River flow across the Eurasian pan-Arctic: contemporary tendencies and future projections

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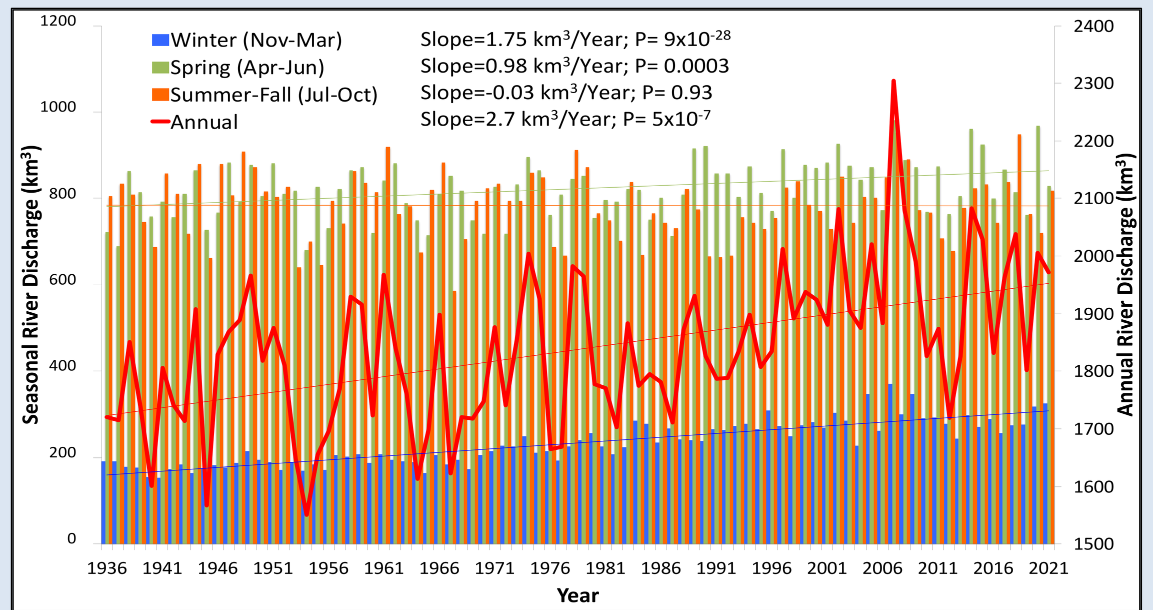
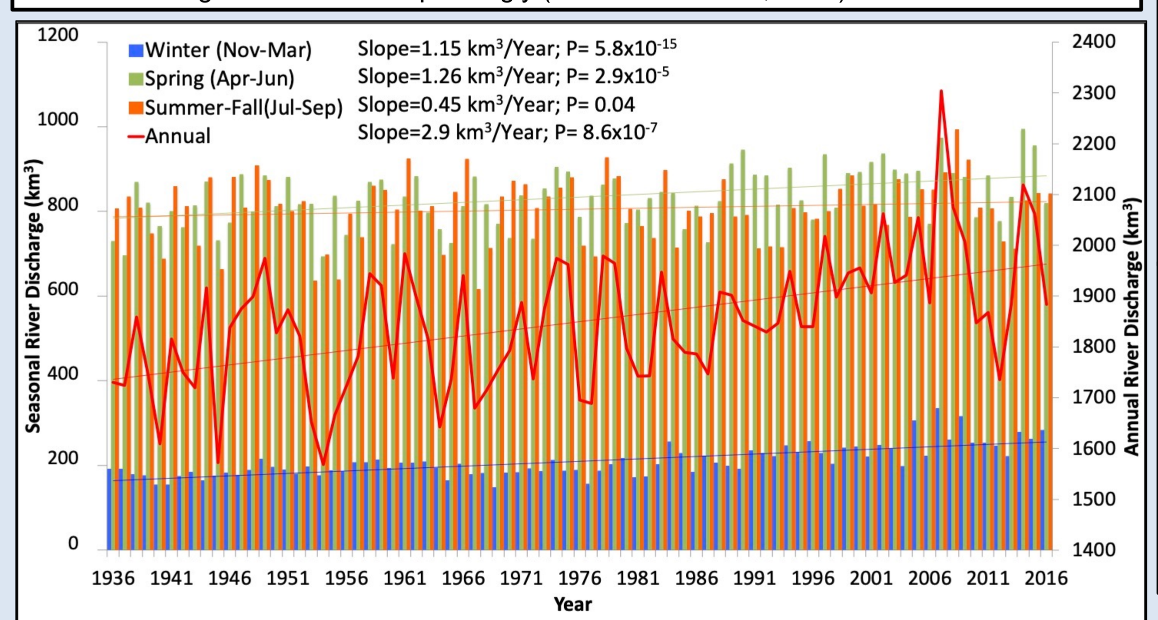
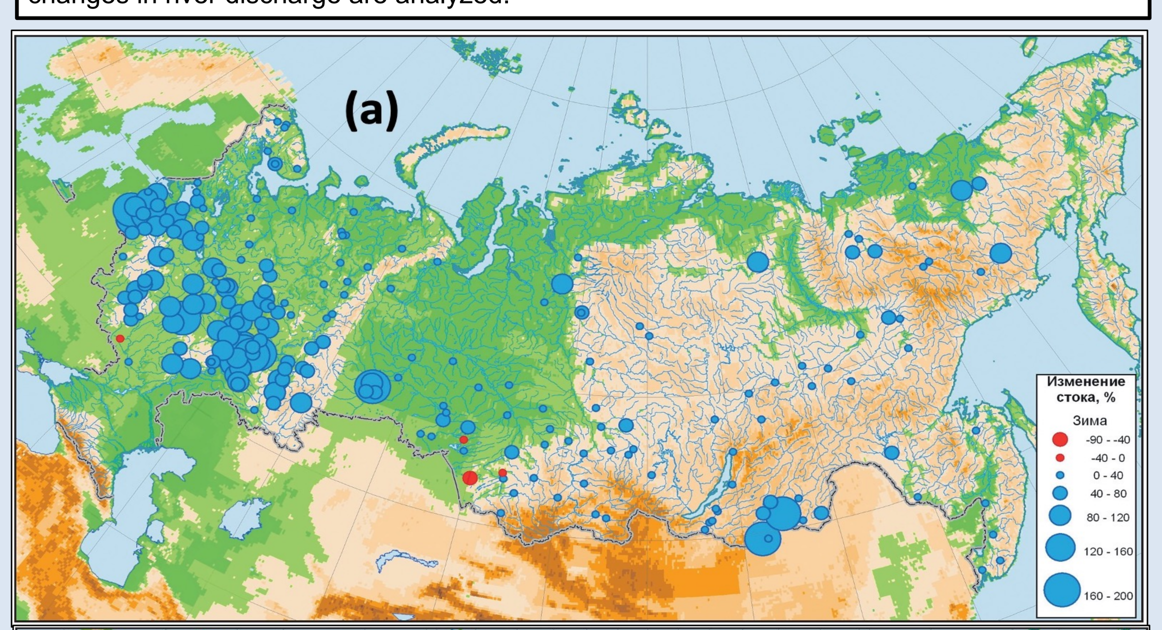
Observed changes in river flow

