Detect and predict the impacts of climate change on the flow regimes of rivers originated from plateaus in Asia

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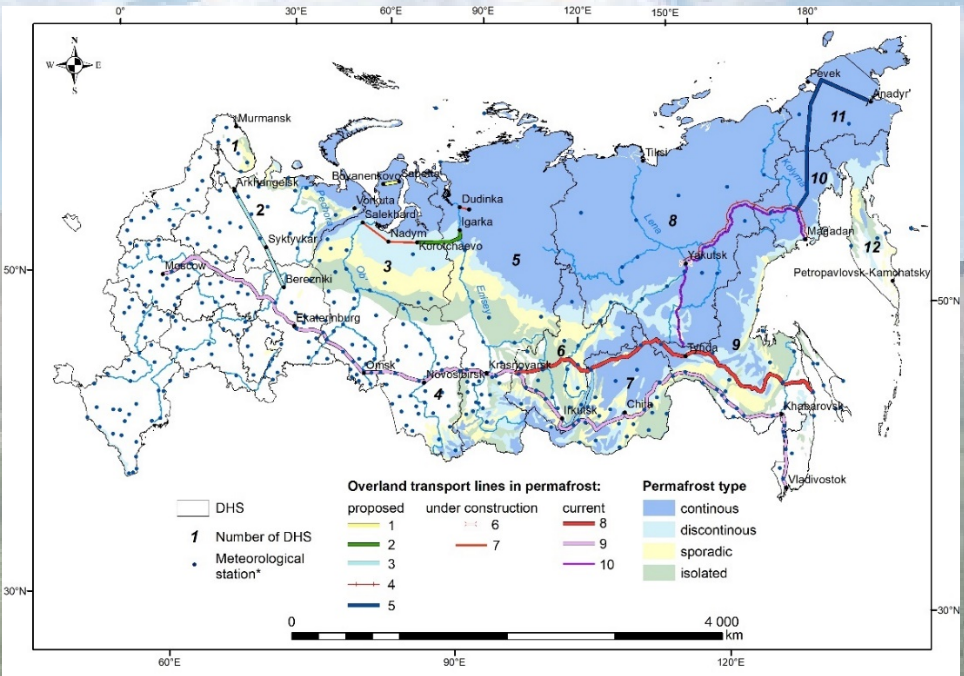
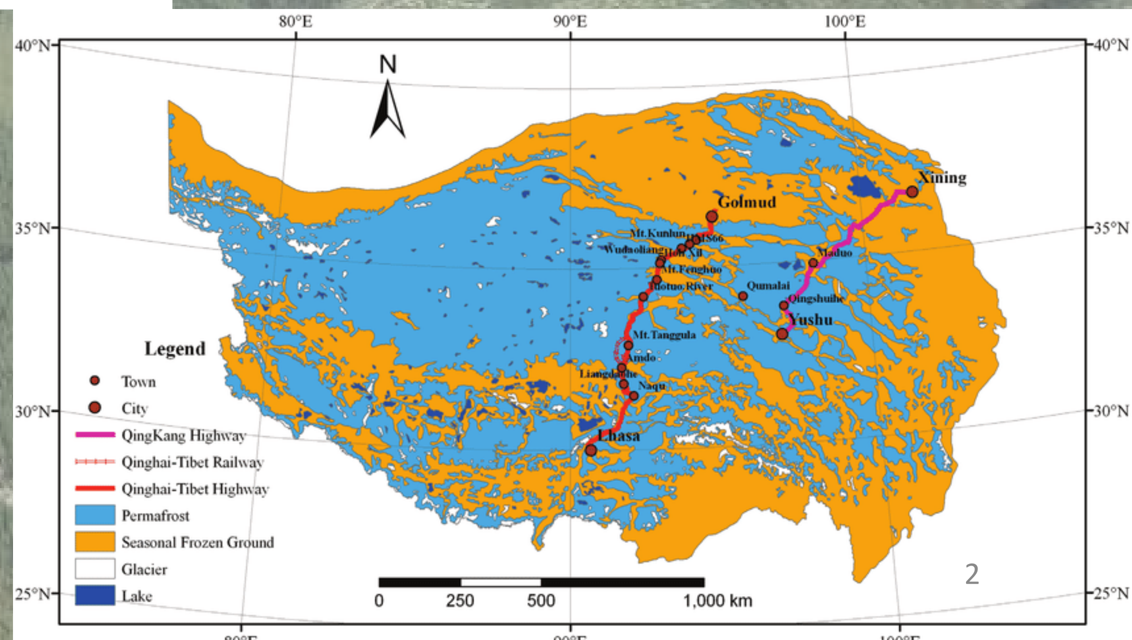
Relevance



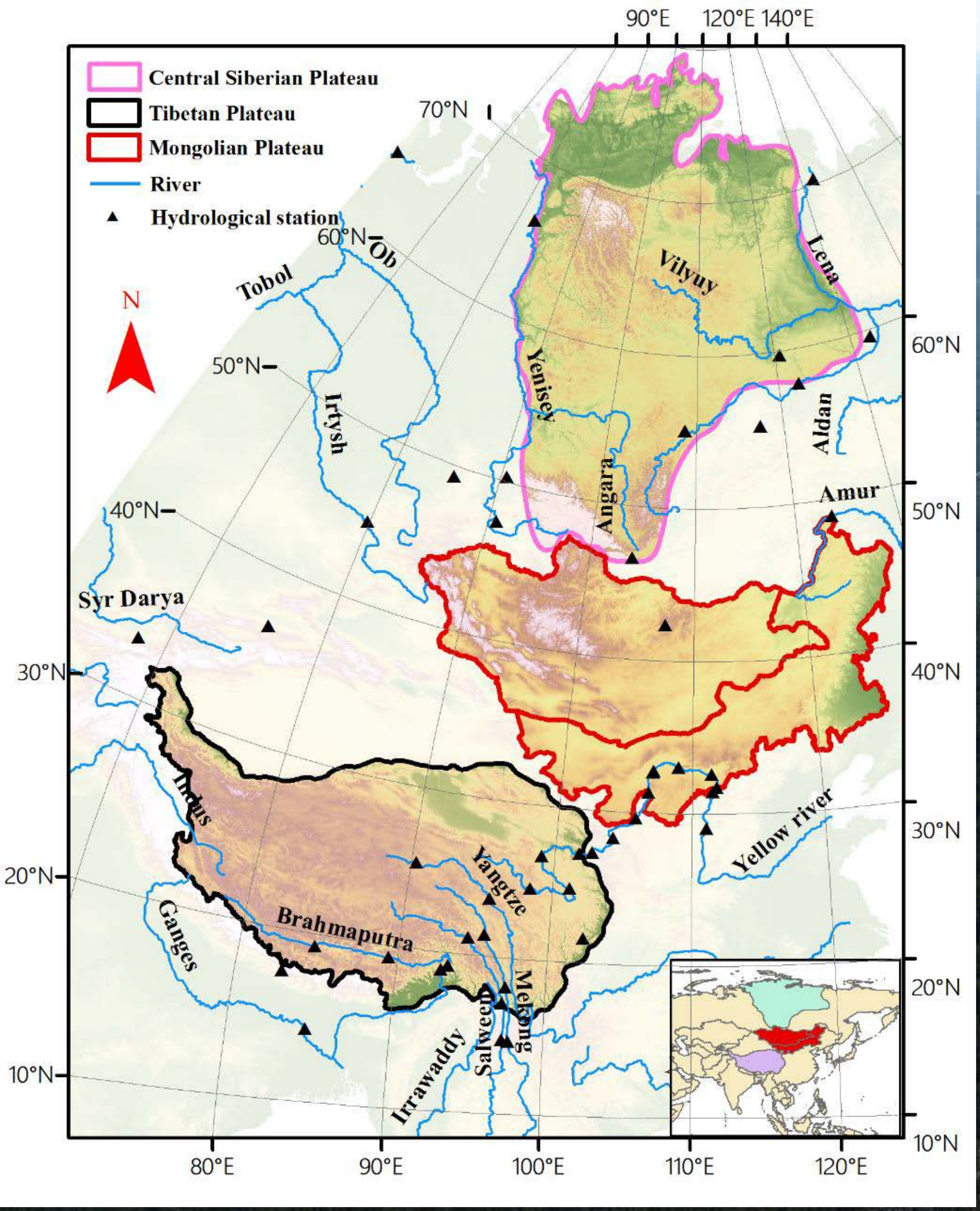
- Climate warming
- Degradation of permafrost
- Change of hydrological regime
- Hazards

The rivers originated from the plateaus of Asia feed more than 2 billion people (China, India!).

In Russia the total cost of support and maintenance of road infrastructure owing to permafrost degradation from 2020 to 2050 is expected as much as $7 billion for the existing network, with no additional development.



