1st International Conference

Global Warming and the Human-Nature Dimension in Siberia

Social Adaptation to the Changes of the Terrestrial Ecosystem, with an Emphasis on Water Environments

to be held and co-organized with the

6th Annual International Workshop

C/H_2O/Energy balance and climate over boreal and arctic regions with special emphasis on eastern Eurasia

7-9 March, 2012

Location: RIHN Lecture Hall

Organized by

Research Institute for Humanity and Nature (RIHN)

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A group photograph of the conference

Excursion at Kyoto

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Preface

We were happy to host the first international conference on "Global Warming and the Human-Nature Dimension in Siberia: Social Adaptation to Changes in the Terrestrial Ecosystem, with an Emphasis on Water Environments" in Kyoto, Japan, on 7-10 March, 2012. This conference was held and co-organized with the sixth annual international workshop on "C/H2O/Energy balance and climate over boreal and arctic regions with special emphasis on eastern Eurasia", which reflects more than ten years of joint Russian, Japanese and European science on the importance of eastern Eurasia to the global climate system.

This conference was also organized on the basis of the Implementation Agreement (IA) among the following institutions: the Research Institute for Humanity and Nature (RIHN), the Institute for Biological Problems of the Cryolithozone (IBPC), the Institute of Humanities and Indigenous Peoples of the North (IHIPN), and the Melnikov Permafrost Institute (MPI) of the Siberian Branch of the Russian Academy of Sciences. We are greatly honored by the opportunity to cooperate in research on climate, biogeochemistry, hydrology, ecology, and the humanities in Siberia.

This conference in Kyoto had 61 participants from six countries: Russia, the Netherlands, USA, China, Korea and Japan. It examined three aspects of climate-related environmental change: 1) current and likely future variation in water and carbon cycles; 2) ongoing field observation of the effects of carbon and hydrologic variability in Eastern Siberia, and the key driving forces associated with these effects; and 3) the distinct social economies of multi-ethnic Siberian societies and their potential capabilities for adaptation to predicted changes in climate and terrestrial ecosystems. Based on these topics, seven sessions were organized: i) Water and carbon budgets on the plot scale, ii) Water and carbon cycles on the regional-continental scale, iii) Permafrost degradation and greenhouse gases emission, iv) Permafrost landscape and groundwater regime, v) Flood-induced hazards and benefits, vi) Wild and domestic animals in the sub-Arctic region, and vii) Adaptation to climate change.

In the general discussion session we recognized the importance of a) long-term monitoring of permafrost temperature/surface soil moisture, b) decadal-scale climate analysis of atmospheric water cycles, c) the vegetation feedback induced by radiation/moisture on the regional climate, and d) further study of local minority peoples' social-cultural adaptations to environmental and social changes. It also became clear that traditional knowledge, social networks, money, and technology are key factors affecting the capacity to adapt to climate change.

We hope this proceeding will prove valuable for the participants at the conference, as well as those who are interested in the scope of human-nature interaction and climate-social changes in Siberia.

November 2012

Tetsuya HIYAMA
Research Institute for Humanity and Nature, Japan

Purpose

Global warming will likely transform Siberian environments. Our long-term joint studies from 1992 indicate that carbon and hydrologic cycles are undergoing rapid change, with potentially grave impacts on Siberian flora and fauna. Human populations, which have adapted to great changes in social structure and environment in the past, will be forced to adapt again, but in this case to an unprecedented sequence of cascading environmental changes. The RIHN research project “Global Warming and the Human-Nature Dimension in Siberia” uses multiple satellite and surface monitoring systems to track changes in carbon and hydrologic cycles in the terrestrial ecosystems, in order to improve social adaptability to ecological change in Siberia.

This conference will examine three aspects of climate-related environmental change observed in the project research: 1) current and likely future variation in water and carbon cycles; 2) ongoing field observation of the effects of carbon and hydrologic variability in Eastern Siberian landscapes, and key exchanges or driving forces associated with these effects; and 3) the distinct social economies of multi-ethnic Siberian societies, and their potential capabilities for adaptations to predicted changes in climate and terrestrial ecosystems.

Contributions on these three aspects, or on the following key themes, are welcomed.

Key themes

a) Physical and plant physiological processes of C/H_2O/Energy cycles in Siberian ecosystems
b) Forest and tundra ecosystem structure related to C/H_2O/Energy cycles
c) Permafrost / cold climate processes and their impacts on C/H_2O/Energy cycles
d) Usage of satellite remote sensing techniques and the development of C/H_2O/Energy cycle models
e) Interaction between wild/domesticated animals and terrestrial vegetation
f) Vulnerabilities of landscapes, human subsistence systems, and infrastructures in permafrost areas
g) Ethnographic accounts of human-nature relations in conjunction with climate change
h) Local knowledge of, adaptations to, and policies for responding to the changing climate
i) Research status, cooperative arrangements, and plans for the future

Organizing committee

HIYAMA Tetsuya	RIHN	FEDOROV Alexander	MPI
FUJIWARA Junko	RIHN	MAXIMOV Trofim	IBPC
OHTA Takeshi	GSBS, Nagoya University	IGNATIEVA Vanda	IHIPN
YAMAGUCHI Yasushi	GSES, Nagoya University	DOLMAN Han	VU University Amsterdam
TAKAKURA Hiroki	CNEAS, Tohoku University	MOORS Eddy	Wageningen University

Program of the conference

Wednesday 7 March (Location: RIHN Lecture Hall)

09:00 Registration

09:30 Opening ceremony

Takanori Nakano (Program Director) (*opening address*)

Tetsuya Hiyama (*introducing objectives of the conference*)

[Session 1] Water and carbon balance at the plot scale chaired by Yuji Kodama

09:50 Trofim C. Maximov (*keynote speech*)

The main results of 20-year-old joint studies between Russia and Japan on a changing climate and permafrost in North-East Siberia, Russia

10:15 Ayumi Kotani, Takeshi Ohta, Alexander Kononov, Trofim C. Maximov

Seasonal variation of linkage between net ecosystem exchange of H_2O and CO_2 over boreal forest at eastern Siberia

10:40 Alexander V. Kononov, Ayal P. Maksimov, Roman E. Petrov, Trofim C. Maximov

Key features of soil CO_2 efflux in taiga Larch forests of Central and South-Eastern Yakutia

11:05 Break

11:20 Yuji Kodama

Snowmelt heat balance of the snowpack in a larch forest in eastern Siberia

11:45 Takeshi Yamazaki

Simulation of soil water and temperature in eastern Siberian taiga forests by a one-dimensional land-surface model

12:10 Shunsuke Tei, Atsuko Sugimoto, Hitoshi Yonenobu, Trofim C. Maximov

Changes in relationship between larch tree growth and climate in eastern Siberia over past 100 years

12:35 **Discussion**

13:00 Lunch and Poster presentations

[Session 2] Water and carbon cycles at continental scales chaired by Eddy Moors

14:00 Eddy Moors (*keynote speech*)

Feedback mechanisms between the water and carbon cycle at a regional scale

14:25 Kazuhiro Oshima, Tetsuya Hiyama

Seasonal and interannual variations of Lena River discharge and those relationships with atmospheric water cycle

14:50 Tetsuzo Yasunari, Tatsuro Watanabe, Hatsuki Fujinami

Interannual variation of summer hydro-climate in East Asia

15:15 Break

15:30 Atsuko Sugimoto, A. Popova, M. Liang, S. Tei, R. Shingubara, T. Maximov

Ecosystem function of taiga-tundra boundary in Eastern Siberia

15:55 Hisashi Sato, H. Kobayashi, N. Delbart

Simulation study of the vegetation structure and function in eastern Siberian larch forests using the individual-based vegetation model SEIB-DGVM

16:20 **Discussion**, closure at 17:00

Thursday 8 March (Location: RIHN Lecture Hall)

[Session 3] Permafrost degradation and CH_4 emission chaired by Jacobus van Huissteden

09:00 I. Kleptsova, M. Glagolev, E. Lapshina, S. Maksyutov (*keynote speech*)
Landcover classification of the Great Vasyugan mire for estimation of methane emission

09:25 A. Budishchev, Y. Mi, A. Gallagher, J. van Huissteden, G. Schaepman A.J. Dolman, T.C. Maximov
Validation of methane emission model using eddy covariance observations and footprint modeling

09:50 Angela Gallagher, Bingxi Li, Artem Budischev, Jacobus van Huissteden, Monique Heijmans
Increased greenhouse gas emission from thaw ponds in Siberian arctic tundra on continuous permafrost

10:15 Break

10:30 Jacobus van Huissteden, Angela Gallagher, Artem Budischev
Ecosystem recovery: a neglected factor in carbon release by permafrost degradation

10:55 Ake Nauta, Monique Heijmans, Daan Blok, Frank Berendse
Removal of *Betula nana* causes permafrost degradation and triggers changes in geomorphology and hydrology

11:20 Kazuki Aiba, Takahiro Sasai, Yasushi Yamaguchi
Analysis of water, heat and carbon balances over the Siberia region by using biosphere model BEAMS

11:45 **Discussion**

12:15 Lunch and Poster presentations

13:15 RIHN tour

[Session 4] Permafrost landscape and groundwater regime chaired by Alexander Fedorov

14:00 Alexander Fedorov, P.P. Gavriliev, P.YA. Konstantinov, T. Hiyama, Y. Iijima, G. Iwahana
The Water Balance of Thawing Lakes in Central Yakutia

14:25 Leonid Gagarin, Alexander Kolesnikov
Effect of Extreme Hydroclimatic conditions on groundwater systems in permafrost, Central Yakutia

14:50 Tetsuya Hiyama, Kazuyoshi Asai, Alexander Kolesnikov, Leonid Gagarin, Victor Shepelev
Residence time estimation of permafrost groundwater at Yakutsk region, Eastern Siberia

15:15 Break

[Session 5] Flood-induced hazards and benefits chaired by Hiroki Takakura

15:30 Hiroki Takakura
The local conceptualization of river ice thawing and the spring flooding of Lena River under the global warming

15:55 Toru Sakai, Tetsuya Hiyama, Junko Fujiwara, Semen Gotovtsev, Leonid Gagarin
Flood disaster caused by permafrost degradation in the far north of Siberia

16:20 Vanda Ignatyeva
Regional problems of the reducing vulnerability to extreme floods and climate change: Yakutia case

16:45 Junko Fujiwara
Flood and migration policy in the Republic of Sakha in Siberia

17:10 **Discussion**, closure at 17:45

Friday 9 March (Location: RIHN Lecture Hall)

[Session 6] Wild and domestic animals in Arctic region chaired by Shirow Tatsuzawa

09:00 Innokentiy M. Okhlopkov (*keynote speech*)
Current Status of the wild reindeer populations and domestic reindeer farming in Sakha Republic

09:25 Shirow Tatsuzawa, Innokentiy M. Okhlopkov, Egor V. Kirillin, Egor A. Nikolaev, Nikita G. Solomonov
The migration of eastern Siberian wild reindeer: where,when, how and why do they do?

09:50 Atsushi Yoshida
Reindeer herding and environmental change in the Kobyai and Olenyok districts, Sakha Republic

10:15 Atsushi Nakada
Reindeer herding and environmental change in the Tompo district, Sakha Republic

10:40 Break

10:55 Tohru Ikeda
Furbearer hunting and invasive alien species issues in Yakutia

[Session 7] Adaptation to climate change chaired by Susan A. Crate

11:20 Susan A. Crate (*keynote speech*)
Water, water everywhere: perceptions of chaotic water regimes in northeastern Siberia, Russia

11:45 Sardana Boyakova
History of development of transport infrastructure in Yakutia

12:10 Kyong Wan Lee
Biblical suggestions of CSR in regard to energy projects in Lensk district, Republic of Sakha: focusing on climate and environmental problems

12:35 **Discussion**

13:00 Lunch and poster presentations

14:00 **General Discussion**

15:30 Closing ceremony
Tetsuya Hiyama (*concluding remarks*)
Tsugihiro Watanabe (Deputy Director-General of RIHN) (*closing address*)

Poster presentations (Location: Front Space of the RIHN Lecture Hall)

Core time: Around 30 minutes in the lunch time (every 3 days)

P01 Heon-Sook Kim, Shmail Maksyutov, Tazu Saeki, Dmitry Belikov, Toshinobu Machida
Analysis of Siberian CH_4 flux during 1994-2010

P02 A. Sabrekov, M. Glagolev, I. Kleptsova, S. Maksyutov
Methane emissions and its seasonal cycle in subtaiga zone

P03 Ekaterina Ivanovna Kuzmenko
The climate dimension and human-nature succession in ecosystems boreal taiga of western Siberia

P04 Monique Heijmans, Jeroen Pullens, Ake Nauta, Bingxi Li
Development of a dynamic tundra vegetation model for analysis of long-term vegetation-soil-permafrost feedbacks

P05 Bingxi Li
Effect of vegetation composition on soil-permafrost conditions and the interaction between them in moist tundra in NE Siberia

P06 Egor V. Kirillin, Innokentiy M. Okhlopkov, Shirow Tatsuzawa, Egor A. Nikolaev
Reacclimatization of the muskox in the arctic zone of Yakutia: results and prospects for further research

P07 Egor A. Nikolaev, V.V. Stepanova, Innokentiy. M. Okhlopkov, Shirow Tatsuzawa, Tohru Ikeda
Current status of hunting by the indigenous minorities in Yakutia

P08 Ayal Maksimov, Alexander V. Kononov, Marina Terentyeva, Trofim C. Maximov
Larch photosynthesis in south-eastern part of Yakutia, eastern Siberia, in comparison with central taiga zone

P09 Shogo Ito, Takeshi Ohta, Ayumi Kotani, Trofim C. Maximov, Alexander V. Kononov
Interannual variation of the carbon dioxide flux in an eastern Siberian larch forest

P10 Miho Hanamura, Takeshi Ohta, Ayumi Kotani, Shogo Ito, Trofim C. Maximov, Alexander V. Kononov, Ayal P. Maximov
Variability analysis of evapotranspiration in an eastern Siberian larch forest over a 12-year period (1998-2011)

P11 Miharu Hayashi, Ayumi Kotani, Takeshi Ohta, Trofim C. Maximov, Alexander V. Kononov, Ayal P. Maximov
Comparison of CO_2 flux between two sites (SpasskayaPad, Elgeeii) in eastern Siberian boreal forest

P12 Ryo Shingubara, Go Iwahana, Shinya Takano, Megumi Nakamura, Trofim C. Maximov, Atsuko Sugimoto
CH_4 flux and its stable isotope in a taiga-tundra ecotone, East Siberia

P13 Maochang Liang, Go Iwahana, Shunsuke Tei, T.C. Maximov, Atsuko Sugimoto
Factors controlling C assimilation by larch in taiga-tundra boundary ecosystem in eastern Siberia with special references on C and N contents and stable isotope ratios of larch needle

P14 Leonid Gagarin
Feature of suffosion process in permafrost area

P15 Iijima Yoshihiro
Eco-hydrological changes in relation to permafrost degradation under humidified conditions in central Yakutia

P16 Hotaek Park, John Walsh, Alexander N. Fedorov, Artem B. Sherstiukov, Yoshihiro Iijima, Tetsuo Ohata
Identification of seesaw pattern in active layer thickness between Eurasian and North American watershed systems

The main results of 20-year-old joint studies between Russia and Japan in a changing climate and permafrost in North-East Siberia, Russia

T.C. Maximov

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Key words: investigations programs, permafrost forests

Hence, in 1991 the Russian-Japanese biological investigations on studying the influence of climate changes on cryosphere and biosphere of the Siberian permafrost regions in Yakutia were started within the frames of the triple agreement between the Institute of Low Temperature Science, Hokkaido University, Yakut Institute of Biology SD RAS and Permafrost Institute SD RAS.

Since 1992, field studies with over 200 participating researchers from Japan have been conducted in 12 regions of Yakutia. As a result of investigations specific distinctions for certain ecological systems were found in dominant plant species at morphological, physiological and biochemical levels, expressed in reorganization of plant sink-source systems. The conducted investigations and descriptions of 1992 were a temporary bench mark, a reference point for the next study of dynamic processes in flora and fauna in all next monitoring investigations.

A complex system for the study of regional, continental and global cycles of energy, water and carbon has been established in the Institute for Biological Problems of Cryolithozone SB RAS within 13 Russian-Japanese international and intergovernmental projects on climate change. The system consists of a series of 30 m high observational towers in Central Yakutia (Spasskaya Pad station, N62) and East-Southern Yakutia (Elgeeii station, N60) that combines projects from Asia (AsiaFlux) and Europe (CarboEurope); it is a regional outposts of complex investigations on climate change. In 2008 the forest tundra station “Boydom”, N69 was established as well at the north-east of Yakutia.

For the first time in the conditions of Eastern Siberia an attempt has been made to ground the photosynthetic productivity of plants in terms of physiology, and quantitative parameters of the productive process were obtained. Original data on sink-source relations of plants are stated at the levels of whole plant organism and community. A number of specific results have been got: 1) conclusion was made about high depositing role of the root system of high latitude plants; 2) micrometeorological estimates of carbon balance were done; 3) quantitative dependence of CO_2 concentration on the season period, weather condition and forest fire intensity was shown; 4) carbon parameters of forest and tundra ecosystems were investigated; 5) attention was drawn to short growing season of plant development – this feature contributes to enrichment of the atmosphere of high latitudes by carbon dioxide.

The main strategy of plants in cryolithozone under conditions of moisture and nutrient deficit is to survive and reproduce progeny sometimes to the detriment of their high productivity. In conditions of taiga zone of Central Yakutia the woody plants exhibit relatively small biomass of photosynthesizing organs. Thus, larch needle mass in Yakutia (1.68 tons/ha) is twice less than in countries with humid climate. Small leaf biomass along with low LAI (up to 2) and short period of photosynthetic activity stipulated reduced net primary productivity of the main forest-forming species in Yakutia – the larch (NPP=3.1 tons/ha year). The period before the formation of generative organs is of most importance in plant productivity under dry conditions of Yakutia, when vegetation is quite sensible to moisture deficit. A degree of root system development is particularly significant in this period, i.e. its ability to deposit the funds of assimilates that are transported later to generative organs. Photosynthesis is inhibited in the conditions of Yakutian permafrost. Therefore the magnitude of root assimilate deposits may become a substantial factor in the formation of plant biological productivity (Maximov et al., 2005a,b). To clarify the seasonal course of carbon allocation patterns among needles, branches, stem and roots, we pulse-labeled 10 Larix gmelinii growing in a continuous permafrost zone with $^{13}CO_2$. Conversely, a higher proportion of July and August photoassimilate was allocated to below-ground parts (32 – 44 and 12 –24%, respectively) (Kagawa et al., 2006).

The effects of increased CO_2 and temperature on the photosynthetic capacity of Siberian white birch and Japanese white birch were measured. Birch seedlings were raised with a CO_2 partial pressure of 36 ± 0.3 Pa (i.e., ambient) or 70±0.6 Pa at day/night temperatures of either 30/16°C or 16/12°C. Siberian birch leaves were smaller and thicker than Japanese birch leaves. Water use efficiency (WUE) and nitrogen use efficiency (NUE) of Siberian birch grown in the CO_2-enriched air were higher than those of Japanese birch. Both species showed a physiological adjustment to the growth CO_2 partial pressure. Carboxylation efficiency and quantum yield of both species grown in CO_2 enriched air were lower than those of seedlings grown in ambient CO_2. The adaptation of Siberian and Japanese birch to elevated CO_2; and temperature are discussed in relation to predicted climate change (Koike et al., 1994). At climate warming the course of cryoturbation processes, directly effecting on the cycle of main nutrients, will be a dominating factor of the forest productivity increase. Productivity of Siberian tree populations under climate warming will mainly be limited by endogenous factors (stomatal conductance), exogenous also be of importance (provision with water and nutrients, especially nitrogen) (Maximov et al., 2003).

Permafrost forests at present are estimated by carbon budget as areas of significant carbon sink. However, under predicted climate warming, their functions as carbon absorbers will essentially depend on the result of coordination of antagonistic processes: 1) increasing of carbon accumulation owing to prolonged growing season and elevated summer air temperatures; 2) frequency raise of forest fires that result in increased carbon dioxide emission into the atmosphere. Sensible ecosystems of the cryolithozone may be not only significant sinks of atmospheric carbon dioxide preventing global climate change but also sources of CO_2 depending on season of year, climatic factors and forest fires.

Growth and development of woody species in Yakutia during the short growing season are supported by high levels of physiological processes (photosynthesis and transpiration) at relatively low dark and nighttime respiratory expenses for the growth and maintenance. Large interannual variability of photosynthesis and respiration of *Larix cajanderi* testifies to its fine adaptation to peculiar climatic conditions of the cryolithozone.

Stable oxygen isotope ratios of plant water (sap water) were observed by Atsuko Sugimoto (2002) at Spasskaya Pad experimental forest near Yakutsk, Russia. The $d^{18}O$ of sap water in larch trees (*Larix gmelinii*) decreased soon after leaf unfolding every year, indicating that snowmelt water was used in the beginning of summer. During mid to late summer, a clear difference in the water source used by plants was observed between wet summers and severe drought summers. The $\delta^{18}O$ values of water in larch trees were high (−17.8 to −16.1‰) in wet summer, but low (−20.4 to −19.7‰) in drought summer. These results indicated that plants used rain water during a wet summer, but melt water from permafrost was used by plants during a drought summer. One important role of permafrost is to provide a direct source of water for plants in a severe drought summer; another role is to keep surplus water in the soil until the next summer. If this permafrost system is disturbed by future global warming, unique monotypic stands of deciduous larch trees in east Siberia might be seriously damaged in a severe drought summer.

According to our studies carbon pools in Yakutia forest and tundra soils ecosystems are 17 Gt (total forest area 125,5 Mha and tundra 37 Mha). They are about 25% of the total carbon reserves in Russian forest soils. The total carbon stock of vegetation of Yakutia is 2.4-4.5 Gt, including 0.053 Gt of tundra and meadow vegetations. Multi-year observations showed that during short but warm growing season (end of May – first decade of September) the permafrost forest ecosystems are a sink of carbon dioxide with a maximal capacity of 6.1 kg C ha^{-1} day^{-1}.

Seasonal photosynthesis maximum of forest canopy vegetation in dry years falls into June, and in humid ones – into July. During the growing season the woody plants of Yakutia uptake from 1.5 to 4.0 t C ha^{-1} $season^{-1}$ depending on water provision. Night respiration is higher in dry and extremely dry years (10.9 and 16.1% respectively). Dark respiration of larch during the season makes 22 to 57% of maximal photosynthesis (Maximov et al., 2005).

The temperature of soil is a key factor influencing soil respiration in the larch forests of Central Yakutia. Average soil respiration for the growing season comes to 6.9 kg C ha^{-1} day^{-1}, which is a characteristic of Siberian forests in total, but is three times as less as those for the forests of Europe and North America. Annual average soil CO_2 emission is 4.5±0.6 t C ha^{-1} yr^{-1} (Maximov et al., 2005a).

Interannual variation of net ecosystem exchange (NEE) in permafrost makes 1.7-2.4 t C ha^{-1} yr^{-1} that results in the upper limit of annual sequestering capacity of 450-617 Mt C yr^{-1} at the total forest area in Russia of 257.1 Mha. In connection with climate warming there is a tendency of an increase in the volume of carbon accumulation by larch forests in the result of prolongation of the growing season. This is also supported by changes in land use as well as by CO_2 sequestration in the form of fertilizer.

Sensible forest ecosystems of the cryolithozone may be not only significant sinks of atmospheric carbon dioxide preventing global climate change but also sources of CO_2 depending on season of year, climatic factors and forest fires (Maximov et al., 2005a).

These data can be used as fact material for the verification and assessment of Russia's carbon pool that is in concordance with UNO Kyoto Protocol providing the implementation of activities on the reduction of global climate change consequences.

Empirical estimates of the magnitudes of photosynthesis and soil respiration as well as analysis of eddy-covariance data allowed us to calculate the net balance of carbon dioxide in permafrost forest ecosystems (Fig. 1).

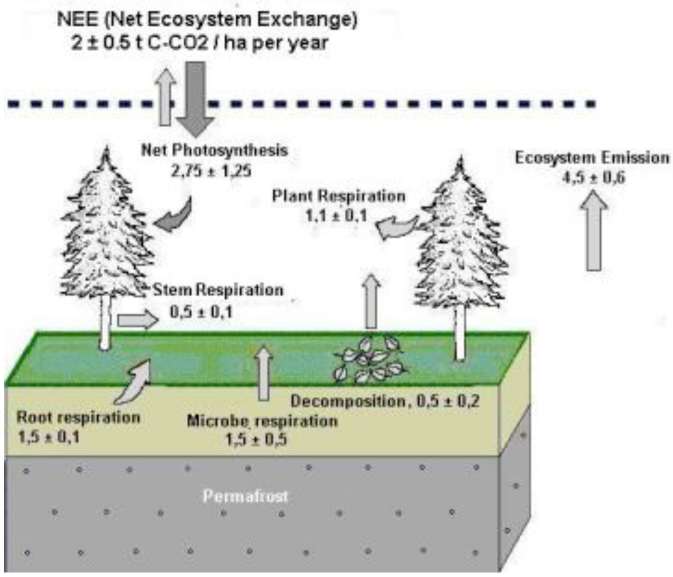

Fig. 1. Components of carbon dioxide exchange in ecosystem, tC ha^{-1} yr^{-1} (Maximov et al., 2003; Maximov et al., 2005).

The peculiarities of soil water regime in Yakutia are determined by permafrost, which causes the specificity of moisture and salt turnover as well as temperature regime of the seasonally thawing layer. The dynamics of hydrothermal regime depends much on the process of ground thaw, which ends just at the start of winter. The formation of vegetation is closely related to the character of this process.

The presence of a high positive correlation between multi-year annual increments in the crown biomass of *Larix cajanderi* and rise of environmental temperature and WUE in the region indicates an increase in the productivity of Yakutian forests for the last 50 years.

The energy and water fluxes above a larch forest have been measured during 1996-2001 at the Spasskaya Pad experimental forest within the frame of GAME (GEWEX Asian Monsoon Experiment)-Siberia.

The latent heat flux increased rapidly as the larch stand began to foliate, and the sensible heat flux dropped at the same time. The latent heat flux peaked at the beginning of July and decreased gradually after the middle of August. Melting snow did not have a direct effect on the changes in the energy balance above the canopy, and plant activity was important for the seasonal variation in the water and energy exchanges.

The seasonal variation in the Bowen ratio was clearly „U"-shaped. The minimum values, about 1.0, occurred from the middle of June to the middle of July. The Bowen ratio was quite high in the early spring, and reached 10 – 25. The canopy resistance (rc) far exceeded the aerodynamic resistance, and it fluctuated widely. The value of rc min was 100 s m-1. The saturation deficit and air temperature controlled the canopy resistance, and the saturation deficit strongly limited the canopy resistance. The canopy resistance was higher during the leaf-fall season than in the foliated season, as the saturation deficit had the same value. This suggests that the senescence of the foliage also affects the canopy resistance.

Our multi-year (1996-2008) studies of water balance show that evapotranspiration over dry larch canopy makes 1.5-2.2 mm day-1 from May to August (Special issue.., 2008). The maximum is observed at the beginning of July, 2.9 mm day-1. Total evapotranspiration from the larch forest in permafrost is 151-258 mm. According to our estimates, evapotranspiration over canopy made 35-50% of the total. Water interception was 15-30% of the overall precipitation at open site. Total evapotranspiration usually prevailed over precipitation, and the outcome deficit was balanced by aboveground and snowmelt waters. In the result of multi-year studies we compiled a schematic model of the annual water budget in larch forests of the cryolithozone that shows an increase in the water deficit at warming of permafrost grounds and utilization of accumulated moisture (up to 50 mm) (Fig.2).

Using a Jarvis-type model, we examined the variation of Gs in five different mature forests from three climate zones (boreal, cool- and warm-temperate) in the Far East. First, we applied the model using summer time e Gs data from each site separately (within-site analysis). We evaluated the maximum surface conductance Gs_{max} and parameters related to the response of Gs to the environments. We found that these values differed among the locations. Second, we applied the model for pooled Gs data from all the sites and calculated a common parameter set (pooled analysis). The results suggest that the surface conductance of the various mature forests had the same maximum value and response properties, although we were not able to verify this. Our new parameterization concept for pooled Gs data should be effective for simultaneous evaluations of the water, energy and CO_2 exchanges of forests over wide regions (Special issue.., 2008).

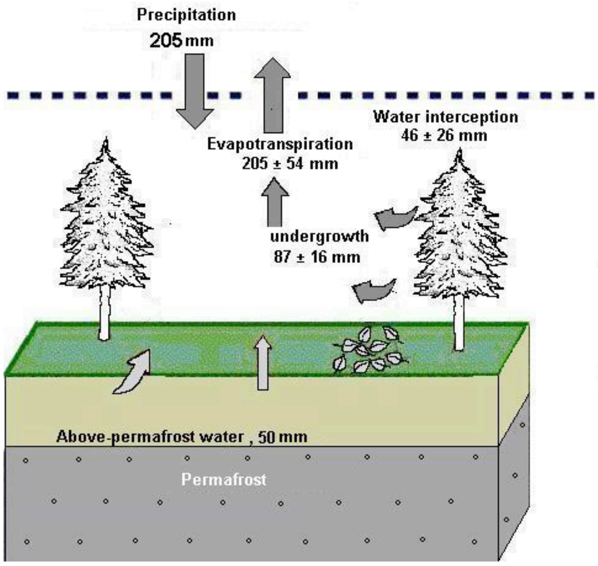

Fig. 2. Annual water balance of larch forests in cryolithozone, mm yr^{-1}
(Maximov et al., 2003; Maximov et al., 2005).

The present study focuses on the linkage between the permafrost degradation and ecohydrological change in North-East Siberia. Deepening of active layer in accordance with over-saturated soil moisture under the wetting climate activates thermokarst subsidence and correspondingly causes fatal damage to the growth of boreal (larch) forest in this region. According to the multi-year sap flow measurements, transpiration from the forest significantly reduced because the matured trees standing in the concaved micro-topography in conjunction with deepening and moistening active layer have been withered and dead after the perennial waterlogged conditions. These facts indicate that the wetting climate in permafrost region in relation to arctic climate change may lead to unexpected ecohydrological responses corresponding with the permafrost degradation in eastern Siberia (Iijima et al., 2010).

The compiled schematic models of annual carbon and water balance in larch forests of the cryolithozone testify to increasing moisture deficit at warming of permafrost grounds and expenditure of accumulated moisture. Taking into account significant reductions in the accumulation of carbon dioxide in dry years and raised frequency of forest fires in such periods, we can say with a high certainty about a noteworthy balance change in the turnover of carbon and water in permafrost ecosystems at climate warming predicted.

All the territory of the North-East of the Russian Federation is a considerable sink of carbon assessed. In connection with climate warming there is a tendency of an increase in the volume of carbon accumulation by larch forests in the result of prolongation of the growing season. This is also supported by changes in land use as well as by CO_2 utilization in the form of fertilizer.

Monitoring observations over fluxes of energy, water and carbon dioxide in the cryolithozone, started by an initiative of international scientific communities, should be expanded both from territory point of view and number of parameters investigated.

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Seasonal variation of linkage between net ecosystem exchange of H_2O and CO_2 over boreal forest at eastern Siberia

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Key words: evapotranspiration, photosynthesis, ecosystem water use efficiency

Introduction

The roles of the forest ecosystem and permafrost in water and carbon exchanges in eastern Siberia have been investigated during the past decade, revealing some important findings. For example, observations at Yakutsk in the middle reaches of the Lena River showed the simultaneous increase in latent heat flux and the emergence of leaves (Ohta et al., 2002), and the strong regulation of evapotranspiration and CO_2 assimilation by the forest ecosystem (Dolman et al., 2004). These water and carbon exchanges between the forest ecosystem and the atmosphere have linkage through the leaf stomatal control, which depends on the local climate and the leaf physiology.

To improve understanding of relation between water and carbon cycles over eastern Siberia boreal forest, two observation sites at a larch dominated forest in the middle and southern part of Lena basin were analysed in this study.

Site and methods

One is the Spasskaya Pad station (SP) at Yakutsk (62° 15′N, 129° 14′E). The other station named Elgeeii station (EG) (60° 0′N, 133° 49′E) is located at 300 km southeast of Yakutsk. Average of annual precipitation during 1986-2004 is 290mm and 230mm at Ust-Maya, which is the nearest station at a distance of 60km from Elgeeii, and Yakutsk, respectively, while difference of the other meteorological values such as air temperature and humidity is small (Suzuki et al., 2007). The dominant species in the forest is larch (*Larix cajanderi*), mixed with birch (*Betula pendula*), willow (*Salix bebbiana*) and pine (*Pinus sylvesrtis*). The stand density of larch trees is 720 and 1040 trees ha^{-1} (1800 and 2600 trees ha^{-1} including birch, salix and pine) at SP and EG, respectively. The mean stand height of upper canopy, which is comprised of larch trees, is around 20m at SP and 25m at EG, and plant area index measured in August 2011 is 1.4 at SP and 2.1 at EG.

In these forests, meteorological measurements including radiation, wind, temperature, and humidity above and inside the canopy, ground temperature (0.1–5 m), and soil water content (0.1–1.2 m) were conducted. CO_2 and water vapour fluxes above the canopy were measured with the eddy covariance system. Observed CO_2 flux represents net ecosystem exchange NEE, which was divided into gross ecosystem production GEP and ecosystem respiration ER and data gaps were complemented using empirical equation of flux and environmental variables (e.g., Stoy et al., 2006). Water vapour flux, i.e., evapotranspiration ET, was also gap-filled by the multiple imputed methods (Hui et al., 2004). These continuous flux data was used to derive daily cumulative sums. Data obtained during growing season (April through September) in 2010 and 2011 were used in this study.

Results and Discussion

Seasonal change of NEE and GEP showed that maximum uptake was observed at June at both sites, and EG forest absorbed more than SP through the growing season. Evapotranspiration gradually increased toward the peak at first half of July at both sites. The total amount of ET was not so different between two sites, while NEE and GEP were 1.5 and 1.2 times, respectively, at EG compared to SP (figure1). The difference in total GEP was explained mainly by difference in the PAI, that is, the tree biomass above ground, rather than the climate condition (Hayashi et al., in this workshop).

The time lag of peak period of GEP and ET made seasonal variation of ecosystem water use efficiency WUE, which was defined as ratio of GEP to ET. Generally, daily scatter was more remarkable than seasonal trend and therefore WUE was normalized by vapour pressure deficit D; WUE D^{-1} declined during midsummer especially at EG (figure2). The negative correlation between WUE and D was observed till around D = 20hPa, which consisted to the previous studies (e.g., Morén et al., 2001), but WUE decreased beyond this threshold (Figure3). During July in 2011, sporadic hot days were observed at SP. In such days, D

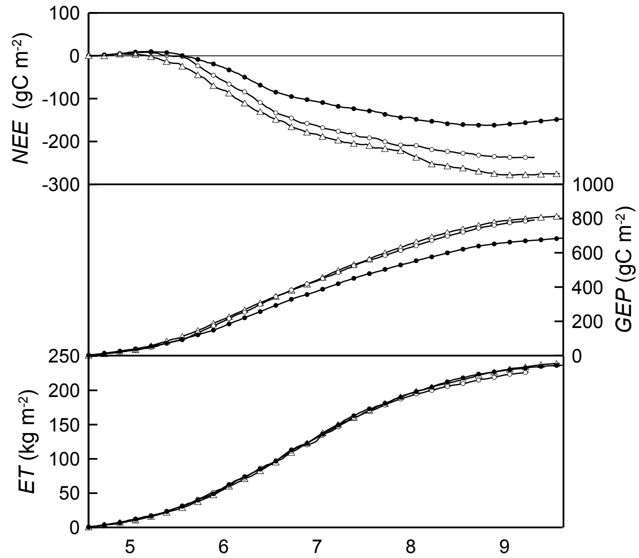

Figure 1. Cumulative fluxes; NEE(a), GEP(b), and ET(c) at EG2010 (open circles), EG2011 (open triangles) and SP2010 (closed circles). Each point is drawn in 5-days interval

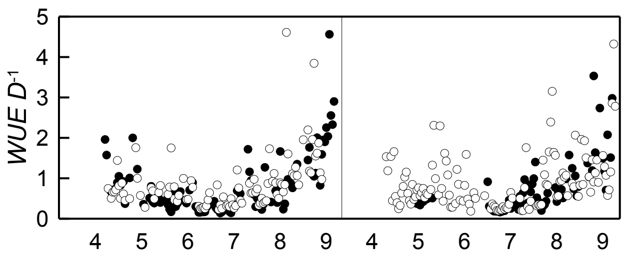

Figure 2. Seasonal variation of ecosystem water use efficiency divided by vapor pressure deficit at EG (open) and SP (closed circles). Each point represents 5-days average.

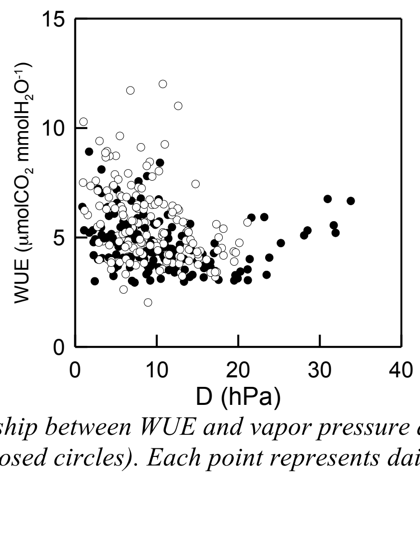

Figure 3. Relationship between WUE and vapor pressure deficit at EG (open) and SP (closed circles). Each point represents daily average.

was high and such situation reduced surface conductance and evapotranspiration, but influence on the CO_2 uptake was unclear, which leaded to increase of WUE. This fact partly contradicted the conclusion of Dolman et al. (2004), in which, compared to evapotranspiration, CO_2 uptake was more affected by increasing humidity deficit, to stabilize evapotranspiration variability and prevent water loss under dry summer condition at continental climate.

Conclusions

To improve our understanding of water and carbon exchange over eastern Siberian boreal forests, two forest-sites in a larch-dominated forest in the southern Lena basin-were analysed. Measurements during two years growing season at Elgeeii site showed that net CO_2 assimilation were higher than those at Yakutsk especially during June (the first half of the growing season), while evapotranspiration was not different. The time lag of peak period of CO_2 assimilation and evapotranspiration made seasonal variation of ecosystem water use efficiency, which declined during midsummer. The extremely hot and dry condition modified relationship between fluxes. The mechanism and influence on the seasonal variability should be investigated.

Acknowledgement

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Key features of soil CO_2 efflux in taiga larch forests of Central and South-Eastern Yakutia

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Key words: soil respiration, soil carbon dioxide flux, larch forest, permafrost, Yakutia

Introduction

Soil respiration – one of the most intense flux component of global carbon balance, it's almost equal to NPP, and ranges in a scale of 68±4 to 100 Gt C year^{-1} [1, 2]. Even very small shifts of soil respiration values highly affect the annual balance of CO_2 in an ecosystem-atmosphere system [3, 4]. At the same time, soil respiration depends on many environmental factors (generally on soil temperature and moisture) and changes temporally (daily, seasonal, annual and inter-annual variability) and spatially (depending on microrelief, soil properties, vegetation types etc.). In natural conditions all these factors act simultaneously, strongly perplexing the studies.

Thus, particularly in the conditions of a changing climate, we need to estimate precisely the characteristics and properties of soil CO_2 emission (R_s) processes, including the resultant value – seasonal and annual accumulated flux sums, especially taking into account dependencies of that on changes in environmental factors. The following tasks were set up to understand these features in two plots (Central and South-Eastern Yakutia): 1) a comparative study of seasonal and inter-annual courses of soil CO_2 emission together with concomitant environmental conditions in both plots; 2) to investigate the patterns of environmental dependencies of soil respiration, with following determination of most important environmental parameters reliably influencing CO_2 efflux in the study plots; 3) to estimate and compare the seasonal and annual accumulated sums of CO_2 efflux from soils of larch forests in a cryolithozone.

Objects and methods

Studies were carried out in 2010 and 2011 during a season from early April to the end of October simultaneously at both sites, 'Spasskaya Pad' and 'Elgeeii' (Figure 1).

'Spasskaya Pad' plot (YAK) is located on the left bedrock bank of the Lena River (62°15' N, 129°37' E) in a 180-year-old cowberry Larch forest (Laricetum vacciniosum). Soils are permafrost pale-solodic based on light old-alluvial sandy loam. A full-automated soil respiration system (ASRS, Alterra, Netherlands) was used including a CIRAS SC CO_2 IRGA (PP Systems, UK) to measure CO_2 samples taken every 1 hour by 4 auto-operated 32 cm diameter soil chambers installed on 30 cm deep soil rings. The chambers were set-up with 10 m gap between them, with 4 complementary soil temperature and moisture sensors at 10 cm depth and 1 precipitation sensor. Some environmental data (precipitation, soil and air temperatures and moistures, net radiation and PAR) at various depth and height were used from a meteorological system at the tower, located 30 m east of the plot.

'Elgeeii' plot (ELG) is located on the left bedrock bank of the Aldan river (60°00' N, 133°49' E) at southern boundary of Central Yakutia in Amga-Aldan interfluve in a 150-year-old cowberry Larch forest (Laricetum vacciniosum). Soils preliminary were determined as permafrost-taiga (pale-yellow-brown) podzolic ones. An automatic soil respiration system ACE-001/L (ADC Bioscientific Ltd.) was used with soil temperature and PAR sensors. Method: measuring CO_2 samples taken every 2 hours by an auto-operated 32 cm diameter soil chamber, installed on a 30 cm deep soil ring. Contemporary soil temperature parameters were measured near the system at a 10 cm depth and precipitation, net radiation, PAR, air/soil temperature and moisture data at various height or depth were used from a meteorological system located 30 m away of the study point. Data error-check and smoothing was made using MS Excel, for both sites.

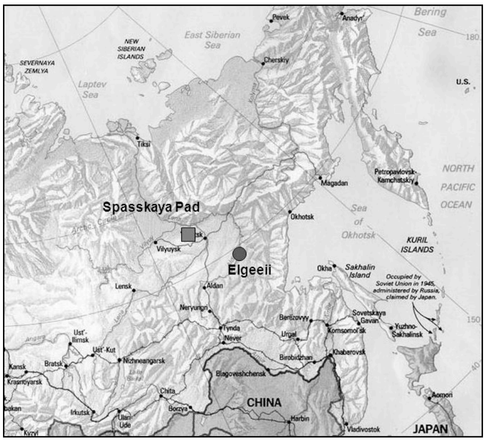

Figure 1. Map of study sites. 'Spasskaya Pad' site: Central Yakutia, 62°15'N, 129°37'E; 'Elgeeii' site: south-eastern Yakutia, 60°00'N, 133°49'E. Distance between sites is 335 km.

Results and discussion

The environmental conditions of sites are presented in Table 1. It is clearly shown that there are no big differences in environmental conditions among the sites during the season and summer except twice higher soil moisture content (SMC) in the south-eastern site. Seasonal sums of precipitation amounts (PP) differ not so much among the sites, but summer-time precipitation part is 10-20% less in Central Yakutia. Average air and soil temperatures (Ta and T_s) are almost same at both sites, fluctuating little depending on year. Soil thawing depth is almost similar in YAK and ELG sites and reaching in average 1.8 m.

Table 1. Seasonal and summer average environmental parameters at 'Spasskaya Pad' plot (YAK)and 'Elgeeii' plot (ELG) in 2010-2011.

Parameter	Years	Season (Apr-Sep)		Jun-Aug	
		ELG	YAK	ELG	YAK
T_a, °C, monthly average	2010	10.2	11.0	16.6	17.3
	2011	10.3	10.7	17.1	17.6
T_s, °C, monthly average	2010	4.9	5.3	9.5	6.8
	2011	4.9	6.0	9.3	11.5
SMC, %, monthly average	2010	39.8	23.2	49.0	29.1
	2011	30.2	16.0	34.9	14.9
PP, mm, monthly sum	2010	156.0	154.7	101.0	79.8
	2011	125.0	123.8	104.0	91.9

Seasonal course of soil CO_2-efflux has a dome-like form at both sites (Figure 2). Some small CO_2 release from soils starts around the middle of April (DOY 100-110). Valuable soil carbon dioxide emission begins coincidently at both sites – in second decade of May (DOY 125-135) despite much earlier thawing of the upper soil layers in South-Eastern Yakutia. There was a big difference in timing of maximum soil CO_2 release (Fmax) among the sites – in YAK it was usually observed from mid-July to mid-August (DOY 195-225) with the highest efflux in early August (DOY 215). Meanwhile, in ELG the maximum occurred 2-3 weeks earlier, in the middle of July (DOY 180-210, Fmax at DOY 195), which probably indicates that earlier soil warming-up in the South-Eastern site initiates a bigger soil biota propagation and higher activity in ELG. A multi-year average of F_{max} in YAK (4.7 µmol m^{-2} s^{-1}) is twice lower than that in ELG (10.3 µmol m^{-2} s^{-1}).

Soil respiration in YAK usually runs out in the middle of October (DOY 285-290). In ELG we measured soil respiration only until early October, but we can estimate the timing to be similar: probably at the end of October.

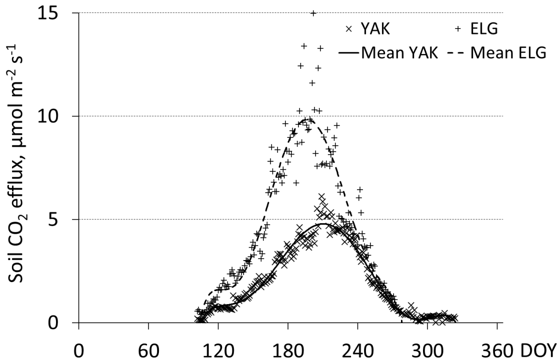

Figure 2. Seasonal graphs of soil CO2 efflux in 'Spasskaya Pad' plot (YAK, multi-year daily averages, 2001-2010) and 'Elgeeii' plot (ELG, 2010-2011 daily averages); corresponding mean trends are shown.

Environmental dependencies of soil respiration were discovered using a simple regression analysis. The soil CO_2-efflux values during the season (F_s) has strong positive correlation with the trend of soil temperature T_s in both sites (r^2=0.74±0.07 for YAK and r^2=0.79±0.08 for ELG). Correlation coefficients of F_s with soil moisture (η) in YAK is always negative during the season, but in middle summer and later, when the upper soil layers go under drought condition, the negative correlation or F_s vs η becomes higher. But in ELG during the first half of summer, along with soil moisture rise, there is some positive correlation of F_s with η but during soil drought after mid-July no dependence of F_s on η was observed there. It means, probably, that in ELG the soil biota is more drought-resistant compared to YAK.

Temperature response of F_s (many-years average Q_{10} values) in YAK equals 4.89 and is almost identical to that one in ELG (4.85), but base respiration (T_0) is one third higher in ELG (1.53 vs 0.99 in YAK). It probably means that bigger CO_2 flux in 'Elgeeii' site is explained not only by relatively higher Ts, but also by some endogenous reasons, for example, more massive microbial community.

During soil drought against the background of high soil temperatures at mid-summer period, even very small precipitation (2-3 mm day^{-1}) causes much higher soil respiration rate increase (by 24-30%) in comparison with much stronger storm-rains (15-20 mm day^{-1}) during wet periods (by 10-15%). At the same time, considerable amounts of precipitation during the cold period of late summer and early autumn do not affect much the soil respiration course, because low soil temperatures inhibit respiratory metabolism of roots and soil organisms although existing sufficient soil moisture condition.

Analysis of other environmental factor dependencies showed that there are no essential soil CO_2-efflux correlations with net radiation, PAR, soil heat flux etc.

Preliminary soil physics study in ELG indicates that, probably, these soils are also heavier and less aerated than in YAK. Soil moisture content in ELG is much higher as well, so transpiration activity of deep soil biota in ELG should be depressed by oxygen unavailability due to soil over-wetting.

But despite these facts much higher annual soil carbon release (cumulative CO_2-flux) was observed in "Elgeeii" site.

Seasonal accumulated CO_2 fluxes (F_a) were calculated for both sites. It is clearly shown that cumulative soil carbon emission during the season in ELG is almost twice higher than in YAK (see Table 2 and Figure 3). The average seasonal sum of soil carbon release in ELG for 2010-2011 reached 8.64 tC ha^{-1} per season compared to many-years average of accumulated soil carbon efflux in YAK equaling 4.34 tC ha^{-1}.

The cumulative flux in ELG starts to exceed that of YAK already in June and keeps high level until the end of August, while CO_2-flux in YAK decreases after mid-August. Maximum accumulated soil efflux was observed in July, being about 35% of total seasonal sum at both sites. Early summer soil carbon efflux is usually smaller than that in late summer.

Table 2. Soil carbon accumulated fluxes in 'Spasskaya Pad' and 'Elgeeii' sites, by monthly averages and total sum per season (April-September), tC ha^{-1}, 2010-2011.

Site	Year	Months			Season
		Jun	Jul	Aug	
YAK	2010	0.67	1.4	1.3	4.22
	2011*	0.72	1.5	1.41	4.46
ELG	2010	1.65	3.33	2.22	8.56
	2011	2.09	2.93	1.77	8.72

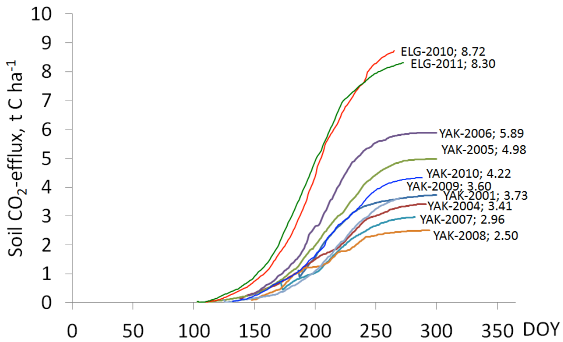

Figure 3. Soil carbon accumulated flux in 'Spasskaya Pad' site (2001-2010) and 'Elgeeii' site (2010-2011).

Conclusion

Maximum soil respiration during season in "Elgeeii" plot was observed in mid July (10.3 μmol CO_2 m^{-2} s^{-1}), but in "Spasskaya Pad" plot it was discovered in early August (4.7 μmol CO_2 m^{-2} s^{-1}). The main environmental factor, affecting soil CO_2 flux, is soil temperature in both sites. At the same time, precipitation (and, accordingly, soil moisture) plays an important role on seasonal scale as well. Calculated accumulated carbon flux in the south-eastern site was more than twice higher than in Central Yakutia (8.64 tC ha^{-1} vs 4.34 tC ha^{-1}, respectively). The main reason of this difference most probably is a higher soil biota activity in the south-eastern site.

Increasing of precipitation amount and temperature along with global climate changes will cause escalating of soil biological activity and dramatic fluctuations in soil carbon pools, CO_2 emission and finally – soil degradation with abrupt changes of carbon exchange processes in northern ecosystems.

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* In 2011 in YAK we had available only collection of very short datasets because of many electricity supply faults. Thus, accumulated soil carbon fluxes for YAK in 2011, presented in Table 2, are approximate calculations.

Snowmelt heat balance of the snowpack in a larch forest in eastern Siberia

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To clarify the features of the heat and water balances of the snowpack and their influence on the permafrost during the snowmelt season, and further to assess the change of these features in a decade, observations of the snow water equivalent, snowmelt rates, water vapor flux at the snow surface, and meteorological elements were made in a larch forest in the middle reaches of the Lena River basin in 1998 and 2010. The maximum snow water equivalent is smaller and melt period started earlier in 2010 than in 1998. Other features were not different in these two years: The snow temperature reached 0 ºC only at the snow surface in the pre-melt period, and reached 0 ºC in all layers of the snowpack in the melt period; Among the heat balance components, the net all-wave radiation contributed more than 60% of the available heat in both periods; The heat for consumption was mainly the latent heat flux in the pre-melt period and the heat for melt in the melt period; The runoff ratio of meltwater from the snowpack was estimated from the snow water equivalent and surface snowmelt rates and they were about 40 and 80% of the meltwater in the snowpack flowed out to the permafrost in the pre-melt and melt periods, respectively; The contribution of evaporation to snow ablation was larger in the pre-melt period than in the melt period; The meltwater infiltrated the frozen permafrost and raised the temperature of the frozen soil by releasing the fusion heat of refreezing in both periods.

Simulation of soil water and temperature in eastern Siberian taiga forests by a one-dimensional land-surface model

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Key words:Soil moisture, Soil temperature, land-surface model, Soil thaw depth, Snow depth

Introduction

Meteorological and hydrological observations continued in a larch taiga forest at Spasskaya Pad near Yakutsk of eastern Siberia on a permafrost zone since 1998 (Ohta et al., 2001). Moreover, we have 40 years or more routinely observed meteorological data in Russia. We estimate long-term water/energy budgets and soil/snow situations at this forest site before the start of tower observation.

Soil moisture and temperature have been rapidly increased and active layer became deep since 2004 (Ohta et al., 2008; Iijima et al., 2010). Iijima et al. (2010) pointed out this soil warming caused by abnormally high pre-winter rainfall and snowfall rather than air temperature rising. We tried to simulate the recent rapid change of soil condition with use of a land-surface model. Moreover, we discuss which pre-winter rainfall and snowfall affect soil moisture and temperature increase.

Method

The estimation method is same as Yamazaki et al. (2007):
1) The relationships of meteorological data between Yakutsk and the tower at Spasskaya Pad are established from 1998 to 2000.
2) Past meteorological conditions over the taiga forest are estimated using the equations obtained step 1). Diurnal variations are given with empirical equations.
3) The heat fluxes and soil/snow situations are estimated using a one-dimensional land surface model.

Land-surface model

The land surface model (2LM) used in this study is a one-dimensional model described in Yamazaki et al. (2004). It includes three submodels; vegetation, snow cover, and soil. It can calculate water and energy fluxes above and within forest, if meteorological data over the forest are given as input (Fig. 1).

The snow submodel can consider depth hoar to adapt intensely cold regions Yamazaki (2001). The submodel is multi-layer, the number of snow layers depend on snow depth. It can calculate profiles of snow temperature, density, and liquid water content as well as snow depth.

The soil submodel is a multi-layer model having a thickness of 0.1 m except for the top layer (0.2 m). It can calculate profiles of soil temperature and water content. Heat of fusion of frozen soil is taken into account with a method in which heat capacity is regarded as larger in a small temperature range between -1 and 0°C.

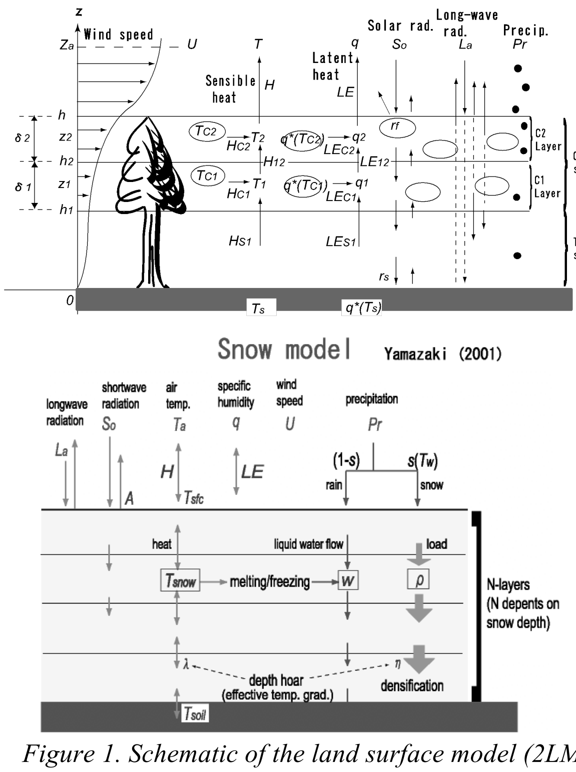

Figure 1. Schematic of the land surface model (2LM). Upper: vegetation submodel, Lower: Snow submodel.

Jarvis type parameterization is used for stomatal conductance, which controls transpiration from tree; common parameters (Yamazaki et al., submitted) are given according to a concept of potential response.

Data

The routine data used in this study is Baseline Meteorological Data in Siberia (BMDS) Version 5 (Yabuki et al., 2011). It consists of daily mean, maximum and minimum air temperature, precipitation amount, water vapor pressure, mean and maximum wind speed, duration of sunshine, snow depth, and other elements. BMDS includes no data of solar radiation and long-wave radiation, which are necessary for the model as input. Thus they are estimated from duration of sunshine etc. Although the data from 1950 to 2008 are recorded for Yakutsk, the data from 1966 to 2008 are used for the calculation because all data including duration of sunshine are available in this period. Wind speed data in 1983 are missing, thus monthly mean obtained from the other year data is used instead of daily wind speed in this year.