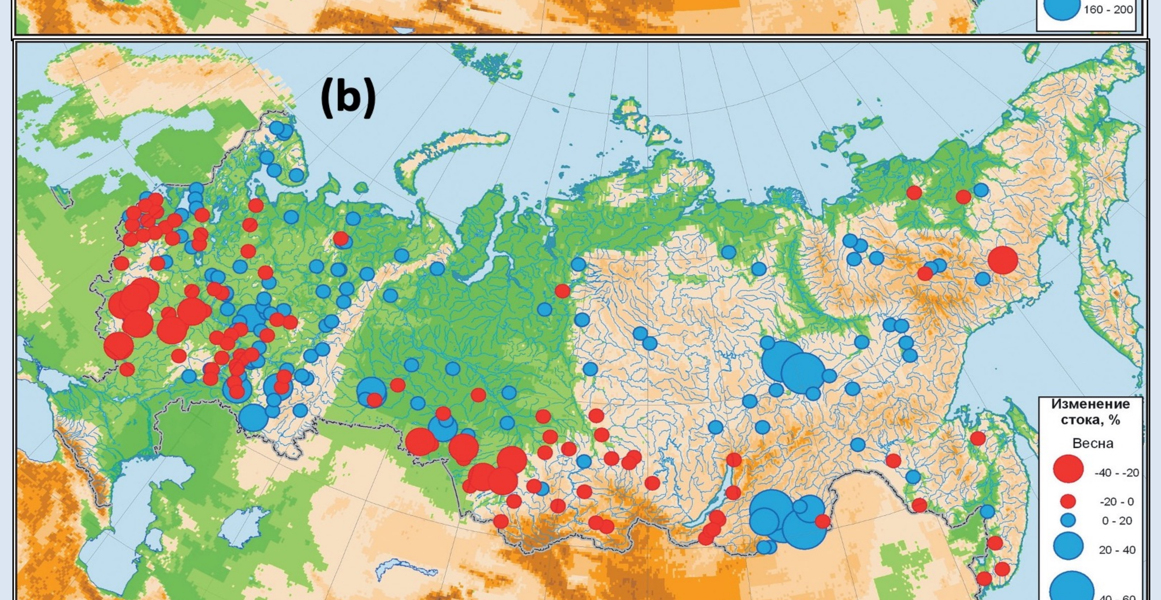


Observed increase in river flow to the Arctic Ocean can slow down oceanic thermohaline circulation and lead to dramatical changes in climate of Northern Hemisphere (Peterson et al, 2002). Annual and seasonal variations of total observed river discharge for six largest Eurasian rivers flowing to the Arctic Ocean (Yenisey, Lena, Ob, Kolyma, Pechora, Sev, Dvina). Change in observed winter and spring discharge accounts for 65% and 35% of annual discharge increase correspondingly (Shiklomanov et al, 2021).



Annual and seasonal variations of total naturalized river discharge for six largest Eurasian Arctic rivers. Naturalization of discharge records to eliminate the human impacts and better quantify climatic causes of changes in river flow has been made with the Hydrograph Transformation Model developed at AARI (Tretiakov & Shiklomanov, 2022). Significant differences in observed and naturalized seasonal river flow was found. Change in "naturalized" winter and spring discharge accounts for 40% and 44% of annual discharge increase correspondingly. Human impacts mainly due to reservoir regulation play significant role in seasonal river flow to the Arctic Ocean and it is often ignored when possible causes of changes in river discharge are analyzed.





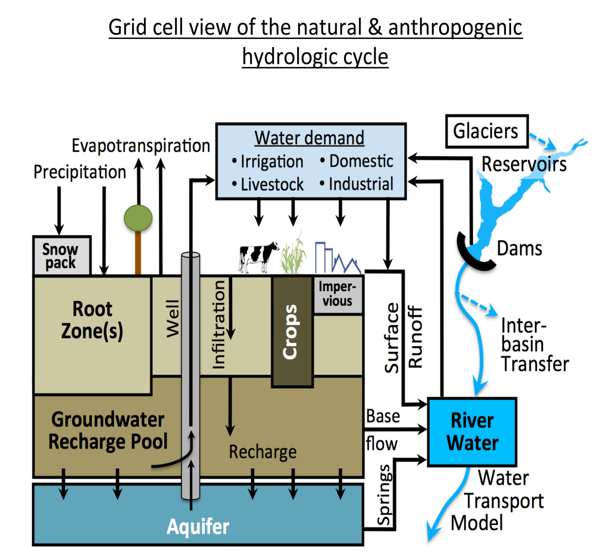
Anomalies of winter (a) and spring (b) runoff (%) across Russia over 1978-2010 relatively to 1940-1977

