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Focus Siberian Permafrost – Terrestrial Cryosphere and Climate Change

International Symposium

Institute of Soil Science – Universität Hamburg

23 – 27 March 2020

Edited by

E.M. Pfeiffer, T. Eckhardt, L. Kutzbach, I. Fedorova,
L. Tsibizov & C. Beer

HELMHOLTZ

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Herausgeber
Dr. Horst Bornemann

Redaktionelle Bearbeitung und Layout
Birgit Reimann

Editor
Dr. Horst Bornemann

Editorial editing and layout
Birgit Reimann

Alfred-Wegener-Institut
Helmholtz-Zentrum für Polar- und Meeresforschung
Am Handelshafen 12
27570 Bremerhaven
Germany

www.awi.de
www.awi.de/reports

Alfred-Wegener-Institut
Helmholtz-Zentrum für Polar- und Meeresforschung
Am Handelshafen 12
27570 Bremerhaven
Germany

www.awi.de
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Titel: Eisreiche Permafrost-Ablagerungen des Yedoma-Eiskomplexes, Bol'shoy Lyakhovsky, Neu-Sibirische Inseln (Foto: Josefine Walz)

Cover: Ice-rich permafrost depostits of the Yedoma ice-complex, Bol'shoy Lyakhovsky, New Siberian Islands (Photo: Josefine Walz)

International Symposium

Focus Siberian Permafrost – Terrestrial Cryosphere and Climate Change

Institute of Soil Science – Universität Hamburg
March 23 – 27, 2020
Hamburg, Germany

Editorial board
E.M. Pfeiffer, T. Eckhardt, L. Kutzbach, I. Fedorova,
L. Tsibizov & C. Beer

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Welcome to International Symposium

Focus Siberian Permafrost - Terrestrial Cryosphere and Climate Change,

March 23 to 27, 2020 in Hamburg

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 strengthen 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 is realized through the support of the Center of Earth System Science and Sustainability (CEN), the cluster of excellence Climate Science, Climate Change, and Society (CliCCS) at the Universität Hamburg, the German Society of Polar Research (DGP), the German Research Foundation (DFG) and the Ministry of Education and Research (BMBF).

The proceedings at hand comprise all abstracts, which have been submitted to the Symposium „Focus Siberian Permafrost“ and cover a broad variety of research from microbial processes to soil-vegetation-interaction in different permafrost-affected landscapes to the complexe impact of climate change in Siberia. The colloquium of the BMBF funded German-Russian- project „Carbon in Permafrost“ (KoPf) will provide a major contribution to answer open questions of permafrost research. „Focus Siberian Permafrost“ will discuss 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. We hope an inspiring exchange with everybody interested in Siberian permafrost research.

Enjoy reading the abstracts of the oral and poster presentations and 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 understanding of the global carbon cycle as well as current and future greenhouse gas fluxes from changing permafrost landscapes in Russia.

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

Hamburg, March 2020

Symposium „Focus Siberian Permafrost", 23 – 27 March, 2020, Hamburg, Germany

	Monday, 23rd March	Tuesday, 24th March	Wednesday, 25th March	Thursday, 26th March	Friday, 27th March
08:30 – 09:00		**Registration**	**Registration**	**Registration**	
08:45 – 09:00					
09:00 – 09:15		Official Opening Pfeiffer, Overbeck, Fretzdorff, Graener	Jongejans	Kaverin	**Group meetings**
09:15 – 09:30			Pastukhov	Tsibizova	
09:30 – 09:45			Mangelsdorf	Zdorovennova	
09:45 – 10:00		Kutzbach	Prokushkin	Yurkevich	
10:00 – 10:15		Wischhoefer	Lisovski	Overduin	
10:15 – 10:30		Abakumov	Heim	Buchwal	
10:30 – 10:45		Grosse	Sabrekov	Zdorovennov	
10:45 – 11:00		Lashchinsky	Walz	Evgrafova	
11:00 – 11:15		**Coffee Break**	**Coffee Break**	**Coffee Break**	
11:15 – 11:30					
11:30 – 11:45		Rößger	Dietze	Morgenstern	
11:45 – 12:00		Fedorova	Eliseev	Panel discussion ‚*Importance of permafrost ecosystems for future climate*'	
12:00 – 12:15	**Registration** *Institute of Soil Science, Allende-Platz 2*	Brovkin	Pravkin		
12:15 – 12:30		Shevtsova	Rivkina		
12:30 – 12:45		Knoblauch	Wild	**Closing session**	**Individual lunch**
12:45 – 13:00		Poliakov	Rusakov	**Individual lunch**	
13:00 – 13:15		**Group photo**	**Individual lunch**		
13:15 – 13:30		**Individual lunch**			
13:30 – 13:45				**Excursion to a periglacial soil in northern Germany** *(led by Lars Kutzbach & David Holl)*	
13:45 – 14:00					
14:00 – 14:15			Kut		
14:15 – 14:30		Beer	Tsibisov		
14:30 – 14:45		Stepanenko	Zaplavnova		
14:45 – 15:00		Winkler	Runge		
15:00 – 15:15		Porada	Faguet		
15:15 – 15:30		**Coffee Break**	Kartoziia		
15:30 – 15:45			Veremeeva		
15:45 – 16:00		Habeck	**Coffee Break**		
16:00 – 16:15		Fiencke			
16:15 – 16:30		van Delden	Poster Session *Foyer, Geomatikum*		
16:30 – 16:45		Sanders			
16:45 – 17:00		Strauss			
17:00 – 17:15		Ramm			
17:15 – 17:30		Short poster presentation			
17:30 – 17:45					
17:45 – 18:00					
18:00 – 18:15	**Ice-Breaker** *Institute of Soil Science, Allende-Platz 2*	**Öffentlicher Abendvortrag - Martin Heimann**	**Individual dinner**	**Individual dinner**	
18:15 – 18:30					
18:30 – 18:45					
18:45 – 19:00					
19:00 -		**Conference Dinner**			

Sessions

- Carbon transformation and greenhouse gas release from thawing permafrost (KoPf)
- Formation and degradation of permafrost landscapes
- Past permafrost ecosystem dynamics
- Recent biogeochemical dynamics in permafrost ecosystems
- Projected future permafrost ecosystem dynamics

Sessions / Registration: Lecture Hall H2, Geomatikum, Bundesstrasse 55
Conference dinner: geological-palaeontological museum

Program of the international Symposium

“Focus Siberian Permafrost – Terrestrial Cryosphere and Climate Change”

23 – 27 March 2020

Hamburg, Germany

Monday, 23 March 2020

(Arrival)

12:00 – 18:00 Registration & group meetings *(Institute of Soil Science, Allende-Platz 2)*

18:00 – 21:00 Ice-Breaker *(Institute of Soil Science, Allende-Platz 2)*

Tuesday, 24 March 2020

08:30 – 09:00 Registration *(Geomatikum, Bundesstrasse 55)*

09:00 – 09:45 Official opening of the Symposium
Welcome greetings by

Prof. Dr. Eva-Maria Pfeiffer (UHH)

Dr. Norbert Overbeck (BMBF)

Dr. Susanne Fretzdorff (PTJ)

Prof. Dr. Heinrich Graener (UHH)

“Carbon transformation & greenhouse gas release from thawing permafrost”

Session chair: Christian Beer, Alexandra Veremeeva

09:45 – 10:00 *Lars Kutzbach, N. Rößger, T. Sachs, C. Wille, J. Boike, I. Fedorova, M.N. Grigoriev, E.-M. Pfeiffer*
Methane flux dynamics across scales in polygonal tundra of the Siberian Lena River Delta

10:00 – 10:15 *Philipp Wischhöfer, J. Melchert, G. Norén, S. Holm, L. Sauerland, C. Knoblauch, J. Rethemeyer*
Carbon dynamics in a retrogressive thaw slump: Insights from three consecutive years of ^{14}C analysis of microbial respired CO_2

10:15 – 10:30 *Evgeny Abakumov, V. Polyakov*
The role of microparticles of organic carbon in degradation of ice cover of polar regions of the Earth and in the process of soil-like bodies formation

10:30 – 10:45 *Guido Grosse, I. Nitze, A. Runge, M. Fuchs, T. Henning, B. Heim, B. Heim, F. Günther, M.Grigoriev*
Remote Sensing of Landscape Change in the Lena Delta Region

10:45 – 11:00 *Nikolay Lashchinskiy*
Primary plant succession on freshly degraded edoma (Ice Complex) in Lena Delta (Eastern Siberia)

11:00 – 11:30 Coffee break

11:30 – 11:45 *Norman Rößger, C. Wille, L. Kutzbach*
Scaling and balancing carbon fluxes in a heterogeneous tundra ecosystem of the Lena River Delta

11:45 – 12:00 *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

12:00 – 12:15 *Victor Brovkin*
Permafrost carbon in earth system models: Progress and challenges

12:15 – 12:30 *Iiulia Shevtsova, U. Herzschuh, B. Heim, L. Schulte, S. Stünzi, L.A. Pestryakova, E.S. Zakharov, S. Kruse*
Recent vegetation composition and above ground biomass changes in central Chukotka

12:30 – 12:45 *Christian Knoblauch, A. Schütt, C. Beer, S. Liebner, L. Sauerland, G. Norén, E. Abakumov, J. Rethemeyer, E.-M. Pfeiffer*
Carbon dioxide and methane production and release from eroding permafrost deposits of northeast Siberia

12:45 – 13:00 *Vyacheslav Poliakov, E. Abakumov*
Molecular composition of humic acids from selected soils from the Russian Arctic: Characterization of by two-dimensional ^{1}H-^{13}C HETCOR and ^{13}C CP/MAS NMR spectroscopy

13:00 – 13:15 Group photo

13:15 – 14:15 Individual lunch

"Projected future permafrost ecosystem dynamics"

Session chair: Zoé Rehder, Leonid Tsibizov

14:15 – 14:30 *Christian Beer, N. Zimov, J. Olofsson, P. Porada, S. Zimov*
Protection of permafrost soils from thawing by increasing herbivore density

14:30 – 14:45 *Victor M. 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

14:45 – 15:00 *Alexander J. Winkler, R.B. Myneni, G.A. Alexandrov, V. Brovkin*
Earth system models underestimate carbon fixation by plants in the high latitudes

15:00 – 15:15 *Philipp Porada, C. Beer*
Impact of mosses and lichens on future carbon emissions from permafrost soils

15:15 – 15:45 Coffee Break

Part I "Recent biogeochemical dynamics in permafrost ecosystems"

Session chair: Alexey Eliseev, Josefine Walz

15:45 – 16:00 *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

16:00 – 16:15 *Claudia Fiencke, T. Sanders, E.-M. Pfeiffer*
Microbial transformation and availability of dissolved nitrogen in the active layer of cryosols

16:15 – 16:30 *Lona van Delden, M. Marushchak, C. Voigt, G. Grosse, A. Faguet, N. Lashchinskiy, J. Kerttula, C. Biasi*
Towards the first circumpolar N_2O budget – Extrapolating to the landscape scale

16:30 – 16:45 *Tina Sanders, M. Fuchs, K. Dähnke*
Fate and transport of nitrogen in soils, sediment and water of the Lena Delta, northeast Siberia

16:45 – 17:00 *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*
Changing Arctic Carbon cycle in the cOastal Ocean Near-shore (CACOON): A project focussing on the dynamic interface between land and ocean in the Arctic

17:00 – 17:15 *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 NIFOCLIM project

17:15 – 17:45 Short poster presentation *(chair: Tim Eckhardt)*

18:00 – 18:45 Öffentlicher Abendvortrag *(lecture hall H2, Geomatikum)*
Martin Heimann, M. Goeckede, S. Zimov, N. Zimov
Auf der Suche nach Treibhausgasemissionen aus dem Permafrost in Nordost-Sibirien

19:00 – 22:00 Conference dinner *(geological-palaeontological museum, Geomatikum)*

Wednesday, 25 March 2020

08:30 – 09:00 Registration *(Geomatikum, Bundesstrasse 55)*

Part II "Recent biogeochemical dynamics in permafrost ecosystems"

Session chair: Lutz Beckebanze, Irina Fedorova

09:00 – 09:15 *Loeka Jongejans, S. Liebner, C. Knoblauch, G. Grosse, J. Strauss*
CO_2 and CH_4 release from in-situ thawed Yedoma sediments in the Yukechi alas, Yakutia

09:15 – 09:30 *Aleksandr Pastukhov, D. Kaverin, C. Knoblauch, C. Beer, I. Ryzhova*
Permafrost-affected peatlands and their vulnerability to warming in the south of the European Russian cryolithozone

09:30 – 09:45 *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

09:45 – 10:00 *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

10:00 – 10:15 *Simeon Lisovski*
Seasonal timing of snow melt and primary productivity in the Lena Delta region

10:15 – 10:30 *Birgit Heim, S. Lisovski, I. Shevtsova, S. Kruse, J. Boike, A. Morgenstern, U. Herzschuh, S. Evgrafova, E. Abramova, C. Rixen*
‚Seeing' Arctic vegetation greening after snowmelt in the Lena Delta, Siberia, using NASA MODIS optical satellite time series

10:30 – 10:45 *Aleksandr Sabrekov, I. Terentieva, Y. Litti, M. Glagolev, V. Vavilin*
Methane production in west Siberian boreal wetlands as a function of organic matter decomposition pathways and microbial communities

10:45 – 11:00 *Josefine Walz, F. Gehrmann, E.A.S. Anderson, E. Dorrepaal*
Sources of winter CO_2 fluxes

11:00 – 11:30 Coffee break

"Past permafrost ecosystem dynamics"

Session chair: A. Morgenstern, Vyacheslav Polyakov

11:30 – 11:45 *Elisabeth Dietze, S. Kruse, K. Mangelsdorf, A. Andreev, B. Heim, 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

11:45 – 12:00 *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

12:00 – 12:15	*Sergei Pravkin, D. Bolshiyanov, A. Aksenov* The first river terrace and the ice complex of the Lena Delta: Common origin and evolution
12:15 – 12:30	*Elizaveta Rivkina, T. Vishnivetskaya* Biogeochemical processes in permafrost
12:30 – 12:45	*Birgit Wild, J. Martens, A. Andersson, G. Hugelius, L. Bröder, J. Vonk, J.W. McClelland, P.A. Raymond, D. Kosmach, O. Dudarev, A. Charkin, N. Shakhova, I. Semiletov, N. Belyaev, E. Romankevich, A. Vetrov, L. Lobkovsky, Ö. Gustafsson* Reconstructing terrestrial permafrost thaw at the continental scale using rivers and the ocean as integrators across heterogeneous landscapes
12:45 – 13:00	*Alexey Rusakov, A. Sheinkman, S. Sedov* Cryotrasological indication of paleosols identified to the north of the European and western Siberian loess belt: Reflection at meso- and micromophological levels of their organization
13:00 – 14:00	**Individual lunch**

“Formation and degradation of permafrost landscapes”

Session chair: N. Lashchinskiy, Tina Sanders

14:00 – 14:15	*Anna Kut, V. Spektor* Micromorphology of quartz grains in Edoma sediments of Abalakh plate, central Yakutia
14:15 – 14:30	*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
14:30 – 14:45	*Anna Zaplavnova, V. Potapov, V. Olenchenko, A. Shein* Geoelectrical section of the permafrost from the estuary part of the Lena River Delta using MTS data
14:45 – 15:00	*Alexandra Runge, G. Grosse* A comprehensive remote sensing-based assessment of retrogressive thaw slump dynamics across north Siberia for 1999-2019
15:00 – 15:15	*Alexey Faguet, A. Kartoziia, N. Lashchinskiy* Permafrost evolution in Lena Delta as seen on 2016-2019 drone survey data. An overview.
15:15 – 15:30	*Andrei Kartoziia, A. Mishina* Geomorphological mapping of periglacial landscapes using UAV data GIS-analyze
15:30 – 15:45	*Alexandra Veremeeva, I. Nitze, F. Günther, G. Grosse, E. Rivkina* Thermokarst lake changes in Yedoma regions (1999-2018), north-eastern Siberia

15:45 – 16:15 **Coffee break**

16:15 – 18:00 Poster session *(Foyer, Geomatikum)*

18:00 – **Individual dinner**

Thursday, 26 March 2020

08:30 – 09:00 Registration *(Geomatikum, Bundesstrasse 55)*

Part III “Recent biogeochemical dynamics in permafrost ecosystems”

Session chair: Alexandra Runge, Alexey Faguet

09:00 – 09:15 *Dmitry Kaverin, A. Khomutov, M. Sadurtdinov, M. Sudakova, A. Pastukohv*
Application of high-frequency ground penetrating radar to study permafrost-affected soils in peat plateaus

09:15 – 09:30 *Ekaterina Tsibizova, N. Yurkevich, T. Fedorova*
Chemical composition of water and bottom sediments in thermokarst lakes on Kurungnakh island, Lena Delta

09:30 – 09:45 *Galina Zdorovennova, I. Fedorova, A. Shadrina, T. Efremova, R. Zdorovennov, N. Palshin*
Dissolved oxygen in ice-covered lakes

09:45 – 10:00 *Nataliya Yurkevich, A. Karotziia*
Water ecosystems of the Siberian tundra: Geochemical and geomorphological features (Samoylov and Kurungnakh islands, Lena Delta)

10:00 – 10:15 *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

10:15 – 10:30 *Agata Buchwal, G. Rachlewicz, B. Heim*
Dendrochronological records from tundra shrubs in the vicinity of Samoylov island

10:30 – 10:45 *Roman Zdorovennov, G. Zdorovennova, A. Guzeva, S. Evgrafova, S. Golosov, I. Zverev, I. Fedorova*
Thermal regime and hydrodynamics of Arctic lakes and rivers

10:45 – 11:00 *Svetlana Evgrafova, V. Kadutskii, O. Novikov, G. Guggenberger, D. Wagner*
Greenhouse gas release in field-based incubation experiment with buried soil, Lena Delta, Siberia

11:00 – 11:30 **Coffee break**

11:30 – 11:45 *Anne Morgenstern*
Summary of the workshop ‚Development of a joint strategy for future research on Samoylov island and in the Lena Delta region‘

11:45 – 12:30	**Panel discussion** ‚Importance of permafrost ecosystems for future climate‘
12:30 – 12:45	**Closing session**
12:45 – 13:30	**Individual lunch**
13:30 – 18:00	Excursion to a periglacial soil in northern Germany *(led by Lars Kutzbach & David Holl)*
18:00 -	**Individual dinner**

Friday, 27 March 2020

09:00 – 12:15	Group meetings

(Departure)

Contents

ABANDONED SOILS OF THE RUSSIAN SUB-ARCTIC ON THE EXAMPLE OF SALEKHARD, SOUTHERN YAMAL

Evgeny Abakumov[1], I. Alekseev[1]

[1]Saint Petersburg State University, Saint Petersburg, Russia

Systematic and very intensive studying and exploitation of natural resources of Far North of Russia has been started in the 1920s. Due to the development of industry and growth of the population, necessity in localization of food support products was growing intensively and arable soils became typical component of the subject of study. Nowadays, however, almost all the former agricultural lands are abandoned or exposed to various anthropogenic activities from time to time. Content of these elements as well as content of such technogenic pollutants as heavy metals and pesticides serve as a good indicator for estimation of the level of anthropogenic influence on urban ecosystems *(Bullock, Gregory 1991).* Abandoned agricultural soils in suburban territories of Salekhard were studied with the aim to evaluate the alteration of soil morphology and chemistry under agricultural practices and to clarify its specificity in case of permafrost-affected soils. Predominance of sandy textured parent materials was found as one of the main reason for favorable agricultural using of land in the north of Western Siberia in previous years. Soil organic carbon content depended mainly on the character of current land use and varied significantly in the studied soils. Most of the soil samples showed the highest levels of nutrients in topsoil horizons. Former arable horizons were stable in time in terms of morphological features and agrochemical state. In spite of the high level of soil acidity, content of nutrients in anthropogenically affected topsoils was still high after 20 years of abandonment. This indicated that agrosoils with relatively high fertility of arable topsoils could exist during long time in case of sandy textured parent materials. It has been found very high levels of available phosphorus content for all the topsoil horizons (>500 mg kg-1). However, for the lowest horizons it has been found low levels of this element content (<200 mg kg-1). So, agrochemical state of the topsoil is stable even after 20 years staying in abandoned state. It has been previously found that in urban landscapes accumulation of phosphorus and potassium and increasing of their content are observed in the end of vegetation period (*Nikitina, 2015*). Possible technogenic accumulation of the nutrients in urban agricultural soil could be considered as a reason of stable agrochemical state of soil investigated. The active layer depths have been identified using vertical electrical resistivity sounding (Schlumberger geometry approach). Vertical profile of electrical resistivity value in urban soils is more complicated and has a number of fluctuations due to higher rates of ground mixing, mechanical pressure and high amount of artefacts. The main trend of their change within the soil profiles is connected with gradual increasing of Ra values with the depth, which is caused by lower temperatures lower amount of gravitational water and higher amount of sand fraction in lower parts. Cryopedogenesis leads to cryogenic mass transfer, homogenization of soil mass and to complication of profile distribution of electrical resistivity values, but these processes are overlapped by anthropogenically caused mixing of soil mass leading to appearance of more fluctuations in profile distribution of electrical resistivity values. The data reported in this work could be used for the assessment of anthropogenic influence on urban ecosystems and should be used for the further ecological monitoring on key plots.

