Permafrost-dominated Ecosystems in a Changing Climate

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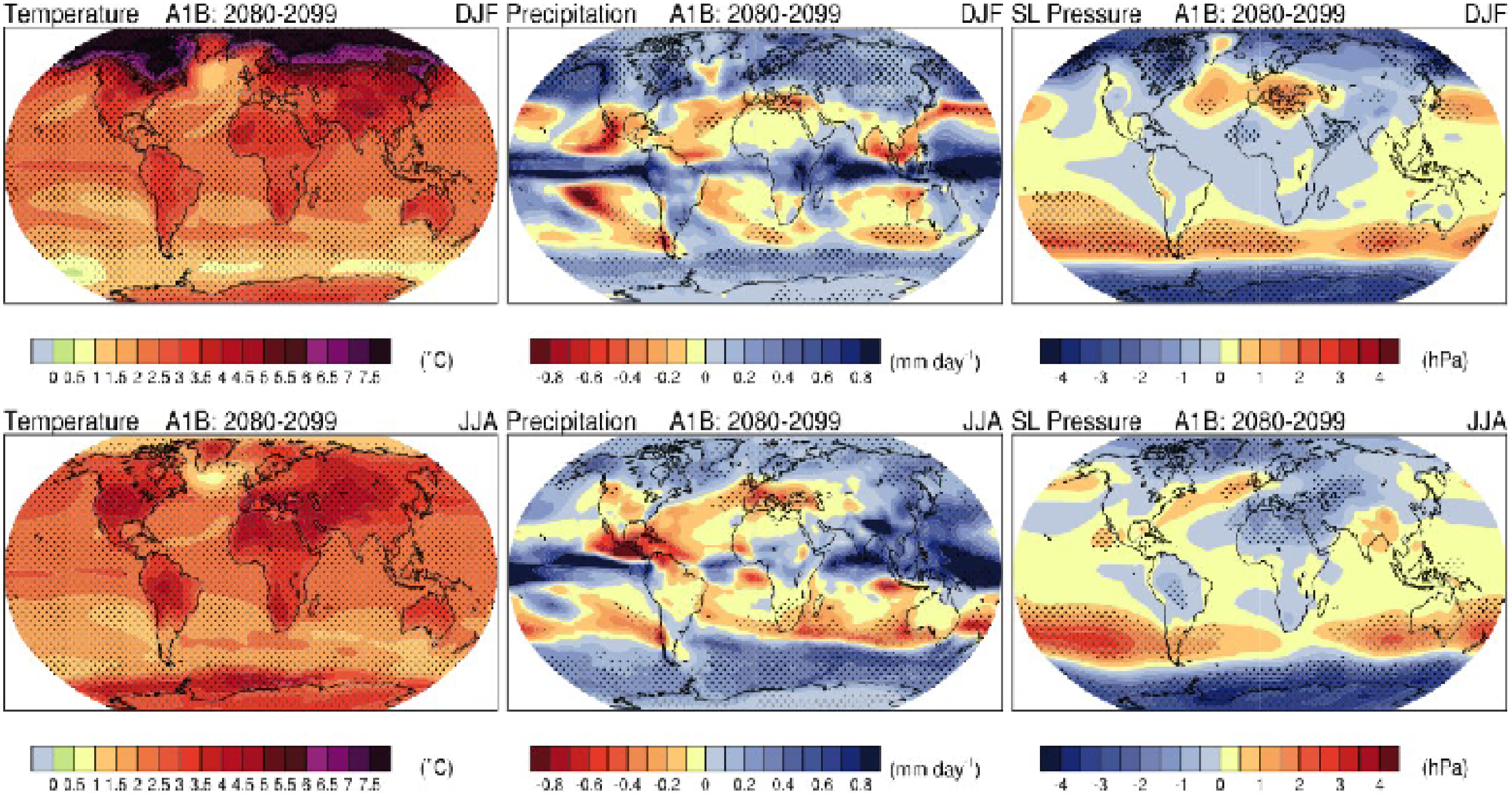
Outline

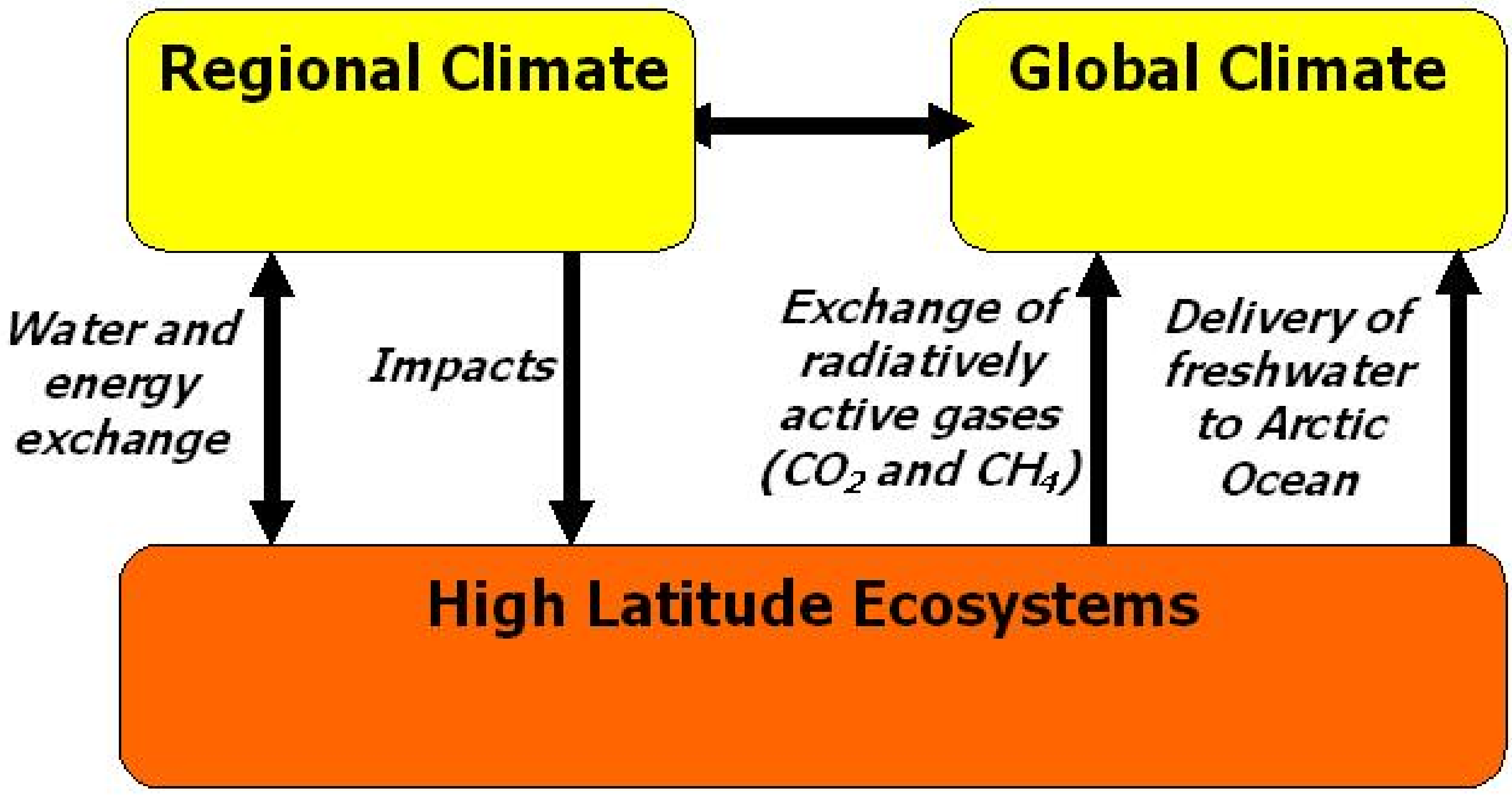
1. Overview of changing of climate
2. On infrastructure of experimental sites
3. Long-term obtained results (past, current, future)

Global warming strongest in the arctic



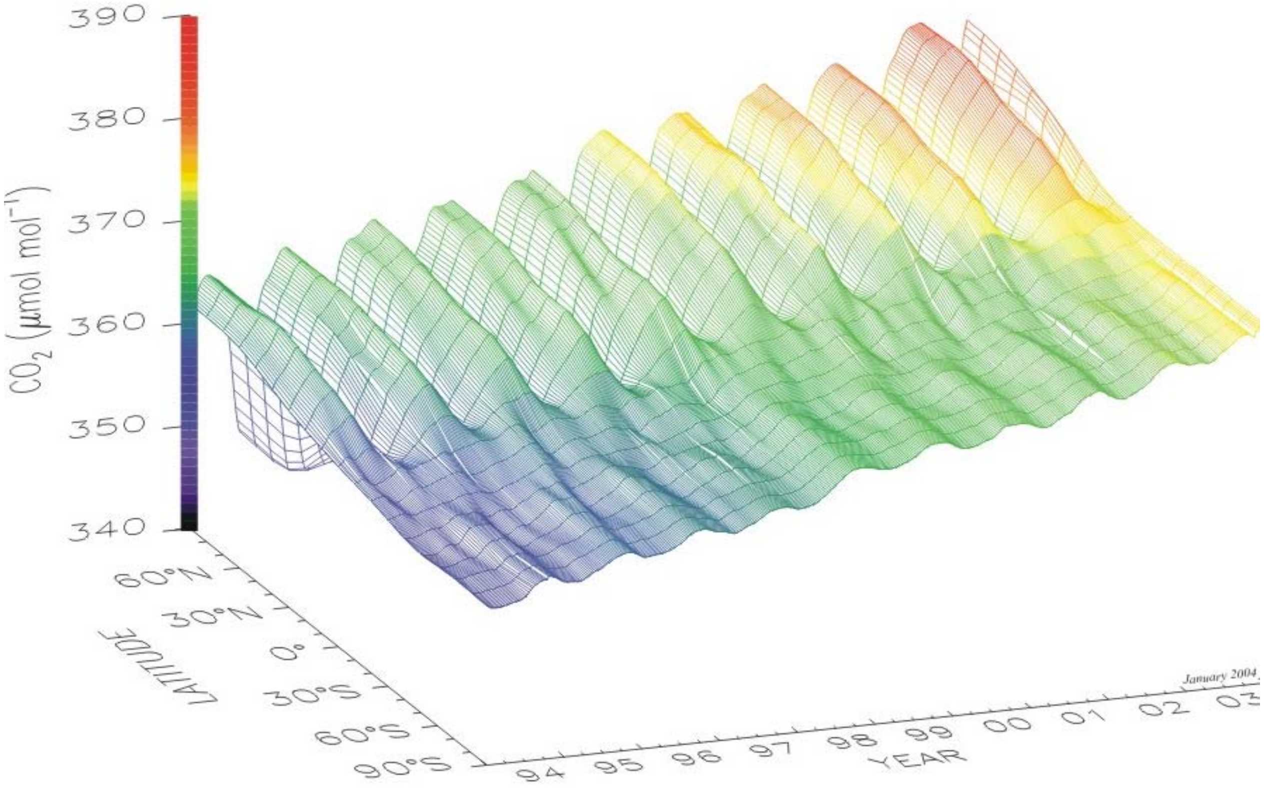
Strongly increased temperatures and precipitation
In particular in winter

The major pathways through which high latitude ecosystems may influence the climate system



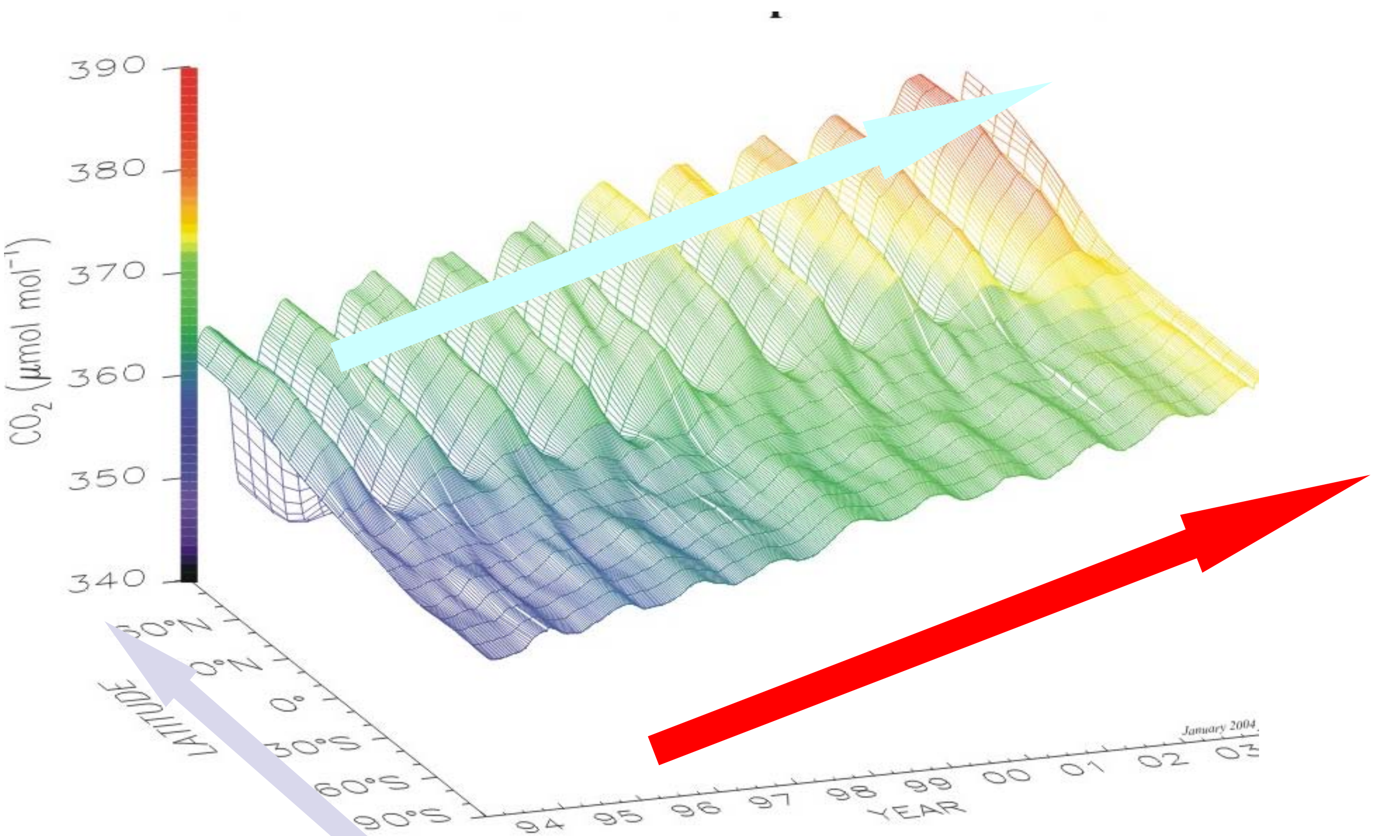
McGuire et al., 2005

Global distribution of atmospheric [CO_2]



Three dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigators: Pieter Tans and Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678 (pieter.tans@noaa.gov, http://www.cmdl.noaa.gov/ccgg).

Global distribution of atmospheric [CO_2]



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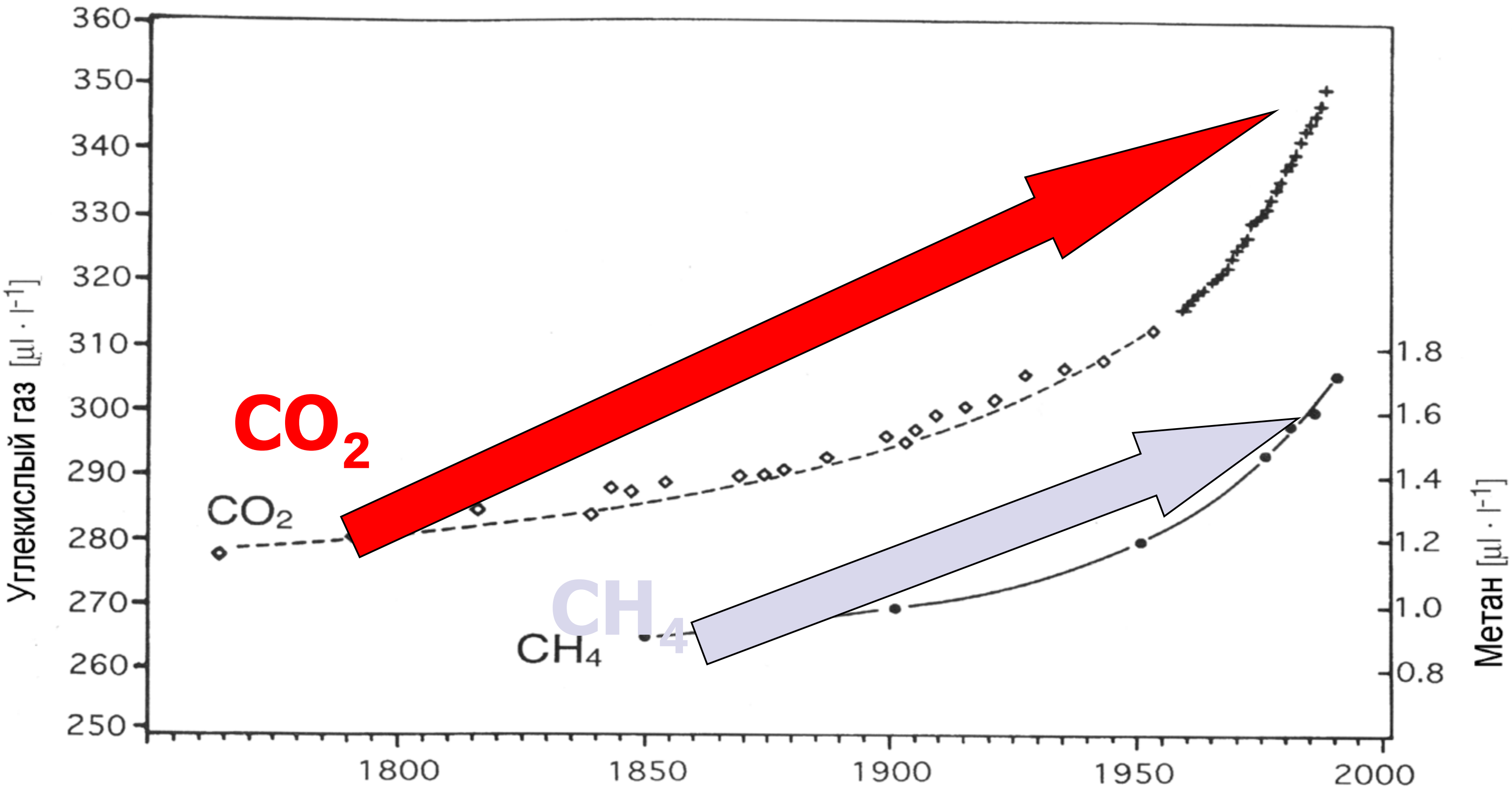
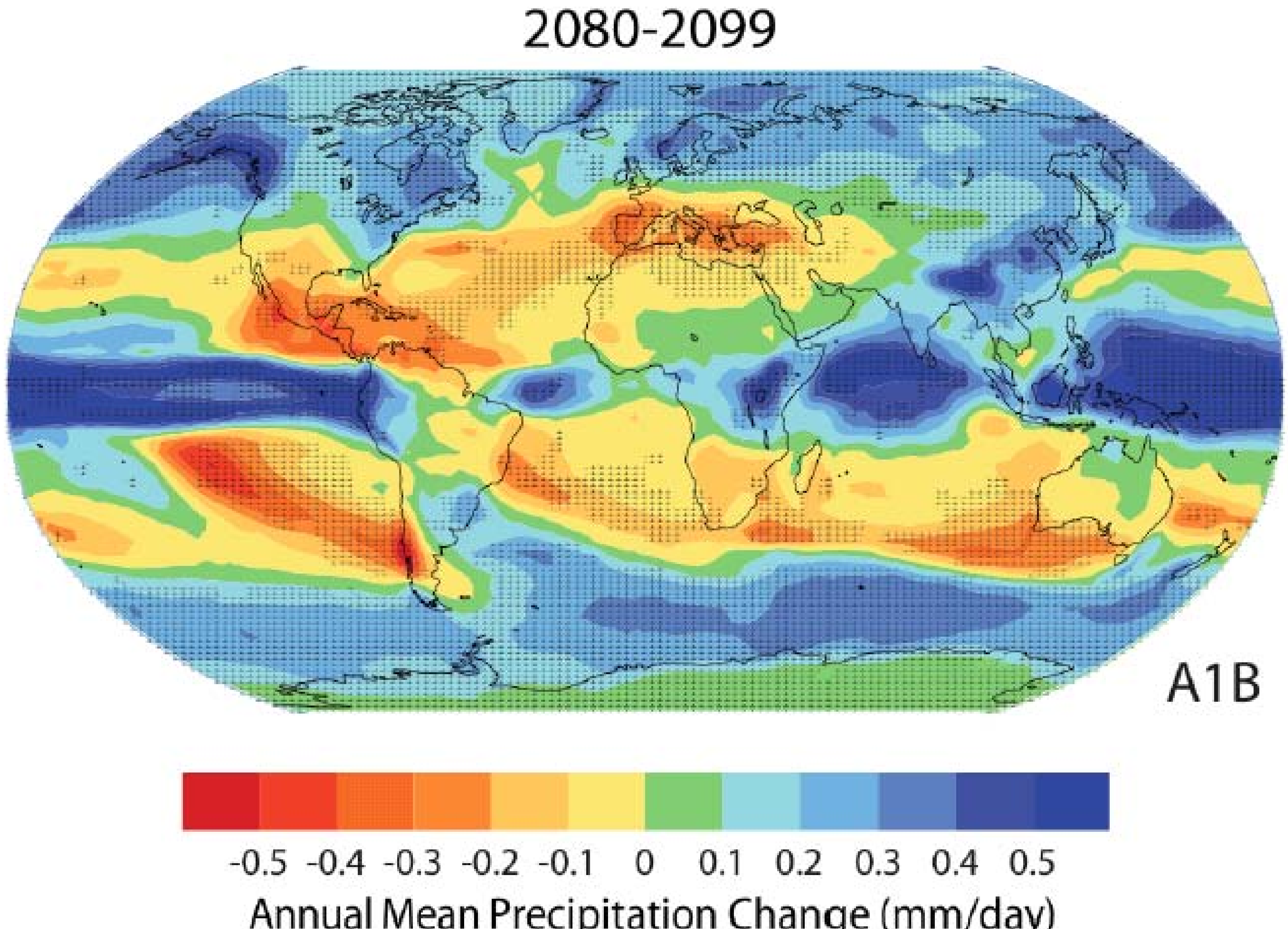
Increasing [CO_2] and [CH_4] in atmosphere from XVIII century



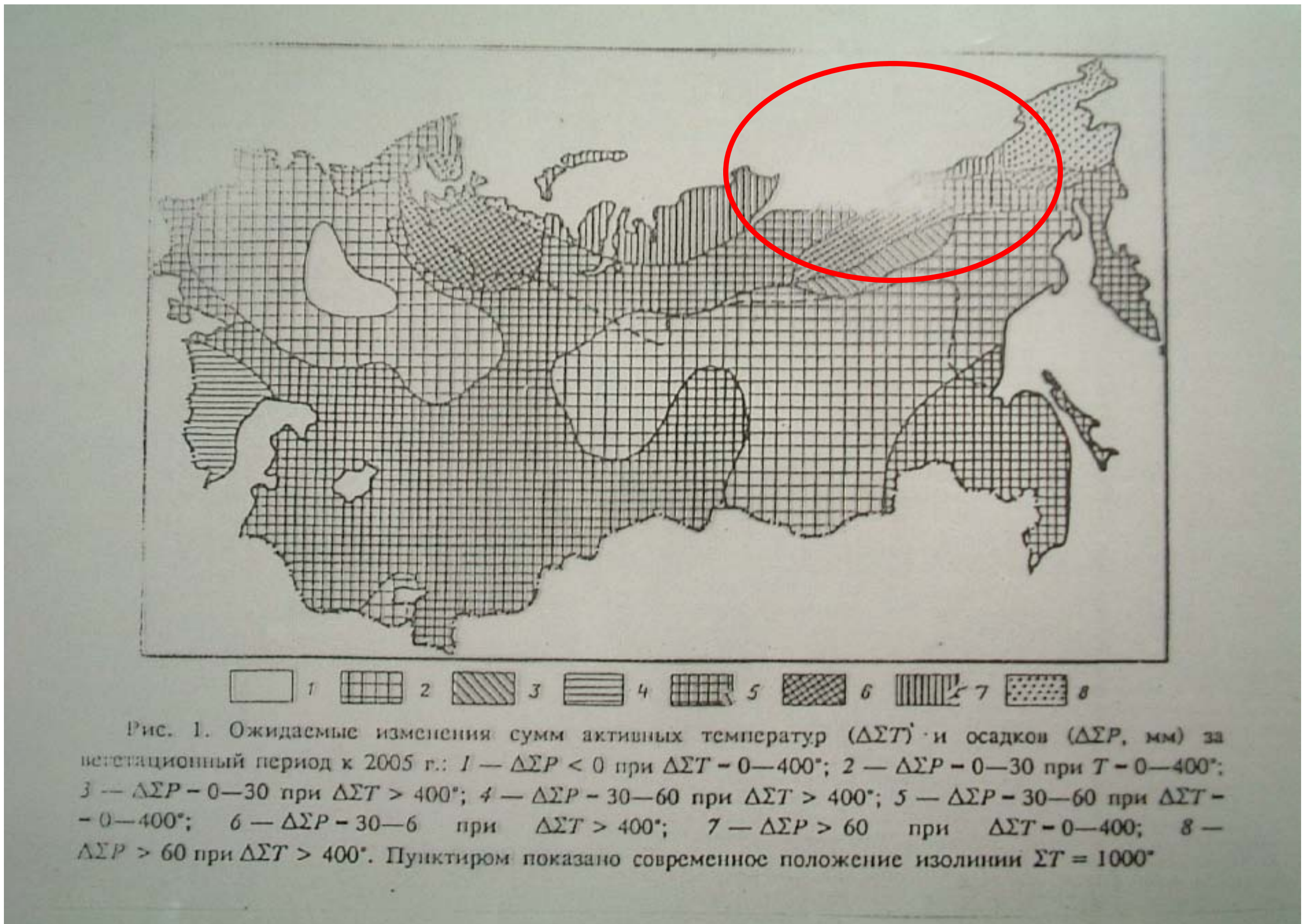
Увеличение концентрации CO2 и метана в атмосфере с 18-го века.

(По Keeling et al., from IGBP 1990 and WMO 1990)

More rain or less rain? (IPCC Report)

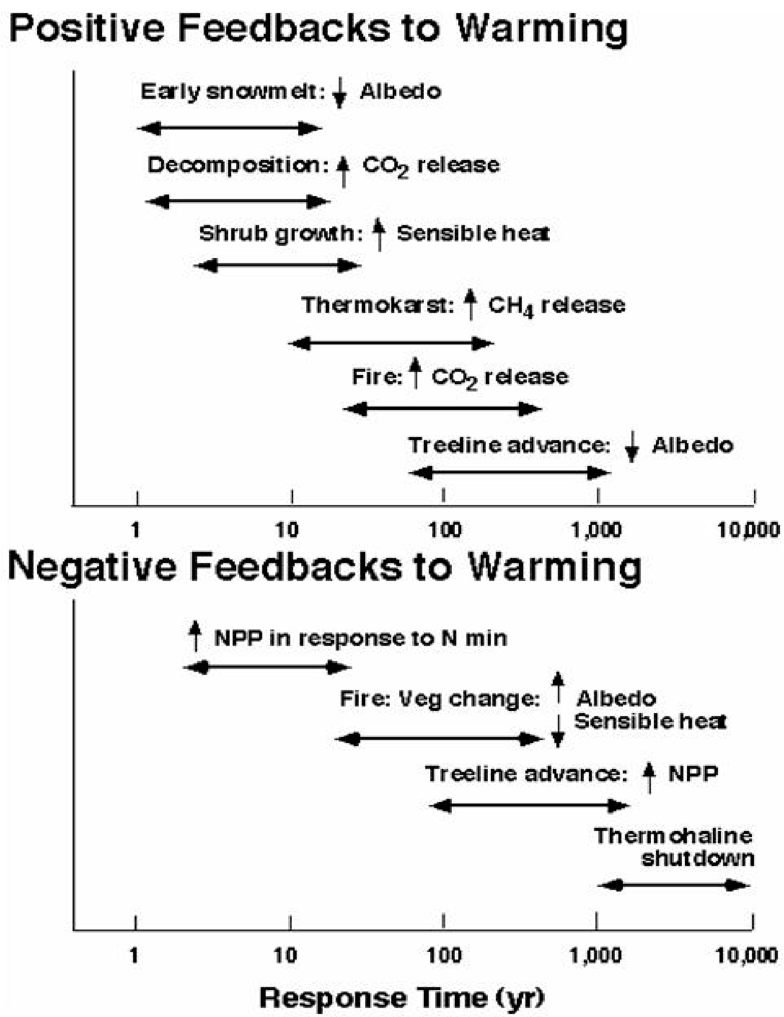


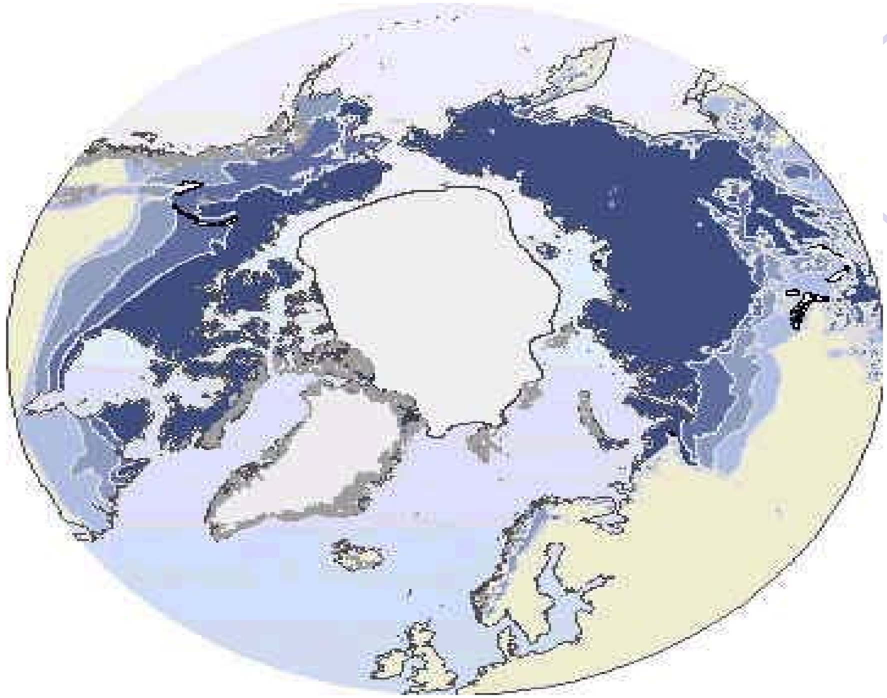
Expected changes in the sum of active temperatures (ΔΣ T) and precipitation (ΔΣP,mm) over growing season by 2005



Zavel'skaya et al., 1999

The response times over which different positive and negative feedbacks to climate are most pronounced