Linear relationships are recognized on daily each meteorological data between Yakutsk and the tower. Therefore those linear regression equations are used. Daily precipitation amount is assumed as 1.12 times of that in Yakutsk.

The leaf-out date is parameterized as the date of ‘soil temperature at 10 cm becomes greater than 5°C’ and ‘accumulated daily mean air temperature becomes greater than 100°Cday after daily mean air temperature is beyond 0°C’. The period until leaf-out finish is assumed as 16 days. It is assumed that the fallen leaf starts at 1 Sep. and finishes 30 Sep. in every year.

The initial soil temperature and water content are obtained as follows. At first, whole period simulation is carried out with tentative initial soil situation that are constant temperature of annual mean air temperature and constant water content of 0.2. Ten set of the soil temperature and water content of January 1 from 1999 to 2008 calculated by this tentative simulation are used as initial condition for regular simulation. The reason ten member initial values are used is that uncertainty due to initial condition and length of influence of initial condition can be estimated.

Results

Figure 2 shows simulated soil thaw depth and snow depth. The simulated thaw depth tends to increase after 2004. In particular, it is estimated that the soil thawed deepest from 2006 to 2008 during this 40 years. Figure 3 shows interannual variation of calculated soil water content in the layer of 0 – 2 meters depth. The influence of initial soil condition disappears after about 8 years. In general, soil water increases in snowmelt season, it decreases after that, it increases again in autumn and it keeps almost constant in winter. However, sometimes it significantly increases in late summer and high soil water continues in winter (e.g. 1976 and 2006). The periodic variation with about ten year period can be found. The soil water from 2006 to 2008 is in highest level during 40 years. It supports observed rapid wetting of the soil and damage of larch trees which has never seen in the past (Iwasaki et al., 2010).

The model simulated soil water is compared with reconstructed soil water using analysis of stable isotope in tree annual rings by Tei et al. (in preparation) (Figures 4 and 5). Variation patterns of both agree, however, the absolute value by the model is slightly large especially in 1970s.

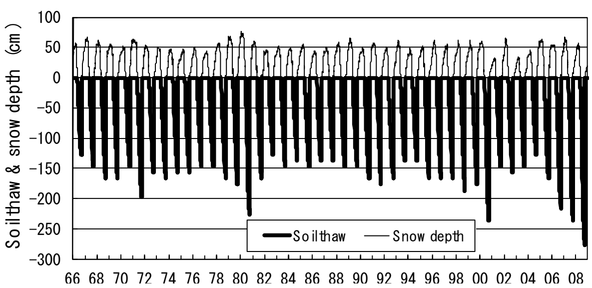

Figure 2. Simulated soil thaw depth and snow depth.

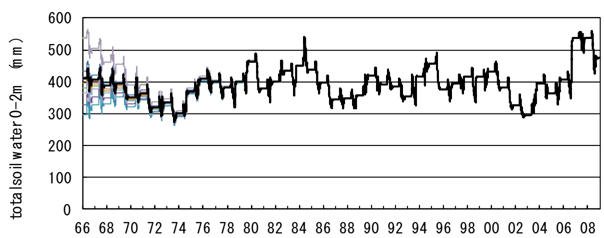

Figure 3. Calculated total column soil water from 0 – 2 m depth. Thin lines indicate ten members with different initial soil condition. Thick line is average of ten members.

The example of comparison of soil temperature between model and observation are indicated in figure 6. Calculated soil temperature is high but recent temperature rising is simulated. One the other hand, although calculated soil water content tends to increase, recent observed drastic increase cannot be reproduced (figures are omitted). This corresponds with the discussion that recent increasing of soil water can not be explained without water supply from lateral or deep boundary (Ohta et al., 2008). They estimated the amounts of entering water from outside are 43.3, 167.0 and 101.1 mm in 2004, 2005 and 2006, respectively. However, the one-dimensional model can not consider this kind of entering water from the outside.

Increasing of soil thaw depth might be affected by increase of summer precipitation (soil water content in fall) and increase of snowfall in early winter rather than air temperature rising (Iijima et al., 2010). At first, data of summer (May – Sep) and fall (Oct – Nov) precipitation are shown in Fig. 7. Figure 8 indicates the relationship between model calculated annual maximum soil thaw depth and summer/fall precipitation. It is found that fall precipitation is strongly connected with thaw depth. Moreover, we discuss the effect of precipitation change on soil condition by the method of sensitivity test with the model. Figure 9 shows the result for two cases of precipitation change. One is FME: precipitation is replaced by mean value in fall or early winter (October and November) from 2005 to 2007. The other is SME: precipitation is replaced by mean value in summer (from May to September) from 2005 to 2007. The deepening soil thaw is affected by fall precipitation rather than summer precipitation in this simulation. Fall precipitation causes deep snow that plays insulation role, thus soil temperature does not drop in winter and it rises easily after spring.

Conclusion

1) Soil situation was simulated in an eastern Siberian larch forest using a one-dimensional land-surface model from 1966 to 2008. It corresponded with reconstructed soil water by stable isotope in trees.
2) After 2005, soil becomes wet and warm in the simulations, however, it is not drastic compared with observations.
3) Autumn precipitation (snow depth) might affect the recent warming soil.

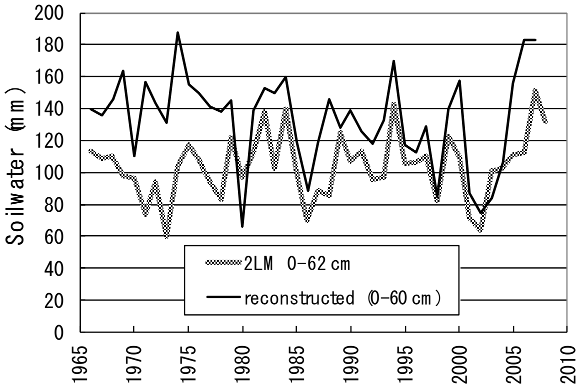

Figure 4. Time series of simulated soil water and reconstructed soil water by analysis of stable isotope (Tei et al.)

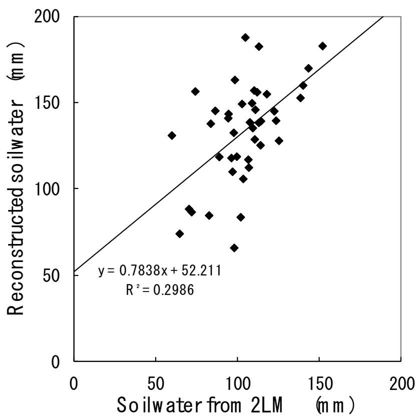

Figure 5. Comparison between simulated soil water and reconstructed soil water by analysis of stable isotope (Tei et al.)

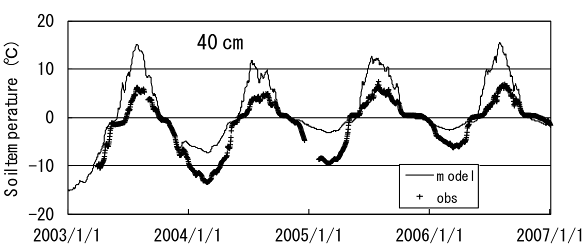

Figure 6. The comparison of soil temperature between model estimation and observation at 40 cm depth.

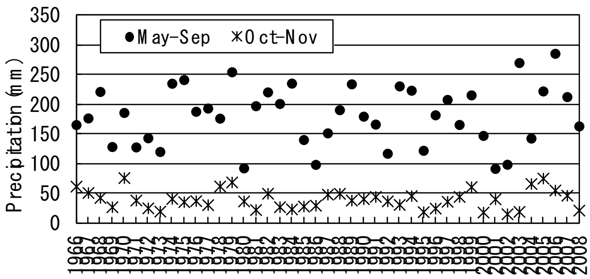

Figure 7. Time series of summer and fall precipitation.

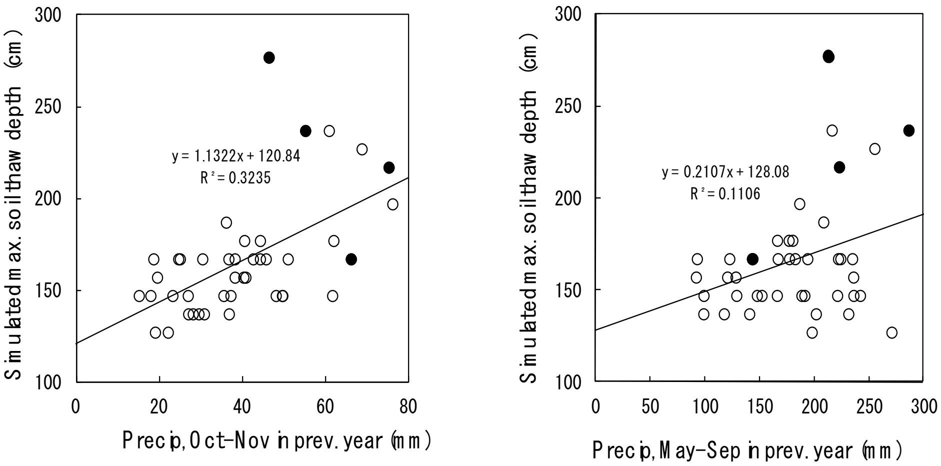

Figure 8. Relationship between model calculated annual maximum soil thaw depth and seasonal precipitation. Left: summer. Right: fall.

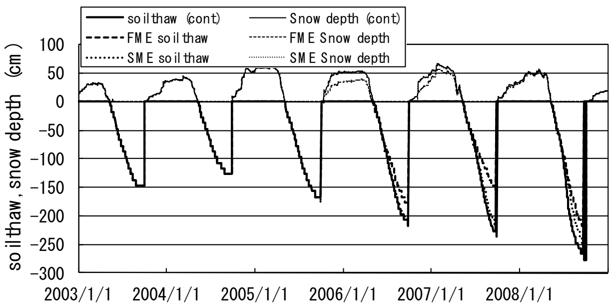

Figure 9. Effect of precipitation change on soil thaw and snow depth. FME: precipitation is replaced by mean in fall itation (October and November) from 2005 to 2007. SME: precip is reduced by mean in summer (from May to September) from 2005 to 2007.

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Changes in relationship between larch tree growth and climate in eastern Siberia over past 100 years

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Dendrochronological studies in high-latitude region focused on the positive growth of trees to warmth (D`Arrigo and Jacoby, 1993). From these results, it had been expected that warming would lead to more tree growth and expansion of trees in tundra. However, from middle of 20th century positive sensitivity of trees growing in northern high-latitude to temperature has declined (Briffa *et al*., 1998) and temperature induced drought stress may limit radial growth of trees (Barber et al., 2000). That is, trees growing in high-latitude region are on water stress and moisture condition is likely to be limiting factor for tree growth (Kagawa *et al*., 2003). Here, we report an analysis of tree ring and climate data including soil moisture reconstructed form delta-^{13}C of tree ring to explore the tree growth-climate relationship and a change in this relationship over the past 100 years in eastern Siberia.

Larch trees (*Larix cajanderi*) collected in Yakutsk (62°N, 129°E) were used for the analyses of tree ring width and its carbon isotope ratio. The samples were crossdated with ITRDB's (International Tree-Ring Data Bank) ring-width records in eastern Siberia. Soil moisture for the past 100 years was reconstructed form the delta-^{13}C of tree ring (Tei *et al*., in preparation).

Tree ring width showed positive and negative correlation with soil moisture reconstructed form delta-^{13}C of tree ring ($r=0.56$, $P<0.001$) and July-August temperature ($r=-0.20$, $P<0.05$) in previous year over the past 100 years, respectively. However, these correlations were not stable and the correlation coefficients changed over time. Moving-interval correlation analysis showed that the relationship between tree growth and late summer soil moisture and temperature in previous year became gradually stronger. These results show that water stress during the late summer in the previous year caused a reduction of tree growth.

Feedback mechanisms between the water and carbon cycle at a regional scale

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Key words: Climate change, snow cover, carbon dioxide exchange

Introduction

Climate change including changes in variability and social economic changes will have a large impact on land cover. Through feedback mechanism, these changes in land cover will also have an impact on the hydrological regime and exchange of moisture, heat and CO_2 of the land surface with the atmosphere.

It has been demonstrated in different regions of the world that the change of land cover can directly influence the water, energy and carbon cycle of a region (see e.g. Ter Maat et al., in review).

Future global warming could drastically alter the larch-dominated taiga–permafrost coupled system in Siberia, with associated changes of water-energy-carbon processes and feedback to the climate (Zhang et al., 2011).

Key questions that need to be addressed at the regional scale are:

- What are the sensitivities of the carbon cycle and ecosystems to climate change?
- How do extreme events (drought, heat, flood) change surface controls (e.g. temperature and soil moisture) affecting landscape scale atmospheric concentrations and surface-atmosphere GHG fluxes?

Feedbacks

Koven et al. (2011) showed for terrestrial ecosystems north of 60°N a potential shift from being a sink to a source of CO_2 by the end of the 21st century when forced by a SRES A2 scenario. Although there is a relatively wide range in the total numbers, depending on the processes included in the models. Increases were attributed to CO_2 fertilization, permafrost thaw. Warming-induced increased CH_4 flux densities were partially offset by a reduction in wetland extent.

It was shown by Lee et al (2011) that on a per gram carbon basis, deep permafrost mineral soils had carbon release rates similar to organic soils for some soil types. Indicating that, independent of soil type, permafrost carbon in a relatively aerobic upland ecosystems may have a greater effect on climate when compared with a similar amount of permafrost carbon thawing in an anaerobic environment, despite the release of CH_4 that occurs in anaerobic conditions.

Feedbacks between land and atmosphere playing a major role in eastern Siberia are first order feedbacks such as albedo changes (e.g. Flanner et al., 2011), but also more complicated second order feedbacks in particular those influencing thermal insulation. For example timing of the snow cover is essential for the thermal insulation of the soil, which will impact water uptake, depth of the active layer, cryoturbation, decomposition, respiration rates, species composition, growth and photosynthesis. In permafrost soils the phase transitions from ice to liquid water and vice versa represent a important tipping points whose effect on ecosystem dynamics and therefore on carbon exchange are poorly captured in current modelling approaches.

That feedbacks between the land, vegetation and atmosphere are not straightforward, is among others demonstrated by Iwasaki et al (2010). They reported that elevated precipitation amounts in the relatively dry region of eastern Siberia rather than improving growing conditions, adversely affected the growth of larch *trees*. This implies that if increased precipitation is to extend for more than two years, forest recovery may not be expected and emission of greenhouse gas might increase. At the same time it is found that larch trees maintain permafrost by controlling the seasonal thawing of permafrost, which in turn maintains the taiga by providing sufficient water to the larch trees (Zhang et al, 2011). With increased temperatures, a forest with typical boreal tree species (dark conifer and deciduous species) would become dominant and decoupled from the permafrost processes.

For the tundra area dominated by *shrubs*, Blok et al (2011) postulated that wet summers facilitate shrub growth in the following growing season.

Because of their insulation effect on heat and water transport, *mosses* may exert strong controls on understory water and heat fluxes. Changes in moss or shrub cover may have important consequences for summer permafrost thaw and concomitant soil carbon release in tundra ecosystems (Blok et al., 2011).

The importance of insulation was also demonstrated by Koven et al. (2009). They simulated the impact of thermal insulation by soil carbon changes and vertical mixing of soil organic matter by cryoturbation on the total carbon stocks. They show that including these two effects together leads to up to 30% higher soil carbon stocks in the top meter of permafrost soils, as well as large stocks of carbon below 1 m in the upper permafrost soil layers.

Ways forward

To improve our understanding of the impacts of climate change on the carbon and water cycle of the eastern Siberian region, an improved understanding of the different regional processes and feedbacks is needed. Especially the effect on permafrost degradation on regional and global climate needs improved knowledge.

Known weaknesses are:

- Temperature and surface state moisture controls on regional patterns in moisture and CO_2 exchange;
- The effect of land cover, especially of forests and the snow cover at the start and end of the winter season on the regional recycling;
- The impact of seasonal and inter-annual variability, i.e. the effects of droughts (e.g. van der Molen et al., 2011), heat waves (e.g. Teuling et al., 2010) and excess precipitation;
- The hydrological forcing of the carbon cycle dynamics, i.e. the freeze/thaw state functioning as a primary seasonal surface temperature biophysical "on-off switch".

To enable the step towards implementing these processes and feedbacks adequately in RCMs en GCMs, there is a need to first implement this improved understanding in regional coupled atmospheric-hydrological high resolution (+/- 1x1 km^2) models. These high resolution models will enable us to test the sensitivity of the models for different spatial and temporal resolutions for the atmospheric drivers and the land surface feedbacks, as well as the integrated effect on the net carbon exchange.

For such a model evaluation, in situ data combined with remote sensing data are a prerequisite. Long term data sets will greatly help to capture the effects of extreme events such as droughts on processes and physics unique to high latitude permafrost regions such as the vertical distribution of soil carbon, to capture the steep temperature gradients and the inhibition of decomposition in frozen soils.

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Seasonal and interannual variations of the Lena River discharge and those relationships with atmospheric water cycle

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Key words: Lena River, river discharge, net precipitation, atmospheric water cycle

Introduction

Freshwater budget in the Arctic Ocean is important for the Arctic sea ice formation and for the ocean conveyor belt, which affects climate in Europe and several other regions. Sources of the freshwater inflow into the Arctic Ocean include river discharges from the land, net precipitation from the atmosphere, and ocean currents from the ocean. Net precipitation is the difference between precipitation (P) and evapotranspiration (E), that is, the net input of water from the atmosphere to the surface. The net precipitation over the Arctic Ocean is equivalent to about half of total river discharge into the Arctic Ocean (Oshima and Yamazaki 2004). The river discharges from the three great Siberian rivers (Lena, Yenisei and Ob) account for about 20% of the total freshwater inflow and the Lena River discharge accounts for about 7%. Therefore the Lena River is one of the large freshwater sources to the Arctic Ocean.

Several studies have been made on terrestrial and atmospheric water cycles of the Siberian river basins. Among the studies, Fukutomi et al. (2003) showed an interesting result that summer precipitation in the Lena River basin is negatively correlated with that in the Ob River basin; when precipitation is large in the Lena River basin, it is small in the Ob River basin. Those precipitation anomalies are related with East-West seesaw pattern of atmospheric moisture transport over Siberia. These results were shown by using the dataset during 1980s to mid-90s. More recently, several drastic changes in terrestrial water cycle are observed near Yakutsk: flood in Yakutsk (Sakai 2010), deepening of active layer, large precipitation and wet condition around the Yakutsk, especially during 2005-2008 (Iijima et al. 2010, Ohta et al. 2008).

Based on the previous studies, the purposes of this study are as follows: First, we examine seasonal and interannual variations of the river discharges (R) and of the net precipitation (P-E) for the Lena, Yenisei and Ob Rivers. Second, we further examine how the net precipitation in the Lena River basin is related with the atmospheric water cycle, which means moisture transport and associated large-scale atmospheric circulation. Third, we compare the relationships among the river discharge, net precipitation and atmospheric water cycle in the present with those in the past.

Data and methods

We used monthly mean river discharges (R) observed near the mouths of the Lena, Yenisei and Ob Rivers from the ArcticRIMS archives, and 4 times daily specific humidity and wind data from an atmospheric reanalysis (JRA25/JCDAS, Onogi et al. 2007) for the period 1979-2008. Because it is difficult to estimate net precipitation (P-E) from direct observations of P and E on large spatial scales, in our analysis, we estimated the net precipitation on the basis of atmospheric reanalysis data without using P and E datasets. We calculated vertically integrated moisture flux using the atmospheric reanalysis and then estimated the net precipitation from the moisture flux and precipitable water by means of the atmospheric water budget method. This is the same method as our previous studies (Oshima and Yamazaki 2004, 2006, Tachibana et al. 2008). In principle, when calculated as an average over a long time period, the net precipitation integrated over the whole river basin area should be nearly equal to the river discharge at the mouth of the river.

Table 1: Long-term mean river discharges of Lena, Yenisei and Ob Rivers (R) and net precipitations (P-E) in each river basin. Two components of P-E transported by mean flow and cyclone activity are also shown. These values are averaged over the past 29 years (1980-2008). Unit is mm/year.

	R	P-E	mean flow	cyclone activity
Lena	228	204	59	145
Yenisei	247	199	112	87
Ob	136	133	127	6

Atmospheric and terrestrial water budgets

First, we evaluated the water budget between river discharge and net precipitation in the three Siberian rivers (Table 1). As expected, on average during 1980-2008, the amounts of net precipitation in the Lena, Ob and Yenisei River basins are comparable in magnitude to the river discharges of each river, while the net precipitations are 10 to 20% smaller than the discharges. Our previous studies already produced good estimates of net precipitation in the Arctic and Antarctic regions (Oshima and Yamazaki 2004) and in the Amur River basin (Tachibana et al. 2008). Therefore, all these results indicate that the estimation of net precipitation using atmospheric reanalysis is an effective way to evaluate and quantify the atmospheric and terrestrial water cycles of a large river basin or at larger spatial scales.

Seasonal cycles

Next, we examined seasonal cycles of the river discharge and net precipitation in the Siberian rivers (Fig. 1). The Lena River discharge shows a maximum in June due to river ice melting. While the precipitation in the Lena River basin shows a maximum in July, the net precipitation shows a minimum at nearly zero flow in that month. This indicates that the evapotranspiration is as large as the precipitation in summer. These features of the seasonal cycles in the Lena River are almost the same as in the Yenisei and Ob Rivers (figure not shown).

In spring, the net precipitations are positive over most areas of the Lena, Yenisei, and Ob River basins (Fig. 2a). This means precipitation is greater than evapotranspiration in these regions. This spatial pattern is almost similar to the climatological precipitation pattern in July (Takashima et al. 2009). These net precipitations are caused by eastward moisture transport associated with westerly jet (Fig. 2a).

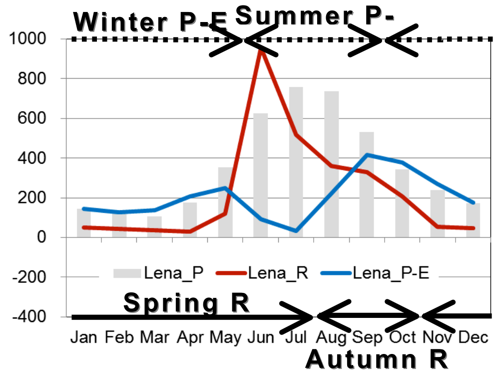

Figure 1: Climatological seasonal cycles of Lena River discharge (R, red) and net precipitation in the basin (P-E, blue). Gray bar denotes precipitation (P) in the basin. Unit is mm/year. Two arrows with solid (dashed) lines drawn along the horizontal axis indicate the periods defined as spring and autumn discharge (winter and summer P-E).

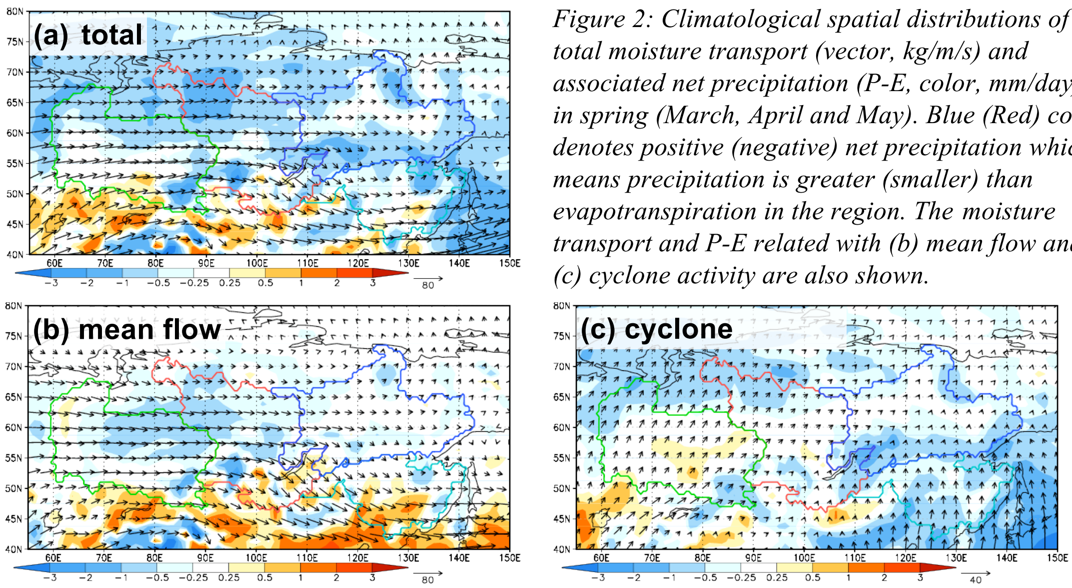

Figure 2: Climatological spatial distributions of (a) total moisture transport (vector, kg/m/s) and associated net precipitation (P-E, color, mm/day) in spring (March, April and May). Blue (Red) color denotes positive (negative) net precipitation which means precipitation is greater (smaller) than evapotranspiration in the region. The moisture transport and P-E related with (b) mean flow and (c) cyclone activity are also shown.

We examined feature of the moisture transport in the following way. The total moisture transport can be divided into two components. One is moisture transport caused with mean flow and the other is moisture transport caused with cyclone activity. The total net precipitations in the Ob and Yenisei River basins (Fig. 2a) show similar pattern of the mean flow component (Fig. 2b), on the other hand, the total net precipitation over the Lena River basin (Fig. 2a) shows almost similar pattern of the cyclone activity component (Fig. 2c). The moisture transports show the same feature. This indicates that, in spring, the total net precipitation in the Lena River basin is mainly caused by the cyclones. These results are almost same as in winter and in autumn (figure not shown). In summer, the net precipitations are negative in the Ob and Yenisei River basins and in the midstream of the Lena River basin. This means evapotranspiration is greater than precipitation in these regions. Spatial patterns of the total moisture transport and total net precipitation show similar to those of the mean flow component. This indicates that the mean flow dominates the total net precipitation and moisture transport in summer.

We can also see these features in the water budgets for each river (Table 1). In the Lena River basin, the total net precipitation is mainly caused by moisture transport associated with cyclone activity. In contrast, in the Ob it is caused by moisture transport associated with the mean flow, while in the Yenisei it is caused by both of cyclone activity and mean flow. The intensity and path of the cyclones show different features in each season (Sorteberg and Walsh 2009). They play an important role for the spatial distributions of moisture transport and associated net precipitation over the Lena River basin and Siberian region in each season.

Interannual variations

We further examined interannual variations of the Lena River discharge (R) and net precipitation (P-E) over the basin. Comparison of the river discharge to net precipitation indicates that, in the Lena River, summer net precipitation quantitatively corresponds to autumn discharge and winter net precipitation corresponds to spring discharge (Figs. 1, 3). The river discharge and net precipitation in each seasonal combination show strong positively correlations (Fig. 3, Correlation coefficients (CC) for each season are as follows. Autumn R and summer P-E, CC=0.87. Spring R and winter P-E, CC=0.72. Annual mean R and P-E, CC=0.85). These variables do not show any significant trends during past three decades (Fig. 3).

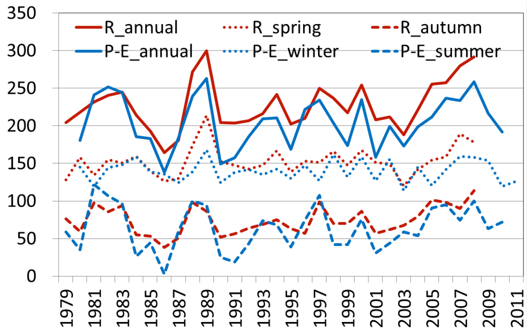

Figure 3: Interannual variations of the R and P-E of the Lena River. R in annual mean (red solid), spring (red dot) and autumn (red dashed) means, and P-E in annual mean (blue solid), winter (blue dot) and summer (blue dashed) means are shown. Unit is mm/year.

We examined moisture transport and net precipitation anomalies related with summer net precipitation over the Lena River basin (Fig. 3) based on the seasonal combination. The result shows that when the net precipitation is large over the Lena River basin, it is small over the Ob River basin. The moisture transports show counter-clockwise pattern over the Lena River basin and clockwise pattern over the Ob River basin. These results are almost consistent with Fukutomi et al. (2003). While they used dataset during 1980s to mid-90s (1979-1995), we used more recent extended dataset during past three decades (1979-2008).

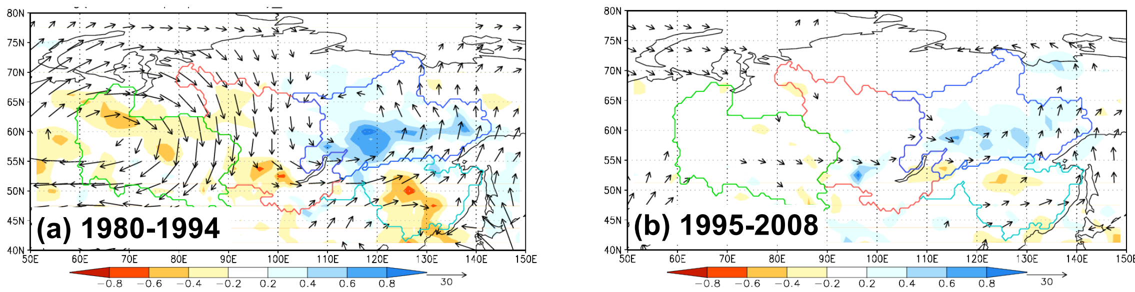

Figure 4: Spatial distribution of moisture transport and net precipitation (P-E) anomalies related with summer P-E in the Lena River basin. Vector and colors indicate the same as in Figure 2. The analyzed time periods are (a) first half (1980-1994) and (b) second half (1995-2008) of past three decades.

To compare the time-series of the net precipitations over the Lena and Ob river basins, we calculated correlation coefficient in 13-year running window during past three decades (figure not shown). As expected from the result of Fukutomi et al. (2003), during 1980s to mid-90s, the correlation is strong negative and the East-West pattern of moisture transports emerges clearly over Siberia (Fig. 4a). However the correlation becomes weak during recent decades. During recent decades, the moisture transport anomalies show weak counter-clockwise pattern only over the Lena River basin (Fig. 4b). There are no significant anomalies over the other regions of Siberia.

In addition, we can use river discharge dataset during past seven decades (1936-2009) and we examined the relationships between the Lena and Ob Rivers using the discharge dataset. Similar to the net precipitation, the correlation of discharges is strong negative during 1980s to mid-90s, while it is weak during recent decades. On the other hand, during 1950s to 60s, the correlation is strong positive correlation. The strong positive (negative) correlation appears only during the period 1950s to 60s (1980s to mid-90s). This indicates that the relationship between the Lean and Ob River discharges are different in each era.

Summary

The observed discharges (R) of the Lena, Yenisei, Ob Rivers are comparable in magnitude to the estimated net precipitation (P-E) over the each basin based on atmospheric reanalysis. The net precipitation in the Lena River basin shows a minimum in summer due to large evapotranspiration in this season. The features of moisture transports are different over the eastern and western Siberia. The net precipitation in the Lena River basin mainly caused by the moisture transport associated with the cyclone activity (Yenisei, both of mean flow and cyclone activity. Ob, mean flow). The autumn Lena River discharge corresponds to the summer net precipitation, while the spring discharge corresponds to the winter net precipitation. They do not show any significant long-term trends during past three decades. The relationship of the summer net precipitations and the autumn discharges between the Lena and Ob Rivers is different in each era, while they show strong negative correlation during 1980s to 90s. This is under way and we need to examine further about what happened in these eras.

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Interannual variation of summer hydro-climate in East Asia

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The hydro-climate condition and its interannual and long-term variations are crucial for considering the resiliance and/or vulnerability of the taiga-permafrost coupled system in east Siberia, since this system is likely to be sensitive or vulnerable to the hydro-climate condition particularly in summer. For example, it has been suggested that the warming condition of 2 degree C or higher in summer in this region is critical for surviving this taiga-permafrost system (e.g., Zhang, Yasunari and Ohta, ERL, 2011). However, few observational studies have attempted to examine this issue, based upon more qualified hydro-climate data (precipitation, moisture flux and its divergence, and atmospheric circulation, etc.).

Here, we examine space-time variability of precipitation and associated atmospheric water balance and circulation for the recent 30 years (1979-2008) when the warming trend is remarkable in east Siberia as well as the whole higher latitudes of the northern hemisphere. A preliminary result has suggested that the interannual variability of the summer hydro-climate of this region is likely to be affected by a couple of the large-scale climate and circulation systems, i.e., the continental-scale atmospheric circulation mode across the whole Eurasia, the Asian summer monsoon variability and presumably the summer Arctic Oscillation. The coupling and/or association of these dominant climate variability modes with the biome, permafrost, topographic and geographic conditions of this region will also be discussed.

Ecosystem function of taiga-tundra boundary in Eastern Siberia

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Larch forest so-called taiga covers a large area of Eastern Siberia, and this forest ecosystem plays an important role in carbon and water cycles for not only regional but also global scale. Moisture condition of this ecosystem is strongly affected by the permafrost existing beneath. Taiga forest coverage is found up to around 70 °N where taiga-tundra boundary ecosystem is formed.

Taiga-tundra boundary is expected to be an important tuning point from methane consumption to emission, and vegetation, moisture condition and material cycling are controlling the functional change and interacted each other. Therefore, growth and physiological condition of larch trees in this region are quite important to know how this ecosystem function will change under warming condition. We thus conducted the observations of year to year variations in tree growth, needle photosynthesis, N dynamics, needle C and N isotope ratios and so on at two areas of taiga forest ecosystems: Spasskaya Pad Experimental Forest near Yakutsk (62N, 129E), where locates in a central place of plain taiga in Lena river basin, and the other is in taiga-tundra boundary near Chokurdakh (70 N, 148 E) in lowland of Indigirka river basin.

Overstory trees observed at both areas are larch, however different species Larix cajanderi and Larix gmelinii are growing at Yakutsk and Chokurdakh respectively. At both areas tree growth depended on moisture condition. Over-wetting caused a fatal damage to the trees at both sites. In addition, observational results showed that moisture condition may affect nutrient dynamics, then tree growth. However, different responses of tree growth and photosynthetic activities were also observed for two areas. In this talk, we will compare the response of larch trees to environmental factors for these two different areas.

Simulation study of the vegetation structure and function in eastern Siberian larch forests using the dynamic vegetation model SEIB-DGVM.

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Key words: larch, carbon cycle, permafrost, dynamic vegetation model

Introduction

Siberian larch forest covers 7.8×10^6 km^2, making it the largest coniferous forest region in the world [Schulze et al., 1995]. With its huge area and vast potential carbon pool within the biomass and soil, this ecosystem plays a major role in the global carbon balance. Because climate models predict that mean annual ground temperatures in eastern Siberia may rise by 2-6°C by 2099 [Sazonova et al., 2004], it is crucial to develop a terrestrial ecosystem model that captures ecosystem dynamics of this region as a function of climate. In this study, we have adapted the Spatially Explicit Individual-Based DGVM (SEIB-DGVM) [Sato et al., 2007] to larch forest at the Spasskaya-pad tower site in Yakutsk, Russia. Unlike previous models for Siberian larch forest (eg, Ito [2005], Beer et al. [2007]), SEIB-DGVM is based on individual trees, and thus it can analyze interactions between stand structure and ecosystem material cycles.

The Model

Detailed description of the SEIB-DGVM is available at Sato et al. [2007]. The spatially explicit model with 30 × 30-m resolution creates a "virtual forest" in which individual trees establish, compete, and die. Trees establish as saplings of 1 cm diameter at breast height (dbh). These individual trees are composed of three organs: the crown and trunk, both of which are cylindrical, and the fine roots that are formless. For each tree, the model simulates light conditions by considering the spatial relationships with other trees and determines the photosynthetic rate of each tree. A grass layer exists under the tree layer. Plant dynamics in the virtual forest work in conjunction with the carbon and water cycles. The computational time step is daily for all physical and physiological processes except soil decomposition, tree growth, tree death, establishment, and wildfires.

We adapted the SEIB-DGVM for a larch forest at the Spasskaya-pad tower site (62°15′ N, 129°37′ E; 220 m above sea level) near Yakutsk, where intensive empirical ecological studies have been conducted. From forest inventory data collected at this forest, we formulated tree height, crown area, and biomass of each organ as functions of dbh. To determine the larch leaf emergence date, a remote-sensing-based parameterization was applied [Picard et al., 2005]. The long-term meteorological dataset of Yamazaki et al. [2007] was employed. This dataset contains daily mean values for 14 yrs, which were repeatedly input into SEIB-DGVM. Note that CO_2 concentration was assumed to be 355 ppm.

Results

Figures 1 and 2 show a typical pattern of forest development after stand replacing fire. Grass leaves quickly appeared and was gradually replaced by trees leaves (Fig. 2a). Tree LAI monotonically increased over the initial 70 yrs and reached equilibrium at approximately 1.7, which is close to observed values. Annual GPP increased after fire and reached equilibrium at 5.2 Mg C/ha/yr after approximately 60 yrs, while annual NPP decreased continually with time (Fig 2b), probably due to that larger trees have lower growth efficiency. On the other hand, aboveground biomass monotonically increased (Fig. 2c). These changes in NPP and aboveground biomass were consistent with field observations. Figure 2d shows simulated changes in the carbon pool. The litter pool was largest at the beginning of the simulation. It then gradually decreased and reached equilibrium after about 70 yrs. These values are within the observed range for larch forests in Yakutsk, although observed SOM carbon varied considerably among stands and soil types; our model did not consider this variation.

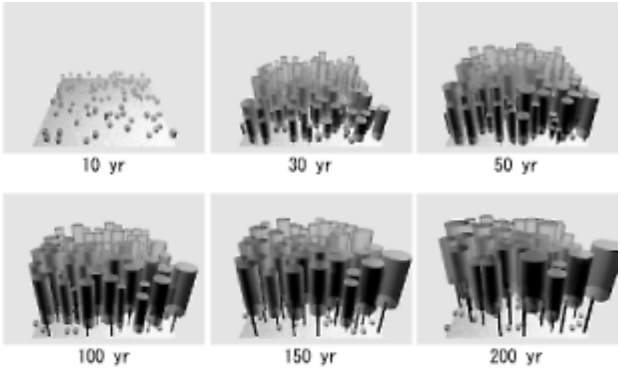

Figure 1. Typical simulated changes in physiology over 200 yrs from bare ground at Spasskaya-pad. Only larch trees were explicitly simulated; other tree species were included in the grass layer, which is not presented here.

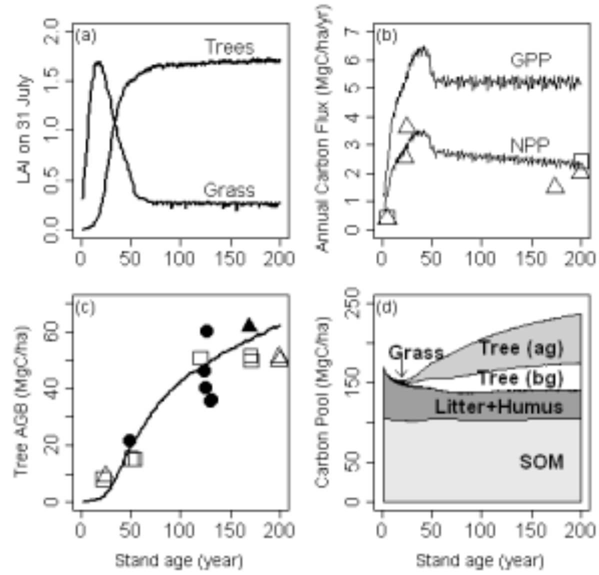

Figure 2. Simulated vegetation dynamics after a stand-replacing fire at Spasskaya-pad. Ten independent simulations were conducted and averaged. (a) LAI of trees and grass on 31 July, (b) annual GPP and annual NPP, (c) aboveground tree biomass, and (e) carbon pool accumulation. Here, ag, bg, and SOM indicate, respectively, carbon within aboveground biomass, belowground biomass, and soil organic matter. Points on the figure show observations.

Figure 3a and 3b compare simulated and estimated seasonal changes in production rates (GPP and NPP). Estimated values were generated from ASCII data subsets of acceptable quality from Moderate Resolution Imaging Spectroradiometer (MODIS) Daily Photosynthesis Products (MOD17) [Running et al., 2000] for the Spasskaya-pad tower site from 2000 to 2006. Both the simulated and estimated NPP dropped about halfway through the growing season (days of year 160~180).

This decline of NPP was likely caused by abundant transpiration (Fig 3c), which reduced water surplus during the growing season. The fact that simulated Bowen ratio is close to field observations (Fig. 3d) indicates that simulated evapotranspiration (transpiration + evaporation + intercepted precipitation) during the growing season is acceptable.

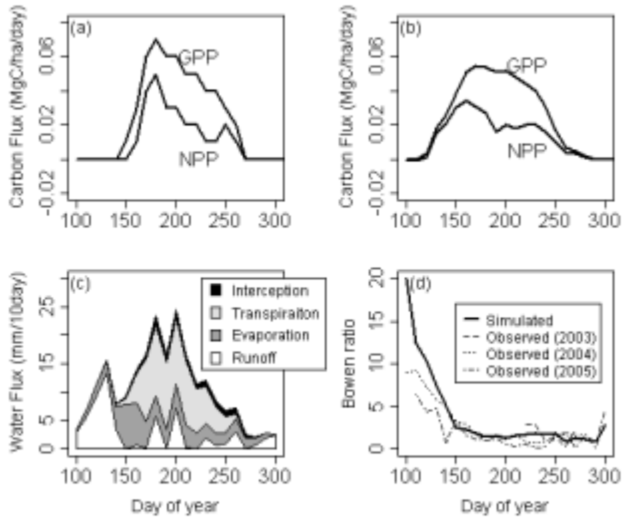

Figure 3. Simulated and observed seasonal changes in ecosystem functions. Simulated results display averages of ten independent runs for a 200-yrs-old forest. (a) Simulated GPP and NPP, (b) estimated GPP and NPP based on MODIS remote sensing data, (c) simulated water flux, (d) simulated Bowen ratio compared with measured values at the Spasskaya-pad tower site [Ohta et al., 2001].

Discussion

SEIB-DGVM produced an appropriate simulation of post-fire development of forest structure and carbon cycling, both of which had been measured empirically around the Spasskaya-pad tower site. The model also provided a reasonable simulation of seasonal changes in carbon and heat fluxes in mature forest. It also reconstructed the declining NPP:GPP ratio with increasing tree size, which is a widely observed phenomenon in forest ecosystems [Kira, 1975; Ryan et al., 2004]. We should emphasize that this analysis of interactions between forest inventory and ecosystem function was firstly enabled by the SEIB-DGVM, which is characterized by its individual-tree-based representation of forest.

Note that this study was published as [Sato et al., 2010], and program code of the SEIB-DGVM is available on Internet (http://seib-dgvm.com/).

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Land cover classification of West Siberian wetlands and its application for estimating methane emissions

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Key words: methane, wetlands, middle taiga, West Siberia

Introduction

Atmospheric methane produces the second-largest radiative forcing among the long-lived greenhouse gases after CO_2. Therefore, estimation of the relative contribution of CH_4 sources to the atmosphere is an important task in addressing the problem of global warming. Since wetlands are considered to be the major natural sources of methane, accurate estimation of its emissions at the regional scale is required. West Siberian wetlands belong to the biggest wetland area in the world with the mire area of 68.5 Mha or 27% of the region area (Peregon et al. 2009). It comprises approximately 12.9% of the global peatlands (Matthews and Fung, 1987). West Siberian CH_4 budget have been studied since 1990 (Glagolev et al., 2000, 2008). Further progress in this field was made recently by chamber method (Glagolev et al., 2011) and inverse modeling (Kim et al., 2011).

Field survey data obtained by chamber method were consolidated by Glagolev et al., (2011) into the methane emissions inventory which is based on flux data, periods of methane emissions and wetland classification map by Peregon et al (2009). Among the factors contributing to the uncertainty of the regional budget is accuracy of the wetland mapping. A number of wetland maps are available for west Siberian wetlands, among them the map by Romanova et al. (1977) appears most detailed, but not directly applicable for methane emission inventory. The area fractions of wetland micro-landscapes (or basic wetland units with different methane emission rates) are necessary for total flux calculations. The map of Romanova et al., (1977) includes only wetland type mixtures composed of several micro-landscape types without the information on its fractional coverage. Peregon et al. (2009) complemented the map by estimating relative ratio of area fractions using high-resolution images for 5 test areas of a Landsat image size to derive zonal area coverage fractions. Further reduction of the mapping uncertainty suggests increasing the number of the test areas or full area coverage with Landsat data, which became easily available recently.

Thus the main goals of this study are: (1) to develop a new wetland map based on Landsat imagery; (2) and to apply it for estimating the total CH_4 emission of middle taiga zone as a case study.

Materials and methods

Middle taiga zone was chosen for the case study as it has the largest relative mire area in West Siberia. It belongs to *raised patterned ridge-hollow landscape* mire zone (Kats and Neishtadt, 1963). Distinguished micro-landscapes are predominantly belonged to these landscapes.

Ridge-hollow complexes commonly occupy watersheds. They have a peat layer of several meters deep which is composed by sphagnum peat with small addition of other plants. Since these wetlands are growing on surface, a relief composed of well-developed central plateau with gentle slopes is formed. Central plateau depressions with stagnant water usually include groups of secondary lakes. Dryer complexes consisting of narrow ridges and vast hollows instead of lakes occupy better drained gentle slopes. The most drained sites are dominated by dwarf pines with shrubs and sphagnum mosses ("ryam"). Finally, poor fens and fens develop along the wetland edges characterized by low lateral water flow and relatively high nutrient availability (Kats and Neishtadt, 1963).

To map of West Siberian wetlands we used Landsat-5 and Landsat-7 images. Since the vegetation of West Siberian plane includes various types of forests, meadow, burnings, agricultural fields and others, so for prevention of misclassification, wetland environments were distinguished from other landscapes using Green-Red (GRVI) and Normalized Difference (NDVI) vegetation indices (Motohka et al., 2010). Wetlands were predominantly distinguished using GRVI, while NDVI were used to make lake mask. Mask noises were further filtered in MatLab using generalization algorithm.

Masked image supervised classification was carried out in MultiSpec using 4-5 and 3 spectral bands. Different mire types were recognized by color, relative position within a landscape, shape and its spectral signature. As far as possible, high-resolution QuickBird images were used for map classification and verification. To train wetland landcover classification algorithm ground-truth data including detailed botanical descriptions with photographs of each site, pH and electrical conductivity data were used. Available cartographic materials and another published data (Liss et al. 2001, Usova, 2005, Lapshina, 2003) were also used. More than 50 land cover classes were discriminated during classification and further generalized to several wetland types. Classification errors were calculated for reference areas. When the error for any wetland type reached 20% reference areas were modified. Classified image was also filtered using generalization algorithms. Fifteen classes of wetland environments were designated during the classification and then generalized into 6 micro-landscape types which were further used in CH_4 flux calculations:

1. Ombrotrophic hollows or open bogs: open parts of ridge-hollow landscapes forming in gentle slopes perpendicular to water flowing. Water table is near the surface.
2. Ridges: wooded parts of ridge-hollow landscapes. Water table is about 20-40 cm below the surface.
3. Ryams or wooded bogs: pine-shrub-sphagnum landscapes occupying areas with the best drainage. Water table is about 30-50 cm below the surface.
4. Lakes: parts of ridge-hollow-lake landscapes occupying its central plateau with water stagnation.
5. Floating mats: flooded parts of different wetland landscapes.
6. Fens: nutrient rich landscapes. They include poor fens with the moderate nutrient supply, fens with the high nutrient supply and sogras or wooded fens.

Poor fens, fens and sogras were combined to the single class for methane emission calculations since they have similar flux rates.

The total methane emission was estimated by multiplying the average emission rates of the mire micro-landscape types with the fractional area coverage of each ecosystem types, and the periods of methane emission in each zone. Bc8 emission inventory (Glagolev et al., 2011) was used for estimating total methane flux. Middle taiga mire area of 19.5 Mha (Peregon et al., 2009) was used in both wetland area calculations.

Results and Discussion

Comparison of wetland area fractions by two maps and its application for CH_4 emission estimation are shown at Table 1. In consequence of new wetland map application, we obtained 130% higher methane emissions from middle taiga zone. Such considerable revision of emission estimation is directly related to the variations in relative area fractions of strongly and weakly emitting landscapes. The less important CH_4 sources regardless of their area are relatively dry landscapes as ryams and ridges. They emit only 0.03 and 0.13 $mgC\cdot m^{-2}\cdot h^{-1}$, respectively. According to Romanova's map upgraded by Peregon et al. (2009) these landscapes are fully dominating in middle taiga zone accounting for 75.8% of the mire area. This study revealed that ryam and ridge area became one and a half times fewer; these landscapes presently cover 46.2% of the mire area. Moreover, the ridge area didn't change while the ryam area decreased from 54% to 27%.

Remaining 30% were redistributed between such intensively methane emitting landscapes, as fens and floating mats contributing additional 0.63 MtC/yr to the regional flux.

Despite the considerable methane emission increase, new estimation is justifiable. Map by Romanova et al (1977) was based on topographic maps which were further extended by detailed wetland classification using aerial photographs. Finally, 25-km scale map which is applicable only for detection of large wetland landscapes was created. In the middle taiga zone these mire landscapes are presented by ridge-hollow complexes including ryams as a significant part of them. However, fens found to be so important at the regional scale are commonly developing as a number of small areas with stagnant water or wetland waterstreams. Probably, majority of them were misclassified by aerial photographs or not revealed.

Table 1. Comparison of wetland area fractions and its application for estimation of CH_4 emission (Middle taiga mire area in both cases was accepted as 19.5 Mha (Peregon et al., 2009)).

Micro-landscape type	Area, %		Total flux, tC/yr		$mgC \cdot m^{-2} \cdot h^{-1}$
	This study	Romanova et al. (1977)	This study	Romanova et al. (1977)	
Water	8.9	3.8	32896	13906	0.49
Floating mats	8.7	2.5	314663	90124	4.72
Hollows	18.8	17.2	394563	361484	2.76
Ryams	27.1	54.1	5474	10919	0.03
Poor fens and fens	17.2	0.8	423571	18502	3.22
Ridges	19.1	21.7	18734	21321	0.13
SUM			$1.19 \cdot 10^6$	$0.52 \cdot 10^6$	

This inaccuracy was worsened by Peregon et al. (2009). Their wetland inventory didn't take into account middle taiga poor fens at all and fen areas were found to be too small. Ground-truth data suggest the fens and poor fen area was underestimated in former maps, too.

Landsat imagery provides multispectral capability and has a high resolution. It makes possible to calculate different vegetation indices which are frequently used for distinguishing of high and low productivity environments, such as fens and ryams. Comparison of considered wetland classifications for the same area is shown at Figure 1.

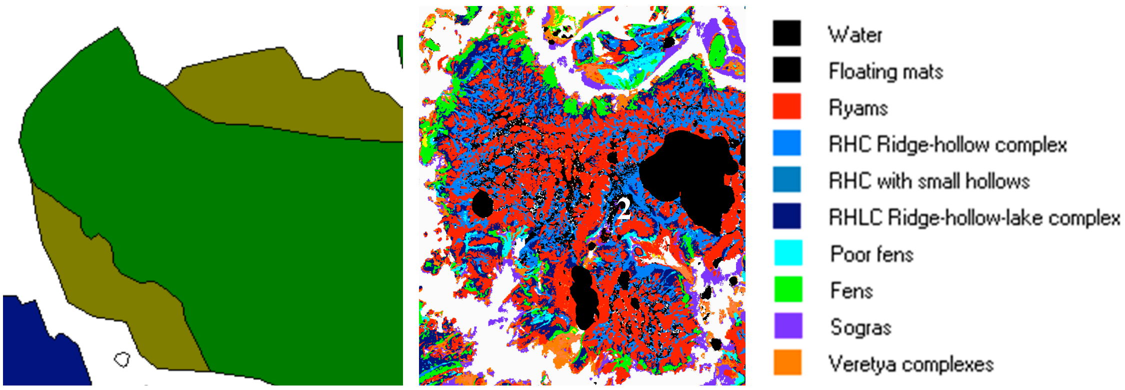

Figure 1. Comparison of the two wetland classifications for the same area (about 20 km width).*
* Maps have different projections: left - Romanova et al., (1977), right - new wetland classification map.

Finally it seems probable that the total methane emission from West Siberia mires accounting 2.93 $TgC \cdot yr^{-1}$ was also underestimated and will increase after applying new map. According to that estimate, West Siberian mires contribute 2.4% to the global CH_4 emission from mires.

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Validation of methane emission model using eddy covariance observations and footprint modeling

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Key words: CH_4 emission, eddy covariance, footprint modelling

Introduction

Several methane emission models were developed recently to quantify methane emissions. However, calibration of these models is currently performed using chamber flux methane measurements, which have a number of limitations, such as small footprint area and low temporal resolution. Furthermore, chamber measurements are unsuitable to register ebullition events, which can have a significant influence on observed fluxes. Eddy covariance measurements on the other hand provide high frequency (5 to 20 Hz) data and cover larger areas, while being a non-intrusive way to measure fluxes and account for ebullition.

In this study, we present a validation of methane emission model using eddy covariance data, collected in summer periods at the Indigirka lowland site in Eastern Siberia. The *Kormann & Meixner, 2001* flux footprint model was used together with a high-resolution vegetation map, of the area, to retrieve vegetation distribution within the flux footprints. Subsequently, this information with eddy covariance data is used to validate methane emission model.

Site and methods

Site description

The site (70°49′44.9″N, 147°29′39.4″E) is located approximately 30 km northeast of Chokurdakh – a settlement on Indigirka River in North-eastern Siberia, Russia (Figure 1). It is an Arctic tundra area with developed polygonal structures, underlain by continuous permafrost. Vegetation distribution is influenced by the hydrology of the site, with *Betula nana* and *Salix pulchra* occupying dryer areas, sedges such as *Arctagrostis latifolia, Eriophorum angustifolium* and *Carex aquatilis* dominating wet areas with *Sphagnum* in transition areas.

Methane emission model

PEATLAND-VU model was calibrated with methane flux measurements, collected using technique described by *van Huissteden et al., 2005*. It is a process-based model of CO_2 and CH_4 emission and consists of four submodels: a soil physics submodel, a CO_2 submodel, a CH_4 submodel and an organic production submodel (*van Huissteden et al., 2006*).

Eddy covariance

EC setup included Gill R3-50 ultrasonic anemometer, LI-7500 CO_2/H_2O gas analyser, and LGR DLT-100 fast methane analyser. All the instruments were positioned 4.7m above ground. Data collection frequency was 10 Hz and averaging period 30 minutes. Fluxes were calculated following *Aubinet et al., 2000* Euroflux methodology. The data was then screened for atmospheric stability ($-3 < z_m/L < 3$) and turbulent friction velocity ($u_*/u < 1$) to limit the dataset to conditions, where footprint model shows plausible results.

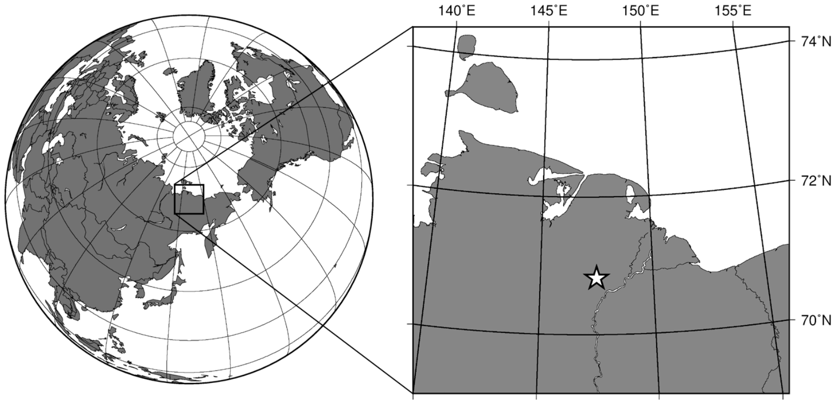

Figure 1. Location of the Kytalyk research site.

Flux footprint model

Flux footprint model by *Kormann & Meixner, 2001* was employed for footprint analysis. It is a purely analytical approach for estimation of flux footprints. This model uses power-law profiles for vertical distribution of wind velocity and eddy diffusivity, and Gaussian distribution of footprint function in crosswind direction. Two-dimensional footprint function can be expressed as:

$$\phi(x,y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y}{\sigma}\right)^2} \times \frac{1}{\Gamma(\mu)} \frac{\xi^\mu}{x^{1+\mu}} e^{-\xi/x}, \tag{1}$$

Vegetation map

The high-resolution vegetation map used in the analysis was derived from GeoEye-1 image taken on 19th of August 2010. Thirty-one validation plots were used as ground truth data for supervised classification. Maximum likelihood classification algorithm implemented in ENVI software package was used.

