Yamal LCLUC Synthesis:

A synthesis of remote-sensing studies, ground observations and modeling to understand the social-ecological consequences of climate change and resource development on the Yamal Peninsula, Russia and relevance to the circumpolar Arctic

Grant NNX14AD90G

Annual Report, 31 January 2015

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Abstract

This report summarizes the first nine months (April–December 2014) of research for the NASA-LCLUC project entitled "Yamal LCLUC Synthesis: A synthesis of remote-sensing studies, ground observations and modeling to understand the social-ecological consequences of climate change and resource development on the Yamal Peninsula, Russia and relevance to the circumpolar Arctic" (NASA Grant No. NNX14AD90G). The two primary goals of the Yamal synthesis are to develop a better understanding of variations in Arctic ecological systems along the Eurasia and Circumpolar Arctic climate gradient to aid in interpretation of remotely sensed imagery, and to develop remote-sensing tools that can be used for adaptive management that will help Arctic people, government agencies and policy makers predict and adapt to impending rapid climate change and rapid resource development.

Scientific accomplishments during the first year include:

- Four synthesis chapters in a new book describing the unique permafrost conditions and landslides, and hazard mapping on the Yamal Peninsula Russia;
- Discovery of a large, deep crater on the Yamal produced by an explosive outburst of subsurface methane;
- Synthesis of active layer and permafrost measurements from an 1800-km Eurasia Arctic;
- Report of a recent decline in circumpolar NDVI patterns, particularly in Eurasia;
- Publication of a long-term (62 year) history of cumulative effects of infrastructure and climate change in the Prudhoe Bay region, AK.

Other accomplishments include:

- An ArcticBiomass workshop in Fairbanks, AK, 2-3 September 2014;
- A Yamal-Synthesis Workshop at the Arctic Change 2014 conference in Ottawa, ON, Canada, 9 December 2014;
- A new initiative called "Rapid Arctic Transitions due to Infrastructure and Climate (RATIC)," including a workshop at the Arctic Change 2014 conference in Ottawa, ON, Canada, 9 December 2014.

This report includes: (1) The proposed study objectives; (2) a summary of our accomplishments, focusing on the recent accomplishments of the Russian participants at the Earth Cryosphere Institute; and (3) four appendices that contain: (A) titles of papers presented at the ArcticBiomass Workshop; (B) agenda for the RATIC Workshop, Ottawa, Canada, 9 December 2014; (C) abstracts of 27 project-related papers and posters presented at the Arctic Change 2014 conference; and (D) a list of Yamal Synthesis publications and presentations to date including publications from earlier rounds of funding.

A new Yamal-Synthesis web page (www.geobotany.uaf.edu/yamal) is in progress and will contain all project-related information including publications, reports, proposals, photos, participants, and workshops.

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Yamal-synthesis study objectives

The two primary goals of the Yamal synthesis activities are to 1) develop a better understanding of variations in Arctic ecological systems along the Eurasia and Circumpolar Arctic climate gradient to aid in interpretation of Arctic remotely sensed imagery and 2) develop remote-sensing tools that can be used for adaptive management that will help Arctic people, government agencies and policy makers predict and adapt to impending rapid climate change and rapid resource development. We are synthesizing a wide variety of biophysical and social data that have been collected during five LCLUC expeditions along an 1800-km Arctic transect in the Yamal-Franz Josef Land region and from related projects on the Yamal and in Alaska conducted by collaborators.

The project consists of the three science components:

Component 1: Synthesis of Eurasia Arctic Transect (EAT) data: A major achievement during previous rounds of LCLUC funding was the completion of the Eurasia Arctic Transect (EAT) that traverses all five Arctic bioclimate subzones from the forest-tundra transition south of the Yamal Peninsula and to the extreme High Arctic in Franz Josef Land. Component 1 is examining the EAT data hierarchically by first developing a compendium of disciplinary papers that synthesize the vegetation, soil, permafrost, and remote-sensing information from the EAT. The results from these papers will then be used in an interdisciplinary overview paper that summarizes the main results and conclusions from the EAT transect. We will further address science questions related to landscape and spectral-reflectance variation along the EAT in comparison to a similar transect in North America, which is much less intensively grazed, and has more loamy soils and a more continental climate. At a circumpolar scale, the results from both transects will be combined with Arctic-wide climate, sea-ice, and land-temperature data to help interpret spatial and temporal variations of regional and Arctic-wide patterns of productivity as indicated by the Normalized Difference Vegetation Index (NDVI).

Component 2: **Synthesis of social-ecological data:** The consequences of rapid climate change and resource development vary with different social-ecological systems across the Arctic. This component focuses on the different effects of hydrocarbon development in the Bovanenkovo gas field versus the Prudhoe Bay oil field in Alaska. It also compares their effects on the reindeer-herding Yamal Nenets people compared to the Iñupiat hunters in Alaska. Project collaborators conducted social-ecological studies in these two regions primarily with funds from other sources. Both studies relied heavily on remote-sensing information to trace the history of development and for use in studies of local perceptions of change. A synthesis paper will focus on the remote-sensing aspects of these two studies. We are also developing a "Rapid Arctic Transitions due to Infrastructure and Climate" initiative to be presented at the International Conference on Arctic Research Planning (ICARP III) to help shape future approaches to adaptive management of resource development in the Arctic.

Component 3: Synthesis of modeling studies: The modeling component of our previous LCLUC projects helped develop the ArcVeg Model for application to questions related to climate change reindeer herding on the Yamal Peninsula. ArcVeg is a plot-level, tundra vegetation dynamics model that focuses on the response of a suite of common tundra plant functional types to changes in temperature and soil nutrients. The field observations along both the EAT and the North American Arctic Transect (NAAT) were used to improve the parameterization of the ArcVeg Model. This component will synthesize the earlier studies and apply the ArcVeg model to a circumpolar synthesis. Another task of this component will be to synthesize information from our studies and those of others regarding tall-shrub-expansion across Russia.

Data management will consist of three major elements: a Yamal Arctic Vegetation Archive (YAVA), a Yamal Arctic Map Archive (YAMA), and a Yamal Arctic Atlas Portal (YAAP).

Accomplishments in 2014

Special recognition for the Russian contributions

This summary first focuses on the accomplishments of the Russian participants in the Yamal Synthesis project, who have made the project possible through their significant logistical efforts to arrange five expeditions along the EAT and their many scientific achievements. A brief summary of these includes:

- Organized field studies and assisted in fieldwork along the EAT. Organized expeditions in 2007 (Nadym, Laborovaya, Vakiny Dachi), in 2008 (Kharasavey), in 2009 (Bely Island), 2010 (Hayes Island), and 2011 (Kharp).
- Conducted permafrost, active layer, and soil studies at all locations, and revisited locations to collect data. Annual visits to Nadym and Vaskiny Dachi before and after 2007. Revisited Laborovaya and Bely Island three summers.
- Continued research and recent major publications regarding the unusual landslides on the Yamal Peninsula.
- Collected general physiographical and climate information for all sites along the EAT from a number of key publications, and presented at workshops in Moscow, Russia, Rovaniemi, Finland, and in Canada.
- Summarized existing information on vegetation, soils and permafrost for the transect locations and Yamal as a whole. Collected partially and published in a number of papers, mainly in Russian.
- Conducted geobotanical studies at all sites jointly with U.S. colleagues.
- Organized a LCLUC workshop (First Yamal Land-Cover Land-Use Change Workshop, Moscow, Russia, January 2008).
- Translated 20-page summaries of two Russian PhD dissertations.
- Discovered and published information regarding deep craters in Central Yamal.
- Published and presented results at Russian at a number of international conferences, NICOP, EUCOP3, TICOP, EUCOP4, and AC2014.

Four book chapters on Yamal landslides

A new book, *Landslides in Cold Regions in the Context of Climate Change* (Shan et al. 2014), contains four chapters produced by Marina Leibman and her colleagues at the Earth

Cryosphere Institute in Tyumen and Moscow that synthesize information from several aspects of the landslide situation in the central Yamal Peninsula. The landslides are the result of unusual geologic conditions that create highly dissected landscapes typical of the central Yamal region (Fig. 1), and which present hazards to gas development and other land uses in this region. Leibman and her colleagues have studied these features since 1989 during annual expeditions to Vaskiny Dachi and other key research sites on the Yamal and Yugorsky peninsulas. These expeditions have examined the strong impact of cryogenic landslides on all components of the geosystem including vegetation, soils, active layer, and ground water, but detailed information on these studies were mainly available only in Russian and in English abstracts from international permafrost conferences. The overview chapter describes discovery, description, dating and mapping of the Yamal landslides, and suggests mechanisms, forcing factors, and triggers of landslide processes (Leibman et al. 2014b). Another chapter provides an assessment of the geohazards and mapping of these features using remote sensing methods (Khomutov and Leibman 2014). A chapter by Anatoly Gubarkov describes the erosional processes involved with the formation of complex drainage networks associated with landslide terrain (Gubarkov and Leibman 2014). The fourth chapter describes the complex relationships between permafrost, soils, and vegetation (Ukraintseva et al. 2014). This study showed that the landslide process causes desalinization of marine sediments and enriches the active layer with salts that cause unique successional processes for plant communities that colonize the landslide surfaces. This is an important peculiarity of cryogenic landslides in the region with saline permafrost distribution.

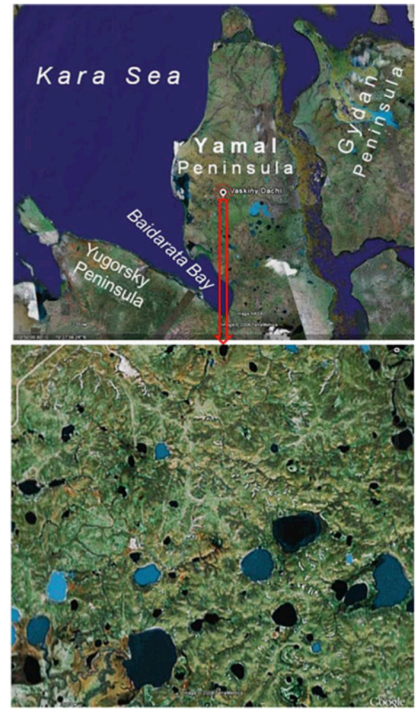

Figure 1. Yamal Peninsula and location of the key site of landslide research at Vaskiny Dachi. The lower Digital Globe image shows the highly dissected landscapes caused by cryogenic landslides that are typical of this region.

A newly discovered permafrost feature: a recent deep crater on the Yamal Peninsula

The most exciting and totally unexpected event related to the work of Russian participants in the project was the discovery of a deep crater about 25 km southeast of the Bovanenkovo gas field. The crater probably formed in fall of 2013. Marina Leibman and colleagues described the crater in summer and fall 2014. They published a paper in the Russian journal *Geography, Environment, Sustainability* (Leibman et al. 2014a) and another is in press in *Earth Cryosphere* (Kizyakov et al. n.d.).

The Yamal crater is now known to be one of three or four that appeared within the last two years. A parapet that resulted from expulsion of ice and rocks from beneath the surface surrounds the crater. The authors conclude that the origin of this crater can be attributed to the air-temperature-warming trend along with the extreme temperatures of 2012. The increased ground temperature and amount of unfrozen water in the permafrost, combined with expanding pockets of methane gas produced by gas hydrate decomposition within permafrost, created a pingo-like mound that burst due to high pressure. Similar temperature anomalies may increase in number in future decades, presenting risks for human activities in the region. This conclusion is supported by recent studies of gas-hydrate behavior in the upper permafrost as well as by subsea processes in gas-bearing provinces where an analogue mechanism is known to produce pockmarks — subsea depressions. The event was widely reported in the Russian media (e.g., http://siberiantimes.com/science/casestudy/news/foreign-scientists-welcome-to-join-research-into-siberias-mysterious-giant-holes/?comm_order=best; http://sciencefirsthand.ru/pdf/sfh_59_13.pdf); and in the international media (e.g., www.washingtonpost.com/news/morning-mix/wp/2014/08/05/scientists-may-have-cracked-the-giant-siberian-crater-mystery-and-the-news-isnt-good).

Summary of information from the Eurasia Arctic Transect (EAT)
The Eurasia Arctic Transect covers 1880 km from the forest-tundra transition south of the Yamal Peninsula near Nadym (65°18'51''N, 72°51'43''E) to the extreme High Arctic at Hayes Island, Franz Joseph Land, (80°35'56''N, 57°54‘20''E) (Fig. 2). Data reports from five NASA-GOA Russia EAT expeditions in 2007-2011 are available online at www.geobotany.uaf.edu/yamal/reports.

A synthesis of the active-layer information from five research locations along the Yamal transect is in progress. The study of active layer dynamics is using Circumpolar Active Layer Monitoring (CALM) protocols at 100 x 100-m plots characterized by relief, geological structure, surface properties and cryogenic processes (Khomutov et al. 2013, 2014). The plots were equipped for measurement of ground temperature and depth of seasonal thaw. The zonal patterns in the spatial distribution of various parameters of cryolithozone were analyzed along the EAT.

