



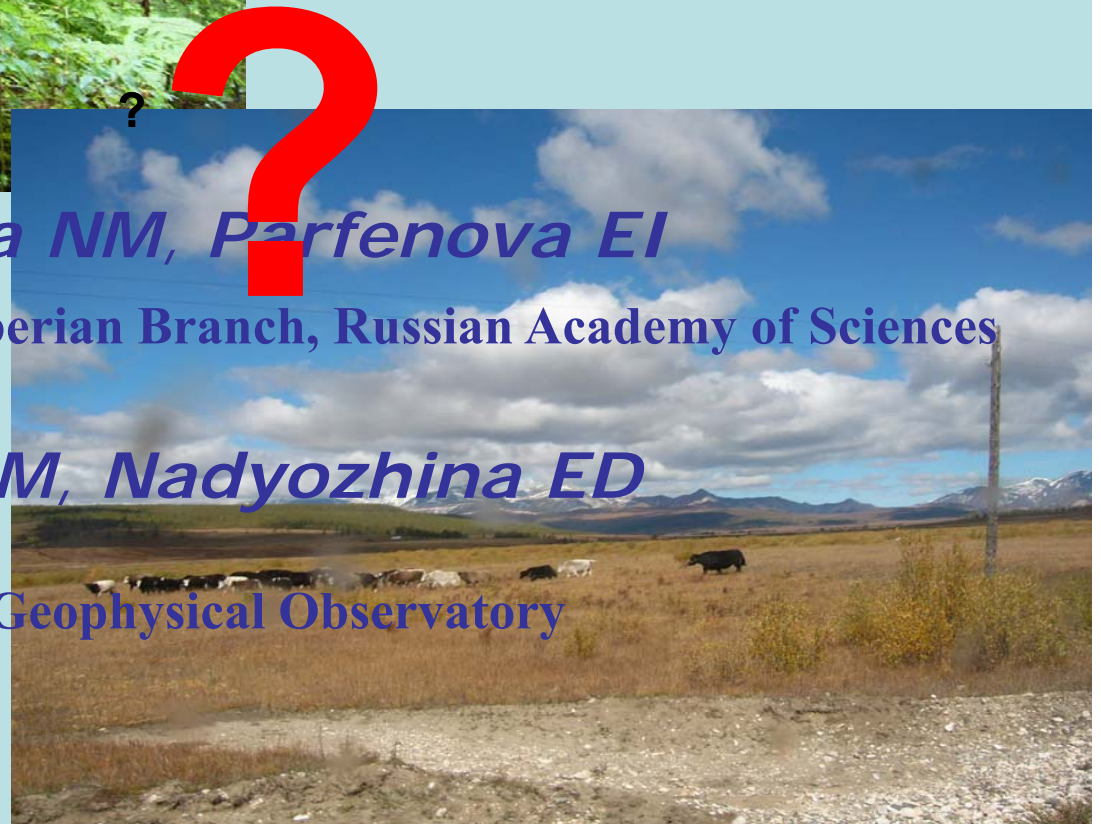
**Use of a MGO regional climate model for assessing
vegetation change in Siberia in the 21st century**

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Voeikov Main Geophysical Observatory



Study Area



Main goals

- To assess potential vegetation change across Siberia using the MGO (Main Geophysical Observatory) regional climate model for Siberia from 2000 to 2050 and 2100;
- To compare future vegetation change simulated by the regional MGO (Voeikov Main Geophysical observatory) and global HadCM3 B1 (Hadley Centre) climate models.

Climate-vegetation modeling

- “***Climate*** is the primary factor controlling the distribution of plants” (Plesheev, 1797; Humboldt, 1807);
- Dokuchaev (1900) formulated the idea of zonality into a geographical law of nature that zonality is caused not only by the amount of heat and water but their relative proportions as well;
- By the mid-20th century, climate-vegetation biogeography static models were developed based on large-scale vegetation classifications which were used later to predict the equilibrium response of potential vegetation to climate change;
- In the 90-s, dynamic biogeography models were developed to simulate transient response of vegetation structure and function.

We developed an envelope-type static biogeography model, the **Siberian bioclimatic model, SiBCliM**, based on the vegetation classification of Shumilova to assess potential vegetation change across Siberia in a changing climate

Vegetation classification of Siberia of Shumilova

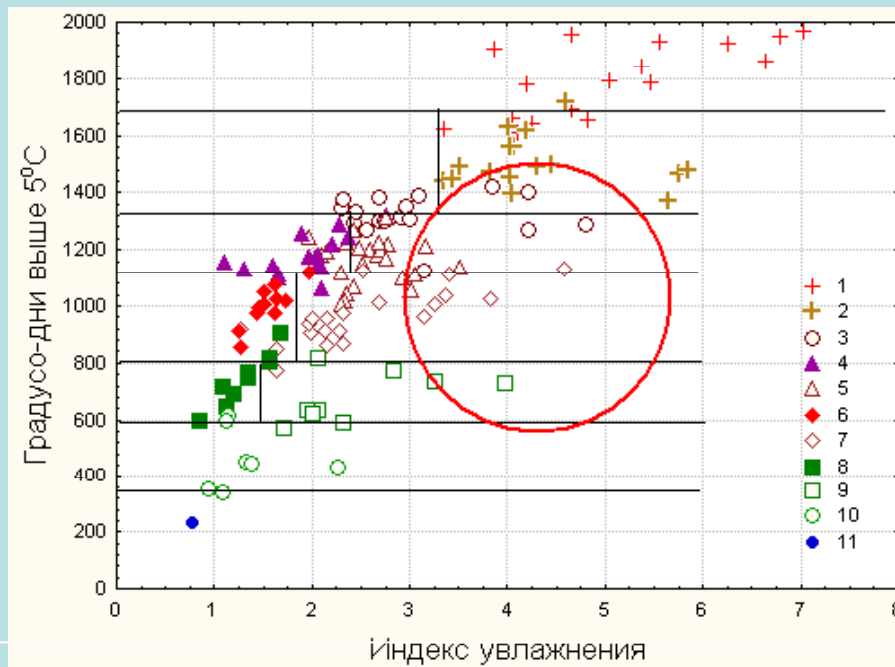
East

	East Europe	West Siberia	Central Siberia	East Siberia
		Tundra	Polar deserts/ Tundra	Polar deserts/ Tundra
		Forest-tundra: spruce, larch	Forest-tundra: larch	Forest-tundra: larch
<i>S</i> <i>o</i> <i>u</i> <i>t</i> <i>h</i>		Dark-neededled Taiga: spruce, fir, cedar, and Subtaiga: aspen, birch	Light-neededled Taiga: larch, pine, and Subtaiga: pine, birch	Larch Taiga (<i>L. dahurica</i>)
	Forest-Steppe (oak)	Forest-Steppe (aspen, birch)	Forest-Steppe (larch, pine)	Forest-Steppe (larch, pine)
	Steppe	Steppe	Steppe	Steppe