Results and Discussion

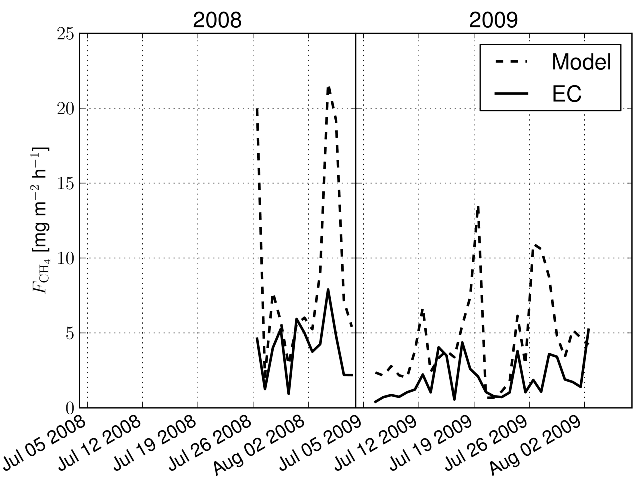

Figure 2. Comparison of modelled flux vs. eddy covariance flux data for years 2008 (left) and 2009 (right). Modelled flux is indicated with dashed line, eddy covariance flux - with solid line.

In Figure 2, the comparison of methane flux measured by the eddy covariance system (solid line) vs. PEATLAND-VU model flux (dashed line) is shown for 2008 and 2009. Both observed and modelled fluxes show high day-to-day variability. The results obtained from the model were consistently higher, with occasional overestimations up to three times, than the eddy covariance flux. The model, despite the mismatch, captures temporal variability. We hypothesize that overestimation of the model can, at least partially, be explained by different contribution of unit source areas to the total flux depending on their positions in footprint.

Conclusions

PEATLAND-VU model was able to capture temporal variability of methane fluxes despite mismatch. The model tends to overestimate methane emissions with maximum of up to three times the eddy covariance flux.

However improved methodology is required to perform accurate validation. It is necessary to weigh unit source areas within the flux footprints according to footprint function in order to better reflect contribution of these areas to total flux.

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Increased greenhouse gas emission from thaw ponds in Siberian Arctic tundra on continuous permafrost

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CO_2, CH_4, permafrost, thaw pond, vegetation succession

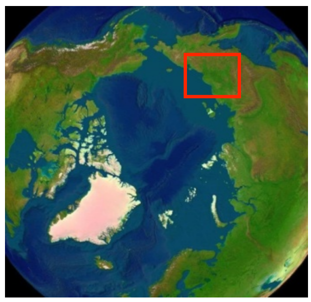
Introduction

Rising global temperatures threaten the stability of continuous permafrost environments, which is estimated to contain twice the current level of atmospheric carbon. Permafrost thaw and decomposition of previously frozen organic carbon is considered one of the most likely positive climate feedbacks of terrestrial ecosystems.

Accelerated permafrost degradation will be experienced on both a large scale and small scale phenomena, such as the expansion of thaw lakes, superficial pond formation and increased occurrence of mass wasting sites. The increased occurrence of small thaw ponds could create a potential positive feedback, increasing the degradation of permafrost, releasing carbon stores within the ice, while also creating ideal anoxic conditions for methane producing bacteria as the water level rises. Therefore the level of carbon dioxide (CO_2) and methane (CH_4) emission is expected to increase in northern high latitudes due to permafrost degradation.

The development of thaw pools will impact on the vegetation populations within the immediate area, causing die back of shrubs and the resetting of vegetation succession. This resetting of vegetation succession and the various subsequent stages of succession is likely to impact on the rate of greenhouse gas emissions (GHG) from newly formed thaw ponds. Therefore it is essential to understand exactly how the different vegetation type will impact GHG fluxes due to these newly formed thaw ponds. The aim of this study is to quantify the number of ponds formed due to climate change induced permafrost degradation and to measure GHG fluxes from these thaw ponds in order to determine the impact of different invading vegetation types may have on the GHG fluxes.

Site and methods



The Kytalyk research station is located in Indigirka lowlands of Northeast Siberia. This area is located on the drained bed of an Early Holocene thaw lake. The area is characterised by the presence of low palsas (flat ice mounds), covered with mosses and *Betula nana*. The edges of these palsas are subject to frequent thawing, creating shallow ponds with decaying palsa vegetation, sedges and sphagnum species. The increased number of thaw ponds was determined using high resolution satellite images from 1977 (American Keyhole project image) and from 2010 (Geoeye). The GHG fluxes from ponds and vegetation plots were measured using an Innova 1312 photo-acoustic gas analyzer, employing the chamber method.

Results and Discussion

Comparisons of these two images showed that the number of thaw ponds has increased three fold since 1977. Flux measurement showed elevated emission of CO_2 and CH_4 from a selection of these ponds. A fresh pond containing decaying *Betula nana* showed fluxes of 261 mg CO_2 m^{-2} hr^{-1} and 29.6 mg CH_4 m^{-2} hr^{-1} in the summer of 2010 and 113 mg CO_2 m^{-2} hr^{-1} and 4.62 mg CH_4 m^{-2} hr^{-1} in 2011, significant levels of N_2O fluxes were not detected. However, a decrease of greenhouse gas fluxes occurred when *Carex* and *Eriophorum* (sedges) and sphagnum species began to invade these ponds. The CH_4 emissions of these vegetation types were still high but they were compensated by the rapid CO_2 uptake.

Conclusions

Preliminary results indicate that the resetting of vegetation succession due to thaw pond formation and each subsequent stage of succession may impact differently on the level of GHG fluxes from these ponds. As the largest source of CO_2 and CH_4 comes from the initial loss of *B. nana,* due to decaying vegetation, it is important to determine the extent that this vegetation type may be susceptible to permafrost degradation and the subsequent rate of ecosystem recover. Therefore it is expected that the GHG emission from this type of shallow permafrost degradation is strongly influenced by the rate of degradation and the ecosystem recovery rates. The study of these ponds is crucial to increase our understanding of carbon dynamics in this delicate ecosystem in the context of predicting the likely impacts of anthropogenic climatic change.

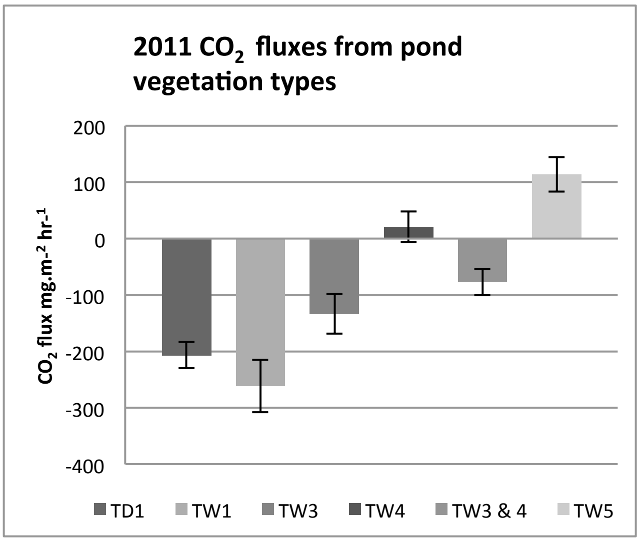


Figure 1. Mean CO_2 fluxes from a range of vegetation types taken in 2011, error bars indicate standard error.

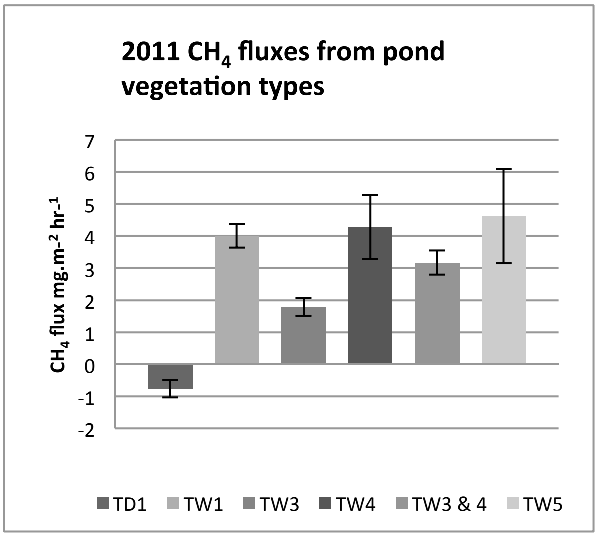


Figure 2. Mean CH_4 fluxes from a range of vegetation types taken in 2011, error bars indicate standard error.

Table 1. Vegetation classification, based on the dominant vegetation type.

	Vegetation Classification
TD1	Palsa/polygon ridge, with *Betula nana*
TW1	Depression/drainage channel/pond, sedges, *Eriophorum*
TW2	Thawing ice wedge, pond, standing water
TW3	Depression / pond with Sphagnum hummocks
TW4	Pond with submerged Sphagnum
TW5	Pond with decaying *Betula nana*

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The importance of ecosystem recovery for quantification of greenhouse gas fluxes from permafrost degradation

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Key words: carbon cycle, greenhouse gas, permafrost degradation, ecosystem

Introduction

Arctic soils contain large amounts of organic carbon (Tarnocai et al., 2009). This arctic soil carbon pool is highly vulnerable. Future climate change is strongest in the Arctic and may cause the release of an unknown part of its carbon to the atmosphere as either CO_2 or CH_4, further exacerbating global warming. This is known as the arctic carbon feedback.

Typical permafrost degradation features such as thaw lakes and ponds or active layer slides may emit large quantities of greenhouse gases (GHG), as demonstrated by flux measurements (e.g. Walter et al., 2006; Turetsky et al., 2007). However, these permafrost degradation features have a finite lifetime. After a certain number of years, vegetation may be re-established, decreasing the GHG fluxes and possibly restoring GHG sinks. Quantification of greenhouse gas fluxes from permafrost degradation rarely accounts for this lifetime. We demonstrate, that such a recovery of ecosystems is highly important to quantify the arctic carbon feedback.

Permafrost thaw and greenhouse gas emission

Our examples are derived from the Kytalyk research station near Chokurdagh, This area is located in the drained basin of an Early Holocene thaw lake (Van der Molen et al., 2007). The area is characterised by the presence of low palsas (flat ice mounds), covered with mosses and *Betula nana*. The edges of these palsas are subject to thawing, creating shallow ponds with decaying palsa vegetation. The increased number of thaw ponds was determined using high resolution satellite images from 1977 (American Keyhole project image) and a 2010 (Geoeye). The GHG fluxes from ponds and vegetation plots were measured using an Innova 1312 photo-acoustic gas analyzer, using the static chamber method (Van Huissteden et al., 2005; Gallagher et al., 2012).

In the area the number of thaw ponds is rapidly increasing, it has increased threefold since 1977. However the ponds are also colonized by vigorously growing *Carex* and *Eriophorum* after some time (Figure 1). Probably the high production of these species is stimulated by increased nutrient availability. Linking the emission data from Gallagher et al. (2012) to succession stages, it shows that open water in the ponds is a source of CO_2 and CH_4. After invasion of *Carex* and *Eriophorum*, the CO_2 flux is reversed and compensates for the high CH_4 flux from this type of vegetation. At a hypothetical later succession stage, CH_4 emission may decrease by establishment of a *Sphagnum*-dominated vegetation. Similar successions have been described by Turetsky et al. (2007).

Thaw lakes are also expanding in the area. Active thaw lakes are large sources of CH_4 (Walter et al., 2005). The satellite images show expansion of a thaw lake approximately 20 m into an adjacent ice-rich yedoma ridge. Van Huissteden et al. (2011) modelled thaw lake expansion, and showed that it is strongly limited by drainage of lakes after contact with rivers. After drainage and re-establishment of vegetation in the lake bed, the GHG balance may be near neutral or negative (Van der Molen et al., 2007).

Similarly, permafrost active layer slides associated with slopes near lake or river banks, laterally export carbon. However, stabilization and re-vegetation results in the establishment of a high brush vegetation, which is (although difficult to measure) likely a carbon and GHG sink. The vegetation growth may be stimulated by increased nutrient availability.

Figure 1. Typical thaw pond with decaying Betula nana in the middle, from the sides it is invaded by Carex/Eriophorum vegetation. The palsa is situated in the right background (dark green Betula nana vegetation.

Model

The data from the Kytalyk site show that permafrost degradation tend to stabilize after some time, resulting in regrowth of vegetation. In this case GHG emission is strongly reduced, or the sites may become a carbon and GHG sink. We developed a simple model to illustrate the importance of these recovery effects.

Suppose that a permafrost thaw feature *P* (thaw pond, drained lake, active layer slide et) with a maximum greenhouse gas (GHG) flux $F_{P,\,avg}$ (averaged over all *P*) is subject to a vegetation succession that restores a near-neutral greenhouse gas balance ($F_P = 0$) after some time. We distinguish two possible cases: an exponential decline for F_P ($F_P = e^{-at}$, a constant, case A), or a temporary GHG sink such as in a newly established forest ($FP = e^{-at} \cos bt$, a and b constant, case B). This is contrasted with a constant GHG source without recovery (case C). Next assume that due to increasing climate warming, the number of newly forming *P* increases linearly with a factor of 0.1 per year starting with 1 per year per unit area. Then case C would result in an exponential growth of GHG emission, while cases A and B result in an increase to a much lower emission level (Figure 2).

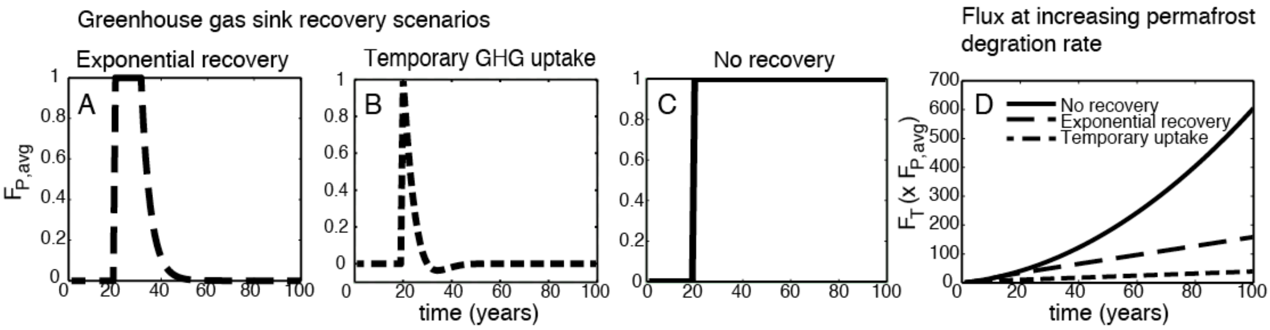

Figure 2. Scenarios for decrease of GHG source by vegetation succession after permafrost degradation. A: exponential decreasing GHG source. B: Exponential decrease followed by temporary net uptake. C: no recovery, constant GHG source. Vertical axis: unit emission. D: Effect of vegetation recovery scenarios in A, B or C on GHG emissions of permafrost degradation, assuming a linear increase of the incidence of permafrost degradation features with time.

Conclusions

The large differences in GHG emission between these cases clearly demonstrate that a better understanding of the life cycle of permafrost degradation is urgently needed to improve models. The study of paleo-successions may be very helpful in this respect. For instance, ancient thaw lake sedimentary successions dating from the Last Glacial have been found in Europe and Siberia (e.g. Van Huissteden, 1990). Likewise, peat successions contain a history of permafrost degradation in boreal and arctic peatlands.

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Removal of *Betula nana* causes permafrost degradation and triggers changes in geomorphology and hydrology

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In 2007 a removal experiment was started. In this experiment *Betula nana* was removed in circular plots of 10 meter diameter. Due to the large plot size, the removal of *Betula nana* caused an increase in thawing depth and degradation of the permafrost. In 2011 we measured that the surface in the removal plots has subsided and resulted in wetter plots. The surface subsidence is explained by the presence of pure ice layers that disappeared after increasing the thawing depth. In the wetter removal plots we measured an expansion of graminoids and limited regrowth of *Betula nana*, as the wet circumstances in the removal plots are more beneficial to graminoid vegetation. It is amazing that a disturbance in the vegetation causes such a rapid chain of reactions resulting in a totally different environment. This also emphasizes the vulnerability of the tundra ecosystem to disturbances.

Analysis of water, heat and carbon balances over the Siberia region by using biosphere model BEAMS

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Key words: carbon cycle, permafrost, biosphere model, BEAMS

Introduction

The last three decade records of surface and air temperature changes clearly indicate that global warming has been most significant in the high latitude areas. Warming will be further enhanced in the high latitude areas according to the projected surface and air temperature changes for the 21st century (IPCC, 2007). Land surface processes in Siberia are drastically changing due to the climate change. Recent studies relevant to Siberia suggest that the changes of land surface processes (snow, soil moisture, soil heat, permafrost) with the climate change are giving a large influence on the terrestrial carbon cycle via plant activities and soil microbe. For instance, if snow melting increases, soil moisture also increases that possibly activates plant photosynthesis. On the other hand, snow cover blocks carbon dioxide emission from soil to the atmosphere, temporally stores carbon dioxide in snow, and releases it when snow melts (Fahnestock et al., 1998). Snow cover has an insulation effect that possibly changes the soil decomposition rate (Zhang, 2004) as well. An active layer, a thin layer overlying permafrost, seasonally thaws during the summer and freezes in the winter, is an important component in the water, heat and carbon cycles in Siberia. In frozen soil, there are no carbon fluxes among the atmosphere, soil, and litter (Edward et al., 2008). When the active layer thaws, soil moisture increases and plant photosynthesis is activated. The objectives of this study are to develop a terrestrial biosphere model including the multi-layer water and heat transport processes and to assess the interaction of the water, heat and carbon cycles in Siberia.

Methods

We estimated spatial and temporal patterns of the water, heat and carbon fluxes in Siberia with the improved BEAMS (Biosphere model integrating Eco-physiological And Mechanistic approaches using Satellite data) (Sasai et al, 2005, 2010).The BEAMS is a diagnostic terrestrial biosphere model with inputs of remotely sensed data. The processes newly integrated into the BEAMS are; (1) a snow cover fraction to describe restrictions by snow cover on carbon emission from soil to the atmosphere and (2) multi-layer soil heat and water processes to describe an active layer (Fig. 1).

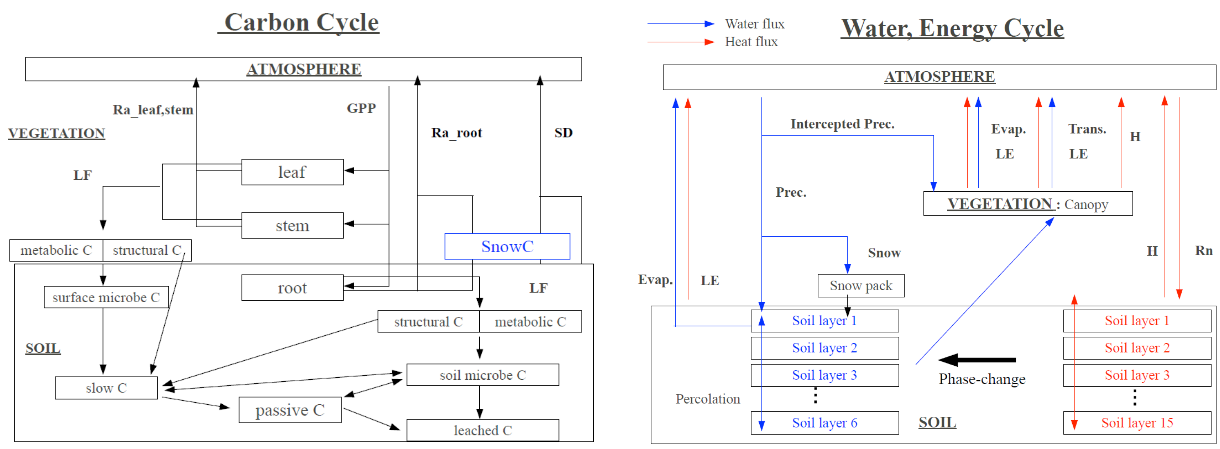

Figure 1. Model structures of carbon cycle and water and energy processes in the improved BEAMS.

In order to describe the effect of snow cover on carbon cycle, we introduced a snow cover fraction into the BEAMS model. Since snow cover largely restricts soil respiration in a heavy snowfall area, we divided one pixel into snow-covered and non-snow subgrid areas by using a snow cover fraction (Takata et al., 2003). In a snow-covered area, we added a snow carbon pool between snow pack and soil into the carbon submodel, and calculated carbon emission from soil surface via snow pack (Fahnestock et al, 1998). To describe the soil condition of an active layer, we added 15 soil heat pools and 6 soil water pools into the energy and water submodels to calculate soil temperature and soil water contents. Soil temperature is calculated with the one-dimensional thermal equation, and soil water contents are calculated with the Darcy's law. Interactions between soil heat and soil water are described with thermal conductance, heat capacity in soil, and soil water melting and freezing.

For the purpose to study the regional carbon flux, the improved BEAMS was operated with 10km grid resolution by using satellite, climate, and soil datasets from 2001 to 2010 over Siberia. The study area is northern Eurasia (N45°~N80°, E60°~W170°). Table 1 shows a list of the input data sets.

Table 1. Input datasets for regional analysis.

Parameter	Dataset Name
LST	MOD11A2, MYD11A2
fPAR, LAI	MOD15A2, MYD15A2
Albedo	MOD43B3
Air temperature	NCEP/NCAR reanalysis
Incoming solar radiation	MODIS PAR product
Wind speed	NCEP/NCAR reanalysis
Relative humidity	NCEP/NCAR reanalysis
Precipitation	NCEP/NCAR reanalysis
Atmospheric CO_2 concentration	Observation at Mauna Loa
Elevation	ASTER GDEM, SRTM, GTOPO30
Soil texture	FAO soil texture group
Land cover map	MOD12Q1

Results and Discussion

The improved BEAMS was validated by the ground measurement data obtained at two flux sites; Spasskaya Pad (SPA) and Elgeeii (ELG) in Siberia. Figures 2 and 3 show comparisons of the soil temperature at 20cm depth and the net ecosystem production (NEP) measured at the flux sites and the estimation derived from the improved BEAMS. They coincide well for both annual and inter-annual patterns. It was also confirmed that the BEAMS showed reasonable seasonal and annual patterns of the soil moisture contents and latent heat flux, although there seems to be a room for further model improvement.

The total NEP was estimated at 185.7MtC/year for the whole study area (Fig. 4). This means that the Siberian terrestrial ecosystem played a roll as a carbon sink from 2001 to 2010. NEP decreased in the west area and increased in the east area, and the total increase was +4.37MtC/year for the whole study area. In the recent 10years from 2004 to 2010, carbon uptake of this area had been increasing and the terrestrial ecosystem had been growing larger as a carbon sink.

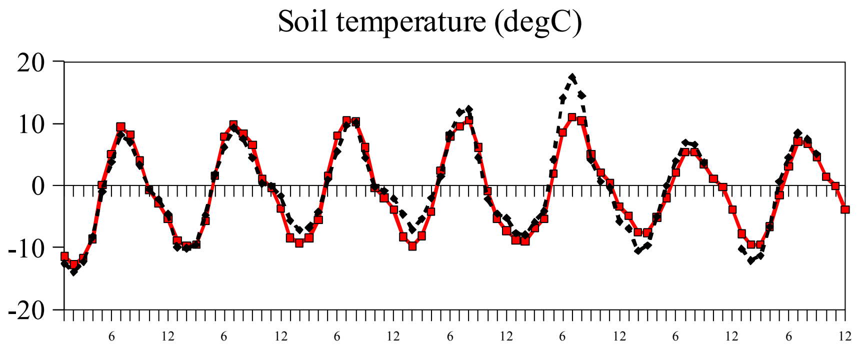

Figure 2. A comparison of soil temperature between the ground measurements (black line) and model estimation (red) at Spasskaya Pad (SPA) from 2004 to 2010.

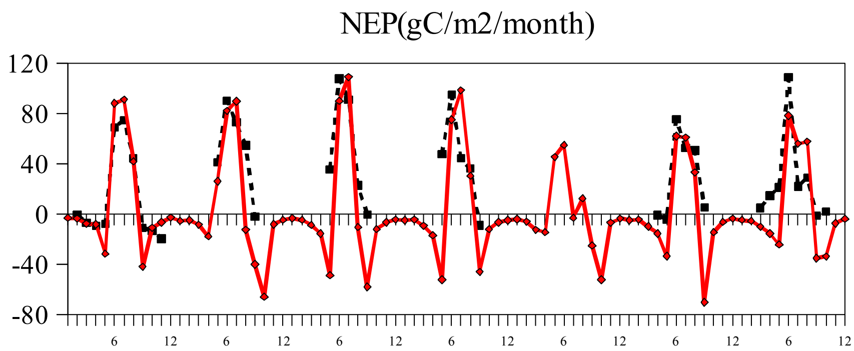

Figure 3. A comparison of NEP between the grand measurements (black line) and model estimation (red) at Spasskaya Pad (SPA) from 2004 to 2010.

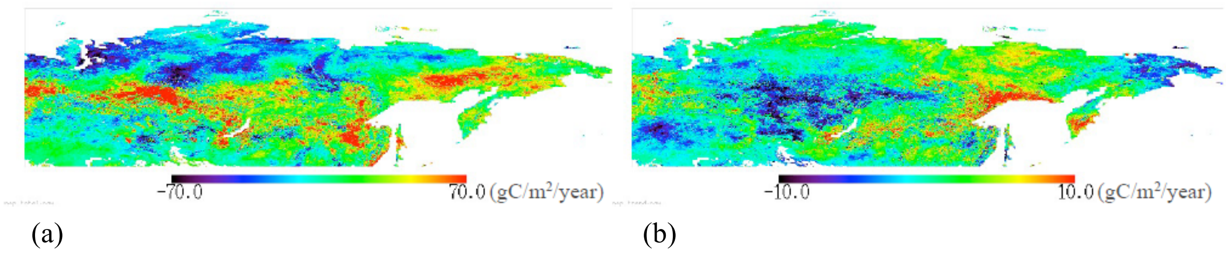

Figure 4. Spatial patterns of NEP; (a) yearly total average, and (b) rate of annual change.

The trend analysis of the input parameter and model outputs indicated two major control factors on NEP and GPP in Siberia (Fig. 5). Namely (1) the change of precipitation indirectly affected on the carbon cycle by controlling active layer thickness and soil water, (2) fPAR and solar radiation directly controlled the photosynthesis activity. Particularly fPAR was the controlling factor in 2004, while wind speed in 2008. NEP was less sensitive to LST and temperature despite their large fluctuations. According to the sensitivity analysis, relative contributions to NEP as controlling factors are; fPAR >> solar radiation, wind speed, surface temperature, vapor pressure > air temperature >> precipitation, LAI, albedo. Whether the Siberian ecosystem was a carbon sink or source changed by a year.

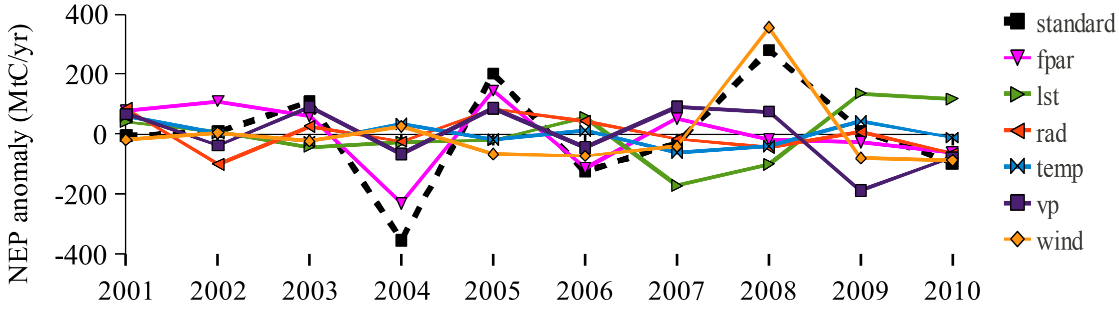

Figure 5. Sensitivity analysis; factors of NEP change.

Conclusions

The carbon fluxes in Siberia were estimated by the improved BEAMS, which was modified to include the water and heat transportation processes. The Siberian terrestrial ecosystem was a carbon sink in 2001 to 2010 (185.7MtC/year), and the carbon uptake by the ecosystem had been increasing at 4.37 MtC/year. The active layer depth increased in east and decreased in west of the study area. This difference might be mainly due to the surface temperature change. fPAR was the strongest controlling factor to NEP, but wind speed largely contributed in 2008.

Our remaining tasks include further improvement of the model such as carbon fluxes in the frozen soil, overall accuracy improvement, and addition of other processes. We also plan to make a comparison of the regional analysis with other studies.

Acknowledgements

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The Water Balance of Thawing Lakes in Central Yakutia

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Key words: permafrost, thermokarst, ground ice, water balance

Introduction

Starting from 1992 the RAS SB Melnikov Permafrost Institute monitored the dynamics of young thermokarst depressions at the Yukechi site located 50 km to the southeast from Yakutsk at the right bank of the Lena River.

The studied thermokarst depressions are represented by young formations the occurrence of which is associated with anthropogenic activity. Thermokarst subsidence is not defined in the air photos of 1944 yet, but some inhomogeneities of the plough land can be already seen in 1952 air photos. By the beginning of our monitoring in 1992 the relative depth of thermokarst depressions was about 2 m. The water depth in the deepest channels between high-centered polygons reached 0.8 m. In most locations the depth was 0.4-0.6 m.

The studied site is an alas landscape typical of Central Yakutia. The deposits are represented by an ice complex with ice wedges. Dusty clayey silt and silt, sometimes with dusty fine- and small-grained sand interlayers prevail in the composition of upper Quaternary horizons. Ice wedges are developed within inter-alas areas throughout the territory. Ice wedges occurs at a depth of 2-2.5 m. The width of the upper part of ice wedges varies from 1-1.5 to 2.5-3 m. The cross dimension of ground blocks between ice wedges usually does not exceed 4-6 m in plan. The thickness of the ice complex is 20-25 m.

Our monitoring of the Yukechi site between 1992 and 2010 shows that thermokarst development rates are quite intensive. For example, the average surface subsidence rates in the major observed thermokarst depressions made 5-10 cm per annum. The maximum subsidence made about 2 m in the absolute value; the water depth grew from 0.4-0.6 to 2-2.5 m. The area of deep young thermokarst lakes got wider by 2.5 times. These changes began to influence the landscapes structure.

Site and methods

The work was completed on the basis of the data generalization of cryogenic landscapes comprehensive monitoring for the Yukechi site in Central Yakutia (1992-2008), and the relative estimates.

We used the following equation for the young thermokarst lake water balance to evaluate cryogenic landscapes development and transformation trends. The equation takes into account climatic, geocryological, hydrogeological, hydrological, landscape and other conditions and factors:

$$W_{lk}=(P_{pr}+W_{ic}+S_s+W_{sp}+C)-(E_o+E_{sn})$$

where W_{lk} – water balance of the growing thermokarst lake; P_{pr} – amount of precipitation; W_{ic} – waters from ice complex thawing-out; S_s – surface runoff; W_{sp} – suprapermafrost runoff; C – condensation; E_o – evaporation from the water surface; E_{sn} – moisture evaporation from the snow surface.

The main water supply sources include atmospheric, surface and suprapermafrost runoffs, and permafrost supply. Atmospheric supply was evaluated on the basis of the precipitation amount at the nearest Yakutsk weather station. Surface water runoff determining the slope supply type was studied in due course (Chistyakov 1964, Buslaev 1981). The runoff coefficient for Central Yakutia makes on average 10-20% from the total precipitation volume. The suprapermafrost runoff in represented by active layer water inflow from the catchment basin area. Permafrost is supplied with water through the thawing-out of ice wedges and ground texture ice. The average volumetric ice content of these deposits makes 0.5 and 0.2 for the specified ice varieties respectively. The values given predetermine the major proportion of permafrost supply in the input part of the water balance of thermokarst water bodies.

In 2008 the catchment basin area of the thermokarst lake under study made 6775 m^2, and the lake water surface area was 3135 m^2, i.e. the catchment basin area was almost twice as big as compared to the lake's area.

Evaporation from the water surface and moisture evaporation from the snow surface are the main output components of water balance. The evaporation power values E_o are defined through calculation methods and experimental methods with the use of the GGI-3000 evaporator. At RAS SB Melnikov Permafrost Institute stations evaporation from the water surface made 202-403 mm for May-September in different years, whereas according to the Yakutsk weather station data it made 398-436 mm. Evaporation from the snow surface was studied in detail by A.L. Are (1976). On open sites it can make 7.5 to 26% (16% on average) from all snow cover moisture reserves.

Bottom dynamics monitoring of the thermokarst depression (lake in the future) and the bank line in the lake was conducted by means of levelling of the whole thermokarst subsidence area with the grid 2 x 2 m relative to the system consisting of 6 benchmarks buried in permafrost at 3-4 m. The measurements were completed in September 1992-1993 and 2008, during the maximum ground thawing period. Benchmark elevations remained unchanged during almost 20 research years. Control points monitoring in order to follow the dynamics of thermokarst subsidence bottom surface and lake level was conducted annually at the end of September. The water surface level and area were surveyed regularly as well.

We calculated the water balance on the basis of the water volume in the lake. Regular measurements of the subsidence, the thermokarst lake bottom surface and the lake bank line dynamics allowed calculating the water volume for a specific period. The SURFER 8 software was used for the treatment of levelling results and the calculation of the required water area and the volume values for the lake.

Then the water volumes from precipitation which fell directly on the lake water surface and the water volumes from ground ice thawing-out were calculated. The volume of the water evaporated from the lake was calculated with account of the evaporation power at the Yakutsk weather station. We did not divide the runoff into surface and suprapermafrost, and it was calculated as a remainder of the water balance equation. Moisture condensation as an input part element does exist, and we do not have specific data for its calculation. We included it into the remainder together with the runoff for water balance calculation.

Results and Discussion

Water Volume from Precipitation. According to the nearest Yakutsk weather station data for 1993-2008, 239 mm of precipitation fell on average per annum, with the maximum value being 326 mm (2006) and the minimum value being 134 mm (2001). The water supply was estimated for the summer (May-September) and the winter (October-April) periods. Between 1994 and 1998 the total water supply increase with account of the annual lake area change per the thermokarst lake as such made 516.4 m^3 in summer and 147.6 m^3 in winter (excluding mean evaporation from the snow surface equal to 16% of winter precipitation). In 1999-2003 the water supply from precipitation made 900.8 m^3 in summer and 371.4 m^3 in winter, and in 2004-2008 - 2266 m^3 and 714.0 m^3 respectively.

Water Losses from Evaporation. According to the Yakutsk weather station data for 1993-2008, the evaporation power made on average 0.36 m, with the maximum value being 0.39 m (1993) and the minimum value being 0.30 m (2000). Between 1994 and 1998 1141.4 m^3 of water evaporated from the lake which was changing in area, between 1998 and 2003 – 2233.1 m^3, between 2004 and 2008 – 4855.0 m^3. While the total evaporation volumes during the first five-year periods were commensurable, the evaporation volumes became extremely notable with the significant increase of the total water supply and the lake widening.

Water Volume from Ice Complex Thawing-out. We calculated the water supply from ground ice thawing-out in three different conditions - directly from under the lake, from the shallow-water area and from the thermokarst depression slopes. Annually 9.6 m^3 (1993) to 440 m^3 (2008) arrived directly from under the lake, the area of which varied from 195 m^2 in 1993 to 3135 m^2 in 2008.

The annual mean lake bottom subsidence as per our monitoring in 1994-1998 made 0.054 m, in 1999-2003 - 0.136 m, and in 2004-2008 - 0.176 m. Based on these values we calculated that the ice complex with volumetric ice content 0.5 thawed on average for 0.1 - 0.27 - 0.35 m during these years. This data was included into our calculations.

Water supply due to ground ice thawing-out in the shallow-water zone was calculated independently. The subsidence rate in the shallow-water zone made 0.05 m per annum, like in the shallow lake between 1994 and 1998, and the annual ice complex thawing-out was estimated as equal to 0.1 m.

Ground subsidence up to 0.02 m per annum occurs also on relatively steep slopes of the thermokarst depression. This was also taken into account in the water supply calculation due to the ice complex thawing. We estimate the annual ice complex thawing-out at these sites as equal to 0.04 m.

Water supply due to ice complex thawing-out between 1994 and 1998 made 369.3 m^3 of water, between 1999 and 2003 – 902.8 m^3, and between 2004 and 2008 – 1833.8 m^3 of water.

Water Volume Supplied by Means of Surface and Suprapermafrost Runoff, Including Condensate. On residual principle, 417.0 m^3 fell on the total runoff with condensate in conditions of all known water balance equation values in 1994-1998, 566.2 m^3 – in 1999-2003, and 2646.5 m^3 – in 2004-2008.

The catchment basin area was estimated on the basis of the field topography survey in 2008. Taking into account the widening of the thermokarst lake, the catchment basin area varied from 9716 m^2 in 1993 to 6775 m^2 in 2008. In total, between 1994 and 1998 the water volume supplied to the catchment basin made 10224 m^3, between 1999 and 2003 – 8804 m^3, and between 2004 and 2008 – 9574 m^3. Only 4% of this precipitation reached the lake in 1994-1998, 6% in 1999-2003 and 29% in 2004-2008. The earlier estimated runoff coefficient in Central Yakutia was 10-20% (Chistyakov 1964, Buslaev 1981). The anomalous runoff between 2004 and 2008 is primarily associated with the precipitation regime and the snow thawing regime in spring (the increase of winter precipitation, anomalous autumn precipitation). These played a significant role in flooding of all Central Yakutia lakes in the studied period.

Conclusions

The produced calculations allowed evaluating the water supply formation structure in the young thermokarst lake – the input and the output components as well as the water balance during the specific time periods.

Input components of water balance are consisting from precipitation – 40-47%, ground ice thawing-out – 24-33% and total runoff – 19-36%. It is interesting, if in 1999-2003 total runoff consist 4-6% only, in abnormal 2004-2008 – 30% from total precipitation in catchment basin. Even in rather dry and warm 1994-2003 when role of runoff was low, ground ice thawing-out gave up to third of input part of water balance. The gradual expansion of lake area has caused essential increase water supply due to ice complex thawing-out, if in 1994-1998 it was 369 m^3 in total only, in 2004-2008 – 1834 m^3.

Therefore, the role of runoff and ground ice thawing-out in the water balance formation in the young thermokarst lake in Central Yakutia is quite significant and makes up to one third of the whole input in the balance.

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Effect of extreme hydroclimatic conditions on groundwater systems in permafrost, Central Yakutia

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Key words: Cryological and hydrogeological systems (CHS), suprapermafrost water, intrapermafrost water, subaerial taliks, climate changing

Introduction

The object of our research is the subaerial aquifer taliks, which discharge occurs in the form of large freshwater springs, Central Yakutia. Specific permafrost-hydrogeological conditions of the territory of the complex interdependent factors, the most significant of which are water-bearing lithologic structure of the aquifer and overlying rocks, of the complex morphology of landscape, climate and other factors.

The cryo-hydro-geological system (CHGS) - it is a complex of interdependent aquifer, aquifuge and air-dry soils, which have a total structure and changed by cyclic cryogenic processes. The features of CHGS: cryogenic aquifuge, decreasing of hydraulic capacity, taliks existing, localization of the underground runoff.

The CHGS were stable up to 2005. However, climatic conditions significantly affected the balance of the system uncharacteristic for the region within a few years.

Underground water has stable chemical composition, protected from surface pollution and has a high quality. Some springs of underground water are natural monument. The territory of investigation is developed at last years. For example, here had constructed railroad already. But we think that exploitation of infrastructure within CHGS distribution may have a hazard due to negative geological processes activization.

The aim of investigation: To estimate response CHGS on climate changing. We have prepared the monitoring places for ground temperature investigations, changing of landscapes, chemical composition of underground water and debit of springs.

Site and methods

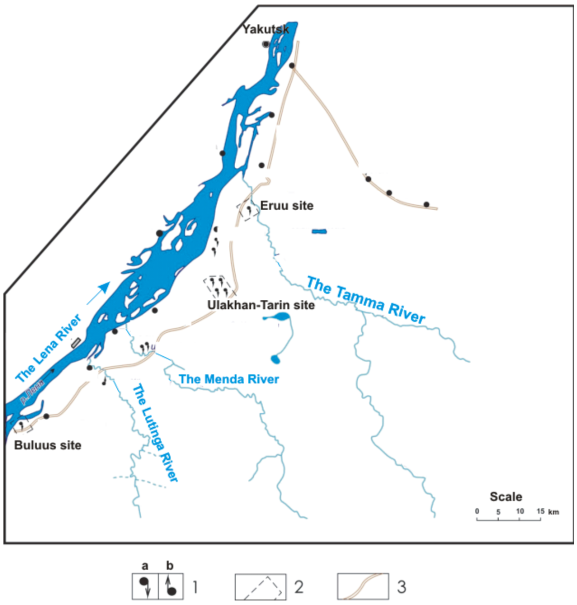
The investigation site is located within the Bestyakhskaya terrace on the right bank of The Lena River, Central Yakutia (Fig. 1). Sharply continental climate is in Central Yakutia.

The long-term annual average of precipitation is about 240-250 mm, and 65% of these are summer precipitation. The thickness of snow cover is from 0.2 m to 0.4 m.

The Bestyakhskaya terrace of The Lena River is composed of fine and medium-grained alluvial sands underlain by the gravel horizon bedding above the Cambrian limestone at the depths 20-100 m. The bank elevation is 30 m. Erosion valley and basin on the surface of the Bestyakhskaya terrace exists. Permafrost has a continuous distribution in the territory of investigation. The thickness of permafrost is 200 m but at the some places until 400 m. Temperatures of frozen ground vary from -0.2 to -0.5 degrees Celsius, but they are decreasing to -2.5 degrees Celsius at the valley bottom. Suprapermafrost and intrapermafrost subaerial taliks exist on the Bestyakhskaya terrace. Overlying layer of aquifer is 16-50 m, and bottom of aquifer is 50-86 m. Suprapermafrost groundwater is charged by snow melt water and precipitations. After infiltrations it comes to intrapermafrost aquifer and filtrates to discharging area. The structure of aquifers is CHGS described above. The biggest CHGS are located at the Ulakhan-Tarin, the Buluus and the Eruu sites on the Bestyakhskaya terrace. More detail in our report focus on the Ulakhan-Tarin.

Cryological and hydrogeological structures of the Ulakhan-Tarin site were obtained in results of long-term investigations. The total area of charging, movement and discharging of ground water at the Ulakhan-Tarin site is 350-400 square kilometers. Discharging place focuses on four areas and is located at the Ulakhan-Tarin sike valley. All discharging groups of underground water at the Ulakhan-Tarin site (the long-term debit is 280-320 l/s) has a stable hydrogeological regime. Near the discharging area are developed suffusion processes.

Suprapermafrost and intrapermafrost water of the Ulakhan-Tarin site have hydro carbonate type of underground water (here is more calcium and after magnesium). Mineralization is 0.2-0.3 g/l. Groundwater of intrapermafrost aquifers at the Bestyakhskaya terrace of The Lena River, characterized by stable chemical composition and good quality drinking water.



Schematic symbols: 1 – downward(a) and upward(b) springs of underground water; 2 – area of investigations; 3 – Federal road

Figure 1. Scheme of springs distribution at the Bestyakhskaya terrace of the Lena river.

Results and Discussion

In our opinion, gradual increasing in mean annual air temperature, the increasing of active layer thickness (lock-in around the world) does not play a significant role in changing of the cryo-hydro-geological systems. Period (since 2005 to 2008) is characterized by high rainfall, high snow depth cover (before 30% more of average for this territory). Powerful floods occurred in the spring (rapid onset of warm weather in the spring). The presence of periods in the warm season, when there was a high rainfall. We observed, that was a quick increasing of debits of the springs in 2005 with maximum in 2006 (Fig. 2). Increasing of surface runoff, increasing of water-level lakes and waterlogging at the Bestyakhskaya terrace of The Lena River were since 2006 to 2008. The new discharging point of underground water was found at the Ulakhan-Tarin site. The climatic conditions began stabilize since 2009. At the same time, the water-level lakes and debits of the springs began decrease, but intensification of suffusion processes is continued. The cryo-hydro-geological systems are stabilized since 2010, but intensification of suffusion processes is also continued.

The extreme hydro-climatic period (since 2005 to 2009) had an impact on hydrogeological regime and landscape situation at the Buluus and the Eruu sites, but to a lesser extent in compare with the Ulakhan-Tarin site. We observed a debit intensification of the Buluus and the Eruu springs only on 25% and not so intense changing of landscapes.

Conclusion

Thus, the hydro-geological regime of suprapermafrost and intrapermafrost underground water of subaerial taliks in the Bestyakhskaya terrace is correspondent with the conditions of atmospheric water supply. This is confirmed by the characteristic change of source yields in extreme hydro-climatic periods.

The cryo-hydro-geological system of the suprapermafrost and intrapermafrost complex of underground water of subaerial taliks in the Bestyakhskaya terrace has a significant potential which becomes more obvious with change of the water supply value.

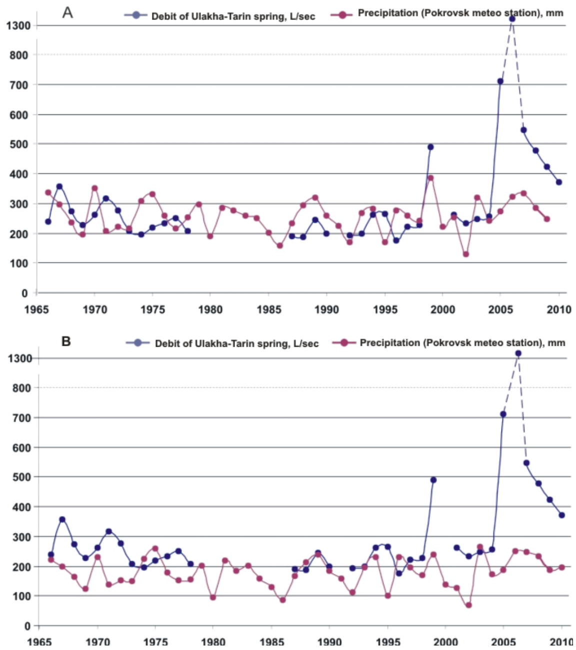


Figure 2. Correlation of the Ulakhan-Tarin spring debit with annual (A) and summer (B) precipitation (data from Pokrovsk meteorological stations).

Residence time estimation of permafrost groundwater at Yakutsk region, Eastern Siberia

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Key words: permafrost, talik, supra-permafrost groundwater, intra-permafrost groundwater

Introduction

The cryolithic water environment and associated hydrologic changes are crucial subjects to address given current problems caused by global warming. Better understanding of groundwater dynamics in the permafrost region is needed to assess the vulnerability of this region to a changing climate.

To determine the residence time of groundwater in arid, semi-arid, and humid regions, hydrologic tracers such as chlorofluorocarbons (CFCs) and sulfur hexafluoride (SF_6) have been widely used (Busenberg and Plummer, 1992; Busenberg and Plummer, 2000; IAEA, 2006). However, few studies have used such tracers in the cryolithic region. The Melnikov Permafrost Institute (MPI) of the Siberian Branch of the Russian Academy of Sciences (RAS) has historically monitored supra-permafrost and intra-permafrost groundwater in central Yakutia of Eastern Siberia. The present study was conducted in collaboration with the MPI.

Study Site

We estimated the residence time (groundwater age) of a mixture of supra-permafrost and intra-permafrost groundwater at two springs in central Yakutia of Eastern Siberia: Buluus spring (61º20'N latitude, 129º04'E longitude) and Ulakhan-Taryn spring (61º34'N, 129º33'E). The sites are located within the Bestyakh Terrace (130–160 m a.s.l.) of the Central Yakutian Lowland with elevations ranging from 80–100 to 250–300 m a.s.l. The Lowland grades into the Lena-Aldan (Pre-Lena) structural-denudation plateau of the Siberian Plain to the south and into the Vilyui Plain of the Central Siberian Plain to the west and northwest.

Central Yakutia lies in the zone of continuous permafrost. Drilling data show that open taliks perforating the permafrost exist only beneath the Lena River and large lakes. The thickness of permafrost penetrated by key holes on the Bestyakh Terrace ranges from 200 to 420 m. The depth of seasonal thaw depends on surface energy balance and soil moisture content of the layer, and varies over a wide range from 0.5–0.6 to 3.0–4.0 m.

Hydrogeologically, the study area is located within the first-order Yakutian Artesian Basin, an area approximately 400 square kilometers in size. Supra-permafrost taliks (unfrozen zones), several tens of meters in thickness with soil temperatures above 0ºC, are detected at the boundary of the Bestyakh Terrace and the Tyungyulyu Terrace. Intra-permafrost groundwater in deposits with 0ºC temperatures are found in the Bestyakh Terrace (Kolesnikov, personal communication).

Methods

Understanding groundwater regime characteristics such as pathways and residence time are the most important research issues in groundwater hydrology as well as for sustainable use of groundwater resources. Tritium (^3H) concentration has previously been used for estimating the residence time of groundwater, especially in the Northern Hemisphere. Atmospheric ^3H concentration peaked around 1963 due to nuclear testing. The half-life of ^3H is relatively short (12.3 years), and therefore when nuclear testing was terminated the concentrations declined (Shimada et al., 1994). However, if the residence time of permafrost groundwater is around 50–60 years, ^3H may be used to estimate its residence time.

Other hydrologic tracers such as CFCs and SF_6 can also be used to estimate residence time (IAEA, 2006). CFCs are anthropogenic gasses that were emitted into the atmosphere from the 1930s to 1987.

Atmospheric concentrations of the major CFCs such as dichlorodifluoromethane (CCl2F2; CFC-12), trichlorofluoromethane (CCl3F; CFC-11), and trichlorotrifluoroethane (C2Cl3F3; CFC-113) peaked in the early 1990s. SF_6 emissions began in the 1960s as it was used as an isolation gas, and its use continued through recent decades. CFCs can be used to estimate groundwater residence time in the study region, as it was recharged ~20 to 60 years ago. SF_6 can also be used for groundwater recharged around 1 to 40 years ago.

Hence we used these three tracers to estimate the residence time at the two springs described above. We made two assumptions: that the sampled water truly contained CFCs and SF_6 concentrations of the target groundwater in the aquifer, and that the recharged water reached full equilibrium in solubility with the atmosphere and the dissolute CFCs and SF_6 were preserved within the aquifer. The dissolute CFCs and SF_6 in the sampled water were used to estimate recharge age using Henry's solubility law (e.g., Warner and Weiss, 1985). For accurate chemical analyses of dissolute CFCs and SF_6 concentrations in the sampled water, the samples were kept isolated from the ambient atmosphere. The details of the analytic methodologies used are described in Thompson et al. (1974), Thompson and Hayes (1979), and Bullister and Weiss (1988).

Using analyzed concentrations of CFC-12, CFC-11, CFC-113, and SF_6 from the sampled spring water together with temperature and elevation data, the recharge year (when the sampled water entered the aquifer) was estimated using Henry's solubility law.

Sampling

Spring water samples were taken July 28–29, 2009, and July 28–29, 2010, at both sites. The samples for ^3H and SF_6 were collected with duplicates in 550 mL glass bottles with ethylene propylene rubber seal liner screw caps. Samples for CFCs were collected with duplicates in 125 mL glass bottles. Sample bottles were flushed with approximately 3 L sample water, then filled and capped underwater to prevent contact with the atmosphere. A peristaltic pump (Welco model Wpx-1000) was used to take water from wells.

Water samples were transported to Japan in August 2010. Water sampled in 2009 was stored at room temperature at the Melnikov Permafrost Institute (MPI) of the Siberian Branch (SB) of the Russian Academy of Sciences (RAS), Russia, until transport to Japan.

Analyses

^3H counting was conducted using a low-background liquid scintillation counter, Aloka model LB5, following electrolytic enrichment of ^3H by a factor of about 25 using Fe–Ni electrodes. Total analytical precision was better than ±0.23 tritium unit (TU) (±1σ). The ^3H measurements were conducted at the Geo-Science Laboratory Co. Ltd, Nagoya, Japan.

CFC content in the samples was measured using a purge and trap gas chromatography procedure with an electron capture detector (GC-ECD) at the Geo-Science Laboratory Co. Ltd, Nagoya, Japan. The procedure involved stripping 40 mL sample water of CFCs using an ultra-pure nitrogen gas. The extracted CFCs were purified and concentrated usin a cold trap, and finally injected into the GC-ECD. The precision and detection limit of the analysis were less than 2% and 1 pg/L, respectively.

SF_6 content in the samples was measured using the same procedure and GC-ECD at the Geo-Science Laboratory. The only difference was that, after stripping 400 mL sample water, the extracted SF_6 was purified and concentrated using two cold traps. The precision and detection limit of the analysis were less than 3% and 0.05 f mol/L, respectively.

Results

Groundwater age estimation using ^3H

The analyzed ^3H concentrations are shown in Table 1. The concentration at Buluus spring was higher (9–10 TU) than that at Ulakhan-Taryn spring (1–2 TU). The clear difference between the springs indicates that the origin and mixing conditions of groundwater are different between the two sites. There was no significant difference in ^3H concentration between the sampling years.

Figure 1 shows the ^3H concentrations of all samples, together with a time series of concentrations in precipitation samples collected at 15 sites in the Northern Hemisphere, obtained by IAEA (International Atomic Energy Agency). The ^3H concentration of precipitation at Yakutsk was around 100 TU in 1980 and 20 TU in 2000, and it was highest in Russia. This might be because Russia is at a high latitude, not far from the atomic bomb experiment sites of the former Soviet Union. Although recent ^{3}H concentrations in precipitation at Yakutsk were not recorded, a value of around 15 TU can be estimated from its declining trend from the 1970s to the 2000s.

Table 1. Tritium (^{3}H) concentrations of spring water samples and estimated recharge year.

No.	Name of samples	Year	Tritium (^{3}H) concentration				Estimated recharge year	
			(T.U.)		(Bq/L)		Old	New
1	Buluus	2009	10.5	±0.3	1.27	±0.03	1970	2005
2	Buluus	2010	9.1	±0.3	1.08	±0.03	1970	2005
3	Ulakhan-Taryn A	2009	2.7	±0.2	0.32	±0.02	1955	1985
4	Ulakhan-Taryn E	2010	1.4	±0.2	0.16	±0.02	1955	1985

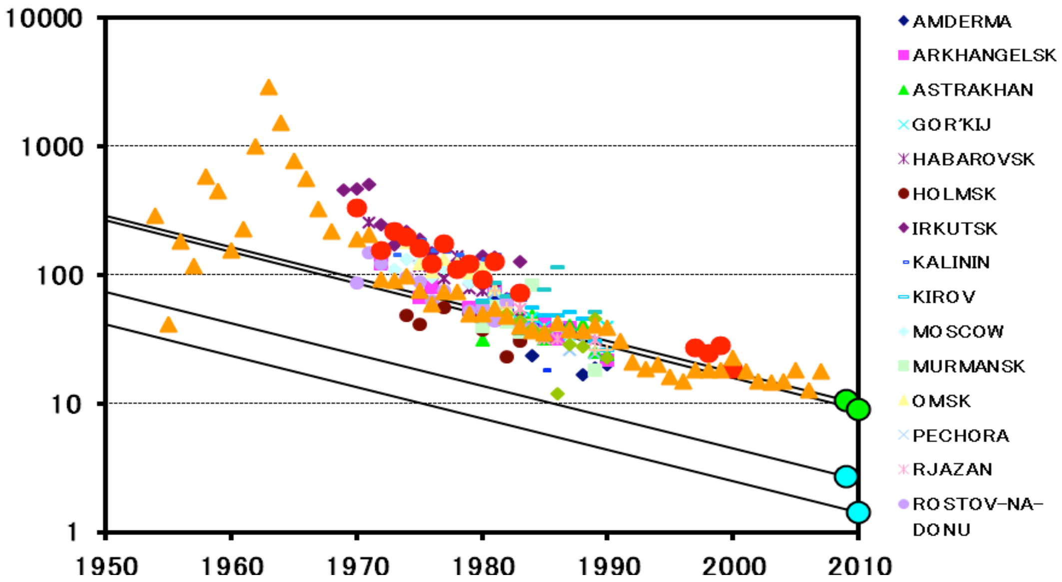

Figure 1. ^{3}H concentration (TU) of spring water samples obtained in 2009 and 2010. Green solid circles Represent those for Buluus and blue ones for Ulakhan-Taryn. Also shown are time series of those of precipitation water obtained at 15 sites of northern hemisphere.