Acknowledgments:

This study was supported by RFBR grant № 19-416-890002 «Microbiome of abandoned soils of Yamal-Nenents autonomous region agroecosystems: diversity, properties, taxonomy, dynamics».

References:

Nikitina, M.V. (2015). The content of soil nutrition elements as a diagnostic indicator of processes in urban soils of Arkhangelsk. Arctic Environmental Research, 4, 83-89.

Bullock, P., Gregory, P. (1991). Soils in the Urban Environments. Blackwell Scientific Publications, Oxford, 174 p.

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

Evgeny Abakumov[1]

[1]Saint-Peterburg State University, Department of Applied Ecology, Saint-Petersburg, Russia
[2]State Research Center, City, Country

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 characterizes by very low enrichens of soil organic matter by nitrogen. At the same time, soils of maritime Antarctic show increased portions of the organic carbon in the fine earth. Taking into account that fact that there is also increased portion of the fine earth in soils of maritime zone, one can conclude that the rate accumulation of organic matter here is essentially higher than in soils of continental part. The aim of this research was to evaluate stocks, content and molecular compositions of organic matter, formed under two vascular plant, which are indigenous for 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 enrichness of fine earth by organic carbon and nitrogen is higher in normal soils under the lichens and mosses. More over the composition of individual precursors of humification in soils, formed under vascular plants is essentially differ from those under lichens and mosses. That is why organic matter stabilization rate is higher in soils under two higher plants, mentioned above. The most important fact, which can effect the stabilization degree, is amount of aromatic compounds of different structure and origin in case of soil formation under flowering plants. Thus, the current expansion of these Antarctic herbscaused by factor of ornitohoria, within the inland territories, should result in increasing of the areas, occupied by soils with high organic matter stabilization degree.

Acknowledgments:

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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

Evgeny Abakumov[1], V. Polyakov[1]

[1]Department of Applied Ecology, Saint-Petersburg State University, Saint-Petersburg, Russia

Rapid glaciaers retrearment in polar and mountain regions of the Earth is resulted from not only direct effect of the climate changes, but, at the same time, with the global transfer of micropartciles. An accumulation of these microparticles on the glaciers surface result in chaning 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 space-developed web of organo-menral material, which finally result in intensification of deglaciation. In this context this report is aimed for complex investigation of this process with use if 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 glaciers 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 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 formation of aliphatic fragments in the humic acids. In general, soils of the studied region characterizes by low stabilized soil organic matter which is indicated by low aromaticity of the HAs. The cryoconites contains more stabilized organic matter than soils.

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VARIABILITY OF CARBONATE SYSTEM COMPONENTS IN ARCTIC WATER ECOSYSTEM

Natalia Alekseeva[1,2], I. Fedorova[3], S. Romanov[4], A. Chetverova[2,3]

[1]The Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Science, Novosibirsk, Russia
[2]Arctic and Antarctic Research Institute, Saint-Petersburg, Russia
[3]Saint-Petersburg State University, Saint-Petersburg, Russia
[4]State Company «Mineral», Saint-Petersburg, Russia

During 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 ranged from 3 to 26 mg/ l, in the lakes 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 varied slightly from the surface to the depth. However, the increased dissolved gas concentration noted at the main channel (25 mg/l). The lakes characterized by no trace of a change in the concentration of CO_2 with depth, but there are as alkalizing and slightly acidified lakes with atypical concentration values. The absence of carbon dioxide in one of 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.

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LATERAL CARBON EXPORT FROM POLYGONAL TUNDRA CATCHMENTS ON SAMOYLOV ISLAND, LENA RIVER DELTA

Lutz Beckebanze[1,2], J. Walz[1,3], B.R.K. Runkle[4], D. Holl[1,2], I. Fedorova[5], M. Helbig[6], L. Kutzbach[1,2]

[1]Institute of Soil Science, Universität Hamburg, Hamburg, Germany
[2]Center for Earth System Research and Sustainability, Universität Hamburg, Hamburg, Germany
[3]Department of Ecology and Environmental Sciences (EMG), Umeå University, Umeå, Sweden
[4]Department of Biological and Agricultural Engineering, University of Arkansas, Fayetteville, USA
[5]Institute of Earth Sciences, St. Petersburg State University, St. Petersburg, Russia
[6]School of Geography & Earth Sciences, McMaster University, Hamilton, Canada

Permafrost-affected soils contain a large quantity of soil organic carbon (SOC). The carbon balance defines whether a soil acts as a source or sink of carbon. In recent decades, many researchers observed and analyzed the carbon balance of permafrost soils. In most cases, the focus lays on observations of the vertical carbon flux (CO_2 and CH_4) to estimate the carbon balance. However, there is lack of information regarding the lateral losses of carbon via dissolved organic carbon (DOC) or dissolved inorganic carbon (DIC) in ground- or rainwater.

In this study, we estimate the lateral carbon fluxes from a permafrost-affected site in north-eastern Siberia, Russia. Long-term measurements of vertical carbon fluxes have been conducted at this study site. By considering both, the vertical and the lateral carbon fluxes, we estimate the complete carbon balance for one growing season in 2014 and discuss the contribution of the lateral carbon flux to the overall carbon balance.

The results show that vertical CO_2 fluxes dominate the carbon balance during the growing season from June 8th – September 8th (-19 ± 1.2 kg-C m^{-2}). The lateral fluxes of DOC and DIC reached values of +0.1 ± 0.01 and +1.4 ± 0.09 kg-C m^{-2}, respectively, whereas the vertical fluxes of CH_4 had values of +0.7 ± 0.02 kg-C m^{-2} integrated over this time. By considering the lateral carbon export, the net ecosystem carbon balance of the study area was reduced by 8%. On shorter time scales of days, the relationship between lateral and vertical flux changes. Early in the growing season, the lateral carbon flux outpaces the weak vertical CO_2 uptake for a few days and converts the estimated carbon balance from a sink to a source.

We conclude that lateral carbon fluxes have a larger influence on the carbon balance of our study site on time scales of days (early and late growing season) and that this influence decreases with annual time scales. Therefore, the vertical carbon flux can be seen as a good approximation for the carbon balance of this study site on annual time scales.

PROTECTION OF PERMAFROST SOILS FROM THAWING BY INCREASING HERBIVORE DENSITY

Christian Beer[1,2,3], N. Zimov[4], J. Olofsson[5], P. Porada[1,2,6], S. Zimov[4]

[1]Department of Environmental Science and Analytical Chemistry, Stockholm University, Sweden
[2]Bolin Centre for Climate Research, Stockholm University, Sweden
[3]Institute of Soil Science, Department of Earth Sciences, Faculty of Mathematics, Informatics and Natural Sciences, Universität Hamburg, Germany
[4]North-East Scientific Station, Pacific Institute for Geography, Far-East Branch, Russian Academy of Sciences, Cherskii, Russia
[5]Department of Ecology and Environmental Sciences, Umeå University, Sweden
[6]Institute of Plant Science and Microbiology, Department Biology, Faculty of Mathematics, Informatics and Natural Sciences, Universität Hamburg, Germany

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. As a consequence, theoretically 80% of current permafrost-affected soils (<10m) is 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.

WARMING OF PERMAFROST IN THE LENA RIVER DELTA AND ON SPITSBERGEN

Julia Boike[1,2], F. Goldschmidt[1], N. Bornemann[1], C. Lehr[1], M. Langer[1,2], B. Cable[1], S. Lange[1], J. Nitzbon[1,2], M. Grigoriev[3]

[1]Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Potsdam, Germany
[2]Humboldt-Universität zu Berlin, Geography Department, Berlin, Germany
[3]Melnikov Permafrost Institute, Siberian Branch, Russian Academy of Sciences, Yakutsk, Russia

Warming of permafrost over the last few decades has been reported from many circumarctic boreholes (Biskaborn et al., 2018). Warming and thawing of permafrost and an overall reduction in permafrost area have been predicted under future climate change scenarios by the CMIP5 climate models, but at widely varying rates. Continuous observations, not only of the thermal state of permafrost but also of the multiple other types of data required to understand the changes to permafrost, are therefore of great importance. We present borehole temperature data from three different boreholes in Siberia and Spitsbergen. Samoylov and Sardagh are located in the “cold” permafrost of Siberia, in the central Lena River Delta, approximately 50 km apart from each other. The borehole on Samoylov is located near the new research base and a water pipeline. This raised the question whether these physical structures might cause local permafrost warming due to artificial snow accumulation (Boike et al. 2019). In contrast, Sardagh is located on the Yedoma complex without any buildings or structures nearby. The third borehole (Bayelva) is situated in the “warm” permafrost of Spitsbergen, Norway. The borehole data were recorded at Samoylov from 2007 to 2018, at Sardagh from 2010 to 2018 and at Bayelva from 2011 to 2017. All boreholes are equipped with temperature chains logging hourly data (hourly to six hourly intervals). The annual temperatures at about 20 meter depth at the cold sites of Samoylov and Sardagh were increasing continuously throughout the observation period at about 0.1°C/year. The similar warming trends at Samoylov and Sardagh suggest a negligible effect of the research base station Samoylov, but rather a regional warming trend. While the Lena Delta warming trends are in agreement with other circumarctic cold permafrost sites, the warming trend at Bayelva of 0.06°C/year at about 9 meter depth is characteristic for a warm permafrost site.

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PERMAFROST CARBON IN EARTH SYSTEM MODELS: PROGRESS AND CHALLENGES

Victor Brovkin[1,2]

[1]MPI for Meteorology, Hamburg, Germany
[2]CEN, Universität Hamburg, Hamburg, Germany

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 development of the offline permafrost carbon module in MPI-ESM that includes interactions between vegetation dynamics, fire disturbance, and hydrology. Within the KoPf project, soil module of JSBACH has been considerably improved, for example by accounting for vertical heterogeneity of 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 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

Agata Buchwal[1], G. Rachlewicz[1,2], B. Heim[3]

[1]Adam Mickiewicz University, Poznán, Poland
[2]Xi'an Jiaotong-Liverpool University, Suzhou, China
[3]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 (72ºN, 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 so called 'recently drained lake' on Southern Kurungnakh Island. Whereas, *Betula* and *Larix* specimens will be applied into climate-growth relationship analyses.

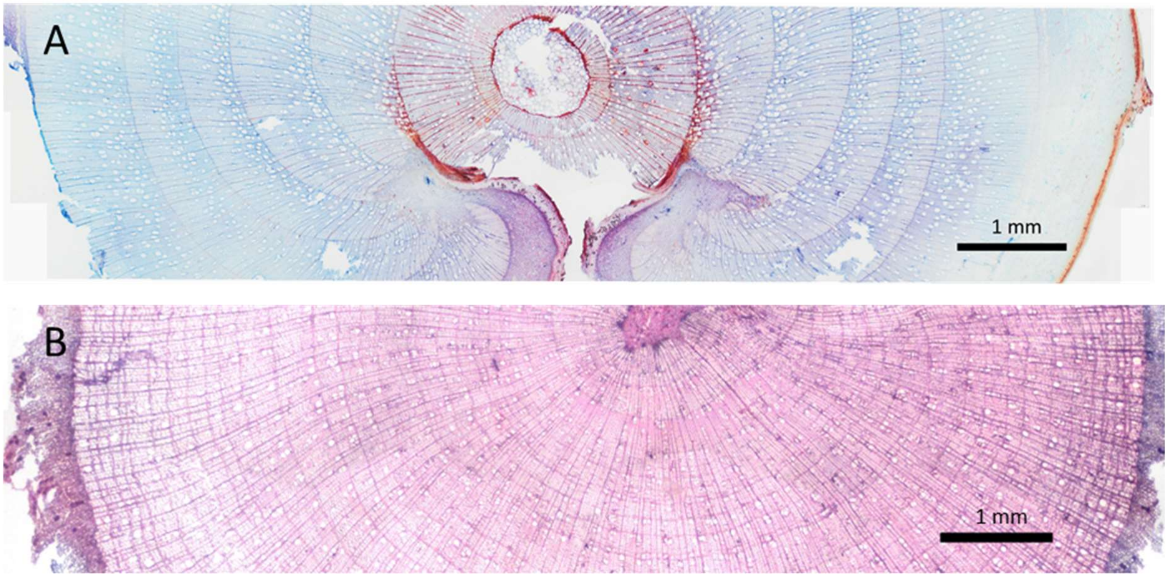

Fig. 1. Growth ring pattern of tundra shrubs in Lena delta: A) *Salix* spp. from flood plain area (Samoylov Island) with a scar formed during spring break up in 2014; B) *Betula nana* from Southern Kurungnakh

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RESPONSE OF THE HIGH-LATITUDE CARBON CYCLE TO CHANGES IN ATMOSPHERIC GREENHOUSE GAS CONCENTRATIONS

Philipp de Vrese[1], V. Brovkin[1]

[1]Max Planck Institute for Meteorology, Hamburg, Germany

High-latitude terrestrial ecosystems are recognised as an increasingly important factor for the global carbon cycle. Rising atmospheric CO_2 concentrations and global warming are expected to increase the vegetation’s carbon uptake, while large quantities of effectively inert organic material stored within the frozen soils could become exposed to microbial decomposition in a warmer climate. We investigated the response of the high latitude's carbon cycle to in- and decreasing atmospheric greenhouse gas (GHG) concentrations using the JSBACH model, the land-surface component of the Max-Planck-Institute for Meteorology's Earth system model (MPI-ESM). More specifically, we used an adapted version of JSBACH, that accounts for the organic material stored in the permafrost affected soils of the high northern latitudes (de Vrese et al., 2019). The model was forced with different climate scenarios that assume an increase in GHG concentrations, following the Representative Concentration Pathway RCP8.5, until a peak in the year 2025, 2050, 2075 or 2100, respectively. The peak is followed by a decrease in atmospheric GHGs that returns their concentrations to the levels at the beginning of the 21st century. 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 time-scales, 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 GHG 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. Consequently, we find that methane emissions will play only a minor role in the northern high latitudes' contribution to global warming, even when considering the gas's high global warming potential. Finally, we found that the high-latitude ecosystem acts as a source of atmospheric CO_2 rather than a sink, with the net fluxes into the atmosphere increasing substantially with rising atmospheric GHG concentrations. This is very different to scenario simulations with the standard version of the MPI-ESM in which the region continues to take up atmospheric CO_2 throughout the entire 21st century, confirming that the omission of permafrost-related processes and the organic material stored in the frozen soils leads to a fundamental misrepresentation of the carbon dynamics in the Arctic.

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

Elisabeth Dietze[1], S. Kruse[1], K. Mangelsdorf[2], A. Andreev[1], B. Heim[1], L. A. Pestryakova[3], U. Herzschuh[1,4,5]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Polar Terrestrial Environmental Systems, Potsdam, Germany
[2]GFZ German Research Centre for Geosciences, Section Organic Geochemistry, Potsdam, Germany
[3]Institute of Natural Sciences, North-Eastern Federal University of Yakutsk, Yakutsk, Russia
[4]Institute of Environmental Sciences and Geography, University of Potsdam, Potsdam, Germany
[5]Institute of Biochemistry and Biology, University of Potsdam, Potsdam, Germany

Forest fires are an important factor in the global carbon cycle and high-latitude ecosystems. Eastern Siberian tundra, summergreen 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. We present fire-vegetation-climate feedbacks on millennial to orbital timescales from late glacial to interglacial sediments of Lake El’gygytgyn, located c. 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

Alexey V. Eliseev[1,2,3], V.V. Malakhova[4]

[1]Lomonosov Moscow State University, Moscow, Russia
[2]A.M. Obukhov Institute of Atmospheric Physics RAS, Moscow, Russia
[3]Kazan Federal University, Kazan, Russia
[4]Institute of Computational Mathematics and Mathematical Geophysics, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia

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.

GREENHOUSE GASES RELEASE IN FIELD-BASED INCUBATION EXPERIMENT WITH BURIED SOIL, LENA DELTA, SIBERIA

Svetlana Evgrafova[1,2], Valerii Kadutskii[2], Oleg Novikov[2], Georg Guggenberger[3], Dirk Wagner[4]

[1]V.N. Sukachev Institute of Forest, FRC KSC SB RAS, Krasnoyarsk, Russia
[2]Siberian Federal University, Krasnoyarsk, Russia
[3]Institute of Soil Science, Leibniz University of Hannover, Germany
[4]GFZ German Research Centre for Geosciences, Potsdam, Germany

Frozen buried soil was taken from Holocene permafrost that had been exposed by erosion of the Lena river bank on Samoylov island. We transferred the material partly to the top of the active layer and partly into the subsoil in a rim of an ice-wedge polygon. The intention was that formerly frozen soil was moved to the active layer, while still residing in the subsoil to mimic cryoturbation processes, or was exposed to the soil surface to simulate eroded riverbank. Since experiment set up (August, 2015), during July-August 2016, August 2017, 2018, and 2019 we measured CO_2 and CH_4 released from the soil surface of both variants of 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. Mean values of measured release of the gases are presented in Fig.1. It has been shown that significant difference between values of greenhouse gas release (CO_2, CH_4) from the buried soil has appeared after 3 years of experiment set up.

