Appendix S1

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Electronic supplementary material S1: "Siberia's climate characteristics"
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Title: **Siberian Environmental Change: synthesis of recent studies and opportunities for networking**

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Siberia's climate characteristics

Introduction. Being located in the middle of the largest continent, Siberia presents a natural laboratory in which different global climatic processes, in interaction with their regional counterparts and feedbacks, form the regional climate and determine its variability and dynamics. This territory contains a significant part of the Earth's land, biosphere and cryosphere that interacts with the global atmospheric and oceanic circulations and make important inputs into the state of the global climate and its changes.

Due to highly nonlinear interactions between the components of the climatic system, some variations are inherent in any regional climate. In Siberia, periods of such variations vary from millennia to years. The most well-known manifestation of these changes is the nearly open northern sea route in 1930-1940. Also, the study of treeline variations (MacDonald et al., 2008) reveals long term summer temperatures and growing season length variations.

Possibilities to characterize ongoing climate variability are based on analysis of available data of local and remote instrumental meteorological observations and on results of reanalysis, that is retrospective meteorological modelling performed with assimilation of observed characteristics. This Supplementary Material presents information on Siberia's climate characteristics additional to that in the main text.

Snow. Data characterizing snow cover come from surface observations, remote sensing, and models (reanalysis and land surface models). Russian data, from a substantial network of snow transects, has been made available via the All-Russia Research Institute of Hydrometeorological Information-World Data Centre (RIHMI-WDC) website (http://meteo.ru/english/climate/snow.php and http://meteo.ru/english/climate/snow1.php)/
These datasets contain data from routine snow surveys and snow water content operated at meteorological stations from 1966. It should be mentioned that there is

considerable inter-dataset variability. Also, due to inherent regional variability of snow characteristics there is no single strongly pronounced tendency in their changes under ongoing climate change. Nevertheless, analysis (Mudryk, et al., 2020) of the multi-dataset ensemble shows that in the Northern Hemisphere during 1981–2018 SCE (Snow Cover Extent) and SWE (Snow Water Equivalent) trends are negative for all months between November and June. The CMIP6 ensemble, also strongly suggests that, on a hemispheric scale, future SCE changes can be rather unambiguously related to surface temperature. However, a recent study (Pulliainen, J. et al. 2020) reveals high regional variability of SWE changes. Also, according to Zhong et al. (2021), long-term (1971–2000) mean annual SCDs (Snow Cover Duration) increased with latitude, the longest being more than 270 days along the Arctic coast. Statistically significant long-term trends of delayed onset and advanced disappearance of snow cover from1966 through 2012 have been observed. Changes in SCD were closely related to changes in air temperature and snowfall in autumn and increasing air temperature in spring.

Glaciers. Ongoing deglaciation in the mountain systems has some specifics in Siberia. There are several glacier areas in Siberia. In the Altai Mountains, located on the junction of Russia, Kazakhstan, Mongolia and China, the Kuznetsky Alatau Mountains, and South-East Siberian mountainous regions (East Sayan, Baikalsky and Kodar ridges), 923.1 km^2 are covered by glaciers according to the IGU (International Geophysical Union). The observed air temperature has increased by 1.2 ◦ C over northern Eurasia during the last 120 years, affecting the degradation of the Siberian glaciers. In general glacier response to regional climate change is modified by local factors—glacier morphology, snow accumulation conditions and the glacier exposure. It appeared (Kotlyakov et al. 2017) that there are two types of glacier front reactions to air temperature increases which depend on glacier mass, annual balance and bed relief. On one hand, glaciers react only to the secular temperature changes, while on the other hand, they react to these changes and other local changes.

Aridit**y.** Temporal and spatial changes of aridity are occurring in Southern Siberia, caused by global climate change planetary-scale changes in atmospheric circulations like Hadley cell poleward expansion (Lu e al., 2007) and continent-scale atmospheric and oceanic oscillations. General hydrothermal conditions of a territory, either drought or waterlogging, are studied using various integrated indicators, which in most cases are various combinations of air temperature and rainfall values. In Russia, the Hydrothermal Coefficient of Selyaninov (HTC) and Ped's drought index indicators are usually used, while the most common worldwide indicators are the Standardized Precipitation Index (SPI) / the Standardized Precipitation and Evaporation Index (SPEI) and the Palmer Index (PDSI) / Palmer Self-Calibrating Index (sc-PDSI). A comparative analysis of the applicability of these indices for Siberia was done by Voropay and Riazanova (2018).