The four lines in Figure 1 show the dating trends of four springs, which were drawn using the half-life (12.3 years) of ^{3}H. Where precipitation intersects ^{3}H concentration indicates the bulk recharge year of the spring water. As shown in the figure, ^{3}H concentrations at Buluus intersected with precipitation values at Yakutsk from 1970 to 2005. Thus, the Buluus spring water may have originated from precipitation that recharged the aquifer after the nuclear testing period of the 1960s. If we assume that groundwater pathways have a piston-like flow, the bulk age of the Buluus spring water can be estimated to be about 5 to 40 years old. However, because the ^{3}H concentrations of the Buluus samples were not significantly higher than those of precipitation at Yakutsk, the spring water may contain older precipitation recharged before nuclear testing.

While the ^{3}H concentration at Ulakhan-Taryn was high, it was lower than that at Buluus. It did not intersect with the ^{3}H concentration of precipitation after the nuclear testing era. As the concentration of the

Ulakhan-Taryn samples was clearly lower than that of precipitation that fell after the 1960s, it may have been recharged mostly by precipitation before the 1960s. If we set the ^3H concentration of precipitation after the 1960s at 15 TU (the current value at Yakutsk), and that before the 1960s as 0.5 TU (the concentration of the 1950s), the percentages of precipitation recharge before the 1960s to the Ulakhan-Taryn spring water are 85% for the 2009 sample water and 94% for the 2010 sample water. Again, if we assume that groundwater pathways have piston-like flow, the bulk recharge year of the spring water can be estimated as 1955 to 1985, i.e., the age of the groundwater is 25 to 55 years.

Groundwater age estimation using CFCs and SF_6

The concentrations of CFCs and SF_6 are shown in Table 2. The concentration differences between 2009 and 2010 samples were small for both springs. Thus the methods of preservation for the 2009 samples produced no issues in terms of analyzing concentrations or estimating groundwater age.

Although CFC concentrations at both sites were low, CFC-12 was detected at both. Three kinds of CFCs (CFC-12, CFC-11, CFC-113) were detected at Buluus spring whereas CFC-113 was not detected at Ulakhan-Taryn spring, which may have been caused by deoxidizing conditions at that site; under deoxidizing conditions, methane-producing bacteria appear to remove dissolved CFC-11 and CFC-113 (Happell et al., 2003). Indeed, the gas chromatography analysis detected CH_4 at the Ulakhan-Taryn spring, which is associated with deoxidization. Because three kinds of CFCs were detected at Buluus, microbial decomposition likely plays a smaller role at that spring, and its groundwater age could be estimated more reliably.

Concentrations of SF_6 ranged from 1.97 to 3.75 fmol/kg, and were higher at Buluus than at Ulakhan-Taryn. This result is similar to those of the CFCs analysis, suggesting that the groundwater age of the Buluus spring is younger than that of the Ulakhan-Taryn spring.

Table 2. CFCs and SF_6 *concentrations of spring water samples.*

No.	Name of samples	Year	CFCs (pg/kg)			SF_6 (fmol/kg)
			CFC-12	CFC-11	CFC-113	
1	Buluus	2009	117	179	14	3.30
2	Buluus	2010	109	160	12	3.75
3	Ulakhan-Taryn A	2009	32	1	0	2.01
4	Ulakhan-Taryn E	2010	18	21	0	1.97

The equivalent air concentration (EAC) of the three CFCs and the SF_6 were calculated using Henry's solubility law (e.g., Warner and Weiss, 1985), in which the solubility potentials of CFCs and SF_6 depend on the air temperature and air pressure when the precipitation fell. Current annual mean air temperature in the region is -8.9ºC. However, because the water should be recharged above 0ºC, representative value of the temperature was assumed to be 0ºC. Mean surface elevation of the recharge area was assumed to be 150 m based on the topography. Calculated EACs are shown in Table 3.

The estimated recharge years based on the EACs of CFCs and SF_6 are also shown in Table 3. These recharge years are bulk estimates from the samples. If we assume piston-like groundwater flow, the bulk groundwater ages are possible to estimate (not shown). As shown in the table, the bulk recharge years using the CFC method were around 40 years older than those using SF_6.

The estimated recharge years based on CFCs (Table 3) were similar to older values based on ^3H concentrations (Table 1). However, those based on SF_6 were significantly younger than those based on ^3H. This may be associated with the characteristics of SF_6 as a hydrological tracer.

Table 3. EACs (equivalent air concentrations) of CFCs and SF_6. Values of the estimated recharge year are also shown.

No.	Name of samples	Year	Equivalent air concentration (EAC: pptv)				Estimated recharge year			
			CFC-12	CFC-11	CFC-113	SF_6	CFC-12	CFC-11	CFC-113	SF_6
1	Buluus	2009	105	35	6	5.4	1968	1967	1970	2004
2	Buluus	2010	98	31	5	6.2	1968	1966	1969	2007
3	Ulakhan-Taryn A	2009	29	0	0	3.3	1959	1947	1953	1994
4	Ulakhan-Taryn E	2010	16	4	0	3.2	1955	1955	1953	1994

Discussion

If we assume groundwater moves with a piston-like flow, ^3H is theoretically a good tracer for determining groundwater age. However, as shown in Table 1, the ^3H-based ages varied widely (~30 years). This is because we applied a simple piston-like flow scheme to the groundwater system, and the samples were a mixture of supra-permafrost and intra-permafrost groundwater. It was not possible to separate these two types of permafrost in this study.

Comparing Tables 1 and 3, it can be concluded that the CFC-based ages were similar to the upper values of the ^3H-based ages. SF_6-based ages, however, were younger than the youngest ^3H-based age. If we were to assume that the ^3H-based ages are correct, the following three points could be derived based on the CFC and SF_6 characteristics: 1) the ages based on CFC-12 are reliable, because they are similar to the ^3H-based ages, and they appear to be the least affected by microbial decomposition; 2) the SF_6 concentration might have increased due to the mixture of SF_6 from basement rock with permafrost groundwater, which would cause a younger estimate of SF_6-based groundwater age; 3) due to over-dissolution, redundant SF_6 may have dissolved into the recharging water, leading to overestimated SF_6 levels and thus younger groundwater ages.

Regarding the second point, the basement rock of the study area consists of carbonate sedimentary rocks (limestone, dolomite, and marl) of Cambrian age, which may not introduce SF_6 to the permafrost groundwater. However, it is difficult to completely deny the possibility of introduction of SF_6. The third point is especially relevant at the Buluus spring because the recharge area includes a thermokarst-derived open lake and talik water. Hence, the effects of dissolution into open water surfaces (e.g., Heaton and Vogel, 1981) should be carefully considered. We assumed here that SF_6 shows stronger effects of dissolution than CFCs. We suggest that careful attention should be paid to this potential effect when using SF_6 as a hydrologic tracer in the permafrost region.

Conclusions

We found that the age of bulk groundwater at Ulakhan-Taryn spring is older than that at Buluus spring. The recharge year of Buluus was estimated to be between 1970 and 2005, and that of Ulakhan-Taryn was estimated to be between 1955 and 1985. About 80% of the spring water at Ulakhan-Taryn appeared to contain water recharged by precipitation before the 1960s nuclear testing era. We also confirmed that CFC-12 can be used to reliably estimate groundwater age in this region, whereas SF_6 is not recommended, mainly due to the existence of open water surfaces (i.e., lakes) which may lead to dissolution effects.

Moreover, our results indicate that ^3H and CFC-12 are both valid for estimating groundwater age in Eastern Siberia. Because the permafrost taliks in the cryolithozone hold special kinds of groundwater, ^3H and CFC-12 could be used to assess the intra-permafrost and supra/intra-permafrost groundwater throughout the alluvium of middle terraces along the west bank of the Lena River. Springs discharging from these areas would be the best target for such an analysis.

The next step related to the present study would be to separate out the age estimations for supra-permafrost and intra-permafrost water. This analysis would allow estimation of the contribution ratio of supra- and intra-groundwater for both springs. The analysis would require analyzing intra-permafrost groundwater during the winter, as most of the supra-permafrost groundwater would be completely frozen. In addition, it would be necessary to obtain ^3H concentration data from ground-ice, although that ice may not include ^3H because it formed before the last glacial maximum.

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The local conceptualization of river ice thawing and the spring flood of Lena River under the global warming

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Abstract

This paper explores the limit of adaptability of the Sakha people to the spring river flooding. The flooding or overflowing happens every thawing period during spring in Lena River, mainly because of outbreak of ice-jam. Lena rises in the Baikal Lake in south and discharges into Arctic Ocean in north. The local population or Sakha rural community in the middle basin of the river has devised the subsistence calendar as their tradition on the assumption of this natural phenomenon. However, the recent hazard of the spring flood featured by scale expansion and high frequency rather brings disastrous effects to the local communities. In this presentation, I consider the local human-river relations, explaining the indigenous knowledge of the river freezing and thawing and the related subsistence activities. I also describe the recent ice-floating conditions and patterns of flooding. Then I argue what condition breaks out the disastrous flooding and discern what kind of disaster in the local socio-cultural setting.

Disaster and anthropology

Disaster is the extreme scale of the natural hazard in a particular place, but if no people and no building there, we don't' recognize it disaster. It is embodied in the socio-cultural contexts of the human societies, which include the histories, traditions and societal-technological relations. In this sense, the disaster is the socio-cultural phenomena with some continuity located in the historical-geographical matrix. Anthropological approach to disaster is to reveal these local contexts that configure the forms and degree of a particular disaster.

Rather than the immediate quantification of disaster, or the evaluation of policies and measures treating with the disaster, anthropologists prefer to ask in the following way: is it really disaster for the local people? Can local communities correspond the disastrous situation, and if so how they do? If not, why? Are the local population are always the weak against this setting who should be one-sidedly protected by the administrative measure? Is the cultural background and social system of the local communities adaptively useful to the preparation for the dealing with the disaster? If so or not, under what conditions and what degrees?

Questions in this paper

Recently the hazard of the spring flood of Lena River has increased and which causes the serious socio-economic damages in the local communities in the region along the Lena river system (Filippova 2010, Sakai 2011). The construction of the effective polices and measures against the disaster are urgently required by the local administration and national government.

The Sakha people has traditionally lived in the riverine valley locus where repeatedly occurs the freezing and thawing of the river according to seasons (Okumura et al 2011, Takaura 2012). The natural environment inevitably brings about the spring flood caused by the river thawing. Why this natural phenomenon recently becomes the disastrous effects? Many natural scientists focus on the recent climate change: the global warming closely relates to the acceleration of the scale and frequency of the spring flood and the change of the outbreak time which results somehow relatedly would appear as a disaster (see also Beltaos et al 2006, Yoshikawa et al 2011).

Anthropologists cannot inquire the cause-effect relations on this matter; rather their question is to explore the local contexts of the spring flood in the life of local population and the way it works as the disaster. How the local people conceptualize the flood? What human-nature relations they invent in terms of subsistence in the freezing and thawing riverine valley environment? Is the local indigenous knowledge and traditional subsistence activities adaptive to the recent disastrous spring flood? If either so or not, under what condition people act the way they do?

The first task of this paper is to describe the local knowledge and subsistence activities in the riverine valley environment and to find the local socio-cultural contexts of the Lena spring flood. The second task is to consider the role and effects of the local knowledge and subsistence related to the policies and measure for the disaster of flood. How do two things connect each other?

Feature of the local human-ice relations

Through the description of the ice-basket fishing and the ice cube collecting in this region, I explore a uniquely feasible way of the human-ice relations. Its feature is the selective and intensive usage of the certain degrees of coldness in temperature and related condition of the ice including the process of freezing and the thawing. People also develop their own conceptualization on this process and can give the expression. In addition, their subsistence activities are dependent on the premise of the moderate scale of the spring flood. The natural disturbance of the river environment is the necessary element of the local resource procurement. If not disastrous setting, the spring flood is a rather benefaction for the local subsistence activities.

Indigenous knowledge and disaster

Is the local knowledge on the river dynamics adaptive to the disastrous scale of the spring flood? It may be true that the person who knows it can assume a series of the possible events from the beginning of the ice thawing. But generally speaking, the local knowledge provides the concept of each conditioned form of the ice and its total framework of the changing procedure. Therefore the local people can foresee what feasible events during the river thawing season and prepare something to do in mind.

But they cannot predict the when the concrete events starts and how the scale is. One needs the quantitative date and how these date interlocked one other under a certain condition in order to estimate the scale and timing of the particular hazard. Much precise information is necessary for the implementation of the practical activities against the disastrous flood.

As shown in the previous section of the case studies of the spring flood disaster, it is certain that the two focused villages differently corresponded to the disaster and the result showed the different forms. X village, which is the veteran for the disaster, prepared well and no damage to the livestock. Y village, which is not the veteran, undertook the much heavy damage to the livestock. However, both villagers are dependent on the emergency information from local administration and local media when they started the concrete measures against the disaster and evacuation.

On the other hand, it does not mean that the indigenous knowledge is not useful and out of date. One needs to remember the selective and intensive of the certain degrees of coldness for the subsistence in early winter. Some people even recognize it in the defined period for two weeks from the end of October to 1st week of November. Importantly the knowledge is evolved by the accumulation of the local empirical observation and execution.

Criticality of indigenous knowledge and disaster policies

How can the indigenous knowledge contribute the practical measure for the disastrous spring flood? At this moment, the local knowledge on the river dynamics provide people the feasible scenario of the series of the events on the river thawing, but unfortunately it can not show the local people the concrete action policies against the disastrous setting.

The indigenous knowledge on the freezing and thawing process should be re-explained by some quantitative range of metrological records that local people can observe. The local concepts such as *kyd'ymamakh* or frazil ice should be armed by the time-place quantitative theory. One example is the question is to ask under how many temperature accumulations and in what the character of the place the frazil ice appears in spring. The combination between the indigenous knowledge and local metrology should be implemented. It is necessary for the local people to manipulate the indigenous knowledge under the changing condition. The much local persons can enhance the ability somehow to predict the concrete events in terms of his/her perspectives, the more room the people can get for the preparation for the disaster. It must be supportive to establish the legal and economic policies against the Lena spring flood both in local and national administration.

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Flood disaster caused by permafrost degradation in the far north of Siberia

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Keywords: ALOS/PALSAR, flood, global warming, microwave remote sensing, permafrost

Introduction

High latitude regions are experiencing the greatest climate warming. At Alazeya River Basin in the far north of Siberia, the annual mean air temperatures have risen by 4.6°C for the last 50 years (IPCC 2007). The warming rate is 6.1 times faster than that of global average. The increase in air temperature thaws permafrost which underlays 25% of the northern hemisphere. Effects on permafrost thawing are particularly important for global climate, because permafrost thawing promotes decomposition of soil carbon, and releases greenhouse gases such as methane into the atmosphere. It is said that high latitude regions contain one third of the global terrestrial pool of soil carbon. Therefore, there is a concern that how permafrost thawing affects global carbon balance as positive feedback. In addition, permafrost thawing also changes water balance. As flood is caused when a large amount of the thawed water flows into the river, date of permafrost thawing is important. Extreme hydrologic events such as flood have already been observed, and are predicted to further increase in the frequency and magnitude. Microwave remote sensing enables to monitor spatial and temporal pattern of hydrological parameters such as soil moisture and snow surface properties. The transition of dry to wet soil during the permafrost thawing may appear as change in backscatter signals from volume to surface scattering. However, backscatter signal of permafrost is rather complex throughout the time. If the process of permafrost thawing can be determined by monitoring the temporal pattern of reflectance, it is possible to map the permafrost degradation at large scales. The detailed map can serve as valuable resource for assessing both carbon and water balance. The objective of this research is to develop a robust indicator for onset of permafrost thawing, and advance the knowledge regarding climate change in the northern Siberia regions.

Study site

The Alazeya river is located at the northeastern part of Yakutia. The length is 1590 km. The river flows generally northeast and then north, emptying into the Arctic Ocean at approximately 71 degrees North Latitude. The basin has a subtle elevation gradient ranging from sea level in the north to 100 m in the south. The area of the basin is 64700 km^2. There are more than 24000 lakes in the basin. The Alazeya river is frozen for 7-8 months of the year because of extremely hard climatic conditions. Figure 1 shows annual mean air temperature from 1957 to 2009 and daily air temperature in 2007. Annual mean air temperature is below the freezing point. The climate is characterized by very low air

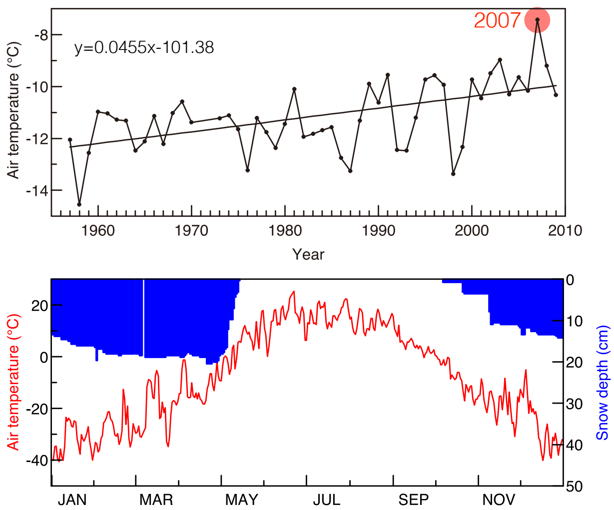

Figure 1. Annual mean air temperature from 1957 to 2009 (upper) and daily air temperature in 2007 (lower).

temperature with a low amount of precipitation. However, annual mean air temperature was gradually increasing due to global warming, and air temperature in 2007 was extremely high. It is thought that more permafrost melted during summer by warmer-than-normal air temperature in 2007.

Data

Microwave satellite remote sensing, such as Synthetic Aperture Radar (SAR), has great potential for mapping and monitoring due to their ability to operate day and night through cloud cover, and recent improvement in data availability (Rogan and Chen 2004). Many studies have focused on the spectral and polarimetric dimensions of SAR data in land cover classification (Chen et al. 2003, Cloude and Potter 1997, Lee et al. 1994). SAR data are also available for high-resolution topographic information. In this study, the L-band ALOS/PALSAR data were acquired in the Fine Beam Dual (FBD) mode, i.e., dual polarization HH (horizontal-horizontal) and HV (horizontal-vertical), with a pixel spacing of 9.4 m (slant range) by 3.2 m (azimuth). The data were downloaded from the Global Earth Observation Grid (GEOGrid). The nominal spatial resolution of the data sets is 12.5 m in UTM.

Long-term flood of Alazeya river

In 2007, a big flood occurred in the Alazeya river basin. Floods in this area are characterized by long-term overflow. Figure 2 shows interannual changes in flood. Color composite of the ALOS/ALSAR for three years (R:G:B=2007:2008:2009) was acquired. After this process, interannual changes in flood were represented as difference in color. Light blue area was flooded for one year in 2007. Dark blue area is flooded for two years in 2007 and 2008. In upstream area around Svatai, flood didn't occurred. Flood occurred between Svatai and Argahtah in 2007. Flood damage around Argahtah was only in 2007. However, flood damages were quite different at location in the short-distance of approximately 200 km. In downstream area around Andryushkino, flood damage continued for two years in 2007 and 2008. The flooded water flowed slowly toward the north, because landscape in this area is almost flat without slope. Therefore, the flood in 2007 was carried over next year at Andryushkino. The local people who lived in Andryushkino suffered flood for a long time.

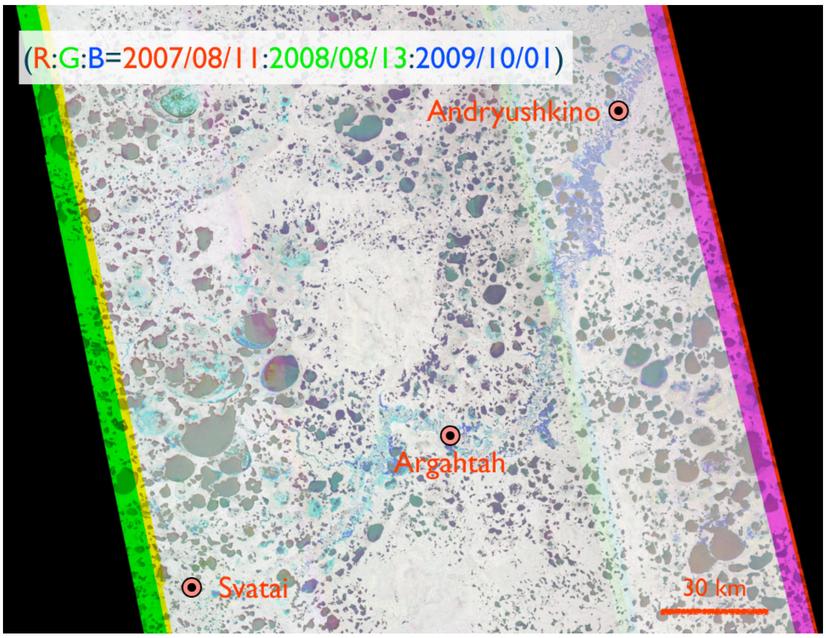

Figure 2. Interannual changes in flood using ALOS/PALSAR.

Permafrost degradation and flood occurrence

Although Alazeya region was consistently low precipitation area, air temperature in 2007 was drastically high (Fig. 1). Air temperature in 2007 was always high throughout the year. Therefore, much permafrost melted in summer of this year, and big flood was caused due to the permafrost degradation. Figure 3 shows soil profile in the permafrost degradation. In the permafrost, ice wedge is included. (i) When permafrost melts due to the increased air temperature, active layer grows thick and ice wedge melts [a→b]. (ii) After ice wedge melting, the melted water gushes from the ground [b→c]. (iii) Then, the melted water flows into a nearby river, leading to floods [c→d]. Figure 4 shows topographic depression after the melted water flowed into Alazeya river, as shown in Figure 3[d]. After permafrost degradation, the ground sinks. Figure 5 is the result of ground subsidence. Ground subsidence by permafrost degradation was measured using ALOS/PALSAR. Differential interferometric synthetic aperture radar (DInSAR) can provide measures of vertical movement at landscape scale. Two images in 2007 and 2008 were used to analyse at Andryushkino. During this period, the ground sinked several centimeters. The amount was large near the Alazeya river. There are many factor of ground subsidence, such as earthquake, landslide, volcano and so on. However, probability of permafrost degradation is high in Alazeya.

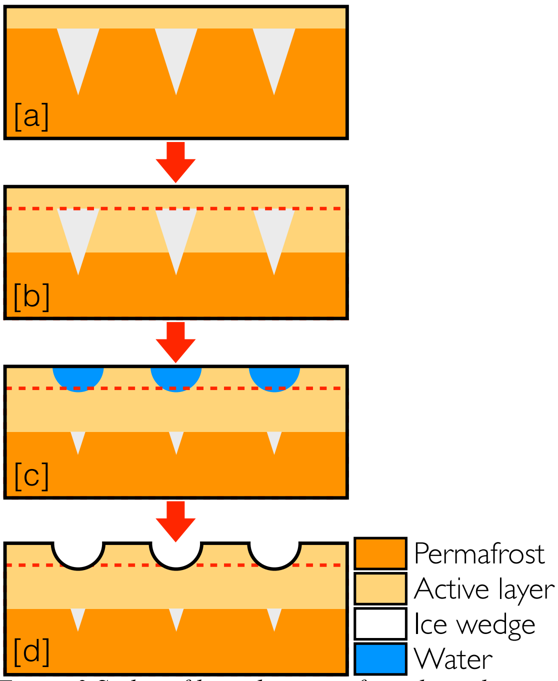

Figure 3 Soil profile in the permafrost degradation.


Figure 4. Topographic depression after water flowed into Alazeya river, as shown in Figure 3[d].

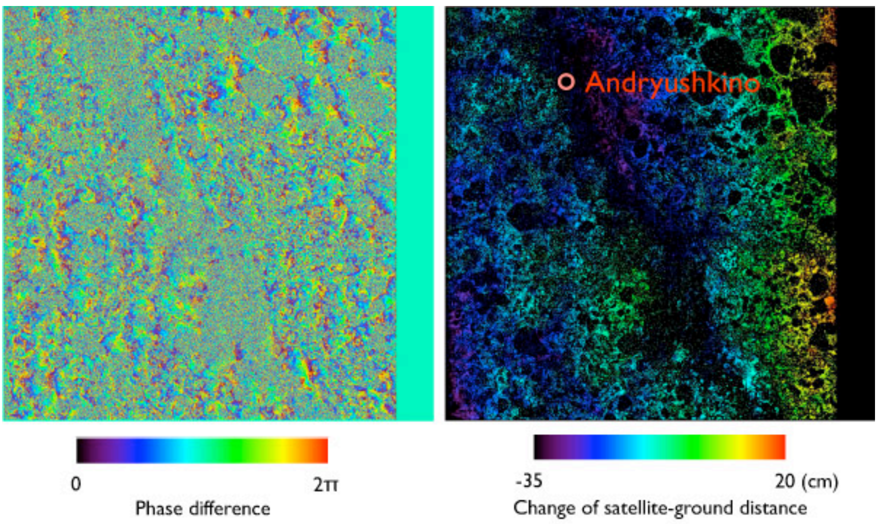

Figure 5. (a) Wrapped phase image and (b) unwrapped phase image between 2007/08/11 and 2008/08/13.

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Regional problems of reducing vulnerability to extreme floods and climate change: Yakutia case

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Key words: climate change, indigenous peoples*,* measures of adaptation

Introduction

As is known most of the indigenous peoples of Yakutia live in rural areas. The basis of their livelihood are: for Sakha – horse and cattle breeding, for the minority peoples of the North – reindeer herding, hunting, fishing and fur trades, picking wild berries and medicinal plants. This type of economy is based on the use of biological resources of nature, small technologies and closed circle of exchange, which allows one to consider the traditional land use to be the basis for sustainable development of the indigenous peoples of Yakutia. That is why the problem of technogenic, antropogenic and climate impacts on the environment is sensitive to them. In particular, the results of sociological surveys of the rural population of Yakutia show that issues of ecology and environmental changes are always present in the list of the stressful subjects along with such vital issues as unemployment and rising commodity prices. In this regard, my project was aimed at studying the social and economic aspects of climate change through the prism of the observations, opinions and assessments of rural people themselves.

Table 1. Brief description of the areas of field work.

	Abyi	**Verkhoyansk**
Geographic coordinates	Longitude - 146 ° 25' E Latitude - 68 ° 32' N	Longitude - 134°39' E Latitude - 67°39' N
Area (km^2)	69.4	134.1
Population (thousand)	4.1	11.8
Population density (persons per 1 km^2)	0.06	0.1
Rural population (in thousands)	6.2	1.9
Ethnic groups (%)	Sakha – 80.9 Russians – 10.8 Evens and Evenks – 5.9	Sakha – 70.2 Russians – 20.2 Evens and Evenks – 3.2
The dominant agricultural sector	horse-breeding reindeer-herding fishing	horse-breeding cattle breeding hunting
The administrative center of Ulus	p.Belaya Gora	p.Batagay
The distance from the ulus center to Yakutsk (km^2):		
by road	2900 (from late December to March)	1423 (from mid-November to April)
by water	3243 (from mid-July to September)	2875 (from late May to September)
by air	1160	660
Climate	sharply continental	Subarctic, sharply continental
Average temperature:		
the coldest month (January)	–44°C	–48°C
the warmest month (July)	+14°C	+17°C
The average annual rainfall (mm)	200-220	150-300

Site and methods

Considering the fact that my Japanese colleagues have worked mainly in Central, Eastern and Southern Yakutia, for my field work I chose two northern districts – Abyi and Verkhoyansk. They are located beyond the Arctic Circle in the area of continuous distribution of permafrost. Up till now, they are some of the hardest-to-reach regions of Yakutia. External communications of the districts throughout the year are carried out only by air. Other means of transportation are seasonal in nature and function: water – in summer and autumn, automobile – in winter and spring.

90% of goods are transported by water up the River Lena, then – via the Northern Sea Route, and finally down the Yana and the Indigirka. The cargo delivery scheme is as follows: in Ust-Kut the goods are loaded on the river fleet, in Yakutsk they are transferred to a "river-sea" class vessel, and at the mouth of the rivers Yana and Indigirka – they are transloaded to the shallow-draft vessels. Most of cargo unloaded in autumn is delivered to the settlements in winter by road. The complex logistics of delivery determines the high cost of any item – from food and oil and lubricants.

Using the field data – the results of a survey of local residents, interviews with key informants, I will try to outline the local projections of climate change, identify the existing and potential security risks of the life of the rural population of Yakutia.

Results and Discussion

During the mass survey it was revealed that many people recognize the fact of the reality of climate change and cite as arguments examples from their personal observation. The respondents' answers to the question: “What exactly do you include in the concept of “climate change” which affects the environment?” helped to outline the following characteristics of the contemporary climate and condition of the local ecosystems of the Abyi and Verkhoyansk regions.

The respondents include in the list of changes: changes in seasonal temperature, annual rainfall, shifting seasons, the unpredictability of the weather, more frequent extreme weather and meteorological phenomena, the changes in the surrounding landscape, the degradation of the animal world, the emergence of new species of flora and fauna.

Most of all, the local residents are alarmed by the degradation of forest due to the increasingly frequent forest fires and the spread of forest pests. People are concerned about the increase of dead forests and their resources in the area. Forest fires also damage the soil cover, which directly causes the development of adverse cryogenic effects. Thus, the deterioration of the soil leads to water logging and forest destruction.

Along with the threat of forest fires north forests are threatened with pests, in particular, the Siberian moth. As is known the episodic mass reproduction of the silkmoth occurred mainly in the central and southern parts of the republic. The information about the mass occurrence of the Siberian moth in the Abyi district can be found in the publications of the newspaper *Hotugu kyym*. They report on the detection of foci, which were already in the grading phase of the peak and the defoliation of larch by the caterpillars was endemic.

The literature indicates that most of the permafrost zone in Yakutia contains rocks with high content of ice, which determines the low stability for the northern permafrost complexes. The increase in temperature contributes to processes occurring in the upper shell of permafrost, in particular, a significant increase in the depth of the active layer.

Information related to the melting of permafrost, is obtained from the local old-timers. They say that: *"In recent years the sun has begun to grow hotter, sometimes permafrost has already started to melt. They visited various places and were surprised at how one or another area had changed – in one place gullies formed, in another, on the contrary, soil had bulged and in yet another there was frost that melts only in the autumn, and in some other place a small lake had disappeared. All we have seen with our own eyes is the evidence of climate warming.”*

The key informants include in the register of environmental change the degradation of forest soils, the formation of gullies, the destruction of coastal forests due to landslides on thawing slopes, erosion and destruction of river banks. The head of the Adycha nasleg administration M.Osipov reported that: *"The village is gradually losing its riparian lands. Due to the constant caving-in of the river banks the people are* *forced to move their homes and outbuildings. In view of this we will have to develop a new "Master plan of the village of Betenkes."*

The sharp changes in weather and temperature have the worst impacts on the stability of horse breeding. For example, last year the stud farms of the Abyi district suffered a great loss due to rain, which occurred at the end of April. As a result of the warming, rapidly followed by cooling, the fluffy snow, beneath which there is grass grazed by the horses, turned into an impenetrable icy shell. Many farms have suffered losses because they had to buy additional hay for the horses deprived of the food. Besides, the lack of fodder led some young horses to die, which will negatively affect the dynamics of the horse population.

According to local hunters and fishermen, the emergence of new species of animals, birds and fish demonstrates the sensitive response of wildlife to climate warming. For example, local residents not the addition to the avifauna of the Verkhoyansk district of non-endemic species such as lapwing and gulls, and Abyi district – Bewick's swan, white crane, etc. (the lapwing is found to the south of the Arctic Circle, the gull – in the middle of the Eurasian continent and Bewick's swan – in the tundra zone of Yakutia, from its western to eastern borders).

Among the exhibits of the local history museum of the Abyi district there is a stuffed river otter, produced by local hunters. As the museum employees said, "the hunters themselves were very surprised by the emergence of the beast previously unseen in these parts and killed it out of curiosity" (the river otter in Yakutia is only located in its southern part). The museum also exhibits a stuffed salmon - common on both sides of the Pacific. According to the accounts of local fishermen, in recent years, chum salmon are regularly coming to the Indigirka to spawn. At first they *"shied away from this fish-like mutant,"* and now, even when caught, these fish are usually thrown back into the river, because *"even dogs do not eat its meat."* Many people complain about the increase in the number of this predatory fish, eating fish of different ages, and expressed concern that this may adversely affect the local fish fauna.

Old-persons of the Abyi district noticed an increase in rainfall: *"it rains a lot nowadays, more than it should according to the Orthodox calendar."* They complain that, due to the heavy rains the water level in alaas lakes rises and floods the grasslands, and as a result – the quality and quantity of hay harvested in the winter leaves much to be desired.

The heavy impact on the rural life of the changing environment, primarily from the violation and the intensification of the water cycle, now forms a pivotal problem, the solution of which is very important for the development of rural areas, communities and residents. It should be recognized that the current settlement system contributes to the risk of flooding of rural settlements of Yakutia, usually located on the banks of rivers and lakes.

Heavy and prolonged rains lead to the flooding of settlements of the Yakutia. For example, the last devastating flood in the Verkhoyansk village of Betenkes that occurred in 2008, was also caused by heavy raining. Enormous damage was caused not only to dwelling houses, but also to the rural infrastructure, in particular, it washed away roads, streets, driveways, and other communications. The water ruined the outbuildings, the stocks of wood and hay. But, most importantly, it killed the livestock, which did not have time to withdraw to a safe place. For the rural residents the losses were just devastating.

It is clear that one cannot assert the existence of a direct causal link between climate change and the examples given by my respondents. However, one cannot completely deny the obvious parallels between the climatic shifts and the increases in frequency and magnitude of floods.

The respondents included into the list of proposed climate-related risks the threat of recurrence of heavy floods; the reduction of the area of hayfields and pastures due to the changes in the natural landscape of local ecosystems; the deterioration of natural water bodies, which are used as the main source of drinking water; ecological ill-being and worsening conditions of cattle, horses, habitats of commercial hunting animals, birds and fish, which may be harmful to livestock breeding, hunting and fishing; the growth of cardiovascular disease and meteopathic reactions. As noted by key informants, in the case of prolongation or aggravation of climate change there is a real threat of the decline of agriculture. It is clear that this will entail not only mass poverty, but also the deformation of the original farm economy of the indigenous peoples of Yakutia.

The results of my field work suggest that rural residents were the first to suffer the troubles associated with changing climatic conditions. Therefore the problem of vulnerability and adaptation to climate change in our republic has a significant ethnic and social context. For example, for the inhabitants of the transpolar village of Betenkes climate change is not a distant prospect, but a directly experienced reality to which they are now trying to adapt. In particular, many of them, who do have too little money to maintain the standard of living, are forced to spend their money and labor on adaptation to the climatic processes. This can be illustrated by the construction of houses on wooden piles. Betenkes has an underdeveloped infrastructure for flood protection: no weather monitoring and early warning systems, as there is no meteorological station and watchtower; works on stabilization of the bed river and banks of the Adycha and construction of dams are not carried out due to lack of funding. Therefore, adaptation to the increased risk of flooding is reduced here to the construction of houses, whose peculiarity consists in the fact that they are built on large wooden piles, submerged into the earth 2.5 m deep. One pile costs 800 rubles, and for the construction of the pile field for a medium-size house there should be approximately 40 piles. In addition, the processing of the piles themselves costs approximately 12 thousand rubles, that is, in all, the total sum is about 45 thousand rubles. As is known the Government of Yakutia gives to the households affected by floods compensation of 20 thousand rubles plus two thousand rubles for each family member. It is clear that such construction increases inequality at the level of rural households, as different rural families have different abilities. It should be said that the limited material, financial, technological and investment resources of rural settlements of Yakutia make their population dependent on external aid.

During my fieldwork, I was convinced that all my respondents have in common a great sense of dignity, an amazing zest for life and positive life attitude. This is evidenced by the fact that even in the event of worsening of the adverse effects associated with climate change, the majority of residents (63.6%) intend to actively adapt to them. The “climate skepticism” current in Russian society is shared only by a small portion (18.2%) of population, who suggest to “think over a plan of action for the transfer of human settlements to the more favorable places” and “to search without delay for other types of employment for rural people”.

Conclusions

The planning of measures of adaptation to climate change in foreign countries is the sphere of interests and activities of national and regional governments, local authorities, urban municipalities and insurance companies, donor organizations and NGOs. In contrast to the developed countries with a wide range of adaptation strategies: from “The program to combat climate complications” in the UK to the federal law “On the control of floods” in Germany, in Russia there is not yet a uniform state policy on climate change, there is no national plan for adaptation, and no such plans on the level of individual regions or specific sectors of the economy. The Government of the Russian Federation prepared only the draft “Climate Doctrine” (2009), which has not been approved yet.

In opinion of the respondents, the reality of climate changes necessitates the need to develop a climate policy in Yakutia. The development of strategy of response to the risks produced by the climate, must be the prerogative of the state and not private or public initiatives. The creation of adaptation strategies at the sectoral (by industry) and regional levels (taking into account geographical, natural and climatic, socio-economic and demographic characteristics of the districts), will help reduce the vulnerability of economies and populations of the districts to climate fluctuations.

Finally I want to emphasize the importance of constant discussion of the climate issues. The increased attention to them from the population of Yakutia should be a major factor, stimulating the republican government to intensify activities in the field of climate change adaptation and mitigation. The uncertainty of the vector of modern climate change should not be an insurmountable obstacle for the scientific community, which calls for more action from the state.

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Climate change in remote places hard to access: Case studies in the Republic of Sakha

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Key words: remoteness, climate change, social change, adaptation

1. Introduction

One of the major characteristics of the Republic of Sakha is its remoteness and difficulty of access. In the Republic of Sakha, climate change because of global warming has been a phenomenon after the late '90s. In this presentation, I'd like to show how climate change influences daily life in remote places hard to access. When I discuss this theme, I'd like to consider social change, in other words, market economization, after the collapse of the Soviet regime, which occurred before climate change.

The investigation area is four villages in the Republic of Sakha: Argakhtakh, Sinsk, Beriozovka, and Khatystyr. They are troubled by climate change. The investigation period is 2008 through 2011. The investigation method is interview with residents, cultural anthropological participant-observation, gathering administrative documents, and collecting information in the mass media.

2. Remoteness and climate change in the Republic of Sakha

Before showing case studies of four villages, I'd like to give you some basic information about the remoteness and climate change of the Republic of Sakha. The Republic of Sakha is a large area, but its population is very small. It is 0.3 people per kilometer. In Japan, it is 339 people per kilometer, so Sakha's population density is more than 1000 times lower than Japan's.

Because of the permanently frozen ground, pavement with asphalt is difficult, and roads are poor. There is no railroad to the capital of the republic. In the republic of Sakha, winter roads play an important role in daily life. People can transport commodities by car or truck on frozen rivers or lakes in 3-4 months of winter.

"A remote place hard to access" is the official concept of the republic. It was established by a republican law in 2002. "A remote place hard to access" is defined by the republic as follows: It is such a place where roads or canals are not usable throughout the year and where there are natural obstacles disturbing the traffic, where there is no maintained airport, and which is far from the center of the district. As of 2007, 233 townships are designated as "remote places hard to access" (Zakon 2002). However, there are in fact more villages matching this definition.

Recently, the biggest problem occurring because of global warming is flooding. Sakha is rich in aquatic resources. There are more than 700,000 rivers comprising more than 10 kilometers in length, and this is why Sakha is so vulnerable to flood damage. According to the republican government, almost all townships are at risk of flooding (Postanovlenie 2010). The republican government decided to move 10 villages often hit by flooding (Postanovlenie 2002). In Sakha, there have been floods since the old days, but after the late 1990s, they became larger and more frequent.

3. Case studies

Now I'd like to show you four examples. These are villages troubled by climate change. I will show each example in the following order. At first I will show social change in the 1990s from the perspective of access, then adaptation to social change, next influence of climate change after the late 1990s, and finally the difficulties caused by climate change.

3-1. Argakhtakh Village

The first example is Argakhtakh Village in Srednekolymskii District of the Alazeia Basin. The population of the village is 567 (179 families). The ethnicity is mainly Sakha. The main subsistence is horse breeding, cattle breeding, fishing, and others. The distance from the center of the district is 140 km.

In the Soviet era, there were four regular cheap flights a week to the center of the district in all seasons. So the people could move about very conveniently. Goods produced by the village were carried by air, and products of the town were also flown in. So, in the village stores, there were always things to buy. There was free transport to production activity spots by the sovkhoz.

But in the post-Soviet era, all kinds of access became worse. There is no flight now to town in the winter, but people have come to use the winter road. It is a stable way of moving, so for three to four months in the winter, people travel move conveniently. But summertime travel is very problematic. In principle, there is one flight a week, but actually, it is very irregular and expensive. So now in the summer, people can't travel freely, can't carry village products and get money, and can't carry products of the town to the village stores. Access to production activity spots is also problematic in the post-Soviet era. The sovkhoz has almost collapsed, so now, people need to find transportation themselves, but it is very expensive. Gasoline has become expensive and because of poor access, it is very difficult to get. So sometimes, people can't work because of a lack of money.

In the post-Soviet era, the remoteness of this village increased, but people adapted to the new situation. Now, instead of collective farming, productive activity in the family has become more popular. They produce more food in the family to survive with minimum cash. In addition, they have built a new lifestyle. Now, only one car trip to town in the winter is enough to live. At this time, they carry all the necessary things, such as wheat flour, sugar, vegetable oil, and macaroni. And they store a large quantity of food in the house and underground storehouse.

The kind of disaster by climate change after the late 1990s in this village is special long-term flooding caused by fusion of permafrost. Because of the flooding, difficulty of access further increased. A runway was buried under water, and airplanes did not fly from 2007 to 2008. Because grazing land and mowing ground around the village for oxen and horses were buried under water, it was necessary to go far. And a boat became necessary even for going to the neighboring house. In addition, erosion of land was accelerated and underground storehouses were submerged under water or deteriorated.

People solved these problems as follows. They moved the grazing pastures to a more distant location and transported workers there by helicopter. The absence of two years' airplane flight did not influence their life so much, because after the collapse of the Soviet regime, residents built a new lifecycle of a one-year unit.

The peak of flooding was in 2007, and afterwards, it subsided. So now, almost all problems are solved, but deterioration of underground storehouses continues to be a serious problem. It prevents adaptation in the post-Soviet era by storing a lot of food. In addition, the remoteness impedes shore protection works to prevent erosion. Residents can work only in the summertime, but materials for the work can be carried only in the winter. People need to wait for materials for a long time, and if there are insufficient materials for the work, additional materials can only be carried in the following year.

3-2. Sinsk Village

The second example is Sinsk Village in Khangalasskii District of the Lena Basin. The population of the village is 1052 (345 families). The ethnicity is mainly Sakha and Russian. The most important method of subsistence is potato cultivation. In addition, there is horse breeding, cattle breeding and others. The distance from the capital of the republic is 231 km.

In the Soviet era, there was transportation system of potato by sovkhoz. But in the post-Soviet era, sovkhos collapsed and now there is no transportation system of potato.

However people have already adapted to the new situation. After the collapse of the sovkhoz, farmland was distributed between residents and they came to grow more potatoes as family units. Instead of a potato transportation system by the sovkhoz, a barter economy with the potato developed. Now, the potato is a local currency in this village. People can buy various products with the potato at village stores. This is exchange rate of the potato. Four sacks of potato (160 kg) can be exchanged for 1 sack of wheat flour. Five to six sacks of potato (200-240 kg) can be exchanged for 1 sack of sugar (50 kg). Potato can be exchanged even for clothing or stationaries. People of this village often say, "We can live if we have the potato."

The influence of climate change is the appearance of thermo-erosional gullies (in Russian, овраги). Because of the heavy rains of June 2007, five ravines suddenly appeared and divided the village. Size is of the biggest gully is around 1 kilometer in length, 20 meters in width, 6 meters in depth. In addition, from about 2006, water appeared in underground store spaces for potatoes in the spring and autumn.

Regarding the appearance of the thermo-erosional gullies, the villagers made their own efforts such as building a small bridge for walkers. With a federal budget of 5 million rubles, 30% of the gullies were filled in April 2009, but most of them have still not been filled. Now, because the village has been divided to some parts, when people go by car or tractor, they must make a detour. To make a detour, people need more gasoline.

Regarding water in underground store spaces, people are making efforts to save the potatoes. Underground store spaces were very convenient for storing potatoes, because their temperature was always 4 degrees. But now, people need to first store potatoes at in rooms warmed with firewood, and after disappearance of water in October, people put the potatoes in their store space. However, the potatoes now rot easily and they sometimes cannot be stored all winter until spring because the humidity in the wintertime has also risen. After the collapse of the Soviet regime, they adopted the potato, but now, the people are facing new difficulties because of climate change.

3-3. Beriozovka Village

The third example is Beriozovka Village in Srednekolymskii District of the Beriozovka Basin. The population is around 300. The residents are mainly Even. This is ethnic village of Even people. The main subsistence is reindeer breeding. On four collective farms in the village, there are 3,000 reindeer. The distance from the center of the district is 185 km.

In the soviet era, this village also had convenient access by plane to the center of the district, Srednekolymsk. Now, in the three winter months, people can use the winter road, but summer transportation is problematic. Air flights are irregular and expensive. In summer, they can use the waterway, too, but when the water level is low in the river, they need to drag the boat on the way.

The influence of climate change in this village is that flooding has become more frequent than before. Because of the heavy snowfall, blocking of the river, or melting of the permafrost, this village now suffers flood damage almost every year.

In 2002, the Sakha Republican Government decided to remove the village to an upper-place nearby village and to provide twenty panel houses for residents. But remoteness and poor access prevented people's activities here again. By river and marine transportation, materials for the houses arrived at the center of the district only in 2009. In principle, these materials needed to be transferred farther into the village by the winter road. But some materials were too big to transfer, and others were in a state of near-collapse, having been in the containers for too long. As a result, among the twenty panel houses, only ten houses arrived at the village in 2010. Another ten houses have been built in the center of the district, and village residents use them when they sometimes come to town to go to hospital or for shopping. Owning houses in town is also useful for villagers, of course, but because of the distance, they became useless as an anti-disaster measure.

3-4. Khatystyr Village

The forth example is Khatystyr Village in Aldanskii District of the Aldan Basin. The population is 1461 (378 families). The residents are mainly Evenki. This is an ethnic village of Evenki people. The main subsistence is reindeer breeding. There is one collective farm and 24 communes for reindeer breeding.

There is no problem with access to the center of the district. The distance is only 60 km and people can use the roads in all seasons. But access to reindeer-breeding spots became worse in the post-Soviet era. In the Soviet era, there was a sovkhoz and employees could use the helicopter to get to reindeer-breeding spots. But now there is no sovkhoz, but only a poor collective farm or communes of family units. They can hardly use the helicopter. Breeding spots are often located in remote places, where there is no normal road for vehicles. For example, reindeer breeders have to go by reindeer for one week to one particular breeding spot.

The influence of climate change on this village is also flooding. In the spring of 1998, there was a big flood and half the village was soaked in water. Soon after the big flood, by this summer, the Sakha Republican Government conducted a questionnaire survey on the damage by the flood and paid a little compensation money. But some reindeer breeders' family couldn't answer this survey, because they were in very faraway breeding spots and they could not come back to the village soon after the flood. As a result, in this survey, the damage to such families was not reflected and these families could not receive compensation money from the government.

4. Conclusion

From the above-mentioned four examples we can conclude that the difficult-to-access remote places and the relationship between social change and climate change have the following influences:

- Generally, remoteness in the post-Soviet era continues to increase because of climate change.
- In some cases adaptation in the post- Soviet era can help adaptation to climate change.
- But in other cases climate change can prevent the adaptation in the post-Soviet era.
- Remoteness can prevent implementation of disaster prevention measures beforehand, the provision of emergency relief and enabling the authorities to grasp the extent of the damage, or remoteness can render the provided help useless.

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Current Status of the wild reindeer populations and domestic reindeer farming in Sakha Republic

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Key words: wild reindeer, domestic reindeer farming, tundra, Yakutia

Sakha Republic (Yakutia) is the largest subnational governing body in Russia, and from time immemorial, the habitat of major wild reindeer population. Here, aboriginals have been traditionally involved in domestic reindeer herding, which is still one of the key sectors of the economy of the peoples of the North. Millions of hectares of pastures in the tundra and forest-tundra zones that cannot be used by other kinds of domestic animals are productively utilized, thanks to these unique animals.

Up to 1993 Yakutia was one of the major reindeer herding regions in Russia, with the total reindeer numbers approaching 670 thousand, including 380 thousand domestic reindeer (third place after Tchukotka and Yamal) and 280-290 thousand wild reindeer (second place after Taymyr).

However, presently the total number of reindeer in the republic is only about 390 thousand, including 200 thousand wild and 190 thousand domestic reindeer.

Yakutia is the habitat of three geographical forms of wild reindeer: tundra reindeer of the Lena-Olenyok population, tundra reindeer of the Yana-Indigirka and the Sundrun population as well as the forest form of reindeer.

Yakutian mainland tundra is the habitat of three big populations of wild reindeer: Yana-Indigirka, Lena-Olenyok (Bulun), and Sundrun (Indigirka-Kolyma). There is also an isolated population on New Siberian Islands.

Yana-Indigirka population inhabits the interfluve of the Yana and Indigirka Rivers. Lena-Olenyok population's habitat is the plateau and planes of North-West Yakutia. Sudrun population inhabits the Kolyma Lowlands in the winter migrates to Alazeya Plateau (Fig. 1).

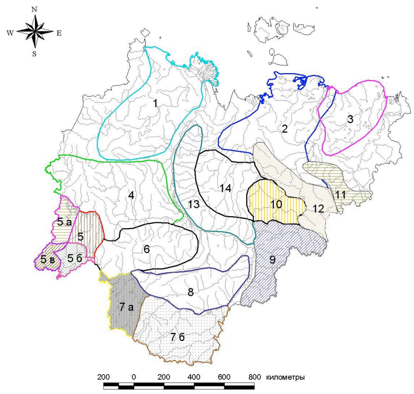

Figure 1. Areas and main territorial groups of wild reindeer in Yakutia. ***Tundra:*** *1 - Lena-Olenyok tundra; 2 - Yana-Indigirka; 3 - Sundrun;* ***Forest population groups:*** *4 - West Yakutian or Lena-Olenyok forest; 5 - South-Western; 5 a - Tchona; 5 б-Nyuy, 5 в - Peleduy; 6 - Lena-Vilyuy; 7 - South Yakutian; 7 a - Olekmo-Tchara; 7 б - Aldan Mountains and Stanovoy Range; 8 - Lena-Aldan; 9 - South-Eastern Verkhoyanye; 10 - Elginsk Plateau; 11 - Momskiy Range; 12 - Tcherskiy Range; 13 - Predverkhoyansk; 14 - Verkhoyansk.*

During the transitional period of economic reforms of the 1990s, the size Yana-Indigirka population, the biggest in Yakutia, declined dramatically. Presently, it shows unfavourable demographic structure; the numbers continue to drop, and it has practically lost its significance from the commercial harvesting point of view. In 1987-1993 it amounted to 85-130 thousand and by 2002 only 34 thousand survived. Sundrun (Indigirka-Kolyma) population shows a steady shrinking tendency. In 2002 its size was estimated at about 20 thousand. The only population that tends to grow is the Lena-Olenyok population of wild reindeer. In 1988 its size amounted to 73 thousand, in 1994 - 77.8 thousand, in 2001 - 90 thousand, in 2001 - 90 thousand, and in 2009 - 95 thousand (Fig. 2).

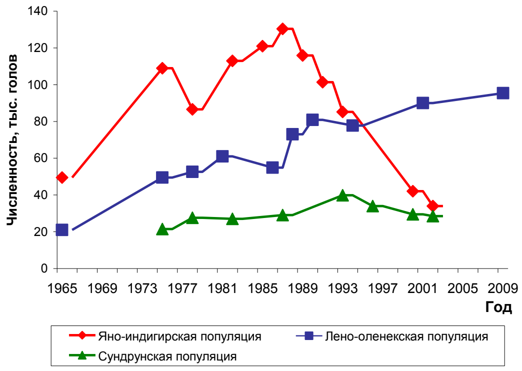

Figure 2. Wild reindeer populations changes in Yakutia [1; 2].

Thus, we are presently witnessing the degradation of one of the biggest populations of wild reindeer in Yakutia - the Yana-Indigirka population. As already mentioned, the Sundrun population also exhibits tendency to shrink. Relatively problem-free situation in the Lena-Olenyok population is, according to V.M. Safronov [1], based not on the internal reserves of the herds, but on the periodic inflow of the reindeer from the neighbouring Taymyr population.

The state of the Yana-Indigirka population of wild reindeer has been a source of major concern in the recent years. Its size has obviously reached a critically low level and its habitat, particularly in the areas of winter pastures, has shrunk dramatically. It is necessary to survey the size of the Yana-Indigirka and the neighbouring Sundrun populations. According to the latest aerial surveys the size of Sundrun population has been gradually shrinking, but its present condition also remains unclear.

The collected data shows the necessity of the development of a complex of measures aimed at revival of this, once biggest population in Yakutia, followed by planning the strategy of sustainable utilization of its resources. Presently, introduction of a complete ban on reindeer harvesting from the Yana-Indigirka population is indispensable.

The survey of the migration activity of the Lena-Olenyok population of wild reindeer demonstrates substantial changes in the terms and routes of seasonal migrations. The reasons for these changes are so far unknown. Further research of the migration activity and the use of the winter and summer pastures by this population is required. It is evidently necessary to change strategies and methods of utilization of the resources of this population.

According to O.V. Yegorov's reference data [3], in early 1960s total number of wild forest reindeer in Yakutia amounted to about 100 thousand. Y.Y. Syroyetchkovskiy [4] estimated the size of this population in 1975 at 90 thousand. Later the numbers were reported at 57 thousand [4]. V.M. Safronov [1] estimated the number of wild forest reindeer in Yakutia at 50-60 thousand. According to the results of aerial survey that this presenter conducted in 2001-200£, the size of the forest population was estimated at 30 thousand. Thus, we believe that the forest population of wild reindeer is also showing the tendency to shrink.

The economic crisis of the 1990s had a devastating effect on the northern farms of Yakutia and resulted in the decrease of domestic reindeer. During this period the livestock decreased 7 times compared to the highest numbers (1980) - from 385 thousand to 139 thousand. However, thanks to the efforts of the Sakha Republic (Yakutia) government, starting from 2003 the livestock has been showing the annual increase of 5-15 thousand (6-8%). At the beginning of 2001, Yakutia had 190 thousand reindeer (15% of all the domestic reindeer of the Russian Federation). Thus, we believe that in the near future domestic reindeer herding will regain the lost ground and will continue to develop, as it is essential to the lifestyle of indigenous minorities of Yakutia.

With the enactment of new Russian Federation law regulating hunting and preservation of hunting resources, many indigenous communities in Yakutia were able to lease hunting grounds for 49 years. For the first time, indigenous people gained the right to hunt all year round in order to satisfy their personal needs and maintain a traditional lifestyle.

Now is the time to work out the strategies of the involvement of indigenous people in wildlife management. Until recently everything was based on the inborn nature conservation sentiment of the indigenous people and government regulation in the form of harvest quotas and the system of fines for illegal harvesting. Today after the so-called "perestroyka" young generation is stepping in, and, compared to their fathers, it tends to gravitate towards consumerism,.

Industrial development of the northern territories occurs in pockets and presently impacts the tundra populations of reindeer only marginally. Widening network of mining enterprises causes deviations from the usual reindeer migration routes. Permanent embankment roads and temporary winter roads construction create obstacles on the routes of reindeer migrations and also makes poaching easier. One example is the highway Ust-Kuyga - Deputatskiy, where 14 to 25 thousand migrating reindeer tended to flock, before distinctly changing the route of their migration [5].

In 2010, using radio collars and the Argos satellite system, we discovered the impact of the operation of a diamond-mining enterprise on the migration routes of the Lena-Olenyok population. There a motor road, overhead power transmission lines, and waterline pipes became the obstacle for further normal migration. Consequently, up to 5 thousand of reindeer flocked in the area.

The industrial impact on the forest reindeer population of Southern Yakutia is particularly alarming. For example, in the areas around the Talakan and Tchayanda oil and gas fields, sharp decrease in wild forest reindeer numbers was noted; furthermore, from 1999 to 2001 the density of the population decreased almost 4 times. If in 1999 the density in the mentioned regions was 0.93-1.16/10 sq. km., being the highest in Yakutia, in 2001 it dropped to 0.26/10 sq. km. Dramatic decline of the density (from 0.31/10 sq. km. in 2001 to 0.18/10 sq. km in 2007) is also noted in the Neryungri region, in the eastern part of the Olyokminsk region, and in the southern part of the Aldan region.