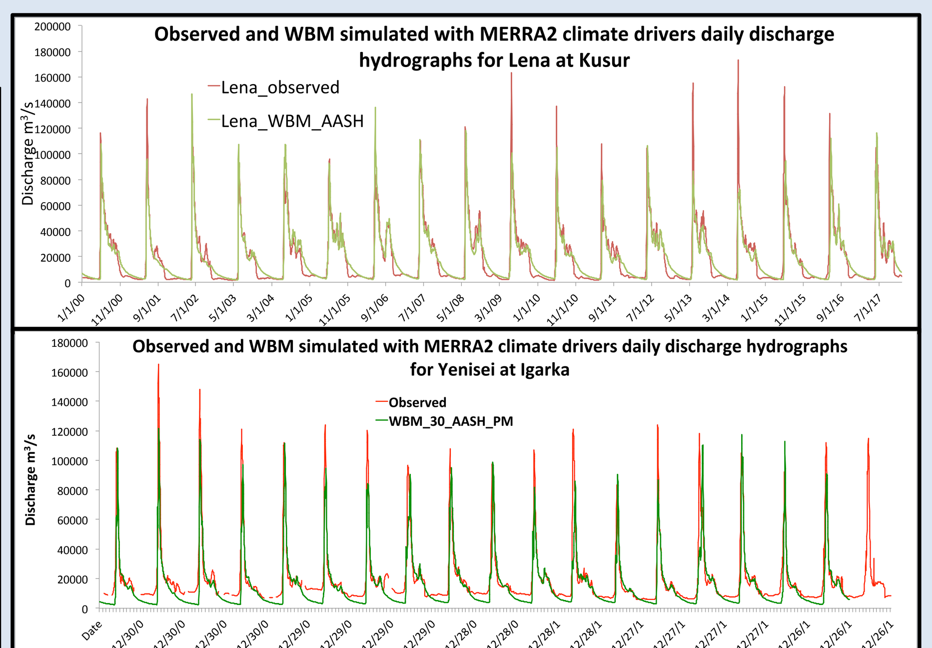
Hydrological model

WBM description

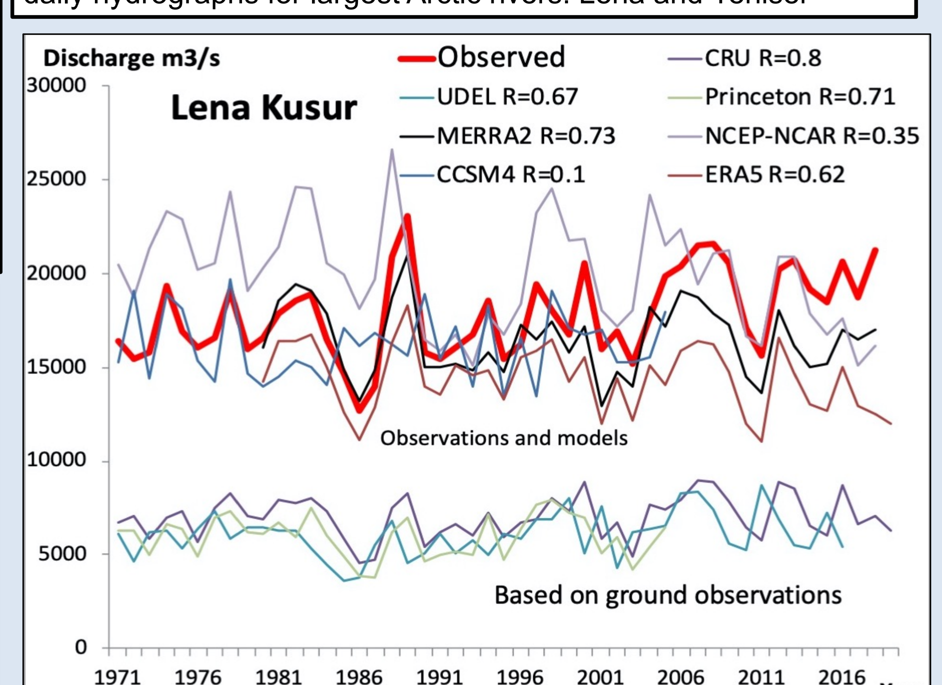
Inputs: Natural
- Climate *temperature and precipitation*
- Land surface topography
- Soil properties
- Vegetation properties
- Aquifer properties
- Lake locations
- Glacier melt