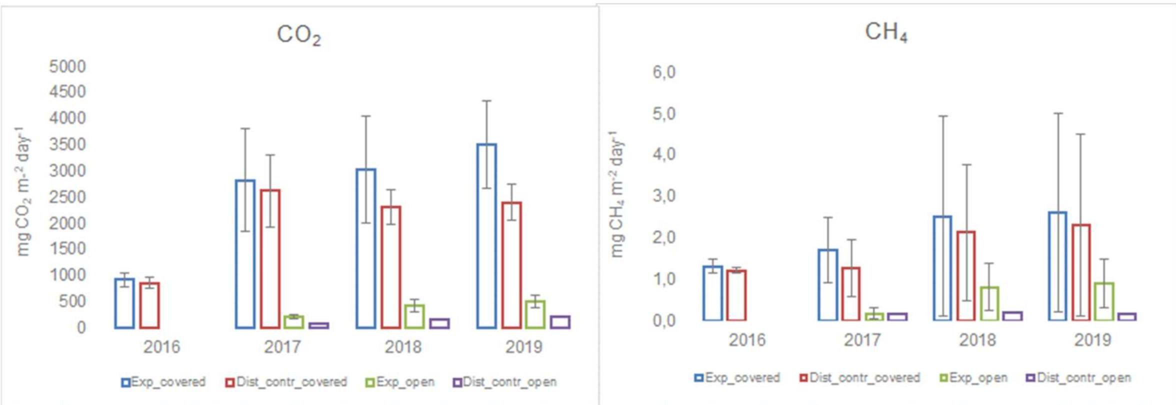

Fig. 1. Greenhouse gases release (CO_2, CH_4) in field-based incubation experiment. Legend: *Exp_covered* – mean value of plots with buried soil covered by groundcover (5 cm thickness); *Exp_open* – mean value of plots with uncovered buried soil; *Dist_contr_covered* – mean value between plots without buried soil, covered by groundcover (5 cm thickness); *Dist_contr_open* – uncovered plots without buried soil. Bars indicate standard deviations (n=3).

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

Alexey Faguet[1,2], A. Kartoziia[1,2,3], N. Laschinskiy[1,2,4]

[1]A. A. Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia
[2]Novosibirsk State University, Novosibirsk, Russia
[3]V. S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
[4]Central Siberian Botanical Garden SB RAS, Novosibirsk, Russia

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 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

Irina Fedorova[1], E. Shestakova[1,2], A. Pashovkina[1], A. Chetverova[1,2], G. Nigamatzyanova[3], R. Zdorovennov[4], G. Zdorovennova[4], N. Alekseeva[2,5], V. Dmitriev[1]

[1]Saint Petersburg State University (SPbSU), St. Petersburg, Russia
[2]Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia
[3]Kazan Federal University, Kazan, Russia
[4]Northern water problems Institute, Petrozavodsk, Russia
[5]The Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of RAS, Novosibirsk, Russia

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 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 3,12 nm-1. The seasonal dynamic 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 founded. 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 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.

The projects have been realized with 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

Claudia Fiencke[1,2], T. Sanders[3], E.-M. Pfeiffer[1,2]

[1]Institute of Soil Science, Universität Hamburg, Hamburg, Germany
[2]Center for Earth System Research and Sustainability, Universität Hamburg, Hamburg, Germany
3Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, Geesthacht, Germany

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 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 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 young floodplain (Fig. 1). Higher N-availability correlated with highest potential net nitrification rates. 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 and nitrate concentrations might sources of N_2O that should be further investigated.

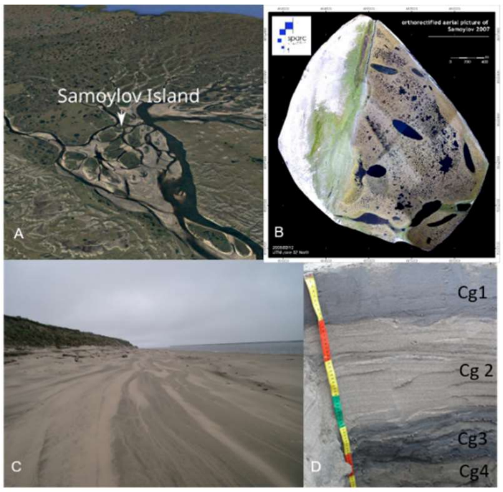

Fig. 1 A: Location of Samoylov Island in southern part of the Lena River delta dominated by non-vegetated young floodplains, B: Aerial picture of the island with western young floodplain and eastern river terrace (2007, Bolshiyanov et al., 2015), C: Less N-limited site and D: Soil profile of the Psammentic 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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SOBO-SISE CLIFF. RAPID EROSION OF A YEDOMA REMNANT BY THE LENA RIVER

Matthias Fuchs[1], I. Nitze[1], J. Strauss[1], F. Günther[2,3], S. Wetterich[1], A. Kizyakov[4], T. Opel[1], M.N. Grigoriev[5], G.T. Maksimov[5], G. Grosse[1,2]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Institute of Geosciences, University of Potsdam, Potsdam, Germany
[3]Laboratory Geoecology of the North, Faculty of Geography, Lomonosov Moscow State University, Moscow, Russia
[4]Department of Cryolithology and Glaciology, Faculty of Geography, Lomonosov Moscow State University, Moscow, Russia
[5]Melnikov Permafrost Institute, Siberian Branch of the Russian Academy of Science, Yakutsk, Russia

Ice-rich permafrost deposits are prone for degradation and have the potential to release large quantities of organic carbon (C) and nitrogen (N). This has severe effects on local ecosystems as well as global implications, as the freshly thawed permafrost C and N can be released as greenhouse gases into the atmosphere. In this study, we investigate the degradation of Sobo-Sise cliff. This very ice-rich yedoma cliff is up to 27.7 m high and located on the Sardakhskaya channel in the Lena River Delta. With remote sensing imagery (Corona, Hexagon, Landsat and Planet) and field data, we quantify the erosion rates for 53 years (1965-2018) and calculate the amount of C and N released annually into the Lena River. Our study shows that the mean annual erosion rate for Sobo-Sise cliff is 9.8 m yr^{-1} with locally and temporally varying rates of up to 22.3 m yr^{-1} for the time period 1965-2018. This strong erosion led to a mobilization of 17.65 x 10^6 m^3 of yedoma deposits which results in a total release of 152.6 x 10^6 kg C and 12.0 x 10^6 kg N over the investigated time period. On average, at least 2.9 x 10^6 kg organic C and 0.2 x 10^6 kg N were eroded annually into the Lena River. This shows the importance of this massive fluvio-thermal erosion at the Sobo-Sise cliff and asks for further studies to investigate the fate, transformation and quality of carbon and nitrogen released and transported to the Arctic Ocean.

THE IMPACT OF PERMAFROST THAWING ON THE NET PRIMARY PRODUCTION AND NUTRIENTS AVAILABILITY OF THE POLYGONAL TUNDRA IN THE LENA RIVER DELTA, SIBERIA

Leonardo de Aro Galera[1], C. Knoblauch[1], E.-M. Pfeiffer[1]

[1]Institute of Soil Science, Universität Hamburg, Hamburg, Germany

Climate change has been affecting arctic ecosystems more intensely than others, causing it to warm twice as fast as the Earth on average. This trend decreases the permafrost extent and exposes previously stocked carbon to decomposition. Although climate change is depleting soil carbon stocks and increasing greenhouse gas (GHG) emissions in arctic ecosystems, it is also leading to a higher primary productivity. Hence, the main question that emerges from this scenario is whether the Arctic is a sink or a source of C.

Climate change affects the carbon balance by altering its driving processes, namely photosynthesis, respiration, and anaerobic decomposition. It is therefore crucial to implement methods to partition the carbon fluxes. It seems that as a result of permafrost thawing, there is an increase in nutrients availability leading to greater primary productivity in the tundra. Tundra vegetation is characterized by severe nutrient limitation, especially nitrogen. Higher soil temperatures are expected to boost microbial decomposition rates in the Arctic, which lead to higher soil nutrients availability, and it is therefore expected that soil warming will positively influence plant productivity.

This project aims to contribute to the understanding of permafrost thawing’s impact on nutrients availability and net primary production of the Siberian tundra. We intend to conduct a combination of soil analysis and chamber CO_2 and CH_4 flux measurements in sites with different times since thawing on the islands of Kurungnakh and Samoylov in North-eastern Siberia. We hypothesize that the tundra’s nutrients availability and, consequently, the net primary production (NPP) is positively affected by increasing thaw age and depth.

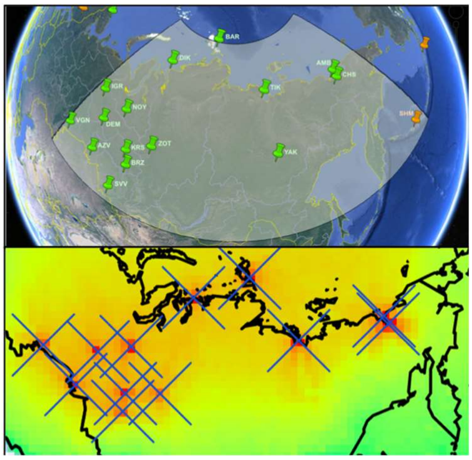
ATMOSPHERIC INVERSE MODELLING TO EVALUATE PROCESS MODEL SIMULATIONS OF SIBERIAN METHANE FLUXES

Mathias Göckede[1], P de Vrese[2], V. Brovkin[2], T. Guillermo Nunez Ramirez[1], F.-T. Koch[1], C. Rödenbeck[1]

[1]Max Planck Institute for Biogeochemistry, Jena, Germany
[2]Max Planck Institute for Meteorology, Hamburg, Germany

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.



Top panel: model domain and atmospheric station network. Bottom panel: Cumulative ‘field of view’ of the core stations within the network in fall, with warm colors indicating high information content.

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 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

REMOTE SENSING OF LANDSCAPE CHANGE IN THE LENA DELTA REGION

Guido Grosse[1], I. Nitze[1], A. Runge[1], M. Fuchs[1], T. Henning[1], B. Heim[1], F. Günther[2], Mikhail Grigoriev[3]

[1]AWI Potsdam, Potsdam, Germany
[2]University of Potsdam, Institute of Geoscience, Potsdam, Germany
[3]Melnikov Permafrost Institute Yakutsk, Yakutsk, Russia

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 (30m resolution). Process dynamics that can be observed include thermokarst lake expansion and drainage, channel shore erosion and channel migration, and thaw slumping (Figure 1). We also use high-resolution (~0.5 m) optical imagery from commercial sensors (WorldView-1, WorldView-2, and GeoEye) in combination with historical 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 Bykovsky Peninsula.

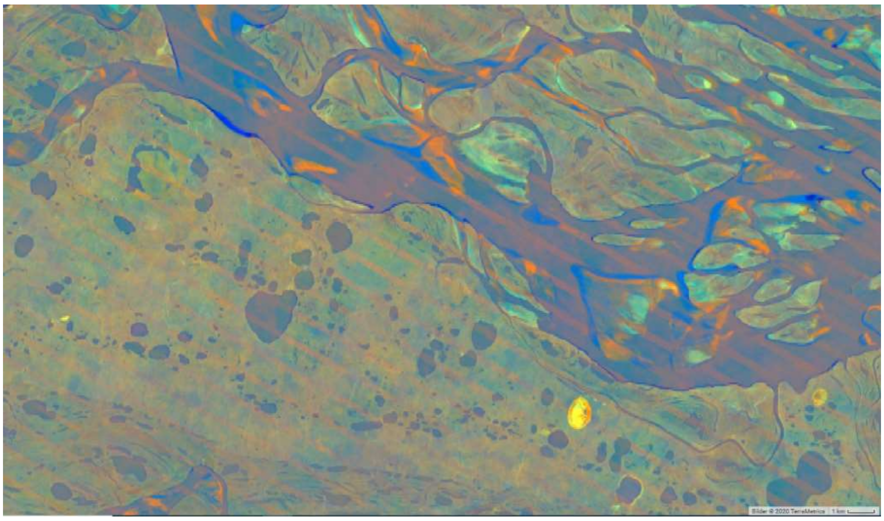


Fig. 1: Tasseled Cap Trend Visualization for the years 2000-2018 over the central part of Sobo-Sise Island and Sardakhskaya channel in the Eastern Lena Delta. Yellow: Lake Drainages; Blue: Erosion; Orange: Deposition.

GEOCHEMICAL FEATURES OF SEDIMENTS OF THE LAKES LOCATED IN THE LENA DELTA, THE RUSSIAN ARCTIC

Alina V. Guzeva[1], I. V. Fedorova[1], N.K. Alekseeva[2,3,4], S. Evgrafova[3]

[1]Saint-Petersburg State University, Saint-Petersburg, Russia
[2]The Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia
[3]V.N. Sukachev Institute of Forest, FRC KSC SB RAS, Krasnoyarsk, Russia
[4]Arctic and Antarctic Research Institute, Saint-Petersburg, Russia

Most parts of the Russian Arctic zone are located in remote areas far from significant industrial objects. However, trace metals can be transported over long distances by atmospheric circulation far from their source. To understand potential sustainability and self-purification capacity of aquatic ecosystems, especially as vulnerable and changeable as polar lake systems, it is important to study geochemical features of sediments. This investigation focuses on study of lakes with different origin (thermokarst and ox-bow lakes) and hydrological regime that are located on different islands of the delta of the river Lena [1]. This area is potentially pristine territory of the Arctic. We researched the content of the trace metals (As, Cd, Cr, Pb, Ni, Co, Zn, V, Fe, Mn) in sediment cores of the lakes to understand the local geochemical background for further environmental monitoring. Furthermore, in this study different chemical fractions of trace metals [2] were studied to reveal the main accumulation patterns of microelements in bottom sediments. The research can help to estimate the capacity of aquatic ecosystems to bind metals to stable forms. For chemical analysis we used ICP AES method (laboratory of Research Park at St. Petersburg University).

The results have showed that most of the trace metals distributed quite homogeneously in depth of sediment cores [3]. The main chemical phase of metals is residual fraction. However, humic substance and oxides of Fe and Mn are significant accumulative phases as well (8-25% of total content of trace metals are connected with these fractions). Cr, Cu, Zn, Ni were identified in the most mobile forms: exchangeable phase (4-5%) and fraction bound with carbonate minerals (10-15%). The findings revealed significant self-purification capacity of the researched lake systems: the most trace metals are bound in stable forms by compounds of sediments.

Acknowledgments:

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The analysis was conducted in Research and Educative Park of chemistry at St. Petersburg State University.

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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

Joachim O. Habeck[1], M. Ulrich[2]

[1]Institute for Social and Cultural Anthropology, Universität Hamburg, Hamburg, Germany
[2]Institute for Geography, Leipzig University, Leipzig, Germany

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 also logging have the potential to exert major changes on permafrost – and thus on water resources and local land-use conditions.

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

Birgit Heim[1], I. Shevtsova[1], N. Landgraf[1], S. Kruse[1], A. Morgenstern[1], A. Runge[1], G. Grosse[1], U. Herzschuh[1], A. Buchwal[2], G. Rachlewicz[2,3], S. Evgrafova[4], E. Abramova[5], A. Kartoziia[6,7], N. Lashchinskiy[7,8]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Adam Mickiewicz University, Poznan, Poland
[3]Xi'an Jiaotong-Liverpool University, Suzhou, China
[4]Forest Institute, SBRAS, Krasnoyarsk, Russia
[5]Lena Delta Nature Reserve, Tiksi, Russia
[6]Sobolev Institute of Geology and Mineralogy, SBRAS, Novosibirsk, Russia
[7]Novosibirsk State University, Novosibirsk, Russia
[8]Central Siberian Botanical Garden, SBRAS, Novosibirsk, Russia

Here, we are applying medium-resolution satellite remote sensing for a synoptic mapping of the current state and dynamics of Above Ground Biomass (AGB) of an Arctic lowland ground-ice rich permafrost landscape in Siberia. In the ongoing Russian-German cooperation on Lena Delta expeditions and with the opportunity of the modern Russian Research Station Samoylov Island and new medium-resolution satellite missions, we assessed above ground carbon stocks and fluxes.

We gained data on AGB during the Expedition Lena2018 from harvesting 27 plots (BMBF KoPf, Russian-German WTZ) and stand age of shrubs (EU INTERACT Dendro5 project, Uni Poznan, PL). We found a difference in magnitudes of high AGB and low stand age linked to high-disturbance regimes related to spring flood or permafrost degradation versus lower AGB and higher stand age of low-disturbance regimes on elevated terraces. We are upscaling AGB and stand age to above ground carbon stock and fluxes using a supervised land cover classification based on Sentinel-2 and in-situ data on vegetation in August 2018 (Fig. 1). Assessments of the applicability will be done by using time-lapse camera data and Unmanned Arial Vehicle based remote sensing data from Novosibirsk.

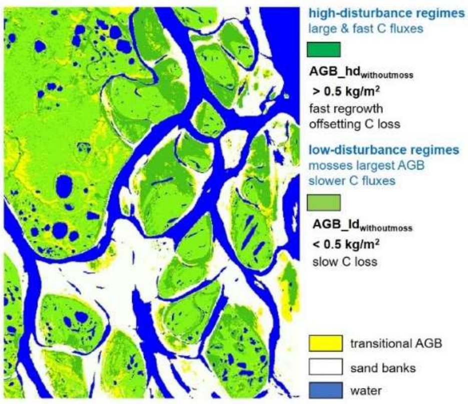


Fig. 1 Synoptic mapping of Above Ground Biomass (AGB) stocks and fluxes derived from Sentinel-2 Land Cover Classification of the Central Lena Delta, Siberia (state of August 2018).

'SEEING' ARCTIC VEGETATION GREENING AFTER SNOWMELT IN THE LENA DELTA, SIBERIA, USING NASA MODIS OPTICAL SATELLITE TIME SERIES

Birgit Heim[1], S. Lisovski[1], I. Shevtsova[1], S. Kruse[1], J. Boike[1], A. Morgenstern[1], U. Herzschuh[1], S. Evgrafova[2], E. Abramova[3], C. Rixen[4]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Forest Institute, SBRAS, Krasnoyarsk, Russia
[3]Lena Delta Nature Reserve, Tiksi, Russia
[4]WSL Institute for Snow and Avalanche Research, Davos, Switzerland

A West to East orientation of vegetation and climatic zones occur across the high latitudes due to the linkage between snow cover, vegetation, and climate. Specifically, in those cold biomes the long snow cover insulates vegetation from too cold air temperatures thereby constraining vegetation by the duration of snow cover. Optical Remote Sensing is a tool capable of areal mapping of snow cover extent and state of vegetation. Commonly optical remote sensing indices used are the Normalized Snow Index, NDSI, for snow, and the Normalized Difference Vegetation Index, NDVI, for vegetation. The NASA MODIS optical satellite missions provide reflectance products since 20 years offering more than one acquisition per day over the same area. This makes also optical remote sensing usable for monitoring spatiotemporal dynamics of snow cover and vegetation specifically at high latitudes.