The negative influence of the industrialization in the region became dramatically severe in 2006-2008 with the start of the construction of the Eastern Siberia-Pacific Ocean oil pipeline, that crosses the habitat of South Yakutian population of the wild forest reindeer and can dramatically impact its well-being, curtailing lichen pastures and inducing changes in seasonal migrations. At the same time the oil pipeline construction makes previously remote areas more accessible for poachers, which is also a source of serious concern. Also, gas pipeline construction is under way in the region.

The industrial development in Southern Yakutia negatively impacts domestic reindeer herding as well. The indigenous people are losing the pastures for their stock. Moreover, the ways to compensate for these losses are not yet stipulated by law.

It is interesting to note that the depression of the wild reindeer populations, noticed everywhere in the northern Siberia in 1930s-1940s, coincides with the period of climate warming that was especially well-defined in the northern latitudes. The reconstitution of the size of those populations falls on 1950s-1960s and corresponds to climatic cooling during that period. We cannot exclude the possibility, that the noted cyclicity in reindeer population is the result of the impact of vegetation mantle changes under the influence of the climatic factor.

Wolves are a serious threat to wild and domestic reindeer populations. Presently the number of wolves in Yakutia is 4.3 thousand. In 2009-2010 wolves were the cause of the loss of 21665 domestic reindeer. The damage caused by wolves to the herds of wild reindeer is about the same.

Presently, the epizootic situation in Sakha Republic (Yakutia) is quite tense due to the changes in people's lifestyle and strengthening anthropogenic impact on the natural biocoenosis. Active new and abandoned land reclamation for hayfields, tillage, and vegetable gardens, the reform of the agrarian sector of the economy and emergence of small farms, uncontrolled delivery of farm animals from other areas, that are sometimes troubled from the epizootic point of view, raise the risk of naturally developed infection outbreaks and formation of anthropurgic infection hot spots.

The territory of Sakha Republic (Yakutia) is problematic in terms of anthrax, rabies, reindeer brucellosis, necrobacillosis, cattle leukosis, strangles and salmonellosis-induced abortions among mares, swine fever, dysentery and atrophic rhinitis, and also numerous parasitic diseases of the animals.

Speaking about infections among reindeer in Yakutia, the most frequently registered ones are anthrax, rabies, brucellosis, tuberculosis, and necrobacillosis.

The most frequently registered parasitic diseases are echinococcosis and dictyocaulosis. On top of this, in 2008 pyroplasmosis was registered for the first time on Yakutian territory.

Presently the most widely spread disease among domestic reindeer is necrobacteriosis. Sakha Republic (Yakutia) reindeer herding suffers annual substantial economic loss because of the diseases, sick animals sometimes amount to 10% of the total numbers.

Commercial harvesting is the main factor impacting the herds of wild reindeer in Yakutia.

Degradation of the Yana-Indigirka population, almost complete extermination of the Ust-Lena herd, that spent summers in the delta of Lena River, regular structural irregularities in tundra populations, reducing their productiveness, attest to mainly inhibitory impact of harvesting on the numbers of wild reindeer in Yakutia.

From the very start of the utilization of the wild reindeer resources harvesting aimed at maximizing the profits and paid little attention to the accompanying problem of sustaining the biological productivity of the populations.

For many years, weak regulatory system, prolonged hunting season that incorporates periods of early spring migrations to the calving areas, and excessive harvesting, including pregnant cows, have been undermining the reproductory abilities of the populations.

Presently, only Lena-Olenyok and Sundrun populations have any significance from the harvesting point of view. The annual quota is 15-18 thousand reindeer, of which 80% falls at Lena-Olenyok and 20% on Sundrun and forest populations.

The development of a rational strategy of harvesting and strengthening harvesting regulations are the major problems in contemporary Yakutia.

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The migration of eastern Siberian wild reindeer: Where, when, how and why do they do?

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Key words: wild reindeer, migration, satellite tracking, habitat use, Republic of Sakha (Yakutia)

Introduction

Reindeer (*Rangifer tarandus*) is the only species that human has succeeded in domestication among the deer family (Cervidae) and so many indigenous peoples in the arctic and the sub-arctic have depended on the both of wild and domesticated reindeer to live. Although wild reindeer was used to be seen in all through the circumpolar area, their number and distribution have been shrinking and some local populations are concerned to be extinct (Henttonen, & Tikhonov 2008, Vors and Boyce 2009, CAFF 2010). These ecological changes in this species affect the lives of many indigenous peoples and have also become a serious social problem (Ulvevadet and Klokov 2004, Yoshida 2012).

In the Russian Federation, 28% (1.246 million animals) of wild and 74% of domesticated reindeer (head 1.3577 million) in the world can be seen, and most of them (90% of the wild, 70% of domesticated) are inhabit in Siberia (Jernsletten and Klokov 2002). In Siberia, two subspecies of wild reindeer (Siberian tundra reindeer, *Rangifer tarandus sibiricus* and Eurasian woodland reindeer *R. t. buskensis*) were described (Grubb 2005), but there has been little scientific information on both (Klein 2005). Klokov (2002) and Working Group on Reindeer in Sakha (2009) reported that a great part (more than 70%) of wild Siberian tundra reindeer are concentrated in only five ranges (Taimyr peninsula, Lena, Indigirka, Sundrun, Chukot) and all but Chukot have decreased in their numbers.

The most drastic changes in Siberian wild tundra reindeer are the reduction of Taimyr population and new establishment of Olenek population. Taimyr population, which was supposed to have the world's largest population of more than 600,000 heads in 1960s, has decreased in the number and moved its distribution range from the peninsula to southern inland area, so that indigenous “reindeer peoples” come to be able to hunt scarce wild reindeer (Korpashkov unpublished). On the other hand, in Olenek district, wild reindeer has increased in the number and intensified conflicts with local people and domesticated reindeer (Working Group on Reindeer in Sakha 2009, Tatsuzawa et al. 2012). Therefore we need to clarify the present status of and ecological relationship between these two populations. For this purpose, we have developed a satellite tracking system suitable in Siberia, and track reindeer practically. In this paper, we will discuss about migration range and habitat use of wild reindeer in Olenek district, especially on the migration from summer range to winter one.

Site and methods

Because of good summer weather (average altitude is 300-500m) and rich grasslands, Olenek district (Fig.1) was one of centers for domesticated reindeer ‘sovhoz’ in the Soviet Union. However, since 1980s, wild reindeer has increased in its population and conflicts with domesticated reindeer (competition over forages) and local people (resource plants or rare vegetation) (Tatsuzawa et al. 2012). Although this new establishment of wild reindeer population is never reported and surveyed, it is supposed to originate from either Taimyr or Rena population.

Since 2008, we made preparations for this study, i.e. testing equipment and location systems, licensing, and organizing local crews. We adopted the Argos satellite-based positioning system (APS) and coordinated technical experts (ES-PAS Co., Moscow) to make the first satellite collar for terrestrial animals in Russia (Fig.2), because APS has not so lower accuracy and higher possibility of frequent positioning than GPS in the Arctic and sub-Arctic areas (Tatsuzawa et al. 2011).

Capturing was carried out between August 12 to 26, 2010 at the upper-middle point of Olenek river (68°23'45"N, 114°38'32"E; Fig. 3). We detected and captured reindeer acrossing the river from two boats. An anesthetized animal was pulled up to shore, external-measured, picked small tissue for DNA analyzing, put an APS collar, and released safely. 0-1 years old and weaken animals were not intended for capturing which were expected to have trouble with collars. We can receive and track their location data in PC sent from Argos satellite via a ground station in France.

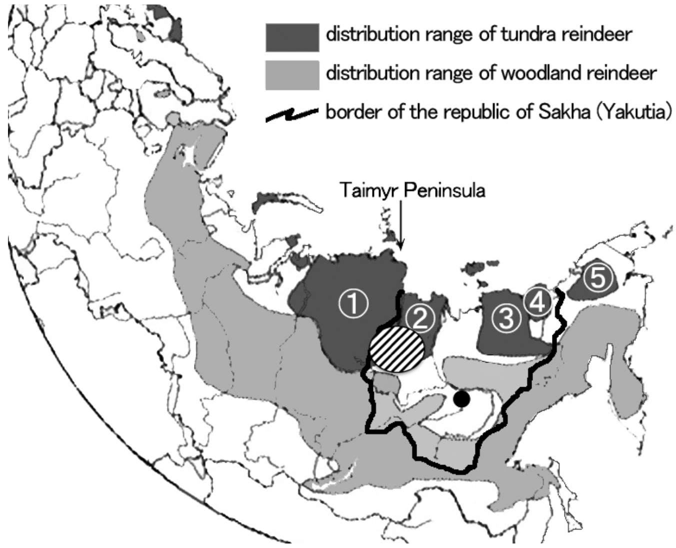

Figure 1. Distribution ranges of wild reindeer in Eurasia (modified from Tatsuzawa et al. 2012) ①-⑤: main populations of tundra reindeer (Taimyr, Lena, Indigirka, Sundrun and Chukot, respectively), oblique: main study site (upper Olenek river), ●: Yakutsk city.

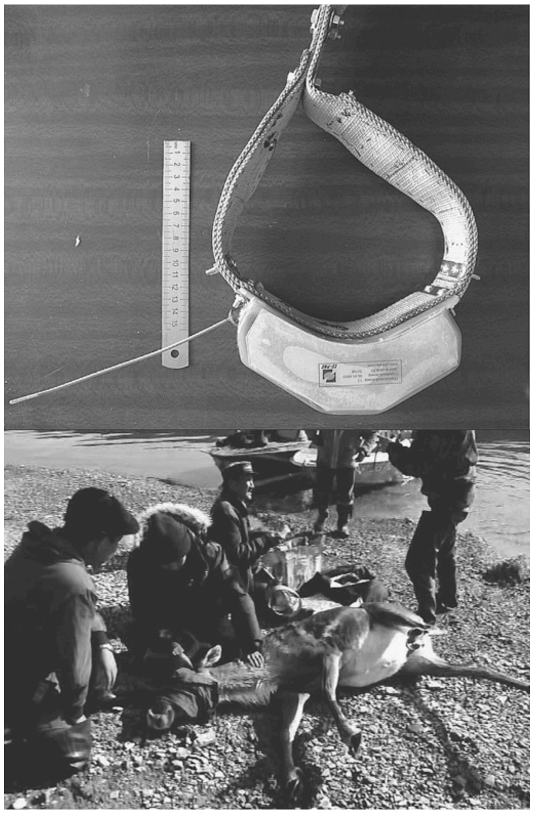

Figure 2. APS satellite tracking collar (upper photo) and Capturing a reindeer on the Olenek river (lower photo)

Results and Discussion

We captured and put satellite collars to a total of 15 animals (seven 2-8 year-old males and eight 2-7 year-old females) (Fig. 3). Though by the end of October, 2 males stopped moving because they might be dead for rutting fights, remaining 13 animals (5 males and 8 females) were tracked until January 2011 since their releasing in mid-August 2010. Positioning data was obtained at intervals of a minimum of 5 minutes to 2 hours. After January 2011, location data became inaccurate and unstable because of the extreme cold.

13 animals showed clearly opposite two migration routes; toward the north (northern migration group=NMG, 4 animals) and the south (southern migration group=SMG, 9 animals) (Fig. 4). NMG migrated 580 km distant in a straight line from the capture point to near the estuary of the Lena river (71°06'26"N, 127°14'06"E) by the end of December 2010. In the other hand, SMG went 390 km down to near Udachny city (64°58'26"N, 112°33'22"E) and stopped migrating by the end of October 2010.

In North America, tundra reindeer populations migrate from north to south in this period except for some special cases (), but we can find no reason why NMG went up to the estuary of the Lena where winter condition is crucially harsh and cold without forages.

Our result shows that two groups from different wintering sites used the same summer habitat in highland area. This means that Olenek population has possibilities to have two sources (Lena and Taimyr), because the Lena delta is the western part of the distribution range of Lena population and Udachny area is close to the boundary between Krasnoyarsk region and Sakha republic (about 200km) which is the southeastern edge of a new distribution range of Taimyr population (Korpashkov personal communication). Including information from local hunters who could see little wild reindeer in winter in this area, Olenek population may be formed mainly in summer because of its more comfortable environment with cool temperature and rich forages than core ranges of their main populations.

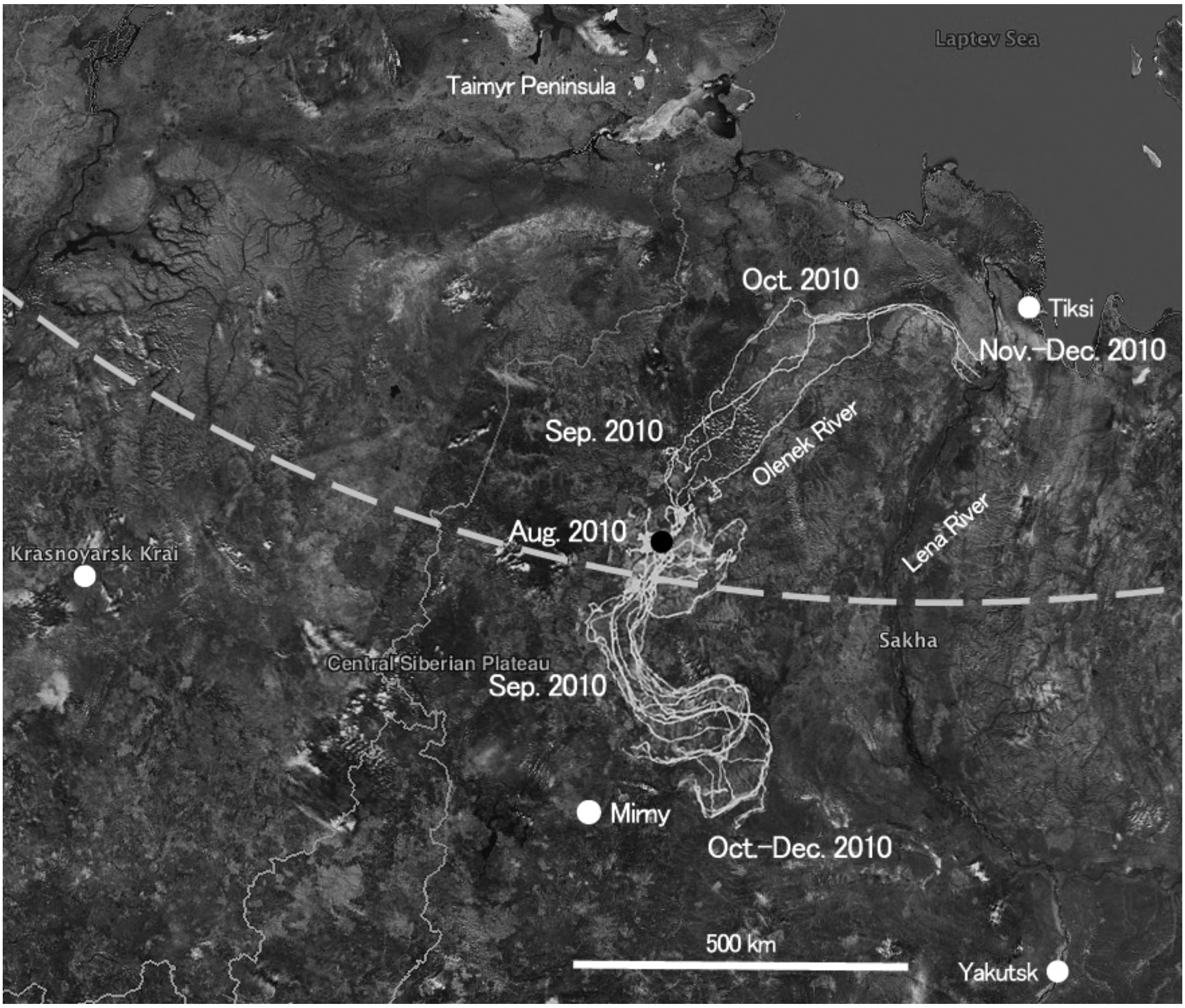

Figure 3. Location points of 15 wild tundra reindeer from mid-August to the end of December 27,126 locations tracked by Argos satellite are showed as white lines. Animals migrated in opposite two directions (southbound and northbound) and reached each wintering sites in October and November, respectively). Black full circl: a capture point, a broken line: the south boundary of the Arctic Circle.

If two migratory groups (NMG and SMG) join or are originated from adjacent main populations (Lena and Taimyr, respectively), the emergence of Olenek population means conjunction of the two largest populations in Siberia. We must, however, notice that these are not range expansions but range shifts, because both of two main populations have decreased in their numbers (Jernsletten and Klokov 2002, Working Group on Reindeer in Sakha 2009). If this supposition is fact, present management regime for wild reindeer in Olenek to control for reducing competition with domesticated reindeer will make their main populations vulnerable.

Olenek population has another problem in conserving biodiversity. The south of Udachny is developed Taiga forest area where other subspecies, woodland reindeer (*R. t. buskensis*) habituates. This means that crossbreeding between two subspecies has already occurred. This is a very rare case for these two types (tundra and woodland types) because little areas where their distribution ranges are overlapped in the world (Jernsletten and Klokov 2002).

Conclusions

In this preliminary study, it is showed that two groups used the same summer habitat and the two largest main populations may conjunct with each other in Olenek range. Moreover, our study found a circumstantial evidence of crossbreeding between two subspecies. Further tracking and genetic studies will show the accurate relationships and proper management regimes among these five characteristic populations.

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Reindeer Herding and Environmental Change in Kobyai and Olenëk districts, Sakha Republic

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Key words: Reindeer herding, Climate Change, Sakha, Tundra Nenets, vulnerability

1. Introduction

Russia has about 1,500 thousand domesticated reindeer now and Sakha republic - about 200 thousand (13% of all Russian heads) and 650 thousand in Yamal Nenets autonomous.district (45%). In Russia there are 17 indigenous peoples of Siberia and North who have been engaged in this traditional mode of subsistence from Saame in the west and Chukchi in the east end of continent.

Reindeer herding in Russia has always been under the pressure of political, socio-economic changes, natural resource exploitation and, in addition to them, climate change throughout 20th century. Beside that the reindeer herding activity itself has also affected the condition of pastures depending on the herding and husbandry method.

2. Possible influence of climate change to reindeer herding

In 21st century not a few international projects, dealing with far northern indigenous peoples and their reaction to the climate change, have already been executed - such as: CAVIAR, RENMAN, IPY EALAT ("good pasture") project, ENSINOR, BALANCE and so on. These projects have brought various results including reindeer husbandry prognosis in the research regions, but East Siberian reindeer herding regions does not seem to have been researched enough.

At first, please pay attention to what kind of factors may influence to reindeer herding, especially to the pasture condition. Before introducing my field research in Sakha republic I will examine the possible factors influencing the reindeer pastures as follows:

- **Anthropogenic factors:**
  - natural - hydrocarbon/mineral/forest – resources' exploitation
  - industrial expansion and workers influx,
  - building infrastructures
  - radioactivity (in some places).
- **Reindeer herding activity itself':**
  - overgrazing, trampling,
  - nutrient inputs from feces/urine of animals
- **Climatic change:**
  - warming temperature
  - snow-freezing regime change
  - freezing-thawing periods/frequency change
  - precipitation amount/ frequency change.

Figure 1. Reindeer Herding Pasture in north-west of Sakha republic (MUP "Oleneksky"; Sept. 2010).

3. Field research and the perception among local people

3-1. GUP "Sebyan" in Kobyai district

In the framework of RIHN Siberia project I performed field research in two districts: GUP "Sebyan" in Sebyan-Kyuelj in Kobyai district (2009) and MUP "Oleneksky" in Olenek village, Olenek district (2010). For comparison it would be helpful to introduce the individual reindeer herding practice among Tundra-Nenets in Yamal-Nenets Autonomous District, West Siberia where I have performed field research from 1995 to 2008.

Sebyan-Kyuelj is an isolated village in Verkhoyansk mountain system in the north-east part of Kobyai district. This village has 800 population about 85% of which are ethnically Even people. There is a reindeer herding governmental enterprise - GUP "Sebyan" It has 11,000 domesticated reindeer and divided into 10 brigades (herds). I stayed one summer camp of Brigades No.9 which located in a river valley Sulanichan (N65°04′E129°53) about 1000 meters above sea level.

The vegetation around the summer camp (the end of August) is sparse larch on the hillsides and surface vegetation – grass and lichen with mushrooms. The grazing range of this brigade is comparatively small and this herd stays at a winter log house around southern part of the grazing zone in winter from December to March.

In this camp and village I interviewed some Even residents and herders and collected following information about the climate change and perceptible phenomena :

- **Temperature change:**
  - lower temperature in spring ; it does not correspond to JAMSTEC meteorological date offered by Mr. K. Yamamoto and K. Oshima, according to which the spring mean temperature from 1950 to 2008 increases (Fig.2).
  - hawing-freezing repeat affects infant mortality of reindeer calves

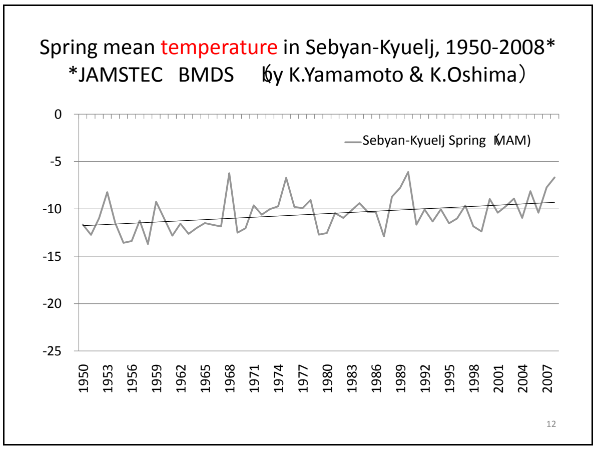


Figure 2. Spring mean temperature in Sebyan-Kyuelj 1950-2008.

- **River flood** induced by summer intensive rainfall occurs frequently in last 20-30 years: pasture degradation around floodplain and river bank erosion. Summer mean precipitation data show that we can detect wide periodic amplitude of annual temperature. Residents can perceive every positive anomaly as intensive rainfall.
- **Change of fauna** or biodiversity: increase of wolves, bears and wolverines - the enemy of domesticated reindeer. In the forest environment these harmful animals affect reindeer every year. But the relationship between climate change and their biomass is not clear.

3-2 MUP "Oleneksky" in Olenek district

What about the case of MUP "Oleneksky" in Olenek district, north-west of Sakha republic?

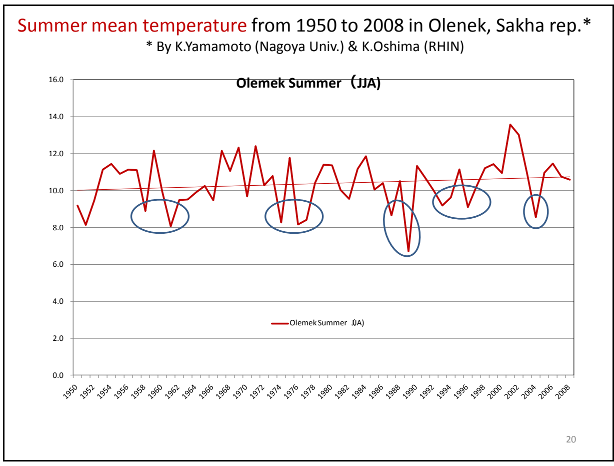
Olenek is a central village on the bank of Olenek river (N68°30′15″E112°26′50″). MUP "Oleneksky" was a former Sovkhoz "Oleneksky" in Soviet time. It has 3500 reindeer at the beginning of 2010 which are divided into 3 herds for each brigade (historically, maximum number of reindeer was 34,000 in 1980's). They graze reindeer in north-western direction far from the village beyond the Sakha rep. and Krasnoyarsk district borderline. There is a tree line in the middle of the grazing range. Southern part is mainly covered with larch forest, and northern part - mountainous tundra zone.

From the end of August to beginning of September 2010 I stayed at six camps of the Three brigades (No.1,5,6) and performed field research in the northern part of the pastures about 600-800 m high above sea level. I stayed a camp which was located 10 km north the tree line (N69°47′30″E109°28′58″) but there was already spare larch forest zone.

Following is the result of interviews of herders among camps:

✦ **Tempereture**: <u>lower in summer, higher in winter</u> in last 20-30 years. (Fig.3)
 ➢ Some herders said - "In summer high temperature spell used to continue a week or so, after that it declines. But last time no such "heat spell" is experienced "
 - If I take short time span of meteorological data, we can detect the same phenomena as indicated in the herders' perception. (Fig.4)
 ➢ Permanent snow cover diminishing.

✦ **Precipitation**: comparative <u>heavy rainfall increases</u>



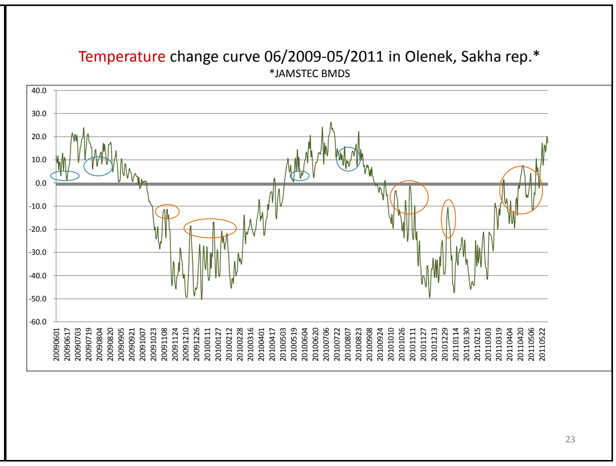


Fig. 3. Summer mean temperature in Olenek 1950-2008. Fig. 4. Temperature change curve 06/2009-05/2011 in Olenek.

✦ **Change of flora**: Northward and upward shift of tree-line
 - When I asked one of herders - "What bothers you in this situation?", he answered half-jokingly, - "It'll take longer time to pass through forest zone, and it'll take more time for us to get to the winter log house."

✦ **Change of fauna**: wild reindeer migration route has changed and frequent conflicts with domesticated herds happen from 1976. In 2010 autumn wild reindeer "abducted" 500 from 1200 domesticated animals of Brigade No.6; returned just 200 in winter.

3-3 Tundra Nenets in Yamal-Nenets a.d., West Siberia

For comparison I introduce the West Siberian reindeer herding condition among the Tundra Nenets practice on the basis of published materials. In the northern parts of Yamal-Nenets autonomous district prevails arctic or dwarf shrub tundra suitable for reindeer grazing. And in these tundra zone counts about 40% of all Russian domesticated reindeer. In this autonomous district there is several research projects worked in 21st century. According to some of them the pasture condition is changing from comparatively stable to more dynamic regime as follows:

✦ **Temperature**：summer air temperature have increased some 2°C over the past 25-30 years. [B.C.Forbes & F.Stammler 2009]

✦ **Change of flora**:
 ➢ Northern shift of vegetation (Shrub)[Goetz et al. 2011]

- ➢ Transformation of shrub- to grass- and sedge-dominated tundra where intensive reindeer grazing is practiced.[Forbes, et. al. 2009; Kumpula et al. 2011]
- ➢ De-lichenification [Bulgakova 2010]

✦ **Change of fauna**: Arctic Fox, Migratory birds (Geese, Ducks, Swans), Sea mammals, Fish (Whitefish=*Coregonidae*) population change. Except arctic fox, these game animals and fowls are important local foods for local people. [Eg.: Noren, et. al., 2011 ; Reist, et. al., 2006]. The change of the biomass might affect the food intake balance and thus dietetic situation.

4. Analysis

Thus, roughly speaking, three reindeer regions in Saka and Yamal-Nenets a.d. have their own features and problems which depend on their ecological environment /taiga or tundra/ and the socio-economic situation, historical background, ethnic or cultural aspects and so on. If I compare the Natural & Socio-economic aspects of environmental change of these regions, it shows as follows:

Table 1. Natural & Socio-economic aspects of environmental change for the reindeer heeders' communities

	Natural – meteorological/biological - aspect	Socio-economic aspect
Common aspects	- Temperature increase - Northward and upward shift of shrub vegetation - (Creep) pasture degradation - Wild reindeer migration	- Nomadic lifestyle - Local/Federal administration's support (affirmative action)
Different aspects S:Sakha Y:Yamal-Nenets	- Pasture condition critical(Y) stable(S) - Overgrazing(Y)	- Prevailing public(S) or private(Y) management - Commercialization of products (Y) - Ethnicity: strong(Y) week(S)

Sakha reindeer herding regions as Sebyan-Kyuelj (Even) and Olenek (Evenki) districts – socio-economically vulnerable in near future in that these enterprises are unprofitable with republic and federal subsidies. At the same time the situation about wild reindeer migration is also critical for reindeer herding management, but at moment the condition of pastures doesn't seem to be critical.

As for the Yamal (Tundra) Nenets case, the situation seems to be critical from the point of view of pasture condition, industrial development and so on. On the contrary, strong "ethnicity" of Nenets people may help to keep their traditional subsistence system on the basis of Local/Traditional Ecological Knowledge.

5. Conclusion - Nomadic reindeer peoples' vulnerability

If we analyze the vulnerability of nomadic "reindeer peoples", it is important to take into account not only natural, but also the socio-economic aspects. We know that reindeer herding, as a type of nomadic pastoralism, is a highly adaptive subsistence system. One of the important factors must be their mobile lifestyle. And the merit of mobile lifestyle for reindeer herding must be based on the existence of vast normal pastures. In this context it is important to investigate and analyze the pasture conditions and the way how to utilize it from various aspects including TEK/LK in our further research.

At the same time, it will be important to examine several approaches toward current and future vulnerability study. For matching Traditional and Scientific Knowledge it'll be important to consider and emphasize social dimensions of climate change [H.Hantington et al. 2004; Ishii 2011].

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Reindeer herding and environmental change in the Tompo district, Sakha Republic

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Key words: reindeer herding, environmental change, Tompo district

Introduction

Wild reindeer populations are reported to decrease at many regions in the northern hemisphere and global warming seems to be one of the causes of it.

Vors and Boyse (2009) reviewed and synthesized literature on global change of reindeer. They gathered population data for 58 major caribou and reindeer herds, and found that 34 were reported as declining, eight were increasing, and 16 had no data. It indicates that populations of reindeer in many regions are decreasing. General consensus among scientists is that climate change is altering plant and insect phenologies, spatiotemporal overlap of species, and increasing the frequency of extreme weather events, such as deep snow and/or freezing rain. These conditions that may have negatively impacted on reindeer regional populations, are apparent already and likely will continue concurrent with climate change.

Global warming affects ecology and behavior of reindeer through changes of availability and nutrition of its diet, distribution of competing species, intensity of insect harassment, and indirectly through acceleration of human development activities (Klein 1991; Weladji et al. 2002; Weladji and Holand 2006).

Same kinds of influences to domestic reindeer are also recognized by reindeer herders at many areas in the north as follows (Oskal 2008).

- Change in biodiversity; spreading of shrubs into the barren tundra areas, important food resources for the reindeer may disappear partially, and changes in insect populations could change reindeer behavior.
- Change in temperature, precipitation and climate variability; rivers to freeze later in the autumn and melt earlier in the spring, causing challenges for the annual migration of reindeer, ice layers in the snow and block the reindeer's access to food on the ground.
- Indirect effects of climate change; increased accessibility of the Arctic regions for human activities.

So it seems that global warming and environmental change, induced by global warming, may also affect reindeer herding in Siberia.

However in Sakha Republic these influences have not been investigated yet. The aim of this study is to estimate influences of environmental change to reindeer herding in the Tompo district, Sakha Republic in eastern Siberia.

Study Site and Methods

Investigation was focused in the Tompo district at middle-eastern part of Sakha Republic (Fig. 1). The distance from Yakutsk to capital town of the district, Khandiga, is about 400 km. The area of the district is 135,800 km^2, and most part of it is mountainous. Vegetation is classified as "mountain-taiga, sparse wood". Mean air temperature is -39.7 C in January, +16.2 C. in July, and mean precipitation is 16.1 mm in January, 100.9 mm in July respectively (in 2007).

Population of the district is 15,300; 9,200 live in the central town, 6,100 live in rural area. Some ethnic groups compose the residents; Russians 48.3 %, Sakha 34.5%, Even 5.4%, Evenki 0.5%, others 11.3% respectively.

At first in order to appraise an outline of reindeer

Figure 1. Study site

herding in the Tompo district, statistical data (number of the domesticated reindeer in 1980-2010, presented by the Ministry of Agriculture of Sakha Republic) are checked.

Field researches are performed with a reindeer herding camp, which belong to a clan community of Even, in summer in 2009 and in autumn in 2010. At the camp some herders held several hundreds of reindeer. Each time I stayed there for about a week, observed their herding procedures and methods, interviewed to some herders.

Furthermore, climate change is estimated by air temperature and precipitation in the district. These data sets are made as follows (processed by Dr. K. Yamamoto and Dr. K. Oshima, both are members of this RIHN project);

In an area in the Tompo district (N62.30-65.00, E135.00-141.00), grid data (each 0.5 point of latitude and longitude) are made from Baseline Meteorological Data in Siberia (BMDS) provided by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) using spline interpolation method. Then monthly average of each grid point is calculated during 1950-2008, and the monthly values are averaged over the area. The values larger than 3 times of the standard deviation are excluded as observational errors. Climate data are analyzed by the four seasons; spring (March, April, May), summer (June, July, August), fall (September, October, November) and winter (December, January, February).

Results and Discussion

Statistical data shows that numbers of domestic reindeer in Sakha Republic dropped sharply after Soviet regime had collapsed, and they are recovering gradually in recent years (Fig. 2). Each district varies in tendencies of the numerical change of the reindeer, however the tendency of Tompo district is similar to the whole Republic. It indicates that serious influence of environmental change to reindeer herding is not found at least in the Tompo district in the moment.

According to my field research, daily herding is conducted as follows. In the morning reindeer which roam freely in the night are collected together at camp-site by a herder. In the day time reindeer are kept at the camp-site and surrounding area. Whenever they are going to leave the area, a herder will put them back. In the night reindeer are tolerated to roam freely.

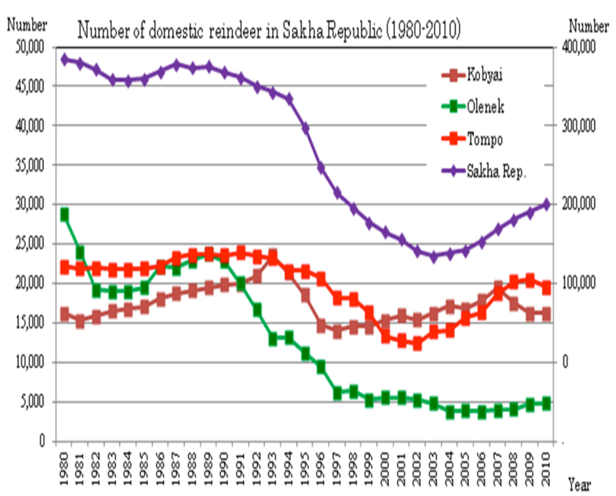

Figure 2. Numbers of domestic reindeer in Sakha Republic and some districts (1980-2010)

Some techniques are used for efficient herding. They include as follows;

- Monitoring of reindeer movement by bells
- Reindeer are attracted around the camp-site by salt.
- Lassos are utilized for catching reindeer.
- Dogs are used for herding.

They used domestic reindeer as foods. Their meat is partly consumed for their daily food and partly for sale. Reindeer milk is occasional delicacy for them. Fur and leather of reindeer are used by themselves for materials to make clothing and goods for daily use. Riding and pulling sledge are also important roles of reindeer.

Generally herders stay at the camp-site for several months. They go hunting for wild animals such as Siberian bighorn, wild reindeer, elks, sables, grouse and so on, go fishing and gather wild berries and mushrooms, besides herding reindeer. In other words, they must be sensitive to environmental change.

Herders perceive fluctuation of air temperature, precipitation, snow depth and so on. However, it seems that they think it is not abnormal weather, but normal change. Possibly for that reason herders' remarks about climate change and its influence to environment are few. Some of them are as follows; "I don't feel any influence of global warming in this area" (reindeer herder, male, 50s), "I think that land slide is increasing" (a reindeer herder, male, 20s.), "Game such as Siberian bighorn and fishes are decreasing" (reindeer herder, male, 30s.). It seems that abnormal environmental change is not generally recognized by them. Oskal et al.

(2009) have also reported similar results in their research in the same district.

Meanwhile meteorological data indicates that air temperature and precipitation in this area are changing gradually.

The mean air temperature tends to rise (Fig. 3). However, this region is famous for extremely low air temperature in winter, it is still less than about - 40 C.

Precipitation tends to increase, markedly in summer, however almost changeless in winter in this district (Fig. 4). It means that snow depth, which may be obstructive to forage of reindeer in winter, is not increasing.

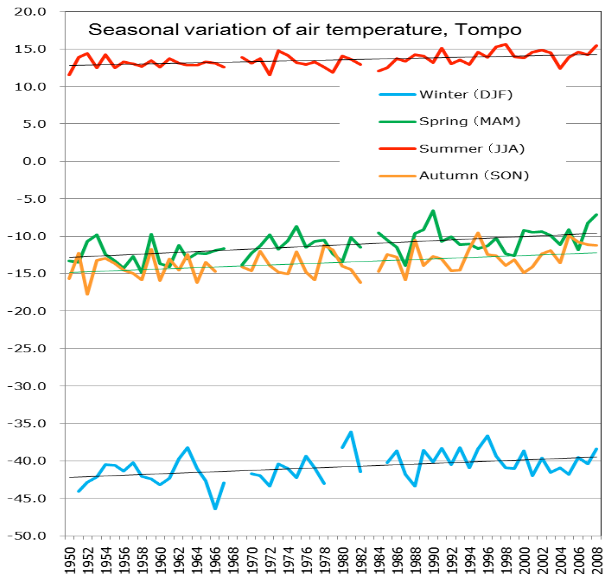

Figure 3. Seasonal variation of air temperature in the Tompo district.

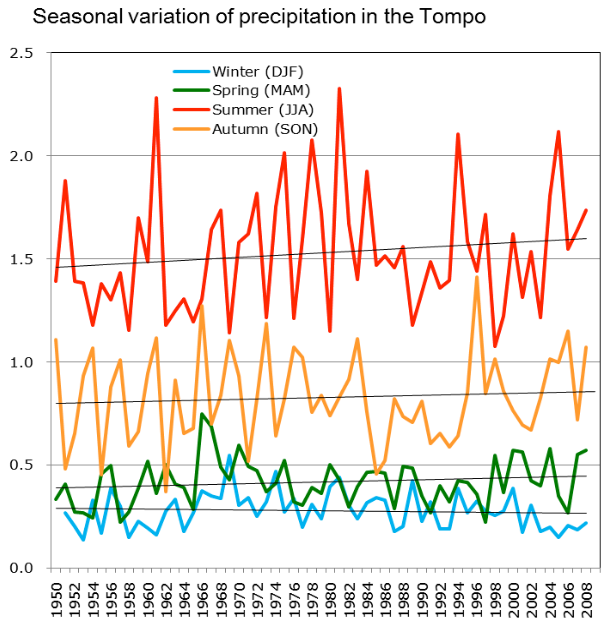

Figure 4. Seasonal variation of precipitation in the Tompo district.

Conclusion

These results indicate that although climate has been changing gradually, it has not harmfully influenced reindeer herding at least in the Tompo district so far. The reasons of this seem that fauna, flora and topography in this region have not seriously damaged by the climate change at the moment. For example, while the air temperature in this region is extremely low, slight rising of it seems not to influence critically natural environment.

Furthermore, social and/or economic factors might be more important to reindeer herding success, because serious decreasing of reindeer numbers took place at the time when Soviet regime collapsed. And now reindeer herding in Sakha Republic is supported by subsidies from the Republic and Russian federation.

However, in order to certificate the relationships between ecological change and reindeer herding, I think that more detailed information about influence of climate change to natural environment in this region, and comparative studies, including areas where climate change and environmental damage have occurred seriously, are required.

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Furbearer hunting and invasive alien species issues in Yakutia

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Key words: furbearer hunting, invasive alien species, muskratt

Introduction.

Furbearer hunting was once main industry in Yakutia. Although present furbearer hunting is no longer a staple industry due to social change after the collapse of the Soviet Union, traditional hunting skills and knowledge have been succeeded by some hunters as minor subsistence.

Objective of this study is to clarify tendency of recent furbearer hunting and look into adaptive strategies against the climate change by furbearer hunters in these circumstances.

Value of furbearers in Siberia.

The fur was cold soft gold in the czarist era. Many furbearers such as sable, ermine, marten, fox, squirrel etc. were hunted and especially sable fur was prized highly and collected as tax The income from the fur reached 1/3 of the national income at the end of 16th century.

In the Soviet era, intensive hunting and highly advanced furbearer farming ware conducted by sovkhoz and kolkhoz.

Impact of the collapse of the Soviet Union on fur industry in Yakutia.

After the collapse of the Soviet Union, politico-economic system changed drastically. The intensive hunting system by sovkhoz and kolkhoz was fallen apart to pieces and cheap ranch mink furs had inflowed from Italy, Greece, China, and so on. In addition, circulation of fake fur coat led to demand drop and price destruction of wild animal fur.

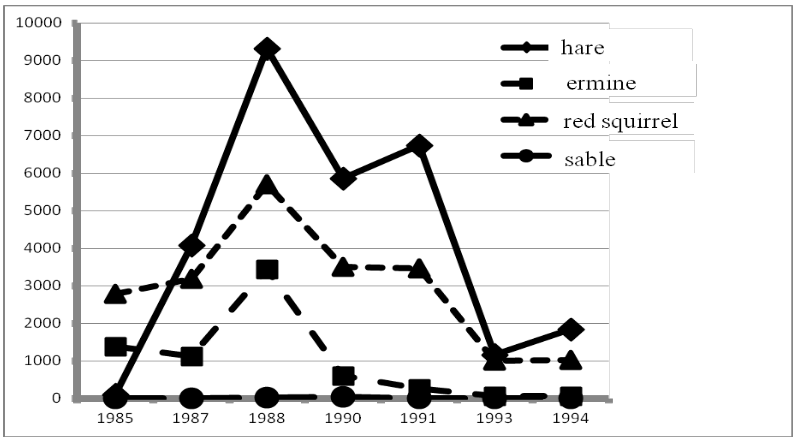

Figure 1. Change in number of hunted furbearers at Batagai-Alyta in Eveno-Bytantaiskii.

Hunting activity as minor subsistence.

Minor subsistence has the characteristics of following features; 1)economically secondary effect, 2) unbroken tradition has been succeeded in activity with pride and pleasure, 3) including element of “play”, 4) with simple tools but highly skilled, 5) having direct and close connection with nature,. Some of present furbearer hunters in Yakutia correspond to such minor subsistence features. They have a good knowledge of animal behavior and ecology, and have simple but highly skilled techniques. Sometimes they make traps using natural fallen trees or ice, and revere hunting god at all times.

Present furbearer hunting in Yakutia : after 1996.

Table 1 shows the change in the number of furbearer harvest in Yakutia after 1996. Sables were hunted stably, and red squirrels showed periodical change in harvest number which may synchronized with periodical change of population. The harvest number of muskrats increased gradually, and hares jumped rapidly.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
sable Соболь	19655	20074	27011	27805	32000	38741	30302	36485	38780	43065	42647
red squirrel Белка	100464	136200	118982	58305	31802	41885	116657	106508	45740	64592	88296
weasel Колонок	418	867	942	1321	1944	4940	3124	2148	2304	1667	1808
ermine Горностай	12201	17419	8364	13913	14507	14983	10292	8146	5821	7897	7955
res fox Лисица			119	157	156	100	50	71	77	190	378
hare Заяц-беляк	456	44	29	69	647	1062	1722	5319	5656	16552	34047
wolverine Росомаха			36	88	141	115	87	105	54		22
lynx Рысь			7	7	7	2	2	5	1		
wolf Волк	1062	1150	881	811	675	739	771	878	727	693	487
arctic fox Песец	1069	622	1477	1648	605	849	476	1379	1055	905	2538
muskrat Ондатра	142367	117734	161681	187995	164729	192689	103501	225163	176899	180273	247818

Table 1. Change in the number of furbearer harvest in Yakutia.

According to these data, the furbearer hunting in Yakutia heads toward recovery from the grave on the face of things. But these superficial facts indicate other aspects.

But increased number of hare hunting means population control for prevention of diseases under high population density, not recovery of hunting behavior. This is a part of wildlife management operation. And prices of pelts are still low. For example, the price of sable pelt is 2000-3000 rubles/pelt, muskrat is 50-85 ruble/pelt and wolf is 10000 rubles/pelt. Main purpose for hunting before 2000 is meat consumption, not for fur and professional hunters are few, and forbearer hunting is still nothing more than extra income for pensioners or unemployed men.

Introduction of muskrats into Siberia as furbearer.

Muskrats are medium-sized semi-aquatic rodent native to North America, and introduced in parts of Europe, Asia and South America nowadays. Muskrats are very successful animals over a wide range of climate and habitats and one of well known invasive alien species in the world. In 1905, 5 muskrats were introduced into Czechoslovakia by prince of Czechoslovakia, then expanded throughout Europe within only 50 years. Some European countries such as Belgium and the Netherlands consider muskrats to be a pest that must be exterminated, because their burrowing behaviour causes heavy damage to the dikes and levees.

Despite these negative impacts , muskrats were introduced into Siberia for the purpose of fur use. 31,132 muskrats were released in East Siberia and Far East from 1932 to 1970（Long, 2003）. In Yakutia, first introduction of muskrats occurred in 1930-31 (Long 2003）. In Eveno-Bytantaiskii district (Northern Yakutia) , muskrats were introduced several times but not naturalized in frigid climate. Ice formation to the bottom of river or pond in winter might interfere with naturalization of muskrats in northern Yakutia.

But increase of alaas and change in ice thickness by global warming may lead to expansion of muskrat distribution. This is a big advantage for hunters in a sense, but big disadvantage for the reason that increased muskrats enlarge flood damage in another sense.

Change and improve of cognition against invasive alien species in Yakutia.

Invasive alien issues are important challenge for conservation of biological diversity in the world. In Yakutia, invasive alien species issues were not recognized seriously before because of high regard for economic activity, not for nature conservation and the lack of ecological concept for ecosystem management. But recently ecosystem management concept becomes widespread. As for muskrats, Sakha government carried out a changeover from planting to control because muskrat could have been threatened to enlarge flood damage. Demotivation for hunting by low price of pelts might facilitate this social decision making.

Perception of global warming and muskrat problem by hunters.

Many hunters don't recognize the global warming as a practical problem. Because the diurnal range of temperature is larger than the fluctuation of the average temperature in recent years (about 2℃), people may not be able to recognize global warming. As for muskrat problem, hunters don't recognize increase of muskrat population due to climate change. Recognition against muskrat changed only because of the possibility of flood damage promotion, without actual data of increased damage by muskrat. Hunters know global warming socially by media reports but don't recognize realistically at this moment.

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Water, Water Everywhere: Perceptions of Chaotic Water Regimes in Northeastern Siberia, Russia

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> "The climate is definitely different from before . . . For people who live with a short summer when there needs to be the right weather to accomplish all for the winter, and there is cool rainy times so that the hay does not dry and has to sit and sit and the quality is bad because of that . . . it is the right time for haying but the conditions are all wrong."-Sakha elder

At the end of a 2003-2005 research project[1] focusing on understanding local definitions of sustainability in Viliui Sakha villages of northeastern Siberia, Russia (2006a), remarks like the ones above by an elderly Sakha woman were common. One explanation for these unprecedented changes, mentioned by 10 of the 33 elders interviewed that summer was that the Bull of Winter was no long arriving (Crate 2008). The Bull of Winter is a mythological being who Sakha believe arrives when the deep Siberia winter, characterized as when conditions become too cold and dry for snow and relatively windless, arrives in late December. In the last 10 years, with overall temperatures softening, the Bull of Winter is not arriving. This led me, trained as an anthropologist and therefore keen to issues of culture and change, want to understand the cultural implications of climate change for Viliui Sakha. I had, at the time, been working with Viliui Sakha since 1991 on various issues of change and adaptation (Crate 2006b). I wanted to know how Viliui Sakha would continue to inhabit their homelands if climate change altered their environment to the extent that they could no longer breed horses and cows, their age-old subsistence strategy. In response I initiated a specific project investigating perceptions, understandings and responses to the local effects of global climate change (Figure 1).

[1] I first thank all Viliui region inhabitants, project collaborators, research assistants, and in-country specialists involved in the research that this article is founded upon. I also acknowledge the National Science Foundation (NSF) and program officers, Anna Kertulla de Echave, Office of Polar Programs, Arctic Social Sciences Division and Neil Swanberg, Office of Polar Programs, Arctic Sciences Division for funding support. This article is mainly based on research from NSF National Science Foundation, Office of Polar Programs, Arctic Social Science Program Grant 0710935 ''Assessing Knowledge, Resilience & Adaptation and Policy Needs in Northern Russian Villages Experiencing Unprecedented Climate Change,'' and NSF National Science Foundation, Office of Polar Programs, Arctic Science Program Grant 0902146 "Understanding Climate-Driven Phenological Change: Observations, Adaptations and Cultural Implications in Northeastern Siberia and Labrador/Nunatsiavut (PHENARC)."

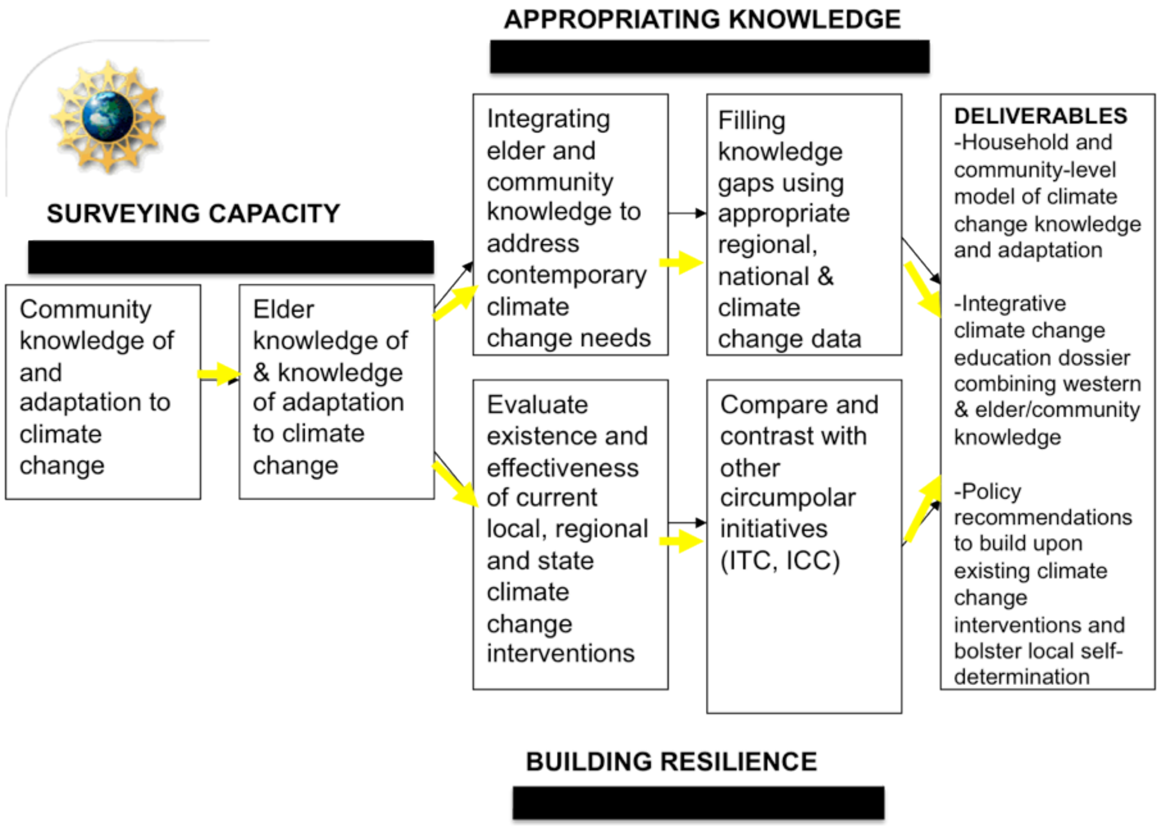

Figure 1: Assessing Knowledge, Resilience & Adaptation and Policy Needs in Viliui Sakha Villages Experiencing Unprecedented Climate Change.

What we found through focus groups and semi-structured interviews was that the majority of participants were observing 9 main changes: 1) winters are warm; 2) the land is water; 3) lots of rain; 4) summers are cold; 5) more floods; 6) seasons arrive late; 7) lots of snow; 8) temperature changes suddenly; 9) less birds and animals. Each of these changes has largely negative effects on Viliui Sakha's horse and cattle subsistence in addition to creating problems with transportation, housing and supplemental subsistence like gardening, hunting and fishing. Overall these changes represent a highly altered climate system and water regime. As I worked with inhabitants for the subsequent years, they shared about warmer winters, increased snowfall, excessive precipitation, changed seasonality, and the transformation of their ancestral landscape due to increased water on the land and degrading permafrost. One urgent change is how the increased water on the land is turning hayfields into lakes, inundating households and ruining transportation networks. The increasing water on the land interferes with subsistence and threatens to undermine settlement (Figure 2).

Figure 2: "Like this, 10 years of water I do not remember—before we hayed all the fields—now we have to go here and there to hay since all our haylands are under water." (Middle-Age Sakha).

Beyond these physical changes, what does the increased water on the land mean to Viliui Sakha? Inhabitants expressed not only concern about their future but also common fear that they would 'go under water.' Water has visceral meaning to Sakha, based on their historically-based belief system, their adaptation the their environment, and knowledge system. In response, continued field research looked in more depth at communities' perceptions of water. Based on Sakha's ancient belief system water, like all pats of the natural world, is sentient or spirit-filled. Therefore, when interacting with water, for example, when crossing a river or fishing in a lake, they spoke specific words and gave gifts to appease the spirit of the water. As an anthropologist, I knew that it was important to understand the 'emic' or local knowledge base, similar to what Arlene Rosen argues in her 2007 book, Civilizing Climate:

> If rainfall is a divine gift, then solving the problems related to drought must involve dealings with the supernatural in the form of pleasing the deity responsible. Failure to adjust to environmental stress is as much a social and cosmological problem as an environmental one (Rosen, 2007:10).

In addition, it was clear that inhabitants were attributing these changes to many other sources besides climate change. Granted, none of the changes were occurring *only* due to climate change but t was certainly a driving force of most of the changes. When asked what they thought was causing the changes, their main explanatory stories, in order of preference, were: 1) Viliui Hydro-electric station reservoir; 2) Nature itself: wet years/ dry years; 3) Too much 'technika'; 4) Global climate change. These explanations, with climate change the least mentioned, showed the extent to which perceptions are historically constructed, here very much formed based on Soviet-period industrial development that severely altered Viliui Sakha's natural environment (Crate 2002). My further investigation into these explanatory stories revealed how they clarify the political ecology of 'water in mind' (Crate 2011). But more pertinent to the immediate situation, I collaborated with Alexander Fedorov, of the Melnikov Permafrost Institute of Yalutsk, whose extensive data from research in the Central regions of the Sakha republic showed that the permafrost degradation and many of the other change Viliui Sakha were observing were in part or completely due to global climate change. At the same time, inhabitants had very locale- and culture-specific knowledge of these changes that would serve to compliment and bring detail to the more global changes of Alexander Fedorov's findings. Therefore, we agreed to conduct what we called 'knowledge exchanges' in the summer of 2010 (Figure 3).

Figure 3: 2010 Knowledge Exchange Team preparing to leave Yakutsk to conduct knowledge exchanges in Viliuisk, Verkhny-viliuisk, Nerba, Suntar, Elgeeii, Kutana, Khoro and Tolon.

We structured the knowledge exchanges to provide maximum opportunity for the audience to share their local observations. We began by inviting audience members to share. In all eight places these stories varied and were quite illustrative of the diversity of experiences people are having and the different ways the local environment is being affected by this global phenomenon. Likewise, when we shared our results working with inhabitants in the villages, audience members were quite moved to understand how they talked about the changes and the effects on their lives. When Alexander Fedorov explained how global climate change is affecting the Earth then brought the audience into the close-up understanding of how it is affecting the Sakha Republic, the audience was rapt. Due to the audiences' overwhelming interest in bringing these two knowledge bases on local change to the rest of the Viliui populations, we are now completing a handbook, designed to lead readers through a very similar process as the knowledge exchanges and incorporating local knowledge, our research findings, and Alexander Fedorov's explanations of global climate change and permafrost degradation. We also hope that we can share this knowledge exchange model with other communities facing the same issues to build understanding on the local level and bolster adaptive responses.

