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Impacts of climate and soil on distributions of major forest-forming conifers in current and future climates over the South Siberia Mountains

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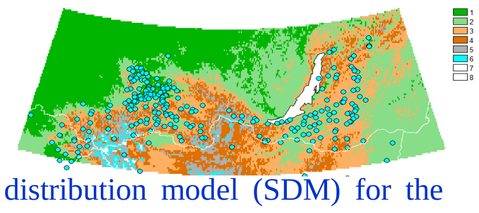
Fig. 1. The South Siberia Mts. Blue and yellow circles are weather stations

Introduction. Forests in the South Siberia Mountains represent a vast massif composed of five major conifers that shape the boreal forest: Siberian pine, Siberian fir, Siberian spruce, Scots pine and Siberian larch. Our goal was to built a bioclimatic model to predict major forest-forming conifer distributions based on atmospheric climate: warmth, water and cold and soil climates: soil moisture.



Methods. A bioclimatic model of major conifers' species distribution model (SDM) for the mountain forests in southern Siberia (80-110 E and 50-56 N) was built using the MaxEnt program (Phillips et al., 2006) in order to predict current and future distributions of the six major conifers. Tree species presence data for our MaxEnt model were derived from the map "The Forests of the USSR" (Isaev, 1990). Our model was based on three major climatic indices that characterized environmental resources for: warmth (Growing-Degree Days, above 5°C, GDD5), water stress (Annual Moisture Index, AMI, a ratio of GDD5/annual precipitation), and cold resistance (Negative Degree-Days, below 0°C, NDD) (Figs 2, 3). The contemporary climate data for building climate layers for both models were collated from 270 weather stations across the South Siberia Mts (www.meteo.ru). Climate data for future climates at the 2050s were derived from the Russian climate model GCM INM-CM5-0for two scenarios ssp126 and ssp585 at the mid-century (www.https://esgf-data.dkrz.de/search/cmip6-dkrz). A soil moisture (W/Wo) model we used was based on the heat budget theory of Budyko (1974) where W is actual moisture and Wo - maximal moisture in the 1-m upper soil layer. Our soil moisture model was verified by comparing to the re-analyses data of GIOVANNI BD (https://giovanni.gsfc.nasa.gov/). The comparison between them showed a significant difference that needs further investigations (Fig. 5).

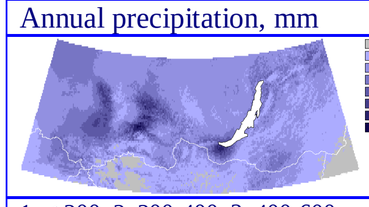
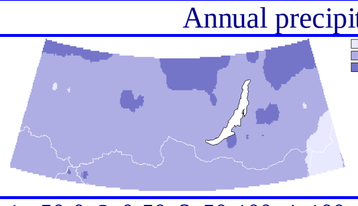
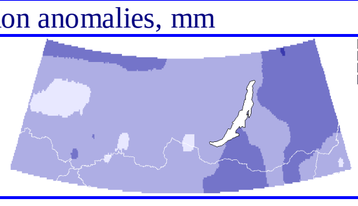
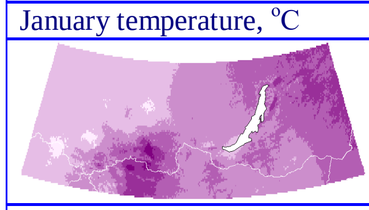
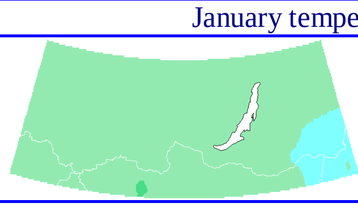
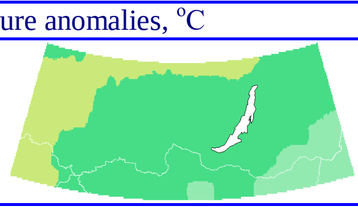
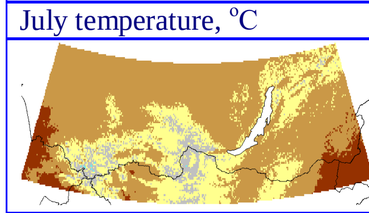
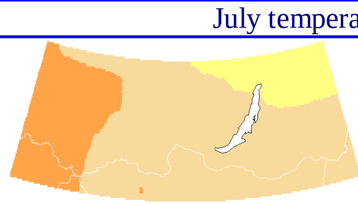
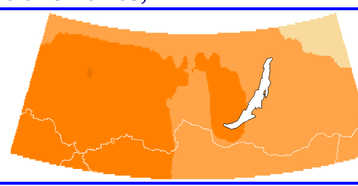
Base climate (1961-1990)	Climate 2050 (МОЦАО INM-CM5-0)	
	ssp126	ssp585
Annual precipitation, mm	Annual precipitation anomalies, mm	
		
