics. Besides, ESMs are still far from being perfect in simulating high-latitude plant productivity, a main input of fresh organic material into the soils *(Winkler et al., 2019).*

The JSBACH group at MPI-M focuses on the development of the offline permafrost carbon module in MPI-ESM that includes interactions between vegetation dynamics, fire disturbance, and hydrology. Within the KoPf project, the soil module of JSBACH has been considerably improved, for example by accounting for vertical heterogeneity of the soil. Results of carbon cycle changes for the last deglaciation (*Schneider von Deimling et al., 2018*), future RCP scenarios (*Kleinen and Brovkin, 2018*), and idealized rump-up – rump-down SSP scenarios (*de Vrese et al., 2020*) show an interesting non-linear behaviour and potential irreversibility of permafrost carbon storages and CH_4 dynamics. A pioneering study of CH_4 fluxes from the subsea permafrost in the Arctic accounting for biogeochemical processes of diagenesis in marine sediments (*Puglini et al., 2019*) indicates small non-turbulent fluxes at present while significant uncertainty for the future. These results and challenges in the permafrost carbon modelling, such as a large gap in a spatial resolution between models and observations, will be highlighted in this and other presentations from the JSBACH group.

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DENDROCHRONOLOGICAL RECORDS FROM TUNDRA SHRUBS IN THE VICINITY OF SAMOYLOV ISLAND

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[1]Adam Mickiewicz University, Poznán, Poland
[2]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

Tundra shrubs form annual growth rings that can be broadly used in dendrochronological studies. With our study, we aim to investigate dendrochronological potential of woody plants, mainly tundra shrubs, in the vicinity of Samoylov Island in central Lena River Delta (72º N, Northern Yakutia, NE Russia). In August 2018 we collected various shrub species (e.g., *Salix* spp., *Betula nana*) in selected habitats, mainly on Samoylov Island and Southern Kurungnakh Island. Additionally, dwarf trees of *Larix* species were sampled on Kurungnakh Island (72° 17’ N), far beyond the northern treeline. *Salix* spp. will be incorporated into two dendroecological studies: i) shrubs growth and survival on a flood plain on Samoylov Island; ii) shrub growth and succession on a so-called ‘recently drained lake’ on Southern Kurungnakh Island. Whereas *Betula* and *Larix* specimens will be applied into climate-growth relationship analyses.

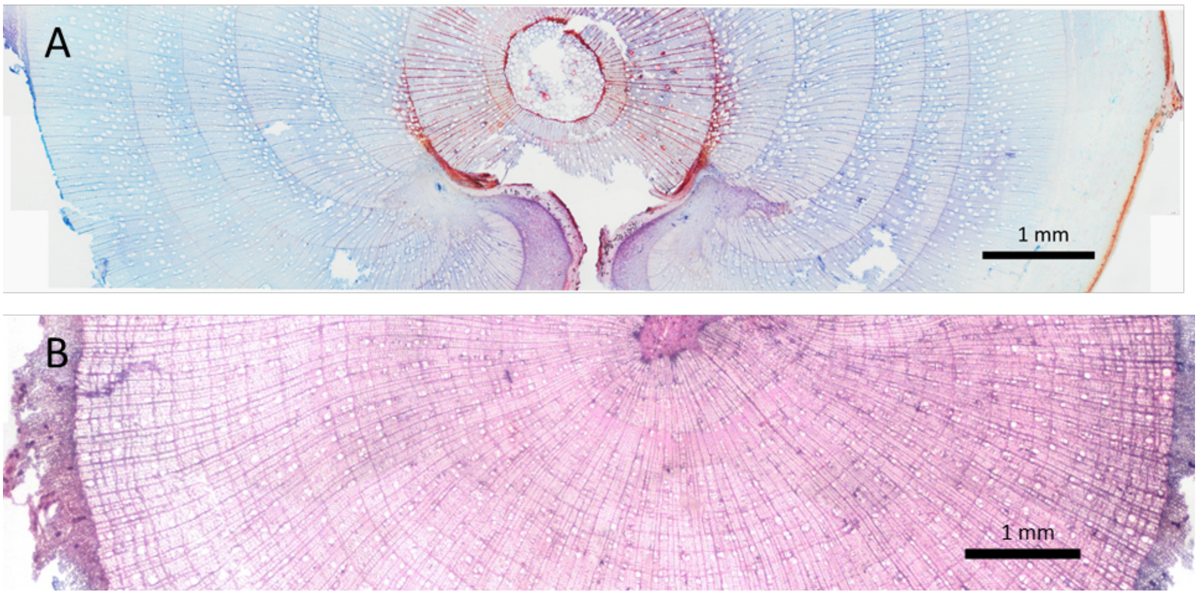

Fig. 1 Growth ring pattern of tundra shrubs in Lena delta: A) *Salix* spp. from flood plain area (Samoylov Island) with a scar formed during spring break up in 2014; B) *Betula nana* from Southern Kurungnakh

Acknowledgements

The research leading to these results has received funding from the European Union’s Horizon 2020 project INTERACT, under grant agreement No 730938.

GEOCHEMISTRY OF BOTTOM SEDIMENTS OF YAMAL ANTHROPOGENICALLY IMPACTED LAKES EXPOSED

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Currently increased heavy metal concentrations in the lacustrine bottom sediments reflect the presence of anthropogenic impact. Most of these chemicals are toxic to benthic organisms and can cause secondary pollution, which leads to further degradation of the lake ecosystem biotic structure. The paper presents the results of studies carried out on two lakes Yamalo-Nenets Autonomous Okrug (YANAO) near the town of Salekhard, and settlements of urban type Kharp in 2018-2019. Trace metal concentrations in water were determined by inductively coupled plasma atomic emission spectrometry ICPE-9000. An atomic absorption spectrophotometer with an ammonium-acetate buffer was used for geochemical analyses of bottom sediments. The following elements were determined: *Pb, Cd, Cu, Zn, Fe, Ni, Cr, Mn, Co*. Sediment's dating was carried out on the non-equilibrium lead.

The analysis shows that the concentration of heavy metals in all water samples does not exceed the MPC (maximum permissible concentration) (Shestakova et al., 2018). According to the analysis of bottom sediments, there has been a gradual increase in trace metals, such as lead and chrome, in the lake between the city of Salekhard and the village of Aksarka during the last 40-50 years. There was also a rise in zinc concentration 80-100 years ago, with a gradual reduction to modern layers. There has also been a gradual increase in the concentration of elements such as cobalt, manganese, zinc, lead and nickel in the lake between the city of Labytnangi and the urban-type settlement of Kharp, over the past 60 years.

The increase of heavy metal concentrations in the columns from the older layers to the modern ones in both lakes is due to the development of YANAO over the past half century. The sharp increase in zinc in one lake also indicates the external introduction of this element to the lake. A large amount of iron and manganese in all the studied reservoirs is a natural process for the study permafrost region. All other elements are distributed evenly over the entire column of bottom sediments.

Acknowledgements

The work was carried out with the support of the RFBR grant 18-05-60291. Geochemical analyses had been done in Chemistry Educational Centre SPbU Research Park.

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THE HIGH LATITUDES' RESPONSE TO TEMPERATURE OVERSHOOT SCENARIOS

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The difficulty to quickly reduce carbon emissions to levels compatible with the long-term goal of the Paris Agreement increases the likelihood of scenarios that temporarily overshoot the respective climate targets. We used simulations with JSBACH, the land surface component of the Max-Planck-Institute for Meteorology's Earth system model MPI-ESM1.2, to investigate how the high-latitude carbon cycle responds to such overshoot scenarios. We found that the soil CO_2 emissions exhibit an almost linear dependency on the surface temperatures that are simulated for the different climate scenarios. Here, each degree of warming increases the fluxes by, very roughly, 50% of their initial value, while each degree of cooling decreases them correspondingly. However, the linear dependency does not mean that the processes governing the soil CO_2 emissions are fully reversible on short timescales, but rather that two strongly hysteretic factors offset each other -- namely the vegetation's net primary productivity and the availability of formerly frozen soil organic material. In contrast, the soil methane emissions show almost no increase with rising temperatures and they are consistently lower after than prior to a peak in the greenhouse gas concentrations. Here, the fluxes can even become negative and the high-latitude soils may act as a sink for atmospheric CH_4 even after the forcing is fully reversed. Furthermore, our results reveal that feedbacks between water, energy and carbon cycles allow for path-dependent steady-states in permafrost-affected regions. These depend on the soil organic matter content at the point of climate stabilization, which is significantly affected by the soil carbon loss resulting from overshooting the climate target. Here, the simulated steady-states do not only differ with respect to the amount of carbon stored in the frozen fraction of the soil, but also with respect to soil temperatures, the soil water content, and even net primary productivity and soil respiration.

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THE ROLE OF FOREST FIRES IN EASTERN SIBERIA – FEEDBACKS BETWEEN FIRE, CLIMATE, VEGETATION, PERMAFROST AND HUMANS ACROSS SPACE AND TIME

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Forest fires are an important factor in the global carbon cycle and high latitude ecosystems. Eastern Siberian tundra, summer green larch-dominated boreal forest on permafrost and evergreen spruce and pine-dominated boreal forest have characteristic fire regimes with varying fire frequencies and intensities. However, it is unknown which role fire plays in climate-vegetation-permafrost feedbacks and how high-latitude fire regimes and ecosystems will change in a warmer world – questions that are crucial considering that boreal and permafrost regions have been identified as tipping elements in the climate system.

While several studies have investigated past fire activity in the Arctic and boreal North America and Europe, very little is known about natural versus human-influenced fire-permafrost-vegetation interactions in Siberia. How special are the recent forest fires within a long-term context? What are the main relationships between fire, vegetation and climate change in Eastern Siberia? We study modern fire regimes using satellite-based fire and land cover products and test if fire frequencies and/or area burnt is different in natural versus human-affected regions. Siberian fire regime changes in the past are reconstructed using lake-sedimentary fire biomarkers and sedimentary charcoal that we compare with pollen-based vegetation reconstructions. Here, we present fire-vegetation-climate feedbacks on millennial to orbital timescales from late glacial to interglacial sediments of Lake El'gygytgyn, located about 100 km north of the current treeline in Chukotka, and first results on modern fire-human interactions based on reconstructions of Late Holocene fire regimes from Lake Khamra, southern Yakutia, located in the transition between larch and evergreen boreal forest within the discontinuous permafrost zone. This will allow us to provide a step forward to understand the regional role of forest fires, its drivers and long-term fire-vegetation-permafrost feedbacks that are crucial for model predictions of future fire regime shifts in the high northern latitudes.

UNCERTAINTY IN TEMPERATURE AND SEA LEVEL DATASETS FOR THE PLEISTOCENE GLACIAL CYCLES: IMPLICATIONS FOR THERMAL STATE OF THE SUBSEA SEDIMENTS

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Temperature and sea level changes in the Pleistocene are uncertain. This leads to uncertainty in the associated response of the thermal state of the subsea sediments. We quantified the upper bound of the latter uncertainty in idealised simulations with a model for thermophysical processes in the sediments. At the coast and at the shallow and intermediate–depth shelves and except during relatively isolated time intervals, this bound for permafrost base depth and for the methane hydrate stability zone (MHSZ) characteristics (depth of its bottom boundary and its thickness) is ≤ 45% provided that the geothermal heat flux (GHF) is not larger than 80 mW/m^2. These values are much smaller than the uncertainty metrics for the forcing data, which are typically ≥ 65%. However, for the intermediate shelf with a larger geothermal heat flux and for the deep shelf irrespective of GHF, different forcing time series may even lead to qualitatively different behaviour of the sediment thermophysical characteristics. We found that prescription of sea level changes plays a crucial role in uncertainty of the simulated subsea permafrost and MHSZ in the deep shelf sediments. In addition, we also quantified uncertainty for estimated apparent response time scales. The relative uncertainty for permafrost base depth and hydrate stability zone thickness time scales is ≤ 20% for most cases. We found no systematic dependence of our results on accounting for millennium–scale temperature variability provided that timescales of the order of 10^4 yr are resolved by forcing datasets.

FIELD-BASED INCUBATION EXPERIMENT IN TUNDRA: BURIED SOIL ORGANIC MATTER DECOMPOSITION

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Frozen buried organic material is a potential substrate for microbial decay and, as a consequence, carbon release into the atmosphere and hydrosphere. Climate change effects, especially those of increasing temperatures on ecosystem structure and function, have been addressed by numerous laboratory studies and field-based experiments. Generally, all natural soil heating experiments have been conducted in tundra permafrost-dominated or forest permafrost-free environments in Northern America and Northern Europe.

To find out a microbial response and carbon release (in gaseous forms: CO_2, CH_4 and other forms) from soil organic matter (SOM) that has been permanently frozen, we placed an *in situ* condition field-based incubation experiment on Samoylov Island, Lena Delta, Russia (72°22’N, 126°28’E) in a rim of ice-wedge polygon. Frozen buried SOM was taken from the eroded Lena riverbank of Samoylov Island and transferred to the soil surface (mimicking cryoturbation processes). The buried soil had relatively much content of organic matter (5.67% organic C and 0.24% total N) which, according to the wide C/N ratio of 23.5, was not much microbially transformed. This is also corroborated by $\delta^{13}C$ ratio of -25.1‰ and $\delta^{15}N$ ratio of 1.77‰. Since the experiment was set up (August 2015), during July-August 2016, August 2017-2019 we measured CO_2 and CH_4 released from the soil surface of both variants of the experiment by the close chamber technique. We aim at identifying the microbial response and associated release of CO_2 and CH_4 from thawing soil that has previously been permanently frozen.

It has been shown that a significant difference between the values of greenhouse gas release (CO_2, CH_4) from the buried soil has appeared after 3 years of experiment set up. In addition, the conditions of soil formation in the Arctic (cryogenic processes, composition of soil microbiota and parent rocks, accumulation of undecomposed organic matter) affect the qualitative composition of humic acids (HAs). HAs are heterogeneous systems of high-molecular condensed compounds formed from the decay of plant and animal remnants in terrestrial and aquatic ecosystems. To investigate the elemental and molecular composition of humic acids (HAs) isolated from buried soils and integral indicators of humification (stabilization) of SOM, we use the modern instrumental technique as a ^{13}C (Cross-Polarization Magic Angle Spinning) NMR spectroscopy. The stabilization of organic material is defined as the transformation of SOM into a state inaccessible to soil microorganisms, and the stabilization property itself is a characteristic stage of carbon dynamics. We noted dynamic changes in the composition of HAs from “initial” buried soils towards SOM that has been exposed in the field experiment. It was shown that with the involvement of buried SOM in modern soil formation, an increase in the proportion of aromatic structures appeared, which indicates SOM stabilization.

Acknowledgements

Research is supported by CARBOPERM and a research grant of the Russian Foundation of Fundamental researches №18-05-60291.

PERMAFROST EVOLUTION IN LENA DELTA AS SEEN ON 2016-2019 DRONE SURVEY DATA. AN OVERVIEW.

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Permafrost evolution in Lena Delta concerns many scientists in the field of glaciology and climatology. It is both due to the ability of interpolating results from Lena Delta to the rest of the Arctic region and at the same time, certain uniqueness of the area, that makes those studies of such a high value. In general, permafrost evolution in Lena Delta can be described as “degradation”, but this degradation is irregular across the vast delta: it can be quick in certain spots and literally invisible in others. This is where high-resolution remote sensing methods come into play – unmanned aerial imaging is a relatively accessible (i.e. cheap and fast) way of gathering valuable data on the terrain and land cover. Drones allow for very high resolution of the orthophotomap (0.05 m/pixel) and digital elevation model (DEM) - 0.2-0.5 m/pixel. This helps us track permafrost progression across short periods of time (3 years) and on a very small scale - single features of a decimeter size (baydzharakhs and thermoerosional gullies at their initial stage). Such resolution gives us the opportunity to estimate the volume of organic-rich sediments that has been processed through an observed timespan and evaluate the amount of greenhouse gas that could have been emitted (provided we have emission values for certain organic matter types and conditions where it evolved).

Our study includes two islands in Lena Delta: Dziellyakh-Aryta (Samoylov Island) and Kurungnakh-Sise. Samoylov is a typical island that consists of the first terrace (eastern part) and a floodplain (western part). Kurungnakh is a third terrace remnant, holding ice-rich permafrost (Yedoma) atop of the sandy basement. This ice-rich permafrost is, in fact, a very potent source of greenhouse gases because of its high organic matter content. Evolution of Yedoma is our primary goal in this study.

High-resolution data coupled with field studies allowed us to map permafrost degradation hotspots (large changes in DEM year-to-year) as well as land cover changes (vegetation evolution). We observed evolution of a very young alas (both in terms of permafrost and vegetation progression), erosional gullies growth and riverbank abrasion, all in high detail. This level of detail allows not only for the confirmation of the fact that permafrost features are a subject to change, but also make it possible for us to deduce some aspects of underlying nature of these processes.

RECENT BIOGEOCHEMICAL DYNAMICS IN ARCTIC LAKES ECOSYSTEMS

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Geochemical investigations of Arctic lakes ecosystems have been done for three representative Arctic regions: the Lena River Delta, Yamal and Kola Peninsulas. Natural and anthropogenic pressed lakes have been studied during 2017-2019. Field investigations showed that the concentration of nutrients from all three regions differ slightly (0.01-0.15 mg/l for ammonium, 0.003-1.44 for phosphates, and 0.00-0.38 for nitrates). The most significant PO_4 and NO_3 concentrations were observed for Lake Big Voudyavr in Kirovsk (Kola Peninsula). Lena Delta lakes are characterized by a higher concentration of ammonium (median is 0.09 mg/l) than in other regions. It was found that iron concentration was above 0.3 mg/l in a quarter of water samples from natural lakes and lakes under the anthropogenic impact. The maximum concentrations were found for natural lakes in the North of Western Siberia. The major concentration of iron, manganese, and aluminium are usually associated with the formation of their organic complexes with humic substances, which is due to the swamps. A minimum value of αCDOM(440) = 2,46 nm-1 is determined for the Kola Peninsula, which is about two times lower than the maximum αCDOM(440) = 5,35 nm-1 determined for the Yamal Peninsula; the Lena River Delta has a middle value of 3,12 nm-1. The seasonal dynamics of CDOM may have a general scheme for all the Arctic aquatic ecosystems with high values during the spring period. However, for the Kola Peninsula, average CDOM concentration in water is bigger for the ice period when lakes are switching to the groundwater feed. Slope coefficient types indicate the predominance of allochthonous CDOM and mean that processes of photodegradation are absent on average.

The predominance of Rotifera representatives in zooplankton species diversity and abundance indicators was found. The provision of zooplankton biomass indicators by large psychrophilic Copepoda species are characteristic features of zooplankton in the Arctic region. Considerable productivity and water mineralization typify for urban aquatic ecosystems. Studied lakes are characterized by quantitative differences of carbon cycle components in three regions of the Russian Arctic, which represent a subtle balance of carbon emission into the atmosphere.

Acknowledgements

The projects have been realized with the support of CARBOPERM and KoPF Russian-German project, RFBR #18-05-60291, #19-05-00683, and by SPbSU scientific program "Urban ecosystems of the Arctic zone of the Russian Federation: dynamics, state and sustainable development". Samples were analysed in Resource educational Center "Chemistry" of SPbSU and Otto-Schmidt-Laboratory of AARI.

MICROBIAL TRANSFORMATION AND AVAILABILITY OF DISSOLVED NITROGEN IN THE ACTIVE LAYER OF CRYOSOLS

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Permafrost-affected soils are rich in organic matter and therefore contain high amounts of organically bound nitrogen. Since microbial nitrogen transformation processes were assumed to be inhibited by low temperatures, these habitats are generally described as nitrogen limited. We investigated the amount of dissolved nitrogen compounds and potential microbial nitrogen transformation, especially nitrification, in the active layer of different Arctic cryosols in the Lena River Delta in North-East Siberia during the vegetation period.

Our investigations showed that soils and landscapes differed in small-scale in dissolved nitrogen availability and nitrification depending on organic matter content, C/N and pH-values, moisture and especially vegetation cover. Ammonium was only detected in organic rich soils at the beginning of the vegetation period combined with low nitrification rates and lower nitrogen availability. In contrast, nitrite was found on cold days with soil temperatures below 5 °C. Higher mineral nitrogen availability in the form of nitrate (up to 90 µg N g dw^{-1}) was only detectable in the absence of vegetation and at the end of the vegetation period in Psammentic Aquorthel located at the young floodplain (Fig. 1). Higher N-availability correlated with highest potential net nitrification rates combined with high varying but significant N_2O production rates in aerobic incubation experiments. In all soils, ammonia-oxidizing bacteria (AOB) and archaea (AOA), especially the AOB genus *Nitrosospira*, were detected (*Sanders et al., 2019*).

