



**Effects of climate, permafrost and fire on
vegetation change in Siberia in a changing climate**

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CLIMATE FIRE AND PERMAFROST

- Underlying principle: ...*climate is the primary factor controlling the distribution of plants*
 - Plesheev, 1797; Humboldt, 1807
- Under the control of climate and weather, *fire* is the dominant driving force of vegetation change in boreal ecosystems
- *Permafrost*, under the control climate, determines the large-scale distribution of species assemblages.

To predict possible effects of a changing climate on the vegetation distribution over Siberia we developed an envelope-type bioclimatic vegetation model based on the vegetation classification of Shumilova (1962)

Vegetation classification of Siberia (Shumilova)

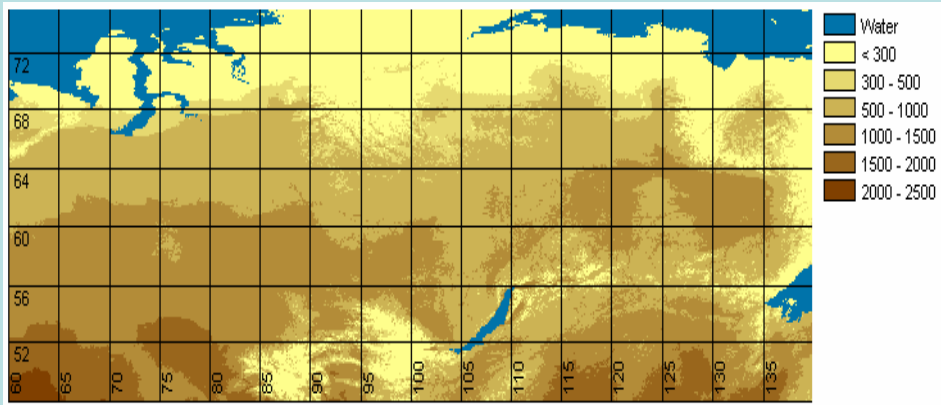
East

	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 o u t 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

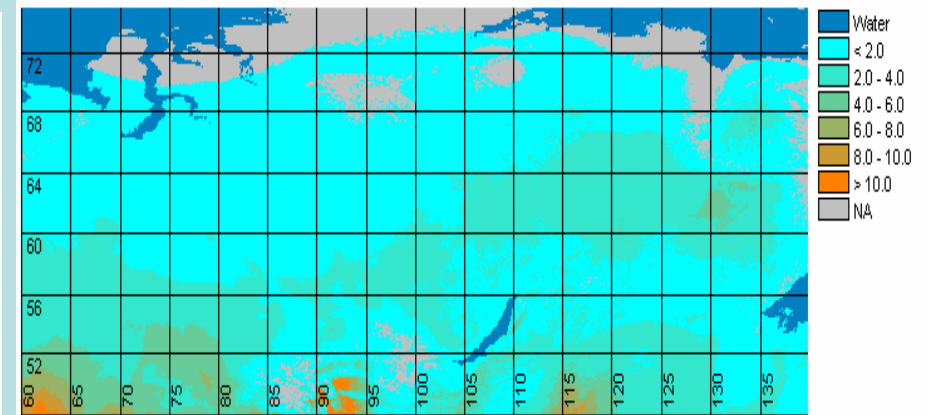
Siberian bioclimatic model SiBCliM

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 /annual precipitation)

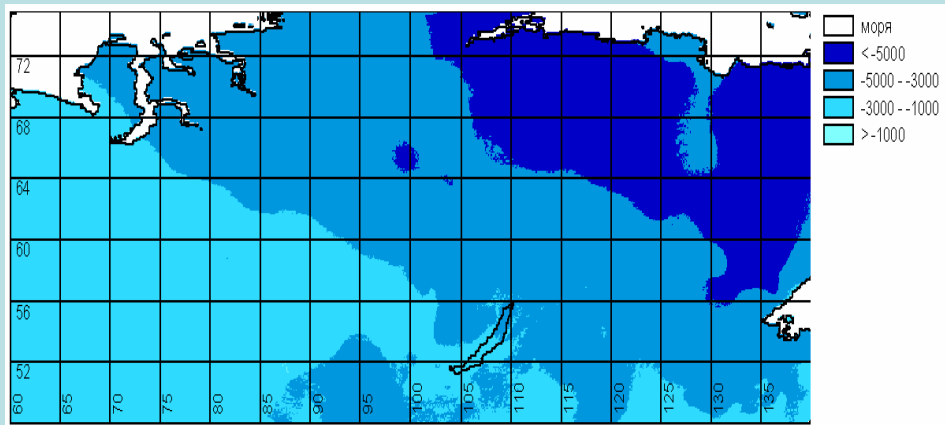
Siberian climatic layers used in “Envelope” model