In addition, we use time-lapse camera data for high temporal resolution assessment on snow cover and snow melt, leaf out and shooting of vegetation by this evaluating the applicability of MODIS NDSI and NDVI landscape-scale products. First results show that in years of early and average snowmelt dates NDVI dynamics during summer seem similar. In contrast to the two years 2004 and 2017 of late snow melt resulting in lower summer NDVI at landscape scale.

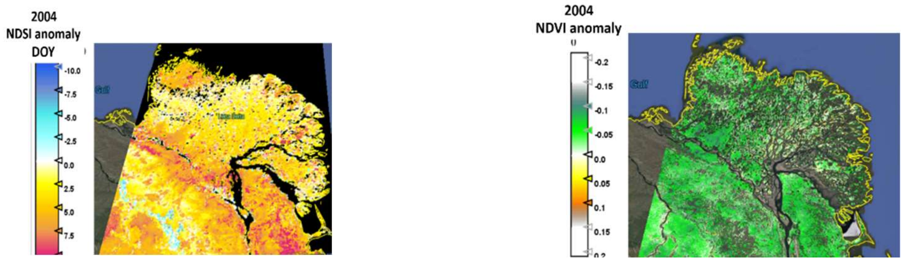


Fig. 1 (left) MODIS NDSI 2004 anomaly vs the mean of last Day Of the Year (DOY) with detectable snow cover within a 1 km x 1 km pixel, NDSI > 0.4 indicating snow coverage. The mean was calculated from a MODIS NDSI time series from 2000 to 2019. 2004 and 2017 were exceptionally late snowmelt years with the main snow melt in the 2nd a the first week in July and 3rd week of May. (right) MODIS NDVI 2004 negative anomaly of the 1st week in July vs the mean of the NDVI of the 1st week in July of a MODIS NDVI time series from 2000 to 2019. MODIS NDVI 2004 negative anomaly at landscape scales is indicating delayed greening in the Lena Delta region.

AUF DER SUCHE NACH TREIBHAUSGASEMISSIONEN AUS DEM PERMAFROST IN NORDOST-SIBIRIEN

Martin Heimann[1], M. Goeckede[1], S. Zimov[2], N. Zimov[2]

[1]Max-Planck-Institut für Biogeochemie, Jena, Deutschland
[2]Northeast Science Station, Cherskii, Russland

Die Permafrostböden in der Arktis enthalten gewaltige Mengen organischen Kohlenstoffs: In den obersten drei Metern befindet sich mehr Kohlenstoff als global in der heutigen Atmosphäre als CO2. Zur Zeit ist dieser Bodenkohlenstoff noch bei Temperaturen unter dem Gefrierpunkt sicher gespeichert. Im Zuge einer fortschreitenden Erwärmung könnte jedoch ein Teil davon auftauen, durch Mikroben abgebaut werden, in Form von CO2 und Methan in die Atmosphäre gelangen und damit den globalen Klimawandel verstärken. Dieser Abbau des oberen Permafrostbodens könnte unter Umständen sogar relativ abrupt vonstatten gehen. Entsprechende alarmierende Meldungen (wie z.B. Hinweise auf eine Arktische “Methan-Bombe”) geistern immer wieder durch die Presse.

Wie ernst ist diese Gefahr? Zuverlässige, langfristige Beobachtungen der Treibhausgase und ihrer regionalen Quellen und Senken gibt es in der Arktis leider nur sehr wenige. Seit 2002 führt das Max-Planck-Institut für Biogeochemie in Jena gemeinsam mit der russischen Northeast Science Station in Cherskii Messungen der Treibhausgasemissionen aus dem Permafrost am Unterlauf des Kolyma-Stroms in Nordost-Sibirien durch. Seit 2014 werden diese ergänzt durch kontinuierliche Beobachtungen der atmosphärischen Treibhausgaskonzentrationen an der russischen Wetterstation Ambarchik am Ufer des Nordmeers. Die vorliegenden Beobachtungen zeigen, dass die Region im Arktischen Kontext zur Zeit noch eine moderate CO2-Senke und eine moderate CH4-Quelle darstellt. Wir sehen zur Zeit auch keine massiv zunehmenden Trends in den Emissionen aus den lokalen Permafrostböden. Wie sich dies in die Zukunft fortsetzt, lässt sich jedoch schwer ermessen.

Aus den Beobachtungen lassen sich wertvolle Hinweise auf wichtige Prozesse gewinnen welche die Treibhausgasemissionen aus den Permafrostböden steuern: Neben der Temperatur spielt der Eis- und Wassergehalt, die lokale Vegetation und im Winter die Schneetiefe eine wichtige Rolle. Aber auch die lokale Mikrotopographie und deren Änderungen z.B. durch Thermokarstprozesse sind von grosser Bedeutung für die potentielle Freisetzung von Treibhausgasen aus dem Permafrost. Die Berücksichtigung dieser kleinskaligen Prozesse in realistischen Modellen des Erdsystems stellt eine grosse wissenschaftliche Herausforderung dar, ist aber unabdingbar um die Entwicklung der Arktischen Treibhausgasbilanzen in Klimaszenarien abzuschätzen. Parallel dazu ist der Aufbau und langfristige Betrieb eines Arktischen Beobachtungssystems gemeinsam mit nationalen und internationalen wissenschaftlichen Partnern wichtig um die Modellentwicklung zu begleiten und um Überraschungen zeitnah zu erfassen.

INTER-ANNUAL VARIABILITY OF CO_2 FLUXES ON SAMOYLOV ISLAND

David Holl[1], C. Wille[2], T. Sachs[2], J. Boike[3], M. Grigoriev[4], I. Fedorova[5], E.-M. Pfeiffer[1], L. Kutzbach[1]

[1]Universität Hamburg, Center for Earth System Research and Sustainability, Hamburg, Germany
[2]Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany
[3]Alfred Wegener Institute Helmholtz-Center for Polar and Marine Research, Potsdam, Germany
[4]Melnikov Permafrost Institute SB RAS, Yakutsk, Russia
[5]St. Petersburg State University, St. Petersburg, Russia

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 the 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 positive AOI denotes rising influence of warm western winds from the Atlantic on Siberia (see Fig. 2).

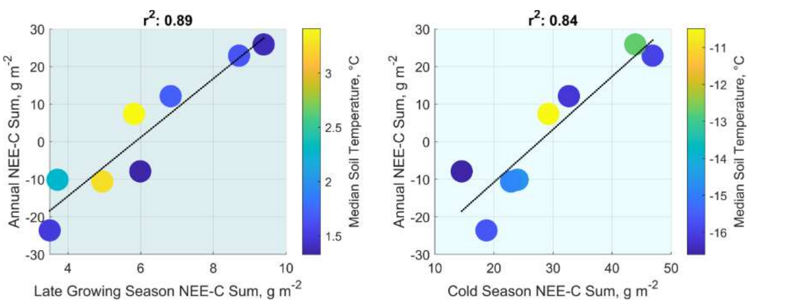


Fig. 1 CO_2-C exchange sums of the late growing (1 Sep to 30 Sep) and cold seasons (1 Oct to 31 May) are good proxies for annual CO_2-C flux sums.

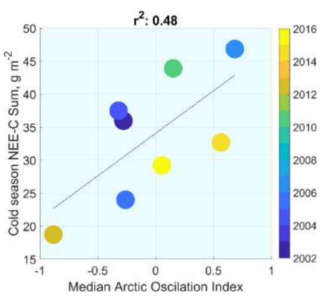


Fig. 2 Cold season CO_2-C exchange sums vary with Median Arctic Oscillation Index.

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

Loeka L. Jongejans[1,2*], S. Liebner[3,4], C. Knoblauch[5], G. Grosse[1,2], J. Strauss[1]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Permafrost Research Section, Potsdam, Germany
[2]University of Potsdam, Institute of Geosciences, Potsdam, Germany
[3]GFZ German Research Centre for Geosciences, Section Microbiology, Potsdam, Germany
[4]University of Potsdam, Institute of Biochemistry and Biology, Potsdam, Germany
[5]Universität Hamburg, Institute of Soil Science, Hamburg, Germany

The permafrost organic carbon inventory is becoming increasingly vulnerable with ongoing climate warming. Deep thaw processes such as thermokarst development can mobilize organic matter to tens of meters deep, allowing organic matter degradation by microbial communities. Respiration rates from thawing permafrost are uncertain as they depend on geochemical, microbial and ecological parameters. We aim to improve greenhouse gas (GHG) release rate estimates from thawing permafrost using laboratory incubation experiments.

We carried out a 1-year-long incubation experiment on sediment cores from Siberian thermokarst lakes in the Yukechi Alas, Yakutia. We compared two 20-m-long sediment cores retrieved below two thermokarst lakes (Alas Lake: 61.76397°N, 130.46445°E; Yedoma Lake: N61.76048, E130.47101). These deposits include lake deposits in the uppermost part, thawed permafrost sediments underneath and permafrost sediments below the thaw bulb. The sediments from the Yukechi Alas Lake have been thawed multiple times, whereas the sediments from the Yukechi Yedoma Lake have been frozen for tens of thousands of years before lake formation. We incubated 10 g of sediment (n=17, 3 replicas) anaerobically at 4°C and measured CO_2 and CH_4 release biweekly.

After 300 days, the cumulative production of both CO_2 and CH_4 was highest in the Yedoma Lake core (Fig. 1). In both sediment cores, the CH_4 production was highest in the surface sediments. Interesting is that the maximum amount of CO_2 produced from the Yedoma Lake core was produced in the deepest sample, ~14 m from the sediment surface. Substantial CH_4 production started mainly from 150 days and onwards.

We found that the sediments that have been frozen for thousands of years (Yedoma Lake core) released more GHG than the Alas Lake sediments.

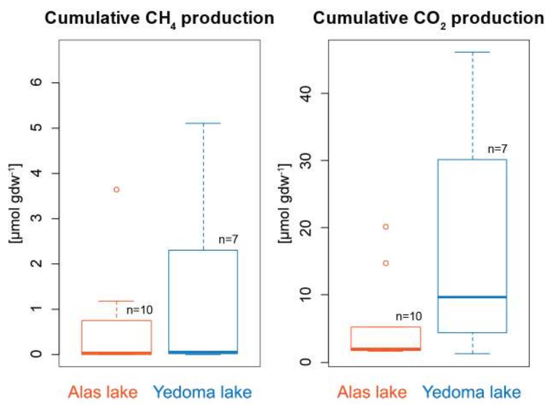


Fig. 1: Boxplots of cumulative CH_4 and CO_2 production in Yukechi Alas Lake sediment core (red) and Yukechi Yedoma Lake sediment core (blue).

Acknowledgments:

We acknowledge the Deutsche Bundesstiftung Umwelt (https://www.dbu.de/stipendien_20018/536_db.html), ERC PETA-CARB (#338335), and the BMBF (project KoPF, 03F0764B) for financial support.

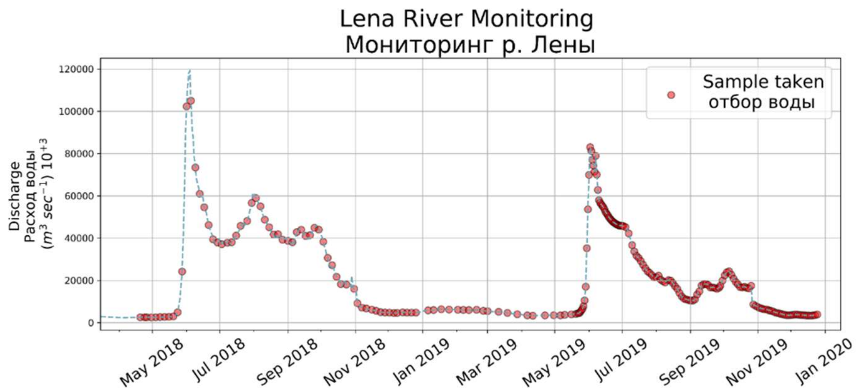
SEASONALITY IN LENA RIVER BIOGEOCHEMISTRY AND DISSOLVED ORGANIC MATTER

Bennet Juhls[1], C. A. Stedmon[3], A. Morgenstern[2], H. Meyer[2], B. Heim[2], J. Hölemann[4], V. Povazhniy[5], P. Overduin[2]

[1]Institute for Space Sciences, Department of Earth Sciences, Freie Universität Berlin, Berlin, Germany
[2]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[3]Marine Ecology and Oceanography, National Institute of Aquatic Resources, Technical University of Denmark, Kgs. Lyngby, Denmark
[4]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[5]Otto Schmidt Laboratory for Polar and Marine Research, Arctic and Antarctic Research Institute, St. Petersburg, Russia

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.



GEOMORPHOLOGICAL MAPPING OF PERIGLACIAL LANDSCAPES USING UAV DATA GIS-ANALYZE

Andrei Kartoziia[1,2,3], A. Mishina[1,2,3]

[1]A. A. Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia
[2]V. S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
[3]Novosibirsk State University, Novosibirsk, Russia

Permafrost degradation is an important topic in modern times. Some natural hazards for Arctic infrastructure concern to this. Also, modern permafrost degradation causes changes in tundra landscapes and greenhouse gas emissions. Because of it, the study of degradation rates in the Arctic using remote sensing data analysis is very relevant.

Previously, we have used GIS technologies for a geomorphological mapping of ice-wedge relief of Samoylov Island (the Lena Delta) (Kartoziia, 2019). We analyzed UAV images, digital elevation model and several morphometry schemes. We got UAV images during the 2016 summer expedition. All these data had unique spatial resolution (less than 0.5 m) that is unattainable for data from space satellites. This allowed revealing micro-landforms very accurately. We mapped ice-wedge polygons that concern to different steps of polygon degradation. We revealed incipient, low-centered, intermediate-centered, and high-centered polygons. Most of them were classified by the presence of water in the polygon centers or between rims. This study showed the territory of Samoylov Island, which was composed of non-degraded polygonal tundra, tundra with first sings of permafrost degradation, and tundra with completely degraded ice-wedge polygons.

After repeating the unmanned aerial imaging of Samoylov in 2019 summer, we got new data about the island landscape. Parameters of the aerial imaging and characteristics of newly gotten imageries and the digital elevation model were identical to previous data. We recognize landscape changes using GIS-analyze and the compering data from 2016 and 2019 summers. Then we estimated rates of topography changes of previously mapped land units and tried to reveal geomorphological and other causes of changes. For example, we identified differences in topography changes of low-centered and intermediate-centered polygons, heterogeneity of incipient polygon topography changes, the influence of river thermal abrasion to island relief, etc.

New results make possible to say that the GIS-analyze of UAV imageries is an effective study method for landscape changes and monitoring of permafrost degradation. This work is done on the state assignment of IGM SB RAS.

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APPLICATION OF HIGH-FREQUENCY GROUND PENETRATING RADAR TO STUDY PERMAFROST-AFFECTED SOILS IN PEAT PLATEAUS

D. Kaverin[1], A. Khomutov[2,3], M. Sadurtdinov[2], M. Sudakova[2,4], A. Pastukhov[1]

[1]Institute of Biology Komi SC RAS, Syktyvkar, Russia
[2]Earth Cryosphere Institute Tyumen Scientific Centre SB RAS, Tyumen, Russia
[3]Tyumen State University, Tyumen, Russia
[4]Faculty of Geology, Moscow State University, Moscow, Russia

High-frequency GPR study of the permafrost-affected soils in peat plateaus of Russian Arctic regions (European North and Western Siberia) have been conducted. Permafrost table depth was measured by GPR using “Zond-12E” system (Radar Systems, Inc., Riga, Latvia) with shielded ground-coupled high-frequency antennas. The obtained GPR data were processed in Prizm 2.60.02 software package. Applied algorithms recommended by the manufacturer for the processing of the obtained GPR data are: removal of «ringing» noise from the GPR data; bandpass filtering using a cosine filter; automatic gain adjustment; signal conversion from time to depth scale. When converting the signal from time to depth scale, the average velocity of electromagnetic wave (v) was taken into account, which in the active layer (AL) is 10 cm / ns at soil dielectric permittivity of $\varepsilon = 9$. For permafrost v = 15 cm/ns, ε_r' = 4, for water-mass (water-logged areas) v = 3.3 cm/ns, ε_r' = 81.

In the discontinuous permafrost zone of the Russian European North, where there are considerable variations of permafrost table depth in the upper 10-meter soil strata, both high-frequency antennas surface shielded antennas (300 and 900 MHz) have been used. The combined use of 300 and 900 MHz-frequency ground-coupled shielded antennas is an effective solution for determining significant variations (0-10 m) in the depth of permafrost table and lithological contacts (the lower limit of the peat layer and technogenic soils) in peat plateaus. Deeper penetration of the 300 MHz antenna signal allows studying the topography of deeper closed taliks (2-8 m) within the road warming impact zone and beneath the fens. A high frequency antenna (900 MHz) allows studying in detail the permafrost table topography in the 0-2 m depth strata, which is critical in the investigations of soil-permafrost complexes. The results of high-frequency GPR surveys revealed that the construction and operation of a cement-concrete highway running across peat plateaus in the southern parts of the permafrost zone contributes to a significant subsiding of the permafrost table (down to a depth of 8 m). The warming (defrosting) effect of the road is significant in the zone up to 50 m in width, comprising the road embankment, roadside depressions and adjacent sites of peat plateaus. The undisturbed sites of peat plateaus are characterized by spatial heterogeneity of permafrost table depth caused by the mesotopography of peat mounds and fens.

In the continuous permafrost zone of Western Siberia high-frequency GPR study (antenna 300 MHz) revealed spatial heterogeneity of permafrost table depth and assessed water content in active layer in the polygonal peat plateaus. An increase in thaw depth is associated to higher water content in active layer (up to 100%), which is resulted from waterlogging due to the presence of ice wedges.

The use of present-day high-frequency GPR technologies allows studying the spatial differentiation of permafrost table and lithological contacts depth as well as configuration of ice wedges, assessment of volumetric water content in active layer.