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History of the development of transport infrastructure in Yakutia

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Introduction

Nowadays global climate changes have been recognized not only as an ecological problem but also as a problem of the economy and life safety of people. In the first place, changes in the environment will affect the functioning of those branches which are sustained and imposed limitations by the components of ecosystems – agriculture, forestry, water management, recreation and leisure industry, energetics, construction, transport, mining industry. At the same time it should be noted that for Siberia and especially its north-eastern regions precisely the development of transport communications has always been defining and any change in the conditions under which these communications are constructed and exploited can complicate the functioning of practically all branches of economy.

In this paper I would like to dwell upon how Yakutia's transport infrastructure evolved, its current state, the possible consequences of climate changes for the infrastructure and which risks in connection with this emerge for the economy of the region and the livelihood of population. The report is based on the archive documents from Moscow, Saint-Petersburg, Vladivostok, Yakutsk, literary sources, statistical data, field materials gathered in Zhigan, Menge-Khangalas and Bulun uluses (districts) of the Sakha Republic (Yakutia) in 2008-2011.

Natural climatic conditions and topography

The modern territory of the Sakha Republic (Yakutia) occupies the north-eastern part of the Eurasian continent and covers 3103.2 thousand square kilometers in total area, including the adjacent islands of the Arctic Ocean. The area extends over 2000 kilometers from north to south and over 2500 kilometers from west to east.

Yakutia is mostly a mountainous region: almost two thirds of its territory are occupied by mountains and plateaus. Several mountain ranges, mainly of meridian direction, pass through the whole north-eastern part of the region. Characteristic of the region is a general slope from south to north in the direction of the Laptev Sea and the East Siberian Sea. Four landscape zones can be distinguished on the territory of Yakutia; the majority of vast spaces (almost 80%) is covered by taiga forests, the rest is covered by tundra, forest tundra and arctic deserts.

Large affluent rivers Lena, Kolyma, Indigirka, Yana, Olenyok, Olyokma, Vilyuy, Aldan and others run through the territory of the republic, crossing the whole region and carrying their waters into the Arctic Ocean. The basins of the lower and middle reaches of the first three rivers are dominated by extensive lowlands: North-Siberian lowland, Yana-Indigirka lowland and Kolyma lowland. They are characterized by the abundance of lakes; these stretch almost continuously, linked with each other and not infrequently with nearest large rivers, small grassy creeks and brooks. The surface of many lakes is measured by hundreds of square kilometers as, for example, Nidjili, Labynkyr, Ozhogino, Chukochie, Nerpichie. Quite often the lowlands are covered for tens of kilometers by swamps, impassable in the summer time, so-called badarans. In addition, the installation of transport communications is considerably complicated by permafrost and sharply continental climate characterized by long cold winters and short warm summer. The snow cover stays on the ground from 6.5 to 9 months a year.

Natural-climatic conditions and the landscape of the region determined its dispersed character and the wide geography of the resettlement of peoples. Low population density and nomadic lifestyle of a part of indigenous peoples made the construction of roads unnecessary, and all movements and transportation of loads were done using pack animals.

The formation of the transport system

The annexation of Yakutia to Russia necessitated the creation of the system of communications in the region, first of all for closer ties with the metropolis. Already in the 17th century the Cossacks laid water and land routes between ostrogs (fortresses) and wintering places. In 1743 the Irkutsk-Yakutsk highway was founded which became the continuation of the main Siberian official highway, with the point of departure in the imperial capital – Saint-Petersburg. Travel on the highway passing along the Lena River was possible all year round thanks to the presence of stations built at regular intervals. The winter road passed on the river ice as well as on the shore, in the summer the waterway was used. For transportation of loads and communication with the Pacific shore and Russian colonies in North America the Okhotsk highway was laid in the second half of the 18th century, then in the middle of the 19th century the Ayan highway was laid. Movement along these routes was also carried out year-round except in the coldest months when temperatures fell down to -50-60 degrees – from December till February.

At the same time regular navigation in the region began: the first steamship on the Lena River appeared in 1856, by 1917 there were already 38 ships. In 1878, the steamboat "Lena" arrived at the estuary of the Lena from Swede, with the expedition of A.E. Nordenskiöld who was making a historical voyage along the Northern sea route. Later on, the steamboat was used for communication between the city of Yakutsk and the lower reaches of the Lena. In the end of the 19th – beginning of the 20th centuries the tributaries of the Lena – Vitim, Vilyuy, Olyokma, Maya – had been mastered. From 1911 sailings began on the eastern part of the Northern sea route: by order of the Russian government the company "Dobroflot" made the first voyage from Vladivostok to Kolyma's estuary. Subsequently these voyages became yearly, the intention was to prolong them until the estuary of the Lena but the plans were foiled by the First World War and the Russian revolution. During the Civil war Kolyma voyages were suspended and the purveyance of goods to the northern districts in Yakutia went over to Americans who also opened a seaway to Kolyma in 1911.

Thus, the formation of Yakutia's transport system was based on natural idiosyncrasies of the region – at the base of it were waterways. Land roads had a mixed character: in the winter the road passed partially on the river ice, in the summer some parts of the road involved the river itself. The construction of transport communications was determined by economic and political priorities. Thus, the development of navigation on the Lena River is directly connected with the beginning of the development of gold deposits.

Rapid development of air transport began in the Soviet time. From 1925 when the first airplane arrived in Yakutia until early 1990's the whole republic had been covered by a network of airfields. Small aircraft aviation underwent rapid development, An-2's flew several times a week even to small villages. For communication with remote camps and other remote areas a park of helicopter units was actively used, based in Magan, Batagay, Nyurba, Tiksi. Therefore almost no roads were built, main efforts were directed not at the internal road construction but at the external one. For the delivery of goods during the winter a route from Big Never to Yakutsk had been paved which connected the republic with the Siberian railroad. Simultaneously, the delivery of goods to Yakutia through the Northern sea route began in 1933. The development of this main artery promoted navigation on the Yana, Indigirka, Kolyma, Olenyok, Anabar Rivers as well as cabotage. In the 1970's in connection with the development of coal deposits in the south of Yakutia the region was reached by a railroad: a branch was built from the Baikal-Amur mainline to Chulman and Berkakit. As is well-known, railroad construction continued also in the post-Soviet period and last year the railroad reached its final point – the city of Yakutsk.

Current state of transport infrastructure

Radical economic reforms, transition to market economy and, as a result, a sharp increase in tariff rates for domestic air travel and cargo traffic brought about a deep and lingering crisis of the transport system of Russia. According to the well-known Russian economist Sergei Glazyev, since the early 1990's annual volumes of capital investment in the development of transport had been rapidly declining and already by 1999 were reduced by 60%. Nowadays, because of a difficult financial situation and bad use of technical facilities, all components of the transport system – roads, waterways, ports, technical equipment – are in a calamitous state. The lifetimes of main equipment, buildings, ships, boats and aircraft have exceeded their prescribed lifetime limits by many times. For Yakutia with its vast territories the most disastrous was the reduction of traffic volume by air and sea transport. Currently, regular air communication (once or several times a week) within the republic is only maintained with district centers. As for all other settlements, a rather stable connection is only possible in winter. In summer, travel is carried out by cutters and boats on rivers and streams or, as in the past, by horses and deer. In the arctic uluses, where average distance between neighboring settlements is around 300-500 kilometers, the republican government finances helicopter flights. However, these flights are subject to limitations and each nasleg (rural settlement) has an annual quota. Moreover, a flight is not made according to a schedule but becomes possible only if it is 65% full both ways which is by far not always possible given scarcity of population. Therefore it happens quite often that passengers have to wait for a flight to their place of destination for a month or even longer than that.

Thus, in fact all transportation in Yakutia is currently carried out by river and road. The importance of waterways of communication as well as of such a specific type of road as winter roads has increased significantly and will most likely remain so in the future.

Main types of transport communications of modern Yakutia and the impact of climate changes on them

Since winter roads are a characteristic feature of transport infrastructure of the north-eastern regions of Russia and, particularly, Yakutia, and since they are directly relevant to the theme of our conference, let me consider in some detail this type of communication.

So, a winter road is a type of road which is laid over the shortest distance crossing swamps, streams and other obstacles frozen in the winter when these roads are in operation. At the present time, a winter road is the most popular type of road. Almost all rivers of Yakutia and part of the continental shelf turn into winter roads since frozen cleared ice is comfortable for the movement even of light cars. Driving on such roads is possible from November till mid-April in central Yakutia and from late December till early May in northern Yakutia. Small rivers freeze quicker and break open earlier. There exist standards and requirements for ice crossings. If the thickness of ice is 30 centimeters, the passage of lighter vehicles (up to 5 tons) is allowed, at ice thicker than 50 centimeters cargo vehicles are allowed but for vehicles with trailers the thickness of ice must be no less than 70 centimeters. The most solid ice, according to specialists, is in March-early April. The opening and closing of crossing and movement along winter roads is determined by a special decree of the government of the Sakha Republic (Yakutia) and depends on weather conditions and, correspondingly, on the rate of rivers freezing. The slide presents the opening and closing dates of the main winter road Lower Bestekh – Yakutsk which ensures the delivery of goods to the capital of the republic and its northern and Vilyuy districts over the last 10 years.

As can be seen, the situation here is relatively stable, due to the peculiarities in the freezing over of the Lena, in accordance with which the river's average thickness of ice and its ice cover is much greater and more intensive compared to the rivers of the European part of Russia and lakes. Apparently, a longer chronological retrospective of observations after the establishment of ice roads on the Lena is required in order to draw more concrete conclusions on the question.

The greatest risk is posed by small rivers and streams which, in contrast to metropolitan and central crossings, lack special posts and exhibit less control over safety. There are also a large number of unauthorized, spontaneously occurring ice crossings. Thus, annually in the vicinity of Yakutsk 12 to 17 such crossings are organized just over the Lena only. Under conditions of climate changes when observations over many years after freezing and breaking open of water bodies as well as evidence from folk meteorology do not correspond to the reality of modern times, a much harsher control is necessary over the activities on crossings and winter roads.

On the other hand, a change in the water regime (later freezing and early clearing) brings about serious changes in the traditional economic activities of indigenous peoples. For example, many hunters in the north of Yakutia are complaining that a belated establishment of the winter sledge road disrupts their natural economic cycle worked out over centuries. Due to a more belated freezing of swamps and streams and a wider spread of such phenomenon as taryns (water flowing over ice) they are forced to start their hunting season with a delay of up to a month which inevitably affects their hunting spoils and, respectively, their profits. Over the last years there was an increase in the number of accidents connected with lowering of movement safety as a result of changes in ice parameters and weather conditions.

The main type of transport during the period of navigation is water transport. Traffic is carried out by the Lena United River Shipping on the Lena River and, if the water is high, on some of its tributaries. Traffic on the other rivers, previously exploited by shallow-draft fleet, nowadays because of a crisis of water transport in Russia in general, is carried out by the locals themselves on small size vessels (motor boats, motor cutter boats). Passenger and cargo traffic is also carried out by private persons.

Cabotage between settlements on the coast of the Arctic Ocean have also been stopped with the demise of the Northern sea route system. An insignificant volume of sea shipping is carried out along the line Vladivostok – Zelenyj Mys (Kolyma's estuary).

Problems of Yakutia's water transport are similar to the all-Russian ones: reduction in the length of water navigable routes, a decrease in the availability of devices to ensure safety of navigation (by 1.5 times compared to 1980), deterioration of port facilities and vessels. Significant damage to port buildings and equipment was caused by disastrous floods of 2001-2010. Also in the last decade, according to observations of old-timers, a more intensive erosion of river banks is taking place. Any environmental burdens, including global climate changes, given the current state of the republic's water transport will pose additional risks for the life safety of people.

In such a way, changes in the climate exert serious influence on the state and development of transport infrastructure and therefore on the state of the economy and the well-being of the people. Among them we can single out:

- Destruction of roads, buildings, pipelines and other objects of transport infrastructure as a result of the thawing of frozen ground.
- A change of transport schemes as a result of a more belated freezing and earlier breaking open of rivers.
- Increased spending on prevention and liquidation of consequences of natural disasters (damaged roads, bridges, port buildings and other objects of transport infrastructure).
- Increased mortality rate among population due to a rise in the number of accidents connected with lowering of movement safety as a result of changes in ice parameters and weather conditions.

The history of the Arctic peoples counts many examples of successful adaptation to the impact of negative phenomena connected with weather and climate, especially floods and drought. Nevertheless, at the present time additional measures of adaptation at the regional and local levels are required in order to diminish adverse effects of climate change whose tempos are growing in high latitudes at an alarming speed even in comparison with other regions of the Earth. These measures could decrease vulnerability of societies to climatic changes both in the short and long run. It is particularly important to work out various strategies of adaptation at the governmental level with respect to such sectors as transport, energetics, water management, agriculture, health care. Regrettably, in the Sakha Republic (Yakutia) there still exist serious obstacles of financial, technological, political, social, institutional and cultural character which restrict the possibilities of adaptive measures and their efficiency.

In order to diminish negative consequences of climate changes on the social and economic development of the Yakut republic it is necessary to work out a complex of measures directed at the prevention and compensation of all the above-mentioned problems.

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Biblical CSR Structures in regard to Energy Projects in Lensky District, Republic of Sakha (Yakutia): Focusing on Climate and Environmental Problems

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Key words: biblical risk management, biblical CSR structure, Lensky district, climate change

Introduction

This paper aims to establish the best biblical structures of risk management and Corporate Social Responsibility (CSR), and apply them to concrete energy projects in Lensky district (ulus), Republic of Sakha (Yakutia), Russian Federation.

Lensky district, with Lensk as administration center, has recently been highlighted as a center of mega-energy projects in regard to oil and gas development, East Siberia-Pacific Ocean (ESPO) oil and gas pipelines under Eastern Gas Program. However, Lensky district has been and will be threatened by natural disasters and social crises from climate change and environmental deterioration. Especially, the runoffs of Lena River and forest fires are threatening the security of social and energy infrastructures, in turn intensifying environmental pollutions all over the Republic of Sakha (Grishin 2006: 207).

Given both the governmental blueprint of robust strategies of energy development in Lensky district and the dismal risk factors threatening the security of all energy projects in climate and environmental dimensions, this paper will suggest the biblical CSR structure in general and the best CSR scenario of risk management and energy development in Lensky district.

Biblical Risk Management and CSR Structures

The biblical worldview is theocentric and Christocentric, acknowledging the hierarchic correspondence and dynamic interaction of the spiritual, human and natural realms in the Universe. Human beings are the only creatures with divine image who are made to perform stewardship over non-human creatures and elements in the natural realm according to God's will. Accordingly, the biblical risk management in regard to climate and environmental issues should entail humans' acknowledgement of their sonship with God and stewardship entrusted by God. The transformation of humans' self-identities will give a continuous momentum to transform our social structures in more environment-friendly ways (Lee 2010: 214-128).

In addition, the biblical risk management is characterized by life-centered, value-seeking, reality-based and problem-solving approaches; the significance of human agents' good motivations and choice of good structures; comprehensive and integral approaches to spiritual, human and natural risk factors, such as religio-cultural deterioration, social polarization and poverty, demographic decline, climate change, environmental pollution, etc.; integration of good elements in non-biblical structures into biblical structures; and the triple sight of best, moderate and worst scenarios of risk management, facing the real risk factors.

In the spiritual dimension, human beings are required to become humble before God as agents, acknowledging His good Sovereignty over the world. And the Bible acknowledges human incompleteness in regard to spirituality, morality and intelligence, and humans' innate sinful nature after Adam and Eve's Original Sins. Accordingly, multiple moderate scenarios of risk management are recommended to be devised in order that they may be more approachable and realizable by more energy stakeholders.

Based on the biblical risk management, this paper suggests the biblical CSR model which is characterized by the division of value-seeking and profit-seeking agenda; prioritization of the satisfaction of basic physical needs of staff and local communities over profit creation; prioritization of cooperation and coordination over competition on the generous gift-giving principle; development of specific structures tailored to local situations on the basis of universal structures; and the triple sight of best, moderate and worst scenarios, trying to reach the best one. These characteristics will be applied to real energy projects in Lensky distract.

Energy Projects and Environmental Risk in Lensky District

When it comes to energy projects in Lensky district, this paper refers to the Russian federal government's long-term energy strategy "Energy strategy of Russia for the period up to 2030" (hereinafter, "ES-2030"), and the regional government's complex development program "Scheme of the complex development of productive forces, transport and energy of Republic of Sakha (Yakutia) till 2020" (hereinafter, "Scheme 2020"). According to "ES-2030" and "Scheme 2020," the Republic of Sakha (Yakutia) identified concrete investment projects for the complex development over the period 2012-2022 years (Yakutia 2006). Most oil and gas condensate fields in the republic are located in Lensky, Suntarsky, Verkhne-Vilyuisky, Vilyuisky districts in the Western energy zone. In Lensky district, there are several oil and gas projects; Lensk oil and gas processing and chemistry factory projects; and power supply projects. Except for them, there is a big investment project of Lensk wood-processing plant.

Main energy enterprises engaging in oil and gas projects in Lensky district are Gazprom, TNK-BP, Rosneft, Surgutneftegas, and other energy companies. Gazprom, main operator of the promising oil and gas projects in the district, proceeds the construction of Yakutia gas production center, including the development of Chayana-Botuobinsky group – Chayandinskoye, Sredne-Botuobinskoye, Tas-Yurjakhskoye, Verkhne-Vilyuchanckoye gas condensate fields – from 2016 and the construction of Sakhalin-Khabarovsk-Vladivostok and Chayanda-Khabarovsky gas pipelines. Power supply projects adjacent to the energy projects should support the development and operation of gas production, processing and transport projects (Yakutia 2011).

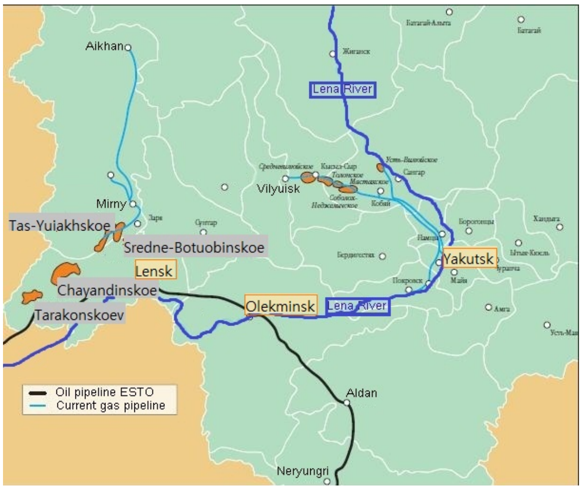

Figure 1. Oil and gas complex in Western Zone of Republic of Sakha (Yakutia)
Source: Borisov 2009, p. 152.

In accordance with "ES-2030," in Lensky district are situated more than 15 investment projects among all the concrete energy investment projects identified by the Republic of Sakha (Yakutia). The projects in Lensky district include 4 oil projects entitled the "formulation of interregional oil and gas cluster in Russian Eastern part"; 3 gas projects under Eastern Gas Program to control all gas activities in the Eastern part of Russia in a unified system; 3 power supply projects for ESPO, residential and industrial sectors in the Western Yakutia and Irkutsk region.

However, in Lensky district there are diverse crucial natural and anthropogenic risk factors threatening all energy projects, such as harsh continental climate pattern and sensitive ecosystem, climate change entailing flooding and forest fire, and environmental pollutions (Nogovitsyn 2010: 1-2; Achad et al. 2006: 327-328; UNDP 2009: 128-129). The proposed risk factors from climate change include global warming and decrease in the number of frosty days by 15-30; fast permafrost thawing and spring flooding; large increase in river runoffs in Lena river; precipitation increase in scale and frequency; deforestation and more frequent forest fires; loss of biodiversity and livelihood; outbreak of enteric fever and other infectious disease (intestinal diseases, insect infections, tick infections); and intensifying demographic decline (Roshydromet 2008: 11-19; Perelet

& others 2007: 12-22; Yakutia 2006: 28-30).

In addition, there are serious environmental pollutions in Lensky district, which are attributed mainly to modern environment-destructive practices in mining and energy industries in Southern, Western and Central parts, nuclear experiments mainly in Mirny and Vilyui districts in Western part, lack of proper laws and regulations for risk prevention and post-treatment (Oldfield 2005: 105; Yakovleva 2005: 134-146). As a result, Lensky district faces serious problems of wastes, industrial pollution of air, water, and land, reduction of biodiversity, which are interacting with risk factors in regard to climate change.

The robust development of energy projects in Lensky district will have additional negative influence on the climate and environmental risk factors activating their interaction, which in turn will undermine the sustainability and profitability of the energy projects.

In addition, given the large-distance of ESPO oil pipeline (1,351.5 km in Lensky district of 1,458km in the Republic of Sakha), future gas pipeline proposed to be laid in parallel with ESPO pipeline, and power grid (1,521km)(ДВЭУК 2009), the oil, gas and power supply from the republic to domestic markets and foreign markets in Asia-Pacific region will be more vulnerable to complicated interaction of diverse risk factors in all areas adjacent to the pipelines: harsh geographic, climatologic, geological conditions; climate change and other natural disasters; environmental pollutions; and social risk factors.

Accordingly, the risk management and sustainable energy development in Lensky district will be more effective when they are implemented comprehensively through the close coordination and collaboration of different energy stakeholders at local, national, regional levels, which are required to include Russian federal and regional governments, municipal organizations, domestic and foreign energy companies, NGOs, local communities, other Northeastern Asian countries, and multi-lateral Northeast Asian and international organizations, etc.

Table 1. Biblical CSR Scenario in regard to Energy Projects in Lensky District.

CSR	Value-seeking agenda	Profit-seeking agenda
Basic items	-Complete prevention of GHG and toxic gases emission, and reuse of associated gas above 95% - Clearing treatment and reuse of industrial wastes (sludge, chemicals) to prevent additional pollution of Nyuya, Chayanda, Lena rivers - Water treatment and drinking water supply to staff and local inhabitants -Social welfare for staff's and local inhabitants' health -Gasification and electrification of rural and remote areas .Renewable energy development (biomass, small-scale hydropower, wind power, etc.) .Establishment of self-subsistent energy supply system in rural areas	-Introduction of the latest environment-friendly technology and methodology -Use of anti-corrosive pipeline, environment-friendly materials -Introduction of energy facilities protection technology and system against flooding and forest fires -Energy saving and improvement of energy efficiency -Reuse of associated gas and other toxic gases, and reuse of cleared wastes - Gasification and electrification of the eastern regions of Russia according to market system -Introduction of comprehensive industrial security in regard to climate and environmental risk factors
Extended items	- Clearing treatment of pre-existing environmental pollutions adjacent to energy projects - Subsidies of the introduction of chemical and biological clearing system of water in Lensk - Subsidies of ecosystem protection programs in the district (the Lena basin) .protection of source of underground water as drinking water .protection of national park	-Commodification of renewable energy resources -Diversification of energy industry by development of oil and gas procession, gas chemistry

The Biblical CSR Scenario in regard to Energy Projects in Lensky District

Given a broad blueprint for regional and global cooperation in regard to risk management and sustainable energy development in the Eastern part of Russia, this paper will suggest the best biblical CSR scenario with a dual structure of value-seeking and profit-seeking agenda in regard to energy projects in Lensky district, focusing on corporate environmental responsibility in regard to gas and power projects, which is as follows.

In the human and natural dimensions the biblical CSR scenario may be slightly differentiated from other CSR scenarios established from non-Christian viewpoints. The biblical alternative may be peculiar in the prioritization of the spiritual, ethical and moral changes of all stakeholders over improvement of technical, capital and social conditions of energy projects. From the biblical viewpoint, the key to success in any best and moderate CSR scenarios is human agents' personal commitment to them.

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Analysis of Siberian CH_4 flux during 1994-2010

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A vast Siberian forest area and the largest West Siberian wetland area in the world play a significant role in the global carbon cycle as a large carbon sink and a major natural source of atmospheric CH_4. Moreover the high Siberian Arctic land areas containing thick permafrost layers with carbon rich soils could release high CO_2 and CH_4 emissions thawing under a warmer climate. In this study, we estimate monthly CH_4 fluxes for 43 regions including 4 regions over Siberia during 1994-2010 using a fixed-lag Kalman smoother and investigate the year-to-year variation of Siberian CH_4 flux to understand climate-induced changes in Siberian CH_4 flux and the significance of Siberia on year-to-year variation of global CH_4 budget. Continuous and event measurement data of atmospheric CH_4 taken from WDCGG are inverted to optimize CH_4 fluxes in this study. Airborne observations of CH_4 at two sites over West Siberia are used to adjust the magnitude of West Siberian CH_4 flux with inverse modeling: at Surgut over wetlands in middle taiga and at Novosibirsk in forested steppe. We use interannually varying CH_4 emissions and interannually repeating OH, Cl and O^1D radicals provided by TransCom-CH_4 project (Patra *et al.*, 2011) in forward simulation by NIES transport model (Belikov *et al.*, 2011).

Methane emissions and its seasonal cycle in subtaiga zone

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Key words: CH_4 emission, wetlands, seasonal cycle

Introduction

High-quality, quantitative estimates of the CH_4 budget are crucial to predicting climate change, managing Earth's carbon reservoirs, and understanding atmospheric chemistry [Mikaloff-Fletcher et al. 2004]. Therefore, estimation of the relative contribution of different methane sources to the atmospheric concentration of CH_4 is an important task in addressing the problem of global warming. Since wetlands are considered to be the major natural source of methane, accurate estimation of its emissions at regional scale is required [Fung et al. 1991].

West Siberia gains the especial importance in this respect as one of the most paludified region in the world with the mire area of 68.5 Mha or 27% of this region area. However, several estimates based on field studies exhibit a large spread in regional fluxes: from 2 to > 22 $MtCH_4 \cdot yr^{-1}$ (review of various estimations ended up with [Glagolev and Kleptsova, 2011]). Closer examination of these studies [Glagolev et al., 2008] revealed a lack of measurements as a main reason of this uncertainty. Aiming at the reliable estimation of the regional emission from West Siberia mire systems, long-term and large-scale investigation was organized, resulting in more certain estimate of 2.6 to 5.2 $MtCH_4 \cdot yr^{-1}$ [Glagolev et al., 2011].

This estimate was obtained using a so-called «standard model» concept of methane emission described in detail in [Glagolev et al., 2011]. According to this concept all variety of wetland types was reduced to 8 micro-landscape types: palsa, ryam (pine-shrubs-sphagnum moss ecosystem), ridge (on patterned bogs), fen, poor fen, ombrotrophic hollow, peat mat and wetland pond. The methane emission from the area was estimated by multiplying the average emission rates of the mire micro-landscape types with the area coverage of each of these ecosystems, and the period of methane emission in each zone.

As the representative emission rates of the mire micro-landscape types medians of CH_4 flux distribution were adopted. Fluxes vary strongly among the different sites and observation periods for each mire micro-landscape type in each zone, resulting in large representation error given limited number of the observations. It is main source of uncertainty of this estimation. There are four types of this variability:

- interannual variability;
- interseasonal variability (caused by seasonal trends of CH_4 emission environmental controls);
- variability among different mires (caused by climate, hydrology or geochemistry);
- spatial variability within mire micro-landscape.

The objectives for the study were (i) to derive the flux estimation uncertainty due to seasonal variation of these environmental controls in a case study at subtaiga zone; (ii) to compare this uncertainty with those contributed by the other types of variability and (iii) to identify the main controlling factors which influence the seasonal dynamic of CH_4 flux. We choose subtaiga zone for this study because two types of the mire micro-landscape (fen and poor fen) accounts for about 90% of the regional CH_4 flux from this zone. Thus, detailed representation of the other micro-landscape types in subtaiga is not important.

Study methods

Measurements (totally about 200) were made by a static chamber method, described in details in [Glagolev et al., 2011].

Methane concentrations were measured by a gas chromatograph «Crystall-5000» («Chromatec» Co., Ioshkar-Ola, Russia) with an FID and 3 m column filled by HayeSep Q (80-100 mesh) at 70 °C with nitrogen as a carrier gas (flow rate 30 $mL \cdot min^{-1}$).

At each site following environmental parameters were measured: air and peat temperatures (at the depths of 0, 5, 15, 45 cm) by temperature loggers "TERMOCHRON" iButton DS 1921-1922 (DALLAS Semiconductor, USA), pH and electric conductivity by Combo "Hanna 98129" ("Hanna Instruments", USA). Botanical descriptions were also recorded.

Description of research sites

The field experiments were carried out during 2011 summer period. Measurements were made in the same season, in which majority of measurements used in [Glagolev et al., 2011] were carried out: 9-12 July, 26-28 July and 20-21 August. Methane fluxes were measured at two research sites in subtaiga zone of Western Siberia (Fig. 1):

1. «Biaza» (56.50° N, 78.31° E) is located 10 km south from Biaza settlement between Tartas River and Tara River on weakly drained watershed. This territory is occupied by relatively young fens dominating by sedge (*Carex cespitosa*) and mosses, depth of peat is less than 40 cm. Mires are dependent on atmospheric nutrient supply, but because of the shallow peat depth, plants can reach for minerals from clay parent rock. This type of mires is dominant in subtaiga zone [Peregon et al., 2009].

2. «Chuvashi» (56.41° N, 78.80° E) is located on the terrace of Tartas River 2 km north-north-west from Chuvashi settlement. The site belongs to Vasyugan mire system. Measurements were made on ridges and hollows in patterned birch poor fen dominated by *Menyanthes trifoliata*, *Comarum palustre* and sphagnum mosses. Depth of peat was near 1.5 m. This type of mires is also widespread in subtaiga zone and in south part of Vasyugan mire system belonging to south taiga zone [Peregon et al., 2009].

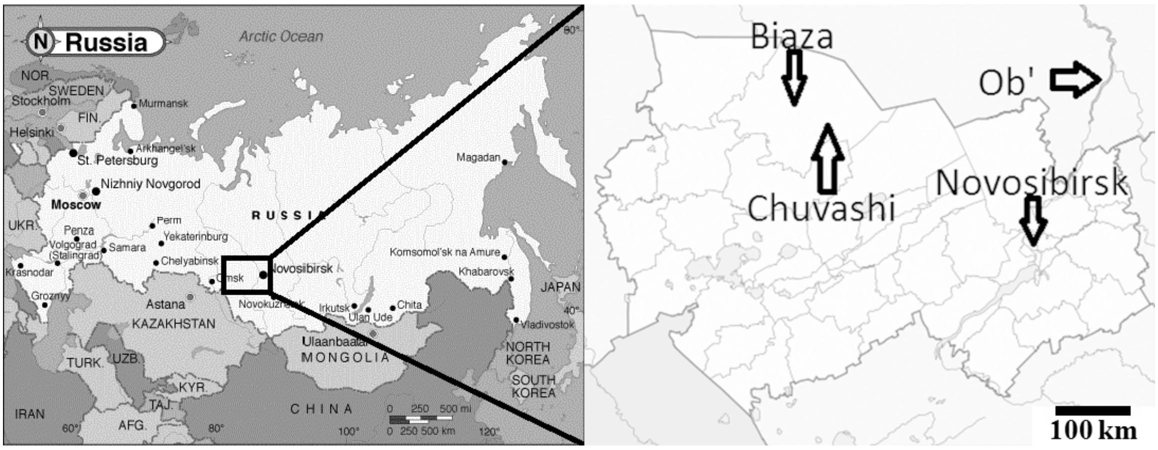

Figure 1. Location of the Biaza and Chuvashi research sites.

Results and discussion

Medians of methane fluxes from both study sites are presented at Table 1. If we use the medians for fens instead of values used previously in [Glagolev et al., 2011], variability of regional flux from subtaiga was about ±10%, or ±30 $ktCH_4 \cdot yr^{-1}$. The same estimates for poor fens give us higher levels of relative variability (±20%), but the same levels of absolute variability (±30 $ktCH_4 \cdot yr^{-1}$). So, this level of variability (about ±30 $ktCH_4 \cdot yr^{-1}$) we can consider as typical uncertainty of regional flux for subtaiga mires, related to seasonal variation of environmental conditions.

Difference in seasonal trends of methane emission obviously depends on seasonal fluctuations of water table level. In the second half of July precipitations in subtaiga region were high (about 100 mm). It led to the inundation of the both study sites (see table 1). At the end of August conditions have changed. As a result poor fen with better drainage become dryer, while the inundation level at weakly drained fen continues to grow. In our case, these fluctuations substantially affect seasonal variation in methane emission.

Table 1. Dynamics of CH_4 flux and its main environmental controls during 2011 summer period (positive or negative values of WTL (water table level) mean situations, when WTL is lower or higher than mean level of moss surface, respectively).

Parameter	**9-12 July**		**26-28 July**		**20-21 August**	
	Fen	**Poor fen**	**Fen**	**Poor fen**	**Fen**	**Poor fen**
CH_4 flux, $mgCH_4 \cdot m^{-2} \cdot h^{-1}$	2.89	0.89	3.24	1.62	3.56	1.31
WTL, cm	0.3	16.5	-3.7	11.4	-5.6	13.7
Temperature on 5 cm depth, °C	14.0	15.4	15.2	15.7	12.2	16.5
Temperature on 15 cm depth, °C	13.1	12.3	13.3	14.1	11.0	13.2

Multiple regression analysis showed that WTL (cm) and peat temperature on 5 and 15 cm depth (T_5 and T_{15}, °C) appeared to be the main environmental controls in considered timescale for both poor fen (F_{pf}, $mgCH_4 \cdot m^{-2} \cdot h^{-1}$) and fen ($F_f$, $mgCH_4 \cdot m^{-2} \cdot h^{-1}$):

$F_{pf} = 2.91 - 0.14 \cdot WTL + 0.00021 \cdot T_5 \cdot T_{15}$; $F_f = 3.53 - 0.10 \cdot WTL + 0.00043 \cdot T_5 \cdot T_{15}$.

It was also noticed that the sensitivity of CH_4 flux for subtaiga mires to WTL and peat temperature fluctuations was close to ones for the same types of Canadian mires [Pelletier et al., 2007; Treat et al., 2007].

Contributions from the other variability types were also determined using measurement data from database by [Glagolev et al., 2011].

1. Interannual variability was estimated using data of ten-years monitoring at 3 sites near Plotnikovo settlement in south taiga zone. For all sites relative variability (one half of the ratio of interquartile range to median of CH_4 flux medians for each year of monitoring) was about ±20% for CH_4 fluxes varying from 3 to 6 $mgCH_4 \cdot m^{-2} \cdot h^{-1}$.

2. Variability among the different mires can be estimated based on subtaiga and forest-steppe measurements of 2010. Medians of CH_4 fluxes, measured simultaneously, in four different forest-steppe mires, which have the similar values of WTL and peat temperature, were 0.05, 0.22, 2.22 and 4.03 $mgCH_4 \cdot m^{-2} \cdot h^{-1}$. Possibly, it was caused by differences in chemical composition of groundwater. The medians of subtaiga CH_4 fluxes for two different mires also measured simultaneously vary wider: from 0.04 to 9.65 $mgCH_4 \cdot m^{-2} \cdot h^{-1}$. In this case it is probably caused by differences in WTL (mean WTL was 9 cm and -8 cm respectively). As long as in database by Glagolev et al., [2011] there are no mire micro-landscapes with data available from more than 4 different sites, this type of variability can lead to a big uncertainty in regional flux estimation.

3. Spatial variability within mire micro-landscapes (determined one half of the ratio of interquartile range to median of CH_4 fluxes weighted means, measured during 1-2 days) can be estimated for 4 mires in subtaiga. According to the data, relative spatial variability within mire micro-landscapes is about ±20-30% for wide range of CH_4 fluxes (from 0.3 to 10.7 $mgCH_4 \cdot m^{-2} \cdot h^{-1}$).

Thus, the seasonal dynamic of CH_4 flux is less significant for determination of regional flux estimation uncertainty than other three types of CH_4 flux variability (Table 2).

Table 2. Comparison of different variability types.

Type of variability	**Level of relative variability, %**	**For what fluxes, $mgCH_4 \cdot m^{-2} \cdot h^{-1}$**
Interannual variability	±20	3 – 6
Intraseasonal variability	±10 or ±20	1.2 or 3
Variability among different mires	Remain uncertain, can be more then ±50%	0 – 10
Spatial within mire micro-landscape	±(20 – 30)	0.3 – 10.7

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Structure and dynamics of forest ecosystems of West Siberia for the assessment of carbon balance components

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Key words: mapping of forest ecosystems dynamics NDVI

Introduction

One of the main problems of Russia and the Siberian regions in the framework of the Kyoto Protocol is an inadequate state of the Greenhouse Gas (GHG) emissions accounting and the data characterizing the carbon sink, i.e. of the inventories in the forestry sector. These inventories are the centre of the national institutional systems, because they are considered as a basis for quantitative assessment for the Kyoto Protocol. The quality of inventories in the forest sector is too mach different. Significant variation in the forest inventory data between regions and administrative areas is evident, so these data are considered as non-compliant by the IPCC.

Western Siberia is a large region of the Asian part of Russia, where a problem of forests state assessment and their restoration after the impact of oil and gas deposits exploitation important. A significant factor affecting the nature of this region is the gas flaring (GHG) emissions. Large companies, particularly *Gazprom*, published GHG inventory data closed to the public within the recent years. So in the Nadym region more than 723 million m^3 of NG burned in 2007. At the same time the atmosphere has received 11,571.6 tons of carbon monoxide, 289.3 tons of methane, and 1735.7 tons of nitrogen oxide.

Statistics on the values of the carbon sink is gradually improving due to changes in the forest cover. Thus, an attempt was made to calculate the flow and balance of carbon emissions in the regions of Krasnoyarsk region and Buryatia, on the basis of forest management. We analyzed stem volume of the major areas and species, and for the calculation of the deposited carbon conversion factors were used. However, there is no in-depth comprehensive forest inventory for these purposes, adjusted by a single method that uses a dynamic classification.

Site and methods

V.B. Sochava Institute of Geography SB RAS (Russia) in cooperation with NIES and the GEF (Japan) are developing a project "Development of a meteorological and forest inventory data for the forest ecosystem typology maps of Western Siberia and modeling of carbon balance". We developed techniques studying the forest ecosystem in the process of their age and succession dynamics for improving a model of the dynamics of boreal vegetation of Ob-Kazym region in Western Siberia and the definition of Production Index ((based on NDVI) according to temporal trends.

For the assessment of the stocks of carbon as a main indicator the current supply of ground phytomass reserves, which can be calculated according to the inventory, when stem timber is taken as a basis. Forecast of phytomass value can be made using the typological models of spatial-temporal dynamics, or yield tables, providing an assessment of species and age structure of forests in each stage of their formation. In this connection it is necessary to create a data bank on the state of forest ecosystems in the dynamics resulting from field work and with the involvement of forest inventory data. For the tuning of the SEIB-DGVM circumpolar vegetation of Eurasia and the differentiation of productive LAI Japanese scientists have successfully used local study of age and succession dynamics of forest communities (Ise and Sato, 2008). Their approaches are consistent with the methodology of the forest typology school, which develops dynamic classification of genetic forest types in Siberia (Kuzmenko, Smolonogov, 2000; Kuzmenko, Mikheev, 2008).

Digital maps of forest vegetation reflecting succession recovery are the most effective tools for the inventory of community structure. We have created a map of the Ob-Kazym rivers watershed within the map page P-42 (Fig. 1). We used the method of automated processing of scanner images Landsat in ArcView GIS, when spectral features (bands, or their combinations) for the detection of forest species or groups (for example, coniferous) were used. Further clustering of a pixel image was carried out including comparison with data for the classification of forest management and subsequent determination of the production coefficients. The NDVI processing to implement Majority analysis technique was applied.

Results and Discussion

On the typology map the genetic types of forests as a synthesis of indigenous and their derivatives in the natural state of change and after the anthropogenic impacts on landscape (deforestation, fires, industrial accidents, etc.) are reflected.

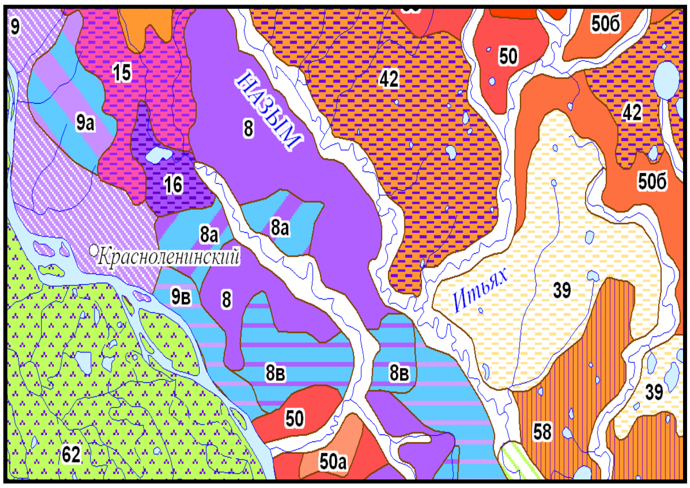

Figure 1. Fragment of the electronic map of forests and forest-bog vegetation of the watershed of the Ob and Kazym rivers (southern part of Belogorsky mainland) (scaled up to 1:1 000 000).

Legend

8 – Siberian stone pine-spruce fox berry-true moss forests of elevated areas of mainland plains on sedentary gley soils (original), *8a – spruce-birch, Siberian stone pine-spruce-birch herbaceous-* fox berry-green moos, rest orated on the areas of disturbed Siberian pine stone-spruce taiga *(short period derivate), 8в – dark-coniferous-parvifoliate grass-true moos forest (perseverant derivate), 9 – fir-Siberian stone pine-spruce with pine of small grass-true moss slopes of mainland plains on slightly humic sedentary gley soils (original), 9a – fir-spruce-birch, fir-Siberian stone pine-spruce-birch small grass-true moss (short period derivate), 9в – dark coniferous-parvifoliate true moss-grass forest (perseverant derivate), 15 – spruce-Siberian stone pine sub shrub-sphagnum or moss open woodlands of low watersheds on bog gley soils, 16 – birch-Siberian stone pine-spruce sedge-sphagnum and humid grass forest of rive rain location on bog gley soils, 39 - oligotrophic forested ridge-pool and swamps and riams of "slopes" of flat interfluves plains in the upland oligotrophic peat lands, 42 -eutrophic-mesotrophic-oligotrophic bogs and pine sub shrub-sphagnum riams of low flat interfluves plains and terraces on the moors, 50 - pine with dark-coniferous forest sub shrub-true moss and pine fox berry –true moss or lichen forest of sandy and loamy rive rain plains on mezopodzol gleyed soils (original), 50a - young birch-pine and pine with dark-coniferous and pine-fox berry-true moss or lichen forest recovering at locations ofdisturbed pine complexes, 50в - middle-aged and maturing pine with birch-fox berry-true moss forest, 58 - pine riams and ridge-pool sub shrub-sphagnum bogs in upland terraces on oligotrophic peat lands, 62 - sedge and reed and canary grass meadows of middle-high floodplain on meadow boggy and silty-gley soils.*

During the formation of an inventory database forestry data describing the structure of phytocenosis: the name of the forest type, stand structure, age, site class, forest density, growing stock (m3/h) and abiotic indicators of environmental conditions such as habitat were associated with each map contour under a number in the table of attributes. These are morphological characteristics of the relief: elevation, slope, exposure, soil type, soil mechanical composition, and soil moisture class.

An inventory of meteorological parameters according to 12 weather stations is carried out for the characterization of climate and microclimate. Air temperature and humidity are analyzed. These are long-term monthly and annual averages: mean, maximum, minimum air temperature and soil surface temperature, precipitation amount and relative humidity. Extrapolation of climatic indicators is carried out. It is found that long-term average air temperature from May to September has a positive value and gradually increases from north to south by 20°C to 15.5°C (Numto) up to 17.5°C (Khanty-Mansiysk). The average annual temperature is generally negative and increases from north to south by 3.9°C (from -5.3 to -1.4°C). The precipitation of distribution over the territory has no clear patterns. They constitute 382-410 mm during the warm half-year (April-October), and in the cold (November-March) - 126-182 mm. Thick snow cover prevents strong cooling of soils and the soil freezing reaches a depth of 1.6-1.8 m only in the north (Kazym Plateau), where long-term soil temperature is much lower 1.3-3.0°C (Kazim, Numto), than the prevailing values 4.0-4.7°C.

An assessment and analysis of vegetation indices to vegetation index NDVI is carried out regarding the climate change on key sectors. Data processing Landsat TM of scanner images were compared with the classification of vegetation and forest management on the map in Fig. 2). For Siberian stone pine-spruce and fox berry moss forest of elevated plains the NDVI index is 0.7-0.8 (red-orange). This value corresponds to the inventory, when the stock of stem wood makes 160-310 m3 / ha (maps contours 8, 9 on Fig. 1),canopy fractional cover is 0.6-0.9. The NDVI of 0.5- 0.6 (yellow) is characteristic for forested ridge-pool swamps and forested wetlands with sparse tree stand. Timber stock is here the smallest - 10-50 m^3 / ha, the canopy fractional cover is 0.2-0.4 (contours 39, 42). The NDVI index of 0.3-0.4 (yellow-green) is characteristic for patterned relief ridge- lake swamps, where the forest vegetation is almost absent. During the period of relief from flood waters the floodplain meadow communities are just barely vegetated; they were not formed and have a low index of NDVI of 0.1-0.2 (emerald green).

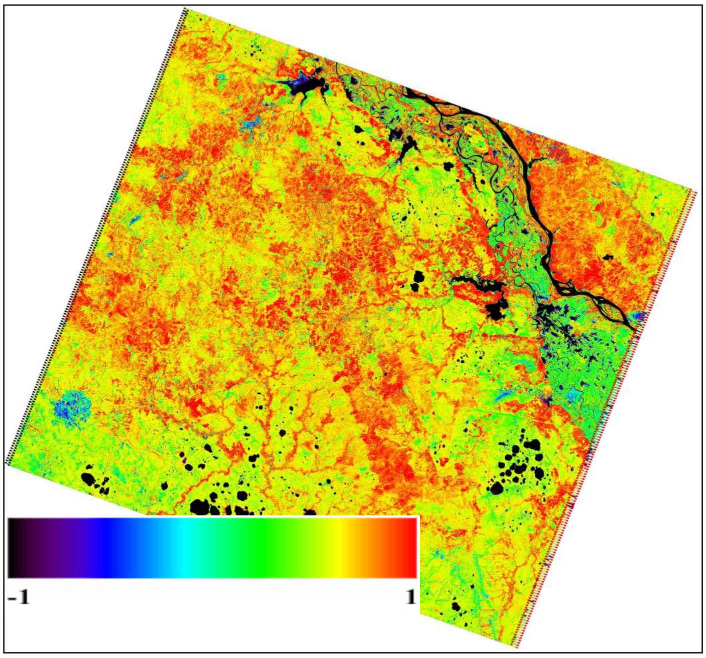

Figure 2. The calculated NDVI values for the southern part of the Belogorsky mainland and Kondinskoye lowland.

Conclusions

The availability of a comprehensive inventory taking into consideration the structure and dynamics of ecosystems on the basis of the digital map allows us to calculate productivity indices and modeling of changes in remotely sensed data, adjusted by ground-based data. Determination of the average values of productivity potential will not only show areas with low, medium and high phytomass in the region on the map, but also to predict changes in the values of sequestered carbon in the course of restoration and succession changes of forest communities.

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Development of a dynamic tundra vegetation model for analysis of long-term vegetation-soil-permafrost feedbacks

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Key words: competition, ecosystem model, nutrients, permafrost, plant functional types, tundra

Introduction

Climate change, which is most pronounced at high latitudes (IPCC 2007), will likely cause large-scale vegetation changes in the Arctic. Many studies report increases in shrub cover around the Arctic (e.g. Callaghan et al. 2011). Field experiments have shown that in response to warming deciduous shrubs, such as *Betula nana*, or graminoids expand at the cost of mosses (Walker et al. 2006, Elmendorf et al. 2012). Mosses are well known for their insulating capacity. Results from our *Betula nana* removal experiment in northeast-Siberian tundra suggest that warming-induced expansion of deciduous shrubs can slow down permafrost thawing (Blok et al. 2010). Consequently, the reduced thawing depth likely reduces soil nutrient availability which may restrict further shrub growth or give the shrubs a competitive advantage over deeper-rooting graminoids. To test such long-term vegetation-soil-permafrost feedbacks we are developing a tundra ecosystem model in which tundra vegetation composition interacts with climate and permafrost dynamics (Heijmans et al. 2012). Such a model should at least include shrubs, graminoids and mosses as plant functional types (PFTs).

Review of current tundra vegetation models

We reviewed existing vegetation/ecosystem models that have been applied to arctic tundra ecosystems, to investigate whether they include 1) shrubs, graminoids and moss as PFTs, 2) competition for light and nutrients, such as nitrogen, and 3) interactions with permafrost dynamics.

Table 1. Overview of some characteristics of current tundra vegetation models.

	LPJ-Why (Wania et al. 2009)	TEM-DVM (Euskirchen et al. 2009)	ArcVeg (Epstein et al. 2000)	LPJ-Guess (Wolf et al. 2008)
Tundra plant functional types (PFTs)	3 PFTs, but no shrub	10 PFTs: shrub, graminoid and moss included	16 PFTs: shrub, graminoid and moss included	6 PFTs, but no moss
Competition?	light	light and nitrogen	nitrogen	light
Permafrost module?	yes	yes	no	no
PFT impact on thawing?	no	no	no	no

All four models checked include relevant PFTs, but the two LPJ models lack either shrub or moss (Table 1). The PFTs compete with each other for either light or nitrogen; only in TEM-DVM competition is for both light and nitrogen (Table 1). However, if competition for nitrogen is included, nitrogen is taken up from a single soil pool and PFTs do not differ in root characteristics (Epstein et al. 2000, Euskirchen et al. 2009). This is a simplification, as we observe that the graminoids root deeper than the low shrubs. Such a difference in root distribution could strongly influence competitive relationships when thawing depth is increasing with climate warming. Two models include a permafrost module, but there seems to be not much interaction between the vegetation and permafrost module and there is no impact of the species composition on thawing (Table 1).

Towards NUCOM-tundra

Our group, led by professor Frank Berendse, has earlier developed NUtrient cycling and COMpetition models for several ecosystems (Van Oene et al. 1999, Heijmans et al. 2008) that do take root characteristics into account. Based on these earlier models we are developing a tundra vegetation model which includes 1) relevant PFTs, at least shrub, graminoid and moss, 2) competition for light and nitrogen, and 3) layered soil and PFT specific root distributions as in Fig. 1. Next, we will add feedbacks between vegetation and a permafrost module.

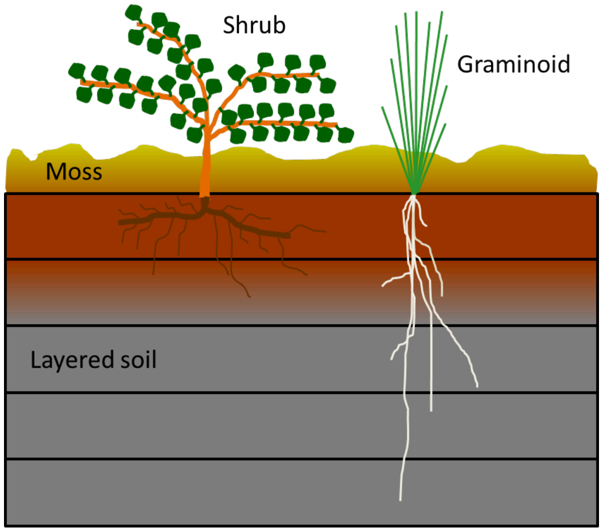

Figure 1. Schematic representation of the first version of our tundra vegetation model which includes layered soil and moss, shallow-rooting shrubs and relatively deep-rooting graminoids. These PFTs compete for light and nitrogen. The top soil has a higher organic matter content and therefore has more nitrogen available.

The first version of NUCOM-tundra describes the carbon and nitrogen balance of a tundra ecosystem at a monthly time step (Pullens 2012). The tundra vegetation is described in terms of shrubs, graminoids and mosses which compete with each other for light and nutrients. Plant growth and soil processes are dependent on climatic conditions. The model includes layered soil: 10 layers of 10 cm thickness and three PFTs: shrub (*Betula nana*), graminoid (*Eriophorum vaginatum*) and moss. Parameter values for these PFTs, e.g. maximum growth rate, minimum nitrogen concentration, plant height, root distribution, are mostly taken from literature. Monthly air and soil temperature data are input to the model and active layer thickness (ALT) is prescribed in this version. The equations, describing plant growth, mortality, decomposition and nitrogen mineralisation of soil organic matter, are based on earlier NUCOM models. A first test was done by comparing simulated biomass with measured biomass data at the Kytalyk tundra field site near Chokurdakh (Blok, unpublished data). Monthly Chokurdakh temperature data were used as input. We tested sensitivity to ALT by increasing ALT by 1 cm each year compared to a constant ALT of 20 cm.

Preliminary results

In the control run with constant ALT of 20 cm, shrubs completely outcompeted graminoids (Fig. 2). Simulated shrub biomass was within the range of measured *Betula nana* biomass at the Kytalyk site. However, even in the dense shrub patches in the field, there are still some graminoids present, though at low biomass. Simulated moss biomass remains present at a biomass that is much lower than in the field. When ALT is gradually increased shrubs and graminoids co-occur. The deeper-rooting graminoids have better access to the available nutrients at depth when ALT increases. When ALT increases further over time, nutrients are not so much limiting plant growth anymore and the shrubs benefit because of their higher maximum growth rate.

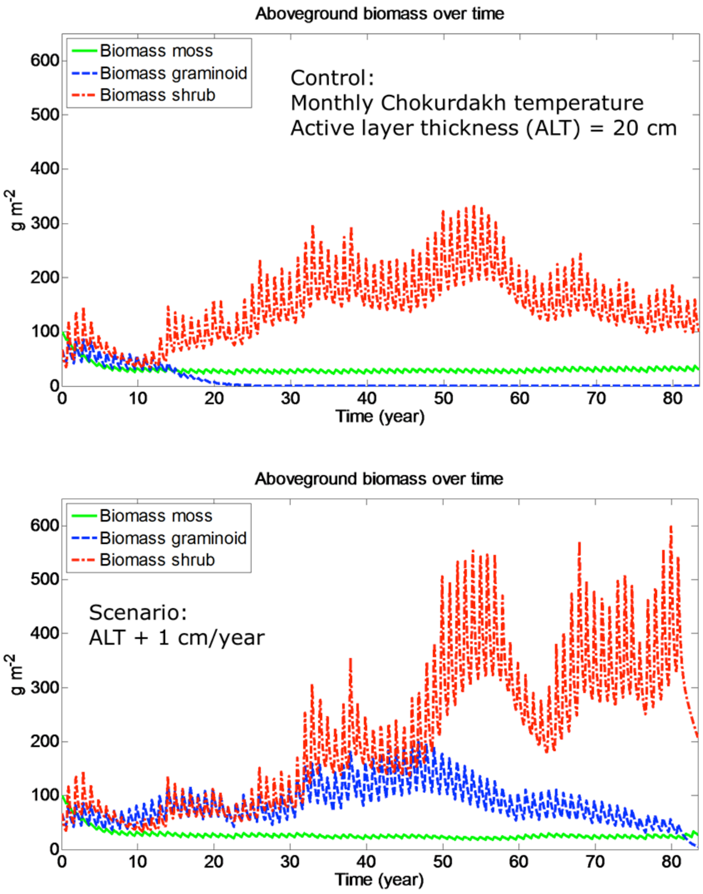

Figure 2. The effect of increasing ALT on tundra vegetation composition in our new tundra ecosystem model. Feedback between vegetation composition and permafrost is not yet included; here ALT is prescribed.

Conclusions

This paper describes the first step in the development of a tundra ecosystem model for the analysis of long-term vegetation-soil-permafrost feedbacks. Although there is still a lot to improve to this tundra vegetation model, we believe that our approach could fill the gap between permafrost models that lack a dynamic vegetation component and dynamic global vegetation models that are not detailed enough for interactions between vegetation composition and permafrost dynamics. Such a model is needed for the analysis of long-term vegetation-soil-permafrost feedbacks in relation to climate change and the consequences for the greenhouse gas balance in tundra ecosystems.

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Post brief: Effect of vegetation composition on soil-permafrost conditions and vice versa in moist tundra in NE Siberia

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In moist tundra, while environmental factors in general pronouncedly influence the vegetation patterns(IPCC 2007), the vegetation sometimes can also largely affect the local environmental conditions. It is interesting to explore the effect of tundra vegetation composition and its succession on the local environment, especially soil-permafrost conditions.