1. < 200; 2. 200-400; 3. 400-600; 4. 600-800; 5. 800-1000; 6. 1000-1200; 7. 1200-1400; 8. >1400	1. -50-0; 2. 0-50; 3. 50-100; 4. 100-150	
January temperature, °C	January temperature anomalies, °C	
		
1. <-35; 2. -35 -30; 3. -30 -25; 4. -25 -20; 5. -20 -15; 6. -15 -10; 7. -10 -5	1. < 0; 2. 0-2; 3. 2-4; 4. 4-6	
July temperature, °C	July temperature anomalies, °C	
		
1. < 5; 2. 5-10; 3. 10-15; 4. 15-20; 5. 20-25	1. <1; 2. 1-2; 3. 2-3; 4. 3-4; 5. 4-5; 6. 5-6	

Fig. 2. Climatic layers in the baseline climate (left) and anomalies for the ssp126 scenario and the ssp585 scenario in a warming climate by the 2050s

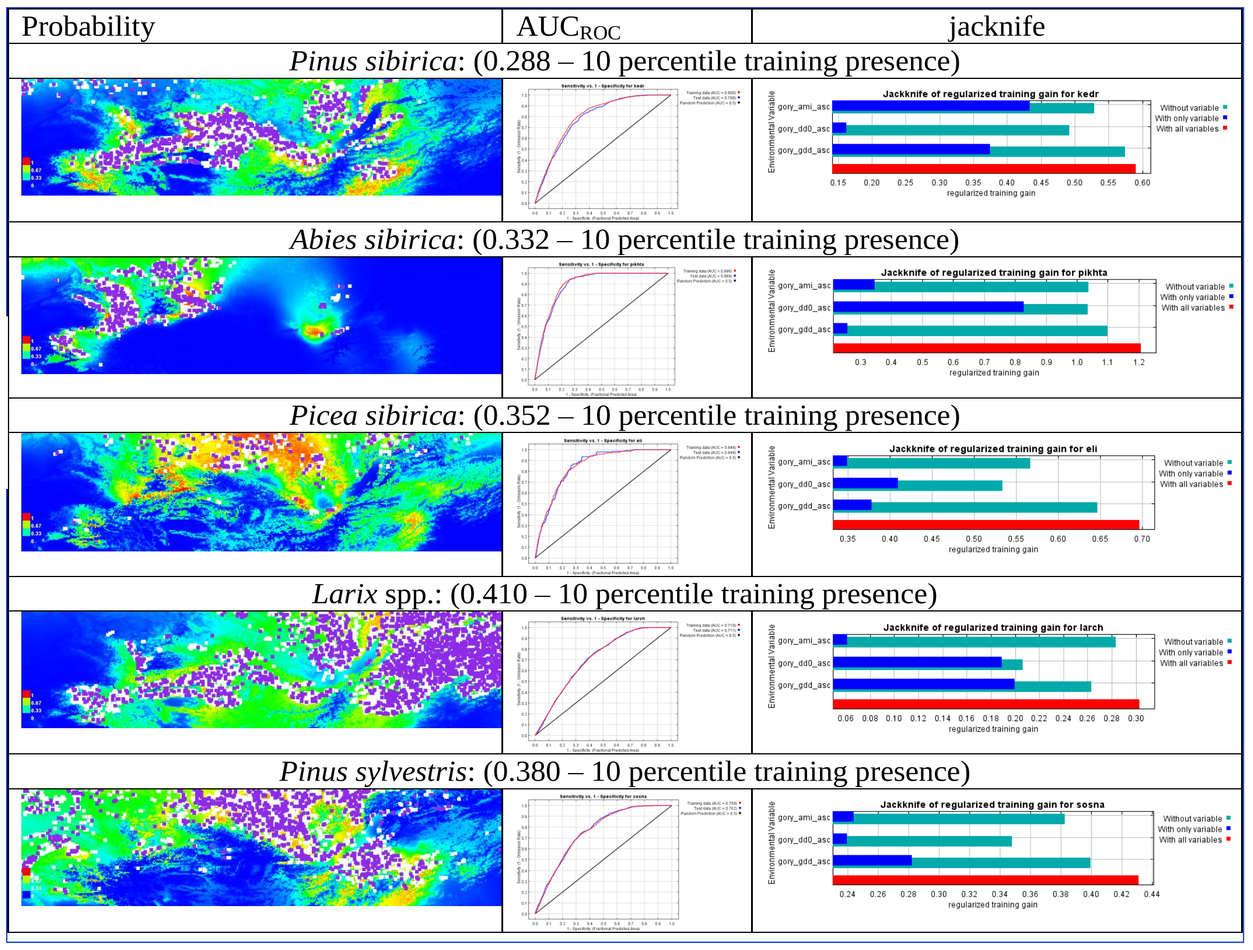


Fig. 3. Distributions of major forest-forming conifers predicted by the MaxEnt model. Key. Left. Probability of the species presence: maximum (red), average (green), minimum (blue); Dark-blue dots are training