Siberian bioclimatic model SiBCliM

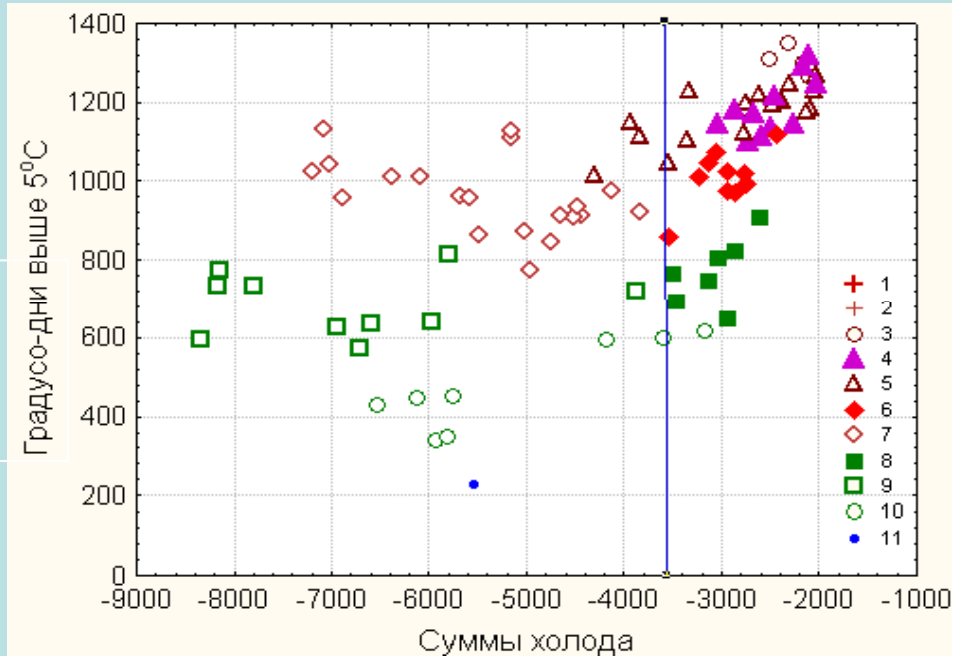
limits “envelopes” for each vegetation class in the Shumilova’s classification based on three principal climatic constrains representing plant requirements for warmth (growing degree-days, above 5°C), and cold tolerance (negative degree-days, below 0°C) water stress resistance (an annual moisture index, AMI, a ratio $GDD_5/\text{annual precip}$)

Vegetation ordination in climatic space:



A. Growing degree-days, 5°C
– Moisture index

150 Siberian weather stations were ordinated in climatic indices to specify limits

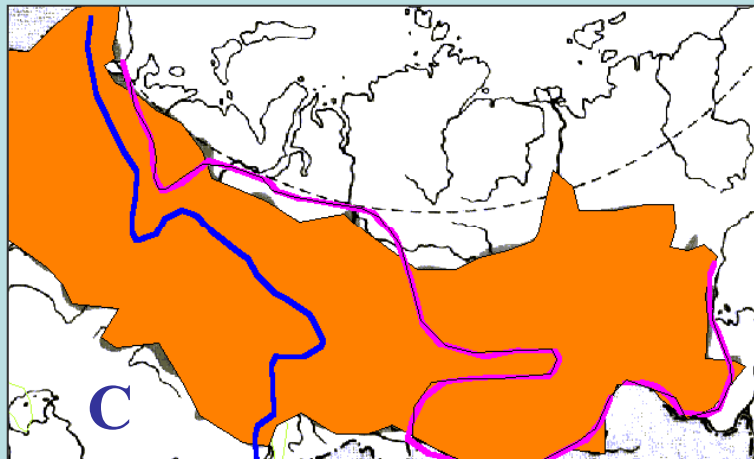
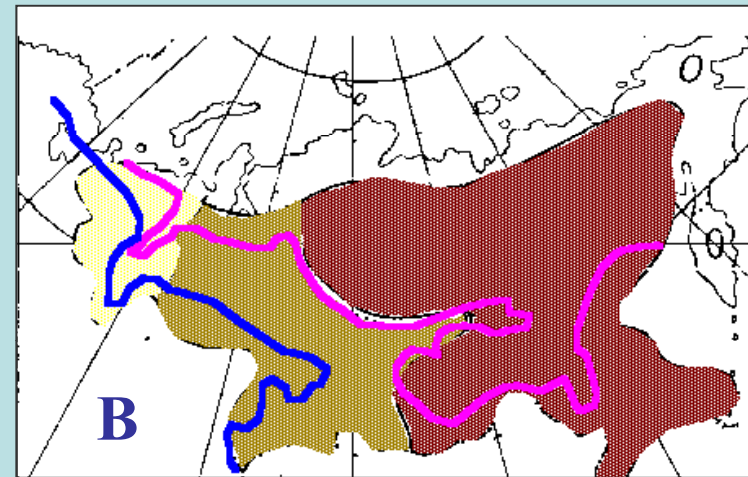
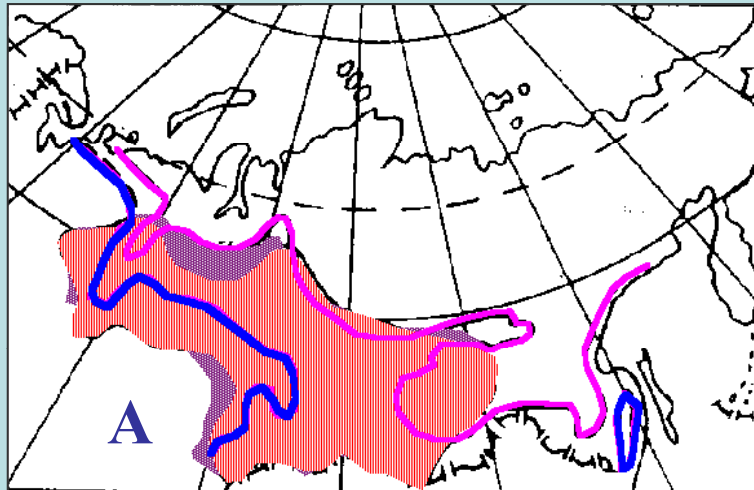


B. Growing degree-days, 5°C
– Negative degree-days, 0°C

PERMAFROST

- Permafrost covers 80% of Siberia and is the primary factor controlling the distribution of forests and their composition in central Siberia and Yakutia;
- In dry climate of interior Siberia with 200-300 mm of precipitation, forests are capable of developing only because the thawing of permafrost provides additional summer moisture to areas where otherwise the vegetation would be steppe or semidesert (Shumilova 1962);
- Permafrost also limits the northward and eastward spread of major conifer species (*Picea obovata*, *Pinus sibirica*, and *Abies sibirica*, *L. sibirica* and *P. sylvestris*). Only *L. dahurica* (*L. gmelini* + *L. cajanderii*), by contrast, is capable of growing on shallow soils which thaw as little as 10—30 cm during the growing season (Pozdnyakov, 1993).

Major Siberian conifer distribution regarding permafrost (Pozdnyakov, 1993)

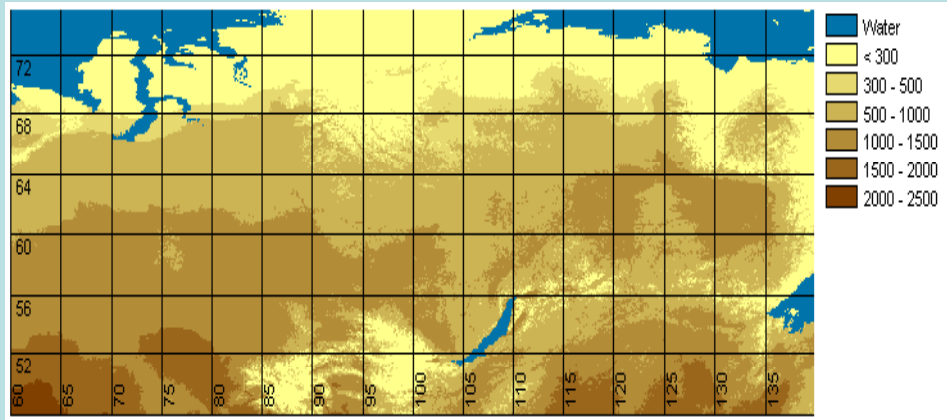


- A.** *Pinus sibirica* and *Abies sibirica*;
B. *Larix* spp. (*L. sukaczewii*, *L. sibirica*,
L. dahurica)