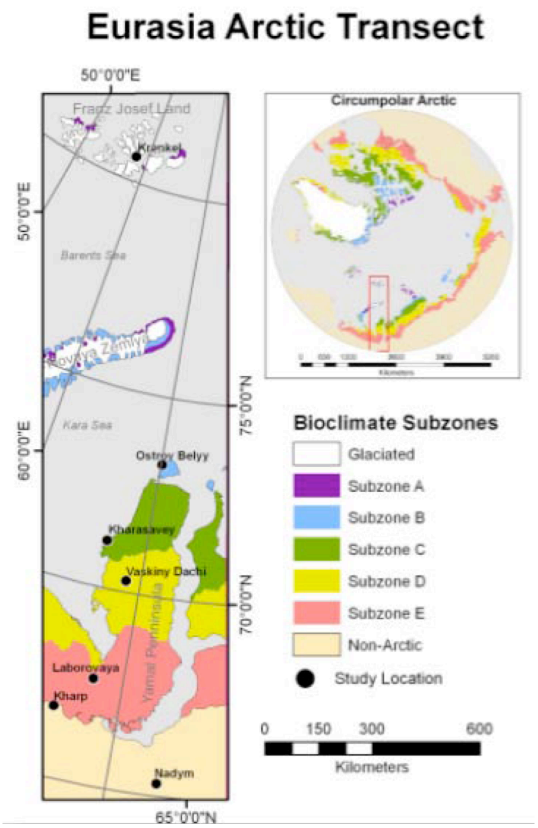

Figure 2. Eurasian Arctic Transect Bioclimate subzones are according to CAVM Team (2003). The seven EAT study locations are also shown.

In Central Yamal measured ground temperature varies from -0.3°C up to -7°C, active layer depth varies from 40 to 240 cm. Temporal variations caused by climate fluctuations range at ±2 °C for ground temperature, and ±5-10 cm for active layer depth. Thus, spatial factors such as lithology and surface covers are of much higher importance compared to climatic factors.

Spatial distribution of permafrost parameters along the EAT (Fig. 3) involves latitudinal zonality based on directional lowering of air temperature northward from the Nadym site in the south to the Hayes Island site in the north. On the whole, there is a consistent trend of thinner active layers toward the north, but local factors connected to relief, drainage degree, soil texture, and location of plots on different landforms distort the zonal pattern.

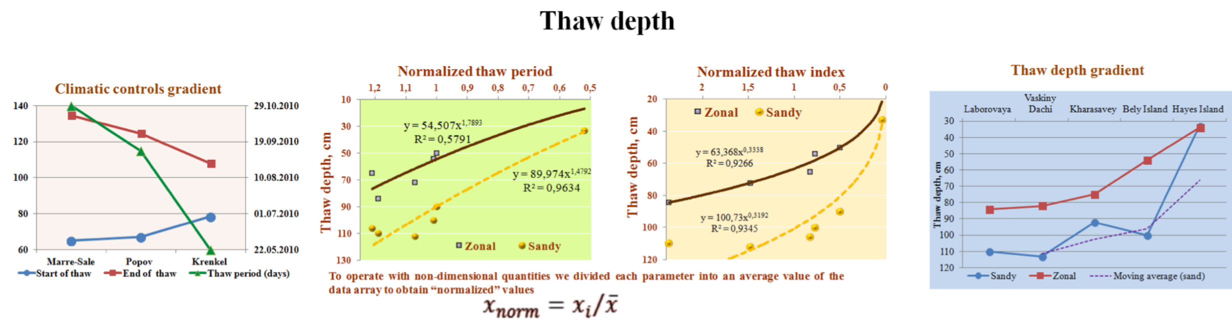

Figure 3. Summary of active layer parameters along the EAT. The left figure summarizes the climate controls along the gradient (start, end and length of thaw period). The next three figures contrast the thaw depth vs. the normalized thaw period, normalized thaw index, and the locations for zonal (loamy) soils with sandy soils along the EAT.

Other key papers for the EAT synthesis will describe the (1) vegetation (Ermokhina, Khitun, and Walker), (2) soils (Matyshak et al.), (3) permafrost and active layer (Leibman et al.), and spectral properties and biomass (Epstein et al.) These include several of the planned papers for the ArcticBiomass special issue of *Environmental Research Letters* discussed above.

Synthesis of social-ecological information from the EAT and NAAT

Key goals for the social-ecological studies include: (1) Comparison of cumulative landscape effects of development in the Bovanenkovo Gas Field (BGF) and the Prudhoe Bay Oil Field (PBO), and (2) comparison and synthesis of the social effects of development on the Nenets people of Russia and the Iñupiat people of Arctic Alaska.

A major synthesis of the 62-year history of landscape and permafrost changes in the Prudhoe Bay region has recently been completed and reports major increases in both infrastructure-related and non-infrastructure-related thermokarst since 1990 (Walker, D. A. et al. 2014, Raynolds et al. 2014) (Fig. 4).

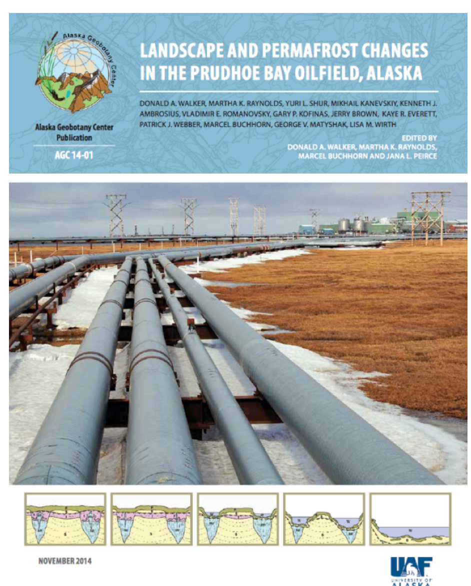

Figure 4. Cover of recent synthesis of 62-year history of the Prudhoe Bay oilfield.

Case studies of the two hydrocarbon fields were presented at a Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) workshop at the Arctic Change 2014 conference in Ottawa, Canada. Conclusions from the two studies include:

- The Bovanenkovo Gas Field (BGF) in Russia and the Prudhoe Bay Oilfield (PBO) in Alaska are among the oldest and most extensive industrial complexes in the Arctic, and both are situated in areas with extensive ice-rich permafrost that have undergone major long-term ecosystem transitions. A better understanding of the full ecosystem consequences of development on ice-rich permafrost is needed.
- The differences in the underlying surficial geology have resulted in very different permafrost conditions and hazards. The BGF is in hilly terrain, with mainly marine clays overlaid by alluvial sands and peat. The PBO is characterized by flat alluvial gravel overlaid by loess and peat. Permafrost hazards and conditions in the BGF consist mainly of tabular ground ice in the uplands, with extensive cryogenic landslides and thermocirques on slopes (Gubarkov and Leibman 2014, Khomutov and Leibman 2014, Leibman et al. 2014b, Ukraintseva et al. 2014). In the PBO, ice-rich loess with extensive thaw lakes, and ice-wedge polygons with extensive ice-wedge thermokarst have developed (Jorgenson et al. 2006, Kanevskiy et al. 2013).
- A recent series of warm summers has triggered a major increase in thermokarst in the PBO and themocirques near the BGF.
- Both oil and gas fields were discovered at about the same time (PBO: 1968; BGF: 1972). The PBO infrastructure network developed rapidly and by 1977 was connected to the rest of Alaska by the Dalton Highway and the Trans-Alaska Pipeline, which permitted additional development of adjacent oilfields and export of the oil to an ice-free port at Valdez. The BGF development proceeded much more slowly. Transport of gas out of the region still awaits construction of pipeline linkages to other gas fields on the Yamal and points further south in Russia and Europe.
- The small populations of indigenous people in both areas have benefited economically from resource development (Kumpula et al. 2006, Forbes et al. 2009, Kumpula et al. 2011), but with major social consequences. Most threatening to both groups is restricted free access by hunters and herders to their traditional lands.
- Future mega-expansion of infrastructure in both areas, combined with climate-induced changes to local landscapes and permafrost, present unprecedented challenges to local communities (Kofinas et al. 2014). The sheer scale of the proposed hydrocarbon developments in the next few decades could overwhelm the ability of local communities to adapt to the changing conditions.
- Successful adaptive management will require full engagement of local people and governments with industry and national governing agencies.
- The new Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) initiative provides a forum for developing and sharing new ideas and methods to facilitate best practices for assessing, responding to, and adaptively managing the cumulative effects of Arctic industrial infrastructure and climate change.

Global scale syntheses

Key products for the broader inter-continental comparisons and pan-Arctic studies include: (1) Raster-based vegetation map of the Arctic (Raynolds et al. in prep.); (2) annual updates of the Arctic Report Card (Epstein et al. 2014); and (3) seasonality patterns of sea-ice, sea-surface temperature, land-surface temperatures, snow, and NDVI (Bhatt et al., in prep. to ERL).

Among the highlights of the 2013 global analysis reported in NOAA's *Arctic Report Card: Update 2014* (Epstein et al. 2014) are:

- Peak tundra greenness (MaxNDVI) was still relatively high in 2013 for North America and the Arctic as a whole, indicating a continued trend in increasing vegetation productivity since satellite observations began in 1982.
- Temporally-integrated greenness (TI-NDVI, sum of the bi-weekly growing season values) had historically low values in 2013 for both Eurasia and the Arctic as a whole, suggesting a shorter growing season.
- During the latter half of the remote sensing record (1999-2013), there has been a substantial increase in the areas of tundra with declining TI-NDVI (i.e., there has been a "browning" of the tundra, suggesting a longer-term decline in growing season length) (Fig. 5).
- Recent studies indicate that Arctic tundra greening trends, at least in the more southern arctic tundra, are strongly linked to the expansion of woody vegetation (Urban et al. 2014) and particularly the spread of tall shrubs (Frost and Epstein 2014, Frost et al. 2014).

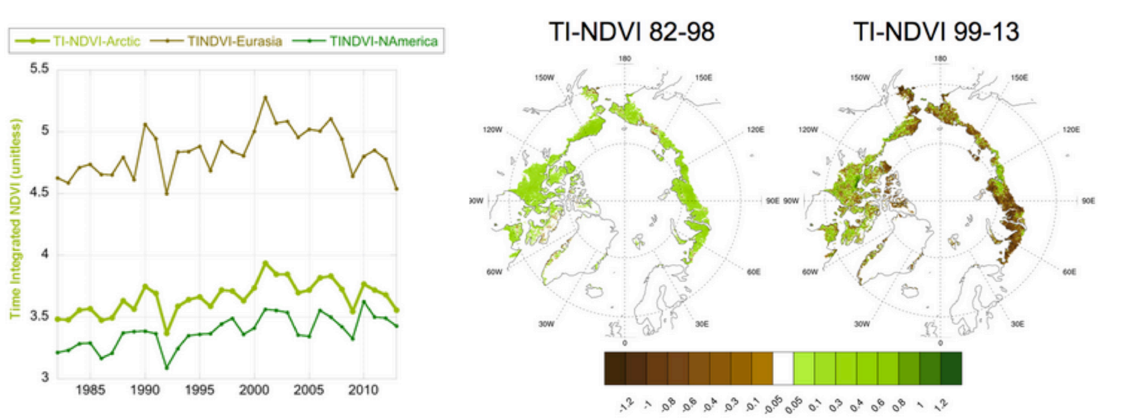

Figure 5. Left: Trends in the magnitude of TI-NDVI for North America, Eurasia and the Arctic as a whole (1982-2013). Right: Circumpolar patterns of greening trend pattern broken into 1982-1998 period and 1999-2013 period illustrating the widespread decrease in TI-NDVI during the past 15 years particularly in Eurasia. The causes of reduced TI-NDVI and their relationship to, for example, the changing snow cover are yet to be determined for the Arctic tundra as a whole. (From Epstein et al. *2014).*

ArcticBiomass Workshop, Fairbanks, AK, 2-3 September 2014.

The main topics of the September 2014 ArcticBiomass meeting in Fairbanks, Alaska, were biomass estimation and monitoring from plot scale to satellite. Presentations on related themes, including circumpolar Arctic and boreal monitoring of vegetation, UAS systems, spectrometry, were also presented. Hans Tommervik, Norwegian Institute for Nature Research (NINA), and Scott Goetz, Woods Hole Research Center, were the primary organizers of the workshop, and the University of Alaska Fairbanks (UAF) assisted with conference organization and local logistics for field excursions to Denali National Park, Circle, and the Yukon River followed the workshop on 4-9 September 2014. The participants agreed to develop an ArcticBiomass special issue for *Environmental Research Letters*. The list of papers presented at the workshop and a list of authors and tentative titles for the *ERL* ArcticBiomass special issue are included in Appendix A.

Yamal LCLUC Synthesis project meeting, 9 December 2014, Ottawa, Canada

Our first Yamal Synthesis project meeting was held in Ottawa, Canada, during the Arctic Change 2014 conference (AC2014), 8-12 December 2014. We received $10,000 from the International Arctic Science Committee (IASC) for Association of Polar Early Career Scientists (APECS) to attend, and four of these were Russian students who participated in the LCLUC activities. Eight of the meeting participants were from the USA, nine from Russia, and two from Finland. The meeting focused on review of the commitments in our NASA proposal.

Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) initiative

Figure 6. The RATIC workshop was organized around infrastructure case studies from the Prudhoe Bay oil field, AK, the Bovanenkovo gas field, Russia, and northern Canadian communities.

The indigenous people within the Arctic keenly feel the effects of the combination of resource development and climate change, as do governments, agencies, and industries operating in these regions. The combined effects of infrastructure and climate change, however, have not received much interdisciplinary scientific study. The Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) initiative is a forum for developing and sharing new ideas and methods to facilitate the best practices for assessing, responding to, and adaptively managing the cumulative effects of Arctic infrastructure and climate change. The initiative was developed by D. A. Walker and endorsed by the International Arctic Science Committee (IASC).