dots that cover red (maximum) probabilities; Center. Area Under Curve (AUCROC) characterizes the model quality; Right. Importance of each factor in a species distribution.

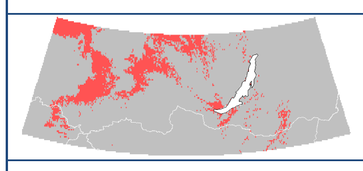
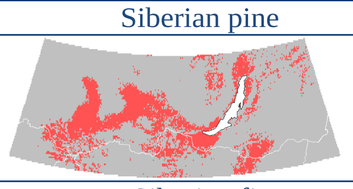
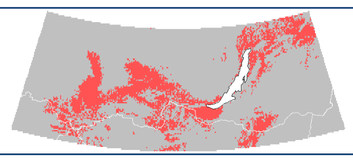
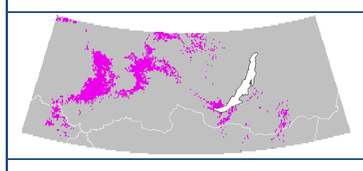
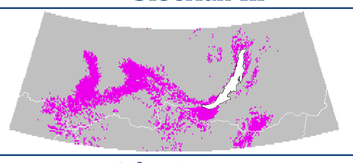
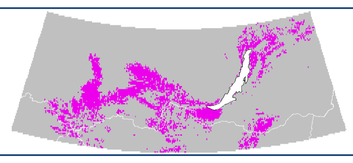
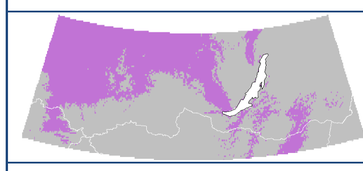
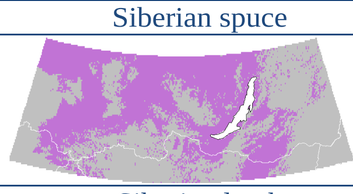
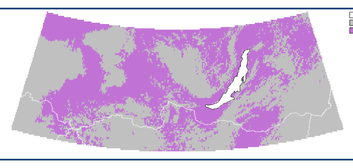
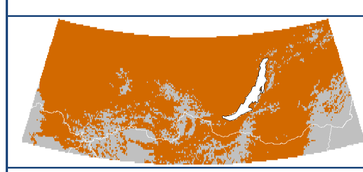
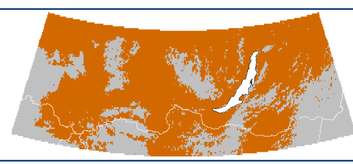
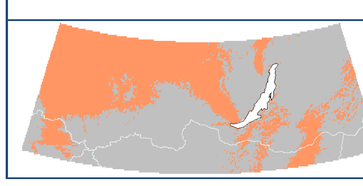
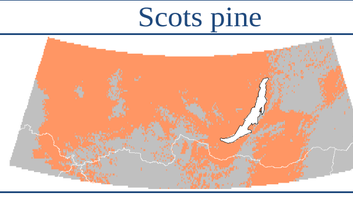
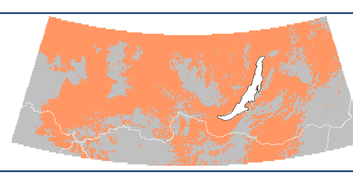
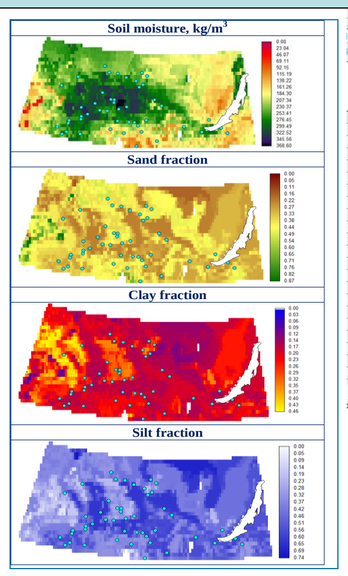
Current climate	Climate of INM-CM5-0/ 2050	
	ssp126	ssp585
Siberian pine		
		