Since nitrification is the main source of nitrite and nitrate in this habitat and therefore the key driver of nitrous oxide (N_2O) formation, these non-vegetated beach soils with high potential nitrification rates, significant nitrate concentrations and N_2O formation in laboratory experiments, might be sources of N_2O that should be further investigated.

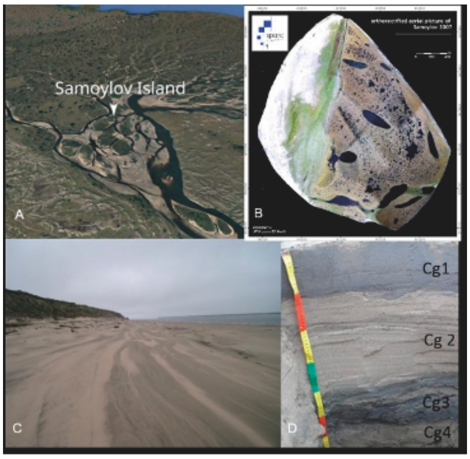

Fig. 1 A: Location of Samoylov Island in southern part of the Lena River Delta dominated by non-vegetated young floodplains, B: aerial picture of the island with western young floodplain and eastern river terrace (2007, Bolshiyanov et al., 2015), C: less N-limited site and D: soil profile of the Psammentic Aquorthel (ST) located at the young floodplain of Samoylov Island. Cg = alluvial deposits with gleying properties. C, D photos of July 2008.

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APPLYING COMPUTED TOMOGRAPHY (CT) SCANNING FOR SEGMENTATION OF PERMAFROST CONSTITUENTS IN DRILL CORES

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Computed X-ray Tomography is a non-destructive technique that allows three-dimensional imaging of soil samples' internal structures, determined by variations in their density and atomic composition. This study's objective was to develop an image processing workflow for the quantitative analysis of ice cores using high-resolution CT in order to determine the volume fraction and vertical distribution of ice, mineral, gas, and organic matter in permafrost cores. We analyzed a 155 cm permafrost core taken from a Yedoma permafrost upland on Kurungnakh Island in the Lena River Delta (Northeast Siberia). The obtained results were evaluated and compared with the results of detailed, but sample-destructive laboratory analysis. The frozen permafrost core was subjected to a computerized X-ray imaging procedure with a resolution of 50 micrometers. As a result, we obtained 31000 images. Noise in the raw images is removed with a non-local means denoising filter. We chose multilevel thresholding method for the image segmentation step. Threshold values were determined based on the histograms of the images. We measured the volumetric ice content (VIC) using Java-based image processing software (ImageJ). In addition, the vertical profiles were analyzed in 1-2 cm intervals. We received bulk densities and VIC by freeze-drying and standard laboratory analysis. From the top of the core and until roughly 86 cm, it mainly consists of ice and organic, with an average of 67% and 30% results, respectively. The rest of the volume is divided almost equally between air and mineral parts. Below 86 cm, it consists almost entirely of pure ice. The ice content constitutes around 97% of the composition, and air rises to roughly 3%, while mineral and organic are almost equal to zero. The difference between VIC derived through CT scan and laboratory-derived VIC lies within the range of -37% to 25%. However, the vast majority of values lies within the range of -10% to 10%. This image processing technique to quantify VIC provides a non-destructive analog to traditional laboratory analysis that could help increasing the vertical resolution for quantifying mineral, ice, gas, and organic components in permafrost cores as well as enhancing the volumetric estimate.

EVALUATING HISTORICAL SIMULATIONS OF MPI-ESM FOR KEY PERMAFROST-RELEVANT CLIMATIC VARIABLES IN HIGH NORTHERN LATITUDES

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The representation of permafrost-related processes in Earth System Models (ESM) remains a challenge. A recent synergy between two related projects (Kohlenstoff im Permafrost (Carbon in Permafrost) – KoPf, and Study of the Development of Extreme Events over Permafrost areas – SODEEP) yielded a new vertical structure of the soil column in JSBACH, the land component of the Max Planck Institute (MPI) for Meteorology ESM (MPI-ESM). This feature resulted in a better representation of the vertical soil moisture dynamics and the energy transfer due to soil freezing and thawing, which is particularly relevant for the high northern latitudes. In the present study, we evaluate a historical simulation of this improved MPI-ESM-PF version that was conducted in an AMIP-type setup using prescribed SST and sea ice from an existing CMIP6 MPI-ESM simulation. Our evaluation focuses on an Arctic region consisting of the Pechora Delta and Northwest Siberia.

Although some near surface variables (2m air temperatures and total precipitation) of high northern latitudes are simulated reasonably well with the MPI-ESM, Snow Water Equivalent (SWE) is generally underestimated for the whole terrestrial Arctic. A systematic review of the data representing interaction between near surface climate (hydrometeorological observations and ERA-Interim atmospheric reanalysis) and active layer thickness – ALT (Circumpolar Active Layer Monitoring – CALM, and ESA Permafrost CCI ALT) within the framework of SODEEP project identified patterns of anomalous and extreme climate that precedes the end of season deepening of the active layer. Here, we can identify similar patterns in the MPI-ESM-PF simulation for our focus region. Comparable to the observed increased frequency and intensity of extreme climate events relevant for permafrost dynamics, the MPI-ESM-PF historical simulation also shows a stronger deepening of ALT in the first decades of the 21st century. However, one difference between observations and the MPI-ESM-PF historical simulation is notable. In observations and ERA-Interim reanalysis, the increasing near surface temperature seems to be the major driver of permafrost degradation, while components of the hydrologic cycle can modify the intensity of the end of season thaw deepening. In contrast, a preliminary analysis of the MPI-ESM-PF simulation suggests that precipitation and SWE thickness and extent might have at least an equally important if not even more important role in triggering abrupt soil thawing events.

Careful sensitivity study with JSBACH driven by idealized forcing is needed in order to investigate the role of near surface climate parameters in initiating abrupt soil thawing events. We aim to extend this analysis to high northern latitudes.

ATMOSPHERIC INVERSE MODELING TO EVALUATE PROCESS MODEL SIMULATIONS OF SIBERIAN METHANE FLUXES

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Methane (CH_4) is one of the most important greenhouse gases, but unexpected changes in atmospheric CH_4 budgets over the past decades emphasize that many aspects regarding the role of this gas in the global climate system remain unexplained to date. With emissions and concentrations likely to continue increasing in the future, quantitative and qualitative insights into processes governing CH_4 sources and sinks need to be improved in order to better predict feedbacks with a changing climate. Particularly the high northern latitudes have been identified as a potential future hotspot for global CH_4 emissions, but the effective impact of rapid climate change on the mobilization of the enormous carbon reservoir currently stored in northern soils remains unclear.

Process-based modelling frameworks are the most promising tool for predicting CH_4 emission trajectories under future climate scenarios. In order to improve the insights into CH_4 emissions and their controls, the land-surface component of the Max-Planck Earth System model, JSBACH, has been upgraded in recent years. In this context, a particular focus has been placed on refining important processes in permafrost landscapes, including freeze-thaw processes, high-resolution vertical gradients in transport and transformation of carbon in soils, and a dynamic coupling between carbon, water and energy cycles. Evaluating the performance of this model, however, remains a challenge because of the limited observational database for high Northern latitude regions.

In the presented study, we couple methane flux fields simulated by JSBACH to an atmospheric inversion scheme to evaluate model performance within the Siberian domain. Optimization of the surface-atmosphere exchange processes against an atmospheric methane mixing-ratio database is used to identify the large-scale representativeness of JSBACH simulations, including its spatio-temporal variability in the chosen domain. The impact of the selected model parameter settings on the agreement between bottom-up and top-down techniques was tested, therefore highlighting how sensitive regional scale methane budgets are to dominant emission sources and processes.

REMOTE SENSING OF PERMAFROST LANDSCAPE CHANGE IN THE LENA DELTA REGION USING MULTISPECTRAL TIMESERIES AND SPATIALLY VERY HIGH-RESOLUTION CHANGE DETECTION

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In this presentation, we summarize our remote sensing activities in the Lena Delta region that focus on understanding and quantifying landscape changes in recent decades. In particular, we will highlight the great value of Landsat and Sentinel-2 based trend datasets allowing unique insights into delta-wide permafrost and fluvial landscape dynamics since the 2000s in high spatial detail (30 m resolution). Process dynamics that can be observed include thermokarst lake expansion and drainage, channel shore erosion and channel migration, and thaw slumping (Fig. 1). We also use high-resolution (~0.5 m) optical imagery from commercial sensors (WorldView-1, WorldView-2, and GeoEye) in combination with historical (1960s-1980s) Corona and Hexagon imagery to quantify erosion and thaw slumping dynamics along lake and river shorelines in the Lena Delta and surrounding areas. Focus areas are the Sobo-Sise, Kurungnakh, and Samoylov Islands as well as the Bykovsky Peninsula.

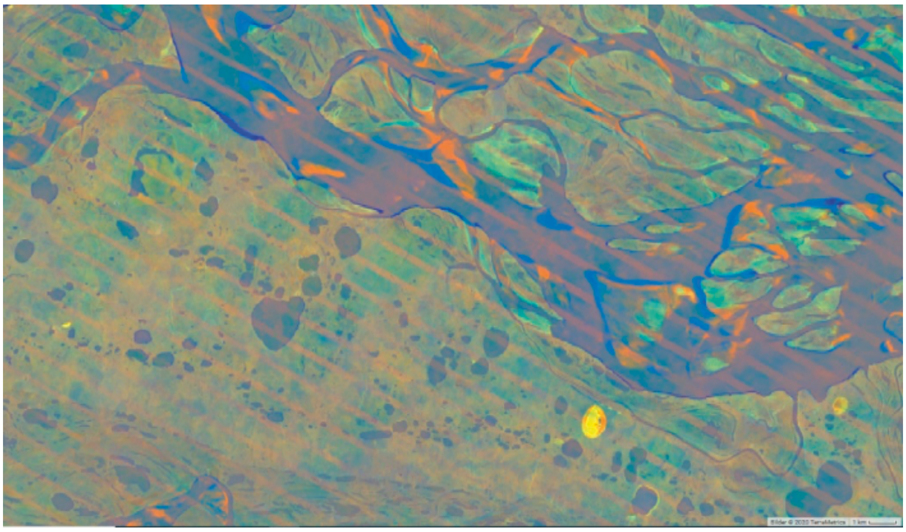

Fig. 1: Tasseled Cap Trend Visualization for the years 2000-2018 over the central part of Sobo-Sise Island and Sardakhskaya channel in the Eastern Lena Delta. Yellow: Lake Drainages; Blue: Erosion; Orange: Deposition.

GEOCHEMICAL FEATURES AND MOLECULAR COMPOSITION OF HUMIC ACIDS ISOLATED FROM LAKE SEDIMENTS OF THE LENA DELTA

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Lake sediment is a natural deposit matrix and its geochemical characteristics help to estimate the integral condition of an aquatic ecosystem. Humic substances are a ubiquitous type of organic matter in terrestrial and aquatic ecosystems. Transformation of organic matter in north permafrost-affected aquatic ecosystems proceeds under specific climate conditions that affect processes humification and mineralization of organic matter consequently its elemental and molecular composition. The predominant fractions of humic substances are humic acids (HAs). They actively interact with organic and inorganic sediment components, particularly, with potentially toxic elements. The formation of organo-mineral compounds of trace elements with humic acids is one of the most important mechanisms in their fixation in sediments of water bodies and other natural environments. However, chemical features of HAs-metal compounds depend on the molecular structure of the acids and the type of metal ion.

This work focuses on the investigation of the molecular composition of Humic acids extracted (the method of IHSS) from the sediments of 13 lakes located within the Lena delta. The studied lakes have different origins and flood regimes. We identified typical molecular fragments of HAs using modern instrumental methods (nuclear magnetic resonance spectroscopy (CP/MAS 13C-NMR)). Analysis of the humic acids showed that aliphatic compounds prevail in the organic matter of all lakes but the low aromaticity of the HAs indicates low stabilized sediment organic matter. Furthermore, we analyze the proportion of oxygen-containing fragments carboxyl (– COOR), carbonyl (–C=O), –C–OR alcohols, esters. These fragments actively react with microelements.

Acknowledgements

Research is supported by a research grant of the Russian Foundation of Fundamental researches №18-05-60291. Field materials were collected during the Russian-German expedition “LENA 2019”.

The laboratory analyses were conducted in St. Petersburg State University Research Park: “Magnetic Resonance Research Centre”, “Chemical Analysis and Materials Research Centre”.

ANIMAL HUSBANDRY IN PERMAFROST REGIONS OF SIBERIA AND NORTHERN MONGOLIA: HOW PERMAFROST HAS SHAPED THE ECOLOGICAL CONDITIONS FOR PASTORAL FORMS OF LAND USE, AND HOW THE LATTER INTERACT WITH PERMAFROST DYNAMICS

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The interrelation of animal husbandry and permafrost in Eurasia has thus far been perceived in a unidirectional way: it is usually assumed that permafrost degradation will have strongly negative impacts on reindeer herding, cattle farming and other forms of local (so-called traditional) land use. However, novel research investigates the ways that herbivores, including reindeer and cattle, exert an influence on vegetation, snow cover, albedo, and consequently on permafrost. As founding members of the IPA Action Group "Permafrost and Culture" (2014-2018), we are investigating the links between permafrost dynamics and local forms of land use in the context of socio-economic and climate change.

Central Yakutia is arguably the region where the interaction of permafrost and land use has been studied best – in terms of time span and level of detail. The Action Group could build on long-standing cooperation with researchers in Yakutsk and international partners. Central Yakutia is an exemplary region, with *alas* areas as a particular and yet widespread feature of thermokarst processes resulting from climate changes in previous millennia, providing the preconditions for Sakha (Yakut) horse and cattle economy to emerge over the last 500 to 800 years. Hence, permafrost degradation *enabled* a certain form of land use. What is more, Sakha pastoralists actively acquired and ameliorated alas areas as pasture lands and meadows, for example through drainage and selective removal of vegetation. In Soviet times, such changes were induced at larger scale through drainage, irrigation and logging. Thus, land use practices affected and continue to affect landscape and permafrost dynamics (Crate et al. 2017).

Much less is known about the interaction of animal husbandry and permafrost in *Mongolia*. The Action Group organised a workshop in Ulaanbaatar in 2019 to bring together scholars and students in geo-, environmental and social sciences. Most relevantly, permafrost determines the water supplies for the grasslands and pastures upon which livestock herders depend. Without permafrost, vast areas of present-day pasturelands in Mongolia would not exist, given the country's overall arid climate. Similar to adjacent Siberia, pastoralism is an important source of income and subsistence for many inhabitants. In permafrost regions, changes in the landscape and thus in the resource base may proceed rather rapidly and in unprecedented ways. Reversely, animal husbandry (e.g., heavy grazing) and logging have the potential to exert major changes on permafrost – and thus on water resources and local land-use conditions.

Reference

Crate S, et al. (2017). Permafrost livelihoods: a transdisciplinary review and analysis of thermokarst-based systems of indigenous land use. Anthropocene, 18, 89-104.

REMOTE SENSING FOR ASSESSING ABOVE GROUND CARBON STOCKS AND FLUXES IN THE LENA DELTA, RU

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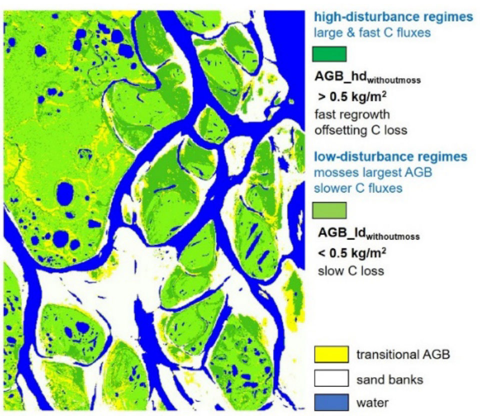
We investigated the applicability of landscape-level remote sensing for assessing above ground carbon dynamics of the tundra landscape of the Lena River Delta in Siberia, Russia. During the LENA2018 expedition, we set up plots for plant projective cover and Above Ground Biomass (AGB). AGB is providing the magnitude of the carbon flux, whereas stand age is irreplaceable to provide the cycle rate. The EU INTERACT Dendro-5 team, Uni Poznán, Poland, sampled shrubs for shrub-ring analyses in 2018. AGB data and shrub age data clearly show a separation between i) low disturbance landscape types with dominant AGB moss contribution, but always low vascular plant AGB (< 0.5 kg m^{-2}) characterised by old shrubs of several decades of stand age versus ii) a much higher vascular plant AGB contribution (> 0.5 kg m^{-2}) with only young shrubs in high disturbance regimes. The low disturbance regimes are represented on the Holocene and Pleistocene delta terraces in the form of azonal polygonal tundra complexes and softly dissected valleys with zonal tussock tundra. In contrast, the high disturbance regimes are sites of thermoerosion, such as along thermo-erosional valleys and on floodplains.

We upscaled AGB and above ground carbon pool ages using a Sentinel-2 satellite acquisition from early August 2018 (Fig. 1). We classified via classification training using Elementary Sampling Units that are the 30 m x 30 m vegetation field plots. We then used the land cover classes and grouped them according to their settings either in high disturbance or low disturbance regimes with each associated AGB value ranges and shrub age regimes. The final AGB product for the central Lena Delta shows realistic spatial patterns of biomass distribution. However, patches of high shrubs in the tundra landscape could not spatially be resolved.



We found that high disturbance regimes with linked high and rapid above ground carbon fluxes are distributed mainly on the floodplains and as patches along thermo-erosional features, e.g., valleys. Whereas the low disturbance landscapes on Yedoma upland tundra and Holocene terraces occur with larger area coverage representing decades slower and in magnitude smaller above ground carbon fluxes.

Fig. 1 Synoptic mapping of Above Ground Biomass (AGB) stocks and fluxes derived from Sentinel-2 Land Cover Classification of the Central Lena Delta, Siberia (state of August 2018).

'SEEING' VEGETATION GREEN-UP AFTER SNOWMELT USING MODIS SATELLITE TIME SERIES IN THE LENA DELTA, SIBERIA

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The Lena River Delta in Siberia is the largest delta in the Arctic and as a snow-dominated ecosystem particularly vulnerable to climate change. In this regional study, we used the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite reflectance for the years from 2001 to 2019 to investigate a possible linkage between the timing of snow melt and subsequent tundra vitality. We approximated snow by the application of the Normalized Difference Snow Index (NDSI), and vegetation greenness by the Normalized Difference Vegetation Index (NDVI), deriving both from the 8-day interval MODIS surface reflectance.