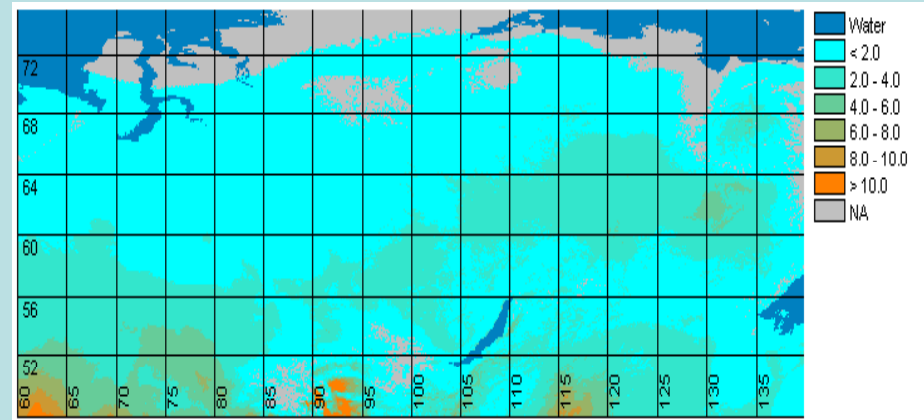
- C.** *Pinus sylvestris* and *Picea obovata*
Spruce and pine can reach high latitudes
on sandy warmer soils along big river
valleys.

Blue is the border of discontinuous and **pink** is the border of continuous permafrost

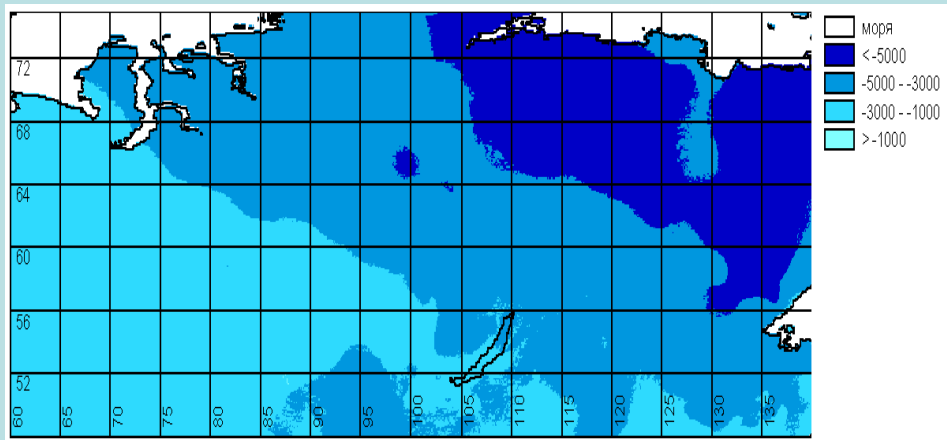
Climatic layers of Siberia



Growing Degree Days, above 5°C



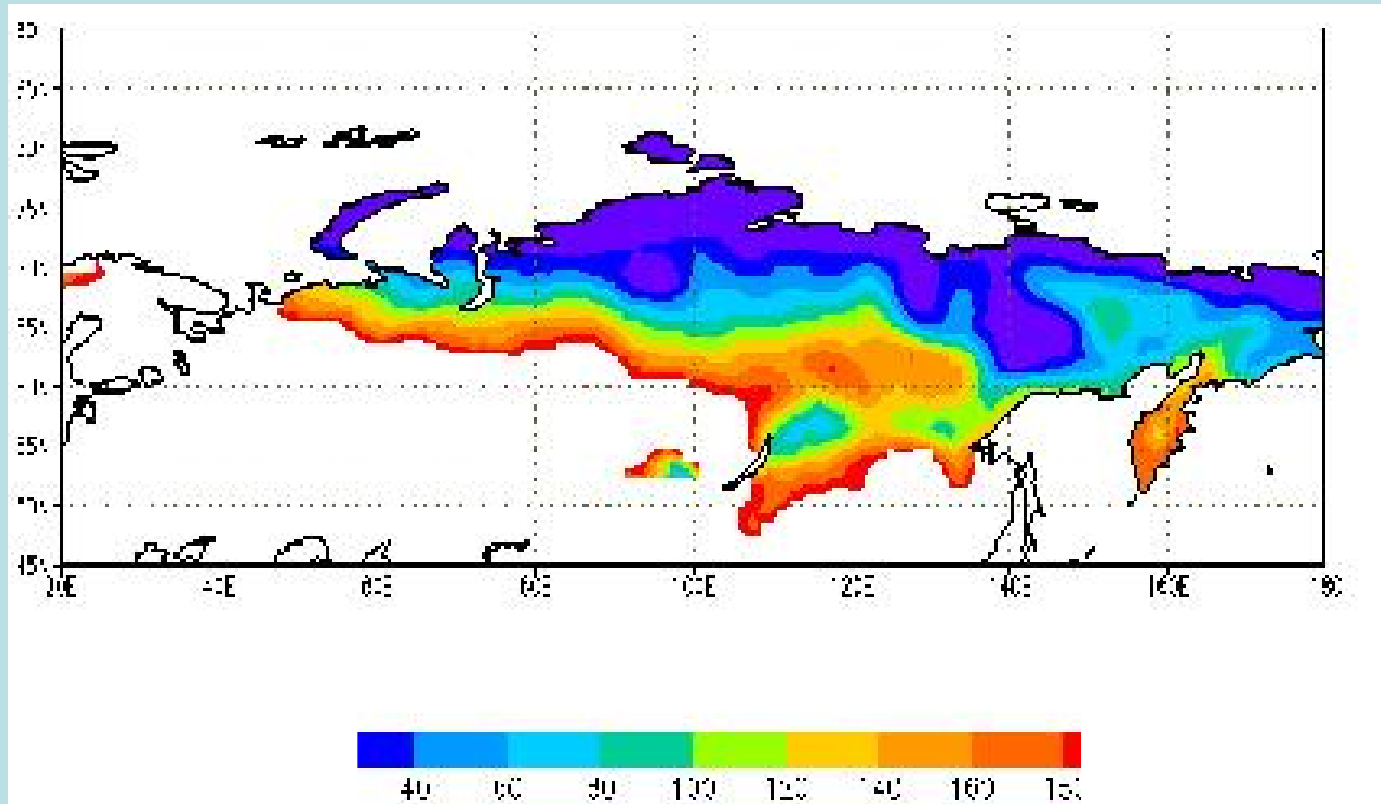
Annual Moisture Index, AMI



Degree Days below 0°C

To model Siberian vegetation, three climatic indices were mapped. First, indices were calculated from data of some 1000 stations across Siberia and then interpolated for a pixel on DEM of 1 km using Hutchinson (2000) thin plate spline procedures