Growing Degree Days, above 5°C



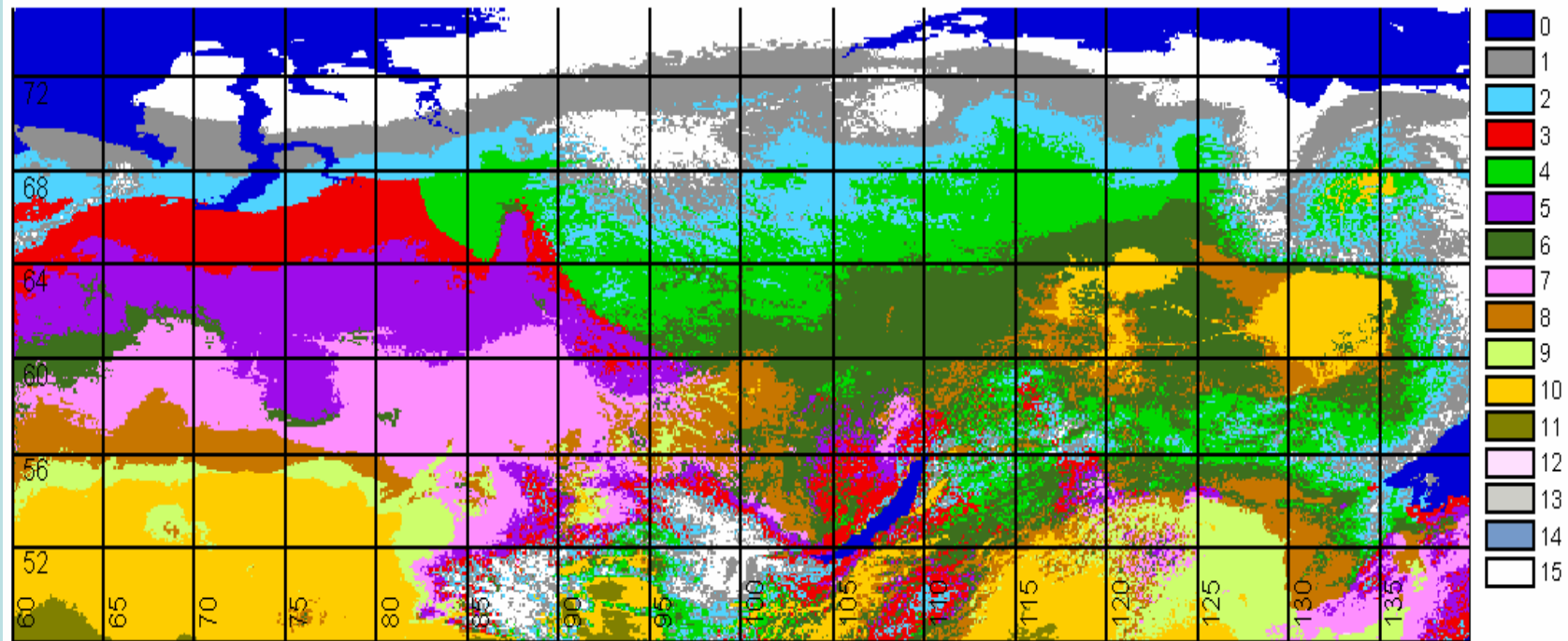
Annual Moisture Index, AMI



Degree Days below 0°C

To model Siberian vegetation, three climatic indices were mapped (Shumilova). 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 vegetation distribution over Siberia predicted from the three climatic indices using SiBCliM

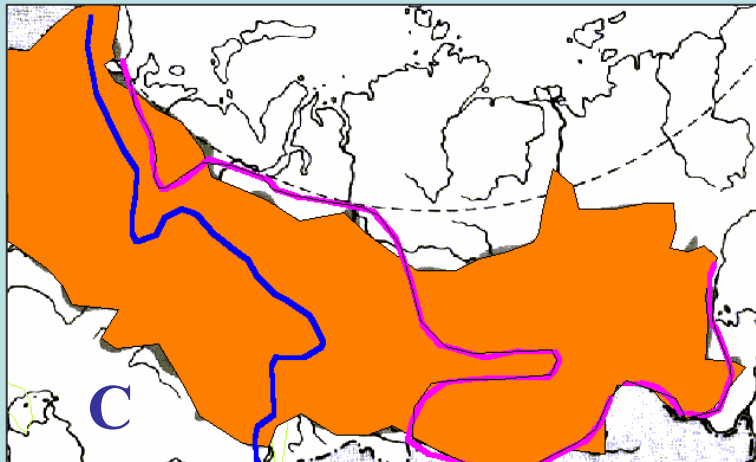
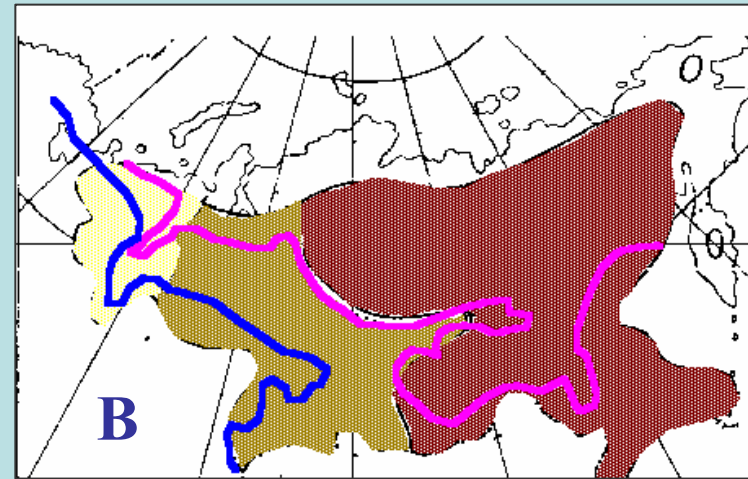
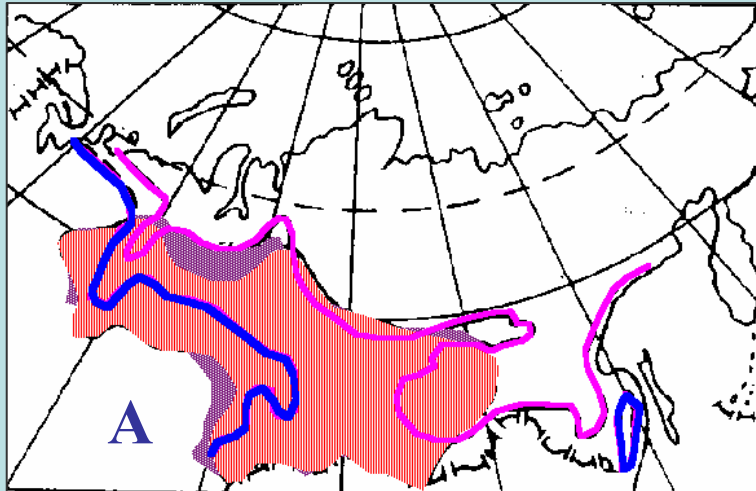