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

Johanna Kerttula[1], H. Siljanen[1], M. Marushchak[1], C. Voigt[2], J. Ronkainen[1], C. Biasi[1]

[1]University of Eastern Finland, Kuopio, Finland
[2]University of Montréal, Montréal, Canada

Microbial community composition and relative abundance of nitrogen cycling functional genes were studied to gain understanding of N_2O dynamics from thawing ice-rich yedoma deposits in the Lena River Delta. 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 nitrous oxide (N_2O) is overlooked. N_2O contributes to ozone depletion (Ravishankara *et al.*, 2009) and is a strong greenhouse gas with the global warming potential (GWP_{100}) of 265 (Myhre *et al.*, 2013). In the light of recent findings, showing that some Arctic peat soils act as hotspots for high N_2O emissions (Repo *et al.*, 2009, Marushchak *et al.*, 2011), we identified freshly thawn yedoma deposits as another potential N_2O source. For the first time, nitrifier and denitrifier community structure and functional gene abundance of N-cycling organisms were sequenced and quantified from yedoma deposits, shown to emit N_2O with rates varying from negligible to high in the field conditions. Correlations were found between *nosZ* functional gene abundance and net mineralization rates, indicating a tight coupling between N production and consumption in these soils. A better understanding on N cycling processes and microbial controls on N_2O production and consumption in thawing permafrost is needed to estimate climate feedbacks from the Arctic including N_2O.

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CARBON DIOXIDE AND METHANE PRODUCTION AND RELEASE FROM ERODING PERMAFROST DEPOSITS OF NORTHEAST SIBERIA

Christian Knoblauch[1], A. Schütt[1], C. Beer[1], S. Liebner[2], L. Sauerland[1], G. Norén[3], E. Abakumov[4], J. Rethemeyer[3], E.-M. Pfeiffer[1]

[1]Institute of Soil Science, Universität Hamburg, Hamburg, Germany
[2]GFZ German Research Centre for Geosciences, Potsdam, Germany
[3]University of Cologne, Cologne, Germany
[4]Saint Petersburg State University Saint Petersburg, Russia

Permafrost thaw liberates formerly frozen organic carbon, which is decomposed by microorganisms to carbon dioxide (CO_2) and methane (CH_4). The release of these greenhouse gases (GHG) from soils may form a positive feedback to atmospheric CO_2 and CH_4 concentrations and accelerate climate change. Quantifying the contribution of CO_2 and CH_4 from permafrost, which is thawing at the bottom of the seasonal thaw layer (active layer) is challenging, since GHG fluxes from the surface of permafrost affected soils originate from both the active layer and the thawing permafrost below. Incubation studies with thawed permafrost material are used to quantify the potential formation of CO_2 and CH_4 after permafrost thaw. However, it is unclear how far the results from such laboratory studies represent GHG production under in situ conditions and how far the results from laboratory incubations may be related to in situ GHG fluxes. We here present data on CO_2 and CH_4 fluxes from non-vegetated thawing ice-rich permafrost deposits (Yedoma) in an active thaw slump at the banks of the Lena River, northeast Siberia. To evaluate how far data from laboratory studies may be used to calculate in situ fluxes, the same thawing permafrost material was incubated at constant temperature. Mean in situ CO_2 fluxes in July 2016 ranged between 0.5 and 2.7 g CO_2-C m^{-2} d^{--1}, which is in the higher range of the few reports of CO_2 fluxes from Siberian Yedoma deposits. Methane fluxes were substantially lower with mean rates between 6.5 - 23.3 mg CH_4-C m^{-2} d^{-1}. However, while all sites were clear sources for CO_2, not all emitted CH_4. The absence of CH_4 emissions could be explained by CH_4 oxidation in the unsaturated surface soil at one site and by the absence of CH_4 production in two other sites, due to a lack of a CH_4 producing microbial community in the recently thawed permafrost. Methane represented less than 1% of total GHG fluxes. Based on the mean GHG fluxes, only about 1% of the thawed permafrost carbon was emitted over one thawing season as CH_4 and CO_2 into the atmosphere. Aerobic short-term laboratory incubations substantially overestimated in situ CO_2 fluxes by a factor of 1.3 to 6.4 (mean 3.9 ± 1.9). In contrast, in situ CH_4 fluxes were generally significantly higher than upscaled short-term incubation fluxes with a mean ratio between in situ and laboratory fluxes of 0.4 ± 0.5. The low CH_4 production in short-term laboratory incubations is explained by a disturbance of the methanogenic community during sample preparation.

The presented data indicate that despite relatively high GHG fluxes only a minor fraction of thawing permafrost carbon is decomposed to CO_2 and CH_4 in one thawing season and that data from short term incubations substantially overestimate in situ CO_2 fluxes while underestimating CH_4 production.

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

Anna Kut[1], V. Spektor[1]

[1]Melnikov Permafrost Institute, Yakutsk, Russia

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 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 sediments were transported 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 fluvial environment with different dynamic: from river flow to stagnant lake. The study of the surfaces of the quartz grains shows source is processed river flow sediments, surface of quartz grain has signs of intensive fluvial abrasion as well. In transportation and accumulation process, additional material was involved presumably from bed rock by water flow. A detailed micromorphological analysis of quartz grain from Ice complex shows for loams (19,75-20,30 m) effects of frost weathering were observed on 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 profile.

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

Lars Kutzbach[1], N. Rößger[1,2], T. Sachs[2], C. Wille[2], J. Boike[3], I. Fedorova[4], M.N. Grigoriev[5], E.-M. Pfeiffer[1]

[1]Institute of Soil Science, Center for Earth System Research and Sustainability (CEN), Universität Hamburg, Hamburg, Germany
[2]Helmholtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum (GFZ), Potsdam, Germany
[3]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[4]Institute of Earth Sciences, Saint Petersburg State University, St. Petersburg, Russia
[5]Melnikov Permafrost Institute, Yakutsk, Siberian Branch of Russian Academy of Science, Yakutsk, Russia

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 mean annual CH_4 budget amounted to 165 ± 31 mmol m^{-2}. About 60 % of this budget derived from the growing season (June to September). Intra-annual variability of CH_4 fluxes was best explained by soil temperatures at depths around 10 cm. CH_4 fluxes during the cold season were well correlated with carbon dioxide fluxes indicating a physical release of gas stocks that accumulated during the growing season. Especially during the autumn refreezing period, CH_4 flux bursts were associated with wind speed peaks and/or air pressure drops. Mean growing season CH_4 fluxes ranged between 6 and 13 nmol m^{-2} s^{-1} and were positively linearly correlated (r^2 = 0.9, n = 15) to cumulated growing degree days, which were calculated from observed air temperatures. Similar correlations were obtained with air temperatures from reanalysis data, thereby indicating potential for large-scale modelling. 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

Sebastian Laboor[1], S. Muster[1], B. Heim[1], A. Haas[1], C. Schäfer-Neth[1], I. Nitze[1], A. Bartsch[2], G. Grosse[1]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]b.geos GmbH, Korneuburg, Austria

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) and to facilitate data discovery, data view and supports 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

PRIMARY PLANT SUCCESSION ON FRESHLY DEGRADED EDOMA (ICE COMPLEX) IN LENA DELTA (EASTERN SIBERIA)

Nikolay Laschinskiy[1,2]

[1]Central Siberian Botanical Garden SB RAS, Novosibirsk, Russia
[2]Trofimuk Institute for Petroleum Geology and Geophysics, SB RAS, Novosibirsk, Russia

Edoma or Ice Complex (IC) is a special type of Pleistocene deposits which consists of loam or sandy loam with high content of organic matter and contains from 50 to 90% of ice. Nowadays, IC actively degraded because of climate changes. This degradation is especially active on riversides and on lake shorelines. In course of IC degradation, ice wedges melt and soil organic substances are consumed by microbes. As a result, a lot of available plant nutrition appears in soil and soil itself is saturated with water. On slopes, this degradation is accompanied by active erosion when wet melted soil slides down the slope and is partly washed out to the river or lake. This freshly eroded substrate is colonized by plants. Studying of this succession is important because plants slowdown erosion and fixate mobile minerals in their bodies. In addition, newly appeared plant communities could be good indicators of certain soil processes.

Primary plant succession was studied in few sites on Kurungnakh and Sardakh islands along Lena river channels and around few lakes on Kurungnakh island. Four main stages could be distinguished in course of succession:

1- Mosses and seedlings – it starts on naked ground and lasts from two-three months to one year depending on date of starting point. At this stage, vegetation is only presented by fragmented cover of young mosses and few seedlings of vascular plants. Plant determination is quite difficult at this stage because plants are young and not fully developed. This stage may be longer in case of active repeated erosion. Sometimes it includes fragments of tundra vegetation which slid down the slope and gradually died.

2- Erosiophytes – this second stage lasts one-three years depending on slope steepness. Plants cover from 20 to 60% of soil surface. Main dominants are *Descurainia sophioides* and *Tephroseris palustris.* Another characteristic species for this stage is *Cochlearia arctica.* All these species occur only on degraded IC and are completely absent in intact tundra. They all are annuals and often act as ruderals in settlements south from this area. More and more perennials appeared at the end of this stage. Among them, *Puccinellia neglecta* is a specific plant for this stage and this habitat type.

3- Grasslands – third stage of succession presented by closed communities with *Arctagrostis arundinacea* as main dominant. Vegetation completely covers soil surface. Most of the plants are perennials but also occur only in these habitats. This stage lasts from 10 to 20 years. One of the characteristic features of this stage is dense litter on soil surface made of grass remnants.

4- Species-rich herbaceous communities – fourth stage also with *Arctagrostis arundinacea* as main dominant but enriched by many perennial herbs (*Artemisia tilesii, Delphinium chamissonis, Saussurea tilesii* etc.). On this stage, typical tundra plants appeared in species composition but moss layer is still absent or very weakly developed. There are not enough data to determine the duration of this stage but it is at least few tens of years.

SEASONAL TIMING OF SNOW MELT AND PRIMARY PRODUCTIVITY IN THE LENA DELTA REGION

Simeon Lisovski[1]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

Especially in the Arctic, warming has been observed at unprecedented rates. The effects on the physical environment are well documented and include melting of icecaps and glaciers, deepening of the summer thawing of permafrost and decrease in snow and sea-ice cover. However, these effects are known to be inhomogeneous over space and time and may even vary at local scale. Remote sensed images can help to characterize and quantify some of these effects helping to understand temporal dynamics across spatial scales as well as providing the basis for further analyses and testing of hypotheses. As a starting point of an attempt to extract seasonal dynamics and temporal trends of snow cover and biomass across the Arctic tundra, I choose the Lena Delta and adjacent areas to assess the usability of different satellite images and to validate statistical methods. Here, I will present the results from the Lena Delta region, focusing on how timing of snow melt varies within and across years (2000-2019) and effects subsequent pattern of primary productivity. The results will also be discussed in the light of further analyses and the potential to use them across disciplines in the future.

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

Valentina Malakhova[1]

[1]Institute of Computational Mathematics and Mathematical Geophysics, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia

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 occurring 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

Kai Mangelsdorf[1], J. G. Stapel[1], L. Schirrmeister[2], J. Walz[3], C. Knoblauch[3]

[1]GFZ Potsdam, Germany
[2]AWI Potsdam, Germany
[3]Universität Hamburg, Germany

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. Eemian 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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ROCK-MAGNETIC INSIGHT INTO PERMAFROST HISTORY: ALAS CASE STUDY ON KURUNGNAKH ISLAND (LENA DELTA)

Galina Matasova[1], N. Mikhaltsov[2]

[1]Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia
[2]Novosibirsk State University, Novosibirsk, Russia

Rock-magnetic analysis was performed on the sediment of three cores taken in different parts of the alas. On the base of a number of measured and calculated magnetic parameters, an interpretation of the results is carried out within the framework of generally accepted methods (*Thompson & Oldfield, 1986; Dunlop, 2002; Evans & Heller, 2003*).

Magnetic minerals in the studied sediments make up 2 groups: (1) terrigenous magnetite and possibly rich Fe titan magnetite represented by large multidomain grains (partly oxidized to maghemite) and (2) superparamagnetic (or possibly of a single-domain size) authigenic magnetically hard minerals (hematite and/or goethite) of inorganic origin due to in-situ process of frost weathering.

In all studied cores, the highest content of concentration-dependent magnetic parameters and therefore the greatest accumulation of magnetic minerals is observed in the lower part of the humus horizon at a depth of ~ 15 cm. Noticeable differences are observed in the underlying permafrost sediments. In sediments closest to the expected source area, a significant correlation is found between the concentration of magnetic minerals and the amount of sand fraction (100-250 microns). This indicates the predominance of terrigenous magnetic minerals and their crucial influence on the magnetic properties here. These sediments were formed under slow monotonous decrease in the terrigenous material input without changing its composition and therefore without changing its source. The largest content of authigenic magnetic grains is found in the sediments farthest from the source area, which indicates that those sediments here underwent a significant post-sedimentary alteration. Thawing-freezing cycles intensively reworked the sediments to a depth of ~ 50 cm and with a lower intensity to a depth of 90 cm.

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THE DENUDATION VOLUME ESTIMATION OF KURUNGNAKH ISLAND THERMOKARST HOLLOWS (THE LENA DELTA) BY MEANS OF GIS-ANALYZE

Anastassiya Mishina[1,2,3], A. Kartoziia[1,2,3]

[1]A. A. Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia
[2]V. S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
[3]Novosibirsk State University, Novosibirsk, Russia

We have studied the thermokarst landscape of Kurungnakh Island (the Lena Delta). This island is composed of quaternary sediments including ice-rich deposits (Ice complex, Edoma). Different thermal denudation processes have affected the landscape of Kurungnakh during the Holocene. It led to an appearance on an island's surface thermokarst hollows, gullies, pingos and other components of thermokarst relief.

Thermokarst is an important process that can lead to changes in the geomorphology and ecology of affected Arctic landscapes. The future thermokarst activity obviously will change Arctic landscapes. For the successful prediction of future landscape changes, we need to estimate morphometry parameters of thermokarst hollows, which were developed during Holocene. Thus, the main aim of our study was the denudation volume estimation of the thermokarst hollows of the Kurungnakh Island south-eastern part.

Previous studies have defined the age of Kurungnakh Island thermokarst hollows and some aspects of their morphometry (Morgenstern et al., 2013). However, some new remote sensing data have appeared in the last years. For example ArcticDEM with horizontal spatial resolution 2*2 m. It allowed us to reveal all thermokarst hollows of the south-eastern part of Kurungnakh Island and their drainage basins more accurately. We used the hydrology tools of GIS software package ArcGIS 10.2.2 from ESRI. After revealing drainage basins of thermokarst hollows, we estimated their denudation volumes.

The result of our study is the map of thermokarst hollows of the Kurungnakh Island south-eastern part with their morphometry parameters and denudation volumes. It allows revealing the volume of thawed material during the Holocene, estimating thermokarst impact to topography changes, and discovering the correlation between mentioned factors and hydrochemistry properties of thermokarst lakes and lakes' bottom sediments. This work is done on the state assignment of IGM SB RAS.

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

Gesine Mollenhauer[1], J. Hammes[1,2], T. Gentz[1], H. Grotheer[1], J.Hefter[1], B.Koch[1], O. Ogneva[1], J. Boike[3], A. Morgenstern[3]

[1]Alfred Wegener Institute, Bremerhaven, Germany
[2]University of Bonn, Bonn, Germany
[3]Alfred Wegener Institute, Potsdam, Germany

Ponds and lakes make up roughly 16% 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, 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 and 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

Olga Ogneva[1], G. Mollenhauer[1,2], H. Grotheer[1], M. Fuchs[1], J. Palmtag[3], T. Sanders[4], P. Mann[3], J. Strauss[1]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven and Potsdam, Germany
[2]Department of Geosciences, University of Bremen, Bremen, Germany
[3]Department of Geography and Environmental Sciences, Northumbria University, Newcastle-Upon-Tyne, United Kingdom
[4]Institute for Coastal Research, Helmholtz-Zentrum, Geesthacht, Germany

Rapid climate warming in 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 Laptev Sea but its quantity, quality, transport and transformation features are still not fully understood.

With this study, we want to close this knowledge gap. We aim to determine the sources (e.g., permafrost, soil, peat, phytoplankton, vegetation, etc.), quality and age of organic carbon transported by Arctic rivers is important 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, changes during the transport and further fate of organic matter discharged by Lena river to the Laptev sea (see Strauss et al 2020, this abstract book). To assess these data, we have had an intensive fieldwork in the Russian Arctic in early spring and late summer 2019. Samples were collected across a 200 km transect from the centre of Lena Delta to the Nearshore zone, covering the fresh-salt water transition and an additional sampling was provided in summer across a 1300 km transects from Yakutsk via Zhigansk to the Lena Delta.

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.

Our first results show relatively homogenous POC-$\Delta^{14}C$ values in the Lena stream from Yakutsk to the Lena Delta, variations of POC isotopic composition between seasons for Lena Delta samples and trends in the distribution of isotopic POC composition according to the water depth for the nearshore zone in the Laptev sea. It shows that summer POC is more depleted in $\Delta^{14}C$ compared to winter POC, thus it contains higher input of ancient organic matter sources (such as permafrost soils and Yedoma Ice deposits) into POC origin. Surface nearshore water represents fresh Lena river water layer on the top of saline water, it is enriched in $\Delta^{14}C$ while POC from deeper water layers is significantly older.

These results show complexity and inhomogeneity of OM quantity in the Lena Delta compared to Lena river upstream and fresh water input into biological and physical processes across the nearshore environment.

REMOBILIZATION, TRANSPORT AND FATE OF TERRESTRIAL ORGANIC CARBON UPON THE COASTAL REGION OF THE KOLYMA RIVER

Juri Palmtag[1], P.J. Mann[1], M. Bedington[2], M. Fuchs[3], G. Grosse[3,4], G. Mollenhauer[3,5], B. Juhls[6], O. Ogneva[3], P. Overduin[3], L. Polimene[2], R. Torres[2], J. Strauss[3]

[1]Northumbria University, Newcastle upon Tyne, United Kingdom
[2]Plymouth Marine Laboratory, Plymouth, United Kingdom
[3]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[4]University of Potsdam, Potsdam, Germany
[5]University of Bremen, Bremen, Germany
[6]Free University, Berlin, Germany

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 (McClelland et al., 2012). 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 and extensive permafrost thaw. As a result, the rivers are releasing larger quantities of water from land to the ocean which are fuelled with significant amounts of particulate and dissolved organic carbon (Mann, P. J. et al.,2012; 2015). Yet, mechanisms affecting the remobilization, transport and fate of terrestrial organic carbon are still largely unknown primarily because most research has focused on sampling campaigns during late summers.

Rivers are an important source of dissolved inorganic carbon (DIC) to the adjacent coastal waters which originates from weathering of rocks and the degradation of terrestrial organic carbon. On the other hand, primary production (photosynthesis) and outgassing of CO_2 to atmosphere withdraws DIC again from river. Recent studies have shown a distinct degradation of terrestrial organic carbon over the East Siberian Arctic Shelf (Alling et al., 2012).

During two field campaigns we were able to sample 78 sampling sites 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. The study is based on stable carbon isotopic composition of DIC ($\delta^{13}C$) and the DIC concentration. First results of this study show strong variations of DIC and DIC $\delta^{13}C$ between the different seasons. In addition, our data seems to indicate a significant processing and degradation of terrestrial organic matter in the low salinity near shore zone of the Kolyma river delta. Also, we will compare out results to similar studies conducted in the Lena river delta.