We found snow melt following altitudinal and latitudinal patterns during mid to late May. Earlier landscape-level snow melt occurred in April to early May from 2011 to 2014, whereas the main event of snow cover occurred as late as in June in 2004 and 2017 for large parts of the delta. However, *we only found in two of the six earlier or later snow melt years also a positive or negative deviation of the intensity of the subsequent summer vegetation greenness.*

We complemented the landscape-level **remote sensing analyses locally with** analyses of **air temperature, ground temperature and time-lapse camera images from LTO-Samoylov located in the central delta.** *The highest vegetation greenness in 2018 occurred together with high June temperatures persisting in the weeks after the snow melt. The* **LTO-Samoylov** *record also showed that in all early snow melt years, warm air temperature after snow melt favoured the absence of vegetation-damaging freezing events. Further LTO monitoring could reveal if this may be a re-occurring mechanism for the Lena River Delta region.*

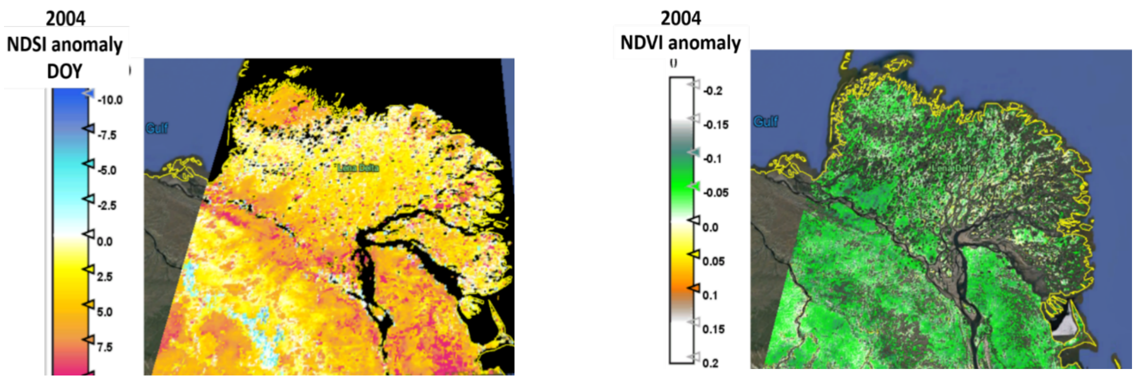

Fig. 1 Left: MODIS NDSI 2004 positive anomaly vs the mean of last 8-Day Of the Year (DOY) period with snow (NDSI > 0.4 indicating snow coverage). The mean snow melt time of a NDSI time series from 2000 to 2019 occurs during the 1st week of May. 2004 was an exceptionally late snowmelt year with the main snow melt in the 2nd to 3rd week of May. Right: MODIS NDVI 2004 negative anomaly (1st week in July) vs the mean (1st week in July) of a NDVI time series from 2000 to 2019. MODIS NDVI 2004 negative anomaly at landscape scales is indicating delayed green-up in the Lena Delta region.

IN SEARCH OF GREENHOUSE GAS EMISSIONS FROM THE PERMAFROST IN NORTH-EAST SIBERIA

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Arctic permafrost soils contain enormous amounts of organic carbon: in the upper three meters, there is more carbon than CO_2 in today's atmosphere globally. At present, this soil carbon is still safely stored at temperatures below 0°C. However, due to warming progresses some of them could thaw, be decomposed by microbes, enter the atmosphere in the form of CO_2 and methane, and thus intensify global warming. This degradation of the upper permafrost could even be relatively abrupt. Alarming reports to this effect (such as references to an Arctic "methane bomb") keep circulating through the press.

How serious is this danger? Reliable, long-term observations of greenhouse gases and their regional sources and sinks are unfortunately very few in the Arctic. Since 2002, the Max Planck Institute for Biogeochemistry in Jena, together with the Russian Northeast Science Station in Cherskii, has been carrying out measurements of greenhouse gas emissions from the permafrost at the lower reaches of the Kolyma River in north-eastern Siberia. Since 2014, these have been supplemented by continuous observations of atmospheric greenhouse gas concentrations at the Russian weather station Ambarchik on the shore of the Northern Sea. These available observations show that the region in the Arctic context is currently still a moderate CO_2 sink and a moderate CH_4 source. We also see no massive increasing trends in emissions from the local permafrost soils at present. However, it is difficult to gauge how this will continue in the future.

The observations provide valuable information on important processes that control greenhouse gas emissions from permafrost soils: in addition to temperature, ice and water content, local vegetation and winter snow depth play an important role. But also the local microtopography and its changes, e.g., through thermokarst processes, are of great importance for the potential release of greenhouse gases from the permafrost. The consideration of these small-scale processes in realistic models of the Earth system represents a major scientific challenge but is indispensable for estimating the development of Arctic greenhouse gas balances in climate scenarios. In parallel, the establishment and long-term operation of an Arctic observing system together with national and international scientific partners is important to accompany the model development and to detect surprises in a timely manner

MICROMODEL: MICROSCALE CONTROLS ON GREENHOUSE GAS PRODUCTION FROM THAWING PERMAFROST

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The relative roles of ancient versus modern microbial community activities in Yedoma permafrost carbon decomposition are unknown. We anaerobically incubated sediments collected from a Yedoma profile in Interior Alaska using two treatments: controls (unaltered sediment) and inoculated with surface sediment containing active CH_4-producing communities from an adjacent thermokarst lake. Using a microscale-level approach, we examined: (1) interaction between thawed substrate and microbial community composition; (2) how mixing modern CH_4-producing communities with microbial communities present in frozen permafrost affects community composition following thaw; and (3) subsequent effects on temperature sensitivity and CO_2 versus CH_4 production. Incorporating this microscale approach into larger models will aid in accounting for the complexities and interactions present in natural systems, and potentially work towards reconciling discrepancies in GHG emissions estimated using experimental versus modelled approaches.

For most depths, inoculation with modern CH_4-producing communities increased CH_4 (7.6 - 390x) and CO_2 (1.0 - 2.7x) production, increased temperature sensitivity (1.0 – 2.2 increase in Q_{10} values), and decreased CO_2:CH_4 ratios (36 – 99 % decrease) compared to controls. The inoculations had the strongest effects in Yedoma sediments that had not thawed since their formation. Coupled with shifts in substrate utilization measured via FT-ICR-MS, this suggests greenhouse gas (GHG) production is microbially-limited.

Interestingly, at our deepest depth (12 m) inoculation decreased CH_4 production by 30% and CO_2 production by 60-70% compared to controls, despite the high initial substrate potentials (high relative abundance of aliphatic and peptide-like compounds) measured via FT-ICR-MS. We suggest proportions of CH_4 produced via hydrogenotrophic versus acetoclastic methanogenesis affected both GHG production rates and proportions of C mineralized as CO_2 versus CH_4 at this depth, and further research is required to constrain why negative priming was observed.

INTER-ANNUAL VARIABILITY OF CO_2 FLUXES ON SAMOYLOV ISLAND

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Permafrost-affected soils in the Arctic have been accumulating organic matter for thousands of years and form a carbon storage of global relevance. Large fractions of this carbon pool may, however, be remobilized in the form of greenhouse gases through the effects of Arctic warming and permafrost degradation. Within several Russian-German cooperation projects, we have been investigating the inter-annual variability of CO_2 exchange fluxes of lowland polygonal tundra on Samoylov Island in the Lena River Delta in the Siberian Arctic (72°N, 126°E) with the eddy covariance technique.

Our results from field campaigns during 16 consecutive years indicate that the polygonal tundra on Samoylov Island is on average a small annual net CO_2-C sink (median: -0.2 g m^{-2} a^{-1}), while inter-annual variability is high (max: 25.9 g m^{-2} a^{-1}; min: -23.6 g m^{-2} a^{-1}). We found that annual CO_2-C balance variability is best explained by the variability in NEE sums of the cold and late growing season (see Fig. 1). Additionally, cold season NEE sums increase with the Arctic Oscillation Index (AOI) and therefore vary with large-scale weather patterns, where a positive AOI denotes rising influence of warm western winds from the Atlantic on Siberia (see Fig. 2).

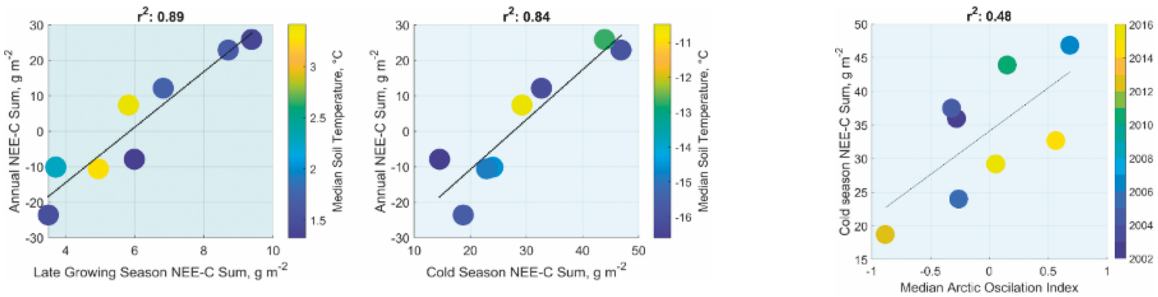

Fig. 1 CO_2-C exchange sums of the late growing (1 Sep to 30 Sep) and cold seasons (1 Oct to 31 May) are good proxies for annual CO_2-C flux sums.

CO_2 AND CH_4 PRODUCTION IN IN-SITU THAWED YEDOMA SEDIMENTS IN THE YUKECHI ALAS, YAKUTIA

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The permafrost organic carbon (OC) inventory is becoming increasingly vulnerable with ongoing climate warming. Deep thaw processes such as thermokarst development can mobilize organic matter (OM) down to tens of meters deep, allowing microbial decomposition. Respiration rates from thawing permafrost are uncertain, as they depend on geochemical, microbial and ecological parameters. We analysed two 17-m-long sediment cores from below thermokarst lakes in Yakutia, Russia: one from a young upland Yedoma lake and one from an Alas lake formed in a Holocene basin. We carried out one-year-long anaerobic incubations at 4°C and measured GHG production biweekly. In addition, we measured the dissolved OC (DOC) content, as well as n-alkanes concentrations.

After one year, the cumulative GHG production was highest in the Yedoma lake core. The higher CO_2 production in the still frozen sediments indicates that the labile OM was preserved here. The highest CH4 production in the talik sediments suggests that methanogenic communities have established upon thaw. OM decomposition during previous thermokarst lake formation likely explains the lower GHG production in the Alas lake sediments. We found that CO¬$_2$ production was highest in samples with a high DOC content and a low n-alkane average chain length (ACL) (Figure 1). Hence, these parameters likely represent a more labile OM fraction. Our parameters could not explain the CH_4 production. We present novel insights that are relevant for mineral-dominated, ice-rich permafrost deposits vulnerable to thermokarst lake formation.

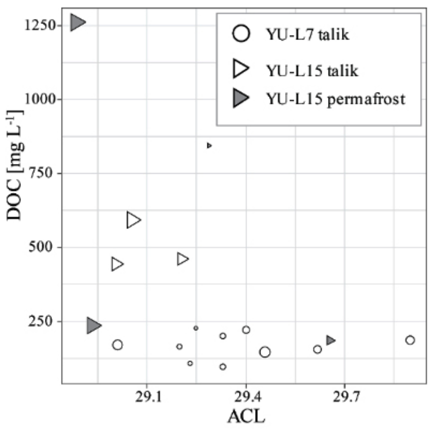

Fig. 1 Relation between the ACL and DOC with the cumulative CO2 production (symbol size)

Acknowledgements

We thank the Deutsche Bundesstiftung Umwelt, ERC PETA-CARB (#338335), and the BMBF (project KoPF, 03F0764A) for financial support.

SEASONALITY IN LENA RIVER BIOGEOCHEMISTRY AND DISSOLVED ORGANIC MATTER

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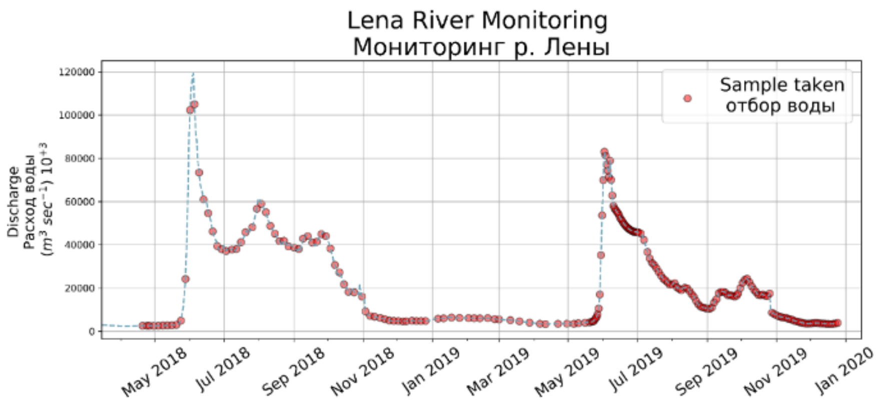
The carbon export by rivers to the Arctic Ocean is expected to increase in response to the rapidly changing climate in the Arctic. Arctic rivers monitoring is necessary to observe changes in the mobilization of dissolved organic matter (DOM) from permafrost. The Lena River delivers approximately one fifth of the total river discharge to the Arctic Ocean and is the main source of DOM in the Laptev Sea shelf. To date, river fluxes of DOM have been based on sparse coverage of sample across the hydrograph about 700 km upstream. The effects of low frequency sampling on load estimates are unknown. Here, we present results from a unique high frequency sampling program (~4 days) and evaluate its viability to monitor export fluxes of DOM and its biogeochemistry in the Lena River.



The sampling takes place close to the river mouth at the Research Station Samoylov Island in the central Lena River Delta. The station allows a unique chance for continuous sampling since it operates throughout the year.

This new dataset represents the first year of a planned long-term monitoring program and provides a reference data set against which future change of this large integrative system may be measured.

GEOECOLOGICAL STUDIES OF THE TUNKINSKAYA DEPRESSION (BURYATIA, RUSSIA)

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The Tunkinskaya Depression is situated in Buryatia western Baikal Lake. Geology of the depression is a paleolake bottom, it had periods of volcanism 10-12 kyr BP. Currently, the Tunkinskaya Depression is a lowland with a sporadic permafrost, the local landscapes have been changed due to irrigation (drying for agriculture during the second part of XX century) with wetlands recovering in the last 30 years. First observations of the Tunkinskaya Depression’s specific overwatering were carried out. Geophysical, hydrological and peat studies had been made in 2020 in addition to the previously obtained soil sample and data on temperature dynamics since 2011. Borehole automatic soil temperature loggers have 3.2-5 m depth. The temperature varies in the range of -0.5/-3.5 °C during the year (mainly wetlands) in the areas of isolated permafrost. In summer, the depth of the active layer does not exceed 1-1.2 m.

Ground Penetrating Radar (GPR) profiles clearly show the permafrost table on 60-65 cm around the studied lake with wetland catchment and 90-95 cm – in forest landscape nearby a river. Permafrost bottom has been determined by GPR at the depth of about 5 m. GPR measurements are confirmed by the drilling results. However, anthropogenic modified soil and burned landscapes do not have a permafrost table in 10-15 m according to the geophysical (GPR) data.

Koymorskiye wetlands are characterized by mineral groundwater springs that effect on plant cover and, therefore, peat deposit type. Salt water welling up can easily be recognized due to the loss of the georadar signal that had been supported by measurements of aquifer electrical conductivity. So, at the edge of the forest (the boarder of overwatered lake catchment), aquifer mineralization was 417 mg/l, between the lake and the forest in the swampy area - 1056 mg/l, closer to the lake - 206 mg/l, and in the lake itself - 150 mg/l. According to the groundwater income, the lake has a quite good cycling; nutrients from peatland catchment support the intensive growth of macrophytes, water oxidizing and ecosystem self-cleaning. The peat thickness varies from 20-30 cm in the margin of the catchment and reached 63 cm – in a central part near the overgrown lake. The wetland got a sandy bottom. Peculiarities of mineral nutrition support fen peat accumulation. The decomposition of peat is 35-40%. Peat accumulation had two stages. The upper layer of peat (0-13 cm) is characterized by the predominance of lesser tussock sedge *Carex diandra* in plant remnants. Peat deposits consist of different sedges, grasses and green mosses. Sedge peat and hypnum moss-sedge peat were identified. Paleoecologic conditions were rather similar during the peat forming period. Investigations of Koymorskiye wetlands in the Tunkinskaya Depression will be continued. Changes of permafrost table and active layer thickness due to climate change or/and anthropogenic impact caused the recent landscape transformation as well as some dynamics of the water regime of the studied area.

Acknowledgements

Field studies of 2020 were carried out with the financial support of Rosneft Oil Company (donation agreement from 21.06.2019).

IMPACT OF MICROCLIMATIC AND LANDSCAPE CHANGES ON THE TEMPERATURE REGIME AND THAW DEPTH UNDER A FIELD EXPERIMENT IN THE BOLSHEZEMELSKAYA TUNDRA

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To assess the impact of microclimatic and landscape changes on the temperature regime and thaw depth in permafrost-affected soils of subarctic ecosystems at the southern permafrost limit of the European Northeast, a field experiment has been conducted. To carry out the field experiment in 2012 in various types of tundra landscapes (vegetated surfaces of peat mounds and watershed terraces, peat circles), 15 transparent open top chambers were installed. Under the experiment conducted in 2016-2018, local temperature changes above the surface (height 5 cm) and in the upper soil layer (depth 20 cm) were studied. The change in quantitative parameters of landscape components (vegetation height, snow thickness, leaf surface index, soil moisture, the depth of the permafrost upper-water level) affecting the thaw depth was studied.

The use of transparent open-top chambers during the field experiment proved to be quite effective for assessing the changes in the local climatic, landscape and soil-geocryological conditions in the sites located in the southern permafrost zone of the Russian European Northeast.

It was revealed that in the chamber contours, the winter and summer temperatures above the surface and in the upper soil layer, the vegetation height, and snow thickness statistically significantly increase. Under experimental conditions, mean annual air temperature, thawing degree days, and especially freezing degree days, increase above the soil surface. On the experimental sites, the number of temperature transitions through 0 ºC over the soil decreases in the summer and autumn periods. In the active layer of permafrost-affected soils, the autumn period of «zero curtains» is reduced. An increase in snow accumulation during the experiment enhances the protection of tundra shrub vegetation from cold winter air. Therefore, under experimental conditions, the height of the shrub layer increases in vegetated areas of the tundra.

During the field experiment, mitigation of microclimatic conditions, increased snow accumulation and growth of tundra shrub vegetation resulted in a temperature increase and thickening of the active layer. In the south of the regional Cryolithozone, the predicted climatic and landscape changes will contribute to a significant increase in soil temperature. Permafrost-affected soils of peat circles and the loamy watershed sites are the most vulnerable to microclimatic and landscape changes.

Acknowledgements

The study was supported by RFBR project № 18-55-11003.

A NOVEL APPROACH TO PROCESS-ORIENTED CRYOTURBATION MODELLING

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High-latitude permafrost soils store about 727 Pg organic carbon (C), from which around 454 PgC are stored in turbels, a main permafrost soil type that is characterized by specific soil movements due to freezing and thawing cycles that are collectively referred to as cryoturbation. Cryoturbation effectively transfers organic material from the topsoil to lower soil layers where it can be stored for long periods, leading to those major C stocks. While the importance of cryoturbation within the high-latitude C cycle is known, a detailed understanding of the dynamics of the underlying processes is still lacking.

To overcome this knowledge gap, we aim for a 2D cryoturbation model at pedon scale. Here, we present our conceptual ideas and very first results from our several approaches: (1) a 2D model for soil temperature and hydrology with a resolution of less than 10cm to better represent soil heterogeneity, (2) the inclusion of excess ice and the effect of ice formation on soil, (3) vertical and lateral soil movement due to freezing and thawing.

MICROBIAL COMMUNITY RELATED TO OBSERVED HIGH N_2O EMISSIONS FROM THAWING YEDOMA PERMAFROST

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While the crucial importance of CH_4 and CO_2 release from thawing permafrost and the feedbacks to the atmosphere are well recognized, the role of Arctic ecosystems as a source of the strong greenhouse gas nitrous oxide (N_2O) has been overlooked. Although increased N_2O emissions have been observed after permafrost thaw (Elberling, Christiansen and Hansen, 2010; Voigt *et al.*, 2017; Yang *et al.*, 2018), very little is known about the microbial communities behind these N_2O emissions. Here, we studied the abundance of functional genes participating in soil nitrogen (N) cycling and related microbial community composition to gain understanding of N_2O dynamics from a thawing ice-rich Yedoma permafrost exposure in the Lena River Delta. We quantified the abundance of key nitrifier (bacterial and archaeal *AmoA*) and denitrifier (*nirS*, *nirK*, *nosZ*) genes with qPCR amplification, and studied the community structure of N cycling microbes by targeted metagenomical sequencing (Aalto *et al.*, 2020) of the organisms carrying genes involved in N_2 fixation, nitrification, nitrate (NO_3^-) reduction, denitrification, and dissimilatory nitrate reduction to ammonium (DNRA). Our results show that the abundance of bacterial ammonia oxidisers is low in recently thawed Yedoma, indicating suppressed nitrification and thereby also denitrification, which is tightly coupled with nitrification via NO_3^- supply. The microbial limitation of the nitrification-denitrification processes is released over time in N rich Yedoma permafrost, seen as increasing abundance of bacterial *amoA* genes in earlier thawed and revegetated Yedoma sites. Simultaneously, the relative abundance of the nosZ gene, encoding N_2O reductase, decreases in relation to the denitrifier genes *nirK* and *nirS* (increasing *nir*/*nosZ* ratio), meaning that more N_2O is produced in denitrification compared to atmospherically inert N_2. These changes in microbial community composition clearly reveal how the recovery of microbial functioning after thaw supports N_2O release from Yedoma permafrost, providing the first *in situ* evidence for the functional limitation of N cycle in freshly thawed Yedoma, earlier shown in laboratory (Monteux *et al.*, 2020). Better understanding on N cycling processes and microbial controls on N_2O production and consumption in thawing permafrost is needed to estimate the climate feedbacks associated with permafrost N.