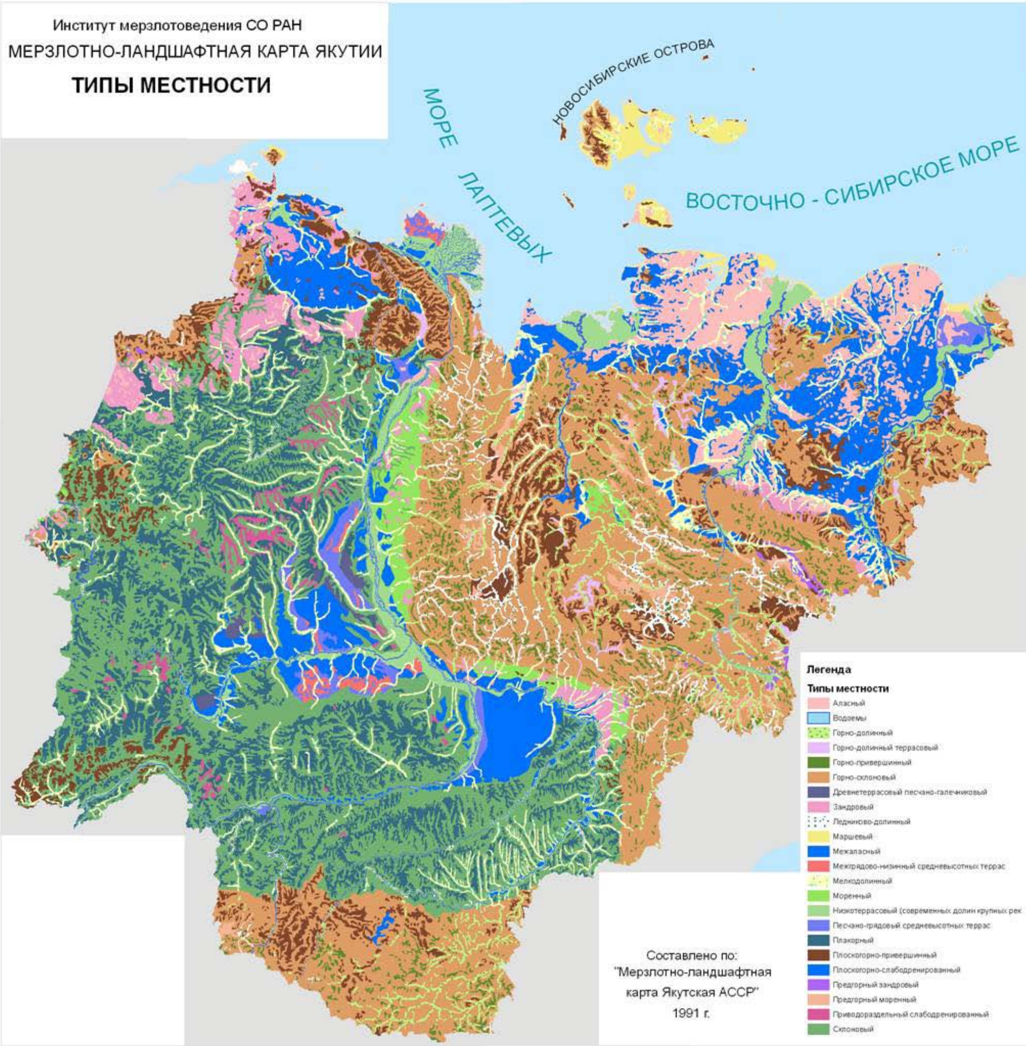
Whole Permafrost Zone	**35 mln sq.km**
Northern Hemisphere	22
Russia	11
Yakutia	3
Canada	5.7
Alaska	1.5
Greenland	1.6
China, Mongolia	1.2
Antarctica	13.5

Important role of Yakutia (3.1 mln. sq.km) in the Earth's climate ecosystem

i) As an integral Arctic part within the boundaries of the Indivisible Circumpolar ecology space, differs by a number of specific natural climatic conditions that influence the directions, scales and forms of economy, use of nature and keeping environment safe

ii) There are all the environmental-forming components of the North that can be transformed with the climate change: The Arctic Ocean, permafrost, northern forest frontier, northern species of flora and fauna.

iii) Accumulation of CO_2 via flexible system of 1997 UN Kyoto Protocol on Reduction of Greenhouse Gases Emission into the Atmosphere



Potential of thermokarst distribution in Yakutia (Permafrost Landscape map of Yakutia, 1991)

Thermokarst – Alas formations

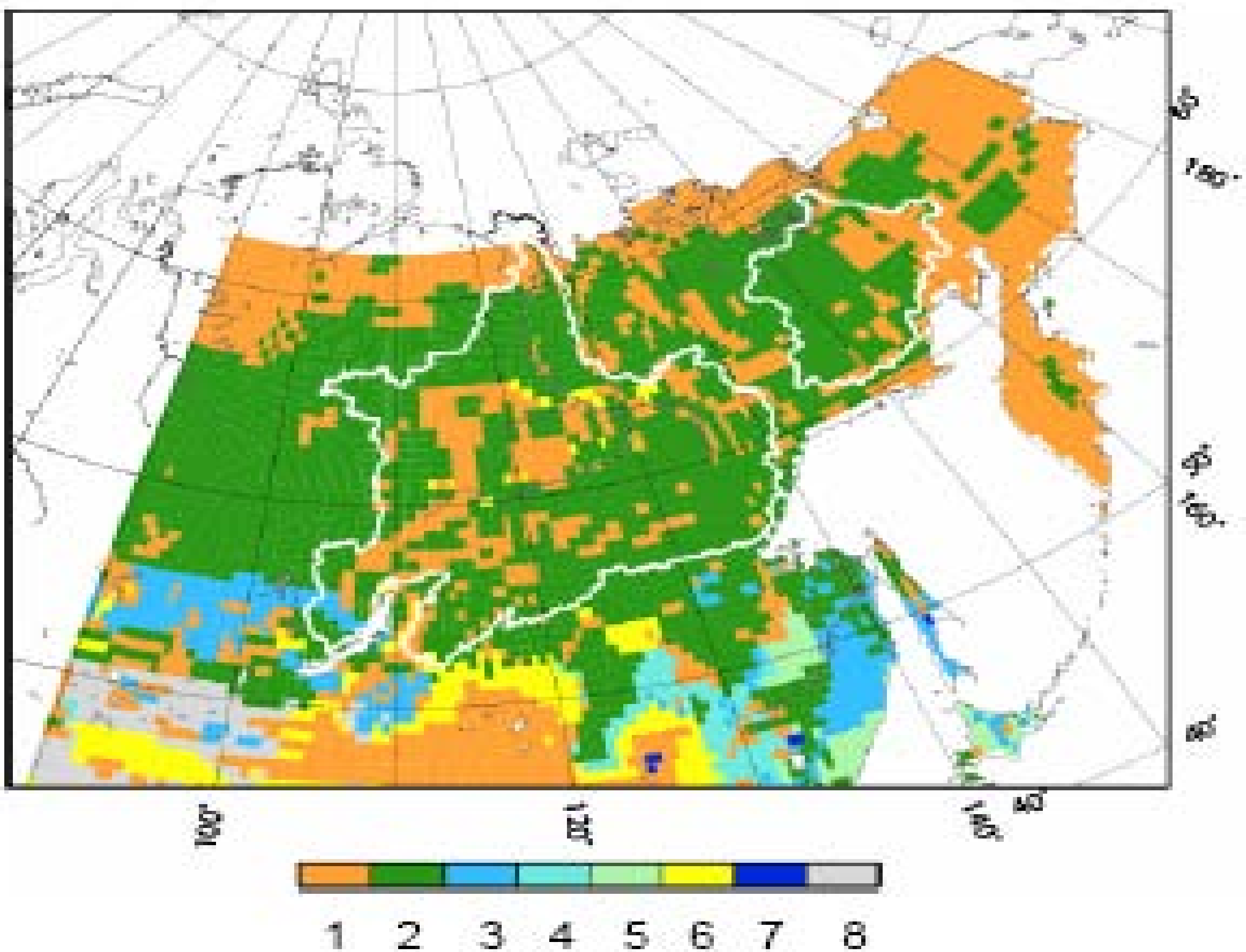
10%	Inter-Alas with big Ice-Wedges (Ia II-III)
2,5%	Moraine with big Ice-Wedges (g,fg II-III)

Thermokarst with Surface Subsidence

1,2%	Marsh with small Ice-Wedges (b III-IV)
4,1%	Alas with small Ice-Wedges (t III-IV)
6%	Valley with small Ice-Wedges (a III-IV)

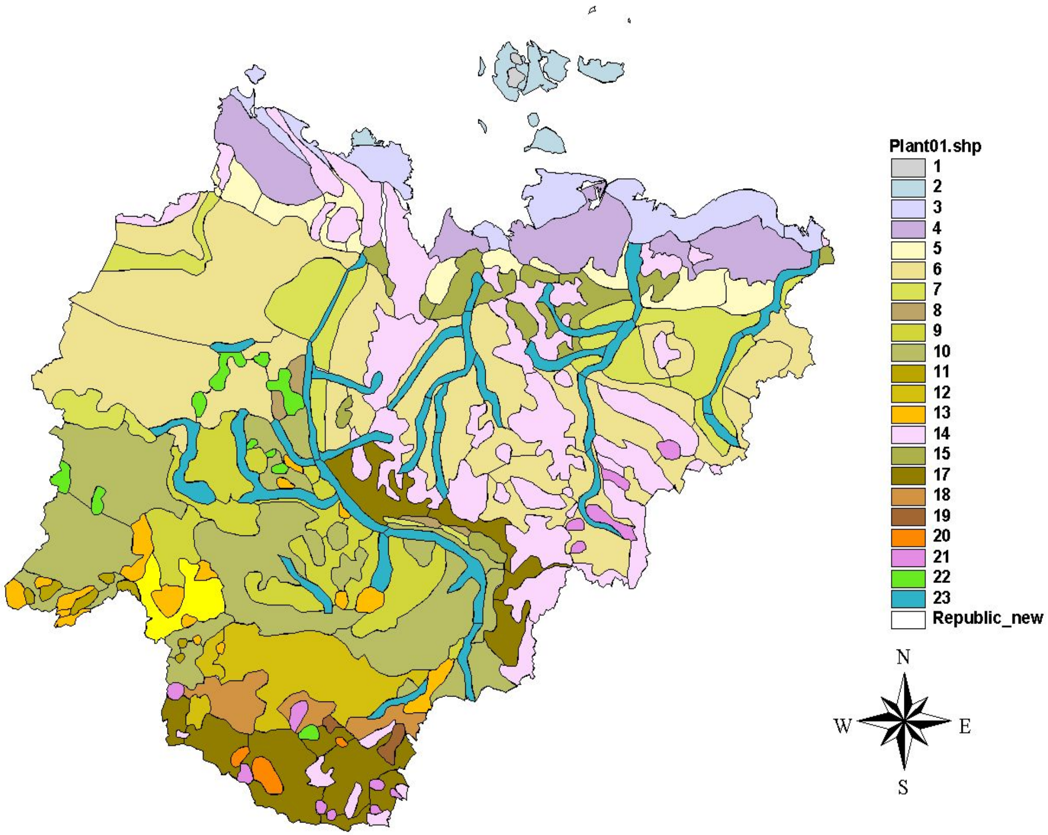
Fedorov, 2007

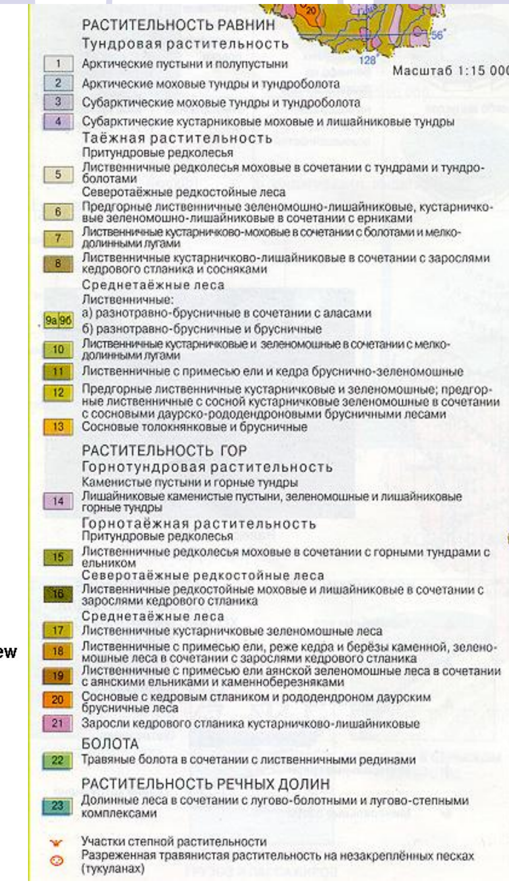
Distribution of the re-categorized land-cover types



The category is defined as follows; 1: tundra, 2: taiga/boreal forest, 3: cool deciduous conifer forest, 4: cool deciduous broad-leaved forest, 5: cool mixed forest, 6: grassland, 7: permanent wetland, 8: permanent snow and ice

Vegetation map of Yakutia





The territory of Yakutia is weakly populated (980 ths people over 3,1 mln km^2), 90% of the area is free from large industrial and agrarian units.

Vast areas of virgin lands allow us to recommend this region as a model one to arrange a network for the complex monitoring of the environment including making a prognosis of possible trends and consequences of the global environmental change as well as finding the ways to mitigate them.

Sliding 10-year average temperatures, °C, Arctic, Northeastern and Central Yakutia

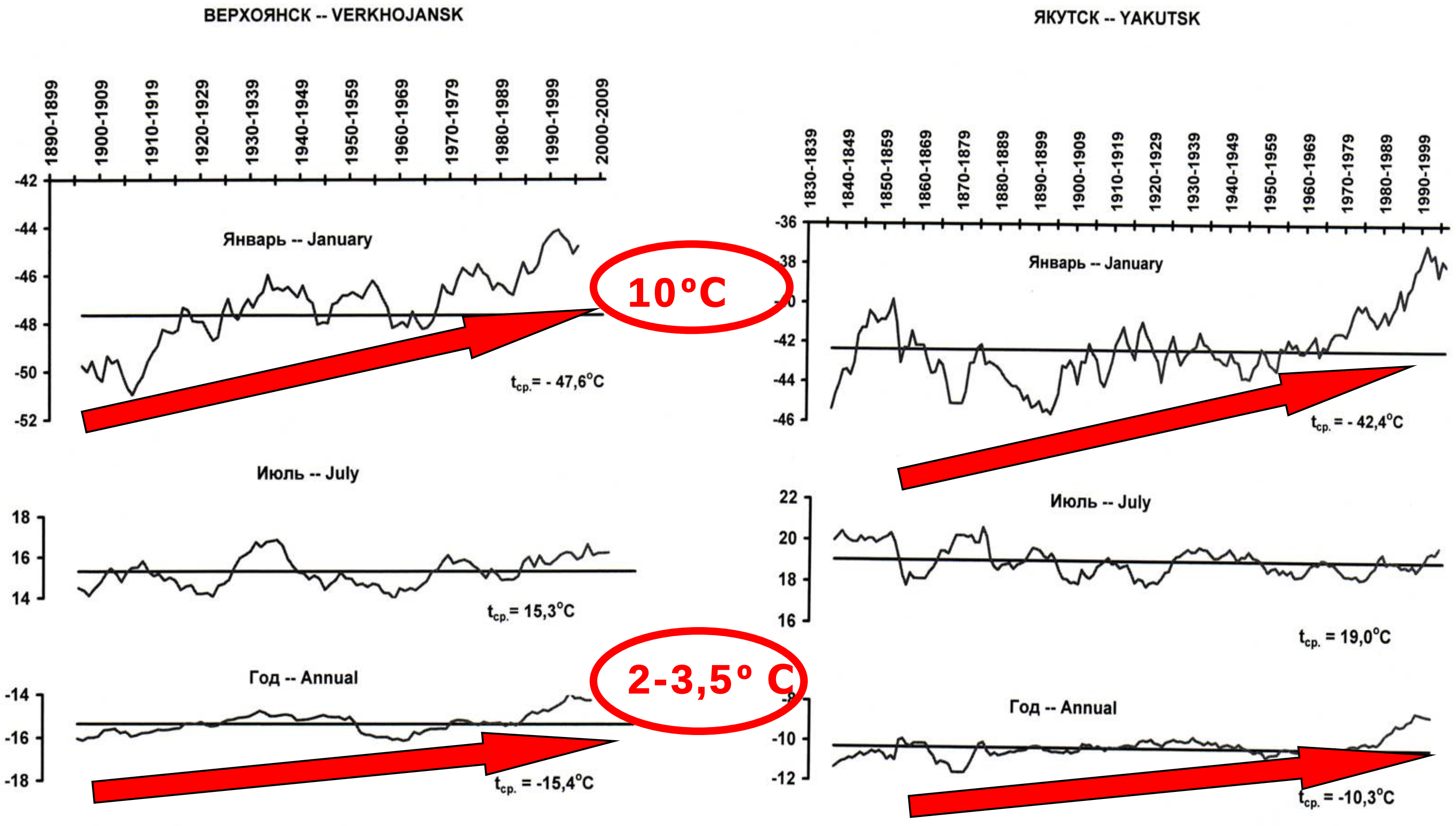


Рис. Скользящие 10 - летние средние температуры воздуха, °C. Северо - Восточная Якутия

Fig. Sliding 10 - year average temperatures, °C. The North - Eastern Yakutia.

Рис. Скользящие 10 - летние средние температуры воздуха, °C. Центральная Якутия.

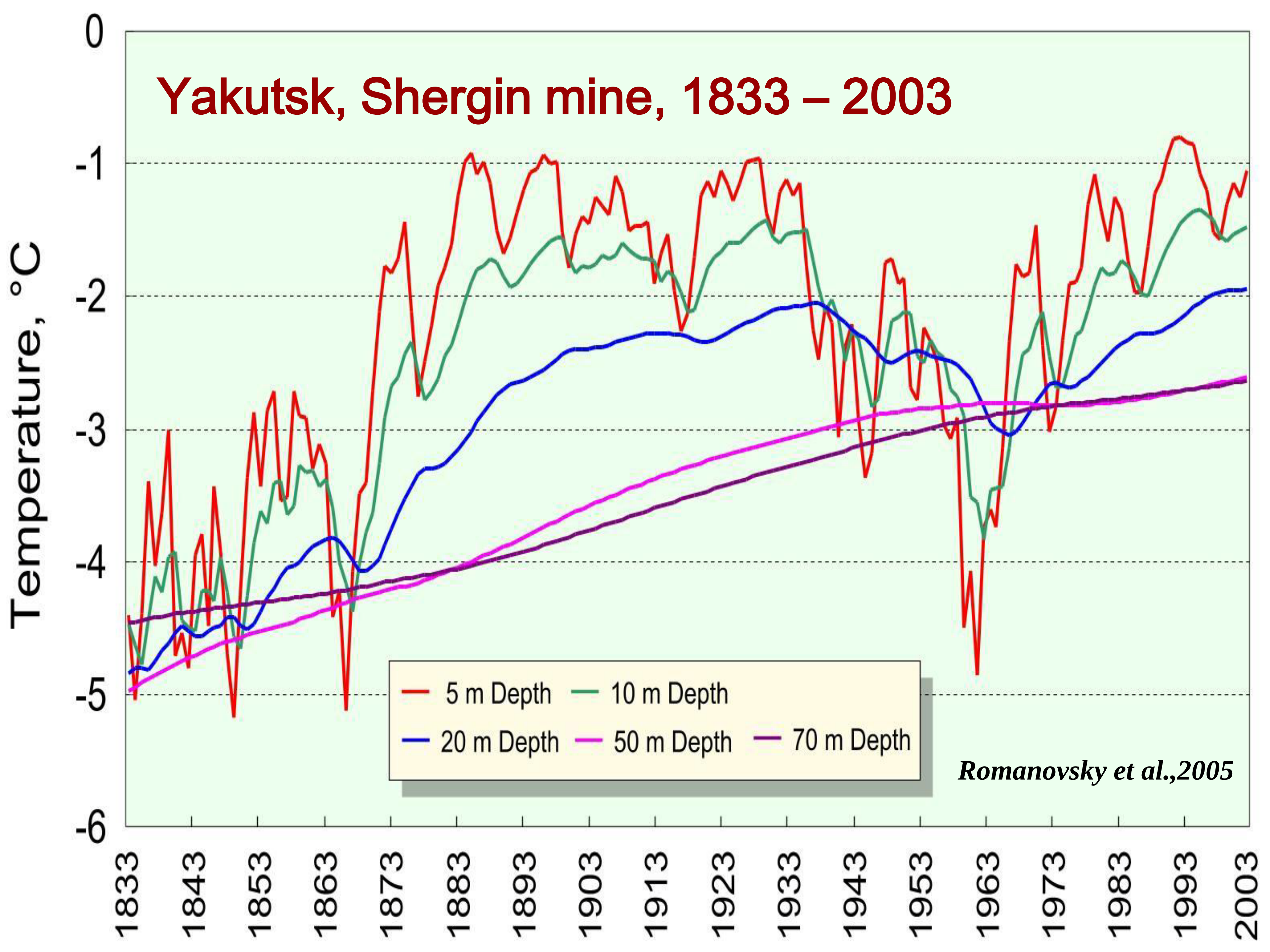
Fig. Sliding 10 - year average temperatures, °C. Central Yakutia.

Gavrilova, 2007

Meteorological observations for the last 100-150 years in «ever frost» region of Siberian and Central Asia

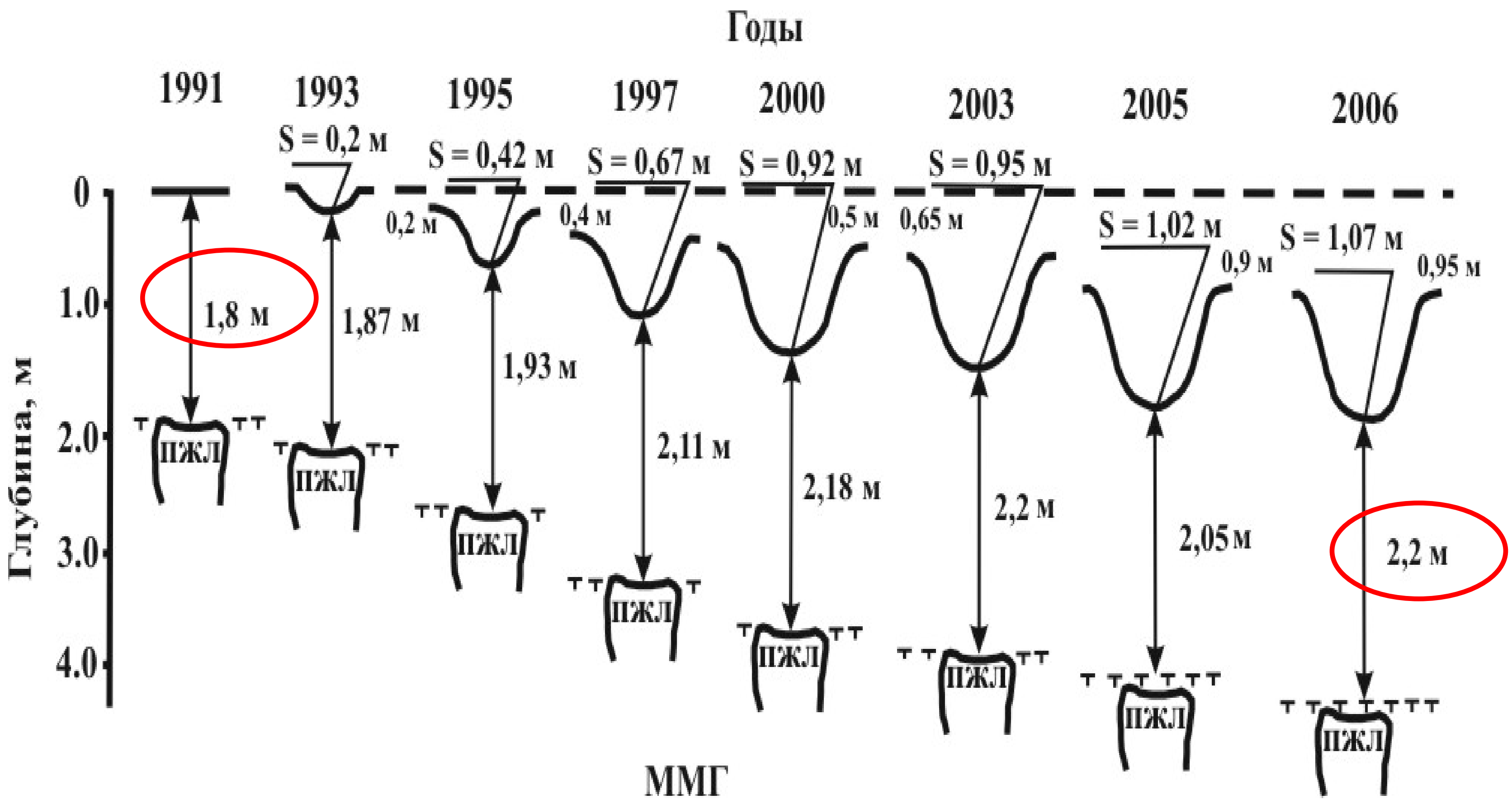
- XX century was warmer than XIX, over all the northern half of Asia. So, for 100 years since the end of before last century, winter temperatures in Eastern Siberia (Yakutia) have arisen by 10 ºC. Annual temperatures for the last century increased by 2-3.5 ºC everywhere.
- Steady warming appeared at the second half of XX century, especially since 70-80s. For the last 50 years the temperature in Yakutia increased by 7 ºC for January, i.e. 1.5-2 times as intensive as at the first half of the century. Annual temperatures rose by 1-2 ºC.
- The trend of warming at high latitudes (Central and Eastern Yakutia) is 1.5 times as much as in Southern Siberia and 3 times of that in Mongolia.

Gavrilova, 2003



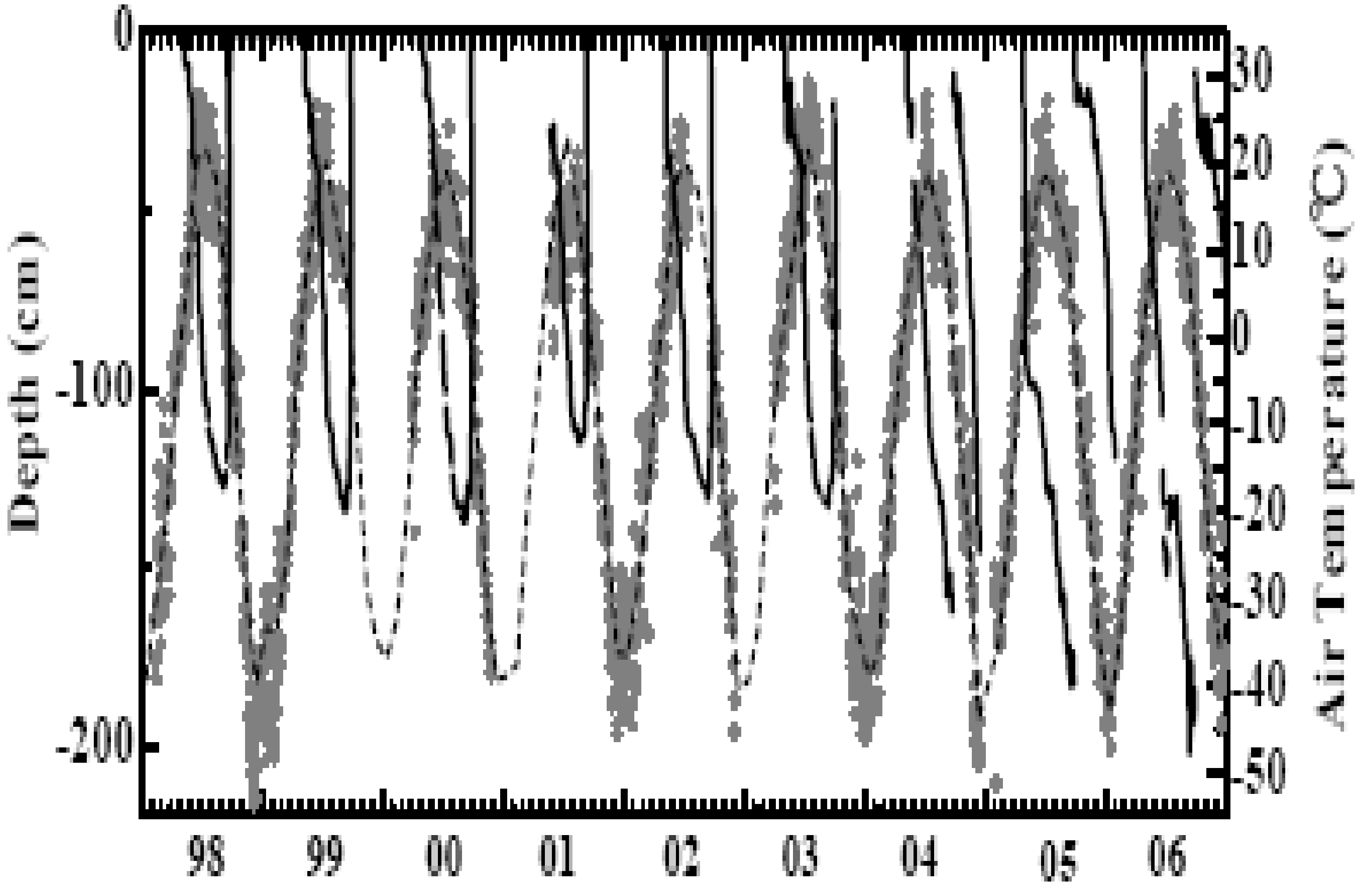
Yakutsk, Shergin mine, 1833 – 2003
Temperature, °C
0
-1
-2
-3
-4
-5
-6
1833
1843
1853
1863
1873
1883
1893
1903
1913
1923
1933
1943
1953
1963
1973
1983
1993
2003
5 m Depth
10 m Depth
20 m Depth
50 m Depth
70 m Depth
Romanovsky et al.,2005

Dynamic of thawing of ice wedge and development of thermo depression, Dyrgyabai Ataga polygon within 1993-2006

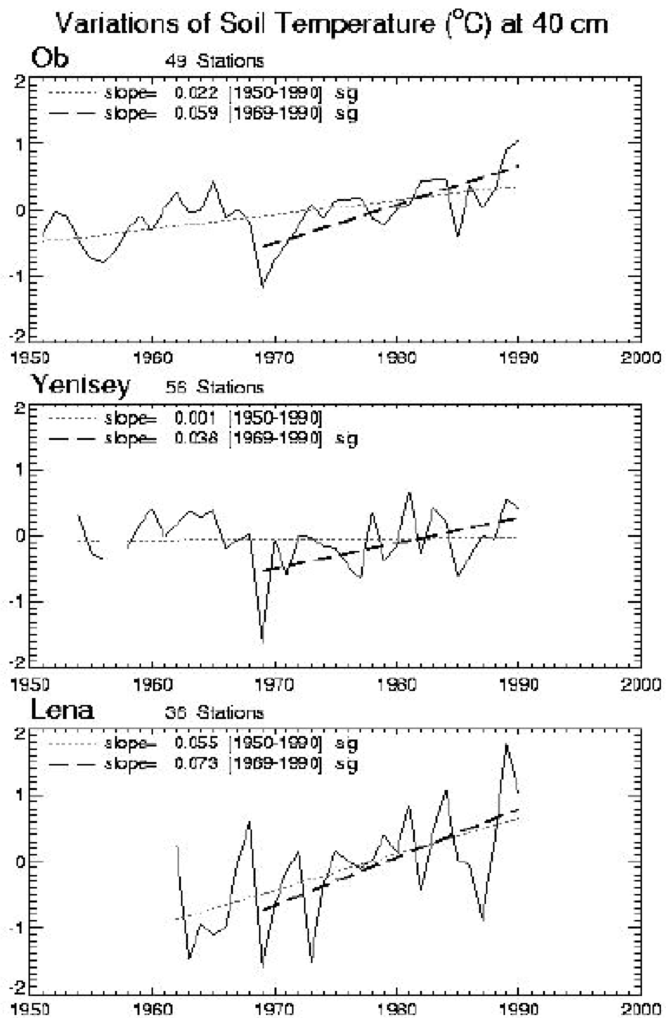


Gavrilyev,2007

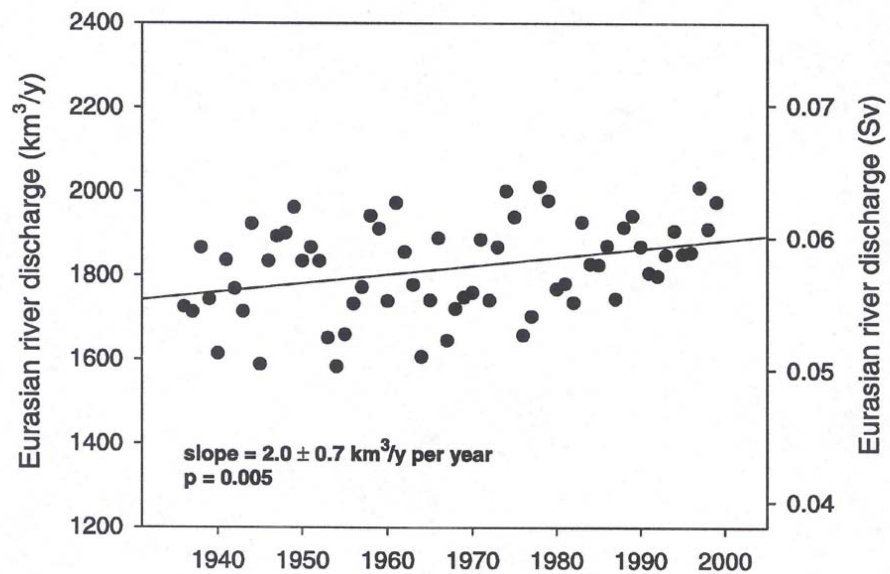
Time series of the depth of soil temperature of 0°C (soild line), daily mean air temperature at Spasskaya Pad (gray dots) and monthly mean air temperature in Yakutsk (dotted line)