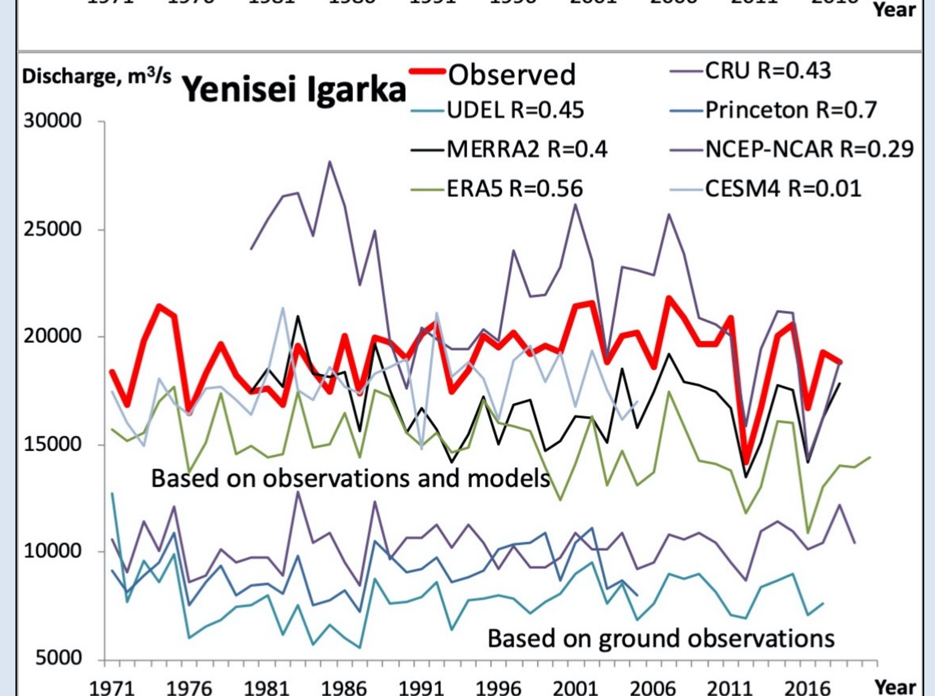
Inputs: Human
- Dams & reservoirs
- Population density
- Crops and irrigation
- Livestock
- Impervious surfaces (i.e., pavement)
- Interbasin transfers (canals across basins)





WBM validation: intercomparison of observed and WBM simulated daily hydrographs for largest Arctic rivers: Lena and Yenisei

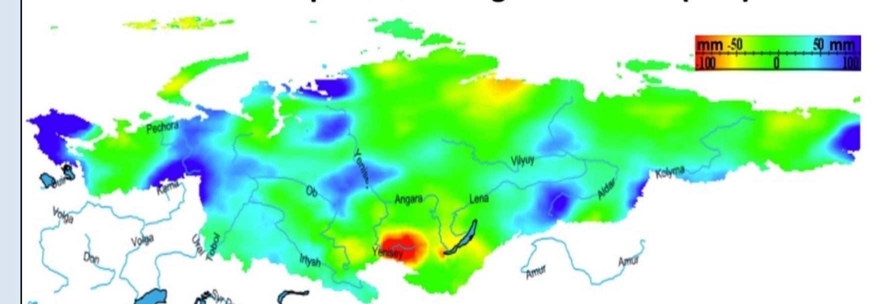




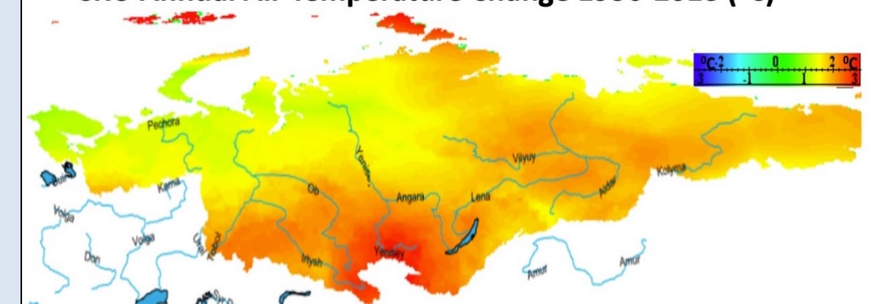
WBM validation: intercomparison of simulated and observed annual river discharge has shown: 1) precipitation in observational data are underestimated; 2) trends of simulated discharge based on climate reanalysis do not correspond observational ones.

Contemporary changes

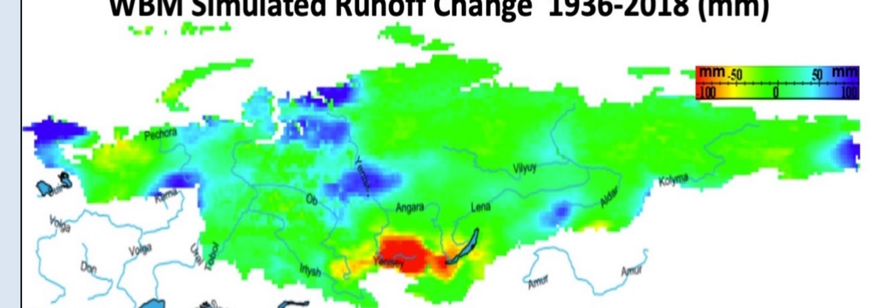
CRU Annual Precipitation Change 1936-2018 (mm)



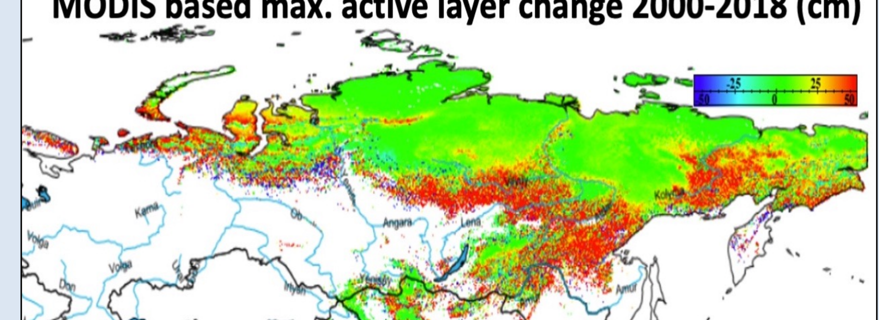
CRU Annual Air Temperature Change 1936-2018 (^{0}C)