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CARBON DIOXIDE AND METHANE RELEASE FOLLOWING ABRUPT THAW OF PLEISTOCENE PERMAFROST DEPOSITS IN ARCTIC SIBERIA

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The decomposition of thawing permafrost organic matter to carbon dioxide (CO_2) and methane forms a positive feedback to global climate change. Abrupt permafrost thaw affects only a small part of the permafrost region but may contribute almost 50% to future carbon emissions from thawing permafrost. Data on in situ CO_2 and methane fluxes from thawing permafrost are scarce, and organic matter degradability is highly uncertain. Therefore, projections of future greenhouse gas release largely depend on laboratory incubations. However, their representation of in situ fluxes remains unclear. This study combines in situ CO_2 and methane emission measurements from permafrost deposits affected by abrupt thaw with laboratory incubations and dynamic modelling. In situ CO_2 fluxes of 0.49 - 2.7 g CO_2-C m^{-2} d^{-1} and 0.76 - 1.7 g CO_2-C m^{-2} d^{-1} were measured during the first year and three years later, respectively. When normalizing CO_2 fluxes to thawed organic carbon, a decrease in CO_2 production was detected, indicating a depletion of the initial labile carbon pool. While all sites were CO_2 sources, methane was emitted only from four sites with mean rates between 6.5 and 15.8 mg CH_4-C m^2 d^1. The absence of methane emissions could be explained by efficient methane oxidation and a lack of active methanogens in the permafrost. In situ CO_2 emission accounts for a decomposition of about 1% of thawed carbon over one thawing season. Short-term laboratory incubations substantially overestimate in situ CO_2 fluxes but generally underestimate in situ methane fluxes. In contrast, a dynamic decomposition model, calibrated with long-term incubation data from the same deposits, simulates a similar amount of CO_2 production as observed under in situ conditions. Hence, field observations combined with long-term incubation data provide meaningful rate constant parameters for dynamic models, which are used to project future greenhouse gas fluxes from abrupt permafrost thaw.

MICROMORPHOLOGY OF QUARTZ GRAINS IN SEDIMENTS OF ABALAKH PLATE, CENTRAL YAKUTIA

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In this study, we examine sediments for the Pleistocene and Holocene environments of Abalakh plate in Central Yakutia. The Abalakh plate is characterized by ice-rich permafrost deposits called "Ice complex" or "Edoma". Its origin is still a controversial subject for discussion. The concepts, widely discussed in the literature are: slope waterborne sediment movement (*Ivanov M.S., 1984*), lacustrine and alluvial (*Soloviev P.A., 1961*), aeolian (*Tomirdiaro S.V., 1980*) and polygenetic origin (*Agadhzanyan A.K., et al., 1973*). In order to reproduce the conditions under which sediments were transported, a 94,5 meters profile was subjected to analyze rounding and grain surface micromorphology under scanning electron microscope (SEM). The micromorphology of the quartz grains shows traces of a fluvial environment with different dynamics: from river flow to stagnant lake. The study of the surfaces of the quartz grains shows that the source is processed river flow sediments, the surface of the quartz grain has signs of intensive fluvial abrasion as well. In the transport and accumulation process, additional material was involved, presumably from bedrock by water flow. A detailed micromorphological analysis of quartz grains from the Ice complex shows loam (19,75-20,30 m) effects of frost weathering were observed on the grain surfaces. Afterwards, these particles were transported with wind and accumulated in stagnant lake. Thus, results of analyses of the micromorphological structure of quartz grain surfaces indicate the significant role in grain processing is fluvial processes in generally along the profile.

Acknowledgements

The reported study was funded by RFBR and NSFC according to the research project №18-55-53054.

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METHANE FLUX DYNAMICS ACROSS TEMPORAL SCALES AT POLYGONAL TUNDRA OF THE SIBERIAN LENA RIVER DELTA

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Increased methane (CH_4) release from a warming Arctic is expected to be a major feedback on the global climate. However, due to the complex effects of climate change on Arctic ecosystems, projections of future CH_4 emissions are highly uncertain. At the same time, empirical data covering the pronounced temporal variability of CH_4 fluxes is rare due to the logistic and technical difficulties associated with experimental investigations in the Arctic. Here, we present multi-annual CH_4 flux data from polygonal tundra in the Siberian Lena River Delta (72.4° N, 126.5° E), which was recorded by the eddy covariance method during 16 campaigns between 2002 and 2019.

The average annual CH_4 emission was estimated as 175 ± 30 mmol m^{-2}. About 60% of this emission derived from the thaw season (June to September). The explanatory power of relevant flux drivers varied with temporal scale. CH_4 fluxes were characterised by a moderate diurnal course related to the diurnal variability of atmospheric turbulence strength as indicated by the friction velocity. Also on the time scale of synoptic weather events (several days), friction velocity was an important flux driver since CH_4 flux bursts were associated with stormy conditions, especially during the autumn freeze-back period. CH_4 fluxes during the cold season (October to May) were well correlated with carbon dioxide fluxes (R^2 = 0.78), indicating a physical release of gas stocks that accumulated during the growing season. During the first part of the thaw period, from June to August, soil thaw depth showed strong explanatory power on the CH_4 flux (R^2 = 0.73). The annual-scale variability was best explained by soil and air temperatures (R^2 > 0.8) as fundamental controls of physiological processes of soil microorganisms and plants. Similarly high explanatory power was obtained with air temperatures from meteorological reanalysis data, thereby indicating potential for large-scale modelling. The inter-annual variability of summer peak emissions (comparison period: 1st July to 15th September) was positively linearly correlated with soil temperature at 30 cm depth in wet polygon centres (R^2 = 0.76).

Our findings suggest that a warmer Arctic climate stimulates the production of CH_4, which is directly reflected in increased CH_4 emissions. On the other hand, warming effects on CH_4 oxidation appear limited because transport processes that bypass the soil oxidation zone, i.e., plant-mediated transport and ebullition, dominate CH_4 emission from wet tundra landscapes.

THE ARCTIC PERMAFROST GEOSPATIAL CENTER – A PORTAL FOR HIGH-QUALITY OPEN ACCESS SCIENTIFIC DATA RELATED TO PERMAFROST IN THE ARCTIC

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Thematic Open Access data portals foster and support an open data culture in order to reduce knowledge gaps and data uncertainty. We here present the Arctic Permafrost Geospatial Center (APGC), which provides open access, high-quality geospatial data in the field of permafrost research. The distribution and easy access of a wide range of data products supports multi-scale and interdisciplinary analysis of combined field, remote sensing and modelling permafrost data.

The APGC mission is (i) to provide data that is of high usability, significance and impact, and (ii) to facilitate data discovery, data view and metadata documentation and exchange via the APGC Data Catalogue at https://apgc.awi.de/.

The catalogue structure can host a variety of data models of varying themes, format, spatial and temporal extents. Data can be searched by location – using spatial keywords or by interactively selection locations on a base map. Data can further be searched by category, product type, project, tags, keywords, license type, or data format. Data can be downloaded directly via link to the publishing data repository such as PANGAEA.

The Data Catalogue is based on the open source CKAN data catalogue architecture, which uses the metadata standard DCAT. Data is documented according to the fair data principles. Each catalogue entry has a data abstract, data preview and extensive metadata that can be accessed in RDF/XML-, JSON- or Turtle-format.

APGC, initially supported by the ERC PETA-CARB and the ESA GlobPermafrost projects, currently features over 200 selected datasets from these and several other projects. Data products provide information about surface and subsurface permafrost characteristics in the Arctic, Antarctica, or mountain permafrost areas, e.g. soil temperatures, soil carbon, ground ice, land cover, vegetation, periglacial landforms, subsidence and more. Data include in situ measurements, earth observation, and modelling and are provided in vector or raster format. Collections of datasets allow users to easily get an overview of the spatial distributions of datasets or their availability in different formats. A WebGIS application is available for most of these data sets, which allows users to explore the data interactively (https://maps.awi.de).

APGC invites submissions from both individual users as well as project consortiums. New data submissions to the catalogue are evaluated according to the following access criteria: permafrost focus, significance and impact, access, quality, and metadata. APGC datasets must be archived in a long-term repository such as PANGAEA to provide easy user access and guarantee long-term availability.

COMBINATION OF ICE AND WIND EROSION IN DELTA LANDSCAPE DESERTIFICATION (EASTERN SIBERIA)

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About two thirds of the Lena Delta islands are presented by the first terrace surface elevated about 6-10 meters above sea level with well-developed polygonal relief (Grigoriev, 1993; Schwamborn at al., 2002). Geologically, these islands consist of composite deposits formed by numerous layers of sand, intervened by layers of coarse peat-like plant remnants. The vegetation of these islands is complex and strictly depends on micro relief features. Green moss tundra develops on rims and convex polygons, but concave polygons are covered with water vegetation on green moss mires depending on water content. The richest plant communities in terms of vascular plant species diversity inhabit a narrow stripe close to the terrace cliff. Here, vegetation is presented by Dryas tundra with up to 35 vascular plant species per 100 square meters. Species composition includes some plants of dry habitats (*Kobresia myosuroides*, *Coeloglossum viride* etc.) and indicates the driest conditions on the terrace. It could be explained by overdrainage caused by the vertical cliff surface exposed to the wind and sun. This statement is perfectly in line with the depth of an active layer.

In the course of vegetation survey in this stripe near the cliff, we found few spots of rectangular form with naked ground and hillock of the removed substrate at the inland end of the spot. These spots are made by the ice blocks in early spring. In times of high water, ice blocks are pumped up and pushed inland by the river. On the way, they bulldozer the surface layer with vegetation and leave naked ground behind. If the surface layer underlying vegetation consists mainly or exclusively of sand in this overdrained position, sand quickly dries out and becomes the subject of eolian transportation. Shortly after, a small dune field appears and moves inland burying vegetation underneath. With time, vegetation recolonized this spot, but in the form of a specific psammophitic community. There are very few obligate psammophytes in floristic composition of such communities, but many typical tundra plants react on these conditions by changing life forms or "inventing" new survival strategies. It means that dune fields are rather new in Lena Delta environment, and there was not enough time for specialized plant species to evolve or to colonize these habitats.

Careful analysis of the high-resolution satellite images showed that small dune fields are quite common throughout all first terrace islands in Lena Delta. They can be considered as initial points of wind erosion and sand desert formation in the course of global warming. Moreover, global warming will cause early ice break in Lena headwaters and high water pressure, which will pump up ice blocks higher and deeper inland, creating more disturbances than now. It seems that joint action of ice and wind on sandy islands in Lena Delta could be a growing problem in the conditions of climate changes, leading to landscape desertification and formation of Arctic sand deserts.

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SUPRAPERMAFROST TALIKS IN CENTRAL YAKUTIA

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The study aims at the assessment of the distribution, seasonal and interannual dynamics of suprapermafrost subaerial taliks in Central Yakutia. We collected soil temperature and groundwater level data in different landscape and geomorphological conditions in the Shestakovka river basin near Yakutsk city, Eastern Siberia, in a continuous permafrost zone for the period 2016-2020. According to the drilling information, geophysical surveys, ground temperature and hydrogeological monitoring, suprapermafrost subaerial aquifers are widespread in the studied small river basin with an area of 170 sq. km. Taliks are found in sparse pine forests on gentle slopes composed of sandy deposits. Annual ERT measurements have shown that the geometry of thawed zones in the same seasons practically coincides from year to year.

The wide distribution of taliks in the small river basin suggests significant talik fraction in similar landscape-geomorphological conditions in the territory of Central Yakutia. The published assessment of the talik fraction for the territory varies from 0.07 to 4.7%. It was believed that taliks are associated with the fraction of lakes. We revealed a wide distribution of suprapermafrost subaerial taliks in the pine forests of the western part of Central Yakutia in the area from Yakutsk to Vilyuisk at a distance of more than 360 km. Taliks were found at nine profiles out of 37 by means of GPR sounding. If we assume that the revealed proportion of suprapermafrost taliks on the studied profiles (24%) is representative for the vegetation type "dwarf and subshrub-green moss pine-larch forests", that occupy 26% along the federal road between Yakutsk and Vilyuisk, then the talik fraction of the region is more than 6% only due to subaerial taliks. This rough estimate does not include lake and river taliks and significantly exceeds the previously published information on the talik fraction of the region.

HOW TO BRING THE POLAR REGIONS AND PERMAFROST INTO THE CLASSROOMS

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The polar regions are rarely discussed in schools. However, as they are a hotspot of climate change, young people need to learn more about these areas. This is particularly true for the phenomenon of permafrost. **Polar Educators Germany** is a nationwide network which cooperates with the scientific polar community. The members are engaged in teaching polar issues in schools. Educators can train on polar expeditions, among other activities, and pass on their experiences to colleagues and students. Numerous new teaching materials on polar topics in different subject areas have been produced. But there is a lack of new teaching materials on permafrost apart from individual great approaches such as the Frozen-Ground Cartoons. Therefore, the permafrost community is encouraged to take Polar Educators on expeditions. Such cooperation brings the topic of permafrost into the focus of schools and creates new teaching materials. These are to be promoted in particular in connection with global warming, permafrost degradation, methane outgassing and the associated positive feedback. Scientists can thus present and communicate their work to a wider public and especially to the younger generation. They can help train teachers at Polar Educators Germany meetings and can learn from them how to communicate their scientific questions, methods and results to young students in an appropriate way.

MICROBIAL CONTROLS ON THE FATE OF METHANE ALONG A THERMOKARST LAKE TO LAGOON TRANSITION

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Greenhouse gas (GHG) emissions from abrupt thaw beneath thermokarst lakes were projected to at least double radiative forcing from circumpolar permafrost-soil carbon fluxes by the end of this century, primarily through the release of methane, a much stronger GHG than CO_2. Thermokarst lagoons represent the first stage of a thermokarst lake transition to a marine setting with so far neglected consequences for GHG production and release. We expected that along the transition from a thermokarst lake to a thermokarst lagoon, sediment concentrations of terminal electron acceptors like sulfate increase with an associated drop in methanogenic activity, a shift towards non-competitive methylotrophic methanogenesis, and the occurrence of sulfate-driven anaerobic methane oxidation (AOM). To explore this, we targeted a variety of geochemical and microbial parameters including sediment methane and CO_2 concentrations, gaseous carbon isotopic signatures, hydrochemistry, GHG production rates, ratios of CH_4/CO_2, and occurrence of methane-cycling microbial taxa in sediments of two thermokarst lakes and a thermokarst lagoon on the Bykovsky Peninsula located in northeastern Siberia adjacent to Tiksi Bay. We found multiple lines of evidence that AOM in sediment layers influenced by Tiksi Bay water (i.e. the lagoon) functions as effective microbial methane filter. Annually, the lagoon is decoupled from Tiksi Bay for more than six months, resulting in more saline conditions below the ice cover compared to Tiksi Bay. Despite sub-zero near-surface sediment temperatures for approximately nine months per year, we show that, at least in early spring, AOM led to near-surface sediment methane concentrations approximating only about 1% of those measured in near-surface thermokarst lake sediments. Structural equation modelling stresses pore-water chemistry and increases in anaerobic methanotrophic abundance as main controls for the drop of in-situ methane concentrations and the corresponding increase in carbon isotopic signature. Shallow sediment layers (i.e. younger carbon) corresponded with higher rates of potential methane production, especially in the non-lagoon settings but even in the lagoon, potential methane production rates in the surface sediment layers were relatively unaffected by the marine influence. We propose that this reflects the overall dominance of non-competitive methylotrophic methanogenesis independent of pore-water chemistry and sediment depth. Overall, our study suggests that thermokarst lake to lagoon transitions have the potential to offset atmospheric methane fluxes from abrupt thaw lake structures long before thermokarst lakes fully transgress onto the Arctic shelf.

THE RESPONSE OF THE GAS HYDRATE ASSOCIATED WITH SUBSEA PERMAFROST TO CLIMATE CHANGES

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We present an assessment of changes in the gas hydrates stability zone of the Arctic Ocean associated with subsea permafrost conditions. To evaluate the formation and dissociation of gas hydrates under the climatic conditions of the last glacial cycle, it is necessary to understand how the thickness of the permafrost has changed after flooding by the sea. To do this, we have combined two numerical models: a model of permafrost dynamics based on the paleoclimatic scenario of changes in temperature and ocean level, and a model of the methane hydrates stability zone (MHSZ). Calculations of changes in the thickness of the submarine permafrost and the MHSZ were carried out for the period of 120 thousand years. The following is an assessment of changes in the stability of methane hydrates under the influence of the climate change for the period of 1948-2015. Our results show that, although changes in the bottom water temperature over the last-decades period affect the hydrate stability zone, the main changes with this zone occur after flooding the Arctic shelf with the seawater. As a result of the combined simulation of the permafrost and state of MHSZ, it was found that in the shallow shelf areas (lower 50 m water depth) after flooding, the hydrate presence conditions in the upper 100-meter layer of the MHSZ are violated. This suggests that the methane coming from this reservoir is concentrated in the bottom sediments of the shelf, and then released into the water, continuing to adapt to changing sea levels, rising bottom water temperatures, and subsea permafrost melting.

ASSESSMENT OF THE SUBSTRATE POTENTIAL OF TERRESTRIAL PERMAFROST DEPOSITS FROM NE SIBERIA FOR MICROBIAL GREENHOUSE GAS PRODUCTION

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For an improved understanding of the impact of thawing permafrost on future climate evolution, it is important to get a better insight into the composition of permafrost stored organic matter (OM) and to assess its potential for microbial greenhouse gas production.
Our investigation was part of the CarboPerm project funded by the BMBF and was an interdisciplinary Russian-German cooperation on the formation, turnover and release of carbon from North Siberian permafrost landscapes. Sample material derived from Buor Khaya Peninsula and Bol´shoy Lyakhovsky Island in the NE Siberian Arctic.
Here, we introduce a new approach for the assessment of the quality of the OM using OM pyrolysis to assess the aliphatic vs. aromatic character and by determining low molecular weight acids (LMWA) being excellent substrates for methanogenesis.
Increased past microbial life within the permafrost sequence is linked to periods of higher terrestrial OM accumulation, often showing an increased aliphatic character. Emian interglacial deposits are low in OM amount and quality, which might be the result of intense degradation during time of deposition.
Yedoma intervals with high OM accumulation are often rich in substrate LMWAs. Thus, this freeze-locked permafrost material appears to be not much different in terms of LMWA than younger surface OM from active layers. Therefore, the future potential for greenhouse gas generation from permafrost deposits seems to depend on the quality and amount of the stored OM rather than on the age (Stapel et al., 2016). First microbial degradation experiments indicate higher CO_2 generation from aliphatic rich OM.

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THAWED YEDOMA PERMAFROST AS A NEGLECTED N_2O SOURCE

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In nitrogen (N) limited northern ecosystems, N released at permafrost thaw represents an invaluable resource that may be used for plant growth or microbial biomass, but it may also support production of the strong greenhouse gas nitrous oxide (N_2O). Despite accumulating evidence on increased N_2O emissions after permafrost thaw, post-thaw N_2O fluxes from ice and N-rich Yedoma permafrost have never been studied. Here, we measured N_2O emissions across two thawing Yedoma exposures in Northeast Siberia: Kurungnakh located by Lena River, and Duvanny Yar located by Kolyma River. To gain insights on the environmental and microbial controls behind the fluxes, we collected data on mineral N pools (both sites), as well as soil N transformation rates and composition of the microbial community responsible for key functions of the soil N cycle (Kurungnakh).

While N_2O fluxes from vegetated Holocene cover and freshly thawed Yedoma varied from negligible to small, emissions from earlier thawed sites revegetated by pioneering plants reached high rates ─ up to two orders of magnitude higher than those typically measured from permafrost-affected soils. High ammonium (NH_4^+) content and gross N mineralization rate in freshly thawed Yedoma indicate high bioavailability of Yedoma N and, thus, high potential for N_2O production. According to our results, this potential is actualized within less than a decade with drying, steady supply of mineral N from organic matter mineralization followed by nitrification, and establishment of microbial community capable of N_2O production. At the same time, permafrost thaw keeps supplying new, N-rich organic matter to the system. With warming, this supply is expected to increase, with important consequences to biogeochemistry at local to regional scales, and feedbacks to climate.