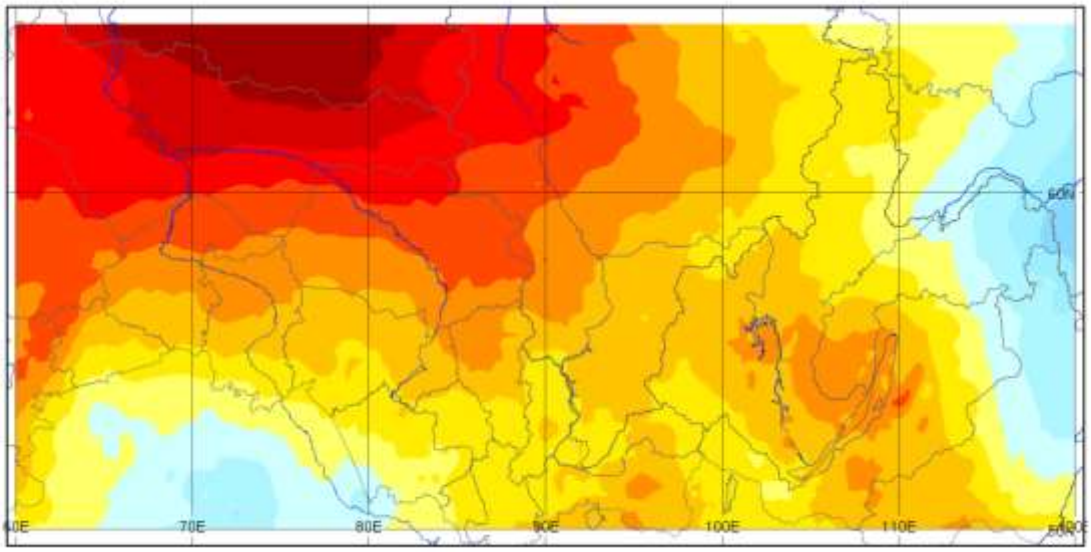
Arctic change in Siberia. Temperature increase impacts tundra vegetation. A recent study (Berner et al. 2020) measures vegetation changes spanning the entire Arctic tundra, from Alaska and Canada to Siberia, using satellite data from Landsat. Greening represents plants growing more, becoming denser, and shrubs encroaching on typical tundra grasses and moss. The NDVI increases detected depend on local temperature gradients, local precipitation, surface wetness, changes in the length of the snow-free period and growing season length. They also reflect tree species migrating northward (Frost and Epstein, 2014) and (Frost et al., 2018). (See main text for more details and complexity of NDVI measurements from space and ground measurements.)

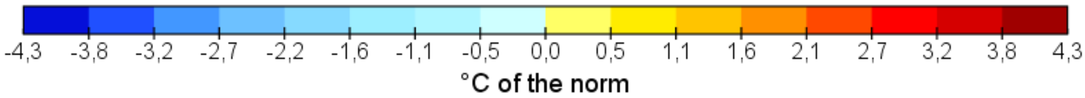
Since warming leads to earlier spring thaw and a later autumn freeze, and the darker surface absorbs more solar radiation, the rate of warming is further increased and results in more pronounced permafrost thawing and higher probability of wildfires. Forecasted high temperatures may lead to continued permafrost degradation and coastal erosion.

Some climatic characteristics illustrating the variability and dynamics of Siberia's modern climate