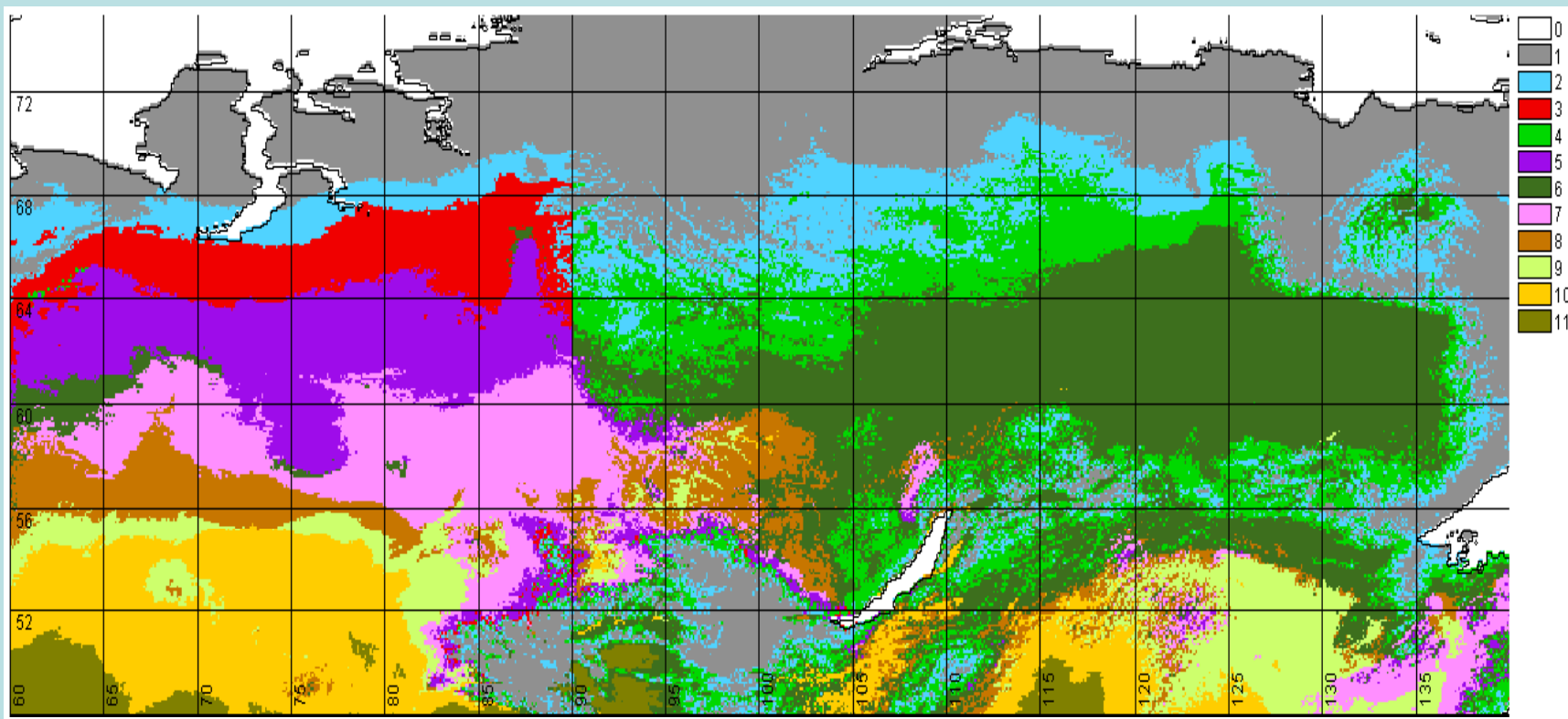
Current permafrost border and active layer depth (*Malevsky-Malevich et al., 2001*)



ALD (summer thawing) < 2 m

To model the border of permafrost we correlated its current position from the above map with GDD_5 , DD_0 and AMI ($R^2 = 0.70$)

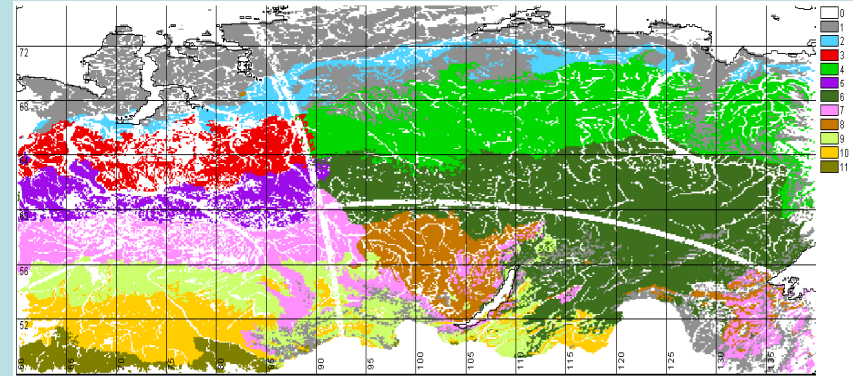
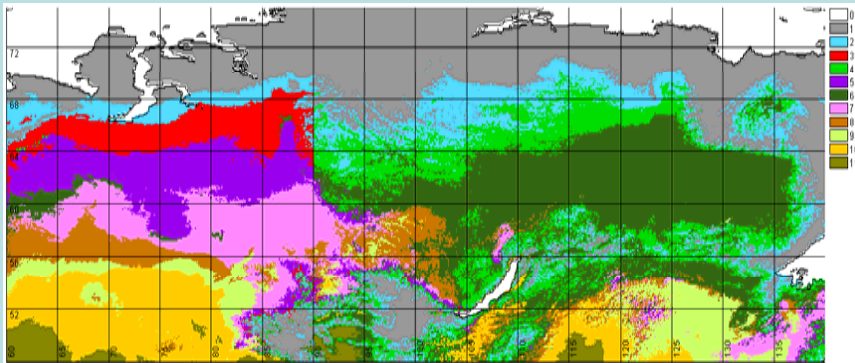
Vegetation distribution over Siberia predicted from the three climatic indices and permafrost using SiBCliM



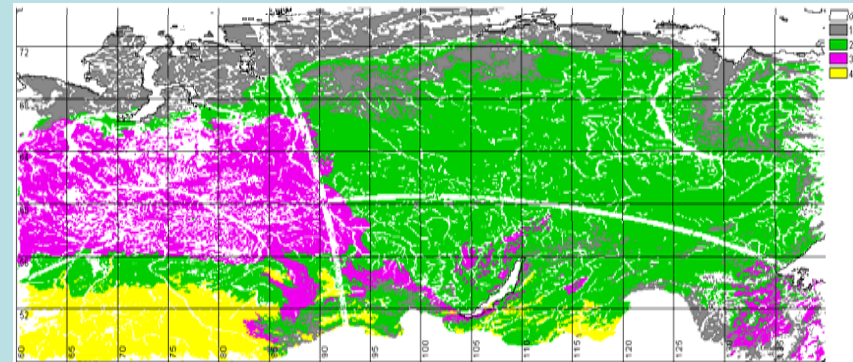
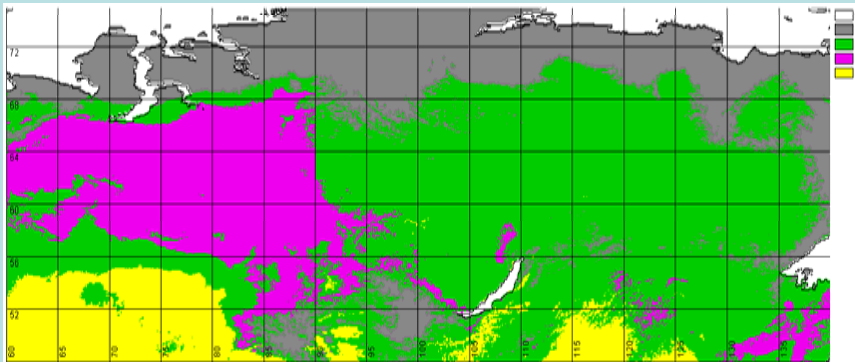
Vegetation classes: *BOREAL*: 1 – Tundra; 2 – Forest-Tundra; Northern Taiga: 3 – darkleaf, 4 – lightleaf; Middle taiga: 5 – darkleaf, 6 – lightleaf; Southern Taiga: 7 – darkleaf, 8 – lightleaf; 9 – Subtaiga, Forest-Steppe; 10 – Steppe; 11 – Semidesert; *TEMPERATE*: 12 – Broadleaf; 13 – Forest-Steppe; 14 – Steppe, 15 – Semidesert