RADIOCARBON SIGNATURES OF DOC AND POC IN SMALL WATER BODIES AND STREAMS OF KURUNGNAKH AND SAMOYLOV ISLANDS

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Ponds and lakes make up roughly 16% of the total surface area of permafrost landscapes. Moreover, they receive large quantities of dissolved organic matter via groundwater infiltration into the thawed surface, the active layer of permafrost deposits. Erosion along the banks of thermokarst lakes additionally supplies considerable quantities of particulate organic matter to these water bodies. Outflow streams carry parts of this organic matter to the large rivers draining the permafrost landscapes, like the Lena River in Eastern Siberia. Dissolved organic matter released from thawing Pleistocene permafrost deposits, Yedoma, has been reported to be highly bioavailable and is readily oxidized in meltwater streams. On Samoylov Island, lakes and ponds were found to account for large fractions of the net landscape-scale CO_2 emissions, attributed to losses of dissolved carbon from these water bodies. On the other hand, lakes in the arid interior of Alaska were found to have a negligible role in mineralizing terrestrial carbon.

We investigated concentrations and radiocarbon signatures in interconnected networks of ponds, lakes and streams in the Yedoma and the outflow to the Lena River on Kurugnakh Island, as well as a series of polygon ponds, lakes and streams on the first terrace, crossing the floodplain and near the outflow to the Lena on Samoylov Island in two consecutive summer seasons (August 2016 and July 2017). We find strongly contrasting patterns of concentration changes and variability in radiocarbon signatures of both carbon pools between the first and the third terrace systems of the Lena Delta.

On Samoylov Island, highest concentrations of DOC (around 5 mg/L) coupled with DOC ^{14}C levels of ~+50 ‰ above the modern atmospheric value were found in polygon ponds, while both concentrations (~3 mg/L) and ^{14}C levels (-11 to +11 ‰) are lower in North and Katya Lakes and outflow streams. An increase in DOC concentration is observed after the crossing of the floodplain. POC concentrations are generally low, and their ^{14}C values are more variable and more depleted than those of the corresponding DOC. This pattern indicates input of DOC from decadal aged deposits from the active layer to the polygons and a dominance of autotrophically fixed carbon in the lake and stream DOC. On Kurugnakh, DOC concentrations were rather uniform between 4.2 and 5 mg/L, but showed highest concentrations in Lucky Lake, and the lowest value was measured near the outflow to the Lena River. Lucky Lake featured the lowest ^{14}C levels of DOC of around -370 ‰, while the values from Oval Lake varied between years in the range of -200 and -320 ‰. Again, POC concentrations are much lower, and the radiocarbon signature of POC samples was more variable than that of DOC. In contrast to Samoylov, POC ^{14}C levels were within a similar range or even less depleted than that of DOC. This pattern may reflect preferential degradation of labile ancient DOC released from Yedoma.

THE PERMAFROST THAW FINGERPRINT: THE ISOTOPIC COMPOSITION OF PARTICULATE ORGANIC CARBON FROM LENA RIVER TO LAPTEV SEA

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Rapid climate warming in the Arctic region intensifies permafrost thaw, increases active layer depth in summer and enhances riverbank and coastal erosion. This causes the release of organic matter (OM) into streams and rivers and result in discharge of terrestrial OM into the Arctic Ocean. The focus of our study, particulate OM (POM) consists of a complex mixture of compounds from different sources with different chemical/physical resistance towards decomposition and mineralization. Particulate organic carbon (POC) transported by the Lena River represents a quantitatively important carbon pool exported to the Laptev Sea, but its quantity, quality, transport and transformation features are still not fully understood.

With this study, we determined the sources (e.g., permafrost, soil, peat, phytoplankton, vegetation, etc.), quality and age of organic carbon transported by Arctic rivers to understand the effects of climate change on the river watersheds as well as on the Arctic coastal nearshore zone. Our study is embedded into the project 'Changing Arctic Carbon cycle in the cOastal Ocean Near-shore (CACOON)', which aims to investigate composition, seasonal effect, and changes during the transport and further fate of organic matter discharged by the Lena River to the Laptev sea (see Strauss et al 2021, this abstract book). To assess these data, we have had an intensive fieldwork in the Russian Arctic in summer 2019. Samples were collected across a ~1500 km transect from the Yakutsk through the centre of the Lena Delta to the Nearshore zone, covering the fresh-salt water transition.

We analysed water samples from one to three different water depths to capture stratification in the water column. In a next step, the water was filtered at Samoylov Research Station through precombusted GF/F filters (25 mm diameter). Filters with POM were stored frozen in pre-combusted glass petri dishes. Later, the filters were analysed at AWI Bremerhaven for total suspended matter, total POC concentration, stable ($\delta^{13}C$) and radiocarbon ($\Delta^{14}C$) isotopes.

We found significant qualitative and quantitative differences between the OM composition in the Lena River main channel and its delta. Further, we found suspended matter and POC concentrations decreased during the transit from the river to the Arctic Ocean. We demonstrate that deltaic POC is depleted in ^{13}C relative to fluvial POC, and that its ^{14}C signature suggests a modern composition indicating phytoplankton origin. This observation likely reflects the difference in hydrological conditions between the delta and the river main channel, caused by lower flow velocity and average water depth.

SEASONAL METHANE AND CARBON DIOXIDE EMISSIONS UPON THE COASTAL REGION OF THE KOLYMA RIVER

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Massive Arctic rivers are feeding ≈11% of the global river discharge into the Arctic Ocean, while the ocean stores only ≈1% of the global ocean volume. The ongoing rapid climate warming has led to pronounced changes in precipitation, active layer thickening, increased air and soil temperatures, increased riverbank and coastal erosion rates, extensive permafrost thaw and increasing freshwater discharge to the Arctic Ocean. Since most studies have focused on rivers or oceans itself and mainly during the late summer, near-shore coastal regions are understudied and crucial in determining the amount of carbon transported and/or released into the Arctic Ocean.

Here, we investigated river-derived carbon dioxide (CO_2) and methane (CH_4) emissions from seven repeated transects of the Kolyma River and nearshore (120 km between Cherskiy and Ambarchik) over the entire open water season between June and September 2019. We estimated the cumulative gross delivery of river-derived CH_4 and CO_2 to the coastal ocean to be around 0.0008 Tg CH4 (800 000 kg) and 0.2 Tg CO_2 (200 000 000 kg). Measurements reveal that more than 50% of the cumulative gross delivery is happening during the fresh period, making the season dynamics extremely important.

MICROBIAL COMMUNITIES IN PERMAFROST-AFFECTED PEATLANDS IN THE SOUTH OF THE EAST-EUROPEAN CRYOLITHOZONE

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Peat plateaus of the East-European plain contain almost 50% of soil organic carbon stocks (SOC) (Pastukhov, Kaverin, 2013), which are considered to be vulnerable to microbial mineralization after permafrost thaw (Schuur et al., 2015). Four key sites of the peat plateau/thermokarst complexes (uplifted mounds and permafrost free fens) were investigated. All sites are located at the extreme southern limit of the cryolithozone, where sparse island permafrost is 0-25 m thick, with MAGTs between 0 and –0.5 ° C. Studied peat plateaus have similar morphology and do not differ from each other on satellite images but their geomorphological location, hydrological regime, nutrient status and genesis during the Holocene are significantly different. Quantitative registration of bacterial, archaeal, and fungal components in the microbiomes of the studied peat samples was conducted using quantitative polymerase chain reaction (qPCR) in a CFX96 Touch System (Bio-Rad).

It is known that the microbial communities and associated decomposition processes of peatlands are vertically stratified with depth, as redox conditions and carbon quality change (Dedysh et al., 2006). However, the stratification highly depends on the phase of the peat accumulation within every specific peat plateau, conditions or disturbances affected the hydrological regime, nutrient status and peat forming vegetation. In all studied peat samples, bacterial biomass of qPCR-adjusted abundance varied from 5.6×10^{7} to 1.9×10^{10} copies g^{-1} (dry weight of soil), the number of archaeal genes was 3.4×10^{6} – 1.0×10^{10} copies g^{-1}, fungal composition ranged from 1.5×10^{6} to 1.2×10^{10} copies g^{-1}. Total microbial biomass peaked in the surface (0–10 cm) layer and decreased rapidly (1-2 orders of magnitude) with minimum in mesotelm[1] layers (from 40-50 to 60-70 cm depth) of the 2 of 4 studied sites (Inta I and Inta 11). Obviously, the upper horizons have high biogenicity due to the transformation processes of organic matter associated with the activity of microorganisms (mineralization of plant residues, synthesis of humic substances, biogenic accumulation of micro and macroelements). However, in Kolva and VodaTy sites, the maximum number of bacterial genes was 1.22×10^{10} and 8.7×10^{9} copies g^{-1} at a depth of 100-110 and 190-210 cm, respectively. There is the similar distribution of archaeal to the bacterial biomass. The maximums of archaea were 5.1×10^{9} and 7.5×10^{9} copies g^{-1} at the same depths in Kolva and VodaTy, respectively. Peat plateau in Kolva has a low number of fungi (from 8×10^{7} to 7×10^{8} copies g^{-1}) compared to the number of bacteria and archaea, whereas in VodaTy, the maximum of fungal biomass reaches 2.5×10^{9} copies g^{-1} at a depth of 190-210 cm. The study showed that the microbial communities reflect the variability in origin and heterogeneity of four investigated sites but do not indicate peat vulnerability to SOC decomposition process but support the hypothesis about the sustainability of peat plateaus especially under anaerobic conditions.

Acknowledgements

The study was supported by the Russian Foundation for Basic Research No. 20-34-70005 (CITiS No. AAAA-A19-119121790049-4) and state budgetary research No. AAAA-A17-117122290011-5.

[1] The interface between oxic (acrotelm) and anoxic (catotelm) layers, founded at this intermediate depth, creates an ecological niche (Clymo and Bryant, 2008). In this horizon within which the water table fluctuates, the simultaneous presence of CH_4 and O_2 creates ideal conditions for methanotrophs.

KOPF SYNTHESIS – CARBON IN TERRESTRIAL PERMAFROST LANDSCAPES OF THE SIBERIAN ARCTIC UNDER A CHANGING CLIMATE

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'KoPf' stands for 'Carbon in Permafrost' and is a joint project in the frame of the Scientific and Technological Cooperation (WTZ) with Russia, supported by the Federal Ministry of Education and Research (BMBF) and the local Russian partners.

KoPf improves - based on observations and numerical simulations - the knowledge on the impact of climate and environmental change on permafrost carbon fluxes and the underlain processes. The terrestrial permafrost research is conducted in a close Russian-German cooperation with a focus on Siberia.

In KoPf, current Earth System Models are optimized concerning permafrost related processes and subsequently applied for different warming scenarios to investigate when the current Arctic carbon sink will turn into a carbon source in future. Based on biogeochemical and microbial process studies, carbon dioxide and methane production as well as the involved microbial communities and long-term degradability of permafrost organic matter are quantified. The project works across local, regional and global scales and determines the contributions of land cover change, their ecosystems and the changes in permafrost soil carbon characteristics to greenhouse gas dynamics. The obtained data are used for further model validation. Furthermore, KoPf supports the education of young researchers in the field of permafrost research as well as strengthens the bilateral network between Russia and Germany.

The involved 14 German and 12 Russian institutions conduct integrating research on carbon in terrestrial permafrost landscapes of the Siberian Arctic. The project is structured in four working packages, led by scientists from six institutions: Universität Hamburg and University Cologne, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research Potsdam, Max Planck Institute for Biogeochemistry Jena, Max Planck Institute for Meteorology Hamburg and Helmholtz Centre Potsdam German Research Centre for Geosciences.

STABILIZATION OF ORGANIC MATTER FROM THE ICE COMPLEX, LENA RIVER DELTA, RUSSIA

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The Arctic ecosystem has a huge reservoir of soil organic carbon stored in permafrost-affected soils and biosediments. During the short vegetation season, humification and mineralization processes in the active soil layer result in the formation of specific soil organic substances – humic substances. Humic acids are high molecular, specific, thermodynamically stable macromolecules. The study was conducted in the Ice Complex (IC) of the Lena River Delta (Kurungnah Isl.). The issue of the origin of the IC of rocks has not yet been resolved. There are several hypotheses that explain the accumulation of sand-silt sediments and their simultaneous freezing. Some researchers associate this process with aeolian transport and the deposition of a huge amount of mineral material from the atmosphere, and there is also a theory about the formation of the IC as a result of alluvial accumulation. Another point of view on the formation of the IC is that in front of the ice sheet, on the shelf of the Laptev Sea there was a stagnant reservoir in which accumulation of sediments of the IC occurred. To determine the rate of stabilization of organic matter from the IC, the molecular composition of humic acids was analyzed by ^{13}C NMR spectroscopy. During the analysis, we found that this material was the most humified among the soil samples, which was analysed before. If we consider theories of the origins of the IC, our data show that a reservoir could exist in place of the IC in which the accumulation and transformation of organic matter took place. Frozen organic matter from the IC is the most stable of all the soil samples we studied through the Lena River Delta. It seems that as a result of the accumulation of various organic residues here and their long-term transformation during the selective degradation of condensed structures, condensation of high-molecular compounds occurred, which led to an increase in the aromaticity of HAs in the soil-like bodies of the IC.

Acknowledgements

This work was supported by the Grant of Russian Foundation for Basic Research, No. 19-05-50107.

IMPACT OF MOSSES AND LICHENS ON FUTURE CARBON EMISSIONS FROM PERMAFROST SOILS

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Carbon release from thawing permafrost soils may substantially enhance global warming in the future, which may result in a positive feedback between climate change and permafrost carbon loss. Due to poorly constrained high-latitude ecosystem processes in global land surface models, however, the magnitude of projected permafrost carbon release is highly uncertain (*McGuire et al, 2018*).

An important factor, which is not sufficiently represented in most global land surface models, is vegetation on the ground, consisting of mosses and lichens (*McGuire et al, 2018*). These organisms contribute significantly to ecosystem productivity (typical values range from 20% to 50%) and thus provide carbon input into the soil (*Turetsky et al, 2010*). Moreover, they cool the ground through insulation in summer, which may protect permafrost carbon (*Porada et al, 2016*). See Fig. 1 for an overview of the effects of mosses and lichens on soil carbon.

Here, we apply a new version of the process-based global land surface model JSBACH to estimate the impact of mosses and lichens on the soil carbon balance at high latitudes in the next decades (*Porada and Beer, in prep*). We compare two scenarios (RCP 8.5) for the soil carbon balance until the year 2100 with JSBACH, one including mosses and lichens, and another one without them.

We find that mosses and lichens double the increase in total soil carbon by the year 2100 compared to a simulation without the organisms, which can be explained by the following two factors: First, the relative cooling effect of mosses and lichens on soil temperature increases by around 1°C from today to 2100. Secondly, increased productivity of mosses and lichens due to CO_2-fertilization results in a larger carbon flux into the soil. Uncertainties in our estimates mainly result from the potential reduction of CO_2-fertilization through nutrient limitation. We conclude that mosses and lichens should be included in projections of the global carbon cycle.

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THE FIRST RIVER TERRACE AND THE ICE COMPLEX OF THE LENA DELTA: COMMON ORIGIN AND EVOLUTION

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The Lena River Delta is a complex polygenetic heterogeneous formation. The first terrace and the Ice Complex (or «Yedoma») are one of the main relief elements. The Ice Complex deposits and the Holocene organic-mineral sediments of the first terrace were forming in similar conditions determined by fluctuations of the sea level. The only significant difference is that the accumulation time of the Ice Complex in the second half of the Late Pleistocene was characterized by more severe climatic conditions, as a result of which the Ice Complex contains a huge amount of vein ice, while the Holocene sediments are pierced by smaller ice veins (Bolshiyanov et al., 2013). However, there is a significant amount of plant residues in both strata of different ages, and both strata are clearly layered with signs of sediment in water basins that were brackish water, which were showed by both Holocene and Pleistocene sediments drilled by a well on Samoylov Island in 2018 and by deposits of the Ice Complex on Kurungnakh Island (Chetverova et al., 2017).

The results of geodesic profiling and dating of sediments of the Holocene terrace and the Ice Complex at their junctions indicate their synchronous tectonic regime. At the same time, a tectonic skew of the delta from west to east was revealed. It is expressed in the different altitude of the surfaces of the Ice Complex and the first terrace. The difference in speed tectonic movements between western and eastern parts of the delta is 1 mm per year during the last 20,000 years. But during the last 2,000 years, speed tectonic movements increased to approximately 2 mm per year (Bolshiyanov et al., 2019). The formation of the first terrace took place during some stages of the Holocene depending on changes of transgressive and regressive phases with a gradual erosion and abrasion of Ice Complex remnants. Sea level rise always stimulated termoabrasion of the Ice Complex and accumulation of organic-mineral sediments of the first terrace. The next marine regression led to the destruction of the accumulated masses of the first terrace by fluvial erosion. During the next transgression, new masses of organic-mineral sediments learned against remnants of the first terrace. The first terrace, composed of different age sediments, formed during this cyclic process. The Ice Complex and the first terrace sediments accumulated in similar conditions. A head of water from the seaside was a main reason of the accumulation of organic and mineral sediments which were frozen at the same time. The Ice Complex has a huge volume of ice in sediments as they formed in very low temperature conditions. First terrace sediments froze in the Holocene when temperature was higher than at the end of the Late Pleistocene. That is why the thickness of Holocene ice is less than in Ice Complex.

This study was conducted by the German-Russian cooperation in the Lena River Delta.

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TRACING THE PERMAFROST CARBON RELEASE USING RADIOCARBON DATING OF DISSOLVED AND PARTICULATE ORGANIC CARBON IN THE YENISEI RIVER AND ITS MAJOR TRIBUTARIES

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There is the significant progress in recent decades in the quantification of terrigenic carbon release to the rivers of the Arctic Ocean basin (e.g., Amon et al., 2012, Wild et al., 2019). However, linkages between soil processes on a watershed scale and properties of the terrestrial carbon released to rivers still require more detailed analysis, particularly in regard to the age of carbon exported from vast permafrost terrain.

In this study, we present ^{14}C data for dissolved organic carbon (DOC) and particulate organic carbon (POC) in the Yenisei River and its major tributaries sampled from 56°N to 68°N at freshet, summer and fall seasons. ^{14}C of soil organic carbon (SOC), as the end member, was determined in several sites situated in the middle taiga (61°N: pine forests, dark conifer forests and Sphagnum peatbogs), northern taiga (64°N: larch and birch forests) and forest-tundra ecotone (67°N: mixed birch-spruce forests, palsa mire). ^{14}C was measured in Max Planck Institute for Biogeochemistry (Germany) by the accelerator mass spectrometry (AMS) system based on a 3MV Tandetron accelerator as described earlier (Steinhof et al., 2017).

Soil organic layers in all studied sites of the Yenisei basin were enriched in ^{14}C (120±19 ‰). Mineral soil ^{14}C-SOC decreased with soil depth from 31±55 ‰ in top 5 cm to -460±213 ‰ in subsoil (50 cm). DOC in the Yenisei main stem and its tributaries was dominated by modern carbon (fMC > 1) during freshet and clearly more ancient DOC was released under low flow conditions (fMC £ 1). The POC of the Yenisei River was sufficiently older (fMC = 0.73-0.92) than DOC and changed with latitude and season. The ^{14}C-POC values in analyzed tributaries at freshet and summer lowflow were increasing with latitude except the largest Eastern tributaries. On the other hand, increasingly more ancient POC was releasing by permafrost-dominated Eastern tributaries on a scale from 584 km^2 (Miroyedikha River) to 1,050,000 km^2 (Angara River). In opposite, ^{14}C-POC of larger Western tributaries showed increased input of more recently fixed carbon. Our findings provided new data on the formation of terrigenic carbon fluxes to the Arctic Ocean from one of the largest river basins in the Arctic.

Acknowledgments

This study was supported by RFBR grants #18-05-60203-Arktika and #19-29-05111. The radiocarbon analyses were kindly supported by Max-Plank Institute for biogeochemistry (ZOTTO project).