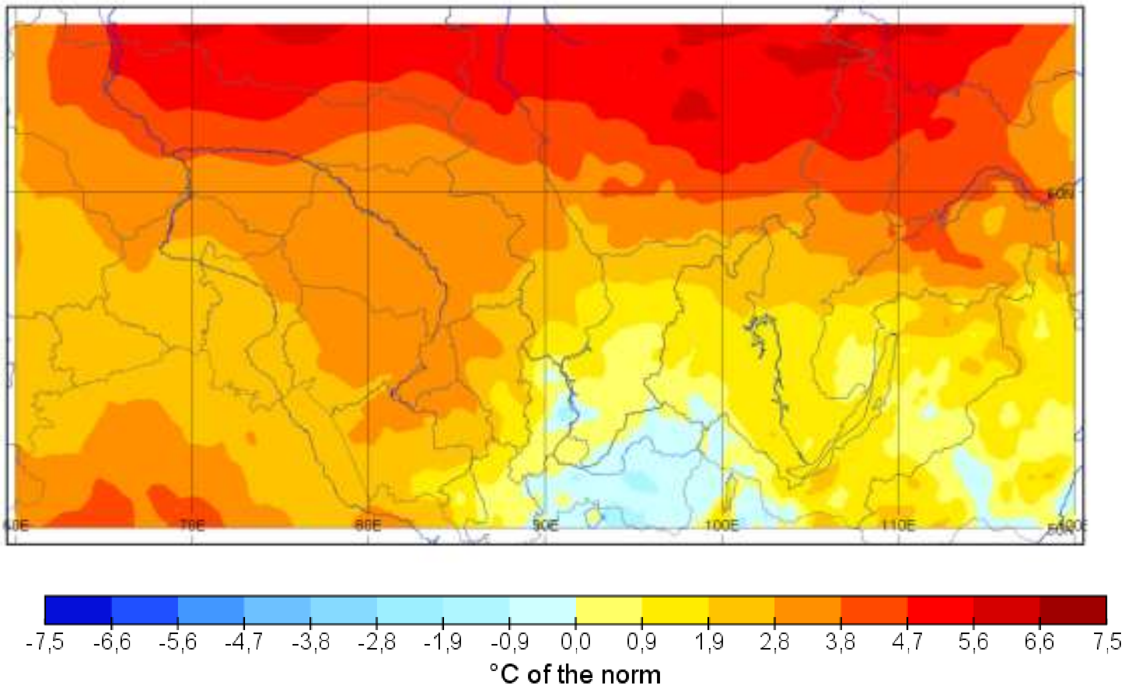
Various climate variability characteristics were calculated using the web-GIS CLIMATE (http://climate.scert.ru) and relevant digital map layers and relevant files which are open for downloading at http://climate.scert.ru/adaptation/library/ and http://climate.scert.ru/Environment/data/archive/,

respectively. The set of climatic characteristics calculated describes qualitatively recent temperature and precipitation changes from year to year in Siberia (50-65 ° N, 60-120 ° E). The following spatial characteristics (among others) are available: anomalies of meteorological characteristics (near surface atmosphere temperature and precipitation, calculated with the base period 1981 - 2010), climate indices developed by the CCI / CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (http://etccdi.pacificclimate.org/index.shtml), and various hydrothermal coefficients. A complete list of climate indices characterizing extreme events includes temperature characteristics, like number of frost days, number of summer days, number of ice days, number of tropical nights, growing season length, maximum of daily maximum temperature, maximum of daily minimum temperature, minimum of daily maximum temperature, minimum of daily minimum temperature, number of cold nights or days, number of warm nights or days, warm and cold spell duration indexes, mean of diurnal temperature range, as well as some characteristics of precipitation, like maximum one-day precipitation, maximum consecutive 5-day precipitation, heavy precipitation days (> 10 mm), very heavy precipitation days (> 20 mm), maximum number of consecutive dry days, maximum number of consecutive wet days, number of very wet days (R95p (the 95th percentile of precipitation on wet days in the base period 1981 to 2010)), number of extremely wet days (R99p), and precipitation amount due to wet days.
Files can be downloaded in various formats (netCDF, GeoTiff, WMS and WFS links) for use in various GIS systems (QGIS, ArcGis, PostGIS, etc.) or customized software. Below are examples of various outputs measured against the base period of 1981 to 2010.