Map comparison

The Kappa statistic is an index which compares the agreement against that which may be expected by chance. Possible values range from 1 – perfect, 0 – no agreement, -1 – complete disagreement



Kappa = 0.53, “fair” match

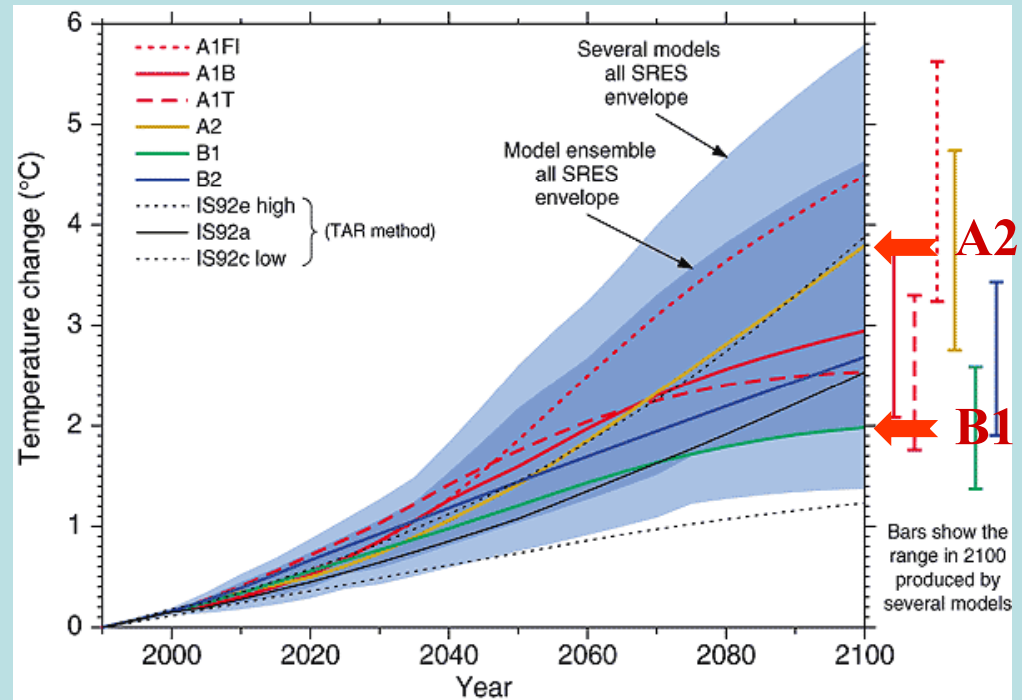
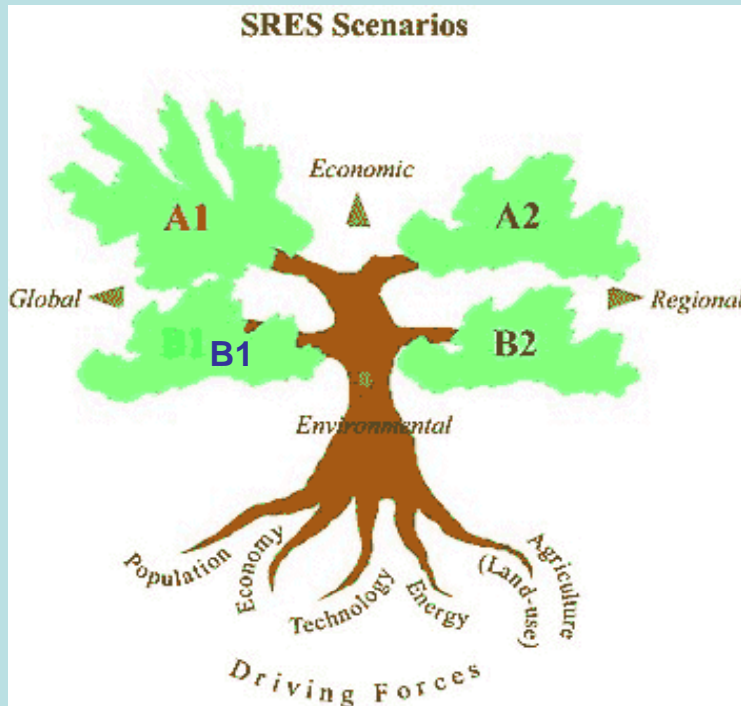


Kappa = 0.76, “very good” match

Current Siberian vegetation predicted from SiBCliM (left)

The actual vegetation map of Isachenko (1988, right)

Climate change scenarios (IPCC, 2001)



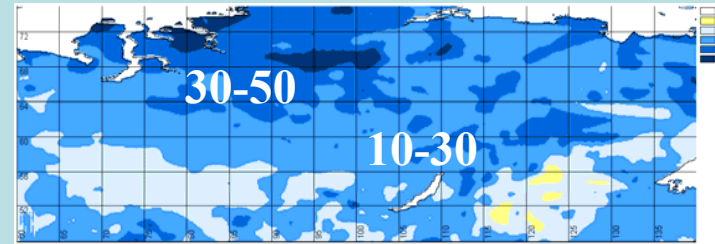
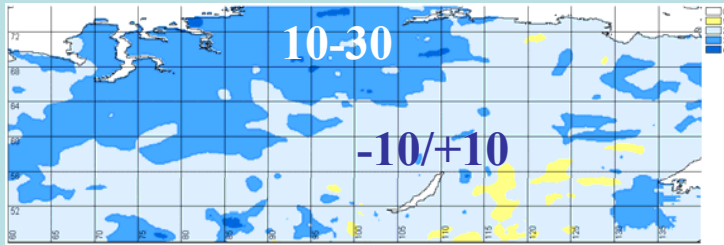
To model vegetation in Siberia under climate change, the MGO regional climate model was used based on A2 of the SRES (Special Report on Emission Scenarios), a harsh scenario. The B1, the lower end of the SRES range, was used for comparison.

Climate change scenarios of the MGO

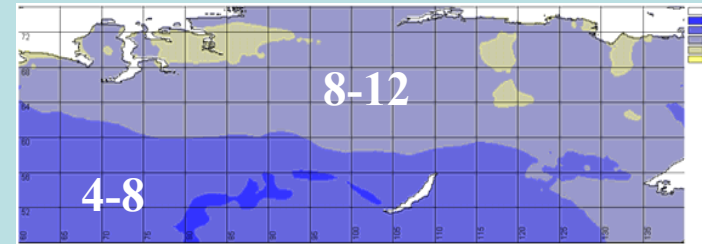
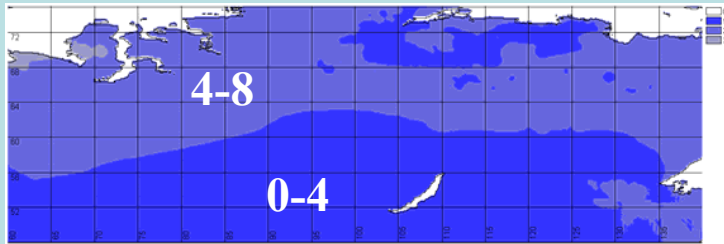
2050