The RATIC workshop and topical sessions at the Arctic Change 2014 conference in Ottawa, 8-12 December 2014, were organized so that international scientists who have been working independently in several areas of the Arctic on issues related to Arctic infrastructure could network with each other and share their findings. The workshop on December 9, 2014, included about 40 participants. We received $10,000 from the International Arctic Science Committee (IASC) for Association of Polar Early Career Scientists (APECS) to attend, and four of these were Russian students who participated in the LCLUC activities. The workshop organized around three infrastructure case studies from Alaska, Russia, and Canada (Fig. 6) (See Appendix B for the meeting agenda).

The two topical sessions on December 11-12 included oral presentations and posters that included first-author papers and posters from Russia (9), USA (9), Canada (6), Finland (2), and Norway (1) (Appendix C).

Several studies emerged as possible models for programs aimed at developing sustainable approaches to Arctic development, including the Integrated Regional Impact Studies (IRIS) and the Arctic Development and Adaptation to Permafrost in Transition (ADAPT) in Canada, the Finnish-sponsored Environmental and Social Impacts of Industrialization in Northern Russia (ENSINOR) project in the gas fields of the Yamal Peninsula, Russia, and the oilfields in northern Russia, the U.S. interagency North Slope Science Initiative (NSSI) and the NSF Arctic Science, Engineering, and Education for Sustainability (ArcSEES) initiative in Alaska.

An IASC-RATIC white paper based on the Ottawa workshop is in preparation and will be presented at the Third International Conference on Arctic Research Planning (ICARP III) in Yohama, Japan, 23-30 April 2015. The meeting offers an opportunity to direct more scientific attention to these complex infrastructure-related issues during the next decade. As first steps, the RATIC group recommends that the combined IASC Cryosphere, Human and Social, and Terrestrial Working Groups collaborate to (1) develop an IASC interdisciplinary RATIC Network; (2) incorporate infrastructure-related issues more explicitly in the working groups' research priorities; and (3) promote regular RATIC workshops at international scientific meetings.

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Appendices

Appendix A. Material from the ArcticBiomass Workshop, Fairbanks, AK, 2-3 September 2014

List of presentations at the ArcticBiomass Workshop

Martha Raynolds and Skip Walker: Welcome to University of Alaska Fairbanks

Hans Tømmervik: Presentation of the ArcticBiomass project

Timo Kumpula, M. Verdonen, Marc Macias-Fauria, and Bruce Forbes: Multiscale and multispectral detection and analysis of recent landcover changes in Central Yamal peninsula Russia.

Colin Tucker: Projecting changes in snow, vegetation and soil processes in Arctic Alaska in response to a changing climate.

Pieter Beck: Pan-Arctic climate controls on shrub growth and tundra productivity.

Marc Macias-Fauria, Timo Kumpula and Bruce Forbes: Pan-Arctic quantification of the influence of sea ice on tundra productivity during the last 30 years: possible mechanisms and future prospects.

Uma Bhatt: Inter- and intra-annual variability of NDVI and correlations to large-scale circulation patterns, sea ice, snow and cloud cover.

Taejin Park, Jorge E. Pinzon, Compton J. Tucker, and Ranga B. Myneni: Comparative analysis of vegetation index data from AVHRR and MODIS over the boreal-Arctic regions

Rune Karlsen: MODIS and Landsat 8 based mapping of the growing season on Svalbard in relation to climate and plant production.

Jarle W. Bjerke, Hans Tømmervik, Stein Rune Karlsen, Kjell Arild Høgda and Jane U. Jepsen: The effects of climate change-induced plant stress on primary productivity in the Nordic Arctic Region.

Hans Tømmervik, Olav Strand, Per Fauchald, Bernt Johansen, Jarle W. Bjerke, Taejin Park,Ranga B. Myneni and Stein Rune Karlsen: Field- and satellite-based monitoring of trends in biomass of reindeer lichen heaths in Finnmarksvidda, Hardangervidda and North-America.

Martha Raynolds: The strong relationship of arctic transect biomass to circumpolar NDVI, despite the many issues in sampling biomass.

Scott Goetz: Arctic vegetation productivity patterns & trends: How well do satellite data sets agree?

Hans Tømmervik: Preparation of a review paper concerning efficient biomass estimation and monitoring in the Arctic.

Donald (Skip) Walker: The North America and Eurasia Arctic Transects: Overview of plot-sample methods (species-cover, environmental, soil, biomass & spectral data).

Marcel Buchhorn: Methods and standards for field spectrometry in the Arctic.

Rune Storvold: Use of UAS in vegetation monitoring

Howard Epstein: NDVI, LAI, and biomass relationships across spatial scales in arctic tundra.

Eugene Euskirchen: Measurements and modeling of leaf phenology, plant community composition, and carbon fluxes in Arctic Alaska.

Bruce Forbes: Ongoing reindeer herbivory and shrub growth research in northern Fennoscandia and Yamal, West Siberia

Bernt Johansen, Hans Tømmervik, Jarle Bjerke and Stein Rune Karlsen: Vegetation and ecosystem transformation due to reindeer grazing on Finnmarksvidda, Northern Norway.

Proposed publications for *Environmental Research Letters* ArcticBiomass special issue

Bjerke et al.: Reduction in evergreen biomass in maritime-buffered Arctic region

Bjerke et al.: Impacts of contrasting winter weather on snow cover, ground ice accumulation, soil frost and grassland productivity in sub-Arctic Norway

Bhatt et al. Trends in seasonality of circumpolar NDVI (biomass?)

Buchhorn: BRDF effects on Arctic biomass mapping – BRDF before and after grazing:

Ejorkman / Beck / Myers-Smith / Frost et al **(shrubhub):** Acceleration in shrub growth drives satellite-observed greening of the Arctic

Epstein & Buchhorn: Landscape scale relationship for hyperspectral reflectance tundra biomass:

Johansen et al.: Lichen biomass changes in the Norwegian Arctic

Karlsen et al.: Time-Integrated NDVI biomass relations on Svalbard

Kumpula et al.: Arctic tundra land cover change on Yamal

Kumpula et al.: Biomass change in relation to infrastructure changes on the Yamal

Park, Myneni et al.: Comparative analysis of vegetation productivity from MODIS and AVHRR over the circumpolar region

Raynolds et al.: Biomass change in relation to infrastructure changes in the Prudhoe Bay Oilfield: Landsat and MODIS NDVI trend analysis

Raynolds / Walker et al. Biomass change in relation to infrastructure changes in the Prudhoe

Walker / Epstein et al.: Panarctic transects as a baseline for examining Arctic biomass

Storvold et al.: Retrieving Arctic biomass parameters using unmanned aircraft

Tommervik / Goetz et al.: Synthesis / overview paper

Appendix B. Agenda for RATIC Workshop, Ottawa, Canada, 9 December 2014

Rapid Arctic Transitions related to Infrastructure and Climate Change (RATIC) Workshop: Arctic Change 2014, Ottawa, Tue Dec 9, 2- 6 pm

2:00-2:15: Welcome, introductions and Overview of RATIC Initiative (see attachment for more details) (Skip Walker)

Three case studies: Each with three 10 minute presentations + 15 minutes for discussion. *Chairs of each Case Study will organize the talks to present an overview of each study, with a summary of major conclusions and where the projects are headed now.*

2:15-3:00: Case Study 1: Cumulative Effects in the Prudhoe Bay Oilfield, AK (Chairs: Skip Walker and Gary Kofinas)

- i. History of infrastructure and landscape changes: M.K. Raynolds and D.A. Walker
- ii. Climate and infrastructure interactions with permafrost: Y. Shur and M. Kanevskiy
- iii. Local communities perceptions of infrastructure and climate changes: toward adaptive management of unpredictable changes: G. Kofinas

3:00-3:30: Break

3:30-4:15: Case Study 2: Russian Arctic oil and gas development and climate change interactions (Chairs: Timo Kumpula and Marina Leibman)

- i. Landcover changes in the Bovanenkovo gas field and Cultural Resilience of Social-ecological Systems of the Nenets: Timo Kumpula & B. Forbes
- ii. Landslide and permafrost regimes in the Bovanenkovo gas field: Artem Khomutov, et al.
- iii. Trace gas fluxes from disturbed tundra: George Matyshak, et al.

4:15-5:00: Case Study 3: Case Study 3: Canadian Arctic Development: The ADAPT and IRIS initiatives (Chairs: Warwick Vincent and Michel Allard)

- i. The Arctic Development and Adaptation on Permafrost in Transition (ADAPT) project: a science program in support of Arctic development: M. Lemay, M. Allard, and W.F. Vincent
- ii. Mapping permafrost conditions for housing and community development in Inuit communities of Nunavik and Nunavut: E. L'Hérault and M. Allard
- iii. ArcticNet's IRISes over Canadian Arctic support of stakeholders and policy makers: An example from the Canadian Eastern and Central Arctic: A. Gaden and G. Stern

5:00-6:00: Round Table Discussion (including audience participation) (Chair: Skip Walker)

Panelists: Michel Allard, Marcel Bucchorn, Tracie Curry, Bruce Forbes, Emmanuel L'Hérault, Ashley Gaden, Misha Kanevskiy, Artem Khomutov, Gary Kofinas, Timo Kumpula, Marina Leibman, George Matyshak, Martha Raynolds, G. Stern, Warwick Vincent

Question 1: How do we progress toward better planning and management of Arctic infrastructure in light of concerns of the local indigenous people and the constraints imposed by ongoing rapid climate change?

Question 2: How do we develop closer exchange of cumulative-effects issues and solutions between the industry, governing agencies, and local communities?

Question 3: Can we develop of a set of shared international objectives focused on developing effective means to address the key issues related to rapid transitions in Arctic social-ecological systems related to infrastructure and climate change?

Question 4: What should we present regarding the RATIC initiative at the ICARP III conference, Yohama, Japan 2015?

Appendix C. Abstracts of papers and posters presented in the RATIC and related sessions at Arctic Change 2014, Ottawa, Canada, 11-12 December 2014

Session T40: **Rapid Arctic Transitions Related to Infrastructure and Climate Change (RATIC)**

Co-chairs: Donald (Skip) Walker (University of Alaska Fairbanks, United States)
Timo Kumpula (University of Eastern Finland, Joenssu, Finland)
Michel Allard (Université Laval, Canada)

Session abstract

Recent studies in Canada, Alaska, and Russia indicate that combinations of climate change and industrial development have resulted in major changes to local Arctic social-ecological systems. The effects are expected to occur more broadly across the Arctic as demand for resources grows and the Arctic continues to warm. This session will be a forum for developing and sharing new ideas and methods to facilitate the best practices for assessing, responding to, and adaptively managing the cumulative effects of Arctic industrial infrastructure and climate change. Papers from a broad range of RATIC themes are solicited, including new remote-sensing and mapping methods to inventory and track rapid changes, infrastructure-scenario modeling (ISM), methods of local community input in all phases of development, and tools that can lead to effective adaptive-management approaches that utilize state-of-the-art science, modeling, engineering, education, and involvement of local people. The Integrated Regional Impact Studies (IRIS) and the Arctic Development and Adaptation to Permafrost in Transition (ADAPT) in Canada, the North Slope Science Initiative (NSSI) in Alaska, and the Finnish-sponsored Environmental and Social Impacts of Industrialization in Northern Russia (ENSINOR) project are emerging as possible models. The results of the session will: (1) Summarize the status of international efforts to examine the cumulative effects of rapid transitions in Arctic social-ecological systems caused by infrastructure development and climate change; 2) develop of a set of shared international objectives focused on developing effective means to address the key issues related to rapid transitions in Arctic social-ecological systems related to infrastructure and climate change; and 3) develop a coordinated international science plan that will be presented at the Third International Conference on Arctic Research Planning (ICARP III) to be held in Yohama, Japan, 23-30 April 2015. The Arctic Science Engineering and Education for Sustainability (ArcSEES) program of NSF, and the Land Cover Land-Use Change (LCLUC) program of NASA provided funds to support the workshop. The International Arctic Science Committee (IASC) provided funds for Arctic Polar Early Career Scientists (APECS) to participate.

Abstracts of papers and posters (in alphabetical order of first authors)

1. EFFLUX OF FROZEN PEATLAND SOILS AT FINE SCALE: THE RELATIONSHIP WITH PERMAFROST CONDITIONS AND THE COMPOSITION OF SOIL ORGANIC MATTER (RUSSIA, CALM SITE R1)

Bobrik, Anna (1) (ann-bobrik@yandex.ru), O. Goncharova (1), G. Matyshak (1), I. Ryzhova (1), O. Ponomareva (2) and O. Ogneva (1)
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The Circumpolar Active Layer Monitoring (CALM) program developed over the last decade as a leading edge in comprehensive efforts to study the impacts of climate change in permafrost environments. Monitoring of active layer thickness, soil moisture, soil and air temperature are typical for all CALM sites. In connection with this CALM polygons are convenient for the study of spatial and temporal variation of soil parameters at fine scales. What does determine biological activity and function of permafrost-affected soils of CALM? It's the main question of our work. The research CALM SITE R1 (Nadym Grid) (N65°20', E72°55') is located in north of Western Siberia (Russia, since 1997) within the zone of sporadic permafrost of north taiga. It is 1-ha (100m*100m) of a square array of permanent stakes separated by 10 m (121 data points per grid for all measurements). For each point of CALM R1 site active layer thickness, carbon dioxide effluxes were measured in August 2013, 2014. Content of total organic carbon, carbon of water extractable organic matter (WEOC) and carbon of microbial biomass (MC) were measured in August 2013. Active layer thickness and soil

CO_2 effluxes are characterized by high spatial and low temporal variability. Active layer thickness varies from 45 to 195 cm (2013) and from 55 to 175 cm (2014); average thickness is 124 and 115 cm respectively. Strong spatial variation of this parameter related with the different soil cover and the organic layers dimensions. Areas with deepest thaw (more then 200 cm) are developed in large sedge-moss pools within peatlands and in bogs and were not included in calculations. In general, soil carbon dioxide emission is low and does not differ from year to year (145 ± 25 – 2013; 135±35 – 2014) mg $CO_2\,m^{-2}h^{-1}$ (ranging from 10 to 350 and from 10 to 450 mg $CO_2\,m^{-2}h^{-1}$ respectively). Average content of TOC in the upper 10 cm of soil is high (36,50±1,50%). Soil of CALM site is characterized with high spatial variation of labile organic carbon (WEOC) and the microbial carbon (MC) in organic layers of soils: average WEOC=0,27±0,05% of soil (ranging from 0,06 to 0,40 % of soil); average MC=3,00±0,20 mg g^{-1} soil (ranging from it varies from 0,11 to 6,55 mg g^{-1} soil). The values of microbial biomass are high, but geocryological and hydrothermal conditions inhibit all soil biological processes. Based on the regression analysis among more than 10 characteristics (hydrothermal, geocryological, soil) for CALM R1 site was revealed a high and significant correlation soil carbon dioxide efflux only with 2 parameters: content of carbon of microbial biomass in the upper 10 cm soil layer (beta=0,965; p-level<0,05) and the active layer thickness (beta=0,333; p-level<0,05). So the main factors which determine the soil carbon dioxide production and carbon fluxes are the active layer thickness and the composition of soil organic matter. Underestimation of the spatial heterogeneity of soil and vegetation cover in the region of sporadic permafrost can lead to substantial distortion of estimates of the total greenhouse gases balance.