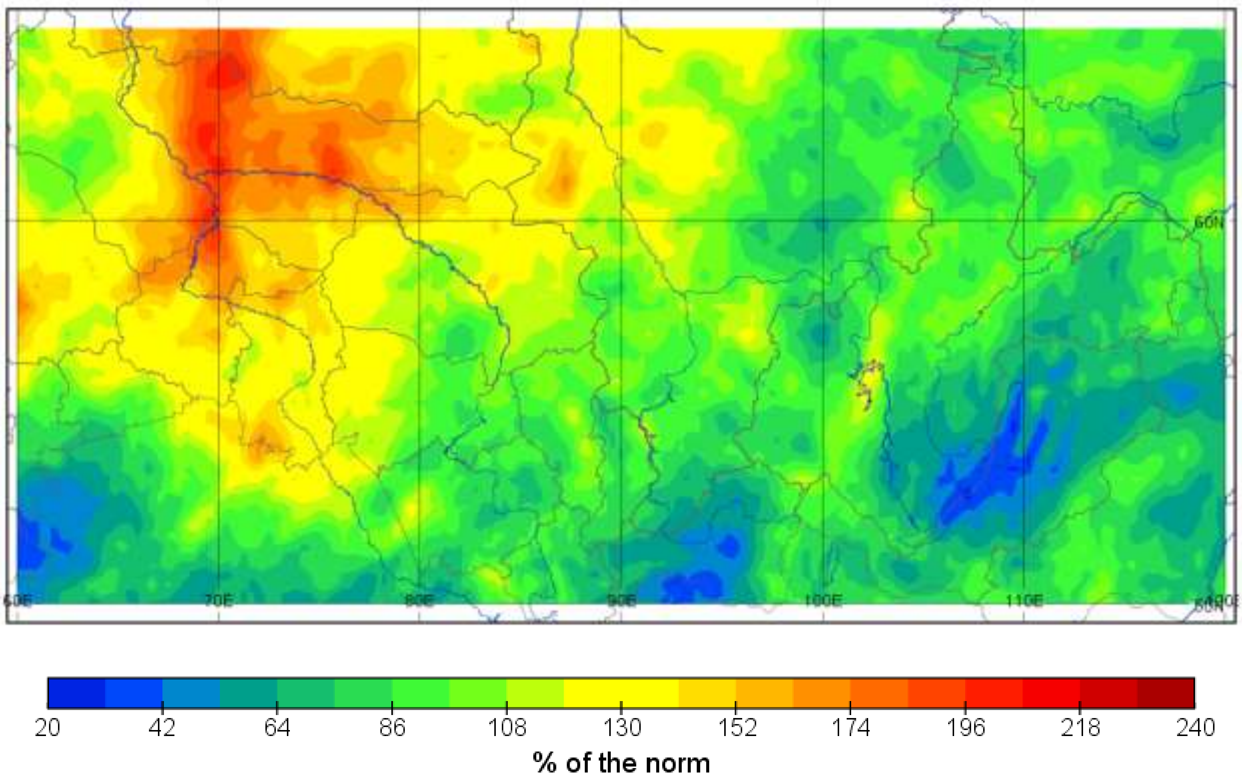




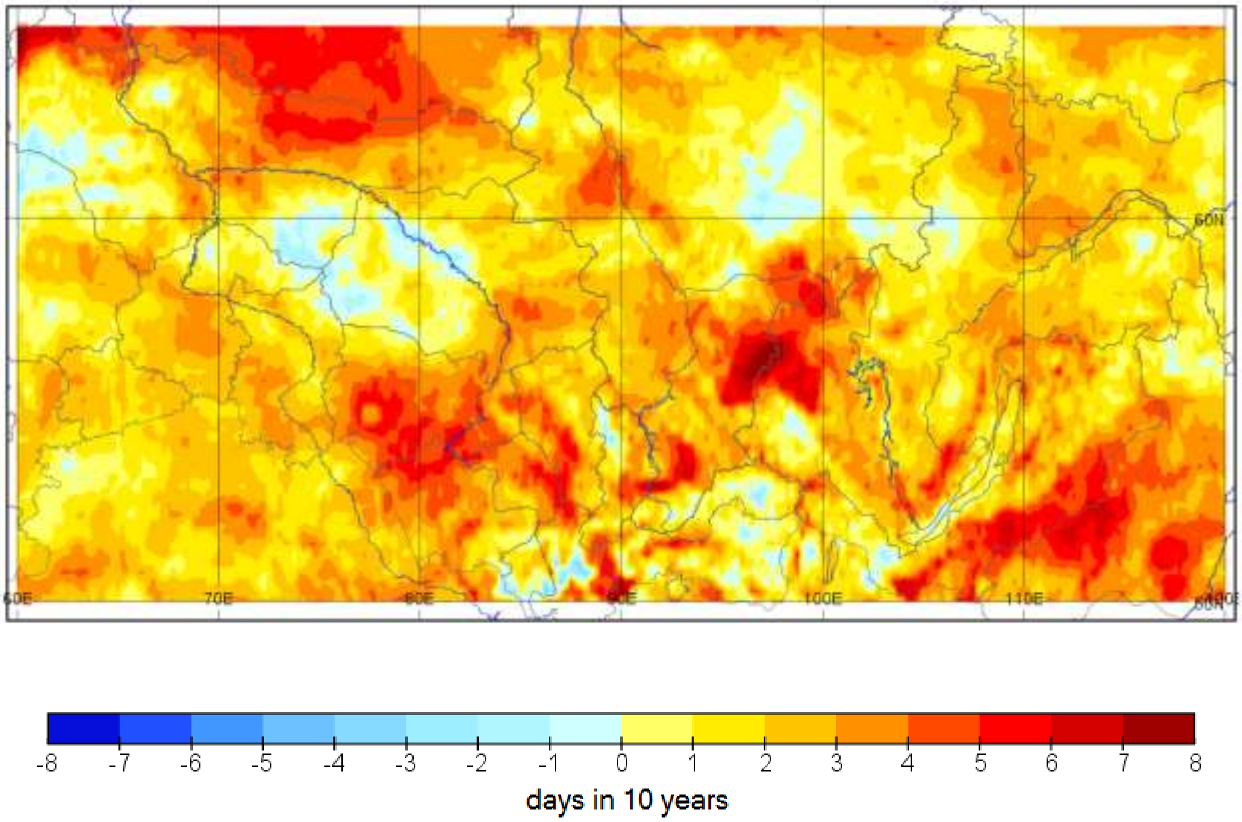
Air temperature anomaly for summer 2016



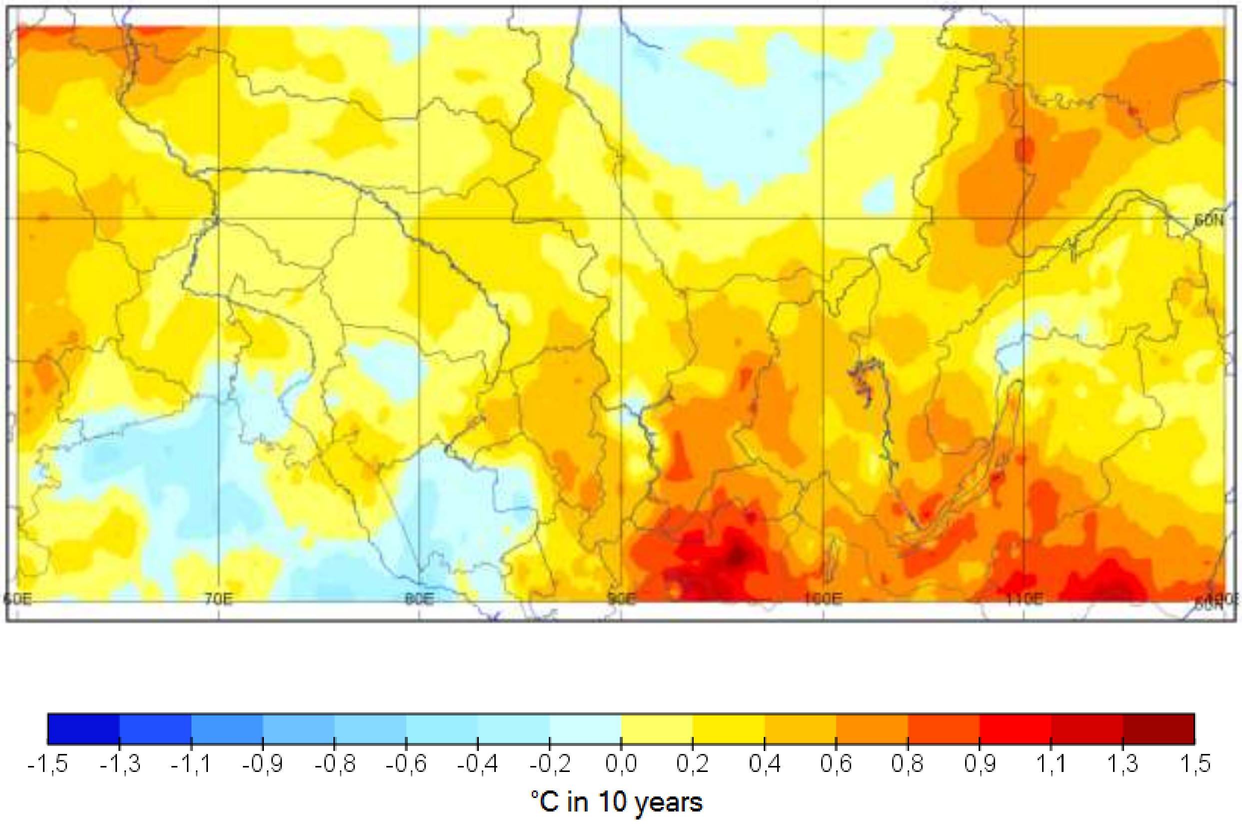