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PERMAFROST-AFFECTED PEATLANDS AND THEIR VULNERABILITY TO WARMING IN THE SOUTH OF THE EUROPEAN RUSSIAN CRYOLITHOZONE

Aleksandr Pastukhov[1], D. Kaverin[1], C. Knoblauch[2], C. Beer[2], I. Ryzhova[3]

[1]Institute of Biology Komi SC UB RAS, Syktyvkar, Russia
[2]University of Hamburg, Institute of Soil Science, Hamburg, Germany
[3]Moscow State University, Soil Science Faculty, Moscow, Russia

Permafrost degradation due to climate warming is currently observed in the European Russia. Peat plateaus underlain by permafrost cover only about 10% of the Russian European cryolithozone but contain almost 50% of soil organic carbon stocks (SOC), which are considered to be vulnerable to microbial mineralization after permafrost thaw. The current study describes permafrost-affected peatlands located in three key sites along the southern permafrost limit. All the peat plateau/thermokarst complexes consist of mounds with shallow permafrost tables interspersed with permafrost free fens and thermokarst lakes. All the sites 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. SOC decomposition was studied by aerobic and anaerobic incubation experiments, conducted at 4 °C for 1301 days. The CO_2 production was measured in peat samples at three key sites from the active layer (AL), the transitional layer (TL), the permafrost layer (PL).

Furthermore, carbon stable isotope signatures and C/N ratios were measured as indicators for SOC decomposition. The minor changes of stable isotopes values (mostly in the range between -25-28‰ $\delta^{13}C$) reflect the different botanical origin (composition) but no degradation. The $\delta^{13}C$ values in our results follow rather similar patterns as the C/N.

During the experiment, the initial CO_2 respiration rates significantly differed in the samples AL, TL and PL in all key sites. The CO_2 respiration rates were 2-5 times higher aerobically than anaerobically at each site in the majority of samples. In anaerobic conditions, in all sites, the CO_2 respiration rate in PL was the lowest, higher in TL and the highest in AL at all sites. Thus, it can be assumed that degradation of permafrost and thawing of permafrost layers in TL and especially PL, peat mineralization will be minimal under anaerobic conditions. However, under anaerobic conditions, the production was only 3.3±0.64 µg CO_2-C g^{-1}C per 1 day, which was significantly less than in other layers where CO_2 respiration rates varied from 5.12±1.71 to 5.18±1.02 µg CO_2-C g^{-1}C per 1 day. Projections of CO_2 aerobically production for 100 years represent from 1.00±0.15 to 9.66±1.23 % of initial permafrost carbon. But under anaerobical conditions, estimates are rather similar and indicate insignificant amounts 0.18…0.40 % of carbon release for 100 years.

The study showed that the C/N and $\delta^{13}C$ reflect the variability in origin and heterogeneity of three investigated sites but do not indicate peat vulnerability to SOC decomposition process. The results of the incubation experiment may seem controversial; however, they still support the hypothesis about the sustainability of peat plateaus especially under anaerobic conditions. It can be concluded that organic matter of peat plateaus are stable regardless the predicted climate warming. Undisturbed permafrost-affected peatlands could preserve the peat stratum regardless the predicted climate warming.

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

Eva-Maria Pfeiffer[1], T. Eckhardt[1], D. Bolshiyanov[2], I. Fedorova[3], M. Grigoriev[4], G. Grosse[5]

[1]Universität Hamburg, Center for Earth System Research and Sustainability, Hamburg, Germany
[2]FSBI "Arctic and Antarctic Research Institute", St. Petersburg, Russia
[3]St. Petersburg State University, St. Petersburg, Russia
[4]Melnikov Permafrost Institute SB RAS, Yakutsk, Russia
[5]Alfred Wegener Institute Helmholtz-Center for Polar and Marine Research Potsdam, Germany

***'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 is 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.

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MOLECULAR COMPOSITION OF HUMIC ACIDS FROM SELECTED SOILS FROM THE RUSSIAN ARCTIC: CHARACTERIZATION BY TWO-DIMENSIONAL ^{1}H-^{13}C HETCOR AND ^{13}C CP/MAS NMR SPECTROSCOPY

Viacheslav Poliakov[1,2*], E. Abakumov[2]

[1]FSBI Arctic and Antarctic Research Institute, St. Petersburg, Russia
[2]Department of Applied Ecology, Faculty of Biology, St. Petersburg State University, St. Petersburg, Russia

Polar soils play a key role in the global carbon balance as they contain maximum stocks of soil organic matter (SOM) within the whole pedosphere. The accumulation of humus in the profile of arctic soils is associated with permafrost retinization processes, cryogenic mass exchange processes, with in situ organic matter formation from root remnants, as well as an inheritance from parent rocks. For investigation of the molecular composition of humic acids (HAs) isolated from Arctic soils, we use modern instrumental methods: two-dimensional ^{1}H-^{13}C HETCOR and 13C CP/MAS NMR spectroscopy. ^{13}C-^{1}H(HETCOR) and ^{13}C (CP/MAS) NMR spectroscopy are powerful tools for studying molecular-level structure and dynamics in HAs. That method allows obtaining detailed information about the number of structural fragments and functional groups of HAs, the presence of aldehydes, ketones and quinoid structures (-COOH), ($-NH_2$), ($-OCH_3$), (-OH) - alcohols, carbohydrates and phenols. HAs of the polar regions as a whole have a similar structure; aliphatic fragments over aromatic fragments prevail in their composition. HAs from cryoconite of Spitsbergen differ from typical soils of the Arctic; up to 34% of aromatic structural fragments accumulate in its composition, which is associated with the specifics of the formation of cryoconites on the Svalbard archipelago. Condensation of low molecular HAs fragments in the soils of Russian Arctic was noted, which leads to the conservation of organic matter in these soils. The use of two methods of NMR spectroscopy allowed for a more detailed study and analysis of the composition of HAs in soils and cryoconites. Analysis of cross-peaks at different time contacts allowed us to correlate H-C bonds and reveal the composition of the HAs.

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

Philipp Porada[1], C. Beer[2]

[1]University of Hamburg, Institute of Plant Science and Microbiology, Hamburg, Germany
[2]University of Hamburg, Institute of Soil Science, Hamburg, Germany

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.

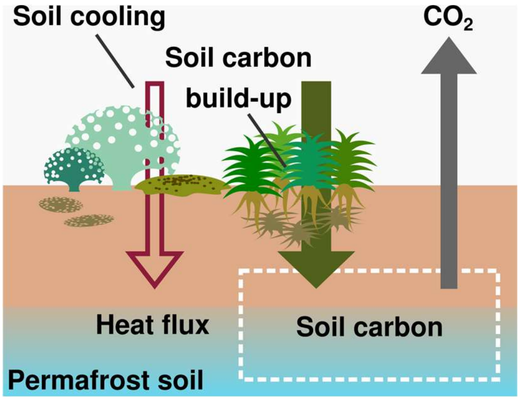

Fig.1 Effects of mosses and lichens on the soil carbon balance.

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

Sergei Pravkin[1], D. Bolshiyanov[1], A. Aksenov[1, 2]

[1]FSBI Arctic and Antarctic Research Institute, St. Petersburg, Russia
[2]Saint Petersburg University, St. Petersburg, Russia

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 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 the 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. Difference in speed tectonic movements between western and eastern parts of the delta is 1 mm per year during last 20000 years. But during last 2000 years, speed tectonic movements increased to approximately 2 mm per year (Bolshiyanov et al., 2019).

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 destroying of accumulated masses of the first terrace by fluvial erosion. During next transgression, new masses of organic-mineral sediments learned against remnants of the first terrace. The first terrace composed of different age sediments has been formed during this cyclic process.

The Ice Complex and the first terrace sediments accumulated in similar conditions. A head of water from seaside was a main reason of 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 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

Anatoly Prokushkin[1], A. Steinhof[2]

[1]V.N. Sukachev Institute of Forest SB RAS, Krasnoyarsk, Russia
[2]Max Planck Institute for Biogeochemistry, Jena, Germany

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 of 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:

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

Elisabeth Ramm[1], C. Liu[2], X. Wang[3], H. Yue[2], W. Zhang[2], Y. Pan[2], B. Hu[4], M. Schloter[5,6], S. Gschwendtner[6], C. W. Mueller[5], H. Rennenberg[4], M. Dannenmann[1]

[1]Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany
[2]State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry (LAPC), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
[3]Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun, China
[4]Center of Molecular Ecophysiology (CMEP), College of Resources and Environment, Southwest University, Chongqing, China
[5]Chair of Soil Science, Science Center Weihenstephan, Department of Ecology and Ecosystem Management, Technical University Munich, Freising, Germany
[6]Research Unit for Comparative Microbiome Analyses Helmholtz Center Munich, Oberschleissheim, Germany

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 the most potent of the long-lived greenhouse gases 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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WHAT DRIVES THE LARGE VARIABILITY OF POND METHANE CONCENTRATIONS IN THE LENA RIVER DELTA?

Zoé Rehder[1,2], A. Zaplavnova[3], L. Kutzbach[4]

[1]Max Planck Institute for Meteorology, Hamburg, Germany
[2]International Max Planck Research School on Earth System Modelling, Hamburg, Germany
[3]Department of Geology and Geophysics, Novosibirsk State University, Novosibirsk, Russia
[4]Institute of Soil Science, Universität Hamburg, Hamburg, Germany

The Lena River Delta is characterized by a large number of water bodies which cover roughly 10% of its surface. Among them, ponds are the most abundant in terms of numbers. Ponds come in different sizes and shapes, which are associated with different stages of permafrost degradation; the ponds also have a large spatiotemporal variability in methane concentrations and fluxes. To better understand this variability, we studied 41 ponds on Samoylov and Kurungakh island. We collected water samples at different locations and depths in each pond and determined methane concentrations using gas chromatography. Additionally, we collected information on the geomorphology, vegetation cover as well as on key physical and chemical properties of the ponds and combined them with meteorological data.

The ponds are divided into three geomorphological types with distinct differences in methane concentrations: water-filled degraded polygon centers, water-filled interpolygonal troughs and larger collapsed and merged polygons. These ponds exhibit mean surface methane concentrations (with standard deviation) of 1.2 ± 1.3 µmol L-1, 4.3 ± 4.9 µmol L-1 and 0.9 ± 0.7 µmol L-1 respectively, while mean bottom methane concentrations amount to 102.6 ± 145.4 µmol L-1, 263.3 ± 275.6 µmol L-1 and 17.0 ± 34.1 µmol L-1.

Using principle components and multiple linear regressions, we show that a large portion of spatial variability can be explained by the ponds' shapes and vegetation. Merged ponds have the least relative vegetation cover, and they also tend to be better mixed, both of which explains the lowest methane concentrations and the lowest variability in these ponds. Vegetation covers larger fractions in polygon centers and troughs, leading to a larger methane variability. Troughs, as they are underlain by ice wedges, exhibit more pronounced stratification and the highest methane concentrations. More results will be presented at the symposium.

BIOGEOCHEMICAL PROCESSES IN PERMAFROST

Elizaveta Rivkina[1], T. Vishnivetskaya[1,2]

[1]Institute of Physicochemical and Biological Problems in Soil Science RAS, Pushchino, Russia
[2]University of Tennessee, Knoxville, USA

Permafrost of the Siberian Arctic was formed, with the exception of certain periods, mainly in humid conditions throughout the Pleistocene and Holocene time. A huge 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 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.

Acknowledgments:

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SCALING AND BALANCING CARBON FLUXES IN A HETEROGENEOUS TUNDRA ECOSYSTEM OF THE LENA RIVER DELTA

Norman Rößger[1], C. Wille[1], L. Kutzbach[1]

[1]University of Hamburg, Hamburg, Germany

The current assessments of the carbon turnover in the Arctic tundra are subject to large uncertainties. This problem can (inter alia) be ascribed to both the general shortage of flux data from the vast and sparsely inhabited Arctic region, as well as the typically high spatiotemporal variability of carbon fluxes in tundra ecosystems. Addressing these challenges, methane and carbon dioxide fluxes on an active flood plain situated in the Siberian Lena River Delta were studied during two growing seasons with the eddy covariance method. The footprint exhibited a heterogeneous surface, which generated mixed flux signals that could be partitioned in such a way that individual fluxes were obtained for each of multiple vegetation classes: bushes, sedges and intermediate vegetation. A comprehensive set of measures corroborated the reliability of the partitioned fluxes and hence confirmed the utility of flux decomposition for enhanced flux data analysis. These decomposed fluxes in turn formed the basis – in conjunction with a classified high-resolution orthomosaic of the flood plain – for the vegetation class area-weighted upscaling. Alternatively, the straightforward upscaling of the footprint budgets (without the preceding downscaling) yielded budgets that underestimated the methane source strength of the flood plain by roughly 42%. Hence, the application of fine-scale information on surface characteristics is crucial for adequately estimating budgets of heterogeneous ecosystems being abundant in the tundra biome. In comparison to similar Siberian flood plain ecosystems, the methane budgets from the individual vegetation classes of the flood plain on Samoylov Island are alike in magnitude except for the distinctly larger emissions from sedge patches at the comparison sites. In contrast to the methane fluxes, the carbon dioxide fluxes of the individual vegetation classes exhibited less pronounced differences among each other. In relation to the average sink strength of various Arctic flux sites, the flood plain constitutes a distinctly stronger carbon dioxide sink. Considering the global warming potential of methane, roughly 42% of this net uptake, however, was on average offset by methane emissions lowering the sink strength for greenhouse gases. With growing concern about rising greenhouse gas emissions in high-latitude regions, providing robust carbon budgets from tundra ecosystems is critical in view of accelerating permafrost thaw, which can impact the global climate for centuries.

A COMPREHENSIVE REMOTE SENSING-BASED ASSESSMENT OF RETROGRESSIVE THAW SLUMP DYNAMICS ACROSS NORTH SIBERIA FOR 1999-2019

Alexandra Runge[1,2], G. Grosse[1,2]

[1]Alfred Wegener Institue Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Insitute of Geosciences, University of Potsdam, Potsdam, Germany

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. Various studies from Alaska and Canada report increasing numbers and sizes of RTS due to recent warming. A frequent key assumption is that high rates of slumping activities are driven by strong precipitation events. 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 not well known. Firstly, often RTS dynamics are not fully understood due to lack of continuous and high temporal datasets. Secondly, this lack of continuous RTS dynamics data also prevents establishing a tight relation to potential climatic drivers. Thirdly, RTS in Siberia are poorly studied as it is not known how many RTS exist across this large region and how active they are.

In this study, we focused our remote sensing analysis on retrogressive thaw slumps and their dynamics in North Siberia and tested whether highest activity of retrogressive thaw slumps was directly associated with strong precipitation events.

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 2019, determining the RTS dynamics based on disturbance year, magnitude of disturbance, disturbance duration and rate of change. Additionally, we assess ERA5 reanalysis climate data test any correlation of high slump activity with potential climatic main drivers, especially focusing on precipitation data. This is the first study that combines the analysis of continuous RTS disturbance dynamics with continuous climate data for a large continental scale region.

CRYOTRASOLOGICAL INDICATION OF PALEOSOLS IDENTIFIED TO THE NORTH OF THE EUROPEAN AND WESTERN SIBERIAN LOESS BELT: REFLECTION AT MESO- AND MICROMORPHOLOGICAL LEVELS OF THEIR ORGANIZATION

Alexey Rusakov[1], A. Sheinkman[2,3,4], S. Sedov[2,3,4]

[1]St. Petersburg State University, St. Petersburg, Russia
[2]Tyumen State University, Tyumen, Russia
[3]Institute of the Earth’s Cryosphere, Tyumen Science Center, Siberian Branch, Russian Academy of Sciences, Tyumen, Russia
[4]Tyumen Industrial University, Tyumen, Russia

Rock freezing affects soil complexes with maximum temperature gradients and forms a set of the specific cryotrasologic features in a solid matrix of soils. Remaining unchanged, these features serve as direct and indirect indicators of the past cryogenic settings. Transformation of the soil mass at the macro- and micromorphological levels is related to the direct indicators. Soil gleyzation in the drained positions is conditioned by the occurrence of frozen aquicludes in past settings; it is related to indirect indicators. We revealed the complex of such features in paleosols to the north of the European and Western Siberian Loess Belt and used them to estimate the cryogenic settings of the Late Pleistocene.

The application of cryotrasological indicators has effectively shown itself in the studied soils of MIS5–2, especially the MIS3 thermochrone (about 55–25 kyr BP), which is important because its course is compared with the current warming. The soils of MIS3 have long been used for indication of the loess belt rocks, but further north, these soils are poorly studied. The trasological indicators allowed us to expand significantly the information base of the soils.

The soils of MIS3, transformed by the cryogenesis, were revealed in the Upper Volga Region and in the northern part of Western Siberia. In the last case, the results are of particular importance, because, here, some researchers accepted the model of a glacier sheet, and they were confident that the appearance of paleosols in this zone is unreal. We analyzed the data of supporters and opponents of this model and made our own research in the northern part of Western Siberia.

The study of the meso- and micromorphological structure of the soils showed distinct manifestation of the cryotrasological indicators in both the Volga and Siberia soils. In both cases the set of such indicators is similar to the MIS3 paleosols with an undisturbed structure.

METHANE PRODUCTION IN WEST SIBERIAN BOREAL WETLANDS AS A FUNCTION OF ORGANIC MATTER DECOMPOSITION PATHWAYS AND MICROBIAL COMMUNITIES

Aleksandr Sabrekov[1], I. Terentieva[1], Y. Litti[2], M. Glagolev[1,3], V. Vavilin[4]

[1]A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia
[2]Winogradsky Institute of Microbiology, Research Center of Biotechnology, Moscow, Russia
[3]Moscow State University, Moscow, Russia
[4]Water Problems Institute, Russian Academy of Sciences, Moscow, Russia

Wetlands are the largest natural source of methane, the important greenhouse gas. Wetlands emit methane as a result of methanogenesis, the final stage of organic matter decomposition in anaerobic conditions. There are several biochemical pathways fulfilling conversion of different organic compounds to methane. Structure of microbial communities, accomplishing biochemical processes in these pathways, is related to the contribution of each of them in total methane production (Conrad, 2020). The goal of this study is to investigate methane production through the coupling of data obtained by traditional laboratory incubations and data on microbial communities' structure obtained by 16S rRNA amplicon sequencing of total DNA extracted from natural peat samples.

Incubation experiments included: 1) the control incubation without any substrate addition, 2) the incubation with the CH_3F as an acetoclastic methanogenesis inhibitor, 3) the incubation with 2-bromoethanesulfonate (BES) as an inhibitor of entire methanogenesis, and 4) the incubation with an additional substrate (H_2/CO_2). During these experiments, the concentration dynamic of methane, carbon dioxide (with their isotopic signatures), hydrogen and low-molecular fatty acids were monitored.

Oligotrophic wetland (OW) in middle taiga zone and oligotrophic, poor fen and swamp in south taiga zone (OS, PFS and SS respectively) were study objects. These types of wetlands represent the wide diversity of West Siberian natural wetland ecosystems, contributing strongly in regional methane emission.