Annual precipitation, %

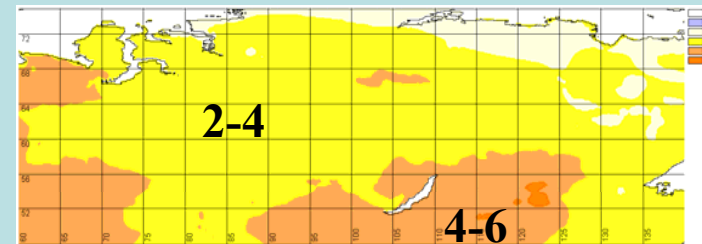
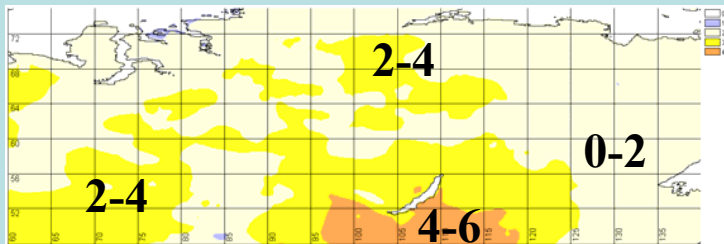
2100



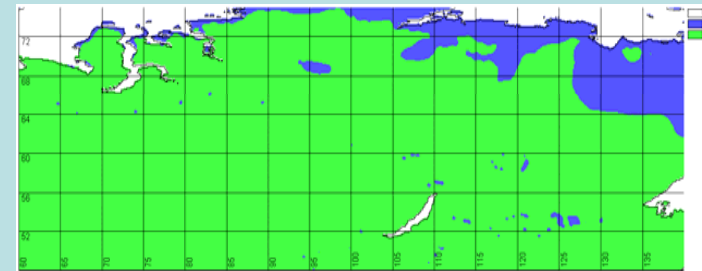
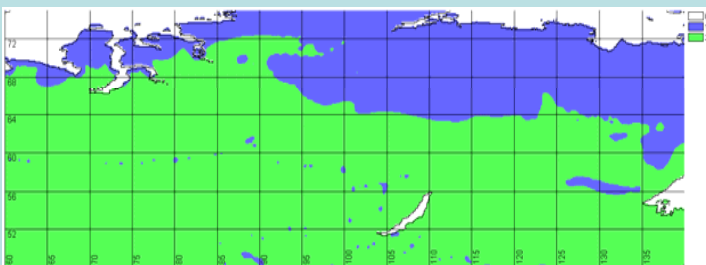
January temperature, °C



July temperature, °C

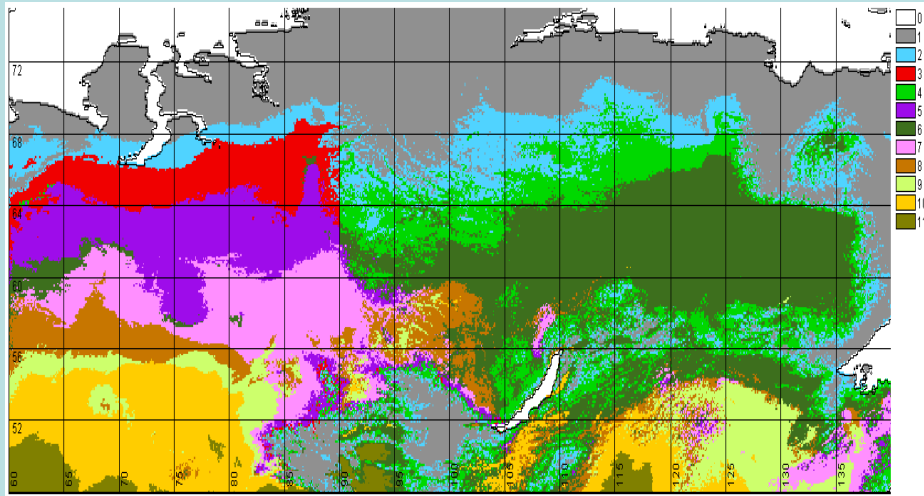


Permafrost distribution

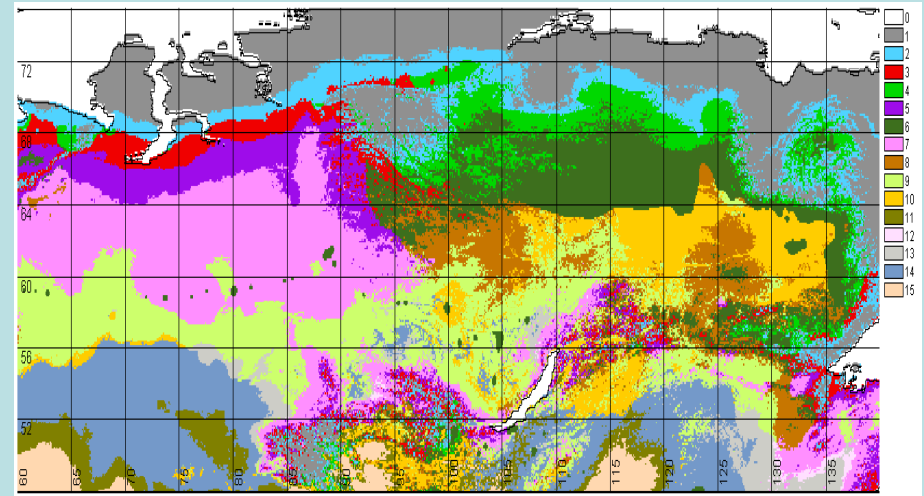


Vegetation change in Siberia in the 21st century predicted from the regional MGO climate model

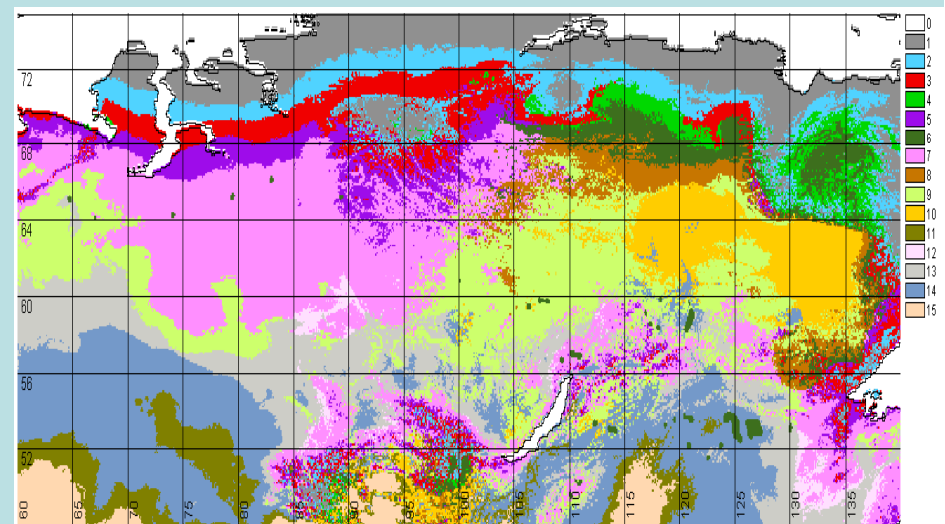
Current climate



2050



2100



Vegetation classes:

BOREAL: 1 – Tundra; 2 – Forest-Tundra; **Northern Taiga:** 3 – darkleaf, 4 – lightleaf; **Middle taiga:** 5 – darkleaf, 6 – lightleaf; **Southern Taiga:** 7 – dark-leaf, 8 – lightleaf; 9 – **Sub-taiga, Forest-Steppe;** 10 – **Steppe;** 11 – **Semidesert**

TEMPERATE: 12 – **Broadleaf;** 13 – **Forest-Steppe;** 14 – **Steppe,** 15 – **Semidesert**