Project aim and the study objects



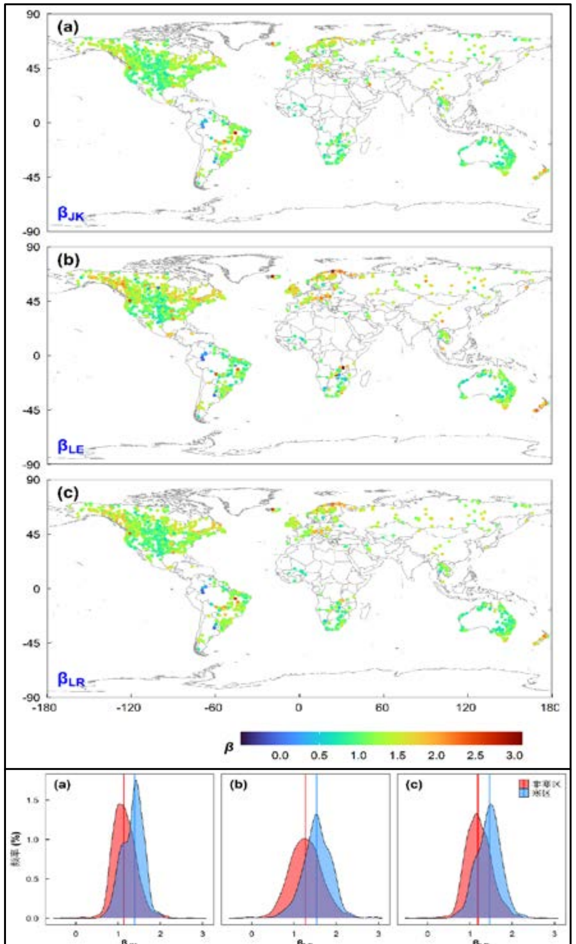
The aim of the project is to detect and predict the impacts of climate change and permafrost degradation on the flow regimes of rivers originated from plateaus in Asia.

1. **Historical data collection and statistical analysis (China)**
2. **Field process studies (Russia)**
3. **Remote sensing data analysis and assimilation (India)**
4. **Process modelling**
5. **Climate projections**
6. **Future prediction**

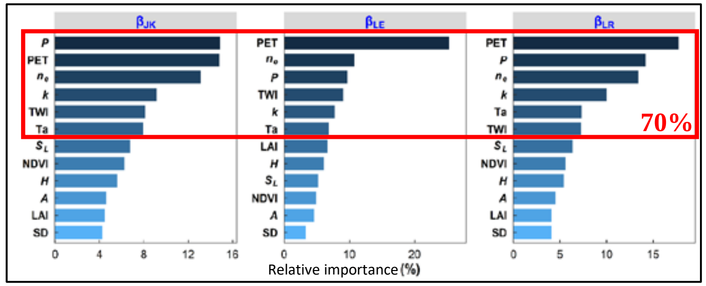
Statistical data analysis on global scale

Spatial distribution of the power-law parameter of catchment storage-discharge relationship (β) and its driving factors

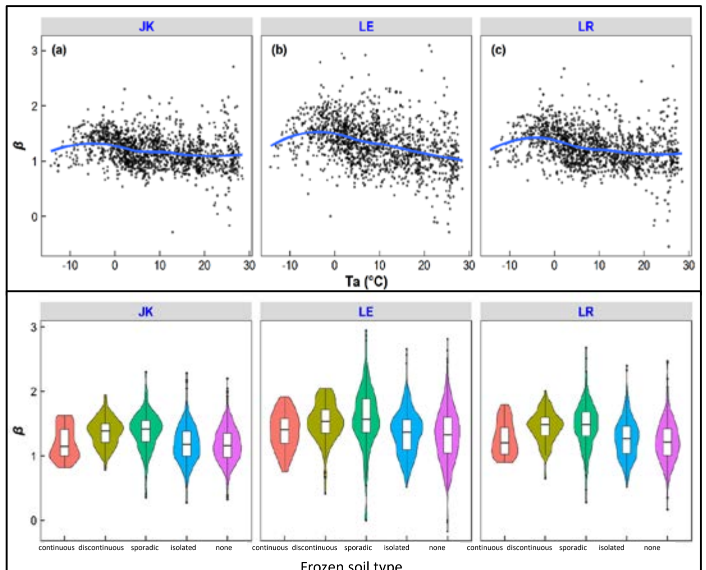
- Spatial distribution of β



- Main driving factors



- β was closely related to the distribution of frozen soil in cold catchments



①β ranged from -1 to 4, and increased with latitude, resulting a higher β in cold regions

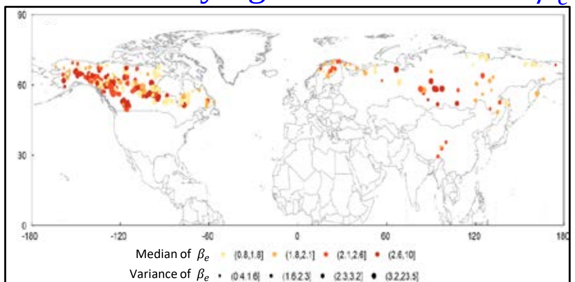
②Potential evaporation , precipitation, hydraulic conductivity, drainable porosity, topographic wetness index and air temperature explained over 70% spatial distribution of β

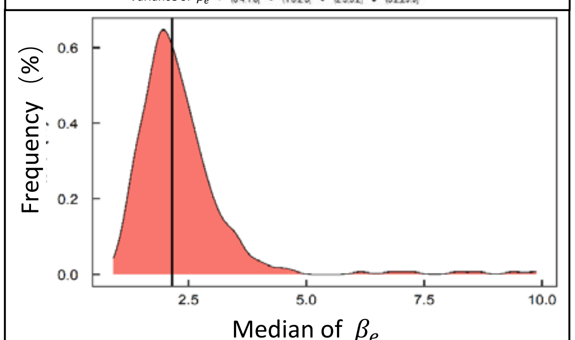
③ The effects of air temperature on β possibly originated from the control of permafrost extent

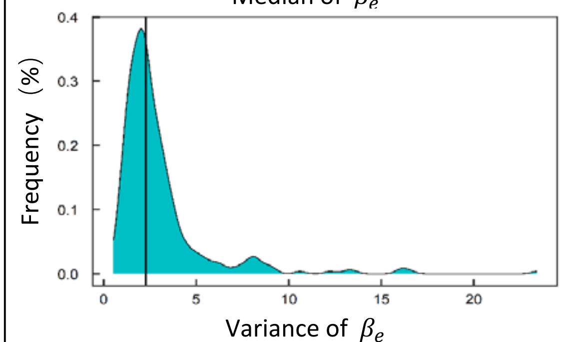
Analysis of runoff patterns changes

Time-varying rule and cause of β_e (i.e. β of flow recession event) in cold catchments

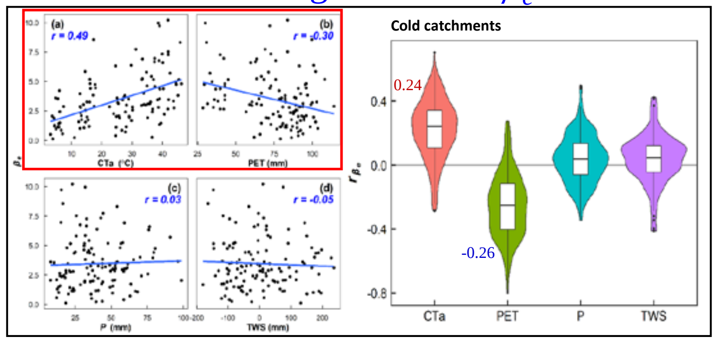
Time-varying characteristics of β_e



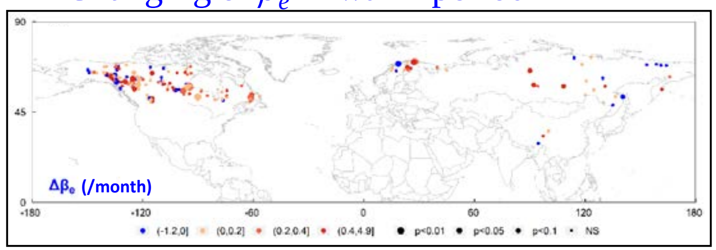




Effects of driving factors on β_e

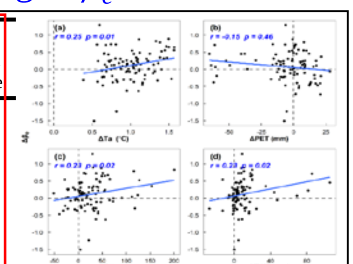


Changing of β_e in warm period



Interdecadal changing of β_e

Trend of time series variable	Median	Percentage of catchments with increased change
$\Delta\beta_e$	0.1	63%
ΔTa	1.0	100%
ΔPET	−0.7	47%
ΔP	21.4	77%
ΔTWS	4.8	77%



①βe was time-varying with median of variance of 2.3 in cold regions

②βe was dominated by PET, followed by CTa (frozen soil)

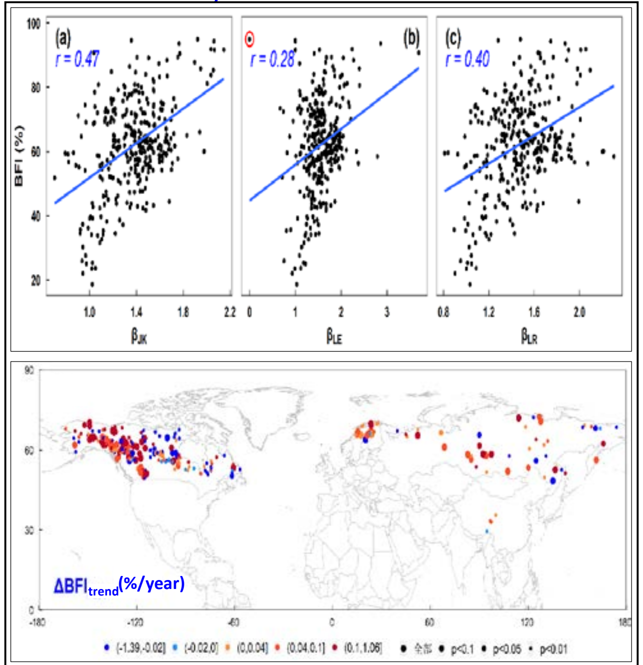
③βe increased in both warm period and interdecadal period