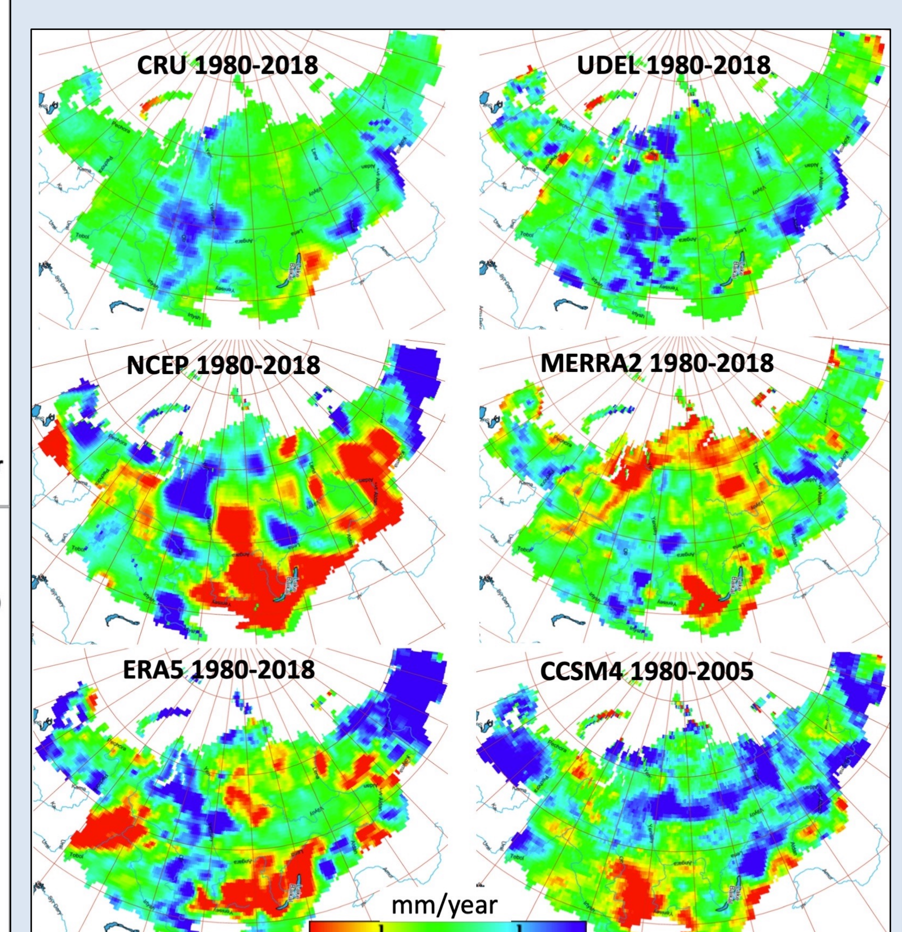
WBM Simulated Runoff Change 1936-2018 (mm)



MODIS based max. active layer change 2000-2018 (cm)



Changes in the observed annual precipitation and air temperature (CRU grids) over 1936-2018 based on linear trend, changes in annual runoff simulated with Water Balance Model using CRU climate data, and changes over 2000-2018 in maximum active layer thickness data derived from remote-sensing data and modeling. Trends in runoff mainly correspond changes in precipitation. Most increases in active layer thickness are observed in areas of discontinuous and sporadic permafrost.

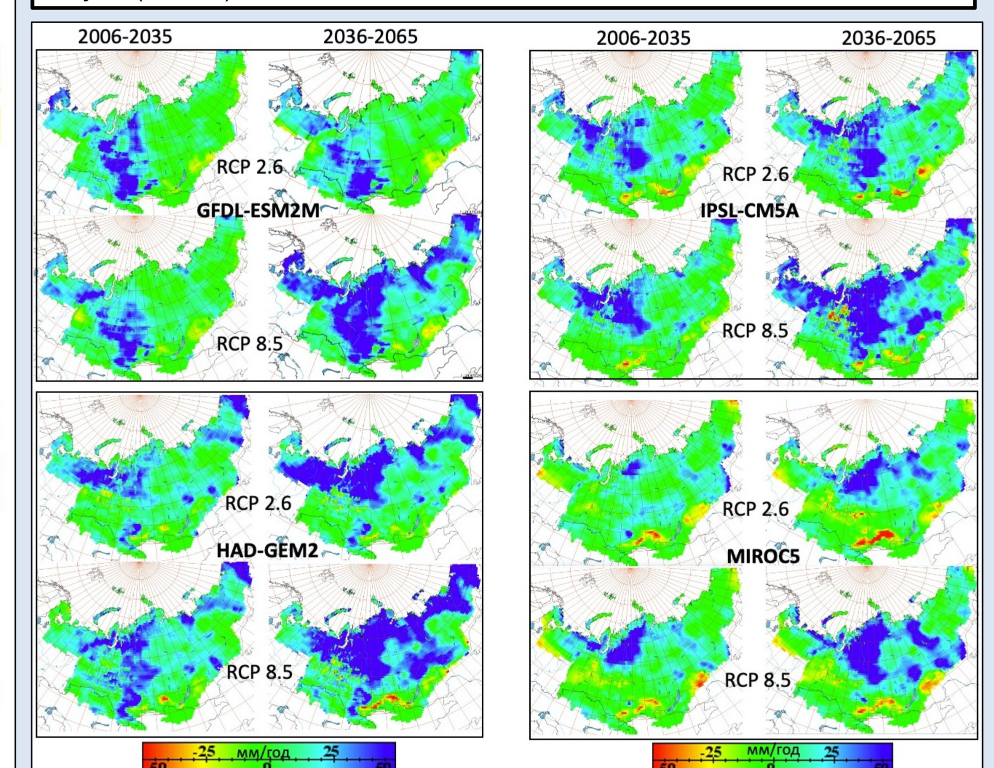


Trends in WBM-simulated annual runoff across Eurasian pan-Arctic basin based on different climate input data. There are large uncertainties in runoff trends evaluated based on observational climate data (CRU and UDEL), re-analysis (NCEP-NCAR, MERRA2, ERA5) and historical GCM (CCSM4).
Monthly changes in WBM simulated runoff based on MERRA2 climate data are shown on right maps. The most significant changes are observed during transition periods April-June and September-November. They are mainly due to earlier snowmelt in spring and later freeze-up in fall.