Air temperature anomaly for winter 2016



Precipitation anomaly for summer 2015



Trend of growing season length for 1979-2018



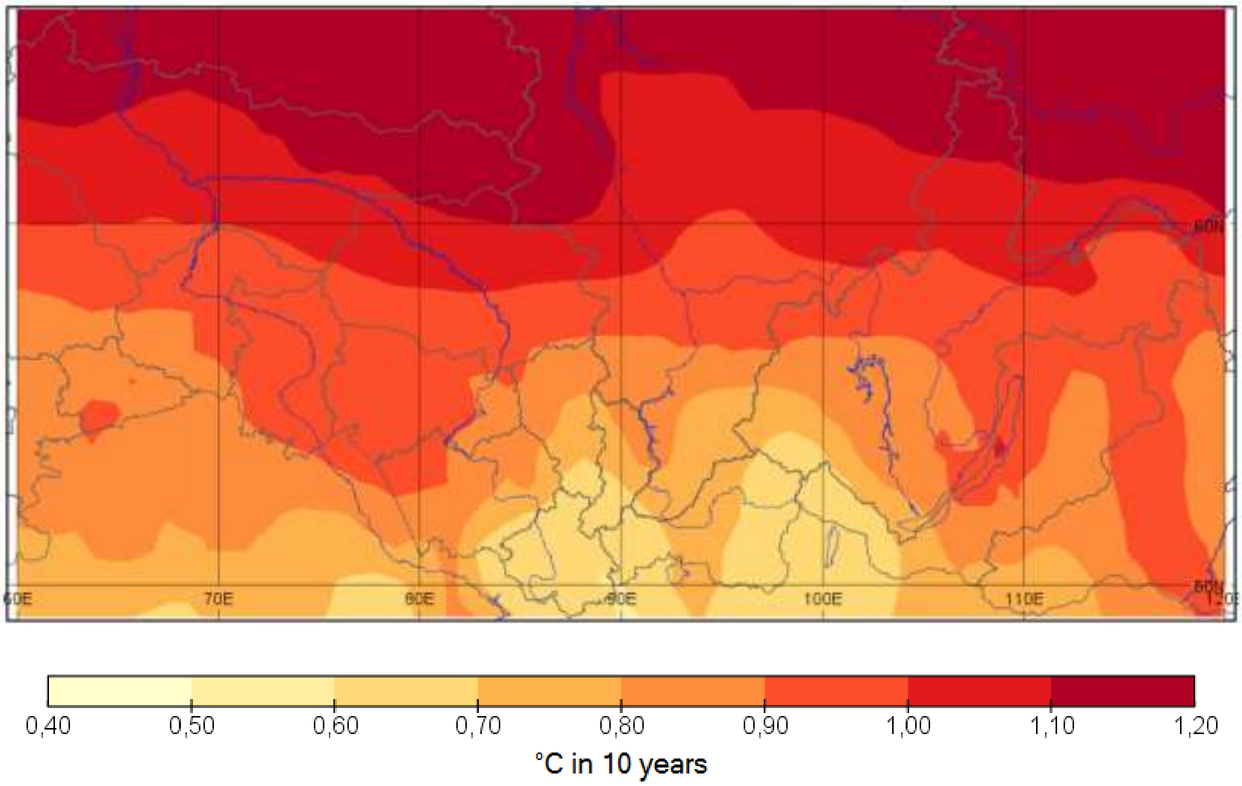
Trend of maximum of daily maximum temperature (TXx) for 1979-2018. TXx is the maximum of daily maximum temperature in a year