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CURRENT RESEARCH ON EURASIAN PERMAFROST IN NORTHEAST CHINA: THE DFG-NSFC NIFROCLIM PROJECT

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In contrast to extensive research on permafrost carbon climate feedbacks, research on permafrost soil nitrogen (N) turnover and associated release of nitrous oxide (N_2O) under a changing climate is strongly lagging behind. N_2O is a very potent long-lived greenhouse gas with a 100-year global warming potential exceeding those of CO_2 and CH_4 by 265 and 28 times, respectively (*IPCC, 2014*). Until recently, the soil N cycle in cold, pristine ecosystems was thought to be largely confined to organic N cycling. Permafrost ecosystems were thus assumed to be extremely weak N_2O sources. However, over the last decade N_2O emissions from permafrost soils are being reported, which are in the order of magnitude as observed for tropical forests or agricultural systems and therefore challenging the old paradigm. In addition, studies hint at a stimulation of N_2O emission by warming, suggesting a potential N climate feedback triggered by thawing permafrost.

In this talk, current research on permafrost N cycling in the Chinese part of the Eurasian permafrost area (Mohe county, Northeast China) will be presented. Mohe is located on the Southern edge of the Eurasian permafrost and hence especially vulnerable to climate change. The interdisciplinary Sino-German NIFROCLIM project funded by DFG and National Science Foundation of China since 2019 joins the expertise of soil biogeochemists, soil scientists, plant physiologists, atmospheric physicists and molecular microbial ecologists in order to investigate N cycling and N_2O emissions in typical boreal permafrost ecosystems under the auspices of climate change. To track sources of high N_2O emissions, NIFROCLIM integrates the complete N cycle, one focus being potentially important N input pathways like biological N fixation.

Combined investigation of soil organic matter properties, molecular analyses of the microbiome, isotope-based biogeochemical process studies and quantification of N losses along hydrological and gaseous pathways are expected to result in a functional understanding of N cycling both in the vertical soil profile and along landscape transects. To test temperature dependency of involved processes, warming experiments are performed.

Hitherto available results point at freeze-thaw events as hot moments of N_2O emissions and a high importance of N-fixing *Alnus sibirica* forests as hot spots of N_2O emissions (> 2 kg N_2O-N ha^{-1} yr^{-1}). First results on seasonal soil-atmosphere N_2O exchange and soil gross N turnover across a range of sites from upland forests to lowland peatlands will be presented.

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NEW MODEL MEEP GIVES INSIGHTS ON THE IMPACT OF METHANE EMISSIONS FROM PONDS ON THE LOCAL METHANE BUDGET IN THE LENA RIVER DELTA

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Ponds are ubiquitous in the Lena River Delta and a steady source of methane. However, it is difficult to assess the contribution of pond methane emissions to the landscape methane budget, because pond emissions show large temporal and spatial variability already on local scale.

We study the impact of ponds in the Lena River Delta with a new process-based model for Methane Emissions from Ponds (MeEP model), which simulates the three main pathways of methane emissions (diffusion, plant-mediated transport and ebullition) as well as the temperature profile of the water column and the surrounding soils. Due to a temporal resolution of one hour, it is capable of capturing the diurnal, day-to-day and seasonal variability in methane fluxes. MeEP also considers one of the main drivers of spatial variability - ground heterogeneity. Depending on where ponds form in the polygonal tundra, they can be classified as ice-wedge, polygonal-centre or merged-polygonal ponds. In MeEP, each of these pond types is simulated separately, and the representation of these ponds was informed by dedicated measurements in the Lena River Delta in summer 2019.

The model performance is validated against eddy-covariance measurements of methane fluxes and against in-situ measurements of the aqueous methane concentration, both obtained on Samoylov Island. Apart from the validations, we will present first results regarding the contribution of each pond type to the landscape methane emissions on Samoylov Island.

BIOGEOCHEMICAL PROCESSES IN PERMAFROST

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Permafrost of the Siberian Arctic was formed, with the exception of certain periods, mainly in humid conditions throughout the Pleistocene and Holocene time. A large number of lakes whose bottom sediments contained a large amount of organic matter, contributed to the occurrence of microaerophilic and anaerobic biogeochemical reactions such as iron and sulfate reduction and denitrification. These processes play an important role in the transformation of organic matter and the creation of favorable redox conditions for the formation of biogenic methane - one of the most important greenhouse gases.

Results of the earlier studies showed that microorganisms preserved in permafrost for a geologically significant period of time (from several thousand to million years), retain their viability. During that time, they are continuously exposed to the adverse conditions of sub-zero temperatures, absence of free water, and natural radioactivity of the host rock minerals.

The presence of inorganic metastable and ephemeral compounds, such as acid-soluble sulfide minerals - greigite (Fe_3S_4) and mackinavite (Fe_9S_8), as well as monovalent anions - nitrite (NO_2^-), in permafrost sediments suggests that there is a possibility of biogeochemical reactions in sedimentary deposits after they became frozen.

We previously showed in the laboratory setting that microbial lipids and methane can be formed at subzero temperatures and that thin films of unfrozen water recorded in frozen soil-water mixture are an important factor in metabolic reactions in permafrost. Obviously, most of the products of the microbial biogeochemical activity were a result of processes that occurred in original deposits before freezing, however, the fact of a possibility of such reactions at negative temperatures is important for understanding the mechanisms by which microorganisms maintain viability in permafrost during long geological time.

Isolation of viable microorganisms and analysis of permafrost metagenomes revealed microorganisms and genes encoding proteins associated with the carbon, sulfur, nitrogen and iron cycles. It is evident that increase of permafrost temperature and thickness of the active layer will contribute to the stimulation of all biogeochemical processes, including those associated with the production of greenhouse gases.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research (19-29-05003-mk) and the National Science Foundation (DEB-1442262).

A COMPREHENSIVE REMOTE SENSING-BASED ASSESSMENT OF ANNUAL RETROGRESSIVE THAW SLUMP DYNAMICS ACROSS NORTH SIBERIA FOR 1999-2020

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Retrogressive thaw slumps (RTS) are highly dynamic permafrost disturbance features. RTS are pulse disturbances that unfold within very short time periods from a few days to years, rapidly affecting the surrounding environment. RTS influence soil organic carbon stocks substantially as they deeply erode ice-rich permafrost soils and mobilise large volumes of sediment and carbon. Although RTS are local features and their overall contribution to areas affected by disturbance is small compared to other processes in the high latitudes, such as wildfires or lake changes, their local impacts on biogeochemistry, hydrology, and geomorphology can be significant. More importantly, their influence on carbon emissions is projected to increase due to greater RTS abundances with ongoing permafrost thaw also in Arctic regions. Various studies from Alaska and Canada report increasing numbers and sizes of RTS due to recent warming and intensifying precipitation. However, there are still significant knowledge gaps since only few features have been studied in detail and the distribution of RTS on a pan-Arctic scale is unknown. Firstly, RTS dynamics are not fully understood due to the lack of continuous and high temporal datasets. Secondly, automatic RTS mapping techniques are missing which inhibits representative large-scale RTS assessment schemes. Thirdly, this lack of high temporal continuous RTS dynamics data prevents establishing a tight relation to potential climatic drivers.

In this study, we focus our remote sensing analysis on retrogressive thaw slumps and their annual dynamics in North Siberia and tested whether highest activity of retrogressive thaw slumps was directly associated with climatic drivers.

We adapted and applied LandTrendr, an algorithm developed to capture forest disturbances and recovery occurrences from spatially moderate (30 m) resolution Landsat time series. LandTrendr creates yearly cloud-free mosaics from multiple images and extracts the temporal trajectory of spectral data on a pixel-by-pixel basis. Furthermore, it segments the temporal trajectories based on regressions and point-to-point fittings of spectral indices, depicting both long-term trends and abrupt changes. We adapted LandTrendr to run with Landsat and Sentinel-2 multispectral images to detect RTS dynamics in North Siberia. Our study presents a continuous time series analysis from 1999 to 2020, determining annual RTS dynamics based on disturbance year, magnitude of disturbance, and duration. Overall, there is a significant increase in RTS activity in the second half of the time series in North Siberia. Additionally, focus areas show high RTS activity at different time periods of the assessment period, which indicates local thawing drivers. Therefore, we assessed ERA5 reanalysis climate data to test any correlation of high slump activity with potential climatic main drivers, especially focusing on precipitation data. This is the first study that presents annual RTS dynamics and combines the analysis of continuous RTS disturbance dynamics with continuous climate data for a large continental-scale region.

ORIGIN OF METHANE SEEPING IN WEST SIBERIAN MIDDLE TAIGA RIVER FLOODPLAINS

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Recently, numerous methane seeps were found in West Siberian middle taiga (WSMT) river floodplains. Seepage occurs on unvegetated flat areas of saturated quicksand deposits and on the bottom of river stream beds. In order to estimate the importance of WSMT seeps for the regional methane budget, it is necessary to reveal the origin of hydrocarbons emitting from them. Three hypotheses of origin were considered for seeping methane: uplift of ancient thermogenic methane from oil and gas reservoirs, release of ancient biogenic methane from degrading relict permafrost in Oligocene deposits, horizontal transport of modern biogenic methane from raised bogs through ground waters in Quaternary deposits.

Study sites were chosen in a way to cover both banks of Ob' and Irtysh in both north-south (250 km) and east-west directions (400 km) using an available road net. For each site, the following samples were taken in August and September of 2019-2020: gas from seeps (for methane concentration, stable isotope ratios of C and H in methane, and radiocarbon content in methane); water flowing from seep (for pH, electrical conductivity (EC), dissolved methane and oxygen concentrations); water from streams and rivers all over the region (for dissolved methane concentration, pH and EC). Water samples were also taken from wetlands (at the depth of 1-2 meters) to measure dissolved methane concentration and stable isotope ratios of C and H in methane. Water from three boreholes (25-, 70- and 210-meters deep household wells) in Shapsha village was taken to measure pH, EC, methane concentration, stable isotope ratios of C and H, and radiocarbon content in a gas dissolved in groundwater.

Obtained results argue in favour of the third hypothesis of origin. Seeping methane is modern and biogenic. Stable isotope ratios for the seep gas of the highest methane concentration correspond to the methane sampled in wetlands. With linear depleting in heavier isotopes, methane concentration also linearly decreases. Linear correlation between $\delta^{13}C(CH_4)$ and $\delta D(CH_4)$ with a slope of 0.310 ± 0.019 was observed for seep methane. This "local biogenic methane line" could show that a) methane in all seeps is of the same origin; b) this fractionation is mainly driven by gas/liquid phase equilibration. Methane from groundwater had close values of $\delta^{13}C(CH_4)$ and $\delta D(CH_4)$ with methane from seeps. This fact could show that there is intensive water exchange between Oligocene and Quaternary aquifers and surface seepage can occur from both. This idea explains seep finding far in the Irtysh floodplain, where several river channels flow between the wetland on watershed (or terrace) and seeps.

Dissolved methane concentration in seeps and rivers of the study region reaches high values (up to 61% of the total saturation capacity under atmospheric pressure) and correlates with EC of water. It provides clear evidence that methane transport is directly linked to groundwater dynamics across the whole region.

Acknowledgements

This study was supported by a grant of the Russian Science Foundation (№ 19-77-10074).

FATE AND TRANSPORT OF NITROGEN IN SOILS, SEDIMENT AND WATER OF THE LENA DELTA, NORTHEAST SIBERIA

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Soils and sediments in the Lena Delta in Northeast Siberia store large amounts of organic matter including organic bound nitrogen. This nitrogen is not directly available for plants and primary production, but can be remineralised in the soils or in sediments after erosion to the Lena River. Our study aims to estimate the load of reactive nitrogen from terrestrial sources into the Arctic Ocean. Therefore, water and sediment samples were collected along a transect (~200 km) from the centre of the Delta to the open Laptev Sea in summer 2019. On the collected samples, we measured dissolved organic and inorganic nitrogen, particulate nitrogen, CN ratio, and the ^{15}N stable isotope values of these components were determined to identify nitrogen sources, sinks and processes of nitrogen transformation. Additionally, we carried out incubation experiments in the field to determine the potential remineralisation rates of various soil types in Lena water and nutrients fluxes of the sediments (Fig. 1). The load of dissolved inorganic nitrogen in the Lena water in the Delta was very low, and low nitrate and silicate concentration indicate uptake by phytoplankton. Outside the Lena Delta, a lens of nutrient depleted freshwater covered the salty Arctic Ocean water, which had higher loads of reactive nitrogen. The nitrogen stable isotope values of the different nitrogen components range between 0.5 and 4.5 ‰, and were subsequently enriched from the soils via SPM/sediment and DON to nitrate. This indicates that nitrogen in the soils mainly originates from nitrogen fixation from the atmosphere. During transport and remineralisation, biogeochemical recycling via nitrification and assimilation by phytoplankton led to an isotopic enrichment in summer from organic to inorganic components. In the coastal waters of the Laptev Sea, the river waters are slowly mixed with marine nitrate containing waters from the Arctic Ocean, and a part of the riverine organic nitrogen is buried in the sediments. We found that especially the unvegetated soils and sediment are sources of reactive nitrogen at the end of the vegetation period (Sanders et al., 2010), and can potentially be sources of nitrous oxide emissions. We assume that the ongoing permafrost thawing and erosion will intensify and increase the transport of reactive nitrogen to coastal waters and will affect the biogeochemical cycling, e.g. the primary production.

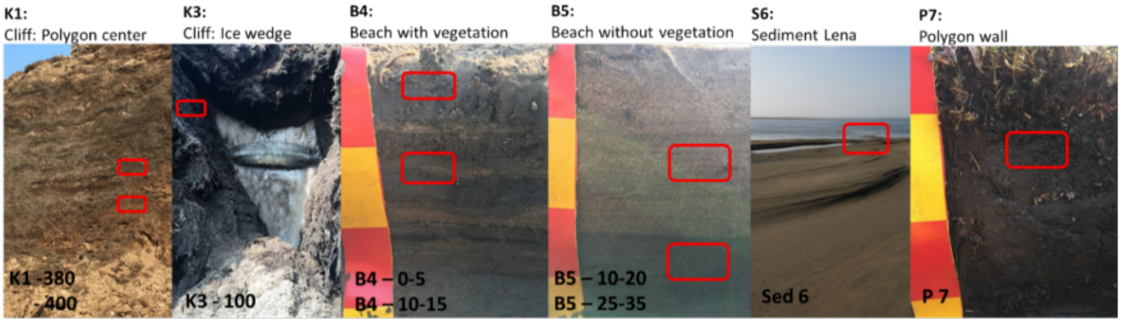

Fig. 1: Sampling site of incubated soil and sediment samples on Samoylov Island

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THERMAL REGIME VARIABILITY OF THERMOKARST LAKES

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The permafrost zone covers a significant area. As is well known, Siberia is the huge storage of permafrost, where the boundary of this zone extends far beyond 600 km in areas of a continuous distribution of permafrost and hydrogeological features of the territory which are largely determined by the spatial relationship of permafrost and thawed rocks and their temperature regime. One of the manifestations of the complex multifaceted interaction of rocks with a spatial temperature field is the thermokarst, and this area is characterized by lowlands with thermokarst lakes. Thermokarst processes are increasing year by year in case of climate change. Investigation of the thermal regime of lakes reflects well the temperature changes in the atmosphere and permafrost (through heat exchange with bottom sediments). Representative thermokarst lakes were chosen for investigating the thermal regime. The research objects are the lakes located in different permafrost areas, such as Taimyr peninsula; The Lena River Delta; Yamal peninsula (south and central parts); Central part of Yakutia. The calculation of the temperature regime and mixing processes in the lake can be performed with the help of the thermodynamic mathematical model FLake using meteorological information and calibration parameters. The model FLake was developed by the collaborators of the Institute of Limnology of the Russian Academy of Sciences. The simulation results are presented with comparing the location of the lakes. A perpetual year solution represents the annual cycle of temperature and mixing in a given lake that corresponds to a given annual cycle. The lakes in the central part of Yakutia and Yamal peninsula have a long period with a water temperature above 10°C. On these lakes, the start of the ice cover break up is later than on all of the studied lakes in the Lena River Delta according to model dates. And further modelling data were created. Thermal interaction between the water column and the bottom sediments is an issue for studying lakes. A seasonal cycle in lakes may be noticeably affected by the accumulation of heat in the bottom sediments during spring and summer and the release of heat from the sediments during autumn and, in particular, winter. Apart from shallow lakes, the bottom heat flux can be set to zero. In case the interaction between the water column and the bottom sediments is to be accounted for, prior empirical information is required to estimate the depth of the thermally active layer of bottom sediments, such information is rarely available. Moreover, one of the examples of thermokarst lake processes is the formation of talik, the change in the boundaries which depends on the size of the lake in terms of volume, water mass, time and nature of thawing rocks, and the temperature regime of bottom sediments. If the depth of fresh water bodies exceeds the freezing depth in winter, then these water bodies have a significant warming effect on the underlying permafrost.

RECENT DYNAMICS OF TOTAL ABOVE GROUND BIOMASS (AGB) AND FUTURE TREE AGB IN CENTRAL CHUKOTKA

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Estimation of above ground biomass (AGB) is a part of an assessment of carbon stocks which is essential to understand how ecosystems respond to recent climate change, especially in the high latitudes, where climate change is very prominent. We quantified total AGB changes in four focus regions in central Chukotka (Russian Far East) from 2000/2001 to 2016/2017 and predicted the future tree AGB in the tundra-taiga for the next 150 years (2020-2170 AD). The focus regions were placed to cover the gradient from tundra via tundra-taiga ecotone to northern taiga. We used pre-processed Landsat spectral indices and field data on foliage projective cover of the dominant taxa in the constrained ordination for coupling the projective cover with the corresponding Landsat spectral indices from 2016/2017. Ordination space was used to project new 2018 field projective cover data into it. The obtained scores were used together with AGB data harvested in 2018 at new sites for the building of a general additive model to predict total AGB. We applied the individual-based spatially explicit vegetation model LAVESI to future larch AGB change, depending on different climate scenarios according to Representative Concentration Pathways (RCPs). Current total AGB ranges from 0 to 16 kg m^{-2}, with the highest contribution to the total AGB being *Larix cajanderi* Mayr (60% and 92% of total AGB in tundra-taiga and northern taiga, accordingly). The recent AGB change rates were the highest in the northern taiga (1.25 kg m^{-2} yr^{-1}), lower in the tundra-taiga (0.05 kg m^{-2} yr^{-1}, Fig. 1a), and close to zero in the tundra. The larch AGB change rates in the tundra-taiga from 2020 to 2170 AD are 0.001 kg m^{-2} yr^{-1} (RCP 2.6) or 0.002 kg m^{-2} yr^{-1} (RCP 4.5, RCP 8.5) for the currently forested areas, and up to 0.008 (RCP 4.5) or 0.01 (RCP 8.5) for open tundra, close to the treeline. Trees are predicted to colonize slopes upwards and move northwards into the treeless tundra (Fig. 1b).

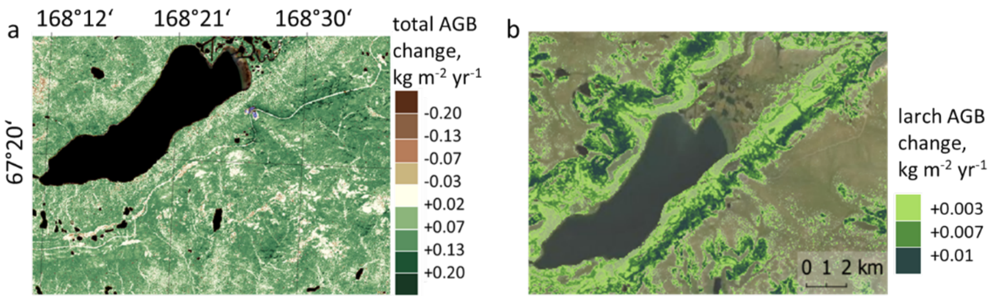

Fig. 1. Recent (2001-2016) above ground biomass (AGB, kg m^{-2}) change (a) and potential future (2020-2170, RCP 8.5) tree AGB change (b) at the northern larch treeline border.