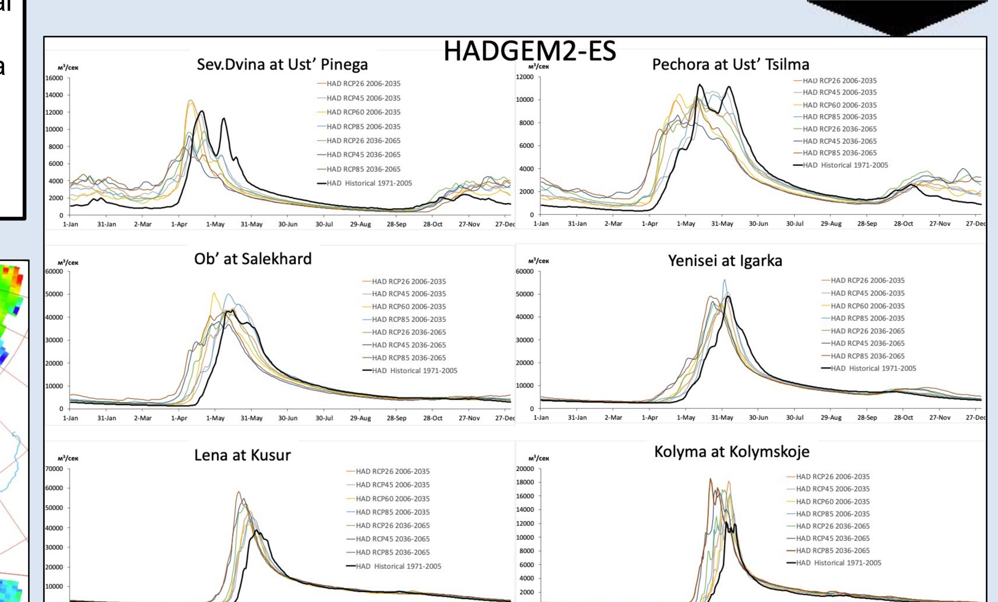
Projected changes in runoff and water balance components

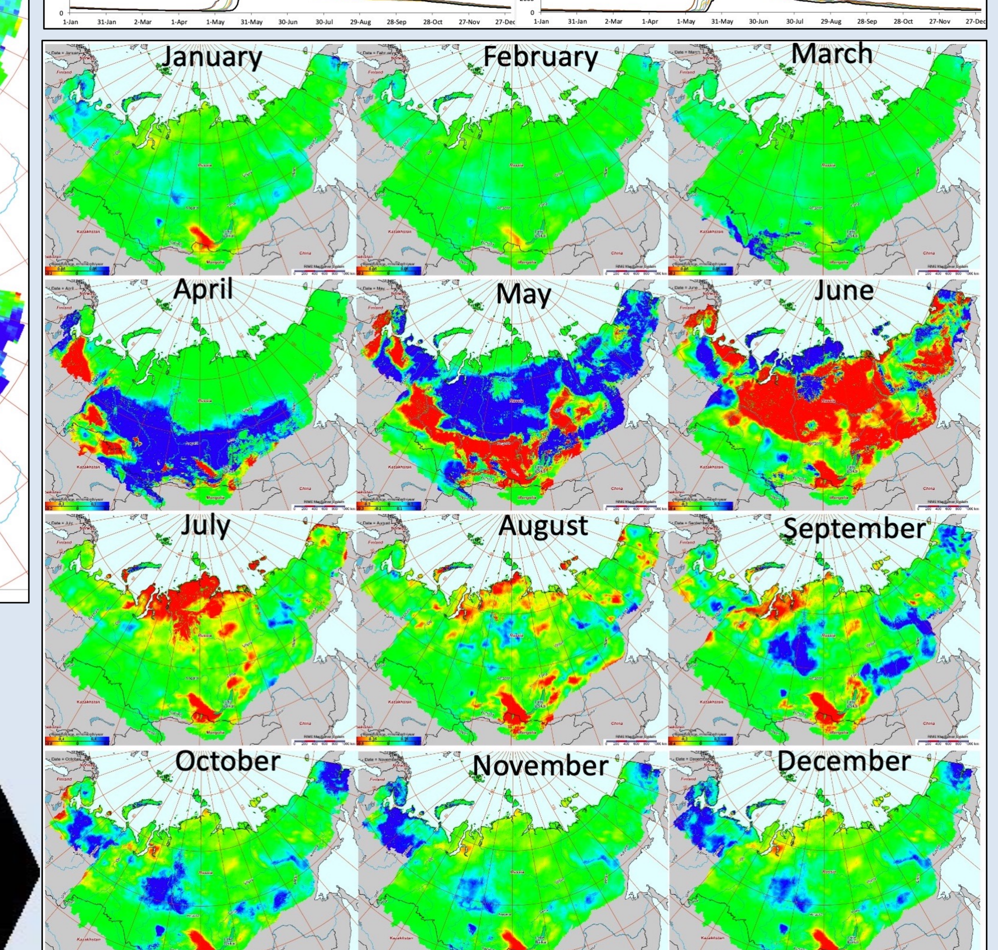
AOGCM	Scenario	Future simulations
GFDL-ESM2M	RCP 2.6, RCP 4.5, RCP 8.5	2006-2065
HadGEM2-ES	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5.	2006-2065
IPSL-CM5A-LR	RCP 2.6, RCP 4.5, RCP 8.5	2006-2065
MIROC5-ESM	RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5	2006-2065
CESM4	SSP2.4.5	2006-2100