④Degradation of frozen soil, climate wetting and increasement of water storage leaded to the interdecadal changing of β_e

Factors governing the runoff changes

Effects of changed catchment storage-discharge relationship on runoff in cold catchments

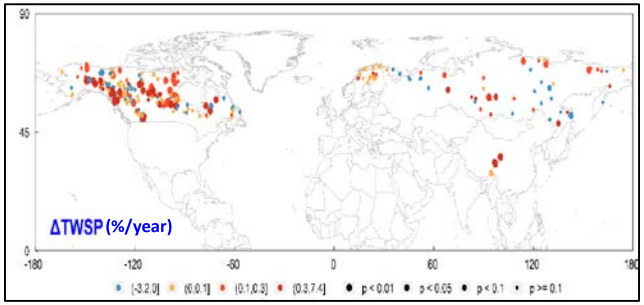
Effects of β on BFI



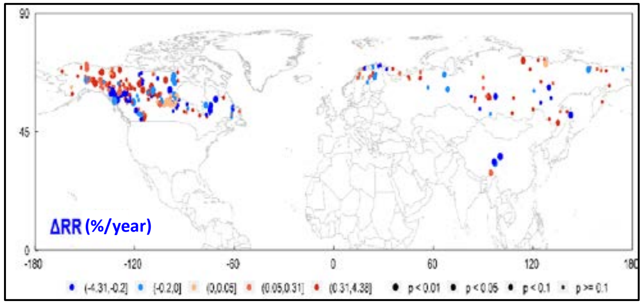
Correlation coefficient between △BFI and △β at different significant levels

Significant level	Number of catchments	r_{JK}	r_{LE}	r_{LR}
total	315	0.21	0	0.15
P<0.1	97	0.47	0.12	0.43
P<0.05	54	0.54	0.15	0.48
P<0.01	39	0.66	0.18	0.58

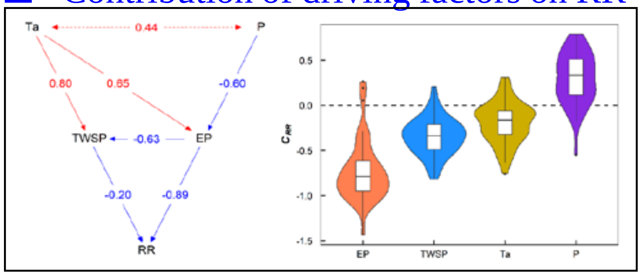
Trend of △TWSP



Trend of △RR



Contribution of driving factors on RR



① β was positive to BFI, the increasing β leaded to the increase of the base flow proportion

② TWSP of most cold catchments (76%) had increased

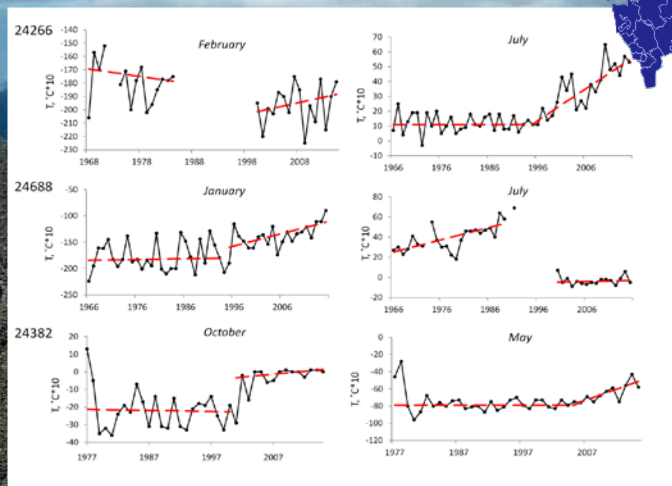
③ RR of most cold catchments (78%) had decreased

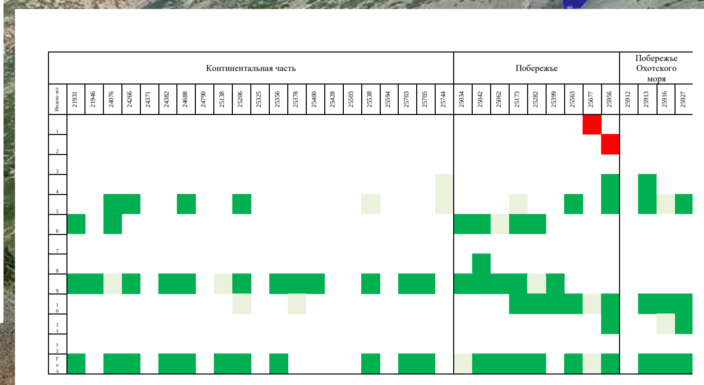
④ TWSP and EP had negative effects on RR, and contributing 34% and 77% of the change of RR, respectively

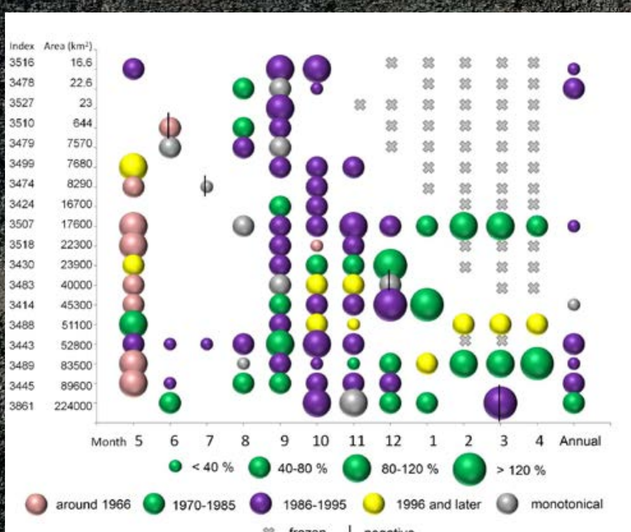
Various aspects of climate change impacts on hydrological regime – field studies

The annual air temperature in the region increased **by 2.3 °C** on average

An increase in the annual soil temperature at a depth of 80 cm by **+1.7 °C**







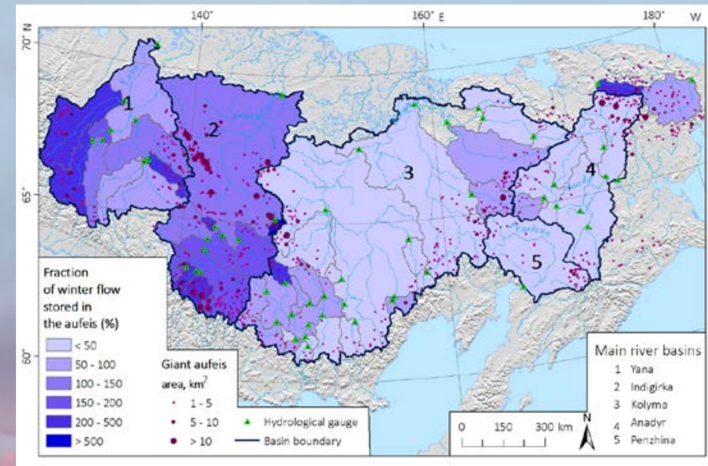
Statistically significant Increase of river flow **in autumn winter period**

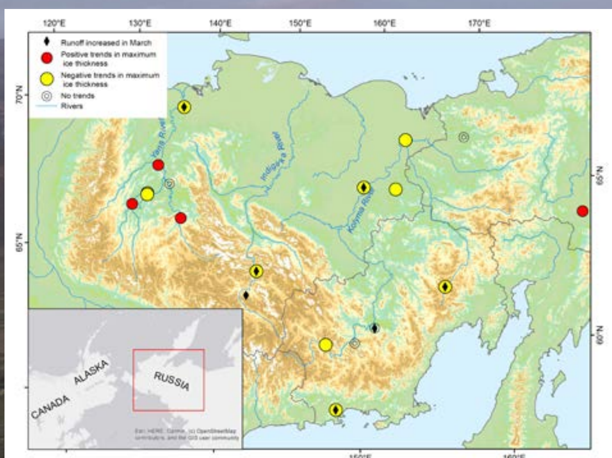
Increase of liquid precipitation, decrease of snow

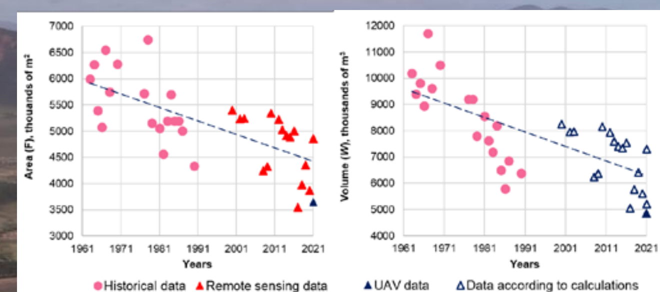
Increase of hazards probability and magnitude related to degradation of permafrost and change of hydrological regime

Impact of climate change on hydrological regime of the North-East

Central Yakutia, the area of the thermokarst lakes **doubled over the 20-year period**





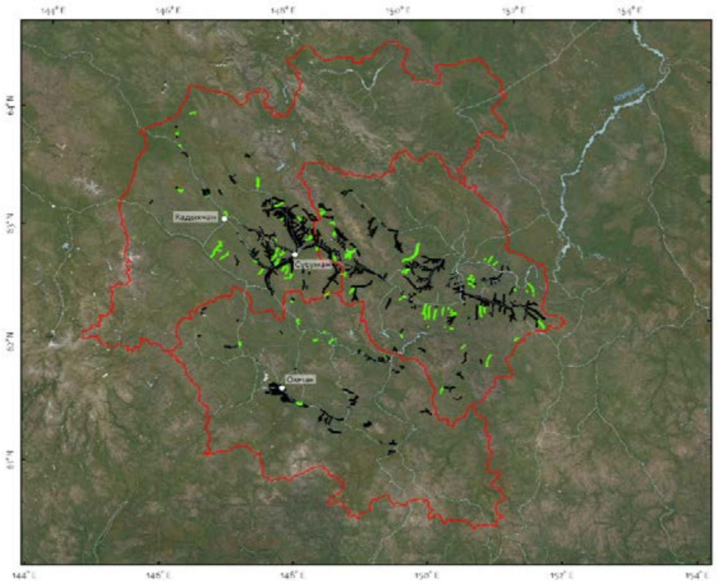


The number of aufeis has increased by **1.4 times**, the total area has decreased by **1.6 times** (1958-2019).