BIOTA AS DRIVER OF MINERAL WEATHERING AND SOIL FORMATION IN MARITIME ANTARCTICA

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Mineral weathering is of ultimate importance for soil formation and nutrient supply to plants, and during the last decades, the perception emerged that biota is strongly involved in this process. Here, we hypothesized that the appearance of higher plants causes an enhanced biotic attack on minerals due to the translocation of photosynthetically produced organic carbon belowground as an easily available energy source to soil microorganisms. To test this hypothesis, we investigated a glacier retreat ecosystem chronosequence in Antarctica, defining phototrophic community succession from (i) bare soils colonized by microalgae and cyano bacteria, to (ii) soils covered by mosses and (iii) a mix of mosses and the higher plant *Deschampsia antarctica* to (iv) a pure *D. antarctica* site.

Soil organic carbon contents as well as the microbial biomass carbon contents increased along with the phototrophic community succession. The presence of vascular plants was also reflected by increasing CO_2 fluxes, indicating a higher energy provision to the trophic chain in form of reduced carbon. A ^{13}C pulse labelling revealed a fast allocation of organic carbon belowground and a tight link between photosynthesis and soil respiration at *D. antarctica* site. Despite phospholipid fatty acids assigned to bacteria were dominating, most of the ^{13}C was allocated to microbial phospholipid fatty acids of fungal origin, indicating the prominent role of fungi in belowground biotic activity. Mineral mescosms consisting of biotite and muscovite incubated in the soils *in situ* for one year, also showed coverage and weathering channels primarily by fungi in case of *D. antarctica*. A close relationship between the gross primary production and the fungal colonization of the minerals suggests that freshly assimilated carbon appears the major energy source of biotic weathering. Untargeted metabolom analysis further revealed that this goes along with a strong increase of Krebs cycle acids, which are mineral weathering agents.

Overall, our results indicate that the occurrence of higher plants mark a tipping point for mineral weathering and soil development of Maritime Antarctica.

REPRESENTING COLD-CLIMATE HYDROLOGICAL PROCESSES IN THE INM RAS-MSU LAND SURFACE MODEL

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This abstract presents the land surface model (LSM) jointly developed by the Institute of Numerical Mathematics (INM) RAS and Moscow State University (MSU) and used in the INMCM Earth System model *(Volodin et al., 2017)*, participating in the CMIP (Coupled Model Intercomparison Project) series of climate simulations. The basis of INM RAS-MSU LSM is a soil model computing vertical distribution of temperature, liquid water, ice and water vapor content in each land grid cell of the ESM *(Volodin and Lykosov, 1998)*. Heat and moisture transfer equations are discretized at 23 levels in soil, whereas for heat and moisture transport in snow, 4 levels are used. Each land grid cell is composed of 5 possible surface types: dry vegetation, vegetation covered by intercepted precipitation, bare soil, snow and inland waters.

Inland water area and depth are adapted from GLDBv2 dataset. The thermodynamic state of lakes is simulated by a simplified version of 1D LAKE model *(Bogomolov et al., 2016)*. The model participates in the Lake sector of ISIMIP project (www.isimip.org). So far, lake temperature, ice and energy fluxes are simulated under picontrol, historical, RCP2.6, RCP6.0, RCP8.5 scenarios as prescribed by ISIMIP2b protocol. Biogeochemical block of the lake model is validated at a number of lakes; current issues towards its implementation in the LSM are discussed.

The novel river module consists of a diffusive wave equation model for dynamics and heat balance equation to compute river temperature *(Stepanenko et al., 2019)*. The effect of inclusion of the river module together with the new snowmelt scheme was a significant improvement of the seasonal cycle of water runoff of Severnaya Dvina River (North of European Russia).

Acknowledgements

The work is supported by the Russian Foundation for Basic Research, grants 20-05-00773, 18-05-60126, 18-05-00306.

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ASSESSING THE DYNAMIC INTERFACE BETWEEN LAND AND OCEAN IN THE ARCTIC: RESULTS FROM THE JOINT BMBF-NERC PROJECT CHANGING ARCTIC ORGANIC CARBON CYCLE IN THE COASTAL OCEAN NEAR-SHORE (CACOON)

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No other region has warmed as rapidly in the past decades as the Arctic. Funded by the British Natural Environment Research Council (NERC) and the German Federal Ministry of Education and Research (BMBF), the Changing Arctic Carbon cycle in the Coastal Ocean Near-shore (CACOON) project investigates how this warming influences Arctic coastal-marine ecosystems. Arctic rivers annually carry around 13% of the globally transported dissolved organic carbon (despite the Arctic Ocean making up only approx. 1% of the Earth's ocean volume). Arctic shelf waters are therefore dominated by terrestrial organic carbon pools, so that shelf ecosystems are intimately linked to freshwater supplies. Arctic ecosystems also contain permafrost organic carbon that may be released with warming. Climate change already thaws permafrost, reduces sea ice and increases riverine discharge, triggering important feedbacks. The importance of the near-shore region, consisting of several tightly connected ecosystems that include rivers, deltas, and the shelf, is however often overlooked. Year-round studies are scarce but needed to predict the impact of shifting seasonality, fresher water, changing nutrient supply and greater proportions of permafrost-derived organic carbon on coastal waters.

The aims of the CACOON project are to quantify the effect of changing freshwater export and permafrost thaw on the type and fate of river-borne organic matter (OM) delivered to the Arctic shore and resulting changes on ecosystem functioning in the coastal Arctic Ocean. We are achieving this through a combined observational, experimental, and modelling approach. We conduct laboratory experiments to parameterise the susceptibility of terrigenous organic carbon to abiotic and biotic transformation and losses, then use the results from these to deliver a marine ecosystem model capable of representing major biogeochemical cycles. We apply this model to assess how future changes to freshwater runoff and carbon fluxes alter the ecosystems.

To reach these aims, we conducted 4 field campaigns in 2019 in the Lena (see https://epic.awi.de/id/eprint/53575/) and Kolyma Delta region. In the Lena Delta, during spring we were using a mobile camp on sledges to collect water samples, ice cores, surface sediments, gas samples as well as CTD profiles. A permafrost cliff (Sobo-Sise) was sampled to analyse terrestrial endmembers of organic matter entering the deltaic and eventually marine system following erosion and transport. During the summer campaign we retrieved samples along a 200 km transect from the centre of the Delta to the Laptev Sea covering the fresh-salt water transition. The aim of Kolyma field sampling was to capture the open water season from the ice breakup to re-freezing and sample the Kolyma River and the near shore area. The lab work on these samples is currently ongoing with first papers lead by CACOON or with project contributions being published already (available here: https://www.researchgate.net/project/CACOON-Changing-Arctic-Carbon-cycle-in-the-coastal-ocean-near-shore).

MAPPING WEST SIBERIAN SEEPS AND FLOODPLAINS USING CONVOLUTIONAL NEURAL NETWORKS

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West Siberian Lowland (WSL), the largest peatland area in the world, attracts interest as a methane source for its potential role in global climate change. While WSL high-latitude wetlands are represented in studies on methane fluxes, much of the uncertainty arises from the lack of field data from WSL floodplains.

During recent investigations, numerous methane seeps were found along large and small floodplains of the WSL middle taiga. Being not typical for that area, they are also characterized by considerable gas emission with an unknown gas origin.

In this study, we made the first attempt to estimate the areal extent of methane using remote sensing techniques. We met several challenges during their mapping.

First, methane seeps themselves are up to 50 cm in diameter, making it impossible to recognize individual seeps directly using satellite imagery. Fortunately, they are usually met in groups of 100 and more seeps covering larger areas along the watercourses (which are usually long and narrow).

To overcome difficulties, we used a multi-scale approach. Sentinel imagery was used to map groups of seeps within the region. Mapping with unmanned aerial vehicle (UAV) was used to receive images of several test sites. It was conducted twice, in August and September, to catch the seasonal changes due to the drop of water. UAV mapping was extremely useful to calculate the number of individual methane seeps and estimate areas of other methane emitting ecosystems to upscale flux measurements.

Second, even groups of seeps could be easily misinterpreted as other types of landscape having similar spectral signatures. In particular, we assigned five main types of ecosystems within floodplains: i) bare lands with methane seeps, ii) bare lands with no seeps, iii) sparse floodplain vegetation, iv) open water, v) high vegetated floodplain. Per-pixel mapping results in severe misclassification.

To avoid it, mapping was done with the convolutional neural network (CNN). Google Earth Engine was used to produce the median Sentinel-2 image using available cloudless images obtained in August and September (when seeps are most prominent). Then we implemented U-Net with one encoder and one decoder layer, softmax activation function, and sparse categorical cross-entropy as a loss function. The input size was experimentally set to 64 pixels. More than 1000 seep polygons were assigned using available field data and Sentinel-2 images (for areas with no ground truth data). As a result, methane seeps were mapped with an accuracy reaching 70%.

The described approach represents a perspective multi-scale technique of detecting hot spots of CH_4 emission to increase the accuracy of flux estimates. It's also promising in the understanding of fine-scale heterogeneity within a landscape and its role in the carbon cycle.

Acknowledgements

This study was supported by a grant of the Russian Science Foundation (№ 19-77-10074).

ISOTOPIC COMPOSITION WITHIN HETEROGENEOUS ICE WEDGE

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Ice wedges can be compositionally diverse in terms of source water and/or ice formation process and rate of freezing, with implications for the isotope composition and paleoclimate inference. The reliability of paleotemperature inferences based on the stable water isotope signal of ice-wedge ice depends greatly on the forming mechanism of this and on its ground ice type. The different genetic types of ice within an ice wedge produce to distort air paleotemperature assessment by the isotopic signature ($\delta^{18}O$ and δD). The saved information in a wedge ice about winter paleotemperatures is directly related to the mechanism of ice wedge formation (*Vasil'chuk, 1991*). Because the ice wedge is formed via fast freezing primarily with meltwater, its isotopic composition shows air paleotemperature. Fast water crystallization within a thermal contraction crack reduce the fractionation process. Thus, the $\delta^{18}O$ values for ice wedges indicate air temperatures at the time of snow accumulation. If crystallization mechanism changes, the fractionation process cannot be ignored, as the experience on ice segregation has shown (*Vasil'chuk et al., 2011*). Slow water freezing causes preferences for heavy isotopes in a formed ice. Ground water is generally enriched compared to the original precipitation due to the loss of lighter isotopes during evaporation. Also, contrary condensation processes may be enriched by light isotopes (*Ekaikin, 2016*).

Micromorphology research of different genetic types of ice within ice wedges clarifies the correct interpretation of isotopic and chemical composition data. Identification of different ice types in ice wedges is a fundamental importance to reconstruct ice wedge formation conditions, to determine to primary and secondary processes, and for isotopic composition interpretation. Stable oxygen and hydrogen isotopic composition of ground ice is useful for assessing the conditions during its formation.

Care must be taken when inferring past winter climates based on ice wedge δD–$\delta^{18}O$ signals since the latter might contain various genetic types of ice. Varying genetic types within the ground ice lead to different paleoclimatological interpretations. Distinctions between genetic types of ice within ground ice have not always been made in previous ice wedge studies, which shows that the paleoclimatic inferences presented in those papers might be erroneous. The mistake depends on where and how an ice wedge was be sampled.

Acknowledgements

The research was carried out within the state assignment of the Research work Plan of the Melnikov Permafrost Institute, project IX.133.1.1. N 0380-2019-0003. The reported study was funded by the Russian Foundation for Basic Research (RFBR) according to the research project No 18-05-60222.

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GEOPHYSICAL STUDIES OF PERMAFROST ON SAMOYLOV AND KURUNGNAKH ISLANDS, LENA DELTA

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Geophysical methods were widely used in permafrost research during the last decades. They provide abundant data on permafrost structure and features at different depth – from the active layer to the lower permafrost boundary. Our studies in the Lena Delta during 2014-2019 focused on the development of a geophysical approach with consideration of local conditions: we applied a set of methods (electrical resistivity tomography, magnetometry, ground penetrating radar, electromagnetic sounding, seismic survey, etc.) on typical permafrost objects such as thermokarst lakes, thermoerosional gullies, ice wedges, pingos and so on. During the period of our research we've managed to produce the following results: established a detailed internal structure of certain areas of Yedoma ice complex (thickness, Pleistocene ice wedge geometry) on Kurungnakh Island; determined boundaries of talik areas and residual temperature anomalies under several themokarst lakes and drained thermokarst depressions; discovered anomalies in ice content distribution and mineral composition in permafrost soils by means of shallow high-detailed survey; suggested the shape of an ice core inside of the pingo with geophysics and verified it with drilling. We also performed deep sounding that provided new data on permafrost depth. In Fig. 1 you can see an example of electrical resistivity tomography under Samoylov Island – the difference in resistivity under the floodplain (left) and the first terrace (right) is obvious, inhomogeneities in the right part correspond to presumable thaw zones in the past. It could be argued that most of the applied methods are useful for the study of the permafrost state and changes in Lena Delta and they can provide a great help for traditional approaches and modern techniques in consecutive areas – permafrost geology, geobotany, soil science and geochemistry, remote sensing. Permafrost study in the Lena Delta requires a multidisciplinary approach, and geophysics looks like one of its most important branches.

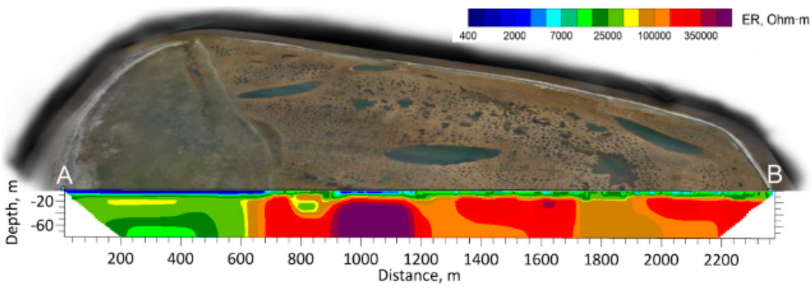

Fig. 1. Electrical resistivity section of Samoylov island

CHEMICAL COMPOSITION OF WATER AND BOTTOM SEDIMENTS IN THERMOKARST LAKES ON KURUNGNAKH ISLAND, LENA DELTA

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Kurungnakh Island in the Lena Delta represents a rest of Yedoma ice complex with shallow Holocene cover. Its surface is processed by thermoerosional and thermokarst processes resulting in a huge amount of thermokarst lakes of different size and depth, a number of flows and thermoerosional gullies. Chemical composition of water and bottom sediments can be ascribed to permafrost degradation processes (*Kokelj et al., 2009; Mesquita et al., 2010*) or be influenced by blowout and wind transfer of soil, anthropogenic pollution and so on. In order to find possible key elements, which credibly point at one or another process, we analyzed a wide range of elements in samples from typical water objects on Kurungnakh Island and applied a statistical approach.

We have taken 29 samples of water and bottom sediments from reservoirs in the Southern, South-Western, and South-Eastern parts of the Kurungnakh Island on the first and third terraces. Some physical parameters were measured in situ, other - mineralogical, granular composition were determined in laboratory. Major cation (Al, Fe, Ca, Mg, K, Na, and Si) and trace element analyses were carried out using ICP-MS method (up to 63 elements). Accuracy of the analyses were estimated to be 10 % or better.

The distribution of chemical elements in the studied samples in general repeats that in the Lena River. Anomalies are detected in concentrations of Fe, Mn, Ni, Cr and rare earth elements in comparison to fresh waters of hydrosphere. It should be noted that elevated concentrations of elements of the first class of danger - As and Be were detected. Concentrations of In, Ta, Hf, and Re were presumably established for the first time ever (no corresponding data was found in literature).

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TOWARDS THE FIRST CIRCUMARCTIC N_2O BUDGET – EXTRAPOLATING TO THE LANDSCAPE SCALE

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Arctic nitrous oxide (N_2O) emissions have long been assumed to have a negligible climatic impact but recently increasing evidence has emerged of N_2O hotspots in the Arctic. Even in small amounts, N_2O has the potential to contribute to climate change due to it being nearly 300 times more potent at radiative forcing than CO_2. Therefore, the ‘NOCA’ project aims to establish the first circumarctic N_2O budget. Following intensive N_2O flux sampling campaigns at primary sites within Northern Russia and soil N_2O concentration measurements from secondary sites across the Arctic, we are now entering the phase of spatial extrapolation. Challenges to overcome are the small-scale heterogeneity of the landscape and incorporating small features that can function as N_2O hotspots. Therefore, as a first step in upscaling the N_2O fluxes, high resolution imagery is needed. We show here novel high-resolution 3D imagery from an unmanned aerial vehicle (UAV), which will be used to upscale N_2O fluxes from plot to landscape scale by linking ground-truth N_2O measurements to vegetation maps. This approach will first be applied to the East cliff of Kurungnakh Island in the Lena River Delta of North Siberia and is based on 2019 sampling campaign data. Kurungnakh Island is characterized by ice and organic-rich Yedoma permafrost that is thawed by fluvial thermo-erosion forming retrogressive thaw slumps in various stages of activity. Overall, 20 sites were sampled along the cliff and inland, covering the significant topographic and vegetative characteristics of the landscape. The data from this scale will provide the basis for extrapolating, by using a stepwise upscaling approach, to the regional and finally circumarctic scale, allowing a first rough estimate of the current climate impact of N_2O emissions from permafrost affected soils. Available international circumarctic data from this and past projects will be synthesized with an Arctic N_2O database under development for use in future ecosystem and process-based climate model simulations.

THERMOKARST LAKE AREA INCREASE TREND AND ITS GEOMORPHIC AND CLIMATIC DRIVERS IN THE KOLYMA LOWLAND YEDOMA REGION, NE SIBERIA

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Thermokarst lakes are typical components of the Yedoma-alas dominated relief in the coastal lowlands of NE Siberia. The aim of our research is to study the thermokarst lake dynamics of the Kolyma lowland tundra zone from 1999 to 2018 based on geomorphological analysis and remote sensing. We estimate lake area changes based on machine-learning based classification of robust trends of multi-spectral indices of Landsat data and object-based lake detection (Nitze et al., 2017). For the geomorphological analysis, we detect Yedoma-alas relief types within varying Yedoma upland fractions based on the TanDEM-X DEM and a Quaternary deposits map created using Landsat images. We used the Quaternary deposits map to distinguish lakes with thermokarst genesis from other lakes and compiled a Yedoma-alas relief types map. Based on this map, we estimate thermokarst lake area changes over the Holocene, where in regions of different Yedoma fraction, lake area decreased from its maximum extent by 81-86%. In contrast, modern lake area changes from 1999 to 2013 showed a slight increase in lake area by 0.89%, and significant increase by 4.15% for the 1999-2018 period due to the very high precipitation during 2014-2018. We analyzed geomorphological factors impacting modern lake area changes for both periods, such as lake size, elevation, and Yedoma–alas relief type (Veremeeva et al., 2021). The increase trend has been observed in all relief types, particularly in low Yedoma fraction areas. We detected a lake area expansion trend in high Yedoma fraction areas indicating ongoing Yedoma IC degradation by lake thermokarst and thermoerosion.

The increase in thermokarst lake area is caused by the general trend of climate warming, precipitation increase and short-term weather fluctuations. However, we suggest that years with higher precipitation and water level increase could trigger lake drainage events in the following years. Therefore, the subsequent lake area dynamics monitoring is necessary to deeper understanding the response of permafrost in Yedoma-alas regions to climate warming. Estimation of the lake area dynamics based on the geomorphological analysis provide the understanding of the spatial thermokarst process development in the past, which is the base to analyze the modern thermokarst lake area changes.

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RUSSIAN-GERMAN HIGHER EDUCATION COOPERATION ON PERMAFROST SCIENCE:

2 RESEARCH-DRIVEN MASTER PROGRAMS BETWEEN UNIVERSITIES SAINT-PETERSBURG AND HAMBURG

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Two interdisciplinary and research-oriented German-Russian Master's programs - "Polar and Marine Science" (POMOR) and the new one "Cold Region Environmental Landscapes Integrated Sciences" (CORELIS) - are offered in English in the frame of Russian-German higher education cooperation and give young scientists the opportunity to integrate into the permafrost research network. The POMOR and CORELIS Master's programs were introduced in 2001 and 2015 respectively by St. Petersburg State University, Universität Hamburg, AWI, Geomar and together with other partners in Germany, Finland, France and Spain. First, 19 POMOR and 11 CORELIS alumni graduated successfully in 2004 and 2018, respectively, were awarded two Master's degrees and were able to use the German semester to join existed distributed research networks. The second generation of CORELIS Master students (15) successfully defended their MSc theses on permafrost-related topics in June 2020 (online). In total, 111 students have graduated from POMOR (8 generations), and 26 students from CORELIS (two generations). The current generation (21 POMOR students and 13 CORELIS students) is studying now, partly with online lectures due to COVID-19. A participation of foreign teachers will be realized mostly online.