Vegetation classes: *BOREAL*: 1 – Tundra; 2 – Forest-Tundra; *Northern Taiga*: 3 – darkleaf, 4 – lightleaf; *Middle taiga*: 5 – darkleaf, 6 – lightleaf; *Southern Taiga*: 7 – darkleaf, 8 – lightleaf; 9 – Subtaiga, Forest-Steppe; 10 – Steppe; 11 – Semidesert; *TEMPERATE*: 12 – Broadleaf; 13 – Forest-Steppe;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

PERMAFROST

- Permafrost covers 80% of Siberia;
- Permafrost limits the northward and eastward distribution of major conifer species (*Picea obovata*, *Pinus sibirica*, and *Abies sibirica*, *L. sibirica* and *P. sylvestris*).
- In the dryer Siberian interior (200-300 mm precipitation), forests are dependent on permafrost melting to provide moisture - otherwise steppe or semi-desert evolve (Shumilova 1962);
- Only *L. dahurica* (*L. gmelini* + *L. cajanderii*) is able to grow on frozen shallow soils (thaw 10-30 cm) (Pozdnyakov, 1993).

Major Siberian conifer distribution regarding permafrost (Pozdnyakov, 1993)

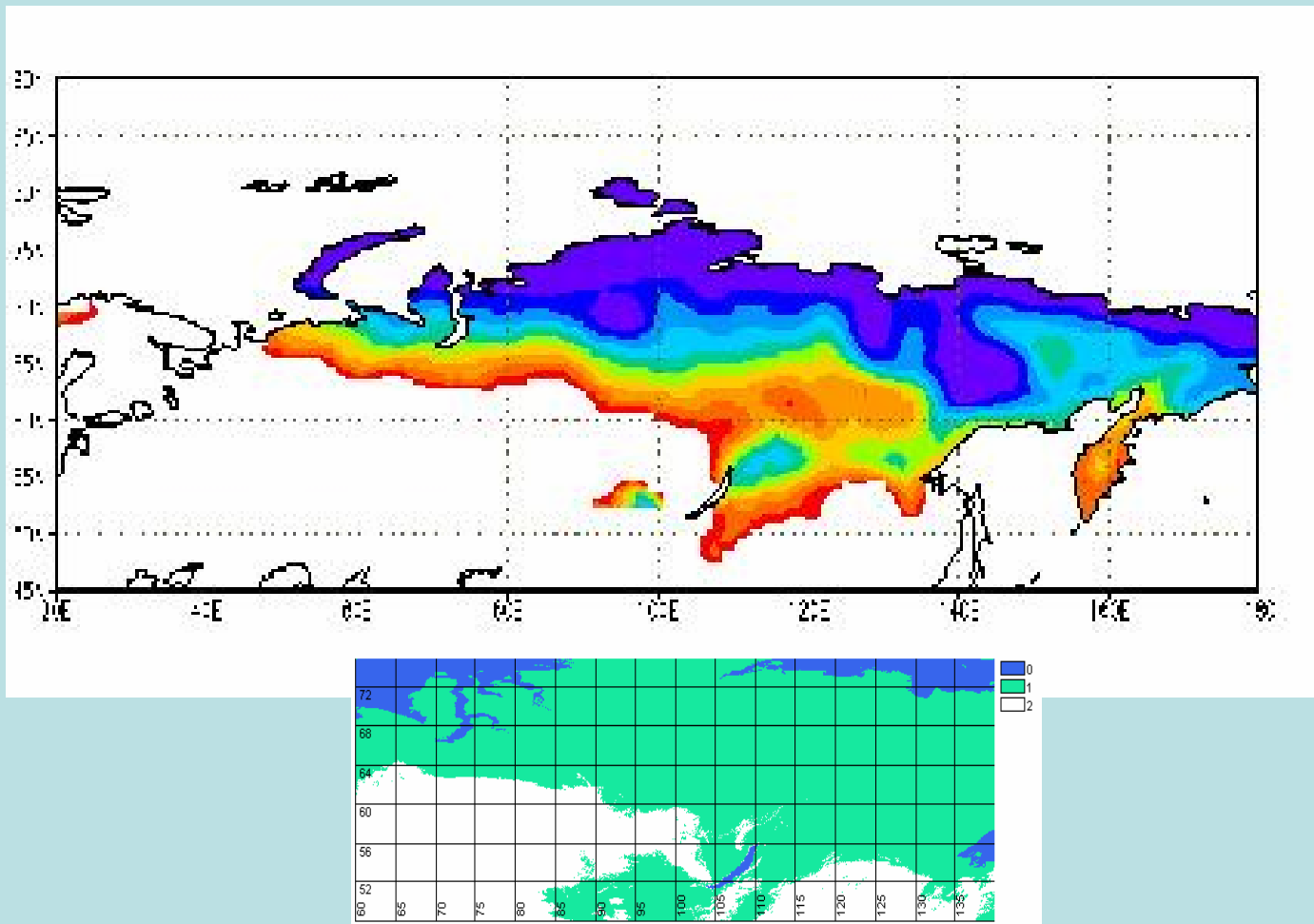


- A. Pinus sibirica and Abies sibirica;*
*B. Larix spp. (*L. sukaczewii*, *L. sibirica*, *L. dahurica*)*