2. PROGRESS ON THE NORTHERN ALASKA PROTOTYPE OF THE ARCTIC VEGETATION ARCHIVE

Breen, Amy L. (1, 2) (albreen@alaska.edu), D. A. Walker (2), L. Druckenmiller (2), S. Hennekens (3), M. K. Raynolds (2), H. Epstein (4), J. Sibík (5), L. Wirth (6), M. D. Walker (7) and the AAVA Team
(1) International Arctic Research Center, University of Alaska, Fairbanks, Alaska USA
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(7) HOMER Energy, Boulder, CO 80302 USA

The Arctic Vegetation Archive (AVA) working group of the Conservation of Arctic Flora and Fauna (CAFF), the biodiversity arm of the Arctic Council, is gathering a baseline record of vegetation plot-data within the Arctic, an area of about 7.1 million km2. The goal of the AVA is to unite and harmonize vegetation data from the Arctic tundra biome for use in developing a pan-Arctic vegetation classification and to facilitate research on vegetation and biodiversity change and ecosystem models. The AVA was launched in 2013-14 with two meetings in Krakow, Poland, and Boulder, Colorado, USA. The AVA working group has started work on two prototype databases for Greenland and northern Alaska. Here we report progress on the Alaska prototype. The Alaska Geobotany Center (AGC) is building the AAVA, which will be made accessible to scientists and the public via the Arctic Alaska Geoecological Atlas (AAGA), an on-line resource being developed by the Geographic Information Network of Alaska (GINA). The AAVA utilizes the Turboveg for Windows database program and follows protocols developed for the European Vegetation Archive (EVA) and the Global Index of Vegetation Databases (GIVD). Vegetation-plot data will also be deposited in the US vegetation archive, VegBank. A PanArctic Species List (PASL, beta 1.0) provides a standard list of accepted vascular plant, bryophyte, and lichen species names for the Arctic biome. A variety of photos, maps, reports, and other ancillary data are linked to each plot's geographic location. High quality plot data and non-digital legacy datasets that are in danger of being lost have the highest priority for entry into the plot archive. Approximately 5600 vegetation plots in northern Alaska are being evaluated for inclusion in the Alaska AVA (AAVA) and nearly 500 plots have been imported thus far. The AAVA received a strong boost with funding from the US National Aeronautics and Space Administration (NASA) in preparation for its Arctic-Boreal Vulnerability Experiment (ABoVE) (http://above.nasa.gov/index.html), which is scheduled to begin in 2015. Abundant ground-based information, such as that contained in the AAVA will be needed to inform the ABoVE remote-sensing and modeling studies. Major contributors to the AAVA include: Keith Boggs & Tina Boucher (Alaska Natural Heritage Program, Anchorage, AK, USA), Helga Bültmann & Fred Daniëls (Münster University, Münster, Germany) David Cooper (Colorado State University, Fort Collins, CO, USA), Marcel Buchhorn , Anja Kade & Will Fisher (University of Alaska Fairbanks, AK, USA), Jim Ebersole (Colorado College, Colorado Springs, CO, USA), Borja Jiménez-Alfaro (The European Vegetation Archive, Masaryk University, Czech Republic), Torre Jorgenson (Alaska Ecoscience, Fairbanks, AK, USA), Michael Lee & Robert Peet (University of North Carolina, Chapel Hill, NC, USA), William MacKenzie (British Columbia Forests and Natural Resources, Smithers, BC, Canada), Udo Schickhoff (University of Hamburg, Hamburg, Germany), Stephen Talbot (U.S. Fish and Wildlife Service, Anchorage, AK, USA), Craig Tweedie & Sandra Villareal (University of Texas El Paso, El Paso, TX, USA), and Patrick Webber (Michigan State University, USA (retired), Rancho de Taos, NM, USA).

3. EFFECTS OF 45 YEARS OF HEAVY ROAD TRAFFIC ON PERMAFROST AND TUNDRA ALONG THE SPINE ROAD AT PRUDHOE BAY, ALASKA

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Two 200-m transects perpendicular to the Prudhoe Bay Spine Road were established north of Lake Colleen in 2014 to document the effects of the road on adjacent tundra, as part of the NSF's Arctic Science, Engineering, and Education for Sustainability (ArcSEES) project. The Spine Road is a heavily- used gravel road built in 1969 as part of the initial development of the Prudhoe Bay Oilfield. The road is currently 10-m wide (14.5 m including the berm) and 1 m above the surrounding tundra, built of gravel mined from the nearby Sagavanirktok River. We present a decadal time series of aerial photographs from 1949 to 2014. Prior to construction, in 1949, the study area was a level residual surface with no obvious signs of previous thaw-lake processes. A rather homogeneous network of low-centered polygons with less than 30 cm of trough-rim elevation contrast covered most of the area. Scattered thermokarst pits with either unvegetated water or aquatic sedge tundra occurred on both sides of the road, indicating high ice content of the permafrost (Walker et al. 1980). Transect 1, which extends to the NE of the road, is still an area of low- centered polygons, though thermokarst pits are now more common. Transect 2, which extends SW of the road towards Lake Colleen, is now an area of seasonally flooded high-centered polygons. An unsupervised classification shows the distribution of vegetation types in the Lake Colleen Study Area. Elevation of the transects ranged from 12.4 to 14.8 m above sea level. Vegetation height of non-water areas averaged 13 cm on the NE side of the road with a Leaf Area Index (LAI) of 0.5, with higher values on the flooded SW side: 21 cm height and 0.7 LAI. Thaw depths (measured in early August) were deepest close to the road, ranging from 105 cm to 29 cm at the far end of Transect 1. The dust horizon from the road traffic was quite evident in the soils, ranging from > 40 cm depth to none at100 m distance on the NE side, but persisting out the full 200 m on the SW side, downwind from the prevailing NE summer winds. Permafrost characteristics of the transects are presented in a separate poster by Kanevskiy et al. Walker DA, Everett KR, Webber PJ, Brown J (eds.) (1980) Geobotanical Atlas of the Prudhoe Bay Region, Alaska, CRREL Report 80-14. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH.

4. HOW PERMAFROST-RELATED LANDSCAPE CHANGES MAY IMPACT FOOD SECURITY OF JEAN MARIE RIVER FIRST NATION, NWT

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The Jean Marie River First Nation (JMRFN) and its project partners combined and shared traditional, local and scientific knowledge to produce climate change vulnerability maps of traditional use areas near Jean Marie River. The landscape of the JMRFN lands is changing. Changes have been observed by the community members and documented by the researchers during the geological field work. It is undeniable that these changes are significant. The impact assessment on food security tells that changes have and will have considerable impacts on country food. For example, an average of 33.4% of sites, indicating the presence of animals used for food, overlap with areas vulnerable to permafrost. The JMR people's diet is composed of 75% country food so this gives them great concerns in terms of food security. The geological survey and mapping results suggests that: 1- Approximately 50% of the study area encompasses grounds having a medium to high vulnerability to permafrost thaw. 2- The permafrost present on our land is warm and close to degradation. Several areas already are experiencing severe degradation processes. 3- The resulting landscape changes affect the wildlife habitat and wildlife behavior. 4- The permafrost degradation process is quite advanced in some areas, and with the ground temperature being close to the 0°C threshold, it is possible that the degradation process will be completed in only a few decades. This information gives an approximate yet short, time frame to develop our adaptation strategies. The vulnerability hazard map resulting from this project is tailored to the needs of the JMRFN community, is culturally oriented and, when overlain with spatial traditional land use information, brings a new, integrated perspective regarding climate change impacts on the JMRFN. In light of the results of this study, there are several issues that require attention: 1- The immediate issues are the access to country food and the quality of the food that is decreasing. 2- In the future the quantity of country food will be added to the list of issues. The quantity of animals and plants that we currently use for food are likely to be reduced as the degradation of permafrost continues to change their habitat. This project represents a prototype for future surveys and mapping aimed at identifying and quantifying the impacts of permafrost degradation from a broader and more holistic viewpoint that combines western science and traditional and local knowledge.

5. PROCESS OF ORGANIC TRANSPORT IN LAKES OF THE YAMAL REGION (POLYAR)

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Climatic and environmental fluctuations in the permafrost zone lead to activation of various cryogenic processes. This activation results in a strong impact on redistribution of substances and changes in biochemical composition of the water bodies. Lakes in the Arctic are good indicators of changing natural conditions. These indicators are expressed in both areal changes of thermokarst lakes, and changes in biochemical composition of water. Thus, we analyze the interconnection between water bodies and their catchments on Yamal peninsula in temporal and spatial extent. Main objective of this research is to study which processes affect the quality and quantity of dissolved organic matter in the water bodies across the Yamal peninsula (central, eastern and coastal parts) in the continuous permafrost zone. The studies are based on bathymetric in-situ measurements and water sampling, optical and SAR remote sensing, and topographic data analysis. From 2011 to 2014 samples for colored dissolved organic matter (cDOM) have been taken at different parts of Yamal. Also in field season permafrost landscapes were observed and described to get more knowledge on lake catchment ecosystems. The Yamal Peninsula is in the area of widely distributed tabular ground ice of up to 20-30 m thick. Degradation of this ground ice leads to thermokarst in depressions and thermal denudation on slopes. Thermokarst features are formed within the ice-wedge polygons as well, which degrade under the observed climate warming. Tabular ground ice degradation resulted in the formation of the deep (15 and more meters deep) thaw lake basins. High coastal cliffs around the thaw lakes potentially provide terrestrial organic matter. It was established that biochemical composition of lake water is affected by sediment transport from the coastal lake cliffs due to coastal erosion and thermal denudation. The research result of this study: connection of the cDOM concentration of the different water bodies, which have different optical properties to coastal retreat activities and catchment properties (vegetation, topography, snow storage). These data supports the model of the contributions of a number of factors (like slope processes, vegetation and snow cover in the lake catchments) in the dissolved organic matter concentration in lakes at variable climatic conditions (summer temperature, winter temperature, precipitation).

6. RECENT TEMPORAL DYNAMICS OF ARCTIC TUNDRA VEGETATION WITHIN THE CONTEXT OF SPATIAL BIOMASS-TEMPERATURE RELATIONSHIPS

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Large-scale spatial gradients are particularly useful for developing relationships between ecosystem properties and environmental variables. Assuming these variables and system properties are dynamic over time, the spatial relationships may be used as a first approximation for how ecosystems respond to environmental changes, i.e. space-for-time substitutions. We used data from two spatial gradients within the arctic tundra to examine how the observed temporal dynamics of tundra vegetation compared to space-for-time projections based on spatial biomass-temperature relationships. Over the past several decades, data were collected on vegetation, soil, climate, and other ecosystem properties, across two long latitudinal gradients in the arctic tundra, spanning all of the major tundra subzones on two continents (North American Arctic Transect and Eurasian Arctic Transect). Field-harvested, aboveground vegetation biomass data were related to satellite- derived temperature data, in this case the Summer Warmth Index (SWI - sum of mean monthly temperatures > 0 °C); total aboveground vegetation biomass increases exponentially as a function of SWI. Field-harvested biomass has also been related to the satellite-derived Normalized Difference Vegetation Index (NDVI), with total aboveground vegetation biomass also increasing exponentially with NDVI. We used a 32-year record (1982-2013) of satellite-derived Land Surface Temperatures and NDVI from Advance Very High Resolution Radiometer (AVHRR) sensors onboard NOAA satellites (GIMMS 3g dataset) to evaluate projected and observed changes in total aboveground vegetation biomass over this time period; SWI was determined from the Land Surface Temperature data. We calculated the annual values of projected vegetation biomass as a function of SWI (space-for-time substitution), and we calculated the annual values of observed vegetation biomass as a function of NDVI. Finally, we evaluated the 32-year trends in projected and observed biomass for three regions: the arctic tundra as a whole, as well as for North American tundra and Eurasian tundra. We hypothesized that 1) NDVI-derived (observed) biomass would have less interannual variability than SWI-derived (projected) biomass, as actual vegetation changes from year-to-year are constrained by biological and abiotic factors other than temperature, and 2) the rate of change in NDVI-derived biomass over the entire record would be less than the projected rate of change (SWI-derived), again likely due to ecosystem constraints. As we expected, interannual standard deviations for SWI-derived biomass were 2.0 – 2.5 times greater than those for NDVI-derived biomass (for all three regions of interest), and the trend lines for NDVI-derived biomass were much “tighter” with greater r2 values than those for SWI-derived biomass. Surprisingly however, the observed rates of change (NDVI-based) in total aboveground vegetation biomass (range of 2.5 to 2.6 g m^{-2} y^{-1}) were greater than the projected rates of change based on temperature (SWI) dynamics (range of -0.2 to 2.2 g m^{-2} y^{-1}) , for all three regions. These results suggest that 1) in addition to changing temperatures, there are other factors (including direct/indirect effects of temperature changes) that are yielding high vegetation biomass responses, and 2) there is the potential for at least the temporary formation of novel tundra ecosystems with respect to the zonal climate (e.g. tall shrublands).