Therefore, in my PhD project I mainly focus on the influence of the different vegetation types in the moist tundra on the permafrost dynamics, especially small-scale permafrost degradation and *vice versa*, and the vegetation dynamics (Figure 1). In addition, their effects on methane emission are also included.

Five different experiments, thus, were or will be implemented: 1. monitoring the five locations with the small scale permafrost degradation; 2. continuing the *Betula nana* removal experiment; 3. dendrochronology research on *Betula nana* shrubs in moist tundra (2012); 4. greenhouse experiment on the competition between *B. nana* and *Eriophorum vaginatum*; 5. *Sphagnum* addition experiment in the field (start in 2011).

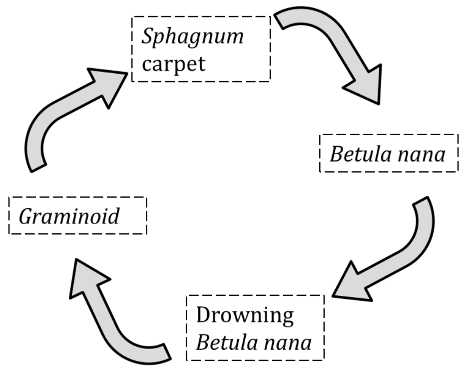

Figure 1: the cycle of the vegetation dynamics in the moist tundra

Investigating the small scale permafrost degradation in the moist tundra is the first the step of the whole project. From this investigation, I hope to collect some background information on different dominated vegetation types and the environment they prefer. Since one of the main target of my whole project is to explore the methane flux in moist tundra, the methane flux and other greenhouse gas fluxes in different vegetation dominated patches were monitored in the growing season in 2011, and will continue in 2012.

The *B. nana* removal experiment have started since a few years ago. Five *B. nana* dominated patches (10m X10 m) have been completely cut. The abiotic and biotic patterns in these removal plots gradually exhibited differently, compared with the conditions in the control plots. Except for the changing of the soil active layer thickness and the vegetation compositions, the potential switch of the greenhouse gas flux is expected.

The dendrochronology research mainly explores the *B. nana* patch dynamics in moist tundra. *B. nana*, as one of the dominated vegetation species, plays a vital role in this ecosystem (ACIA 2004). The dwarf shrubs territories have expanded in Alaska and some other tundra areas during the last decades (Sturm et al. 2001, Tape et al. 2006), but it is yet clear whether the expansion is also happening in our research area. This research will help us to understand the history of the *B. nana* patches in the moist tundra, and its influence on the local environmental factors. Moreover, the consequence also can be linked to the historical environment change (precipitation, temperature and etc.).

The *Sphagnum* addition experiment focuses on the influence of the additional *Sphagnum* carpet on the location permafrost, mainly its abiotic attitudes such as permafrost ALT(active layer thickness), moisture and methane flux. Due to the previous researches on sphagnum mosses . According to our observation, it seems that *Sphagnum* mosses often intrude the sedge dominated area, which may change the local environmental conditions, eventually giving the tundra shrubs a proper environment to establish.

The competition experiment in greenhouse is aimed to reveal the reasons why *B. nana* shrubs can highly dominated in a large part of the moist patch. I expected that relatively low soil nutrient availability and low soil active layer thickness facilitate the shrubs competing over the other species. In the experiment, two plant species are *B. nana* and *E. vaginatum*, one of the dominant gramoinoid species in the moist tundra. Different levels of nutrient availabilities, two different soil depths and two planting strategies (monoculture of *B. nana*, monoculture of *E.vaginatum* and the mixture of the both species in a pot) were included.

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Reacclimatization of the muskox in the arctic zone of Yakutia: results and prospects for further research

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Muskox (Ovibos moschatus Z.) - It is a large animal similar to bulls in appearance, but from a phylogenetic aspect is closer to mountain goat and sheep. The weight of adult males attains 450-500 kg, females' weight is 1/3 less. The body length is up to 225 cm, shoulder height attains 135 cm.

The ancestral forms of the muskoxen inhabited the arctic tundra-steppes in the north of Asia, and from this part they came to America during the Ice Age (Sher, 1971; Wilkinson et. al., 1976).

Palaeontological finds of the muskoxen remains in the Siberian tundra evidence that these animals formerly populating all over the north of Eurasia became extinct or were exterminated by primeval hunters relatively not long ago – about 3 thousand years ago. The last muskoxen are likely to extinct in the Asian north already in the Middle Ages. The muskox skull with traces of a gunshot wound found by the palaeontologists in Taimyr may evidence this fact (Vereschagin, 1959).

Today the muskox is scattered in the north of Canada, Greenland, Alaska, Norway and Russia, the aboriginal forms inhabit Canada and Greenland.

In this way the muskoxen settling in the Eurasia north should be considered as a revival – re-acclimatization of an indigenous species that earlier inhabited the Arctic spaces of Eurasia which disappeared in the post-Ice Age.

Over 35 years have passed since the beginning of the muskoxen re-acclimatization within the tundra zone in the north of Asia.

The idea of restoration of a muskox area in the tundra zone of Russia was discussed in the literature sources late in the 1920s of the 20th century by the well-known experts in game keeping and zoologists of Russia (Buturlin, 1928; Ivanov, 1934 et.al.).

The muskoxen settlement in our country began in the middle of the 1970s. In 1974 the first 10 muskoxen were translocated to East Taimyr from Banks Island as a donation of the Canada Government. Next year the US Government granted 40 muskoxen from Island Nunivak (Alaska) to our country. 20 Nunivak muskoxen were released in Wrangel Island, and the second half was released in the Canadian muskox habitat in Taimyr.

When the first translocated animals gave a rise in number and to solve different logistical matters since further settlement now over Russia occurred in 1996.

Yakutia has become a pioneer to continue this fundamental work. A special technique to capture muskoxen by applying both land and air transport vehicles has been designed. The first capturing was conducted in the Taimyr Peninsula in 1996 and then in 2002 it was carried out in Wrangel Island. In total 175 animals were translocated to Yakutia from 1996 to 2010, of them 150 individuals were released for free grazing into the wild which formed 4 herds living on their own. The first offspring in the muskoxen appeared in the republic in 1999.

This fundamental historic action has been conducted and is being conducted under the guidance of the Department of Biological Resources MNP RS(Ya) in cooperation with the colleagues from "Tsentrohotkontrol" (Control Center for Hunting), Moscow and the Institute of Problems of Ecology and Evolution RAS after A.N. Severtsev, Moscow in association with the scientists from the IBPC SB RAS, Yakutsk.

The first colonizers appeared in Yakutia in 1996. 24 specimens were translocated from Taimyr and released in Bulun District. Then new 22 animals were added to the first cohort in 2010.

In 1997 26 Taimyr muskoxen were released in the continental part of the Anabar District (Yakutia), later in 2000 15 animals joined the first group.

11 muskoxen were released near the mouth of the Indigirka in Allaikha District of Yakutia in 2000 and 27 animals in 2009.

In 2001 20 muskoxen settled on Big Begichev Island in the Laptevs Sea, Anabar District, Yakutia. In 2002 five more Taimyr animals joined them (3 females and 2 males).

Table 1 Muskoxen releases in Yakutia

District (Ulus)	Year	Number of released animals	Total number 2011
Bulun	1996	24	239
Anabar	1997	26	340
Anabar	2000	15	
Allaikha	2000	11	137
Big Begichev Isl	2001	20	120
Big Begichev Isl	2002	5	
Allaikha	2009	27	
Bulun	2010	22	
Total		150	

According to the census data the total number of muskoxen in the Arctic zone amounts to 836 animals including:

137 animals in Allaikha District

239 animals in Bulun District

340 голов. 340 animals in Anabar District

120 голов 120 animals in Big Begichev Island

As compared to 2010 (750 animals) there was an increase in the muskoxen number by 86 heads that corresponds to the natural annual gain (12%). This percentage is relatively low for the translocated population for 15 years (Tsarev, 2004) but there are two reasons explaining this fact: there was no census made on a large scale earlier or the information provided for the preceding years was somewhat overstated.

In the summer the muskoxen form small herds from 8 to 25 individuals while the adult males lead a lonely existence. In the winter they form mixed herds numbering from 20 to 40 animals. The rutting occurs from early August to mid-September with a peak in the last decade of August. The gestation period lasts 8.5 months. Females give birth to one, sometimes to 2 calves a year. Males become sexually mature at the age of 3-5. Females begin breeding when they are 2 or 3 years old.

The muskox tolerance to extremely rigorous climate is striking; the animals can also live on very poor feeding-stuff. Muskoxen do not move for long latitudinal migrations as reindeer do. Seasonal movements of muskoxen are not more than 40-80 km, whereas wild reindeer migrate from the Arctic Ocean's coast covering 700-1200 km.

In October 2010 the officers from four institutions - the Department of Biological Resources MNP RS(Ya), Control Center for Hunting (Tsentroxoncontrol), Moscow, the Institute for Problems of Ecology and Evolution RAS, Moscow and the Institute for Biological Problems of Cryolithozone SB RAS – conducted the work on muskoxen capture within the territory of the Taimyr Autonomous Okrug. 22 captured animals in Taimyr were translocated and released in Bulun District, Yakutia.

A device (Pulsar) for satellite tracking was fixed on one of the muskoxen. Putting a satellite collar was made within the framework of the international Russian-Japanese Project No. 09-04-92111 "Cooperative Ecological Study on the Large-scale Migration and Population Dynamics of Wild Reindeer in Eastern Siberia".

We have selected the largest calf in the group before fixing a collar on him. This species possess a gregarious instinct, so the animals of this species will seek and keep the largest individual and live in the group (herd). The captured calf with a satellite collar was released not far from its muskoxen group.

You can see the map of movements of the translocated animals from Oct.13 to 16, 2010. The group with a tagged animal was released on Oct.13, 2010. For two weeks the animals were searching a suitable place for grazing, possibly they wanted to meet some other muskoxen groups because all animals released were young (under a year of age). About 40 km were covered by the animals. The straight line was as long as 19 km from the place of their release.

In the nearest future the muskox can become a game species. The hunting trophy will finally be a policy reserve to supply the local people and those living near the sea coast with highly qualitative foodstuffs, leather and fur raw materials in the winter time when the wild reindeer migrate from the Arctic Ocean southward hundreds of kilometers far in the forest-tundra and taiga zone. All flesh abandons the Arctic tundra for long 6 winter months but the muskoxen.

In due course hunting muskoxen may maintain the traditional trades of the local people in the Russian North; provide it with fancy products, rawstock, wool and down hair that will make good a loss in number of reindeer.

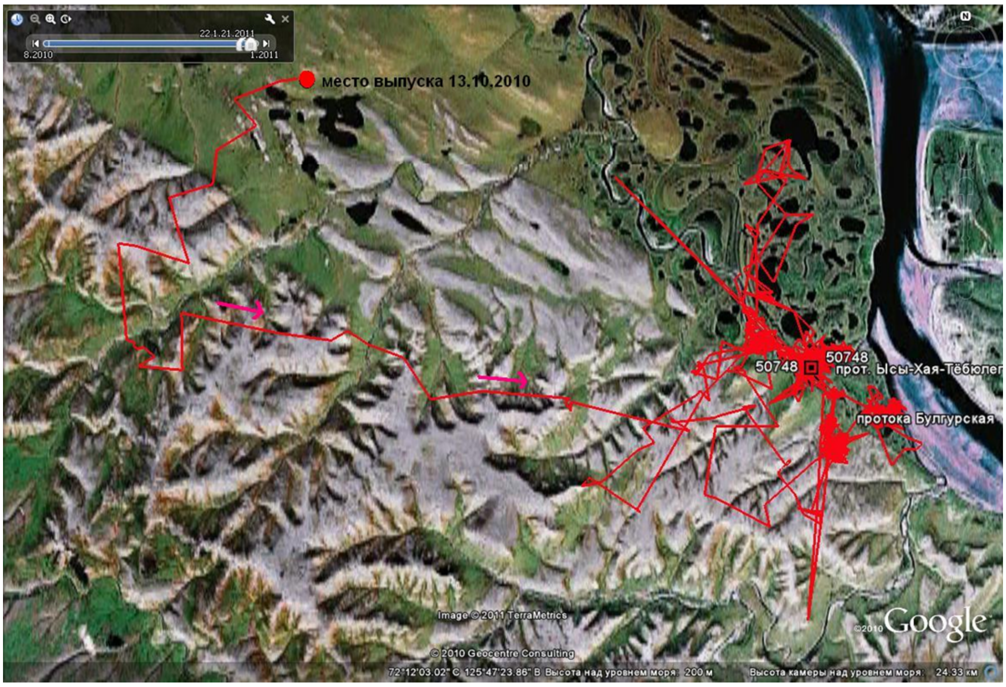

Figure 1. Movements of muskoxen from Oct.13 to Nov 16.2010

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Current status of hunting by the indigenous minorities in Yakutia

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Key words: game animals, hunting management, indigenous minorities, Yakutia

The Republic of Sakha (Yakutia) has considerable resources of fur bearing and game animals and is one of the main suppliers of furs in Russia. Preconditions for this purpose are existence of resources and traditional nature of fur trade in economic activity of indigenous people.

The total area of hunting areas of Yakutia makes about 305616000 hectares. This extensive territory of the republic is habitat of 26 species of the mammals which are objects of hunting. The skins of 17 species of mammals are harvested from them in Yakutia. The main objects of commercial hunting are the squirrel, polar fox, sable, muskrat, ermine, weasel which give more than 97% from the cost of all furs harvested in the Republic. Other species are of no crucial importance in fur semiproducts manufacture.

For the last 8 years the stocks of the hunting resources of Sakha Republic take the leading positions in Russia: moose - 8 %, wild reindeer – 16 %, snow ram – 80 %, brown bear – 10 %, sable - 30 % of all hunting stocks of the Russian Federation.

At actually developed purchase price of one skin the most valuable species are: sable, red fox, glutton, lynx and bear. Then polar fox, wolf, mink follow. The least valuable species are hare, squirrel, ermine, weasel, muskrat.

The sable is especially valuable and high paying fur-trade species and makes more of 80% of “mild gold” cost harvested in Republic for the recent years. Sable ranks third by quantity of the harvested skins after muskrat and squirrel. Since 2003 the growth of sable skins procurements is marked till 2009. Over the last 5 years sable skin harvests make 45 thousand skins.

Species number has increased almost in 2,5 for the last 7 years. Currently about 24% of the total sable population is procured at average, though this rate, most likely, much more than given figure because the part of skins is not registered as taken outside the Republic.

The muskrat ranks second in the balance of fur harvests of Yakutia. It shares about 9,6% of game furs cost harvested in republic.

As a result of artificial and natural moving of a muskrat the range covers now all suitable for habitat territory of Republic.

Muskrat skins procurement leads in fur harvests by species of fur animals. In 2000th muskrat harvests increased but didn’t reach the results of 1980th. The greatest increase of muskrat skins procurements is observed in Central districts.

The squirrel ranks third in balance of fur harvests. Its share is 4,9 % of all furs cost. Over recent years the squirrel population in Yakutia is rather stable with small annual fluctuations. The main suppliers of the squirrel skins – Southwest, Western and Northeastern mountain areas which share is 82% of all skin harvests for the last 18 years. Squirrel harvests are variable. The low rate is registered in 2005.

Currently the decrease of squirrel harvests continues. About 9 % of squirrel population is hunted a year at average. For comparison: average annual squirrel skins procurements made 948 thousand pieces in the middle of the last century and over the last 10 years this rate makes 77 thousand pieces, i.e. they has reduced in 123 times.

The ermine ranks fourth in skins procurements. The ermine in Yakutia is prevalent species: in all natural zones excepting high-mountainous tundra. In the middle of the last century an average annual ermine hunting made about 150 thousand skins that in 15 times more than present data. Northeastern and Kolymo-Indigirsky regions give the most quantity of skins.

For the last 7 years ermine population remains stable with some fluctuations from year to year. Almost everywhere ermine stocks aren't used completely, at average only 5,2% of population is hunted. Significance of ermine as an object of hunt in money value has reduced over the last 10 years in 2 times and unit weight in fur harvests is 2,5% and it ranks fifth.

The wolf ranks fifth in skins procurements. In total about 600 packs of wolves and 250 lone wolves live in Yakutia. The average number of wolves in one pack is 5-6 units. Wolves population number is 3800 units. 18,5 % of the total number of wolves are hunted in Republic.

The main object of meat hunting in Yakutia is a wild reindeer because it is numerous, has gregarious habits and seasonally widely migrates. Reindeer hunting becomes an effective form of management. Population number of a wild reindeer in Yakutia was 700-900 thousand units to the middle of XVII-th century.

At the beginning of the XXth century there were about 360 thousand deer. From 1920th to 1960th tundra populations of reindeer decreased much because of overhunting. Then the herds started to restore. The growth of population was marked almost simultaneously in three remained populations: Leno-Oleneksky, Yano-Indigirsky and Sundrun. At the present days the magnitude of a wild reindeer population is about 150-160 thousand units that approximately makes 30% of wild reindeer population of Russia. At average 20-25 thousand units of reindeer are hunted a year in Yakutia.

In Arctic and Northern regions of Yakutia, areas which are densely inhabited by small national communities of the North, game management and reindeer breeding are the basics of traditional environmental economics. In Yakutia many hunting lands are assigned for temporary use to so-called tribal communities which represent the form of economic activities with purpose of achievement and fulfillment not only economic results but also ethnosocial needs, i.e. protection of primordial living environment, preservation and development of traditional nomadism, folk crafts and culture. The modern tribal community has small structure (at average from 7−10 to 15−20 persons). Small communities (7−10 people) are basically consanguine, big communities (15−20 people) are territorial-neighborly.

231 tribal communities functioned in Sakha Republic (Yakutia) as of January 1st, 2010. The majority of tribal communities are engaged in traditional economic activities of the people of the North – reindeer breeding. In all tribal communities on the beginning of the year there were 44728 units of domestic reindeer that makes 22,27% of reindeer population of all reindeer-breeding economics of Yakutia.

One of the basic traditional occupation of indigenous Arctic peoples is hunting. Hunting for sable gives them the basic income, therefore further we'll look at how communities hunt for sable under conditions of Yakutia.

For hunting for a sable the special license is necessary. The quantity of the granted license depends on number of a sable in the lands are assigned to tribal communities. Hunting for a sable begins when the first snow falls in October and continues till March. Fur of the faded sable the most qualitative from the middle of October till the end of January.

In the autumn when the snow's depth is not much hunting for a sable with gun and dog is the most suitable. In areas where there is a lot of sable people hunt by means of traps. Hunting by means of traps is important when the snow cover is very deep and hunting with a dog becomes impossible. Traps on a sable are very various. Nowadays the self activated traps are basically used.

The device of self-made traps is based on such mechanism: the weight of trap presses down a sable. The pressing device consisting of one log or a pole (with additional weight or without it) beats an animal across its corpus axis pressing down it to a threshold.

A billet is established in a deep notch of wooden device. The front end of base is kept in horizontal position on a crossbeam established between two legs of flyer.

Thus, the game management of Yakutia at the appropriate organization has considerable resource and labor potential of economic growth and increase in employment of indigenous people.

Larch photosynthesis in south-eastern part of Yakutia, Eastern Siberia, in comparison with central taiga zone

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Key words: larch, photosynthesis, respiration, J_{max}, Vc_{max}, Yakutia

Introduction

Larch is a dominating forest species in Yakutia, occupying up to 96% of woodstand, and largely contributes to overall CO_2 flux balance of the forest ecosystem. Photosynthetic characteristics of the larch in central taiga of Yakutia (“Spasskaya Pad” forest station, 62°14’ N, 129°37’ E), being at a close reach, have been studied for a long period (1992-2010) and reported in many publications [Tabuchi et al., 1994; Koike et al., 2000; Maksimov, 2003; Maksimov et al., 2004; Dolman et al., 2004; Maksimov et al., 2006]. However, other forest areas of Yakutia are lacking such researches because of far and cost-based distances, except studies by Vygodskaya et al. (1997) at Aldan plateau. In 2009 one more forest research site was established in south-eastern part of Yakutia (“Elgeeji” forest station, 60°00’ N, 133°50’ E) within joint Russian-Japan project “Global Warming and the Human-Nature dimension in Siberia – The social adaptation to the changes of the terrestrial ecosystem with an emphasis on the water environment”, at which in the growing season of 2011, from June to August, larch photosynthesis was characterized in a comparative aspect with the typical larch forest of Central Yakutia.

Objects and methods

Diurnal net-photosynthesis of twigs of two *Larix cajanderi* trees of nearly same age (120-125 years) was measured at mid-crown level using an infrared H_2O/CO_2 gas analyzer LI-6400 (LI-COR, USA). Access to the crown was provided by a 34 m high duralumin observation tower with stairs and transition landings. Measurement replications were five twigs on each tree, twigs were made sunlight-oriented as possible. Daily measurements were started since sunrise and finished at sunset, with a time interval of 2-3 h. As night measurements, those after sunset and till sunrise were considered, mostly done at 21, 24, and 2 h.

A-Ci(PAR) curve measurements were made at various time during day, possibly trying to do it before midday. One or two twigs were chosen on each tree for *in vivo* measurements, or cut twigs from different locations for *in vitro* procedures.

Needle areas were determined at the season end using a scanner with consequent counting of pixels, as well as with the help of needle photos with a ruler using AnalyzingDigitalImages software, version 11 (Museum of Science, Boston, USA).

Data were averaged as the arithmetic mean, analyses and figures were done using MS Excel 2010. A-Ci (PAR) curves were analyzed using Photosyn Assistant software, version 1.1.2 (Dundee Scientific, UK).

Results and discussion

The measurements showed typical dome-shaped patterns of diurnal photosynthesis with a left asymmetry (Figure 1). Maximum magnitudes of 6-9 μmole m^{-2} s^{-1} happened at 8-9 a.m., after which a gradual decline was observed till zero values at 8-9 p.m. Night respiration (R_{night}) was at -1.5-2 μmole m^{-2} s^{-1} in a stable manner throughout the whole season. The given magnitudes and patterns are of no significant difference from those of central taiga larch characteristics for almost 10 years of observations there. Thus, at a first glance, investigated central and south-eastern parts of Yakutia do not differ between each other on the magnitudes and patterns of photosynthetic carbon assimilation by the larch. General uncertainty is that no parallel measurements were done at Spasskaya Pad station because of logistics and equipment lack. For more reliable deductions seasonal replications of the measurements are needed at Elgeeji site with synchronous control at Spasskaya Pad, and associated analysis of hydroclimatic conditions as well.

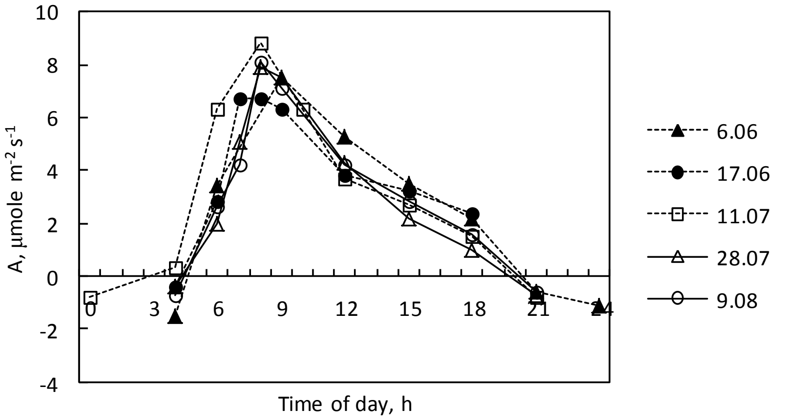

Figure 1. Diurnal net-photosynthesis (A) of L.cajanderi for the growing season, Elgeeji, 2011.

At the same time, net ecosystem exchange (NEE) of the south-eastern ecosystem, measured with eddy-covariance technique, was by about 30% higher of the other, and soil emission – by 100% at all. Provided similar photosynthesis of the larch at both regions, significant contribution to carbon assimilation should be given by other wood species and undergrowth. Possibly, the forest floor plays a greatest role, which under other equal conditions must significantly intercept the extremely high soil efflux in order for the ecosystem to show carbon sequestration by 30% higher compared with the central taiga site. Nevertheless, the abovesaid is speculative as the deductions are based on nonsynchronous measurements of restricted amount of larch trees and they cannot ground the NEE difference themselves; an additional prove for that is very close diurnal photosynthesis patterns throughout the season, which is unlike to be real and means that more samples and with more frequency must be measured to relate larch photosynthesis with NEE.

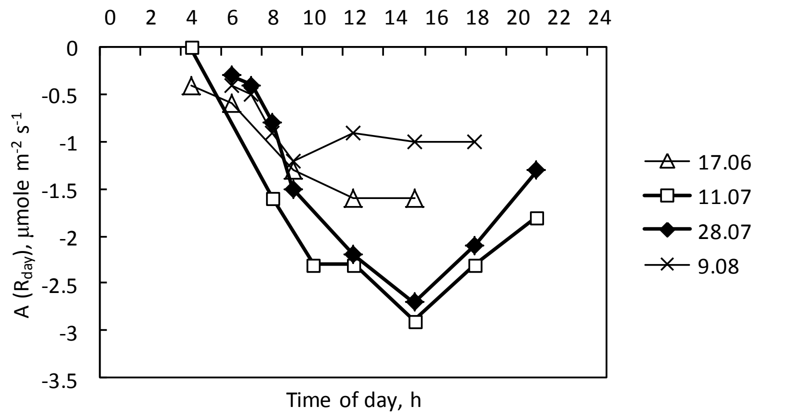

Figure 2. Daytime dark respiration (R_{day}) of L.cajanderi for the growing season, Elgeeji, 2011.

Daytime dark respiration (R_{day}) of the larch has a reverse parabola diurnal pattern (Figure 2). The period of maxima, to all appearance, is the same for the whole season – at 3 p.m. R_{day} is naturally less at the start and the end of the growing season with maxima up to -1.5 and -1 µmole m^{-2} s^{-1} respectively. At mid-season, R_{day} increased twice, having reached -3. Percent ratio of R_{day} to A was strongly varying during the season, from 8 to 200, therefore it makes sense to consider daily averaged values. So, ratio R_{day} : A at the season start and end was 33 and 25 respectively, at mid-season – near 63. During the day though, the highest R_{day} : A magnitudes, from 40 to 200, occurred from midday to 6 p.m. respectively, while at peak morning periods of carbon assimilation R_{day} : A varied mainly from 8 to 20, sometimes reaching 35-40. For comparison, seasonal R_{day} : A mean in central taiga makes 55-67 with a range of 25-118, at morning photosynthesis peak – mainly 35-40 with a variation of 14-76 (IBPC unpublished dataset, 2001-2002). Thus, daytime dark respiration of the larch in these ecosystems differs only at morning peak hours of photosynthesis (2.5 times higher in central taiga), the other parameters being enough close to each other.

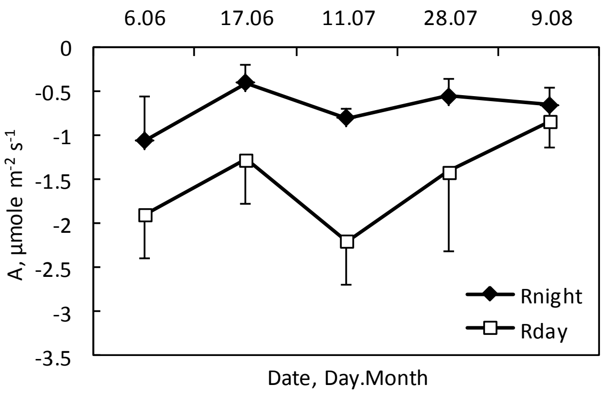

Figure 3. Night and daytime respiration of L.cajanderi for the growing season, Elgeeji, 2011.

R_{night} to R_{day} ratio was coherent (Figure 3), and varied from 31 to 77 with a seasonal mean of 48% from daytime respiration. The difference between the parameters was stable throughout the season and made on average 1 µmole m^{-2} s^{-1} except a magnitude of 0.2 at the season end, when all processes become level, respiration inclusive. Autumn closure of both types of respiration took place around -1 µmole m^{-2} s^{-1}. If compare with analogous data on central taiga, then mean-seasonal R_{night} : R_{day} ratios are more or less comparable (48 vs 60 for Spasskaya Pad) while the seasonal R_{night} : R_{day} variance in Central Yakutia is twice as less (-0.5-0.6 vs -1) as well as the autumn magnitude (-0.5 vs -1).

Overall conclusion on respiration is that considering the range of respiration and that data on central taiga are of decade (10 years) remoteness, the parameters of larch respiration in both ecosystems are identical on the whole.

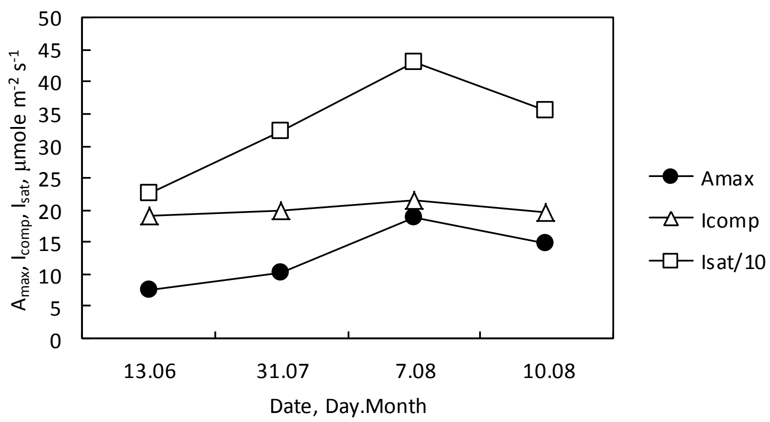

Figure 4. Maximum A (A_{max}), points of light saturation (I_{sat}) and compensation (I_{comp}) of L.cajanderi for the growing season, Elgeeji, 2011.

The points of light saturation (I_{sat}) were relatively high compared to those of Spasskaya Pad for 2010 (indicated in brackets): minimum of 226 (169) µmole m^{-2} s^{-1} at the season start and maximum of 431 (308) at early August, with a seasonal mean of 330 (230). However, earlier much bigger quantities of 500-800 on average were reported for Spasskaya Pad [Saito et al., 2003; IBPC unpublished data, 2001], testifying to wide range of I_{sat} averaging about 300-500, to which Elgeeji dataset fits well. The light compensation point (I_{comp}), unlike I_{sat} and A_{max}, was stably linear for the season (Figure 4); the magnitude was near 20 µmole m^{-2} s^{-1}, which is within the known range for Spasskaya Pad (11-29) [Saito et al., 2003; Maksimov et al., 2003]. However, I_{sat} and I_{comp} seasonal patterns are not significant facts because of paucity of the measurements (only 4 points for the season).

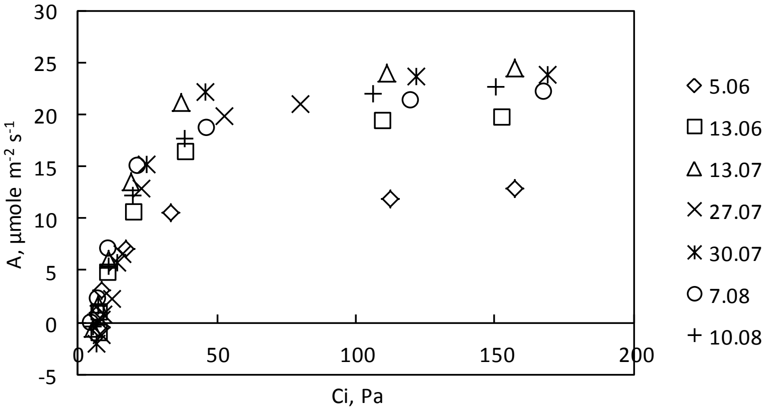

Figure 5. Dependence of A on Ci of L.cajanderi for the growing season, Elgeeji, 2011.

A-Ci curves show (Figure 5) that CO_2 saturation fell on near 500 ppm (50 Pa) regardless of the season period. Average maximum quantities of saturated photosynthesis are within a range of 20-25 µmole m^{-2} s^{-1} with natural exception at the season beginning with a maximum only up to 13. The given values correspond well to those of central taiga larch (IBPC unpublished data, 2003-2005).

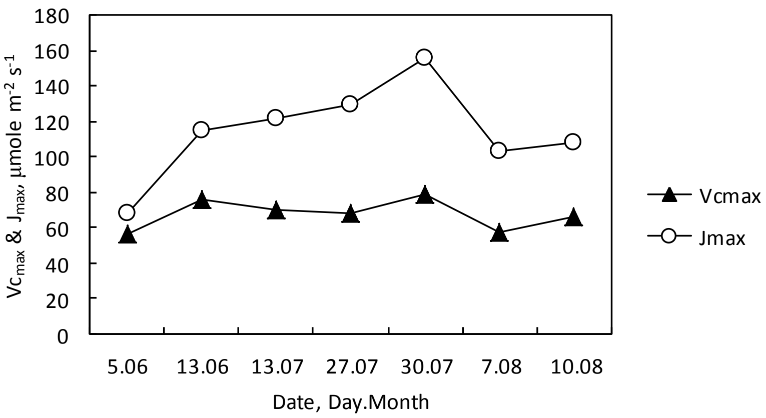

Figure 6. Dynamics of Vc_{max} and J_{max} of L.cajanderi for the growing season, Elgeeji, 2011.

Analysis of the A-Ci curves on maximal carboxylation efficiency (Vc_{max}) and electron transport rate (J_{max}) revealed relatively low J_{max} to Vc_{max} ratio of 1.7 on average (with a range of 1.2-2.0) at usual 2-2.7 for the majority of plants according to literature data [Wullschleger, 1993; Leuning, 2002]. In central taiga the ratio was 3.3 at the expense of larger portion of J_{max} (maximally 212 µmole m^{-2} s^{-1}); here, J_{max} peak was considerably lower (156) at quite comparable maximal Vc_{max} (63 and 79 for Spasskaya Pad and Elgeeji respectively). Thereby we can suppose that towards south-east the share of electron transport rate reduces and carboxylation becomes of a more priority. The magnitudes for the season at Elgeeji site made 56-79 (67 on average) for Vc_{max} and 68-156 (114 on average) for J_{max}.

Along the season the parameters have rather uniform distribution with natural exception at the starting period, as well as of highest output from mid to end July (Figure 6). The seasonal pattern at Elgeeji, compared to Spasskaya Pad, is more smooth, without steep or enough expressed rise from late June to early July as it occurs in central taiga [Maksimov et al., 2006]. Judging by the graph, seasonal rise here is relatively insignificant and lags almost by month, and only for J_{max}. Thus, in comparison with central taiga, the remarkable difference in the biochemical parameters is only in their twice lesser ratio (1.7 vs 3.3) at the expense of reducing J_{max} portion, as well as in vague seasonal change dynamics. Nevertheless, these points need to be checked by further monitoring at seasonal scale.

Conclusions

On the characteristics of larch photosynthesis at Elgeeji site we may assert on the whole that, except pointed out insignificant differences, in total, photosynthesis of *L.cajanderi* in the south-eastern ecosystem does not diverge from that of the central taiga area.

NEE difference between the ecosystems by 30% may indicate on a defining contribution of other factor(s), than larch photosynthesis, to overall CO_2 balance. However it has a high degree of uncertainty related to control, time, sample and frequency issues, and cannot be dealt with as a grounded conclusion.

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Interannual variation of the carbon dioxide flux in an eastern Siberian larch forest

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Key words: Spasskaya Pad, eddy correlation method, CO_2 flux, soil moisture

1. Introduction

The taiga forest that grows in permafrost areas of eastern Siberia has a great effect on the global carbon cycle because it covers a huge area. Therefore, it is important to understand the carbon cycle and the relationship between carbon flux and environmental variables in the Siberian forest. Recently, Iijima *et al*. (2010) reported that soil temperature and moisture had increased dramatically in the middle reaches of the Lena River in eastern Siberia, while Iwasaki *et al*. (2010) reported yellowing and browning of larch trees in an eastern Siberian larch forest in the summer growing season of 2007. They also found that the damaged trees were located at sites with especially high soilwater levels.

Therefore, to examine the effect of the high soil moisture and vegetation changes on the assimilation of CO_2, we investigated the interannual variation in the CO_2 flux by using overstory and understory eddy-covariance measurements in an eastern Siberian larch forest over the 8-year period from 2004–2011.

2. Site description and methodology

The observation site, the Spasskaya Pad Experimental Forest of the Institute for Biological Problems of the Cryolithozone (IBPC) in Russia, is located in the middle reaches of the Lena River in eastern Siberia (62°15′18″N, 129°14′29″E; 220 m a.s.l.). The dominant overstory tree species is larch (*Larix cajanderi*). The understory vegetation is mainly cowberry (*Vaccinium vitis-idaea*) (Ohta *et al*., 2008). In recent years, however, the wet soil conditions have caused a decline in the overstory larch trees (Table 1). In the understory, shrubs (*Betula platyphylla*, *Allnus* sp., *and Salix* sp.) have been growing rapidly, and many grasses that are resistant to excess moisture have invaded the forest floor.

A meteorological observation tower (32 m high) was installed at the site in 1996. Meteorological variables above and beneath the canopy have been measured every 30 minutes since 1998, and latent, sensible, and CO_2 fluxes have been measured above the canopy since mid-August 2003, using an open-path eddy correlation method. In addition, flux measurements by the same method have been performed 3.3 m from the forest floor since 2005. Our analysis used meteorological variables [photosynthetically active radiation (*PAR*), air temperature (*Ta*), vapour pressure deficit (*VPD*), and soil water content (*SWC*)] and CO_2 flux data above and beneath the canopy over the 8-year period from 2004–2011.

The net ecosystem exchange of CO_2 (*NEE*) was separated into ecosystem respiration (*Re*) and the gross photosynthetic productivity of the ecosystem (*GPP*). The daytime (*PAR* > 0 μmol m^{-2} s^{-1}) *Re* was calculated by applying an empirical equation between the night-time (*PAR* = 0 μmol m^{-2} s^{-1}) *Re* (*i.e*., night-time *NEE*) and temperature (*e.g*., Falge *et al*., 2001; Wang *et al*., 2004). The *GPP* was calculated as the sum of net ecosystem production (*NEP* = –*NEE*) and *Re*.

Table 1. Mortality rate of larch trees at the tower site (50×50 m).

Year	The mortality rate of larch trees
2008	16/211
2009	17/211
2010	18/211 (31/211)
2011	19/211 (33/211)

Notes: The denominator and the numerator are population and mortality of larch trees, respectively. The figures in brackets are the mortality rates of larch trees including dawn timber.

3. Results and Discussion

3.1 Environmental variables over 8 years

Figure 1 shows the daily mean values of environmental variables above and beneath the canopy. In June 2011, all environmental variables except *PAR* above and beneath the canopy were treated as missing data.

No significant trend in the *PAR* above the canopy (PAR_A) was observed, except for a drop in 2011. The *PAR* beneath the canopy (PAR_B) increased gradually from 2008 because the overstory larch trees declined since 2008. However, PAR_B decreased in 2011 along with PAR_A.

There were no clear changes in *Ta* and *VPD* above (Ta_A, VPD_A) and beneath (Ta_B, VPD_B) the canopy from 2004 to 2007. However, these variables increased in 2008–2011. In particular, they were much larger in 2008 and 2011 than in other years.

The *SWC* increased in 2005 and stayed high for the remainder of the study period.

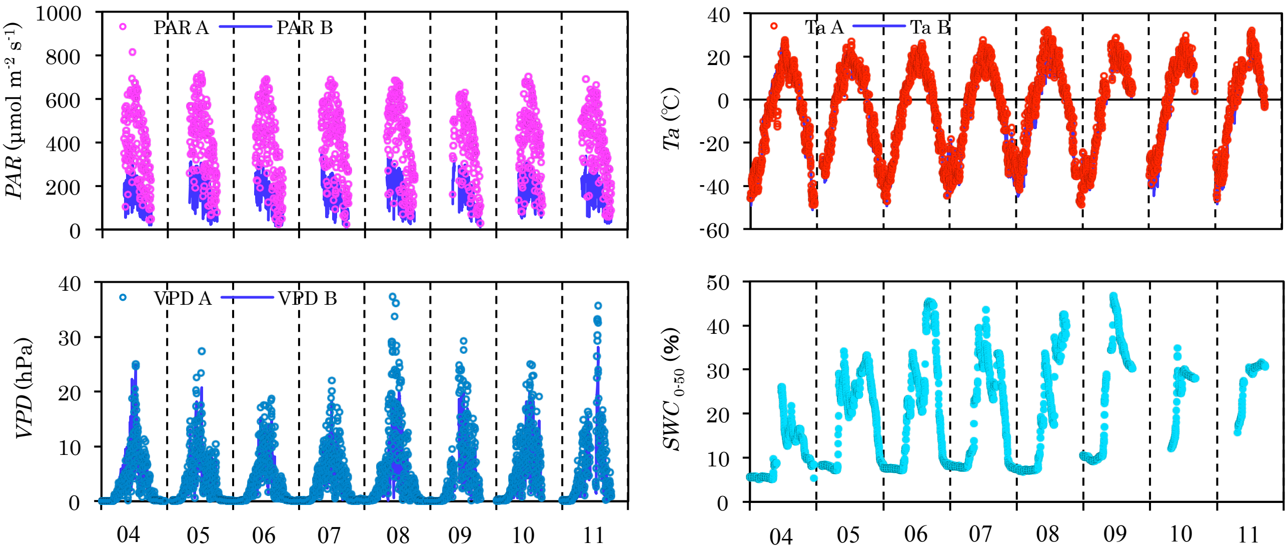

Figure 1. Daily mean values of PAR (left upper), Ta (right upper), VPD (left lower), and SWC at 0-50cm depth (right lower).

3.2 Interannual variation of daytime *GPP*

Figure 2 shows the interannual variation of *GPP* over the entire (GPP_A) and understory (GPP_B) canopy. Figure 3 shows the ratio of the understory contribution to the entire canopy photosynthesis (GPP_B/GPP_A).

The annual mean GPP_A increased gradually from 2004 to 2007, but decreased in 2008–2011.

There were no clear changes in GPP_B from 2004 to 2007, but the parameter increased after 2008, then decreased in 2011. The ratio of the understory contribution to the entire canopy photosynthesis (GPP_B/GPP_A) increased after 2008, but decreased in 2011.

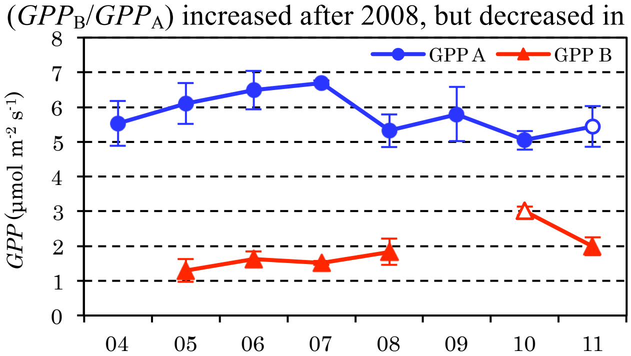

Figure 2. Interannual (JJA mean values) variations of the daytime GPP. The open plots are July and August mean values because missing date in June.

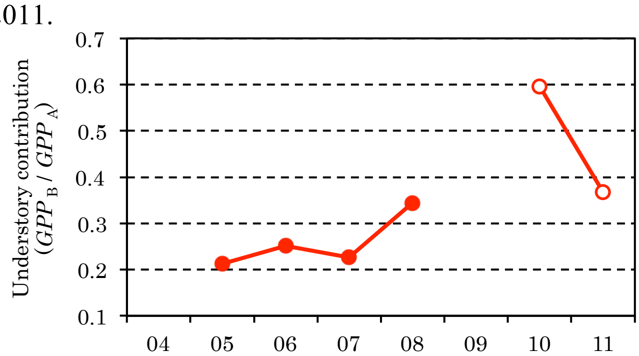

Figure 3. The ratio of the understory contribution to the entire canopy photosynthesis.

3.3 Relationships between environmental variables and *GPP*

Figure 4 shows the relationships between the environmental variables and GPP_A and GPP_B.

In 2004–2007, a relationship between the environmental variables and GPP_A was found mainly for *SWC*. The slope was 0.083 and there was a strong positive correlation (r^2 = 0.99). The GPP_A decreased in 2008–2011 despite the wet soil conditions, which might have been due to the decline in the overstory larch trees in these years. The regression equation changed in 2008–2011 to a slope of 0.049 with positive correlation (r^2 = 0.80). Ohta *et al.* (2008) reported a clear positive correlation between *SWC* and evapotranspiration standardized by potential evaporation in the same larch forest. These results indicate that the interannual variations in GPP_A and evapotranspiration followed that of *SWC* in an eastern Siberian larch forest. We found that GPP_A decreased from 2008, while Hanamura *et al.* (2012) reported that evapotranspiration decreased from 2007 in the same larch forest. We do not know the cause of the one year time lag.

In 2004–2007, there was also a positive correlation (r^2 = 0.63) between Ta_A and GPP_A. However, there was no relationship between the two in 2008–2011, when Ta_A and VPD_A increased considerably. Very hot and dry air may have caused the decrease in GPP_A in these years.

There was a positive correlation (r^2 = 0.83) between PAR_B and GPP_B, except in 2005, when it is conceivable that the understory vegetation change was not yet as large. The PAR_B increased gradually from 2008, because the overstory larch trees declined after this year. This might have caused the increase in GPP_B in 2008 and 2010. In 2011, the decrease in PAR_B may have caused the decrease in GPP_B.

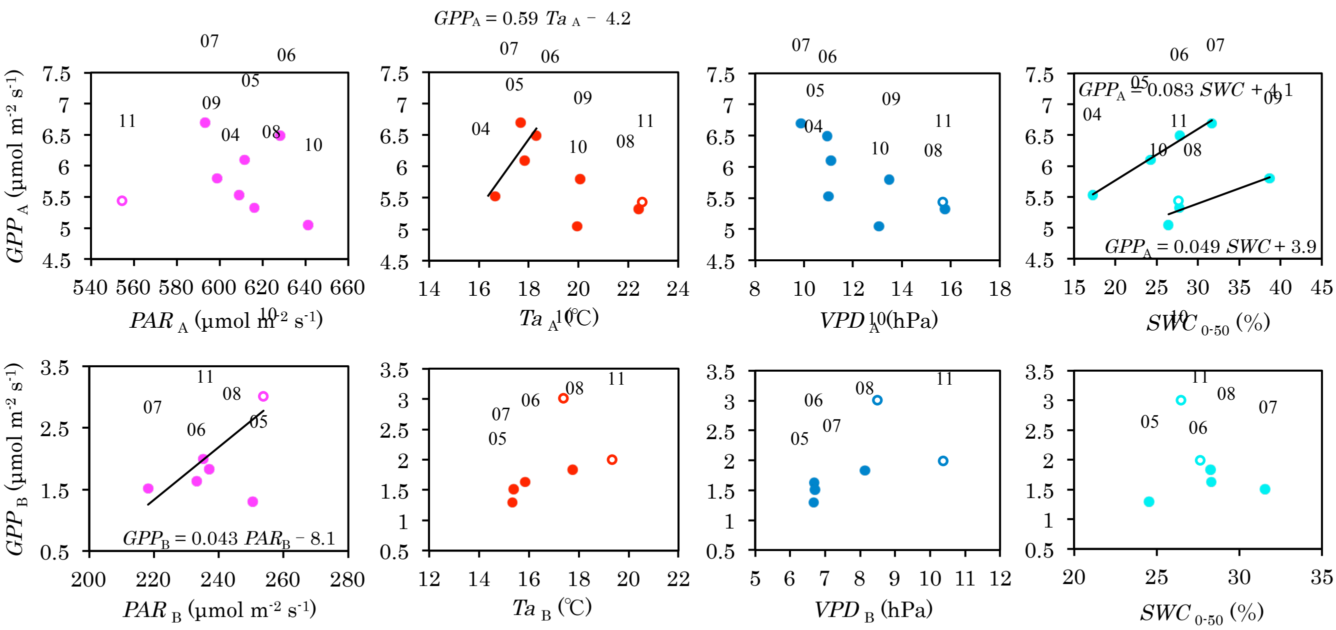

Figure 4. The relationships between the JJA mean daytime environmental variables (PAR, Ta, VPD, and SWC at 0-50cm depth; from left to right) and the daytime GPP (GPP_A; top, GPP_B; bottom). The open circles are relationships between the July and August mean daytime environmental variables and the daytime GPP.

4. Conclusions

We investigated the interannual variation in CO_2 flux using overstory and understory eddy-covariance measurements and the relationships between CO_2 flux and environmental variables (*PAR*, *Ta*, *VPD*, and *SWC*) in an eastern Siberian larch forest over the 8-year period from 2004–2011.

The *SWC* increased in 2005 and stayed high for the remainder of the study period. The relationship between *SWC* and GPP_A was strongly positive in 2004–2007. By contrast, GPP_A decreased in 2008–2011 despite the wet soil conditions, perhaps because of the decline in the overstory larch trees in those years. While the regression equation changed in 2008–2011, there was also a positive correlation between *SWC* and GPP_A in those years. The relationship between Ta_A and GPP_A was also positive in 2004–2007. However, there was no relationship between the two in 2008–2011, when Ta_A and VPD_A increased considerably. Very hot and dry air may have caused the drop in GPP_A in these years.

The relationship between PAR_B and GPP_B was positive in 2006–2011. PAR_B increased gradually from 2008 because the overstory larch trees declined after that year. This might have caused the increase in GPP_B and the change in the ratio of the understory contribution to the entire canopy photosynthesis (GPP_B/GPP_A) in 2008 and 2010.

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Variability analysis of evapotranspiration in an eastern Siberian larch forest over a 11-year period (1998-2011)

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Key words: Evapotranspiration, potential evaporation, evapotranspiration coefficient, extremely wet soil, Siberian larch forest

1. Introduction

Forests cover approximately 30% of the Earth's terrestrial area (FAO, 2005) but account for 45% of the total evapotranspiration from the global land surface (Oki and Kanae, 2006). Current concerns over global warming have highlighted the vulnerability of high-latitude ecosystems (IPCC-WG-1, 2007), including boreal forests. It is important to understand the water balance in boreal forests under changing environmental conditions.

Recent increases in soil temperature and moisture were reported for larch forests in the middle reaches of the Lena River, eastern Siberia (Iijima *et al*., 2010). Yellowing and browning of eastern Siberian larch trees were also observed in the summer growing season of 2007 and were attributed to especially high soil water content at the study sites (Iwasaki *et al*., 2010).

The present study investigated changes in the water balance with high soil water content and vegetation changes in eastern Siberian larch forests. We researched the interannual variation in evapotranspiration (*Ev*) over the 11-year period during 1998–2011 using eddy-covariance measurements.

2. Site description and methodology

Observations were conducted in an eastern Siberian boreal larch forest located approximately 20 km north of Yakutsk in the Republic of Sakha, Russia (62°15′18″N, 129°14′29″E; 220 m a.s.l.). The dominant overstory tree species is larch (*Larix cajanderi*). The understory vegetation is mainly cowberry (*Vaccinium vitis-idaea*) (Ohta *et al*., 2008). Several larch trees at the study site died in 2007, representing 8% mortality in the third year after the onset of high soil water content, and additional larch trees died in 2011, representing 16% mortality. In the understory, several grass species with high tolerance for wet soil invaded the observation site.

A meteorological observation tower (32 m high) was installed at the site in 1996. Meteorological variables have been measured every 30 minutes since 1998, and latent, sensible, and CO_2 fluxes have been measured using an open-path eddy correlation method. In this report, we used the meteorological variables net radiation (*Rn*), solar radiation (*Sd*), air temperature (*Ta*), vapour pressure deficit (*VPD*), soil water content (*SWC*), ground temperature (*Tg*), and precipitation (*Pr*) and evapotranspiration (*Ev*) data collected over the 11-year period from 1998 to 2011.

Evapotranspiration can be described using potential evaporation from a standard land surface:

$$Ev = a \times Ep \tag{1}$$

$$a = \frac{Ev}{Ep}, \tag{2}$$

where *Ev* is the observed evapotranspiration, *Ep* is the potential evaporation from a standard land surface, and *a* is the evapotranspiration coefficient. *Ep* is an index of atmospheric demand for evaporation, and *a* is the amount of regulation of *Ep* by the land surface, including vegetation. We used the index *a*(*Ev/Ep*) for this study.

The surface conductance (G_S) was calculated using the inverted Penman–Monteith equation:

$$\frac{1}{G_S} = \left(\frac{\Delta}{\gamma}\beta - 1\right)\frac{1}{G_a} + \frac{\rho c_p}{\lambda E_\gamma} D, \tag{3}$$

where λE is the latent heat flux, Δ is the rate of change in the saturation vapour pressure at the air temperature, ρ is the density of air, c_p is the specific heat of air at a constant pressure, γ is the psychrometric constant, β is the Bowen ratio ($H/\lambda E$), D is the water vapour pressure deficit, and G_a is the aerodynamic conductance. The last quantity is defined as

$$\frac{1}{G_a} = \left(ln\frac{z-d}{z_0}\right)^2\left(\frac{1}{\kappa^2 U_Z}\right), \qquad (4)$$

where z_0 is the roughness length, d is the zero plane displacement, z is the height, U_Z is the wind speed at height z, and κ is von Karman's constant (0.41). The values of d and z_0 were estimated from the friction velocity, which was determined using an ultrasonic anemometer to measure wind speed profiles under near-neutral conditions, $|z/l| \leq 0.05$, where l is the Monin–Obukhov length (Matsumoto *et al.*, 2008).

3. Results and Discussion

3.1 Environmental variables over 14 years

Figure 1 shows the daily mean values of environmental variables and monthly integrated values of *Pr*. No significant trend in *Rn*, *Sd*, *Ta*, or *VPD* was observed. However, *Rn* and *Ta* gradually increased from 2004 to 2011. Moreover, *VPD* gradually increased during 2008–2011.

The *SWC* increased during 2004–2005, remained high from 2006 to 2009, and then decreased from 2010 to 2011. The *Tg* increased during 2004–2006. The *Pr* increased from 2003 to 2008, particularly during the period 2006–2008.

In short, no significant trend in the atmospheric conditions was found, but notable fluctuations were observed below the soil surface in recent years.

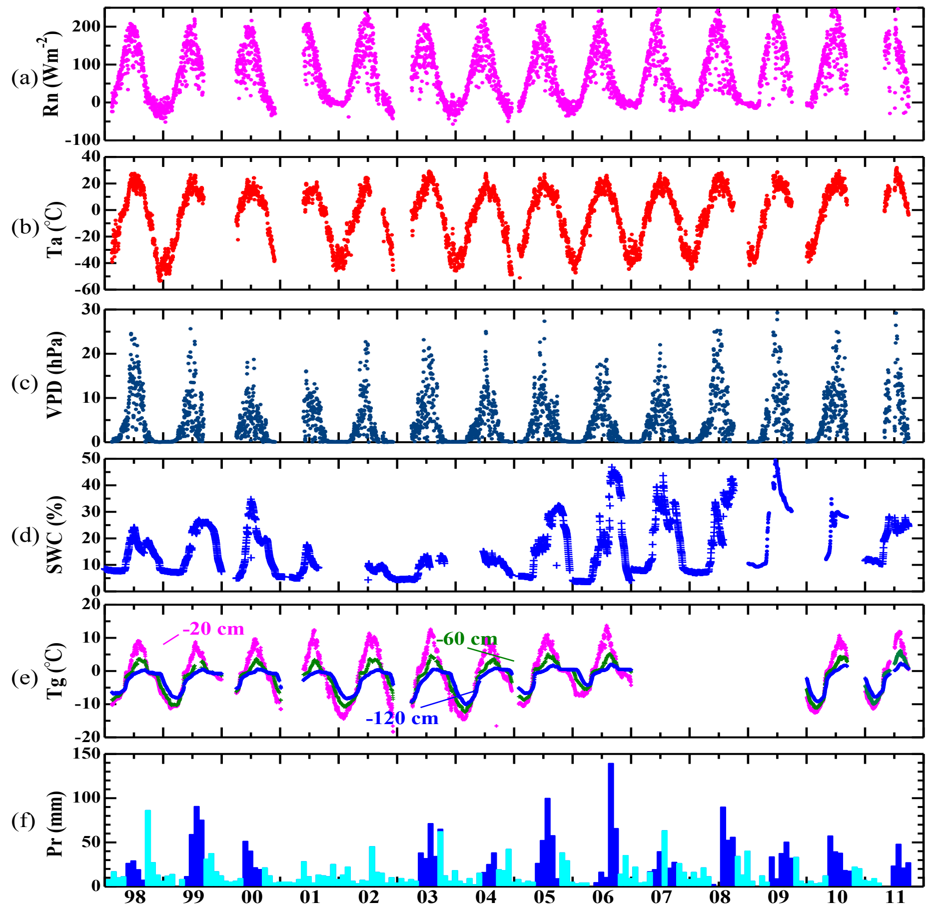

Figure 1. Daily mean values of (a) Rn, (b) Ta, (c) VPD, (d) SWC at 0–50-cm depth, and (e) Tg at 20-cm, 60-cm, and 120-cm depth, and monthly integrated values of (e) Pr. Black bars indicate monthly integrated values of Pr at the study site, and grey bars indicate corresponding monthly integrated values of Pr at Yakutsk.