Obtained results shows that contribution of acetoclastic pathway decreases with depth and reaches highest levels in SS (70-80% of total methane produced). In the peat sampled from 50 cm below water table in OW and OS methylotrophic pathway is the most important (60-80%). Homoacetogenesis (microbial conversion of hydrogen to acetate) is active in all samples but for all samples from OS produced acetate decreases methane production. For other wetland types methane production becomes higher with grown acetate concentration.

Acknowledgments:

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

Tina Sanders[1], M. Fuchs[2], K. Dähnke[1]

[1]Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, Geesthacht, Germany
[2]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany

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 will measure dissolved organic and inorganic nitrogen, particulate nitrogen and CN ratio. In addition, the ^{15}N stable isotope values of these components will be 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 organic matter content of the soils and sediment is highly variable and ranges from 1 to 45 %. This organic matter is the source of reactive nitrogen, which is determined in incubation experiments and using nitrogen stable isotopes. We found that especially the unvegetated soils and sediment are sources of reactive nitrogen in the end of vegetation period (Sanders et al., 2010), and can potentially be sources of nitrous oxide emissions.

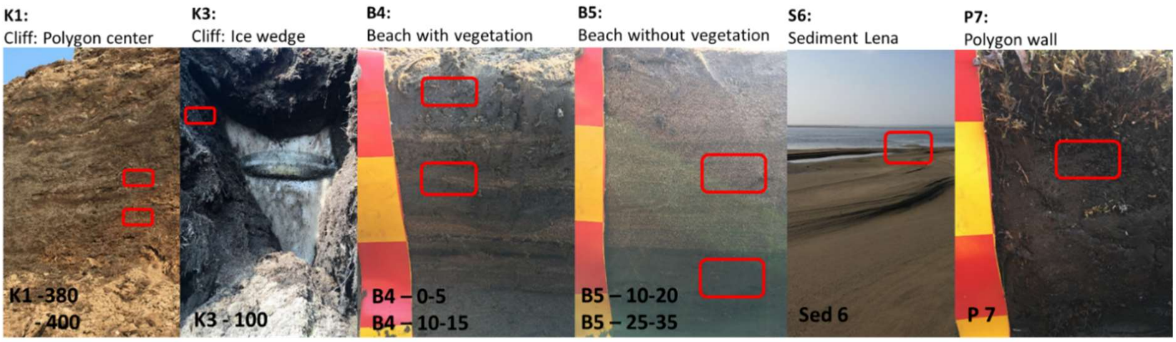

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Fig. 1: Sampling site of incubated soil and sediment samples on Samoylov Island

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RECENT VEGETATION COMPOSITION AND ABOVE GROUND BIOMASS CHANGES IN CENTRAL CHUKOTKA

Iuliia Shevtsova[1,2], U. Herzschuh[1,2,3], B. Heim[1], L. Schulte[1], S. Stünzi[1], L. A. Pestryakova[4], E. S. Zakharov[5], S. Kruse[1]

[1]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Institute of Biochemistry and Biology, University of Potsdam, Potsdam, Germany
[3]Institute of Environmental Sciences and Geography, University of Potsdam, Potsdam, Germany
[4]Institute of Natural Sciences, North-Eastern Federal University of Yakutsk, Yakutsk, Russia
[5]Institute for Biological problems of the Cryolithozone, Russian Academy of Sciences, Siberian branch, Yakutsk, Russia

Estimation of above ground biomass (AGB) is part of an assessment of carbon stocks which is essential to understand how ecosystems respond to recent climate change, especially in the Arctic, where climate change is very prominent. We quantified vegetation composition and AGB changes in four focus regions in central Chukotka (NE Siberia) from 2000/2001 to 2016/2017. The focus regions were placed to cover gradient from tundra via tundra-taiga ecotone to northern taiga. We mapped four vegetation classes: (1) larch closed-canopy forest, (2) forest tundra and shrub tundra, (3) graminoid tundra, and, (4) prostrate herb tundra and barren areas. We used pre-processed Landsat spectral indices (Normalised Difference Vegetation Index, Normalised Difference Water Index, and Normalised Difference Snow Index) and collected field data on foliage projective cover of dominant taxa in 2016. We applied constrained ordination for coupling projective cover with corresponding Landsat spectral indices from 2016/2017. Ordination scores were used in a k-means classification. We inferred significant shrubification in the tundra–taiga zone (20%) and in the northern taiga (40%), as well as notable tree infilling in the northern taiga (9%), and, no significant changes in the tundra. In 2018, another expedition took part to this region, where we described projective cover and harvested AGB at new sites. New projective cover data were projected into the ordination space created before. Ordination scores were used in the building of general additive model to predict total AGB. Total AGB across sampled sites ranges from 0 to 17 $kg*m^{-2}$. AGB and its change in one of the focus regions are represented in Fig. 1.

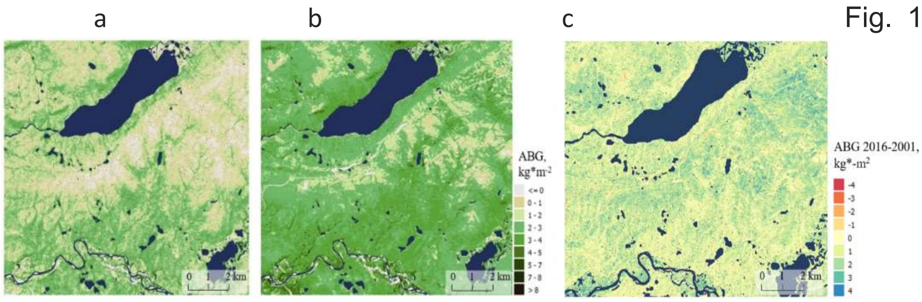

Fig. 1. Above Ground Biomass (AGB, $kg*m^{-2}$) at the northern larch treeline border: a – 2001, b – 2016, c – AGB change from 2001 to 2016.

MAPPED ARCTIC VEGETATION COMMUNITIES AND SOIL NUTRIENT REGIMES IN THE PERMAFROST LANDSCAPE OF THE CENTRAL LENA DELTA, RU

Iuliia Shevtsova[1], B. Heim[1], M. Fuchs[1], A. Runge[1], A. Morgenstern[1], G. Grosse[1], S. Kruse[1], U. Herzschuh[1], N. Landgraf[2], M. Ulrich[2], L. Pestryakova[3], A. Kartoziia[4,5], N. Lashchinskiy[5,6]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]University Leipzig, Leipzig, Germany
[3]North-Eastern Federal University Yakutsk, Yakutsk, Russia
[4]Sobolev Institute of Geology and Mineralogy, SBRAS, Novosibirsk, Russia
[5]Novosibirsk State University, Novosibirsk, Russia
[6]Central Siberian Botanical Garden, SBRAS, Novosibirsk, Russia

We assume that nutrient availability is a major limiting factor of vegetation growth in the Lena Delta besides the general climate characteristics such as low temperature and short growing seasons. We assessed relevant plant communities with projective coverage estimation and biomass harvesting at 27 vegetation plots and sampled soil pits and shallow permafrost cores at 33 sites in the central Lena Delta in August 2018 during the Russian-German Lena 2018 expedition.

For upscaling vegetation cover and in-situ biomass estimates we use a medium resolution satellite data based land cover classification. We applied a supervised random forest classification to a cloud-free Sentinel-2 acquisition from August 2018 using the visible, near infrared and shortwave infrared spectral bands after surface water and sandbank masking with a threshold. We targeted the classification towards classes usable for upscaling of biomass and moisture regimes (Fig. 1).

Prevailing vegetation types on Holocene and Pleistocene terraces are polygonal tundra complexes and moist to wet sedge and moss-dominated complexes characterized by high wetness and high C/N ratio in the subsoil below the moss layer. Terrain temporarily stabilized following active disturbance is frequently characterized by high vegetation biomass, e.g. tall shrub communities on floodplains, at the rim of thermokarst basins, and in thermoerosion valleys linked to drier soils and low C/N ratio indicating higher nutrient availability. This study improves our understanding of nutrient availability in Siberian permafrost soils.

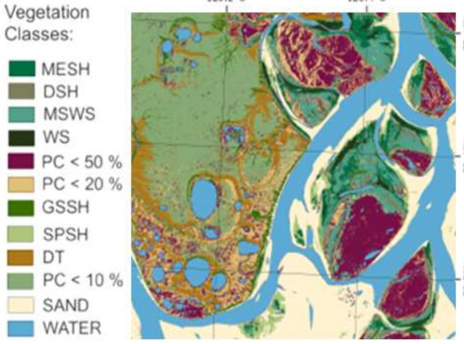

Fig. 1 Spectral Land Cover Classification, central Lena Delta, Floodplain and Holocene terraces: *DSH: dry low shrub communities, MESH: moist-equisetum & high shrub communities, MSWS: moist to wet sedge complex. PCwet<50 %: polygonal tundra complex with wet area coverage up to 50%. PCwet<20%: polygonal tundra complex with wet area coverage up to 20%. SPSH: sparsely vegetated. WS: wet-sedge complex with permanent wet sites*
Pleistocene terraces*: DT dry tundra communities. GSSH: dry grass to wet sedge complexes. PCwet<10%: polygonal tundra complex with wet area coverage up to 10%.*

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

Victor Stepanenko[1], A.I. Medvedev[1,2], V.Yu.Bogomolov[3], A.V.Debolskiy[1,2], E.D.Drozdov[1], E.A.Marchuk[1,4], V.N.Lykosov[5,1]

[1]Moscow State University, Moscow, Russia
[2]A.M. Obukhov Institute of Atmospheric Physics, Moscow, Russia
[3]Institute of Monitoring of Climatic and Ecological Systems, Tomsk, Russia
[4]Hydrometcenter of Russia, Moscow, Russia
[5]G.I. Marchuk Institute of Numerical Mathematics, Moscow, Russia

This abstract presents the land surface model (LSM) jointly developed by 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. Thermodynamic state of lakes is simulated by 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 diffusive wave equation model for dynamics and heat balance equation to compute river temperature *(Stepanenko et al., 2019)*. The effect of inclusion of river module together with the new snowmelt scheme was significant improvement of seasonal cycle of water runoff of Severnaya Dvina river (North of European Russia).

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

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CHANGING ARCTIC CARBON CYCLE IN THE COASTAL OCEAN NEAR-SHORE (CACOON): A PROJECT FOCUSING ON THE DYNAMIC INTERFACE BETWEEN LAND AND OCEAN IN THE ARCTIC

Jens Strauss[1], P. J. Mann[2], M. Bedington[3], M. Fuchs[1], G. Grosse[1,4], C. Haugk[1], G. Mollenhauer[1,5], B. Juhls[6], O. Ogneva[1], P. Overduin[1], J. Palmtag[2], L. Polimene[3], R. Torres[3]

[1]Alfred Wegener Institute, Potsdam and Bremerhaven, Germany
[2]Northumbria University, Newcastle, United Kingdom
[3]Plymouth Marine Laboratory, Plymouth, United Kingdom
[4]University of Potsdam, Potsdam, Germany
[5]University of Bremen, Bremen, Germany
[6]Free University, Berlin, Germany

No other region has warmed as rapidly in the past decades as the Arctic. Funded by the British Natural Environment Research Council and the German Federal Ministry of Education and Research, the 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 carbon pools, so that shelf ecosystems are intimately linked to freshwater supplies. Arctic ecosystems also contain permafrost 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 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 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 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 and Kolyma delta region. In the Lena Delta 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.

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

Leonid Tsibizov[1,2], V. Olenchenko[1,2,] V. Potapov[1,2], A. Faguet[1,2], K. Bazhin[1,3], D. Auynov[1,2], E. Esin[1,2]

[1]Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia

[2]Novosibirsk State University, Novosibirsk, Russia

[3]Melnikov Permafrost Institute SB RAS, Yakutsk, Russia

Geophysical methods were widely used in permafrost research during last decades. They provide abundant data on permafrost structure and features at different depth - from active layer to lower permafrost boundary. Our studies in Lena delta during 2014-2019 were focused on development of geophysical approach with consideration to 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 – difference in resistivity under the flood plain (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 applied methods are useful for study of 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 Lena delta requires a multidisciplinary approach and geophysics looks like one of its most important branches.

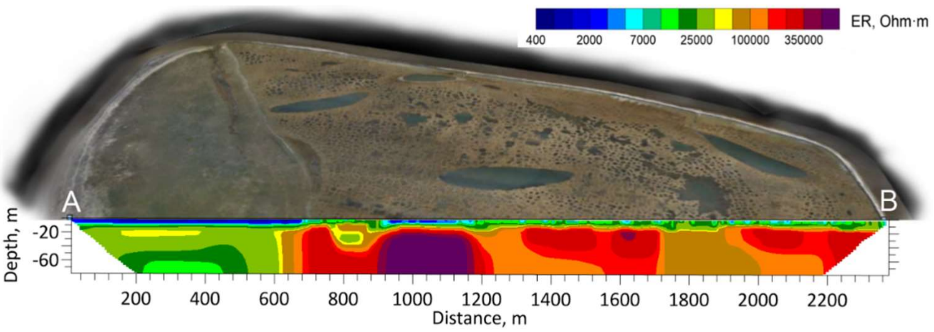

Fig. 1. Electrical resistivity section of Samoylov island

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

Ekaterina Tsibizova[1,2], N. Yurkevich[1,2], T. Fedorova[1,2]

[1]Trofimuk Institute of Petroleum Geology and Geophysics, Novosibirsk, Russia

[2]Novosibirsk State University, Novosibirsk, Russia

Kurungnakh Island in 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.

Distribution of chemical elements in 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

Lona van Delden[1], M. Marushchak[1,2], C. Voigt[3], G. Grosse[4], A. Faguet[5], N. Lashchinskiy[5,6], J. Kerttula[1], C. Biasi[1]

[1]University of Eastern Finland, Kuopio, Finland
[2]University of Jyväskylä, Jyväskylä, Finland
[3]University of Montréal, Montréal, Canada
[4]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[5]Trofimuk Institute for Petroleum Geology and Geophysics, SB RAS, Russia
[6]Central Siberian Botanical Garden SB RAS, Novosibirsk, Russia

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 CHANGES IN YEDOMA REGIONS (1999-2018), NORTH-EASTERN SIBERIA

Alexandra Veremeeva[1], I. Nitze[2], F. Günther[3], G. Grosse[2,3], E. Rivkina[1]

[1]Institute of Physical, Chemical and Biological Problems in Soil Science, Russian Academy of Sciences, Pushchino, Russia
[2]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[3]University of Potsdam, Institute of Geosciences, Potsdam, Germany

Thermokarst lakes are typical components of the yedoma-alas dominated relief in the coastal lowlands of North-Eastern 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 (TM, ETM+, OLI) and object-based lake detection. 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 TM and ETM+ images. Three classes were established: high (>23%), moderate (5-23%) and low (<5%) yedoma coverage relative to a local area yedoma-alas ratio. We used the Quaternary deposits map to distinguish lakes with thermokarst genesis from other lakes, i.e. on floodplains 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 low, moderate, and high yedoma fraction, lake area decreased from its maximum extent by 81.5, 90.5, and 90% respectively. In contrast, modern lake area changes during the last 20 years from 1999 to 2018 showed a slight increase in lake area by 0.53% and this tendency has been observed in all yedoma-alas relief types. Particularly in areas with low yedoma fraction, the lake area increase was 2.5 times more active showing stronger dynamics in low relief alas areas. Also, we observe the expansion of the thermokarst lakes in yedoma areas due to the thermoerosion of the Yedoma IC.

The increasing trend of lake area dynamics is an unexpected result as in a previous study of the eastern part of Kolyma lowland it was shown that the limnicity had a decreasing trend of 0.51% for the 1999-2014 period. The increase in thermokarst lake area is likely caused by the general trend of climate warming, precipitation increase during 2014-2018 years and short-term weather fluctuations. Particularly relatively cold air temperatures in June and heavy rainfall with 50 mm in the end of June in 2018 caused high water levels in lakes and rivers over the entire study region in 2018. 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 and climate data analysis are necessary to more deep understanding the response of permafrost in yedoma-alas regions to climate warming.

Analysis of the modern thermokarst lake area dynamics based on the geomorphological analysis in Yedoma regions provide the understanding of the spatial thermokarst process development in the past which is the base to analyze the modern thermokarst lake area changes.

THE RESPONSE OF CO_2 AND CH_4 PRODUCTION TO CHANGES IN SOIL MOISTURE IN DEGRADING OMBROTHROPHIC BOGS: A REVIEW FOR COOL TEMPERATE AND BOREAL PEATLANDS

Olga Vybornova[1,2], L. Hoeppli[1,2], L. Kutzbach[1,2], E.-M. Pfeiffer[1,2]

[1]Institute of Soil Science, Universität Hamburg, Hamburg, Germany
[2]Center for Earth System Research and Sustainability, Universität Hamburg, Hamburg, Germany

Covering around 3% of the Earth’s land surface, peatland ecosystems can act as sink or source of carbon to the atmosphere, mainly under the form of CO_2 and CH_4. Soil drainage and associated oxygen availability are predicted to increase microbial decomposition of organic matter in northern peatlands. Long-term research on organic matter decomposability has shown that the highest greenhouse gas production is often observed under oxic conditions in the upper organic horizons and usually decreases under saturated conditions. However, the magnitudes and timings of the C release from northern peatlands are still highly uncertain.

In present 134-day incubation study, the moisture dependence of CO_2 and CH_4 production rates along with microbial biomass were examined in upper peat from a degrading bog in Northern Germany, and subsequently compared with data from other ombrothrophic peatlands. The effect of drying-rewetting stress increased peat total C release by 36.8% compared to the initial moisture conditions. Similar trends have been reported for Siberian permafrost peatlands in response to the changes in hydrology and oxygen availability. Additionally, a significant effect on microbial biomass was observed under wet conditions, as indicated by 25-70% higher microbial C and N concentrations compared to drier conditions. The response in aerobic C production to intense drying-rewetting proceedings, confirmed our previous field measurements and revealed that the changes in soil moisture and repeated oxic-anoxic conditions may contribute significantly to faster substrate mineralization.

SOURCES OF WINTER CO_2 FLUXES

Josefine Walz[1], F. Gehrmann[1], E. A. Sherman Andersen[1], E. Dorrepaal[1]

[1]Climate Impacts Research Centre, Institute for Ecology and Environmental Science, Umeå University, Abisko, Sweden

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 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 continue to respire CO_2, weakening the CO_2 sink strength or possibly turning these ecosystems into annual CO_2 sources.

We measured monthly ecosystems respiration (R_{eco}, Fig. 1) as well as the isotopic signature ($\delta^{13}C$-CO_2) of the produced CO_2 at two locations in northern Sweden with similar mixed heath vegetation but different snow depths. To partition the R_{eco} flux into plant- and soil-related sources, we used both a clipping and an isotopic labeling approach. For clipping, all above ground vegetation was removed at the beginning of the growing season. At non-clipped plots, the vegetation was repeatedly labeled during the summer by exposing it to ^{13}C-enriched CO_2. The $\delta^{13}C$-CO_2 of monthly Reco fluxes was then determined in the field through the Keeling approach while the two source signals of plant- and soil respiration was determined in monthly laboratory incubations.