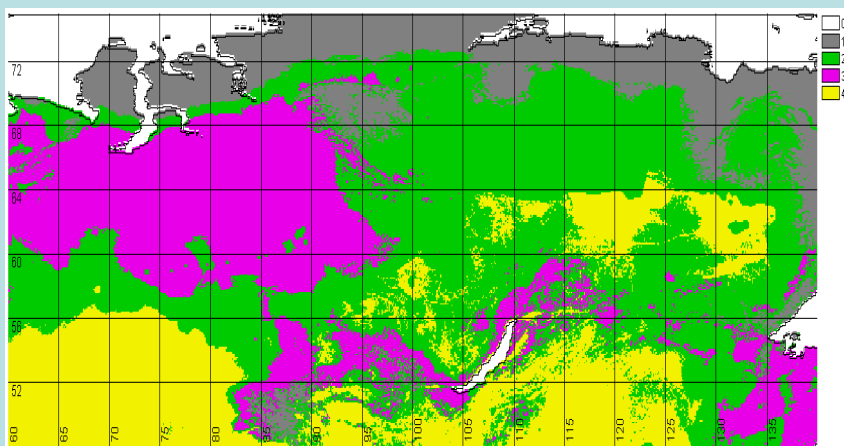
Siberian vegetation change (%) in the 21st century predicted from the MGO regional climate model

<i>Vegetation</i> BOREAL:	<i>Current climate</i>	<i>MGO</i>	
		2050	2100
Tundra	18.3	10.7	6.2
Forest-tundra	8.5	5.2	4.2
Dark Taiga	12.4	22.5	26.6
Light Taiga	39.2	14.5	8.0
Forest-steppe	7.5	14.7	14.0
Steppe	10.0	6.7	5.2
Semidesert	1.5	3.6	4.7
<i>TEMPERATE:</i>			
Broadleaf	0.8	0.3	1.3
Forest-steppe	0.8	2.9	10.9
Steppe	0	12.5	16.0
Semidesert	1.0	2.5	3.0

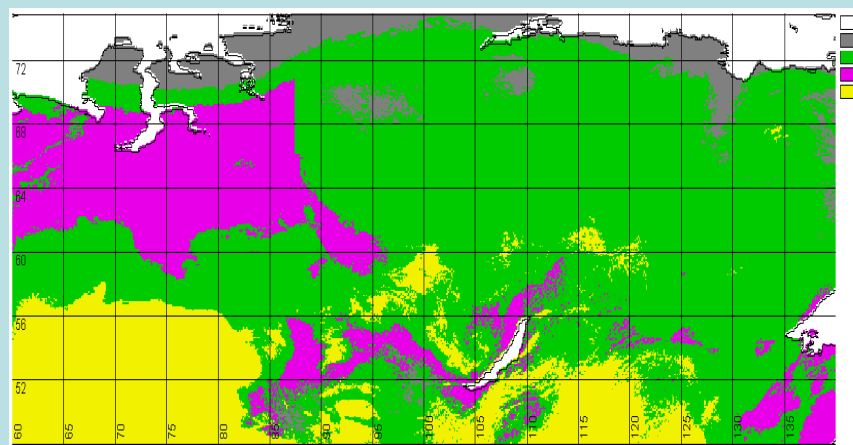
<i>Vegetation</i> BOREAL:	<i>Current climate</i>	<i>MGO</i>	
		2050	2100
Tundra	18.3	10.7	6.2
Forest-tundra	8.5	5.2	4.2
Forest	52.4	41	34.6
Forest-steppe	8,3	14.7	14.0
Steppe	10.0	19.2	21.2
Semidesert	2.5	3.6	4.7

Comparison of vegetation change in Siberia in the 21st c. predicted by MGO and HadCM3 B1 climate models

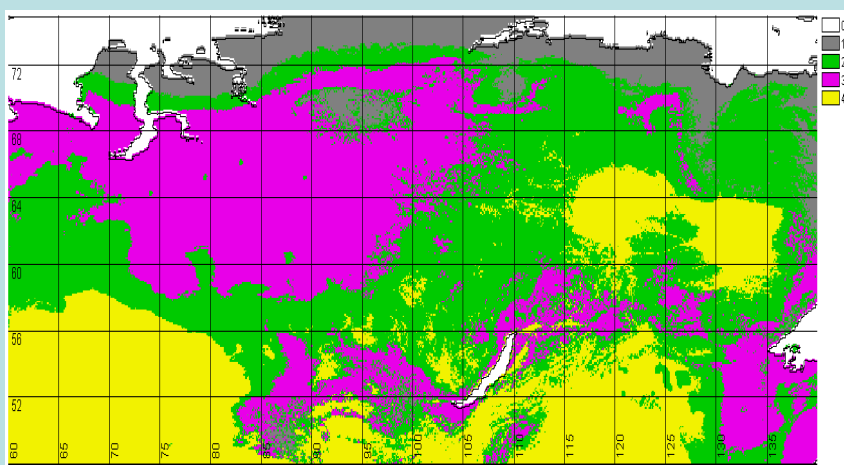
MGO_2050



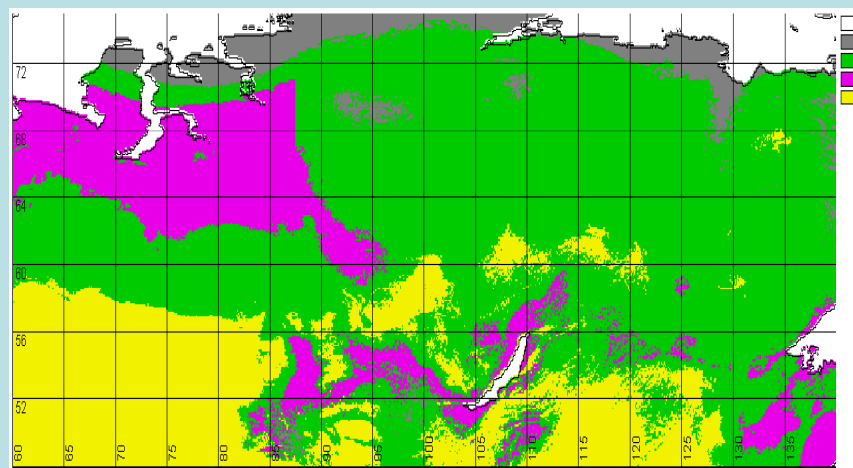
HadCM3 B1_2050



MGO_2100



HadCM3 B1_2080

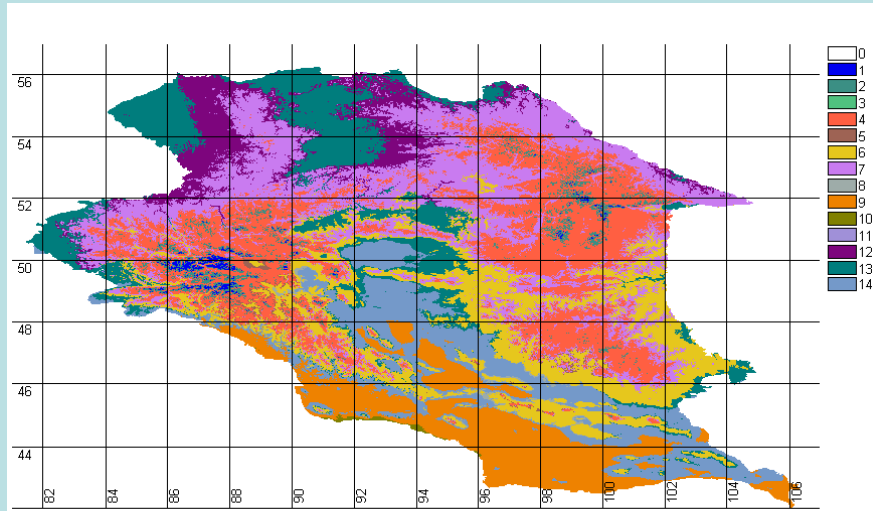


Comparison of vegetation area change (%) in Siberia in the 21st c. predicted by MGO and HadCM3 B1 climate models