3.2 Monthly mean variation in *Ev*, *Ep, and Ev/Ep*

Figure 2 shows the monthly mean values of *Ev*, *Ep*, and *Ev/Ep*. For June 2011, *Ev*, *Ep*, and *Ev/Ep* were treated as missing data. The monthly means of *Ev* and *Ep* were high in June and July. The monthly mean *Ev/Ep* was high in July and August. There were no clear changes in the monthly mean *Ev* and *Ep*, but they gradually increased during 2004–2005 and 2007–2009 and gently decreased during 2005–2007 and 2009–2011. The monthly mean *Ev/Ep* increased during 2005–2006 and then decreased from 2009.

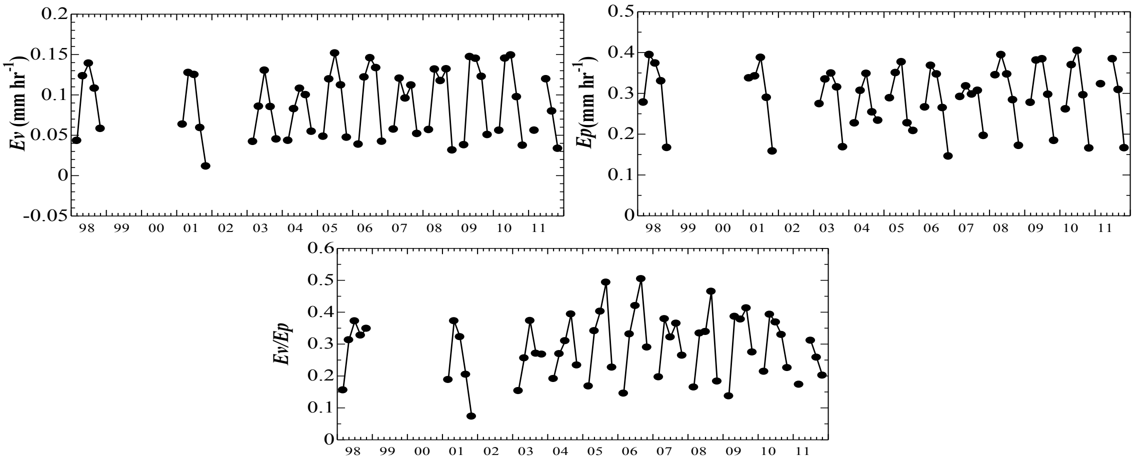

Figure 2. Monthly mean values of Ev (left upper), Ep (right upper), and Ev/Ep (lower).

3.3 Relationships between environmental variables and G_S

Figure 3 shows the relationships between the environmental variables and G_S. There was no relationship between *Sd* and G_S. In the period from 1998 to 2011, strong negative correlations were found between *Ta* and G_S and between *VPD* and G_S. Strong positive correlations between *SWC* and G_S were found in the period from 1998 to 2006 and during 2007–2011. *SWC* values were higher during 2007–2011 than during 1998–2006, and G_S decreased during 2007–2011. The relationships between *Ta and* G_S and *VPD and* G_S can be described each 1 lines. The relationships between *SWC* and G_S can be described the 2 lines. This suggests that extremely wet soil in recent years may have inflicted unrecoverable damage on larch trees. We found that G_S decreased from 2007, whereas Ito *et al*. (2012) reported that *GPP* decreased from 2008 in the same larch forest. The cause of the 1-year time lag is unknown.

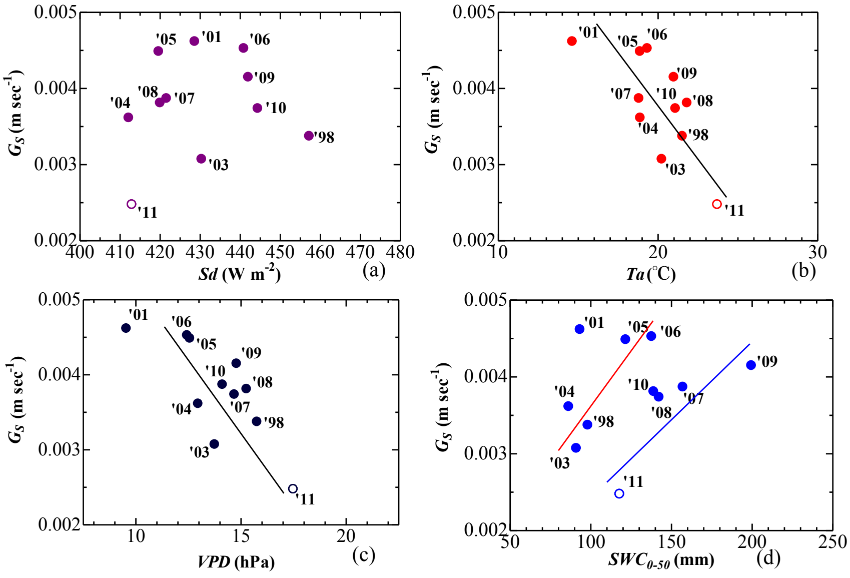

Figure 3. Relationships between G_S and the June, July, and August (JJA) means of environmental variables (a) Sd, (b) Ta, (c) VPD, and (d) SWC at 0–50-cm depth. Open circles indicate the relationships between July and August mean environmental variables and G_S.

3.4 Relationships between *SWC* and *Ev/Ep*

Figure 4 shows the relationships between *SWC* and *Ev/Ep*. Strong positive correlations between *SWC* and *Ev*/*Ep* were found during 1998–2006 and 2007–2011. *SWC* values were higher during 2007–20011 than during 1998–2006, and *Ev*/*Ep* decreased during 2007–2011. This result suggests that, similar to the case of *SWC* and *Ev*, extremely wet soil inflicted unrecoverable damage on larch trees.

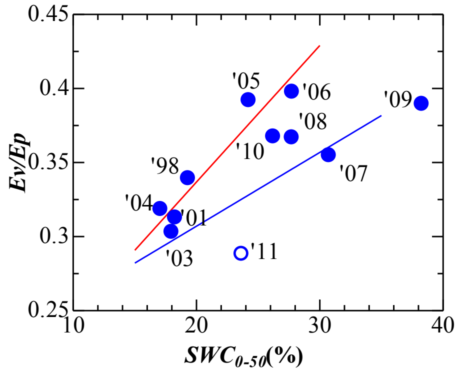

Figure 4. Relationships between the JJA mean SWC at 0–5-cm depth and Ev/Ep. Open circles indicate the relationships between the July and August means of SWC and Ev/Ep.

4. Conclusions

We examined interannual variation in evapotranspiration using eddy-covariance measurements and relationships between environmental variables (*Rn*, *Sd*, *Ta*, *VPD*, *SWC*) and surface conductance, *SWC*, and the evapotranspiration coefficient over the 11-year period from 1998 to 2011. Extremely wet soil conditions have occurred in recent years, and correlations of *SWC* with G_S and *Ev/Ep* changed between the periods 1998–2006 and 2007–2011. It is thus conceivable that the responses of G_S and *Ev/Ep* to *SWC* have also changed in recent years. There was the 1 year time lag between evapotranspiration and photosynthesis. Soil moisture began to increase during 2004–2005, and changes in the correlations between *SWC* and G_S and *Ev/Ep* were found in 2007. During this 2- to 3-year period, impacts on larch trees may have occurred.

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Comparison of CO_2 flux between two sites (SpasskayaPad, Elgeeii) in eastern Siberian boreal forest

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Key words: NEE (Net Ecosystem Exchange), photosynthesis, photoresponse property

Introduction

Carbon exchange from the huge area covered by the eastern Siberian boreal forest has an important effect on the global carbon cycle. Dolman et al. (2004) reported on the seasonal variation in net ecosystem exchange (NEE) at an eastern Siberian larch forest site (Spasskaya Pad) and found that uptake was strongest in June, and then declined. However, climate, vegetation, and other conditions vary throughout the eastern boreal forest. Hence, measurement at one point is not sufficient to understand carbon exchange in the eastern boreal forest as a whole. A comparison of CO_2 flux between several sites in the same climate region would strengthen our understanding of the factors influencing carbon exchange in the forest. Elgeeii, which is also located in the eastern Siberian boreal forest, is characterized by more precipitation and higher soil water content than Spasskaya Pad. Thus, a comparison of CO_2 flux between Spasskaya Pad and Elgeeii would highlight the difference in carbon exchange by location and other factors influencing carbon exchange in the forest. In this study, we compared CO_2 flux at these two eastern Siberian forest sites and investigated factors explaining the difference in CO_2 flux between the two locations.

Methods

Spasskaya Pad is located in the middle reaches of the Lena River in eastern Siberia (62°15′18”N, 129°14′29”E). Elgeeii is located on the Aldan River (a branch of the Lena River; 60°00′56”N, 133°49′28”E). We established the Elgeeii site in 2009 to compare it to Spasskaya Pad, as Elgeeii receives more precipitation and has higher soil water content and a greater amount of aboveground biomass than does Spasskaya Pad. The dominant tree species are larch (*Larix cajanderi*) and birch (*Betula pendula*), and the dominant understory vegetation is cowberry (*Vaccinium vitis-idaea*) at both sites. In 2011, plant area index (PAI) was 1.4 and 1.98, and stand basal area was 24.1m^2 ha^{-1} and 35.3 m^2 ha^{-1} at Spasskaya Pad and Elgeeii, respectively. A meteorological observation tower was set up in Spasskaya Pad in 1996. Meteorological factors have been measured every 30 min since 1998, and CO_2 fluxes have been measured above the canopy since 2003, using an open-path eddy correlation method. A meteorological observation tower in Elgeeii was set up in 2009, and the same measurements have been made since August 2009.

We analyzed CO_2 flux data and air temperature (Ta), photosynthetically active radiation (PAR), vapor pressure deficit (VPD), precipitation (Pr), soil temperature (Tg), and soil water content (SWC) at the two sites from 2009 to 2011.

NEE of CO_2 was separated into ecosystem respiration (RE) and gross photosynthetic productivity (GPP). Daytime (PAR > 0 μmol m^{-2} s^{-1}) RE was calculated by applying an empirical equation between nighttime (PAR = 0 μmol m^{-2} s^{-1}) RE (i.e., nighttime NEE) and temperature (e.g., Falge et al., 2001; Wang et al., 2004). GPP was calculated as the sum of net ecosystem production (NEP = −NEE) and RE. We used active time NEE (9:00–15:30), nighttime RE (PAR = 0 μmol m^{-2} s^{-1}), and GPP (PAR > 0 μmol m^{-2} s^{-1}) to analyze the observed data.

Thus, this study examined the relationship between meteorological factors and CO_2 flux, as measured by the eddy covariance system, at the two sites from 2009 to 2011.

Results and Discussion

Temporal variation in meteorological factors

Figure 1 shows the temporal variation in meteorological factors (Ta, PAR, VPD, Pr, Tg, and SWC) as a monthly average. In June 2011, all environmental variables except PAR and Pr in Spasskaya Pad were treated as missing data.

No significant difference in PAR, Pr, and Tg was observed between the two sites. In 2009 and 2010, the sites did not differ significantly in Ta and VPD, but in 2011 Ta and VPD were higher at Spasskaya Pad than at Elgeeii. Moreover, SWC was usually higher at Elgeeii than at Spasskaya Pad over the observation period. In all, with the exception of SWC, meteorological factors at the two sites did not differ significantly.

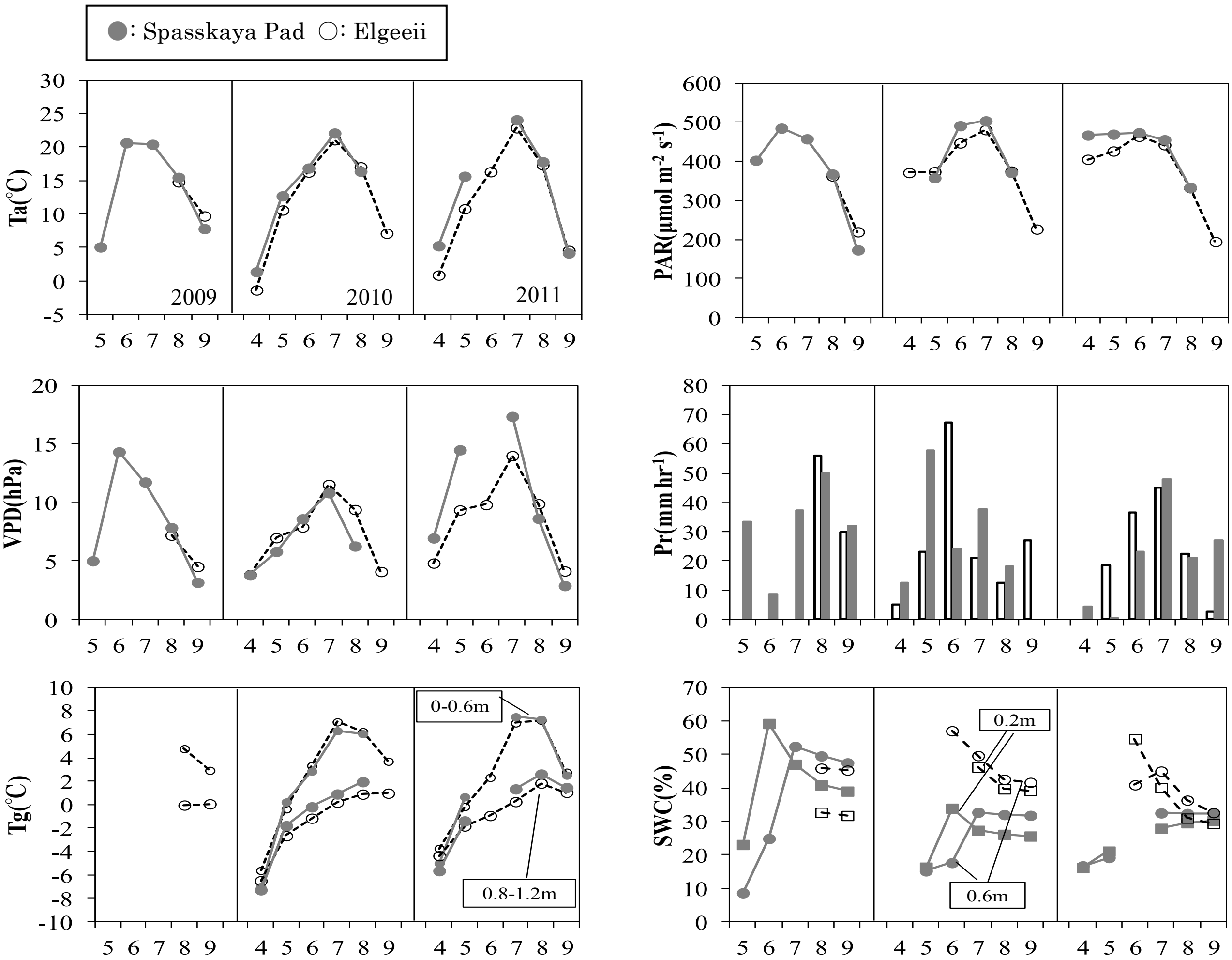

Figure 1. Temporal variation of monthly averaged Ta(left top), PAR(right top), VPD(left middle), Pr(right middle), Tg(left bottom), and SWC(right bottom) over the period from 2009 to 2011.

Temporal variation in CO_2 flux

Figure 2 shows the temporal variation in CO_2 flux (NEE, RE, and GPP) as a monthly average. Net uptake was greatest in June, and then declined from July to September. The seasonal variation in NEE was consistent with that found by Dolman et al. (2004). The difference between the two sites was greater in June and July, NEE being lower at Elgeeii than at Spasskaya Pad. RE gradually increased from May to July, reaching a maximum in July, and then gradually decreased. RE was higher at Elgeeii than at Spasskaya Pad. GPP abruptly increased between May and June, was higher in June and July, and then gradually decreased. GPP was higher at Elgeeii than at Spasskaya Pad. These results indicate that Elgeeii has a greater amount of CO_2 assimilation and release than does Spasskaya Pad.

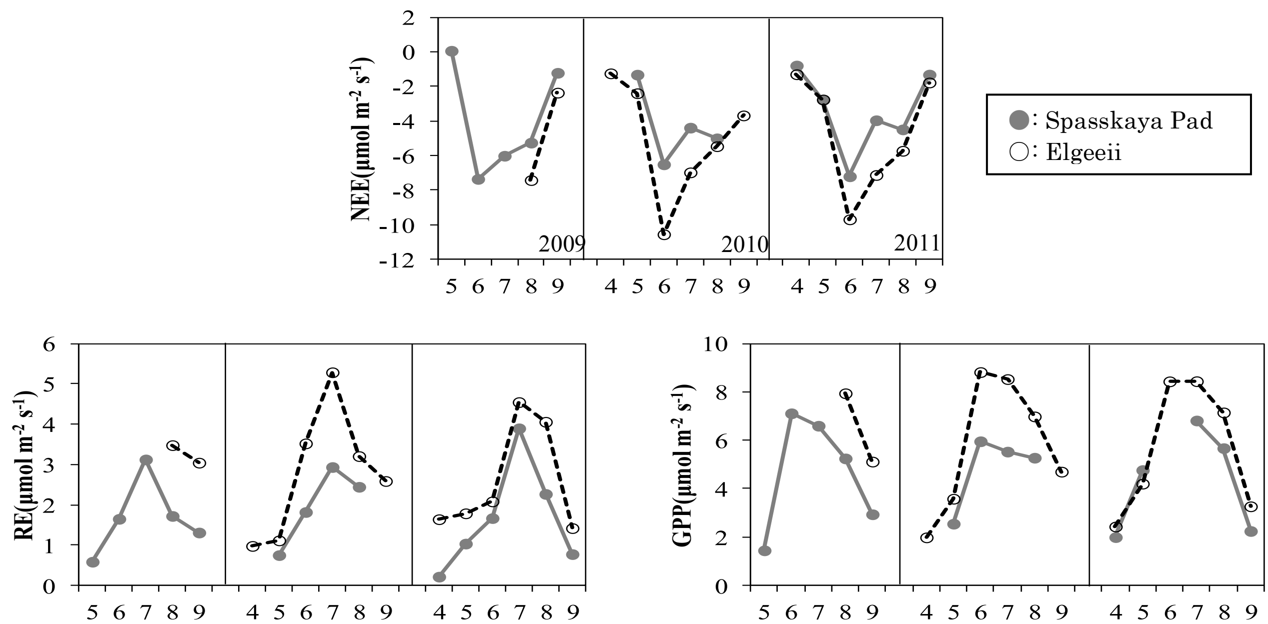

Figure 2. Temporal variation of monthly averaged NEE (active time)(upper), RE(night time)(left lower), and GPP(daytime)(right lower) over the period from 2009 to 2011.

Relationship between CO_2 flux and meteorological factor

First, we examined the relationship between RE and GPP and meteorological factors. The relationships between RE and Ta, Tg, and SWC and between GPP and Ta, VPD, Tg, and SWC were analyzed for each site. Although these relationships differed between the two sites, meteorological factors might not explain the difference in CO_2 flux. Consequently, we examined the relationship between RE and GPP divided by PAI and meteorological factors (Fig. 3). As a result, we could express these multiple relationships as one relationship. By considering PAI, we found the responses of CO_2 flux per unit plant area to meteorological factors to be consistent between the two sites.

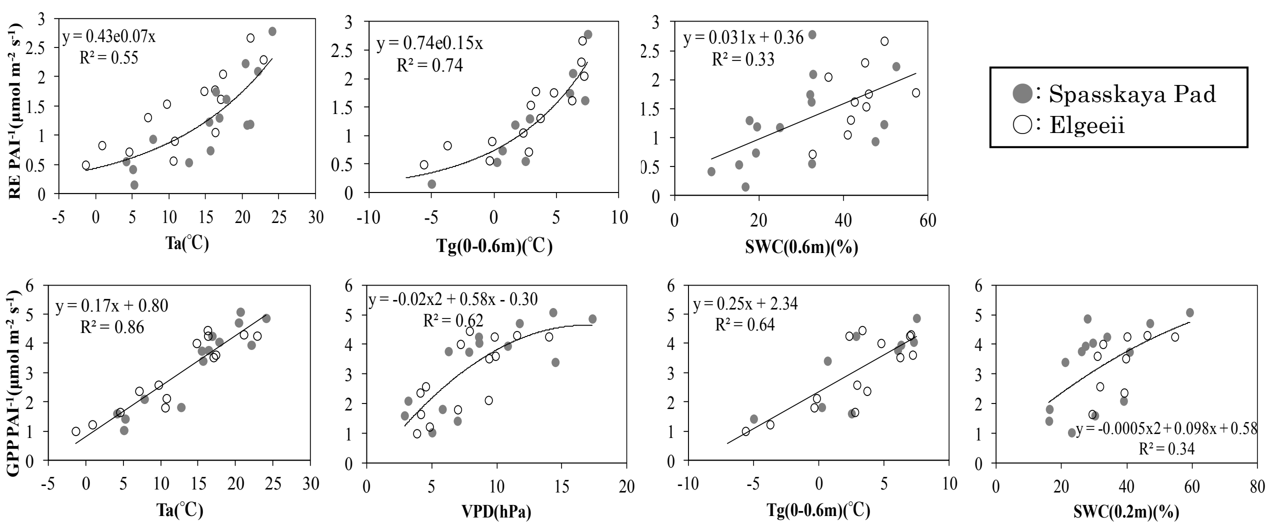

Figure 3. The relationship between meteorological factor (Ta, Tg at 0-0.6m depth, and SWC at 0.6m depth) and RE PAI^{-1} (upper). The relationship between meteorological factor (Ta, VPD, Tg at 0-0.6m depth, and SWC at 0.6m depth) and GPP PAI^{-1}(lower). Each pointer presents monthly average.

Conclusions

Our comparison of two sites (Spasskaya Pad and Elgeeii) in the same climate zone found that SWC was higher at Elgeeii than at Spasskaya Pad, and the amount of aboveground biomass at Elgeeii was larger than that at Spasskaya Pad. Meteorological factors, except SWC, did not differ significantly. Our comparison of CO_2 flux at the two sites found that NEE at Elgeeii was less than that at Spasskaya Pad, and RE and GPP at Elgeeii were greater than at Spasskaya Pad. We examined the relationship between RE and GPP and meteorological factors to understand factors influencing the CO_2 flux difference between the two sites. We found that by considering PAI, the responses of CO_2 flux per unit plant area to meteorological factors became consistent between the two sites. Hence, the amount of aboveground biomass may be the most influential factor in carbon exchange.

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CH_4 flux and its stable isotope ratios in a taiga-tundra ecotone of East Siberia

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Key words: CH_4 flux, East Siberia, taiga-tundra ecotone, $\delta^{13}C$-CH_4, δD-CH_4

Introduction

One of the major sources of CH_4 is natural wetland and CH_4 is partly absorbed into forest soil. Vegetation is used to classify ground surface to study the CH_4 flux between soil and the atmosphere (*van Huissteden et al., 2005; Flessa et al., 2008*). Vegetation generally reflects soil moisture and temperature, and is also known to affect CH_4 flux directly by providing organic matter into soil and by being a conduit for CH_4 emission in case of vascular plants (*Whiting & Chanton, 1993; Joabsson & Christensen, 2001*). Wetland is broadly distributed in the Arctic (*Aselmann & Crutzen, 1989*) and taiga-tundra ecotone (low and high shrub tundra) also covers significant area in the region (*Kaplan & New, 2006*). The vegetation in the taiga-tundra ecotone might be changed by enhanced warming in the Arctic (*Walker et al., 2006*) and also by change in precipitation and in permafrost. As a result, CH_4 flux can also be changed, which is a strong greenhouse gas. In order to estimate CH_4 emission from a region in the taiga-tundra ecotone, it might be necessary to observe CH_4 flux across the boundary from tundra to taiga. In East Siberia CH_4 flux has not been observed from this view point. The objective of this study is (1) to observe CH_4 flux at each vegetation landscape of a taiga-tundra ecotone in East Siberia, (2) to clarify the process of CH_4 emission using stable isotopes, and (3) to know controls of CH_4 flux in the ecosystem.

Site and methods

We set 4 new observation sites with different vegetation in the taiga-tundra boundary of Indigirka lowland near Chokurdakh (70.62N, 147.90E), Russia and observed CH_4 flux by closed chamber method in Jul 2009-2011. The region has a typical tundra station Kytalyk, where CH_4 flux has been observed since 2004 (*van Huissteden et al., 2005*). Our new sites are denoted as V (taiga-like), K (typical boundary), B (tundra-like), which are abbreviations of Verkhniy Khatistakh (70.25N, 147.47E), Kryvaya (70.56N, 148.26E), and Boydom (70.64N, 148.16E). There distributed patches of tree mound areas with larch trees and with moss cover (e.g. *Sphagnum spp.*) and relatively low wet areas with tussocks (typically *Carex spp.*) water-logged usually. K site had a wet area with dead larches without mounds, where vegetation succession seemed to occur. The ground was covered with *Sphagnum spp.* but small hollows with sedge could be seen as well. East Siberia has the most well-developed permafrost and the thaw depth was ca. 15-40 cm at these observation points. In addition we set site F (floodplain; 70.64N, 148.05E) in 2010. Along with flux observation, we measured oxidation reduction potential (ORP), soil temperature, soil moisture, and thaw depth as potential controls of CH_4 flux. In 2011 we measured CH_4 concentration in surface water and in soil pore (at ca. 15 cm) of wet areas. $\delta^{13}C$ and δD of these dissolved CH_4 and emitted CH_4 were analyzed to clarify the production, transport, and oxidation process. GC-FID was used to analyze CH_4 concentration and GC/GC/C(TC)/IRMS for $\delta^{13}C$-CH_4 and δD-CH_4.

Results and Discussion

The observed CH_4 flux was -0.38~7.4 mgC m^{-2} h^{-1} and differed among vegetation types (Table 1). Tree mounds and river terrace (F site) had drier soil with relatively higher ORP than wet areas and the CH_4 flux was very small (-0.38~0.05 mgC m^{-2} h^{-1}). On the other hand at V, B carex wet area, large emission was observed (0.05~7.4 mgC m^{-2} h^{-1}). At K wet area with dead larch (flat sphagnum cover or carex hollow) CH_4 emission was moderate (0.10~2.2 mgC m^{-2} h^{-1}). CH_4 flux didn't correspond to CH_4 concentration in surface water, suggesting that the contribution of CH_4 diffusion throughout the surface water is small and that CH_4 could be emitted from the soil through vascular plants. CH_4 flux was positively correlated with CH_4 concentration in soil pore (ca. 15 cm depth) except for K carex wet area. CH_4 flux at K carex wet area, however, was almost constant and had no correlation with CH_4 concentration in soil pore. When the soil temperature (10 cm depth) was high at wet areas, CH_4 flux was also large. In 2011, when the water level of the river system was remarkably high and the soil was wet, the largest CH_4 flux (Table 1) and low ORP were observed. In that year site F was under the river water even in the end of July.

Table 1. Averaged CH_4 flux observed at each vegetation type in 2009-2011. K wet area (sphagnum or carex hollow) in 2011 means wet areas with dead larches, but in the other years K wet area includes wet area without any trees.

Year	V tree mound	V wet area (carex)	K tree mound	K wet area (sphagnum)	K wet area (carex)	B tree mound	B wet area (carex)	F terrace	F wet area
2009	ND	0.19	ND	0.02	0.60		4.1		
2010	ND	0.05	-0.04 ±0.09	0.03 ±0.02		ND	3.0 ±2.6	-0.23 ±0.23	0.19 ±0.04
2011	-0.04	5.1	ND	1.1±0.7	1.0±0.2	ND	4.9		

ND: Not Detected

Compared to δ ^{13}C of CH_4 in soil pore tends to be lower in higher latitudes (e.g. -83~-70 ‰ at Scotland 55N; *Waldron et al., 1999*), the observed δ ^{13}C values were extremely high (-59~-47 ‰), suggesting that the delta value was affected by diffusion or oxidation in the soil after its production. CH_4 transportation by diffusion is considered to change δ D-CH_4 and δ ^{13}C-CH_4 equally, but CH_4 oxidation changes δ D-CH_4 more than δ ^{13}C-CH_4 (*Chanton, 2005; Happell et al., 1994*). In δ D- δ ^{13}C plot for V carex wet area, not surface water CH_4 but soil pore CH_4 seems to be emitted with its δ values changed by diffusion, which supports the hypothesis that CH_4 was transported mainly by plants.

Conclusions

CH_4 flux was observed using chamber method in the taiga-tundra ecotone of Indigirka Lowland. To estimate CH_4 flux of the region, it might be necessary to consider not only tree mounds and sedge wet areas but also vegetation succession (K wet areas with dead larches), where CH_4 emission was moderate. CH_4 flux was large when the ORP was low and the soil temperature was high. If vegetation changes from tree mound to succession area, or from succession area to sedge wet area, regional CH_4 flux might increase and cause positive feedback on climate.

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Factors controlling C assimilation by larch in taiga-tundra boundary ecosystem in Eastern Siberia with special references on C and N contents and stable isotope ratios of larch needle

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Introduction

Eastern Siberia is covered by taiga forest, world's largest coniferous forest, which is dominated by larch (Sato et al. 2010), and this taiga forest exists on the permafrost (Iwasaki et al. 2010) which is also the largest and deepest in the world. Large amount of C is stored in the forest soil and permafrost, functioning as a global C reservoir. Thus, greenhouse gas emissions through C decomposition may play as a crucial role in global C dynamics (Zhang et al. 2011). Climate change due to greenhouse gas emission is expected to cause global mean temperature to increase by 1.0-3.5 ^{o}C in the next 50-100 years, and that in high-latitude region is expected to be much higher (IPCC, 2007). Therefore, amplified warming at high latitude may cause great changes of vegetation dynamics (Walker et al. 2006). Northern end of taiga forests is a boundary ecosystem between taiga forests and tundra. Therefore, there is a possibility that taiga-tundra boundary ecosystem will change into taiga or tundra. The taiga forests and tundra are totally different in greenhouse gas emission under warming climate. Taiga forests generally play as CO_2 source (Hollinger et al. 1998), while tundra ecosystem emits CH_4 (van Huissteden et al. 2005). Therefore, understanding the response of vegetation dynamics to warming climate is very important to predict C dynamics and consequent feedback process in the future.

Various environmental factors such as temperature, precipitation, soil moisture, growing season and soil nutrient control vegetation dynamics. One of the most important factors is soil moisture. The purpose of this research is to know the response of larch growth to the environment, which is important to know the future possible change of taiga-tundra boundary ecosystem. It is well accepted that plant growth at high latitude is N limited, and soil moisture would greatly affect decomposition and mineralization of soil organic matter, which plays an important role in soil N dynamics. To observe larch growth and controlling factors, we observed photosynthesis, needle mass, nitrogen availability and proxies of stable isotope of C-13 and N-15, and soil N as well.

Observation and analysis

Observations were conducted at different sites in Chokurdakh (70^{0}37'N, 147^{0}53'E), Russia in July from 2008 to 2011. We selected four sites with different trees density. The trees are generally found growing on a mound where the topography level is higher than the surroundings. However, at one site, larch trees are growing not only on a mound but also in a wet area, where many dead trees are found. The trees growing on a tree mound and in a wet area are also compared to know effects of soil moisture on the larch growth dynamics.

The selected trees were labeled at each site in 2009 and observed every summer from 2009 to 2011. The diurnal changes of photosynthesis were measured on July 21st-22nd, 2011 using a portable LCA-4 photosynthesis system (Analytical Development Co., ADC, UK). The intact stem removed of current year shoot was selected and the needles on short branch were measured under natural solar radiation, with 2 h interval for each cycle of measurement. After photosynthesis measurement, needle area was measured by software ImageJ. Annually, the needles were sampled from marked trees and milled into powder, then dried in the oven at 60^{o}C for 48 h. Needle δ^{13}C, δ^{15}N and nitrogen content were then measured with isotope ratio mass spectrometer (Delta V PLUS, Thermo Electron) with element analyzer. To know soil N pool, the cubic soil in thaw depth was sampled in 2011 and soil NO_3^- and NH_4^+ were extracted by water and 2 M KCL solution, then filtered and analyzed with a continuous flow analyzer (Bran+Luebbe, Germany). For air temperature of Chokurdakh, NCEP/NCAR reanalysis data were used.

Results and Discussion

Photosynthetic rate linearly increased with Photosynthetically Available Radiation (PAR) and no light saturated photosynthetic rate was observed. However, photosynthetic rate was limited by high temperature more than 20 ^oC. Tree mound and tree wet area showed no differences in A_{max} (Maximum of photosynthetic rate). However, tree mound showed longer duration of A_{max} than wet area.

As for larch trees from various sites, N per needle area (N_{area}) was positively correlated with $\delta^{13}C$. This indicated that higher N_{area} accounted for higher A_{max} which contributing to higher $\delta^{13}C$. Interestingly, needle $\delta^{13}C$ was positively correlated with needle mass (dry weight per needle) not only among sites but also in year to year variation, which was possibly attributed to A_{max} that positively accounted for both $\delta^{13}C$ and needle mass. Furthermore, needle mass was positively correlated with needle area (foliar area per needle) and needle N (nitrogen amount per needle). Therefore, among the sites, the high N_{area} contributed to high A_{max} and larger needle area which accounted for large needle mass and high needle nitrogen. More interestingly among the sites, the site with larger needle mass still showed higher tree height and larger DBH (diameter at breast height) and higher tree density of larch stands, which indicated that N_{area} accounted for biomass of individual tree and larch stand among the sites.

Sites differences in larch N_{area} was attributed to soil N dynamics. Tree mound showed higher N_{area} than tree wet area. Interestingly, tree mound was higher in the pool of available soil NH_4^+ but lower in soil moisture than tree wet area. Attention should be paid that soil was extremely limited in NO_3^-. Therefore, the pool of available soil NH_4^+ accounted for sites differences in larch $N_{area,}$ which was influenced by soil moisture.

Larch N_{area} varied little in year to year variations. However, needle mass and needle $\delta^{13}C$ showed larger variations. Interestingly the year with high temperature in growing season showed low needle mass and needle $\delta^{13}C$. Higher temperature occurred with high solar radiation which could enhance A_{max}. However, A_{max} was possibly limited by high temperature and resulted in the decrease in needle mass and needle $\delta^{13}C$.

Conclusion

In lowland of the arctic in Eastern Siberia, N availability is one of the important controlling factors for larch growth. The trees growing at mound and wet area are different in needle mass and also in total biomass, suggesting that trees growth were influenced not only by soil moisture but also by soil N. In the past, trees growth was enhanced by high air temperature. However, in the future, the extremely high temperature will possibly limit C assimilation of the larch.

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Eco-hydrological changes in relation to permafrost degradation under humidified conditions in central Yakutia.

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Key words: transpiration, larch forest, sap flow, permafrost degradation

Introduction

High-latitude regions in the northern hemisphere have undergone unanticipated environmental changes during the past few decades. The most prominent feature appears in Arctic Ocean; that is dramatic reduction in sea ice extent in summer. Arctic surface air temperature and associated sea level pressure fields in relation to sea ice reduction have remarkably different spatial pattern at the beginning of the 21st century calling as "Arctic warm period" (Overland et al. 2008). Environmental changes in these regions have been substantially impacted by changes in the hydrological cycle, such as precipitation regime, snow distribution and duration, soil water storage, evapotranspiration and river discharge. The present study examines recent changes within the permafrost environment and evaluates the impact of these changes on boreal larch forests based on intensive hydro-meteorological observation after abrupt increases in depth and moisture within the active layer occurring during periods of wet climate at study sites in eastern Siberia.

Site and methods

Field studies were conducted in the Spasskaya-pad Experimental forest (62°15'N, 129°37', 220m a.s.l.) located approximately 20 km north of Yakutsk in the Republic of Sakha, Russia (Fig. 1). The site is located on the highest terrace of the left bank of the Lena River and is covered with a thin layer of Quaternary deposits consisting of alluvial deposits with low content of ice complex. The site is gentle north-facing slope, covered with pure and mixed stand of larch, birch, and pine forest.

We utilized intensive observational data since 1998 (Ohta et al., 2001, 2008) for detecting temporal and spatial variations in hydrothermal conditions in the central Lena River basin.

Soil temperature, soil moisture, and active layer thickness at Spasskayapad have been measured by the observational network near Yakutsk by Research Institute for Global Change (RIGC) and the Melnikov Permafrost Institute (MPI). Observations were made in the interval of twice a month during warm season (May to October) and once a month during winter (November to April) for soil temperature. Details are described in Iijima et al. (2010).

Soil thermal properties, such as heat conductivity and capacity were measured using portable thermal properties analyzer (KD2 Pro, Decagon Devices Inc.) in September both 2009 and 2010 at Spasskayapad. We measured at pine forest plot, larch forest tower plot, and a sloping waterlogged larch plot.

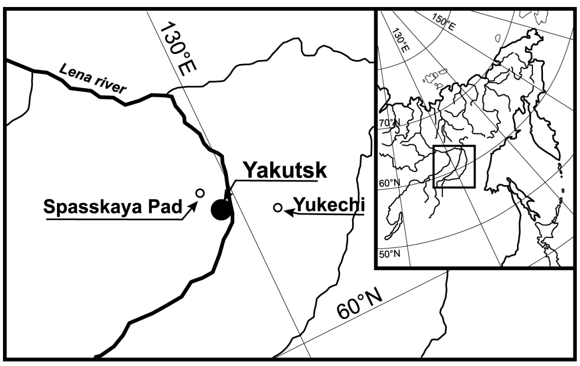

Figure 1. Location of research sites Spasskayapad near Yakutsk.

Long-term meteorological observation has been conducted since 1998 with a 32m boundary layer tower. Soil temperature and moisture within active layer have also been monitored nearby the tower. Soil temperature and moisture were measured using PT-100 Ohm temperature and Time Domain Reflectometry (TDR) probes (P2, IMKO), respectively. Measurements in the tower site were made every 10 seconds and data was recorded in 10 minutes averages on a datalogger (CR-10X, Campbell Scientific Inc.). Fifteen larch trees, representing the range in size of mature trees in the stand, were selected for sap flux measurements near the larch tower site at Spasskayapad. Grainer method sensors (cf. Granier et al., 1996) were used to measure sap flux density (g H_2O m^{-2} sap wood s^{-1}). Each sensor consisted of a pair of 20-mm-long, 2-mm-diameter probes inserted above one another in the sap wood 15 cm apart at a height of approximately 130 cm above ground level on the north-facing side of each tree. The upper probe was constantly heated by a 200 mV heater coil and temperature differences between the upper and lower probes were measured in order to calculate sap flux density.

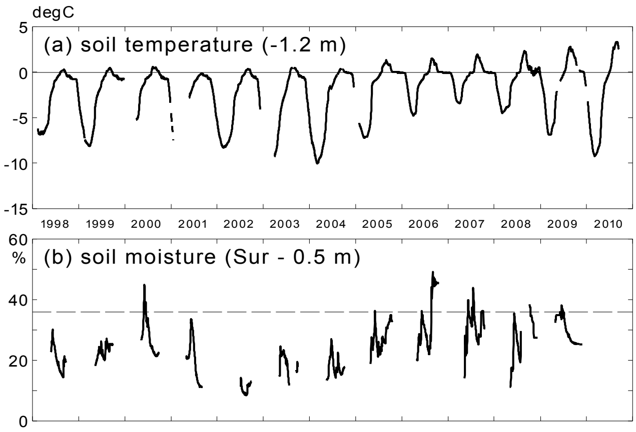

Figure 2. Interannual variations in (a) soil temperature at depth of 1.2 m and (b) volumetric content of soil moisture from surface to 0.5 m depth during the growing season, from 1998 to 2010. Broken line in (b) denotes soil porosity (36 %) observed by GAME-Siberia project.

Sap flow measurements were carried out during the growing season (May to September) in 2006 and 2009. Probes in each tree were replaced in April 2009 and moved to positions 5 to 10 cm removed from previous positions set in 2006 in order to avoid artificial reduction of sap flow surrounding the probes during long-term usage. Temperature differences of all sensors were logged every 10 s and stored as 10-min averages with a data logger (CR-10X, Campbell Scientific Inc.).

Results and Discussion

Figure 2 shows interannual variations in soil temperature and moisture within active layer from 1998 to 2010 at larch tower site, Spasskayapad. As described in Iijima et al. (2010), simultaneous increasing trends of soil temperature and moisture within the active layer were prominent after 2004 winter and lasting through 2010. It should be noted that the soil temperature increase at 1.2m depth was first seen during winter from 2004 to 2007. The increase during summer was subsequently apparent after 2005. Above-average snow accumulation during 2004 through 2007 which is more than 50 cm of maximum snow depth (Iijima et al. 2010) acted as effective insulator. Accordingly, cooling of the soil was reduced in winter.

During the last decade, atmospheric anomalies in Arctic may cause intensifying storm activities from summer to early winter in eastern Siberia. An anomalous increase in summer and winter precipitation after 2004 winter was observed in the central Lena River basin. In Yakutsk, total amount of precipitation from April to September was usually less than 130 mm during 1998 through 2004, whereas the amount exceeded more than 200 mm 2005 through 2007. Thus, the active layer was saturated during both snowmelt and late

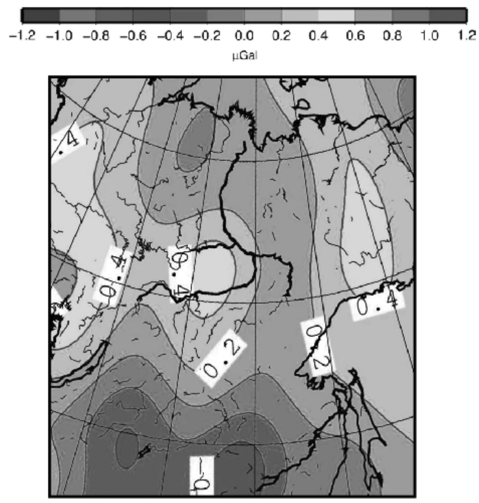

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Figure 3. Interannual trend of gravity change (uGal/yr) detected by GRACE satellite (2003-2008)

growing seasons 2005-2007. The measured soil moisture during snow melt and late growing season exceeded soil porosity 36%, broken line in Fig. 1b; by GAME-AAN data) in 2005-2007, indicating waterlogged conditions.

Vertical structure of averaged late-summer soil moisture showed remarkable difference before (2002-2004) and during (2005-2007) wet climate at Spasskayapad. The profiles exhibit steady increase in soil moisture within active layer from 2002-2004 to 2005-2007. At a mature larch stand nearby larch tower site (S1), active layer thickness (ALT) increased from 1.52 m (2002) to 1.67 m (2007). ALT At a pine stand at top of the hill with sandy soil (S3) was 1.92 m (2002) and 2.1 m (2007). Total increase amount was 215 mm at S1, 103 mm at S3.

The increased soil moisture likely favoured both warmer soil temperature and a deepening of the active layer. The increased soil moisture within active layer affected soil heat capacity and conductivity. The vertical distribution of soil thermal properties shows well-regulated variations at depth. In all sites, top 10 cm layer showed low heat conductivity having less than 0.5 W $m^{-1}K^{-1}$ due to the porous organic layer. The pine forest at the top of hill at Spasskayapad, which has dry sandy soil, showed low heat conductivity and capacity within mineral soil (>0.2 m). Higher conductivity (>0.7 W $m^{-1}K^{-1}$) was observed near the larch tower site with sandy loam soil. The highest heat conductivity (>1.0 W $m^{-1}K^{-1}$) and capacity (>2.0 MJ $m^{-3}K^{-1}$) at Spasskayapad were observed at the larch forest, which active layer was waterlogged after 2006. Iwasaki et al. (2010) also showed saturated soil moisture distributed in lower and flat surface in this larch forest.

Terrestrial water storage by the GRACE (Gravity Recovery Climate Experiment) satellite has identified an increasing interannual trend in the water storage of Siberian rivers from 2003 to 2008, with the largest increase noted in the central Lena River basin (Fig. 3). The water storage changes are linked to the development of closed- and open-talik in the continuous permafrost zone of the watersheds. (Muskett & Romanovsky 2009).

Figure 4a represents seasonal variations in daily totals of sap flow flux from 15 larch trees sampled in 2006 and 2009. Soil moisture was high but larch trees appeared normal in 2006, whereas active layer had been deepened with remaining saturated soil and leaf coverage had decreased markedly in 2009. The total amount of sap flux, presented as an average of 15 trees between July 15th and September 15th was 12% lower in 2009 (1780 kg H_2O) than in 2006 (2025 kg H_2O). Figure 4b shows mean sap flux of control (8) and damaged (7) trees in 2009 as classified by foliation in summer 2009. The control trees maintained active water uptake, having a greater daily amounts than average sap flux in 2006, which was likely due to favourable soil moisture conditions throughout the growing season. In contrast, damaged trees exhibited significant reduction with less than 20 kg day^{-1} in water uptake during the same period.

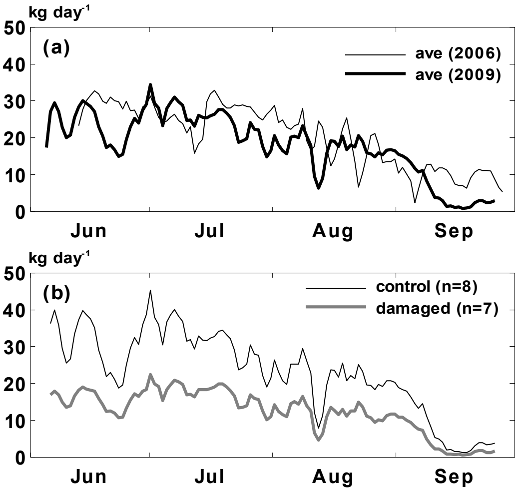

Figure 4. Seasonal variations in daily total sap flow flux (transpiration) of 3-days running mean from 15 larch trees. (a) Averages in 2006 (as denoted by the thin line) and 2009 (as denoted by the bold line) and (b) results from normal (n=8) and damaged (n=7) trees in 2009.

According to long-term eddy covariance observation above the canopy of the larch forest at this site growing season, evapotranspiration declined in 2007 and 2008 compared to levels observed in 2005 and 2006 (Ohta et al. unpubl.). The fact implies that our findings of changes in sap flux from individual trees can also be seen at the larger spatial scales. The central Lena River basin had large amounts of precipitation and forests could all be subject to the similar negative effects imposed by a saturated active layer. Reduction of evapotranspiration in spite of increasing in water storage under wet climate forces the active layer to retain moisture. This ecohydrological positive feedback processes likely lead to further enhancement of water storage within the active layer, causing permafrost degradation and, ultimately, the collapse of larch forests. Further attempt should be made to clarify the extent of reduction in transpiration from entire boreal forest in this region.

Conclusions

Atmospheric anomalies in Arctic may cause intensifying storm activities from summer to early winter (Iijima et al. 2010). An increase in summer and winter precipitation after 2004 winter was observed in the central Lena River basin. The increased precipitation resulted in warming and wetting of the active layer and near surface permafrost.

During this period, the larch forest at Spasskayapad was also damaged by the wet climate. The damaged (consequently dead) trees were distributed in the concave micro topography with deeper and oversaturated active layer. Sap flow measurement clearly showed a reduction of transpiration in damaged trees due to the lack of regular foliation.

In conclusion, the increased precipitation after 2004 winter resulted in high soil moisture content, which led to increased thermal conductivity in summer and a deeper active layer. Consequently, perennial waterlogged active layer could be recognized as a creeping trigger for permafrost degradation under wet climate. Enhanced thermokarst phenomena and larch forest mortality were unexpected eco-hydrological responses corresponding with the permafrost degradation in eastern Siberia.

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Identification of seesaw pattern in active layer thickness between Eurasian and North American watershed systems

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The spatiotemporal variations of active layer thickness (ALT) during 1948-2006 over the terrestrial Arctic regions experiencing climate changes are examined based on a simulation conducted by a coupled hydrological and biogeochemical model (CHANGE). The Ob, Yenisey, Lena, Yukon, and Mackenzie watersheds are foci of the study. ALT exhibited large spatial heterogeneity in the trend. Time series of ALT in Eurasian watersheds showed generally increasing trends, while ALT in North American watershed showed decreases. An opposition of ALT variations was most significant between Lena and Mackenzie watershed, resulting from the combined impact of climate and hydrological variables. Summer temperature represented by an Annual Thawing Index was a major influence on ALT of the two watersheds. However, the warming in air temperature was not simply related to the increase in ALT. Since the early 1980s when the Arctic air temperature entered into a warming phase, for example, the correlation of ALT and Annual Thawing Index in Mackenzie significantly decreased, while the influence of snow depth on ALT increased. In the Mackenzie watershed, both the late snow accumulation and the decreased storm events in the early snow season resulted in the shallower snow depth, which reduced soil warming due to weaker winter insulation. A recent atmospheric cooling in the early summer also contributed to the shallower ALT in the Mackenzie watershed. In contrast, the increasing Annual Thawing Index together with a relatively normal state of snow depth in the Lena contributed to the increase in ALT. It is widely believed that ALT will increase with global warming. However, this hypothesis was may need modification because the ALT has not responded primarily to the warming trend of air temperature, but also exhibits complex and inconsistent responses to variations in snow depth. The dependence of snow on atmospheric weather patterns further increases the uncertainty in the magnitude of the future snow changes. The Lena-Mackenzie seesaw pattern in ALT is examined in this context.

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Some abbreviations

IBPC: Institute for Biological Problems of Cryolithozone

IHIPN: Institute of the Humanities and the Indigenous Peoples of the North

JAMSTEC: Japan Agency for Marine Earth Science and Technology

NIES: National Institute for Environmental Studies

RIHN: Research Institute for Humanity and Nature

1st International Conference on “Global Warming and the Human-Nature Dimension in Siberia: Social Adaptation to the Changes of the Terrestrial Ecosystem, with an Emphasis on Water Environments”
6th Annual International WorkshopC/H2O/Energy balance and climate over boreal and arctic regions with special emphasis on eastern Eurasia

PROGRAM

Wed, 7 March

09:00 Registration
09:30 Opening ceremony
Takanori Nakano
(Program Director of RIHN)
(opening address)
Tetsuya Hiyama
(introducing objectives of the conference)

Session 1
Water and carbon budgets at plot scale
(chaired by Yuji Kodama)

09:50 **Trofim C. Maximov**
(keynote speech)
The main results of 20-year-old joint studies between Russia and Japan on a changing climate and permafrost in north-east Siberia, Russia

10:15 **Ayumi Kotani, Takeshi Ohta, Trofim C. Maximov**
Seasonal variation of linkage between net ecosystem exchange of H_2O and CO_2 over boreal forest at eastern Siberia

10:40 **Roman Petrov, Alexander V. Kononov, Trofim C. Maximov**
Key features of soil CO_2 efflux in taiga larch forests of central and south-eastern Yakutia

11:05 Break

11:20 **Yuji Kodama**
Snowmelt heat balance of the snowpack in a larch forest in eastern Siberia

11:45 **Takeshi Yamazaki**
Simulation of soil water and temperature in eastern Siberian taiga forests by a one-dimensional land-surface model

12:10 **Shunsuke Tei, Atsuko Sugimoto, Hitoshi Yonenobu, Trofim C. Maximov**
Changes in relationship between larch tree growth and climate in eastern Siberia over past 100 years

12:35 **Discussion**
13:00 Lunch and poster presentations

Session 2
Water and carbon cycles in regional-continental scale
(chaired by Eddy Moors)

14:00 **Eddy Moors**
(keynote speech)
Feedback mechanisms between the water and carbon cycle at a regional scale

14:25 **Kazuhiro Oshima, Tetsuya Hiyama**
Seasonal and interannual variations of the Lena River discharge and those relationships with atmospheric water cycle

14:50 **Tetsuzo Yasunari, Tatsuro Watanabe, Hatsuki Fujinami**
Interannual variation of summer hydro-climate in eastern Siberia

15:15 Break

15:30 **Atsuko Sugimoto**
Ecosystem function of taiga-tundra boundary in eastern Siberia

15:55 **Hisashi Sato**
Simulation study of the vegetation structure and function in eastern Siberian larch forests using the individual- based vegetation model SEIB-DGVM

16:20 **Discussion**, closure at 17:00

Thu, 8 March

Session 3
Permafrost degradation and greenhouse gases emission
(chaired by Jacobus (Ko) van Huissteden)

09:00 **I. Kleptsova, M. Glagolev, E. Lapshina, S. Maksyutov**
(keynote speech)
Landcover classification of the Great Vasyugan mire for estimation of methane emission

09:25 **A. Budishchev, Y. Mi, A. Gallagher, J. van Huissteden, G. Schaepman, A.J. Dolman, T.C. Maximov**
Validation of methane emission model using eddy covariance observations and footprint modeling

09:50 **Angela Gallagher, Bingxi Li, Artem Budishchev, Jacobus van Huissteden, Monique Heijmans**
Increased greenhouse gas emission from thaw ponds in Siberian arctic tundra on continuous permafrost

10:15 Break

10:30 **Jacobus (Ko) van Huissteden, Angela Gallagher, Artem Budishchev**
Ecosystem recovery: a neglected factor in carbon release by permafrost degradation

10:55 **Ake Nauta, Monique Heijmans, Daan Blok, Frank Berendse**
Removal of *Betula nana* causes permafrost degradation and triggers changes in geomorphology and hydrology

11:20 **Kazuki Aiba, Takahiro Sasai, Yasushi Yamaguchi**
Analysis of water, heat and carbon balances over the Siberia region by using biosphere model BEAMS

11:45 **Discussion**
12:15 Lunch and poster presentations

13:15 RIHN tour

Session 4
Permafrost landscape and groundwater regime
(chaired by Alexander Fedorov)

14:00 **Alexander Fedorov**
(keynote speech)
Permafrost landscapes response to recent climate changes in eastern Siberia

14:25 **Leonid Gagarin, Alexander Kolesnikov**
Effect of extreme hydroclimatic conditions on groundwater systems in permafrost, central Yakutia

14:50 **Tetsuya Hiyama, Kazuyoshi Asai, Alexander Kolesnikov, Leonid Gagarin,Victor Shepelev**
Residence time estimation of permafrost groundwater at Yakutsk region, eastern Siberia

15:15 Break

Session 5
Flood-induced hazards and benefits
(chaired by Hiroki Takakura)

15:30 **Hiroki Takakura** (keynote speech)
The local conceptualization of river ice thawing and the spring flooding of the Lena River under the global warming

15:55 **Toru Sakai, Tetsuya Hiyama, Junko Fujiwara, Semen Gotovtsev, Leonid Gagarin**
Flood disaster caused by permafrost degradation in the far north of Siberia

16:20 **Vanda Ignatyeva**
Regional problems of the reducing vulnerability to extreme floods and climate change: Yakutia case

16:45 **Junko Fujiwara**
Flood and migration policy in the Republic of Sakha

17:10 **Discussion**, closure at 17:45

Fri, 9 March

Session 6
Wild and domestic animals in sub-Arctic region
(chaired by Shirow Tatsuzawa)

09:00 **Innokentiy M. Okhlopkov**
(keynote speech)
Current Status of the wild reindeer populations and domestic reindeer farming in Sakha Republic

09:25 **Shirow Tatsuzawa, Innokentiy M. Okhlopkov, Egor V. Kirillin, Egor A. Nikolaev, Nikita G. Solomonov**
The migration of eastern Siberian wild reindeer: where, when, how and why do they do?

09:50 **Atsushi Yoshida**
Reindeer herding and environmental change in the Kobyai and Olenyok districts, Sakha Republic

10:15 **Atsushi Nakada**
Reindeer herding and environmental change in the Tompo district, Sakha Republic

10:40 Break

10:55 **Tohru Ikeda**
Furbearer hunting and invasive alien species issues in Yakutia

Session 7
Adaptation to climate change
(chaired by Susan A. Crate)

11:20 **Susan A. Crate** (keynote speech)
Water, water everywhere: perceptions of chaotic water regimes in northeastern Siberia, Russia

11:45 **Sardana Boyakova**
History of development of transport infrastructure in Yakutia

12:10 **Kyong Wan Lee**
Biblical suggestions of CSR in regard to energy projects in Lensk district, Republic of Sakha: focusing on climate and environmental problems

12:35 **Discussion**
13:00 Lunch and poster presentations
14:00 **General Discussion**

15:30 Closing ceremony
Tetsuya Hiyama
(concluding remarks)
Tsugihiro Watanabe
(Deputy Director-General of RIHN)
(closing address)

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