Soil temperature



Run-off increase

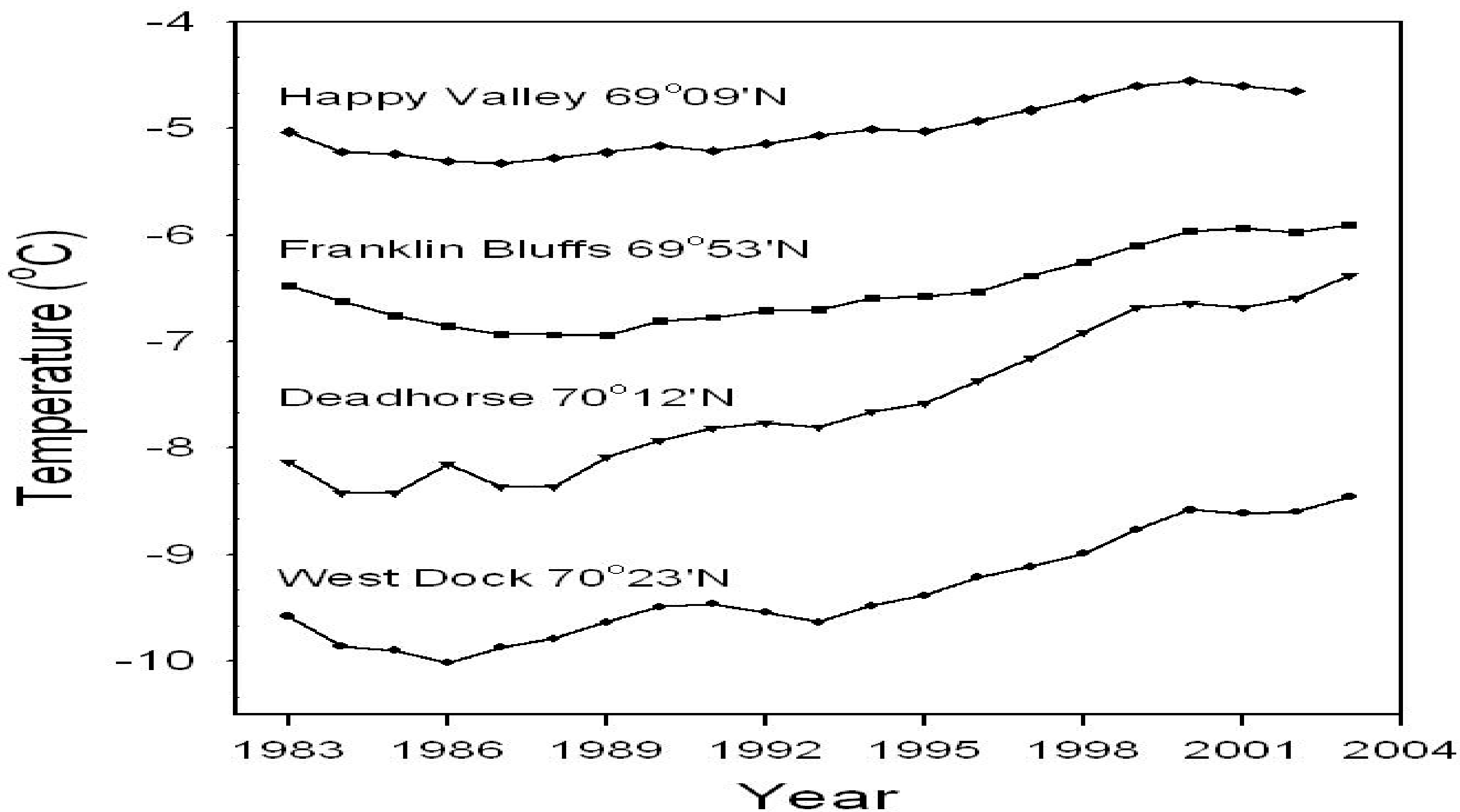


Peterson et al. (2002)

Temperature rise

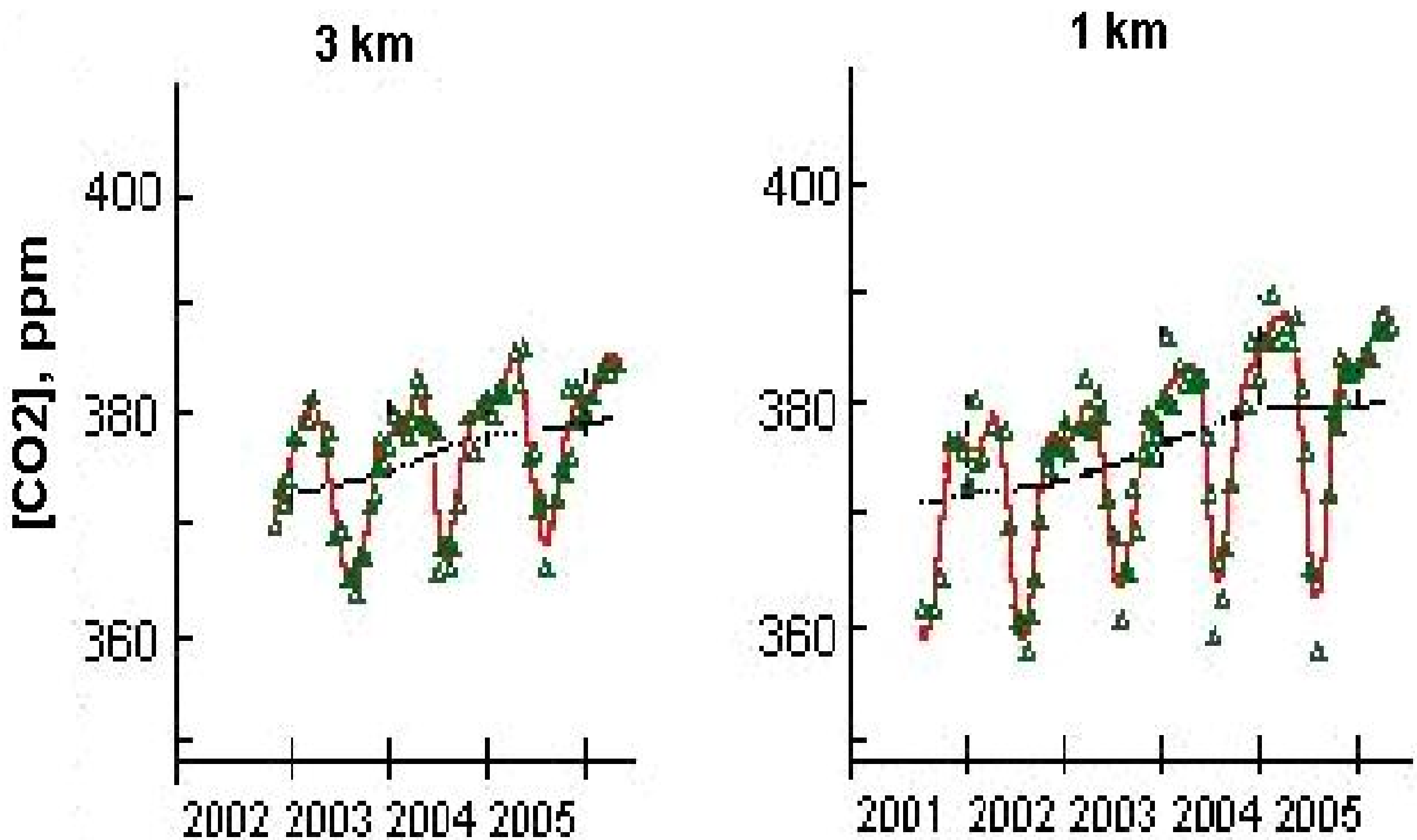
- Ob' - 1.2°C
- Yenisei - 0.8°C
- Lena - 1.5°C
- Forecast: 3-5°C for 50 years

Changes in soil temperature at 20-m depth for several northern sites of the Alaska transect



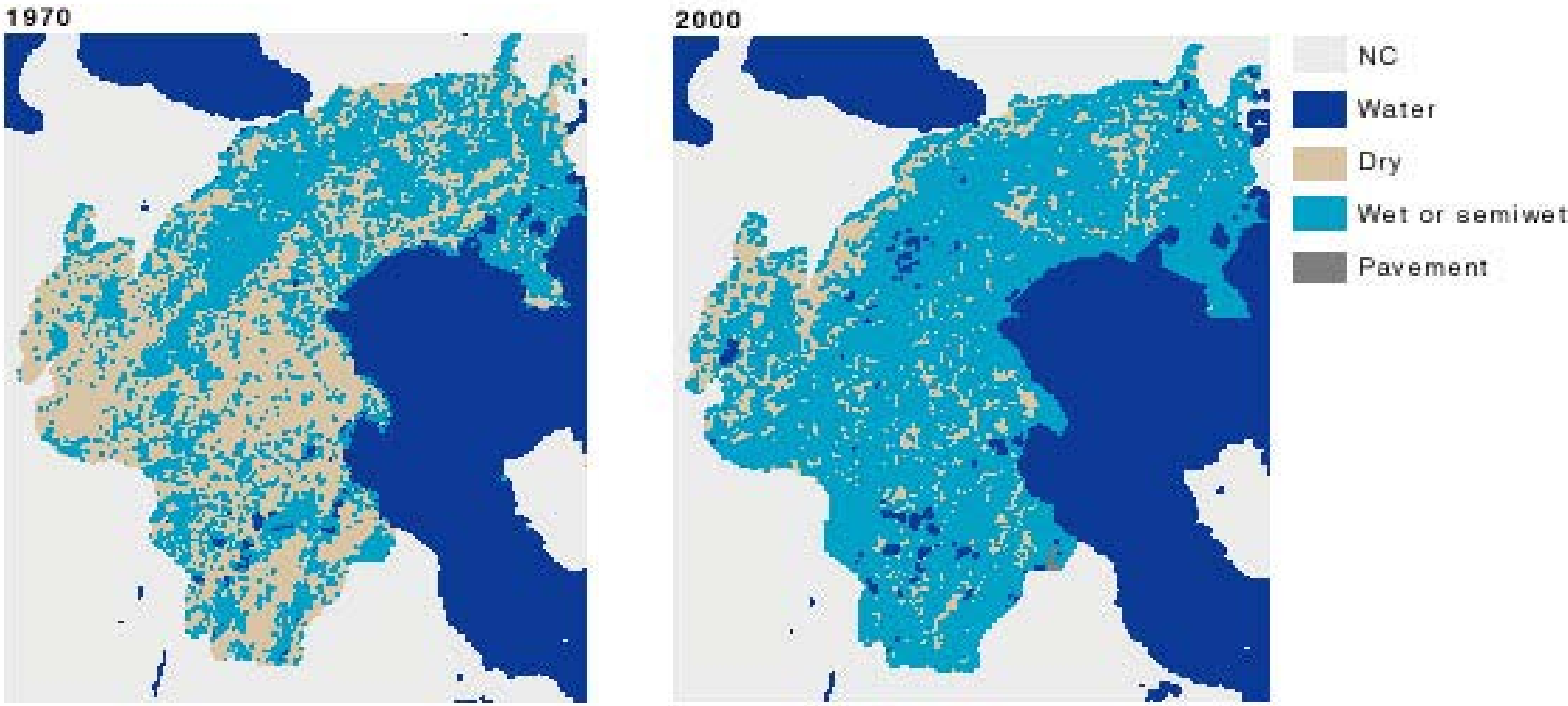
Romanovsky and Osterkamp 1997

Atmospheric [CO_2] over Yakutsk area



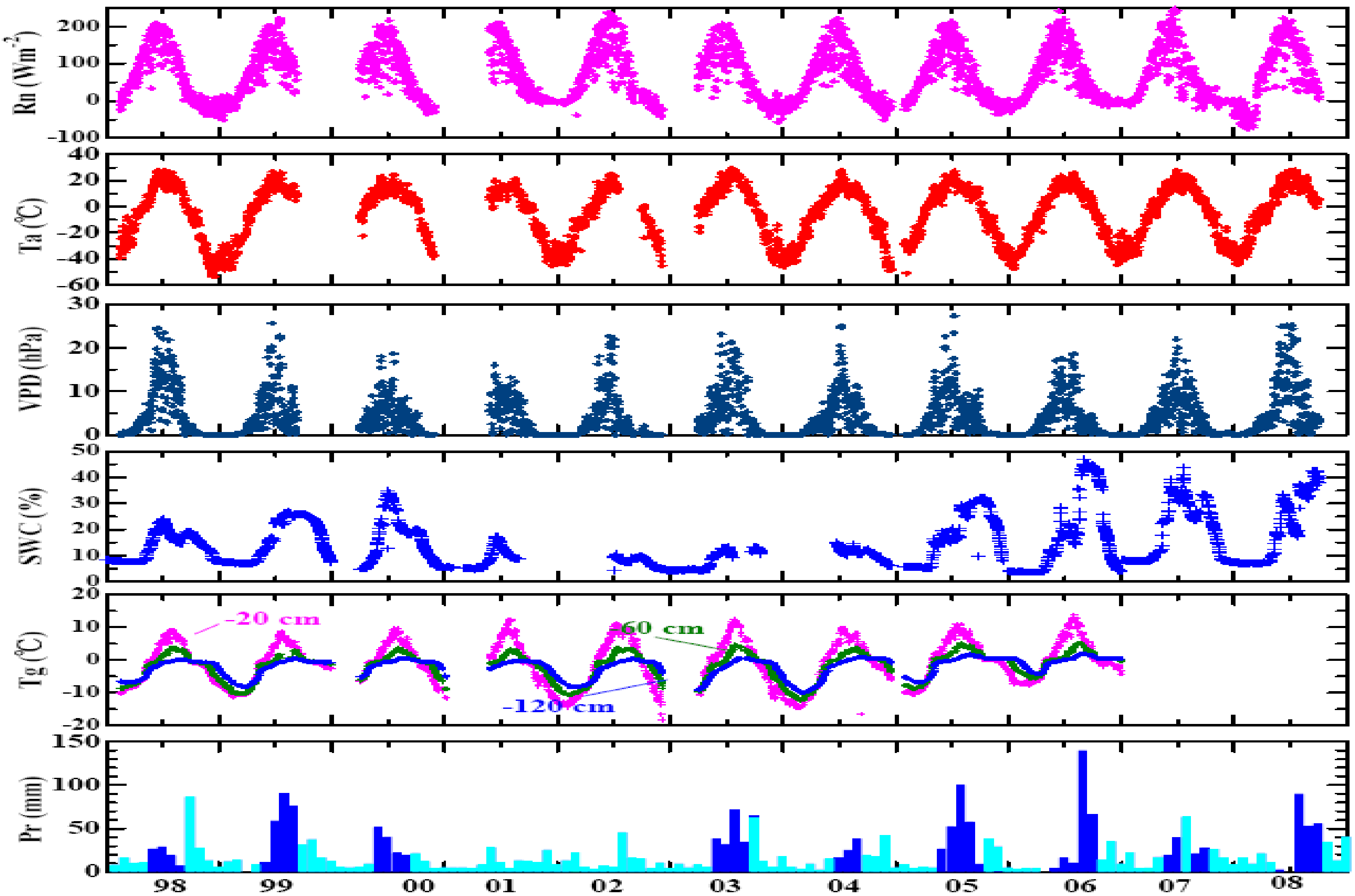
Takahashi et al., 2005

Change in vegetation for 1970-2000

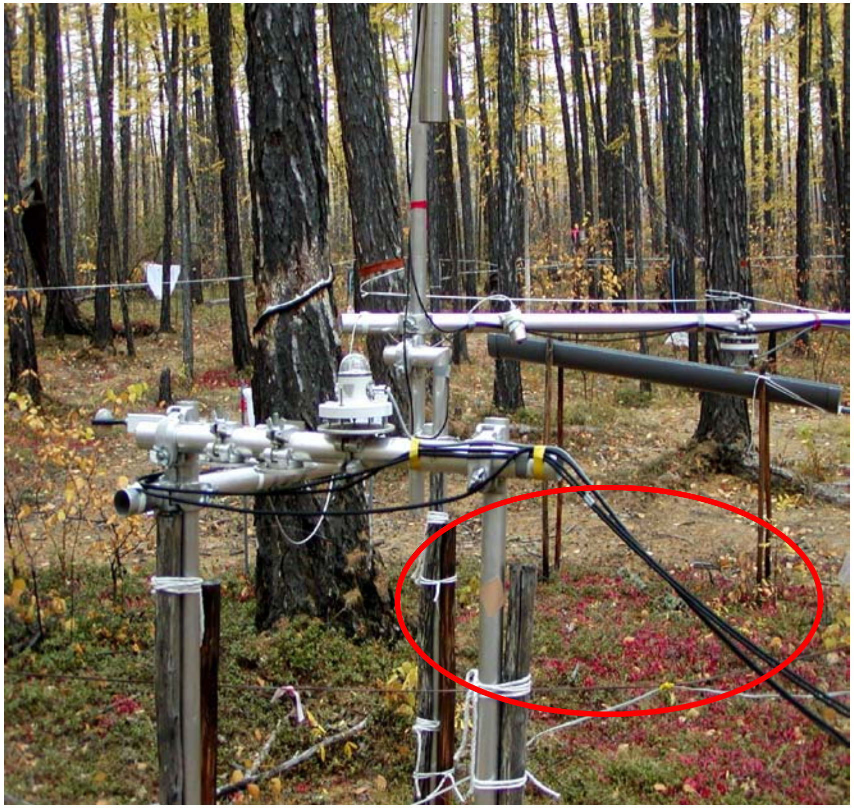


Christensen et al., submitted

Climatic condition variables from 1998 to 2008 at the Spasskaya Pad



Changing of Plant successions during 2001-2009



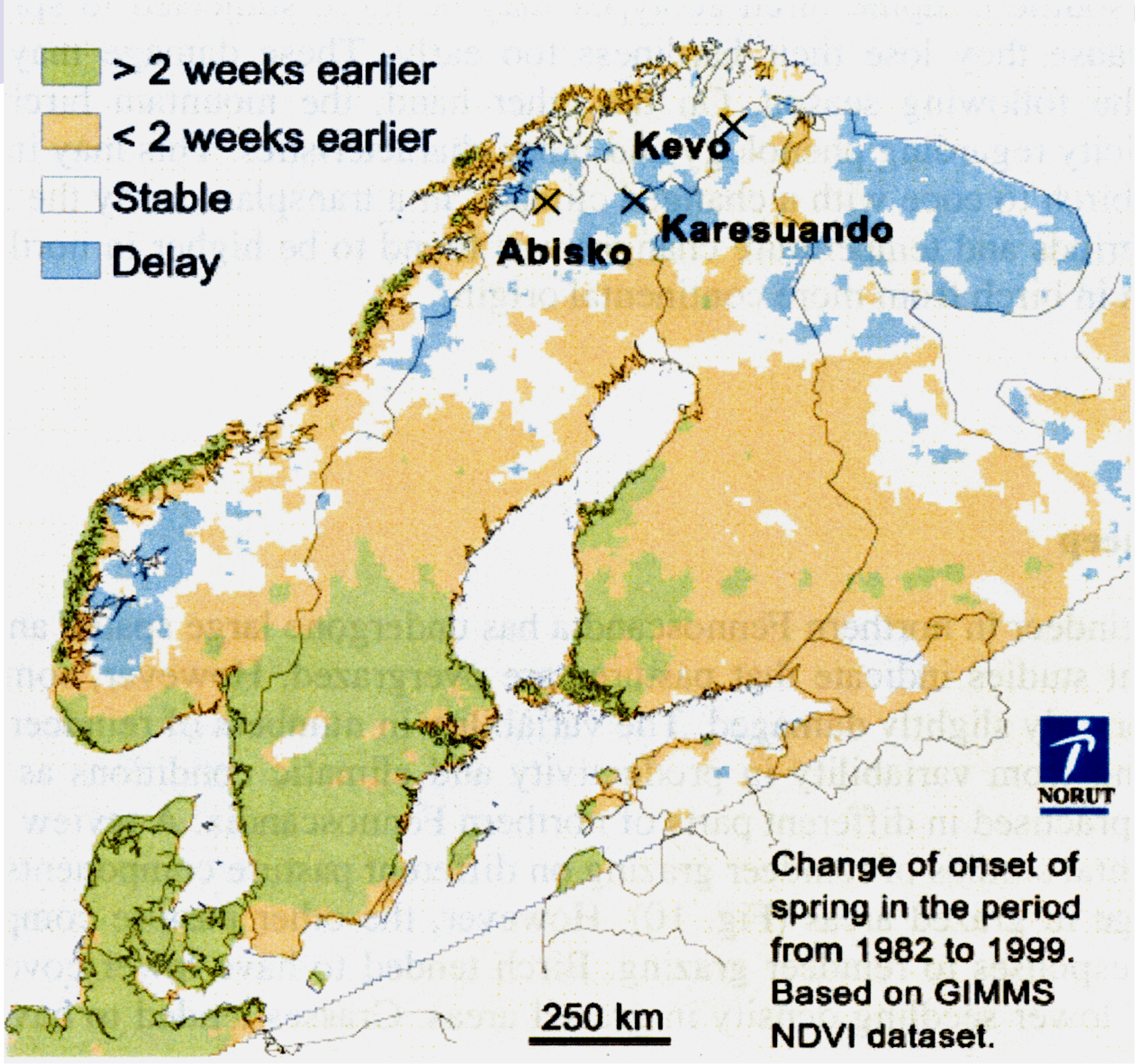
2001 (subshrubs)

Vaccinium vitis-idaea,
Actae erythrocarpa

2009 (grasses)

Calamagrostis epigeios, *Arctagrostis latifolia*, *Equisetum pretense* and *Poa angustifoliahave*

Change in spring time coming, 1982-1999



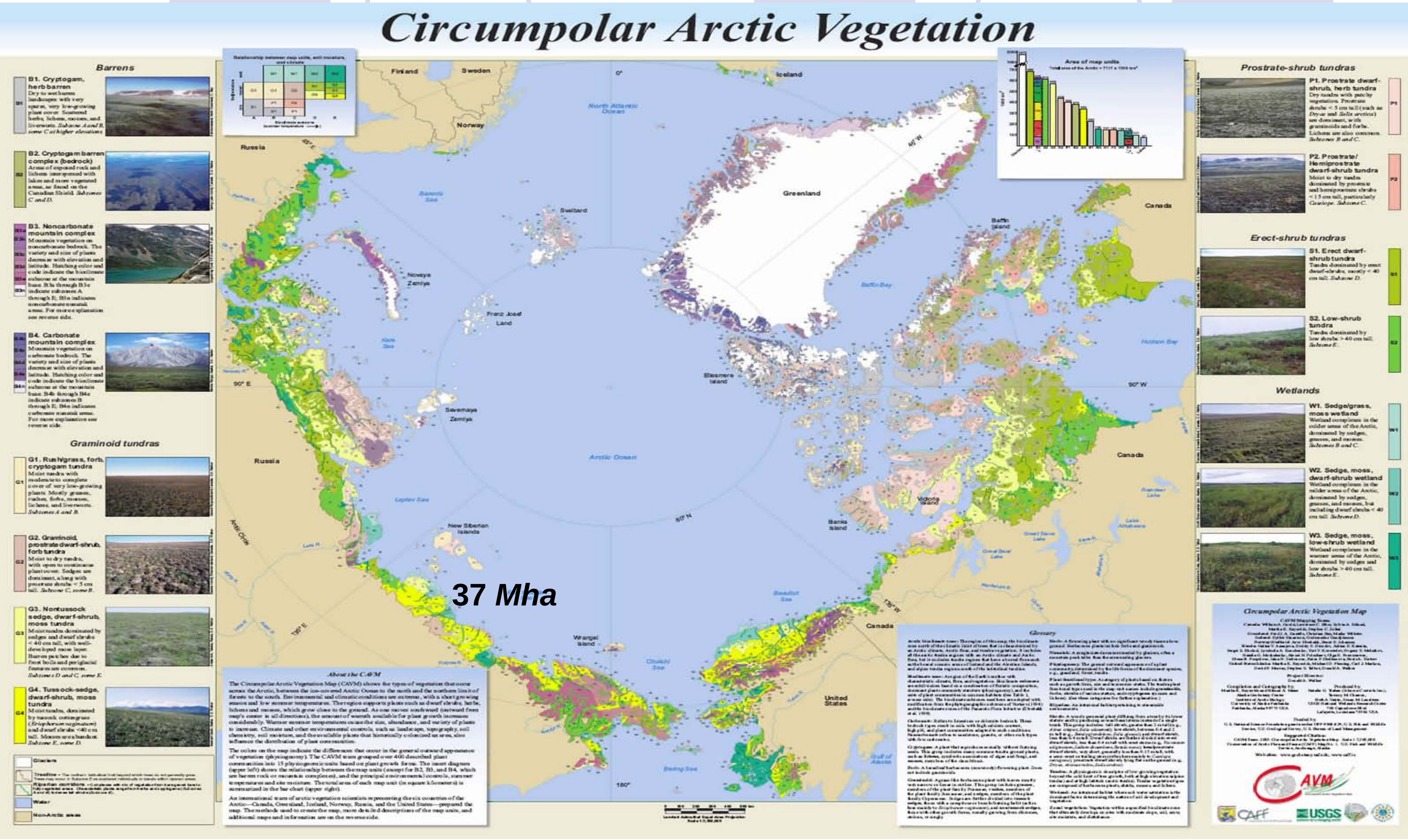
T. Callaghan

Number of described plant and animal species in Yakutia

Group of organisms	Year			
	1935	1965	1995	2000
Fungi			241	>500
Plants:				
- vascular	1190	1560	1839	1916 (76%*)
- cryptogams	577	1830	3609	3609 (62%)
including:				
- mosses	181	236	444	517 (55%)
- lichens	42	300	550	705 (67%)
- algae	354	1300	2615	2836 (65%)
Animals:				
- insects	600	1100	4000	4300(40%)
- fishes (species and forms)	36	53	53	53(97%)
- amphibians	2	2	4	5(99%)
- reptiles	2	2	2	2(99%)
- birds	138	250	280	291(92%)
- mammals	37	60	63	75(98%)

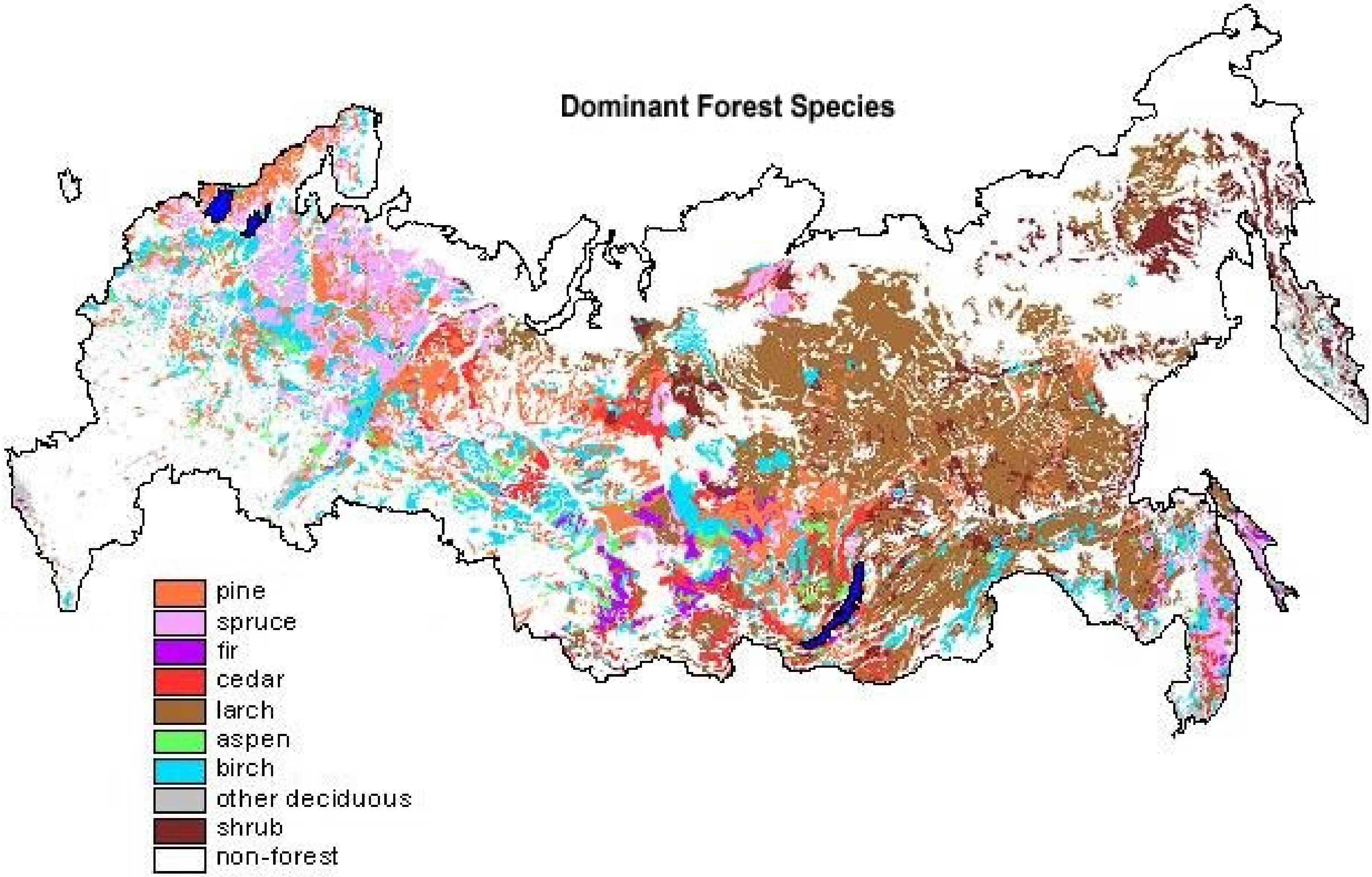
*in parentheses - supposed % of examination

Solomonov, 2004



Circumpolar Arctic Vegetation
Barrens
B1. Cryptogam, herb barren
B2. Cryptogam barren complex (bedrock)
B3. Noncarbonate mountain complex
B4. Carbonate mountain complex
Graminoid tundras
G1. Rush/grass, forb, cryptogam tundra
G2. Graminoid, prostrate dwarf-shrub, forb tundra
G3. Nontussock sedge, dwarf-shrub, moss tundra
G4. Tussock-sedge, dwarf-shrub, moss tundra
Prostrate-shrub tundras
P1. Prostrate dwarf-shrub, herb tundra
P2. Prostrate/Hemiprostrate dwarf-shrub tundra
Erect-shrub tundras
S1. Erect dwarf-shrub tundra
S2. Low-shrub tundra
Wetlands
W1. Sedge/grass, moss wetland
W2. Sedge, moss, dwarf-shrub wetland
W3. Sedge, moss, low-shrub wetland
Finland
Sweden
Norway
Iceland
Russia
Greenland
Svalbard
Novaya Zemlya
Franz Josef Land
Severnaya Zemlya
Arctic Ocean
New Siberian Islands
Wrangel Island
Ellesmere Island
Baffin Island
Banks Island
Victoria Island
Canada
United States
Hudson Bay
37 Mha
About the CAVM
Glossary
Circumpolar Arctic Vegetation Map