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

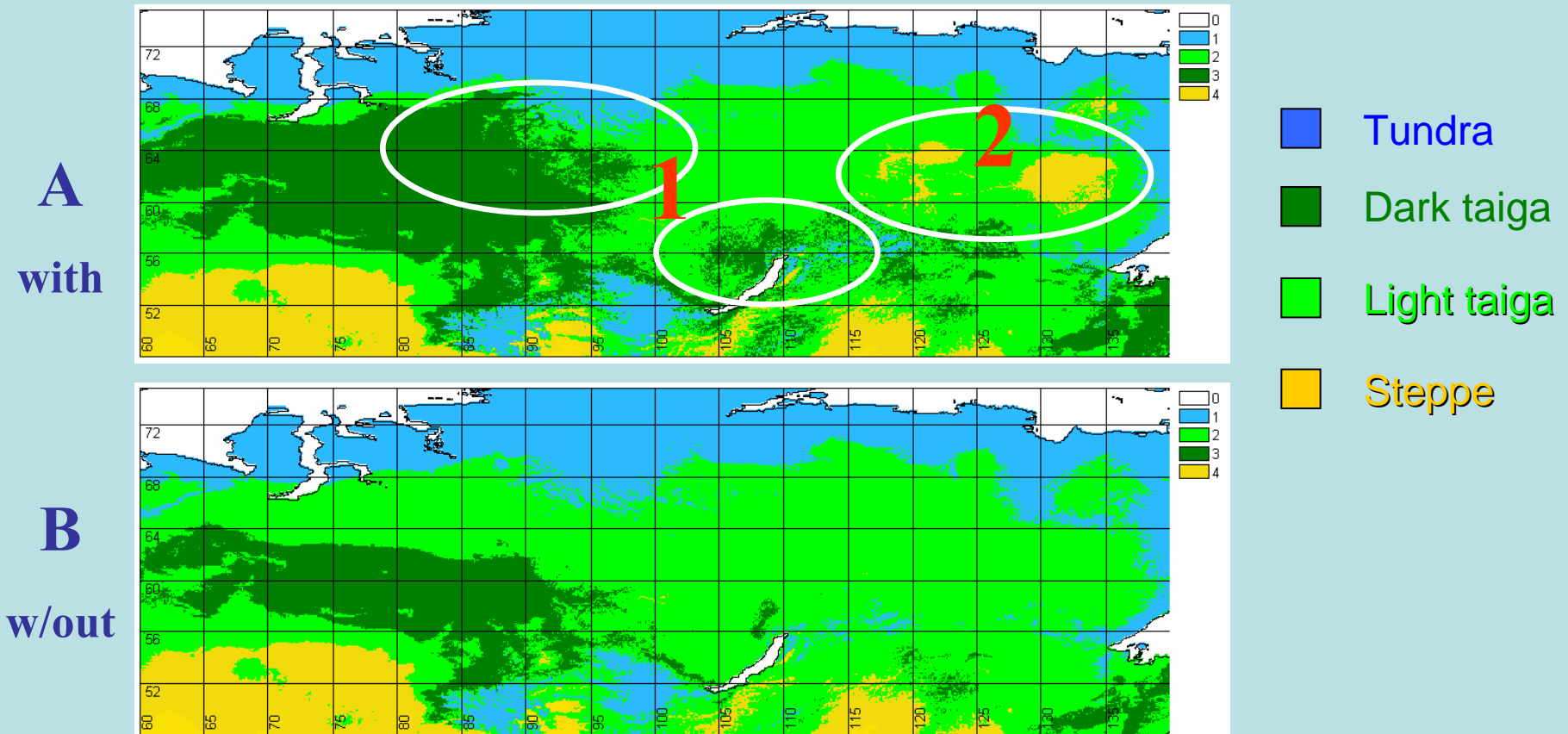
Blue is the border of discontinuous and **pink** is the border of continuous permafrost

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



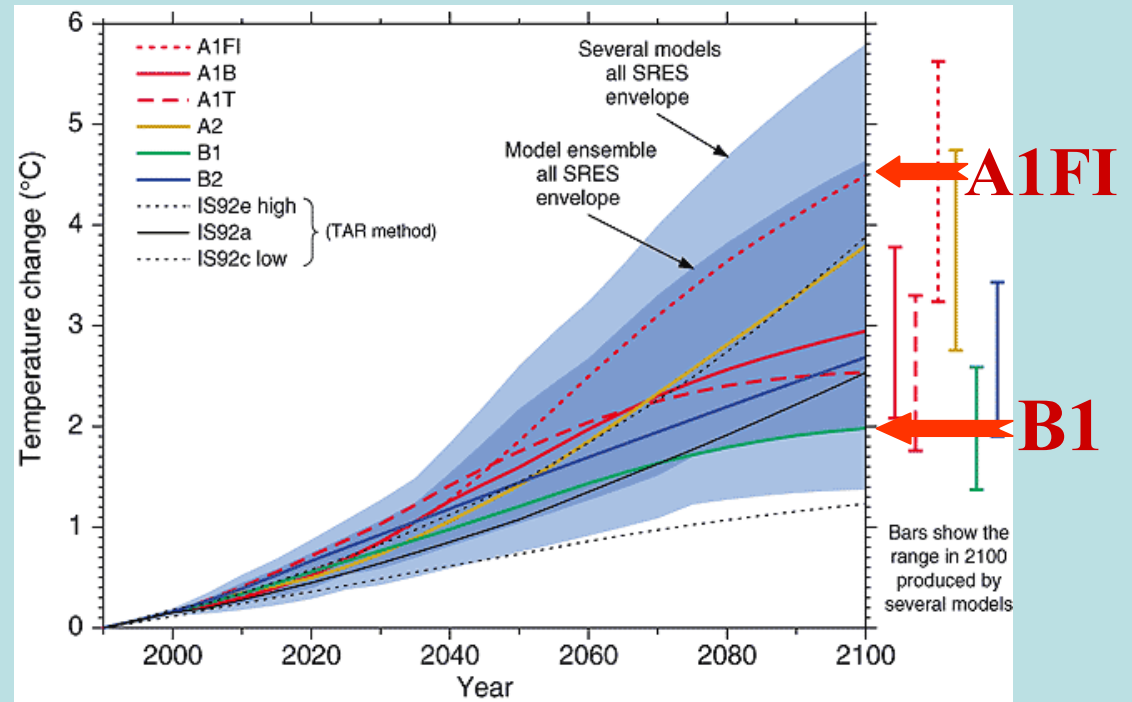
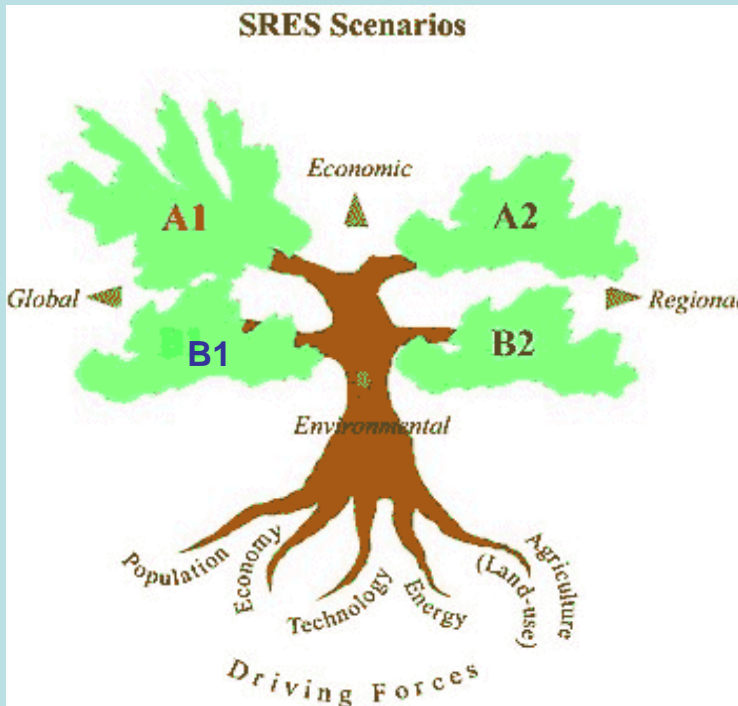
To model the border of permafrost we correlated its current position from the above map with GDD_5 , DD_0 and AMI ($R^2 = 0.70$)