The decrease of river ice cover maximum depth was **39 cm (27%)** and the period of formation of river ice with a thickness of 60 cm has shifted to later period by **7-40 days.**

Anthropogenic impact

Images of active gold mining sites (a) and mined-out areas (b)

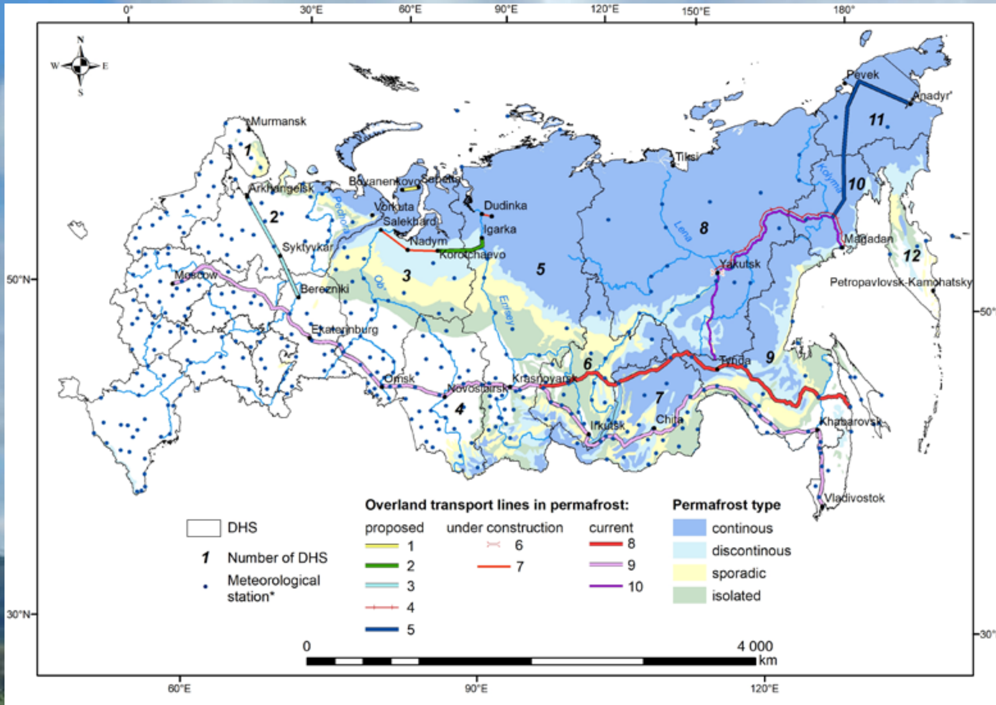


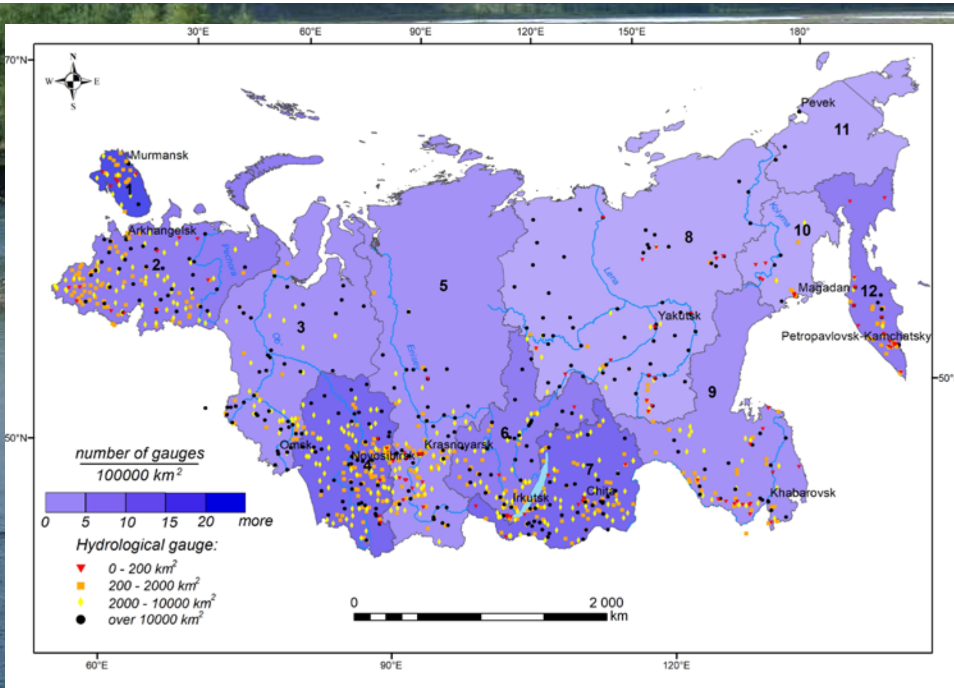
Catastrophic unpredicted floods in disturbed river valleys

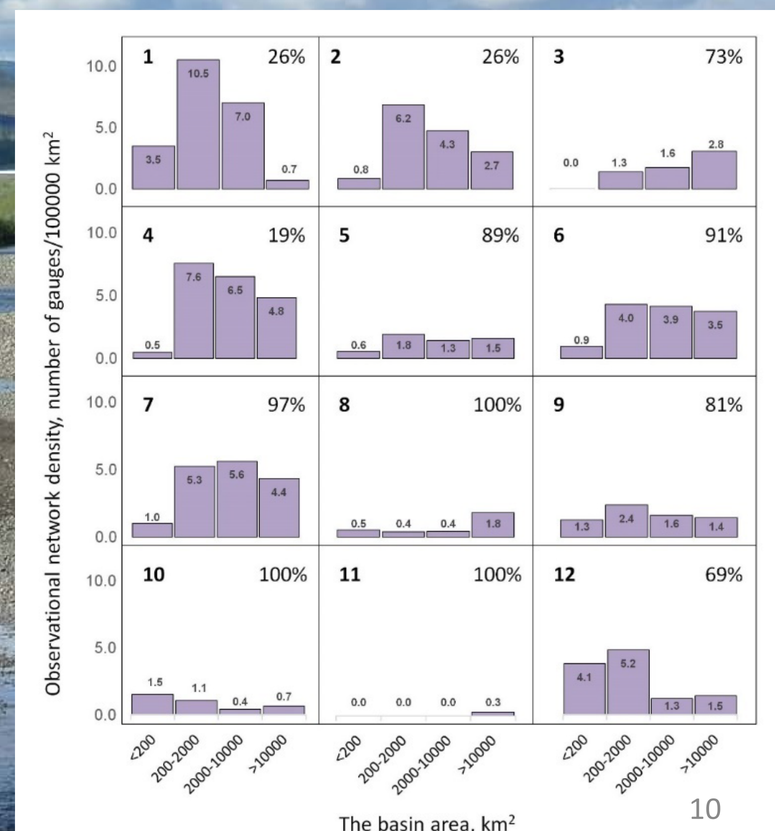
- About 2% of the Upper Kolyma River basin has been disturbed as a result of gold mining, of which only 10% are experiencing vegetation restoration processes.
- At some territories, there is an increase in the area of disturbed lands by more than 7 times over the period 2001-2021.
- Suspended matter concentration increase by 2-16 times depending on a season.