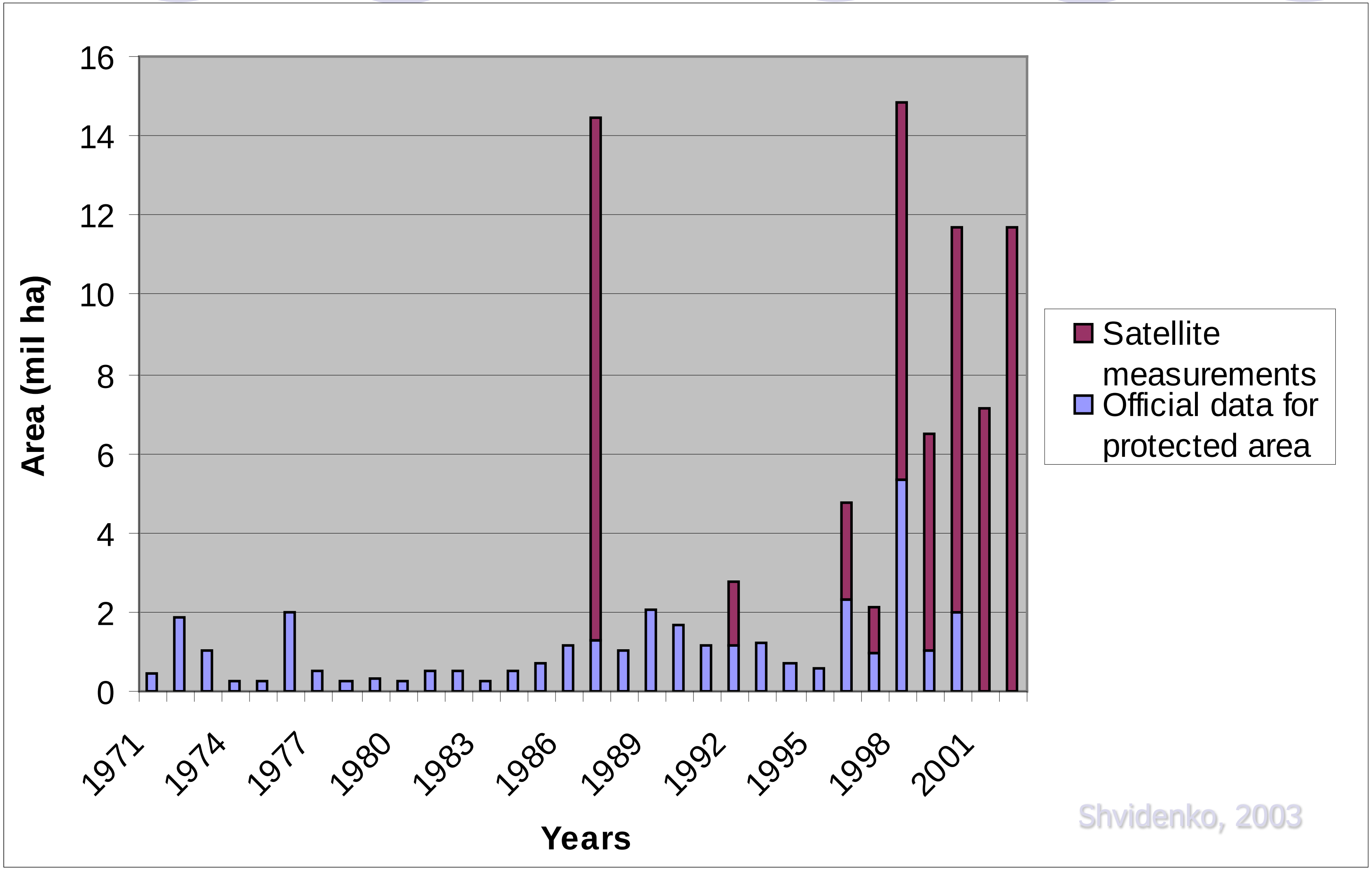
Domination of forest species

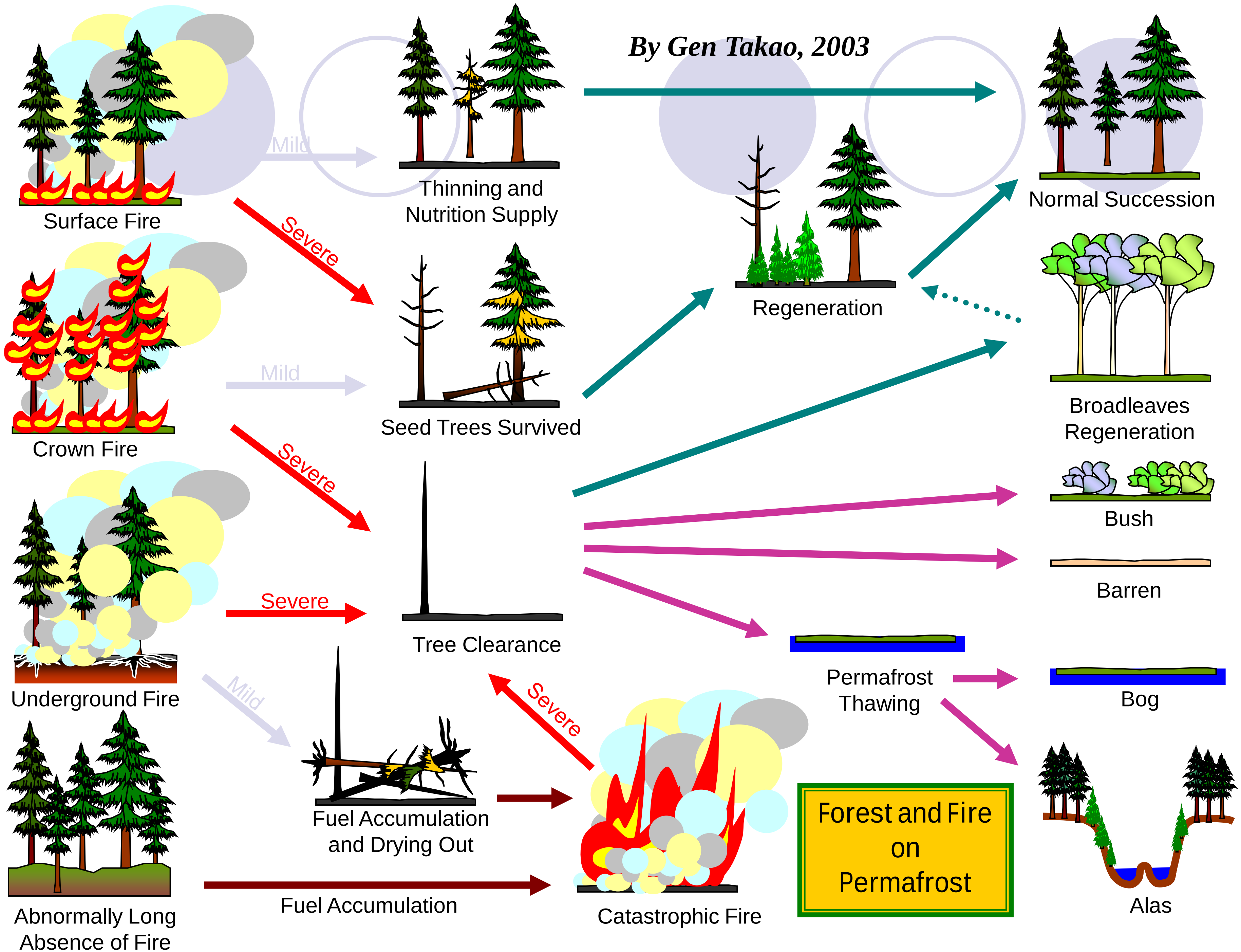


Larch area in Siberia and Far East

Region	Mha
West Siberia	6.0
Krasnoyarsk krai	51.6
Tuva	3.73
Irkutsk oblast	18.23
Buryatia	9.57
Chitinskaya oblast	16.98
Amurskaya oblast	13.9
Khabarovsk krai	19.51
Primorskyi krai	1.1
Sakhalin oblast	1.26
Magadan oblast	9.03
Kamchatka oblast	0.19
Republic of Sakha (Yakutia)	106.0 (12.5%)
Total	257.1 (30.2%)
Whole Boreal forest	850

Vegetation fire in Russia in 1971-2002





By Gen Takao, 2003
Mild
Thinning and Nutrition Supply
Surface Fire
Severe
Seed Trees Survived
Mild
Crown Fire
Severe
Regeneration
Normal Succession
Broadleaves Regeneration
Bush
Barren
Severe
Tree Clearance
Underground Fire
Mild
Fuel Accumulation and Drying Out
Severe
Permafrost Thawing
Bog
Abnormally Long Absence of Fire
Fuel Accumulation
Catastrophic Fire
Forest and Fire on Permafrost
Alas

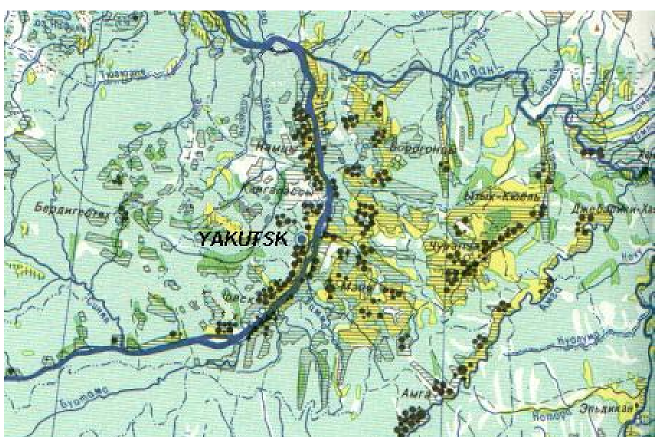
Forest felling

Deforestation

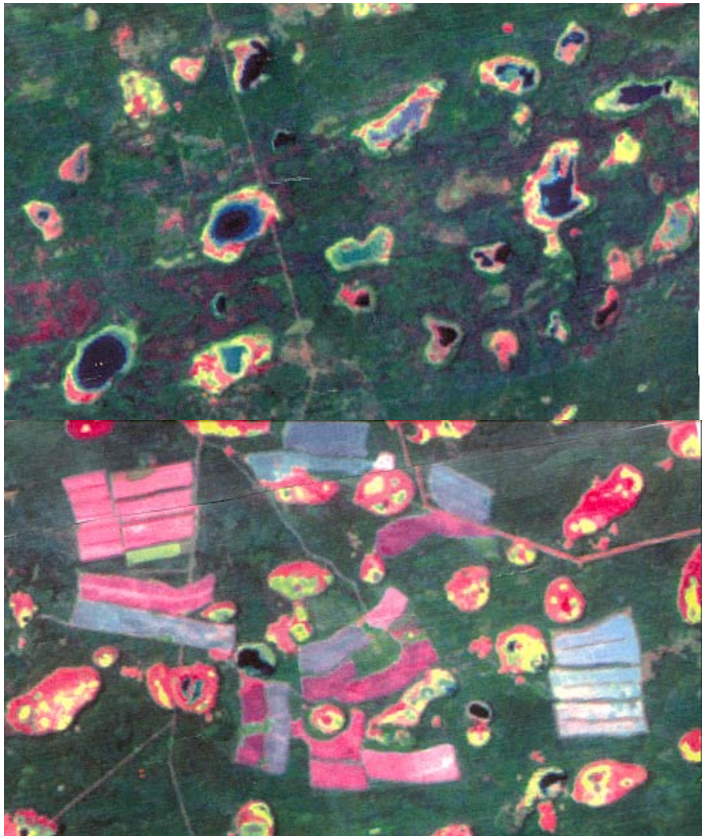
For one steading construction necessary around 100-150 cubic meter of forest, and for one house heating using 25-30 cubic meter firewood annual. Reserves of low productive larch and pine forests amount just 100-110 cubic meter per hectare. It is calculated that all forest users during last thirty year
on the territory of Lena-Amga interfluve thinned out dry low productive larch and pine forests on the area to 1.0-1.3 million hectares.

Destruction of forest for the tillage, road, electric line and other line constructions

Total area of arable lands more than 60 000 ha, even greater area of taiga occupied under line constructions



Anthropogenic degradation of forests in Central Yakutia



Insect

Dendrolimus superans sibiricus Tschetv. –

most dangerous pest of the Siberian taiga

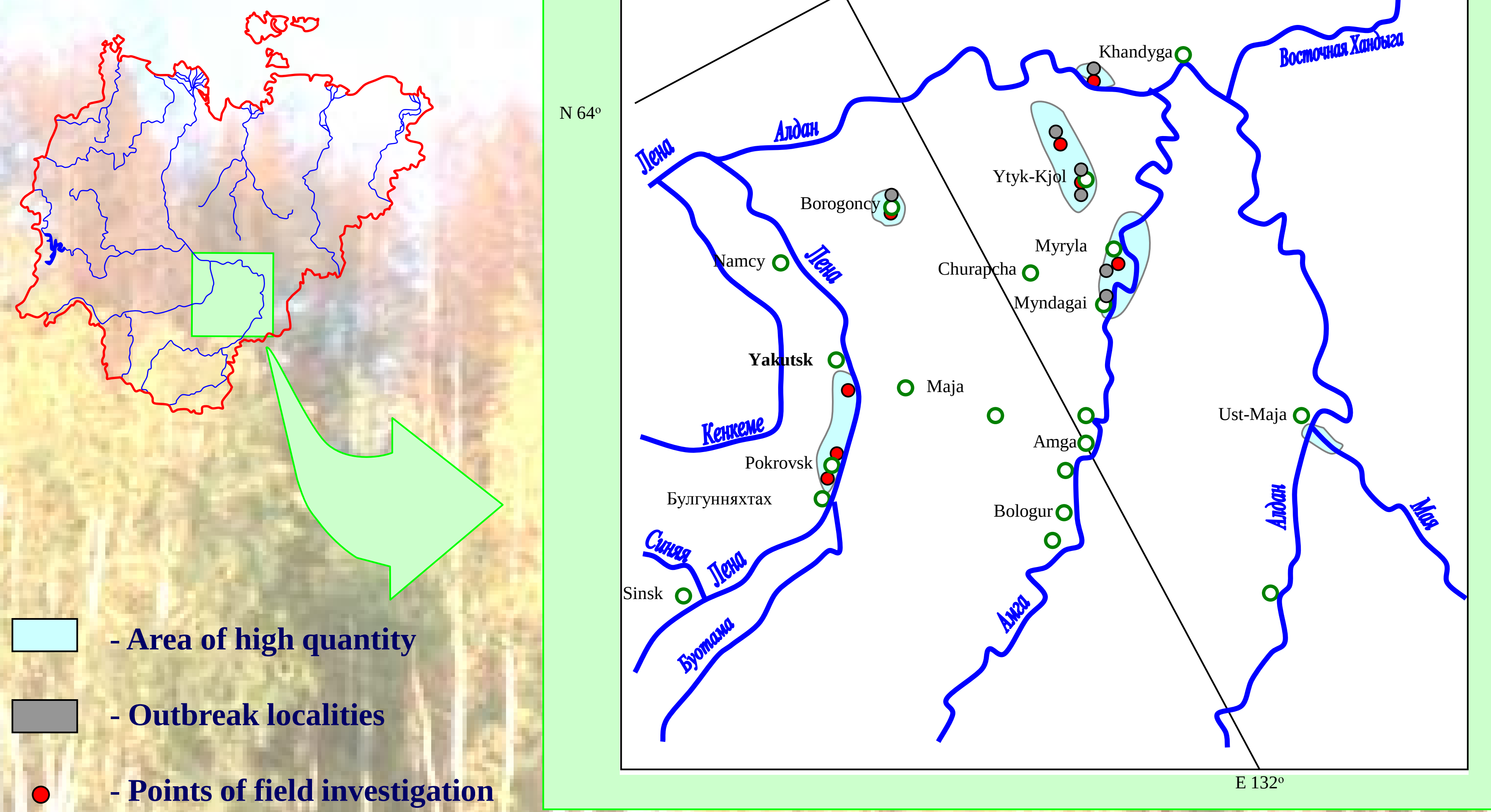
♀

♂

Imago

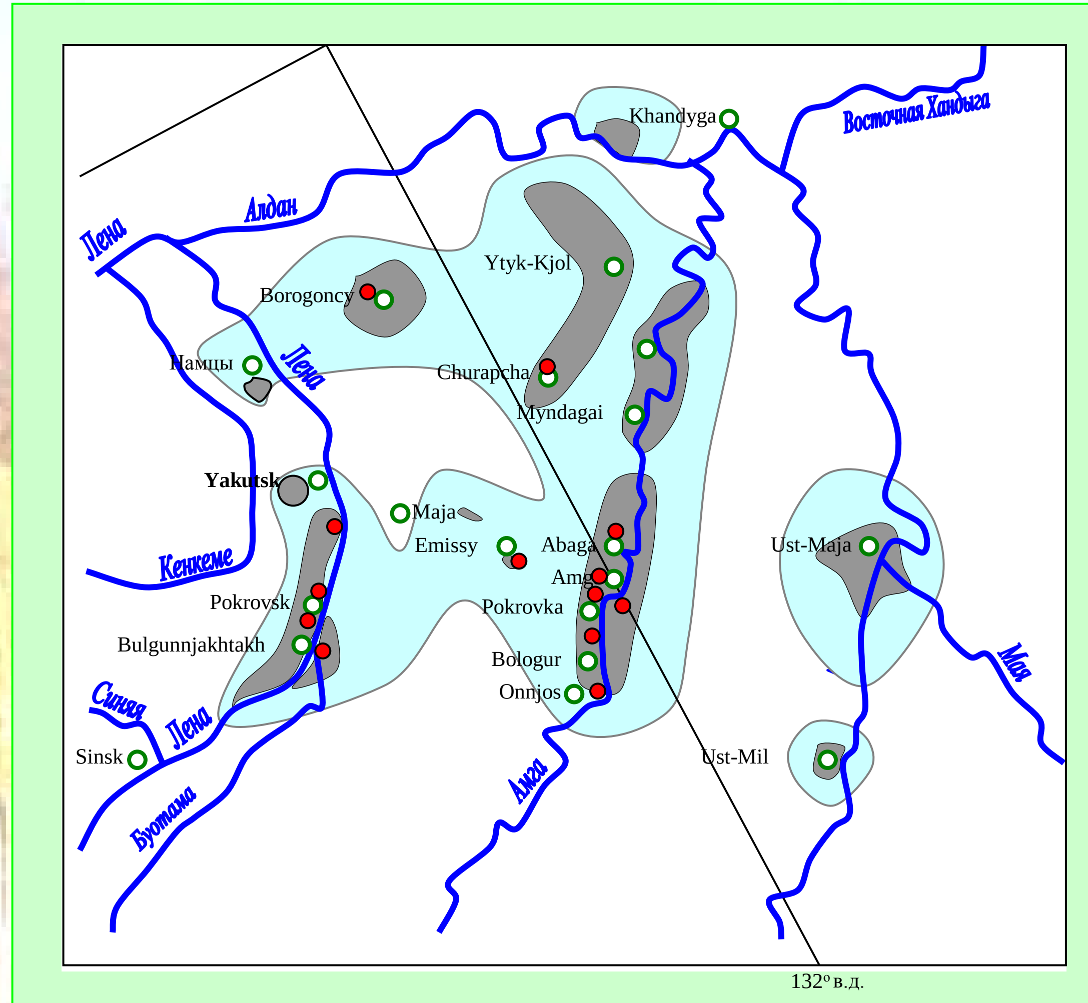
Caterpillars eat of larch needles and defoliate trees

In crown of trees it is possible to find many cocoons, in which develop pupas of butterfly



Distribution of *Dendrolimus superans sibiricus* in Central Yakutia. 1999

Siberian eggar was almost everywhere marked in the Lena-Amga watershed. In mid-summer the area of affection exceeded 10,000 ha, by autumn the area of pest increased up to almost 100,000 ha

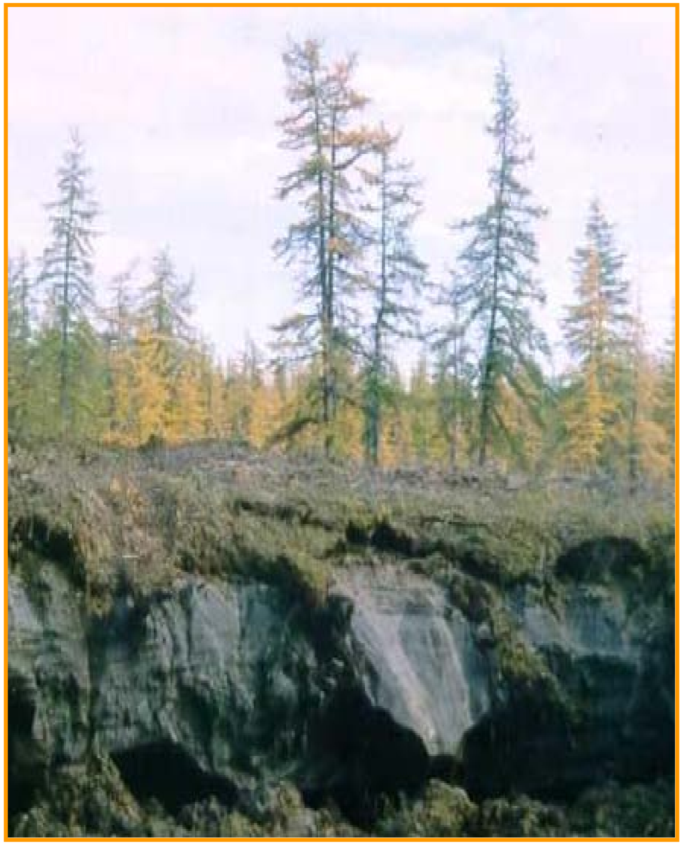


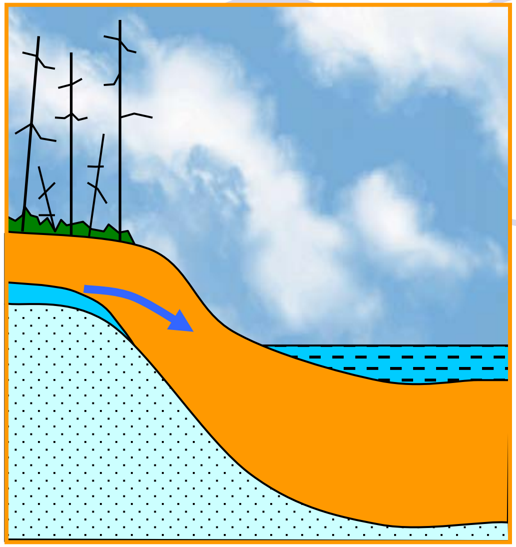
- **Area of high quantity**
- **Outbreak localities**
- **Points of field investigation**

Distribution of *Dendrolimus superans sibiricus* in Central Yakutia. 2000

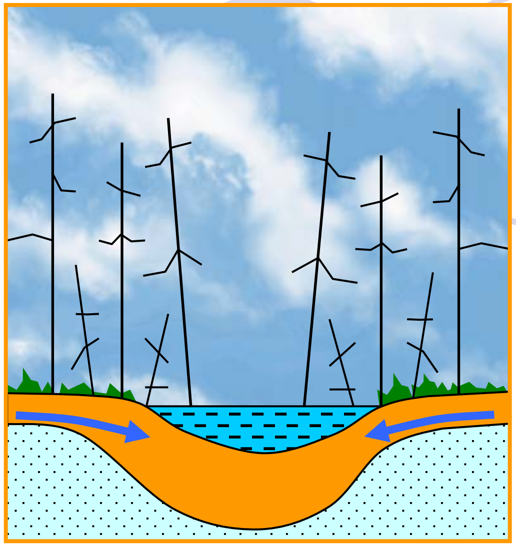
The area of the increased pest density exceeded 5,000 000 ha. The area of complete defoliation amounted 500,000 ha. The inspection of forests showed, that pest is found practically in all larch stands of Central Yakutia

In connection with change of water and temperature regime of soils and plant composition in the some place of dead forest began the thermocarst phenomena, especially on sites with ice complex

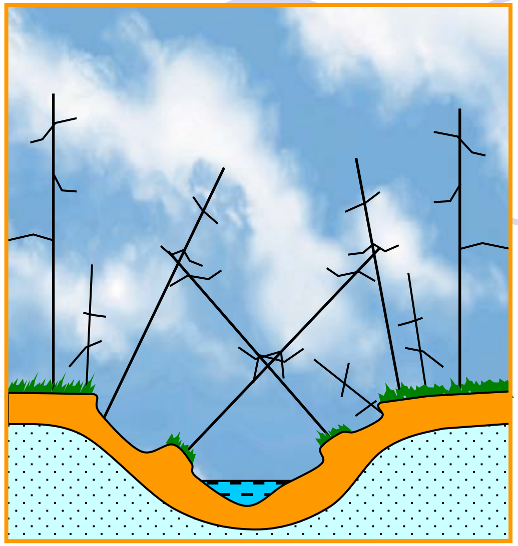




Water from thawing of permafrost is accumulated in lowered places near forests

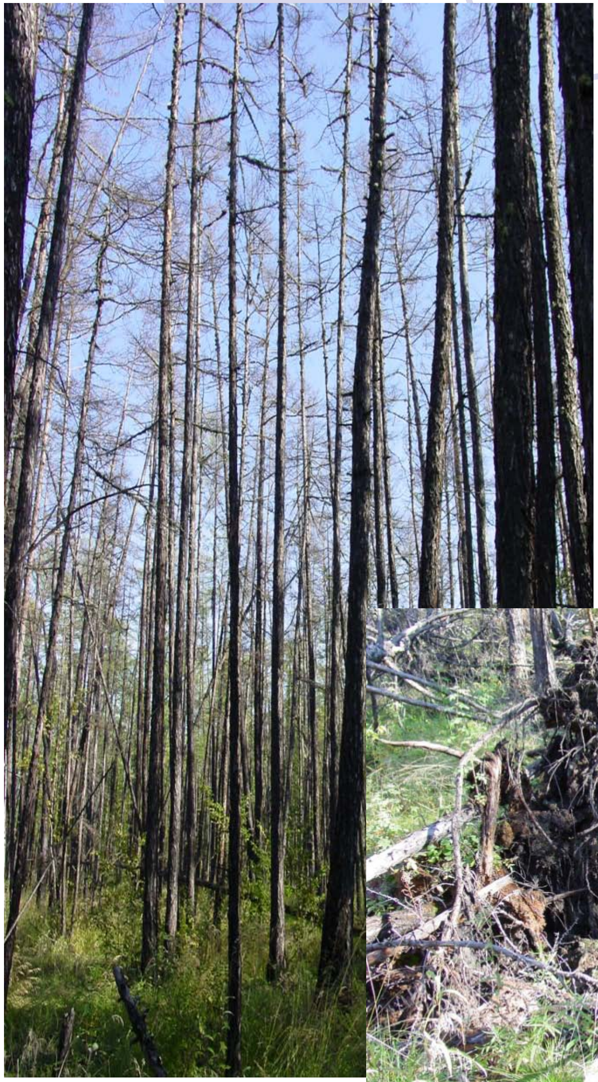


Water is accumulated in lowered places in forest

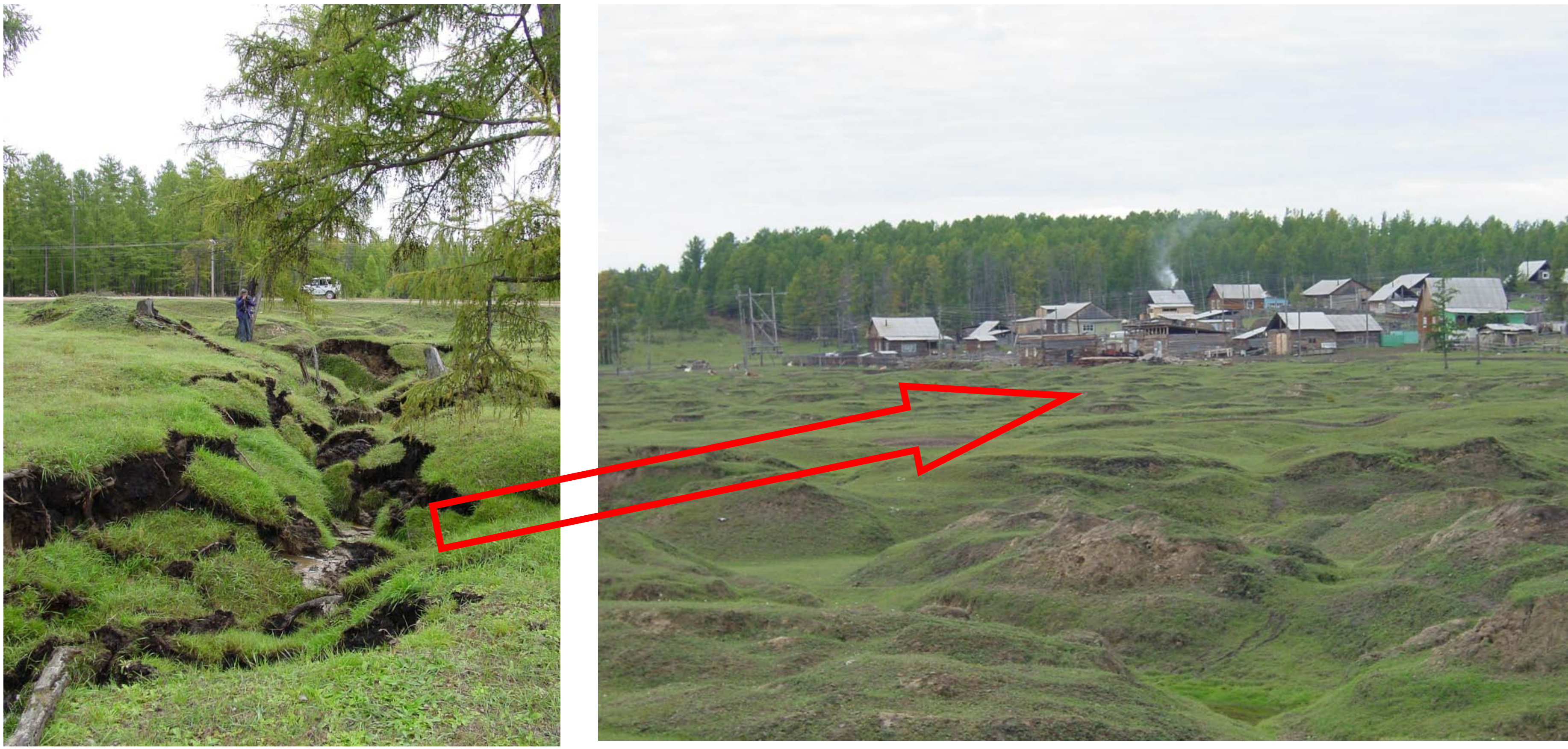


In destructed forests on slopes begin the thermoerosive process

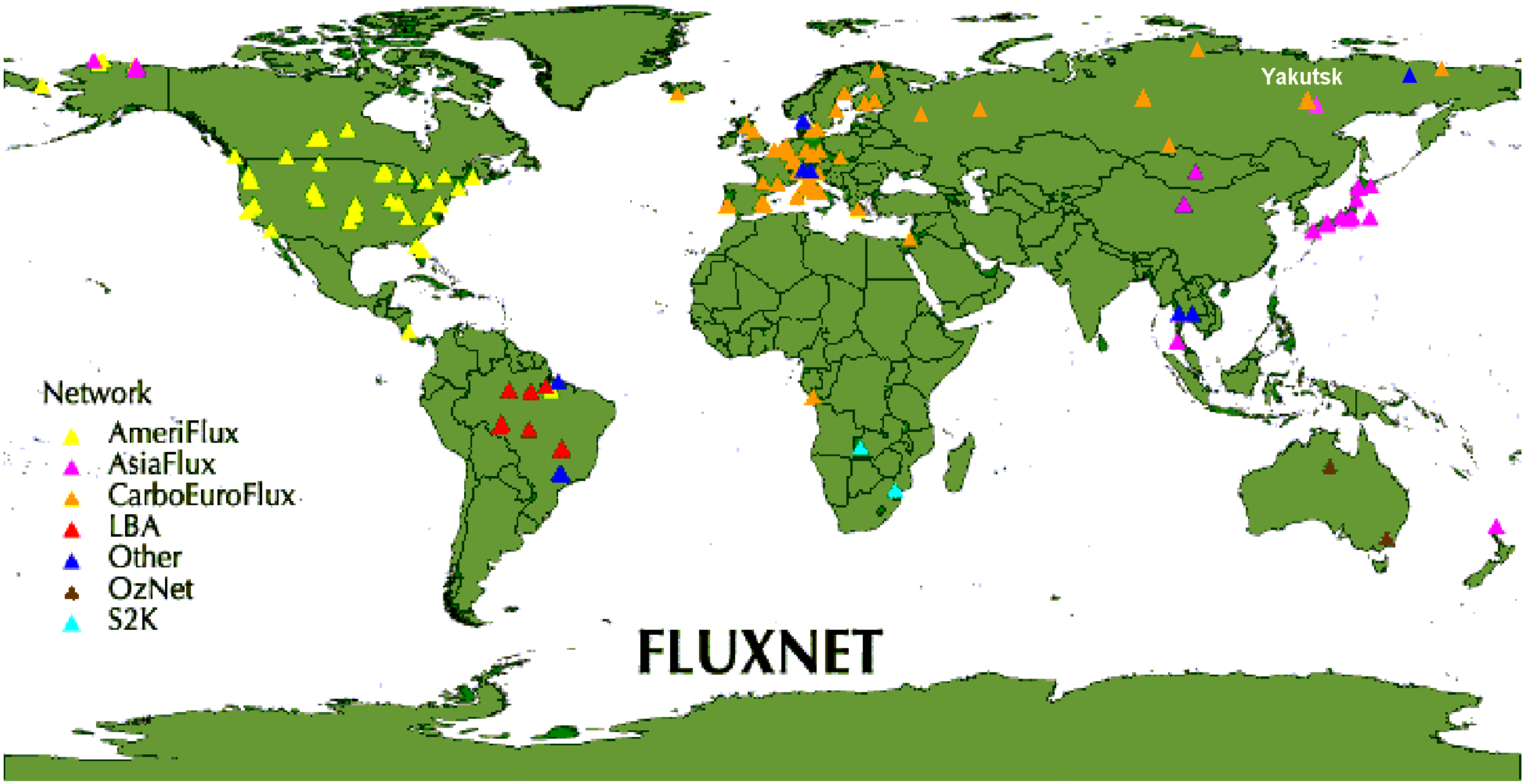
Discoloration of boreal larch forest near Yakutsk in August