Permafrost effects on vegetation distribution in Siberia: with permafrost (A) and without permafrost (B)



Conclusion: Permafrost eliminates: 1. dark-needled conifers in the north of West Siberia and in interior Siberia; and 2. supports larch forests in dry Yakutia in the zone of steppes

Climate change scenarios (IPCC, 2001)

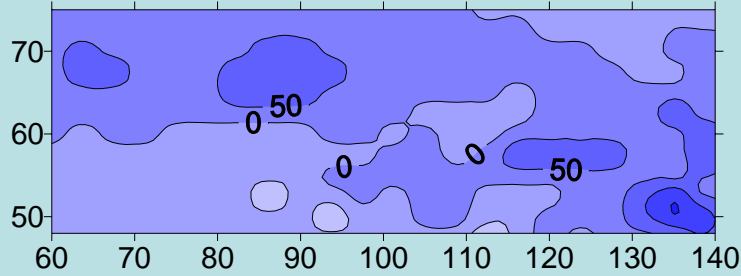


To model vegetation in Siberia under climate change, two climate change scenarios of the Hadley Centre A1FI and B1 were used which reflect opposite ends of the SRES (Special Report on Emission Scenarios) range.

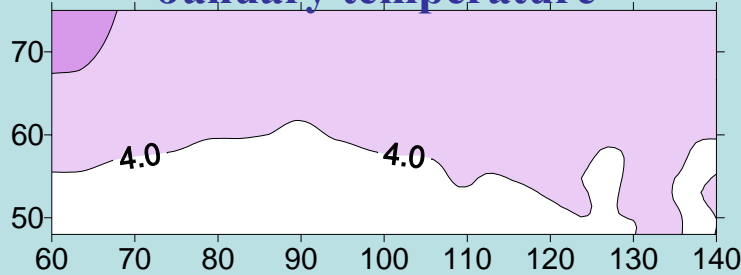
Climate change scenarios of the Hadley Center by 2080