The territories most rich in resources are “white spots”

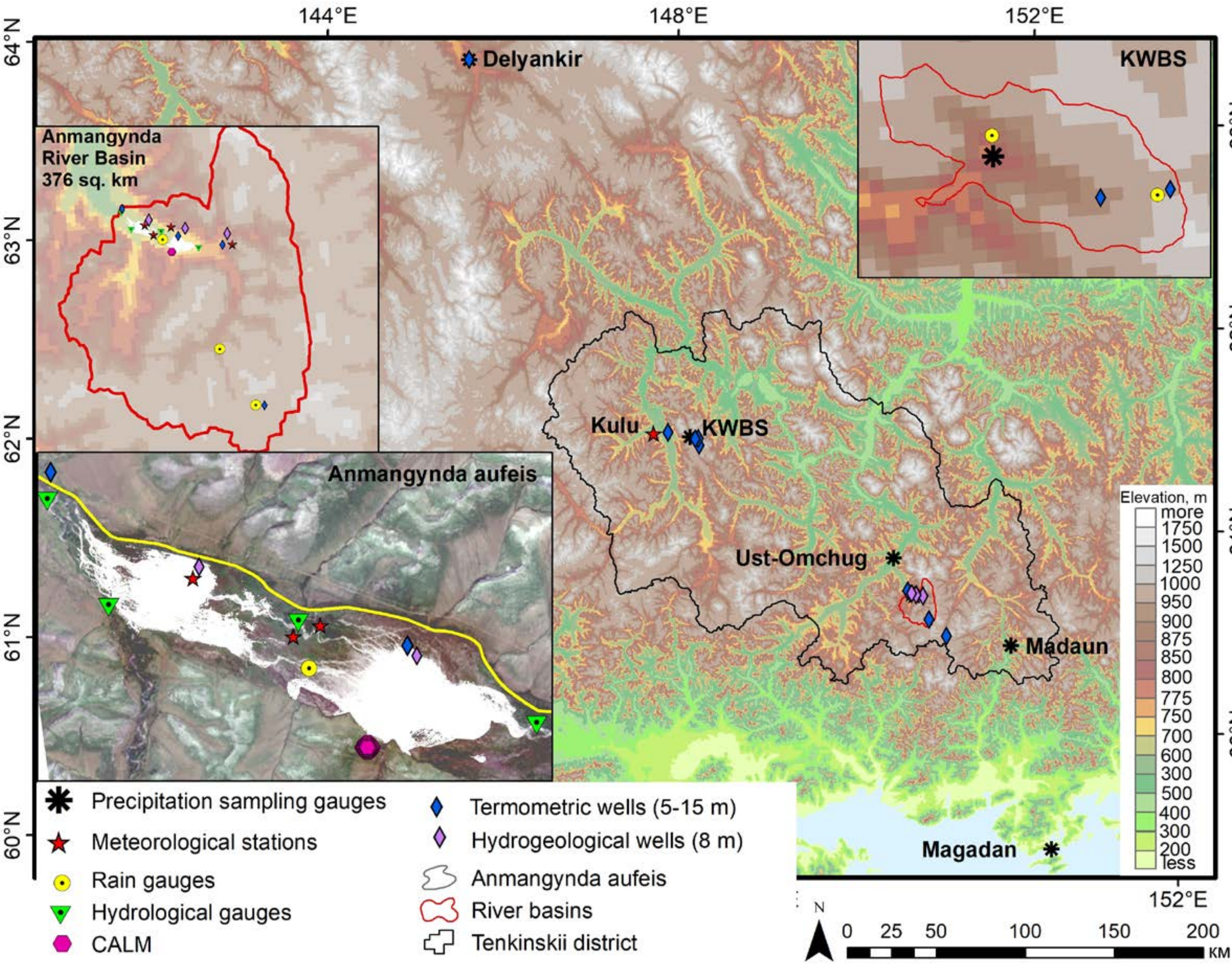
State monitoring network is highly insufficient







Developing research network, NE Russia, 2020-2022



2 meteorological stations

5 rain gauges

4 hydrological gauges

10 thermometric wells (5-15 m)

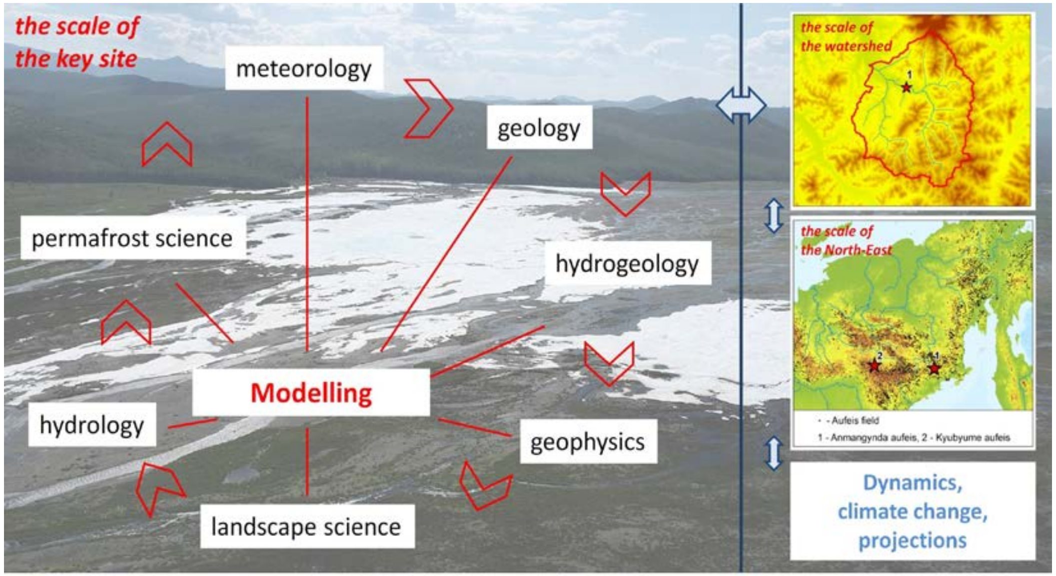
3 hydrogeological wells (5-12 m)

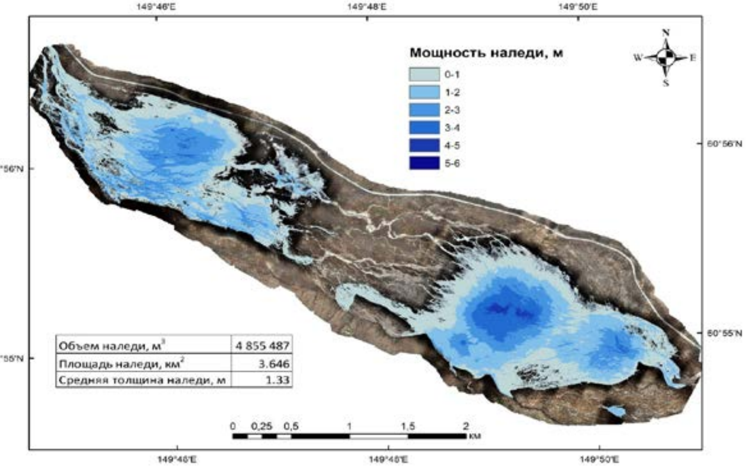
CALM plot (2022)