Future Siberia climate characteristics

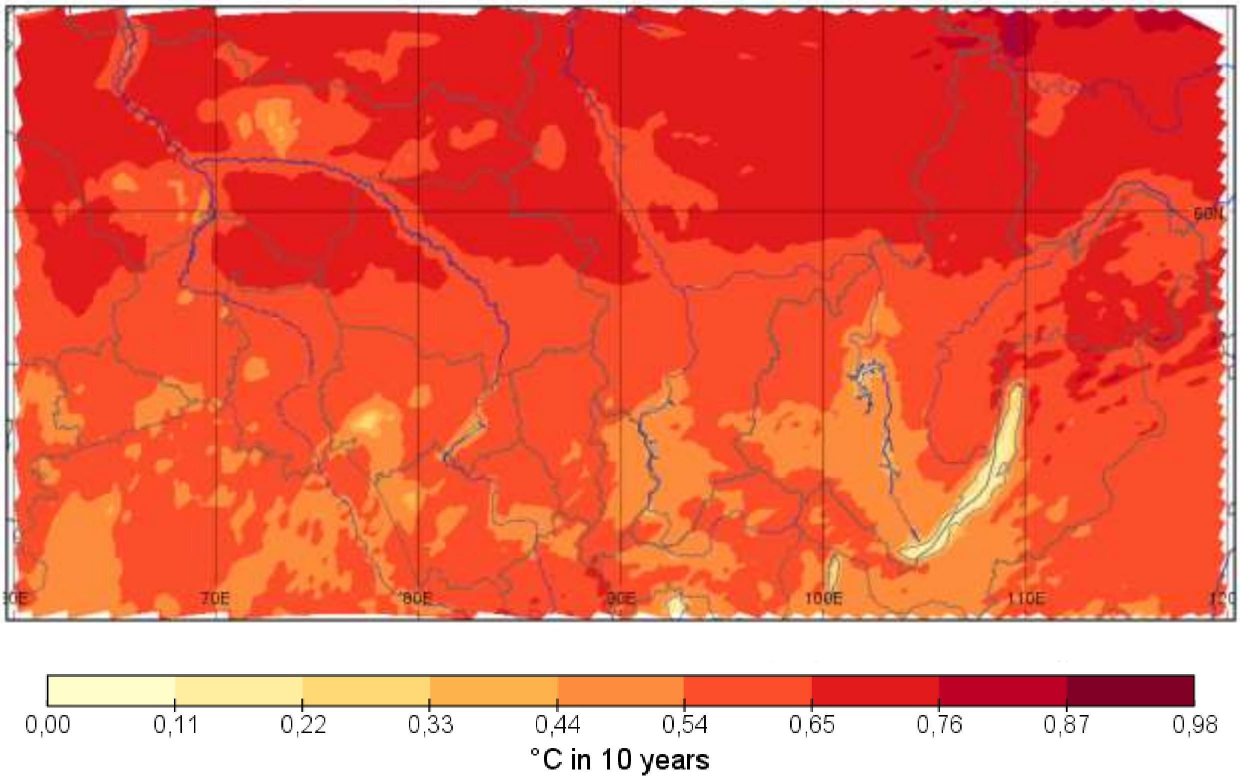
To characterize potential regional climate variability, one has to use results of climatic modelling. There are two sources of relevant data, which are data resulting from CMIP6 - Coupled Model Inter-comparison Project Phase 6 (https://esgf-node.llnl.gov/projects/cmip6/) and data produced by CORDEX (https://cordex.org/), which is a WCRP framework to evaluate regional climate model performance through a set of experiments aiming at producing regional climate projections. To estimate potential climate, the same set of characteristics was calculated on the base of both data archives. In particular, using the CORDEX high-resolution data, the interval from 1971 to 2005 was taken as the base period and the characteristics were calculated by the RCP 8.5 scenario dataset for each season of each year from 2006 to 2100. High spatial resolution data from the CORDEX project for Central Asia (CAS-22) according to the global model of the Earth system MPI-M-MPI-ESM-LR (model of the Max Planck Institute for Meteorology), were used for downscaling using the regional model