HadCM3 B1

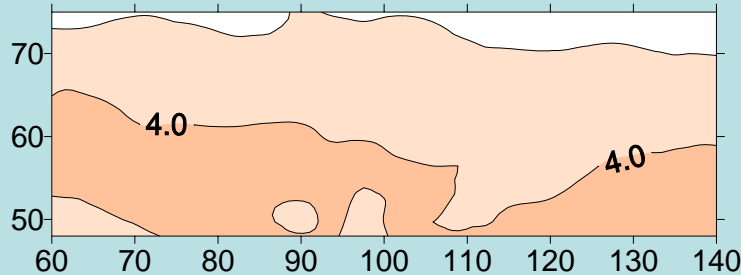
Annual precipitation



January temperature

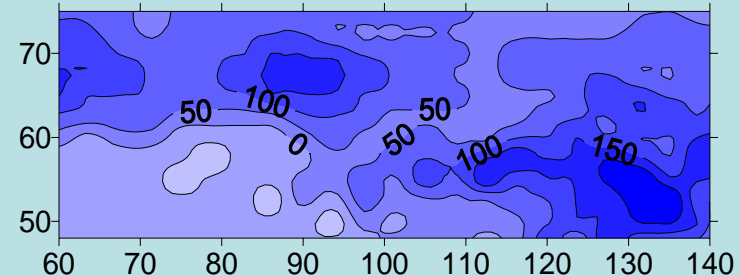


July temperature

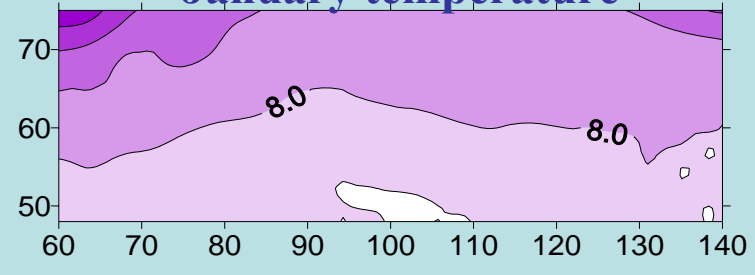


HadCM3 A1FI

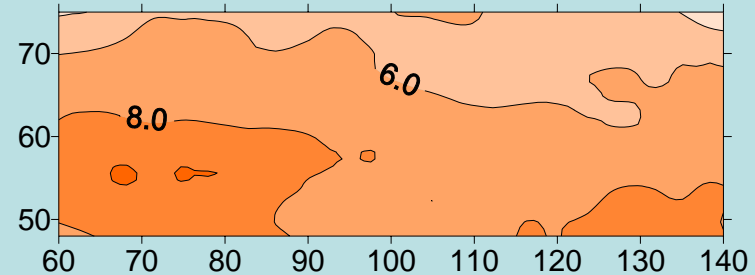
Annual precipitation



January temperature

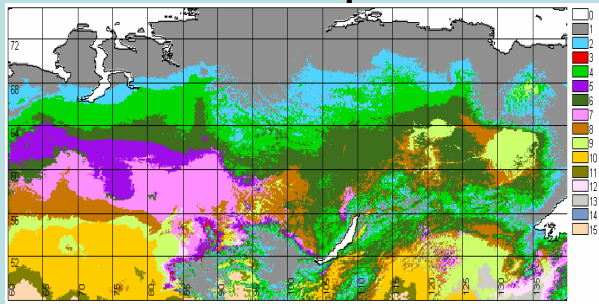


July temperature



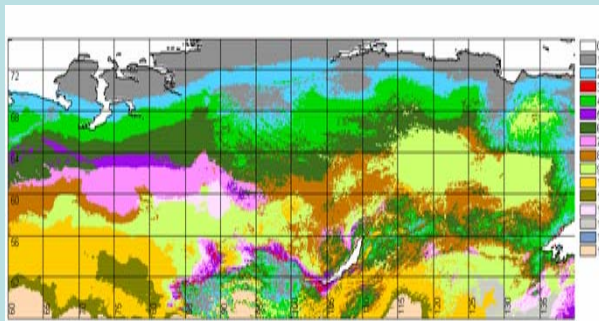
The largest temperature increase 8°C is associated with the A1FI scenario and 4°C is associated with the B1 scenario.

Climate and permafrost effects on vegetation distribution in Siberia in a changing climate

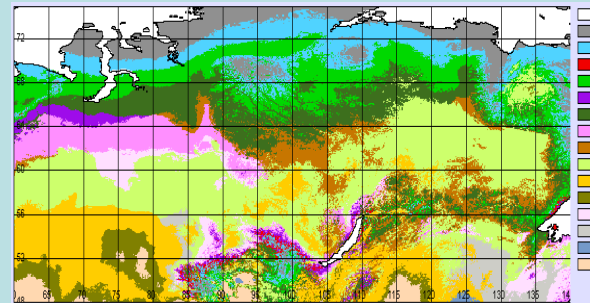


Current climate

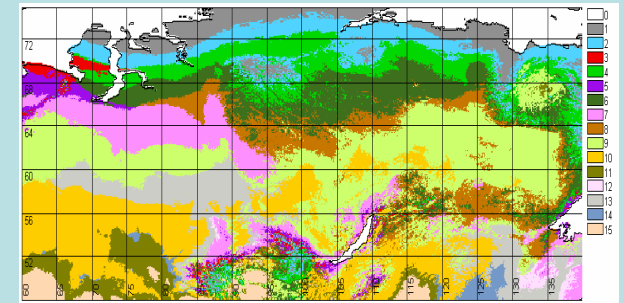
*Vegetation change was mapped by coupling our bioclimatic vegetation model **SiBCiM** with bioclimatic indices and the permafrost distribution calculated from 2 climate change scenarios.*



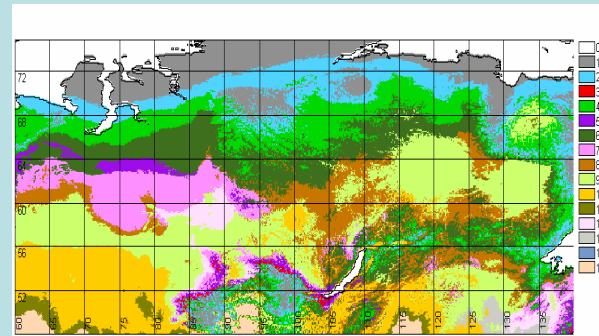
Scenario HadCM3 B1 2020



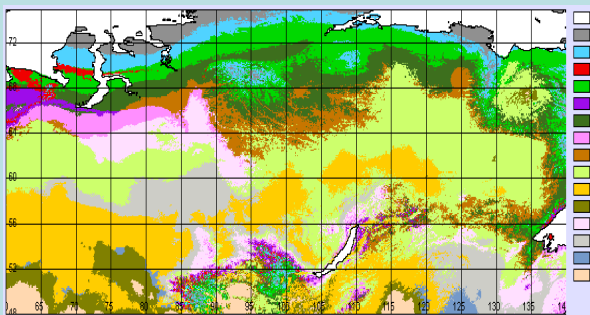
2050



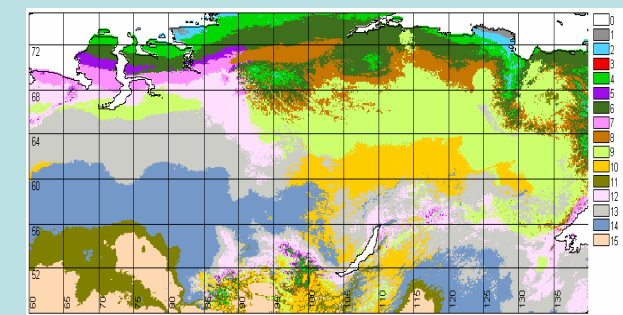
2080



Scenario HadCM3A1FI 2020



2050



2080

**Siberian vegetation distribution (%) in the 21st century
predicted from *HadCM3 A1FI* and *B1* climate change scenarios**