Increasing of thermocarst process near town

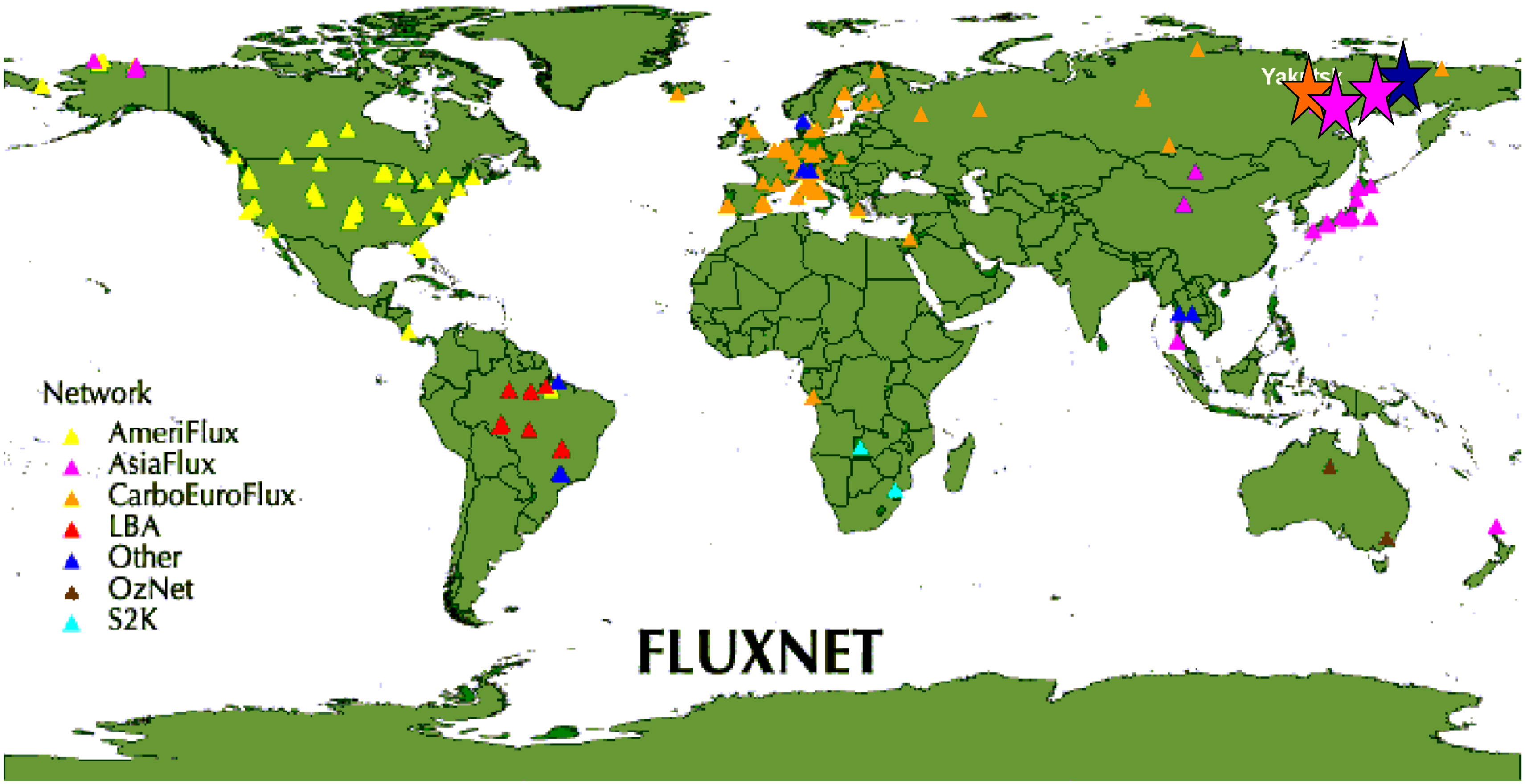


Global, continental and regional observational networks of heat, water and carbon dioxide fluxes



Scientific forest station «Spasskaya Pad» of IBPC SD RAS is the only station in the world that assesses methodologies of scientists of Asia and Europe (*CarboEurope* and *AsiaFlux* projects)

Global, continental and regional observational networks of heat, water and carbon dioxide fluxes



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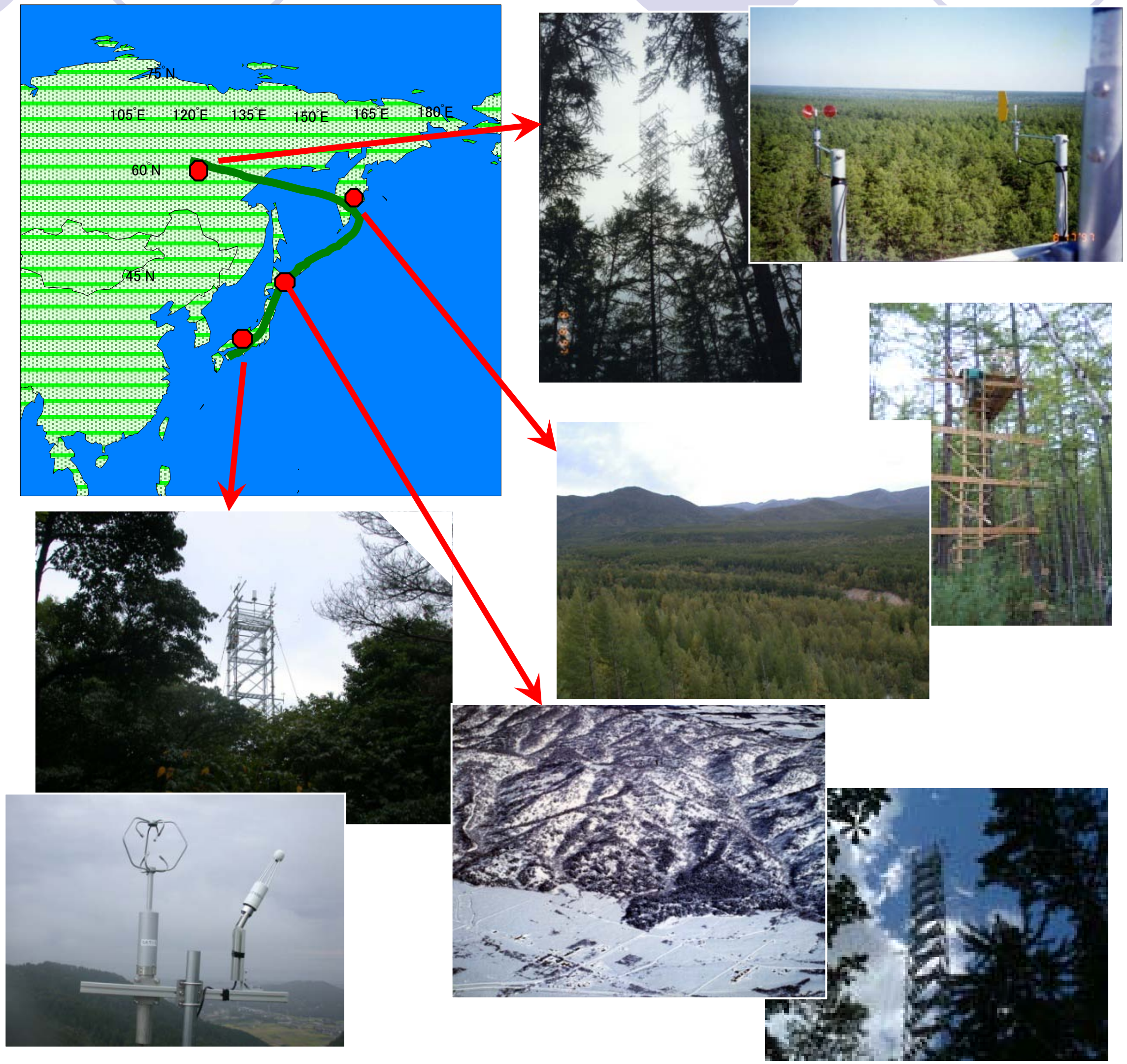
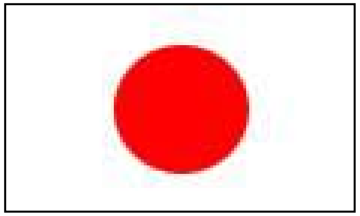
SCANNET (6 countries)

SCANNET (6 countries)

Our experimental stations on BGC in Asia

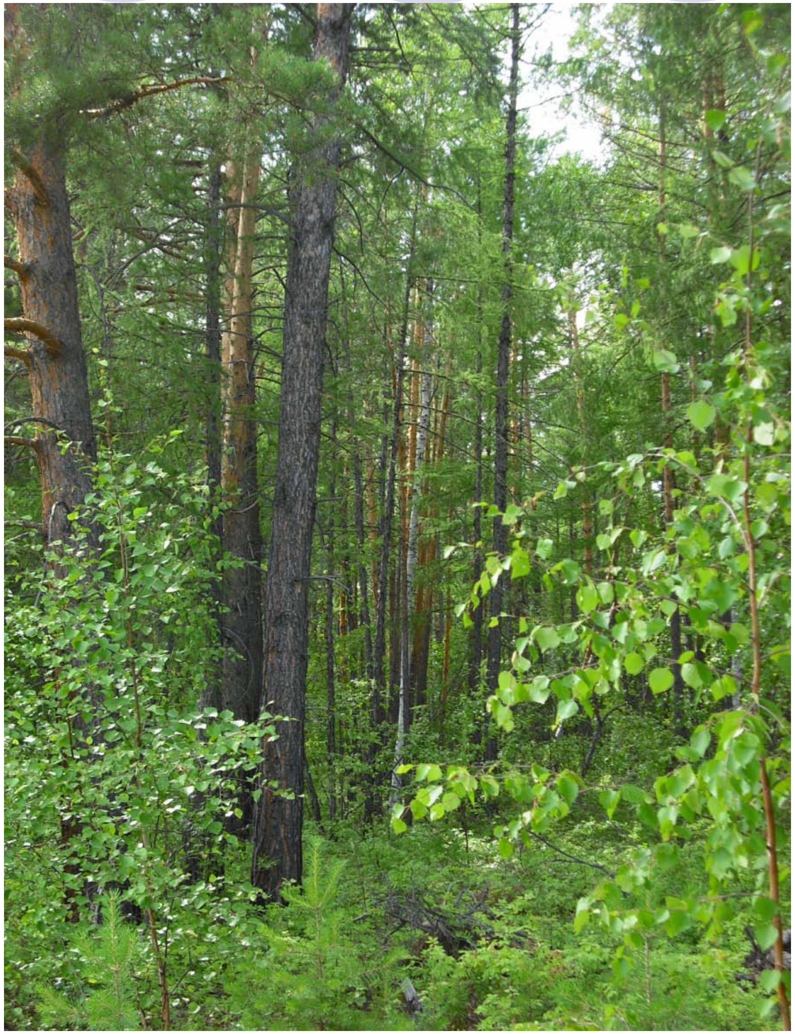


Spasskaya Pad experimental forest station, Central Yakutia

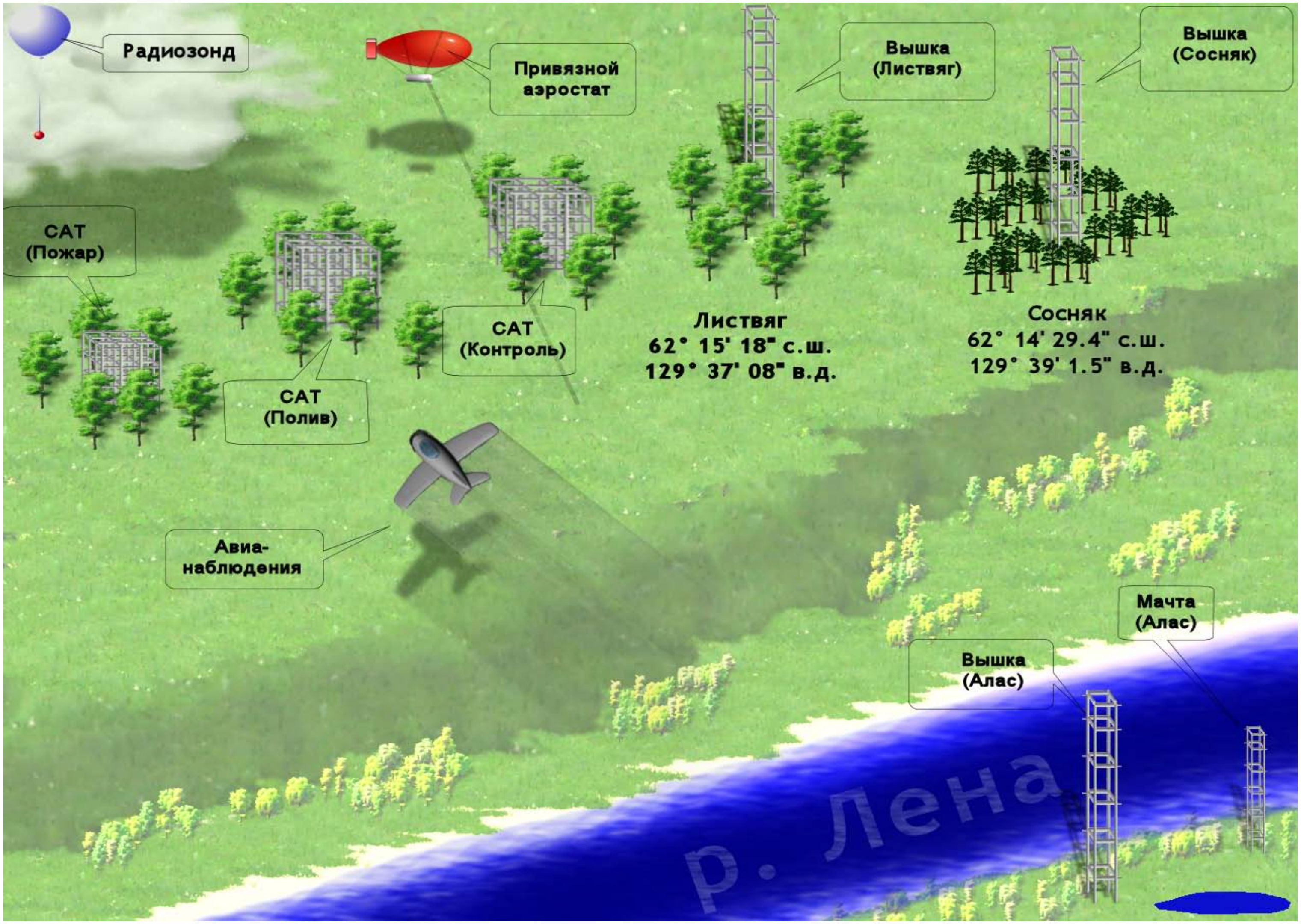


Chokurdakh experimental tundra station, East North Yakutia

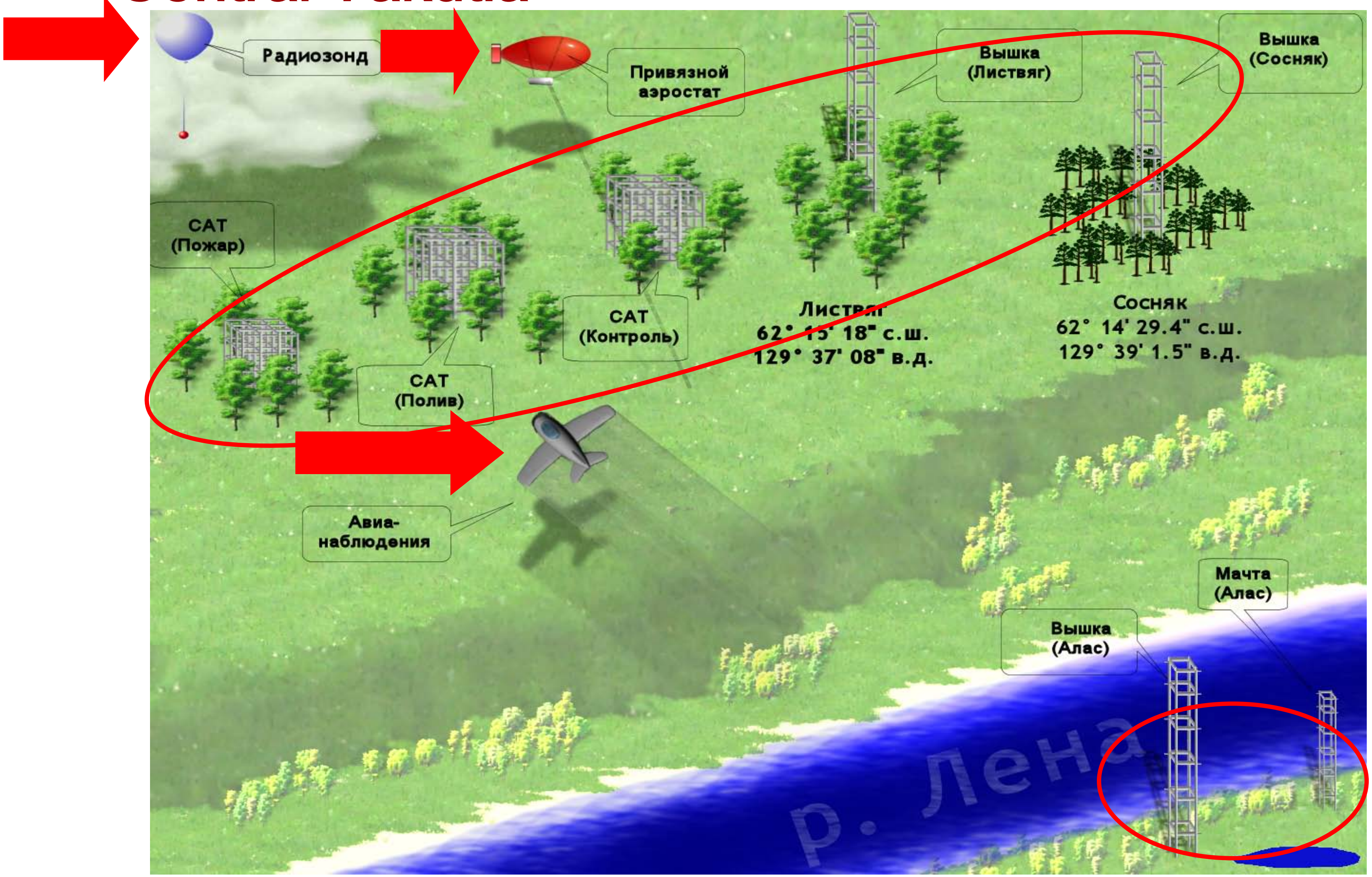
Elgeeii experimental forest station, South Yakutia



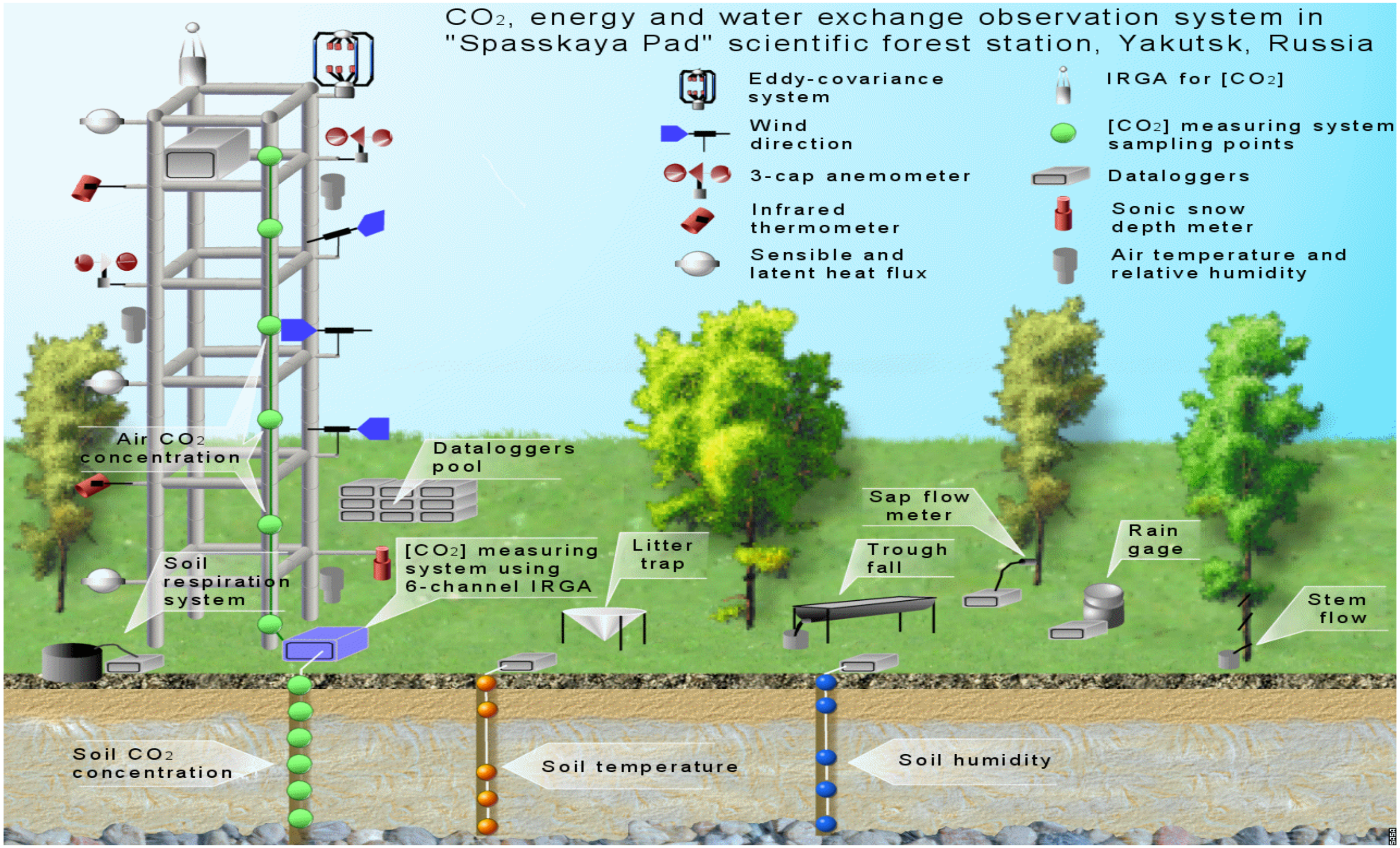
Regional scale of investigations of heat, water and carbon dioxide fluxes in forest ecosystem. Central Yakutia



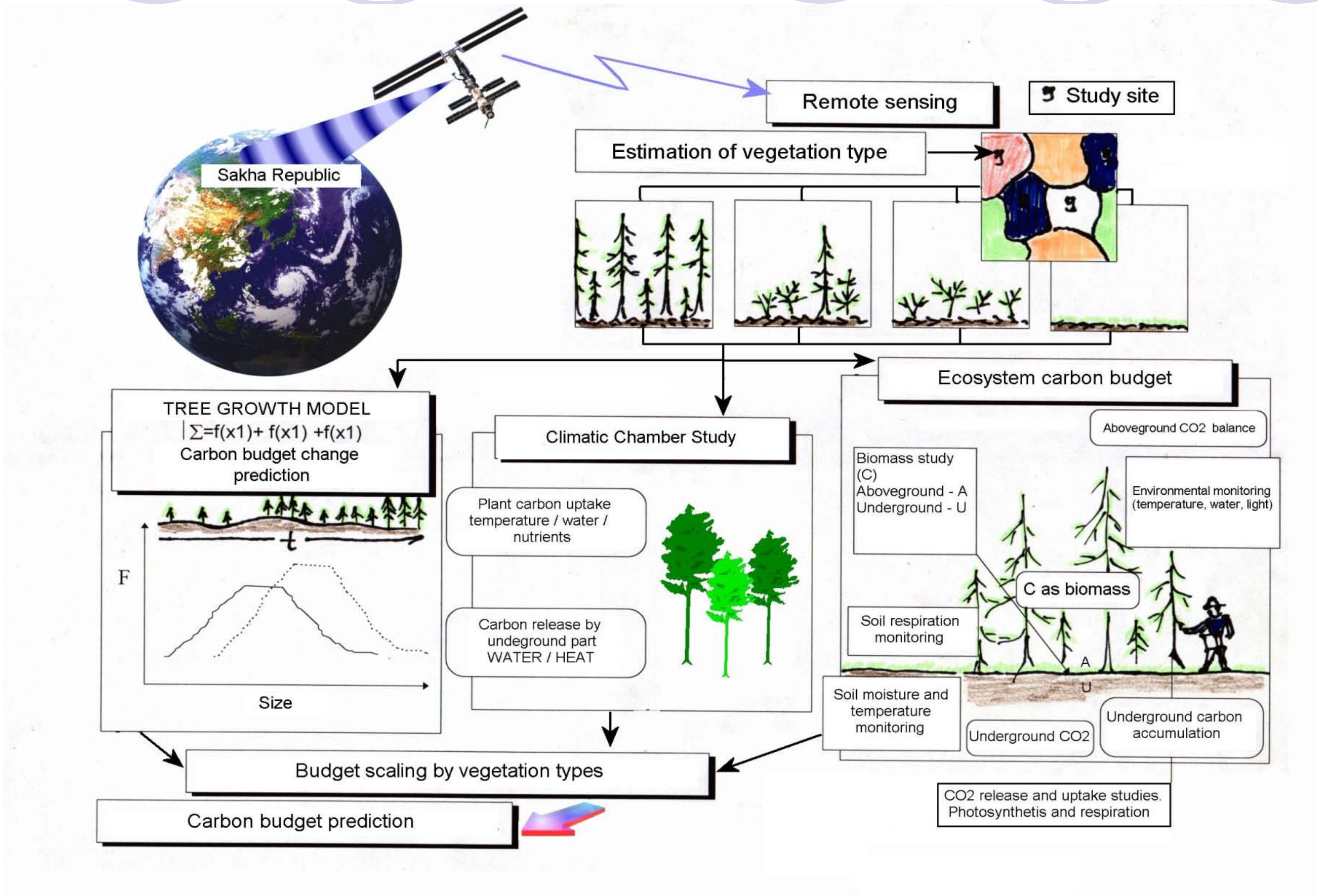
Regional scale of investigations of heat, water and carbon dioxide fluxes in forest ecosystem. Central Yakutia



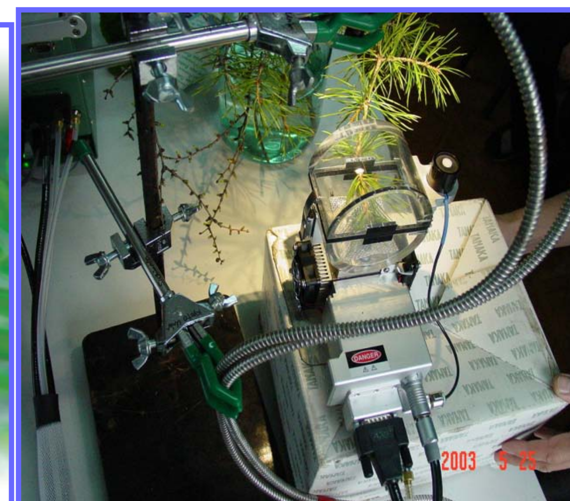
Local FluxNetWork at Spasskaya Pad Forest Experimental Station of IBPC SD RAS. 62°14'29"N, 129°39'2". Central Yakutia



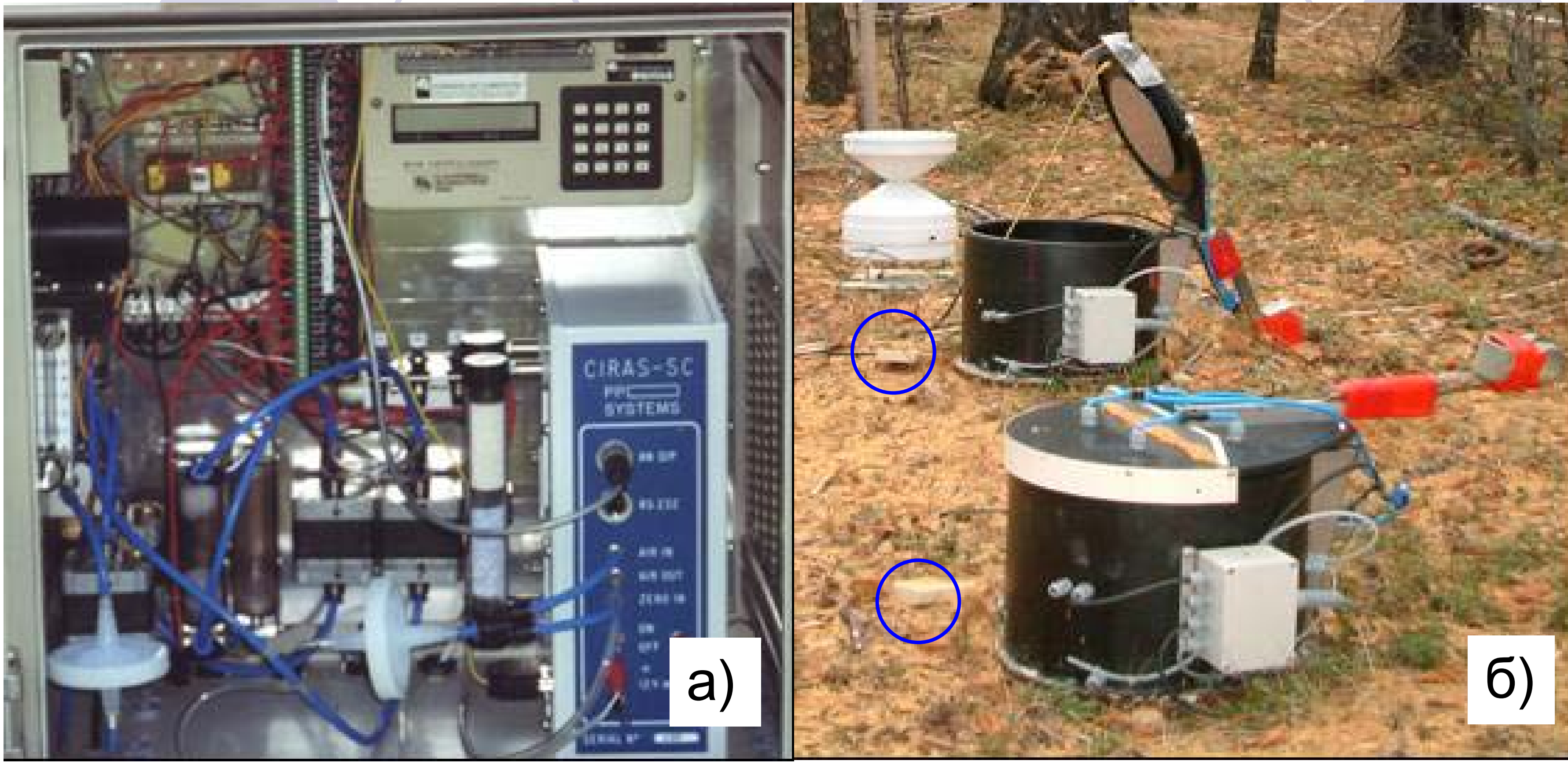
Long term studies on biogeochemical cycles



Chamber measurements.
Open and closed chambers



Chamber measurements. Open and closed chambers



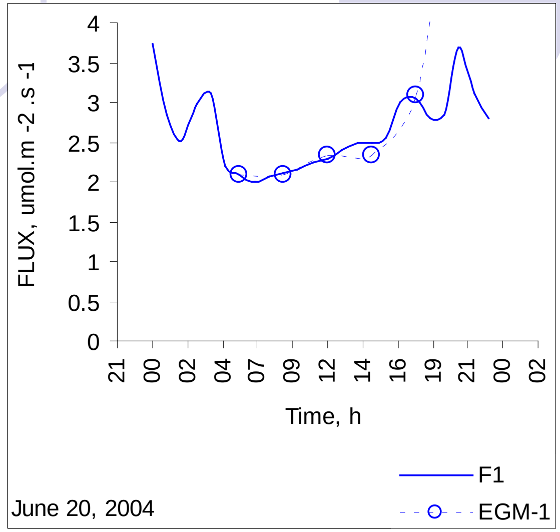
a) Control unit with Ciras-SC IRGA; b) Soil chambers