REMO2015 of the GERICS center (Climate Service Center Germany).While using CMIP6 data, the interval from 1961 to 1990 was taken as the base and the characteristics were calculated by the SSP 585 scenario dataset for each season of each year from 2015 to 2100. CMIP6 project data according to the global model of the Earth system MPI-ESM-HR2 (model of the Max Planck Institute for Meteorology) were used for the calculations.

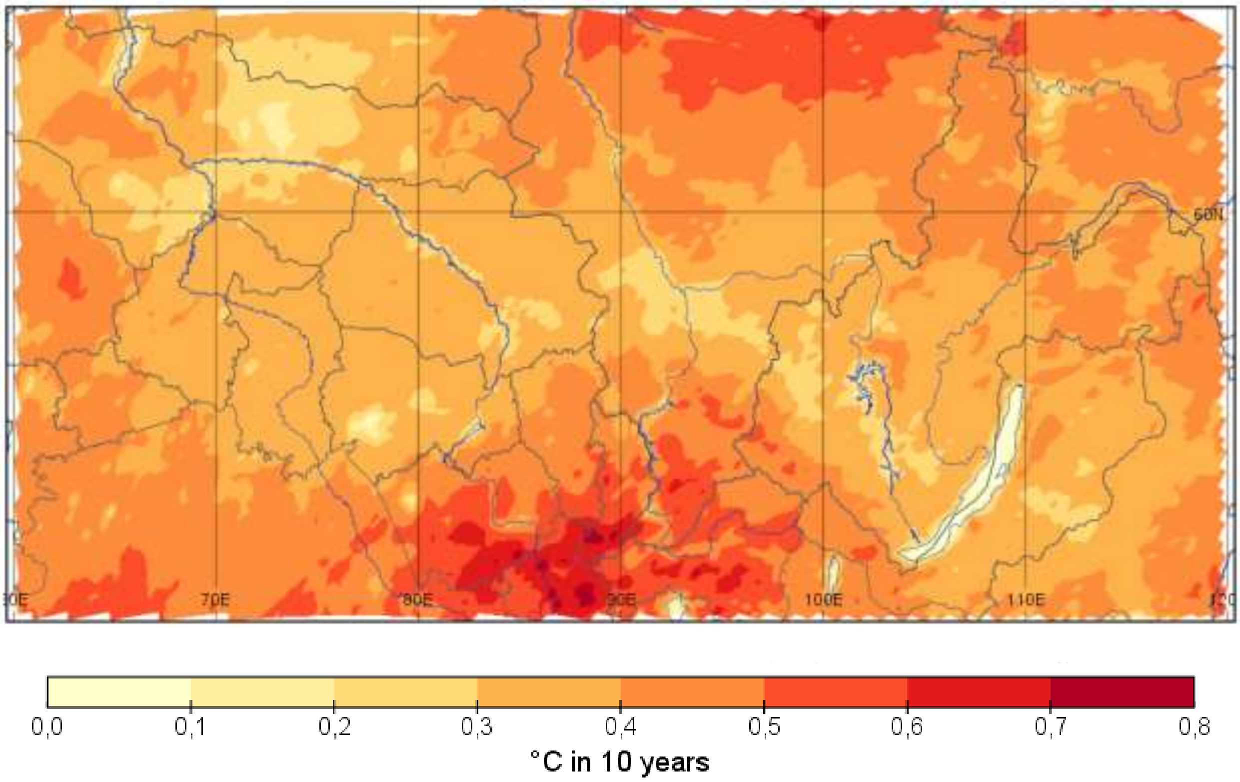
Rather strong potential climatic variability is exemplified below.



Potential trend of winter air temperature for 2015-2100 (CMIP6 data)



Potential trend of autumn air temperature for 2006-2100 (CORDEX data)



Potential rend of maximum of daily maximum temperature (TXx) for 2006-2100.

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