Landscape study profiles

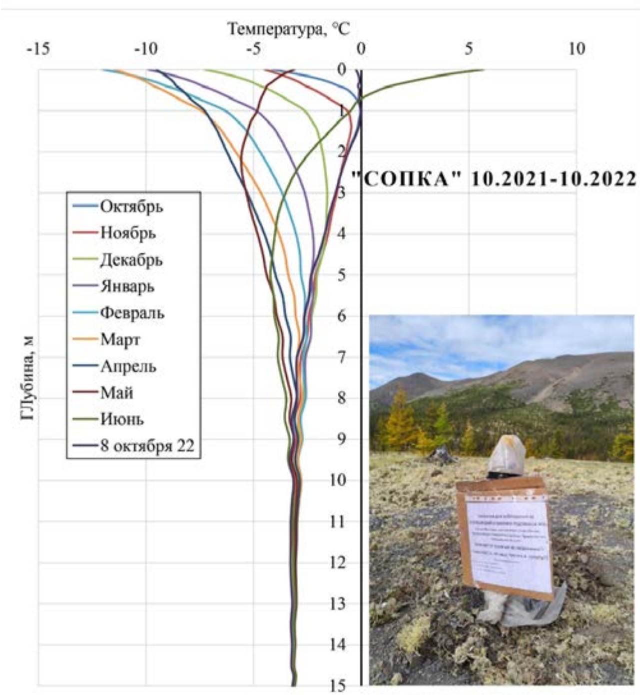
5 precipitation isotope sampling gauges

Multidisciplinary research

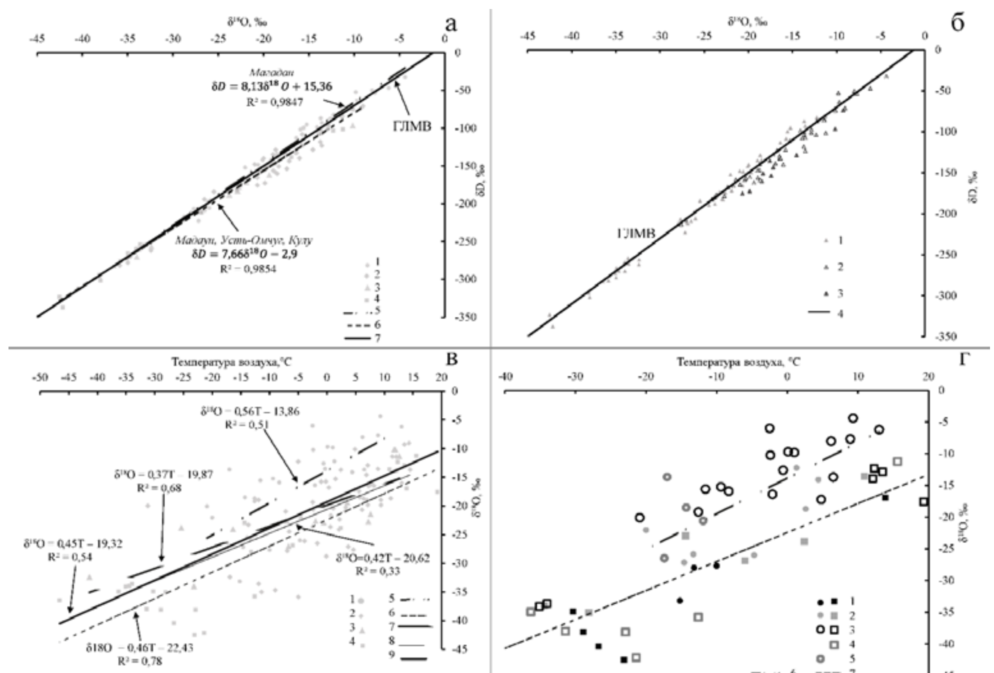




Aufeis research



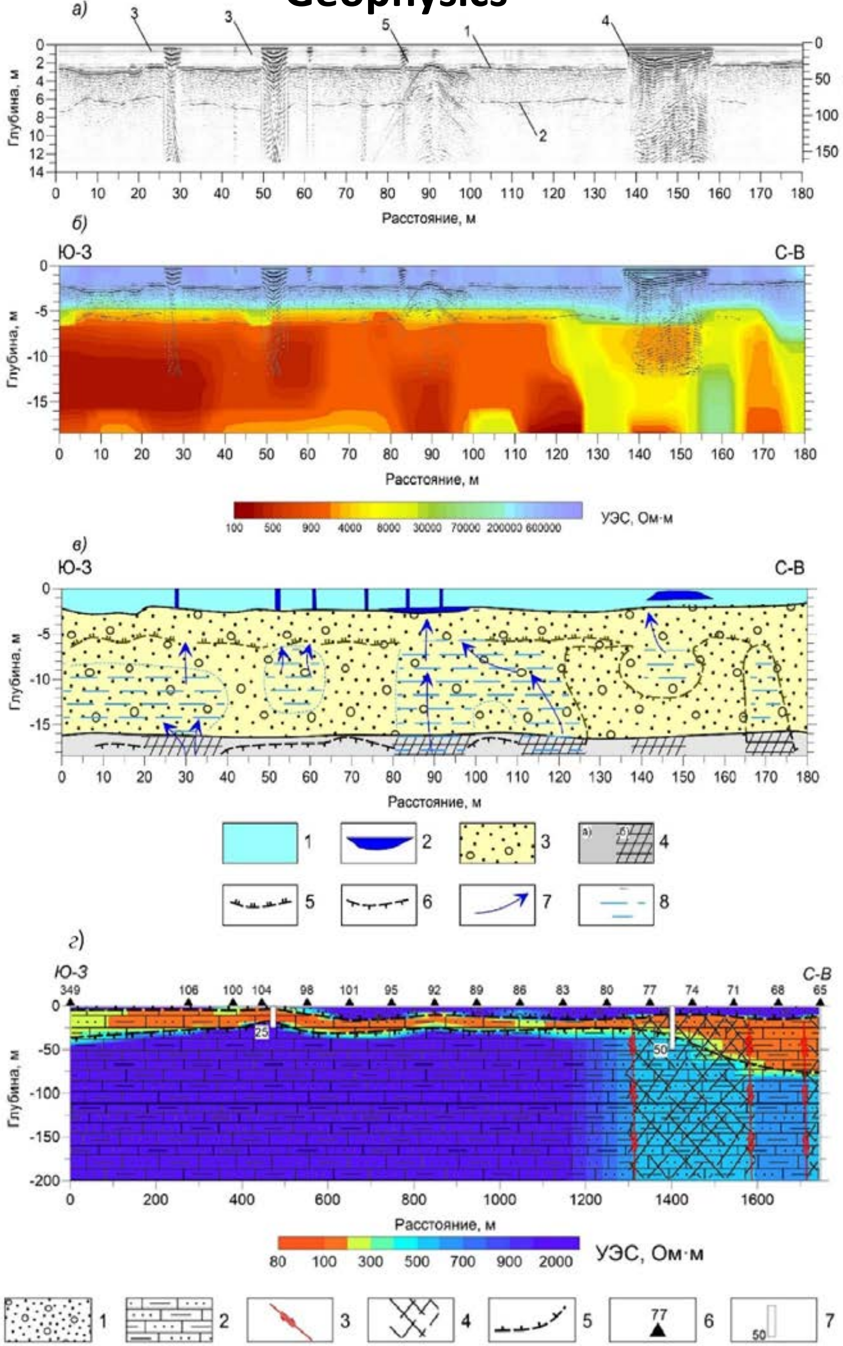
Permafrost studies



Isotope studies

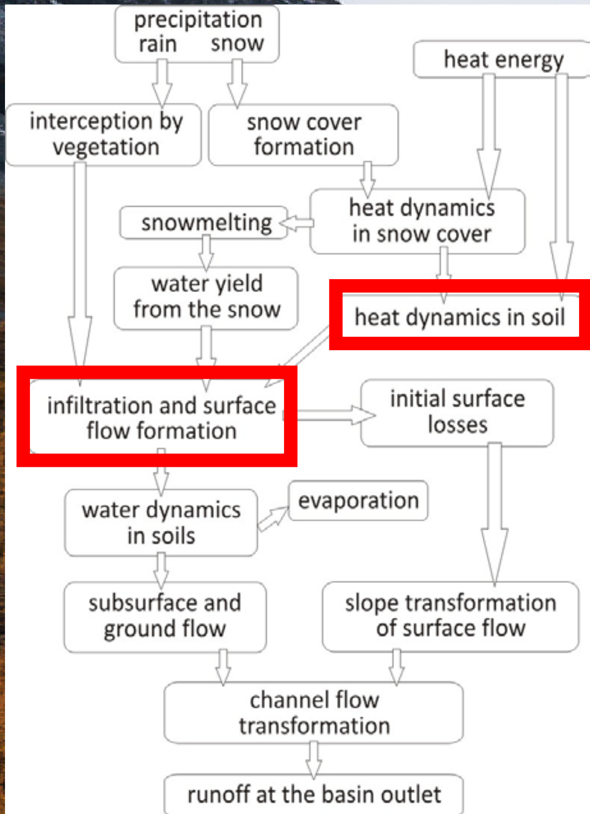
Multidisciplinary research

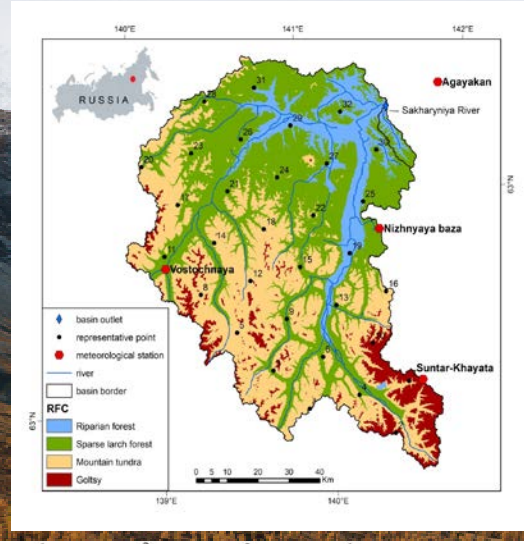
Geophysics



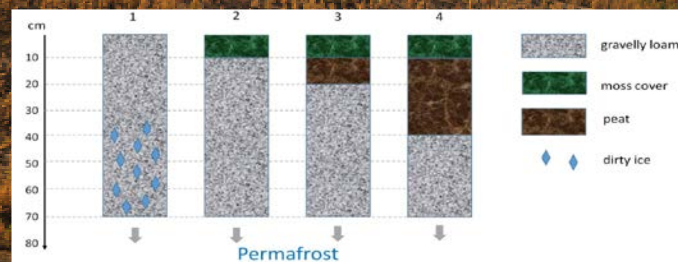
Hydrology

Process-based modelling

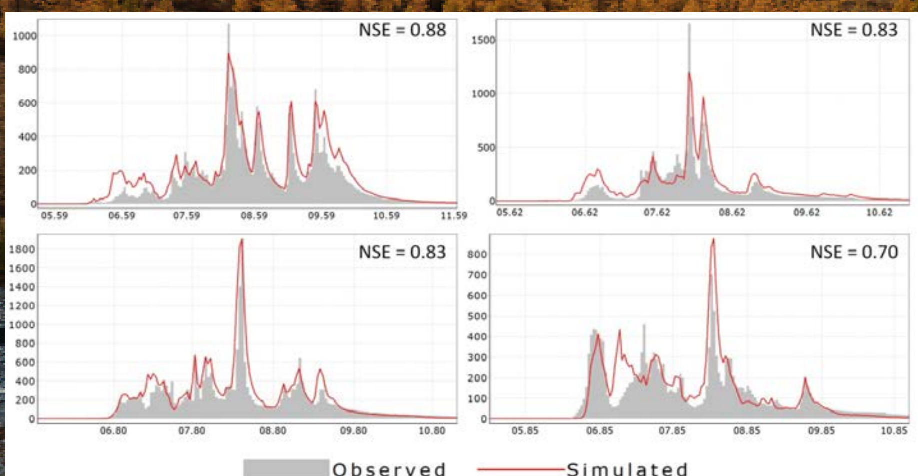


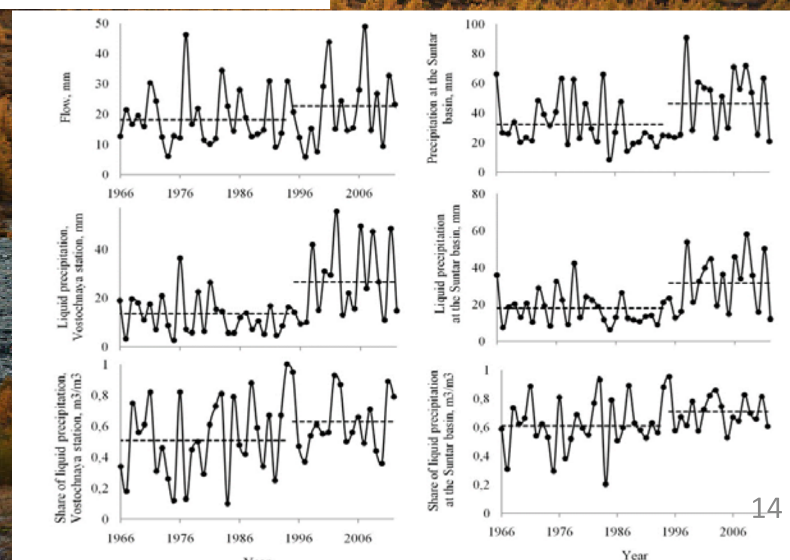


The **Hydrograph model** was successfully used to identify the response of the catchment to climate change and can be applied for prediction and assessment of future changes in streamflow and state variables in catchments in the zone of continuous permafrost.