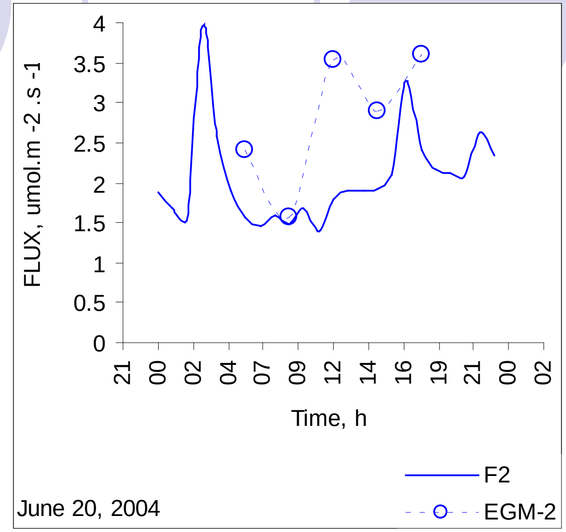
Measured parameters – soil CO_2 flux, Tsoil, η, pp, [CO_2] and [H_2O]
Measurements interval – 1 hour (4 chambers average)

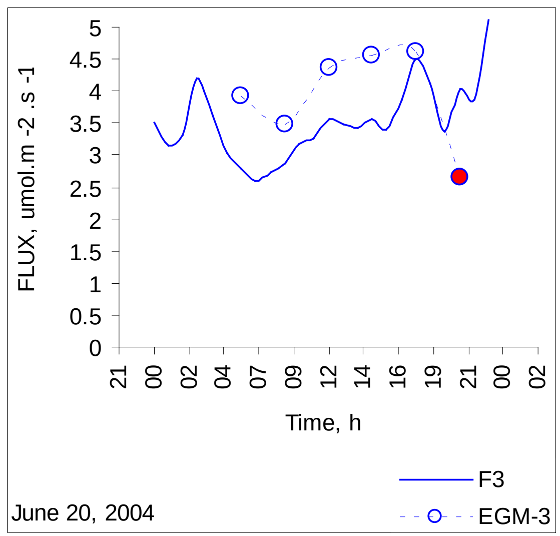
Soil temperature and moisture sensors installation depth – 5 cm

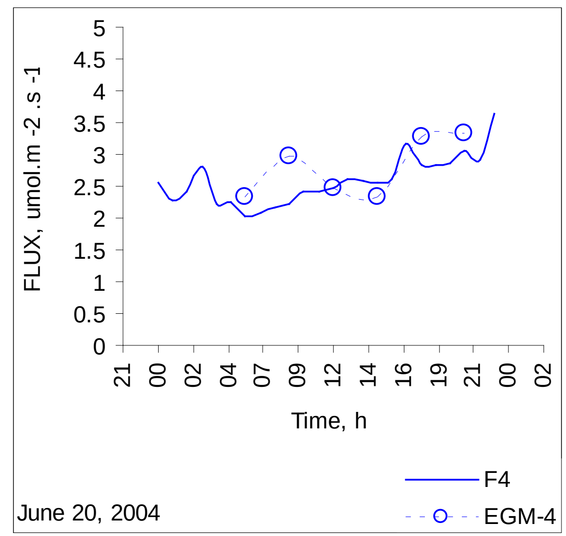
Two methods comparison

EGM-4 (PP Systems, UK)





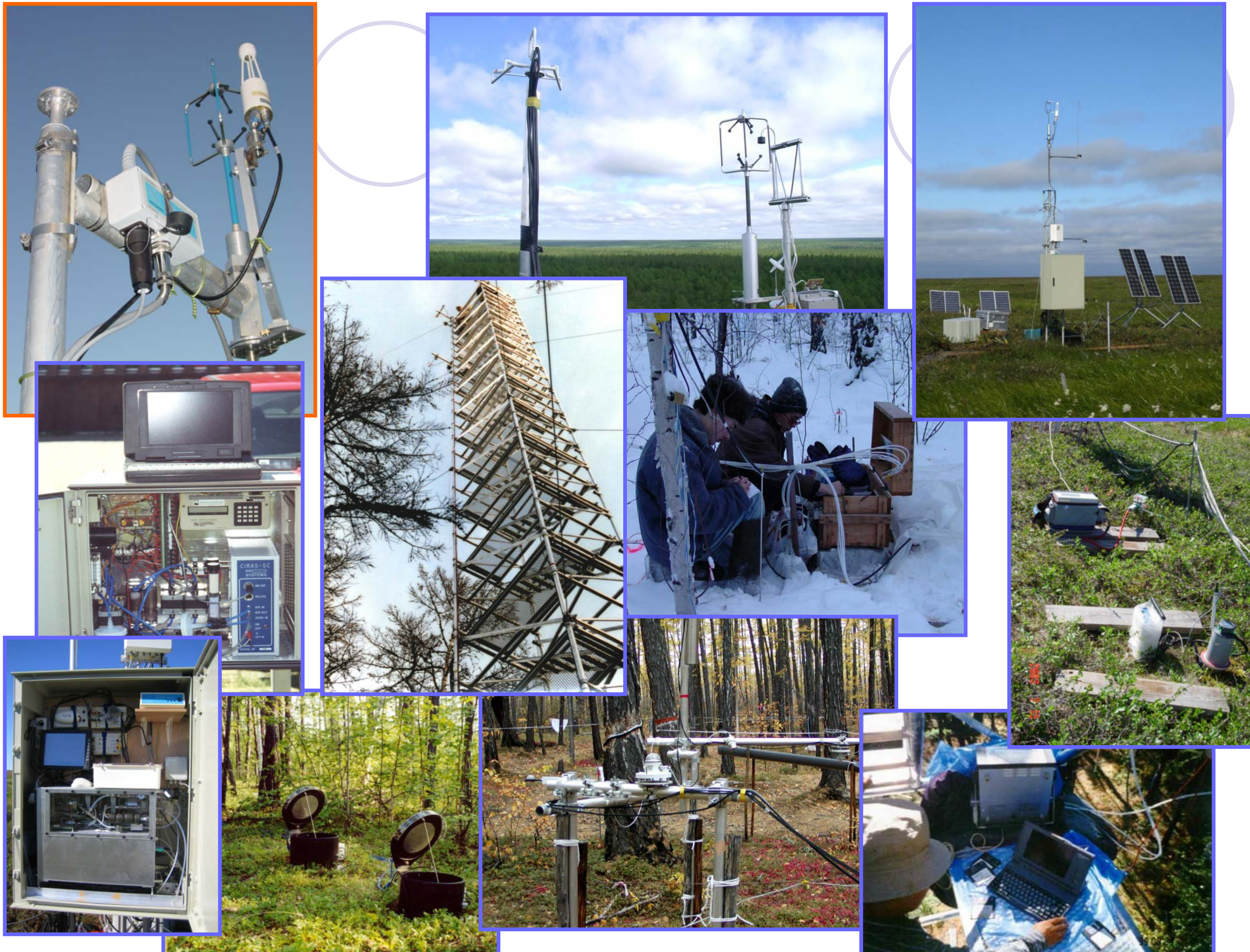




The difference among data obtained by two devices was less than 16%

Eddy covariance (EC) method

Energy, water and carbon fluxtower measurements


CIRAS-SC

EC-measurement for BVOC

- EC – a combination of:
  - 3-D wind measurements (‚sonic')
  - fast concentration measurements
- Proton-Transfer Reaction Mass Spectrometry (PTR-MS)

- PTR-MS uses ‚soft Chemical Ionisation (CI)', BVOCs in sample air are protonated:

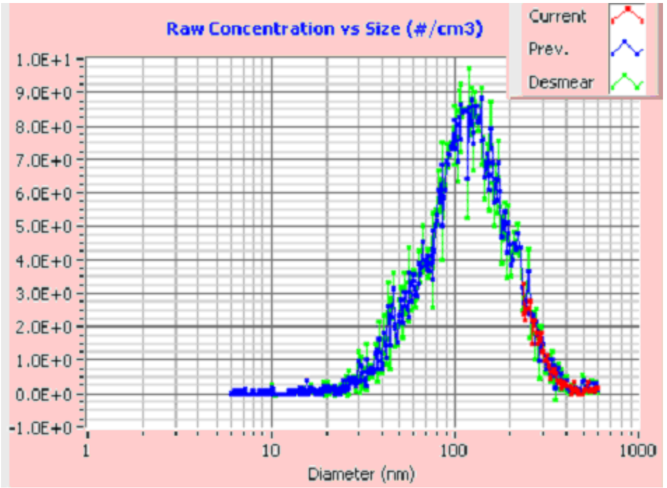
$$VOC + H_3O^+ \rightarrow VOC\text{-}H^+ + H_2O$$

- PTR-MS needs no sample gas conditioning, even mixtures of different BVOC
- very fast (up to 10 Hz), ‚online' results
- can scan for different BVOC in a sequence
- detection limit: ~50ppt

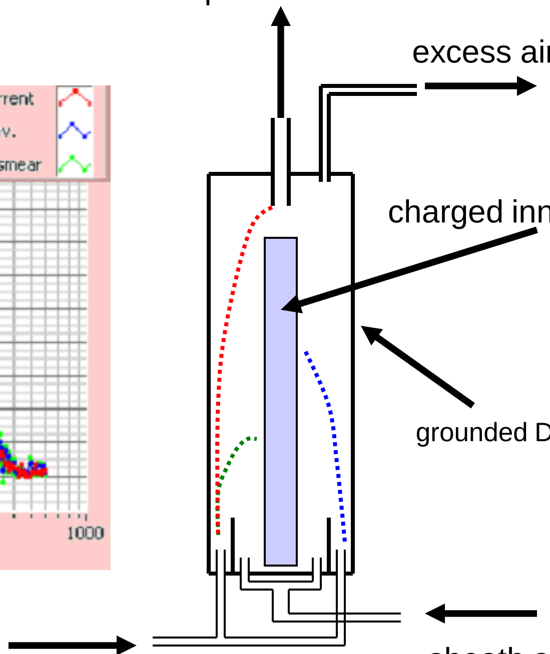
Aerosol measurements

- Scanning Mobility Particle System (SMPS)
  - ca. 6 – 600 nm particle size distribution
- Air Ion Spectrometer (AIS)
  - ca. 0.4 – 40 nm particle size distribution

SMPS



DMA



The basic strategy of northern plants: survival and regeneration to the detriment of high productivity (NPP ~0.8-1.3 t per ha)

Homeostatic adjustment

The physiological response

Larch-dominated carbon density difference in Russia

Region	kg C/m^2	kg C/m^3
Mean 29 regions	3.71(100%)	0.52 (100%)
Ust Maya, SYa	4.67 (26%)	0.43 (17%)
Yakutsk, CYa	3.82 (3%)	0.49 (6%)

Homeostatic adjustment

1) permafrost (acute continental climate);
2) short growing season (less 60 (tundra) and 100 days (forest));
3) early preparation and leaving of plants to winter dormancy (buds- mid of July and early August & vegetation all growing season- quick growth, dormancy on time, autumn hardening);
4) the high duration of daily photosynthesis (15-16 hours in forest and 23 hours in tundra);
5) small celled, xeromorphism;
6) low LAI, transpiration and assimilation surface;
7) the advanced root system;
8) an advancing of growth of roots above growth of an elevated part of plants in the beginning of growing season (1.4 times);
9) economy use of water on creation of unit of a biomass of a plant;
10) equation in use rain and thawed snow water;
11) "self-independent" work powerful plant acceptors (generative organs);
12) pathological lack of photosynthates during formation and development generative organs (low starch : sucrose);
13) low net primary productivity(less than 3.1 t/ha);
14) absence of the big differtence between tree species in photosynthesis rates;
15) high variability (2.5 times) of ecosystem response (NEE,SR, Photosynthesis,NPP,Cannopy conductance etc)
16) …………???

The physiological response

1) high level of transpiration;
2) high stomatal conductance;
3) high water use efficiency;
4) high stability xylem water potential of plants (-1.5 MPa);
5) high level of net photosynthesis rate (till 13.5 μMCO_2/m^2 s^{-1});
6) high variability of photosynthesis rate;
7) high daily productivity of photosynthesis at small dark and night respiration expenses;
8) high rate of photosynthesis in the initial stages of development of plants;
9) high level of deposition and re-assimilation of secondary substances;
10) high level growth inhibitors (ABA and phenol substances);
11) ……………???

Global Carbon Stocks in Vegetation and Soils

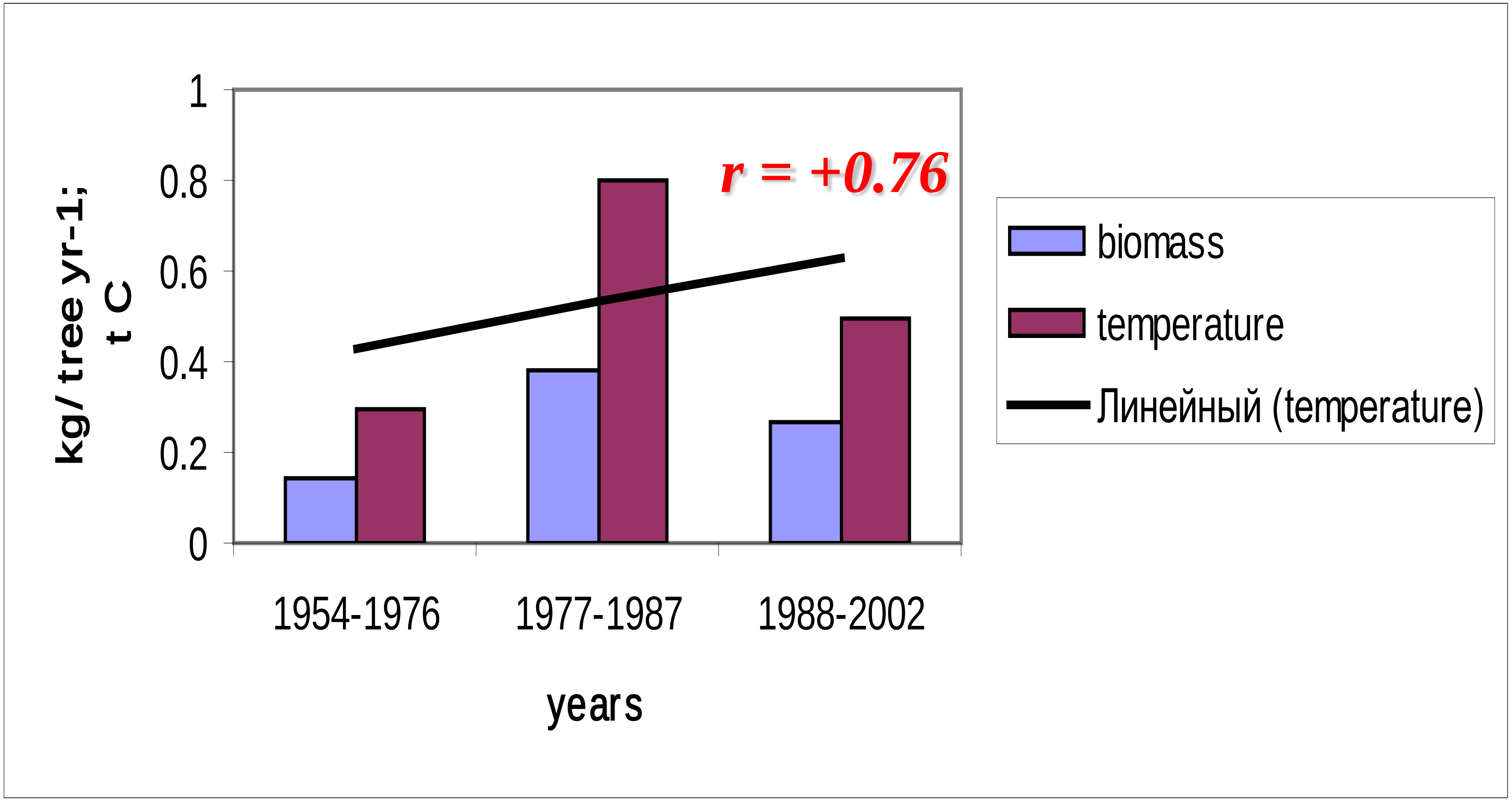
Biome	Area (10^6 km^2)	Global Carbon Stocks (Gt C) Vegetation	Soils	Total	NPP, t C ha $^{-1}$ yr^{-1}
Tropical forest	17.6	212	216	428	11.0 (5.0-17.5)
Temperate forest	10.4	59	100	159	6.3 (2.0-12.5)
Boreal forest	13.7	88	471	559	4.0 (1.0-7.5)
Tropical savannas	22.5	66	264	330	4.5 (1.0-10.0)
Temperate grassland	12.5	9	295	304	3.0 (1.0-7.5)
Deserts & semideserts	30.0	8	191	199	0.05 (0.0-0.1)
Tundra	9.5	6	121	127	0.1 (0.0-0.4)
Wetlands	3.5	15	225	240	0.9 (0.1-3.9)
Croplands	16.0	3	128	131	1.6 (0.2-3.9)
Russuan forest	8.8	33	130	163	3.1 (2.6-3.7)
Yakutian forest	1.1	3	11	14	3.1
Yakutian tundra	0.4	0.1	6	6	0.8
Total	135.6	466	2011	2477	

Carbon pool of Yakutia, *G t C per year*

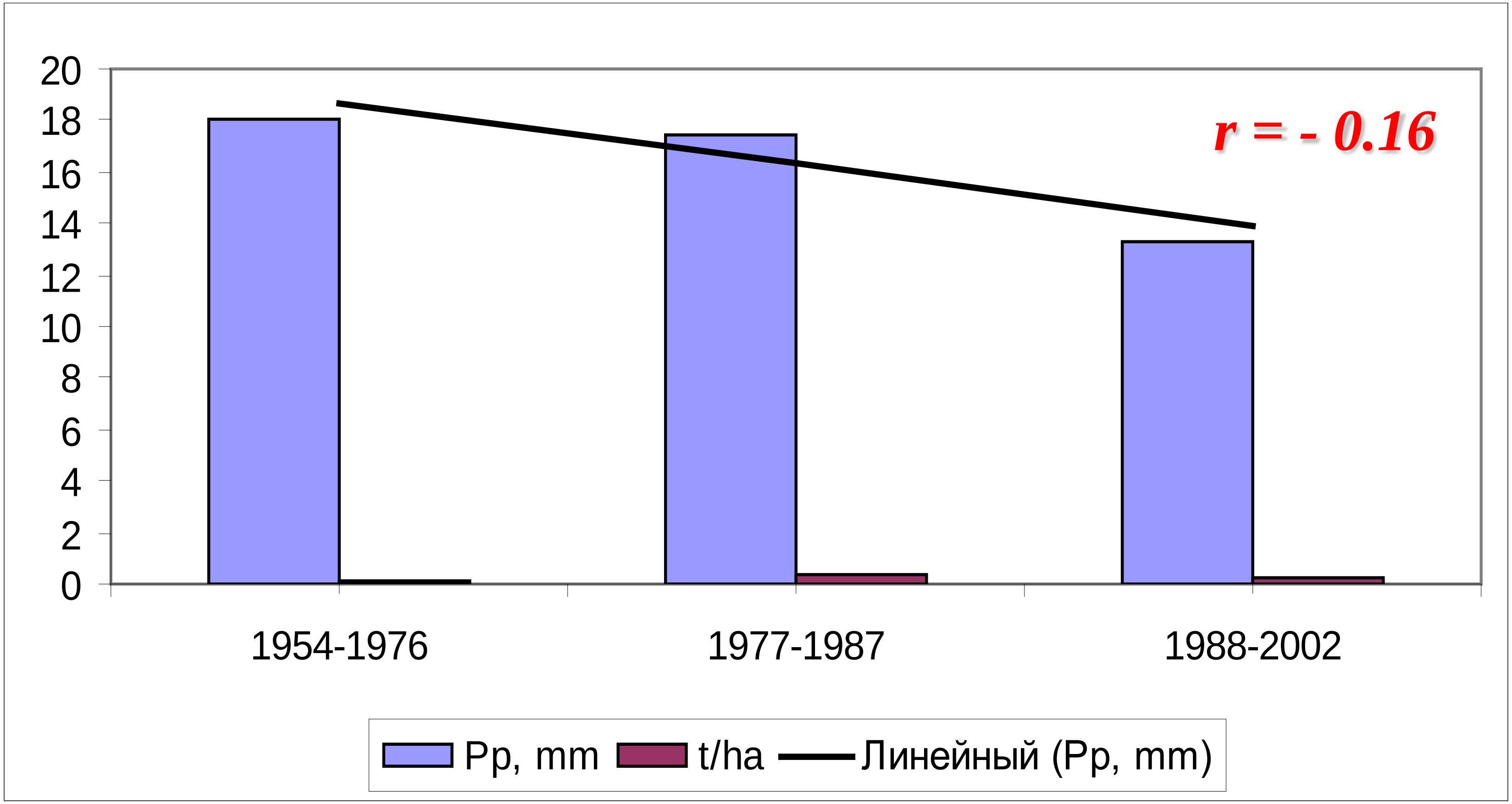
Plant carbon	2.2 -4.1
Soil carbon	17.1
Annual sequestration	0.28
Including:	
Forest	
Area	125.5 *M ha*
Plant carbon	2.2-4.5
Soil carbon	11.2
Annual sequestration	*0.25*
Tundra	
Area	37 *Mha*
Plant carbon	0.053
Soil carbon	5.9
Annual sequestration	*0.03*

Maximov et al.,2005

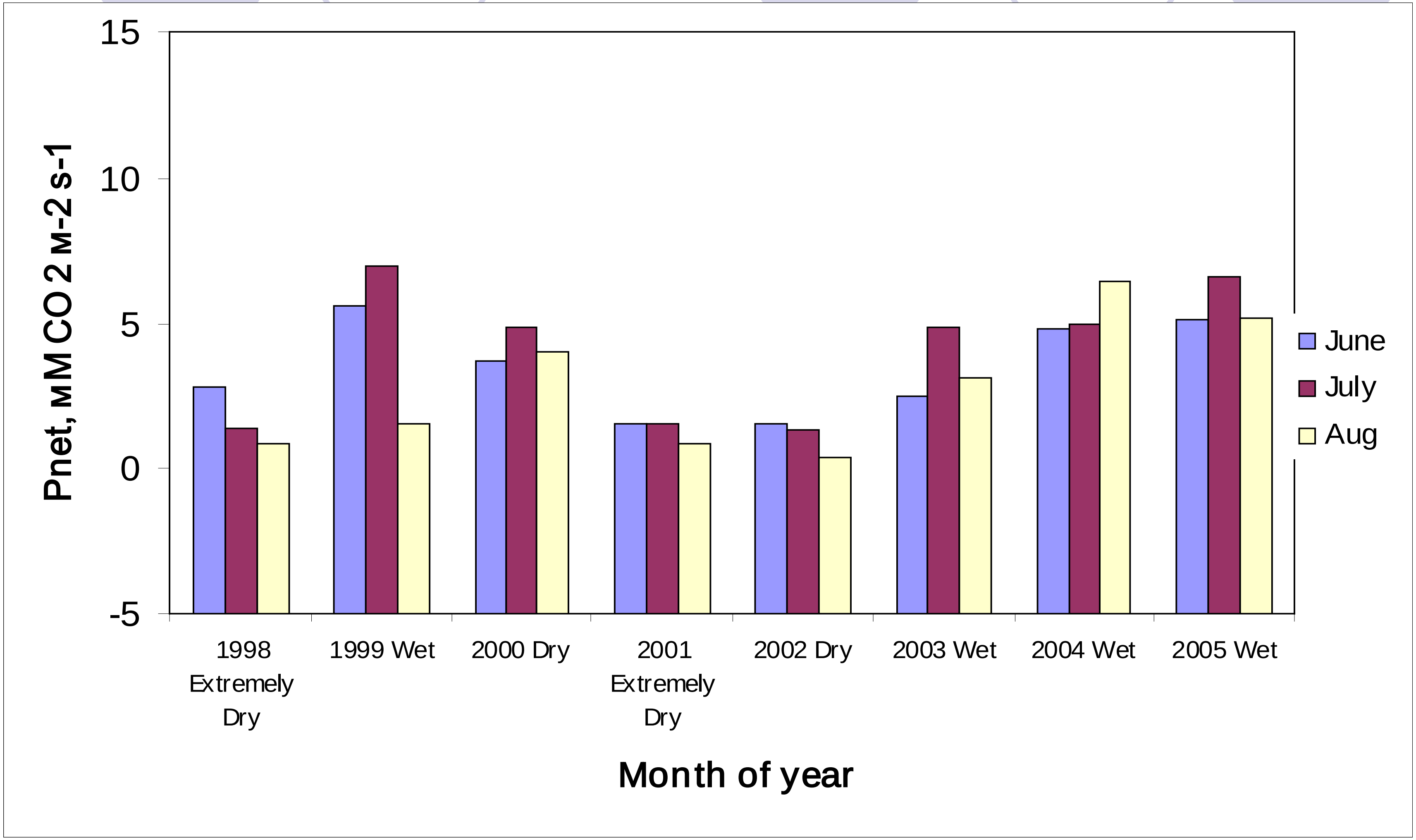
Long term annual growths of *Larix cajanderi* crown biomass and atmospheric temperatures. Spasskaya Pad,1954-2002



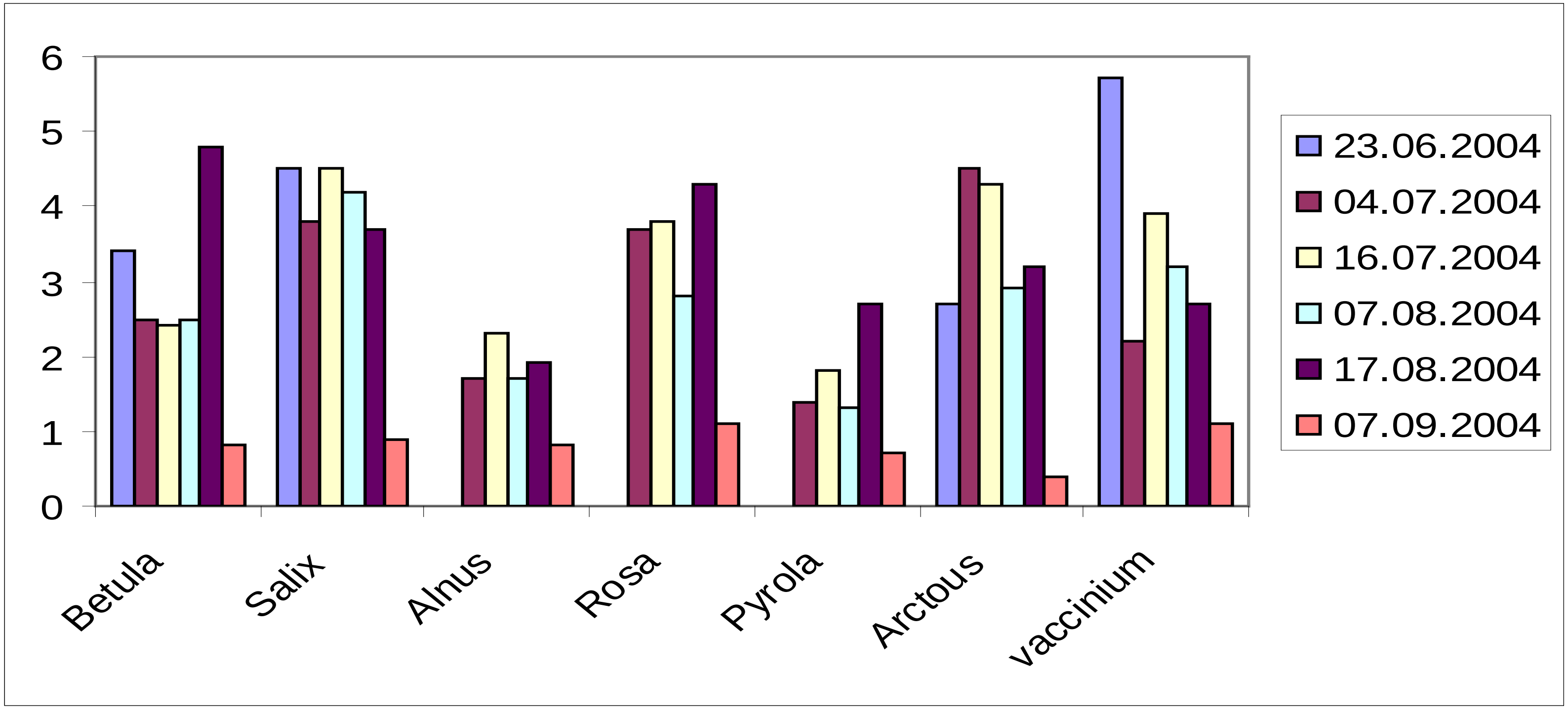
Long term annual growths of *Larix cajanderi* crown biomass and atmospheric precipitation. Spasskaya Pad,1954-2002



Seasonal changes of net-photosynthesis in *Larix cajanderi*, 1998-2006

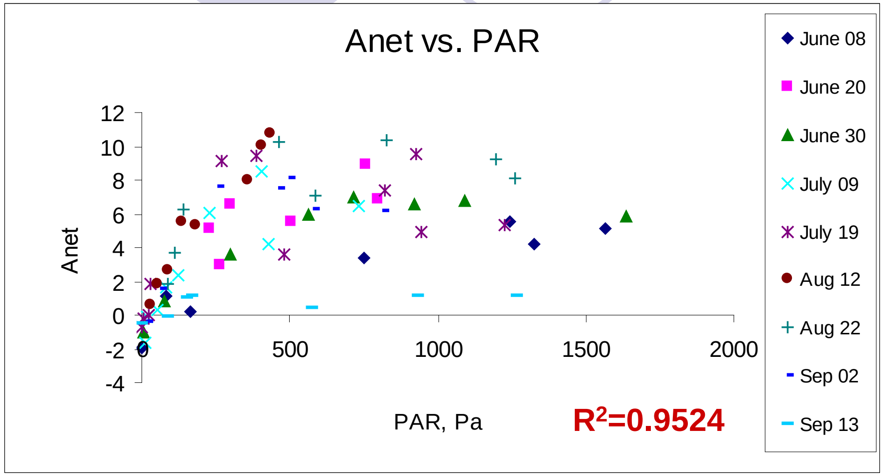


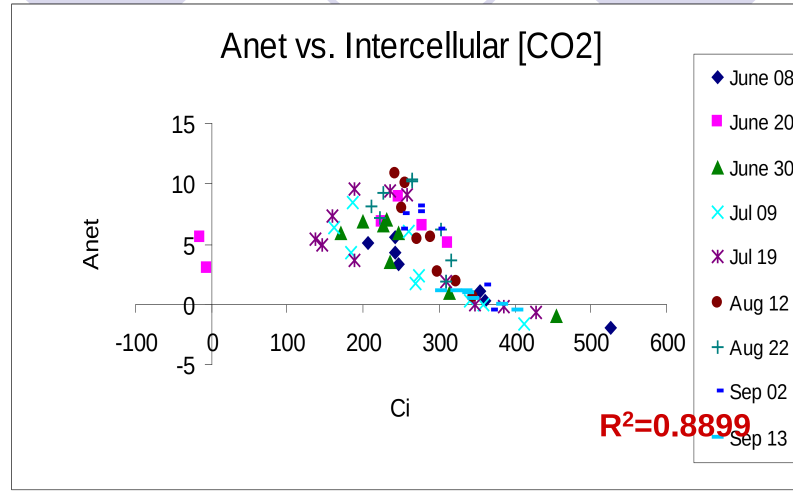
Mean Photosynthesis rate of understorey and floor vegetations, Larix forest, Wet 2004 (n=9)