7. OVERVIEW OF THE WEST SIBERIAN COMPONENT OF THE ARCTIC VEGETATION ARCHIVE

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Vast data on vegetation was collected on the Yamal and Gydan peninsulas (Northwestern Siberia, Russia) since early 60s. The datasets reviewed here are considered to be the most available and complete for this region. S. Ektova and L. Morozova, Institute of Plant and Animal Ecology, UB RAS (Yekaterinburg), have one of the largest datasets (more than 690 relevés). Their research was carried out in the Polar Urals and the Southern, Middle and Northern Yamal Peninsula in 1990-2012. Their relevés include full lists of vascular plants and lichens and dominant bryophyte species. The datasets include additional information on 13 key sites with detailed description of lichen synusias (1600 plots). Eleven sites have phytomass data. The relevés have coordinates and some environmental information. K. Ermokhina, Earth Cryosphere Institute SB RAS

(Moscow), has a dataset containing more than 600 relevés with full lists of species (vascular plants, lichens and bryophytes) from the Polar Urals, Southern, Middle and Northern Yamal Peninsula, and Gydan peninsula. Additional information includes GPS coordinates, cover of species, height of trees and shrubs (when applicable), environmental data (data on soils, permafrost, relief, exogenous processes, etc.). Forty-five plots have phytomass data, and about 200 plots have LAI data. The research was carried out in 2002-2012. 333 relevés were subjected to a preliminary classification analysis using Braun-Blanquet approach. In addition to the relevés dataset there is a set of 4607 photos taken from helicopters, which is held by K. Ermokhina and A. Mikheeva of Lomonosov Moscow State University. All photos include GPS coordinates and orientation data in ARCGIS project file. D. A. (Skip) Walker and colleagues, Alaska Geobotany Center, collected relevés from six locations along a North-South bioclimate transect of the complete Arctic bioclimate gradient that included the Yamal Peninsula and Franz Josef island. The data contain GPS coordinates of all plots, Br.-Bl. cover-abundance values and quantitative percentage cover for all vascular plants, bryophytes, and lichens, biomass (sorted by plant growth forms), mean NDVI, LAI, soil physical and chemical data, soil descriptions, environmental data and photographs of all plots, soils and landscapes. M. Telyatnikov of Central Siberian Botanical Garden SB RAS (Novosibirsk) holds the dataset of 680 relevés with full lists of species (vascular plants, lichens and bryophytes). The research was carried out on Polar Urals, South, Middle and North Yamal in 1987-1995. The additional information in dataset includes GPS coordinates, projective cover of species, height of trees and shrubs (when applicable) and characteristics of the relief and soils. Braun- Blanquet classifications of intrazonal grass communities (212 relevés of the dataset were involved) and dwarf shrub and moss tundras (246 relevés) were made by M. Telyatnikov and S. Pristyazhnyuk. Information from the available Russian Arctic Local Floras datasets (held by O. Khitun and O. Rebristaya) indicate that there is relatively good floristic coverage of much of Yamal, but still large areas with little geobotanical information from almost all the Gydan and Tazovskiy peninsulas, northwest and central parts of Northern Yamal, central parts of Middle Yamal and southeast and northwest parts of South Yamal.

8. CULTURAL RESILIENCE OF SOCIAL-ECOLOGICAL SYSTEMS IN THE NENETS AND YAMAL-NENETS AUTONOMOUS OKRUGS, RUSSIA: A FOCUS ON REINDEER NOMADS OF THE TUNDRA

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Empirical data on resilience in social-ecological systems (SESs) are reviewed from local and regional scale case studies among full-time nomads in the neighboring Nenets and Yamal- Nenets Autonomous Okrugs, Russia. The focus is on critical cultural factors contributing to SES resilience. In particular, this work presents an integrated view of people situated in specific tundra landscapes that face significantly different prospects for adaptation depending on existing or planned infrastructure associated with oil and gas development. Factors contributing to general resilience are compared to those that are adapted to certain spatial and temporal contexts. Environmental factors include ample space and an abundance of resources, such as fish and game (e.g., geese), to augment the diet of not only the migratory herders, but also residents from coastal settlements. In contrast to other regions, such as the Nenets Okrug, Yamal Nenets households consist of intact nuclear families with high retention among youth in the nomadic tundra population. Accepting attitudes toward exogenous drivers such as climate change and industrial development appear to play a significant role in how people react to both extreme weather events and piecemeal confiscation or degradation of territory. Consciousness of their role as responsible stewards of the territories they occupy has likely been a factor in maintaining viable wildlife populations over centuries. Institutions administering reindeer herding have remained flexible, especially on Yamal, and so accommodate decision-making that is sensitive to herders' needs and timetables. This affects factors such as herd demography, mobility and energetics. Resilience is further facilitated within the existing governance regimes by herders' own agency, most recently in the post-Soviet shift to smaller, privately managed herds that can better utilize available pastures in a highly dynamic environment experiencing rapid socio- economic, climate and land use change.

9. REGIONAL PATTERNS OF ICE-WEDGE DEGRADATION SINCE THE MID-20TH CENTURY ACROSS NORTHERN ALASKA

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Ice-wedge polygons are abundant in the continuous permafrost zone of Alaska's North Slope, creating complex microtopography and strong, meter-scale contrasts in hydrologic regime, vegetation, and ground-ice conditions. Rapid and dramatic landscape changes have occurred in recent decades in the coastal plain of the eastern North Slope due to thawing of the uppermost portions of Holocene ice wedges. Thaw of the wedges results in ground subsidence (thermokarst) and the formation of flooded pits along the polygon margins. Secondary impacts, including thermal degradation of permafrost and spatially-variable flooding and drainage of polygon centers, affect areas well beyond the thermokarst pits themselves. Archives of historical (1948, 1955, 1971, 1977–1985) and modern high- resolution imagery support regional-scale detection of ice-wedge degradation across bioclimatic (north-south) and geomorphic (east-west) gradients spanning the North Slope. To characterize the timing and extent of ice-wedge degradation, we quantified the extent of small, flooded thermokarst pits evident in circa 1980 and modern imagery for a network of eleven 43 km2 study areas spanning the North Slope, including sites where we collected field data in 2010–2012. To distinguish thermokarst pits, we exploited near-infrared reflectance values, which are much lower for open water than for tundra vegetation. We focused our analysis on old, residual upland landscapes, where ice wedges have developed over long periods of time and surface water is usually only present in thermokarst pits. Our analysis indicated increases in the total area occupied by flooded thermokarst pits at 8 of 11 landscapes since circa 1980 (median +10.6%; maximum 77.8%). Increases in the extent of thermokarst pits were prevalent on the eolian sand sheet, and eolian silt deposits (yedoma.) Because the ice wedges underlying the North Slope have developed over millennial timescales, the changes observed over the past few decades appear to represent a directional change, rather than a cyclic process whereby local thermokarst is offset by ice aggradation elsewhere. Our results indicate an intriguing regional pattern of ice-wedge degradation, in that thermokarst pit development appears to have occurred earlier on the western North Slope, where residual uplands consist of alluvio-marine deposits. A possible explanation for this pattern is that the high salinity, and resultant lower melting point, of frozen marine sediments makes them more prone to climate-induced thaw. Future work involves remote-sensing and field-based approaches to identify drivers of the changes and regional patterns observed since the mid-20th century.

10. HOW DO LAKE SYSTEMS DETERMINE LATERAL FLUXES OF CARBON IN TUNDRA PERMAFROST LANDSCAPES ?

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What is the influence of lake-rich tundra landscapes on lateral fluxes of carbon? We investigated the carbon storage and lateral fluxes of carbon in two tundra permafrost landscapes in Arctic Siberia: the central Lena Rive Delta (central Siberia) and in central Yamal (Western Siberia). In the central Lena River Delta, Siberia, long-term Russian-German cooperations aided investigation of terrestrial and aquatic tundra ecosystems. In Yamal, Russian-Austrian and Russian-German cooperation projects existed for some years. In both lake-rich tundra permafrost landscapes, we sampled for coloured dissolved organic carbon (cDOM) and dissolved organic Carbon (DOC) across several lake types (deep tundra ponds, floodplain lakes, thaw lakes on Holocene terraces and Pleistocene-aged plateaus, in alas systems, in valleys) and channel and riverine systems. Sedimental facies is common for both investigated regions for all lake and river catchments. The Lena River Delta consists of the Lena River floodplain with swampy shallow floodplain lakes and three different geomorphological terraces with differing lake types. There are active lake-cliff coastlines on the Yedoma geomorphological terrace, and some parts of the thermo-erosional valleys are active. But in summary, the hydrographic system is not as erosive as in the central Yamal permafrost landscape dominated by thermo-erosional processes. The limnic aquatic systems show the low dissolved carbon concentrations as it is

common for tundra landscapes. Drainage systems develop due to thermo-erosional degradation processes of the permafrost landscape. The analyses show low carbon concentrations also from the channel export from the lake systems. Therefore, a lake-rich tundra permafrost landscape seem to mainly export organic- and nutrient-low effluents. How will lake-rich tundra permafrost landscapes determine the fate of lateral carbon fluxes in future?

11. A SYNTHESIS OF EXISTING, PLANNED, AND PROPOSED INFRASTRUCTURE AND OPERATIONS SUPPORTING OIL AND GAS ACTIVITIES AND COMMERCIAL TRANSPORTATION IN ARCTIC ALASKA

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This paper synthesizes quantitative and qualitative information about existing, planned, and proposed infrastructure and operations that support oil and gas production and commercial transportation over the whole of Arctic Alaska, compiling a region-wide vision of these industrial activities that has not previously existed. It presents an overview of the history, current conditions, and plausible future extent of industrial infrastructure in Arctic Alaska. It is intended for use as a factual and unbiased reference for the wide range of stakeholders interested in integrated Arctic planning. In addition to tables and text, the paper contains ten original maps of infrastructure and industrial transportation. It is illustrated by numerous photographs of oil and gas infrastructure in the region. The paper can be downloaded for free at: www.iarc.uaf.edu/en/NX2020/current-projects/oil. The findings indicate that if proposed infrastructure projects develop in the manner described in state and federal analyses, the extent of Arctic Alaska's industrial infrastructure would increase significantly. The number of structures would almost double, from 460 to 816. The number of wells would increase by around one third, from 6,215 to 8,673. Miles of road would more than double, from 1,138 to 2,503. Miles of pipeline would more than quadruple, from 901 to 4,667. Lastly, the infrastructure footprint would increase by about half, with over 27,000acres of Arctic Alaska being directly covered or excavated for industrial development. The area and resources affected by that infrastructure footprint—what the National Research Council refers to as "zones of influence"—would be considerably greater.

12. DEGRADATION AND RECOVERY OF ICE WEDGES IN RELATION TO ROAD INFRASTRUCTURE IN THE PRUDHOE BAY OILFIELD, AK

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Widespread degradation of ice wedges has been observed in the Arctic Coastal Plain of Alaska during the last decades. It strongly affects environment and infrastructure of the Prudhoe Bay Oilfield (PBO). The upper permafrost of PBO contains significant amounts of excess ground ice, including segregated ice and large epigenetic ice wedges (width up to 4 m; vertical extent up to 3.5 m). High ice content makes the study area extremely vulnerable to thermokarst and thermal erosion. In most cases, these processes are triggered by climatic changes or human activities. Road infrastructure in PBO affects the ice- wedge degradation by an increase in the active-layer thickness (ALT) triggered by flooding of large areas due to construction of road embankments; accumulation of dust, which kills vegetation and changes thermal properties of soil; and additional snow accumulation near the embankment. Our studies show that degradation of ice wedges is a cyclic process, which includes five main stages: Undegraded wedges – Degradation-initial – Degradation-advanced – Stabilization-initial – Stabilization- advanced. The processes of ice-wedge degradation and recovery are determined by interactions between the active layer and the underlying transition zone of the upper permafrost, which includes transient layer (TL) and intermediate layer (IL). Accumulation of organic matter in the troughs developing on top of degrading wedges eventually leads to decrease in ALT and formation of the ice-rich IL, protecting ice wedges from further degradation. During 2-14 August 2014, 57 boreholes were drilled in ice-wedge polygon centers and troughs at 5, 10, 25, 100, and 200 m from the Spine Road in the Lake Colleen area along two transects established at the different sides of the road; 35 encountered ice wedges at various stages of degradation and recovery. At the time of drilling, a protective layer of frozen soil 1 to 27-cm thick (which includes frozen part of the active layer and in many cases TL and IL) was observed above the majority of ice wedges. The ice-rich IL up to 19-cm thick, which indicates relative stability of ice wedges, was encountered in 13 boreholes. Two ice wedges experienced thawing at the time of drilling, but calculations indicate that by the end of the thawing season several more wedges will be affected by thermokarst, and during exceptionally warm summers (the summer of 2014 was very cold) up to two thirds of wedges may experience thawing. Thaw subsidence above degrading ice wedges during such summers can reach 8 cm/year. Despite a strong influence of the road construction and heavy traffic on the upper permafrost stability, ice-wedge degradation is a reversible process. Its activation in most cases was triggered by increase in the ALT during exceptionally warm and wet summers. Initial degradation of ice wedges along Transect 2 was probably related to the flooding of the southwest side of the Spine Road triggered by the road construction, but at present time the wedges along this transect (even the wedges under the deep troughs filled with water) are more stable than the wedges along Transect 1, which have not been affected by flooding.