Hydrograph Model

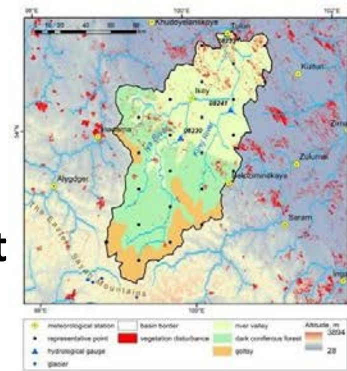


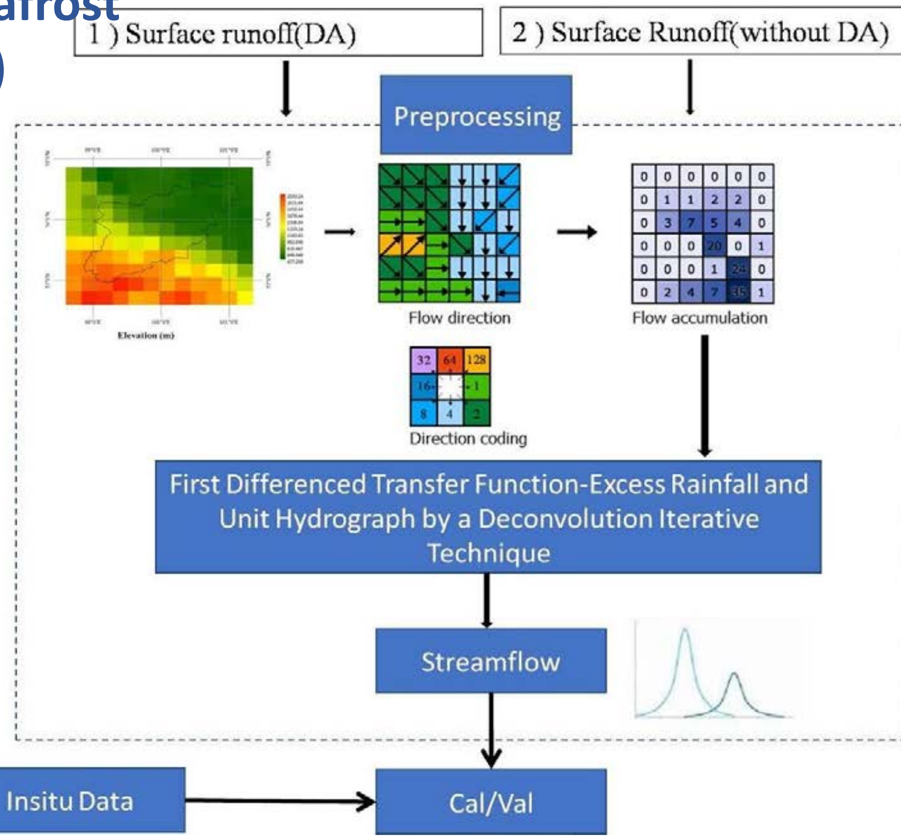


Soil Moisture (SM) Assimilation in Permafrost Affected Regions (India and Russia)

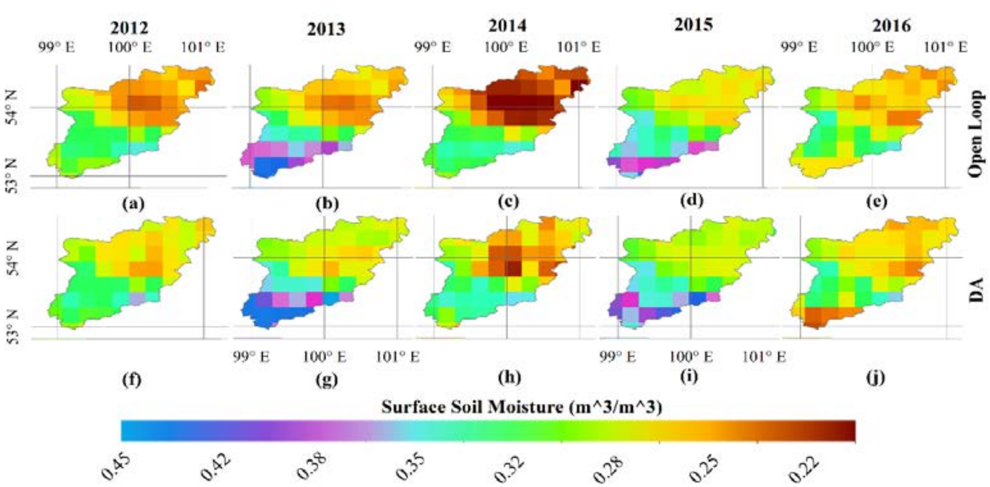
The aim is to use remote sensing data to improve hydrological modelling results

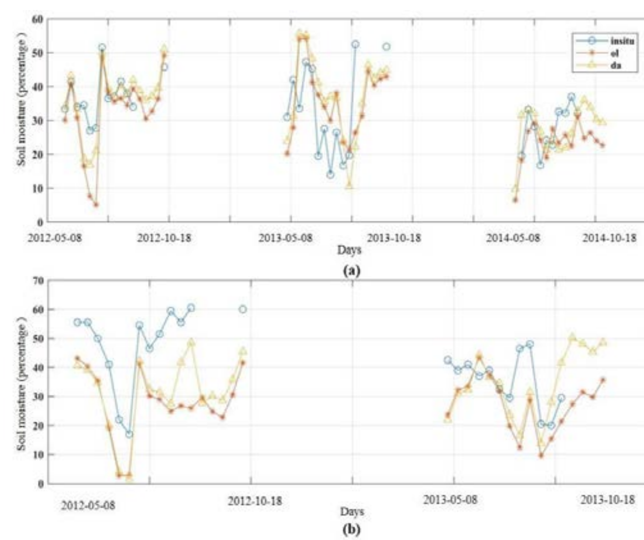
The Iya River catchment, hazardous flood in 2019





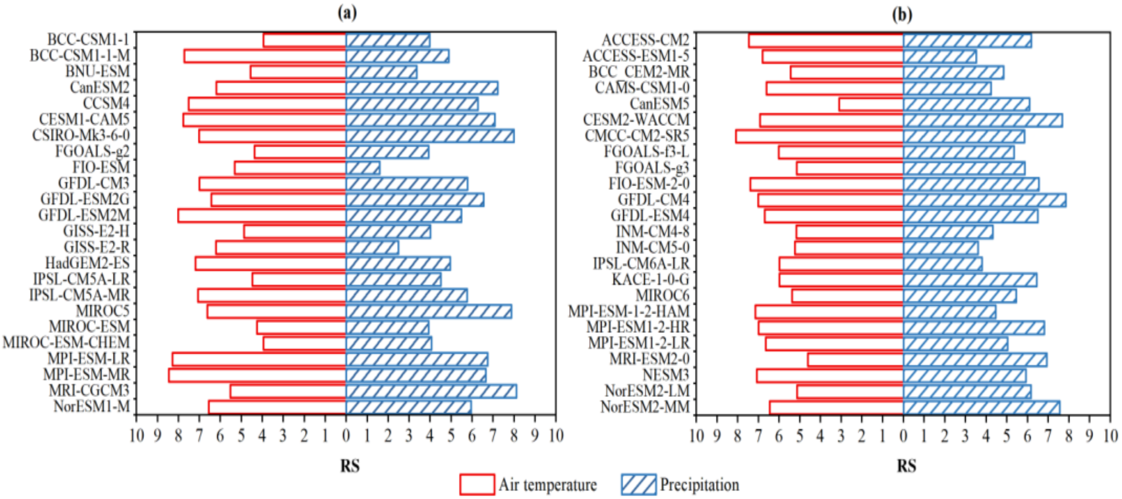
Intercomparison with in-situ station data demonstrates a considerable improvement in correlation between SM after assimilation.