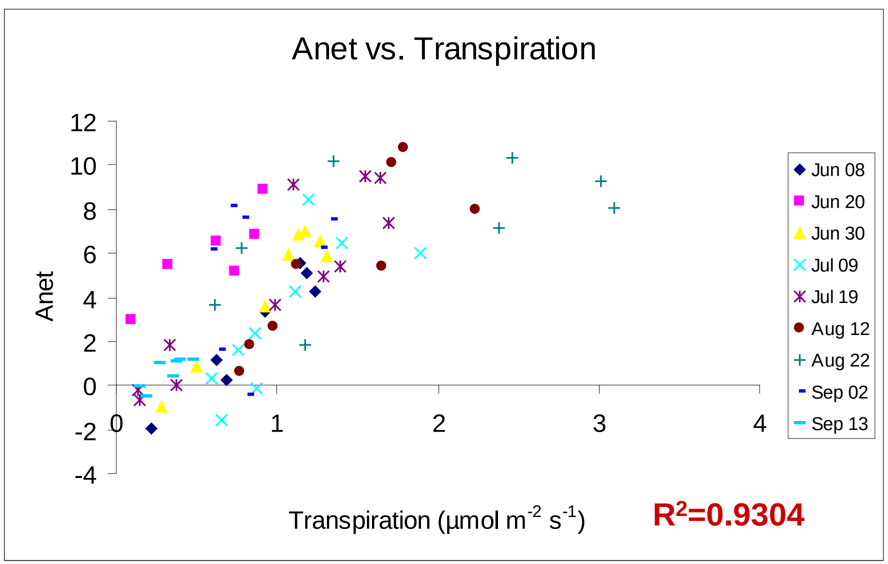


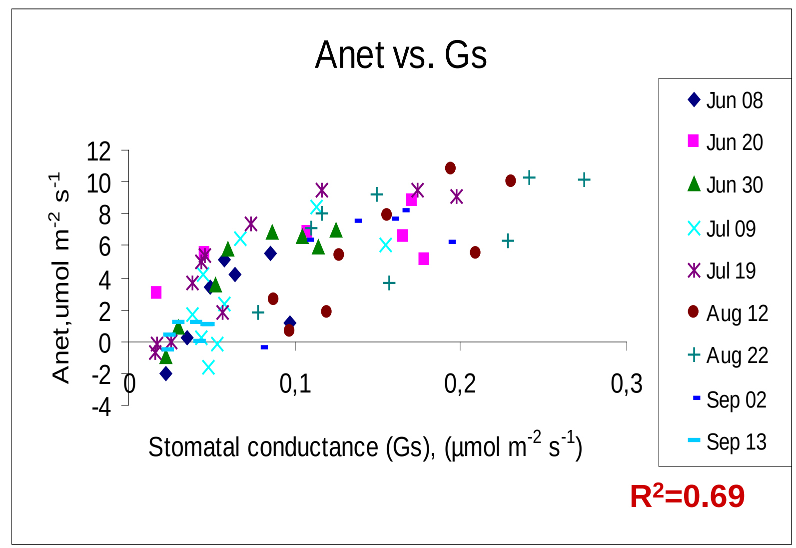
Photosynthesis of Larch	5.2 t C/ha season-1	
Photosynthesis of understorey and floor	3.0	
For the larch ecosystem	4.1	
Photosynthesis for ecosystem	8.2	[100%]
Larch	5.2	63
Canopy	3.0	37

Exogenic and endogenic factors dependency of Larch photosynthesis

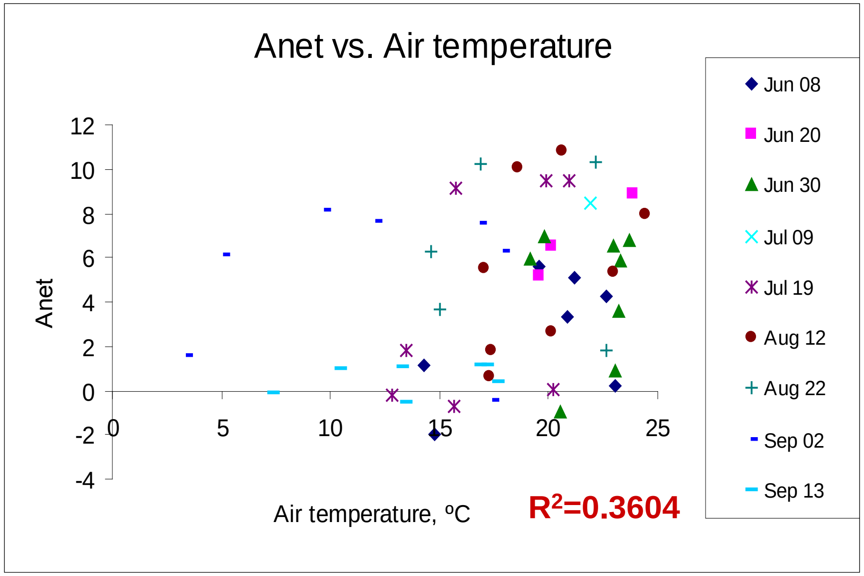




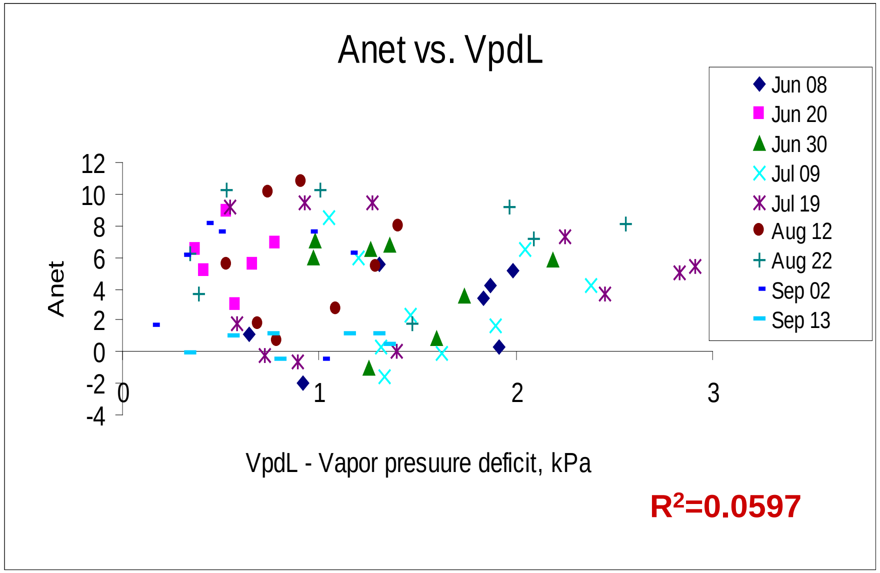




Exogenic and endogenic factors dependency of Larch photosynthesis



R^2=0.3604



R^2=0.0597

Maximum values of carboxylation (Vc max) and electron transport (J max) for some tree species

Ecosystem	Vcmax ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	Jmax ($\mu mol\ E_{hv}\ m^{-2}\ s^{-1}$)	References
Larix gmelinii	45.1	44.5	Korzukhin et al., 2004
Conifer boreal forest	46	123	Baldocchi D.D. Mayers T. 1998
Sparse conifer forest	40	80	Warnant P. и др. 1994
Pinus sylvestris	37,5-117	71-307	Korzukhin et al., 2004
Larix cajanderi	**39.9**	**93.7**	**Our studies**

Monthly and seasonal carbon emission from larch forest soils, t C · ha^{-1}

Year	May	Jun	Jul	Aug	Sep	Seasonal sum, t C·ha^{-1} ± standard deviation
2001	–	–	1,43 / 39,5	1,06 / 29,3	0,26 / 7,2	3,68±0,08
2004	0,41 / 12,4	0,58 / 17,4	0,78 / 23,4	1,13 / 33,9	0,43 / 12,9	3,23±0,21
2005	0,33 / 6,71	0,77 / 15,7	1,56 / 31,8	1,53 / 31,2	0,72 / 14,7	4,82±0,12
2006	–	1,01 / 17,3	2,15 / 36,9	1,84 / 31,6	0,49 / 8,4	5,56±0,37

Numerator – flux, t C ha^{-1}, denominator – percentage from seasonal cumulative sum

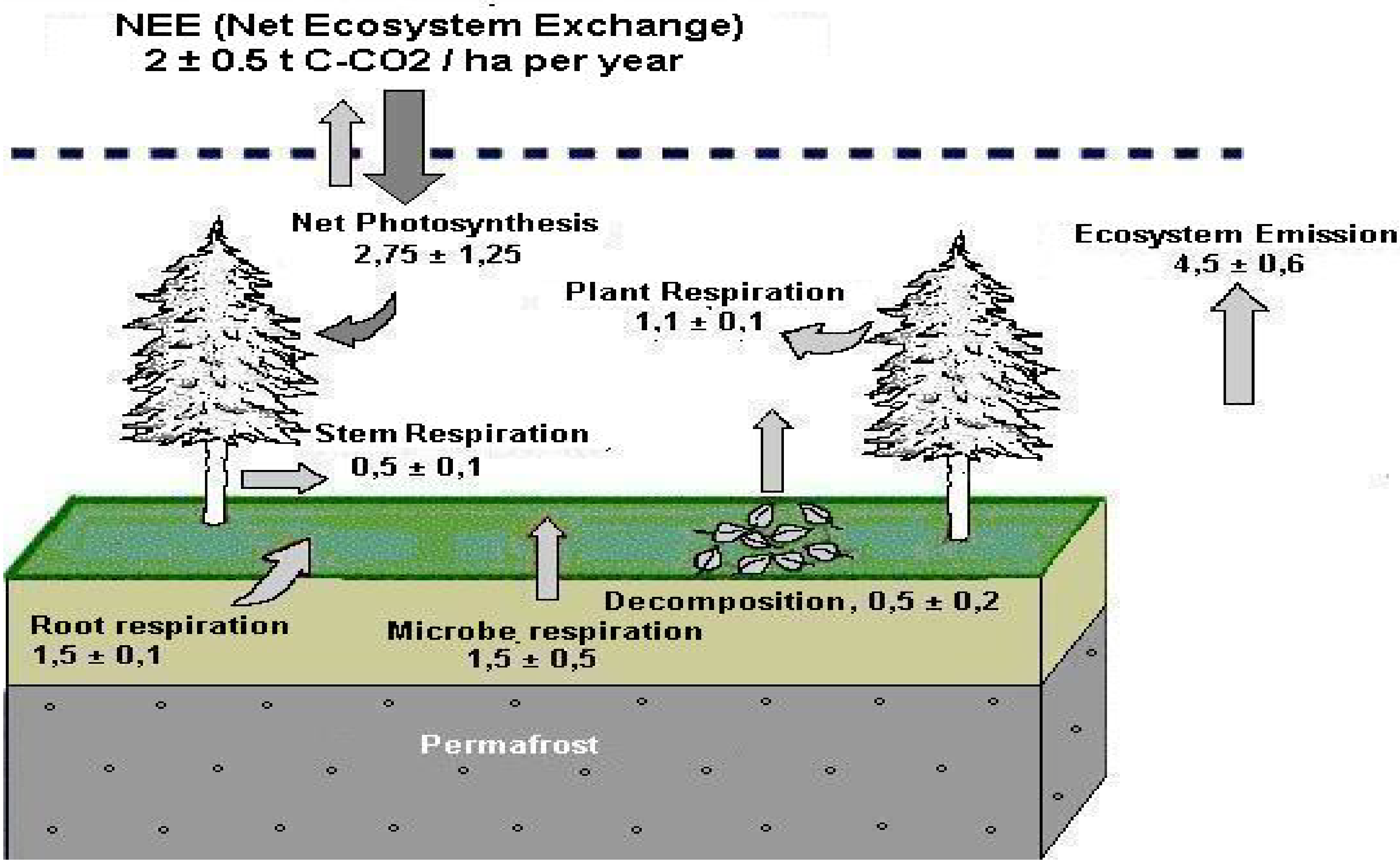
Mean Daily Soil Respiration rate for growing season in different soil climatic zone of Russia

Zone	$g\ C\ /\ m^2\ day^{-1}$
North Taiga	0.47 - 2.10
Middle Taiga	0.65 – 2.67
South Taiga	0.60 – 4.29
Forest steppe	0.56 – 3.34
Steppe	0.48 – 2.96
Permafrost Forest*	2.73 – 3.87

- *our study

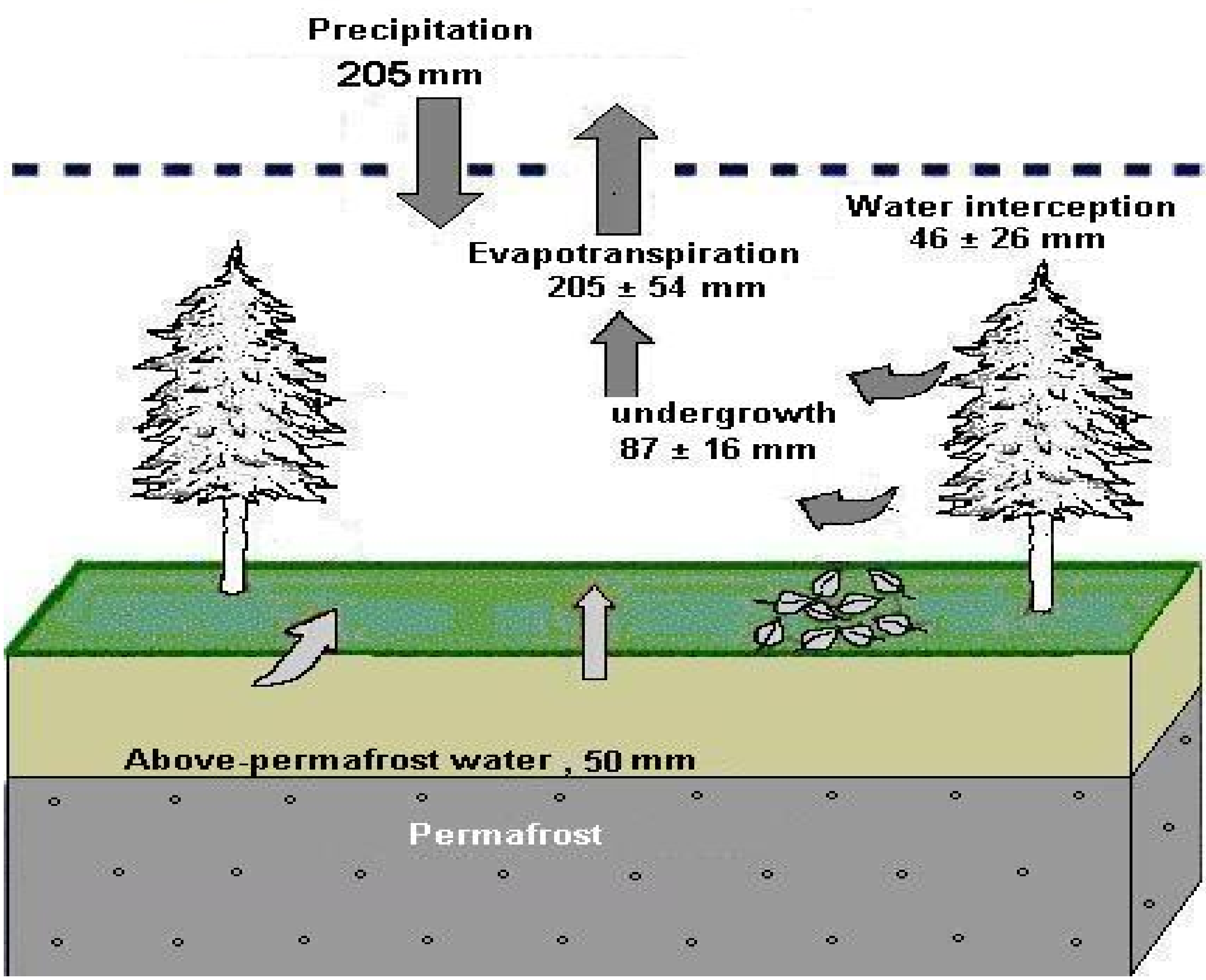
Kudeyarov, 2003

Annual carbon budget of permafrost forest ecosystems, *t C/ha per year*



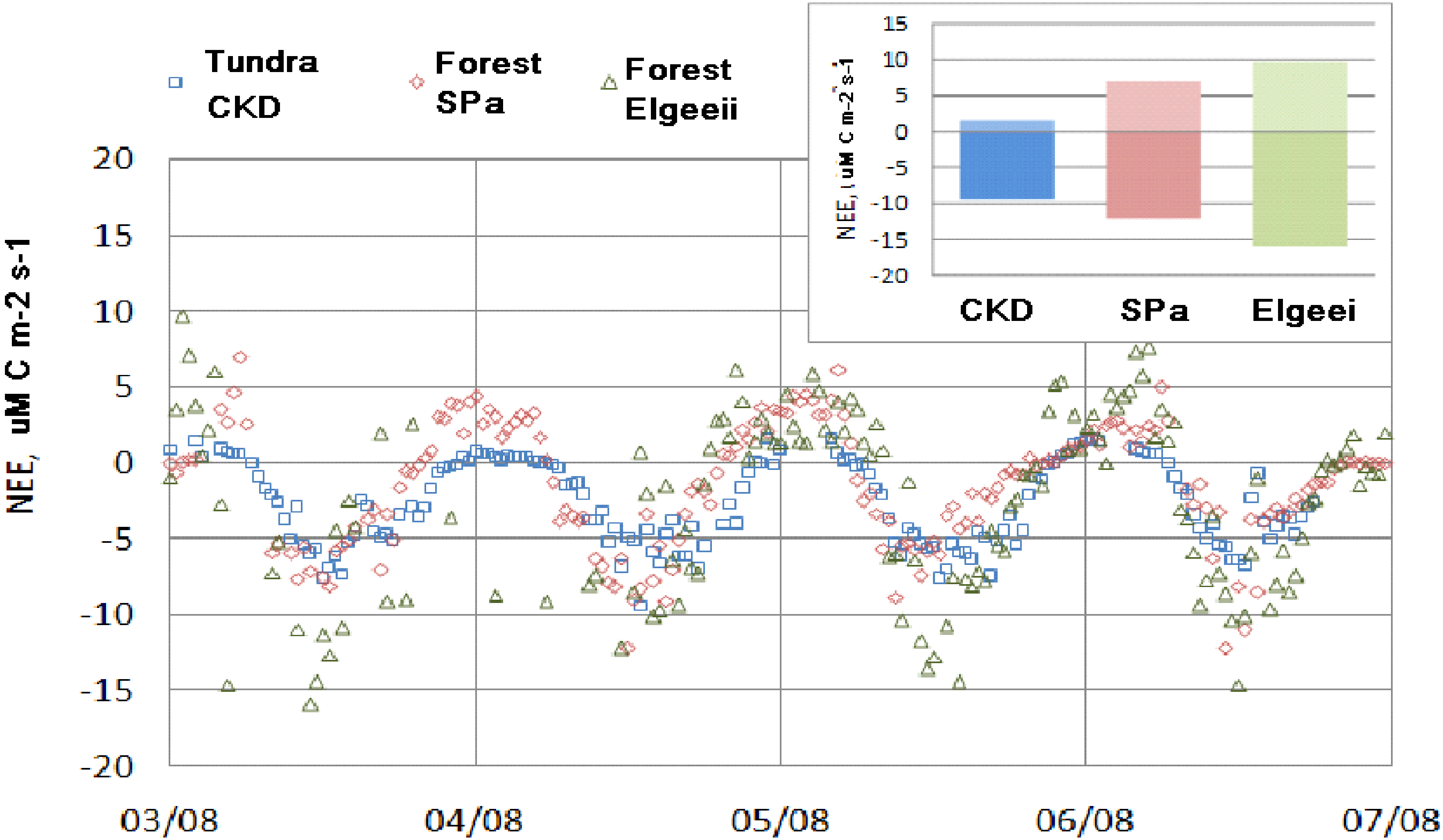
Maximov, 2003

Annual water budget for permafrost forests, *mm per year*

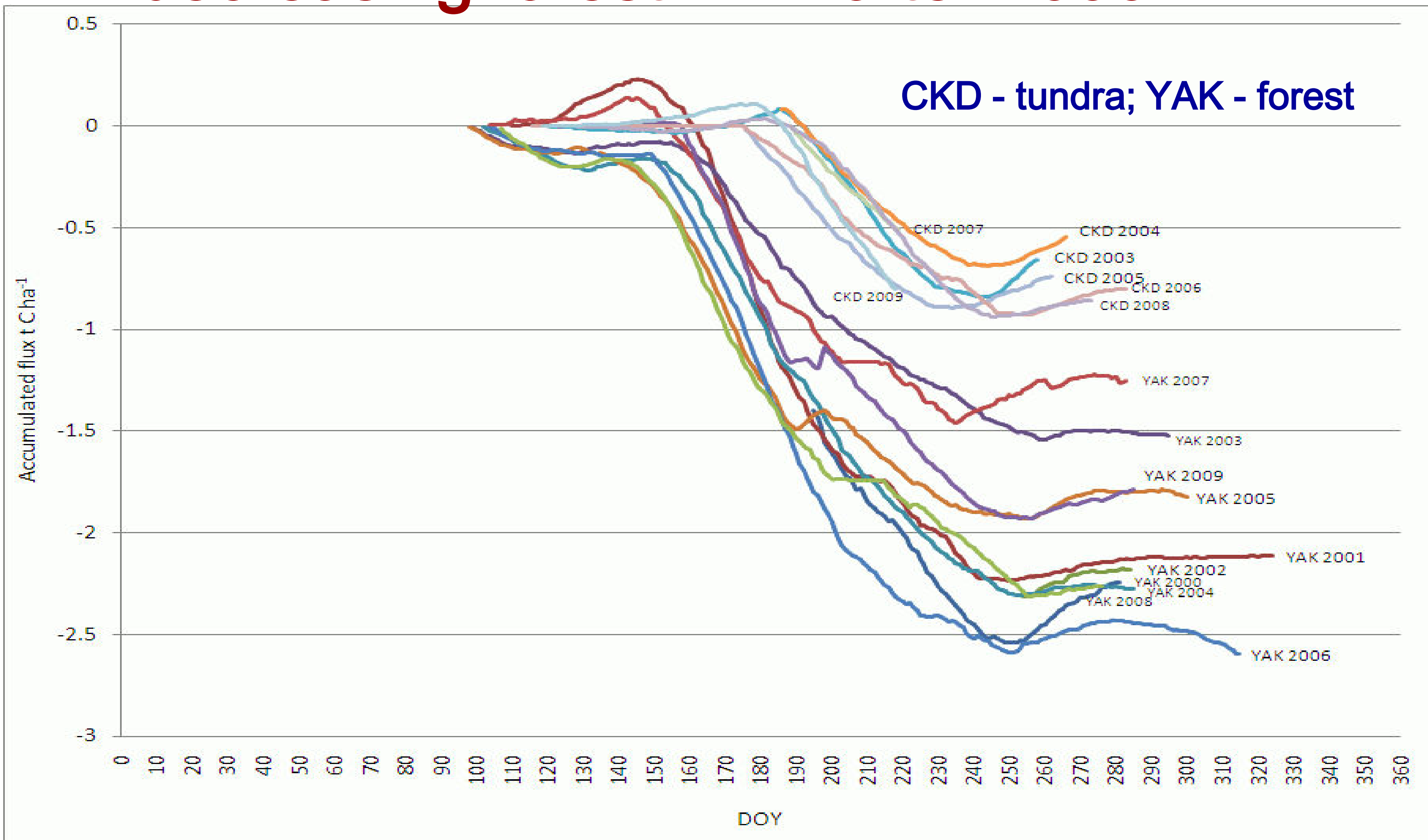


Maximov, 2003

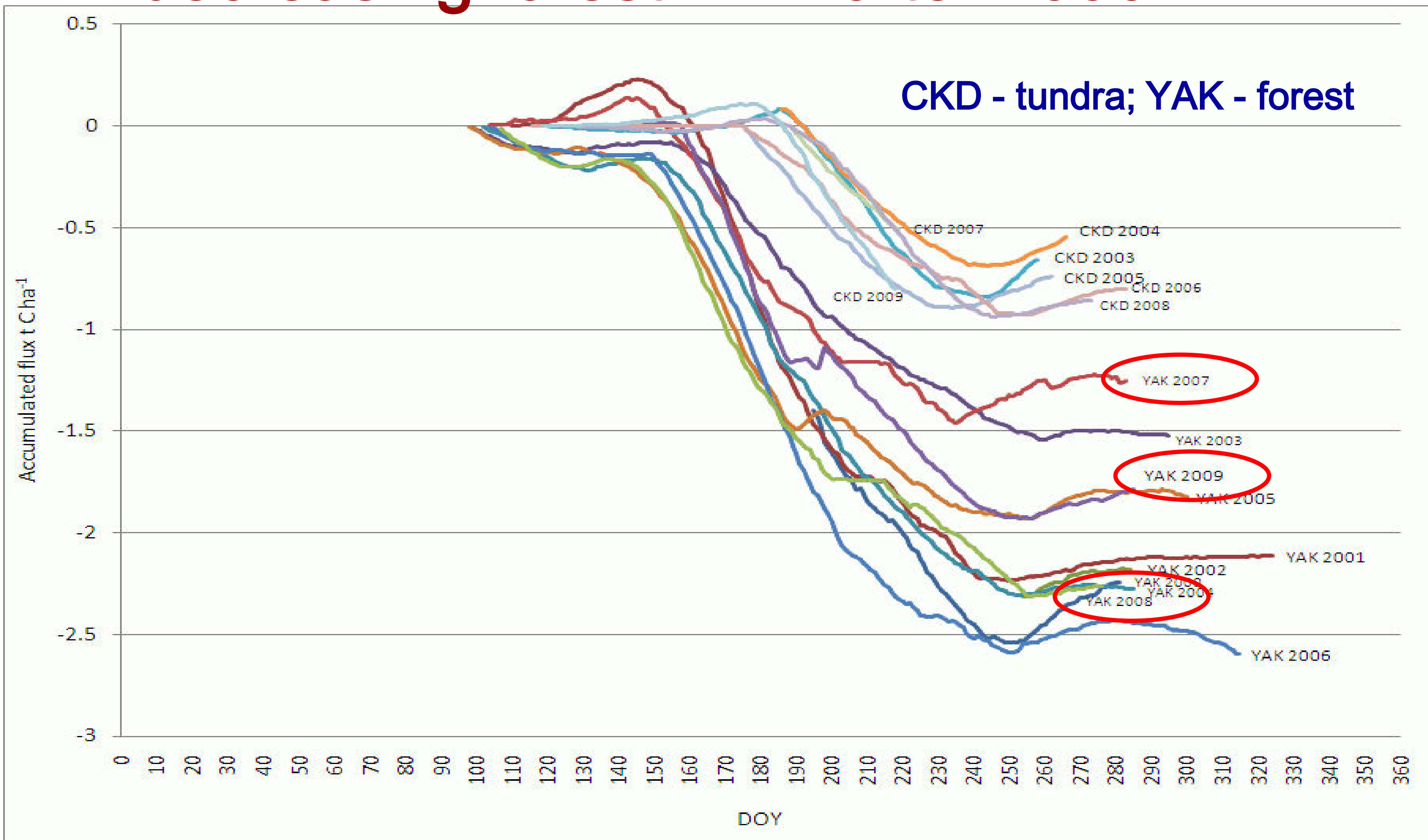
Carbon fluxes comparison between three permafrost-dominated ecosystems



Comparison of carbon sequestration by forest and tundra ecosystems and decreasing forest NEE after 2006



Comparison of carbon sequestration by forest and tundra ecosystems and decreasing forest NEE after 2006



The reasons are,

1. Changing in diversity of vegetations (new successions) during melting of permafrost (subshrubs → grasses)
2. Physiological peculiarity due to plant potential possibility
3. Low rate of decomposition – small nutrients and low fertulization

Summary taiga

- Taiga is an on-off system
- Strong control of humidity
- Relative high rates of NEE in short growing season
- 3 months activity
- Annual uptake 2.0 ton Cha^{-1} (+/-0.5)
- June highest uptake

Summary tundra

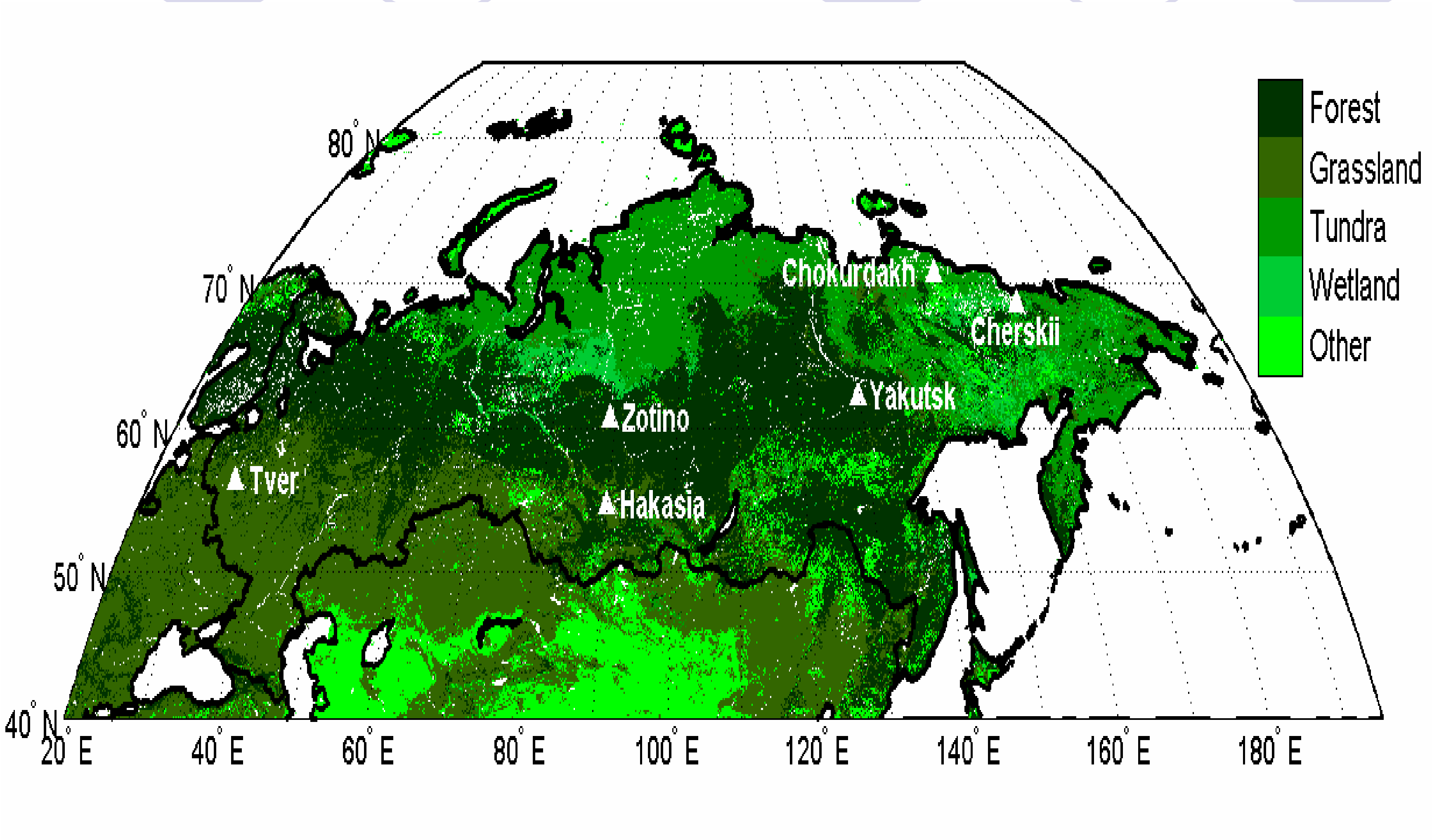
- Only 50% annual uptake of taiga
- Largest uncertainty in beginning and end (respiration bulge)
- 2 months activity
- How is the lateral exchange through the hydrology?
- How spatially variable is the flux

Annual Siberia Larch carbon budget, *G t C per year*

Uptake by Vegetation		
Siberia*	1.3	[100%]
Siberian Larch	0.4-1.0	54
Yakutian Larch	0.2-0.4	23
Emission		
Russian soils**	2.6-3.0	[100%]
Siberian Larch	0.8-0.9	27
Yakutian Larch	0.4	12
NEE Flux		
Russia**	0.82	[100%]
Siberian Larch	0.45	55
Yakutian Larch	0.18	22