13. OVERVIEW OF BIODIVERSITY RESEARCH BASED ON LOCAL FLORA APPROACH IN RUSSIAN ARCTIC AND APPLICATION TO THE CIRCUMPOLAR ARCTIC

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Concept (and method) of “concrete” flora (later called “local”) was introduced by A.Tolmatchev in the 1930s and was widely used by Russian botanists especially when studying extensive and hardly accessible northern territories. It is more efficient and gave more reliable date than travelling through the areas and is less time and labor consuming than method of regular squares. Local flora is a flora of relatively little territory (100-300 km2) studied by radial routes where allsorts of habitats were visited repeatedly and species lists were compiled. Researches of the Far North Vegetation Laboratory at Komarov institute have applied concept of local flora for study of vegetation cover of Russian Arctic for more than 50 years. Study of the big amount of such localities across the Russian Arctic revealed that their floras are characterized by certain species richness and geographical structure. For example, in bioclimatic subzone D local floras in Central Yamal number 130-160 species, in Gydan 150-170, in East European tundra 190-200, in Taymyr 200-250. Knowledge of these values helps to estimate how complete flora of certain locality is revealed, some often overseen species could be specifically searched for and in many cases found. Species richness of local flora depends on the characteristic for the area set of habitats and historical factors. Study of local floras provides information about species populations as both frequency and abundance of each species is recorded. The “Arctic Flora of the USSR” was written mainly on the base of material obtained by studies of local floras. Our database is created in IBIS and contains now species lists and short characteristics of 250 local floras from Arctic and Subarctic (totally about 2000 vascular plant species). Different tables (with both quantitative and qualitative values) can be constructed in IBIS and exported if necessary. We made sketch maps in CorelDraw showing studied localities and on them different floristic parameters can be drawn and their spatial changes can be followed. We are planning to transfer these data to GIS. We use the database for analysis of changes in geographic and taxonomic structure both across latitudinal and longitudinal gradients and for purpose of regionalization but it can have direct implementation for biodiversity conservation issues – indicating areas with any species of interest (rare, endemics, non-endemics), areas with increased species richness etc.

14. DYNAMICS OF VEGETATION ON LANDSLIDES OF DIFFERENT AGE IN CENTRAL YAMAL, WEST SIBERIAN ARCTIC, RUSSIA

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Active layer detachment slides are playing important role in the formation of the local landscapes in Central Yamal. Different succession stages in recovery of cryogenic landslides are described. Four age categories of landslides were studied: 1) young landslides formed in 1989 with pioneer vegetation; 2) landslide formed (according to available aerial photos) in the middle of 1970s; 3) landslide formed (according to aerial photos) in 1960s; 4) ancient landslide cirque dated with radiocarbon method as circa 1,000 year old. Study area is

located within the bioclimatic subzone D, according to Circumpolar Arctic Vegetation Map 2003, which practically coincides with distinguished by Yurtsev (1994) northern hypoarctic tundra subzone. Plant communities on the shear surface, on displaced blocks with preserved but degrading initial tundra vegetation and on undisturbed surroundings were described. In 199, the first botanical survey was done and it was repeated in 2012. Both total projective cover of vegetation and cover
of individual species/life forms as well as species composition changed gradually on young and old landslides, though vegetation on the ancient ones is more stable. The total number of vascular plant species and green mosses slightly increased on all stages of recovery compare to the background. Several grass species are dominant on shear surface forming patches with different dominant (*Deschampsia borealis, Puccinellia sibirica, Calamagrostis holmii* and *Poa alpigena* ssp. *colpodea*, an in run- off troughs - *Dupontia fisheri a*nd *Eriophorum scheuchzeri*). *Carex glareosa* indicating saline deposits was recorded on all landslides. Mosses are playing important role both in recovery and in formation of organic horizon on the young landslides. Natural cryogenic disturbances determine structure and dynamics of vegetation on the marine terraces slopes in Central Yamal. Communities are closely correlated with the age of landslides and their morphological elements. An important reason underpinning these successional dynamics is the decrease of salt content in ground water, which changes from very high in the first years after detachment to slightly higher than background values on the more ancient surfaces. The recovery of bare shear surfaces takes dozens of years, during the first 10-15 years pioneer groupings dominated by grasses establish and they continue to develop for approximately the next 35-40 years, and afterwards are replaced by sedge-willow communities with relatively low (<50cm high) *Salix glauca* and developed cover of mosses typical for tundra shrub communities. The first willow seedlings appear already after 5 years but after 10-15 years they became abundant. In Central Yamal, the alliance *Equiseto-Salicion glaucae* indicates the presence of a landslide process, whereas its associations and sub-association indicate age, degree of mineralization of ground waters and morphological element of the landslide. Over the longer time frames, active layer detachment slides led to the formation of more productive derivative communities. In the severe climatic conditions of the Arctic, certain increases in mineral nutrition availability for plants due to exposure and thawing of ancient marine salts can be considered as a compensating ecological factor, allowing growth of higher willows normally not found in this subzone.

15. ANALYSIS OF OFF-ROAD VEHICLE-TRACK DYNAMICS ON YAMAL PENINSULA, RUSSIA

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Results of the study of vegetation cover and active layer depth dynamics under technogenic impact in permafrost zone, particularly in the typical tundra subzone, are presented. Study of both vegetation cover and active layer disturbance after off-road vehicle traffic at Central Yamal started in 1991 in connection with active gas field development and investigations for railway construction in this area. As a result of 2012 field survey and measurements, vehicle tracks were subdivided into 3 groups according to the degree of disturbance: with low, medium and high technogenic impact. We analyzed the current state of abandoned vehicle tracks that were previously investigated. Noticeable recovery of old vehicle tracks is observed on all sites and recovered communities are similar to the original ones, or are replaced by more hydrophilic species. The least visible is recovery of dwarf shrubs and lichens. It contradicts the results obtained in the more southern subzone in Alaska. Old tracks in shrub tundra of Alaska are marked by dwarf birch while in Central Yamal recovery not only takes more time, but old tracks are marked by willow shrubs. Dwarf birch in old fully recovered tracks has less coverage compared to background. Recent tracks are re-vegetating mainly by grass-sedge pioneer groups. Active layer depths as a rule increase in the vehicle tracks. The degree of deepening results from more or less active traffic, and replacement of initial shrubby communities with high species diversity by mainly sedge communities. The highest increase of active layer depth on old tracks is resulting from thermokarst development. When thermokarst does not develop and surface remains stable, active layer depth moves towards the background values. Next step included mapping of the system of vehicle tracks using aerial images of 1990 and satellite image GeoEye-1 of August 15, 2009. Two time slices were compared. Total length of vehicle tracks was 126 km in 1990 and 235 km in 2009 within 20 square km area.

Total area affected by vehicle tracks was at least 0.51 square km (2.5 per cent) in 1990 and 0.95 square km (4.6 per cent) in 2009. Over 19 years total length of vehicle tracks has increased by 86 per cent. However, most of vehicle tracks appeared not to be actively used, they look like not used for a long time. Only 24.5 km (10.4 per cent) of 2009 tracks could be interpreted as actively used.

16. ADAPTIVE MANAGEMENT OF CUMULATIVE EFFECTS : THEORY VS REALITY

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Rapid change in Arctic social-ecological systems has generated considerable discussion among academics of resource management about the potential benefits adaptive management (AM). Defined as a structured, iterative process of decision making in the face of uncertainty, AM aims to link monitoring, analysis, critical reflection, and decision making with the intent of facilitating social learning while improving resource management. In face of recent trends of directional rapid change, the concepts of adaptive co-management and adaptive governance have been introduced and developed by advocated of sustainability science and resilience theory. The development and use of decision-support systems and "structured decision making" processes, double- and triple-loop learning cycles, cross-scale linkages in adaptive governance, inclusion of local knowledge in AM, and the view of policies as experiments have all been suggested. The successful application of these ideas, however, has come with considerable challenges and in many cases failure. In the context of the Alaska North Slope oil and gas development, the implementation of AM has been the espoused goal of specific agencies (e.g., AK Department of Natural Resources) as well as collaborative efforts (e.g., North Slope Science Initiative (NSSI) and the Arctic Land Conservation Cooperative (LCC)). The NSSI has undertaken this effort by building metadata sets, developing emerging issue papers, and most recently initiating scenarios analyses (Streever et al 2011). At the agency level the results of these efforts have been mixed. For example, a study of Alaska Department of Natural Resources/ Northern Regional Office found a number of organizational and informational constraints in the implementation of AM and CE assessment, including the problem of limited staff size, high turnover of agency personnel, limitations in handling the high number of applications received, a lack of standardized policies and guidelines for addressing applications, limited engagement with a greater community such as university researchers community and regional assessment teams, and inadequate GIS capacity. In other cases problems have followed from the legal constraints in undertaking environmental impact assessments, which do not provide opportunities for simulation modeling and structured decision support tools. Interestingly, our first review of AM shows that industry may have the most experience and success with AM applications. In this paper we present core elements of AM of cumulative effects in theory, and explore the shortcomings in practice. We go on to describe our current research that is exploring the gap between theory and practice, drawing on evidence from industry, government, and Alaska Native community experiences. We undertake the research with the goal of bridging the gap and helping meet the challenges of a changing North.

17. DETECTION AND ANALYSIS OF RECENT LANDCOVER CHANGES IN CENTRAL YAMAL PENINSULA RUSSIA. A CASE STUDY FROM BOVANENKOVO GAS FIELD

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Petroleum production activity causes rapid land use and land cover changes in the Russian Arctic. In central Yamal peninsula in West Siberia both natural and anthropogenic changes have occurred during the past 40 years. Mega size Bovanenkovo gas field (BGF) was discovered in 1972. Giant gas resources of the field makes BGF one of the world's three largest with estimated reserves of 4.9 tcm. The large scale building of infrastructure started in mid 1980's but in early 1990's as the Soviet Union collapsed and economical crisis spread over Russia the gas field went into hibernation mode. In 2006 Gazprom launched a new plan for production and in October 2012 gas production began. Within a few years a new railroad, and pipelines were built to reach BGF. We have studied gas field development and natural changes like increases in shrub growth, cryogenic landslides, thawing lakes in the region. The traditional land use in the Yamal is reindeer

herding practiced by nomadic Nenets herders. The hydrocarbon industry is presently the source of most ecological changes in the Yamal peninsula and socio-economic impacts experienced by migratory Nenets herders who move annually between winter pastures at treeline and the coastal summer pastures by the Kara Sea Employing a variety of high- to very high-resolution aerial photographs and satellite-based sensors (Corona, KH-9, Landsat, SPOT, ASTER Terra VNIR, Quickbird-2, Worldview-2, Terra XS DEM, MODIS and TerraXS), we have followed the establishment and spread of Bovanenkovo, the biggest and first field to be developed in Yamal. Extensive onsite field observations and measurements of land use and land cover changes since 1985 have been combined with intensive participant observation in all seasons among indigenous Nenets reindeer herders and long-term gas field workers during 2004–2007 and 2010–2014. Nenets managing collective and privately owned herds of reindeer have proven adept in responding to a broad range of intensifying industrial impacts at the same time as they have been dealing with symptoms of a warming climate. Here we detail both the spatial extent of gas field growth and the dynamic relationship between Nenets nomads and their rapidly evolving social-ecological system.

18. EFFECT OF CLIMATE CHANGE ON ROAD INFRASTRUCTURE IN NORWAY

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Infrastructures are traditionally designed to face with various stresses along their life, including extreme weather events as historically and currently experienced (Nemry& Demirel, 2012). In Scandinavia, roads in regions that previously enjoyed stable winter conditions are now subject to several freeze-thaw cycles each winter. This will accelerate road deterioration and consequently increase maintenance costs. In general, cold climate countries have to cope with pavement deterioration effects, and in countries such as Norway represent ~30% of the maintenance budget (PIANC, 2010). The Norwegian Green Paper on Climate Change Adaptation, prepared for the government by a committee of experts (Ministry of the Environment, 2010), offers detailed projections of future climate change in Norway, based on three scenarios. It shows annual mean temperatures will increase by 2.3°C to 4.6°C by 2100, with the greatest increase during winter and the least during summer, and major regional differences – northern regions will warm the most, and western Norway the least. Annual precipitation could increase by 5% to 30%, with major seasonal and regional variations, and more frequent torrential rains and massive snowfalls. Some of the bigger concerns identified in the paper relate to how warming will affect the natural environment in the Arctic and in the High North, as well as in higher altitudes; these are areas with "marginal" natural conditions, and they are also where the most warming is expected. Species and ecosystems will become more vulnerable, and adaptation may not be enough to prevent biodiversity loss. Transport infrastructure is also of some concern, especially given existing inadequacies in maintenance and repairs. And the committee notes that because new infrastructure may have many decades' lifespan, climate considerations should be taken into account in planning for infrastructure and facilities. Higher precipitation, higher groundwater levels and more frequent freeze-thaw cycles affect the bearing capacity of roads (Adaptation to climate change, 2012). Frozen layers in the sub-base of roads with poor drainage properties or made of frost susceptible materials prevent melt water or precipitation from draining away from the road structure when thaw sets in. This temporarily reduces the bearing capacity of the road. A higher content of fines due to sub-base wear will increase moisture in the structure and the risk of subsequent frost heave. Due to climate change, frost heave problems may become more frequent in areas that previously had stable winter conditions. In particular, surface layer problems during winter are more common because the period without freezing conditions has increased. The main purpose of our research is specifying the materials and conditional factors that cause frost heave in the road structure, and giving suggestions for making modifications in existing requirements for road construction in Norway.