<i>Vegetation zone</i> BOREAL:	<i>Current climate</i>	<i>Scenario HadCM3 B1</i>			<i>Scenario HadCM3 A1FI</i>		
		2020	2050	2080	2020	2050	2080
Tundra	18.3	8.2	4.7	3.6	7.6	1.8	0.1
Forest-tundra	8.5	7.1	6.3	4.9	7.5	3.0	0.5
Dark-needled Taiga	12.4	8.2	7.9	10.9	9.3	5.1	0
Light-needled Taiga	39.2	35.9	27.8	23.4	35.6	21.7	12.8
Forest-steppe	7.5	17.8	24.4	21.9	19.3	24.8	15.9
Steppe	10.0	12.7	14.2	17.2	13.2	18.7	9.2
Semidesert	1.5	3.9	4.6	4.9	2.2	5.1	6.6
TEMPERATE:							
Broadleaf Forest	0.8	1.8	3.9	0.8	2.4	6.5	8.0
Forest-steppe	0.8	1.4	3.3	8.1	1.0	9.3	19.6
Steppe	0	0	0.3	1.3	0	1.1	17.8
Semidesert/Desert	1.0	2.8	2.6	2.8	18	29	6.8

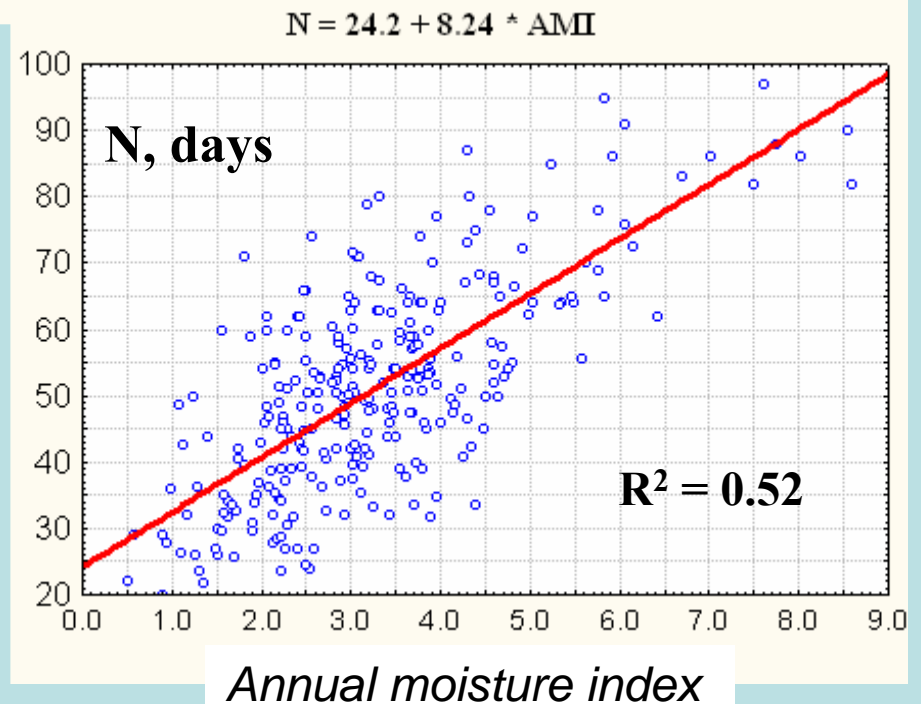
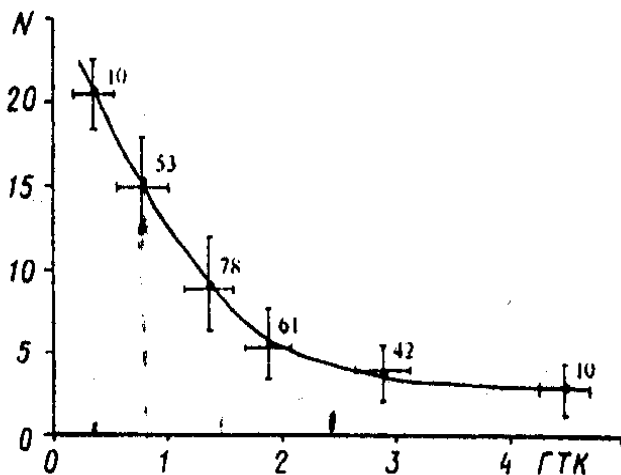
FIRE

- *Wildfire is a catalyst that serves as*
 - 1) a mechanism to maintain stability and diversity of boreal forests with the climate;*
 - 2) a mechanism by which forests move more rapidly toward equilibrium with new climates.*

The relationship between the number of high-fire-danger days (N) and annual moisture index (AMI)

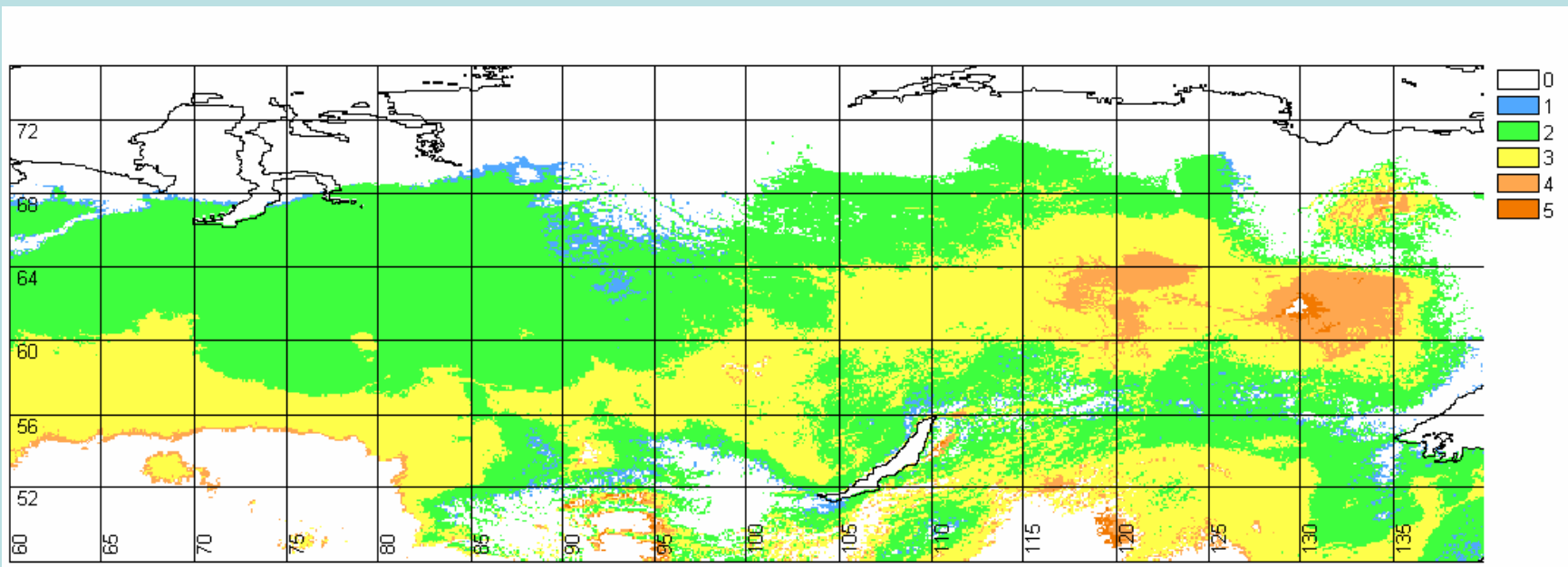
The model of Malevsky-Malevich et al. (2005) was used to calculate the number of days with fire danger greater than 4000 by Nesterov Index for each warm month ($t > 0^\circ\text{C}$) from the hydrothermal coefficient (ratio of monthly temperature to precipitation - GTK).