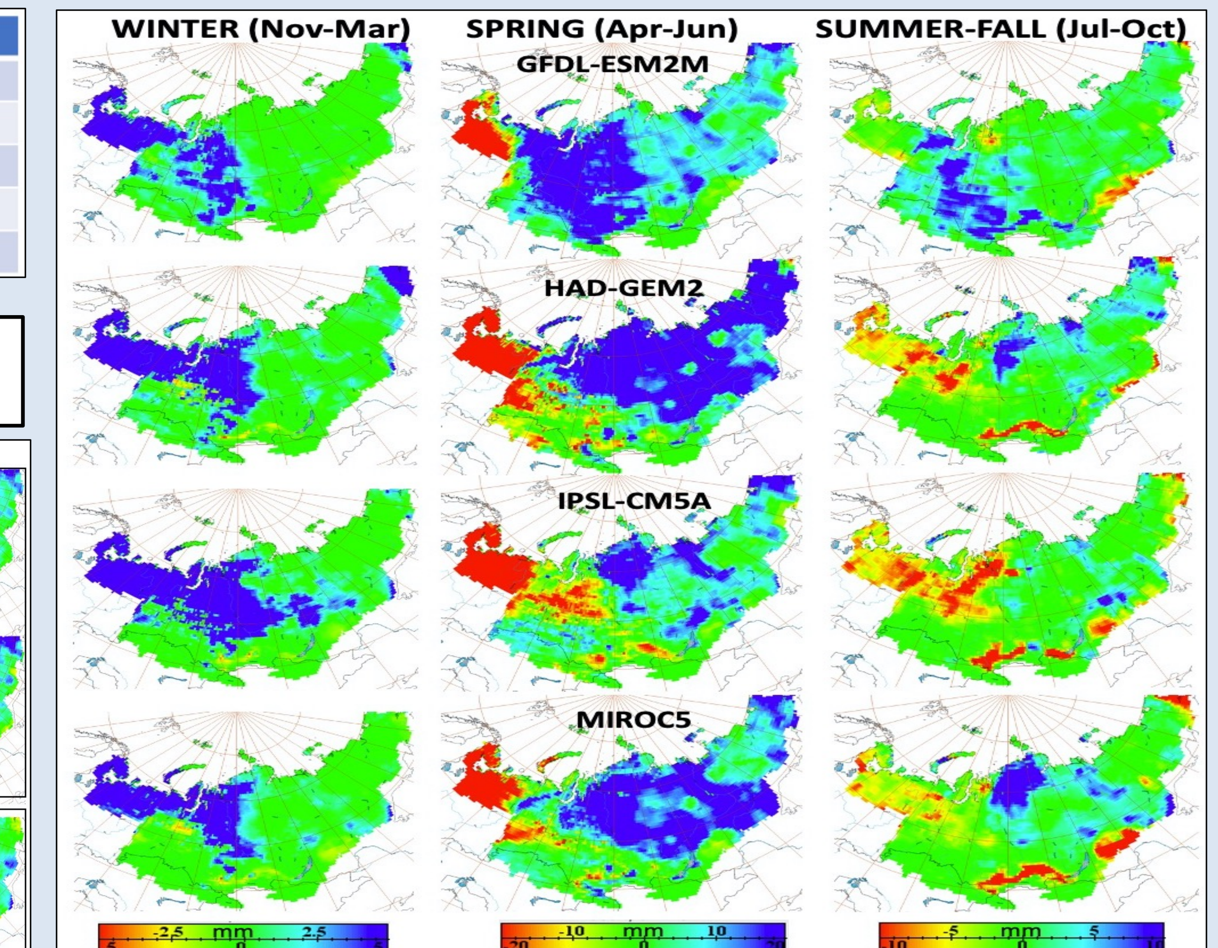
Models and scenarios for future simulations. The climate data from CMIP5 models adjusted under the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) have been used in WBM historical and future simulations



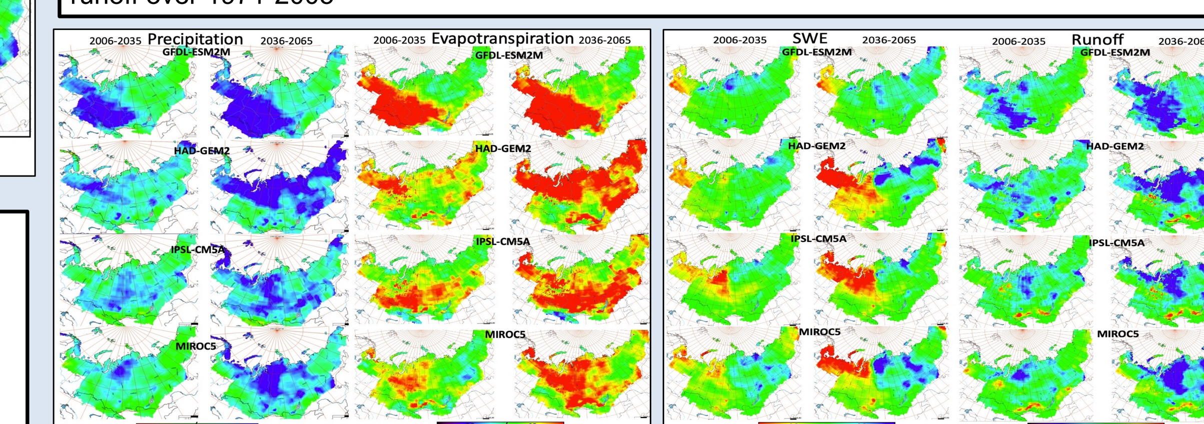
Changes in annual runoff based on different GCMs and future scenarios. There is a general tendency toward further increase in river flow across the Eurasian pan-Arctic. The most significant runoff increases are projected along the Arctic Ocean sea coast and in the Central, Eastern Siberia.
Average WBM-simulated daily discharge hydrographs for historical 1971-2005 (thick black line) and different future climate scenarios/models are shown for 2006-2035 and 2036-2065 periods. Common patterns include: shifts to earlier spring floods, greater winter discharge and higher spring flood discharge in Eastern Siberia