19. SYNTHESIS OF PERMAFROST RESEARCH ALONG THE EURASIA ARCTIC TRANSECT

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Permafrost research along the Eurasia Arctic Transect (EAT) included estimation of the thermal state of permafrost and activity of cryogenic processes through ground measurements and remote-sensing data analysis. The transect crosses the main bioclimatic subzones from south (E, Nadym) to north (A, Hayes Island). The transect length on the mainland Yamal is 635 km, and the Hayes Island site is located 900 km further north of Bely Island. Spatial distribution of permafrost parameters: ground temperature and active layer is highly variable. In Central Yamal measured ground temperature varies from -0.3°C up to -7°C, active layer depth varies from 40 to 240 cm. Temporal variations caused by climate fluctuations range at ±2°C for ground temperature, and ±5-10 cm for active layer depth. Thus, spatial factors, such as lithology and surface covers are of much higher importance compared to climatic factors. Yamal being an area of rapid natural and anthropogenic changes is an excellent object to calculate spatial distribution and temporal dynamics of ground temperature and active layer depth. Permafrost is affected by natural surface disturbances (cryogenic landslides, thermodenudation, thermoerosion, thermokarst), anthropogenic (structures, vehicle tracks, sandpits), and natural-anthropogenic (reindeer pasturing). Highly variable topography, deep dissection in the central part of Yamal compared to relatively flat southern and northern parts of EAT determine the role of precipitation, both winter and summer. Main forcing factor for ground temperature is snow cover thickness. It is the highest on slopes and in the narrow valleys. Snow insulates surface not only from winter cold, but also from summer warming, because snow patches survive at least till mid-July thus reducing active layer depth. At the same time, at the hilltops snow is blown away along with vegetation cover resulting in the lowest ground temperature, but at the same time, deepest summer thaw. Vegetation mat has less effect on ground temperature because in frozen state has higher thermal conductivity, but is the strongest factor of thaw reduction through insulation from summer heat flux. Surface disturbances of all kind as a rule increase snow cover thus increasing ground temperature, and at the same time increase active layer depth because vegetation cover is reduced. Landslides and thermocirques specifically for Yamal expose saline permafrost with complicated phase transition process resulting in seasonal thaw different from the depth of zero temperature. In addition, forcing factors interact with each other. Spatial pattern of vegetation cover is mainly determined by landslide and thermodenudation activity the last several millennia thus affecting distribution of the active layer depth. Spatial distribution of permafrost parameters along the EAT involves latitudinal zonality based on directional lowering of air temperature northward from Nadym site in the south to Hayes site in the north. It is established that, on the whole, consistent trend of bioclimatic subzones northward determines the consecutive change of various parameters of permafrost. However, local factors connected to relief, drainage degree, location of plots on different landforms, which determine snow accumulation and vegetation mat thickness, distort zonal pattern.

20. DEEP CRATER IN CENTRAL YAMAL, WEST SIBERIA, RUSSIA AS A NEW PERMAFROST FEATURE IN RESPONSE TO LOCAL CLIMATE FLUCTUATIONS

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The paper is based on field data obtained during 2 short visits to Yamal Peninsula in summer 2014 to a newly formed permafrost feature: a relatively narrow, deep crater. As new features like this have been reported recently in a number of mass-media publications, the processes leading to their formation may already be underway elsewhere in the region, making the study of their origin and predicting such an activity an urgent task. Our field study included size measurements and photo- video-documentation of the feature and the surrounding environment. The main objective of the reconnaissance was
to outline the range of possible hypotheses of the crater's formation, to exclude impossible and improbable versions of its development, and to lay a basis for predicting such processes in the future. No landform like the crater in Central Yamal discussed in this paper has been reported previously. Yet similar forms: seabed pockmarks have been known and discussed since the 1970's. It is established that permafrost prevents the migration of methane from deep-seated hydrocarbon collectors into the upper permafrost and to the surface. Concentration of methane in frozen Quaternary deposits in the Arctic depends on the age, origin and lithology of the permafrost. The gas and gas- hydrate accumulations are localized in the organic-rich horizons.

The authors' main hypothesis for the crater's formation involves the release of gas inclusions out of initially frozen deposits and tabular ground ice. This assumption is based on the known cryolithology and geochemistry of permafrost in the region, with most of the studies produced in the Bovanenkovo gas field investigations. The Bovanenkovo studies revealed substantial gas concentrations, which are blocked by the permafrost. The possibility of the release of the gas from the collectors near the surface is shown by methane and hydrogen sulfide effusion under the Barents and Kara seas from 70 to 130 m beneath the sea floor. Boreholes at Bovanenkovo gas field revealed gas manifestations in the depth interval 20 to 130 m, most of which were contained in ice-bearing clays. These clays also enclose tabular ground ice and some voids filled with low- density ice. Active release of the gas from permafrost may be caused by change in ground temperature and resulting increase in unfrozen water content. Thus the origin of the Yamal crater hypothesized in this paper is based on the analysis of (a) existing features resulting from gas-release processes in the sea floor as analogues of the observed on-shore landform, (b) climate fluctuations that could have caused changes in thermal state of permafrost, and (c) comparison to other landforms connected to specific cryolithology and geochemistry of deposits. Excluding impossible and improbable versions of the crater's development, the authors conclude that it originated from warmer ground temperatures and an increase in unfrozen water content, leading to an increase in pressure from gas emissions from permafrost and ground ice. This conclusion is also supported by known processes in the paleo-geography of Yamal lakes and recent studies of gas-hydrate behavior and subsea processes in gas- bearing provinces.

21. BARE PEAT SPOTS: PHENOMENON OF FROZEN PEATLANDS OF THE NORTH-WEST SIBERIA.

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The considerable part of mire ecosystems of the Western Siberian plain develops in permafrost conditions. Such mire complexes as frozen peatlands are widespread in these locations. The purpose of this paper is to study a unique development path of frozen peatlands soils. The area of the research is located in the north of Western Siberia (65°18' .55''N, 72°52'.90''E) in a zone of discontinuous permafrost. There is a special formation- "peat spots" – that are diagnosed by extensive spots of bare peat surface, the vegetation on which is completely absent for decades. Usually peat spots are located at the tops of peatlands, have an oval form, their diameter ranges from 0,5 to 5m, and their surface is covered with the overdried peat crust with a peculiar structure. During field works experimental sites were put on peat spots and on the background areas with a vegetative cover. The following features were noted for peat spots soil profile: it is thicker in contrast to typical soils, characterized by high degree of decomposition of organic matter. It was established that emission of CO_2 is lower on sites with bare surface than on sites under vegetation (71,2 mg CO_2 m^{-2} h^{-1}, 155 mg CO_2 m^{-2} h^{-1}, respectively), at the same time concentration of CO_2 at depths 10-60cm has inverse correlation and on average, it is higher for peat spots soil profile. The average annual temperature of peat spots soil profile is lower than that one under vegetated surface. The analysis of chemical properties has revealed an essential difference of peat spots soils to soils of surrounding areas. Peat horizons of peat spots have higher total contents of carbon (50,4% for bare peat soil profile and 45,0% for vegetated soil profile) and nitrogen (2,4% and 1,6%, respectively). The similar correlations have been found for Water Extractable Organic Matter (carbon (WEOC) and nitrogen (WEON)), its content is higher in soils of peat spots: WEOC-672,6 mg kg^{-1} for peat spots soil and 491,0 mg kg^{-1} for vegetated peat soil; WEON-131,5 mg $kg^{-1}$and 89 mg kg^{-1}, respectively. Peat spots have the lower content of such nutrients as potassium (46 mg kg^{-1} for soils of peat spots and 257 mg kg^{-1} for vegetated soils of frozen peatlands) and phosphorus (17,5 mg kg^{-1} and 25 mg kg^{-1}, respectively). So, our results show that peat spots are specific landscape of frozen peatlands and they are diagnosed by the type of peat and by the absence of vegetation on soil surface. Soils of peat spots differ from typical frozen peatlands soils with their chemical properties, their microbiological and morphological characteristics. We suppose that genesis of peat spots relates to different causes. The first one is an impact of cryogenic processes such as frost heaving, turbations (impeding settlement of vegetation) and cycles of freeze-thaw (accelerating mineralization of peat). The second reason is the relict genesis of peat from peat spots and its high degree of decomposition. Thus, peat spots represent a kind of "hot centers" of transformation and conversion of peat soils in a zone of discontinuous permafrost of the North-West Siberia.

22. VEGETATION CHANGES RELATED TO 45 YEARS OF HEAVY ROAD TRAFFIC ALONG THE SPINE ROAD AT PRUDHOE BAY, ALASKA

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Vegetation was sampled at different distances from the Spine Road at Prudhoe Bay, Alaska, as part of the NSF's Arctic Science, Engineering, and Education for Sustainability (ArcSEES) project. The Spine Road is a heavily-used gravel road built in 1969 during the initial development of the Prudhoe Bay Oilfield. The Colleen Study Area is on the northern side of Lake Colleen, in an area of ice-wedge polygonal tundra. Plots were set up at 5, 10, 25, 100 and 200 m from both sides of the road, in polygon centers and in the troughs above ice-wedges. Three additional plots were sampled adjacent to the road in dust-dominated communities, and two plots approximately 350 m from the road in relatively undisturbed tundra (even areas far from roads have had considerable winter traffic). Environmental data collected at each 1x1-m plot included latitude, longitude, elevation, aspect, slope, landform, surficial geology and geomorphology, disturbance, site moisture, snow duration, exposure, height of microrelief, and thaw depth. Plant cover data included life form cover estimates and height measurements, species cover from 100-points, LAI measured using an AccuPAR LP-80 PAR/LAI Ceptometer, and complete species list and cover category estimates for each species (Braun-Blanquet relevé data). Soil data included soil moisture category, measurements of live and dead moss thickness, and thickness of the dust, organic layers and other layers visible in a 40-cm soil plug. Soil moisture, pH and organic matter were determined in the laboratory. Vegetation and environmental characteristics varied dramatically between the two sides of the road and with distance from road, as shown by the data summaries and ordination. Plant community descriptions were also compared with data collected from the same area in the early 1970s (Walker 1972). The SW side of the road is periodically flooded due to the road-blocked drainage. It is currently composed of relatively well-drained polygon centers and polygon troughs with lush aquatic sedge-moss communities. The NE side of the road is more similar to the original low-centered polygon vegetation complex, but there were large decreases in the larger mosses, forbs, and all lichens, and an increase in the abundance of dwarf erect shrubs, especially adjacent to the road (*Salix lanata*). The increase in shrubs is likely related to warmer soils and deeper snow adjacent to the road, as well as possibly to a warmer climate, whereas the declines in mosses, lichens and forbs are likely related to extremely heavy dust loads associated with the roads. All of these changes have an effect on the active layer and abundance of thermokarst in the region. The characteristics of vegetation and leaf area index of the two 200-m transects on either side of the Spine Road are further mapped and described in a poster by Buchhorn et al

23. CHANGES IN PERMAFROST AND ACTIVE-LAYER THICKNESS DUE TO CLIMATE IN THE PRUDHOE BAY REGION AND NORTH SLOPE, AK

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Several permafrost observatories are situated in the immediate vicinity of the Prudhoe Bay Oilfield, Alaska and provide an important background reference for understanding the effects of oilfield infrastructure on permafrost conditions. Most of the permafrost observatories in the Northern Hemisphere show a substantial warming of permafrost since the 1980s. The magnitude of warming has varied with location, but was typically from 0.5 to 3°C. During the second half of the 20th century, permafrost has been already thawing within the southern part of the permafrost domain. However, recent observations documented propagation of this process northward into the continuous permafrost zone. Permafrost temperature at 20 m depth has been increasing between 0.28 and 0.47°C per decade since 2000 on the North Slope of Alaska. In 2013, new record high temperatures at 20 m depth were measured at some permafrost observatories on the North Slope of Alaska and in the Brooks Range, where measurements began in the late 1970s and early 1980s. Changes in

permafrost temperatures at 20 m depth typically lag about one year behind the changes in surface temperatures. The 20 m temperatures in 2013 were 0.03°C higher than in 2012 at West Dock and Deadhorse on the North Slope and 0.06°C higher at Coldfoot in the southern foothills of the Brooks Range. At the rest of the North Slope sites permafrost temperatures in 2013 were similar to those in 2012, except at Happy Valley where they were 0.06°C lower. Permafrost temperatures at 20 m depths were increasing steadily since the beginning of measurements in 2006 at the Imnavait Creek site near Toolik Lake reaching unprecedented for the North Slope value of -3.2°C in 2014. Long-term observations of the air temperature and snow depth available from our three North Slope sites (Franklin Bluffs, Deadhorse, and West Dock) provide evidence that the changes in these parameters are the main driver of permafrost temperatures on the decadal time scale. In 2013, a majority of Alaskan regions reported higher active-layer thickness (ALT) values relative to the 1995-2012 average. On the North Slope of Alaska, for example, ALT was on average 11% higher than the 1995-2012 average of 0.47 m. This is 6% higher than in 2012 and on par with the 20 year maximum recorded in 1998. Changes in the active layer thickness, winter air temperatures and snow cover of the last decades substantially increased the time that is necessary for the complete re-freezing of the active layer during the winter. This time was steadily increasing at our northern- most observational sites, culminating during the 2013-2014 winter. The timing of freeze-up is extremely important for many biological and biogeochemical processes in these tundra environments as well as for the diverse human activities in this region.