The students were financed by third money funding projects between Russia and Germany. The semester abroad offered the students the unique opportunity to build a network with the permafrost research community in Germany and other partners. The students' theses are supervised by one scientist from Russia and one from Germany. The supervision of the different institutes strengthens the collaboration between the German and Russian research communities. The Program Administration counts on the invitation of its students to take part in the summer 2021 field companies from Russian-German scientific projects because of the valuable professional background in Environmental Sciences of both Master program's participants.

About 70 % of all alumni proceed their career in Earth Sciences, 30 % are working in the private sector, 5 % for public authorities. The Institute of Soil Science supervised several Master's theses. Program alumni can also be supervised as PhD students and achieve their doctoral degree at the UHH.

The following support and funding of both, the POMOR and CORELIS programs, is under discussion. A new Agreement on the CORELIS program is in progress at the Universität Hamburg and St. Petersburg State University. The student's support in the two Master's programs is aimed to be included into a new third money funded project.

YEAR-ROUND CO_2 FLUX PARTITIONING FROM SNOW-COVERED ARCTIC HEATH ECOSYSTEMS

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Arctic ecosystems play an important role in the global carbon cycle. During the short summer, plant uptake of carbon-dioxide (CO_2) is often larger than respiratory CO_2 losses, turning these ecosystems into sinks for atmospheric CO_2. The role of the long winter, however, has long been neglected even though arctic plants and soil microbes are not dormant in winter. In particular, snow-covered ecosystems are well insulated and may thus respire CO_2 year-round, weakening the CO_2 sink strength or possibly turning these ecosystems into annual CO_2 sources.

Between September 2019 and August 2020, we regularly measured net ecosystem exchange (NEE) and ecosystem respiration (R_{eco}, Fig. 1) at two locations in northern Sweden with similar mixed heath vegetation but different snow heights. We further partitioned R_{eco} into plant- and soil-related CO_2 sources, using both a clipping and an isotopic labelling approach.

The available data show that winter R_{eco} (October – May) is about 85% lower than summer R_{eco}. Both sites were strong CO_2 sinks in the summer, but weak annual CO_2 sources. Partitioning of R_{eco} showed that presumably recently fixed carbon derived from plant respiration contributes approximately 40-50% to R_{eco} with little seasonal variation between summer and winter. The environmental drivers of seasonal CO_2 fluxes, however, have not yet been analyzed in detail. Especially the effect of snow height is likely to affect soil temperatures and thus soil and plant respiration, especially towards the end of winter, when the differences in snow height between the two sites are largest.

Fig. 1. Chamber measurement of ecosystem respiration (R_{eco}) in a snow cave. In addition to the CO_2 concentration, the ^{13}C isotopic signature of the accumulated CO_2 inside the chamber is measured, allowing to determine the source signal of R_{eco} through the Keeling approach.

LANDSCAPE CONTROLS ON THERMOKARST LAKE WATER FLUXES BETWEEN INUVIK AND TUKTOYAKTUK, NORTHWEST TERRITORIES, CANADA

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The Arctic is warming at twice the rate of the rest of the world, causing precipitation to shift from snowfall to rainfall, permafrost to thaw, longer snow-free land and ice-free lakes, and increased evaporation. How the water balance of lakes formed by thawing permafrost (thermokarst lakes) will respond to the forces noted above is unknown. In some regions, lakes are expanding by thawing adjacent permafrost, while in other regions they are drying up and shrinking, or not changing at all. It is important to understand what governs lake water balance as carbon and other nutrients, some of which come from thawing permafrost, are carried by runoff into lakes. Lake evaporation and water residence time then affect the concentration of nutrients within lakes, ultimately affecting the aquatic ecosystem and greenhouse gas release. Previous research has focused on quantifying the water inputs and outputs of individual lakes, but a better understanding of the drivers and processes controlling lake water balances is required to understand how they will respond to a changing climate. Quantifying lake water balance across the Inuvik-Tuktoyaktuk region, where there is a climate and vegetation gradient, allows such an assessment of how drivers and processes affect lake water balance.

The ~5000 km^2 area between Inuvik and Tuktoyaktuk, Northwest Territories (69° N, 134° W) contains ~7500 thermokarst lakes, covering ~25% of the area. A main control on the volume of water flowing into a lake is the ratio of lake area to the area of land that drains into the lake – known as the lake area catchment area ratio (LACA). Novel methods seldom used in the Arctic were used to measure lake water level, outflow, catchment snow storage, and evaporation at two adjacent thermokarst lakes with different LACA (6.7 vs 84.1) from 2017 – 2019. To compare lake water balance over a larger region, water isotope samples were collected during March – September 2018 from over 120 lakes across a 2000 km^2 area between Inuvik and Tuktoyaktuk. This combination of methods allowed the capture of lake water balance over multiple spatial and temporal scales, landscape gradients, and meteorological conditions.

Paired lake water balance measurements showed that the lake with a larger LACA had a residence time an order of magnitude shorter than the larger lake, and displayed larger fluctuations in water level. The ratio of evaporation to inflow was significantly larger in lakes with smaller LACA, as calculated from 111 isotope samples from 23 lakes. Water isotope compositions also showed that only 10-50% of a lake's water is replaced by snowmelt in spring, while the rest of the snowmelt likely flows over the lake ice. Deeper lakes had significantly less snowmelt mixing, as the volume of water for the snowmelt to mix with was greater than in shallower lakes. These results show that lake water balance can be characterized using lake and catchment properties, allowing future research to more easily characterize lake hydrology and build further understanding about how lake water balance is connected to other aspects of the permafrost environment.

THE FATE OF SUBSEA PERMAFROST UNDER FUTURE CLIMATE WARMING

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Since the last glacial maximum, about 3 million km^2 of permafrost containing soils have been submerged into the Arctic Ocean by rising sea level, where it now constitutes a major part of the Arctic shelf area – especially in the Laptev and East Siberian Seas. At the seabed, these soils are insulated from the sub-cryotic atmospheric temperatures often overlying and stabilizing the present-day terrestrial permafrost soils. Therefore, the subsea permafrost (SSPF) is continuously being degraded also from above. This process can be expected to be accelerated by anthropogenic climate change, leading to rising benthic temperatures. As the terrestrial permafrost, and SSPF contains large but largely unknown amounts of carbon and is acting as a lid for gases (mainly methane) from deeper soil layers, SSPF thawing will lead to an additional release of carbon to the ocean floor and potentially to the atmosphere, constituting a positive feedback to the climate changes.

In previous studies, several thermodynamic models have been used to hindcast the thawing of SSPF, but so far, few attempts have been done to predict the future fate of SSPF, and to our knowledge no Earth System Model has included SSPF. Here, we present the first steps to include SSPF in the Max Planck Institute Earth System Model (MPI-ESM). We adapted JSBACH, the land component of MPI-ESM, to contain the essential SSPF processes, and forced it by CMIP6 scenario driven MPI-ESM runs extended to beyond the year 3000. In the 21st century, no big differences are found between the scenarios, but especially in the 22nd century, thawing rates in the extreme scenario SSP5-8.5 largely exceed those expected in a pre-industrial climate (by a factor of 15), leading to a loss of about 40% of SSPF until the year 3000 (compared to less than 10% in a pre-industrial climate). The low/moderate scenarios SSP1-2.6 and SSP2-4.5 show much more moderate thawing rates – at most shortly exceeding pre-industrial rates by a factor of 4. The exacerbation of SSP5-8.5 seems to be closely linked to the extensive loss of sea ice.

LARGE HERBIVORES AS STABILIZING ECOSYSTEM ENGINEERS IN THAWING TERRESTRIAL ARCTIC ENVIRONMENTS

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With an increasingly warm Arctic, new challenges arise as Arctic permafrost ground starts to thaw further. Thaw destabilizes the ground and makes soil-stored organic carbon available for microbial decomposition. To reduce thaw intensity, we examined the impact of large herbivorous animals on thaw depth in the seasonal active layer and carbon storage in both the active layer and the underlying permafrost in eastern Siberia.

In the Pleistocene Park (Cherskiy, Siberia, 68.512694° N, 161.508736° E), a landscape-scale life-size long-term experiment on recreating a large-herbivore-driven ecosystem in a 50-ha fenced area is being conducted since more than 20 years. There, we sampled locations with different grazing intensity in drained thermokarst lake basins and Yedoma uplands and analysed these samples for organic carbon content and degree of decomposition. We distinguished between "old" undecomposed organic material and freshly introduced organic material associated with the animal grazing itself.

Because of reduced snow depth in winter due to animal trampling, we hypothesize that heavily grazed areas are affected by a shallower thaw depth and therefore result in more carbon-rich permafrost as well as higher carbon amounts in the active layer. We further hypothesize that the expansion of free roaming large Arctic mammals might be a possibility to stabilize permafrost ground conditions in thaw-affected Arctic steppe and tundra regions.

EFFECTS OF A LONG-TERM WARMING SCENARIO ON MICROBIAL COMMUNITY STRUCTURE AND FUNCTIONAL POTENTIAL OF PERMAFROST-AFFECTED SOIL

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Permafrost-affected soils are widespread in the Arctic and subarctic regions and store about half of the global soil organic carbon (Hugelius et al., 2014). This large carbon pool becomes vulnerable to microbial decomposition through permafrost warming and deepening of the seasonal thaw layer (active layer) (Schuur et al., 2015). Here, we combined greenhouse gas (GHG) production rate measurements with a metagenome-based assessment of the microbial taxonomic and metabolic potential changes in the active layer, permafrost transition layer and intact permafrost after five years of incubation under anoxic conditions at a constant temperature of 4°C. Warming led to a rapid initial release of CO_2 and, to a lesser extent, CH_4 in all layers. After the initial pulse, especially in CO_2 production, GHG production rates declined and conditions became more methanogenic. Functional gene-based analyses indicated a decrease in carbon and nitrogen-cycling genes, and a community shift to the degradation of less labile organic matter. This study reveals low but continuous GHG production in long-term warming scenarios which coincides with a decrease in the relative abundance of major metabolic pathway genes and an increase in carbohydrate-active enzyme classes.

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WATER ECOSYSTEMS OF THE SIBERIAN TUNDRA: GEOCHEMICAL AND GEOMORPHOLOGICAL FEATURES (SAMOYLOV AND KURUNGNAKH ISLANDS, LENA DELTA)

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The geomorphological and geochemical investigation of the lakes on the Samoylov and Kurungnakh Islands was carried. We have used GIS-analyze for subdividing lakes depending on their geomorphological position. The altitude of the water surface was revealed from ArcticDEM, the lakes' area - from manual mapping of lakes' borders in UAV imageries and area estimation. We used ArcGIS from ESRI for all GIS operations. We took into account the lakes' geomorphological positions, which were determined manually. We sampled the bottom sediments and waters chemical composition. The Electrical Conductivity, dissolved O_2, Temperature, TOC, pH, and Eh values were measured in waters *in-situ*, chemical elements concentrations were detected in laboratory by ICP-MS.

The distribution of chemical elements in the lakes waters repeats that in the Lena River, there are anomalies in beryllium, iron, manganese, chromium, and nickel. The bottom sediments of the lakes have abnormal Se, Te, Re, Bi, and U contents compared to average in the continental crust.

All lakes were divided into groups: 1) small water bodies on the Edoma upland surface; 2) lakes in six thermokarst hollows; 3) lakes on the first terrace. The lakes bottom sediments on the Edoma are depleted in comparison with sediments of other groups by the Li, Be, As, Zn, Ag, Ba, Pb, and Ba. The distribution of REE in the lakes bottom sediments at the first terrace and Samoylov Island corresponds to the distribution in clays of the Russian Platform. The REE concentrations in the bottom sediments of Edoma lakes and several lakes on poorly degraded surfaces of the third terrace are lower than in other lakes, with exception to La. Complex investigation will allow us to evaluate the main processes, which control the mobility of chemical elements during the permafrost degradation, evaluate the main regional features for adequate ecological monitoring in future.

UPPER PART OF THE GEOELECTRICAL SECTION FROM THE LENA RIVER DELTA USING MTS DATA

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Lena Delta is the largest Arctic delta in the world. This unique territory has a complex deep structure and permafrost layer. However, due to the cover of the Quaternary sediments, the deep structure of the folded region has been studied very poorly. One of our studies main goal was to indicate the depth of the permafrost base or the boundaries of the melting zone in the channel part of the Lena Delta and on its ridges.

The survey was carried out using Canadian MT station MTU -5a from «Phoenix Geophysics Ltd», with a measuring range from 0.003 to 10000 s. The measurements included four components of the MT field (Ex, Ey, Hx, Hy). Standard MTZ measurements plan (x - shape) were used. A step between points was approximately 2 - 3km. The MT profile includes points made in summer of 2019 and 2020.

The preliminary data processing resulted in a 1D model for each point. The technique revealed the structure with a base depth of approximately 10 km. As a result of processing, the section has divided into main layers due to its resistivity. Points with low resistivity levels indicate fault zones. Based on the 1D model of each point, we split our profile into three zones: 0 - 6 km from the south-west, 6 – 28 km, and 28 – 36 km. In the section, two main faults were detected (Fig. 1).

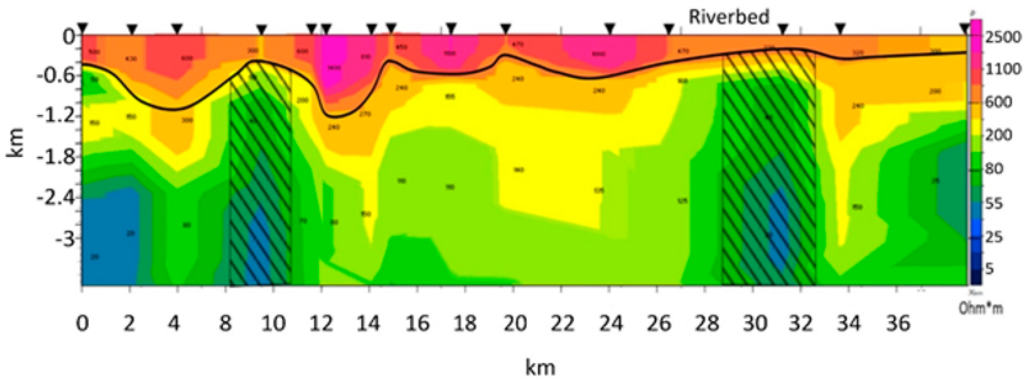

Fig. 1: Upper part of the cross-section. Black triangles mark measurement points. Striped polygons show premilitary fault zones.

Field data processing and interpretation results make it possible to indicate the basing depth of the permafrost layer for 17 profile points. The upper layer's resistance is in the range of 150-2500 Ohm * m, which is typical for frozen rocks. The permafrost basing depth varies from 140 to 730 under the surface. The base depth for this layer varies from 200 m to 1000 m. These thickness variations could be caused by the Lena River and its channels.

The main results of the geophysical studies, using the MT technique, allow splitting the interior (to the depth of 10 km) into main layers, indicating huge faults. Also marking the base depth of the permafrost layer is a significant result. We plan to use these data in conjunction with other techniques.

THERMAL REGIME AND HYDRODYNAMICS OF ARCTIC LAKES AND RIVERS

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The regional climate changes of the recent decades have a significant impact on the thermal regime and hydrodynamics of Arctic lakes and rivers. The study reported here was conducted on the lakes and channels of the Lena River Delta. The water temperature was measured in the three lakes Fish, Molo, and Bannoe-2 (Samoilovsky Island) from July 2009 to August 2012 with a time interval of one hour, and on Lake Fish from 20 April to 23 August 2019 with a time interval of five minutes using 3-7 RBR temperature loggers mounted on a rope. The main stages of the annual thermal cycle of the lakes were determined (ice-on and ice-off dates, spring under-ice convection, spring homothermy, summer heating, and autumn-winter cooling). Numerical modeling of the thermal and ice regime of these lakes was carried out using the one-dimensional parameterized Flake model (http://www.flake.igb-berlin.de/). A comparison of the field against the model showed that the annual variation in water temperature in the lakes is captured by the model quite well. The numerical calculations according to the ERA-5 reanalysis data set (www.ecmwf.int) showed that the average ice thickness and the duration of the ice-period on the lakes of Samoilovsky Island decreased by 3 mm per year and 0.5 days per year in 1979-2018.

The currents were measured on the cross-sections in the Olenekskaya and Bykovskaya channels, as well as in the main channel of the Lena River near Samoilovsky Island on 12-17 April 2019 using the CTD-90M. In the Bykovskaya channel, current velocities reached 20–25 cm/s, in Olenekskaya channel – 5-11 cm/s, and in the main channel – 12-18 cm/s. The data obtained made it possible to calculate the discharge in the channels during the ice-period.

Acknowledgements

The study was supported by the RFBR (project No. 18-05-60291).

DISSOLVED OXYGEN IN ICE-COVERED LAKES

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The presentation reports on the results of the long-term field measurements of the variability of temperature and values of dissolved oxygen conducted on three ice-covered lakes: Lake Vendyurskoe in Karelia (period of measurements April-May 2008-2019, time interval one minute), Lake Big Voudyavr on the Kola Peninsula (21-24 February 2019, time interval one minute), and Lake Fish in the Lena River Delta (20 April-2 June 2019, time interval five minutes). To conduct the measurements, RBR temperature and dissolved oxygen loggers mounted to chains were used. On Lake Vendyurskoe, measurements of under-ice irradiance («Star-shaped pyranometer» «Theodor Friderich & Co, Meteorologische Geräte und Systeme») and concentrations of chlorophyll "a" (CTD-90M «Sea & Sun Technology») were simultaneously conducted. The variability of the temperature and dissolved oxygen in the lakes were considered during the period of winter stagnation and spring under-ice convection. It was shown that in winter, oxygen fluctuations with periods from minutes to several days (up to 0.5 mgO_2/l) can be caused by hydrodynamic processes, such as internal waves, advection, seiches, currents. In addition to these periods, a pronounced diurnal oxygen variability (up to 1 mgO_2/l) was registered in the convective layer of the lake, reaching a maximum during the day and a minimum at night during spring under-ice convection. An increase in the amplitude of diurnal oxygen fluctuations in the convective layer occurred against the background of an increase in under-ice irradiance and the concentration of chlorophyll "a", which suggests a relationship between these processes. Convective upward and downward currents and seiches presumably determine the variability of oxygen with a period from minutes to hours. Involvement in convective mixing of oxygen-depleted bottom waters leads to a decrease in the oxygen concentration in the convective layer, but the total oxygen content in the water column increases due to the activation of photosynthesis.

Acknowledgements

The study was supported by the RFBR (project No. 18-05-60291).

METHANE EMISSION IN THE RUSSIAN PERMAFROST ZONE

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Permafrost is the largest reservoir of organic carbon. It is 12 times greater than the tropical forest reservoir. If permafrost thaws in anaerobic conditions, a quarter of the organic matter is converted into methane, which is a much stronger greenhouse gas than CO_2. In the recent years, permafrost degradation accelerated in every region, and this must be noticed in the atmospheric methane concentration. The most active methanogenesis occurs at maximum temperatures. Therefore, the maximum methane emission from northern bogs should be in July. Near-surface sediments have the highest temperature at that time. Highest temperatures of the lower soil horizons and permafrost degradation, in contrast, are observed in late autumn. Therefore, the highest methane emission from thawed permafrost must be observed also in autumn.

We analyzed satellite data of methane concentrations in the troposphere above the permafrost zone of Russia from 2002 to 2019, and created maps of methane concentration changes over this period for July and September. We did not detect a noticeable increase in the summer methane concentrations. A small methane concentration increase occurred in regions where the climate became warmer and more humid. Methane concentration decreased in regions with a dry climate. September’s data, in contrast, indicate a higher rise of methane concentrations than globally. Half of the territory even overtakes the global trend by 5-15 ppb/yr. This territory matches with Yedoma territory – Pleistocene organic rich frozen sediments. A strong increase of methane concentrations is detected even in the far north – in the north of Taimyr and Novosibirsky islands. Because of the thawing of polygonal ice wedges, a polygonal relief formed there, and permafrost degradation can be detected with satellite imagery.

Also, methane increase is observed in the coastal zone where the sea erodes Yedoma sediments, while no methane increase is detected further inland. If climate warming will continue the same way, emission of greenhouse gases from permafrost could prevail anthropogenic CO_2 emission.

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