$$N_{\text{month}} = \exp \{f(\text{GTK})\}$$



The number of high-fire-danger days over the warm season was related with the average annual AMI. We used data of 35 Siberian weather stations located in different forest zones for various years of the 1950-2000 period.

Distribution of the annual number of high-fire danger days in current climate across Siberia



Blue – 30 days, green – 40 days, yellow – 50 days, orange – 60, red > 60 days

Climate effects on fire:

number of days with high fire danger predicted from various climate change scenarios varies from 10 in the B1 scenario to 30 in the A1FI scenario

	Scenario A1FI	Difference with current climate	Scenario B1	Difference with current climate
2 0 2 0				
2 0 5 0				
2 0 8 0				

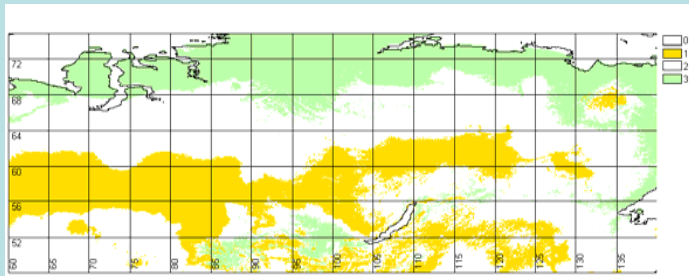
Difference: orange – 40 days; yellow – 30 days; green - 20 days; blue – 10 days

Climate change effects on vegetation and fire danger

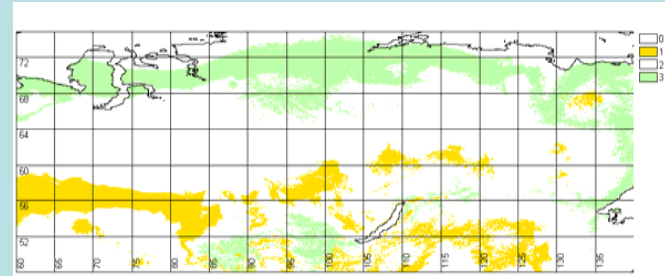
Vegetation “hot spots”:

*tundra-to-forest (green) and forest-to-steppe (yellow) change by 2080
found as the difference in vegetation in 2080 and current climate*

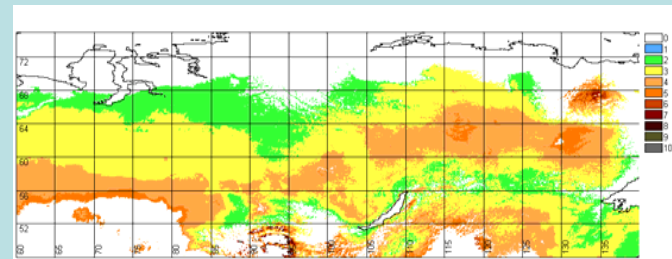
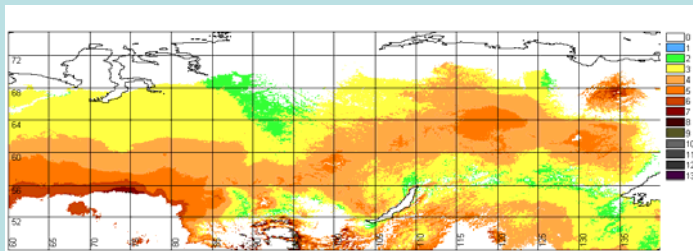
A1FI 2080



B1 2080



High fire danger increase



When superimposed, the vegetation change (increased fuel load) and increased fire danger indicate locations of high fire risks in the south of Siberia and Yakutia

Conclusions

- Under current climate change scenarios, current northern vegetation zones (tundra, forest-tundra, and taiga) would shrink, and southern vegetation zones (forest-steppe, steppe and semi-desert) would proliferate, increasing in area from about 20% of the total to 60%;
- The future climate may also be suited to new temperate broadleaved forests, which do not inhabit Siberia today;
- Fire and the melting of permafrost are viewed as the principal mechanisms promoting the establishment of new vegetation, under the control of weather and climate;
- SiBCliM simulations predict permafrost will not thaw deep enough across Siberia to support dark taiga, so permafrost tolerant *Larix dahurica* taiga will remain the dominant zonobiome;
- A dryer climate will result in increased tree mortality in the southern taiga, thus increasing fire fuel accumulation;
- Fire danger is predicted to increase as climate warms;
- Both factors of fire – fire weather and fuel load increase significantly escalate risks of fires in the south of Siberia.