24. LANDSCAPE HAZARDS MAPPING FOR CLIMATE CHANGE ADAPTATION PLANNING IN YUKON: APPROACH AND METHODS

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Since 2010, the Northern Climate ExChange (Yukon College, Canada) has been evaluating and mapping landscape hazards related to surficial geology, permafrost and hydrology in eight different communities across the Yukon. The thawing of permafrost caused by rising temperatures is resulting in subsidence of the ground surface, increased landslide risks and reduced bearing capacity of the soil, which has important implications for infrastructure maintenance and future developments. Tools like landscape hazards maps help northern communities obtain clear and reliable information for adaptation planning, including identifying suitable locations for future development projects. As part of this project, the research team has been gathering and mapping geoscience data through sample collection, permafrost drilling and coring, geophysical surveys, topographical measurements and other types of field validation. By combining electrical resistivity tomography (ERT), ground penetrating radar (GPR), and coring, we were able to detect more accurately permafrost boundaries, identify the limits between soil types, and better select our sampling sites along geophysical transects. This approach allowed us to cover large areas with precision in a minimal time. To produce maps of landscape hazards, geoscience data were amalgamated and landscape polygons within our map area (identified via new fine-scale surficial geology maps) were ranked in intuitive categories (e.g., high risk, medium risk, no risk) based on the field data and the results of geotechnical analyses performed in the laboratory. We focused on characteristics related to the sensitivity of soil to permafrost thaw (e.g., excess ice content, thaw consolidation, grain-size distribution, etc.). Ranked polygons were then represented graphically (in stoplight colors) on maps covering the study area. By incorporating projections of future climate variability (e.g., temperature, precipitation, freeze and thaw dates), landscape hazards classification reflected both contemporary and potential future conditions. These hazards classification maps incorporated science into decision-making processes by combining and classifying geoscience data to create an easily interpretable ranked representation of current and future hazard potential. The maps were intended to be used as an adaptation planning tool by engineers, planners, consultants, and all levels of government and non-governmental decision- makers to assist with municipal planning activities.

25. EFFECT OF TEMPERATURE INCREASE ON FROZEN PEATLAND SOILS IN NORTH WEST SIBERIA, RUSSIA

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In this study some microbiological activity indexes of frozen peatlands in North-West Siberia were determined. The specific of these peatlands consists in the formation of peat soils developing under the permafrost influence (active layer 60-80 cm). In case of climate changes the response of peat ecosystems to temperature fluctuations seems to be an actual task to solve especially in the conditions of permafrost. The purpose of the study was to estimate the response of frozen peat soils microbiological activity indexes to temperature increase (5 °C, 15 °C, 25 °C). The study included field and laboratory parts. The field studies conducted in August 2014, on Nadym site, north West Siberia, Russia (65o18'.53"N, 72o52'.52"E). Two monitoring sites on frozen peatland were selected to CO_2 efflux and temperature measurements: control and experimental site(a "Greenhouse" was built to simulate the effect of increasing temperature). Field measurements lasted for a week and were triplicated. As a result, we have determined the average daily temperature at the experimental site to be 2 °C higher than at the control site. The CO_2 efflux at the experimental site also increased (88 mg m^{-2} h^{-1}) in comparison with the control site (66 mg $m^{-2}h^{-1}$). Such soil microbiological activity indexes as basal respiration (BR) and substrat-induced respiration (SR) [1] were evaluated in the laboratory study. The medium decomposed moss peat from a depth of 20 cm was taken for BR and SR analysis. Our results showed that BR of peat soil samples subjected to 5 °C was significantly higher (6,9μg C g^{-1} soil) as compared with the samples, underwent to 15 °C (3,7μg C g^{-1} soil) and 25 °C (3,3μg C g^{-1} soil). The same effect was observed during SR analysis: the highest SR value was fixed in the sample subjected to 5 °C (19,9μg C g^{-1} soil) and then tended to decline from 15 °C (16,7 μg C g^{-1} soil) to 25 °C (16,1 μg C g^{-1} soil). Obviously, such temperature conditions (15 and 25 °C) are stressful for psychotropic microorganisms because the average annual temperature of these frozen peatland soils approximately equals to 0 °C and at the depth of 20 cm does not exceed 6 °C as a maximum. To summarize, the response of peat soils microbiological activity indexes to temperature increase may vary a lot and, consequently, further studies are required. The preview results indicated that microbiological activity of frozen peat soils tends to decline as a result of temperature increase to 10 and 20 °C. At the same time, the increase in the temperature of the peat soil surface to 2 °C causes the 30% increase in CO_2 efflux from that soil surface. This fact shows a complex indirect mechanism of CO_2 production by peatland ecosystems. Probably, there is a temperature optimum for soil microorganisms of frozen peat lands: so beyond this optimum the activity of soil microorganisms becomes lower or there is an increase in the contribution of root respiration. Accounting for heterogeneity of response of the CO_2 efflux and microbiological activity of frozen peat soils at elevated temperatures may be significant in balance estimations and also in models that calculate the contribution of soil microorganisms to the global balance of CO_2. 1. Anderson J.P.E. Domsch K.H. A physiological method for quantitative measurement of microbial biomass in soil // Soil Biology & Biochemistry. 1978. v.10. p.215-221.

26. MASS MOVEMENT BY SOLIFLUCTION AND SYNGENETIC DYNAMIC OF PERMAFROST IN THE HIGH ARCTIC, WARD HUNT ISLAND, CANADIAN HIGH ARCTIC.

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The High Arctic is characterized by many extreme climatic and geomorphologic phenomena. According to recent climatic scenarios, climates changes will affect the Arctic more than any other region of the planet. The High Arctic, which is essentially bare of vegetation, will have a strong response to climates changes and will be characterized by an acceleration of periglacial processes associated with permafrost thawing. Mass movements on slopes will be favored by the deepening of the active layer increasing the creep and continuous sliding of the material over the ice-rich permafrost table. Our project focused on the influence of solifluction lobes movements on permafrost dynamics at Ward Hunt Island, Nunavut (Canada). The hydrologic budget of Ward Hunt Island lies essentially on the incoming water from snow melt and from active layer hydrogeology during the short annual thawing period. On the island, many solifluction lobes deform and entrain sediments downslope. Considering the recent deepening of the active layer, the increase of material downslope may modify permafrost dynamics, a question that hasn't been considered by permafrost model scenarios. We used 3D laser scanning techniques and total station surveys to reconstruct the microtopography and volume of solifluction lobes. Permafrost coring and ground penetrating radar surveys were used to characterize solifluction lobes cryostratigraphy. Permafrost cores were then analyzed using micro-computed tomography to quantify the different components of permafrost (sediments, ice, organic

matter and gas). The geotechnical properties (grain size, Atterberg limit, thaw settlement, porosity, hydraulic conductivity and shear strength) of active layer and permafrost soils were measured in the laboratory. Our study demonstrated that solifluction lobes movements led to the development of syngenetic aggradation of ground ice downslope. These findings suggest that substantial accumulation of material downslope modifies permafrost dynamics and creates ice-rich zones which may contribute to slow down the degradation of permafrost, due to the important effect of latent heat represented by this new volume of ground ice.

27. RAPID ARCTIC TRANSITIONS RELATED TO INFRASTRUCTURE AND CLIMATE CHANGE (RATIC): A CASE STUDY FROM PRUDHOE BAY, ALASKA

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The RATIC workshop and special session at AC2014 address the combined consequences of expanding networks of infrastructure and changes related to climate in the Arctic. During this session, research will be presented from site-specific case studies of expanding networks of infrastructure across the Arctic, including the Prudhoe Bay oilfield, Alaska; the Bovanenkovo gas field, Yamal Peninsula, Russia; and Arctic Canada. A primary challenge to developing an approach to adaptive management of oil and gas infrastructure expansion is comprehensive documentation of the changes that have already occurred. The first and most straightforward element of change analysis is an historical analysis of physical changes to the landscape. Alaska's North Slope oilfields are the oldest and most extensive industrial complex in the Arctic. Following the discovery of oil at Prudhoe Bay in 1968, environmental studies periodically documented the changes resulting from the rapidly expanding network of roads and oilfield facilities. A baseline of terrain information was interpreted from 1949 aerial photographs taken by the U.S. Navy. The International Biological Programme's (IBP) U.S. Tundra Biome study began documenting the effects of development at Prudhoe Bay in the 1970s. Aerial photographs and Infrastructure mapping were done nearly annually by the oil industry, starting in the 1980s. An integrated mapping approach documented the historical changes to both infrastructure and the landscape as the oilfield expanded. A recent paper, published in Global Change Biology, presents the 62-year history of infrastructure as well as the spread of indirect effects such as road dust and infrastructure- related flooding. The biggest surprise from this analysis was the rapid thawing of ice-wedges and formation of thermokarst features that occurred between 1990 and 2010, most extensively in areas adjacent to infrastructure but also in areas remote from infrastructure, which is likely a response to a series of recent exceptionally warm summers. The thermokarst typically resulted in more topographically diverse terrain. In summer of 2014, researchers began an in-depth field analysis of the long-term (42-year) effects of infrastructure to the permafrost, topography, hydrology, soils, and vegetation along the Spine Road, the oldest most heavily traveled road at Prudhoe Bay. Early results of this study are presented in a poster at this conference. The local communities perceptions of the changes related to development are presented in another poster. Forty-six years after the discovery of oil at Prudhoe Bay, we are still learning about the ecological consequences of large-scale infrastructure expansion and the impacts of climate change in ice-rich permafrost environments. The authors who were involved with the Tundra Biome studies in the 1970s could not foresee the changes that occurred, but the baseline studies provided a means to document the transitions to the present. The results will provide a basis for new methods to monitor future changes to permafrost and the regional social-ecological systems. The goal is to use the results presented at AC2014 to develop an action plan to address adaptive approaches that utilize state-of-the-art science, modeling, engineering, and education that lead to sustainable management of infrastructure in the Arctic.

Appendix D. Project publications and conference presentations

Published, in press, and nearly completed papers

2015

Bieniek, P. A., Bhatt, U. S., Walker, D. A., Raynolds, M. K., Comiso, J. C., Epstein, H. E., Pinzon, J. E., Tucker, C. J., Thoman, R. L., Tran, H., Mölders, N., Steele, M., Zhang, J. and Ermold, W. 2015. Climate drivers of changing seasonality of Alaska coastal tundra vegetation productivity, submitted to *Earth Interactions* Jan 31, 2015.

Bhatt, U. S., Walker, D. A., Raynolds, M. K., Bieniek, P. A., Epstein, H. E., Comiso, J. C., Pinzon, J. E., Tucker, C. J., Steele, M. A., Ermold, W. and Zhang. J. 2015. Changing seasonality of Pan-Arctic tundra vegetation in relationship to climatic variables (in prep for special issue of *Environmental Research Letters* on biomass).

Dvornikov, Yu. A., Khomutov, A. V., Mullanurov, D. R., Ermokhina, K. A., Gubarkov, A. A., Leibman, M. O. 2015, in press. GIS- and field data based modeling of snow water equivalent in shrub tundra // *Fennia 193*:2, ISSN 1798-5617

Khitun, O.V., Ermokhina, K. A., Chernyadjeva, I. V., Leibman, M. O. and Khomutov, A. V. 2015. Floristic complexes on landslides of different age in Central Yamal, West Siberian Low Arctic, Russia // *Fennia, 193*:2, ISSN 1798-5617. (in press)

Kizyakov, A. I., Sonyushkin, A., Leibman, M. O., Zimin, M. V. and Khomutov, A. V. 2015. Geomorphological conditions of the gas-emission crater and its dynamics in Central Yamal. The Earth Cryosphere (Kriosfera Zemli) XIX(2), (In press) (In Russian). {Кизяков А. И., Сонюшкин А. В., Лейбман М. О., Зимин М.В., Хомутов А. В. Геоморфологические условия образования воронки газового выброса и динамика этой формы на Центральном Ямале. Криосфера Земли, 2015, №2, в печати}.

2014

Bhatt, U. S., Walker, D. A., Walsh, J. E., Carmack, E. C., Frey, K. E., Meier, W. N., Moore, S. E., Parmentier, F. J. W., Post, E., Romanovsky, V. E. and Simpson, W. R. 2014. Implications of Arctic Sea Ice Decline for the Earth System, *Annual Review of Environment and Resources*. *39:*57-89.

Buchhorn, M. 2014. Ground-Based Hyperspectral and Spectro-Directional Reflectance Characterization of Arctic Tundra Vegetation Communities – Field Spectroscopy and Field Spectro-Goniometry of Siberian and Alaskan Tundra in Preparation of the EnMAP Satellite Mission –. Doctoral Thesis (Potsdam, Universität Potsdam). Available from: http://nbn-resolving.de/urn:nbn:de:kobv:517-opus-70189.

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Bhatt, U. S. Changing Seasonality of Tundra Vegetation in Relationship to Climatic Variables, Department of Atmospheric Sciences Information Seminar, Fairbanks, Alaska, Wednesday November 11, 2014.

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