Siberian fir		
		
Siberian spuce		
		
Siberian larch		
		
Scots pine		
		

Fig. 4 Major conifer distributions over Siberia predicted by the MaxEnt program in current and the 2050s climates



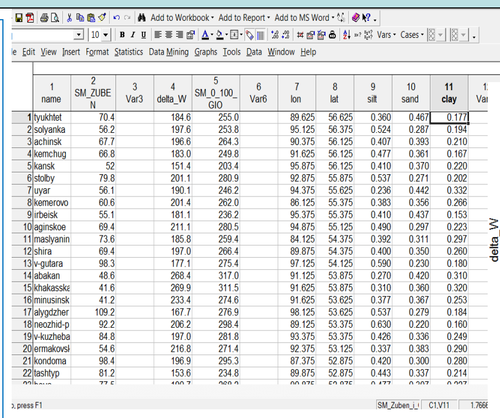


Fig. 5. Soil moisture and texture distributions over the South Siberia Mts. (https://giovanni.gsfc.nasa.gov ; left); a fragment of our soil moisture database (center); and the correlation model of the soil moisture difference (r = 0.80) calculated from the theory of Budyko (1974) and from the re-analyses data of GIOVANNI BD. The comparison between them showed a significant difference which needs further research.

Results and Conclusions.

The ranges of dark-needled (Siberian pine, Siberian fir, Siberian spruce), light-needled (Scots pine and Siberian larch, and their coverage (%) were mapped at the present and at the mid-century (Fig. 4). All evergreen conifers would expand their ranges at the expense of tundra in uplands due to predicted additional heat and plenty of rain. However, deciduous coniferous larches would shrink due to steppe extension in dryer lowlands.

In previous studies, soil climates were found to be important for conifer distributions over the mountains but still less important than the atmospheric climates were (Tchebakova et al. 1986). The genetic soil types and soil warmth and moisture appeared to be most important for the forest composition. Siberian larch and Siberian pine were found to be the most plastic conifers, Siberian fir was found to be the most demanding conifer. In the future climates, under additional heat as follows from the climate change scenarios and plentiful rain across the mountains, hydro-thermal conditions in soils would be favorable for sustainability and productivity of coniferous forests.

Acknowledgments. The study was supported by Projects: FWES-2024-0023