The available data show that winter fluxes (October – February) are about 15% of summer R_{eco} (July – September). Both the clipping and the isotopic partitioning of the R_{eco} flux show that presumably recently fixed carbon derived from plant respiration contributes 30-80% to R_{eco}. The environmental drivers of CO_2 fluxes from the different sources, however, have not yet been studied in detail. Especially the effect of snow depth is likely to affect soil temperatures and thus soil and plant respiration, especially towards the end of winter, when the differences in snow depth between the two sites are expected to be largest.

Fig. 2. 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

Evan J. Wilcox[1], B. Walker[1], G. Hould – Gosselin[2], B.B. Wolfe[1], O. Sonnentag[2], P. Marsh[1]

[1]Cold Regions Research Centre, Wilfrid Laurier University, Waterloo, Canada
[2]Département de Géographie, Université de Montréal, Montréal, Canada

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.

RECONSTRUCTING TERRESTRIAL PERMAFROST THAW AT THE CONTINENTAL SCALE USING RIVERS AND THE OCEAN AS INTEGRATORS ACROSS HETEROGENEOUS LANDSCAPES

Birgit Wild[1,2], J. Martens[1,2], A. Andersson[1], G. Hugelius[1,2], L. Bröder[3], J. Vonk[4], J.W. McClelland[5], P.A. Raymond[6], D. Kosmach[7], O. Dudarev[7,8], A. Charkin[7,8], N. Shakhova[8], I. Semiletov[7,8], N. Belyaev[9], E. Romankevich[9], A. Vetrov[9], L. Lobkovsky[9], Ö. Gustafsson[1,2]

[1]Stockholm University, Stockholm, Sweden
[2]Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden
[3]Swiss Federal Institute of Technology, Zürich, Switzerland
[4]Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[5]University of Texas at Austin, Port Aransas, Texas, USA
[6]Yale School of Forestry and Environmental Studies, New Haven, Connecticut, USA
[7]Pacific Oceanological Institute FEB RAS, Vladivostok, Russia
[8]Tomsk Polytechnical University, Tomsk, Russia
[9]Shirshov Institute of Oceanology, Moscow, Russia

Permafrost thaw is expected to expose large stocks of organic carbon (OC) to degradation and thus induce a positive feedback to global warming. Given the scale, heterogeneity and remoteness of the Siberian Arctic, continent-wide patterns of permafrost thaw and OC mobilization are challenging to constrain. Arctic rivers and the Arctic Ocean offer an opportunity to overcome this scaling problem, as they act as natural integrators of OC mobilization across their vast and heterogeneous catchments. We here employ isotope source apportionment to quantify permafrost-derived OC in aquatic systems across Siberia, building on extensive datasets of ^{13}C and ^{14}C in Arctic rivers, Arctic Ocean sediments, and in potential OC sources.

Our findings demonstrate contrasting mechanisms of permafrost OC release to aquatic systems in western vs eastern Siberia. (1) In western Siberia, OC transfer from permafrost and peat deposits to aquatic systems was dominated by active layer leaching. 83% of permafrost/peat-derived OC in Ob and Yenisey was in dissolved form, and its contribution to the fluvial load increased with seasonal active layer thaw (*Wild et al., 2019*). Kara Sea sediments are strongly influenced by Ob and Yenisey, with often >50% of sedimentary OC derived from active layers. (2) Although also eastern Siberian rivers transport active layer material to the ocean, the permafrost-derived OC flux is dominated by Ice Complex Deposit (ICD) collapse, both inland and along the coasts. This is indicated by a strong contribution (54%) of particulate OC to the permafrost/peat-derived OC flux in Lena and Kolyma pointing at erosion (*Wild et al., 2019*), and by the large fraction (>50%) of ICD-derived OC in sediments of the eastern Laptev and the East Siberian Sea that are strongly affected by coastal erosion.

Our findings demonstrate the potential of quantitative isotope-based fingerprinting of fluvial and marine OC for elucidating continental-scale patterns of permafrost OC mobilization, and for monitoring changes in permafrost OC release over the coming decades.

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LARGE HERBIVORES AS STABILIZING ECOSYSTEM ENGINEERS IN THAWING TERRESTRIAL ARCTIC ENVIRONMENTS

Torben Windirsch[1,2], G. Grosse[1,2], J.O. Habeck[3], M. Ulrich[4], J. Strauss[1]

[1]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]University of Potsdam, Institute for Geosciences, Potsdam, Germany
[3]University of Hamburg, Institute for Ethnology, Hamburg, Germany
[4]Leipzig University, Institute for Geography, Leipzig, Germany

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 thaw depth in the seasonal active layer and carbon storage in both the active layer and the underlaying 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.

EARTH SYSTEM MODELS UNDERESTIMATE CARBON FIXATION BY PLANTS IN THE HIGH LATITUDES

Alexander J. Winkler[1,2], R. B. Myneni[3], G. A. Alexandrov[4], V. Brovkin[1]

[1]Max-Planck-Institute for Meteorology, Hamburg, Germany
[2]International Max-Planck Research School for Earth System Modeling, Hamburg, Germany
[3]Department of Earth and Environment, Boston University, Boston, USA
[4]A.M. Obukhov Institute of Atmospheric Physics, Moscow, Russia

Most Earth system models agree that land will continue to store carbon due to the physiological effects of rising CO_2 concentration and climatic changes favouring plant growth in temperature-limited regions. But they largely disagree on the amount of carbon uptake. The historical CO_2 increase has resulted in enhanced photosynthetic carbon fixation (Gross Primary Production, GPP), as can be evidenced from atmospheric CO_2 concentration and satellite leaf area index measurements. Here, we use leaf area sensitivity to ambient CO_2 from the past 36 years of satellite measurements to obtain an Emergent Constraint (EC) estimate of GPP enhancement in the northern high latitudes at two-times the pre-industrial CO_2 concentration (3.4 ± 0.2 Pg C yr^{-1}). We derive three independent comparable estimates from CO_2 measurements and atmospheric inversions. Our EC estimate is 60% larger than the conventionally used multi-model average (44% higher at the global scale). This suggests that most models largely underestimate photosynthetic carbon fixation and therefore likely overestimate future atmospheric CO_2 abundance and ensuing climate change, though not proportionately.

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CARBON DYNAMICS IN A RETROGRESSIVE THAW SLUMP: INSIGHTS FROM THREE CONSECUTIVE YEARS OF ^{14}C ANALYSIS OF MICROBIAL RESPIRED CO_2

Philipp Wischhöfer[1], J. Melchert[1], G. Norén[1], S. Holm[2], L. Sauerland[3], C. Knoblauch[3], J. Rethemeyer[1]

[1]University of Cologne, Cologne, Germany
[2]GFZ German Research Centre for Geosciences, Potsdam, Germany
[3]Universität Hamburg, Hamburg, Germany

Pleistocene ice-rich permafrost deposits of the Yedoma domain store vast amounts of organic carbon (OC). Due to their high ice content, Yedoma deposits are especially sensitive to global warming induced thaw and thermo-erosion processes, such as thaw slump formation, which rapidly expose previously frozen OC to microbial decomposition. Incubation studies show that a substantial fraction of the OC stored in the Yedoma domain is easily decomposable upon thaw (Knoblauch et al., 2013). However, information on organic matter decomposition in freshly thawed Yedoma deposits under natural conditions is limited.

Here, we present the results of ^{14}C analysis of CO_2 collected from different locations on an active, retrogressive thaw slump on Kurungnakh Island (Lena River delta, Russian Arctic), during the growing seasons of 2017 to 2019. Samples of surface CO_2 emissions and pore space CO_2 (25-75 cm of depth) were collected 1) from the active soil layer in the overlaying Holocene sediments, 2) from freshly exposed thaw mounds of undisturbed Yedoma deposits, and 3) from the thaw slump bottom comprising a mixture of Holocene and Pleistocene Yedoma material. CO_2 released from the intact active layer had ^{14}C concentrations (~1 $F^{14}C$) similar to current atmospheric concentrations, even though bulk soil OC was as old as 4140 years before present (yrs BP; 0.597 $F^{14}C$) in the uppermost 20 cm of the active layer. In contrast, CO_2 from barren thaw mounds and the thaw slump bottom had considerably lower ^{14}C concentrations with minimum values of 0.235 $F^{14}C$ for surface CO_2 emissions and 0.195 $F^{14}C$ for pore space CO_2, corresponding to 11,650 and 31,050 yrs BP, respectively. Thus, a fraction of the Pleistocene OC in the Yedoma deposits is indeed decomposed upon thaw. We do not observe interannual trends in ^{14}C concentrations of surface CO_2 emissions from barren surfaces. Differences between years and sampling sites more likely reflect small-scale spatial heterogeneity of the belowground organic substrates. However, in 2019, surface CO_2 emissions from surfaces recolonized by plants had significantly ($p=0.02$) higher ^{14}C concentrations (mean of 0.870 ± 0.091 $F^{14}C$) than emissions from barren surfaces (mean of 0.666 ± 0.162 $F^{14}C$). This increase in ^{14}C most likely derives partly from root respiration. Yet the increase may additionally indicate that plant colonization gradually stabilizes the Yedoma OC pool by providing soil microbes with easier decomposable substrates.

In conclusion, while Pleistocene OC from Yedoma deposits appears to be decomposable upon thermo-erosion and thaw, the amount of OC released in this process may be controlled by landform stabilization and subsequent recolonization with plants.

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SOURCES OF MICROBIAL RESPIRATION IN THE ACTIVE LAYER OF SIBERIAN POLYGONAL TUNDRA: INSIGHTS FROM ^{14}C ANALYSIS OF SOIL GAS

Philipp Wischhöfer[1], C. Knoblauch[2], J. Boike[3,4], J. Rethemeyer[1]

[1]University of Cologne, Cologne, Germany
[2]Universität Hamburg, Hamburg, Germany
[3]Alfred Wegener Institute Potsdam, Potsdam, Germany
[4]Humboldt-Universität zu Berlin, Berlin, Germany

Ice-wedge polygons are a common landform in Arctic coastal plains and deltas, characterized by strong micro-topography and hence, small-scale variability of vegetation types, soil carbon distribution and hydrology. This distinct heterogeneity makes ice-wedge polygons an interesting environment to investigate the Arctic carbon cycle upon the ongoing climate warming in high latitudes.

Here, we assessed the vulnerability of old (sequestrated before 1950) soil organic carbon (OC) in low-centred ice-wedge polygons of the first geomorphological terrace of the Lena River Delta. We evaluated C sources contributing to CO_2 in the pore space of the active layer based on the carbon isotopic composition ($\delta^{13}C$, ^{14}C) of soil OC, dissolved organic carbon (DOC), and inorganic carbon (IC) derived from diffusive admixture of atmospheric CO_2. Pore space CO_2 was collected during two growing seasons (August 2017 and 2018) from the lower thaw layer (15-25 cm of depth) from elevated polygon rims and depressed polygon centres. The ^{14}C concentration of pore space CO_2 from polygon rims was modern (atmospheric ^{14}C content: 1.015 ± 0.017 $F^{14}C$) to several hundred years old (1.032-0.859 $F^{14}C$), indicating substantial contribution from old soil OC (minimum $F^{14}C$ of bulk soil OC of 0.720 corresponding to 2640 years before present). In contrast, pore space CO_2 from polygon centres was slightly enriched in ^{14}C (1.037-1.093 $F^{14}C$) suggesting a mixture of modern plant-derived C sources and young soil OC from recent decades that was translocated into the lower thaw layer as dissolved organic carbon (DOC). Pore space CO_2 from both, polygon rims and centres, has higher $\delta^{13}C$ values (up to -19.3 ‰ VPDB) than soil OC (-26.6 to -29.3 ‰) and present-day vegetation and litter (-28.1 to -31.4 ‰). For polygon rims, this is explained by diffusion of atmospheric air into the pore space, whereas in water-logged polygon centres, the heavy $\delta^{13}C$ signature most likely derives from admixture of CO_2 from methanogenic organisms.

Overall, depleted ^{14}C concentrations in pore space CO_2 of polygon rims prove that a fraction of the old soil OC is vulnerable to microbial breakdown, even though it appears to be a minor source during peak growing season. Yet, it seems likely that during late growing season, when plant activity ceases and a frozen surface prevents downward percolation of labile DOC, microbial respiration shifts to older OC substrates.

EFFECTS OF LONG-TERM INCUBATION ON MICROBIAL COMMUNITY STRUCTURE AND FUNCTIONAL POTENTIAL OF ACTIVE LAYER AND PERMAFROST SEDIMENTS

Sizhong Yang[1], S. Liebner[1,2], C. Knoblauch[3], J. Walz[3], J. Frank[4], T. Bornemann[5], A. Probst[5], E. Rivkina[6], D. Wagner[1,7], M. in 't Zandt[4]

[1]GFZ German Research Centre for Geosciences, Section 3.7 Geomicrobiology, Potsdam, Germany
[2]Institute of Biochemistry and Biology, University of Potsdam, Potsdam, Germany
3Institute of Soil Sciences, University of Hamburg, Hamburg, Germany
4Department of Microbiology, Institute for Water and Wetland Research, Radboud University, Nijmegen, the Netherlands
5Biofilm Center, Faculty of Chemistry, University of Duisburg-Essen, Essen, Germany
6Institute of Physicochemical and Biological Problems in Soil Science, Pushchino, Russia
7Institute of Geosciences, University of Potsdam, Potsdam, Germany

Permafrost represents a potential positive feedback to climate warming (*Schuur et al., 2009*). Thawing frozen ground will release the long-term organic carbon stocks as greenhouse gases (GHGs) through microbial decomposition (*Knoblauch et al., 2018*). Understanding the microbial response to permafrost thaw is a key factor for better predicting its role in a changing climate. Functional metagenomics can provide insights into microbial survival strategies in ancient permafrost, metabolic shifts along natural thaw gradients, and the role of the microbiota for GHG production. Here, we report on the functional and taxonomic response of the microbial community to more than five years of simulated permafrost thaw under anoxic conditions at 4°C. Our results show that long-term incubation favoured methanogenic conditions relative to non-methanogenic CO_2 production. After an initial peak especially in CO_2 production, GHG production rates remained, however, constantly low. Functional gene based analysis using metagenomics indicates a general decrease in carbon and nitrogen cycling, with a noticeable increase in the production potential of the potent GHG N_2O. Long-term thaw results in an increase in fermentative Bacteroidetes and Firmicutes (Clostridia), and Patescibacteria, in contrast to decreases of Verrucomicrobia, Alphaproteobacteria, Actinobacteria and Acidobacteria. We also observed that microbial functions and community compositions remained remarkably different between the active layer, the permafrost boundary and permafrost after long-term thawing. Based on our study we conclude that differences in soil physical and chemical properties of active layer and permafrost determine diverging microbial responses to long-term anoxic conditions and that both active layer and permafrost switch from labile to recalcitrant carbon with constant but low GHG production on the long-term.

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

Nataliya Yurkevich[1], A. Kartoziia[1,2,3]

[1]Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia
[2]V. S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
[3]Novosibirsk State University, Novosibirsk, Russia

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 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.

GEOELECTRICAL SECTION OF THE PERMAFROST FROM THE ESTUARY PART OF THE LENA RIVER DELTA USING MTS DATA.

Anna Zaplavnova[1,2], V. Potapov[1,2], V. Olenchenko[1,2], A. Shein[1]

[1]Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russia
[2]Novosibirsk State University, Novosibirsk, Russia

The work is applied to investigate the permafrost layer thickness and formation using the magnetotelluric method (MTS) in the Lena river delta estuary.

An MT profile was made, including 7 points. The profile is shown on the Fig. 1.

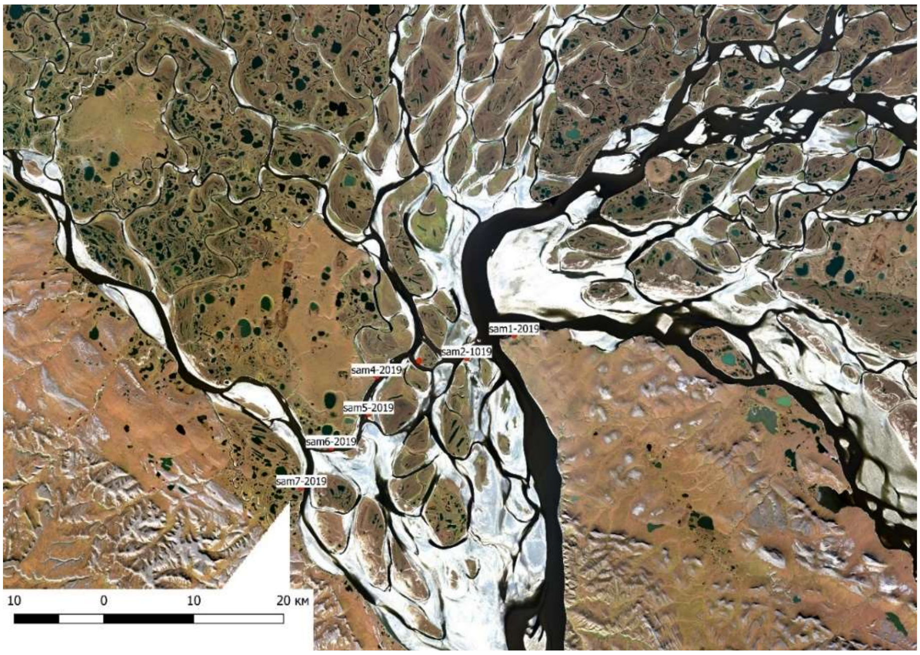

Fig. 1: Location of the measurements points.

Due to the cover of the Quaternary sediments, the deep structure of the folded region has been studied very poorly. Field data processing and interpretation results make possible to indicate the basing depth of the permafrost layer for 7 profile points. The resistance of the upper layer 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. Such variations in the thickness of the permafrost layer are supposedly associated with complex tectonic structure and under channel talik influence.

THERMAL REGIME AND HYDRODYNAMICS OF ARCTIC LAKES AND RIVERS

Roman Zdorovennov[1], G. Zdorovennova[1], A. Guzeva[2,3], S. Evgrafova[4], S. Golosov[2], I. Zverev[2], I. Fedorova[3]

[1]NWPI KarRC RAS, Petrozavodsk, Russia
[2]Institute of Limnology, St.-Petersburg, Russia
3St.-Petersburg State University, St. Petersburg, Russia
4Institute of Forest FIC SB RAS, Krasnoyarsk, Russia

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 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 time interval 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.

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DISSOLVED OXYGEN IN ICE-COVERED LAKES

Galina Zdorovennova[1], I. Fedorova[2], A. Shadrina[2], T. Efremova[1], R. Zdorovennov[1], N. Palshin[1]

[1]NWPI KarRC RAS, Petrozavodsk, Russia
[2]St.-Petersburg State University, St. Petersburg, Russia

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 Gerate 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.

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Telefon 0471 4831-0
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