Projection of future climate change – the Tibetan Plateau

Performance evaluation of GCMs from CMIP5 to CMIP6



	Precipitation		Air temperature	
CMIP	**CMIP5**	**CMIP6**	**CMIP5**	**CMIP6**
1	MRI-CGCM3	GFDL-CM4	MPI-ESM-MR	CMCC-CM2-SR5
2	CSIRO-Mk3-6-0	CESM2-WACCM	MPI-ESM-LR	ACCESS-CM2
3	MIROC5	NorESM2–MM	GFDL–ESM2M	FIO-ESM-2-0
4	CanESM2	MRI–ESM2–0	CESM1-CAM5	MPI-ESM-1-2-HAM
5	CESM1-CAM5	MPI-ESM1-2-HR	BCC-CSM1-1-M	NESM3
6	MPI-ESM-LR	FIO-ESM-2-0	CCSM4	GFDL-CM4
7	MPI-ESM-MR	GFDL-ESM4	HadGEM2-ES	MPI-ESM1-2-HR
8	GFDL-ESM2G	KACE-1-0-G	IPSL-CM5A-MR	CESM2-WACCM
9	CCSM4	ACCESS-CM2	CSIRO-Mk3-6-0	ACCESS-ESM1-5
10	NorESM1-M	NorESM2-LM	GFDL-CM3	GFDL-ESM4

- ✓ With the complex terrain and climate conditions, GCM **simulations of precipitation on the TP are usually more difficult than simulations of average air temperature**, and CMIP6 models perform better, with an average score of 5.71

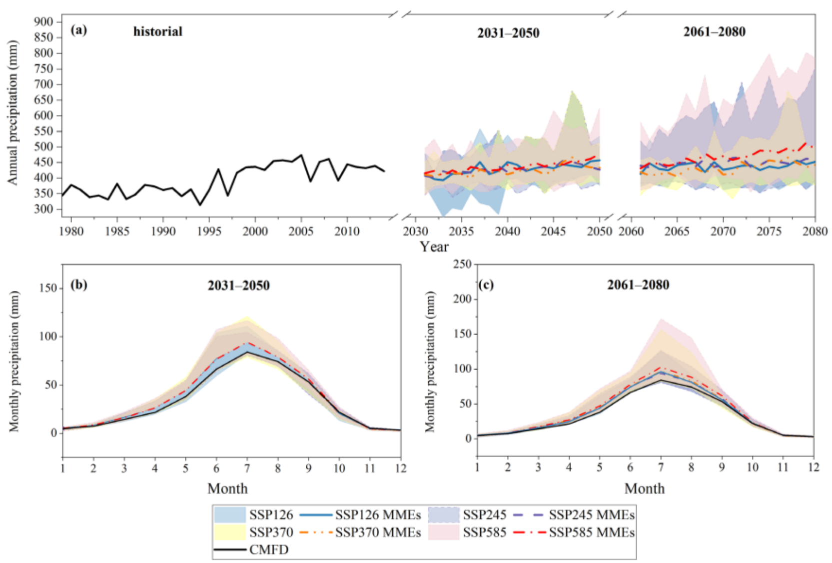
- ✓ Both CMIP5 and CMIP6 **performed well** for the simulation of mean temperature in different models, with mean scores of 6.23 and 6.19, respectively

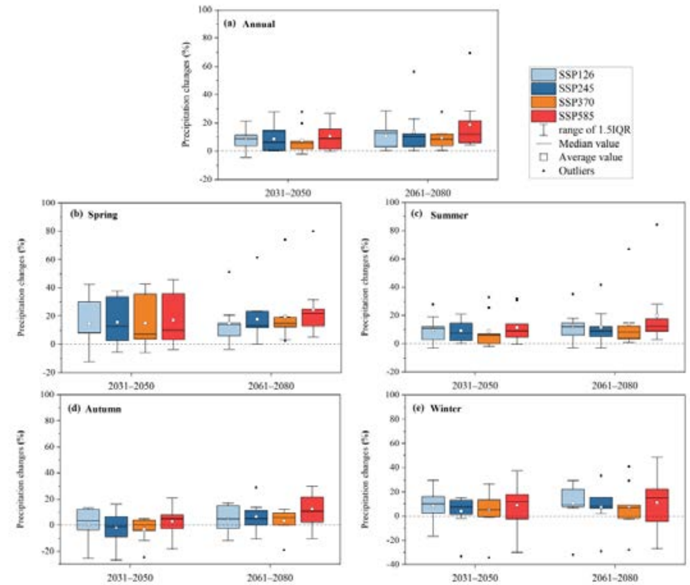
- ✓ **Large differences in simulations of different elements by the same model.** The simulated temperature score of CanESM5 is 3.11 and the simulated precipitation score is 6.09

- ✓ For precipitation and air temperature, **the top 10 models from CMIP5 and CMIP6 were selected for the multi-model ensemble averaging**

Projected future precipitation changes

Temporal change characteristics

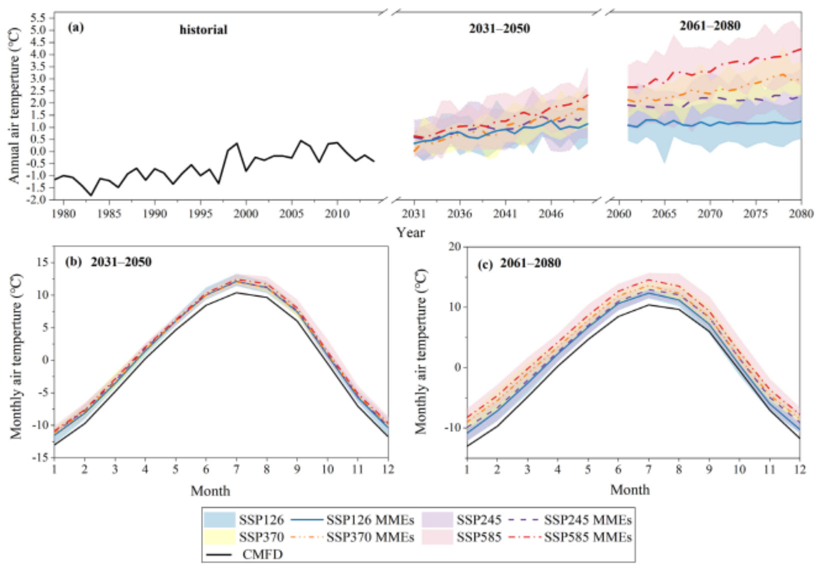


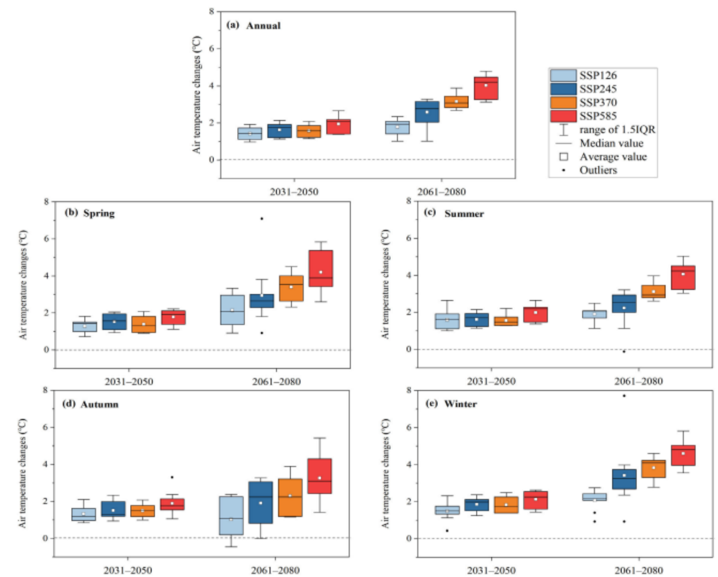


- ✓ CMIP6 multi-model ensemble predictions of precipitation on the Tibetan Plateau show a predominantly increasing trend in annual precipitation
- ✓ Between 2031 and 2050, the annual precipitation on the Tibetan Plateau under the four scenarios ranges from 280 to 660 mm, with the model ensemble averaging between 400 and 470 mm under the different scenarios, and the average increase in precipitation under the different scenarios relative to the base period is 10%.
- ✓ The range of variation in annual precipitation increase between 2061 and 2080 is 11-19%

Projected future air temperature changes

Temporal change characteristics





- ✓ **CMIP6 multi-model ensemble predictions of mean temperature on the Tibetan Plateau show a more pronounced increase in annual mean temperature with increasing scenario levels than precipitation, with a continued warming trend in the future**
- ✓ **From 2031-2050, the overall increase in predicted mean annual temperature is 1.5 °C under the first three SSP scenarios, reaching 2 °C under SSP585**
- ✓ **From 2061-2080, the increase in mean temperature ranges from 1.8 °C (SSP126 scenario) to 4 °C (SSP585 scenario)**

Conclusions

- Terrestrial freshwater pathways have a central role in water, material, and energy exchanges between components of the permafrost domain freshwater system. They connect the atmosphere and ocean over large distances, along which ecosystems and resources are affected by varying geographical characteristics of the terrestrial freshwater systems.
- Most of the permafrost domain are essentially ungauged.
- As some parts of the territories increasingly become subject to settlement and natural resource extraction, it will become more important to separate anthropogenic effects from underlying environmental changes.
- Concerted efforts at studying water, solute, and energy fluxes on various scales will remain important to detect, understand, and project water system changes.
- Despite a growing potential of remote sensing, it remains critical to at least maintain the current ground-based capacity to observe permafrost terrestrial hydrology.

Conclusions

- Permafrost- affected regions play key role in economic development.
- Russia, China and India have common problems and research tasks in permafrost regions.
- Joint efforts allow for increased effectivity of research.
- Cooperation through BRICS programs is effective.
- More joint scientific events (conferences, schools for young scientists, etc.) with on-site presentations should be organized in the nearest future with the government funding.