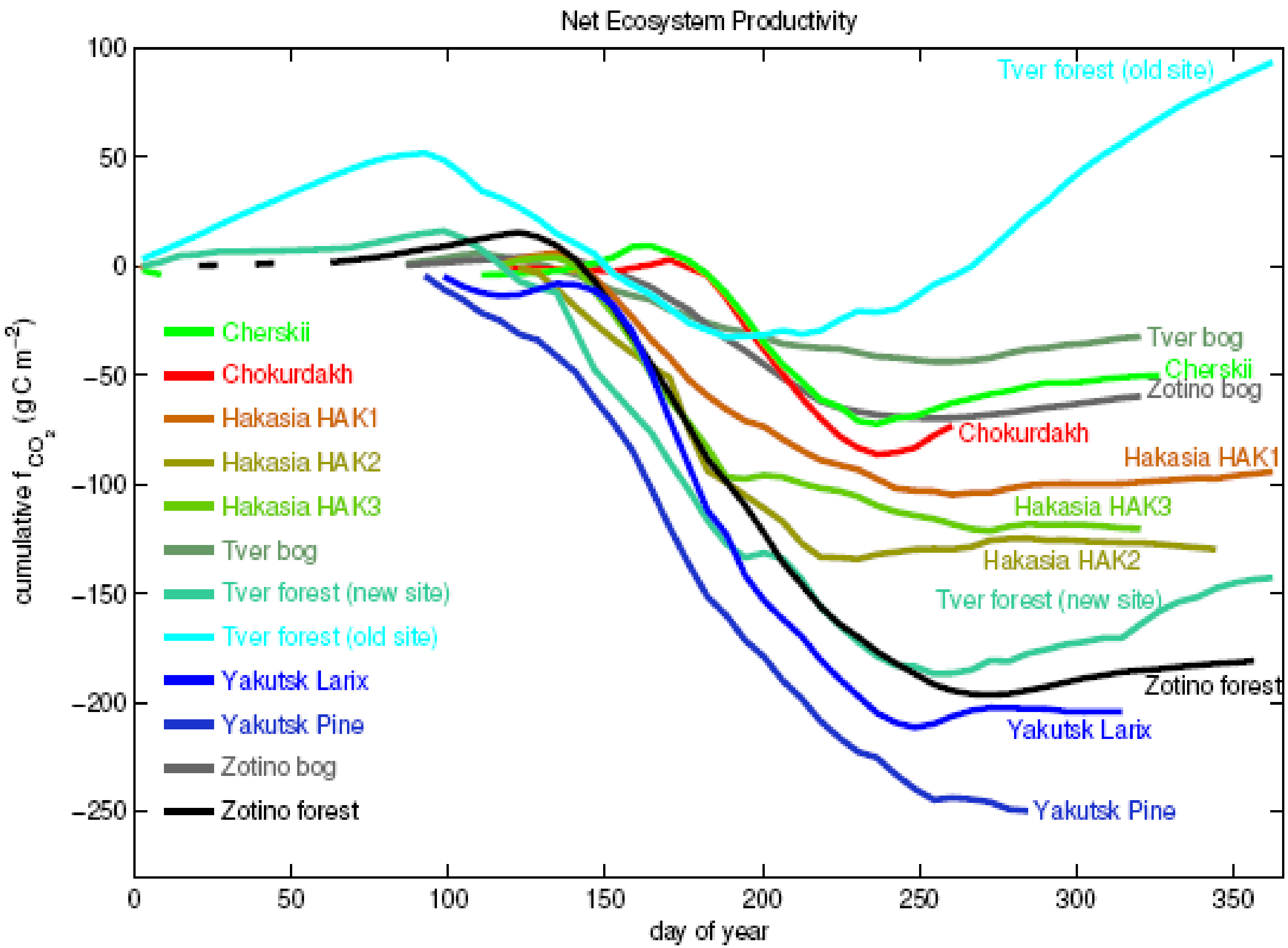
** - Schimel et al., 2001; Goodale et al., 2002.*
*** - Kudeyarov, 2003.*
Without marks- Maximov et al.,2005

Land cover map of the Russian Federation and measurement sites



The multi-annual net NEP derived from EC measurement at the 12 sites in Russia

The data are u-corrected and gap-filled



Van der Molen et al, 2006

Annual carbon fluxes in representative biomes of Russian Federation

47 annual dataset from 12 stations on the frame Project TCOS-Siberia (EU-10) and JST CREST (Japan) *www: michiel.van.der.molen@falw.vu.nl*

	annual flux $g\ C\ m^{-2}\ yr^{-1}$	area $10^{12}\ m^2$	%	annual land cover flux $10^{12}\ g\ C\ yr^{-1}$
land cover type				
wetlands	-54 ± 66	4.4	25.9%	-236 ± 338
grasslands	-115 ± 66	2.7	15.7 %	-310 ± 198
Tver forest oldsite	94 ± 66	1.7	49.1%	158 ± 162
forests	-194 ± 66	6.7		-1306 ± 589
other	-104 ± 66	1.6	9.2%	-166 ± 114
total		17.1		-1861 ± 1401

Our estimate of 1.9 *G t C per year* or 24 % of global emission due to fossil fuel burning (6 *G t C per year*) and deforestation (2 *G t*), forest fire (0.19 *G t*) and river transport (0.020 *G t*)

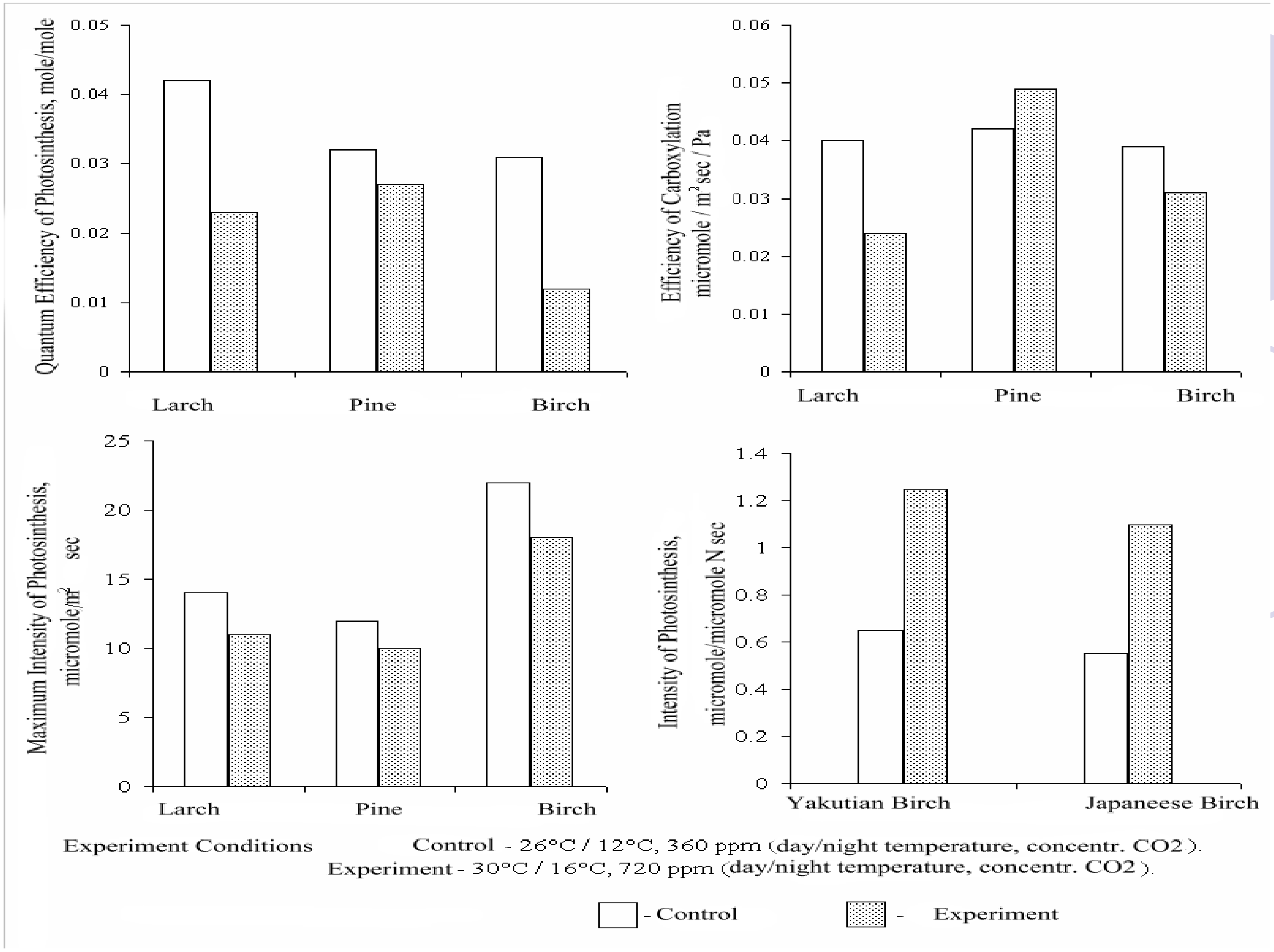
Annual budget of carbon of Russian Federation, *GtCper year*

	Method	Value
Schimel et al., 2001	Model	1.3
Goodale et al., 2002	Model	1.3
Kudeyarov, 2007	Istrum	1.0
Shvidenko ,Nilsson, 2003	Model	0.5
Isaev et al., 2005	Model	0.3

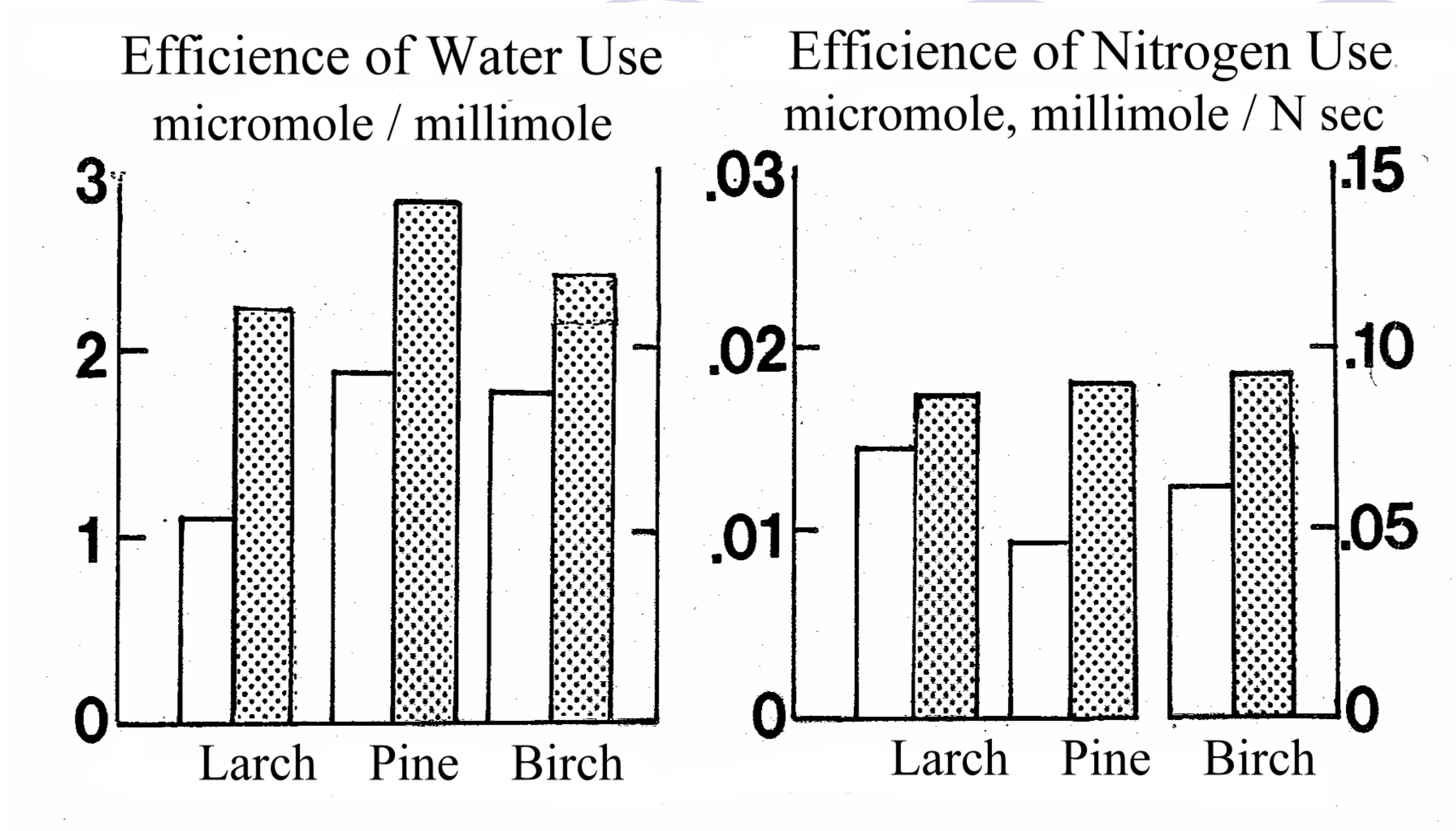
The climate warming is sure to cause

- release of large quantity of nitrogen and carbon resulting from activity of soil microorganisms
- there is a danger that a part of humus and turf horizons rich in organogens may be buried into low layers of the soil profile
- melting of permafrost will cause the wide spread of pedoturbations and mixture of soil mass (Karpachevsky, 1993).
- it may lead to conservation of organic substance and make the main organoges (nitrogen and carbon) come out of the total cycle

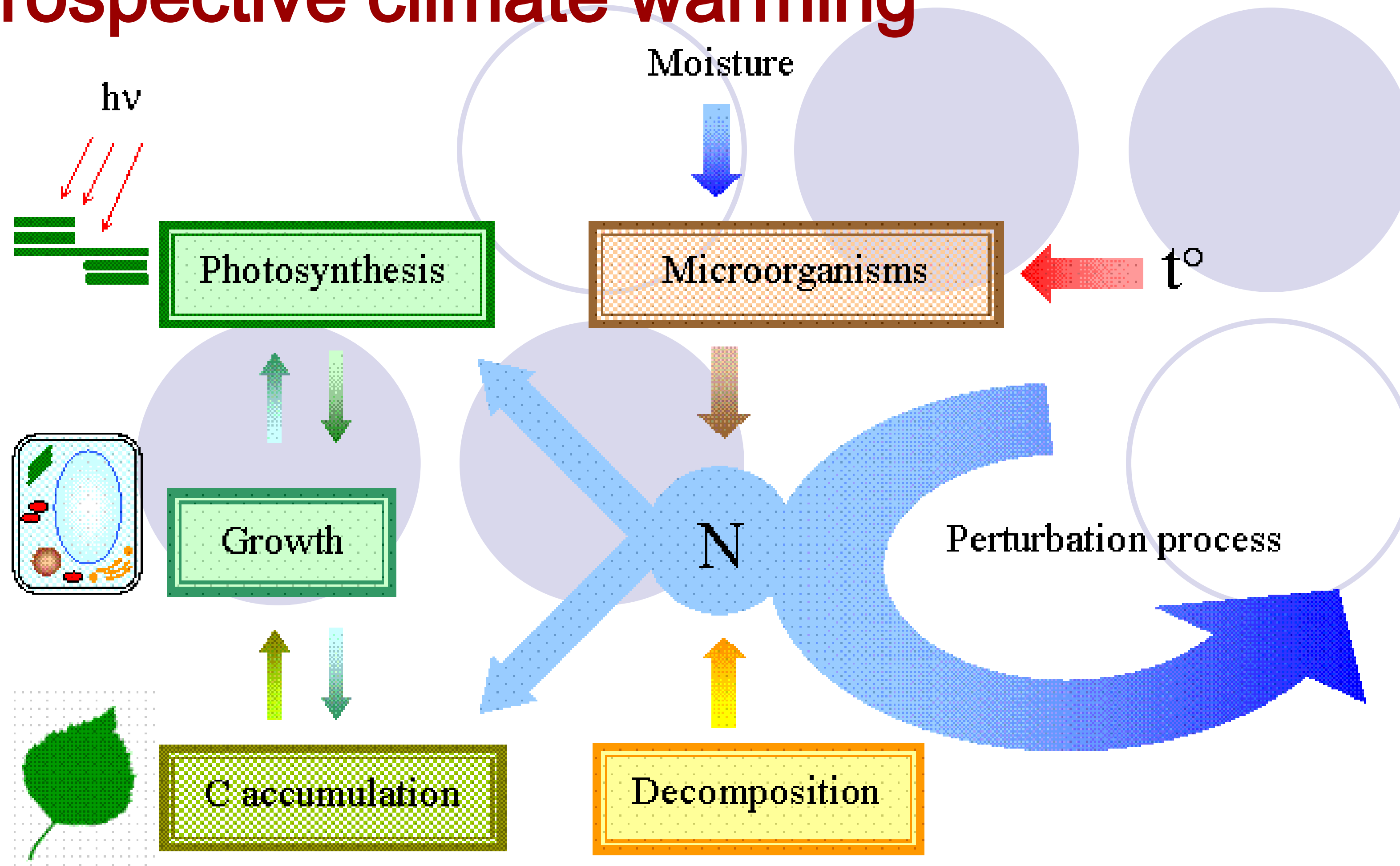
Physiological response of coniferous and deciduous species of Yakutia on temperature rise and doubling of CO_2 concentration in the atmosphere



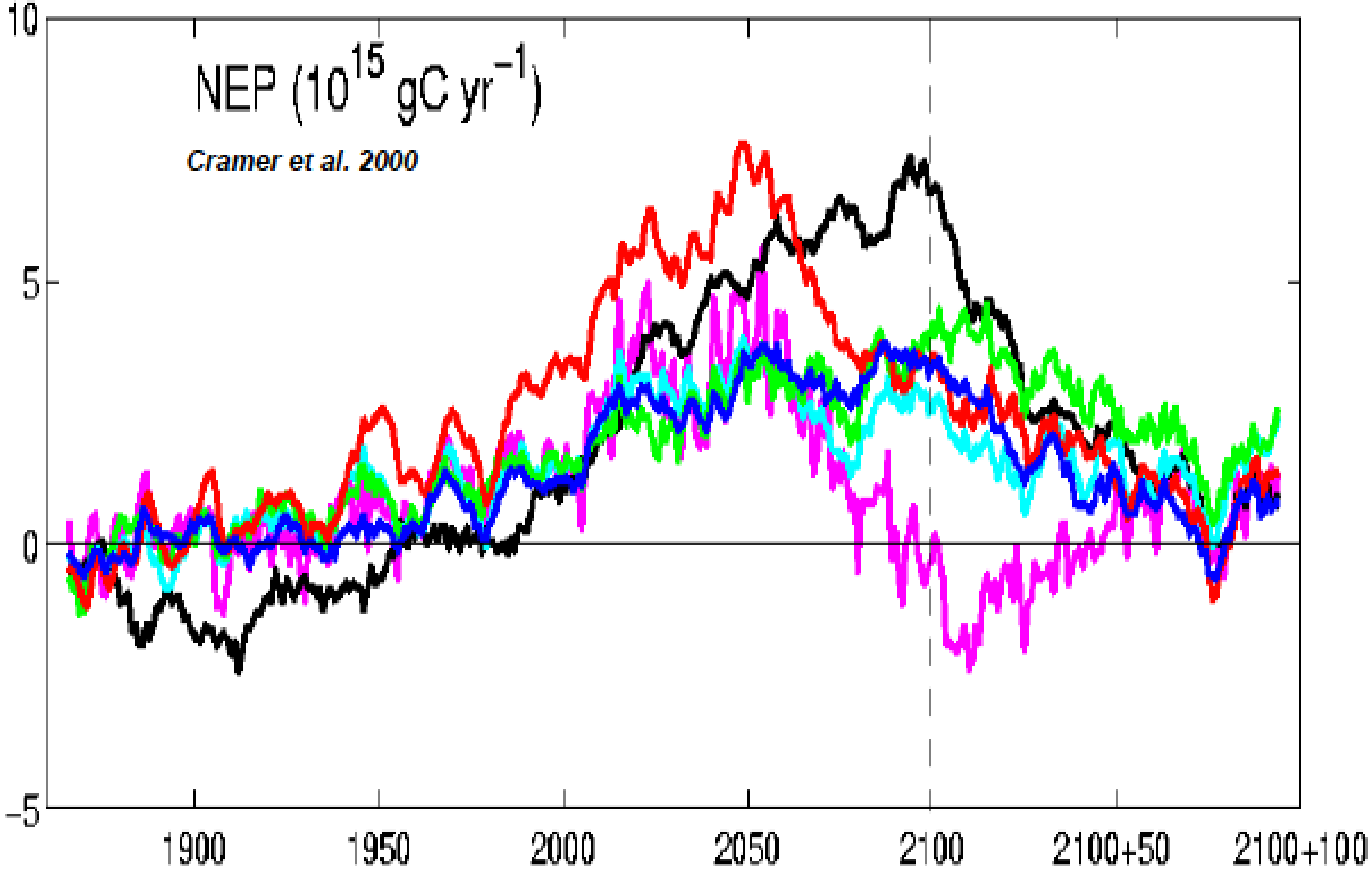
Dependence of activity of the leaf in the process of photosynthesis upon water and nitrogen content



Scheme of supposed physiological response of woody plants of cryolithozone on prospective climate warming



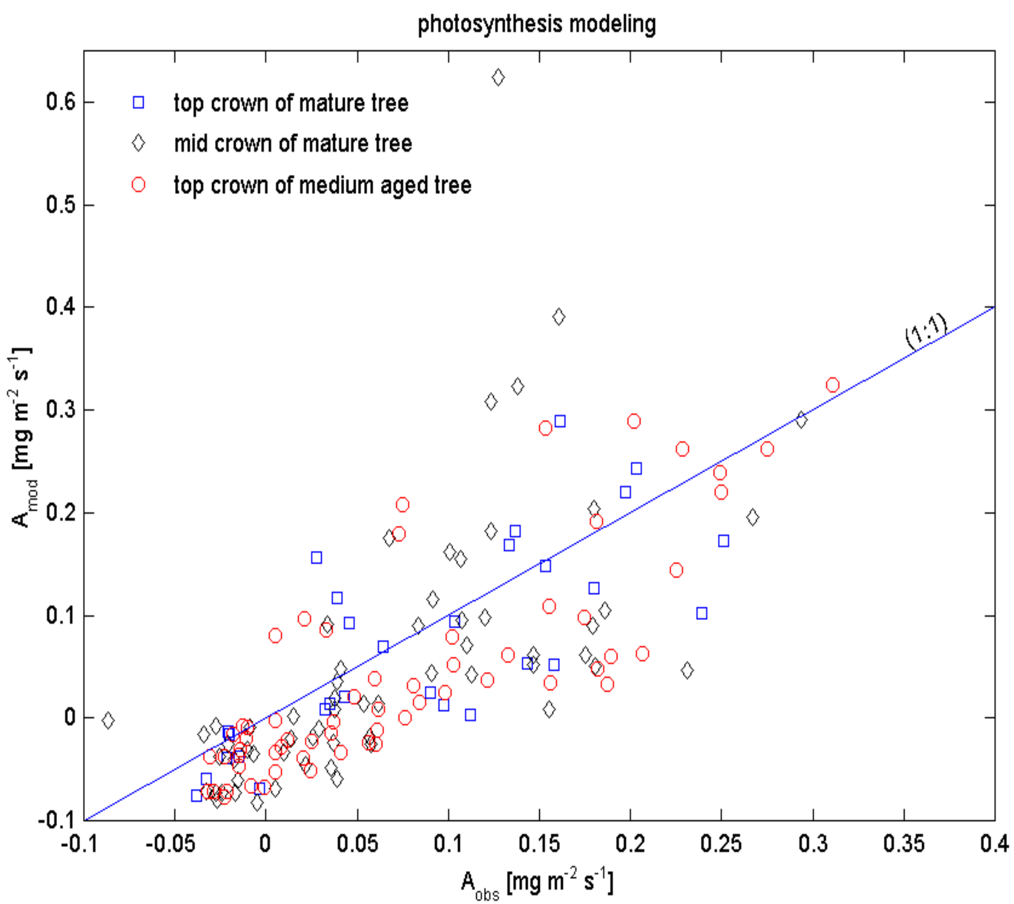
Maximov,2000



Net Ecosystem Production in various prediction models

Modeling Photosynthesis Spasskaya Pad, Yakutsk

$$g_s = g_{s,\min} + \frac{aAh_c}{C_s}$$

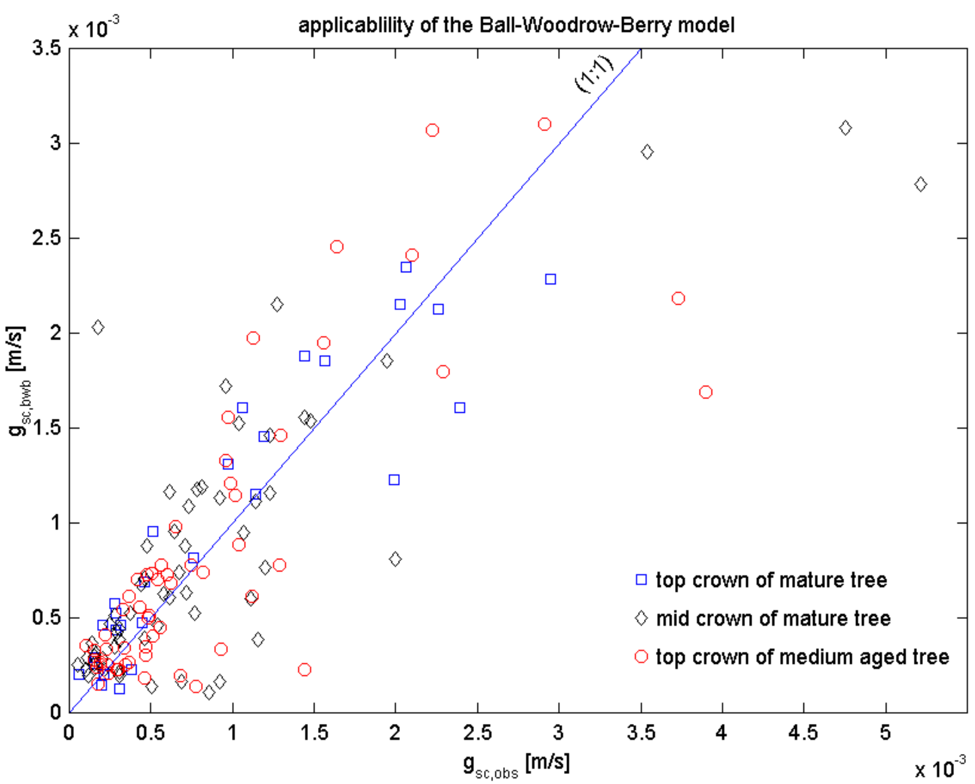


Modeling the photosynthesis rate using Ball- Woodrow Berry -g_s in combination with a biochemical model

Modeling Stomatal Conductance Spasskaya Pad

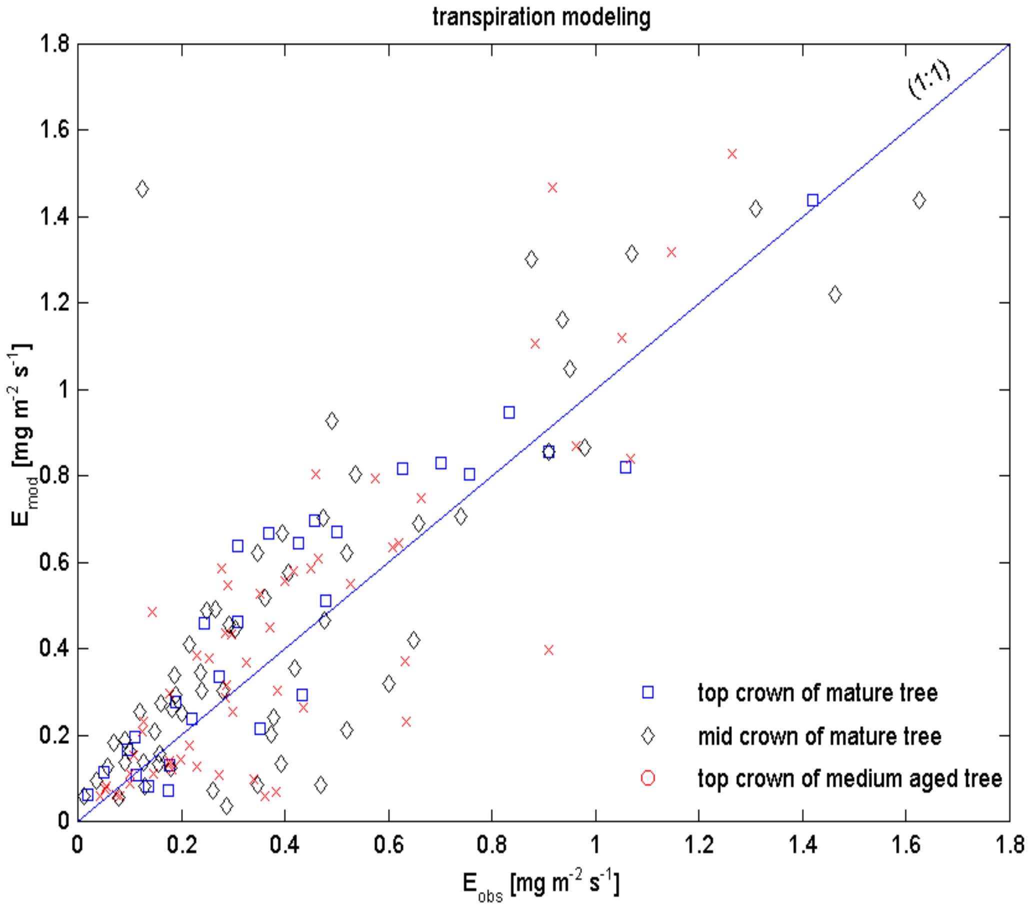
$$g_s = g_{s,\min} + \frac{aAh_c}{C_s}$$

Ball- Woodrow-Berry stomatal conductance model works well for all vegetation levels



Modeling transpiration Spasskaya Pad

Modeling the transpiration rate using BWB-g_s in combination with VPD



Simple modeling

Empirical formulas reflecting dependencies of soil respiration both on soil temperature and moisture

2001: $Fs = 0.32\ T + 0.29\ \eta - 3.02$ [1]

2004: $Fs = 0.32\ T + 0.08\ \eta - 0,74$ [2]

2005: $Fs = 0.62\ T + 0.19\ \eta - 4,30$ [3]

2006: $Fs = 0.67\ T - 0.01\ \eta - 0,79$ [4]

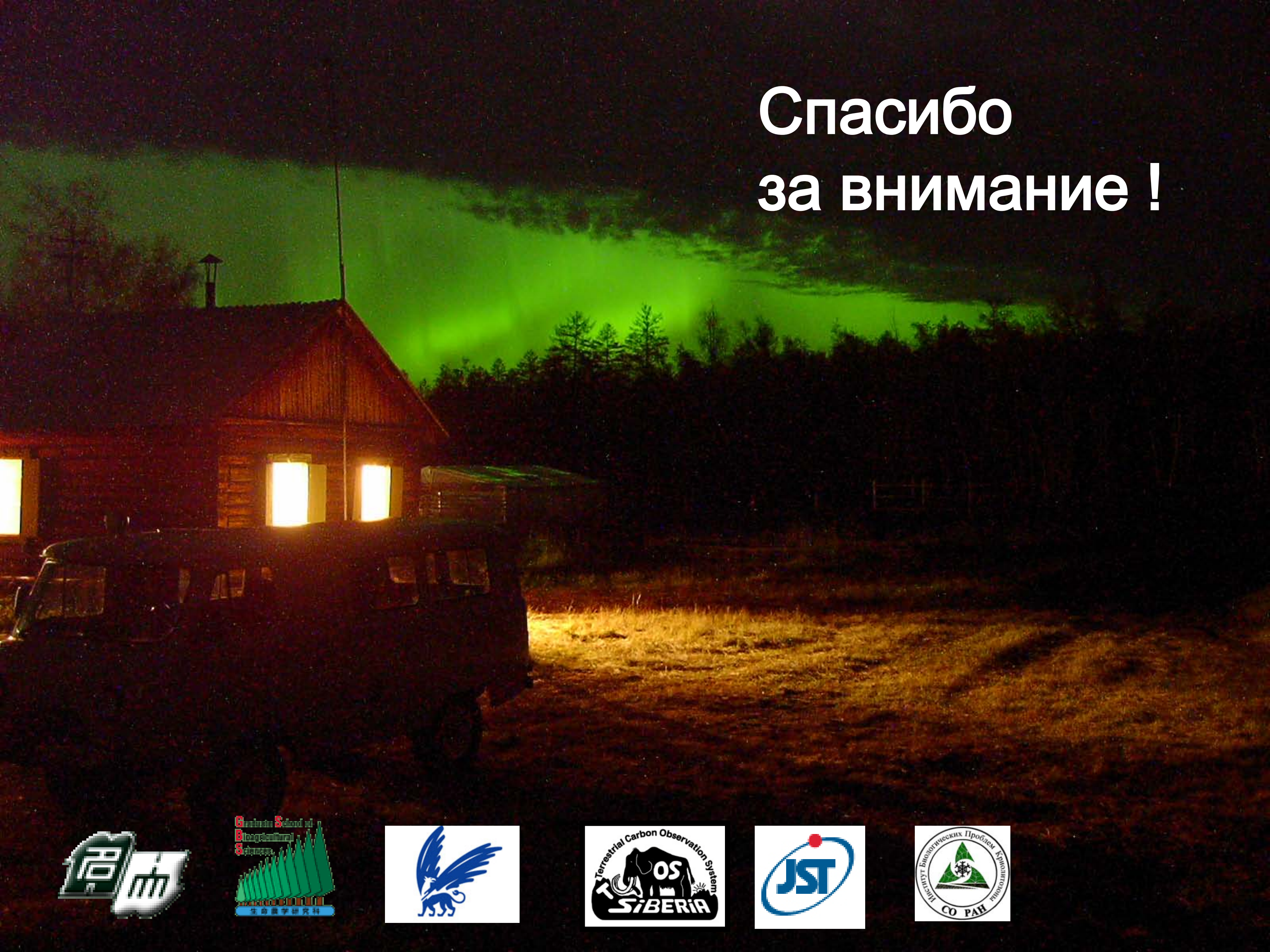
Dry years:

$Fs = 0,32\ T + 0,185\ \eta - 1,88$ [5]

Wet years:

$Fs = 0,645\ T + 0,1\ \eta - 2,545$ [6]

Comparison estimation 3-6%.



Спасибо за внимание !