Projected changes in seasonal runoff by 2036-2065 for RCP4.5 scenario relative to mean runoff over 1971-2005

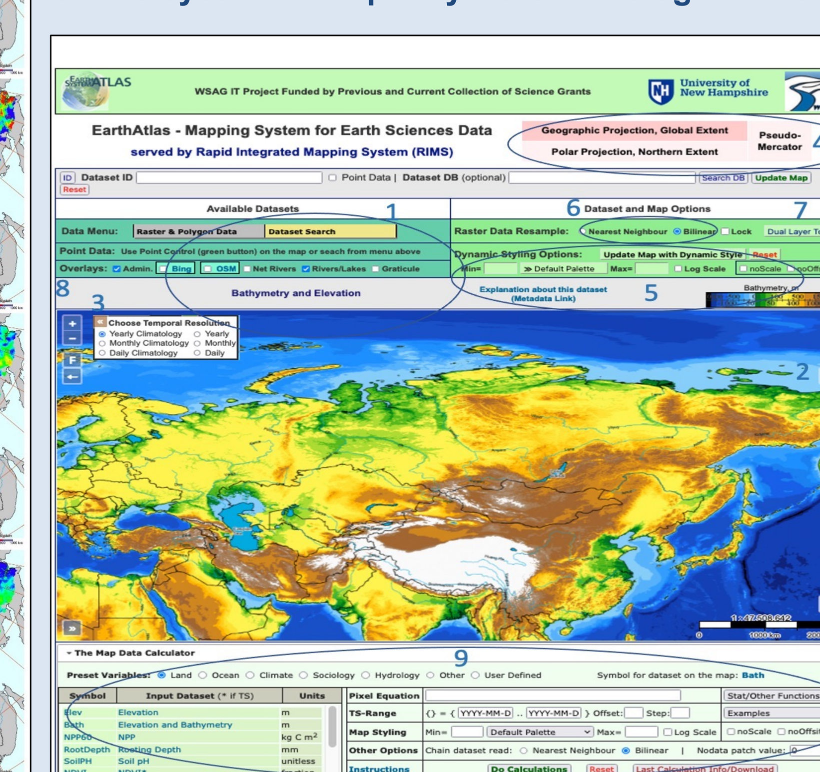


Deviations of average projected annual precipitation (P) and WBM-simulated evapotranspiration, snow water storage and runoff for RCP4.5 scenario from their average values over 1971-2005.

Projected changes in river flow (%) for large Eurasian Arctic rivers by 2050

River Basin	GFDL-ESM2M		HAD-GEM2		IPSL-CM5A		MIROC5		Average	
	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Russian Pan-Arctic	10.98	20.93	18.02	26.30	13.12	19.56	6.90	15.86	12.26	16.53
Ob	24.07	29.38	14.97	19.81	13.35	15.34	-1.85	13.72	12.64	15.65
Yenisei	8.39	13.46	11.37	20.76	14.29	20.38	4.56	13.51	9.65	13.62
Lena	0.90	15.54	16.16	30.38	9.43	21.31	12.60	15.75	9.77	16.60
Kolyma	11.74	37.00	43.43	66.04	19.80	18.38	23.88	41.27	24.71	32.54
Dvina	3.91	13.17	18.78	8.35	8.33	13.88	-3.00	8.77	7.01	8.83
Indigirka	17.56	61.47	62.51	87.09	30.35	38.21	36.05	53.00	36.62	47.96
Pechora	10.38	15.11	22.79	15.68	12.08	18.48	5.26	16.67	12.63	13.19
Khatanga	6.02	25.86	24.53	44.33	19.16	38.02	23.38	26.21	18.27	26.88
Taz	7.45	15.79	19.72	25.59	8.98	14.55	13.34	8.54	12.37	12.89
Yana	17.53	57.22	41.51	46.04	18.09	20.60	28.83	39.38	26.49	32.65
Anadyr	15.47	26.38	27.39	52.10	17.14	25.79	-1.42	10.11	14.64	22.87
Pyasina	3.97	23.23	17.99	39.35	13.69	22.36	19.00	20.61	13.67	21.11
Taymyra	3.50	23.30	26.20	44.86	16.27	23.61	22.50	27.51	17.12	23.86
Anabar	12.11	35.50	27.07	54.86	27.66	42.26	38.00	40.62	26.21	34.65
Mezen	11.19	16.15	19.98	11.81	8.03	17.25	5.29	16.68	11.12	12.38
Penzhina	2.00	19.22	23.60	44.19	19.21	13.50	-1.06	16.26	10.94	18.64
Alazeya	24.38	71.87	71.67	125.2	29.46	21.31	23.40	44.19	37.23	52.50
Uda	0.31	0.79	4.96	10.71	0.62	-1.77	10.21	7.00	4.02	3.35
Onega	6.55	16.79	11.70	2.93	8.68	16.11	-4.23	6.42	5.68	8.45
Nadym	10.37	19.66	18.08	19.72	5.27	1.16	9.45	8.50	10.79	9.81
Omoloy	18.63	62.74	45.82	78.32	31.69	47.15	33.61	57.19	32.44	49.08

Online system for rapid hydro-climatological analysis earthatlas.sr.unh.edu



Rapid Integrated Mapping System (RIMS) for earth science data analysis earthatlas.sr.unh.edu

1) data search/selection, spatial navigation, etc.;

2) pixel query tool (i-tool) gets coordinates, country, watershed, and map data value;

3) time series navigation tool;

4) tool for projection selection

5) tool for custom maps

6) spatial interpolation tool

7) dual layer mapping tool

8) overlays data mapping e.g. Bing and OSM maps, river networks etc.

9) data Calculator application to perform mathematical and logical functions over gridded or vector datasets with PDL

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