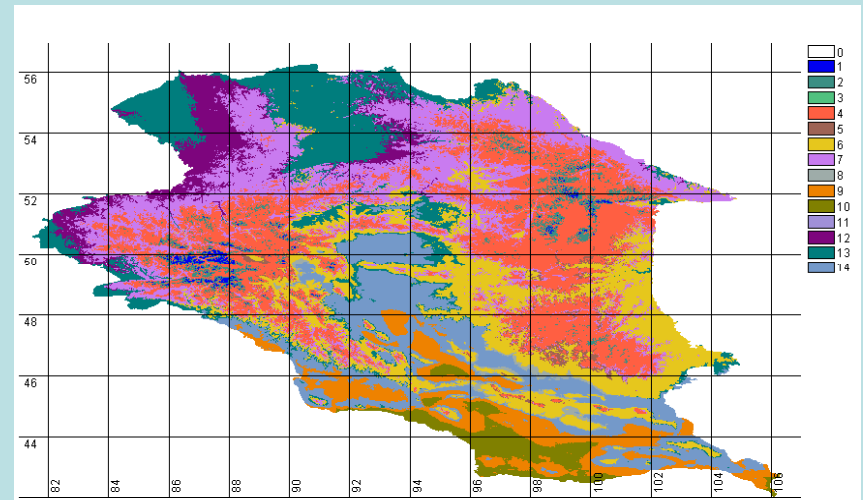
<i>Vegetation</i>	<i>Current climate</i>	<i>MGO</i>		<i>HadCM3 B1</i>	
<i>BOREAL:</i>		2050	2100	2050	2080
Tundra	18.3	10.7	6.2	4.7	3.6
Forest-tundra	8.5	5.2	4.2	6.3	4.9
Forest	52.4	41	34.6	39.6	35.1
Forest-steppe	8,3	14.7	14	25.7	30
Steppe	10.0	19.2	21.2	14.5	18.5
Semidesert	2.5	3.6	4.7	7.2	7.7

Mountain vegetation of the Altai-Sayans ecoregion in the Holocene: reconstructed from pollen-based climate change scenarios and predicted from the climate change scenario HadCM3 B1 (*Tchebakova et al 2009*)

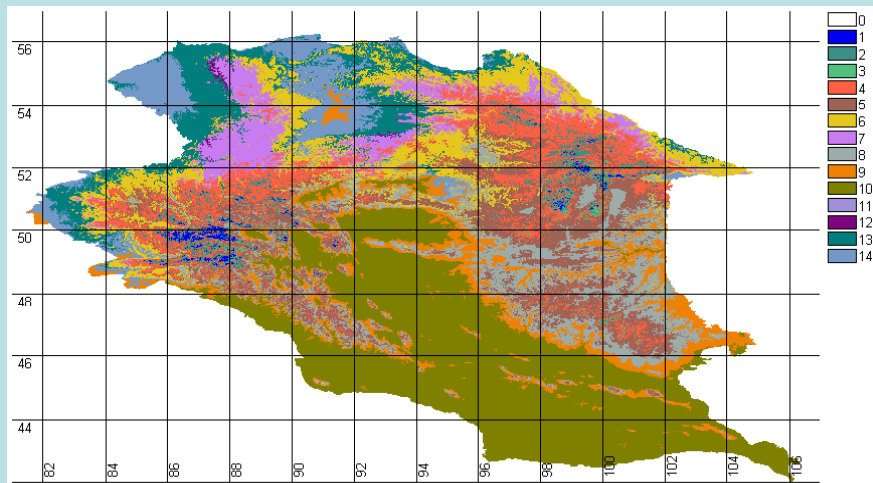
5300 BP



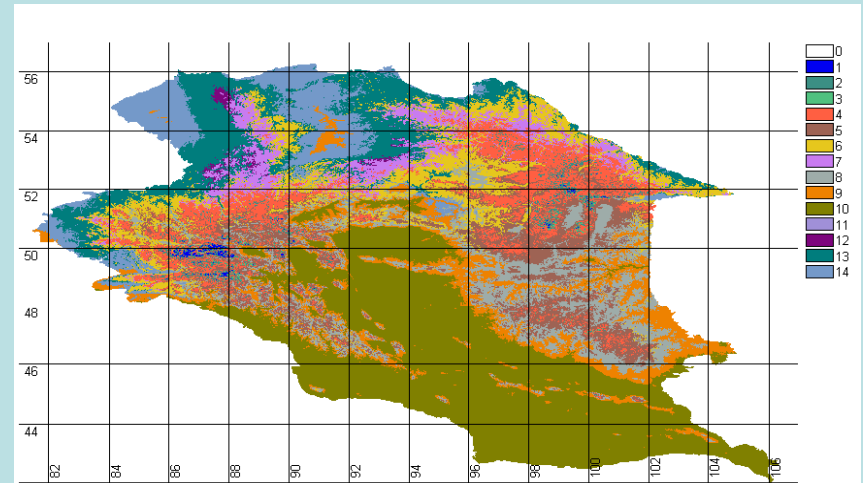
8000 BP



HadCM3 B1 2050



HadCM3 B1 2080



Some evidence of climate-caused vegetation change in Siberia

- *At the northern treeline, the forest shifted into tundra and open forests and become more stocked (Kharuk et al., 2005);*
- *In Evenkia, in the permafrost zone dominated by only *L. dahurica*, undergrowth of Siberian cedar, fir and spruce of some 40 years old was found (Kharuk et al., 2005; Ivanov 2004) probably because of permafrost melting;*
- *Upper treeline shift 40-100 m uplope was registered in the mountains in the south: Altai (Timoshok, et al. 2003), Ovchinnikov et al., 2002), in Kuznetsky Alatau (Moiseev, 2002) and even in the north in Putorana Plateau (Abaimov et al., 2002);*
- *At the lower treeline, the *P. sibirica* seed production significantly decreased in the West Sayan for 1990-1999 possibly because of the cone damage by the moth *Dioryctria abietella* (Schft.) that may produce two generations for a longer vegetation period (Ovchinnikova and Ermolenko (2003).*

Conclusions

- Impacts of global warming on the Siberian vegetation will be pronounced by the end of the 21st century;
- Climate change effects should shift vegetation zones. Habitats for northern vegetation classes (tundra and forest-tundra) would 2.5 times shrink, habitats for forests would 2 times shrink, southern vegetation (forest-steppe, steppe and semidesert) should proliferate, increasing in area from about 20% of the total to 40%;
- The wetter and warmer future climates at middle latitudes and permafrost retreat would favor dark conifers thriving rather than *Larix dahurica* taiga withstanding permafrost in interior Siberia today. Dahurian larch taiga will remain the dominant zonobiome only in East Siberia;

Conclusions

- The future climate may also be suited to new temperate biomes like steppes, forest-steppes, and broadleaved forests which do not inhabit Siberia today except some refugia;
- The MGO and Had CM3 B1 climate models are similar in their prediction of vegetation change during the 21st century except the forest structure. In the forests, dark conifers are predicted to dominate by the MGO model rather than light conifers predicted by the Had M3 B1 due to the permafrost distribution;
- Fire and the melting of permafrost are viewed as the principal mechanisms promoting establishment of new vegetation and, therefore, the shifting vegetation zones;
- Extent of the projected impacts is so profound that maintaining equilibrium between vegetation and climate would require humans to assist in plant migration to mitigate and adjust climate change negative effects.

A photograph of Siberian orchids (Cypripedium) in a lush green field. The flowers are a vibrant pinkish-red color with a prominent, inflated, pouch-like structure (the labellum) that is characteristic of this genus. The leaves are long, narrow, and bright green, creating a dense background for the flowers. The lighting is bright, suggesting a sunny day.

Siberian orchids

THANK YOU